

NACO/MLT polarimetric differential imaging of the protostar Elias 2-29

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We present adaptive optics differential polarimetric observations of the protostar Elias 2-29. The main goal of the observations is to spatially resolve the vicinity of the target in order to characterize its circumstellar environment.

1. The target: Elias 2-29

- Class I protostar in the Rho Oph association (d~160 pc, age < 1 Myr)

The central star is surrounded by circumstellar matter (disk + envelope). However, the circumstellar environment of Elias 2-29 is not fully understood given that different observations suggest different geometries:

Observations that support the presence of a nearly edge-on disk:

- Absence of thermally-processed ices along the line of sight (Boogert et al., 2000, 2002)
- Detection of bipolar molecular outflows in the NW-SE direction (Sekimoto et al., 1997; Brandner et al., 1996)
- Detection of a bipolar nebula with ISAAC/MLT (Fig. 1) (Brandner et al., 2001)
- Detection of compact H₂ emission at both sides of the source in the NW-SE direction (Fig. 5) (Khandzadyan et al., 2011)

Observations that support the presence of a nearly face-on disk:

- Flat SED (Boogert et al., 2002)
- X-ray data: strong X-ray luminosity (not absorbed by circumstellar matter) and strong Fe fluorescence line (Favata et al., 2005)

In this poster we present diffraction-limited polarimetric observations of Elias 2-29. The main goal is to resolve and characterize the circumstellar matter and to constrain the geometry of the disk.

2. NACO-CONICA observations

The observations presented here were carried out with NACO-CONICA (NACO), the adaptive optics (AO) facility at the VLT. NACO is equipped with an infrared wavefront sensor that allows to close the loop on very red sources. The target itself is very bright (K=7 mag), so we used it as a reference star.

We use the Wollaston prism and a set of broad-band and intermediate-band filters in the H- and K-band. The Wollaston prism divides the incoming light into two beams, ordinary (o) and extraordinary (e), with orthogonal polarization vectors. The Stokes vectors, Q & U can be derived subtracting these two beams (see Figure 2). The main advantages of this method in comparison with direct imaging or coronagraphy are the following: (i) it allows to suppress the unpolarized light from the central star in a very clean way providing high dynamic Adaptive Optics (AO) observations and, (ii) second, it allows to reduce the speckle noise by a factor of ~100, since both beams are observed simultaneously with the same AO correction.

Although two rotator angles are enough to obtain the Stokes vectors (see Fig. 2), we took observations at four rotator angles (0, 45, 90 and 135 degrees) in order to compare and combine redundant data-sets.

The field of view (FOV) is limited by a special mask placed at the focal plane in order to avoid the overlap of the 'o' and 'e' beams (Fig. 2). The final FOV is ~3" x 3".

Short and long exposures were taken in order to analyze the inner and outer regions around Elias 2-29, respectively. The long exposures were saturated on the core of the PSF in order to have a better signal to noise ratio in the outer parts.

Unpolarized and low-polarized standards were observed with the different setups in order to derive the instrumental polarization.

Conclusions: AO Differential imaging is a powerful technique to obtain high-contrast images with reduced speckle noise. This technique has allowed us to resolve the circumstellar matter around Elias 2-29. The target is surrounded by a disk of high inclination. Comparison with theoretical models will allow to derive the disk properties.

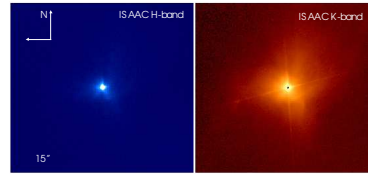
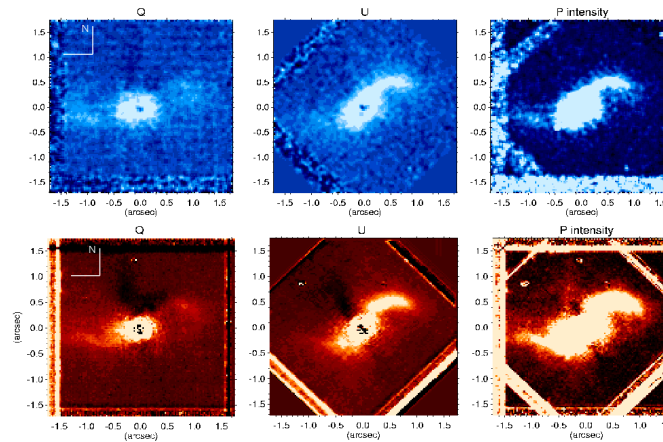


FIGURE 1 -- The vicinity of Elias 2-29 as seen by ISAAC/MLT. H & K images of Elias 2-29. The displayed field of view is 1" x 1". Both frames show diffuse emission around the central target (Brandner et al., 2001). A bipolar nebula is detected in the two bands, although brighter at longer wavelengths.



3. Data Analysis

The Q & U frames of Elias 2-29 are displayed in Figure 3. In both the H- and K-band images we detect polarized light as close as 0.1" from the central source. This corresponds to 16 AU at a distance of 160 pc. The polarized light is symmetrically distributed at radii < 0.5". At radii larger than 0.5", the frames show a bright and compact structure in the NW direction and a more diffuse structure in the opposite direction.

The P-intensity image, $P = \sqrt{Q^2 + U^2}$, is displayed in the right panels of Figure 3. The polarized light seems to be symmetrically distributed with respect to a dark lane located at a position angle of PA~30 deg. However, the NW structure is still brighter than the SW one, which is probably related with the orientation and projection of the system on the sky.

The normalized polarization image in the K-band is displayed in Figure 4. A dark lane is detected in the NE-SW direction at a PA of ~30 degrees. This dark lane is perpendicular to the direction of the previously reported molecular outflows and the K-band structures shown in Figure 5. The two bright polarized structures are detected in the perpendicular direction. The comparison of all the Figures suggests the presence of a highly inclined circumstellar disk, closer to edge-on than to face-on configuration.

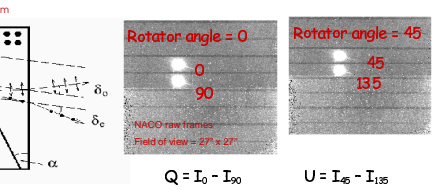


FIGURE 2 -- Wollaston prism and Stokes vectors

Left: The Wollaston prism divides the incoming light into two beams, ordinary (o) and extraordinary (e), with orthogonal polarization vectors.

Right: NACO raw images of Elias 2-29 at two rotator angles, 0 and 45 degrees: these two images are enough to build the Stokes vectors, Q & U, by subtracting the e and o beams. The dark stripes are caused by a special mask placed at the focal plane in order to avoid the overlap of the two beams.

Figure 3 -- The circumstellar environment of Elias 2-29 as seen by NACO-CONICA

NACO observations of Elias 2-29 in the H- (blue) and K-band (red). The displayed FOV is 3" x 3". The figure shows the G8U-emission together with the polarization intensity image, P.

The individual exposure times were 120 sec in H and 20 sec in Ks. The central source was saturated in order to get a higher signal in the outer parts.

The most remarkable features are (i) the bright and compact structure in the NW direction, (ii) the more diffuse structure in the SE direction and (iii) the dark lane of ~30 degrees in the NE-SW direction.

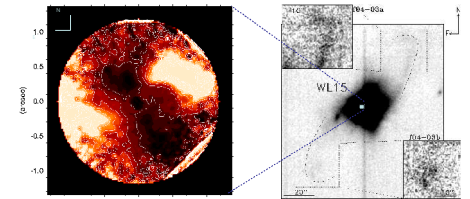


FIGURE 4 -- normalized polarization image

Normalized K-band polarization image of Elias 2-29. A dark lane is seen in the NE-SW direction, while the two bright extended structures, previously detected in the Q & U frames are located perpendicular to this dark lane. The observations suggest that Elias 2-29 is surrounded by a highly inclined circumstellar disk, that is, closer to edge-on than to face-on.

FIGURE 5 -- The vicinity of Elias 2-29 as seen by SOFINT

Ten minutes K-band (NB_2.12 filter) exposure obtained at NTT/ESO. The region studied with NACO is marked with a filled square.

Compact H₂ (bowshock like) emission is detected at both sides of the source, at a distance of ~1" and PA of 150 and 330 degrees, respectively. This compact emission is perpendicular to the dark lane detected in the NACO images, and it is probably related with a jet.