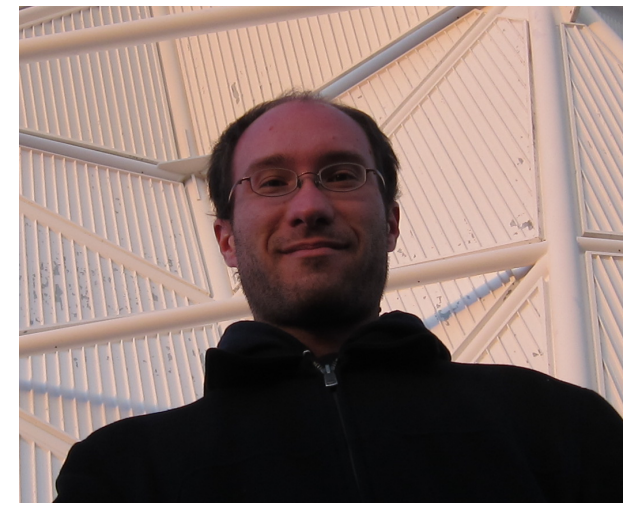
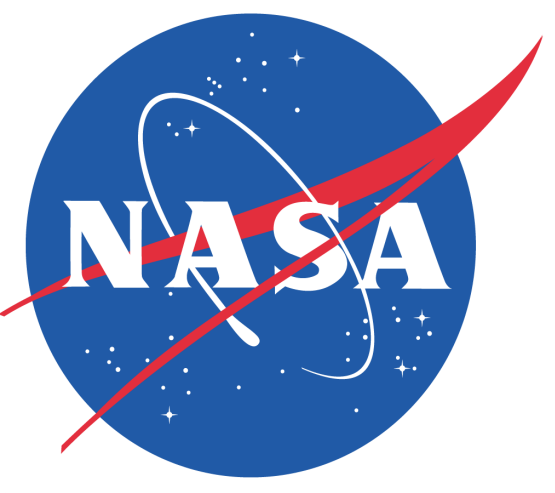


WARM, DENSE GAS NEAR THE MASSIVE PROTOSTARS AFGL 2136 AND AFGL 4176 REVEALED BY WATER ABSORPTION



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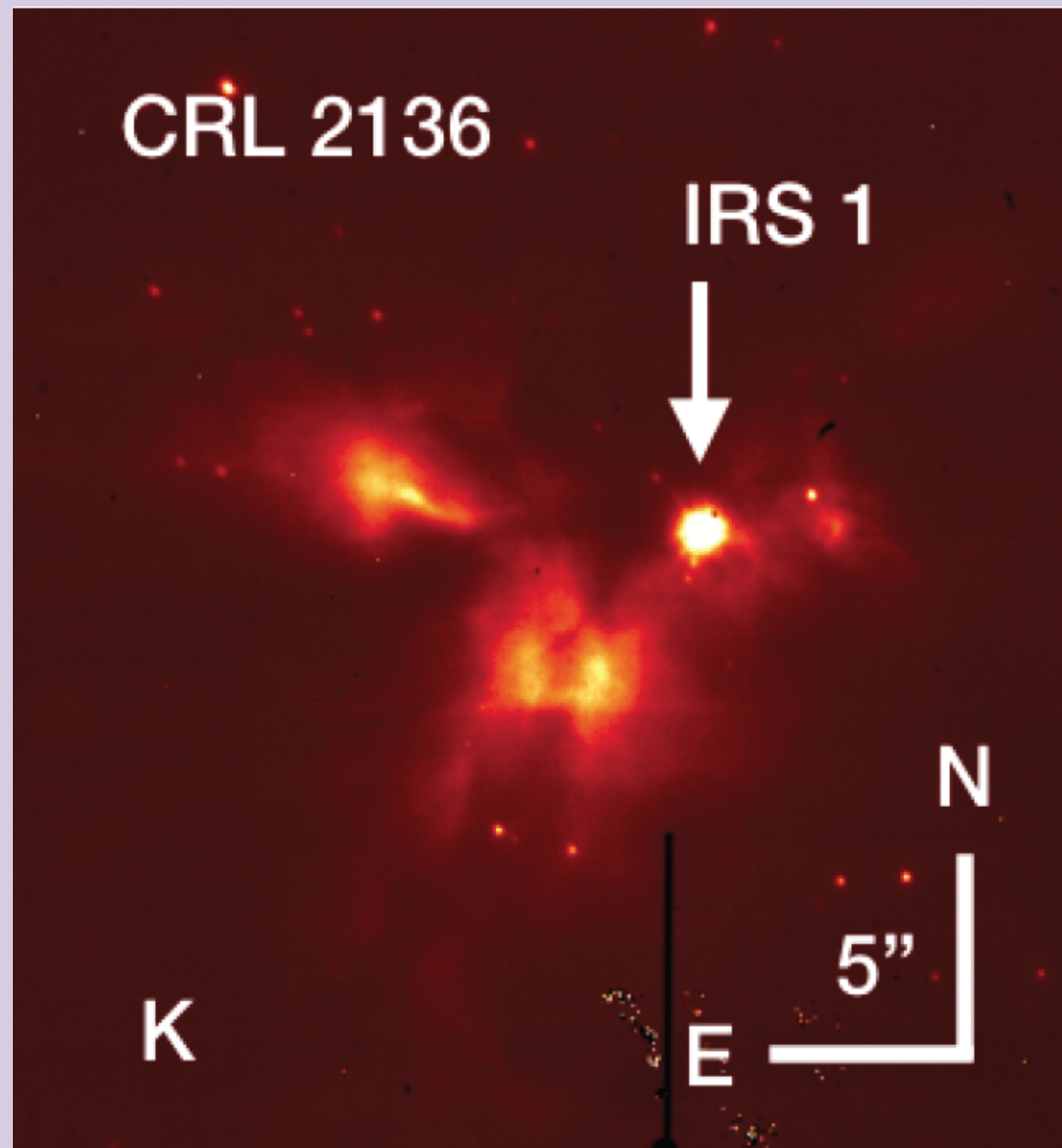


Data presented herein were obtained using CRIRES at VLT through the programs 089.C-0321 and 091.C-0335. Results on AFGL 2136 IRS 1 are presented in Indriolo, Neufeld, Seifahrt, & Richter 2013 (submitted to ApJ)

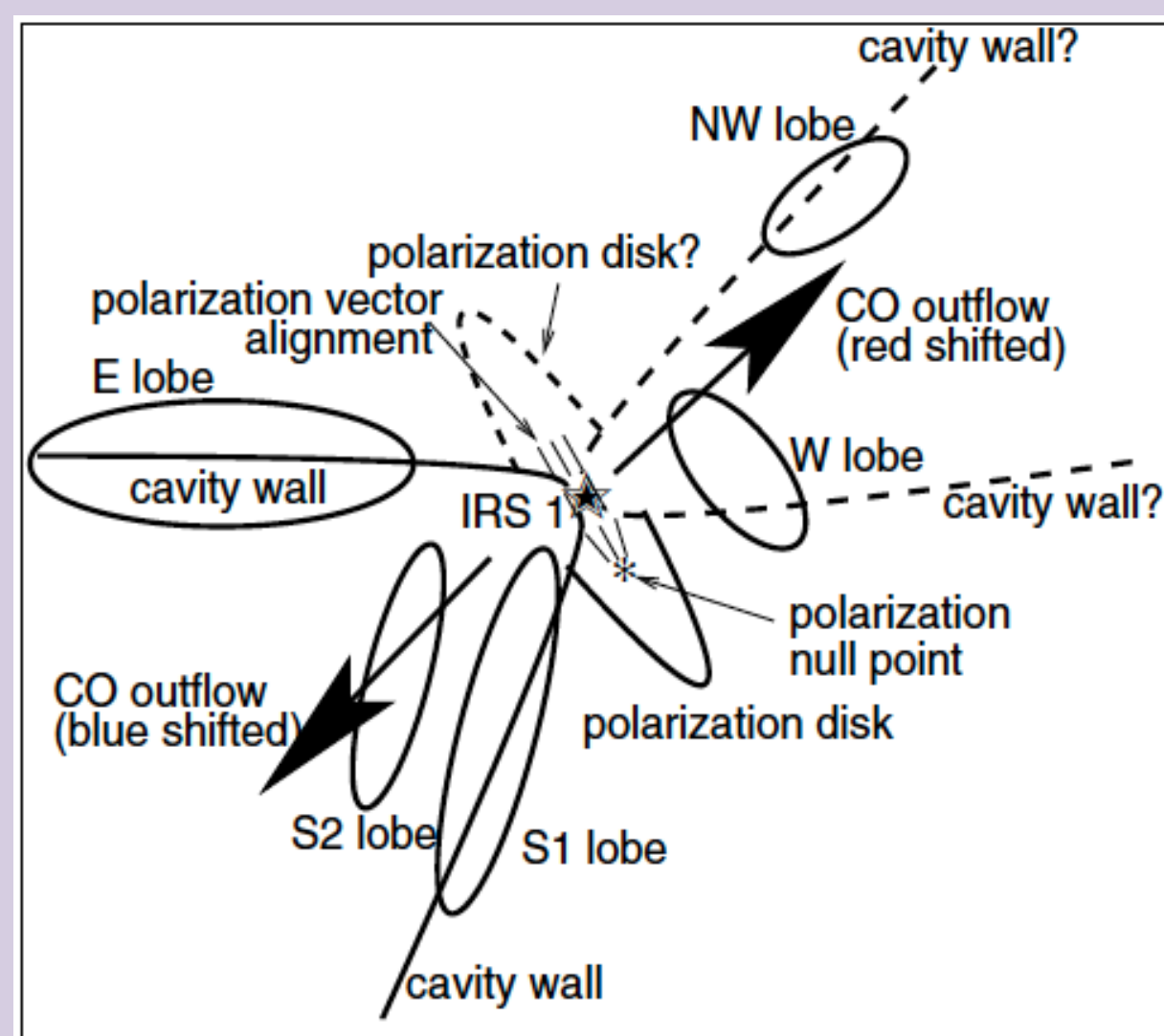
Funded by NASA Research Support Agreement 1393741 provided through JPL

The AFGL 2136 Region

Left: Adaptive optics image in K-band taken at the Subaru Telescope.



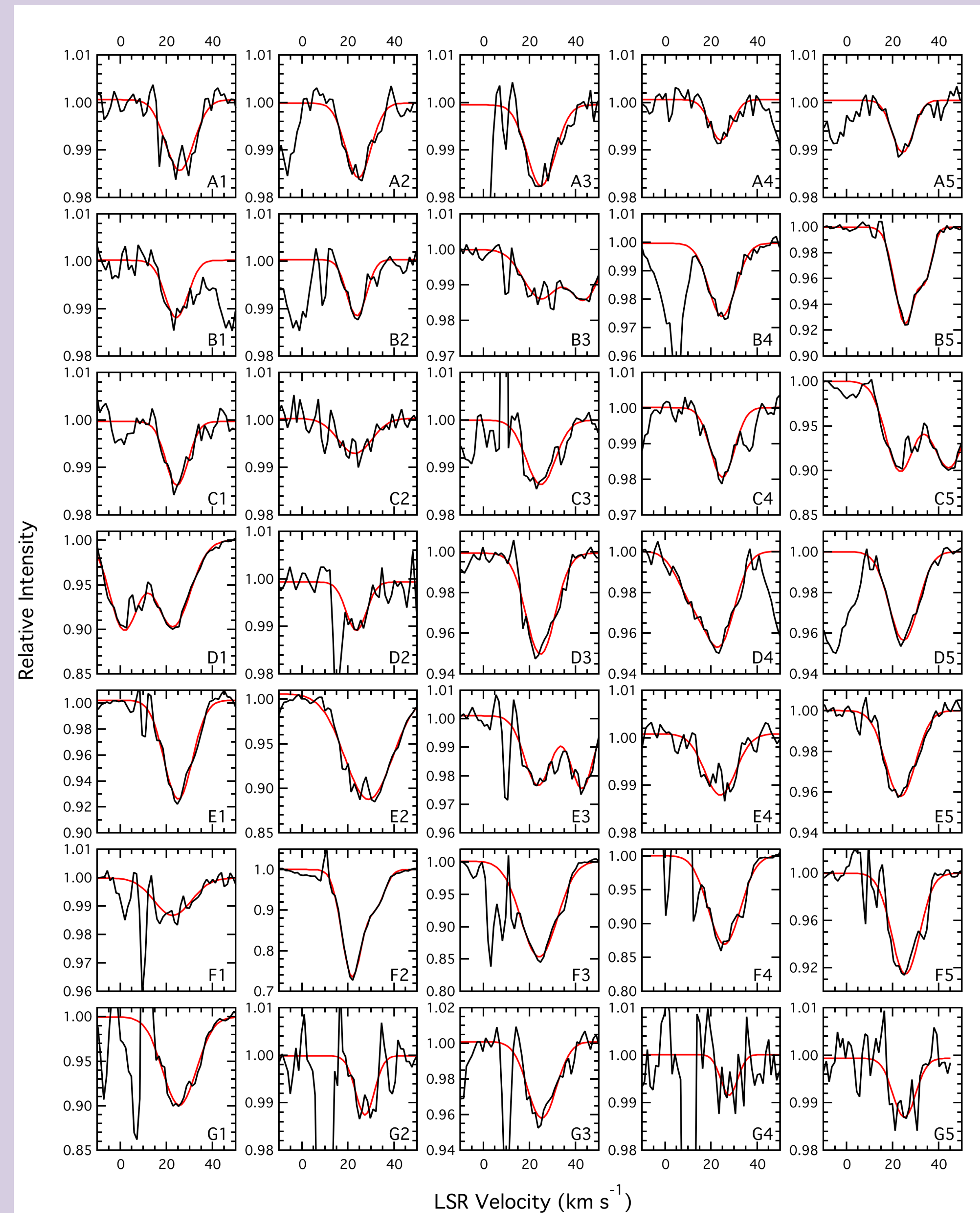
Right: Cartoon schematic of region



Murakawa et al. 2008

The central protostar (IRS 1) is likely driving a bipolar outflow. A disk and/or torus surrounds the protostar and is inclined about 40° with respect to edge-on (Kastner et al 1994; de Wit et al. 2011). A cold foreground cloud is observed in CO, CS, and H_2CO emission at $v=22.8 \text{ km s}^{-1}$ LSR (van der Tak et al. 2000). Warm, dense gas observed in ^{13}CO absorption (Mitchell et al 1990) and 22 GHz H_2O maser emission (Menten & van der Tak 2004) is seen at $v=27 \text{ km s}^{-1}$ LSR.

Water Absorption Lines in AFGL 2136

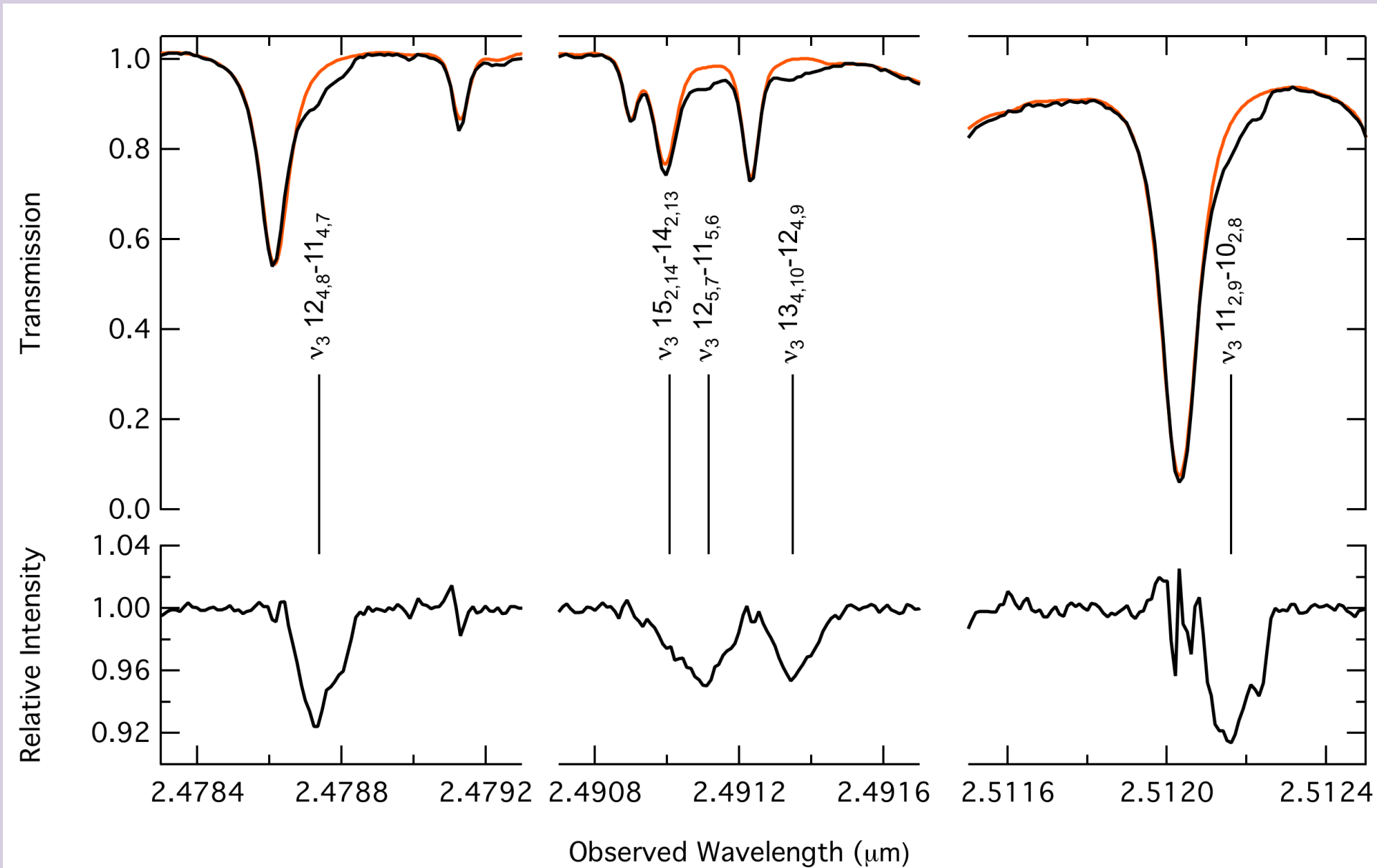


We find 35 absorption features due to 47 different transitions of the v_1 and v_3 bands of H_2O (see attached handout for labels). Mean FWHM=13.6 km s^{-1} , and mean velocity=24.6 km s^{-1} .

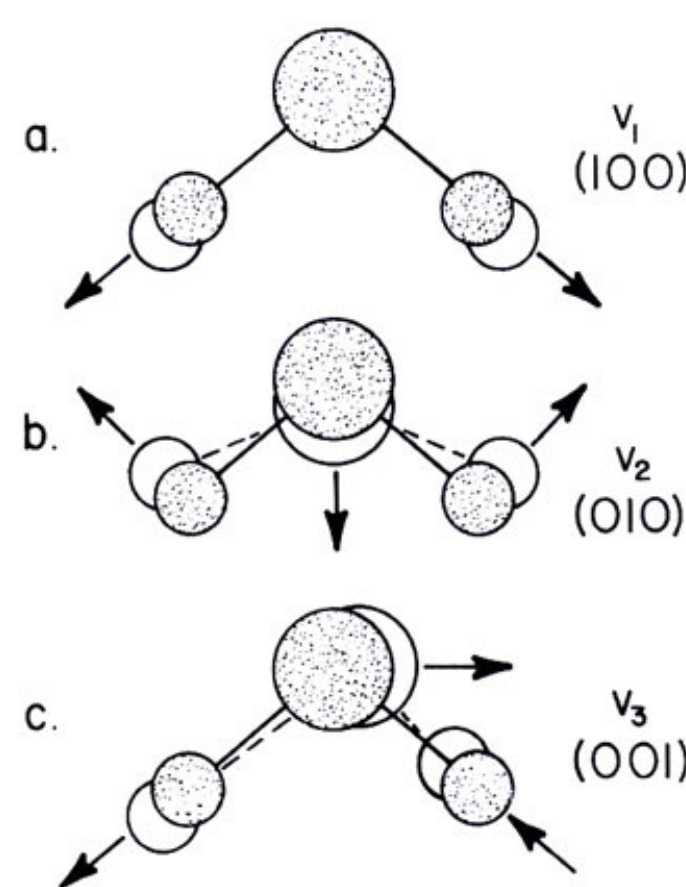
Observations

- CRIRES at VLT provides $\sim 3 \text{ km s}^{-1}$ spectral resolution in the NIR
- Continuum level S/N \sim 500 achieved in 66 min. exposure time
- Wavelength coverage 2.468–2.561 μm with gaps between detectors
- Covers several transitions from v_1 and v_3 ro-vibrational H_2O bands

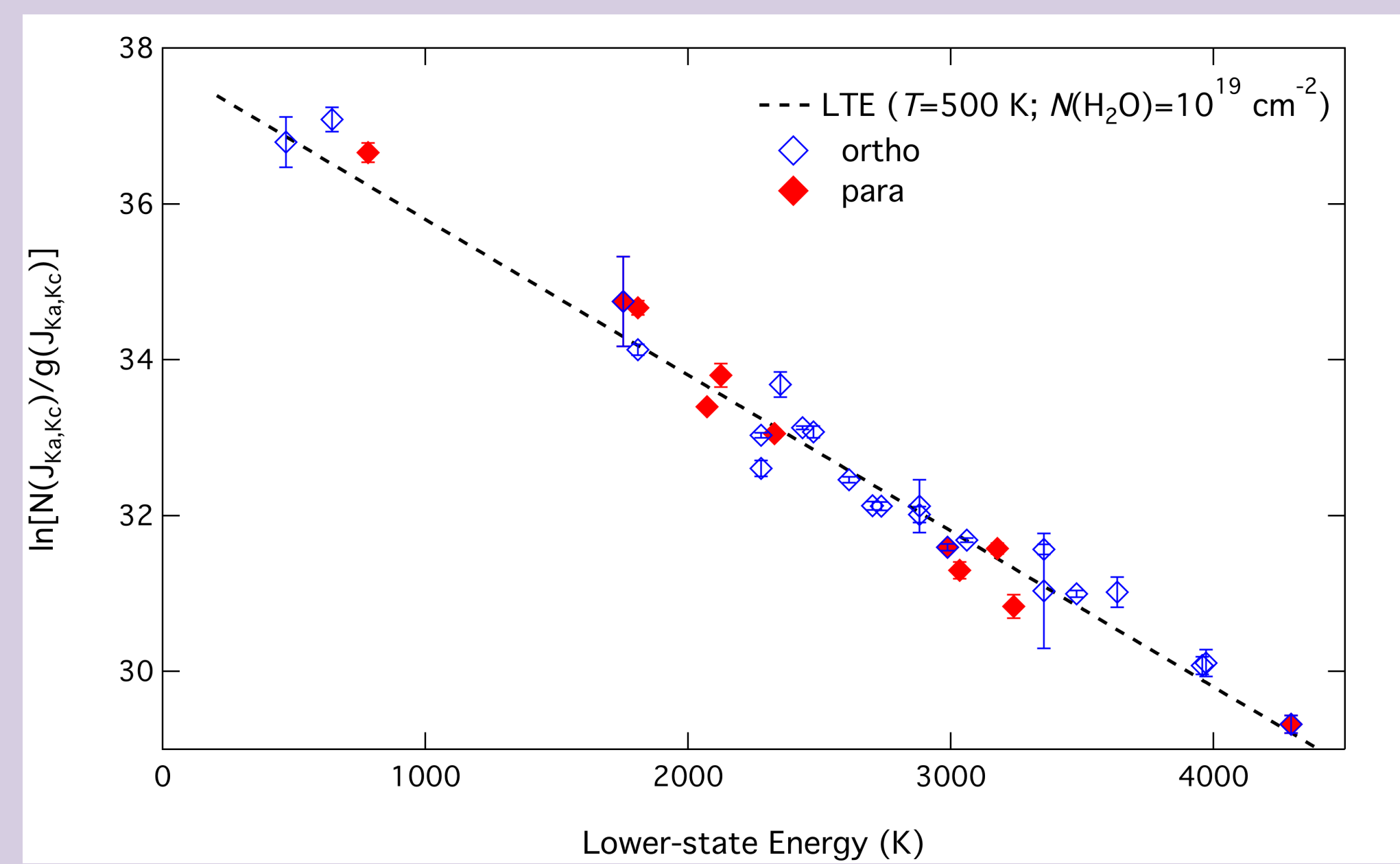
Science and Model Atmospheric Spectra



Top: Science spectra (black) and model atmospheric spectra (orange). Astrophysical absorption is seen at +15 km s^{-1} with respect to atmospheric lines. **Bottom:** Ratio between science and atmospheric model spectra showing H_2O absorption.

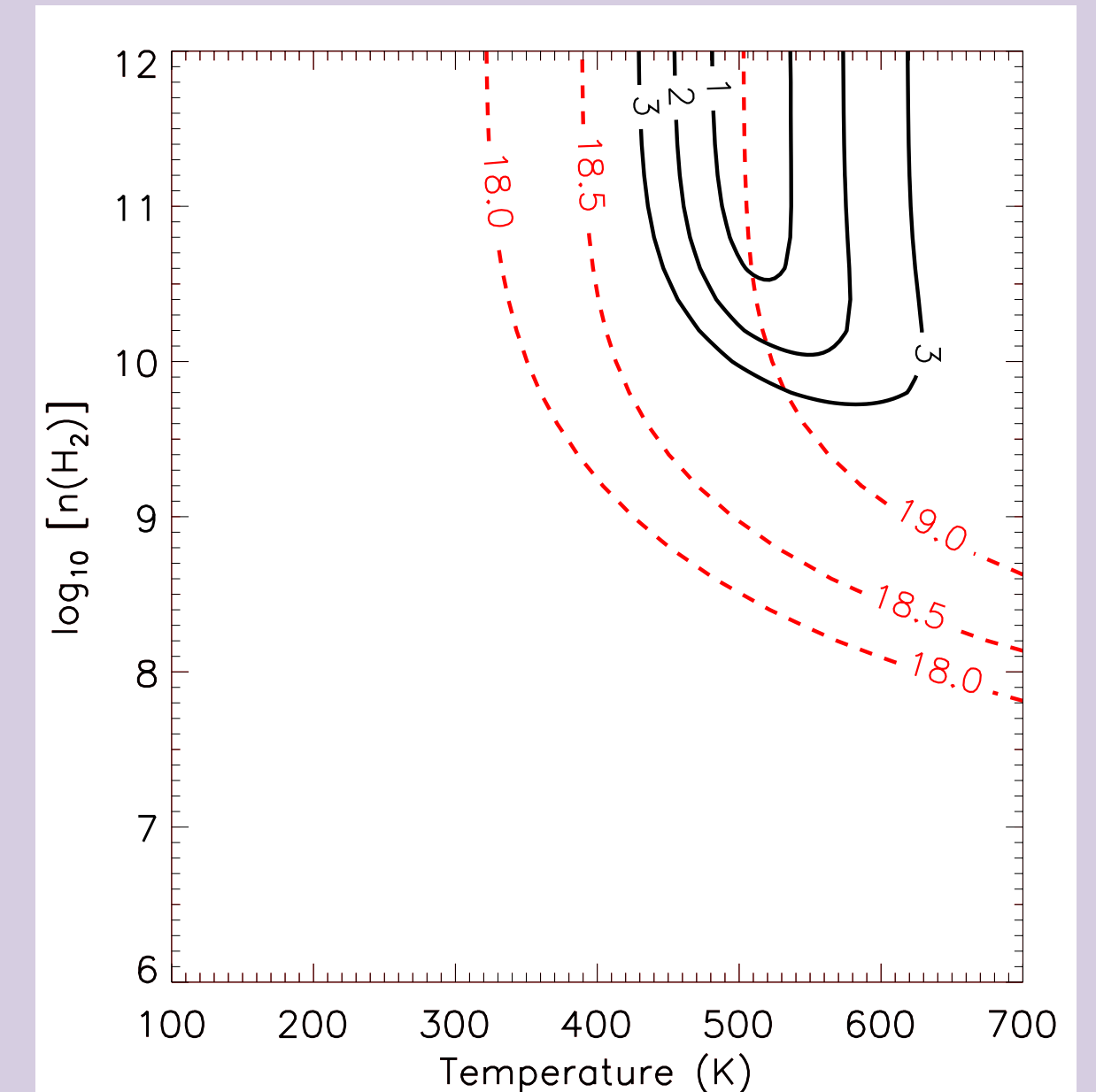


Rotation Diagram



Left: Rotation diagram for unblended transitions with ortho states in blue and para states in red. The dashed line gives predicted values of $\ln(N/g)$ at $T=500 \text{ K}$ and $N(H_2O)=10^{19} \text{ cm}^{-2}$. **Right:** Best-fit temperature and density determined by statistical equilibrium analysis of level populations. Solid black contours show 1, 2, and 3σ confidence limits, and dashed red curves show the values of $\log[N(H_2O)/\text{cm}^{-2}]$ required to fit the data.

Best-Fit T , n , & $N(H_2O)$



Inferred Parameters for AFGL 2136

Molecule	Density (cm^{-3})	Temperature (K)	Column Density (cm^{-2})	Reference
H_2O	$>5 \times 10^9$	506 ± 25	1.0×10^{19}	1
H_2O	...	500 ± 200	1.5×10^{18}	2
CO	$>10^{10}$	580 ± 55	1.8×10^{19}	3
HF	$>10^9$...	1.6×10^{15}	4
HCl	...	250 ± 10	9.8×10^{15}	5

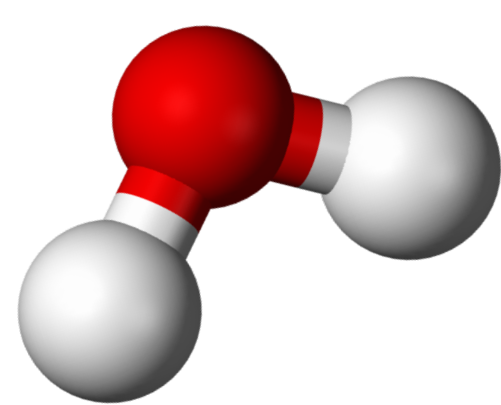
References: (1) – this work; (2) – Boonman & van Dishoeck 2003; (3) – Mitchell et al. 1990; (4) – Indriolo et al. 2013; (5) – Goto et al. 2013 (A&A submitted)

Key Findings

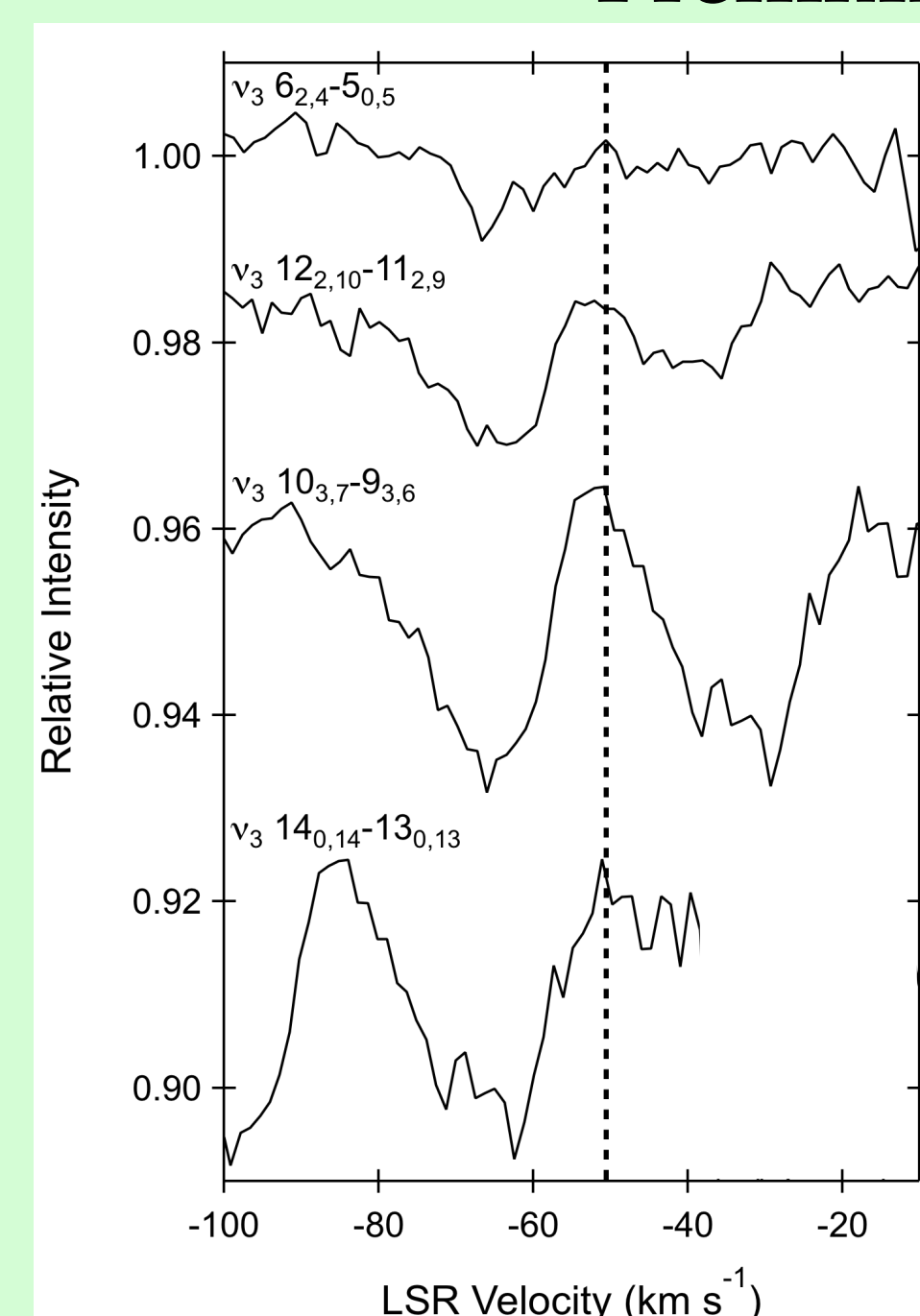
- 47 different transitions of the v_1 and v_3 bands of H_2O are detected toward AFGL 2136
- Absorption detected from states between 469 K and 4294 K above ground
- Warm ($T=500 \text{ K}$), dense ($n>5 \times 10^9 \text{ cm}^{-3}$) gas is in close proximity to the central protostar
- Likely resides in region only $\sim 10 \text{ AU}$ in size
- Potential new probe of gas conditions near massive YSOs

References

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Preliminary Results for AFGL 4176



- 20 absorption features arising from 28 transitions of the v_1 and v_3 bands of H_2O
- Lower state energies between 324 K and 3478 K
- Boonman & van Dishoeck 2003 inferred $T=400 \pm 250 \text{ K}$ and $N(H_2O)=1.5 \times 10^{18} \text{ cm}^{-2}$
- Emission lines of CS and $C^{17}O$ previously reported at -50.5 km s^{-1} (Fontani et al. 2005; see dashed line in figure at left)
- Strongest H_2O absorption features are near -65 km s^{-1} , but in many cases it appears that there is emission at -50 km s^{-1} partially filling in an absorption profile that extends from -80 km s^{-1} to -30 km s^{-1}
- Complex line profiles will make an analysis similar to that done for AFGL 2136 more difficult
- Additional CRIRES observations of CO ($v=1-0$ band) and H_2O are in hand and await processing