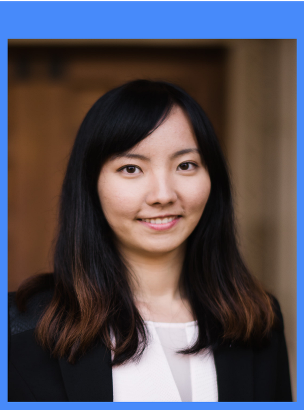


Discovery of NIR Gas Emission with JWST/NIRSpec in a Debris Disk

Cicero X. Lu[1,2], Isabel Rebollido[3,4], Sean Brittain[5], Tracy Beck[6], Christine Chen[6,7], Kadin Worthen[7], Joan Najita[1], Aoife Brenan[8], John Debes[6], Kevin France[9], Luca Matra[8], Amaya Moro-Martin[6], Marshall Perrin[6], Aki Roberge[10]

1. Gemini Observatory/NSF NOIRLab, Hilo, HI, USA 2. Science Fellow, Gemini Observatory; 3. European Space Agency (ESA), European Space Astronomy Centre (ESAC), Camino Bajo del Castillo s/n, 28692 Villanueva de la Cañada, Madrid, Spain 4. ESA Fellow 5. Department of Physics and Astronomy, Clemson University, Clemson, SC, 29634 6. Space Telescope Science Institute, Baltimore, MD, USA 7. Department of Physics and Astronomy, The Johns Hopkins University; 8. Trinity College, Dublin, Ireland; 9. University of Colorado, Boulder, CO, USA; 9. NASA Goddard Space flight Center, Greenbelt, MD, USA

ABSTRACT

In the past decade, studies using UV and optical absorption spectroscopy have discovered hot atomic gas close to the star. The hot gas population indicates the existence of falling and evaporating bodies, also known as exocomets in a handful of debris disks. Furthermore, ALMA-based studies have also revealed tenuous cold gas in a dozen disks. The co-existence of hot (close-in) and cold (>20AU from star) gas in a handful of systems has been attributed to the existence of exocomets. Exocomets likely contribute to the warm and cold gas on their trajectory from the exo-Kuiper belts, through the terrestrial zone into the inner region of the debris disks. A survey to search for signatures of warm gas in a sample of disks, where hot and cold gas co-exist, has been carried out in JWST Cycle 1 (PI: Rebollido, PID 2053). I present here NIRSpec observations of the debris disk HD 131488. We discovered CO emission in the NIR corresponding to ro-vibrational modes. This is the first time that CO fundamental emission has been discovered in NIR for a debris disk. At a resolution of R~2700, we identify the existence of ^{12}CO and its isotopologue ^{13}CO emission lines in the NIRSpec spectrum. Our phenomenological modeling of the emission signatures has revealed a population of hot gas and a population of cold gas creating absorption signatures. The results show a large discrepancy in the rotational and vibration excitation temperatures, indicating UV fluorescence emission of CO gas. Our model also requires a large temperature gradient in the gas to reproduce the observed emission signatures.

METHOD

Because of the extensive line blending due to NIRSpec spectral resolution (R~2700), it is impossible to directly measure the rotational and vibrational temperatures of the gas from the individual line fluxes. Thus, we adopt a phenomenological model of the gas.

We assume 2 populations of CO, warm and cold. For the foreground cold gas, we simply treat it as a slab with a uniform temperature. For the warm gas, we assume n concentric rings (n_{rings}) of emitting gas and an inner edge to the innermost ring. We describe the level population for each ring (at radius r) as following,

- Rotationally-Excited Level Populations

$$N_J = N_v g'_J e^{-E'_J/kT_{rot}(r,\alpha)}$$

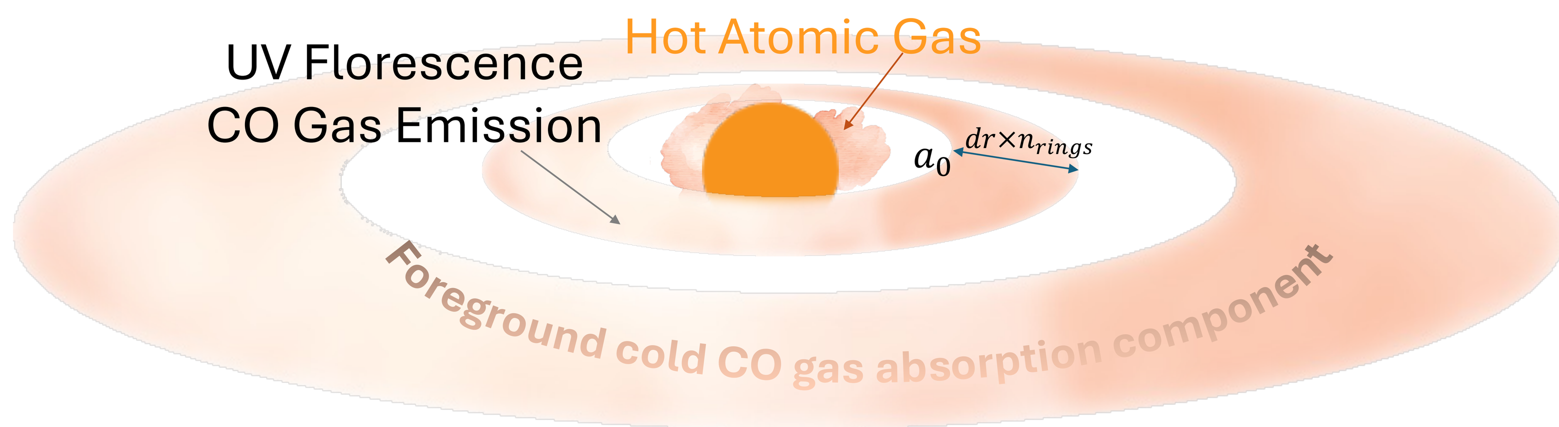
- Vibrationally-Excited Level Populations

$$N_v = N e^{-E'_v/kT_{vib}(r,\beta)}/Q$$

Where N is the total column density of the CO, g'_J is the statistical weight of the level, which equals to $2J+1$, k is the Boltzmann Constant, and Q is the partition function.

- The rotational and vibrational temperature are defined as power laws.

$$T_{rot}(r,\alpha) = T_{rot,0} \cdot r^{\alpha}$$
$$T_{vib}(r,\beta) = T_{vib,0} \cdot r^{b}$$



RESULTS

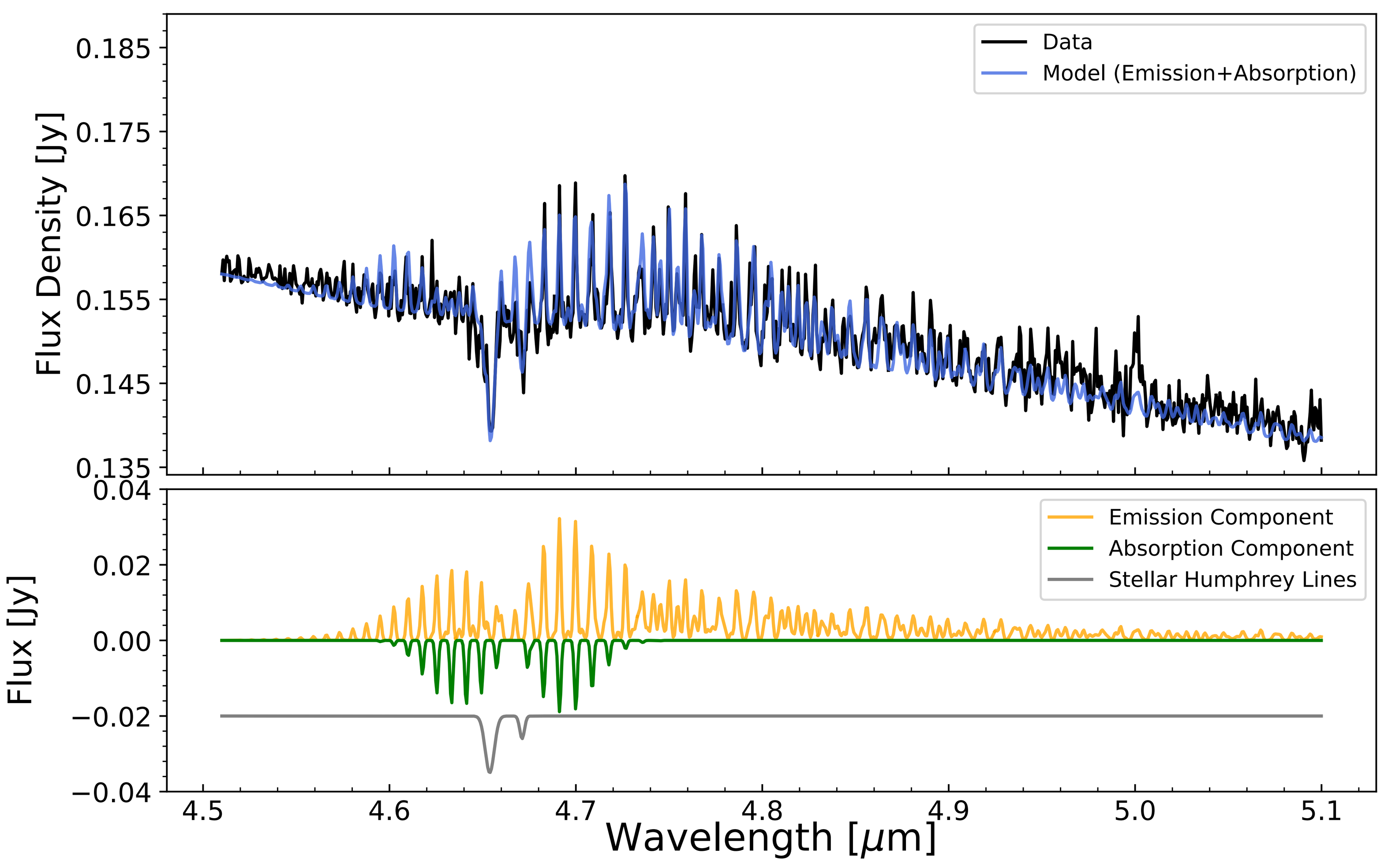


Fig 1. CO Model for HD 131488 with an Emission and an Absorption Gas Component. Top: Original data in black plotted again a model shown in blue. Bottom: The model decomposition of an emission component (orange), an absorption component (green) and a stellar Pfund and Humphrey absorption lines.

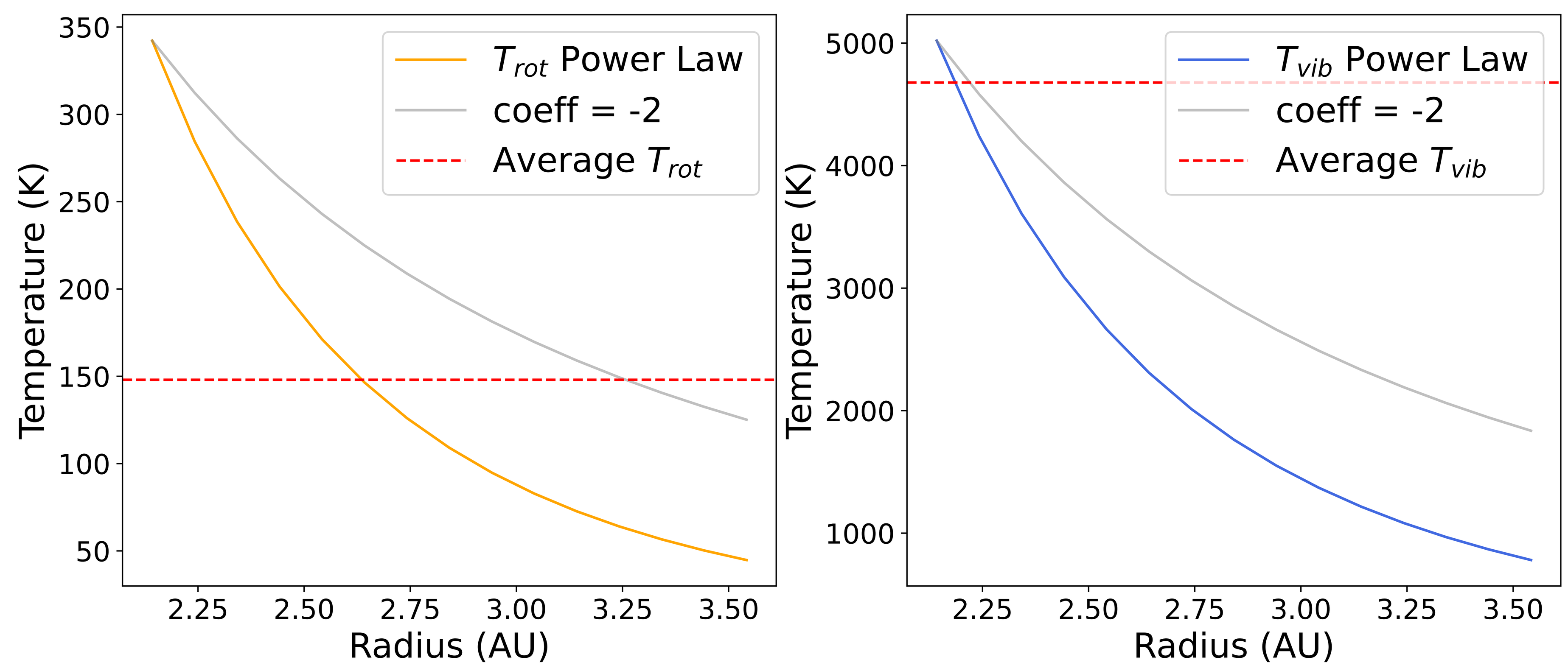


Fig 2. Gas Radial Distribution Profile. Left: The gas temperature power law index for T_{rot} in orange compared to optically thin power law index of -2. Right: Similar as the left panel, but is for T_{vib}.

CONCLUSIONS

- The first time discovery of NIR Gas Emission in a Debris disk
- UV Fluorescence CO Gas Emission: The large discrepancy between the rotational and vibrational
- The warm CO gas is roughly a million times smaller in mass than the ALMA cold CO gas, showing JWST/NIRSpec spectra is sensitive to a very small amount of CO gas.
- Our discovery of warm gas is potentially located in the terrestrial planet zone, where the blackbody temperature of the dust in its vicinity also terrestrial-temperature like (~300K).
- Future high-resolution spectroscopic and/or NIR IFU observations are needed to break the degeneracy of the emitting area of the gas with the emitting temperature in our current model.

Table 2. Best-Fit Model Parameters

Parameter	Best Fit Value
log(N(^{12}CO))	$14.09^{+0.7}_{-0.7} cm^{-2}$
T_{rot} Power law Index	-2.9^{+1}_{-1}
T_{vib} Power Law Index	-3.9^{+1}_{-1}
$^{12}CO/^{13}CO$	5.4^{+25}_{-6}
T_{kin}	220^{+285}_{-133} K
T_{vib}	7590^{+500}_{-2400} K
T_{abs}	34^{+16}_{-11} K
a_0	$3.6^{+1.2}_{-1.3}$AU
dr	$1^{+0.3}_{-0.3}$ AU
χ^2	0.029

Table 3. Properties of Gas

Parameter	Value	Reference
Average T_{kin}	148 K	This Work
Average T_{vib}	4680 K	This Work
M(warm^{12}CO)	$5.8^{+39}_{-7.8} \times 10^{19}$ g ($1.6 \times 10^{-7} M_{moon}$)	This Work
M(ALMA^{12}CO)	$(8.9 \pm 1.5) \times 10^{-2} M_{\oplus}$	Moór et al. (2017)