MOLECULAR GAS IN YOUNG DEBRIS DISKS

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ABSTRACT

Gas-rich primordial disks and tenuous gas-poor debris disks are usually considered as two distinct evolutionary phases of the circumstellar matter. So far only a very few debris disks with measurable gas component have been known. We carried out a survey with the APEX radio telescope to detect molecular gas at millimeter wavelengths in 28 infrared-luminous young debris disks, and discovered two new systems with substantial amount of CO. Motivated to understand the origin, physics, and evolutionary status of the gas in these systems we observed one of them, HD 21997, with ALMA and Herschel. Our results suggest that HD 21997 may be a hybrid system where secondary debris dust and residual primordial gas coexist. This poses a serious question to the current paradigm, since the age of the system (30 Myr) significantly exceeds model predictions for disk clearing and the ages of the oldest transitional disks.

INTRODUCTION

- According to the current paradigm, disks around young stars evolve from **gas-rich primordial** to **gas-free debris dust disks** on a timecale of <10 Myr. Debris disks are composed of second generation dust, the product of collisions between planetesimals.
- Indeed, very few debris disks with a detectable gas component are known. Containing both molecular and atomic gas: **49 Ceti** (40 Myr, A1-type; Zuckerman et al., 1995, Roberge et al., 2013), **β Pic** (12 Myr, A5; Roberge et al. 2006). Containing only atomic gas: **HD 32297** (~20 Myr, A6; Redfield 2007, Donaldson et al., 2013), and **HD 172555** (12 Myr, A5; Riviere-Marichalar et al. 2013).
- We carried out a survey with the APEX radio telescope to search for CO gas in 28 prominent, young (12-100 Myr) debris disks, and discovered two new gaseous systems around **HD 21997** and **HD 131835**.

MOTIVATION

- The origin of gas in young debris disks is unclear: it can either be **second generation** produced from planetesimals or **residual primordial** that survived in the outer disks.
- Do the known gaseous systems form a homogeneous group (in terms of gas origin, host star, disk parameters)?
- Observation with the **Atacama Large Millimeter/submillimeter Array (ALMA)** and **Herschel Space Observatory (Herschel)** can clarify 1) what is the spatial location of dust and gas in the system and 2) the origin of the gas.
- The evolutionary sequence of the dust component of debris disks is rather well studied (e.g. Wyatt, 2008). The parallel evolution of gas has not yet been characterized. Our observations constitute the first steps in this important direction.

OBSERVATIONS

Surveys with the APEX radio telescope (PIs: A Moór, Th. Henning)

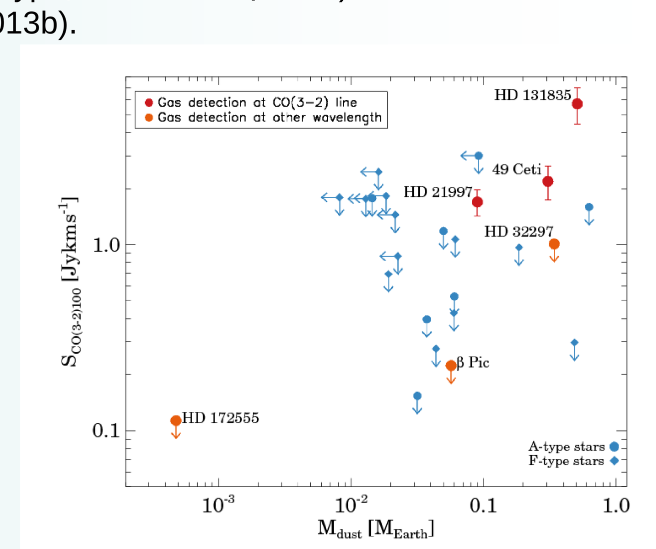
- CO J=3-2 line, FWHM ~ 18''
- 28 infrared-luminous, young (12-100 Myr) debris disks around A- and F-type stars, in total ~90h observing time

Follow-up observations of HD 21997

- **ALMA Cycle 0 (PI: Á. Kóspál)**
  - compact configuration, spatial resolution: 1.5'' - 2.0''
  - continuum maps at 886 μm
  - ^{12}CO (J=3-2, 2-1), ^{13}CO (J=3-2, 2-1), and C^{18}O (J=2-1) lines, spectral resolution: 0.16 – 0.23 kms^{-1}
- **Herschel Space Observatory (PI: P. Ábrahám)**
  - imaging in six bands from 70 to 500 μm with PACS and SPIRE, spatial resolution: 5 – 36''
  - [OI] and [CII] line spectroscopy with PACS

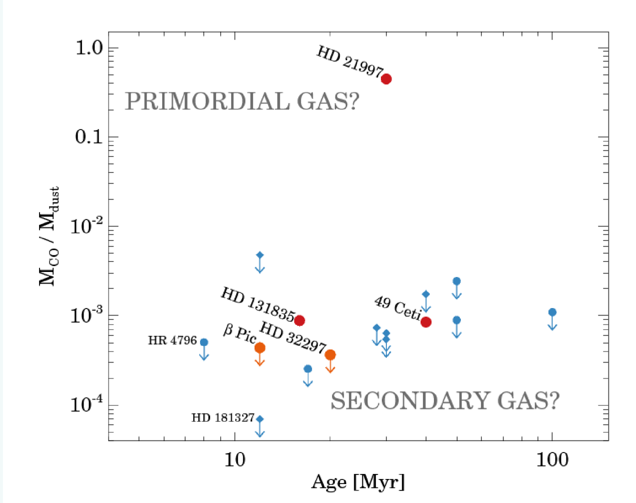
RESULTS OF THE APEX SURVEY

- For a long time, only one debris disk, 49 Ceti, was known to harbour cold CO gas detectable at mm wavelengths (Zuckerman et al., 1995). Our survey revealed two new gaseous debris disks around HD 21997 (30 Myr, Columba moving group, A4-type, **Moór et al., 2011**) and HD 131835 (16 Myr, Upper Centaurus Lupus, A6-type, Moór et al., 2013b).
- All three systems seem to harbour unusually massive debris disks. Interestingly, β Pic and HD 32297, two disks where gas was detected at other wavelengths, also share this property.



Integrated CO (3-2) fluxes or upper limits for our sample and for some other debris disks around A-type stars from literature data (Dent et al., 2005, Greaves et al., 2000, Kamp et al., 2003) normalized to 100 pc are plotted against dust masses of the disks

- The origin of gas in debris dust disks
  - The gas in β Pic system is claimed to be secondary (Fernandez et al., 2006)
  - The origin of gas in 49 Ceti disk is debated, however recent papers (Zuckerman & Song 2012, Roberge et al., 2013) proposed that the observed CO is of secondary origin.
  - Disks around β Pic, 49 Ceti, and HD 131835 show similar M_{CO}/M_{dust} ratio suggesting that their gas component has a common origin.
  - For HD 21997 the M_{CO}/M_{dust} ratio is significantly higher and indeed, based on our ALMA observation we found that it may rather harbour primordial gas.
  - BUT NOTE, for HD 21997 the CO mass estimate was derived from the ALMA C^{18}O observation, while 49 Ceti and HD 131835 were detected only in ^{12}CO and their CO mass was calculated assuming optically thin emission. Thus their real CO mass could be higher!



Ratio of the derived CO gas masses or upper limits to the estimated dust masses as a function of age.

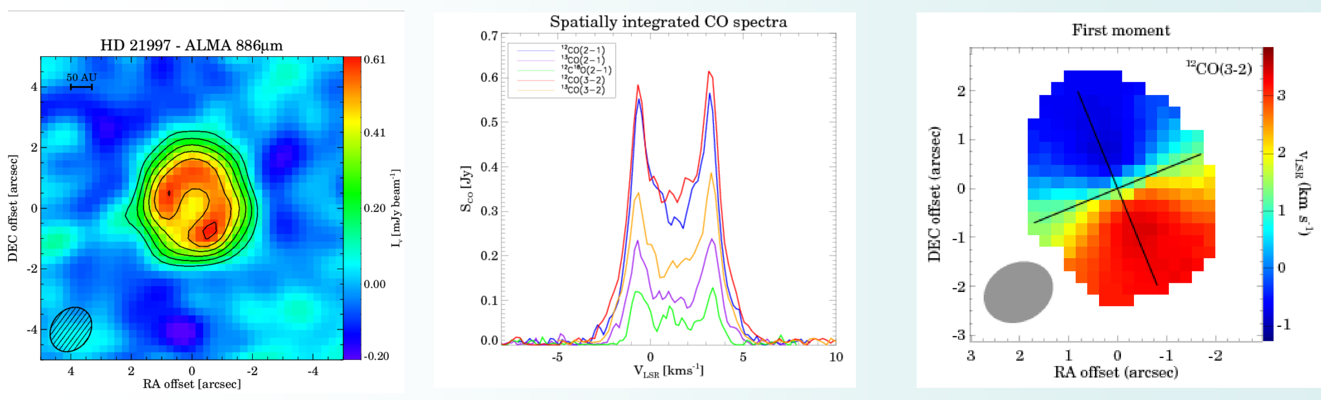
ALMA AND HERSCHEL OBSERVATIONS OF HD 21997

ALMA results (Kóspál et al. 2013; Moór et al. 2013a)

- The continuum emission is clearly resolved into a ring-like structure encircling the stellar position. The morphology can be fitted with an ellipsoidal ring with an outer diameter of 4.5'' (320 AU).
- Spatially/spectrally resolved CO emission in all observed transitions. The molecular gas is in Keplerian rotation. Disk position angle: 22.6º±0.5º, inclination: 32.6º±3.1º (based on the analysis of first moment maps).

Herschel results

- The disk was spatially resolved at all PACS wavelengths (Moór et al., 2013a)
- Non-detection of the OI and CII lines.



Conclusions

- ^{12}CO and ^{13}CO lines are optically thick, M_{CO} ~ 0.06 M⊕ based on the optically thin C^{18}O line measurement.
- CO brightness distribution could be reproduced by a gas disk with inner and outer radii of <26AU and 138 AU.
- Inner and outer radii of the dust disk is ~55 and ~150 AU, respectively, with a dust mass of 0.09 M⊕ in this region. Our data supported by modelling hints at an extended cold outskirt of the ring.
- Thus, dust and gas are only co-located in the disk between 55 and 140 AU, but within 55 AU there is a dust poor inner region.
- **Origin of gas:** secondary origin would require unrealistically high gas production rate and would not explain why gas and dust are (partially) not co-located. We propose that HD 21997 is a **hybrid system: secondary debris dust + old primordial gas co-exist.**

CONCLUSIONS

- By carrying out a survey with the APEX radio telescope we discovered two debris disks, HD 21997 and HD 131835 that show submillimeter CO emission.
- For HD 21997 we performed follow-up observations with the ALMA and Herschel Space Observatory. Considering the distribution and the physical properties of the dust component, HD 21997 looks like a normal debris disk system. However, our ALMA line observations revealed a large amount of CO gas. Its mass is comparable to the dust mass, and significantly exceeds the CO content of other debris disks. **Based on our results, we suggest that HD 21997 harbours a hybrid disk in which secondary debris dust and residual primordial gas co-exist.** If the observed gas in the HD 21997 system was of primordial origin, it poses a serious question to the current paradigm of disk evolution, since the age of the system (30 Myr) significantly exceeds model predictions for disk clearing and the ages of the oldest transitional disks.

Common properties of young gaseous debris disks:

- All of them encircle A-type stars (A1-A7);
- Apart from HD 172555 all of them harbour massive, cold, outer disks;
- Apart from HD 21997, most of them may contain secondary gas produced from planetesimals. However, in most cases, the origin of gas is not well established yet and additional observations (e.g. with ALMA) are needed to consolidate the results.

ID	SpT	Outer disk radius [AU]	Dust mass [M⊕]	Gas detection method	Origin of gas (proposed)
β Pic	A6	75 - 110	0.06	Different atomic species and CO via UV/optical abs. lines	Secondary
49 Ceti	A1	85 - 200	0.31	CO rotational line, CII emission	Secondary?
HD 21997	A4	55 - 150	0.09	CO rotational line	Primordial
HD 32297	A6	65 - 135	0.34	NaI D absorption, CII emission	Secondary?
HD 131835	A6	50 - 180	0.51	CO rotational line	Secondary?
HD 172555	A7	4 - 8	4.8x10^{-4}	OI emission	Secondary

List of currently known debris disks with gas content.

RELATED LITERATURE

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