Future Directions

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Summary. A special session was held on Tuesday evening of the conference to discuss the key future research directions for the field as a whole. Seven active young astronomers presented their views, all which are summarized here. Highlights of the discussion are also described.

Key words: planetary nebulae, protoplanetary nebulae, preplanetary nebulae

1 Invited Presentations

The field of proto-Planetary (pPNE) and Planetary Nebulae (PNe) studies is ripe with opportunity. AGB stars almost uniformly find a way to transform their mass loss geometry from states of spherical symmetry to states of asphericity and bipolarity. When and how this happens is one of the largest challenges to the theory of stellar evolution.

Despite a decade of study, critical issues such as the rôle of binaries and magnetic fields remain unresolved. Vital clues are expected to lurk in the observations of properties of the ejected mass and measurements of chemical and isotopic abundances.

However, the key mass ejection and shaping processes seem to lie within a few AU of the stellar surface where they cannot yet be resolved observationally. This is the size scale of common envelopes or strongly magnetized stellar winds. On these size scales the riddle of outflow collimation escapes empirical description and must be gleaned from circumstantial evidence and theoretical models.

While each of us contributes to this field in diverse ways, we must somehow focus our efforts on the key problems if this field is to remain as vibrant as it has been. In the era of modern astronomy, organized community campaigns have been a promising way to make progress through teamwork and the coordination of the work of individual investigators.

A panel discussion was held one evening of the APN4 conference. Seven successful mid-career researchers spanning several important subdisciplines and research methodologies were charged to articulate their view of the key research theme for the next decade and to explain it with the emphasis on providing scientific direction to the others in the audience. They were asked to provide a summary of their remarks for this volume. Their responses are provided below followed by general remarks from the audience discussion that followed.

1.1 Noam Soker

Do the envelopes of AGB stars behave erratically?

Other questions are more fundamental to the shaping processes of PNe, but I think we know more about the answers to these questions (although much more should be done), and there are already studies carried on these questions. Examples:

(a) Are the shaping processes due to binary companions? Definitely yes. One of the main open questions here is the rôle of massive planets.

(b) What are the properties of companions? Some PNe are known to harbor close stellar companions (orbital periods of days), and some related objects are known to have companions with a year orbital period (e.g., symbiotic nebulae).

(c) Can a large scale dipole magnetic field of the AGB envelope form bipolar PNe? No. Note: The magnetic fields might play a significant rôle in launching jets from accretion disks. But this should not be confused with an AGB dipole field. Magnetic fields can play a rôle in AGB stars (see below), and influence local shaping (such as formation of blobs), but this should not be confused with a large scale shaping.

Therefore, I am left with the question posed as the title.

I think we are missing key processes in the transition from the AGB to the PN phase. This happens when the AGB envelope becomes $\sim$0.1 $M_\odot$. I will consider two possible non-canonical processes, but more should be discovered and explored.

1) The rôle of opacity (Soker 2006). On the upper AGB the opacity of the photosphere (O-rich stars) is at almost the minimum possible value. This implies that the density of the photosphere is relatively high. The envelope average density, on the other hand, is very low. Such an envelope structure is not possible, as the average density must be larger than photospheric density, and the envelope must shrink and heats up before the AGB star depleted its envelope. Traditional mass loss processes which are based on pulsation and dust formation predict a decline in the mass loss rate. This is not compatible with observations. I suggested that another possible semi- stable structure might exist if the envelope expands by a

factor of $\sim$2, such that its effective temperature is $\sim$2000 K. This much larger and much cooler envelope results in a much larger mass loss rate. With the presence of a close companion a transition to a non-spherical PN can occur. If this over-expansion process is semi-periodic, it might lead to the formation of semi-periodic concentric shells. The transition to the over-expanded phase requires a non- canonical trigger such as dynamo activity.

2) Turbulence dynamo. The turbulence in AGB stars is very strong: Most of the envelope is turbulent, and the eddy speed is close to the speed of sound. A dynamo is very likely to occur. Such activity might lead to semi-periodic enhanced mass loss rate, and to an extended envelope. In AGB stars the mass above the convective region is $\sim$0.005 $M_\odot$. In the Sun the magnetic activity heats a small mass to millions of degrees. In AGB stars, instead, it is possible that the much larger mass is heated to lower temperatures, and forms an extended envelope. This might form the over-expanded envelope discussed above, and by itself can lead to enhanced mass loss rate, and the formation of semi-periodic concentric shells.

Research for the next APN: I highly encourage detailed studies of the dynamics and structure of AGB stars with envelope mass of 0.01-0.1 $M_\odot$, looking for non-canonical processes as discussed above, aiming at answering the question posed as the title. The first stage of such studies can be completed by the APN-5 meeting.

1.2 Valentín Bujarrabal

What are the time scales and what is the nature of gas ejection by a highly evolved star?

I foresee three subjects of research in this field that, in my opinion, will be widely addressed in the future: The time scales and nature of the ejection of material by the central star, the relation between the inner Keplerian disks and the dynamics and shaping of the larger PNe, and the rôle of shocks in the overall nebular dynamics.

I will only discuss here the first subject: the different kinds of mass ejection processes that yield the different parts of planetary nebulae. Note that we are mainly interested in the properties of the mass ejection by the star, not of the shaping effects within the outflow itself.

In many young PNe, we have quite a good idea of the density and velocity distribution for most of the nebular mass from molecular line studies. Because of the Hubble-like velocity law found in many sources, we can readily surmise that the gas has been expanding ballistically without significant acceleration during most of the post-AGB phase. Thus we can infer the mass distribution several hundred years ago, shortly after the nebular mass was ejected. In other cases, in which acceleration and compression could have occurred recently, we can at least calculate limits to the total extent in the past.

From such estimates, we systematically find that a high amount of mass, between 0.1 and 1 $M_\odot$, was enclosed within a very small volume in the past. Provided that we know the expansion velocity (or a lower limit), we can calculate the characteristic times and mass-loss rates of the stellar wind responsible for the ejection by the star of all this material. We so deduce characteristic ejection ages (size/V_{exp}) shorter than 1000 yr – sometimes $\sim$100 yr – and very high mass-loss rates, $\sim 10^{-3}$ $M_\odot$ per year.

This sudden ejection of relatively large amounts of mass is in sharp contrast to the smooth, gentle, sustained wind of AGB stars. For instance, the well known AGB star IRC +10216 presents an isotropic wind with mass loss $\sim 10^{-5}$ $M_\odot$ per year that has been active during at least 10^4 yr. The total mass of this circumstellar envelope is not negligible, but it looks very different from and far smoother and spherical than the denser, brighter, highly structured cores of PNe; in fact the AGB shells are very similar to the large halos observed in PNe.

The quasi-explosive very copious stellar wind, responsible for the ejection of the bulk of the PN in the early post-AGB or late AGB phase, is so different to the standard AGB wind that we cannot claim that the ejection of the (asymmetrical) main component of PNe is just a continuation of the AGB wind. Understanding the cause of this change in mass ejection rate, time scale, and geometry is, in my opinion, a primary challenge for the next decade.

1.3 Orsola De Marco

What is the rôle of binary stars in shaping planetary nebula?

I wish to emphasize four binary-related topics:

1) Planetary nebulae should not be extragalactic distance calibrators (e.g. Jacoby & Lesser 1981), because in younger galaxies one expects brighter PNe with more massive central stars than in the old populations of elliptical galaxies. It is however empirically demonstrated that the PN Luminosity Function is indeed an excellent standard candle since in every galaxy there is a population of equally bright PNe. The best explanation out of this conundrum is that there is an ever-present population of (relatively) massive central stars descending from stellar mergers (some kind of blue struggler merger; Ciardullo et al. 2005).

2) There should be no PNe in globular clusters (GCs), because the maximum expected central star mass in these old populations is too low to make a visible PN. However, there are four PNe in the 150 surveyed GCs (Jacoby et al. 1997). Although this population is likely to be heterogeneous, one way to ease the problem is to have some of these PNe formed through common envelope (CE) evolution: the CE effectively propels the future central star to a hotter temperature than it would have upon leaving the AGB as a single star (it shortens the transition time). This is due to the fact that the CE curtails the primary's stellar radius in a very short time, making the star hotter. This would allow lower mass post-AGB stars to heat fast enough to make a visible PN.

3) The number of PNe in the Galaxy is predicted to be ∼50,000 (Moe & De Marco 2006). It cannot be so high. We know of ∼3000 PNe so far in the Galaxy and even the deepest surveys only discover a few hundred at most. It is not probable that there are many tens of thousands of PNe hiding on the plane and behind the galactic center. Also, such a large number would be extremely high in the context of the PN populations of the local group (Peimbert 1990). A way out is if only a subset of the stars currently thought to be able to make PNe actually do. This subset could be those stars where binary interactions occur (De Marco et al. 2007).

4) Searches for binaries should turn up about 50% binaries with P<3 months - why don't they (yet; De Marco et al. 2004, Sorensen & Pollacco 2004, Afsar & Bond

2005)? The biases are very hard to assess. The contamination of wind variability totally scrambles a potential radial velocity signal from binarity. We are currently estimating to what extent the current results are or are not consistent with a high population of close binaries. We are also planning new surveys using non-windy (dim) central stars.

1.4 Martín Guerrero

How do we get the Big Picture of the "What" and the "When" of PN shaping?

We look at these collections of observations of PNe obtained at different wavelengths and we see a wild variety of morphologies and fine small-scale structures. I think there is a general consensus that there is not a single mechanism able to produce the wealth of morphologies and structures observed in PNe. In its moment, the Interacting Stellar Winds (ISW) model explained reasonably well the emergence of shells and rims in PNe; however, the discovery of fast collimated outflows and small-scale structures in PNe, and the onset of axisymmetry in the early phases of PN formation posed a problem to the ISW model that demanded the consideration of additional shaping agents influencing the formation of PNe.

Among these multiple shaping agents, we can quote the action of collimated stellar winds or fast outflows (either produced by the evolution in a binary system, induced by rotation, associated to magnetic fields, or everything together). We also need to consider the geometry of the mass lost at the end of the asymptotic giant branch, the effects of the sudden ionization of the nebula by the central star, and the interaction of the fast stellar wind with the nebular envelope.

My point is that all these processes that contribute to the shaping of PNe do not act simultaneously, but they operate at different phases of the nebular evolution. Therefore, their relative importance shifts from one phase to another of the PN formation. Using Bruce's terminology, we can say that in some (if not most) proto-PNe, collimated outflows are the primary shaping agents, responsible of the "primary" designation, but later on the nebular evolution, they may be responsible of "secondary" or "tertiary" designations, while the ionizing flux from the central star or its fast stellar wind assume the rôle of primary agents of the PN shaping.

It is necessary to determine which agents operate at different times of the stellar evolution and whether its action will take place or not in a given object. It is also of the utmost importance to determine what is the extent of the action of each shaping agent and how it affects the action of future shaping agents. For instance, collimated outflows deposit energy and momentum in the nebular envelope in early phases of the PN formation, but will the effects of this interaction survive later phases of the nebular evolution, or will it be washed out by the sudden increase of thermal pressure induced by the ionization of the nebula? Will the remains of collimated outflows keep their identity and result in the wide number of small-scale structures seen in PNe?

So far, we have isolated pictures that are trying to tell us a story (or several ones). There is an emerging tale. We see that post- AGB stars of a given chemistry can be associated to different incipient morphologies and that these may result in the different morphologies observed in proto-PNe. Detailed observations of PNe are needed, of course, but there is a lot of work to do making the connections of the morphologies and structures observed in the post- AGB and proto-PN phases and these seen in PNe. Realistic models that can trace the evolution of the wild variety of shapes and small-scale structures through the action of different shaping agents are mostly needed.

1.5 Eric Blackman

Are binaries and magnetic fields required to make and/or shape prePNe?

Although there is enough radiation from a single star to power spherically symmetric PNe, the oft-observed asphericity demands post- launch shaping or a non-radiative asymmetric launch. The latter is particularly essential for pPNe, which reveal rapid turn-on of powerful collimated outflows. Likely underlying the asphericity is rotational energy and angular momentum transport. but (i) what supplies the rotational energy? (ii) How is it extracted to produce the observed structures? If the need for rotational energy is accepted, then questions (i) and (ii) are equivalent to the title of this document: Binaries have received special attention because of mounting observational evidence that they are common among asymmetric PNe, if not necessary for all pPNe. They also offer a timely supply of angular momentum and orbital free energy that can be extracted by magnetic fields? another key ingredient.

All pPNe with close enough binaries could evolve through an aspherical phase. Common envelope (CE) evolution offers four paradigms: (1) direct hydrodynamic equatorial ejection of the envelope (2) accretion (+ dynamo) powered poloidal outflows around the secondary (3) accretion (+ dynamo) powered poloidal outflows around the primary (4) envelope-dynamo mediated outflows. For CE induced asymmetries, the companion could be a massive planet. Non-CE binary interactions e.g. accretion onto a secondary stellar companion can also drive asymmetric outflows, albeit with less outflow power.

The variety of asymmetries may result from a combination of age and mechanism but we do know which, if any, of the above paradigms dominate. Moreover, the processes by which free energy in (differential) rotation supplied by binaries can dynamo amplify large- scale magnetic fields and subsequently mediate MHD outflows are non- trivial. There has been little work which continuously follows the dynamical field origin in the sub-Alfvénic launch regime to the asymptotic propagation. How are dynamo-driven jets launched? Can a supersonic/super- Alfvénic collimated launch obviate the need for further active collimation at large scales? Are outflows steady or bursty? How is the Poynting flux extracted and what influence does it have on the stellar structure, let alone accretion disk evolution? How is the magnetic field on large scales related to that in the engine? The physics of steady vs. transient dynamos in disks and stars and their connection to jet launch and propagation, highlight fundamental MHD questions and pPNe provide an urgency to study them further.

Predictions from theoretical models must be developed and organized. For example, an absence of Carbon rich post-AGB sources is expected if the CE prematurely truncates the AGB before significant Carbon dredge up. Dust distribution would be torus- like rather than shell- like when angular momentum is important, but detailed studies of the dust spectra are required to distinguish winds form tori. What is the relation between dust tori and bipolar outflows; when exactly does the asymmetry originate? What is the relation between the earliest post-AGB maser jets and late stage PNe? How do specific MHD mechanisms reveal themselves? Can we follow a system from binary coalescence to dynamo, to MHD collimated outflow? Can we understand the underlying physical principles beyond the morphological outputs from simulations?

Although some version of binary induced MHD outflows may emerge as the "textbook paradigm", isolated stars are not entirely ruled out. If the star's rotation profile is provided only by angular momentum conservation from the main sequence, localized differential rotation is drained before the MHD outflow can unbind the star. But redistribution of angular momentum within convectively unstable stars is not fully understood and may provide a loophole.

1.6 Hans van Winckel

How do binaries evolve? Can we always blame the companion?

One of the problems being faced in the context of this conference series is that, despite many efforts by many people, the number of confirmed binaries in PNe is much smaller than the number of objects where a binary central star is suspected. But how well founded are these putative binarity suggestions? "Binarity" may be used too often as a magical word to explain whatever is hard to explain by a single star evolutionary model (jet formation, asymmetry in general, excess linear momentum, abundance anomalies, etc. etc.). Do we know what to expect from the final evolution of a star in a binary system in the first place?

The conference illustrated again that many outstanding questions do remain in this context. A hard, but probably rewarding, way to tackle the issue is to investigate the evolutionary connections between different samples of confirmed evolved binaries. These samples should cover a whole evolutionary sequence, so they should also cover binaries which harbour AGB, post-AGB and WD stars, with or without symbiotic or chemical effects due to interaction with a compact companion. Needless to say that all individual samples are plagued with different observational bias effects. In what follows I refer to the most relevant contributions in these proceedings in this context.

A sobering thought is that the observational record of confirmed binaries with an AGB primary (hence the putative precursors of the APNe) is not very large. For the early AGB stars in the solar neighbourhood, the binary rate is about 10% (e.g. Frankowski). The strong pulsations of *evolved* AGB stars make direct detection of a binary companion extremely hard (except for the D-type symbiotics). The exception is of course Mira itself and, interesting enough also for such a wide binary, we witness on this very moment the interaction between both objects (e.g. Podsiadlowski). Remember that in the Magellanic clouds, the D and E sequences in the P-L diagram of AGB stars (Wood et al., 1999) are probably related to binaries.

When we consider post-AGB stars, the situation is quite different. There is now growing evidence that the binary objects in a post-AGB evolutionary state are surrounded by gravitationally bound dusty discs (e.g. Deroo). The quantified orbits so far cover the range from 200 to some 2000 days, with the outstanding property that circularisation is avoided in many systems. The global picture that emerges from those studies is that in all objects, the primary evolved in a binary system which is too short to accommodate a full grown AGB star. During a badly understood phase of strong interaction (on the challenges of the theoretical models of near-common-envelope evolution see e.g. Taam; Frankowski; Podsiadlowski), a circumbinary stable dusty disc was formed. The objects did not evolve on single-star evolutionary tracks and, despite the strong interaction, the systems did neither suffer dramatic spiraling-in. The formation structure and evolution of the compact disc is far from being understood, but it does appear to be a key ingredient in our understanding of the late evolution of a very significant binary population. All post-AGB objects with SEDs indicative of such a compact disc, are likely binaries with un-evolved companions.

Resolved proto-planetary nebulae display a surprisingly wide variety in shape and structure, very early in their evolution off the AGB (e.g. Sahai). For those resolved objects with SEDs indicative of an outflow of the circumstellar material (this in contrast to the disc sources), the connection to binarity is much less clear. Long term monitoring efforts (e.g. Hrivnak) were, till now, not successful to recover any binary motion in the radial velocity data. Note that many of these objects do have a momentum excess in their outflow (e.g. Bujarrabal) and/or show very asymmetric nebula in reflected light.

The possible *progeny* of PNe in binary systems are objects with WD companions. They reveal themselves by the presence of symbiotic activity (e.g. Sokoloski, Mikolajewska) or (not often 'and') by the presence of an imprint of accreted, chemically enriched AGB material (the Ba-star family). For the latter Ba-star subgroup, the quantified orbits are complete but also here the period-eccentricity distribution remains poorly understood (e.g. Izzard). It is interesting to note that the period and eccentricity range observed in Ba-stars is very similar to what is observed for post-AGB binaries: all periods cover the range from a few hundred to a few thousand days. Remarkably, both samples differ significantly in their chemistry: while in Ba-stars the former AGB star was obviously rich in s-process elements and Carbon, in the post-AGB sample all objects are O-rich and do not show s-process enhancements. Despite the very similar $e - log(P)$ diagrams, both samples seem not to be connected by evolutionary paths. In contrast to the periods found in these systems, the period distribution found in White Dwarf - Red Dwarf systems (likely systems with a large mass ratio to start with), is very well in-line with the theoretically expected bimodal distribution (e.g. Farihi) and the distribution shows a lack of intermediate orbital periods.

While uncovering the binary connection in the PNe evolutionary phase is intrinsically very challenging, this is less so for the precursors and progeny. A systematic investigation of the (orbital) properties of those objects to unravel the evolutionary connections(s) in the broader picture of binary stellar evolution is both an observational and theoretical challenge for the coming years, but it will certainly be rewarding. See you in APN V...

1.7 Albert Zijlstra

Is morphology a tool to study post-AGB evolution?

Stellar evolution during the post-AGB phase is still an observational nightmare. The luminosities fall into a narrow range, so that the evolutionary tracks are very close together in the HR diagram, even for stars of widely different initial masses:

the so-called post-AGB bottleneck. Observationally, luminosities are uncertain by perhaps a factor of a few, due to distance uncertainties, bolometric corrections, and non-isotropic outcoming radiation. The vast majority of post-AGB stars have core masses in the range 0.55-0.65 $M_\odot$: over this range the luminosities differ by less than a factor of 2. Thus, in the HR diagram the evolutionary tracks for different masses are indistinguishable.

The final stellar mass can aid distinguishing single stars from interacting binaries. For single stars, the final mass is determined by the AGB superwind. For interacting binaries, it comes from common envelope evolution as well as mass transfer, which will lead to a wider mass distribution. In some cases, the main mass loss event may even be on the RGB. The main problem in binary evolution I would like to see answered in the next 5 years is the effect of binary evolution on the AGB mass loss.

Can we use morphology to separate different evolutionary tracks? Tentatively, the answer seems to be yes. We know that bipolar nebulae are, statistically, indicative of high-mass progenitors -although we do not know whether this applies to both binaries and single stars. Common envelope evolution leads to near-instantaneous mass loss, while the AGB superwind is a long-lasting event. The characteristic haloes of PNe are indicative of a mass-loss history, as are the rings: both may therefore indicate single-star evolution. Finally, a normal AGB wind will sweep up the surrounding ISM, which eventually makes the later PN appear as if it is situated in a hole in the ISM. All these morphological aspects can give information on the status of the underlying star. By building samples of nebulae showing these individual characteristics, evolutionary sequences could be build up.

However, there are problems with this wish list. There is no one-to-one correspondence between progenitor stars and morphology. For instance, we see very similar ranges of morphologies in stellar populations of very different ages and metallicities. On the other hand, we see large variations in the distribution of morphologies for different phases of evolution. Among PNe, elliptical nebulae account for 2/3 of all objects, with the majority of the remainder bipolar. For the nebulae around less evolved post-AGB stars, only 1/4 are elliptical, with the remainder again bipolar. Finally, the envelopes of AGB stars are predominantly spherical. This discrepancy puts the validity of evolutionary sequences into doubt. Even worse is the discrepancy for binary parameters. For PNe, the known binaries are either short-period (hours to days) or very long (100 yr or longer). For post-AGB stars, the distribution of binary period peaks sharply around 1 year. The lack of overlap suggests the two groups are tracing different evolutionary tracks.

To be able to use morphologies to trace stellar evolution, we need to resolve several problems. First, we need to understand how the various morphologies originate and evolve. Second, the observational bias for each evolutionary phase needs to be understood and quantified. Third, the different evolutionary sequences leading to envelope ejection need to be understood. These are important questions in themselves, but they will also turn morphologies into a tool for studying stellar evolution.

2 Summary of Open Discussion

Harriet Dinerstein – dual dust chemistry nebulae in two objects suggests binarity before this meeting. At this meeting Luciano Cerrigone said that half of his sample has dual chemistry. Are we learning something critical about binarity?

Orsola De Marco – perhaps there is an oxygen-rich disk and carbon-rich mass loss from the central star.

Harriet Dinerstein – I wonder if this may be a result of sample bias, or whether it is insight into the status of binarity.

Albert Zijlstra – where are the actual detections of binaries?

Orsola De Marco – 25 people are grouping to make a coordinated assault to find more binaries.

Letizia Stanghellini – need models of radiation pressure on dust for O- and C-rich dust grains in the AGB atmosphere.

Kevin Volk – "explosive mass loss" in $<$100 years – what is the process? Eric Blackman told us that accretion scenarios cause a destabilization, and that various physical time scales need to be identified and exploited to develop cohesive ejection scenarios.

Noam Soker – different binaries have a wide range of possible ejection endpoints, so we must not use binaries as an alias for some particular endpoint.

Detlef Schönberner – halos shows that regular and fairly smooth mass loss (lasting a few thousand years?) has preceded the sudden ejection of mass. Balick reminded us that Guerrero emphasized that many processes shape PNe at various times on their evolution.

Bruce Balick – Radio observations presented by the IRAM group have been one of the most exciting facets of this meeting, and we look forward to more of these studies (and plans for ALMA) by the time of APN5.

Agnes Acker – we need to be very careful to detect and trace all of the mass lost by a post-RGB star. Letizia says that the absence of good distance data for galactic PNe makes LMC/SMC PNe the next frontier for tracing masses and other intrinsic and fundamental properties of PNe.

Angela Speck - Early mass loss is unrecoverable.

References

1. Afsar, M., & Bond, H.E., 2005, MmSAI, **76**, 608.
2. Ciardullo, R., et al., 2005, ApJ, **629**, 499.
3. De Marco, O., et al., 2004, ApJL, **602**, 93.
4. De Marco, O., et al., 2007, ApJ, submitted.
5. Jacoby, G.H., et al., 1997, AJ, **114**, 6.
6. Jacoby, G.H., & Lesser, M.P., 1981, AJ, **86**, 185.
7. Moe, M., & De Marco, O., 2006, ApJ, **650**, 916.
8. Peimbert, M., 1990, Rev. Mex. AA, **20**, 119.
9. Soker 2006, NewA, **11**, 396.
10. Sorensen, P., & Pollacco, D., 2004, APNIII, ASPC, **313**, 515.
11. Wood et al., 1999, IAUS, **191**, 151.