Metal Pollution around **Massive White Dwarfs** as a Tool to Constrain Planetary Occurrence Rates

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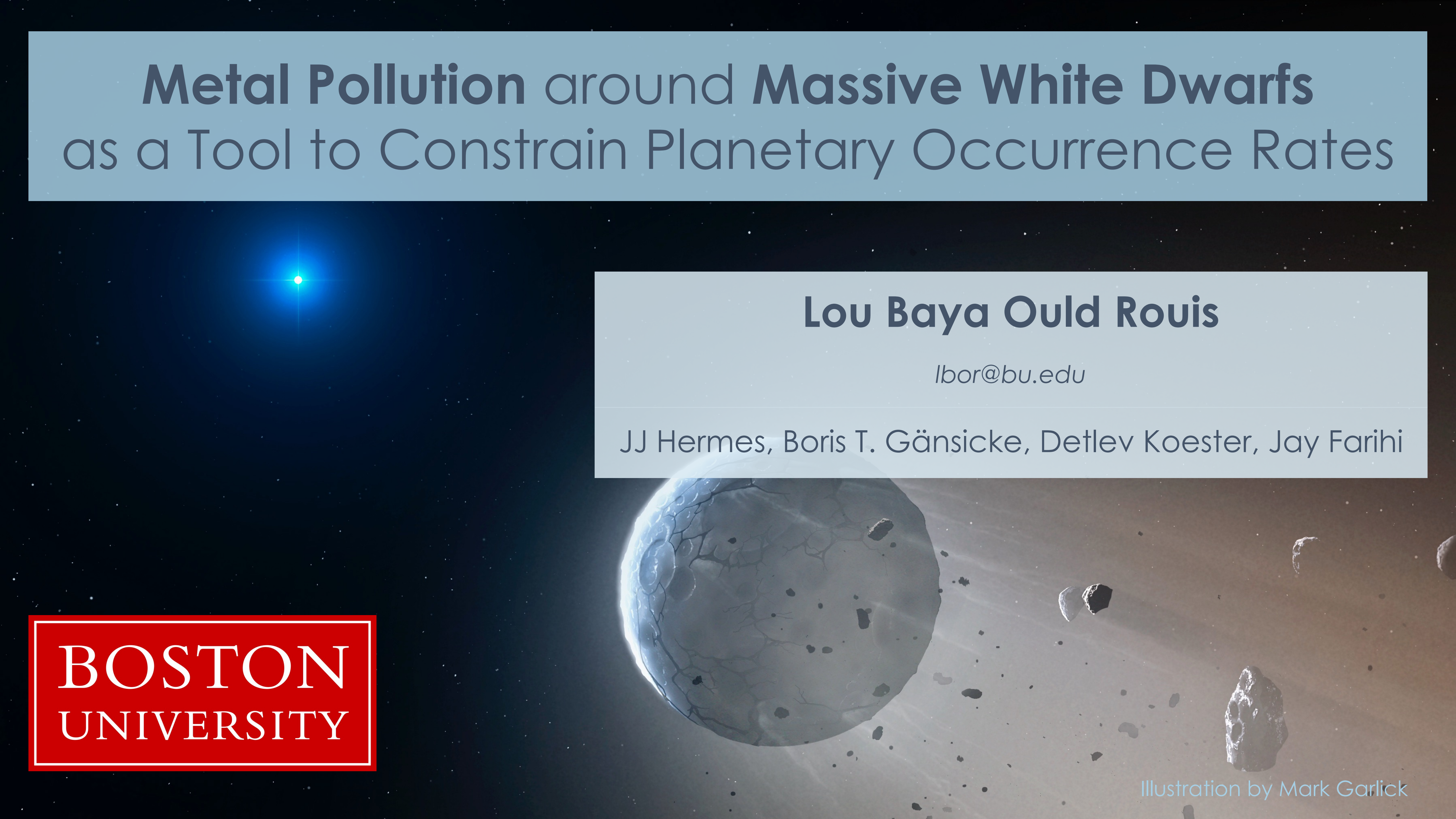
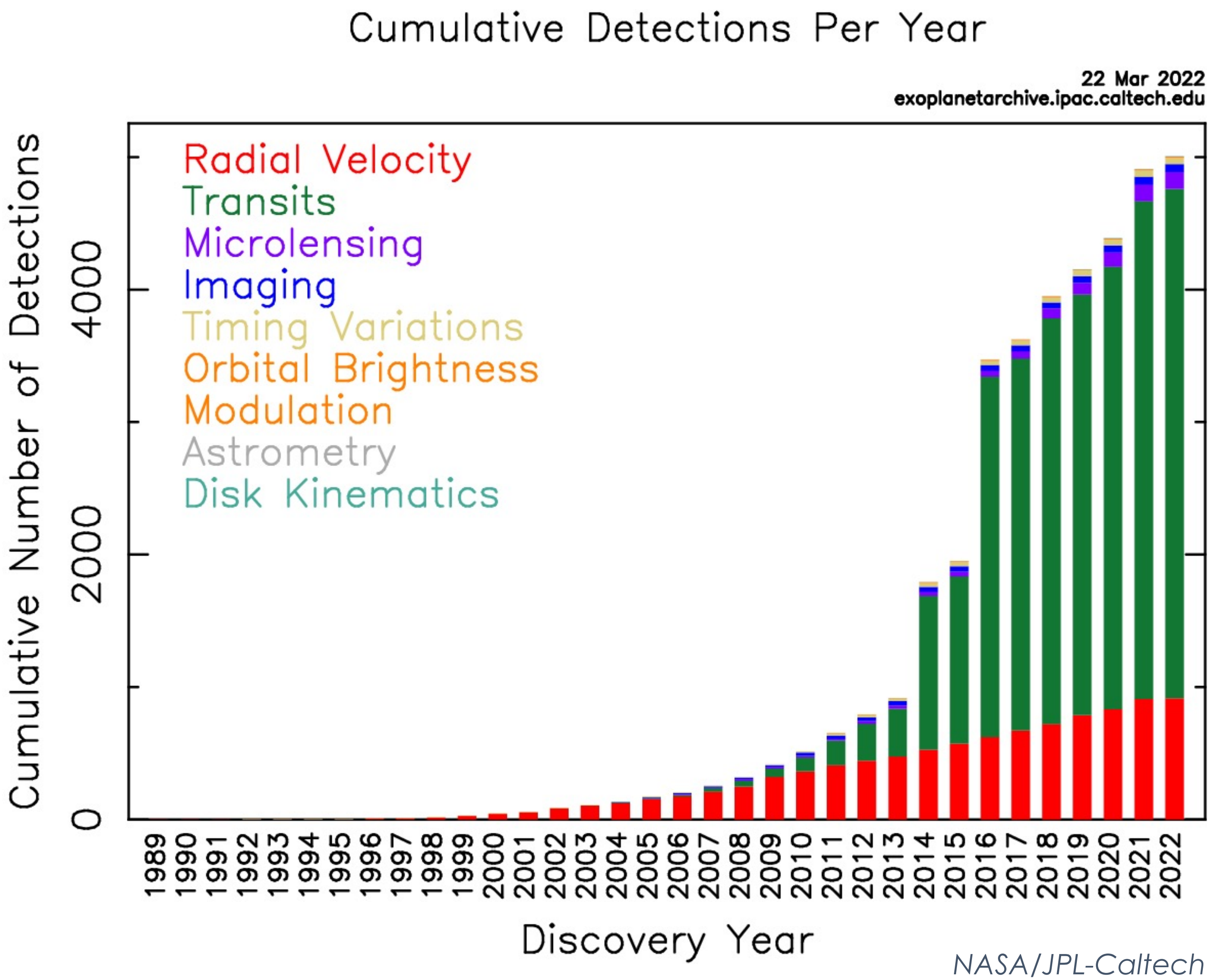


Illustration by Mark Garlick

The boom of exoplanet detections

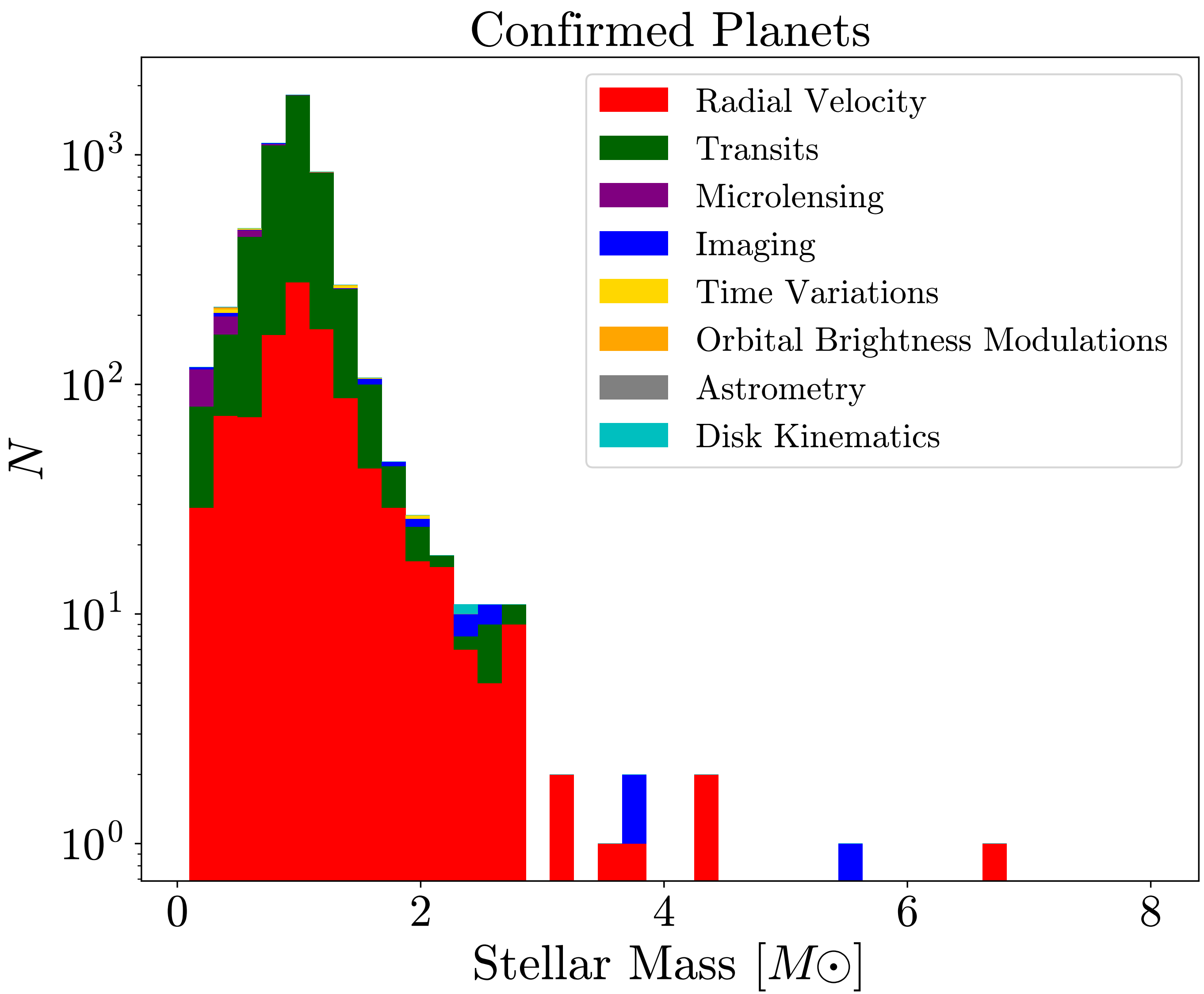
Transits surveys (Kepler, TESS) revolutionized the search for planets around the stars of our galaxy.

As of 2022, over **5 000** confirmed exoplanets!



NASA/JPL-Caltech

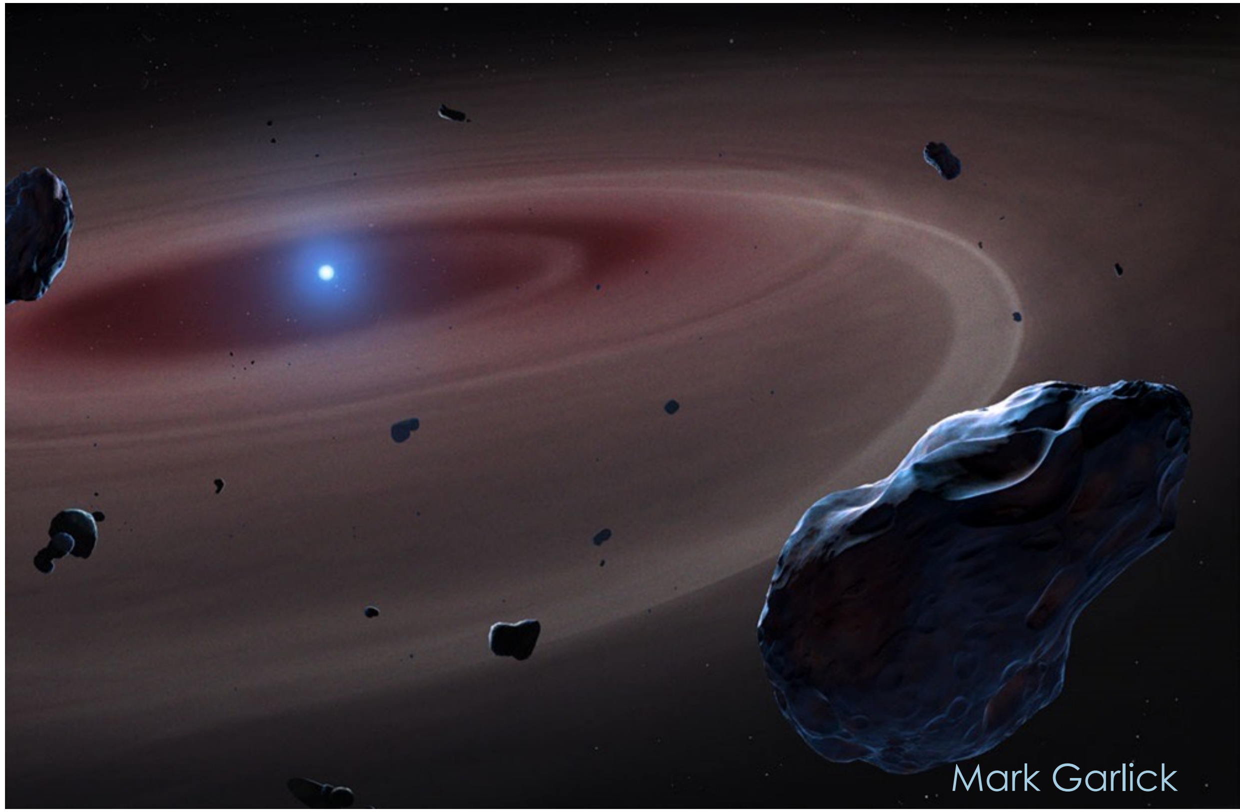
Yet, few constraints on hosts with $M > 3.5\ M_\odot$



Metal polluted white dwarfs offer a surprising clue

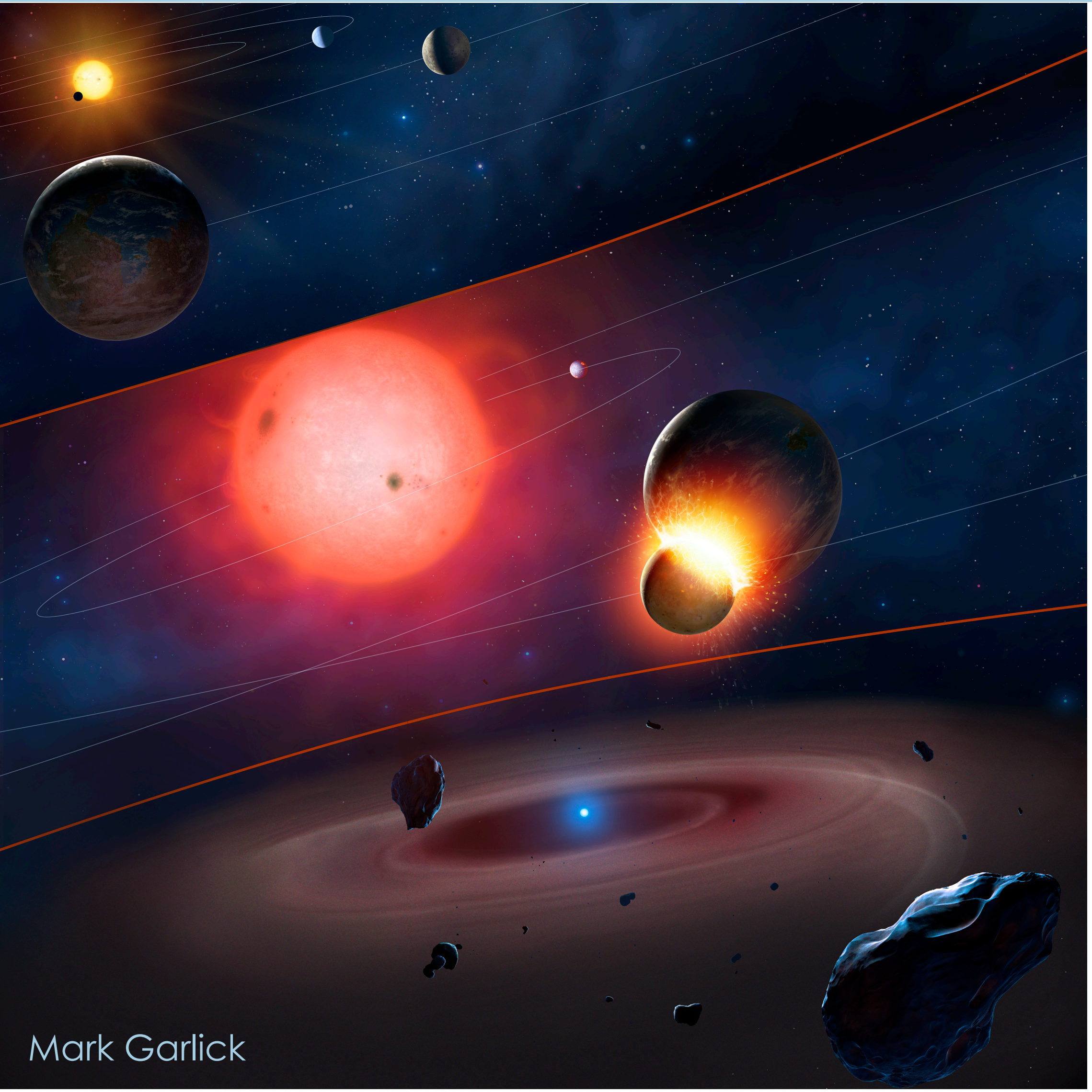
- Roughly 50% of WD are metal polluted
- Less than 10% of **massive** WDs are metal polluted

$M_{WD} > 0.8\ M_{\odot}$
descending from ZAMS mass $M > 3.5\ M_{\odot}$

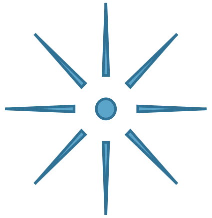


Does the lack of metal pollution in massive WDs represent single star evolution alone?

Remnant planets around white dwarfs



As star radius increases, planets are disrupted. While the star loses mass, **orbits expand**.



Planetesimals' orbits are destabilized. Planets at distant orbits may survive.

Metal pollution in white dwarfs

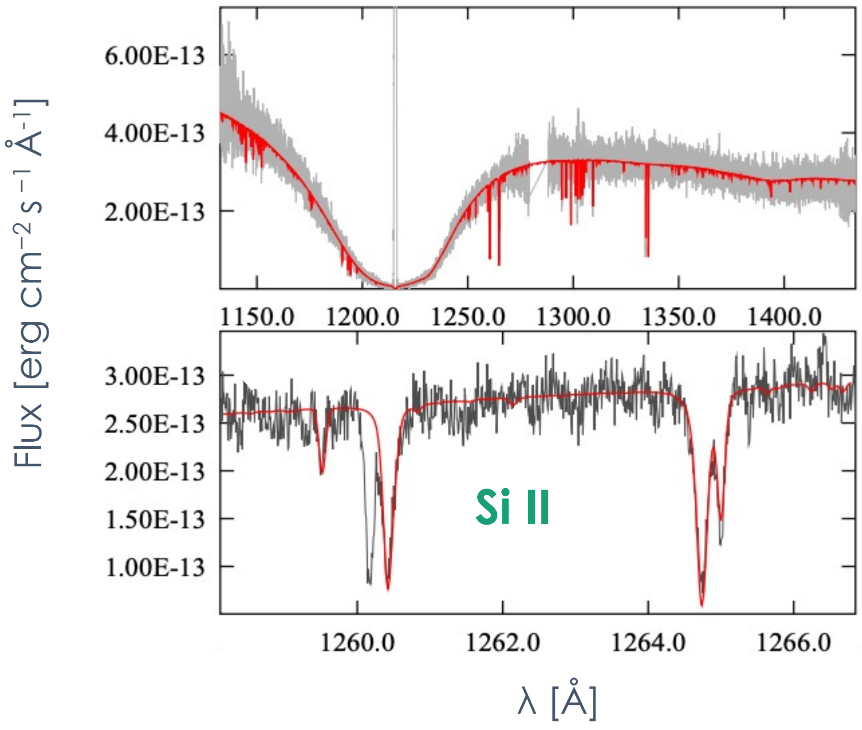
Accretion of scattered, tidally disrupted planetary debris onto the WD.

WD abundances are alike **Bulk Earth** with elements such as Fe, O, Mg, or Si. *(Xu+ 2014)*

Pollution detected through photospheric trace metals with **silicon** absorption lines.

Indicates 1 surviving planet and a reservoir of planetesimals *(Veras 2016, Farihi 2016)*

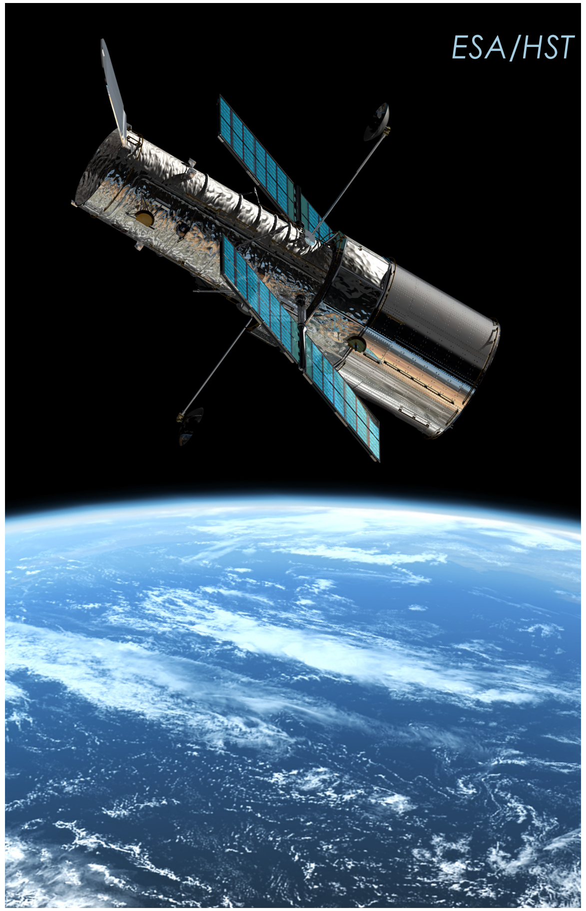
complete COS spectral range



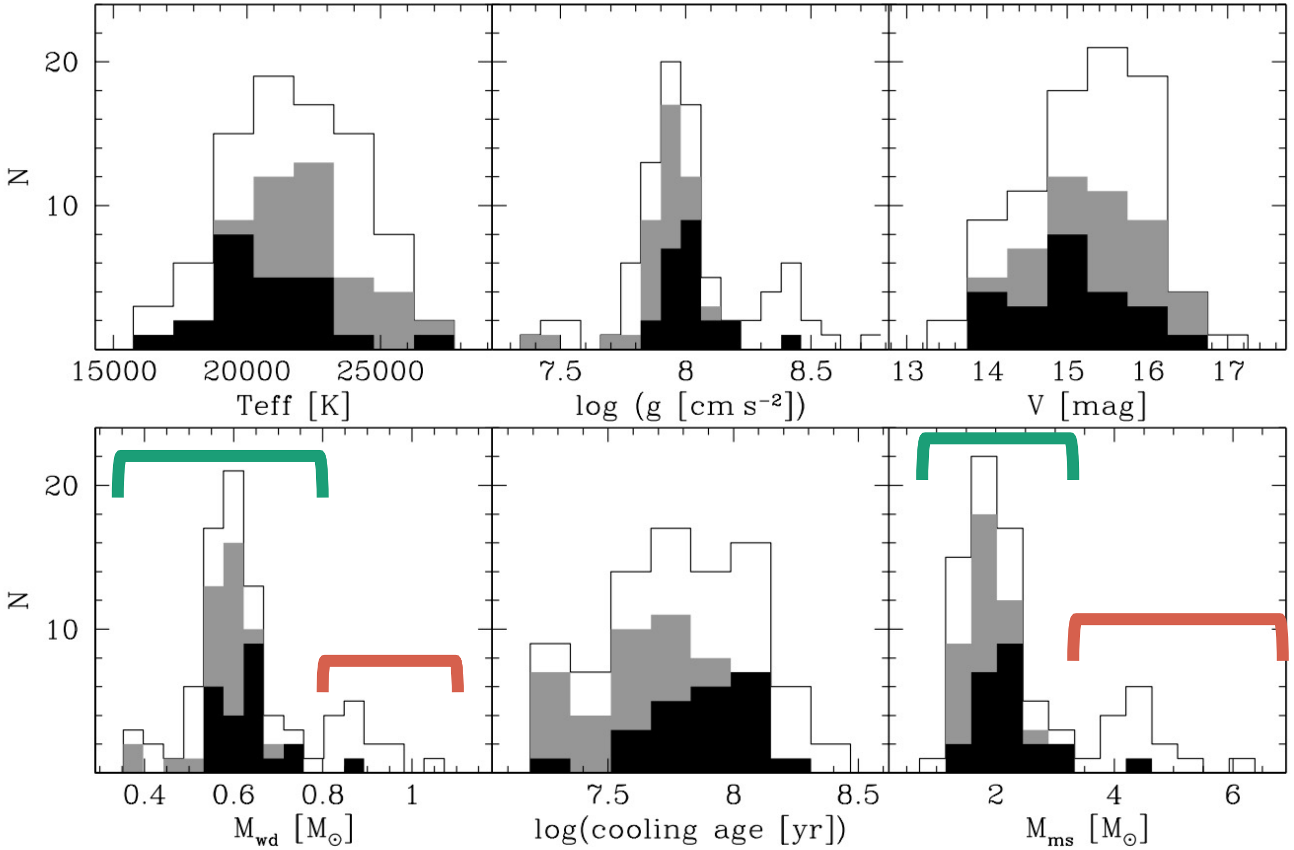
Koester, Gänsicke & Farihi. 2014

Snapshot Program with *HST/COS*

HST/COS: UV spectra of bright, hot WDs sensitive to metal pollution.



2014 : ~ 100 stars observed

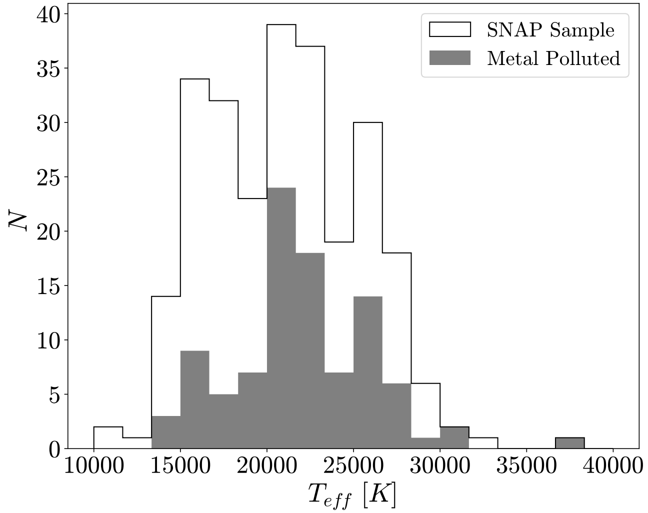


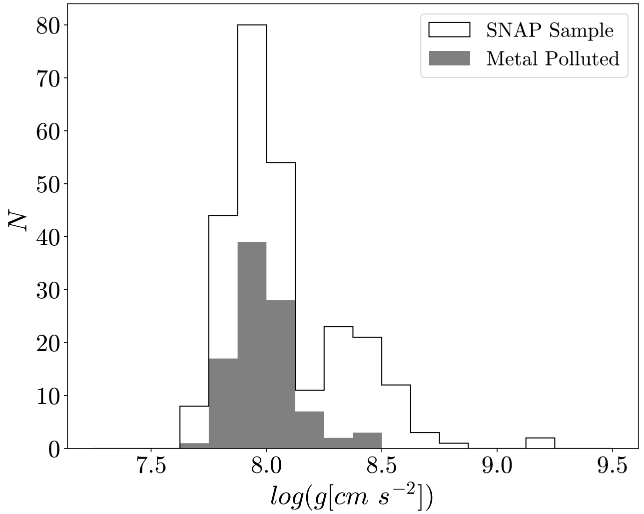
- WDs with ZAMS mass 1.0-3.5 $M_\odot$: **30-50%** metal polluted (48/85)
- WDs with ZAMS mass M > 3.5 $M_\odot$: **< 10%** metal polluted (1/12)

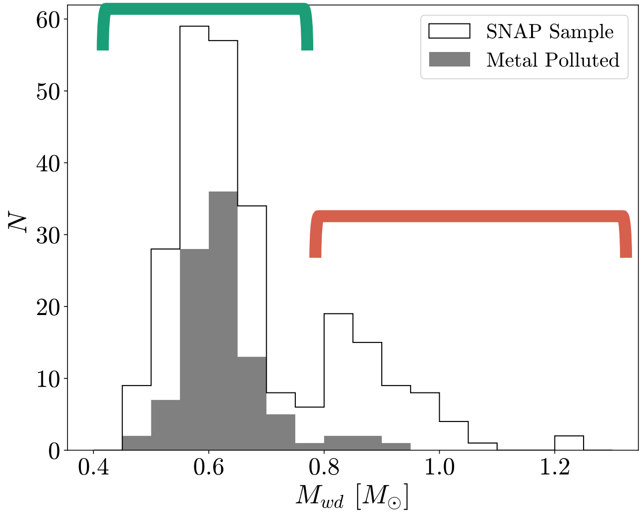
Si detected, active accreted
Si detected, likely recent accretion

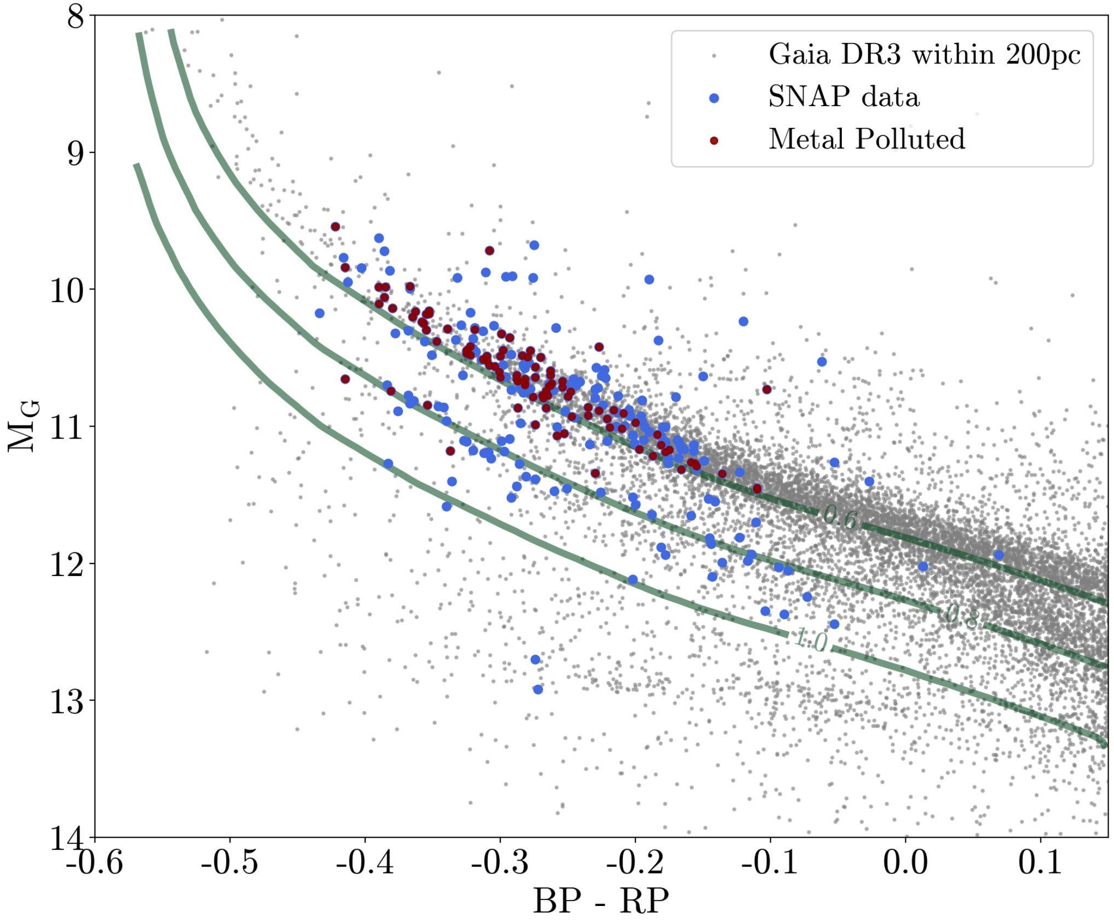
Koester, Gänsicke & Farihi. 2014

Snapshot Program with HST/COS









Cycle 25: ~ 300 WDs

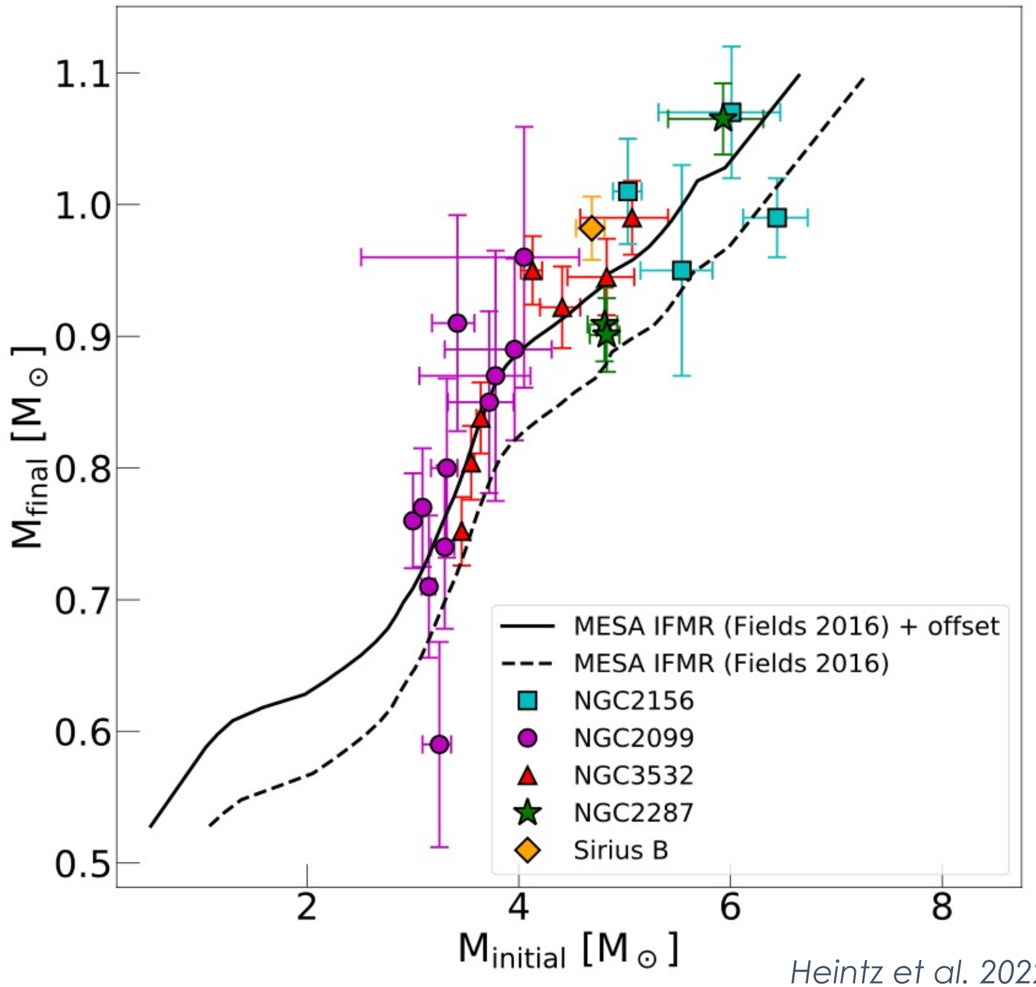
Mass derived from **spectroscopic** temperature and surface gravity.

When increasing the size of the sample, the parameters distributions seem to stay consistent.

Connecting progenitor mass

Atmospheric models to determine WD mass and cooling ages *(Bédard+22, Camisassa+2019)*

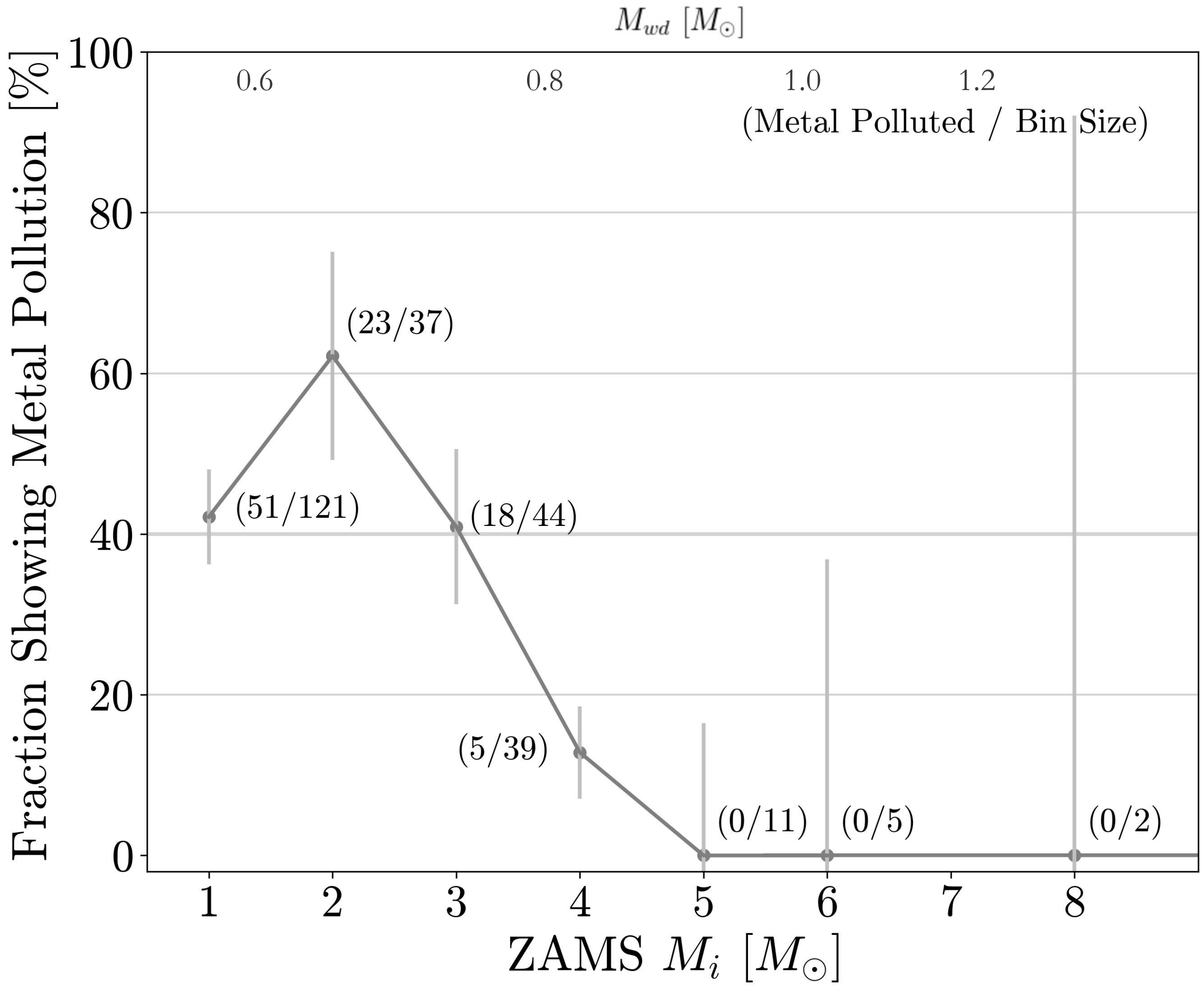
Initial-final-mass-relation (**IFMR**) calibrated using wide binaries gives ZAMS mass. *(Heintz+22)*



Heintz et al. 2022

⚠️ Other factors may create uncertainties such as metallicity, rotation rates…

Metal pollution fraction consistent with 2014 analysis



- **SNAP sample 37% ± 6% metal polluted** detected to a limit of log(Si/H) ~ -7.5 or 10^5 g/s

- WDs with ZAMS mass **M < 3.5 $M_\odot$** : **46% ± 5%** metal polluted
- WDs with ZAMS mass **M > 3.5 $M_\odot$** : **9% $\pm^{6}_{4}$%** metal polluted
- **WDs with ZAMS M > 4.5 $M_\odot$: <10% metal polluted!**
  (0/18)

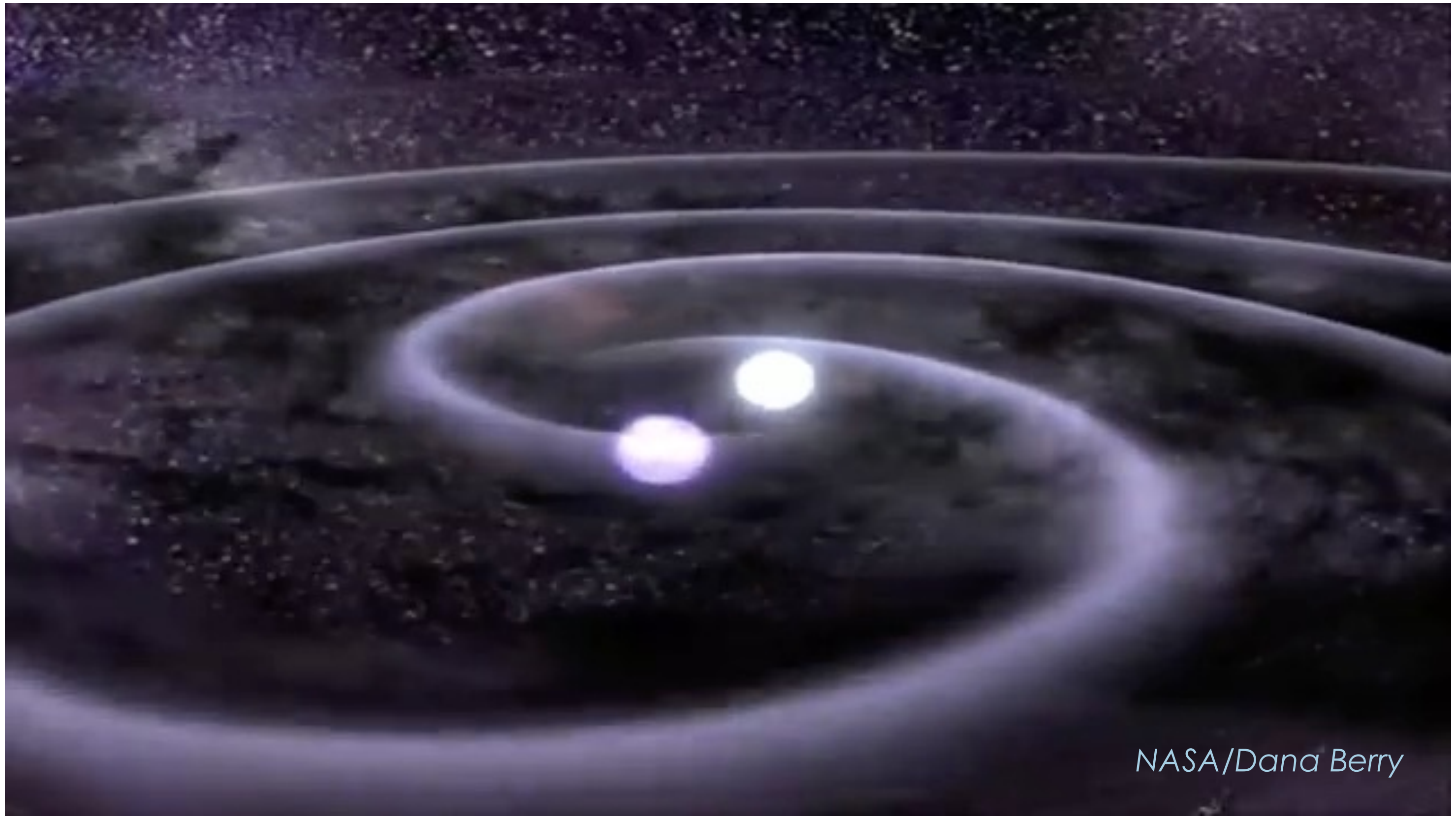
The number of stars increased at least 3 times, yet we observe similar statistics.

What does this say about planetary occurrence rates?

Consensus that a substantial number of massive WDs are the product of **mergers**.

Violent evolution of merger remnants would make the survival of planetary bodies unlikely.

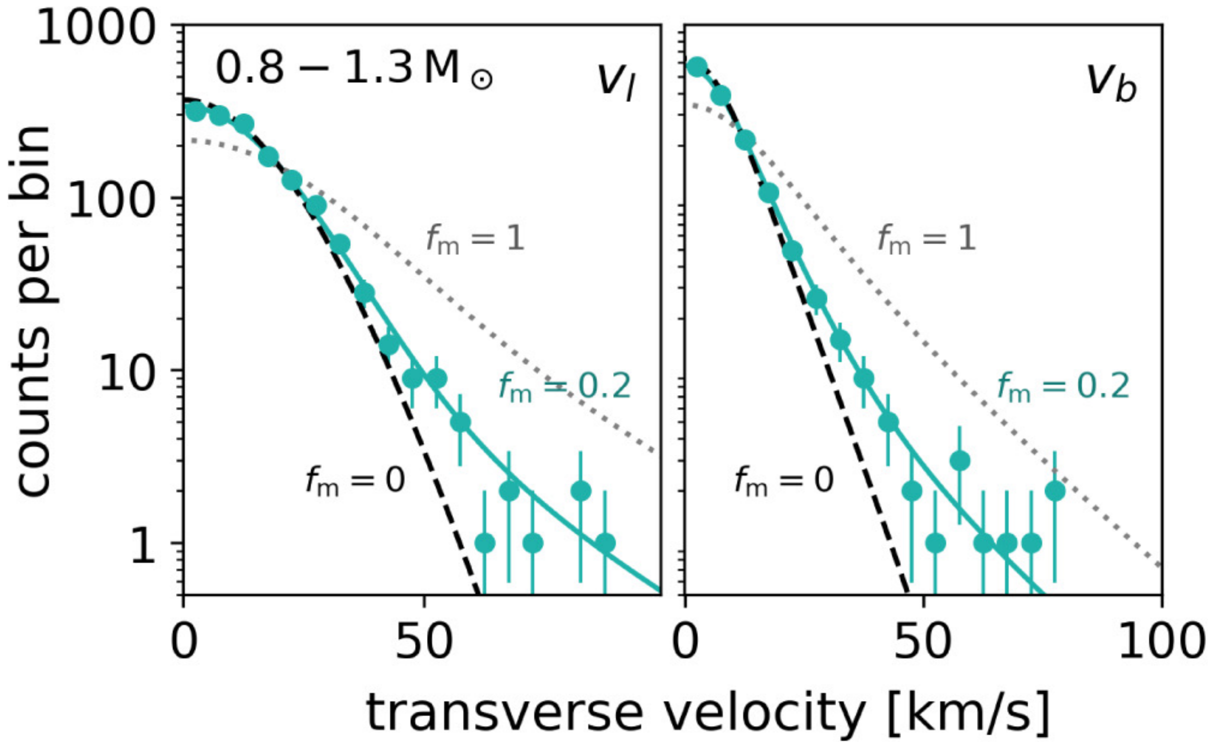
Could merger byproducts contamination explain the metal pollution distribution?


NASA/Dana Berry

Gaia shining light on merger remnant contamination

Massive WDs are expected to have slow kinematics.
Predicted velocity distributions correlated with WD ages (Holmberg et al. 2009).

Based on Gaia DR2, WDs with mass > 0.8 $M_\odot$ show
20% merger byproducts contamination (Cheng+2020)



Cheng et al. 2020

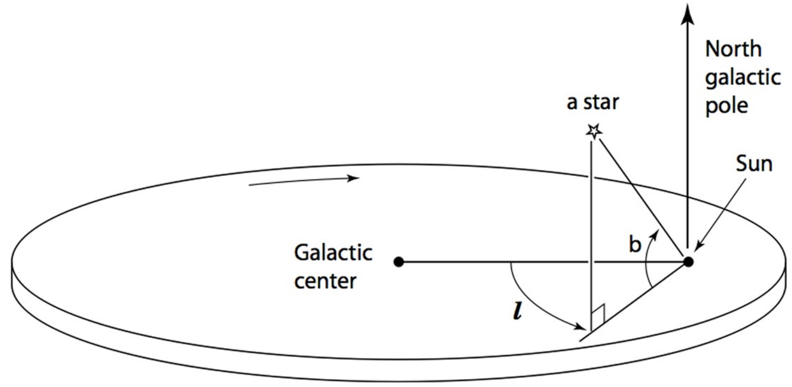
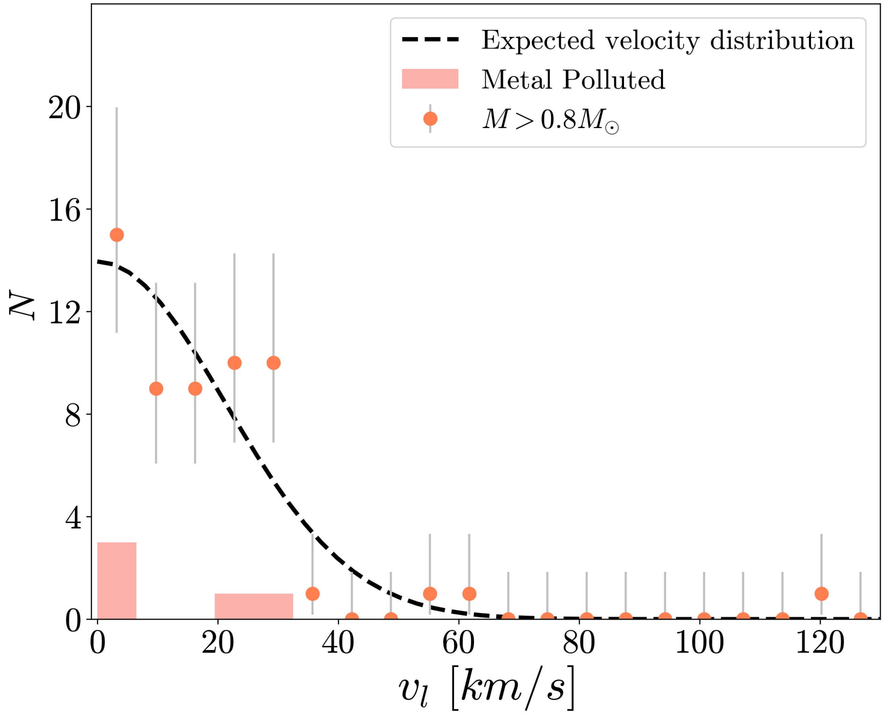
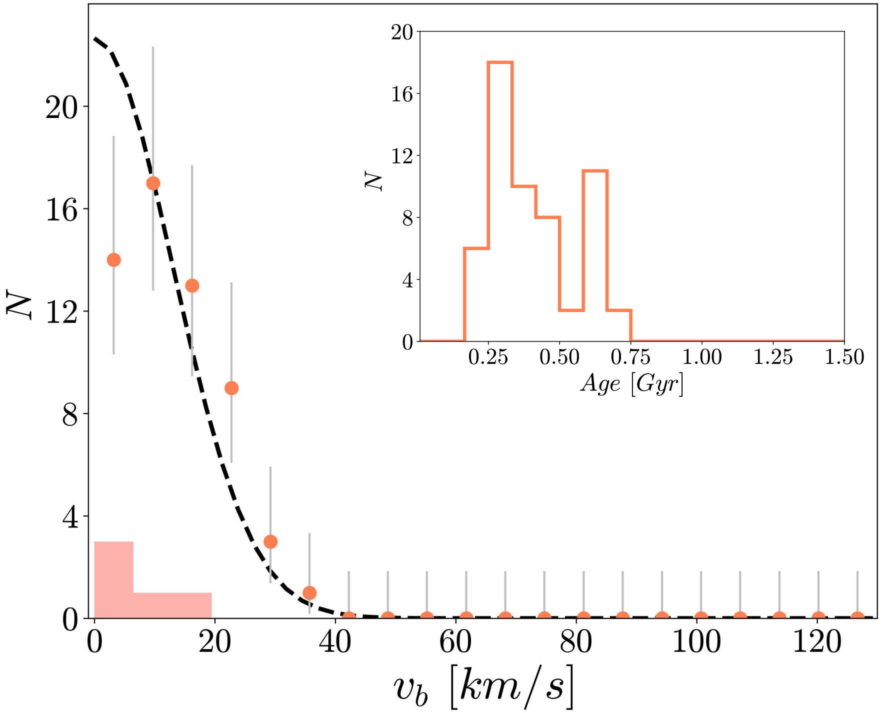


Figure 1.3 A schematic picture of the Sun's location in the Galaxy, illustrating the Galactic coordinate system. An arrow points in the direction of Galactic rotation, which is clockwise as viewed from the north Galactic pole.

Binney & Tremaine, Galactic Dynamics (2nd edition)

Velocity Distributions of *HST* SNAP





- **WDs with ZAMS mass M > 3.5 $M_\odot$ show few kinematics outliers**

Kinematics outliers would be representative of mergers within the sample.
The massive SNAP sample is consistent with mostly single-star kinematics, $f_m = 0$.

We cannot conclude high merger remnant contamination.

Future Work

- Higher number statistics to further rule out merger remnants contamination hypothesis.

Further connect metal pollution of WDs to planetary occurrence around B stars on the main sequence:

- Explore **planetary disks lifetimes** around massive stars.
- Explore **planetary architecture**
- Explore **binary fraction** among massive WDs.

Summary

- *HST*/COS cycle 25 Snapshot program has confirmed that **massive WDs ($M > 3.5\ M_\odot$)** have a **metal pollution fraction of $9\% \pm^{6}_{4}\%$.**

- **On average**, we observe **$37\% \pm 6\%$ metal polluted** white dwarfs over the SNAP sample.

- After exploring the kinematics, the SNAP sample is **not dominated by merger remnants at $M > 3.5\ M_\odot$** and is consistent with mostly single-star evolution.