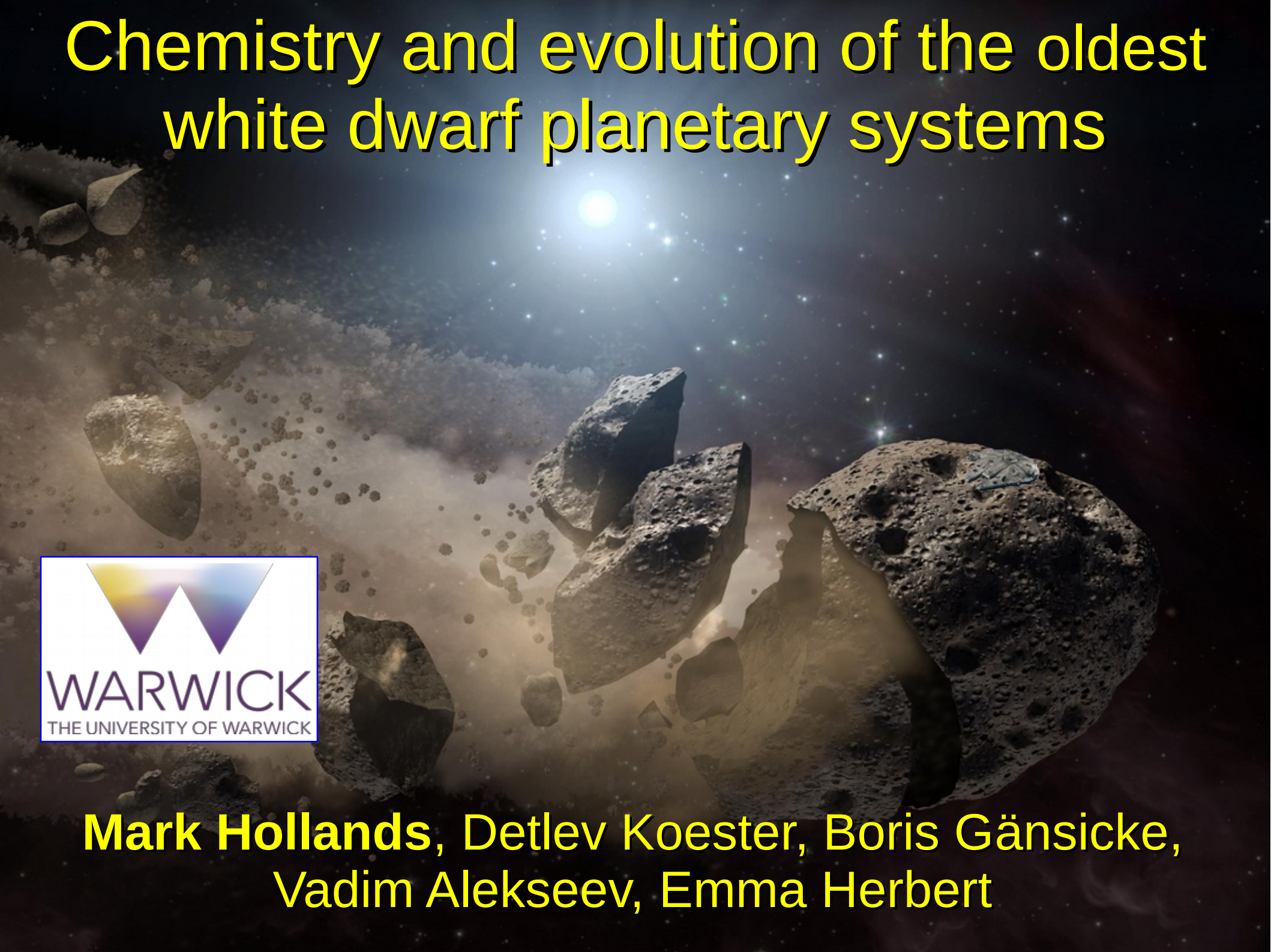
Chemistry and evolution of the oldest white dwarf planetary systems



Mark Hollands, Detlev Koester, Boris Gänsicke, Vadim Alekseev, Emma Herbert

WARWICK
THE UNIVERSITY OF WARWICK

Talk outline

- DZ white dwarfs
- Chemical analysis
- Ca-rich and Fe-rich outliers
- Evolution of WD planetary systems

Image credit: NASA/JPL-Caltech/UCLA

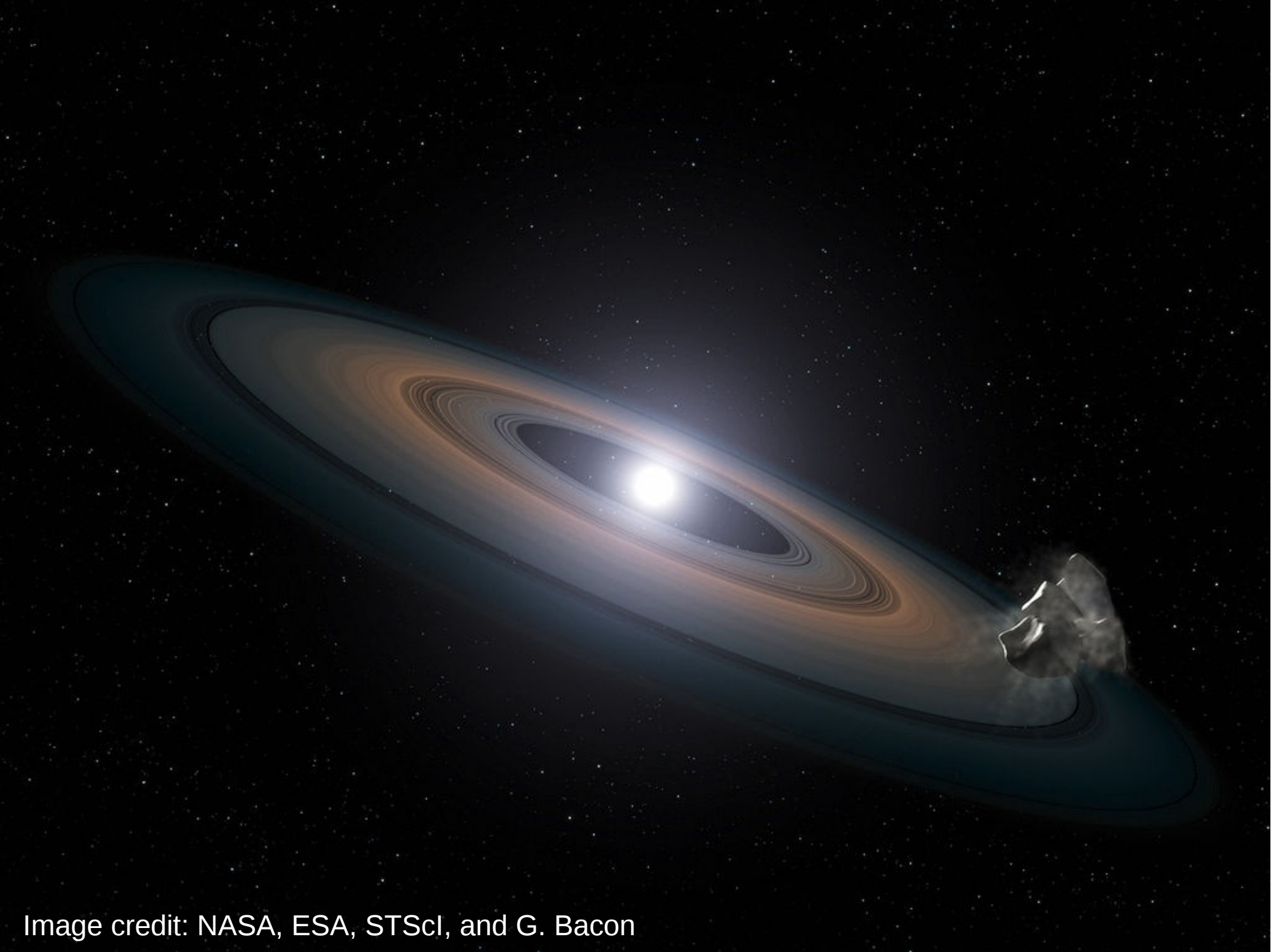
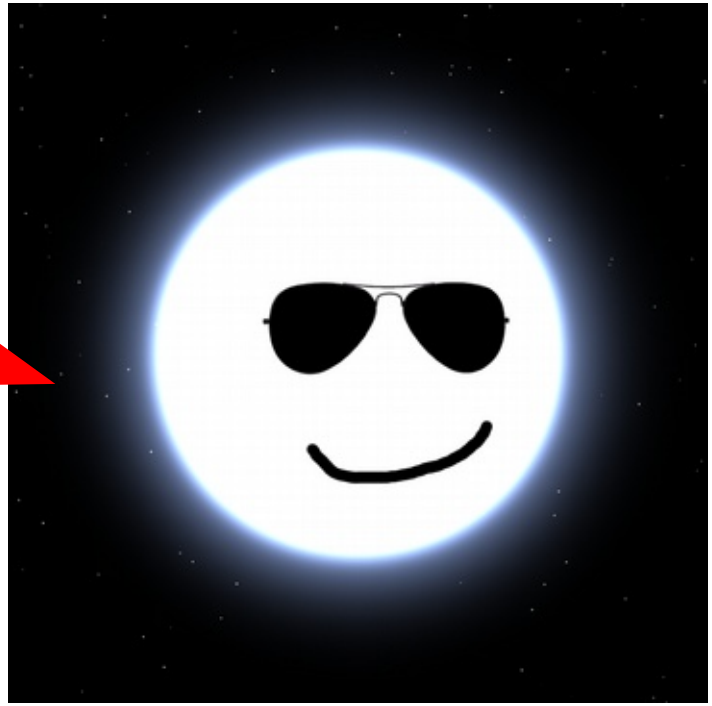


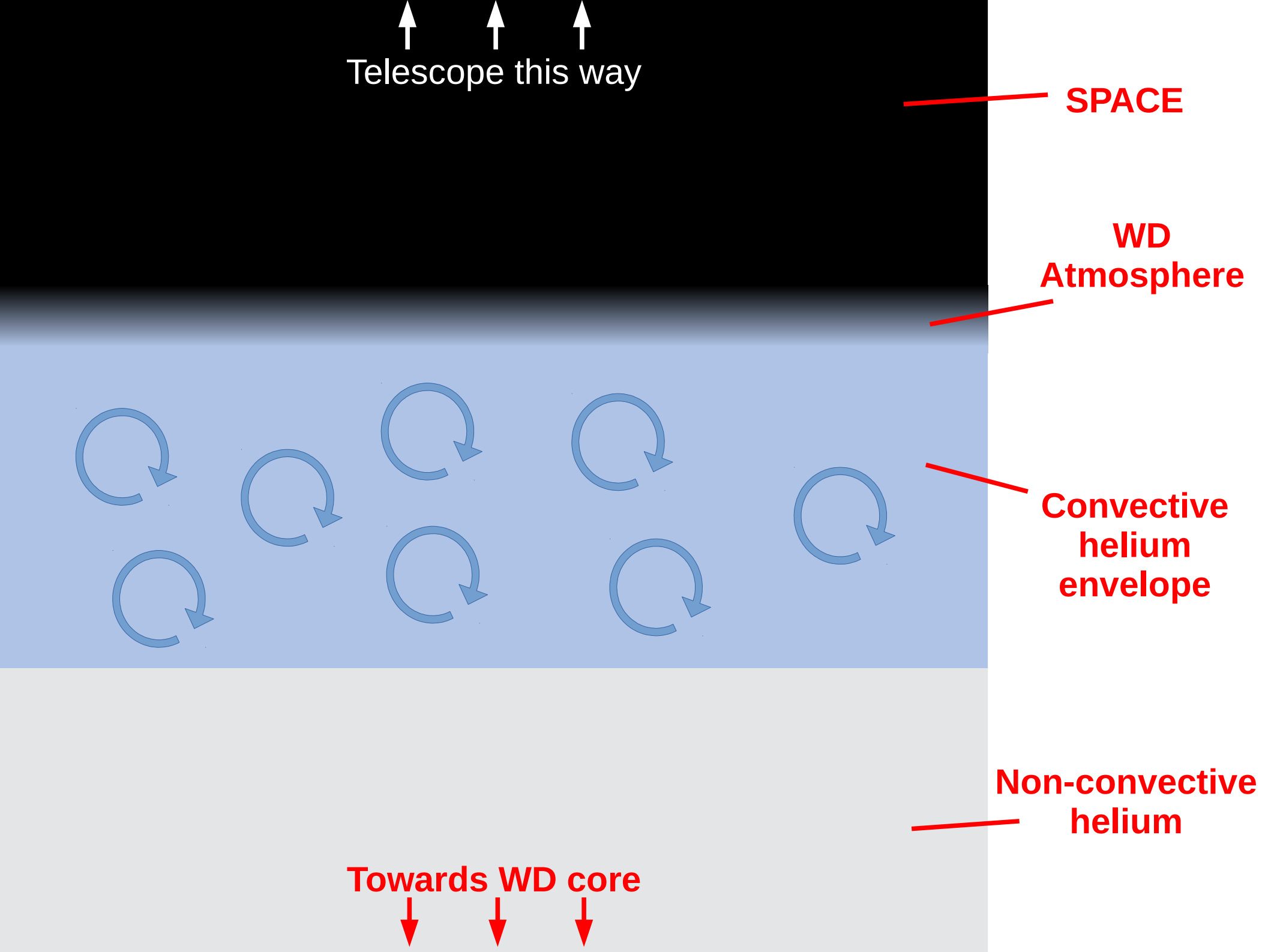
Image credit: NASA, ESA, STScI, and G. Bacon

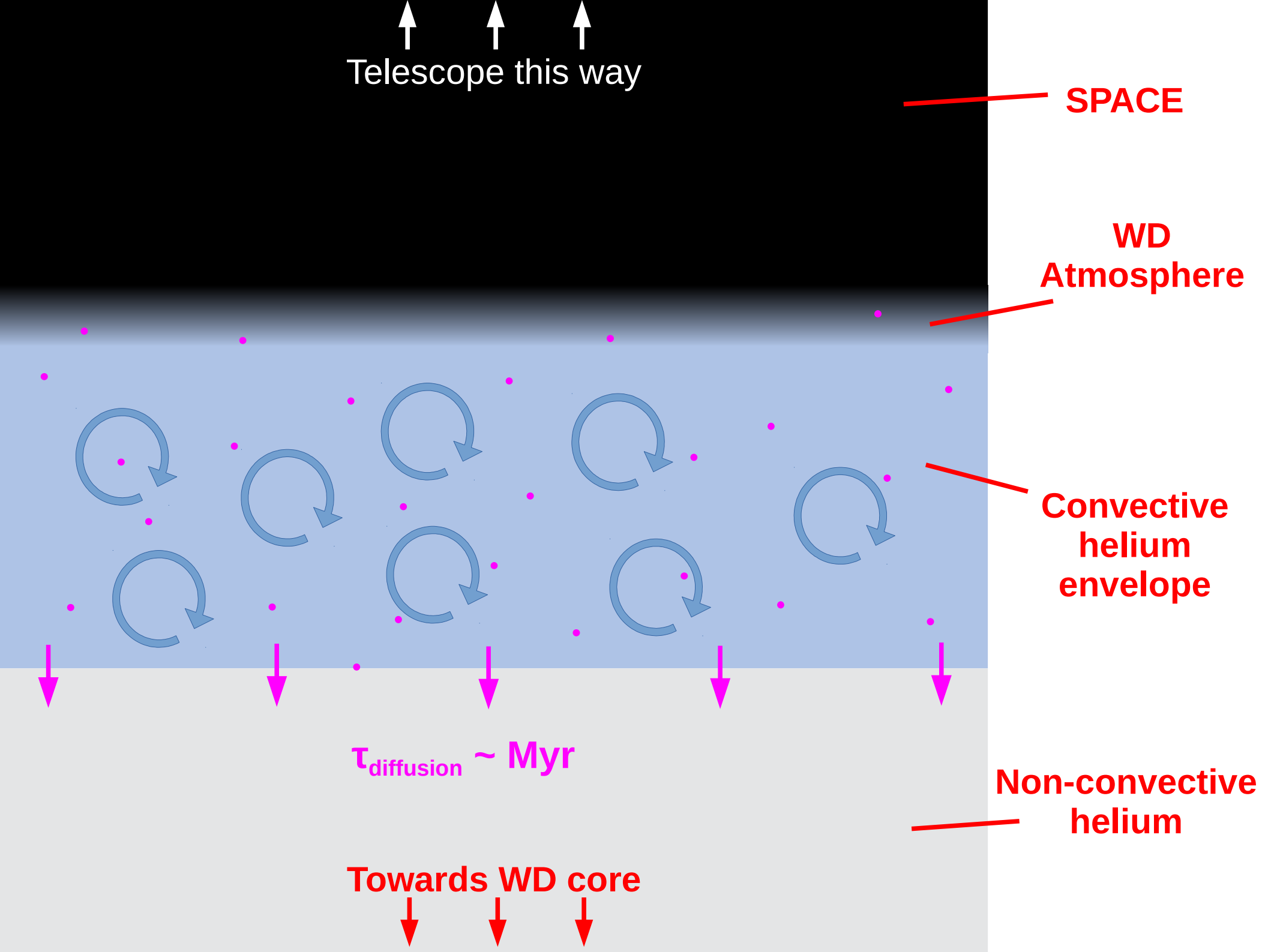
Cool DZ white dwarfs

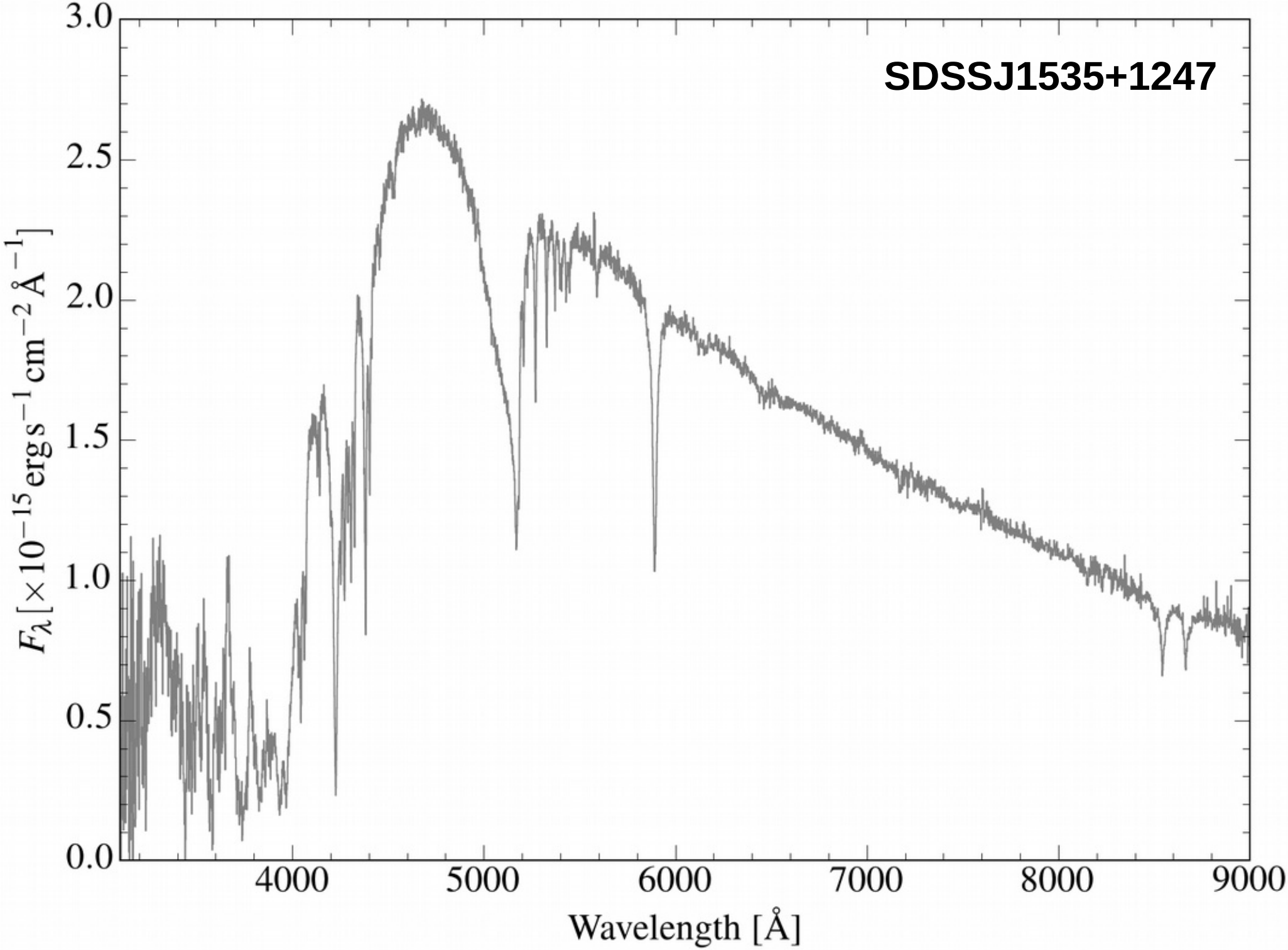
- Only metal lines in spectra
- Helium-dominated atmospheres
- Cool (Teff < 12000K)

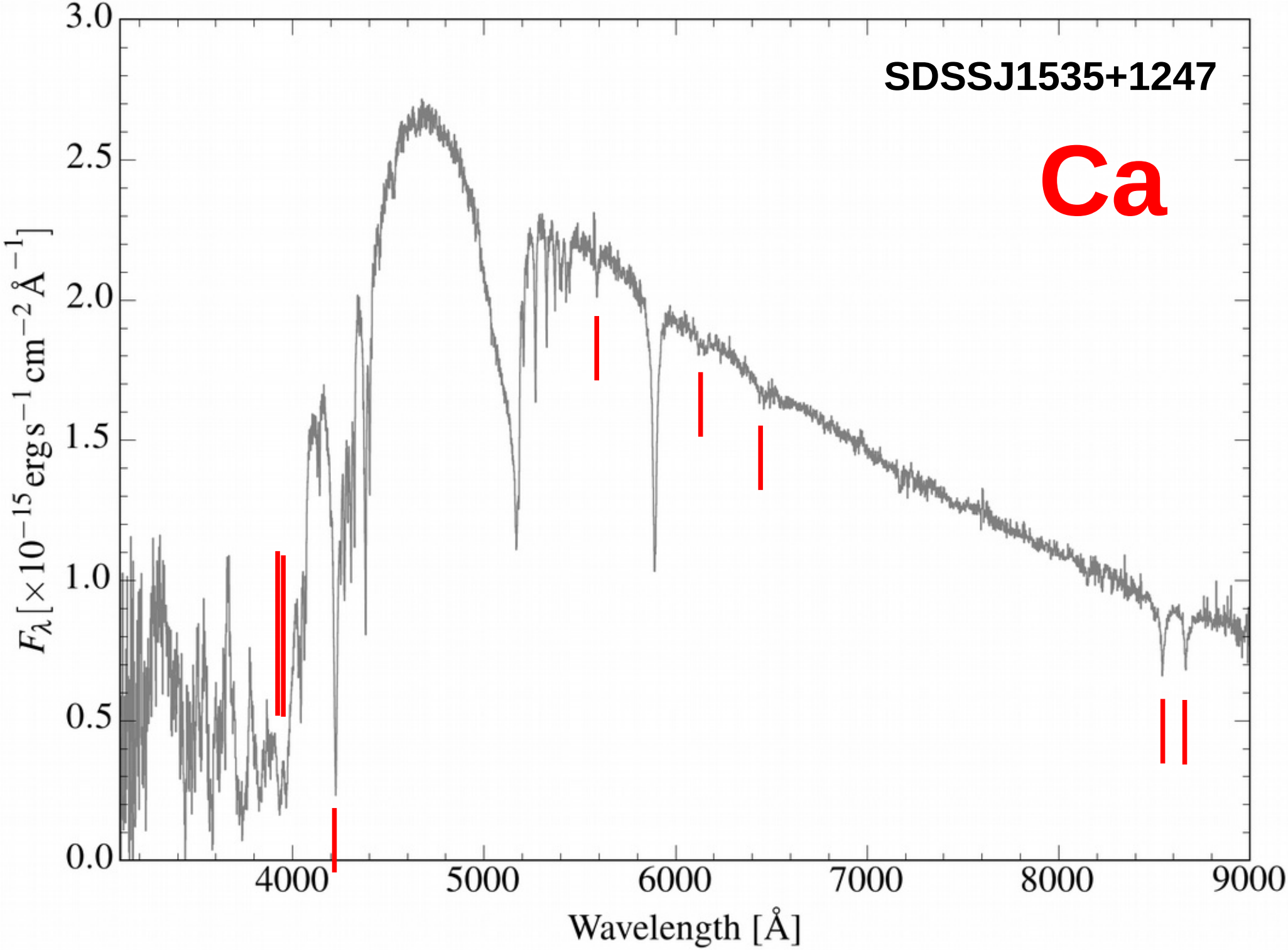
“artist's” impression of a cool DZ WD

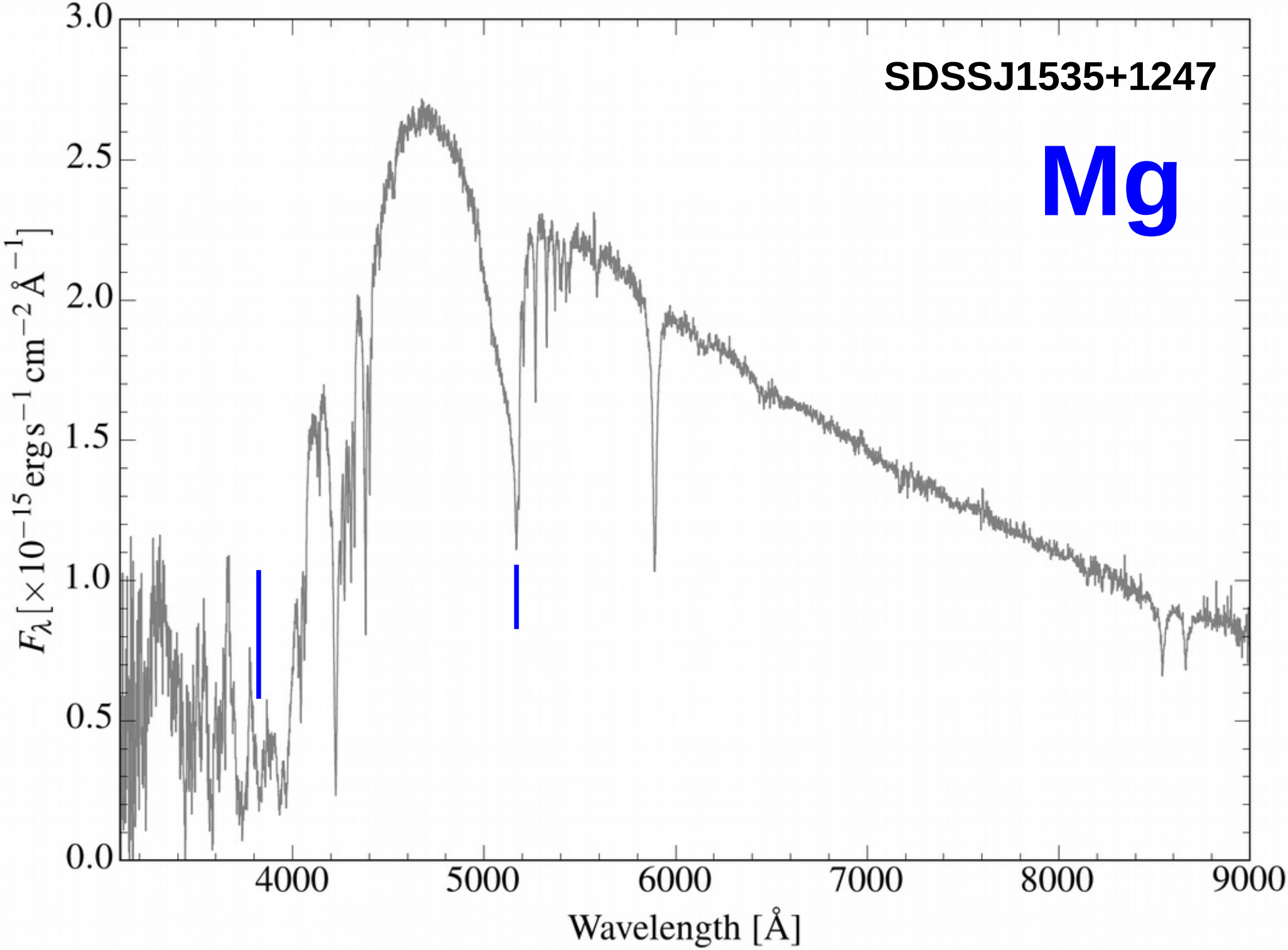


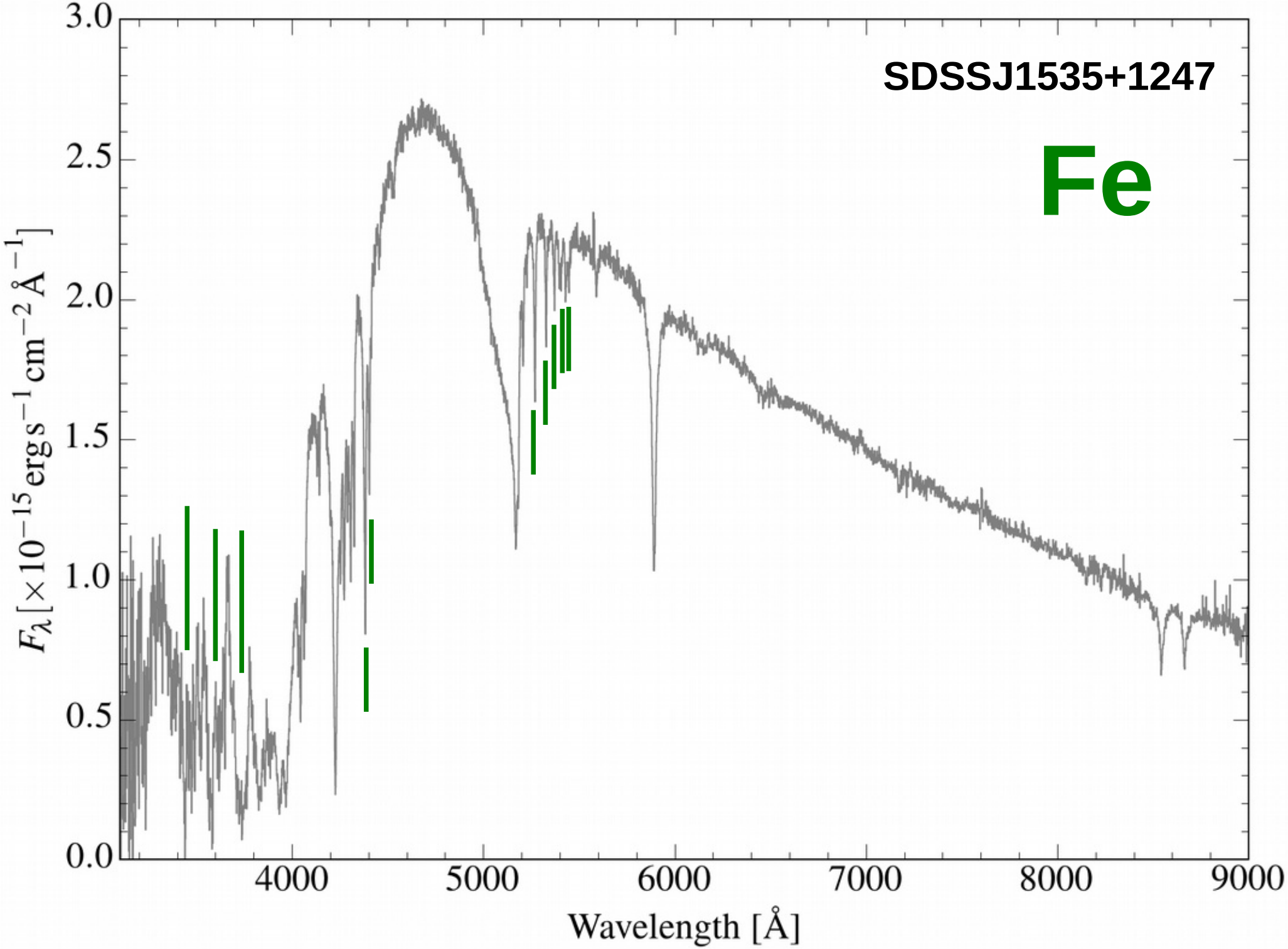

Telescope this way
SPACE
WD
Atmosphere
Convective
helium
envelope
Non-convective
helium
Towards WD core

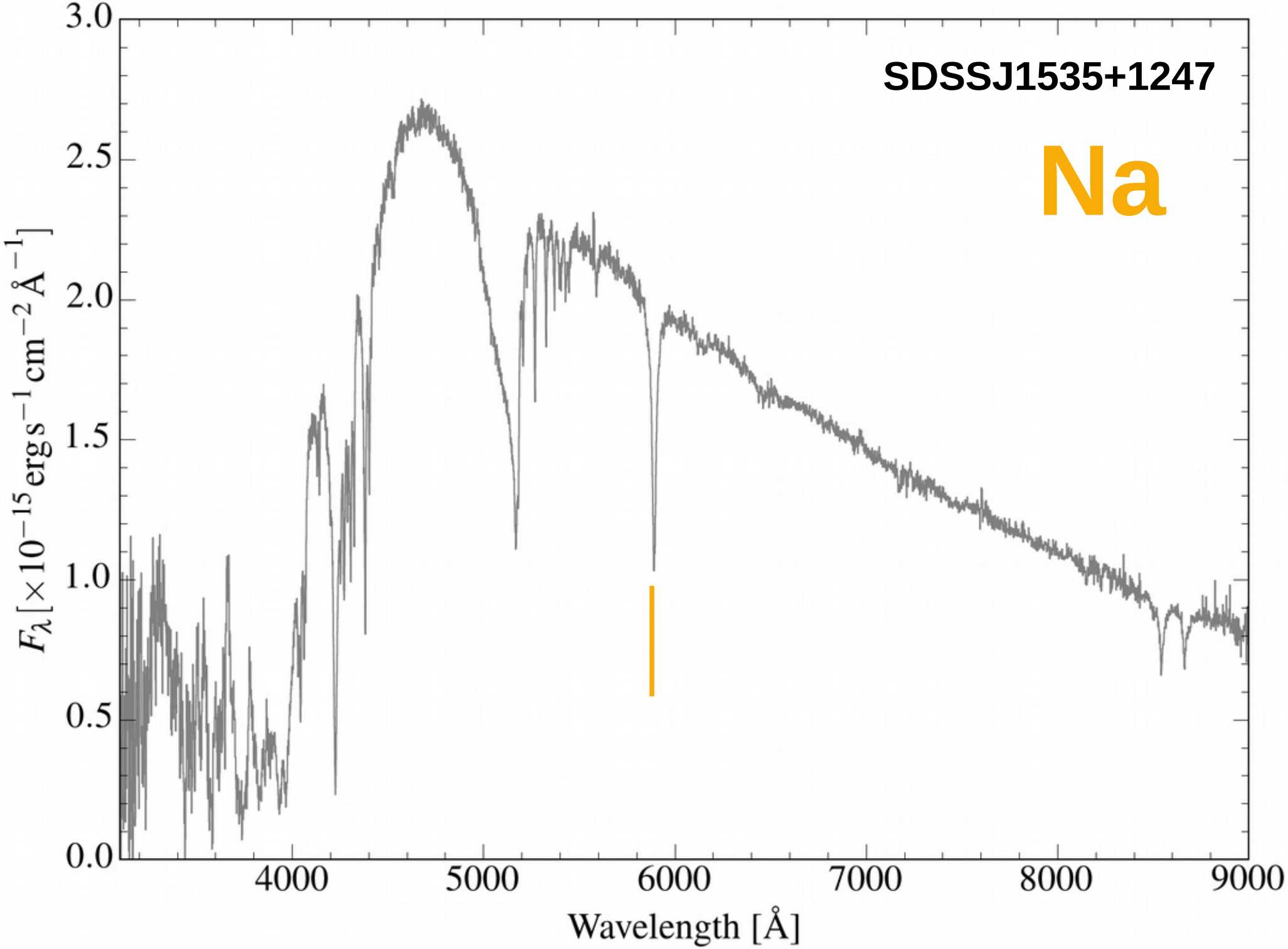

Telescope this way
SPACE
WD
Atmosphere
Convective
helium
envelope
$\tau_{diffusion}$ ~ Myr
Non-convective
helium
Towards WD core

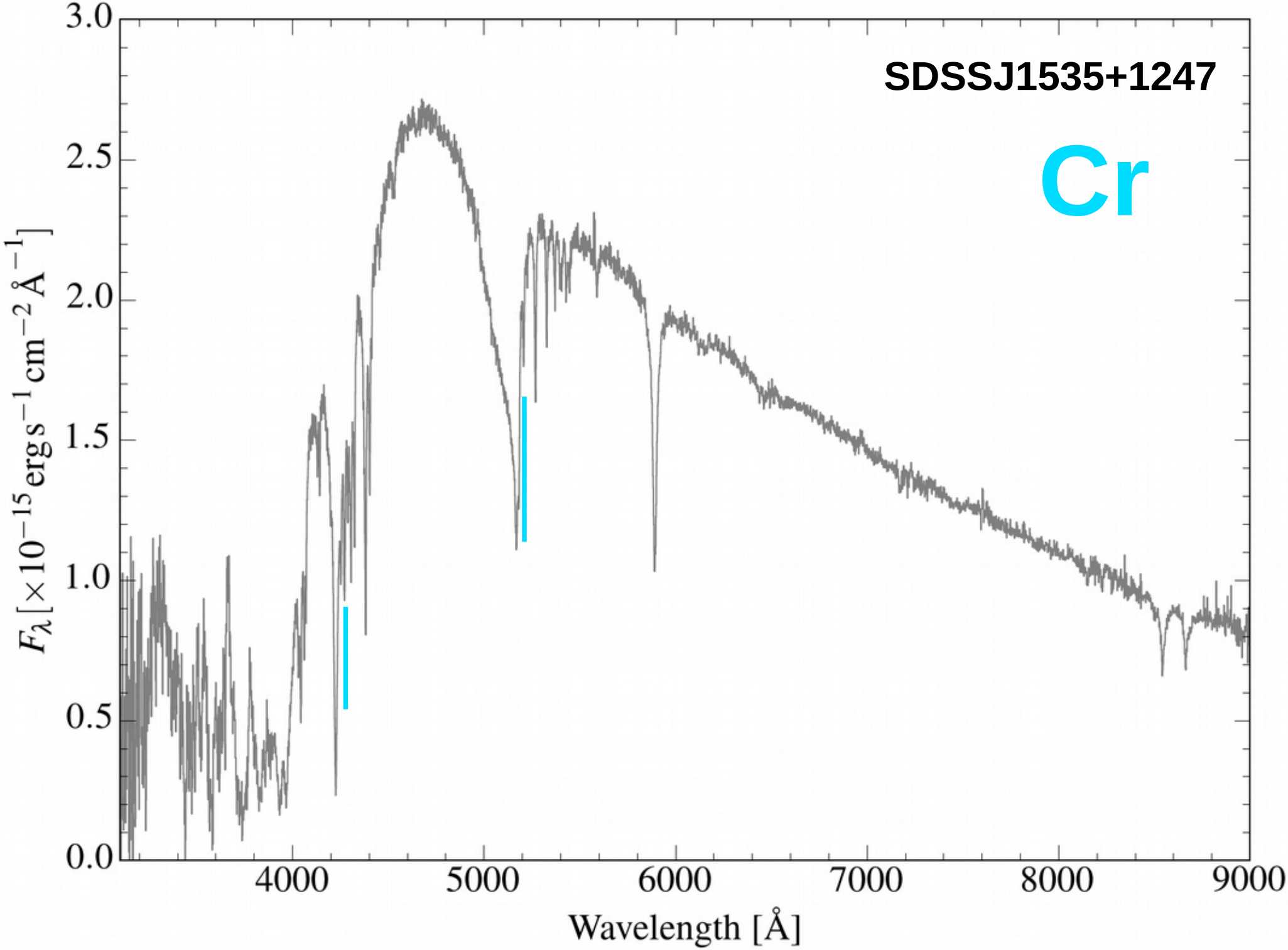

SDSSJ1535+1247
3.0
2.5
2.0
1.5
1.0
0.5
0.0
$F_\lambda [\times 10^{-15} \mathrm{erg\,s^{-1}\,cm^{-2}\,Å^{-1}}]$
4000
5000
6000
7000
8000
9000
Wavelength [Å]

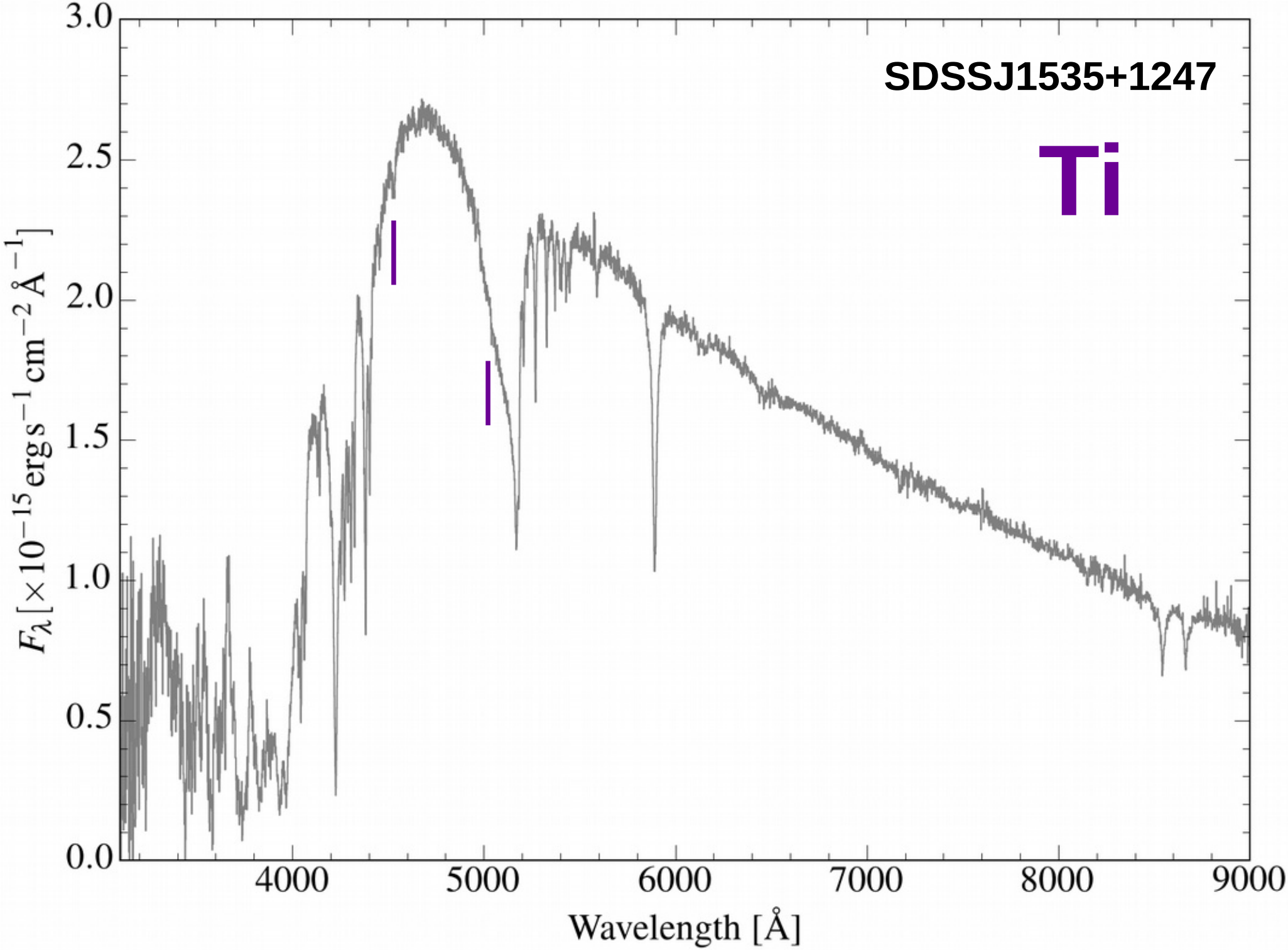

SDSSJ1535+1247
Ca
3.0
2.5
2.0
1.5
1.0
0.5
0.0
$F_\lambda [\times 10^{-15} \mathrm{erg\,s^{-1}\,cm^{-2}\,Å^{-1}}]$
4000
5000
6000
7000
8000
9000
Wavelength [Å]

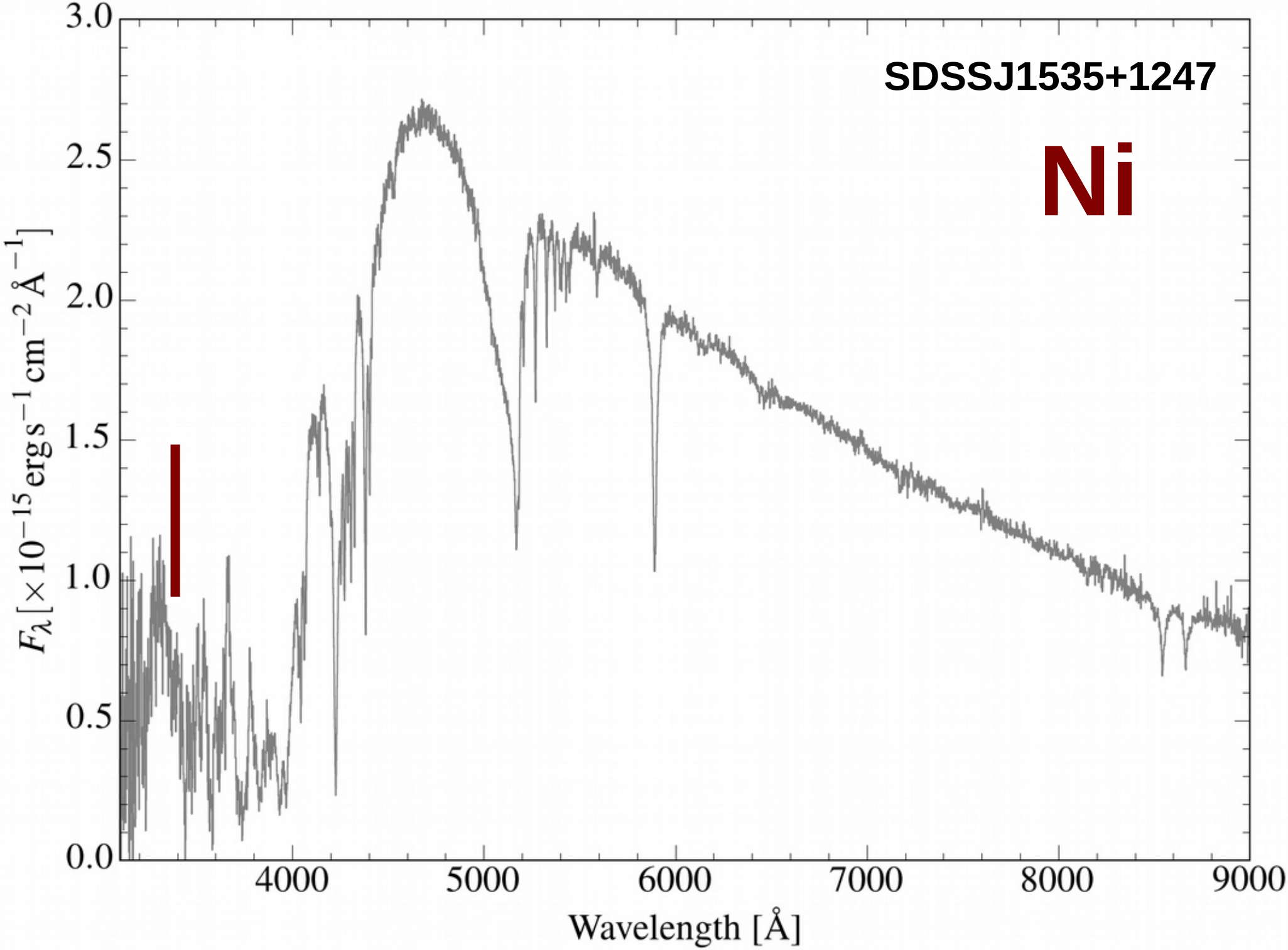

SDSSJ1535+1247
Mg
3.0
2.5
2.0
1.5
1.0
0.5
0.0
$F_\lambda [\times 10^{-15} \mathrm{erg\,s^{-1}\,cm^{-2}\,Å^{-1}}]$
4000
5000
6000
7000
8000
9000
Wavelength [Å]

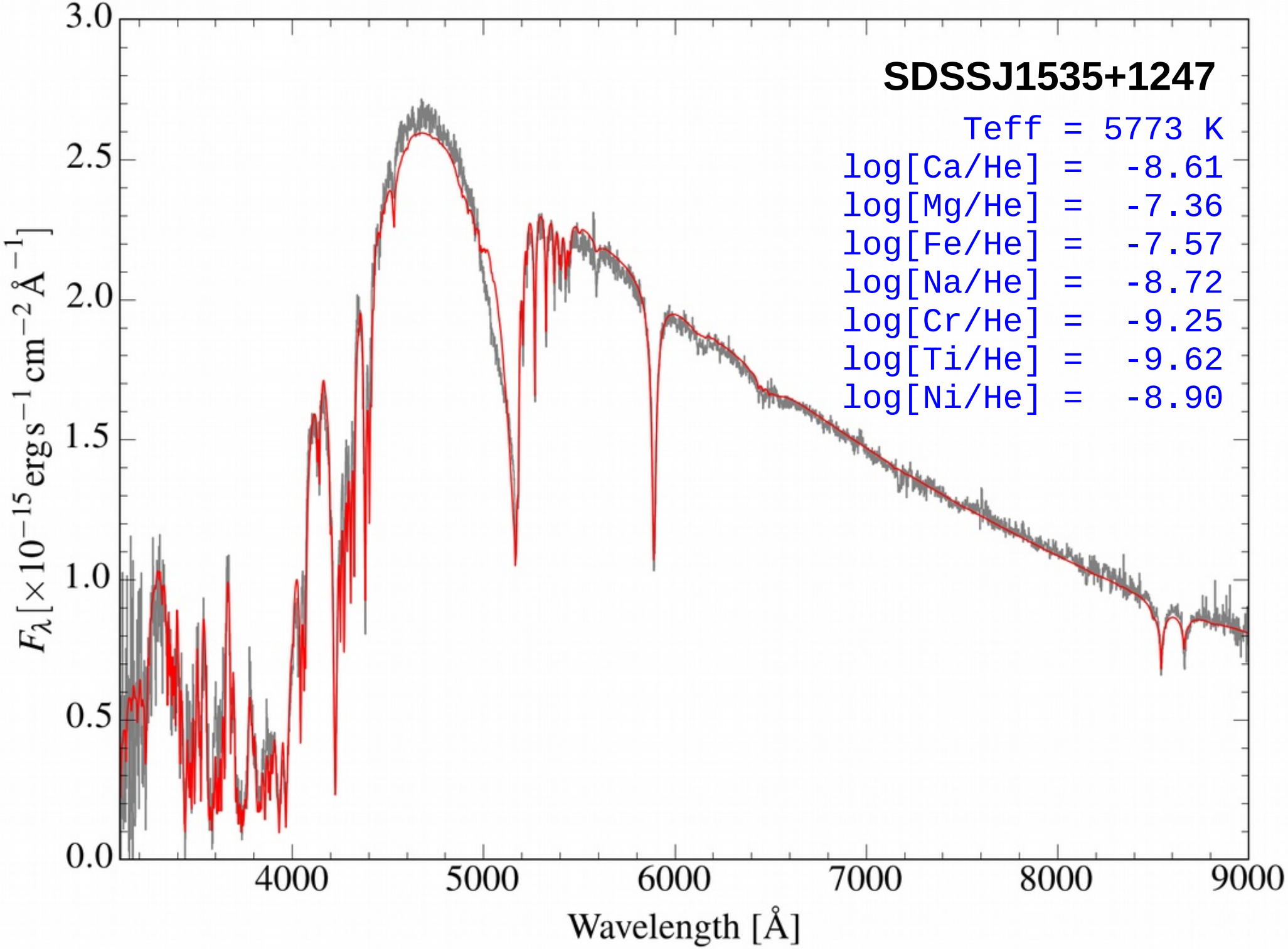

SDSSJ1535+1247
Fe
3.0
2.5
2.0
1.5
1.0
0.5
0.0
$F_\lambda [\times 10^{-15} \mathrm{erg\,s^{-1}\,cm^{-2}\,Å^{-1}}]$
4000
5000
6000
7000
8000
9000
Wavelength [Å]

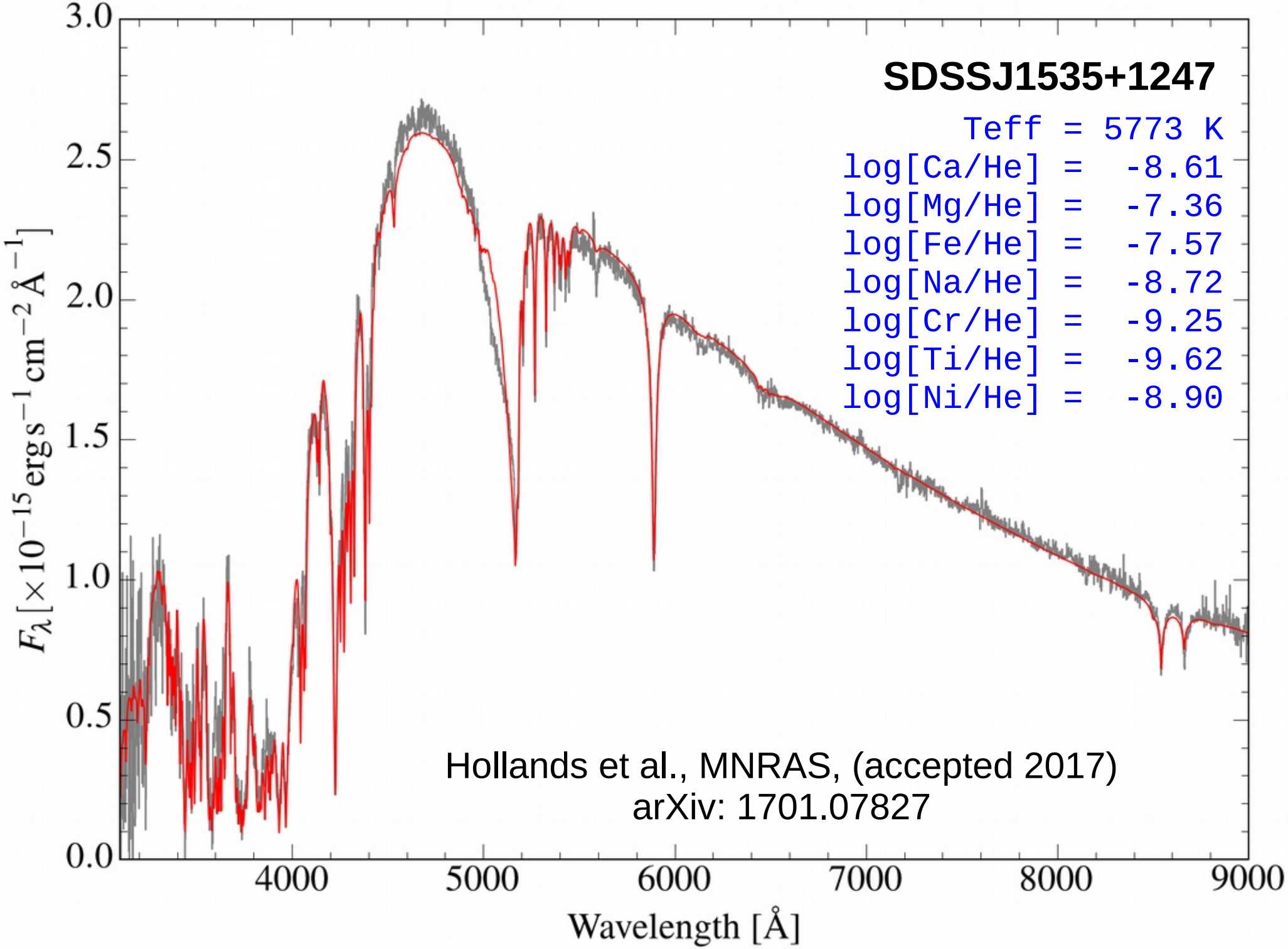

SDSSJ1535+1247
Na
3.0
2.5
2.0
1.5
1.0
0.5
0.0
$F_\lambda [\times 10^{-15} \mathrm{erg\,s^{-1}\,cm^{-2}\,Å^{-1}}]$
4000
5000
6000
7000
8000
9000
Wavelength [Å]


SDSSJ1535+1247
Cr
3.0
2.5
2.0
1.5
1.0
0.5
0.0
$F_\lambda [\times 10^{-15} \mathrm{erg\,s^{-1}\,cm^{-2}\,Å^{-1}}]$
4000
5000
6000
7000
8000
9000
Wavelength [Å]


SDSSJ1535+1247
Ti
3.0
2.5
2.0
1.5
1.0
0.5
0.0
$F_\lambda [\times 10^{-15} \mathrm{erg\,s^{-1}\,cm^{-2}\,Å^{-1}}]$
4000
5000
6000
7000
8000
9000
Wavelength [Å]


SDSSJ1535+1247
Ni
3.0
2.5
2.0
1.5
1.0
0.5
0.0
$F_\lambda [\times 10^{-15} \mathrm{erg\,s^{-1}\,cm^{-2}\,Å^{-1}}]$
4000
5000
6000
7000
8000
9000
Wavelength [Å]


SDSSJ1535+1247
Teff = 5773 K
log[Ca/He] = -8.61
log[Mg/He] = -7.36
log[Fe/He] = -7.57
log[Na/He] = -8.72
log[Cr/He] = -9.25
log[Ti/He] = -9.62
log[Ni/He] = -8.90
$F_\lambda [\times 10^{-15} \mathrm{erg\,s^{-1}\,cm^{-2}\,Å^{-1}}]$
Wavelength [Å]
0.0
0.5
1.0
1.5
2.0
2.5
3.0
4000
5000
6000
7000
8000
9000


SDSSJ1535+1247
Teff = 5773 K
log[Ca/He] = -8.61
log[Mg/He] = -7.36
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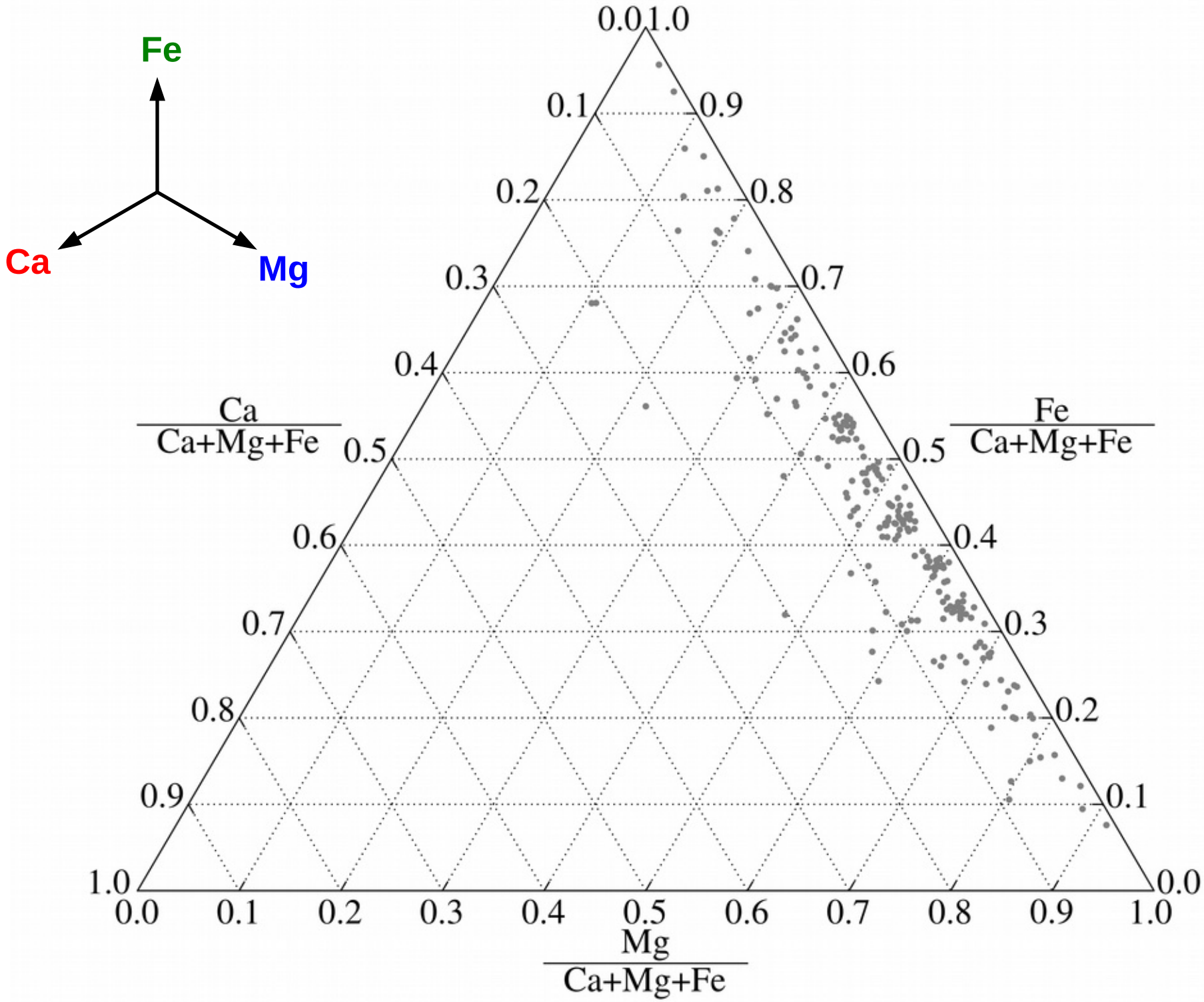
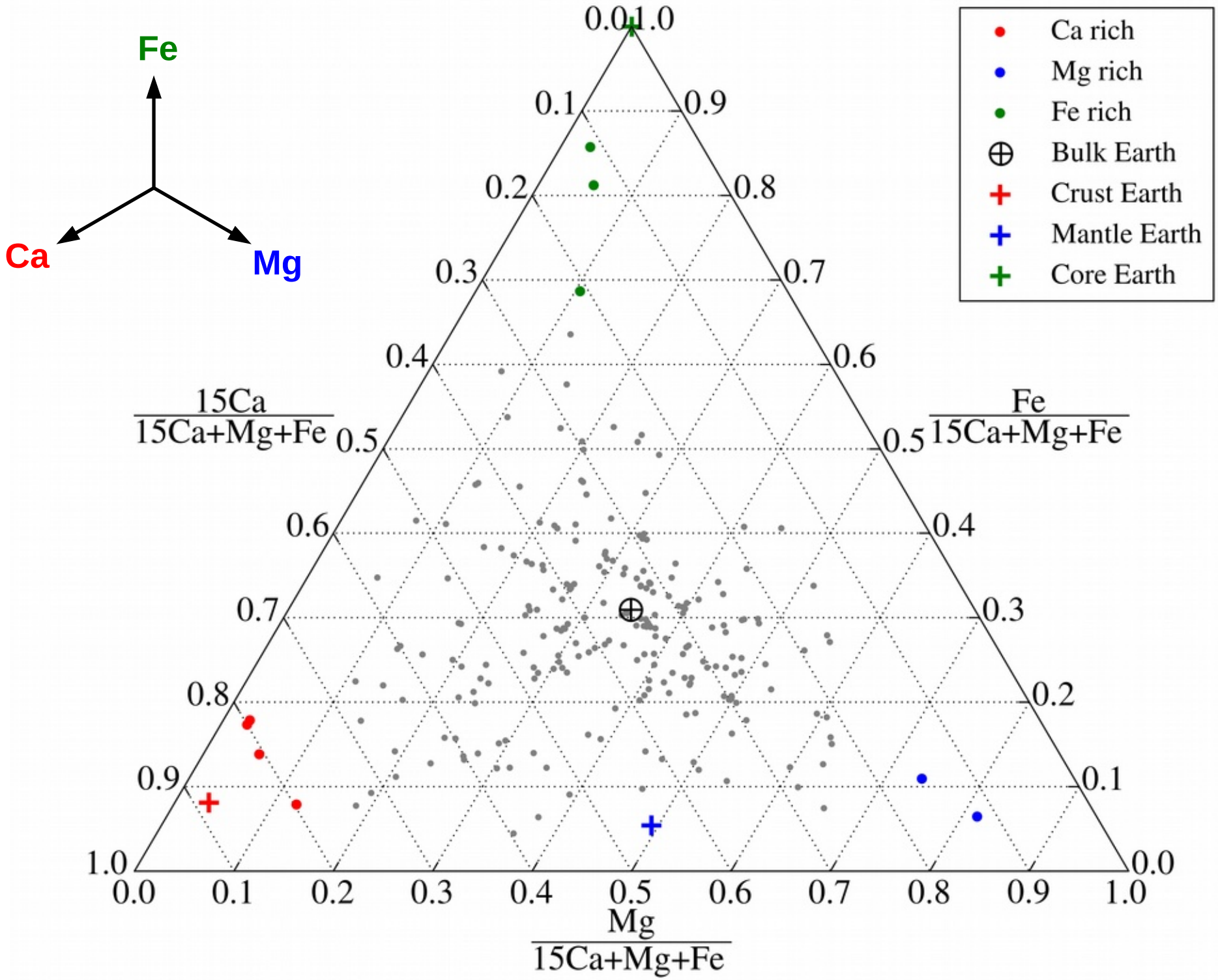
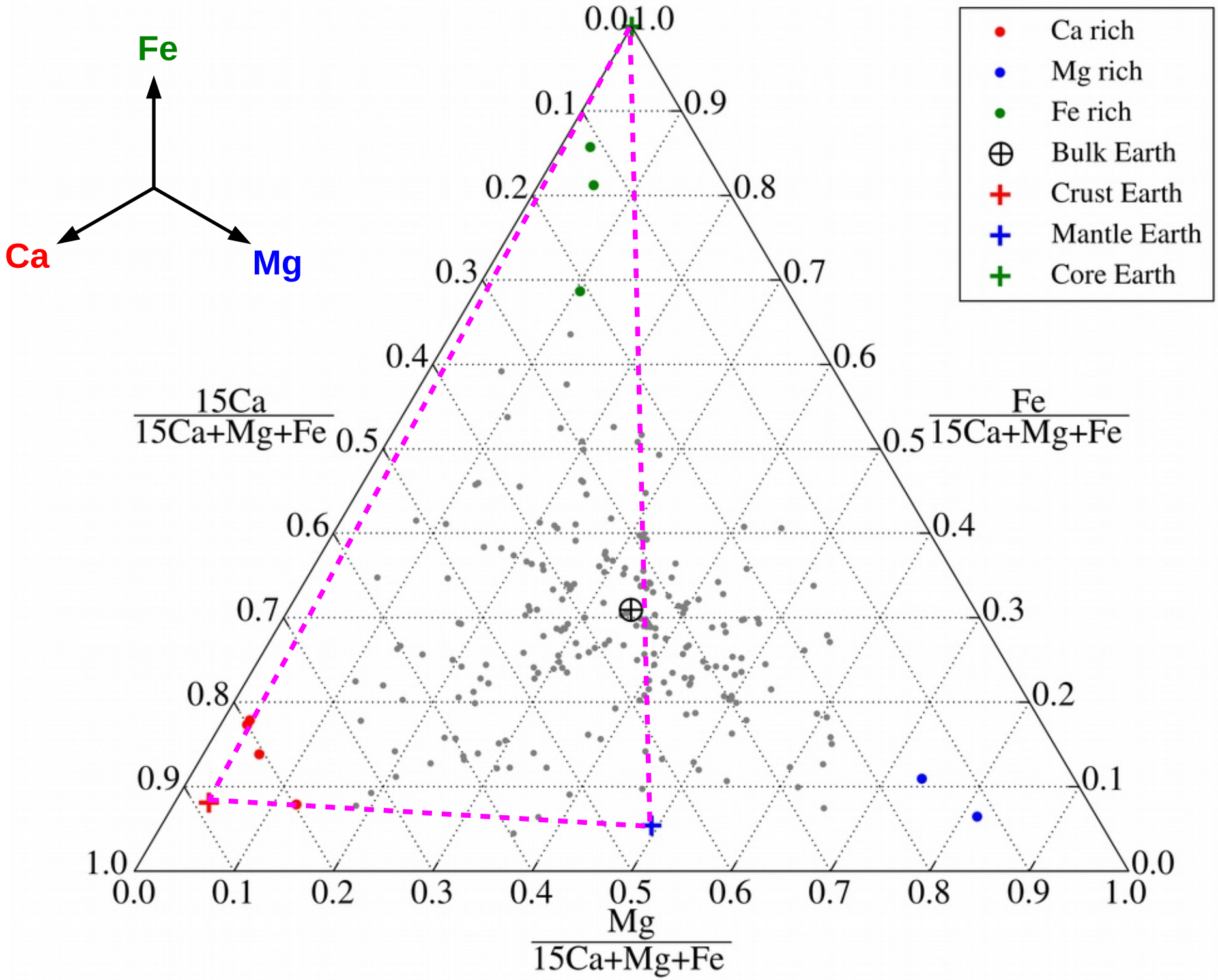
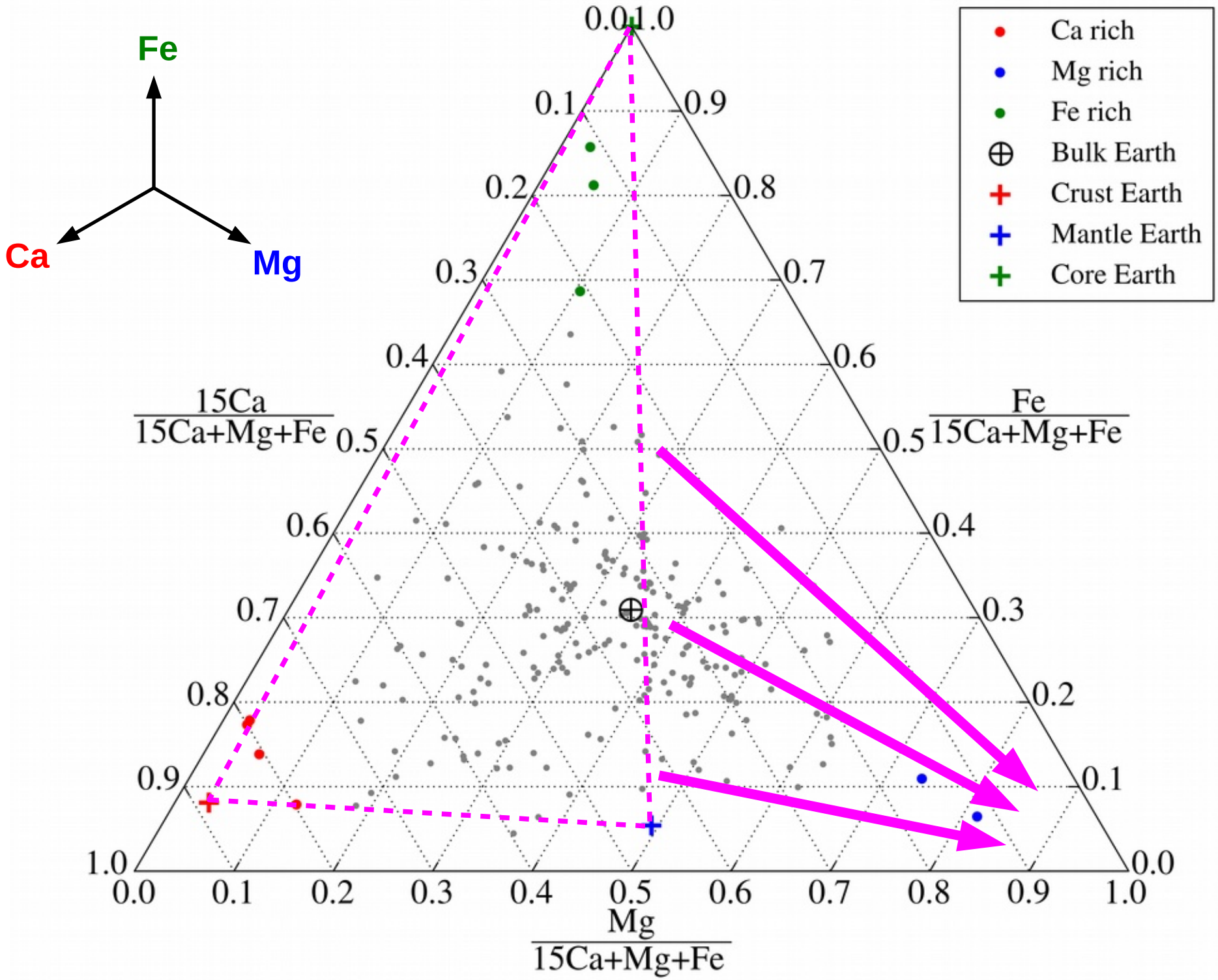
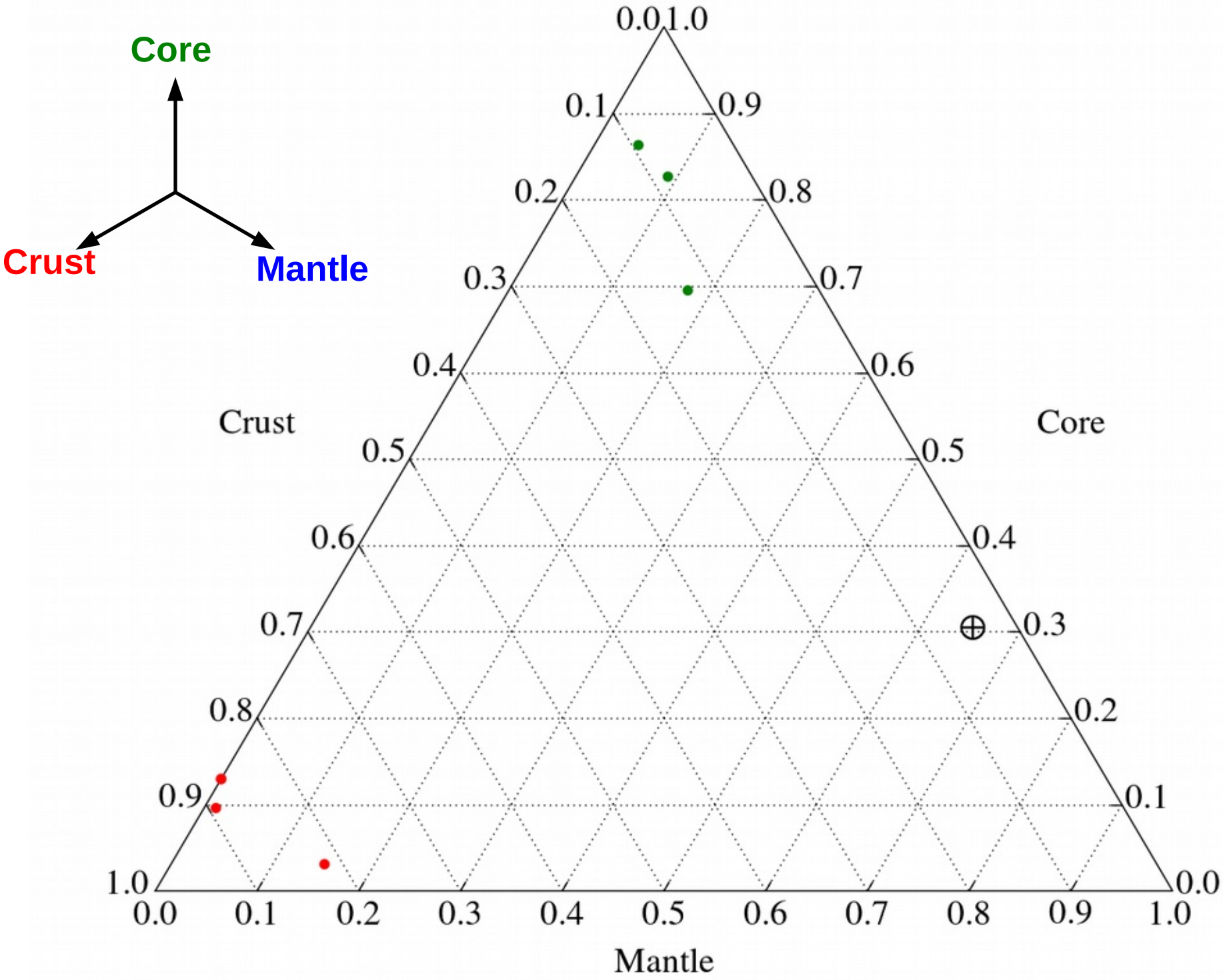
log[Na/He] = -8.72
log[Cr/He] = -9.25
log[Ti/He] = -9.62
log[Ni/He] = -8.90
Hollands et al., MNRAS, (accepted 2017)
arXiv: 1701.07827
$F_\lambda [\times 10^{-15} \mathrm{erg\,s^{-1}\,cm^{-2}\,Å^{-1}}]$
Wavelength [Å]
0.0
0.5
1.0
1.5
2.0
2.5
3.0
4000
5000
6000
7000
8000
9000

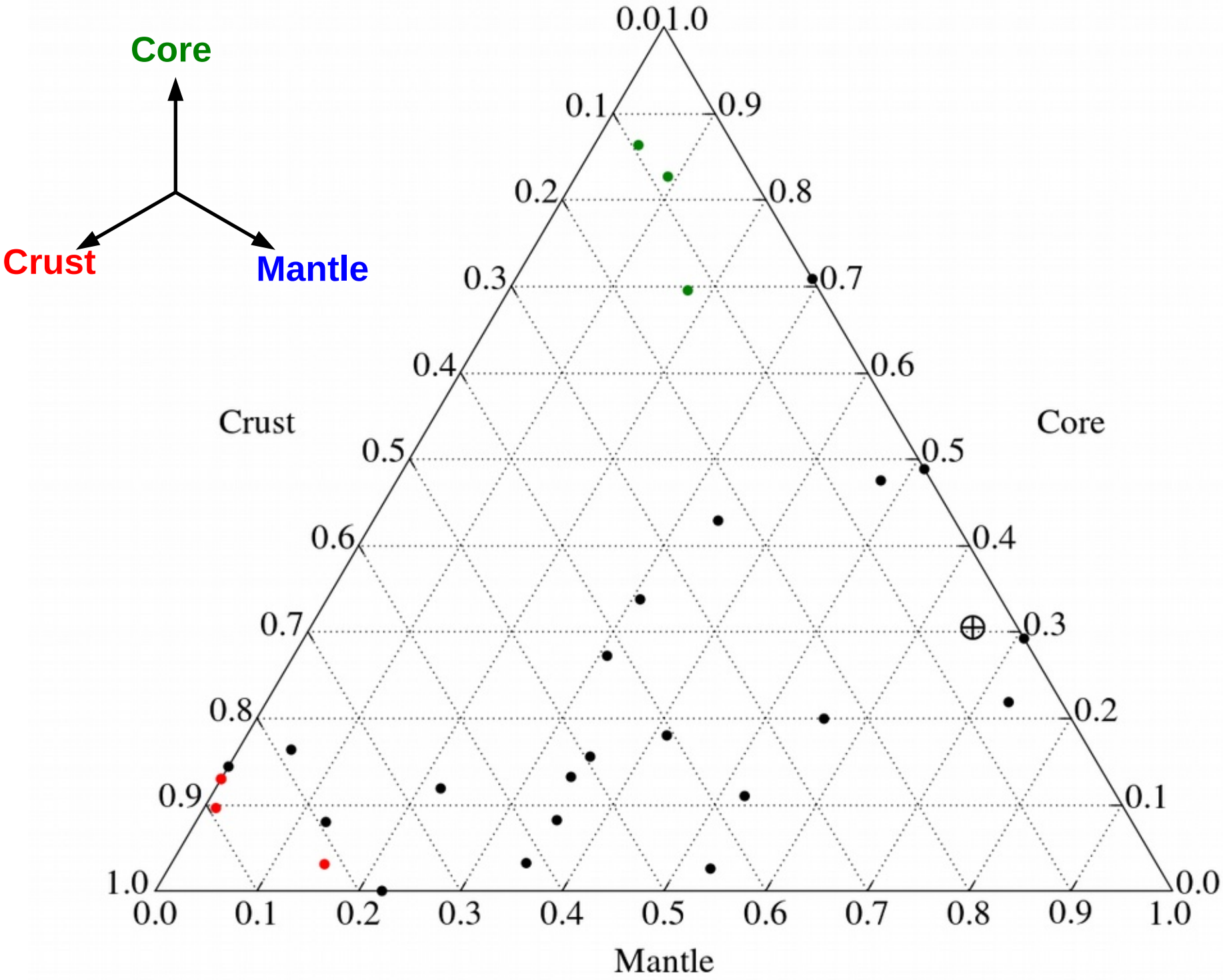

Fe
Ca
Mg
Ca / Ca+Mg+Fe
Fe / Ca+Mg+Fe
Mg / Ca+Mg+Fe
0.0 1.0
0.1 0.9
0.2 0.8
0.3 0.7
0.4 0.6
0.5 0.5
0.6 0.4
0.7 0.3
0.8 0.2
0.9 0.1
1.0 0.0
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

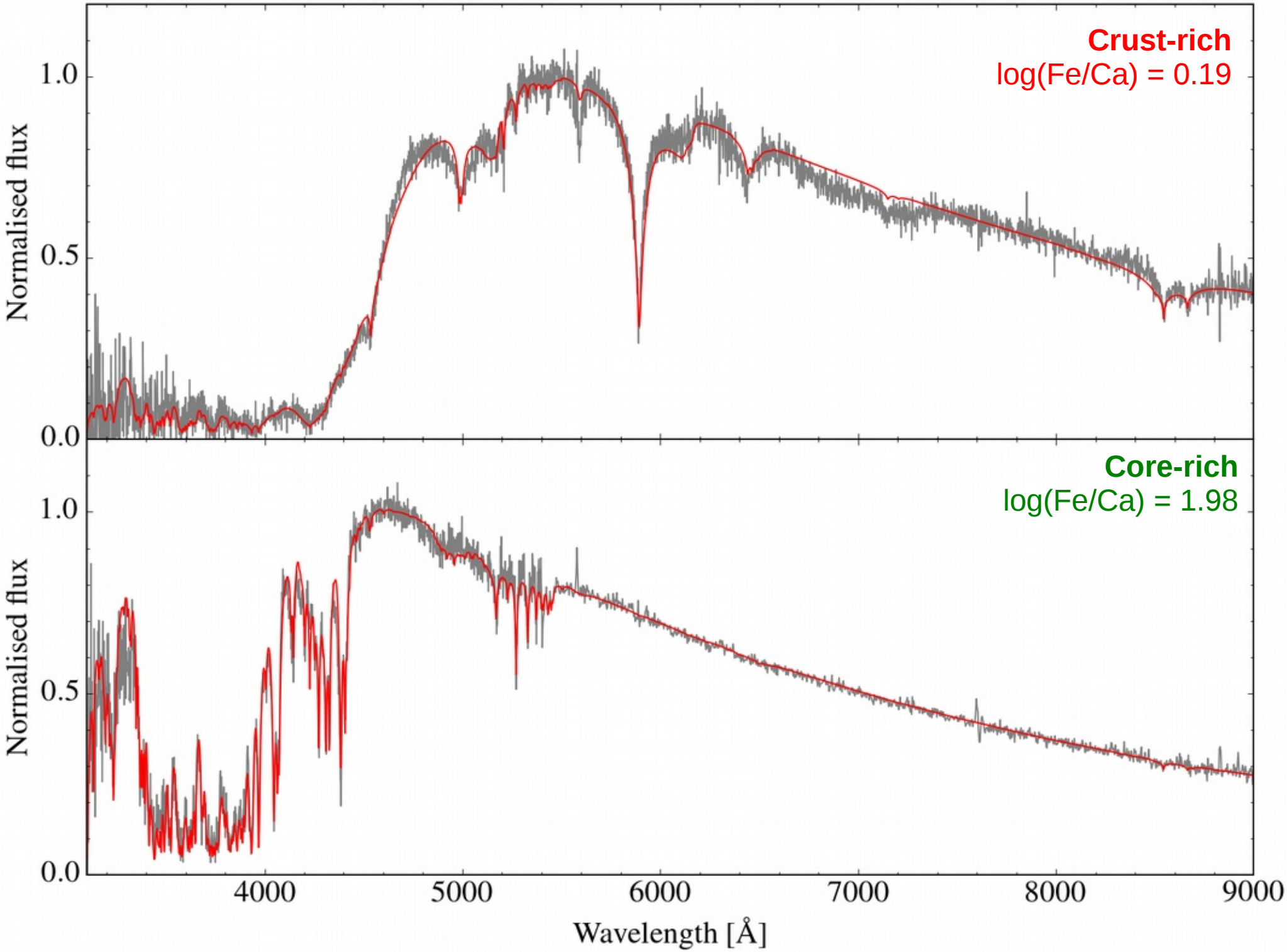

Fe
Ca
Mg
Ca rich
Mg rich
Fe rich
Bulk Earth
Crust Earth
Mantle Earth
Core Earth
15Ca / 15Ca+Mg+Fe
Fe / 15Ca+Mg+Fe
Mg / 15Ca+Mg+Fe
0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0

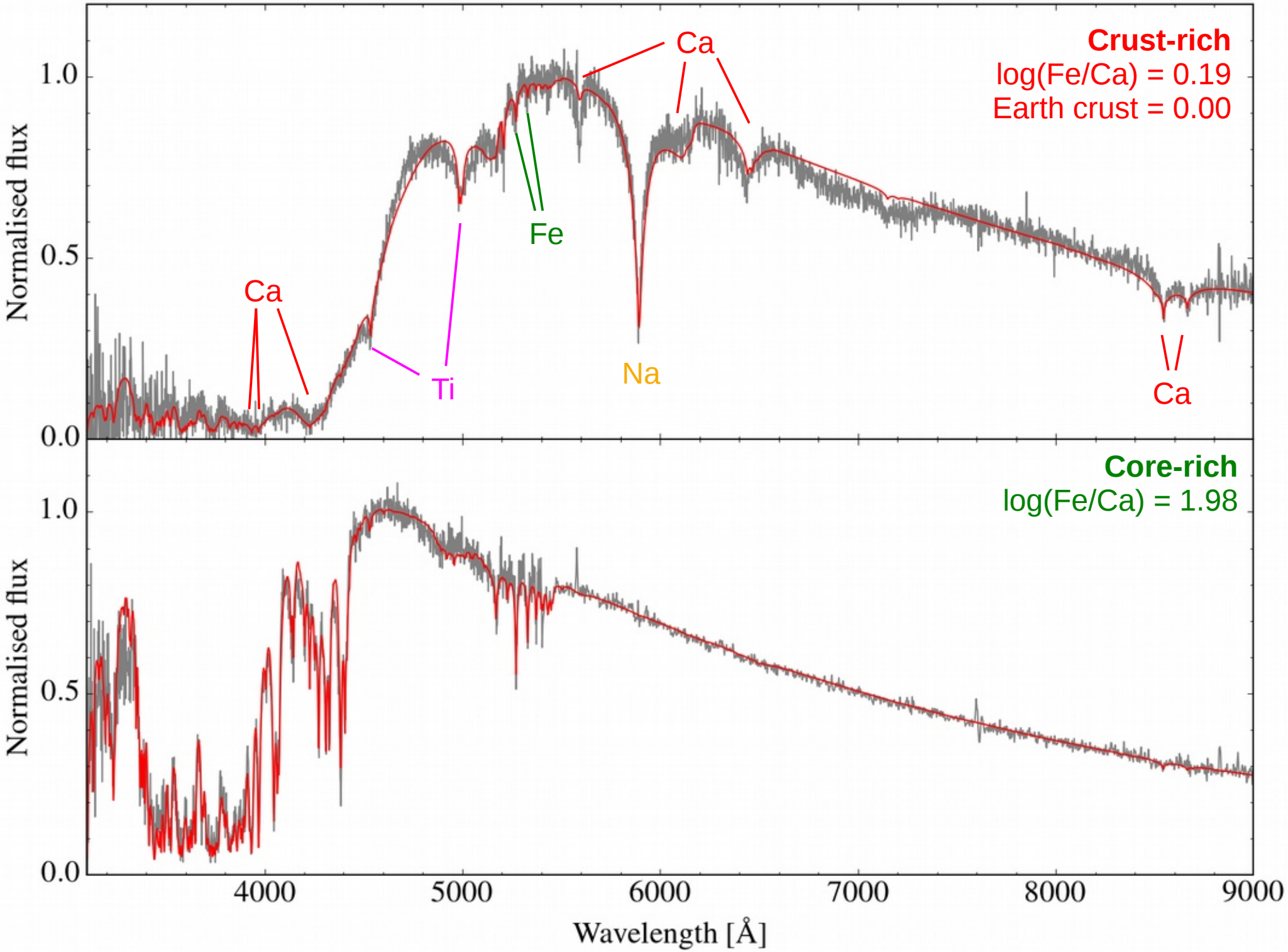

Fe
Ca
Mg
Ca rich
Mg rich
Fe rich
Bulk Earth
Crust Earth
Mantle Earth
Core Earth
15Ca / 15Ca+Mg+Fe
Fe / 15Ca+Mg+Fe
Mg / 15Ca+Mg+Fe
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

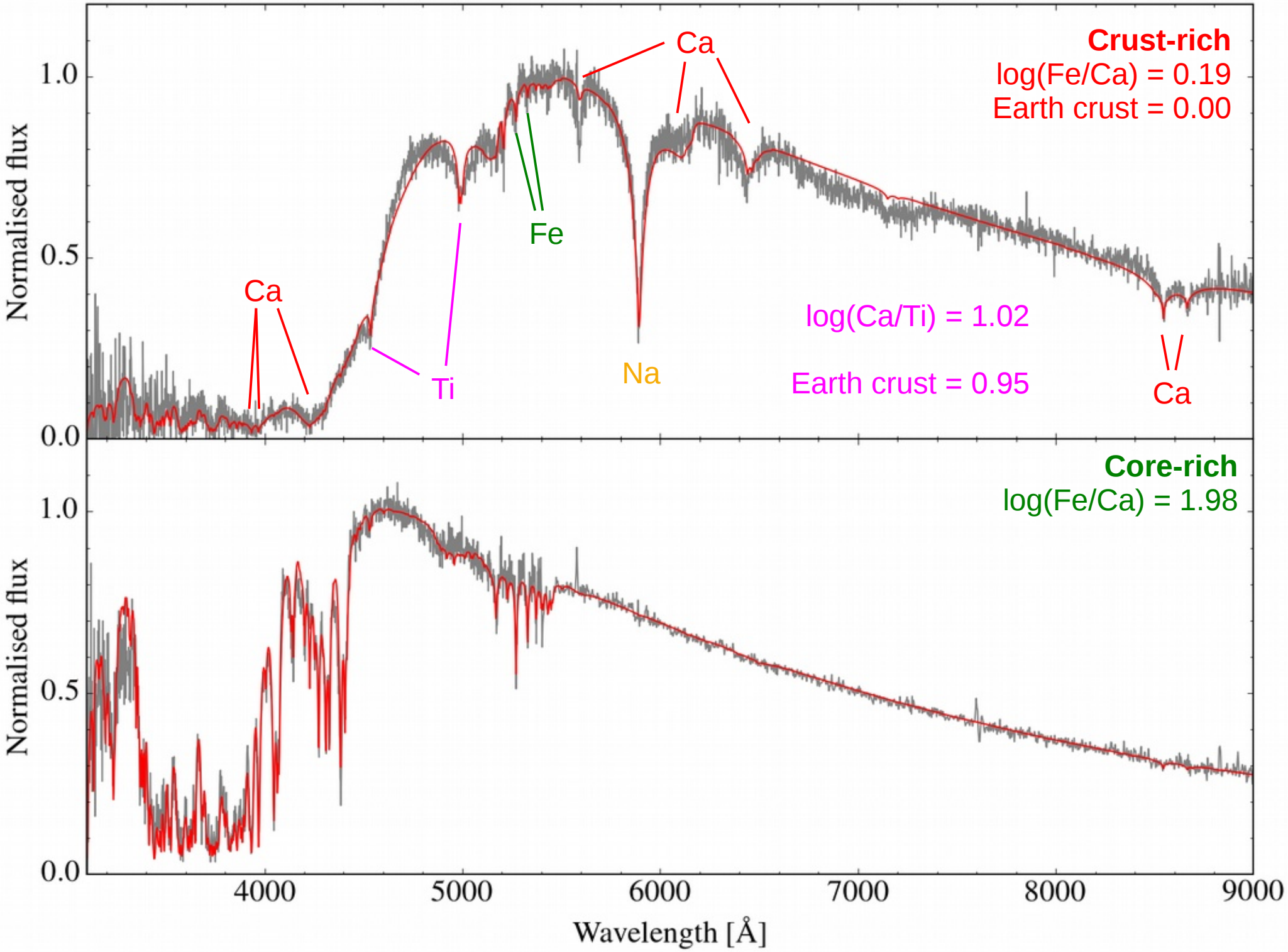

Fe
Ca
Mg
Ca rich
Mg rich
Fe rich
Bulk Earth
Crust Earth
Mantle Earth
Core Earth
15Ca / 15Ca+Mg+Fe
Fe / 15Ca+Mg+Fe
Mg / 15Ca+Mg+Fe
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

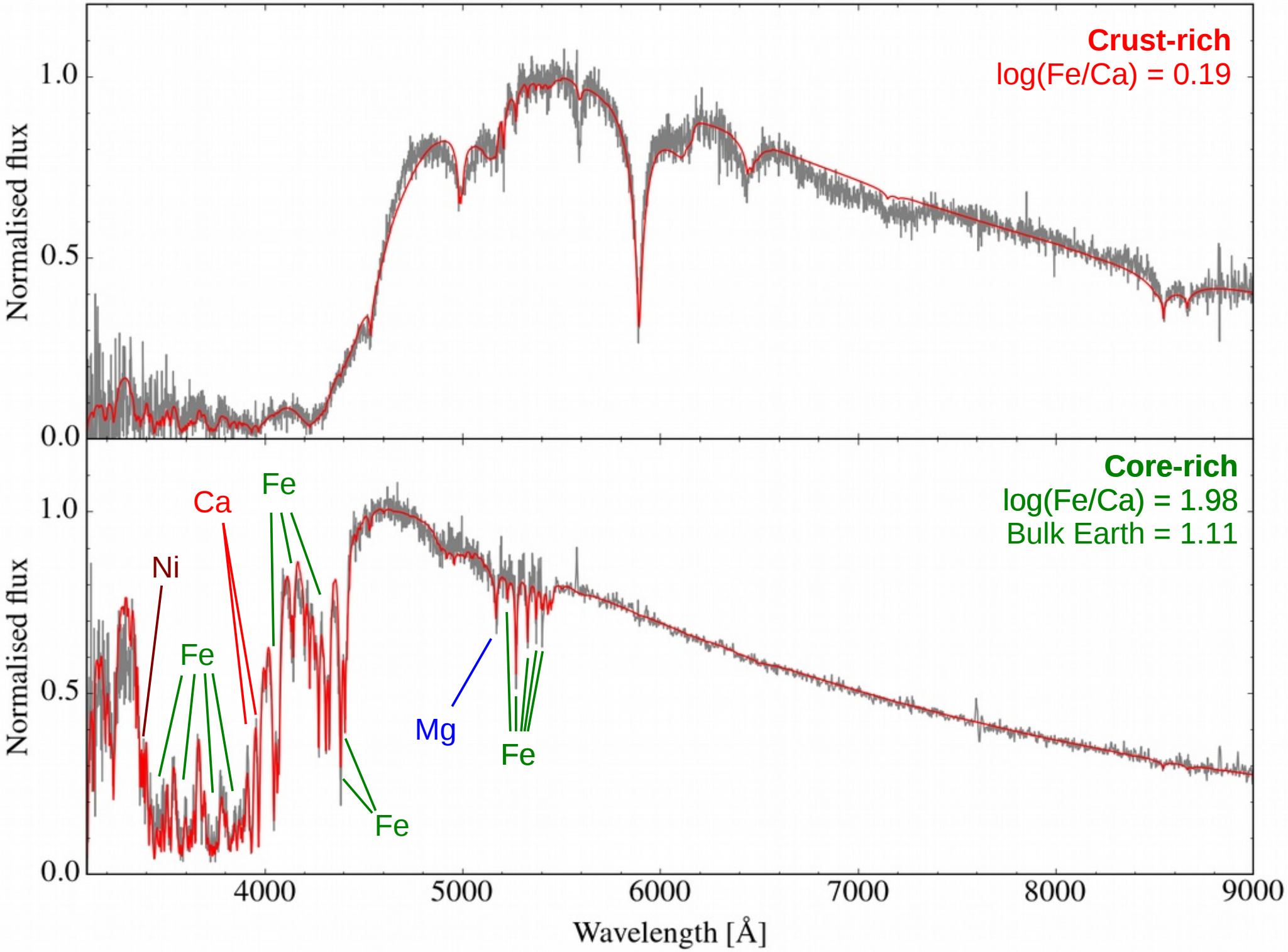

Core
Crust
Mantle
Crust
Core
Mantle
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0

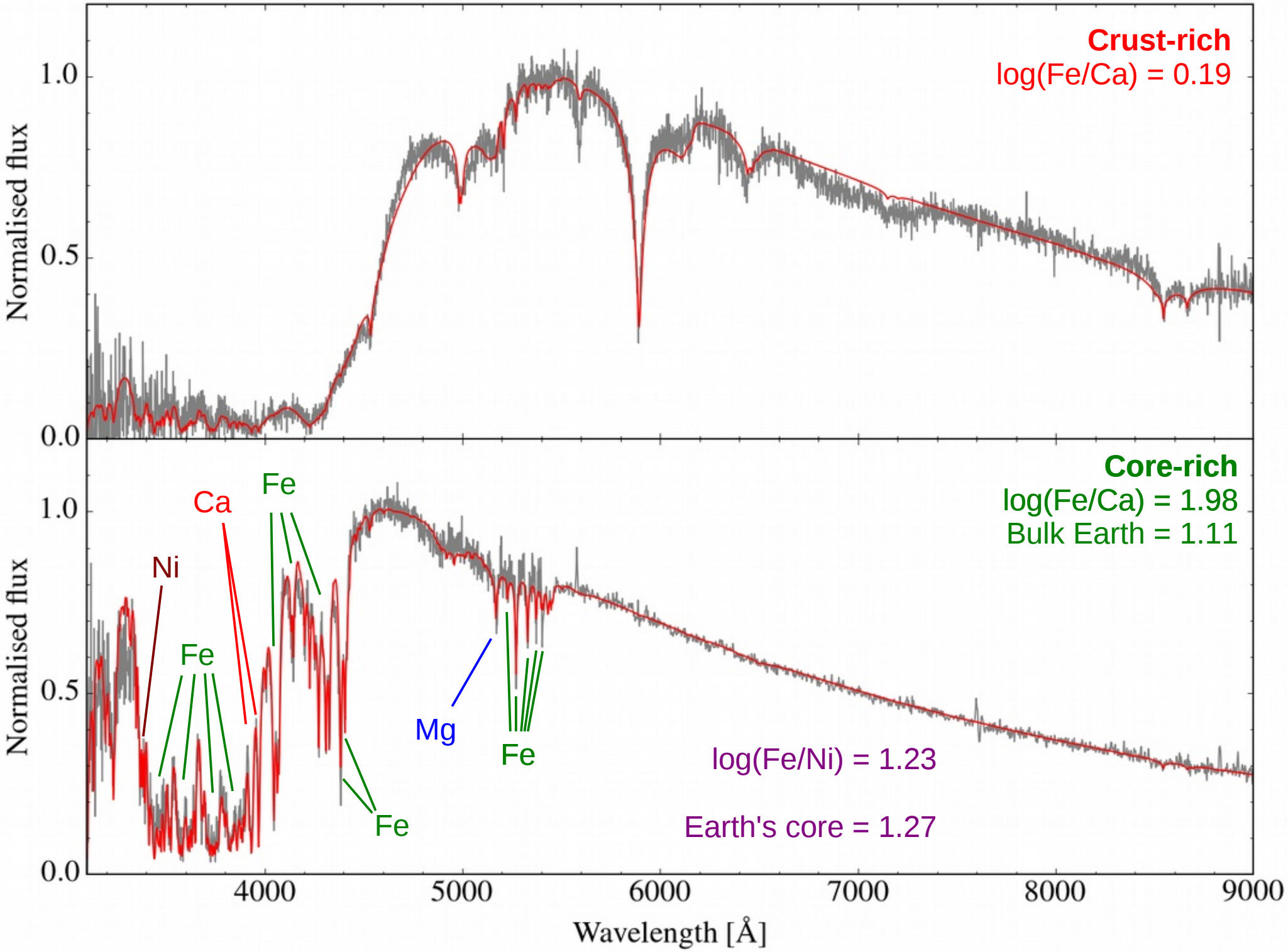

Core
Crust
Mantle
Crust
Core
Mantle
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1.0


Crust-rich
log(Fe/Ca) = 0.19
Core-rich
log(Fe/Ca) = 1.98
Normalised flux
Normalised flux
1.0
0.5
0.0
1.0
0.5
0.0
4000
5000
6000
7000
8000
9000
Wavelength [Å]


Crust-rich
log(Fe/Ca) = 0.19
Earth crust = 0.00
Core-rich
log(Fe/Ca) = 1.98
Ca
Fe
Ti
Na
Ca
Ca
Normalised flux
Normalised flux
1.0
0.5
0.0
1.0
0.5
0.0
4000
5000
6000
7000
8000
9000
Wavelength [Å]


Crust-rich
log(Fe/Ca) = 0.19
Earth crust = 0.00
Ca
Fe
Ca
Ti
Na
Ca
log(Ca/Ti) = 1.02
Earth crust = 0.95
Core-rich
log(Fe/Ca) = 1.98
Normalised flux
1.0
0.5
0.0
4000
5000
6000
7000
8000
9000
Wavelength [Å]

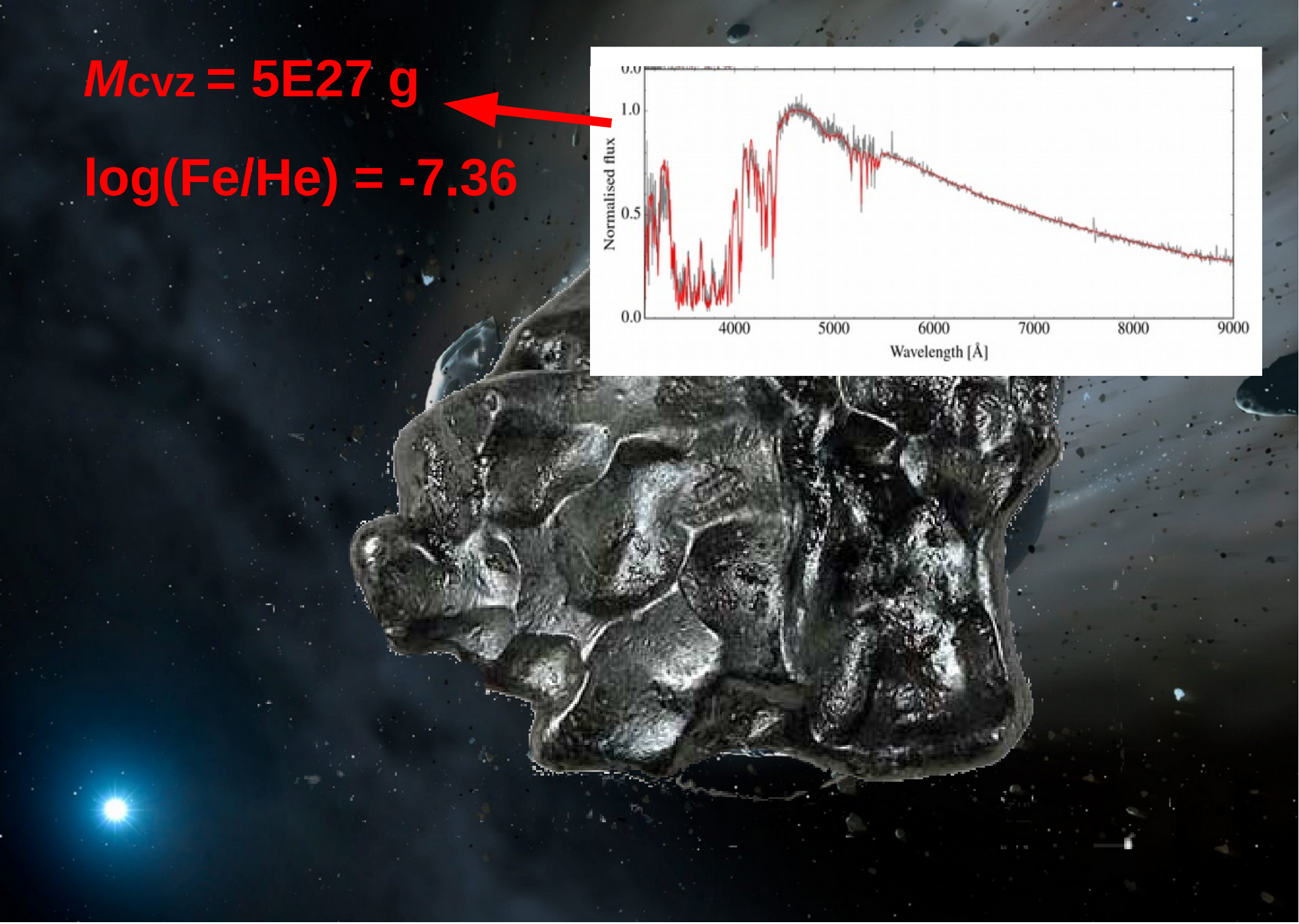

Crust-rich
log(Fe/Ca) = 0.19
Core-rich
log(Fe/Ca) = 1.98
Bulk Earth = 1.11
Ni
Ca
Fe
Fe
Fe
Mg
Fe
Normalised flux
Normalised flux
1.0
0.5
0.0
1.0
0.5
0.0
4000
5000
6000
7000
8000
9000
Wavelength [Å]


Crust-rich
log(Fe/Ca) = 0.19
Core-rich
log(Fe/Ca) = 1.98
Bulk Earth = 1.11
Ni
Ca
Fe
Fe
Mg
Fe
Fe
log(Fe/Ni) = 1.23
Earth's core = 1.27
Normalised flux
Normalised flux
1.0
0.5
0.0
1.0
0.5
0.0
4000
5000
6000
7000
8000
9000
Wavelength [Å]

Metallic asteroids/meteorites

Fe /Ni mixture

Original artwork by Mark Garlick (2013) – adapted poorly by me



Original artwork by Mark Garlick (2013) – adapted poorly by me

Original artwork by Mark Garlick (2013) – adapted poorly by me

16 Psyche

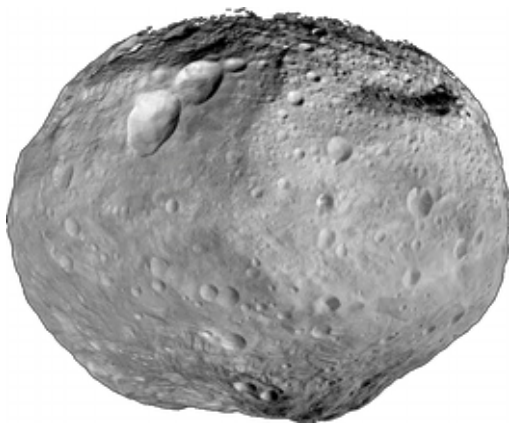
M_{ast} = 2.72±0.75E22 g

Mean diameter = 213±13 km

ρ = 4–8 g cm^{-3}

Loosely bound Rubble Pile

$$R_{td}^3 = \frac{3M_\star}{4\pi\rho}$$



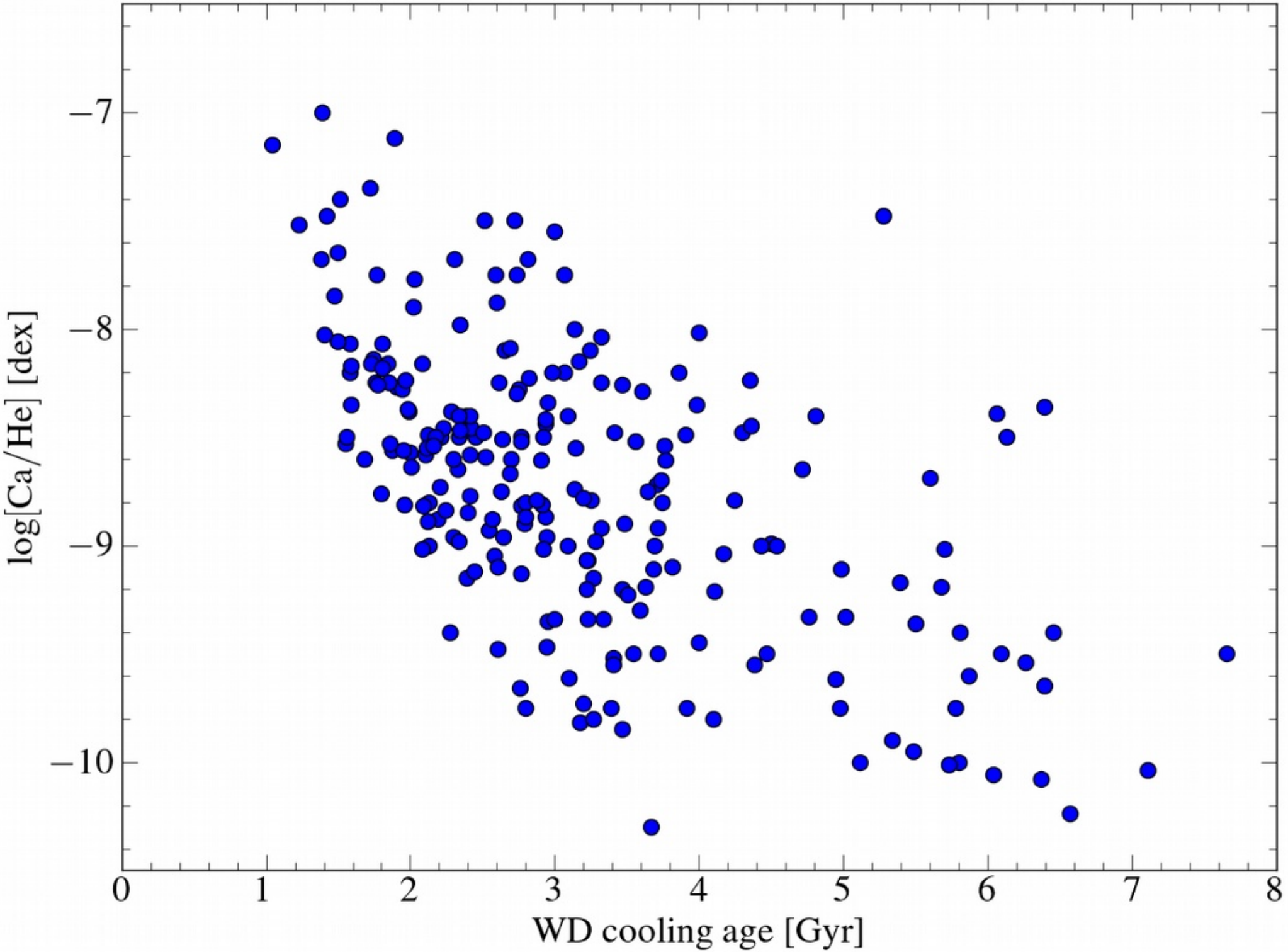
Internal Strength Dominated

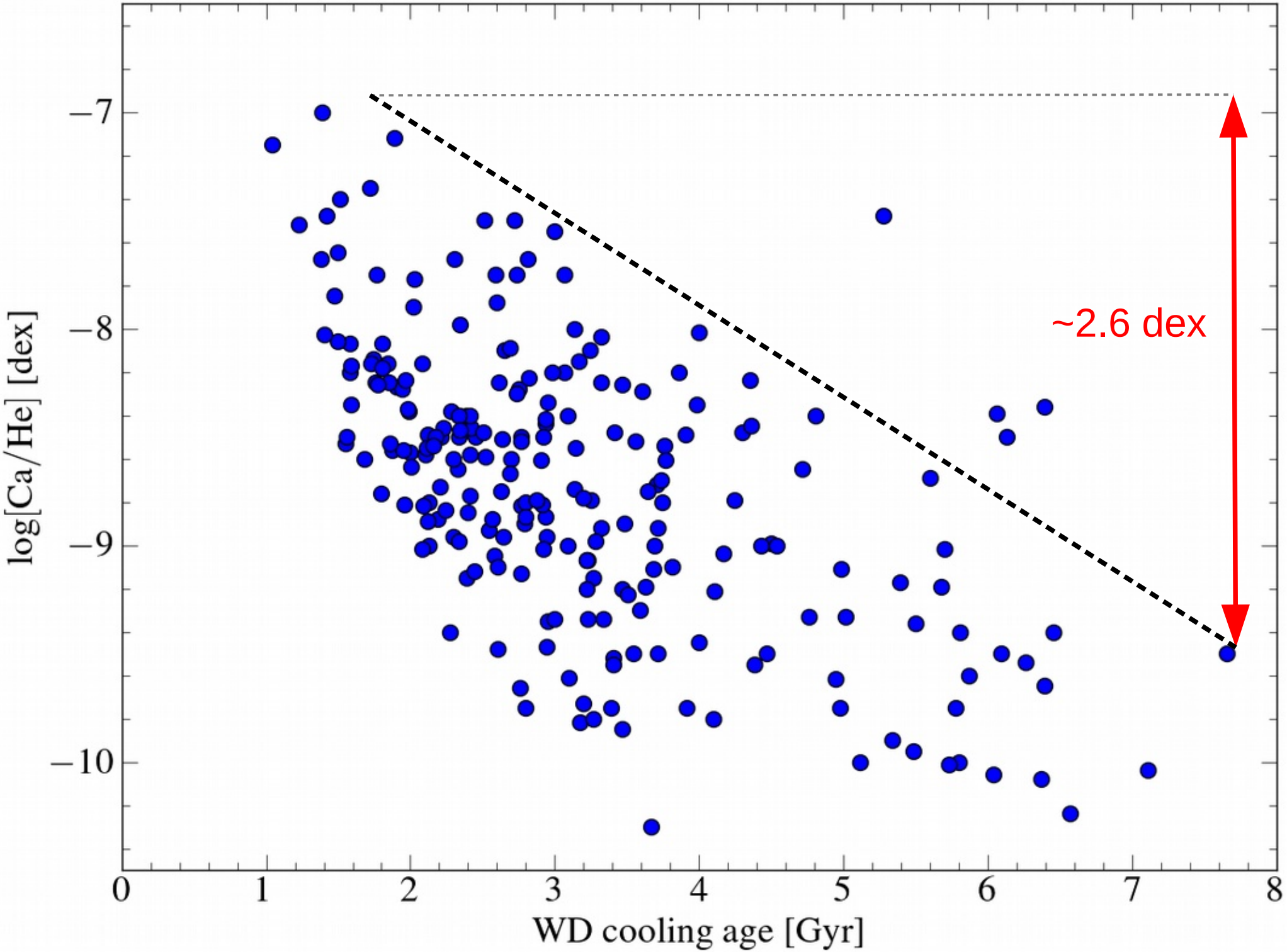
$$R_{td}^3 = \frac{2GM_\star\rho r^2}{S}$$

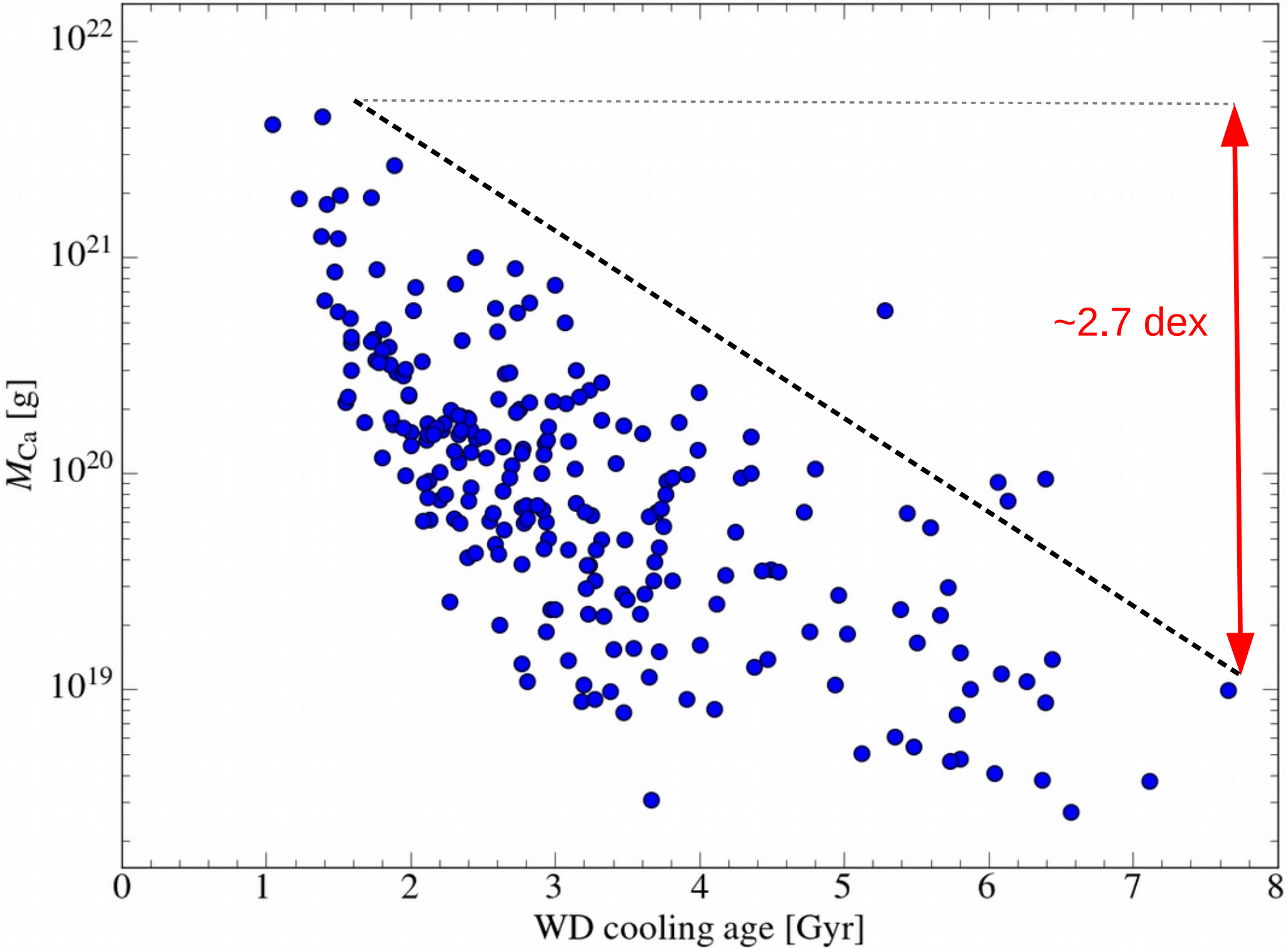
For asteroid : r = radius, ρ = density, S = tensile strength

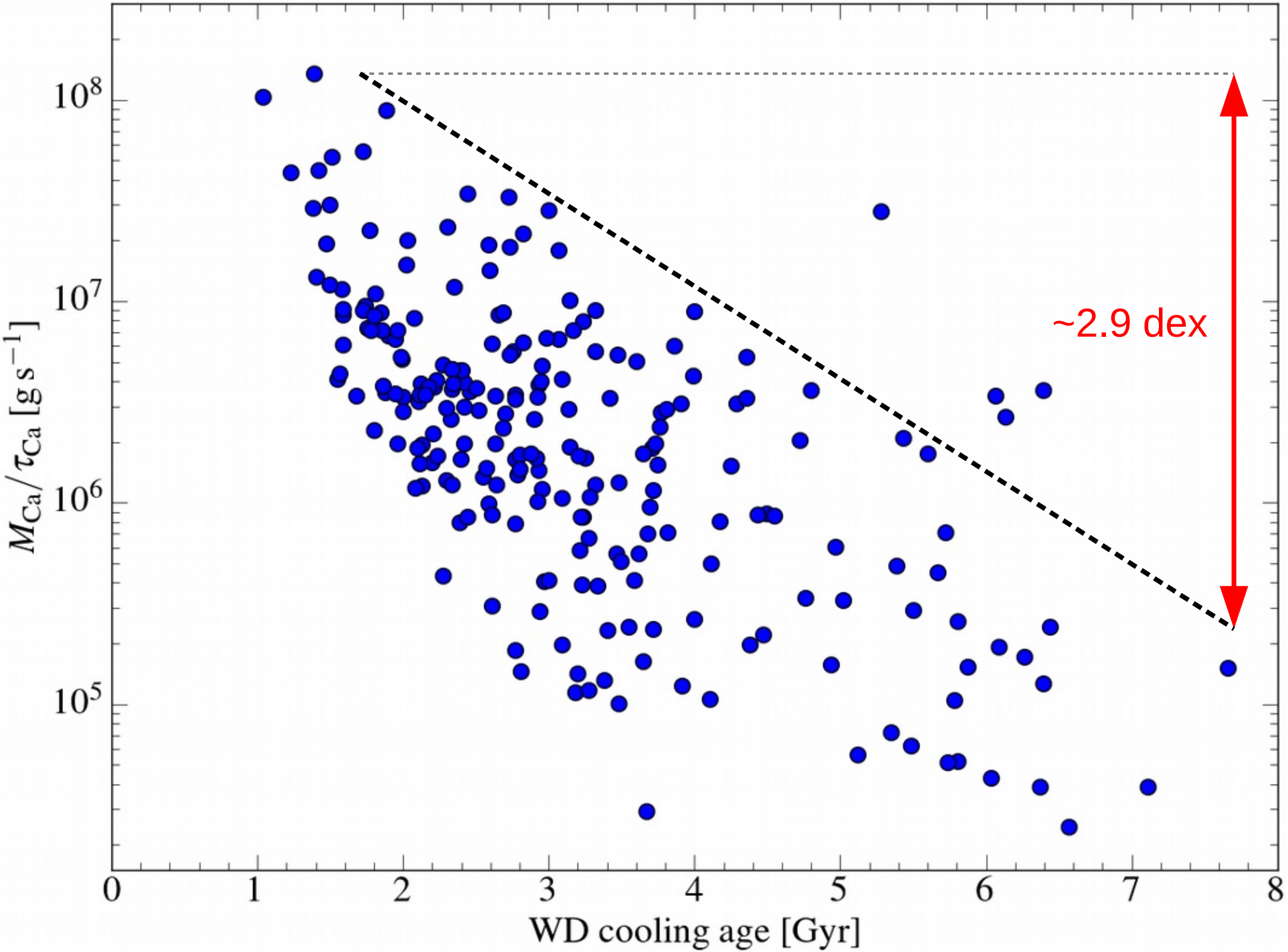
Evolution of cool WDs

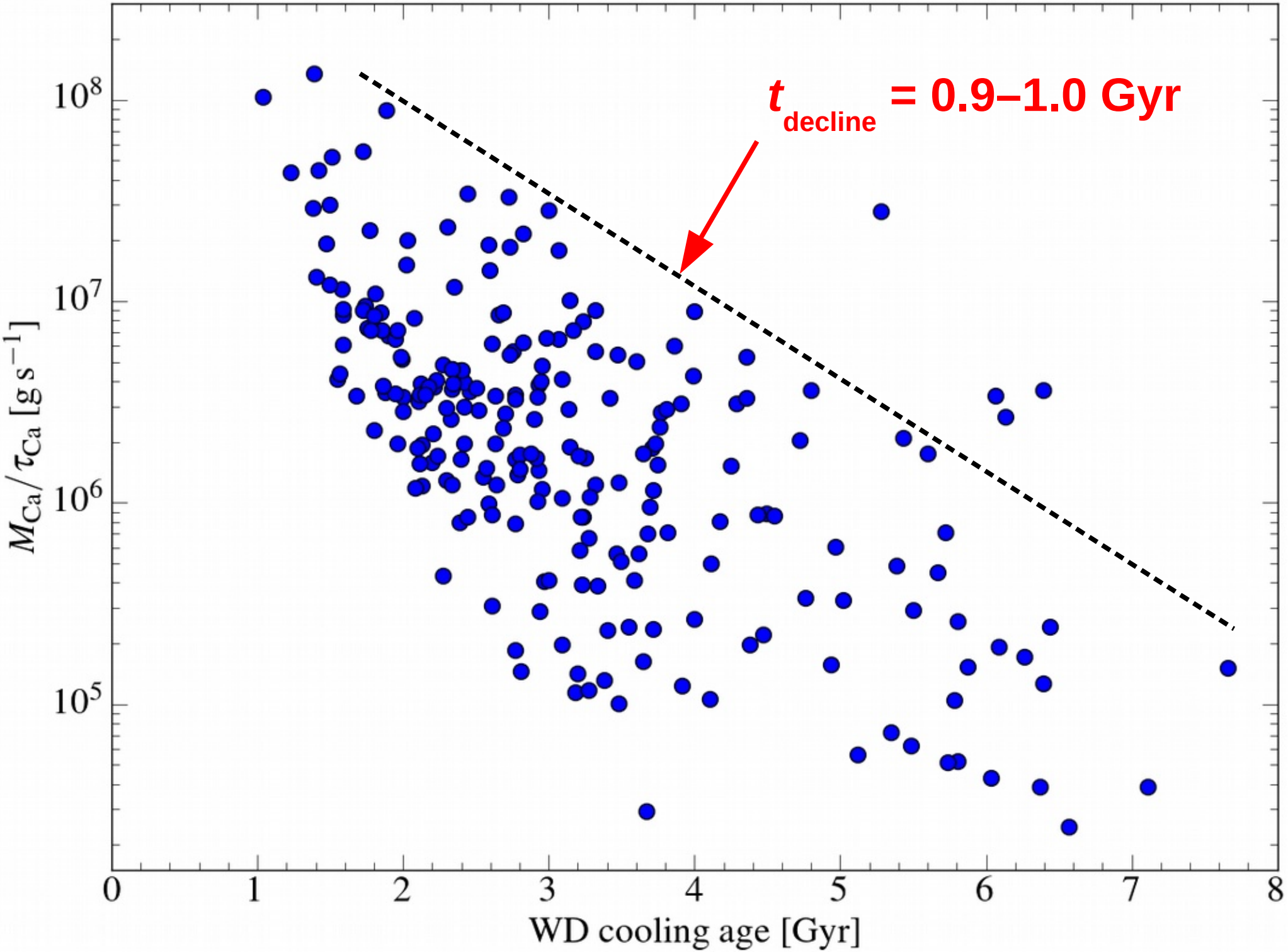
- T_{eff} 4400 – 9000 K for our sample
- $t_{\mathrm{cool}}(T_{\mathrm{eff}}, M_{\mathrm{wd}})$
- Hottest/youngest system 1.0±0.2 Gyr
- Coolest/oldest system $7.7^{+0.3}_{-0.9}$ Gyr


−7
−8
−9
−10
log[Ca/He] [dex]
0
1
2
3
4
5
6
7
8
WD cooling age [Gyr]


~2.6 dex
log[Ca/He] [dex]
WD cooling age [Gyr]
−7
−8
−9
−10
0
1
2
3
4
5
6
7
8


10^{22}
10^{21}
10^{20}
10^{19}
M_{Ca} [g]
0
1
2
3
4
5
6
7
8
WD cooling age [Gyr]
~2.7 dex


~2.9 dex
M_{Ca}/τ_{Ca} [g s^{-1}]
10^8
10^7
10^6
10^5
0
1
2
3
4
5
6
7
8
WD cooling age [Gyr]

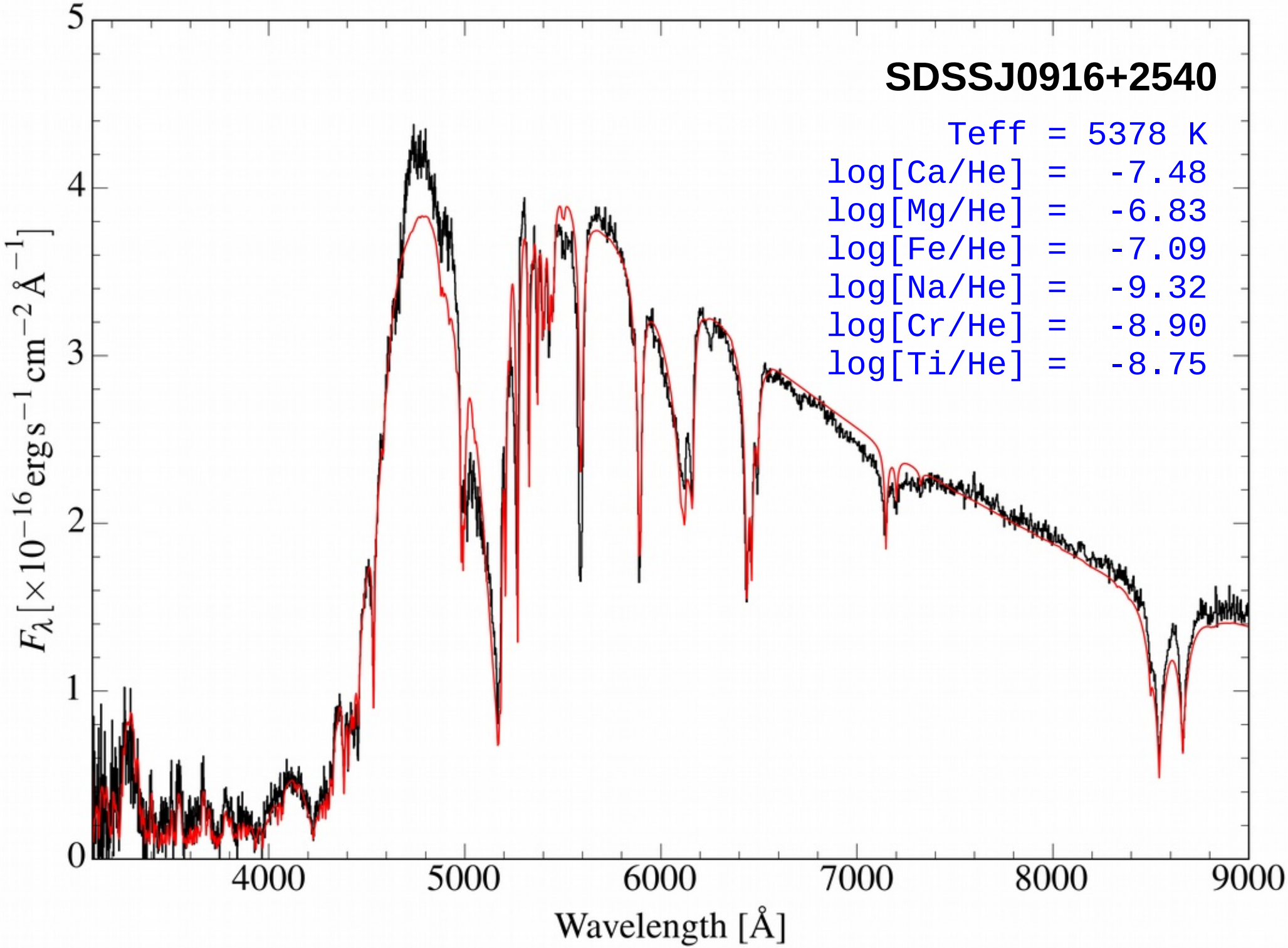

$t_{decline}$ = 0.9–1.0 Gyr
10^8
10^7
10^6
10^5
M_{Ca}/τ_{Ca} [g s^{-1}]
0
1
2
3
4
5
6
7
8
WD cooling age [Gyr]

Any questions

- Identified a large sample of cool DZ white dwarfs
- Diverse range of compositions with some unusual crust-rich core-rich outliers
- Remnant planetary systems deplete their mass reservoirs on ~1Gyr e-folding timescale

Looking for a postdoc..?

M.Hollands@warwick.ac.uk


SDSSJ0916+2540
Teff = 5378 K
log[Ca/He] = -7.48
log[Mg/He] = -6.83
log[Fe/He] = -7.09
log[Na/He] = -9.32
log[Cr/He] = -8.90
log[Ti/He] = -8.75
$F_\lambda [\times 10^{-16} \mathrm{erg\,s^{-1}\,cm^{-2}\,Å^{-1}}]$
Wavelength [Å]
0
1
2
3
4
5
4000
5000
6000
7000
8000
9000