Evidence for an accretion bridge in the DX Cha circumbinary system

Tímea Juhász

junior research fellow, HUN-REN Research Centre for Astronomy and Earth Sciences, **Konkoly Thege Miklós Astronomical Institute**

Co-workers: **József Varga, Péter Ábrahám, Ágnes Kóspál, Lei Chen**

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Introduction: Herbig Ae stars

- young objects ($< 10\,\mathrm{Myr}$)
- A spectral type
- mass: 1.5–3 $M_\odot$
- circumstellar disk
- disk evolution are related to the central star
- binary stars $\rightarrow$ more complexity

- inner disk region $\rightarrow$ size scale of a few au
- significant radiation in infrared
- 0.01 arcsec resolution is required $\rightarrow$ infrared interferometry

DX Cha

- spectroscopic binary
- Herbig A4V and K3
- 20 days period (Böhm et al. (2004))
- 0.22 au semi-major axis
- $M1 = 2.2 \pm 0.2\ M_\odot$, $M2 = 1.4 \pm 0.3\ M_\odot$ (Garcia et al. (2013))

- DX Cha in group II (Meeus et al. (2001))
- $d = 106.5 \pm 0.5$ pc (Bailer-Jones et al. (2021))
- $A_V = 0.31$ mag (Gontcharov & Mosenkov (2018))
- $L = 47 \pm 11\ L_\odot$ (Varga et al. (2018))

DX Cha

- Dunhill et al. (2015): smoothed particle hydrodynamics (SPH) simulations
  - cavity and accretion bridges
  - precession period is approximately 40 years
  - for 2 years $\sim$ 18 degrees, and for 4 years $\sim$ 36 degrees...
  - this precession effect will be testable with the VLTI

Our goals:

- study the disk structure within 10 milliarcseconds
- check the presence of the cavity based on the MATISSE measurements
- detect changes over time
- possible changes: disk origin? stellar origin?
- explanation for the asymmetry experienced in the closure phases

MATISSE data

- GTO programmes 0104.C-0782(D), 106.21Q8.003, 108.22HB.001 and 110.23X2.002
- reduced with Data Reduction Software package (DRS) measurements
- we used the L band data
- N band data: separate study?

Table 1: Overview of VLTI/MATISSE observations of DX Cha used in our work

	Target					Calibrator		
Instrument mode	Date and time (UTC)	Seeing ()	τ_0 (ms)	Stations	Configuration	Name	LDD (mas)	Time (UTC)
stand-alone	2020-03-22T05:54	0.54	7.25	K0-G2-D0-J3	Medium (AT)	HD 105340	2.22	05:29
GRA4MAT	2021-03-11T04:45	0.68	6.49	K0-G2-D0-J3	Medium (AT)	HD 120404	2.94	04:18
stand-alone	2022-01-23T07:37	0.49	10.40	U1-U2-U3-U4	UT	HD 92682	2.12	07:04
GRA4MAT	2023-01-18T06:15	0.76	6.48	A0-B2-D0-C1	Small (AT)	HD 92305	4.61	05:46

MATISSE data

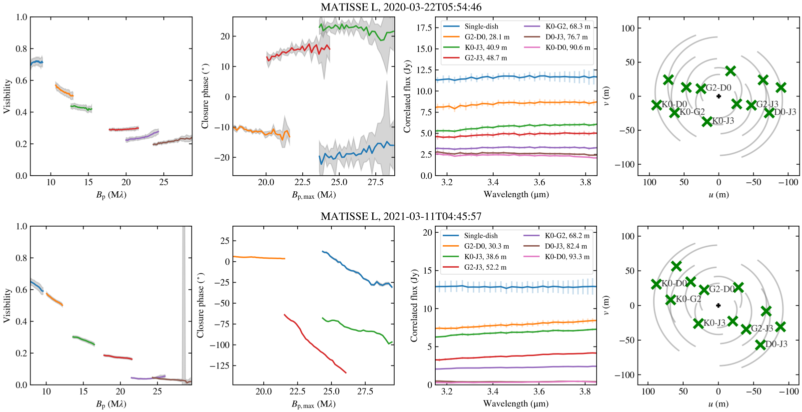


Figure 1: The calibrated MATISSE L band data sets from 2020 and 2021

MATISSE data

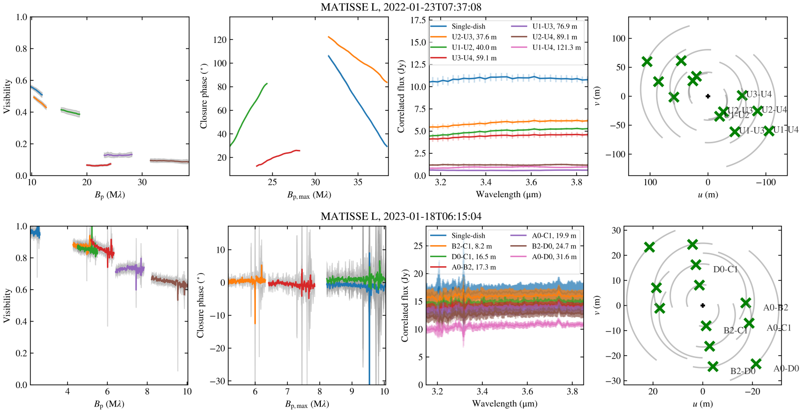


Figure 2: The calibrated MATISSE L band data sets from 2022 and 2023

SED analysis

- $T_1 = 8250$K and $T_2 = 4800$K (Cowley et al. (2013)) $\rightarrow$ PHOENIX synthetic spectra
- radii are not precisely known
- Cowley et al. (2013): flux ratio on 557.6 nanometers = 1/9.9
- scaling of the spectra
- checking based on photometric data

Result: flux ratio on the L band
disk : primary star : secondary star = 85:9:6

SED analysis

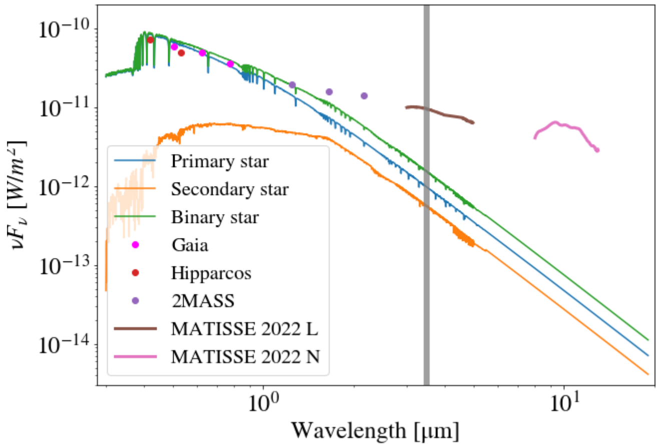


Figure 3: SED of DX Cha. The grey band shows the wavelength range we modeled.

Modelling

- Oimodeler modelling software
- we built a customized model:
  - disk: azimuthally modulated smoothed ring with a fitted:
    - d (diameter)
    - FWHM (full width at half maximum)
    - A_{mod1}, A_{mod2}, A_{mod3} (amplitude of the azimuthal modulation in the time of the three fitted measurements)
    - Φ_{mod1}, Φ_{mod2}, Φ_{mod3} (position angle of the azimuthal modulation in the time of the three fitted measurements)
  - DX Cha system is almost face on: pa $= 0$ and the elong $= 1$
  - binary star: two point sources on Keplerian orbit with a fitted:
    - Ω (longitude of the ascending node)
    - t_0 (time of periastron passage)
    - other orbital elements were fixed parameters (based on Böhm et al. (2004))
    - flux ratios of the model elements were also fixed parameters (SED study)

Modelling

- MCMC algorithm (emcee ensemble sampler, Foreman-Mackey et al. (2013))
- 50000 steps with walkers 26
- best-fit values $\rightarrow$ the first 25000 steps was discarded

Modelling results

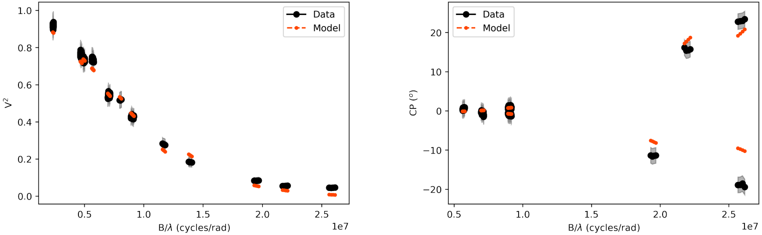


Figure 4: Model fitting of the 2020 and 2023 data. $\chi^2_{red} = 0.62$

Modelling results

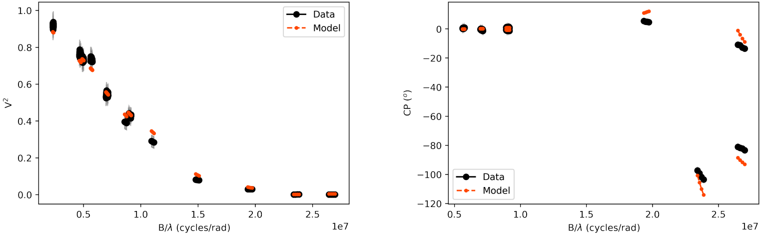


Figure 5: Model fitting of the 2021 and 2023 data. $\chi^2_{red} = 0.76$

Modelling results

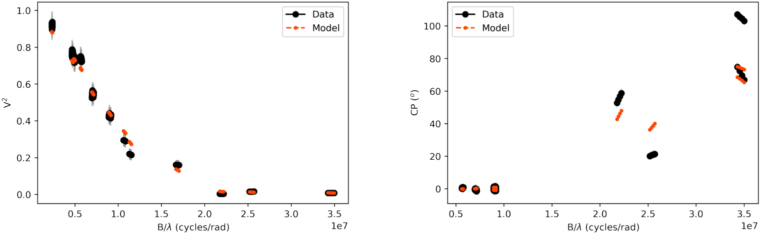


Figure 6: Model fitting of the 2022 and 2023 data. $\chi^2_{red} = 2.38$

Modelling results

Table 2: The best-fit parameters of the modeling, with a $\chi^2_{red} = 1.19$. Position angles of the modulations are measured east of north.

d [mas]	$FWHM$ [mas]	A_{mod1} [°]	A_{mod2} [°]	A_{mod3} [°]	Φ_{mod1} [°]	Φ_{mod2} [°]	Φ_{mod3} [°]	Ω [°]	t_0 [MJD]
$8.05^{+0.38}_{-0.44}$	$1.28^{+0.34}_{-0.55}$	$0.73^{+0.45}_{-0.31}$	$0.63^{+0.32}_{-0.25}$	$0.79^{+0.27}_{-0.20}$	$97.87^{+45.36}_{-61.17}$	$239.11^{+72.52}_{-36.27}$	$273.64^{+39.85}_{-28.30}$	$319.81^{+254.51}_{-135.06}$	$58921.22^{+4.46}_{-3.54}$

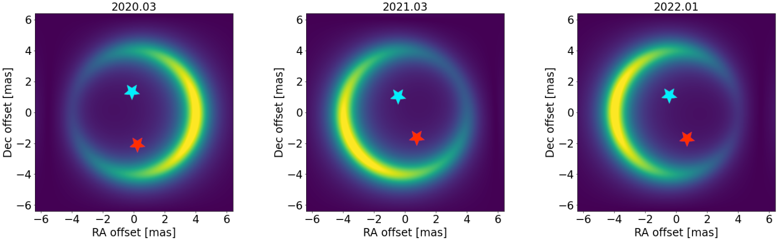
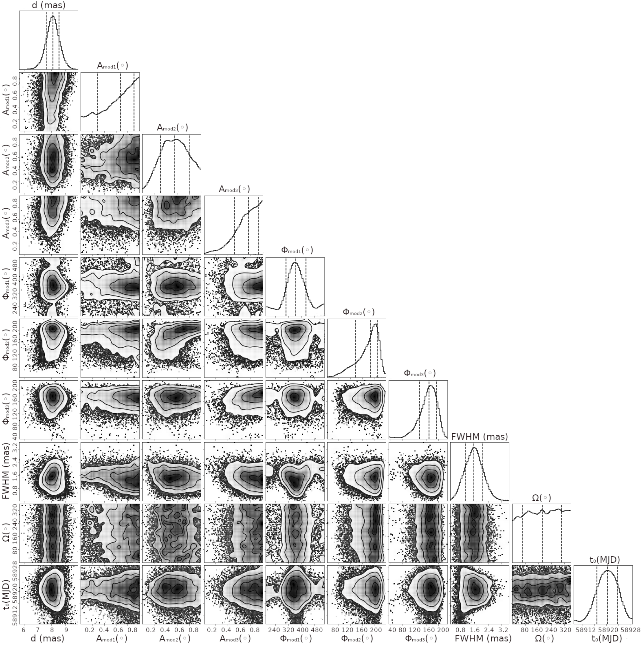


Figure 7: Model images of the 2020, 2021 and 2022 epochs. The primary is marked by a blue star symbol, the secondary by a red star symbol.

Modelling results



Discussion

- the assumed Keplerian orbit agrees with the data
- A_{mod1}, A_{mod2}, A_{mod3} $\rightarrow$ significant asymmetry in the innermost disk region
- temporary changes in the ring asymmetry $\rightarrow$ periodicity is unknown from the data
- narrow ring in the L band with a diameter of 8 mas
- previous hydrodynamic studies $\rightarrow$ larger inner cavity (Dunhill et al. (2015))
- accretion bridge?

Discussion

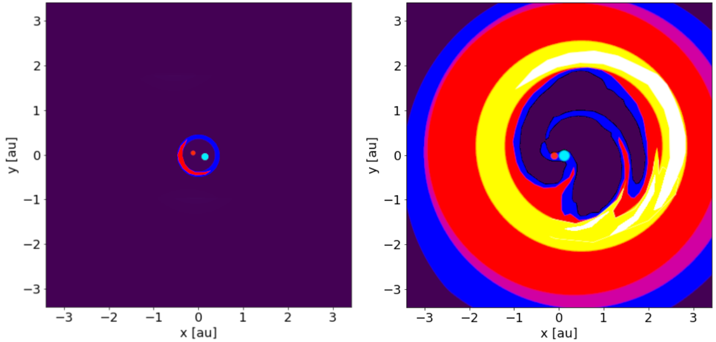
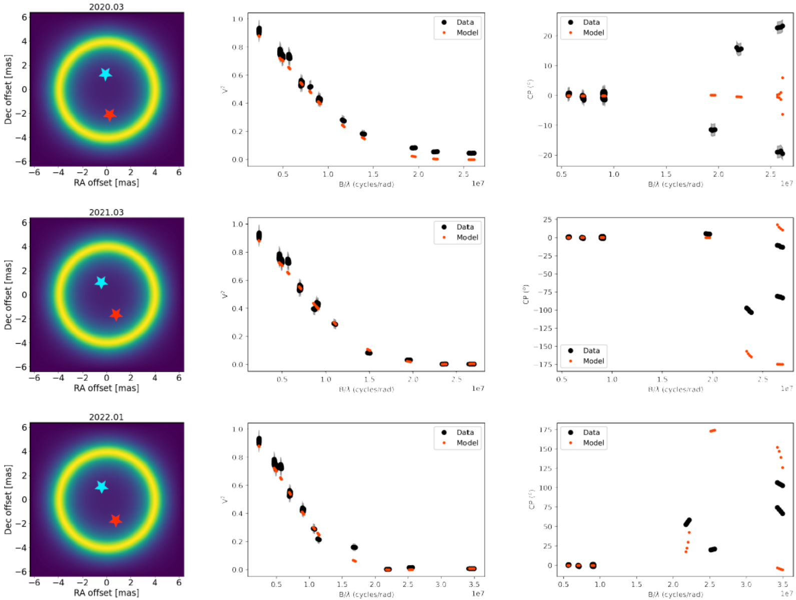


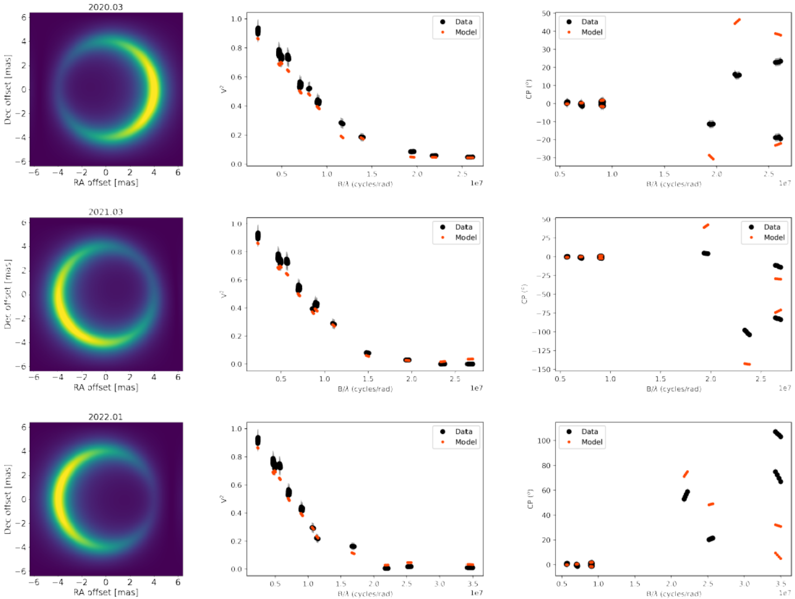
Figure 8: Schematic representations of models of DX Cha. **Left:** our model, showing the *L*-band brightness distribution. **Right:** sketch of the surface density map from the SPH simulation by Dunhill et al. (2015)

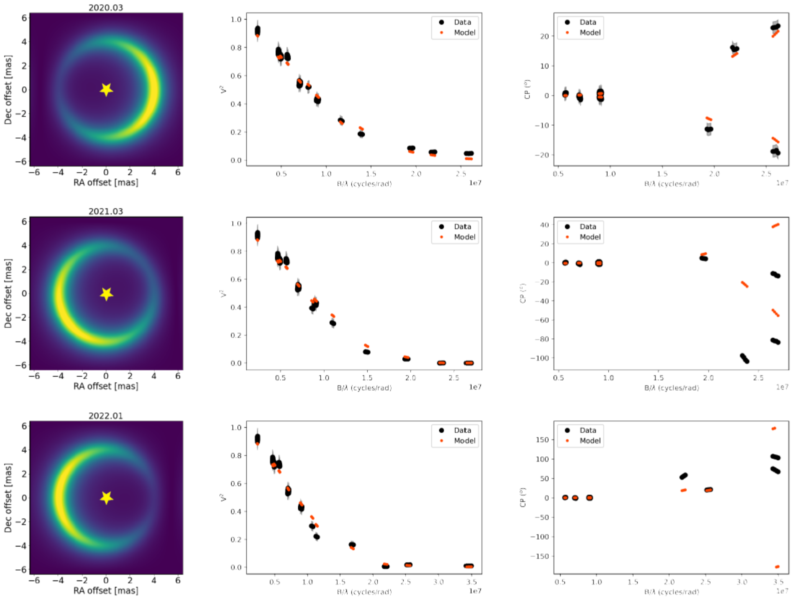
Discussion

- asymmetry: stellar or disk origin?
- test models:
  - symmetric disk around the binary star
  - asymmetric disk without point sources
  - asymmetric disk with one, central point source (with the brightness of the binary star)
- we experienced large closure phases in all tests
- it cannot be determined whether the binary star or the disk is more significant
  - epoch 2020: disk asymmetry determines the closure phases
  - other epochs: the signal of the binary star is also important



2020.03
2021.03
2022.01
Dec offset [mas]
RA offset [mas]
Data
Model
V^2
B/λ (cycles/rad)
1e7
CP (°)


2020.03
2021.03
2022.01
Dec offset [mas]
RA offset [mas]
V²
B/λ (cycles/rad)
1e7
CP (°)
Data
Model



2020.03
2021.03
2022.01
Dec offset [mas]
RA offset [mas]
Data
Model
V²
CP (°)
B/λ (cycles/rad)
1e7

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Evidence for an accretion bridge in the DX Cha circumbinary system from VLTI/MATISSE observations*

Tímea Juhász [1,2,3] József Varga [1,3] Péter Ábrahám [1,3,2] Ágnes Kóspál [1,3,2] Foteini Lykou [1,3] Lei Chen [1,3]
Attila Moór [1,3] Fernando Cruz-Sáenz de Miera [4,1,3] Bruno Lopez [5] Alexis Matter [5] Roy van Boekel [6]
Michiel Hogerheijde [7,8] Margaux Abello [5] Jean-Charles Augereau [9] Paul Boley [6] William C. Danchi [10]
Thomas Henning [6] Mathis Letessier [9] Jie Ma [9] Philippe Priolet [9] Marten Scheuck [6] Gerd Weigelt [11] and
Sebastian Wolf [12]

[1]*Konkoly Observatory, HUN-REN Research Centre for Astronomy and Earth Sciences, Konkoly-Thege Miklós út 15-17, 1121 Budapest, Hungary*
[2]*Institute of Physics and Astronomy, ELTE Eötvös Loránd University, Pázmány Péter sétány 1/A, 1117 Budapest, Hungary*
[3]*CSFK, MTA Centre of Excellence, Konkoly-Thege Miklós út 15-17, H-1121 Budapest, Hungary*
[4]*Institut de Recherche en Astrophysique et Planétologie, Université de Toulouse, UT3-PS, CNRS, CNES, 9 av. du Colonel Roche, 31028 Toulouse Cedex 4, France*
[5]*Université Côte d'Azur, Observatoire de la Côte d'Azur, CNRS, Laboratoire Lagrange, France*
[6]*Max Planck Institute for Astronomy, Königstuhl 17, D-69117 Heidelberg, Germany*
[7]*Leiden Observatory, Leiden University, P.O. Box 9513, 2300 RA Leiden, The Netherlands*
[8]*Anton Pannekoek Institute for Astronomy, University of Amsterdam, the Netherlands*
[9]*Univ. Grenoble Alpes, CNRS, IPAG, 38000 Grenoble, France*
[10]*NASA Goddard Space Flight Center, Astrophysics Division, Greenbelt, MD 20771, USA*
[11]*Max-Planck-Institut für Radioastronomie, Auf dem Hügel 69, 53121, Bonn, Germany*
[12]*Institute of Theoretical Physics and Astrophysics, University of Kiel, Leibnizstr. 15, 24118 Kiel, Germany*

ABSTRACT

DX Cha (HD 104237) is a spectroscopic binary consisting of a Herbig A7.5Ve-A8Ve primary star and a K3-type companion. Here we report on new 3.55 μm interferometric observations of this source with the Multi Aperture Mid-Infrared Spectroscopic Experiment (MATISSE) at the Very Large Telescope Interferometer (VLTI). To model the four MATISSE observations obtained between 2020 and 2023, we constructed a time-dependent interferometric model of the system, using the `oimodeler` software. The model consists of an asymmetric ring and two point sources on a Keplerian orbit. Our best-fit model consists of a circumbinary ring with a diameter of 0.86 au (8.05 mas), featuring a strong azimuthal asymmetry. We found that the position angle of the asymmetry changes tens of degrees between the MATISSE epochs. The ring is relatively narrow, with a full width at half maximum (FWHM) of ~0.14 au (1.31 mas). The presence of circumstellar dust emission so close to the binary is unexpected, as previous hydrodynamic simulations predicted an inner disk cavity with a diameter of ~4 au (~37.5 mas). Thus, we argue that the narrow envelope of material we detected is probably not a gravitationally stable circumbinary ring, but may be part of tidal accretion streamers channeling material from the inner edge of the disk toward the stars.

Thank you for your attention!