Session 8: First results from Gaia and looking to the future

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Gaia and the Planetary Nebulae

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Abstract. About three years after Gaia was set into orbit, the first release of Gaia data, DR1, has been published by ESA and DPAC. Gaia's first archive contains the results from the analysis of the initial 14 months of mission data. Outstandingly, it includes TGAS, Gaia-Tycho2 astrometric solution for about 2 million stars up to visible magnitude around 11.5.

In addition to the five parameter astrometric solution for the sky (positions, parallaxes and proper motions), future Gaia data releases will provide the spectral energy distributions from 330-1050 nm, together with radial velocities, for sources brighter than visible magnitude 16. Within this context, the relevance of Gaia data for the study of PN is be briefly presented.

Keywords. Gaia, distances, astrometry, parallax

1. Parallaxes and distances in DR1/TGAS

Gaia DR1 (Brown *et al.* 2016 and Prusti *et al.* 2016) consists of three parts: 1) an astrometric data set which contains the positions, parallaxes, and mean proper motions for about 2 million of the brightest stars in common with the Hipparcos and Tycho-2 catalogues (TGAS); 2) the positions and G-band magnitudes for an additional 1.1 billion sources (the secondary astrometric data set); and 3) the G-band light curves of ∼3000 Cepheid and RR Lyrae stars. As a consequence of the very preliminary nature of this first Gaia data release, there is a number of important limitations to the data quality. These limitations are documented in the A&A papers that followed Gaia DR1, with further information provided on-line (gaia.esac.esa.int). TGAS astrometric uncertainties as a function of Gaia passband magnitude G are summarized in Table 1. It should be noted that an extra systematic error as large as 0.3 mas has been reported by DPAC, a fact not to be ignored in DR1.

A sample of 22 bright PN and proto-PN is contained in TGAS. However, only 7 of those appear with relative parallax errors (1-sigma) below 43%. Table 2 shows such data, and some of the derived distances in comparison with other non model-dependant previously published distances. This information is presented and analysed in detail by Stanghellini *et al.* in these proceedings. It is worth noting that deriving distances by

G (mag)	σ_π **(mas)**
9.3	0.24
11	0.32
12	0.64

Table 1. TGAS uncertainties in parallax.

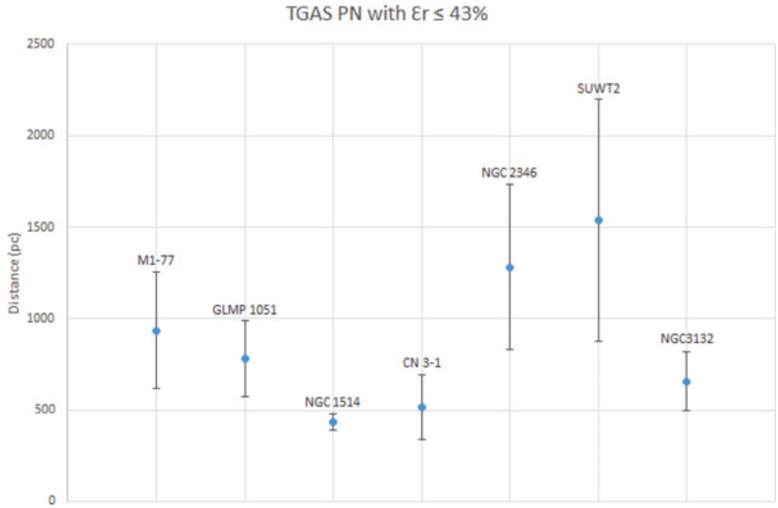

Figure 1. Distances to PN in DR1.

largerly uncertain parallaxes is not straithforward and some prior information regarding the star distribution should be taken into account as for instance in Astraatmadja & Bailer-Jones (2016). Figure 1 shows TGAS distances for PN with parallax relative errors less than 43%. In future releases, as more Gaia epoch measurements will be added, most accurate parallaxes will be derived.

DPAC end-of-mission (eom) expectation is that Gaia parallaxes will improve by a factor of 20-30. This will imply that PN brighter than magnitude 15 can be expected to have their eom parallaxes derived with accuracies of the order of 25 microarcsec, which turns into relative errors around 10% at 5 kpc and 20% at 10 kpc.

2. Spectral Energy Distributions from Gaia BP/RP photometers

Observations from the photometric instrument will be specially interesting to planetary nebula research. Gaia blue and red spectrophotometers (BP/RP) cover, respectively, the $330 - 660$ nm and $650 - 1050$ nm wavelength regions, with a dispersion ranging from $4 - 32$ nm per pixel in the blue to $7 - 15$ nm in the red. These spectra have the potential to discover a significant number of young compact PN and postAGB objects with emission lines. In fact, the most intense emission lines are visible in BP/RP simulated spectrophotometry. This enables DPAC to define spectral indices to diagnose the physical nature of the sources and to disentangle PN from other emission line objects. DPAC has developed an algorithm for unsupervised classification of Gaia spectrophotometric observations based on Self Organizing Maps (SOM), that is expected to facilitate the segmentation of astronomical object types (Fustes, Manteiga *et al.* (2013)), in order to make a full use of Gaia potential to discover new objects.

3. PN morphological information from the astrometric instrument and the Sky Mapper detections

Gaia will observe not only point sources but many objects with a structure (extended objects). These are expected to be essentially galaxies, but may also be star forming regions or planetary nebulae. The morphological information of the structure of these

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PN G name	other name	π(mas)	$1/\pi$(pc)	$\sigma(\pi)$	$\epsilon_r(\pi)$	G(mag)	other distance
PN G104.8-06.7	M 2-54	-0.33		0.35		12.147	
PN G076.6-05.7 proto	V* V1853 Cyg	0.27		0.38	141	11.030	
PN G89.3-02.2	M1-77	1.07	935	0.36	34	11.825	2500 ± 500
PN G099.3 -01.9 proto	GLMP 1051	1.28	781	0.35	27	12.273	
PN G029.1-21.2 proto	LSIV-12 111	-0.64		0.56		11.312	
PN G165.5-15.2	NGC 1514	2.29	437	0.24	10	9.220	550 ± 190
PN G64.7+05.0	BD+30 3639	0.28		0.43	154	10.242	2689
IRAS 18371-3159 proto	PM 1-248	0.63		0.87	138	11.992	
PN G038.2+12.0	Cn 3-1	1.93	518	0.66	34	12.304	4680 ± 1620
PN G166.1+10.4	IC 2149	0.25		0.4	160	11.216	1950 ± 450
PN G345.2-08.8	IC1266	0.22		0.49	223	11.246	2670 ± 760
PN G332.9-09.9	He 3-1333	0.19		0.65	342	11.094	9840 ± 3360
PN G334.8-07.4	Hen 3-1312	0.31		0.24	77	11.057	4400
PN G315.1-13.0	He 2-131	0.09		0.35	389	10.676	590 ± 180
PN G331.1-05.7	Hen 2-172	0.74		0.68	92	11.648	
PN G215.6+03.6	NGC 2346	0.78	1282	0.27	35	11.147	1060 ± 340
PN G321.0+03.9	He 2-113	0.36		0.62	172	11.219	7600 ± 2170
PN G052.7+50.7 proto	BD+33 2642	0.1		0.3	300	10.709	
PN G311.0+02.4	PN SuWt 2	0.65	1538	0.28	43	11.911	2300 ± 200
PN G316.1+08.4	He 2-108	-0.01		0.87		12.635	3630 ± 1040
PN G291.3+08.4	PHR J1134-5243	0.19		0.41	216	12.961	5080 ± 1010
PN G272.1+12.3	NGC 3132	1.52	658	0.36	24	10.040	540 ± 140

Table 2. Parallaxes and errors for PN in DR1. Column 6 contains relative errors in parallaxes. See text for details.

objects is present in Gaia observations and can, therefore, be retrieved from them. Current DPAC software is prepared to analyse extended sources using the astrometric field (AF) CCD scans. The windows that will be transmitted to Earth for image reconstruction have pixel angular resolutions of 59 mas AL (along scan) and 177 mas AC (across scan), respectively. Windows sizes vary depending on the source magnitude, from 1.06x2.12 arcsec (ALxAC) for sources brighter than $G = 13$, to 0.71x2.12 arcsec for fainter ones (Krone-Martins, Ducourant *et al.* (2013)). For each image, 2D maps will be measured and described by parameters such as concentration of light, asymmetry, smoothness and momentum. Then, a morphological classification will be performed via a Support Vector Machine algorithm. This morphological information will be published in Gaia final DR, around year 2023. Compact PN will be included in this analysis.

Gaia Sky Mapper (SM) CCD windows have angular sizes of 4.72x2.12 arcsec (ALxAC) and a pixel resolution $\geqslant 118$ mas and they can also be retrieved for further analysis. SM is used to detect and select objects for higher resolution in the AF. The detection criteria of pointlike sources had to de relaxed for the detection of solar system objects. As a result, the filamentary structures of ionized gas around PN are being recovered. Figure 2 (from Castañeda-Pons (2015)), shows such detections around NGC 6302, the Butterfly Nebula, whose central star (CS) was not detected in these Gaia observations. An astrometric

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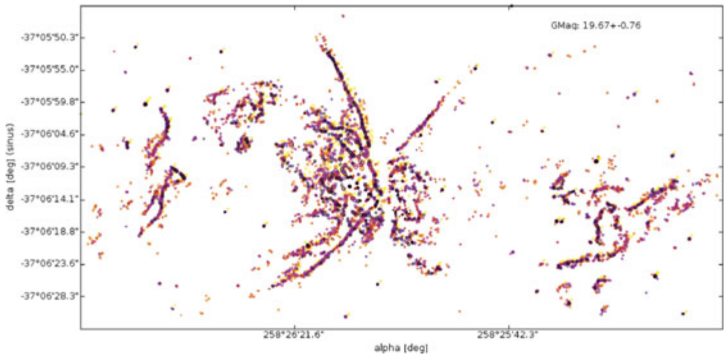

Figure 2. Ionized gas detections around NGC 6302 as scanned by Gaia Sky Mapper. Credits: Castañeda-Pons (2015)

accuracy of around 70 mas, for such SM detections along different observation epochs, has been found (Mignard (2016), DPAC). This means that both SM and AF detections around PN can be used for kinematics studies when, for instance, combined with HST images. This opens a whole new area of studies.

4. Conclusions

Gaia is certainly providing useful measurements for the study of PN. Some of the main possibilities offered by the mission data can be summarized as follows:

- TGAS parallaxes are, by now, very limited by source brightness and accuracy. We need to wait for the next data releases for accurate distance derivations
- Gaia AF instrument detections can provide parallaxes for nebulae with no CS detected
- We expect that BP/RP SEDs can allow to identify new PN (not to forget that Gaia is dealing with big statistics)
- Images of compact nebulae (sizes $\leqslant 4.72$ arcsecs) will be treated and classified
- Morphological information from SM detections can be obtained for extended PN
- SM and AF detections around PN can be used for kinematics (combined with HST) studies

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