Near and mid-infrared study of the “dipper” star RY Lup with Optical Interferometry

Mathis LETESSIER[(a)], J-C. AUGEREAU[(a)], A. MATTER[(b)], J. VARGA[(c)], K. PERRAUT[(a)], Y. BOUAROUR[(a)] and the MATISSE Consortium

The T-Tauri star **RY Lup** has been extensively studied since the 1930s. It is known to **exhibit temporal variability** of a **3.75-day** luminosity modulation in the **V-band**. This behaviour may be linked to **dusty material orbiting the star** and **periodically obscuring its light** ("dipper” star) [1].
In this work, we use recent **VLTI/MATISSE** observations in the **L, M, and N bands** (3–12 µm), and older **VLTI/PIONIER** and **VLTI/GRAVITY** observations in the **H** and **K band** (1.5-2.5μm) [2,3] to model the **inner regions** of RY Lup’s protoplanetary disk.

What’s a Dipper? :

Dippers are Young Stellar Objects that appear to have a **varying luminosity** in optical, especially in **V Band**. They are periodic, quasi-periodic, or irregular **deep dimming events** of usually several magnitudes that can go from **days to months**.
The dimming events are caused by **dust obscuring the stellar light** along the line of sight, but the exact mechanism isn’t yet well understood.
Figure 1 represents the current model for the dippers [4].

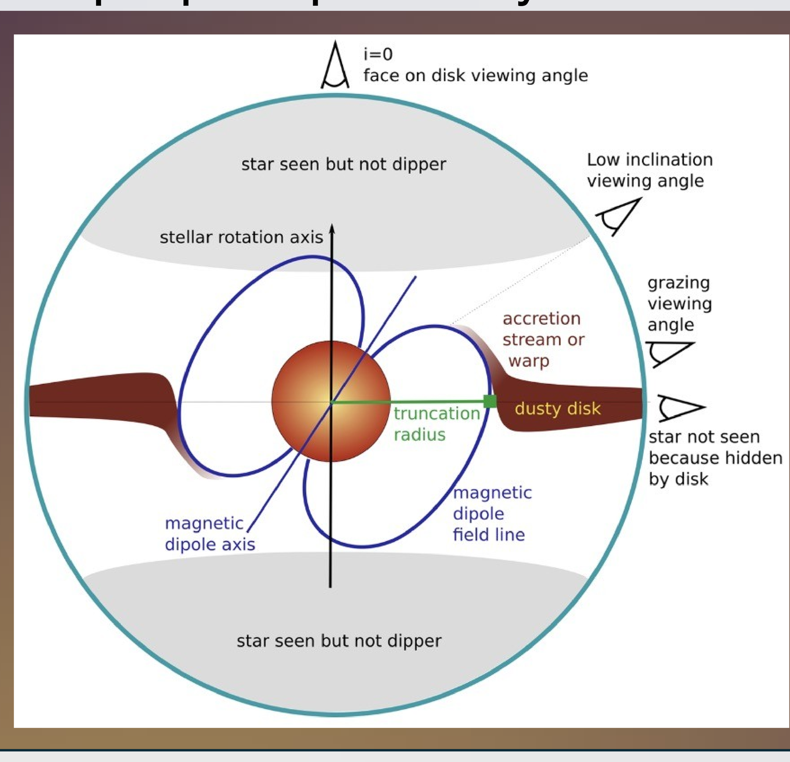


Figure 1 (Left): Dipper schematics [4] showing the need for an inclined magnetic field and low viewing angle in order to observe the dust occultation of the stellar light.

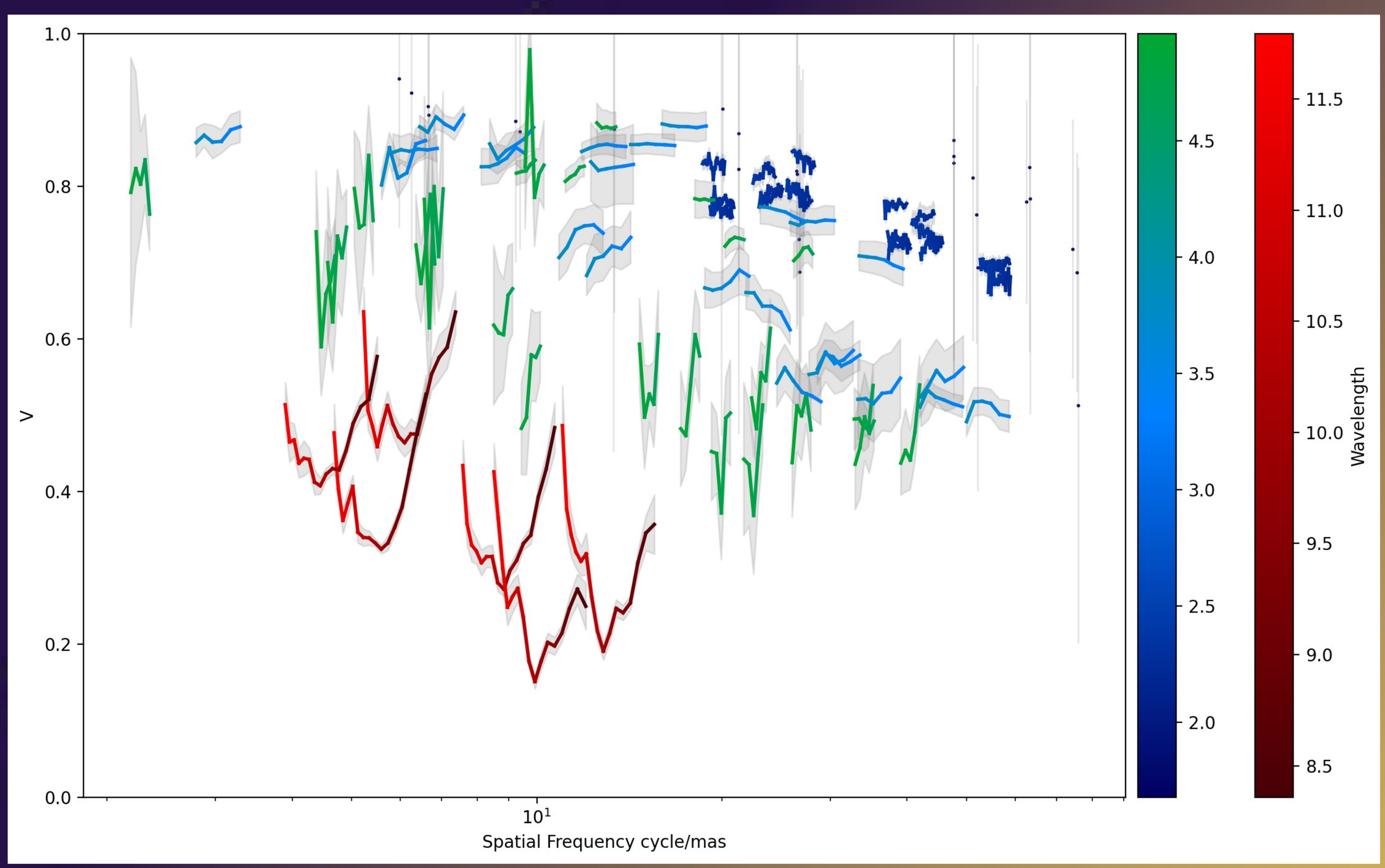


Figure 2 (Above): Plot of the dataset used in the modelling, with the Visibilities as a function of the spatial frequencies. The color represents their associated wavelengths from 1.5 to 12μm (H, K, L, M and N band).

Data sample :

Optical interferometry makes use of **two telescopes** observing the **same target.** The obtained light can then create an **interference pattern** when combined, from which we get two quantities:
Spatial frequencies (B/λ) represent the **observed scale of the object** (larger scales for smaller spatial frequencies and smaller scales for higher spatial frequencies).

The **visibility** reflects how much the object is **resolved**, ranging from 1 (unresolved) to 0 (fully resolved).

The observations (Figure 2) were carried out with the VLTI (Paranal, Chile):
- in **5 spectral bands** (H, K, L, M, N), ranging from 1.5 to 12 microns
- using **3 telescope configurations** for the 1.8m (AT) telescopes (L and M bands), and **1 configuration** for the 8m (UT) telescopes (L, M, and N bands)

Geometrical modelling :

Model fitting is performed using the **OIMODELER** software, which generates **synthetic visibilities** and fits the data via a Monte Carlo Markov Chain (**MCMC**) method.
The data from each spectral band and telescope configuration (between UT and AT) are fitted **independently**.

The chosen model is composed of 3 components:
- An **unresolved point** (star)
- A **circumstellar component** (here a 2D Gaussian)
- An **over-resolved component** (called ”Halo”)

The model is composed of 3 spatial free parameters and 2 flux ratio free parameters (per wavelength point).

We see a **spread in the inclination** and an apparent **rotation in the position angle** as a function of the wavelength. The FWHM behaves as expected and show that we are indeed observing **thermal emission** (colder emissions are further out from the star).

The total flux in the N band also shows that the **10μm silicate feature** appears to **have a non-negligible emission from the Halo** and thus further out than the inner disk.

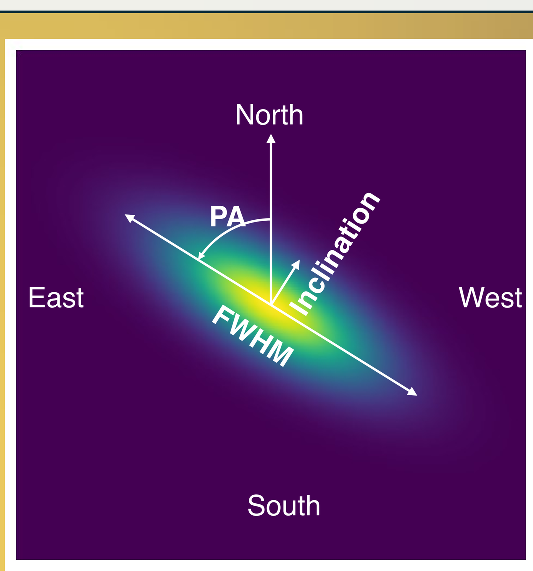


Figure 3 (Left): Schematics of the three spatial free parameters of the model. The Position Angle (PA) is the angle between the North and the semi-major axis. The Full Width at Half Maximum (FWHM) is the size of the semi-major axis. The Inclination is the "flattening" of the Gaussian mimicking the viewing angle of a flat disk (0° being Face-on and 90° being Edge-on).

Figure 4 (Below): Plot of the results of the three spatial free parameters as a function of the wavelength. The modelling of the UT and AT data are in blue and orange, respectively. Each dataset has a Chromatic and Achromatic model. Parameters from the outer disk from VLT/SPHERE and ALMAare represented by the red and black dashed line.

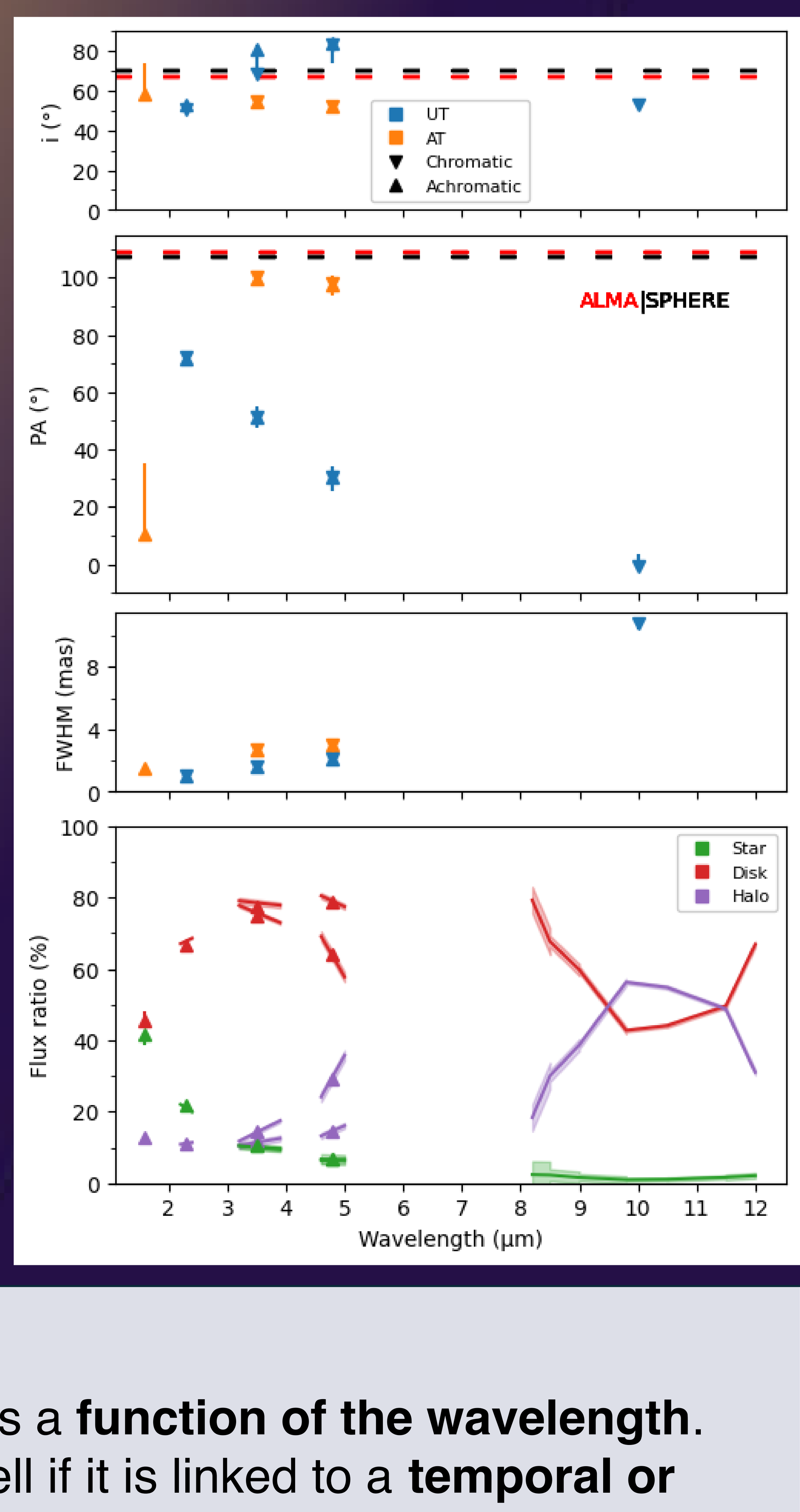
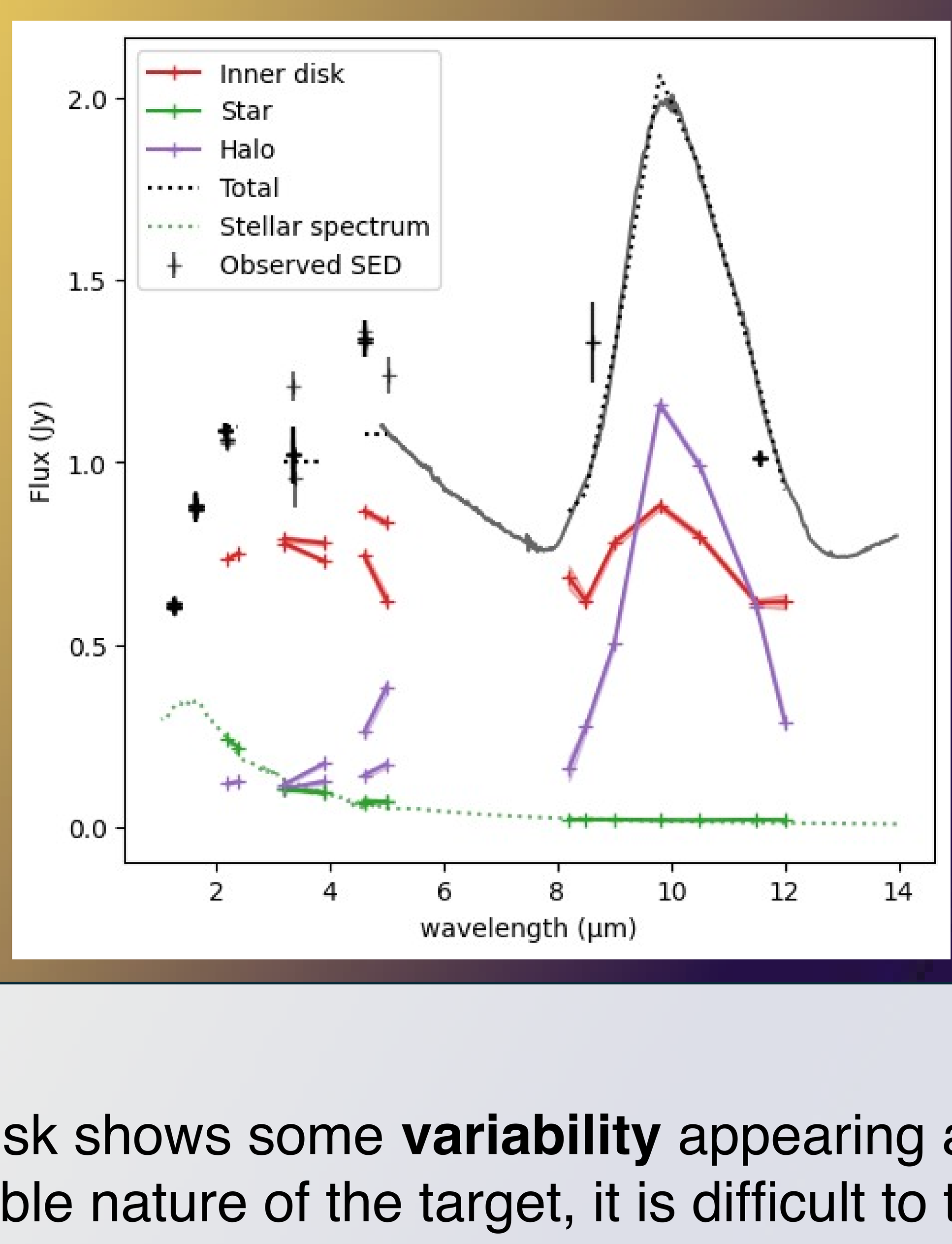


Figure 5 (Below): Plot of the flux repartition of each of the 3 components of the model for the UT and AT as a function of the wavelength.



Conclusion :

The modeling of the inner emission of RY Lup’s protoplanetary disk shows some **variability** appearing as a **function of the wavelength**. With the observations being taken **years** apart and with the variable nature of the target, it is difficult to tell if it is linked to a **temporal or geometrical variation**. In order to resolve this uncertainty, we have proposed **new observations** during the ESO call for proposals of P117. The **N band** seems to indicate that the **silicate feature** is linked to a region that is **further out** from the star and is planned to be studied in more detail with a **gradient temperature model.**

[1] Bouvier, J., et al. (1999),A&A, 349, 619
[2] GRAVITY Collaboration, et al. (2020), A&A, 642, A162
[3] GRAVITY Collaboration, et al. (2021b), A&A, 655, A73
[4] Bodman, E. H. L., et al. (2017), MNRAS, 470, 202

(a) Univ. Grenoble Alpes, CNRS, IPAG, 38000 Grenoble, France
(b) Université Côte d’Azur, Observatoire de la Côte d’Azur, CNRS, Laboratoire Lagrange, France
(c) Konkoly Observatory, Research Centre for Astronomy and Earth Sciences, HUN-REN, Konkoly-Thege Miklós út 15-17, 1121 Budapest, Hungary

MATISSE

IPAG Institut de Planétologie et d'Astrophysique de Grenoble

Université Grenoble Alpes