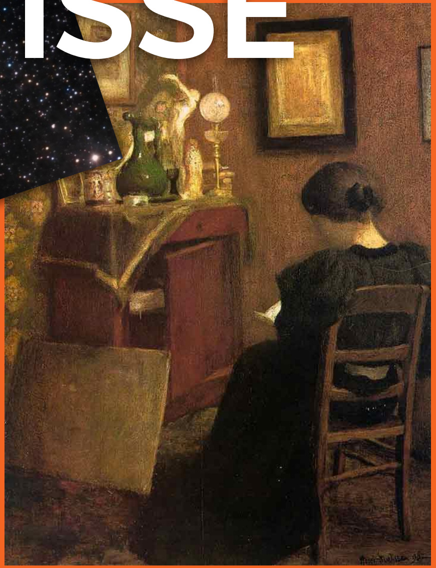
KONKOLY
CSFK
HUN-REN
Hungarian Research Network

Young eruptive stars with MATISSE

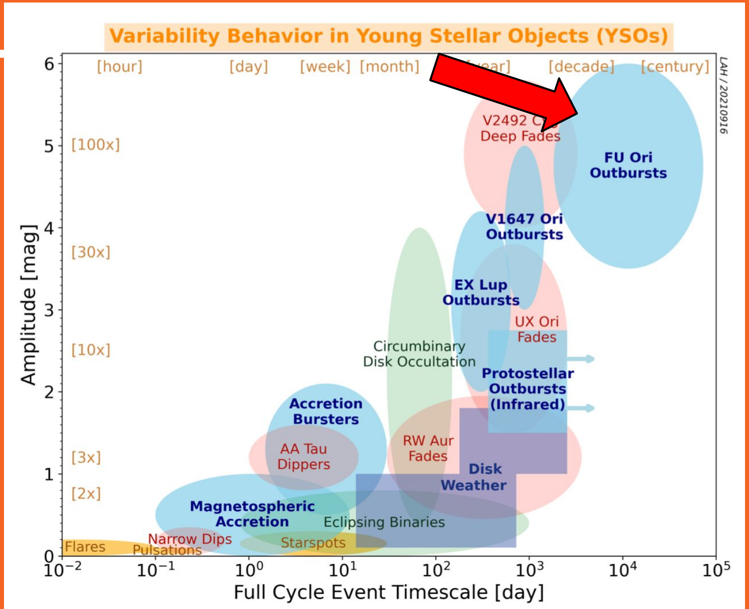


Foteini (Claire) Lykou
Konkoly Observatory CSFK

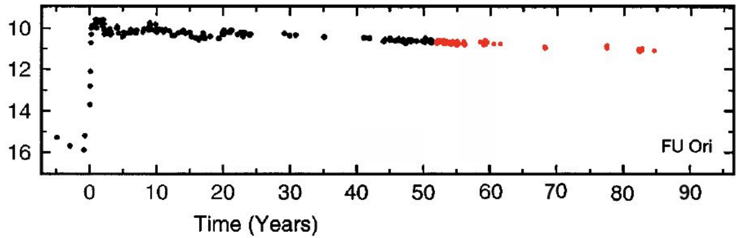
MATISSE Meeting, OCA Nice, 7 November 2024

Eruptive stars



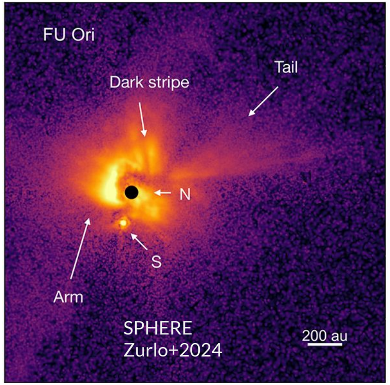
- What causes those eruptions?
  - (sub)stellar companion flyby?
  - Cloudlet capture, streamer collision?
  - Viscous-thermal instability?
  - Gravitational or magneto-rotational instability?
  - Planet ingestion?
- Do all low/intermediate mass stars pass through eruptive phases, and is it part of the evolutionary sequence?
- How do outbursts affect structure, mineralogy, and chemistry in the protoplanetary disks? ($\dot{M}_{acc}$~ 10^{-8} -> 10^{-4} M_{sun}/yr)
- FUor-outbursts can pile as much as 10 Mjup on the protostar; are their disks large and massive?
- Need interferometry to test all these at small spatial scales (<= 10 au)

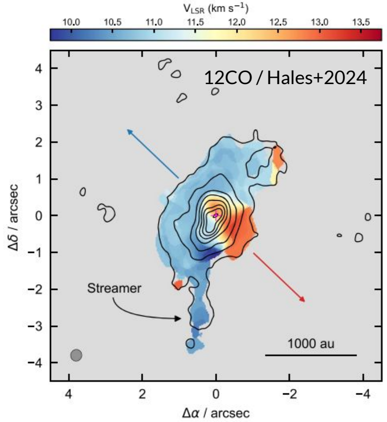
FU Orionis

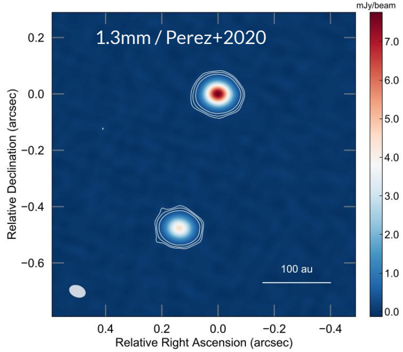


- Archetype of its class!
- Has not returned to quiescence since 1936 outburst.
  - Slowly fading in all bands including the N-band.
- NIR interferometry suggests the *inner disk region is shrinking* (*r<0.15 au*; Bourdarot+2023).
- Binary system (FU Ori N) with complex circumbinary environment (polarimetric imaging, Takami+2008). ALMA continuum suggests two disks are coeval (Perez+2020).
- Large-scale bipolar outflow (CO), and a potential streamer from ALMA (Hales+2024).

Jim Thommes







FU Orionis

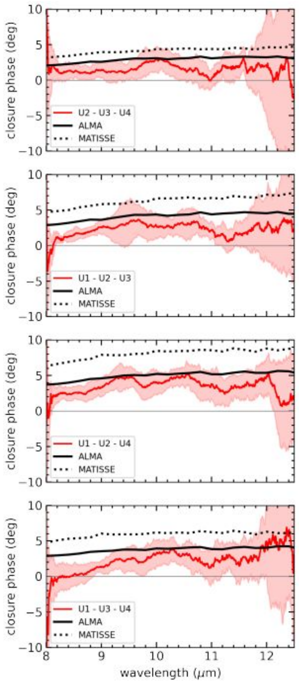
- Has the geometry of the disk changed? *Misalignment*?
- Has there been any *change in the SED and/or accretion rate*?
- Material from the streamer? *Tertiary companion*?
- Do we see any changes in the *disk's inner radius*? (at ~402pc, 10au~25mas)

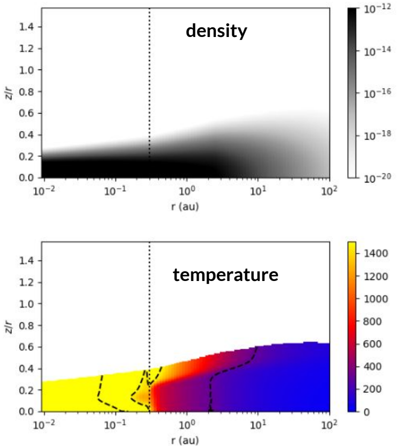
Reference	Instrument	Band	Incl.(°)	P.A. (°)
Malbet+2005	PTI, IOTA, VINCI	H+K	55	47
Quanz+2006	**MIDI**	N	55	~19?
Liu+2017	VLA	33GHz	34	~8?
Perez+2020	**ALMA**	1.3mm	38	44
Labdon+2021	CHARA, VLTI	J,H,K	32	34
Bourdarot+2023	PIONIER, GRAVITY	H,K	33	~55

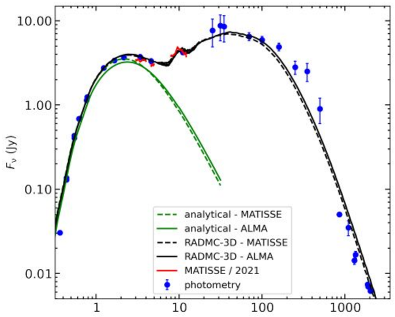
- MATISSE GTO snapshot observations as a testbed
- 5 epochs 2019-2021 (UTs, ATs (medium+large), GRA4MAT // R=30,230)
- Not all good as it's quite faint and small!
- 1 publication (Lykou+2022, A&A)

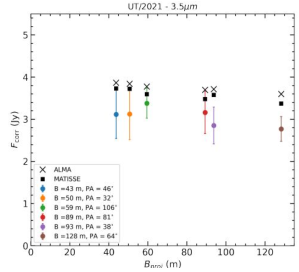
FU Orionis

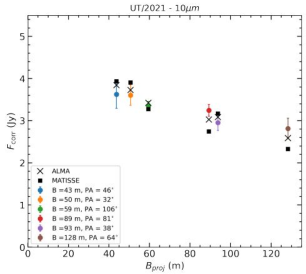
- Geometric models:
  - FWHM < 2 mas (L) and ≤ 5 mas (N)
  - N-band P.A.~15° and inclination ~55° (but large uncertainties)
- Complex model:
  - Analytical model of steady-state accretion disk
  - New photometry
  - Two model geometries MATISSE vs. ALMA (Perez+2020)
  - Feed into RADMC-3D RT of hot inner disk and passive dusty disk (flared).
  - Silicate (bulk) and carbonaceous mixture
- $\dot{M}_{acc}$ ~ 2 x 10^{-5} M_{sun}/yr
- ALMA orientation is favoured!
- MIR-emitting region smaller than expected (r~0.3 au) now comparable to recent studies (Bourdarot+2023)





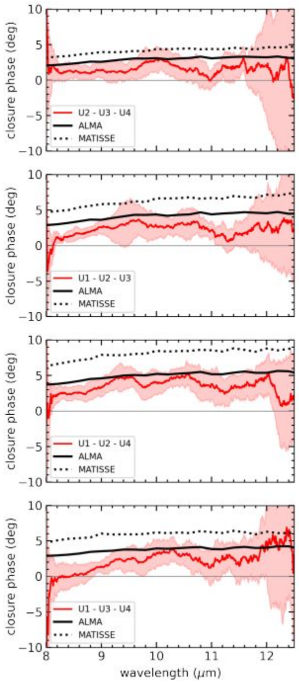


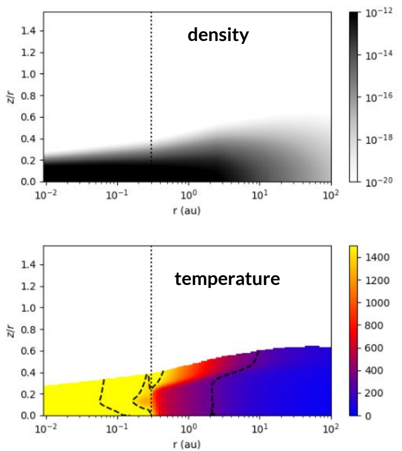


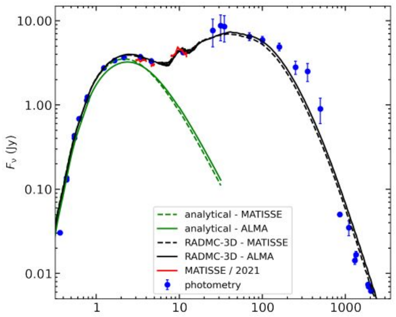


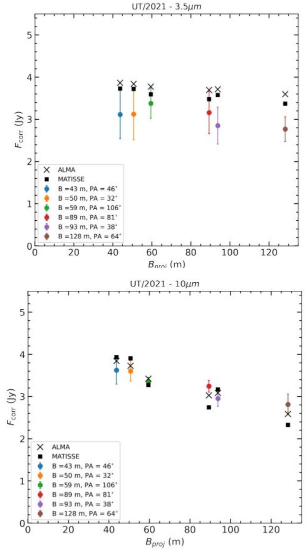
FU Orionis

- Dust mineralogy
  - No radial variation
  - No differences (flux,shape) since MIDI 2004
  - No signatures of crystalline silicates
  - Large-sized (=>1µm) silicate amorphous grains
- Tertiary companion, streamer
  - FU Ori S, outside UTs FOV
  - No hints of a dusty component from a streamer
  - N-band data insufficient to constrain tertiary companion
  - L-band data exclude a companion inside 20-100 mas at flux ratio >5%.

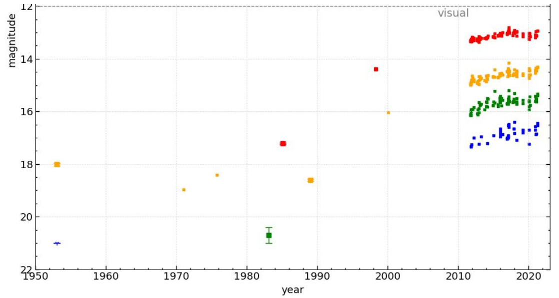




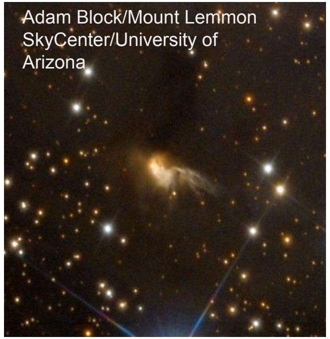


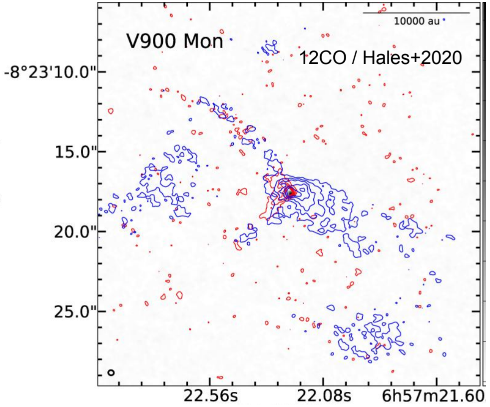


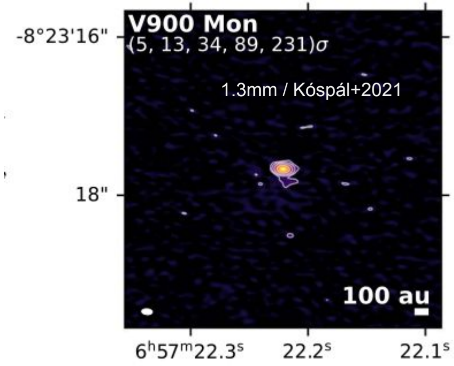
V900 Mon

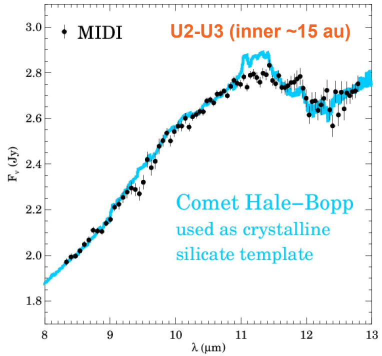


- Reflection nebula discovered by amateur astronomer (Jim Thommes).
- Eruption sometime in the 1990s
- FUor-type spectra (Reipurth+2012); high CS+IS extinction (Av=13 mag)
- ALMA suggests (Takami+2018,Hales+2020,Kóspál+2021):
  - Compact disk at 1.3mm (gravitationally unstable)
  - Bipolar outflow 12CO with western cavity (blue-shifted) smaller in size
- Presume MIDI 2013 data hinted at crystalline silicates(?)...<u>would have been the first FUor</u>





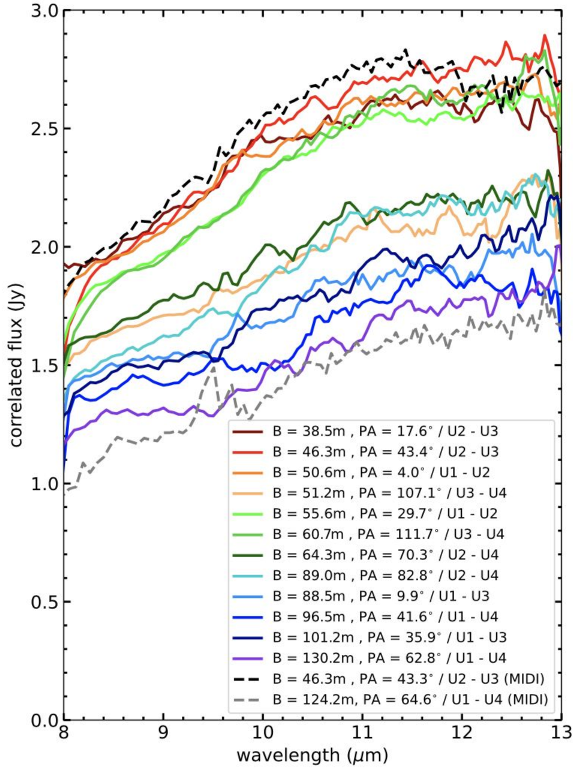




V900 Mon

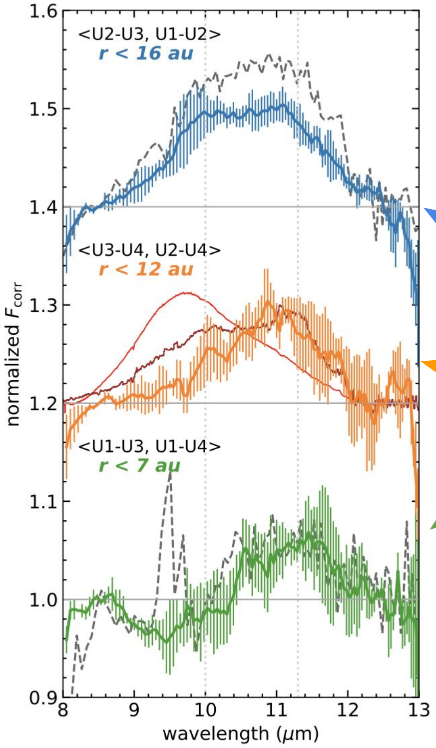
- MATISSE UTs (PI: Ábrahám)
- Standalone snapshot, L-LOW, N-LOW
- 2 epochs 2019,2020 (not all good, very faint target, bad observing conditions)
- 1 publication (Lykou+2024, A&A)

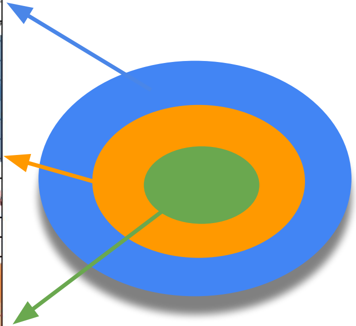
- Geometric model: marginally-resolved inner-disk diameter (L-band) <2.5 mas <= 3 au
- Analytical (inner) disk model SED fitting:
    - R_{out} = 1.5 au, Av=8.8 mag, $M\dot{M}_{acc}$ ~ 4.1 x 10^{-5} M^2_{sun}/yr
- Correlated fluxes comparable to MIDI 2013 data
- No crystalline silicates!
- Radial variation of silicate feature!

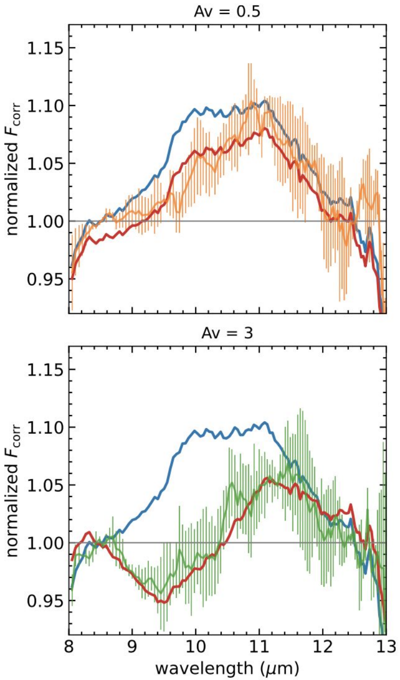


Reference	Major axis (mas)	Minor axis (mas)	PA (deg)	Inclination (deg)
Takami et al. (2019)	67 ± 8	58 ± 8	–	0/60 (†)
Hales et al. (2020)	72 ± 11	60 ± 20	164 ± 63	50 (†)
Kóspál et al. (2021) (*)	43 ± 4	38 ± 8	169 ± 73	28 ± 20
This work, MATISSE	$6.24^{+1.54}_{-0.29}$	6.05 ± 1.61	158^{+3}_{-119}	14^{+4}_{-3}

V900 Mon



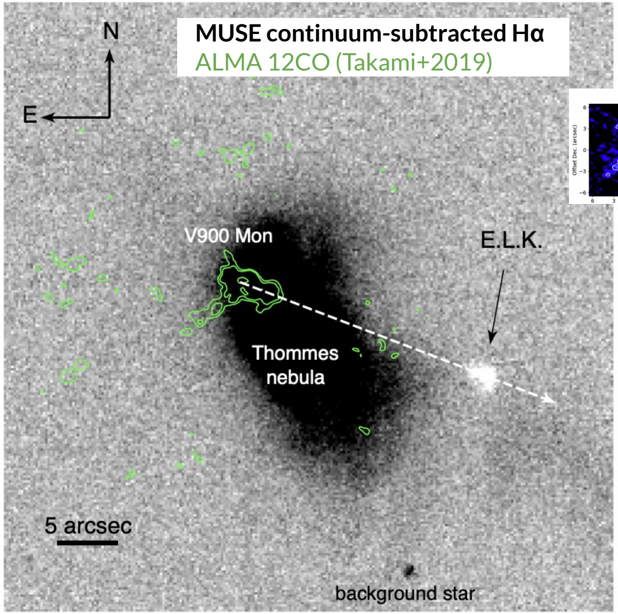


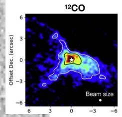


- MATISSE uv-coverage & S/N insufficient to confirm presence of a companion within 50au
- Circumstellar extinction increases towards the center
- A dust 'circumstellar screen' ?
  - Small grains < 1μm
  - Av ~ 3 mag -> τ_{sil} ~ 0.23
  - Dust mass ~Ceres
- Interstellar Av:
  - ~3 mag (MUSE data)
  - ~3 mag (DIBs, Carvalho & Hillenbrand 2022)
  - 4.1 mag (X-rays, Kuhn & Hillenband 2019)

V900 Mon

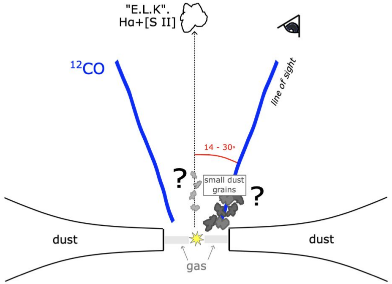
- MUSE IFU (PI: Cruz-Sáenz de Miera) in 2021
- 4650-9300AA with WFM mode (200 mas/spaxel) FOV 1’
- 1 publication (Lykou+2024)

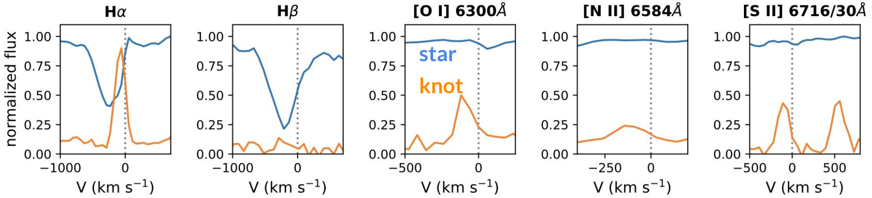




- Discovery of shock-excited jet-like emission! (~100 km/s)
- Aligned (PA~250) to slow 12CO outflow (<20 km/s)
- Knot size 1.3”x1” and kinematic age ~5150 yr
- Possibly created from previous eruption?
- Not possible to detect material ejected since 1990s

Circumstellar extinction near the inner disk (MATISSE) and shock-excited emission above it (MUSE) ??





Conclusions

- MATISSE has been an essential tool in studying geometry, mineralogy, and evolution of eruptive star disks, and it can be combined with other instruments (e.g., MUSE).
- The MIR-emitting regions in FUor disks found to be smaller than expected (<<5 au).
  - Difficult to ascertain disk misalignments, cavities, tertiary companions, …
- Mineralogical studies point to absence of crystalline silicates in FUors
  - Not the right conditions? Too hot?
- At least 2 FUors have jet-like signatures
  - A common occurrence? What is the mechanism?
- Towards model-independent imaging but model-dependent interpretation (e.g., temperature gradient, radiative transfer, MHD)

- GREYS mini-survey; FUors with GRAVITY (UTs/High-res)
- Z CMa imaging paper to be submitted soon
- Follow-up on V900 Mon
- VISIR aperture masking of FUors
- P115 imaging of HAe disk (TBC)

Thank you!

Péter Ábrahám, József Varga, Fernando Cruz-Sáenz de Miera, Ágnes Kóspál, Lei Chen, Mike Sitko, Stefan Kraus, Alexis Matter, Jeroen Bouwman, Ray Russell, Monika Pikhartova, Michal Siwak, Zsófi Szabó, Zhaohuan Zhu, Baobab Liu, Thorsten Ratzka, Bruno Lopez and the MATISSE GTO team!!