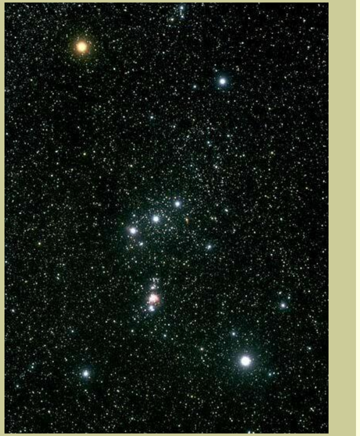


SCTF Teletalk - Feb 15, 2012

Multi-λ analysis of Betelgeuse’s CO

→ SOFIA-GREAT, CARMA, Gemini-S, HST

Graham M. Harper
Astrophysics Research Group, School of Physics
Trinity College, Dublin (Ireland)

Outline

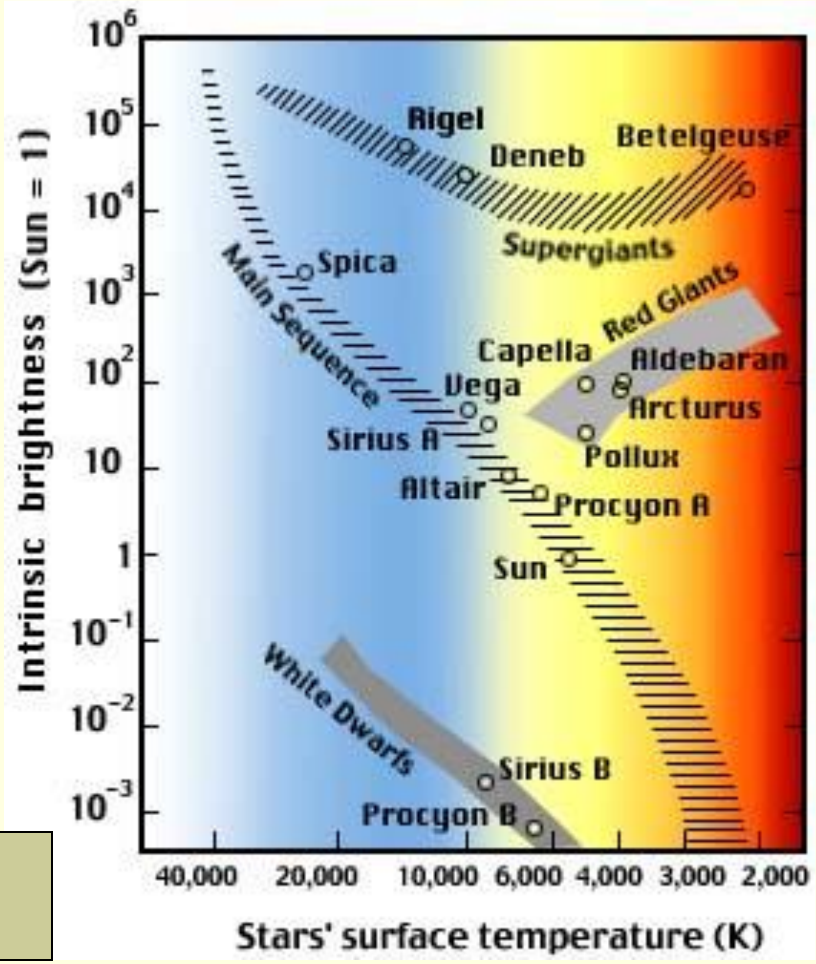
- Mass loss in the Hertzsprung-Russell Diagram
- Betelgeuse as a key to help understand mass loss
- Circumstellar signatures of $^{12}C^{16}O$ $^{13}CO^{16}O$
- Why GREAT on NASA-SOFIA?

Cohorts for CO project

- Electronic Transitions: Hubble Space Telescope (GHRS, STIS)
  - Kenneth Carpenter (GSFC)
  - Tom Ayres (CU Boulder)
- Vibrational Transitions: Phoenix - Gemini
  - Nils Ryde (Lund Observatory, Sweden)
- Rotational Transitions low-J: CARMA
  - Alex Brown (CU Boulder) & Joanna Brown (CfA)
  - Eamon O’Gorman (Trinity College, PhD student)
  - Seth Redfield (Wesleyan University)
- Rotational Transitions high-J: SOFIA (GREAT)
  - Matthew Richter (UC Davis)
  - Goran Sandell (USRA)
  - Sarah Kennelly (Trinity College, PhD student)

Mass loss in the Hertzsprung-Russell Diagram

- Luminous hot stars (left O-B)
  - radiation pressure on ions
- Very luminous and cool (late-M) stars
  - radiation pressure on dust
- Cool main-sequence
  - coronal “Parker-like” winds
- F-G giants
  - coronal “Parker-like” winds
- Luminous and cool (Miras)
  - Pulsation + something extra
- K & mid-M giants and supergiants
  - unknown



NASA Observatorium

Need empirical constraints to guide theory

Vitals - Betelgeuse

Spectral Type	Red Supergiant M2 Iab
Surface Temperature	3600 K (cool star)
Log(L/Lsol)	5.12
Distance	197 +/- 45 parsec (pc) 640 Light Years
Mass (Birth)	~20 M(sun)
Mass (Now)	~18 M(sun)
Mass Loss Rate	3×10^{-6} M(sun)/yr (current)
Wind speed V_w	9, 16 kms^{-1} (current, old)
Age	~10 Myr
Origin	O-type (hot) main-sequence Runaway Star
Fate	Supernova Type II

Dust

Betelgeuse – not enough dust for wind?

Image Credit:
VLT/Visier
mid-IR camera.

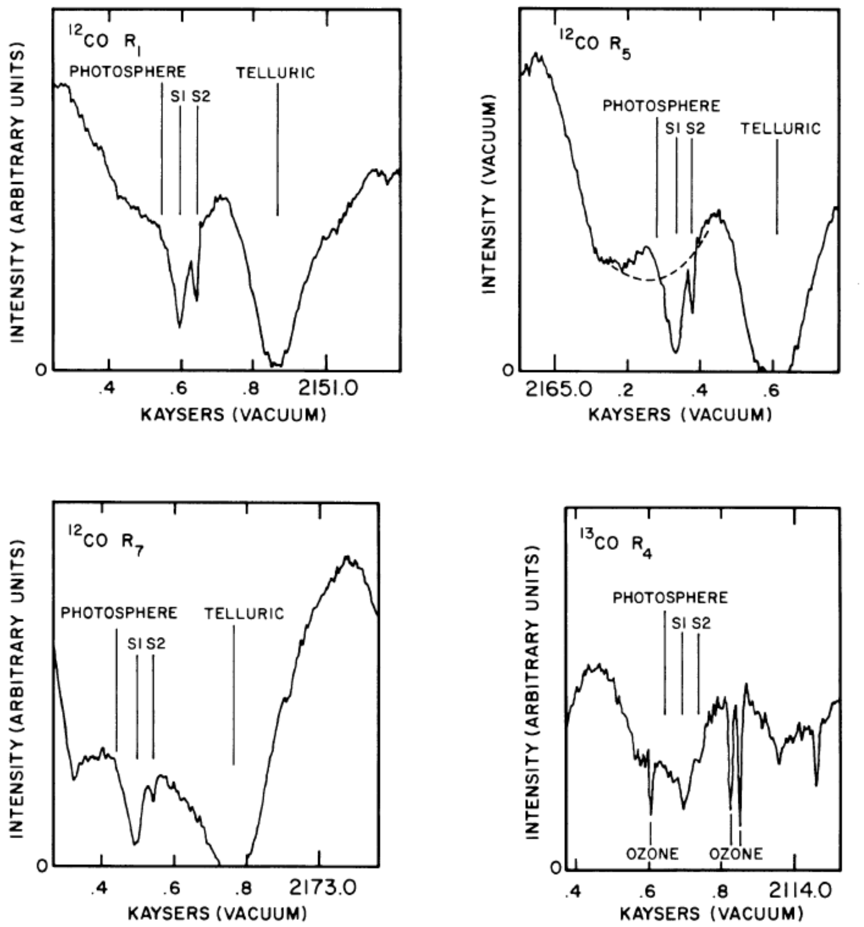
ESO/P. Kervella

CO Molecule $X\ {}^1\Sigma_0^+$

$$E = BJ(J+1) + h\nu_{\mathrm{vib}}(\mathrm{v} + 1/2) + h\nu_{ele}$$

- Rotation: ΔE = 5.5*J* (K) for J->J-1
- n_{crit}~ 1000 cm^{-3} (low-J rotational)
- Vibration: ΔE ~ Δv x 3100 K
- Electronic: ΔE ~ 90,000 K

Bernat et al. 1979, ApJ, 233, L135

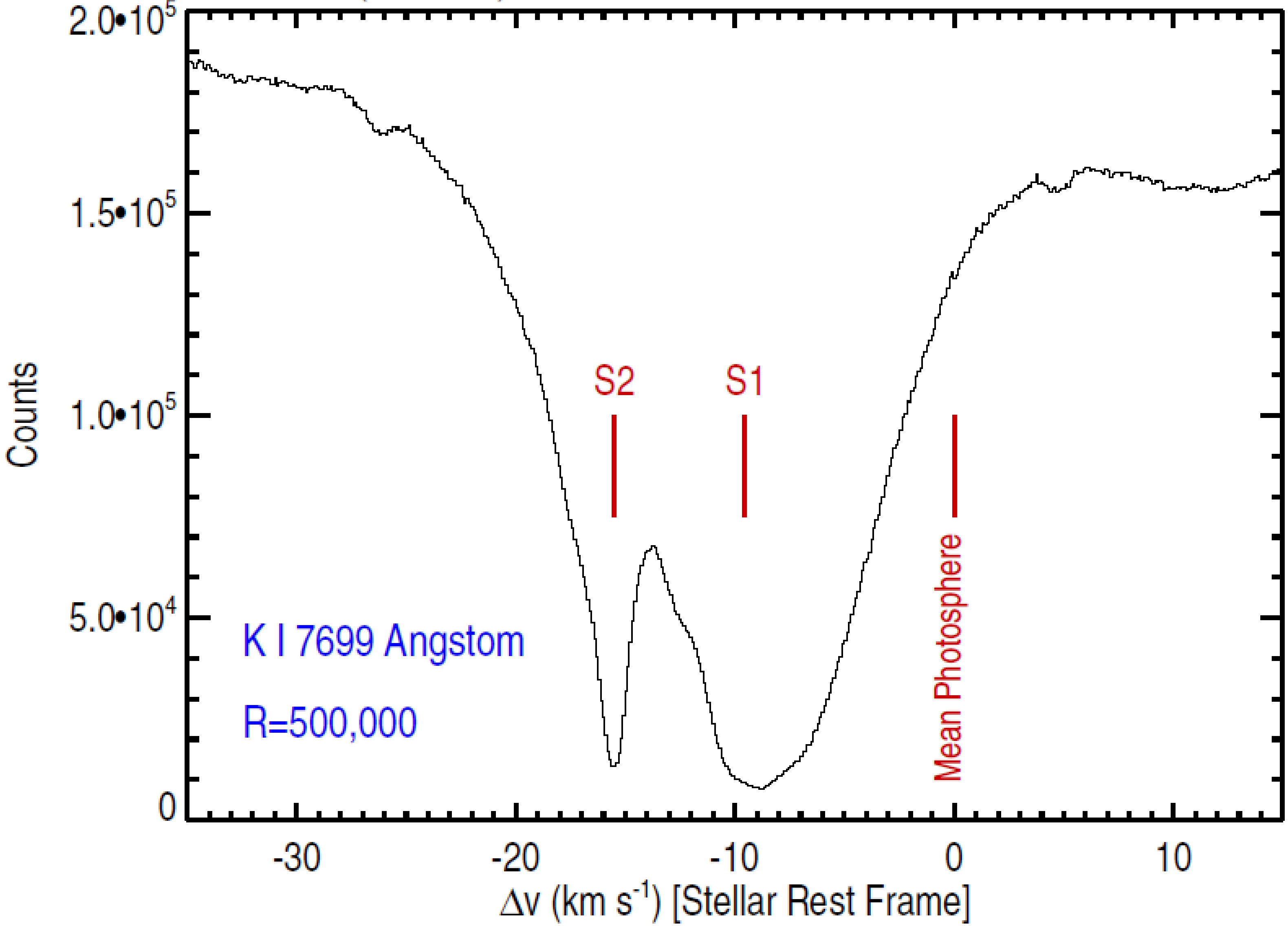


$^{12}C/^{13}C \sim 7$

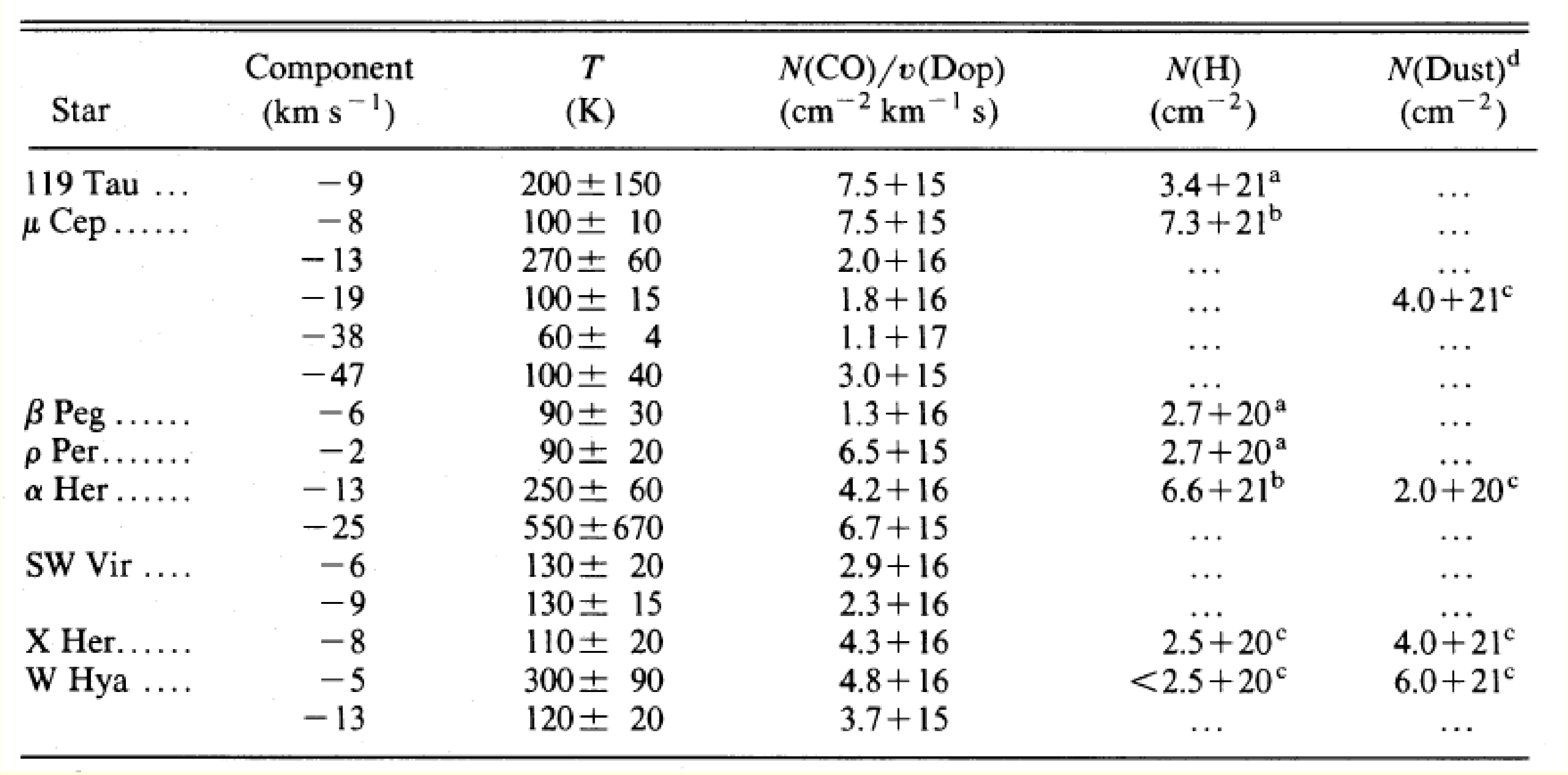
Same as photosphere

Line-of-sight only!

α Ori (M2 Iab) McDonald Obs. Harlan J. Smith 2.7m



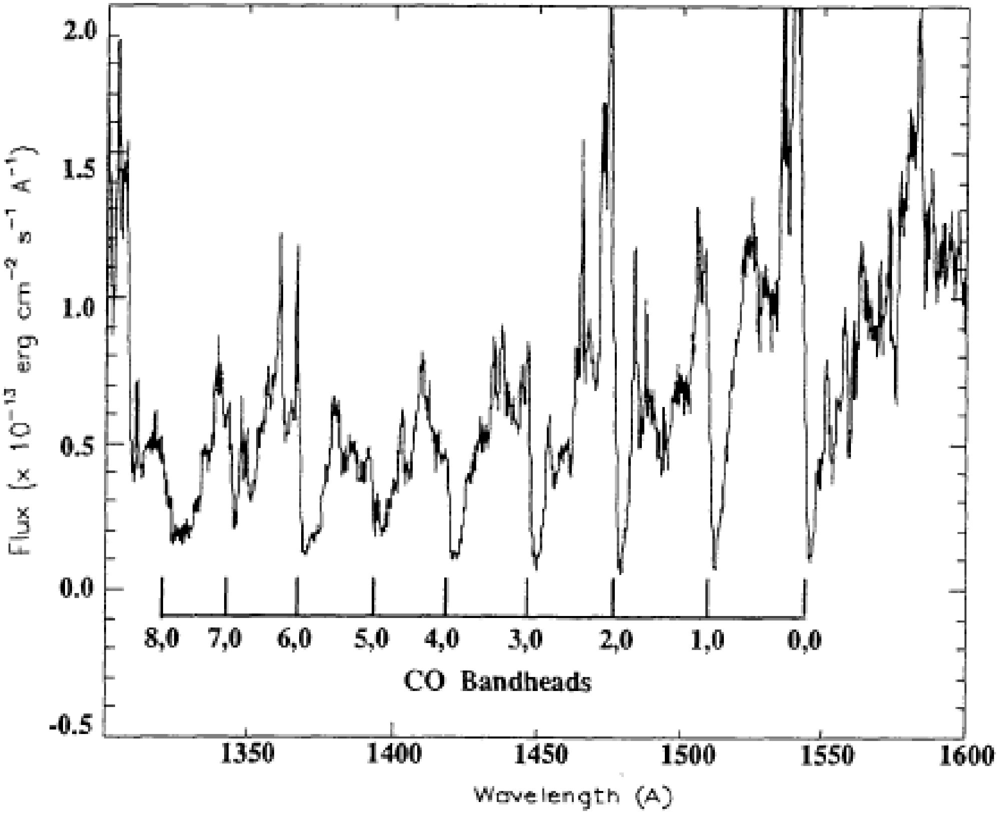
Bernat et al. 1981, ApJ, 246, 184



Star	Component (km s^{-1})	*T* (K)	*N*(CO)/*v*(Dop) (cm^{-2} km^{-1} s)	*N*(H) (cm^{-2})	*N*(Dust)[d] (cm^{-2})
119 Tau	−9	200±150	7.5+15	3.4+21[a]	…
μ Cep	−8	100± 10	7.5+15	7.3+21[b]	…
	−13	270± 60	2.0+16	…	…
	−19	100± 15	1.8+16	…	4.0+21[c]
	−38	60± 4	1.1+17	…	…
	−47	100± 40	3.0+15	…	…
β Peg	−6	90± 30	1.3+16	2.7+20[a]	…
ρ Per	−2	90± 20	6.5+15	2.7+20[a]	…
α Her	−13	250± 60	4.2+16	6.6+21[b]	2.0+20[c]
	−25	550±670	6.7+15	…	…
SW Vir	−6	130± 20	2.9+16	…	…
	−9	130± 15	2.3+16	…	…
X Her	−8	110± 20	4.3+16	2.5+20[c]	4.0+21[c]
W Hya	−5	300± 90	4.8+16	<2.5+20[c]	6.0+21[c]
	−13	120± 20	3.7+15	…	…

Multiple shells found around evolved M stars

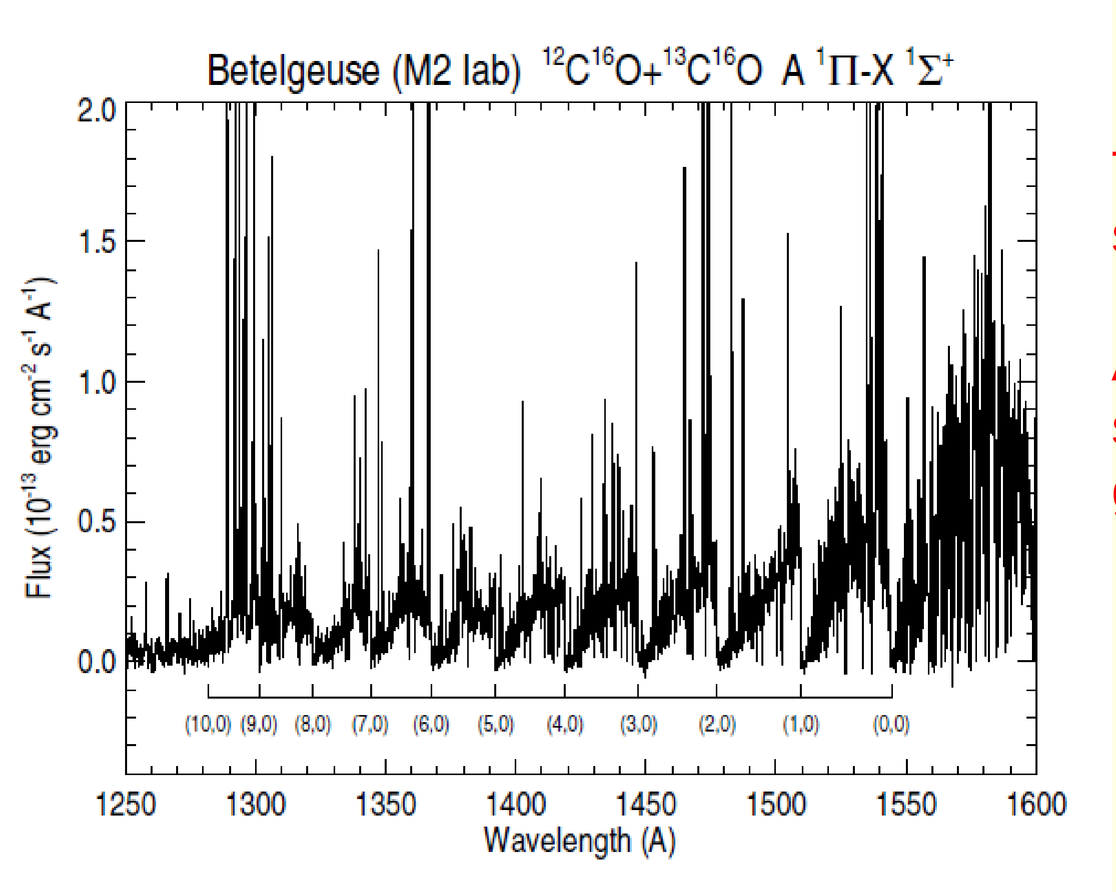
Electronic Fourth Positive System: HST/GHRS



S1 and S2 shells similar to that needed to form UV spectrum

Wahlgren et al. 1992, CS7, ASP Conf. Ser. 26, 37.

Electronic Fourth Positive System: HST/STIS-E140M



This is smoothed – and spikes are real!

Absorption is line-of-sight. Emission is global

Tom Ayres HST Cycle 18 “ASTRAL” project 146 orbits

(1,0) band head: HST/GHRS

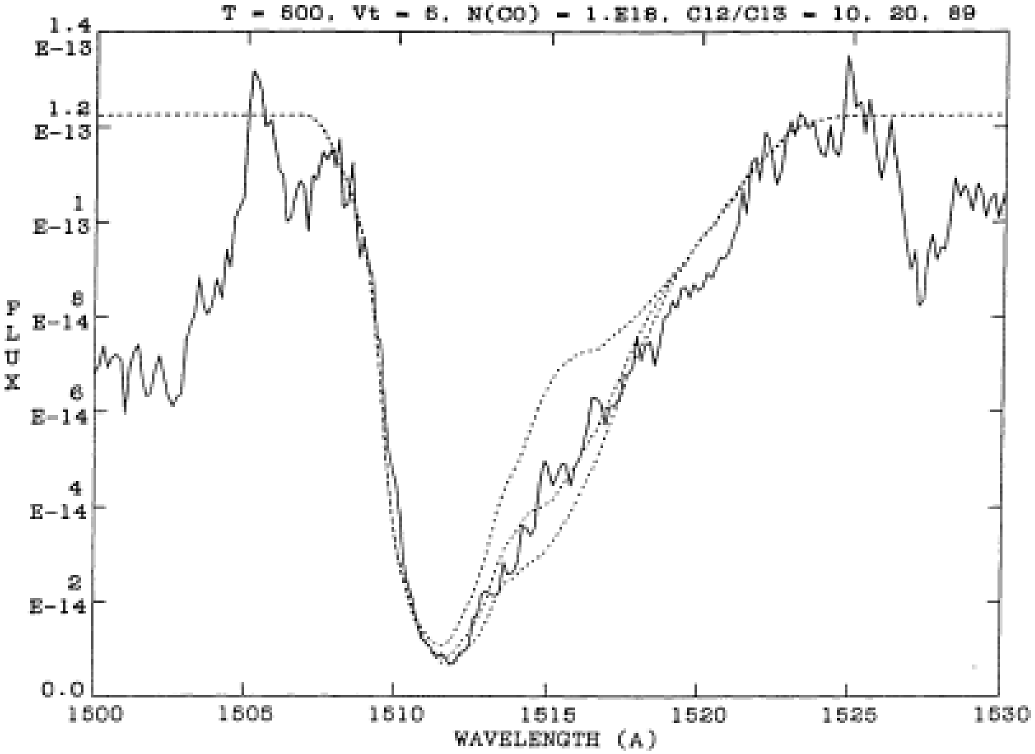
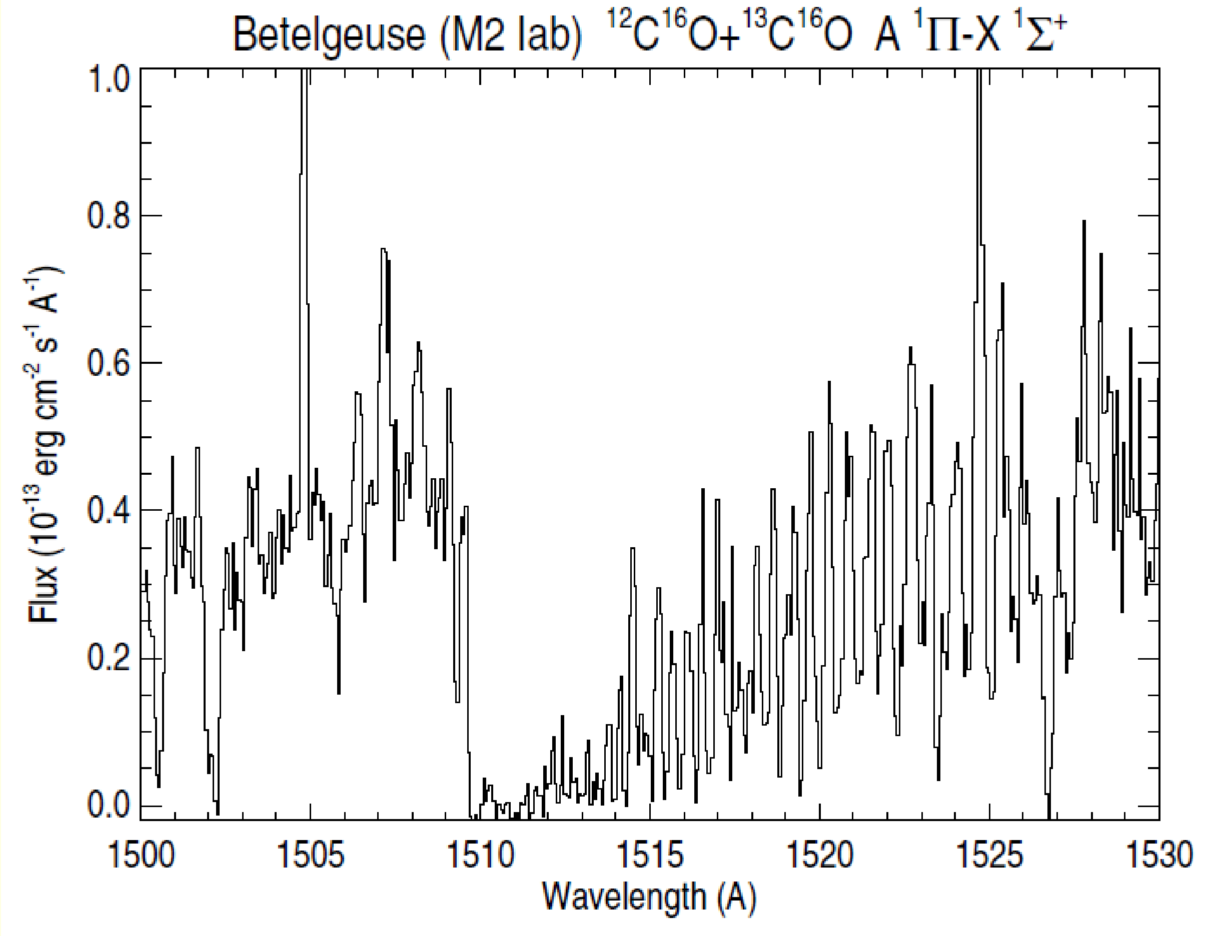


Fig. 2. The observed spectrum (solid) is compared against the best fit slab model (dashed) for, top to bottom, $^{12}C/^{13}C = 89, 20,$ and 10.

Detail reveals by HST/STIS: (1-0) Band

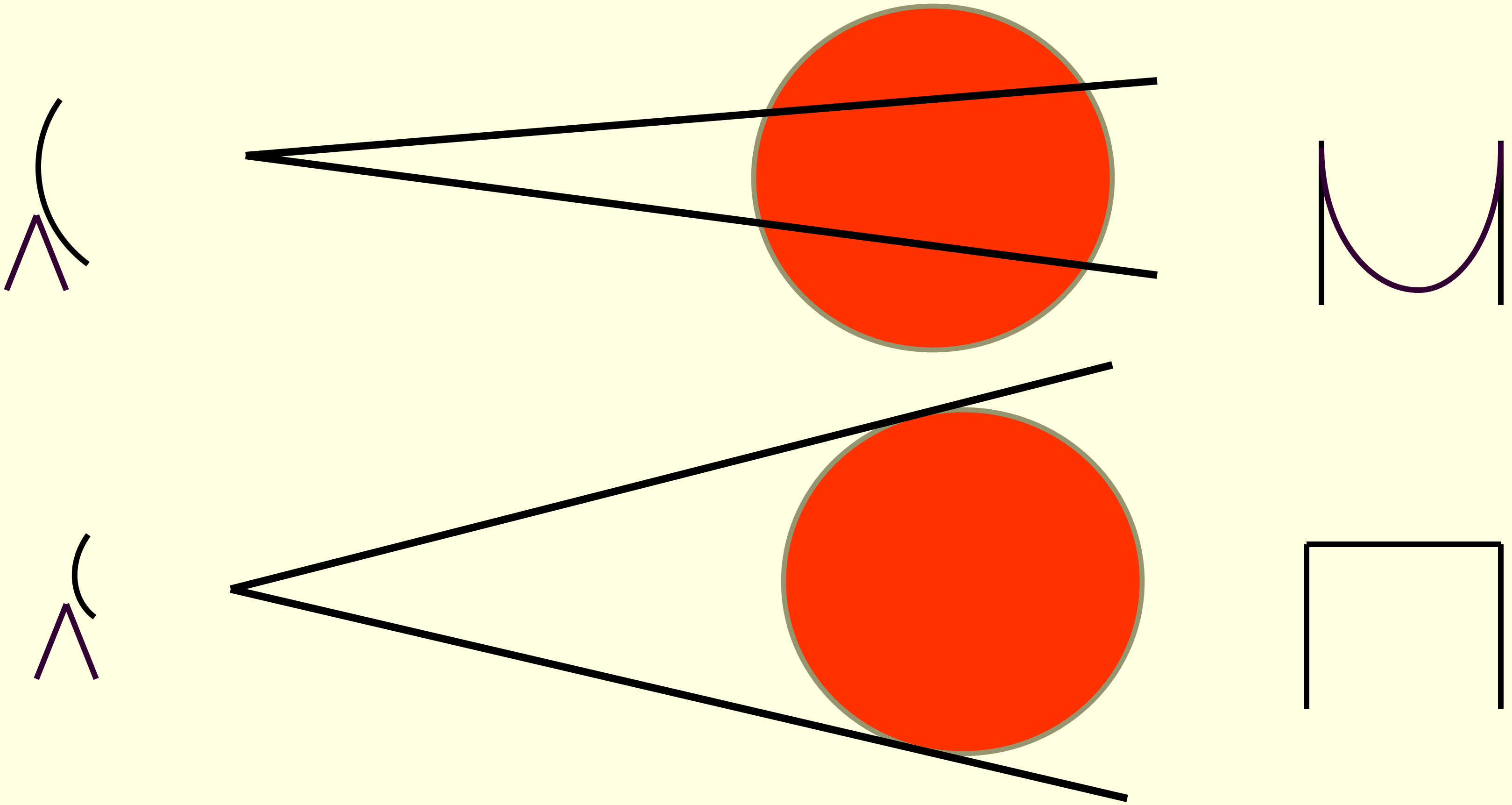


R=30,000
(10 kms-1)

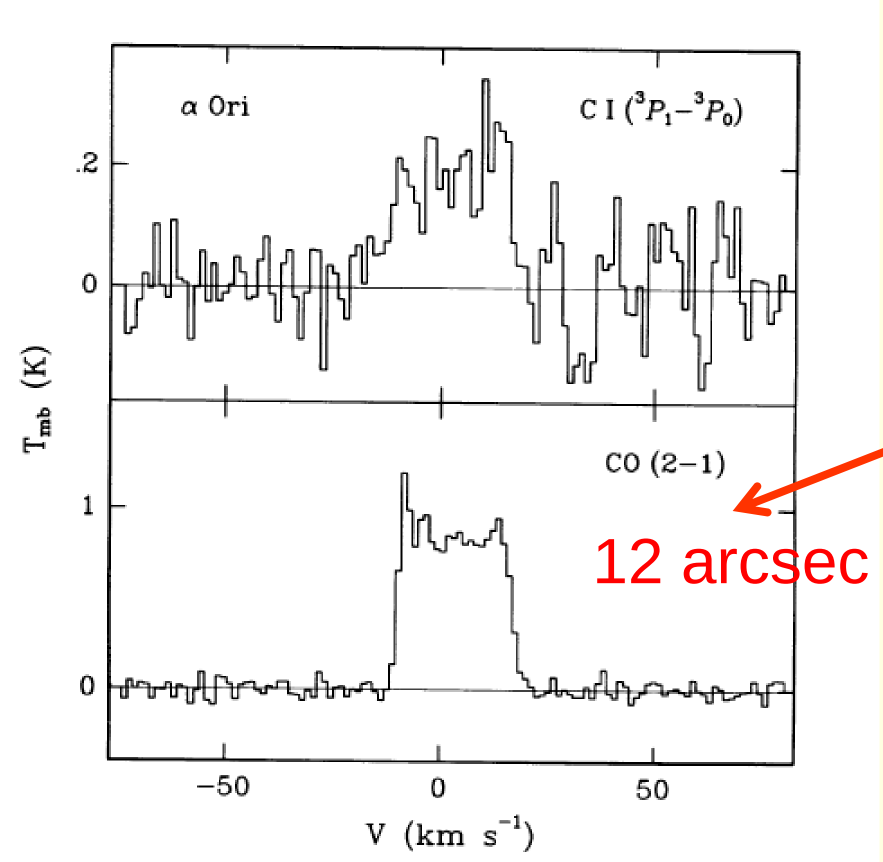
New generation of models - need constraints on S1 and S2 sizes.

R = 4 x 10^4 (8 kms^{-1} FWHM), centroid accuracy 1 kms^{-1}

Riddle of the beams size $\tau < 1$



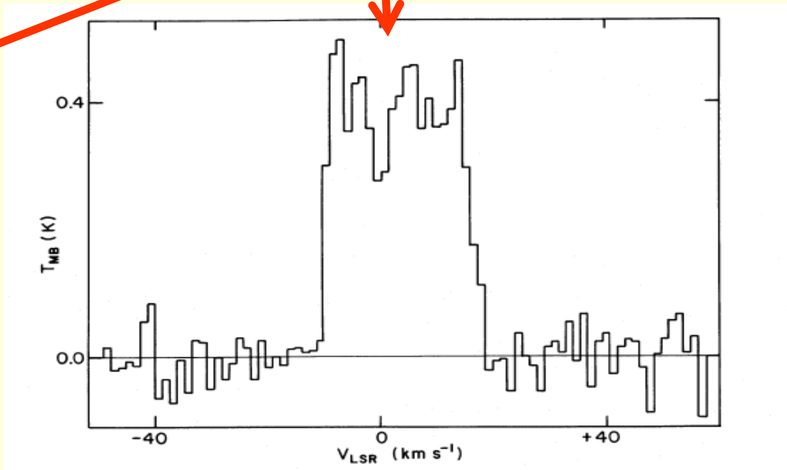
Single Dish: Riddle of the line profiles



Beam size matters (HPBW)

32 arcsec

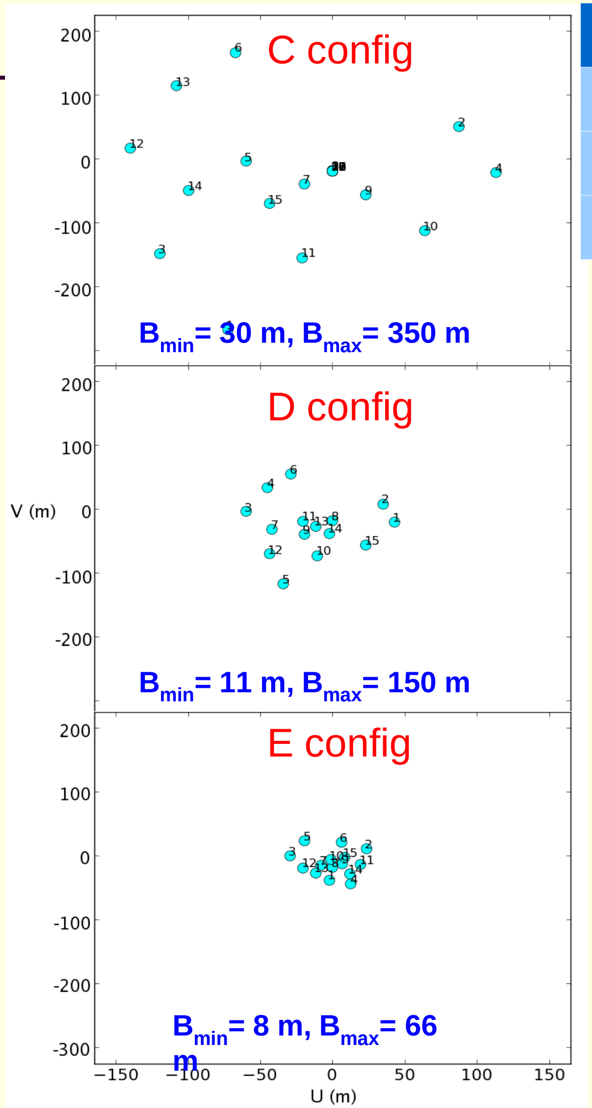
12 arcsec



Huggins, 1987, ApJ, 313, 400, Huggins et al 1994, ApJ, 424, L127

Rotational Transitions: CARMA

CARMA Observations



Date	Config	Tracks	Time (hr)	Resolution (")	Max Scale (")
Jun 07	D	5	9.5	1.8	24.4
Jul 09	E	1	3.25	4.0	33.5
Nov 09	C	5	8.75	0.8	8.9

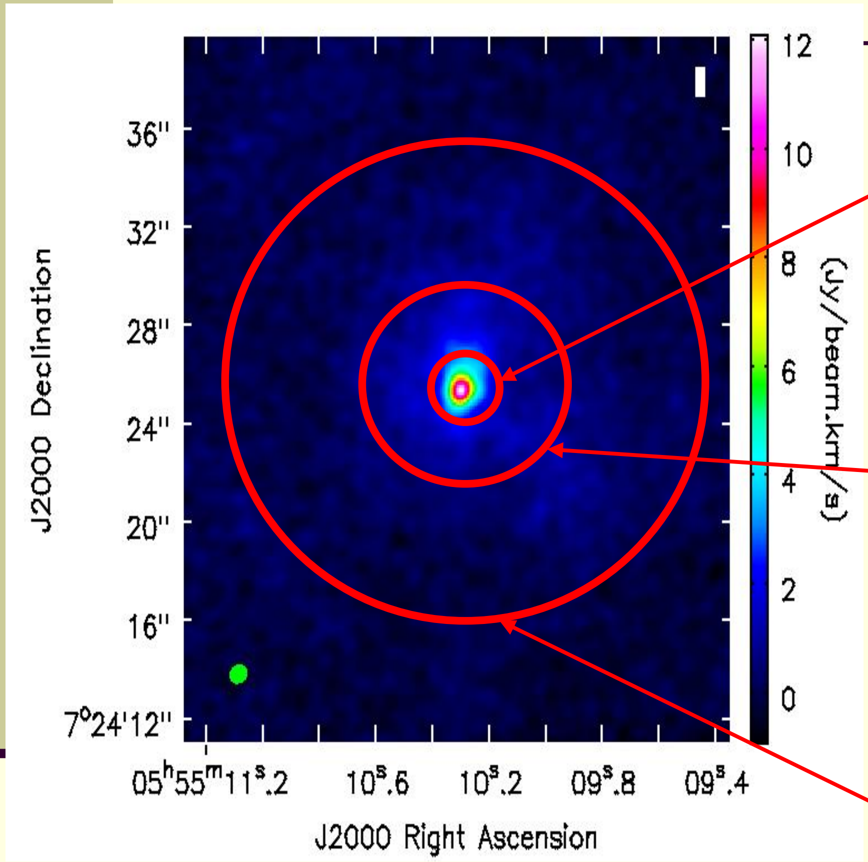
3 separate bands: All centered on line

(1) Maximum bandwidth of 468 MHz (15 channels)

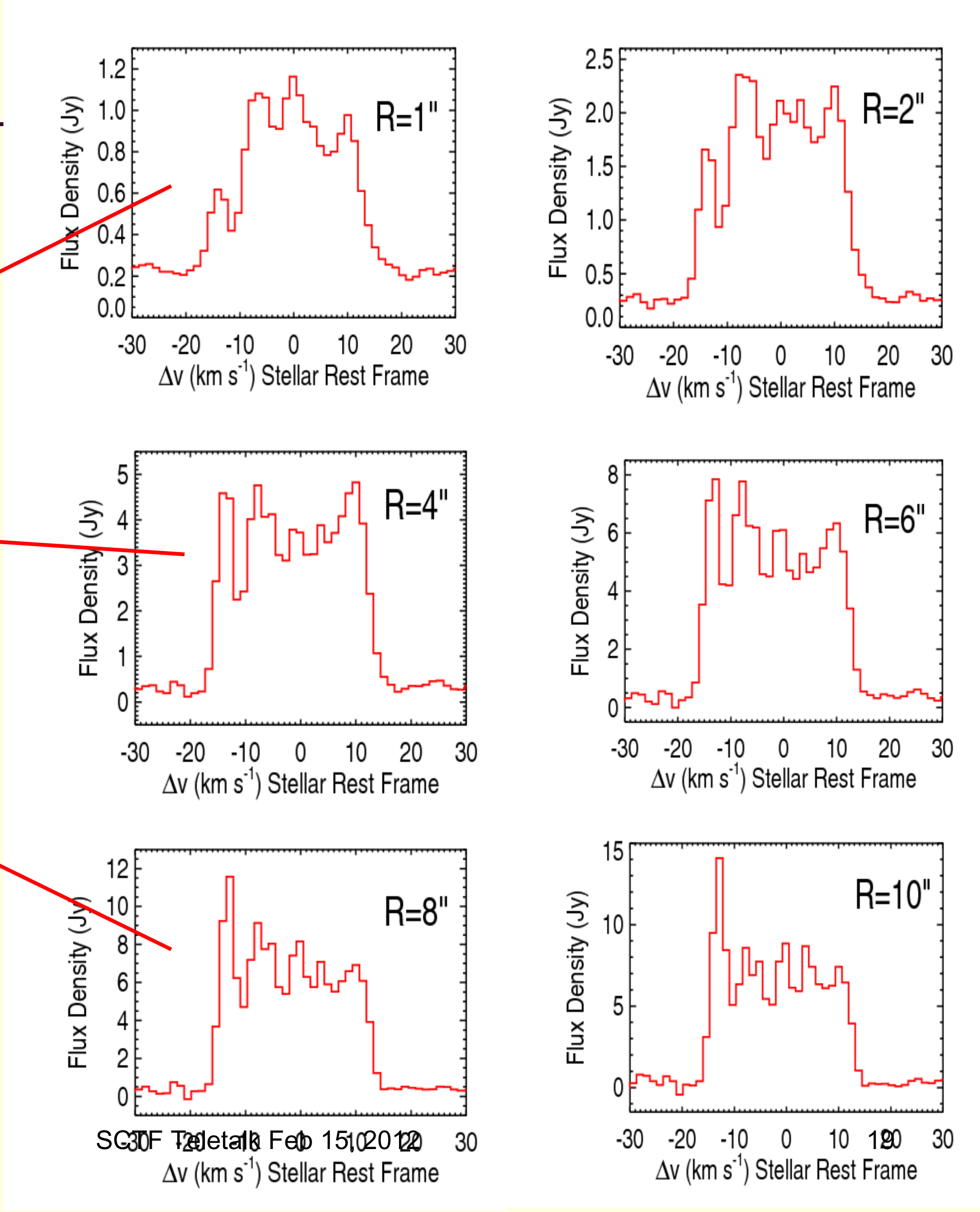
(1) 62 MHz of bandwidth across 63 channels (1 MHz or 1.3 km s^{-1} resolution)

(1) 31 MHz of bandwidth across 63 channels (0.5 MHz or 0.65 km s^{-1} resolution)

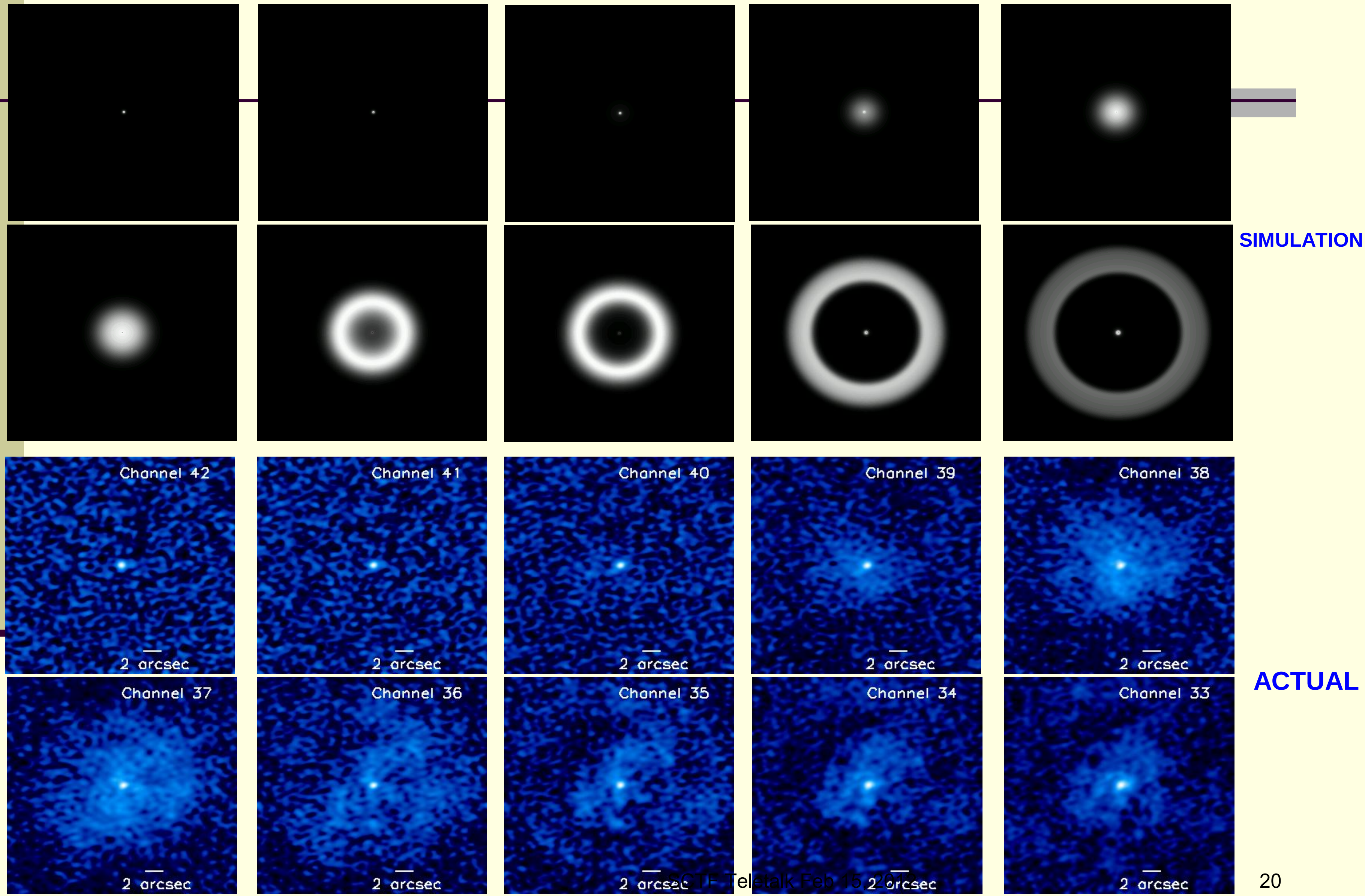
Results: Combined Configurations



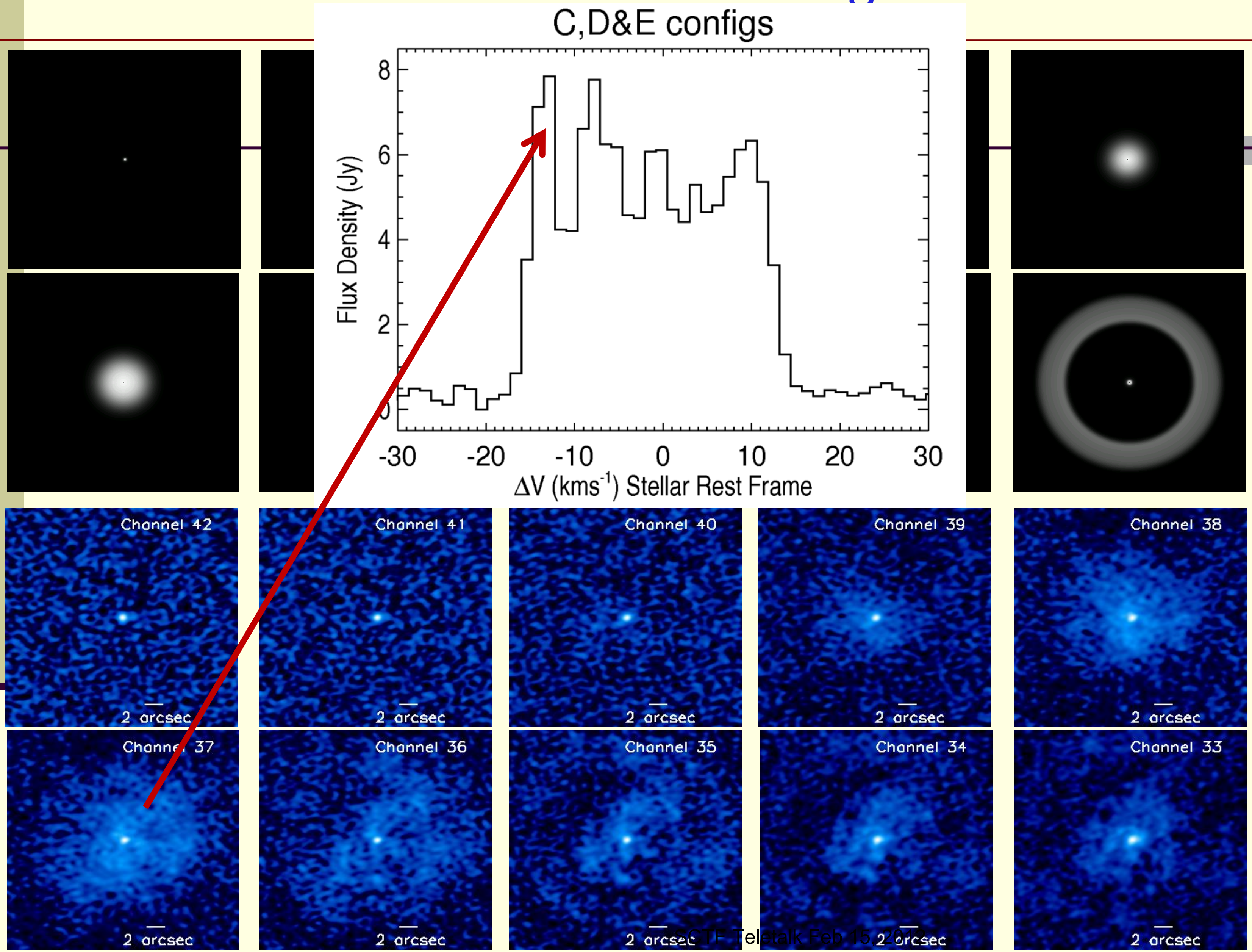
Integrated intensity map



Results: Combined Configurations



Results: Combined Configurations



SIMULATION

ACTUAL

ISO High-J CO rotational lines

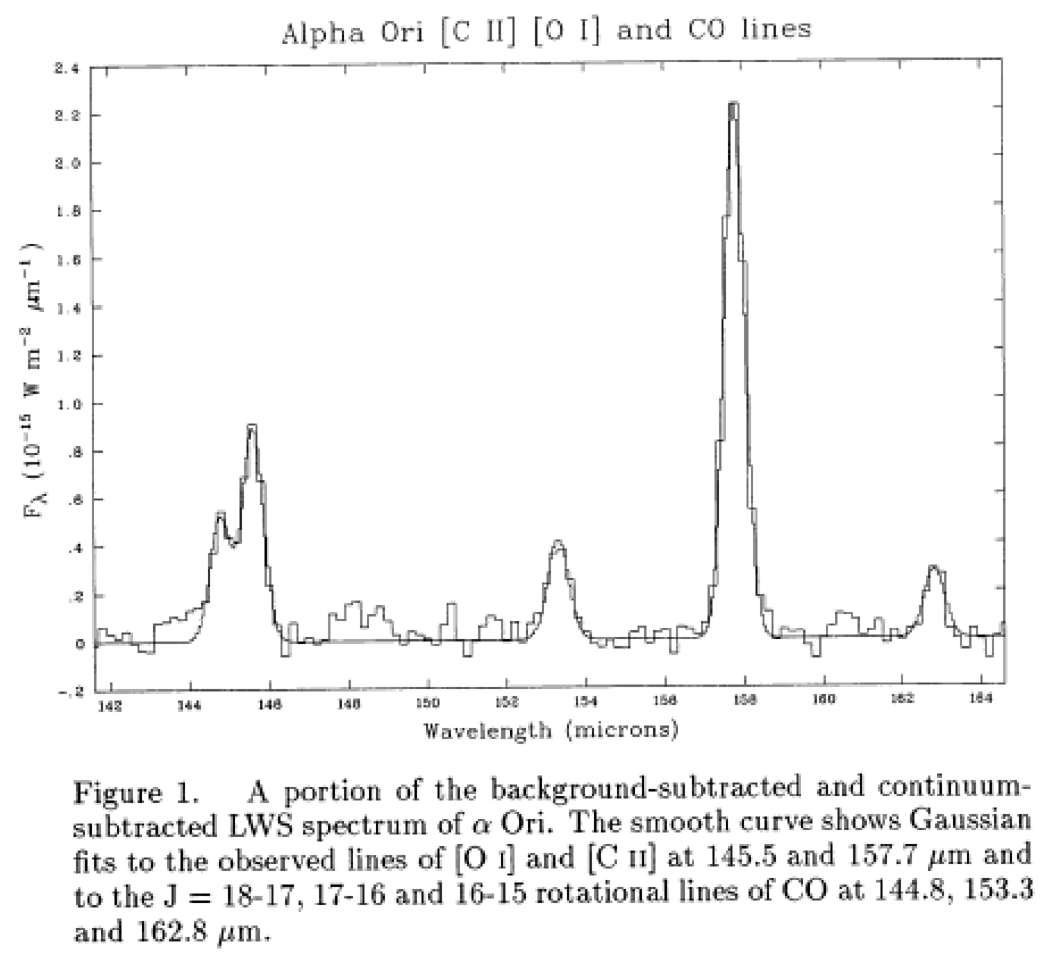


Figure 1. A portion of the background-subtracted and continuum-subtracted LWS spectrum of α Ori. The smooth curve shows Gaussian fits to the observed lines of [O I] and [C II] at 145.5 and 157.7 μm and to the J = 18-17, 17-16 and 16-15 rotational lines of CO at 144.8, 153.3 and 162.8 μm.

M. J. Barlow,
1999, IAUS 191, 353

(obtained 2 days before the end of ISO mission)

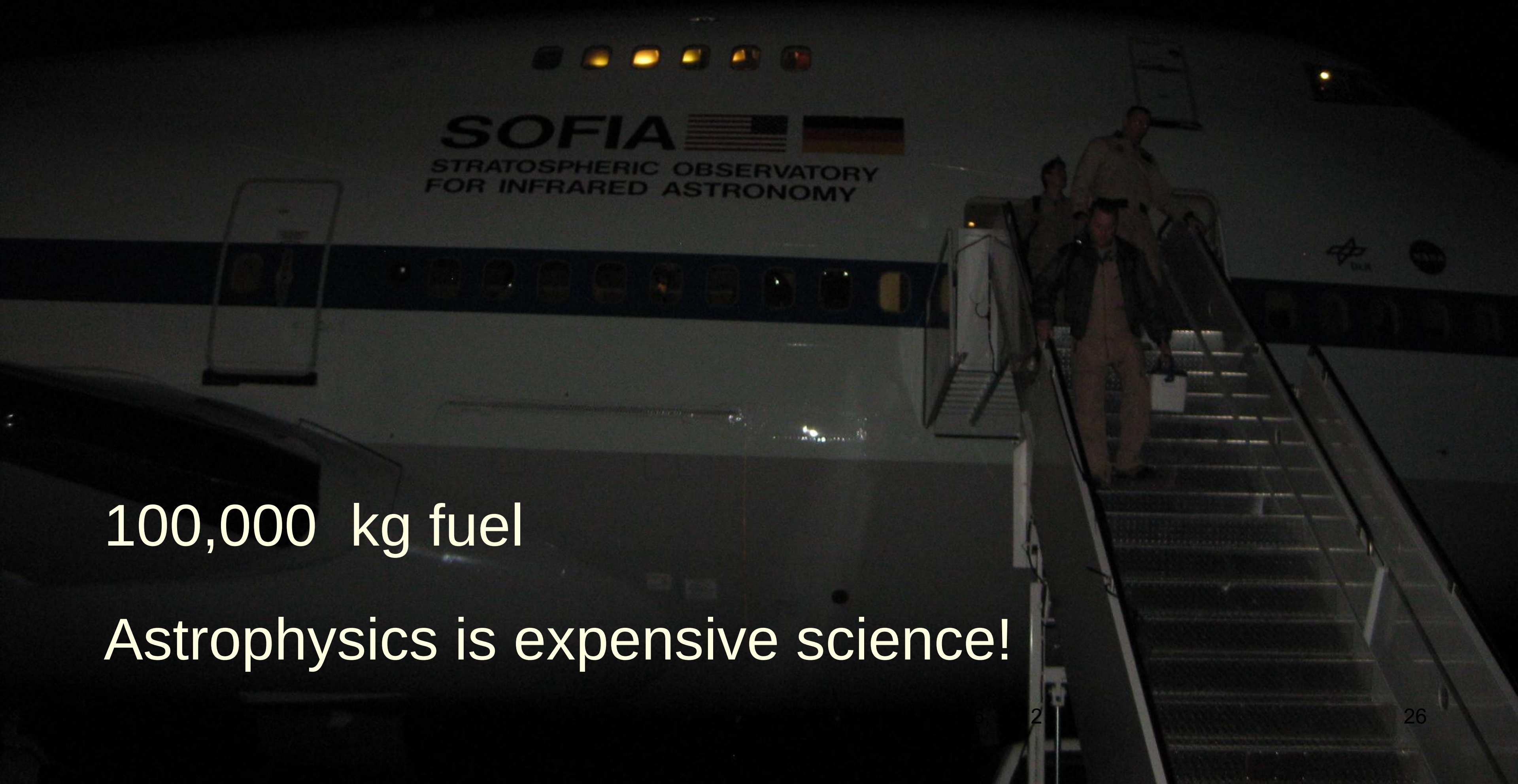
SOFIA 747-SP (43,000 feet)

German REceiver for Astronomy at Terahertz Frequencies

PI Dr. Rolf Güsten (Max-Planck-Institut für Radioastronomie, Bonn)

Observe high-J CO rotational lines J>11

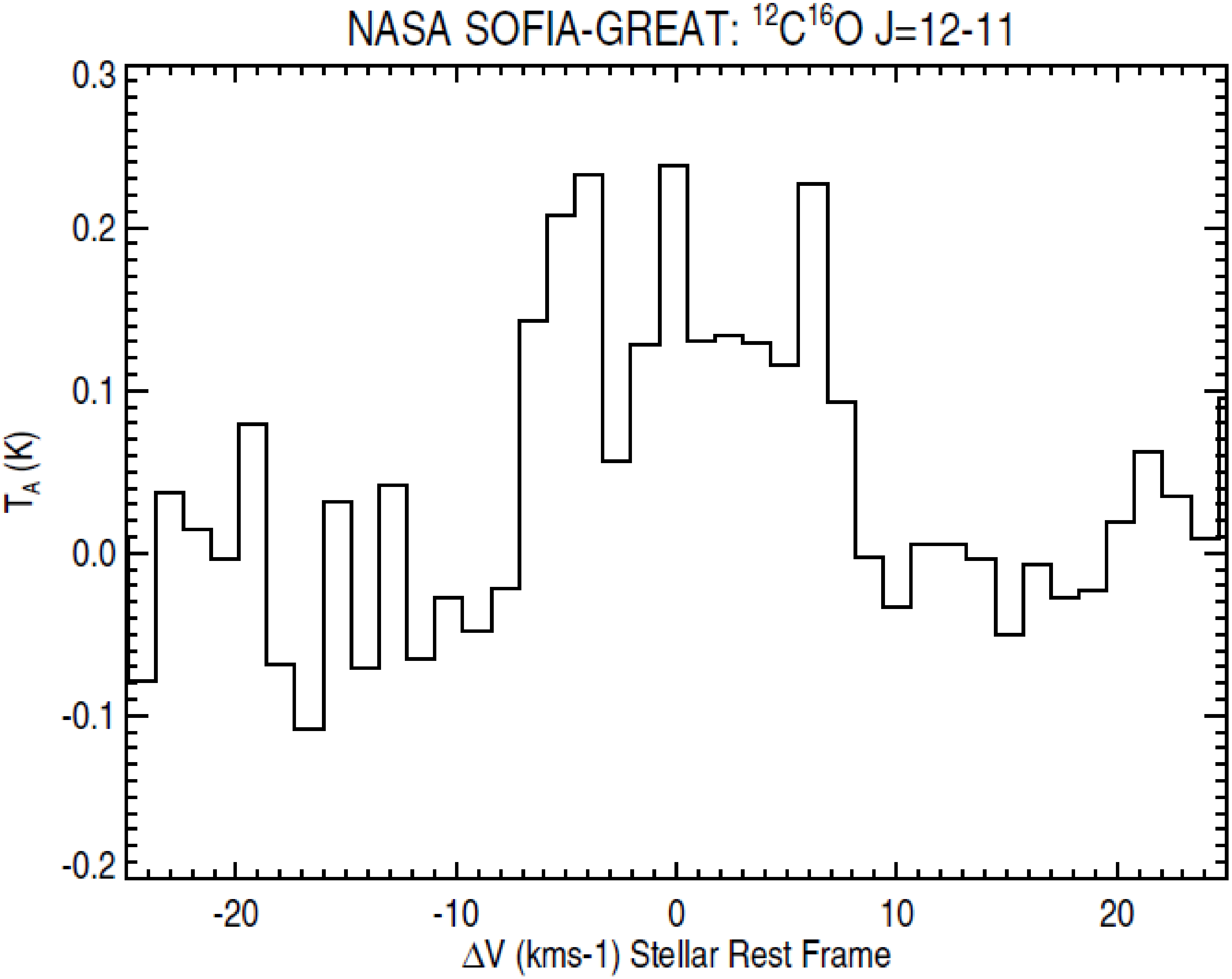
REBOOT



100,000 kg fuel

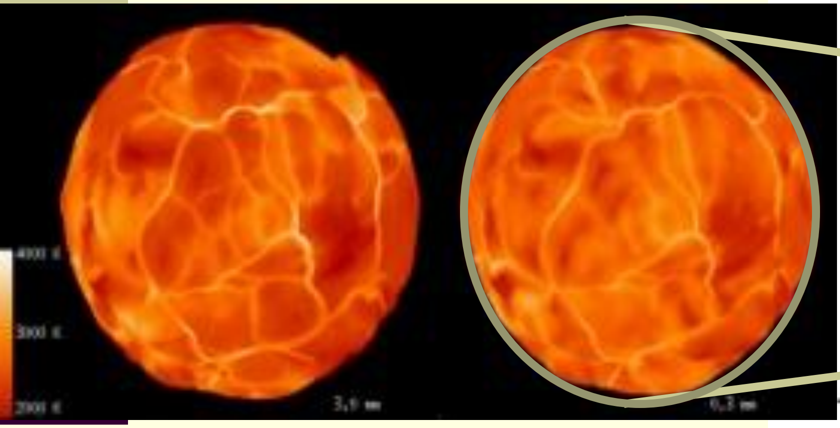
Astrophysics is expensive science!

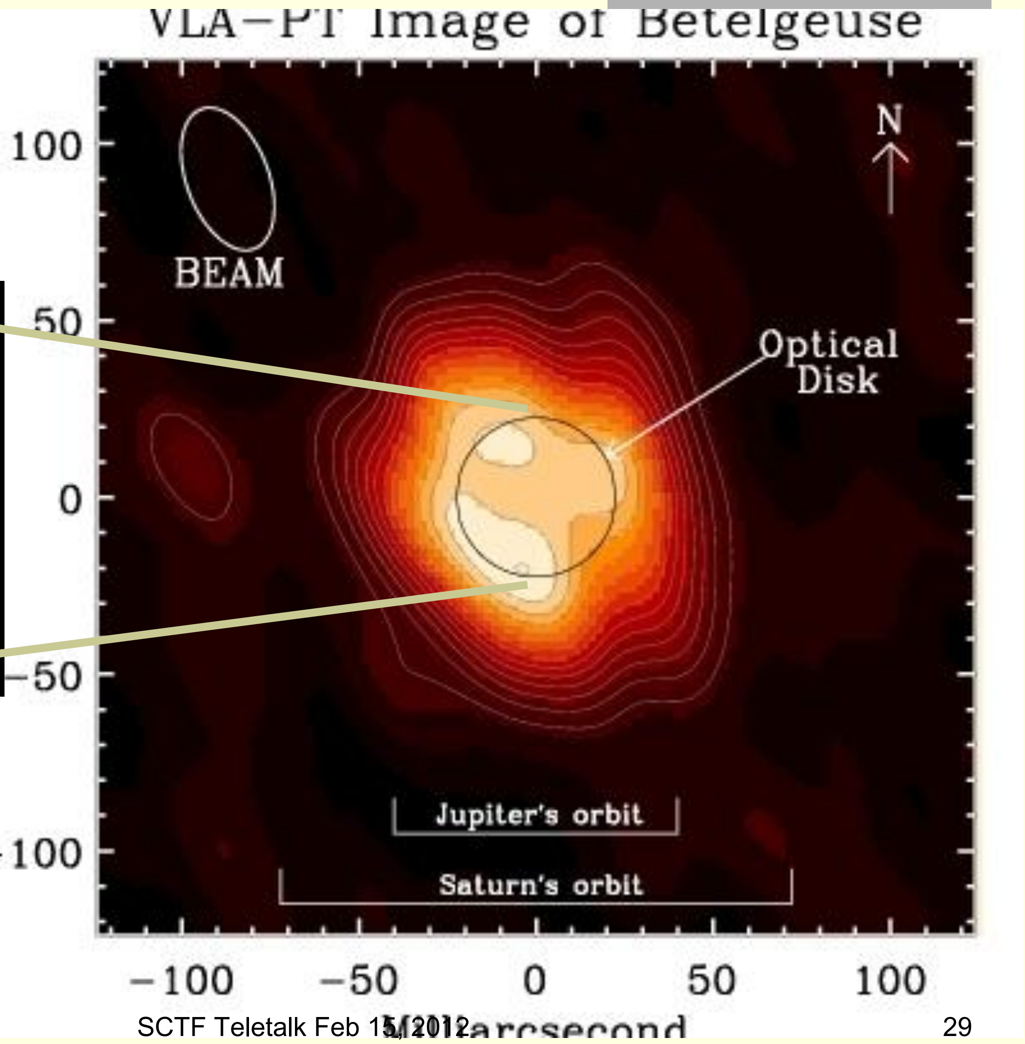
Line profile is narrow indicative of the
S1 high excitation component




SOFIA
STRATOSPHERIC OBSERVATORY
FOR INFRARED ASTRONOMY
TRINITY COLLEGE
15 92
DUBLIN

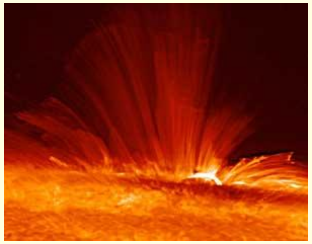
Star-in-Box Simulations (B. Freytag)

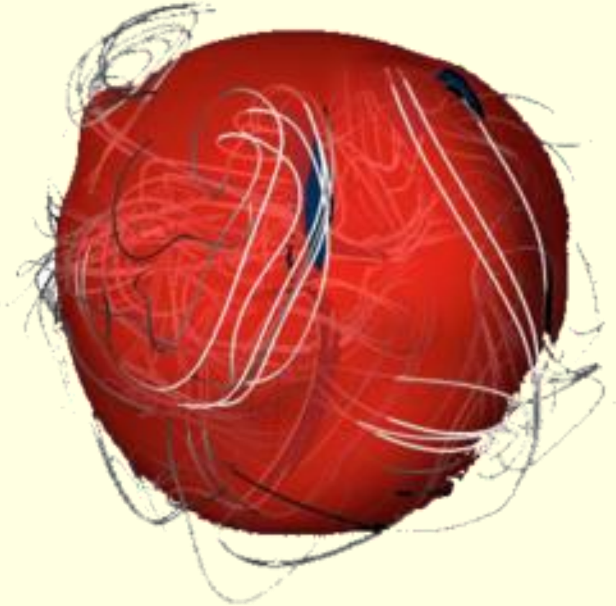




- Star-in-Box Simulations do not track matter leaving star

Wave-driven winds?



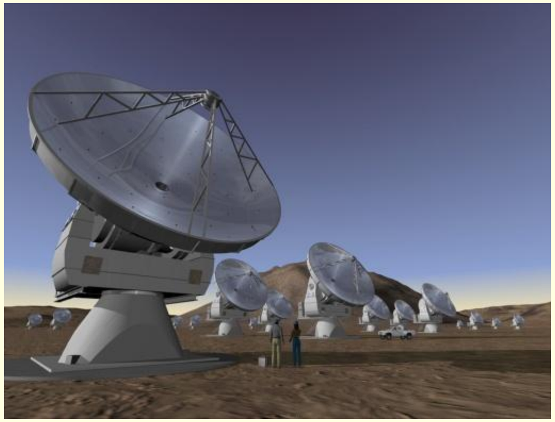


Bernd Freytag: star-in-a-box 3D RH. S. Bertil Dorch (2004 A&A, 423,1101)

For wave-driven winds …
(wave energy flux = F_{wind})

- $F_{wind} \sim C\rho <v^2> v_{prop}$
- C ~ O(1)
- $<v> \sim 11$ kms^{-1}
- ρ (density) from model
- $v_{prop} = 5\text{-}10$ kms^{-1}
- Alfvén, Fast-MHD $v_{prop} = B/\sqrt{4\pi\rho}$
- B ~ 1-10 Gauss
- Wave damping must be different
  - geometry (diverging)
  - damping rates (mag^{n}s)

Atacama Large Millimeter Array (ALMA)



- 5000m Chajnantor plain of the Chilean Andes
- 54 @12m + 12 @ 7m antennae
- 100-950 GHz (0.3 -0.03 cm)
- Max baseline 16 km = spatial resolution ~8 mas
- Resolve chromosphere at 5x higher resolution
  - 10 beams across photosphere

Thank you for listening