M 1-92: THE DEATH OF AN AGB STAR TOLD BY ITS ISOTOPIC RATIOS

Presented by

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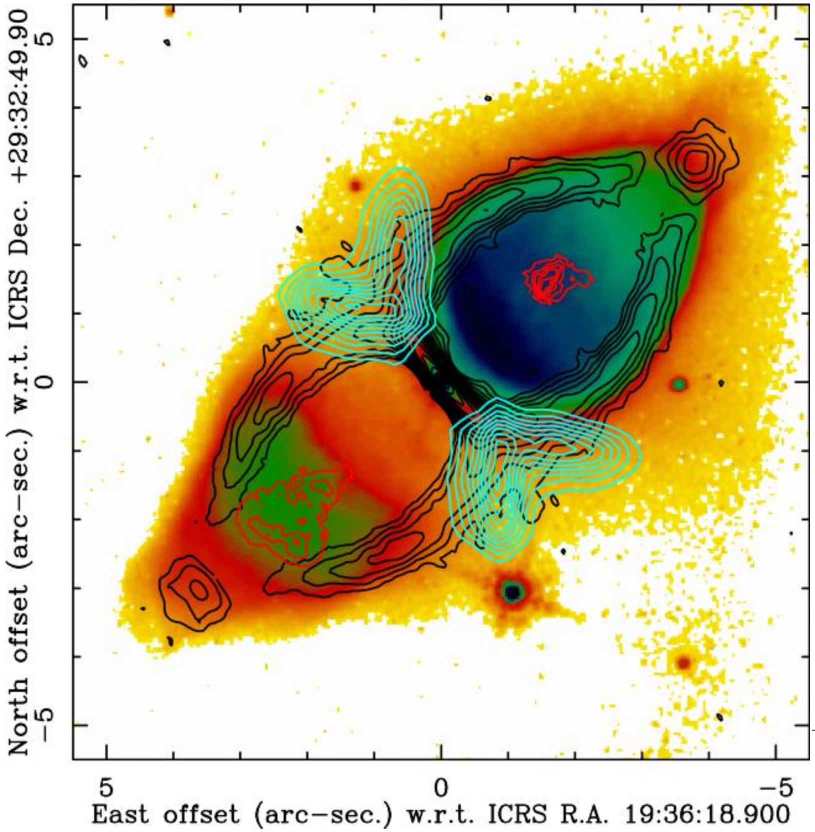
nebulae web

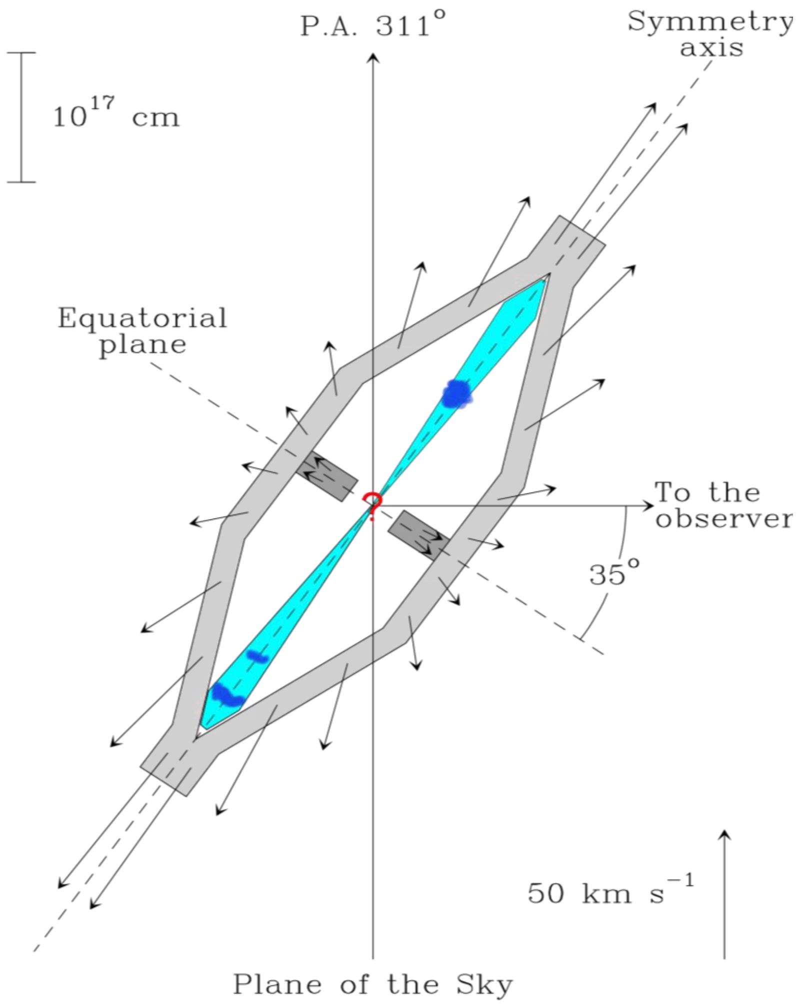
M1-92: THE PRE-PLANETARY NEBULA

Minkowski's footprint:

- 2.5kpc away, around a B-type post-AGB star.
- Bipolar shape of 11" x 6".
- 0.9 $M_\odot$ with Hubble-like velocity gradient (1200 y.o.).
- HH-like knots with large velocity dispersion (600 y.o.).
- More than 20 molecular species detected.
- C-rich and O-rich characteristics.

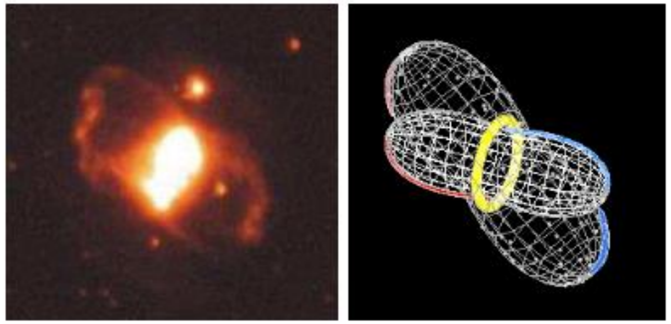
From Hubble Space Telescope





From Alcolea *et al.* 2022 and Bujarrabal *et al.* 1998

SHAPE + SHAPEMOL: THE MODELLING TOOL

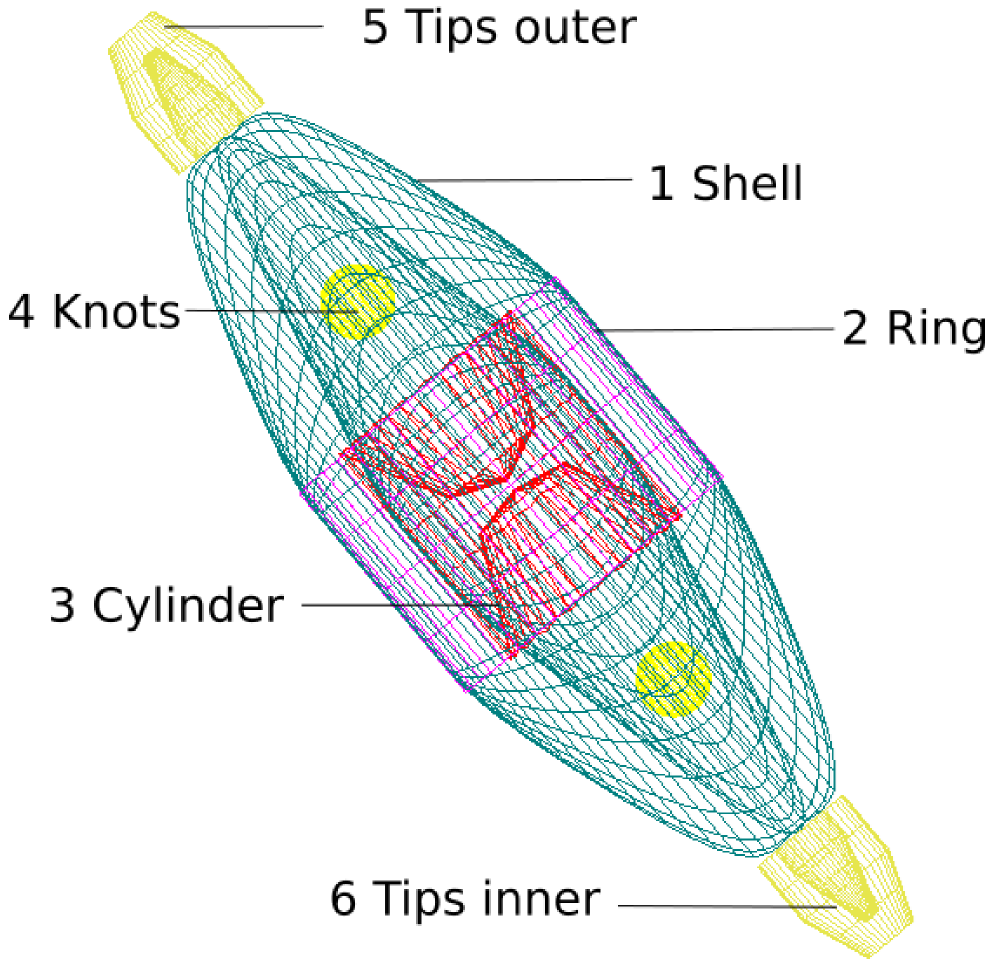


From Sabin *et al.* 2010 and Bandyopadhyay *et al.* 2020

- 3-D Modelling software of emission from gas nebulae
- Shapemol for molecular lines
- Radiative transfer
- LVG aproximation
- **New molecular species!!** (Masa *et al.* 2024 in prep.)

M1-92 MODEL: STRUCTURES

1. Shell: cold & dense
2. Ring: cold & dense
3. Cylinder: warm & dense
4. Knots: hot & faint & high turbulence
5. Tips outer: cold & dense
6. Tips inner: hot & faint & turbulence



Masa *et al.* 2024 in prep

PROJECT OVERVIEW

1. Observational data is collected: 23 line profiles (5 of ^{12}CO, 2 of ^{13}CO, $C^{17}O$ and $C^{18}O$, and 3 of HCO^+, HCN, $H^{13}CO^+$ and $H^{13}CN$) together with 5 interferometric maps of the J=2-1 transition (^{13}CO, $C^{17}O$, $C^{18}O$, HCN and HCO^+). From IRAM 30m, IRAM NOEMA and HSO/HIFI.
2. CO defines the overall nebula structure in our model.
3. HCN and HCO^+ define the physical properties of active shocks regions.
4. Once built, the model should reproduce observational data from all lines and species at the same time, adjusting only relative abundances.
5. Molecular distribution and isotopologue ratios can be derived and analysed.

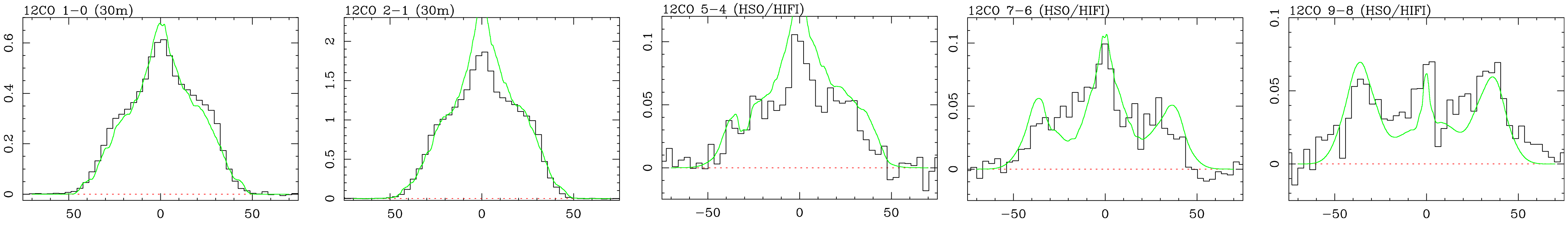
^{12}CO: BUILDING THE MODEL

It's the only species whose observational data covers enough energy range to show all structures.

Constrains the double layer structure as well as most physical properties.

Predicts CO in all structures, including the knots despite not being detected in any observational map.

Tmb vs v (km/s)

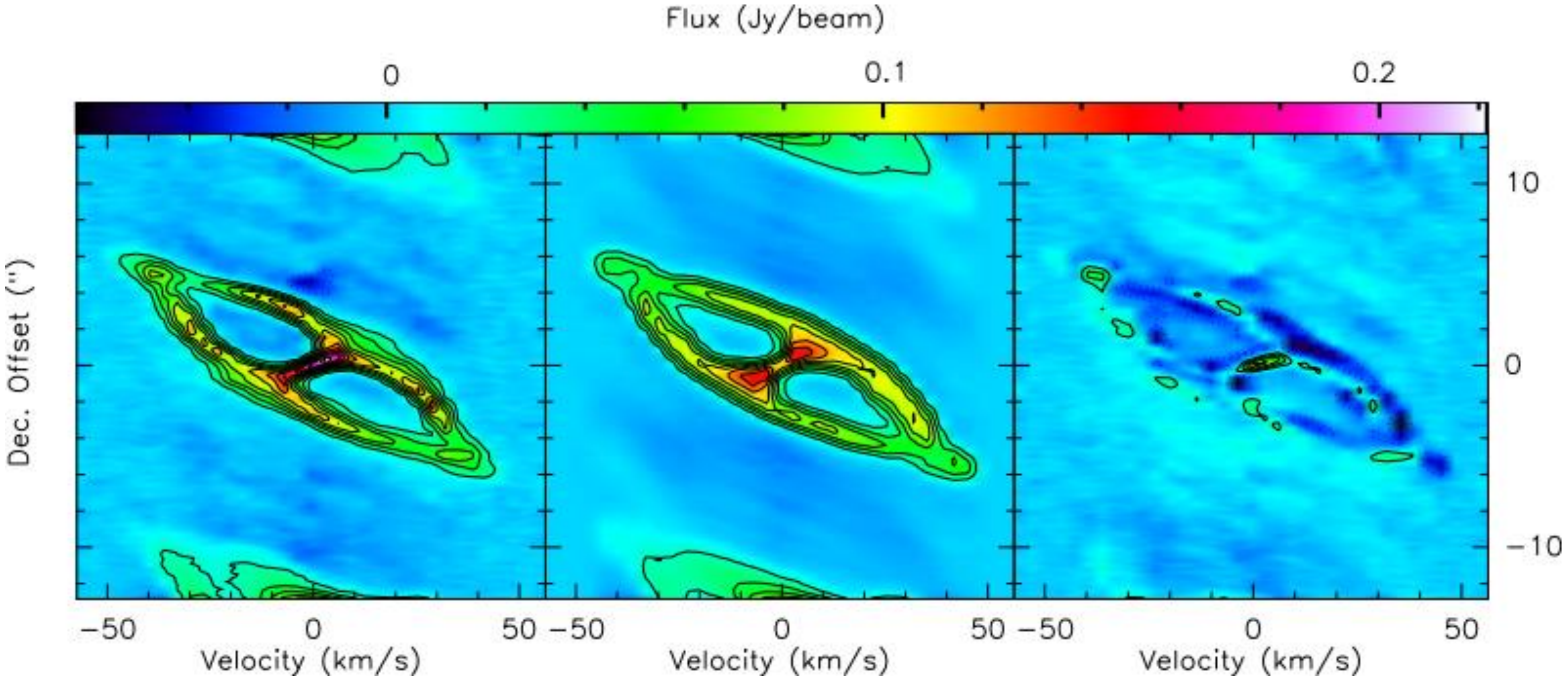


^{13}CO MAP: GEOMETRY

Allows a precise location of each structure (except knots) and its velocity.

Resolves degeneracy in location vs brightness.

P-V diagram from map



Observational data | Model rep. (interf.) | Res = data-model

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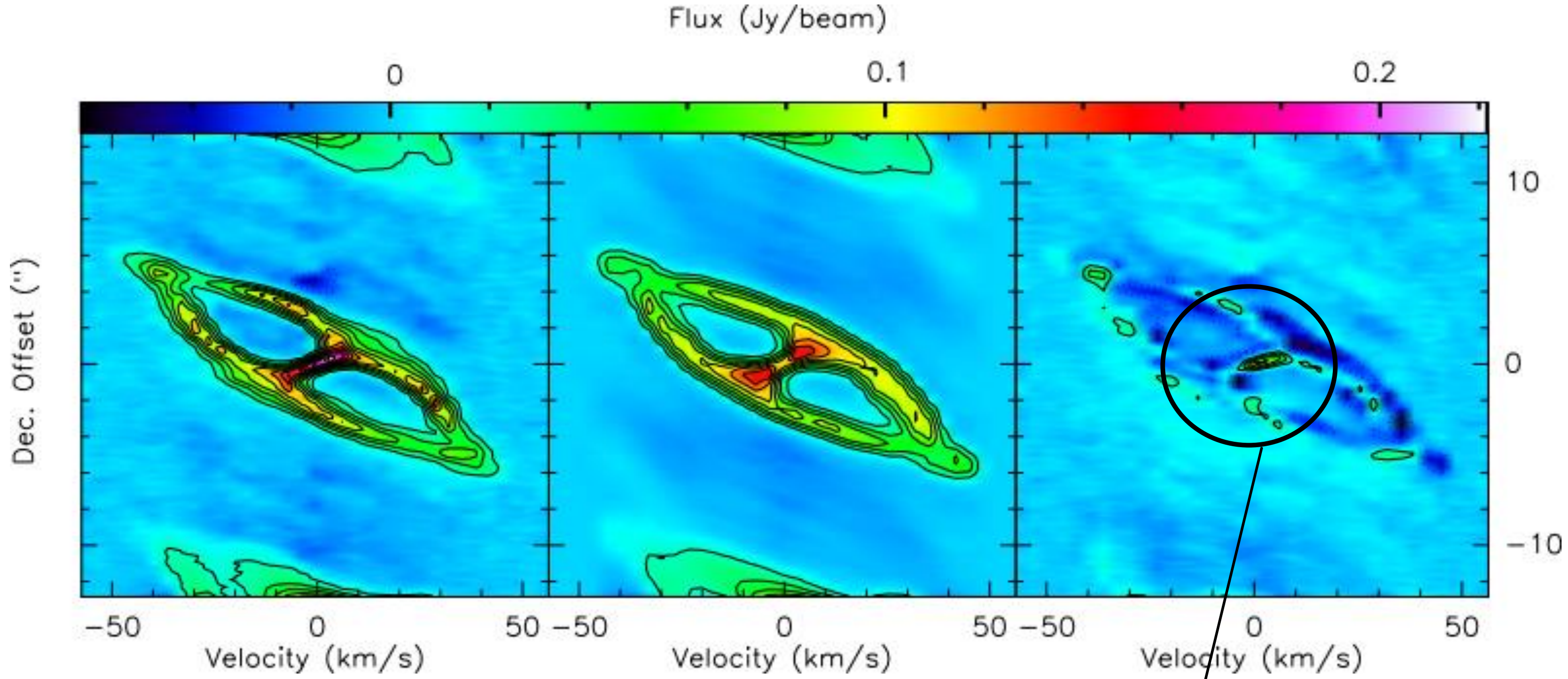
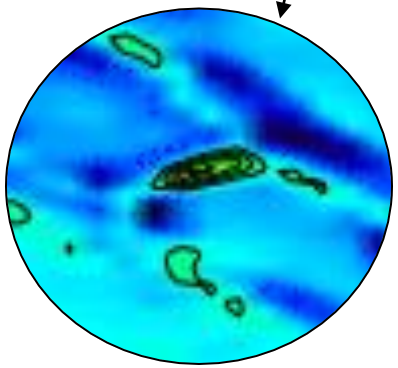


Observational data

Model rep. (interf.)

Res = data-model

A bright asymmetric spot remains!



CO: ISOTOPES AND THEIR RATIOS

Once the specific physical properties have been found, the model will require certain abundance values to reproduce observational data.

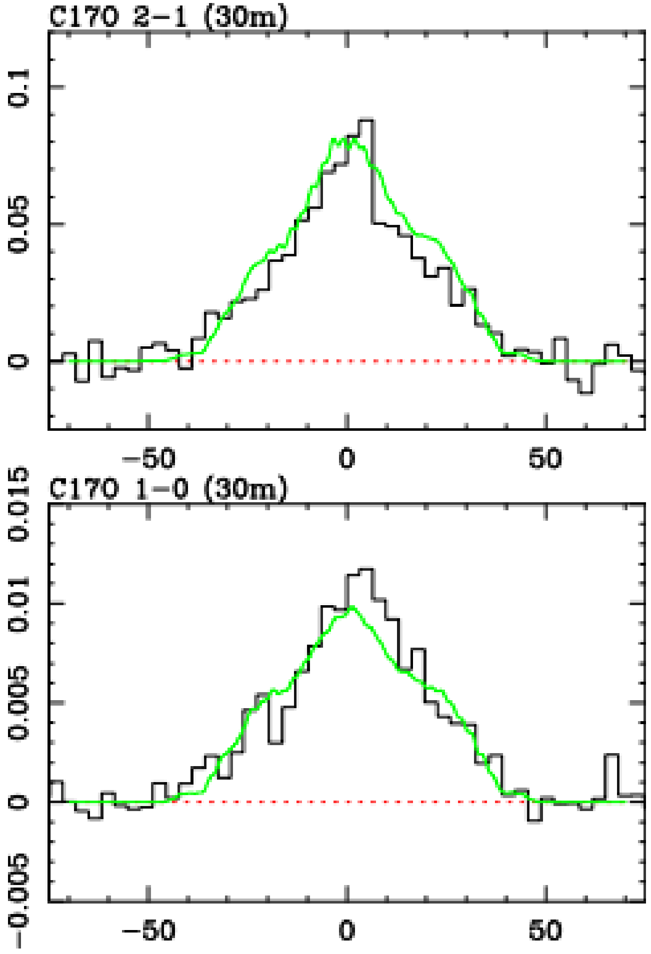
$^{12}CO/^{13}CO = 30$

$C^{17}O/C^{18}O = 1.6$

$^{12}CO/C^{17}O/C^{18}O = 1/550/880$

Tmb vs v (km/s)

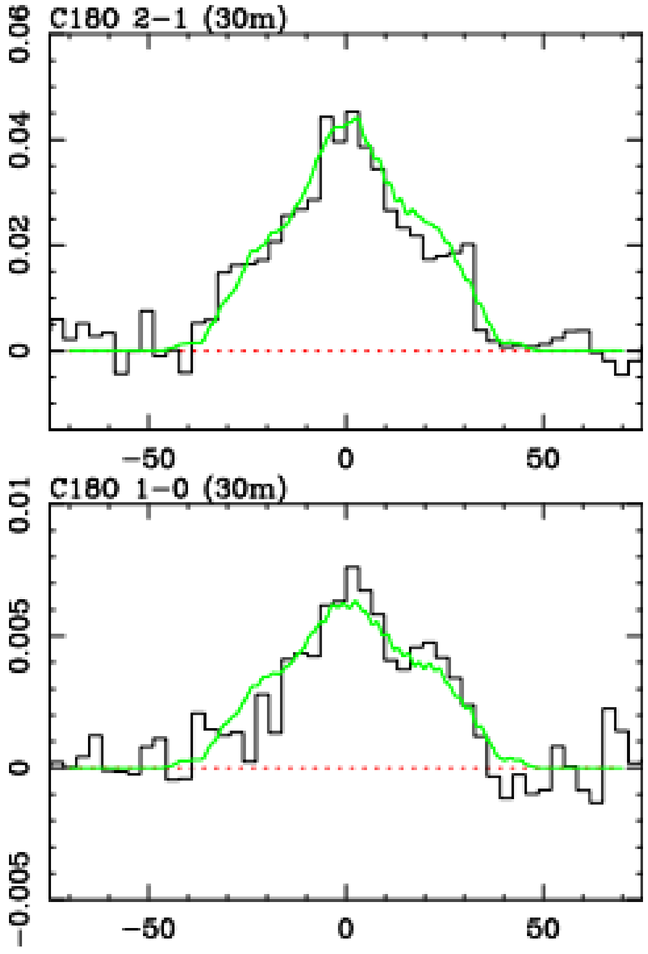
$C^{17}O$



Rel. Ab.: 10^{-6}

Tmb vs v (km/s)

$C^{18}O$



Rel. Ab.: $6 \cdot 10^{-7}$

CO: FINDINGS AND DEDUCTIONS

- A $^{17}O/^{18}O$ ratio of 1.6 corresponds to an initial mass for the central AGB star of ~1.7$M_{\odot}$ (Karakas *et al.* 2014, Cristallo *et al.* 2011, Stancliffe & Eldridge 2009). That mass is enough to be on the TP-AGB phase for long enough to become C-rich despite its O-rich chemistry.

- A $^{12}C/^{13}C$ ratio of 30 aligns with an S-type star chemistry (Ramstedt *et al.* 2014).

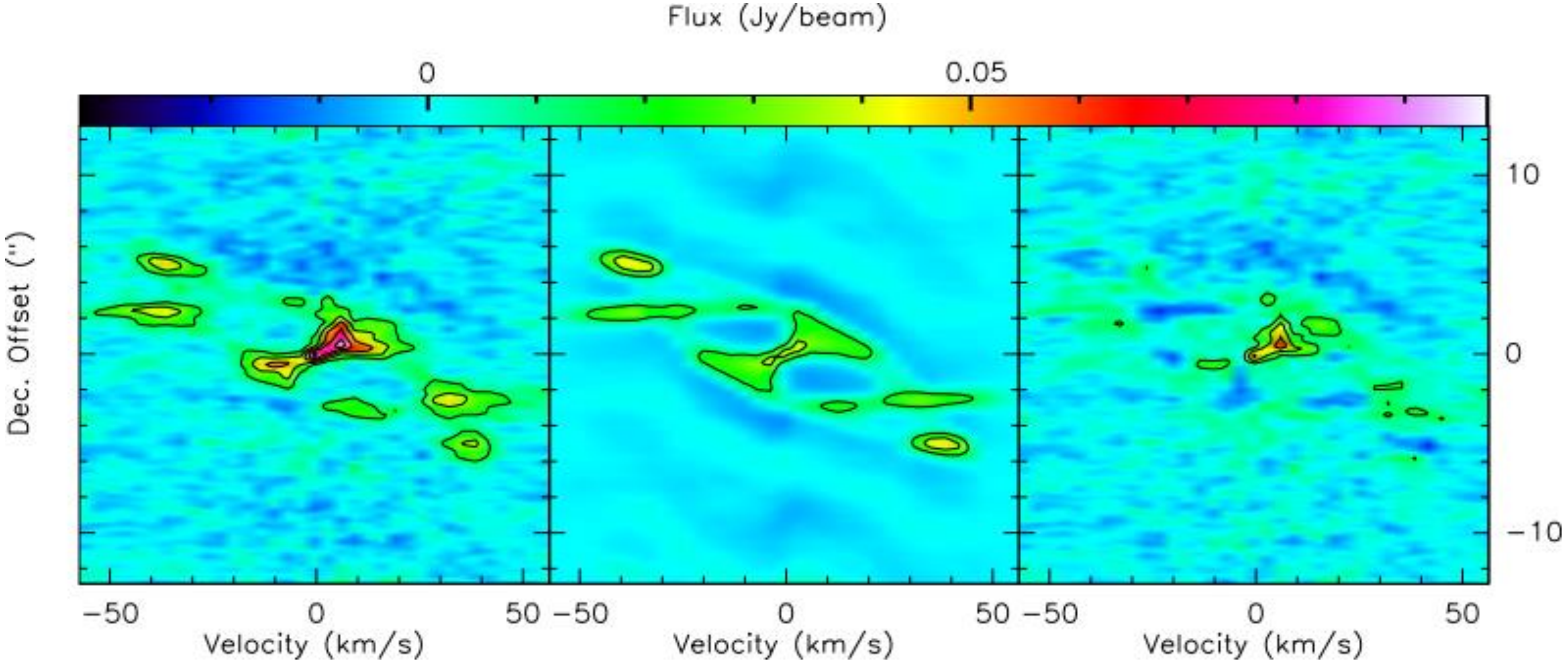
- For a central star with 1.7$M_{\odot}$, 0.9 $M_{\odot}$ is ~80% of the expected mass-loss during the AGB phase.

- These isotopic ratios support the previous hypothesis (Alcolea *et al.* 2007) that a Common Envelope Event could have interrupted the AGB phase preventing the star to become C-rich.

HCN & HCO^+: A NEW VISION

- They trace different dynamic behaviour.
- Some areas are invisible in low-J CO lines.
- Extremely turbulent knots with a shock front-like velocity distribution.
- Different relative abundance values across structures.

HCO^+ P-V diagram from map



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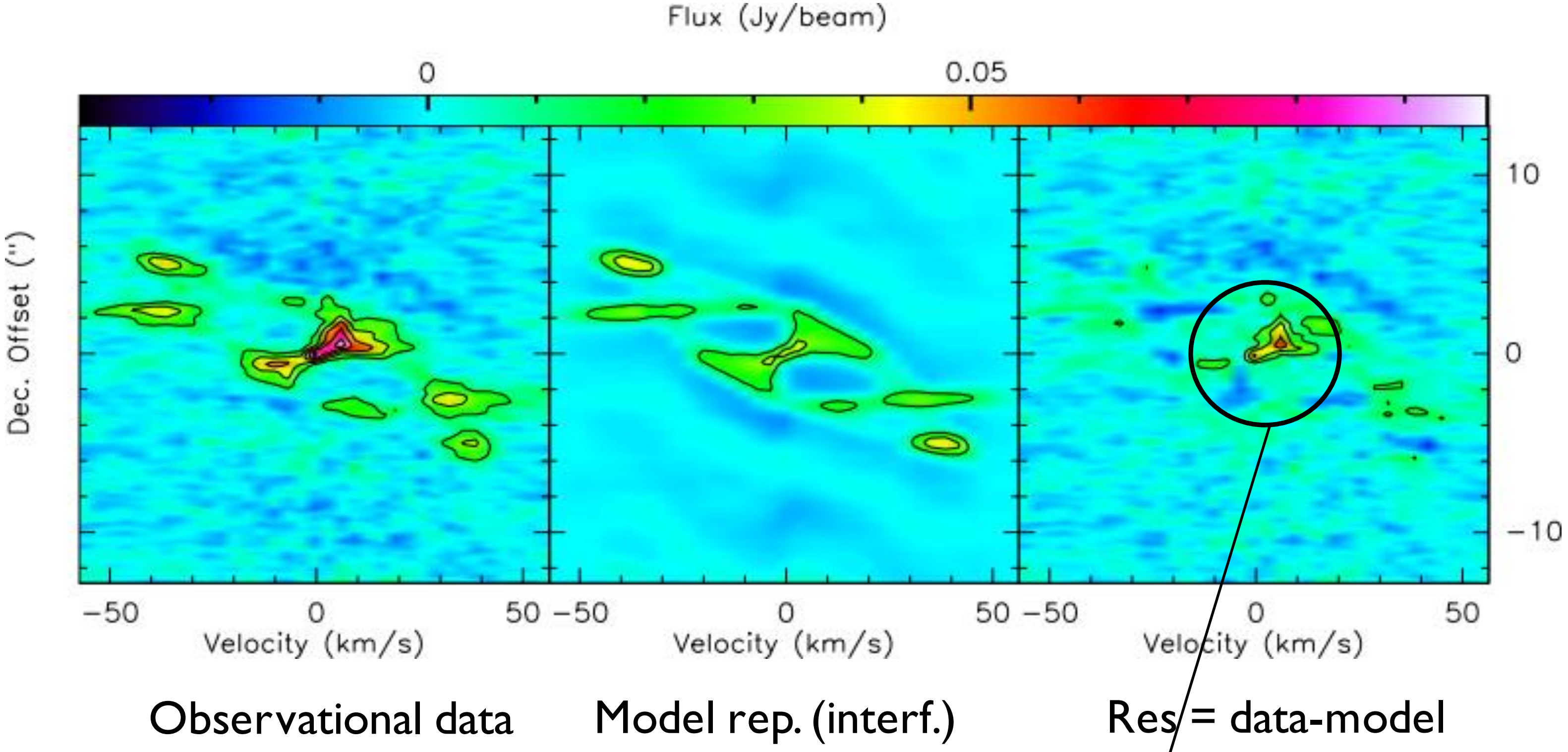
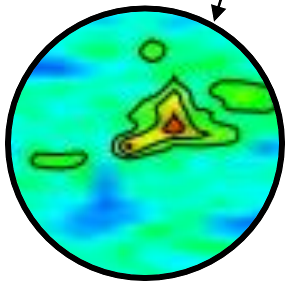


The bright spot is there again!



HCN & HCO$^+$: ISOTOPIC RATIOS

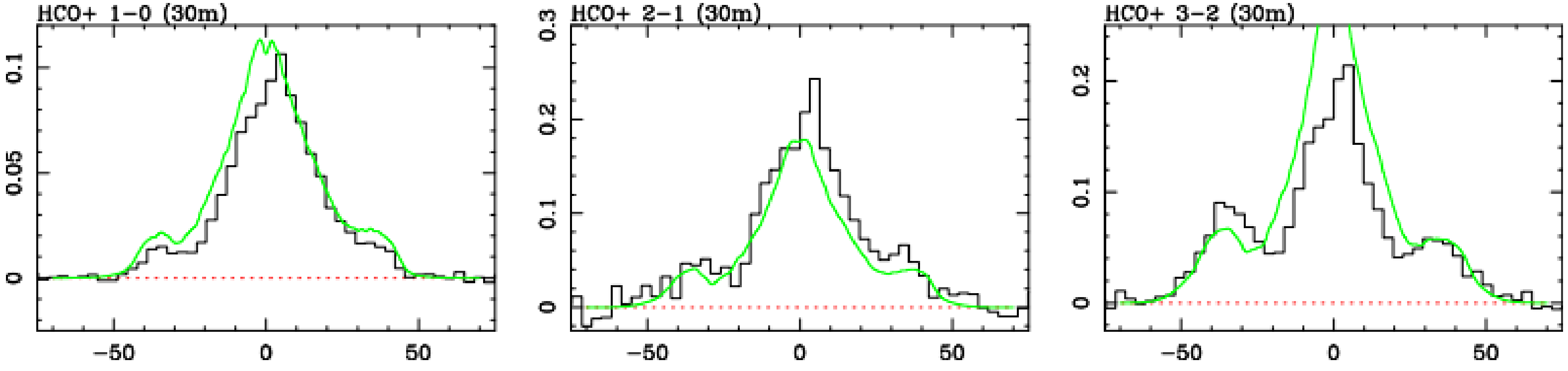
- Single-dish data allow us to find abundances for H^{13}CN and H^{13}CO$^+$.

H^{12}CO$^+$/H^{13}CO$^+$ = 10!!

- The bright spot is even more prominent in H^{13}CO$^+$ lines.
- H^{13}CN lines are also compatible with these ratio findings.

Tmb vs v (km/s)

H^{12}CO$^+$ line profiles:



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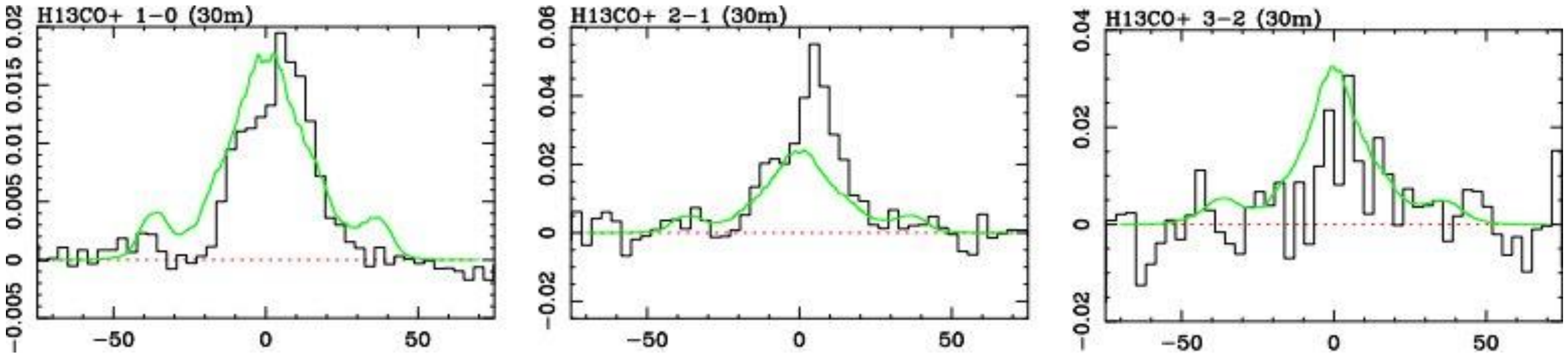


HCN & HCO^+: ISOTOPIC RATIOS

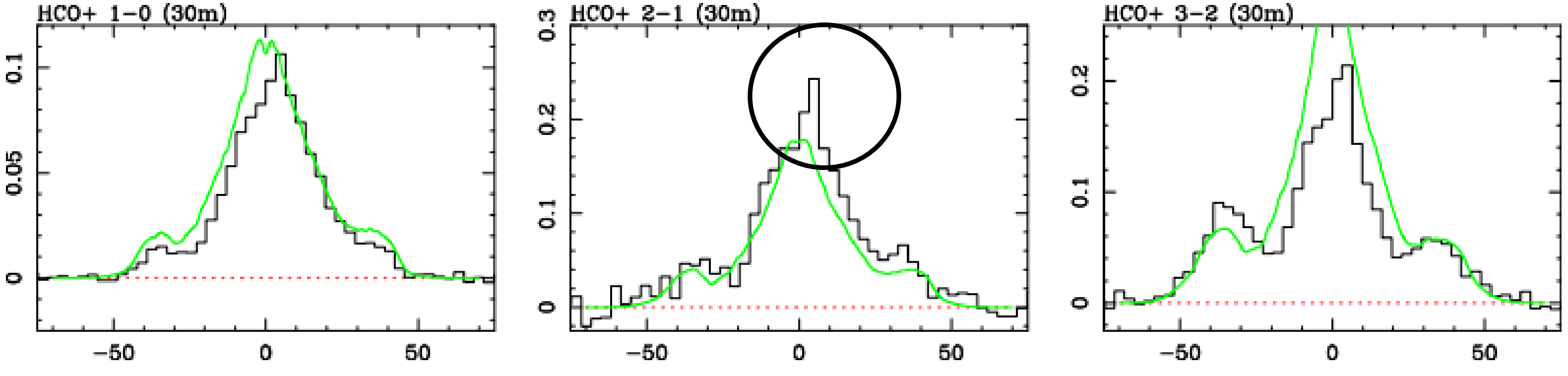
- Single-dish data allow us to find abundances for $H^{13}CN$ and $H^{13}CO^+$.

$H^{12}CO^+/H^{13}CO^+ = 10$!!

- The bright spot is even more prominent in $H^{13}CO^+$ lines.
- $H^{13}CN$ lines are also compatible with these ratio findings.

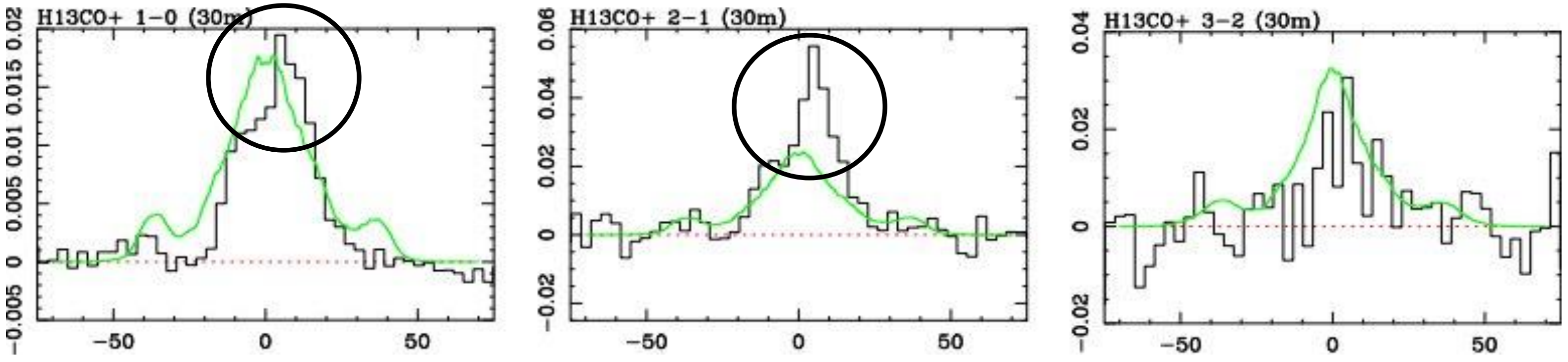
Tmb vs v (km/s)

$H^{12}CO^+$ line profiles:



Tmb vs v (km/s)

$H^{13}CO^+$ line profiles:

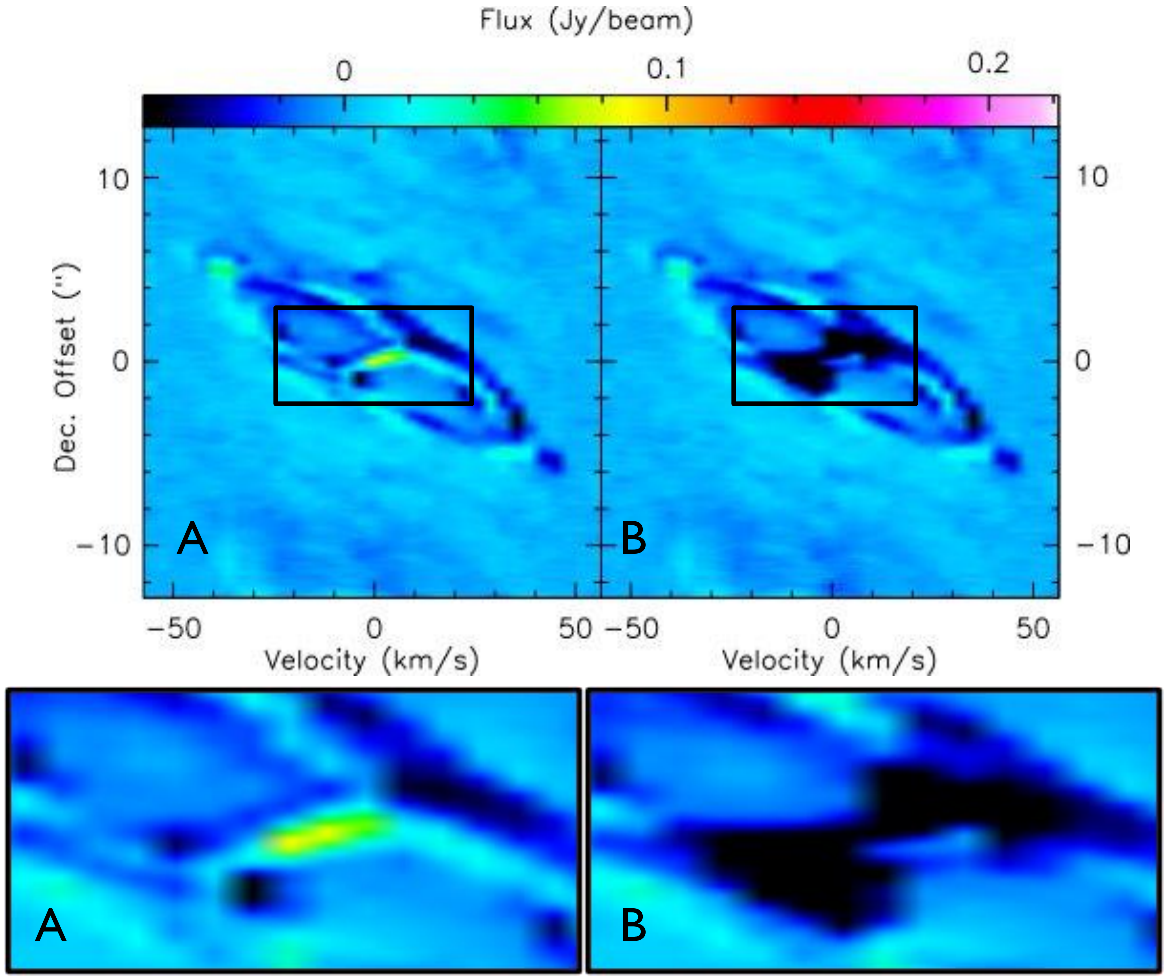


$^{12}C/^{13}C$: A CONTRADICTORY RESULT?

- Option A: $^{12}CO/^{13}CO$ ratio of 30 for all structures.
- Option B: $^{12}CO/^{13}CO$ ratio of 30 for outer structures (shell, ring and tips outer) and 10 for inner ones (cylinder, knots and tips inner).

These ratios are compatible if applied only to the inner structures!!

^{13}CO P-V diagram:
Data-model for options A and B



CONCLUSIONS AND OPEN QUESTIONS

- A common envelope ejection is supported by CO ratios and physical characteristics of the nebula.
- Significant mass ejection kept happening after the sudden mass-loss. Is it still happening?
- What is the nature of the central hot spot? Inhomogeneities? A brand new mass ejection?
- Isotopic ratios change across structures and during the ejection of the nebula. How is it possible?
- Further observations mapping the nebula are required to better constrain CO, HCN and HCO^+ line excitation and confirm our model for the structures along the axis.