

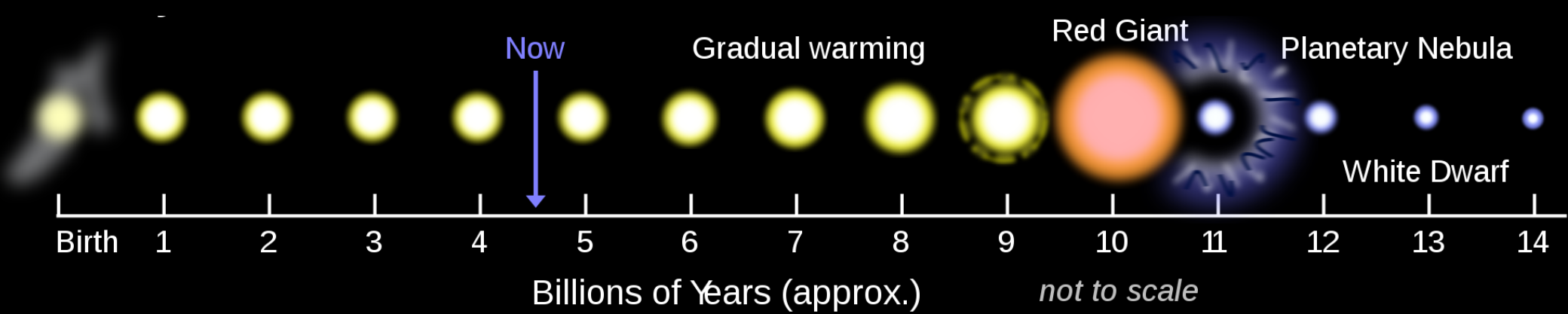


What **White Dwarfs** Reveal
About **Rocky Exoplanets**
and **Exo-asteroids**

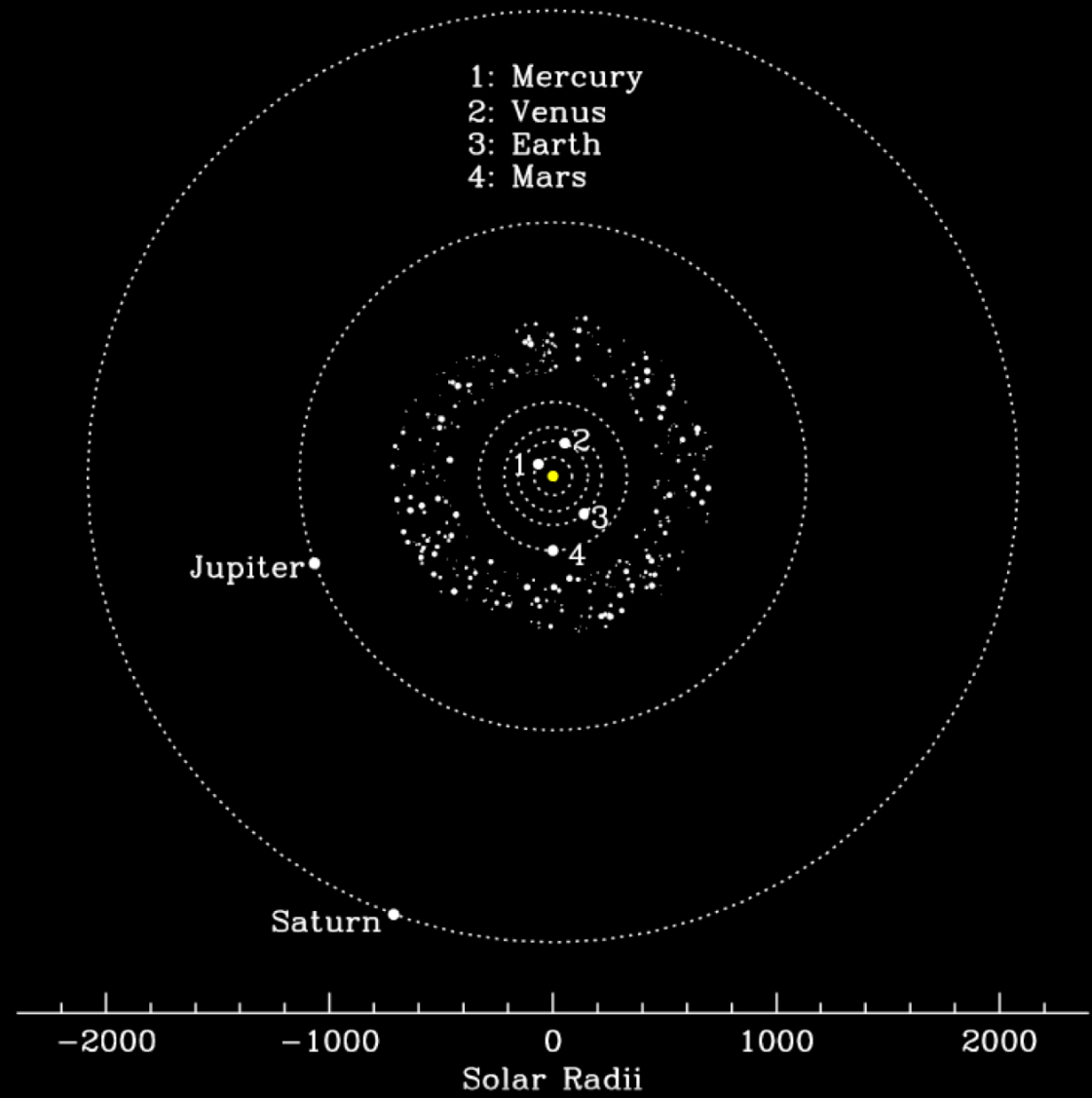
J.J. Hermes

<http://sites.bu.edu/burwd>

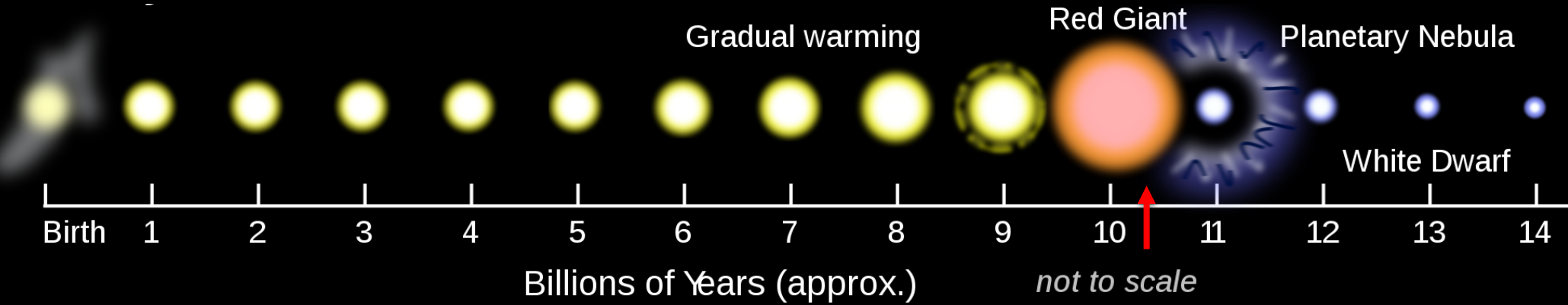
**BOSTON
UNIVERSITY**



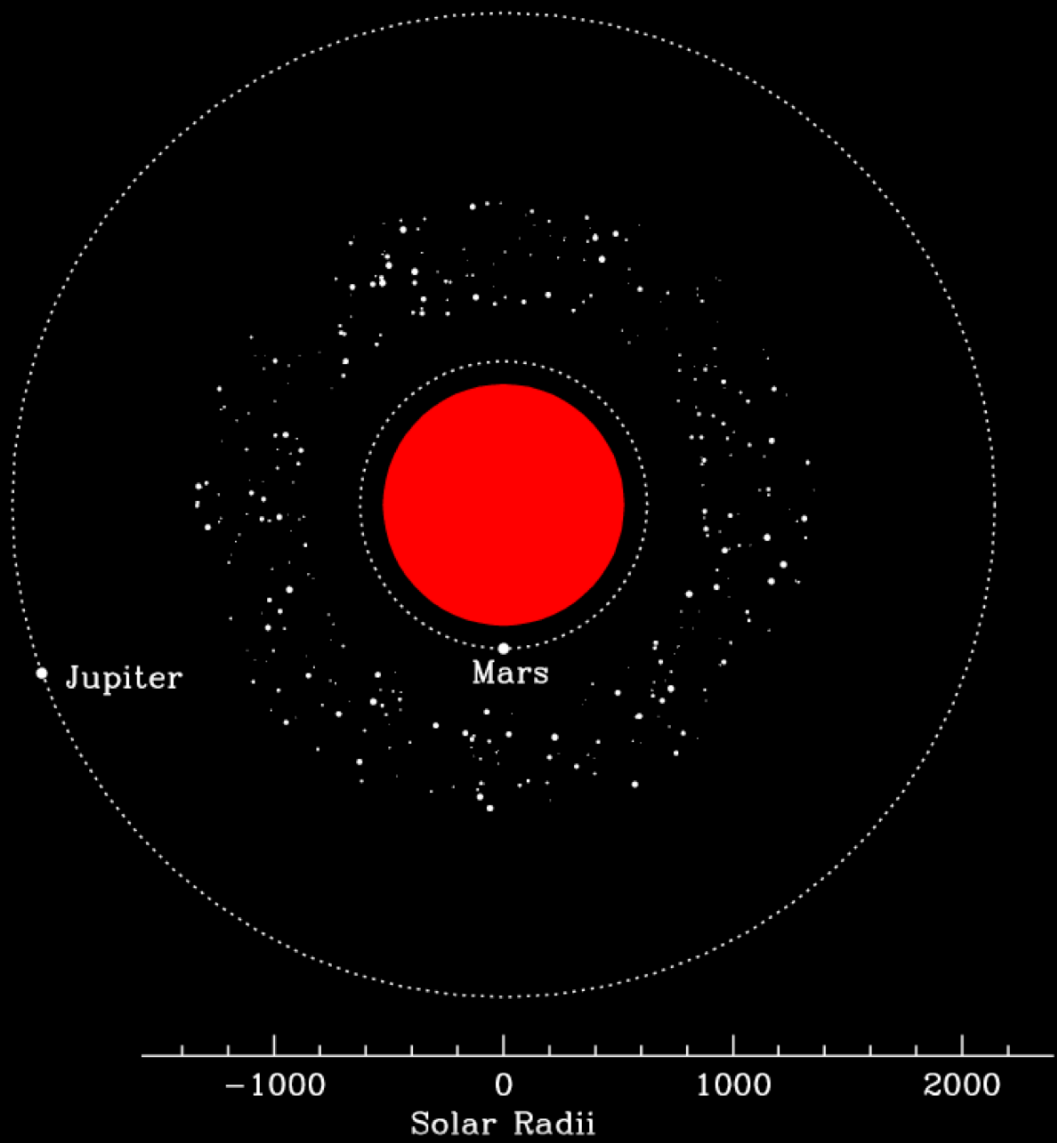
Today



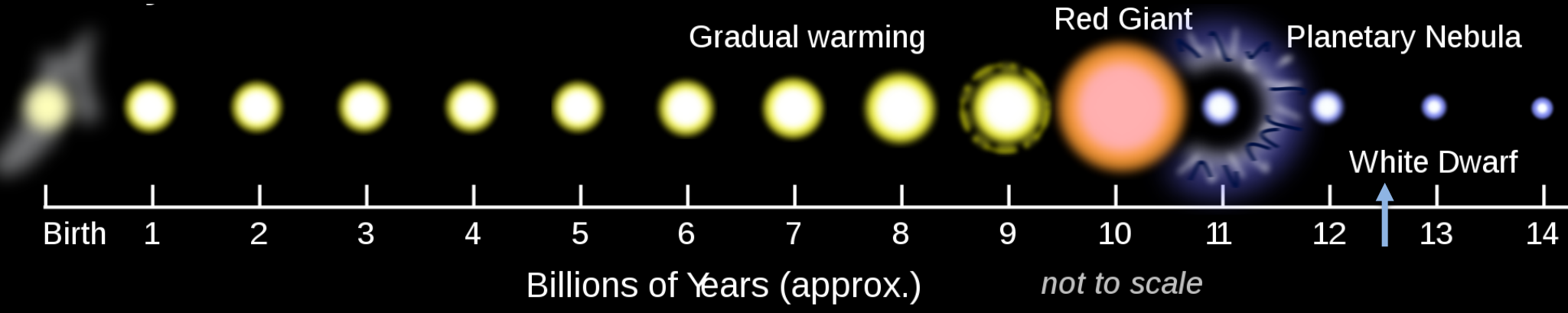
Boris Gänsicke



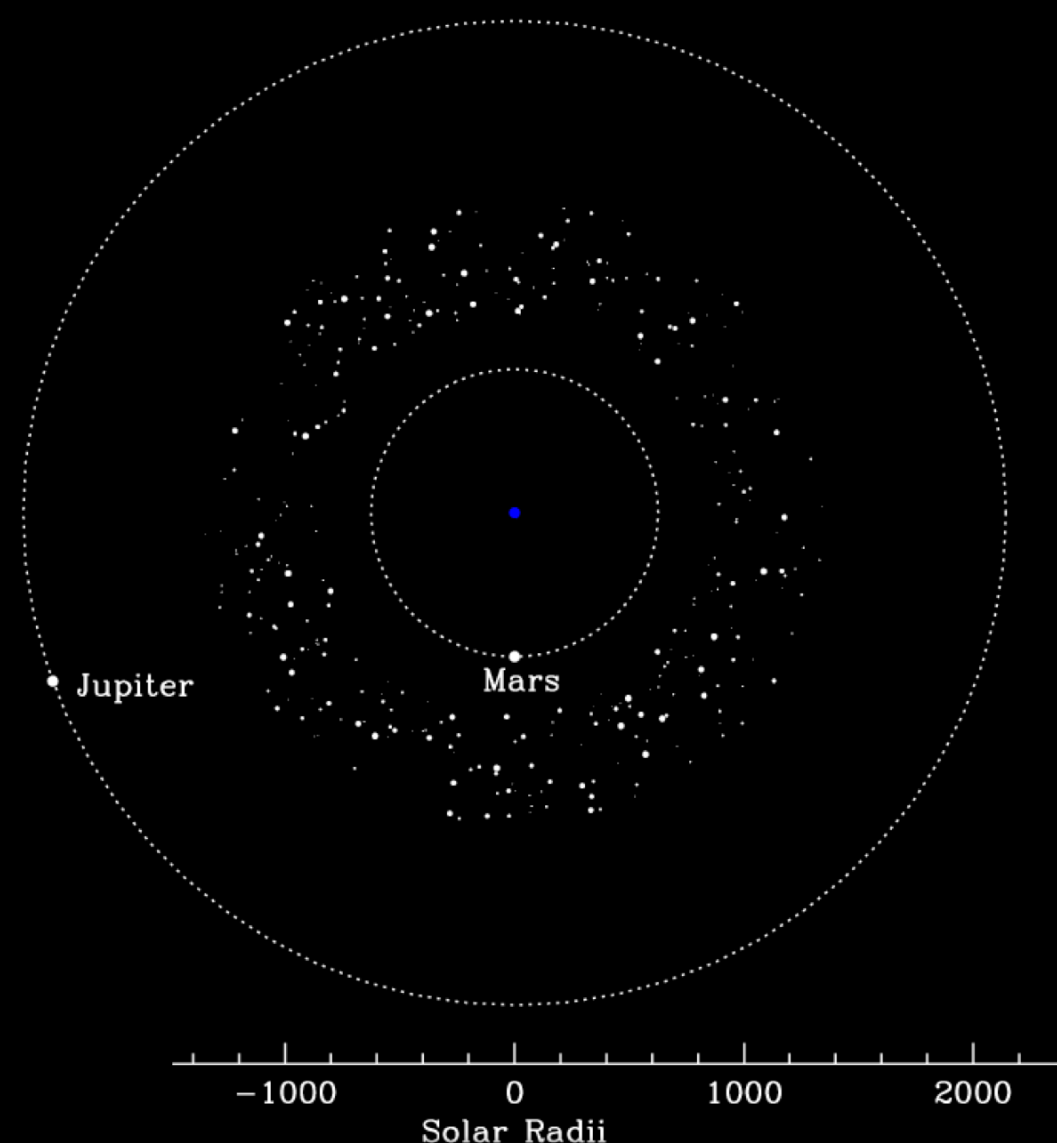
5 billion years from now



Boris Gänsicke



8 billion years from now



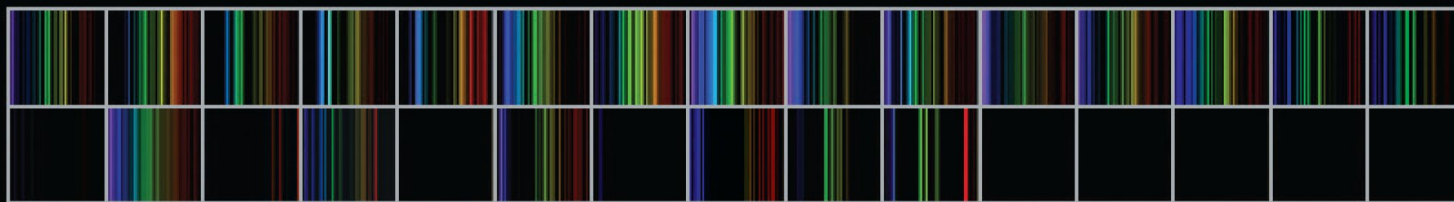
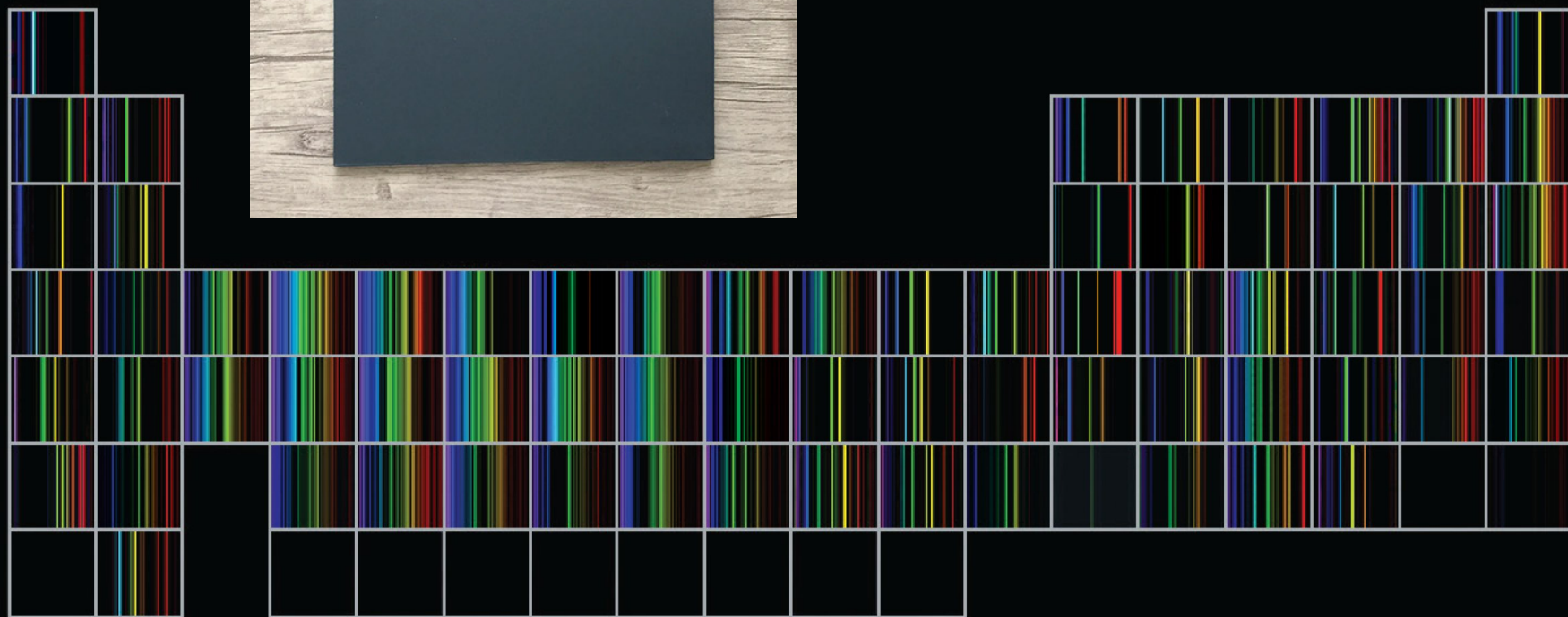
Boris Gänsicke



SDSS

1''

N
E

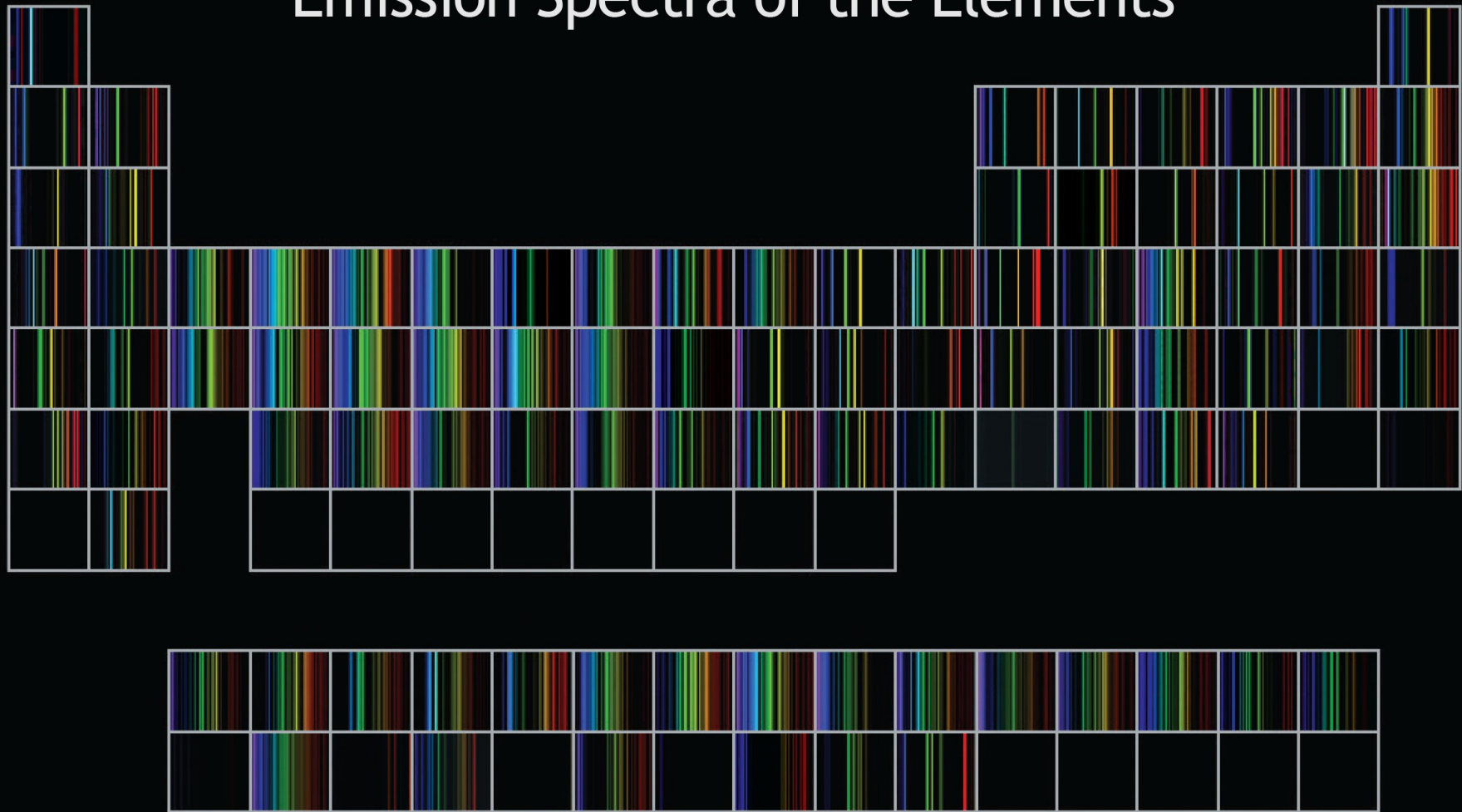


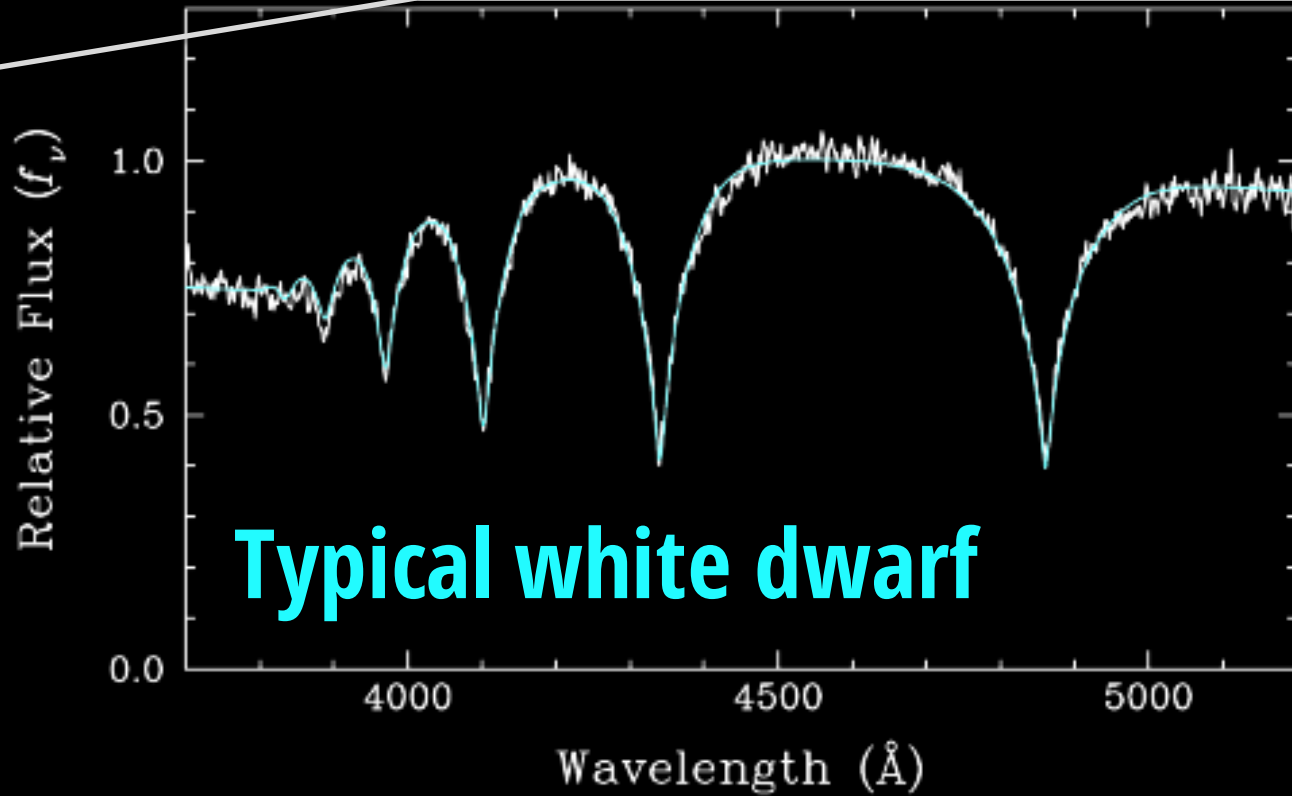
 field·tested·systems™
REAL-TIME CLASSROOM SPECTROSCOPY

www.fieldtestedsystems.com/ptable/

Hydrogen

Emission Spectra of the Elements

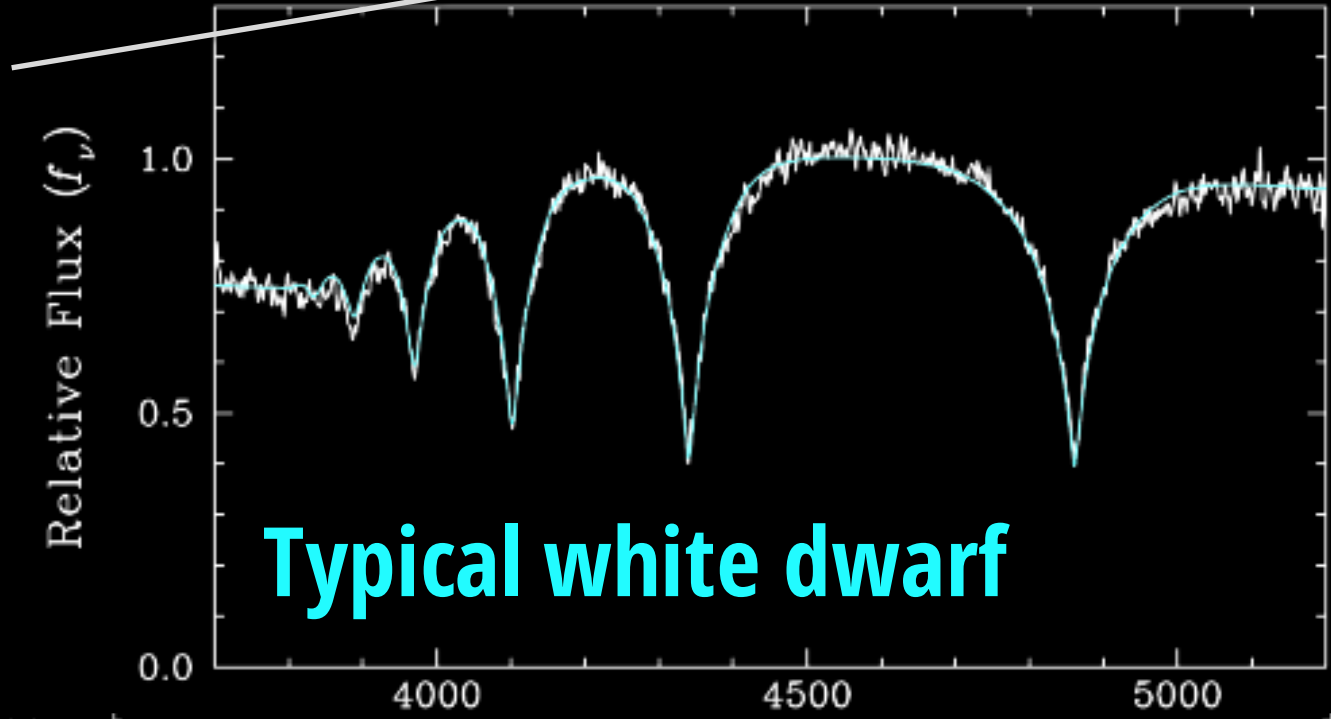
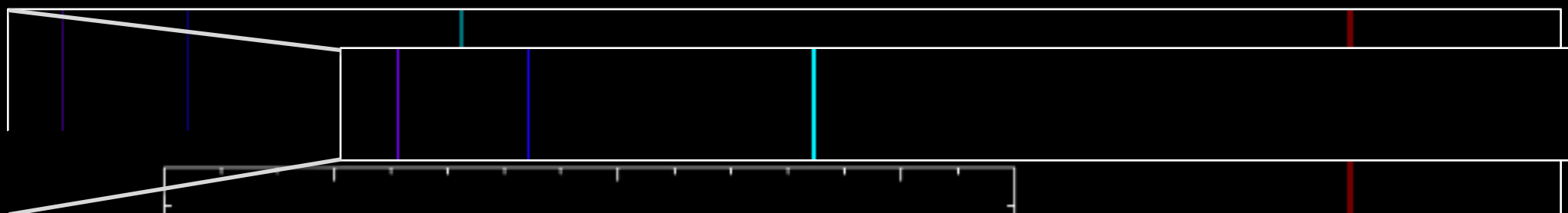




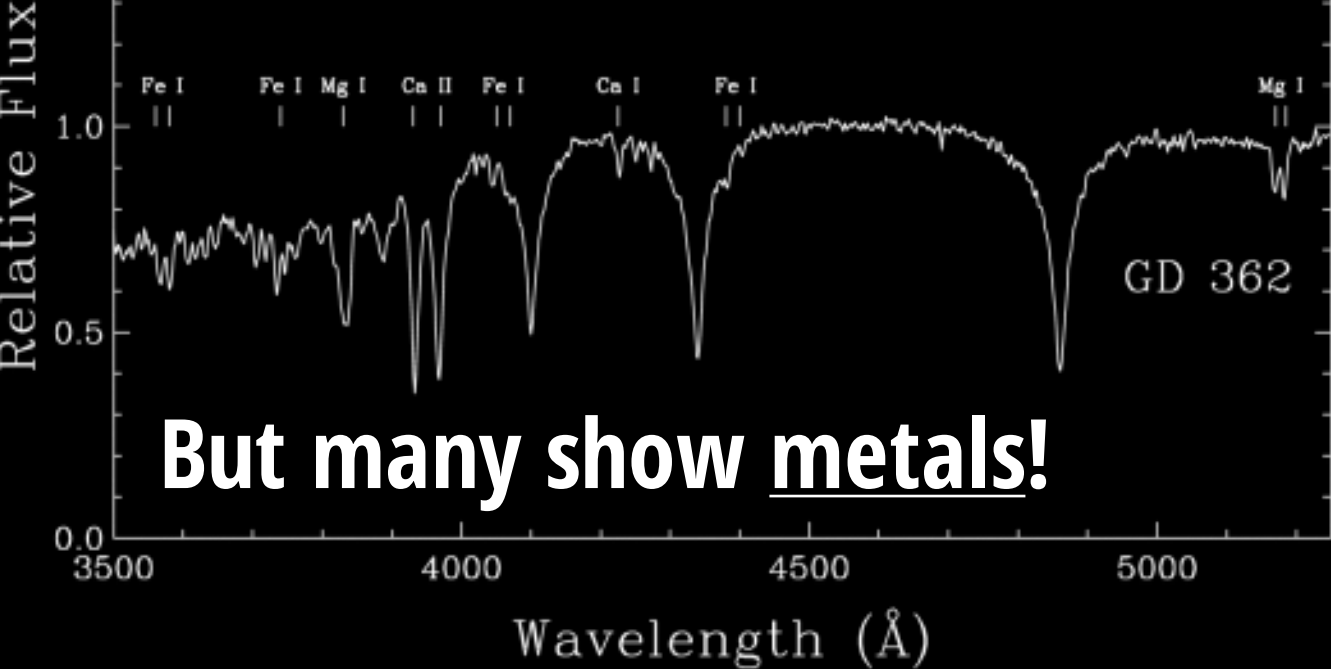
Settling times \ll years

Expect pure hydrogen photospheres





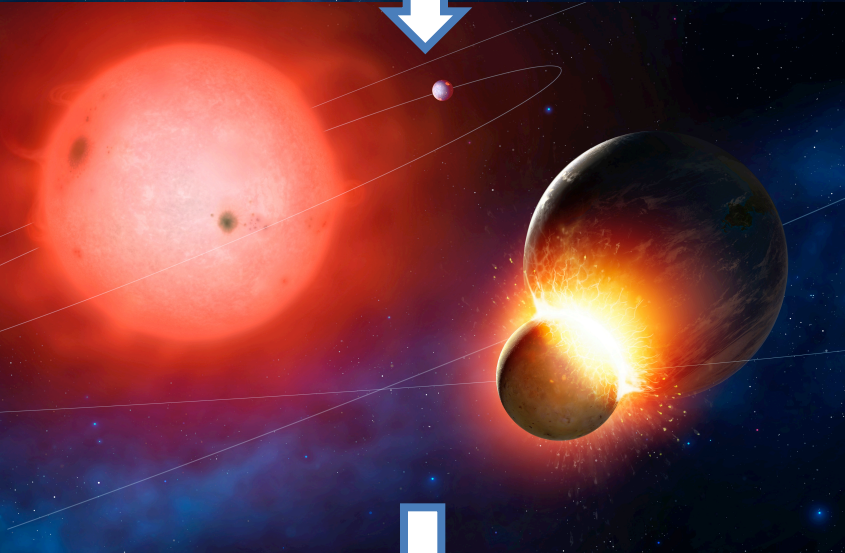
Typical white dwarf



But many show metals!



Sharyn Morrow



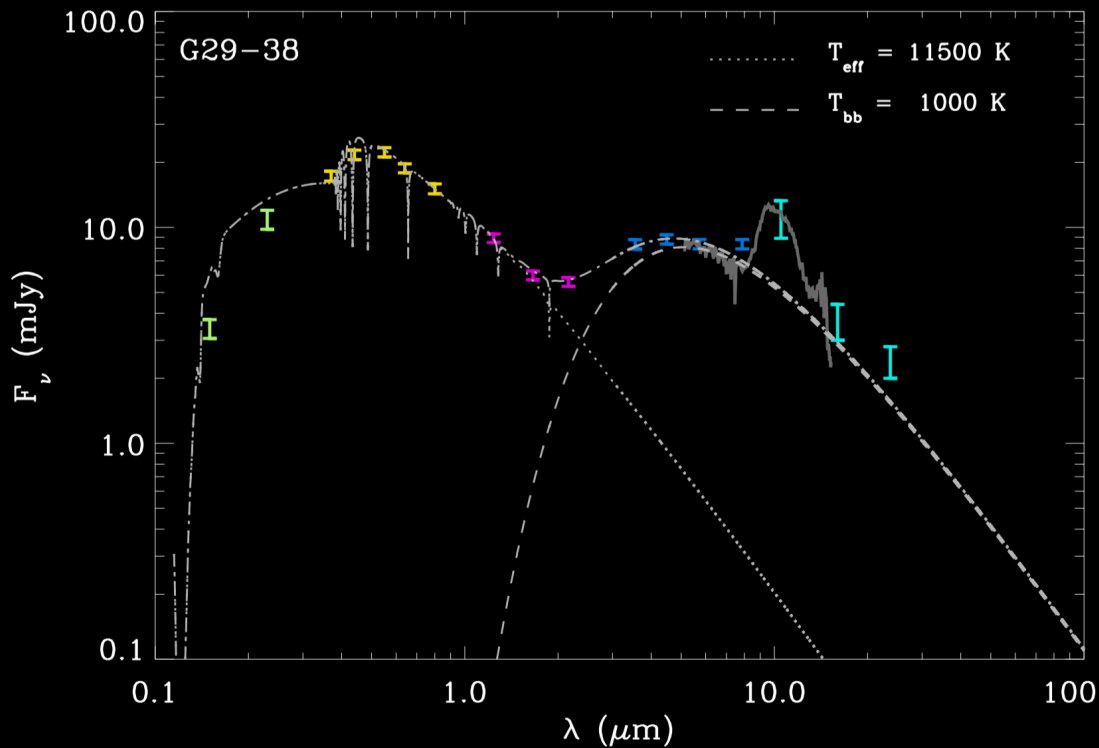
1. Pollution in white dwarfs reveals the future of planetary systems around stars like our Sun.

2. As the star evolves, the **orbits** of surviving planets **expand**. Objects destabilize, some **scatter** in.

3. Ancient solar systems have leftover debris. We can see it if it pollutes a pristine **white dwarf**.

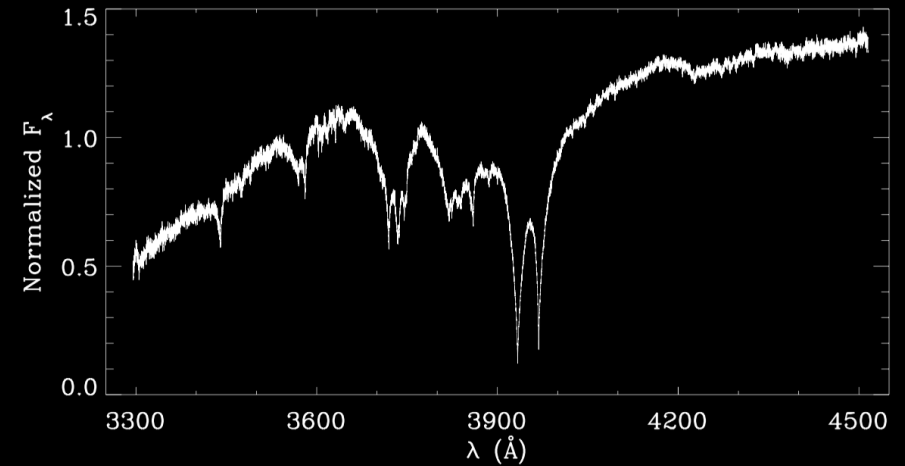
Observational evidence for this hypothesis:

(b) IR excess (**dust** disks)

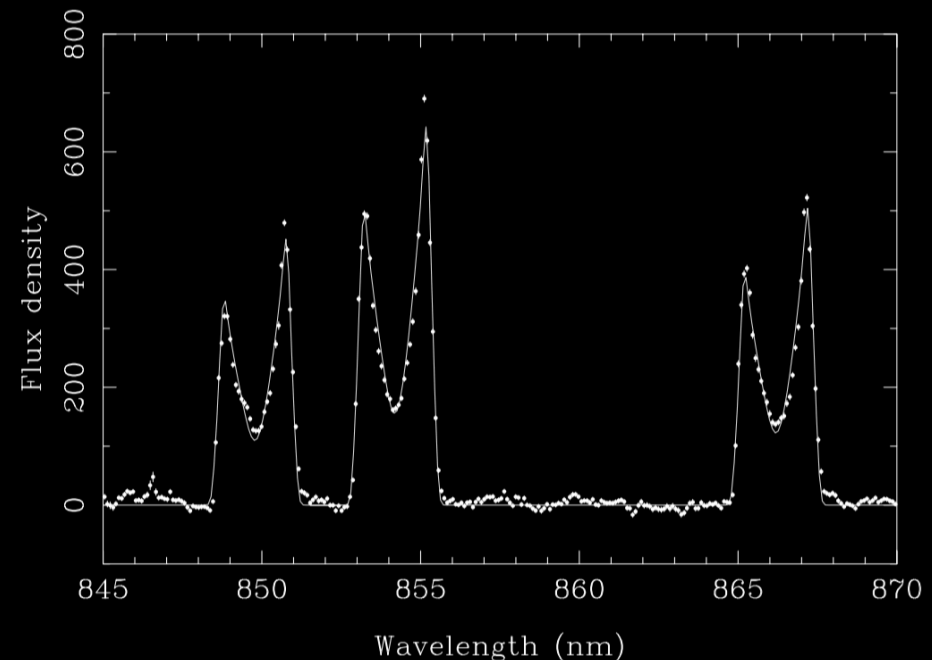


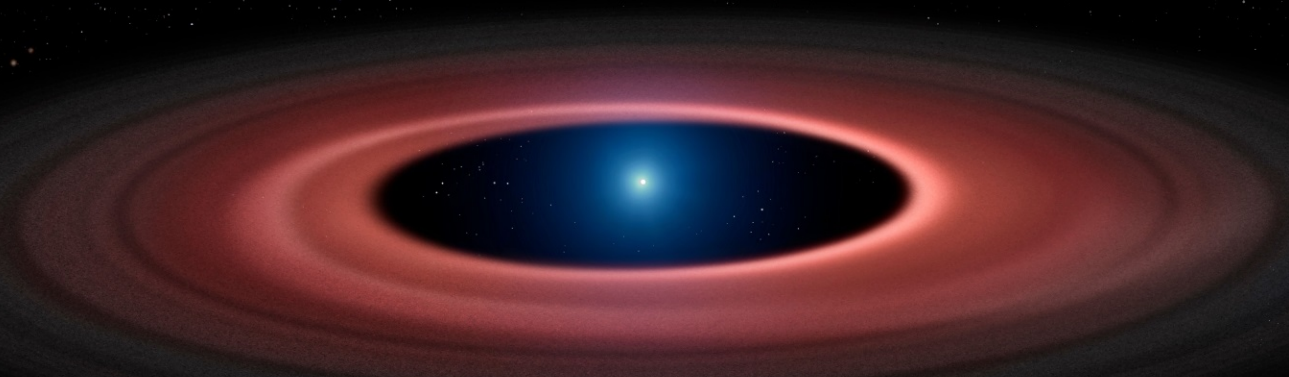
Farihi 2016, Veras 2016

(a) Photospheric pollution



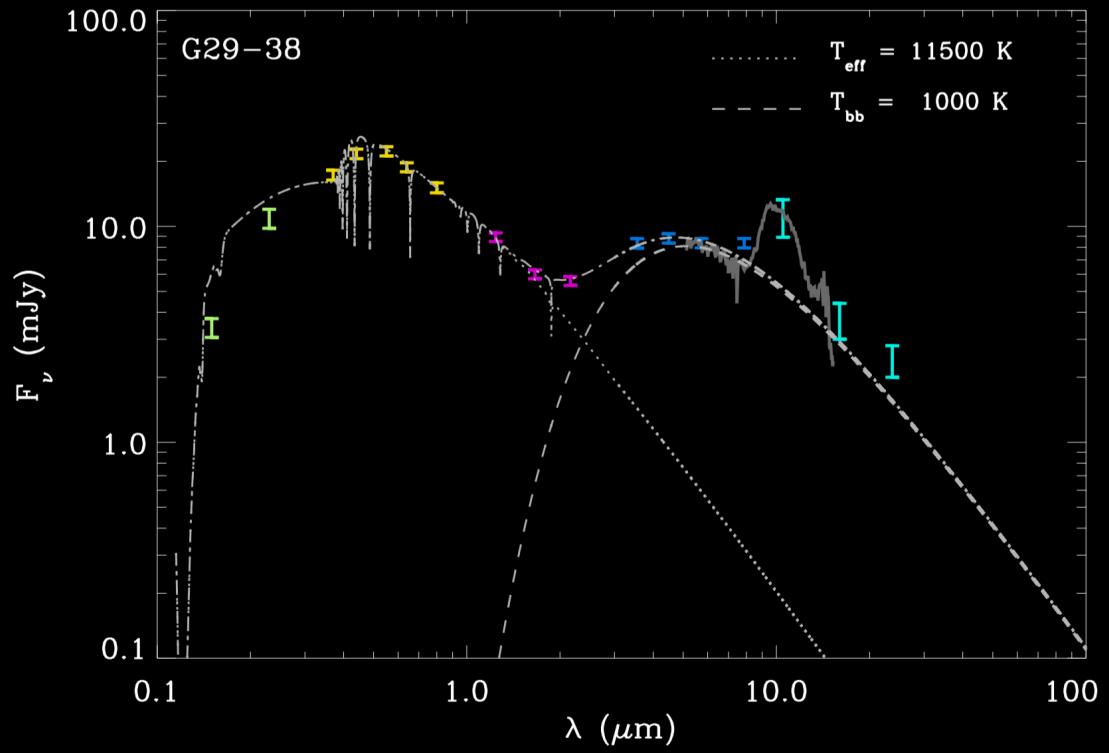
(c) Ca emission (**gas** disks)



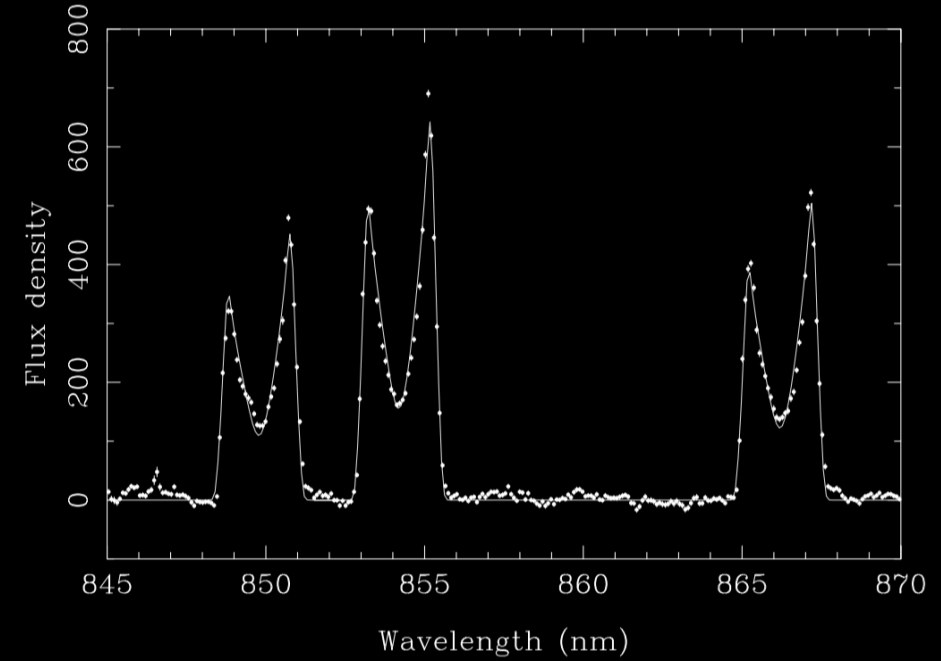


Mark Garlick

(b) IR excess (**dust** disks)



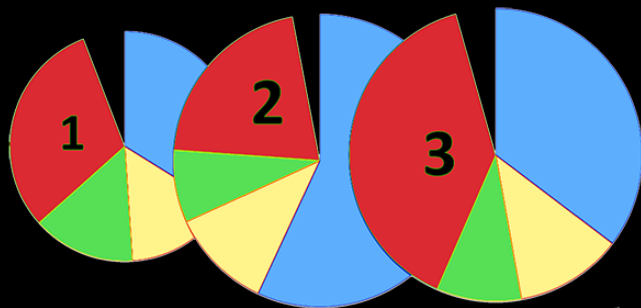
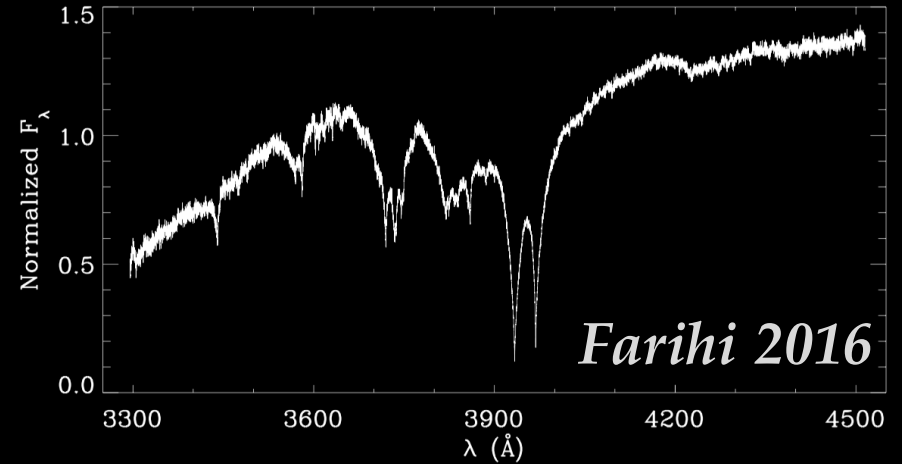
(c) Ca emission (**gas** disks)



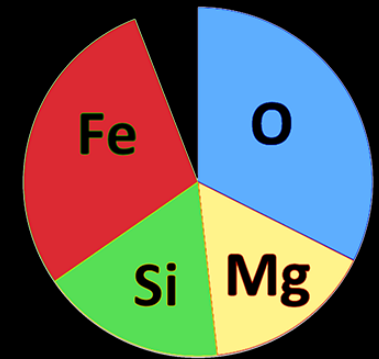
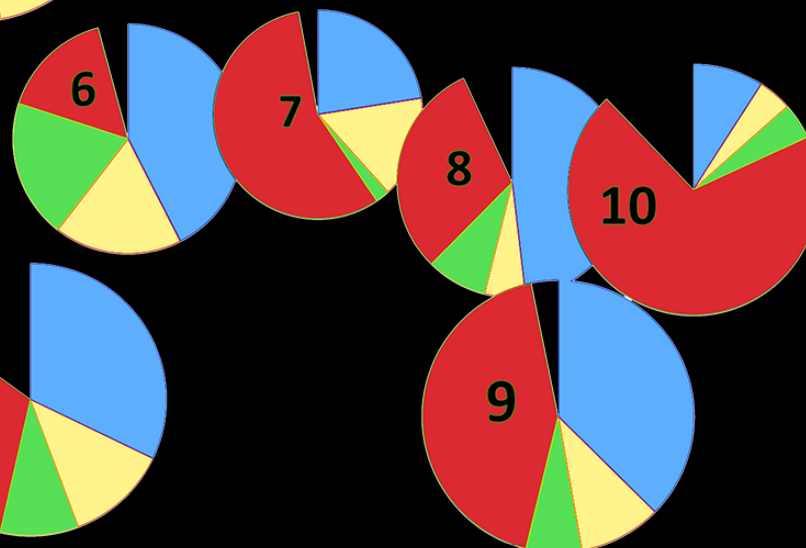
Farihi 2016, Veras 2016

(a) Photospheric pollution

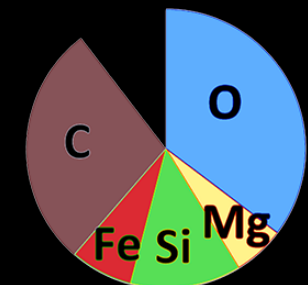
We can **directly**
measure **abundance**
ratios with spectroscopy



Abundances of rocks
falling on 10
different white dwarfs:



Bulk Earth



Comet Halley

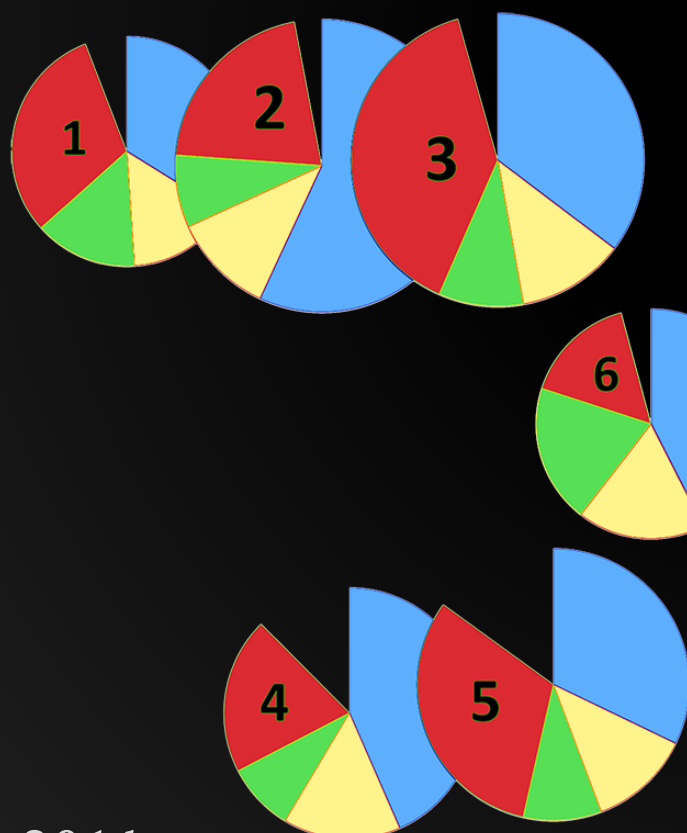


Xu et al. 2014

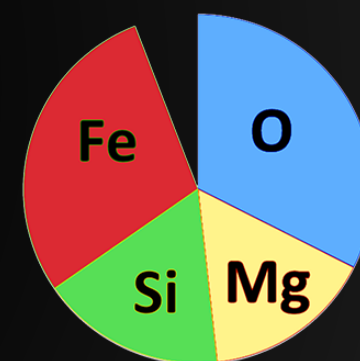
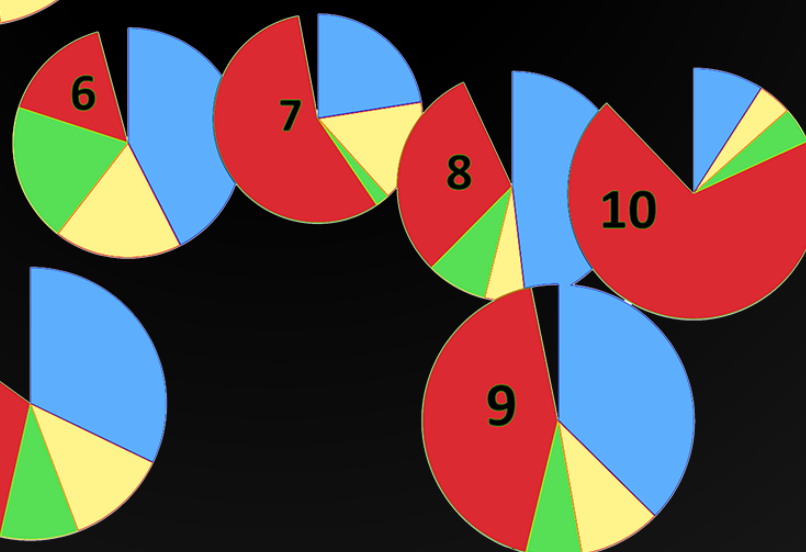
**Comets crash into our Sun
all the time.**

**Each one contributes less than
0.0000000000000001% of the Sun's
metals**

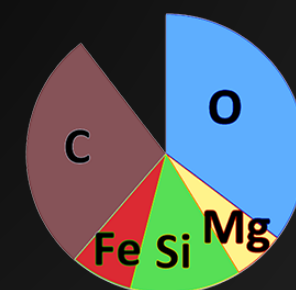
We can **directly**
measure **abundance**
ratios with spectroscopy



Abundances of rocks
falling on 10
different white dwarfs:



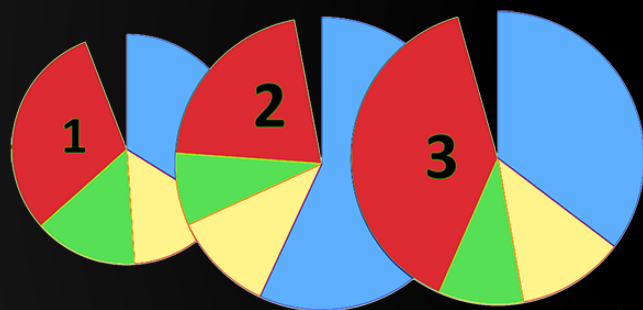
Bulk Earth



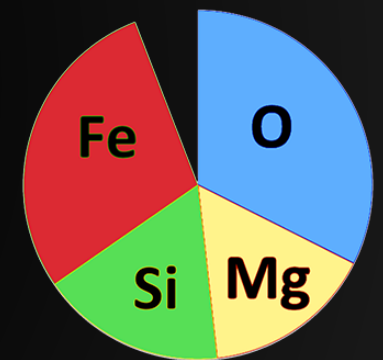
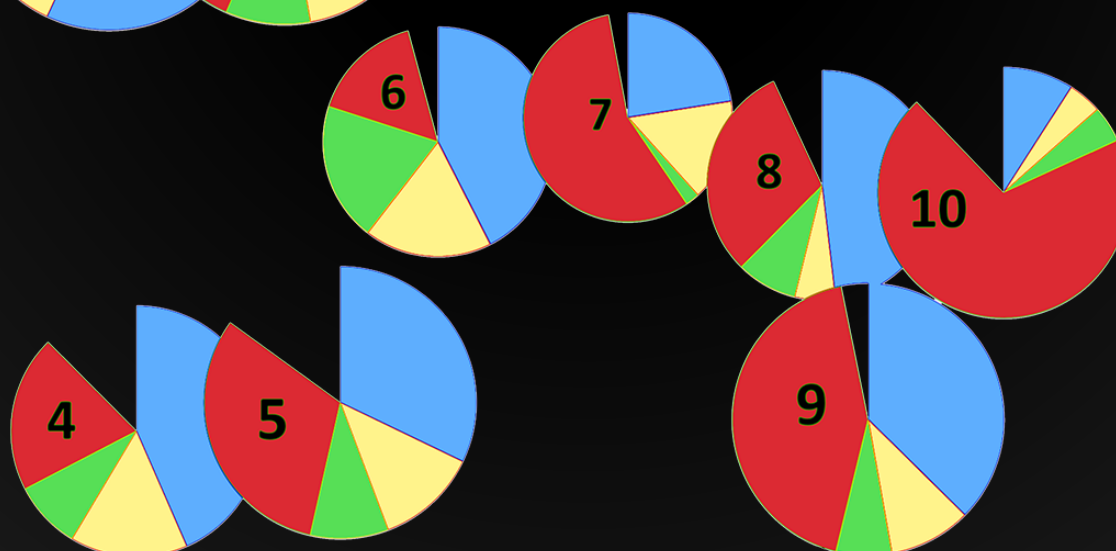
Comet Halley

Rocks = MgO, Al₂O₃, SiO₂,
CaO, TiO₂, Cr₂O₃,
MnO, FeO, Fe₂O₃, ...

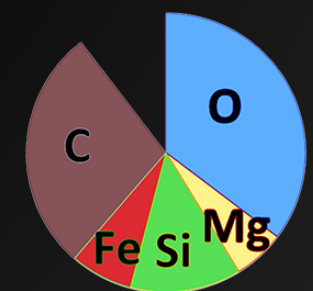
Volatiles = CO₂, H₂O



**Abundances of rocks
falling on 10
different white dwarfs:**



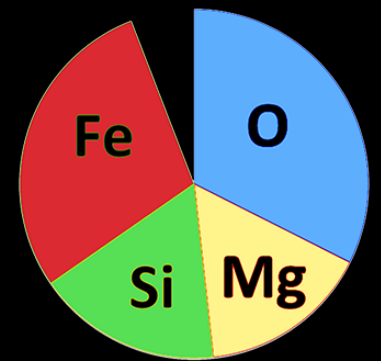
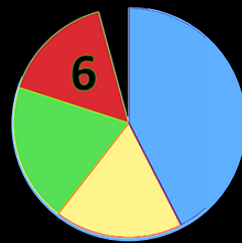
Bulk Earth



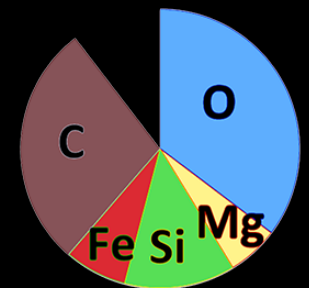
Comet Halley

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

Volatiles = CO_2 , H_2O



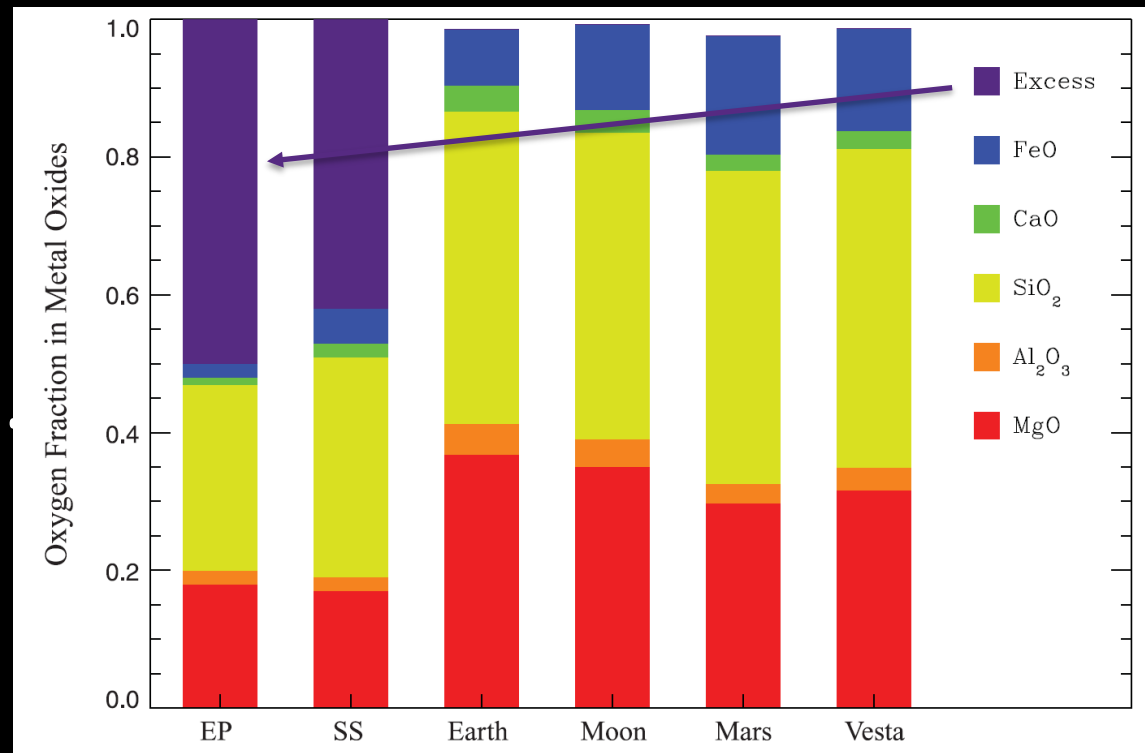
Bulk Earth



Comet Halley

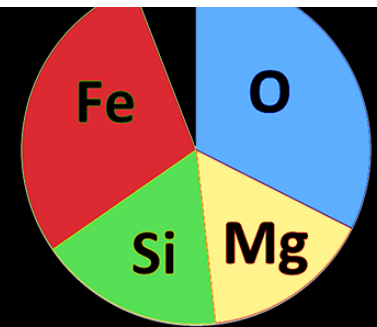
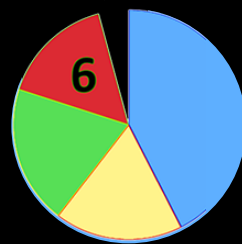
Rocks = MgO, Al₂O₃, SiO₂,
CaO, TiO₂, Cr₂O₃,
MnO, FeO, Fe₂O₃,

Volatiles = CO₂, H₂O

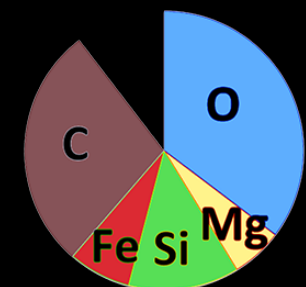


This white dwarf has very little Carbon, so **excess Oxygen likely from H₂O**

Farihi et al. 2013

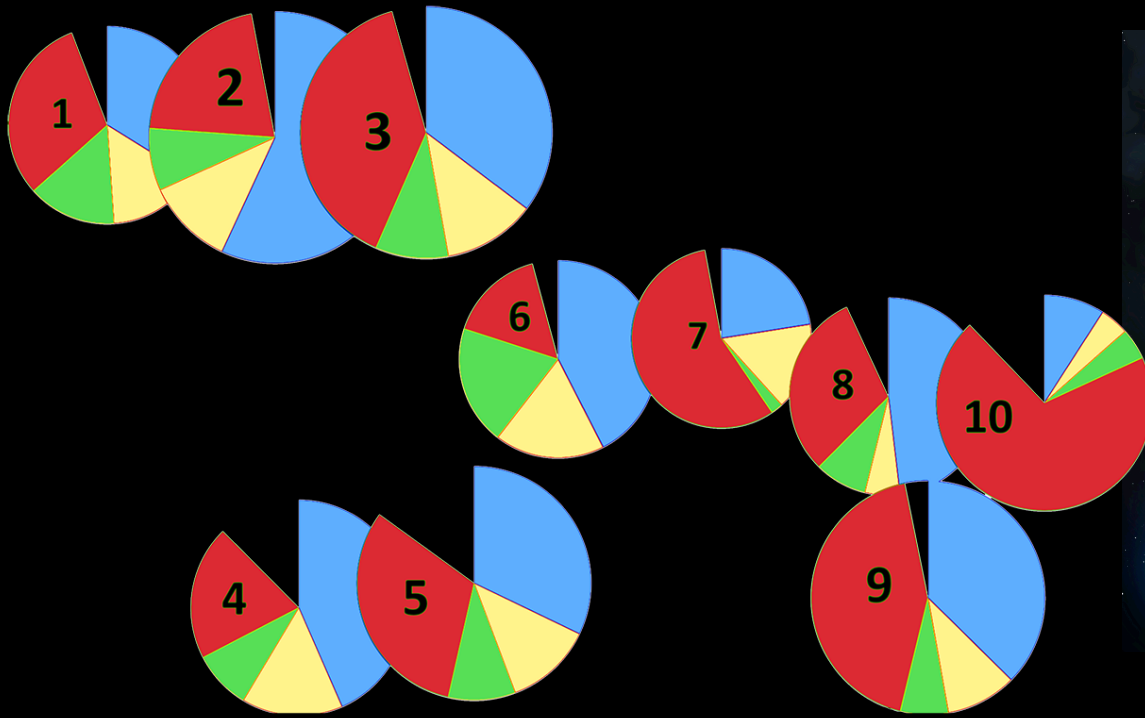


Bulk Earth



Comet Halley

The parent body was originally composed of 26% water by mass



Mark Garlick

As with bulk Earth the dominant elements in exo-asteroids are **Iron**, **Oxygen**, **Silicon**, **Magnesium**

1 H HYDROGEN 1																		2 He HELIUM 4																	
3 Li LITHIUM 7		4 Be BERYLLIUM 9																		5 B BORON 11		6 C CARBON 12		7 N NITROGEN 14		8 O OXYGEN 16		9 F FLUORINE 19		10 Ne NEON 20					
11 Na SODIUM 23		12 Mg MAGNESIUM 24																		13 Al ALUMINUM 27		14 Si SILICON 28		15 P PHOSPHORUS 31		16 S SULFUR 32		17 Cl CHLORINE 35		18 Ar ARGON 40					
19 K POTASSIUM 39		20 Ca CALCIUM 40		21 Sc SCANDIUM 45		22 Ti TITANIUM 48		23 V VANADIUM 51		24 Cr CHROMIUM 52		25 Mn MANGANESE 55		26 Fe IRON 56		27 Co COBALT 59		28 Ni NICKEL 59		29 Cu COPPER 64		30 Zn ZINC 65		31 Ga GALLIUM 70		32 Ge GERMANIUM 73		33 As ARSENIC 75		34 Se SELENIUM 79		35 Br BROMINE 80		36 Kr KRYPTON 84	
37 Rb RUBIDIUM 85		38 Sr STRONTIUM 88		39 Y YTTORIUM 89		40 Zr ZIRCONIUM 91		41 Nb NIOBIUM 93		42 Mo MOLYBDENUM 96		43 Tc TECHNETIUM 98		44 Ru RUTHENIUM 101		45 Rh RHODIUM 103		46 Pd PALLADIUM 106		47 Ag SILVER 108		48 Cd CADMIUM 112		49 In INDIUM 115		50 Sn TIN 119		51 Sb ANTIMONY 122		52 Te TELLURIUM 128		53 I IODINE 127		54 Xe XENON 131	
55 Cs CESIUM 133		56 Ba BARIUM 137		57 La LANTHANUM 139		58 Ce CERMIUM 140		59 Pr PRASEODYMIUM 141		60 Nd NEODYMIUM 144		61 Pm PROMETHIUM 145		62 Sm SAMARIUM 150		63 Eu EUROPIUM 152		64 Gd GADOLINIUM 157		65 Tb TERBIUM 159		66 Dy DYSPROSIUM 163		67 Ho HOLMIUM 165		68 Er ERBIUM 167		69 Tm THULIUM 169		70 Yb YTTERIUM 173		71 Lu LUTETIUM 175			
87 Fr FRANCIUM 223		88 Ra RADIUM 226		72 Hf HAFNIUM 178		73 Ta TANTALUM 181		74 W TUNGSTEN 184		75 Re RHENIUM 186		76 Os OSMIUM 190		77 Ir IRIDIUM 192		78 Pt PLATINUM 195		79 Au GOLD 197		80 Hg MERCURY 201		81 Tl THALLIUM 204		82 Pb LEAD 207		83 Bi BISMUTH 209		84 Po POLONIUM 209		85 At ASTATINE 210		86 Rn RADON 222			
89 Ac ACTINIUM 227		90 Th THORIUM 232		91 Pa PROTACTINIUM 231		92 U URANIUM 238		93 Np NEPTUNIUM 237		94 Pu PLUTONIUM 244		95 Am AMERICIUM 243		96 Cm CURIUM 247		97 Bk BERKELIUM 247		98 Cf CALIFORNIUM 251		99 Es EINSTEINIUM 252		100 Fm FERMIUM 257		101 Md MENDELEVIUM 258		102 No NOBELIUM 259		103 Lr LAWRENCIUM 262							

KEY

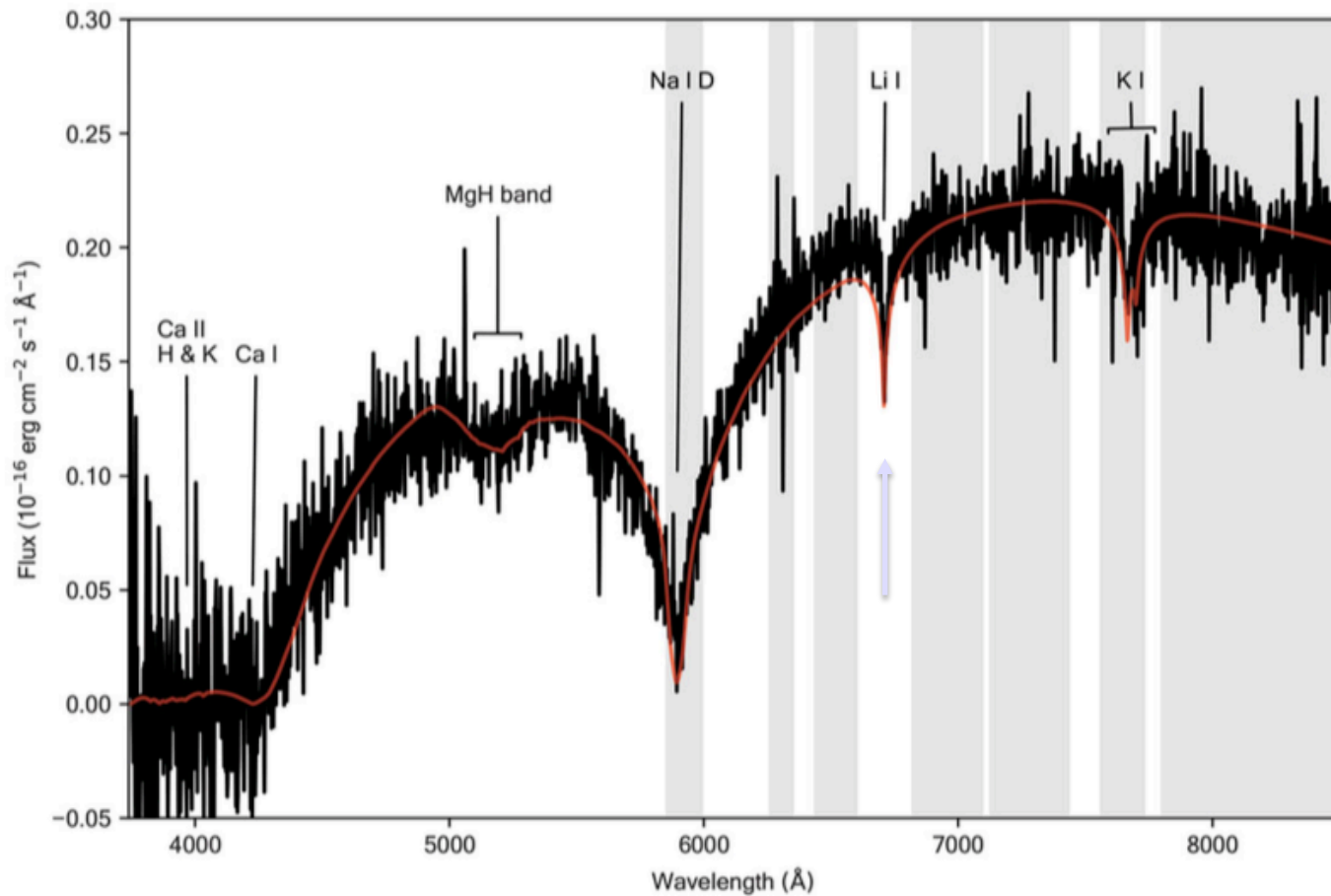
- = Solid at room temperature
- = Liquid at room temperature
- = Gas at room temperature
- ☛ = Radioactive
- ♣ = Artificially Made

6 ← Atomic Number = Number of Protons = Number of Electrons

C ← Chemical Symbol

CARBON ← Chemical Name

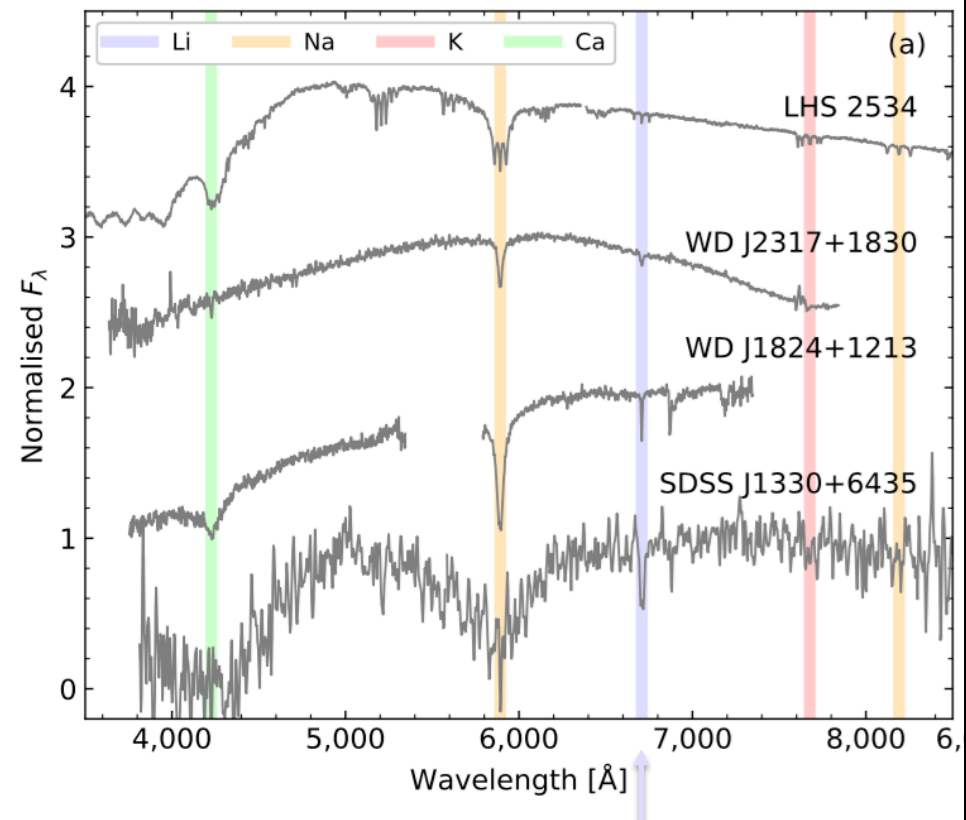
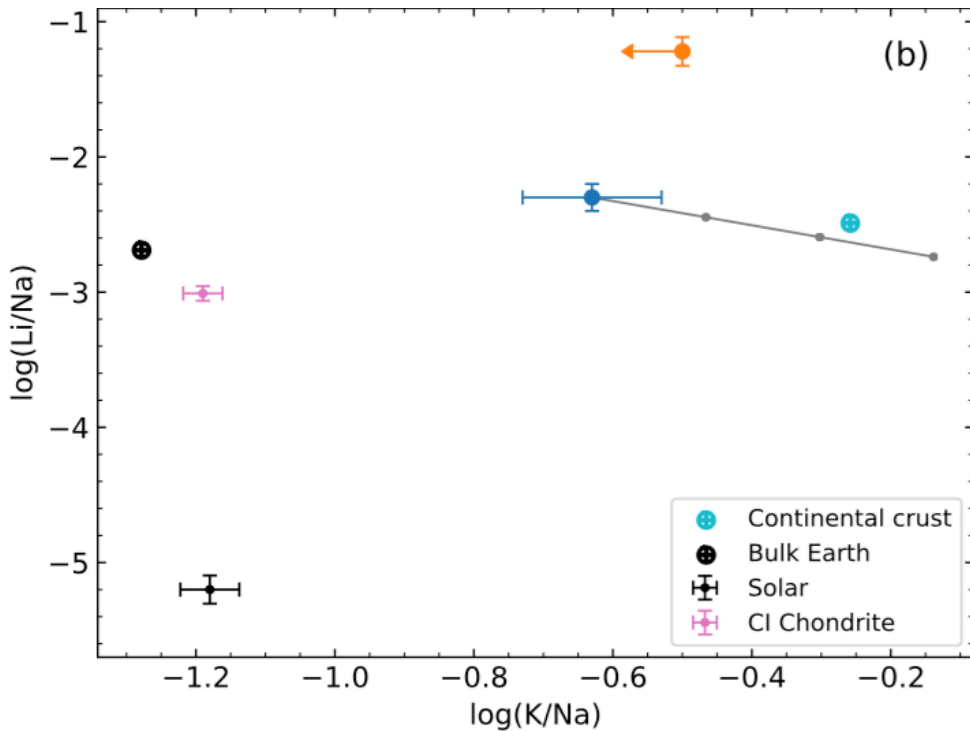
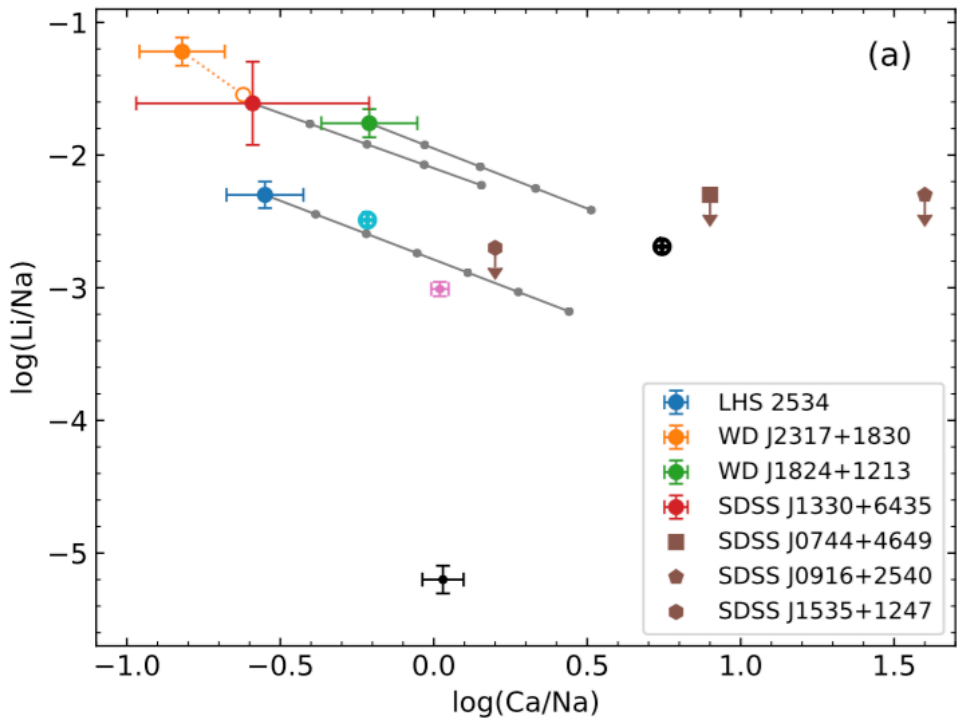
12 ← Atomic Weight = Number of Protons + Number of Neutrons*



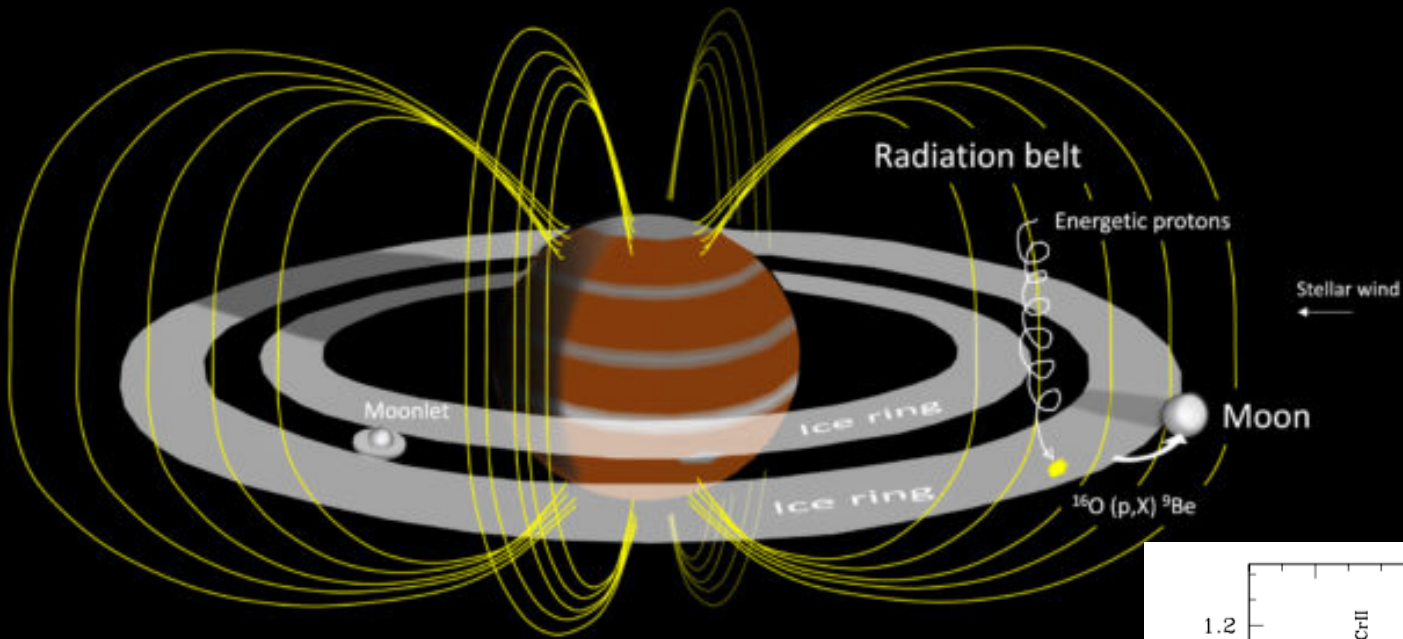
Lithium has recently been found in cool white dwarfs



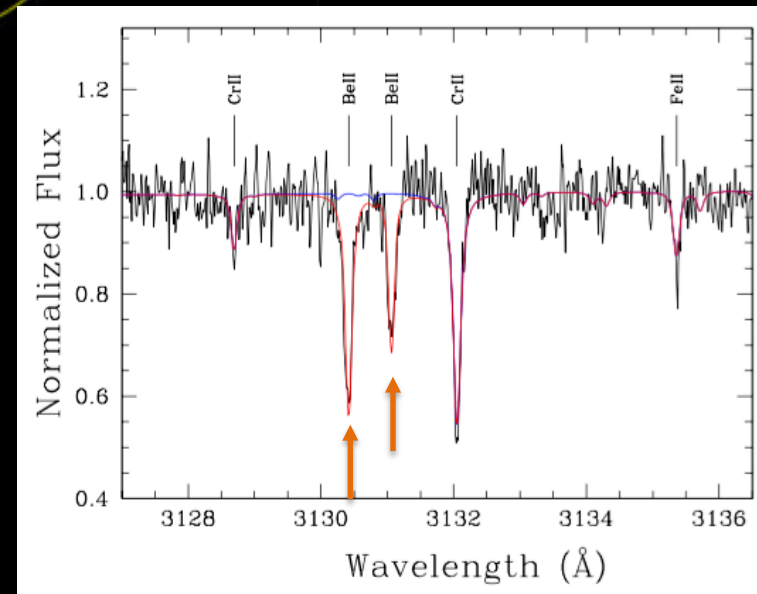
Kaiser et al. 2021



Lithium may reveal that at least some rocks polluting white dwarfs come from the **crusts** of larger planets



Beryllium has also recently been detected in two white dwarfs



Klein et al. 2021

One theory: **Be** found in high abundances produced by **spallation** on an icy moon around a giant planet



Doyle et al. 2021

Simply by observing **metals** in white dwarfs we can directly constrain the **composition of exo-asteroids**

Bottom Line: Alien Rocks are **Just Like Rocks in our Solar System**

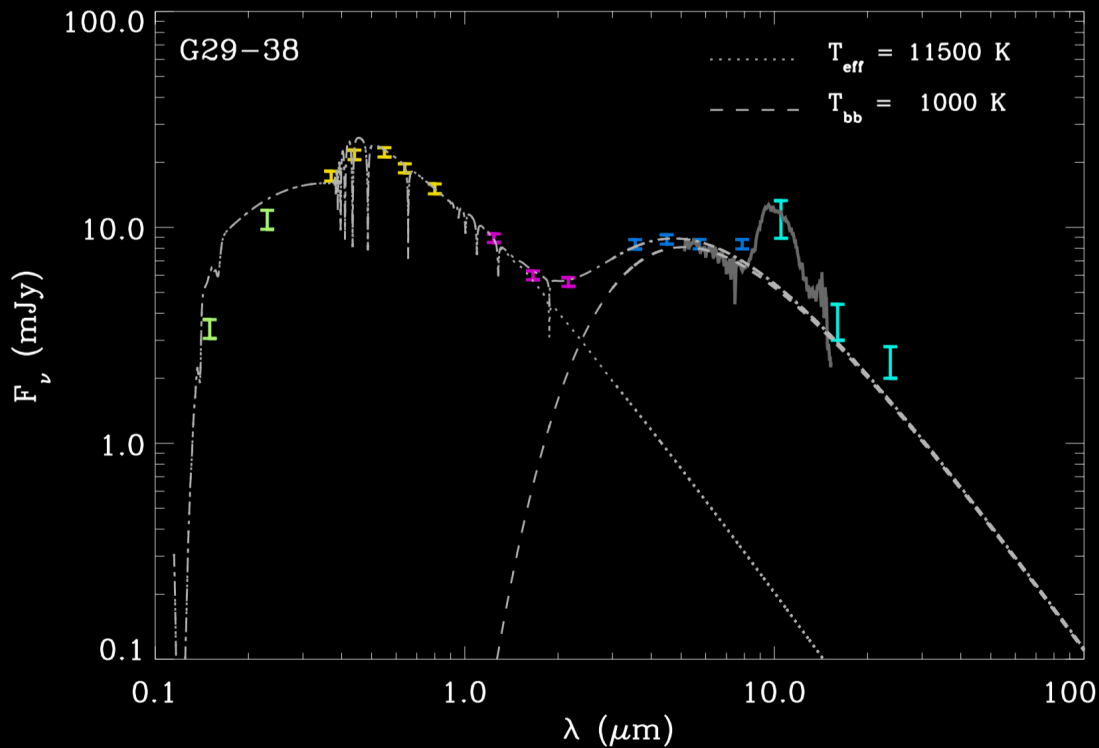
They are mostly composed of:

Iron, Oxygen, Silicon, Magnesium ... and Water!

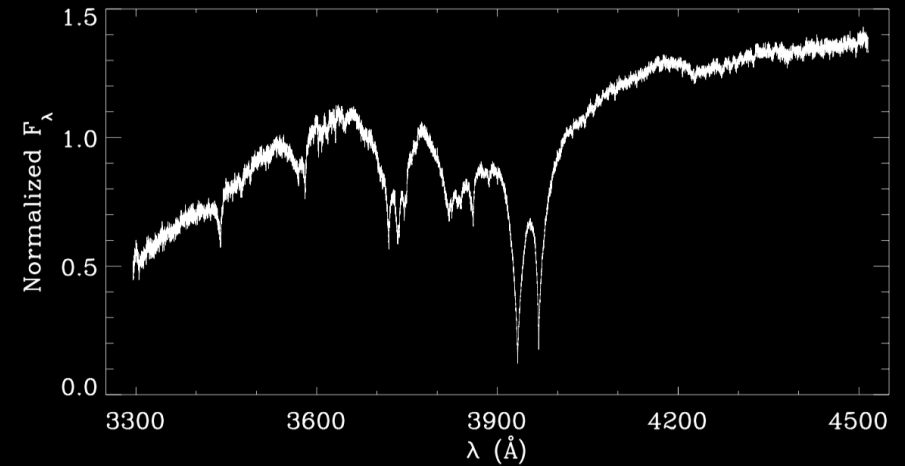


Observational evidence for this hypothesis:

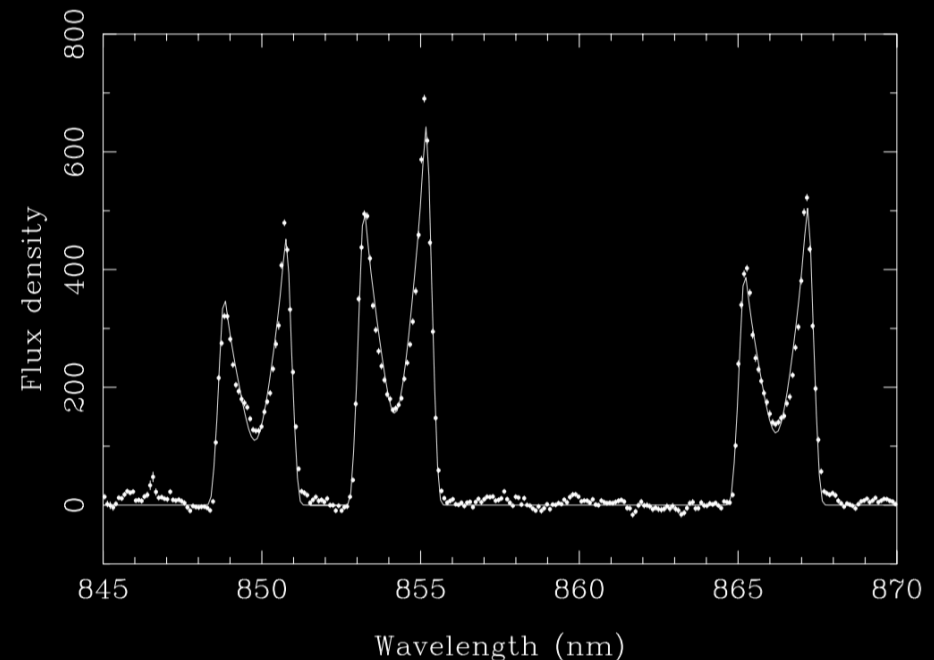
(b) IR excess (**dust** disks)



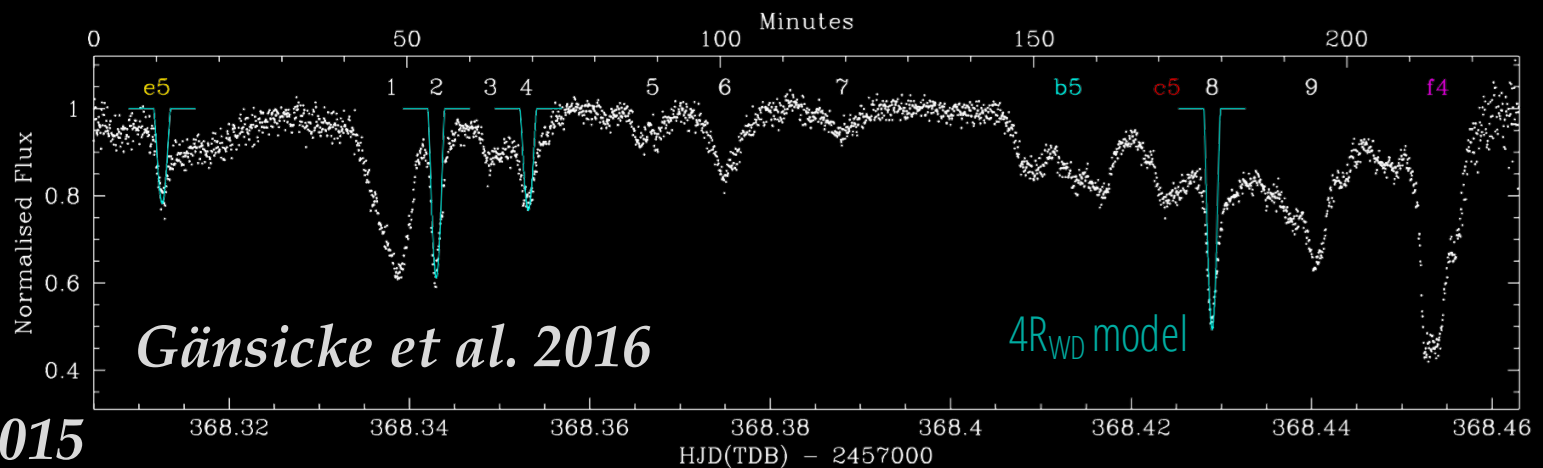
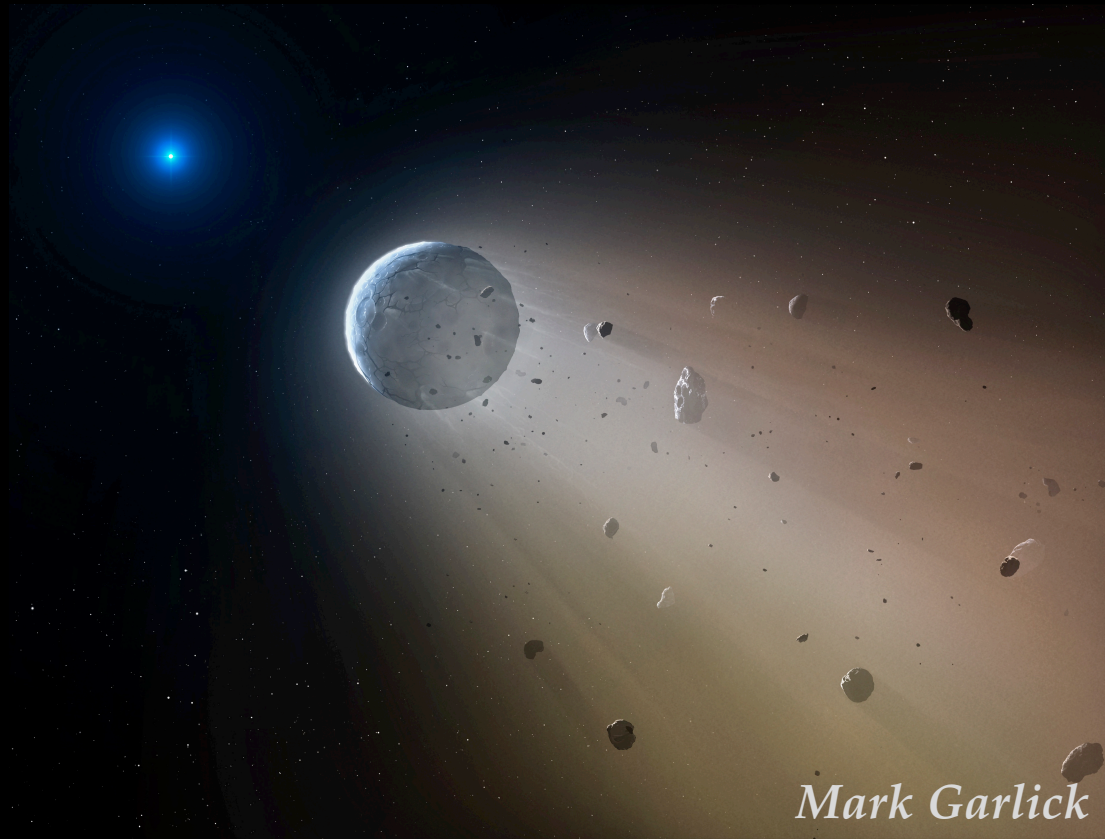
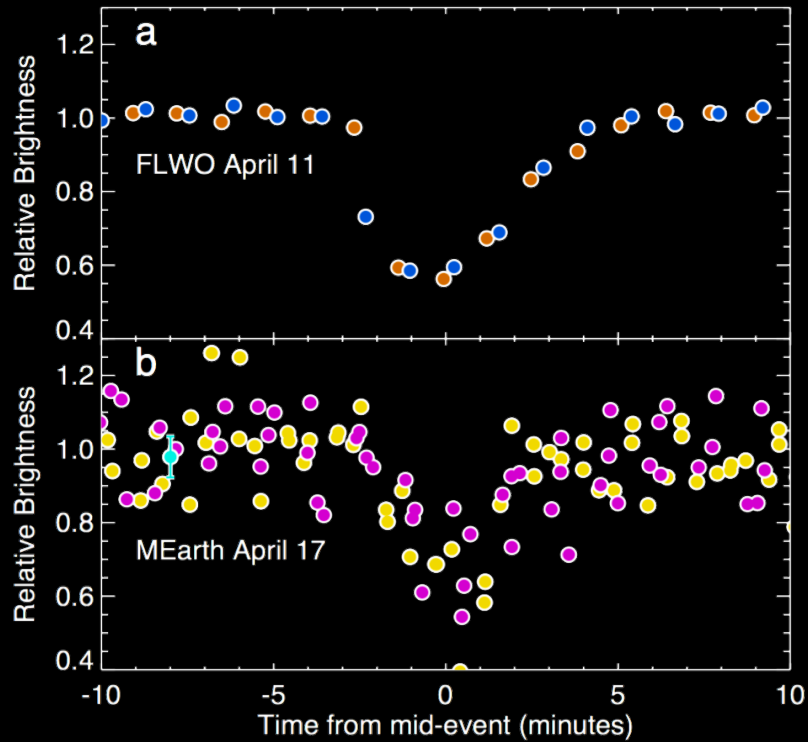
(a) Photospheric pollution



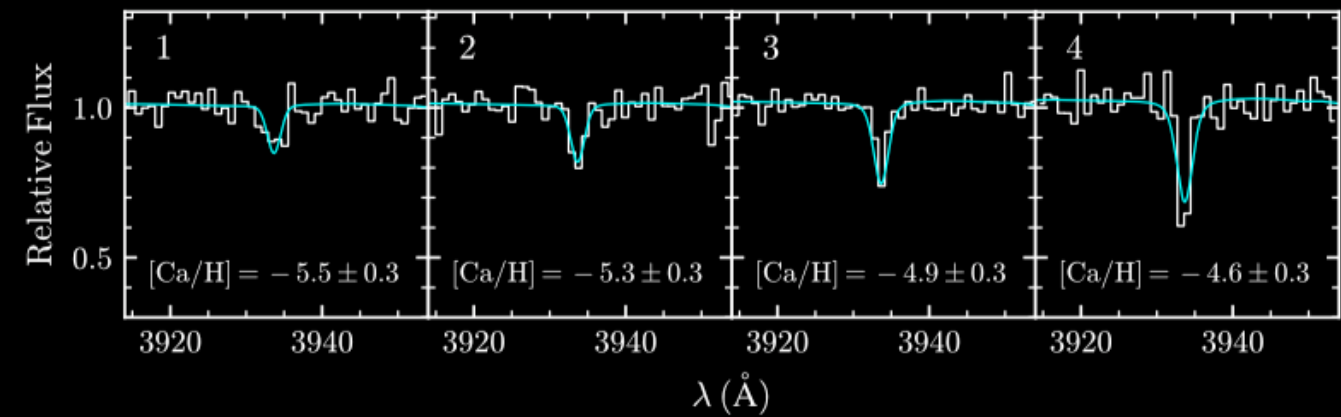
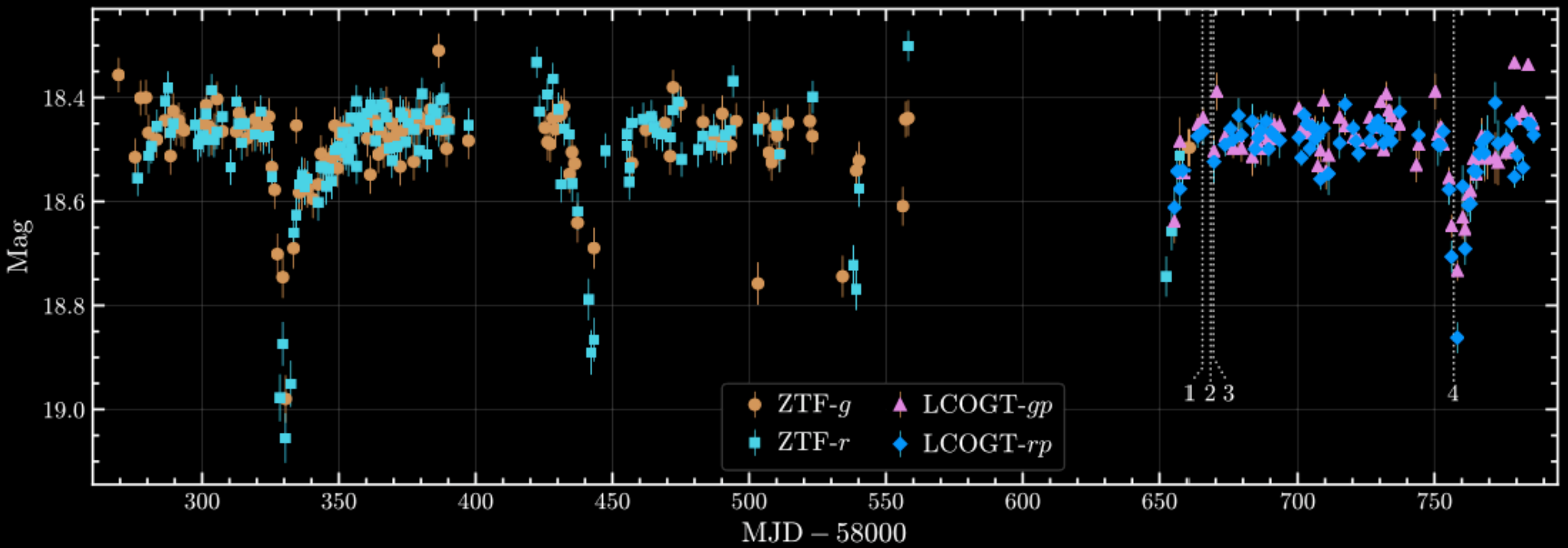
(c) Ca emission (**gas** disks)



(d) Transits of the white dwarf (WD1145+017)

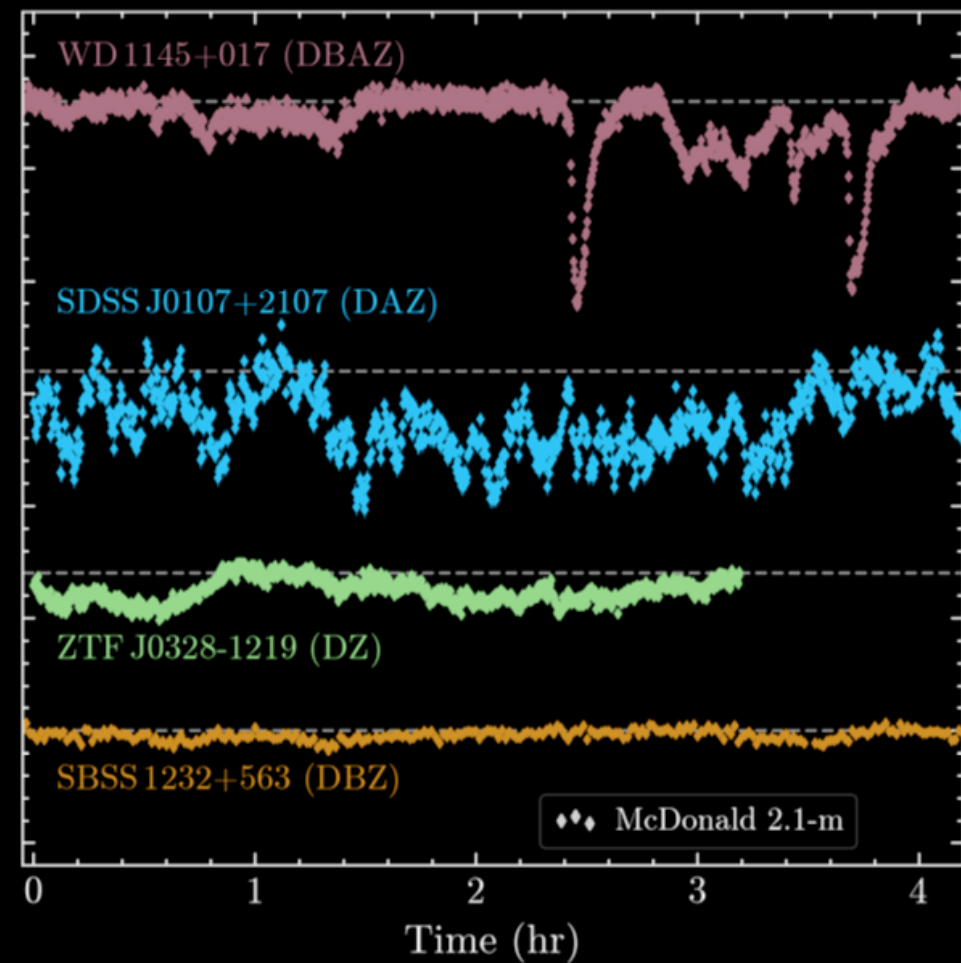
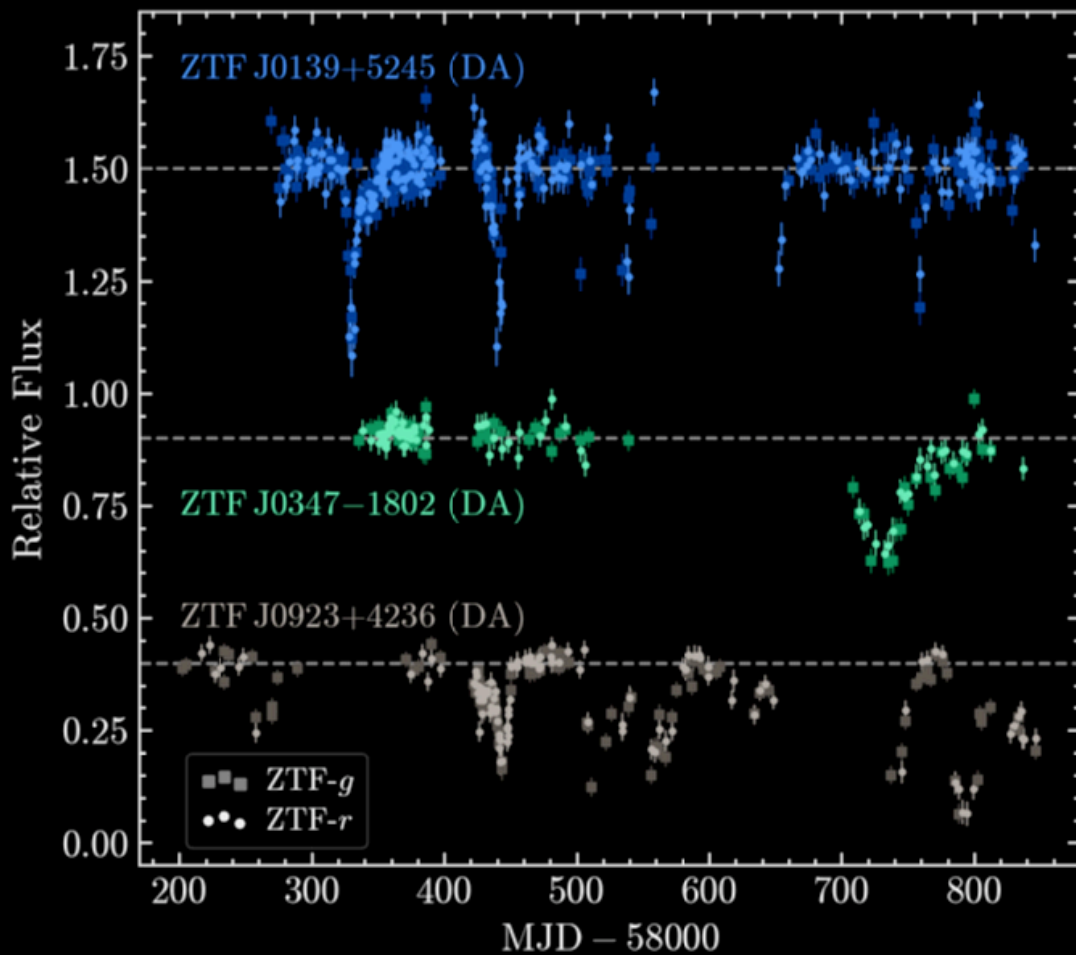


Vanderburg et al. 2015



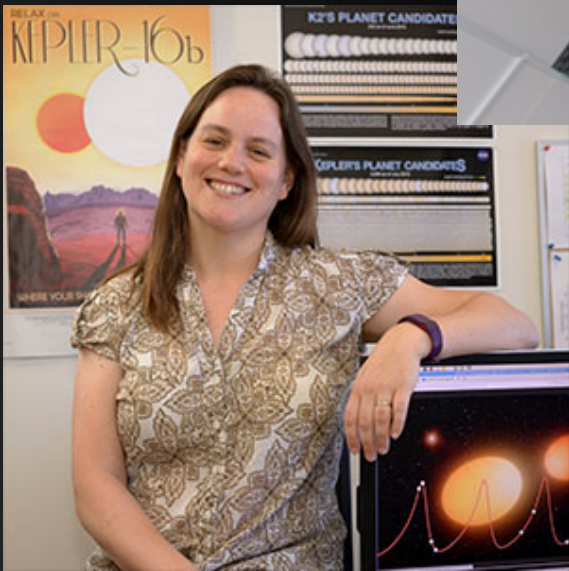
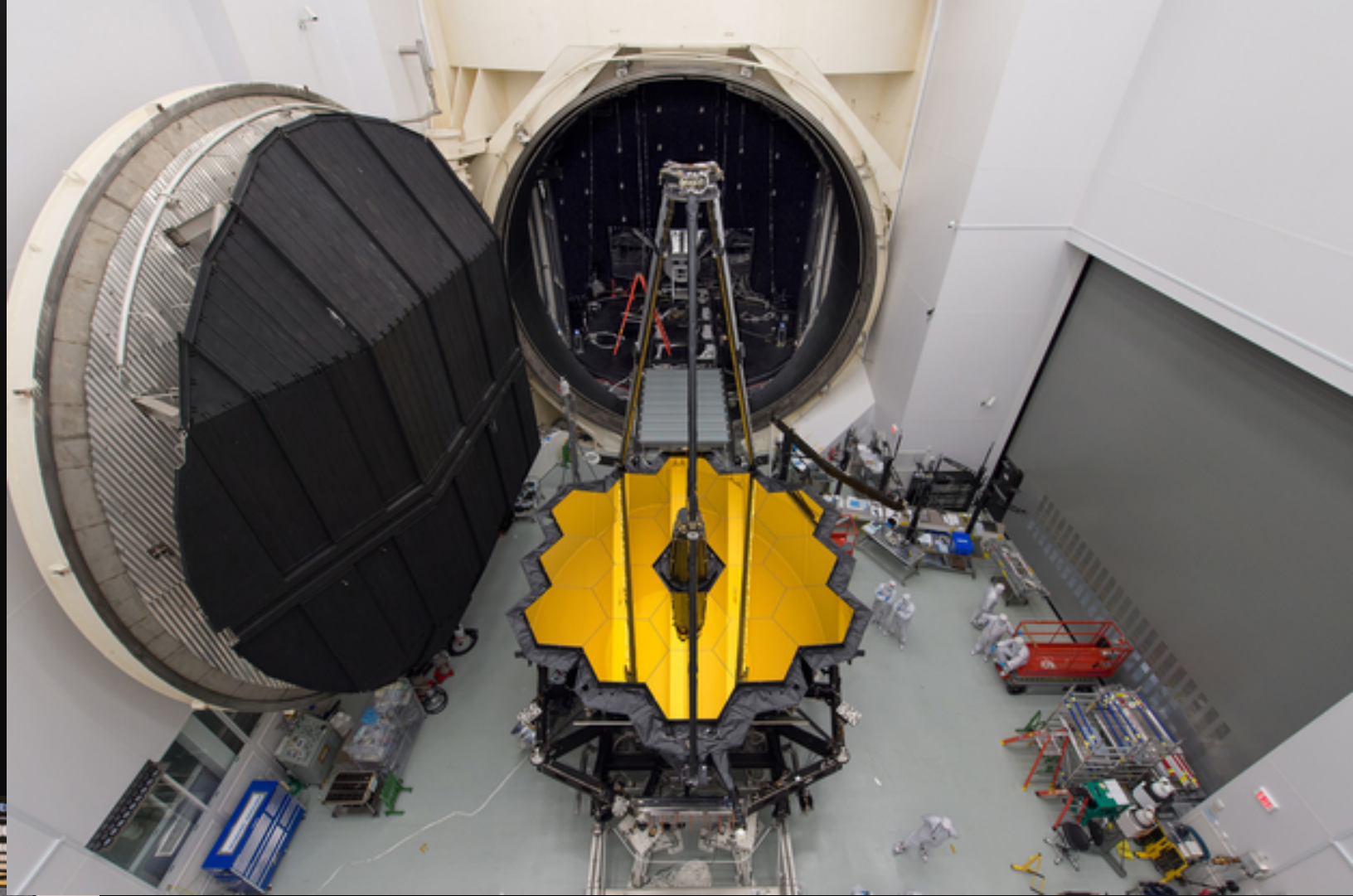
We are finding more white dwarfs with
periodic transits from debris

Vanderbosch, Hermes, et al. 2020



We are finding more white dwarfs with
periodic transits from debris

Guidry, Vanderbosch, Hermes, et al. 2021



PI: Susan Mullally

24.6 hr of JWST time awarded to look for surviving **giant planets** around **4 white dwarfs** in Cycle 1

Many white dwarfs show metals: they are being actively polluted.

The composition of these polluting rocks is revealed by spectroscopy of white dwarfs.

Most alien rocks resemble those in our Solar System.

**Some have lots of water.
Some may be shredded planets or moons.**

Planets that survive stellar evolution still have a perilous future!