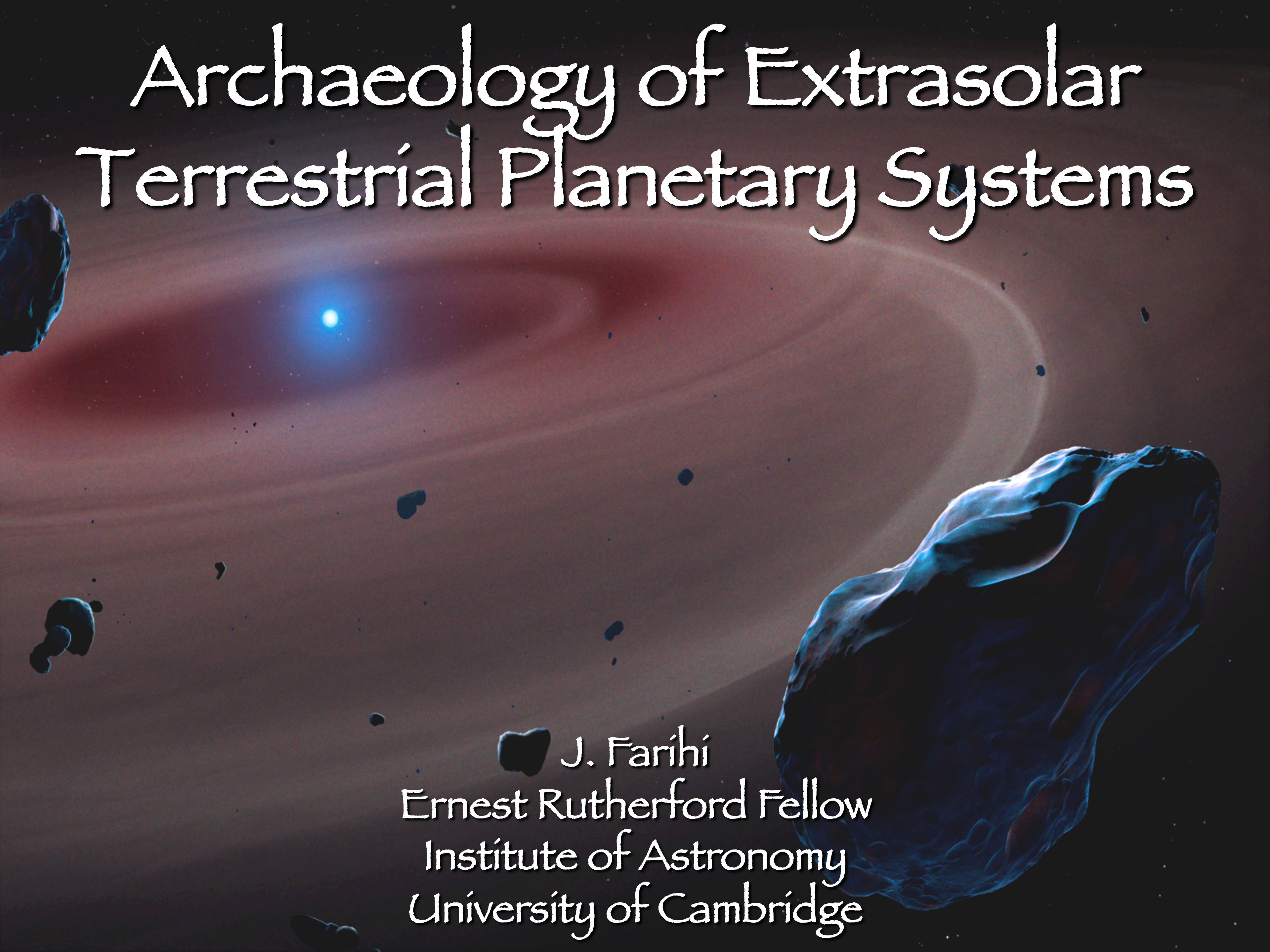
Archaeology of Extrasolar Terrestrial Planetary Systems



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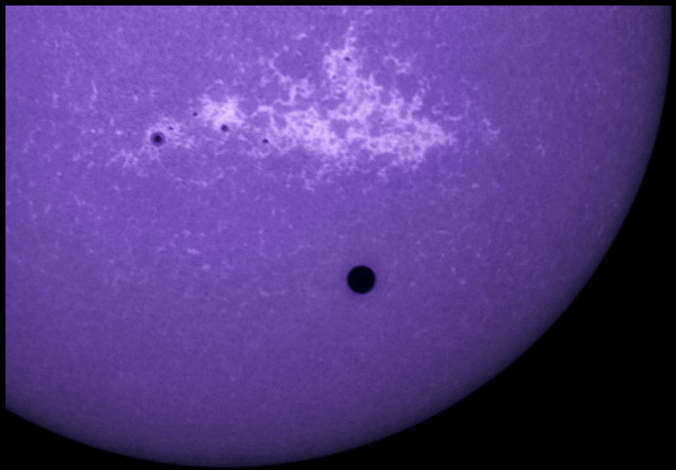
University of Cambridge

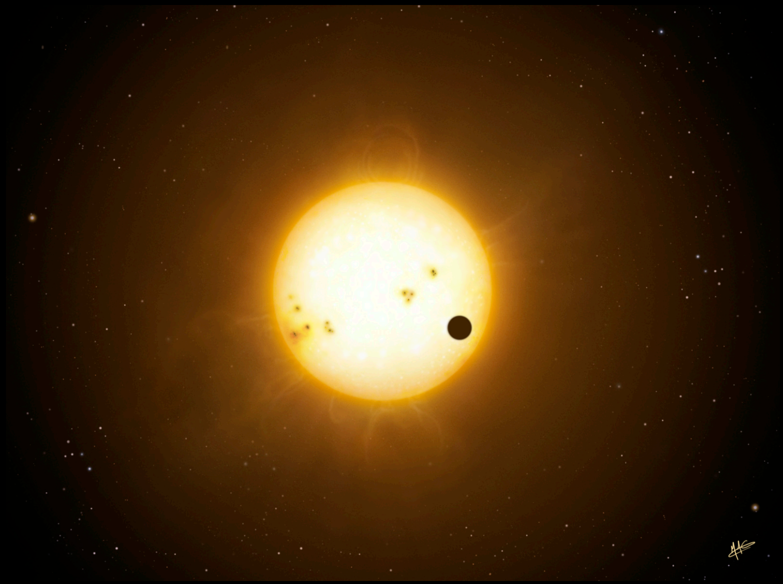
Exoplanetary Archaeology

- Frequency of terrestrial planet building
- Bulk chemistry of solid planetary bodies
- Mass constraints for exoplanetary building blocks
- Frequency of water-rich exo-asteroids
- Constraints on habitable environments

Solid Exoplanets on the Rise

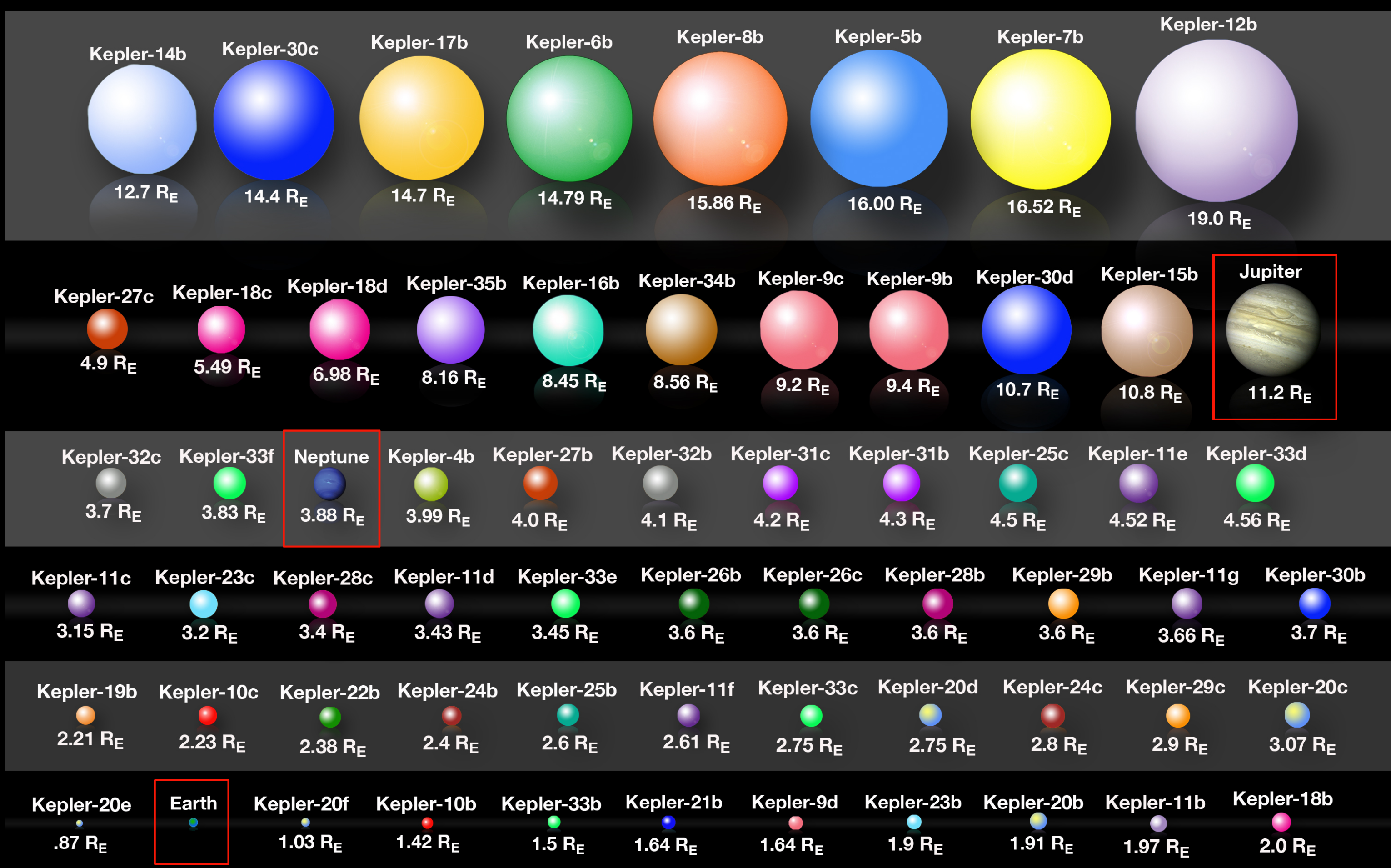


Venus transit 2012

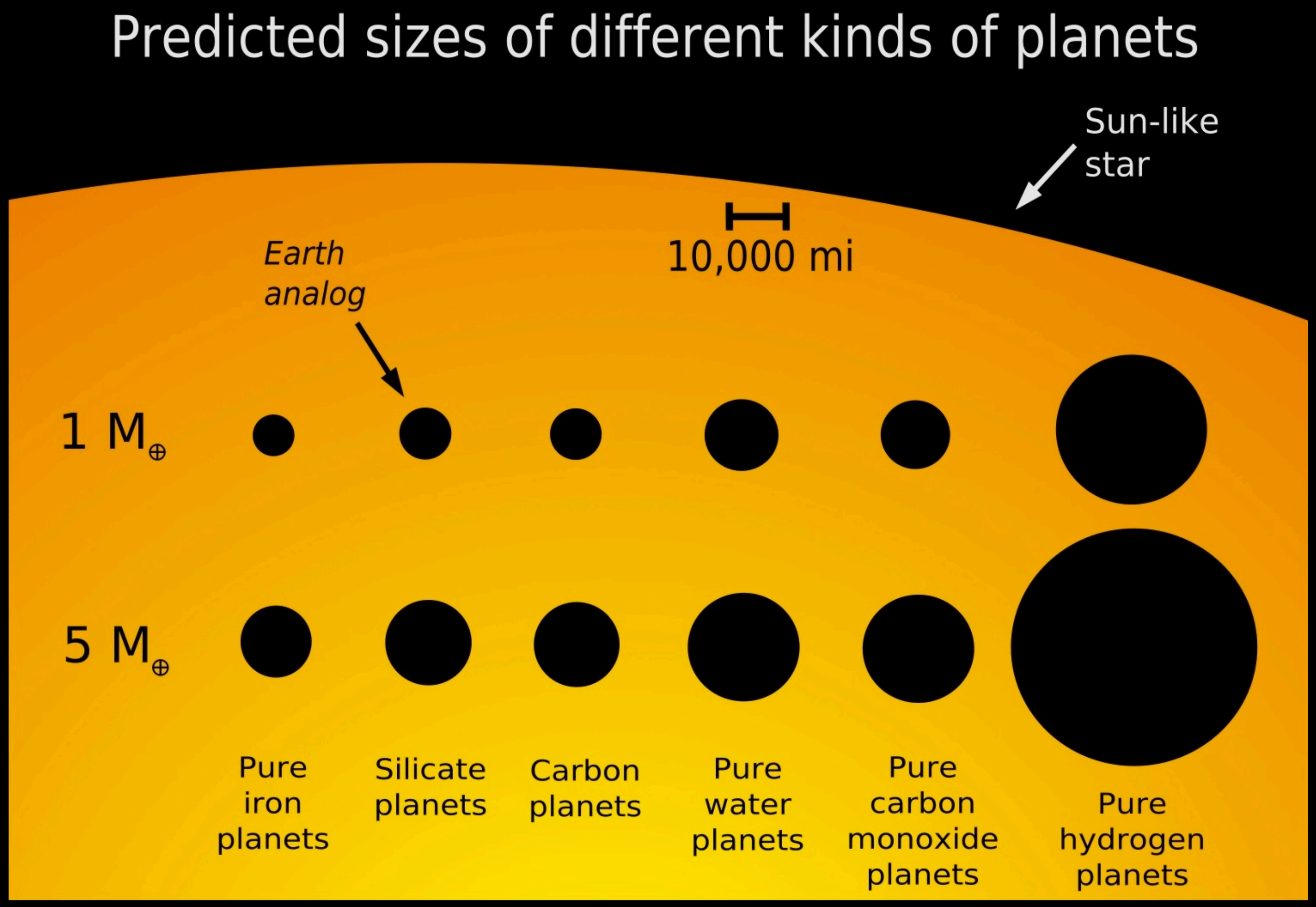


Exoplanet transit

Kepler Zoo 2012.2

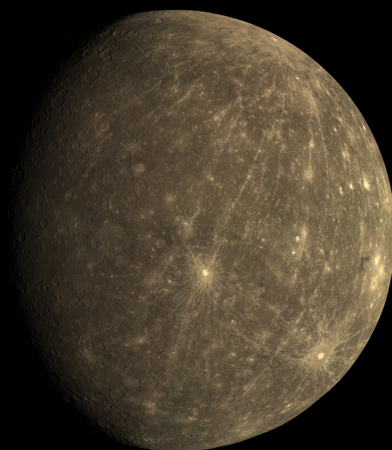


Planet *R–M* is Degenerate



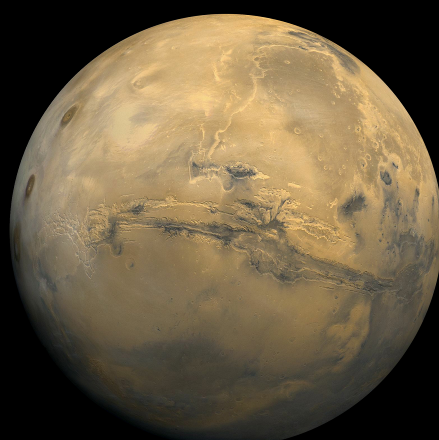
Some Possible Compositions

Iron-rich
(Mercury)



Iron-poor
(Moon)

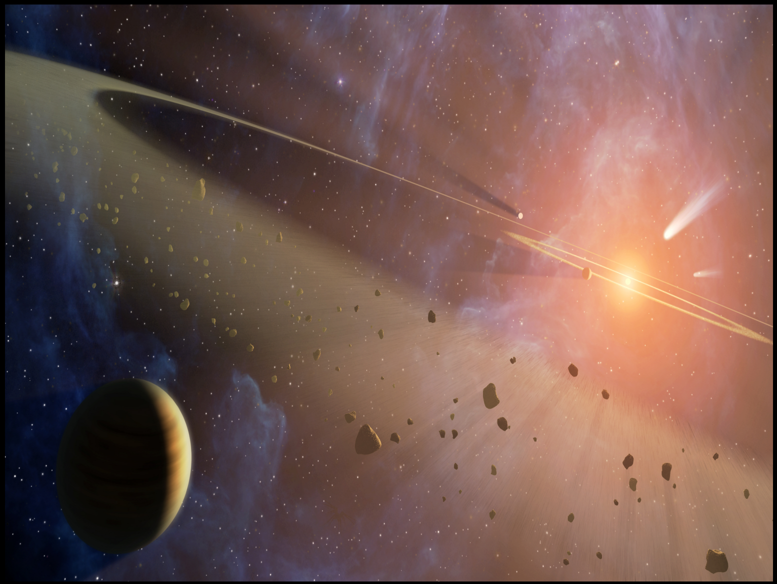
Silicate-rich
(Mars)



Earth-like

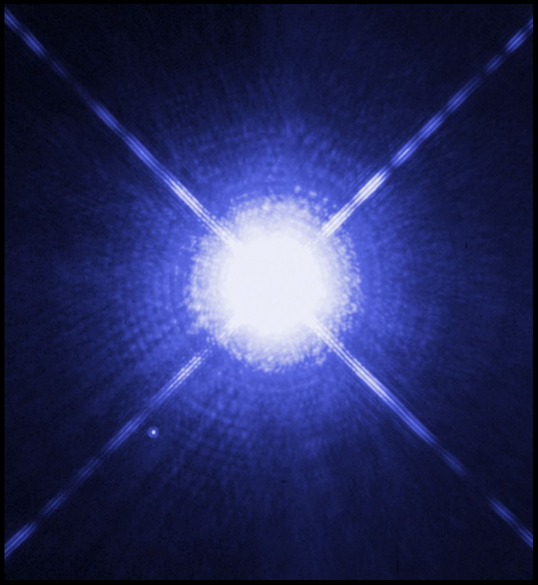
Asteroids are Terrestrial

- Primordial building blocks of the terrestrial planets
- Meteorites are fragments



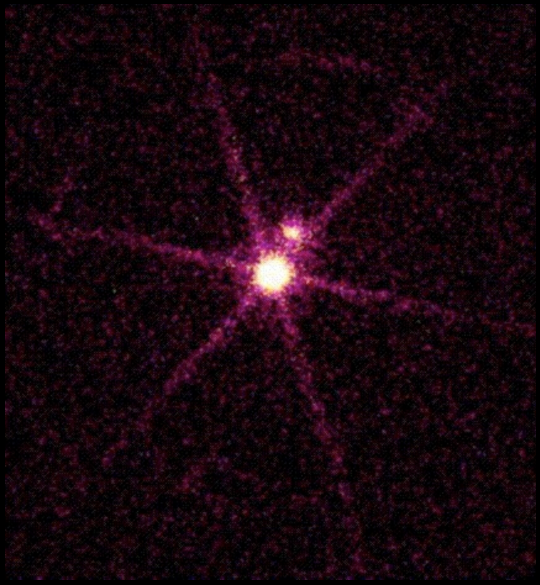
- Possibly delivered Earth's water & volatiles

Sirius B: Future Sun



Optical

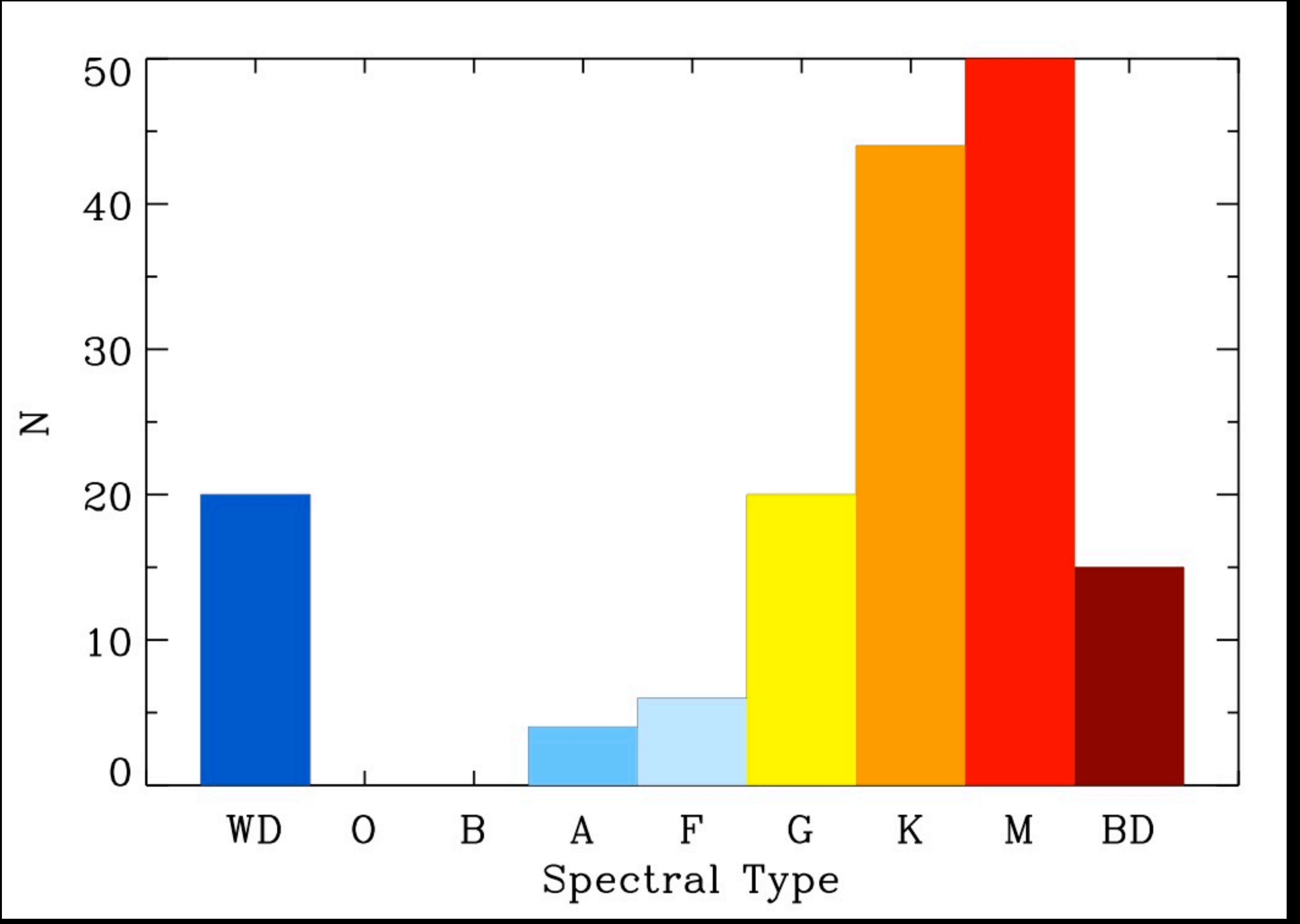
Artist



X-ray

Known Stars $d < 10$ pc

(RECONS Project: T.J. Henry)

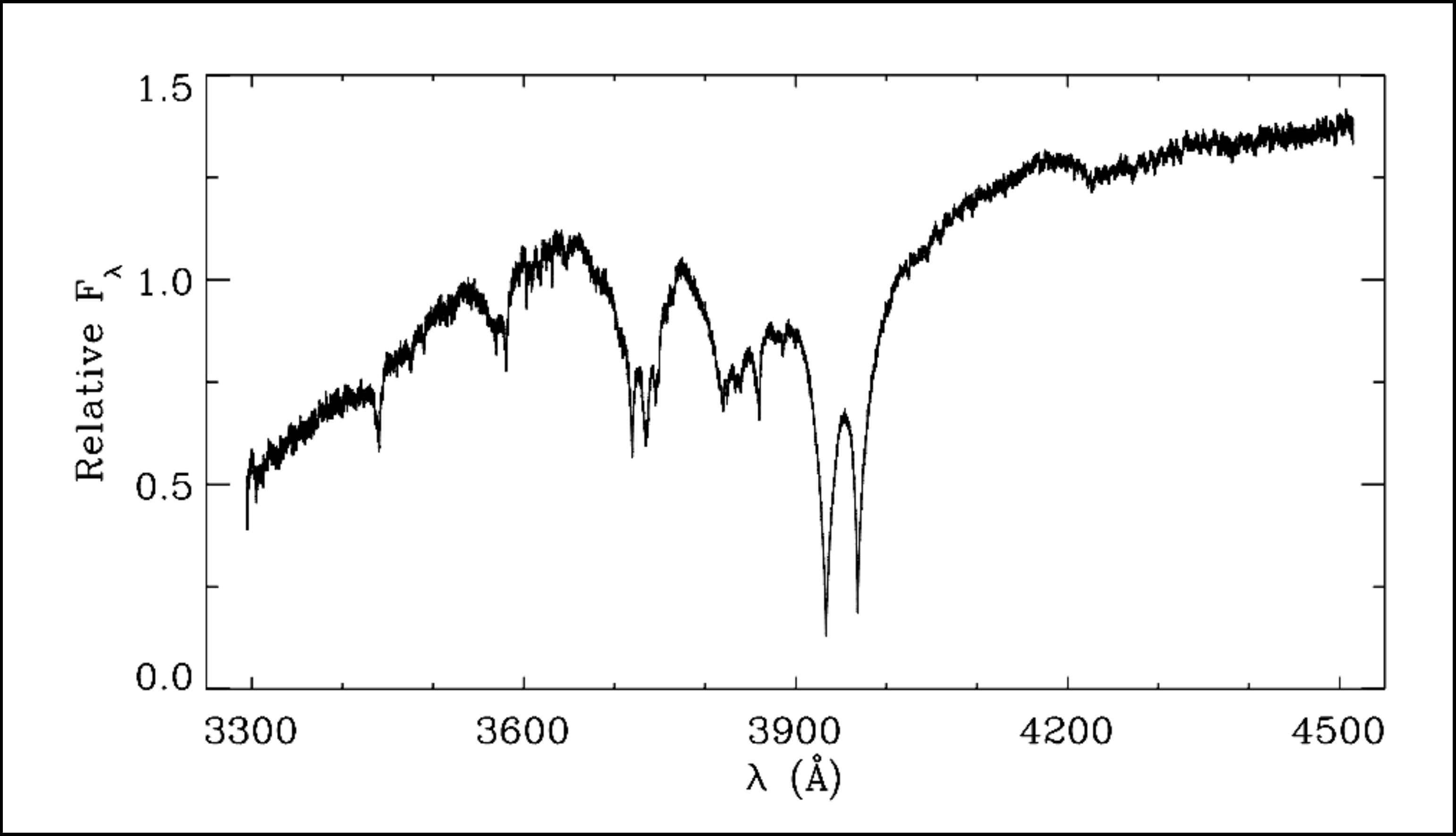


Planetary Archaeology

- White dwarfs are evolved but not necessarily old
  - Sirius B
  - Pleiades, Hyades
- Populous in Solar neighborhood
- Earth-sized for excellent contrast

van Maanen's Star

(van Maanen 1917; SPY project: R. Napiwotzki)



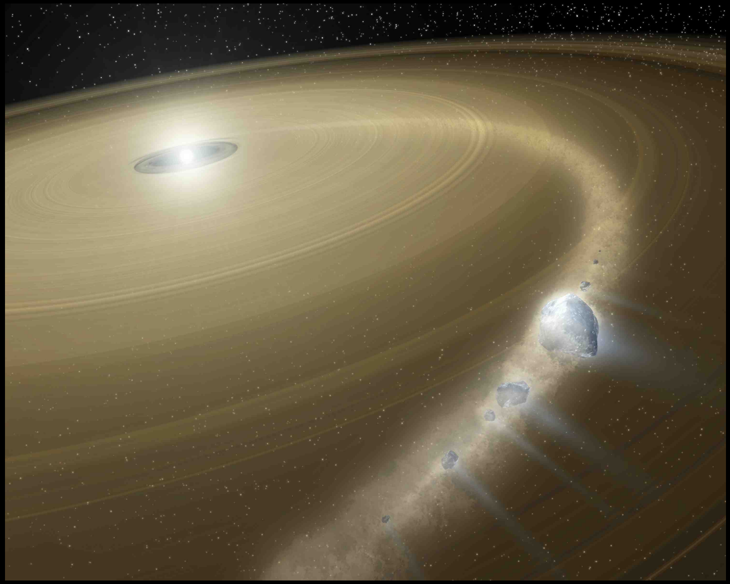
Metal-Contaminated Stars

- Gravity strong and radiation weak as they cool
  - pure H or He atmospheres
- Externally polluted
  - phenomenon is not ISM or companions
- Excellent astrophysical detectors
  - *the photospheric abundances of polluted white dwarfs measure the composition of the accreted matter*

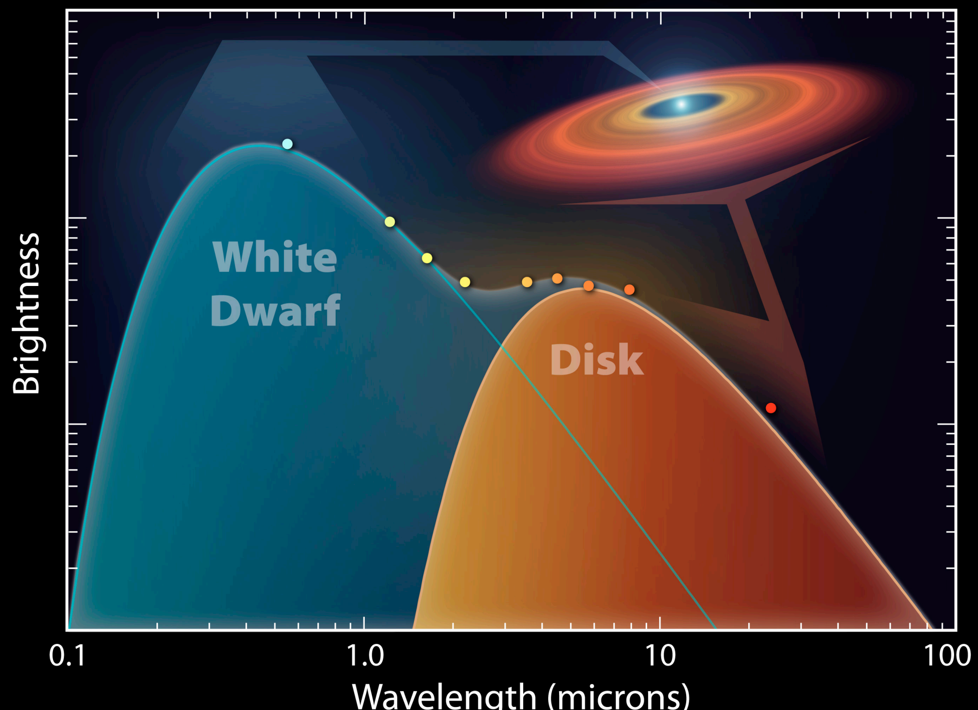
Asteroid Destruction

(Jura 2003; Debes & Sigurdsson 2002)

- White dwarfs are *compact*
  - Asteroids tidally shredded
- White dwarfs are *pristine*
  - Star is polluted by debris
- How do we know this?
  - Disk mass, location, composition; heavy elements in star

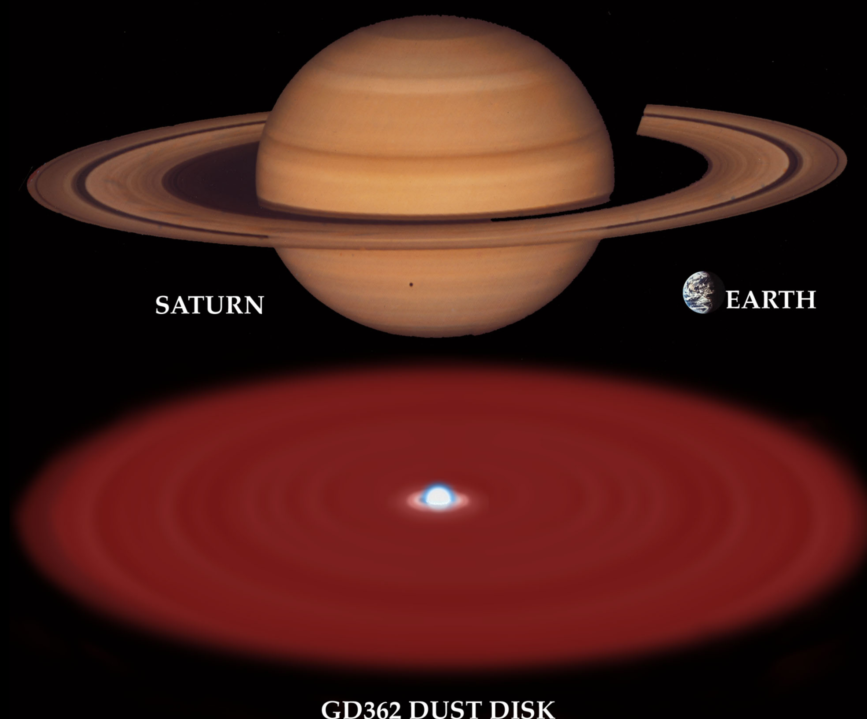


Typical Dust Disks
(Farihi, Jura, Zuckerman 2009)

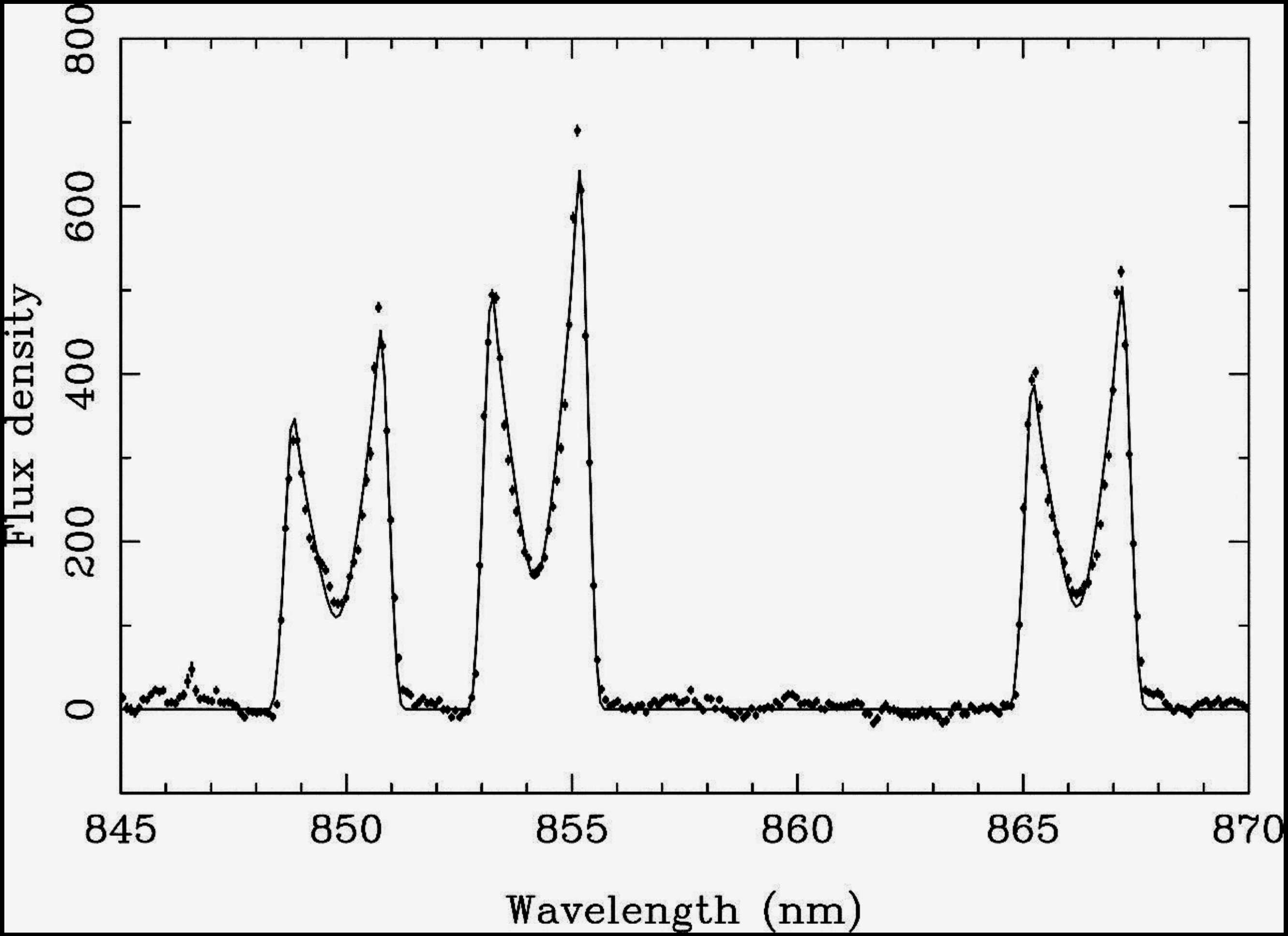


Spectrum of White Dwarf System GD 16
NASA / JPL-Caltech / J. Farihi (University of Leicester)

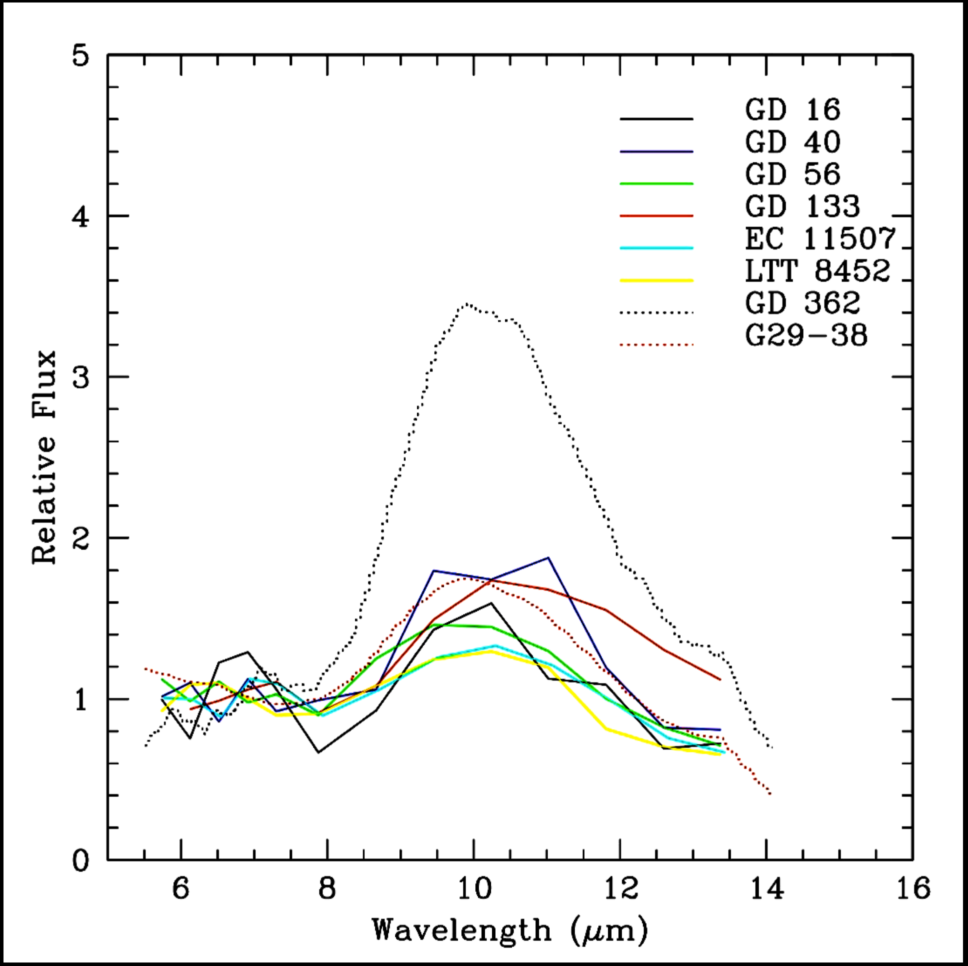
Spitzer Space Telescope • IRAC • MIPS
sig09-002



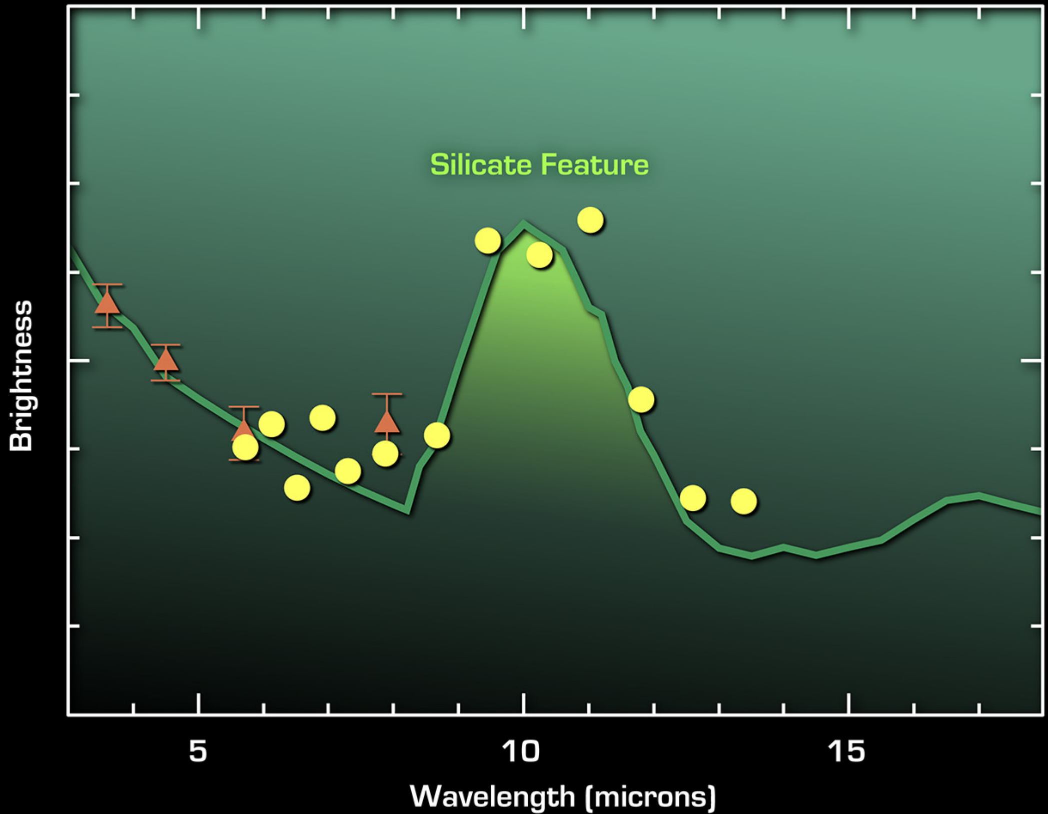
Metal Emission
(Gänsicke et al. 2006)

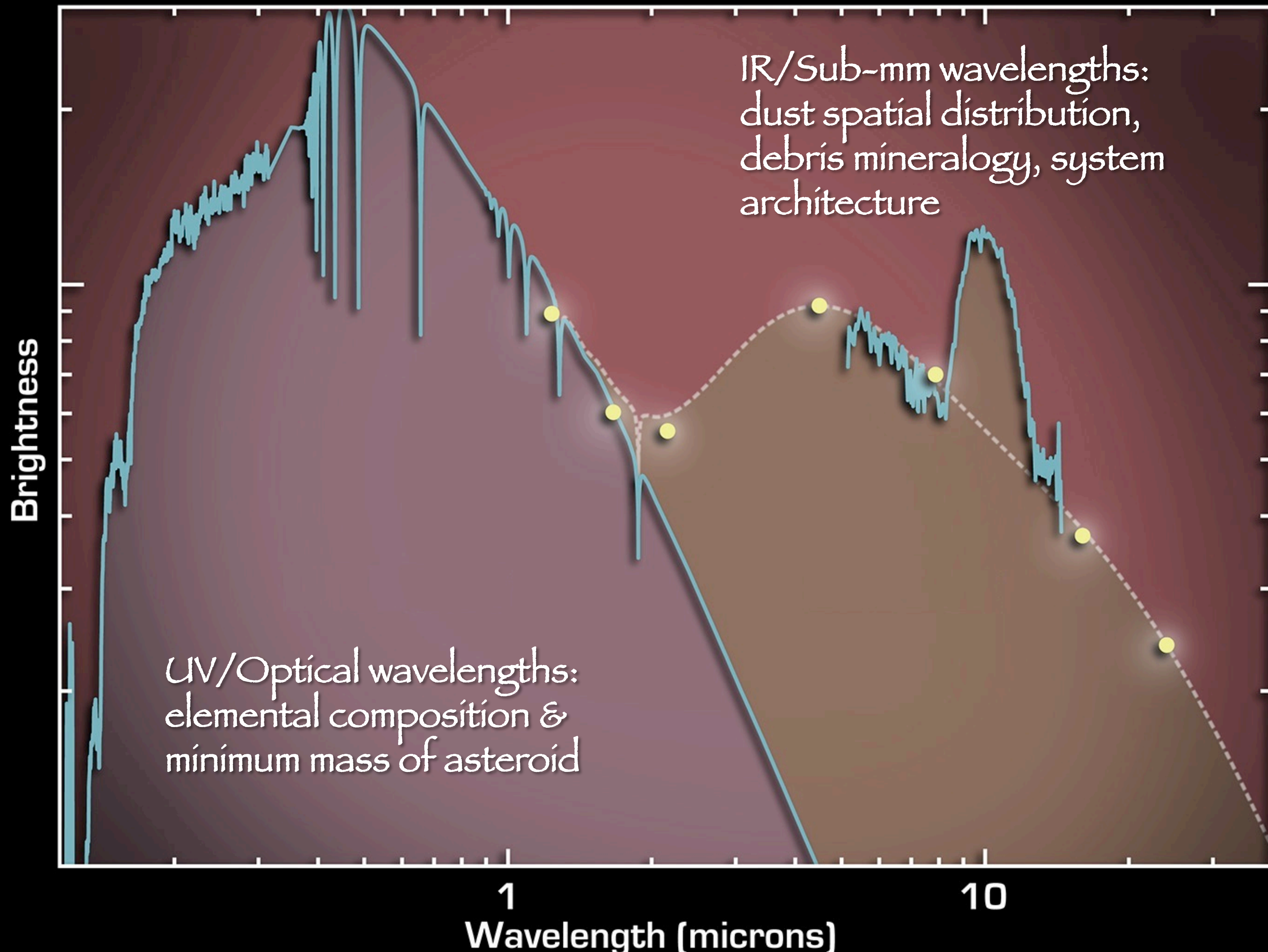


Silicate Emission
(Jura, Farihi, Zuckerman 2009)

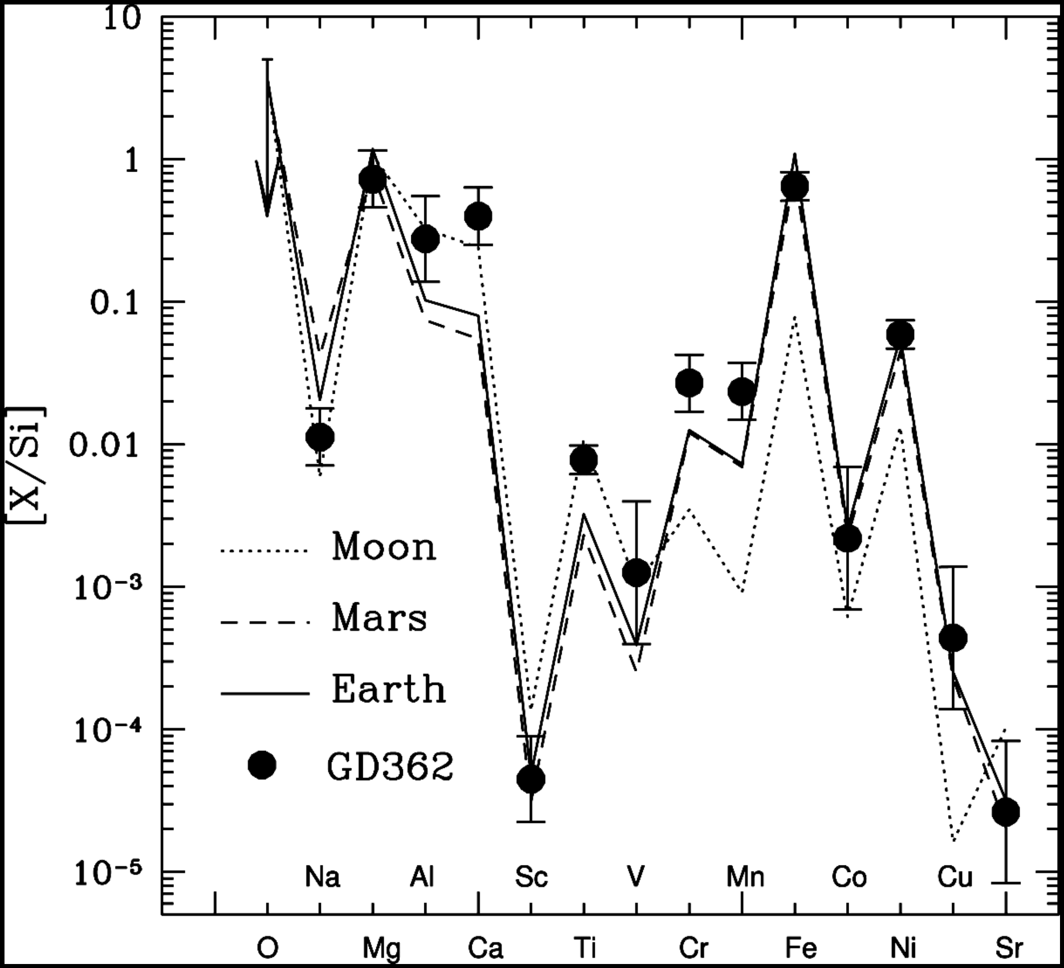


Olivine is Terrestrial



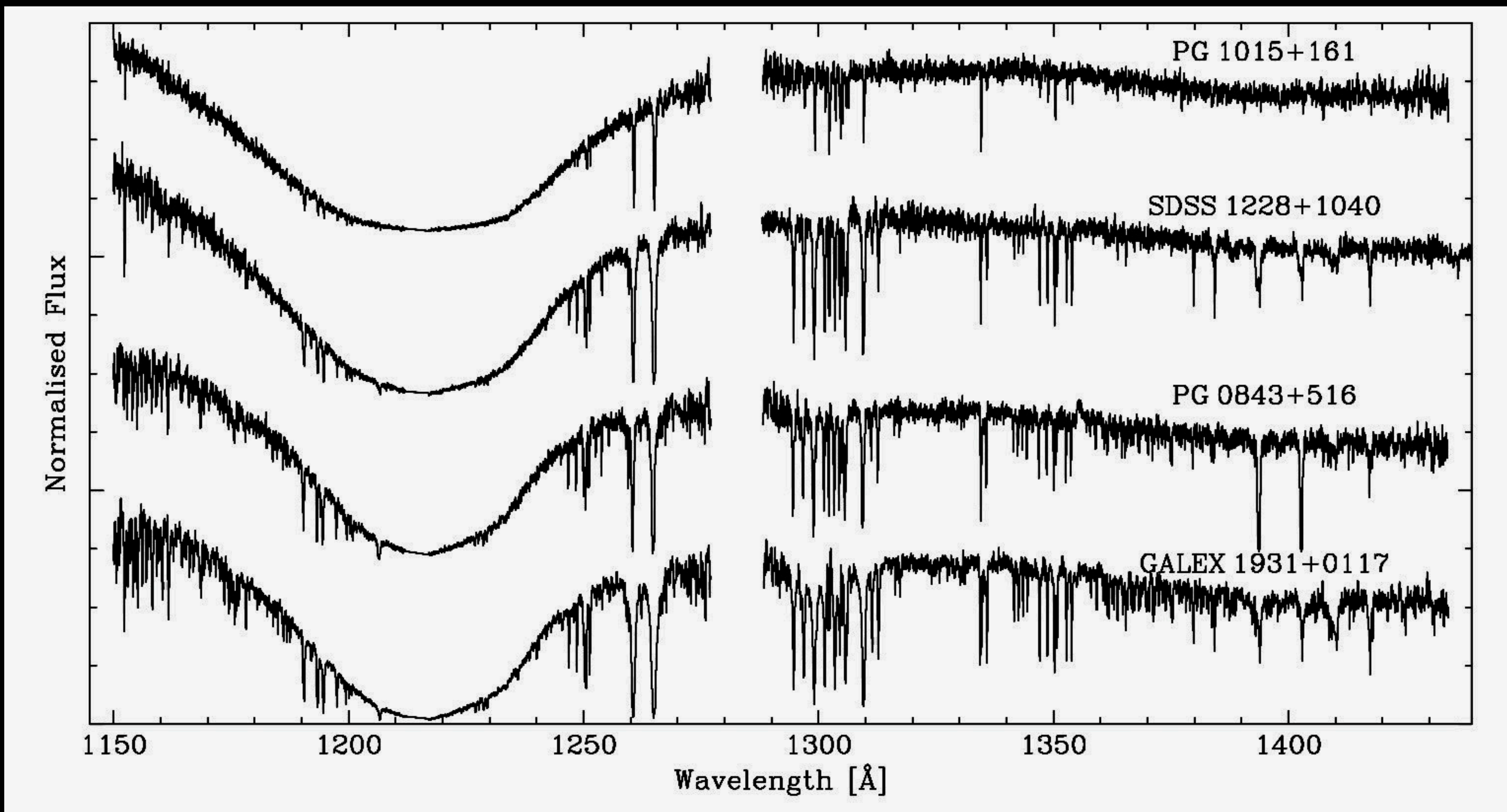

IR/Sub-mm wavelengths:
dust spatial distribution,
debris mineralogy, system
architecture
UV/Optical wavelengths:
elemental composition &
minimum mass of asteroid
Brightness
1
10
Wavelength (microns)

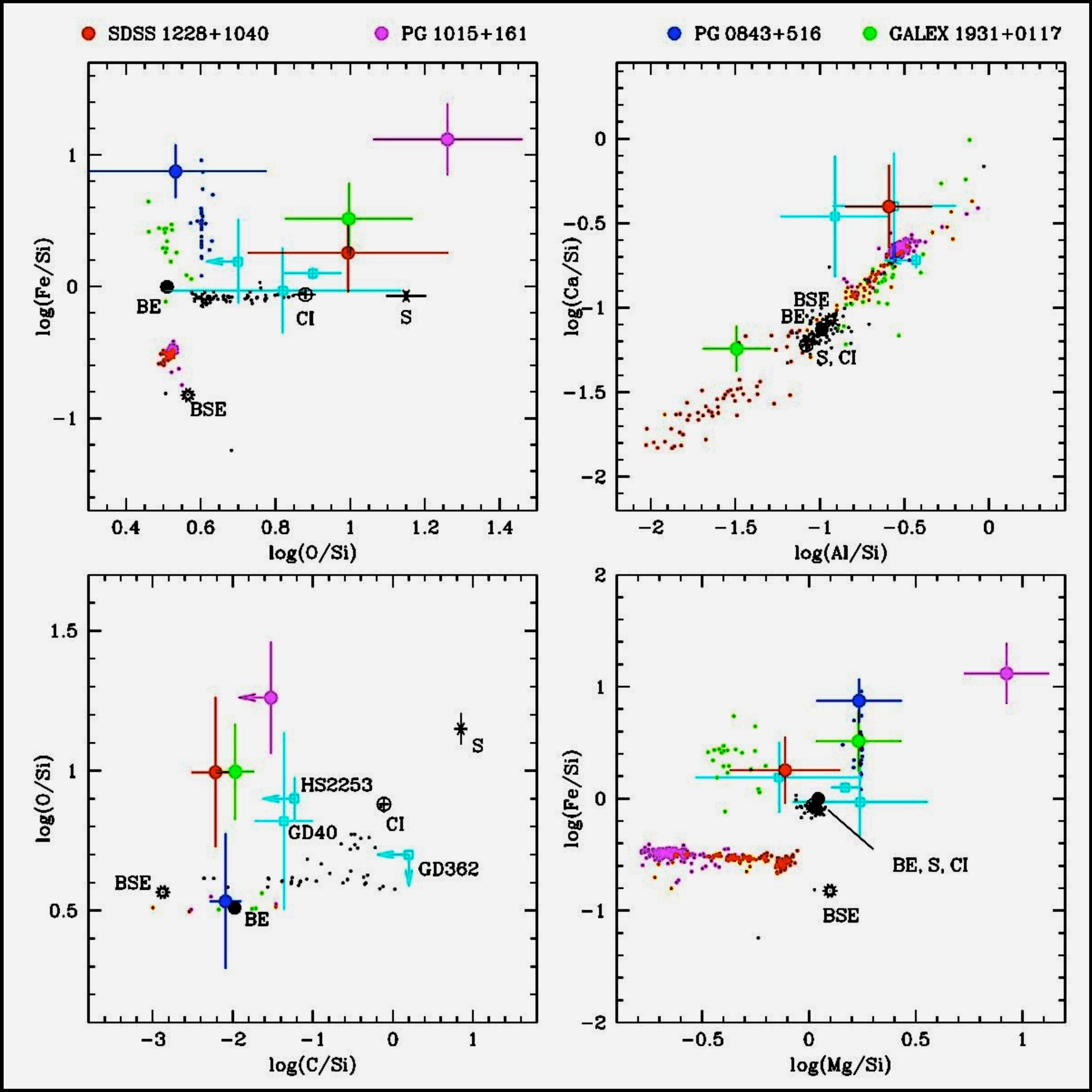
Rocky Debris in GD 362
(Zuckerman et al. 2007)



Rocky Debris Confirmed by *HST*

(Gänsicke, Koester, Farihi, et al. 2012)



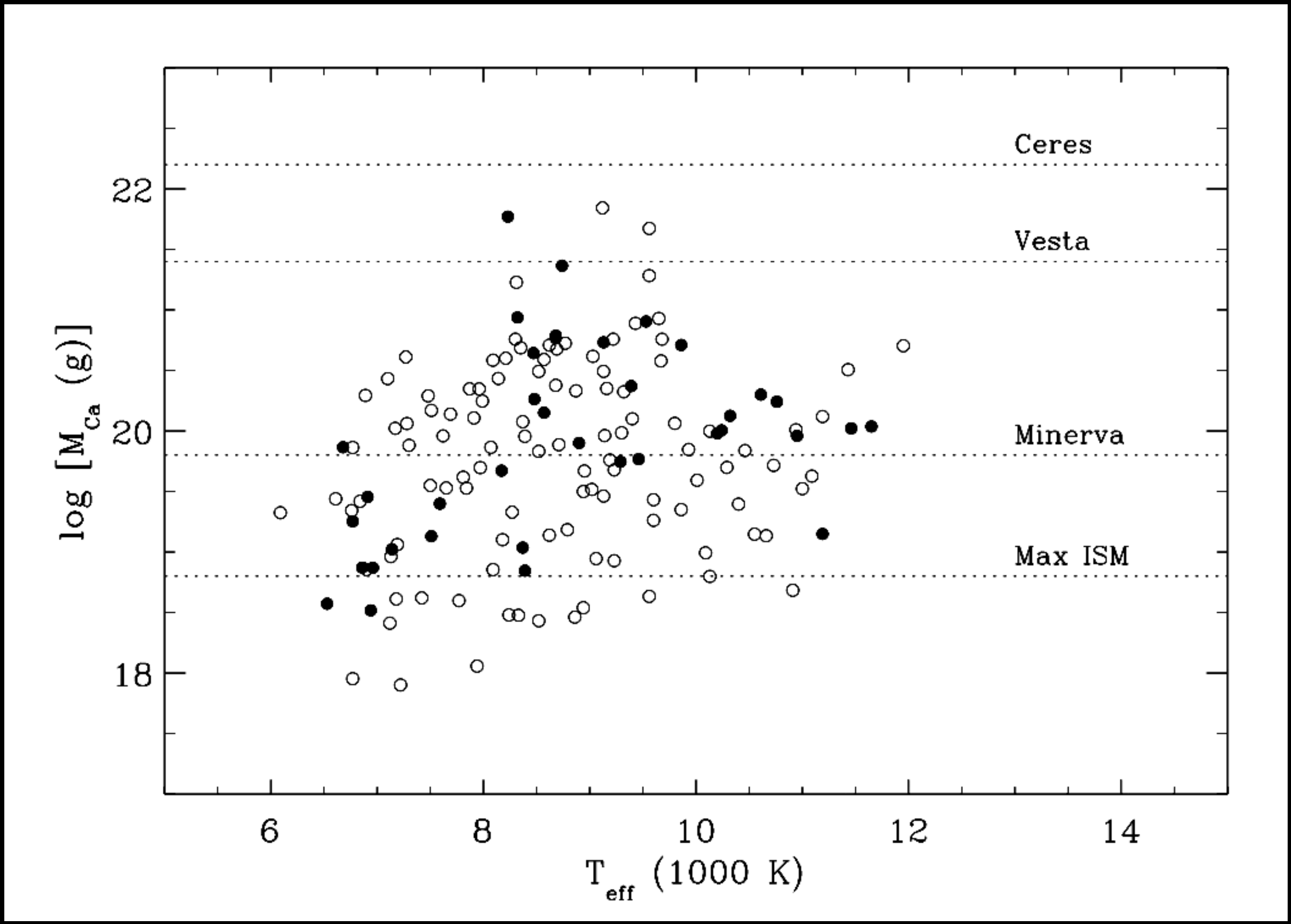

SDSS 1228+1040
PG 1015+161
PG 0843+516
GALEX 1931+0117
log(Fe/Si)
log(O/Si)
BE
CI
S
BSE
log(Ca/Si)
log(Al/Si)
BSE
BE
S, CI
log(O/Si)
log(C/Si)
HS2253
GD40
GD362
CI
S
BSE
BE
log(Fe/Si)
log(Mg/Si)
BE, S, CI
BSE

Debris Properties

- Stellar pollution is refractory-rich, volatile-poor
  - dominated by Mg and Fe silicates
- Overall abundances broadly mimic the bulk Earth
  - more carbon-depleted than chondrites
- Some evidence for differentiated bodies
  - stripping, melting, collisions (e.g. Moon)
- $M_{accreted} > 10^{22}$ g; up to 10^{25} g (Pluto)

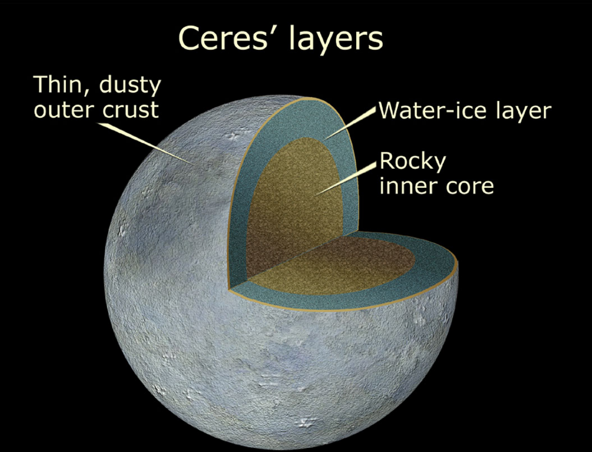
Sizable to Large Asteroids

(Farihi, Barstow, Redfield, Dufour, Hambly 2010)



Water-Rich Asteroids

- Asteroids strong candidates for Earth's water
  - e.g. Ceres

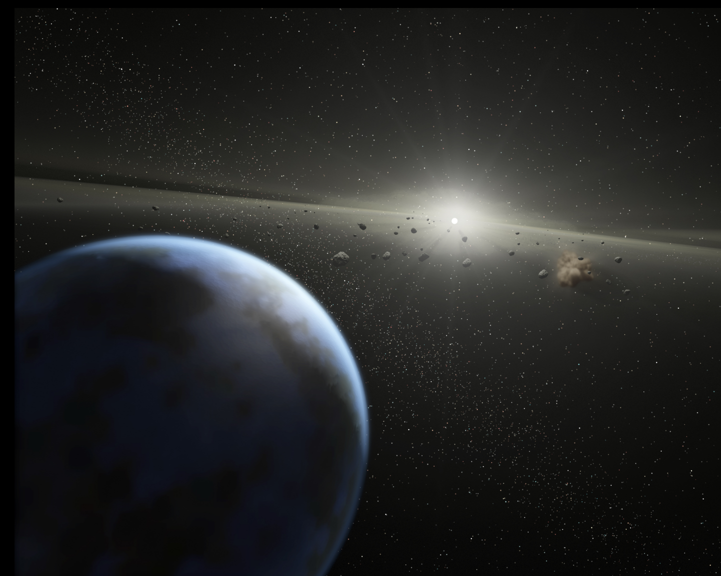


- Search for water-rich analogs

- Rocks composed of metal oxides: MgO, SiO_2, etc.
  - Excess O in debris can indicate H_2O

Initial Results on Water

- Water likely identified in the debris at GD 61
  - Farihi et al. 2011, ApJL, *728*, 8



- 17% H_2O by mass

- Asteroid the size of Vesta

- Superior data with Keck & *Hubble* confirm result

The Need for E-ELT HIRES

- Few stars can be done with Keck + VLT
- SDSS + *GAIA* will produce hundreds of targets
- E-ELT for detailed chemistry, exo-asteroid families
- Rock chemistry as a function of Galactic Age
- Synergy with ALMA

The Need for E-ELT HIRES

- UV needed for transitional, refractory elements
  - Mg, Al, Si, Ca, Ti, V, Cr, Mn, Fe, Co, Ni
- Red needed for volatile metals, disk emission
  - O, Na, Ca triplet, possibly C
- Multiple transitions, multiple lines for accuracy
- High resolution, high UV throughput


End