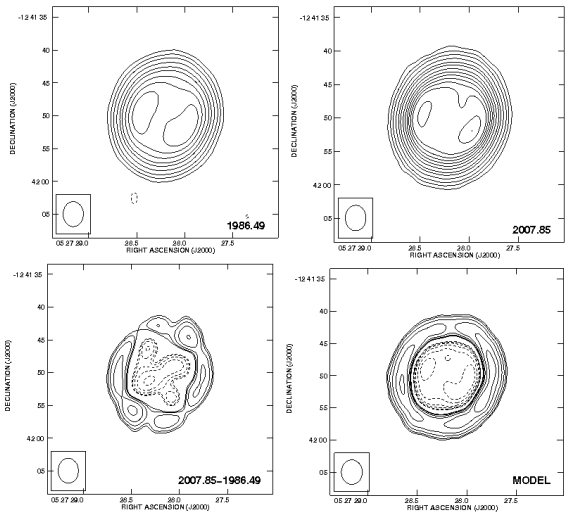

Fig. 1. Top: contour images of the 6 cm emission form IC 418 for 1986.49 (left) and 2007.85 (right). The contours are −5, 5, 10, 30, 50, 60, 80, 100, 150, 200, 250 and 300 times 350 μJy, the average rms noise of the images. Bottom: contour images of the 6 cm difference image (left) and of the model (right) obtained as described in the text. The contours are −20, −15, −10, −7, −5, −4, 4, 5, 7, 10, 15 and 20 times 460 μJy, the rms noise of the difference image.

epoch we estimated the radius of maximum emission, θ to be $6\farcs700 \pm 0\farcs006$. Using this value and ϵ's value we can calculate the angular expansion rate, $\dot{\theta}$ to be 5.8 ± 1.5 mas yr^{-1}.

To deduce the distance from the angular expansion rate calculated above, one must know the physical velocity $v_{\rm exp}$ at which the ionization front is expanding: $[{\rm D/pc}] = 211[v_{\rm exp}/{\rm km\ s^{-1}}][\dot{\theta}/{\rm mas\ yr^{-1}}]^{-1}$.

Traditionally, $v_{\rm exp}$ has been estimated using high spectral resolution observations of some emission lines and assuming a relation between the shape of the line profile and the movement of the emitting gas. For this nebula IC 418, we used the high resolution spectra of Hβ, [NII] and [OIII] lines published by Gesicki et al. (1996). Using a detailed three-dimensional photoionization model of the nebula, Morisset & Georgiev (2009) reproduced these three profiles using a $V \propto R^4$ expansion law. According to this model, the expansion velocity near the outer edge of the nebula (where we detect the expansion at radio wavelengths) is 30 km s^{-1}. Using this value we can calculate the distance to IC 418, we obtained a distance of 1.1 ± 0.3 kpc.

To calculate this distance we have assumed that the velocity of the ionization front (pattern velocity) is the same as the Doppler velocity of the material itself, deduced form spectral lines. For conditions appropriate for planetary nebulae (PNe), Mellema (2004) showed that the ionization front tends to expand somewhat faster than the material. Using their Figure 5, we estimated that the expansion velocity of the ionization front in IC 418 is 1.2 ± 0.1 faster than the expansion velocity of the gas. Taking this effect into account leads to a distance to IC 418 of 1.3 ± 0.4 kpc.

Using the distance value, we can derive the physical parameters of the nebula like the electron density (n_e) and the mass of ionized gas (M_i) and using the angular expansion rate we can derive the dynamical age of the nebula ($t_{\rm dyn}$). All these parameters together with the emission measure (EM) calculation are listed in Table 1.

TABLE 1

PHYSICAL PARAMETERS OF IC 418

Parameter	Value
$t_{\rm dyn}$	1200 yr
EM	$(5.05 \pm 0.01) \times 10^{-6}$ cm^{-6} pc
n_e	$(6.2 \pm 1.7)(d/1.1\ {\rm kpc})^{-0.5} \times 10^3$ cm^{-3}
M_i	$(8.7 \pm 2.4)(d/1.1\ {\rm kpc})^{2.5} \times 10^{-2}\ M_\odot$

3. CONCLUSIONS

In this document, we presented observations of the 6 cm radio continuum emission from the well studied PN IC 418 obtained at two epochs separated by more than 20 years. This data allowed us to detect the angular expansion of the nebula, and to estimate its distance. Depending on the assumption made on the relative velocity of the matter and of the ionization front, we obtained a distance of 1.1 ± 0.3 kpc, or 1.3 ± 0.4 kpc. Using this distance we derived the physical parameters of the planetary nebula IC 418.

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