1. Overview

Planetary nebulae (PNe) are one of the last phases in the evolution of low and intermediate mass stars (<8 solar masses). Their immediate precursors are stars in the asymptotic giant branch (AGB), characterized by a strong mass-loss (with rates up to 10^{-4} solar masses per year), followed by a short (10-10000 years) transitional post-AGB phase. While the morphology of the mass-loss processes in the AGB is mainly spherical, PNe usually show complex bipolar and multipolar structures. It is thought that this PN shaping is due to highly collimated jets ejected during the post-AGB and early PN phases, which open cavities in the previously ejected AGB envelope. However, the ultimate powering agent of these jets and their timescale of action are still largely unknown. A possibility is that collimated jets in post-AGBs and young PNe are magnetically collimated, which in its turn may imply the presence of circumstellar disks.

The visit of Dr. Jose Francisco Gomez to Japan has been devoted to strengthen an incipient collaboration with Japanese researchers, especially with Dr Imai's group at Kagoshima University, to carry out a multiwavelength study of the processes taking place during the post-AGB and early PN phase of stellar evolution, specially aimed to tackle the problem of PN shaping. Both Dr. Gomez' and Dr. Imai's groups are expert in the study of maser emission in evolved objects, and a close collaboration between their groups could provide first-class results in this area. Moreover, with the advent of new (and future) radio astronomical instrumentation, it is important to be in a situation to exploit the new capabilities that these facilities will provide. In particular, our groups will focus their effort in the exploitation of the Australian Square Kilometer Array Pathfinder (ASKAP), and the Atacama Large Milimeter Array (ALMA).

In the following we will detail the specific activities carried out during Dr. Gómez' visit to Japan, in several aspects:

a) Scientific discussions.
b) Advances in common research.
c) New proposals for observing time at international radio telescopes.
d) University courses and scientific seminars.
e) New collaborations
f) Attendance to the meeting "Revolution in Astronomy with ALMA: the third year"

We note that the scientific advances and future projects undergone during this fellowship cover a very wide range of wavelengths: 18 cm (ASKAP), 1cm (Tidbinbilla, VERA, VLBA), 7mm (Robledo), and submm (ALMA).

2. Dates and location of scientific activities for this fellowship

Dr Gomez visited Kagoshima University from November 4th 2014 to November 29th 2014. There he worked with Dr Hiroshi Imai and his group.
In the second part of his stay, he visited the ALMA Regional Center, located in the Campus of the National Astronomical Observatory of Japan in Mitaka (Tokyo), from November 29th 2014 to December 13th 2014. He worked there mainly with Dr. James Chibueze. During his visit to Tokyo, he had the opportunity to attend the international meeting "Revolution in Astronomy with ALMA: the third year", held at the Tokyo International Forum from December 8th to 11th.

3. Scientific discussions

Several meetings and discussions were held during Dr. Gómez' visit to Japan. The main topics of discussion were:

- Evaluate the results of previous astronomical data obtained in the framework of our collaboration.
- Determine new avenues to explore with these data.
- Prepare and submit new observing proposals
- Discuss plans for future collaboration.

We consider these discussions very fruitful. The results of discussions an related work carried out during this visit is detailed in the following sections.

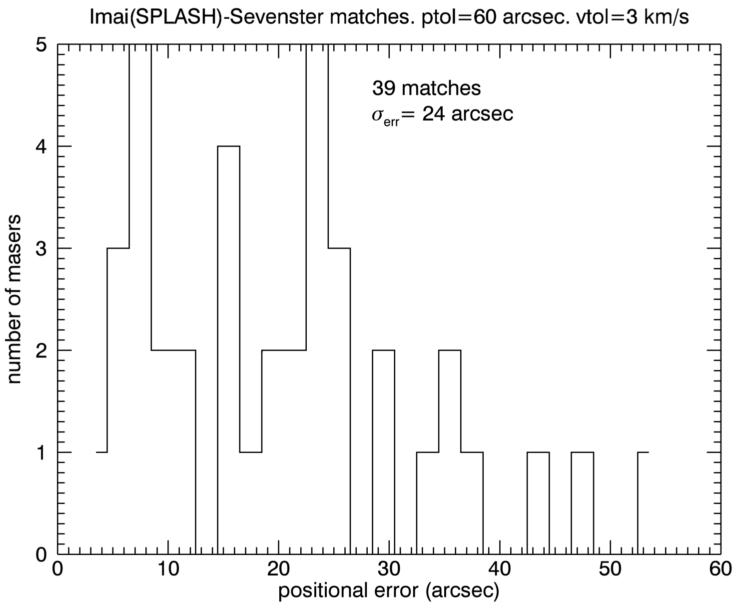
4. Advances in common research

The first scientific contact between Dr. Imai and Dr. Gomez dates back to 2009, when both independently sent expressions of interest (EoI) to carry out Science Surveys with the upcoming ASKAP telescope. In both cases, they proposed the observation of OH masers in evolved stars. Their EoIs were favorably evaluated by the ASKAP committee as technically feasible, but we were advised to coordinate with other groups who send EoIs aiming to observe spectral lines on our Galaxy. From this coordination the Galactic ASKAP spectral line survey (GASKAP) was born. The GASKAP proposal was submitted and approved, and it will carry out 8000 hours of observing time with ASKAP, simultaneously mapping the HI and OH lines in the Galactic Plane south of declination 40º, at wavelengths 18-21 cm (Dickey et al. 2013, PASP, 30, 3). While we are still waiting for completion of ASKAP building and commissioning, we are currently involved on a "precursor" survey: The Southern Parkes Large-Area Survey in Hydroxyl (SPLASH), which will map the southern galactic plane in OH with the 64m antenna in Parkes (Australia). The results from SPLASH pilot zone (covering galactic longitudes 334º to 344º) were recently published (Dawson et al. 2014, MNRAS, 439, 1596).

Observations of SPLASH have already finished, and data processing is under way. A common interest in our groups regarding SPLASH is the detailed study of OH maser emission from evolved stars. Some of our scientific discussions were devoted to the information we could obtain from them. In particular, we are interested in how the mass-loss rates and velocities of AGB stars change in different areas of the Galaxy, and how these characteristics can be related with other observational properties, such as infrared luminosities as provided by several surveys (obtained with IRAS, 2MASS, MSX, Spitzer, Akari, WISE). We are also interested in identified new members of special classes of sources, such as "water fountain" candidates (evolved stars showing the first manifestation of collimated mass-loss) or OHPNe (planetary nebulae with OH maser emission, which could represent extremely young PNe).

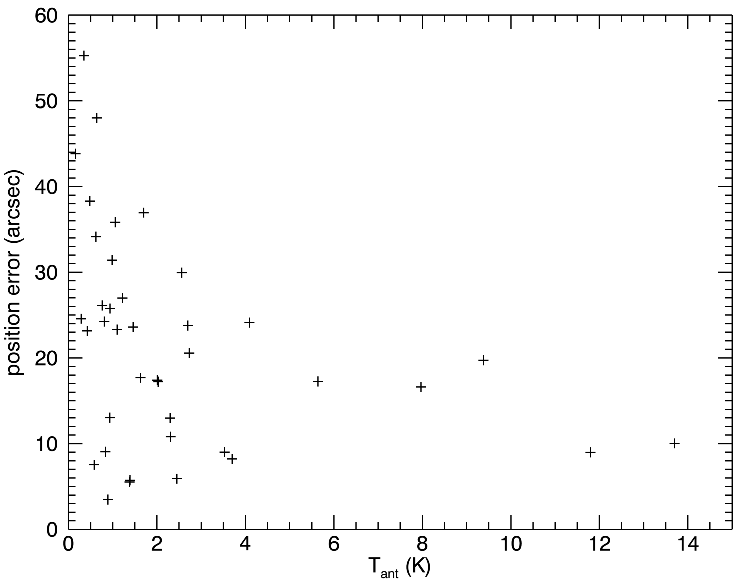
A potential problem when working with the SPLASH survey is the relatively low angular resolution of the observations (12.6 arc minutes). This has a direct impact on the positional accuracy of the data. If the positional accuracy is low, we will not be able to attain our goals with SPLASH data alone, since it would be impossible to ascertain from which source the OH maser emission arises. During Dr. Gomez' visit to Kagoshima we have evaluated this problem using the data from the Pilot region.

Using the images from the pilot region, we identified by eye the components in each channel and made Gaussian fits with AIPS. This gives the best possible positional accuracy we can obtain from SPLASH OH maser detections. We then obtained the OH maser detections in the same area published by Sevenster et al. (1997, A&AS, 124, 509), obtained with the ATCA interferometer, i.e., with a potentially much higher positional accuracy. We wrote an IDL procedure to read and compare both our Gaussian fits and Sevenster's detections. The procedure finds the closest match within a tolerance (both in position and velocity). It then calculates the statistics of the matches, to determine the positional accuracy. The next figure gives the results for positional and velocity tolerances of 60" and 3 km/s, respectively



The figure shows that the standard deviation of SPLASH positions with respect to the Sevenster's data is of only 25", much better than the Parkes beam size. This is promising, since we estimate that it will be enough to properly identify the sources emitting OH masers detected in SPLASH.

As expected, the lowest positional accuracies are those of weak masers. Next figure shows the positional error as a function of maser flux density.

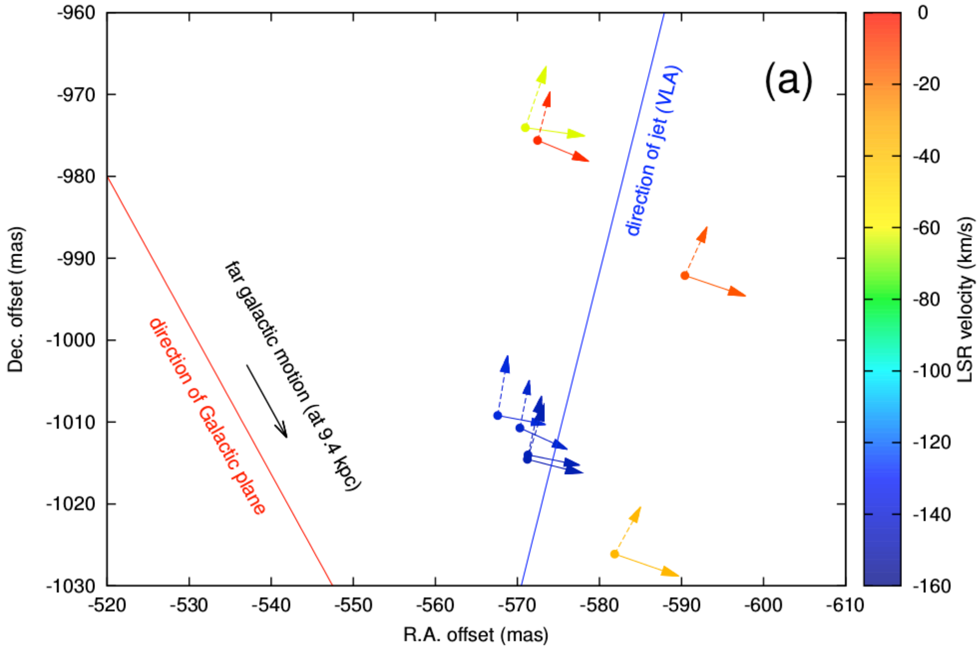


Note that the error goes below 20” for the strongest masers.

We then searched for masers between the new OH maser detections in SPLASH pilot region and different catalogs of planetary nebulae: The Strasbourg-ESO Catalogue of Galactic Planetary Nebulae (Acker 1992, ISBN 3-923524-41-2), The Catalogue of Galactic Planetary Nebulae (Kohoutek, 2001, A&A, 378, 843), The MASH catalog of Planetary Nebulae (Parker et al. 2006, MNRAS, 373, 79; 2008 MNRAS, 384, 525), and sources marked as PN in the Red MSX Survey (Lumsden et al. 2013, ApJS, 208, 11). We found a very likely new case of PN with OH maser emission (IRAS 16333-4807) that, if confirmed, would add to the rare group of OH-emitting PN (only 6 cases confirmed so far, Uscanga et al. 2012, A&A, 547, 40). We expect that the full SPLASH survey would provide more new cases.

In preparation for the whole SPLASH data, we have investigated the performance of the source-finding program Duchamp (http://www.atnf.csiro.au/people/Matthew.Whiting/Duchamp/), on the Pilot region detections. We note that only in the pilot region 196 OH maser sources have been detected. Therefore, manually identifying sources in the whole SPLASH survey is probably impractical. Duchamp seems to provide good results, and we plan to continue focusing on it in the future. There are some sources detected manually that are not detected by Duchamp and vice versa; we are currently evaluating the reasons for these discrepancies.

A second major topic of common research is the detailed study of water fountains. These are evolved objects with high-velocity (>100 km/s) water maser emission (at 1 cm) tracing collimated jets. These objects could represent one of the earliest manifestations of collimated mass-loss in evolved stars and thus, their study can provide key clues to understand the shaping of PN. In the framework of our collaboration, we have two active proposals to carry out Very Long Baseline Interferometry studies of water maser emission in the water fountain IRAS 18113-2523, the galactic evolved object with the maser jet with the highest velocity (> 500 km/s velocity spread, Gomez et al. 2011, ApJ, 739, 14). We were approved observing time with the Very Long Baseline Array (VLBA) to measure the maser proper motions, in order to determine the 3-D velocity structure of the jet. Observations are now on their way. On the other hand, we have observed three epochs with the VERA array (out of 8 approved), to determine the annual parallax and thus, the distance to the source. Our preliminary results seem to favor a long distance to the source (9.4 kpc). The solid arrows in the figure show the total proper motions measured with VERA, and the dashed arrows are the resulting motions after subtracting the galactic motion at the far kinematic distance of 9.4 kpc. Note that the dashed arrows align well with the direction of the maser jet.



The long distance to the source implies that the annual parallax is very small (110 micro arcseconds), so the approved 8 VERA epochs may not be enough for an accurate distance determination.

5. New observing proposals

These VERA results have prompted us to submit a new proposal to continue the monitoring of the water maser emission in IRAS 18113-2523. Our estimate is that observing with VERA for an additional year (8 more epochs), to bring accuracy in the distance determination down to 20%. This is important to reconstruct the 3D structure and the scales of the jet, and to determine the physical parameters, evolutionary status and orbit of the host star in the Milky Way Galaxy. We finished and submitted this proposal during Dr. Gomez' visit to Kagoshima, and we are waiting for the report of the time allocation committee.

Moving on to other water fountain sources, during this visit we also prepared and submitted a new proposal to monitor all confirmed water fountains with NASA's 70m radio telescope at Tidbinbilla (Australia). Despite their suspected importance in explaining asymmetric stellar mass loss, very little is known about the evolutionary sequence of water fountains and the lifetime of water masers in their jets and central regions. We have proposed, for the first time, the systematic monitoring of H2O masers in all confirmed water fountains. Using these observations, we can create a public database on the long-term variability of water masers in these sources, to help the planning of VLBI monitoring programs and get a better insight into the mass-loss characteristics and evolution of water fountains.

6. Courses and scientific talks

During his visit to Japan, Dr. Gomez gave two lectures aimed to different audiences. First, he gave a 3 hour lecture for graduate students at the Kagoshima University. This lecture provided official credits for students. The topic was a review on the different radiative processes in planetary nebulae (from cm to optical wavelengths), and the physical information that can be obtained by observing at different wavelengths. We covered topic such as forbidden lines, recombination lines, free-free continuum, thermal dust and molecular line emission. A special attention was devoted to maser emission in evolved stars.

During his stay in the ALMA Regional Center at NAOJ (Mitaka), he gave a scientific talk on "Maser emission in the transition to PNe". As mentioned above, the optical images of PNe usually show complex morphologies, although stars in previous phases have spherical symmetries. The processes occurring around the beginning of the PN phase will probably determine these shapes. Maser emission is a useful tool to study objects in the transition to PNe, since they can trace morphological and kinematical structures at extremely small scales. Moreover, this emission can pinpoint extremely young PNe, because it is not believed to be present in more evolved PNe. Dr. Gomez presented his studies of pre-PNe and young PNe with maser emission (including studies in collaboration with Prof. Imai), tracing jets and tori that can be related to the shaping of PNe. He also discussed in detail the particular case IRAS 15103-5754, an object that could be the youngest PN known.

7. New collaborations

While Dr. Gomez' stay in Kagoshima was important to strengthen his collaboration with Prof. Imai's group, and to advance in their common research, his stay in Mitaka was useful to establish new collaborations. In particular, he discussed new possible research lines with Dr. Chibueze on the study of evolved objects. From these discussions new ideas emerged, which will focus on the exploitation of NASA's 35m antenna in Robledo (Madrid) to carry out surveys of SiO maser emission (at 7mm) in post-AGB stars and PNe. These observations have a great scientific potential (e.g., no SiO detection has ever been obtained toward a PN), and will make use of a very sensitive radio telescope which has a newly installed 7 mm receiver.

8. Attendance to the meeting "Revolution in Astronomy with ALMA: the third year"

This international meeting was held at the Tokyo International Forum from December 8th to 11th. ALMA is the leading radio telescope in the world, and has just completed its third year of operation. Dr. Gomez had the opportunity to learn the latest scientific advances provided by this impressive instrument. ALMA has been especially important in the study of protoplanetary disks, since it is now possible to obtain images that give clues to the processes leading to planet formation.

However, it is worth noting that not many studies have been carried out with ALMA on evolved stars, compared with the multiple observations of star-forming regions or external galaxies. Probably the most interesting result on evolved stars is the discovery of a spiral pattern in the circumstellar envelope of the AGB star R Sculptoris (Maercker et al. 2012, Nature, 490, 232), most likely due to the presence of a binary companion. The scarce number of ALMA projects on evolved stars indicates that there is an important niche to be explored in our mutual collaboration. In particular, it is imperative to carry out high-resolution observation of submillimeter gas and dust emission in water fountain stars, to determine the mass-loss history of these objects and how the jets traced by water masers are carving cavities on the circumstellar envelope expelled during the AGB phase. We plan to submit observing proposals on this topic, as part of the collaboration between Dr. Gomez and Imai's groups.