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Spectroscopy of Galaxies in the Nearby Universe with Herschel

A brief review of recent results

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Overview

- Herschel's Spectroscopic Capabilities
- Low Metallicity Dwarfs

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- FIR emission from Metal Cooling Lines
- Molecular Coolants: From Spitzer to Herschel
- Building understanding towards High Redshift



Herschel's Three Spectrometers





[CII]

[OI]

[OI]







SOME KEY FIR LINES Observable with Herschel

Important cooling line of the atomic gas. Warm neutral gas, shocked regions, PDR

Other important Fine Structure lines

[NII] 122 μ m [NII] 205 μ m [NIII] 57 μ m [OIII] 52 μ m (Detectable with PACS if z>0.1)

[OIII] 88 µm

158 µm

145 µm

63 µm

Many molecular species including CO, H₂O Rotational lines 0.5 to 1.5 THz range











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PAC



Low Metallicity Dwarf Galaxies

The SPIRE Local Galaxies Working Group (SAG 2) And PACS: SHINNING

Thanks to: Suzanne Madden and especially Diane Cormier













NGC 4214 : ratio maps

[O III] 88 / [CII] 158 with C II 158 contours

[O I] 63 / [CII] 158 with C II 158 contours



36.340 2 36.350 4

-0 The [O III] 88 μm line traces the sources of ionization [OIII]/ [CII] ~ 2 ..much larger than dusty startburst (M82 ~ 0.8)

[OI] and [CII] have similar distributions Suggests [CII] follows PDRs in this galaxy





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Low metallicity environments, higher 158µm [CII] / CO observed Less dust attenuation => may reduces the CO core



Normal galaxy

Low metallicity galaxy may have much larger volume of dissassociated molecular envelope—high PDR volume

CII

CO

CII

CO

Cormier, Madden, Hony, Contursi, Politsch et al. (2010)





CII

CO









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DUSTY STARBURST SYSTEMS OF HIGHER METALLICITY

 M82 PACS/SPIRE AND HIFI
 STARBURST RING IN NGC 1097 PACS SPECTROSCOPY





Metal Cooling in Starburst Environments

e. g. PACS MAPPING of M82

A. Contursi and the SHINING TEAM

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Full sampled PSF mapping [CII] @ 158 μm [OI] @ 145 and 63 μm



2.5







Figures adapted from Contursi et al. pesentation at ESTEC last week



Line ratios vary in minor-axis outflows





lonized/neutral

outflow

medium emphasizes

[OI] and [CII] probably follow PDRs in disk with clumps in outflow

Cesa_

RICH DATASET: SHOWS THE TREMENDOUS POTENTIAL OF PACS SPECTROMETER







Modeling the CO Ladder in M82



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Prominent CO ladder along with [C I] and [N II] lines. Modelling of CO lines clearly indicates the presence of a warm gas component at ~550K in addition to the cold (~25K) component found by ground-based studies. The temperature and mass of warm gas are in agreement

with the H₂ rotational lines observations from Spitzer and ISO.

H₂ is the dominant coolant instead of CO

Turbulence generated by stellar winds and supernovae may be the dominant heating mechanism.















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 Strength of H2O⁺ Molecular species is exciting result (see also later for Mk 231) In M82 Weiss et al. conclude the H2O⁺ comes from a diffuse component perhaps related to PDRs

Observations of H2O⁺ molecules might provide quantitative information about molecular reaction rates in the presence of other excitation processes such as Cosmic Ray heating, Shocks etc in these high-pressure starburst environments. More results from HexGal on new systems is eagerly anticipated!

















NGC 1097: a late-type spiral with a prominent bar and starburst ring

(From Beirai, Armus, Appleton et al.. 2010 and the KINGFISH collaboration-PI Kennicutt)

D ~19 Mpc Low luminosity AGN





















Hifi

minsc



SPIRE



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n<10³ cm⁻³: [OI]/ [CII] traces mainly radiation field intensity
Effects of infalling on shockedheating of [OI] small

PACS

I]/[CI)~200 sumi









SPIRE

Velocity field [OI]



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- Rotation velocity: +-220 km s⁻¹
- Consistent with Hα (Fathi et al. 2006) and CO 2-1 (Hsieh et al. 2008)

SEE ALSO MOVIE AT END?

PACS

minsc



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OUTFLOWS and MOLECULES













NGC 4418- A heavily Obscured ULIRG



Spitzer IRS spectra by Henrick Spoon et al. IRS Spectrum shows extremely strong Silicates & Frozen Water Ice + Crystalline Silicates and High-density molecuar features (acetlyne and HCN)















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SPIRE

PACS



FINALLY—Mk 231

Most luminous ULIRG in local universe



PACS SPECTA SHOWS EVIDENCE FOR SPECTACULAR OUTFLOWS in OH and maybe also in some H2O lines!

J. Fischer et al. (2010) and SHINING TEAM



Estimate outflow mass of $7x10^7 M_{\odot}$ outflow velocities of -1400 km/s Mechanical energy $\ge 10^{56}$ ergs Outflow may indicate clearing of molecular cocoon

Unusually high ratio ${}^{18}\text{O}/{}^{16}\text{O}$ in outflow > 10 time solar (after correction CH⁺ contamination) This could be due to a top-heavy IMF? (Fischer et al 2010).





SPECTACULAR RESULST FROM SPIRE TOO!! Gonzalez-Alfonso et al. (2010) and Van der Werf et al. (2010)

HerCULES Herschel Comprehensive ULIRGS Emission Survey



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High level CO transitions need additional heat source

PDRs cannot explain shape of profile without overpredicting the FIR flux.

XDR from AGN is good explaination

Very powerful H20+ and OH+ detected 1/3 strength CO













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WATER LINES IN Mk 231

7 rotational H2O lines : Extremely strong emission lines

Data does not favor a classical ensemble of PDRs.

The strength of the upper level transitions are favored over the lower level ones >> Suggests IR pumping of upper levels

Observations suggest a multi-phase medium with H2O in three different phases.

The IR pumping actually constrains the power coming from a compact source—which would have to have 40% of the total bolometric luminosity of Mk 231











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We are learning at lot from Herschel already in JUST 1 year!!

THESE WILL FEED INTO OUR UNDERSTANDING OF HIGH-z OBJECTS

LIKE z = 6.42 QSO J1148+5251 DETECTED IN [CII] and CO (6-5)!



Fig. 3 *Top:* first detection of [CII] at high redshift in the z = 6.42 QSO J1148+5251 (Maiolino et al. 2005). *Bottom:* brightest CO transition (J = 6) in the same source (Bertoldi et al. 2003; Walter et al. 2003). Note that the [CII] line is brighter by a factor of ~ 5

[CII] from Maiolino et al. 2005, CO (Bertoldi et a;. 2003, Walter (2003)













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Thanks also to the many teams that I have tried to represent here.





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We live in exciting the offered of the sector of the secto

Hifi







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THE END









