ALMA Studies of Eruptive Stars

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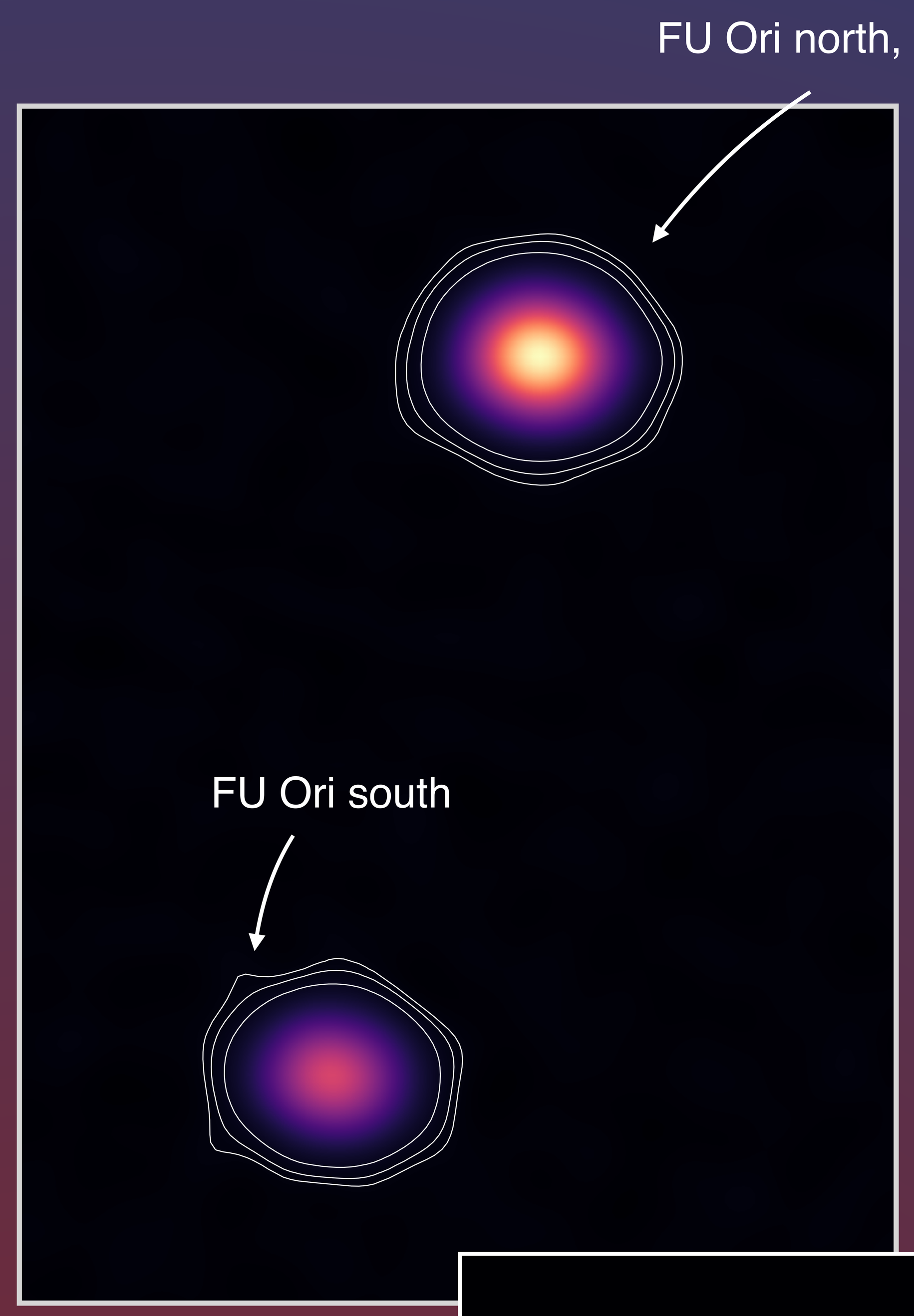
1. Eruptive stars and episodic accretion in star and planet formation

ALMA opened a new regime for studying episodic accretion in FU/EX Ori objects. Despite becoming highly popular in the last 15 years we are still trying to understand episodic accretion, a process relevant to the formation of low-mass stars, binaries, and planets.

Gravitational and thermal instabilities, disk fragmentation, forming planets and stellar encounters are some of the different proposed triggering mechanisms for the outbursts. From recent ALMA and eVLA results (e.g. Cieza et al. 2016, Hales et al. 2018, Liu et al. 2019), it is becoming clear that the highest resolutions are needed to image the very compact disks that surround these objects, and map the instabilities that might be driving the activity. By imaging the inner regions we can fit the temperatures and masses to estimate Toomre's Q and check for the conditions to drive instabilities.

Here we show our attempts to understand these disks with today's ALMA capabilities, but very high resolution imaging at lower frequencies (ALMA Band 1 and the next generation VLA, or ngVLA) will allow to measure and correct for non-thermal contribution from the disk winds, which is crucial for estimating the disk temperatures in the optically thick bands.



2. Probing triggering scenarios

FU Orionis s a known binary composed of two disks resolved by the first time in our ALMA 1.3 mm observations (Pérez et al. 2020; figure on the left).

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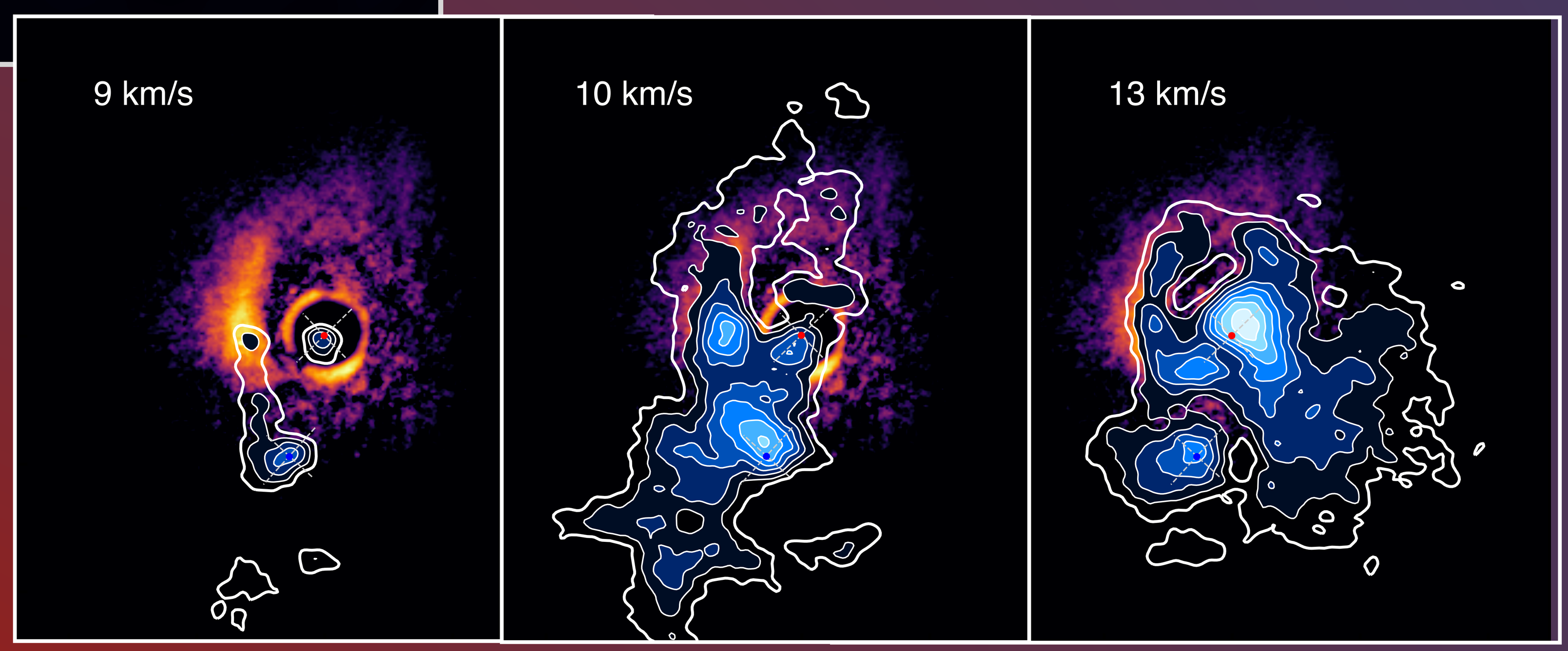
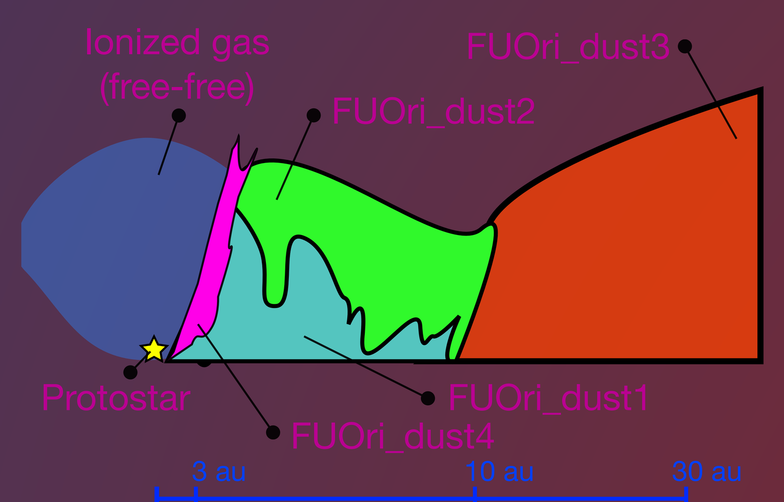
Complex kinematics with CO gas possibly connecting the two disks might support a binary interaction scenario to explain FU Orionis (Pérez et al. 2020, figure below).



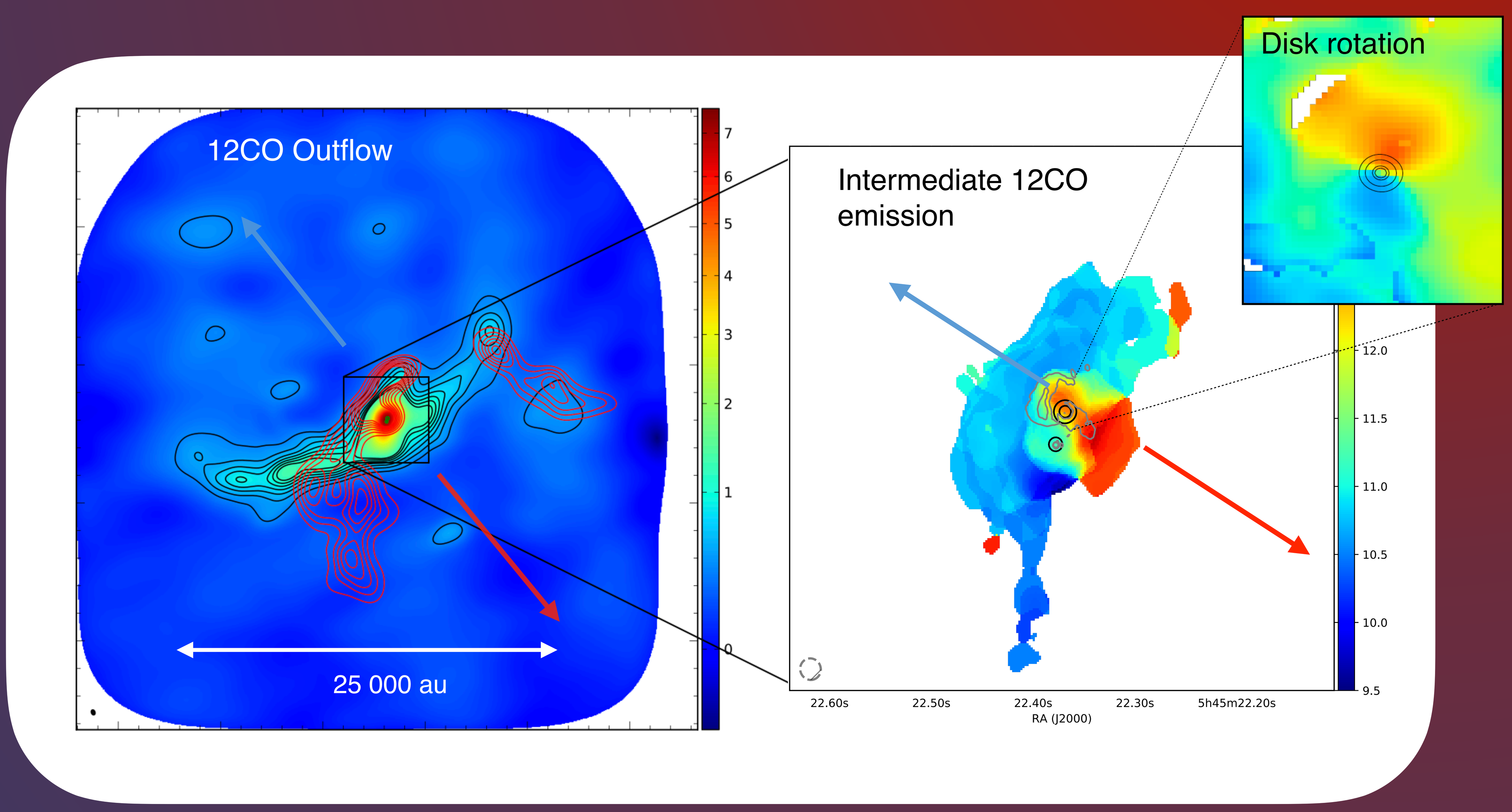
3. The Big Picture of the FU Ori system

3.1 The disk



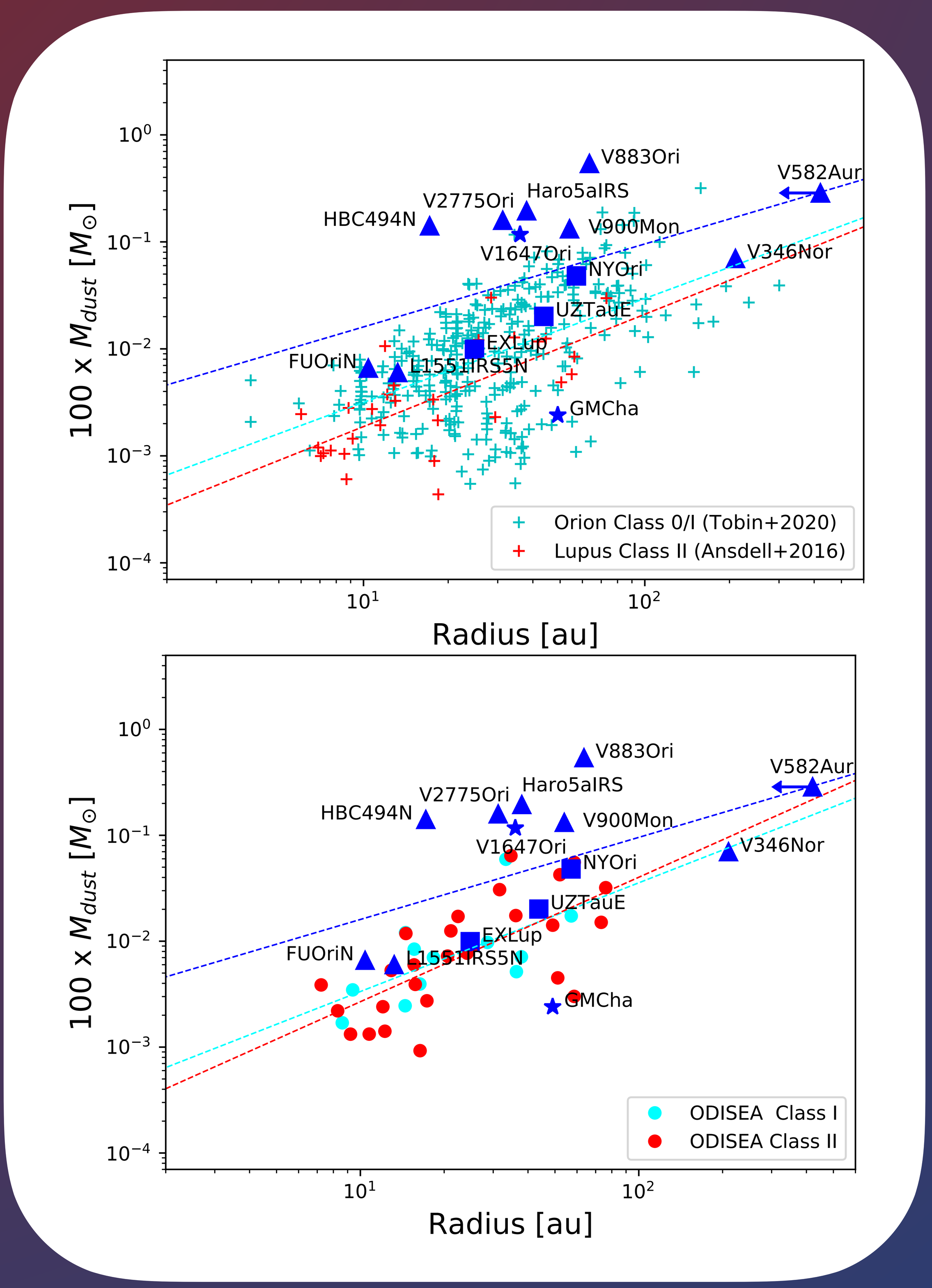
Multi-wavelength observations (VLA, ALMA, VLTI) suggested a disk with an inverted temperature profile (Liu+2019) consistent with viscous dissipation in a 10^{-4} M$_\odot$ yr^{-1} accretion disk (Zhu+2009).

3.2 Large scale outflows in FU Orionis



Prominent outlfows are detected for the first time about the class prototype FU Ori (Hales et al, in prep). Intermediate 12CO emission shows complex kinematics but we do resolve rotation around the primary (top right inset, Pérez et al. 2020).

4. Dust disk masses in FU/EX or sources



Relationship between disk mass and disk radius for FUor/EXor sources from Hales et al. (2020) and the literature. Squares are EXors, triangles are FUors, and objects with double FUor and EXor classification are marked with a star symbol. The disk size and mass for HBC494 correspond to the ones measured towards the brightest component of the binary, HBC494 North (Nogueira et al., in prep).
Top panel: Light blue crosses show the disk masses and radii for Class 0 and I protostellar disk candidates in Orion derived from 0.87 mm ALMA observations Tobin et al (2020). Red crosses show the disk masses and disk radii for Class II sources in Lupus from Ansdell et al (2016). The dashed lines correspond to power law fits to the Class 0/I, Class II and FU/EXor data respectively.
Bottom panel: Same as left panel, but now comparing the FU/EXor data to Class I and Class II sources in Ophiuchus from the ODISEA sample Cieza+2019.

Also watch contributed talks by Kóspál and Wendeborn!

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References:
Ansdell et al. 2016, ApJ, 826, 46
Cieza et al. 2016, Nature, 535,258
Cieza et al. 2019, MNRAS, 483, 4114
Hales et al. 2018, ApJ, 859, 111
Hales et al. 2020, ApJ, 900, 7H
Kóspál et al., 2017, ApJ, 843, 45
Kóspál 2018, ESO Conf. Proceedings
Liu et al. 2019, ApJ, 884, 97
Pérez et al. 2020, ApJ, 889, 59
Segura-Cox et al., 2018, ApJ, 866, 161S
Sheehan et al. 2019, ApJ, 874, 136
Tobin et al. 2020, ApJ, 890, 130T
Takami et al. 2019, ApJ, 884, 146