What are ‘debris disks’ & why interesting?

Discovery by IRAS: ‘IR excess’
- Surprise discovery: ~15-20% of nearby A-K stars show larger IR flux than predicted from the stellar photosphere (e.g. Aumann 1985)
- ‘Vega phenomenon’ – ‘Fab four’:
  - Vega – A0V at 7.8 pc, ~350 Myr
  - β Pictoris – A5V at 19 pc, ~12 Myr
  - Fomalhout – A3V at 7.7 pc, ~200 Myr
  - ε Eridani – K2V at 3.2 pc, ~800 Myr

Confirmed by later studies
- ISO @60 µm (Habing et al. 2001):
  - 14 of 84 (17%) A-K stars at <25 pc
  - A stars over-represented
- Spitzer @70 µm (Trilling et al. 2006):
  - A stars: ~ (26 +10/-7) %
  - FGK stars: ~ (21 +7/-5) %
  - M stars: 0

Interpretation of observed IR excess
- Dust grains around stars
- Need to be replenished, on time-scales short compared to stellar ages
- Infer planetesimals (<10s of km), dust produced by ‘collisional cascades’
- Connection to planets ‘unclear’

Our solar system
- Asteroid (‘zodiacal’) and EKB
- Could not be observed if at 10 pc!
Comet massacre around Fomalhaut

Herschel/PACS @70 μm

Acke et al. 2012
A&A 540, A125
Comet massacre around Fomalhaut

- Optically large >50 $\mu$m grains, thermal small (blow-out) grains => ‘fluffy aggregates’
- Replenishment time $\sim$1700 yrs
- Mass loss (=production) rate $\sim$2000 (1 km) comets per day
- Reservoir of $\sim$10$^{13}$ comets, with a total mass of $\sim$100 $M_{\text{Earth}}$
- Currently a remarkably violent system!
• Spitzer/IRAC 22-34 um
• Herschel/PACS 69 um band => Mg-rich crystalline olivine
• Mg-rich => ‘pristine’
• Fe-rich => ‘processed’
Debris Disks and DUNES Open Time KP

Overall objective: Detect and characterise faint exo-solar analogues to the solar system Edgeworth-Kuiper Belt (EKB)

- Direct proof of incidence of planetesimal systems (possible indirect one of planets)
- Specifically, to evaluate the
  - fraction of solar-type stars with faint, EKB-like, discs
  - collisional and dynamical evolution of these EKB analogues
  - dust properties and size distribution of these EKB analogues
  - incidence of EKB-like discs versus host star properties, including the presence of planets
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**The DUNES sample**

- FGK stars <20 pc (+known planet/disk stars <25 pc)
- Detect photosphere ($L_{\text{star}}$) with SNR >5 @100 $\mu$m, puts reqs on background => avoid galactic plane
- Time allocation: split & share with DEBRIS
- DUNES 20 pc sample: 20 F, 50 G, 54 K, $\Sigma$ 120
- DEBRIS 20 pc sample: 32 F, 16 G, 8 K, $\Sigma$ 56
- **Sun:** EKB peaks ~50 $\mu$m, PACS fluxes ~0.1-0.4 mJy, and ‘fractional luminosity’ $f_d = \frac{L_{\text{disk}}}{L_{\text{star}}} \sim 10^{-7}$
<table>
<thead>
<tr>
<th>Spectral type</th>
<th>F</th>
<th>G</th>
<th>K</th>
<th>Σ</th>
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<tbody>
<tr>
<td>Sample</td>
<td>20</td>
<td>50</td>
<td>54</td>
<td>124</td>
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<tr>
<td>Excess #</td>
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<td>11</td>
<td>10</td>
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Points noted:

- Of these 124 stars 15 (12%) have Spitzer disk detections
- Herschel disk detection is a factor 25/15 (~1.7) higher
- Herschel has resolved many more disks
- Mean $f_d$ values for ‘new’ & ‘old’ disks are $\sim 4 \times 10^{-6}$ & $\sim 4 \times 10^{-5}$
- Mean disk temp $T_d$ for ‘new’ & ‘old’ disks are $\sim 34$ K & $\sim 64$ K
- Mean black body radius for ‘new’ & ‘old’ disks are $\sim 82$ AU & $\sim 38$ AU

Herschel has detected fainter, colder, larger disks – as expected

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Eiroa et al. 2013  A&A 555, A11
Example observations

Top: HIP13402, PACS 100 µm, PACS 160 µm, SED; bottom HIP 14954

Eiroa et al. 2013 A&A 555, A11
What do we learn – correlations!?

Legend
• F stars
• G stars
• K stars
• $f_d$ units of $10^{-7}$

Correlations?
• $f_d$ vs age?
  – no
  – surprise!?
• $R_d$ vs age?
  – weak?
• $T_d$ vs age?
  – weak anti?

Eiroa et al. 2013
A&A 555, A11
Comparison of 37 stars known to host RV planets with 11 DUNES/DEBRIS cold debris disks – disk incidence ~30%

Legend
- Disks: debris disks, triangles: upper limits
- Data points:
  - Blue – low mass planet (<30 $M_{\text{Earth}}$~0.1 $M_{\text{Jup}}$)
  - Green – hot giant planet (>0.1 $M_{\text{Jup}}$, $R_{\text{P}}$<0.1 AU)
  - Red – cold giant planet (>0.1 $M_{\text{Jup}}$)

Correlations?
- Fract luminosity $f_d$ vs stellar age – no
- Metallicity [Fe/H] vs $f_d$ – ?
- Photospheric temp vs $f_d$ – no
- Mass of most massive planet vs $f_d$ – ?
- Orbit eccentricity of innermost planet vs $f_d$ – no
- Orbit semi-major axis of outer exopl vs $f_d$ – no

Legend
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Correlations?
- Metallicity \([\text{Fe/H}]\) vs \(f_d\) – (?) (19 sub- & 18 supra-solar Z)
- 9 disks low Z stars & 2 disks high Z stars
- Low mass planets – all 10 low Z stars, many (5/10) disks
- Cold giant planets – all stars, some (6/22) disks
- Hot giant planets – all 5 high Z stars, no (0/5) disks

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Correlations?
• Mass of most massive planet vs $f_d$ – ?
• Low mass planets – w/wo disks
• Cold giant planets – w/wo disks
• Hot giant planets – no disks!

In summary, what we observe:

- **All 10 low mass planets** with low Z stars (10/19 vs 0/18), many (5/10) with disks.
- Cold giant planets – with low (9/19) & high Z (13/18) stars, some (6/22) disks, (4/9) low Z & (2/13) high Z stars.
- **All 5 hot giant planets** with high Z stars (5/18 vs 0/19), none (0/5) with disks.

What we see:

- **All 10 low mass planets** with **low Z** stars (10/19 vs 0/18), many (5/10) with disks
- Cold giant planets – with low (9/19) & high Z (13/18) stars, some (6/22) disks, (4/9) low Z & (2/13) high Z stars
- **All 5 hot giant planets** with **high Z** stars (5/18 vs 0/19), none (0/5) with disks

Correlations

- Exoplanet host star sample is **not** significantly different from the (larger and unbiased wrt to planets) DUNES sample
- **No trend** wrt disks and **spectral type** of FGK stars
- **Hot giant planets** and other planets do **not** come from same underlying distribution of stars, and have **no disks**
- **Low Z** stars are more likely to have **low mass planets**, and to have **detectable debris disks**
- **Low mass planets** are more likely to be **associated with debris disks**

Some thoughts

It must not be forgotten:
• We are talking relatively small number statistics
• We define ‘stars with debris disks’ (SDD) and ‘stars with planets’ (SP), but we must not forget that
  • SDD have disks of certain $f_d$, but possibly all (FGK) stars have DDs at some level

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Some thoughts & possible scenario

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‘Scenario’: low Z stars, low mass planets, and debris disks
• A star forms surrounded by a protoplanetary disk of gas and dust
• Gas is lost/stripped from the disk too quickly for gas giants to form
• Low mass planets form, but do not scatter planetesimals strongly enough
• Speculative – time will tell!

THANK YOU!