Far-Infrared and Submillimeter Emission of the Interstellar Medium: Models meet extragalactic and Galactic Observations

FIR Workshop 2007
November 5 – 7, 2007
Physikzentrum Bad Honnef

Abstract Book
and Logistics

Edited by R. Simon & C. Kramer (KOSMA)

The conference is organized by

Kölner Observatorium für submm Astronomie (KOSMA)
I. Physikalisches Institut, Universität zu Köln
Zülpicher Str. 77
50937 Köln, Germany

www.astro.uni-koeln.de/FIR07

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Sponsor
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Objectives

Star formation is often shrouded in mystery by the parental dusty interstellar medium. However, the absorbed energy induced by deeply embedded young sources is largely reradiated at submillimeter and far-infrared wavelengths. This cooling emission provides the key tool to study the interplay between the ISM and star formation. FIR emission from gas and dust thus allows to study the role of the ISM in the cycle of matter in widely different environments, from high-z galaxies to local star formation in the Milky Way. In the forthcoming years, new ground- and space based observatories with unprecedented sensitivity and high resolution will invigorate this field. Herschel and SOFIA in particular will offer for the first time the possibility to observe spectrally resolved Extragalactic and Galactic FIR cooling lines of the ISM on a regular basis.

The main goal of this workshop is to stimulate the exchange of knowledge on the structure and composition of the ISM, near and far, bringing together modellers and observers. It thus follows-up and extends on the Onsala workshop 2005 (www.oso.chalmers.se/workshop). The workshop will consist of invited talks, contributed talks, and poster contributions.

Key questions

- Chemical tracers: What are the key chemical tracers of the physical conditions of the ISM in different environments in the Milky Way and in external galaxies?
- Heating mechanisms: What is the relative importance of shocks, UV-photons, X-rays, cosmic rays in different galactic environments?
- What is the mutual relation between star formation and turbulence?
- Phases of the ISM: The cold and dense molecular ISM is a prerequisite for any star formation. How does it form and how is it dispersed? What do we know about the cycle of interstellar matter through the various phases of the ISM?

Contents

Information for speakers

There will be 15 invited talks of 30 min. (+10 min. for discussions) each and about 20 contributed talks of 15 min. (+5 min. for discussions).
We plan to install two laptops, one running Windows (PowerPoint), the other Linux (OpenOffice). We therefore encourage speakers to copy their presentation to a USB stick and copy it to one of these laptops in one of the breaks before their talk. To avoid any technical problems, use simple pdf files! In any case, you may of course also use your personal laptop for those fancy movies and animations.

Information for those presenting posters

The maximum size of a poster is 120 cm (width) and 150 cm (height). Poster presenters are encouraged to bring A4 or Letter size copies of their poster for distribution to interested participants (we are happy to link these to the titles on the workshop web pages).

Opening of registration

The conference registration will be open on **Sunday, November 4, from 16:00 – 19:00** at the Physikzentrum Bad Honnef. Registration will also be open on Monday morning, starting at around 8:15.

Internet access at the workshop

Internet access via wireless LAN will be provided during the workshop.

Workshop proceedings

The proceedings of the workshop will be published under the auspices of the European Astronomical Society (EAS) at EDP Sciences (www.edpsciences.org/eas).

Deadline for submission of contributions to the proceedings is end of 2007. Please plan some time for writing your contributions after the workshop. We plan to publish the proceedings before mid-2008. Contributions will be indexed on ADS.

Do not forget to fill out the ”Copyright transfer” statement and please return it to EDP Sciences as described on the EAS web pages (”Copyright transfer” link on the left hand side).

Depending on the kind of presentation at the workshop, your contribution to the preceedings is limited to the number of pages as listed below:

Invited talks	**6 pages**
Contributed talks	**4 pages**
Posters	**2 pages**

As for the abstracts, the proceedings contributions have to be written in LaTeX and any figures must be included as eps files. Color figures are ok if they are well readable in b/w for the printed version. The figures will appear in color in the electronic version. In exceptional cases, color figures may be acceptable for the printed version but, depending on the costs, the fee may have to be paid by the authors.

Please fetch the LaTeX macro package at EAS and read the Instructions for authors (”Instructions for authors” link on the left hand side of the EAS web page).

Please name your tex file and any accompanying figure files according to the convention:
lastname.tex and *lastname_fig01.eps*, etc.
and send them by email to Carsten Kramer (kramer@ph1.uni-koeln.de) who will be one of the editors.

How to get to Bad Honnef and the meeting

From the airport

- **From Frankfurt**
  - Train via Siegburg or Cologne to Rhöndorf (duration 2.5 hours).
  - Alternative train via Koblenz to Rhöndorf (much cheaper, same duration).
- **From Cologne/Bonn**
  - Direct train connection to Rhöndorf every hour, duration 32 min.
  - Taxi to the Physikzentrum (38 km, fare about 40 Euro).

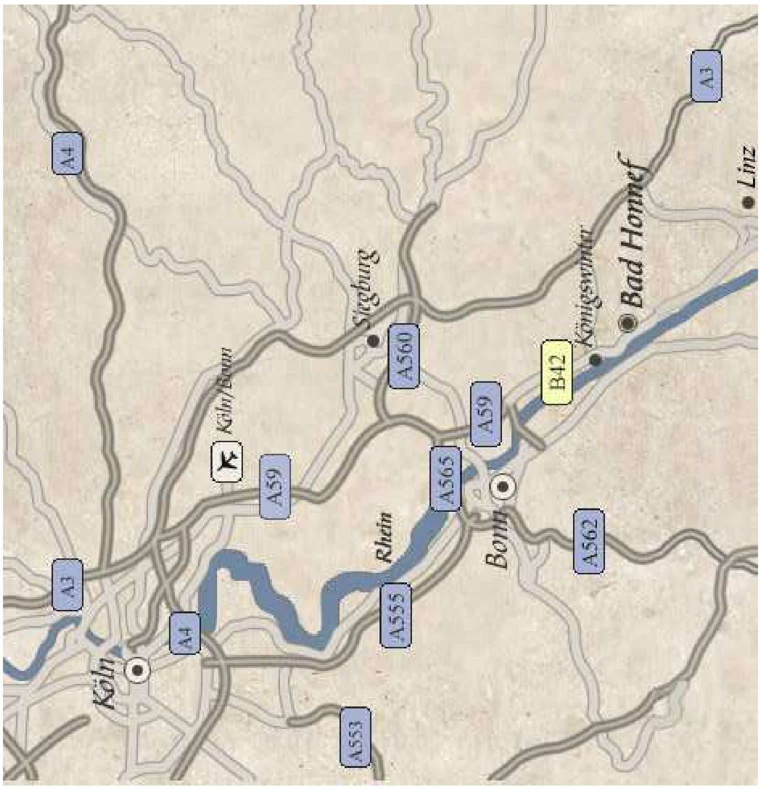
By train

- **From Cologne**
  - Direction Koblenz (right side of the Rhine River). Step off at Rhöndorf or Bad Honnef (duration 45 min). Walk to PBH (distance 2.5 km, see City Map) or take a taxi (about 5 Euro).
- **From Frankfurt**
  - Via Siegburg or Cologne to Rhöndorf (duration 2.5 hours).
  - Alternative train via Koblenz to Rhöndorf (much cheaper, same duration).
- **From Bonn main station**
  - Taxi from the front of the railway station to PBH (distance 18 km, about 25 Euro).
  - Alternatively, take the commuter train (S-Bahn) No. 66 destination Bad Honnef (duration 35 min). Step off at ”Am Spitzenbach”. Walk to PBH (400 m, see City Map).

By car

- **From the north**
  - Motorway A3 to ”Autobahn-Dreieck Heumar” then motorway A59 direction ”Bonn/Köln Airport” or ”Bonn/Königswinter”. A59 continues as B42 to Bad Honnef, exit ”Rhöndorf”. Follow the ”Rhöndorfer Strasse” to ”Hauptstrasse”, after 2 km from the exit, you will see PBH on the left side. Attention: radar speed control -max. 50 km/h- in Rhöndorf.
- **From the south**
  - Motorway A3 Frankfurt-Köln exit ”Bad Honnef/Linz”. After approx. 4 km turn to the right at the first intersection with traffic lights and follow the valley down to Bad Honnef. Attention: radar speed control -max. 60 km/h- before entering Bad Honnef. Cross the city in northern direction (see City Map) and find PBH on the right side.

Maps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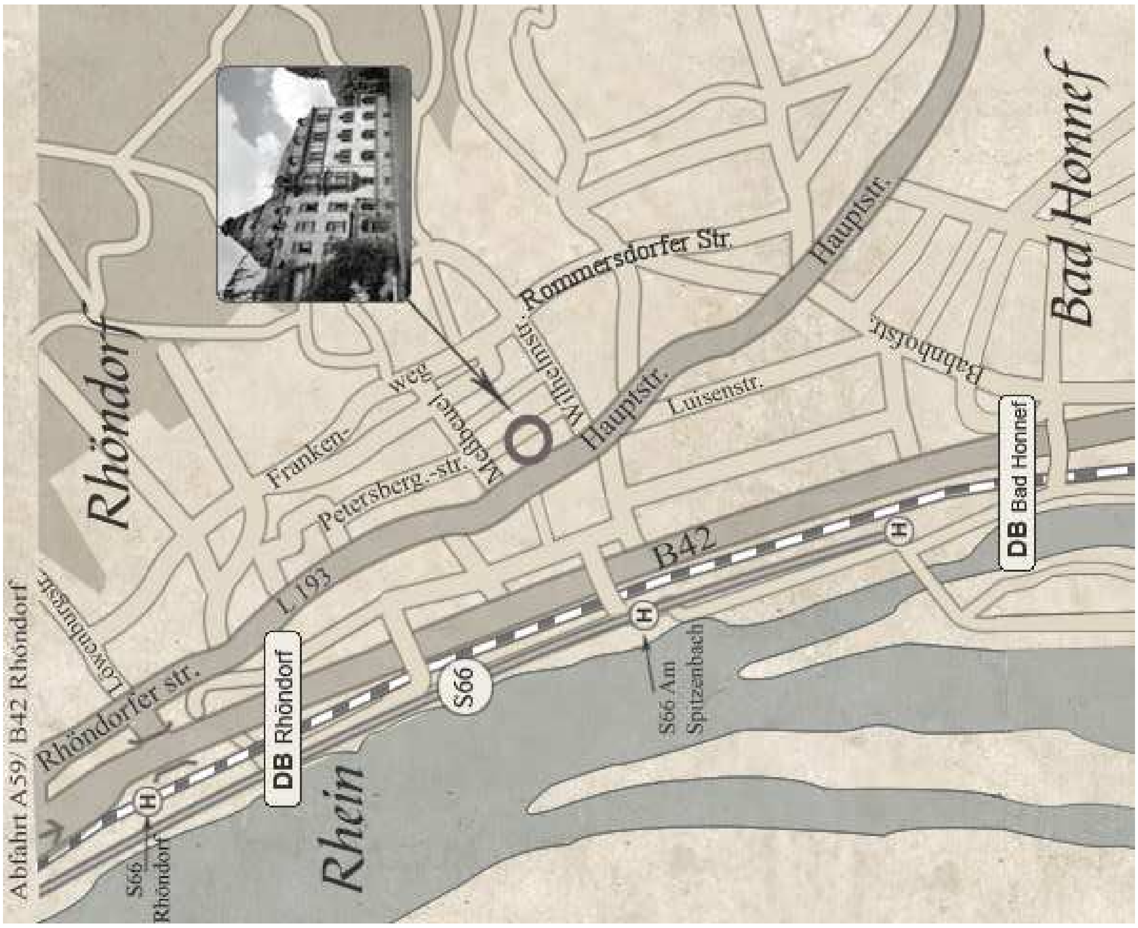
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Wilhelmstr.
Rommersdorfer Str.
Hauptstr.
Hauptstr.
Luisenstr.
B42
S66
S66 Am Spitzenbach
Bahnhofstr.
DB Bad Honnef
Bad Honnef

Lodging and meeting place

The workshop will be held in the

Physikzentrum Bad Honnef
Hauptstr. 5
53604 Bad Honnef

http://www.pbh.de/en/index.shtml

Programme

Monday **November 05**

09:00 – 09:10 **Carsten Kramer**
Welcome address

Session I:	ISM phases and star formation	
09:10 – 09:50	**Ralf Klessen** (invited) *ISM Turbulence and Star Formation*	Chair: Marco Spaans
09:50 – 10:30	**Maria Cunningham** (invited) *Large scale turbulence: the Delta Quadrant Survey*	
10:30 – 10:50	**Patrick Hennebelle** *Structure of the turbulent atomic gas and formation of molecular clouds*	
10:50 – 11:20	**COFFEE BREAK and POSTER SESSION**	
11:20 – 12:00	**Miguel de Avillez** (invited) *Phases and feedback*	
12:00 – 12:20	**Markus Cubick** *Modelling of clumpy photon dominated regions*	
12:20 – 12:40	**Carsten Kramer** *Warm and dense gas and dust in Carina*	
12:40 – 14:00	**LUNCH**	

Session II:	Gas & dust, heating & cooling	
14:00 – 14:40	**Jacques Le Bourlot** (invited) *PDR models: Radiative Transfer and Line Formation (e.g., H_2O)*	Chair: Maryvonne Gerin
14:40 – 15:20	**Jerome Pety** (invited) *Galactic PDRs: the millimeter view*	
15:20 – 15:40	**Michael Kaufman** *PDR Models with Photodesorption and Grain Chemistry*	
15:40 – 16:10	**COFFEE BREAK and POSTER SESSION**	
16:10 – 16:50	**Marco Spaans** (invited) *The importance of the HCN/HCO^+ ratio in PDRs*	
16:50 – 17:10	**Gary Ferland** *Magnetic field: the HII Region/PDR connection*	
17:10 – 17:50	**Serena Viti** (invited) *Millimeter emission from hot cores*	

Tuesday **November 06**

Session III:	Galactic nuclei	
09:00 – 09:40	**Kotaro Kohno** (invited) *Tracing star formation in galaxies*	Chair: Suzanne Madden
09:40 – 10:00	**Javier R. Goicoechea** *The Far-IR view of Sgr B2 and Orion KL – lessons from ISO*	
10:00 – 10:20	**Jesus Martin-Pintado** *Chemical complexity as a tracer of nuclear activity*	
10:20 – 10:40	**Paul Jones** *A 3-mm molecular line study of the Central Molecular Zone*	
10:40 – 11:10	**COFFEE BREAK and POSTER SESSION**	
11:10 – 11:30	**Raquel Monje** *Molecular Chemistry as diagnostic tool for starbursts and AGNs*	
11:30 – 11:50	**Santiago Garcia-Burillo** *Molecular line probes of activity in galaxies*	
11:50 – 12:10	**Frank Israel** *The nuclei of 70 galaxies*	
12:10 – 12:30	**Yu Gao** *The FIR-HCN correlation*	
12:30 – 14:00	**LUNCH**	
14:00 – 14:40	**Linda Tacconi** (invited) *Molecular Line Emission as a Tool for Studying Distant Galaxies*	Chair: Kotaro Kohno
14:40 – 15:00	**Masatoshi Imanishi** *NMA observations of luminous infrared galaxies*	
15:00 – 15:20	**Masako Yamada** *The AGN/Starburst connection: 3d radiative transfer*	
15:20 – 15:40	**Toshikazu Onishi** *Star formation activity and ISM properties in the Magellanic Clouds*	
15:40 – 16:10	**COFFEE BREAK and POSTER SESSION**	
16:10 – 16:30	**Floris van der Tak** *Detection of extragalactic* H_3O^+	
16:30 – 16:50	**Willem Baan** *Molecular diagnostics and evolution of the nuclear ISM in ULIRGs*	
18:00 – 21:00	**CONFERENCE DINNER**	

Wednesday **November 07**

Session IV:	Galaxies and the importance of dust	
09:00 – 09:40	**Antonio Usero** (invited) *Large-scale shocks in galaxies*	Chair: Santiago Garcia-Burillo
09:40 – 10:20	**Suzanne Madden** (invited) *The ISM of low metallicity galaxies*	
10:20 – 11:00	**Markus Röllig** (invited) *Metallicity effects in PDRs*	
11:00 – 11:30	**COFFEE BREAK and POSTER SESSION**	
11:30 – 12:10	**Bruce Draine** (invited) *SINGS and interstellar dust*	
12:10 – 12:50	**Takashi Onaka** (invited) *The infrared view of the ISM*	
12:50 – 14:00	**LUNCH**	

Session V:	Chemistry at high redshifts	
14:00 – 14:40	**Alain Omont** (invited) *Dust and gas at high-z*	Chair: Susanne Aalto
14:40 – 15:00	**Gordon Stacey** *Detection of ^{13}CO(6-5) in NGC253*	
15:00 – 15:20	**Thomas Nikola** *[CI] and CO Observations of ULIRGs and Starburst Galaxies with ZEUS*	
15:20 – 15:40	**Steven Hailey-Dunsheath** *Detection of [CII] in FS10026+4949 at z = 1.12*	
15:40 – 16:10	**COFFEE BREAK and POSTER SESSION**	
16:10 – 16:30	**Matt Bradford** *Broadband Millimeter-Wave Spectroscopy of Galaxies with Z-Spec*	
16:30 – 16:50	**Christian Henkel** *Extragalactic Ammonia*	
16:50 – 17:30	**Marco Spaans** *Workshop summary and discussion*	

List of posters

Name	Title of poster	Number
Aguirre, James	A Millimeter Line Survey of Local ULIRGs with Z-spec: First Results and Prospects for Detection of High Redshift CO	P1
Bayet, Estelle	Hot core chemistry in extragalactic star formation regions	P2
Bayet, Estelle	Comparison of CO - PAH+/PAH0/VSG emissions in external galaxies	P3
Emprechtinger, Martin	Hot Molecular Gas in NGC 2024	P4
Hitschfeld, Marc	Detection of [CI] 1-0 and CO 4-3 in NGC4945 and Circinus	P5
Juvela, Mika	Cold cloud cores	P6
Kaneda, Hidehiro	ISM in nearby elliptical galaxies revealed by AKARI and Spitzer	P7
Loenen, Edo	Molecular diagnostics of (U)LIRGs: matching data and models	P8
Minnier, Vincent	FIR/submm studies of star formation at all scales in the Universe with bolometer arrays on ground-based telescopes	P9
Muehle, Stefanie	Taking the Temperature in Starburst Galaxies - Formaldehyde as a Tracer of Extragalactic Molecular Gas	P10
Okada, Yoko	Mid- to Far-infrared Mapping Spectroscopy of Galactic Star-forming Regions with ISO, Spitzer, and AKARI	P11
Ossenkopf, Volker	Prospectives of PDR observations using Herschel	P12
Perez-Beaupuits, Juan-Pablo	High density tracers in Seyfert galaxies	P13
Pineda, Jorge L.	Sub-millimiter observations of the N159W region in the Large Magellanic Cloud	P14
Porter, Ryan	Expanding Cloudy with Third-Party Databases	P15
Schulz, Andreas	Heating the interstellar medium of spiral galaxies via PDRs	P16
Simon, Robert	The PDR structure of the Monoceros Ridge in the Rosette Molecular Cloud	P17
Sun, Kefeng	A multiline study of the Cepheus B molecular cloud	P18
Tosaki, Tomoka	NRO 45m and ASTE observations of dense gas in giant HII regions of M33	P19
van Hoof, Peter	Modeling X-ray ionization of grains and molecules with Cloudy	P20
Volgenau, Nikolaus	CONDOR observations of CO 13-12 emission from Orion KL	P21
Wiedner, Martina, C.	Astronomical Observations at 1.5 THz with the CO N+ Deuterium Observations Receiver	P22

Abstracts of talks

Molecular diagnostics and evolution of the nuclear ISM in ULIRGs

W. BAAN

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Broadband Millimeter-Wave Spectroscopy of Galaxies with Z-Spec

C.M. Bradford,[1,2] B.J. Naylor,[1,2] L. Earle, [3] J.E. Aguirre, [3,4]
J. Glenn, [4], J.J. Bock, [1] H. Nguyen,[1] J. Zmuidzinas[2], H. Matsuhara[5], H. Inami[5]

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[5] Institute of Space and Astronautical Science, Sagamihara, Japan

We present first astronomical results obtained with our new 200-300 GHz grating spectrometer Z-Spec at the Caltech Submillimeter Observatory (CSO). Z-Spec covers the full 1-mm atmospheric band instantaneously at a resolving power of 250-350 with 160 bolometers, and the instrument now operates very close to the photon-noise limits at the CSO. We have observed a handful of nearby starburst and ULIRG galaxies. In addition to the ^{12}CO $J=2\rightarrow1$ we measure fluxes for ^{13}CO $J=2\rightarrow1$, CN $J=2\rightarrow1$, HCN $J=3\rightarrow2$, HNC $J=3\rightarrow2$, and HCO$^+$ $J=3\rightarrow2$ in most of the sources. Our spectrum of the nucleus of M82 is shown in Figure 1 as an example. Z-Spec is uniquely suited to simultaneous measurement of the continuum and integrated line intensities. We find that the HCN to HNC$^+$ $J=3\rightarrow2$ intensity ratio varies from less than 1 to a few in our sample, indicating variability in the dense molecular gas properties as suggested by Aalto et al. (2003, 2007), though our results differ in detail. We find that the $J=2\rightarrow1$ CN / CO intensity ratio is approximately constant, unlike for the corresponding $J=1\rightarrow0$ ratio presented in Aalto et al. (2003).

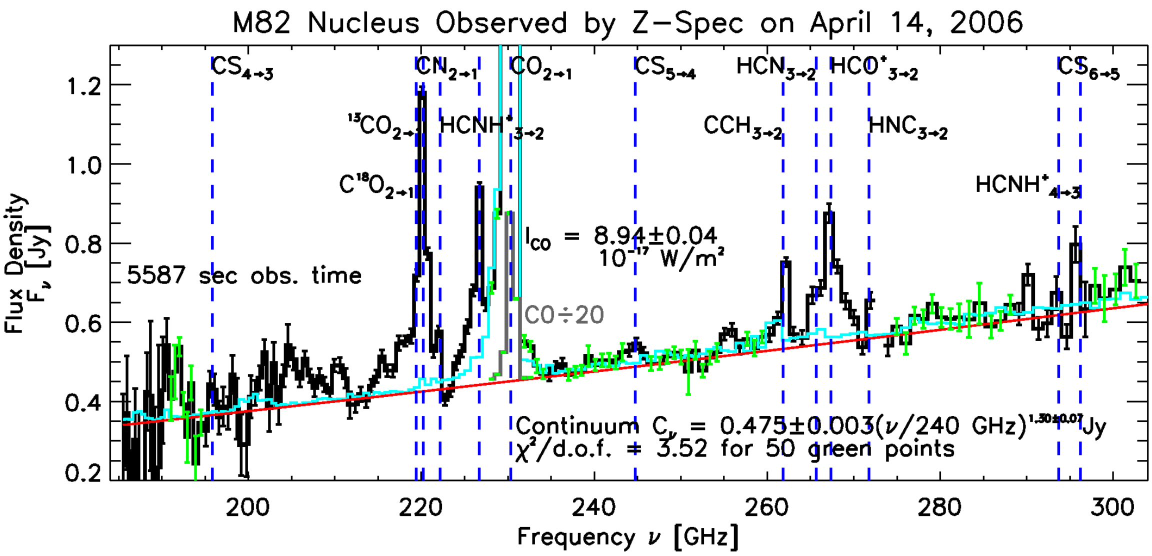

Figure 1: Spectrum of the starburst nucleus of M82 obtained with Z-Spec in 1.5 h at the CSO.

References:
S. Aalto, A.G. Polatidis, S. Hüttemeister, and S.J. Curran, 2003, A&A, 381, 783
S. Aalto, M. Spaans, M.C. Wiedner, and S. Hüttemeister, 2007, A&A, 464, 193

Modelling of clumpy photon dominated regions (PDRs)

M. CUBICK[1], M. RÖLLIG[1,2], V. OSSENKOPF[1,3], C. KRAMER[1], AND J. STUTZKI[1]

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Observations of the interstellar medium (ISM) reveal structure on all scales. Quantification of the structure by decomposition of the observed intensity distributions into clumps results in power law distributions of the clump number and size versus clump mass (e.g. Heithausen et al.1998). This has been shown to be consistent with a fractal structure of the observed clump distributions (Stutzki et al. 1998). The conclusion of this result is a surface dominated structure of the ISM. The stellar UV-radiation penetrating the Galactic ISM in consequence dominates its physical and chemical conditions. Thus the bulge of the ISM can be identified as photon dominated regions (PDRs) (Hollenbach & Tielens 1999).

The large scale FIR emission of our Galaxy has been observed by the FIRAS instrument on-board the COBE (cosmic background explorer) satellite. The flux of various molecular line transitions, as CO J=1-0 to 6-5 and 8-7 rotational transitions, [CI] 609 μm, [CII] 158 μm and [NII] 205 μm and 122 μm fine structure line transitions, and the combined flux of the CO J=7-6 and [CI] 370 μm transitions has been obtained at a spatial resolution of 7°. This means that a large number of clouds contribute to the measured flux. The observed emission, in particular the [CII] emission, cannot be reproduced by standard PDR models with plane parallel geometry (e.g. Fixsen et al. 1999).

The KOSMA-τ PDR code, provides the physical and chemical structure of clumps with spherical geometry per radiative transfer calculations and solution of a chemical reaction network at given mass, density, ultraviolet radiation field and metallicity. Furthermore, the surface integrated line intensities of those clumps are calculated (e.g. Störzer et al. 1996). To account for the fractal structure of the ISM we created ensembles according to the power law distributions and computed the resulting emission. For the Galactic radial distributions of the gas mass, density, and the FUV-flux, we created a simple disk model of the Galaxy, taking recent results from the literature (e.g. Wolfire et al. 2003) into account.

With this model, containing basically no free parameters, we are able to reproduce the Galactic FIR line intensities of [CII] 158 μm, [CI] 609 μm, [CI] 370 μm + CO 7-6, CO 1-0 to 6-5 and 8-7, and [OI] 146 μm within factors of about 3 in the longitudinal average.

References:

Fixsen, D. J., Bennett, C. L., & Mather, J. C., 1999, ApJ, 526, 207
Heithausen et al., 1998, A&A, 331L, 65
Hollenbach, D. J., & Tielens, A. G. G. M., 1999, Reviews of Modern Physics, 71, 173
Röllig et al., 2007, A&A, 467, 187
Störzer, H., Stutzki, J., & Sternberg, A., 1996, A&A, 310, 592
Stutzki et al., 1998, A&A, 336, 697
Wolfire et al., 2003, ApJ, 587, 278

Large scale turbulence: the Delta Quadrant Survey

MARIA CUNNINGHAM[1], CARSTEN KRAMER[2], NADIA LO[1], INDRA BAINS[3], PAUL JONES[1], MICHAEL BURTON[1], TONY WONG[4], VOLKER OSSENKOPF[2,5], BHASWATI MOOKERJEA[6].

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[5] SRON, National Institut for Space Research, Groningen, The Netherlands.
[6] Tata Institute of Fundamental Research, Mumbai (Bombay), India.

The Delta Quadrant Survey is a multi-wavelength survey of the G333 / RCW 106 region, aiming to put together a comprehensive picture of massive star formation throughout an entire giant molecular cloud complex. The aim of the project is to to answer observationally some of the key questions about the dynamical processes surrounding massive star formation (e.g. massive stellar winds and large-scale galactic flows) and their relative importance in regulating the star formation process. These dynamical processes drive the turbulent motions which are ubiquitous in giant molecular clouds (GMCs).

We have used the new broadband capabilities of the Mopra telescope to map the distribution of around 20 different molecules in an approximately 1 degree square region of the southern Galactic plane (the G333.6-0.2 giant molecular cloud complex) (Bains et al. 2006; Lo at al. 2007). The multi-molecular line nature of this survey is what distinguishes it from similar surveys, and is crucial for gaining a clear picture of the energetics and dynamics of the gas. Different molecular transitions trace different regions of gas in terms of density and excitation, and so can be used to follow energy transfer through the molecular cloud complex. Our initial investigations are showing a picture where turbulence is injected at large scales (hundreds of parsecs), and passes through to smaller parsec scales with little dissipation. However, at these smaller scales, the star formation is heavily influenced by local events, such as the feedback from nearby star formation, and triggering seems to be common.

Investigating and understanding the chemistry of this region is a necessary part of this project if the molecular line observations are to be correctly interpreted, and is an interesting goal in itself. In addition to the molecular line observations we have observed continuum emission at sub-millimetre and centimetre wavelengths, and radio-recombination lines. These observations are being combined with existing infrared and atomic hydrogen data to put together a comprehensive picture of massive star formation, and its relationship to the chemistry and dynamics of the entire cloud complex.

References:

Lo N., Cunningham M., Bains I., Burton M. G., Garay G., 2007, MNRAS, 381, L30
Bains I., et al., 2006, MNRAS, 367, 1609

Phases and feedback

M. DE AVILLEZ

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Dust in the SINGS Galaxy Sample

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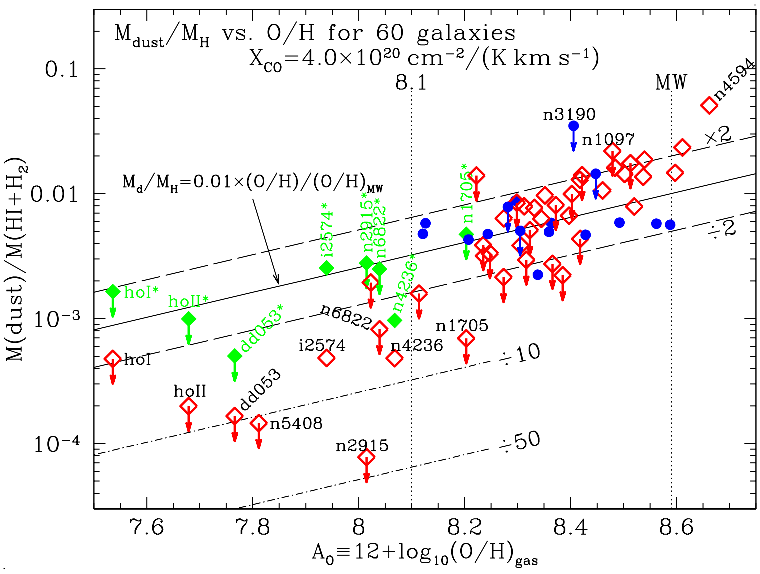
Dust models have been applied to interpret the IR and submm emission from 65 galaxies in the Spitzer Infrared Nearby Galaxies Survey (SINGS; Kennicutt et al. 2003) for which we have good IRAC and MIPS global photometry; SCUBA 850μm photometry is also available for 17 of the SINGS galaxies. We employ a dust model (Draine & Li 2007) consisting of a mixture of amorphous silicate and carbonaceous particles, with the smallest carbonaceous particles having the physical and optical properties of PAHs. The dust is heated by starlight. The shape of the emission spectrum depends on the assumed distribution of starlight intensities and the assumed abundance of PAHs.

The dust model successfully reproduces the emission observed from the SINGS galaxies, including the 850μm photometry when available. The best-fit models yield estimates of the total dust mass in each galaxy, the PAH abundance (measured by a parameter $q_{\rm PAH}$, the fraction of the total dust mass contributed by PAHs containing $< 10^3$ C atoms), and characteristics of the starlight intensity distribution.

The observed SEDs, including galaxies with SCUBA photometry, can be reproduced by models that do not contain very cold ($T < 10$K) dust, although such dust could obviously be present provided it does not dominate the global emission even at 850μm.

The dust masses estimated from our modeling can be compared to gas masses obtained from HI 21cm and CO 1-0. The observed dust-to-gas ratios are consistent with $M_{\rm dust}/M_{\rm H} \approx 0.01(A_{\rm O}/A_{\rm O,\odot})$, where $A_{\rm O}$ is the oxygen abundance. This requires that much or most of the refractory elements (C, Mg, Si, Fe) in the interstellar medium be in solid grains.



Dust-to-H mass ratio for 60 SINGS galaxies (from Draine et al. 2007). Arrows indicate upper limits for galaxies where CO measurements are unavailable. Solid circles are galaxies with SCUBA photometry. Open diamonds are global results for galaxies lacking SCUBA photometry. For many low-metallicity systems (e.g., NGC1705) with extended HI envelopes, the filled diamonds show dust-to-H ratios for the portion of the galaxy where IR emission is observed.

We also confirm previous findings that the fraction of the dust mass contributed by PAHs correlates with metallicity. The 52 galaxies with $A_{\rm O} > 0.3A_{\rm O,\odot}$ have median $q_{\rm PAH} = 3.6\%$, while 9 galaxies with $A_{\rm O} < 0.3A_{\rm O,\odot}$ have median $q_{\rm PAH} = 1.0\%$.

References:

Draine, B.T., Dale, D.A., Bendo, G., et al. 2007, ApJ, 663, 866
Draine, B.T., Li, A. 2007, ApJ, 657, 810
Kennicutt, R.C., Armus, L., Bendo, G., et al. 2007, PASP, 115, 928

The H II Region / PDR Connection

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A PDR is actually the boundary layer between an H II region and its background molecular cloud. It is energized by the central star cluster that produces the H II region and its properties are set by this cluster. I will describe holistic investigations of Orion and M17 that combine X-ray, optical, IR, and radio observations of the three layers. These include measurements of the pressure in the hot gas surrounding the star cluster, the gas pressure in the H II region, and the magnetic & turbulent pressures in the PDR. Hydrostatic equilibrium reproduces the observed geometries surprisingly well. The total pressure in the PDR, predominantly magnetic and turbulent pressures, is set by the outward momentum of the stellar radiation field. Most of this radiation is emitted at ionizing energies, underscoring the importance of including all three regions in any study. The high magnetic fields found in PDRs are the result of flux-freezing as radiation pressure from the star cluster pushes surrounding gas away. Enhanced magnetic fields should be accompanied by increased cosmic ray densities, providing an additional heating source for the PDR.

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The FIR–HCN Correlation over Ten Orders of Magnitude

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From a survey of 65 galaxies, we have found a strong linear relationship between HCN $J = 1 - 0$ (tracer of dense molecular gas) and the FIR luminosity for galaxies ranging over 3 orders of magnitude in $L_{\rm FIR}$. This leads to a global star formation (SF) law that the SF rate (deduced from the FIR) is linearly proportional to the mass of dense molecular gas. Recently, this work has been extended to both low and high FIR luminosity ranges that both individual GMC cores and early molecular galaxies at high-z appear to follow this FIR–HCN correlation spanning ten orders of magnitude. Therefore, the SF rate appears to be in proportion to the dense molecular gas mass in all known star-forming systems.

Molecular line probes of activity in galaxies

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Current mm-interferometers can provide a sharp view of the distribution and kinematics of molecular gas in the circumnuclear disks of nearby galaxies. In particular, the use of specific molecular tracers of the dense gas phase can probe the feedback influence of activity on the chemistry and energy balance/redistribution in the interstellar medium of nearby galaxies, a prerequisite to interpret how feedback may operate at higher redshift galaxies. We will present the results of an ongoing survey allying the IRAM 30m telescope with the Plateau de Bure Interferometer (PdBI), devoted to probe the feedback of activity through the study of the excitation and chemistry of the dense molecular gas in a sample of local universe starbursts and AGNs. We also present new observations used to probe the dense molecular gas content in a sample of 17 local luminous and ultraluminous infrared galaxies (LIRGs and ULIRGs). We find the first observational evidence that the star formation efficiency of the dense gas, measured as the L_{FIR}/L'_{HCN} ratio, is significantly higher in LIRGs and ULIRGs than in normal galaxies. This may imply a statistically significant turn upward in the Kennicutt-Schmidt law. We will also present observations devoted to study the chemistry of molecular gas in two prototypical high-redshift QSOs.

The Far–IR view of Sgr B2 and Orion KL: from ISO to Herschel.

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THE MAPSO HERSCHEL OPEN-TIME KP CONSORTIUM.

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Due to the atmospheric opacity, the far–IR (FIR) domain has been the last spectral window used in Molecular Astrophysics. The potential of opening a new spectral frequency range through molecular spectroscopy begun to be fully exploited with the Infrared Space Observatory (ISO/esa). The spectral resolution and sensitivity of the instrumentation on board the satellite had no comparison with the few previous space or airborne observations carried before the launch of ISO. Most of the operative range of ISO in the FIR ($\sim$50–200 μm or $\sim$6000–1500 GHz) was not explored before. Hence, the FIR spectrum of the most significant sources was unknown. The brightest FIR regions of the sky, Orion KL and Sgr B2, are paradigmatic objects for our understanding of the chemical composition, dynamics and energy budget associated with giant molecular clouds in the galactic disk and nucleus respectively. Besides, the ISO spectra of these high mass star forming regions were also used as *template* to interpretate the FIR molecular signatures observed in extragalactic sources such as NGC 253 or NGC 1068 (starburst vs. AGN).

In this talk I will summarize our FIR spectral surveys and large scale rasters of Orion KL and Sgr B2 with ISO, as well as the radiative transfer and chemical model results obtained to interpretate these observations. Special emphasis will be given to the detection and modeling of FIR H_2O and OH lines in high temperature environments (outflows and shocks vs. PDRs) and to the observation of FIR fine structure lines to characterize the neutral ([O I] and [C II]) versus the ionized ([N II], [N III] and [O III]) phases. These species and associated FIR lines constitute a major target for the Herschel Space Observatory, the next great space mission to cover the FIR range ($\sim$2008) at much improved sensitivity and resolution. In particular, we have proposed an Open–Time Key Program to map Orion KL and Sgr B2 with the 3 instruments on board Herschel.

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Detection of the 158 μm [CII] Line from FS10026+4949 at z = 1.12

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We report the detection of redshifted [CII] line emission from the hyperluminous galaxy FS10026+4949 using our new direct detection submillimeter spectrometer, ZEUS, on the CSO. ZEUS is a long-slit echelle grating spectrometer with a resolving power of 1000, optimized for detection of broad extragalactic lines in the short submillimeter telluric windows. ZEUS is currently configured to observe simultaneously in the 350 and 450 μm windows, delivering an instantaneous 16 element spectrum in each band. The observations reported here were undertaken in March 2007.

The 158 μm [CII] line is among the brightest emission lines from galaxies. It arises from warm, dense gas in photodissociated regions (PDRs) formed on the surfaces of molecular clouds that are exposed to the far-UV radiation of nearby O/B stars. As such, the line is an indicator of starformation activity in galaxies. The far-IR continuum radiation from starforming galaxies also largely arises from PDRs, and the [CII] to far-IR continuum luminosity ratio, R, is a sensitive function of the strength of the ambient far-UV radiation field parameterized in units of the local interstellar radiation field, G. For stronger fields, R decreases both due to the build up of grain charge (reducing the efficiency of photo-electric heating) and, for dense PDRs, due to increased cooling in the [OI] 63 μm line. Thus a measurement of R can be used to derive G. Most of the stellar far-UV continuum heats the dust in PDRs, and is re-radiated in the far-IR continuum. Therefore, the ratio of the observed far-IR continuum intensity to the derived far-UV continuum intensity is the beam filling factor. Comparing the beam filling factor to the linear size of the beam yields the source size.

We have made the first detection of the [CII] line from a galaxy at redshift between 1 and 3. This is a critical epoch to investigate star/galaxy formation in the Universe as it includes the peak of the starformation rate per unit co-moving volume. We detected the line from FS10026+4949, an extremely IR luminous ($L_{IR} \sim 6.5 \times 10^{13} L_\odot$) system at z = 1.12. The line is also very luminous ($L_{[CII]} \sim 4.5 \times 10^{10} L_\odot$) resulting in R $\sim 0.07\%$. The far-UV field is therefore quite intense: G $\sim$ 2000, similar to that in nearby starburst galaxies. The inferred source size is $\sim$ 10 kpc in diameter, indicating that the galaxy is undergoing a global starburst. The large scale starburst is consistent with the contention that FS10026+4949 has an enormous starformation rate of $\sim$ 2000 $M_\odot$/year stimulated by collisions with multiple close partners (Farrah et al. 2002). Our conclusions are similar to those of Chapman et al. (2004) who studied 12 submillimeter bright galaxies at similar redshifts and found that 2/3 of their sample were undergoing a galaxy-wide starburst.

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Extragalactic Ammonia

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Ammonia is one of the most important species in the dense cool interstellar medium. In particular, the metastable inversion lines serve as a reliable temperature tracer and have been observed out to redshifts of z=0.9. The rotational lines involving non-metastable inversion doublets are, however, much more difficult to detect, being located not at cm- but at sub-millimeter wavelengths and requiring either extremely good weather conditions or measurements with satellites. Summarizing previously obtained observations, possibilities of future sub-mm line research are outlined, emphasizing prospects after a successful launch of Herschel.

Structure of the turbulent atomic gas and formation of molecular clouds

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The atomic interstellar gas (HI) is a 2-phase and turbulent medium. Modeling HI is of great relevance for the prospect of understanding the structure of the interstellar medium. It is also extremely important for the star formation process since molecular clouds form by condensation of interstellar atomic gas. Indeed, studying self-consistently the formation of molecular clouds is necessary to constrain the initial conditions which lead to the gravitational collapse and the formation of stars.

From the numerical point of view, it is a challenging issue because of the large scale dynamics which is required to cover the various physical scales relevant for the problem. Here, we present very large numerical simulations (2D and 3D) allowing to describe these physical scales accurately (Audit & Hennebelle 2005, Hennebelle & Audit 2007). As an example, Figure 1 shows the density field of a bidimensional numerical simulation with $10{,}000^2$ grid points. As can be seen, the structure of the resulting turbulent, 2-phase flow is very complex and show that the interstellar phases are deeply interwoven. The consequence for the formation of the cold neutral medium (CNM) and the molecular clouds will be discussed as well as the influence of the gravity and the magnetic field.

Various statistics inferred from the simulations (Hennebelle et al. 2007) will be presented, such as the mass spectrum, the velocity dispersion, the mass-size relation of the CNM clouds or the column density distribution. Comparison with the statistics inferred from observations of CO clumps (e.g. Kramer et al. 1998, Heithausen et al. 1998) reveal strong similarities.

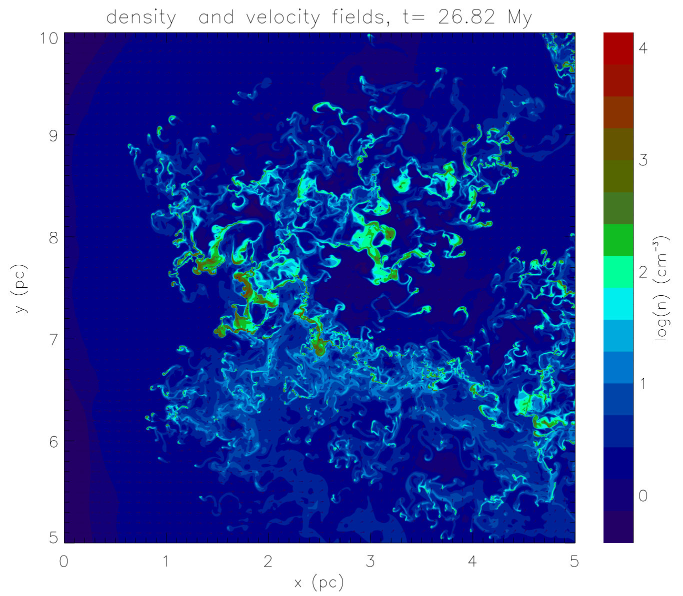

Figure 2: Density field of a 2D $10{,}000^2$ cells numerical simulation of a collision between two HI flows.

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Distinguishing the enigmatic highly obscured energy sources of luminous infrared galaxies through Nobeyama Millimeter Array molecular gas observations

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We present the results of systematic interferometric observations at 3-mm, using the Nobeyama Millimeter Array, of luminous infrared galaxies (LIRGs). We have observed HCN (J=1–0) and HCO^+ (J=1–0) molecular emission lines simultaneously, and derived the HCN to HCO^+ brightness-temperature ratios, to investigate whether the observed ratios are similar to those expected from X-ray dissociation regions (XDRs) around a strongly X-ray emitting AGN, or photo-dissociation regions (PDRs) in a starburst. LIRGs with (without) luminous buried AGN signatures in our infrared spectra tend to distribute in the range occupied by AGN-dominated (starburst-dominated) galaxies (Figure 1). This distribution is expected to reflect the chemical effects in XDRs and PDRs. Since dust extinction is negligible in this wavelength range, this millimeter interferometric method is potentially an effective tool to unveil the nature of enigmatic energy sources deeply buried in LIRGs' nuclei.

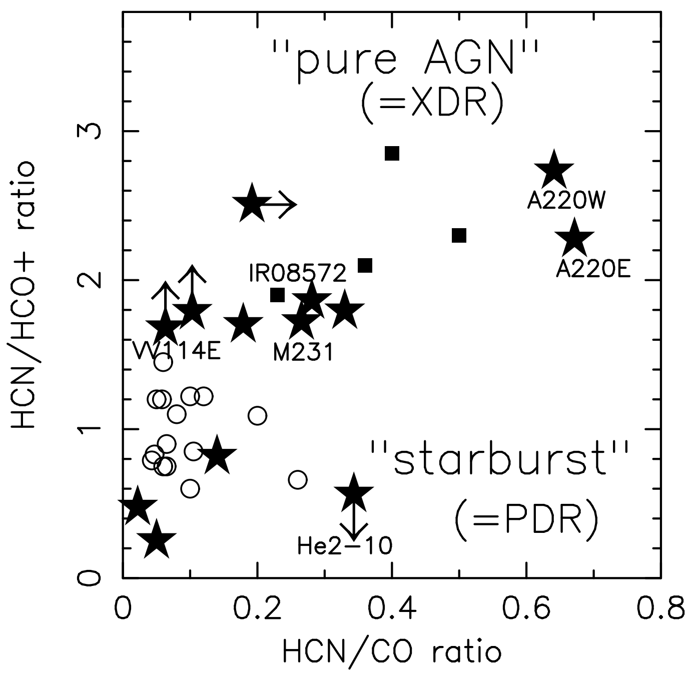

Figure 3: HCN/HCO^+ (ordinate) and HCN/CO (abscissa) ratios of LIRGs (filled stars) in brightness temperature ($\propto \lambda^2 \times$ flux) (Imanishi et al. 2004, 2006; Imanishi & Nakanishi 2006). Unpublished data points (Imanishi et al. in preparation) are labeled with object names. Other data points are taken from Kohno (2005), where sources with AGN-like (starburst-like) ratios are marked with filled squares (open circles).

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Physical characteristics of central molecular gas concentrations in a large sample of galaxies

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A sample of about 100 nearby late-type spiral galaxies has been surveyed in ^{12}CO and ^{13}CO line emission with the IRAM 30m, JCMT 15m and SEST 15m telescopes. For 50 galaxies, both isotopes were measured in the first three rotational transitions; 17 of these were also observed in the J=4–3 CO and J=1–0 [CI] transitions. Especially the isotopic ratios show a relatively large range of values. In a significant fraction of these galaxies, central CO concentrations were mapped in the J=2–1 and J=3–2 transitions over typically an arminute squared. The data do not only allow, but in many cases require, modelling with two distinct molecular cloud components: relatively cold and dense, and relatively hot and tenuous gas. I will present results and preliminary conclusions on the characteristics of molecular gas in galaxy centers.

A 3-mm molecular line study of the Central Molecular Zone

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We are studying the Central Molecular Zone (CMZ) in the inner few degrees around the Galactic Centre, by mapping a large number of 3-mm molecular lines. This uses the 22-m Mopra telescope in Australia, with the new capabilities of the 8-GHz bandwidth MOPS digital filter bank.

In pilot observations during 2006, we covered a 5 x 5 arcmin area of the Sagittarius B2 molecular cloud complex, with spectral coverage of nearly all of the range 81.7 to 113.5 GHz with 4 tunings of the wide-band mode. We imaged over 50 spectral lines with strong extended emission (24 of which we also observed with higher velocity resolution in the zoom mode) and around 120 more lines which were weak, or concentrated at the Sgr B2(N) and Sgr B2(M) cores. We find substantial differences in chemical and physical conditions within the complex.

During 2007 we covered the larger region of longitude -0.2 to 0.9 deg. and latitude -0.20 to 0.12, including Sgr A and Sgr B2, in the frequency range 85.3 to 91.3 GHz. This includes lines of C_3H_2, CH_3CCH, $HOCO^+$, SO, $H^{13}CN$, $H^{13}CO^+$, SO, $H^{13}NC$, C_2H, HNCO, HCN, HCO^+, HNC, HC_3N, ^{13}CS and N_2H^+.

The observations probe the rich molecular ISM of the Central Molecular Zone of our Galaxy, in its kinematics, and different physical and chemical conditions. They complement other recent surveys of the CMZ in a range of wavelengths, particularly in the millimetre and sub-millimetre, and provide a local detailed reference for studies of the active nuclear regions of other galaxies.

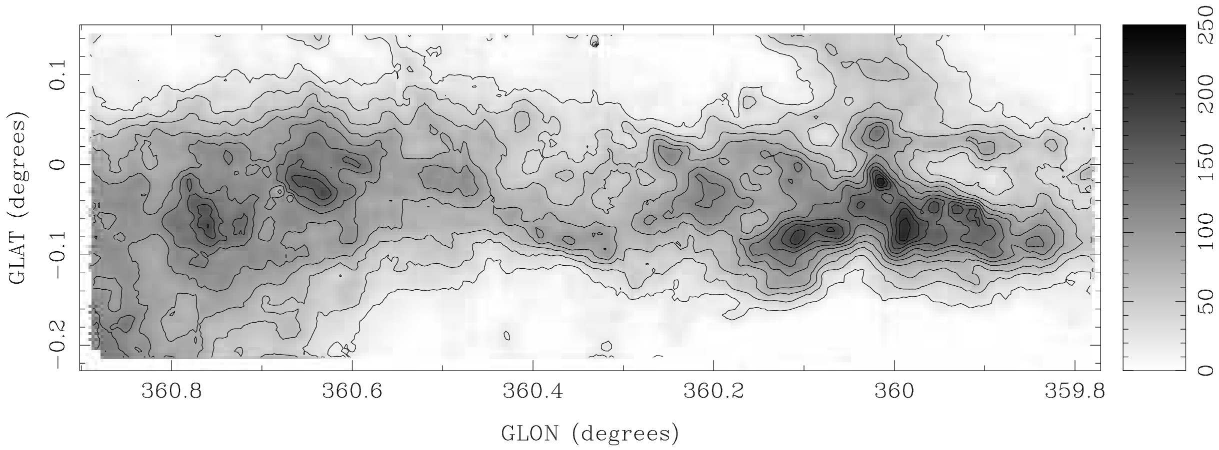

Figure 4: Integrated emission (from -180 to 200 km/s) of HCN 1 - 0 at 88.63 GHz, in the region of Sgr B2 and Sgr A, from 2007 Mopra observations.

Tracking Water, O_2 and Ice in Molecular Clouds: PDRs Models with Photodesorption and Grain Chemistry

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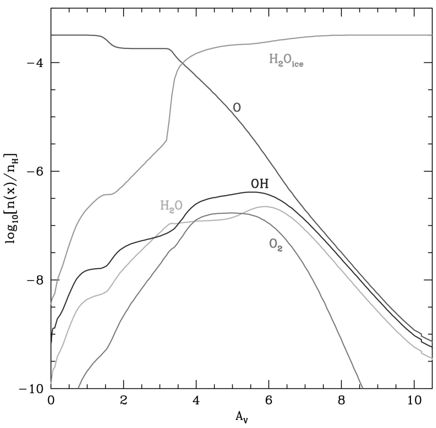
Oxygen is the third most abundant element in the universe, and a basic knowledge of oxygen chemistry in molecular clouds is essential in order to understand the chemical structure, thermal balance, and diagnostic line emission from star-forming gas in galaxies. Recent observations of the principal O-bearing species H_2O and O_2 in dense molecular clouds have yielded surprising results: H_2O abundances $\sim 3 \times 10^{-8}$ (Snell et al. 2000 with SWAS) and O_2 abundances $< 10^{-7}$ (Larsson et al. 2007 with Odin). Gas-phase models of dense clouds (e.g. Langer & Graedel 1989, Bergin et al. 1998) had predicted the abundances of both species would be about two orders of magnitude larger. Time dependent models allowing freeze-out of H_2O onto dust grains in cloud interiors could be constructed to explain the observed abundances, but required cloud ages to be fine-tuned in order to match the observations. A further constraint was provided by observations of diffuse clouds, where the gas-phase H_2O abundance reached values of $10^{-7} - 10^{-6}$ (Neufeld et al. 2002; Plume et al. 2004), two orders of magnitude larger than observed in dense clouds.

We propose a new explanation for the observed H_2O and O_2 abundances in which water is produced in the surface (PDR) layers of molecular clouds. Here it is formed on dust grains and liberated into the gas phase by photodesorption of ice. Deeper into the cloud, O-bearing species freeze out onto grains. As a result, H_2O is abundant (x(H_2O)$\sim 10^{-7}$) only in a narrow plateau so that the column-averaged abundance lies well below this level. The abundances of other O-bearing species follow the same trend. The model includes photodesorption and simple grain-surface chemical reactions.



Model of a PDR with grain surface chemistry and photodesorption for gas density n=10^4 cm^{-3} and FUV field 100 times the average interstellar field.

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ISM Turbulence and Star Formation

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Tracing star formation in galaxies with molecular line and continuum observations

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Massive stars are formed in the high density regions of molecular clouds. Therefore, observations of dense interstellar medium (ISM) through millimeter and submillimeter wavelengths provides us with important clues on the star formation in galaxies. They are free from dust extinction, so dust-enshrouded star formation can be uncovered with these observations. It is also expected to be a useful tracer to separately assess the nuclear star formation associated with the active galactic nuclei because molecular abundances and excitations in X-ray dominated regions (XDRs) seem somewhat different from those in photo-dissociation regions (PDRs).

Here we report recent progress on extragalactic molecular line and continuum observations, including (1) HCN, HCO^{+}, and CN imaging survey of Seyfert and starburst galaxies using the Nobeyama Millimeter Array (NMA), (2) high-J CO observations (J=3–2 observations using the Atacama Submillimeter Telescope Experiment (ASTE) and J=2–1 observations with the Submillimeter Array (SMA)) of galaxies, and (3) λ 1.1 mm continuum observations of nearby and distant galaxies using the bolometer camera AzTEC mounted on ASTE.

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Warm and dense gas and dust in Carina

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The Carina region is an excellent astrophysical laboratory for studying the feedback mechanisms of newly born, very massive stars within their natal giant molecular clouds (GMCs) at only 2.35 kpc distance. We use a clumpy PDR model to analyse the observed intensities of atomic carbon and CO and to derive the excitation conditions of the gas. The NANTEN2-4m submillimeter telescope is used to map the [CI] $^3P_1 - ^3P_0$, $^3P_2 - ^3P_1$ and CO 4–3, 7–6 lines in two $4' \times 4'$ regions of Carina where molecular material interfaces radiation from the massive star clusters. One region is the northern molecular cloud near the compact OB cluster Tr 14; the second region is in the molecular cloud south of ηCar and Tr 16. These data are combined with ^{13}CO Mopra spectra, HIRES/IRAS 60 μm and 100 μm maps of the FIR continuum, and maps of 8 μm IRAC/Spitzer and MSX emission. We use the HIRES far-infrared dust data to create a map of the FUV field heating the gas. The northern region shows a FUV field of a few 10^3 χ_0 while the field of the southern region is about a factor 10 weaker. While the IRAC 8 μm emission lights up at the edges of the molecular clouds, CO and also [CI] appear to trace the H_2 gas column density. The northern region shows a complex velocity and spatial structure, while the southern region shows an edge-on PDR with a single Gaussian velocity component. We construct models consisting of an ensemble of small spherically symmetric PDR clumps within the $38''$ beam (0.43 pc) which follow canonical power-law mass and mass-size distributions. We find that an average local clump density of $2\,10^5$ cm^{-3} is needed to reproduce the observed line emission at two selected interface positions.

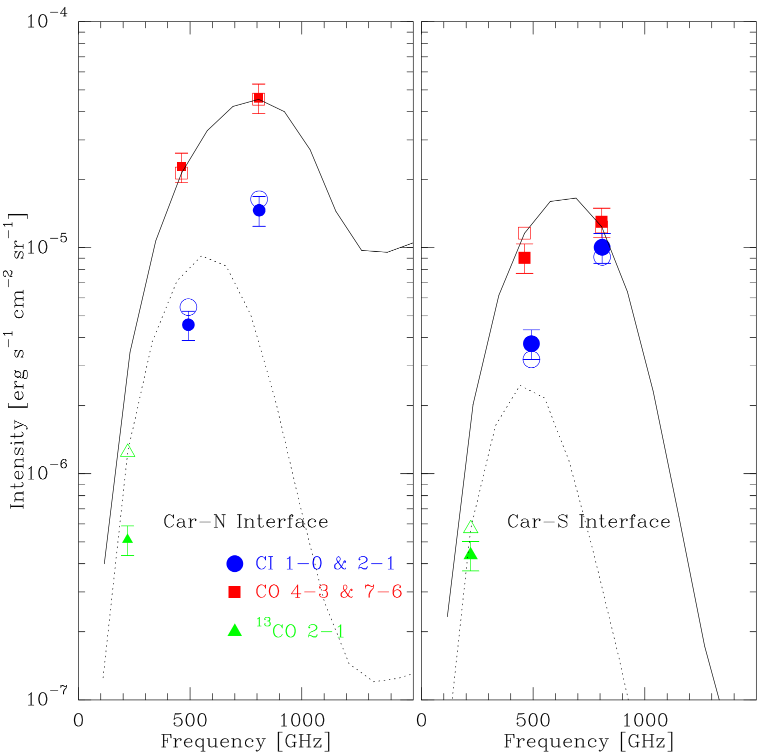

Figure 5: Integrated intensities at the two interface positions in Carina-North and South. Filled symbols show the observed ^{13}CO 2–1, [CI] 1–0, 2–1, ^{12}CO 4–3, and 7–6 intensities. Error bars denote the 15% calibration error. Model results of the best fitting clumpy PDR model are shown by drawn (^{12}CO) and dashed lines (^{13}CO), and open symbols.

PDR Models - Line formation and radiative transfer

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PDR are "Photon Dominated Regions". This must be understood literally; i.e. their dynamics is dominated by radiative processes. Therefore, models of PDR have to be built with that constraint ever present in mind. Two largely independent questions arise then: how do lines, as seen from the Earth, form within the cloud? and what level of precision on the interaction between radiation and matter is needed to get a fair understanding of the physical processes at work? These two different points of view must no be confused, and in this talk we will show how some current PDR models have chosen to tackle the various difficulties one meet to build the most useful tool possible with ever limited computing power.

The ISM of low metallicity galaxies

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Chemical complexity as a tracer of nuclear activity

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In recent years our knowledge of the chemical complexity in the nuclei of galaxies has dramatically changed. The availability of wideband more sensitive receivers in single dish telescopes has provided a complete chemical description of the nucleus of the Milky Way and of the starburst galaxy NGC253, as well as the detection of complex organic molecules like methanol in the Ultraluminous Galaxy (ULIR) Arp220. The Galactic center appears to be the largest repository of complex organic molecule like aldehydes and alcohols in the galaxy. We also measure large abundance of methanol in starburst galaxies and ULIRs suggesting that complex organic molecules are also efficiently produced in the central region of galaxies with strong star formation activity. From the systematic observational studies of molecular abundance in regions dominated by different heating processes like shocks, UV radiation, X-rays and cosmic rays in the center of the Milky Way, we are opening the possibility of using chemistry as a diagnostic tool for studies of galactic evolution, star formation, starbursts and feedback in the highly obscured regions of galactic centers. I will present recent advances of molecular observations in external galaxies and in the nucleus of our Galaxy. The templates found in the nucleus of the Milky Way will be used to establish the main mechanisms driving the heating and the chemistry of the molecular clouds in galaxies with different type of activity. The role of grain chemistry in the chemical complexity observed in the center of galaxies will be also briefly discussed.

Molecular Chemistry as diagnostic tool for starbursts and AGNs

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I will discuss recent results on nuclear and extended molecular gas in interacting starbursts and AGNs - with a focus on physical conditions and chemistry. Molecular studies are particularly useful for probing the deeply enshrouded dusty nuclei of luminous infrared galaxies. Statistical surveys and targeted high resolution studies can be used to model the extreme environments in the nuclei of starbursts and AGNs. The interpretation of the observed line ratios require parallell development of theoretical chemical and radiative transport models.

[CI] 370 μm and CO (7-6) and (6-5) Observations of ULIRGs and Starburst Galaxies with ZEUS

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We have begun a survey of the [CI] 370 μm fine structure line and of mid-J CO line emission from ULIRGs and starburst galaxies using our spectrometer ZEUS on the CSO. Here we present observations of the [CI] line and of the CO (6→5) and (7→6) rotational transitions of six ULIRGs (e.g. Fig. 6) that we obtained with ZEUS on the CSO in December 2006 and March 2007. ZEUS is a grating spectrometer with a resolution of about 1500. This resolution is well matched to the line widths expected from nuclear regions in galaxies. ZEUS is currently equipped with a 1 by 32 pixel thermistor sensed bolometer array, with the 32 pixels along the dispersion direction. The bandpass filters are arranged in a way so that the detector covers the 350 and 450 μm telluric bands simultaneously, with 16 pixels for each band.

The combination of the [CI] and CO lines trace the density and temperature of the interstellar medium. By fitting detailed LVG models to our data and modeling the structure of the active and star forming regions we determine whether an AGN or a starburst is the main energy source for the observed ULIRGs. We also hope to address the issue of the weakness of the observed [CII] emission from some of the ULIRGs.

Another important question we address is the evolution of the star formation in these regions. Is the enhanced star forming activity or the nuclear activity supporting or hindering further star formation? The energy released from the star formation activity or nuclear activity heats the molecular gas thereby raising the internal pressure and possibly halting collapse of molecular clumps, hence suppressing further star formation. On the other hand shock waves from stellar winds can compress the surrounding molecular gas and thus trigger further star formation.

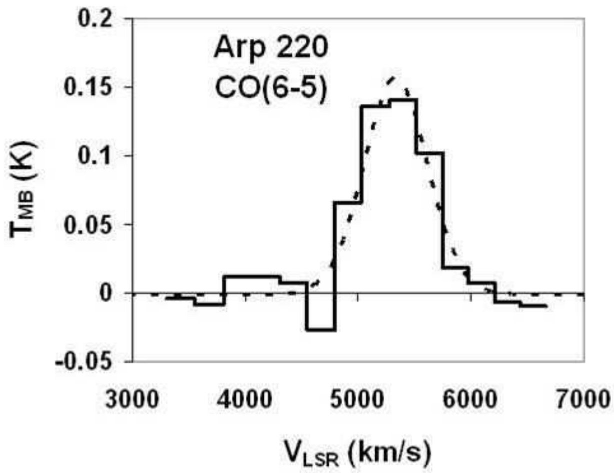

Figure 6: CO (6→5) spectrum of the nucleus of Arp 220 obtained in Mar 2007.

Dust and gas at high-z

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Infrared View of the Interstellar Medium

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Infrared observations offer a unique and important means for the study of the interstellar medium (ISM). Continuum emission from near- to far-infrared region is dominated by emission from various kinds of dust grains, including polycyclic aromatic hydrocarbons (PAHs), nanometer size grains, and submicron size particles. The infrared spectral region also has a wealth of transition lines from atoms, ions, and molecules. A combination of the continuum and line spectroscopy in the infrared thus provides us with an opportunity to investigate the properties of dust and gas in a given target at the same time. Observations of *ISO* (Kessler et al. 1996), followed by recent *Spitzer* (Werner et al. 2004) and *AKARI* (Murakami et al. 2007), have clearly demonstrated the significance of infrared observations for the study of the ISM.

The behavior of the infrared spectral energy distribution (SED) of dust emission in various regions can test the current dust model. The unidentified infrared band (UIR) emission has been shown to correlate linearly with the far-infrared intensity to some extent, supporting the stochastic heating model for the emission (Onaka et al. 1996; Peeters et al. 2004). Mysterious non-linear behavior seen in the mid-infrared excess (25–60 μm) seems to be contrary to the model prediction (Onaka 2000), however, it can be accounted for if dust grains in various radiation field intensities on the line-of-sight are taken into account (Onaka et al. 2007). Similar models also successfully account for the infrared SED of galaxies (Dale et al. 2001; Draine et al. 2007), suggesting that the mid-infrared excess can be used for diagnosis of the recent star-formation activity (Sakon et al. 2006).

Infrared spectroscopy is a quite efficient tool to study the physical conditions of interstellar gas. It can probe high excitation regions (Peeters et al. 2005) as well as photodissociation regions (e.g. Liseau et al. 1999) to derive their physical conditions. The study of the gas abundance in various regions is also interesting, providing a first opportunity to investigate the gas depletion, and thus the dust composition, in dense regions, which cannot be carried out by observations in the ultraviolet. Recent observations, in fact, indicate that the depletion of silicon seems to be low in active regions (e.g. Mizutani et al. 2004; Okada et al. 2003, 2006), suggesting that silicon may reside in rather volatile dust components. This effect should be taken into account in interpreting the infrared SED from the diffuse ISM as well as of external galaxies since the diffuse infrared emission originates mostly from active regions.

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Star formation activity and ISM properties in the Magellanic Clouds

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The Magellanic System offers an ideal laboratory to study how the interstellar medium evolves and how stars are formed at the unrivaled closeness to us. The formation of stellar clusters is one of the biggest issues in Astronomy. In our Galaxy, the currently formed clusters are only open clusters; no ”young” globular clusters have been observed. On the other hand, in the LMC, stellar clusters called ”populous clusters” are found to be forming at present. Comparative studies of young stars as well as the properties of giant molecular clouds both in our Galaxy and LMC are therefore of vital importance.

NANTEN telescope revealed the properties of about 300 molecular clouds in the Magellanic Clouds (Fukui et al. 2001; 2007 submitted). We find that about 76% of the GMCs are actively forming stars or clusters, while 24% show no signs of massive star or cluster formation in the LMC. These GMCs without high mass star formation are, on the other hand, rarely seen in the Galaxy. Effects of supergiant shells (SGSs) on the formation of GMCs and stars are also studied. The number and surface mass densities of the GMCs are higher by a factor of 1.5-2 at the edge of the SGSs than elsewhere. Some of the GMCs were observed in rotational transition lines of CO by using SEST, MOPRA, and ASTE to reveal the precise physical properties of the molecular gas (e.g., Minamidani et al. 2007 submitted). Sub-millimeter observations in the 460/810GHz bands were also carried out toward some of the molecular clouds by using NANTEN2 telescope.

Spizter/SAGE dataset provides most comprehensive and complete knowledge on the dust and YSO distributions in the LMCs (Meixner et al. 2006; Whitney et al. 2007 submitted). We also present the statistical comparison of the distribution of YSOs with that of CO molecular clouds detected by NANTEN CO survey throughout the entire galaxy (Onishi et al. 2007 in preparation). The distribution of SAGE sources with a cold spectrum shows good correlation with that of molecular clouds, indicating that these sources are good candidates for YSOs. Star formation activities in the molecular clouds were estimated, and we found that the star formation activity shows strong correlation with the cloud mass.

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Galactic PDRs: The millimeter view

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Photodissociation region (PDR) models are used to understand the evolution of the Far UV illuminated interstellar matter both in our Galaxy and in external galaxies. To prepare for the unprecedented spatial and spectral resolution provided by ALMA and Herschel/HIFI, chemical models are being benchmarked against each others http://www.ph1.uni-koeln.de/pdr-comparison/intro1.htm. It is obvious that chemical models also need well-defined observations that can serve as references. Photodissociation regions (PDRs) are particularly well suited to serve as references because they make the link between diffuse and molecular clouds, thus enabling astronomers to probe the largest variety of physical and chemical processes.

In this talk, I will discuss how several recent millimeter observations of a few Galactic PDRs (including the Horsehead PDR) compare with PDR models. I will emphasis the observational constraints (needs for observations at different wavelenghts, for observations at similar angular resolution, for an adequate knowledge of the geometry and physical parameters) to propose good observational templates to PDR models. I will describe what the current (IRAM, CSO, APEX,...) and future (Herschel, ALMA,...) generation of (sub)-millimeter instruments can or will achieve in PDR studies.

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Metallicity effects in PDRs

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How massive stars form from their parental clouds is one of the key questions in contemporary astrophysics. Its answer requires a well understanding of the physical interactions between stars and the ambient interstellar medium (ISM). The physical and chemical properties of stars are the heritage of their parental clouds. Stars are born from interstellar gas and release metal-enriched material to the ISM when they die. Radiation from the stars is the prime heating source for gas and dust in nearby molecular clouds and may additionally trigger velocity and density fluctuations, that stimulate further star formation. To understand the formation of these next generation stars, it is important to understand how the previous generation interacts with its parental clouds. The energy incident on the clouds in the form of stellar far ultraviolet (FUV: 6 eV$\leq h\nu \leq$ 13.6 eV) radiation is countered by cooling emission of atomic fine-structure lines and by molecular rotational lines. On their way into a molecular cloud, FUV photons are absorbed, and a depth-dependant chemical balance is established. Models of these so-called photon dominated regions (PDRs) are used to predict the chemical and physical conditions in the molecular clouds.

Almost all properties of a PDR depend on its metallicity. The heating and cooling efficiencies that determine the temperature of the gas and dust, the dust composition, as well as the elemental abundances that influence the chemical structure of the cloud are just three examples that demonstrate the importance of metallicity effects in PDRs. If we want to understand the star formation history of our own Galaxy and of distant low-metallicity objects we need to understanding how metallicity acts on PDR physics and chemistry.

The importance of the HCN/HCO+ ratio in PDRs and XDRs

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The nuclei of active galaxies harbor massive young stars, an accreting central black hole, or both. In order to determine the physical conditions that pertain to molecular gas close to the sources of radiation, numerical models are needed that determine the thermal and chemical balance of gas exposed to X-rays (1-100 keV) and far-ultraviolet radiation (6-13.6 eV), as a function of depth (e.g., Meijerink & Spaans 2005). We present a grid of XDR and PDR models (Meijerink, Spaans & Israel 2006, 2007; see http://www.strw.leidenuniv.nl/$\sim$meijerin/grid/) that spans ranges in density ($10^2 - 10^{6.5}$ cm^{-3}), irradiation ($10^{0.5} - 10^5 G_0$, $F_X = 1.6 \times 10^{-2} - 160$ erg cm^{-2} s^{-1}, $\zeta_{CR} = (5 - 500) \times 10^{-17}$ s^{-1}), and column density ($3 \times 10^{21} - 1 \times 10^{25}$ cm^{-2}). Predictions are made for the most important atomic fine-structure lines, e.g., [CII], [OI], [CI], [SiII], and for molecular species like HCO$^+$, HCN, HNC, CS and SiO up to $J = 4$, CO and ^{13}CO up to $J = 16$, and column densities for CN, CH, CH$^+$, HCO, HOC$^+$, NO and N_2H^+. We find, among others, that the line ratios HCN/HCO$^+$ and HNC/HCN, as well as the column density ratio CN/HCN, discriminate between PDRs and XDRs, as does highly excited CO ($J > 8$). In particular, the HCN/HCO$^+$ 1-0 ratio is < 1 (> 1) for XDRs (PDRs) if the density exceeds 10^5 cm^{-3} and the column density is larger than 10^{23} cm^{-2}. For modest densities $n = 10^4$ cm^{-3} and strong radiation fields (> 100 erg s^{-1} cm^{-2}), HCN/HCO$^+$ ratios can become larger in XDRs than PDRs. Also, the HCN/CO 1-0 ratio is typically smaller in XDRs, and the HCN abundance in XDRs is boosted only for high (column) density gas, with columns in excess of 10^{23} cm^{-2} and densities larger than 10^4 cm^{-3}. In this, the XDR/AGN contribution will typically come from a smaller (beam diluted) angular scale and a small PDR contribution can dilute XDR distinguishing features like HCN/HCO$^+$.

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Detection of ^{13}CO(6-5) in the Starburst Galaxy NGC 253

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We report the detection of ^{13}CO(6-5) towards the nucleus of the starburst galaxy NGC 253 with ZEUS, our submillimeter grating spectrometer. This is the first detection of a mid-J isotopic line of CO from an external galaxy. ZEUS is a long slit echelle grating spectrometer operating simultaneously in the 350 μm and 450 μm telluric bands. It utilizes a 1×32 array of thermistor-sensed bolometers delivering an instantaneous 16 element spectrum in both bands. The system has a resolving power of $\sim$1000, well matched to typical nuclear line widths. The observations of NGC 253 were made at the CSO in December 2006.

Our prior mapping of NGC 253 in the CO(7$\rightarrow$6) line together with an LVG model of the run of ^{12}CO and ^{13}CO line brightness with J indicated that most of the 2 to 5×10^7 $M_\odot$ of molecular gas in the inner 180 pc of NGC 253 is both very warm (T $\sim$ 120 K), and very dense (n(H_2)$\sim 4.5 \times 10^4$ cm^{-3}, Bradford et al. 2003). There is 10 to 30 times more warm molecular gas than atomic gas (as traced by the [CII] and [OI] lines) in photodissociation regions (PDRs). Such a large molecular to PDR gas mass ratio is inconsistent with PDR models where the gas is heated by far-UV starlight. We discuss other plausable gas heating sources including shocks from cloud-cloud collisions, X-rays, and cosmic rays. Cosmic rays can provide the heating, and it appears shocks and/or X-rays may strongly contribute as well. All of these mechanisms provide a natural means for heating the full volume of molecular gas.

The ZEUS/CSO detection of the ^{13}CO(6$\rightarrow$5) confirms and underscores these conclusions. With their smaller optical depths, the mid-J ^{13}CO lines sample deeper into the molecular clouds challenging the models. The observed line intensity is very near our model predictions, confirming that most of the molecular ISM is in the warm, dense component. So, the starburst in NGC 253 has heated the surrounding molecular clouds, inhibiting further collapse and starformation. Therefore the starburst in NGC 253 is self-limiting.

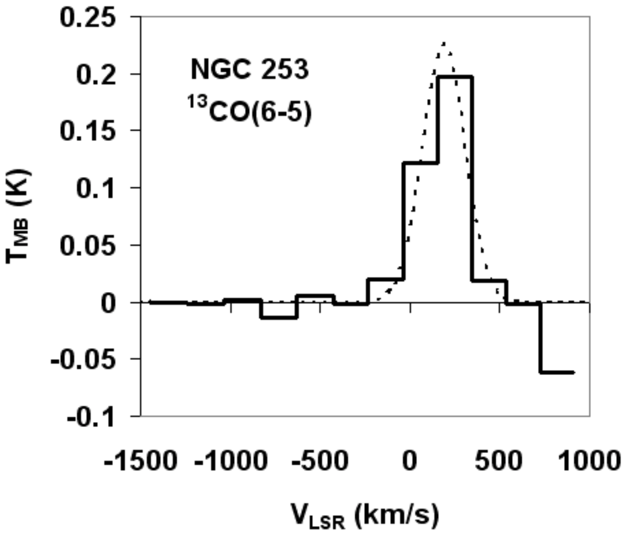

Figure 7: ^{13}CO(6-5) spectrum of the starburst nucleus of NGC 253

Molecular Line Emission as a Tool for Studying Distant Galaxies

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In standard cold dark matter cosmology galaxies form as baryonic gas cools at the centre of collapsing dark matter halos. Mergers of halos and forming galaxies within them are key drivers of the hierarchical growth of galaxy mass. The details of galaxy assembly are still unclear, however, and molecular line observations offer a unique tool for answering some of the many outstanding questions: When and how were the first disks formed? How are disk and bulge formatio related? What are the roles of feedback from energtic starbursts and AGN? How are central massive black holes grown? Many of these and other important questions will be answered by studying the distributions, dynamics and physical properties of the cool gas and dust. In this talk, I will focus on studies of galaxies at redshift 2-3, the epoch of the peak of star formation and QSO activity. I will attempt to assess the impact that ALMA will have by giving examples from ongoing studies of galaxies with current mm interferometers.

Large-scale shocks in galaxies

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The interstellar medium in starburst galaxies can be sweep by large-scale shocks driven by the same mechanisms that feed the star forming regions, as well as by the ensuing feedback processes. Galaxy interactions, density waves or star-triggered galactic winds can become major shock mechanisms at different stages of the starburst episodes and may affect the subsequent evolution of galaxies. These mechanical perturbations can process in particular the molecular interstellar medium, the ultimate fuel of stars. The imprints of large-scale shocks in the distribution, kinematics, excitation and chemical composition of the molecular gas provide several ways to identify the underlying mechanisms and to asses their effects.

In this talk we review some recent and on-going studies of the shock-driven molecular gas chemistry in nearby star-forming galaxies. Millimeter line observations show that the gas-phase abundances of molecules which are usually depleted onto grains (e.g. SiO, CH_3OH, sulfur bearing species) can increase by a few orders of magnitude across hundreds of parsecs. Such dramatical changes are ascribed to the enhanced disruption of grains caused by large-scale shocks. When mapped at high-spatial resolution the emission of those molecules reveals substantial differences among galaxies. The location of shocks, as inferred from the observations, depends on the dominant underlying mechanism and thus indicates the evolutionary stage of the starburst episode. Complementary observations of chemical shock tracers allow to characterize the large-scale shocks beyond the qualitative picture, constraining basic parameters like the shock velocity regime and the energy dissipation rate.

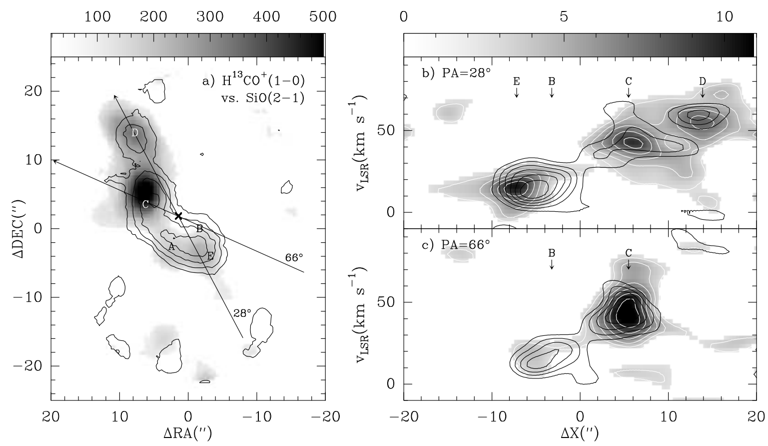

Figure 8: *Left:* SiO(2–1) (grey scale) and $H^{13}CO^{+}$(1–0) (contour) maps of IC 342. *Right:* Position-velocity diagrams of the same lines taken along the directions indicated in the left panel (Usero et al. 2006).

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Detection of extragalactic H_3O^+

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The hydronium ion H_3O^+ is a powerful probe of the oxygen chemistry and the ionization rate of dense circumnuclear gas in galaxies. We report the first detections of the H_3O^+ molecule outside our Galaxy. Using the JCMT, the 364 GHz line was detected toward the nuclei of the active galaxies M 82 and Arp 220. The line profiles suggest a location of the H_3O^+ in the Western nuclei of both galaxies, while some extended emission may exist in the case of M 82. By comparing the derived H_3O^+ abundances and H_3O^+ / H_2O abundance ratios to the results of PDR and XDR model calculations, we estimate the ionization rate of the molecular gas due to UV and X-rays, and compare the situation to that in the Galactic Center.

Millimeter signature of massive star formation at low and high redshifts

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In this talk I will review both theoretical and observational aspects of massive star formation in extragalactic environments from low to high redshifts. In our Galaxy, observations of molecular line emissions from hot cores, remnants of massive star forming regions, have allowed us to infer both the history of the star formation process and the details of the local physical and chemical conditions. I will show that, although observations of extragalactic star forming environments can potentially be used to infer the physical conditions in the gas at higher redshifts, the formation and properties of extragalactic hot cores (such as dust:gas ratio, metallicity, temperatures, radiation fields, elemental abundances etc) need to be carefully investigated. Since molecular observations at high redshift have only just recently started to be possible, nearby active galaxies, as well as interesting in their own right, may provide a low-redshift analogue of star forming systems in the early part of the Universe evolution.

Three Dimensional Molecular Line Transfer Study of Extragalactic ISM : AGN/Starbust Connection

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Molecular gas in external galaxies is a subject of crucial importance for observational and theoretical studies of galaxy formation. Among the interstellar medium (ISM) in external galaxies, compact molecular gas around an active galactic nuclei (AGN) is expected to be an energy budget from AGN and/or the central starburst. Recent observations suggest line ratios in millimeter and submillimeter band may be a good tool to reveal the long-standing question on the origin of activity – AGN or nuclear starburst. In spite of numerous observational studies towards the compact molecular gas or AGN torus at the center of external galaxies, current instruments have not succeeded in resolving internal hydrodynamical and/or thermal structures. We have constructed a powerful "telescope" of theory, three-dimensional nonLTE line transfer code, preceding the forthcoming high resolution and sensitivity observations, such as ALMA.

In order to study the internal structures of AGN molecular torus, we performed line transfer calculations of CO, HCN, and HCO^+ lines along with high resolution hydrodynamic simulation. We first examined models of uniform chemical structure as the simplest case, then considered the effect of X-ray from the central AGN (XDR model). Since hydrodynamical and thermal structures of an AGN molecular torus should be quite inhomogeneous, the intensity distributions of each line and the excitation temperatures also show complicated structure, even with uniform chemical abundance distribution. Our results of excitation temperatures show that line ratio $R_{\rm HCN/HCO^+} > 1$ is quite difficult to achieve unless fractional abundance of HCN is much greater than that of HCO^+, even if we take account of XDR chemistry. The results of high density tracer lines (HCN and HCO^+) demonstrates that when inhomogeneous ISM is subthermally excited and marginally thick ($\tau_0 \approx 1$), interpretation of observational results should be done carefully. For example, calculated intensity distribution shows a significant scatter around the intensity averaged over the field of view (64^2 pc^2 in our simulation). The stimulated emission can dominate the intensity in a part of the field of view, and in such a region molecular line intensity measures the excitation condition rather than the column density. These results emphasizes the ability and applicability of our approach, that is, the compilation of high-resolution hydrodynamic simulations and three-dimensional radiative transfer calculations. We will present our results of AGN molecular torus and implications for AGN/starburst connections as one of the first fruit of our "telescope" of theory.

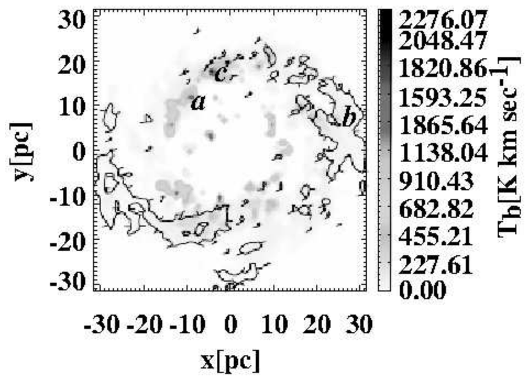

Figure 9: The integrated intensity distribution of HCN(1-0) line (gray scale) and $\tau_0 = 1$ region (contour) of the face-on model AGN torus. Three lines of sight at the points labeled a, b, and c correspond different circumstances, due to inhomogeneous torus structure and excitation condition.

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Abstracts of posters

A Millimeter Line Survey of Local ULIRGs with Z-spec: First Results and Prospects for Detection of High Redshift CO

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Z-spec [1,2,3,4] is a new, broadband, millimeter-wave, diffraction-grating spectrometer which covers the 1 mm atmospheric window between 185 and 305 GHz with a resolving power of 250 — 350. The detectors are 160 cryogenic micromesh bolometers. After extensive laboratory and telescope tests at the Caltech Submillimeter Observatory (CSO), Z-Spec performs well across the band 200 — 300 GHz, with sensitivities within a factor of two of the photon background limit. Furthermore, the instrument seems to integrate down in our longest observations to date (approximately 12 hours).

Z-spec was designed for the determination of the redshifts of high redshift, ultra-luminous dusty galaxies (commonly referred to as "submillimeter galaxies") by placing two CO lines in the band for $z > 1$. Z-spec's resolution and broad bandwidth are also well suited to line surveys of nearby galaxies, where ^{12}CO($2 \rightarrow 1$),^{13}CO($2 \rightarrow 1$),C^{18}O($2 \rightarrow 1$), HCN($3 \rightarrow 2$), HNC($3 \rightarrow 2$) and HCO^{+}($2 \rightarrow 1$) may all be detected simultaneously along with the dust continuum.

As a first scientific project, spectra were acquired on a sample of both starburst and AGN dominated ULIRGs, including Arp220, UGC5101, Mrk231, Mrk273, and NGC6240. We discuss the status of data reduction and preliminary results from the comparison of these galaxies.

Our next goal is the detection of CO in submillimeter galaxies. The CO excitation spectra of submillimeter galaxies have been measured in a few cases (e.g. [5]). Using this information and the instrument sensitivity as determined at the CSO, we discuss prospects for the detection of CO emission from submillimeter galaxies with Z-spec. I will also discuss possible algorithms for determining the redshift of a source from Z-spec data without prior knowledge ("blind detection").

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Hot core chemistry in extragalactic star formation regions

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Multi-wavelength studies completed by astrochemical models appear powerful and relevant tools to increase our knowlegde on the formation of stars in external galaxies, especially the most massive. In UCL and in the CESR, we developed these two complementary approaches to gather more information on the chemical and physical conditions taking place in the nearby and more distant star formation regions.

In UCL it has been developed an astrochemical model of hot core (Rawlings et al. 1992, Viti et al. 1999, 2001 and Lintott et al. 2005) based on a rich chemical network. This model predicts the chemical abundances relative to H2 of more than 200 species, especially the most complex as CH_3OH, CH_2CO, CH_3CN, C_2H_5OH, $HCOOCH_3$, H_2CO... already seen in the vicinity of Galactic hot cores. Understand better the extragalactic high mass star formation activity is one of the most excited work for the latest years. Results obtained are very interesting. In addition, they provide usefull tools for preparing future high-z observations with ALMA and Herschel.

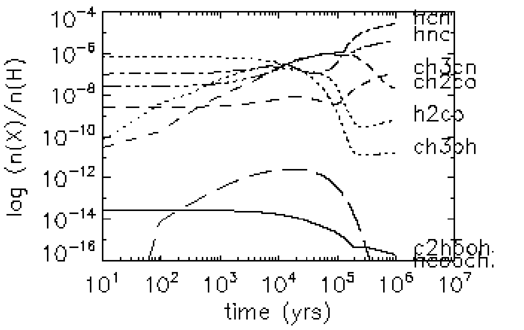

Figure 10: Example of relative abundances of various species for a standard galactic UCL hot core model, except the cosmic ray ionization rate value which is the tenth of the standard value. Varying input parameters (as metallicity, gas-to-dust ratio...) in the UCL hot core model we studied the influence of each on the derived hot core chemistry.

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Comparison of CO - PAH+/PAH0/VSG emissions in external galaxies

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Multi-wavelength studies completed by astrochemical models appear powerful and relevant tools to increase our knowlegde on the formation of stars in external galaxies, especially the most massive. In UCL and in the CESR, we developed these two complementary approaches to gather more information on the chemical and physical conditions taking place in the nearby and more distant star formation regions.

In the CESR, we performed, for the first time, in a sample of nearby galaxies, a comparison between the extragalatic dust-grains components emissions (ionized PAHs, neutral PAHs, VSGs, Spitzer IRAC 8μm - See Berne et al. 2007, Rapacioli et al. 2006, Witt et al. 2006) derived from Spitzer Space Telescope data with the extragalactic molecular gas emission usually traced by CO (Wilson et al. 2000, Bayet et al. 2004, Kramer et al. 2005 and Bayet et al. 2006). For M 82, we also compared these dust components emissions with extragalactic dense gas tracers emissions (HCO^+, $H^{13}CO^+$) from Garcia-Burillo et al. (2001) and Garcia-Burillo et al. (2002). We obtained superimposition at high angular resolution (< 5") showing very interesting results.

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Hot Molecular Gas in NGC 2024

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NGC 2024 is an HII region at a distance of 415 pc, which is embedded in the massive molecular cloud ORION B (L 1630). Hence it is one of the closest sights of high mass star formation. The ionizing source of the HII region, a late O or early B type star, is obscured by an ridge consisting of dust and molecular gas, which has an optical extinction of ~20 mag. Previous studies of this source have shown, that it exhibits a complex geometry including several components of ionized and molecular gas.

We present observations of velocity resolved ^{12}CO J=13-12 lines towards five selected positions in NGC 2024. These observations have been conducted using the CONDOR receiver (Wiedner et al. 2006) at the APEX telescope in November 2005. The ^{12}CO J=13-12 line enables us to investigate the physical conditions of the hot (several 100 K) and dense ($\sim 10^6$ cm^{-3}) molecular gas, which is expected to be located at the HII/PDR interface. Additional observations of ^{12}CO and ^{13}CO lines, we observed the J=6-5 and J=3-2 lines in both species, allow us to model the structure of NGC 2024.

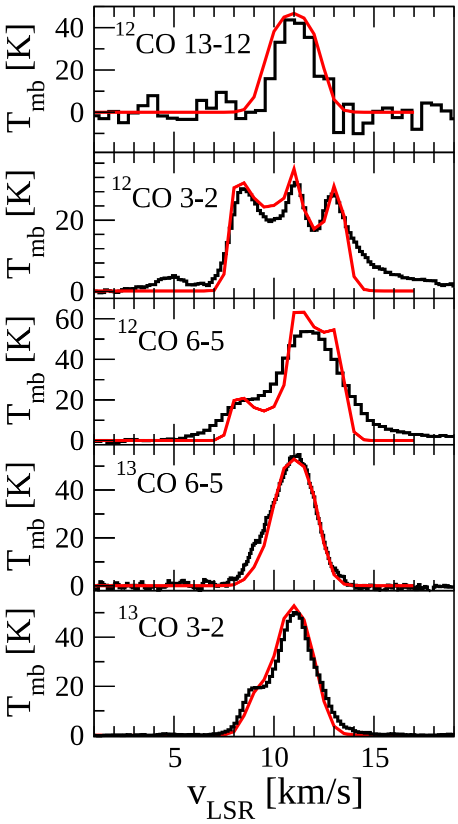

Figure 11: Observed (black) and modelled (red) spectra towards IRS 3 in NGC 2024.

To derive the physical conditions of NGC 2024, we modelled the observed emission lines towards IRS 3, which is the peak position of the high- and mid-J ^{12}CO lines. For modelling we used the radiative transfer code SimLine (Ossenkopf et al. 2001). Previously NGC 2024 has been modelled as a thin molecular cloud obscuring an HII region (e.g. Graf et al. 1993), which itself lies in front of a massive molecular cloud. The strong ^{12}CO 13-12 emission and the complex shape of the low-J CO lines (see Fig. 1) require at least two layers with different physical conditions both in the thin foreground and in the thick background cloud
One important conclusion of the modelling is that, besides a warm component ($T \sim 80$ K), which is known from previous studies, a second, hot ($T \sim 300$ K) gas layer is essential to explain the emission of the ^{12}CO 13-12 line. This gas layer is most likely located at the interface of the HII region and the molecular gas. Furthermore structures on sub-beamsize scale might play an important role.

This study shows, that the investigation of high-J CO line (i.e. $J_{up} > 10$) are an important tracer of the HII/PDR interface regions and therefore crucial for the understanding of the transition form ionised gas to molecular gas.

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CO 4-3 and [CI] 1-0 in Circinus and NGC4945

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Studying molecular gas in the central regions of the star burst galaxies Circinus and NGC 4945 enables us to characterize the physical conditions and compare to previous local and high-z studies (Hitschfeld et al. 2007).
We estimate temperature, molecular density and column densities of CO and atomic carbon. Using model predictions we give a range of estimated CO/C abundance. Using the new NANTEN2 4m sub-millimeter telescope in Pampa La Bola, Chile, we observed for the first time CO 4–3 and [CI] 1–0 in the centers of both galaxies at linear scale of 732 pc and 682 pc, respectively. We compute the cooling curves of ^{12}CO and ^{13}CO using radiative transfer models and estimate the physical conditions of CO and [CI].
The centers of Circinus and NGC 4945 are very [CI] bright objects, exhibiting [CI] 1–0 luminosities of 67 and 91 Kkms^{-1}kpc^2, respectively. The [CI] 1–0/CO 4–3 ratio of integrated intensities are large at 3.1 in Circinus and 1.23 in NGC 4945. Combining previous CO J= 1–0 , 2–1 and 3–2 and ^{13}CO J= 1–0 , 2–1 studies with our new observations, the radiative transfer calculations give a density $n = 10^3 - 3\times10^4$cm^{-3} and a wide range for the kinetic temperature $T_{\rm kin} = 20 - 100$K depending on the density (Fig.1). To discuss the degeneracy in density and temperature we study two representative solutions. In both galaxies the estimated total [CI] cooling intensity is stronger by factors up to $\sim 1 - 3$ compared to the CO cooling intensity. The CO/C abundances are 0.2-2, similar to values found in Galactic translucent clouds (Stark et al. 1994). Our new observations enable us to further constrain the excitation conditions and estimate the line emission of higher–J CO– and the upper [CI]–lines. For the first time we give estimates for the CO/C abundance in the center regions of these galaxies. Future CO J= 7–6 and [CI] 2–1 observations will be important to resolve the ambiguity in the physical conditions and confirm the model predictions (Fig.1).

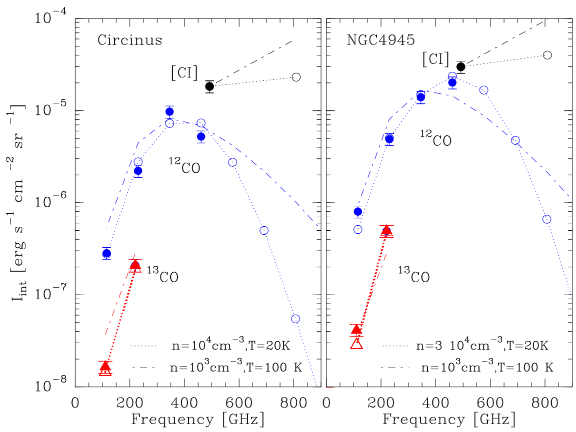

Figure 12: Filled symbols show the observed [CI] 1–0, CO 1–0, 2–1, 3–2, 4–3, and ^{13}CO 1–0, 2–1 data. Dashed lines show two solutions of the radiative transfer analysis. The [CI] 1–0 and CO 4–3 data are new detections with NANTEN2. Low-J ^{12}CO and ^{13}CO data were obtained by Curran et al. (1998, 2001) and Mauersberger et al. (1996).

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Cold cloud cores

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The fundamental aspects of star formation (stellar mass distribution, formation efficiency, clustered vs. isolated modes, evolution timescales, etc.) are closely linked to the initial conditions in the cold molecular cloud cores. The properties of the cores are still poorly known, partly because of the observational difficulties. At the stage when the star formation has not yet started the temperatures can be very low ($T_{\rm dust} << 15\,{\rm K}$) and the cores can be detected only at FIR or longer wavelengths. In these conditions most molecular species have frozen onto dust grains and only a few gas phase tracers are available for line observations.

I will present some observational results from line and continuum studies of cold cores. I will also discuss recent MHD runs that are being used to simulate the formation and properties of these objects. With the help of radiative transfer modelling predictions are being made of the total intensity and polarization of the sub-mm continuum emission that is detectable by future FIR and sub-mm satellites. I will briefly present plans for using the Planck and Herschel satellites to catalogue and study the Galactic cold cores.

ISM in nearby elliptical galaxies revealed by AKARI and Spitzer

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Elliptical galaxies provide a unique interstellar environment, i.e. old stellar radiation fields without active star formation and interstellar space mostly dominated by hot plasma. Far-infrared emission has been detected from many elliptical galaxies; the presence of cold gas in elliptical galaxies now appears to be the rule rather than the exception (e.g., Knapp et al. 1989; Temi et al. 2004; Kaneda et al. 2007a). The dust masses seem to be larger than those determined by the balance between replenishment by stellar mass loss and sputtering destruction by hot plasma, suggesting an external origin for the dust (Goudfrooij & de Jong 1995). Recent studies with *Spitzer* and *AKARI* suggest even the presence of polycyclic aromatic hydrocarbons (PAHs) emission features in dusty elliptical galaxies (e.g. Kaneda et al. 2005; Kaneda et al. 2007b). How can such small particles as PAHs survive in the hot plasma environment?

We present our recent results of *Spitzer* and *AKARI* observations of nearby elliptical galaxies. As an example, Figure 1 shows the mid- to far-infrared spectra of NGC 4589 that exhibit the presence of mid-infrared excess above the thermal dust continuum, unusual PAH emission features (i.e. faint 7.7 μm feature in contrast to prominent 11.3μm and 17μm features), pure rotational emission lines of molecular hydrogen at 28.22, 17.04. 9.67, and 6.91 μm, and strong atomic emission lines such as [Si II] 34.82 μm. We discuss the mid- to far-infrared properties of the ISM in elliptical galaxies as well as their spatial distributions relative to the stellar distribution, which will provide important clues to the origin and fate of the ISM, and thus trace the evolutionary histroy of the elliptical galaxies.

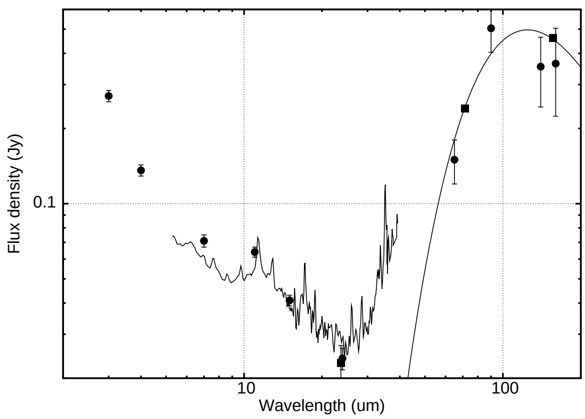

Figure 13: Spectral energy distribution of NGC 4589, constructed from *AKARI*/IRC&FIS and *Spitzer*/MIPS photometric data points, as well as *Spitzer*/IRS SL&LL spectra. The IRS spectra are scaled to match the AKARI photometric data points.

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Molecular diagnostics of (U)LIRGs: matching data and models

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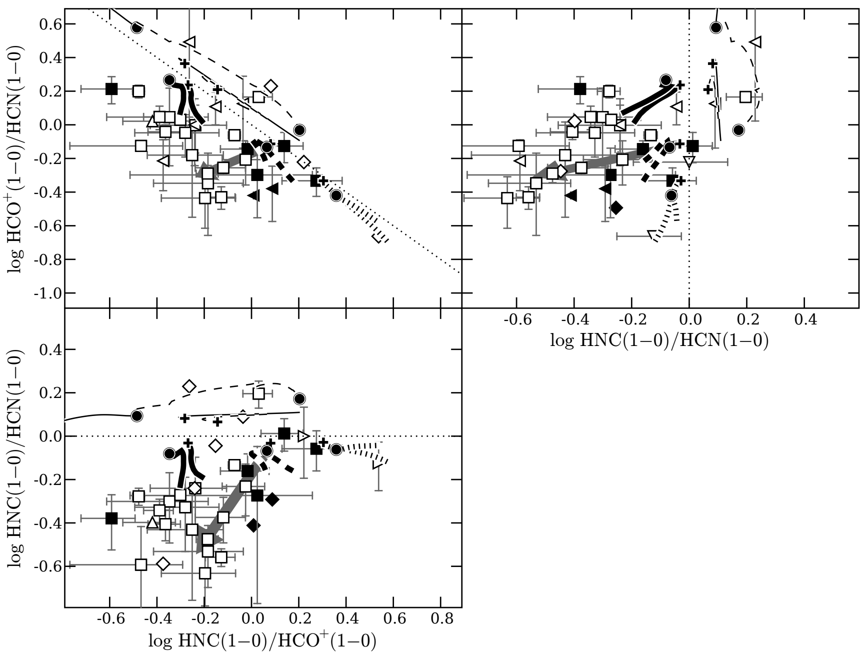
High- and low-density tracer molecules have been observed in (Ultra-)Luminous Infrared Galaxies in order to initiate multiple-molecule multiple-transition studies to evaluate the physical and chemical environment of the nuclear medium and the ongoing nuclear activity (Baan et al., 2007).

Comparing the $J = 1 - 0$ transition lines of different high-density tracers and their ratios to PDR and XDR models (Meijerink & Spaans, 2005; Meijerink et al., 2007) reveals information about physical characteristics of the gas. The HCO^+/HCN and HCO^+/HNC line ratios are good proxies for the density of the gas, due to the different critical densities of the species. PDR and XDR sources can be distinguished using the HNC/HCN line ratio: PDR sources all have ratios lower than unity and XDRs have ratios larger than 1 (see Figure).

A large number of sources show HNC/HCN ratios that are much lower than are achieved by the PDR-XDR models. In these sources the gas is heated by additional mechanical processes (e.g. shocks, winds, turbulence dissipation). At temperatures above 100 K (which are not reached in the pure radiative PDR and XDR models) HNC is converted into HCN (Schilke et al., 1992; Talbi et al. 1996). This HCN anhancement and HNC depletion is indicated by the grey arrow in the figure.



top left: Integrated HCO^+(1-0)/HCN(1-0) versus HNC(1-0)/HCO^+(1-0) ratios. *top right:* Integrated HCO^+(1-0)/HCN(1-0) versus HNC(1-0)/HCN(1-0) ratios. *bottom left:* Integrated HNC(1-0)/HCN(1-0) versus HNC(1-0)/HCO^+(1-0) ratios. Lines are results from the PDR (thick lines) and XDR (thin lines) models. Different line styles indicate different densities. The grey arrow indicates the effect of mechanical heating.

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FIR/submm studies of star formation at all scales in the Universe with bolometer arrays on ground-based telescopes

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Taking the Temperature in Starburst Galaxies — Formaldehyde as a Tracer of Extragalactic Molecular Gas

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There is growing evidence that the properties of the molecular gas in the nuclei of starburst galaxies may be very different from those seen in Galactic star forming regions. Unfortunately, among the fundamental parameters derived from molecular line observations, the kinetic temperature of the molecular gas in external galaxies is often not well determined due to a lack of suitable tracer molecules.

In this talk, we will show that selected transition lines of formaldehyde can be a powerful tool to derive the properties of extragalactic molecular gas. Formaldehyde (H_2CO) is a slightly asymmetric top molecule with a rich mm and submm line spectrum and can thus be used as a molecular thermometer as well as an excellent tracer of the molecular gas density. In addition, its ortho-to-para abundance ratio may shed light on the formation temperature of the dust grains.

As a proof of concept, we present the results of our multi-transition line study of the para-H_2CO emission from the prototypical starburst galaxy M 82. Using our large velocity gradient model, we tightly constrain the physical properties of the dense gas in the prominent molecular lobes, completely independent of the standard ”cloud thermometer” NH_3 or other molecular tracers. Our results agree well with the properties of the high-excitation molecular gas component found in the most comprehensive CO studies. Our observations also indicate the presence of methanol in at least one of the molecular lobes.

Mid- to Far-infrared Mapping Spectroscopy of Galactic Star-forming Regions with ISO, Spitzer, and AKARI

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We report the results of mid- to far-infrared spectroscopic observations of Galactic star-forming regions with three satellites, Infrared Space Observatory (ISO; Kessler et al. 1996), Spitzer Space Telescope (Werner et al. 2004), and AKARI (Murakami et al. 2007). From all the observations, we derived the spatial distributions of several emission lines or the far-infrared (FIR) continuum emission, providing the physical properties such as the density, radiation field strength, and the gas-phase abundance.

We have made mapping observations with the Infrared Spectrograph (IRS; Houck et al. 2004) on board Spitzer for 14 star-forming regions with Long-High module (18.7 μm–37.2 μm). We have detected [Si II] 35 μm at all the observed positions, [Fe II] 26 μm and [Fe III] 23 μm at more than half of the observed positions in most targets. Together with the previous observations, e.g. far-infrared spectroscopy with ISO (Okada et al. 2003, 2006), we derived the gas-phase abundance of Si and Fe as several tens of percent and several percent, respectively, of the solar abundance. The gas-phase Si abundance is much larger than that in cool interstellar clouds. This indicates the presence of dust grains with plenty of Si atoms and being destroyed easily by UV radiations from exciting stars (Okada et al. in preparation). In addition, we observed three regions also with Short-High module (9.9 μm–19.6 μm) and examine the physical properties further in these regions.

We also have made imaging spectroscopy with the Fourier Transform Spectrometer (FTS), which is the spectroscopic component of the Far-Infrared Surveyor (FIS; Kawada et al., 2007, Murakami et al., in preparation) on board AKARI by two array detectors of 3×20 pixels and 3×15 pixels covering the wavelength range of 60–110 μm and 110-180 μm, respectively. Two-dimensional maps of emission lines such as [O III] 88 μm, which traces highly ionized gas, have been derived. Especially, G333.6-0.2 has been observed both by Spitzer and AKARI, and physical properties are discussed in detail.

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Prospectives of PDR observations using Herschel

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Observations using the HIFI and PACS instruments aboard the Herschel satellite provide a unique way to study the chemical inventory and the energy balance in dense interstellar clouds heated by UV radiation (PDRs) or by shocks from massive stars.

The wide spectral coverage of the instruments allows to observe the key species in the chemical network, like CH or H_3O^+, in their ground states. This will solve many of today's puzzles in the interstellar chemistry. We propose to study a selection of Herschel unique lines from PDRs and shocks in a selection of prototype regions which are well characterized and studied at other wavelengths, enabling easy comparisons with sophisticated models.

With the spectral resolution of HIFI it will be possible to separate the role of shocks and PDRs, to study the dynamical structure of evaporating molecular clouds, to determine the gas pressure of the different components, and to distinguish between different structures within the telescope beam in these typically clumpy environments. For components which are well separated in velocity, the high spectral resolution of HIFI will virtually serve as a higher spatial resolution of the telescope. The Herschel observations are accompanied by ground-based observations for the CI, mid-J CO, and H_2 lines, the sub-mm continuum and other species that can be detected through the atmospheric windows.

The combination of line and continuum observations will allow to test the available models on the energy balance in the interstellar medium and to improve the understanding of the physical and chemical processes controlling the interaction between star formation and ISM evolution. The better understanding of the relevant microphysics and the calibration of the modeling tools using the data from the selected prototype sources will result in a significantly improved understanding of the modeling of the ISM in star-forming regions. This will provide a breakthrough in the interpretation of observations from more distant and complex objects, in particular external galaxies.

HNC and HCN in Seyfert Galaxies

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Bright HNC 1–0 emission, rivalling that of HCN 1–0, has been found towards several Seyfert galaxies. This is unexpected since traditionally HNC is a tracer of cold (10 K) gas, and the molecular gas of luminous galaxies like Seyferts is thought to have bulk kinetic temperatures surpassing 50 K. We propose 4 possible explanations for the bright HNC: (a) Large masses of hidden cold gas; (b) chemistry dominated by ion-neutral reactions; (c) chemistry dominated by X-ray radiation; and (d) HNC enhanced through mid-IR pumping. Our aims are to distinguish the cause of the bright HNC and to model the physical conditions of the HNC and HCN emitting gas.

We have used SEST, JCMT and IRAM 30m telescopes to observe HNC 3–2 and HCN 3–2 line emission in a selection of 5 HNC-luminous Seyfert galaxies. We estimate and discuss the excitation conditions of HCN and HNC in only two galaxies of our sample, - NGC 1068 and NGC 3079 - based on the observed 3–2/1–0 line intensity ratios. We also observed CN 1–0 and 2–1 emission and discuss its role in photon and X-ray dominated regions.

We summarize our results as follows: The J=3–2 transition line of HNC and HCN was detected in both galaxies NGC 3079 and NGC 1068. The HCN 3–2/1–0 ratio is lower than 0.3 in NGC 3079. The HCN/HNC 1–0 and 3–2 line ratios are larger than unity in both galaxies.

We conclude that in these two galaxies the HNC emissions emerge from gas of densities $n \lesssim 10^5\ \mathrm{cm}^{-3}$, where the chemistry is dominated by ion-neutral reactions. The line shapes observed in NGC 3079 show that this galaxie has no circumnuclear disk. In NGC 1068 the emission of HNC emerges from lower ($< 10^5\ \mathrm{cm}^{-3}$) density gas than HCN ($> 10^5\ \mathrm{cm}^{-3}$). Instead, we conclude that the emissions of HNC and HCN emerge from the same gas in NGC 3079. The observed HCN/HNC and CN/HCN line ratios favor a PDR scenario, rather than an XDR one, which is consistent with previous indications of a starburst component in the central regions of these galaxies. However, the $N(\mathrm{HNC})/N(\mathrm{HCN})$ column density ratios obtained for NGC 3079 can be found only in XDR environments.

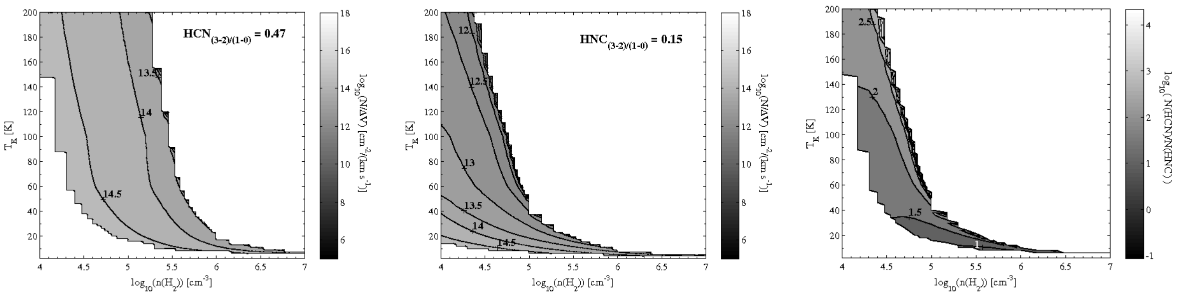

Figure 1 Excitation conditions modelled for the 3–2/1–0 line ratios of HCN (*left*) and HNC (*middle*) observed in **NGC 1068**. The conditions required for the HCN and HNC molecules overlap in a narrow region. The relative column densities in the overlap zone of the excitation conditions of these molecules is shown in the *right* plot. The optical depth in the whole region explored for HCN ranges between 0.03 and 10 in the J=1–0 line, and between 0.32 and 30 in the J=3–2 line. In the case of HNC the optical depth ranges between 0.01 and 30 in the J=1–0 line, and between 0.003 and 30 in the the J=3–2 line. The optically thin limit of both molecules and lines is depicted by the right edge of the excitation conditions, whereas the optically thick limit correspond to the left edge of the figures above.

Sub-millimiter observations of the N159W region in the Large Magellanic Cloud.

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We present high-angular resolution sub-millimiter observations in the N159W region in the Large Magellanic Cloud (LMC) obtained with the NANTEN2 telescope. We present detections of the ^{12}CO $J = 4 \rightarrow 3$, $J = 7 \rightarrow 6$, and ^{13}CO $J = 4 \rightarrow 3$ rotational and [C,I] $^3P_1-^3P_0$ and $^3P_2-^3P_1$ fine-structure transitions. The ^{13}CO $J = 4 \rightarrow 3$, ^{12}CO $J = 7 \rightarrow 6$, and [C,I] $^3P_2-^3P_1$ transitions are detected for the first time in the LMC. We derive physical properties of the low-metallicity molecular gas using an escape probability code and a self-consistent solution of the chemistry and thermal balance of the gas is given using a photon-dominated region (PDR) model. Our analysis indicates that the molecular gas in the N159W region have temperatures about 80 K and densities between $10^{4.5}$-10^5 cm^{-3}, i.e substantially higher densities than previously reported in this region.

Expanding Cloudy with Third-Party Databases

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Recent improvements to the plasma simulation code Cloudy will allow the inclusion of model ions and molecules from third-party databases. These models will have important effects on Cloudy predictions at a wide variety of conditions and energies. Here we present a few first results of this work by focusing on the far infrared spectra of molecular clouds and comparing with standard benchmarks. (Presented by R. L. Porter.)

Heating the interstellar medium of spiral galaxies via PDRs

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For three prototypical spiral galaxy objects, a variety of CO line observations is modeled in conjunction with atomic fine structure lines and many other data from low-frequency radio to X-ray emission: The centre of the 'normal spiral' IC342 (Schulz et al. 2001), the starburst galaxy M82 (Mao et al. 2000), and the merging system of the Antennae galaxies (NGC4038/39, Schulz et al. 2007). Classical LVG models to fit the CO observations (disregarding the atomic lines) either fail completely or give results for the physical parameters of the molecular gas which are meaningless or discrepant to other investigations. On the other hand, many infrared observations show evidence of widespread PDRs (Photon Dominant Regions) existing in these objects. Our applied PDR models yield - regardless of the used cloud geometry - in all three cases consistent fits of the observed CO line ratios (up to the CO (7-6) transition observed in M82) constraining well the physical parameters of the molecular gas which is highly clumped allowing the interstellar radiation field to penetrate the clouds through large distances. For the central clouds of IC342, the obtained inner CO cloud temperatures match the low temperatures derived from HCN observations tracing much denser gas. Furthermore, for all three objects the model results also agree with observations of atomic fine structure lines, particularly [CII]. The [CII] line luminosity extrapolated from observations of the Galactic Centre is in accordance with the value obtained for IC342 where the observed area is very much larger. Other properties of the molecular clouds in the centre of IC342 appear also to be very similar to those of our Galactic Centre.

The analysis shows that even for the merger system of the Antennae galaxies PDRs appear at the present to be the major heating source for the ISM compared to shocks, cosmic rays or other heating sources, although initially most of the energy released in this system should stem from cloud collisions. But shocks have small dissipation times whereas the B stars providing the soft UV radiation causing the PDRs are living for much longer time. Regarding the successful PDR modelling in such different types of spiral systems and also in view of similar investigations in other spirals (e.e. see Kramer et al. 2005), we should expect that PDRs considerably contribute to the heating of the ISM in spiral galaxies.

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The PDR structure of the Monoceros Ridge in the Rosette Molecular Cloud

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The Rosette H II-region/molecular cloud complex at 1.6 kpc distance (Williams et al. 1995) harbors the OB cluster NGC 2244, which, at a projected distance of 20 pc from its center, creates a number of prominent edge-on PDR interfaces at the border of the Rosette molecular cloud (Schneider et al. 1998a,b). In preparation of the Herschel/HIFI guaranteed time key project (WADI: the Warm and Dense ISM) to study PDRs over a wide range of physical parameters (e.g., density and FUV field), we are building a comprehensive data base on Galactic PDR observations. Due to its edge-on geometry, small distance, and FUV radiation field of $\sim$100 times the interstellar radiation field, the Monoceros Ridge interface is one of the targets for WADI as it covers the so far poorly observed moderate UV field regime.

In this poster, we give an overview of the Monoceros PDR and present the data obtained so far in context with optical (DSS), far-infrared (C^+, KAO), and mid-infrared (Spitzer) imaging of the region. The new data include mapping observations in CO isotopomeric lines (IRAM 30 m, APEX, and NANTEN2) and cuts through the interface in a variety of chemical tracers and transitions: HCN, HNC, HCO^+, CN, CCH, and CS, in some cases including rarer isotopomers (IRAM 30 m and APEX).

These data will be the basis for a detailed analysis of the structure, excitation, and chemistry of the PDR/molecular cloud gas in the Monoceros Ridge PDR. As a first results, we do find evidence for a layered structure perpendicular to the impinging UV radiation in selected chemical and excitational tracers.

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A Multiline Study of the Cepheus B Molecular Cloud

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We report first results from a multi-line study of the photo chemistry in the molecular cloud interfaces of the nearby star forming region Cepheus B, representing PDRs exposed to UV field of 10^2 - 10^3 G_0 estimated from the FIR continuum (Mookerjea et al. 2006).

Following up on our previous studies (Beuther et al. 2000; Ungerechts et al. 2000; Masur 2005; Mookerjea et al. 2006) of the PDRs in Cepheus B, the aim of the present chemical survey is to resolve the temperature, chemical, and excitation structure of the transition zone from the HII region to the dense molecular cloud.

The study has been conducted with the IRAM 30 m telescope at frequencies between 85 and 272 GHz. We have detected 23 transitions of HCN, HCO^+, CS, CN, HNC, C_2H, **c**-C_3H_2, HC_3N and HCO including the minor isotopic species of the first three species. We conducted two cuts through the interfaces into the main cloud (Fig. 1) and selected two positions at the interface for deep integrations. Data at the two cuts were combined with low - J ^{12}CO, ^{13}CO, and $C^{18}O$ IRAM-30m maps (Ungerechts et al. 2000).

In a first step, we estimate the relative abundance of each molecule along the cuts assuming Local Thermodynamic Equilibrium (LTE). Detailed PDR models provide a self-consistent picture of the physical and chemical structure.

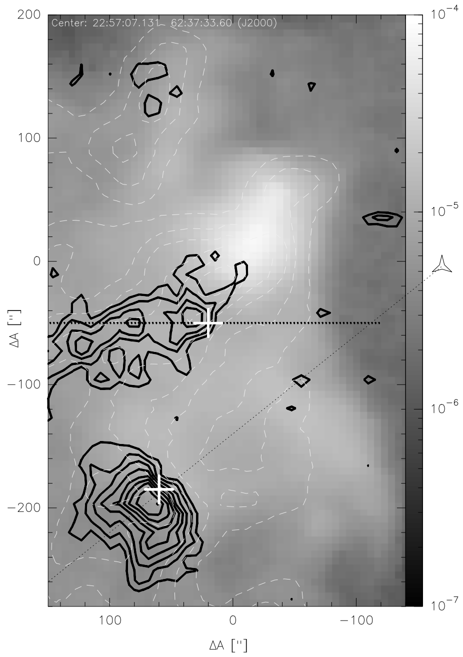

Figure 14: The MSX 8 micron PAH map of the Cepheus B PDRs overlayed by $C^{18}O$ 1–0 (black contours) and ^{12}CO 1–0 (white dashed contours). The two dotted lines indicate the cuts we observed. The two white crosses show the two interface positions. One of the illuminating stars, HD 217061, is denoted by an open triangle.

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NRO 45 m and ASTE 10 m observations of dense gas in giant HII regions of M 33

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Giant or supergiant HII regions (hereafter referred to as GHRs) are one of the most prominent objects in star-forming galaxies at the optical wavelength (Kennicut 1984). Central star clusters in GHRs appear to have formed during the initial stages of the formation of GHRs, and are expected to have a strong impact on their natal molecular clouds due to their strong UV radiation, stellar wind, and supernova explosion. Therefore, GHRs provide us with an ideal environment to understand the clustered OB star formation process, and their impact on the ambient interstellar medium (ISM). These physical processes are also crucial in the evolution of starburst in galaxies.

To address this issue, we present the ^{12}CO(J=3–2) and ^{12}CO(J=1–0) observations of NGC 604 in the nearest face-on spiral galaxy M 33 using the Atacama Submillimeter Telescope Experiment (ASTE) 10-m and the Nobeyama Radio Observatory (NRO) 45-m telescopes (Tosaki et al. 2007).

We found a high CO(J=3–2)/CO(J=1–0) ratio gas with an arc-like distribution (“high-ratio gas arc”) surrounding the central star cluster of the supergiant HII region NGC 604. The discovered “high-ratio gas arc” extends to the south-east to north-west direction with a size of $\sim$ 200 pc. The western part of the high-ratio gas arc closely coincides well with the shells of the HII regions traced by Hα and radio continuum peaks. The CO(J=3–2)/CO(J=1–0) ratio, $R_{3-2/1-0}$, ranges between 0.3 and 1.2 in the observed region, and the $R_{3-2/1-0}$ values of the high-ratio gas arc are around or higher than unity, indicating very warm ($T_{\rm kin} \geq$ 60 K) and dense ($n_{\rm H_2} \geq 10^{3-4}{\rm cm}^{-3}$) conditions of the high-ratio gas arc. We suggest that the dense gas formation and second-generation star formation occur in the surrounding gas compressed by the stellar wind and/or supernova of the first-generation stars of NGC 604, i.e., the central star cluster of NGC 604. Thus, NGC 604 is an example of a large-scale sequential star formation.

We also present new results of (1) high resolution ^{12}12CO(J=1–0), HCN(J=1–0), and 3 mm continuum observations of NGC 604 region using Nobeyama Millimeter Array, and (2) wide field CO(J=1–0) and 1.1 mm continuum observations of other GHRs in M 33 using NRO 45 m and ASTE 10 m telescopes.

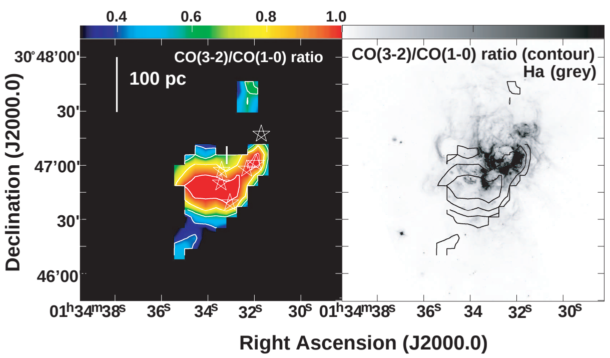

Figure 15: Maps of the ratio of ^{12}CO(J=3–2) to ^{12}CO(J=1–0) (left panel) and the Hα emission by HST (right panel; from the HST archive). The contour levels are 0.4, 0.6, 0.8, and 1.0. The crosshairs in the center indicate the position of the central star cluster of NGC 604, while the stars represent the peak positions of the HII regions detected by λ 3.6-cm radio continuum emission (Churchwell and Goss. 1999).

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Modeling X-ray ionization of grains and molecules with Cloudy

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X-rays are present in many PDRs. E.g., it is well known that many star-forming regions are X-ray sources, but also in PDRs surrounding hot planetary nebulae and in the molecular torus around AGN, X-rays should be ubiquitously present. The X-rays can easily penetrate through ionized gas as well as dust to reach the PDR. A versatile PDR code should therefore be capable of including the effects of X-rays in the modeling. These include inner-shell photoionization and Compton recoil. These processes have been treated by Cloudy for atomic species for many years. We are currently in the process of extending this treatment to grains and molecules. This can be done by treating the grains and molecules as a collection of atoms and using atomic data to calculate the appropriate cross sections. The treatment for grains largely follows Weingartner et al. (2006). The work for molecules follows a similar approach. In my paper I will discuss the progress in more detail and present first results.

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CONDOR Observations of CO J=13-12 Emission from Orion KL

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The 1.5 THz (200 μm) heterodyne receiver, **CONDOR** (**CO N$^+$ D**euterium **O**bservations **R**eceiver), was installed on the APEX telescope in November 2005. [For a description of CONDOR, see Wiedner, *et al.* (2006) and the contribution by Wiedner, *et al.* to this conference.] We present CONDOR observations of CO J=13-12 emission from the Orion KL region in OMC-1. We obtained spectra from 11 positions in a cross pattern centered on Orion IRc2. Because of CONDOR's high spatial ($\theta_{MB} < 5''$) and spectral resolution, we can decompose the spectrum into a narrow "spike" component ($\Delta V = 5$ km s^{-1}), a "hot core" component ($\Delta V = 13.5$ km s^{-1}), and a "plateau" component, and analyze these components individually.

The spike component is detected at all positions except 60$''$ north of IRc2, suggesting that the area of the PDR on the front surface of OMC-1 decreases in CO lines further up the J ladder. We find the strongest spike components at positions to the south and east of IRc2, i.e. closer to the Trapezium stars, which energize the PDR. The gradient in spike velocities from north (9.7 km s^{-1}) to south (10.7 km s^{-1}) is similar in magnitude and orientation to that observed in lower-J CO lines (Marrone, *et al.* 2004). By comparing spike components in several CO datasets (Marrone, *et al.* 2004, Wilson, T., *et al.* 2001, Boreiko, *et al.* 1989), we also detect a velocity gradient along the line-of-sight, which suggests that the hotter material traced by higher-J CO lines recedes more rapidly than the cooler material deeper within the Orion Ridge. Modeling the $J_{up} > 13$ CO emission in the spike with a homogeneous, isothermal cloud layer yields characteristic temperatures of $T_{kin} = 340 \pm 50$ K, densities of $n(H_2) = 3.3 \pm 0.5 \times 10^7$ cm^{-3}, and column densities of $N(\mathrm{CO})/\Delta V = 1.5 \pm 0.1 \times 10^{16}$ cm$^{-2}/\mathrm{km\ s}^{-1}$. The more realistic KOSMA-τ model, which describes the PDR surface as an ensemble of UV-irradiated clumps, indicates that the CO line intensities can only be produced by dense ($\langle n(H_2)\rangle > 10^{5.5}$ cm^{-3}) clouds within a UV field $\geq 10^5 \chi_0$. Measurements of the plateau out to ± 40 km s^{-1} of V_{LSR} agree with the trend in line wing velocities of lower-J CO observations (Rodríguez-Franco, *et al.* 1999, Schulz, *et al.* 1995). However, more complete spatial sampling is necessary to determine the extent and morphology of the core and plateau in high-J CO emission.

These observations demonstrate the utility of CONDOR, as well as the promise of high-resolution THz astronomy from ground-based observatories.

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FarIR Astronomy with the CO N^+ Deuterium Observations Receiver (CONDOR)

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To this data there are very few astronomical observations at THz frequencies (1-10 THz,300μm-30μm) at high spectral resolution. This is partly due to the poor (Earth) atmospheric transmission at these frequencies, partly due to the difficulties in building heterodyne receivers above 1 THz. However, this frequency regime harbors a multitude of astronomically interesting molecular and ionic transitions. The excitation energy of these lines mostly lie between a few tens to a few hundred Kelvin, low enough to be excited in the warm to hot interstellar medium. Therefore high spectral resolution observations at THz frequencies provide an ideal tool to study the chemical and kinematic properties of the ISM, e.g. in star forming regions.

Currently, there are only two operating THz heterodyne receivers in use, one on the Receiver Lab Telescope (RLT), the other is CONDOR, our CO N^+ Deuterium Observations Receiver. CONDOR has successfully obtained first light observations in Nov 2005 on APEX. A modified CONDOR will be the low frequency extension of the German REceiver At THz-frequencies (GREAT), which has been selected as one of the two first flight instruments on the Stratospheric Observatory For Infrared Astronomy (SOFIA).

CONDOR was built with a focus on studying star formation processes. It covers a frequency range of 1.25 to 1.53 THz (240μm - 196μm) and can simultaneously observe 0.8 GHz (about 160 km/s), hopefully soon 2 GHz (400km/s). As it is a front end receiver only, the spectral resolution depends on the backend used, but usually lies around 100 kHz (0.02 km/s). Technically CONDOR resembles standard submillimeter heterodyne receivers. However, there are two particular challenges to be overcome when working at the THz range: As the standard SIS mixers do not work at those high frequencies, we use Hot Electron Bolometer (HEB) fabricated in-house (Munoz et al. 2004). Secondly, because there is little Local Oscillator (LO) power available at THz frequencies, we employed a Martin Puplett interferometer, in order to overlay the LO with the sky signal with very small losses. CONDOR has a DSB receiver temperature of 1500 K, which is among the best reached for THz receivers.

The name CONDOR suggests, which molecules/ions we are most interested in observing: the high-J CO transition lines (J 11-10, 12-11, 13-12), the fine structure line of N^+ at 205μm and the ground transition of p-H_2D^+. The high-J CO lines trace hot (E_{up} $\sim$500 K), dense (ρ_{crit} $\sim$$10^7$cm^{-3}) molecular gas, as it can be found in high mass star forming regions. The N^+ emission at 205 μm is the third strongest emission line in the Milky Way in the range of 104 to 4400 μm ($\sim$ 3 - 0.1 THz) (Fixsen, Bennett, & Mather 1999). The emission probably stems from the Warm Ionized Medium as well as from HII regions. In cold molecular environment H_2D^+ is the key molecule for deuterium chemistry, as all deuterated molecules are formed via H_2D^+. In addition,it is one of the few molecules not to freeze out and it is therefore one of the last remaining molecular tracers in the cold ISM.

At the conference, we will show a poster explaining the science goals of CONDOR. Volgenau's poster (see separate abstract) will present the first results obtained by CONDOR during our observations at APEX in Nov 2005. If space permits, there will also be a poster with the technical details of CONDOR.

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