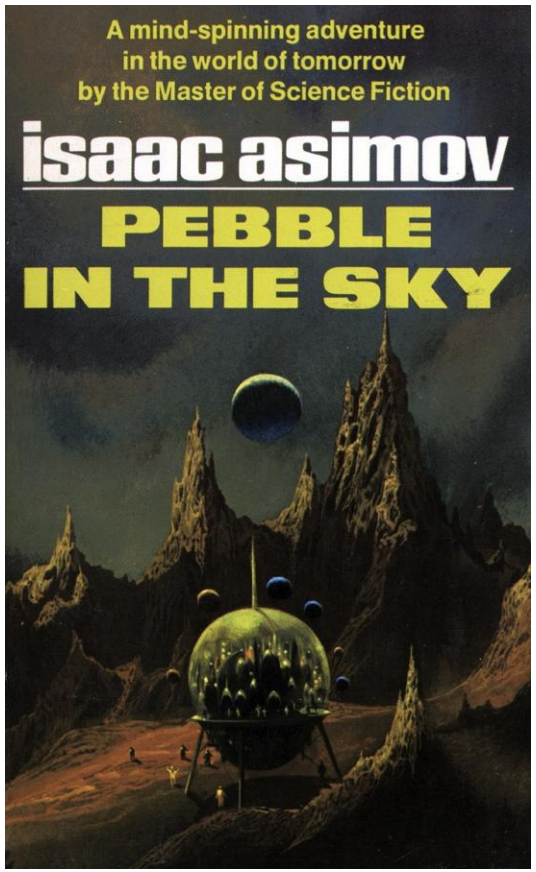
Extrasolar Cosmochemistry



Is Earth “normal”?

UCLA Ph.D.’s -- Siyi Xu; Beth Klein

E. Young + B. Zuckerman + D. Koester

Talk Outline

- 1. White dwarfs and their pollutions
- 2. Zero order results: basic compositions
- 3. First order results: differentiation, 26Al widespread, solar system “ordinary”

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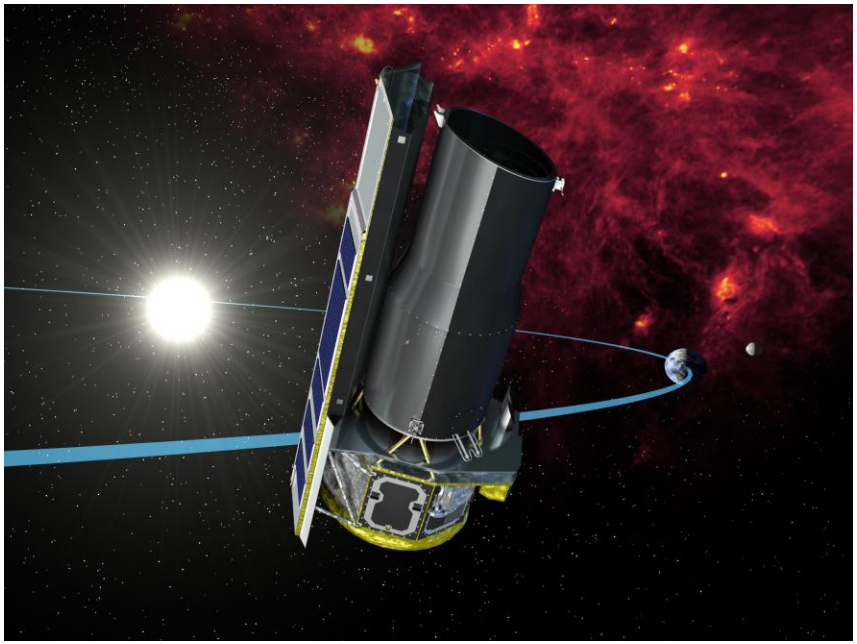


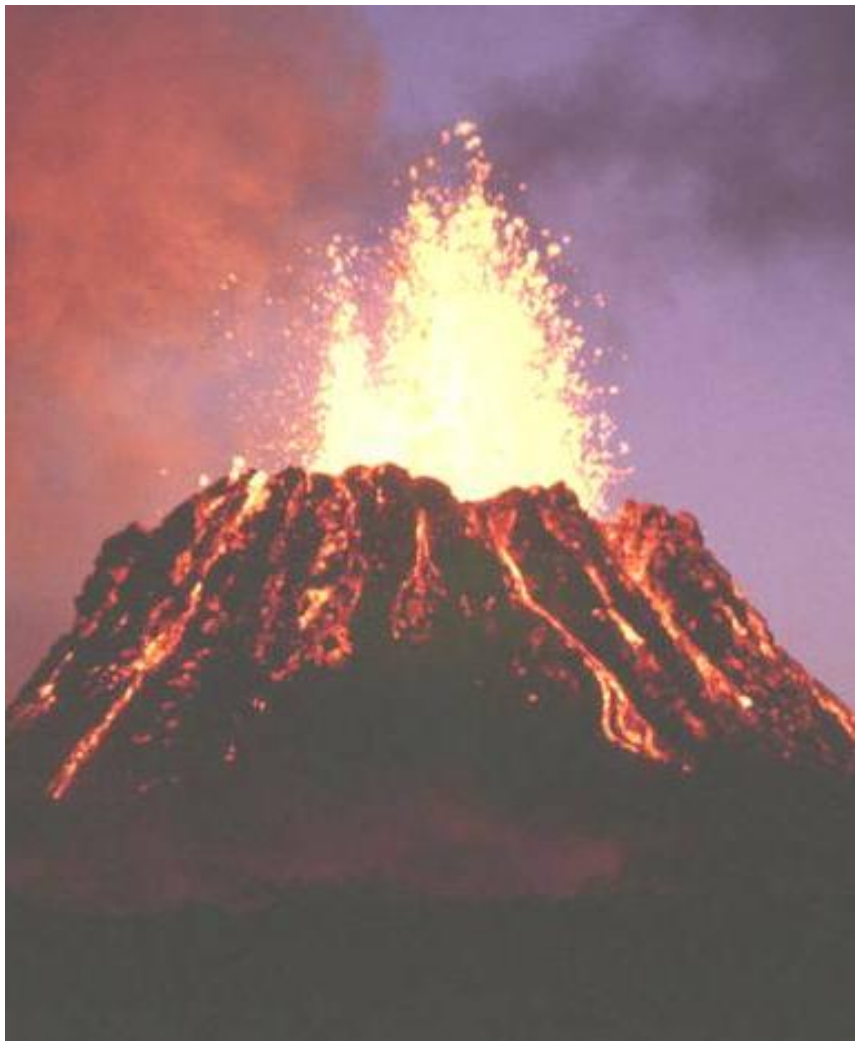
- Spitzer Space Telescope
- Keck/HIRES – University of California
- HST/COS
- NSF + NASA

Types of Solid Planets?

- Earth-like
- Ice-rich
- Iron-rich
- Carbon-rich
- Refractory-rich
- ???

Extrasolar Planetary Physics

- Do they differentiate into cores, mantles and crusts?
- Are mutual collisions important in their formation and evolution?
- What important physical processes occur in the protoplanetary disk? (like “snow lines”)



Earth: Largely 4 elements – O, Mg, Si, Fe; we live on a "dry" carbon desert

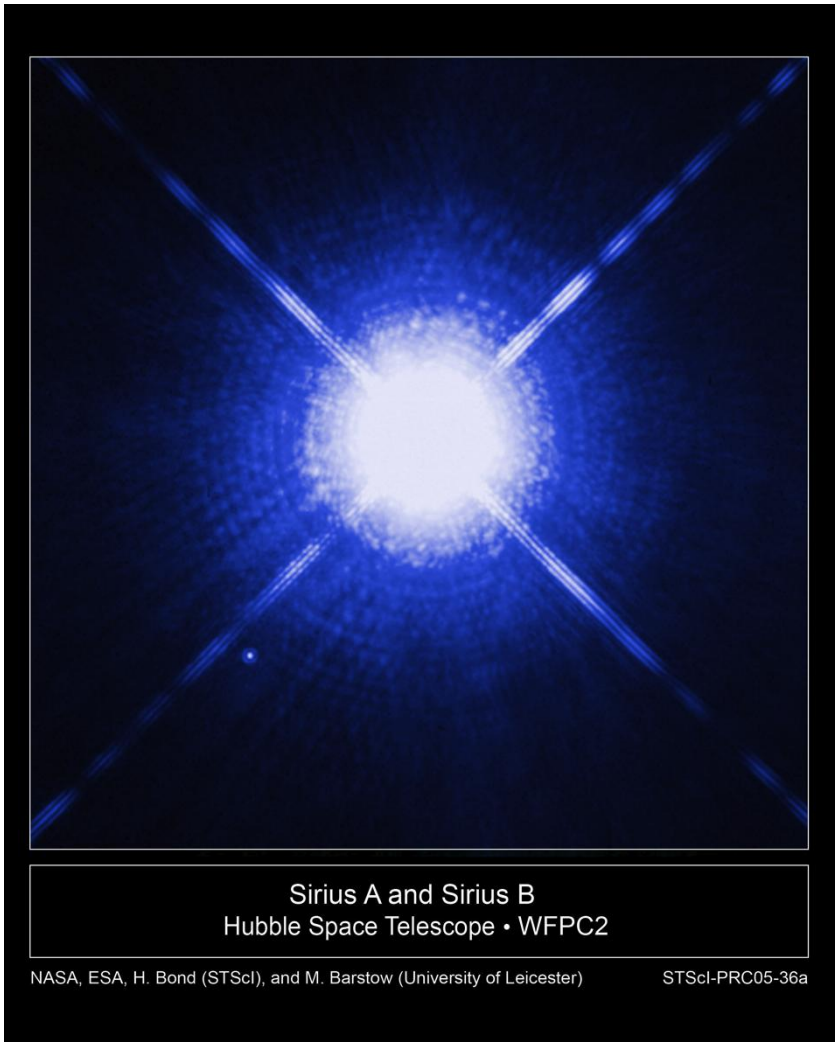
- [C]/[Fe] ~ 0.015 [by mass] in bulk Earth
- [C]/[Fe] ~ 1.8 [by mass] in the Sun
- Less than 1% water
- Elements with condensation T < 1100 K are deficient
- Differentiated: core/mantle/crust

Main Story

White dwarfs "smash" asteroids that stray within the tidal radius – forming an orbiting ring of material (sometimes dusty)

- Material then accretes from disk into stellar atmosphere

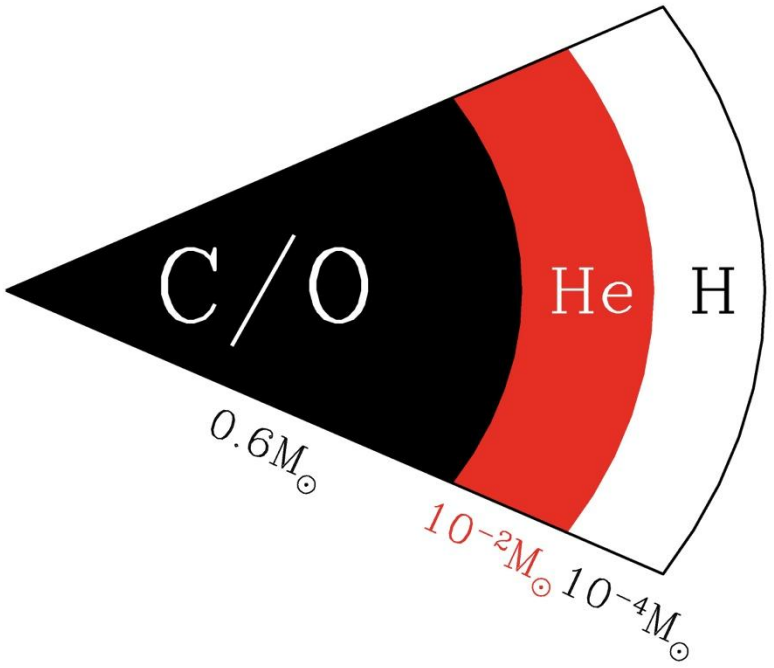
White Dwarfs



- Radius ~ Earth
- Mass ~ 0.6 mass (Sun) [substantial mass-loss]
- Very high gravity
- Cooling embers, characterized by atmospheric temperature
- Fate of Sun
- Common: ~10% of nearby stars (but very faint and hard to find)

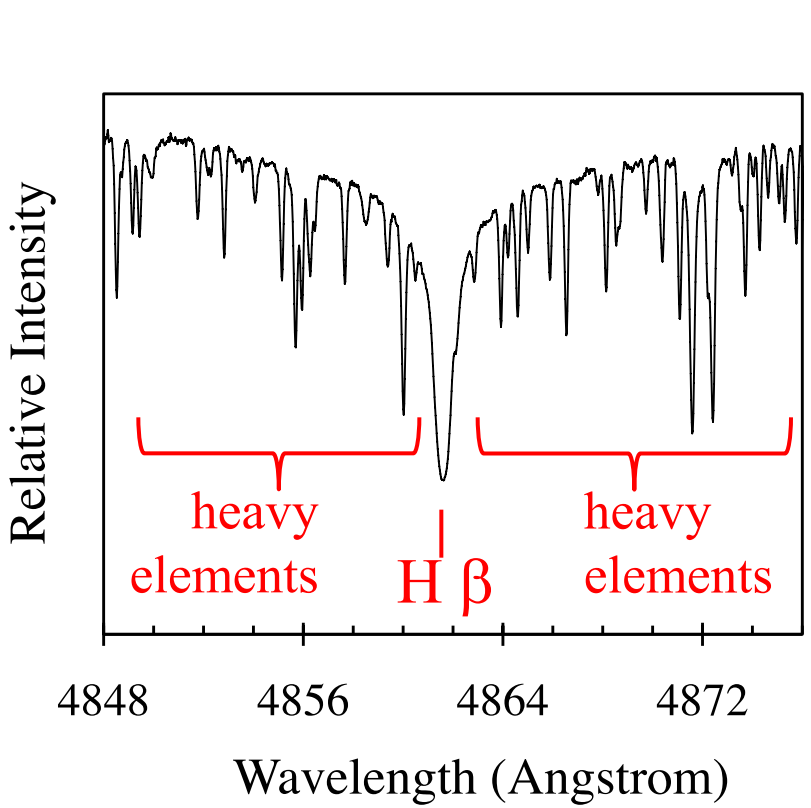
Expectations for White Dwarfs with atmospheric temperature, T_{eff} < 20,000 K

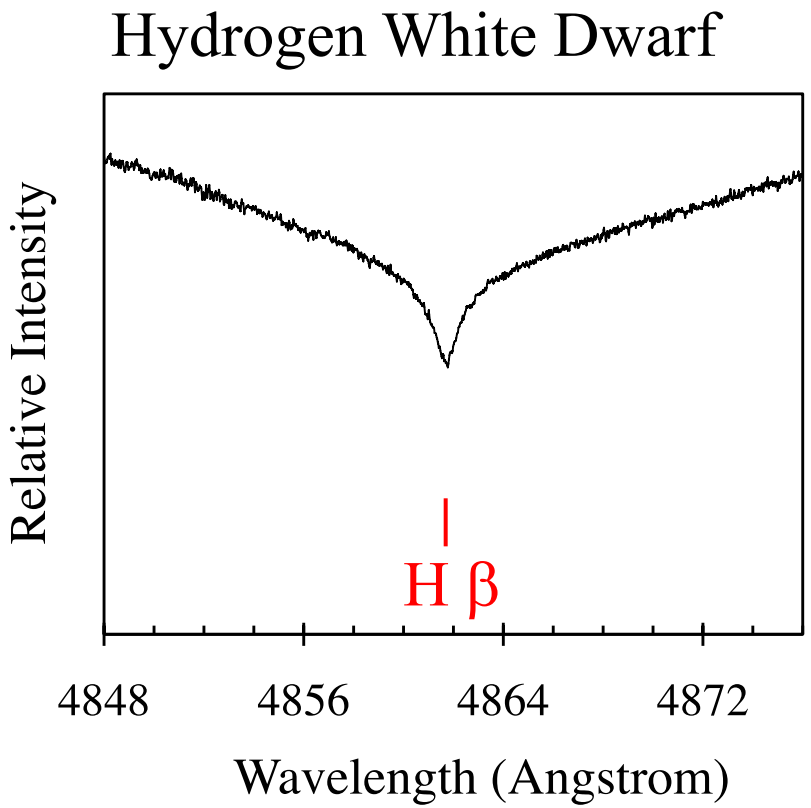
- High gravity: settling time of heavy elements < 1 Myr; always much less than cooling age of > 0.1 Gyr
- Usually: atmosphere pure H or pure He
- NO HEAVY ELEMENTS



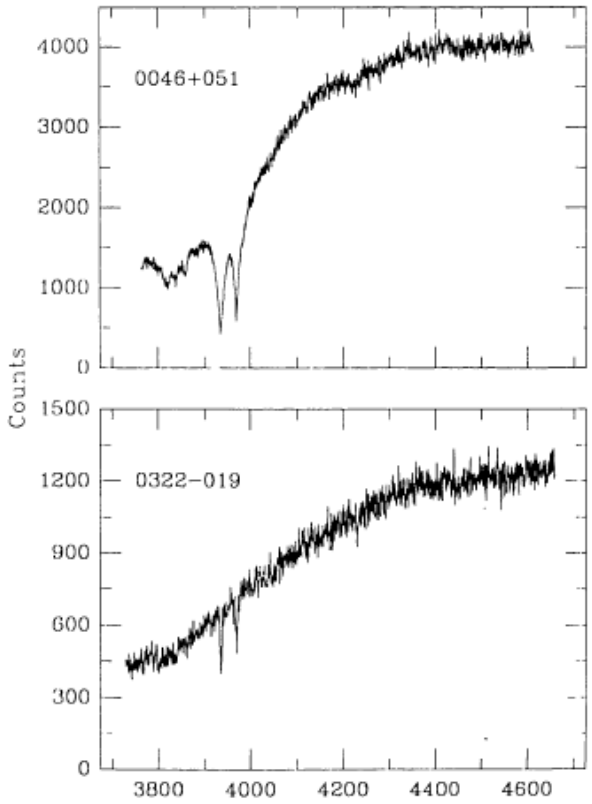
Pure H and/or He Atmospheres

" It is well known that white-dwarf spectra have only a remote resemblance to spectra of ordinary stars. "
- Kuiper, 1941



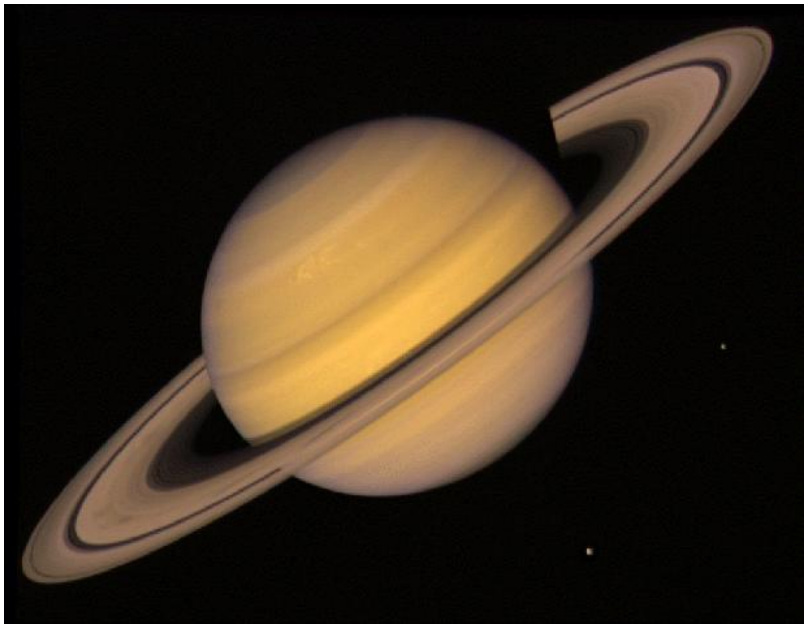


Examples of Externally-Polluted White Dwarfs



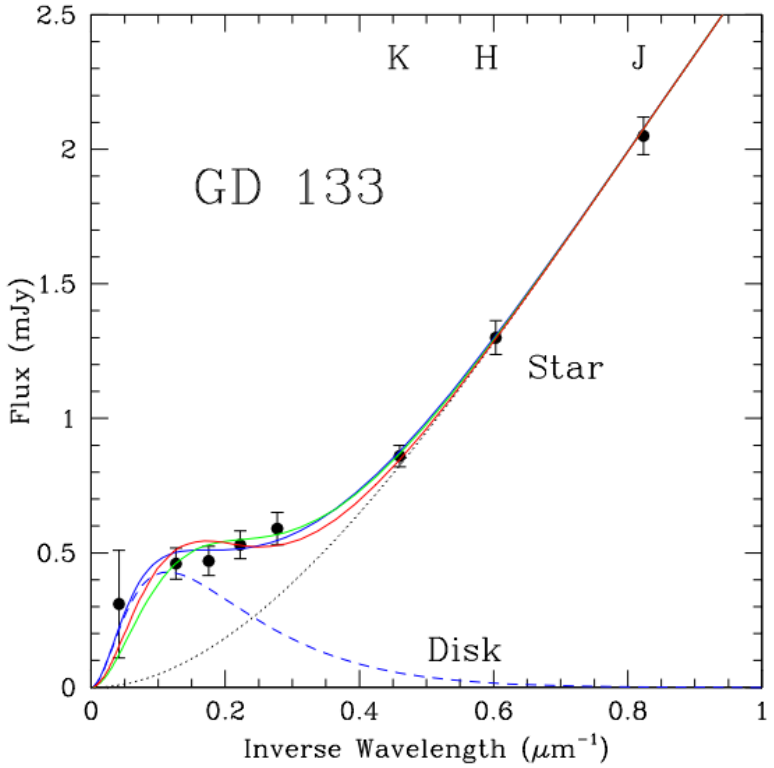
- Cooling Ages ~ 4 Gyr
- Ca settling time ~ 1 Myr
- [Ca]/[He] << Solar Ratio

Famous Comparison Object



- White dwarfs are smaller than Saturn
- White dwarf rings are larger than Saturn's; dust rather than ice
- ~4% of warm white dwarfs have dust rings; ~25% are externally-polluted

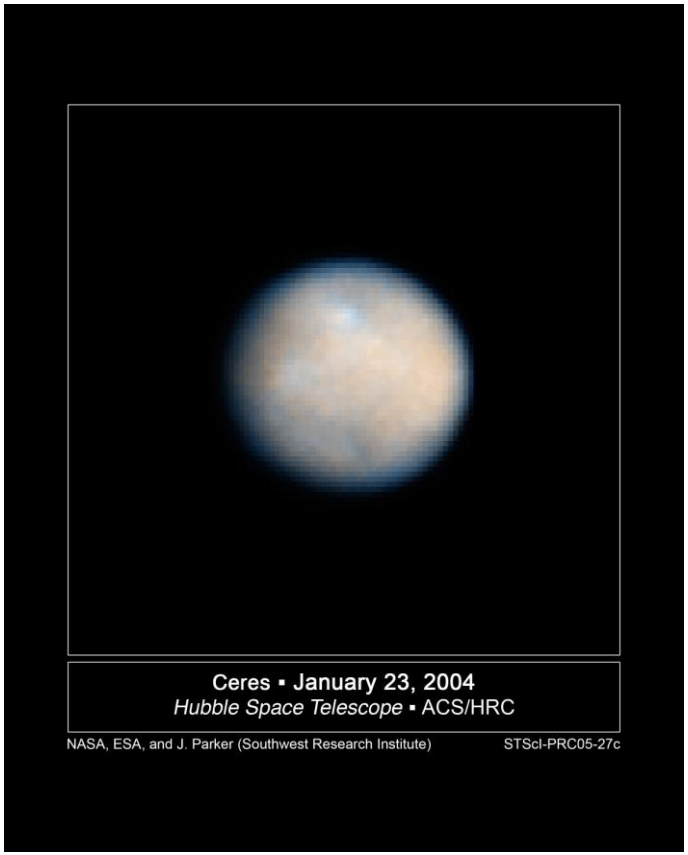
Disk model and data for GD 133



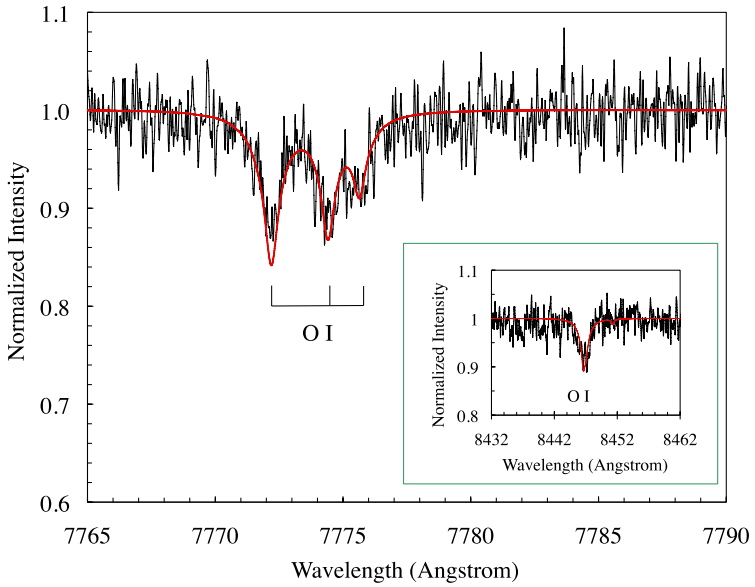
- T(inner) = 800-1200 K (silicate sublimation)
- T(outer) = 300-600 K (tidal radius)
- Tilt of disk uncertain
- Note: linear scale
- Factor of 400 less flux at 24 microns than expected for accretion of interstellar grains – disfavored model

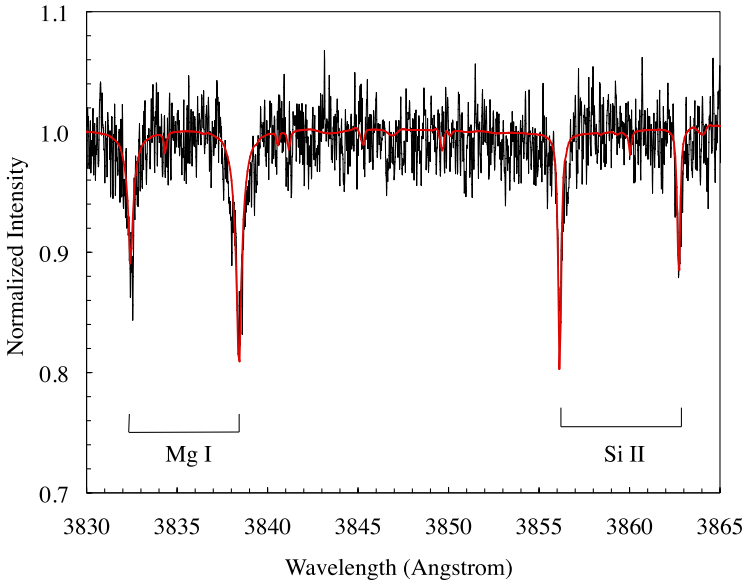
Minimum Accreted Masses similar to that of asteroids

- GD 362 -- 3% of Ceres
- GD 40 -- 4% of Ceres
- WD J0738+1835 – 70% of Ceres
- We are studying building blocks of extrasolar rocky planets

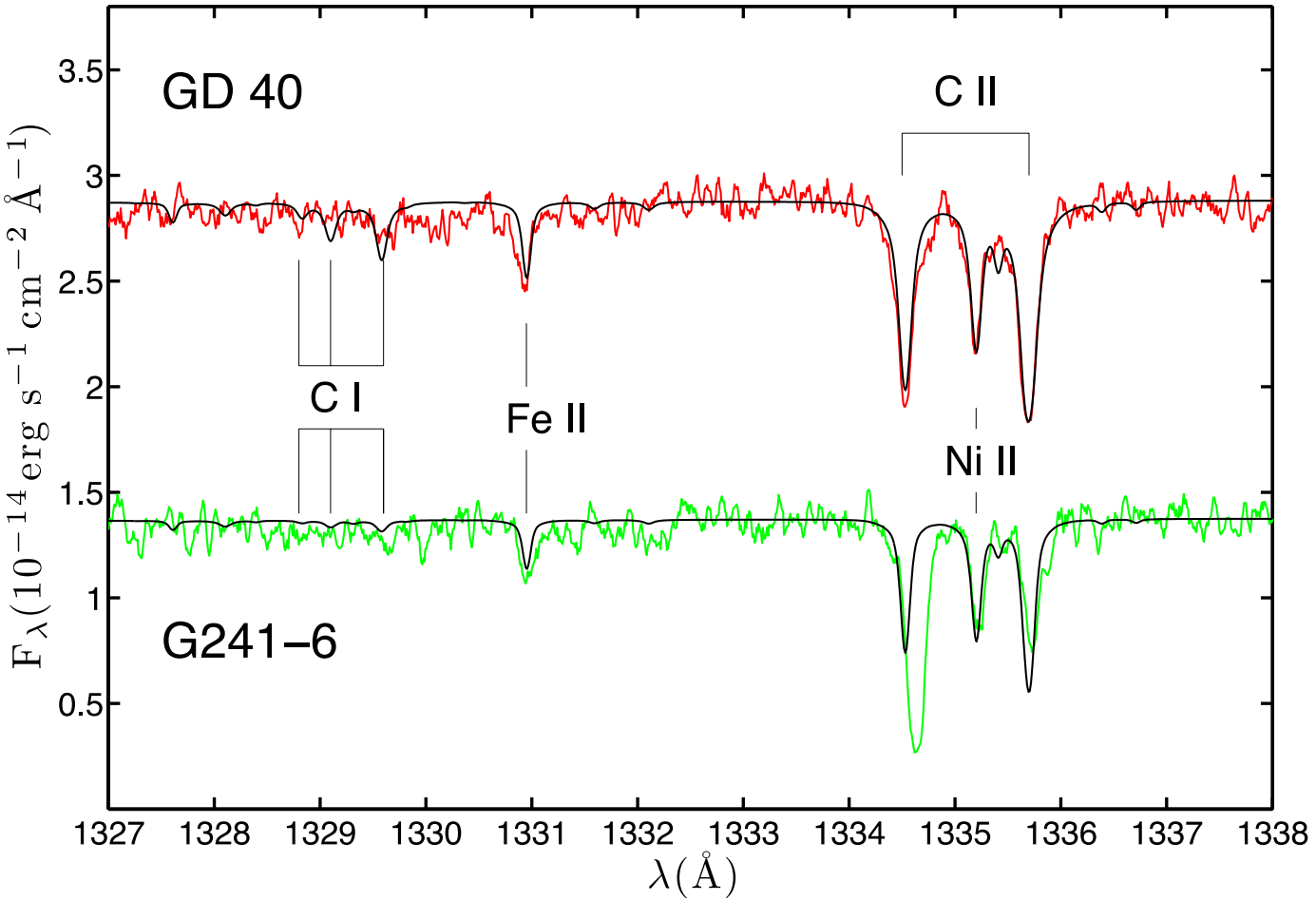


Keck Spectra of GD 40

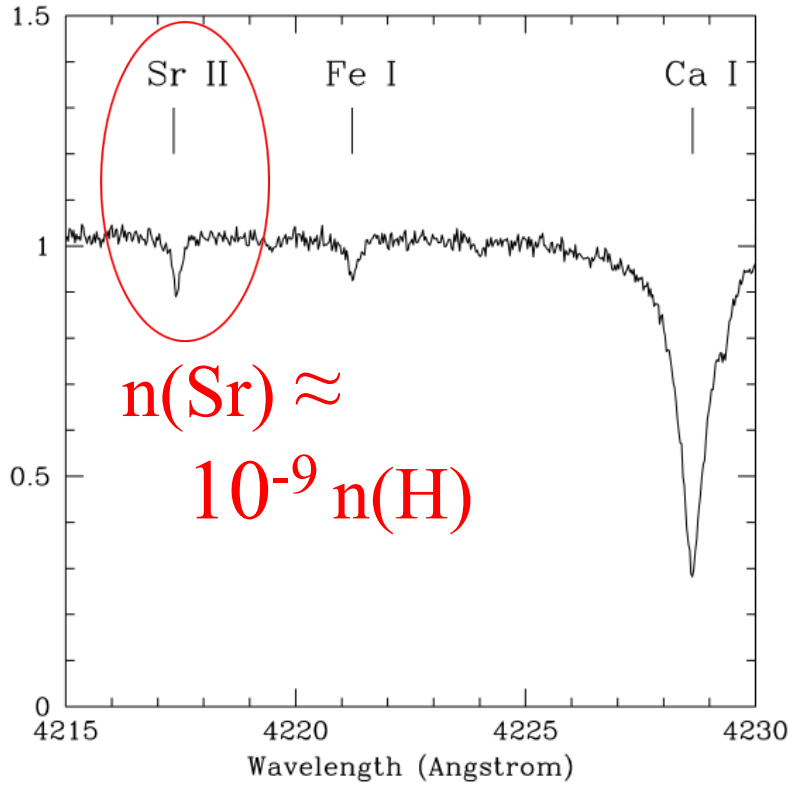


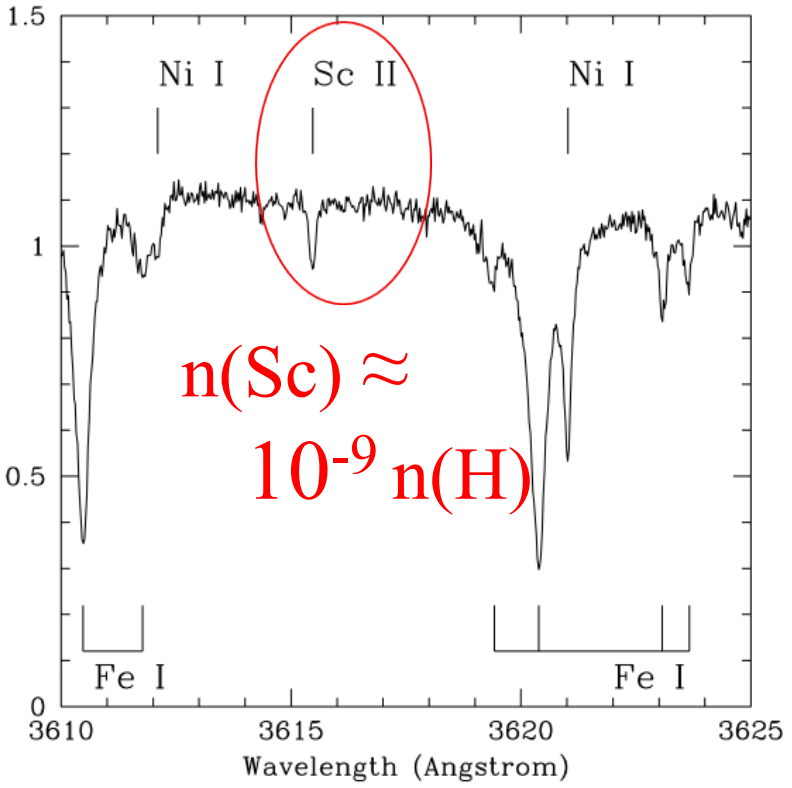


HST Spectra of GD 40 and G241-6



High resolution spectroscopy: exquisitely sensitive to even trace amounts of material.



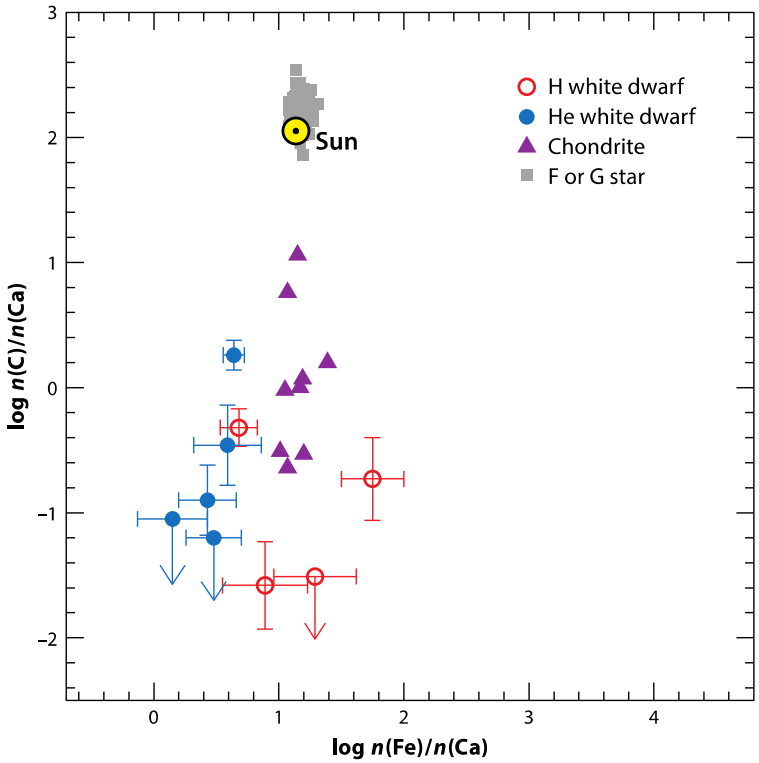


Inventory of Detected Heavy Elements

- 19 heavy elements positively detected in some star:
- C,O, Na, Mg, Al, Si, P, S, Ca, Sc, Ti, V, Cr, Mn, Fe, Co, Ni, Cu,Sr

- Most Richly Polluted White Dwarfs (All have dust disks):
- GD 362 – 16 elements
- WD J0738+1835 – 14 elements
- GD 40 – 12 elements
- WD 1929+012 – 12 elements
- Most elements only seen in a few stars

Carbon Deficiencies



- Logarithmic Scale: carbon deficient by orders of magnitude
- Carbon mass fractions similar to Solar System rocks – not Interstellar
- Almost certainly occurs during asteroid formation within disk

Why is carbon so deficient?

- Carbon in solid interstellar grains (depleted from gas phase, 2200 A feature in the ultraviolet) + PAHs
- Once vaporized, it can form volatile gases like CO but how does this happen?

- "… the accretion disk at the radius of the asteroid belt probably was never hot enough to vaporize all solids."

--McSween + Huss (2010) in Cosmochemistry

Evidence for Snow Lines?

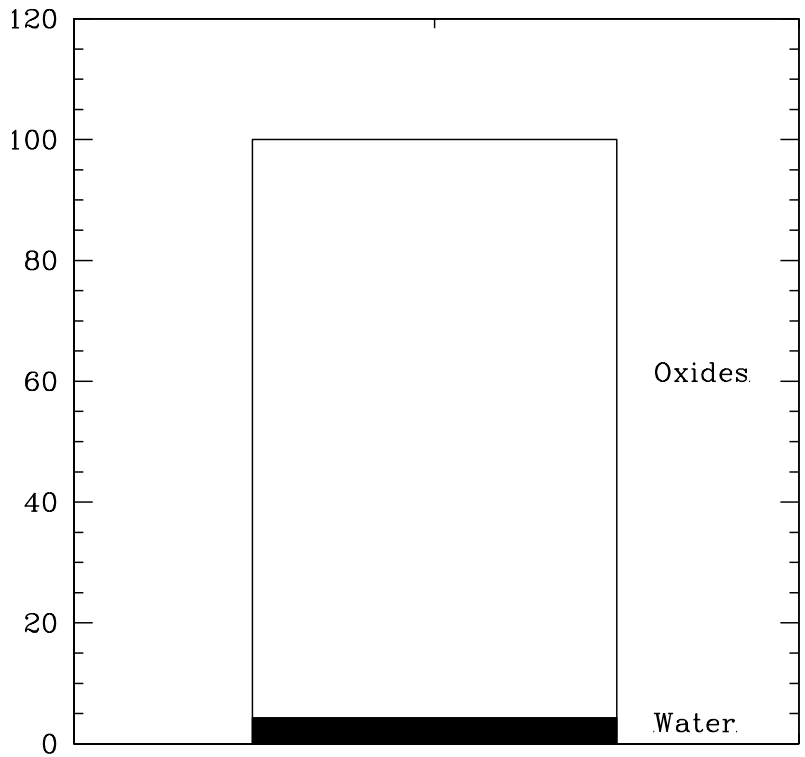
- Internal water survives AGB evolution – thermal conduction takes too long to heat up interior
- Ice and/or hydrated minerals?

Little Water in Planetesimal Accreted by WD J0738+1835

- T = 13, 950 K
- 0.84 M(Sun) – White Dwarf
- 4.5 M(Sun) – Main Sequence
- m(g) = 17.6 mag (SDSS)

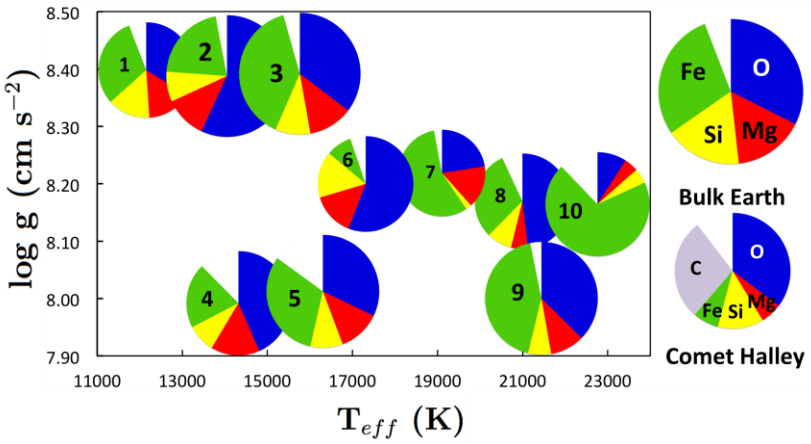
- < 1% water from small amount of H compared to heavy elements in this He-rich atmosphere

Oxygen Budget: Ensemble of Local He-Atmosphere White Dwarfs



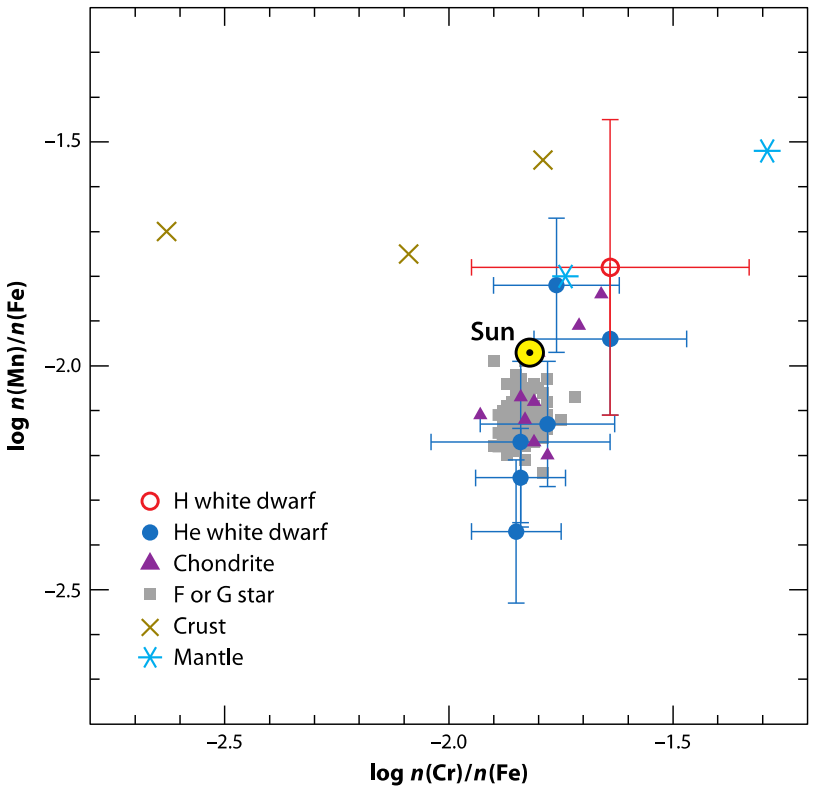
- Volume-limited sample within 80 pc (57 stars)
- Little H, most O must be assigned to oxides of Si, Mg, Ca and Fe

Results -- Earth-like objects (0th order)



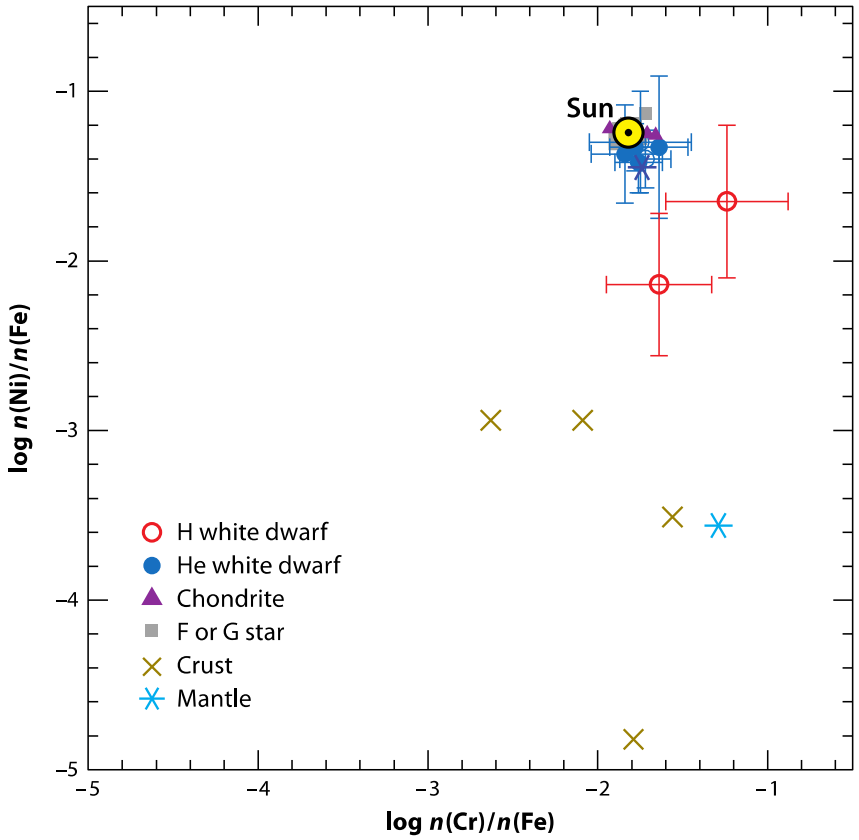
- Dominated by 4 elements: O, Mg, Si, Fe
- Carbon – typically very deficient
- Typically low in water
- Evidence for differentiation; both high Fe and low Fe objects

Minor Constituents: Mn/Fe vs. Cr/Fe



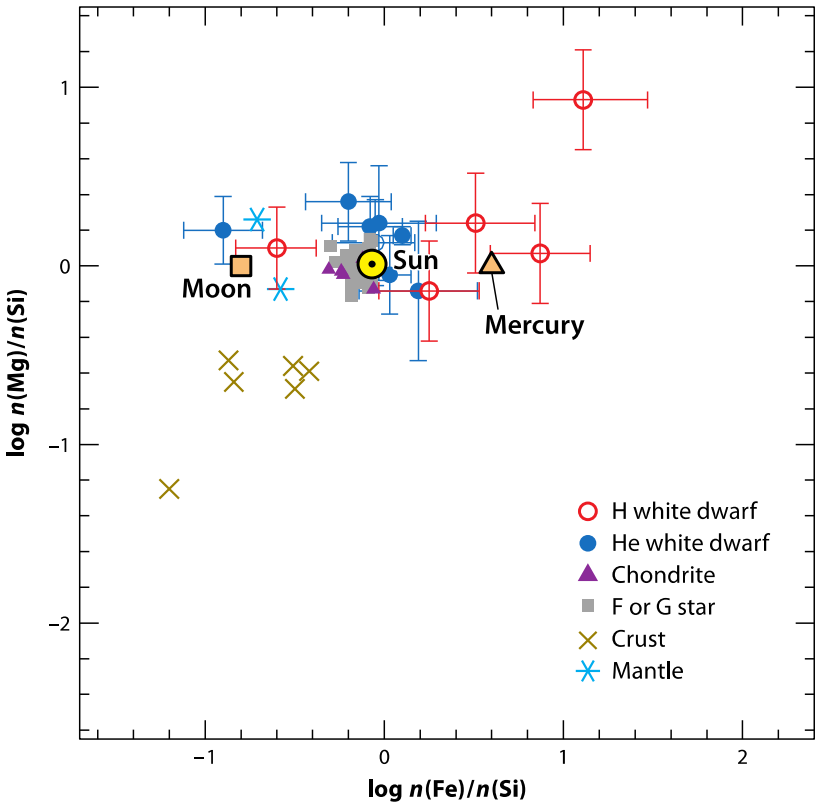
- Mn more volatile, wider spread in Mn/Fe than Cr/Fe; also seen among chondrites

Minor Constituents: Ni/Fe vs. Cr/Fe



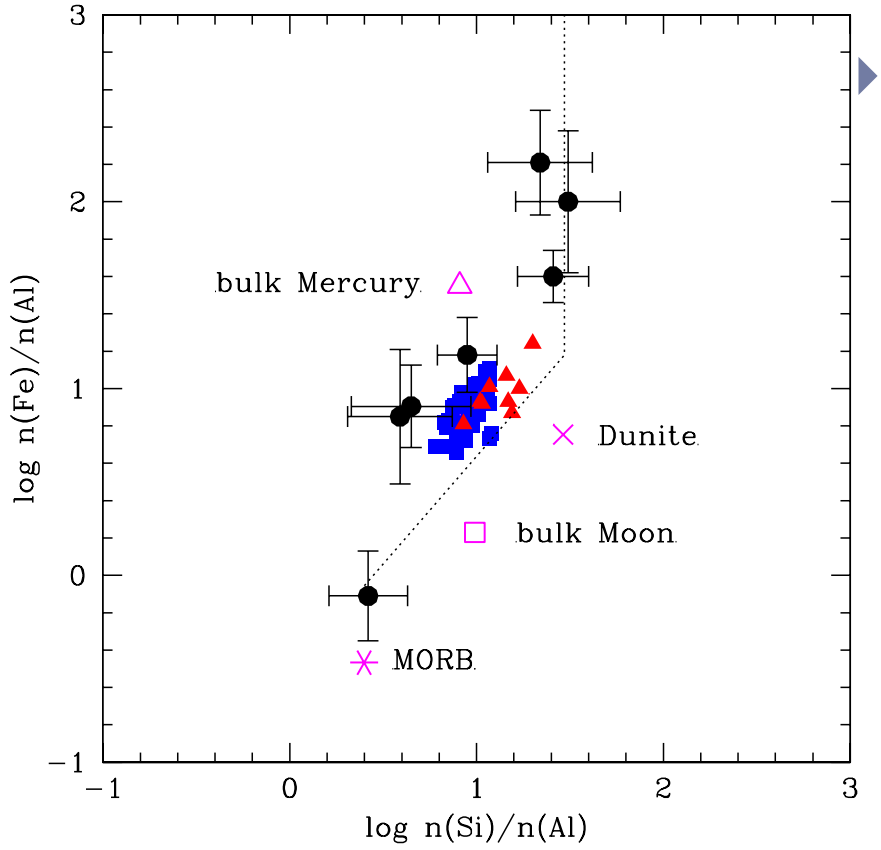
- Pattern “familiar”
- Data/analysis consistent among different groups

Patterns in the Ensemble: Mg, Si, Fe



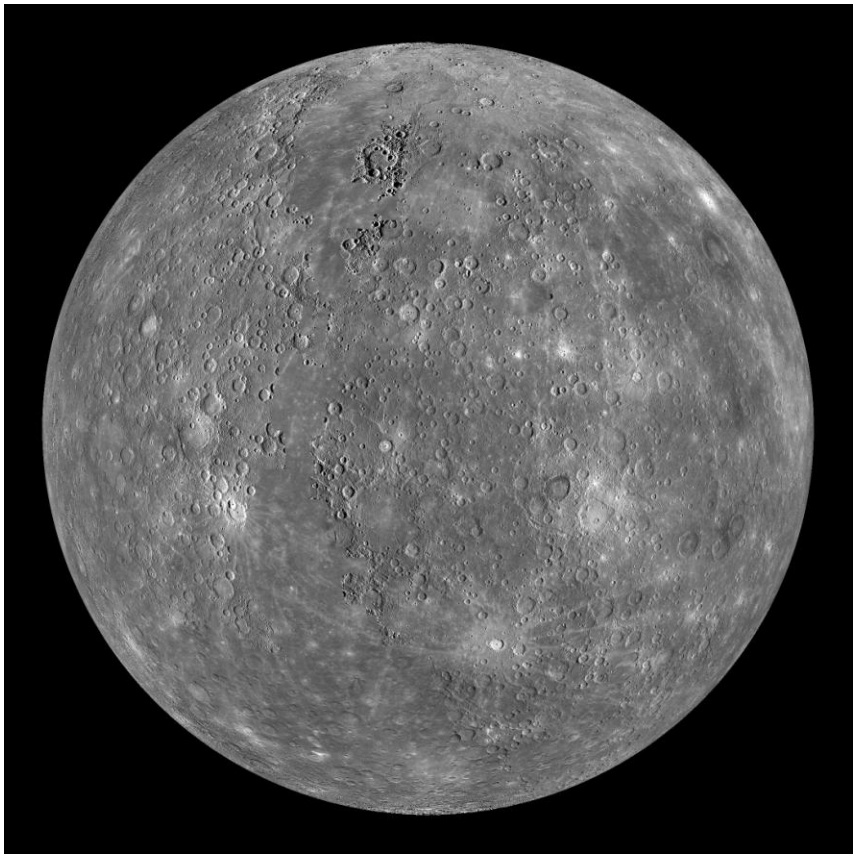
- Greater variation of Fe than Mg – core formation?
- No systems are purely "crustal"
- Not just chondritic
- Evidence for Differentiation

Fe/Al vs. Si/Al



- Large range in Fe/Al – NOT stellar
- Differentiated objects

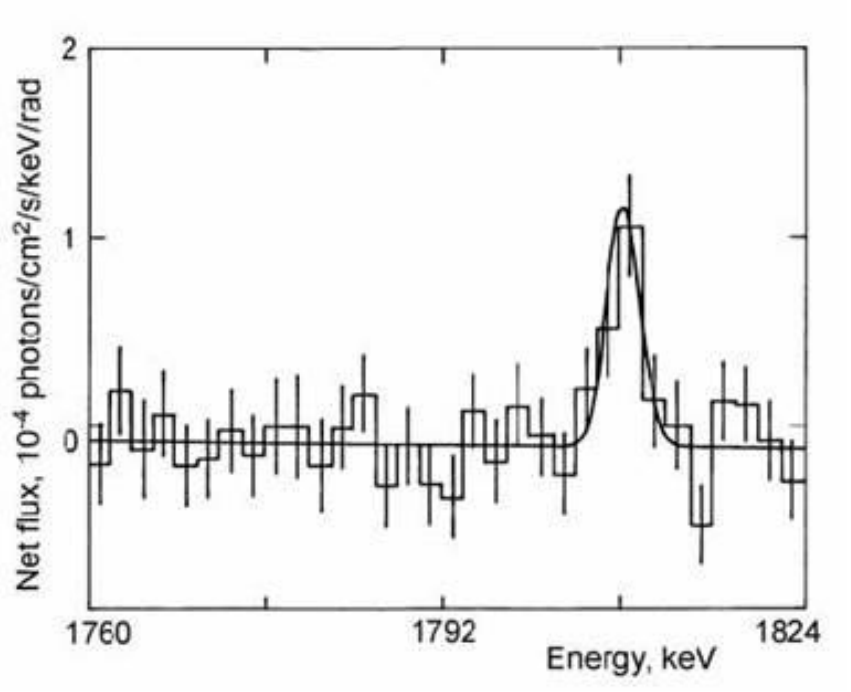
Iron Planets?



- KOI 1843.03 period of 4.2 hours
- Mean density ~7 g cm^{-3}
- Probably largely composed of Fe

26 Aluminun is Widespread

- Explains widespread differentiation
- Explains gamma ray background if confined to molecular clouds
- Solar system was NOT unusual



Summary

- At 0-order, extrasolar minor planets resemble bulk Earth (mostly O ,Mg, Si, Fe, little C or water)
- No known C, Al/Ca/O, or kryptonite planets
- Differentiation: cores + crusts
- Solar system normal, 26Al widespread