Modeling [OI] Emission from Molecular Clouds

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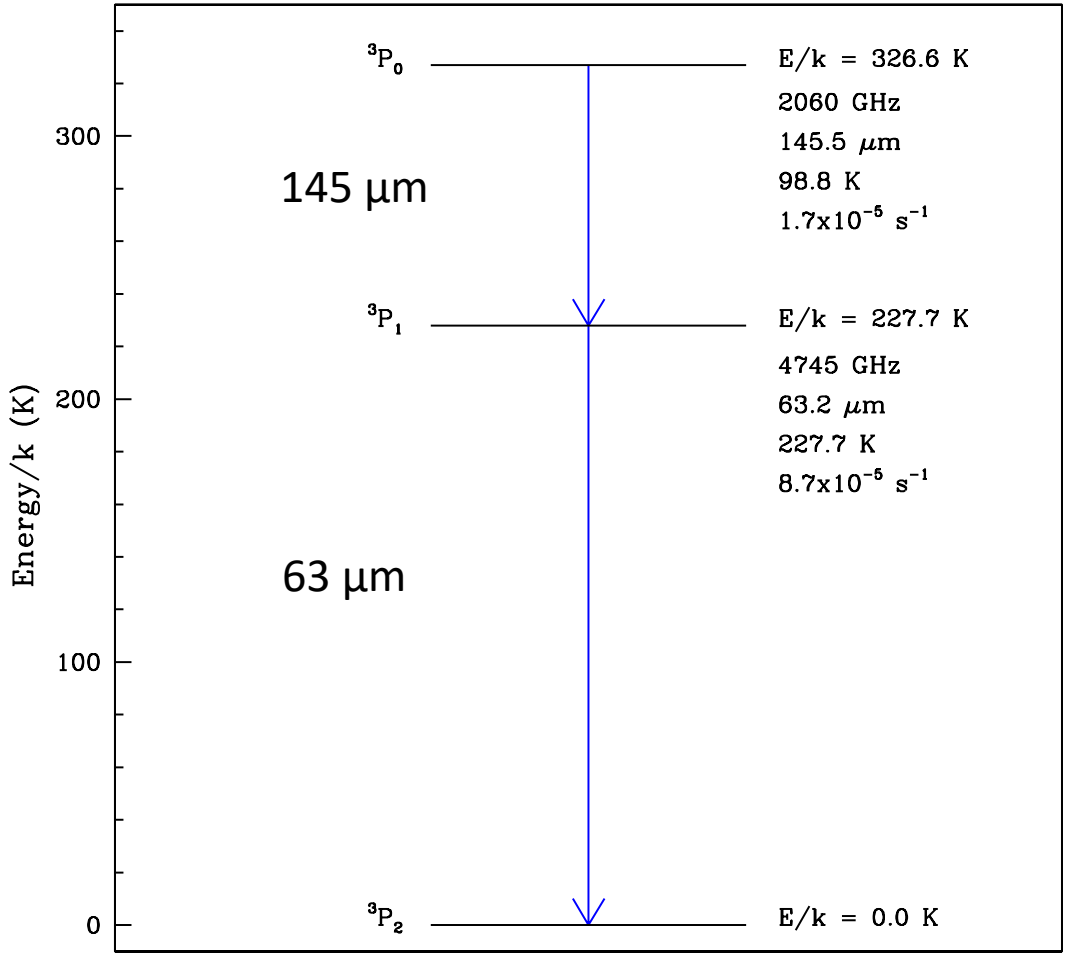
Atomic Oxygen

- Dominant form of the 4th most abundant element and a critical coolant of warmer portions of the ISM, notably
  - Warm Neutral Medium (WNM)
  - Photon Dominated Regions (PDRs)
- Regions of importance defined by energies of fine structure levels
- Inverted level structure with J = 2 ground state
- Excitation by collisions with H^0 and H_2 –
- Refined quantum collision rates now available (Lique et al 2018) that consider o-H_2 and p-H_2 individually



[OI] Excitation and Emission

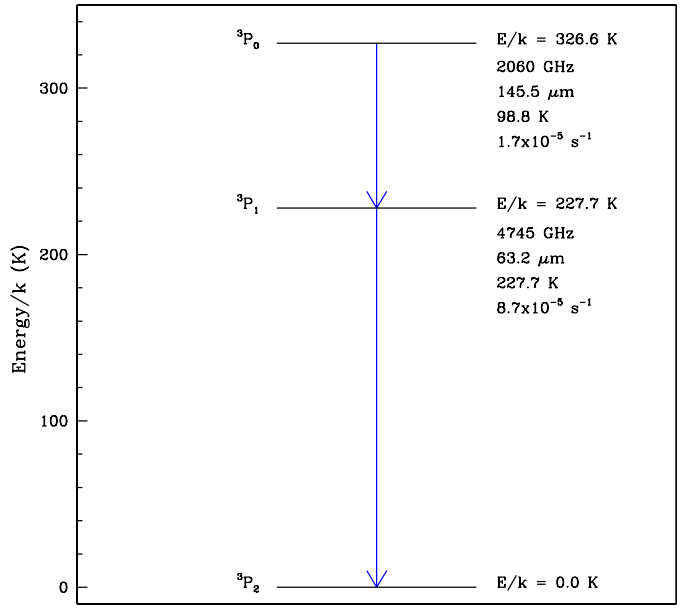
- Collision rates with H^0 and H_2 differ;
  $^3P_0$-$^3P_1$ forbidden to 1st order for H_2
- Critical density for 63 μm line ~$6x10^5$ cm^{-3}
- Primary excitation path is from J=2 (gnd state)
- Upper (145 μm) transition inverted @ low dens.
  but is rapidly quenched by buildup of radiation
- OPTICAL DEPTH of 63 μm line can be large

Under most conditions τ(63 μm) = 1 for Av = 1

146 μm line will almost always be optically thin

Critical Densities

Transition	$n_c(H_2)$ (cm^{-3})	$n_c(H)$ (cm^{-3})
145	5.8×10^6	2.0×10^5
63	5.0×10^5	7.8×10^5



Modeling [OI] Fine Structure Line Emission

- LVG model is inadequate-cannot deal with varying conditions along line of sight that communicate radiatively or predict line profiles
- With upGREAT on SOFIA, both [OI] lines can be observed with high spectral resolution (but observations of 146 μm are very rare)
- Two powerful computer codes are
  - Molpop-CEP (Elitzur & Asensio Ramos (2018) - extremely efficient solution of stat. equilibrium & rigorous radiative transfer; can include varying conditions
  - Meudon PDR code (Le Petit et al. 2006 & updates)– calculates self-consistent chemistry and thermal balance plus radiative transfer with specified external radiation field

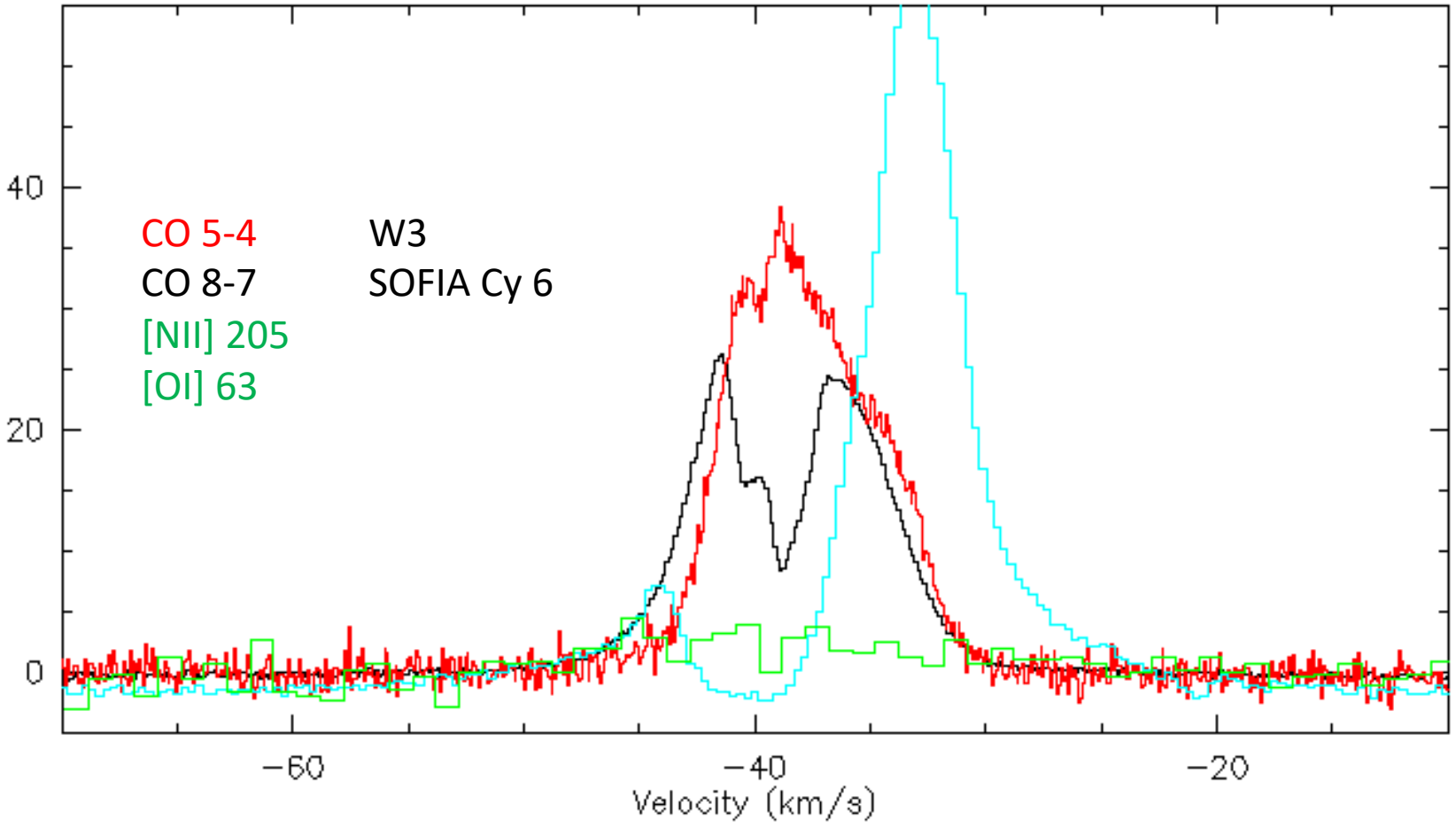
Absorption (or self-absorption) of [OI] 63 µm line is a real issue!

Becomes clear when compare with other lines

Most ionized and neutral gas is at 40 km/s

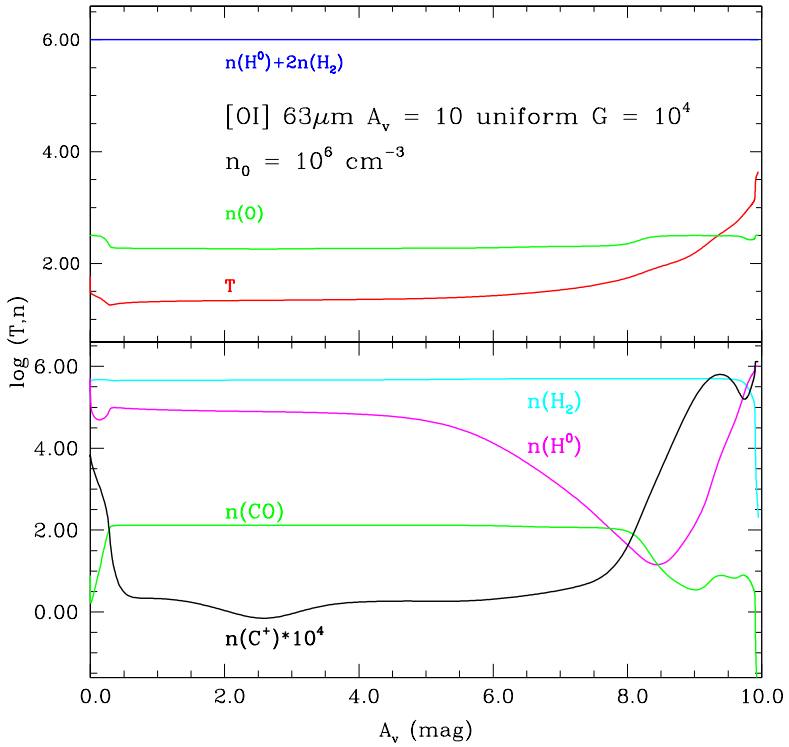
[OI] is hugely self-absorbed

The true flux of [OI] line would be grossly underestimated by taking the integrated intensity OR from an unresolved spectrum



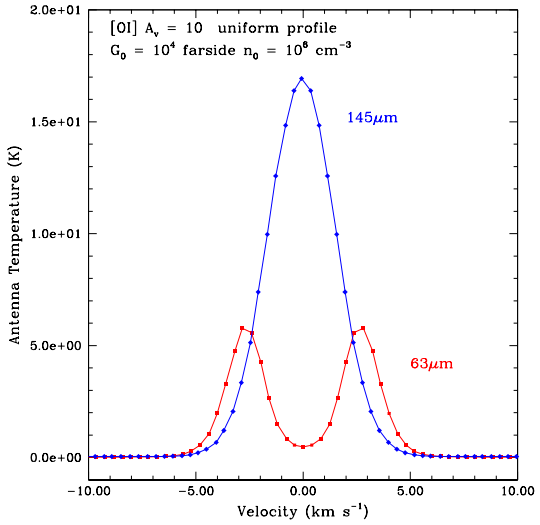
Even simple geometry (uniform density) has huge temperature variation resulting from external heating, presumably from massive young stars that also produce ionized gas

Observed emission CRITICALLY dependent on geometry

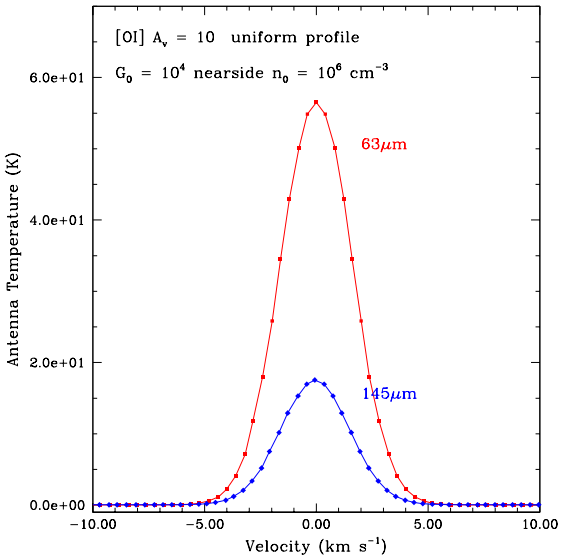


Note log scale for T

O^0 present throughout



Heating on far side



Heating on near side

Conclusions

Understanding [OI] fine structure line emission is critical for unraveling structure of PDR regions, massive star formation, and determining the feedback to placental material

However, the high optical depth of the 63 μm line makes it very susceptible to absorption by cooler/less excited atomic oxygen along the line of sight

The result is that using [OI] 63 μm as direct tracer of energy input from massive young stars is perilous

Combined observations of both fine structure lines is hugely powerful as 146 μm line is optically thin.

This should be considered in planning for future missions, especially those *without* capability of resolving these lines