Debris Disks in the Nearest OB Association

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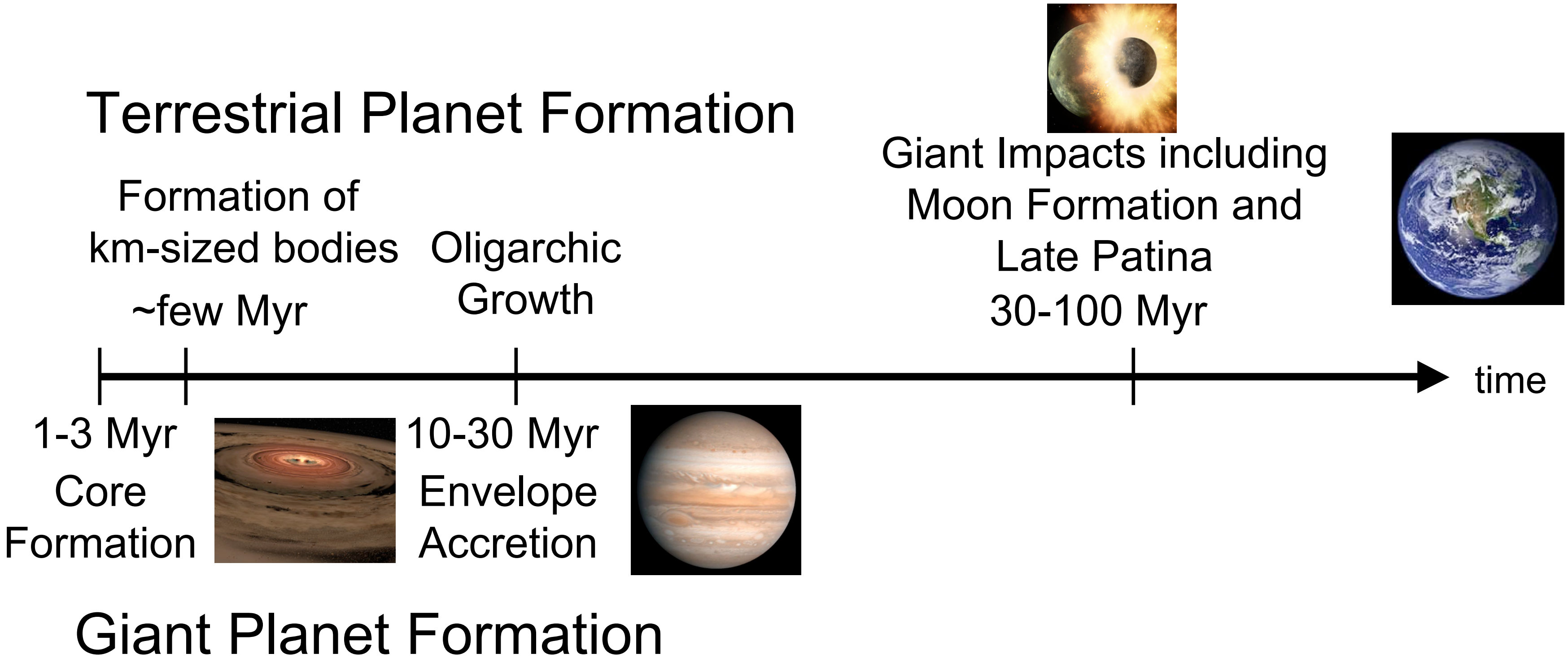
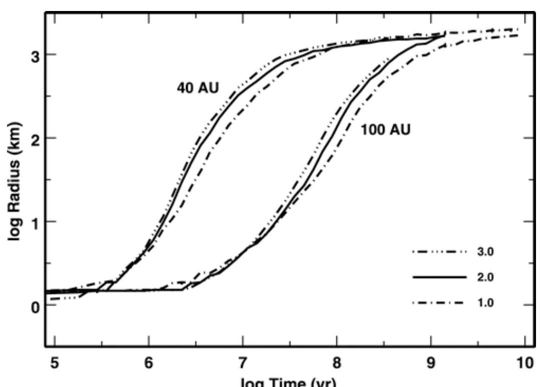
Planet Formation in Our Solar System



- Once gas has dissipated, km-sized bodies agglomerate into oligarchs that stir small bodies
- Infrared observations of dust can help constraint disk properties during the period of oligarchic growth to determine average properties and magnitude of variation

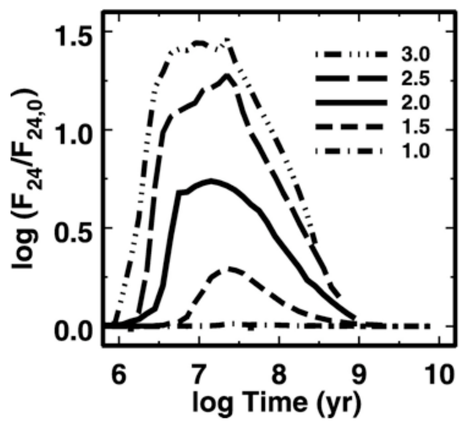
Stellar Properties Impact Disk Evolution

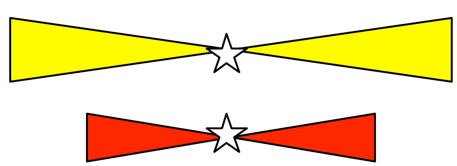
Mass	Luminosity	Wind
⇩	⇩	⇩
Oligarch Formation Timescale	Disk Thermal Radiation	Dust Removal Mechanisms

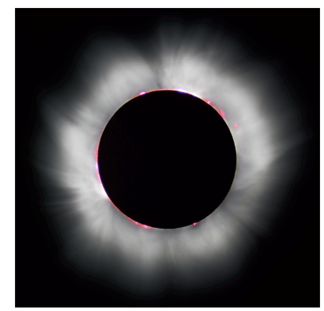


$$t \quad \left(\frac{a}{80\,\mathrm{AU}}\right)^{3}\left(\frac{2M_{sun}}{M_{*}}\right)^{\frac{3}{2}}$$

Kenyon & Bromley 2008





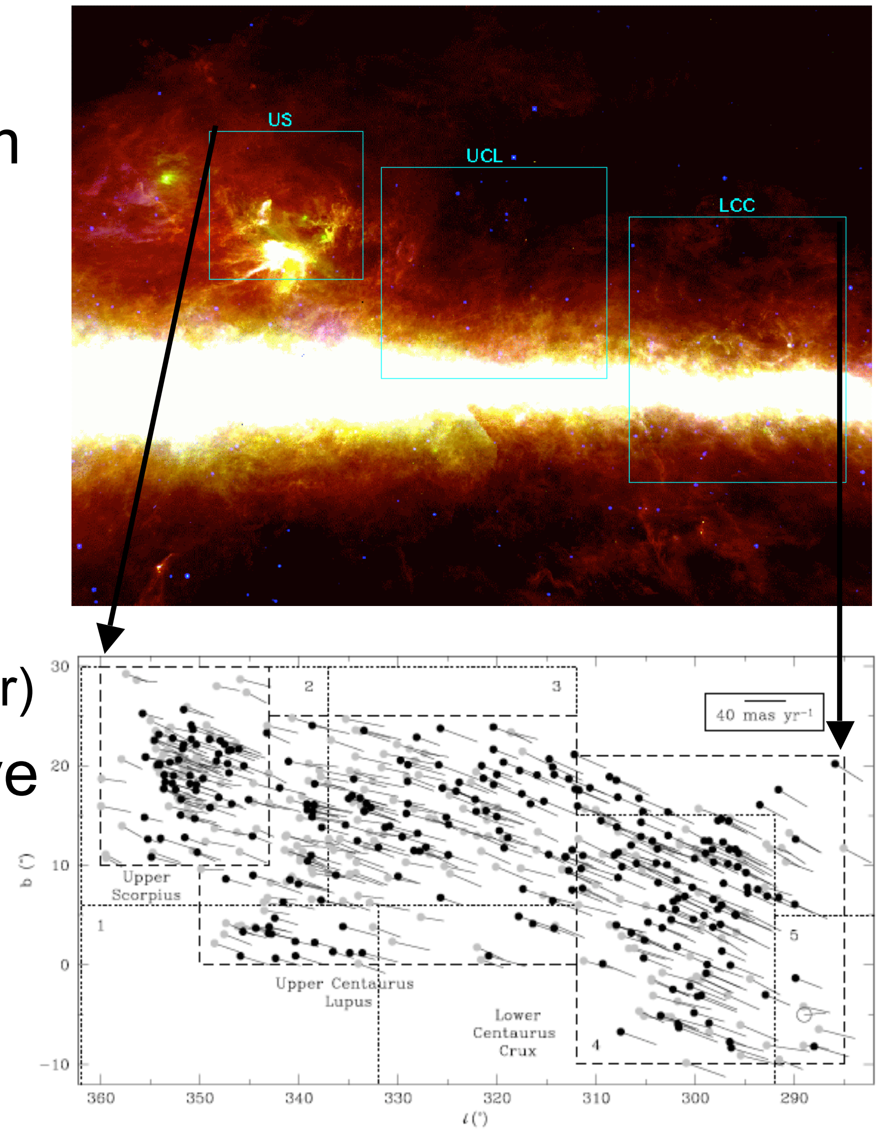


$$\frac{v_{drag}(SW)}{v_{drag}(PR)} = 1 + \frac{\dot{M}_{wind}c^{2}}{L_{*}}$$

Chen et al. 2005

Scorpius-Centaurus OB Association

- Nearest OB association from the Sun with typical stellar distances 100-150 pc
- Contains 3 subgroups:
  - Upper Scorpius (5 Myr)
  - Upper Centaurus Lupus (15 Myr)
  - Lower Centaurus Crux (17 Myr)
- F- and G-type members have been identified based on Hipparcos common proper motion (de Zeeuw et al. 1999)

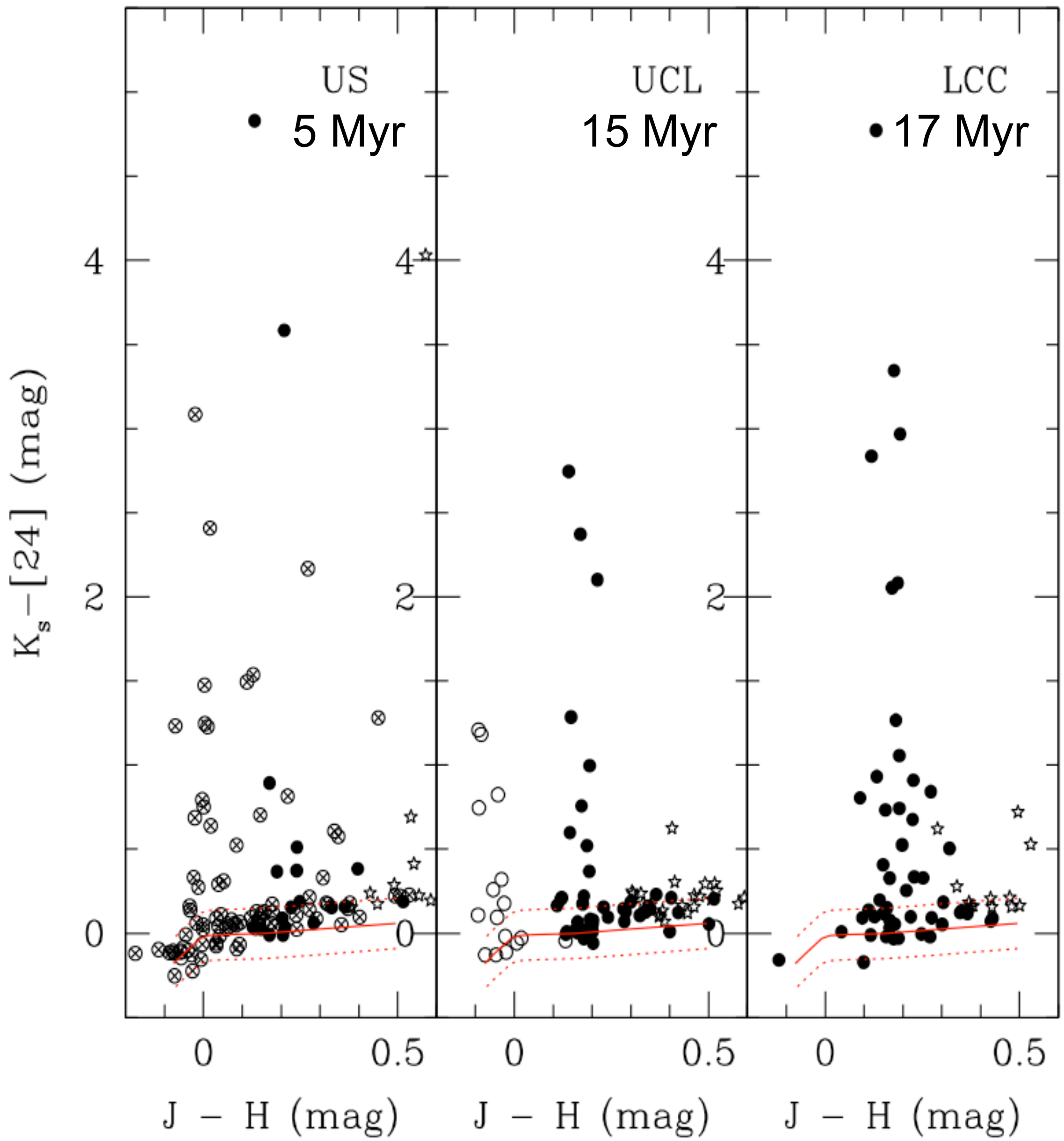


Prebisch & Mamajek 2008

Observations

- Magellan MIKE high resolution (R~60,000) visual spectroscopy
  - Gas phase studies: Hα, CaII H and K/Na I D absorption
  - Stellar Activity Measurements: R'_{HK}, $v\sin i$
- Spitzer MIPS 24 and 70 μm photometry
  - Identify excess candidates
- Follow-up Spitzer IRS low resolution (R~60) mid-infrared spectroscopy
  - Characterize grain composition, size, distance, mass
- Follow-up Spitzer SED mode (R~10) far-infrared observations
  - Characterize grain composition, size, distance, mass

MIPS 24 μm Color-Color Diagram



- Stars with older ages possess more late spectral type stars with 24 μm excess
- Stars with J-H < 0.02 possess significantly larger 24 μm excesses than those of later spectral type

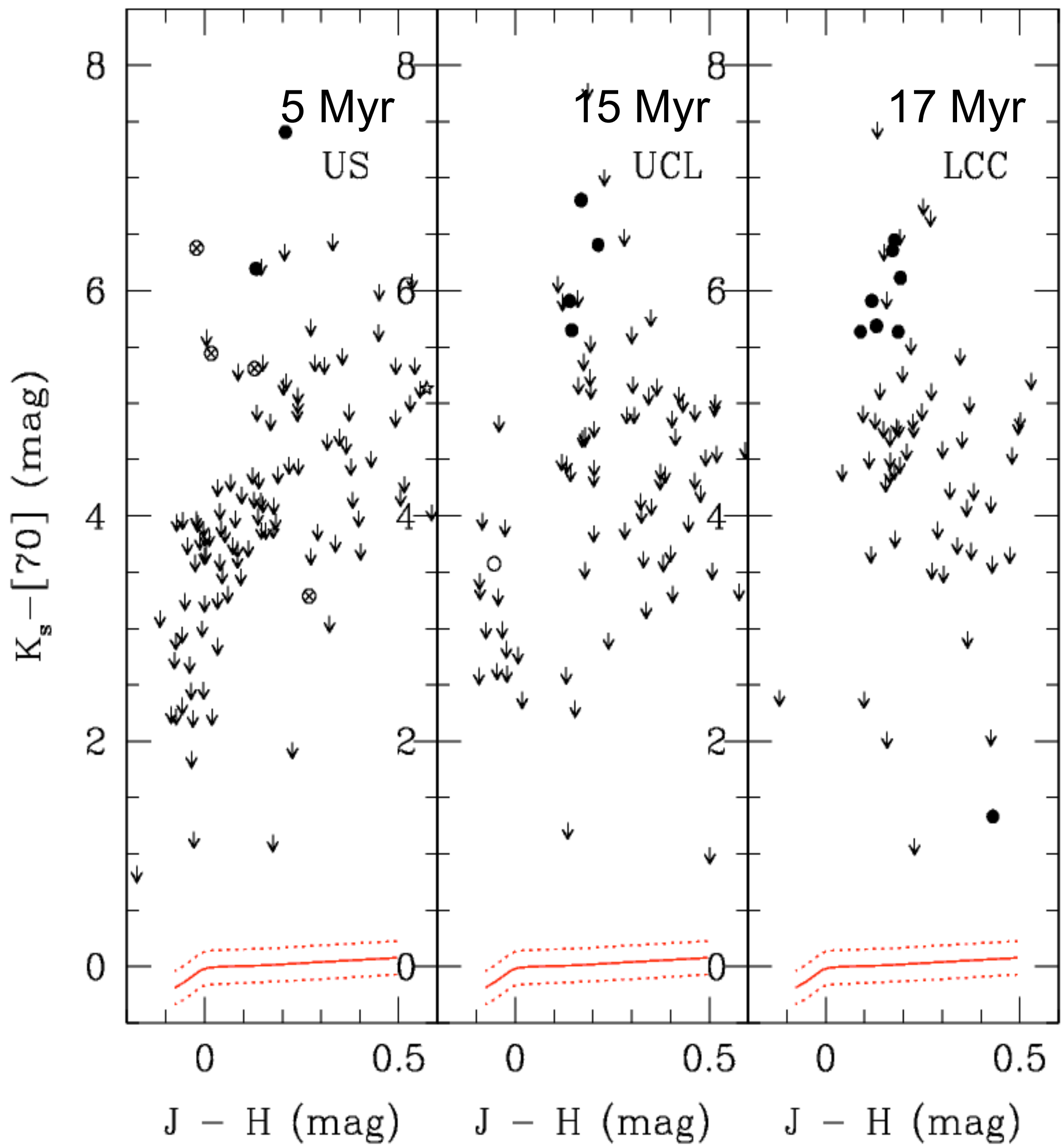
ScoCen F- and G-type Stars: 24 μm Disk Fraction

	FEPS Carpenter 08	US Carpenter 09	ScoCen This work	Total
US 5 Myr	6/9	4/29	6/18	16/56 (29±7%)
UCL 15 Myr	2/10		8/46	10/56 (18±6%)
LCC 17 Myr	7/13		19/49	26/62 (42±8%)

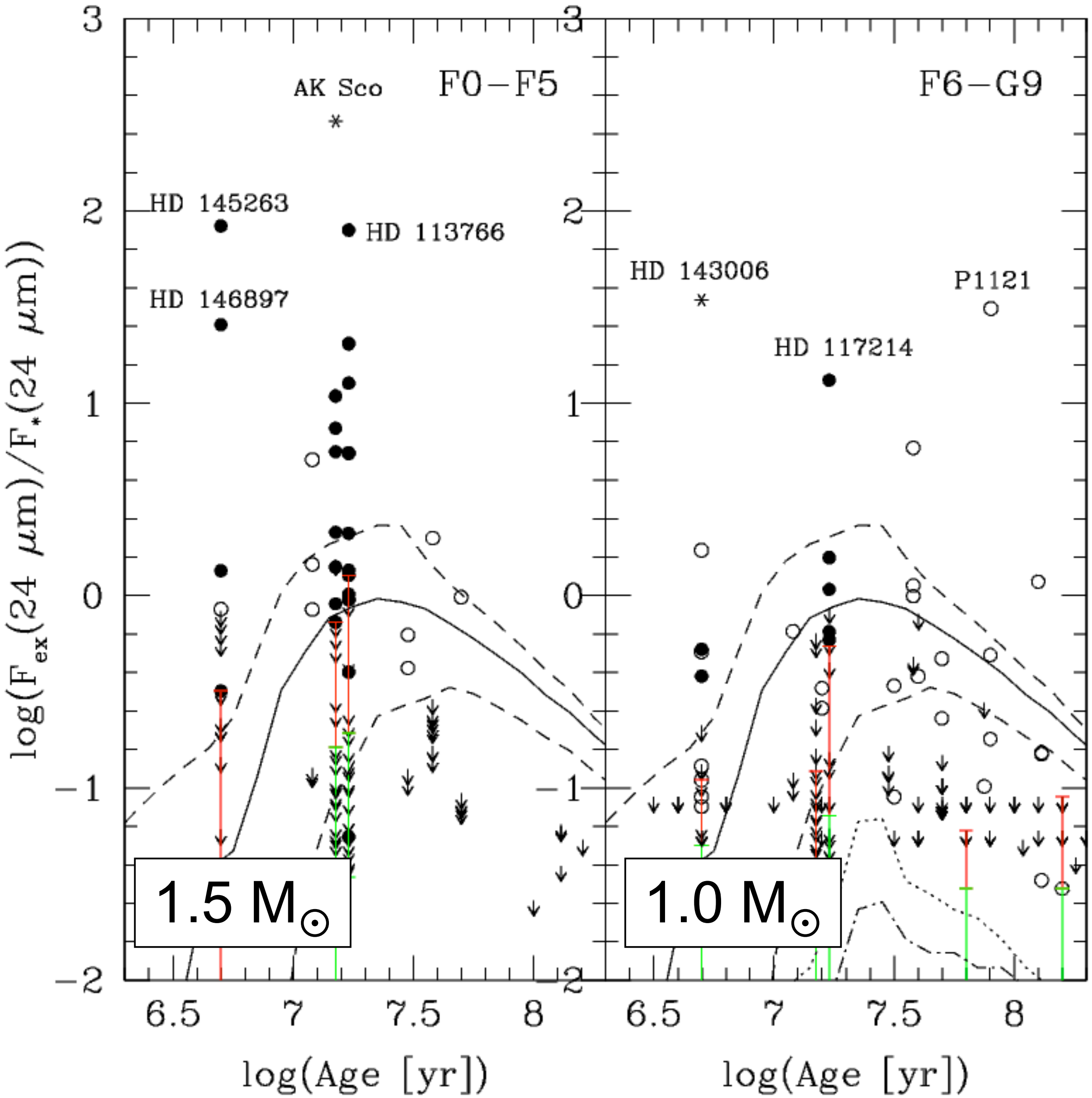
- LCC possesses the highest fraction of F- and G-type stars with 24 μm excess

MIPS 70 μm Color-Color Diagram

- Our MIPS 70 μm observations were very shallow (1 cycle of 10 sec integrations) and were not sensitive to stellar photospheres
- We detect several objects with very bright 70 μm excess



MIPS 24 μm Excess Evolution

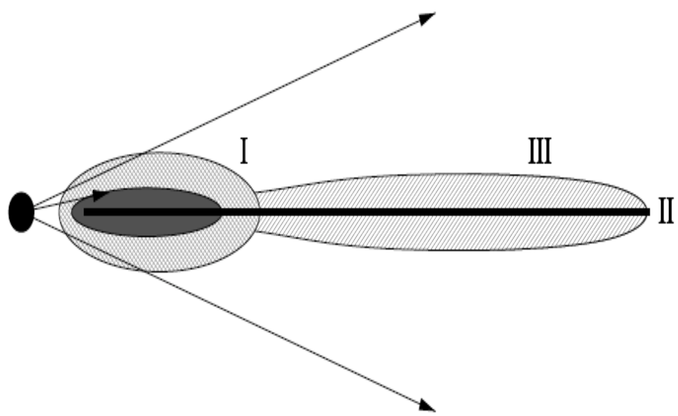


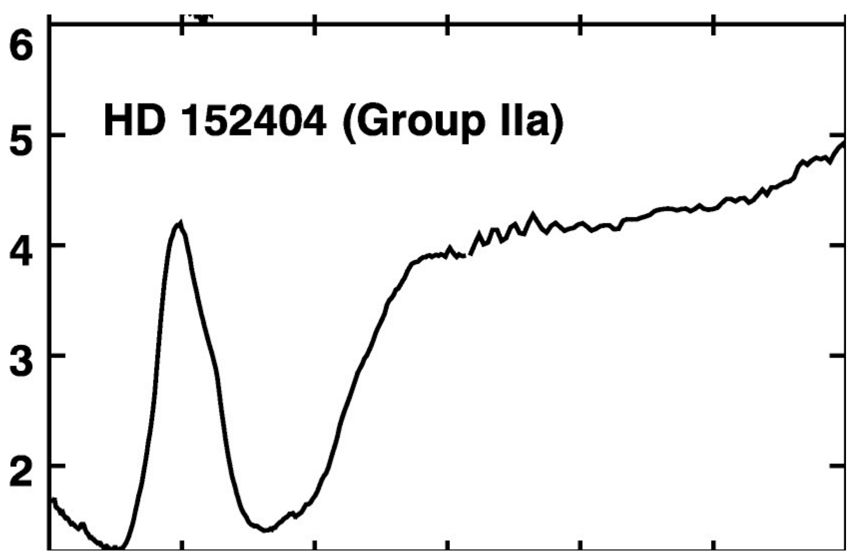
- Our MIPS 24 μm observations of F0-F5 stars are consistent with the Kenyon & Bromley (2008) models, indicating a peak in 24 μm excess at 15-30 Myr

- The Carpenter et al. (2009) observation of US indicate that the late-type stars possess larger 24 μm excess than expected from the models

Both Primordial and Debris Disks Present

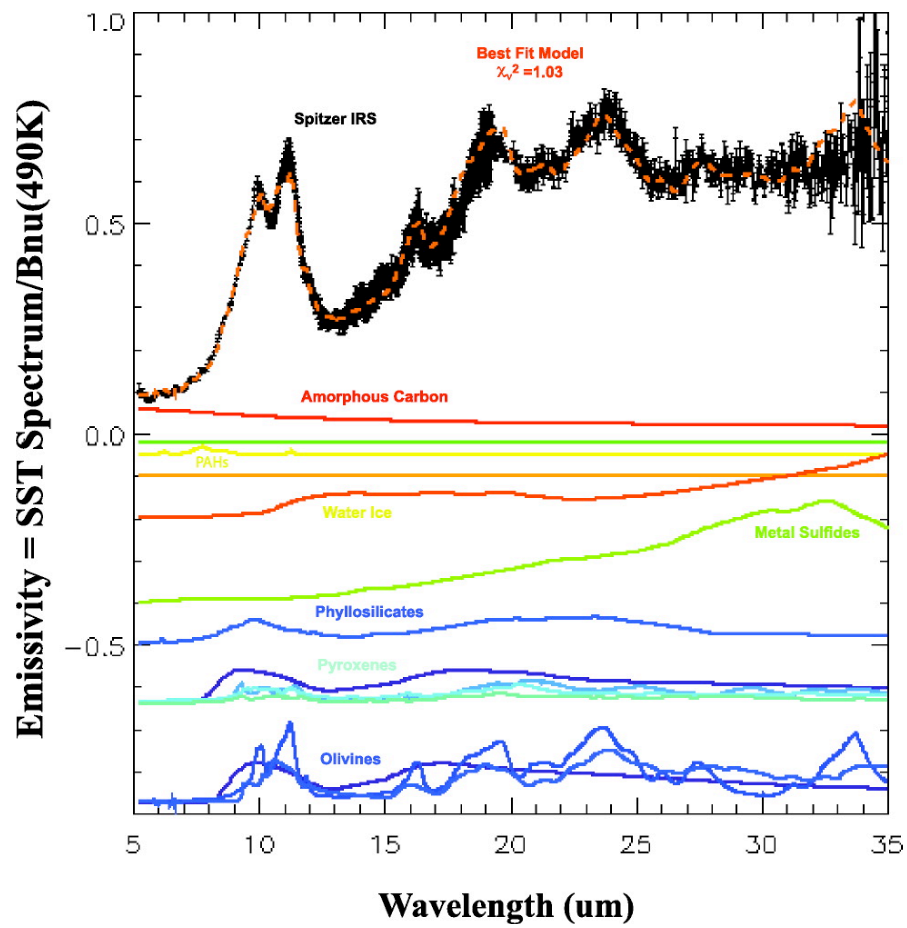
AK Sco in UCL (15 Myr)
PMS Spectroscopic F5 Binary
$dM/dt = 9\times10^{-8}\ M_\odot\ yr^{-1}$





Keller et al. 2008

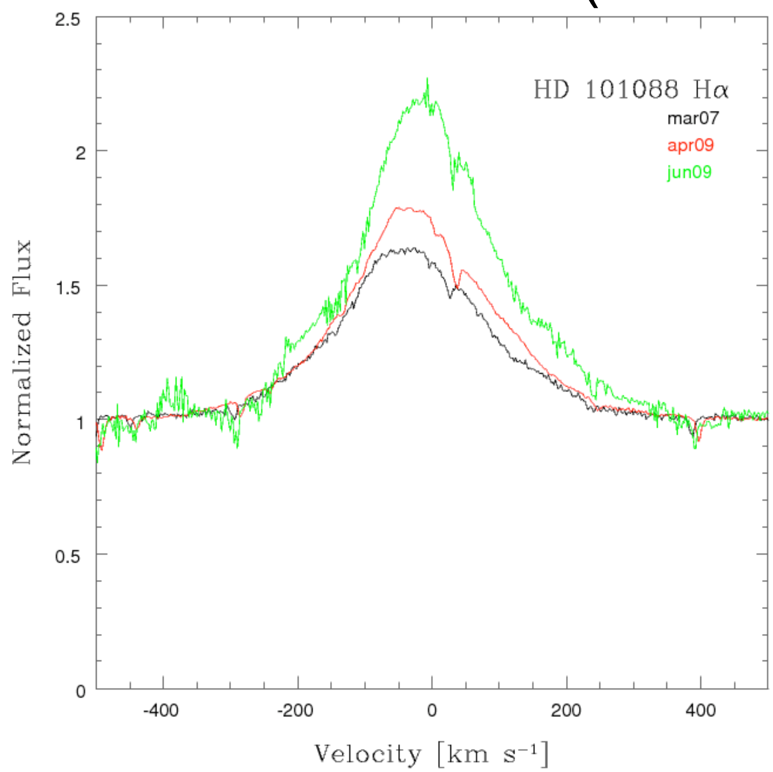
HD 113766 in LCC (17 Myr)
MS 1.3" (170 AU) F3/F5 V Binary
$L_{IR}/L_* = 0.002$

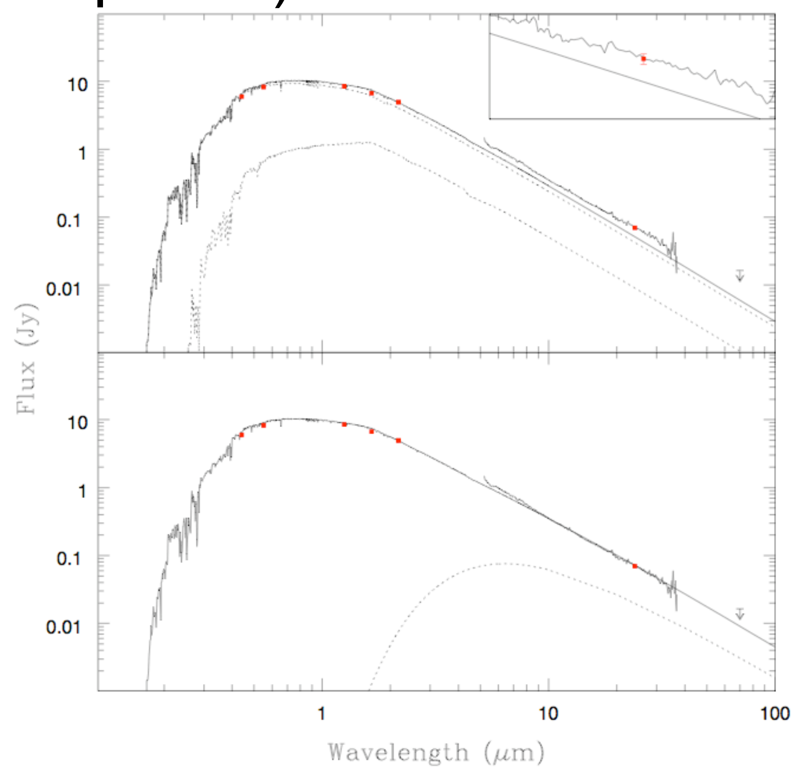


Lisse et al. 2008

HD 101088: An Accreting Binary with a Weak Infrared Excess

(M. Bitner poster)

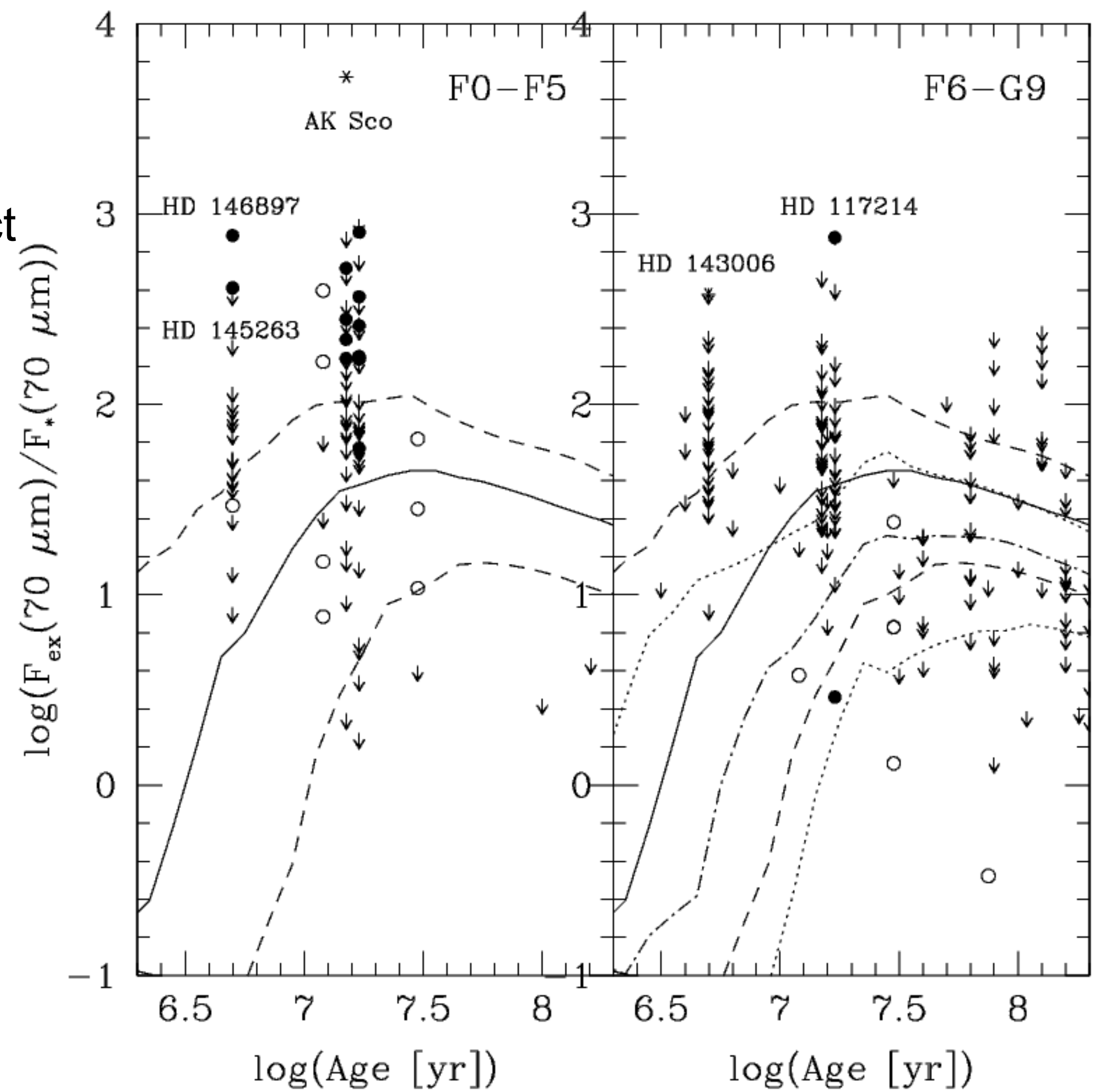




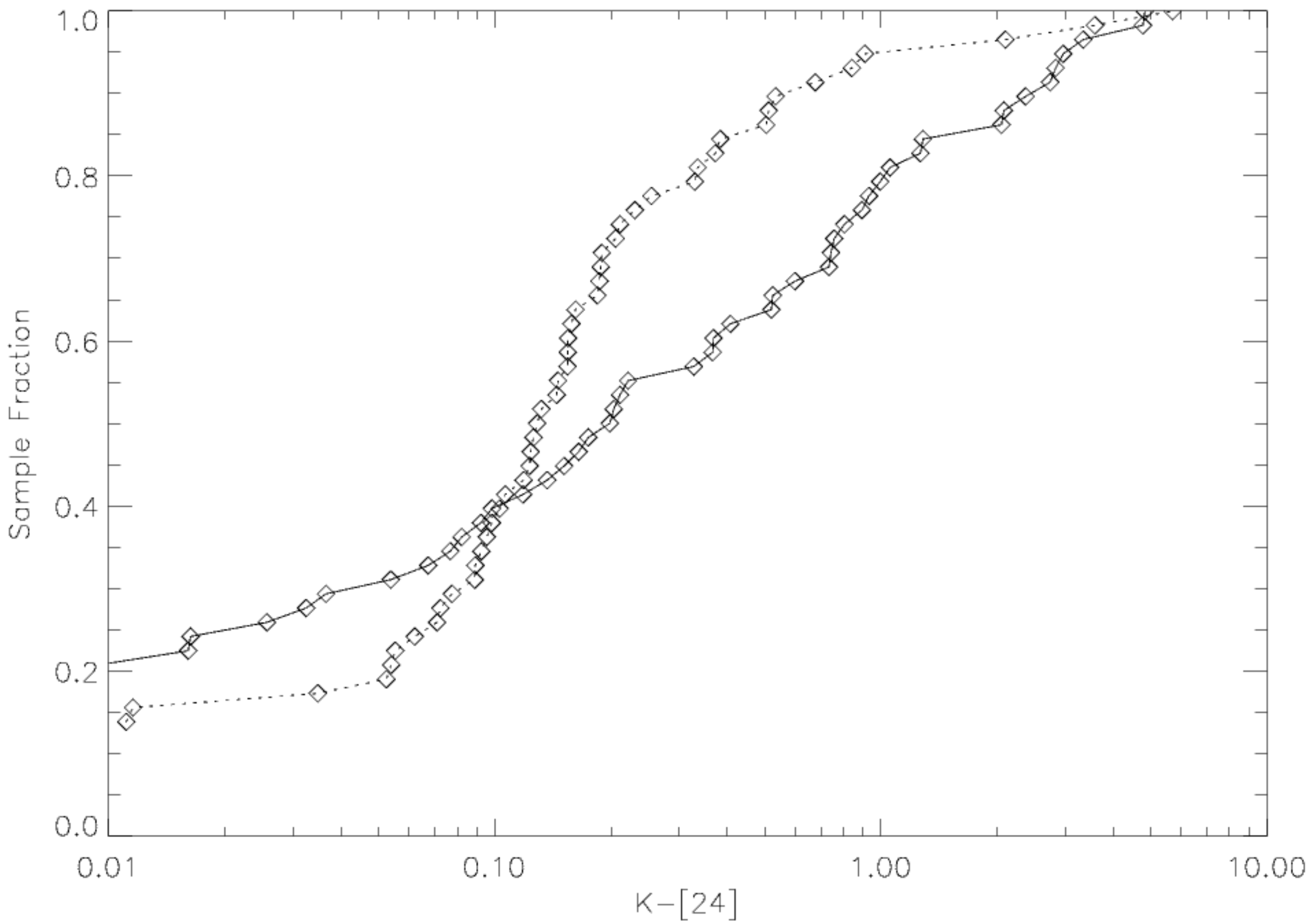
- Time-variable, broad Hα emission, consistent with an accretion rate $\sim 10^{-8}$ $M_{\odot}$ yr^{-1}
- MIPS 24 μm and IRS excess ($L_{IR}/L_{*} = 10^{-4}$): if grains are large, then T_{gr} = 500 - 1500 K.
- MIPS 70 μm upper limit

MIPS 70 μm Excess Evolution

- Kenyon & Bromley (2008) models predict that disks should be bright at 70 μm
- Our MIPS 70 μm observations of Sco-Cen are not sufficiently deep to test the self-stirred disk models at far-infrared wavelengths



Disk Properties Depend on Spectral Type



- The probability that the F0-F5 stars and the F6-G5 stars possess the same distribution of K-[24] excess is 3%

Why Do the Early and Late-Type Stars in Our Sample Behave Differently?

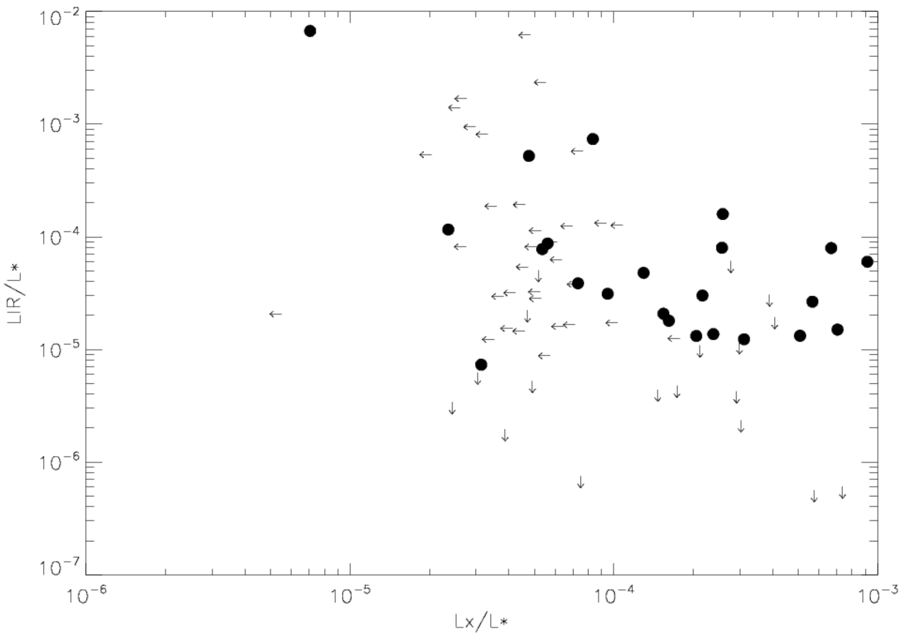
Differences Anticipated by KB08 Models:

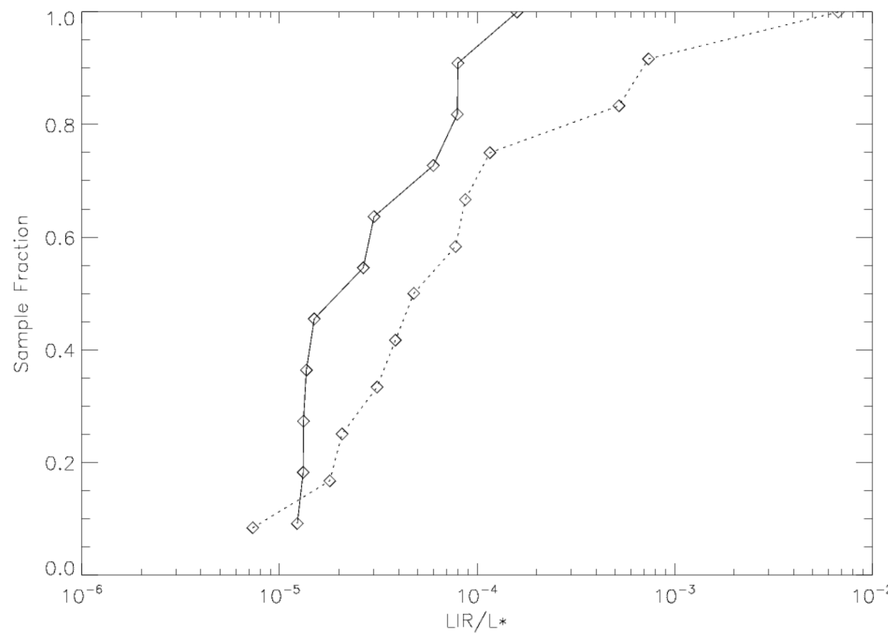
- Stellar Luminosity
  - $F_{ex}(24\ \mu m)/F_{*}(24\ \mu m)$
- Stellar Mass
  - Collisional Grinding Timescale

Stellar Wind Drag:

- Stars with Spectral Type F0-F5 are evolving onto MS at 15-20 Myr; their envelopes are changing from convective to radiative
- Late-type stars with winds would be expected to possess less dust

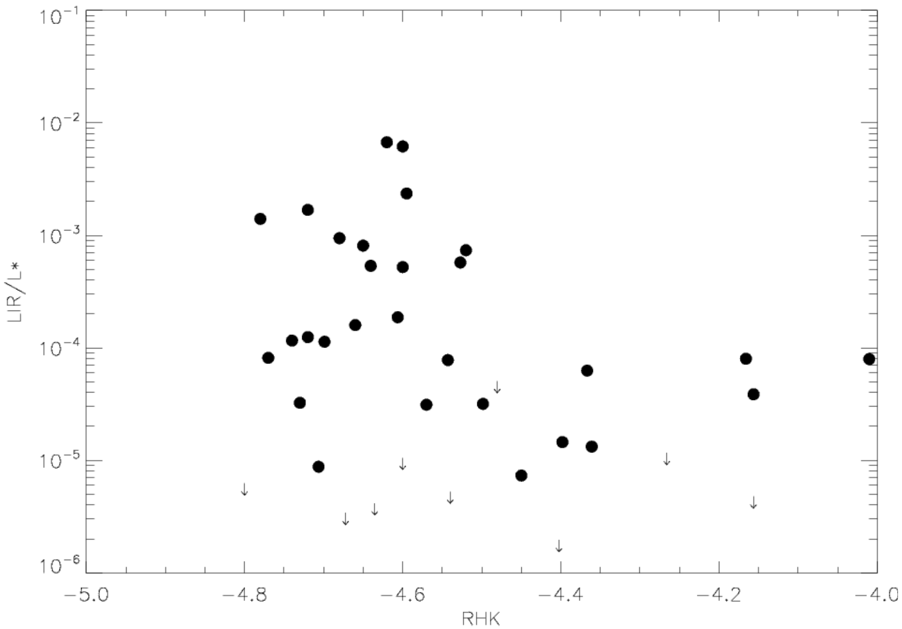
Stellar Wind Drag Diagnostics: L_x/L_*

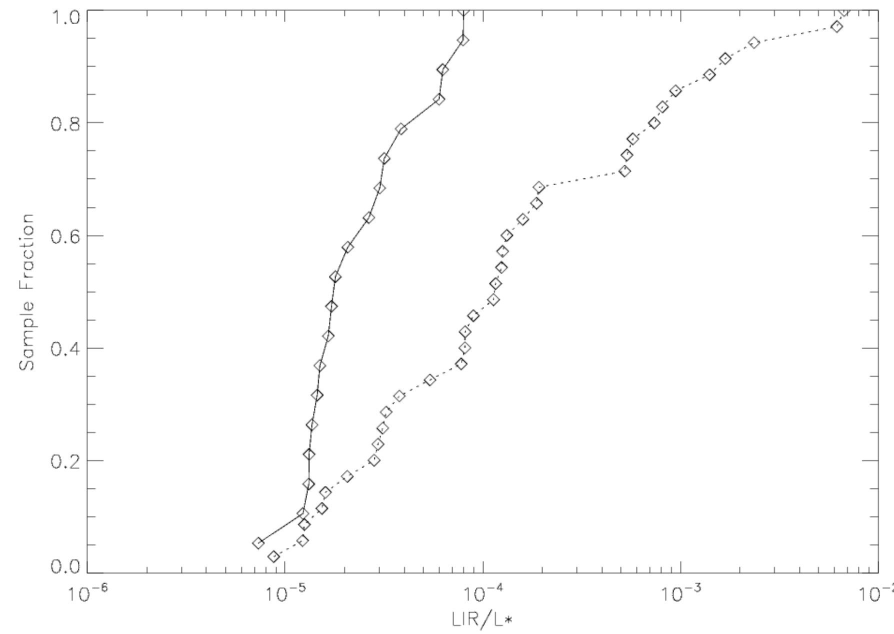




- Chen et al. 2005 argued that a possible anti-correlation between L_{IR}/L_* and L_x/L_* argued for stellar wind drag as a possible dust removal mechanism
- ROSAT All Sky Survey is insensitive at the distance of Sco-Cen for inferring the presence of stellar winds <1000x that found in our solar system
- The probability that the x-ray "active" ($L_x/L_* > 2\times10^{-3}$) and "inactive" stars are drawn from the same population is ~28%

Stellar Wind Drag Diagnostics: R'_{HK}





- R'_{HK} measured from Magellan/MIKE R~60,000 visual spectra for (almost) all of the stars in our sample
- The probability that R'_{HK} “active” (R_{HK} <-4.5) and “inactive” stars are drawn from the same population is 0.03%
- R'_{HK} is typically used as an activity indicator for stars with spectral type later than F7V; therefore, anti-correlation may be tracing the effect of a parameter other than activity

Conclusions

- Early and late-F type stars in each of the Sco-Cen subgroups possess different disk fractions and excess magnitudes
- The fraction of F0-F5 stars with excess, and the magnitude of their excess appears to rise to a maximum at the age of ~17 Myr, consistent with collisional grinding in a self-stirred disk
- The fraction of F6-G9 stars with excess and the magnitude of those excesses are smaller than for early F-stars, consistent with self-stirred disk models
- Infrared excess and x-ray luminosity are weakly anti-correlated, suggesting that stellar wind drag may remove dust grains at these ages
- Infrared excess and CaII R'_{HK} are strongly anti-correlated