Molecules in Orion

Peter Schilke, MPIfR

- What is so special about Orion?
- What can we learn from observations of many different molecules?
- How do we get there?

Why molecules?

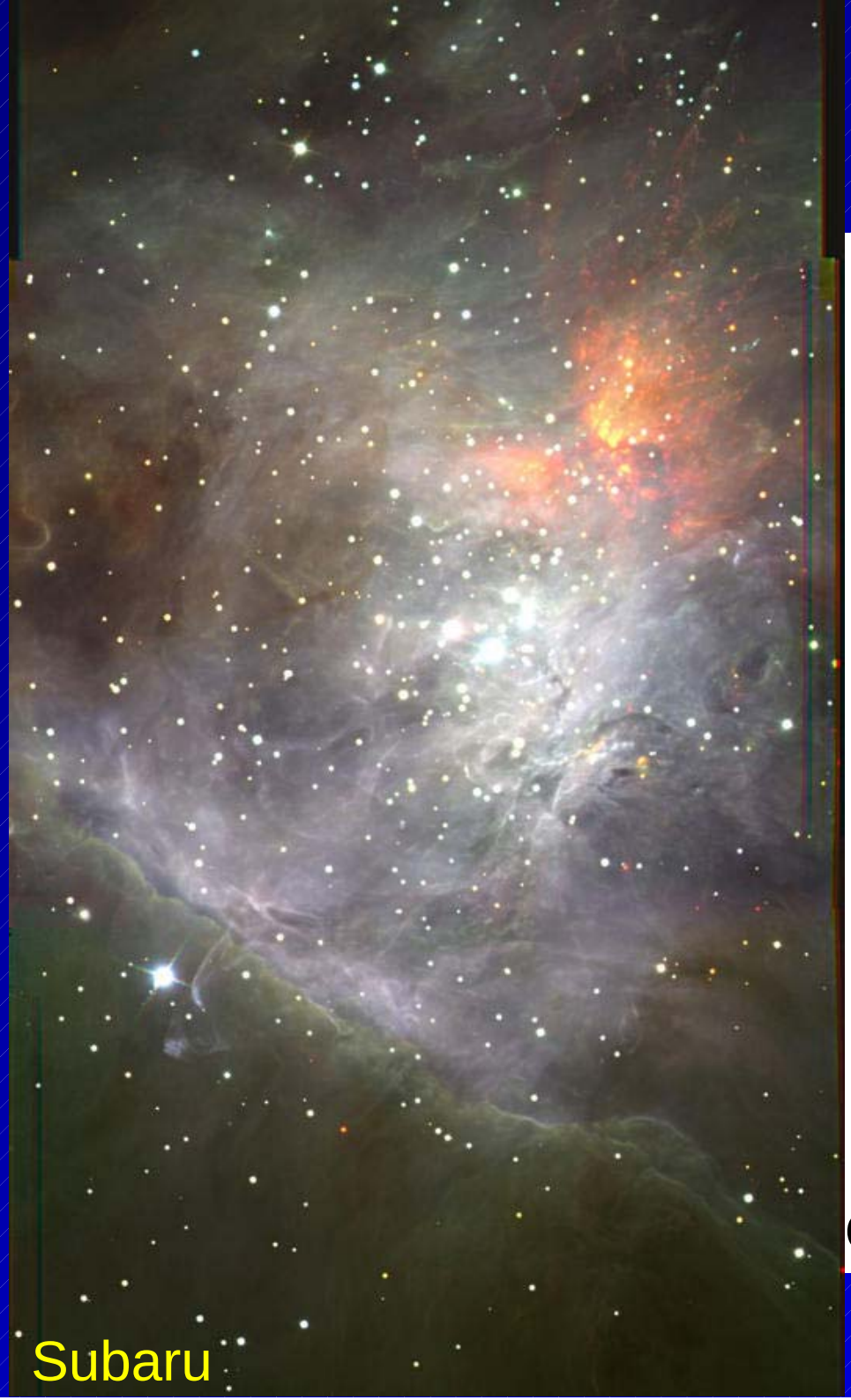
- Why any molecules?
  - molecular lines teach us
    - about excitation conditions
    - present-day distribution of temperature and density
- Why many molecules?
  - molecular abundances teach us
    - about history
      - since chemical time scales are longer than excitation time scales, relative abundances of molecules retain a memory of the past
        - before freeze-out
        - while on grains
        - after switching on
        - (in)famous chemical clocks
    - only works if we understand chemistry

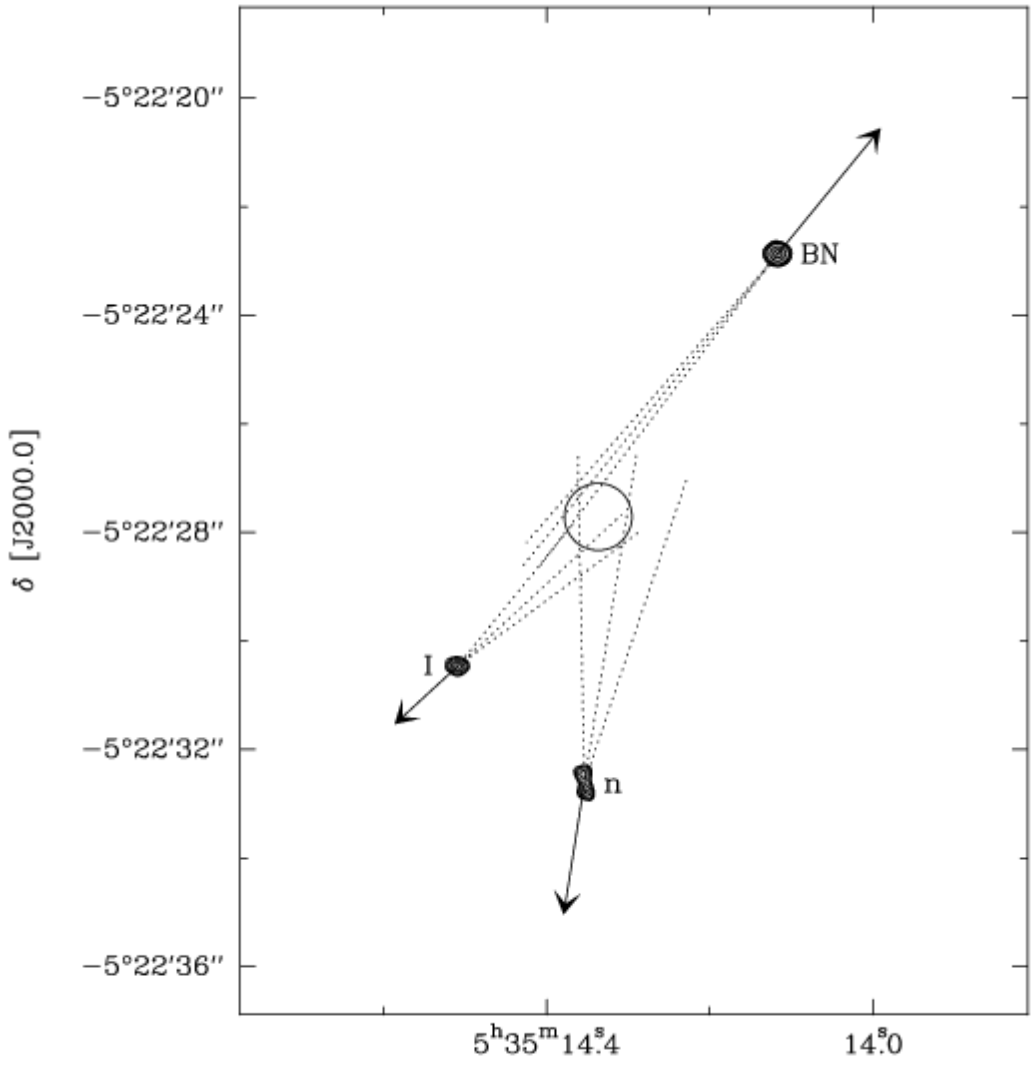
Why Orion?

- Considered template for high-mass star formation
- Very close by (450 pc)
  - Interferometers can see all the details
  - Curse or blessing?
- Contains many stages of star formation
  - KL: hot core
  - South: lower mass/earlier time
  - Bar: PDR
    - unique chemistry: radicals (HCO), ions (CO^+, CF^+), pieces of PAH or dust (horsehead)
  - intermediate massive protostars: OMC2, OMC3

Orion KL – really a template?

- Orion KL is a wimpy source as far as high mass star forming regions go
  - If it wasn't that close, nobody would bother
- Orion KL has a weird geometry (HII region in front has eaten away foreground gas)
- Orion KL has a weird outflow (explosion?)
  - Chemistry modified by shocks?
- Orion KL has a weird SiO maser
  - related to outflow?
- Orion KL has a weird sulphur chemistry
  - consequence of outflow shocks?

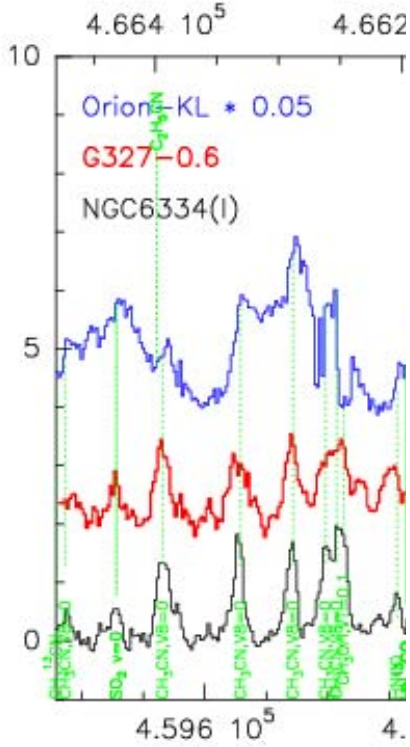




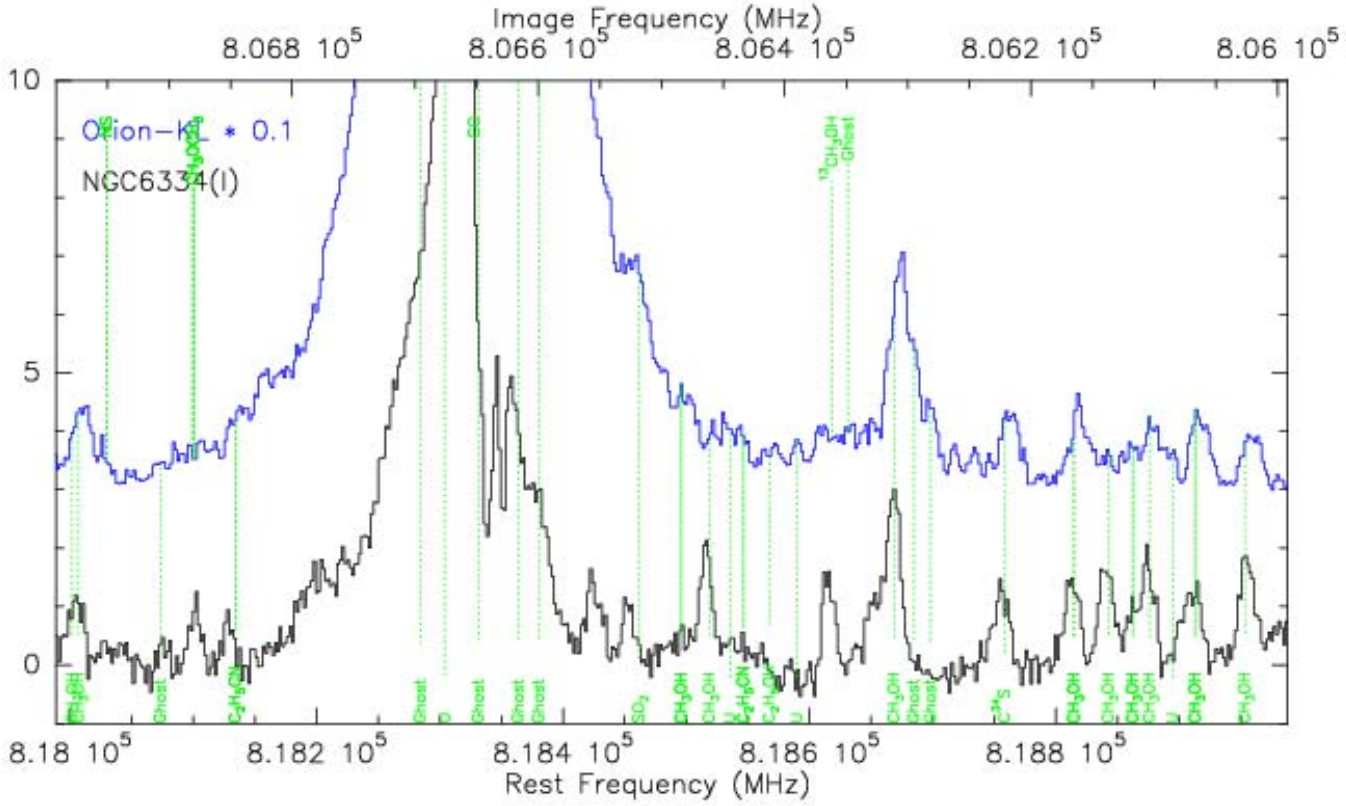
Gomez et al. 2005

Orion and the rest of the world

Schilke et al. 2006; Orion: White et al. 2003



Schilke et al. 2006; Orion: Comito et al. 2005



Life of Orion

ORION:

Look. You've got it all wrong.

You don't need to follow me. You don't need to follow anybody! You've got to form stars for yourselves. You're all individuals!

HOT CORES:

Yes, we're all individuals!

ORION:

You're all different!

HOT CORES:

Yes, we are all different!

NGC6334:

I'm not.

HOT CORES:

Shh. Shhhh. Shhh.

Freak among freaks?

- (Unusual?) things have happened in Orion
- No reason to believe similar things haven't happened elsewhere – massive star formation is violent after all
- OK to observe Orion as long as it's understood that
  - it is but one piece in the puzzle
  - many of its features probably cannot be generalized

Clusters

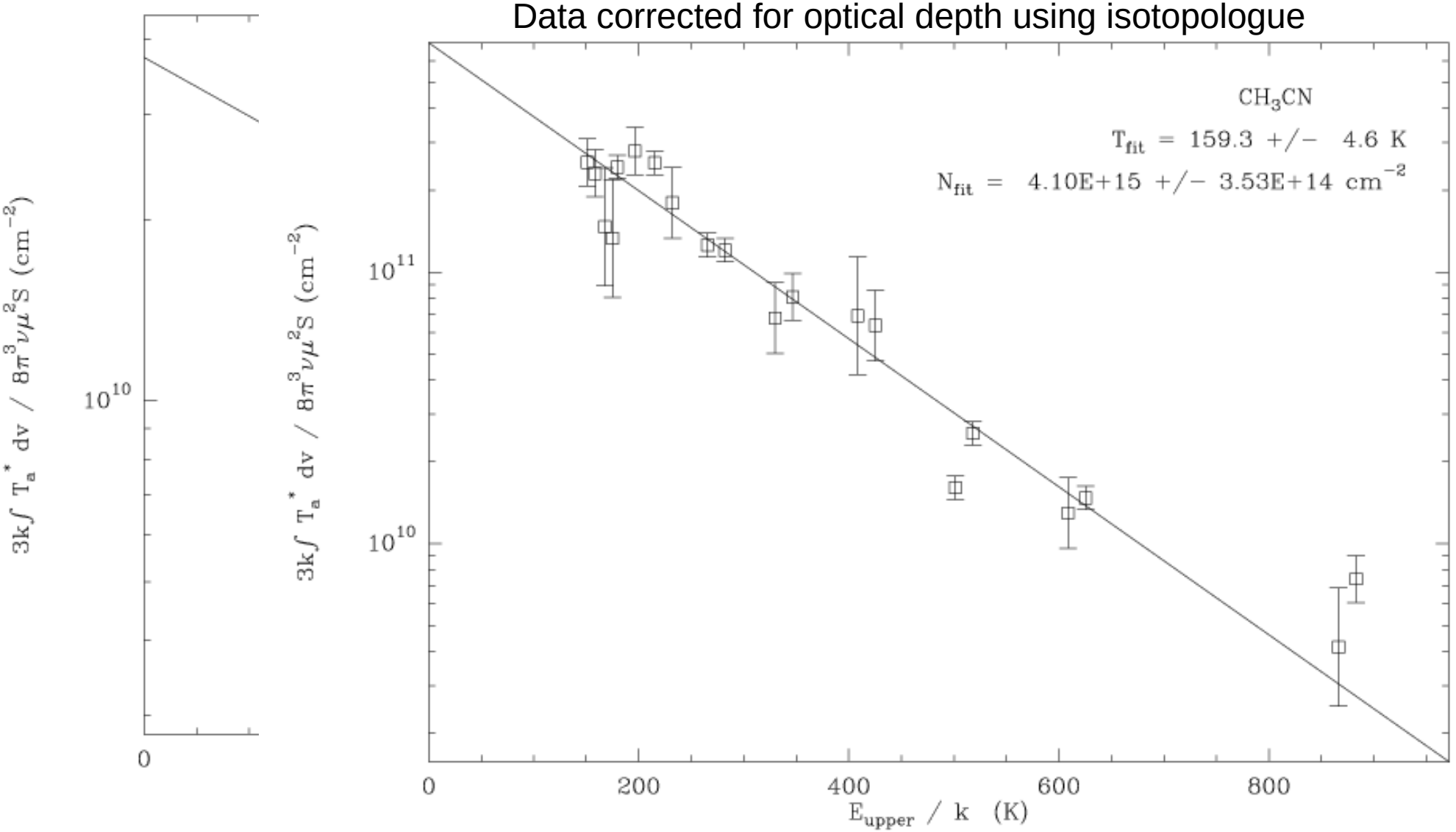
- One should keep in mind that most (probably all) high-mass star forming regions are forming *clusters*, not single stars
- With low (i.e. > 100 au = 0.05” @ 5 kpc) spatial resolution confusion (spatial) is the rule
- Interactions
  - direct (through close encounters: disk ruptures, truncations)
  - Indirect (through outflows)

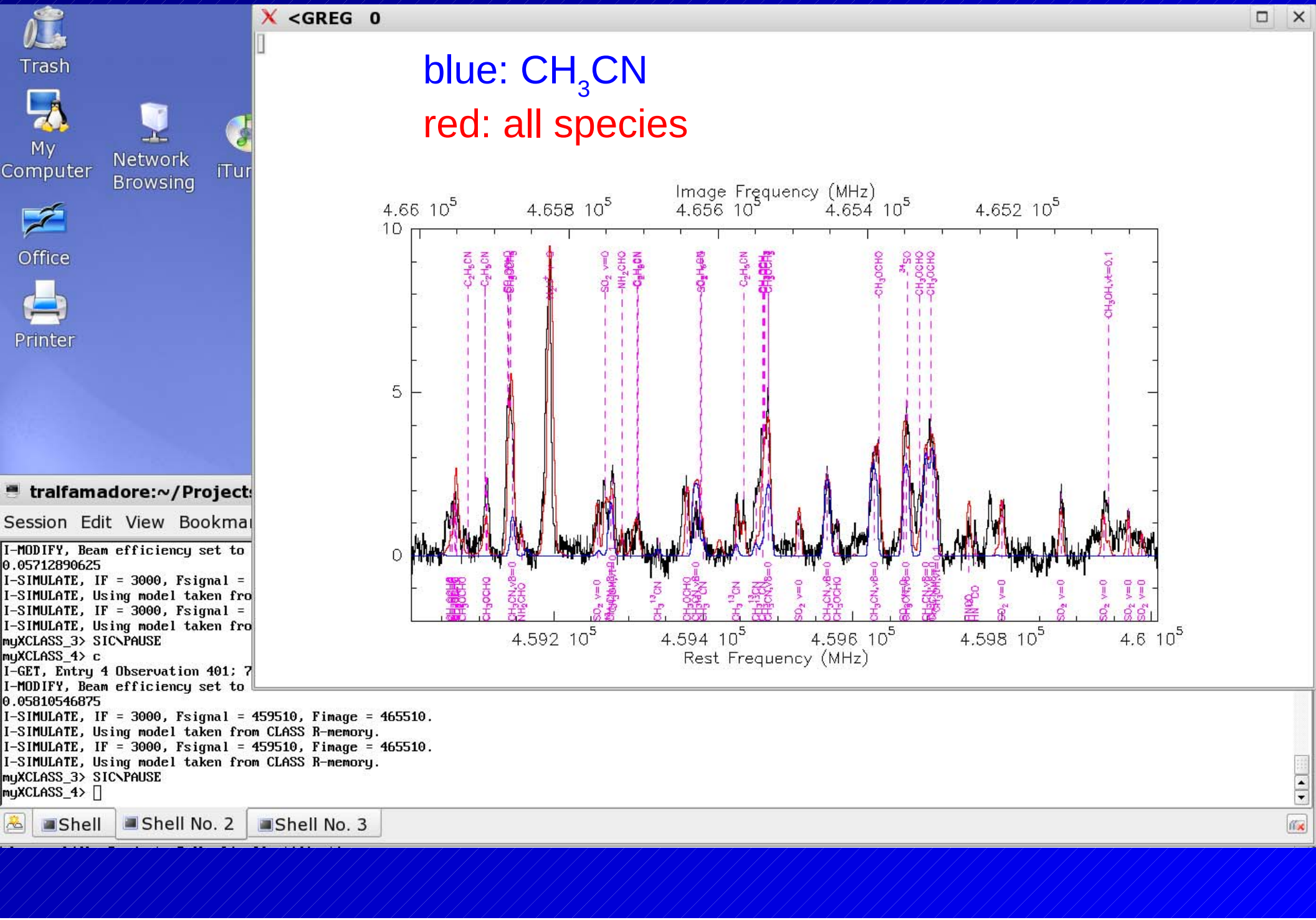
Embarrassment of riches

- In line surveys thousands of lines in total
- In some cases, about a thousand lines per species (methanol) are observed
- Noone has really done a good analysis of all of this
  - Rotation diagrams no good any more (optical depth)
  - Real radiative transfer too time consuming
  - Not enough input data (collision rates)
- With ALMA, we can get thousands of maps...

Rotation diagrams

Data corrected for optical depth using isotopologue

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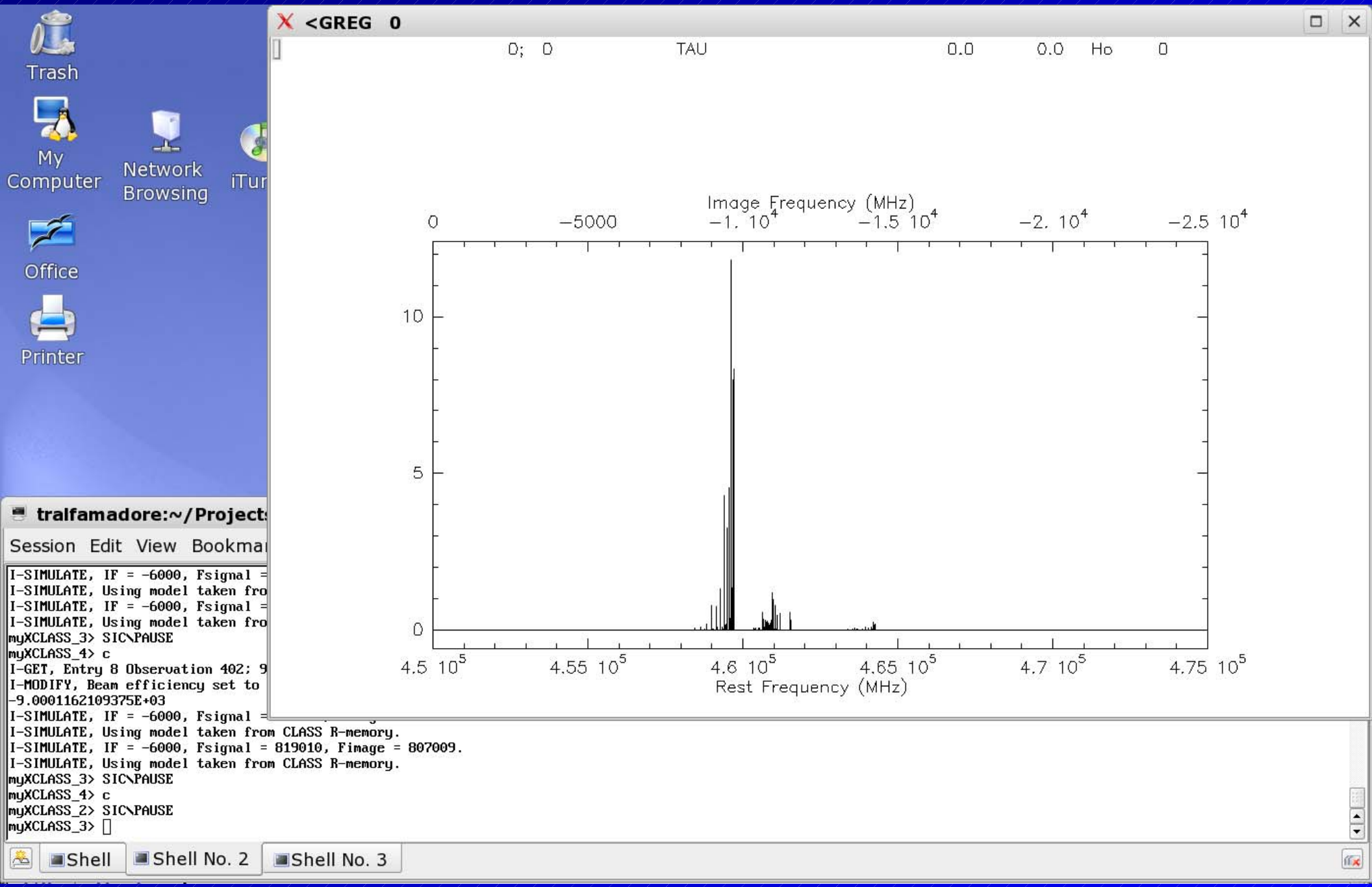
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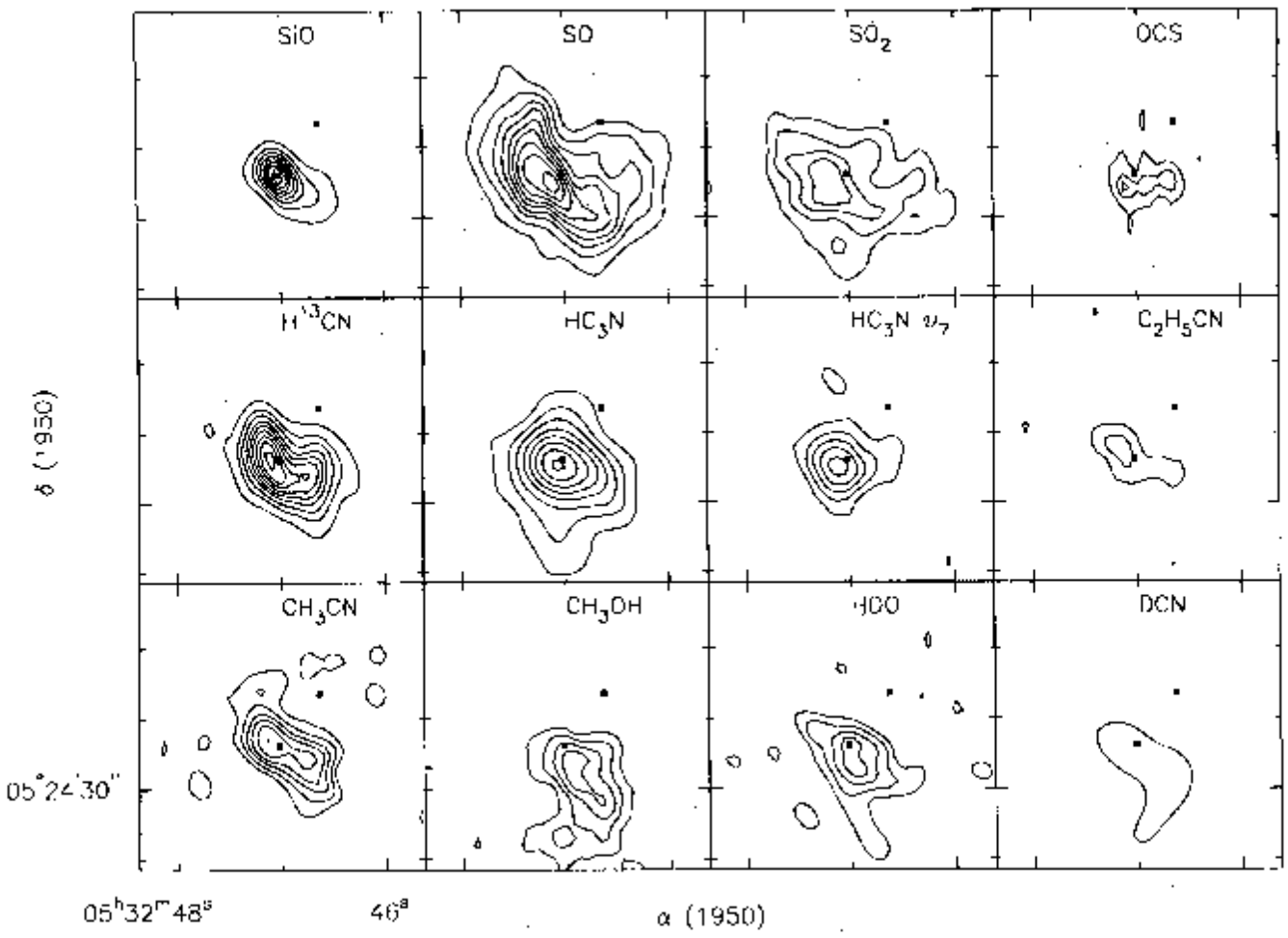
The porridge problem

Looking at Orion is like looking at a bowl of porridge and trying to figure out why there is a carrot here and a bean over there.

Raoul Taco Machilvich

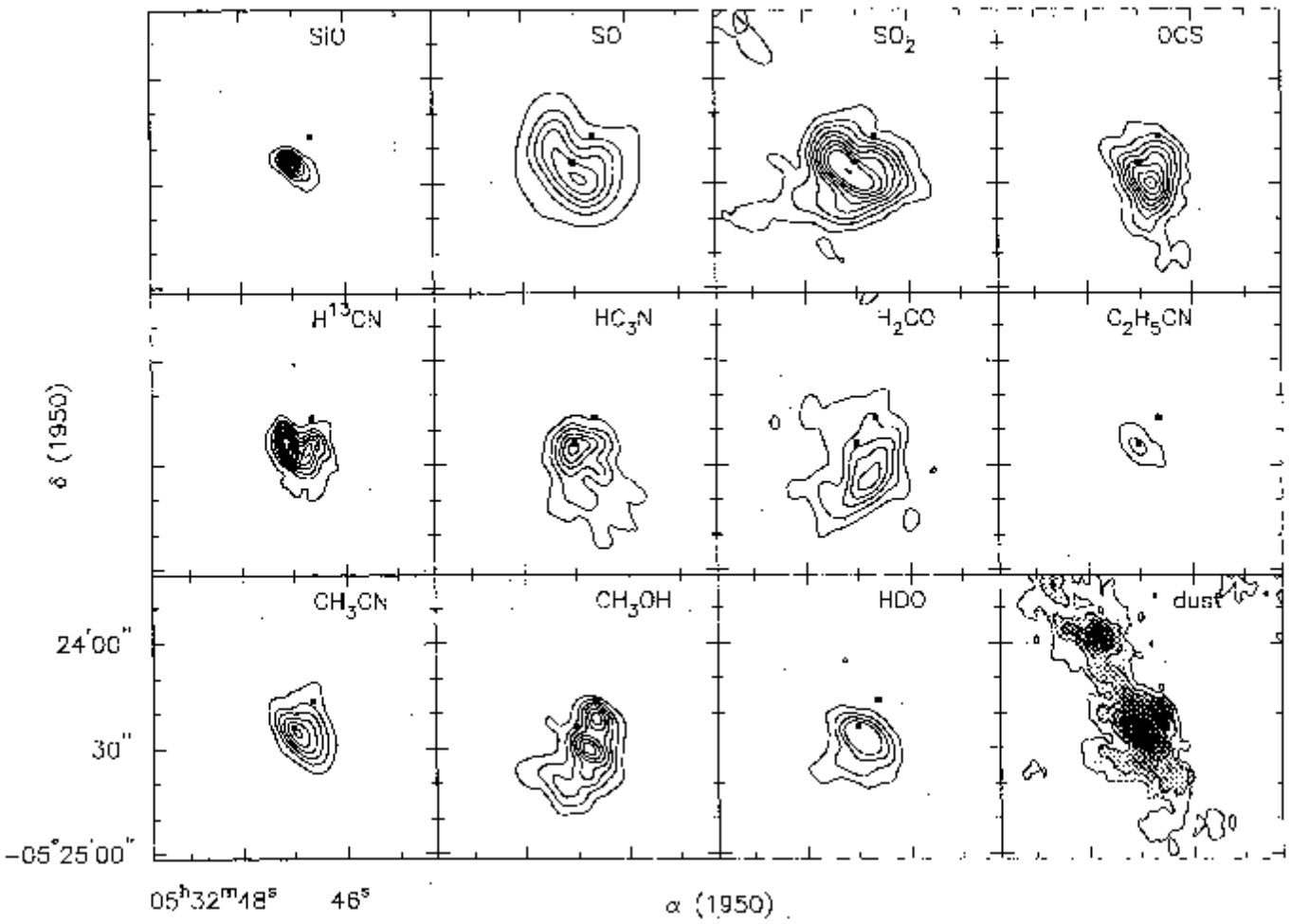
In how far is the chemistry of high mass star formation reflecting the physics, and how much does it only reflect initial conditions?

Carrots of Orion: hot core



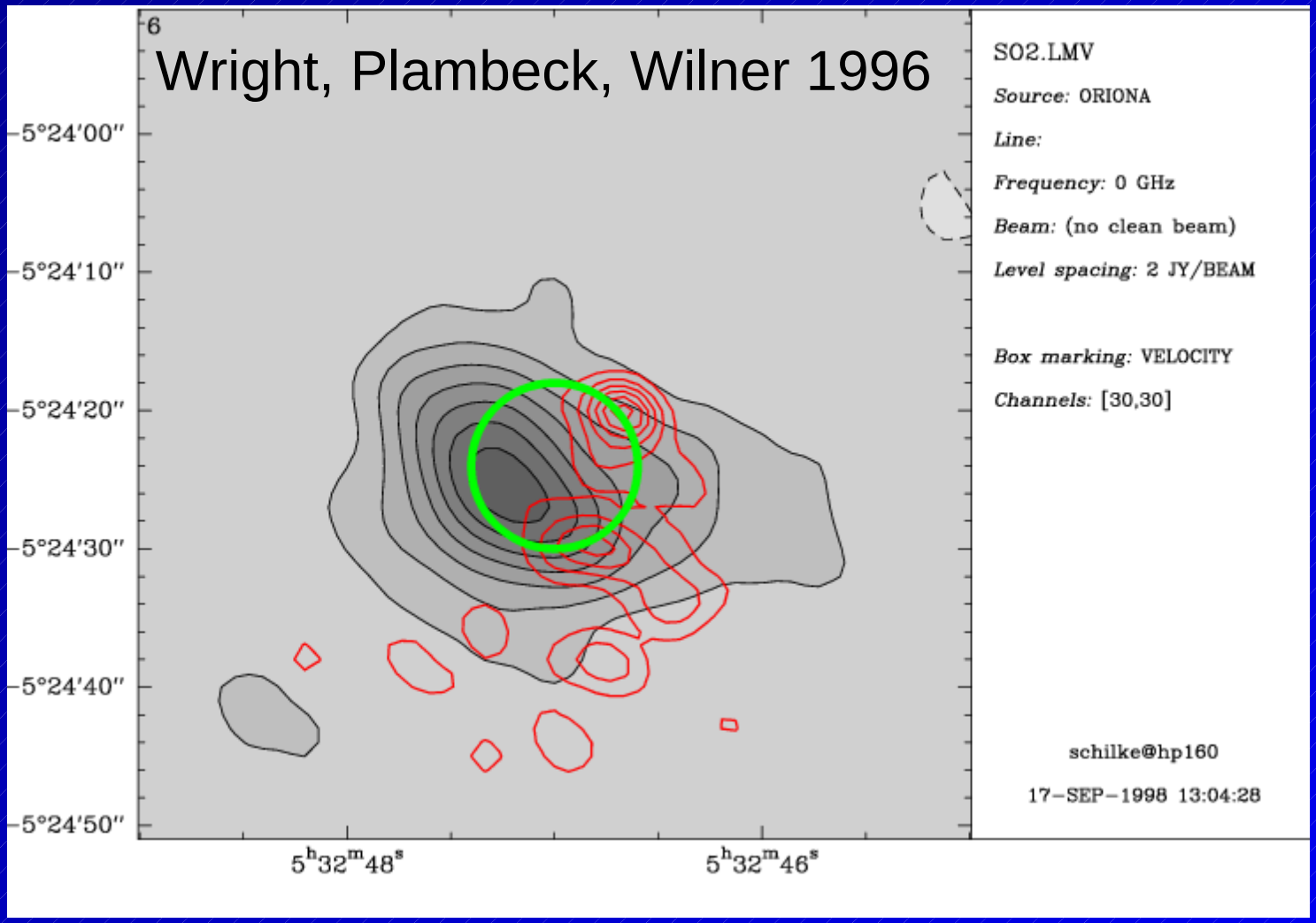
Wright, Plambeck, Wilner 1996

Beans of Orion: compact ridge

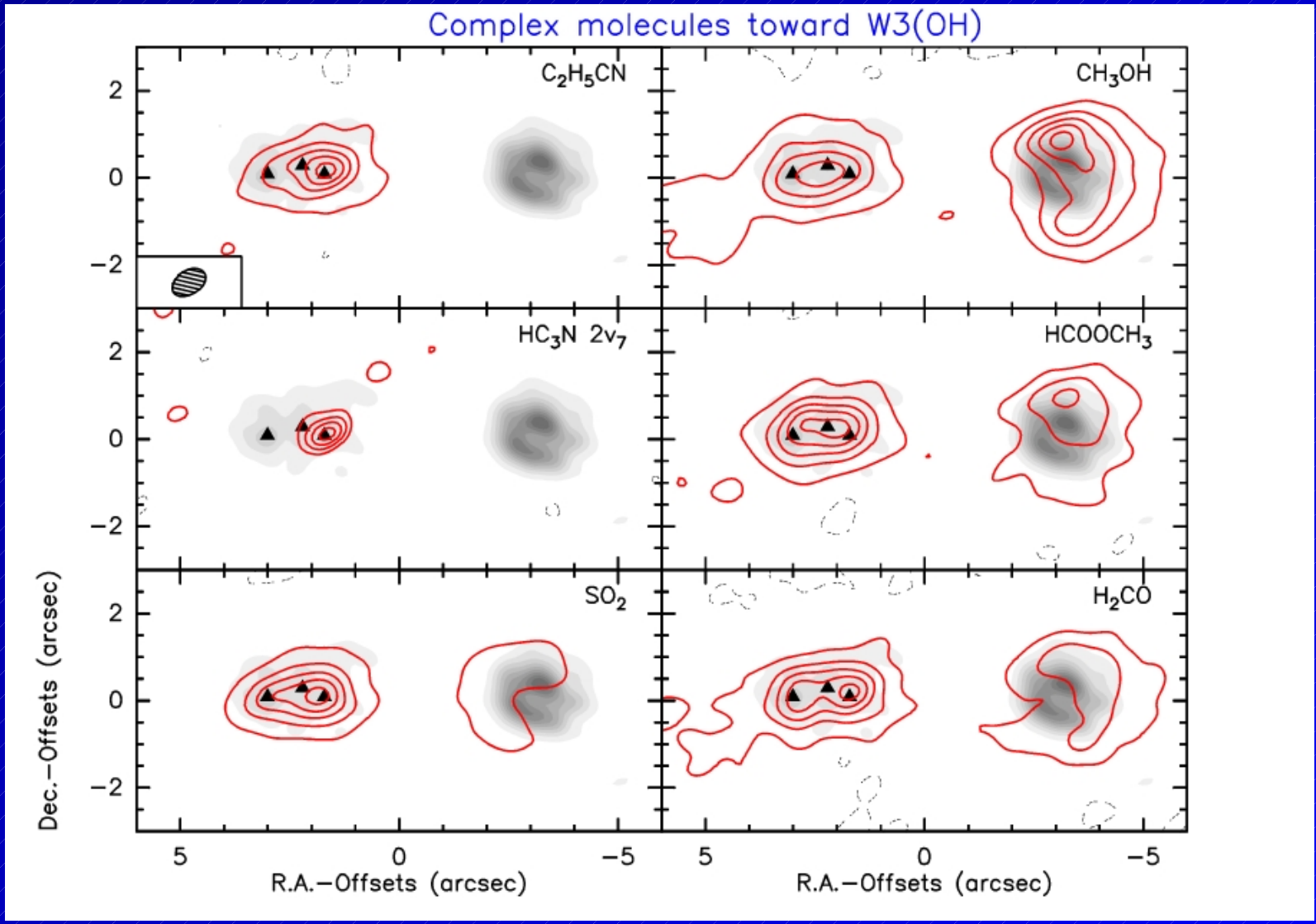


Wright, Plambeck, Wilner 1996

Putting it together



Orion isn't alone



Wyrowski et al. 1999

What does it mean?

- Differentiation:
  - nitrogen bearing in hot core
  - oxygen bearing in compact ridge
- Chemical models come in different flavors

1) reflects thermal history during gravitational collapse
   a) different abundances of N, O bearing molecules in ices
   b) no CO freeze-out in dense, warmer center (proto-hot core, but in colder surroundings (proto-compact ridge) [Caselli, Hasegawa & Herbst 1993]
2) reflects thermal history after evaporation (gas phase chemistry) [Rodgers & Charnley 2001, 2003]
3) reflects thermal history of evaporation (binding energy, trapping in water ice, thermal profile)]Nomura & Millar 2004, Viti et al. 2004]

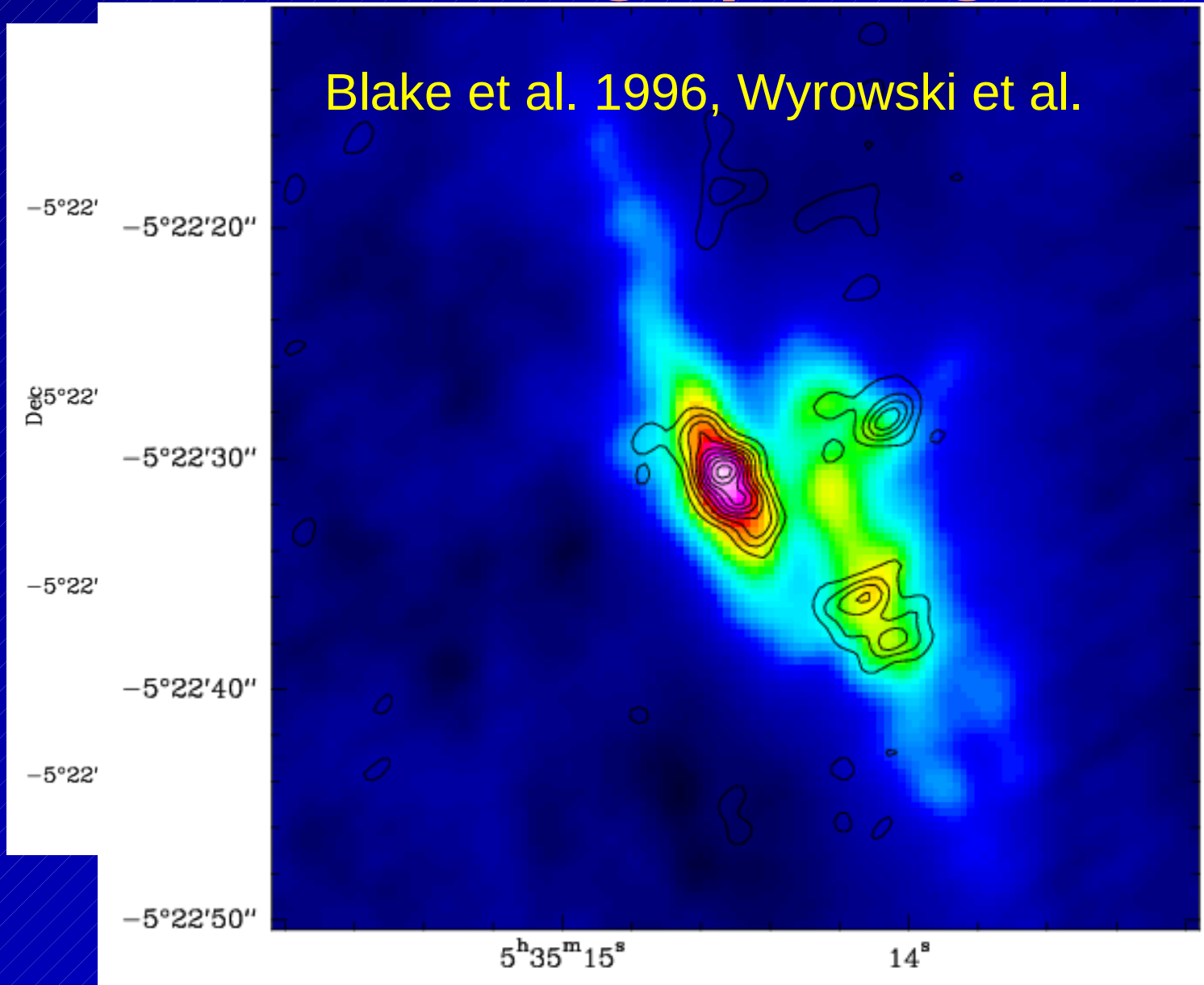
The meaning of carrots

- Whichever model is correct (maybe all of them are, to some degree), we learn something about some stage of the event that led to star formation
- Needed:
  - good observations
    - of many lines to understand excitation (to get the local abundances)
    - of many sources with high spatial resolution (not only Orion, for de-freaking, ALMA to the rescue!)
  - good models
    - understanding of gas phase reactions
    - understanding of adsorption/desorption
    - understanding of surface processes
    - understanding dynamics (shocks...)

Speaking of good observations

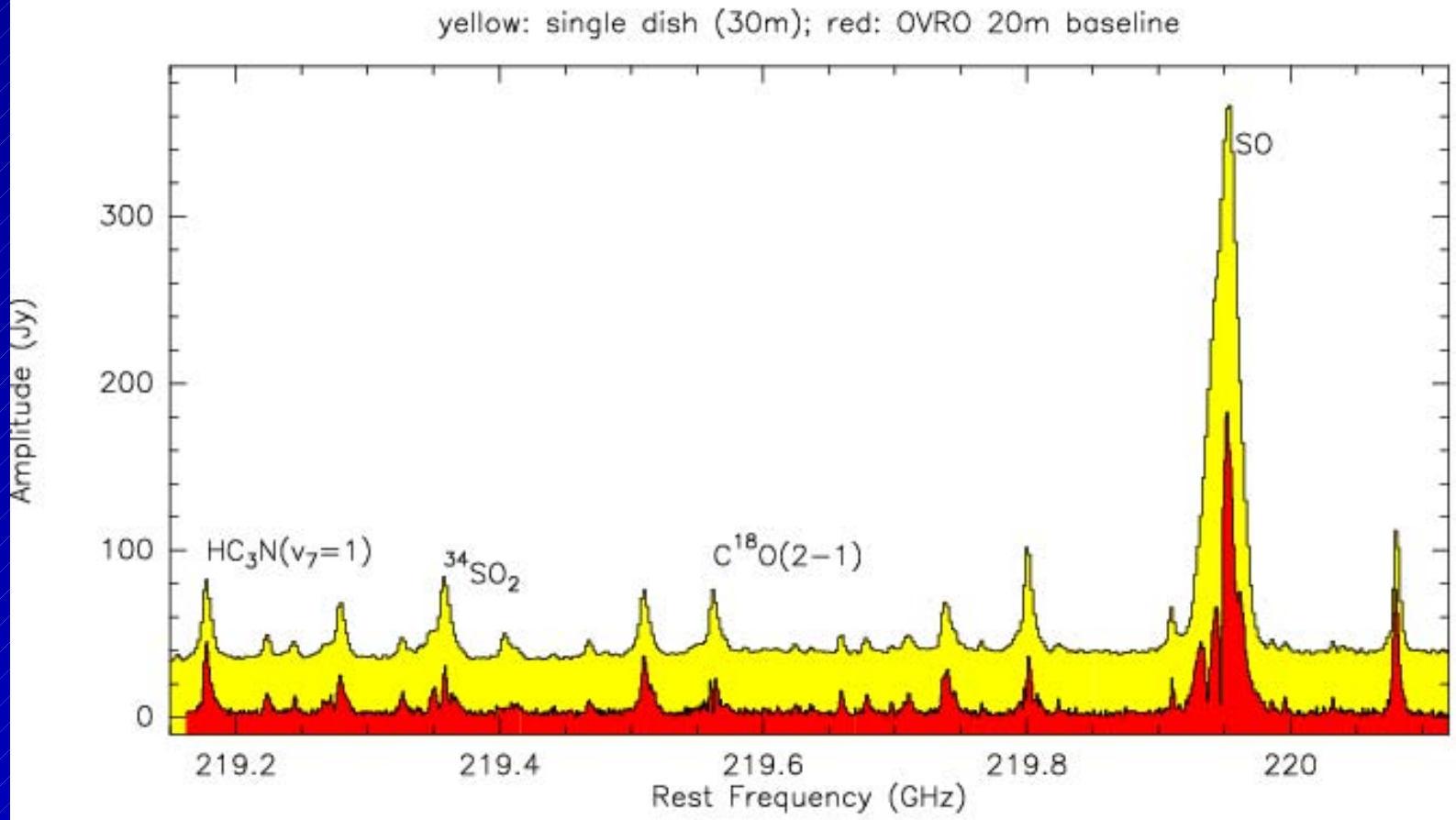
- Observations should tell us how sources really look like
- Not as trivial as it sounds, since
  - Interferometers are telescopes with a lot of holes in them
  - Interferometric images are nothing but models which are compatible with observations
  - There is an infinite number of models with is compatible with observations
  - Many of these models differ in interesting ways

Missing spacings: maps



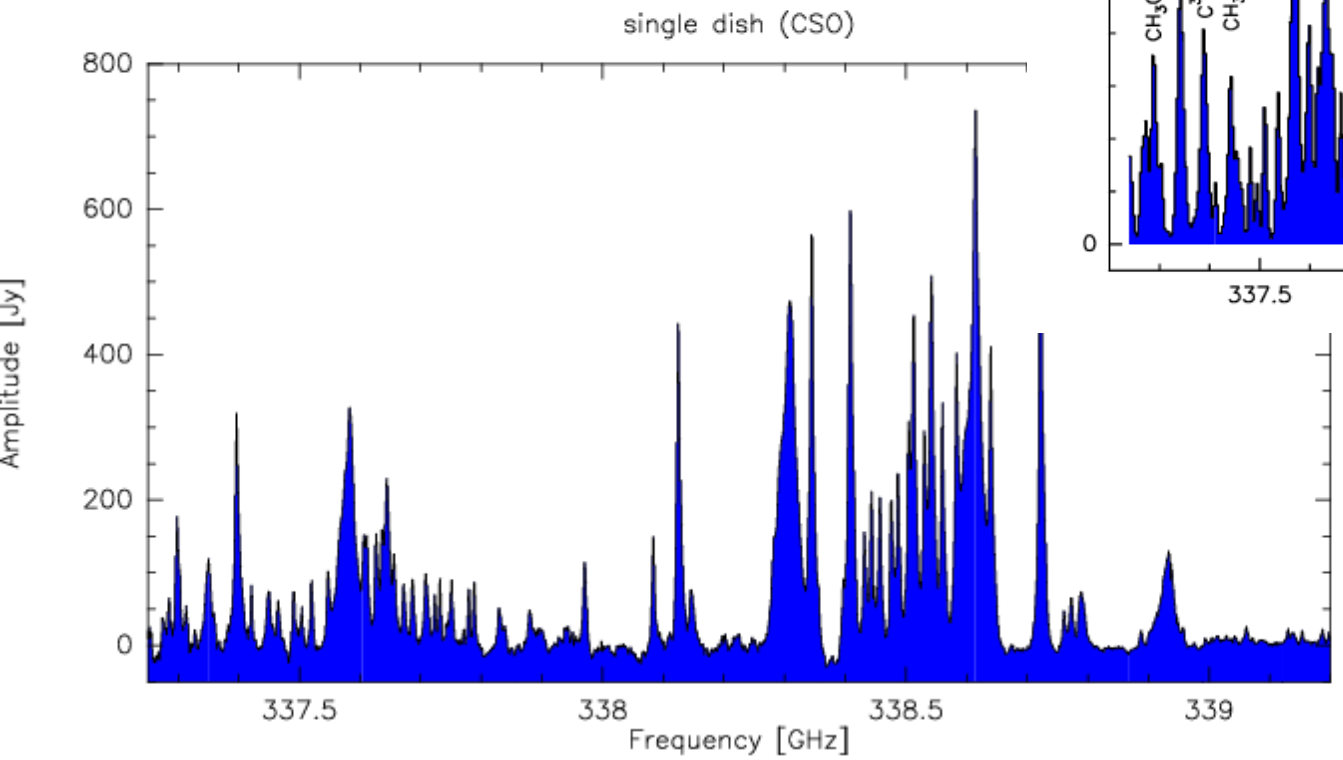
Missing spacings: spectra I

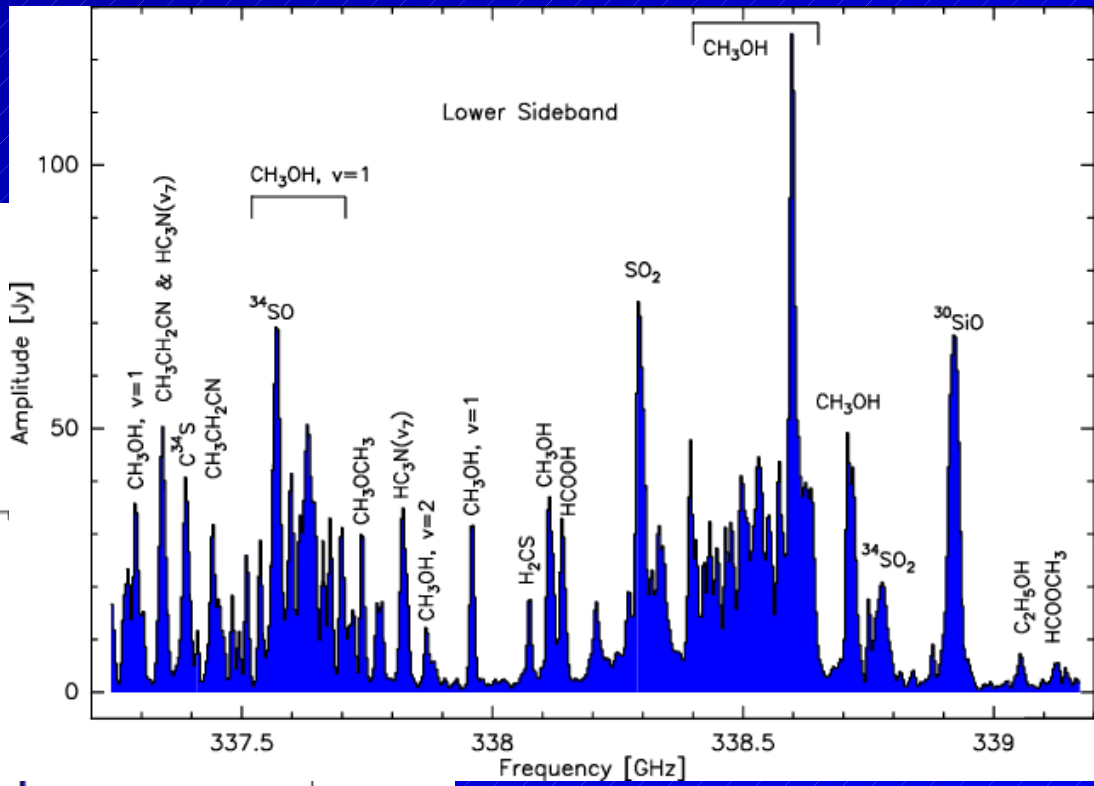
Blake et al. 1996, Wyrowski et al.



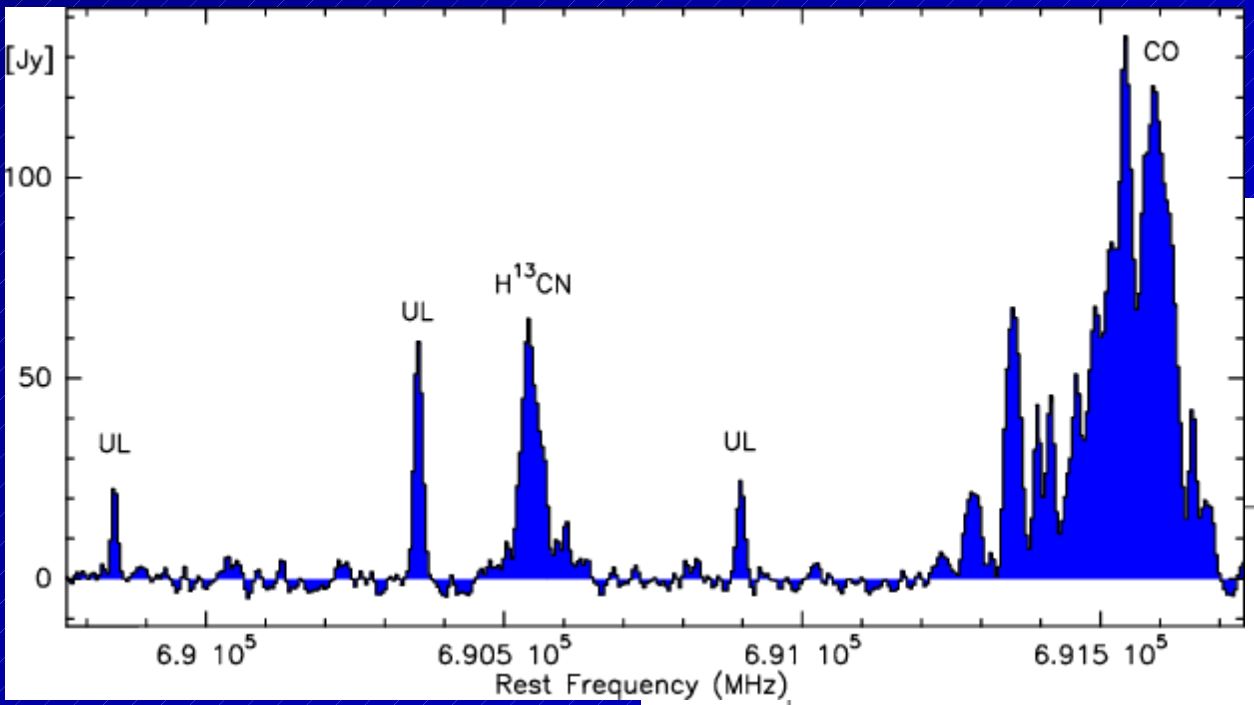
Missing spacings: spectra I

CSO: Schilke et al. 1997
SMA: Beuther et al. 2005





Missing spacings: spectra II



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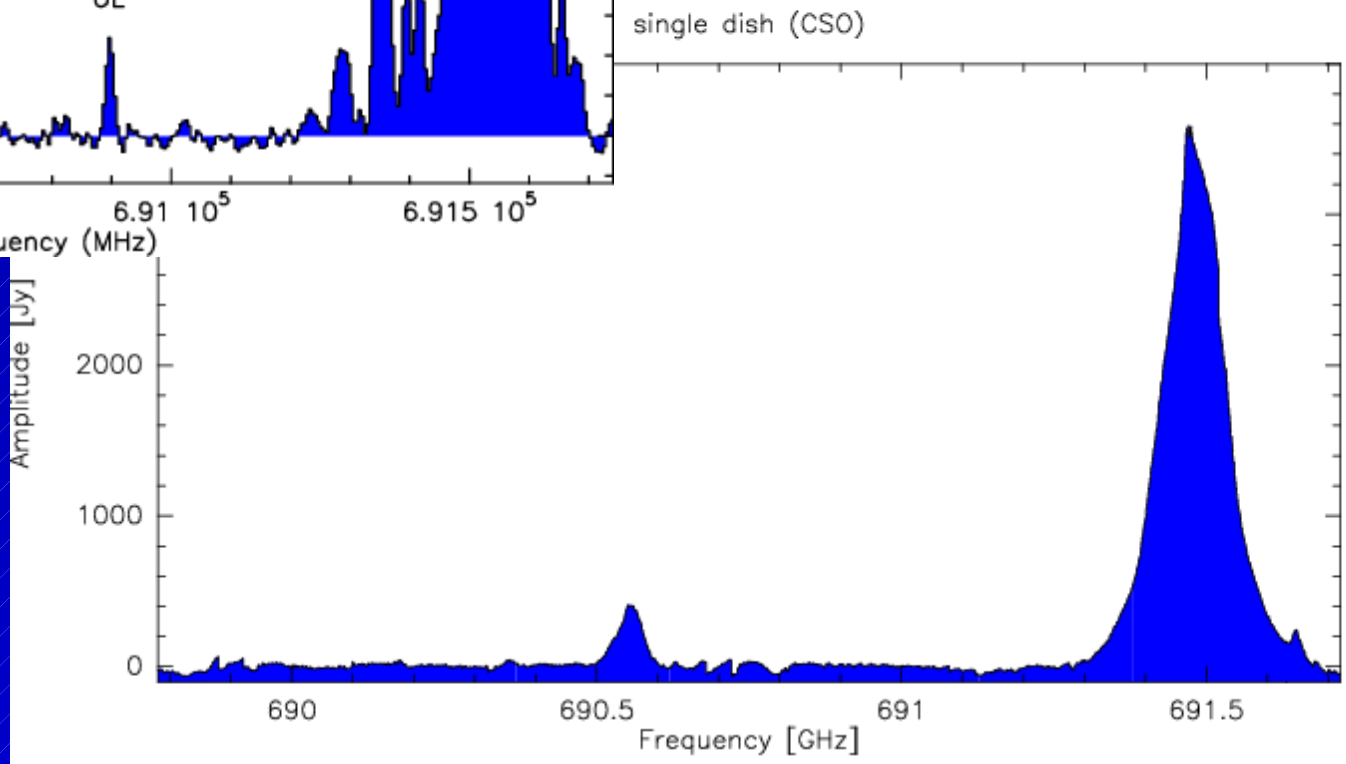
SMA: Beuther et al. 2006



ALMA needs HIgh FIdelity

- Try to fill uv-plane as much as possible
  - NOT just short spacings!
- Awareness of problem
  - The real problem is not the data, it is misinter-pretation!
- Simulations
  - “observe” source models
- ALMA has many more baselines than cur-rent mm or submm interferometers
  - but not an infinite number
  - particularly in extended configurations a lot of flux will be missing

Conclusion

- It can be done
- It's not easy
  - Good observations
    - good instrument at a good site: ALMA
  - Good analysis
    - needs lab data: frequencies, collision rates
  - Good models
    - need lab data: reaction rates in gas phase and dust
  - Bad news: it's a lot of work!
  - Good news: it's a lot of work!
    - ...but interesting
    - ...but managable
    - so it's a lot of fun!