The JWST project: Applications to PDRs or shocks

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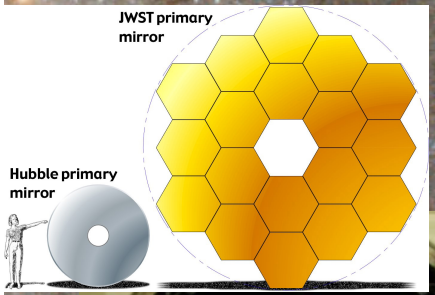
The JWST
The 4 main instruments
PDRs
Shocks
Conclusions

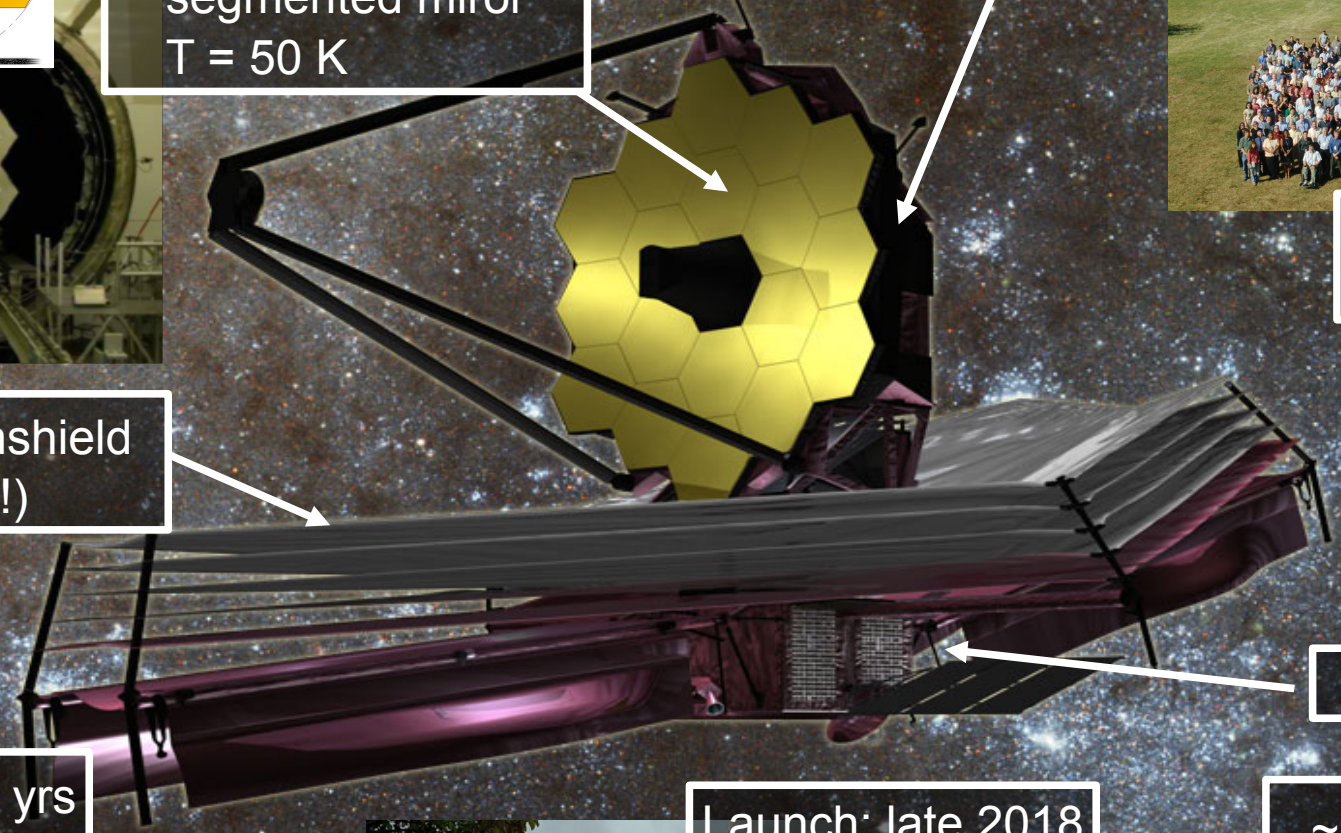
The JWST : Numbers



6.5 m diameter segmented miror
T = 50 K

4 instruments IR
T = 40 K

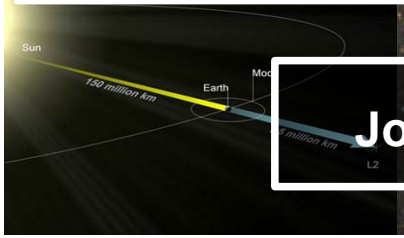
6 tons

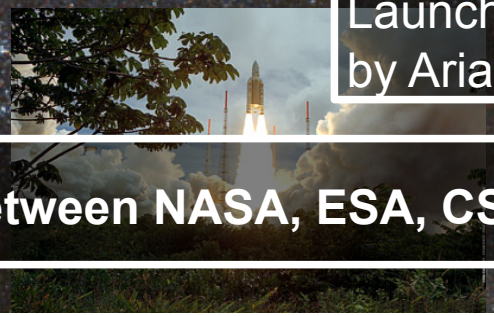


Multi-layer sunshield
(a tennis court!)

Electronics

Lifetime: 5.5 -10 yrs
at L2 point





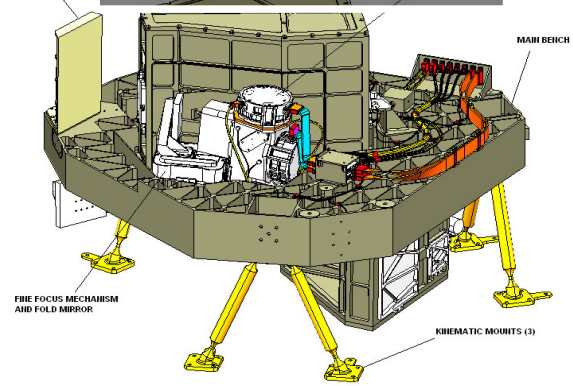
Launch: late 2018
by Ariane 5

~ 8.8 billions $
(5,5 years
of operations)

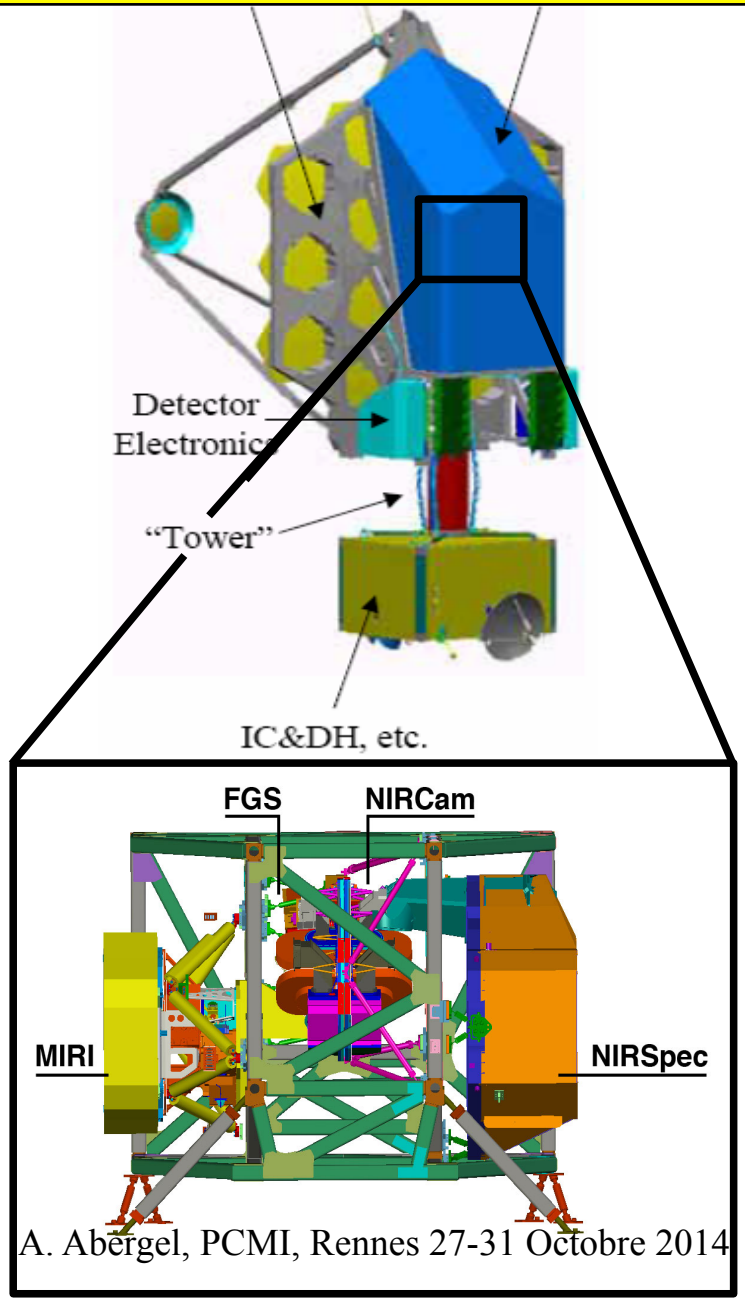
Joint mission between NASA, ESA, CSA (Canada)

JWST's 4 IR instruments

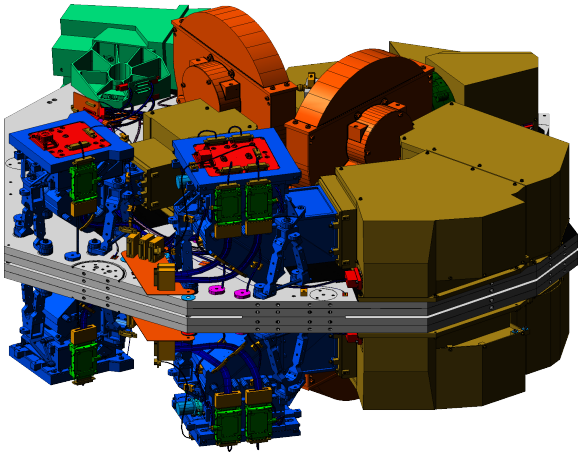
FGS/NIRISS



0.6 - 5 µm

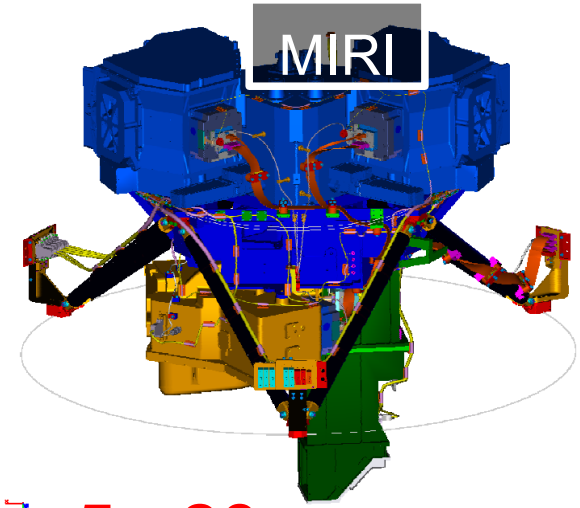


NIRCam



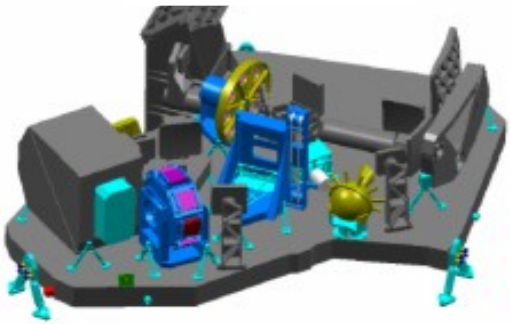
0.6 - 5 µm

MIRI



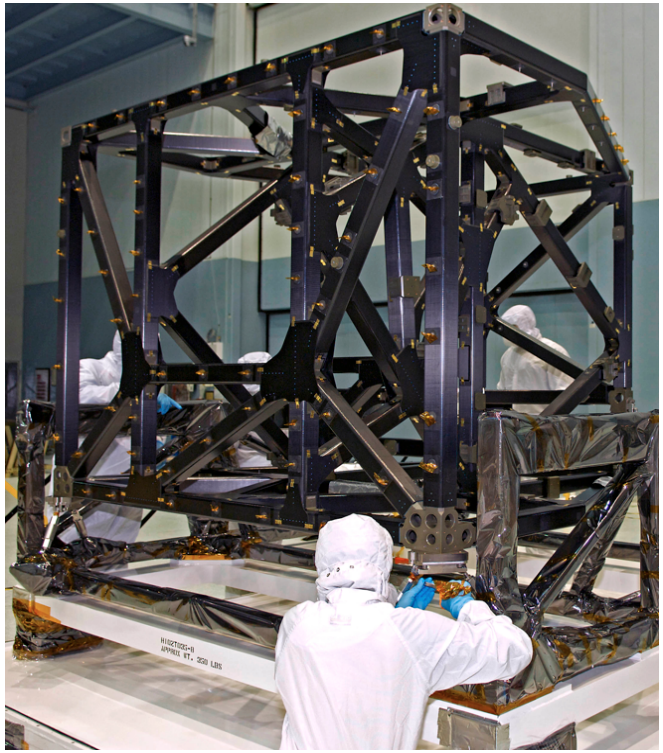
5 - 28 µm

NIRSpec

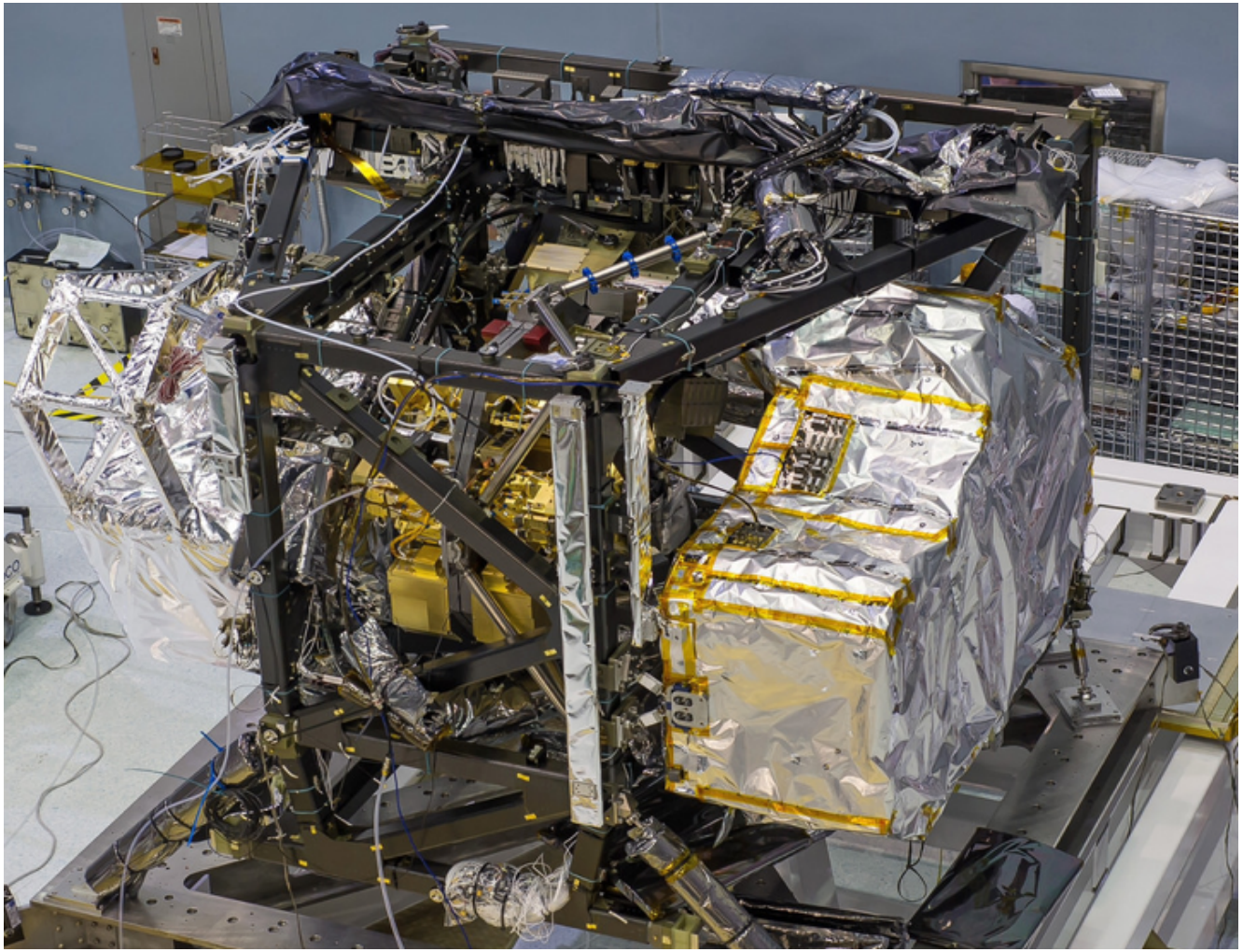


0.6 - 5 µm

Four instruments mounted on the Integrated Science Instrument Module (ISIM)

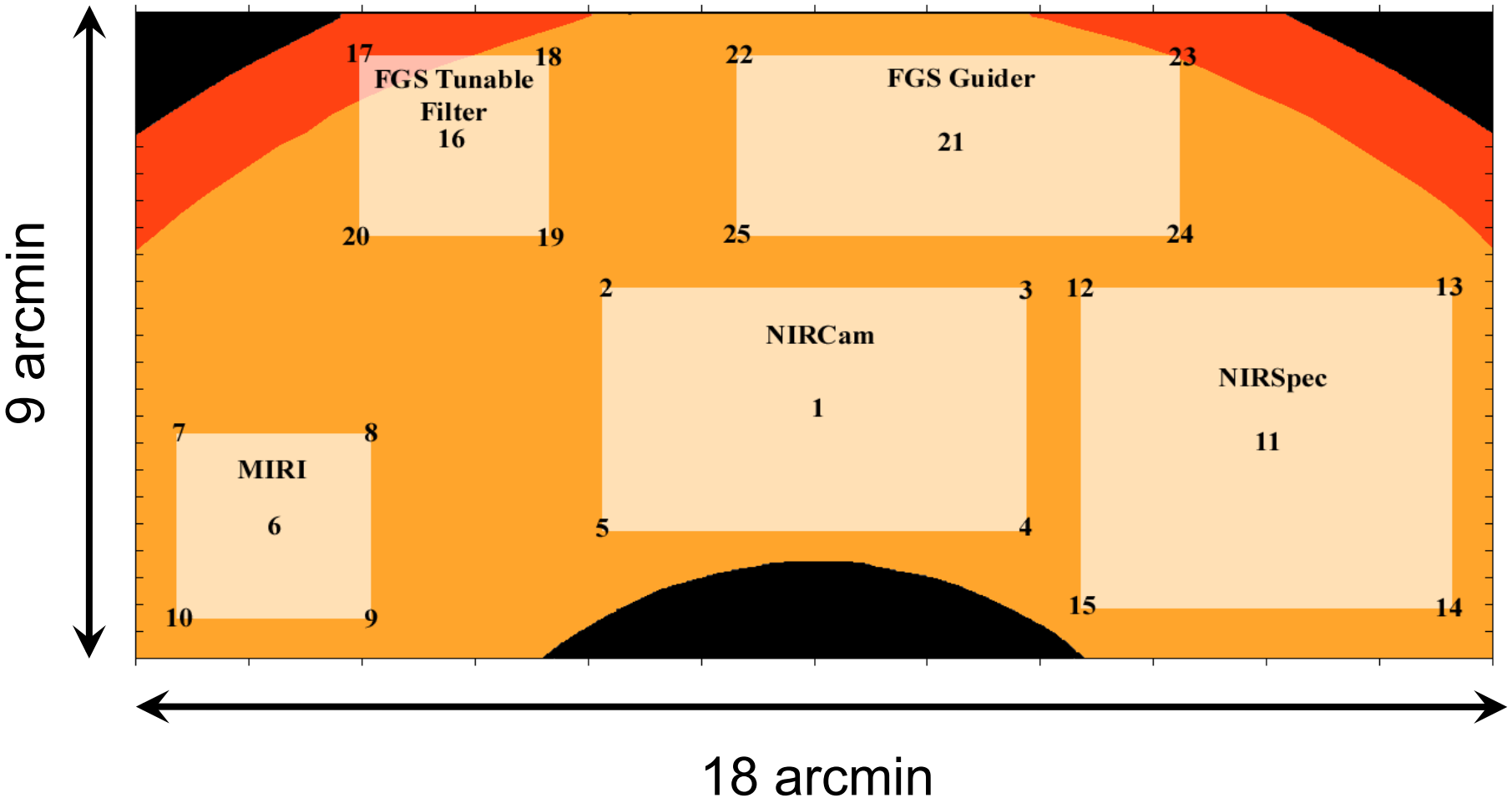


NASA

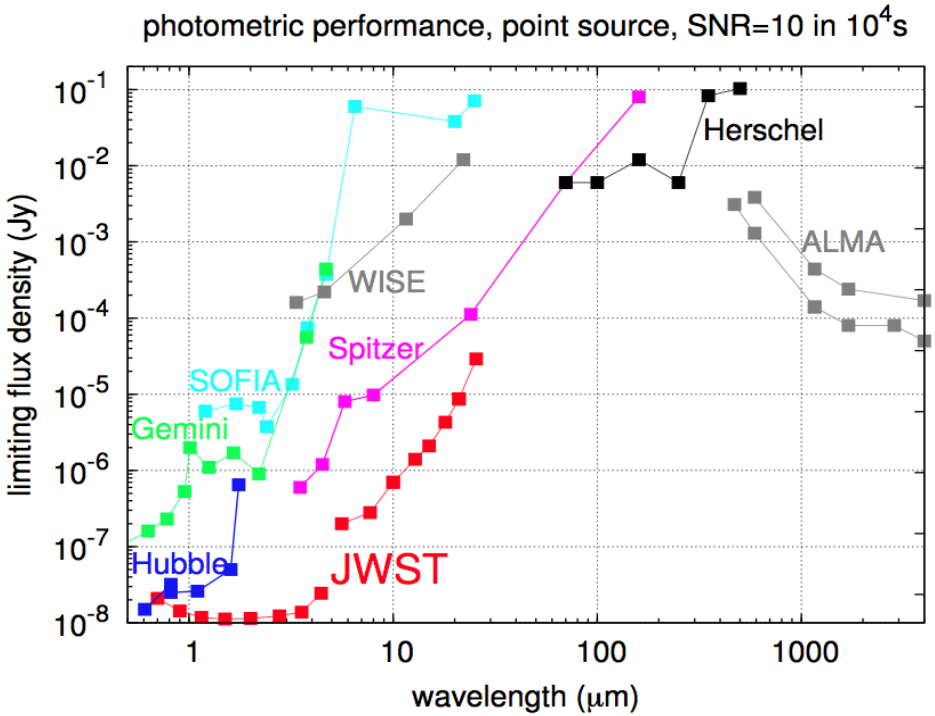


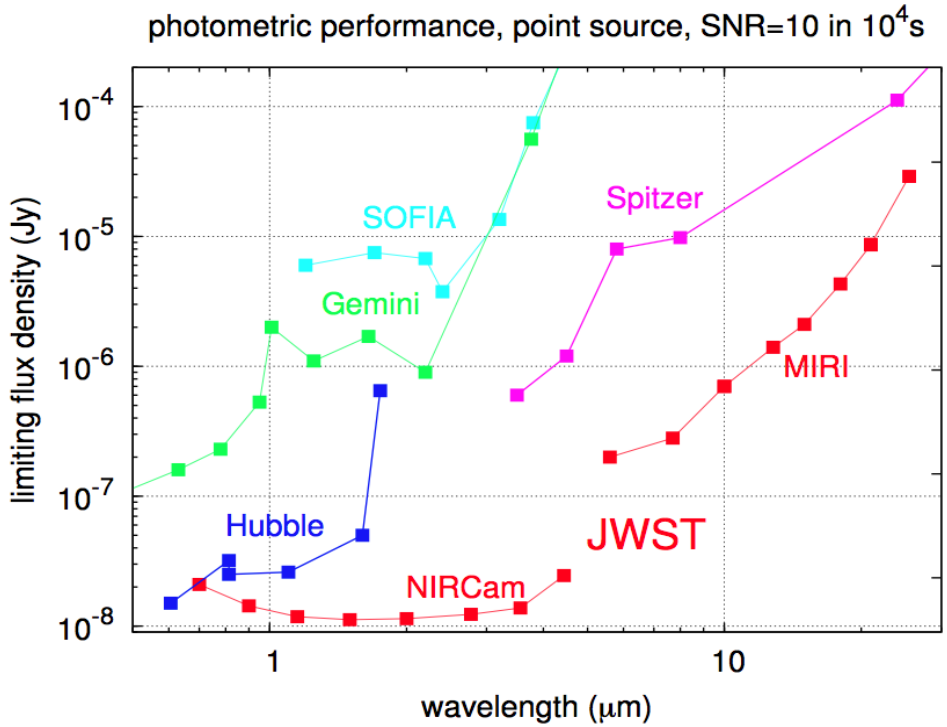
NASA

Field of View Layout



JWST photometric sensitivity

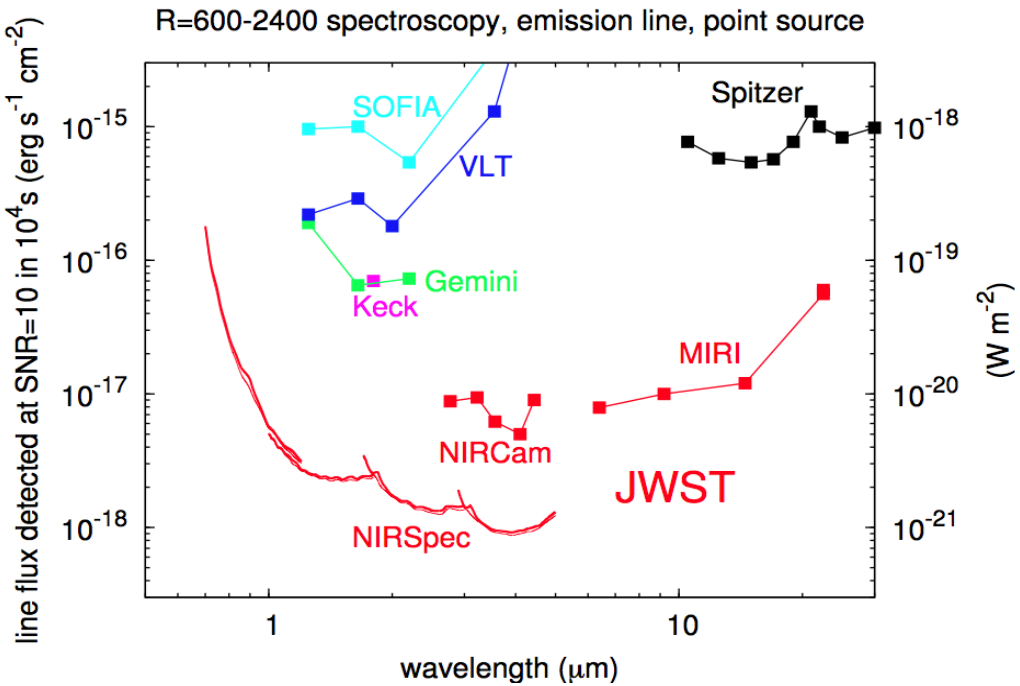


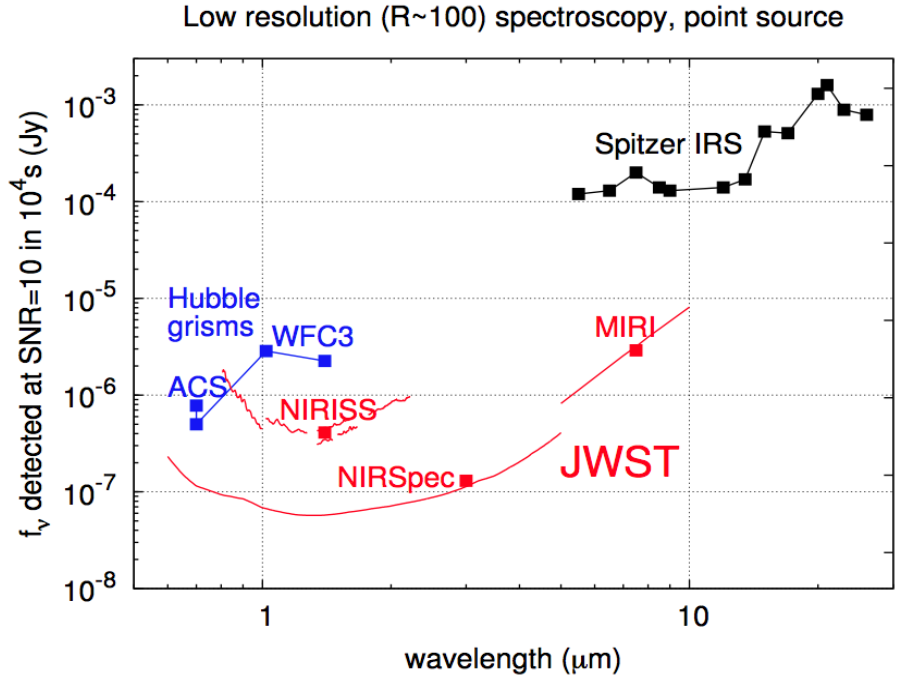


28 (NIRCAM) + 10 (MIRI) + 7 (NIRISS) = 45 filters !

Angular resolution: 0.1-1”

JWST spectroscopic sensitivity





The 4 instruments: NIRSPEC, MIRI, NIRISS, NIRCAM, with a lot of capabilities …

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

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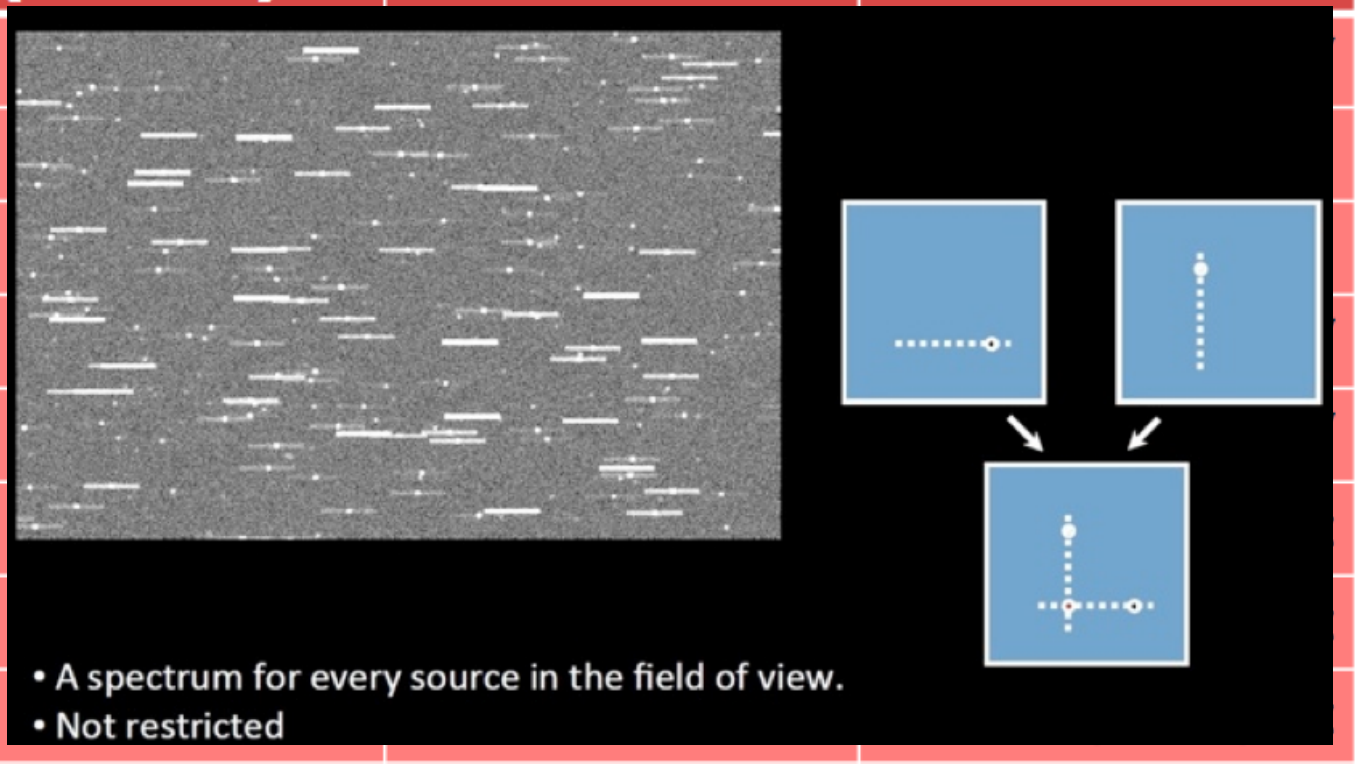
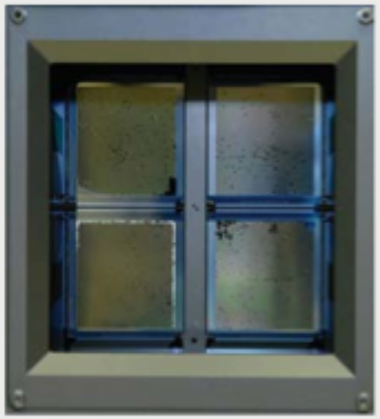


JWST spectroscopic capabilities

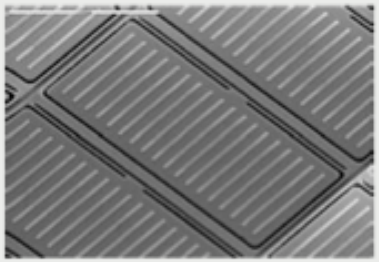
Instrument	Type	Wavelength (mic	Spectral	Field of view
NIRISS	slitless			2′ x 2.2′
NIRCam	slitless			2′ (TBC)
NIRSpec	MOS			arcmin.
NIRSpec	IFU			3″ x 3″
MIRI	IFU			x >3.9″
NIRSpec	SLIT			e object
MIRI	SLIT			e object
NIRISS	Aperture			e object
NIRSpec	Aperture	0.6-2.5	700	Single object

Using 4 arrays of 365x171 micro-shutters each, provided by NASA GSFC.

This gives us a total of almost **250 000** small apertures that can be individually opened/ closed



MEMS device – 105x206 micron shutters



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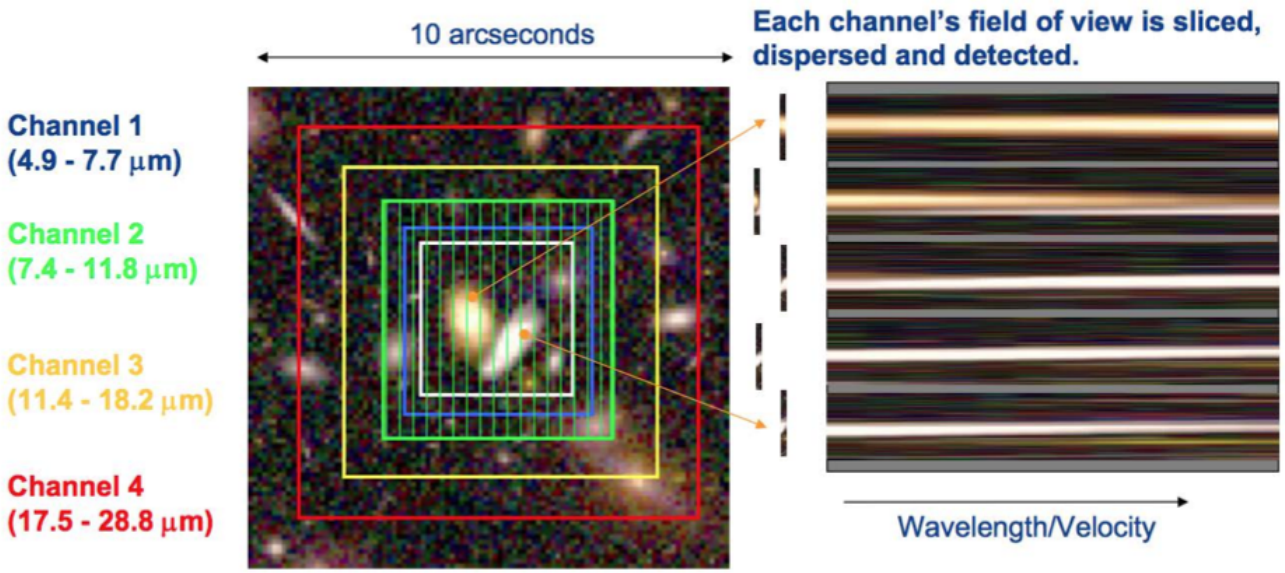
NIRSpec	MOS			
NIRSpec	IFU			
MIRI	IFU			
NIRSpec	SLIT			
MIRI	SLIT			
NIRISS	Aperture			
NIRSpec	Aperture	0.6-2.5	700	Single object

- **MIRI IFU**
  - Covering the 4.9-28.8 micron range continuously in 3 exposures!
  - Mapping spectrally your objects over a field of view larger than 3″ x 3.9″.



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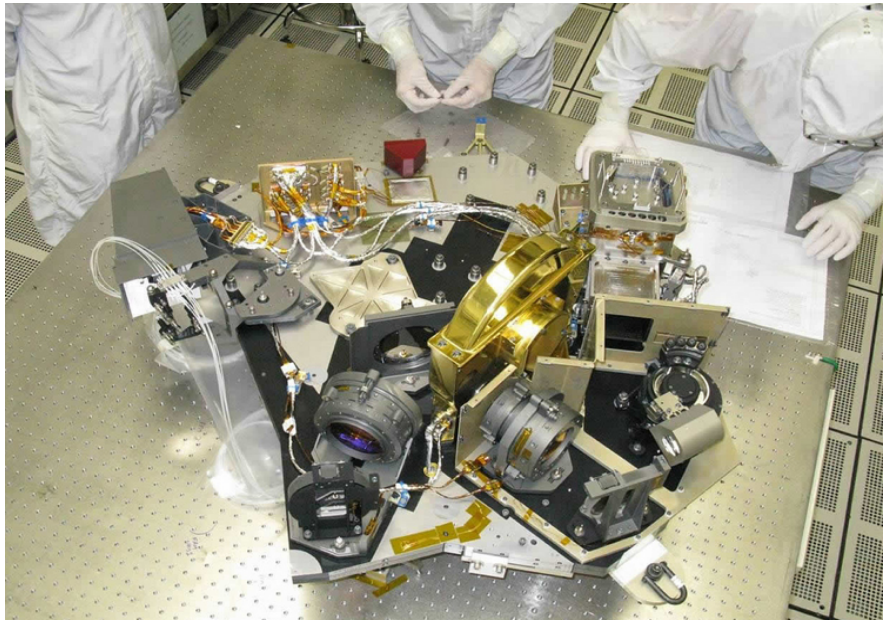
NIRCAM



- Univ. of Arizona plus Lockheed ATC
- 0.6-5 μm range
- short (0.6-2.3 μm) and long (2.4-5 μm) arms, same area observable simultaneously
  - 2.2 x 4.4 arcmin total field of view
  - 16 and 4 Mega pixels detectors operating at 80 K and 42 K
  - Diffraction limited at 2 and 4 μm
  - Pixel scale : 0.032” and 0.064”
  - 28 broad, intermediate, and narrow band filters (R = 4, 10, 100)…
  - Coronographic capability (moving focal plane masks/Lyot stop in the pupil wheel)
  - Also a grism in the long channel (2.4-5 μm slitless spectroscopy, R = 2000)
  - Use to phase the 18 segment primary mirror

NIRCam Filters & Sensitivity

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

Short Wavelength Module

Name	Center	Bandpass	Sensitivity	Use
F150W2*	1.5	1		DHS Blocking
F070W	0.7	0.175	20.9	General purpose
F090W	0.9	0.225	14.3	General purpose
F115W	1.15	0.2875	11.8	General purpose
F150W	1.5	0.375	11.2	General purpose
F200W	2	0.5	10.4	General purpose
F140M	1.4	0.14	28.1	Cool *s, H_2O steam
F162M	1.62	0.151	26.6	Cool *s, off-band
F182M	1.82	0.221	25.5	Cool *s, H_2O steam
F210M	2.1	0.21	25.7	CH_4
F164N	1.644	0.0164	268	[FeII]
F187N	1.8756	0.0188	267	Pα
F212N	2.1218	0.0212	265	H_2
F225N	2.2477	0.0225	232	H_2

Long Wavelength Module

Name	Center	Bandpass	Sensitivity	Use
F322W2	3.22	1.61		Background Min.
F277W	2.77	0.6925	12.3	General purpose
F356W	3.56	0.89	13.8	General purpose
F444W	4.44	1.11	24.5	General purpose
F250M	2.5	0.1667	38.1	CH_4
F300M	3	0.3	26.8	H_2O ice
F335M	3.35	0.335	28	PAH
F360M	3.6	0.36	29.7	BDs, planets
F410M	4.1	0.41	36.7	BDs, planets
F430M	4.3	0.2	71.5	CO_2
F460M	4.6	0.2	55.7	CO
F480M	4.8	0.4	72.6	BDs, planets
F323N	3.235	0.0324	240	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

NIRSPEC

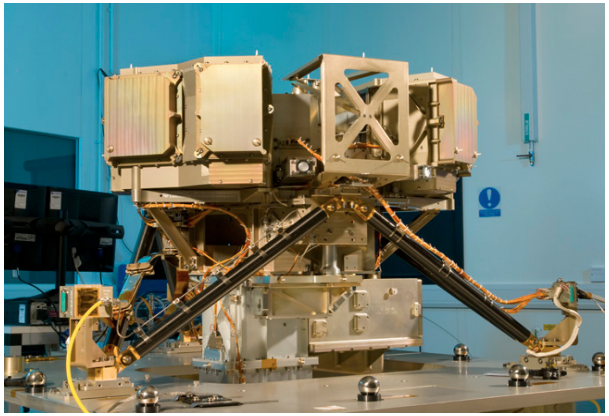
- Provided by ESA, built by Airbus Defense and Space in Germany

- 0.7-5 μm range, 3.4’ x 3.6’ FOV (3' x 3' for Multi-object spectroscopy)
- 730 X 342 Micro-Shutter Assembly (MSA) for multiple apertures
  - for compact, faint and numerous (>100) sources
- 3 fixed slits : 0.1" x 1.9”, 0.2" x 3.3", 0.4" x 3.8”
- Integral Field Unit (IFU)
  - 3” x 3”, with 30 image slices,
    each 0.1” (dispersion) x 3” (spatial)
- 3 spectral resolutions:
  - 100 (0.7 - 5.0 μm - single prism)
  - 1000 (1.0 - 5.0 μm - 3 gratings)
  - 2700 (1.0 - 5.0 μm - 3 gratings)
- 2 x 4 Mega pixels HgCdTe arrays at 30-40 K

Near-InfraRed Imager and Slitless Spectrograph (NIRISS)

- Provided by the Canadian Space Agency and designed, built and tested by COM DEV International.
- 4 observing Modes:
  - Wide-field grism spectroscopy, 1 - 2.5 μm at R ~ 150
  - Single-object grism spectroscopy, 0.6 - 3.0 μm at R ~ 700
  - Aperture-masking interferometry (exoplanet detection)
  - Broad-band imaging, 1.0 - 5.0 μm, 2.2’ x 2.2’, 7 filters (spare model of NIRCAM filters)
- HgCdTe matrix with 2048 × 2048 pixels

MIRI



- Developed by the US and Europe (50%-50%)
- European consortium with 10 countries. ESA supervision.

1. MIRIM: Imaging and Coronography + Low Resolution Spectroscopy RAL

   Responsible SAp/CEA (co-PI P.O Lagage) + LESIA + LAM + IAS

- 9 photometric bands from 5 to 28 μm, R ~ 5, Field of View: 74" X 113”
- Coronography : 3 four-quadrant phase masks at 10.65, 11.4, & 15.5 μm and Lyot mask at 23 μm
- Low-Res Spectroscopy, R ~ 100 at 7.5 μm, 5 to ~ 14 μm, slit 0.6" X 5.5”

2. MRS: Mid Resolution Spectroscopy

   Netherland: Spectrometer Main Optic

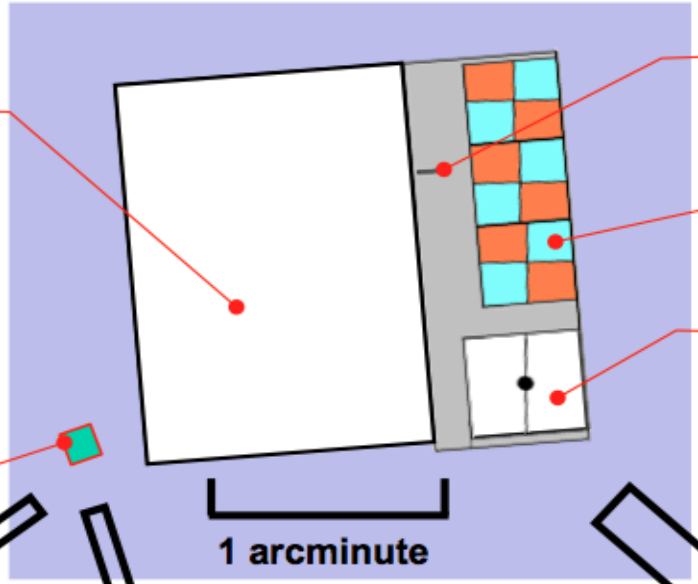
- R ~ 2070 - 3730, 4.9 to 28.8 μm, IFU with FOVs of 3.7" to 7.7”

1+2 = 3 1024 X 1024 SiAs detector array (US). Operating temperature : 7 K (cryocooller)

The MIRI Focal Planes (Entrance + Detector)

Imager
75 x 113 arcsec field
0.11 arcseconds/pixel
Nyquist sampled at 7 μm
It is not possible to simultaneously observe the same field with imager and spectrometer

R ~ 3000, 4 Channel Integral Field Spectrometer

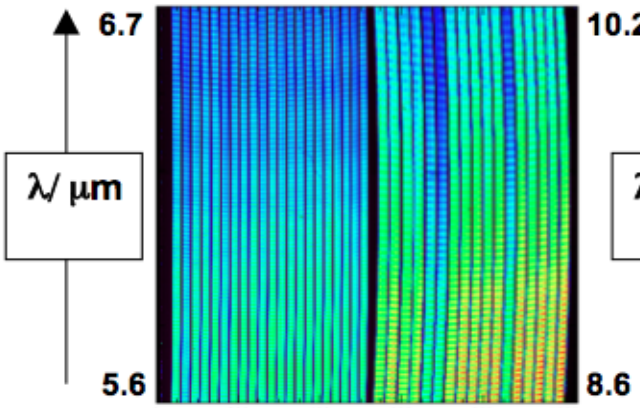


Low Resolution Spectrometer
5 x 0.6 arcsec

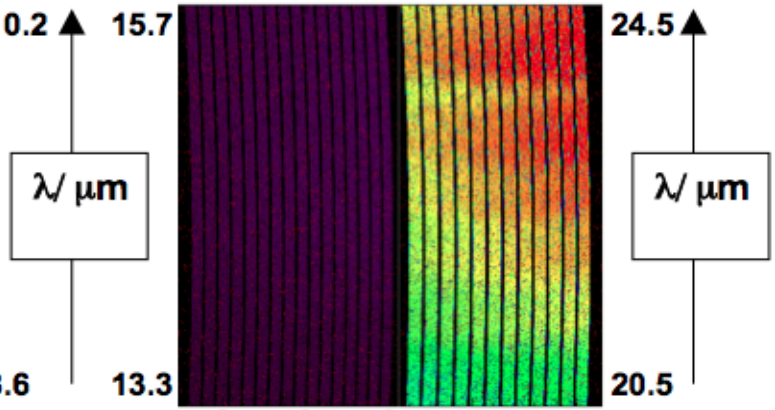
Three 4QPM Coronagraphs
24 x 24 arcsec

Lyot Mask 23μm
30" x 30"

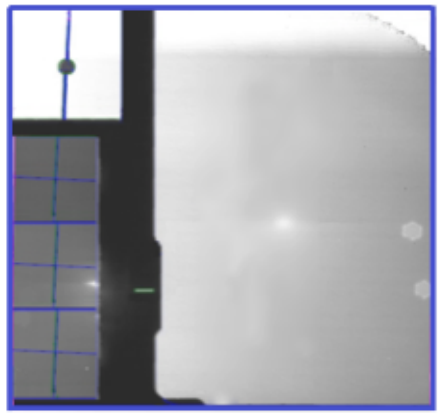
MIRI VM Spectral Image



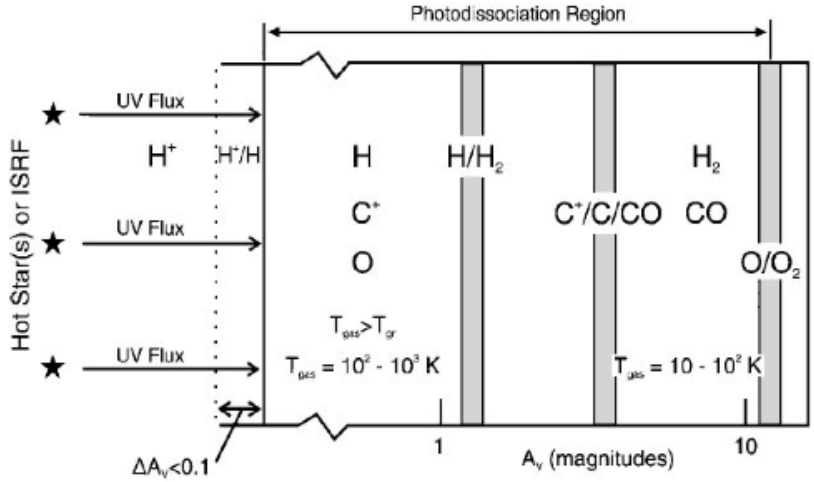
Specsim simulated image



MIRI FM Imager (non-flight detector fitted)

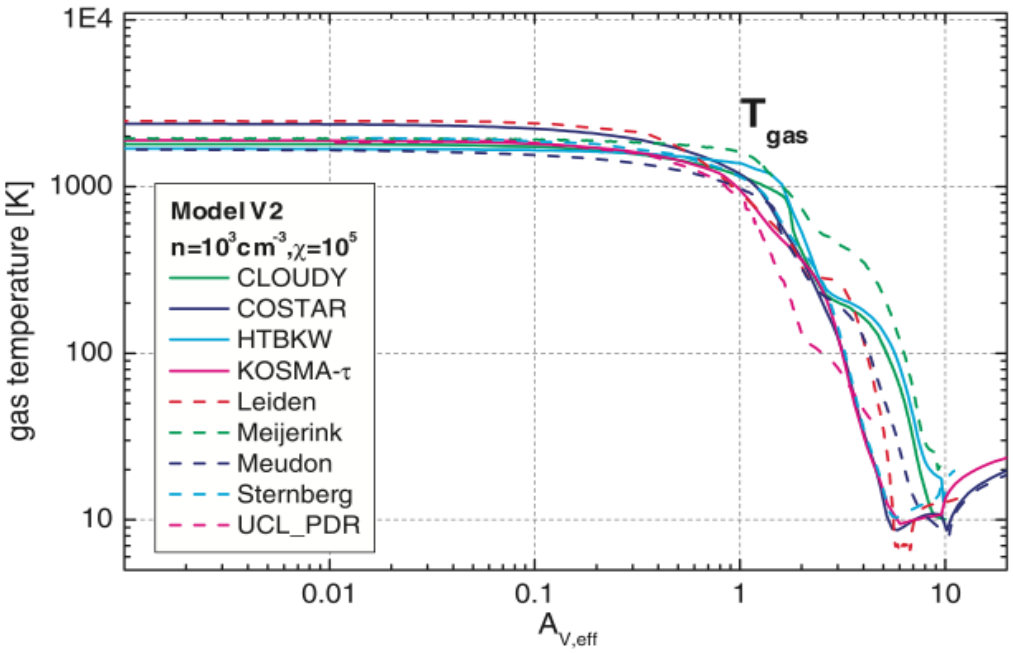


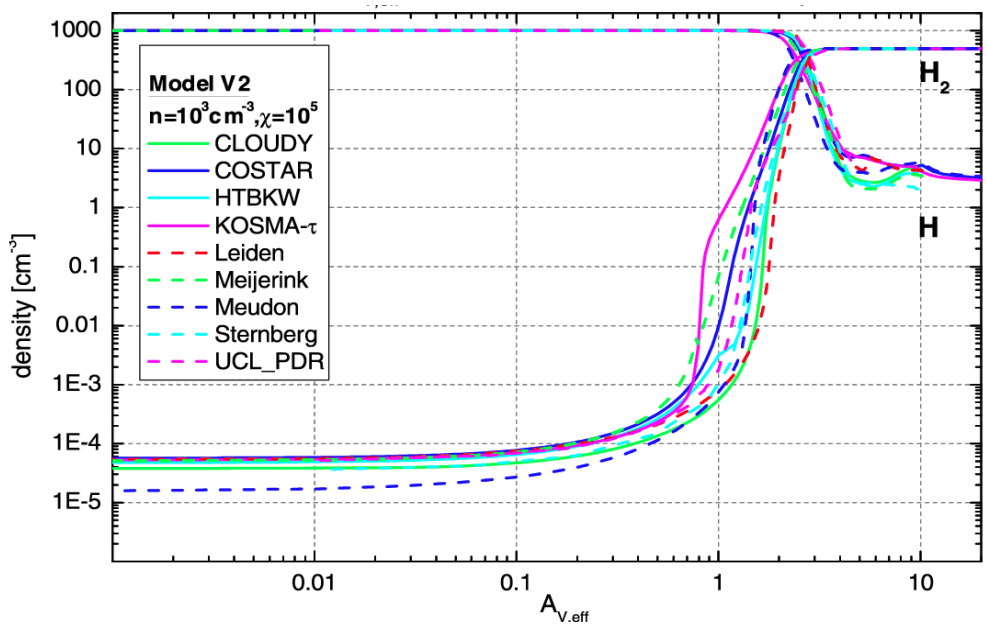
PDRs



Laboratories to study radiation-dominated processes

The physical conditions vary on short scales :

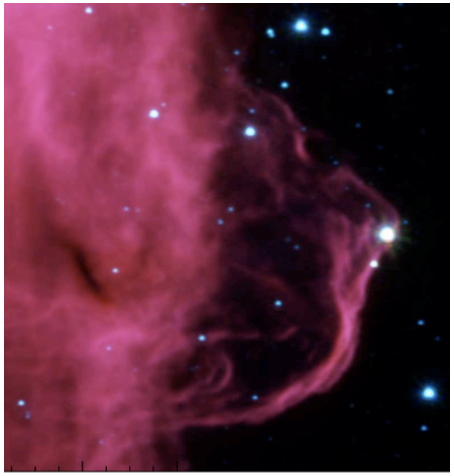




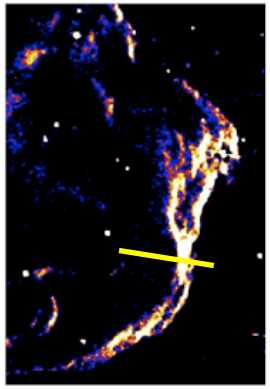
Röllig et al. 2007

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

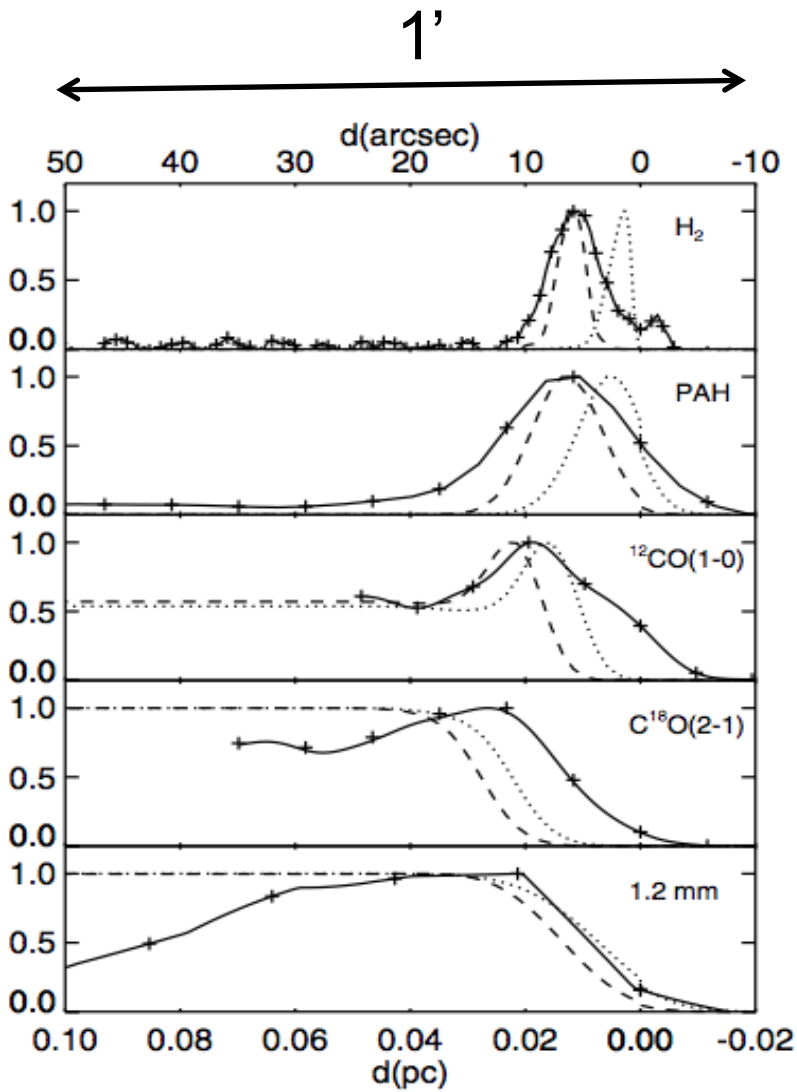
The Horsehead Nebula



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



H2, 2.12 mic
Habart et al. 2005

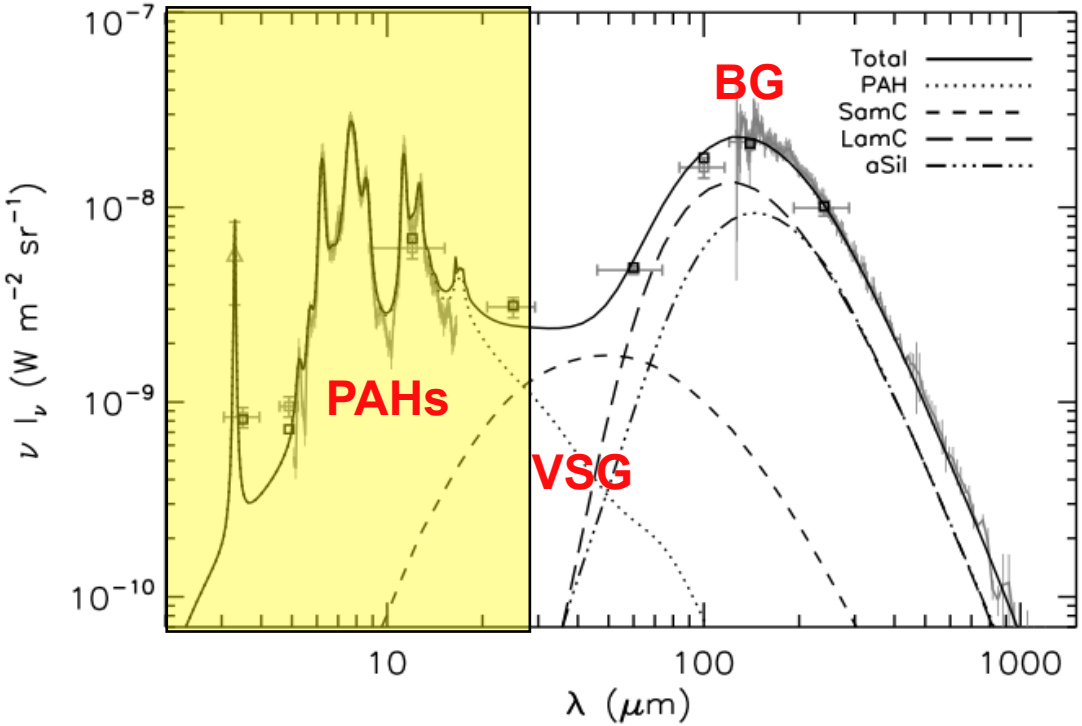


Habart et al. 2005

Dust Emission spectrum

Diffuse ISM SED from DUSTEM

Compiegne et al. (2011)

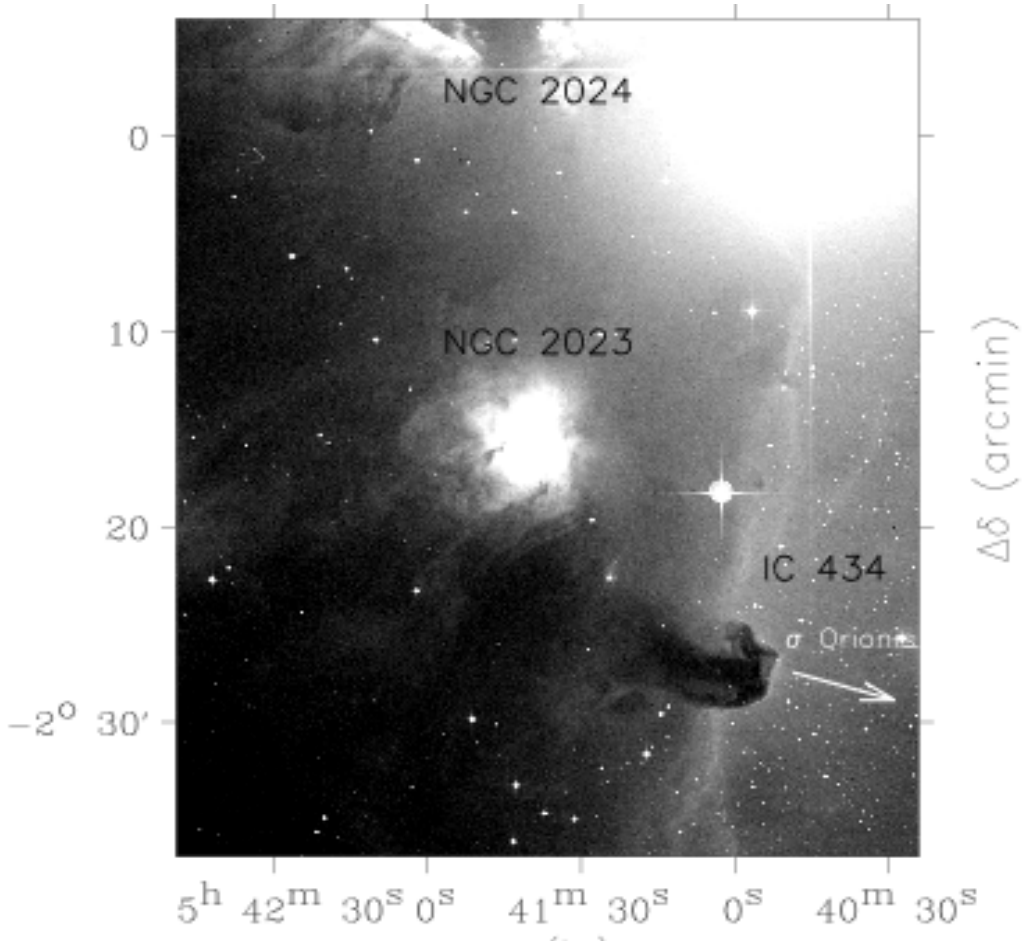


- "Big Grains" : Large Amorphous Silicate (aSil) and Carbon (LamC)

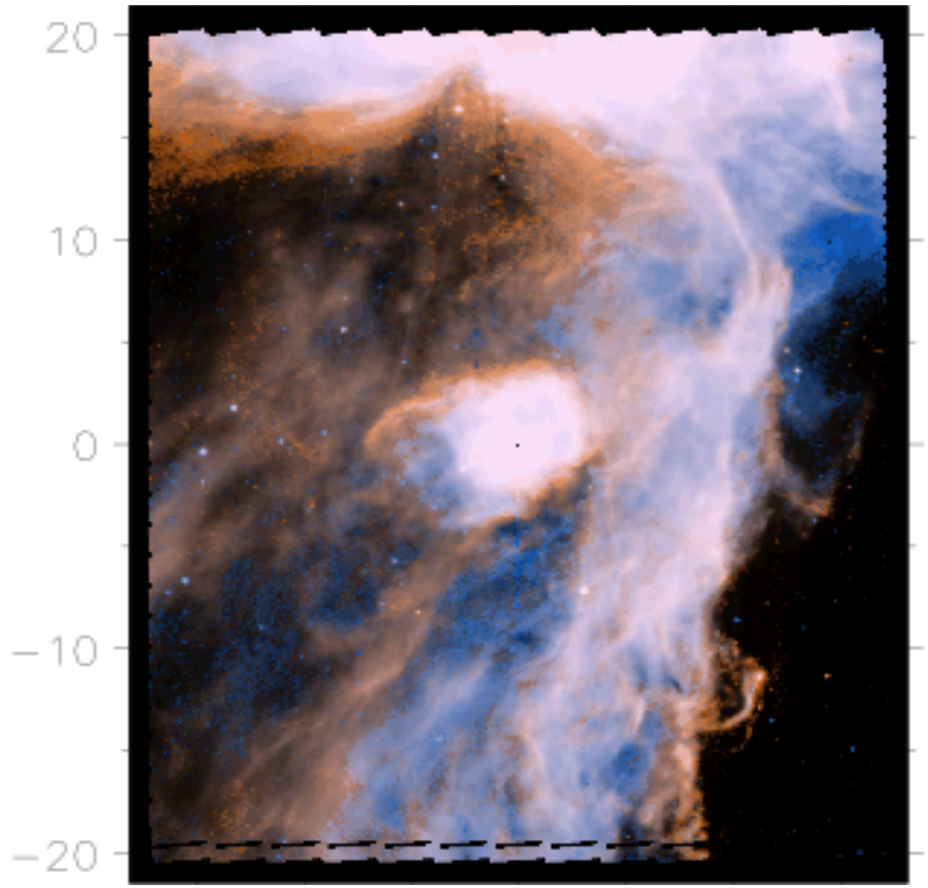
- Very small dust particles : "PAHs" & "Very Small Grains" (Small Amorphous Carbon)
  Play a major role : Heating, Formation of molecules (H_2, …), Extinction
  Evolution (properties, abundance, size distribution, …) in response to local conditions as illustrated in PDRs…

Maps of the emission of very small dust particles in PDRs

Orion B molecular cloud in the visible



Aromatic 5-8 μm / Cont. at 15 μm



ISOCAM (Abergel et al. 2002)

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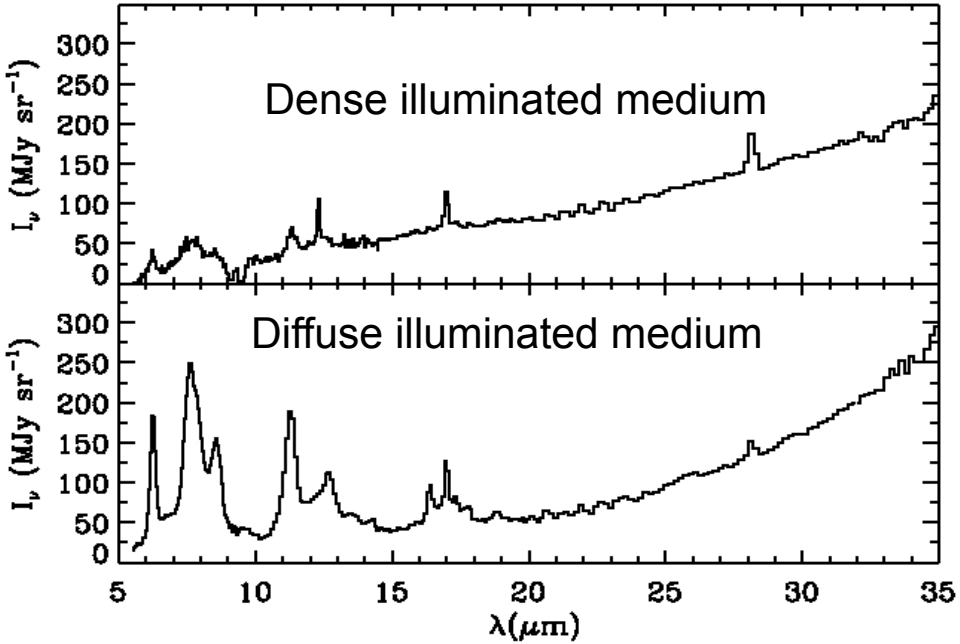
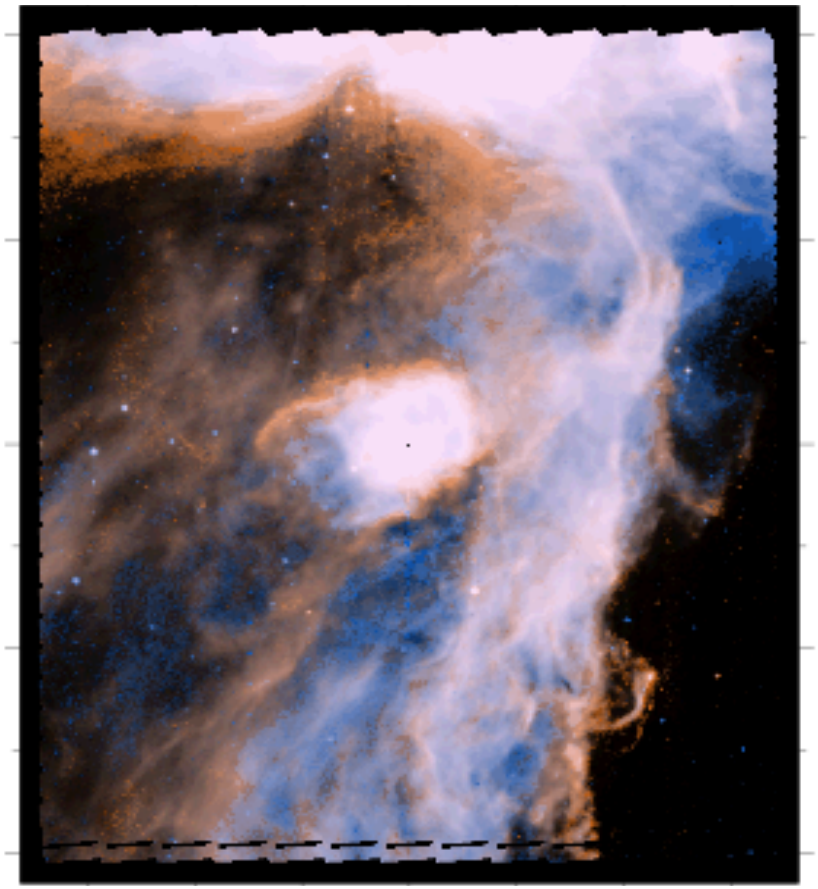


Aromatic 5-8 μm / Cont. at 15 μm

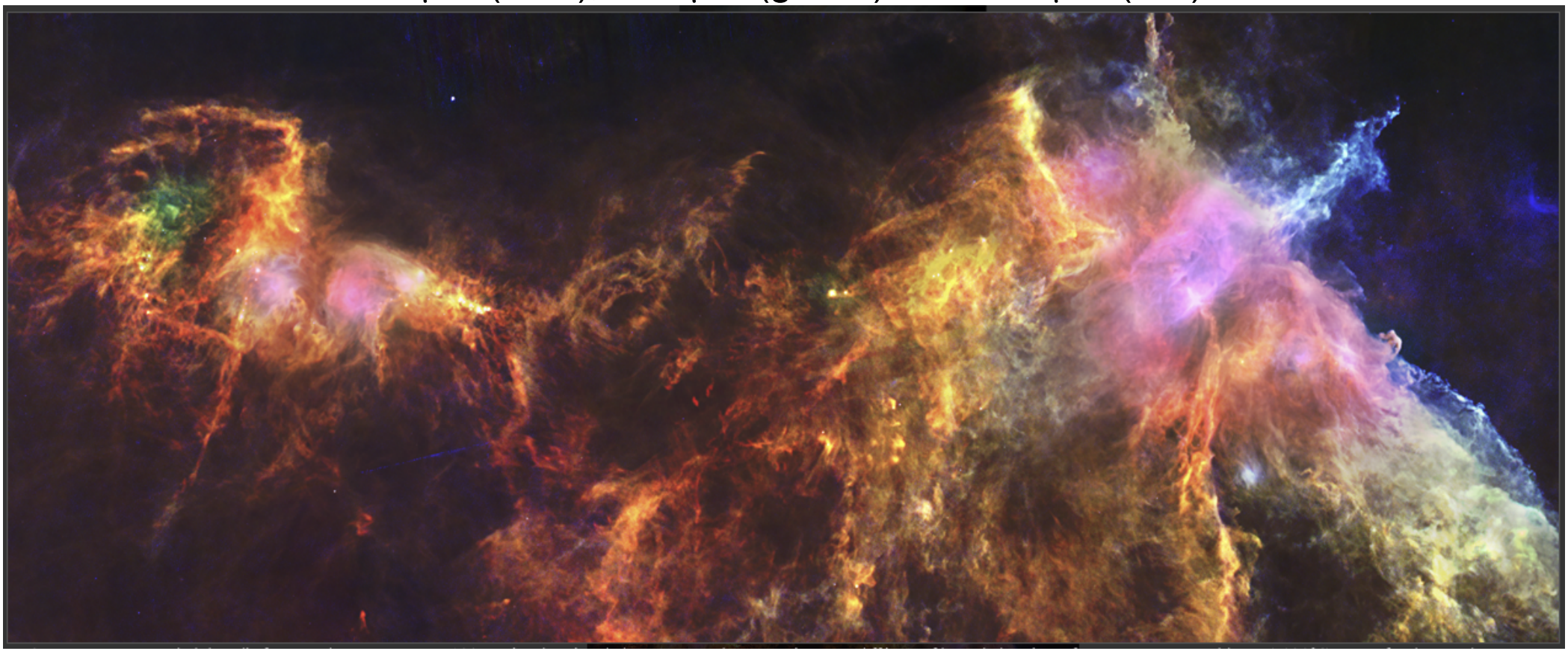


ISOCAM/CVF or Spitzer/IRS spectroscopy:
(Abergel et al. 2002, Compiegne et al. 2008, Habart et al 2005
Rapacioli et al. 2005, Berné et al. 2007, …)

- Strong colour evolution at dense illuminated ridges (traced by H_2) which directly reveals evolution of the emitters at the opposite of Herschel maps…

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 are mainly due to variations of the dust temperature, due to variations of the local heating

Rho Oph molecular cloud mapped with Spitzer

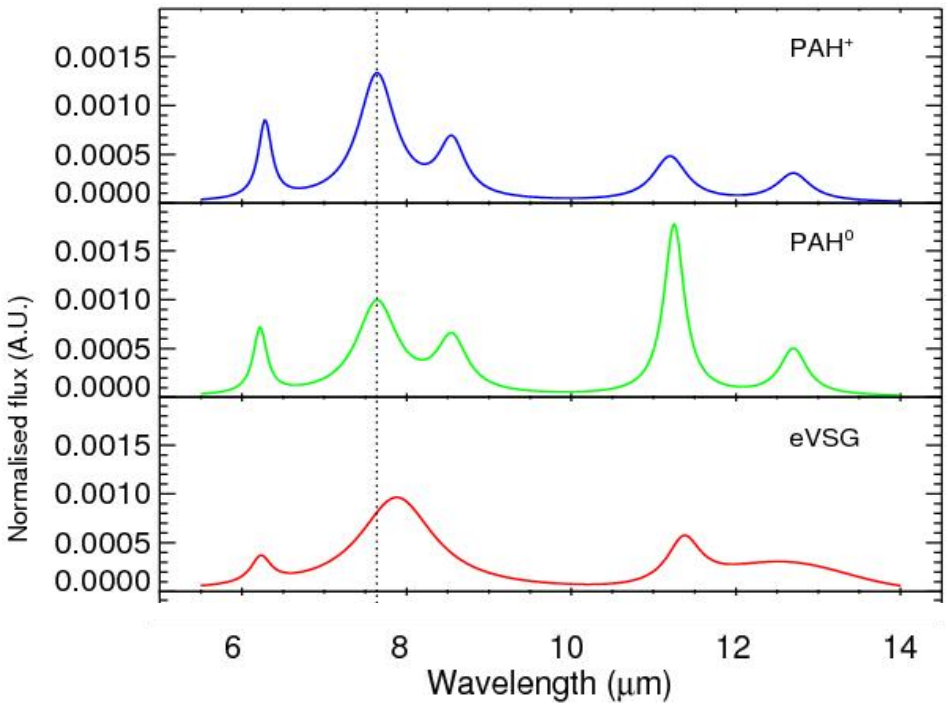
Blue: 3.6 μm , green : 8 μm , red 24 μm

NASA/JPL-Caltech/Harvard-Smithsonian CfA

The colour variations in the IR reveals evolution of the emitters, due to the stochastic heating

Photo-processing of dust grains in PDR
Decomposition of ISOCAM & Spitzer/IRS spectra

Using Blind Signal Separation (BSS) methods (Rapaciolli et al. 2005, Berné et al. 2007 & 2009, Joblin et al. 2008, Pilleri et al 2012), creation of spectral templates with at least three components :



small PAH cations :

low C-H (11.2 μm) over CC (7.7 μm) band ratio

small neutral PAH :

large C-H (11.2 μm) over CC (7.7 μm) band ratio

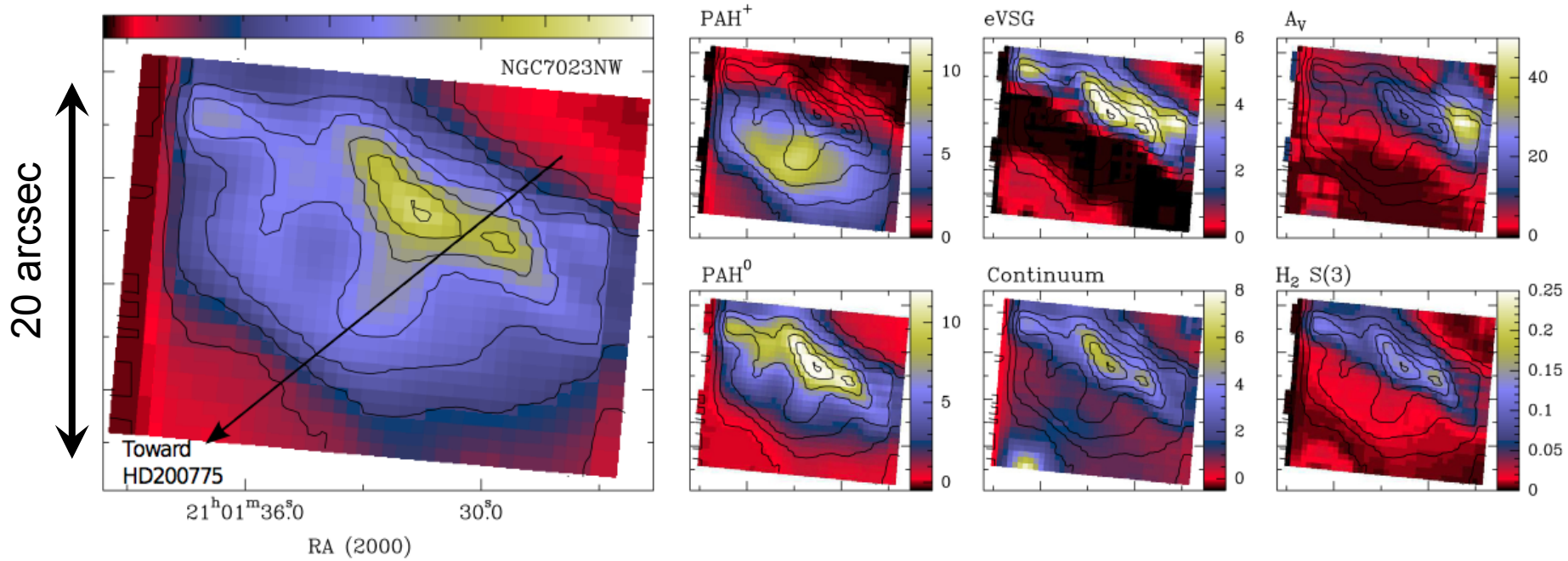
''evaporating VSGs''

+ continuum

used for the decomposition of the spectra for each pixels of the spectral cube…

Photo-processing of dust grains in PDRs
Maps of extracted components from Spitzer/IRS spectral cubes

Exemple in NGC 7023 (see the next talk and Pilleri et al 2012)

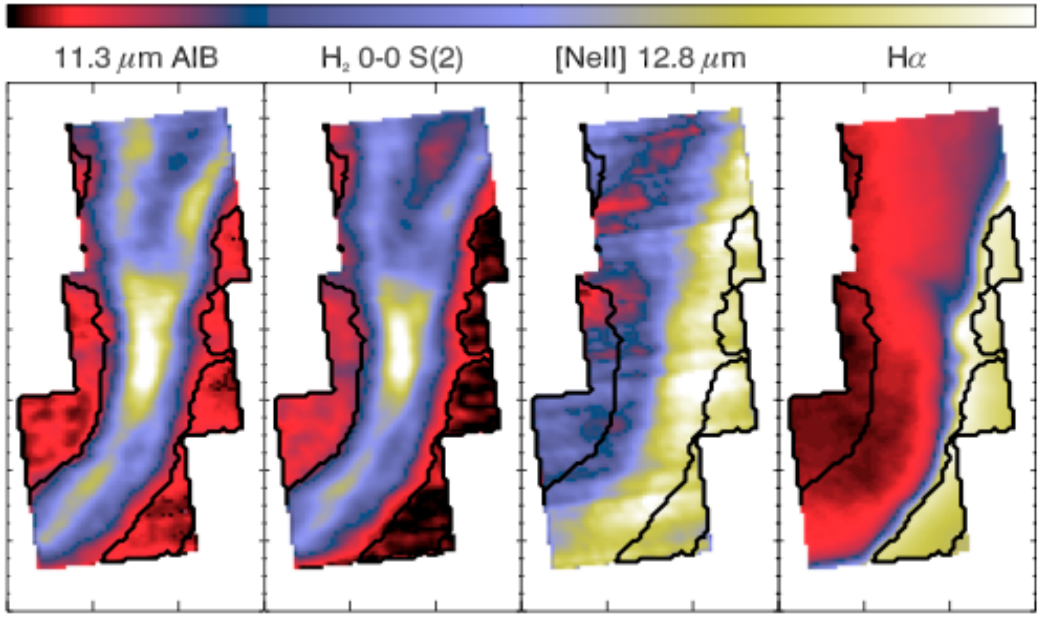


Going towards the stars, eVSGs followed by PAH^0 and PAH^+ are successively dominant
Interpretation :
At the illuminated of PDRs, eVSGs destroyed by UV photons to produce free-flyer PAHs

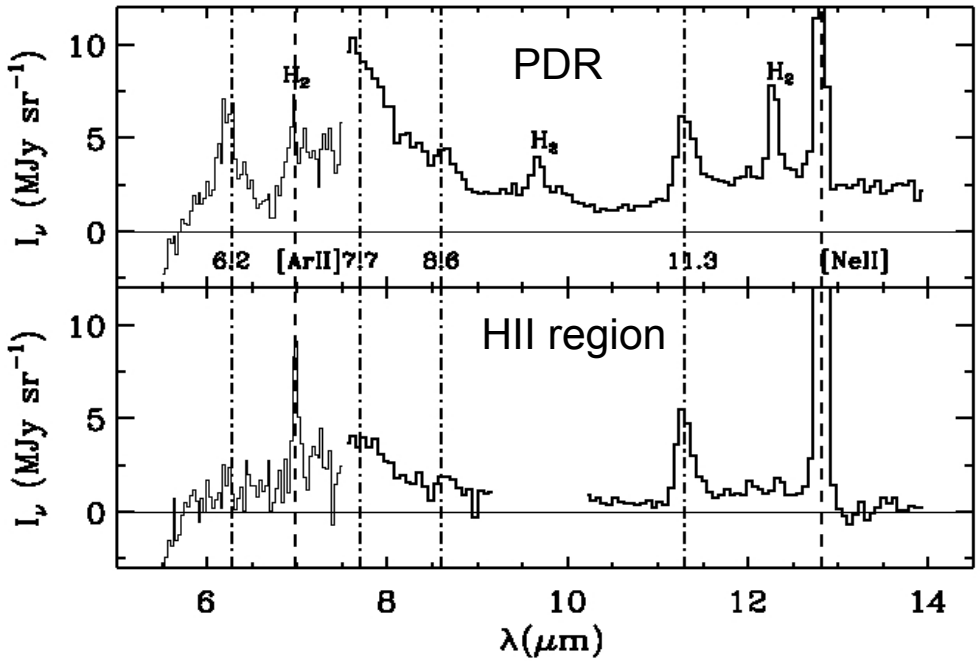
But the angular resolution is limited, ~ 3.6 arcsec

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

Evolution of the charge state of PAHs : Example in the Horsehead



1 arcmin



Spitzer/IRS (Compiègne et al., 2007)

- PDR spectrum: PAH$^+$ (UV photons and lack of free electrons)
- HII region: neutral PAH (strong 11.3 μm emission) due to moderate radiation field

The JWST has the sensitivity and the spatial resolution to see the transition between the dense shielded matter and the newly photo-ionised gas

Molecular Hydrogen

- Everywhere where dust shields it from UV photons (Av > 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.

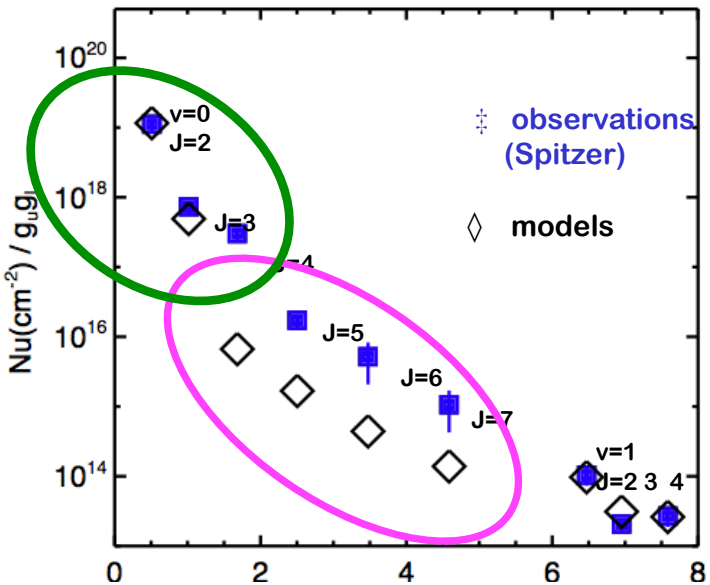
- Excitation
  - Far UV pumping to excited electronic states
  - Inelastic collisions to lower energy levels
  - Internal energy due to H_2 formation on dust grains
  - X-ray excitation

- 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

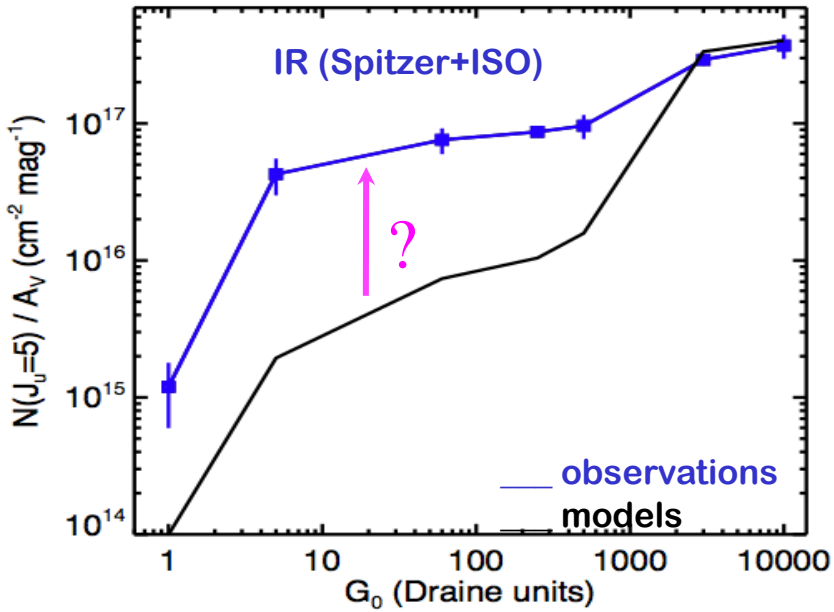
- Higher pure rotational lines probe the small fraction (< 1%) of photon- or shock-heated gas.

Excitation of H_2 in PDRs with Spitzer

Horsehead at the peak position (G_0=60)



Different objects at the peak positions



Habart et al. 2011

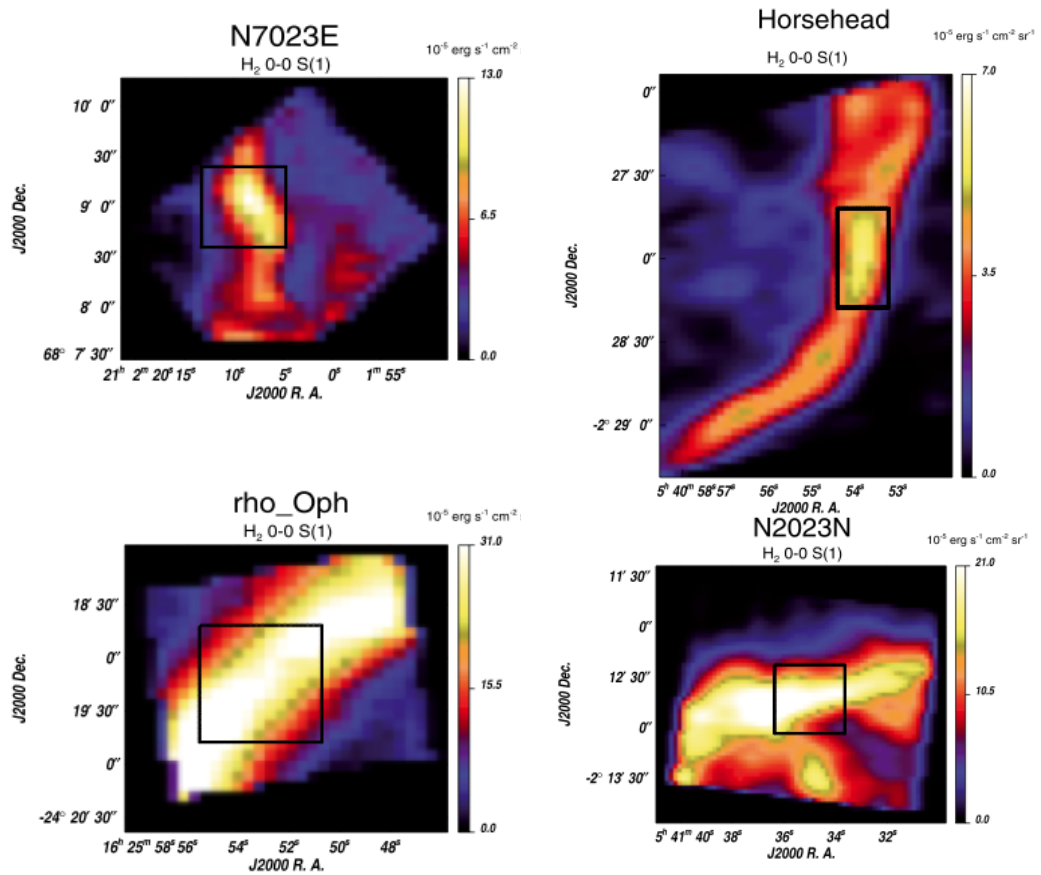
- The first low rotational lines probe the bulk of the gas at moderate temperature

- 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 (see J. Le Bourlot and E. Bron presentations) ?
  - Local increased of the dust photoelectric heating rate ?
  - Additional heating sources (shocks, turbulence) ?
  - Out-of-equilibrium process (see P. Lesaffre presentation) ?

Observation of H_2 in PDRs with Spitzer : Main limitation

- Limited angular resolution & sensitivity

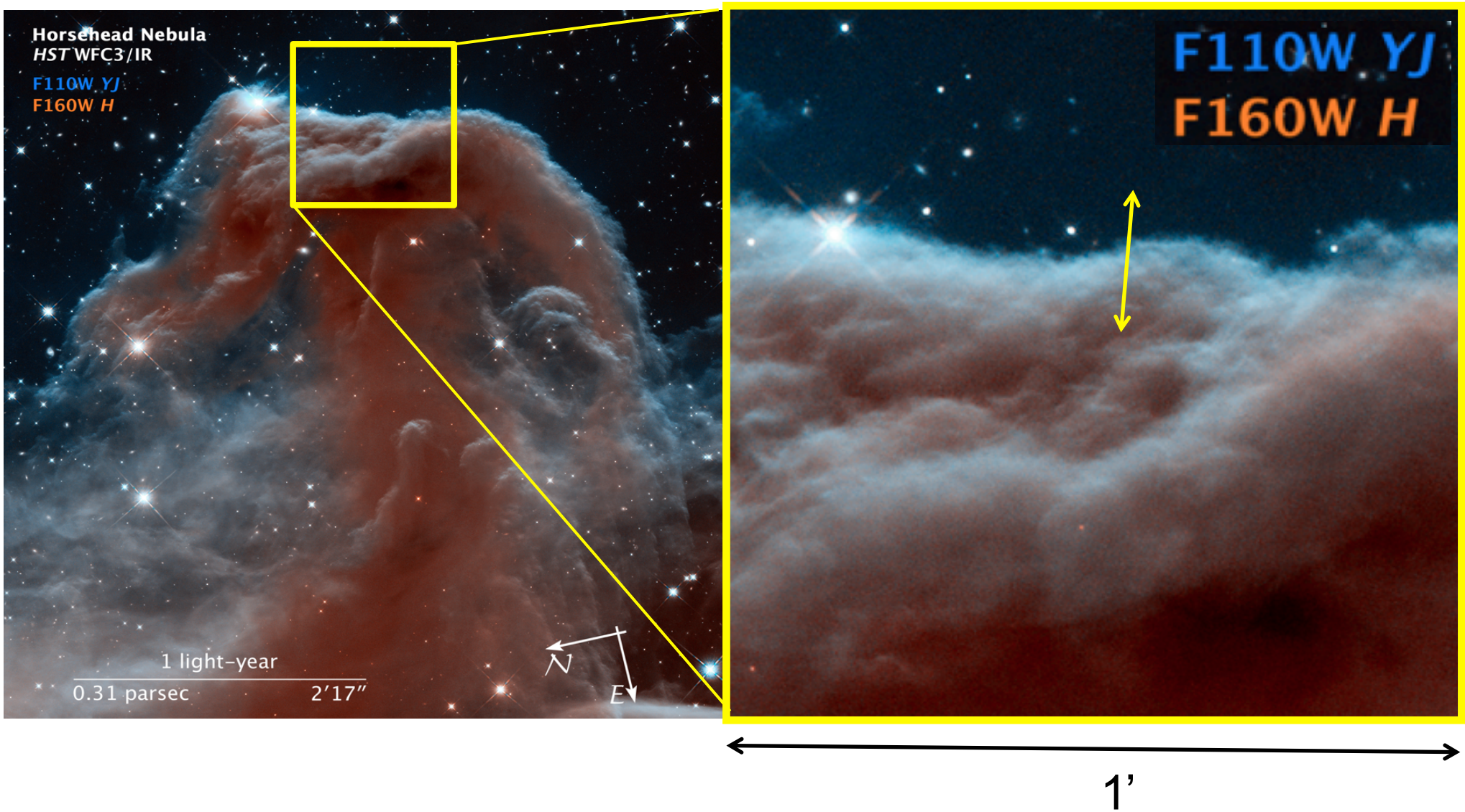
All is done at the peak positions !



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] 7.0, [Ne II] 12.8, [Ne III] 15.6, [S III] 18.7, [S I] 25.2 µm, HD, H_2O, H_3O^+, CH_4, C_2H_2, HCN, OH, …

The Horsehead Nebula (J & H bands)



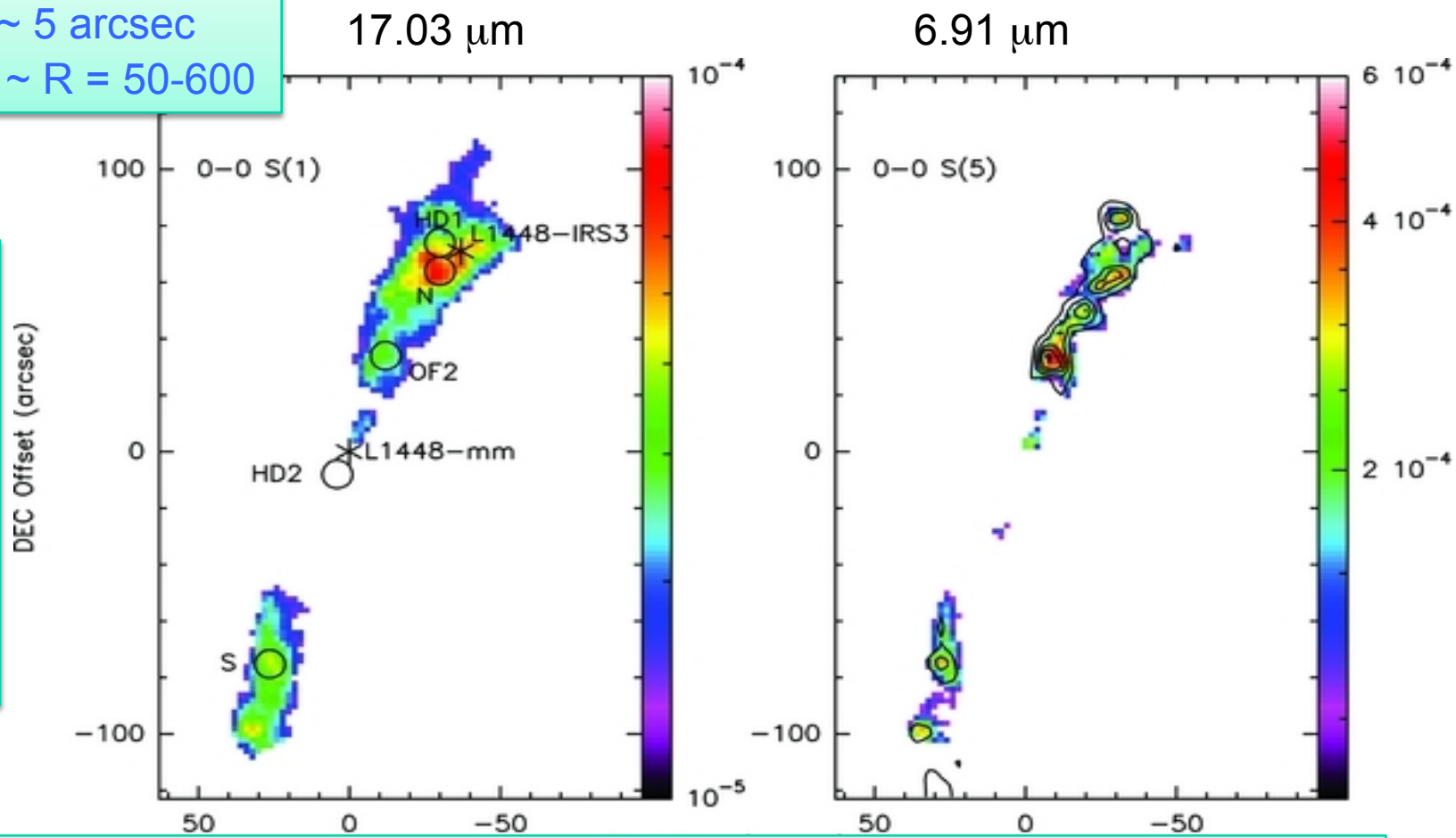
Proto-stellar outflows with H_2 rotational lines

Spitzer IRS
Angular resolution ~ 5 arcsec
Spectral resolution ~ R = 50-600

Limited angular & spectral resolutions

No kinematical information about warm H_2

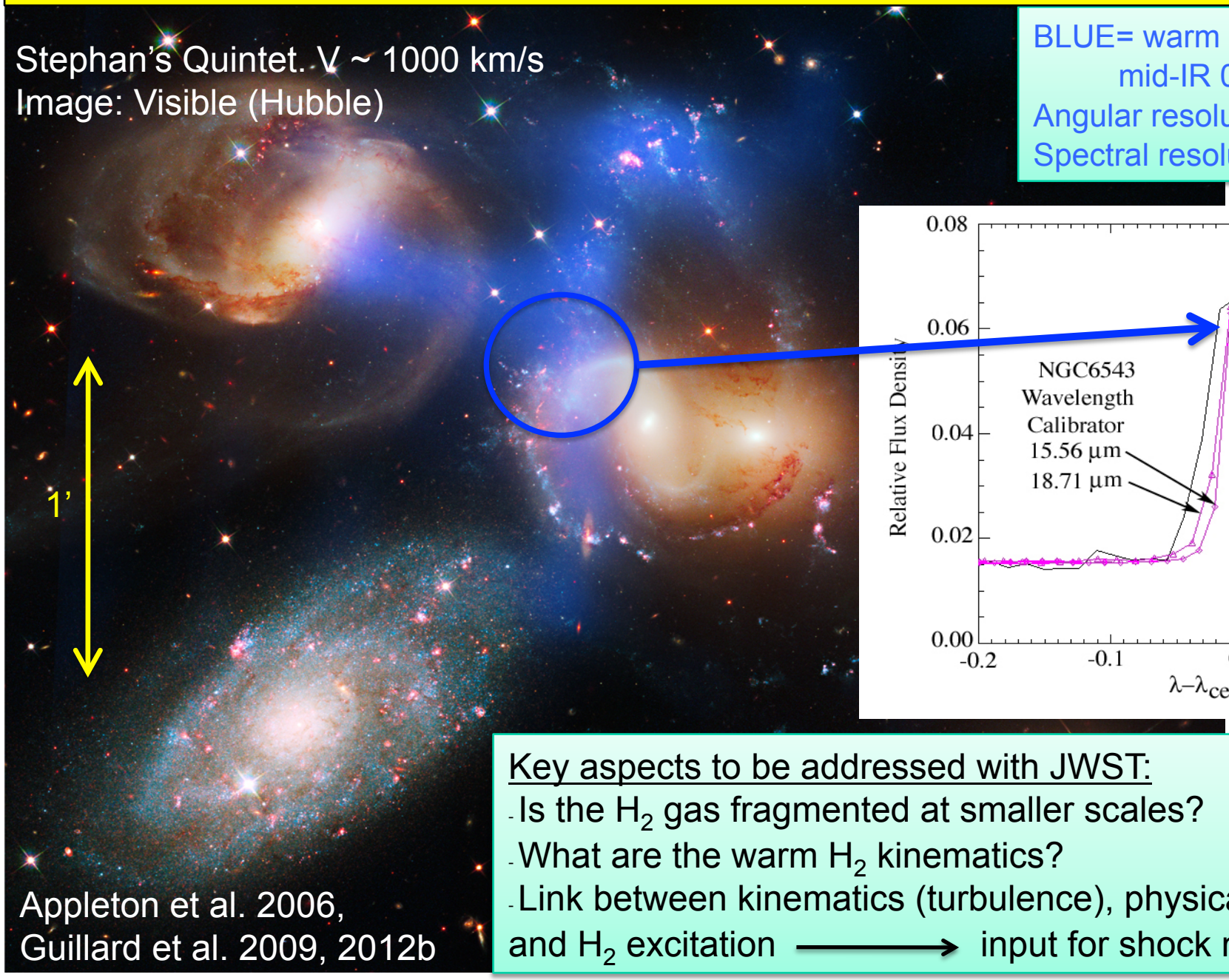
Giannini et al. 2011: H_2 Emission in L1448 (Spitzer IRS)



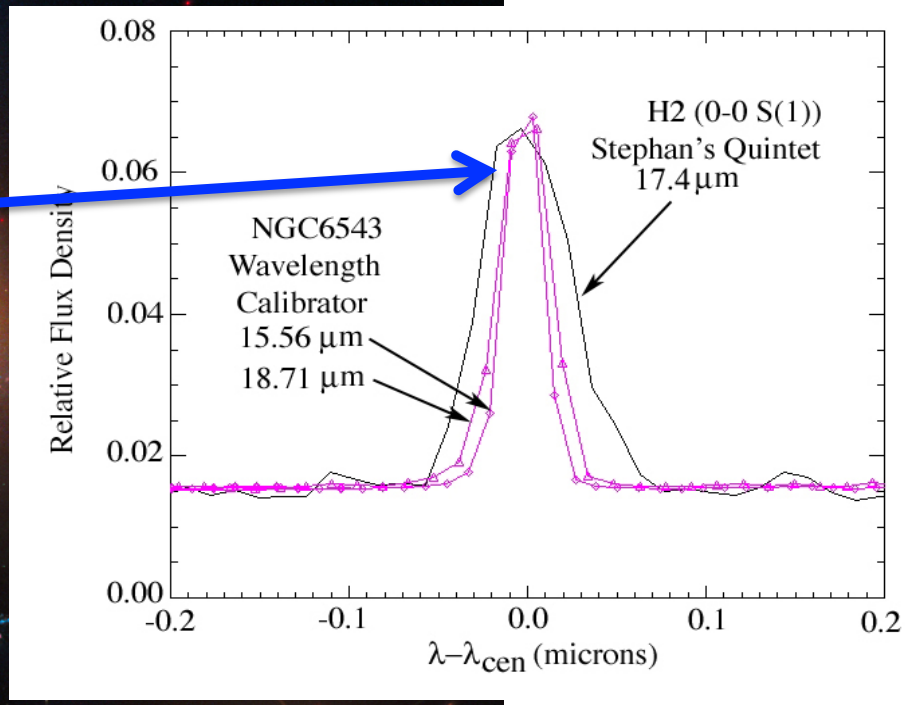
<u>JWST allows:</u>

- **To link H_2 kinematics with its excitation**
- **To benchmark shock codes**

Structure, physical state and kinematics of H_2 gas in galaxy collisions



BLUE= warm H_2 (Spitzer IRS)
mid-IR 0-0 S(1) 17μm
Angular resolution ~ 5 arcsec
Spectral resolution R ~ 600



<u>Key aspects to be addressed with JWST:</u>

- Is the H_2 gas fragmented at smaller scales?
- What are the warm H_2 kinematics?
- Link between kinematics (turbulence), physical structure and H_2 excitation ⟶ input for shock models

Conclusions

Unique capabilities : Angular resolution, spectral resolution, sensitivity

but slow : 90 deg/hr slew rate, many timing and scheduling constraints, designed for detailed study of a few objects,

- Lifetime : 5,5 years. Limited by the amount of fuel for maintening the orbit. 10 years possible.

- JWST is on track for a launch late 2018.

- **More than 80% of available observing time for submitted proposals**

- More than 15% of the total observing time to ESA member states applicants (as HST)

- Cycle 1 call for proposal : late 2017 (then 1 call each year)

- Cool down and commissioning: Launch + 6 months

- Early release/first look data delivered to the community

- Cycle 1 observations from mid-2019

- **Meeting « Exploring the Universe with JWST » at ESTEC (12-16 October 2015)**

- Centre d'expertise français for MIRI in discussion (SaP, IAS, LESIA)