Minkowski's Footprint : an ejected common envelope ?

J. Alcolea[1], R. Neri[2], and V. Bujarrabal[1]

[1] Observatorio Astronómico Nacional (Spain) `j.alcolea,v.bujarrabal@oan.es`
[2] Intitut de Radio Astronomie Millimétrique (France) `neri[at]iram.fr`

Summary. M 1–92, also known as Minkowski's Footprint, is a very well studied bipolar pPN. In fact, it can be considered an archetype of these type of sources: it shows a clear axial symmetry, along with the kinematics and momentum excess characteristic of this class of envelopes around post-AGB stars. We performed sub-arc second resolution interferometric observations of the J=2–1 rotational line ^{13}CO in M 1–92, with the new extended configurations of the IRAM Plateau de Bure interferometer, for better studying the morphology and velocity field of the molecular gas in the nebula, particularly in its central part. We found that the equatorial structure dividing the two lobes, is a thin flat disk which expands radially with a velocity proportional to the distance to the central stellar system. The kinetic age of this equatorial flow is very similar to that measured in the two lobes, suggesting that the whole structure was formed as a result of a single event some 1200 yr ago, after which the nebula reached an expansion velocity field with axial symmetry. The small widths and velocity dispersion in the gas forming the lobe walls confirm that the acceleration responsible for the nebular shape could not last for more than 100–120 yr. In view of the similarity to the case of η Car, we speculate on the possibility that the whole nebula was formed as a result of a magneto-rotational explosion in a common-envelope system. The role of this mechanism in the context of global PNe and pPNe shaping should be further examined.

Key words: Circumstellar matter, post-AGB stars, M 1–92

1 Introduction

M 1–92 (a.k.a. Minkowski's Footprint) is a bipolar pre-planetary nebula (pPN). The central object is a binary system consisting of a 6,500 K primary star and a 18,000 K secondary [2]. A distance of 2.5 kpc is assumed adopting a normal post-AGB luminosity of $10^4\,L_\odot$ [5]. The nebula has a size of 11″ in the axial direction and 6″ in the equatorial one, consisting of a two-lobe reflection nebula divided by a dense equatorial component. The two lobes define a clear axis of symmetry, oriented at a position angle (P.A.) of 311°. This axis is inclined with respect to the plane of the sky by 35°, with the northwest lobe pointing to us. Optical spectroscopy shows the presence of flows of ionized gas close to the star, with expansion velocities up to 750 km s^{-1} [2]. Line emission in Hα, OI, OIII, NII, and SII is detected from the middle of the two lobes, tracing the location of shocks propagating along these jets [4]. The mass of the ionized gas is very low, $10^{-3}\,M_\odot$, compared with the total mass of the nebula, $0.9\,M_\odot$ [3], which is still largely in the form of molecular gas (traced by CO) and dust grains (seen in scattered light, about ~1% in mass of the gas content).

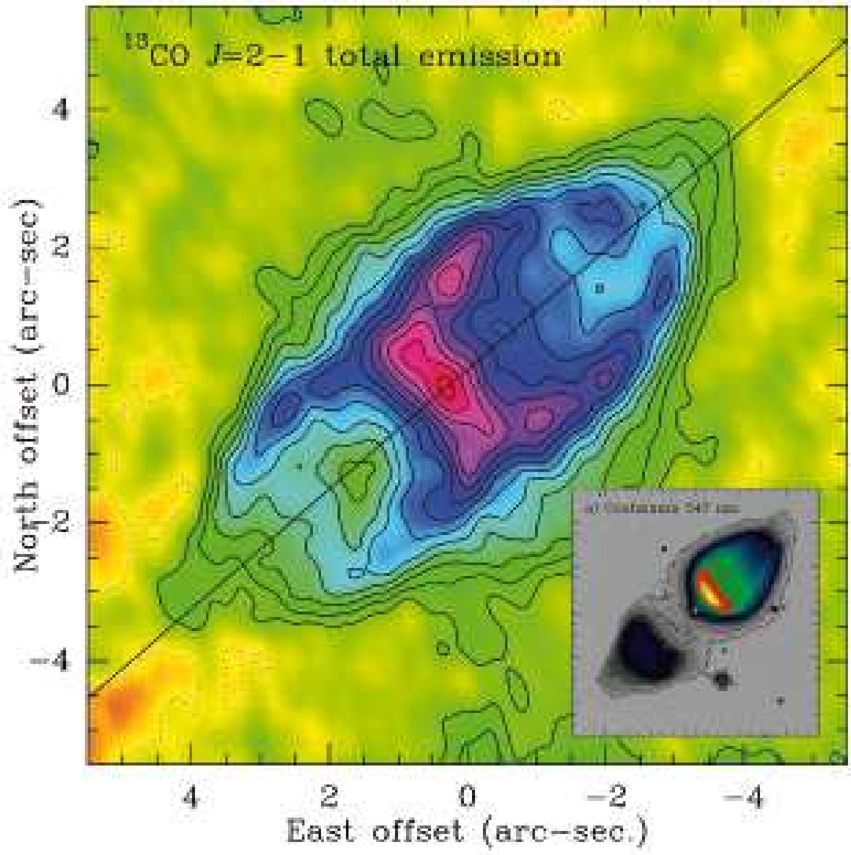

Fig. 1. Total ^{13}CO J=2–1 intensity map of M 1–92 obtained with the combination of the old [3] and new data. Levels are 7% to 91% by 7% steps of the maximum emission. The inset in the bottom-right corner shows the HST-WFPC2 in the 547W filter after [4]. The plotted area is the same in both cases.

2 ^{13}CO Observations

Using the new extended configurations of the IRAM Plateau de Bure Interferometer, we conducted additional observations of the J=2–1 rotational line of ^{13}CO at 220 GHz in M 1–92. We obtained new data in the A6q & B6q antenna layouts in the winter of 2006. After calibration, map production and cleaning we found that 30%-70% of the flux was lost because of the lack of short baselines in the new data. Since the new data set was obtained with the same spectral setup as before, we merged these data with those from our previous observations [3]. This resulted in maps with no significant missing flux, but with sub-arc second spatial resolution: beam size of $0\farcs50\times0\farcs35$ (see Fig. 1). We also produced higher detailed maps using just the most extended (6Aq) configuration. Although these maps have low S/N and most of the flux is lost, they are very useful to investigate the structure and dynamics of compact features such as the equatorial disk dividing the two lobes (see Fig. 2).

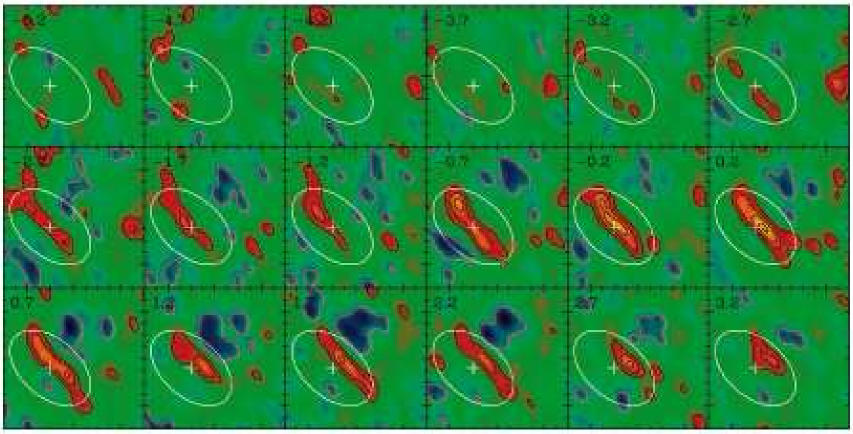

Fig. 2. 0.5 km s^{-1} spectral resolution channel maps of ^{13}CO J=2–1 in the central parts of M 1–92 with the highest spatial resolution (beam size of $0\farcs46\times0\farcs26$, 6Aq data only). The white ellipse delineates the extent of the flat disk, $1\farcs4$ in diameter, traced by the molecular gas in this region.

3 Results

The results (see figures) clearly display the structure and kinematics of the molecular gas in M 1–92. The two emptied lobes and the dividing equatorial structure are obvious, as well as the prominent linear velocity gradient in the axial directions: the Hubble-like velocity field often found in pPNe (see Fig. 3). It is noteworthy the small width of the walls of the lobes, less than 10^{16} cm, and their low excitation (brightness temperature about 10 K). However, most surprising is that the velocity field seen in the equatorial region is not compatible with a relic of an AGB envelope. We do not see the signatures of an expansion with a constant radial velocity. On the contrary it seems that the velocity increases linearly with the distance in this equatorial plane too. We derive a kinetic life-time of 1370 yr for the disk, to be compared with the 1060 yr found for the bipolar axial flow. In fact, adopting an inclination angle of the symmetry axis of 38°5 (still compatible with all the data), both ages become the same, 1200 yr. (However, see the contribution by P.J. Huggins in this volume on the possible existence of a systematic jet/disk-launching time-lag in pPNe.)

4 The origin of M 1–92

If we assume that a single Hubble-like velocity field applies to all parts of the nebula, the easiest explanation for this kinematics would be that M 1–92 resulted from a single acceleration event. Given the small width and velocity dispersion of the lobe walls, this interaction should have lasted less than about 10% of the kinetic age of the gas, i.e. less than ~120 yr, resulting in the astonishing mass loss rate of at least $7.5\,10^{-3}\,M_\odot\,\mathrm{yr}^{-1}$. Apart from a very faint halo, we see no traces of a former massive AGB envelope, but just the result of this huge post-AGB explosion. The above depicted scenario resembles a 1–2 orders of magnitude scale-down version of the η Car nebula. For this unique object, a model has been developed in which a magneto-rotational explosion can launch flows in the axial and equatorial directions [7]. Maybe this mechanism could also apply to M 1–92 and other pPNe [6]. For this mechanism to operate, it is necessary to have a binary system in a common envelope phase [8]. A scenario that we believe should be further investigated for the case of M 1–92. If true, the nebula will be just the result of the explosive ejection of the common envelope of the system.

References

1. Alcolea, J., Neri, R., Bujarrabal, V.: Minkowski's footprint revisited. Planetary nebula formation from a single sudden event? A&A**468**, L41–L44 (2007)
2. Arrieta, A., Torres-Peimbert, S., Georgiev, L.: The Proto-Planetary Nebula M 1–92 and the Symbiotic Star MWC 560: Two Evolutionary Phases of the Same Type of Object? ApJ**623**, 252–268 (2005)
3. Bujarrabal, V., Alcolea, J., Neri, R.: The Structure and Dynamics of the Protoplanetary Nebula M 1–92. ApJ**504**, 915 (1998)
4. Bujarrabal, V., Alcolea, J., Sahai, R., Zamorano, J., Zijlstra, A.A.: The shock structure in the protoplanetary nebula M 1–92: imaging of atomic and H_2 line emission. A&A**331**, 361–371 (1998)
5. Cohen, M., Kuhi, L.V.: Studies of bipolar nebulae. II. Optical spectropolarimetry of CRL 2688 (the CYG EGG nebula) and M 1–92. ApJ**213**, 79–92 (1977)
6. Matt, S., Balick, B.: Simultaneous Production of Disk and Lobes: A Single-Wind MHD Model for the η Carinae Nebula. ApJ**615**, 921–933 (2004)
7. Matt, S., Frank, A., Blackman, E.G.: Astrophysical Explosions Driven by a Rotating, Magnetized, Gravitating Sphere. ApJ**647**, L45–L48 (2006)
8. Nordhaus, J., Blackman, E.G.: Low-mass binary-induced outflows from asymptotic giant branch stars. MNRAS**370**, 2004–2012 (2006)

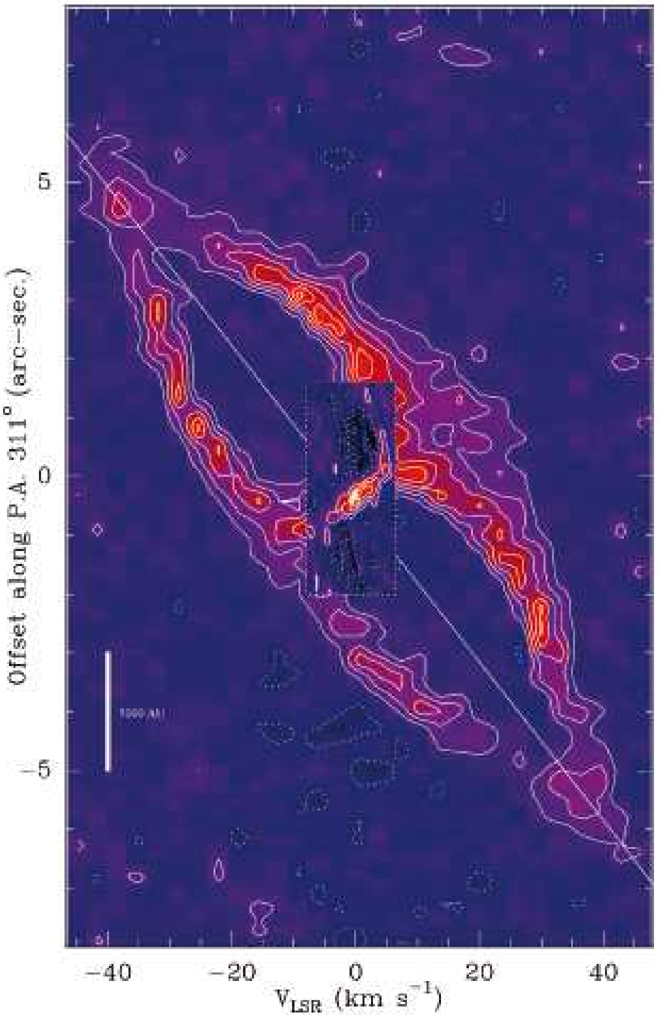

Fig. 3. Diagram of the position along the major (symmetry) axis of the nebula vs. projected (observed) velocity, from the whole data set, except for the central rectangle, where data only from the 6Aq (most extended) configuration is displayed. Note the large velocity gradient along the major axis (white line). The perpendicular stripe delineated by the data at the central parts of the nebula reveals the presence of a flat disk in expansion, in which the radial velocity also increases linearly with the distance to the binary system. Assuming that in all the nebula the same Hubble-law holds, we can directly translate the observed velocities into depths along the line of sight. In this case, this diagram also depicts the 3D structure of the molecular gas, adopting axial symmetry along the major axis of the nebula. We would be looking at the nebula from the left. Use the vertical white bar for linear sizes.