

A Systematic Search and Characterization of Dusty Debris Disks



Photo Credit:
T. Pyle (SSC)

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UCLA Journal Club

Why should one care about dusty debris disks?

In 1983 when IRAS first discovered dust particles orbiting Vega and many other main sequence stars, it was not clear whether these “Vega-like” stars were signposts for planetary systems or, rather, signified failed planetary systems.

It is now evident that these dusty disks are associated with planets!

An early observation of a debris disk



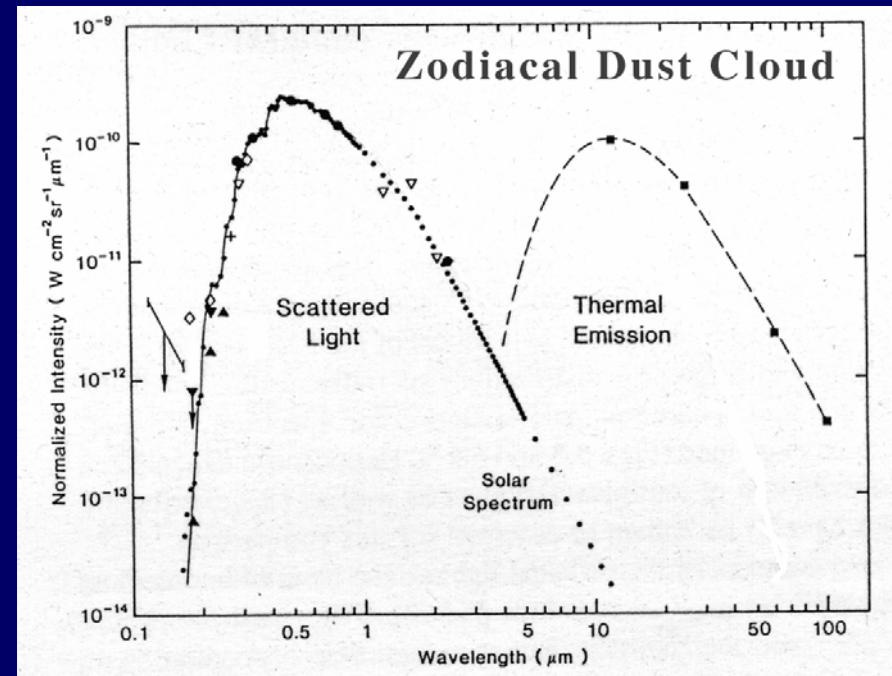
The light at its brightest was considerably fainter than the brighter portions of the Milky Way... The outline generally appeared of a parabolic or probably elliptical form, and it would seem eccentric as regards the sun, and also inclined, though but slightly to the ecliptic. (Captain Jacob 1859)

Paul Kalas

Disk Imaging

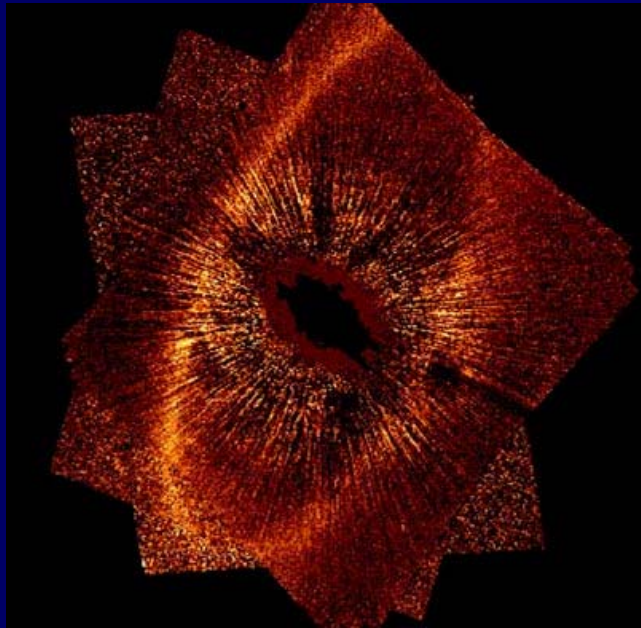
Scattered light at visual and near-IR wavelengths with HST (ACS & NICMOS) and with AO on large telescopes (Keck, VLT, Gemini).

Thermal emission at mid-Infrared wavelengths (e.g. with Keck) and submillimeter wavelengths (with SCUBA at JCMT).

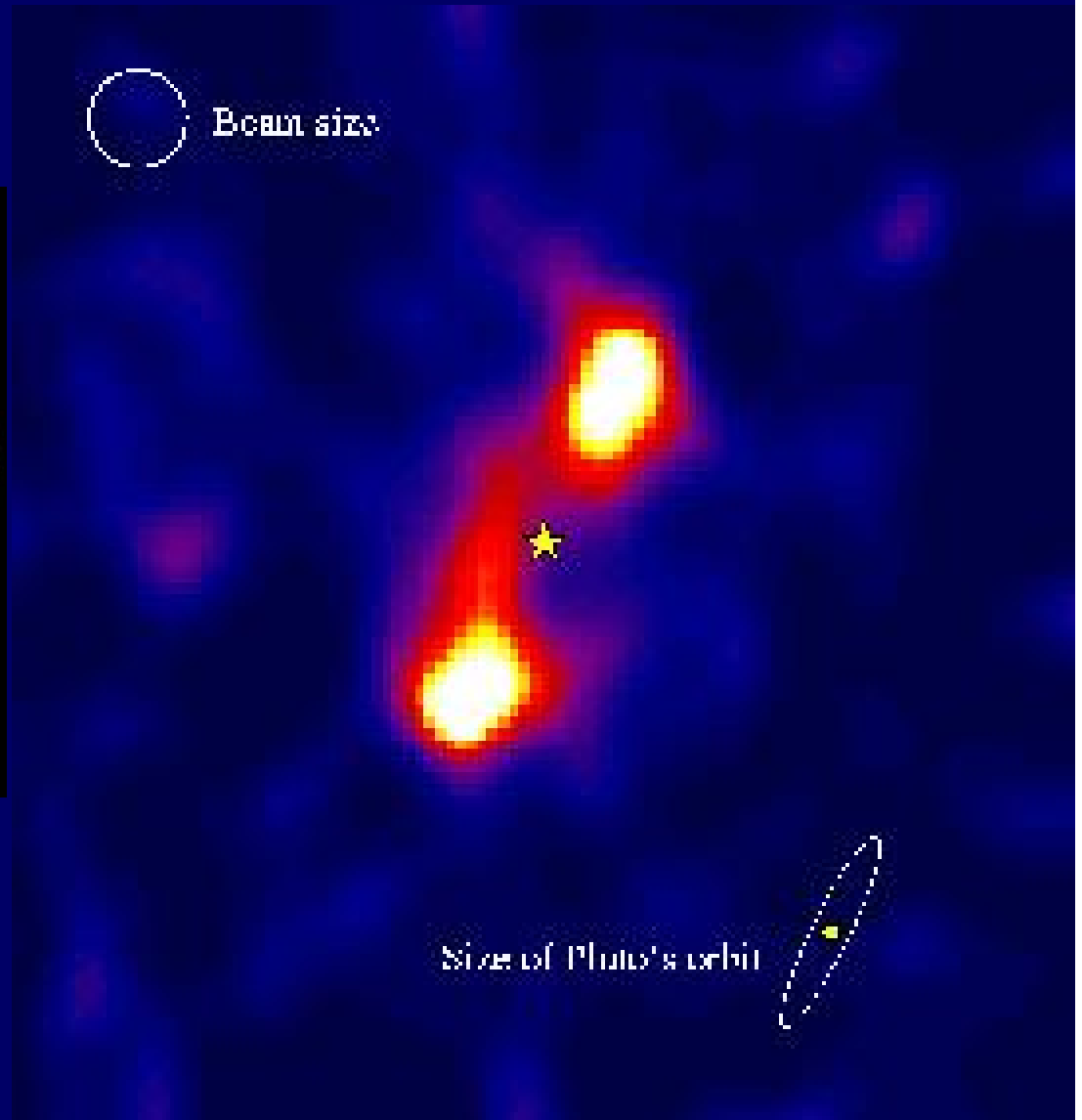


Leinert & Gruen 1990

HST Fomalhaut detection -- consistent with sub-mm maps



Hubble Space Telescope



JCMT SCUBA 450 micron map (Wyatt & Dent 2002)

Debris disk are discovered in the far-infrared: IRAS, ISO, Spitzer

- IRAS was an all-sky survey and made the first debris disk discovery. ISO and Spitzer followed as pointed telescopes.
- It appears that the frequency of disks does not rise rapidly with the sensitivity to decreasing dust mass. Thus, notwithstanding their superior sensitivity, ISO did not and, so far, Spitzer has not added very many newly detected debris disks to those found by IRAS.

Dusty systems discoveries:

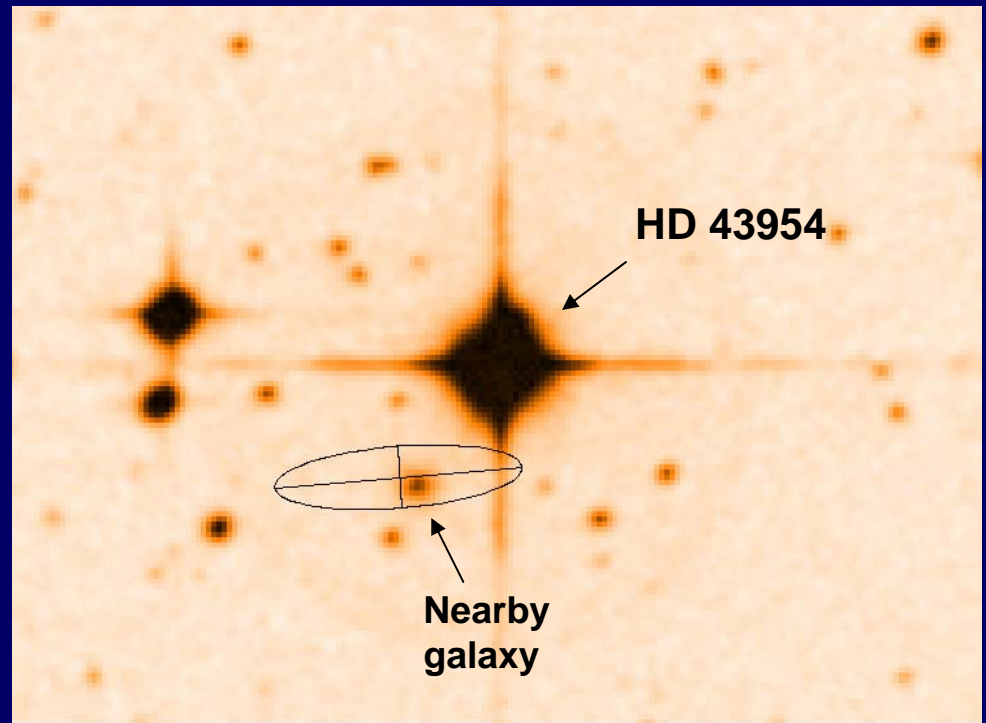
- IRAS ~154 ISO ~22 Spitzer ~few dozen

Why find additional dusty systems?

- Establishment of evolutionary sequences requires large/clean samples of dusty systems of various ages, spectral types.
- Association with binary systems where the secondary might be of stellar or planetary mass or both.
- Previous, IRAS surveys for new dusty disks have been plagued by limited search spaces (stellar catalogs), false positives, poor knowledge of stellar ages, etc.

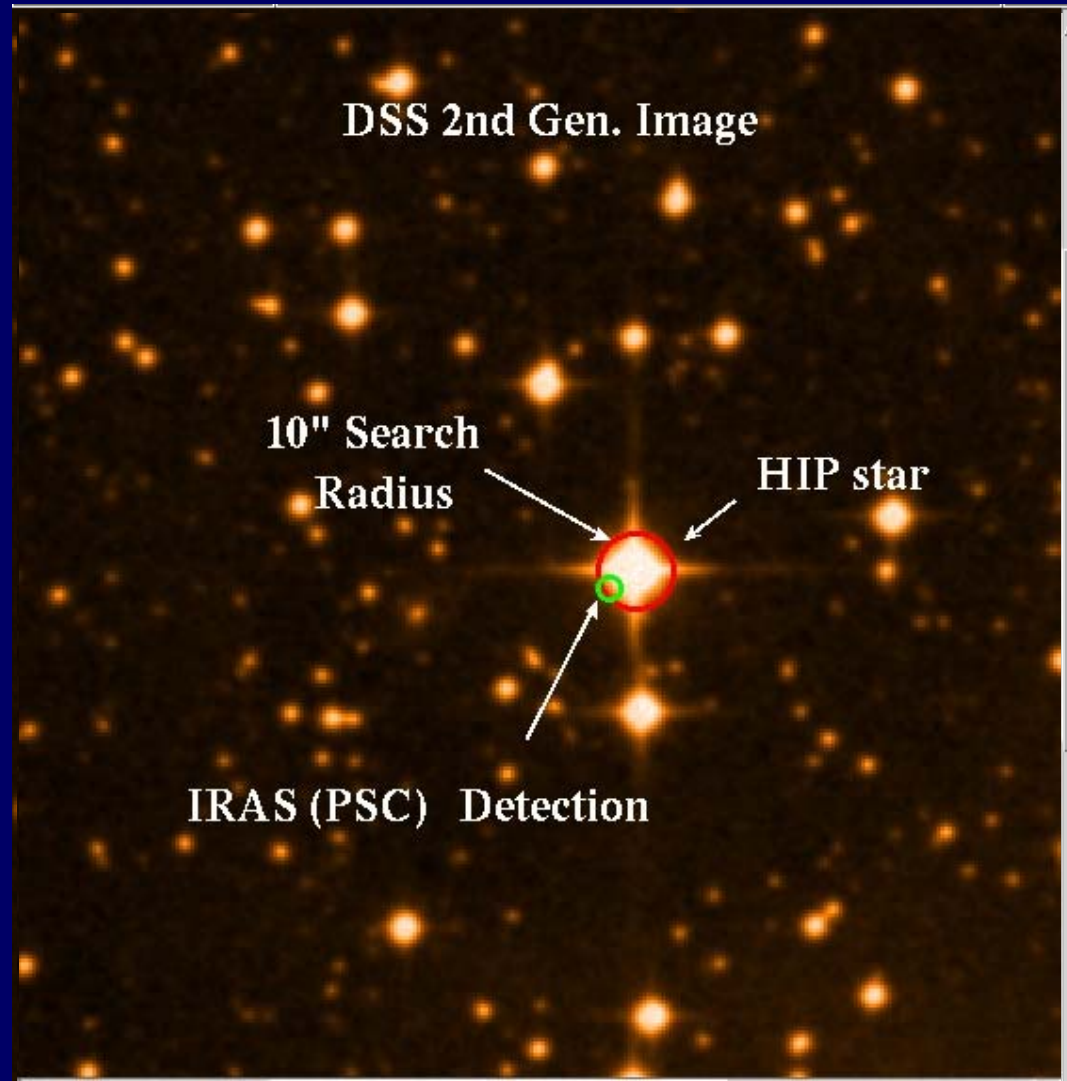
What's the Rumpus?

- Over 900 IR excess stars claimed in literature (ROE debris disk database).
- > 50% false positives due to mis-identification (galaxy contamination, IS cirrus, etc.)
 - HD 43954 (M&B 1998)
- Need a clean list of IR excess stars!
- IRAS being the only IR all sky survey for next 4+ yrs until Astro-F

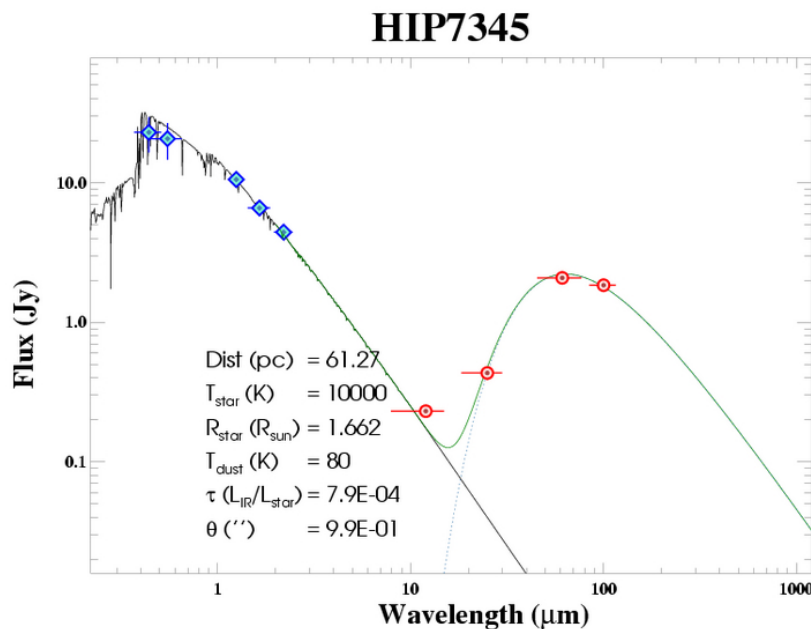
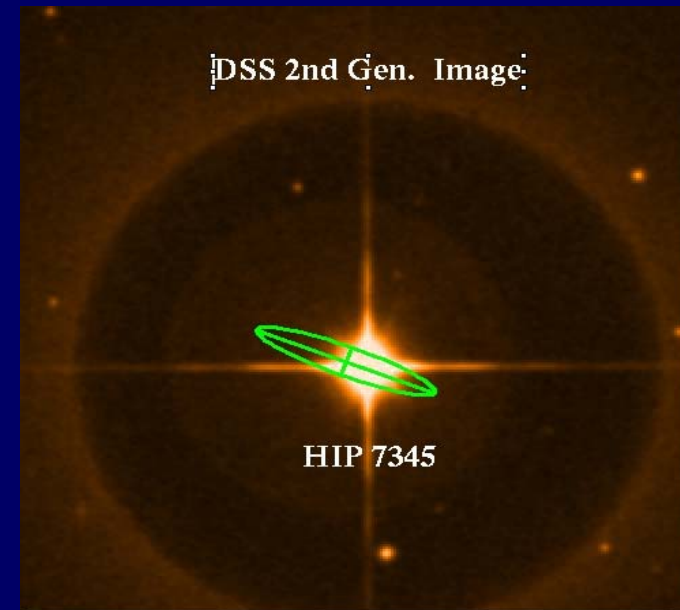
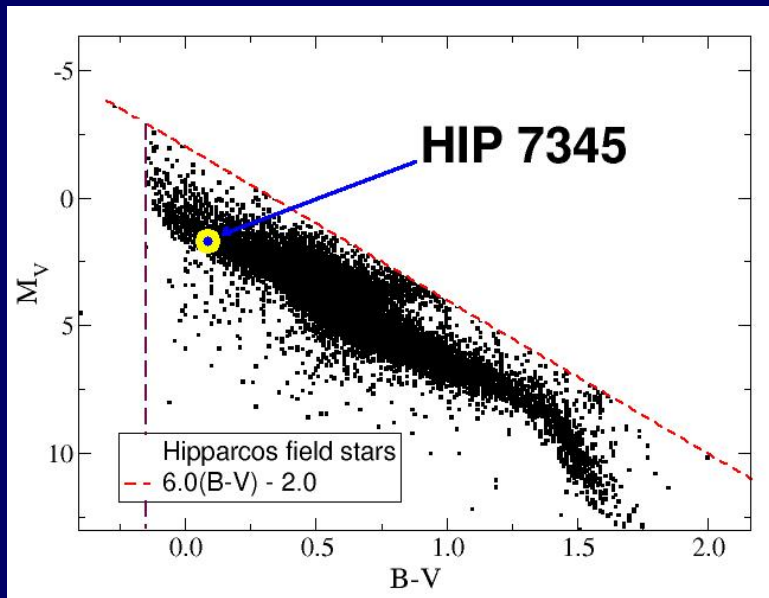


Search Methods

1. Start with the Hipparcos catalog (118,218 stars)
 - ▶ Eliminate giant “contaminants” (~42% of stars -- 68,054 candidates left)
- 2a. IRAS FSC was cross correlated with the 53,157 candidates located out of the galactic plane ($|b| > 10^\circ$)
 - ▶ Make a 45" cross correlation of a Hipparcos MS source and an IRAS (~99.1% of previous candidates eliminated -- ~481 candidates left)
- 2b. IRAS PSC was cross correlated with the 14,897 stars located in the galactic plane.
 - ▶ Make a 10" cross correlation of a Hipparcos MS source and an IRAS (~99.4% of previous candidates eliminated -- 76 candidates left)
3. Remove O1-B5 SpT
4. Remove stars at $d > 120$ pc
5. Visual inspection of detection, for background contaminant (galaxies, interstellar cirrus)
6. SED fit identified PMS stars

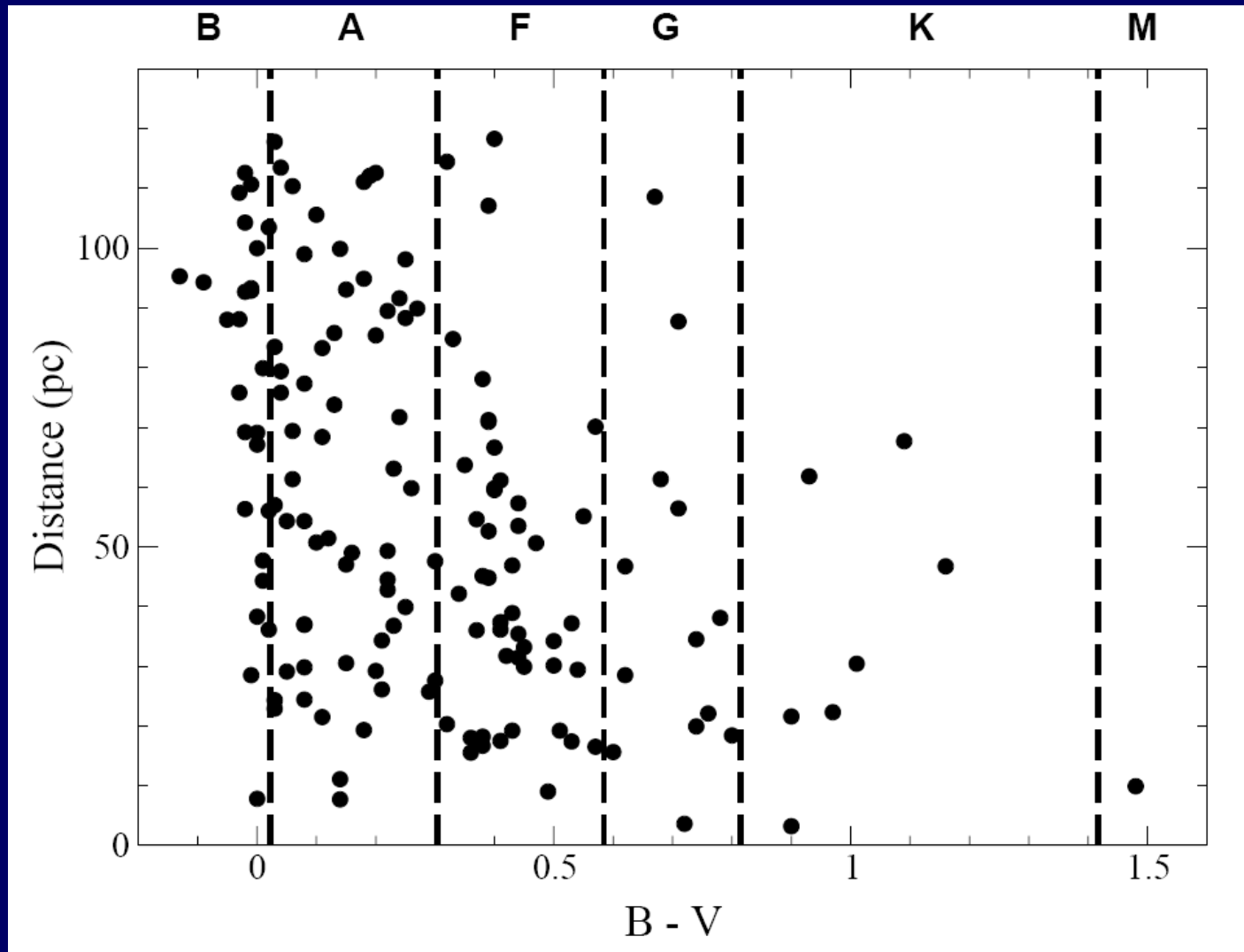


Bona Fide IR Excess Stars



- 154 IRAS Identified Hipparcos dwarfs
- 36 new candidates
- T_{star} , T_{dust} , R_{star} , R_{dust} , τ
- Age estimation
 - Zuckerman & Song (2004)

Distance vs. SpT



Disk Mass and Semi-major Axis (as a function of time)

- Probably the most interesting macroscopic properties of the dusty debris disks are their masses (M) and dimensions (semi-major axis = R).
- $M = \rho N 4\pi a^3 / 3$
- $\tau = N \pi a^2 / 4\pi R^2$ ($= L_{\text{IR}}/L_{\text{bol}}$)
- $\tau / M = 1 / \rho a R^2$

How good a proxy for disk mass is the more easily measured quantity “ τ ”?

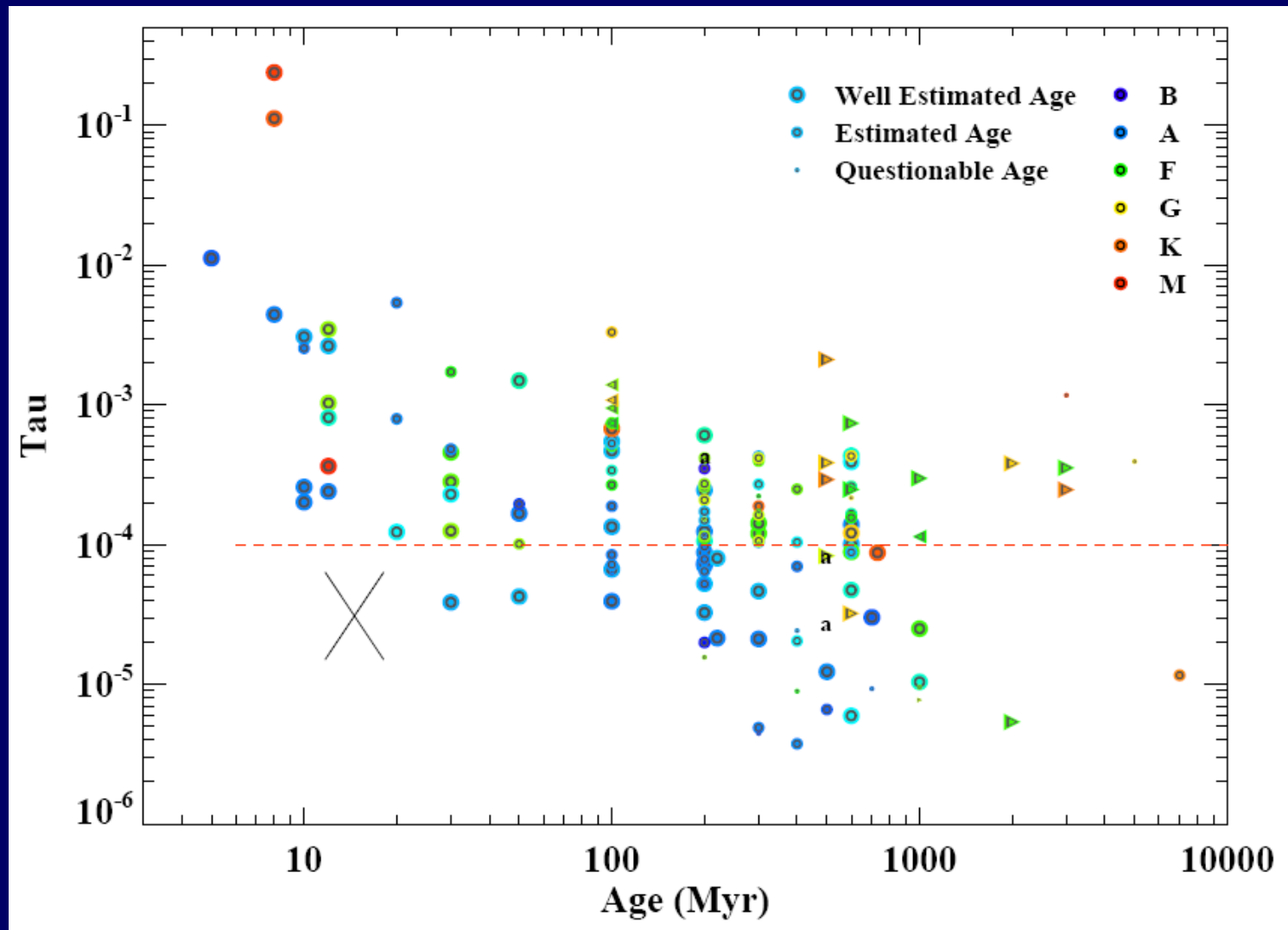
- For a variety of reasons, total disk mass is best measured at submillimeter wavelengths. But τ , which is a measure of far-IR excess emission, is much easier to measure and has been determined for an order of magnitude more stars than has dust mass.

Solar system time scales and ages of young nearby stars

- Formation of Jupiter < 10 Myr
- Formation of Earth's core ~ 30 Myr
- Era of heavy bombardment in inner solar system ~ 600 Myr

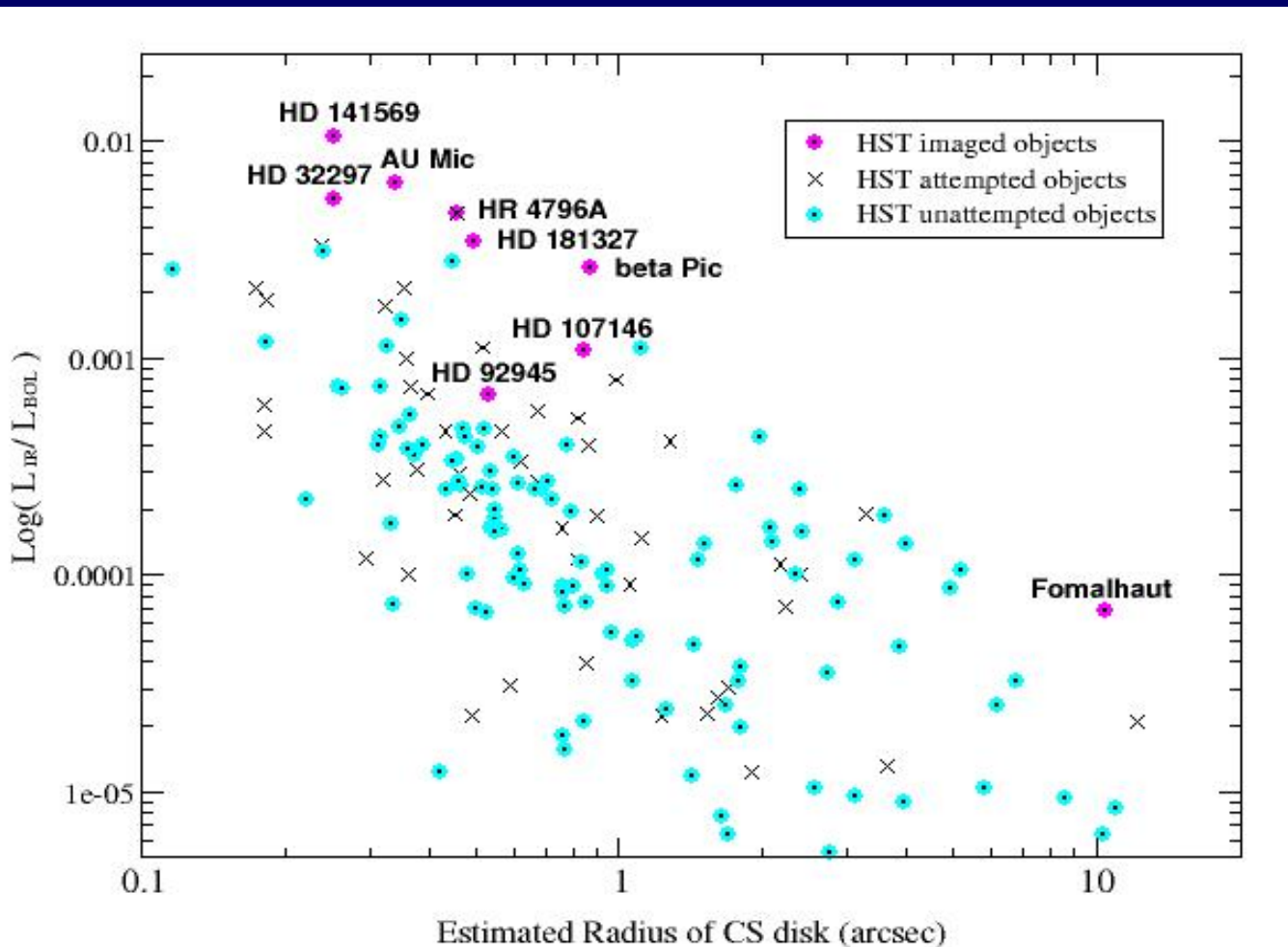
- η Cha cluster 8 Myr
- TW Hydrae Assoc. 8 Myr
- β Pictoris moving group 12 Myr
- Tucana/Horologium Assoc. 30 Myr
- AB Dor moving group 70 Myr

Temporal Evolution of τ



Follow-up Observations

- Spitzer MIPS Photometry with NEOWISE and HST properties.

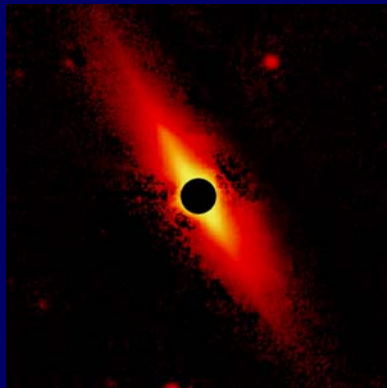


Conclusions

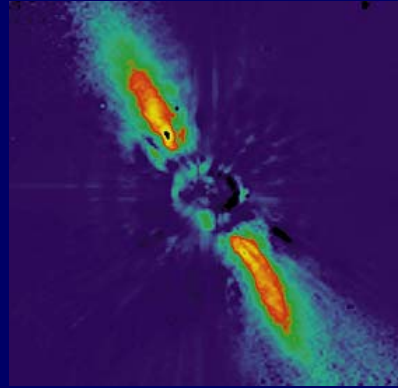
- A correlation of the IRAS and Hipparcos catalogs can be used to identify dusty debris disks.
- Dust masses and disk radii can be estimated from fitting the IR SED, and in combination with the stellar ages, temporal evolution correlations can be inferred.
- IRAS detected excess emission from about 20% of nearby A-type stars.
- Dust masses lie in the range between 0.001 and 1 Earth mass, and they appear to be have little dependence on age.

The End.

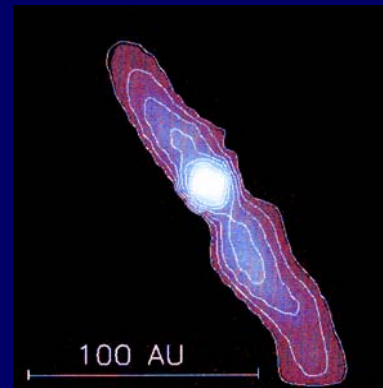
0.5 μm



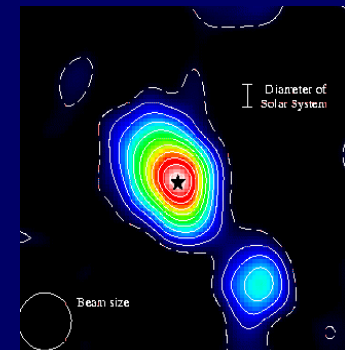
2.2 μm



10-20 μm



850 μm



Images courtesy of Paul Kalas