

DISCOVERY OF NEW MORPHOLOGICAL STRUCTURES OF NGC 6309

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We present new high resolution narrow-band [O III] $\lambda 5007$ images, as well as long-slit high resolution echelle spectra of the planetary nebula NGC 6309 at unprecedented detail, confirming the presence of a halo circumscribing the quadrupolar outflows and discovering two diffuse emission blobs which seems to be related to collimated ejections from the central star. Radial velocities of these faint blobs are very low, but qualitative correspond to the radial direction of the quadrupolar lobes. Some possible scenarios are discussed, including collimated outflows from the central star, interaction of wind with field material, among others.

INTRODUCTION

NGC 6309 has been described by Vázquez et al. (2008) as a quadrupolar PN formed by a bright central torus, two systems of bipolar lobes oriented at different directions, a system of point-symmetric knots tracing the edges of the lobes, as well as a faint halo, just surroundings the entire nebula. The torus expands at 25 km s^{-1} , whereas the polar expansion velocity of the lobes is 75 km s^{-1} for the bipolar system at $\text{PA}=+76^\circ$, and 86 km s^{-1} for the bipolar system at $\text{PA}=+40^\circ$. Assuming a distance of 2 kpc for the nebula, the kinematic ages of the structures ranges from 3700 to 4000 yr, suggesting that they have been formed in a short time span. Vázquez et al. (2008) also have determine the physical conditions in the central region of NGC 6309 as $T_e = 10,700 \text{ K}$, $N_e[\text{N II}] = 1600 \text{ cm}^{-3}$ (some knots $>3500 \text{ cm}^{-3}$), and $N_e[\text{Cl III}] = 2200 \text{ cm}^{-3}$. Chemical abundances obtained from this study are compatible with the possibility that NGC 6309 is a type II PN, according to the classification of Peimbert (1978).

OBSERVATIONS

NORDIC OPTICAL TELESCOPE: Narrow-band $\text{H}\alpha$, $[\text{N II}] \lambda 6583$, and $[\text{O III}] \lambda 5007$ images (Fig. 1) of NGC 6309 were acquired on 2009 July 21 using ALFOSC at the 2.56m NOT Telescope of the ORM (La Palma, Spain). The log of the observations is shown in Table 1. The EEV 2048 x 2048 CCD with pixel size $13.5\text{-}\mu\text{m pix}^{-1}$ was used as detector. The images have a plate scale of 0.184 pixel^{-1} , a field of view (FoV) $6.3' \times 6.3'$, and a spatial resolution of $0.7''$, as determined from the FWHM of stars in field. (See Table 1).

MANCHESTER ECHELLE SPECTROGRAPH: High resolution, long-slit spectra were obtained on June 6, 2013 with the MES (Meaburn et al. 2003) in the 2.1 m telescope at OAN-SPM². A e2v $13.5\text{-}\mu\text{m pix}^{-1}$ CCD with 2048 x 2048 pixels was used as detector in its 4 x 4 binning mode ($0.7 \text{ arcsec pix}^{-1}$ plate scale). The spectra were centered at the $[\text{O III}] \lambda 5007$ emission line using a filter ($\Delta\lambda=60 \text{ \AA}$) to isolate the 87th order (0.1 \AA pix^{-1} spectral scale). Exposure time was 1800 s for each spectrum. Figure 1 shows the slit paths and Figure 2 the 2D spectra, which were calibrated using a ThAr lamp and IRAF standard techniques for long-slit spectroscopy.

HUBBLE SPACE TELESCOPE: Broadband images from de MAST¹ Archive were used in order to improve the general view of the internal morphology of NGC 6309 (proposal ID: 6119; PI: H.E. Bond; Date of observation: 1995 August 26). Figure 3 shows the image using the filters *F555W* and *F814W*.

PRELIMINARY RESULTS

Our new $[\text{O III}]$ image shows the complex morphology of NGC 6309 in great detail. In particular, we confirm the presence of the halo surrounding the quadrupolar lobes. In addition, we discover two faint blob-like features outside the halo along a direction similar to that of the bipolar lobes. These structures show some similarities, but their origin is puzzling.

We found radial velocities of 2.6 km s^{-1} for the NE blob and -3.8 km s^{-1} for the SW blob with respect to the systemic velocity of $V_{\text{LSR}} = -32 \pm 2 \text{ km s}^{-1}$ (Vázquez et al. 2008). The location and kinematics of these extended blobs are nearly consistent with the two bipolar axes: the NE blob is aligned close to $\text{PA}=+76^\circ$, whereas the SW blob is close to $\text{PA}=+40^\circ$. Indeed, the SW blob seems to be in perfect alignment with a region of diminished emission of the SW lobe. The kinematics of the blobs is consistent in direction (blue- and red-shifted) with the lobes of NGC 6309.

Vazquez et al. (2008) suggest that the knots at the edges of the bipolar lobes could be evidence of rapidly precessing bipolar jets that carved cavities in the envelope ejected during the late AGB. This would suggest that the blobs are working surfaces of ancient jets, although the low radial velocity of the blobs and small distance to the central star seem to preclude this interpretation. Alternatively, the blobs may have been ejected after the formation of the quadrupolar lobes, breaking through them along the regions of diminished emission of the lobes. This interaction may have sped down the blobs to their present low radial velocity. Finally, the blobs can also be interpreted as sections of a larger structure ejected earlier in the PN evolution, in the late stages of the AGB phase. The blobs corresponds to the regions of this structure which are now illuminated along holes in the quadrupolar lobes.

The blobs of NGC 6309 remind some features shown in the *HST* $[\text{O III}]$ imaging of PK 053+241, but in an early phase (see poster of Ramos-Larios et al). A more detailed analysis, including deeper spectroscopy, will be published shortly.

REFERENCES

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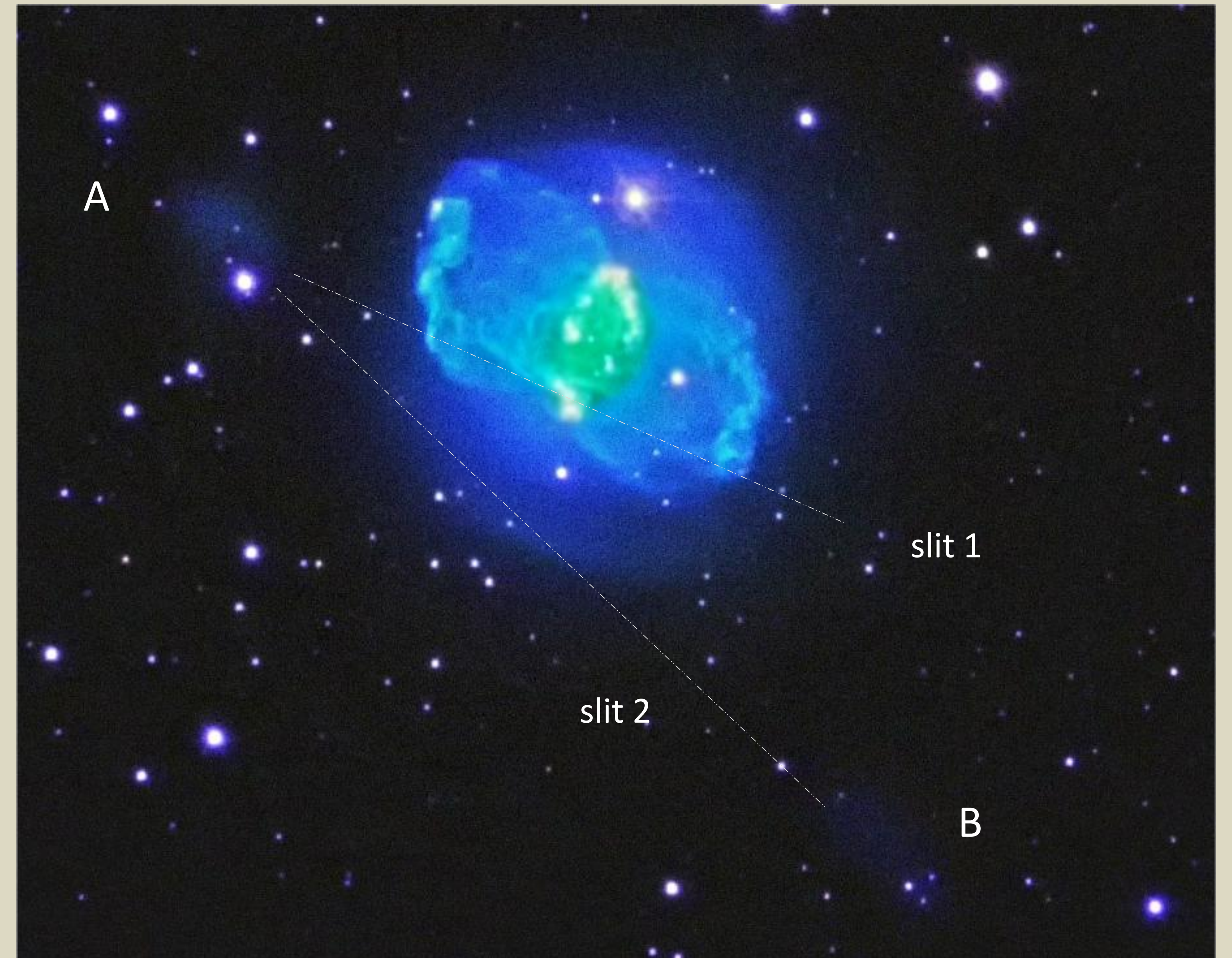


Fig. 1. NOT Color-composite of NGC 6309 showing the blobs (labels A and B) and the slits paths.

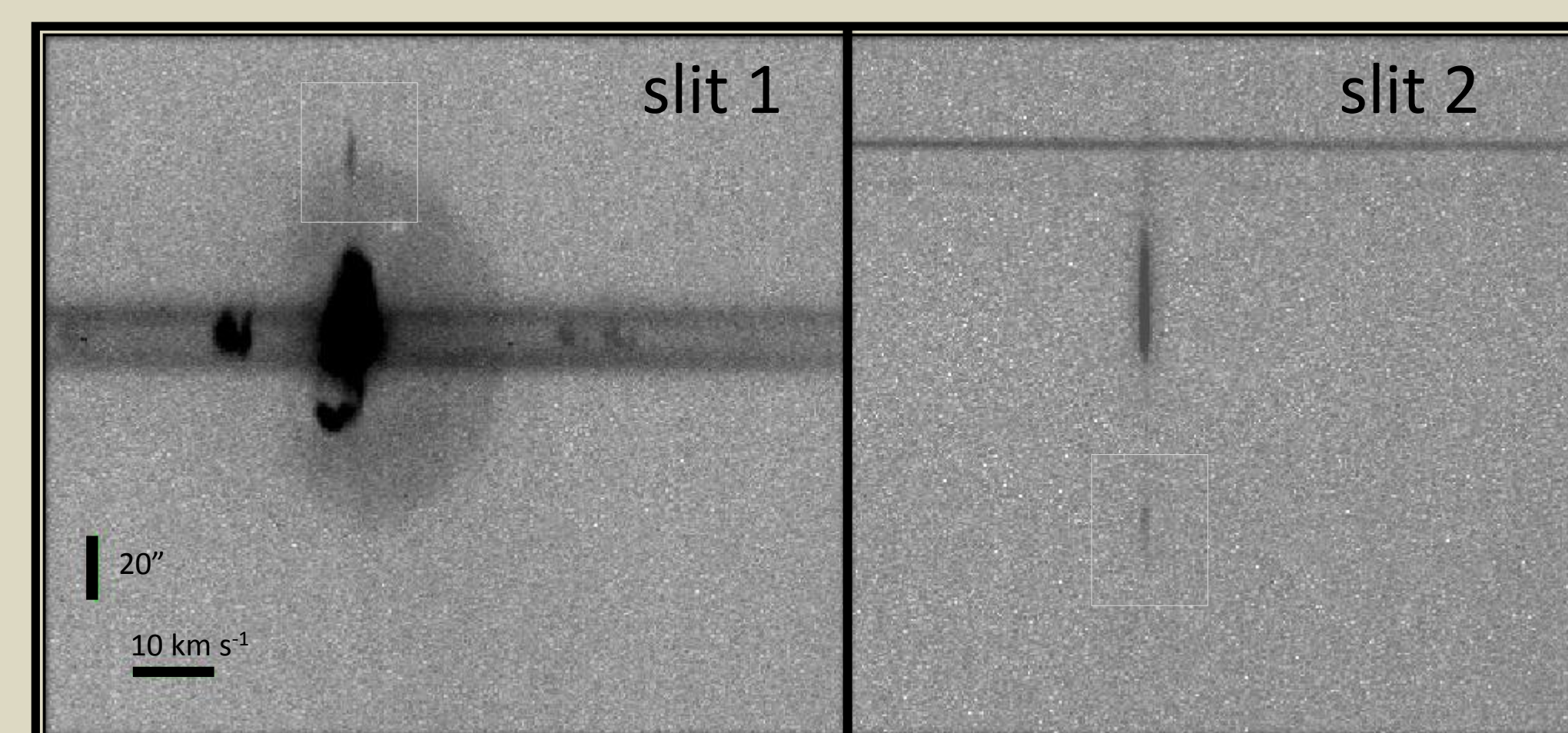


Fig.2. Echelle spectra.

Table 1

Telescope	Filter	λ_c (Å)	$\Delta\lambda$ (Å)	Exposure time (s)
NOT	[O III]	5007	30	600
NOT	H α	6567	8	900
NOT	[N II]	6588	9	900
HST	F555W	5410	1605	140
HST	F814W	8353	2555	600

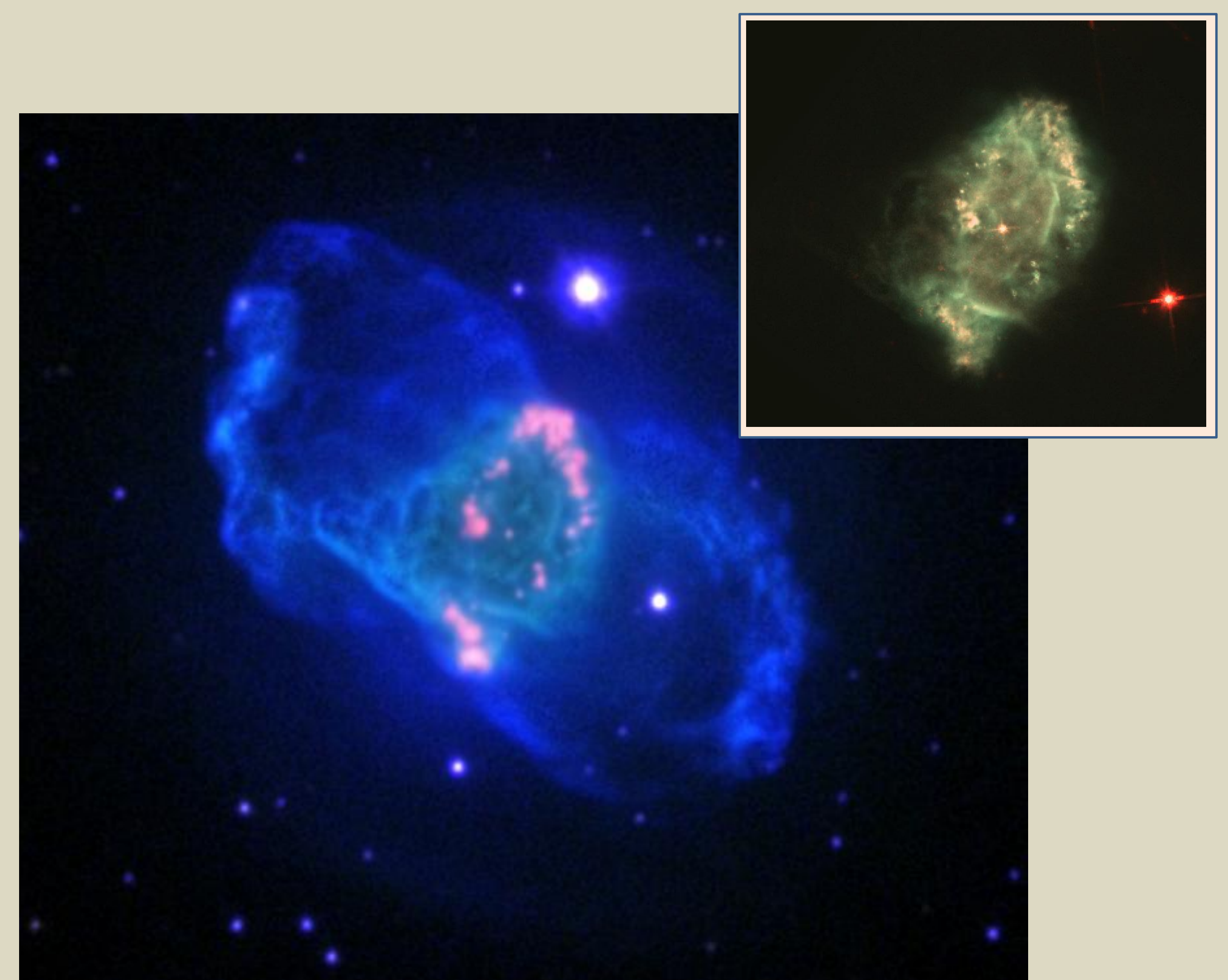


Fig. 3. Close up of the Figure 1 showing fragmented $[\text{N II}]$ emission at the central torus. Upper panel: *HST* image composition using *F555W* and *F814W* filters.

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