AMBER+FINITO+UT Science Demonstration Proposal

Resolving the magnetic wind confinement region of the Orion Trapezium star θ^1 Ori C

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Abstract:

θ^1Ori C, the most massive star in the famous Orion Nebula Cluster, is a perfect target for the study of young hot stars. Detailed studies have established the picture of an oblique magnetic rotator, whose fast stellar winds are channeled along strong magnetic field lines. Whether this wind confinement occurs near the stellar surface in polar cups or in an extended equatorial cooling disk is the subject of ongoing debates. In order to address this question and to demonstrate the unique scientific capabilities provided by AMBER with FINITO fringe tracking, we propose to spatially resolve the Brγ line-emitting region with a high spectral resolution of $R = 12,000$, tracing the shocked hot plasma around the star.

Scientific Case:

The Orion Nebula Cluster, at a distance of just 450 pc, is the nearest high-mass star-forming region and a perfect laboratory for studying the birth of massive stars. In particular the brightest and most massive ($44 \pm 5 M_\odot$, Donati et al. 2002) of the Trapezium stars, θ^1Ori C, has been the target of numerous studies. With an age $\lesssim$ 1 Myrs, this O7V-type star is also one of the youngest O-type stars known in the sky, and its strong Lyman radiation dominates the whole Orion Nebula. θ^1Ori C also illuminates the proplyds and shapes its environment by strong stellar winds. Furthermore, this star is known to be a close binary system, with a separation of $\approx$ 23 mas (epoch October 2008; Weigelt et al. 1999; Schertl et al. 2003; Kraus et al. 2007, Kraus et al., subm. to A&A).

Long series of spectroscopic observations have revealed that both the intensity and the profile of emission and absorption lines detected towards θ^1Ori C vary in a strictly periodic manner. Most remarkable is the 15.422 ± 0.002 day period, which was found in the hydrogen recombination lines and various photospheric and stellar-wind lines (Stahl et al. 1993, 1996, 2008; Walborn & Nichols 1994; Oudmaijer et al. 1997). In 1993, Stahl et al. identified the 15.422 d period with the stellar rotation period and suggested that the observed spectral variability could be explained with an oblique magnetic rotator model. The magnetic origin of the variability is also strongly supported by spectropolarimetric observations, which revealed Zeeman signatures (Donati et al. 2002). Furthermore, Gagné et al. (2005) detected evidence for occultation of the emitting plasma in Chandra light curves, indicating that the X-rays originate from a region very close to the star (≈ 1.5 R$_\star$, see also Schulz et al. 2001).

To explain these outstanding properties, in 1997 Babel & Montmerle applied the *magnetically confined wind shock* (MCWS) model to θ^1Ori C. This model, originally developed for magnetic Ap-Bp stars, describes how radiation-driven winds from both hemispheres are channeled along the magnetic field lines and collide at high velocities, forming a thin, nearly stationary shock region in the equatorial plane (see Fig. 1a). Within this disk-like structure, the plasma corotates with the field lines, cools, and is then either transferred back onto the star or expelled as asymmetric wind (Donati et al. 2002).

Taking into account that the stellar radius R$_\star$ is 10.6 ± 1.5 R$_\odot$(Simón-Díaz et al. 2006) and that the disk structure is expected to extend out to 3...5 R$_\star$, the apparent diameter of the cooling disk can be estimated to 0.6 ... 1 mas (at 450 pc). For VLTI/AMBER, this spatial scale is well within reach, especially when differential techniques are applied (a diameter of 1 mas corresponds to a drop in visibility of 0.25 on the UT1-UT4 baseline, assuming a Gaussian intensity profile). A good tracer line for the hot plasma in the wind confinement region around θ^1Ori C is the strong Brγ 2.166 μm line, which was found to be in emission ($I_{\rm line}/I_{\rm cont} = 1.3$).

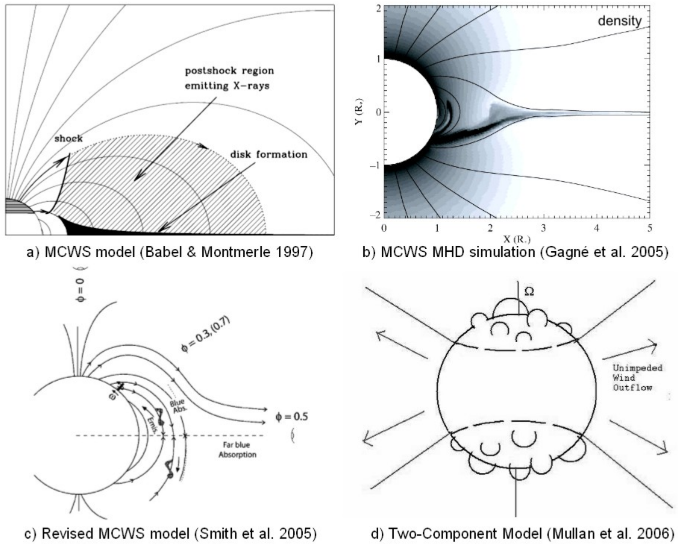

Figure 1: Schematics showing some of the scenarios which have been proposed for the geometry of the wind-confinement region from Θ^1 Ori C.

We propose AMBER+FINITO UT observations of the Brγ line in order to spatially localize and resolve the line-emitting region, obtaining direct constraints on the physical origin of the detected UV/optical/X-ray variability. Furthermore, the high spectral resolution of $\lambda/\Delta\lambda = 12,000$, which can now be achieved with AMBER+FINITO, will allow us to measure the wind geometry for several gas velocities, providing a unique combination of spatial and kinematical information about the line-emitting plasma. This spectro-interferometric information will allow us to distinguish between models (see Fig. 1) which predict an extended equatorial disk structure (standard MCWS model; e.g. Babel & Montmerle 1997; Donati et al. 2002; Gagné et al. 2005), longitudinally circulating blobs (Smith & Fullerton 2005), or stellar surface structures (Mullan & Waldron 2006).

This programme will demonstrate the outstanding scientific capabilities provided by AMBER's high spectral resolution mode and FINITO fringe tracking. With correlated magnitudes of K=4.9 and H=5.0, the required observations are well within the specifications for FINITO fringe tracking with the UTs. The UT1-UT2-UT4 telescope tripet is very well suited for the presented study, since the longest baselines are required to resolve the line-emitting region.

Calibration strategy:

The primary goal of our science project is to measure the differential signatures within the Brγ 2.166 μm line with high spectral resolution and good SNR. A good absolute calibration is not required.

In order to derive the size and relative position of the line-emitting region, a correction for the continuum signature of the close-by companion has to be applied. This correction can be applied with sufficient accuracy using an available binary orbit solution (Kraus et al., subm. to A&A).

Targets and number of visibility measurements

Target	RA	DEC	V mag	H mag	K mag	Size (mas)	Vis.	Mode	# of Vis.
Theta 1 Ori C	05 35 16	-05 23 22	5.1	4.5	4.4	1.0	0.8/0.7/0.6	HR 2.172	2

Note: Given the binary nature of the object, the continuum visibility ranges between 0.6 and 1.0 on all baseline lengths, resulting in a high correlated flux even on the longest UT baseline. Our science case is to measure within the Brγ-emission line the geometry and kinematics of the equatorial wind-collision zone around the θ^1Ori C primary star, which is expected to have a characteristic size of 0.5 to 1.0 mas.

Time Justification:

To measure the expected elongation of the line-emitting region, measurements at two different hour angles are required. However, already with a single measurement, important science could be done, determining the characteristic size of the wind-confinement region.