Can Herschel Detect Gas Emissions from Debris Disks?

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Abstract: Several studies have established that there are trace amount of gas in dusty debris disks. This gas is likely not primordial, but arise from dust grains.

The very environment of this gas – next to a bright star and embedded among dusty particles – can heat it up to high temperatures, mostly due to photoelectrons knocked out from dust grains. For debris disks around early type stars (A-F type), the gas mostly radiates its heat via infrared atomic cooling lines like OI 63 micron, CII 157 micron lines.

We calculate the thermal, ionization and excitation balances of this trace gas. For beta Pic like debris disks, the strongest infrared cooling lines have luminosities of order 10^{-8} solar luminosities and may be detectable by Herschel.

This then allows us to study the chemical composition of the trace gas – and by inference, the chemical make-up of the extra-solar Kuiper belts.

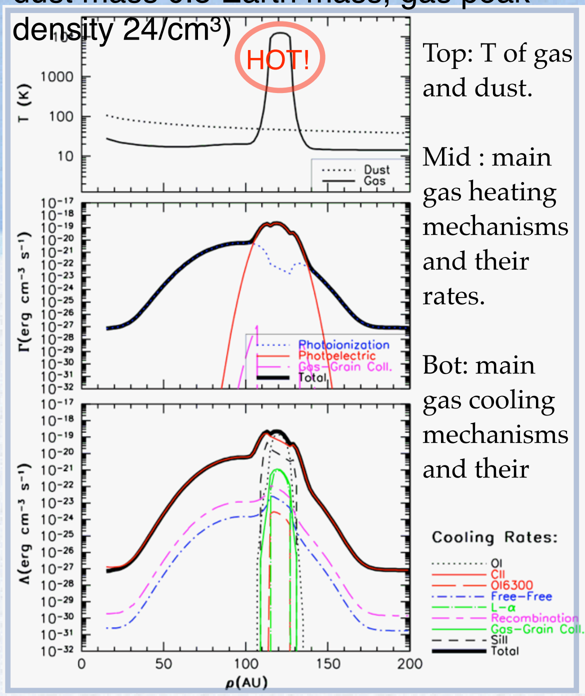
Set-Up: gas heating: dust photoelectric effect, photo-ionization, gas-grain collisions

gas cooling: hyper-fine transitions (CII 157 micron, OI 44/63/145 micron, SiII 35 micron), OI 6300A, Ly-alpha, free-free, recombination. No molecular lines included. The simplified cooling responsible for unrealistically high temperature (>5000K) in the densest regions.

atomic transitions: 90, 10, 10 levels for CII, SiII & OI atoms respectively ; also, detailed SE calculation of CI/II, NaI, SiI/II, FeII, CrI/II, and other observable species (for optical studies)

dust/gas spatial distributions: radial Gaussian rings, vertical Gaussian distributions; gas hydrogen-poor.

Fig 1. a fiducial model (2 solar mass star, dust mass 0.5 Earth mass, gas peak density 24/cm³)



Top: T of gas and dust.

Mid : main gas heating mechanisms and their rates.

Bot: main gas cooling mechanisms and their

Fig 2. cooling luminosities can be roughly estimated by

$$\int dV \Lambda_{\rm fine} \approx \int dV \Gamma_{\rm pe}$$
$$\approx \int dV \int_{s_{\rm min}}^{s_{\rm max}} ds \frac{dn}{ds} \pi s^2\, 1\,{\rm eV}/eJ_e$$
$$\sim \frac{2L_{\rm dust}}{L_*} \times 4\pi R^2 \times \frac{J_e}{e} \times 1\,eV$$
$$\sim 10^{-8} L_\odot \left(\frac{T_{\rm gas}}{100\,{\rm K}}\right)^{-1/2} \left(\frac{R}{100\,{\rm AU}}\right)^2$$
$$\times \left(\frac{L_{\rm dust}/L_*}{10^{-3}}\right) \left(\frac{n_e}{20\,{\rm cm}^{-3}}\right) \left(\frac{e\phi}{2\,{\rm eV}}\right),$$

Fig 3. integrated line fluxes in the fiducial model

Line	Luminosity $[L_\odot]$	Flux at 20 pc $[{\rm erg\,s^{-1}\,cm^{-2}}]$
C II 157.7 μm	2.8×10^{-8}	2.2×10^{-15}
O I 44.1 μm	4.8×10^{-15}	3.9×10^{-22}
O I 63.2 μm	3.2×10^{-9}	2.6×10^{-16}
O I 145.5 μm	1.9×10^{-10}	1.5×10^{-17}
Si II 34.8 μm	3.8×10^{-9}	3.1×10^{-16}

Fig 4. Values for different stellar spectral type

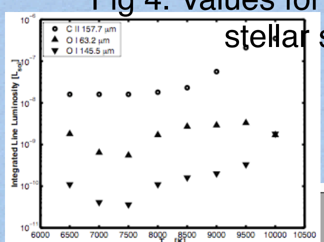
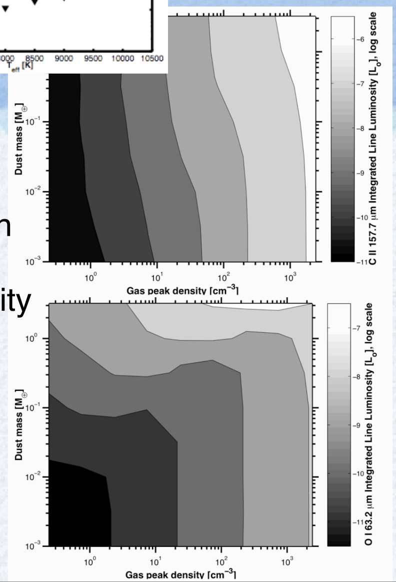


Fig 5. Values depend on gas and dust density



Conclusions: For early A-F stars, atomic cooling in CII 157 micron & OI 63 micron lines, for a beta pic like disk at 20pc, have flux densities of order 10^{-18} W/m². This is (only) reach-able by Herschel. As such, Herschel will present an exciting opportunity for characterizing debris disk gases.

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