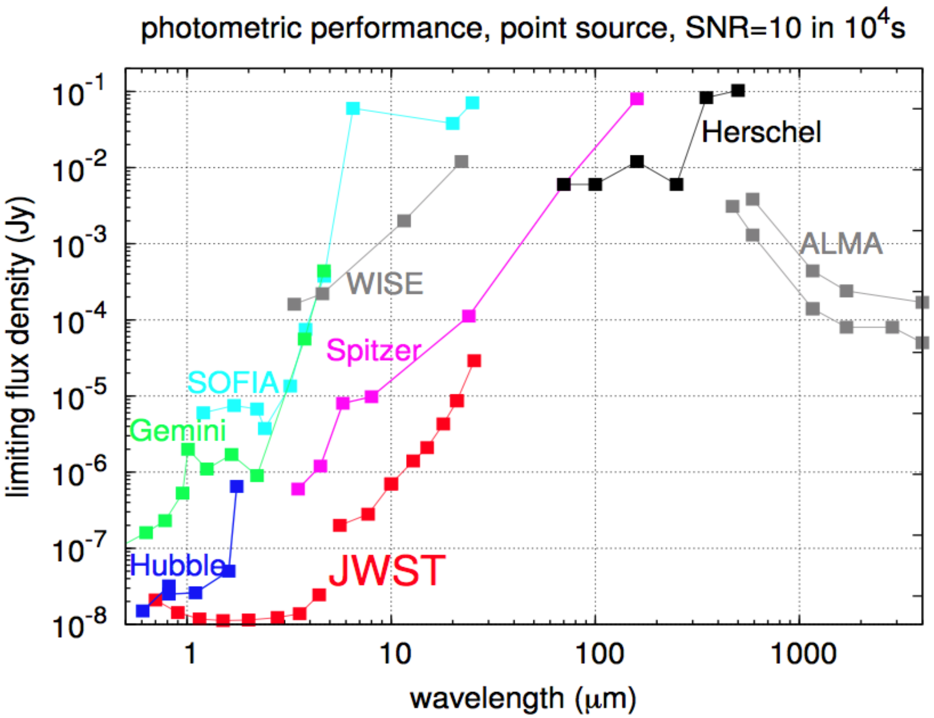
The interstellar matter observed with the JWST

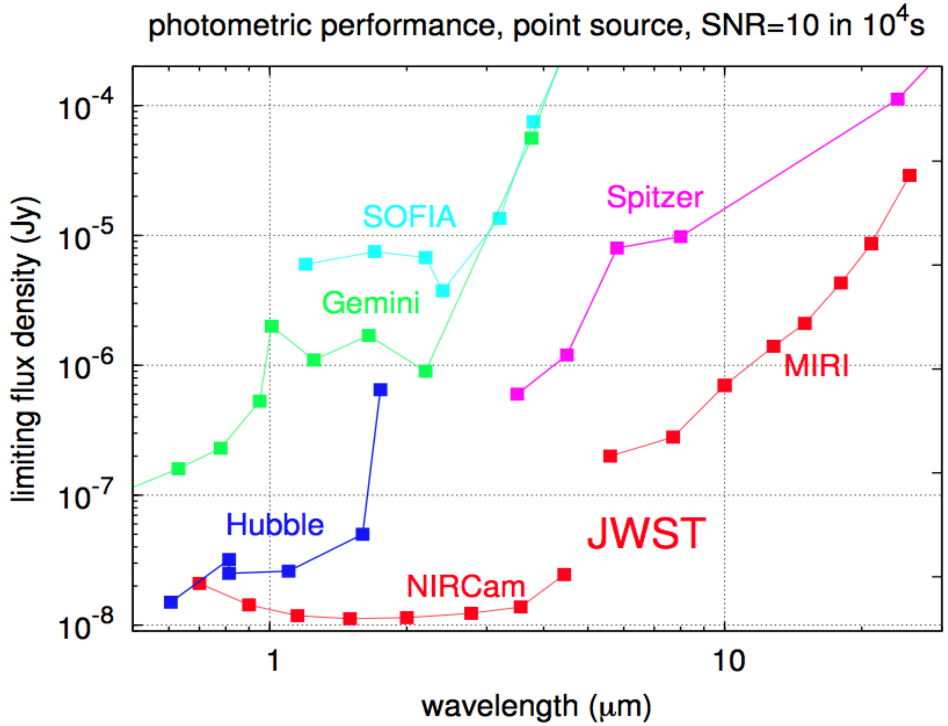
Alain Abergel[1], Pierre Guillard[2] & Emilie Habart[1]

1: IAS, Université Paris-Sud/CNRS, 2: IAP UPMC/CNRS

- Unprecedented performances of the JWST for ISM observations
- Which studies ?
- A few illustrations in photodissociation regions
- Conclusions

JWST : Photometry





- **Sensitivity X 10-100**
- **Angular resolution: 0.1-1"**
- **28 (NIRCAM) + 10 (MIRI) = 38 broad-band or narrow-band filters for imaging**

  + 7 (NIRISS, spare models of NIRCAM filters)

NIRCam Filters & Sensitivity

Wavelengths in µm, Sensitivity in nJy, 10σ in 10000 s

Short Wavelength Module					Long Wavelength Module				
Name	**Center**	**Bandpass**	**Sensitivity**	**Use**	**Name**	**Center**	**Bandpass**	**Sensitivity**	**Use**
F150W2*	1.5	1		DHS Blocking	F322W2	3.22	1.61		Background Min.
F070W	0.7	0.175	20.9	General purpose	F277W	2.77	0.6925	12.3	General purpose
F090W	0.9	0.225	14.3	General purpose	F356W	3.56	0.89	13.8	General purpose
F115W	1.15	0.2875	11.8	General purpose	F444W	4.44	1.11	24.5	General purpose
F150W	1.5	0.375	11.2	General purpose	F250M	2.5	0.1667	38.1	CH_4
F200W	2	0.5	10.4	General purpose	F300M	3	0.3	26.8	H_2O ice
F140M	1.4	0.14	28.1	Cool *s, H_2O steam	F335M	3.35	0.335	28	PAH
F162M	1.62	0.151	26.6	Cool *s, off-band	F360M	3.6	0.36	29.7	BDs, planets
F182M	1.82	0.221	25.5	Cool *s, H_2O steam	F410M	4.1	0.41	36.7	BDs, planets
F210M	2.1	0.21	25.7	CH_4	F430M	4.3	0.2	71.5	CO_2
F164N	1.644	0.0164	268	[FeII]	F460M	4.6	0.2	55.7	CO
F187N	1.8756	0.0188	267	Pα	F480M	4.8	0.4	72.6	BDs, planets
F212N	2.1218	0.0212	265	H_2	F323N	3.235	0.0324	240	H_2
F225N	2.2477	0.0225	232	H_2	F405N	4.0523	0.0405	260	Brα
					F418N	4.1813	0.0418	271	H_2
					F466N	4.656	0.0466	334	CO
					F470N	4.705	0.0471	341	H_2

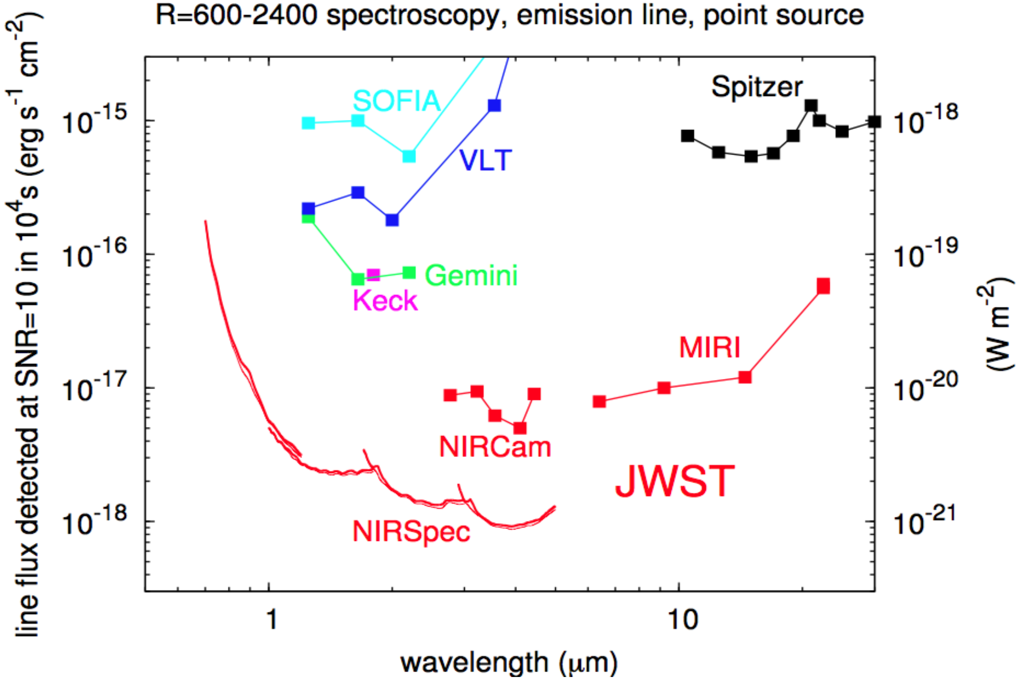
- A lot of filters for specific lines or features (H_2, CO, H_2O ice, CH_4, CO, CO_2, PAHs, …)

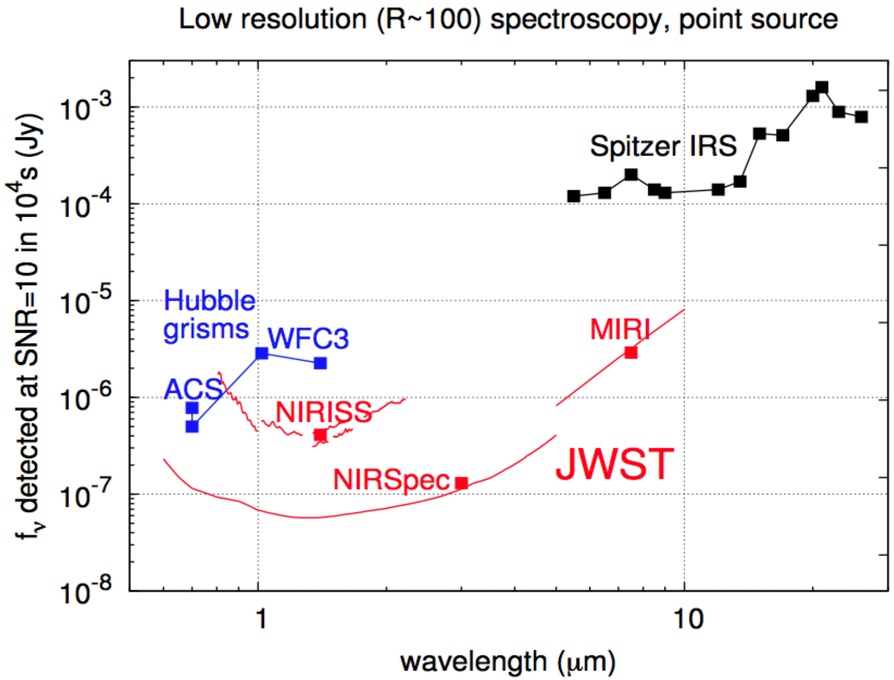
MIRI filters

	λ(μm)	Δλ(μm)	Comment
F560W	5.6	1.2	Broad Band
F770W	7.7	2.2	
F1000W	10	2	Silicate, Broad Band
F1130W	11.3	0.7	PAH, Broad Band
F1280W	12.8	2.4	Broad Band
F1500W	15	3	Broad Band
F1800W	18	3	Silicate, Broad Band
F2100W	21	5	Broad Band
F2550W	25.5	4	Broad Band
F2550WR	25.5	4	Redundant Filter, Risk Reduction
FND	Neutral Density		For Coron. Acquis.
F1065C	10.65	0.53	Phase mask, NH3, silicate
F1140C	11.4	0.57	Phase mask, cont. or PAH
F1550C	15.5	0.78	Phase mask, cont.
F2300C	23	4.6	Focal Plane Mask, Debris Disk
OPAQUE	Blackened Blank	N/A	For Darks

- 9 different broad band filters (2 for PAHs)

JWST spectroscopic sensitivity





- **Sensitivity: X10-100**
- **Angular resolution: 0.1-1”**
- **Spectral resolution : Spitzer: R= 50-600 → JWST: R= 60-3500**
- **Fantastic diversity of capabilities (with the 4 instrument)**

JWST spectroscopic capabilities

Instrument	Type	Wavelength (microns)	Spectral resolution	Field of view
NIRISS	slitless	1.0-2.5	~150	2.2′ x 2.2′
NIRCam	slitless	2.4-5.0	~2000	2.2′ x 2.2′ (TBC)
NIRSpec	MOS	0.6-5.0	100/1000/2700	9 square arcmin.
NIRSpec	IFU	0.6-5.0	100/1000/2700	3″ x 3″
MIRI	IFU	5.0-28.8	2000-3500	>3″ x >3.9″
NIRSpec	SLIT	0.6-5.0	100/1000/2700	Single object
MIRI	SLIT	5.0-10.0	60-140	Single object
NIRISS	Aperture	0.6-5.0	100/1000/2700	Single object
NIRSpec	Aperture	0.6-2.5	700	Single object

Observing the interstellar matter with the JWST

Dust (emission, scattering, extinction) & Gas (emission & absorption)

- Formation, Nature, Structure, Abundance, Evolution, Heating, Excitation
- Ice mantles (Expected detections of a lot of complex molecules…)
- Dust-Gas interactions
- Stellar energy injection mechanism
- Shocks
- Structure : ISM, cores, disks, … → Galaxies

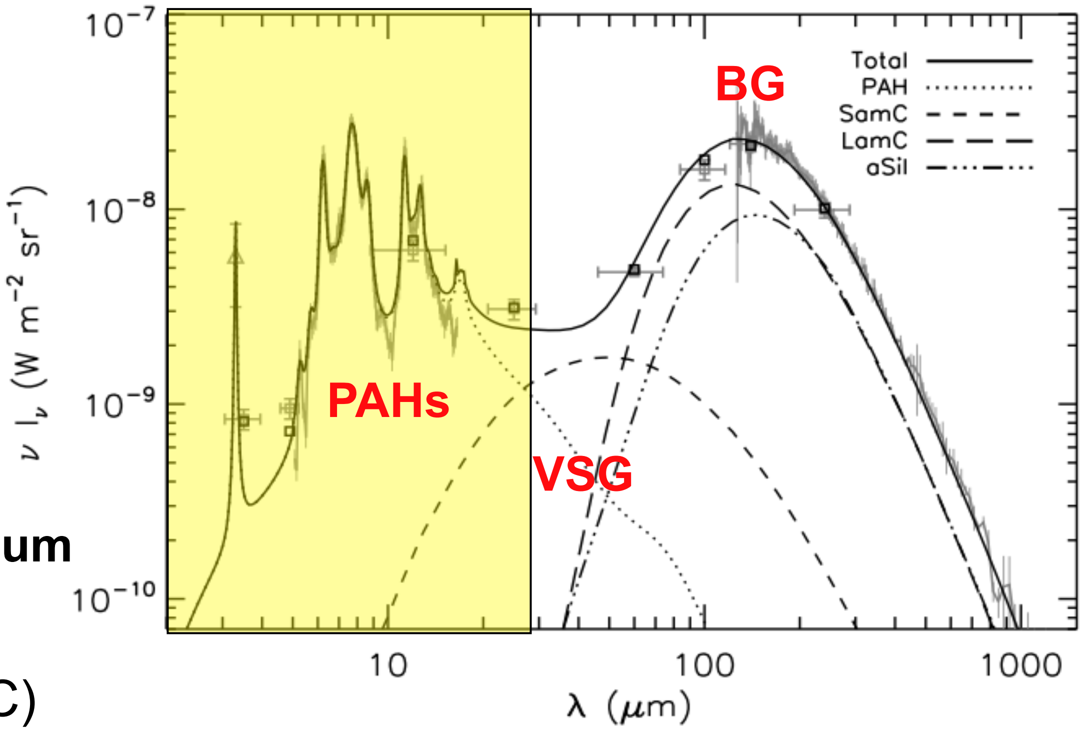
Example for dust and H_2 observations of Photodissociation Regions (PDRs)

- Combining MIRI/NIRCAM imaging + NIRSPEC spectroscopy
- Program in discussion between the european and american MIRI consortia and also the NIRCAM consortium

Dust Emission spectrum

Diffuse ISM SED from DUSTEM

Compiegne et al. (2011)



- **"Big Grains" (BG) in thermal equilibrium**

  Large Amorphous Silicate (aSil)

  Large Amoprhous Carbon (LamC)

- **Very small dust particles : Stochastically heated**

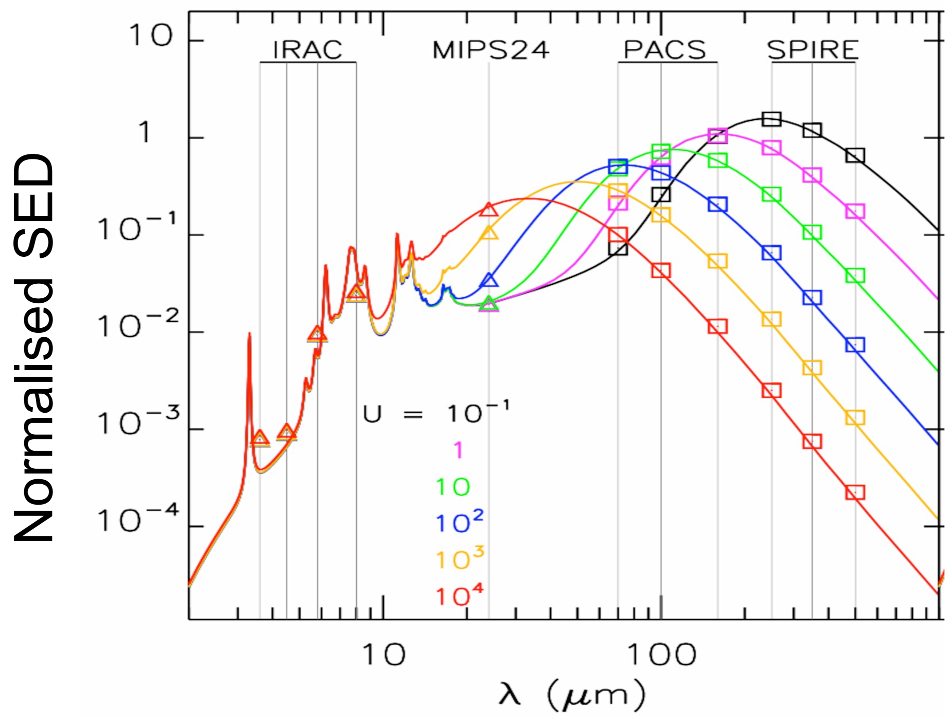
  Aromatic particles (**PAHs**) & Small Amorphous Carbon (**VSG: Very Small Grains**)

  Play a major role : Heating, Formation of molecules (H_2, …), Extinction

Variation of the dust SED with the intensity of the radiation field

from DUSTEM

Compiegne et al. (2011)

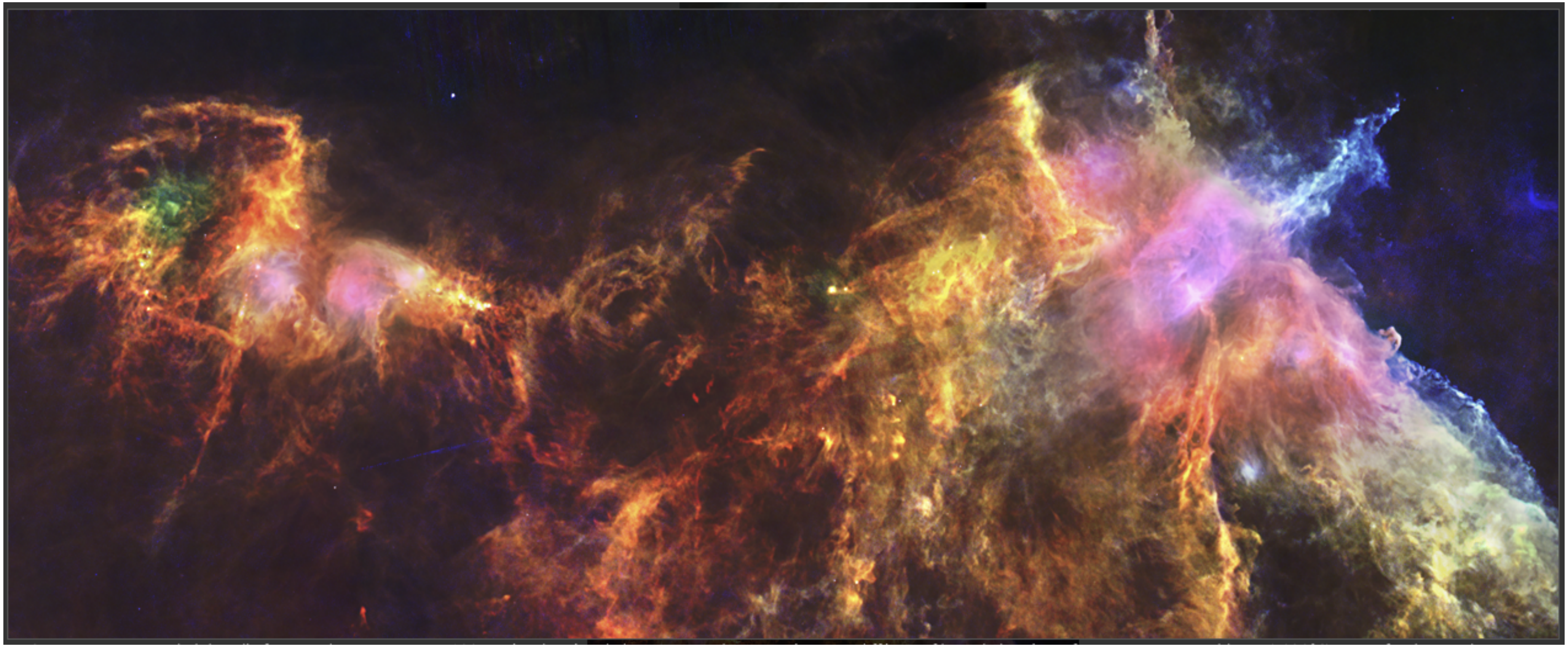


- **“Big Grains” (BG) in thermal equilibrium**

  The FIR spectrum strongly depends on the intensity of the radiation field, since the equilibrium temperature increase with the radiation field…

Herschel map of Orion B

70 μm (blue), 160 μm (green) and 250 μm (red)



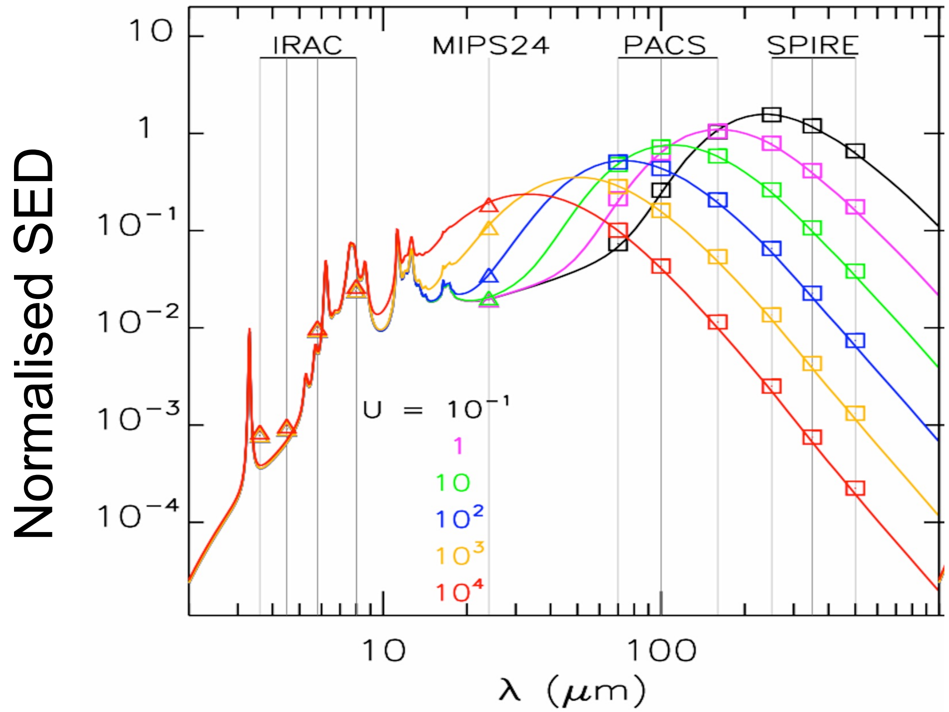
ESA/Herschel/PACS, SPIRE/N. Schneider, Ph. André, V. Könyves for the 'Gould Belt survey' Key Programme

The colour variations in the sub-mm at a first order due to variations of the dust temperature, related to variations of the local heating

Variation of the dust SED with the intensity of the radiation field

from DUSTEM

Compiegne et al. (2011)



- “**Big Grains**” **(BG) in thermal equilibrium**

  The FIR spectrum strongly depends on the intensity of the radiation field, since the equilibrium temperature increase with the radiation field

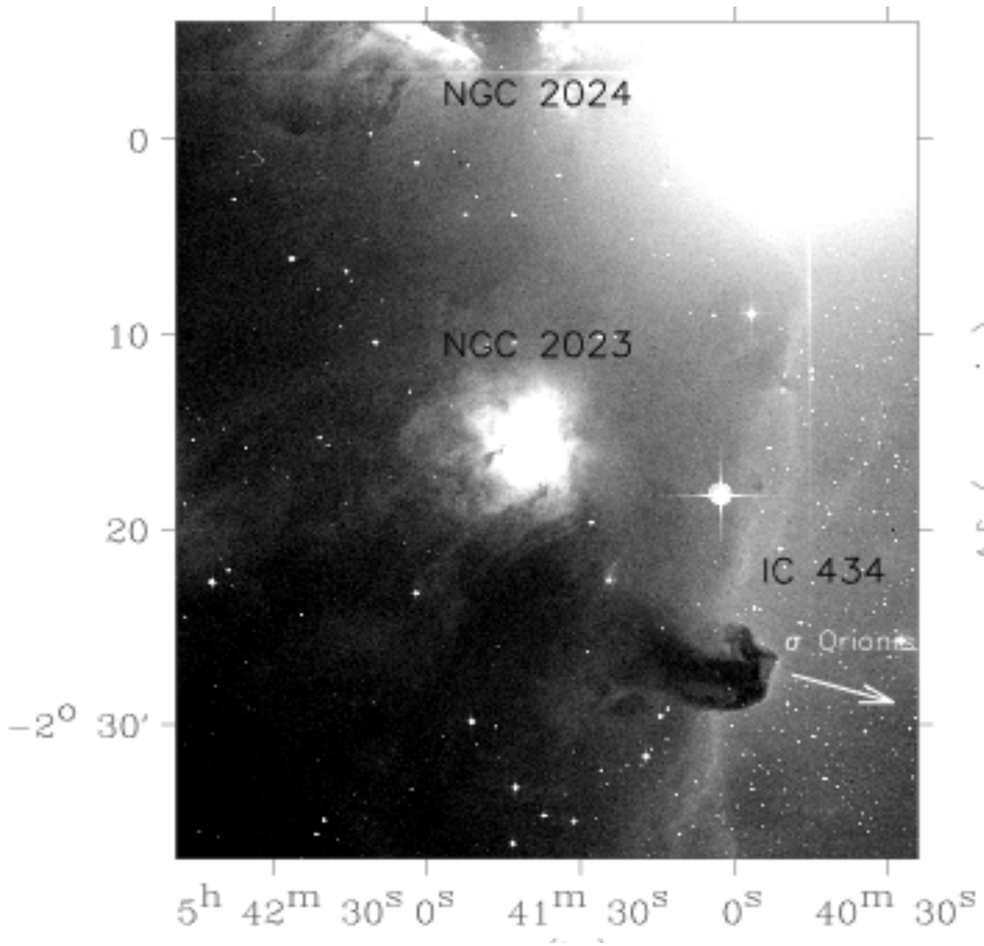
- **Very small dust particles : Stochastically heated**

  The IR emission is proportional to the intensity of the radiation field

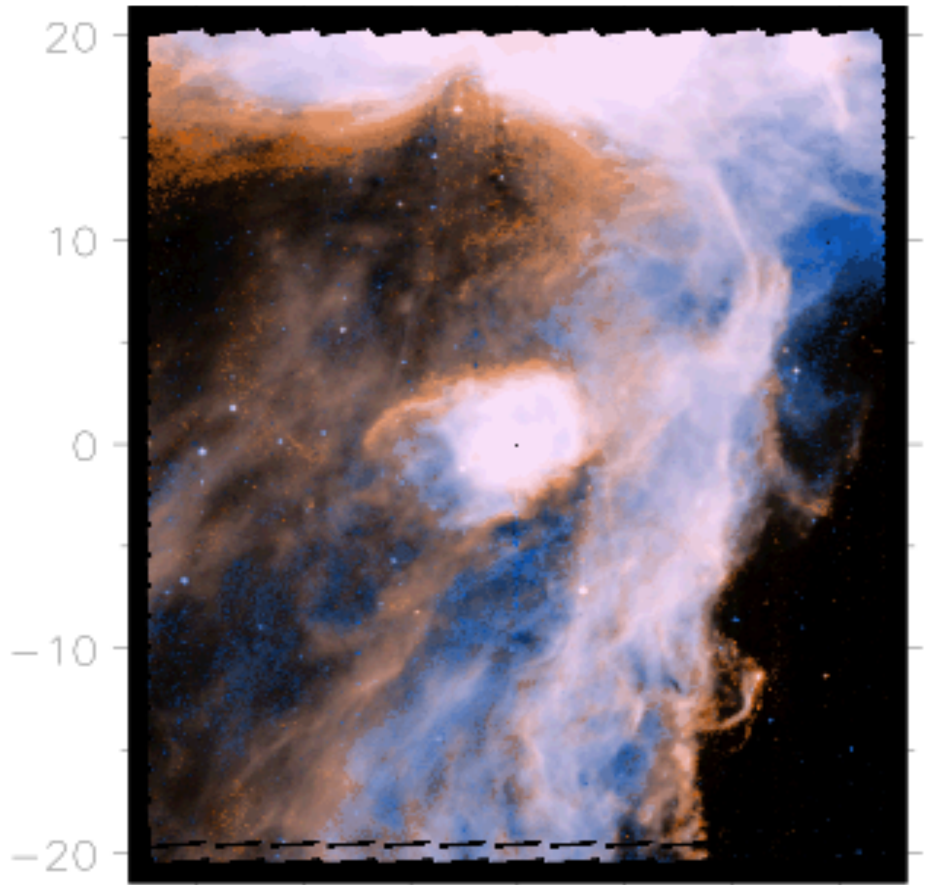
  The shape of the IR spectrum does not change (if no evolution)…

Maps of the emission of very small dust particles in Orion B

Orion B molecular cloud in the visible

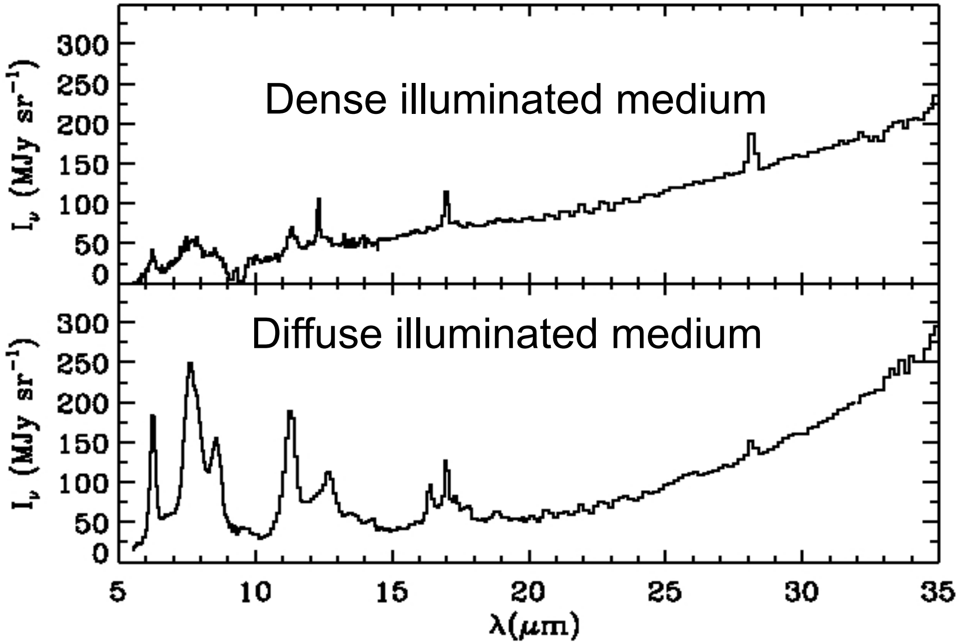


Aromatic 5-8 μm / Cont. at 15 μm

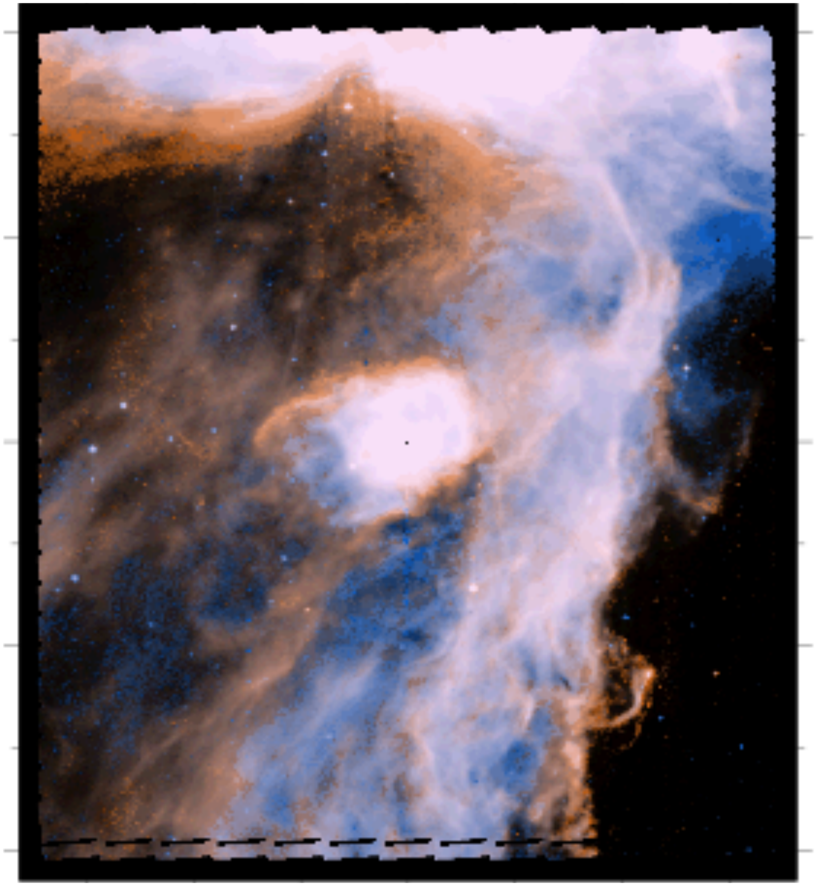


ISOCAM (Abergel et al. 2002)

Maps of the emission of very small dust particles in Orion B



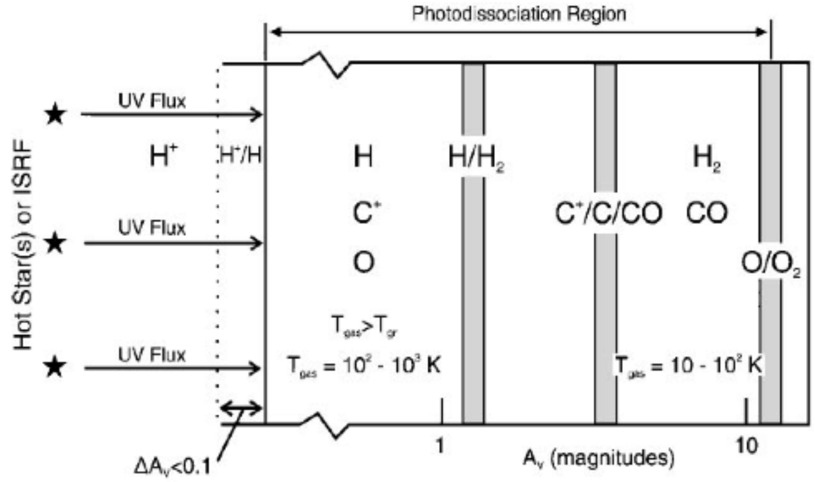
Aromatic 5-8 μm / Cont. at 15 μm



ISOCAM/CVF or Spitzer/IRS spectroscopy:
(Abergel et al. 2002, Compiegne et al. 2008, Habart et al 2005
Rapacioli et al. 2005, Berné et al. 2007, …)

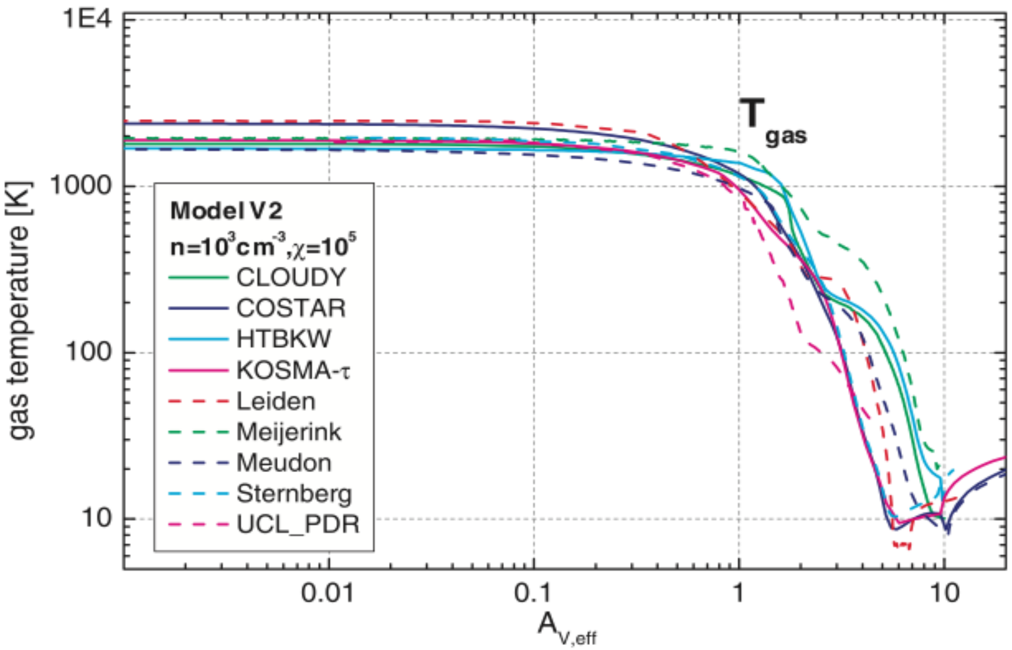
Strong colour variations which are at a first order due to evolution of the emitters (properties, abundance, size distribution, …) in response to local conditions

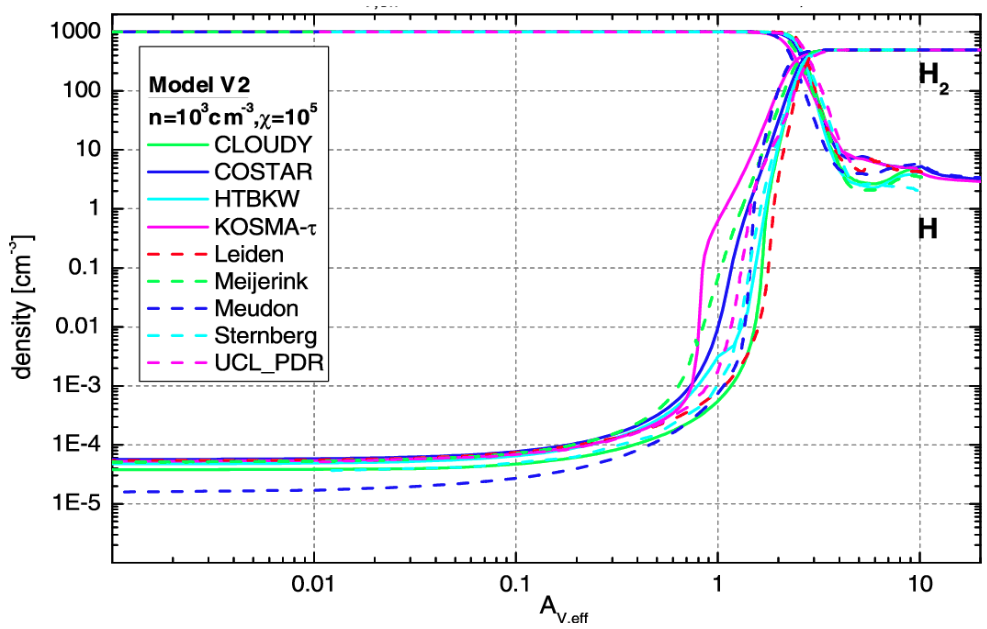
Photodissociation Regions
PDRs



Laboratories to study radiation-dominated processes

The physical conditions vary on short scales :



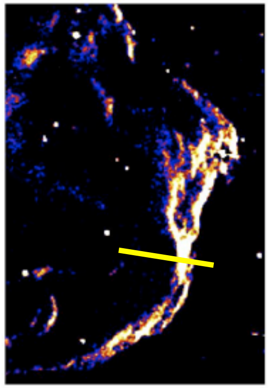


Röllig et al. 2007

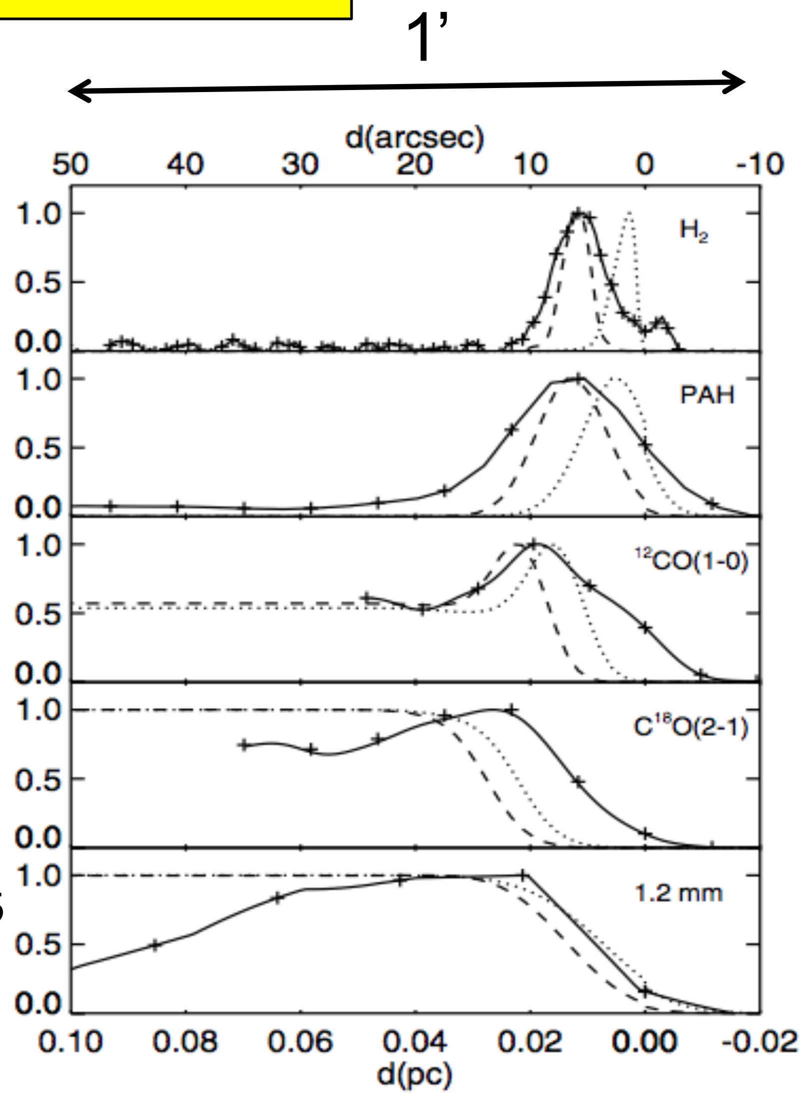
And in response all PDRS tracers (dust, molecular and atomic emissions)…

The Horsehead Nebula

IRAC: 3.6, 4.5, 8 mic,
Bowler et al. 2009



H2, 2.12 mic
Habart et al. 2005

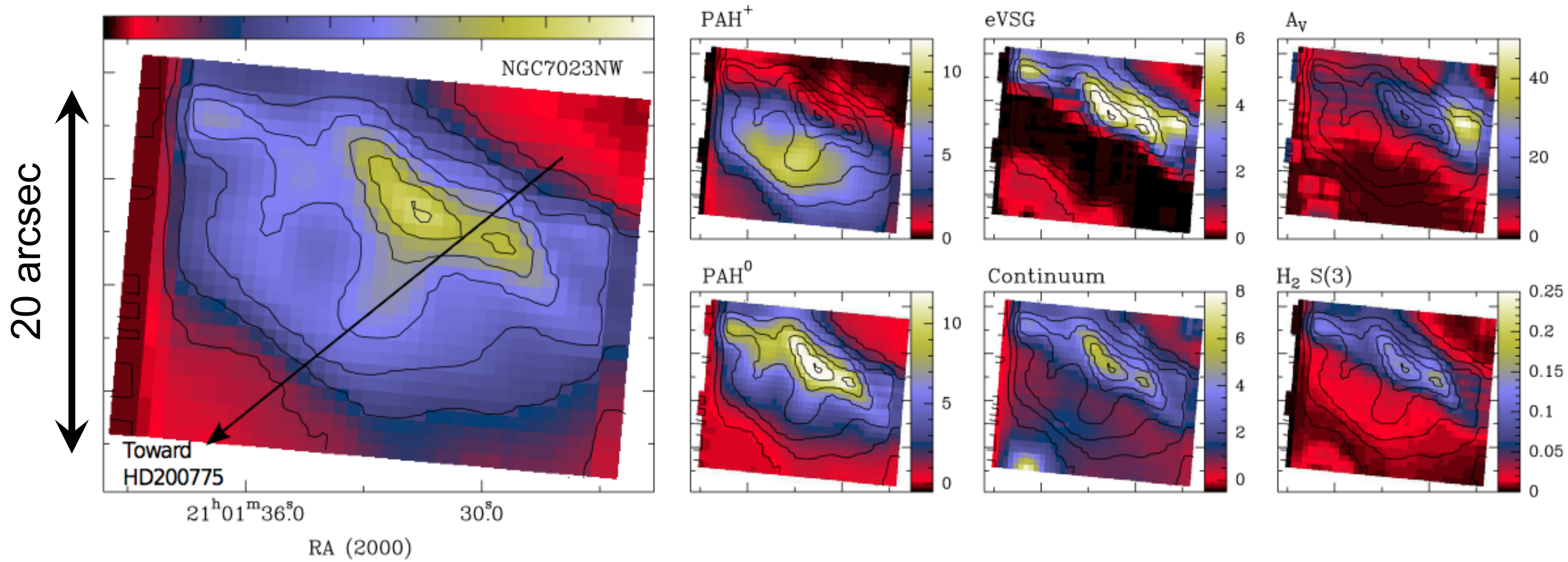


The angular resolution and the sensitivity are crucial !

Habart et al. 2005

Photo-processing of very small dust particles in PDRs from Spitzer/IRS spectral cubes

Example in NGC 7023 (see next talk and Pilleri et al. 2012)

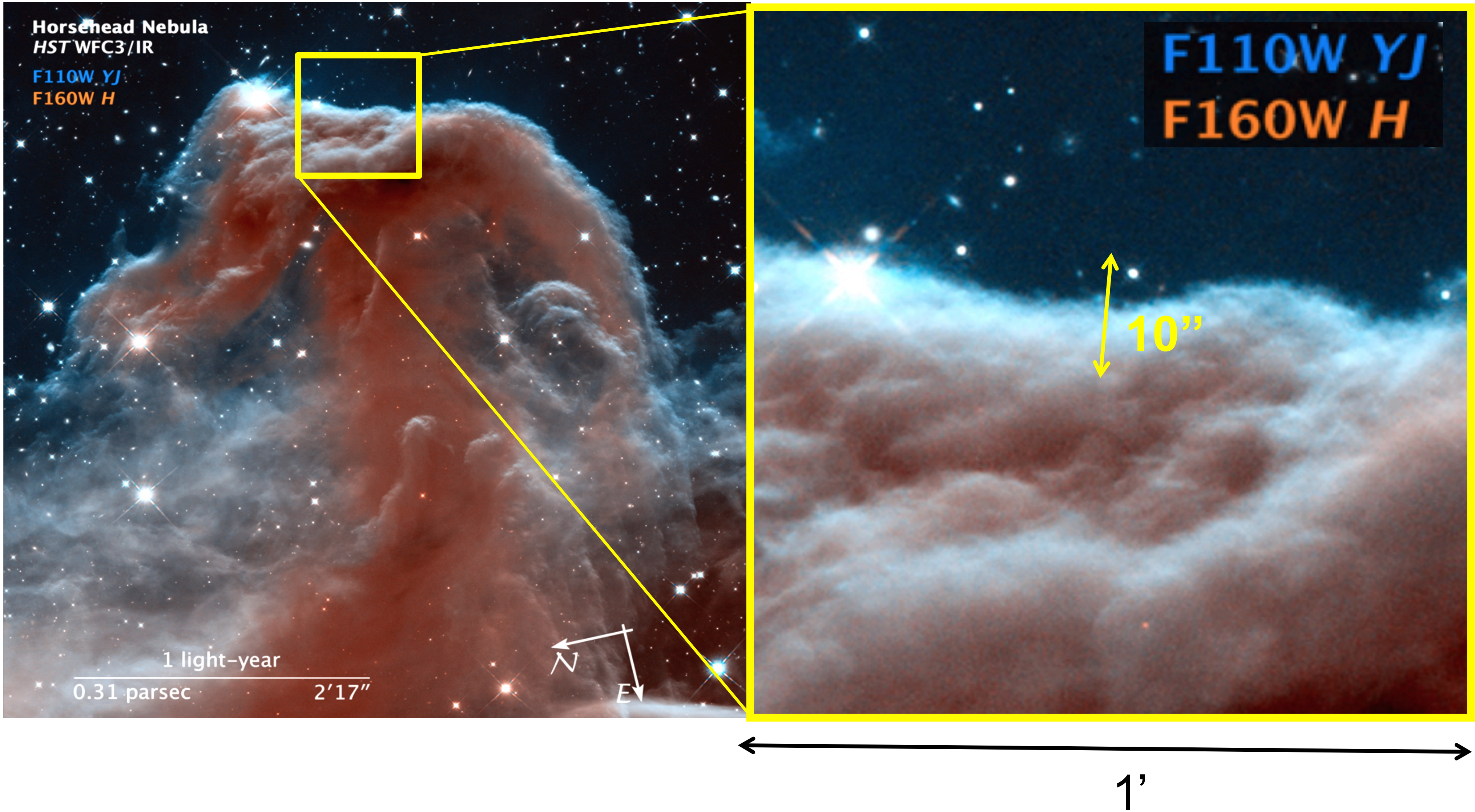


Going towards the stars, eVSGs followed by PAH^0 and PAH^+ are successively dominant
Interpretation :
At the illuminated edge of PDRs, eVSGs destroyed by UV photons to produce free-flyer PAHs

But the angular resolution is limited, ~ 3.6 arcsec

The JWST has the angular resolution to resolve the transition regions…

The Horsehead Nebula (J & H bands) with the HST



Molecular Hydrogen

- Everywhere where dust shields it from UV photons ($A_V > 0.01-0.1$ mag)

- Two key roles in ISM processes

  H_2 formed on grains initiates interstellar gas phase chemistry.
  One of the major contributors to the cooling of astrophysical media.

- Excitation

  Far UV pumping to excited electronic states
  Inelastic collisions to lower energy levels
  Internal energy due to H_2 formation on dust grains
  X-ray excitation

- JWST: IR emission lines of H_2

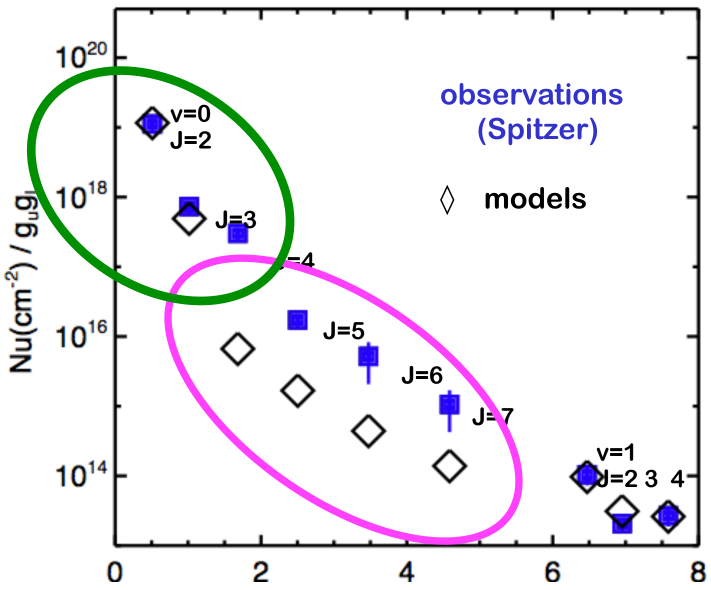
  - J = 0-0 S(0) at 28.22 μm and J =0-0 S(1) at 17.03 μm generally thermalized

    Mass and temperature of the bulk of warm molecular gas

  - Higher pure rotational lines probe the small fraction (< 1%) of photon- or shock-heated gas.

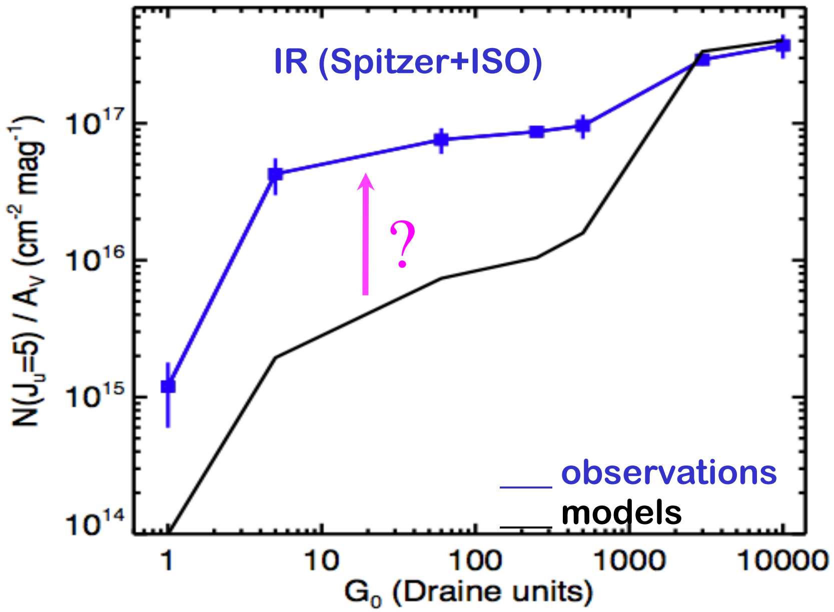
Excitation of H_2 in PDRs (at peak positions) with Spitzer

Horsehead at the peak position (G_0=60)



T upper level energy (10^3 K)

Different objects at the peak positions



Habart et al. 2011

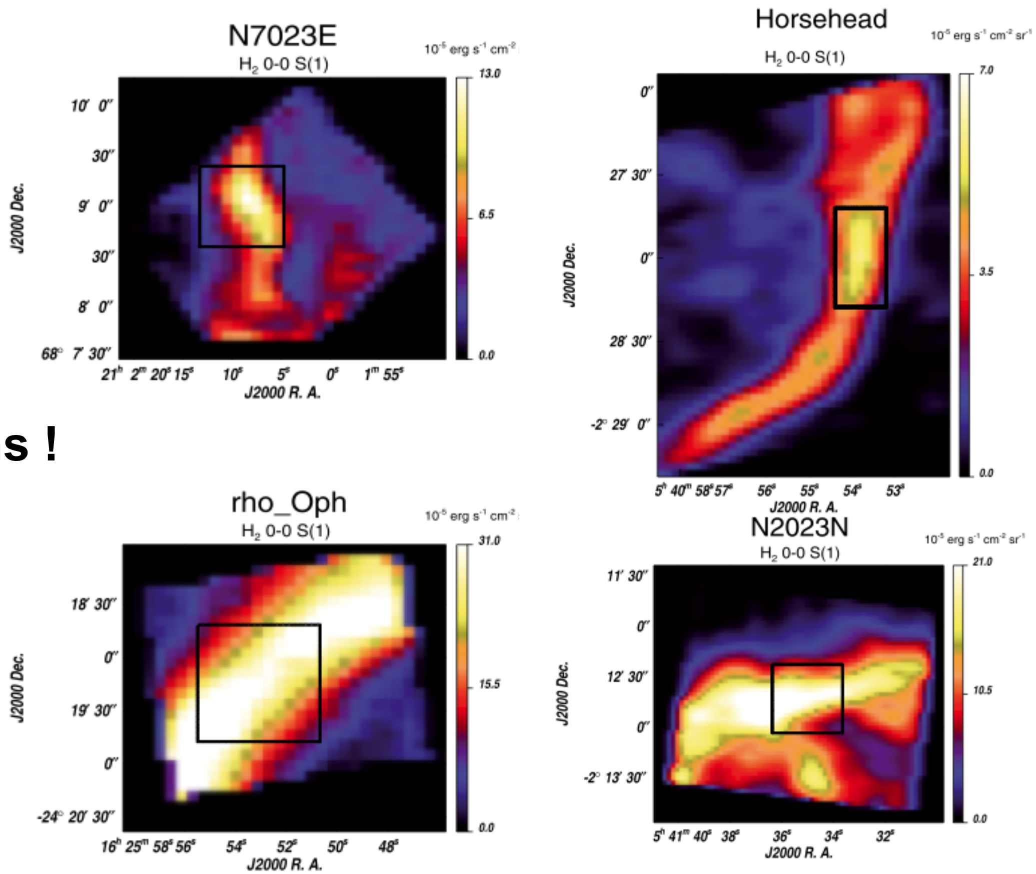
- The first low rotational lines probe the bulk of the gas at moderate temperature

- Unexpected rotationally excited H_2 for limited ($G_0 < 10^4$) FUV incident radiation field compared to static equilibrium models (while OI and C+ lines observed with Herschel can be reproduced)
  - H_2 formation ? Impact of the evolution of dust particles which act as catalysts ?
  - Local increased of the dust photoelectric heating rate ?
  - Additional heating sources (shocks, turbulence) ?
  - Out-of-equilibrium processes ?

Observation of H_2 in PDRs with Spitzer : Main limitation

- Limited angular resolution & sensitivity

All was only done at the peak positions !



JWST: Follow the excitation within individual objects, G_0 decreasing down to 0
Spatially resolve the very small dust and line emission profiles,

Not only H_2 : [Ar II], [Ne II], [Ne III], [S III], [S I], Fe II], [Fe III], [O I], HD, H_2O, H_3O^+, CH_4, C_2H_2, HCN, OH, He, …

Conclusions

- Unique capabilities : Angular resolution, Sensitivity, Spectroscopy

- In nearby galactic objects, the JWST will resolve spatial scales where numerous key processes are acting

Will help the interpretation of a lot of JWST data (not only in the local universe) which use dust or gas as tracers

- but slow : 90 deg/hr slew rate, many timing and scheduling constraints, limited field of view

- Very good position of the French community :

- Strong expertise from ISO, Spitzer, Herschel, IRAM, ALMA, VLT, …

Data processing, Analysis, Modeling, Laboratory works, …

- Strong expertise on MIRI (MICE: SAP/AIM, IAS, LAM, LESIA) & NIRSPEC (IAP)