INAF
ISTITUTO NAZIONALE
DI ASTROFISICA

YOUNG STELLAR POPULATIONS: THE ORIGIN OF STARS AND PLANETS

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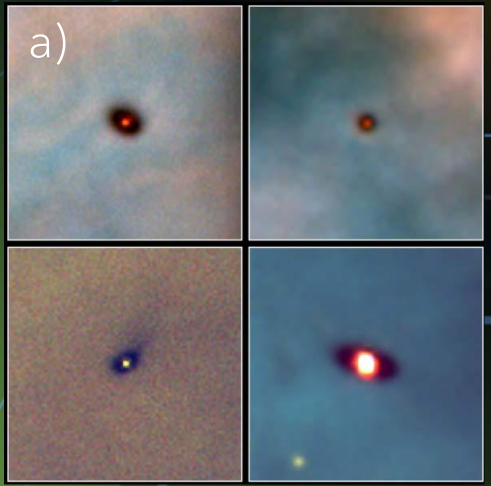
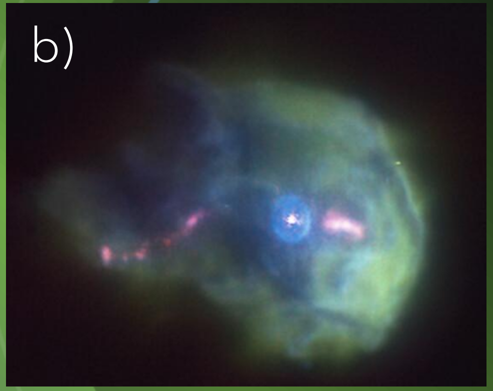
INAF OSSERVATORIO ASTRONOMICO DI PALERMO





Class I/II YSOs: star + protoplanetary disc + surrounding envelope

Timescale for 1 $M_\odot$ star < 3-10 Myrs

a) Stars with discs in Orion – HST *(Bally+2000)*;
b) YSO 244-440 – MUSE *(Kirwan+2023)*

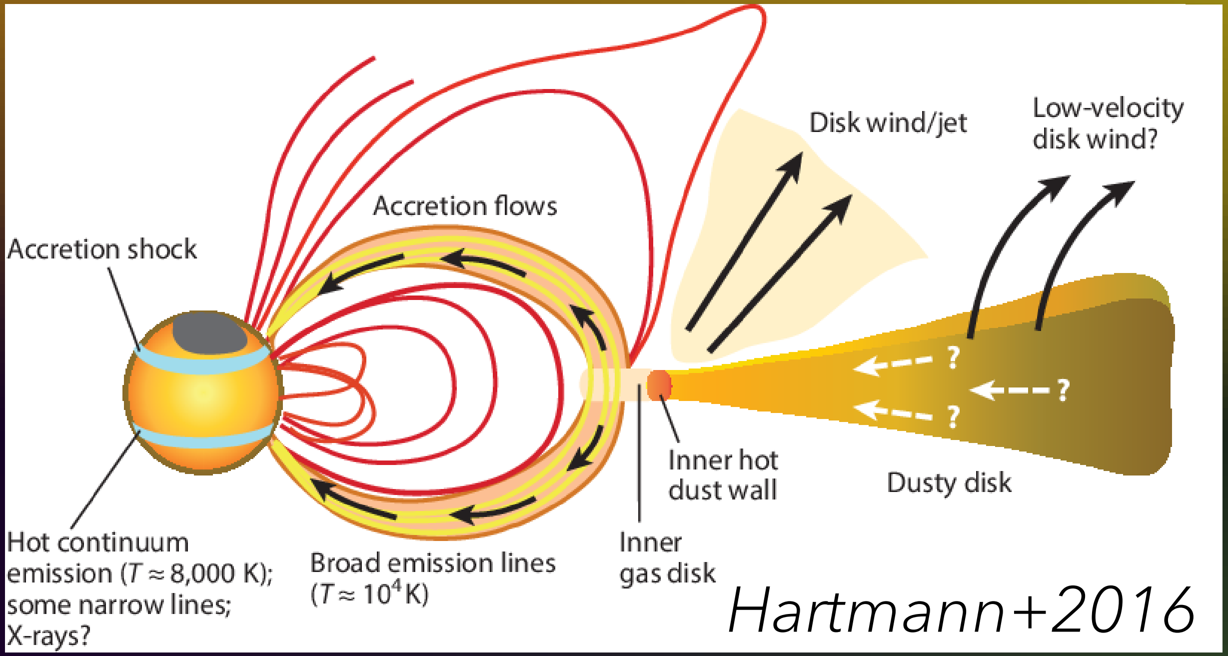
Class III YSOs: stars still contracting toward the MS + debris disc (?) + planets (?)

Timescale for 1 $M_\odot$ star: approximately 50 Myrs

c) stars in h and χ Persei

Class I/II host complex phenomena

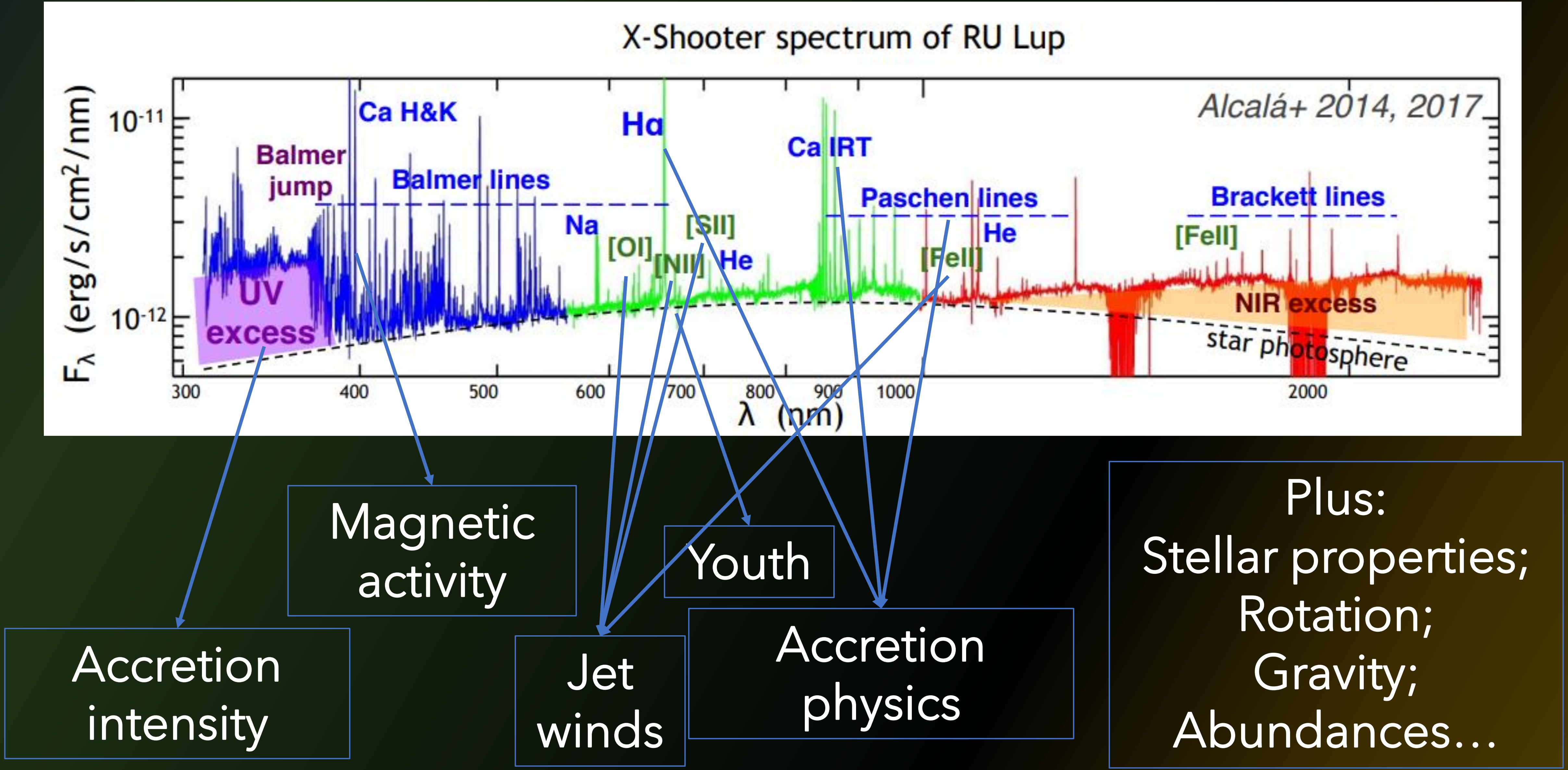
- Gas accretion from the disc onto the central star
- MHD and photoevaporative wind from the disc
- Elongated and higly collimated jets
- Enhanced magnetic activity
- Time variable extinction by circumstellar material



Hartmann+2016

HH 221
JWST
(Caratti o Garatti+2024)

OPTICAL/NIR SPECTRUM OF AN ACCRETING PRE-MS STAR



Accretion intensity

Magnetic activity

Jet winds

Youth

Accretion physics

Plus:
Stellar properties;
Rotation;
Gravity;
Abundances…

Two science cases which require high resolution spectroscopic observations of YSOs:

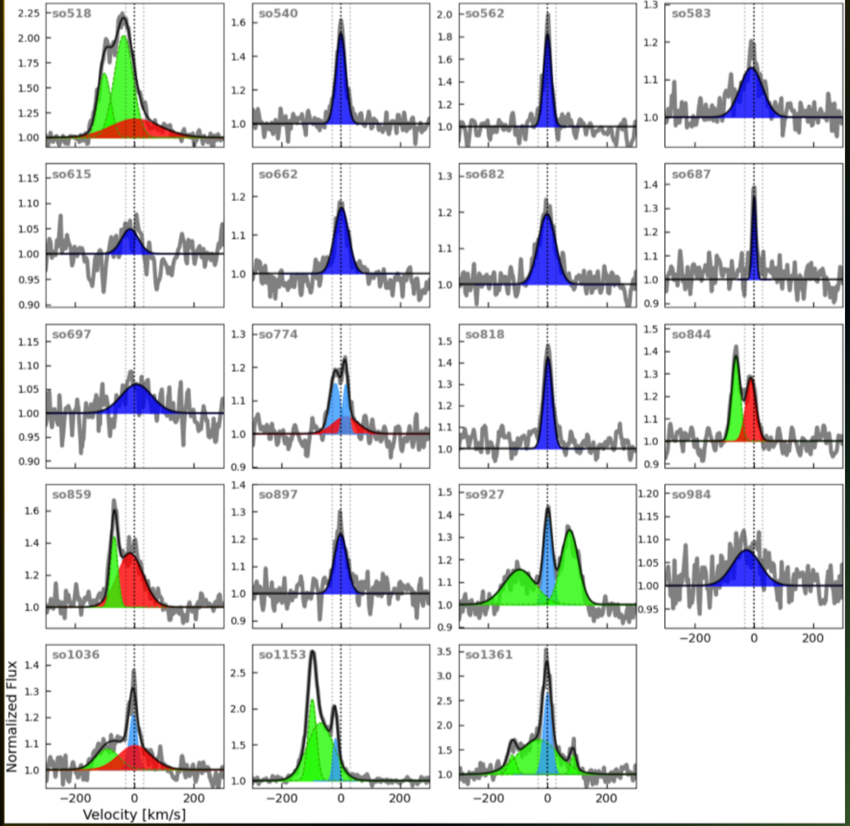
Accretion and outflow physics from line profile analysis

Accretion variability

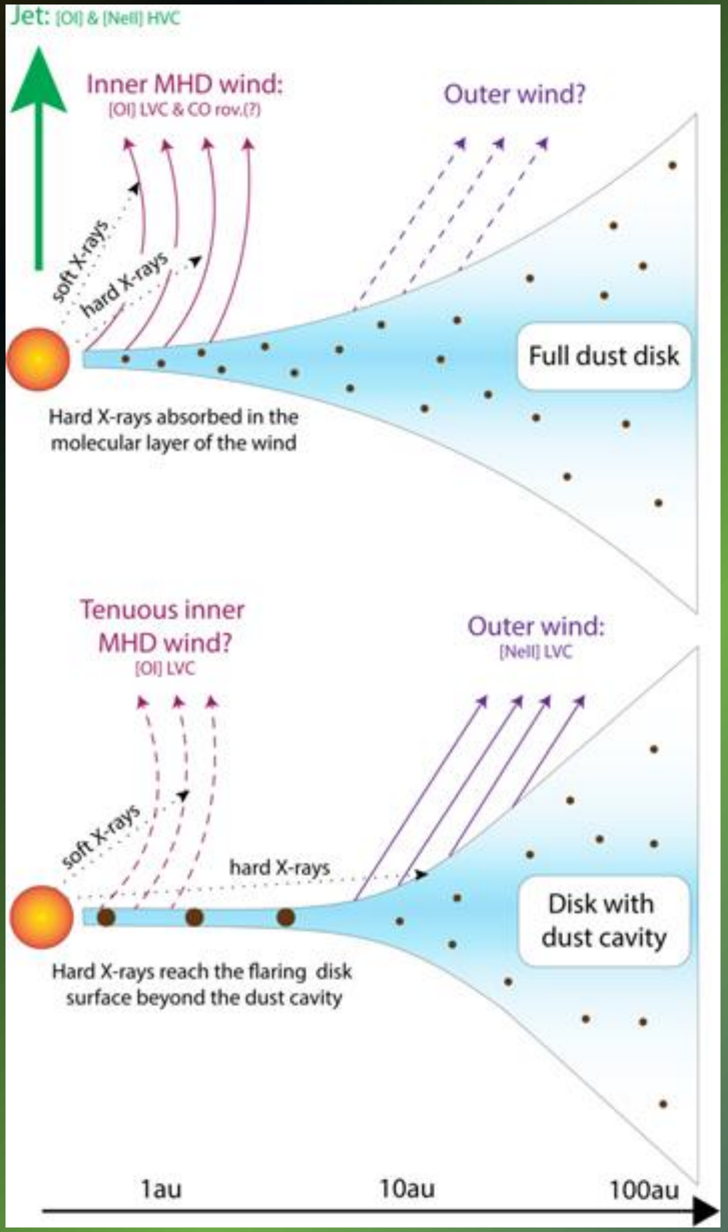
Profile fitting of emission lines at high R probes the complex structure of accretion and outflow (jets, MHD and photoevaporative wind).

When large samples are studied, one can connect the physics of the outflows to the properties of the star, the environment, and the evolution of the protoplanetary disc.

Large FoV and sensitivity!

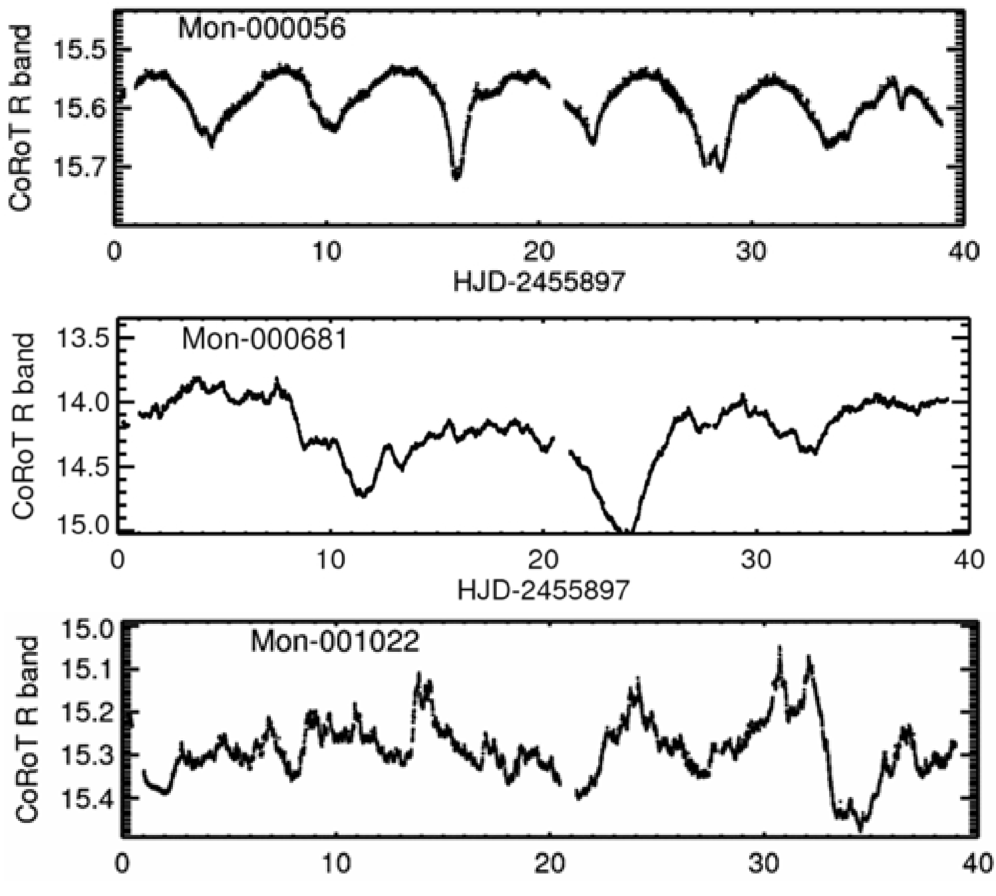


[OI] λ6300 of stars in σ Ori line fit profiles for the MIKE spectra (R=28K). Components: single, low-velocity narrow, low-velocity broad, high-velocity.
Mauco+2024

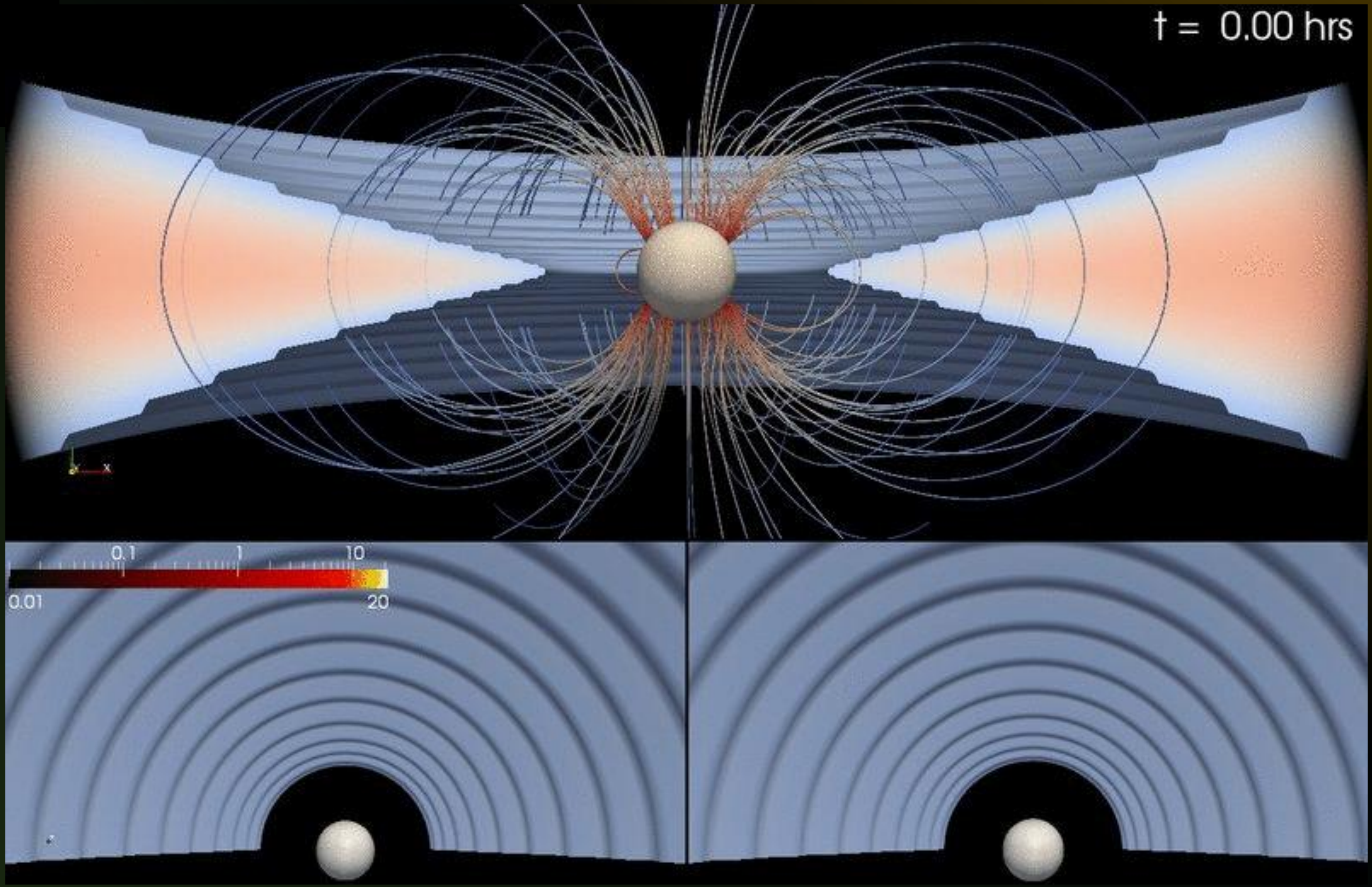


Outflows evolution (Pascucci+2020)

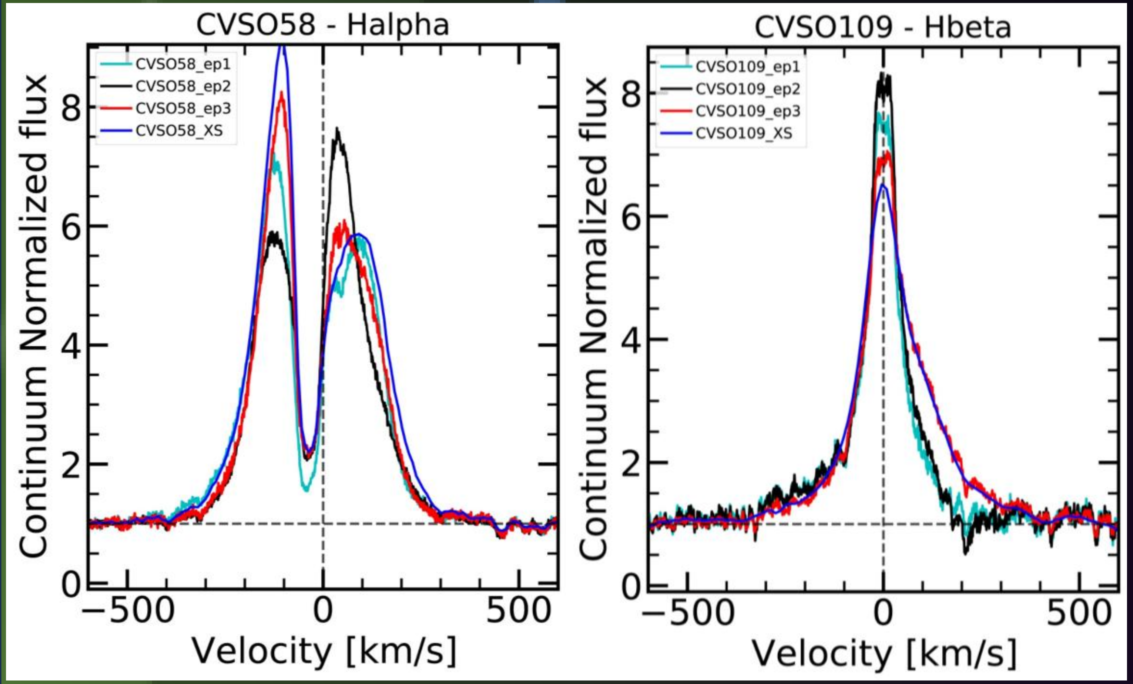
Accretion, variable extinction and magnetic activity+stellar rotation casue variability on several timescales, from hours to years



CoRoT light curves of PMS stars in NGC2264 (Cody+2014)



MHD simulations of unstable accretion in a class II source (Colombo+2019)



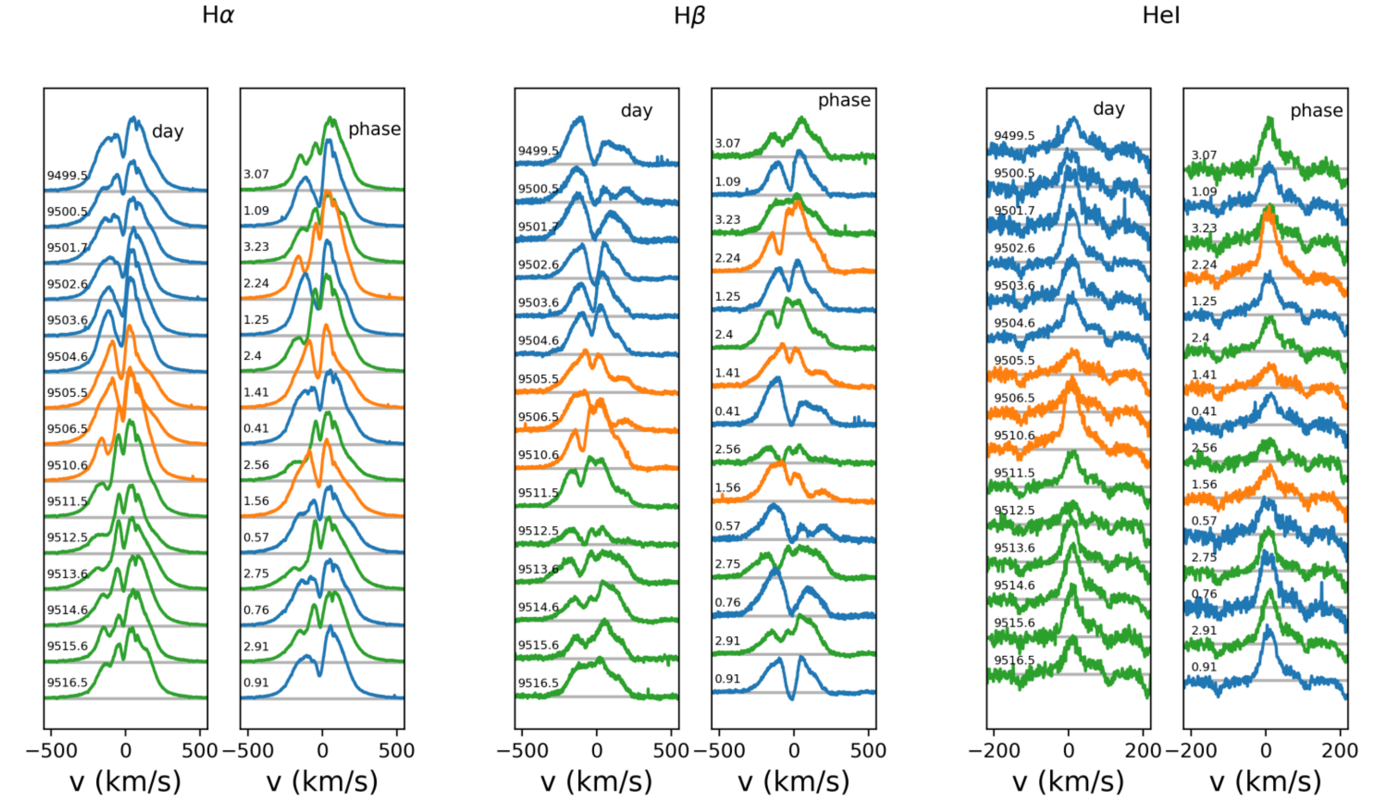
Accretion variability can be probed by:

Flux/EW variability (from days to years)

Rapid line profile variability (hours to days)

e.g. Campbell-White+2021

1-day timescale emission line profiles variability in two YSOs (UVES and X-shooter)
Manara+2021



1-day timescale emission line profile variability in GM Aur
Bouvier+2023

Episodic accretion bursts – hundreds of candidates in Gaia transient alerts

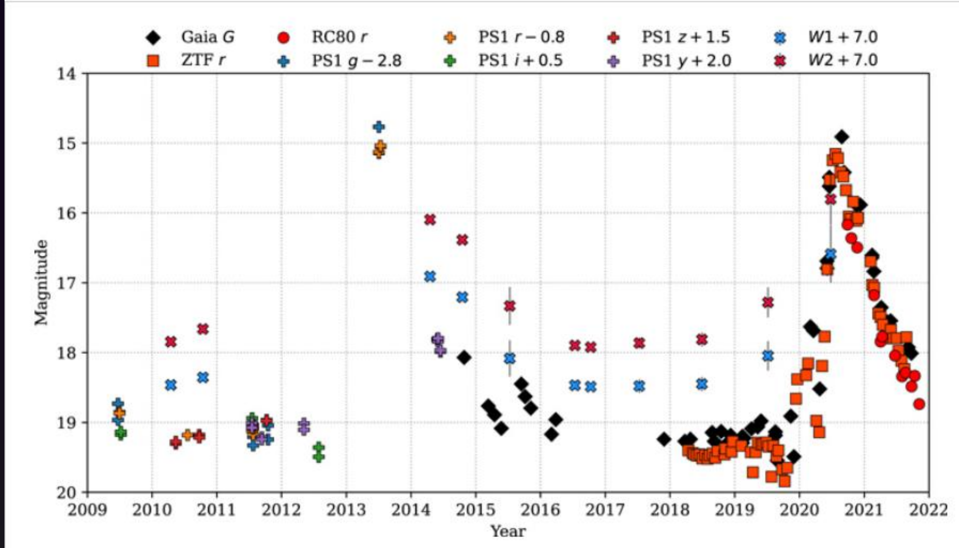
	FU ORI	**EX ORI**
Δmag	6-8	2-5
Variability	From decades to centuries	Month to years
$\dot{M}\ (M_\odot/yr)$	$10^{-4} - 10^{-5}$	$10^{-6} - 10^{-7}$
Spectral Features	Hα P Cygni profile, He I, metals, water and TiO in absorption	Accretion lines and CO in emission
Properties	Accretion through the equatorial plane; small and massive discs	Magnetospheric accretion

The number of new accretion bursts exploded with Gaia and will further increase with future missions (LSST)

Spectroscopic observations at high sensitivity, high R, large FoV needed for study and classification

What is the physics behind bursts?

What is their role in the evolution of discs?



Light curve of Gaia20eae (EX Ori type)

Cruz-Sáenz de Miera+2022

Do we really need to push our capability to study YSOs at large distances?

The Solar neighborhood is quite well studied…

Several observations of specific regions, such as:

Lupus *(Alcalà+2014, 2017, 2019)*
Chamaeleon I *(Manara+2016, 2017)*
Upper Scorpius *(Manara+2020)*
ρ-Ophiucus *(Manara et al. 2015)*
σ-Orionis *(Rigliaco+2012, Mauco+2023)*
Taurus *(Herczeg & Hillenbrand 2008, 2014, 2025)*
TWA: *(Venuti+2019)*
NGC1333: *(Fiorellino+2021)*

Extensive surveys, such as:

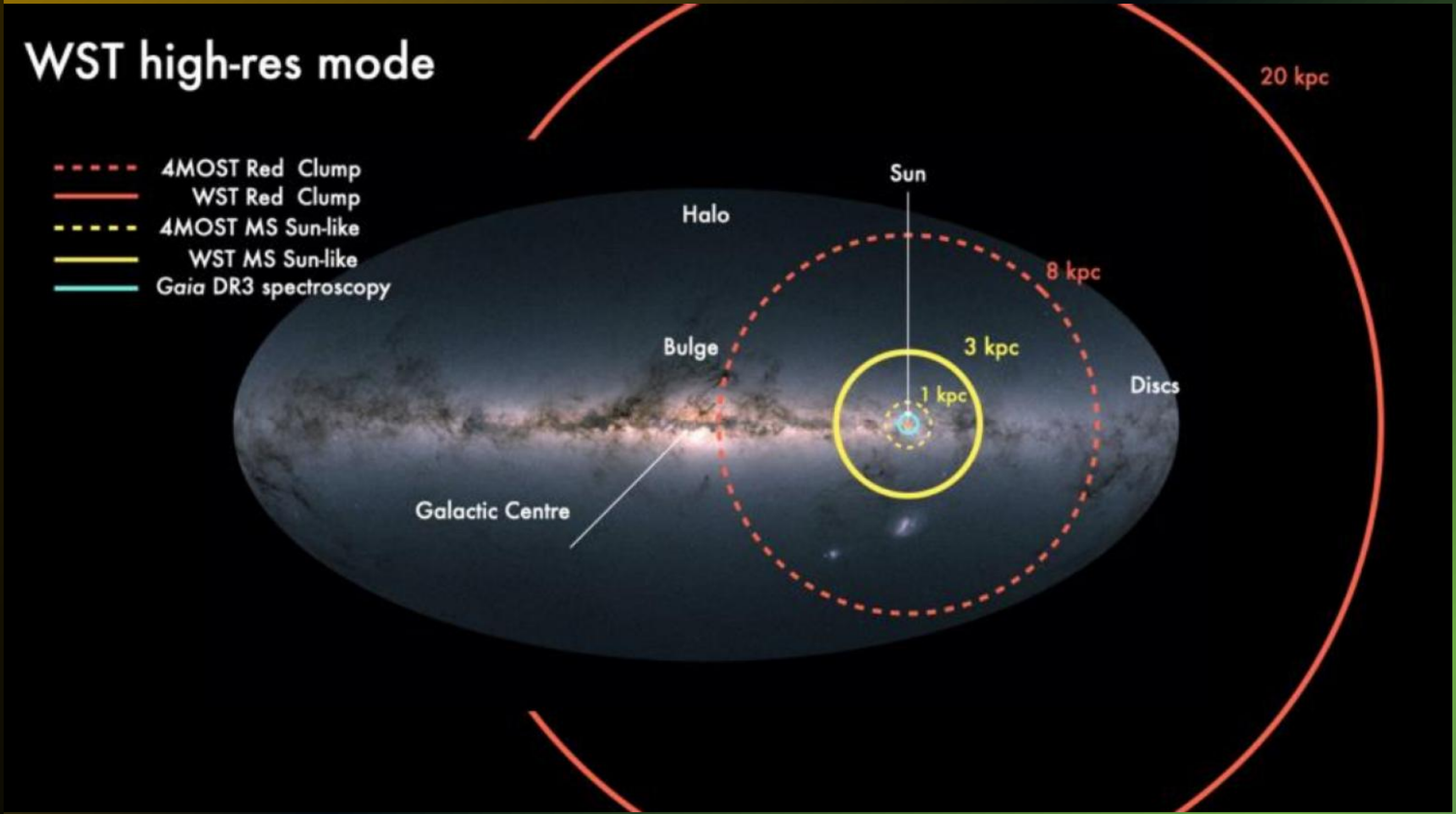
Gaia-ESO *(Gilmore+2012)*
4MOST-4SYS *(P.I. Sacco)*
GALEX Nearby Young Star Search *(Nagananda+2024)*
WEAVE/SCIP *(P.I. Drew)*
Stellar Clusters in 4MOST *(P.I. Lucatello)*
ULYSSES *(Roman-Duval, J. et al. 2020)*
PENELLOPE *(P.I. Manara)*
ODYSSEUS *(Espaillat+2022)*

Nearby young clusters are typically low- to intermediate mass, and provide a limited view of the Galaxy

Two reasons to observe distant star forming regions:

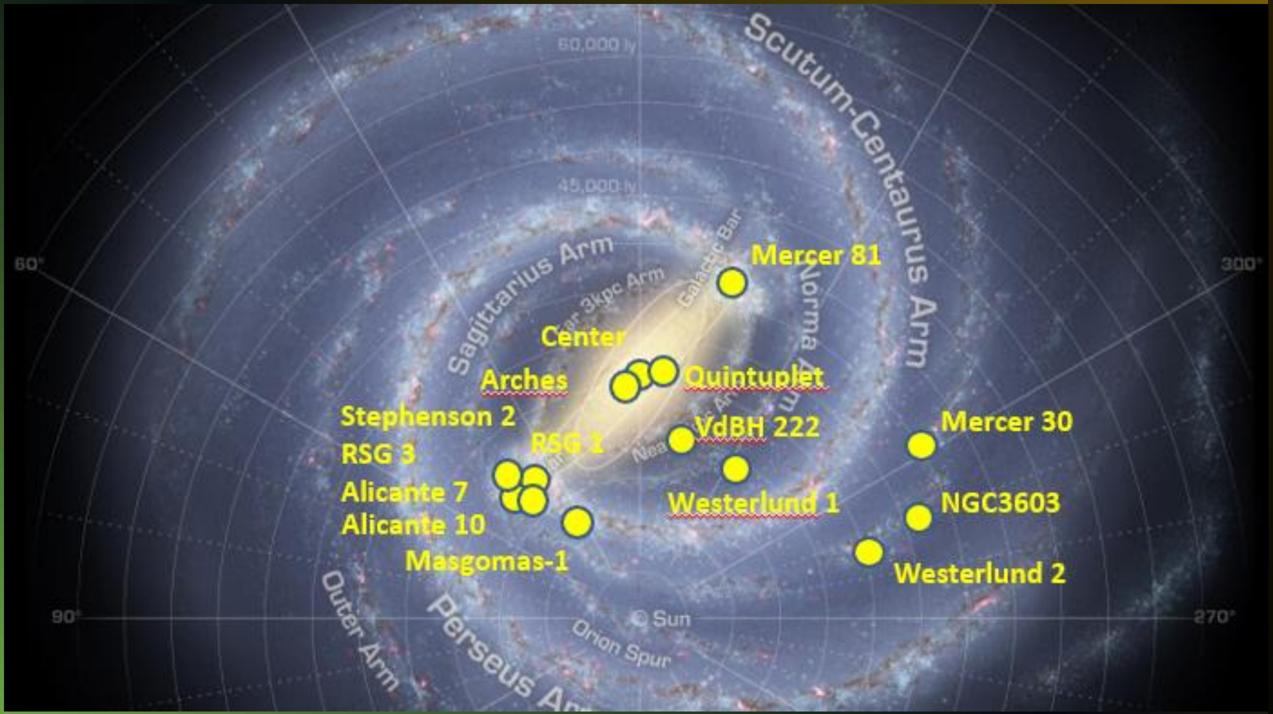
YSOs in massive star forming environment

Galaxy structure through young stars in clusters, associations, strings



Area solar-type stars can be observed in HR with WST and 4MOST, plus the region where Gaia DR3 spectroscopy is available

(WST Science White Paper)



Westerlund 1

Carina Nebula

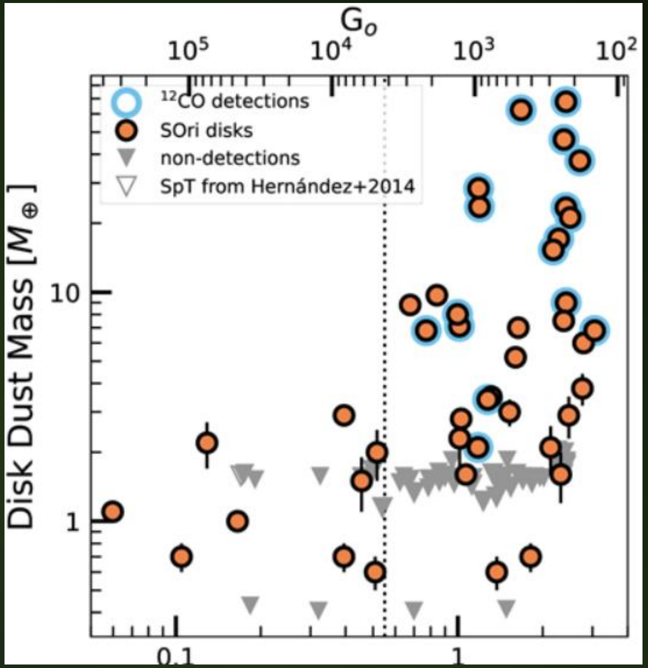
Very massive $(>10^4\,M_\odot)$ young clusters are more distant than 2 kpc (one exception: CygOB2)

Their environment is dominated by massive stars, large stellar density, and relativistic particles

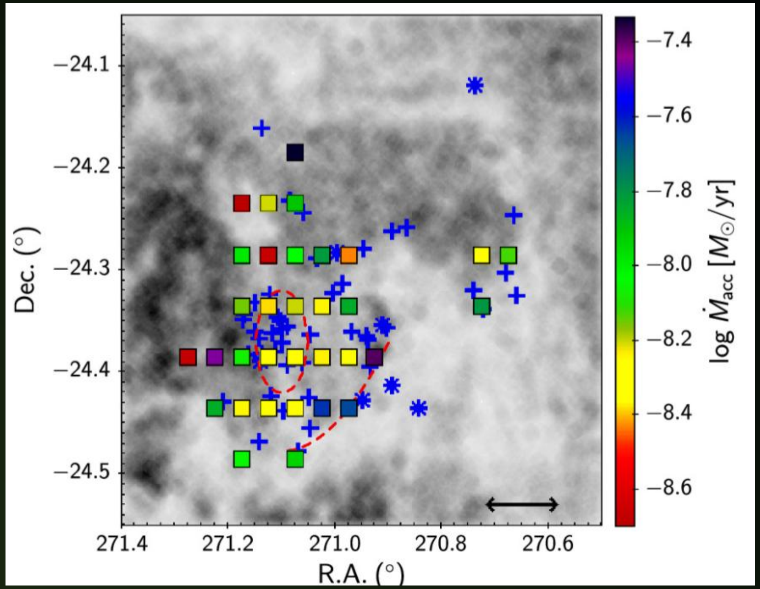
Such an environment affects star formation products and discs evolution, dispersal and properties.

Accretion, outflows, stellar properties (IMF) are needed to test star formation and disc dispersal in massive environment

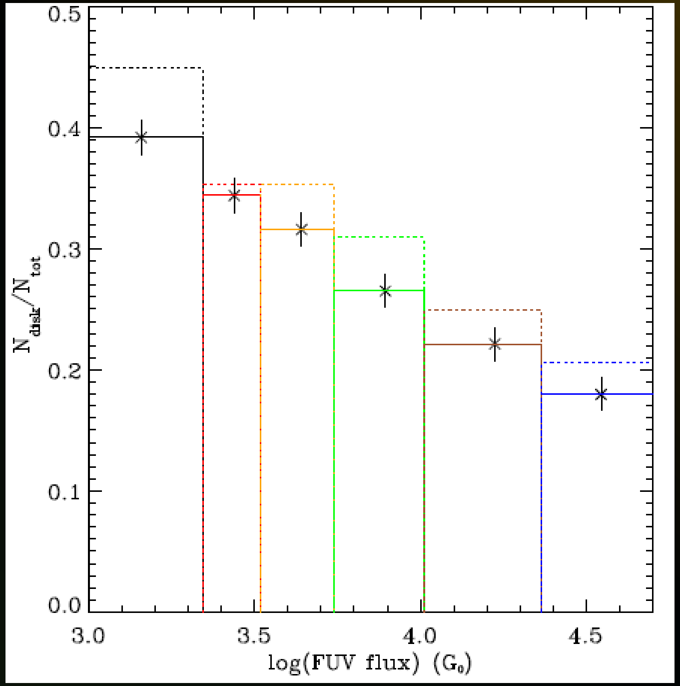
With a few exceptions, our knowledge on impact on disc properties by the environment comes from nearby, intermediate massive regions, where some disc properties is observed to depend on the local environment.



Disc mass vs. local G_0 in σ Orionis (Mauco+2023).



Average accretion rates across the Lagoon Nebula (Venuti+2024)



Decline of the fraction of stars with discs in CygOB2 as a function of local UV flux (Guarcello+2023)

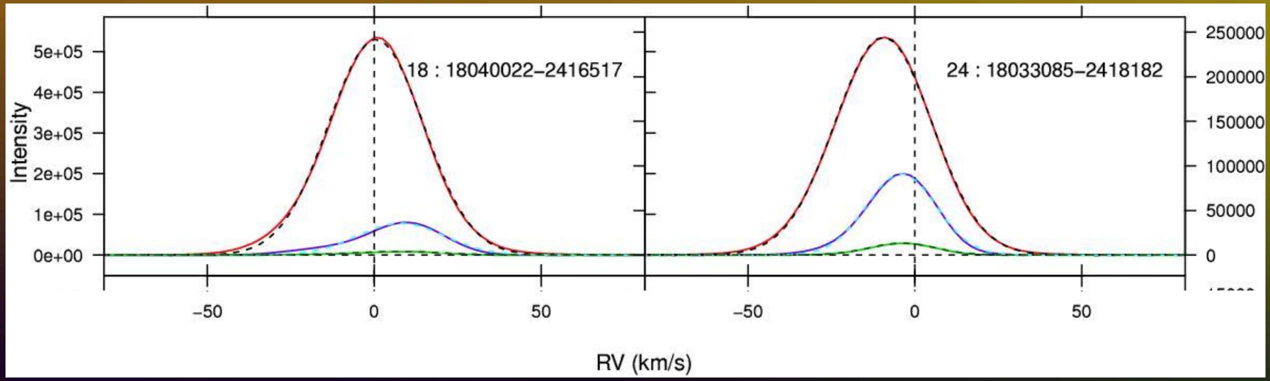
One complication: nebular lines!

Very young clusters host a complex and dense nebula, often dissociated or ionized.

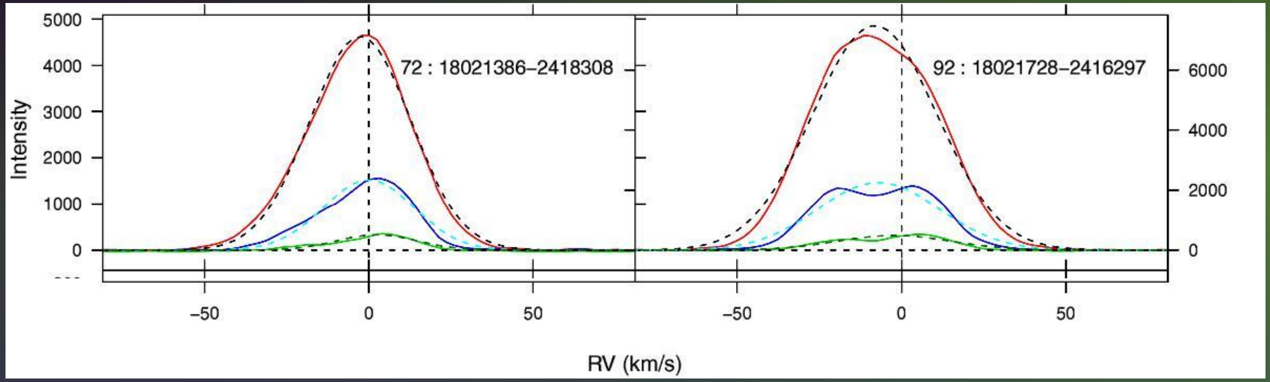
The nebulosity spectrum is characterized by emission lines coincident with important stellar diagnostics.

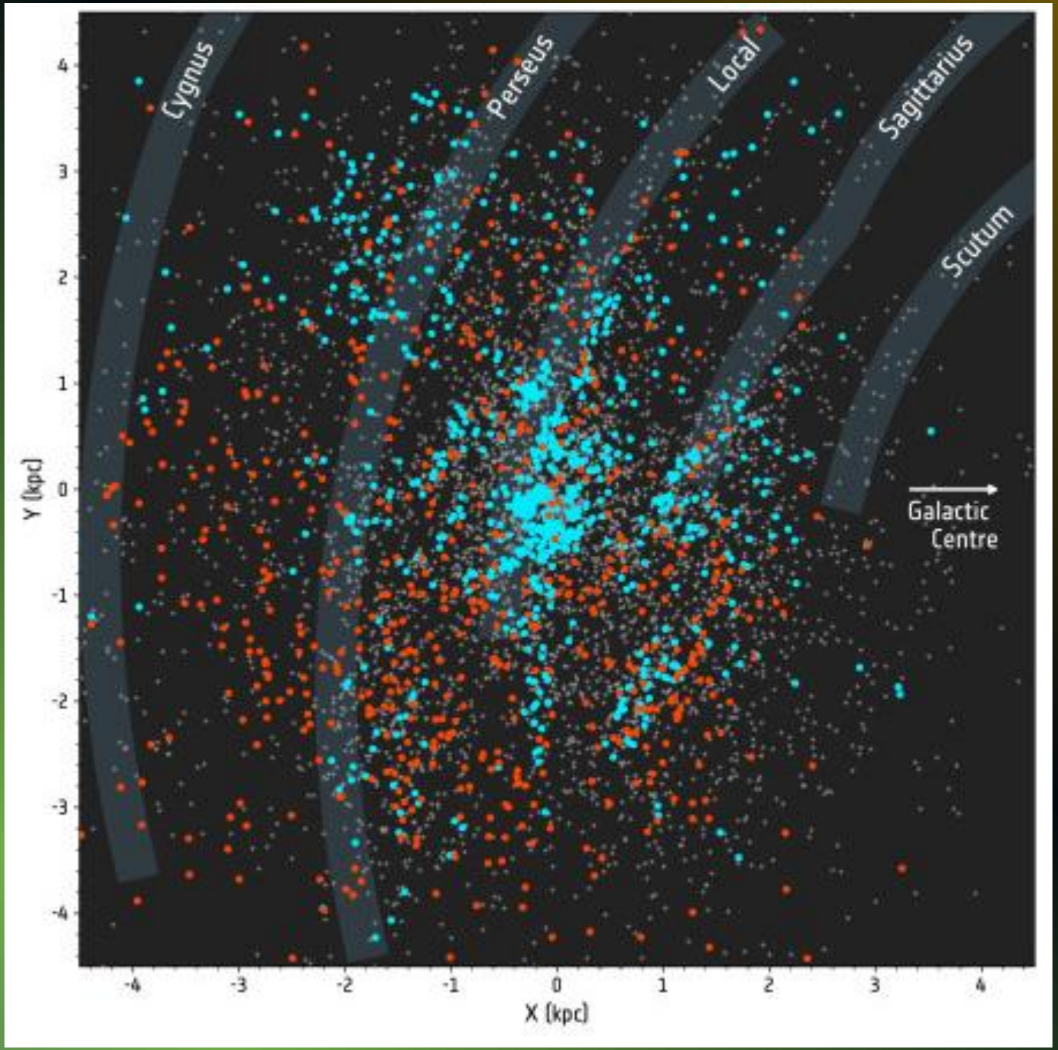
Such signal must be removed. How?
No universal solution exists yet…

… but having a large number of nebular spectra available helps a lot (and also provides a lot of science)



NGC6530, nebular line profiles of Hα (red), [N II]6584 (blue), [S II] 6731 (green) from FLAMES. Lines are intense, asymmetric, blue- or red-shifted and even double-picked (Damiani+2017)





Distribution of clusters < 30 Myrs (cyan) and > 800 Myrs (red) from Hunt and Reffert (2023). Galaxy model from Reid+2019

Gaia has improved our knowledge of the Galactic structure also thanks to clusters demographic.

It is crucially important to extend the selection of clusters members at large distances.

Spectroscopic surveys are powerful to confirm membership, also in the extended clusters halo, and determine stellar properties.

Needed: high sensitivity and large FoV.

VS.

Star formation occurs mainly in clusters (e.g. Lada & Lada 2003)

Star formation occurs across the whole spectrum of stellar density (Kruijssen+2012).

Selection and study of YSOs on a kpc-scale volume needed.
Not only in clusters (and their coronae, Meingast+2021) but also in:

Associations (remnant of dense clusters or born with low density? *Wright+2014*)

Strings (are they real? *Kounkel & Covey (2019), Manea+2022*)

Diffuse field

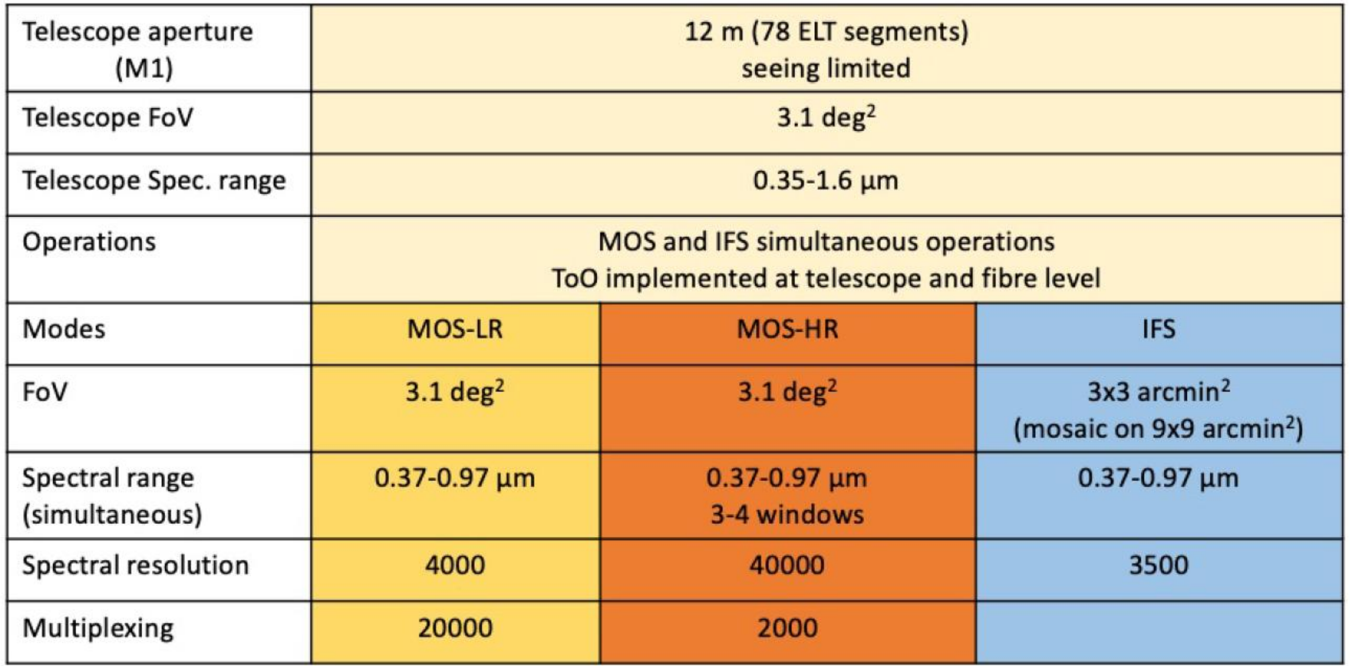
CONCLUSIONS

1) Pre-main sequence stars are very complex objects – high R, high FoV, high sensitivity is crucial to fully understand the complex interplay between infall, outflow, disc and stellar properties and environment feedback.

2) A few very massive star forming environment similar to starbursts exist in the Milky Way at large distance, Av, and crowding. WST will allow us to unveil their populations

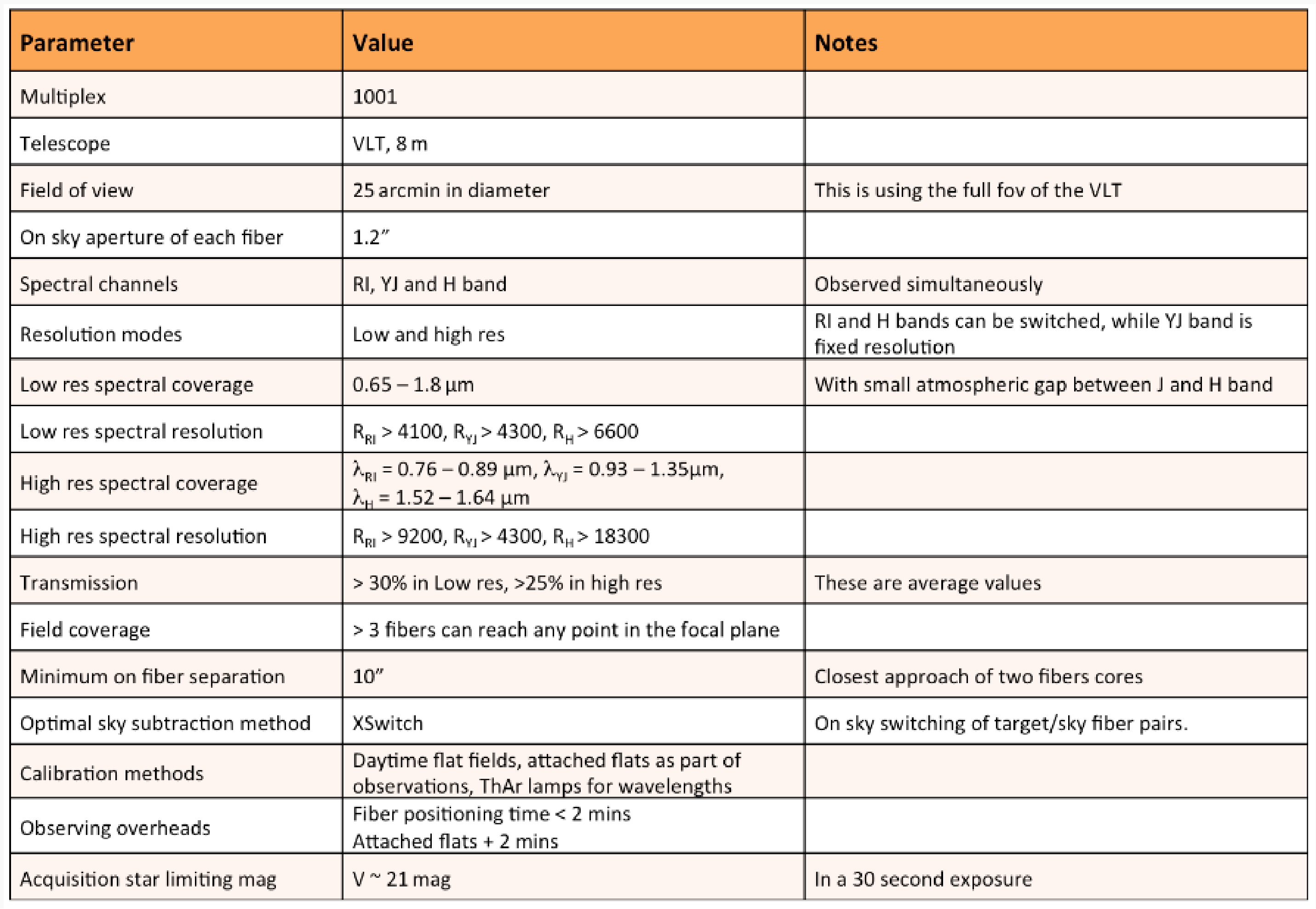
3) The demographic of young clusters unveils the structure of the Milky Way. We need to push the horyzon at further distances

12m Telescope; MOS FoV 2degrees diameter; IFS 9x9 arcmin; MOS and IFS operate simultaneously
Spectral range 0.35-1.6 micron; Southern Emisphere



Telescope aperture (M1)	12 m (78 ELT segments) seeing limited		
Telescope FoV	3.1 deg^2		
Telescope Spec. range	0.35-1.6 μm		
Operations	MOS and IFS simultaneous operations ToO implemented at telescope and fibre level		
Modes	MOS-LR	MOS-HR	IFS
FoV	3.1 deg^2	3.1 deg^2	3x3 arcmin^2 (mosaic on 9x9 arcmin^2)
Spectral range (simultaneous)	0.37-0.97 μm	0.37-0.97 μm 3-4 windows	0.37-0.97 μm
Spectral resolution	4000	40000	3500
Multiplexing	20000	2000	

At low spectral resolution, WST will provide a S/N per Angstrom of three down to magnitude 24.5 (MOS) and 25.2 (IFS) in one hour exposure (point sources, AB magnitudes, 0.7 arcsec seeing, airmass 1.0) over ≈ 90% of the wavelength range. At high spectral resolution WST will obtain a S/N per Angstrom of 30 (100) down to magnitude 19.4 (17.8) in one hour exposure (point sources, AB magnitudes, 0.7 arcsec seeing, airmass 1.0) in the selected wavelength windows.



Parameter	Value	Notes
Multiplex	1001	
Telescope	VLT, 8 m	
Field of view	25 arcmin in diameter	This is using the full fov of the VLT
On sky aperture of each fiber	1.2″	
Spectral channels	RI, YJ and H band	Observed simultaneously
Resolution modes	Low and high res	RI and H bands can be switched, while YJ band is fixed resolution
Low res spectral coverage	0.65 – 1.8 µm	With small atmospheric gap between J and H band
Low res spectral resolution	$R_{RI} > 4100$, $R_{YJ} > 4300$, $R_{H} > 6600$	
High res spectral coverage	$\lambda_{RI} = 0.76 – 0.89$ µm, $\lambda_{YJ} = 0.93 – 1.35$µm, $\lambda_{H} = 1.52 – 1.64$ µm	
High res spectral resolution	$R_{RI} > 9200$, $R_{YJ} > 4300$, $R_{H} > 18300$	
Transmission	> 30% in Low res, >25% in high res	These are average values
Field coverage	> 3 fibers can reach any point in the focal plane	
Minimum on fiber separation	10″	Closest approach of two fibers cores
Optimal sky subtraction method	XSwitch	On sky switching of target/sky fiber pairs.
Calibration methods	Daytime flat fields, attached flats as part of observations, ThAr lamps for wavelengths	
Observing overheads	Fiber positioning time < 2 mins Attached flats + 2 mins	
Acquisition star limiting mag	V ~ 21 mag	In a 30 second exposure