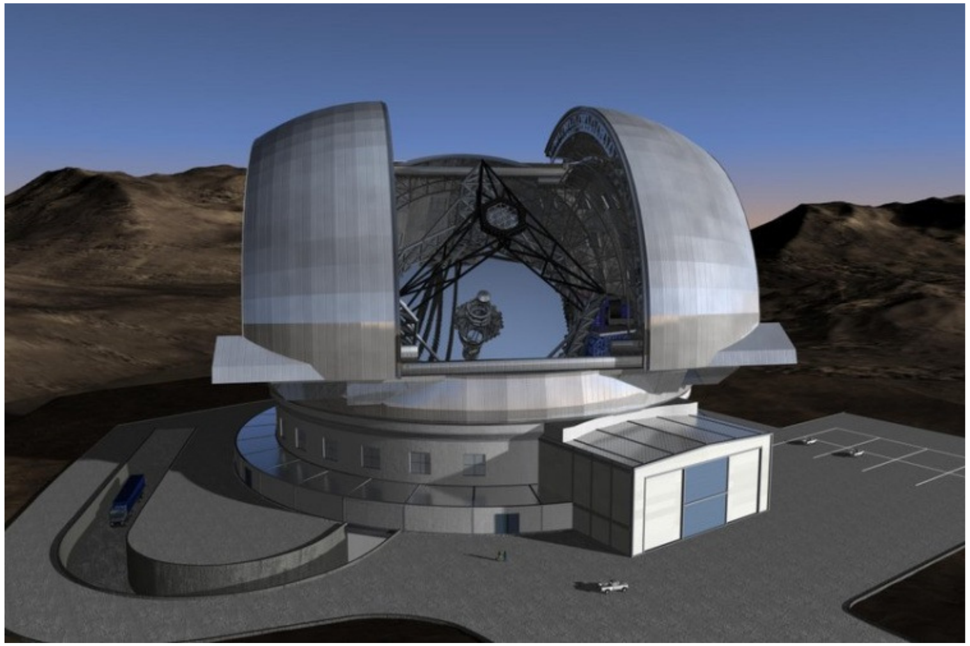
METIS

Mid-infrared
E-ELT Imager and
Spectrograph



Mid-IR Science with METIS

Bernhard Brandl & Ralf Siebenmorgen

DRSP Workshop @ ESO, Garching 27-05-2009

NOVA
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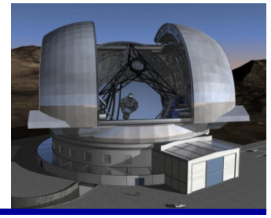
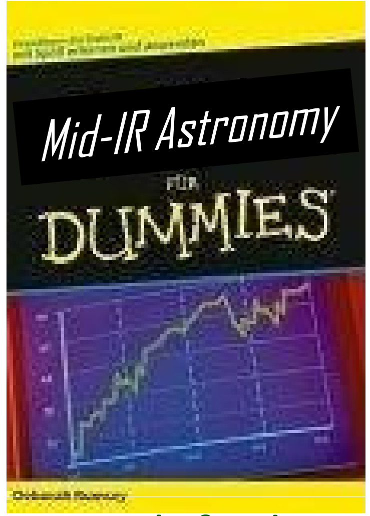
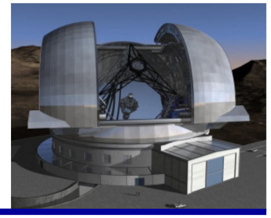
Why Mid-IR?



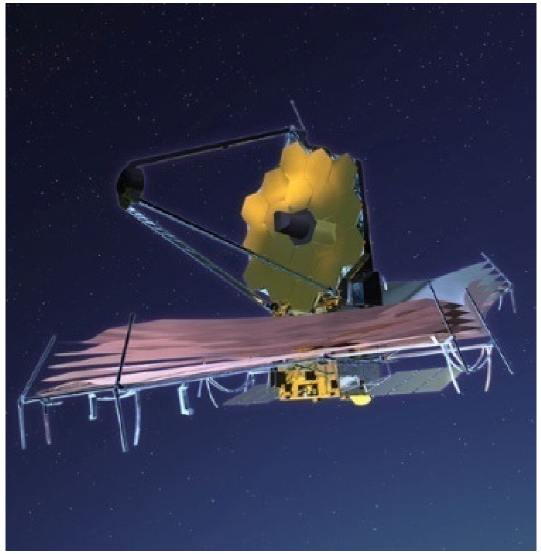


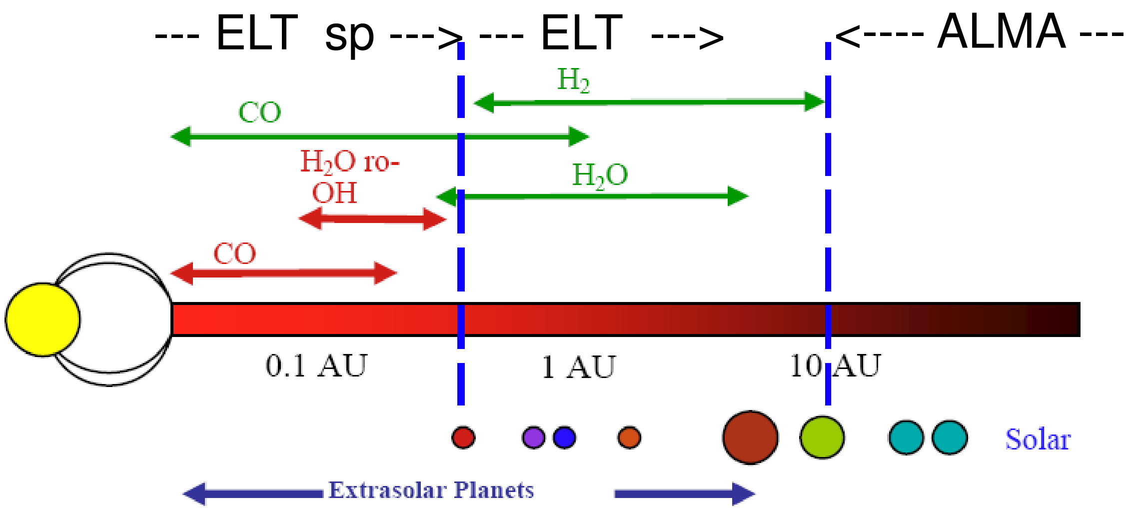
1. *Objects that are very dusty:* $\tau_{vis} \sim 15 \times \tau_{MIR}$ (e.g., newly forming stars and centers of galaxies)
2. *Objects that intrinsically cool:* $\Delta T_{1-2.5\mu m} = 1200 - 2900K$, $\Delta T_{LMN} = 200 - 1000K$ (e.g., brown dwarfs, planets, molecular clouds as well as reradiated light ("warm dust") from very massive stars or active galactic nuclei)
3. *Redshifted objects:* $\lambda_{obs} = \lambda_{rest} \times (1 + z)$. (e.g., H-$\alpha$, Pa-$\beta$, Br-$\gamma$ shifted into the L-band)
4. *Richness in unique spectral features* (atomic fine-structure and hydrogen lines, isotopes, H_2 pure-rotational transitions, PAHs, crystalline and amorphous silicates, features of H_2O, CO, CH_4, CH_3OH, NH_3, OCN^-, H_3^+, C_2H_2, HCN, OH, ...)
5. *Magnetic field measurements:* magnetic field → dust grain alignment → passing radiation becomes partially polarized →(spectro-)polarimetry of dust (e.g., YSOs, AGN, ...)

The Unique Mid-IR Parameter Space for the E-ELT



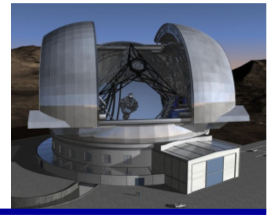
- with respect to JWST:
  - 6.5 times higher **angular resolution**
  - unique **high spectral resolution**
  - unique **polarimetric** measurements
- with respect to ALMA
  - complementary **temperature** zones
  - complementary **molecular species**





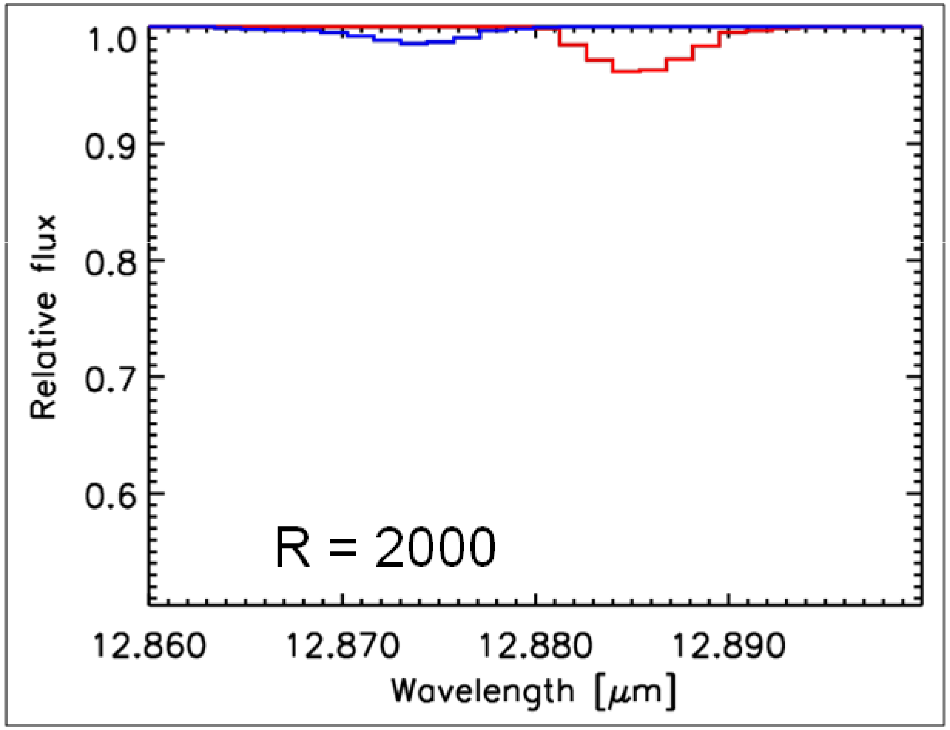
wavelength (nm)

METIS Low ⇔ High Spectral Resolution

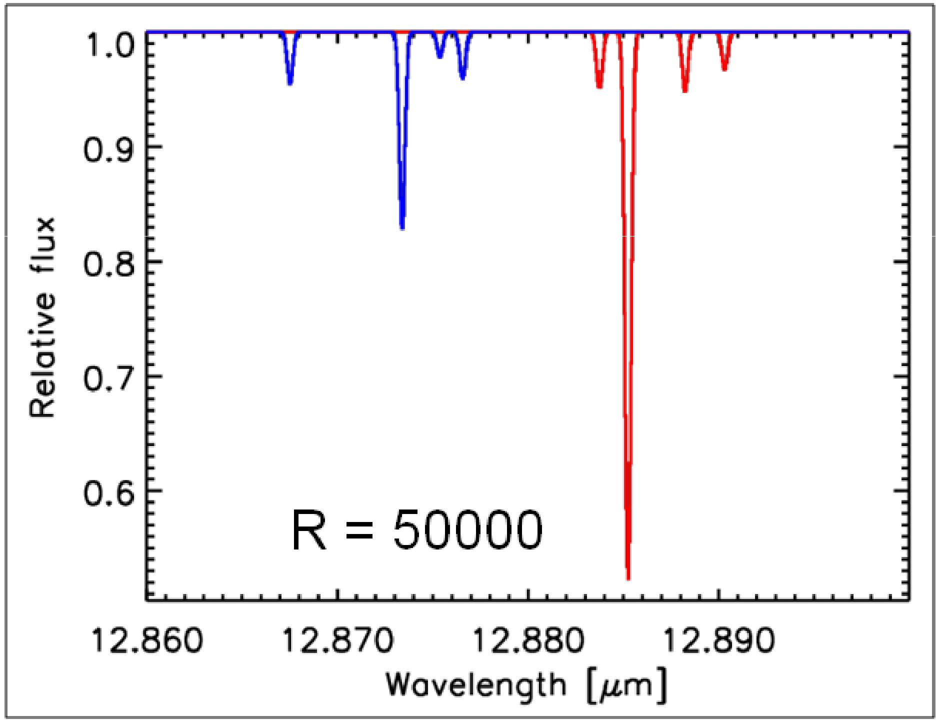


model spectra of disks with C_2H_2 at 900K and HCN at 600K

JWST-MIRI

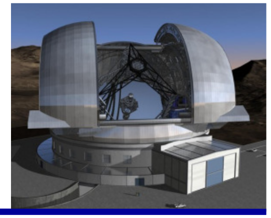


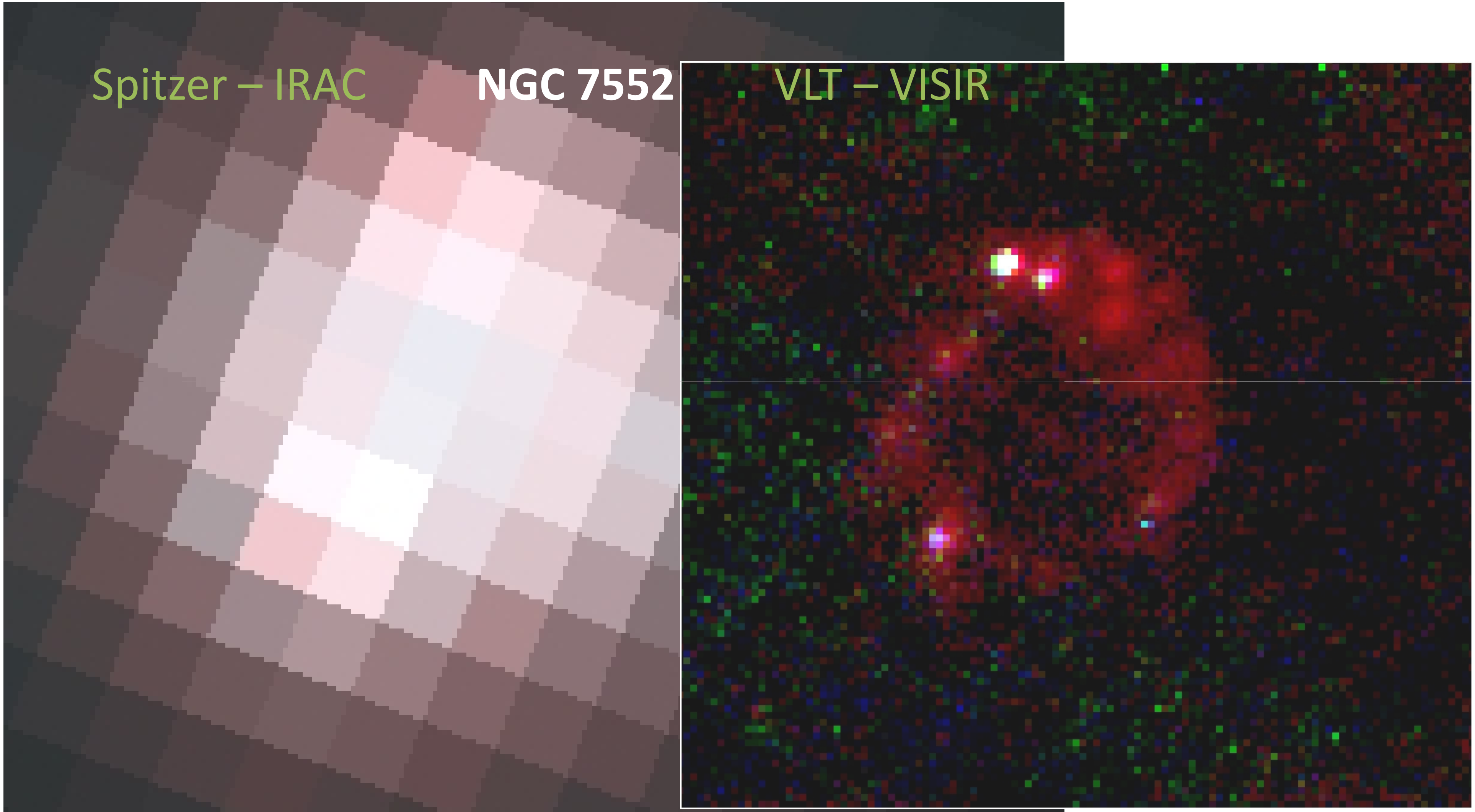
METIS



1. higher sensitivity
2. more information

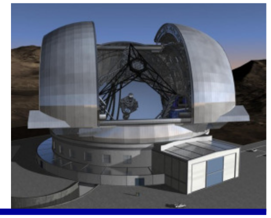
Low ⇔ High Spatial Resolution



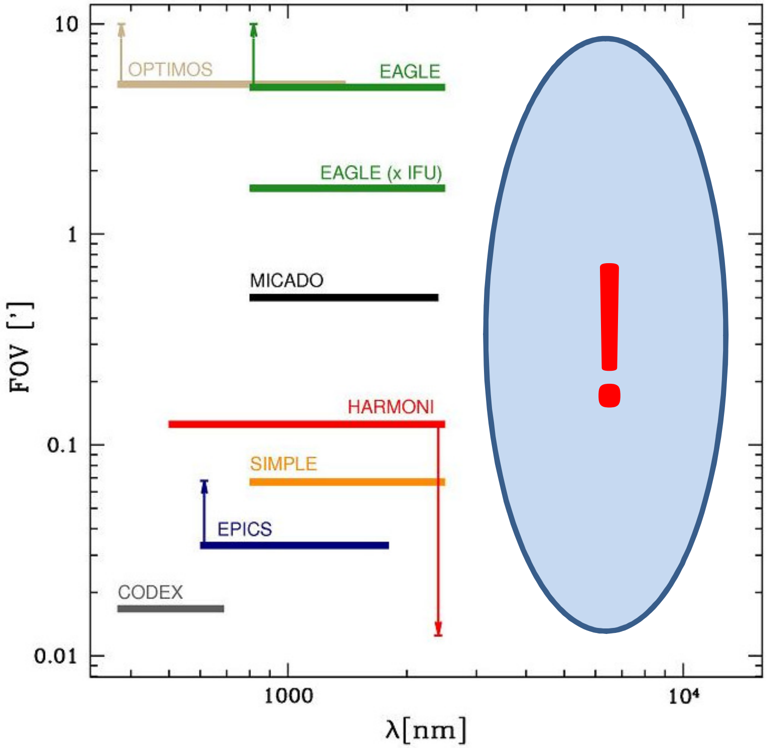


Similar aperture ratio than for ***JWST – MIRI*** **⇔** ***E-ELT – METIS***

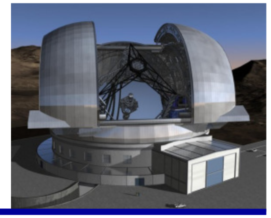
Science Wishlist for a Mid-IR Instrument



- A diffraction limited imager for 3 – 14µm
- A low resolution spectrometer
- A high resolution (R~100,000) spectrometer (IFU?)
- Coronagraphy?!
- Polarimetry?!

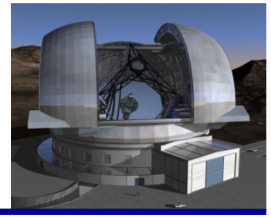


Galactic METIS science cases



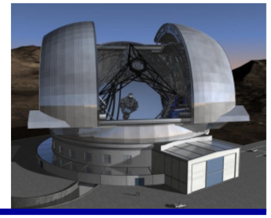
- **Conditions in the Early Solar System**
- **Formation and Evolution of Proto-planetary Disks**
- **Properties of Exoplanets** ← talk by Wolfgang Brandner
- Chemical Pathways in the Martian Atmosphere
- Kuiper Belt Objects
- Properties of Brown Dwarfs
- Formation of Massive Stars
- Galactic Center ← talk by Andreas Eckart
- Life Cycle of Cosmic Dust
- Massive Star Forming Regions (IMF, Disks, …)

Extragalactic METIS science cases



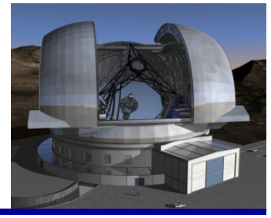
- **The Growth of Supermassive Black Holes**
- Properties of the Hosts of Sub-mm Galaxies
- Formation and Evolution of Super Star Clusters
- Assembly of Galaxies at intermediate *z*
- Gamma-Ray Bursts as Cosmological Probes

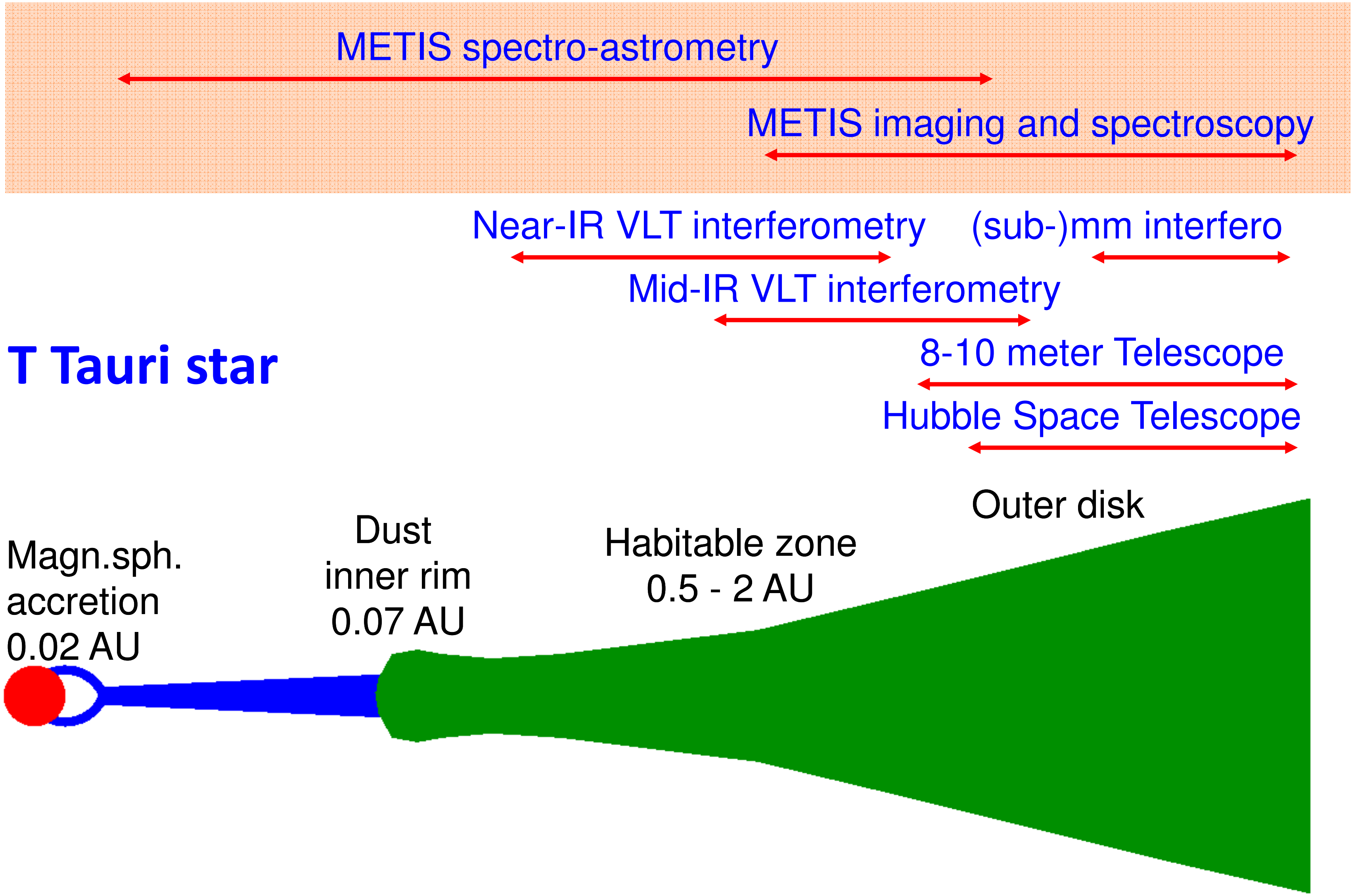
Proto-planetary Disks – Goals



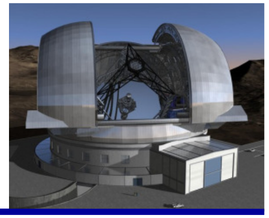
- Physical structure of the **gas vs. dust disk**? Is there evidence for young planets, e.g., through the presence of holes or gaps in the planet-forming regions?
- Timescale and mechanism for **gas dissipation** (photo-evaporation, disk winds, planets, …).
- Dynamics and **turbulence of the gas** as a function of radius. Departures from Keplerian rotation and continuing infall?
- **Chemical content** of the inner disk as a function of radius (water, organic molecules, grain growth, annealing of silicates, …).

Probing the Inner Disk Regions





Spectro-Astrometry



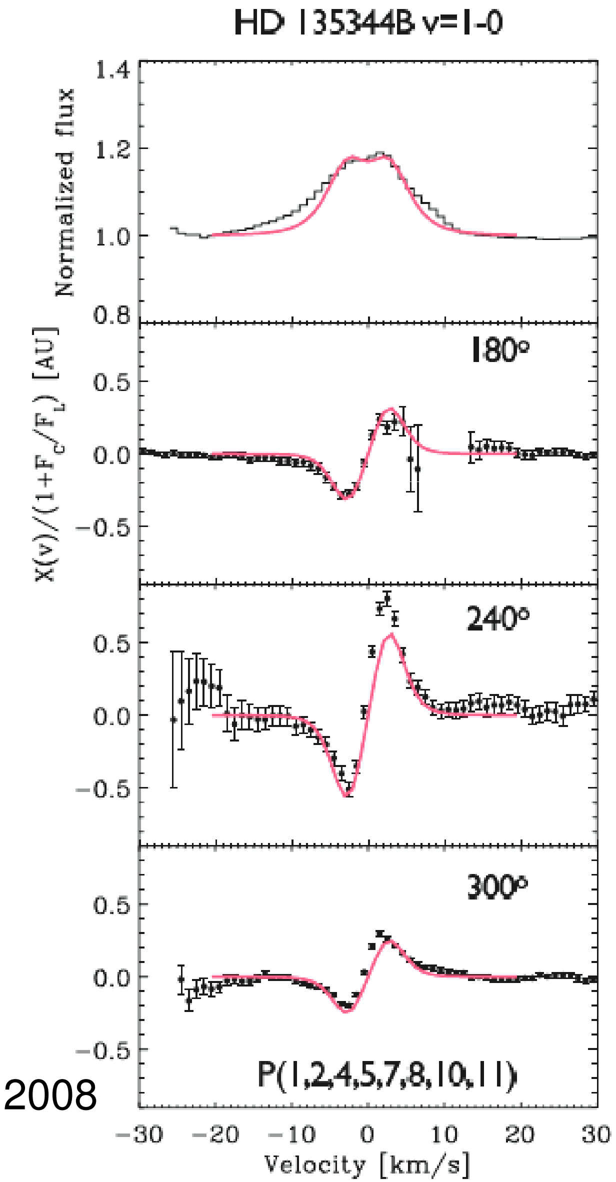
1. Take a slit spectrum.

2. At each wavelength fit a Gauss to the spatial emission profile.

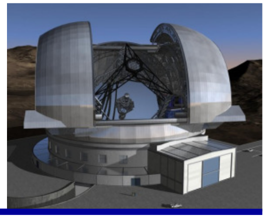
3. Plot the centroid as a function of wavelength.

➔ Huge gain in resolution compared to the diffraction limit* (but only for 0th moment).

*0.1 marcsec with CRIRES!



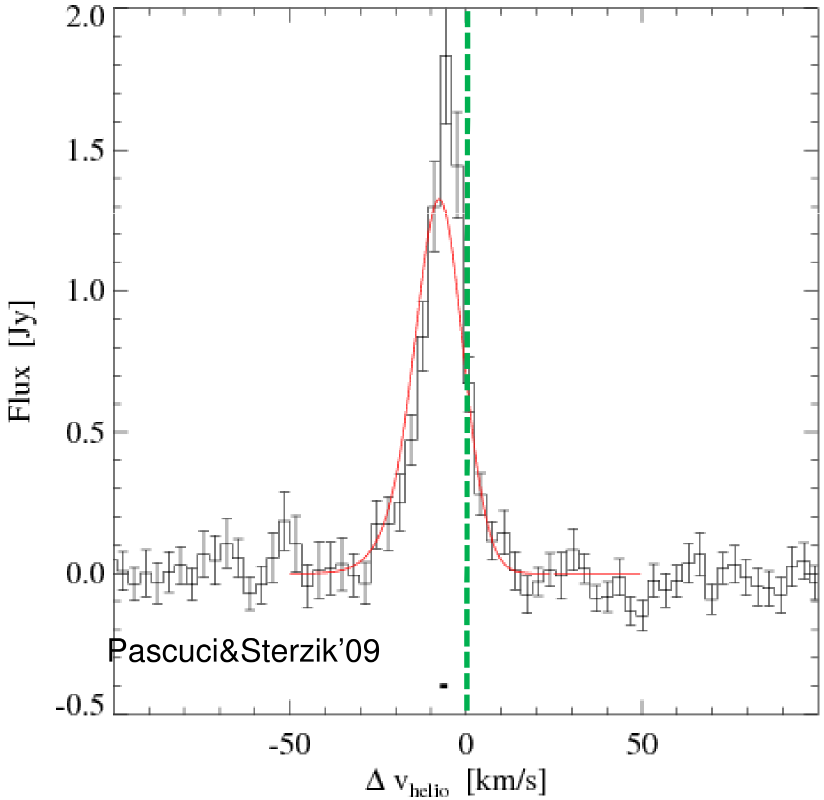
Pontoppidan et al. 2008



Information in the Line Profile

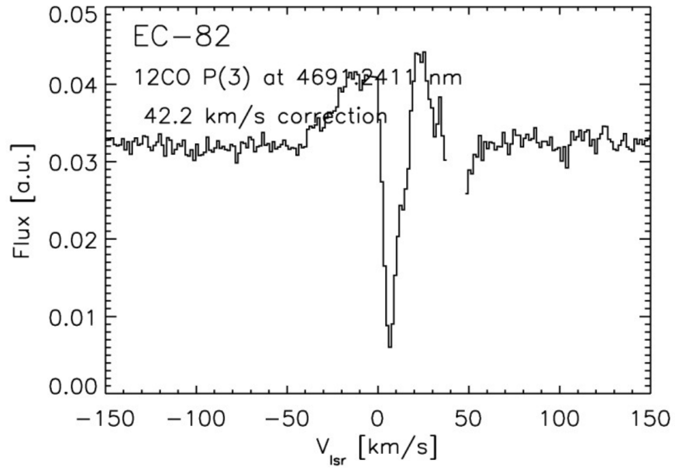
Photo-evaporation of disks

[Ne II]12.8μm in TW Hya

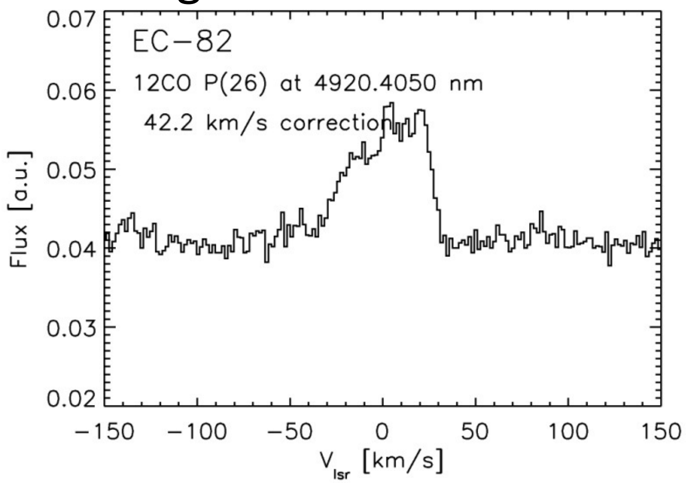


Departures from Keplerian rotation?

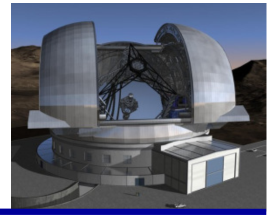
^{12}CO low J = cold dust = outer disk

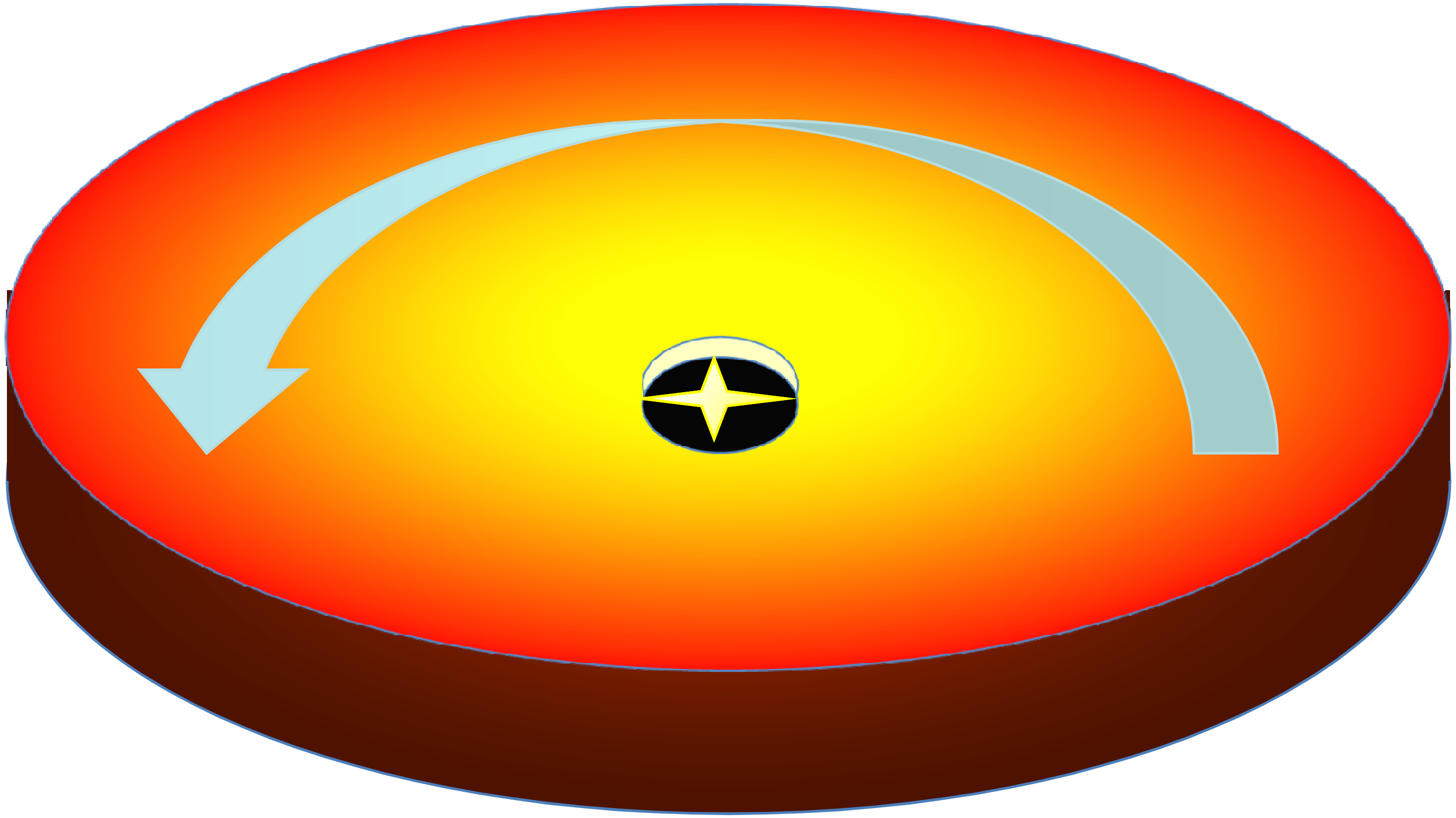


^{12}CO high J = warm dust = inner disk



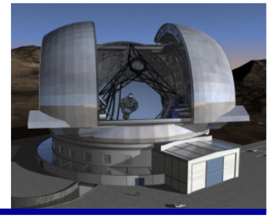
Imaging H_2O Vapour in the Planet-forming Zone

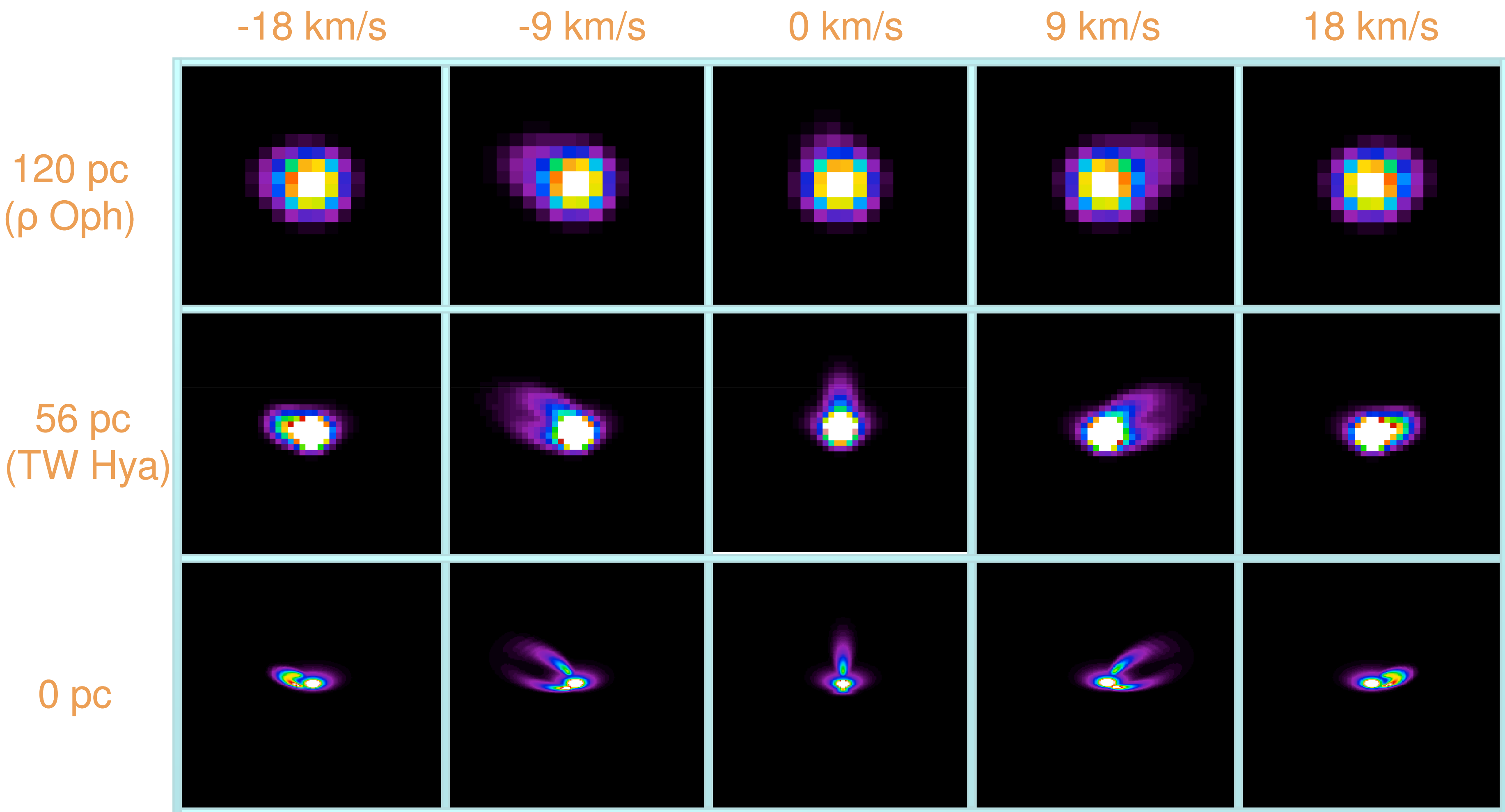




- 3µm H_2O hot band lines, $1M_o$ star
- Model made with RAD-Lite by Klaus M. Pontoppidan and Cornelis P. Dullemond
- Includes gas lines *and* dust continuum

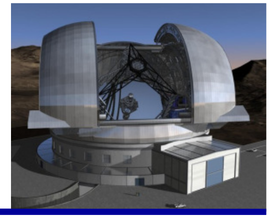
Imaging H_2O Vapor – Model and METIS Observations



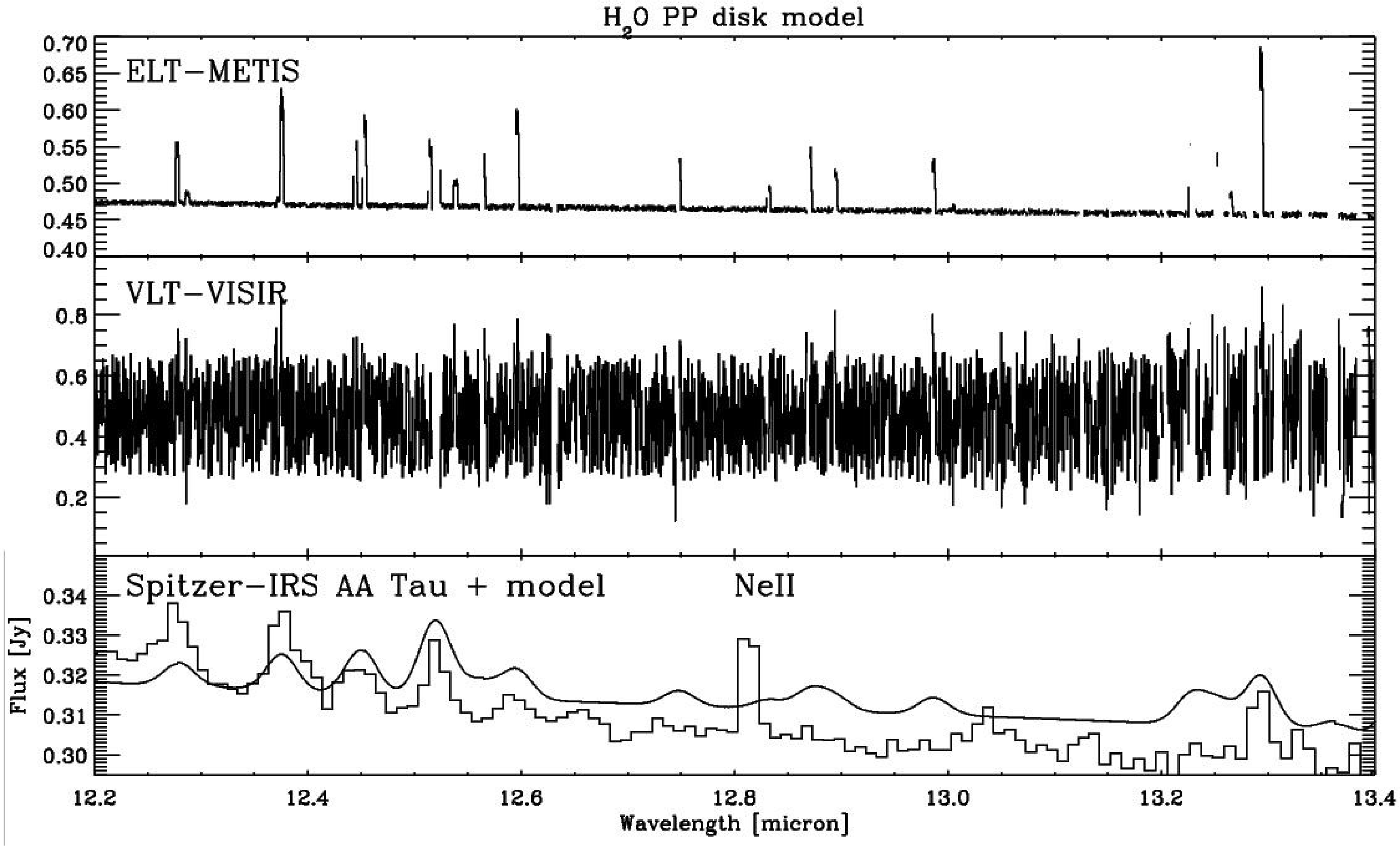


→ *Spatially resolved spectroscopy is essential!*

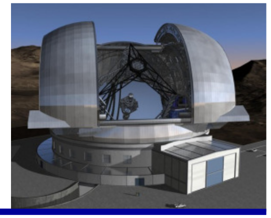
Comparison: METIS ⇔ VISIR



Molecular Spectroscopy: *Simulations of 1 hour VISIR and METIS in the 12 μm range as seen from Paranal (only H_2O is modelled) – courtesy Klaus Pontoppidan*

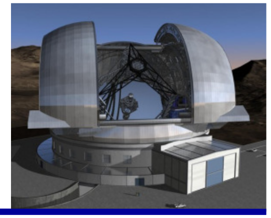


Example Observing Programs



- **PP disk imaging** in the interesting region of 5-10 AU at the distance of the nearest star forming regions, ~ 150 targets, ~1 hour per target.
- **Debris-disk imaging** will show the exo-zodiacal light in the “habitable zone” and search for exoplanets by the indirect technique of “footprints” in a disk. ~300 nearby stars, ~ 1 hour per target.
- **Spectro-astrometry** via CO kinematics for 50 – 100 disks, ~2 hr per target.
- **Disk spectroscopy in the H_2 S(2) 12µm lines**, ~25 excellent targets ~1 hour per target.
- **Key program for H_2O** (← Spitzer, Herschel, JWST) water for 50 – 100 disks, ~5 hr per target.

Active Galaxies – Goals



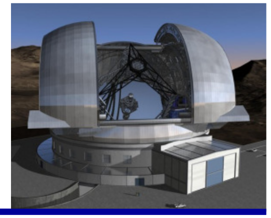
The Growth of Supermassive Black Holes (SMBHs):

- origin of the relation between SMBH and bulge/galaxy mass
- understand QSO activity at high-z
- understand evolution of nuclear starburst activity

Formation and Environment of Super Star Clusters:

- Are the most luminous starbursts scaled up versions of local regions of massive star formation? → SB unit cells? SFE? Triggering? Feedback? IMF? ISM structure?

...and the relation between the two in the active centers of galaxies



Growth of SMBHs

Sphere of influence of a SMBH: $\theta_{\mathrm{BH}} = 0.03'' \left(\frac{M_{\mathrm{BH}}}{10^8 M_{\odot}} \right)^{0.5} \left(\frac{100\ \mathrm{Mpc}}{D} \right)$

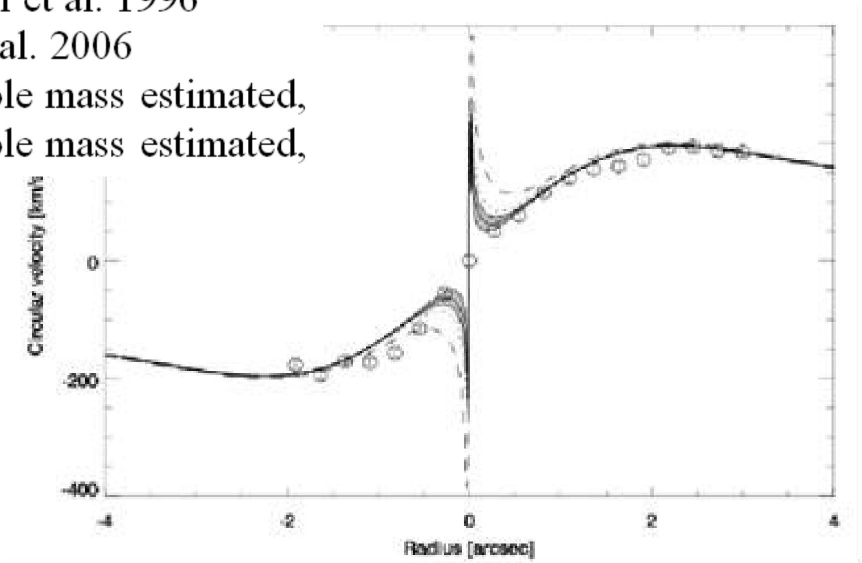
Table 3-4: Black hole masses and radii of influence for nearby AGNs and (U)LIRGs.

Target	D [Mpc]	M_{BH} [$M_{\odot}$]	θ_{BH} ["]	Notes
Cen A	3.5	$4.5 \cdot 10^7$	0.6	Neumayer et al. 2007
Circinus	3.9	$1.3 \cdot 10^6$	0.09	Greenhill et al. 2003
NGC4945	4.0	$1.4 \cdot 10^6$	0.09	Greenhill et al. 1997
NGC1068	14	$1.0 \cdot 10^7$	0.07	Greenhill et al. 1996
NGC7582	21	$5.5 \cdot 10^7$	0.11	Wold et al. 2006
Arp220	70	$\approx 10^8$	0.06	Black hole mass estimated,
NGC6240	100	$\approx 10^8$	0.03	Black hole mass estimated,

Unresolved with VLT, hopeless for JWST-MIRI but doable with METIS!

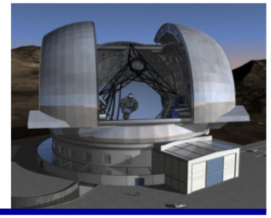
About 100 good targets to z=0.1 on one hemisphere; ~5hr per target

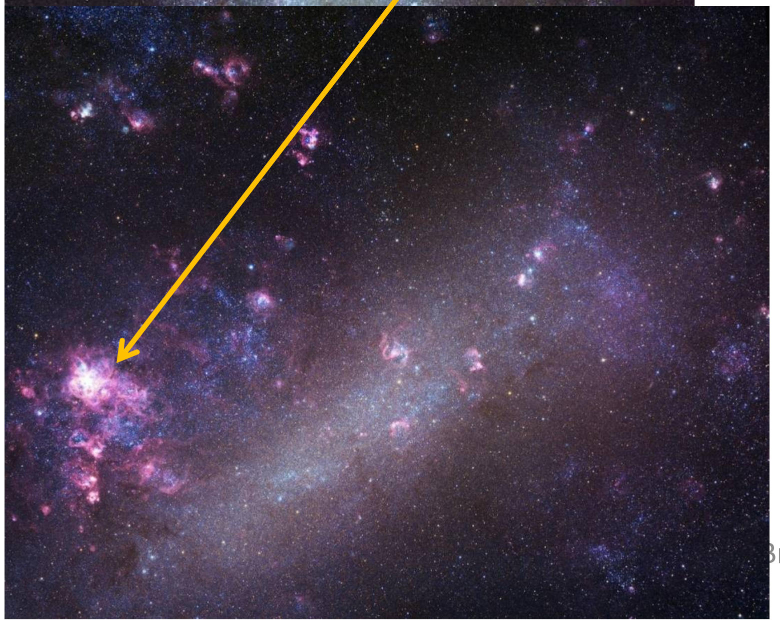
[NeII] 12.8µm velocity field of NGC7582



(Wold et al. 2006) – VISIR at 0.4" resolution.

Super Star Clusters as we (don't) know them

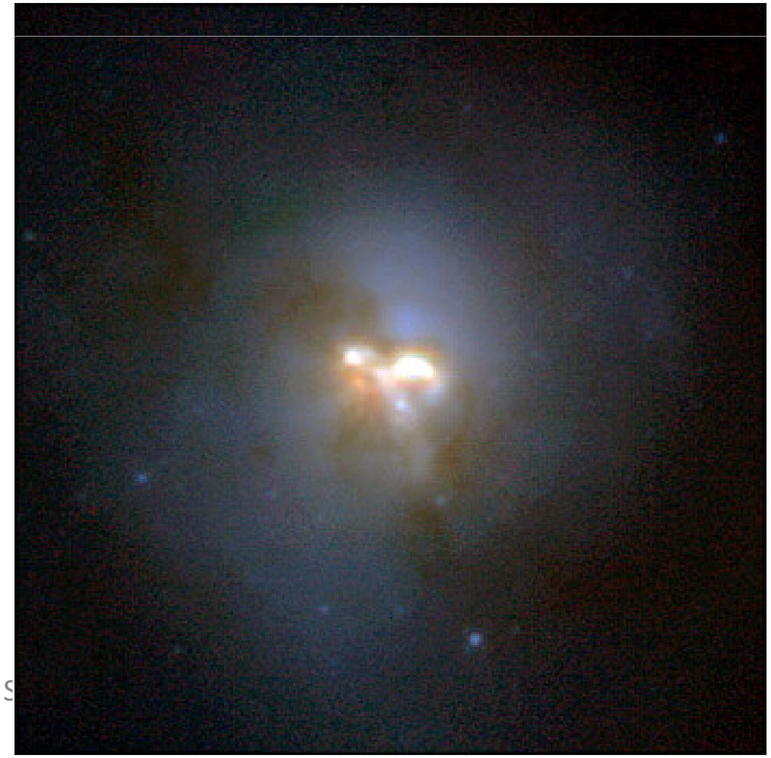




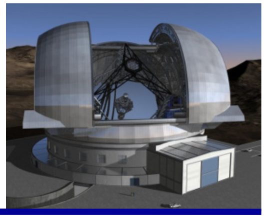
- NGC 604 in M33
- 30 Dor (NGC 2070) in the LMC

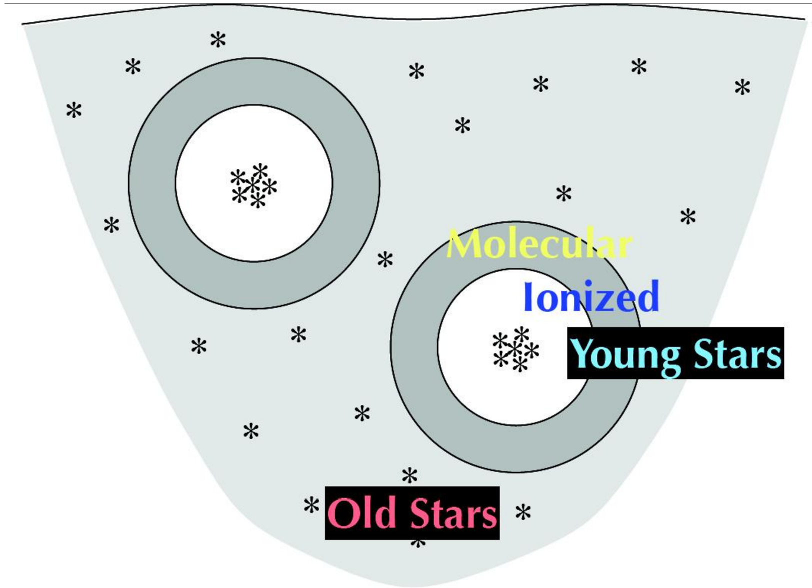
are located in "quiescent" regions

Are those scalable to Arp 220 – type environments?

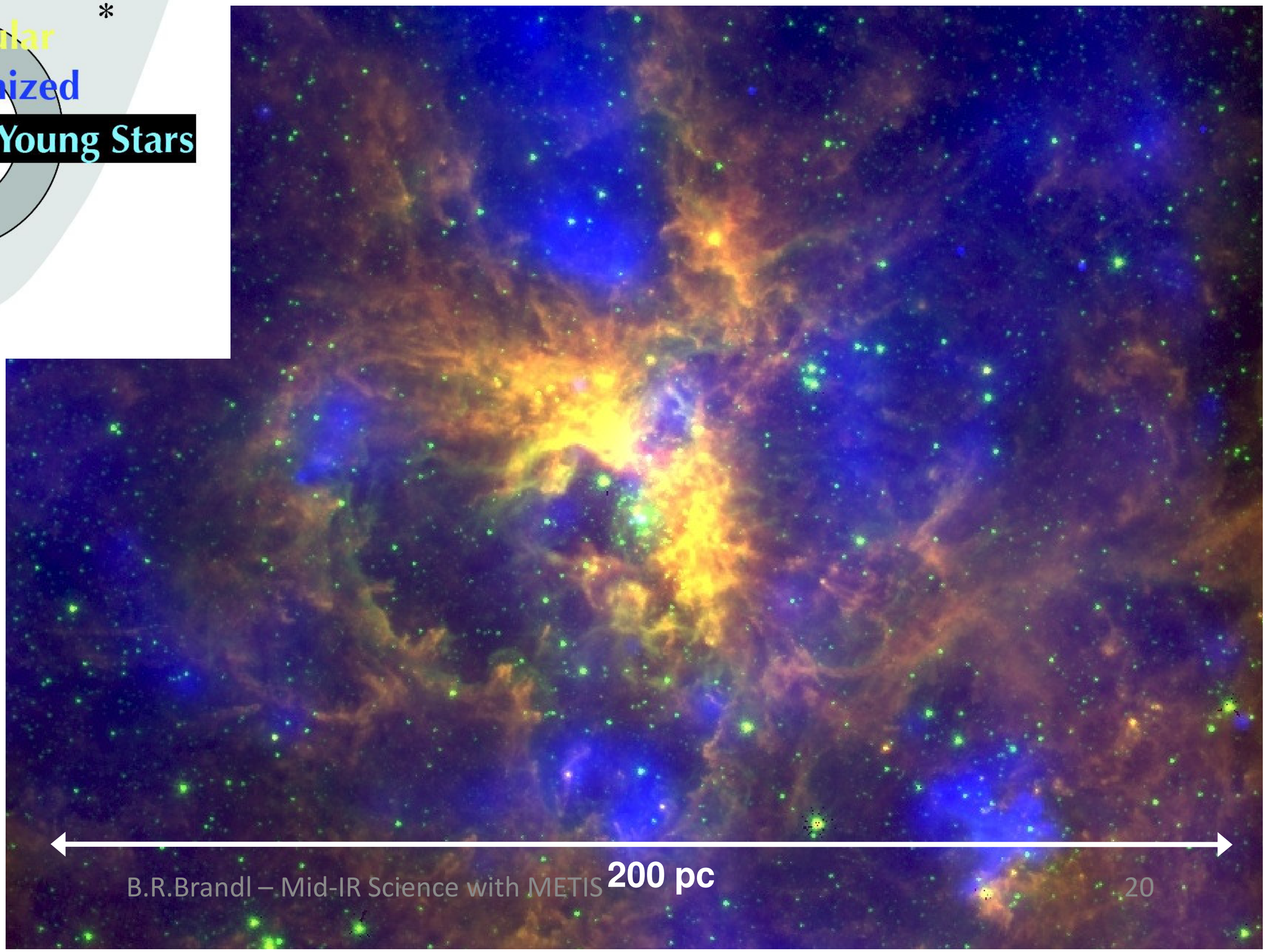


Super Star Clusters and their Surroundings





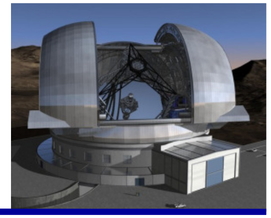
← idealized picture of an HIIR/PDR interface (Charlot & Fall 2000) – and a real example:

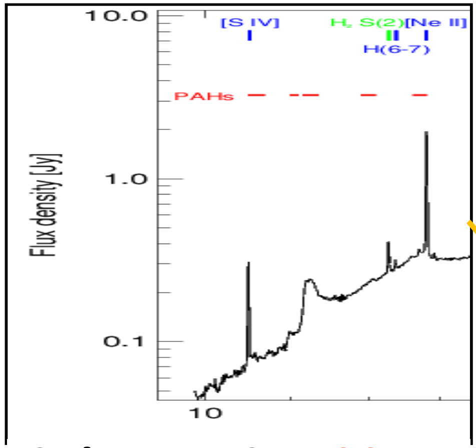


Chandra 0.5 – 0.7 keV
IRAC 3.2 – 4.0 µm
IRAC 6.5 – 9.4 µm

SSCs in the Antennae

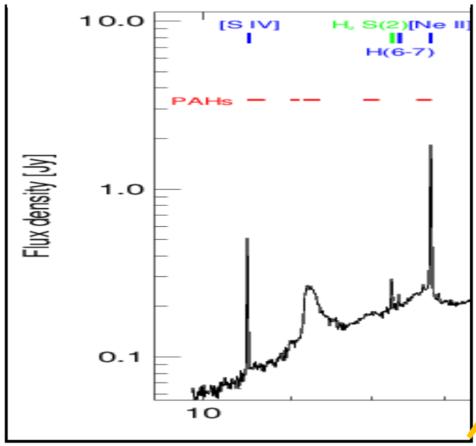
(each one: $SFR = 2 M_o/yr$, $L_{IR} = 10^{10} L_o$)

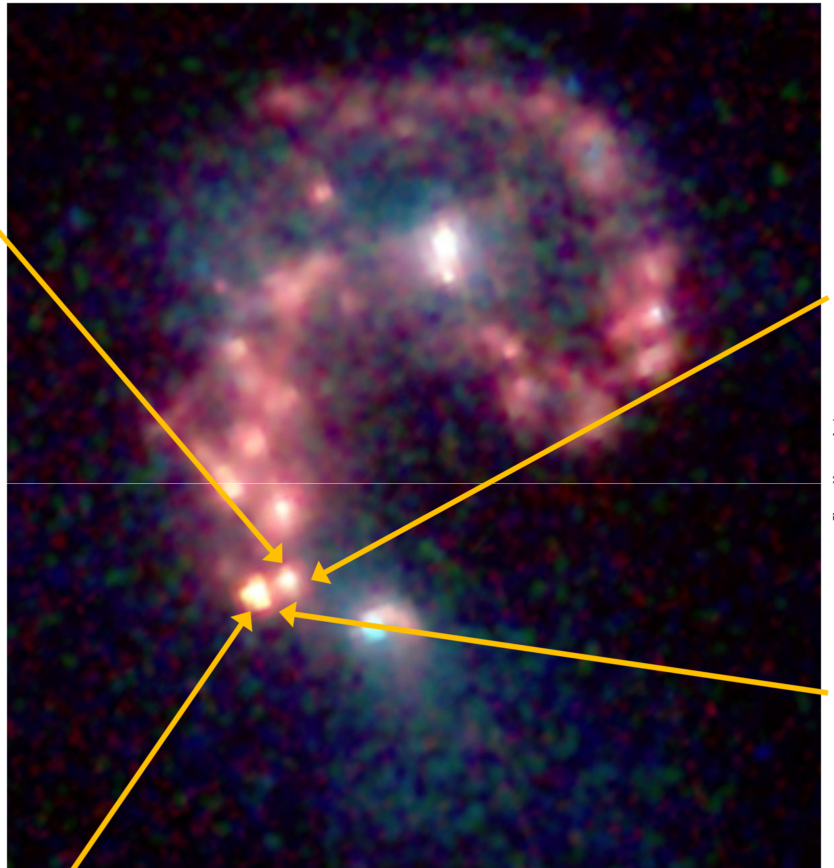




Spitzer-IRS ~500pc

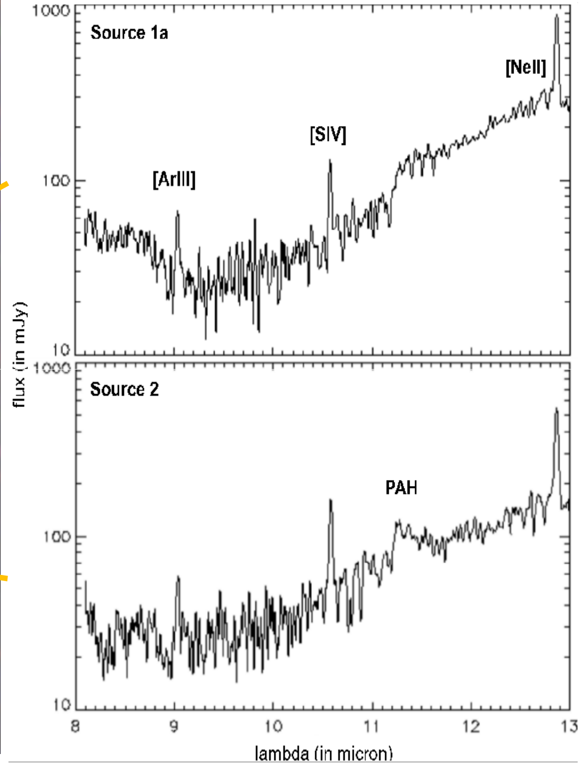
Brandl et al. (2009)





VLT-VISIR ~55pc

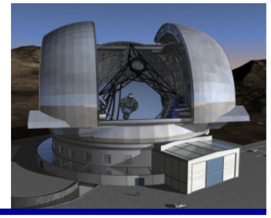
Snijders et al. (2006)



Same continuum fluxes, but very different PAHs, H_2, … →
Result = f {resolution} ☹

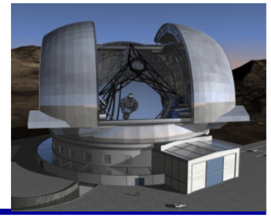
E-ELT – METIS: 10 pc resolution → resolve HII / PDR / diffuse ISM

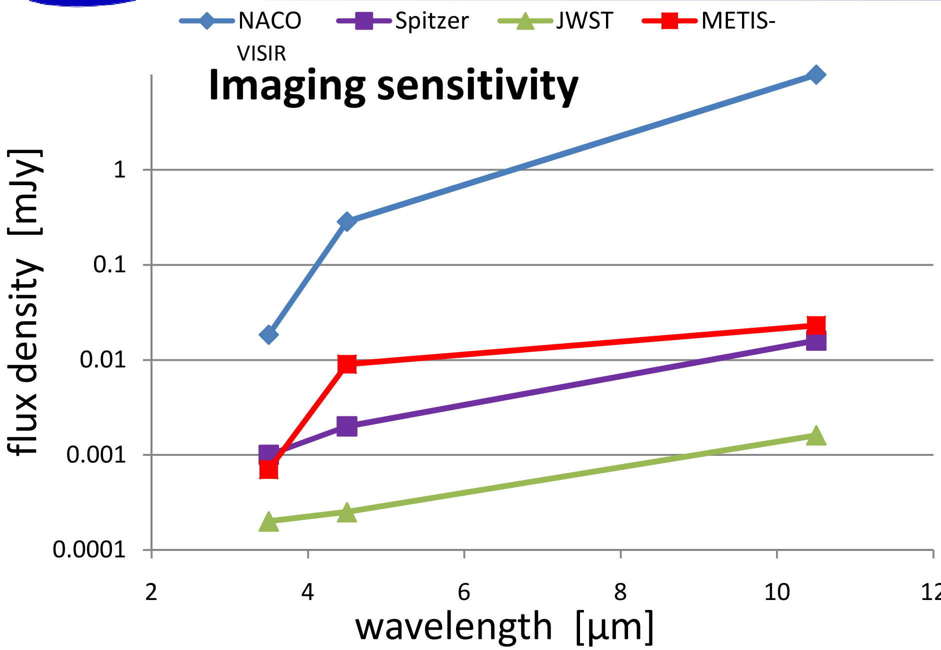
The METIS Instrument Baseline

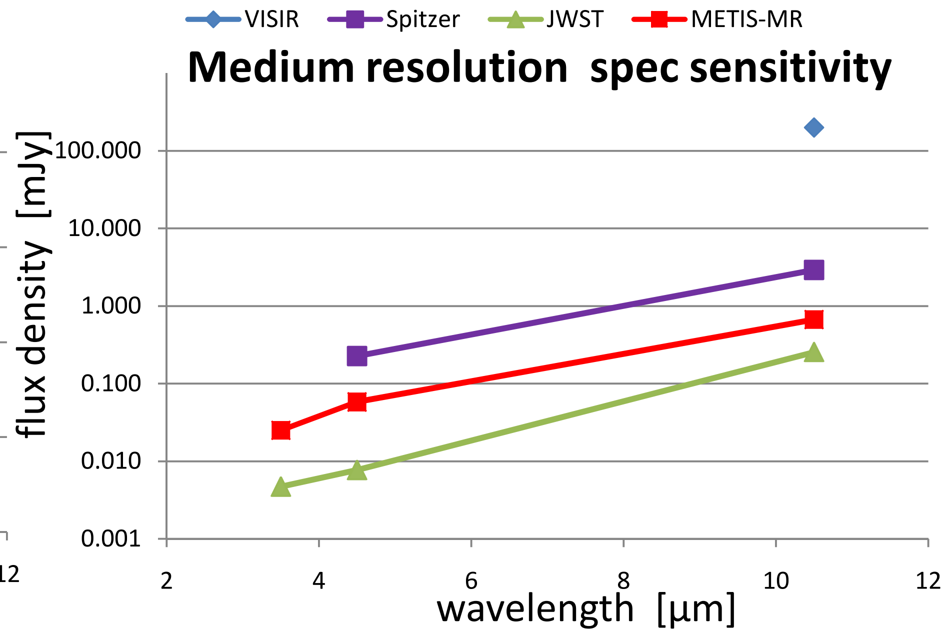


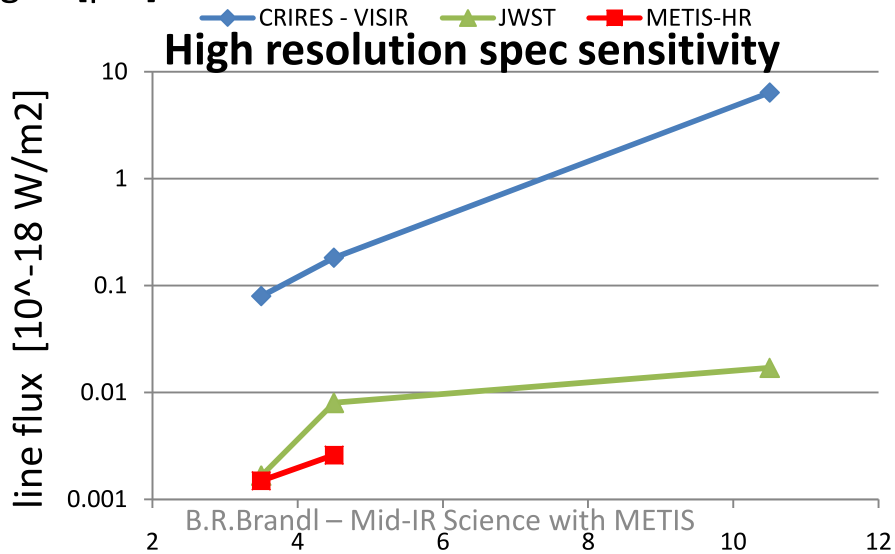
- Diffraction limited imager [18″×18″] for L/M, and N band
  - includes 4QZOG coronagraph (N-band only)
  - includes low-resolution (R ≤ 5000) long-slit spectrometer
  - includes polarimeter (N-band only)
- High resolution IFU [≥ 0.4″×1.6″] spectrograph for L/M [2.9 – 5.3μm, R ~ 100,000] band

METIS Sensitivity in Comparison





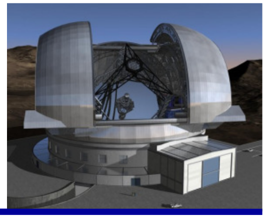


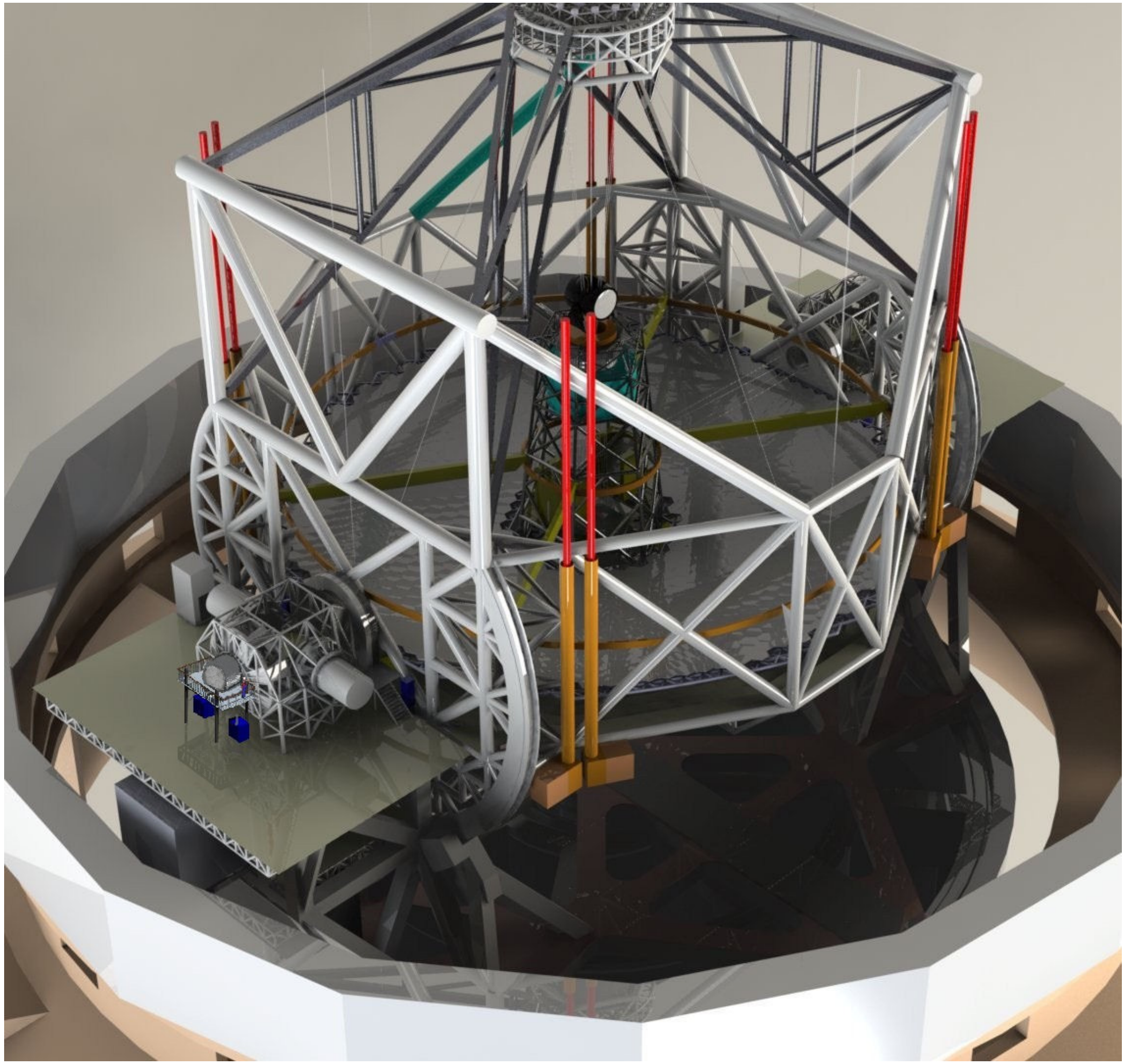


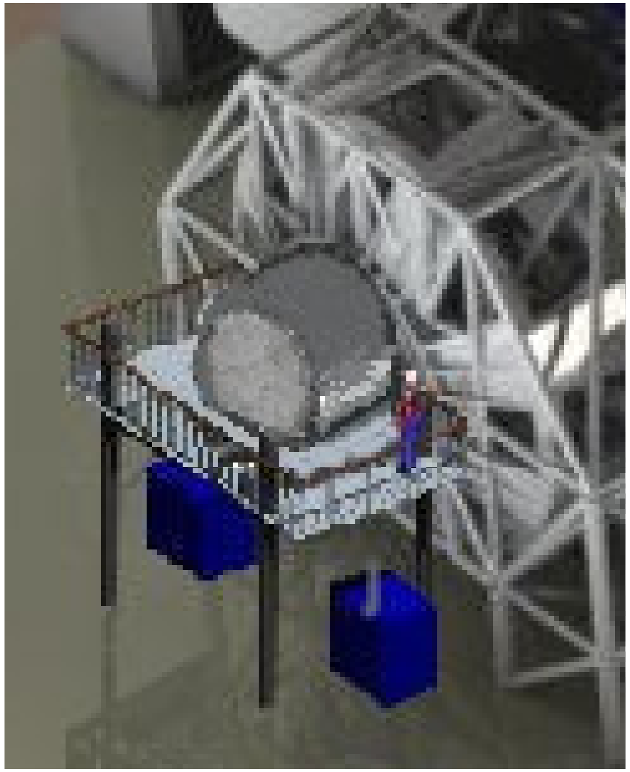
JWST has no high resolution spectroscopic capability

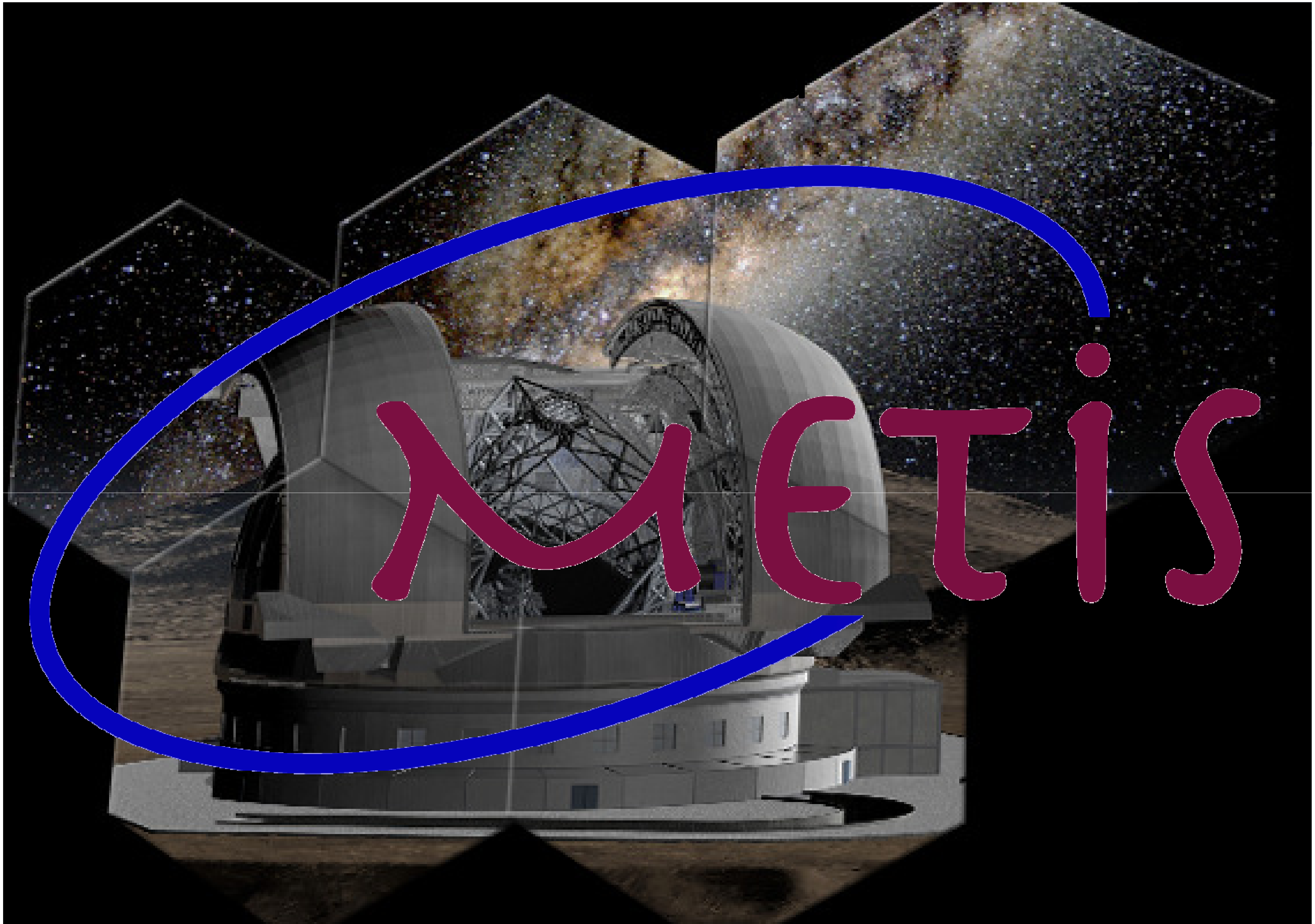
METIS

METIS at the Telescope








METIS