MASER EFFECTS IN RECOMBINATION LINES: THE CASE OF ETA CARINAE

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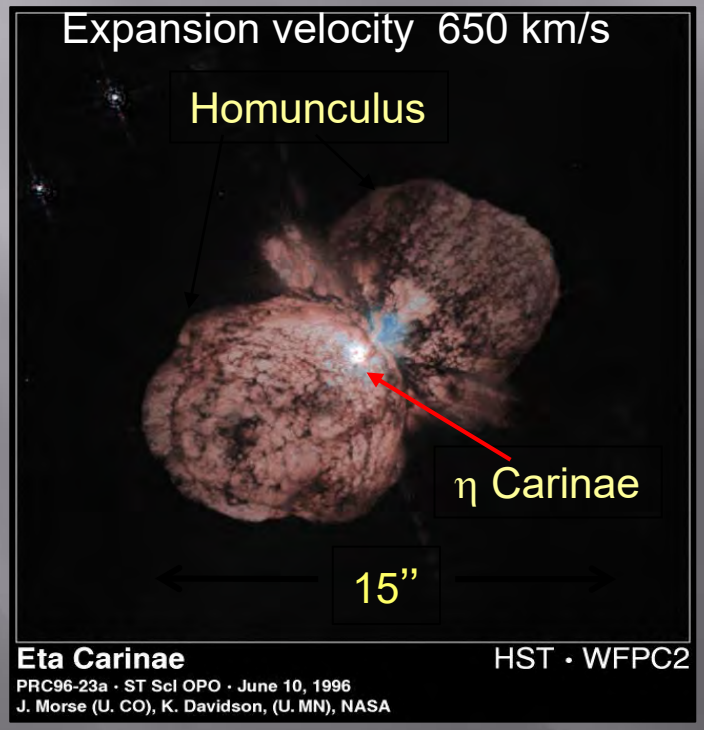
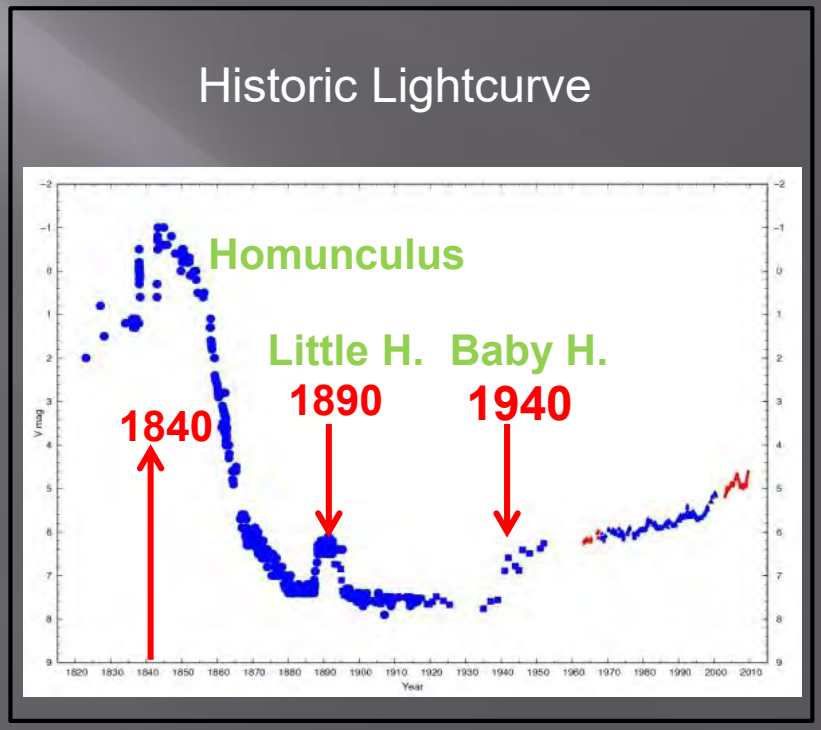
Introduction

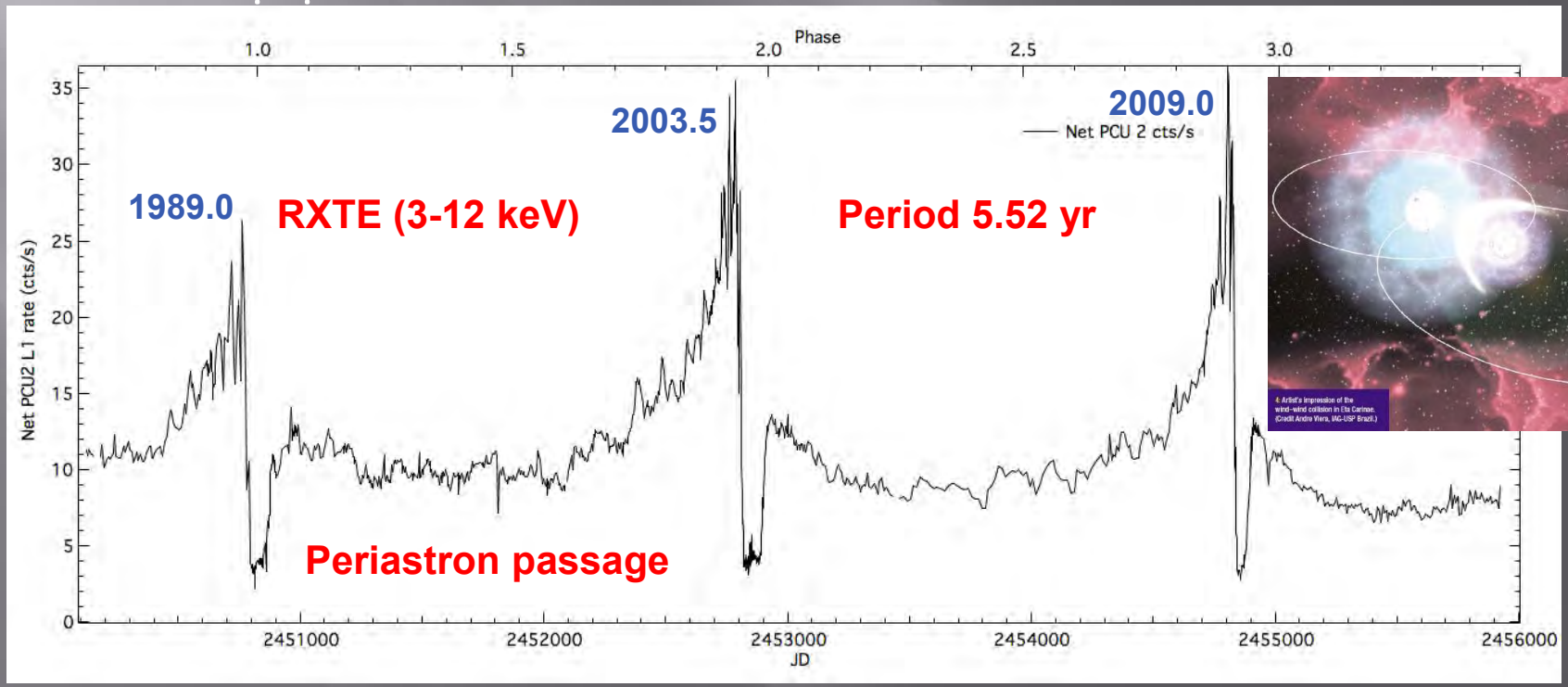
- η Carinae is one of the most massive stars in our Galaxy (150 $M_\odot$)
- It is possible and LBV
- In 1840 it had a very strong episode of mass loss (about 12 $M_\odot$) that formed the Homunculus Nebula, now expanding at 600 km/s





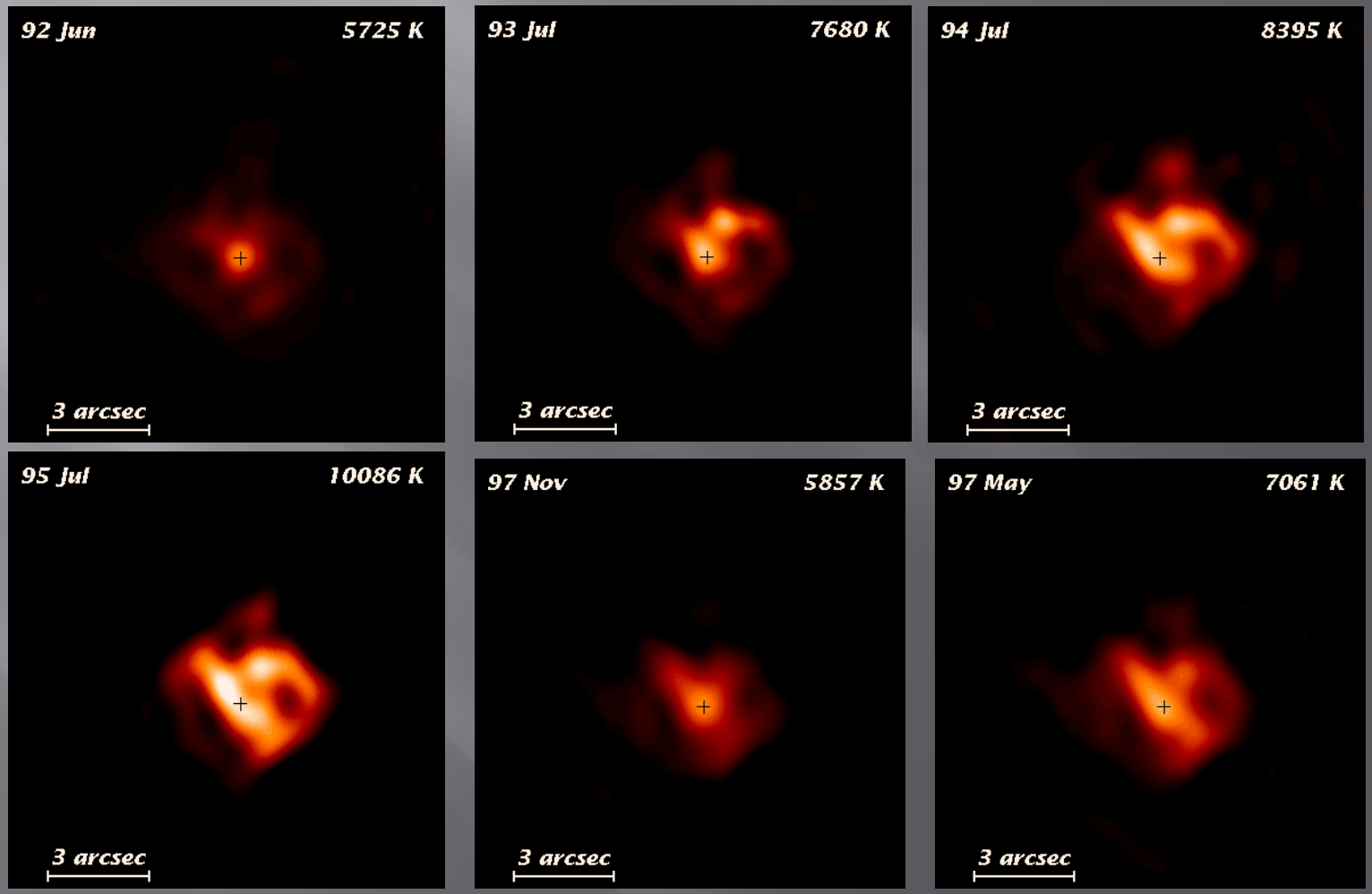
Introduction

- It is really a binary system, in a highly eccentric orbit,
- The companion star is not visible due to the absorption of the Homunculus nebula and the strong wind of η Carinae
- The secondary star has also a wind
- Wind-wind collisions produce X-rays
- The binary system is confirmed by a very strict periodicity in the light curves of transitions of highly ionized elements, X-rays and radio



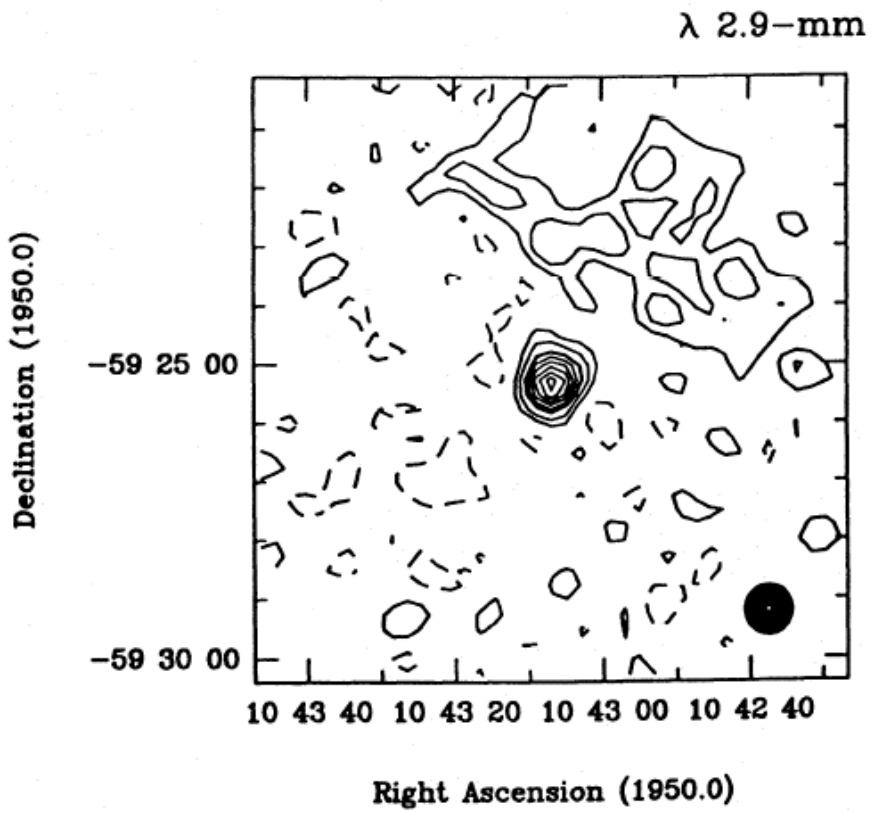
Radio Variability Interpretation disk ionized by secondary star

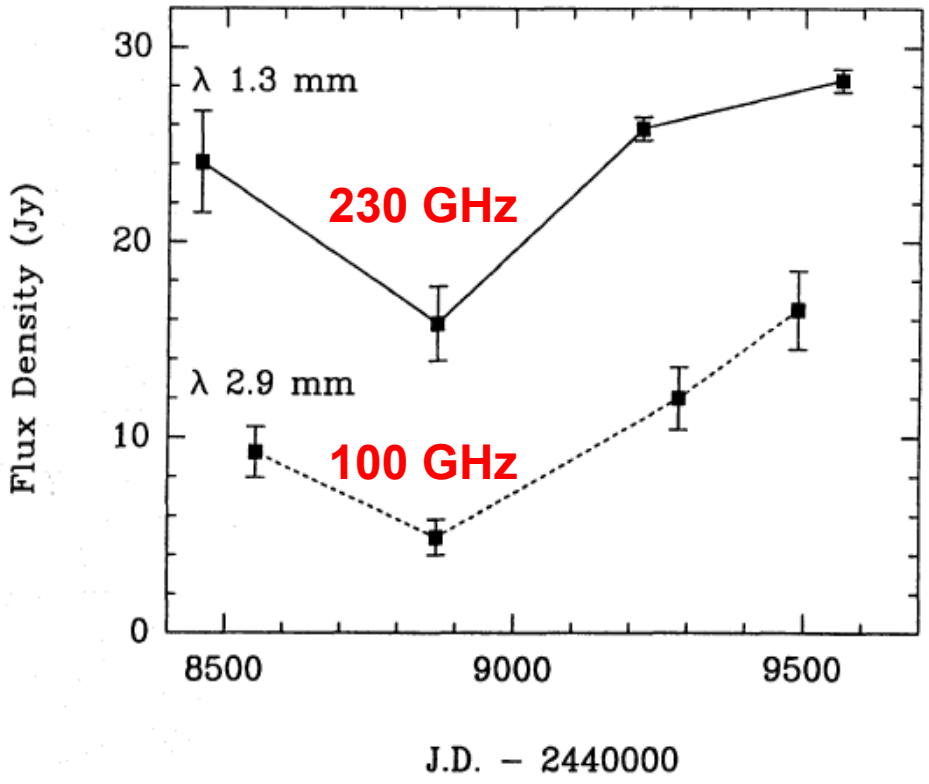
5 GHz observations with ATCA, Duncan & White (1996)



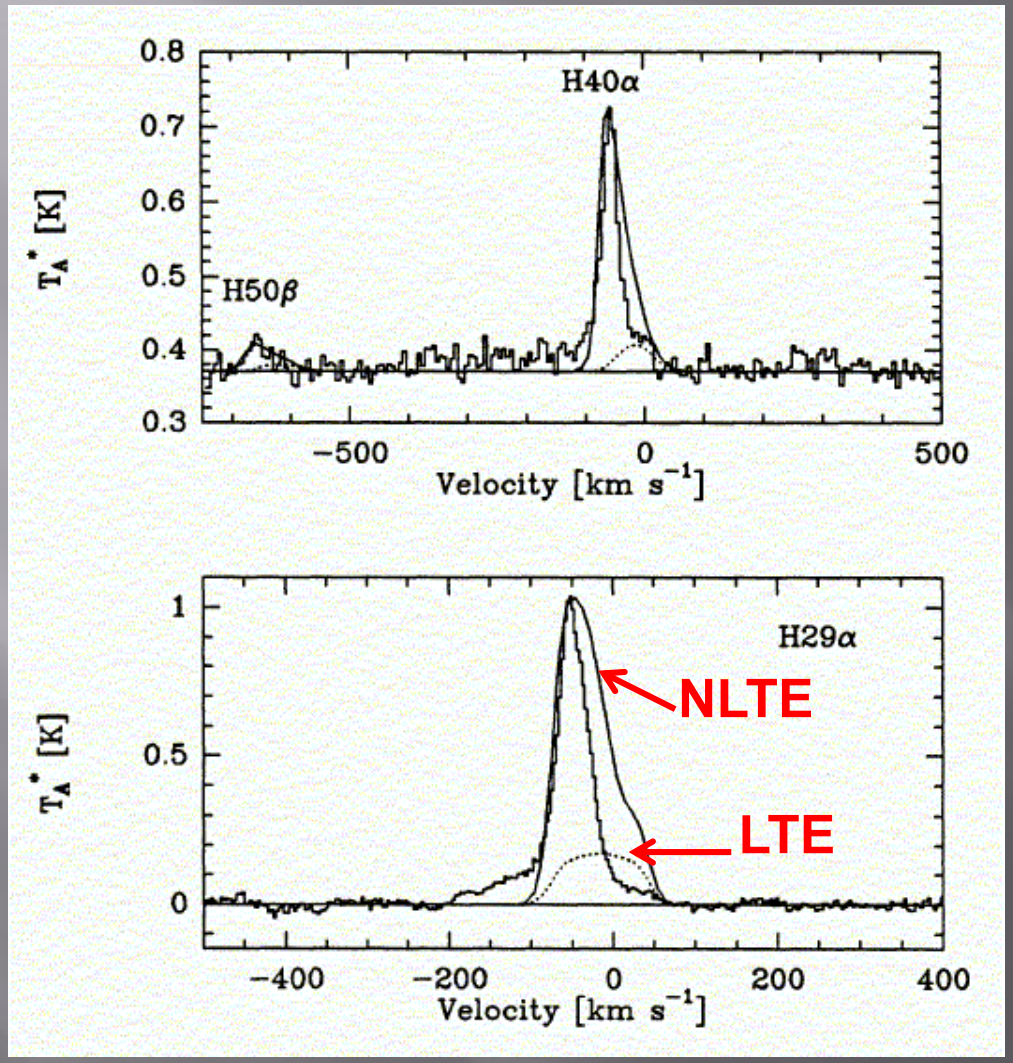
Higher frequencies: continuum

Cox et al. (1995) **SEST**



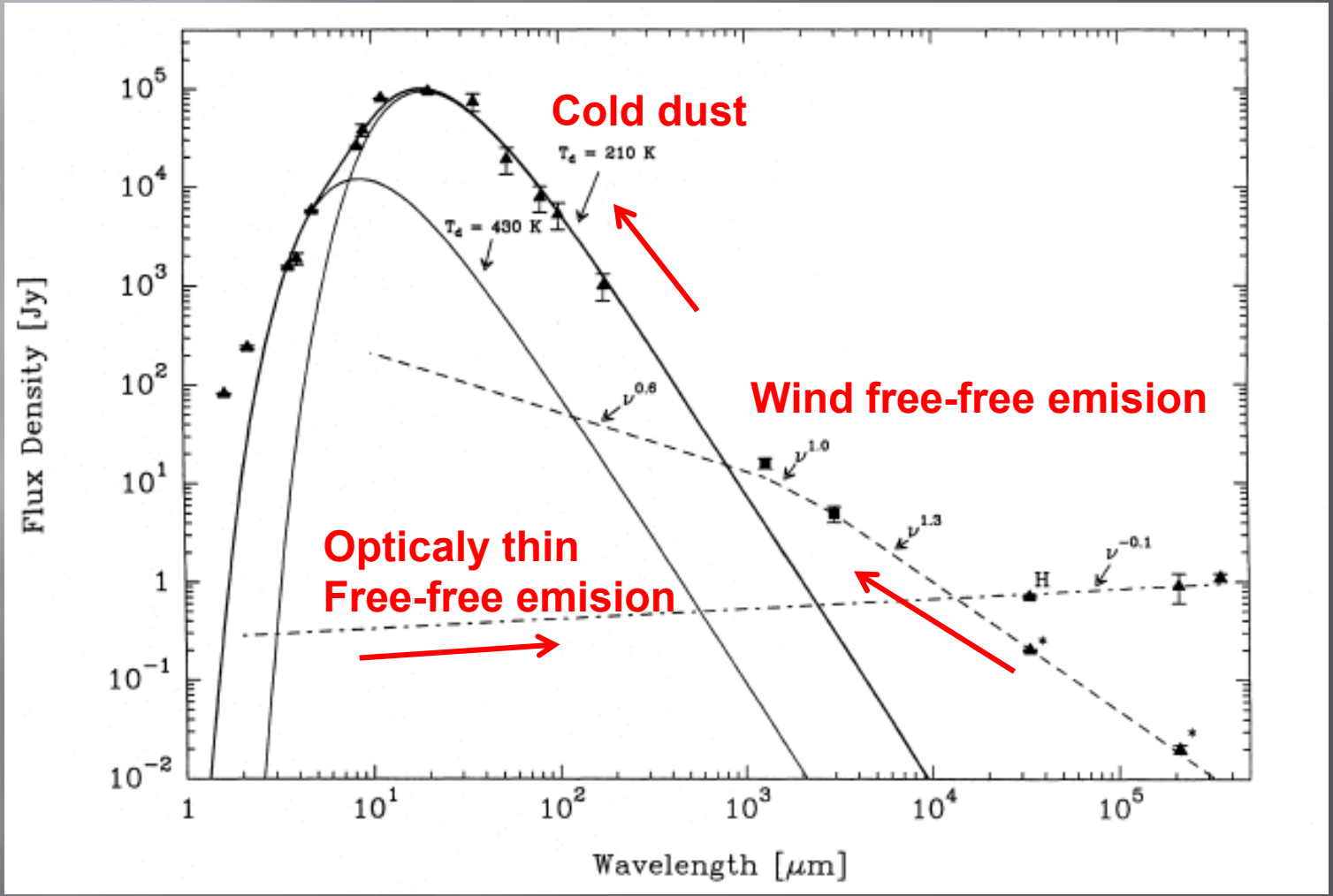


Recombination lines (maser effects)

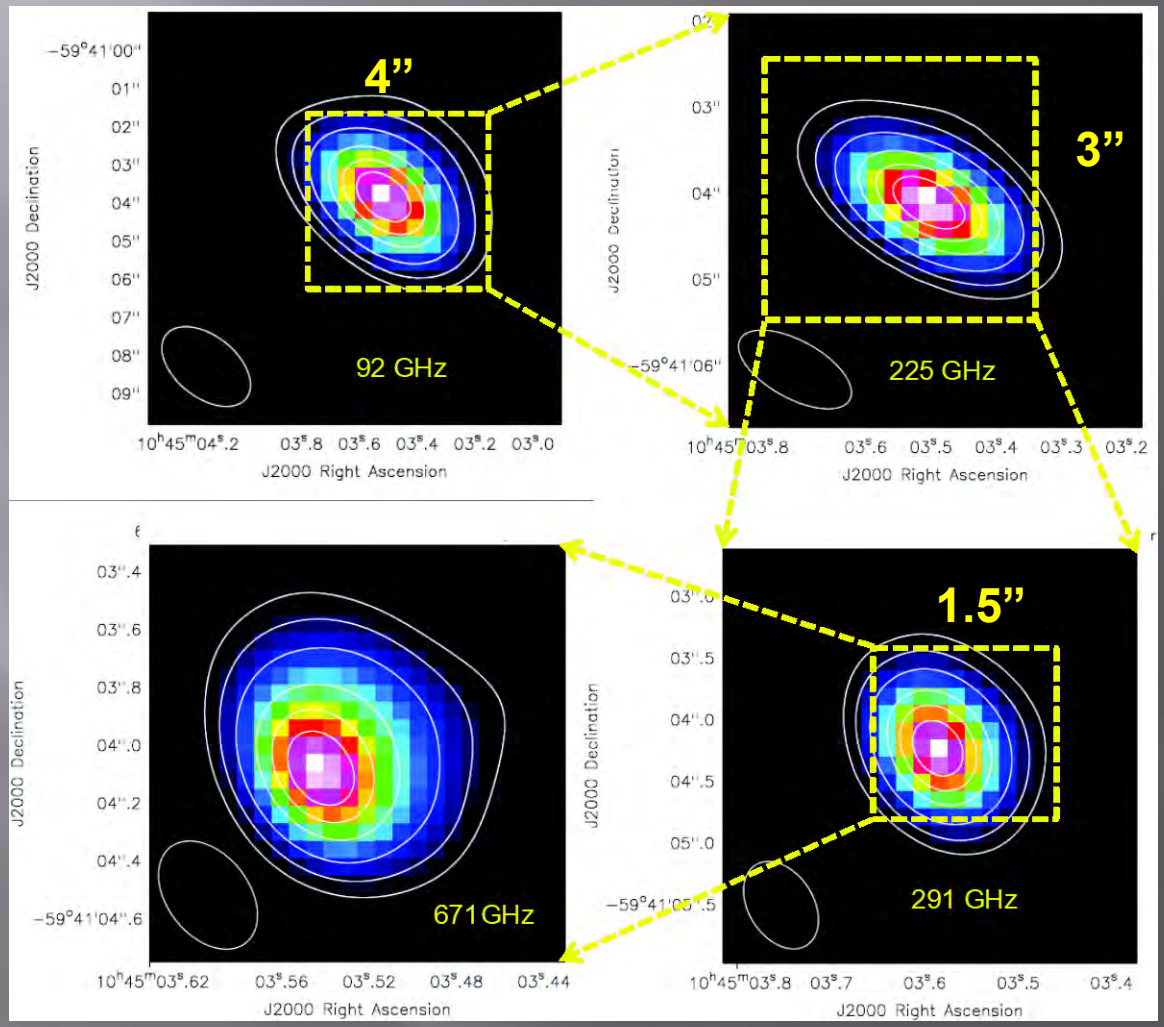


Cox et al. (1995)

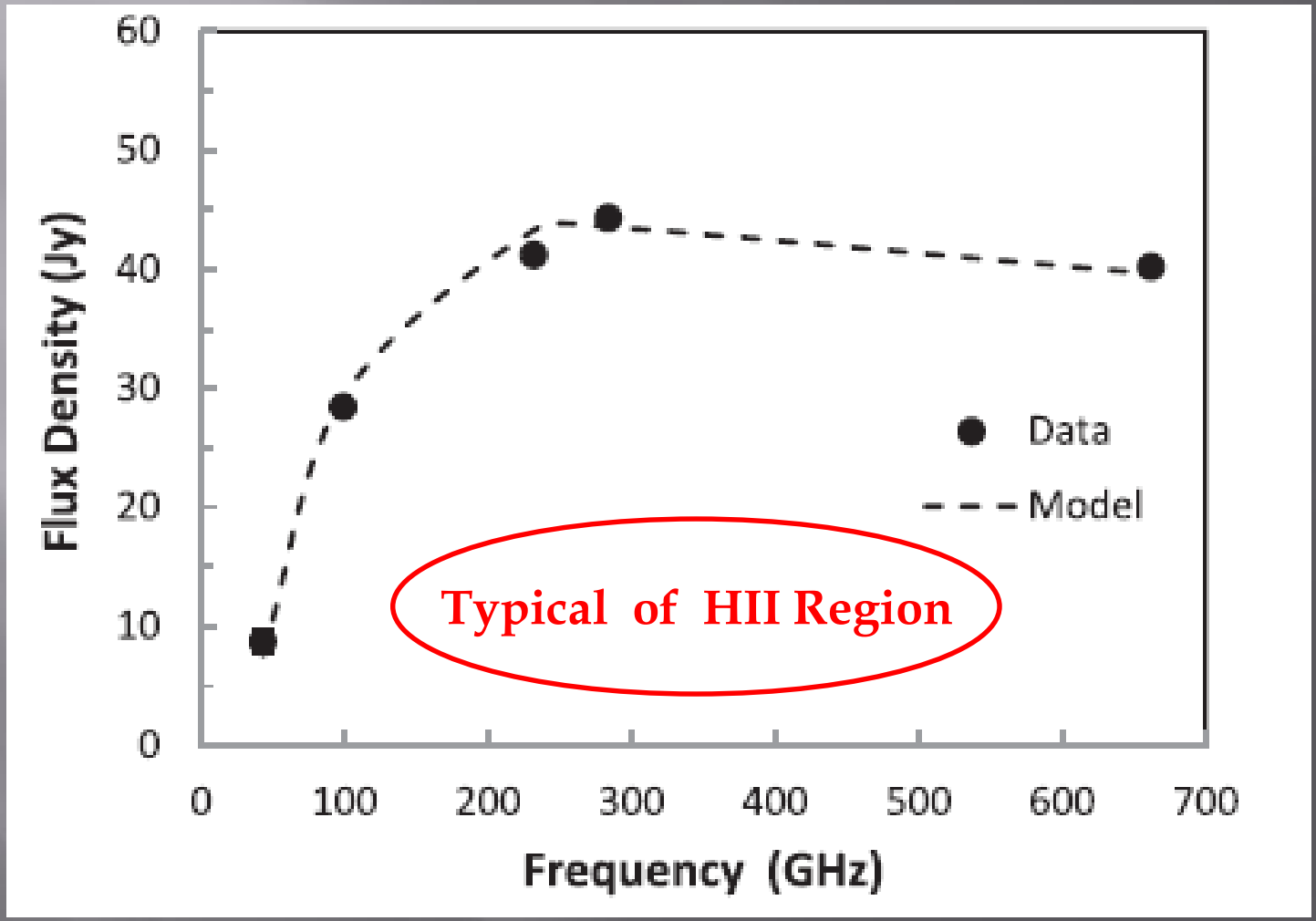
Interpretation Cox et al. (1995)



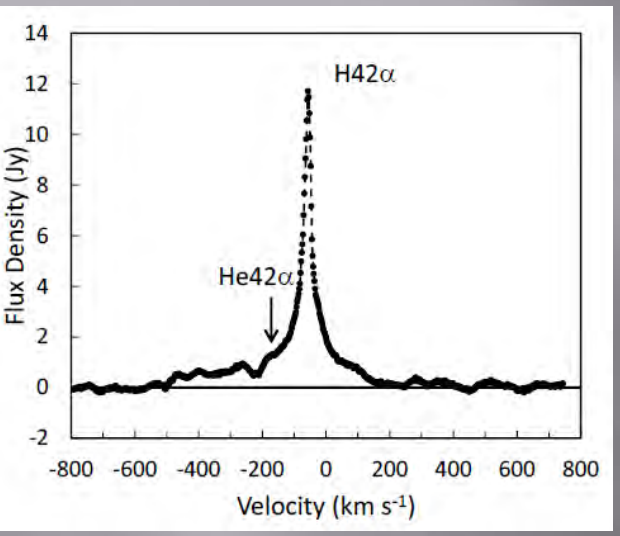
ALMA observations: CLEAN maps

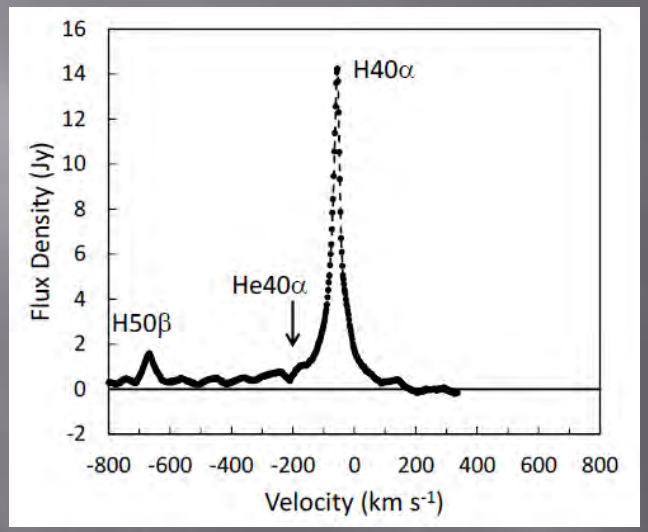


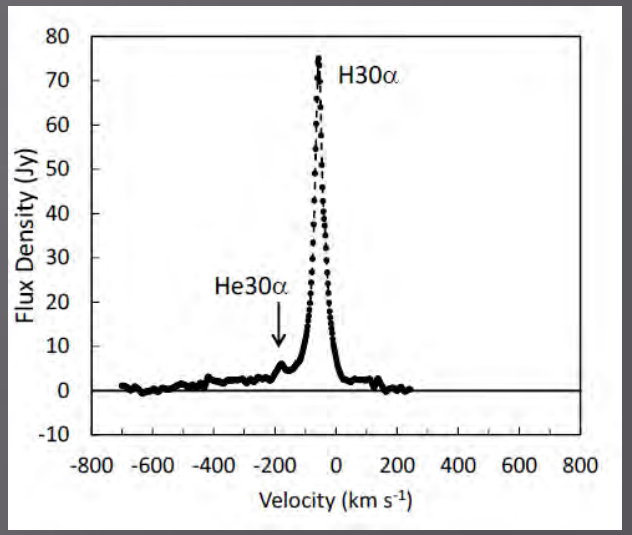
Integrated Continuum Spectrum

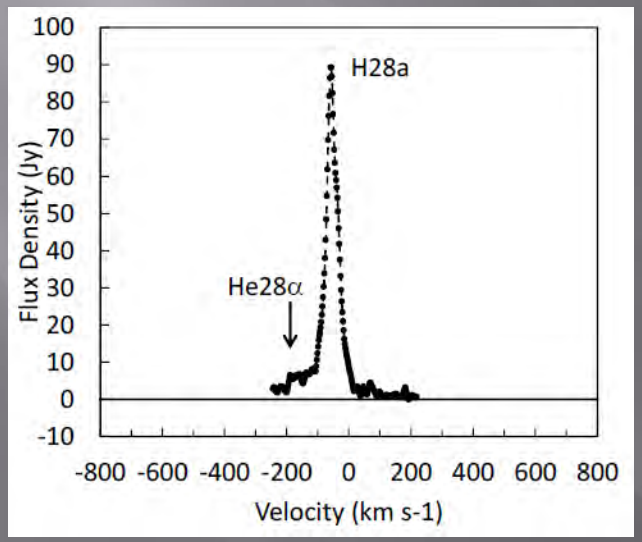


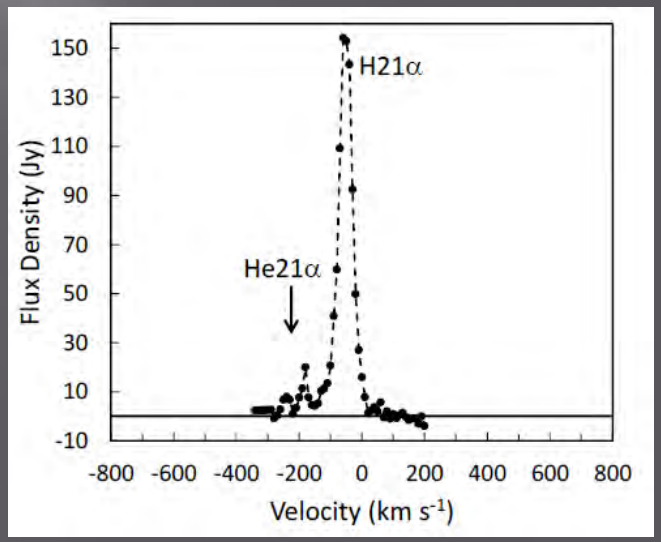
Line Profiles



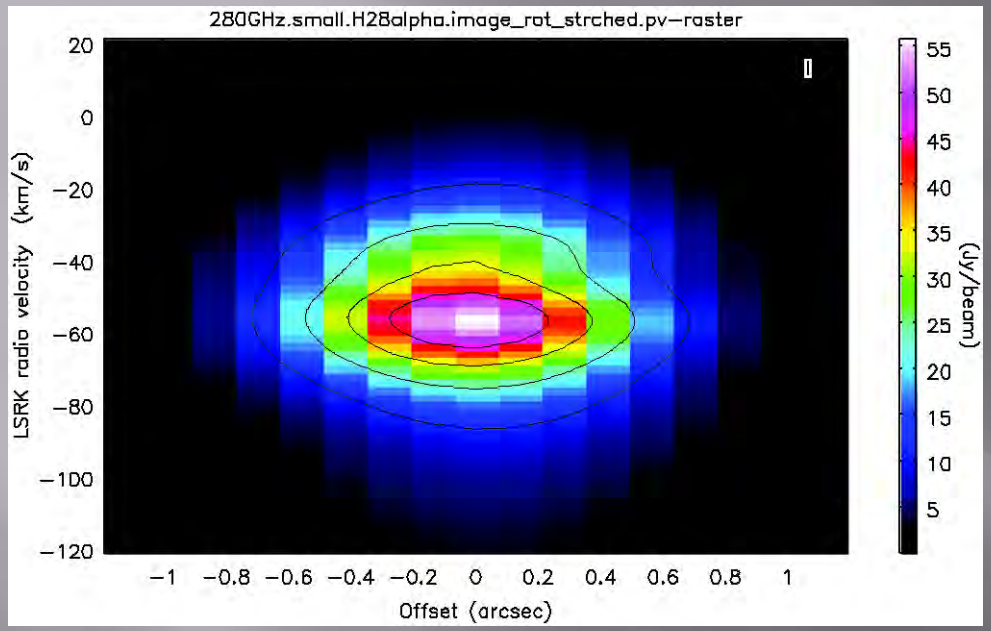


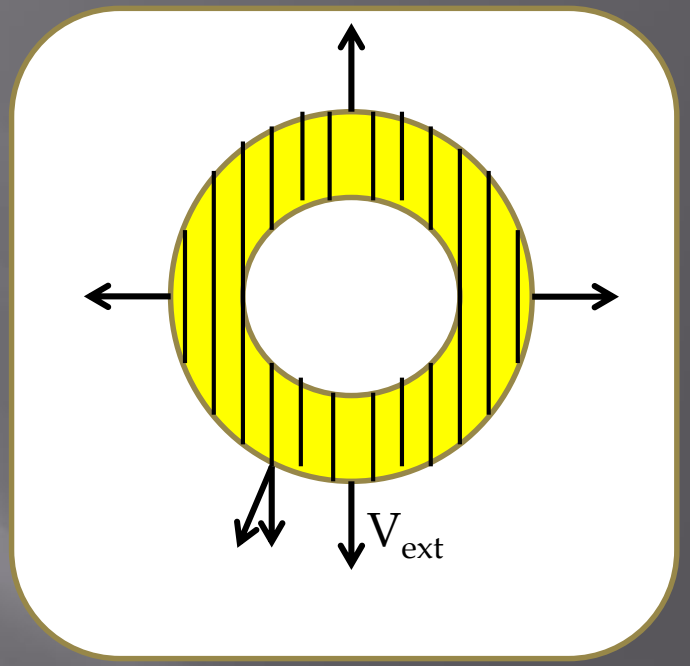






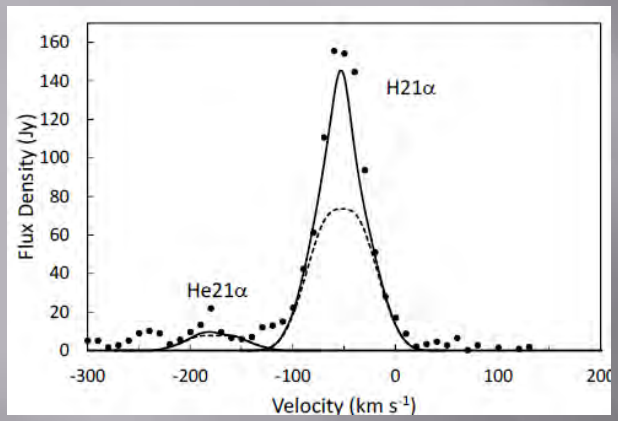
Model: Expanding shell

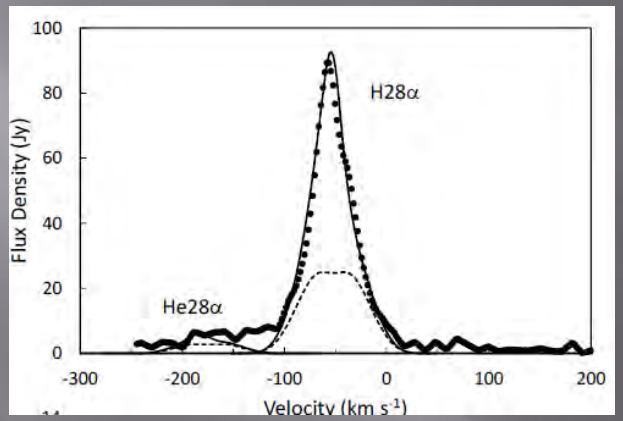


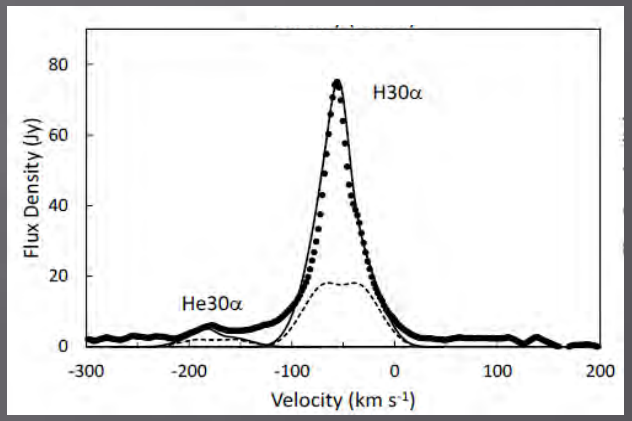


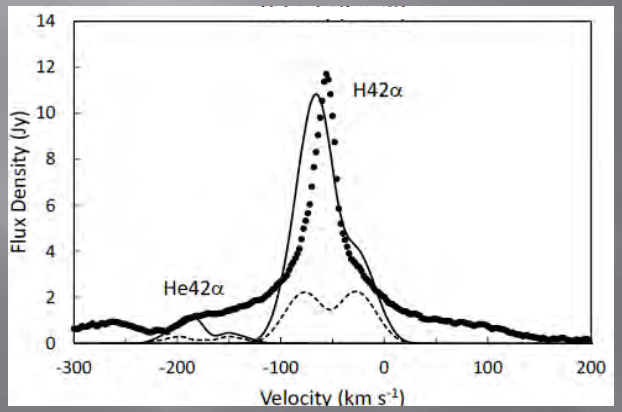
- Modeled the source as an expanding shell.
- Parameters: size, shell width, density, temperature, velocity and velocity gradient
- We solved the transfer equations for the continuum and NLTE H line emission.
- To do that, we had to take into account the expansion velocity along the line of sight, including the thermal velocity.

Best fit to the line profiles

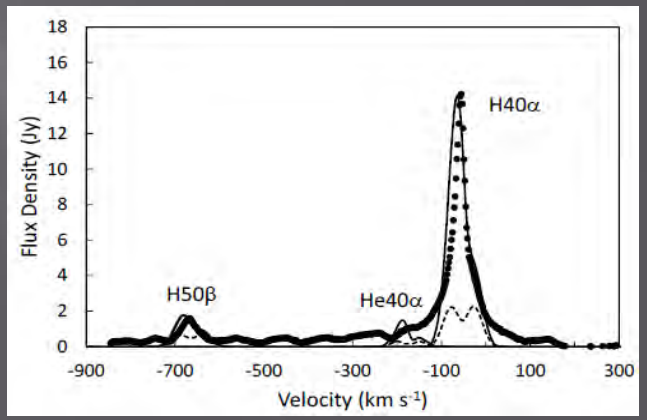








$R=2.2\times10^{-3}$ pc
$\Delta R/R=0.1$
$Te=1.7\times10^{4}$ K
$Ne=1.25\times10^{7}$ cm^{-3}
V_{bulk}= -52 km/s
V_e=-20 km/s
V_i=-60 km/s
t_0= 1942
M_{shell} = 0.002 $M_\odot$



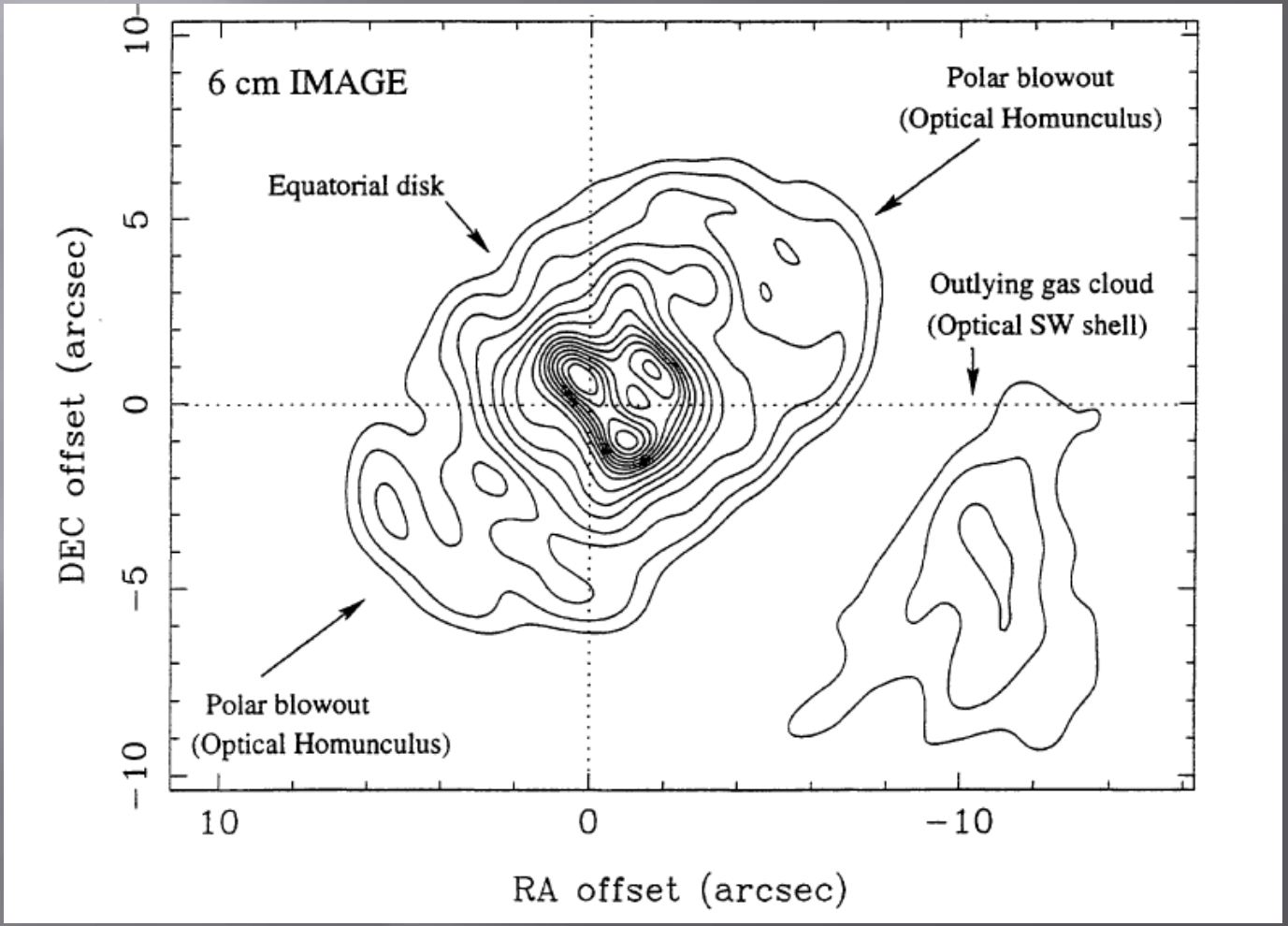
Conclusions

- ALMA observations did not resolve the source, even at the highest frequency
- However, simultaneous observations at frequencies between 43 and 660 GHz showed a spectrum characteristic of a compact source, which is different than the spectrum of extended wind.
- The simultaneous observation of H and He recombination lines at many frequencies allowed the determination all the model parameters
- Regions with consitions similar to η Carinae: hyper-compact HII regions.
- Targets for observation in single dish with the Brazilian-Argentinian LLAMA radiotelescope (30-700 GHz).

Grazie!

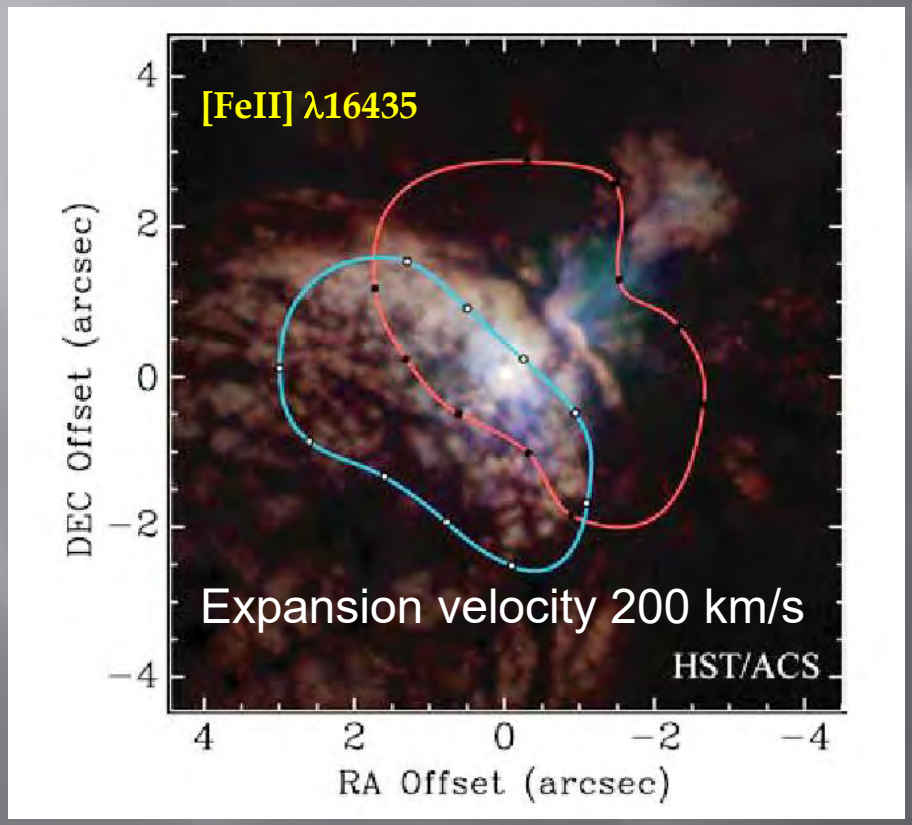
IAUS 336 Cagliari, Italy
September 4-8 2017

The Homunculus: radio (ATCA)

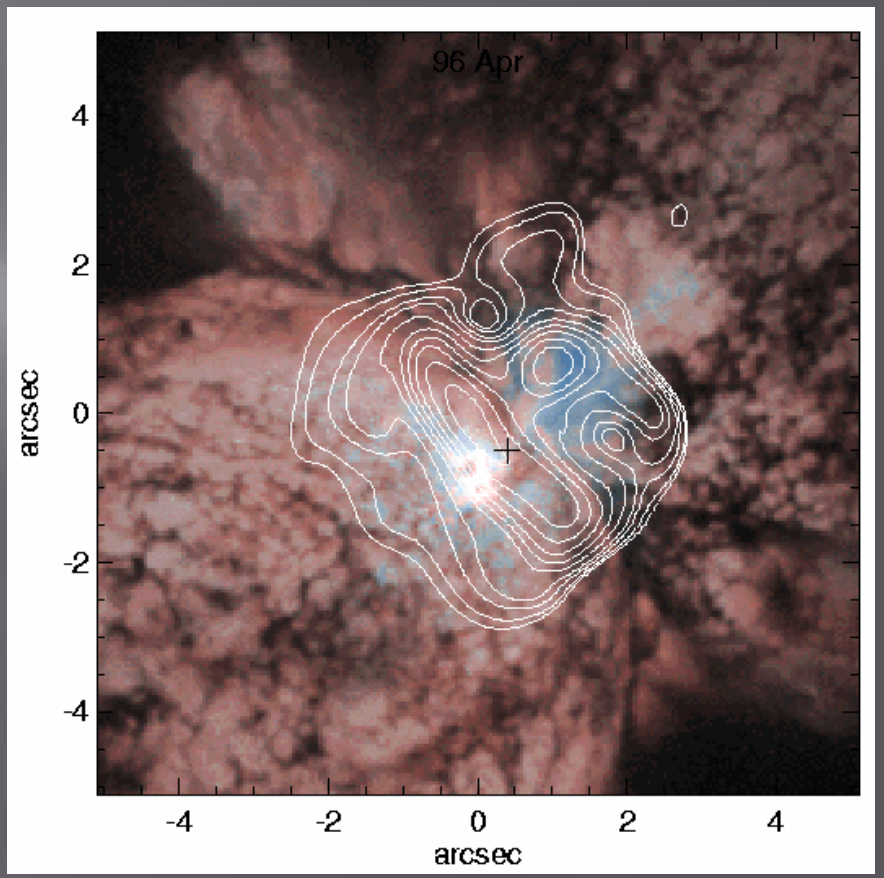


The Little Homunculus

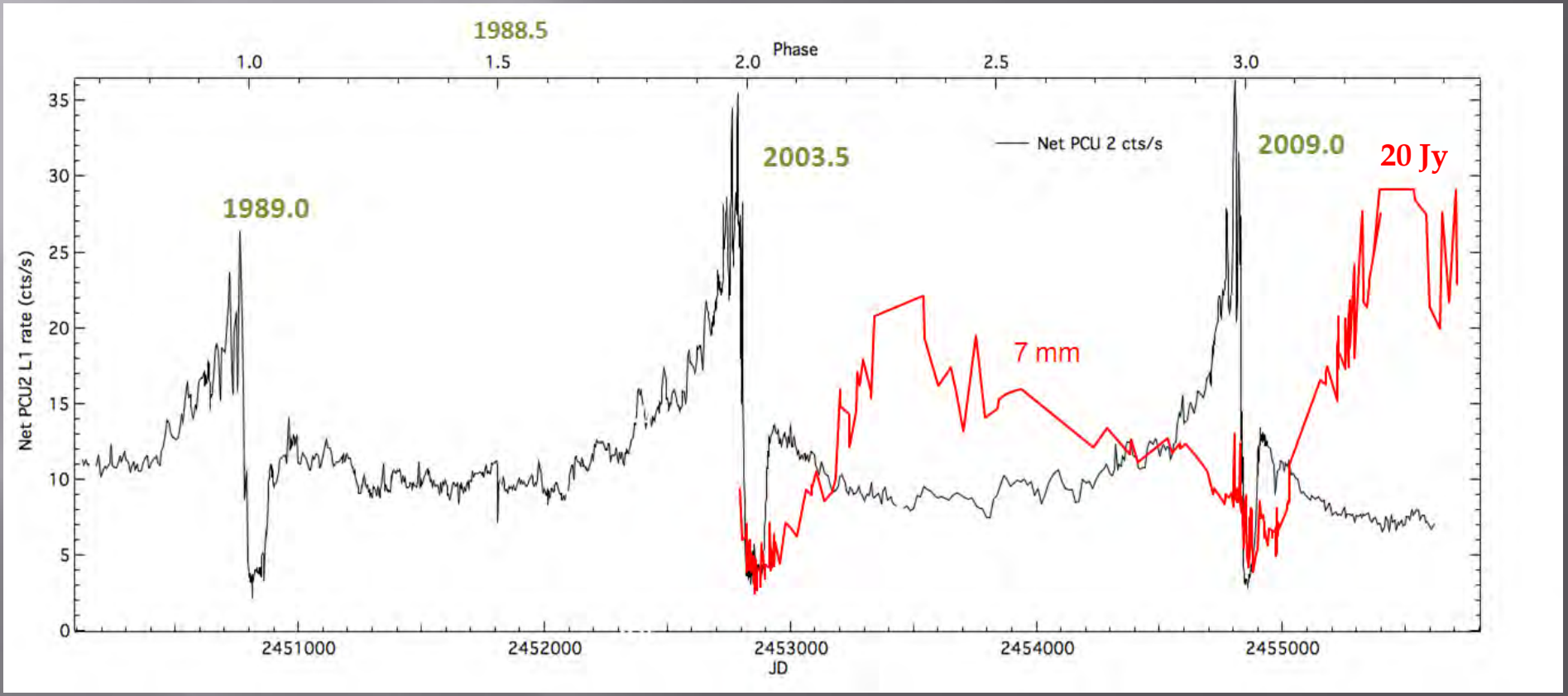
Ishibashi et al. (2003)



ATCA 3 cm



7 mm (43 GHz) observations at Itapetinga



ALMA, Atacama
66 antenas operando entre 43 e 900 GHz



Observations with SEST 1999-2003

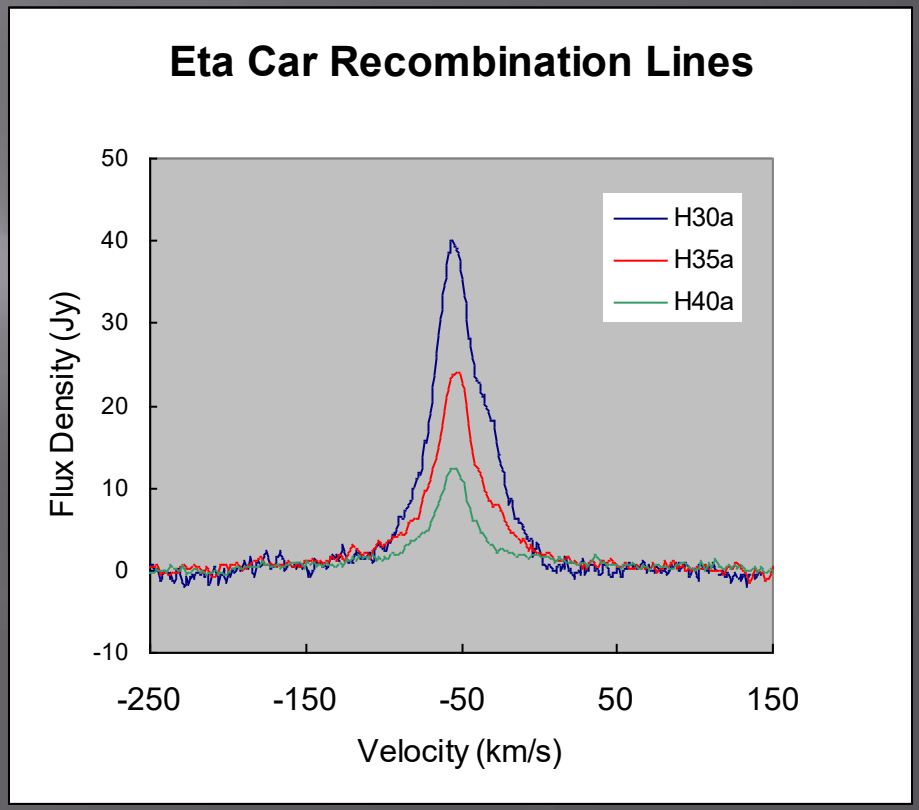
Continuum at 100, 150 and 230 GHz

Recombination lines H30α, H35α and H40α

Resolution between 50”and 24”

Long integrations, problems with pointing model

No calibration sources

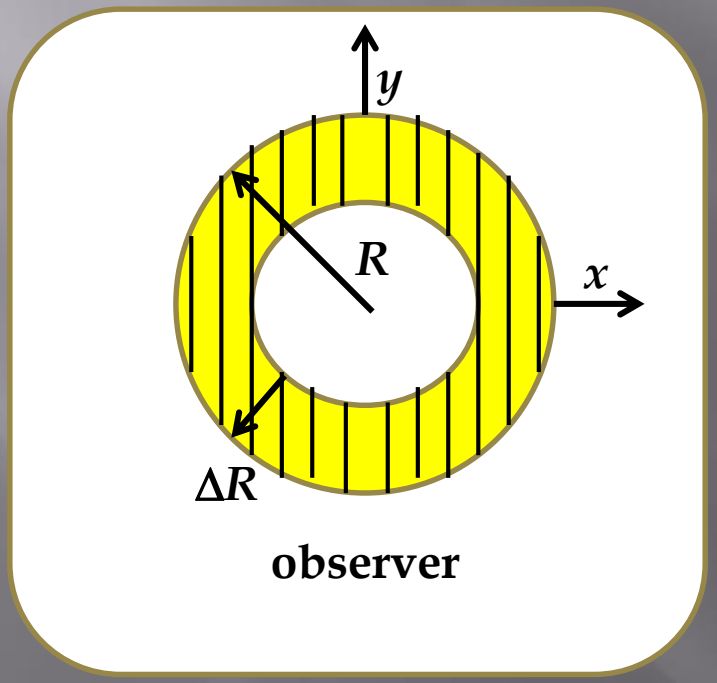


ALMA proposal

- It was very similar to the SEST proposal
- Make continuum observations in all the possible frequency range to see if the spectrum corresponded to the expanding wind or free-free emission from a stationary plasma.
- If resolved, see the shape of the emitting region
- Make observations of recombination lines in the same frequencies and use the NLTE condition to find the plasma electron density and temperature

Continuum spectrum (integrated)

- Assumed spherical shell of radius R and width ΔR constant electron density and temperature
- Solved the radiative transfer equation for free-free radiation
- Obtain the sets of parameters that fit the continuum spectrum

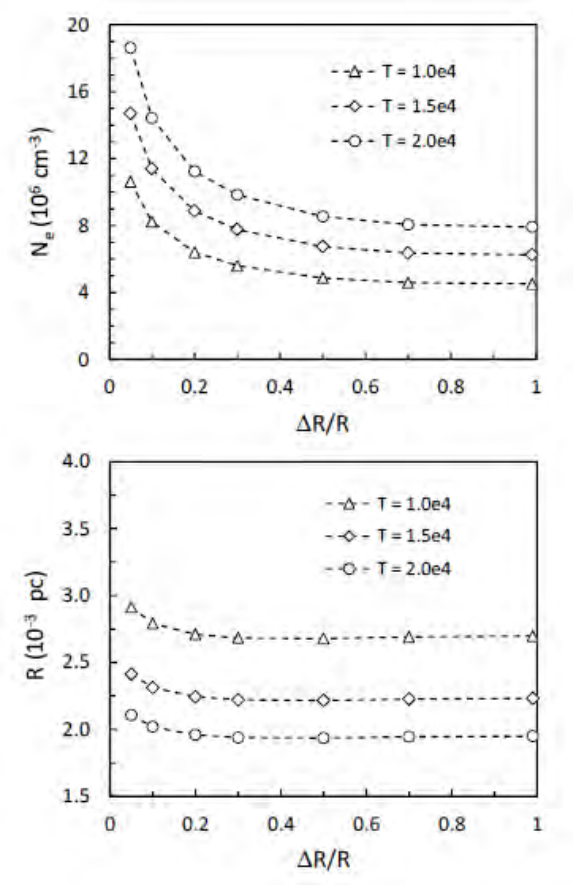


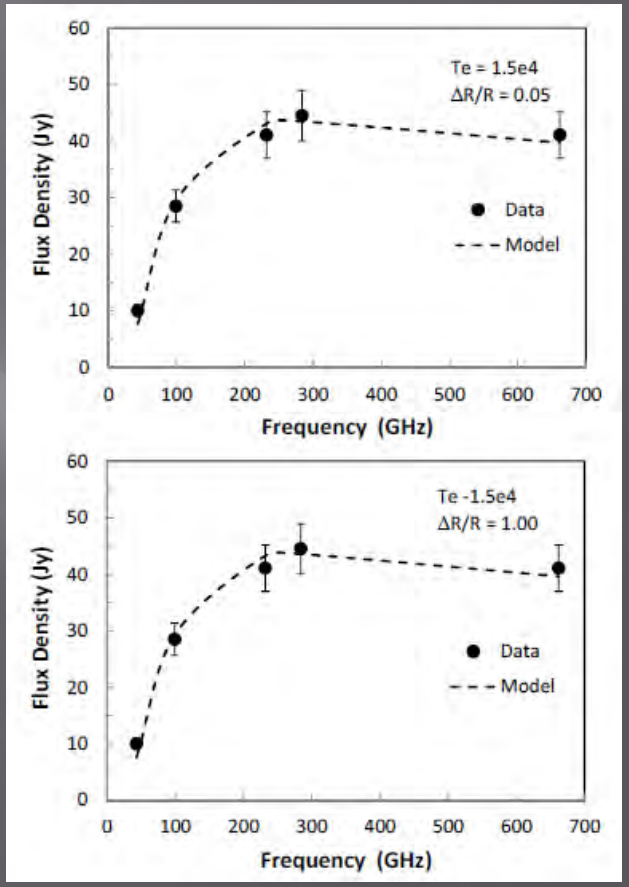
$$S_\nu^c(x, y) = \frac{2\pi\nu^2}{c^2} kT_e\left[1 - \exp\left(-\tau_\nu^c(x, y)\right)\right]\frac{\Delta x \Delta y}{D^2},$$

$$\kappa_\nu^c = 6.94 \times 10^{-8}\frac{N_e N_i}{\nu^2}\left(\frac{10^4}{T_e}\right)^{3/2} g_{\rm ff}\ {\rm pc}^{-1},$$

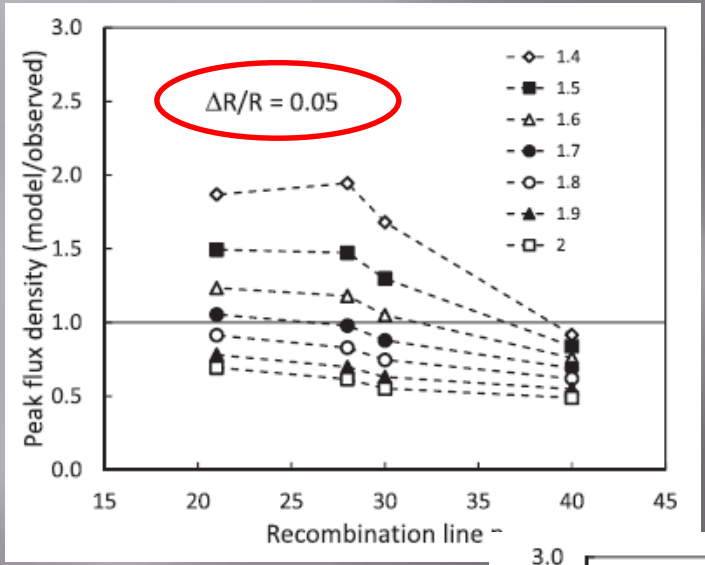
$$g_{\rm ff} = (4.69 + 1.5\ln T_e - \ln \nu).$$

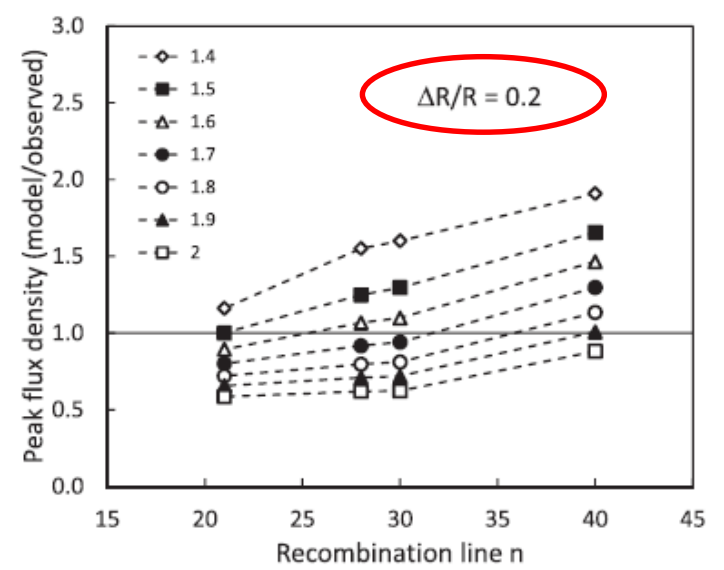
Continuum spectrum (integrated)

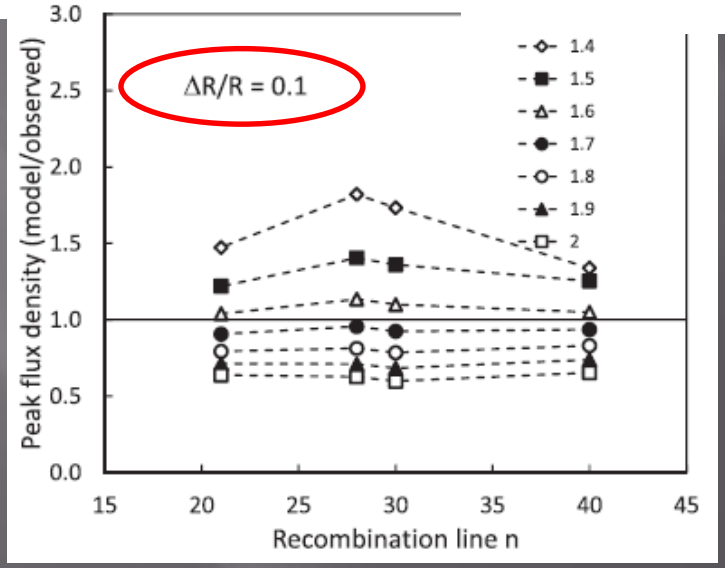




Maximum intensity of the model profile relative to the observations







Line Profiles

- Besides, the NLTE effects were strong, giving rise to negative opacities (or amplification)
- We used as input parameters those obtained from the fitting of the continuum spectra
- We calculated the line shapes for the H21α, H28α, H30α, and H40α lines, for different values of T_e and $\Delta R/R$