PACS Observations and Models of the Debris Disk around HD 181327

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The *Gas in Protoplanetary Systems* (GASPS) Open Time Key Programme will be the first extensive, systematic survey of gas in circumstellar disks over the critical transition from gas-rich protoplanetary disks to gas-poor debris disks.

1- INTRODUCTION

HD 181327 is an F5.5V star located at 50.6pc (Perryman et al. 1997). Its spectral energy distribution shows a Vega-like far-IR excess (Backman & Paresce (1993). HD 181327 was identified as a main sequence debris disk candidate with an $L_{IR}/L_* = 0.2\%$ (Mannings & Barlow 1998), HD 181327 is a member of the young (~12 Myr) β Pictoris moving group (Zuckerman & Song 2004; Mamajeck et al. 2004). Schneider et al. (2006), from NICMOS coronagraphic observations, discovered a ring-like disk of circumstellar debris seen in scattered light (see Figure 1). The ring is inclined by 32 deg from face-on. The total 1.1 µm flux density of the light scattered by the disk (9.6 mJy) corresponds to 0.17% of the starlight. 70% of that scattered light appears to be confined in a 36 AU wide annulus centered on the peak of the radial surface brightness profile 86 AU ± 4 AU from the star. The ring shows strong directionally preferential scattering well represented by a Henyey-Greenstein scattering phase function with asymmetry parameter $g_{HG} = 0.30 \pm 0.03$. No photocentric offset is seen in the ring relative to the position of the central star. A low surface brightness diffuse halo is seen in the NICMOS image to a distance of ~4″. Deeper 0.6 µm ACS PSF-subtracted coronagraphic observations reveal a faint (V ≈ 21.5 mag.arcsec^{-2}) outer nebulosity from 4″ < r < 9″. In this poster we present the Herschel observations, the SED and line model fitting we performed and discuss the results.

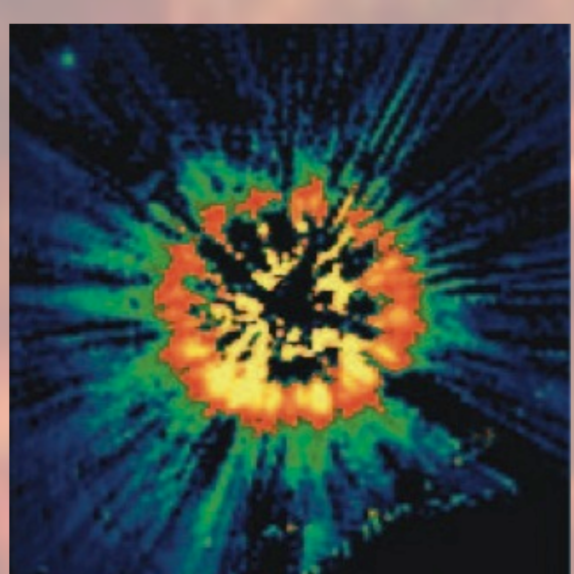

Figure 1: Coronagraphic image of the HD 181327 disk. The image, which was taken with *HST* NICMOS at 1.1 µm, shows light scattered off a ring of dust located 86 AU from the central star (Schneider et al. 2006).

2- OBSERVATIONS, DATA ANALYSIS

HD 181327 was observed by the GASPS programme during the Science Demonstration Phase. The data were recalibrated with HIPE, using the processing scripts from the Jan. 2010 Data Processing Workshop. The observations are:

– Point-source chop-nod photometry in the blue channel (70 µm) and in the red channel (160 µm). See Figure 2.

– Line scan spectroscopy targeting [OI] at 63 µm.

– Range scan spectroscopy targeting [CII] at 158 µm and [OI] at 145 µm. Recalibrated spectra extracted from the central spaxel appear in Figure 3.

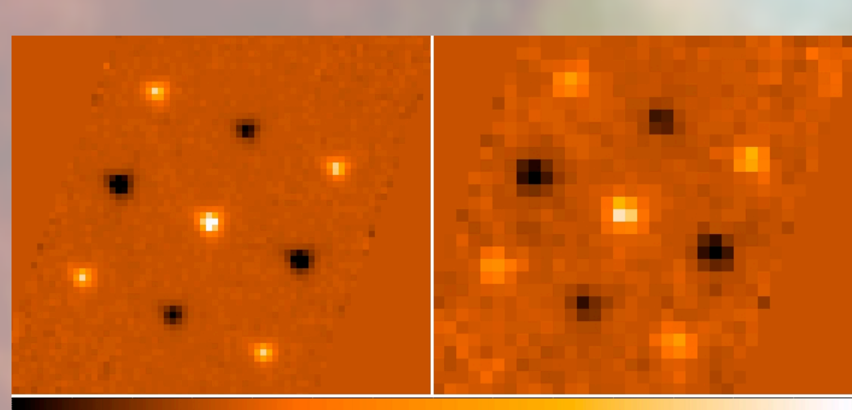

Figure 2: *Herschel* PACS images of HD181327, taken in point-source chop-nod mode. *Left*: Blue channel (70 µm). *Right*: Red channel (160 µm). The source is in the center of each frame; the other positive & negative sources are artifacts of the chop-nod mapping scheme. The images have the native pixel sizes (3.2 arcsec for the blue camera, 6.4 arcsec for the red camera). The continuum flux values from aperture photometry appear in Table 1.

Table 1: Observational Results

Observing Mode, Wavelength	Flux +/- Stat. Error
Continuum	
PacsLineSpec, 63.2 µm	1.76 +/- 0.04 Jy
PacsPhoto, 70 µm	1.90 +/- 0.03 Jy
PacsRangeSpec, 145.5 µm	0.77 +/- 0.03 Jy
PacsRangeSpec, 157.7 µm	0.76 +/- 0.03 Jy
PacsPhoto, 160 µm	0.87 +/- 0.03 Jy
PacsRangeSpec, 179.5 µm	0.40 +/- 0.05 Jy
Emission lines (3-σ upper limits)	
Spectroscopy, [OI] 63 µm	$< 9.3 \times 10^{-18}$ W/m^2
Spectroscopy, [OI] 145 µm	$< 8.0 \times 10^{-18}$ W/m^2
Spectroscopy, [CII] 158 µm	$< 8.5 \times 10^{-18}$ W/m^2

3- DUST DISK MODELING

We used the GRaTer code (Augereau et al. 1999) to compute a grid of models to reproduce the dust continuum emission of the debris disk of HD 181327. The SED fitting is further constrained by the surface brightness profile of the disk. The procedure assumes a single grain size distribution: $n(a) \propto a^{-\kappa}$ between a_{min} and a_{max} = 4 mm. The dust is ISM-like, i.e., a mixture of porous particles of astronomical silicates, amorphous carbon and ices. In total, ~340000 models were ran. Results are presented in the box below and in Figure 4, for fits using 27 (left panel) or 7 (right panel) photometric data points, see caption for details.

Results of the SED fitting

a_{min}= 1.44 µm (resp. 1.13 µm) ; κ = -3.71 (resp. -3.50)
ice fraction = 50% ; porosity = 0.60
Disk mass: 0.05 M_{earth} (resp. 0.11 M_{earth})
Temperature of a_{min} grains at 88 AU : 82K (resp. 78K)

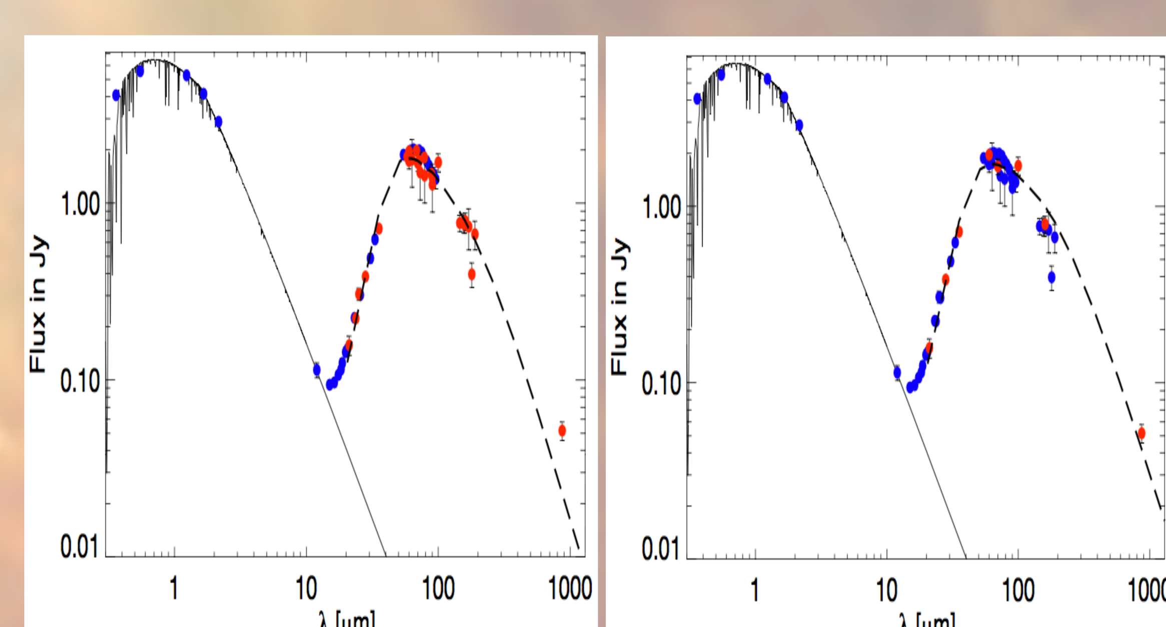

Figure 4: Best-fit SED. Red dots: data points used in the fit ; blue dots are ignored. Used to provide a different weighting scheme. Dashed line: best-fit model. Left: 27 points are used. Right: only 7 points.

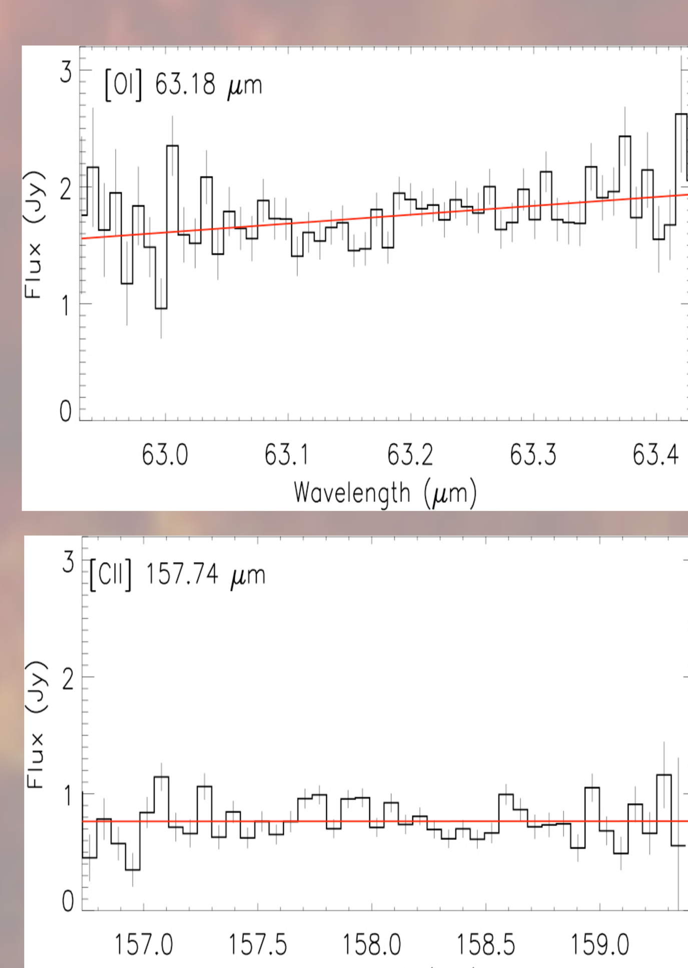

Figure 3: *Herschel* PACS spectra of HD 181327, centered on the expected positions of the [OI] 63 µm and [CII] 158 µm emission lines. No gas emission was detected from HD 181327. 3-σ upper limits on the line fluxes appear in Table 1. Dust continuum fluxes from the spectra also appear in Table 1.

4- GAS DISK MODELING

The GASPS team uses an advanced thermochemical disk modeling code, called Protoplanetary Disk Model (ProDiMo) (Woitke, Kamp, & Thi 2009) and a 3-D continuum and line radiative transfer code, MCFOST (Pinte et al. 2006, 2009). The density structure derived from the SED fitting was injected in ProDiMo to predict flux ratios in the OI, CII and CO (3-2) lines. The goal is to derive a limit for the gas-to-dust (G/D) ratio in the disk. Predictions are shown in Table 2 and should be compared with the flux upper limits listed in Table 1. As the G/D ratio is decreased CO is not efficiently produced anymore (or can not efficiently self-shield). As the main coolant CO is destroyed, the gas warms up, and the gas energy-balance becomes the interplay between photo-electric heating against OI,CII,H2 line cooling.Since the [OI]63 line is very temperature-sensitive, lowering gas/dust first increases the line flux, before it decreases for G/D ≤ 1. As a consequence, the non-detections of OI and CII do not provide an unambiguous constraint on the G/D atio. However, coupling with other tracers, e.g., CO lines, offers a hope to put much better limits on the low gas content of debris disks. For comparison, ALMA should allow to detect 2e-22 W/m2 in 60sec with 1km/sec spectral resolution in the CO (3-2) line, and therefore detect the CO gas in 30m if G/D = 1.

Table 2: Line flux predictions as a function of Gas-to-Dust ratio

Gas to Dust ratio	OI [63] (W/m²)	OI [145] (W/m²)	CII [158] (W/m²)	CO (3-2) (W/m²)
100	4.5 e-19	7.2 e-21	2.1 e-19	2.2 e-19
10	1.1 e-18	3.7 e-21	5.1 e-19	5.1 e-21
1	1.2e-18	9.2 e-21	1.3 e-18	1.0 e-23
0.1	6.1 e-19	3.2 e-20	7.0 e-19	5.1 e-26
0.01	7.6 e-20	7.8 e-21	6.8 e-20	1.2 e-27

5- Final Remarks

HD 181327 is easily detected in the continuum by Herschel/ PACS at 70 and 160 microns. Fitting of the continuum SED simultaneously with the brightness profile of the debris ring observed by HST provides evidence that grains are large and porous, as expected for debris disks.

Using the density profile inferred from the SED and assuming the gas, if any, in the ring follows the same distribution, we estimated the line fluxes for various Gas-to-Dust ratios in the ring.

The current non-detections of OI and CII lines *alone* do not provide *unambiguous* upper limits to the gas content. However, the predictions show that coupling with other tracers, in particular with CO lines, offers much better prospects to reach lower limits on the gas content of debris disks.

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