AMBER+FINITO+UT Science Demonstration Proposal

Title: Density wave in circumstellar disks of Be stars.

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Abstract:

Density waves in circumstellar disks are a key ingredient to explain mass transfer and disk secular evolution, including planet formation. In this context, Be stars form an ideal laboratory to study the general properties of disk instability and/or oscillations. We propose to use the unique capabilities of AMBER+FINITO+UTs in its high spectral resolution mode to probe the kinematics and the structure of the "one-armed" oscillation discovered in ζ Tau (and two other adequate Be stars).

Scientific Case:

Density waves are a key ingredient to explain mass transfer and secular evolution in circumstellar disks (including planet formation). To study them, decretion disks around rapidly rotating Be stars are ideal laboratory: *(i)* Their asymmetric double-peak profiles of Balmer emission lines (quantified with the V/R ratio) have been interpreted as a consequence of a density perturbation traveling across the Keplerian disk. *(ii)* They are known for long time, and long sequence of photometric, spectroscopic and polarimetric data are available. *(iii)* They are just close enough to be spatially resolved by the most up-to-date optical/near-IR interferometers like VLTI or CHARA.

Important progress in understanding the oscillation characteristic have already been done these last years thanks to spatially resolved observations. Gies et al. (2007 ApJ 654) determined geometrically the size, inclination and orientation of 4 northern Be-star disks by the mean of broad band (K') observations at the CHARA array. Latter, Meilland et al. (2007 A&A 464) detected an asymmetry in the disk of κ CMa using the spectro-interferometric capabilities of AMBER at Medium Resolution (MR, $R = 1\,200$), even if this seems to be poorly explained within the "one-armed" viscous disk framework.

Recently, our group compiled a wealth of observations of the classical Be star ζ Tau, including photometric, spectroscopic, polarimetric and interferometric AMBER MR observations (Stefl et al., paper I in prep). The main interest of ζ Tau is to show a clear pseudo periodic behavior in the V/R ratio, as well as other periodic spectral features (e.g appearance of triple-peak Hα line profiles), linked to the "one-armed" oscillation traveling the disk with a period of 1500 d. We have carried out a detailed three-dimensional, NLTE radiative transfer calculations using the code HDUST, with the goal to conduct a critical quantitative test of the global oscillation scenario (Carciofi et al., paper II in prep). The results of a global fit are impressively consistent for all kinds of observations (V/R time series, interferometric snapshot, polarimetry), including the general geometry and size but also the *phase of the "one-armed" density wave* (see Fig. 1).

The next step is to constraint not only the phase, but also *the shape and the kinematic* of this density wave. The best road to achieve this goal is to: *(i)* increase the spectral resolution of the interferometric observations to better resolved the double-peak emission line (which is only resolved over 5 pixels in our dataset), *(ii)* increase the super-resolution effect by improving the data SNR (our data set was obtained without fringe-tracking) and *(iii)* increase the temporal coverage to catch the wave at different azimuthal positions within the disk (see Fig. 1).

The SD run of AMBER+FINITO+UTs is perfectly suited to initiate this observing campaign, since it enables High Resolution interferometry (HR, $R = 12\,000$) at high accuracy, and within a short time line (ζ Tau only becoming observable again in 7 months). Moreover, in October 2008, the ζ Tau disk oscillation will be approximately at the opposite phase (V/R maximum) compare to our AMBER observation of December, 2006 (V/R minimum), which makes these two data sets very complementary.

Based on our previous modeling, we believe a single observation of ζ Tau at $R = 12\,000$ in Oct. 2008 will already provide wealth of information on the density, shape, and velocity field of the oscillation. We propose to observe this star in the emission lines Brγ and He I in order to model the structure of the density wave at different distances from the central star (He I being formed much closer). The overdensity was barely detected in our previous He I observations (December 2006) but we believe it is now well feasible thanks to the gain in SNR obtained with FINITO.

In addition to ζ Tau, we propose to observe 2 more Be stars with proved disk oscillation (Rivinius et al., 2006 A&A 459) and similar parallax and general properties as ζ Tau (so spatially resolved by AMBER/VLTI). They represent a limited sample with compact properties, and so already permit a test of the excitation mechanism. For all of them we have many spectra and we have already done their analysis. However, unlike for ζ Tau, due to variable lengh of individual cycles, we cannot predict the m=1 phase of the oscillation.

All together, the proposed AMBER measurements promises to lead to an important leap in our general understanding of the density wave phenomena in circumstellar disks.

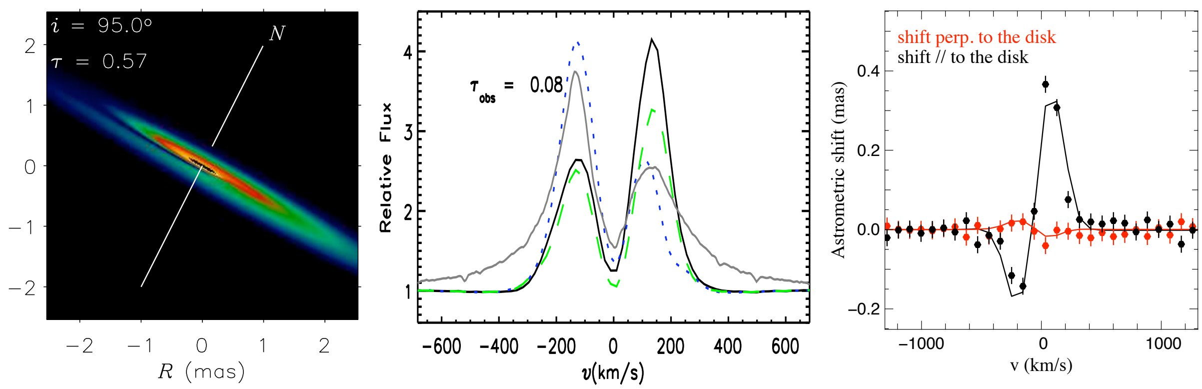

Figure 1: **Left:** Our best-fit model of the nearly edge-on disk around ζ Tau, showing the "one-armed" overdensity pattern in red (central star has been removed, celestial North is up and East is right). **Middle:** Hα emission line showing the V/R variation, which was the first clue of a traveling overdensity. This profile periodically shows 3 peaks which may be a phase with decisive information. **Right:** Our Brγ AMBER MR ($R = 1\,200$) observations converted into astrometric shift, superimposed with the result of the model (solid lines). Note the clear lack of spectral resolution to study the line kinematic, as well as the impressive spatial accuracy ($\sim 25\,\mu$as) which would be even overcome with higher SNR data.

Calibration strategy:

As shown in this proposal, our team has a strong expertise in Be stars, disk-modeling, and AMBER observations. Our main interest is in differential quantities within the lines, and we have no special need of absolute calibration. We can easily share the calibrator(s) with other programs requiring the same mode, even far in sky and time.

Targets and number of visibility measurements

The target are ranked from highest (ζ Tau) to lowest priority. Already a successful observation of one of these stars in a single band (Brγ or He I) would already provide wealth of information on the overdensity.

Target	**RA**	**DEC**	**V** mag	**H** mag	**K** mag	**Size** (mas)	**Vis.** (cont.)	**Mode**	**# of** Vis.
ζ Tau	05 37 38	+21 08 33	3.3	3.1	2.8	2	>0.5	HR 2.172, HR 2.056	1
ν Gem	06 28 57	+20 12 43	4.1	4.5	4.3	2	>0.5	HR 2.172, HR 2.056	1
28 Tau	03 49 11	+24 08 12	5.0	5.0	4.9	2	>0.5	HR 2.172, HR 2.056	1

Time Justification:

For a given star and for a given spectral band, one measurement is enough to achieve our goals. ζ Tau and ν Gem can only be observed at the end of the nights (for an airmass below 1.5), but they can be used to test/try the system at higher airmass, since we don't have any specific LST constraints.