UCLA

THE FATE OF PLANETS IN EVOLVING BINARY SYSTEMS: THROWING ICEBERGS AT WHITE DWARFS

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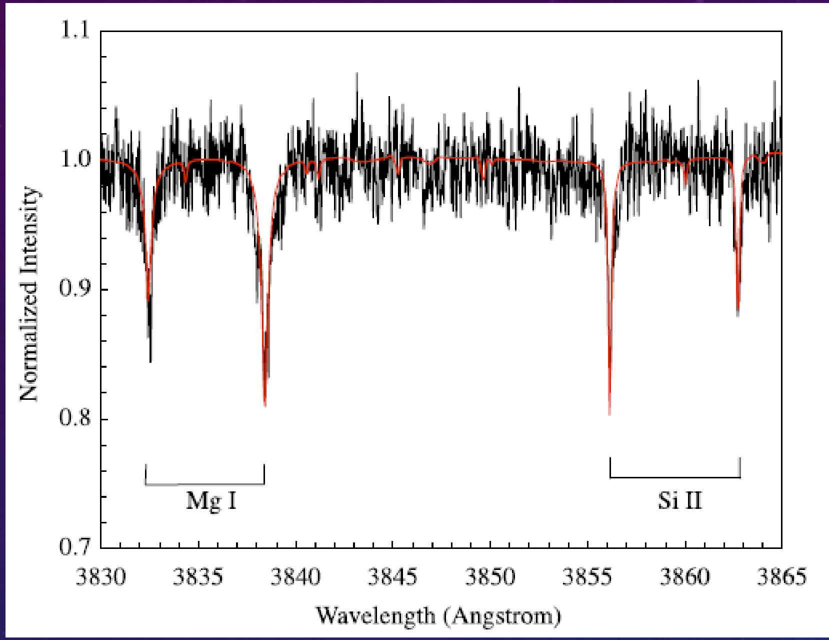
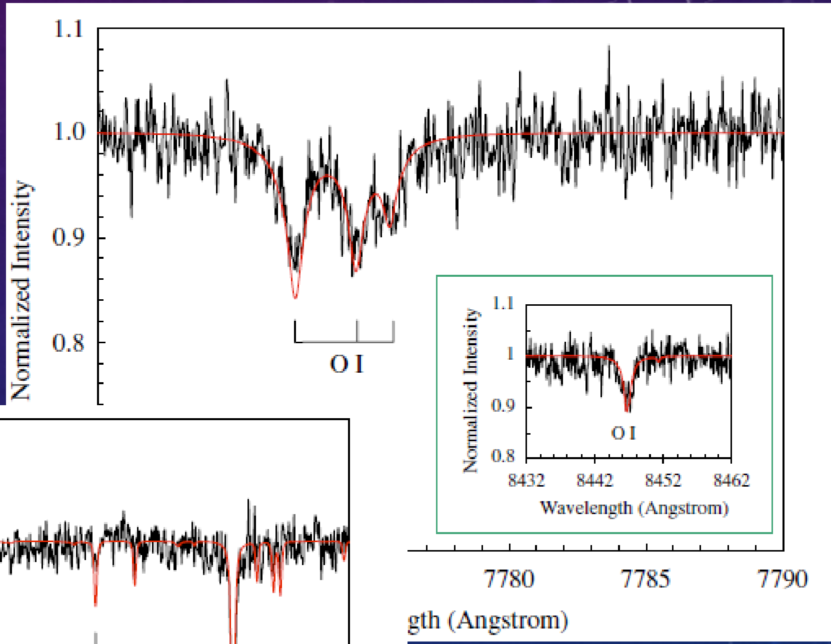
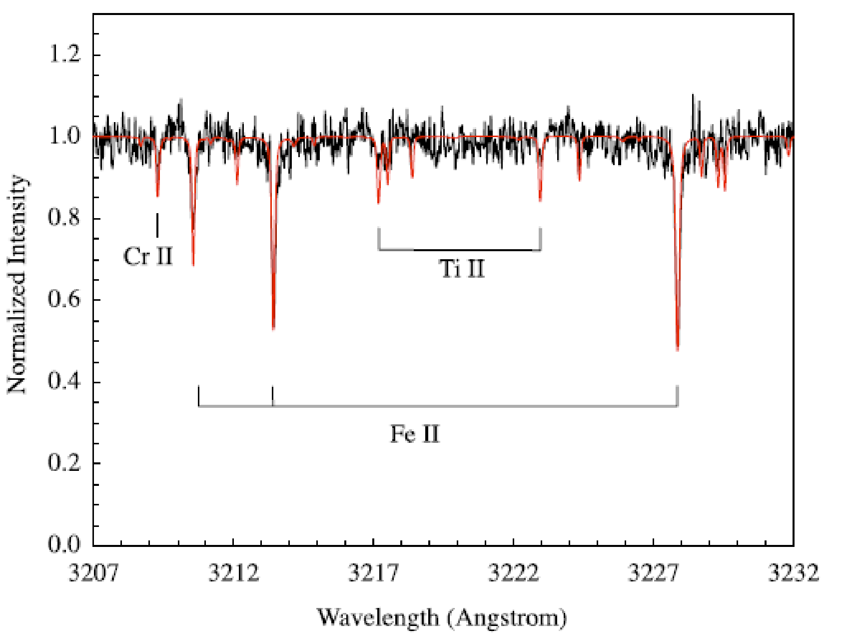
THE UNIVERSITY OF CALIFORNIA · LET THERE BE LIGHT · UCLA

WHITE DWARF POLLUTION - PROBE FOR EXOPLANET COMPOSITION



Example: GD 40





See also works by:
Jura 2003, 2006, 2008, Jura et al. 2007ab, 2009ab, etc.
Zuckerman et al. 2003, 2007, 2010, etc.
Koester et al. etc, Farihi et al. etc,
Su et al. etc, Klein et al. etc.

Figures from
Klein et al. 2010

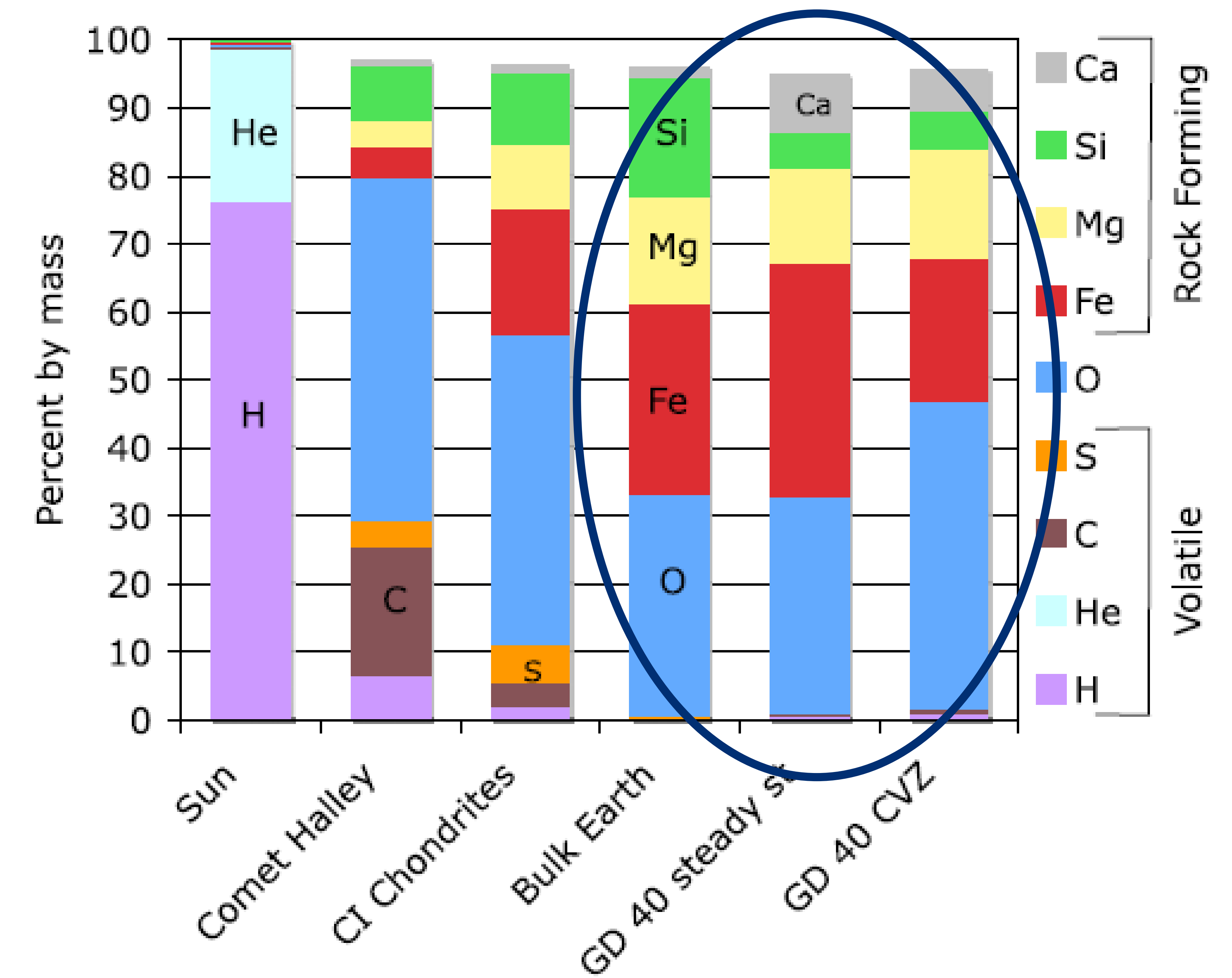


Figure from
Klein et al. 2010

WHITE DWARF POLLUTION – VOLATILES?

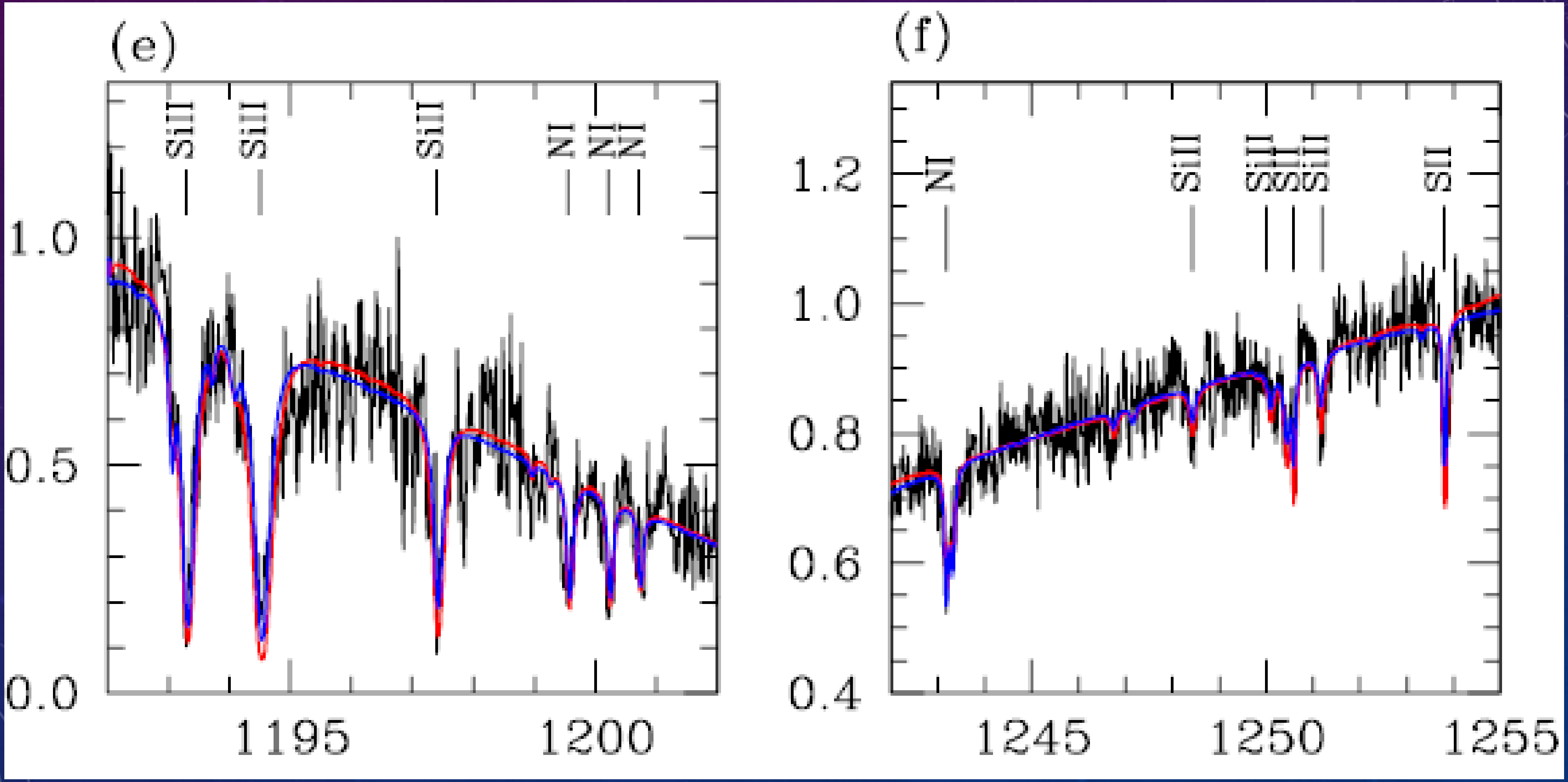


Figure from Xu et al. 2017

POLLUTION COMPOSITION OF WD 1425+540

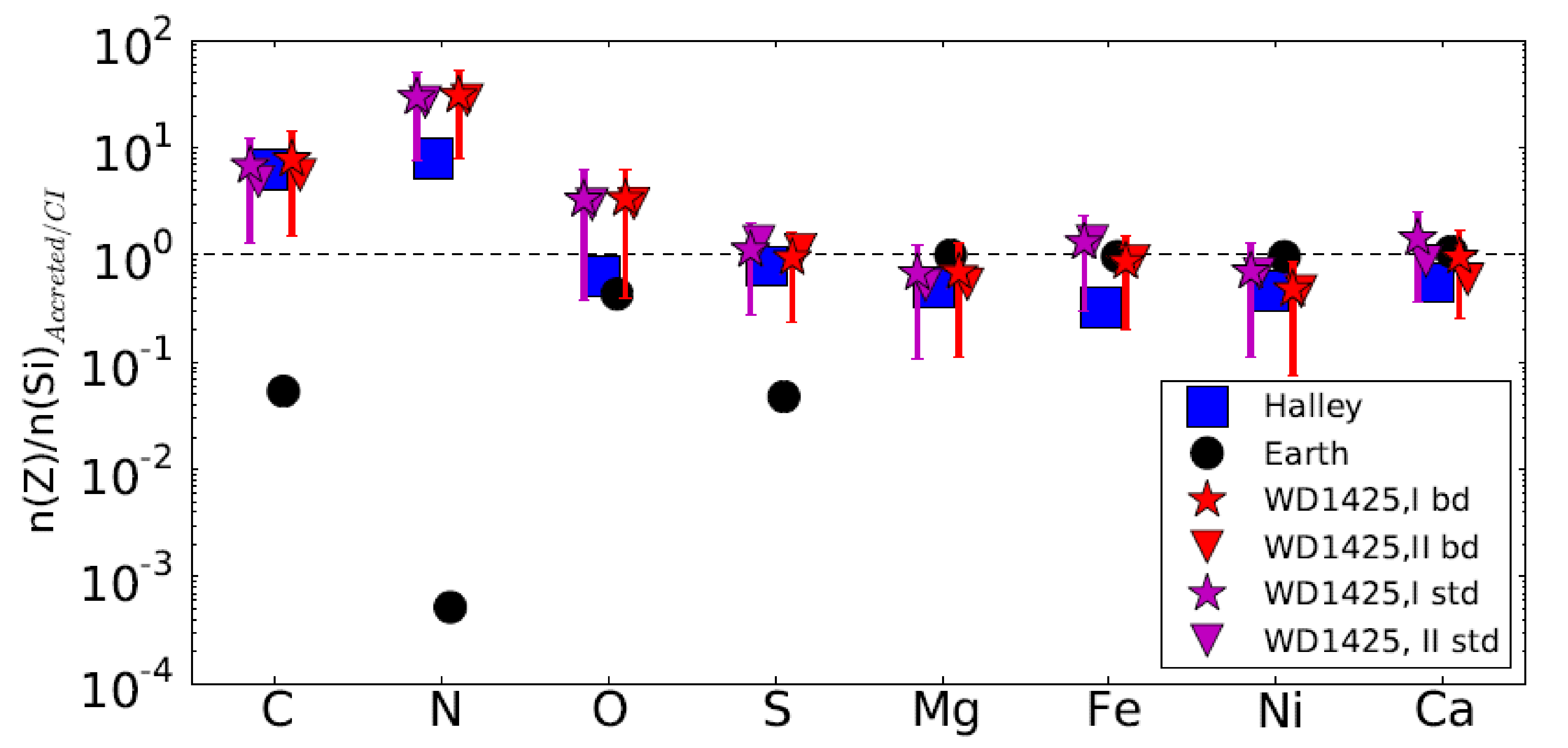
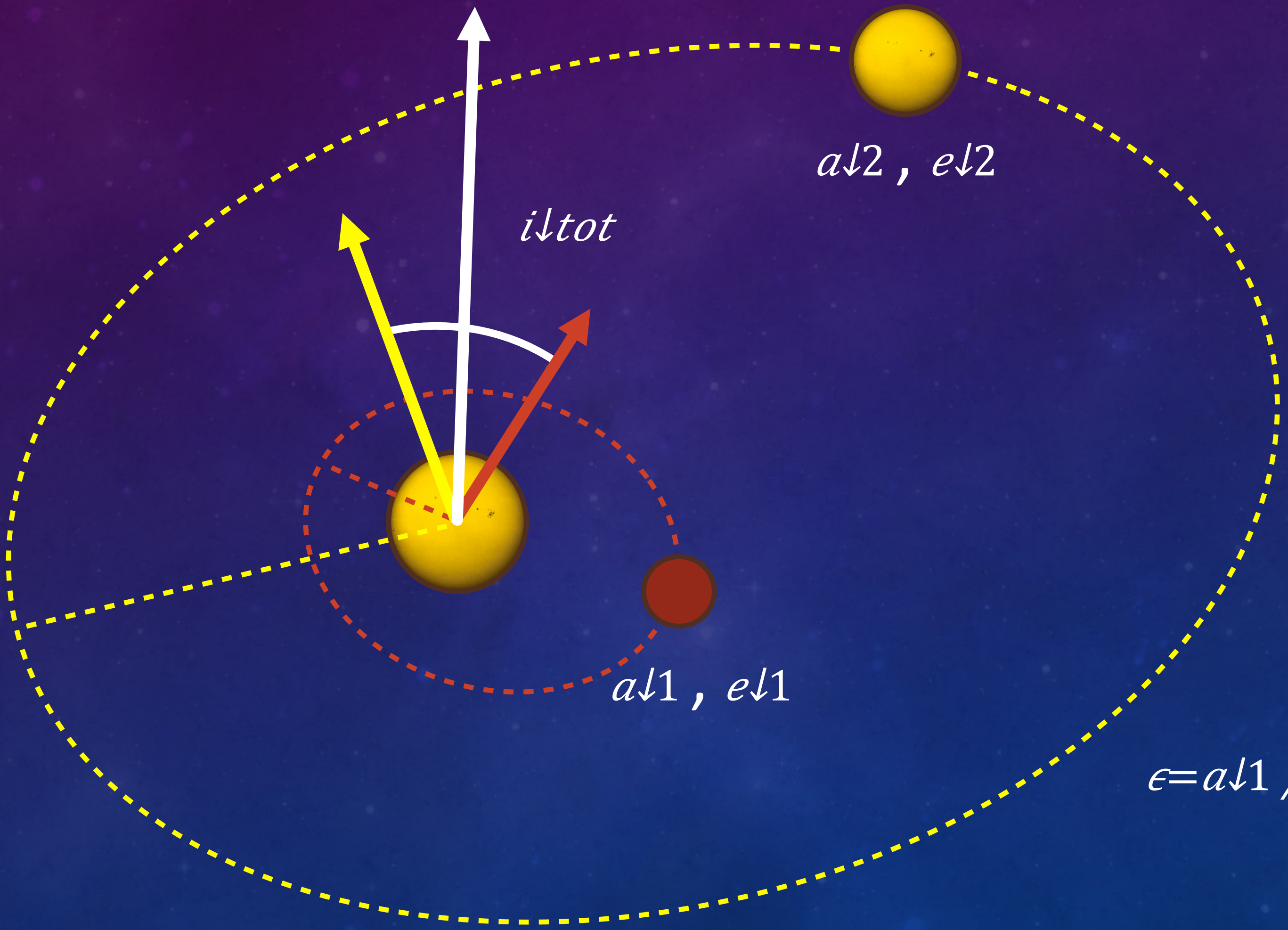


Figure from Xu et al. 2017

HIERARCHICAL TRIPLES

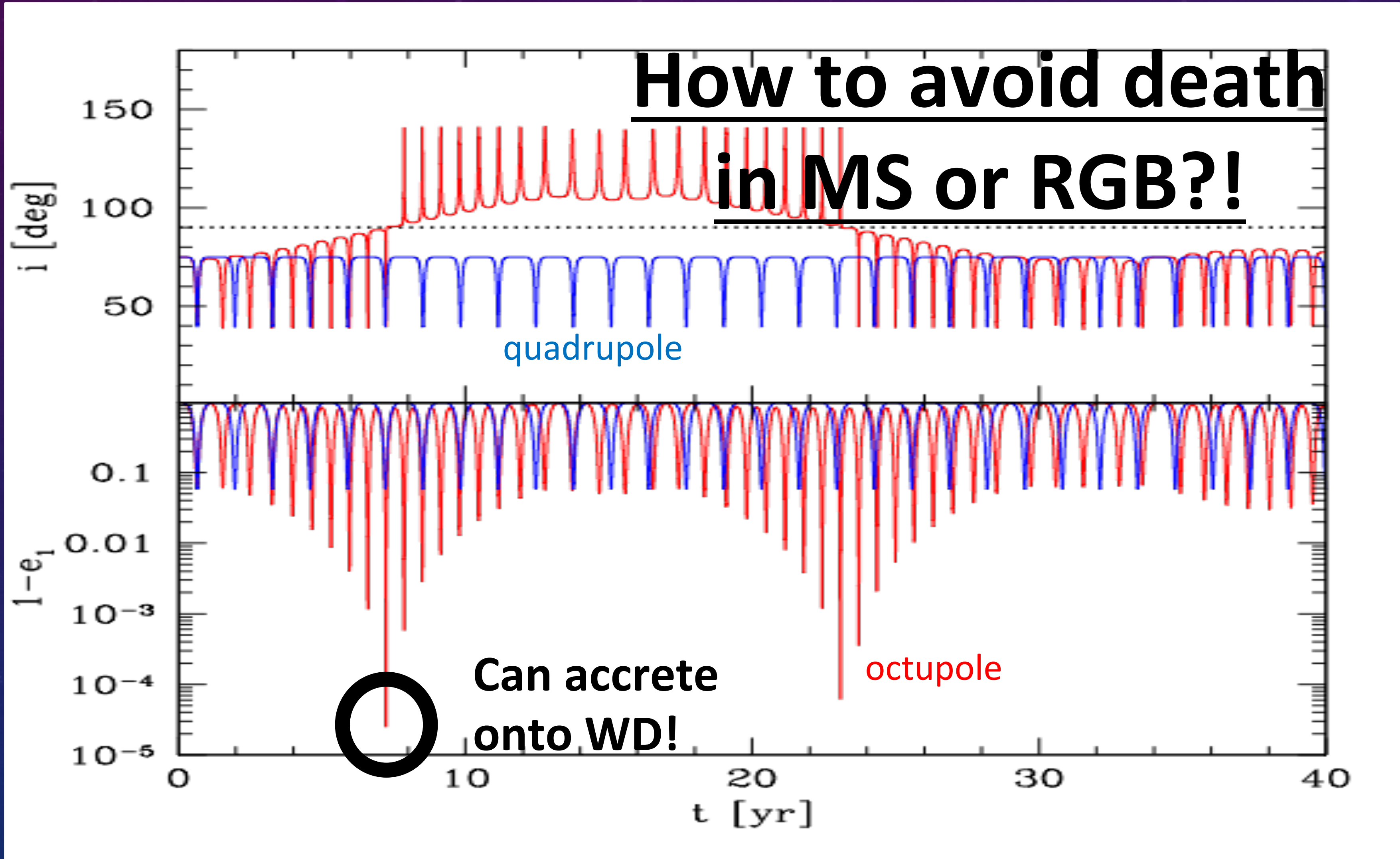


*Not to scale

$a_2 > 10 \times a_1$

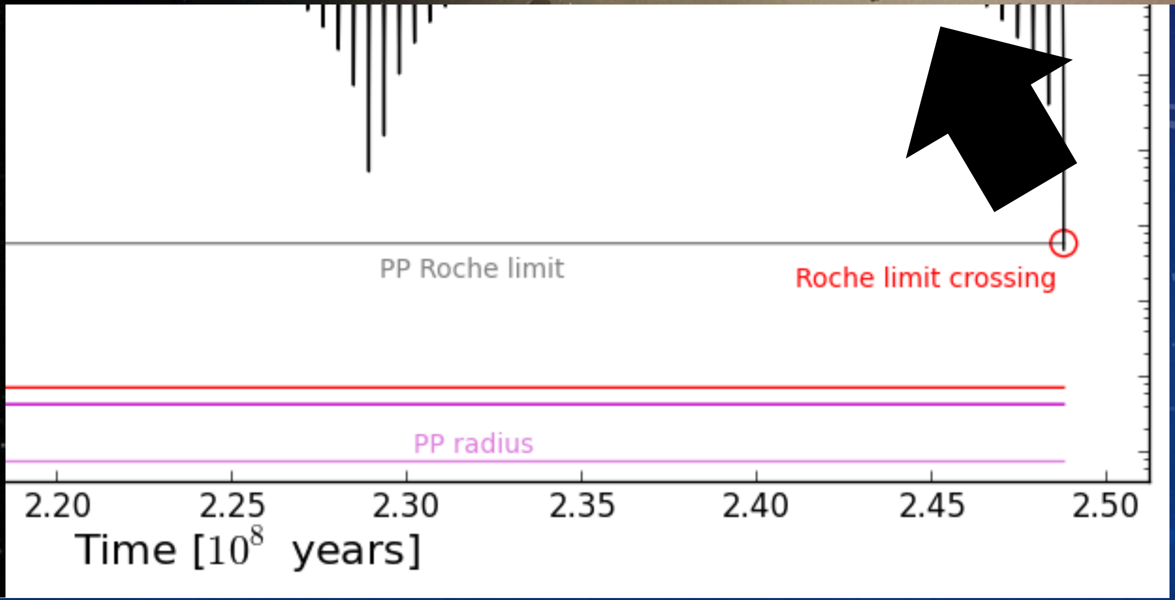
$\epsilon = \frac{a_1}{a_2} \frac{e_2}{1 - e_2^2} < 0.1$

ECCENTRIC KOZAI-LIDOV OSCILLATIONS



Naoz (2016)

KUIPER BELT ANALOG OBJ



NASA/ESA/STScI/G. Bacon

CfA/Mark A. Garlick

SUMMARY

- White Dwarf Pollution serves as a probe for Exoplanet composition
- Binary stars can trigger pollution with volatile material through EKL oscillations, caused by stellar mass loss
- Indicates that Kuiper-belt analogs or long-period Neptune-like planets must exist, even if currently not directly observable

MAIN REFERENCES

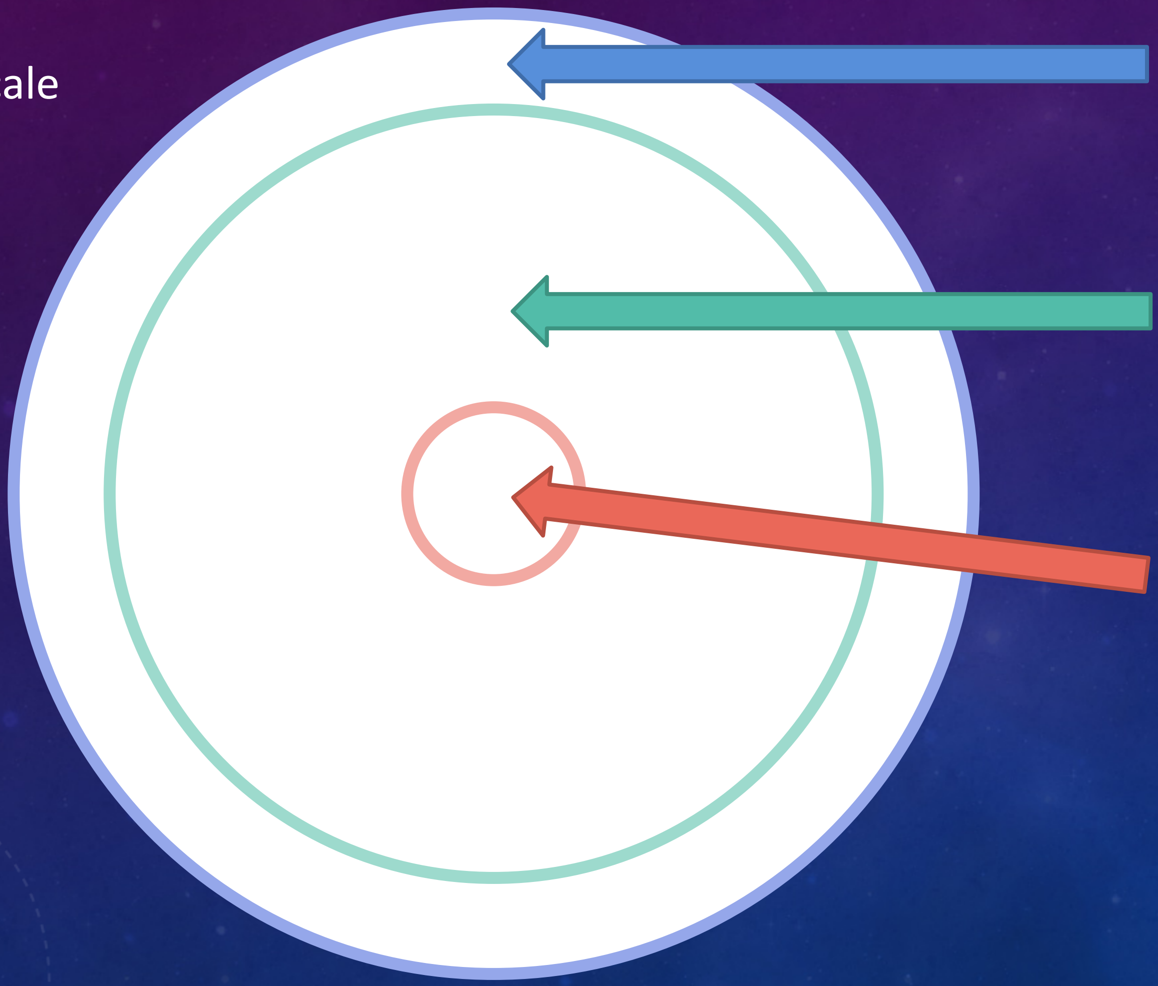
- **Stephan, Naoz, Zuckerman, 2017. *Throwing Icebergs at White Dwarfs*. ApJ Letters, Vol. 844, L16**

- Xu, Zuckerman, Dufour, Young, Klein, Jura, 2017. *The Chemical Composition of an Extrasolar Kuiper-Belt-Object.* ApJ Letters, Vol. 836, L7

BONUS SLIDES

WHITE DWARFS STRUCTURE

*Not to scale



Hydrogen atmosphere (sometimes)

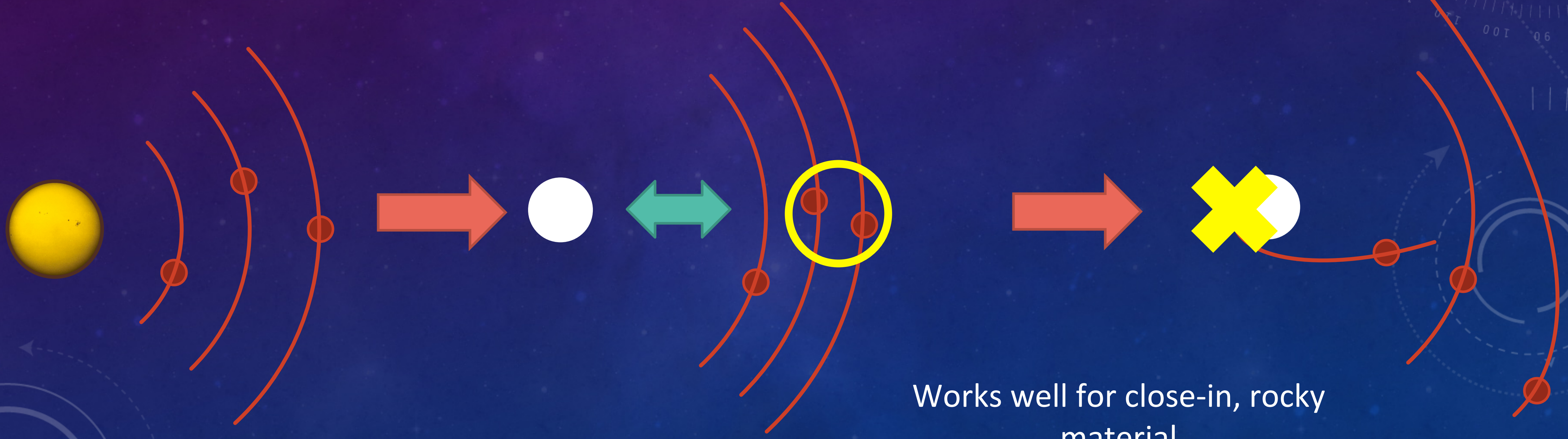
Helium interior

Heavy elements sink to center

→ **No absorption lines expected**

HOW DO ASTEROIDS AND MINOR PLANETS GET ONTO WHITE DWARFS?

- Most promising models: planet-planet scattering, dynamical instabilities (e.g. Veras et al. 2013, 2014, 2017, etc.)



Works well for close-in, rocky material

*Not to scale

OTHER MODELS

- Kozai-Lidov Mechanism: e.g. Hamers & Portegies Zwart 2016, Petrovich & Muñoz 2017.
  Caveat: need mechanism to prevent planets from dying during main sequence and RGB

- Oort cloud comets: e.g. Veras et al. 2014
  Caveat: very low amount of material, mostly for hydrogen

- Galactic tides: Bonsor & Veras 2015
  Caveat: Extremely slow mechanism

HOW DID IT GET THERE?

WD 1425+540 HAS A COMPANION!

K dwarf

$\sim 0.75\ M_\odot$

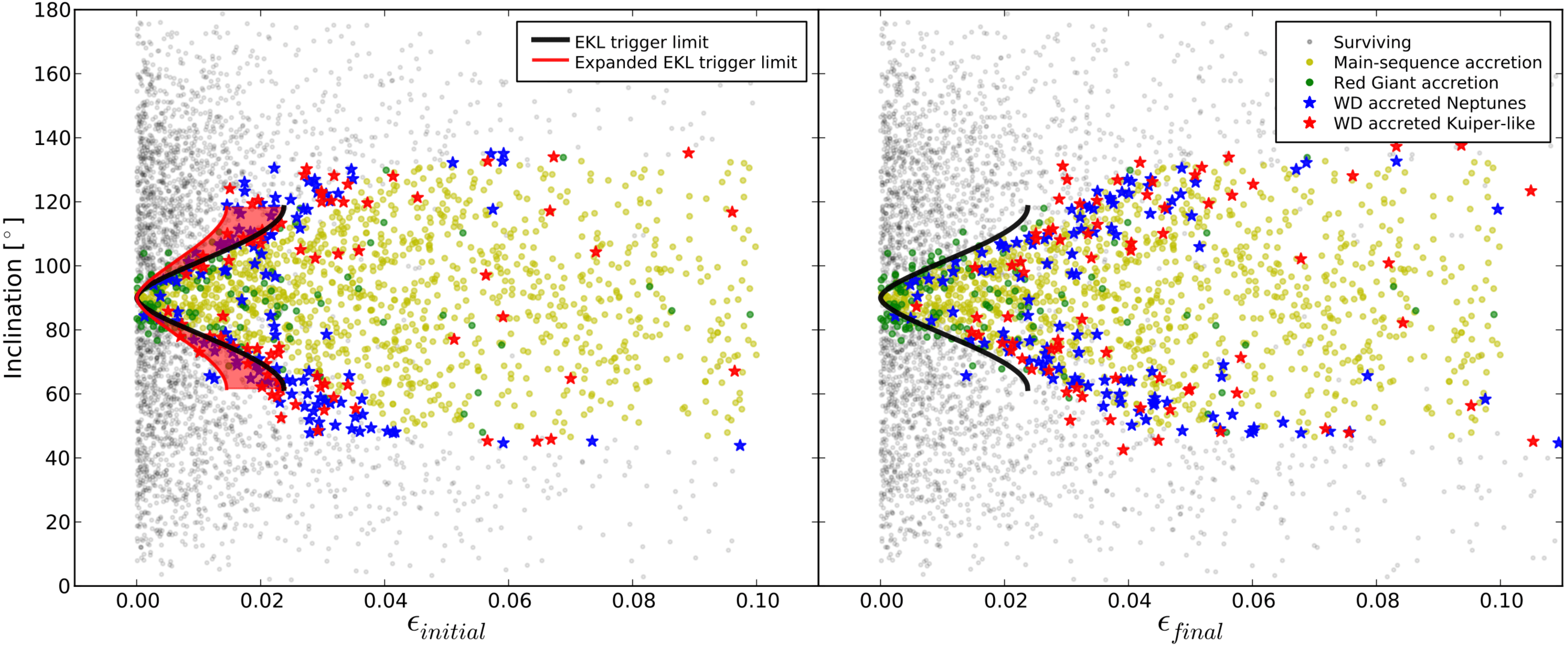
(Wegner 1981)

STELLAR EVOLUTION CHANGES ORBITS

- EKL strength depends on: $\epsilon = \frac{a_1}{a_2} \frac{e_2}{1-e_2^2}$
- Stellar mass loss in binaries with planets can lead to enhanced EKL strength
  - Mass loss expands orbits: $a_f = a_i \left(\frac{m_i}{m_f} \right)$
  - Expansion is larger for planet than for companion star, leading to increasing ϵ:

$$\epsilon_f = \epsilon \frac{m_1}{m_{1,f}} \frac{m_{1,f} + m_2}{m_1 + m_2}$$

See, e.g., Perets & Kratter 2012, Shappee & Thompson 2013, Hamers & Portegies Zwart 2016, etc.



EKL trigger limit
Expanded EKL trigger limit
Surviving
Main-sequence accretion
Red Giant accretion
WD accreted Neptunes
WD accreted Kuiper-like
Inclination [°]
$\epsilon_{initial}$
ϵ_{final}
0
20
40
60
80
100
120
140
160
180
0.00
0.02
0.04
0.06
0.08
0.10

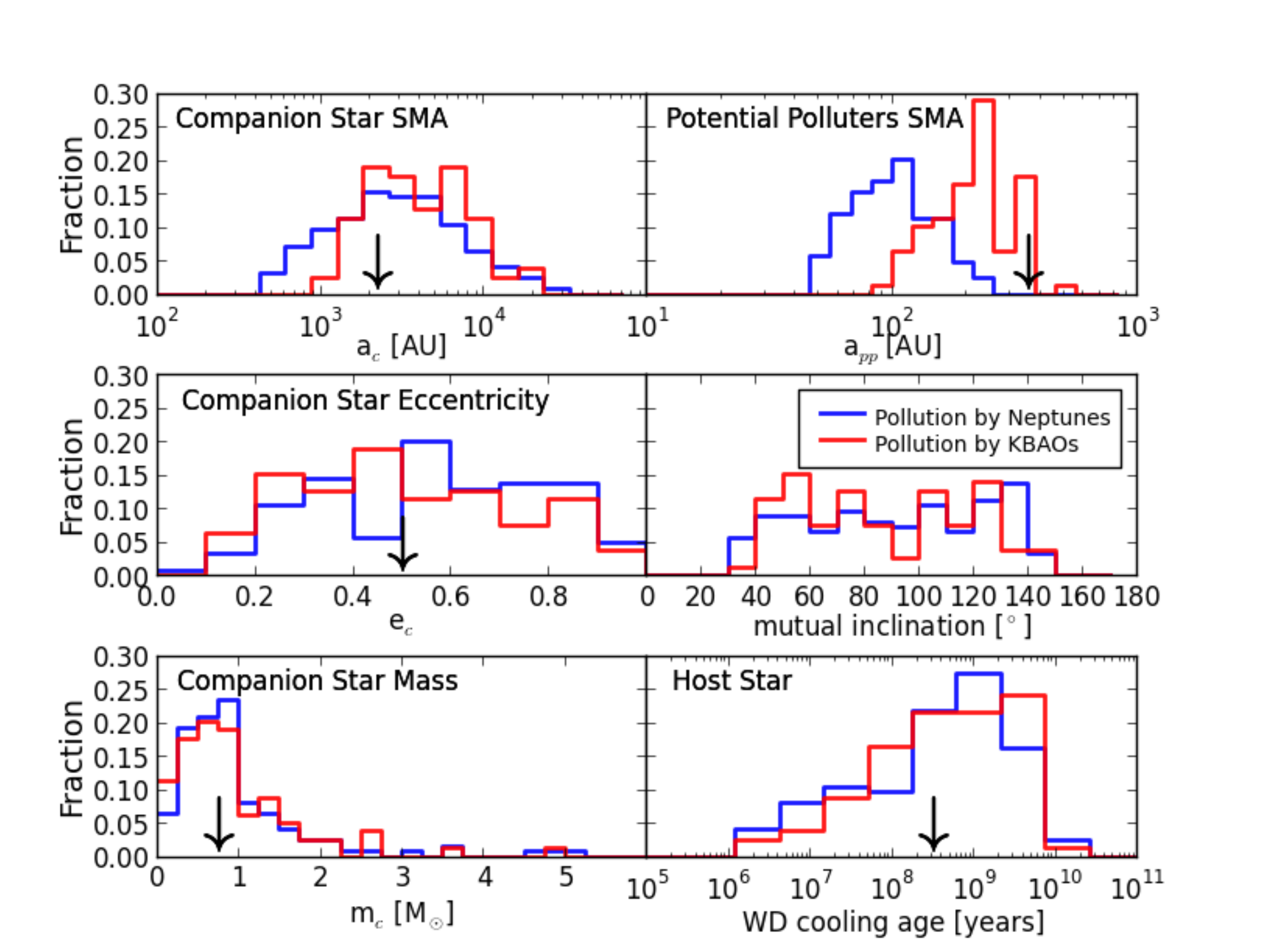
PREDICTIONS FROM MONTE-CARLO SIMULATIONS

Wide binaries (>1000 AU)

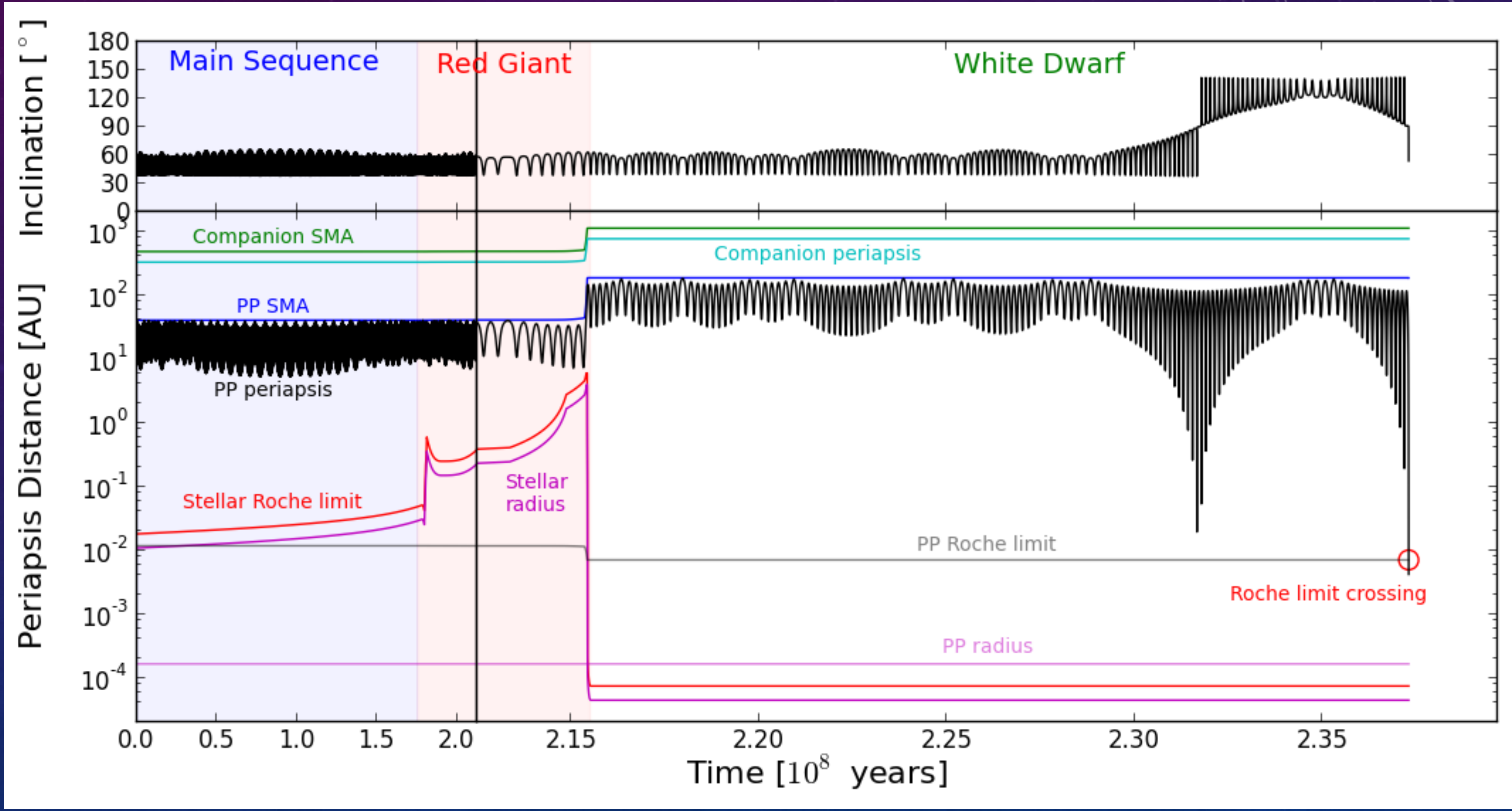
Low mass companion star

Works at all ages

Also works for distant planets, e.g. Neptune analogs!



NEPTUNE ANALOG ACCRETION



Stephan et al. 2017