Dust in PDRs with Herschel: the Orion Bar

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Key project : Evolution of interstellar dust

Survey of the properties of interstellar dust with different conditions

Av, Illumination, Density, History, Star forming activity

To look at the contribution of all processes acting on dust particles

Fragmentation, Coagulation, Condensation, Evaporation, Photo-processing

From very diffuse regions to sites of star formation in the Milky Way

Combination of spectroscopy and mapping (PACS and SPIRE)

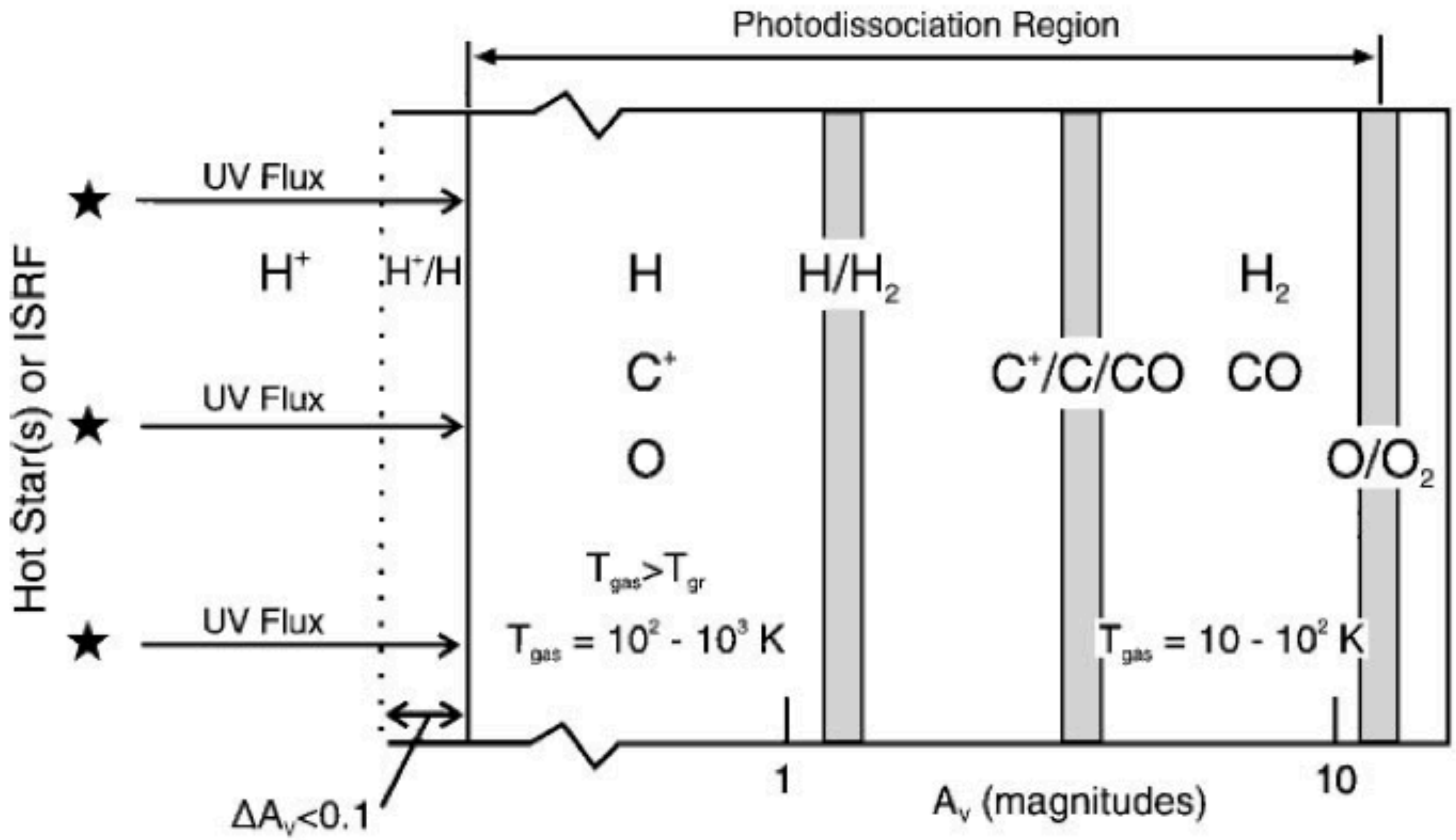
Dust SED : Continuum

Physical conditions : mainly CI, CII, OI, high-level lines of CO

Strong emphasis on the spatial information within individual objects

Photodissociation regions (PDRs)

Regions dominated by radiation
Radiation field intense enough to dissociate molecules without ionizing H
Interface between HII regions and molecular clouds

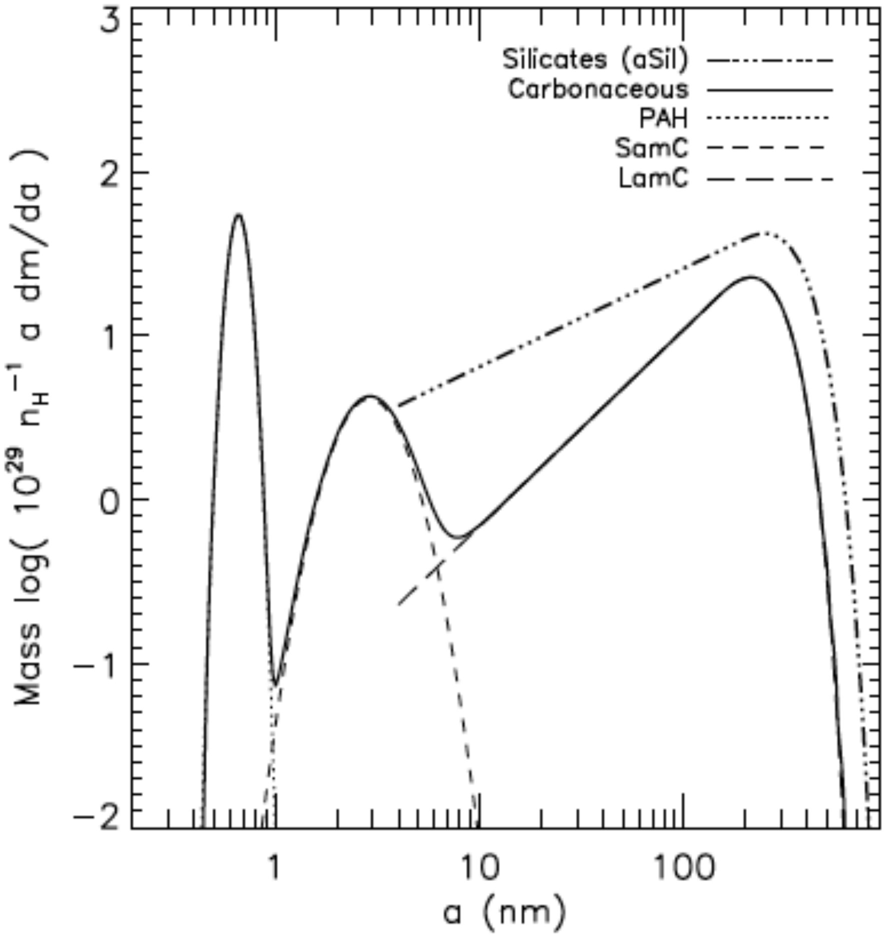


Hollenbach & Tielens (1997)

DustEM model

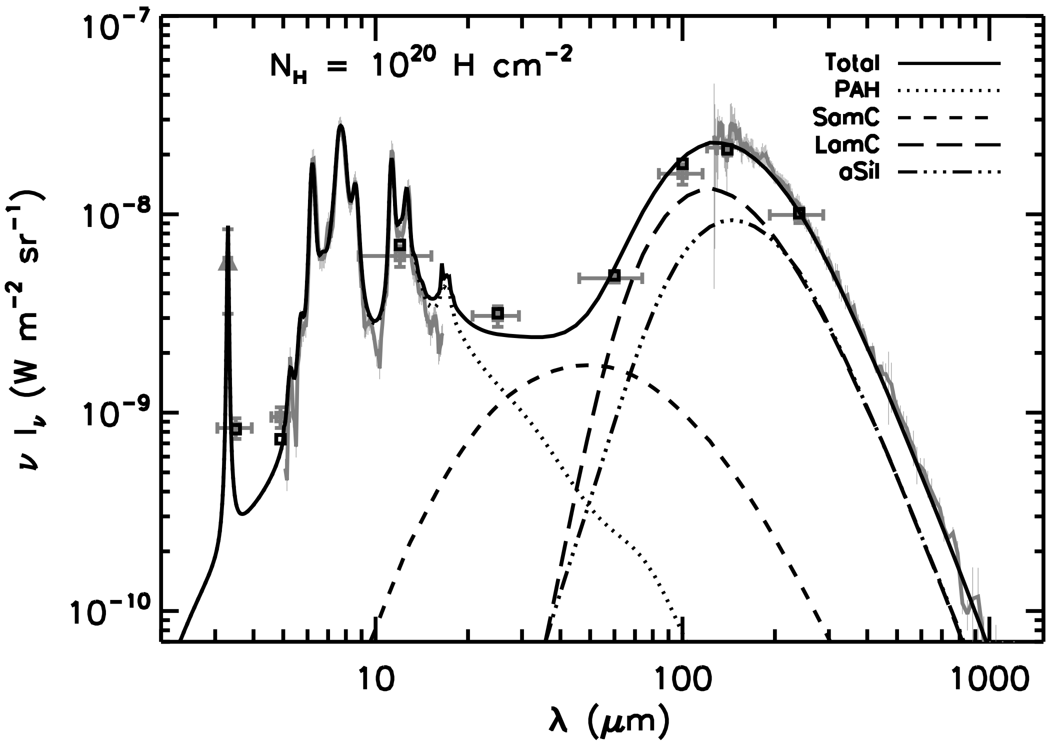
Numerical tool described in Compiegne et al. (2011)
computes dust extinction and emission
available at http://www.ias.u-psud.fr/DUSTEM/

Diffuse High Galactic Latitude dust model:

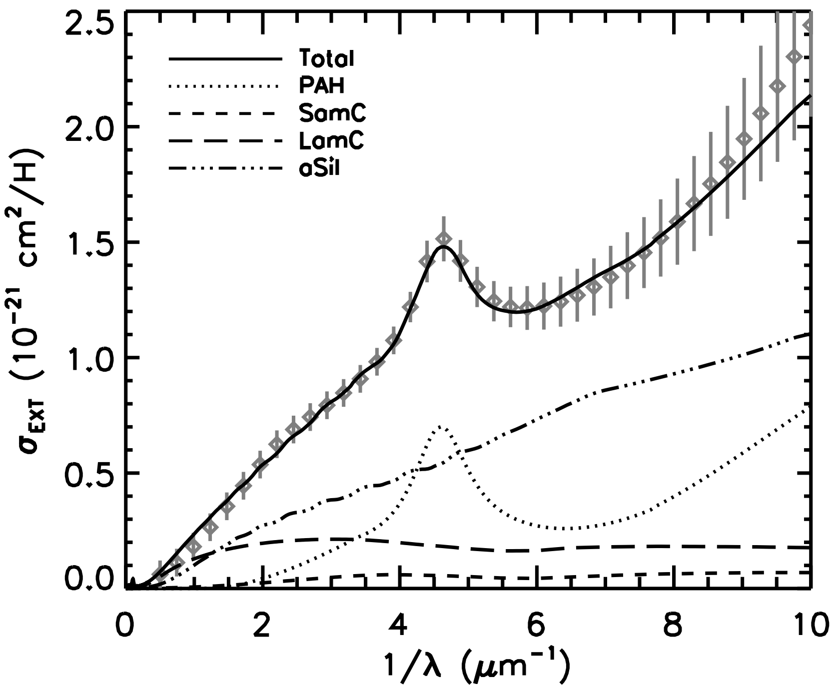


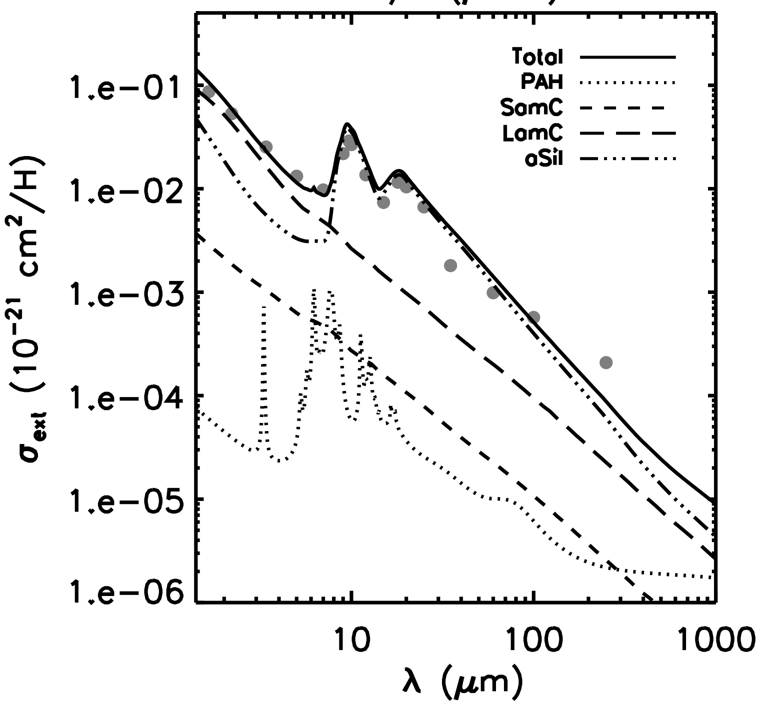
3 dust components:
- PAH
- Hydrogenated amorphous carbon
- Astronomical silicates

DustEM model



Compiegne et al. (2011)





The Orion Bar

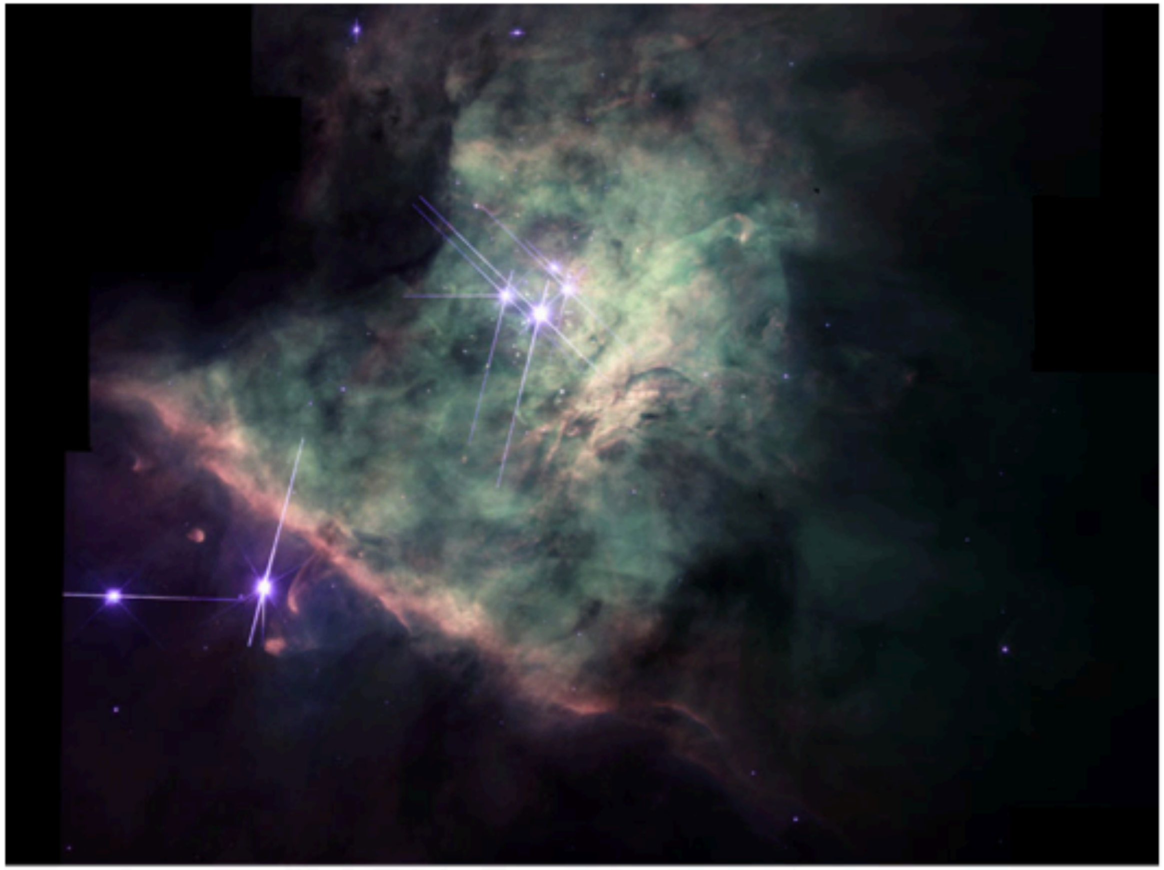
Part of M42 (Orion Nebula)

d = 414 pc (Menten et al. 2007)

Radiation field : Trapezium stars mainly θ^1Ori C (O6)

$$\left[1-4\right]\times 10^{4}\,G_{0}$$

Marconi et al. (1998)
Tielens & Hollenbach (1985)



HST – WFPC2
Blue: V band, Green: [OIII], Orange: Hα, Red: [NII]

Many studies and papers…

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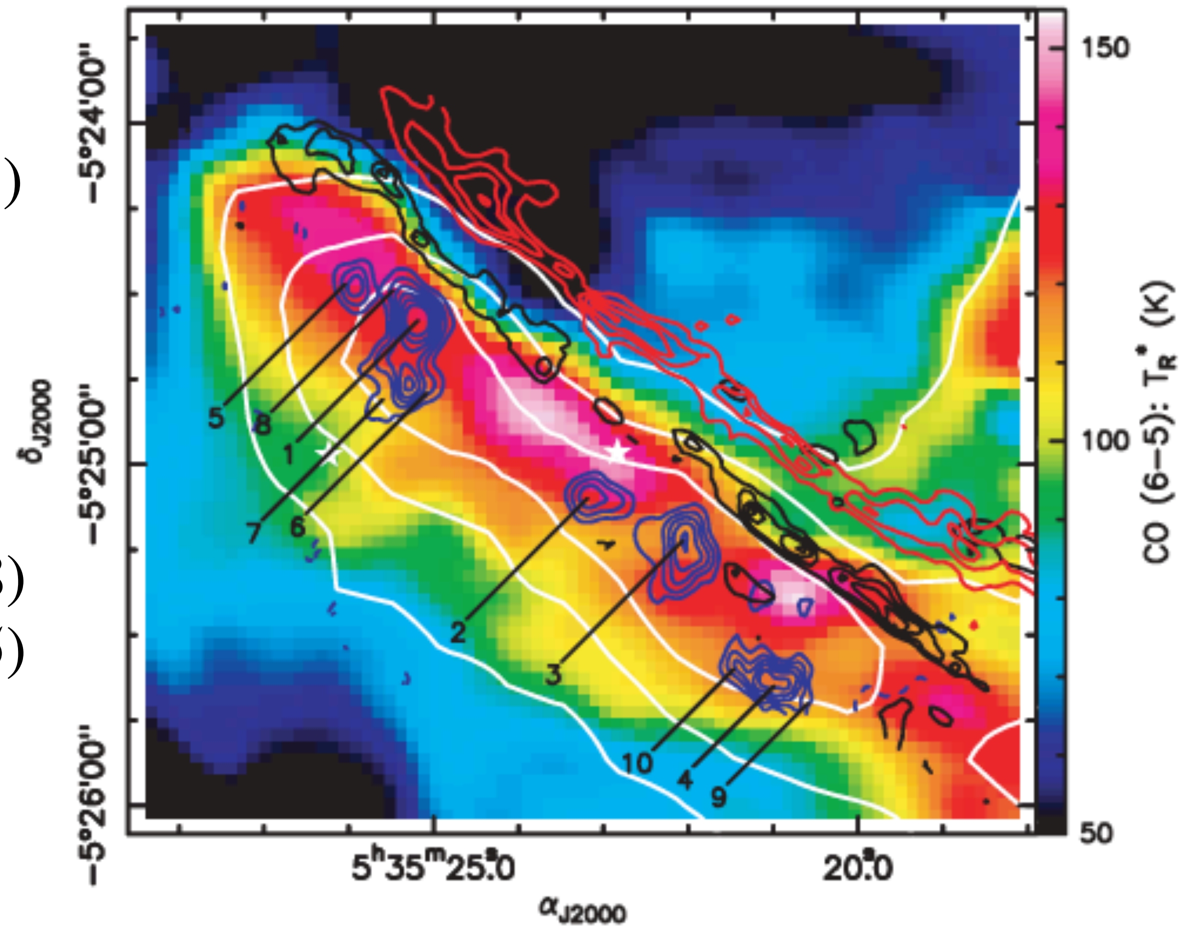
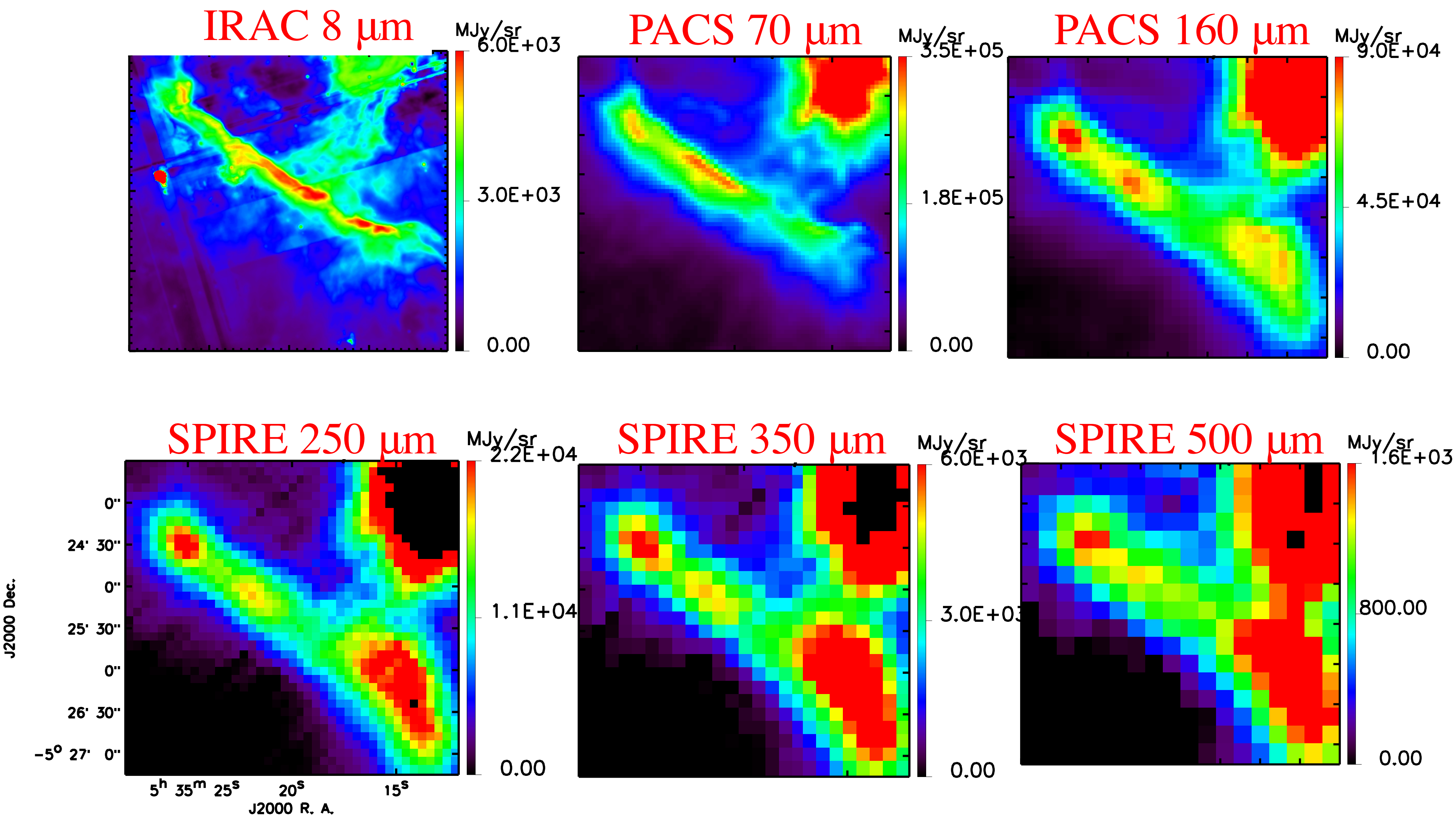


Lis et al. (2003)
Red: OI 1.32 µm; Black: H_2 v=1-0 S(1); White: ^{13}CO (3-2), Blue: $H^{13}CN$ (1-0)

The Orion Bar - Observations



Arab et al. (in prep)

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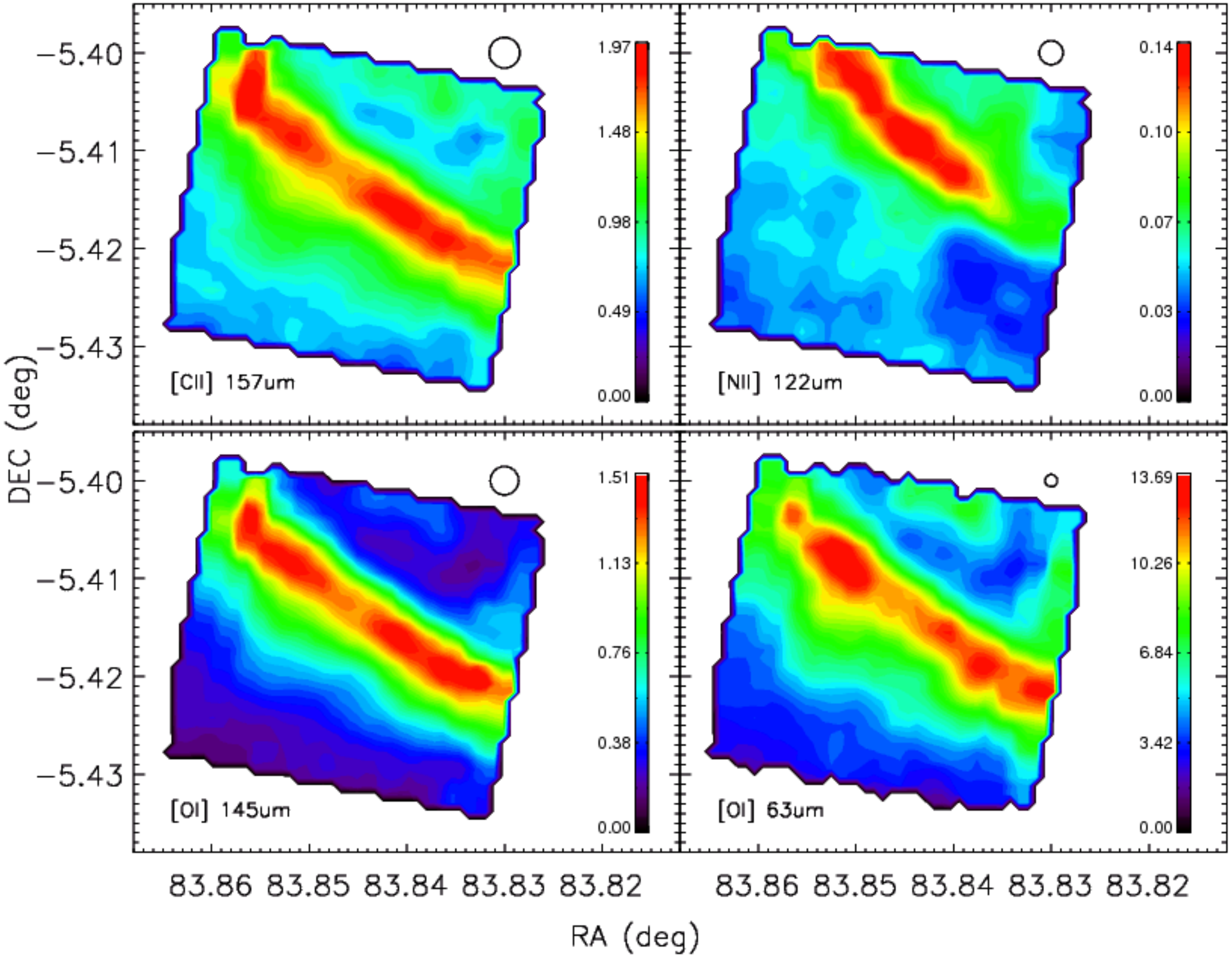

J. Bernard-Salas et al. (in prep)

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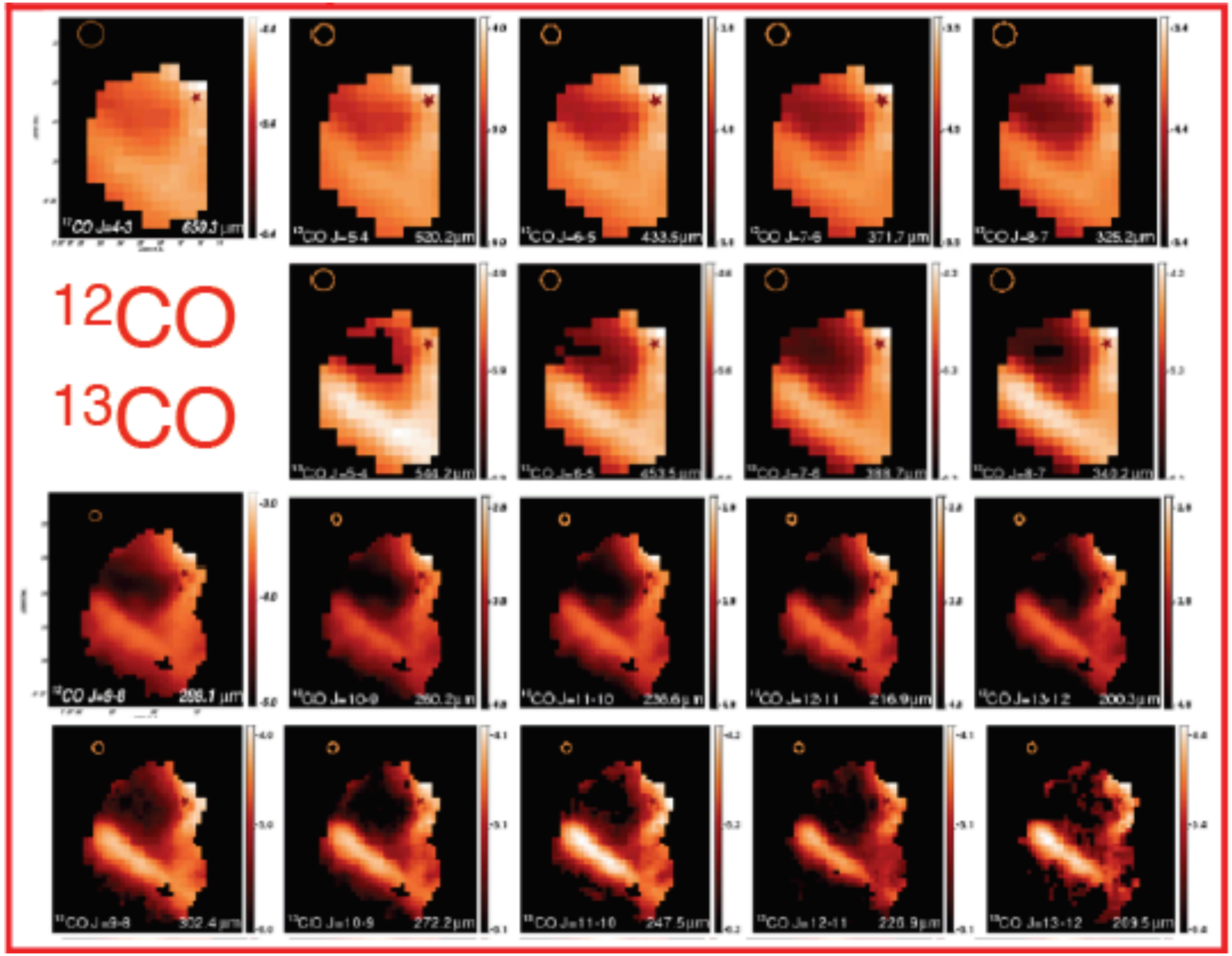
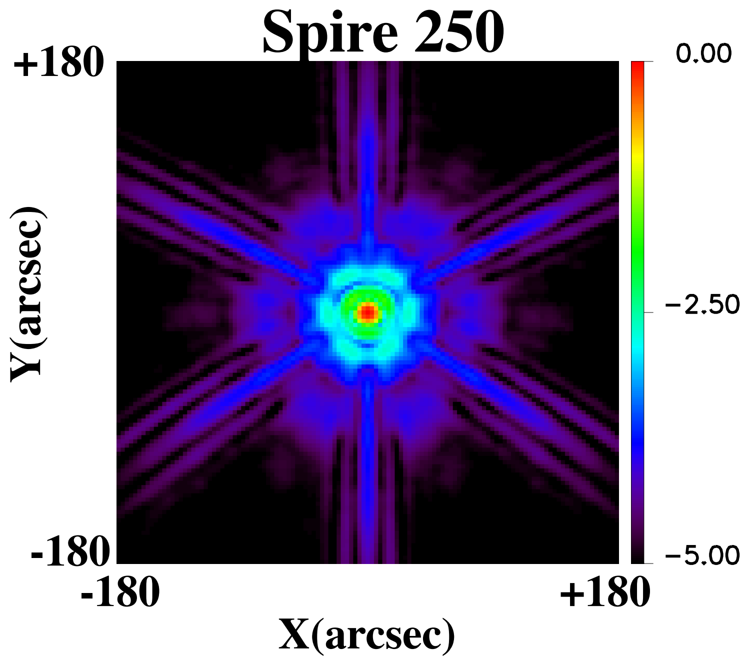


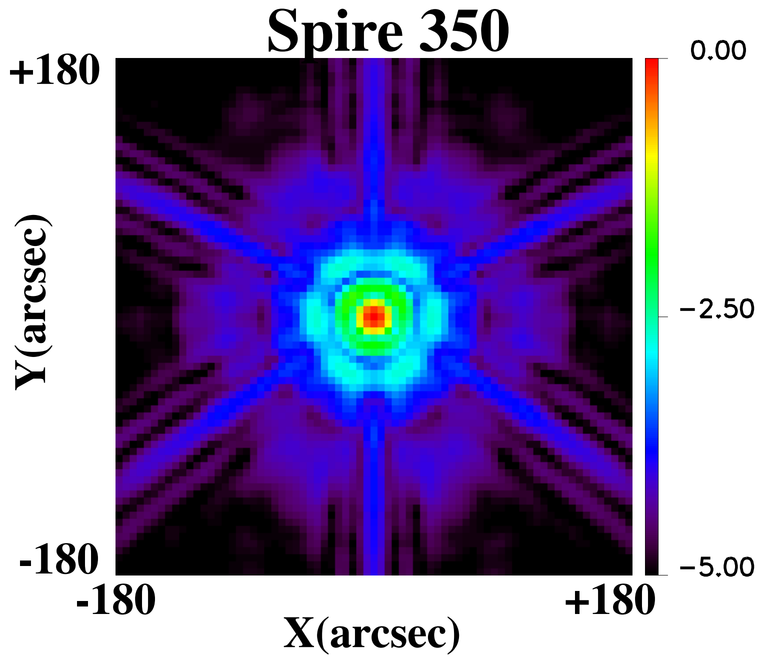
Habart et al. (in prep)

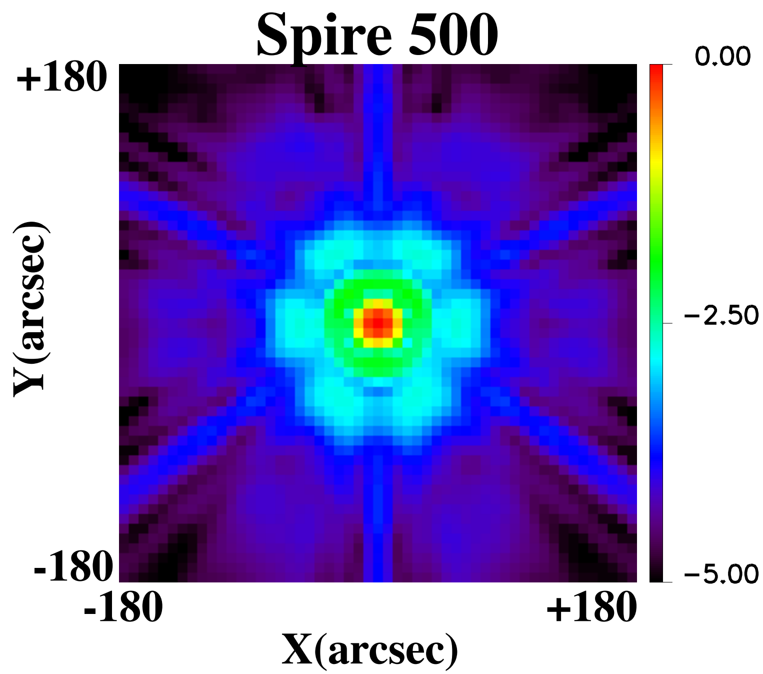
Herschel's beams



Computing transition PSFs from PSF_1 to PSF_2

Regularized least-square method



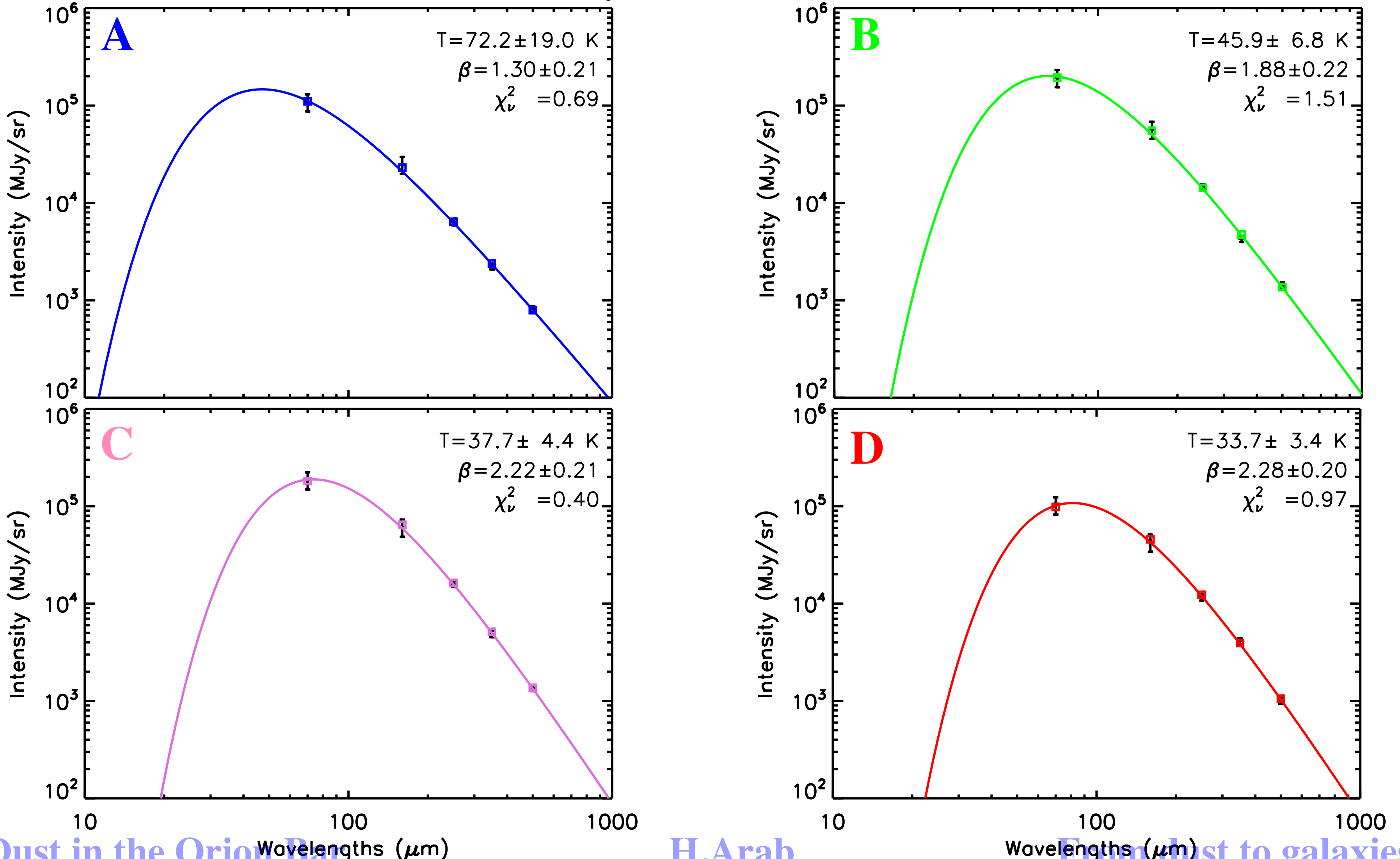


BGs spectrum

Modified blackbody

Compute : - temperature T
- dust emissivity index β
- dust emissivity at λ_0

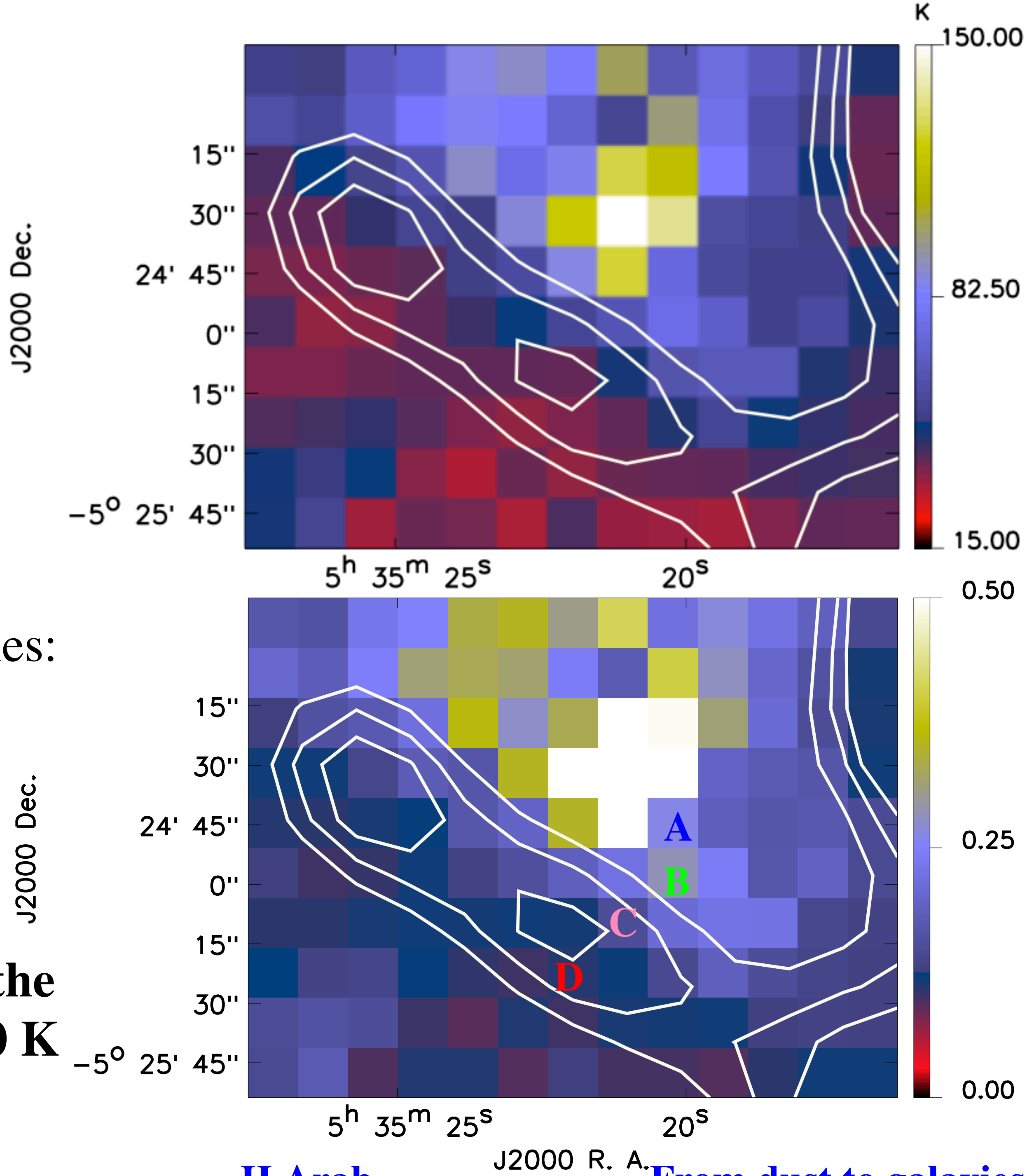
$$I_\lambda = \varepsilon_{\lambda_0}\left(\frac{\lambda}{\lambda_0}\right)^{-\beta} B_\lambda(T)$$



BGs spectrum

Temperature map derived from the fits.
Contours : SPIRE 250 µm emission

Relative error map (photometric uncertainties: 20 % for PACS 7% for SPIRE)

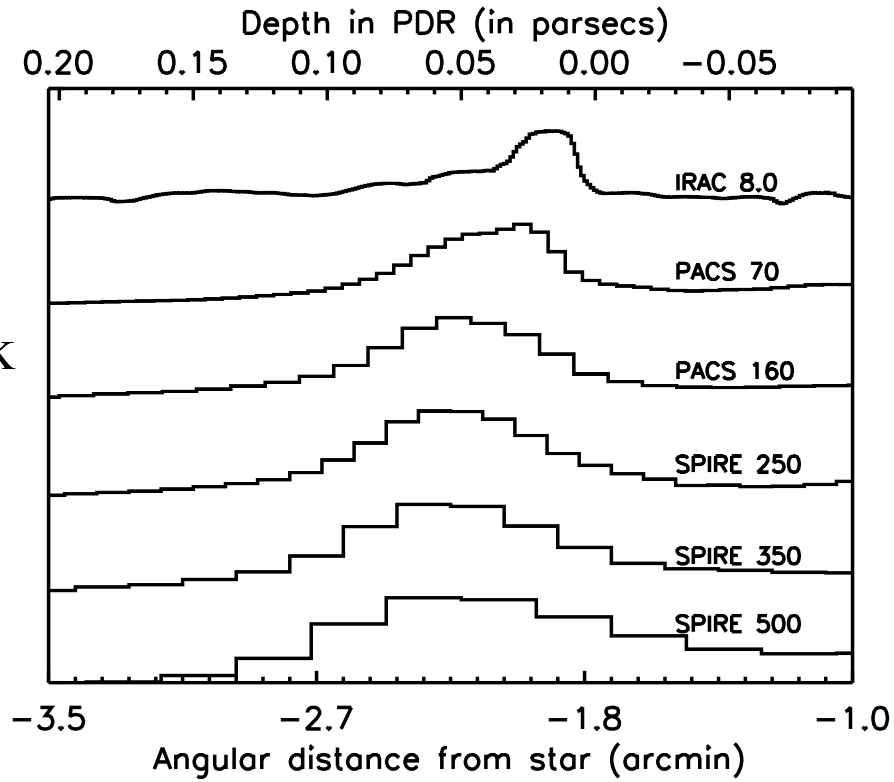


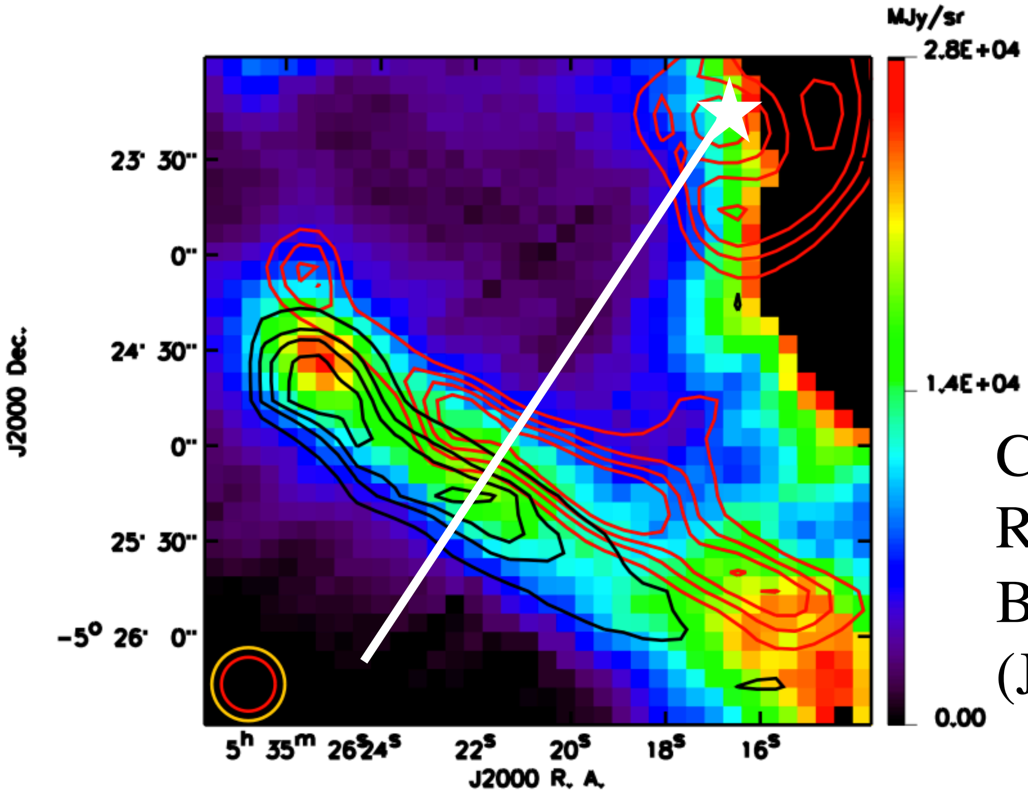
Cooling of the BGs in the PDR from ≈ 60 K to 30 K

Spatial distribution

Shift in the intensity profiles
Larger is the wavelength, further is the peak

Not an angular resolution effect



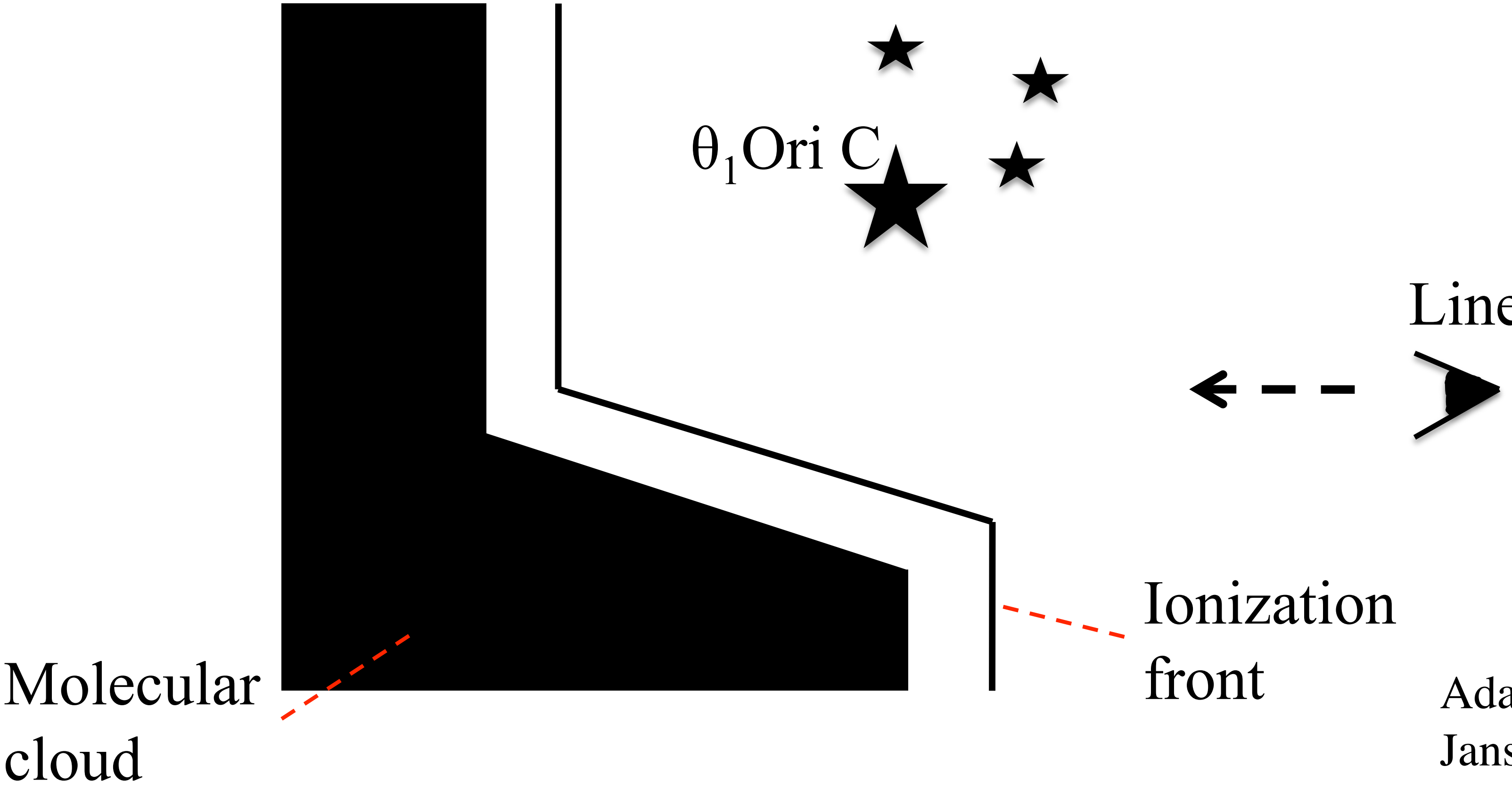


Colour map: SPIRE 250 µm
Red contours: IRAC 8 µm (same beam)
Black contours: SPIRE/FTS map $C^{18}O$ (J=8-7)

Modeling the dust emission

Aim: Underline the evolution of dust properties and abundances within the PDR

Approach: To model the brightness profiles at each wavelength using dustEM coupled with a radiative transfer code.



Adapted from Jansen et al. (1995)

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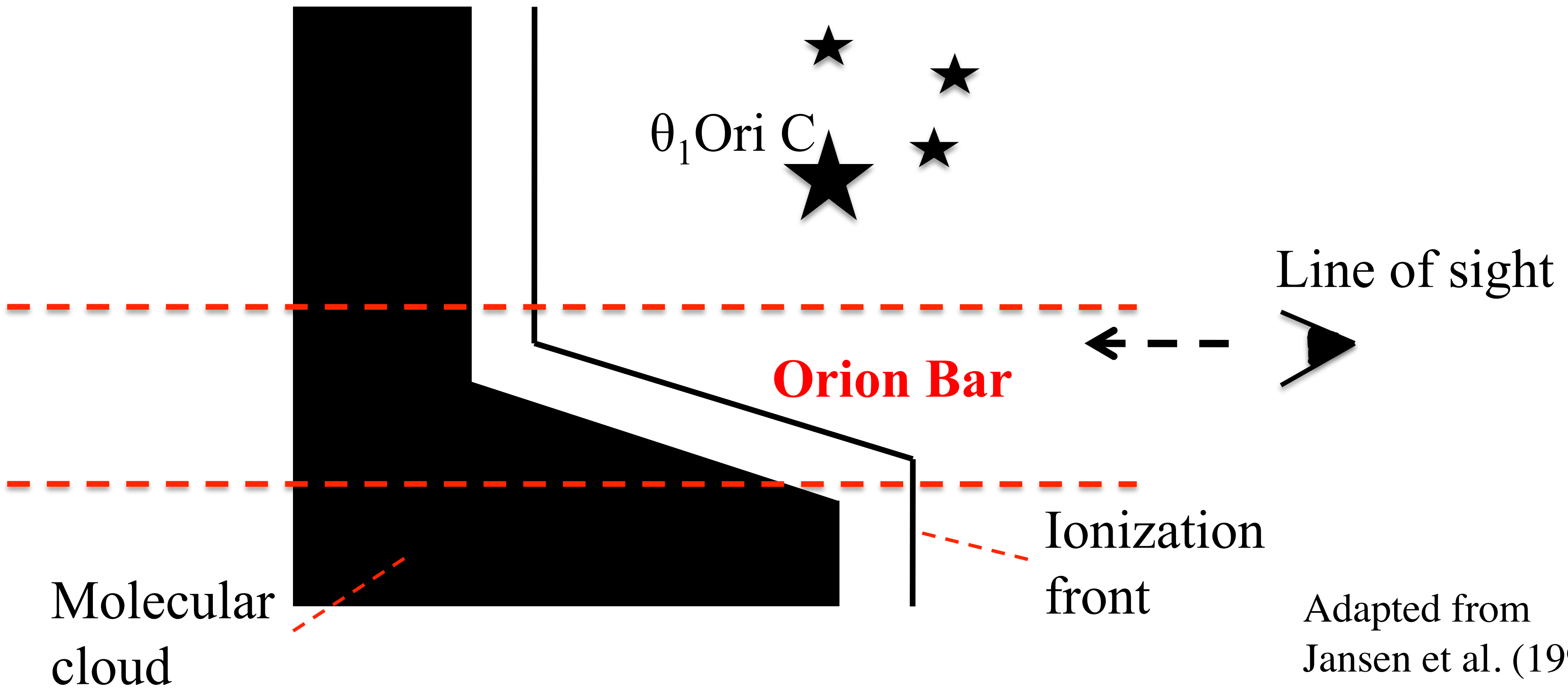

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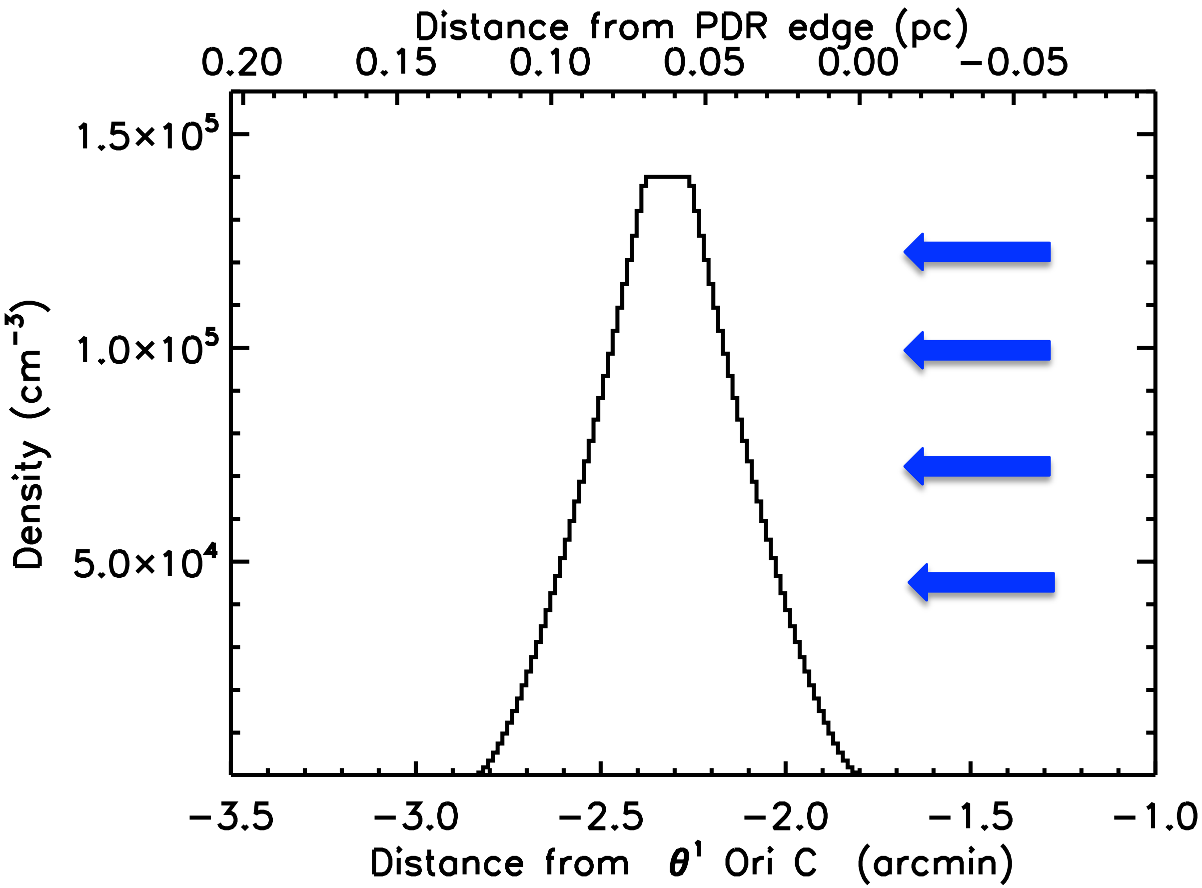
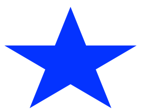
Modeling the dust emission

Density profile:



$$n(z) = n_0 \times \left(\frac{z}{z_0}\right)^{\alpha}$$

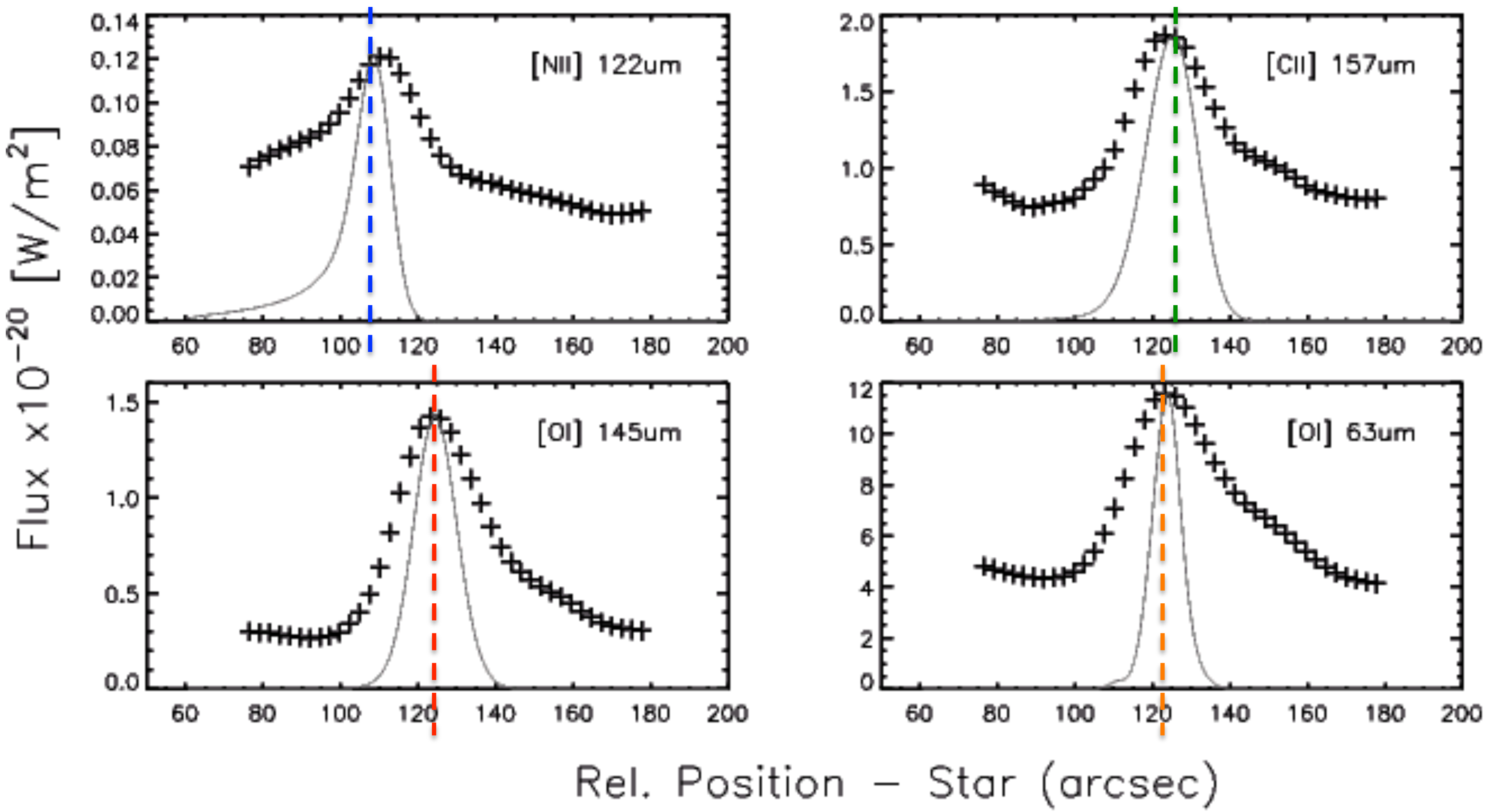


$n_0 = 1.4\ 10^5\ cm^{-3}$
$z_0 = 5.4\ 10^{-2}\ pc$
$\alpha = 1.5$

$l_{PDR} = 0.46\ pc$ ⇔ $N_H = 2.10^{23} cm^{-2}$ (at the density peak)

Modeling the dust emission

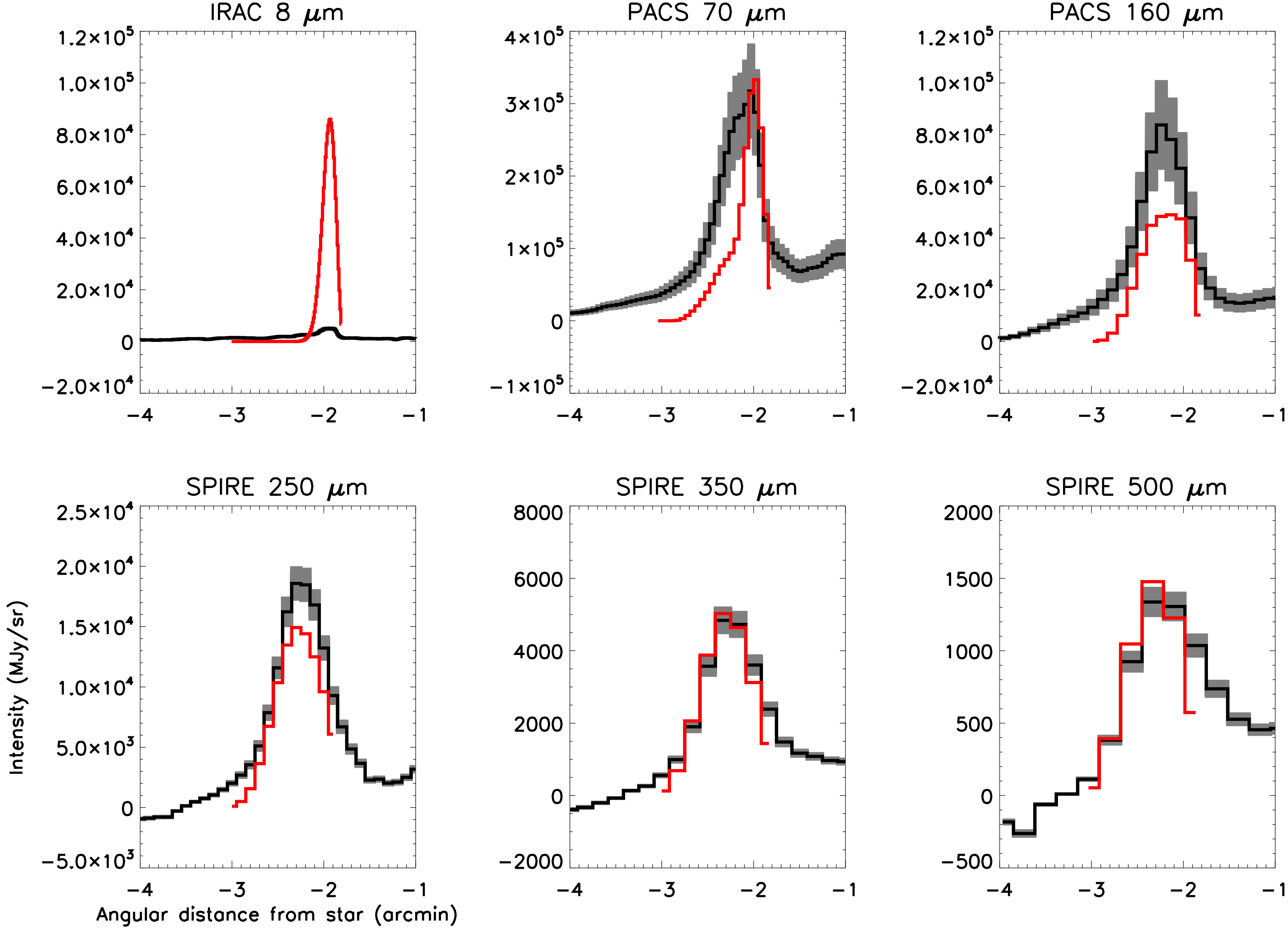
Cloudy model and comparison with PACS spectroscopic data



Bernard-Salas et al. (in prep)

Modeling the dust emission

Diffuse ISM abundances and properties



Dust in the Orion Bar H.Arab From dust to galaxies 2011

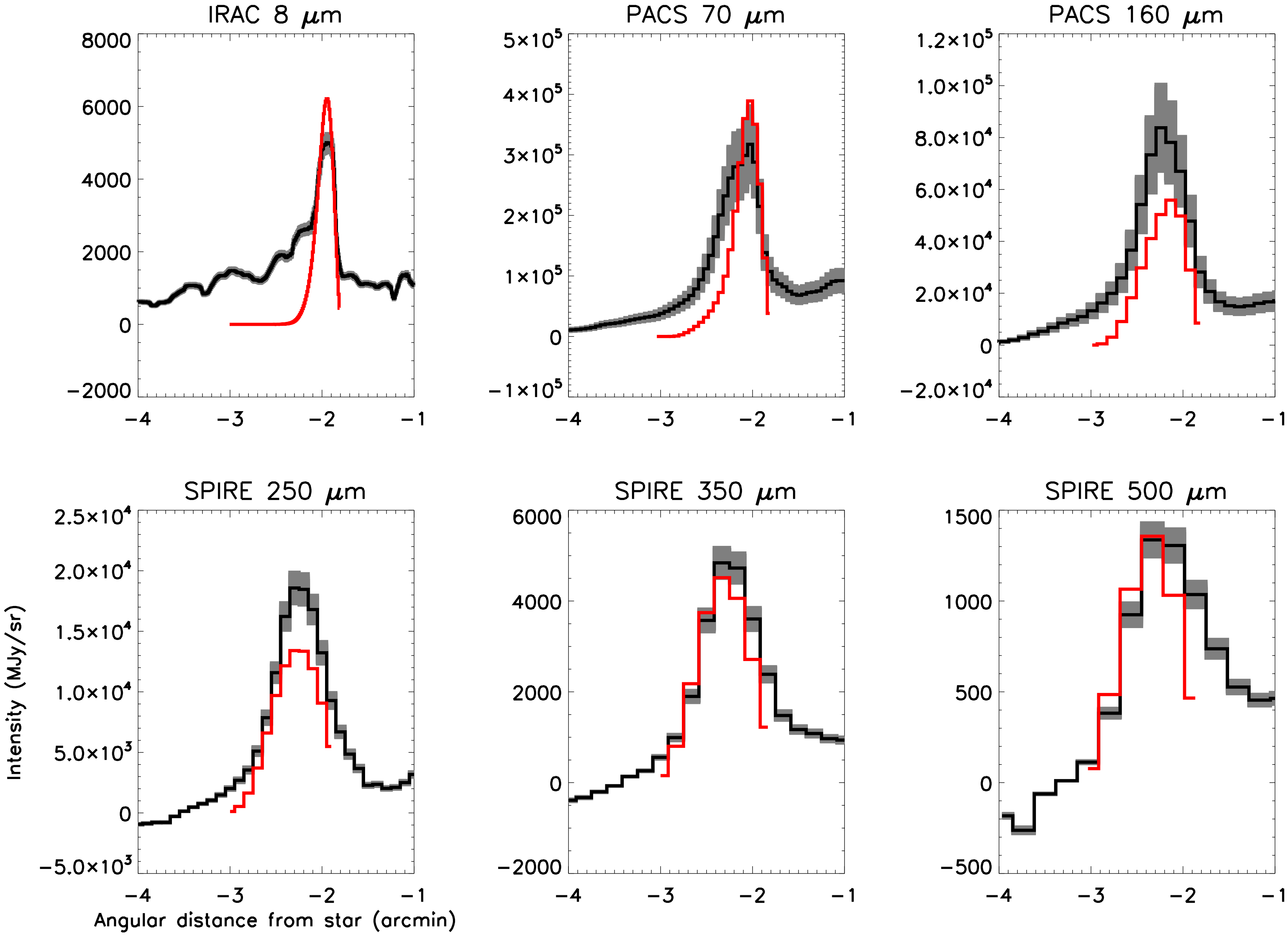
Discussion

- Good agreement in the BG emission range.
- The small underestimate at 160 and 250 μm can be explained by a β emissivity index too low in the model (1.5 in dustEM whereas 1.8 in the data.
- Strong overestimate at 8 microns.

Abundance variations ?

Modeling the dust emission

PAH and VSG abundances divided by 45 and 8 respectively



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Variation of l_{PDR}? CERTAINLY given the geometry

Conclusion and perspectives

Herschel data complete the large dataset on the Orion Bar.

Bring new constraints on the structure of this PDR.

But the Orion Bar is an extreme case complicated by huge G_0, density and geometrical effects.

Apply this kind of study on other objects of various properties to understand the dust properties.

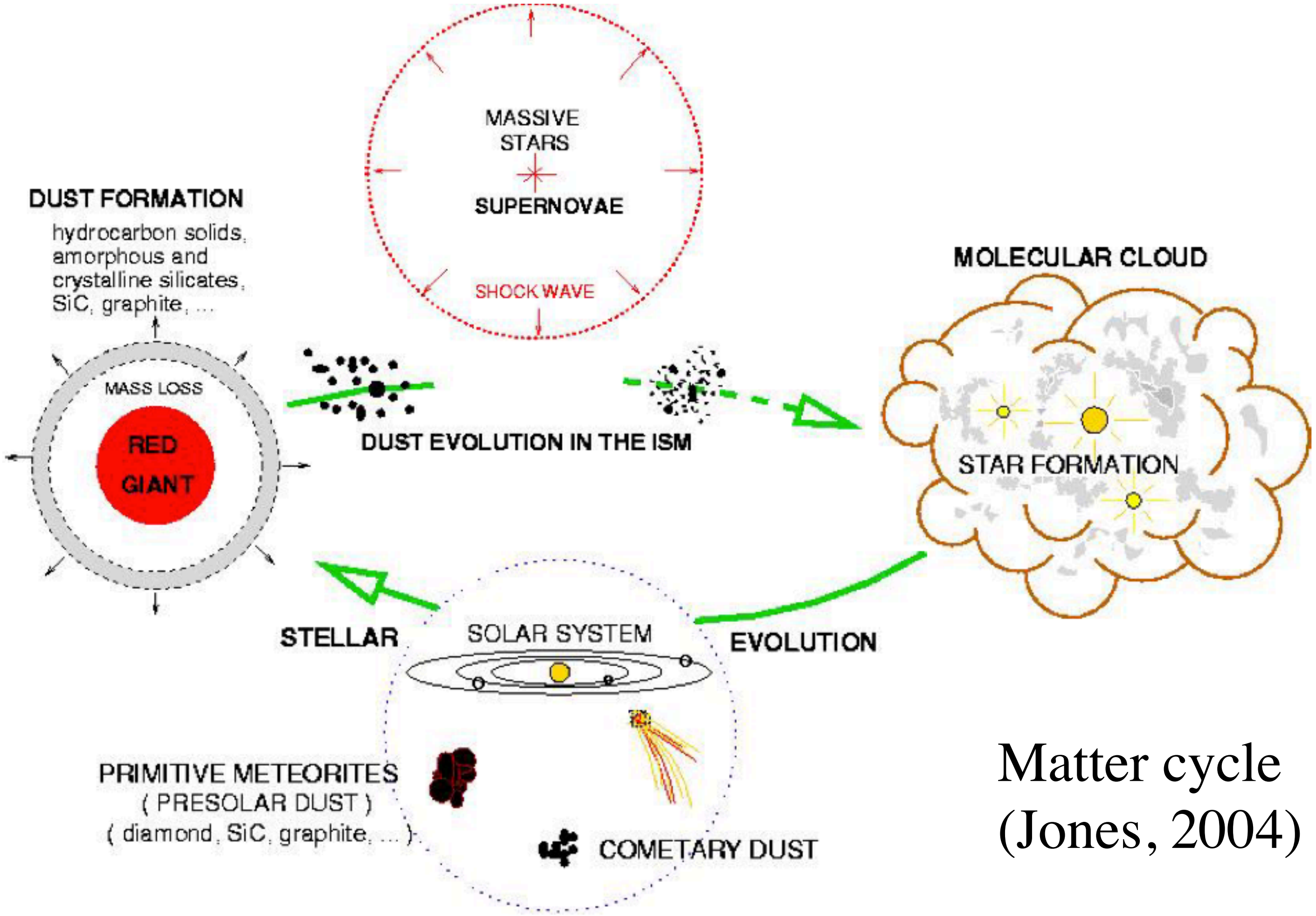
Thank you …

Interstellar dust

Evolution: Size, structure and chemical composition modification
(Erosion, fragmentation, condensation, coagulation)
Size distribution of interstellar grains

Destruction: in shocks (Supernovae) or in star formation

Grain lifetime: 4.10^8 yr



Matter cycle (Jones, 2004)

Interstellar dust

- Absorb the UV / visible radiation and re-emit it in the IR / sub-mm

- Allow molecular formation in the ISM

- Hold a large part of the elements heavier than hydrogen

- Contribute to the gas heating (photoelectric heating)

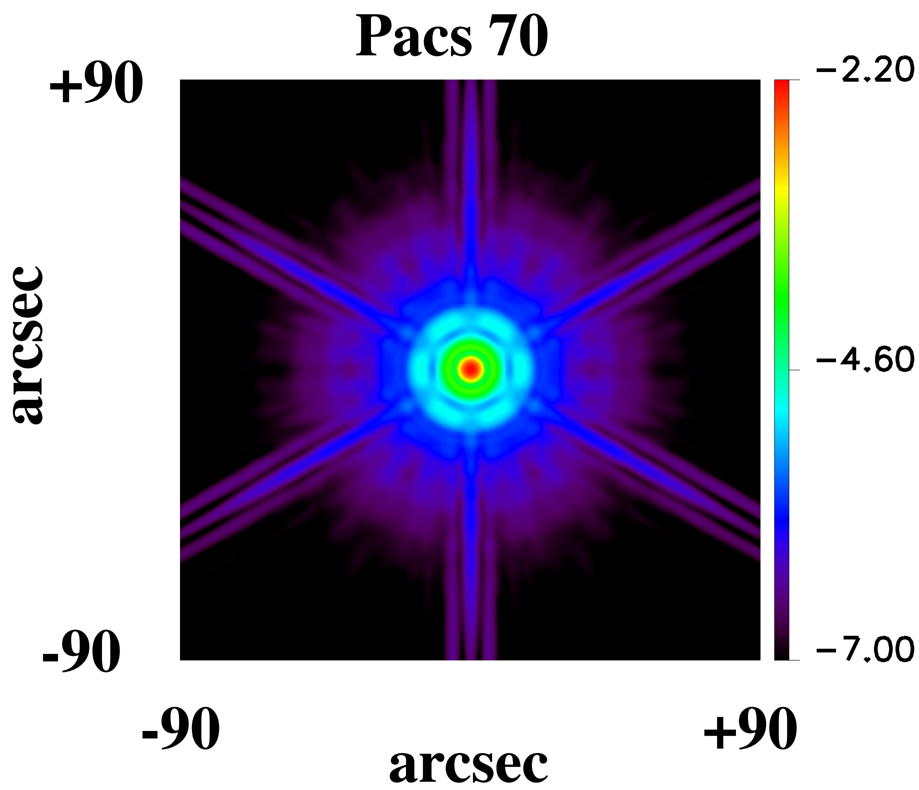
- Crucial component in the stellar and planetary formation

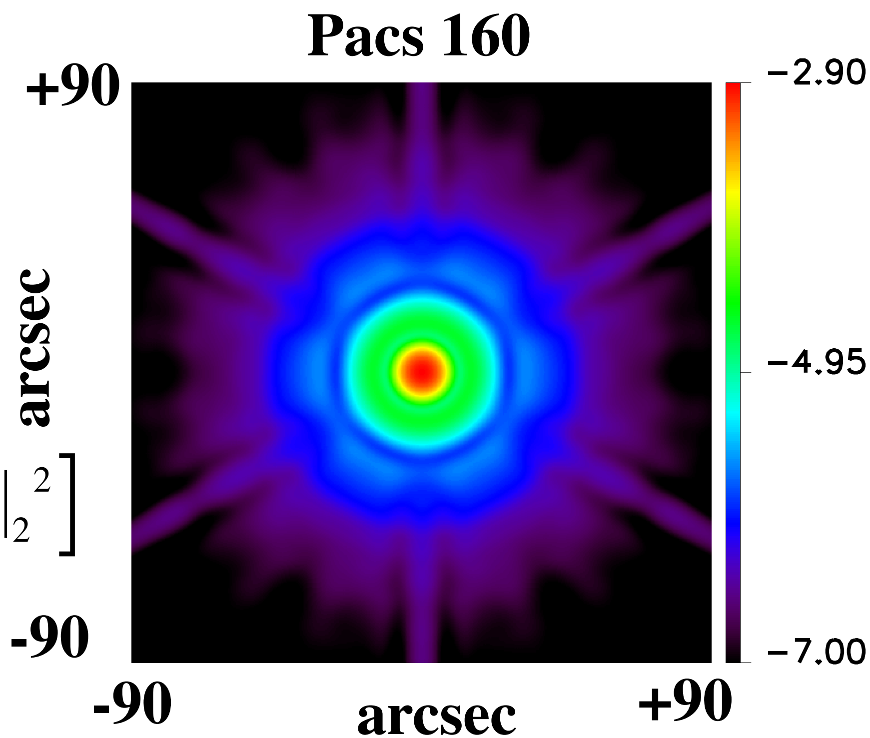
Formation: Dominated by the input form evolved stars (RGB/AGB and Supernovae ?)

C-rich stars → PAHs, Graphite, amorphous carbon

O-rich stars → Oxides & amorphous silicates

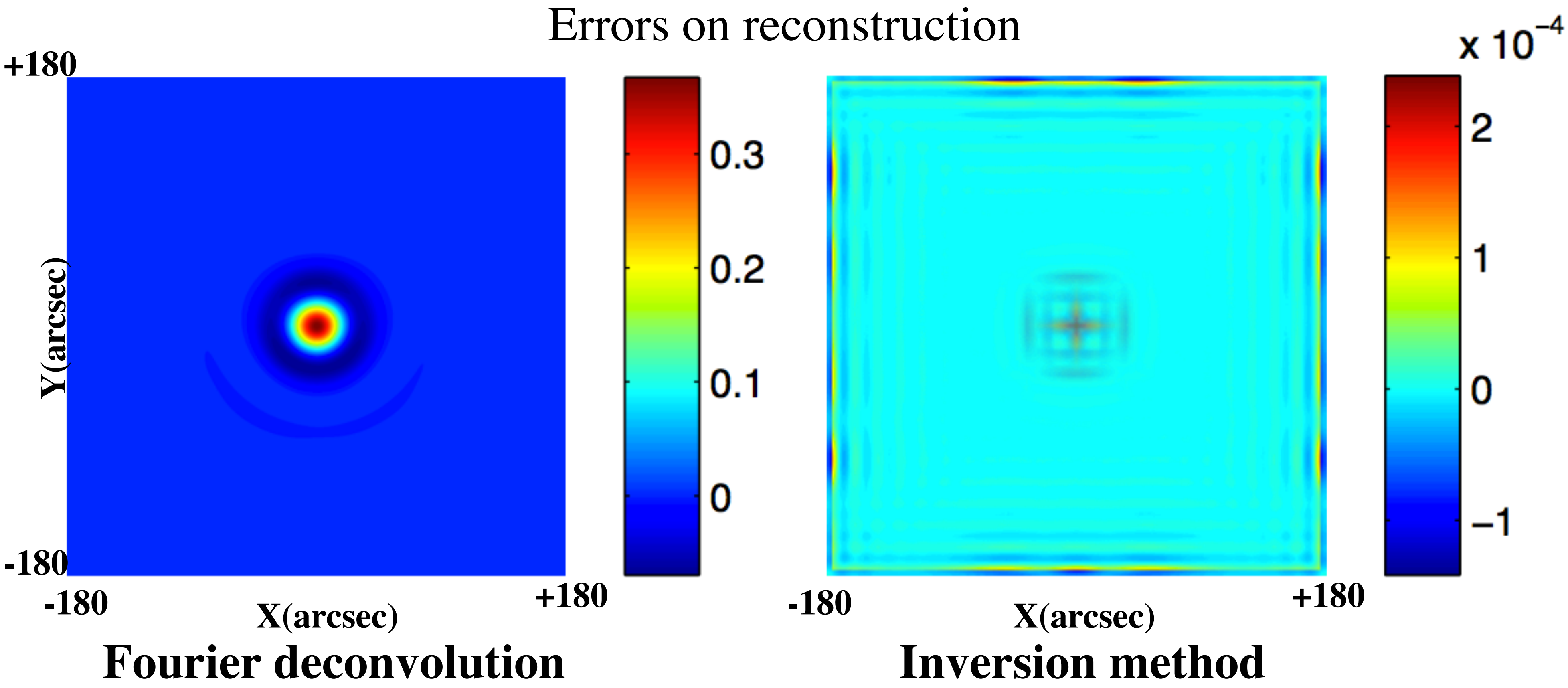
Herschel's beams





$$\hat{k} = \arg\min\left[\left\|PSF_2 - PSF_1 * k\right\|_2^{\,2} + \mu\left\|\Omega(k)\right\|_2^{\,2}\right]$$

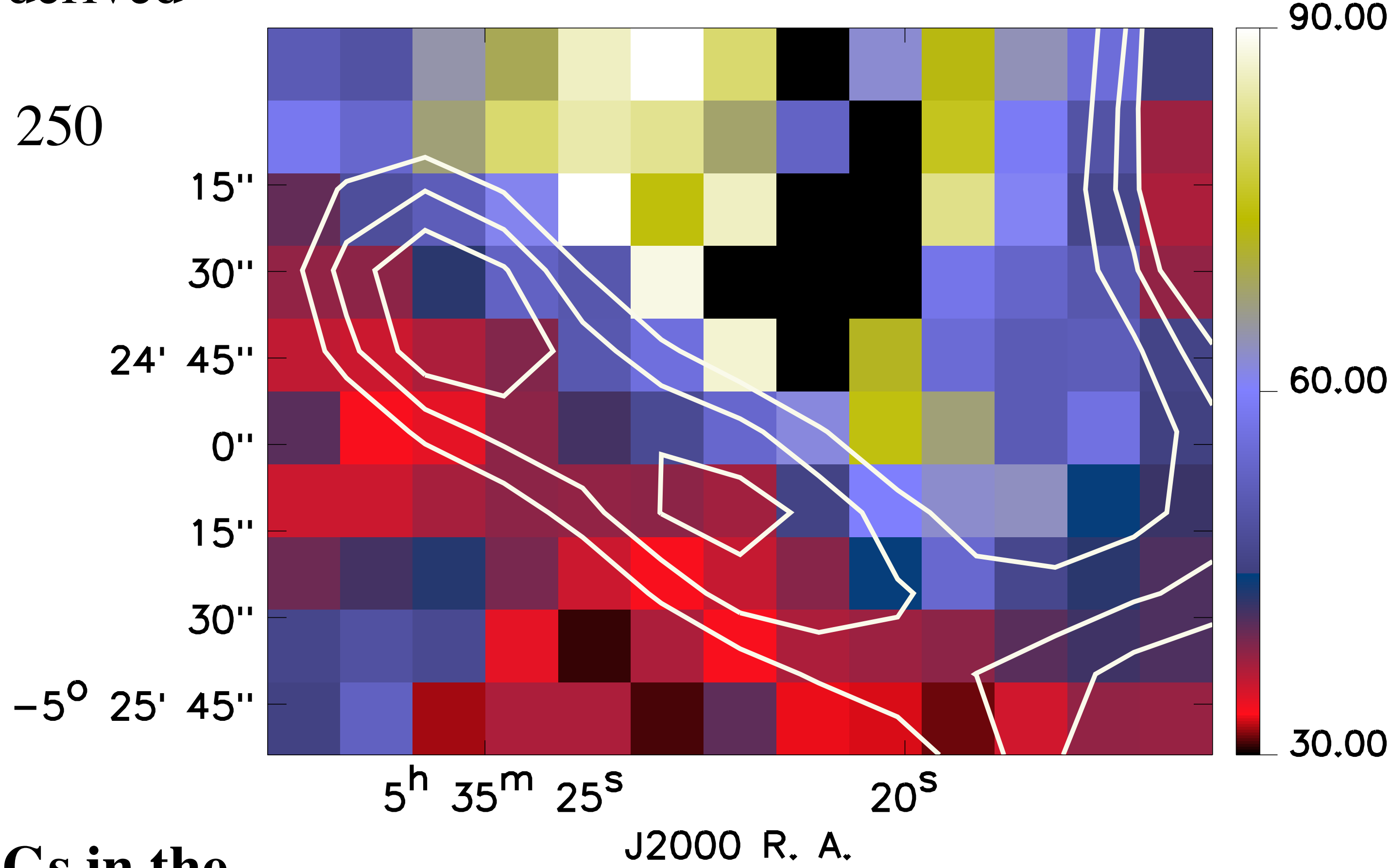
Herschel's beams



- More satisfactory than Gaussian convolution (especially at the edge of bright structure)
- Better reconstruction of k than Fourier deconvolution respecting the balance between spectral information and the level of noise

BGs spectrum

Temperature map derived from the fits.
Contours : SPIRE 250 emission



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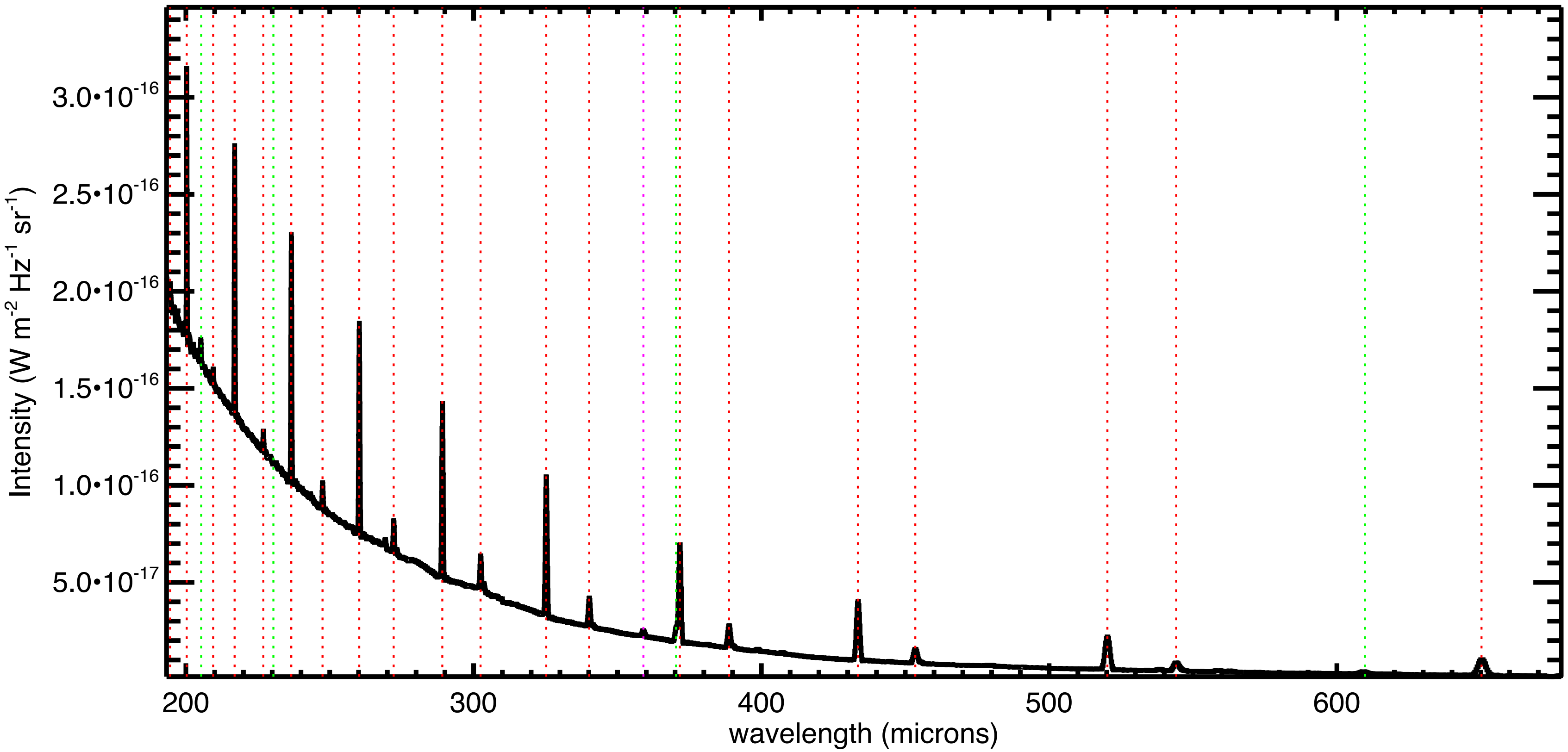

Habart et al. (in prep)

SPIRE/FTS spectrum at the peak position