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

I. C. Leão et al.: The CSE of IRC+10216

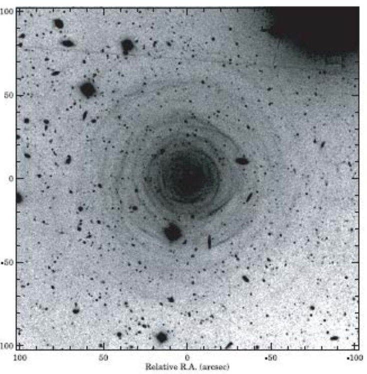
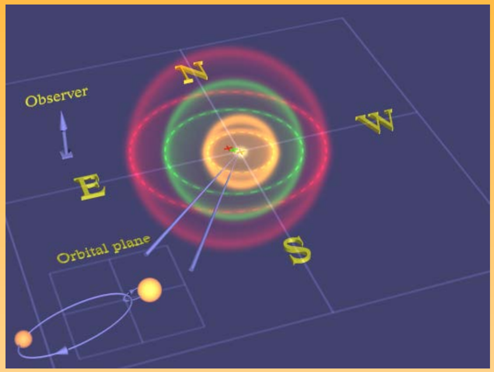


Fig. 3. FORS1 deconvolved *V*-band image of IRC+10216. North is up and East is left.



Radio Stars, Haystack, November 2nd, 2017,

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A&A 2017/31619 in press (already in arXiv)

OUTLINE

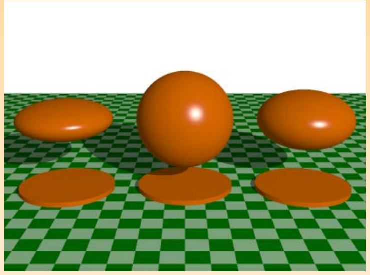
Part I: New IRC+10216 observations

- *Why* study IRC+10216?
- *Large scale* CO maps (SMA+IRAM 30m)
- *Very high resolution* CO, C_4H, 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:

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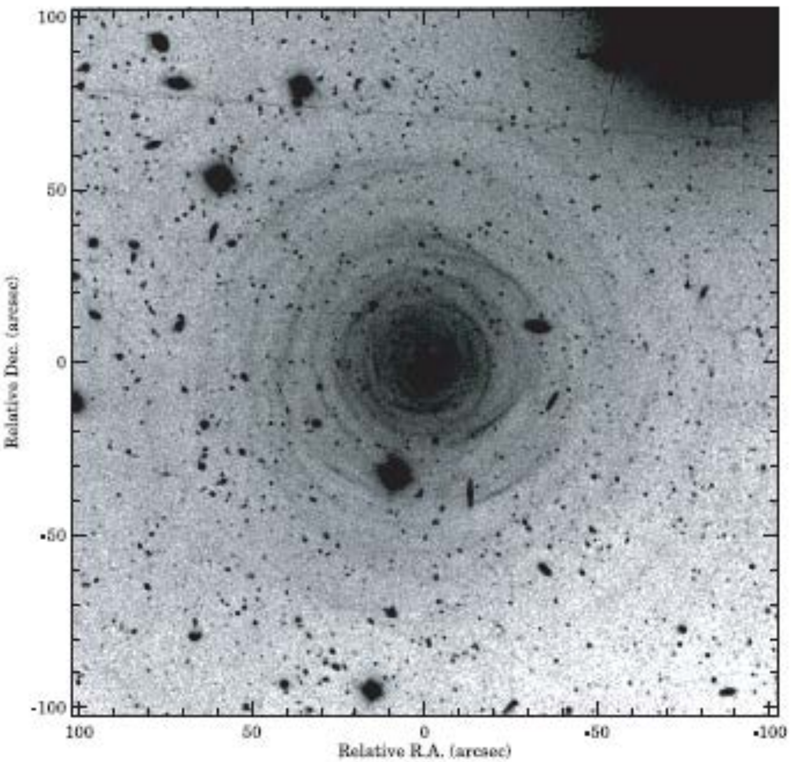
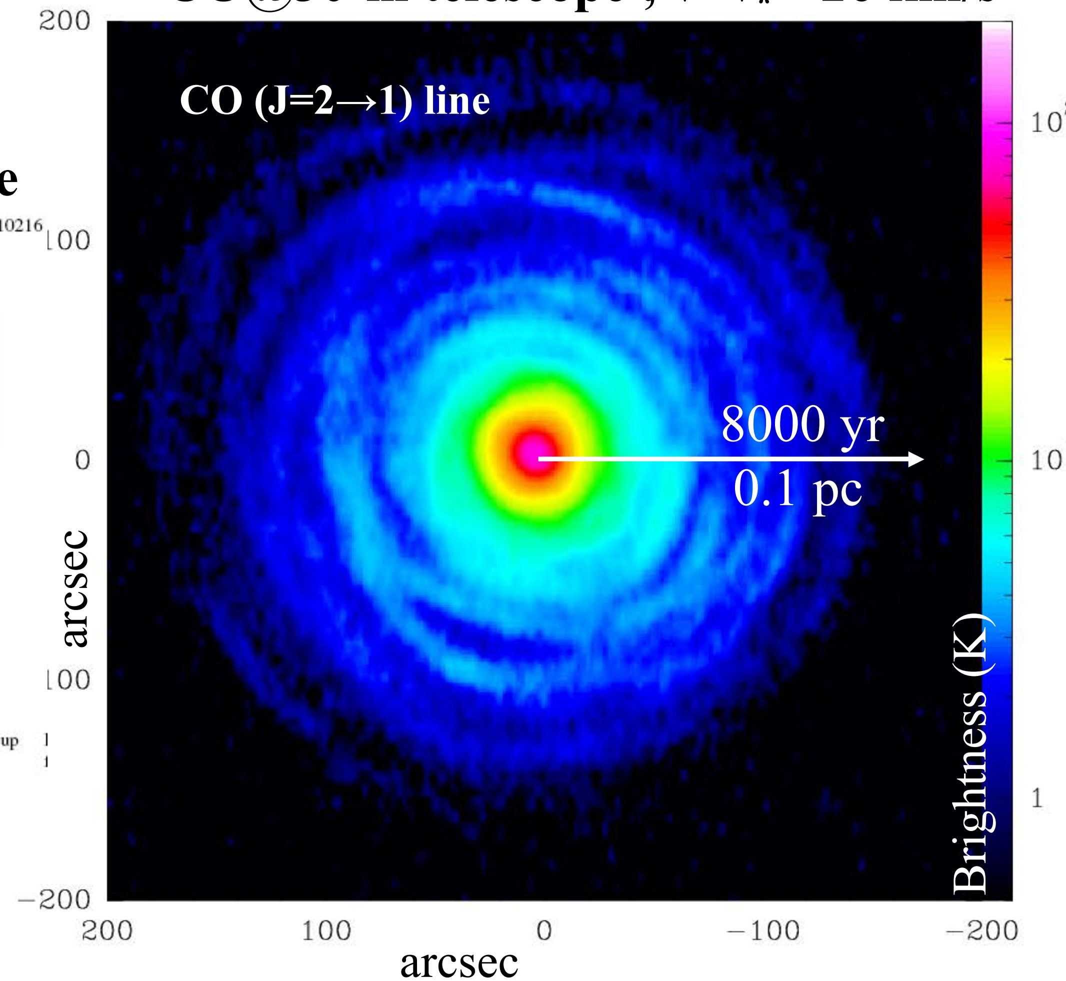


Fig. 3. FORS1 deconvolved *V*-band image of IRC+10216. North is up and East is left.

- 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_4H and CO emissions in the plane of the sky <u>at the same scale</u>

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



VLT –V-band optical image

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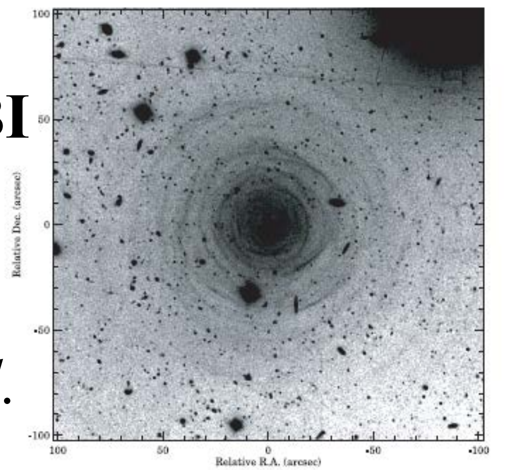
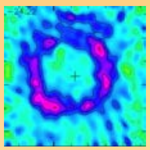


Fig. 3. FORS1 deconvolved V-band image of IRC+10216. North is up and East is left.

C_6H @ PdBI

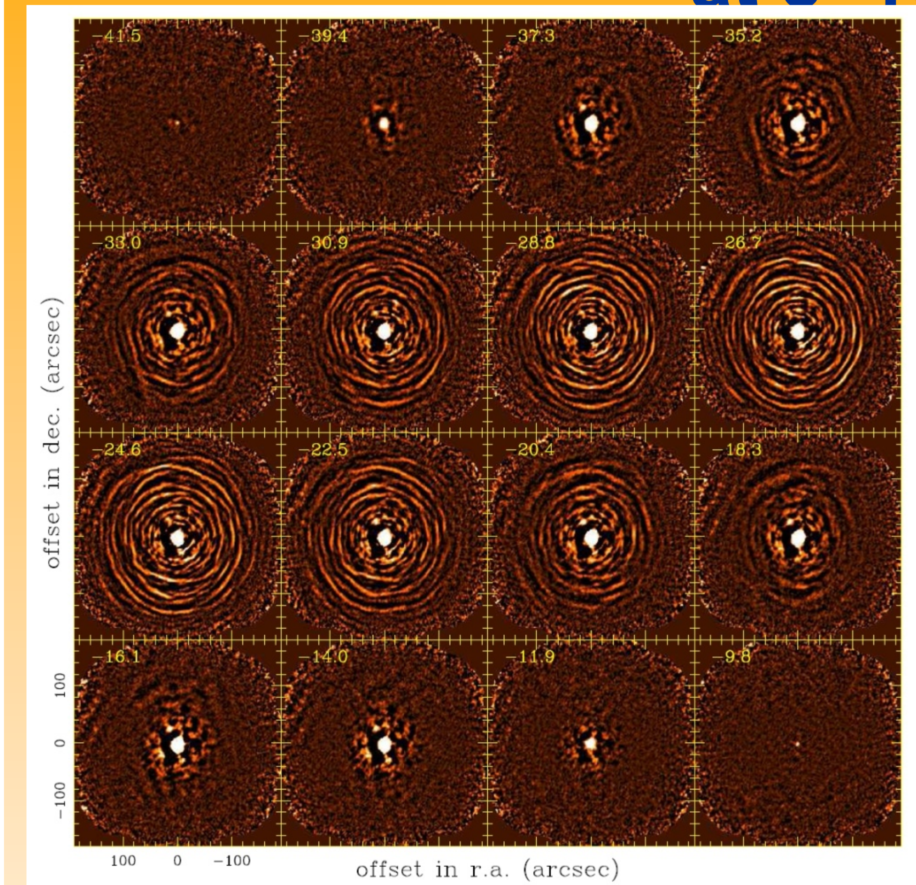


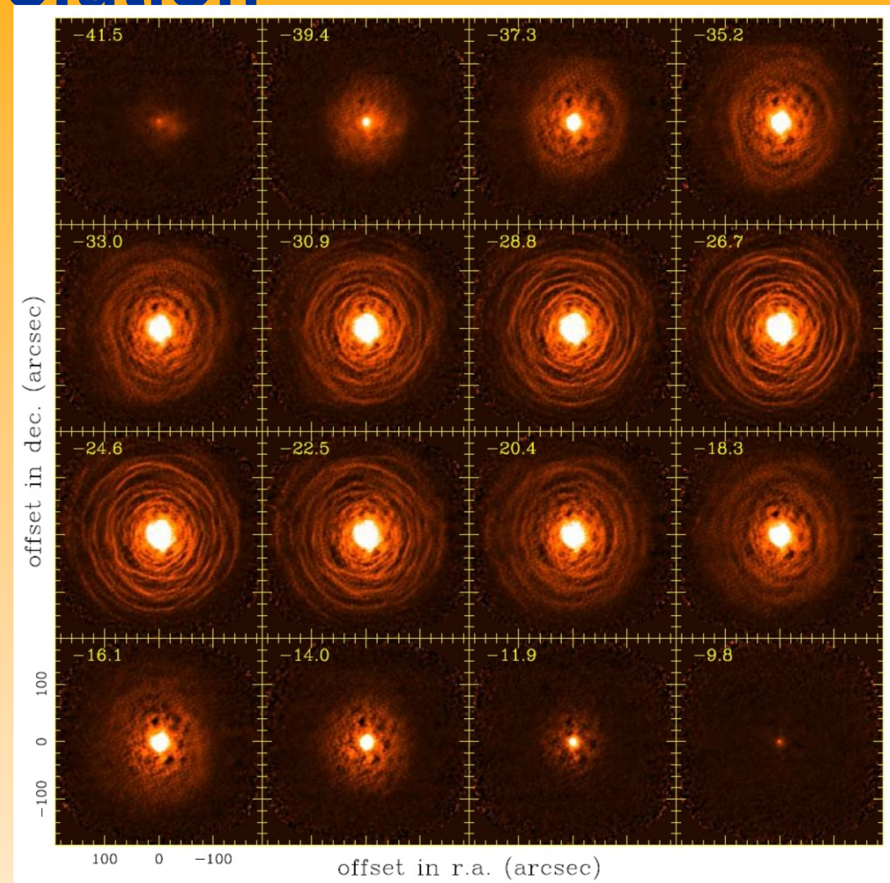
Guelin et al. 1999

Leao et al. 2006

Cernicharo et al. 2014

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





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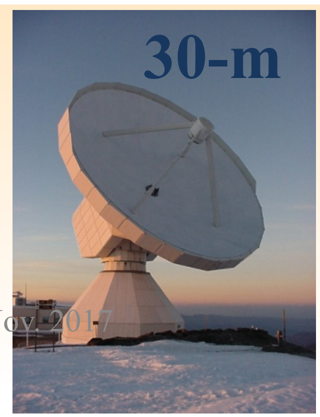

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CO(2-1) X,Y,V cube: central 1.5 arcmin at 0.3” resolution

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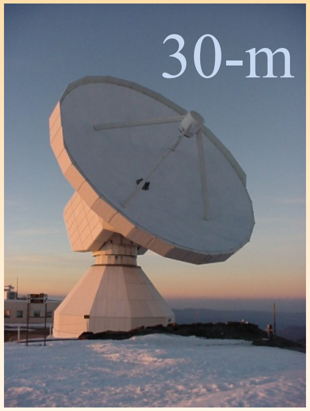
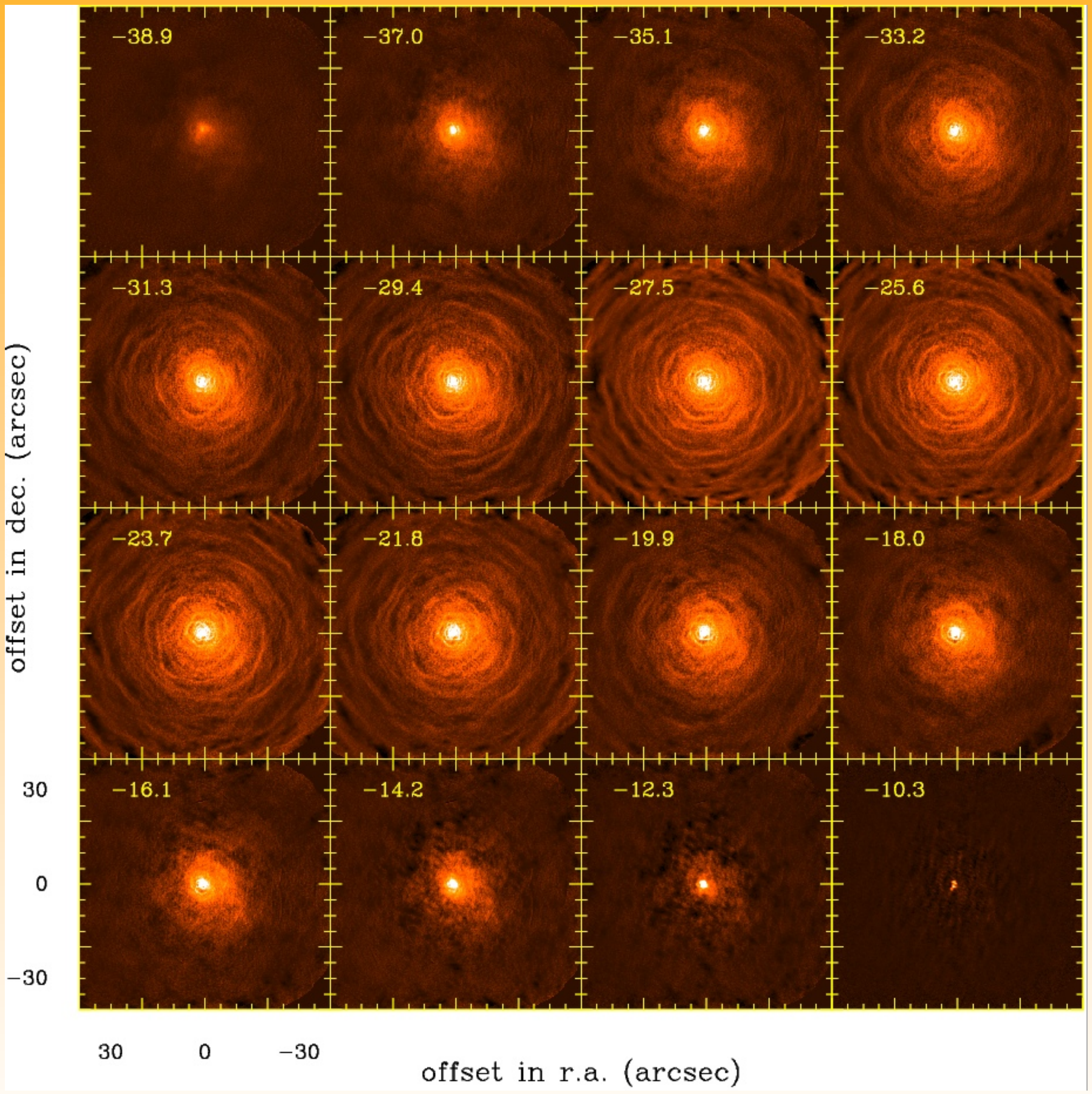
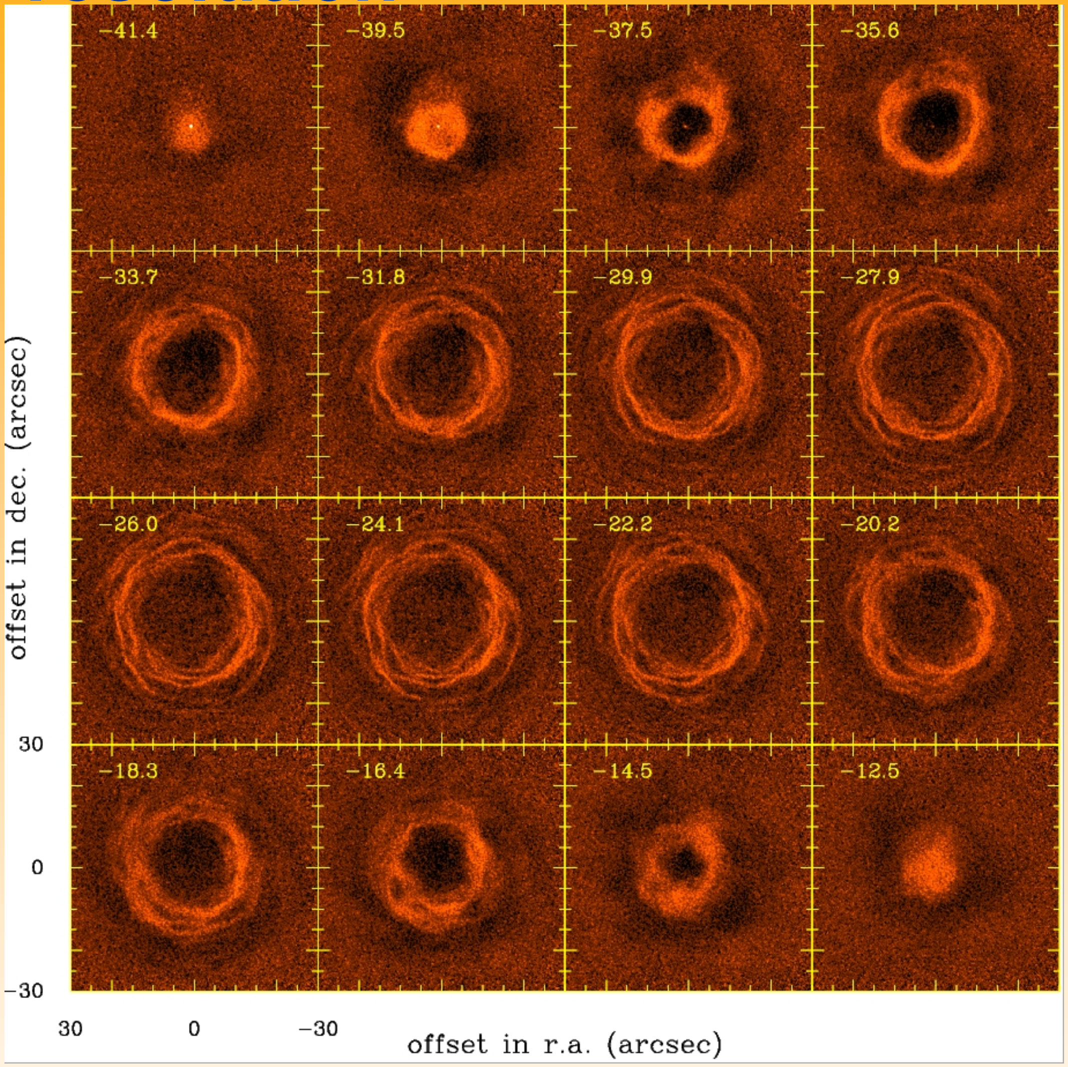
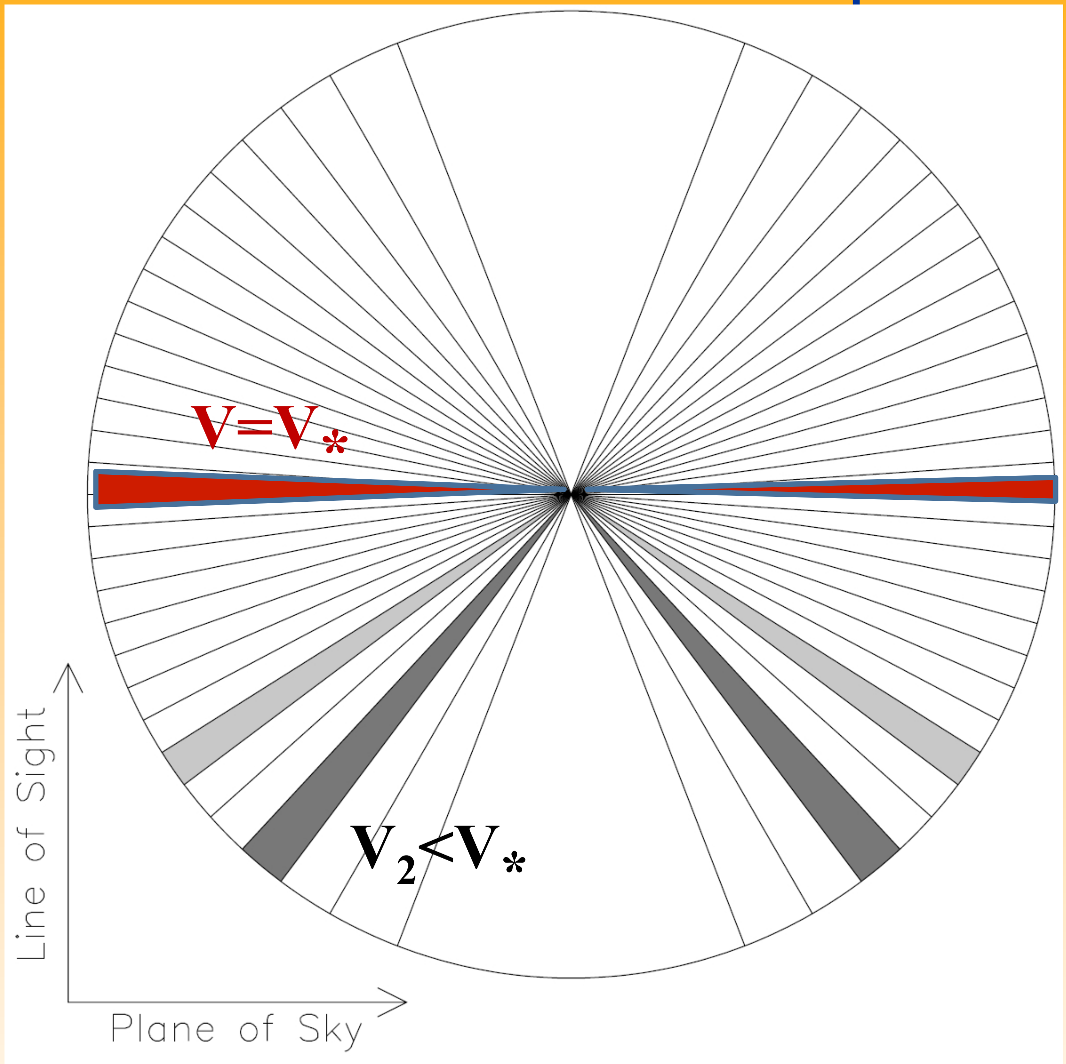




C_4H(24-23) X,Y,V cube: central 1.5 arcmin at 0.3” resolution



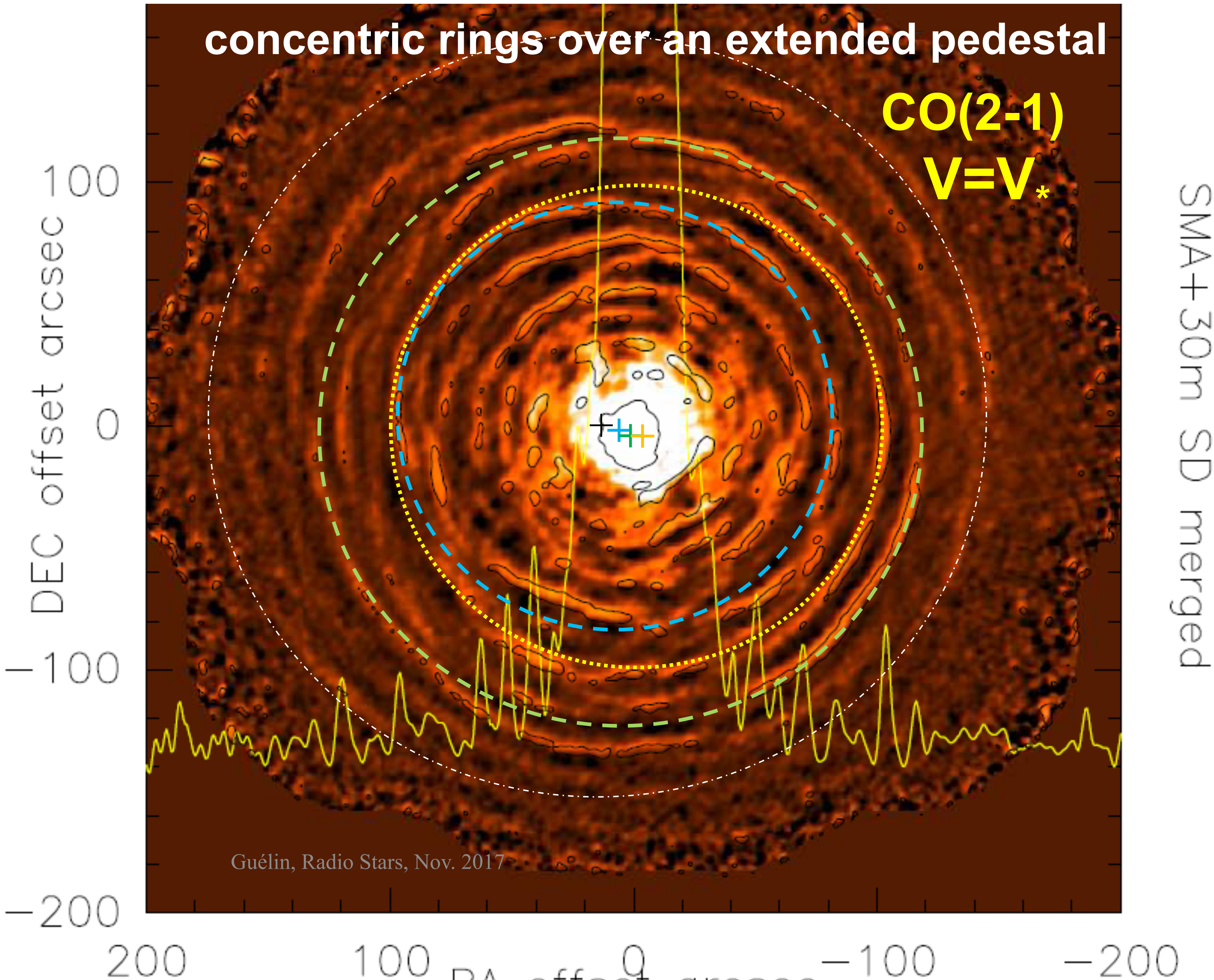
Velocity-channel maps for uniformly expanding sphere



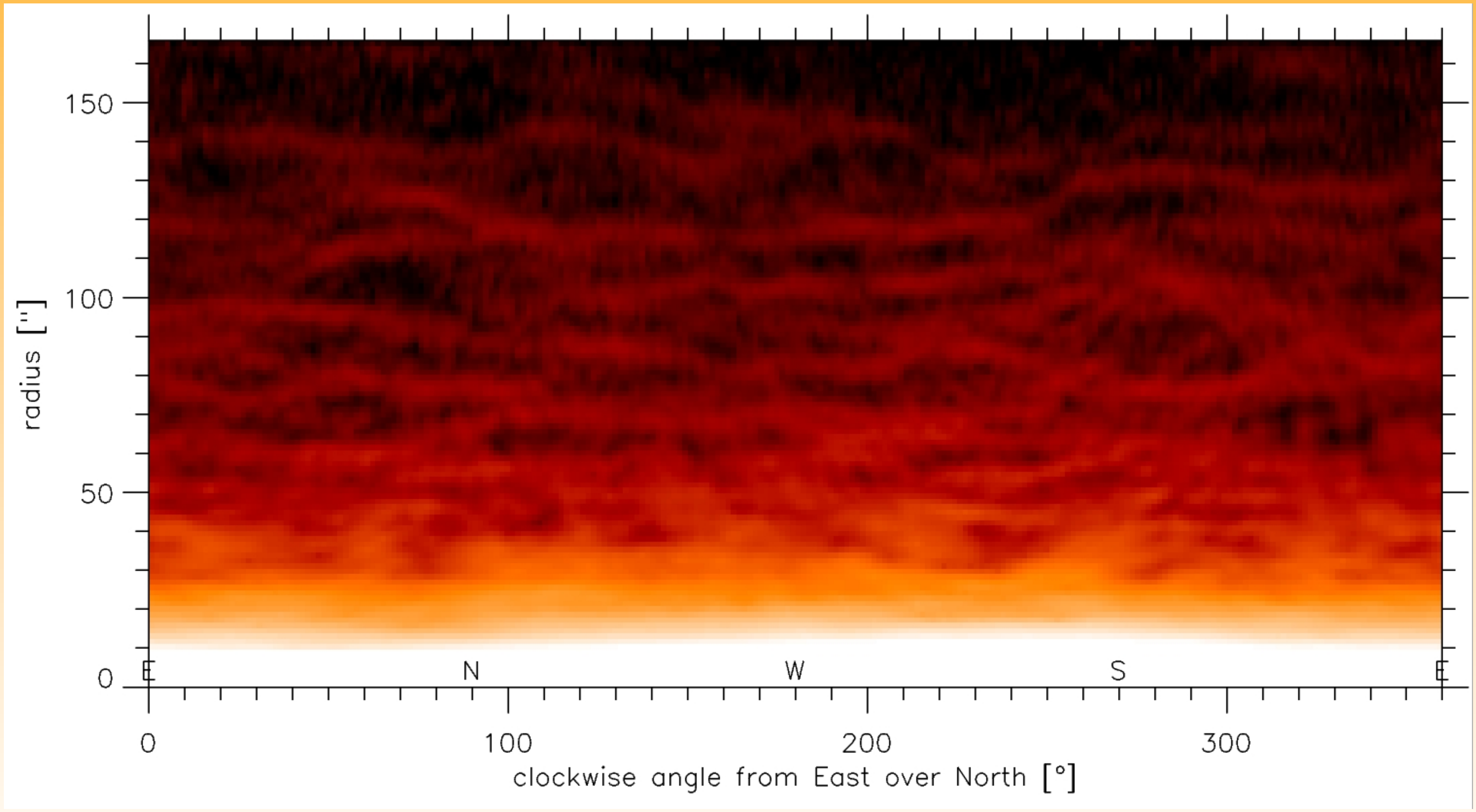
Velocity-channel maps (X,Y,V) trace the emissivity distribution from conical shells

Velocity-channels close to the systemic velocity V_* (X,Y,V_*) trace the gas in the meridional plane parallel to the plane of the sky

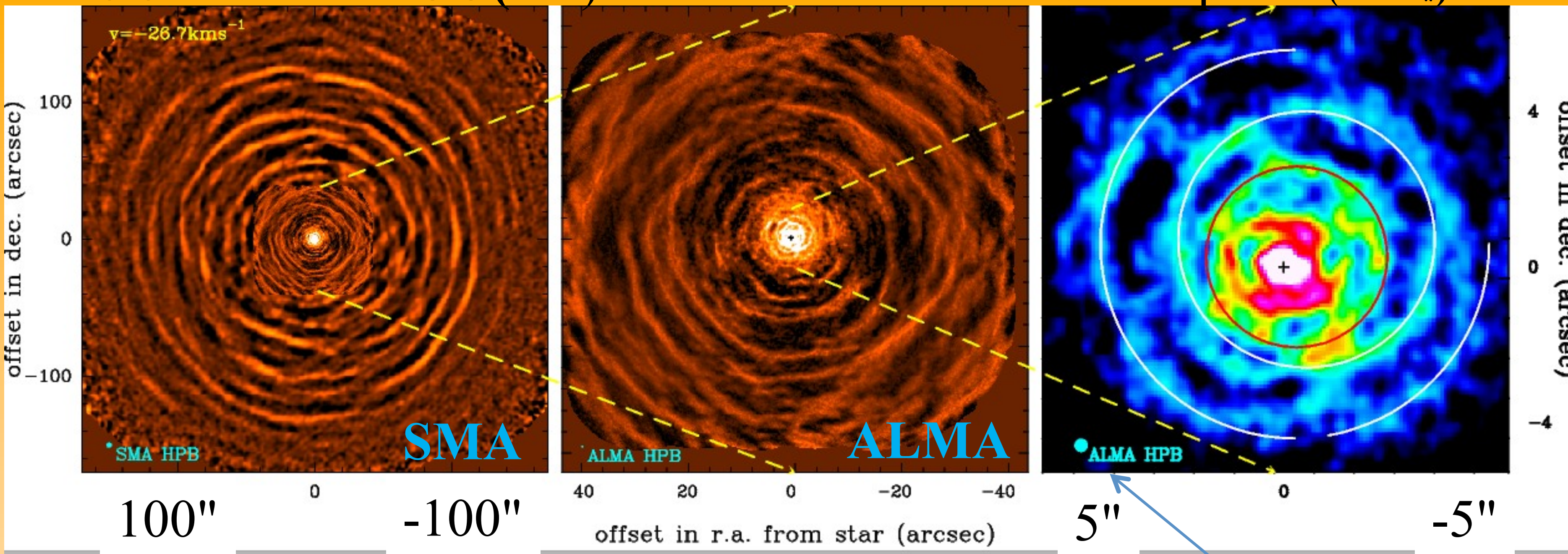
CO(2-1) emission in the meridional plane: a set of nearly



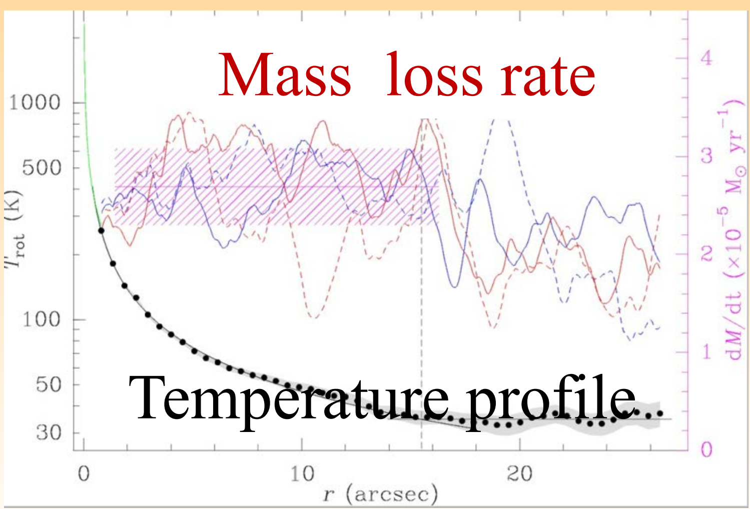
Same image in polar coordinates

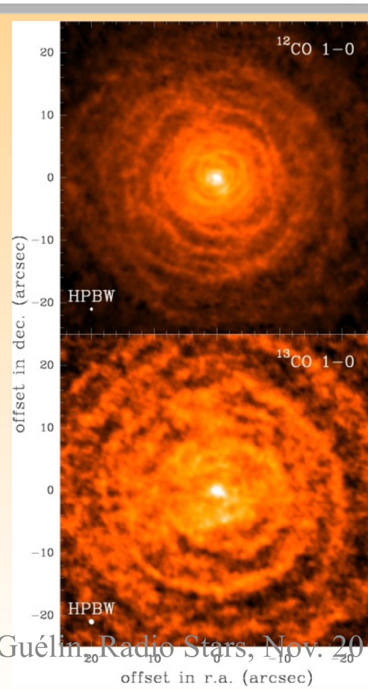


ZOOM on the ^{12}**CO(2-1**) emission in the meridional plane (**V**=**V**$_*$)



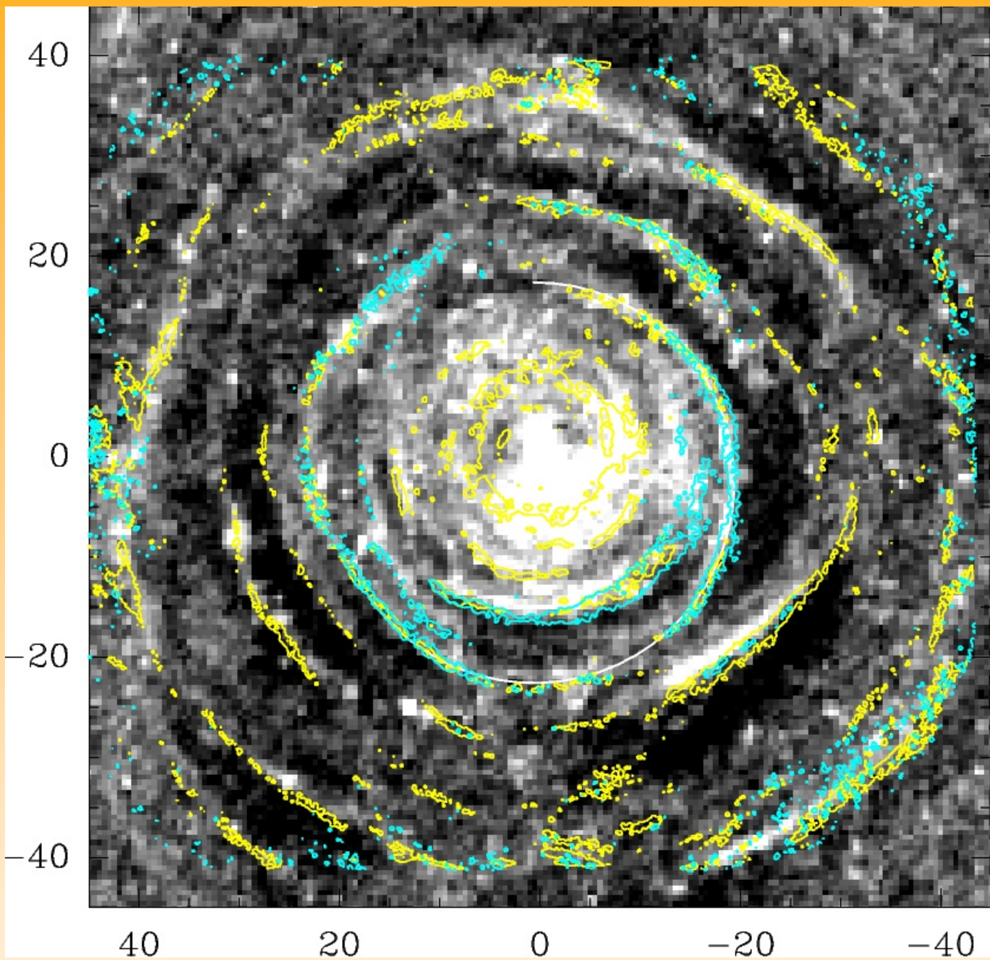
HPBW 0.3“
(or ~16 yr)



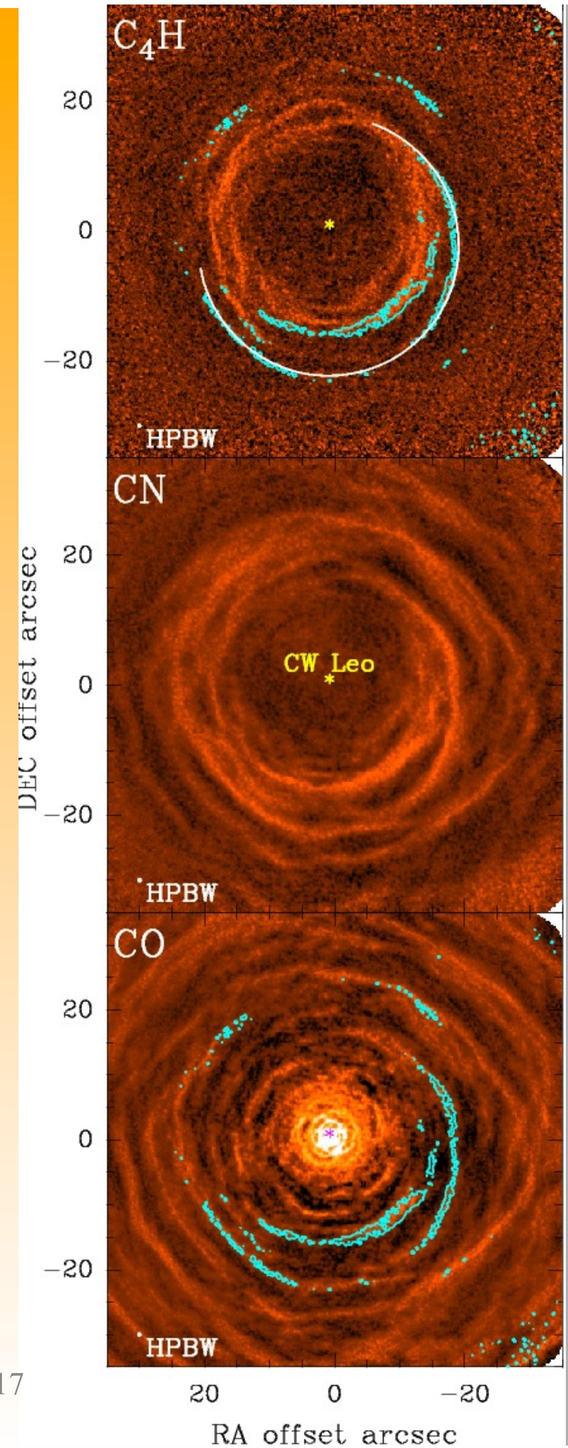


^{12}**CO(1-0)**

^{13}**CO(1-0)**



CO (yellow) and CN (cyan) emission contours on VLT optical image

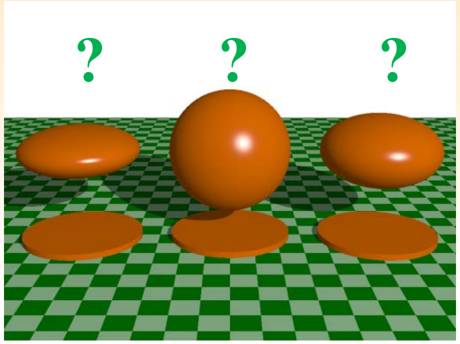


V=V*

FIRST CONCLUSIONS from meridional plane images

- Quasi-regular pattern of CO-bright shells
- Typical shell spacing in the outer envelope is ~16” or 700 yr
- Pattern is tighter inside 40”
- Very good correlation between CO, C_4H, CN and dust ==> density pattern
- Shell-intershell density contrast of ~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?



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

Non-iterative: (A)

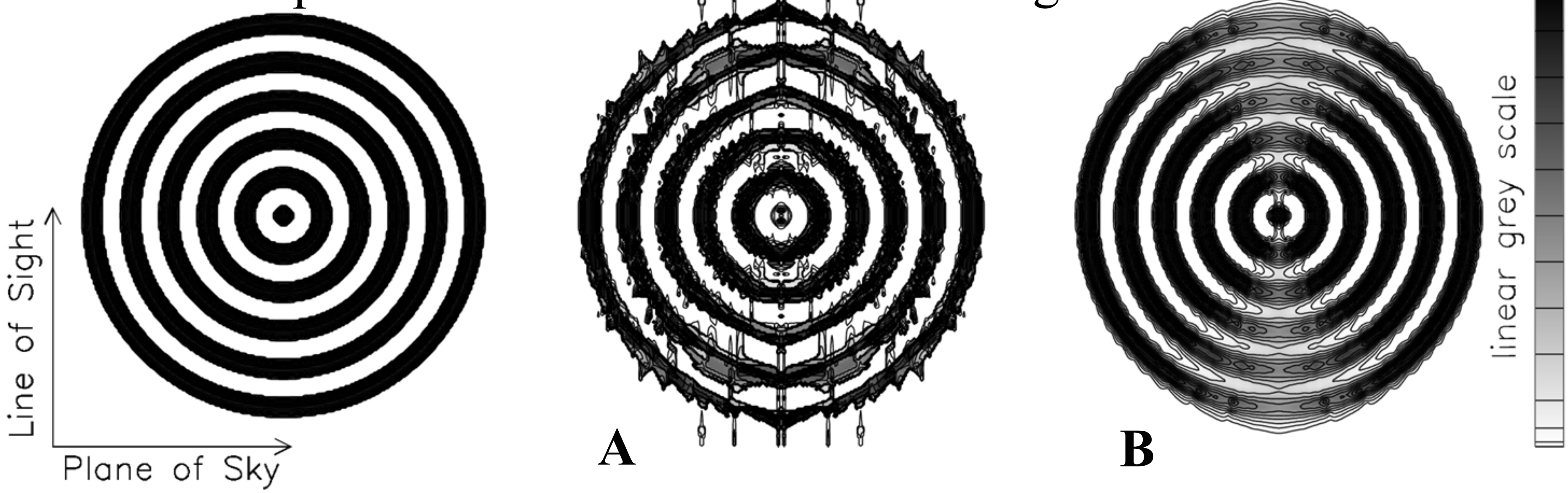
Starts from the V* velocity bin and moves alternatingly to neighboring velocity bins. Tries to match velocity images.

Iterative: (B)

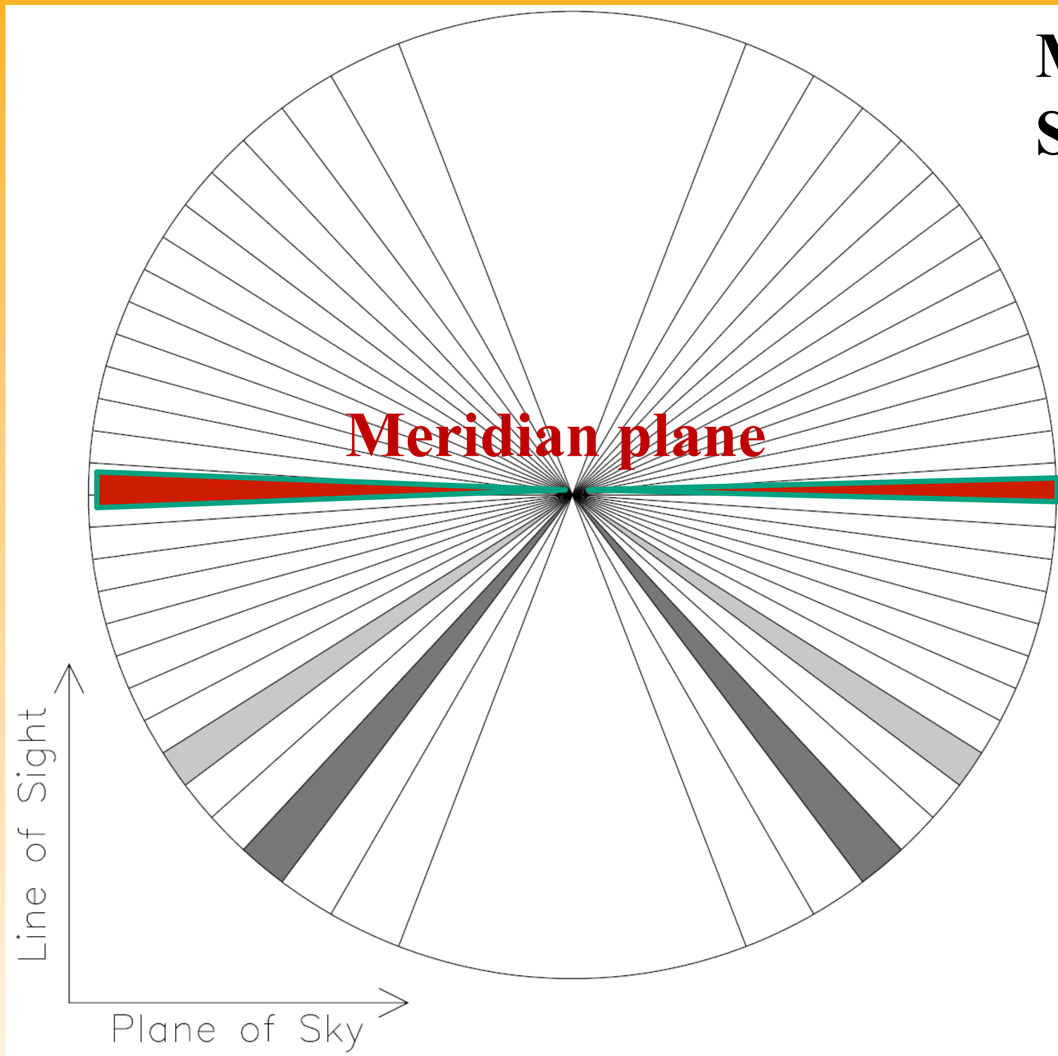
- Converts initial model to spherical coordinates.
- Smoothes the spherical grid in polar θ direction,
- Converts back into Cartesian and normalize to match velocity images

Test model: spherical shells

Results using methods A and B



Result: the 3-D reconstructed envelope

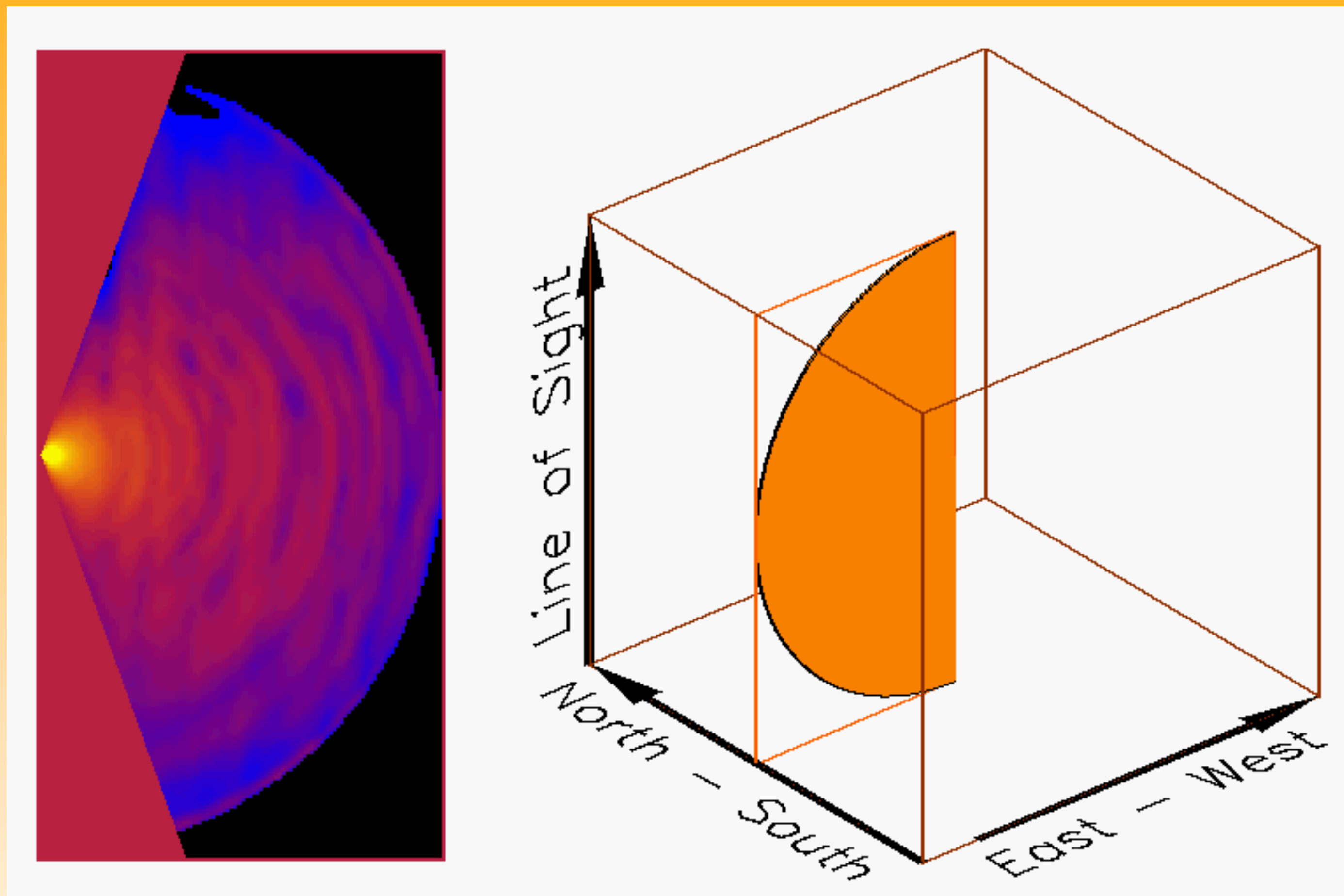


Methods A and B yield
Similar results for IRC+10216

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.

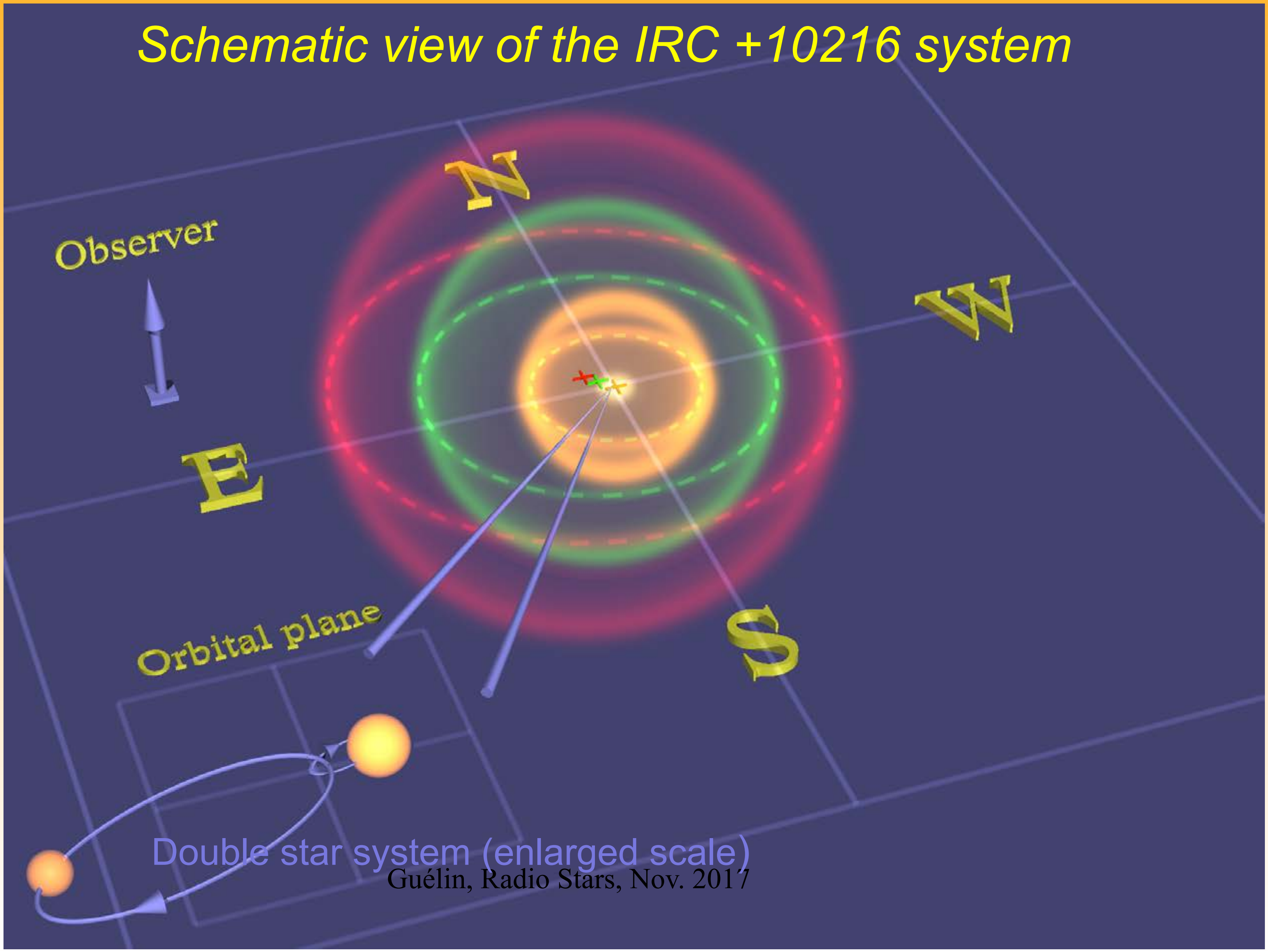
Now, using the reconstructed 3-D XYZ cube, we can follow the shells throughout the whole envelope , e.g. following a set of inclined meridional planes

IRC+10 216 in 3-D



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!



Thank you !