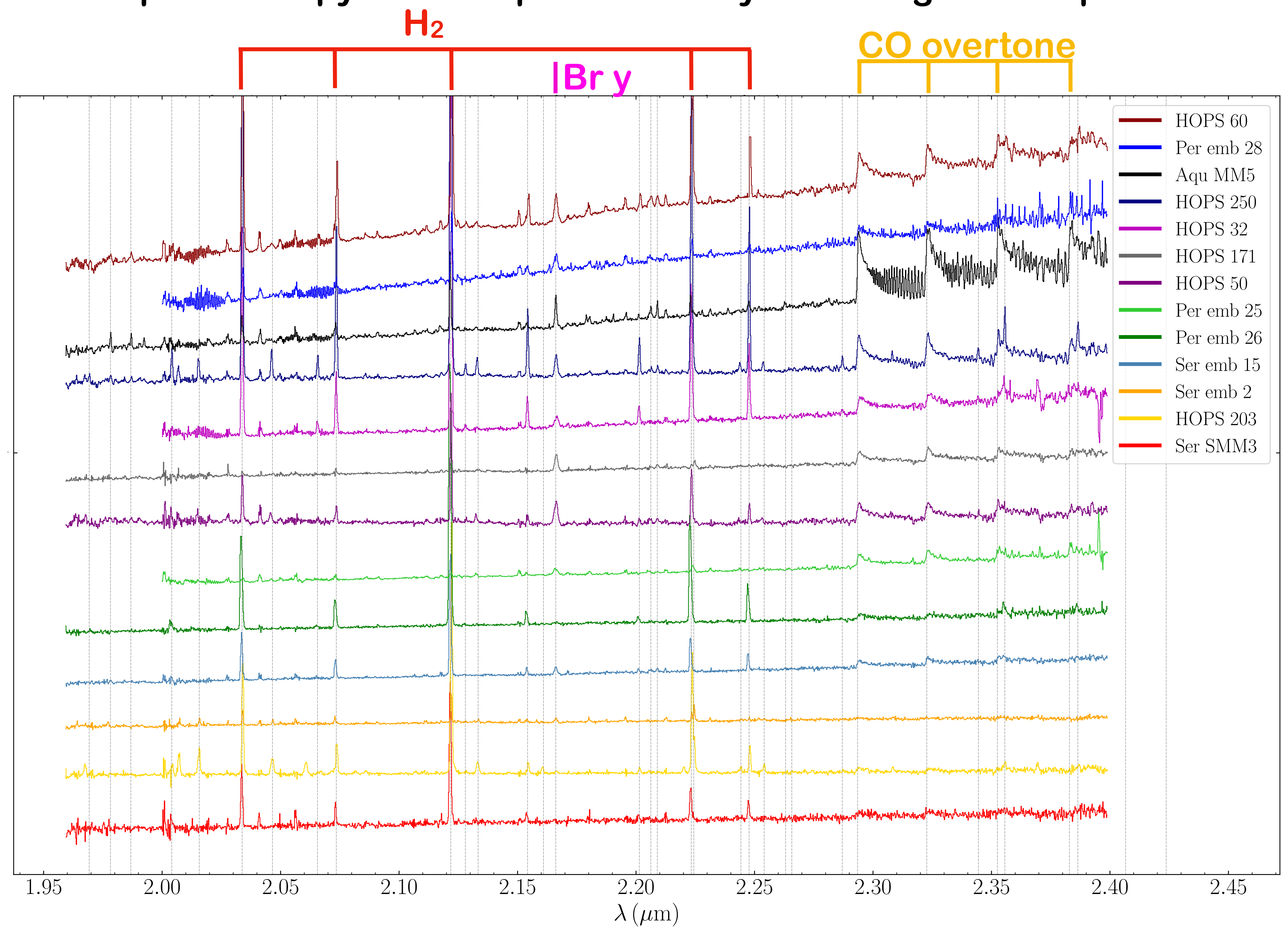
The accretion/ejection properties of Class 0 protostars studied with NIR spectroscopy

Exploring the new observations of SMM3

Valentin J. M. Le Gouellec (ICE-CSIC), Tom P. Greene (IPAC), Lynne A. Hillenbrand (Caltech), Doug Johnstone (NRC Herzberg), Antoine Gusdorf (LPENS), and JWST 1186 GTO team

Sun-like stars acquire most of their mass during the embedded Class 0 phase, when accretion and outflow activity are at their peak. Direct probes of these processes are challenging because key near-infrared (NIR) diagnostics are heavily obscured by the surrounding envelope. However, scattered NIR light escaping through outflow cavities can reveal the immediate circumstellar environment. Here we present new Serpens SMM3 observations obtained with the James Webb Space Telescope NIRSpec integral-field spectrograph. We detect numerous H I, H_2, and CO ro-vibrational lines that trace accretion, shocks, and outflow activity. H_2 emission probes the jet and wind structure, while CO fundamental emission originates near the base of the outflow. CO overtone emission traces the dense inner disk, and CO absorption features provide a rare glimpse of the protostellar photosphere. The observed line luminosities indicate vigorous accretion, consistent with the earliest stages of star formation. These data demonstrate the unique capability of JWST/NIRSpec to simultaneously probe inner disk conditions, accretion energetics, and jet/wind properties, providing new constraints on the processes that regulate stellar mass assembly in deeply embedded protostars.

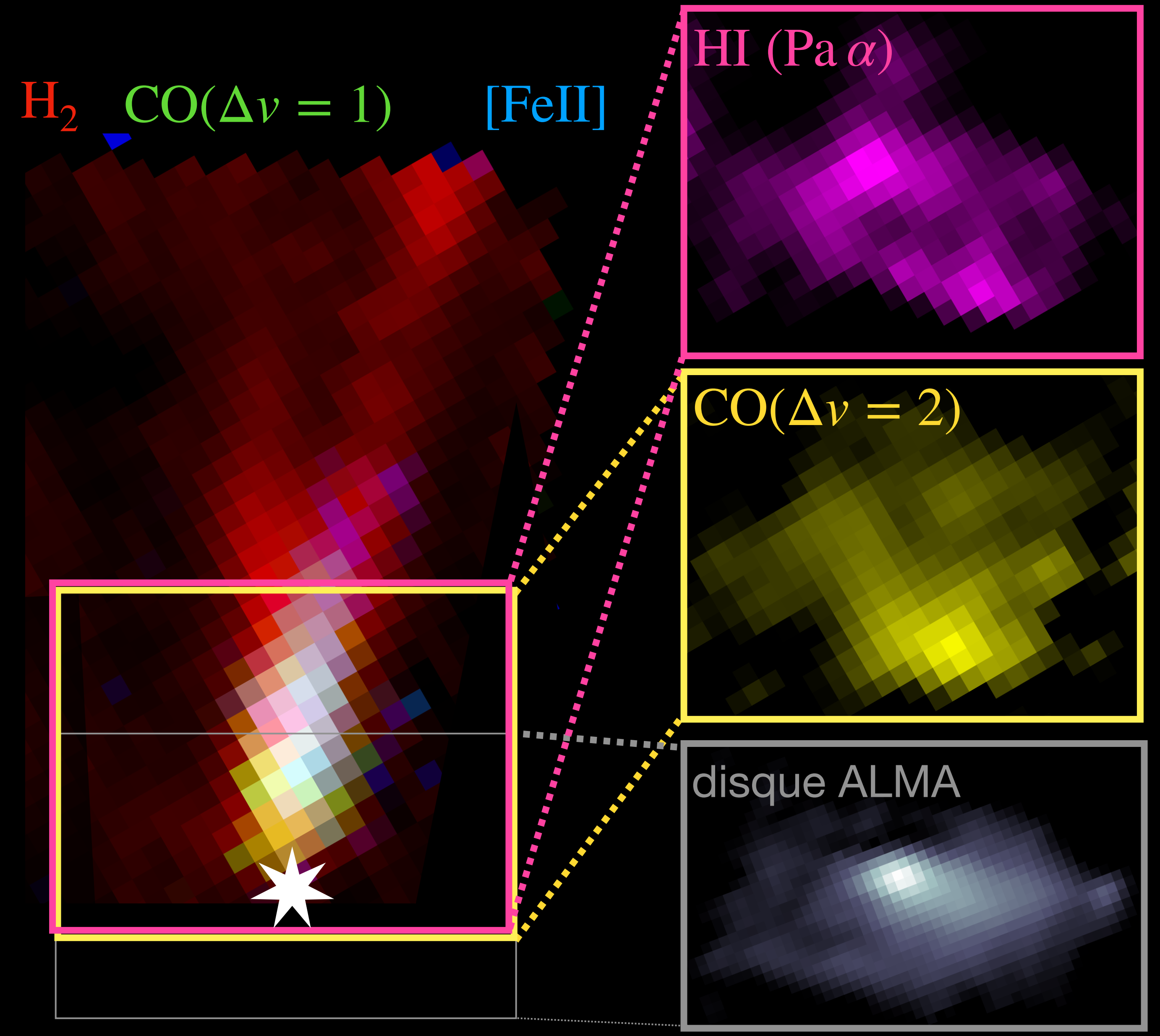
Near-IR spectroscopy of a sample of actively accreting Class 0 protostars



[Left Figure] The accretion properties of Class 0 protostars can be studied with Near-IR spectroscopy. This study gathers the largest sample of Class 0 mid spectral resolution (R~3000) K-band observations. We find that **several spectral features seem to be prototypical of the youngest protostars** (Greene et al. 2018, Laos et al. 2021, Le Gouellec et al. 2024). The CO overtone emission is much more abundant in Class 0s compared to Class Is. Such emission is typical of episodes of high accretion rate, such as EXors-type objects (e.g., Lorenzetti et al. 2009, Aspin et al. 2010, Kóspál et al. 2011), where enhanced UV photons emitted by the accreted material can heat the inner disk producing both the CO in emission and high IR veiling. This suggests Class 0s accrete via **more frequent episodes of high accretion activity** than the more-evolved Class I protostars.

HI, CO overtone, and H_2 emission lines are also statistically more luminous in the Class 0 than in the Class I stage, suggesting the mass accretion/ejection is on average more vigorous in the Class 0 stage. More accurate determination of the extinction law/value and of the contribution from scattered light will enable to further quantify this statement.

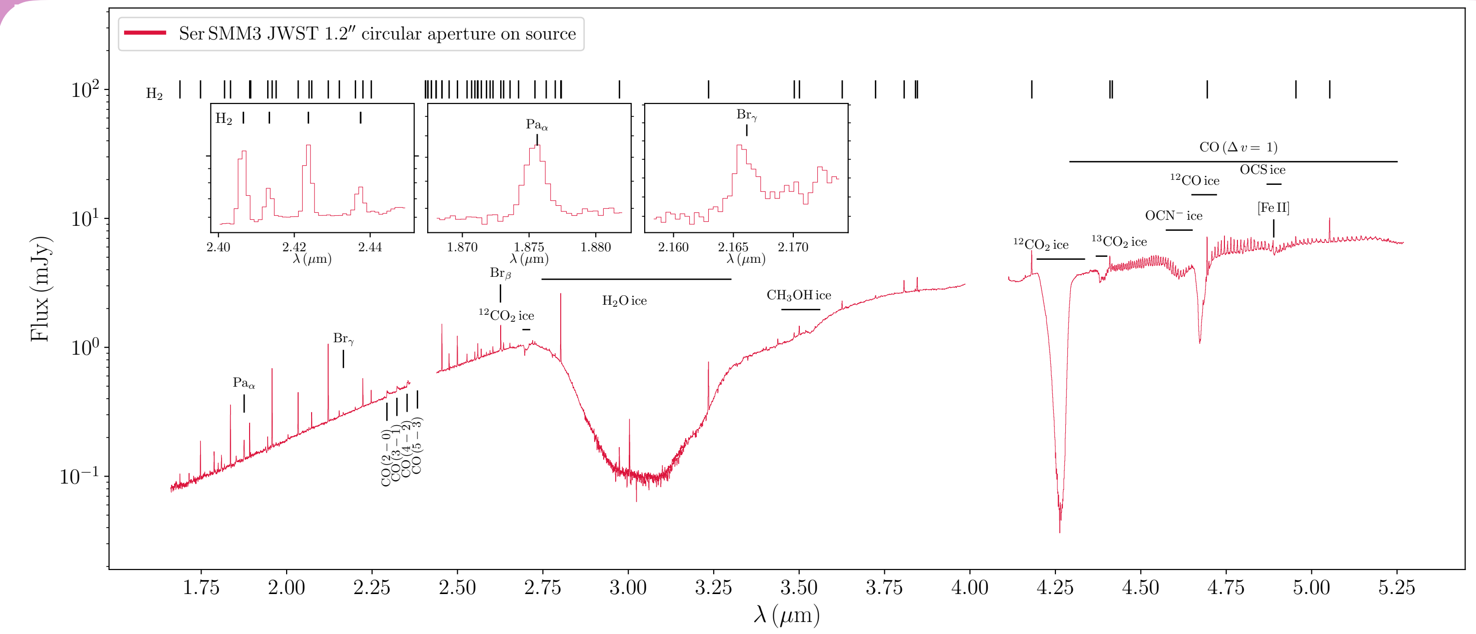
NIRSpec-ALMA view of the SMM3 Class 0



Constraining both the accretion and ejection properties through scattered light radiative transfer modeling, resolving the mm disk, measurement of the NIR accretion and ejection tracers emission lines

References

Lorenzetti et al. 2009, ApJ 693:1056-1073
Aspin et al. 2010, ApJ 719:L50-L55
Kóspál et al. 2011, ApJ 736:72
Greene et al. 2018, ApJ 862:85
Laos et al. 2021, ApJ 921:110
Lee et al. 2021, A&A 648,A101
Poorta et al. 2023, A&A 676, A122
Ahmad et al. 2024, A&A 687, A90
Le Gouellec et al. 2024, ApJ 966:91
Le Gouellec et al. 2025a, ApJ 985:225
Le Gouellec et al. 2026, submitted



[Top Figure] JWST 1.8 — 5.5 microns NIRSpec extracted spectrum of the Class 0 protostar Serpens SMM3 (Le Gouellec et al 2025b). Several features related to the accretion activity (CO overtone bands, HI recombination lines), ejection activity (H_2, FeII, CO fundamental), hot inner disk (thermal continuum), and the cold foreground envelope (H_2O, CO, CO_2 absorption bands) are observed. Le Gouellec et al 2025a presents **how these observables can be used to constrain the mass accretion/ejection rate of such embedded protostars.** The shocks propagating in cavities can be modeled to infer the energetics of the ejecta, and the inner disk temperature can be analyzed to constrain the accreting-induced heating.

[Bottom Figure] JWST NIRSpec IFU analysis of the emission lines tracing the high velocity jet: H_2, CO fundamental ($\Delta v = 1$), and FeII. Their line of sight velocity with respect to the driving source is shown on the left. On the right are presented the energetics (mass ejection rate) of the mediums traced by each of these jet tracer, as well as the cold entrained outflow traced with ALMA with CO rotational lines.