The Composition of Terrestrial Exoplanets via Asteroid Archaeology

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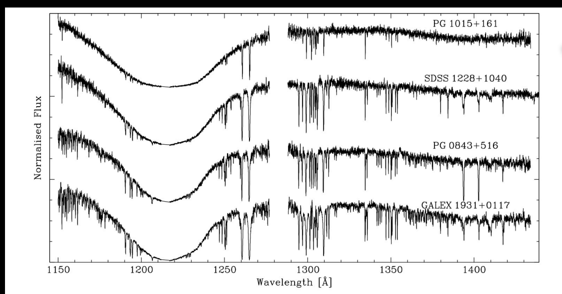
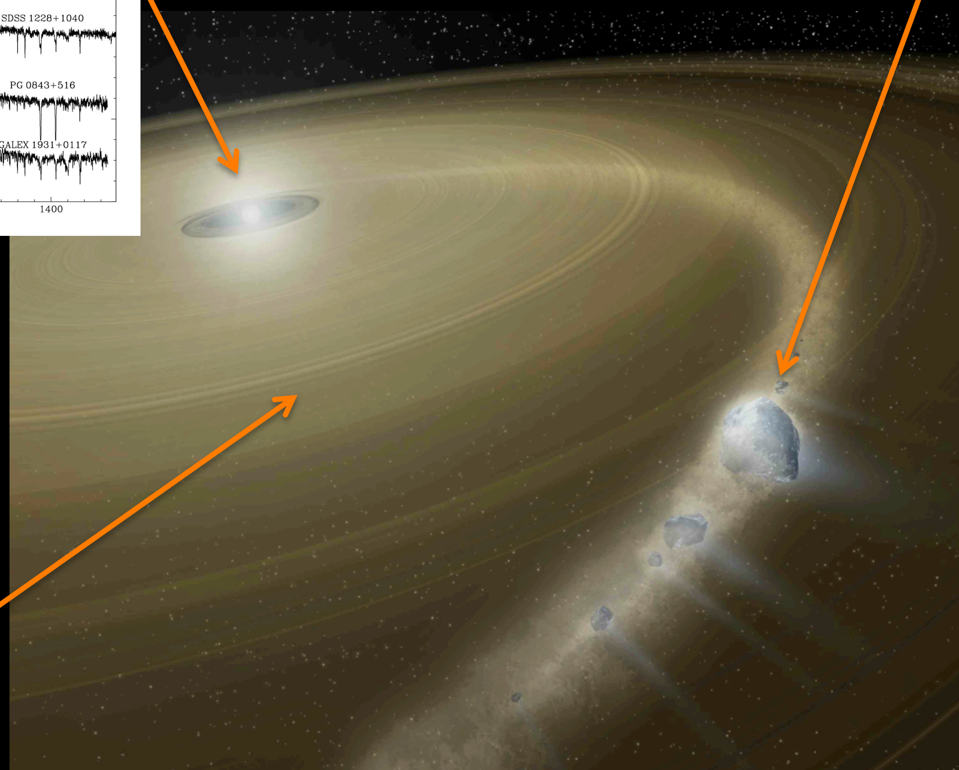
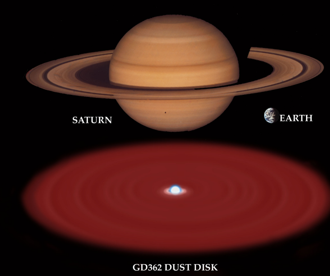
Asteroid-Polluted Stars

Asteroid chemistry observed in star

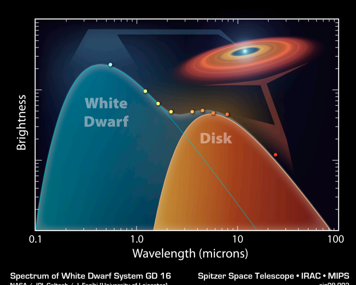


Tidally disrupted asteroid
(a la Saturn's Rings)





Disk emits in
infrared

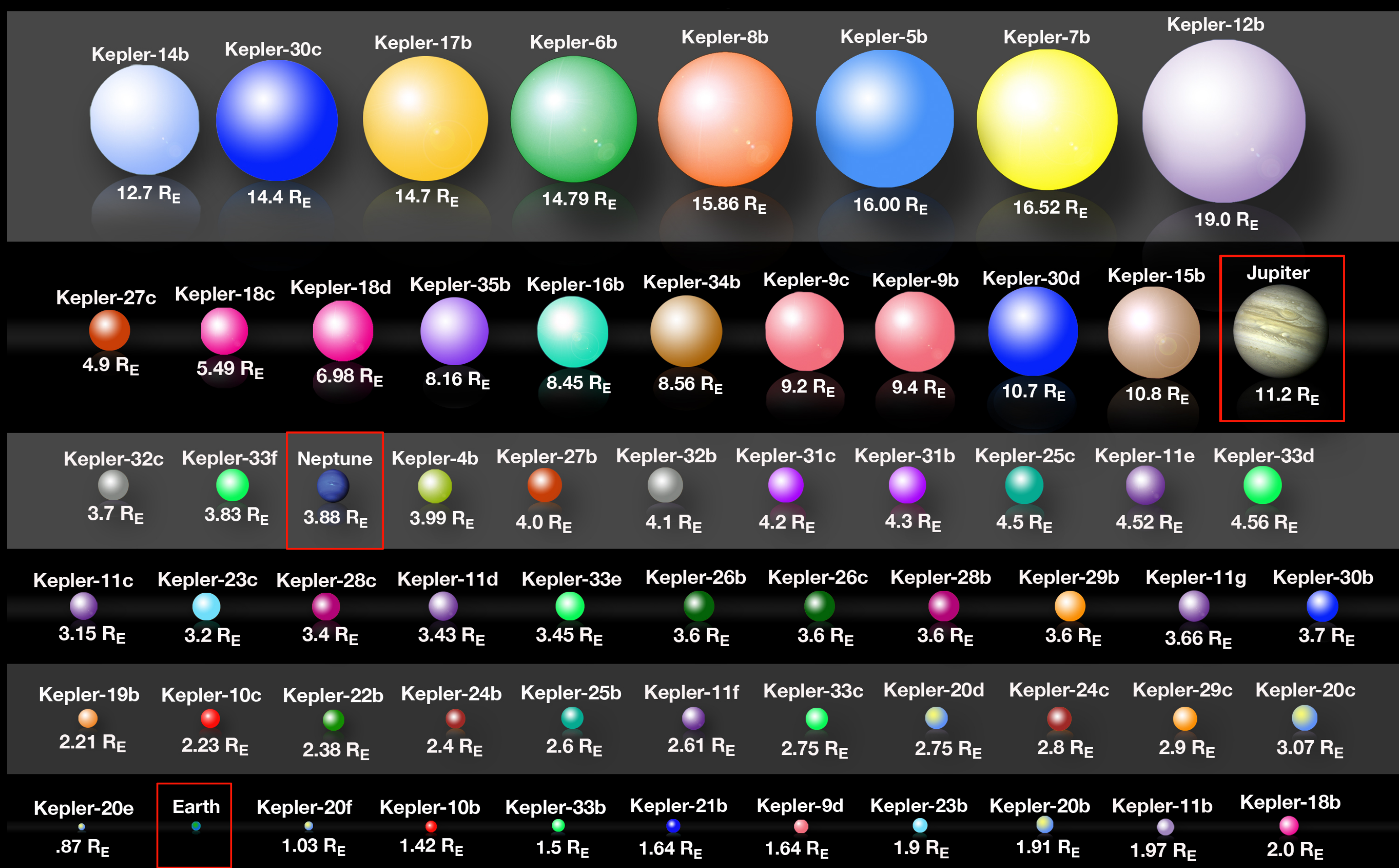


Goes far beyond scratching the surface...
we get the entire planetesimal / minor planet

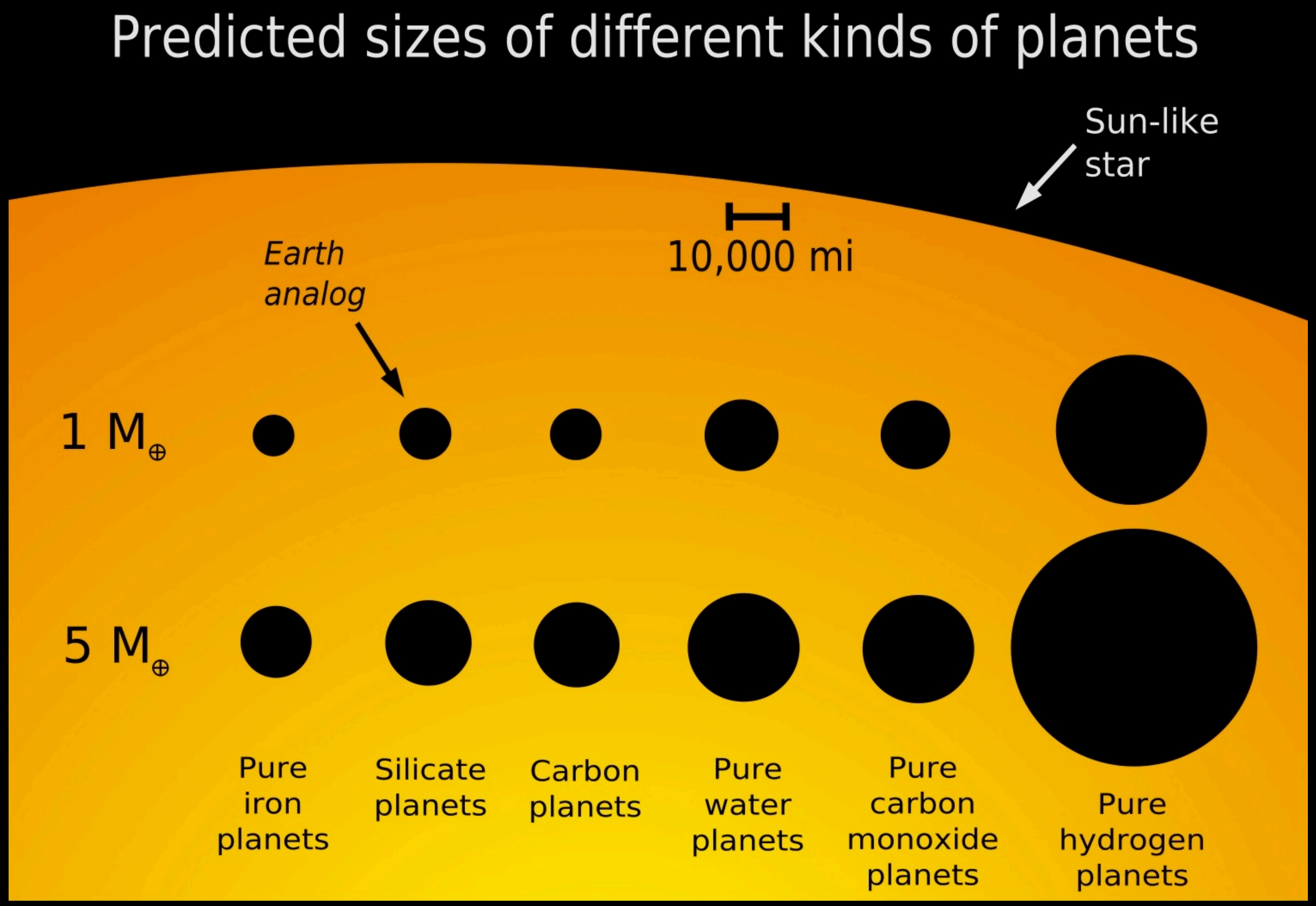
Who Cares About Old Rocks?!

- Exo-earths are an E-ELT science driver
  - composition will remain unknown & model dependent
  - bulk ingredients critical for determining 'Earth-like'
- Meeting relevance & discussions
  - planetesimals: outcome of initial disk chemistry / evolution
  - asteroids: building blocks of terrestrial planets
- Both planets and an asteroid-like belt are required
  - 'Holey Disks' likely related; e.g. Main Belt Kirkwood gaps

Kepler Zoo 2012.2

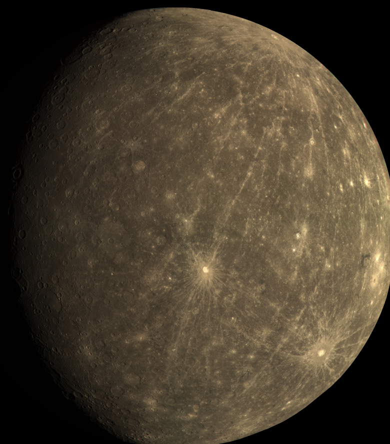


Planet *R–M* is Degenerate



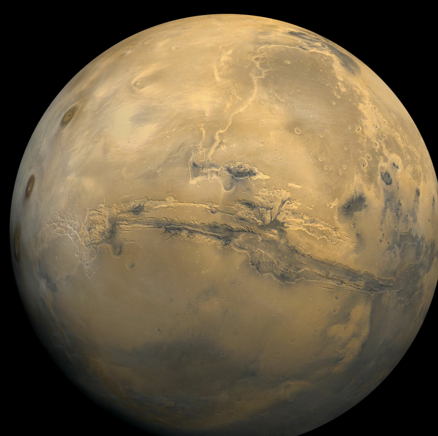
Some Possible Compositions

Iron-rich
(Mercury)



Iron-poor
(Moon)

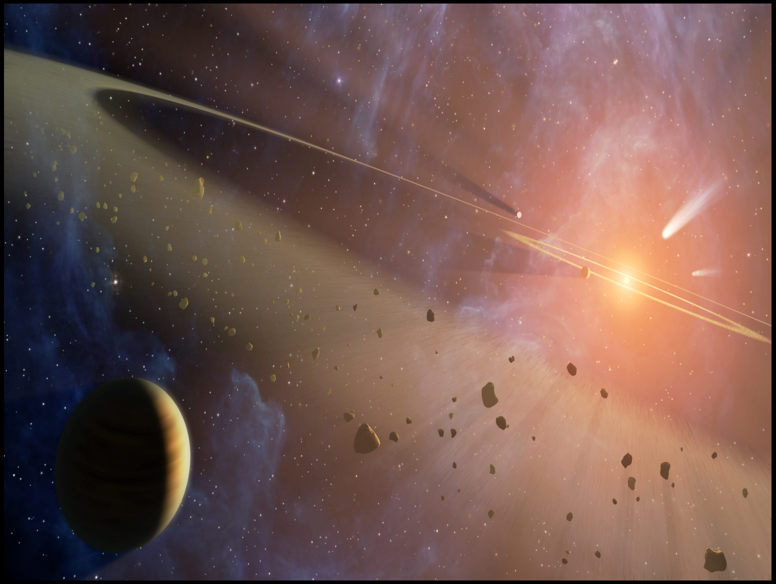
Silicate-rich
(Mars)



Earth-like

Asteroids are Terrestrial

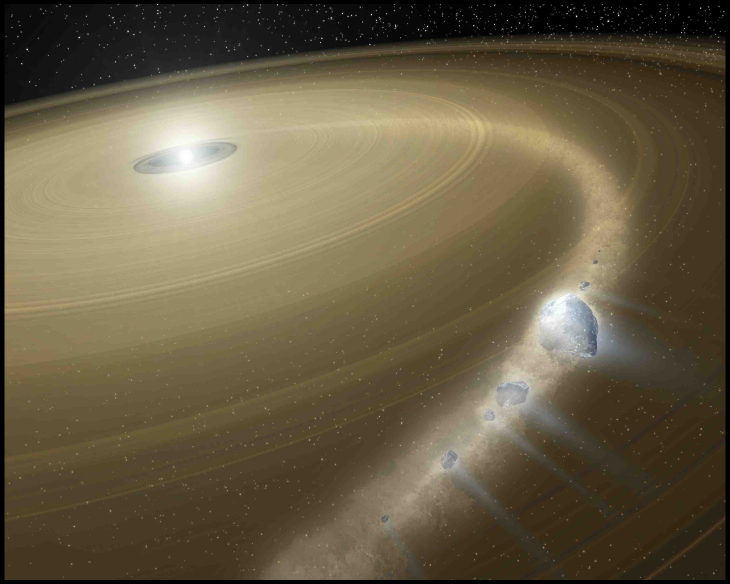
- Primordial building blocks of the terrestrial planets
- Meteorites are fragments



- Possibly delivered Earth's water & volatiles

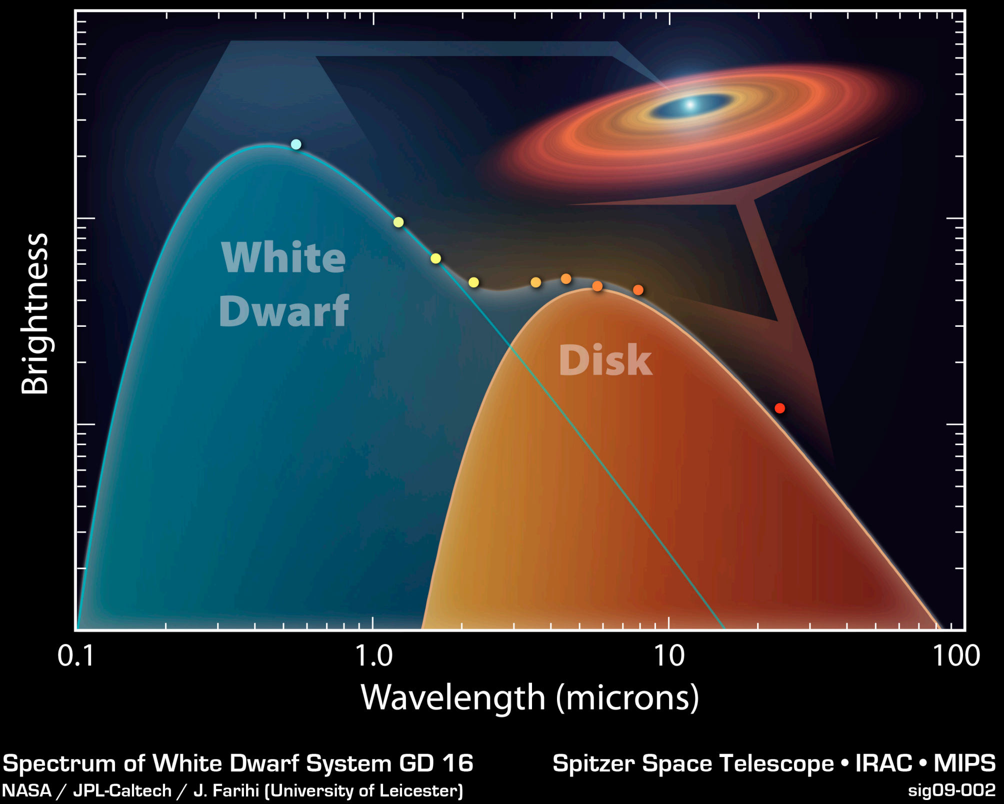
Asteroid Destruction

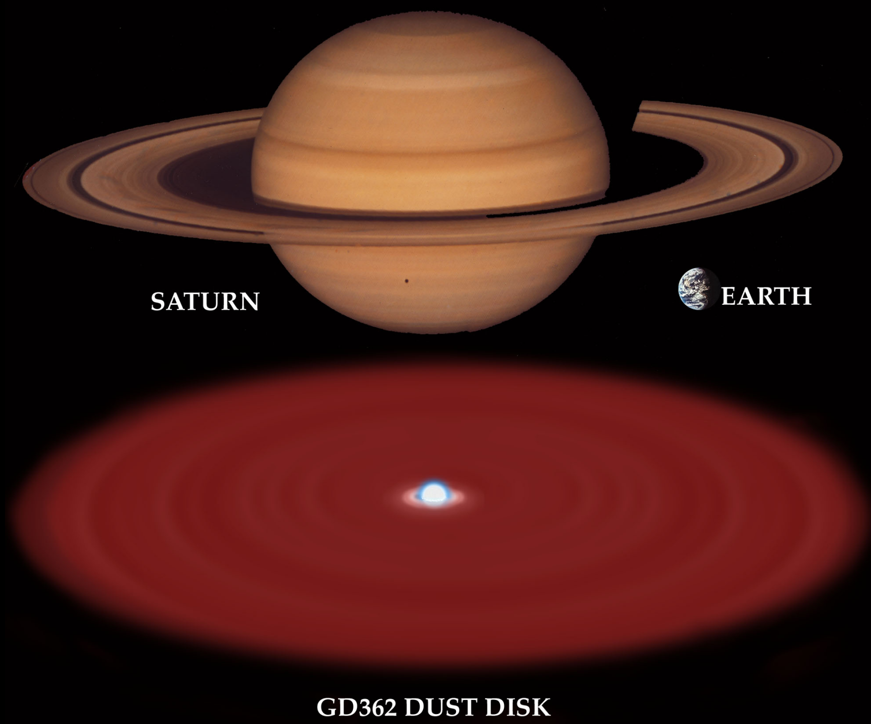
- White dwarfs are *compact*
  - asteroids tidally shredded
- White dwarfs are *pristine*
  - star is polluted by debris
- How do we know this?
  - disk mass, location, composition; heavy elements in star



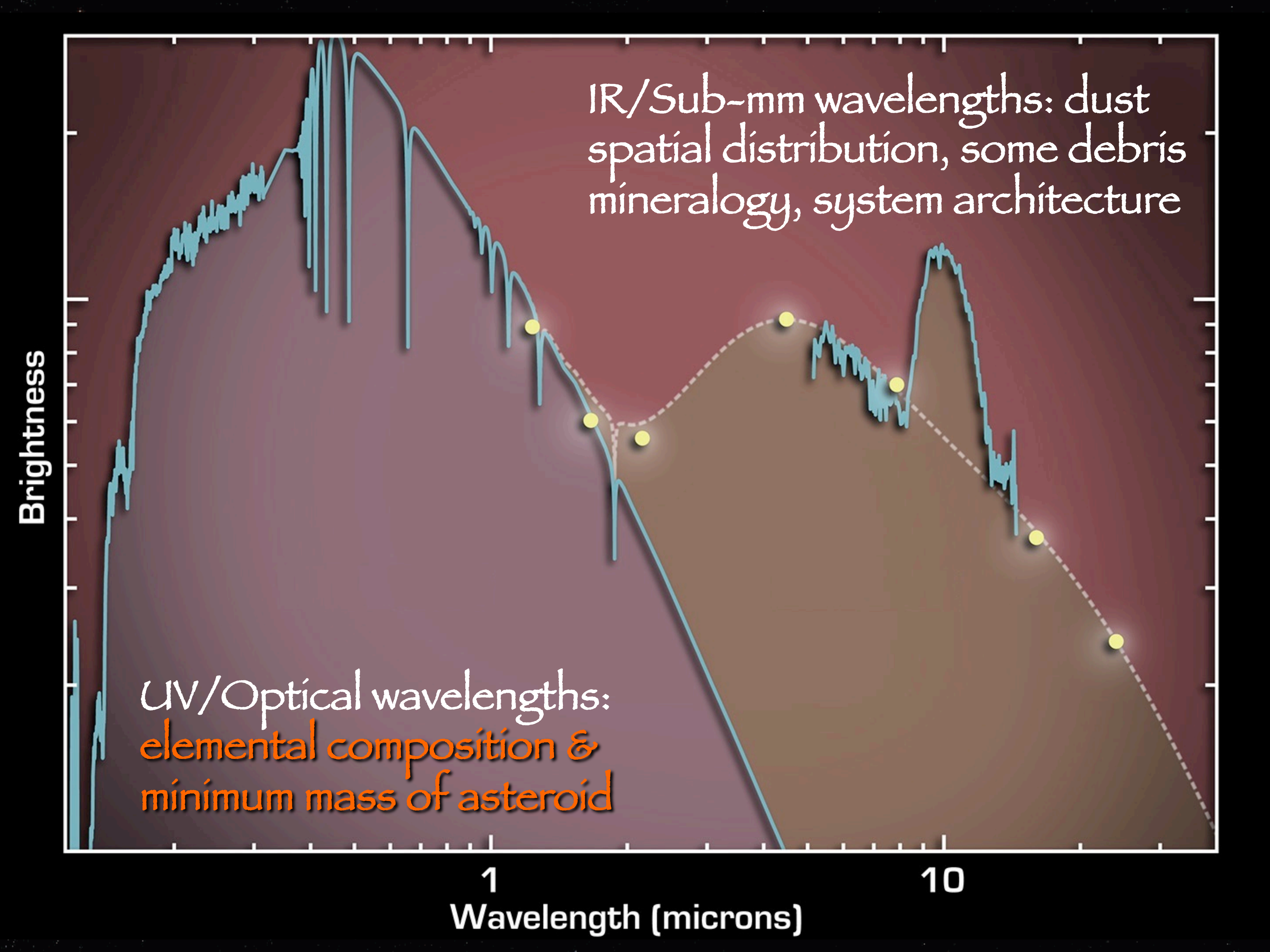
Graham et al. 1990; Jura 2003; Rafikov 2011, 2012

Typical Dust Rings

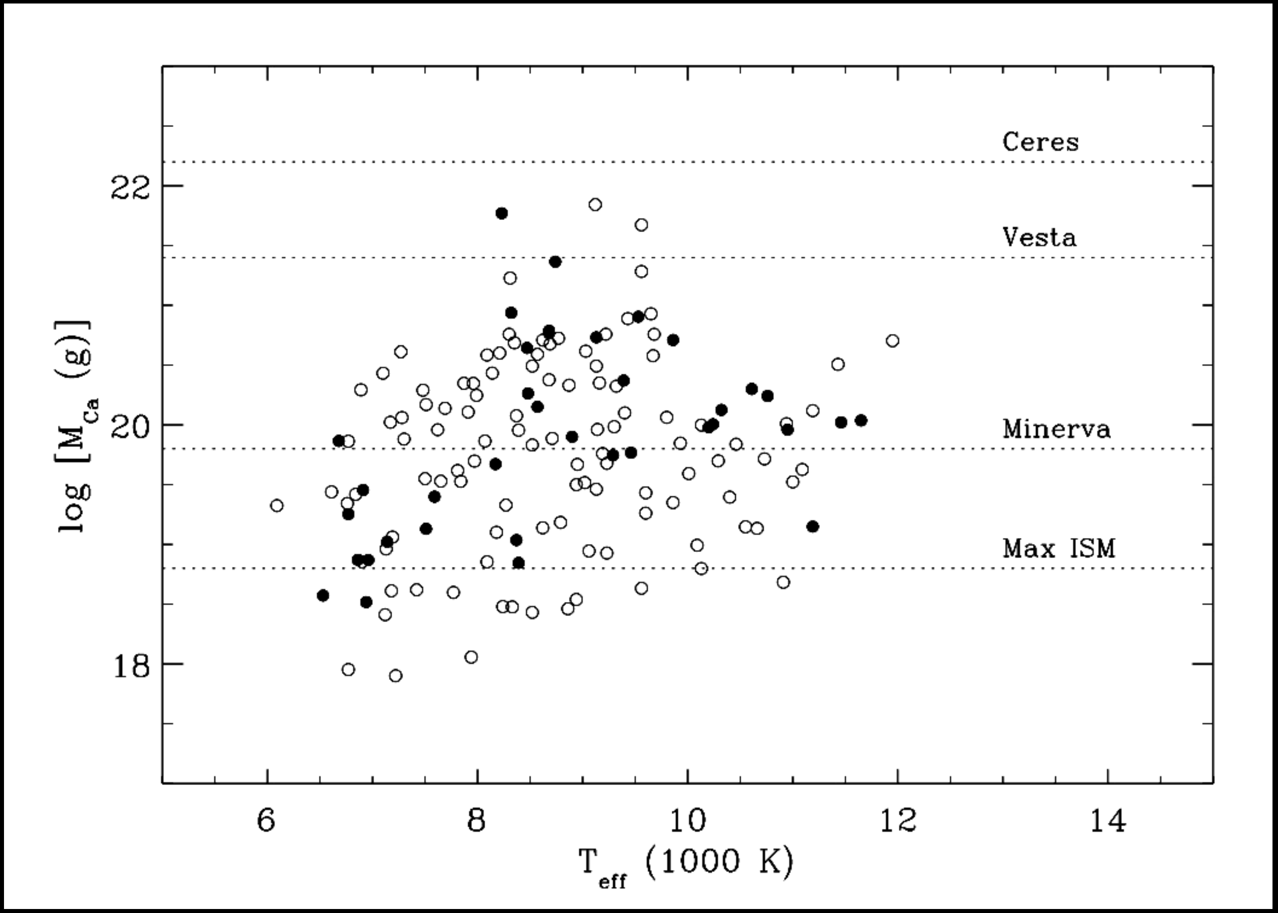




Farihi et al. 2009

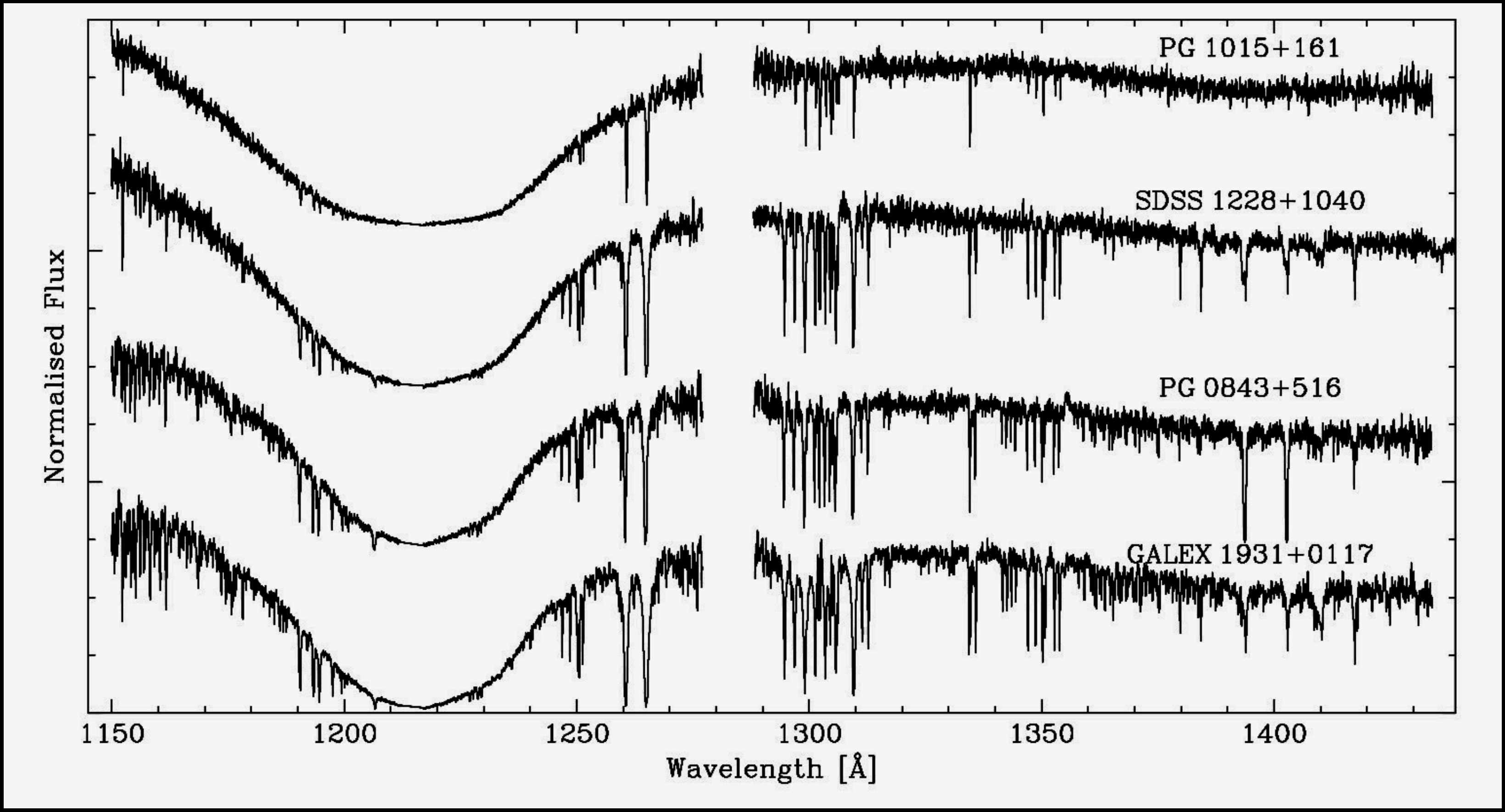

IR/Sub-mm wavelengths: dust spatial distribution, some debris mineralogy, system architecture
UV/Optical wavelengths:
elemental composition & minimum mass of asteroid
Brightness
1
10
Wavelength (microns)

Sizable to Large ($d > 150$ km) Asteroids

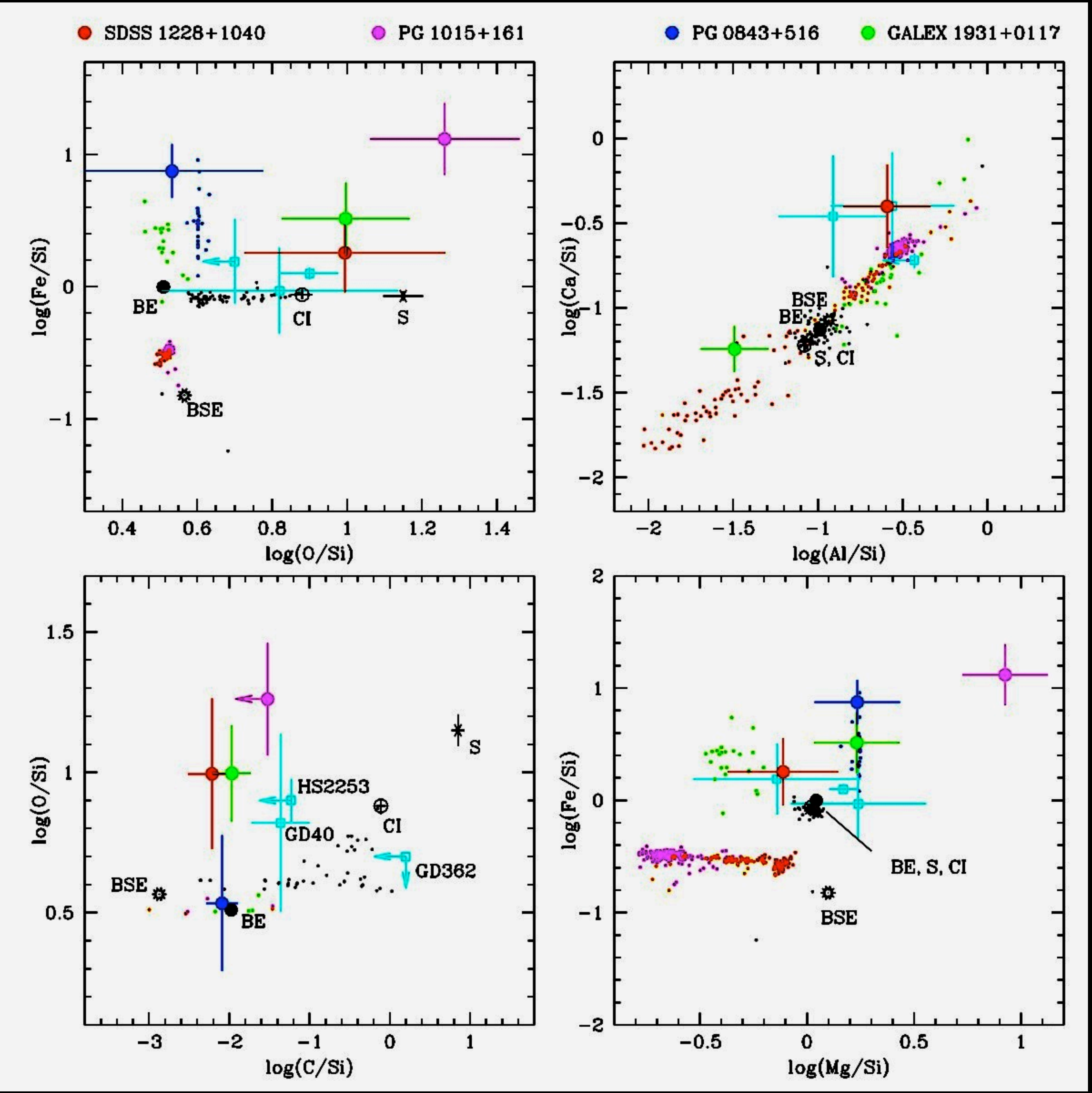


Farihi et al. 2010

HST COS Confirms Rocky Debris



Gänsicke 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)
S, CI
log(C/Si)
HS2253
GD40
GD362
log(Mg/Si)
BE, S, CI

Planetary Debris Properties

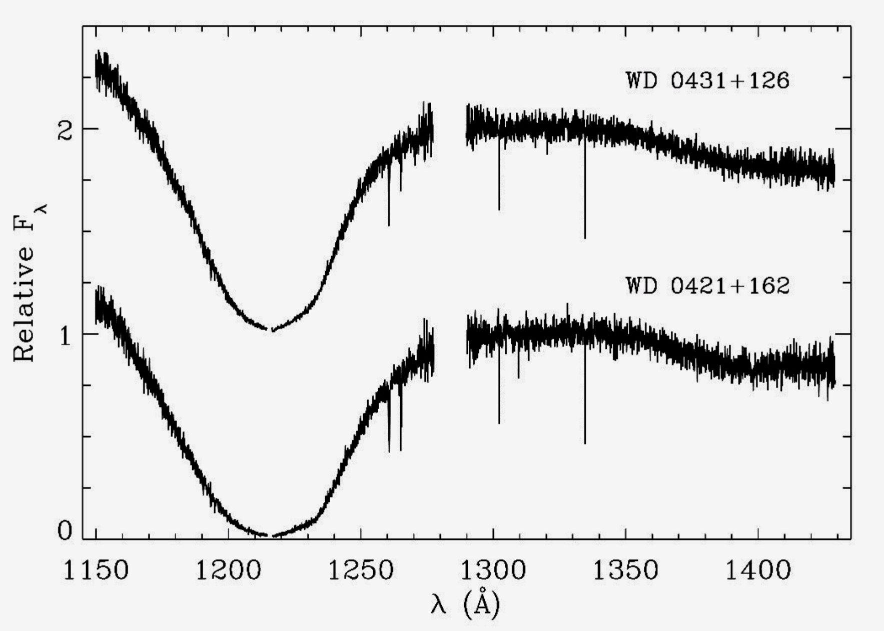
- Stellar pollution is refractory-rich, volatile-poor
  - dominated by Mg and Fe silicates

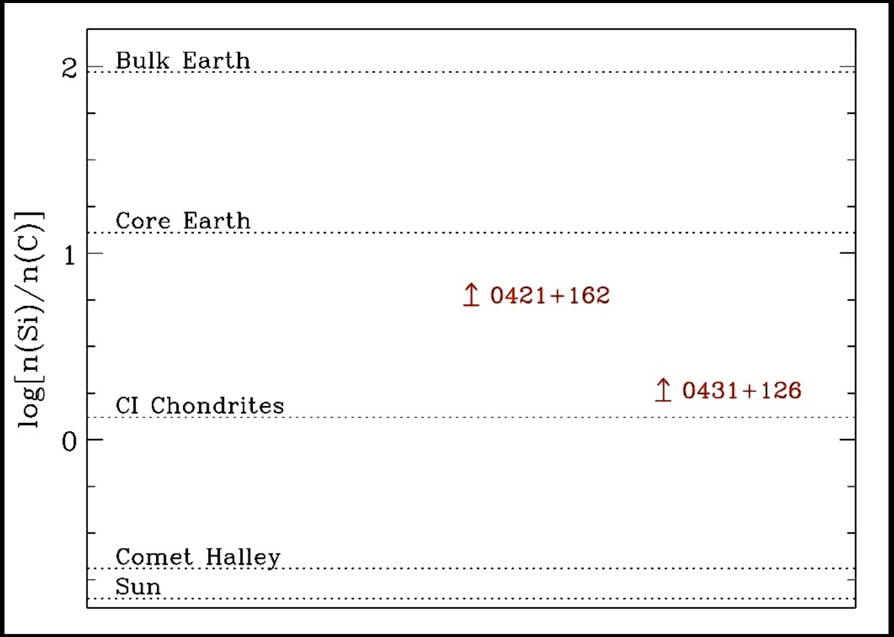
- Overall abundances broadly mimic the bulk Earth
  - C-depletion > chondrites; formed interior to snow line
  - at least as diverse as different meteorite classes

- Some evidence for differentiated bodies
  - stripping, melting, collisions (e.g. Moon)

- $M_{accreted} > 10^{22}$ g; up to 10^{25} g (Pluto)

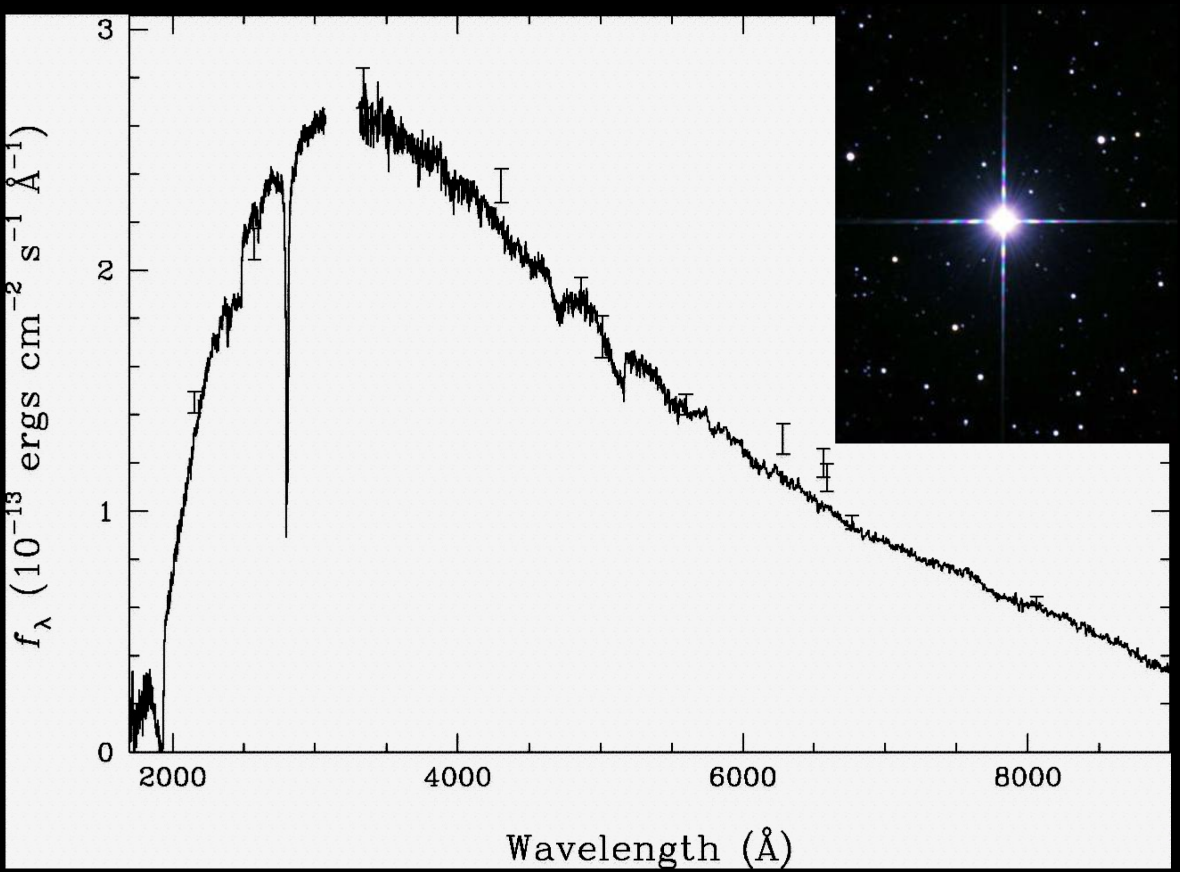
Asteroid-Polluted Hyads at 625 Myr





Farihi et al. 2013a

Procyon B is Polluted



Farihi et al. 2013b

A Snow Line Exo-Asteroid

- Water identified in the debris at GD 61

- 26% H_2O by mass
- Asteroid the size of Vesta

Farihi et al. 2013c

- Multiple datasets (e.g. *HST*, Keck) confirm result

The Need for Future Instruments

- Few stars can be done with Keck + VLT + *HST*
- SDSS + *GAIA* + ____ will yield hundreds of targets
- E-ELT: detailed chemistry, exo-asteroid families
- Terrestrial chemistry over Galactic history/environs
  - clusters, streams, thin and thick disk, halo, etc.

A Possibility for E-ELT

- UVB needed for transitional, refractory elements
  - Mg, Al, Si, Ca, Ti, 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, decent UVB-Red throughput

Exoterrestrial Archaeology

- White dwarfs are the end of > 95% of all stars
  - at least 20% - 50% polluted by terrestrial-like debris

- Main-sequence A and F star progenitors
  - at least 20% - 50% build terrestrial planets

- Metal-rich white dwarfs indirectly measure the bulk composition of extrasolar, rocky planetesimals, the building blocks of terrestrial exoplanets

- Future UVB spectroscopy critical