Imaging the Globules in the Core of the Helix Nebula (NGC 7293)

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Introduction

NGC 7293 is one of the closest planetary nebulae and the only one in which small scale structures can be easily resolved on ground-based images. The distance is about 130 pc [1] and the central star has an effective temperature of ~ 120,000 K [2] making it a typical high ionization planetary nebula with emission lines of He II and higher ionization species. On account of its proximity the projected size of the nebula is very large – the bright inner rings are 13′ in diameter but there is a prominent ring structure of radius 10′ and faint extensions, clearly belonging to the nebula, out to at least 15′; the projected size is thus at least half a degree (eg. [3]). On the large scale, the nebula shows some resemblances to a helix (hence its name) in the low ionization emission (eg [N II]) but in high ionization emission a central, nearly spherical, volume [4] is seen. Some attempts have been made to understand the velocity structure in terms of a radially expanding helix but the real 3-D structure is probably more barrel-shaped with an expansion velocity of ~ 25 km/s, although higher velocity structures have been found ([5], [3]).

Knots and Tails

Around the periphery of the inner low ionization shell there are numerous small (~ 1″) emission knots, some with tails pointing radially away from the star [6]. With the NTT and EFOSC2 in 1990 (before the commissioning of EMMI) we obtained CCD images in low (Hα + [N II]) and high ([O III]) ionization emission in good seeing of some of these knots. The result was unexpected: whilst in low ionization emission the knots show up as bow-shaped structures with a bright tip on the side of the globule nearer to the central star and a tail extending radially outwards, at [O III] no emission was seen, only a depression in the local smooth [O III]; the knots were thus seen *in absorption*. On consideration, this is not so surprising if the knots are dusty and are seen against background [O III] emission [7]. If a dense dusty knot lies on the near side of the central emitting [O III] volume then it will absorb the background [O III] radiation and appear dark. Of the knots observed by Meaburn et al. [7] the one with the highest absorption had a central extinction of 0.5 mag. and a projected diameter of 1.4″ (3×10^{15} cm). If such a globule were spherical and had a dust content typical of interstellar gas and with interstellar gas-to-dust mass ratio then the density is ~ 5×10^{5} cm^{-3} and its total mass $\geq 10^{-5}$ $M_{\odot}$.

New Observations

With the new large CCD chips and the big field available for imaging at the Cassegrain focus of the NTT with EMMI we can obtain in one image the whole of the central region of the Helix nebula and examine in detail all the knots and tails. This was done in August 1992 and some of the spectacular images are shown here. Figure 1 shows the whole of an Hα + [N II] Thomson 1024^2 CCD image covering the central 7.5′ of NGC 7293. The star at the centre is the ionizing star of the nebula. In Figure 2 is shown the corresponding [O III] image. Comparison of Figure 1 and 2 shows that not all the globules seen in emission

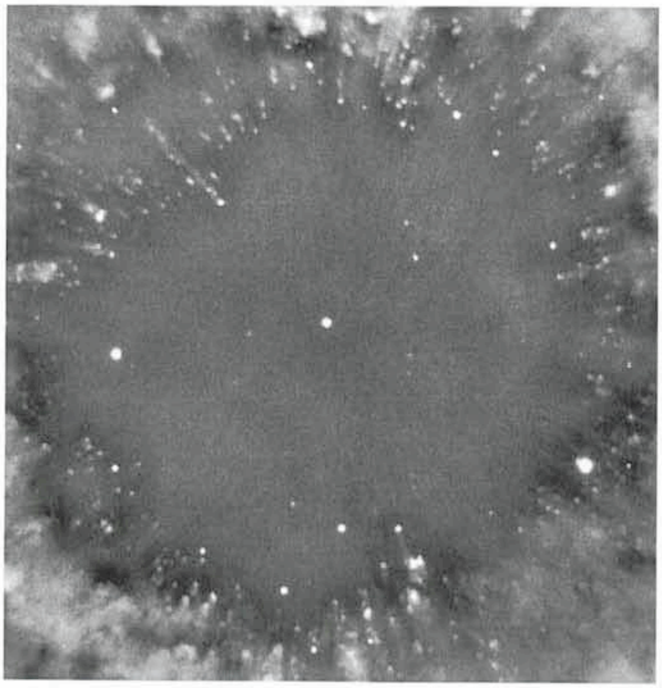

Figure 1: *A photographic representation of the NTT + EMMI CCD image of the core of NGC 7293 taken with an Hα + [N II] filter. A logarithmic intensity scale was used and the size of the field is 450 × 450″ (10″ = 1.9×10^{16} cm); north is at the top and east to the left.*

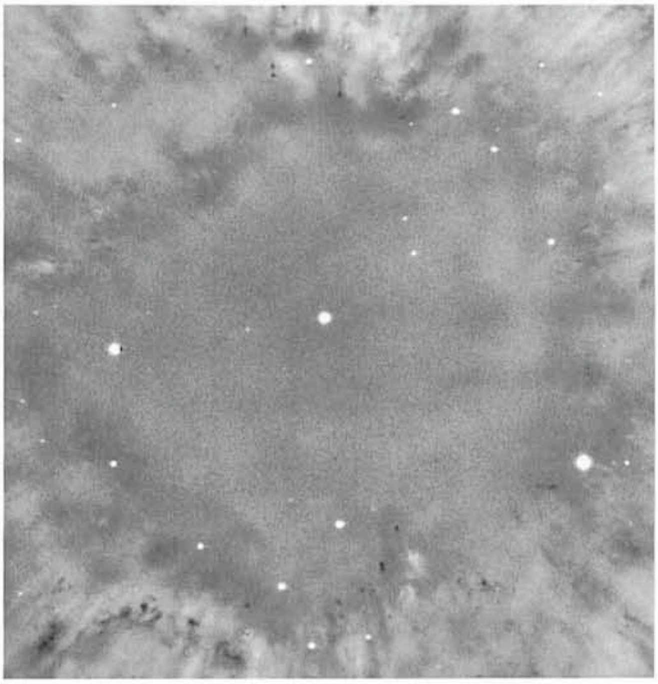

Figure 2: *A photographic print of the NTT + EMMI CCD image of the Helix nebula taken with an [O III] 5007Å filter is shown at the same scale and orientation as Figure 1.*

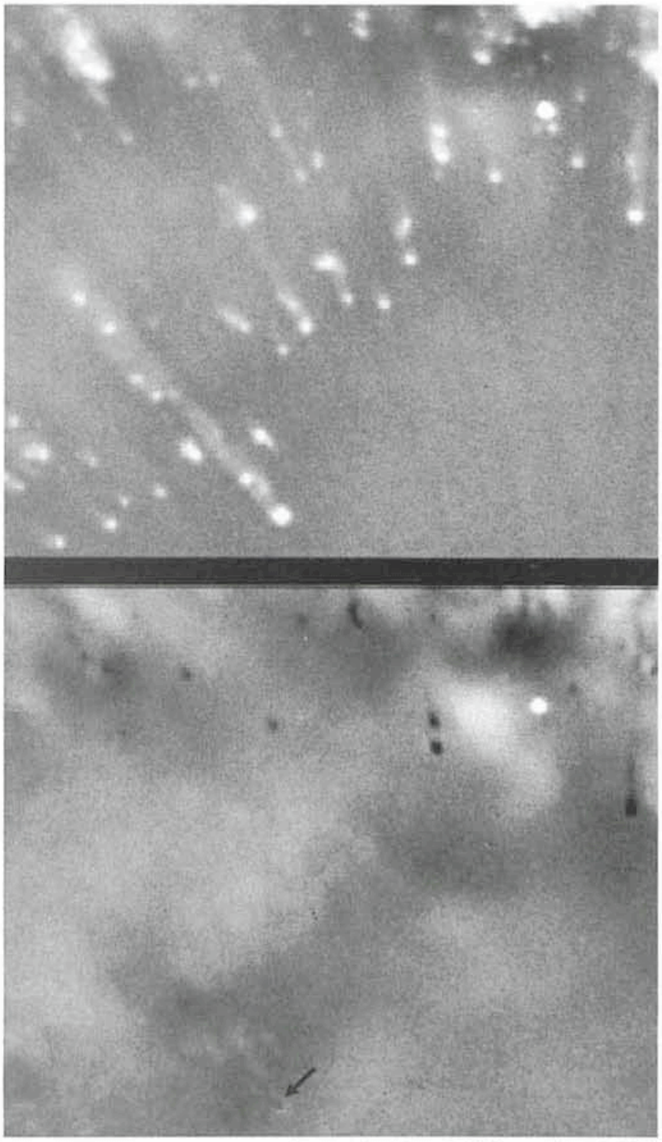

Figure 3: *An enlarged view of both the Hα + [N II] (upper) and [O III] (lower) images of the globules and tails in the north-east corner of Figure 1 is shown. The bright globule which shows both Hα + [N II] and [O III] emission is arrowed.*

Figure 4: *An enlarged view of both the Hα + [N II] (upper) and [O III] (lower) images of the region of extended dust absorption to the south-east of the core of the Helix nebula. The largest globule with the deepest absorption is indicated.*

on Figure 1 are found on Figure 2. This can be simply understood in terms of the globules being distributed along the line of sight through the nebula, some being on the near side of the [O III] zone, some on the far side; only those on the near side give rise to observed absorbing globules. Of the ~600 globules counted in emission on Figure 1, some 40% are found in absorption in Figure 2, consistent with this hypothesis. Only three globules were seen with [O III] emission from the bow-shaped heads, and one of these is seen in the lower left of Figure 3 (arrowed), which is an enlargement of a region to the north-east of the central star. The three globules with [O III] emission are also those closest in projected distance to the central star; presumably they must be embedded in the [O III] zone whilst the other globules are in lower ionization surroundings. Figure 4 shows an enlargement of the large scale dust feature to the south-east. The globule in the centre of this field (arrowed), which appears to have no low ionization emission, is the largest found with a maximum diameter of 4″ and also has the deepest absorption.

Nature of the Globules

The low ionization crescent-shaped heads to the globules are presumably attributable to radiative ionization by the photons from the central star, with most globules being beyond the O^{++} ionizing zone where the photons have lower energy. However, central stars of planetary nebulae are known to have high velocity winds (typically 2000 km/s and mass loss rates $\sim 10^{-8}\ M_{\odot}\ yr^{-1}$) so that there may be wind impacting the neutral globules and producing a bow shock around the globule. In addition, if the globules are stationary then there will be ionized gas streaming past at ~20 km/s from the expanding nebula. All these effects may contrive to drag material off the globule and entrain it in a radial tail as observed. Meaburn et al. [7] showed that the size and density of the globules are such that they could survive long enough for such ablation processes to be important.

One of the abiding puzzles is the ionization mechanisms for the tails. Early work ([8], [9]) suggested they could be ionized by the diffuse radiation field since they are shadowed by the optically thick globule from the direct ionizing radiation of the central star. Hartquist & Dyson [10] and Dyson, Hartquist & Biro [11] suggest that the material in the tail could be a low Mach number shock ionized flow caused by interaction with a low velocity wind, perhaps arising in the expanding ionized gas rather than in the stellar wind itself. Clearly the ionization mechanism in the vicinity of these globules and their tails need to be explored more closely and NGC 7293 provides an excellent site.

Where do the globules come from? Perhaps they represent clumpy ejecta from the progenitor asymptotic giant branch (AGB) star ejecta during a phase of mass loss or are formed through instabilities when the hot fast wind from the central star collides with the slow higher density red giant wind. Dyson et al. [12] have suggested that the knots could be remnants of SiO maser spots which were formed in the atmosphere of the AGB star and have survived ejection and photoionization. CO emission has been detected from some of the globules even though the beam is larger than the globules themselves [13]. The CO linewidths are small suggesting molecular gas at ~25 K. Further observations at high spatial resolution in the optical and millimetre will enable the parameters of the globules, such as the gas and dust content, to be determined and their formation and evolution to be more thoroughly investigated. So far no other planetary nebulae with similar small-scale structures have been observed but there is no reason to think that the Helix is atypical and such structures probably exist in all planetary nebulae. Until more are found the Helix will continue to be an ideal laboratory for the study of these ionized-neutral/dusty interfaces.

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OTHER ASTRONOMICAL NEWS

Detection of Faint Extended Structures by Multiresolution Wavelet Analysis

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1. Introduction

The wavelet transform, in common with other image transforms such as the Fourier or the Haar transforms, can be used to produce insightful perspectives on image data. Some particular attributes of the wavelet transform will be discussed in the next section, which seem to make it very appropriate for astronomical image data. Two illustrative examples will be used, where the original images do not provide much indication of underlying faint extended structure. The wavelet transform can effectively uncover such faint structure. It is a new mathematical tool which ought to be kept in mind when exploring and analysing image data.

2. Multiresolution Analysis with the Wavelet Transform

We will briefly motivate the use of wavelets by making reference to (i) the property of multiresolution usually associated with the wavelet transform; and (ii) the perspective of the wavelet transform as a discrete convolution filter.

It has been known for a long time that multiresolution approaches to images allow an image to be interpreted as a sum of details which appear at different resolutions. Furthermore, each scale of resolution may pick up different types of structure in the image. For example, a coarse resolution may pick up gross structure, and finer resolutions allow progressive insights into faint and textured structures.

Consider the convolution of an image with a Gaussian. The effect is to smooth the image. Now consider that Gaussian to have a scale parameter, a function of the standard deviation (e.g. $1s$, $2s$, $3s$, ..., where s is the standard deviation). By varying the scale parameter, a sequence of Gaussian-filtered images is arrived at. These provide a sequence of resolution scales. The Gaussian function is not a wavelet; for the latter certain properties are required, such as translation invariance, and a "scaling property" – a dilation invariance property – which relates the filtered images at two successive scales. The wavelet used in this article is isotropic, which is unlike some other wavelets used to enhance alignments or to develop useful strategies for image compression. An isotropic wavelet appears to be a good choice for the investigation of astronomical objects.

The natural incorporation of a suite of resolution scales in the wavelet transform has been beneficially used in different application fields. Such multiresolution analysis is particularly appropriate for astronomical data since the structures we want to recognize have very different scales. A priori we cannot know the size of a local neighbourhood where contrast should be enhanced, i.e. we cannot define in advance an optimal resolution level for analysing an image. The wavelet transform implicitly caters for a more sophisticated astronomical image model than the simple "background plus objects" image model. The latter, implicitly, is very widely used: object detection packages estimate the local background, and then define protrusions from this as objects; or in image restoration, a two-channel algorithm regularizes the background differently from non-background objects. In practice, astronomical images