IRC+10216 in 3-D: morphology of a TP-AGB star envelope

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OUTLINE

Part I: New IRC+10216 observations
  - Why study IRC+10216?
  - Large scale CO maps (SMA+IRAM 30m)
  - Very high resolution CO, C₄H, CN maps (ALMA)
    → Physical conditions+Mass loss mechanism

Part II: Reconstruction of the envelope in 3-D
  - 3-D modeling with velocity fields
  - Test cases
  - Application to the observed X,Y,V cube
    → IRC +10 216 3-D model
IRC+10 216 is the dusty envelope surrounding the closest TP-AGB star. It has:

- A **massive** envelope of **large** apparent size (several arcmin)

- A **simple** symmetrical shape

- A **uniform expansion** velocity (14.5 km/s)
  
  1 arcsec ~ 130 A.U.~50yr

- A **rich molecular content**
  (>80 molecular species, including all known **IS** anions)
**IRC+10 216: V-band, C$_4$H and CO emissions in the plane of the sky at the same scale**

**VLT – V-band optical image**

C$_6$H @ PdBI

**Guélin et al. 1999**

**Leao et al. 2006**

CO@30-m telescope ; $v=v_*= -26$ km/s

CO (J=2→1) line

8000 yr

0.1 pc

800 yr

0.1 pc

**Cernicharo et al. 2014**

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CO(2-1) X,Y,V cube: whole envelope (6 arcmin) at 3” resolution

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ALMA

+ 30-m

CO(2-1) X,Y,V cube: central 1.5 arcmin at 0.3\(^\prime\) resolution

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$^{13}$C$_4$H(24-23) X,Y,V cube: central 1.5 arcmin at 0.3” resolution

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Velocity-channel maps (X,Y,V) trace the emissivity distribution from conical shells.

Velocity-channels close to the systemic velocity $V_\star (X,Y,V_\star)$ trace the gas in the meridional plane parallel to the plane of the sky.
CO(2-1) emission in the meridional plane: a set of nearly concentric rings over an extended pedestal.

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Same image in polar coordinates

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ZOOM on the $^{12}$CO(2-1) emission in the meridional plane ($V=V_*$)

Mass loss rate

Temperature profile

HPBW 0.3" (or ~16 yr)

$^{12}$CO(1-0)

$^{13}$CO(1-0)
CO (yellow) and CN (cyan) emission contours on VLT optical image

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FIRST CONCLUSIONS from meridional plane images

• Quasi-regular pattern of CO-bright shells
• Typical shell spacing in the outer envelope is $\sim 16''$ or 700 yr
• Pattern is tighter inside 40''
• Very good correlation between CO, C$_4$H, CN and dust $\implies$ density pattern
• Shell-intershell density contrast of $\sim 3$
• Pattern may be explained with mass loss modulation by a low-mass companion (with orbit in the plane of the sky)

BUT, IS THE MASS LOSS ISOTROPIC?

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Two Algorithms were developed for the envelope reconstruction in 3-D XYZ, starting from the XYV cube.

**Non-iterative: (A)**
Starts from the V* velocity bin and moves alternatingly to neighboring velocity bins. Tries to match velocity images.

**Iterative: (B)**
- Converts initial model to spherical coordinates.
- Smoothes the spherical grid in polar θ direction.
- Converts back into Cartesian and normalize to match velocity images.

Test model: spherical shells

Results using methods A and B
Result: the 3-D reconstructed envelope

Methods A and B yield Similar results for IRC+10216

So far, with the XYV=V* velocity-channel maps, we have considered the trace of the dense CO-bright shells in one single Meridional Plane parallel to the plane of the sky.

Now, using the reconstructed 3-D XYZ cube, we can follow the shells throughout the whole envelope, e.g. following a set of inclined meridional planes.
Animation of the IRC +10 216 CO(2-1) emission in 3-D, with its shell structure in logarithmic scale. The two extreme velocity channels with high opacity have been masked. **The shells have spherical shapes** and can be followed over large angular ranges (>3 sterad).
Conclusion: The mass loss is isotropic or nearly isotropic!

Schematic view of the IRC +10216 system

Double star system (enlarged scale)

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Thank you!