Subarcsecond knots and filaments in the molecular hydrogen of the bipolar PN NGC 2346

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Abstract

Molecular hydrogen images of NGC 2346 in the H_2 (1-0)S(1) 2.122 μm line were recently obtained during the System Verification (SV) of the newly commissioned Gemini South Adaptive Optics Imager (GSAOI) with Gemini Multi-Conijugate Adaptive Optics System (GeMS). Image quality is about 80 milliarcseconds over the whole FOV (85 x 85 arcseconds), which is slightly better than the Hα image obtained with HST/WFPC2. At a distance of 700 pc this corresponds to 56 AU. We were able to resolve the molecular knots and filaments; models predict these to be formed after the fast wind ceases. The central star is a binary system with a separation of 0.16 AU. The mass and orbital separation of the binary is compatible with a system that might have evolved through the common envelope (CE) phase. Knots sizes vary from 56 UA to 150 UA, and they at located at distances from the central star ranging from 0.0056 to 0.15 pc. In order for the knots to survive the photo-ionization front they would need a minimum density of 15000 cm^{-3}, which is consistent with densities found in knots and clumps (1-10 x 10^4 cm^{-3}). As the star is declining its luminosity, most of the knots are expected to survive the photo-ionization front and populate the interstellar medium.

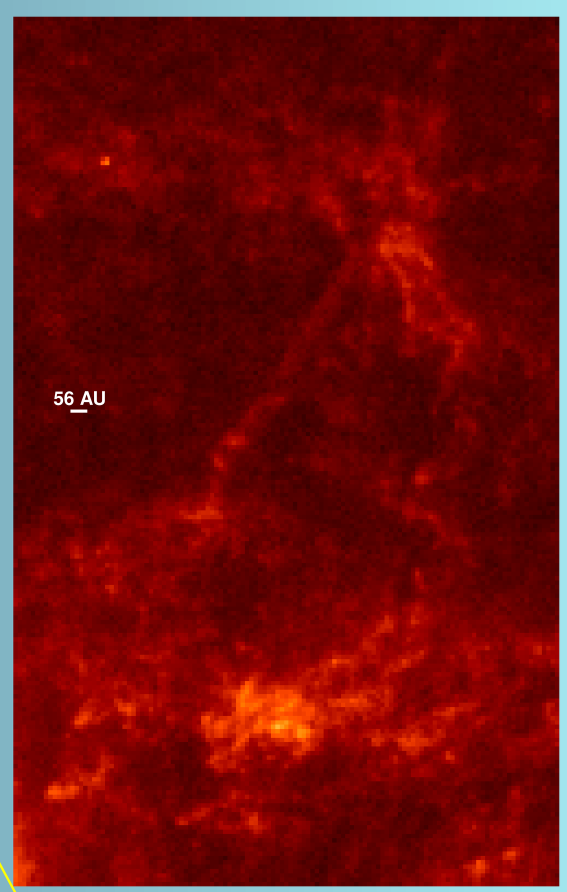
NGC 2346

NGC 2346 was chosen as test target because the emission mechanism and kinematics of the molecular hydrogen are well known (Arias et al 2001). In addition the central star is a binary system with the period and companion star well know (Méndez & Niemela 1981), therefore the distance to the nebula is well determined.

Analysis of the clumps

At a distance of 700 pc, each pixel corresponds to 13.97 AU. As can be seen in Figure 1, the H_2 emission has a clumpy structure, as opposite to the ionized gas (Figure 2) which has a smoother structure. The knots are at distances 0.0056 to 0.15 pc from the central star. Typical sizes in the 56 to 150 AU range. In Figure 1, can be seen that most of the knots are concentrated on the waist of the nebula (East-West), and at the edges of the lobes (at a distance of 0.02 pc from the central star).

In the lobes, at distances further than 0.02 pc from the central star, the H_2 emission is more diffuse.



Observations

Gemini Multi-Conjugate Adaptive Optics System (GeMS) + Gemini South Adaptive Optics Imager (GSAOI) during System Verification (March 2013).

Gemini Multi-Conjugate Adaptive Optics System (GeMS) comprises multiple deformable mirrors, three Natural Guide Stars (NGS) and five sodium Laser Guide Stars (LGS), producing over 10W of output power, each, at the sodium wavelength (589nm).

The Gemini South Adaptive Optics Imager (GSAOI) is near Infrared (NIR) camera used with GeMS on Gemini South. GSAOI provides diffraction limited images in the 0.9 - 2.4 µm range, using a 2 x 2 mosaic Rockwell HAWAII-2RG 2048 x 2048 arrays. GSAOI field of view is 85'' x 85'' with a scale of 0.02''/pixel and a gap between the arrays of ~ 2mm.

Narrow band images in the H_2 1-0 S(1) 2.122, Brγ 2.166, and H_2 2-1 S(1) 2.248 µm filters.

Integration time; 20 minutes on-target for each filter

Data reduction, including distortion correction, was carried out using the Gemini IRAF package v1.12, gsaoi.

After the combination of all the images for each band the FWHM varies over the whole FOV, between 60 and 90 milliarcseconds, with and average value of 80 milliarcseconds,. This is better than the spatial resolution of the HST in the K band, and similar to the HST resolution in the V band. Figure 1 shows the resulting image of the H_2 1-0 S(1) 2.122 µm. There was no emission in the Br γ 2.166, and the H_2 2-1 S(1) 2.248 µm filters. For comparison in Figure 2, we show a color-composite image of the [S II] collisionally excited, and Hα recombination lines obtained with HST/WFPC2/ACS.

On the formation of the clumps

García-Segura et al. 2006, explored the dynamics of ionization-bounded planetary nebulae after the termination of the fast stellar wind. When the stellar wind becomes negligible, the hot, shocked bubble depressurizes, and the thermal pressure of the photoionized region, at the inner edge of the swept-up shell, becomes dominant. The shell tends to fragment, creating clumps with comet-like tails and long, photoionized trails in between, while the photoionized material expands back toward the central stars as a rarefaction wave.

In Figure 3, we show the snapshot of the density , from Figure 1 in García-Segura et al. (2006), of model B, 7000 years after the cessation of the fast wind.

Central star

Spectroscopy binary system (Méndez & Niemela 1981) with a Period of 15.99 days

Companion star:

A5V, M_2 = 1.8 $M_\odot$, Teff= 8000k,

distance 700 pc

Ionizing star:

UV excess compatible with L=50 $L_\odot$

Teff=100000 K

Ionizing photons S_*= 4 x 10^{45} s^{-1}

Mass function f(M) = 0.0073

Assuming the orbital angle is parallel to the inclination of the nebula waist: 30°< i < 50°

for i= 30° M1= 0.64 $M_\odot$

for i= 40° M1= 0.51 $M_\odot$

for i= 50° M1= 0.45 $M_\odot$

For i = 30°, 40° and 50° the separation between the binary system is 0.167, 0.164 and 0.162 AU.

For i= 40°, the separation is 35 $R_\odot$

The binary system might have undergone the common envelope (CE) phase.

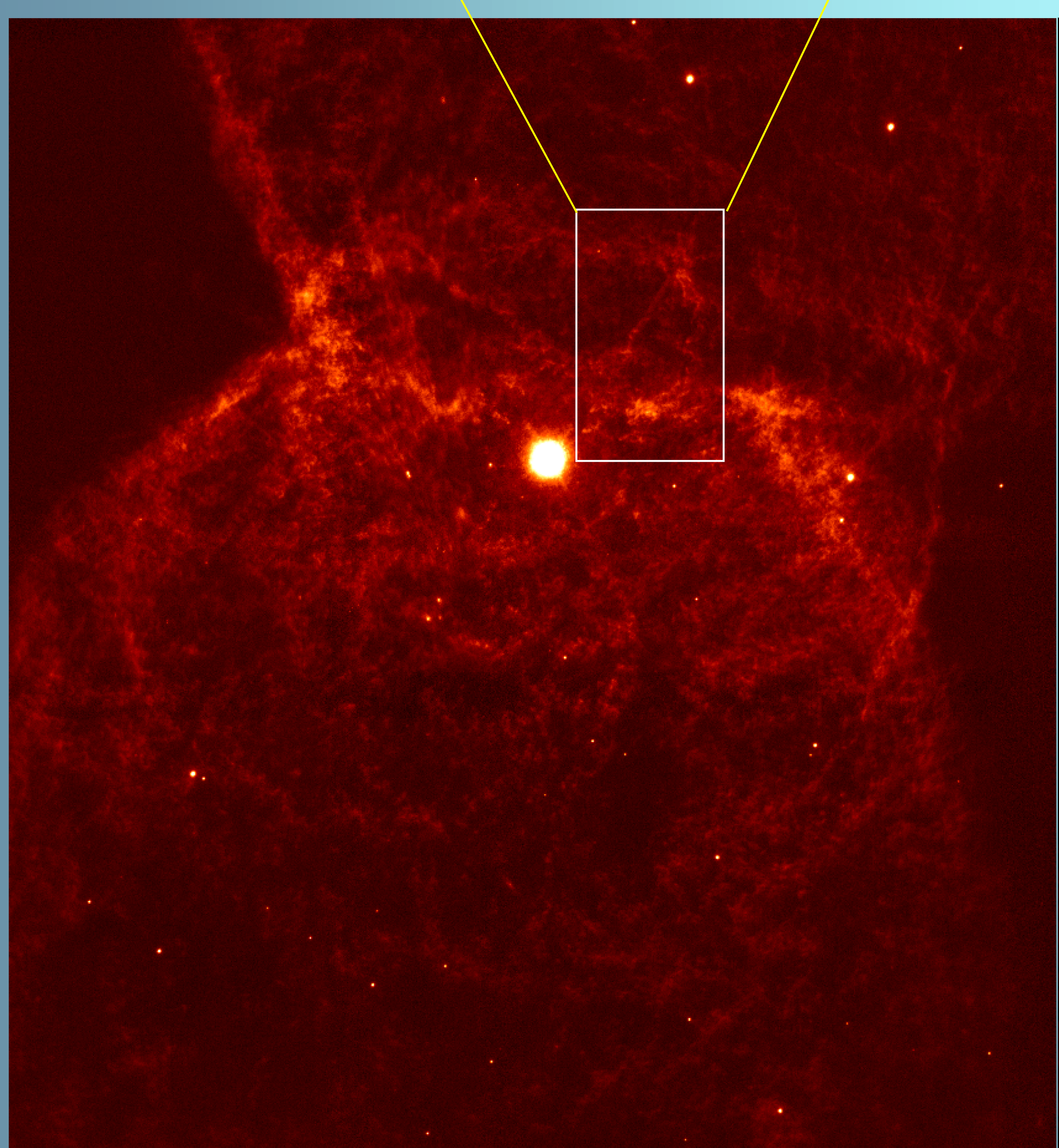


Figure 1: H_2 1-0 S(1) 2.122 micron image of NGC 6853. N is up and E left. The size of the image is 68 x 73 arcseconds.

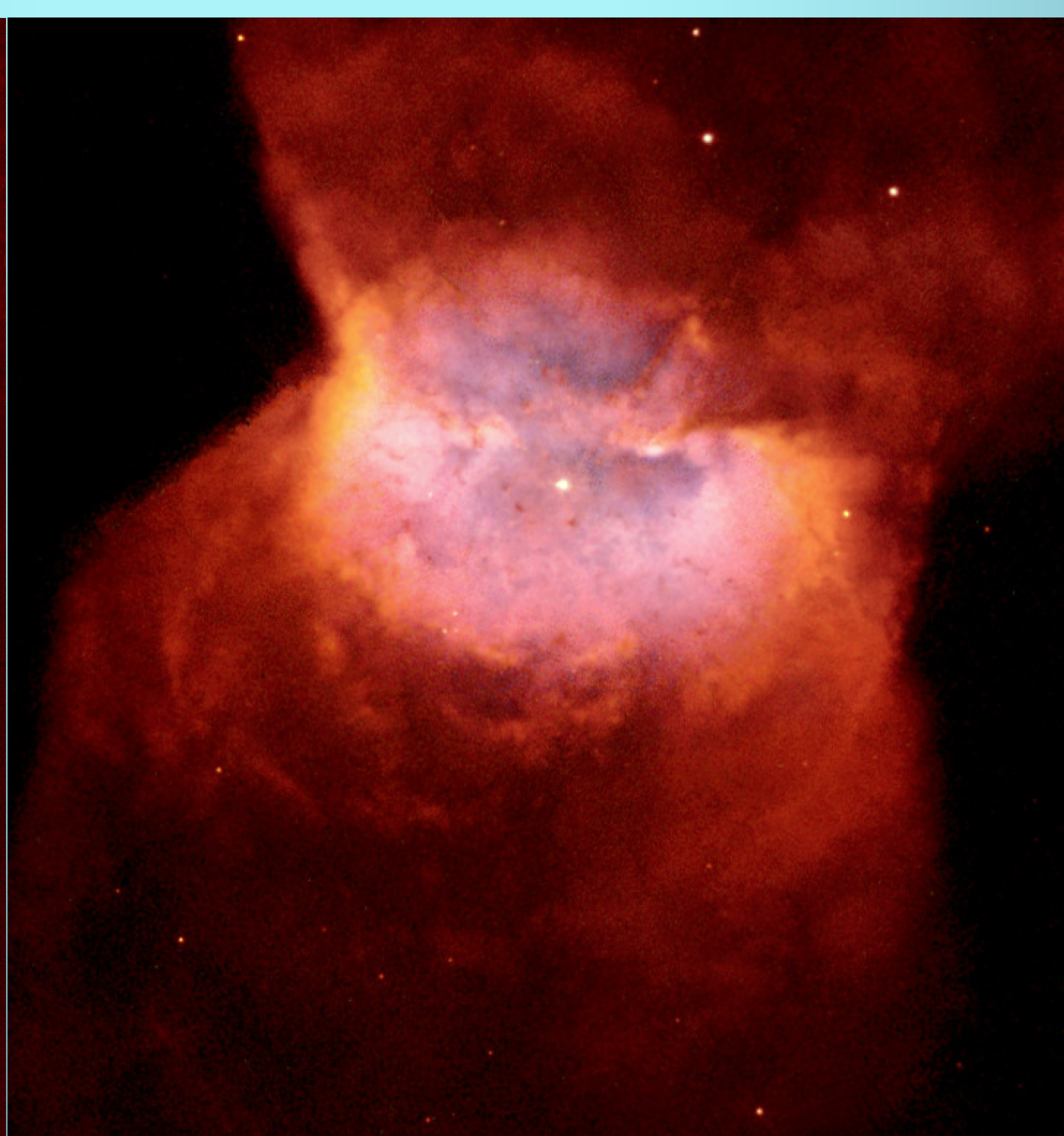


Figure 2: Color-composite HST image of NGC 2346. Blue color corresponds to [S II] (673 nm), green to Hα (656 nm), and red to R band (675 nm).

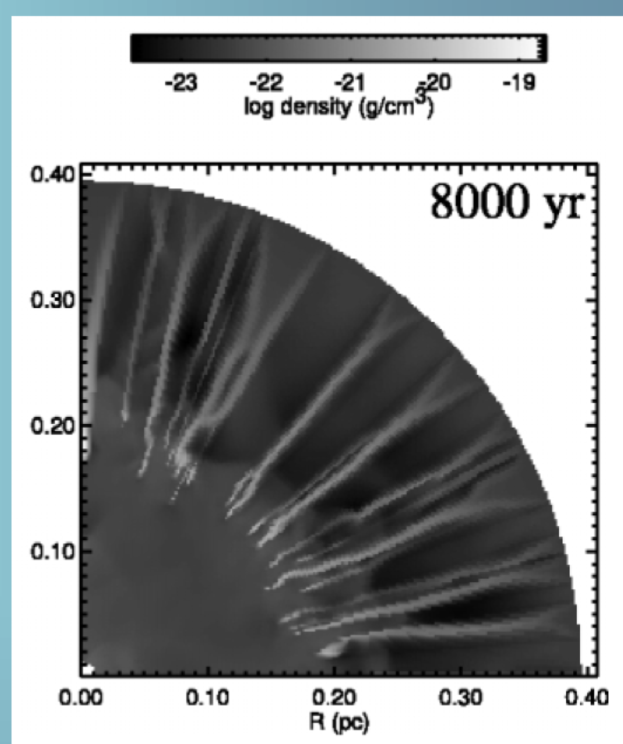


Figure 3: Snapshot of the density , from Figure 1 in García-Segura et al. 2006, of model B, 7000 yr after the cessation of the fast wind.

Dynamical and evolutionary ages

The expansion velocity of the knots is 8 km s-1 and the dynamical age is 3500 years (Arias et al. 2001).

As the star have gone through the CE phase the evolution can be very fast. The spiral-in phase can last of the order of 2 yr (e.g. Sandquist et al 1998)

The evolutionary time of the star can be much shorter (a few thousand years) than for a single star (between 30000 to 50000 yr), following the Vassiliadis & Wood (1994) tracks).

Evolutionary age may be consistent with the dynamical age.

On the surviving of the H2 clumps

In order for the knots to survive the photoionization front, they would need a minimum density of 1.5 x 10^4 cm^{-3} , following Dyson & Williams (1997), eq. 7.5

$$\frac{dR}{dt} = \frac{S_*}{4\pi R^2 n_0} - \frac{1}{3} R n_0 \beta_2$$

Where;

S_* = 4.0 x 10^{45} s^{-1},

dR (clump size) = 8.4 x 10^{14} cm, dt = 3500 yr

R (distance to the clump) = 1.7 x 10^{16} cm

n0 = 15000 cm^{-3}

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