Observational approach on the Planet formation : from AKARI to SPICA

1. Introduction – debris disks (1p)
2. Debris disks – planets relationship (5p)
3. AKARI survey (1p)
3. Warm debris disks population (4p)
4. Discussion & summary (1p)

SPICA
Space Infrared Telescope for Cosmology and Astrophysics

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Introduction

Fig. 1 Imaginary picture of debris disks

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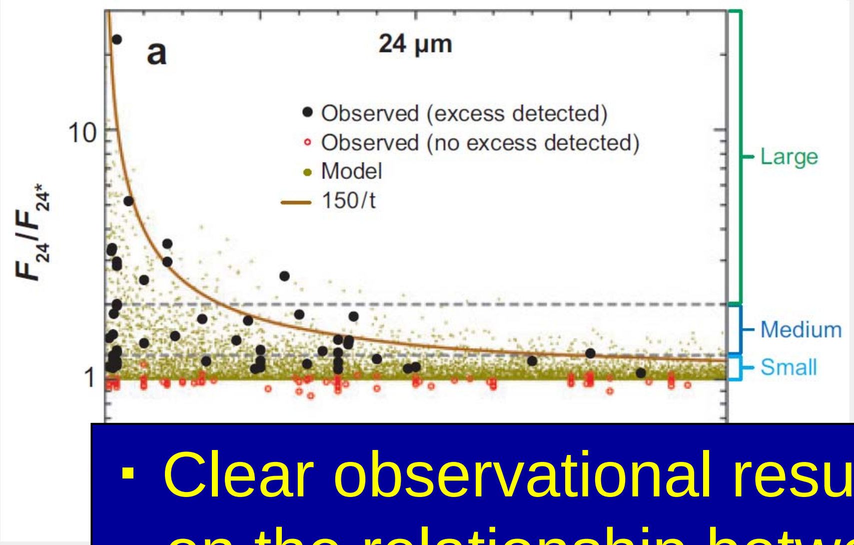


Fig. 2

» Debris disks

Circum-stellar dust around main-sequence stars found by excess in infrared emission.

» Origin

Continuously replenished through collisions between planetesimals or growing proto-planets.

» Infrared observations

IRAS (1983～)

- Vega (Aumann et al. 1984)
- Several hundred stars (Oudmaijer+1992, Mannings&Barlow 1998)

ISO (1995～)

- τ ～400 Myr ? (Habing+ 2001)、
- Fdust∝(age)-1.76 (Spangler+ 2001)

007)

- Clear observational results on the relationship between debris disks & planets has been studied and expected for log time.

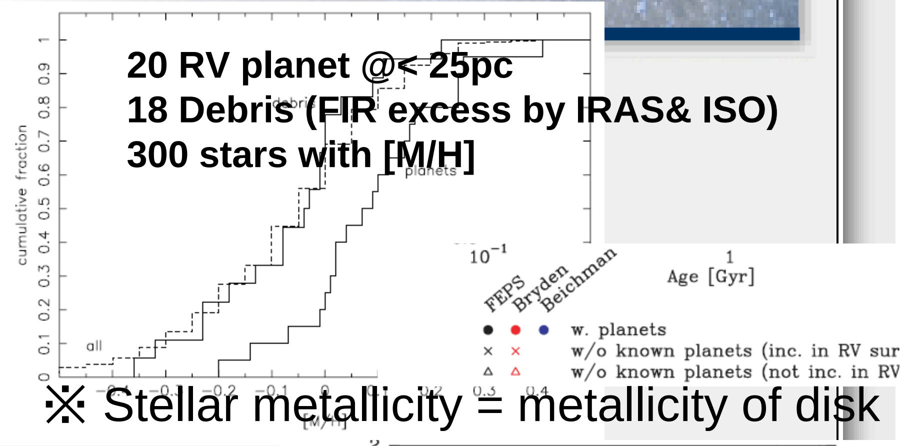
Debris disks – planets relationship (1/4)

» Greaves+ 2006

- RV Planet－metallicity correlation

  (e.g. Gonzalez 1997, Santos+ 2001)

  Absence of debris－metallicity correlation



20 RV planet @< 25pc
18 Debris (FIR excess by IRAS& ISO)
300 stars with [M/H]

※ Stellar metallicity = metallicity of disk

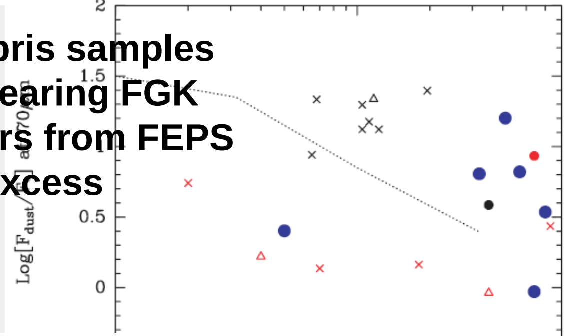
» Moro-Martin+ 2007

There is no significant correlation between close-in planets & debris disks

Metallicity (dusty)

⇒ Fast growth of the planets

⇒ Planetesimals were formed early and expelled due to the orbital evolution of the giant planets

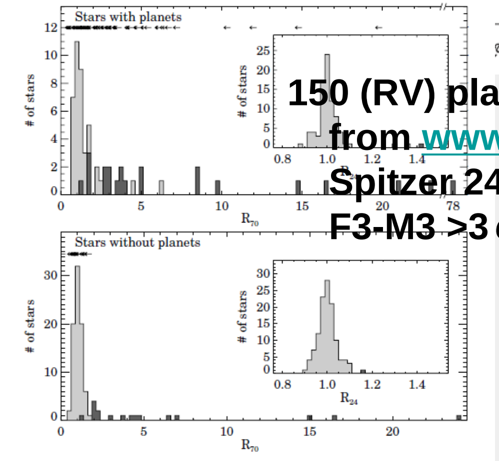


30 planet- debris samples
9 RV planet-bearing FGK
(2-10 Gyr) stars from FEPS
1-star 70um excess

» Kospal+ 2009

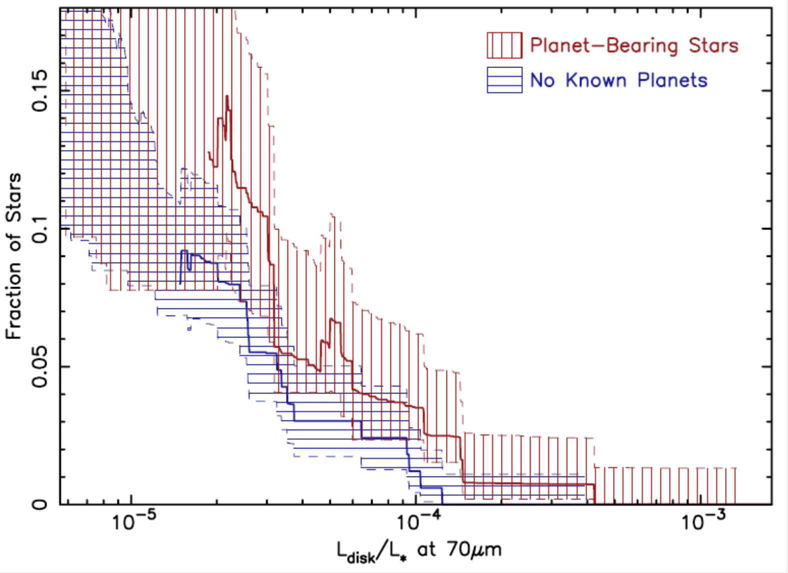
Incidence of 70um debris disks is (marginal higher for planet-having stars

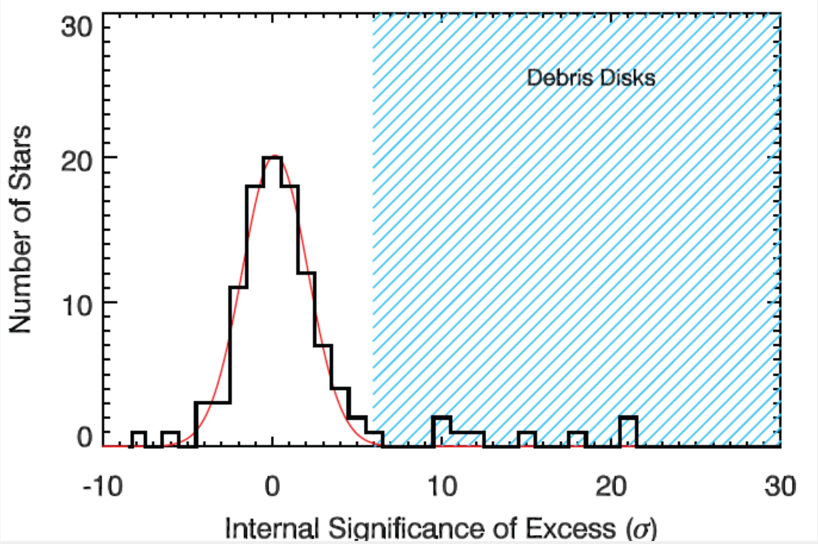
No correlation between planets' orbital parameters and presence of debris disks



150 (RV) planet-bearing stars from www.exoplanet.eu &
Spitzer 24um or 70um fluxes
F3-M3 >3σ excess

Debris disks – planets relationship (3/4)





» Bryden+ 2009

MIPS obs. of 104 RV-planet hosts

Excess rate 14% for w/o planet
9% for w planet

⇒ Difference between debris disks & RV planets is not significant.

⇒ Lack of debris – metallicity relation

» Dodson-Robinson+ 2011

IRS obs. of 105 planet hosts
32 debris disks (30-34um exess)
11% … no correlation

Debris disks w RV planets … < 110K
⇒ RV planet formation
<15 AU (BB), <240 AU (small grains)
⇒ Properties of debris disks
→ planet formation history

Debris disks – planets relationship (4/4)

» Short summary

Cold debris
(>4-5AU)

RV planets

Deb s – … ×
s — Orb. param. of RV planets … ×
disks — Metallicity … ×

Expelled due to
the orbital evolution
of the giant planets

⇒ Planet population at large radi is comparable ?

⇒ Debris disks are common around metal-rich stars w/o planets ?

⇒ Generality and frequency of debris disks

⇒ Strength of debris disk emission ∝ solid mass within proto-stellar disk ?

⇒ Warm debris — planet relation ?

Debris disks search from AKARI (MIR) All-Sky Catalog

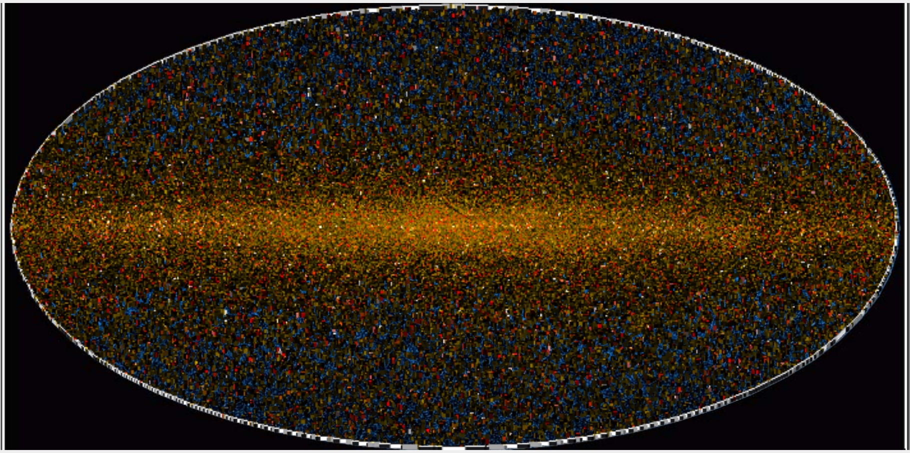


Fig.10 AKARI mid-infrared all-sky catalog
(Ishihara+ 2010)

870,973 sources

⇩

935 reliable MSs (529 w/o Spitzer obs.)

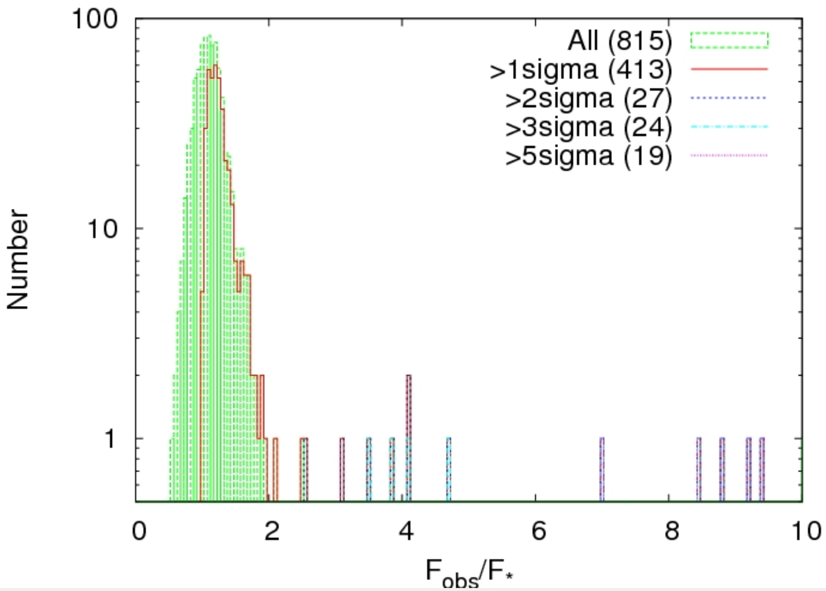
Yet another comprehensive survey
from Spitzer (Bryden+ 2005 etc.)

⇩

24 reliable debris disks ($F_{obs}/F_{\star} > 2$)
(Fujiwara+ 2010)

Expected …

- Accomplishment of statistical result
- Optical spc. ⇒ Age, Metallicity
- J, H, K ⇒ Accurate photometory
- RV ⇒ Upper limit for planets



Debris disks – planets relationship (4/4)

» Short summary

Cold debris (>4-5AU)

RV planets

Debris disks ─ Planets … ×
Debris disks ─ Orb. param. of RV planets … ×
Debris disks ─ Metallicity … ×

Expelled due to
the orbital evolution
of the giant planets

⇒ Planet population at large radi is comparable ?

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⇒ Generality and frequency of debris disks

⇒ Strength of debris disk emission ∝ solid mass within proto-stellar disk ?

⇒ Warm debris ─ planet relation ?

» Yet another approach

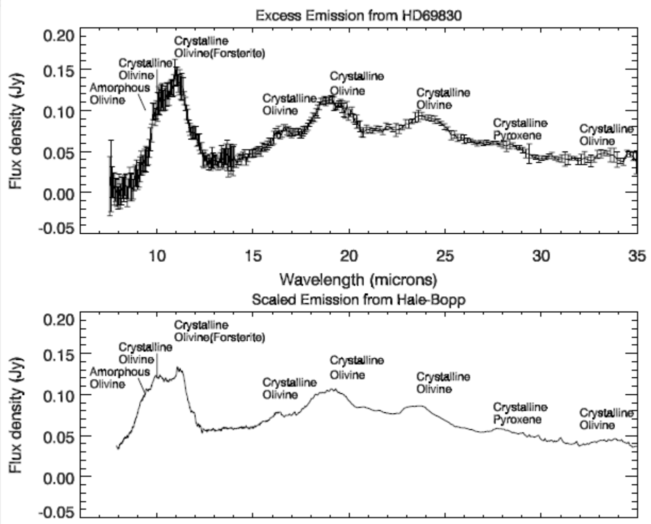
On the observed debris disks…
- Orbit & scale of impacts
- Birth place of colliding planetesimals

- Fractional luminosity,
  Dust temperature, Annealing
- Mineralogy, crystal/amorphous

⇧

Comprehensive understandings
by large sample

Origin of various form of mineral

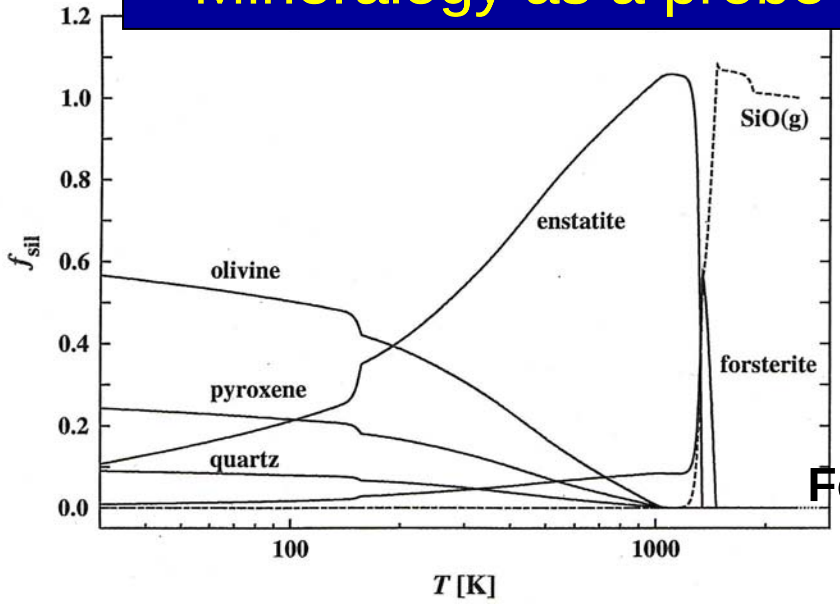


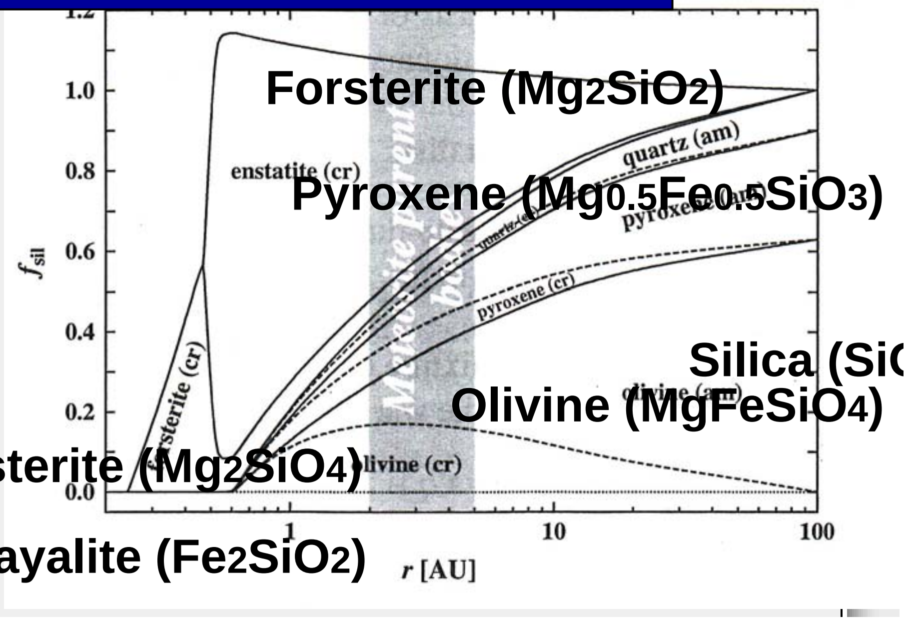
Silicate features
  9～35um, R～100 Spectroscopy

Formed in proto-planetary disk (> 1000 K)

Part of the proto-planetary disk is ionized by magneto-rotational instability (e.g. Inutsuka & Sano 2005)

- Mineralogy as a probe of colliding planetesimals





Forsterite (Mg_2SiO_2)

Pyroxene ($Mg_{0.5}Fe_{0.5}SiO_3$)

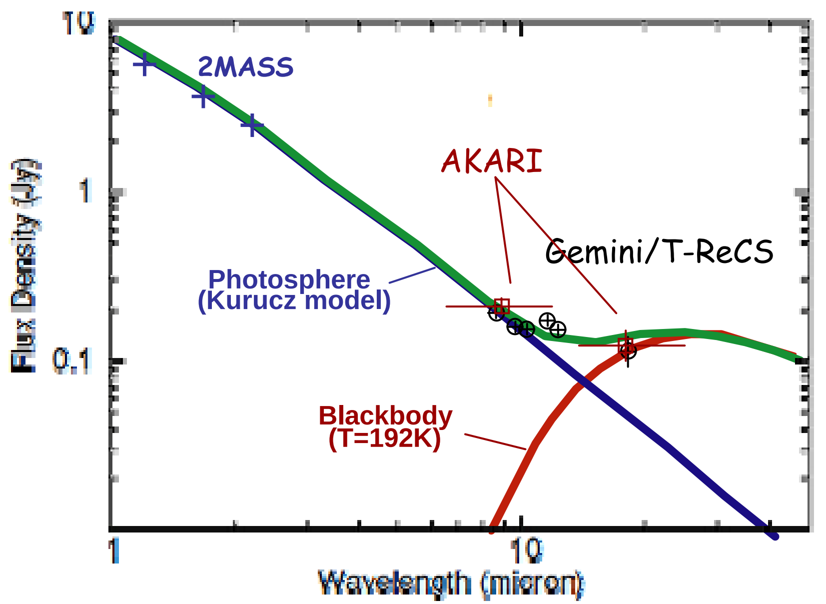
Silica (SiO

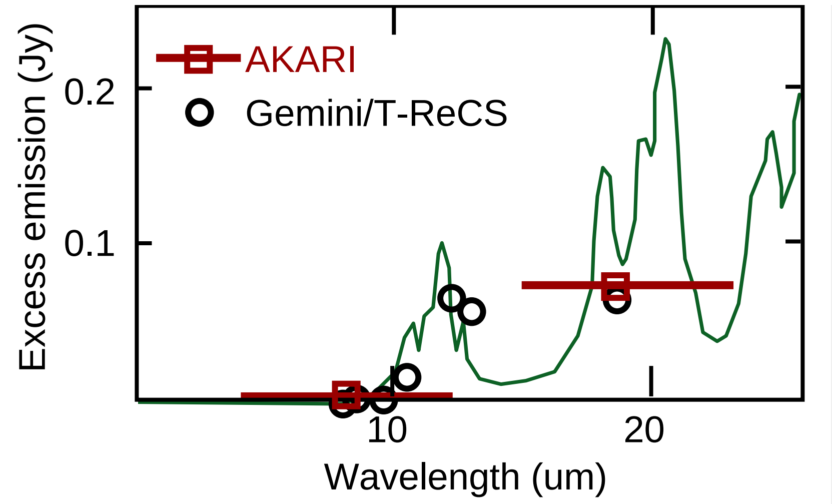
Olivine ($MgFeSiO_4$)

Forsterite (Mg_2SiO_4)

Fayalite (Fe_2SiO_2)

Warm debris disk (1/4)





—Fayalite / 鉄橄欖石 (Fe_2SiO_2)
T=174K, χ^2=1.89

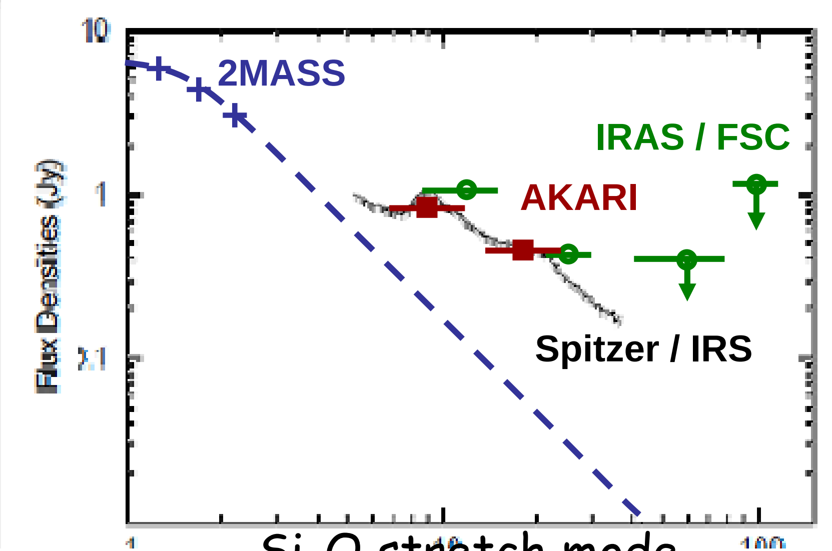
» HD106797 (Fujiwara+ 2009)
A0V, 10-20 Myr, D=96 pc
Multiband imagings by Gemni/T-ReCS

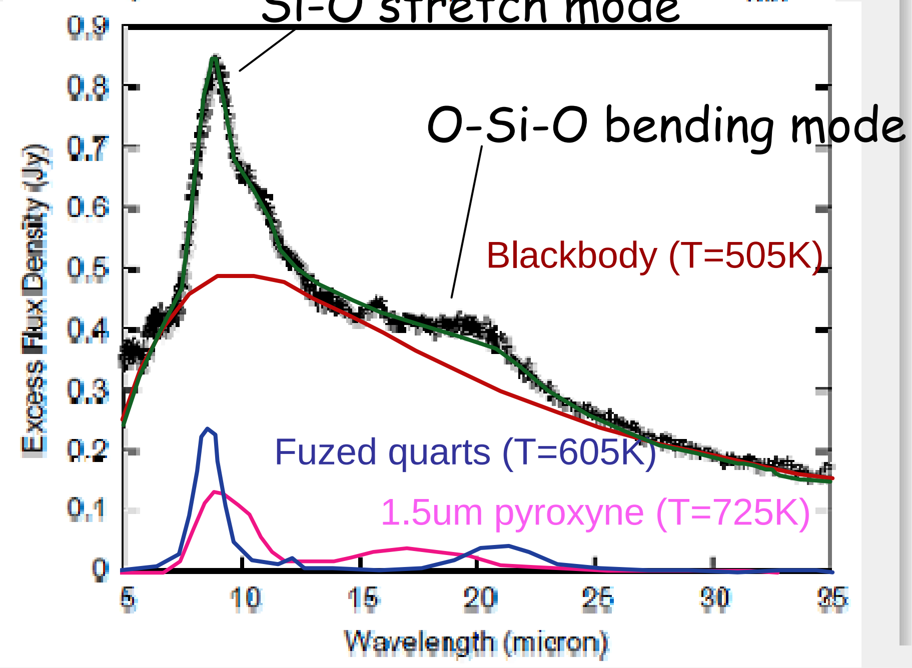
» Features in 9-26um
→ crystalline fayalite (Td～174K)

» **Ldust** / L* = 1.93x10^4 > 10^-4
… from simple steady state model
(Wyatt+ 2007)
→ Recent transient events ?

» Origin of crystalline silicate
Amorphous in ISM (Kemper+ 2004)
6 debris disk with
crystalline silicates (Knacke+ 1993, etc.)
Crystallization requires >800K
(Hallenbeck et al. 2000)
Heated in the center and transported ?
(Bockelee-Morvan+ 2002)
Shock wave - turbulent flow or X-wind
(Harker & Desch 2002)
Heavy bombardment in late stage of
planetary system formation ?

Warm debris disk (2/4)





» A F3V star 2.6 Gyr, D=85pc (Hipparcos)
Spitzer/IRS 5−35um R=100
(Fujiwara+ 2009)

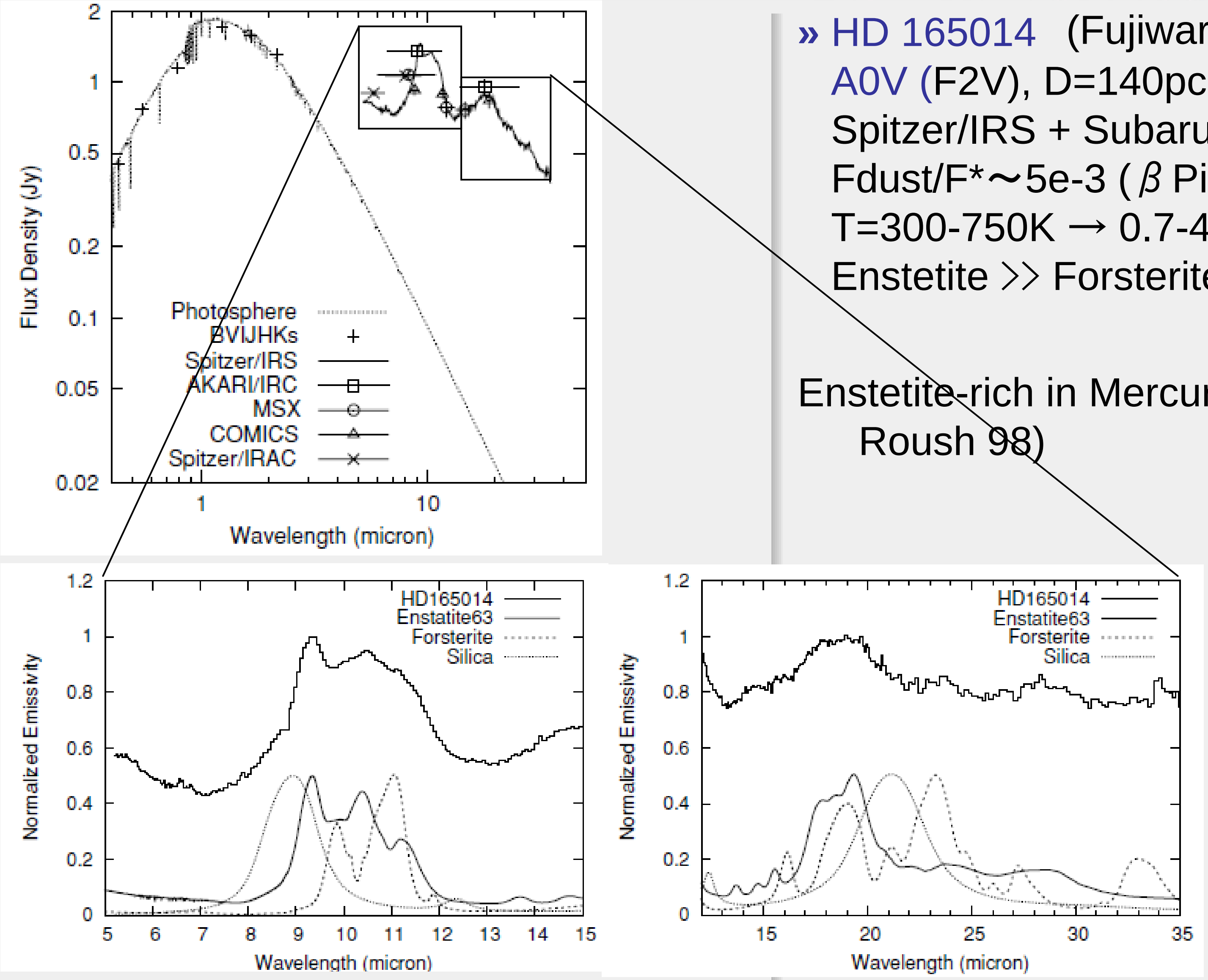
» Excess in 9-26um
BB(505K) + crystalline silicate
(1.5um pyroxyne) + fused quartz (SiO_2)

» **Ldust** / L* = 5.4x10^-3
> 1e-7or 8 predicted from simple
steady state model (Wyatt+ 2007)
→ Recent events ?

» Silica (SiO_2) in space
Not found in ISM
in TTSs (high-T, low-P crystal structure)
General in solar system …
Condrite, Wild2/STARDUST sample,
Earth crusts (amorphous, low-T)

→ Ejected from
surface layer of the proto-planet
with Earth's crust like mineralogy
by impact events with another body ?

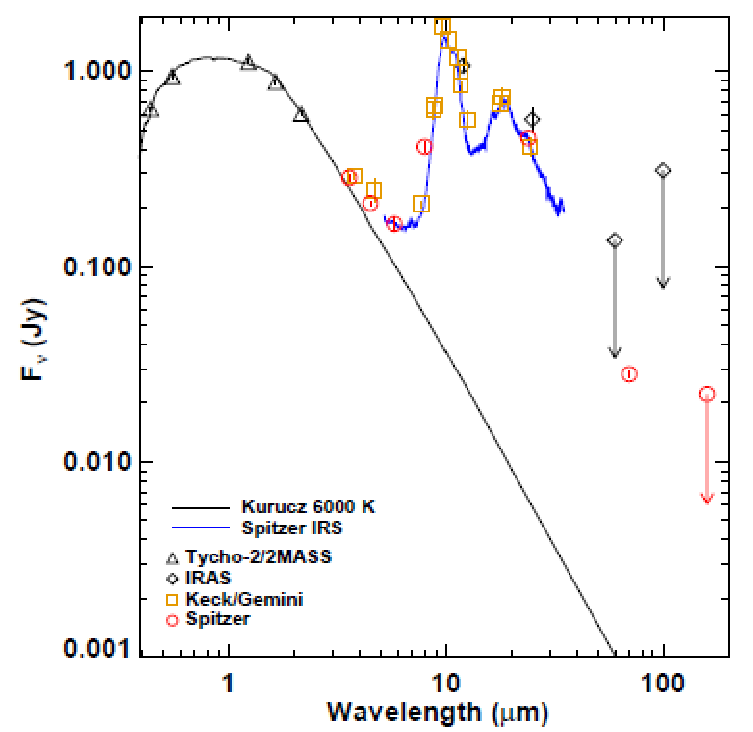
Warm debris disk (3/4)



» HD 165014 (Fujiwara+ 2010)
A0V (F2V), D=140pc
Spitzer/IRS + Subaru/COMICS
Fdust/F*～5e-3 (β Pic class)
T=300-750K → 0.7-4.4AU
Enstetite >> Forsterite

Enstetite-rich in Mercury (Sprangue & Roush 98)

Warm debris disk (4/4)



BD +29 307 (Weinberg+ 2010)
1 Gyr, F8-9?, 96 pc

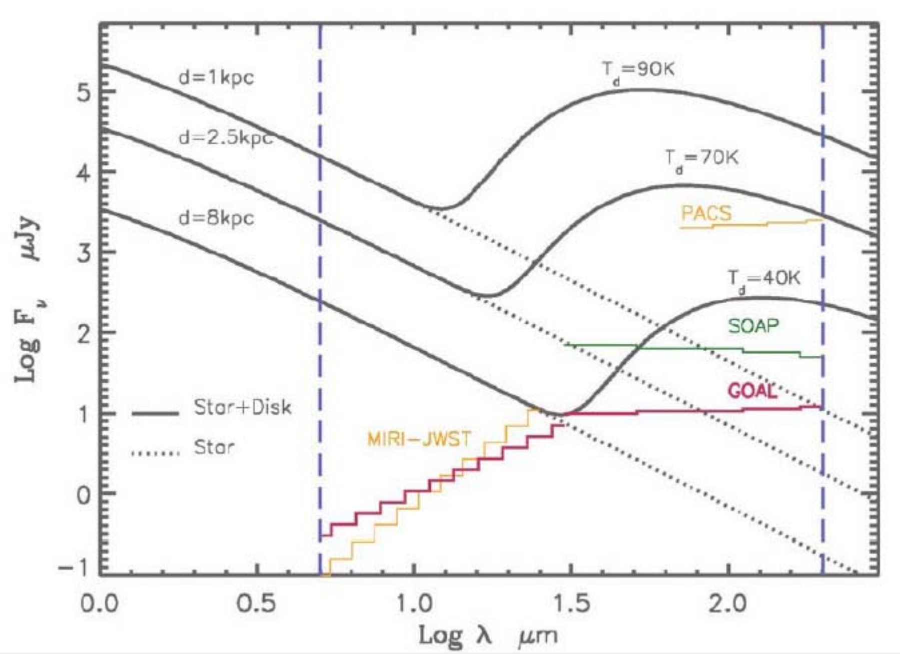
Lobs/L*∼3e-2, 0.85 AU, 200 K
Absence of cold dust
Large amount of amorphous silicate
← Heating of >1000K
+ rapid cooling
(prohibit of pre-crystallization)

» Warm debris disks
- Young planetesimal belts
  (e.g. β Pic; Okamoto+ 2006)
- From outer belts and constrained
  by planets (η Corvi; Wyatt+ 2007)
- Giant impact (LHB) of planetary-scale
  bodies at terrestial zone

» Frequency
- 10 stars known (FGK)
  0.2 impacts / star (during MS life)

» Warm disks vs. planets (Kospal+ 2009)
No significant relation between
24um (∼1.7 AU) debris and Metallicity
and Planets
Too small sample
RV (1.4 AU) ⇒ 2.9 AU dust ring ???

Summary & requests for SPICA



(from MRD)

SPICA / MCS

- Low-res, 5-38um, high-sensitivity spectroscopy of 9&18um excess debris disks
- Combination with ground-based observations

Debris disks – planets connection

- Most of us believes that debris disks indicate planet forming process
- No significant correlation have been given yet.

Warm debris disks from *AKARI* obs.

- Crystalline silicate in HD16797
- Fused quartz in HD15407
- Crystalline enstetite in HD 165014 …

Importance of MIR detections

- Asteroid analogs
- Implication for state and history of planetesimals or proto-planets