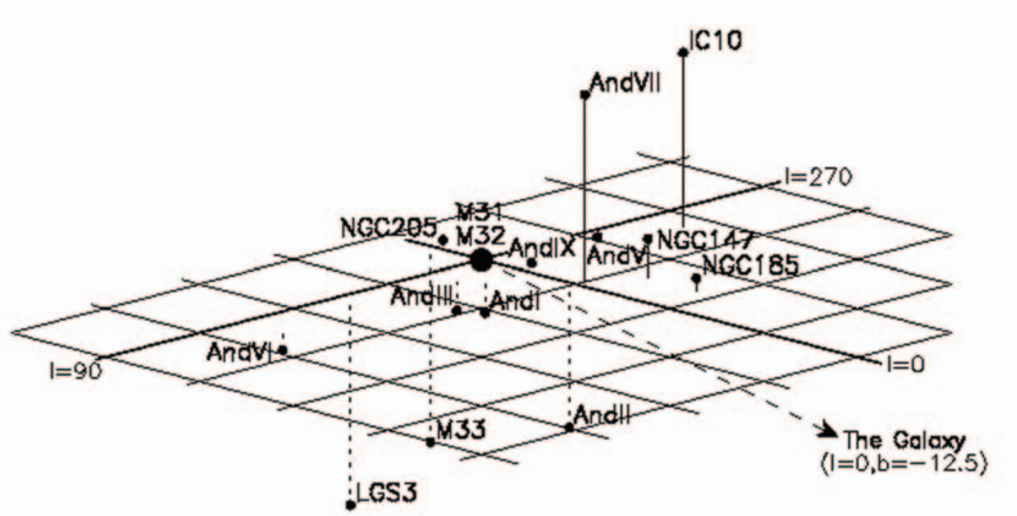

Figure 5. The distribution of the satellite galaxies of M31, as derived from our INT WFC photometry of these objects. The coordinate system is an M31–centric system. The plane is the plane of the disk of M31, and each cell corresponds to 100 kpc×100 kpc. l is a longitude measured around the disk of M31, such that l =0 is the longitude of the Galaxy. b is a latitude, measured from the disk of M31. Solid lines indicate objects located above the plane of the disk, while dashed lines indicate objects below the plane of the disk. A clear tendency for the satellites to lie on the near side of M31 can be observed, and suggests an intriguing correlation between the M31 satellites and our own Galaxy.

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The Bull's Eye Pattern in the Cat's Eye and Other Planetary Nebulae

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The end-point of the evolution of solar-type stars is essentially determined by the onset of a strong stellar wind, which, in a few hundred thousand years completely removes the star's gaseous envelope, thereby removing the fuel that has previously maintained the thermonuclear energy source in its interior. This phenomenon occur during a (second) phase in which the star becomes a red giant, the so-called the Asymptotic Giant Branch (AGB) stage. In the last million years of the AGB, the red giant is dynamically unstable and pulsates with typical periods of few hundred days: a prototypical star in this phase is Mira in Cetus. The mechanical energy of the pulsations pushes large amounts of material far away enough from the core of the star for it to cool down and condense into dust. This newly formed dust is further accelerated out of the gravitational bounds of the star by the pressure of the radiation coming from the hot stellar remnant. Gas, which is coupled to dust by collisions, also leaves the star in this process.

In the last hundred thousand years of the AGB, this mass loss process is so strong that the star is completely surrounded by a thick, expanding dust shell that makes it very difficult to observe what is going on inside it. One way to recover valuable information about this critical phase of stellar evolution is to study the progeny of AGB stars, i.e. planetary nebulae (PNe). These are nothing but the ejected AGB envelopes, heated by the radiation of the hot stellar core, and therefore emitting at the specific wavelengths (emission-lines) typical of the gas that they are composed of.

PNe are fantastic laboratories in which to study a variety of physical phenomena, for example, in the past many aspects of atomic and molecular physics have been addressed by studying PNe. More recently, PNe have become laboratories for investigating the (hydro)dynamical formation of shock waves produced by collisions between stellar winds, with the consequent formation of thin gaseous shells, and bipolar flows or jets which closely resemble those observed in other type of stars or in the nuclei of active galaxies. Now we know that if we understand the formation of the complex and spectacular shapes displayed by PNe, a lot can also be understood about the very late AGB evolution. A few years ago, we have in fact shown that a large fraction of PNe, perhaps the majority, are surrounded by large ionized haloes, one to ten thousand times fainter that their inner regions (Corradi et al., 2003). Figure 1 shows the halo of the well-studied Cat's Eye nebula (NGC 6543); other examples of PNe haloes can be found in the ING Newsletter No. 6, p. 35. These haloes are the fossil remnants of the strongest mass loss phase during the AGB, their edge corresponding to the last thermonuclear runaway (helium shell flash) which occurred in a thin shell inside the stellar envelope before the star left the AGB. These shell flashes are also called "thermal pulses" and occur every 100,000 years for a solar-like star. In thermal pulse, mass loss from the star is first significantly enhanced, and then quickly decreases. Therefore mass loss during the AGB is modulated by the thermal pulses, the last of which leaves an observable signature in the edge of the PNe haloes (the gas loss during the previous thermal pulses

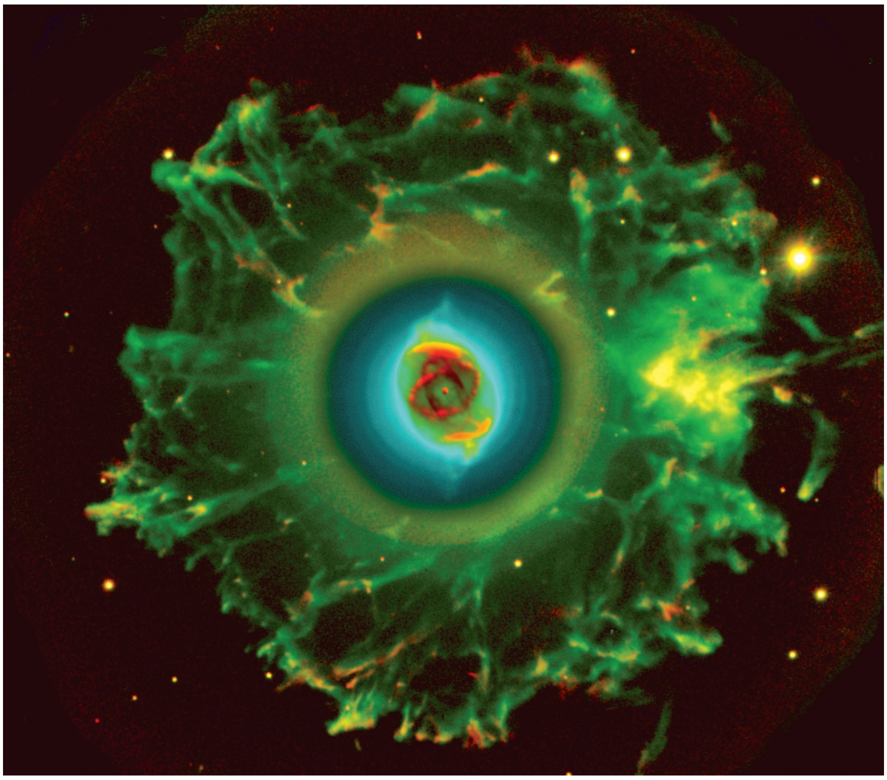

Figure 1. Image of the Cat's Eye Nebula obtained with the Nordic Optical Telescope at La Palma. Rings (displayed in blue in order to better visualise them), are located in the inner regions of the large filamentary halo of the nebula.

Figure 2. Image of Cat's Eye obtained with the Advanced Camera for Surveys (ACS) of the Hubble Space Telescope. Image credit: ESA, NASA, HEIC and the Hubble Heritage Team (STScI/AURA). See also `http://www.spacetelescope.org/images/html/zoomable/heic0414a.html`.

has already diluted so much that is hardly detectable).

In 1999, HST images of the Cat's Eye revealed the presence of a series of shells in the inner regions of its halo (Balick et al., 2001). They appeared to be produced by mass ejected from the star in a series of pulses at about 1500 years intervals during the last 20,000 years of the AGB evolution. Each shell contains about one hundredth of the mass of the Sun, i.e. approximately the mass of all the planets in the Solar System combined. When projected in the sky, these shells appear as "rings" (or sometimes "arcs") composing a sort of "bull's-eye" pattern. A new image of the Cat's Eye, showing the full beauty of the rings, was recently obtained with the ACS camera on the HST, and is displayed in Figure 2.

Discovery of these rings came as a surprise, as mass-loss modulation on a timescale of 1000 years was not predicted by theory (compare with the 100 times longer timescale of the recurrence of thermal pulses). First, it was thought that rings were a rare phenomenon, but recent observations taken with telescopes at ESO and La Palma, and mainly with the Wide Field Camera of the 2.5 Isaac Newton Telescope, have instead shown that these structures are likely the rule rather than the exception (Corradi et al., 2004). They are thus of general relevance to understanding the large mass loss increase that characterises the end of the evolution of a star like the Sun. Figure 3, left, shows examples of these rings in three PNe; these structures are better highlighted by appropriate image processing (e.g. logarithmic derivatives or variations of this method, as shown in Figure 3, right).

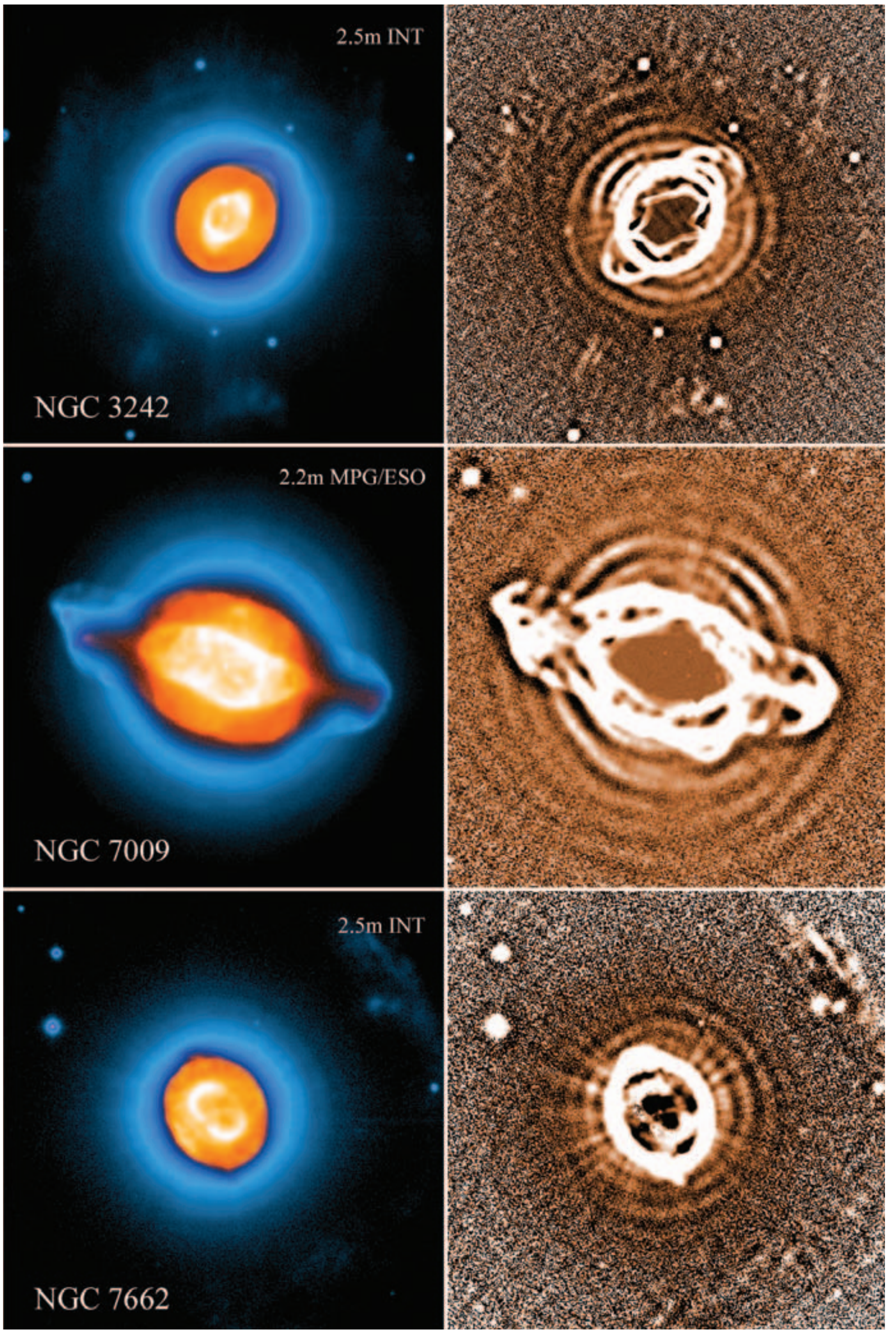

Figure 3. Images of rings recently detected in PNe. Left: [OIII] images. Right: the same images processed to enhance the rings (Corradi et al., 2004, adapted from the A&A cover, April 2004 issue).

Several mechanisms have been proposed for the formation of these rings. They include binary interaction (but the large detection rate weakens this hypothesis), magnetic activity cycles, or stellar pulsations caused by instabilities in the hydrogen burning shell inside the AGB envelope. Another possibility is that gas is ejected smoothly from the star, and rings are created later on due to formation of hydrodynamical waves in the outflowing material that are caused by a complex coupling between gas and dust. This is an appealing hypothesis, as it comes out naturally from our present knowledge of the physics of the AGB mass loss. In any case, whatever the correct explanation, it is clear that any AGB mass loss theory should now confront the evidence that these rings are frequently found in PNe, and thus contain important information relating to the very late evolution of a large fraction of stars in the Universe. ¤

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