Final report on the NKFIH project K-132406

A new beginning in astronomical interferometry: imaging and spectroscopy of the innermost stellar environment

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Summary

The main goals of our program were to promote infrared astronomical interferometry in Hungary, and use this extreme high resolution technique to explore the innermost regions of young circumstellar disks, the birthplace of terrestrial planets. Both goals were successfully achieved, thanks to the support of the NKFIH grant, and in spite of the COVID period which caused that our Greek postdoc, Foteini Lykou arrived to Hungary with several months delay (referring to this we requested a 1-year extension of our program). During the program we obtained new interferometric measurements by submitting 35 observing proposals for ESO's Very Large Telescope Interferometer (VLTI), mainly for the Multi-AperTure mid-Infrared SpectroScopic Experiment (MATISSE), and we could also get access to proprietary MATISSE Guaranteed Time observations. Due to this wealth of new and modern data, we concentrated on the MATISSE observations instead of archival MIDI measurements. We have accomplished 13 research projects with the leadership of our team, including multi-epoch interferometric monitoring of disks which revealed orbiting asymmetric structures which we attribute to a vortex, and also the first high resolution studies of young eruptive stars to outline the effects of outbursts on disk structure. We also contributed to 11 additional interferometry-based papers, mainly led by foreign members of the VLTI/MATISSE consortium, and to 8 other publications. We also led or contributed to several methodological development of MATISSE data analysis; established a new node of the European VLTI Expertise Centres at Konkoly Observatory; presented our results at international conferences; and organised the 11th European VLTI School in Budapest in 2023 June. All these achievements made our group internationally visible and acknowledged on European scale. We were invited to participate in the construction of a new VLTI visitor instrument (NOTT, PI: KU Leuven), where we could contribute via mechanical design of the cold optics mounts and the filter wheel, and preparing to manufacture parts of the instrument by an SME in Hungary. The NKFIH project significantly contributed to making infrared astronomical interferometry part of the Hungarian astronomical culture.

I. PROJECTS WITH LEADING ROLE OF OUR TEAM MEMBERS

[1] Variable Warm Dust around the Herbig Ae Star HD 169142: Birth of a Ring?

The Herbig Ae star HD 169142 is known to have a gaseous disk with a large inner hole, and also a photometrically variable inner dust component in the sub-astronomical-unit region. We studied the temporal evolution of the inner dust component, to learn how late-stage protoplanetary disks evolve to debris disks. We used our near-infrared interferometric observations (PI: Lei Chen) obtained with VLTI/PIONIER to constrain the dust distribution at three epochs spanning six years. Our results indicate that a dust ring at ~0.3 au formed some time between 2013 and 2018, then faded but did not completely disappear by 2019. The short-term variability resembles that observed in extreme debris disks and is likely related to short-lived dust of secondary origin, although variable shadowing from the inner ring could be an alternative interpretation. This may be the first direct detection of secondary dust production inside a protoplanetary disk.

Publication: "Variable Warm Dust around the Herbig Ae Star HD 169142: Birth of a Ring?", Chen, L.,..., Kóspál, Á., Ábrahám, P., et al., ApJ Letters, 887, L32 (2019 Dec). Public access: https://arxiv.org/pdf/1911.10253.pdf

"Variable warm dust in an old protoplanetary disk and a young debris disk", Lei Chen, Attila Moor, Kate Su, Jozsef Varga, Alexander Kreplin, Agnes Kospal, Peter Abraham, Andres Carmona, Fernando Cruz-Saenz de Miera, Karl-Heinz Hofmann, Grant Kennedy, Alexis Matter, Dieter Schertl, Gerd Weigelt, Jacob White, European Astronomy Week, ePoster No. 1997, 2021

[2] The asymmetric inner disk of HD 163296

We characterised the mid-infrared brightness distribution of the inner disk of the young intermediate-mass star HD 163296, from early VLTI/MATISSE observations, taken in the L- and N-bands. We detected potential disk asymmetries. We used simple geometric models to fit the interferometric visibilities and closure phases. We also performed numerical hydro-dynamical simulations of the inner edge of the disk. Our modelling revealed a significant brightness asymmetry in the L-band disk emission. The brightness maximum is located at the NW part of the disk image, nearly at the position angle of the semimajor axis. We confirmed that the morphology of the r < 0.3 au disk region was time-variable. We propose that this asymmetric structure, located in or near the inner rim of the dusty disk, orbits the star. For the physical origin of the asymmetry, we tested a hypothesis where a vortex is created by Rossby wave instability, and we find that a large scale vortex may be compatible with our data. Our models predict that a non-negligible fraction of the L-band disk emission originates inside the dust sublimation radius for μm-sized grains. N-band observations also support that the innermost disk (r <= 0.6 au) lacks small silicate grains, in agreement with our findings from L-band data.

Publication: "The asymmetric inner disk of the Herbig Ae star HD 163296 in the eyes of VLTI/MATISSE: evidence for a vortex?", Varga, J.; Hogerheijde, M.; van Boekel...Ábrahám, P.,...Mosoni, L. et al., A&A 647, A56 (2021)

Varga, J.: "Uncovering inner disk asymmetries with VLTI/MATISSE: the case of HD 163296", contributed talk at the ESO workshop „Ground-based thermal infrared astronomy – past, present and future (2020 October12 - 16), https://zenodo.org/record/4249969#.X-wmVy1f5pQ

Hungarian press release: https://hun-ren.hu/tudomanyos_hirek/bolygokeletkezesre-utalo-forgoszelet-figyelt-meg-a-csfk-csillagasza-vezette-nemzetkozi-kutatocsoport-108236

[3] An interferometric and photometric study of the T Tauri type star DI Cha

DI Cha A is a low-mass, pre-main sequence star, the brightest component of a quadruple star system. We completed an analysis of archival VLTI/MIDI observations of the disk. Both the simple geometrical and the detailed radiative transfer modelling confirmed a very specific inner disk structure, including three components: a narrow ring very close to the star, a gap, and an outer disk. The gap may be caused by an already formed planet. The project was part of the PhD Thesis of Tímea Juhász.

Publication: "A Gap at 1 au in the Disk of DI Cha A Revealed by Infrared Interferometry", Juhász, Tímea ; Ábrahám, Péter; Moór, Attila; Chen, Lei; Kóspál, Ágnes; Varga, József; Regály, Zsolt; Zsidi, Gabriella; Pál, András, ApJ 932, id.79 (2022)

Conference poster: "A gap at 1 au in the disk of DI Cha A revealed by infrared interferometry", Tímea Juhász, at The Sharpest Eyes on the Sky (Exeter, 2022 April 25-29)

Conference presentation: Juhász Tímea, ELTE ÚNKP Conference, 2021 Aug 31, https://www.youtube.com/watch?v=SHP0fWj4sBc&list=PLJ7gTmQWvFNBuBR5n9HH78UnSO1yOpNr3&index=3

[4] VLTI/MATISSE observations of FU Ori

In the framework of our VLTI/MATISSE guaranteed time share, we obtained snapshot observations of the archetypal eruptive young star FU Ori's disk in the L, M and N bands with all available baseline configurations of the ATs and UTs in 2019 December, and 2020 March. Additional UT observations were performed in 2021 January, using the new GRA4MAT mode. The observations were processed and analysed using simple analytical models as well as radiative transfer simulations. The inner accretion disk is modelled with an analytical accretion disk model, providing values for disk radius and for the accretion rate. An unexpected result is that the FU Ori disk is much smaller than anticipated, thus this source is not a suitable target for our planned image reconstruction project.

Publication: "The disk of FU Orionis viewed with MATISSE/VLTI. First interferometric observations in L and M bands", Lykou, F.; Ábrahám, P.; Chen, L.; Varga, J.; Kóspál, Á.; Matter, A.; Siwak, M.; Szabó, Zs. M. et al., A&A 663, id.A86 (2022)

Contributed talk at the ESO workshop „Ground-based thermal infrared astronomy – past, present and future" Lykou, F., 12-16 October 2020

Talk at the Matisse Science Team Meeting (Lykou, F., 2020 Nov 9-10)

Contributed talk "Looking at the disk of FU Orionis Konkoly Observatory with MATISSE/VLTI" (presented by Foteini Lykou) at The Sharpest Eyes on the Sky (Exeter, 2022 April 25-29)

"Eruptive stars with the VLTI : current results from the archetype FU Ori and future challenges" (presented by Foteini Lykou) at European Astronomical Society annual meeting (Valencia, 2022 June 27 - July 1)

Conference presentation: "Looking close at FU Orionis' disk in the mid-infrared with MATISSE/VLTI", Foteini Lykou, Péter Ábrahám, Lei Chen, József Varga, Ágnes Kóspál, Michal Siwak, Zsófia Szabó, Poster at "Star formation: from clouds to disks", Dublin, 2021 October 18-21, https://zenodo.org/record/5570493#.Yc632C__5pQ

[5] An interferometric view of the young eruptive star V900 Mon

Using mid-infrared interferometry, we can determine disk geometry, search for companion, and study dust properties, including grain growth and crystallinity. In the framework of an ESO Open Time proposal (PI: P. Ábrahám) we obtained VLTI/MATISSE observations of V900 Mon, an FU Orionis-type young outbursting system, in 2019 December and 2020 January. The data confirm the silicate emission feature, indicated by MIDI, and outline a radial variation of the feature's profile, which implies both grain growth and the presence of an absorption component in the innermost part of the system. We found no sign of crystalline silicates, thus the long-standing mystery of the lack of crystalline silicates in FU Orionis-type objects remains unsolved.

Publication: "The disk of the eruptive protostar V900 Mon⋆ a MATISSE/VLTI and MUSE/VLT perspective", F. Lykou, P. Ábrahám, F. Cruz-Sáenz de Miera, J. Varga, Á. Kóspál, J. Bouwman, L. Chen, S. Kraus, M. L. Sitko, R. W. Russell, M. Pikhartova, Astronomy & Astrophysics, 682, A75 (2024)

Poster at the European Astronomical Society Annual Meeting (Ábrahám, P., 2020 Jul 1-3)

Contributed talk at the ESO workshop „Ground-based thermal infrared astronomy – past, present and future (Ábrahám, P., 2020 Oct 12-16)

"A sharp view of the silicates in the Konkoly Observatory young outbursting star V900 Mon" (presented by Péter Ábrahám) at The Sharpest Eyes on the Sky (Exeter, 2022 April 25-29)

Poster at the Protostars and Planets VII conference (Kyoto, 2023 April 10-15) presented by Lykou F.

Contributed talk "The eruptive star V900 Mon: relation between the disk found by interferometry and a jet discovered with IFU" at the European Astronomical Society Annual meeting 2024 in Padova, Italy (presented by Lykou F., 2024 July 1-5)

Contributed talk (remote) at Born in Fire conference (Santiago, Chile, 2024 September 24-27) presented by Lykou F., available at www.youtube.com/watch?v=fLoqlCQPv30

[6] The effect of a medium outburst on the disk of EX Lupi

EX Lupi, the prototype of EXor-type young eruptive stars underwent a 2-month medium outburst in 2022 March-April. We organized an extensive observing campaign to cover the high state, and follow the post-burst evolution. Analysing multi-band photometric data and VLT/XShooter spectra we proved that the brightening was driven by increased mass accretion. We also obtained 5-27 um spectra at two epochs with the MIRI instrument on-board JWST. The spectrum revealed a large amount of water in the disk, and the fate of the crystalline silicate particles created in the large outburst in 2008. In a next paper (Ábrahám et al., in prep.) we will outline the spatial structure and mineralogy of the EX Lup disk, and the impact of the burst on them. We observed EX Lup with VLTI/MATISSE and VLTI/GRAVITY in the post-burst phase, and added two archival MATISSE data sets obtained before the burst in 2021, and at the peak of the burst in 2022 March. We check for structural changes triggered by the burst, and answer if a medium burst could crystallise a detectable amount of silicate dust.

Publications: "Brightness and mass accretion rate evolution during the 2022 burst of EX Lupi", Cruz-Sáenz de Miera, F., Kóspál, Á., Ábrahám, P,… Lykou, F., et al., A&A, 678, A88 (2023)

"JWST/MIRI Spectroscopy of the Disk of the Young Eruptive Star EX Lup in Quiescence", Kóspál, Á., Ábrahám, …Chen, L., Cruz-Sáenz de Miera, F., et al. ApJ Letters, 945, id.L7 (2023)

"JWST/MIRI Spectroscopy of the Disk of the Young Eruptive Star EX Lup in Quiescence", P. Ábrahám, EAS 2023, S7 Symp. contributed talk

Press releases:
- Konkoly Observatory: https://konkoly.hu/cikkek/kutatasi-hir/reg-nem-latott-kristalyokat-fedezett-fel-a-james-webb-urtavcso
- HUN-REN: https://hun-ren.hu/en/news/long-lost-crystals-in-the-protoplanetary-disk-of-a-young-star-were-successfully-rediscovered

[7] Geometry and composition of the multi-ringed disk system of HD 144432

We aimed to constrain the structure and dust composition of the inner disk of the young star HD 144432, using VLTI PIONIER, GRAVITY, and MATISSE observations. Our best-fit model has three disk zones with ring-like structures at 0.15, 1.3, and 4.1 au. Assuming that the dark regions in the disk at ~0.9 au and at ~3 au are gaps opened by planets, we estimate the masses of the putative gap-opening planets to be around a Jupiter mass. We find evidence for an optically thin emission from the inner two disk zones at λ>3 um. We find that an iron-rich model provides a better fit to the spectral energy distribution, meaning that in the warm inner regions of disks, most if not all carbon is in the gas phase.

Publication: "Mid-infrared evidence for iron-rich dust in the multi-ringed inner disk of HD 144432", J. Varga, ...,Á. Kóspál, P. Ábrahám, ...Cruz-Sáenz de Miera, ...T. Juhász, et al., and MATISSE & GRAVITY Collaborations, A&A, 681, A47 (2024)

Press releases at the Max-Planck-Institut für Astronomie: https://www.mpia.de/news/science/2024-01-hd144432-iron-rings

[8] Image reconstruction of the environment of Z CMa

We obtained high-angular resolution interferometric observations with MATISSE/VLTI in L (2.9-4.1 μm), M (4.5-4.9 μm), and N (8-13 μm) bands, as well as spectroscopic observations in the near-infrared with SpeX/ IRTF. We analysed the interferometric data using geometric model fitting, image reconstruction algorithms, and orbital simulation tools. The mid-infrared (MIR) emitting regions of the individual protoplanetary disks in the binary system Z CMa are resolved by MATISSE/VLTI. The size of the MIR-emitting disk region of the more massive HBe star increases in size towards longer wavelengths from ≈15 mas at 3.5 μm to ≈60 mas at 11.5 μm. We also note a radial variation of the silicate absorption feature over the disk, where the optical depth increases inwards <40 au radii. This contradicts the assumption of a carved, dusty cocoon surrounding the HBe star. In the case of the less massive FUor companion, the MIR-emitting region is much smaller with an angular size ≤13 mas, or else a physical radius ≤8 au, in all bands suggesting a compact disk. MATISSE data place the orbital separation at 117.88 ±0.73 mas and a position angle of 139.16±0.29 deg east-of-north. Our estimates for the orbital elements gave an eccentric orbit (e~0.20) with a moderate inclination (i~61 deg). The derived total mass is M_{total} = 14.1+1.9 −1.6 $M_\odot$, while the orbital period is approximately 750 years. Our MATISSE imaging of the Herbig disk during outburst indicates a temperature gradient for the disk, while imaging of the FUor companion's disk corroborates previous studies showing that FUor disks are rather compact in the mid-infrared.

Publication: "An interferometric mid-infrared study of the eruptive star binary Z CMa with MATISSE/VLTI I. Imaging the protoplanetary disks during the 2023 outburst", F. Lykou, J. Varga, F. Cruz-Sáenz de Miera, P. Ábrahám, Á. Kóspál, B. Lopez, T. Henning, S. Wolf, G. Weigelt, F. Millour, M. Hogerheijde, L. Chen, T. Ratzka, W. Danchi, P. Boley, J.-C. Augerau, P. Priolet:, Astronomy and Astrophysics, submitted

Talk at the MATISSE Science Team Meeting by Lykou F. on 2024 October 26

Contributed talk at the MATISSE Science Workshop (Nice, 2024 November 6-8) presented by Lykou F., soon to be available online at Zenodo (as of December 2024)

[9] Spatially resolved observations of an extreme debris disk following a dust-releasing impact event

The last stage of rocky planet formation involves giant impacts between planetary embryos. Extreme debris disks are thought to be formed by dust components released by such giant impacts happening in the inner~au region. Numerical simulation of such giant impacts suggests asymmetric and variable dust distribution. We studied such dust distribution and evolution in the star HD 166191, which hosts a debris disk, and underwent a brightening event from 2018 to 2019, likely related to a large asteroid collision in 2018 or earlier. Our multi-epoch observations of HD 166191 employs the infrared interferometer VLTI/MATISSE, and covers 7 epochs from 2019 to 2024. We model the data with chromatic geometric modelling. Our analysis revealed an asymmetric and variable morphology of the dust component. We find the distance of the dust to the star to be~0.9 au, which indicates the dust to be predominantly sub-micron grains. We find the dust to be on a highly inclined disk plane. The rapid weakening of the asymmetry indicates a quick spreading of the initial dust clump from the collision. In this work we present the first ever morphological study of a newly-formed extreme debris disk, using multi-epoch spatially-resolved observations. The work highlight the potential of infrared interferometry in studying the dust distribution and evolution following a giant impact.

Publication: "Spatial distribution of warm dust around the Vega-type star HD 166191 after an asteroid collision", Lei Chen, Attila Moor, Kate Su, Alexis Matter, Jozsef Varga, Peter Abraham, Agnes Kospal, Bruno Lopez, Foteini Lykou, Fernando Cruz Saenz de Miera, Jean-Charles Augereau, Philip Carter, William Danchi, Thomas Henning, Karl-Heinz Hofmann, Michiel Hogerheijde, Meredith Hughes, Grant Kennedy, Julia Kobus, Elena Kokoulina, Zoe Leinhardt, Florentin Millour, Eric Pantin, Romain Petrov, Philippe Priolet, Dieter Schertl, Roy van Boekel, Lewis Watt, Gerd Weigelt, Jacob White, Julien Woillez, Sebastian Wolf, Astronomy and Astrophysics, submitted

Contributed talk at the European Astronomical Society Symposium"Planet formation enters the observational era (Chen, L., 2020 Jul 1-3)
Conference contributed talk: "Asymmetric circumstellar dust distribution after an exosolar asteroid collision" (presented by Lei Chen), at The Sharpest Eyes on the Sky (Exeter, 2022 April 25-29)

Conference presentation: "Variable warm dust in an old protoplanetary disk and a young debris disk", Chen, L.,...Ábrahám, P., et al., European Astronomy Week 2021, ePoster No. 1997

[10] The inner disk structure of DX Cha

DX Cha is a spectroscopic binary consisting of a Herbig A4V primary star and a K3-type companion. We obtained new L-band interferometric observations of this source with the MATISSE instrument at the Very Large Telescope Interferometer (VLTI). To model the four MATISSE epochs taken between 2020 and 2023, we constructed a time-varying interferometric model of the system, using the *oimodeler* modelling software. The model consists of an asymmetric ring, and two point sources on a Keplerian orbit. Our best-fit model shows a circumbinary ring with a diameter of 0.86 au, featuring a strong azimuthal asymmetry. We found that the position angle of the asymmetry have changed between the MATISSE epochs. The ring is relatively narrow, with a full width at half maximum (FW HM) of~0.14 au. The presence of circumstellar dust emission so close to the binary orbit is unexpected, as previous hydrodynamic simulations predicted an inner disk cavity with a diameter of~4 au. Thus, we argue that the narrow band of material we detected is probably not a gravitationally stable circumbinary ring, but it might be part of the tidal accretion streamers channelling material from the inner edge of the disk towards the stars.

Publication: "Evidence for an accretion bridge in the DX Cha circumbinary system from VLTI/MATISSE observations", Tímea Juhasz, Jozsef Varga, Peter Abraham, Agnes Kospal, Foteini Lykou, Lei Chen, Attila Moor, Fernando Cruz-Saenz de Miera, Bruno Lopez, Alexis Matter, Roy van Boekel, Michiel Hogerheijde, Margaux Abello, Jean-Charles Augereau, Paul Boley, William C. Danchi, Thomas Henning, Mathis Letessier, Jie Ma, Philippe Priolet, Marten Scheuck, Gerd Weigelt, Sebastian Wolf, Astrophysical Journal, accepted in press

Contributed talk at the European Astronomical Society (2024 July 1-5) meeting presented by Time Juhasz "Surveying the disk structure of DX Cha using VLTI/MATISSE interferometric observations".

[11] Disk structure and composition of the T Tauri star DG Tau

DG Tau is one of the most intensely studied jet-disk system. To understand better the environment where the jet is launched, we carried out a multi-wavelength and multi-epoch study of the inner disk. We obtained L, M, and N-band interferometric observations with VLTI/MATISSE, performed an N-band spectroscopic monitoring of the uniquely variable silicate feature with VLT/VISIR, and followed the brightness changes of the central star with ground-based optical telescopes. Based on the interferometric data, we analyse the geometrical structure and the mineralogical composition of the disk, including its radial distribution. We detected significant temporal variations in the silicate feature, and interpreted it with a superposition of a central constant absorption and a more extended variable emission components. To look into the innermost part of the system, we also analysed unpublished archival X-ray observations and investigated optical light curves to detect dips, potentially corresponding the localised dusty structures within the disk or the wind. We construct a comprehensive multi-scale picture of the inner disk and relate it with the jet properties deduced from a detailed investigation of the JWST/MIRI integral field mid-infrared spectroscopy, which provides unprecedented 3D information on the extended forbidden line emission, in particular of the NeII line. DG Tauri is a young star, whose mid-infrared spectrum exhibits unusual variability: the 10 um silicate feature changes from emission to absorption. We obtained and analyse two observations with VLTI/MATISSE. We also monitor a 10 micron feature with VLT/VISIR to document temporal changes. The interferometric data reveal a strong asymmetry in the inner disk. The temporal variability is consistent with our previous two-component model based on the MIDI observations.

Publication: "The variable inner disk structure of DG Tauri", J. Varga, P. Ábrahám, M. Güdel, Á. Kóspál, E. Gaidos, Astronomy & Astrophysics, in prep.

"The jet and variable inner disk of DG Tau", Péter Ábrahám, Manuel Güdel, Till Käufer, Ágnes Kóspál, József Varga, contributed talk at Jets and Young Stars: the Passage from Discovery to JWST and Beyond, A Celebration of the career of Professor Tom Ray, DIAS, 2024 Sep 3

Contributed talk at the European Astronomical Society (2024 July 1-5) meeting presented by Jozsef Varga "The variable and asymmetric dust emission in the mysterious disk of DG Tau".

[12] A new data-analysis method to search for faint companions around young stars with mid-infrared interferometry

Methodological development at the Expertise Centre: The publication of a planet candidate in the disk of the intermediate-mass star AB Aur was an exciting discovery (Boccaletti et al. 2020). We started a project to investigate how archival VLTI/MIDI interferometric observations could constrain the 10 micrometer brightness of the hypothetical planet. Companions are expected to leave sinusoidal ripples in correlated spectra from mid-infrared interferometry like VLTI/MIDI. An obstacle to detection of such ripples is that they are entangled with the silicate feature in the N band. We developed a method to detect the weak ripple signals by comparing the correlated spectra for a given target on baselines with similar length. With our method, companions with flux ratio of only several percent could be detected. Tests of the method have been performed using both mock data and real-world observational data, and application of the method for AB Aur is ongoing. Even an upper limit for the 10 micrometer brightness would be informative on the properties of the planet.

Publication: contributed talk at the ESO workshop „Ground-based thermal infrared astronomy – past, present and future (Chen, L.,2020 Oct 12-16), https://zenodo.org/record/4249881#.X-w1mi1f5pQ

[13] Discovery of a companion of T CrA

T CrA is a young star, which has long been suspected to be a binary. Using new VLTI/MATISSE L and N band observations taken in the period between 2023 May and 2024 Aug, we modelled the data with a geometric model. The modelling reveals a companion at an average position of $\Delta\alpha = -152.6 \pm 0.5$ mas, $\Delta\delta = 14.5 \pm 0.2$ mas, relative to the primary, corresponding to a separation of 23 au, at a PA of 275.4°. An orbital fit to the positions derived from our multi-epoch data prefers a nearly edge on binary orbit, implying that the orbit is highly misaligned with respect to the circumprimary disk. Such a configuration can cause the warping and tearing of the disk around the primary, that was proposed by recent studies. In the L band, the companion looks rather extended, with an FWHM size of ≈1 au, suggesting that the emission comes from a disk around the secondary star. The companion flux is 0.2−0.3 Jy in the L band, and 0.2−0.8 Jy in the N band, accounting for about 10% of the total flux emission at those wavelengths. The SED of the companion is compatible with thermal radiation of warm and hot (300−1500 K) dust.

Publication: "T CrA has a companion. First direct detection of T CrA B with VLTI/MATISSE", J. Varga, A. Matter, F. Millour, G. Weigelt, R. van Boekel, B. Lopez, F. Lykou, Á Kóspál, L. Chen, P. Boley, S. Wolf, M. Hogerheijde, A. Moór, P. Ábrahám, J.-C. Augereau, F. Cruz-Saenz de Miera, W.-C. Danchi, Th. Henning, T. Juhász, P. Priolet, M. Scheuck, J. Scigliuto, L. van Haastere, L. Zwicky, Astronomy and Astrophysics, submitted

II. PROJECTS WITH CONTRIBUTION OF OUR TEAM MEMBERS

Due to our strong links to the MATISSE consortium, we were invited to contribute to several MATISSE guaranteed time papers. In these projects our usual role was reading and commenting the manuscript, performing also some analyses if needed. we were also invited to become a co-author in the main MATISSE paper that is the reference for the instrument. Our team members contributed to several non-interferometric papers, too.

1. "First MATISSE L-band observations of HD 179218. Is the inner 10 au region rich in carbon dust particles?", Kokoulina, E.,...,Varga, J.,...,Ábrahám, P. et al., A&A 652, id.A61 (2021)
2. "Mid-infrared circumstellar emission of the long-period Cepheid ℓ Carinae resolved with VLTI/ MATISSE" Hocdé, V.,...,Varga, J.,...,Ábrahám, P.,...,Mosoni, L. et al., A&A 651, id.A92 (2021)
3. "The Remnant and Origin of the Historical Supernova 1181 AD", Ritter, A., Parker, Q., Lykou, F., Zijlstra, A., Guerrero, M.A., Le Dû, Pascal, ApJL 918, id.L33 (2021)
4. "A Study of the Photometric and Spectroscopic Variations of the Prototypical FU Orionis-type Star V1057 Cyg", Szabó, Zs. M.; Kóspál, Á.; Ábrahám, P.; Park, S. et al., ApJ 917, id.80 (2021)

5. "VLTI-MATISSE chromatic aperture-synthesis imaging of η Carinae's stellar wind across the Brα line. Periastron passage observations in February 2020", Weigelt, G.,...,Varga, J. et al., A&A 652, id.A140 (2021)
6. "VLTI-MATISSE L- and N-band aperture-synthesis imaging of the unclassified B[e] star FS Canis Majoris", Hofmann, K. -H.,...Varga, J. et al., A&A 658, id.A81 (2022)
7. “Locating dust and molecules in the inner circumstellar environment of R Sculptoris with MATISSE”, Drevon, J.; …Ábrahám, P. ;…Varga, J. et al., A&A 665, A32 (2022)
8. "The extended atmosphere and circumstellar environment of the cool evolved star VX Sagittarii as seen by MATISSE", Chiavassa, A. ...Varga, J.,... Mosoni, L., A&A 658, A185 (2022)
9. "MATISSE, the VLTI mid-infrared imaging spectro-interferometer", Lopez, B.,...,Ábrahám, P.,...,Mosoni, L.,...,Varga, J. et al., A&A 659, A192 (2022)
10. "A likely flyby of binary protostar Z CMa caught in action", Dong, R.,...Ábrahám, P.,...Kóspál, Á.,...Chen, Lei et al., Nature Astronomy, Vol. 6, p. 331-338 (2022)
11. "The messy death of a multiple star system and the resulting planetary nebula as observed by JWST", De Marco, O.,... Lykou, F. et al., Nature Astronomy, 6, 1421 (2022)
12. “Thermal imaging of dust hiding the black hole in NGC 1068” Gamez Rosas, V., …, Varga, J., et al. Nature, 602, 403 (2022)
13. “Mid-infrared time-domain study of recent dust production events in the extreme debris disk of TYC 4209-1322-1”, Moor, A., Ábrahám, P., Kóspal, Á., et al., MNRAS, 516, 5684 (2022)
14. "Spatially resolving polycyclic aromatic hydrocarbons in Herbig Ae disks with VISIR-NEAR at the VLT", Yoffe, G. ...Varga, J. et al., Astronomy & Astrophysics, 674, id.A57 (2023)
15. "A New Study on a Type Iax Stellar Remnant and its Probable Association with SN 1181", Lykou, F., Parker, Q.A., Ritter, A., Zijlstra, A.A., Hillier, D.J., Guerrero, M.A., Le Dû, P., Astrophysical Journal, 944, id.120 (2023)
16. "An impressionist view of V Hydrae: When MATISSE paints Asymmetric Giant Blobs" Planquart L., ..., Lykou F. et al., A&A 687, A306 (2024)
17. "Images of Betelgeuse with VLTI/MATISSE across the Great Dimming", Drevon, J.,... Ábrahám, P., Varga, J. et al., Monthly Notices of the Royal Astronomical Society: Letters, 527, L88 (2024)
18. “Abundant sub-micron grains revealed in newly discovered extreme debris disks” Moor, A., Ábrahám, P., …, Chen, L., Kóspal, Á., … Varga, J., et al. MNRAS, 528, 4528 (2024)
19. “GRAVITY for MATISSE. Improving the MATISSE performance with the GRAVITY fringe tracker” Woilez, J.,… Varga, J., et al. A&A, 688, A190 (2024)

III. KONKOLY VLTI EXPERTISE CENTRE AND THE 11TH INTERNATIONAL VLTI SCHOOL

Starting at March 1, 2021, we founded the Konkoly VLTI Expertise Centre, as a new node of a Europe-wide network of similar centres. Funding is provided in the H2020 OPTICON RADIONET PILOT program, and also the present NKFIH proposal. We regularly participate in the quarterly meeting of Expertise Centres, and offer help for users of the ESO VLTI facilities, in particular of MATISSE. In 2023, we organised the 11th ESO VLTI School (June 12-17, https://vlti-ec.konkoly.hu/vltischool2023/). We attracted to Budapest experts of European interferometry, as well as representatives from ESO. The 45 students learnt the basics of interferometry. The school was a clear success, and promoted the reputation of the Konkoly team.

The webpage for the centre can be found at https://vlti-ec.konkoly.hu

IV. PARTICIPATION IN THE ASGARD/NOTT PROJECT

Our team joint building a new instrument for the VLTI. The science goal of the nulling L-band interferometer is direct imaging of giant planets at the snowline. The Hungarian contribution is mechanical design of optical mounts and the filter wheel, under cryogenic conditions. The actual design was completed in 2023 by a sub-contractor SME, funded from the OTKA budget.

Publication: "L-band nulling interferometry at the VLTI with Asgard/NOTT: status and plans", Defrère, Denis;… Ábrahám, Péter;… Joo, Andras Peter;…Mezo, Gyorgy;, Proceedings of the SPIE, Volume 13095, id. 130950F, 2024

V. OBSERVING TIME PROPOSALS FOR ESO'S VERY LARGE TELESCOPE INTERFEROMETER

ESO P106 (deadline: 2020 March, for period 2020 October 1- 2021 March 31)

1. "Probing the gap disc structure and radially differentiated mineralogy of DI Cha with VLTI/MATISSE" (106.21QT), PI: Tímea Juhász
2. "Spatially resolving the inner accreting region of FUors with VLTI/GRAVITY" (106.21D7), PI: Lei Chen
3. "Take a closer look - interferometric observations in the first FUor disk that returned to quiescence" (106.219X), PI: Kóspál, Á.
4. "The mysterious origin of extreme debris disks revealed by mid-infrared interferometry" (106.21GK), PI: Varga, J.
5. "The weather in V883 Ori: dust, ice and snow observations with VISIR" (106.21NQ), PI: Lykou, F.

For ESO P107 — no call for proposals was released due to COVID

For ESO P108 (deadline: 2021 March, for period 2021 October 1- 2022 March 31)

6. -"Spatially resolving the inner accreting region of FUORs with VLTI/GRAVITY" (108.22DJ), PI: Lei Chen, accepted
7. "Probing the gap disc structure and radially differentiated mineralogy of DI Cha with VLTI/MATISSE" (108.22KE), PI: Tímea Juhász, accepted
8. "The mysterious origin of extreme debris disks revealed by mid-infrared interferometry" (108.229P), PI: József Varga, accepted
9. "Zooming into Z CMa with MATISSE: the tale of two disks" (108.22M4), PI: Foteini Lykou, rejected
10. "A statistical Study of disk inclination of UXor stars" (108.22K8), PI: Lei Chen, rejected
11. "Snow-lines and dust in the thermal infrared: looking into V883 Ori with VISIR" (108.22LF), PI: Foteini Lykou, accepted

ESO P109 (deadline: 2021 September, for period 2022 April 1 - September 30)

11. "Multi-epoch spatially-resolved observations of variable warm dust around young stars" (109.238V), PI: Lei Chen

For ESO Period 110 (deadline: 2022 March, for period 2022 October 1 - 2023 March 30):

12. "Lasting impacts of the new large outburst of the young star EX Lupi on its planet forming region" (110.24BN), PI: Péter Ábrahám. Accepted
13. "Monitoring the circumbinary disk of DX Cha with VLTI/MATISSE" (110.23X2) PI: József Varga. Accepted.
14. "Imaging Z CMa with MATISSE: the tale of two disks in outburst" (110.23WE) PI: Foteini Lykou. Accepted.
15. "Multi-epoch spatially-resolved observations of variable warm dust around young stars" (110.242J) PI: Lei Chen. Rejected.
16. "A statistical Study of disk inclination of UXor stars" (110.242M) PI: Lei Chen. Rejected
17. 110.245F "Take a closer look - interferometric observations in the first FUor disk that returned to quiescence" (PI: Ágnes Kóspál). Accepted.

For ESO Period 111 (deadline: 2022 September, for period 2023 April 1 - September 30)

18."GREYS: a GRAVITY/VLTI survey of Eruptive Young Stars" (111.24U6) PI: Foteini Lykou. Accepted.
19."Multi-epoch spatially-resolved observations of variable warm dust around young stars" (111.24TR) PI: Lei Chen. Rejected.

For ESO Period 112 (deadline: 2023 March, for period 2023 Oct 1 - 2024 Mar 31)

20."Dusty snow-lines in the thermal infrared: dissecting the disk of V883 Ori with VISIR" (112.25Q1) PI: Foteini Lykou. Accepted.
21."GREYS; a GRAVITY/VLTI survey of Eruptive Young Stars: the Winter targets" (112.25MF) PI: Foteini Lykou. Accepted.
22."The dynamic disk behind the extreme variability of the young accreting star DG Tau" (112.25Z1) PI: Péter Ábrahám. Accepted.

For ESO Period 113 (deadline: 2023 September, for period 2024 Apr 1 - Sep 30)

23."GREYS: a GRAVITY/VLTI survey of Eruptive Young Stars: the Summer targets" (113.26BL) PI: Foteini Lykou. Accepted.
24."Imaging the sub-au details of the extreme debris disk around HD 166191" (113.26KD) PI: Lei Chen. Accepted.
25."Take a closer look - interferometric observations in the first FUor disk that returned to quiescence" (113.26DK) PI: Ágnes Kóspál. Accepted.
26."VLTI imaging of planetary assembly Vol. 2" (113.26BA) PI: József Varga. Accepted.
27."JWST-based systematic investigation of disk dynamics in young stars via mid-infrared variability" (113.26ST) PI: Péter Ábrahám. Accepted.

For ESO Period 114 (deadline: 2024 April, for period 2024 October 1 - 2025 March 31)

28."Going deep: exploration of the faint disk population around T Tauri stars by MATISSE and JWST" (114.27HB) PI: Péter Ábrahám. Accepted
29."JWST-based systematic investigation of disk dynamics in young stars via mid-infrared variability" (114.27H4) PI: Péter Ábrahám. Rejected
30."The origin of dust asymmetries in the inner disk of YSOs" (114.277W) PI: József Varga. Rejected
31."Disassembling the central engine of OH231.8+4.2 with VLTI/MATISSE" (114.271R) d-PI: Foteini Lykou, rejected

For ESO Period 115 (deadline: 2024 September, for period 2025 April 1 - September 30)

32."Imaging au-scale dust sub-structures in the disk of HD150193" (115.27XE) PI: József Varga. Accepted.
33."Disk truncation and companion-disk interaction in the highly dynamical HD142427" (115.27ZV) PI: Foteini Lykou. Rejected
34."Imaging the sub-au details of the extreme debris disk around HD166191" (115.283V) PI: Lei Chen. Accepted.
35."JWST-based systematic investigation of disk dynamics in young stars via mid-infrared variability" (115.2885) PI: Péter Ábrahám. Rejected

VI. OTHER ACTIVITIES AND ACHIEVEMENTS

- Team member Foteini Lykou was elected as the secretary of the European Interferometry Initiative (EII, https://european-interferometry.eu) in 2022 August.
- Team member Lei Chen received a permanent position at Konkoly Observatory in 2022 July.
- We participated in a EU H2020 call "HORIZON-INFRA-2022-TECH-01-01: R&D for the next generation of scientific instrumentation, tools and methods". Our group will participate in an proposed project on optical interferometry (PI: Florentin Millour, Nice), and our team member József Varga worked out a proposed project on "Panchromatic modelling of VLTI data with CoModO-I". The proposal was not supported by EU.
- As a sign of the intensive collaboration with the MATISSE Consortium, our team members are regularly invited as audience or as speaker to the bi-weekly online meeting on the MATISSE disk programme.
- Team member József Varga returned to Hungary in 2022 September, he has a contract with Konkoly Observatory.
- We officially requested a 1-year extension of our project due to the COVID-related delays at the beginning of the work.
- Our NKFIH proposal K147380 ("Transients processes in disks setting the initial conditions of terrestrial planet formation", 2024 Jun - 2028 May, PI: Péter Ábrahám) was accepted.
- At EAS2023 we were involved in the organisation of LS7: "The ESO Very Large Telescope Interferometer window into the universe: a hands-on session for newbie". F. Lykou chaired the session, and have an invited talk on " Supporting European optical/infrared interferometry". J. Varga talked on "What to do with VLTI data? Tools for data processing and interpretation". F. Lykou has an invited talk at the European Forum of Astronomical Communities" entitled "Empowering the European Interferometry community".
- At EAS2024 we were involved in the organisation of two VLTI sessions through our team member F. Lykou, who was a member of the SOC in both sessions and acted as chair, in SS20 "The VLTI at the

ALMA, JWST, and ELT era" and SS37 "Interferometric imaging of the inner few AU of circumstellar environments". Two team members also presented talks at SS37: T. Juhasz "Surveying the disk structure of DX Cha using VLTI/MATISSE interferometric observations" and J.Varga "The variable and asymmetric dust emission in the mysterious disk of DG Tau".

- We also participated in the organisation of the 12th VLTI Interferometry School, held on 2024 September 22-28 in Porquerolles, France, where F. Lykou was part of the SOC and helped organise the School's lectures material.
- Team member F. Lykou was invited to give a lecture on the "Introduction to optical interferometry" at the NEON2024 Observing School (2024 October 13-25).