The chemistry of exo-terrestrial material in evolved planetary systems

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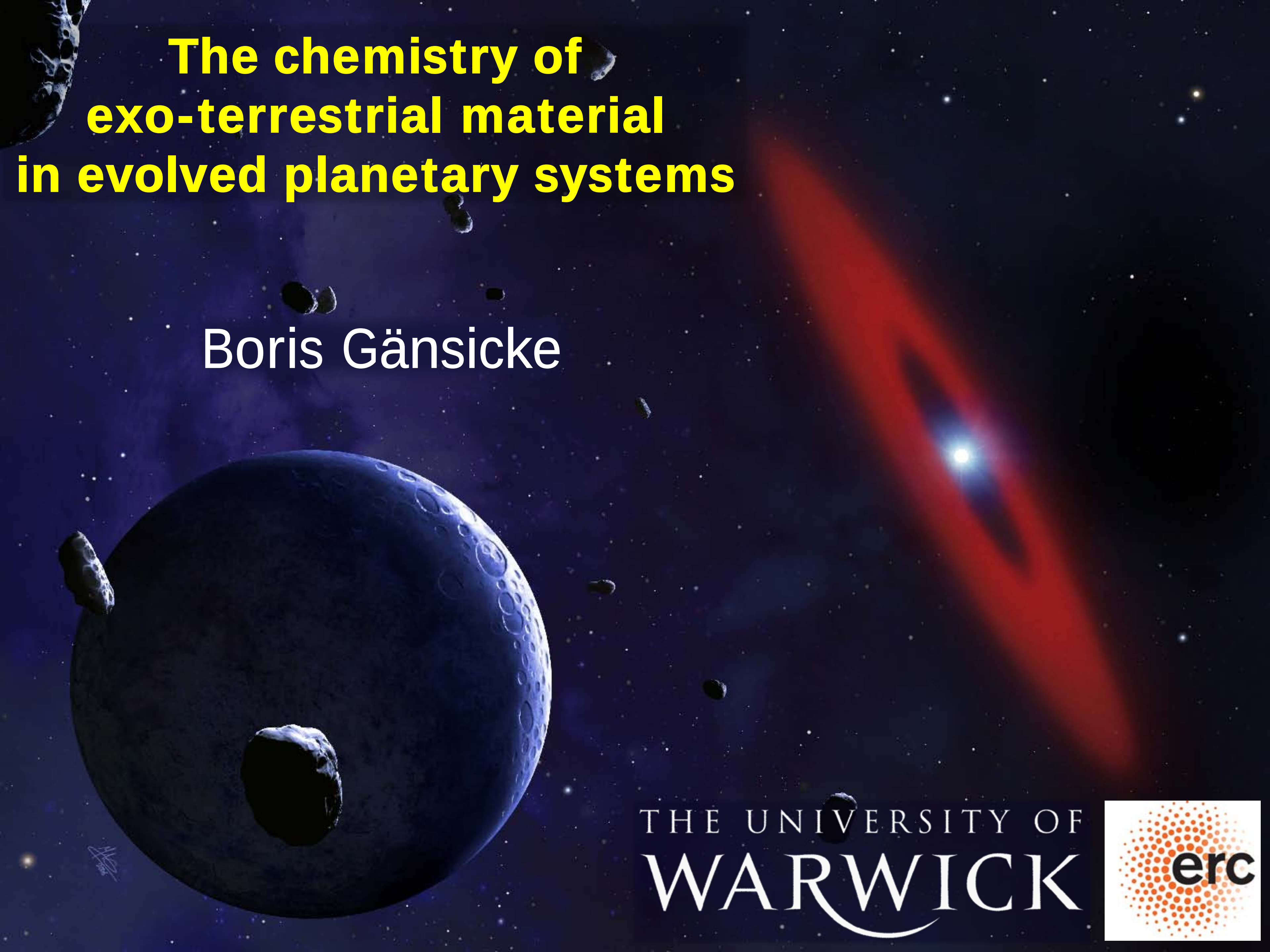
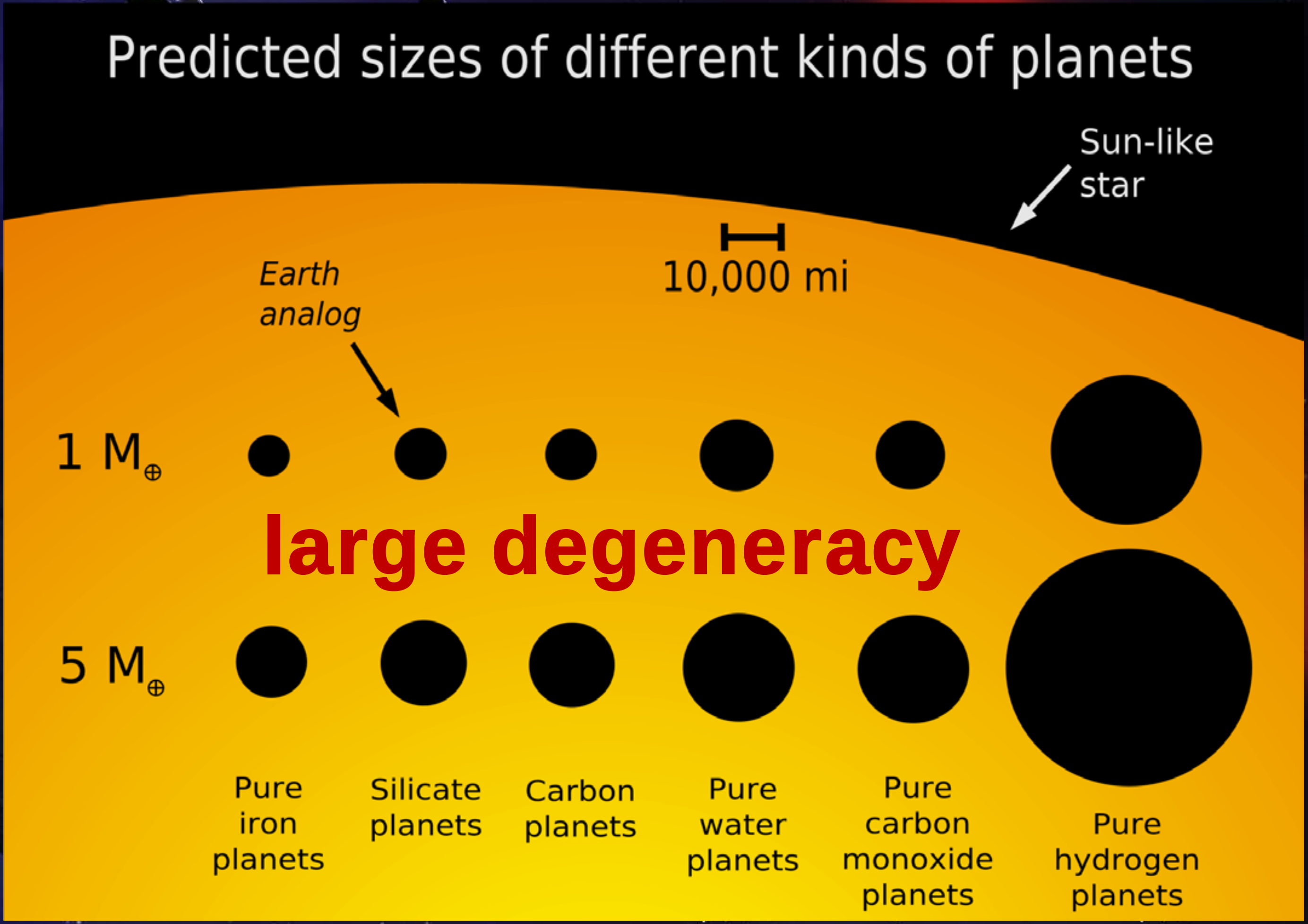


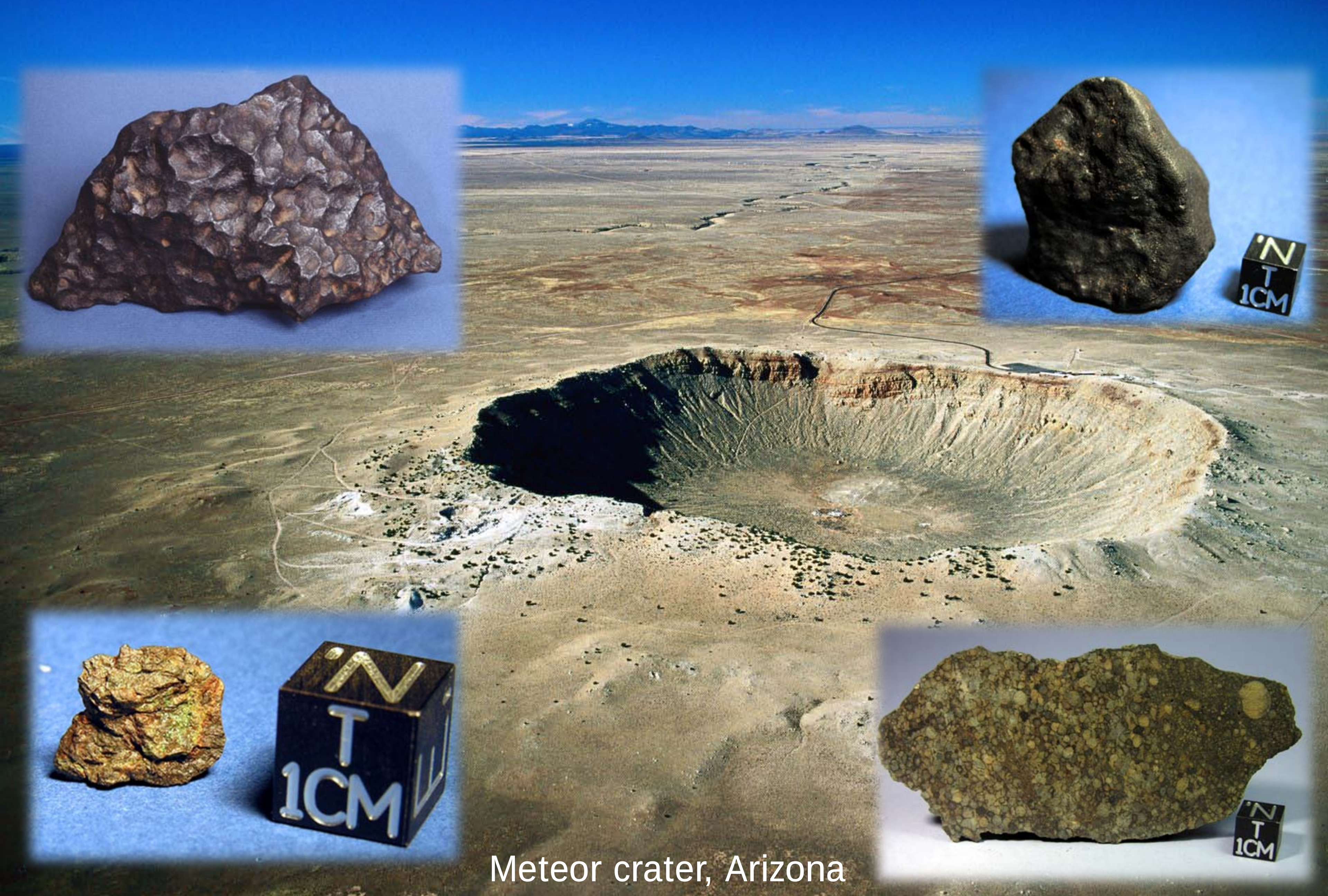
Transiting planets ⇒ M & R ⇒ bulk densities

What is the bulk *composition* of exo-planets?



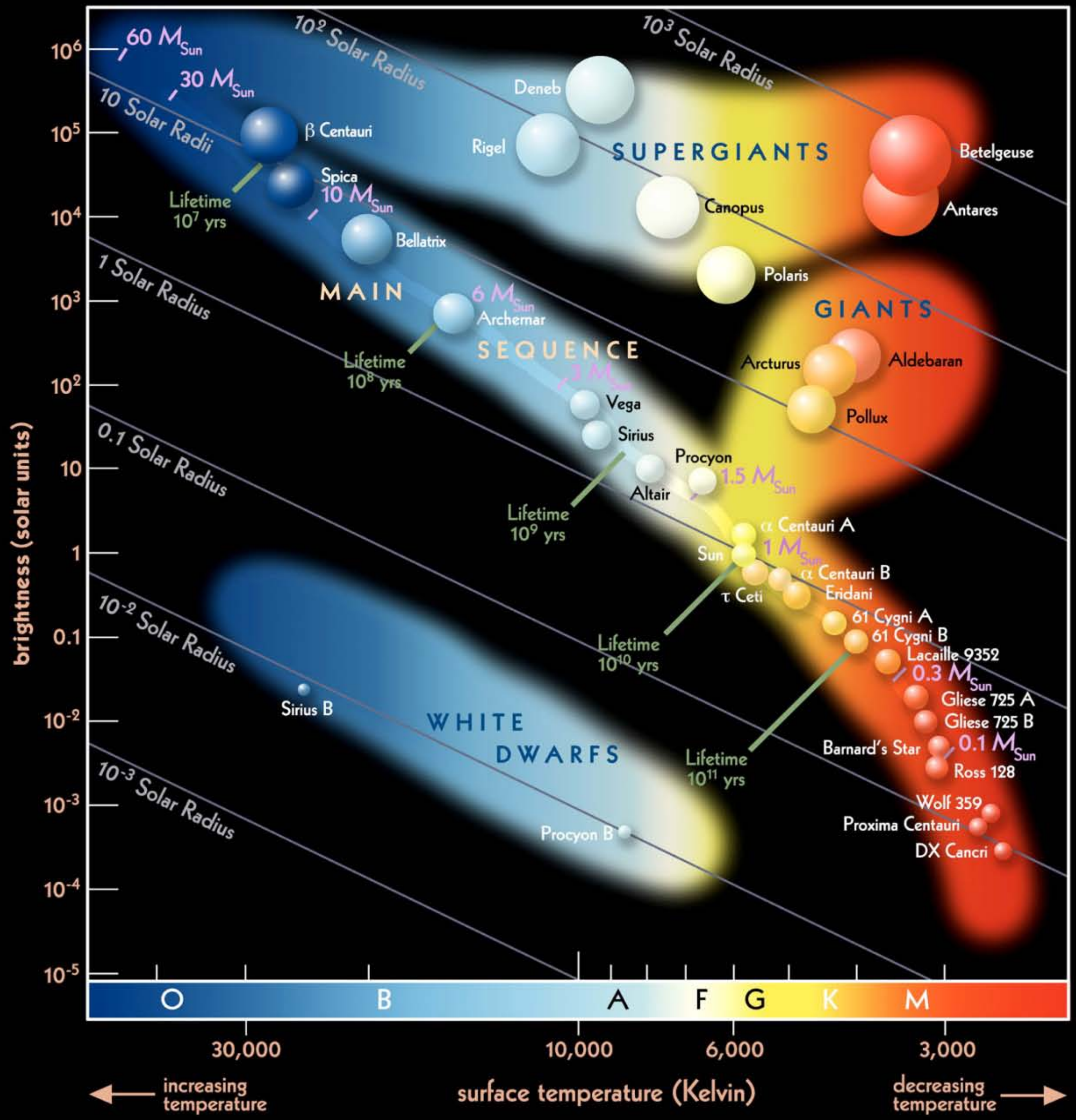
large degeneracy

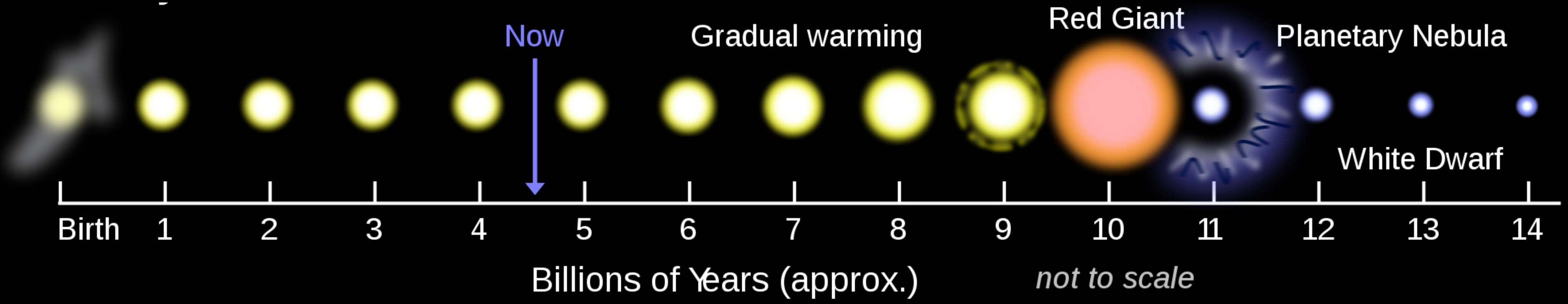
How to measure bulk compositions in the solar system



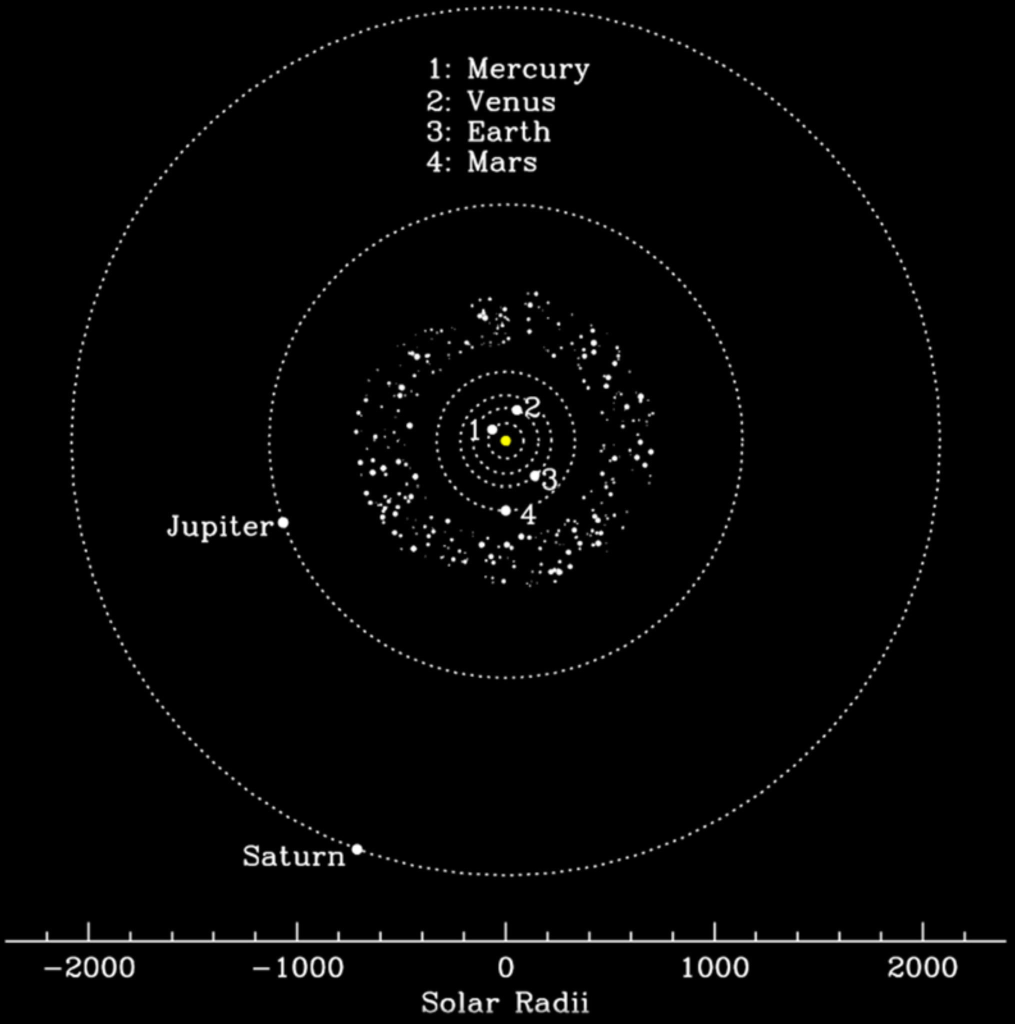
Meteor crater, Arizona

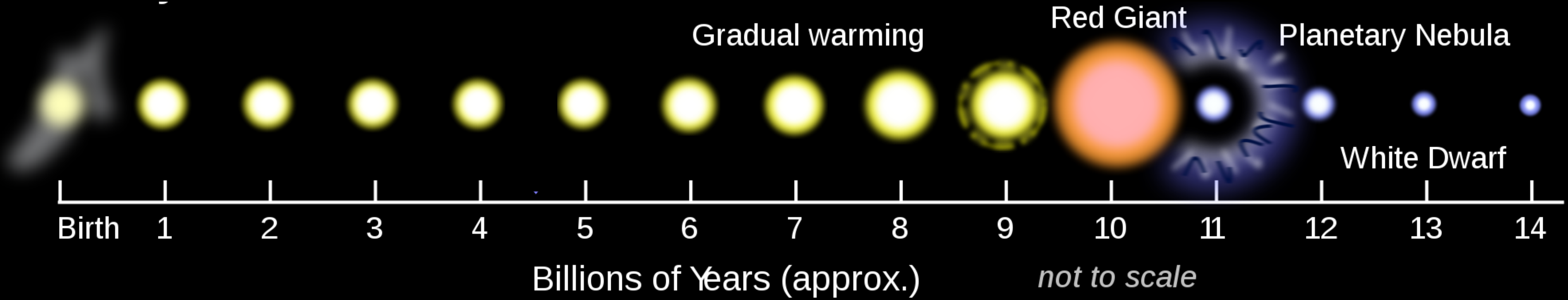
...all planet host stars will become white dwarfs...



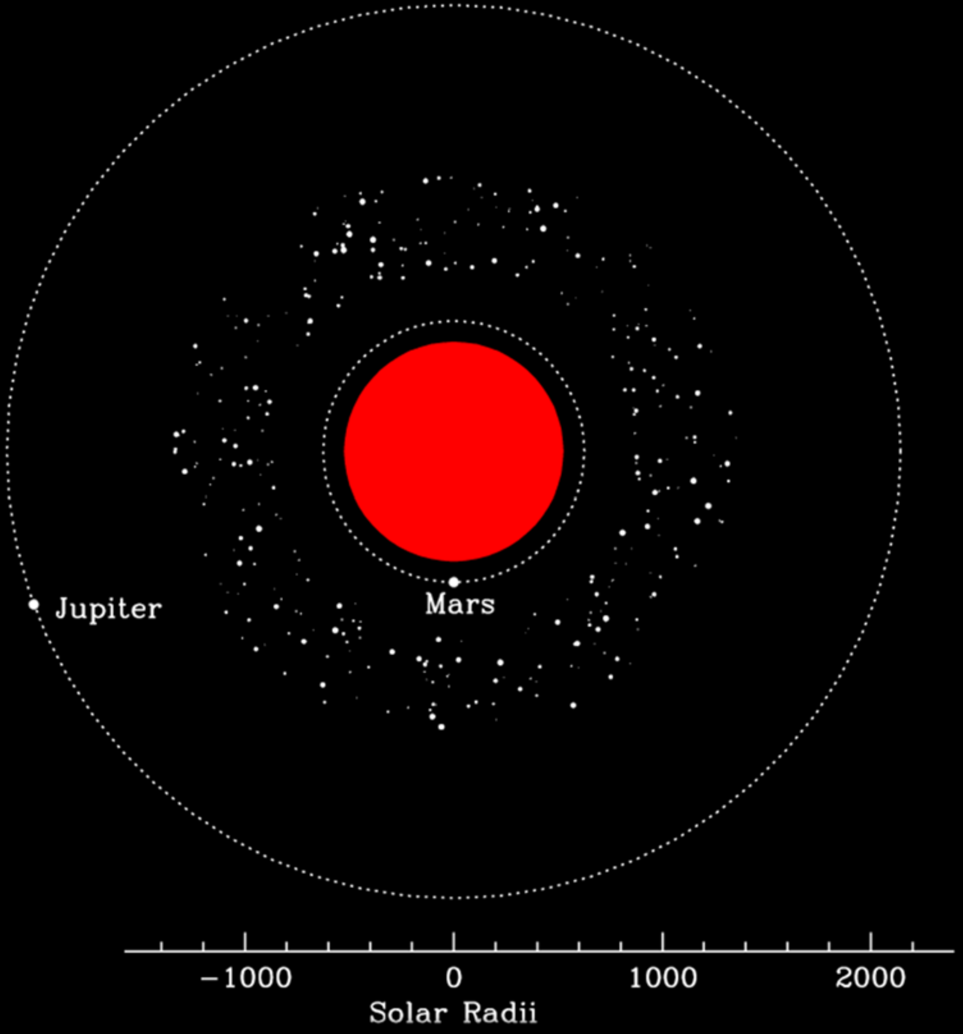

Now
Gradual warming
Red Giant
Planetary Nebula
White Dwarf
Birth
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Billions of Years (approx.)
not to scale

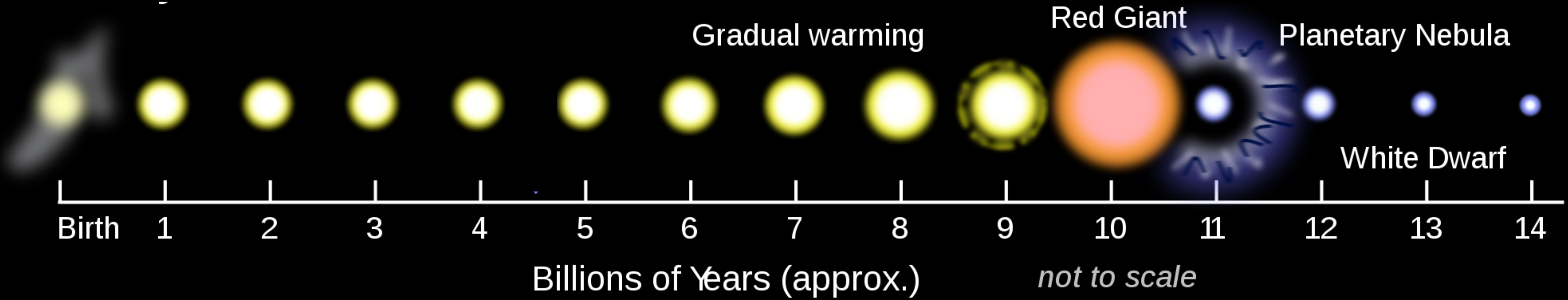
Today


1: Mercury
2: Venus
3: Earth
4: Mars
1
2
3
4
Jupiter
Saturn
−2000
−1000
0
1000
2000
Solar Radii

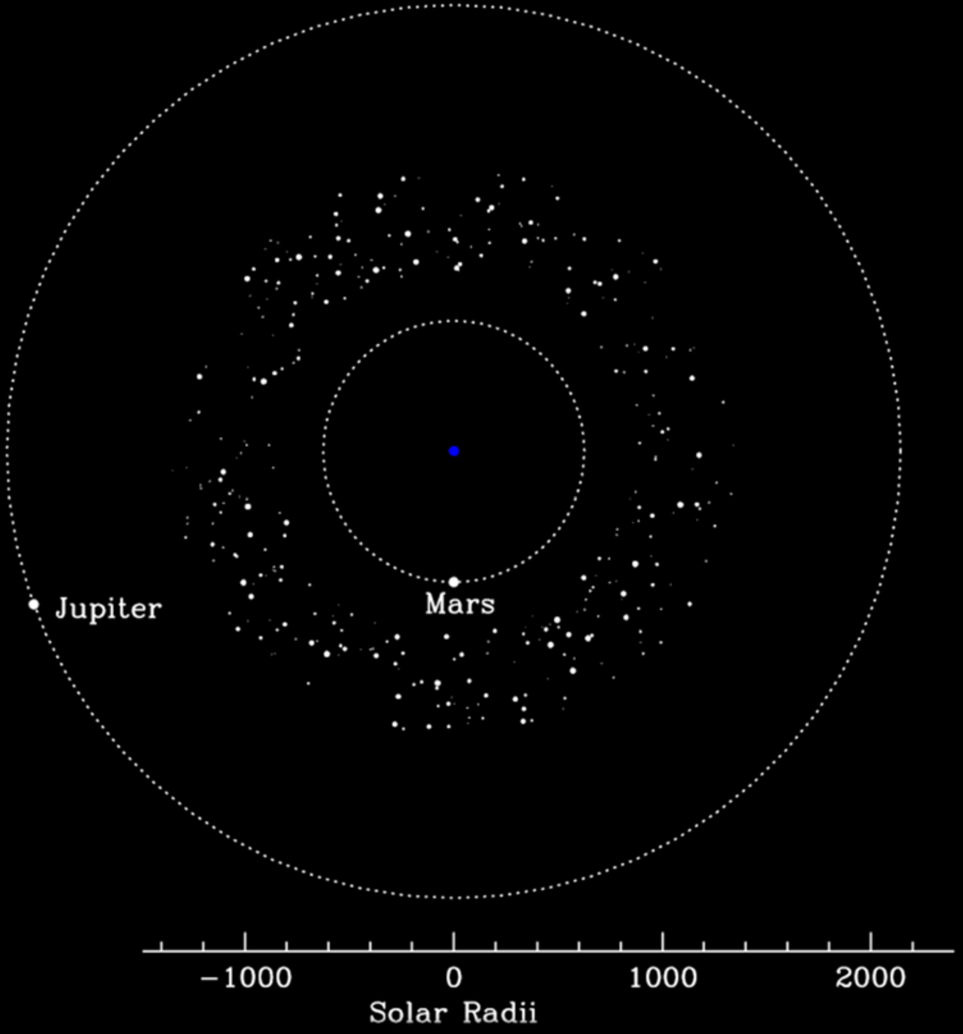


5 billion years
from now





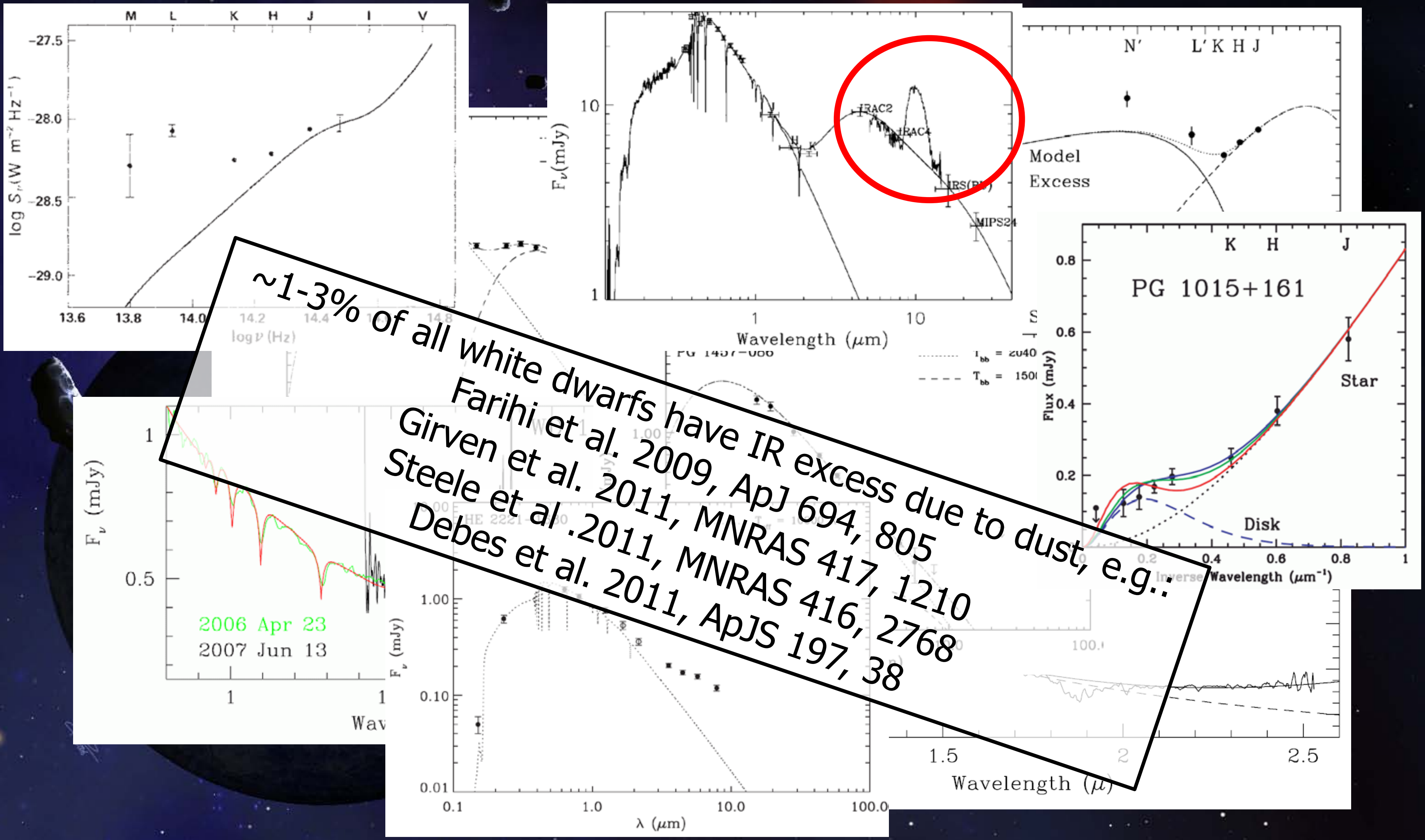
8 billion years
from now



Burleigh et al. 2002,
MNRAS 331, L41

Dust around ~30 white dwarfs

Zuckerman et al. 1987, *Nature* 330, 138; Graham et al. 1990, [illegible] 357, 216; Kilic et al. 2005, ApJ 632, L115; Becklin et al. 2005, ApJ 632, L119; Reach et al. 2005, ApJ 635, L161; Jura et al. 2007, AJ 133, 1927; Kilic et al. 2007, ApJ 660, 641; von Hippel et al. 2007, ApJ 662, 544; Jura et al. 2007, ApJ 663, 1285; Farihi et al. 2008, ApJ 674,431; Jura et al. 2009, AJ 137, 3191; Reach et al. 2009, ApJ 693, 697; Farihi et al. 2009, ApJ 694, 805; Brinkworth et al. 2009, ApJ 696, 1402; Farihi et al. 2010, ApJ 714, 1386; Dufour et al. 2010, ApJ 719, 803; Vennes et al. 2010, MNRAS 404, L40; Farihi et al. 2011, ApJ 728, L8; Debes et al. 2011, ApJ 729, 4; Farihi et al. 2012, MNRAS 421, 1635; Barber et al. 2012, ApJ 760, 26

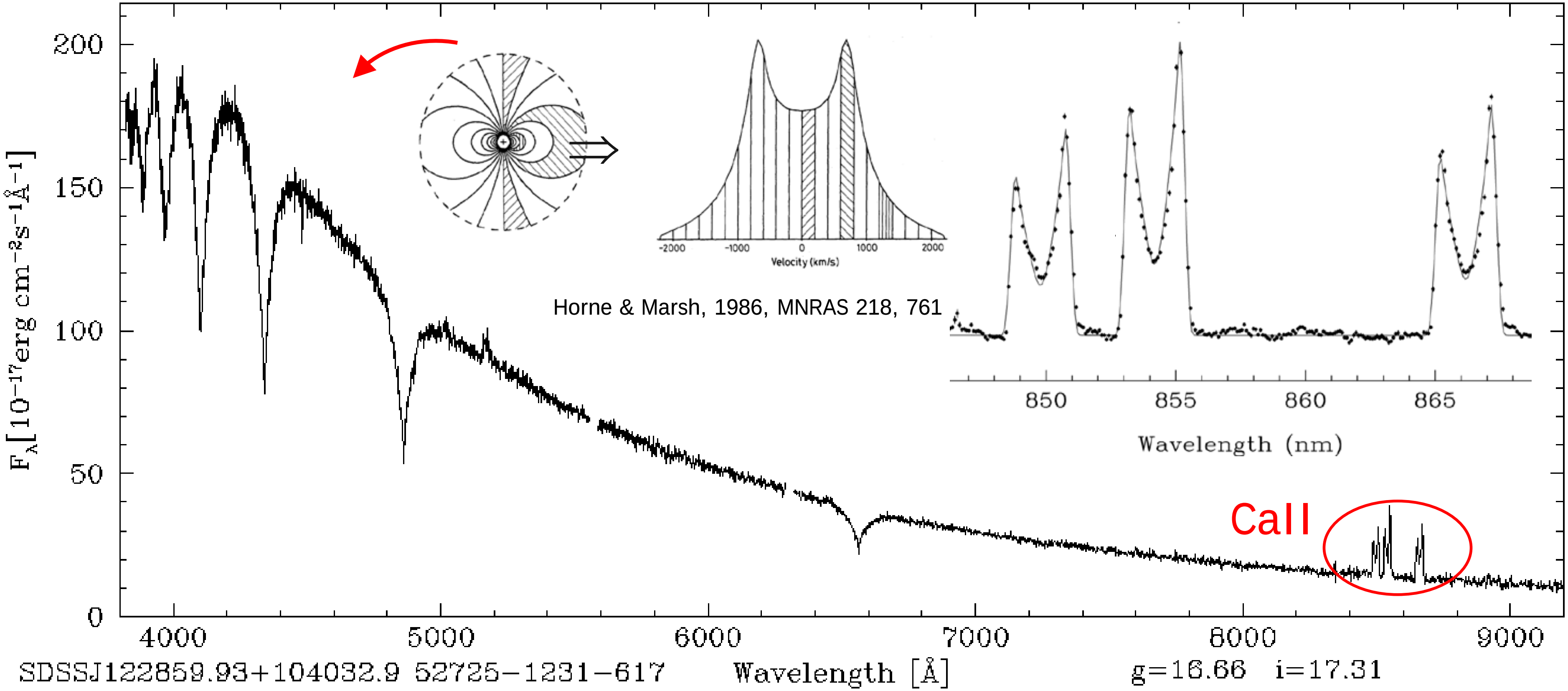


~1-3% of all white dwarfs have IR excess due to dust, e.g.:
Farihi et al. 2009, ApJ 694, 805
Girven et al. 2011, MNRAS 417, 1210
Steele et al .2011, MNRAS 416, 2768
Debes et al. 2011, ApJS 197, 38

Gaseous debris *discs* around 7 white dwarfs

Dynamical constraints on the geometry: flat discs with an outer radius of ~ 1R⊙
⇒ *within the tidal disruption radius of the WD*

Gänsicke et al. 2007, MNRAS 380, L35; Gänsicke et al. 2008, MNRAS 391, L103; Melis et al. 2011, ApJ 732, 90; Hartmann et al. 2011, A&A 530, 7; Gänsicke 2011, AIPC 1331, 211, Farihi et al. 2012, MNRAS 421, 1635; Dufour et al. 2012, ApJ 749, 6; Melis et al. 2012, ApJ 751, L4

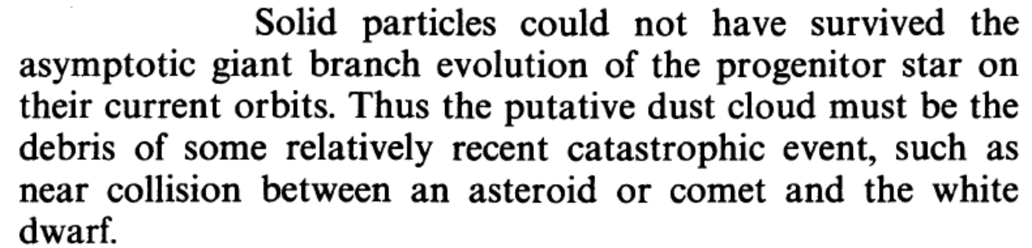


Horne & Marsh, 1986, MNRAS 218, 761

Gänsicke et al. 2006, Science 314, 1908

The “standard model”: Tidal disruption of asteroids

Graham et al. 1990, ApJ 357, 216



Solid particles could not have survived the asymptotic giant branch evolution of the progenitor star on their current orbits. Thus the putative dust cloud must be the debris of some relatively recent catastrophic event, such as near collision between an asteroid or comet and the white dwarf.

Debes & Sigurdsson 2002, ApJ 572, 556

Jura 2003, ApJ 584, L91

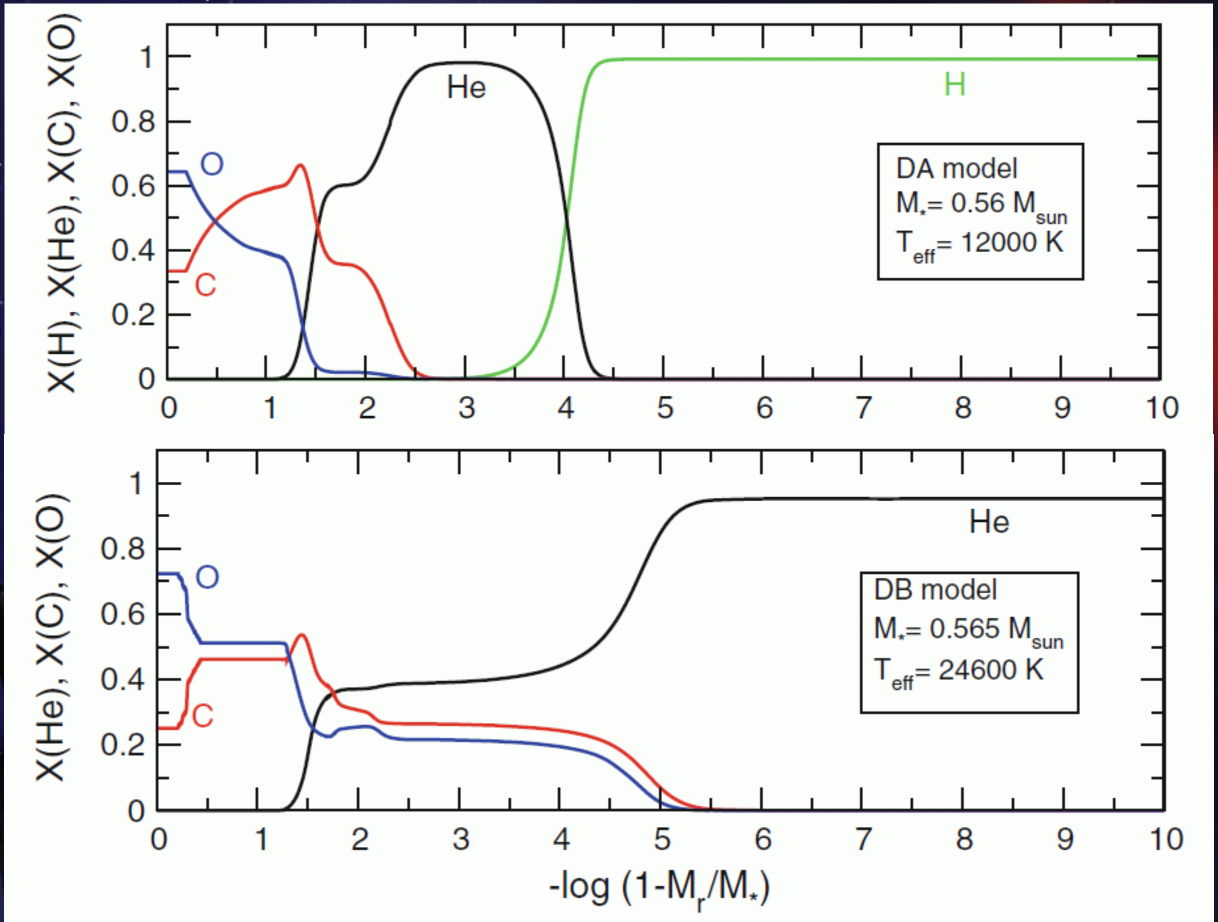
Bonsor et al. 2010, MNRAS 409, 1631

Bonsor et al. 2010, MNRAS 414, 930

Chemical profile of a typical white dwarf

centre 10% 1% 0.1%

visible atmosphere at ~$10^{15\text{-}16}$ = 0.00000001%



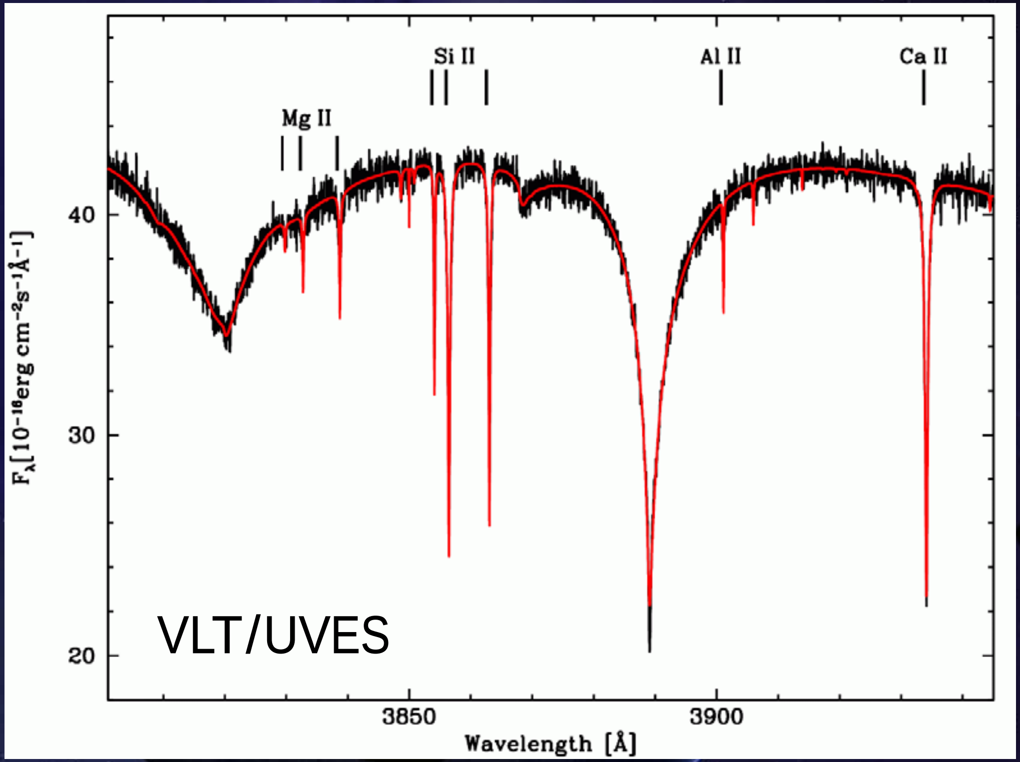
Althaus et al. 2010, A&A Rev 18, 471

Expect a pure hydrogen or helium atmosphere

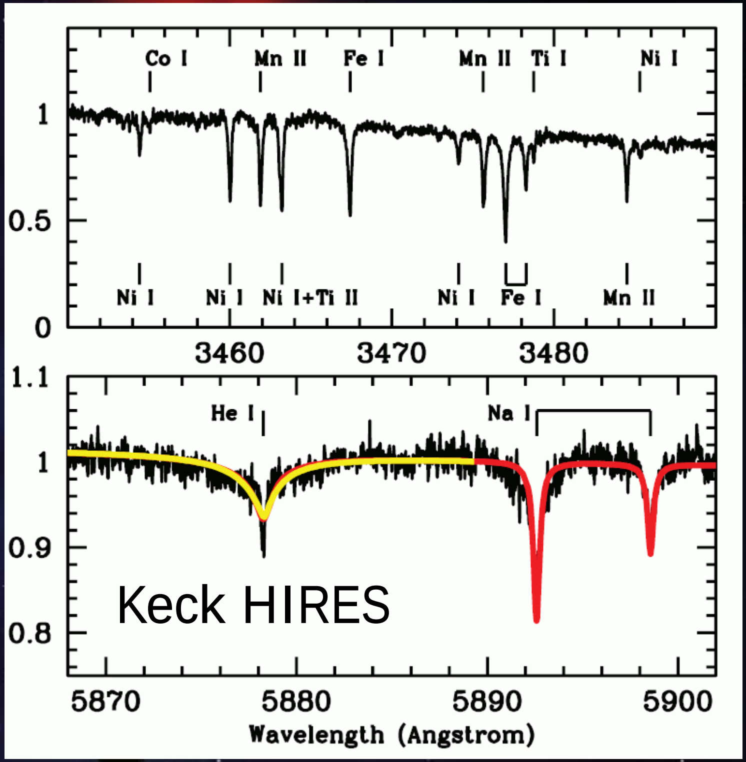
Abundance patterns from ground-based UV

Common hallmark: large abundances of Si, Fe, Mg, O & low abundances of H, C
$\Rightarrow$ consistent with accretion of “rocky” material

Koester et al. 1997, A&A 230, L57; Zuckerman et al. 2007, ApJ 671, 872; Klein et al. 2010, ApJ 709, 950; Dufour et al. 2010, ApJ 719, 803; Klein et al. 2010, ApJ 709, 950; Vennes et al. 2010, MNRAS 404, L40; Melis et al. 2011ApJ 732, 90

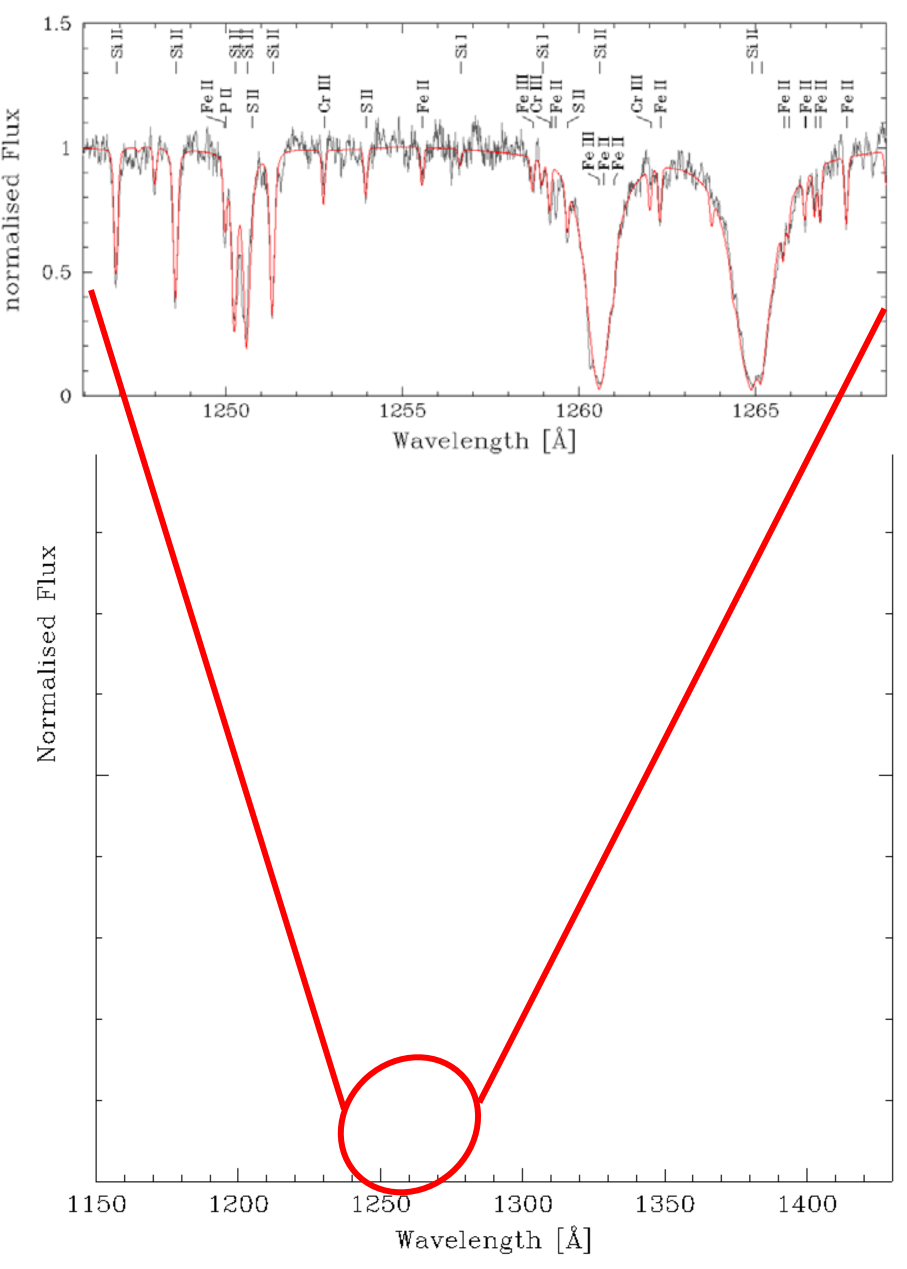


Gänsicke et al. 2014



Zuckerman et al. 2007, ApJ 671, 872

Many more elements accessible in the ultraviolet



HST/COS survey of 87 “young” (~100Myr) hydrogen-atmosphere white dwarfs

⇒ short diffusion time scale:
⇒ if polluted, these stars accrete *now*
⇒ unambiguous abundances of the debris

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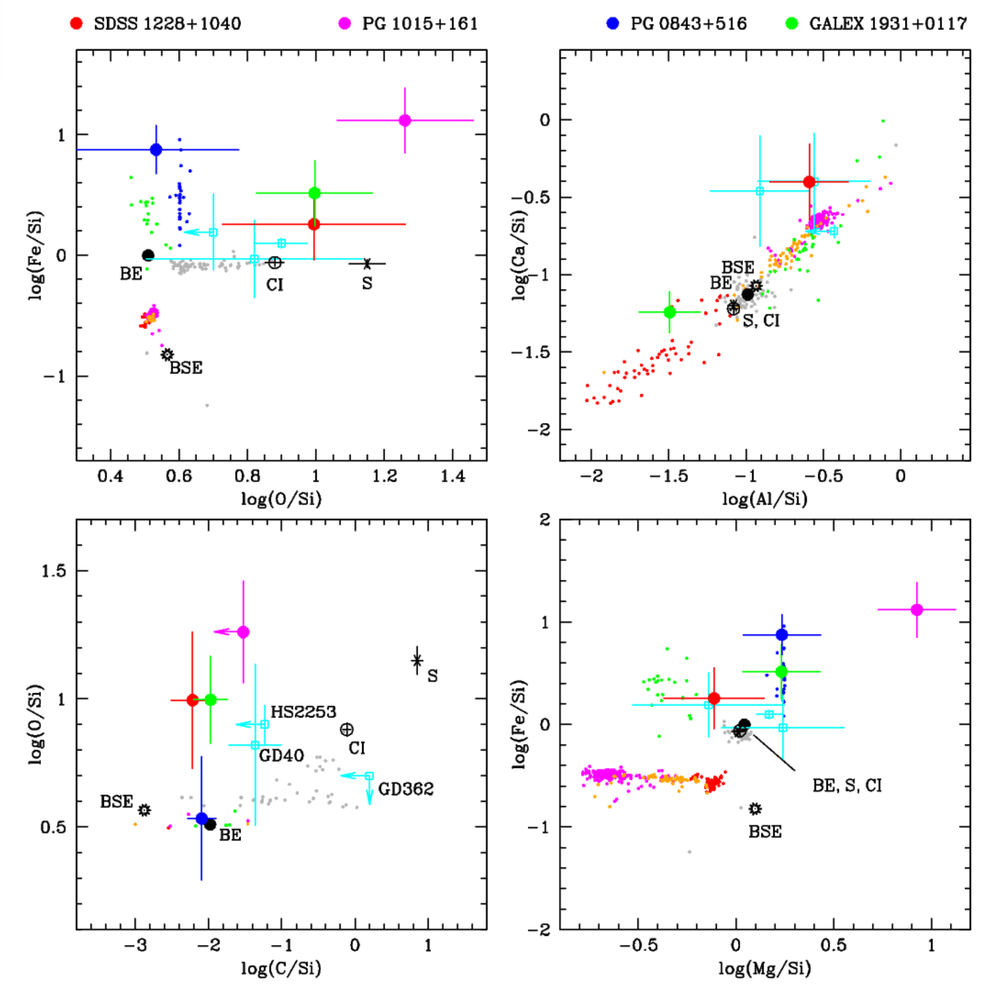
- O, Mg, Si, and Fe are the major constituents of the debris, *and also make up ~93% of the Earth*

(Gänsicke et al. 2012, MNRAS 424, 333)



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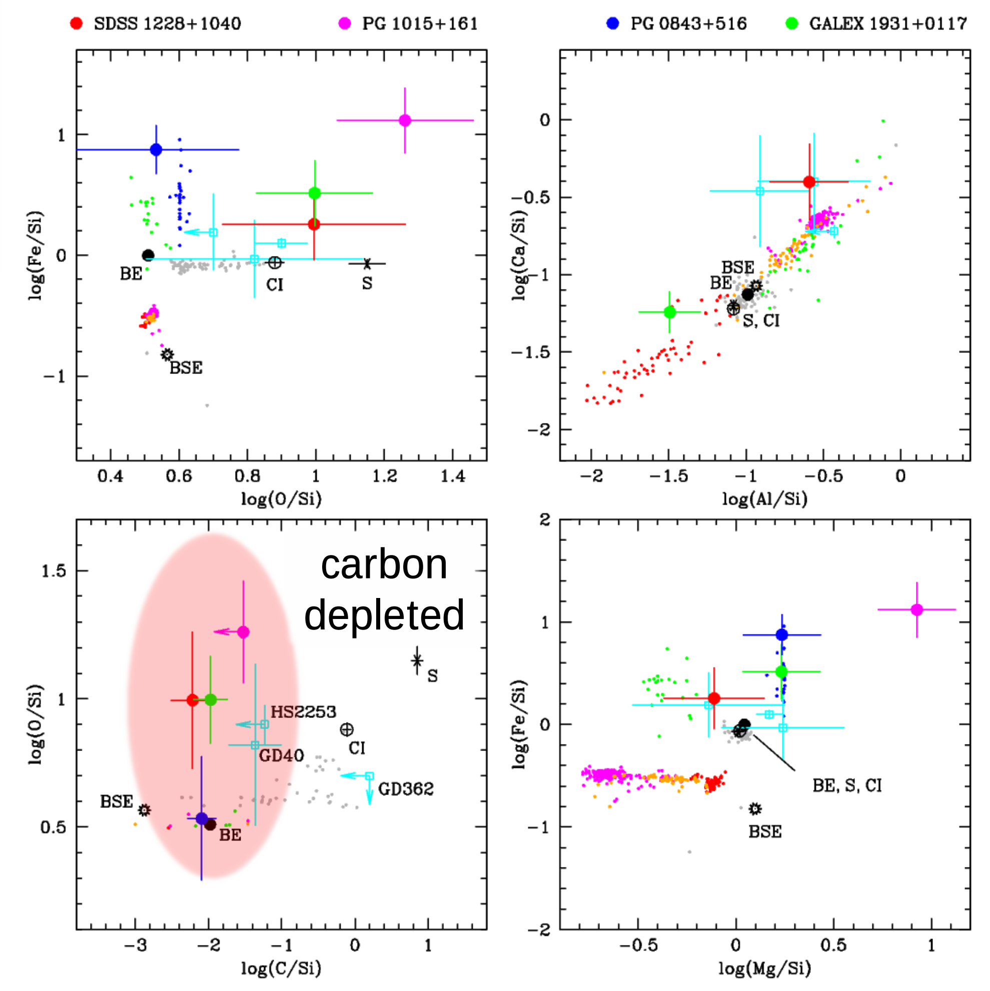

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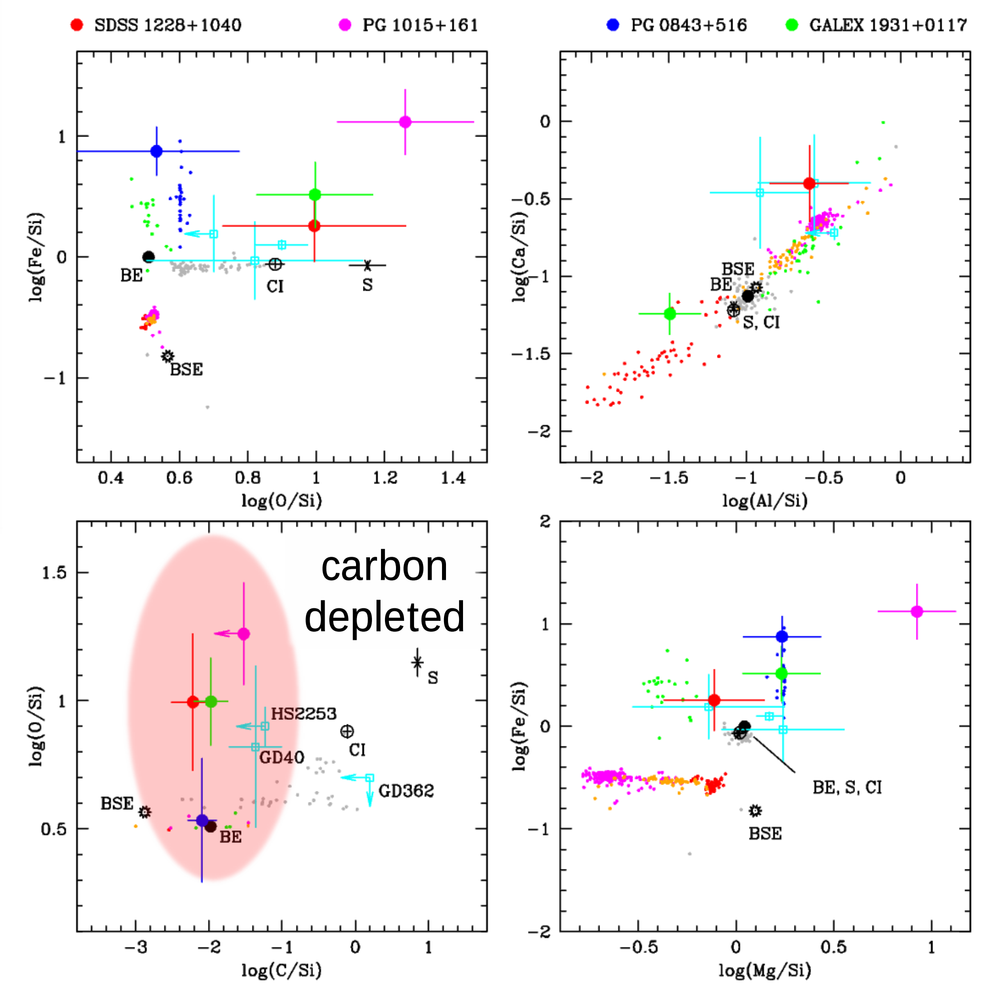

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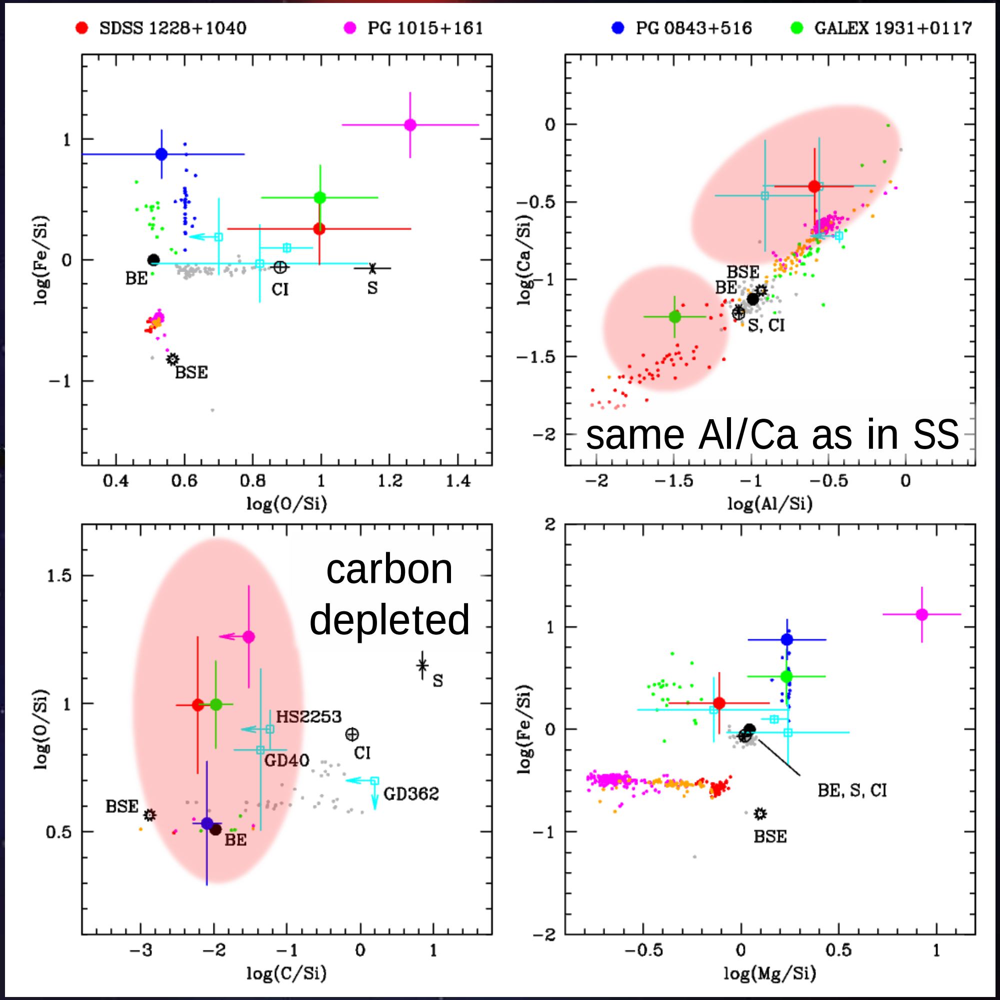

same Al/Ca as in SS

carbon depleted

A HST/COS survey of young (~100Myr) white dwarfs

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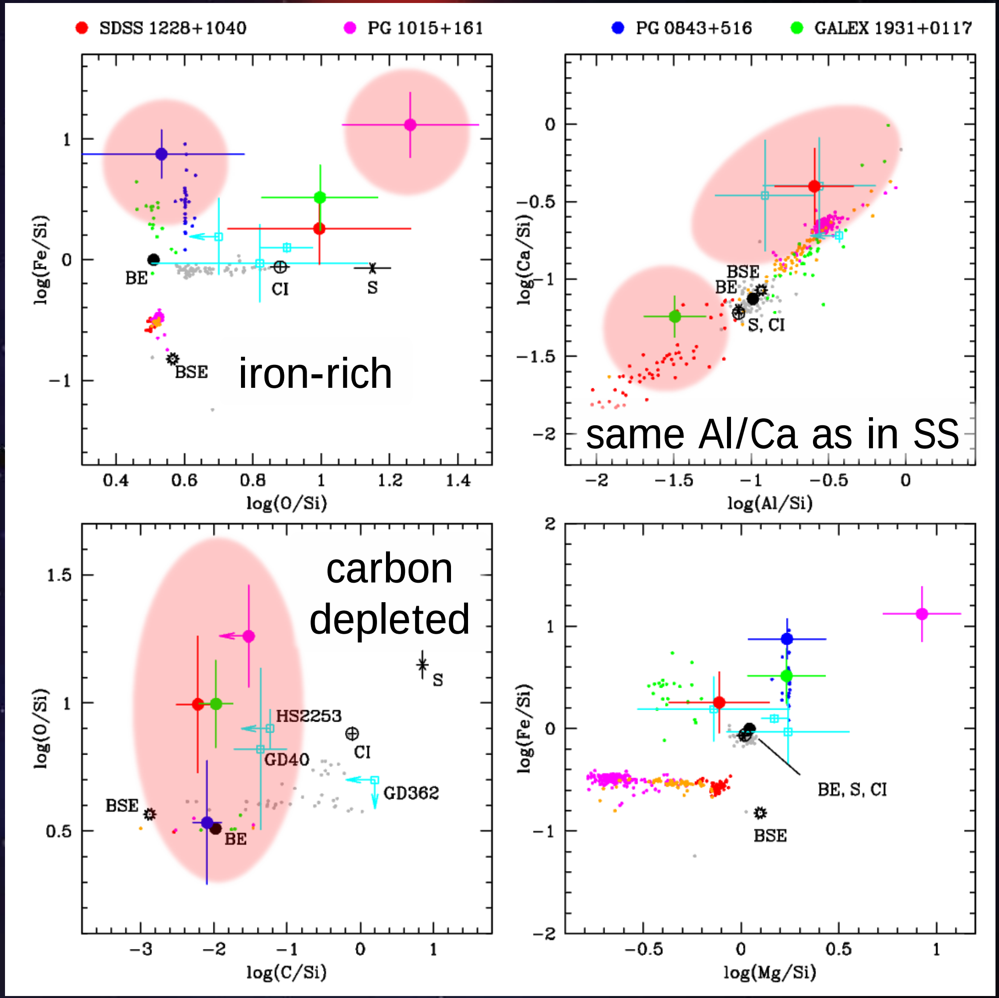
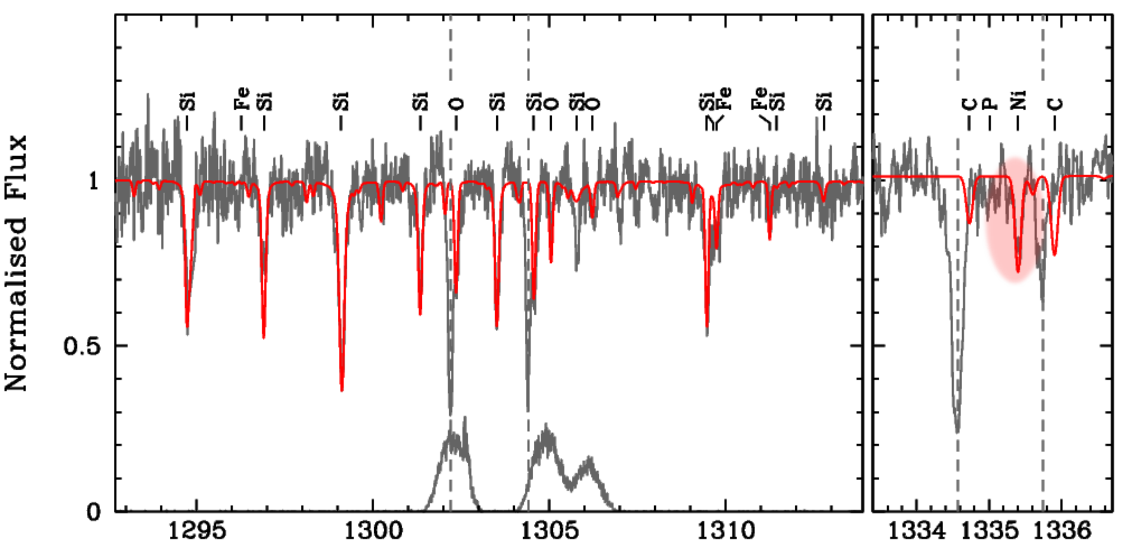
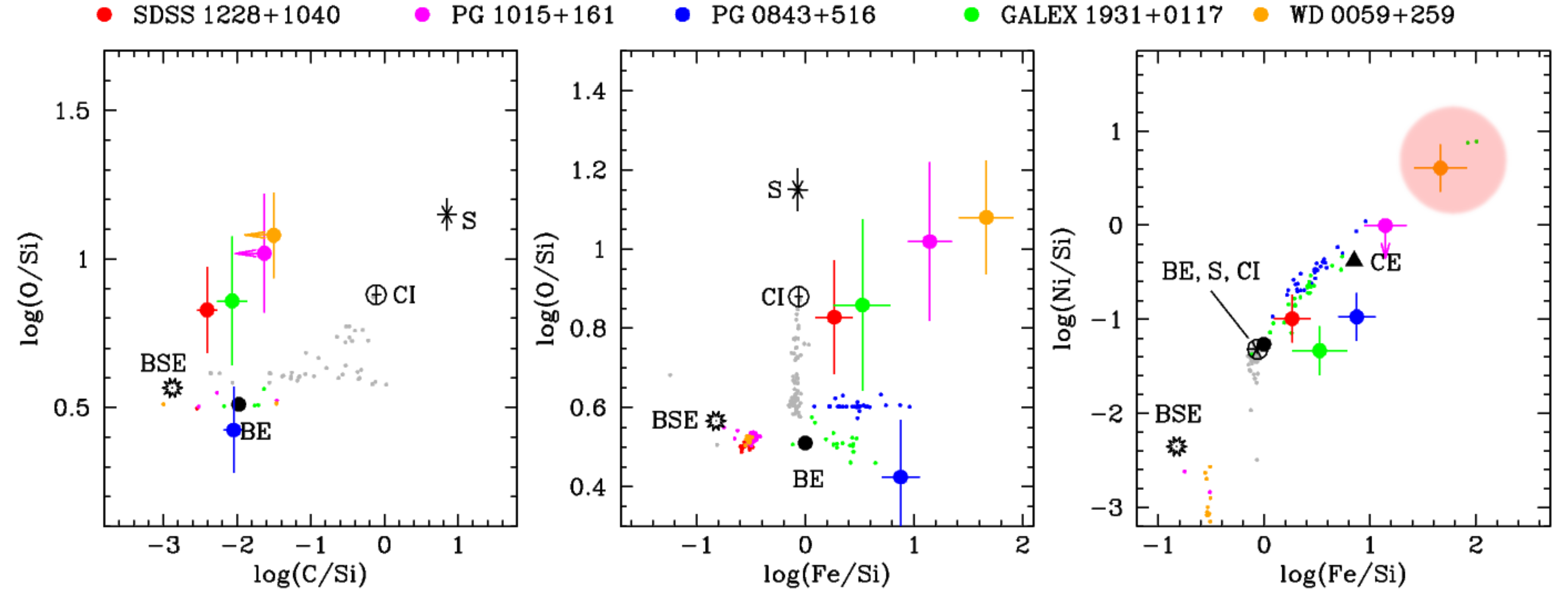
- Refractory litophiles Ca/Al very similar to solar system bodies
- Strong evidence for differentiation (Fe, S, Cr overabundance)

(Gänsicke et al. 2012, MNRAS 424, 333)



WD0059+257: the most Fe/Ni rich debris … An iron meteorite



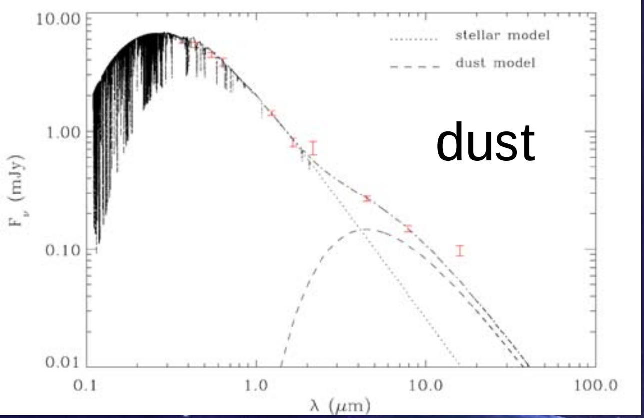


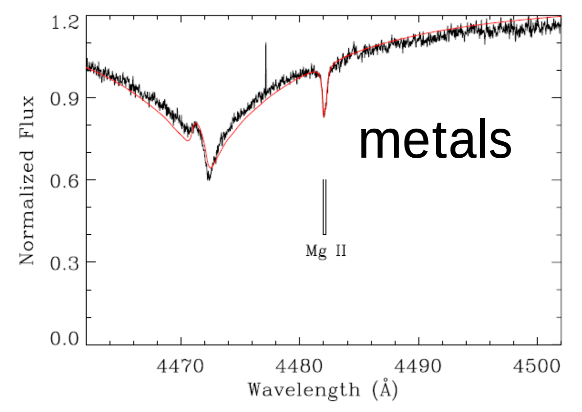
So, we can measure the bulk abundances of rocky material in extrasolar planetary systems

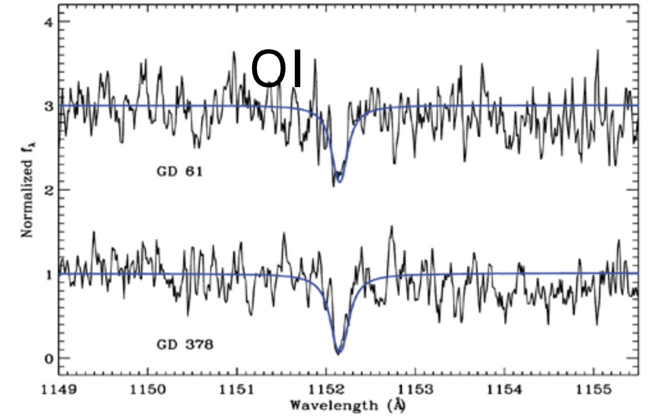
What about water?

A possible oxygen excess in GD61

Farihi et al. 2011, ApJ 728, L8







... oxygen is the most abundant element after He ...
(Desharnais et al. 2008, ApJ 672, 540)

“Rocks” = MgO, Al_2O_3, SiO_2,
CaO, TiO_2, Cr_2O_3,
MnO, FeO, Fe_2O_3, ...

⇒ nominal O-excess of ~20-40%

Accretion of water-rich asteroids?

(see also Jura & Xu, 2010, AJ 140,1129)

… read Friday's
issue of *Science* …

Big asteroids ...!

Minimum mass of the accreted debris:

SDSS0956+5912	~ 4.8×10^{23} g	(Koester et al. 2011, A&A 530, A114)
SDS0738+1835	~ 6.3×10^{23} g	(Dufour et al. 2012, ApJ 749, 6)
HE 0446−2531	~ 8.0×10^{24} g	(Girven et al. 2012, ApJ 749, 154)

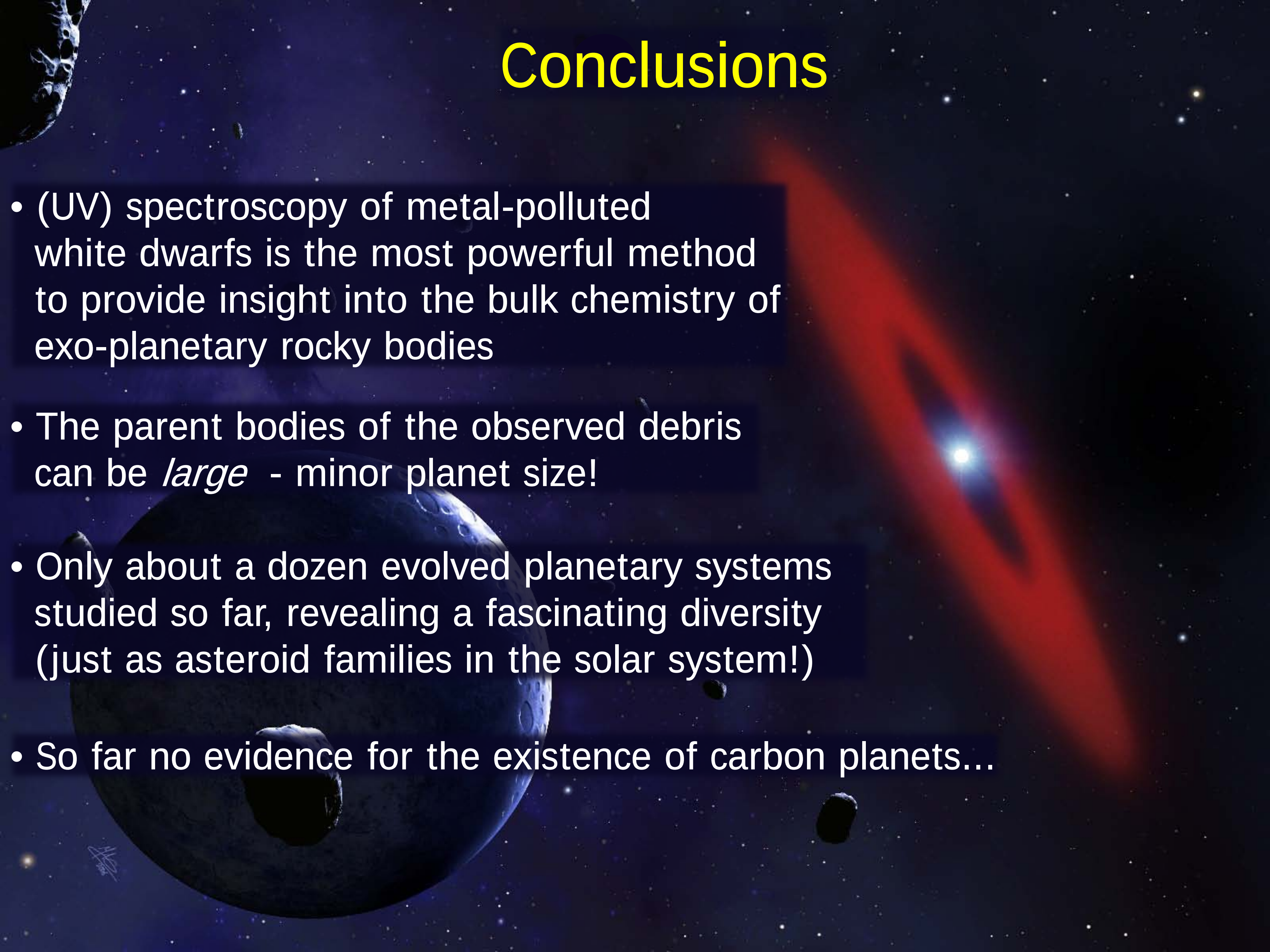
Eris ~1.7×10^{25} g

Pluto ~1.3×10^{25} g
Charon ~1.5×10^{24} g

Ceres ~9.4×10^{23} g

Moon ~7.3×10^{25} g

Earth ~7.0×10^{27} g



Conclusions

- (UV) spectroscopy of metal-polluted white dwarfs is the most powerful method to provide insight into the bulk chemistry of exo-planetary rocky bodies

- The parent bodies of the observed debris can be *large* - minor planet size!

- Only about a dozen evolved planetary systems studied so far, revealing a fascinating diversity (just as asteroid families in the solar system!)

- So far no evidence for the existence of carbon planets…