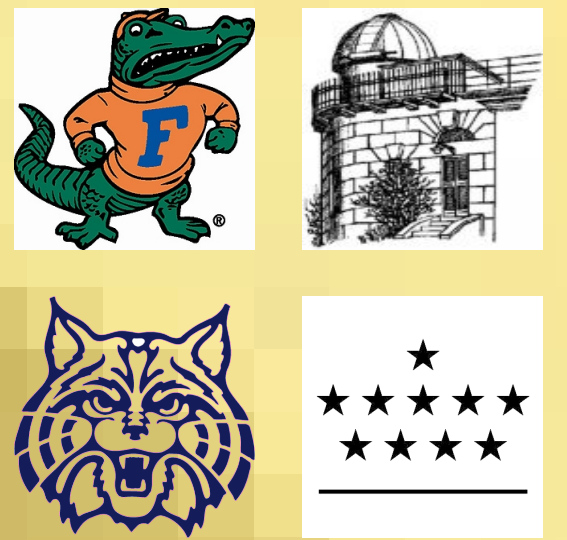


# Spectroscopic Update On the Moon Star

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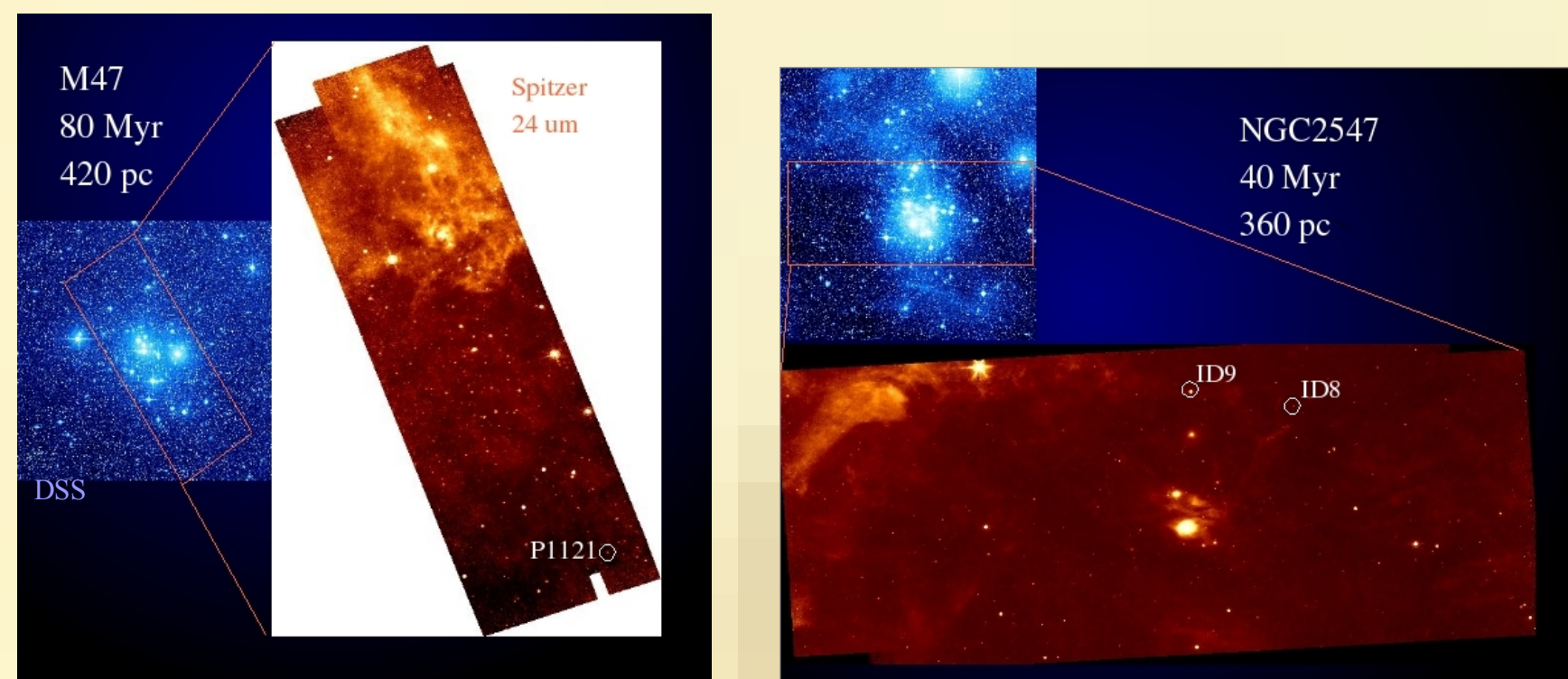
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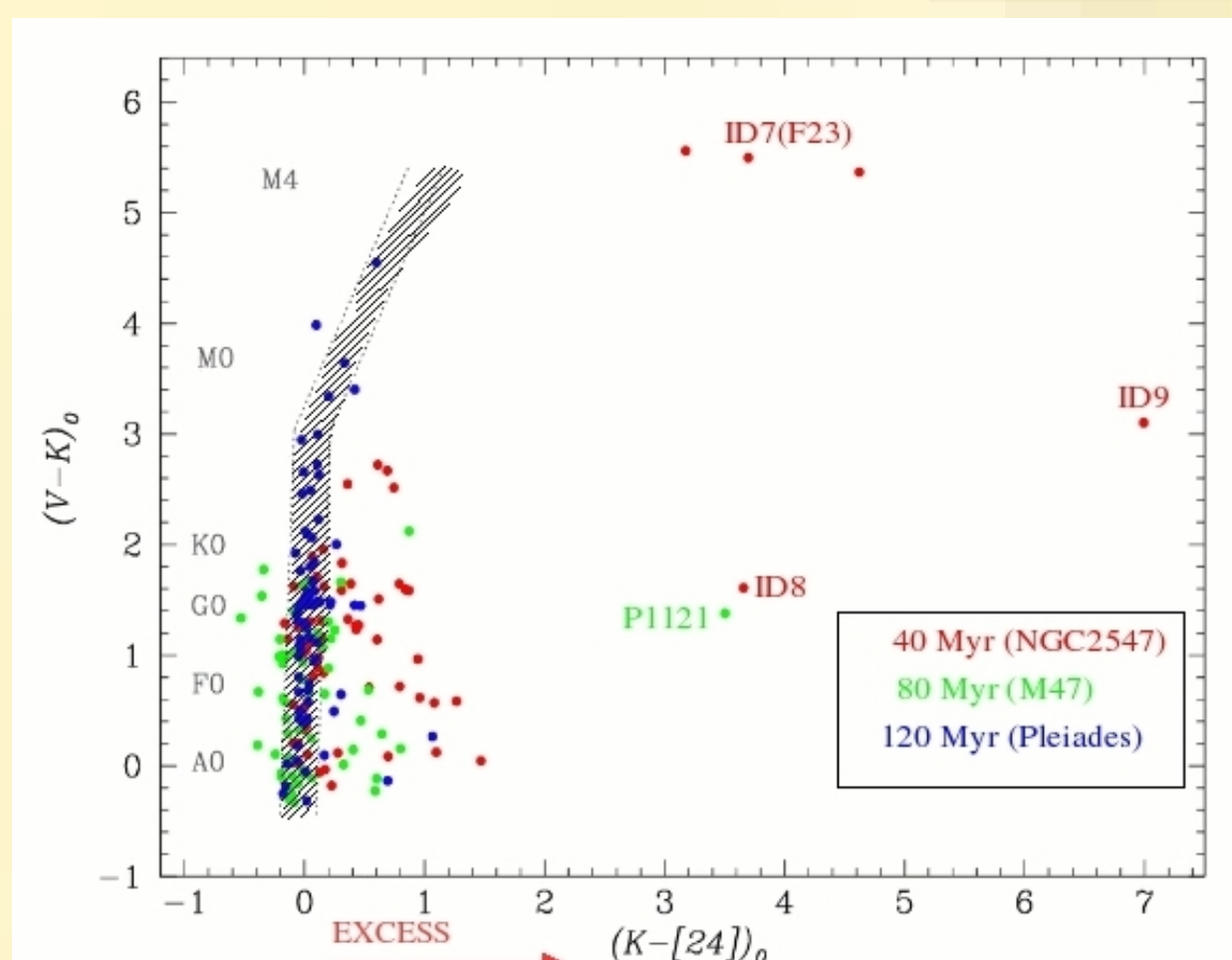
## INTRODUCTION

### Stars with Extreme IR Excesses Discovered by Spitzer

As part of the MIPS guaranteed time open cluster survey, we investigated three intermediate-age clusters: M47, NGC2547, and the Pleiades, by obtaining 24 micron images:



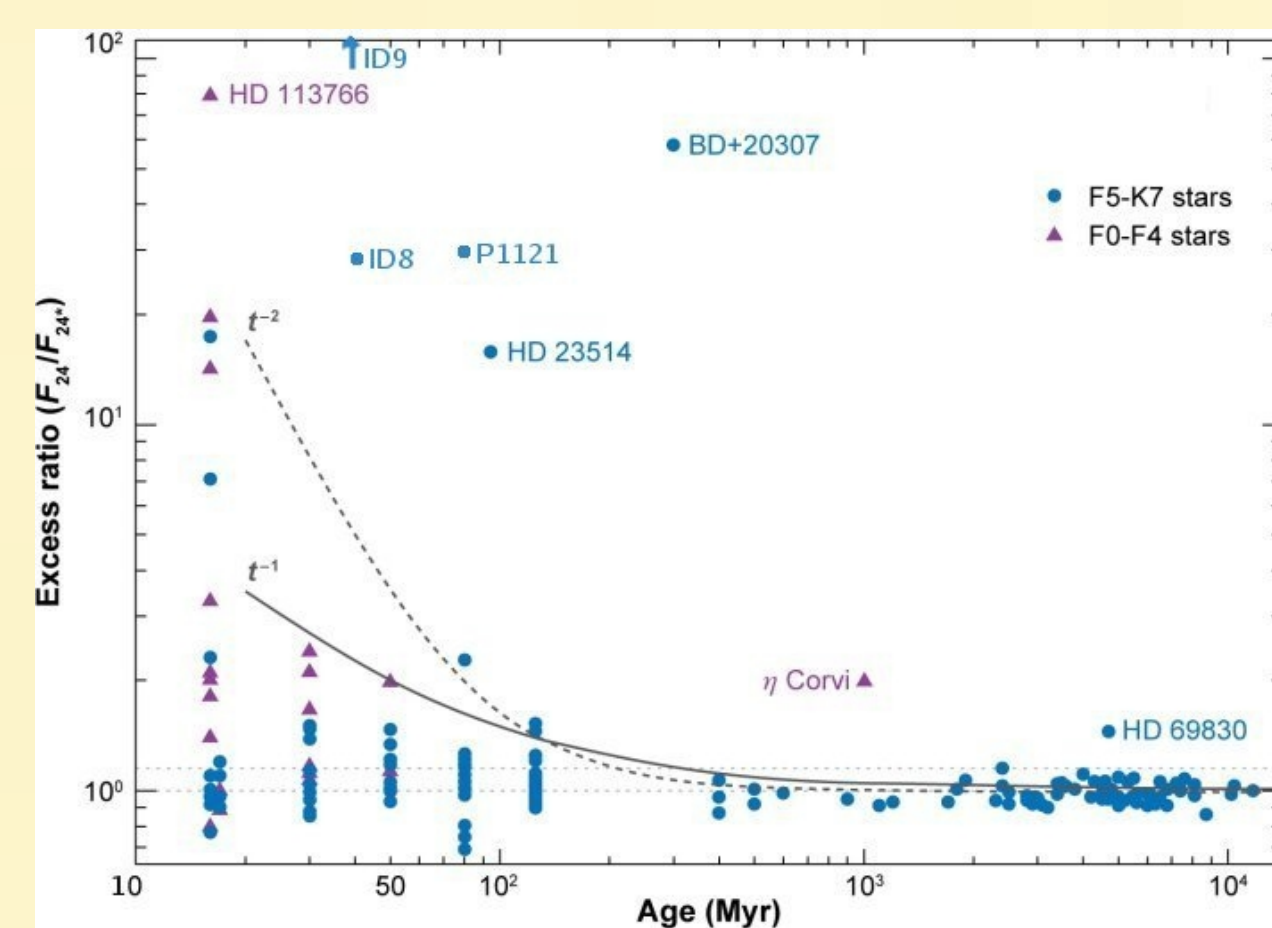
We identified stars with disks by constructing a  $(V-K)$  vs.  $K-[24]$  diagram. Stars inside the hatched area have normal photospheric  $K-[24]$  color, while stars red-ward of it possess an IR excess indicating presence of warm circumstellar dust of  $\sim 120$  K:



About 30% of A-G stars between 30-100 Myr possess IR excess at 24 micron without a near-IR excess, indicating presence of debris disks. Rarely, one observes **extreme excesses**.

Compilation from Gorlova et al. 2004 ApJS, 2006, 2007 ApJ

We found three G-K stars with extremely strong IR excesses - **P1121**, **ID8**, **ID9**. Here is how they compare to other F-K stars discovered with IRAS and Spitzer as reported in the literature:



24 Micron excess decays within  $\sim 300$  Myr, indicating time-scale of planet formation inside  $\sim 5$  AU in the solar-type stars.

**What is the nature of the outlying sources?**

From Wyatt, M. 2008, ARA&A

## CONCLUSION

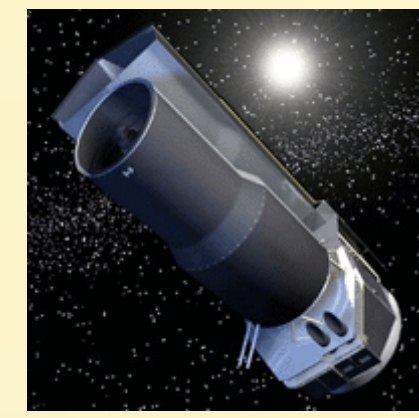
### Nature of Stars with Extreme IR Excesses Discovered by the MIPS team

We confirm **ID8**, the "Moon star", to be a legitimate member of the 40 Myr-old cluster NGC2547, with no trace of gas accretion. It remains a good candidate for the catastrophic collision scenario between two proto-planets. So does the 80 Myr-old **P1121**.

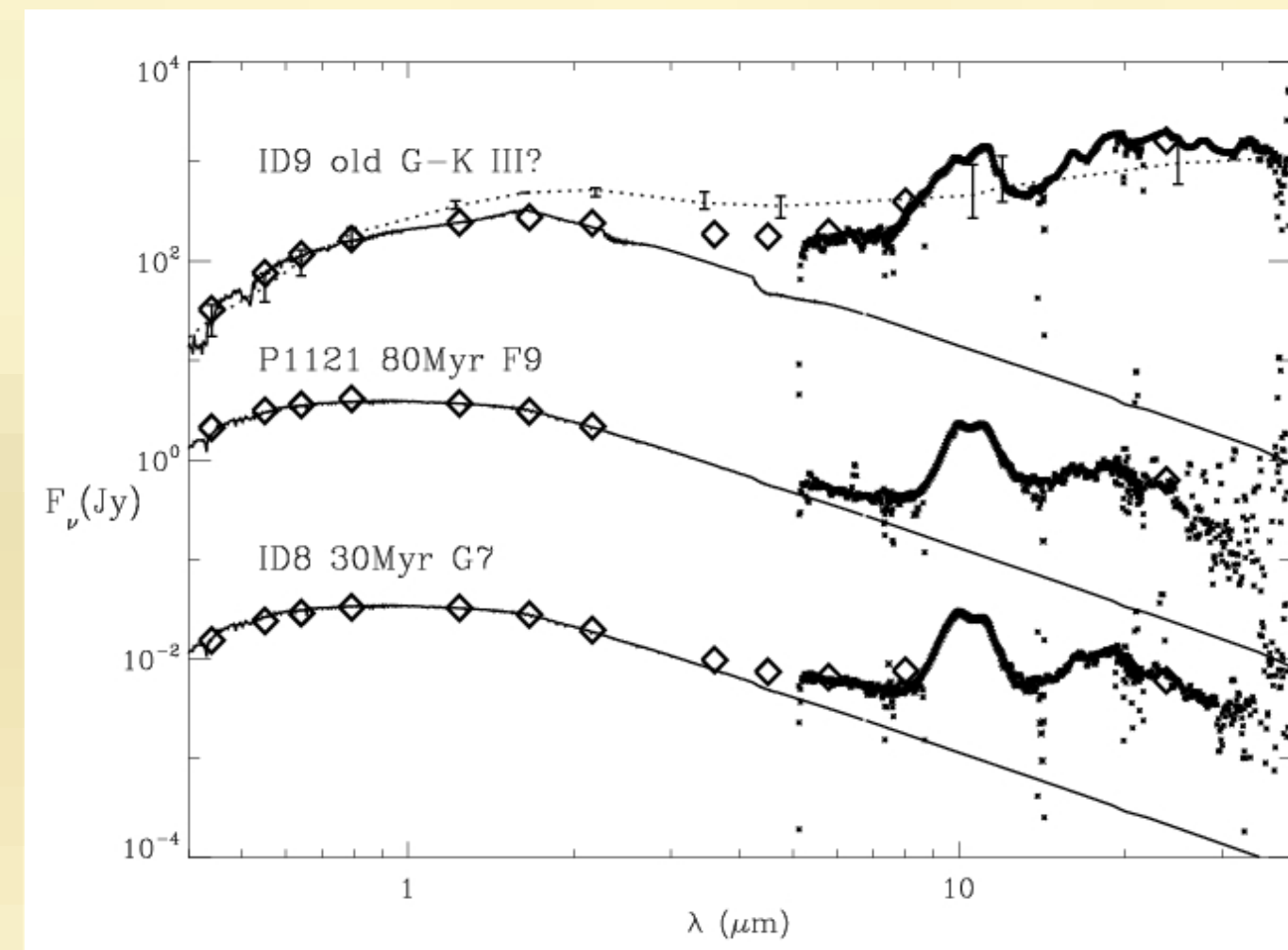
**ID9**, on the other hand, appears a post-AGB system with an edge-on thick disk. Multi-epoch high-resolution spectroscopy is required to confirm this hypothesis.

## PART I

### Spitzer IRS Spectroscopy



In order to understand origin of dust in the extreme excess sources, we constructed the spectral energy distributions (SED) and obtained the low-resolution spectra of them with Spitzer:

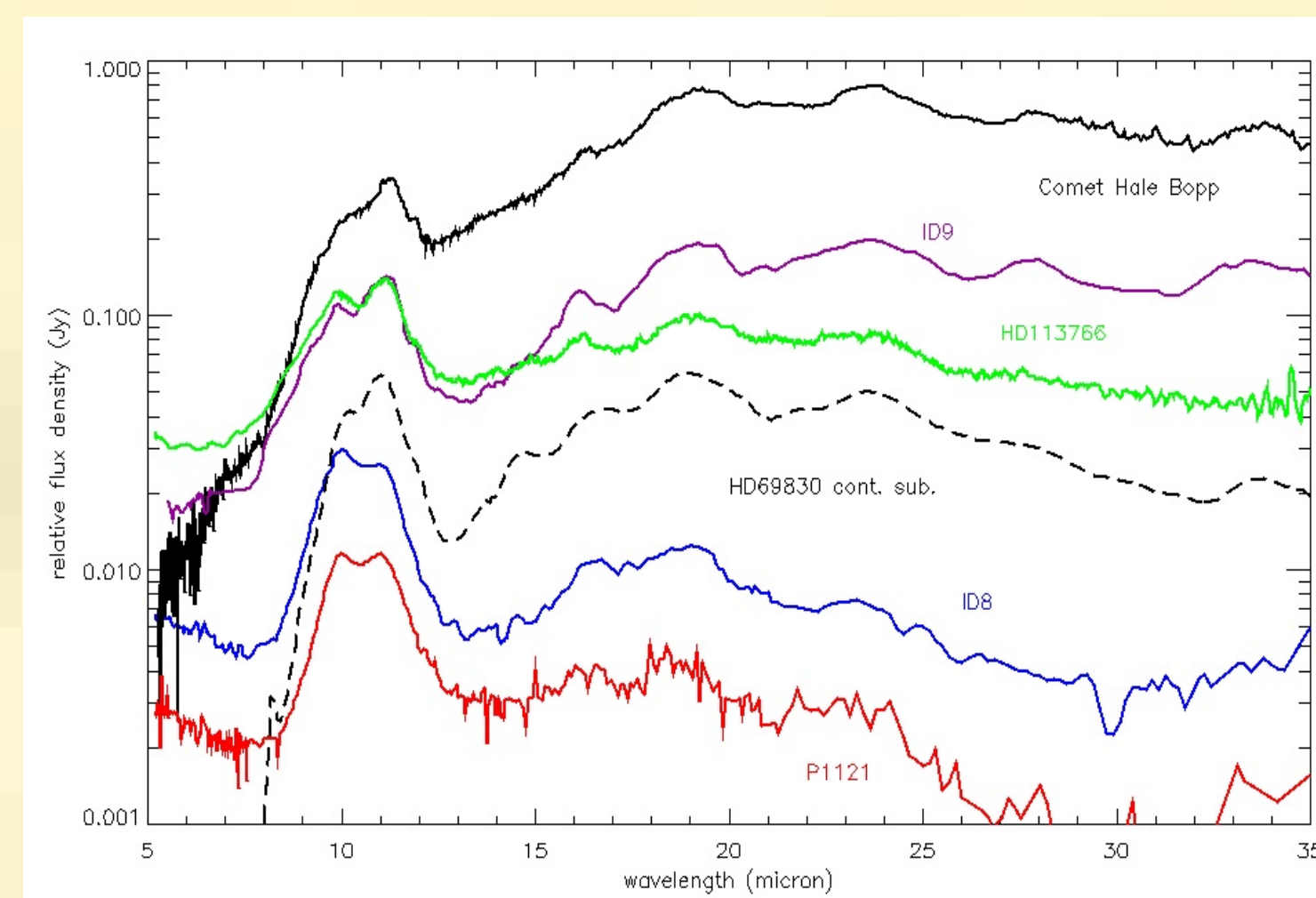


Solid lines show Kurucz's model photospheres of 4250 and 5700 K, dotted line shows median SED of CTTS, and diamonds present observed fluxes (multiplied by 1, 100, and 10000 times for clarity).

From Gorlova, et al. 2007 ApJ and Su et al. in preparation

The SED of ID8 can be described with a disk between 0.1-1 AU containing 3-10 lunar masses of rocky material. The age of its parent cluster, NGC2547, is 30-40 Myrs, coinciding with the origin of the Moon in our Solar system, when a Mars-size body collided with the proto-Earth. The IR excess in this system can therefore originate from the circumplanetary disk, as the left-over rocks grind to dust within  $\sim 1$  Myr time-frame after collision.

**ID8 so far is the best candidate for the extra-solar lunar cataclysm. We therefore dub it the Moon star.**



Compilation from Chen et al. 2006 ApJS, Beichman et al. 2005 ApJ, Lisse et al. 2008 ApJ, Su et al. in preparation

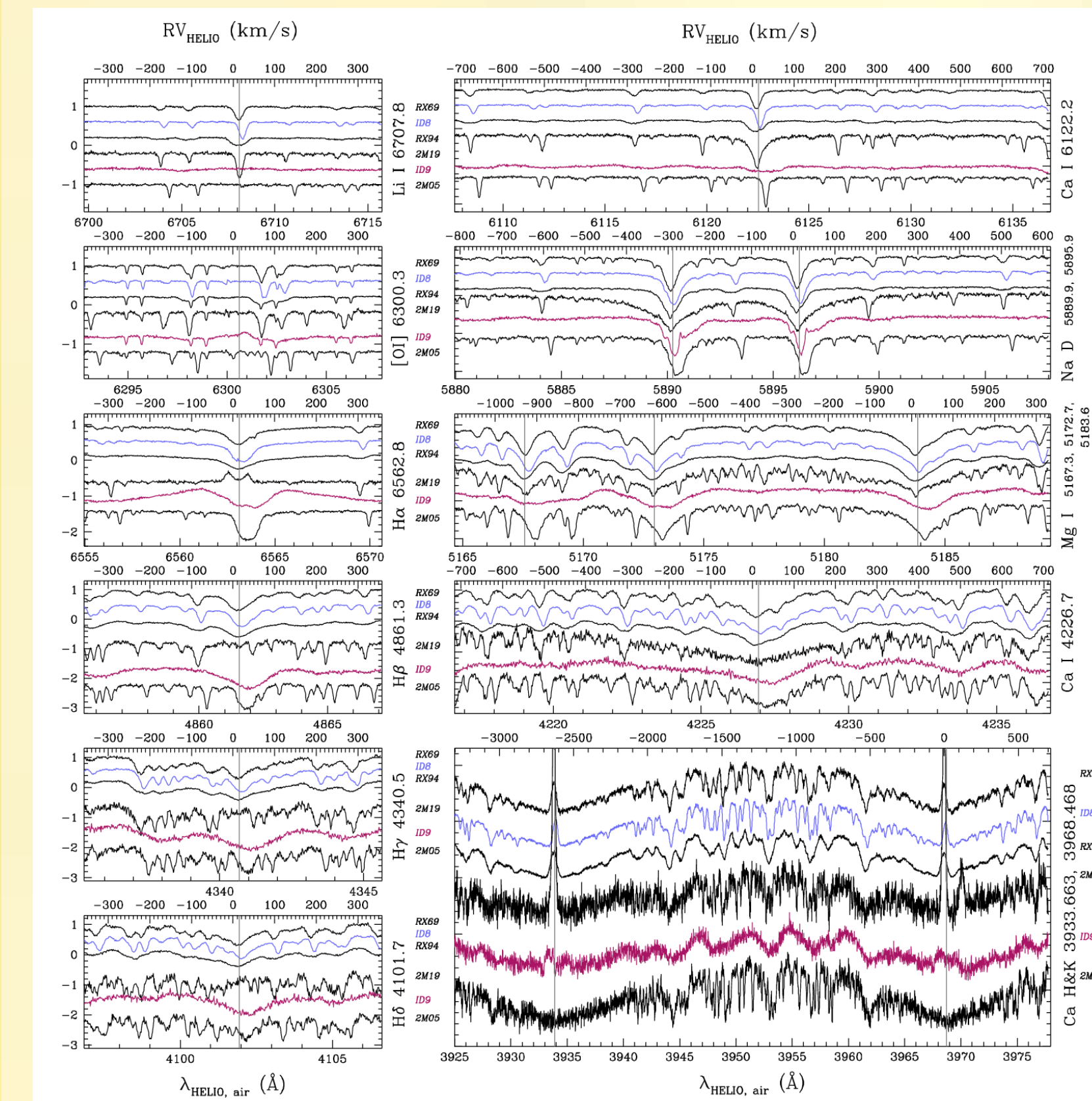
The IRS spectra of the extreme excess stars and a comet to show the rich observed dust features. Only spectrum of the "comet star" HD69830 is continuum subtracted. Spectra are arbitrary scaled for clarity. **The majority of the features are from the micron-size amorphous and crystalline silicates.** Detailed identification of the components can be found in Lisse et al. 2007, 2008 ApJ; 2007 Icarus.

## PART II

### VLT UVES Echelle Optical Spectroscopy

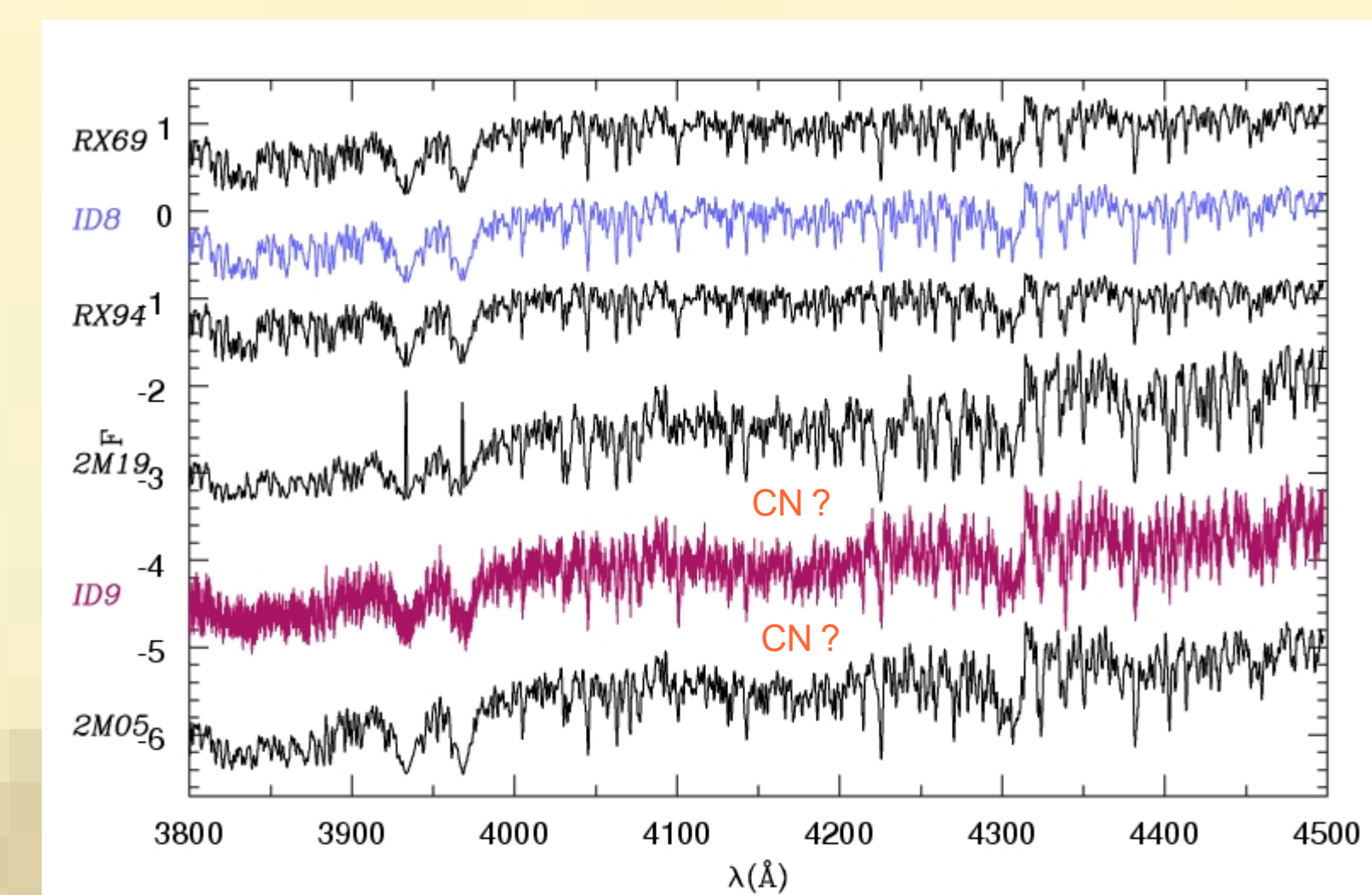


In order to verify whether ID8 and ID9 are the Main Sequence 40 Myr-old stars belonging to the NGC2547 cluster or background giants, as well as whether they are accreting gas, we obtained  $R\sim 60,000$  spectra over 3300-6800 Å range at the VLT. We observed ID8, ID9, and four other NGC2547 stars of similar V-K color but without an IR excess:



Based on the radial velocity (RV) (the cluster mean is indicated with a line), the presence of the Li line, emission in the Ca II H&K lines, and broad wings in the saturated lines, **RX69, ID8, RX94, and 2M19 are cluster members.** Note, however, that RV of ID8 can be variable.

**2M05 and ID9 do not satisfy these criteria and are likely background giants.** Note a broad double-peaked emission in H $\alpha$ , indicating origin in a gaseous disk?



**ID9 is a fast-rotating star** ( $v \sin i \sim 60$  km/s). We consider it to be a red giant primarily based on the CN band (see R. Gray's on-line sp. atlas). **ID9 can be a binary** post-AGB giant with a circumbinary disk such as the **RV Tau systems** RU Cen and AC Her in Gielen et al. 2007 A&A.

This Table summarizes the photospheric parameters we determined from the UVES spectra. We used the line-ratio method for determination of the  $T_{\text{eff}}$  (Kovtyukh & Gorlova 2000 A&A), the LTE WIDTH9 code that utilizes line equivalent widths, and the synthetic spectrum calculations based on the Atlas models.

star	$T_{\text{eff}}$ (K)	SpT	$\log g$ (dex)	$[Fe/H]$ (dex)	$v \sin i$ (km/s)	RV (km/s)
RX69	5581	G7	4.2	-0.04	15	13
ID8	5591	G7	4.5	0.03	7	21
RX94	5711	G6	4.1	-0.1	30	12
2M19	4683	K3	4	-0.02	6	14
ID9	$\sim 5000$	$\sim K0$ III	$\sim 2.5$	-	60	45
2M05	4761	K0 III	2.5	-0.37	2	35

From Gorlova, et al. in preparation

The membership of ID8 is additionally confirmed based on the spectrophot. parallax, surface gravity ( $\log g$ ), and metallicity.