IRC+10216 in high-resolution Molecular Lines

Michael Bremer (IRAM), Michel Guélin (IRAM), Nimesh Patel (CfA), José Cernicharo (CSIC) et al.

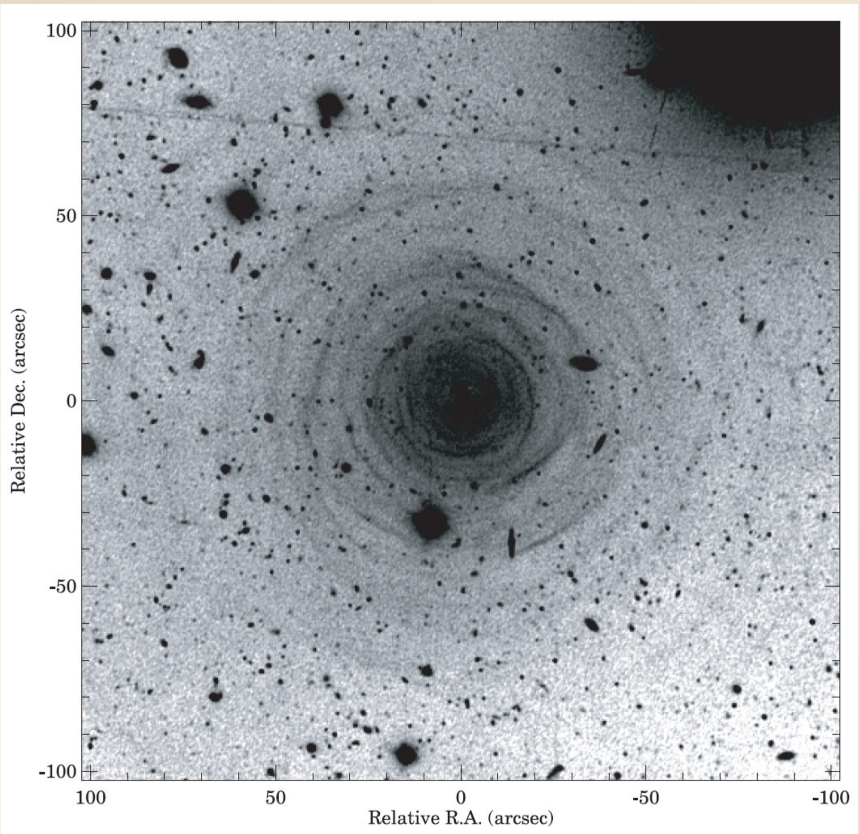
Motivation:

Asymptotic Giant Branch (AGB) stars represent a period in the life of stars when they return large amounts of gas enriched by nuclear synthesis and dust to the interstellar medium.

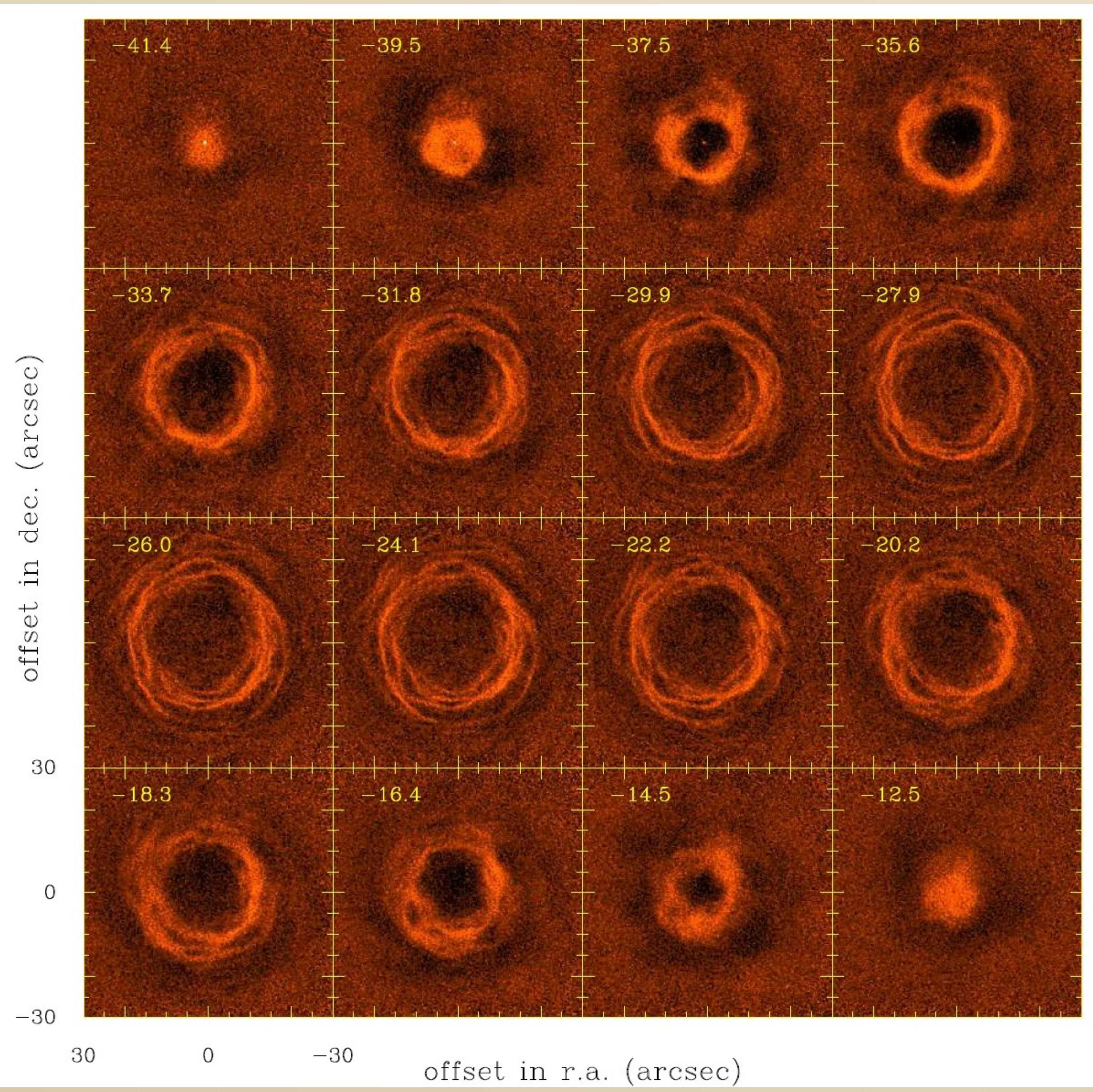
The resulting circumstellar envelopes are opaque to optical and near-IR wavelengths, which makes a study of their detailed morphologies and the underlying mass-loss processes difficult.

The advent of powerful mm-wave interferometers, such as the SMA, NOEMA and ALMA, which combine high angular and spectral resolution with high sensitivity, enables us to penetrate into the deepest hidden layers and to study, through the observations of molecular lines, the envelope structure and velocity field. This approach effectively suppresses most background sources.

The envelope IRC+10216 and its central star CW Leonis are the closest C-rich TP-AGB system relative to the Sun (distance ~130 pc after Menten et al. (2012)), and it exhibits a characteristic pattern of near-concentric shells. We study this system in several molecular lines and reconstruct a 3D model.

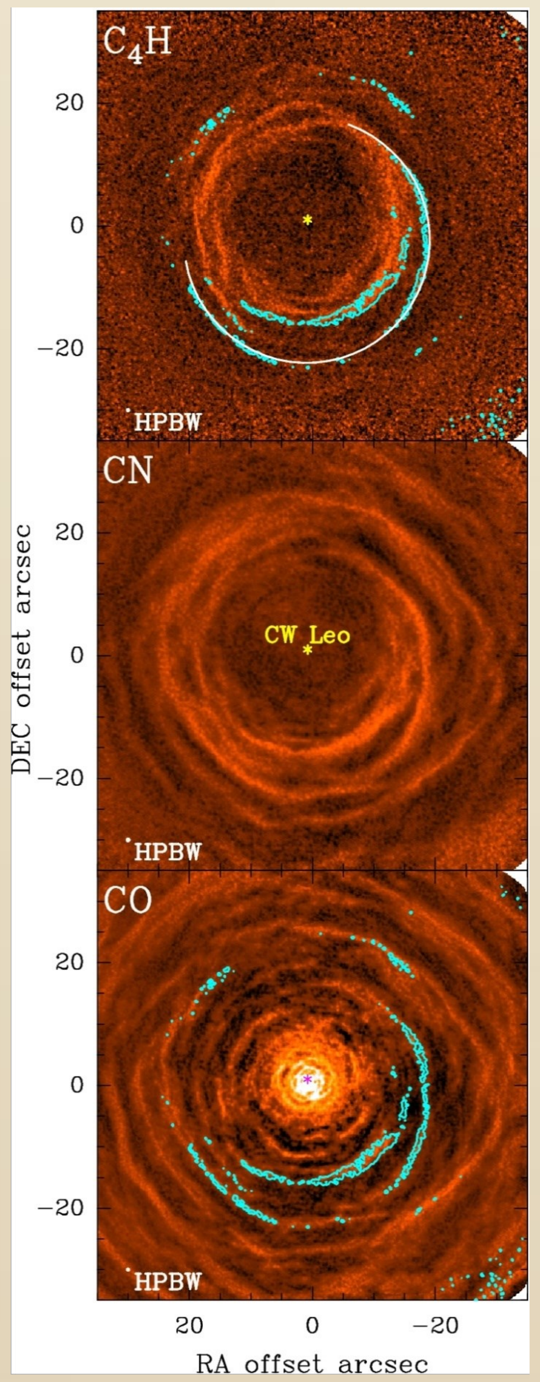


IRC+10216 in the optical V band, observed with the VLT (Leão et al. 2006)
Credit photos: SMA (top) N. Patel, NOEMA (middle) C. Lefèvre , ALMA (bottom) ESO, IRAM-30M (right) N. Billot.



Left: IRC+10216 in C_4H (N=24-23) (228.37 GHz), observed with ALMA. The structure traced by this molecule closely matches a limited radial range of the CO – bright shells, and shows that the shells are indeed closed in the direction of the observer.

Right: Adding the CN (2-1) line at 226.9 GHz to the comparison.

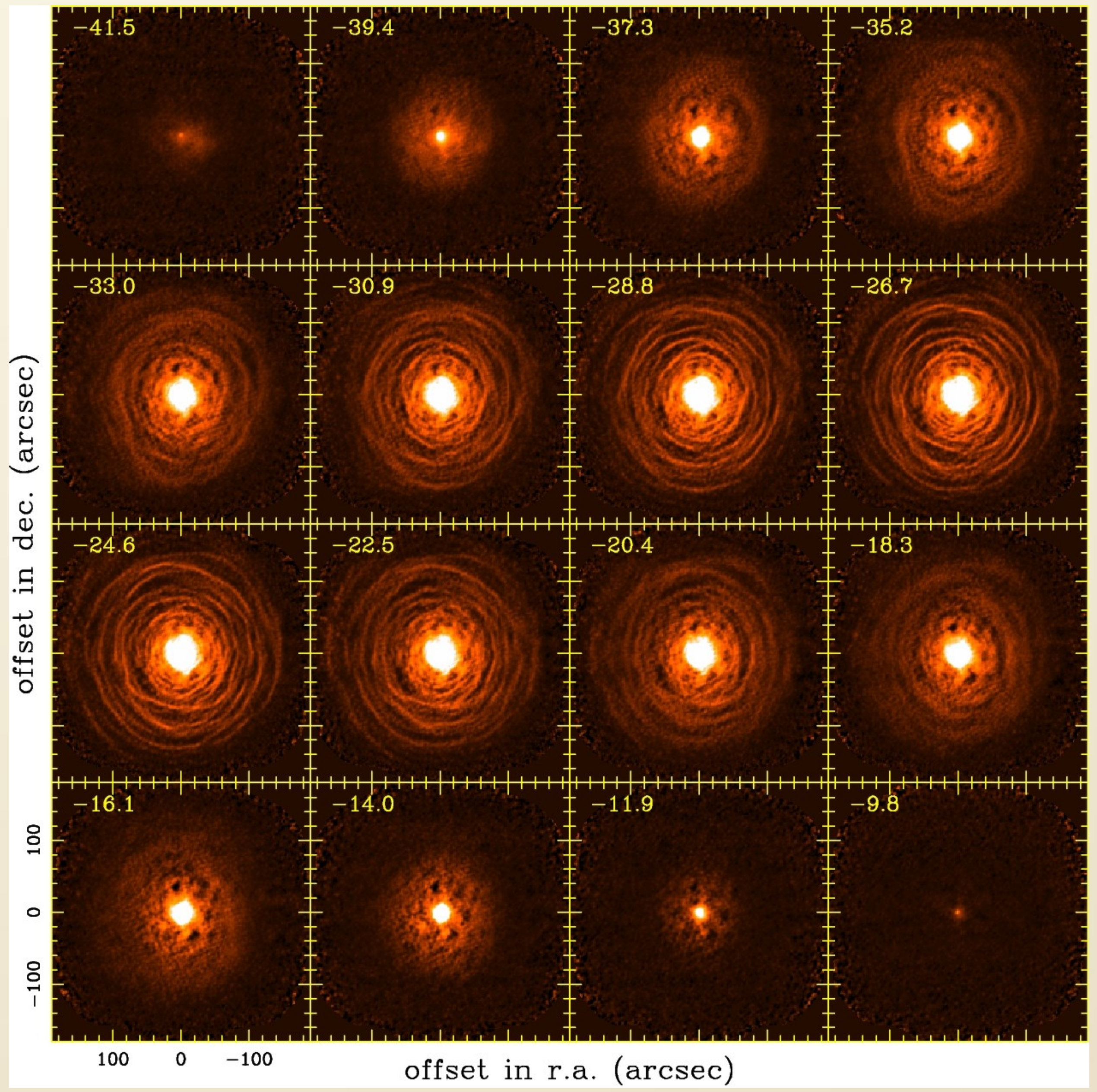


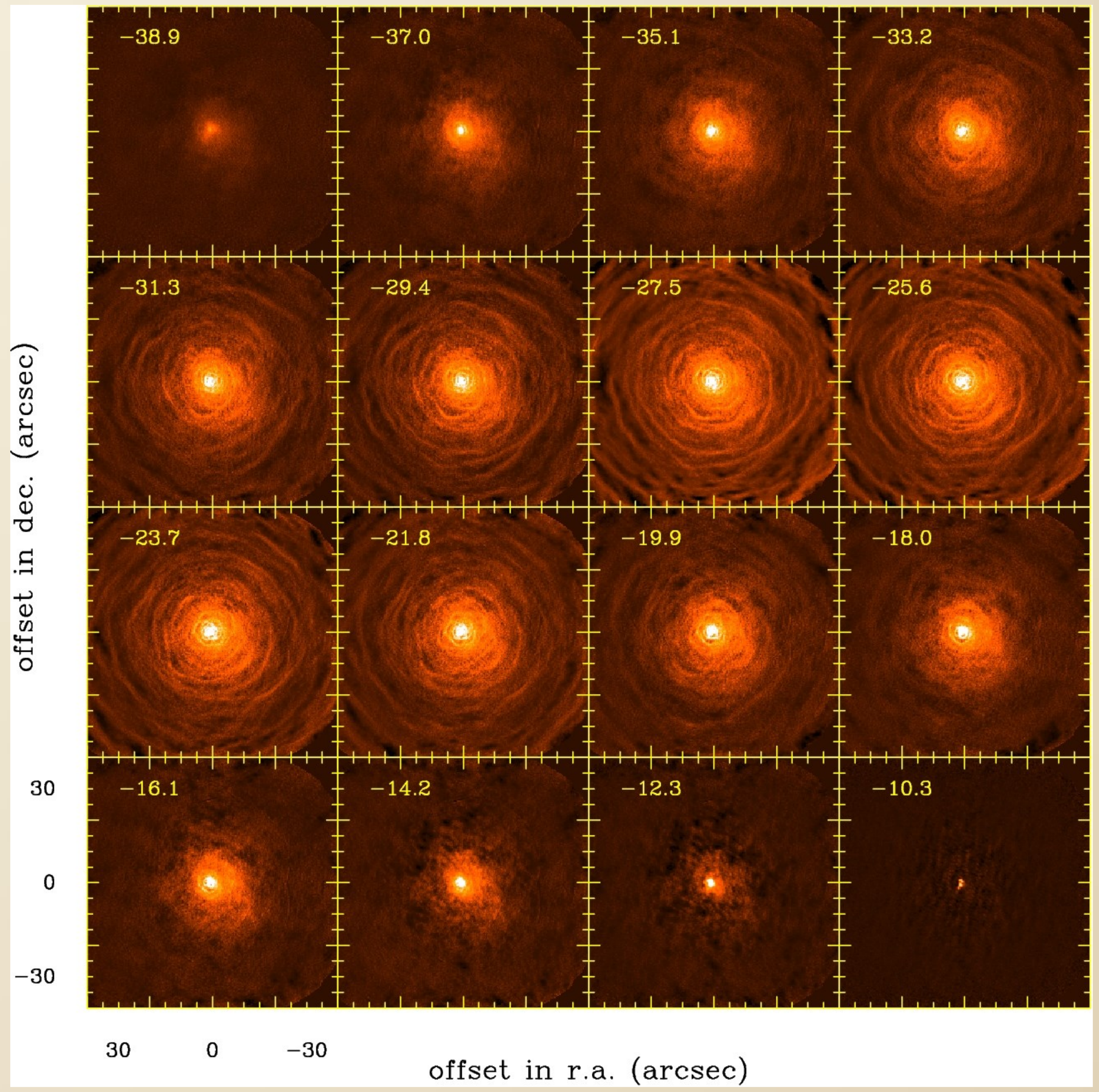
Observations:

IRC+10216 was observed with the Submillimeter Array (SMA) between December 2011 and May 2013.and with the Atacama Large Millimeter Array (ALMA) in December 2014 and January 2015.

As interferometers act as filters for spatial frequencies and suppress extended emission, it was necessary to combine the resulting mosaic maps in the Fourier Plane with single dish data taken with the IRAM 30m telescope.

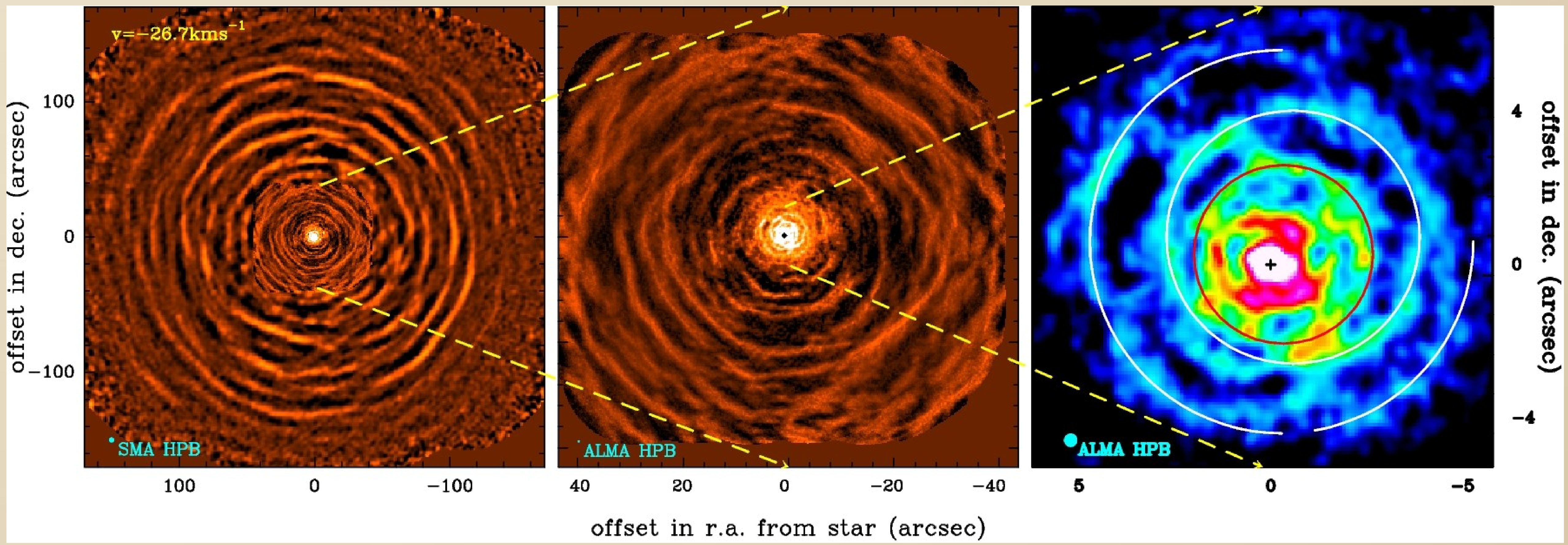
The resulting CO(2-1) maps (230.538 GHz) are displayed **below. Left:** SMA+30m, 380”×380” field of view with 3” spatial resolution and 2.1km/s in velocity, **right:** ALMA+30m, 90”×80” field of view with ~0.34” spatial resolution and 1.9 km/s in velocity.





Below, we take the velocity images of IRC+10216 close to the systemic velocity of CW Leo and do an unprecedented three-fold zoom-in towards the position of the star at

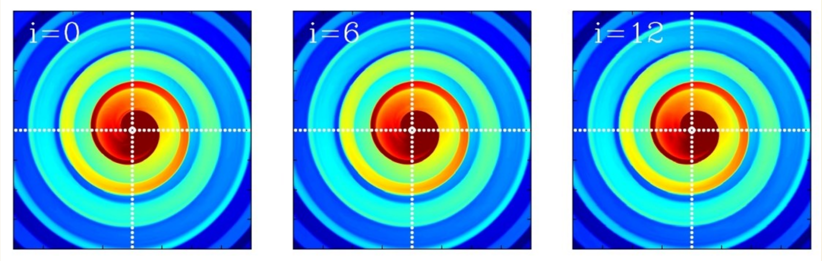
R.A, Dec (J2000) = 09^{h}47^{m}57.4492^s +13º16’ 43.884”

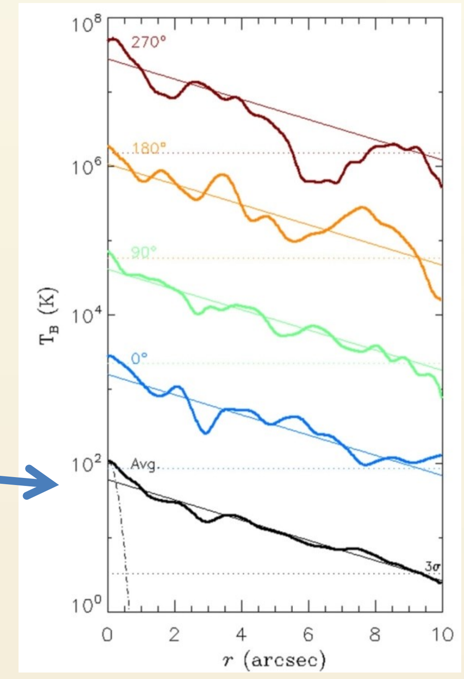


Understanding the object:

The IRC+10216 shell structure is remarkably persistent in spectral line width over molecular species located at different radii (with the only exceptions in lines that are located close to the stellar photosphere). This indicates a high H_2 density within the shells and small mutual interaction between them (otherwise the turbulent velocity and shock-based chemistry would be notable). The periodicity of about 700 years in the outer envelope is neither compatible with a Mira-type oscillation (~1.8 yr in the case of CW Leo), nor with the delay between two thermal pulses (10^4 yr).

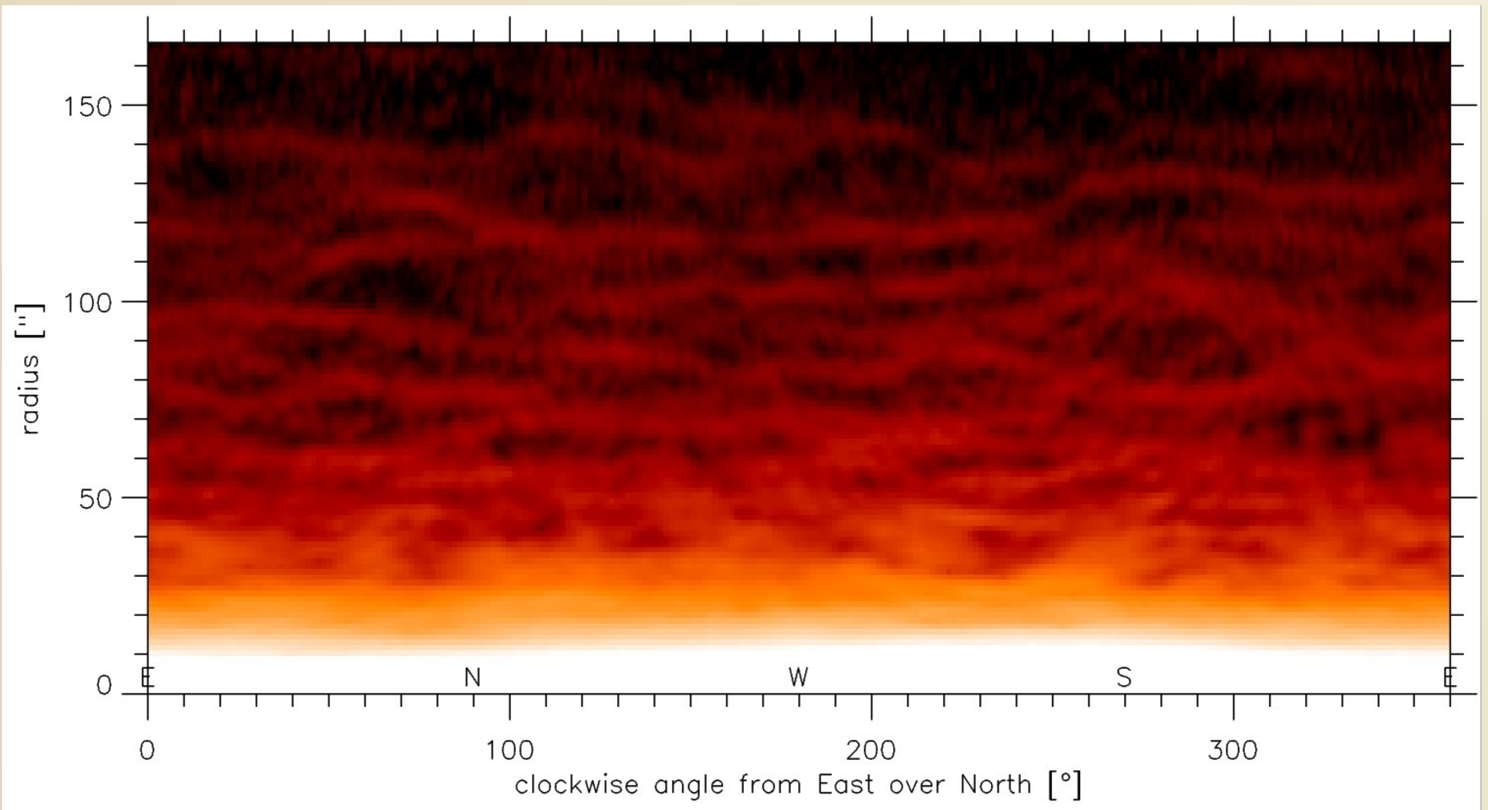
Work by Kim (2012) indicates that binary systems can create spiral shell structures:

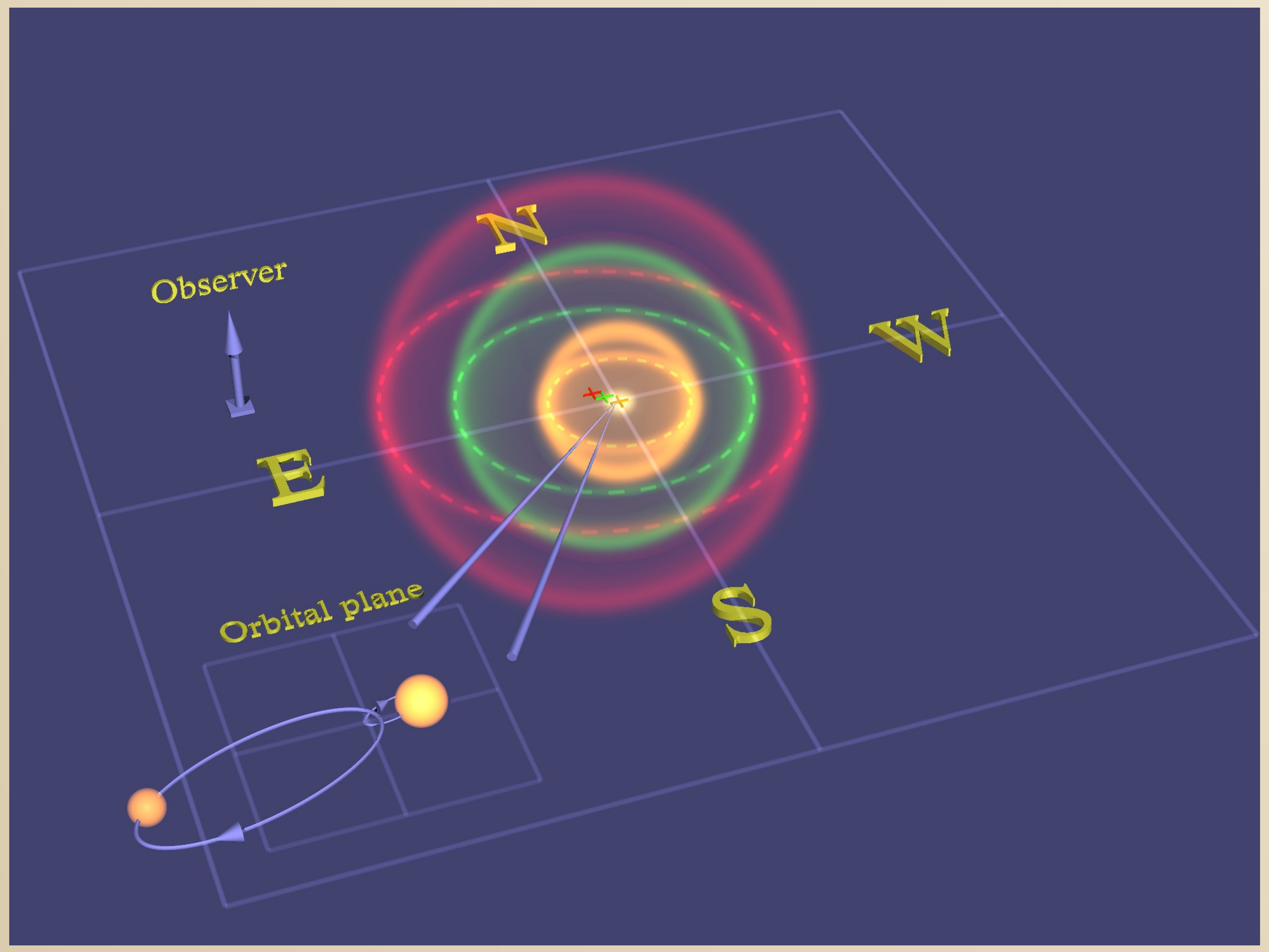




and while this is a good approximation for the carbon star CIT 6 (Kim 2015) this seems not to be so in our case.

For the angular diagram of IRC+10216 (**below**, in logarithmic scale) a fit for a regularly stepped slope would not be successful. We propose that the mass loss is here more episodic due to a long-periodic companion star.

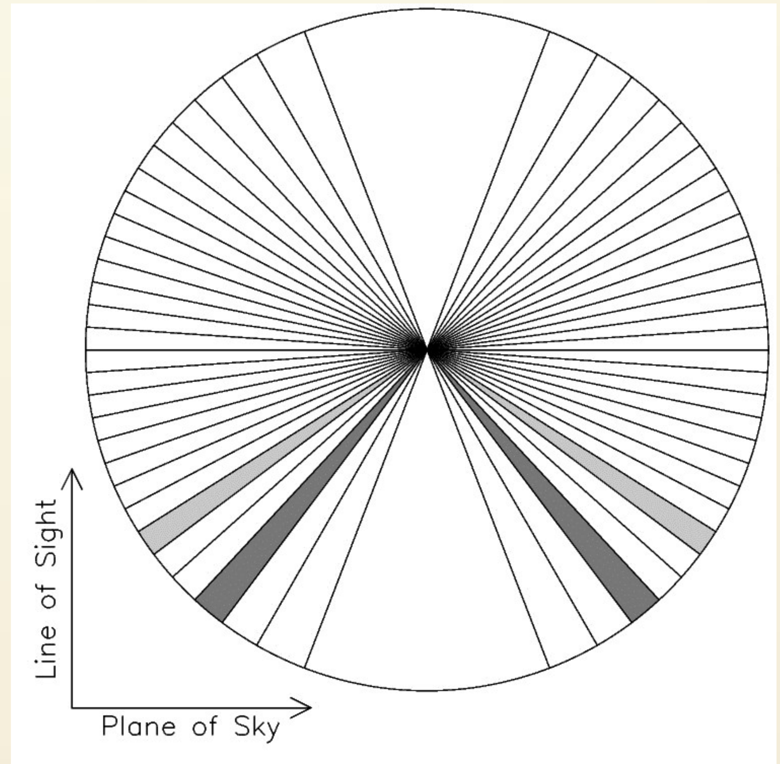


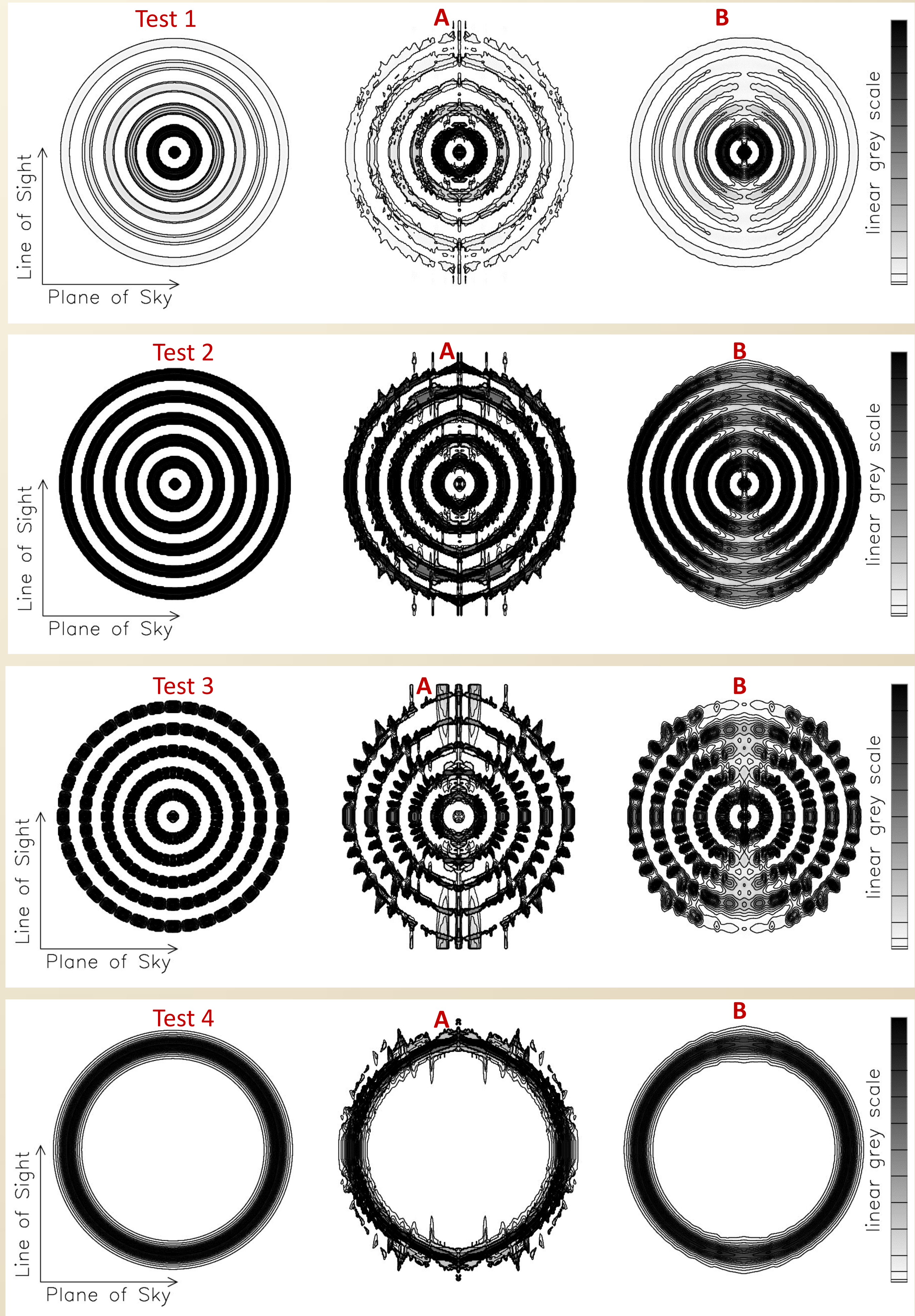


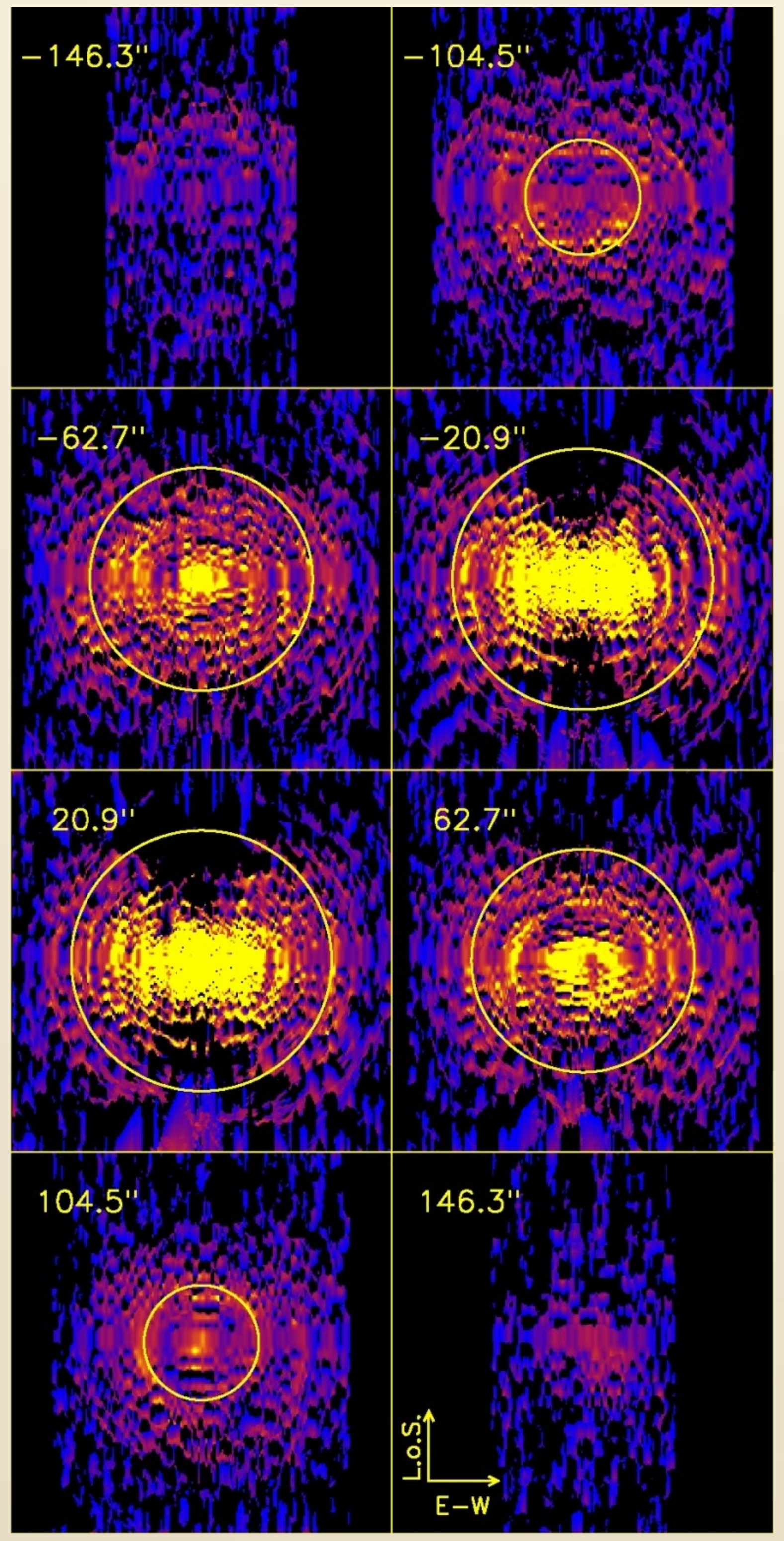
Schematic view of the IRC+10216 system, illustrating how the ejection of shells could be triggered by a double (or multiple) star system. This graphic was produced with the POV-Ray 3.6.1 software.

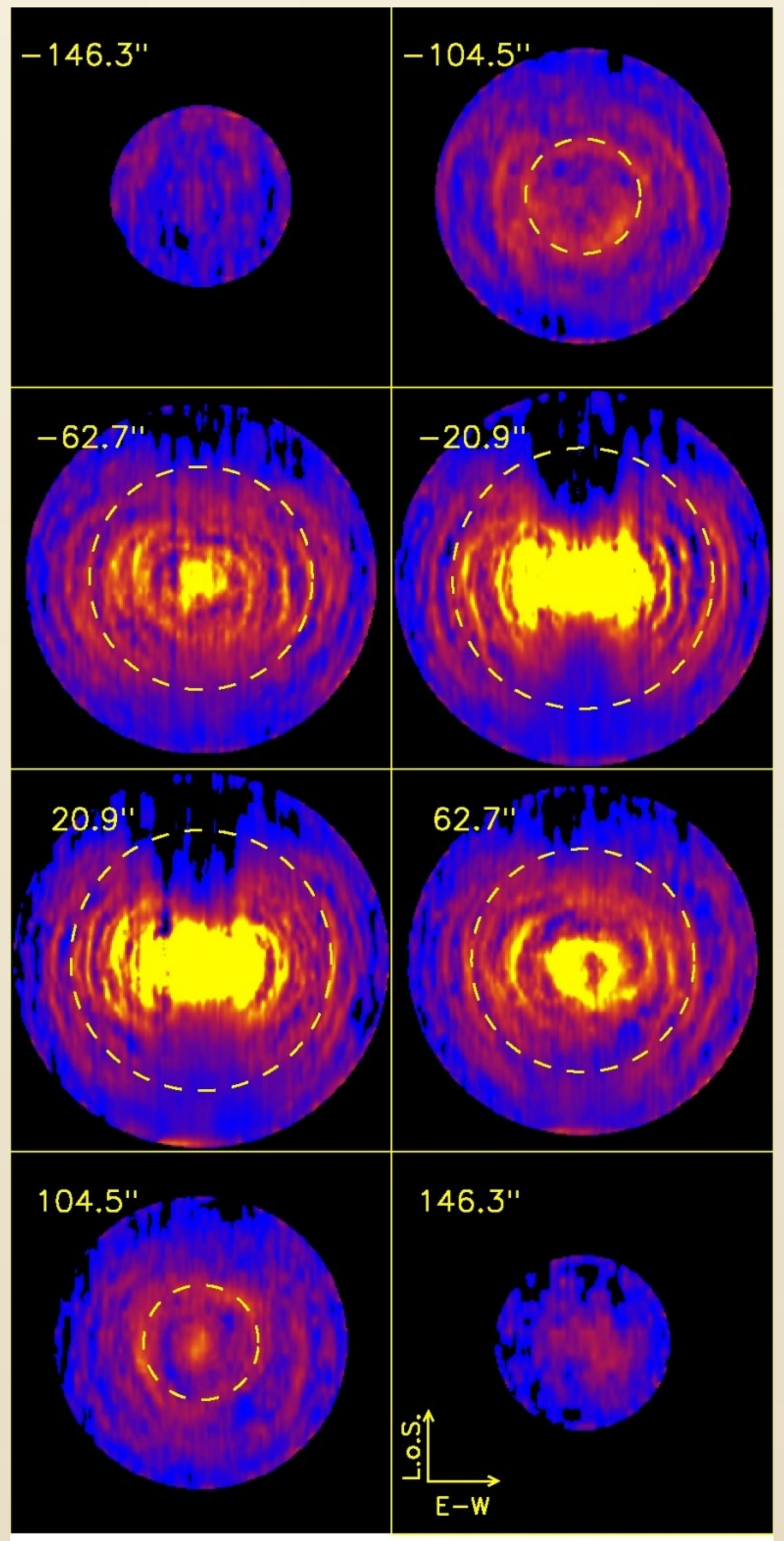
3D reconstruction:

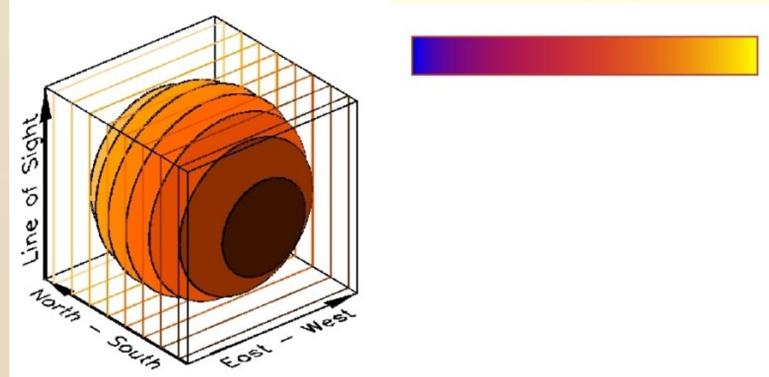
Due to the fact that IRC+10216 has a constant spectral line width across many molecular species, we can assume that the envelope has a constant expansion velocity. This means that for each velocity image velocity bin, the recorded emission comes from a conical shell region in space (**Below**, to the left). Based on this, we have developed two computer algorithms that reconstruct the 3D emissivity distribution of an envelope from its velocity images. **Below**, to the **right** we demonstrate their effect on a number of test distributions by plotting a slice along the line of sight of the test distribution, the same slice reconstructed by **code A,** and finally by **code B**. Code A is non-iterative, while code B iterates until a stable solution is found.











The reconstructions show that the object is not made up of ribbons of cloud in the plane of the sky, but of parts of shells that can be traced over large angular ranges inside and outside the plane of the sky. Close to the star we find a conical space of low density, but this is an artifact due to the high opacity (τ~4) in CO(2-1) along those lines of sight.

(Note: the radius of the indrawn shell in the plots above (left,right) is 118".)

Conclusions and future Work:

We find that IRC+10216 is made of spherical shells shifted against each other in the plane of the sky. This could be due to a companion star on a highly elliptical orbit. We plan to use other molecular lines of the envelope together with single-dish data for more detailed reconstructions for the zone of high opacity in CO(2-1). Also, hydrodynamical studies may be useful to find out to what degree the shell spacing is an emerging structure. The observational data will provide stringent boundary conditions for this.

References:

Guélin et al. (2017), A&A, submitted (AA/2017/31619)
Kim et al. (2015), ApJ 814, 61
Kim & Taam (2012), ApJ 759, 59
Leão et al. (2006), A&A 455,187
Menten et al. (2012), A&A 543, A73