Star and Planet Formation in the Solar neighbourhood and beyond with SHARP

WG3 – Interstellar medium, young stellar objects and planetary systems

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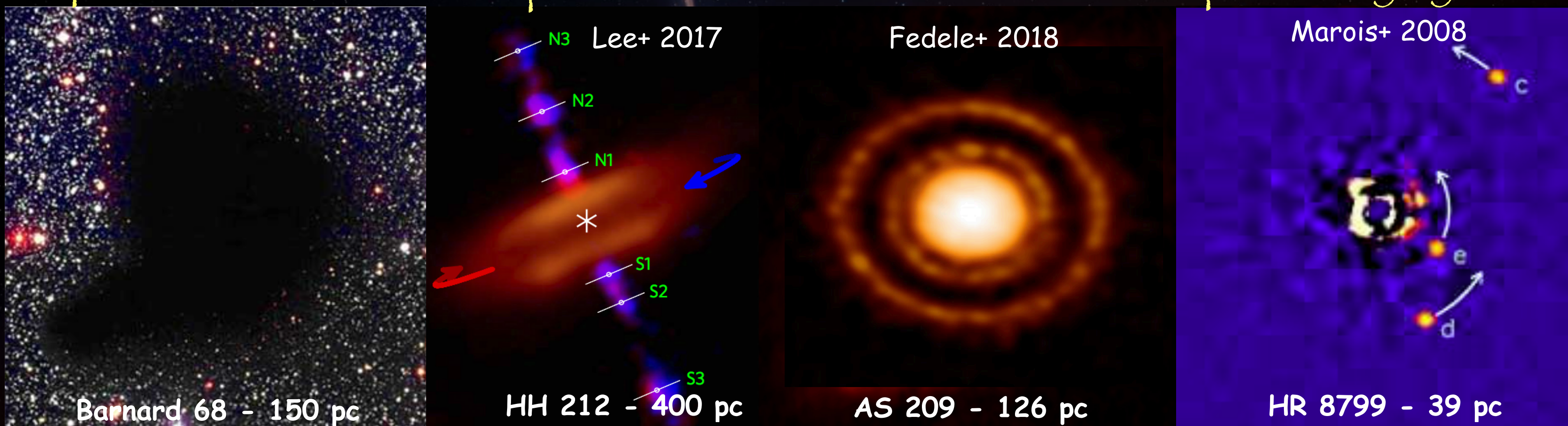
The Star formation process & the birth of planets

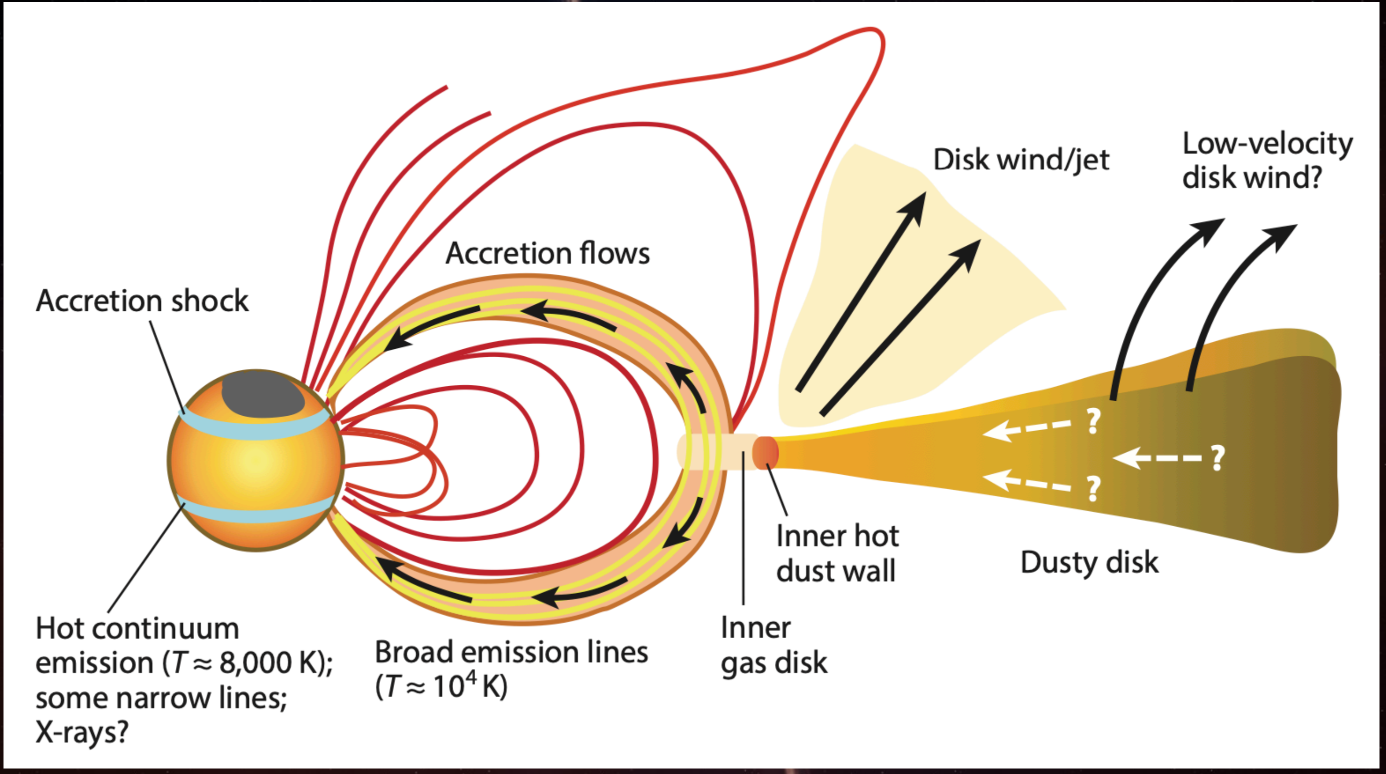
from E. Bianchi PhD thesis

prestellar core | protostar | T Tauri disk | planetary system



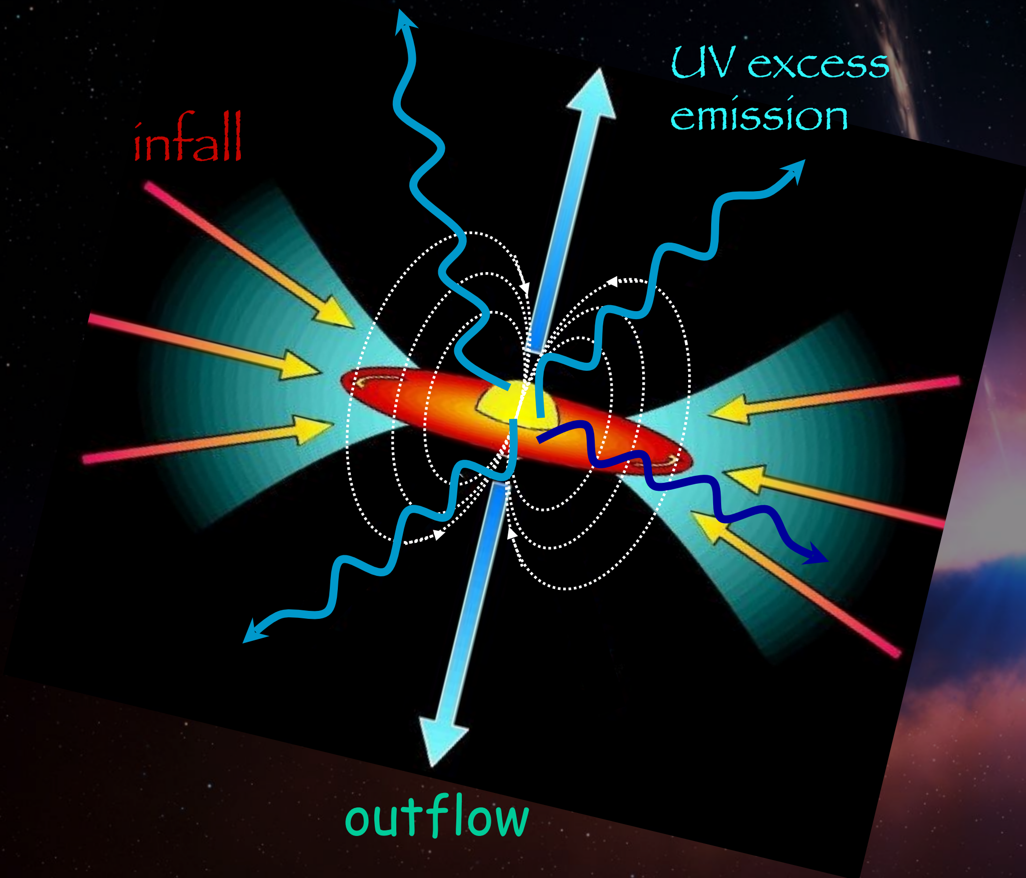
t=0 | 10^4—10^5 yrs | 10^6—10^7 yrs | >10^8 yrs

The output of the star formation process is determined by the interplay between accretion and ejection



Hartmann et al. 2016

Magnetospheric accretion and mass accretion rate



$T \sim 10^4$ K shocked gas emits in:

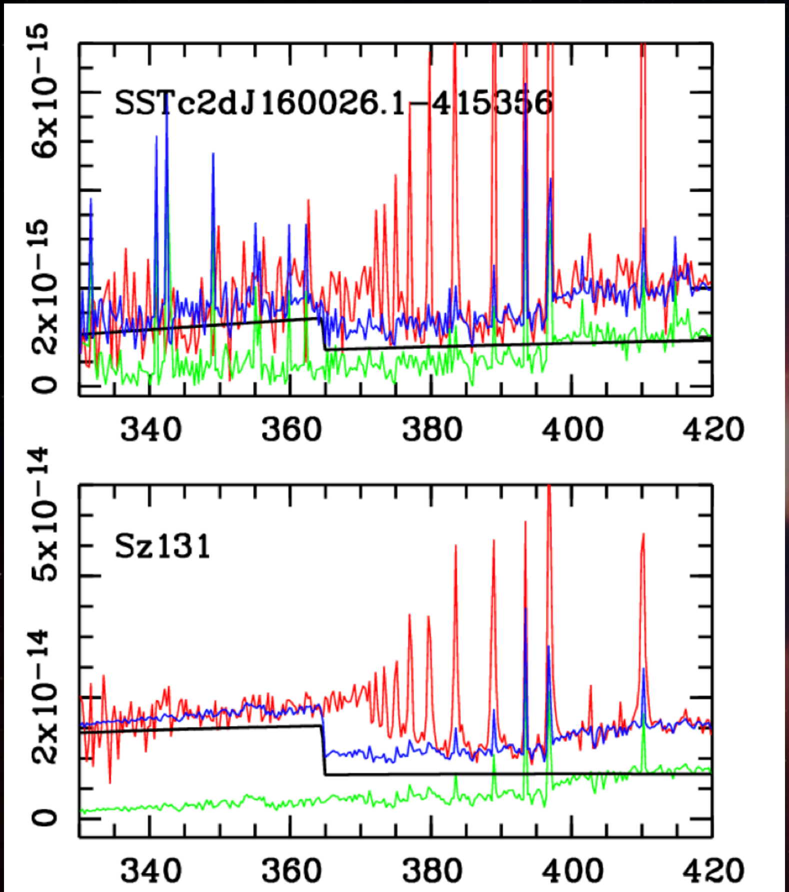
- Balmer & Paschen continua
- Balmer & Paschen series
- CaII IRT, He I, Paβ & Brγ

L_{acc} can be derived from UV continuum excess and / or emission lines

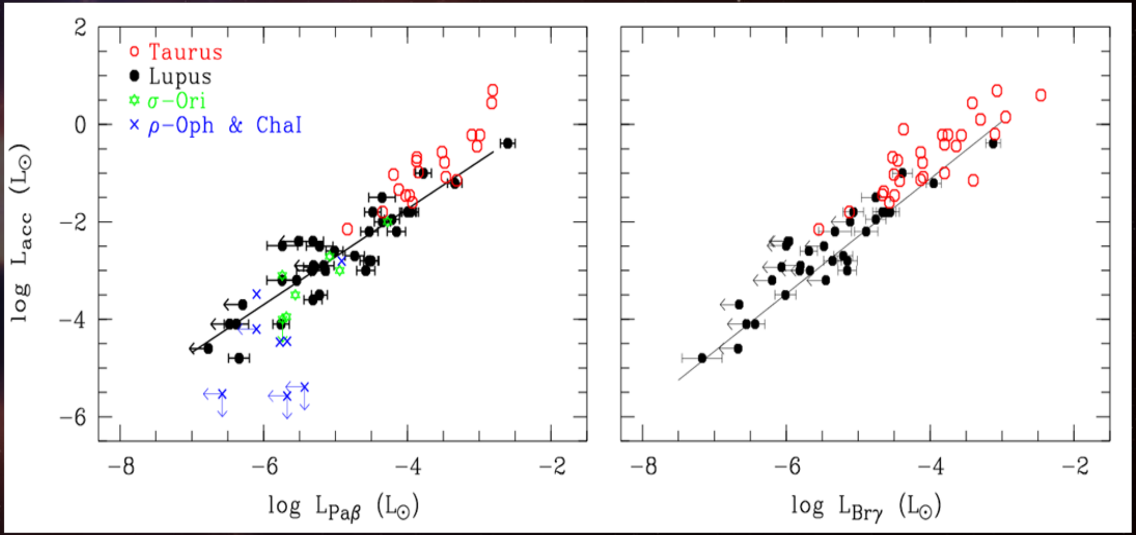
$$L_{acc} = \frac{G M_\star \dot{M}_{acc}}{R_\star} \left(1 - \frac{R_\star}{R_{in}}\right)$$

L_{acc} vs L_{line} correlation

The correlation between the accretion luminosity (derived from the UV-excess) and the line luminosity has been calibrated from Xshooter spectroscopy of nearby SFRs



- Balmer lines up to H15
- Pa5 - Pa10 & Br7
- He I & He II (10 lines)
- Ca II (H & K, IRT)
- Na I D lines



Pa_β & Br_γ rels. extend ~4 orders of mag

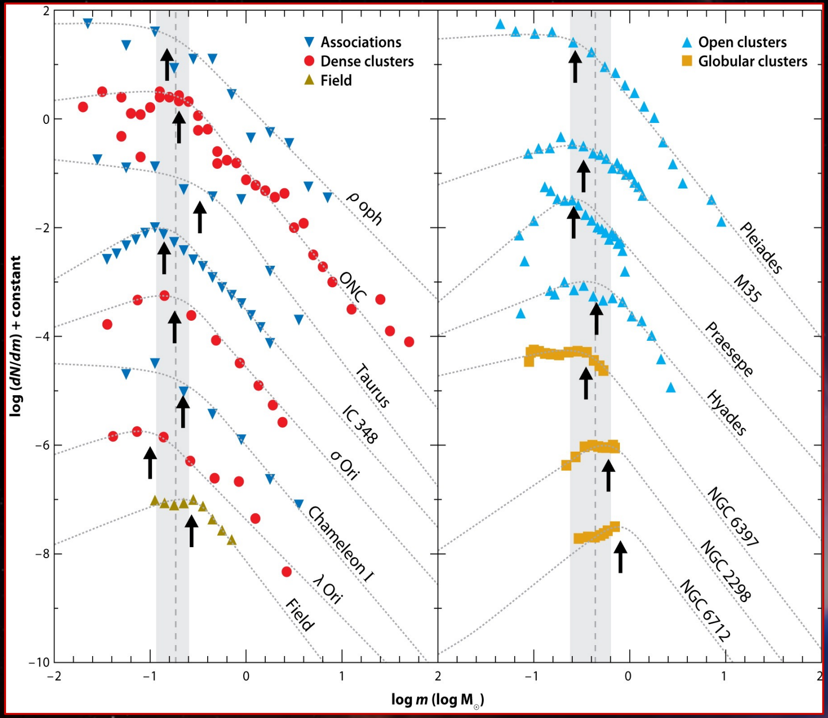
Alcala' et al 2014; 2017

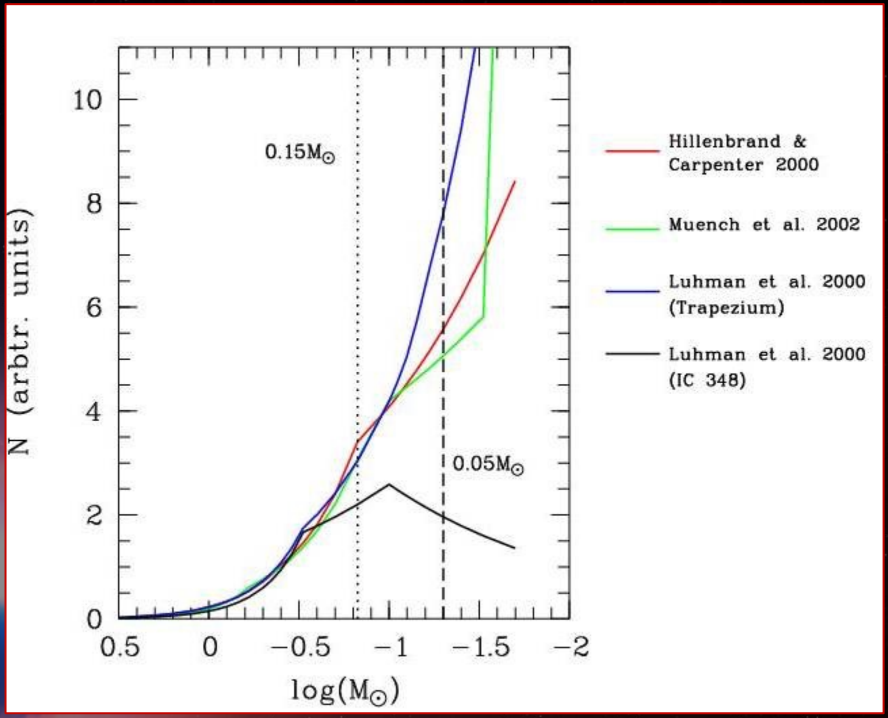
The star formation process
from nearby SFRs to the limits of the MW and beyond

Image Credit: NASA, ESA, CSA, Olivia C. Jones (UK ATC), Guido De Marchi (ESTEC), Margaret Meixner (USRA). Image Processing: Alyssa Pagan (STScI), Nolan Habel (USRA), Laura Lenkić (USRA), Laurie E. U. Chu (NASA Ames)

JWST is starting to do this for a few YSOs…
MORFEO-SHARP will allow to do it for large samples

What are the effects of the local environment on the properties of the forming stars?
What are the IMF, mass accretion rate & disk lifetime in low-metallicity environments?



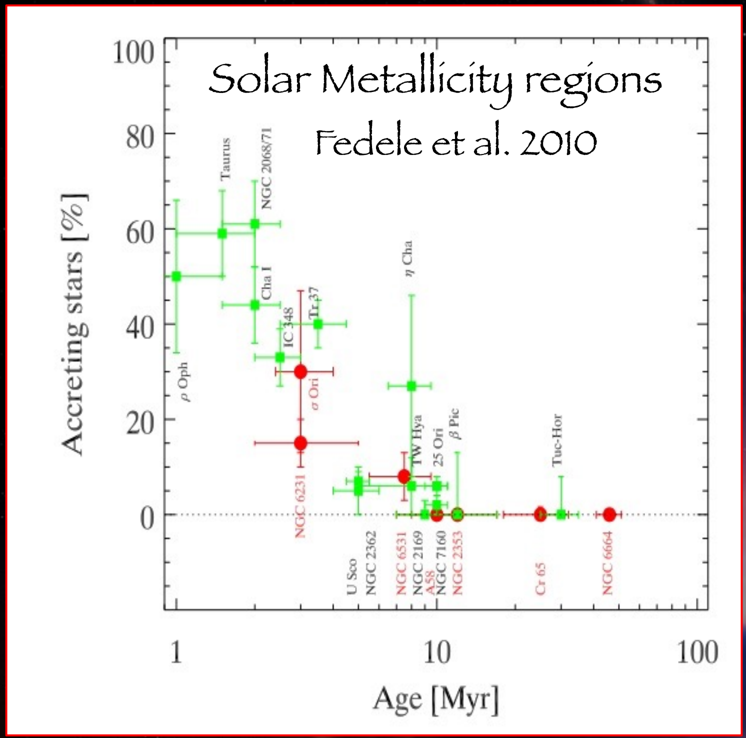


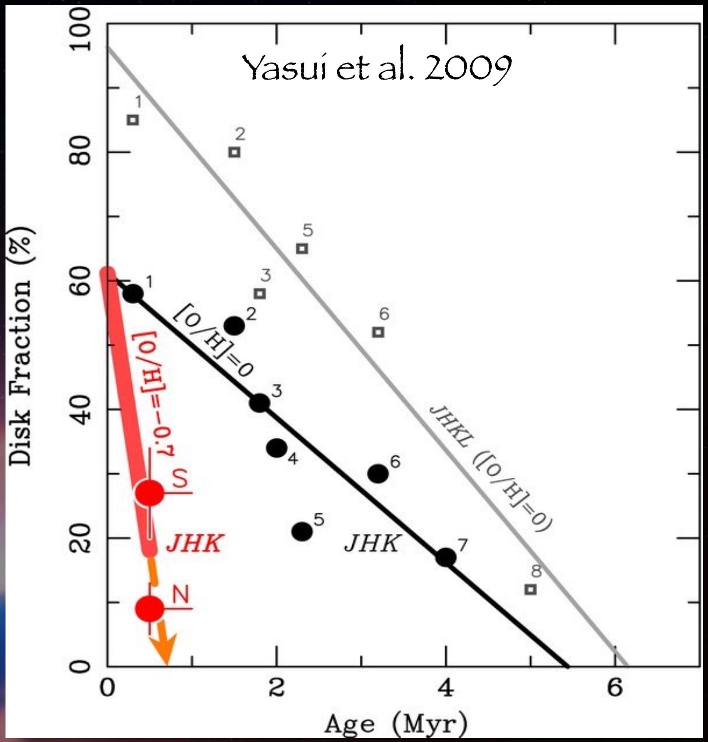
Bastien et. al. 2010 ARA&A

- good agreement for $M > 0.3\ M_{\odot}$
- very uncertain in the low-mass and sub-stellar regimes

➡ low metallicity IMF not determined yet

Accretion & disk lifetime vs Metallicity

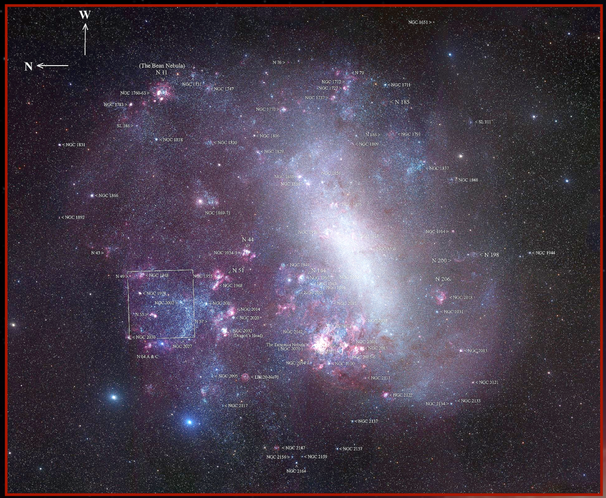




- much lower disk fraction @ low Z (< 0.2 $Z_\odot$)
- disks lifetime much shorter at low Z

➡ much higher accretion rates at low metallicity
consequences for planet formation

Accretion & disk fraction in low-Z environment with SHARP



MOS and m-IFU of low-Z embedded clusters with Nexus and Vesper

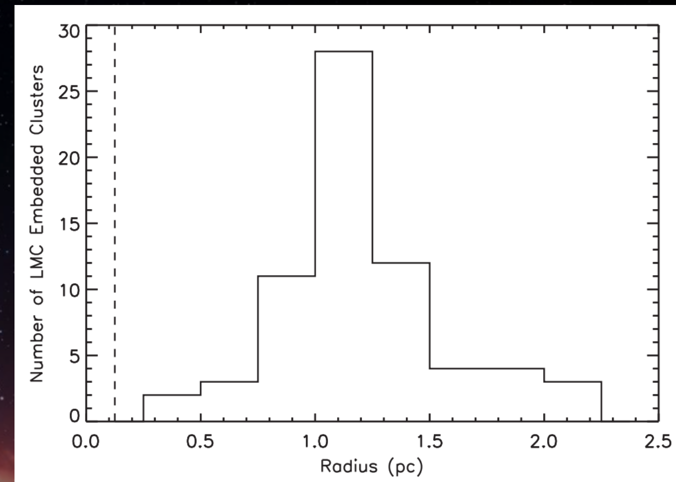
- characterise embedded clusters in LMC-SMC
- investigate low-mass (2 – 0.1 $M_\odot$) YSO cluster members
- detect Paβ & Brγ (+ other) emis. lines & single out accreting YSOs
- derive M_{acc} from L_{acc}-L_{line} correlation calibrated for nearby SFR
- investigate disk fraction through spectroscopic NIR excess
- examine disk-fraction, M_{acc} in low-Z YSOs in comparison with solar metallicity YSOs in the Milky Way

Accretion & disk fraction in low-Z environment with SHARP

Orion Nebula Cluster

size ~33', i.e. ~4 pc @390 pc

MW embedded clusters —> size~1-4 pc



LMC clusters size

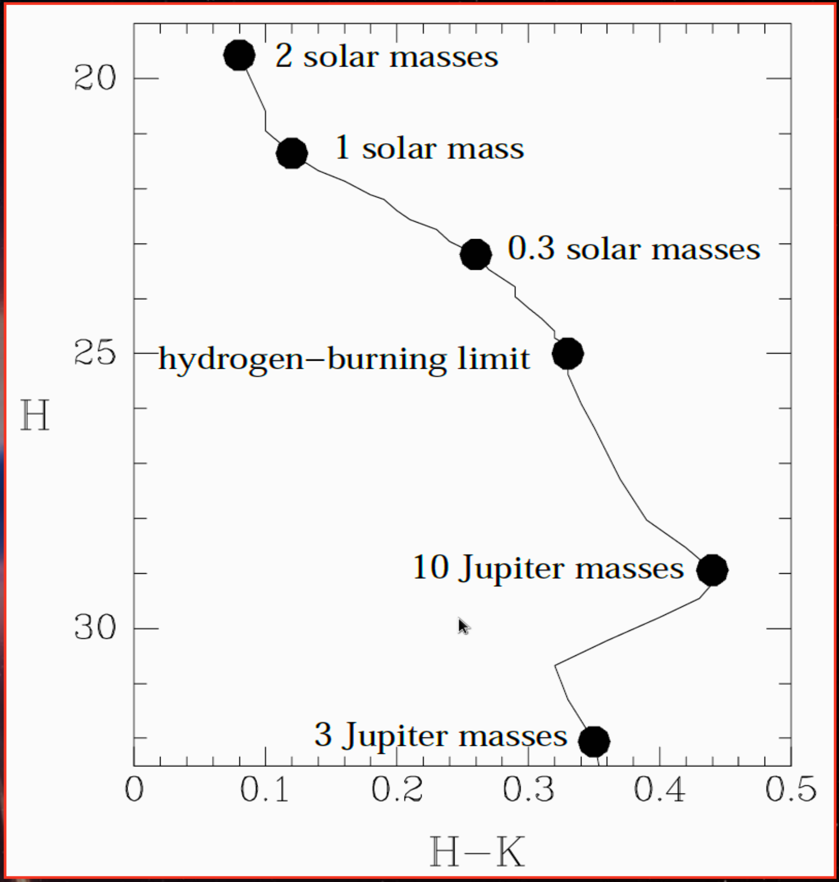
- the cluster size is 4" - 16" @50 kpc —> young clusters are excellent targets for m-IFU Vesper
- 12 IFU (1.7" x 1.5") —> allows observing more YSO simultaneously over FoV: 24"x70"
- 31mas /pix (factor 3.5 better than JWST) —> sep~1550 au @ 50kpc (i.e. wide binaries)
- the IFU allows to subtract background emission

Accretion & disk fraction in low-Z environment with SHARP

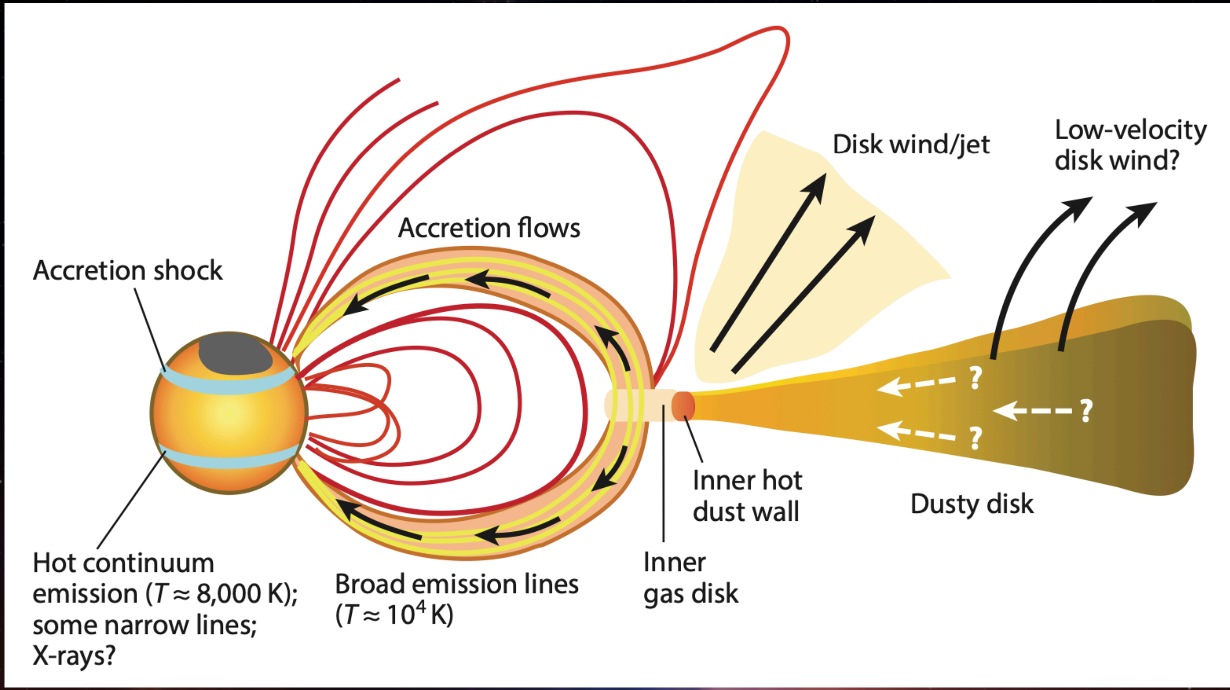
With its sensitivity and spectral/spatial res SHARP Vesper/Nexus will allow us to:

- detect accreting YSOs just above the H-burning limit
- detect 0.3 $M_\odot$ YSOs with F(Paβ) & F(Brγ) ~ 10^{-20} – 10^{-21} erg/s/cm²
- derive Paβ & Brγ YSOs line luminosity
- use L_{acc} – L_{line} relations calibrated using YSOs in nearby SFRs to derive L_{acc} and M_{acc}

5Myr isochrone @ 50kpc



The interplay between accretion and ejection



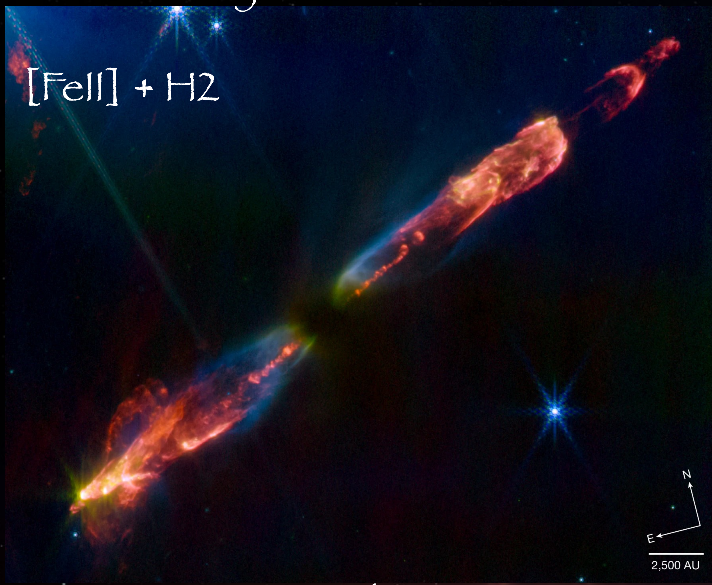
Hartmann et al. 2016

JETS & OUTFLOWS

- extract angular momentum thus allowing accretion onto the YSO
- may carve gaps in the disk thus triggering grain growth & planet formation
- contribute clearing the disk, thus setting the timescale for planet formation

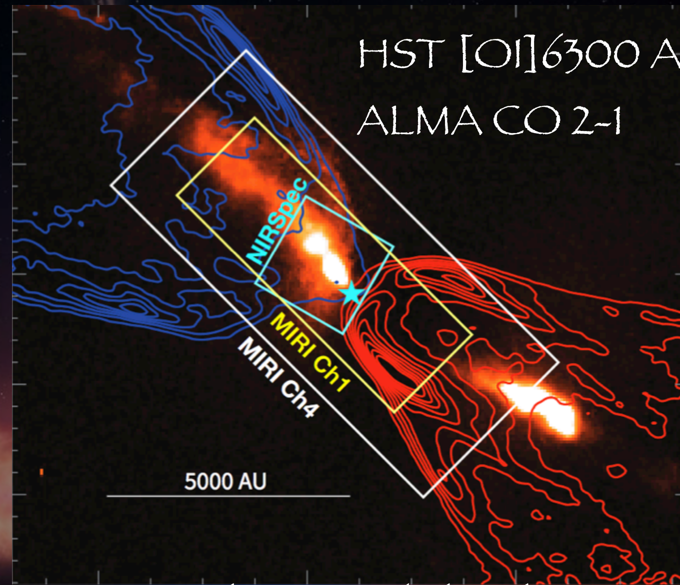
Jets and outflows are observed from UV to mm

HH 211 (Perseus, 320 pc)
observed by JWST



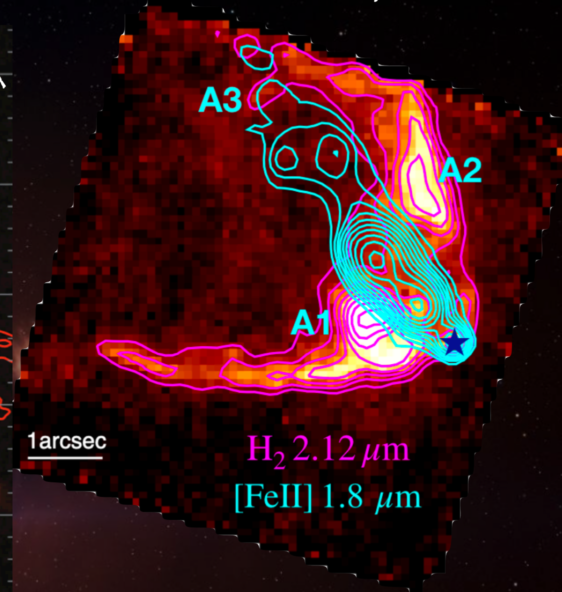
Ray et al. 2024

HH 46-47 at d=450 pc



Arce et al. 2013 + Erkal et al. 2021

JWST-NIRSpec

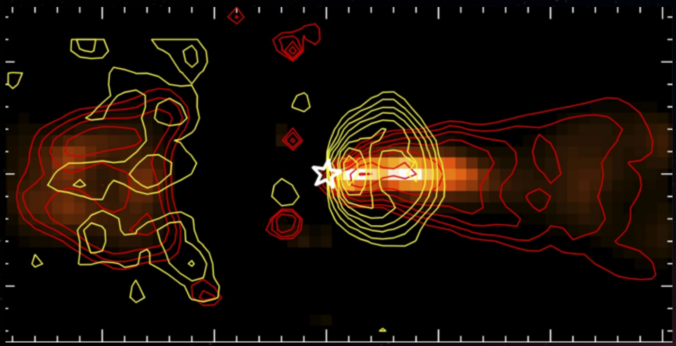


Nisini et al. 2024

Jets produce shocks at the impact with the surrounding medium and emit in forbidden & permitted lines in the NIR, e.g. H2 ro-vibrational & [FeII] lines

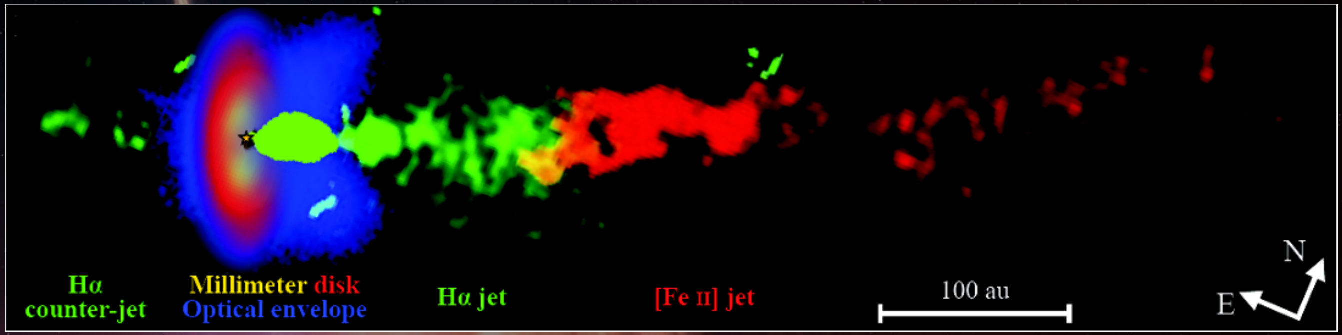
Jets are great targets for AO-assisted imaging and IFU

DG TAU @140pc, [FeII] + H2
with SINFONI IFU (0.2" – R=3000)



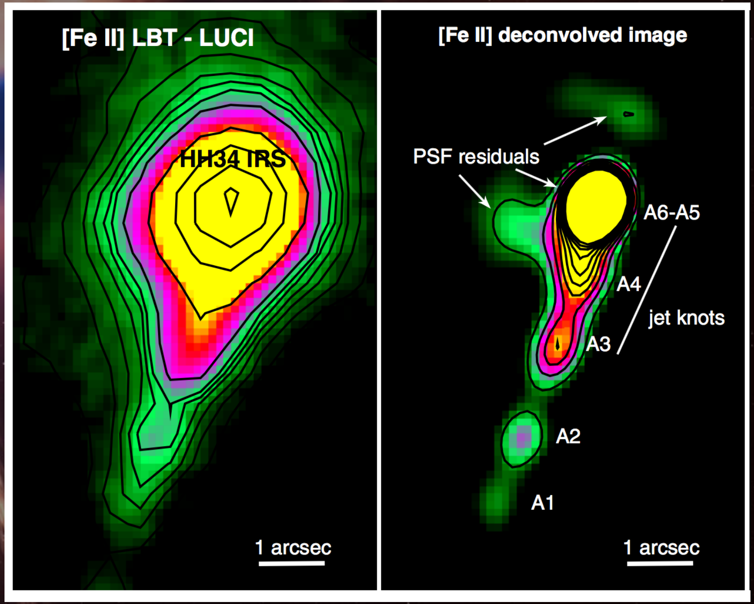
Agra-Amboage et al. 2014

RY TAU @140pc
with SPHERE ZIMPOL & IRDIS (0.1")



Garufi et al. 2019

HH 34 @390pc
with LBT-LUCI

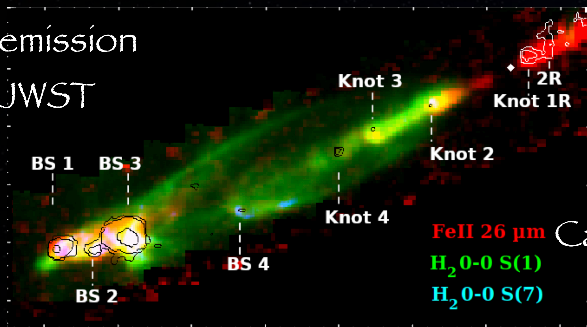


Antoniucci et al. 2014

Key observables: jet velocity, collimation and mass loss rate

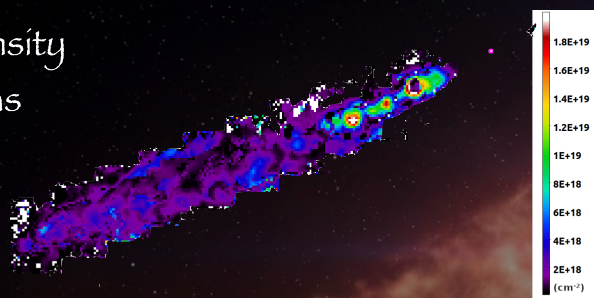
Ellerbroek, Podio+ 2013

[FeII] + H2 emission
seen by JWST

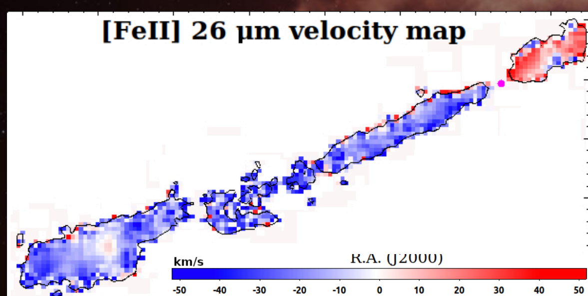


HH 211 jet
Caratti o Garatti
et al. 2024

column density
of H2 gas

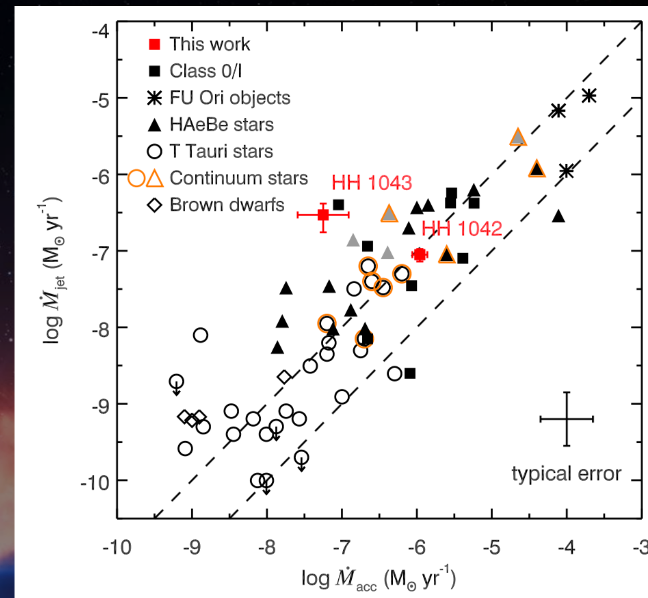


jet
velocity



jet
mass-loss
rate

$$\dot{M}_{jet} = \mu \, m_H \, n_H \, \pi \, r_J^2 \, v_J,$$

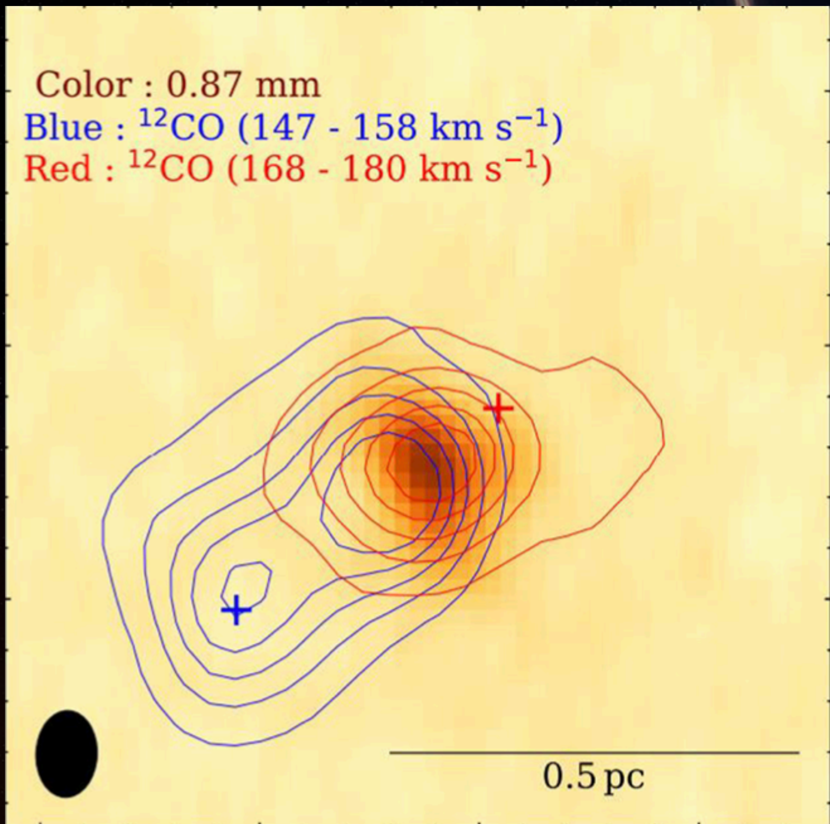


mass loss rate vs mass accretion rate

M_{jet} ~0.1 - 1 M_{acc}

What is the M_{jet}/M_{acc}
in low-metallicity environments?

First detection of an outflow from a YSO in the SMC

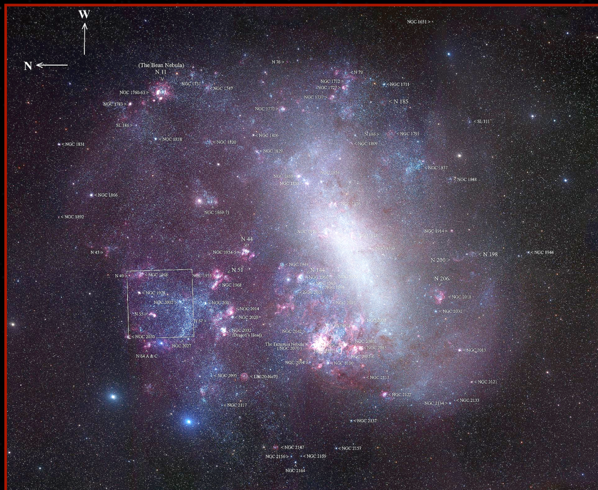


Tokuda et al. 2022

ALMA observations observations of CO 2-1 at a spatial resolution of 0.1 pc toward the massive protostar Y246

molecular outflows, i.e., the guidepost of the disk accretion at the small scale, might be universally associated with protostars across the metallicity range of ~0.2–1 $Z_\odot$.

Jets & Outflows in nearby SFRs and in low-Z environment with SHARP



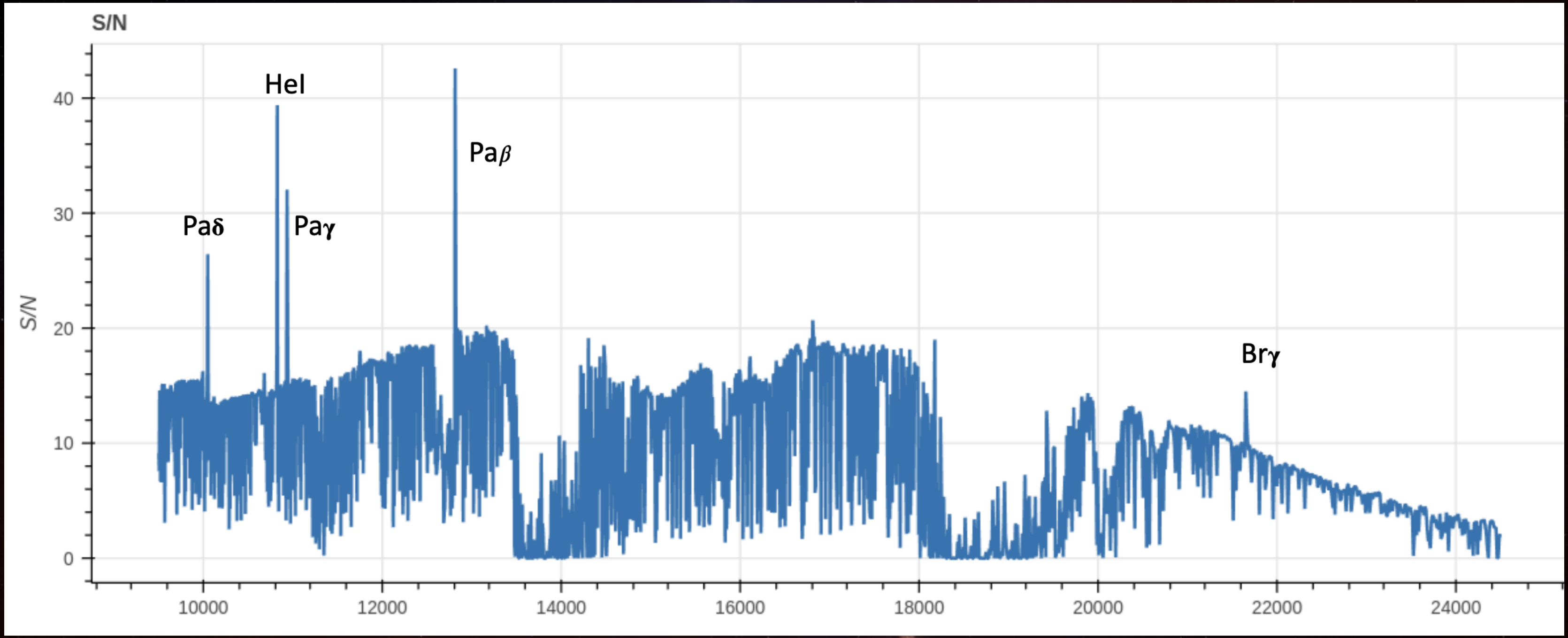
NEXUS (MOS) & VESPER (m-IFU) will allow obtaining high spectral/spatial resolution spectra (30 mas, R=6000) of jets in nearby SFRs and in low-Z embedded clusters

- low-mass (2 – 0.1 $M_{\odot}$) YSO cluster members in nearby SFRs and LMC-SMC
- detect jet emission lines ([FeII], H2)
- derive M_{jet} from L_{line} (+ jet velocity)
- investigate ejection/accretion interplay in low-Z YSOs in comparison with solar metallicity YSOs in the Milky Way

ETC SHARP: accretion/ejection tracers

Input spectrum: CTTS Sz88A, M_*=0.2 M⊙; H(Vega)=23

Airm=1.5; Multi-Congugate AO; Texp=1h; S/N > 10   R=2000



A SHARP view of star & planet formation in the Solar neighbourhood and beyond

Thank you !