Observations interpretation II: Circumstellar envelopes

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Outline

1. Some useful questions to ask about observations
2. Steps to follow before the data interpretation
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4. Interpretation of observations
   - Interpreting line profiles
   - Interpreting interferometric maps

Some useful questions to ask about spectra

- Have you identified the lines correctly?
- Could any of them be blended with other known/unknown line?
- Have you identify/remove the telluric lines (IR/Vis)?
- Are all the lines of a given molecule compatible between them?
- Did you expect the intensity of the lines are what your spectrum indicates?
- Are the profile of the observed lines similar for all of them? If not, can you figure out why?
- Can you find in these lines narrow emission/absorption components, wings or something initially unexpected?
- Can you correlate the line profiles with the kinematics of the source?
- Do you think that any of the observed lines can be optically thick?
- How the baseline looks like?
- Can you find any ripple in the baseline with a wavelength similar to the width of the lines (IR)?
- Can you find any instrumental artifact?

Some useful questions to ask about maps

- Does the dirty beam show large sidelobes?
- Can you find any geometrical pattern in your maps?
- If so, can you correlate this pattern with the dirty beam?
- Is there any bowl in your map?
- In this case, is it close to the source?
- If you have an extended source, do you suspect that it could be affected by the dirty beam in any way?
- What is the Largest Angular Scale (LAS) available in your observations?
- What weight have you used to invert the visibilities?
- What is the RMS noise of the channels?

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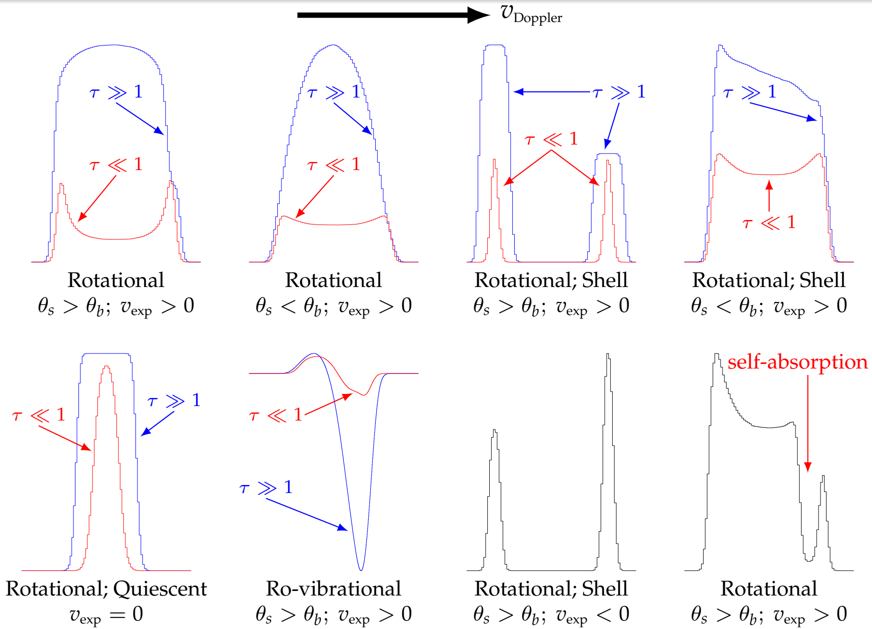
Important!!!
you MUST trust your data before the beginning of the interpretation process

Steps to follow before the data interpretation

1. *Learn to use your telescope*: It is necessary to know how the telescope works and what are its strenghts and weaknesses, although it is likely that you already know everything of your telescope. You wrote the proposal, didn't you?
2. *Learn all you can about the observed source*: Probably, someone has already worked on some facts or details available in your data. Check the literature!
3. *Inspect your raw data*: Try to find any artifact or error in your dataset that could compromise the following steps. Sometimes it is necessary to drop some harmful data.
4. *Calibrate your data*: Your data could need from you to apply some calibration routines or procedures.
5. *Inspect your calibrated data*: Check that everythis goes well.
6. *Prepare your data to be analyzed*: Fix anything that could prevent or hinder you to properly analyze your dataset and to get the most from it.
7. *Find your goals*: Decide what are your goals. Try to define reasonable goals to get some advance in a reasonable period of working time.
8. *Let's work on them!*: It's time to apply your knowledge on this new dataset. Don't worry if you need to learn something to get the best from them, even though this new task takes part of your working time. Your data will wait for you. . . but only during 1 yr before becoming public!

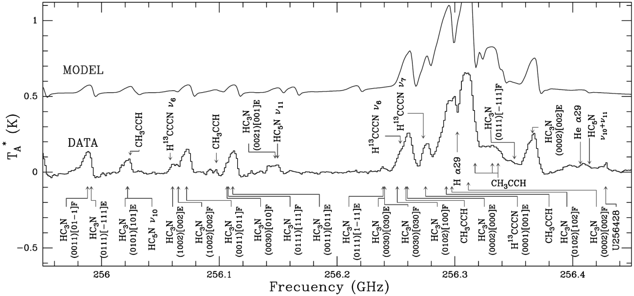
Steps to follow to interpret your observations

1. *Identify all the possible lines*: You cannot analyze your observations if you don't know exactly what you have. If you have some unknown lines, don't worry, you will probably identify them in the future. That's also a result!
2. *Analyze qualitatively these lines*: Parameters such as the line strength, the FWHM, or the overall line profiles could tell you something about what you are observing.
3. *Apply simple techniques to extract unbiased information*: The elaborate methods such as sophisticated models could introduce biases in your results or your reasonings. Extract rough, unbiased results from your data from, e.g., excitation or position-velocity diagrams, or intensity moments.
4. *Derive rough conclusions*: Improve your knowledge of the observed environment and the observations to plan your next step.
5. *Apply more sophisticated methods*: Once you already know *grosso modo* what's happening there, apply the most powerful codes (for instance) you have to test your previous reasonings and to derive detailed information about the observed environment.
6. *Use your imagination to analyze your particular data*: Each dataset is usually different from any other. Follow any further step that could fit to your particular scenario.
7. *Write a paper*: The time has come. Now, write down all you have derived from your analysis in a very beautiful, interesting paper. It's not so easy, but you can do it. Good luck!

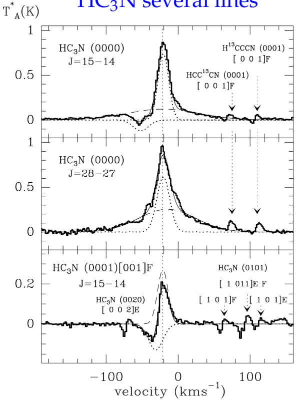

v_{Doppler}
$\tau \gg 1$
$\tau \ll 1$
Rotational
$\theta_s > \theta_b;\ v_{\text{exp}} > 0$
$\tau \gg 1$
$\tau \ll 1$
Rotational
$\theta_s < \theta_b;\ v_{\text{exp}} > 0$
$\tau \gg 1$
$\tau \ll 1$
Rotational; Shell
$\theta_s > \theta_b;\ v_{\text{exp}} > 0$
$\tau \gg 1$
$\tau \ll 1$
Rotational; Shell
$\theta_s < \theta_b;\ v_{\text{exp}} > 0$
$\tau \ll 1$
$\tau \gg 1$
Rotational; Quiescent
$v_{\text{exp}} = 0$
$\tau \ll 1$
$\tau \gg 1$
Ro-vibrational
$\theta_s > \theta_b;\ v_{\text{exp}} > 0$
Rotational; Shell
$\theta_s > \theta_b;\ v_{\text{exp}} < 0$
self-absorption
Rotational
$\theta_s > \theta_b;\ v_{\text{exp}} > 0$

- It is also possible that the lines in the mm range show a kind of extremely wide gaussian baseline if there are high velocity bipolar outflows
- mm range lines can show continuum absorption as the ro-vibrational lines in the IR
- The line profiles depends a lot on what is happening in the source, so we could find almost any profile we could imagine

PPN CRL618
HC_3N several lines



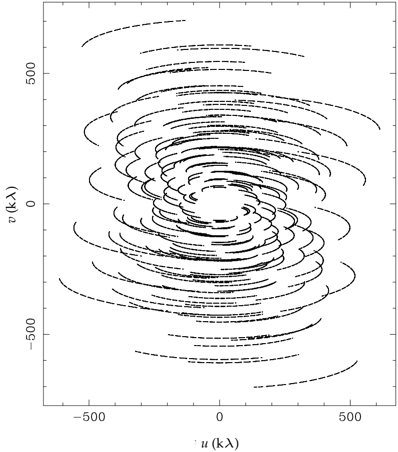
(Pardo et al., 2007 [8])

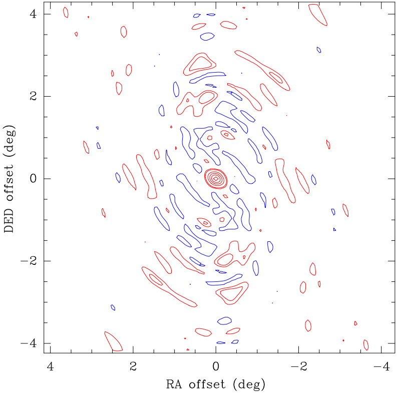


(Pardo et al., 2004 [7])

Dirty PSF / *uv*-plane coverage

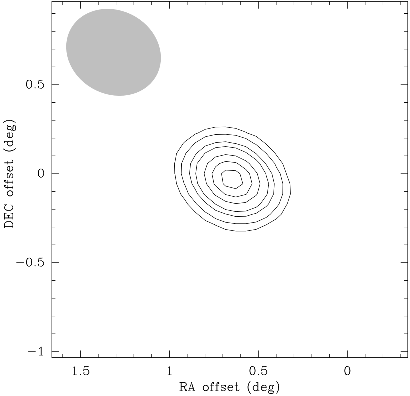
- Having a good coverage of the *uv*-plane is critical to get high quality maps
- If the PSF displays strong positive/negative sidelobes, bowls or unreal sources could arise

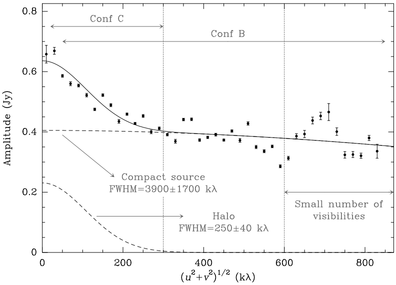




Interferometric maps — Continuum

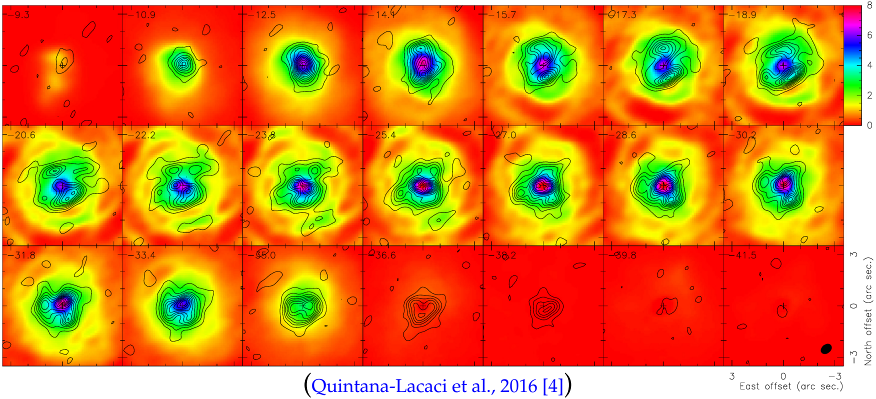
- Even if the continuum source is point-like it is possible to derive some information about the continuum emission structure
- It can be done by directly analyzing the visibilities in the *uv*-plane
- The results could be more difficult to interpret than understanding a map but this method could be useful in some cases





(Fonfría et al., 2014 [5])

AGB star IRC+10216; NaCl(21 − 20) contours; $H^{13}CN(3-2)$ color scale



(Quintana-Lacaci et al., 2016 [4])

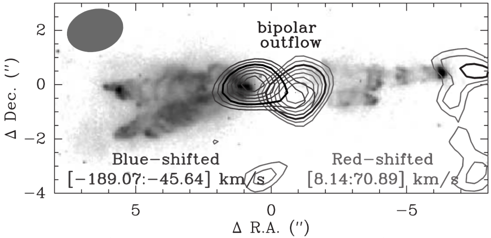
- We show a map per *velocity channel* in a single cube
- Each map *does not represent* a transverse cut of the source. It could be composed of contributions of different cuts
- Getting information about the depth *always* needs to be done through a model that connects expansion velocity with geometry

- The moment 0 map is the integral over the velocity of an interval or the whole cube

$$M_0(\alpha, \delta) = \Delta v \sum_{i=1}^{n_{\mathrm{chan}}} I(\alpha, \delta, v_i)$$

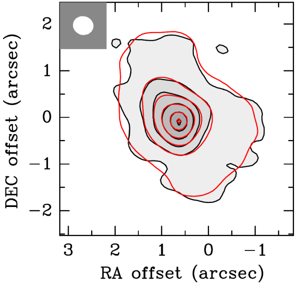
- It is used to see the brightness distribution regardless of the Doppler velocity or to determine where the red- and blue-shifted emission come from

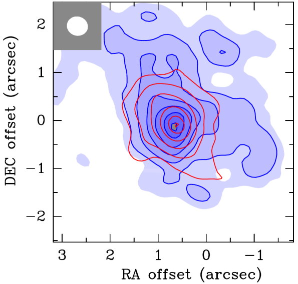
PPN CRL618; $HCO^+(1-0)$



(Sánchez-Contreras et al., 2004 [2])

AGB star IRC+10216; SiO(6 – 5)





(Fonfría et al., 2014 [5])

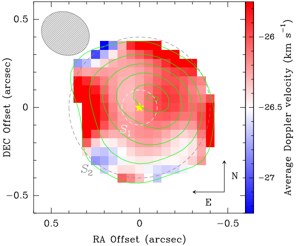
Moment 1 maps

- The moment 1 map is the average Doppler velocity weighted with the brightness distribution in the following way:

$$M_1(\alpha,\delta) = \langle v \rangle = \frac{\sum_{i=1}^{n_{\rm chan}} I(\alpha,\delta,v_i)v_i}{\sum_{i=1}^{n_{\rm chan}} I(\alpha,\delta,v_i)}$$

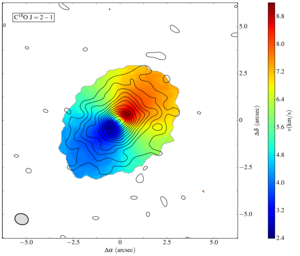
- This moment gives the average velocity for every point in the plane of the sky with respect to the systemic velocity of the source
- Its calculation requires the use of a mask to avoid all the points where there is no emission
- Very useful to detect rotating disks, bipolar outflows or asymmetric expansion velocity fields

AGB star IRC+10216; SiS(14 − 13)



(Fonfría et al., *in preparation*)

T Tau star HD163296; $C^{18}O(2-1)$

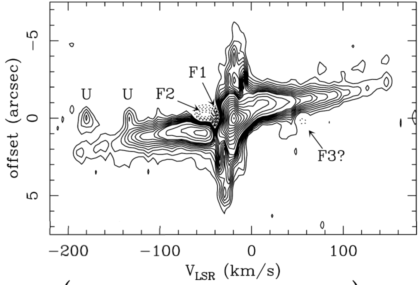


(Boneberg et al., 2016 [6])

Position-velocity diagrams

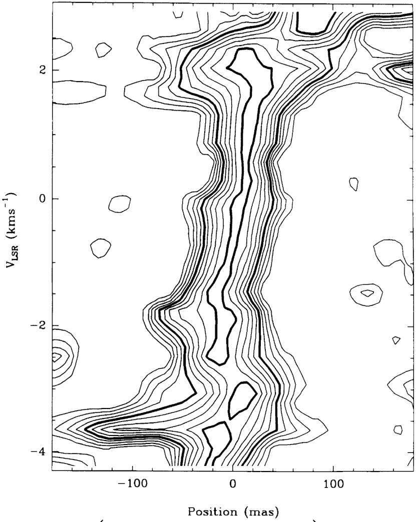
- We plot an angular offset against the Doppler velocity
- Note that the Doppler velocity *is not* a depth
- This diagram is always useful. Use it at discretion

PPN CRL618; CO(2 − 1)



(Sánchez-Contreras et al., 2004b [3])

AGB star R Leo; SiO($v = 1, J = 2 - 1$)



(Cernicharo et al., 1994 [1])

References

[1] Cernicharo et al., 1994, *ApJ*, 423, L143

[2] Sánchez-Contreras et al., 2004, *ApJ*, 602, 960

[3] Sánchez-Contreras et al., 2004, *ApJ*, 617, 1142

[4] Quintana-Lacaci et al., 2016, *ApJ*, 818, 192

[5] Fonfría et al., 2014, *MNRAS*, 445, 3289

[6] Boneberg et al., 2016, *MNRAS*, 461, 385

[7] Pardo et al., 2004, *ApJ*, 615, 495

[8] Pardo et al., 2007, *ApJ*, 661, 250