Low-mass Stars with Extreme Mid-Infrared Excesses: Potential Signatures of Planetary Collisions

Dissertation Defense Talk

Christopher A. Theissen

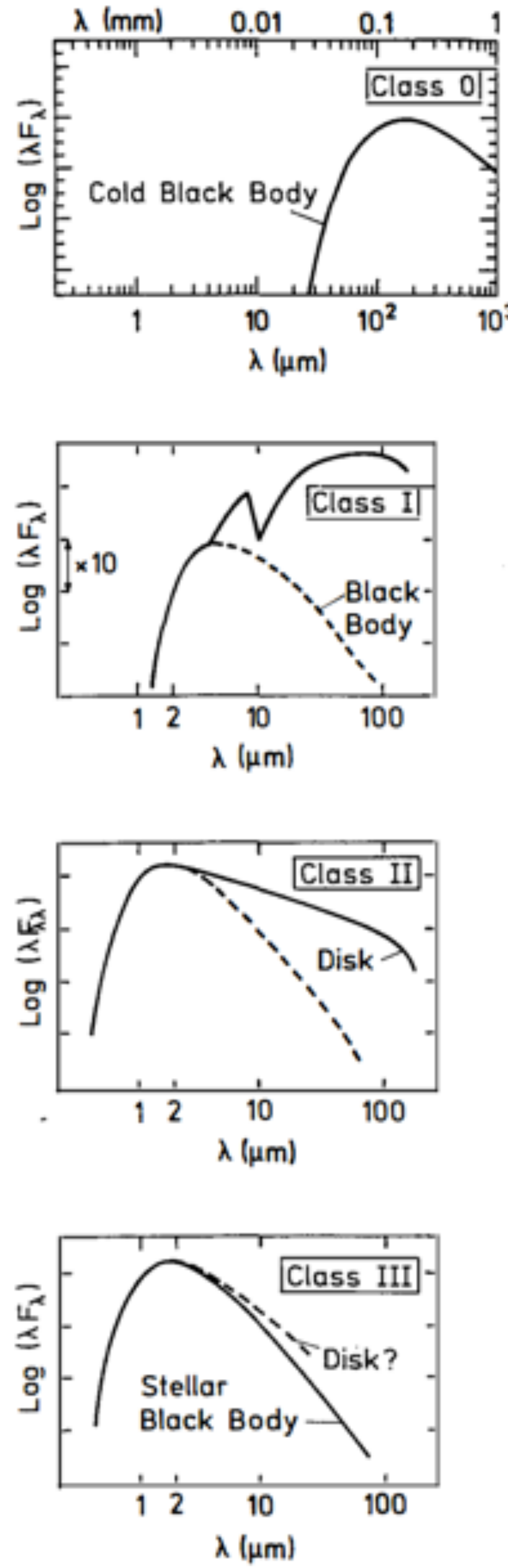
July 17, 2017

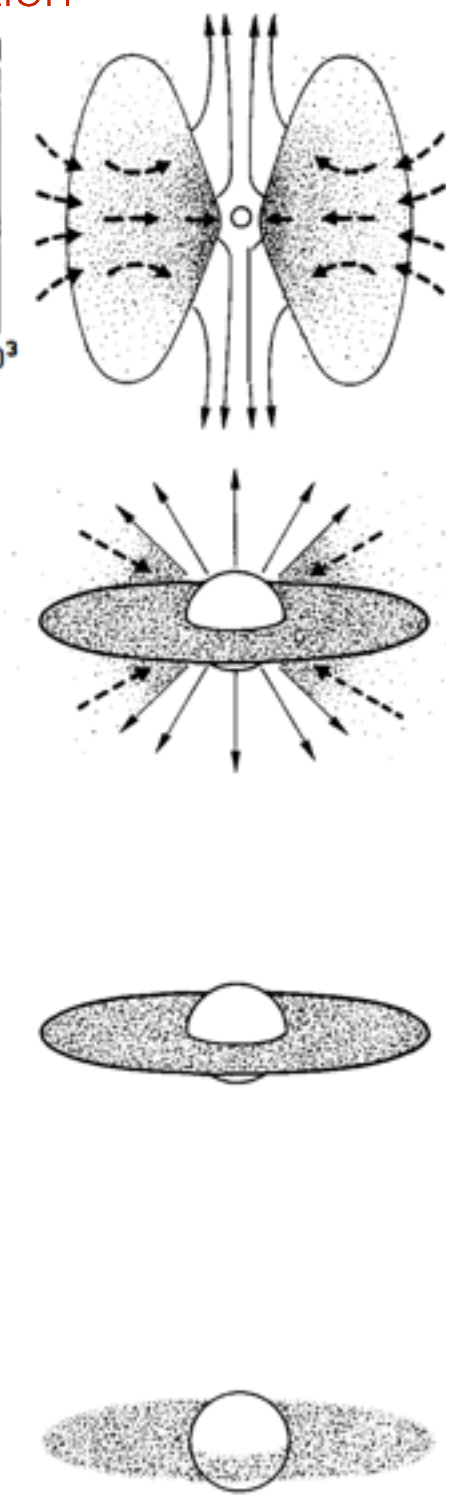
Driving Questions

- How often do low-mass stars in the field exhibit extreme MIR excesses?
- What are the physical trends we observe for low-mass stars exhibiting extreme MIR excesses?
- Do binary systems exhibit extreme MIR excesses more often than single stars?

Star/planet formation in a nutshell

Spectral Energy Distribution





André (1994)

Peaks in the far-IR

< 10,000 years

Peak flux moves to shorter wavelengths

~100,000 years

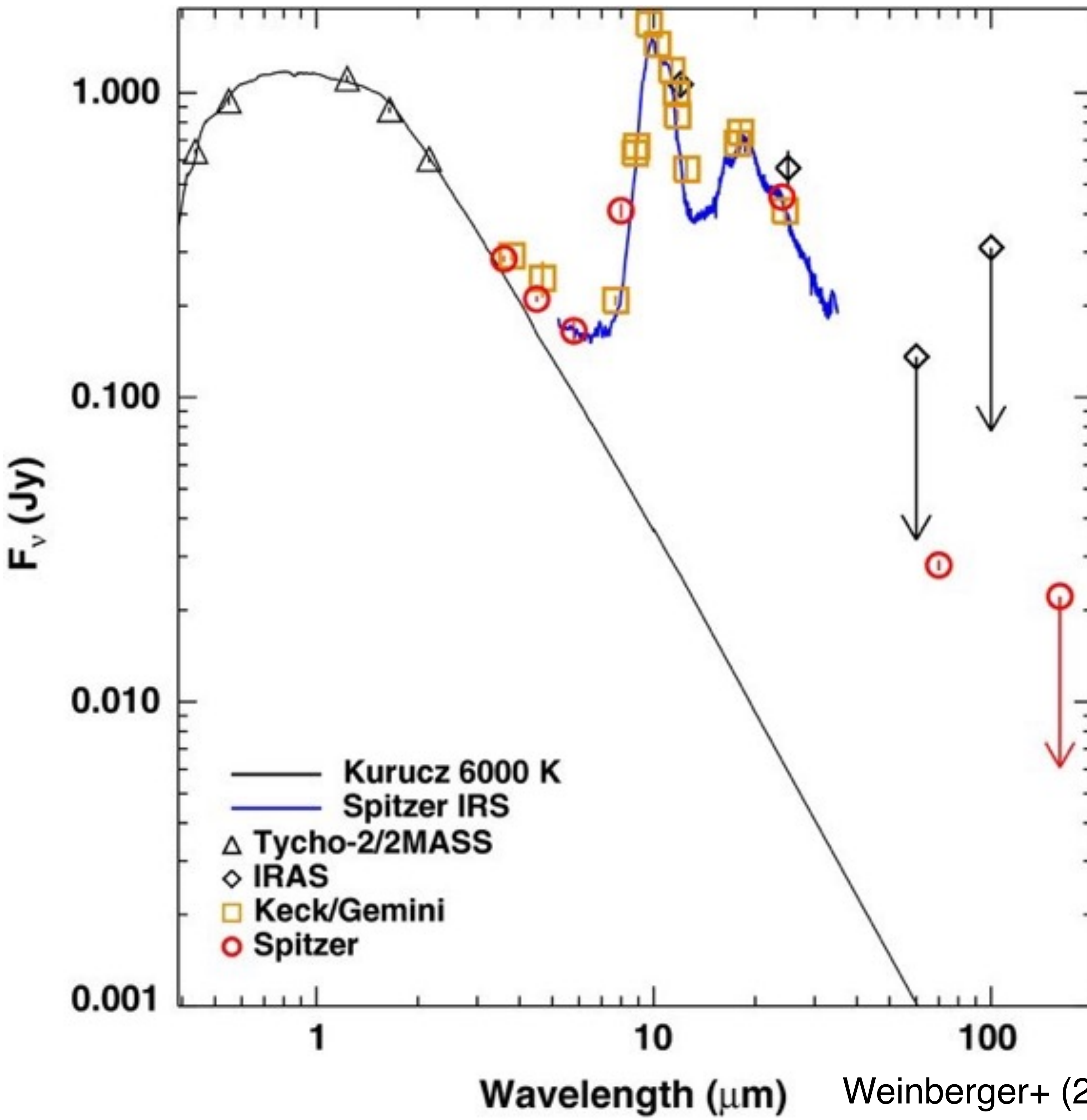
Star is now visible in the optical

~ 1 million years

Flux dominated by star, with a potential small MIR excess

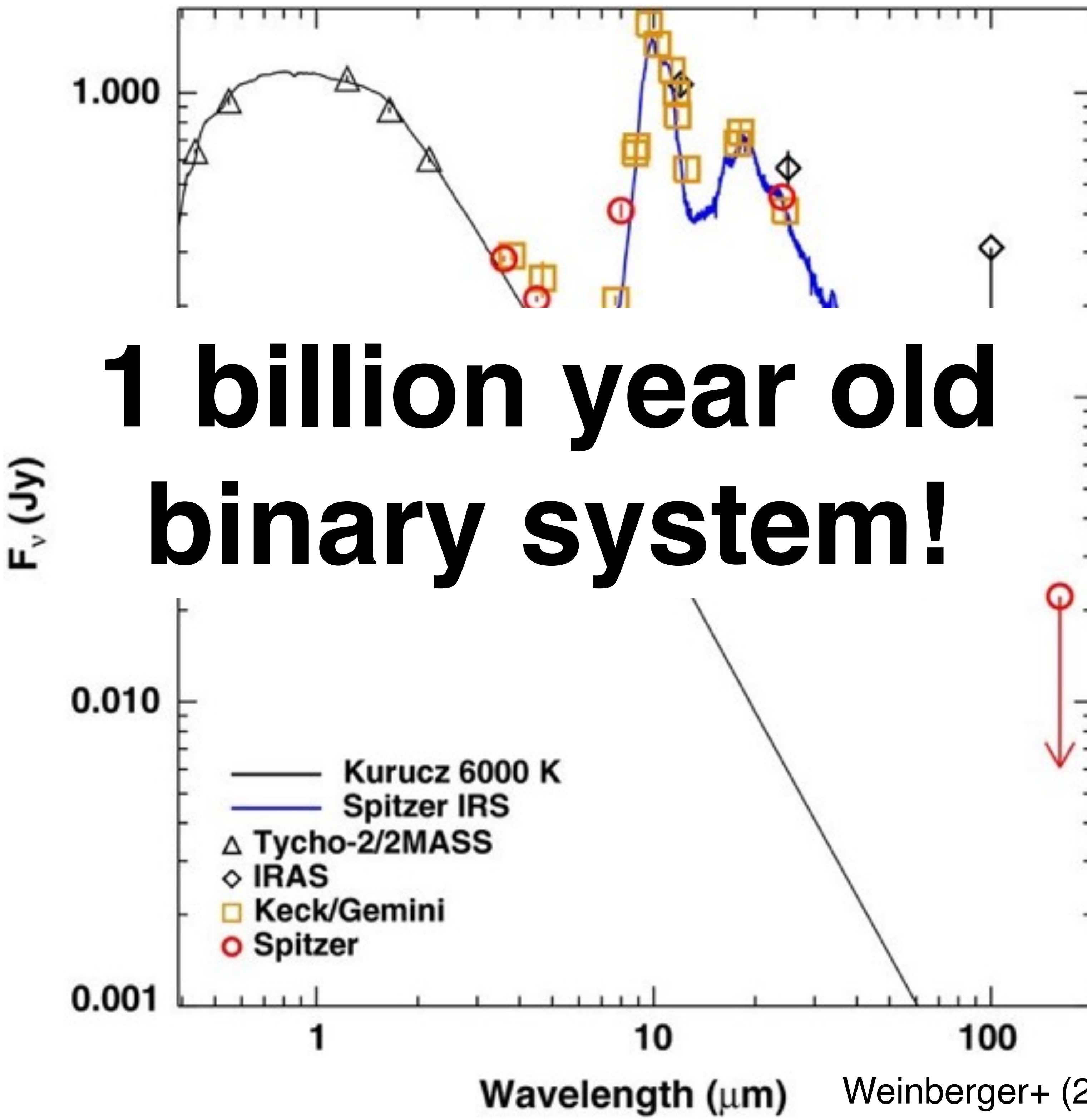
>10 million years

“Extreme” MIR Excesses



Weinberger+ (2011)

“Extreme” MIR Excesses



1 billion year old binary system!

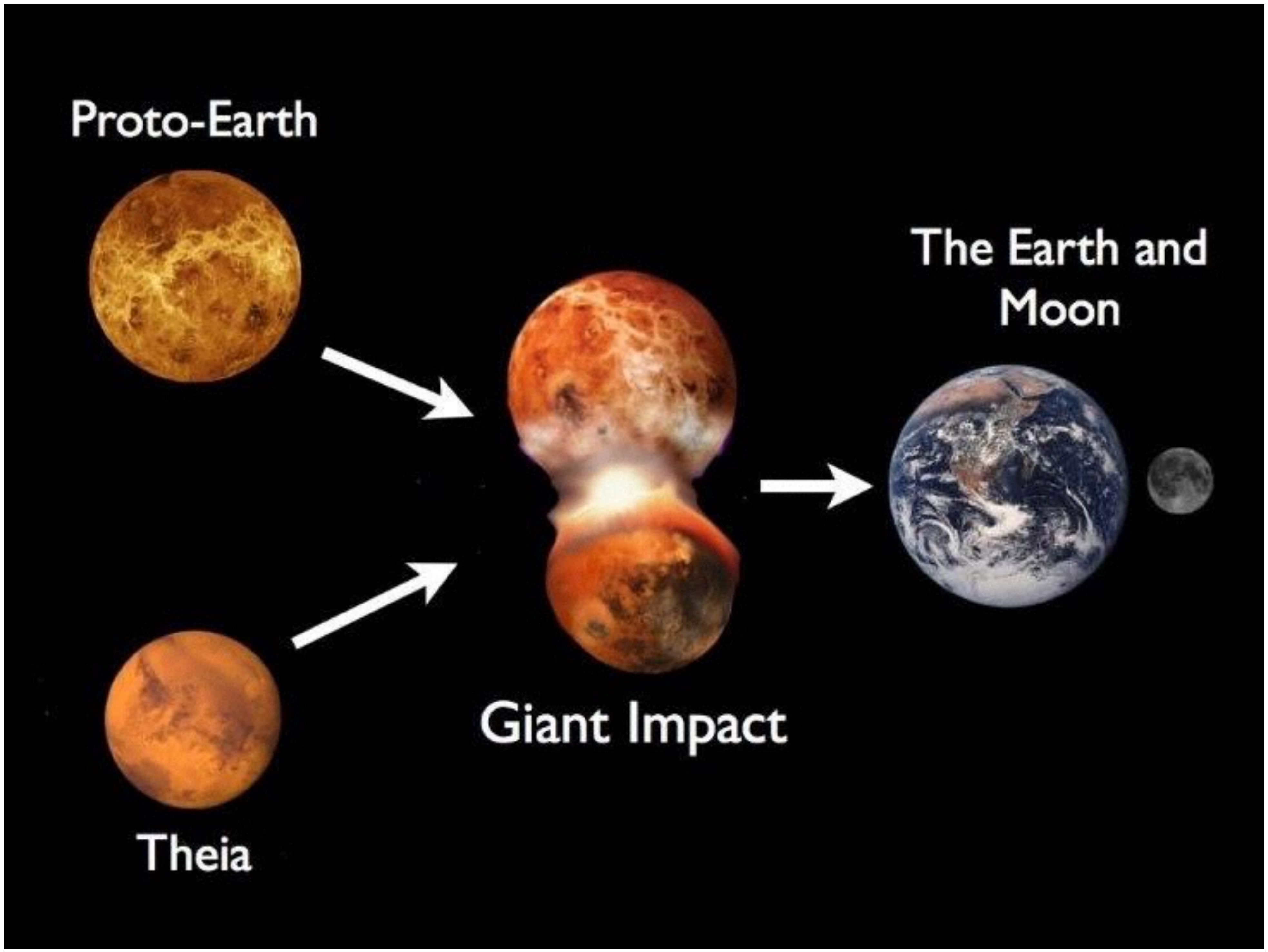
Weinberger+ (2011)

What is the interpretation?

Credit: NASA/JPL

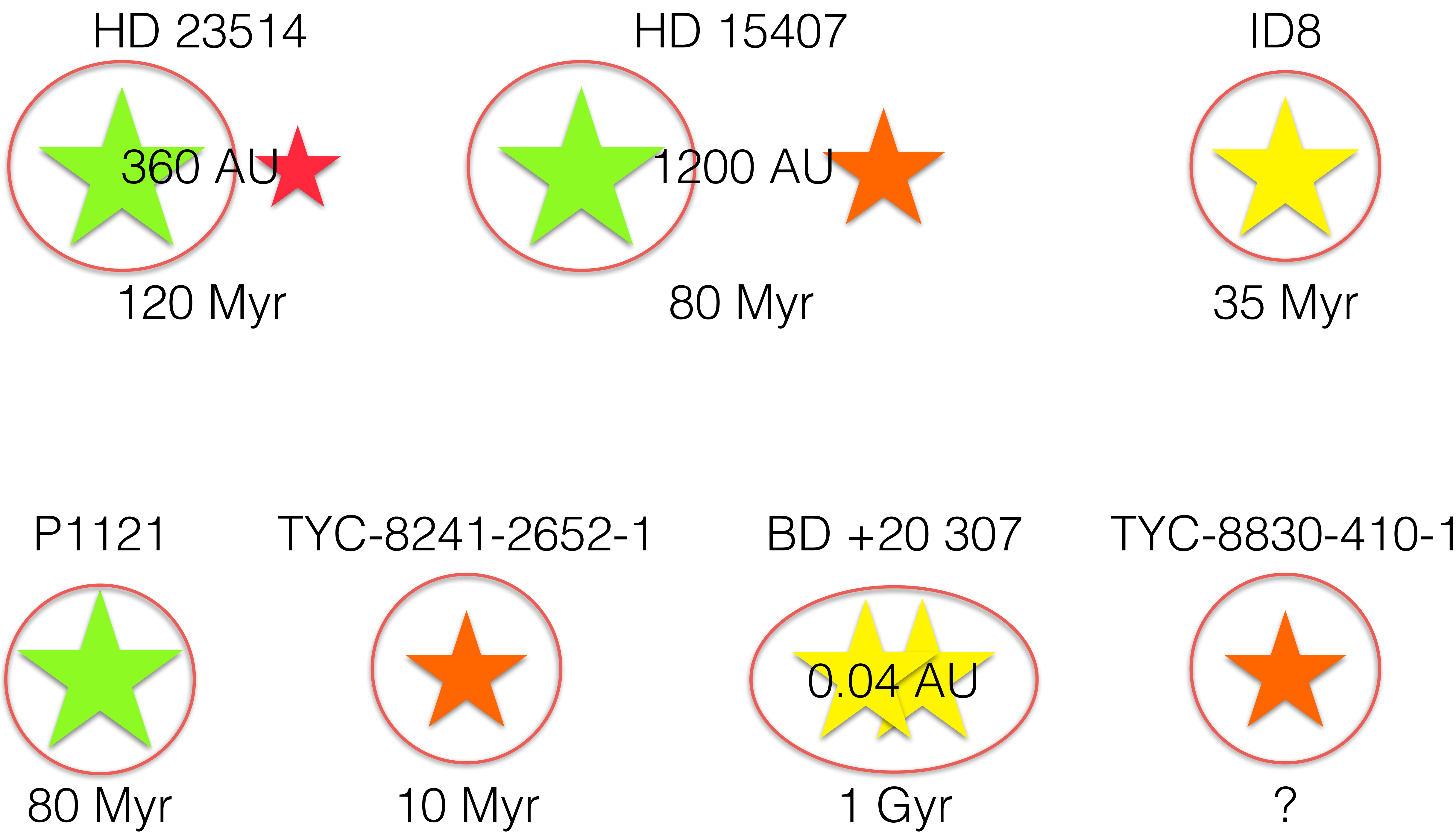
Collisions between terrestrial planets

What is the interpretation?



Credit: S. Raymond

Seven systems currently known



Seven systems currently known

HD 23514

360 AU

120 Myr

HD 15407

1200 AU

80 Myr

ID8

35 Myr

All solar-type (FGK) stars.

Why are there no low-mass stars in the sample?

P1121

80 Myr

TYC-8241-2652-1

10 Myr

BD +20 307

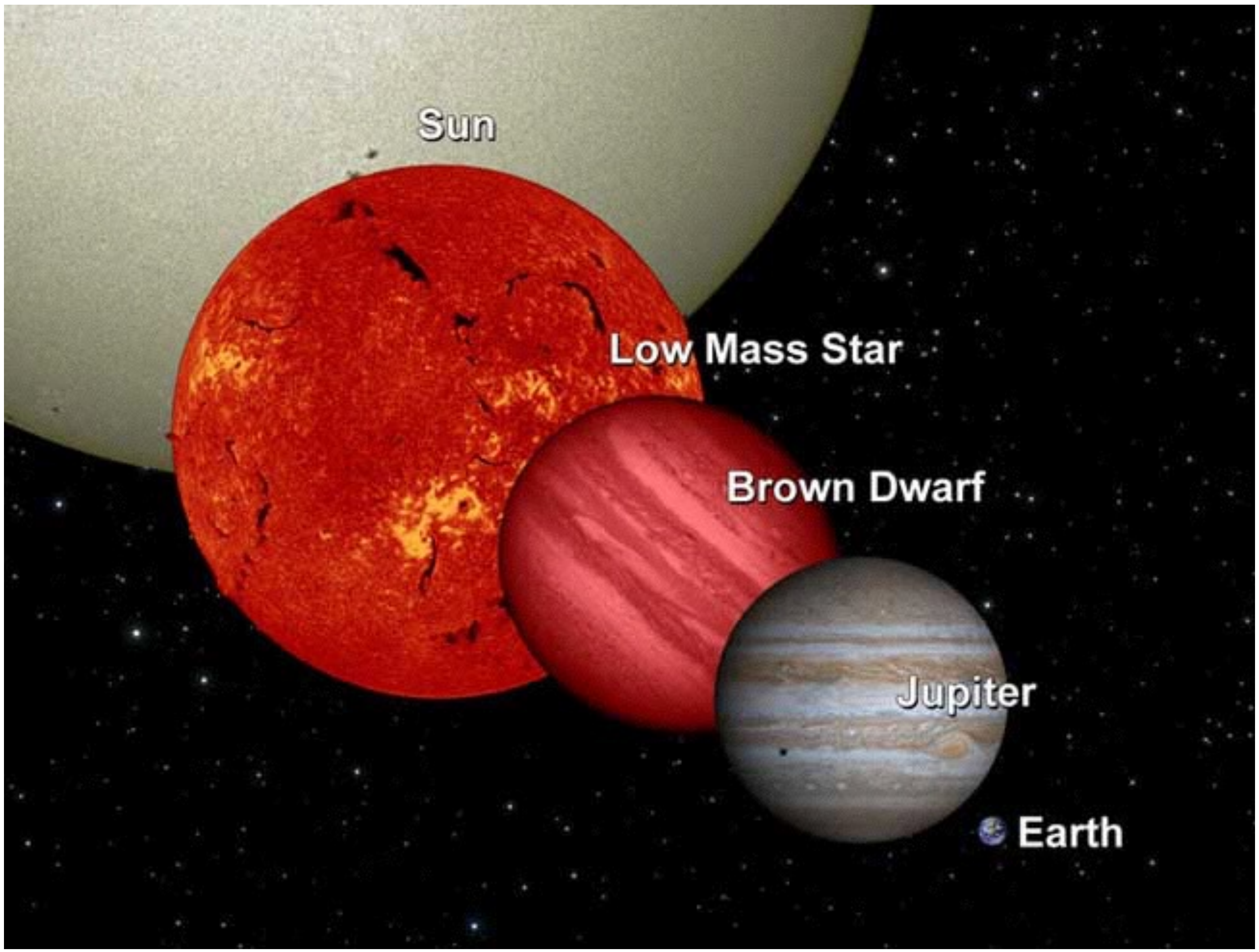
0.04 AU

1 Gyr

TYC-8830-410-1

?

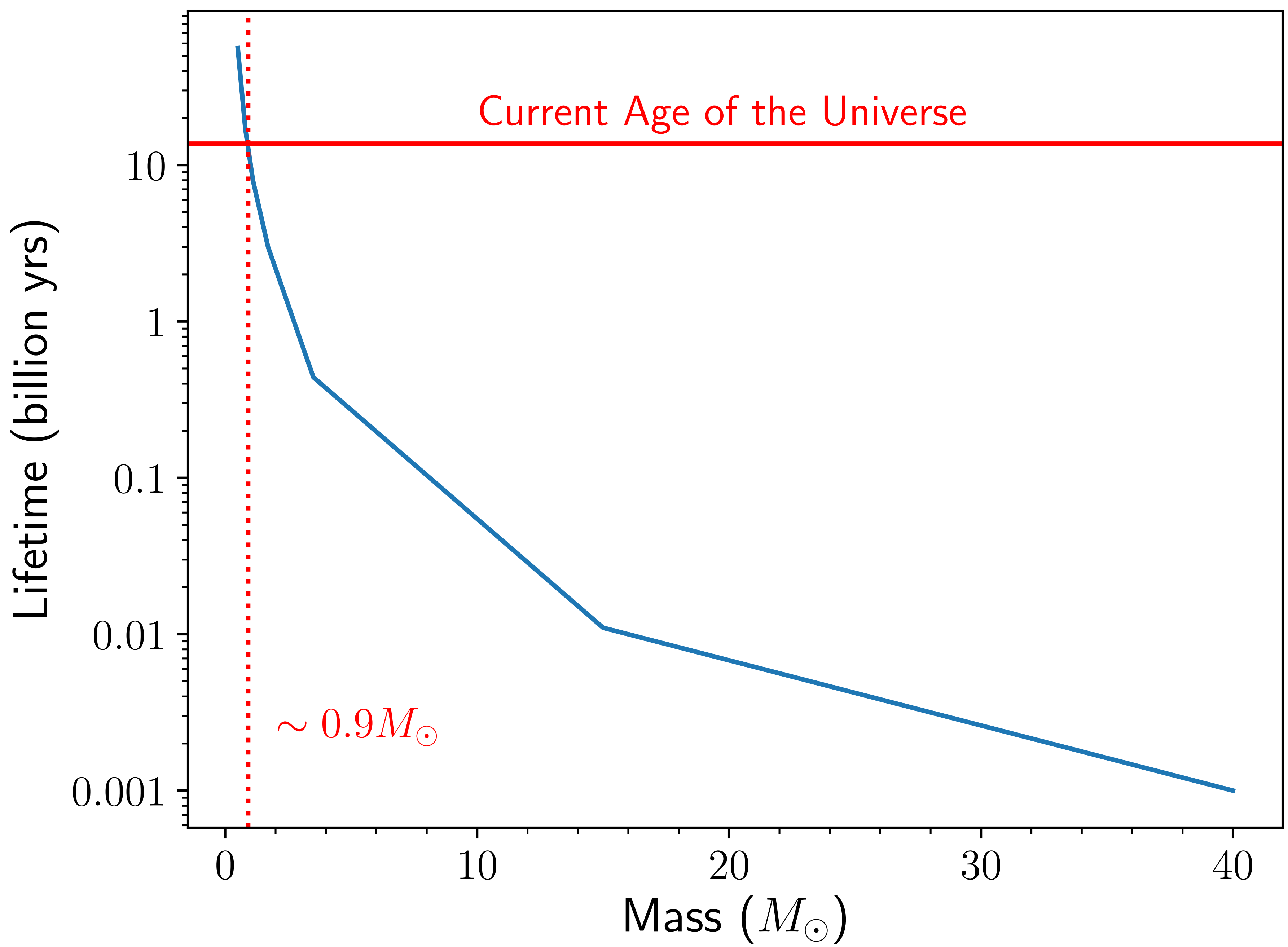
What exactly is a “low-mass” star?



Credit: NASA

- Less than 60% the mass of the Sun
- Cool stars (Temperatures < 4600 K)
- Red dwarfs
- M dwarfs

They have incredibly long (main sequence) lifetimes



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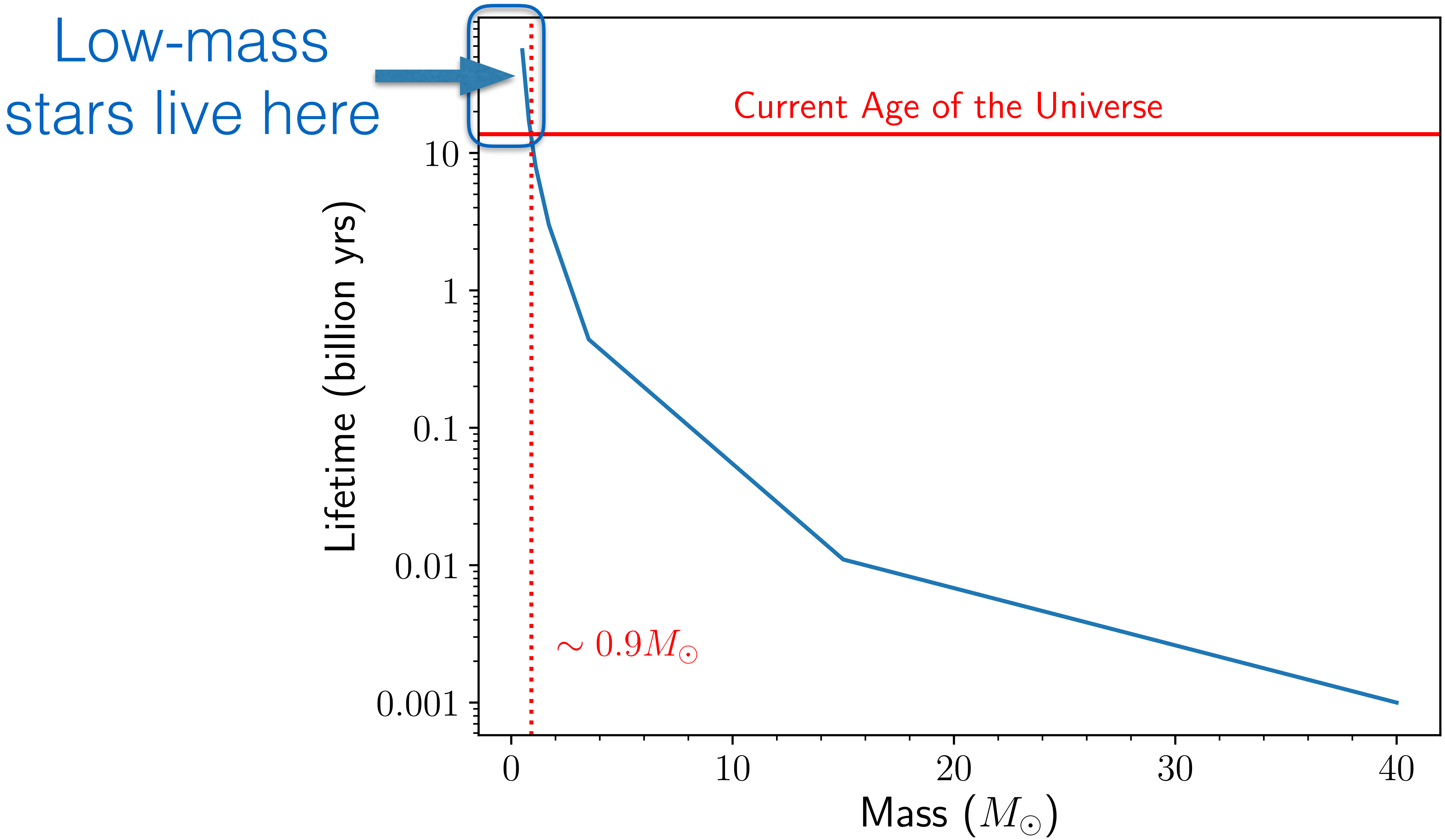
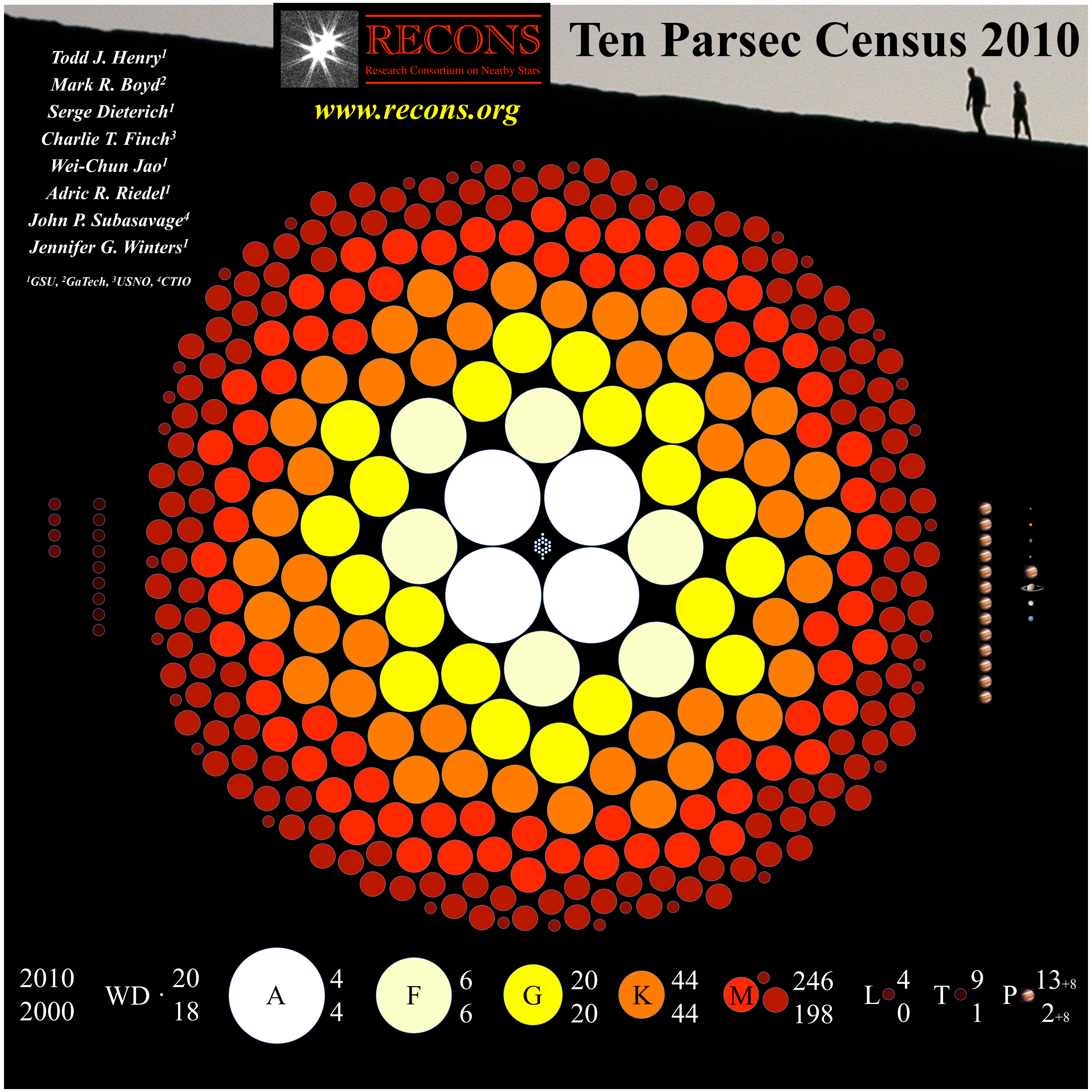


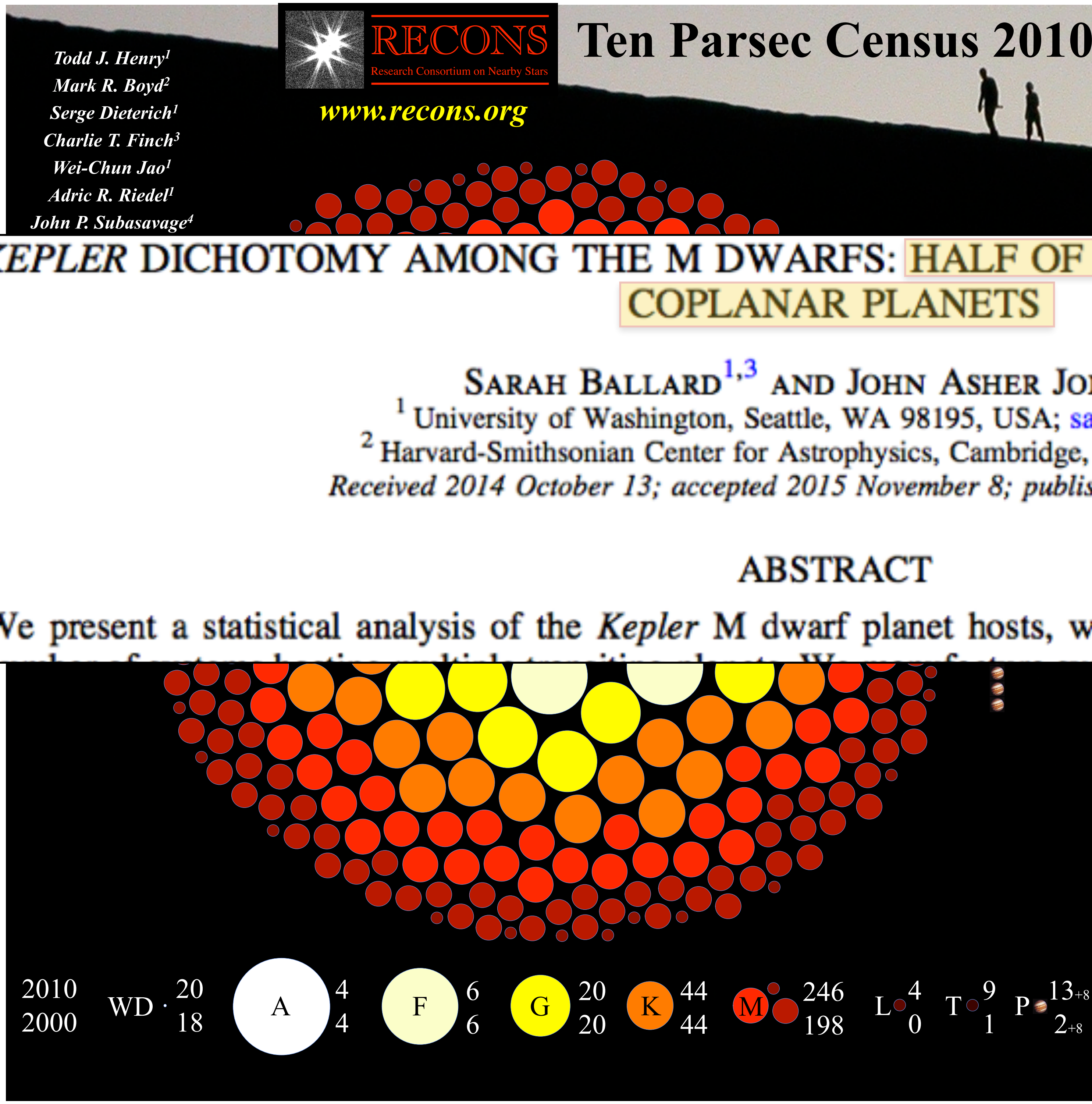
Low-mass Stars are Everywhere



Credit: RECONS

~70% of all stars are low-mass stars

Low-mass Stars are Everywhere (with Earth-sized Planets!)



THE *KEPLER* DICHOTOMY AMONG THE M DWARFS: HALF OF SYSTEMS CONTAIN FIVE OR MORE COPLANAR PLANETS

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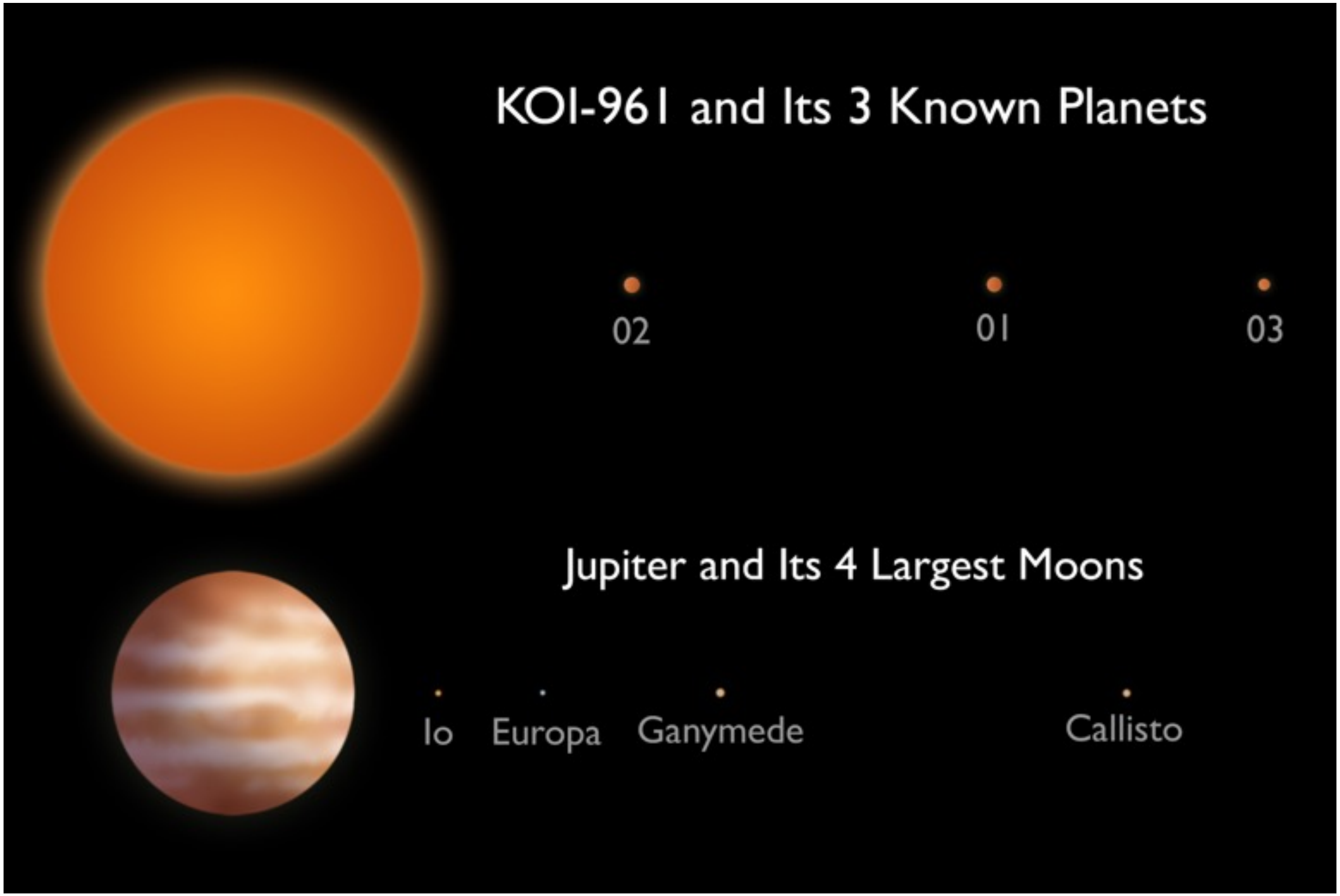
Received 2014 October 13; accepted 2015 November 8; published 2016 January 8

ABSTRACT

We present a statistical analysis of the *Kepler* M dwarf planet hosts, with a particular focus on the fractional

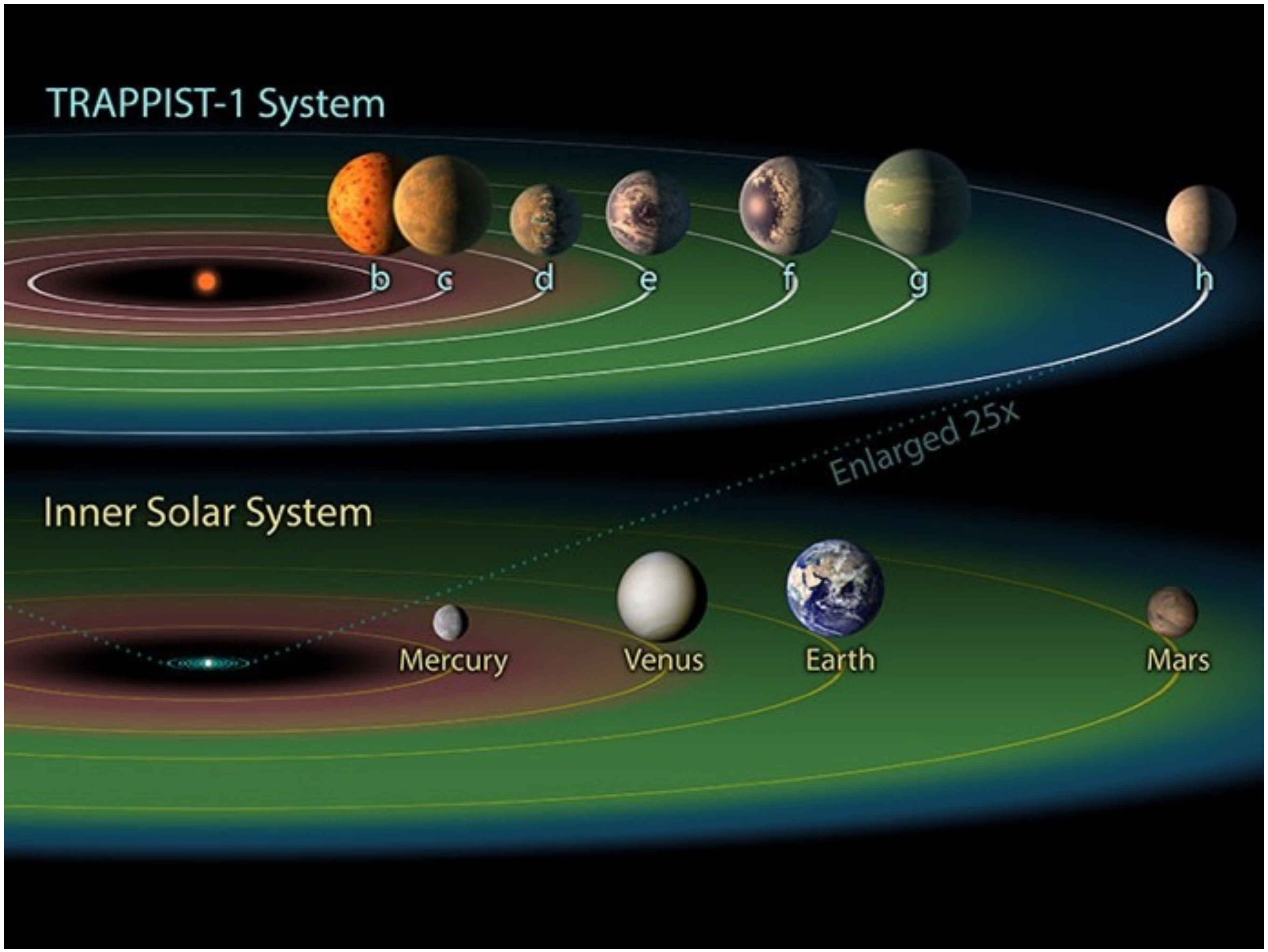
Credit: RECONS

Planets orbit close-in



Credit: Muirhead+ (2012)/NASA

Planets orbit close-in



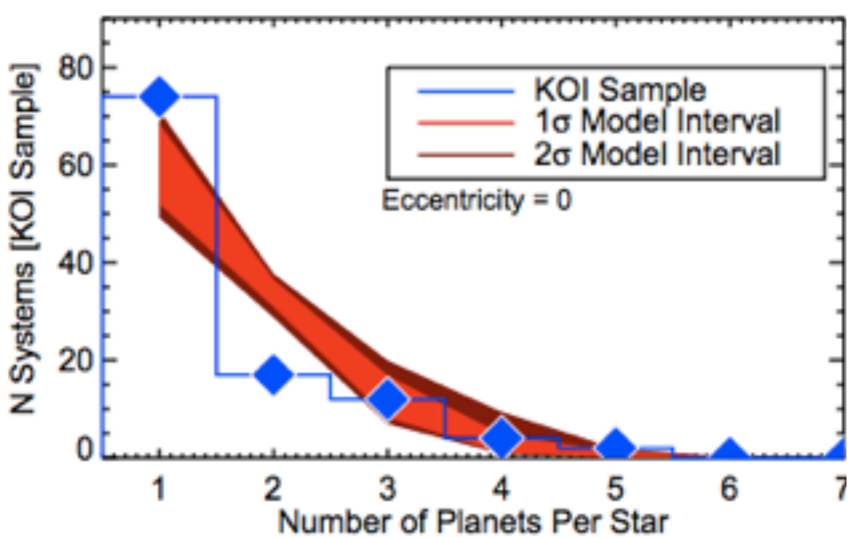
Credit: Gillon+ (2016, 2017)/NASA

The *Kepler* Dichotomy

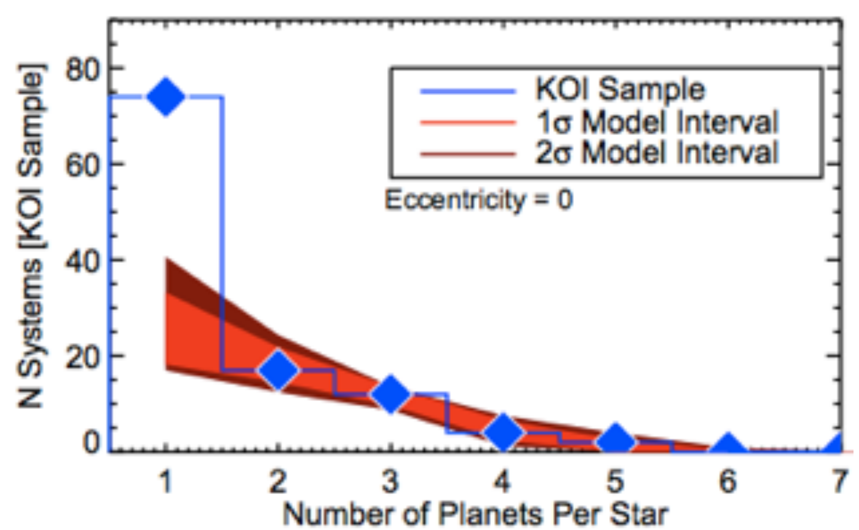
Kepler has found lots of multi- and single-transiting planetary systems.

- Both populations cannot be explained by the same planetary architecture (Ballard & Johnson 2016).

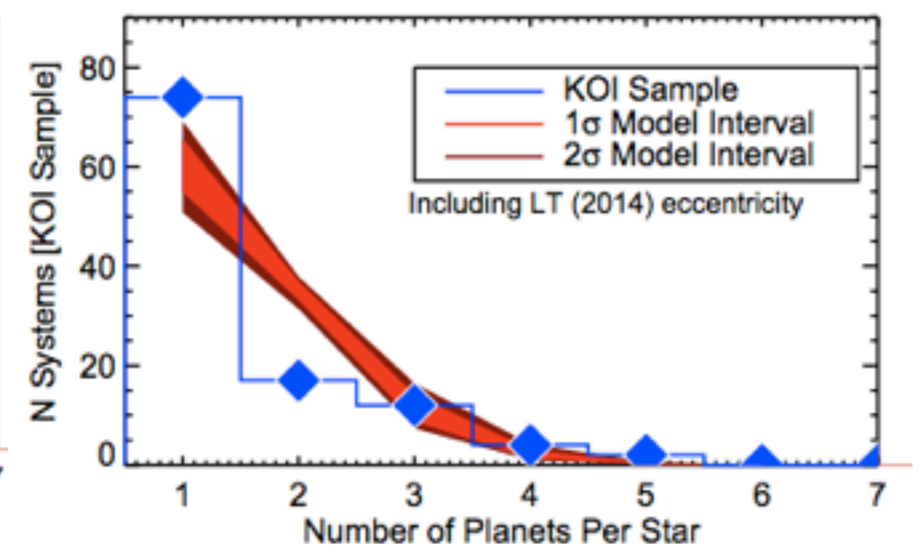
Multi-planet model



Multi-planet model excluding
single-transiting systems

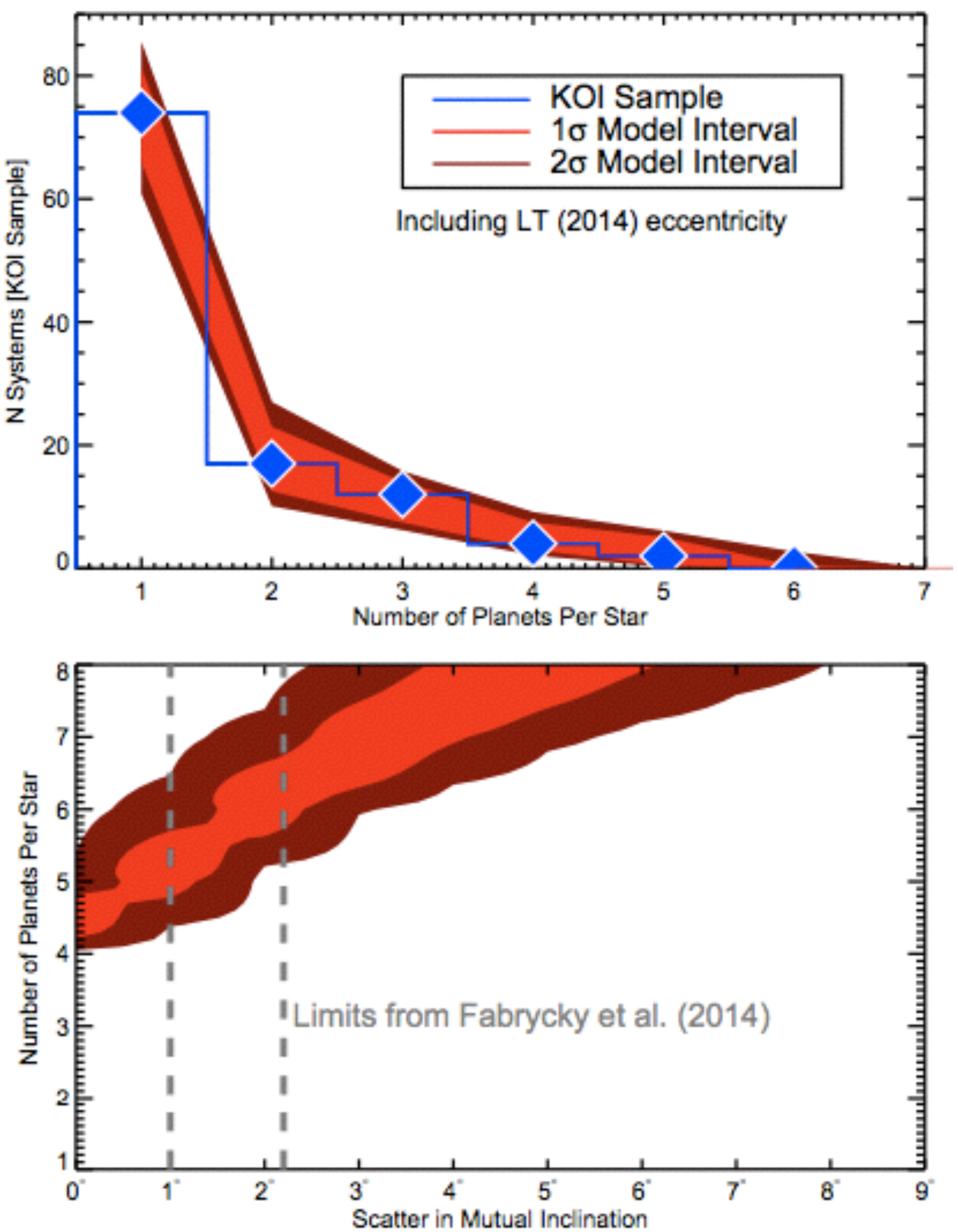


Multi-planet model
with eccentricities



Ballard & Johnson (2016)

The *Kepler* Dichotomy

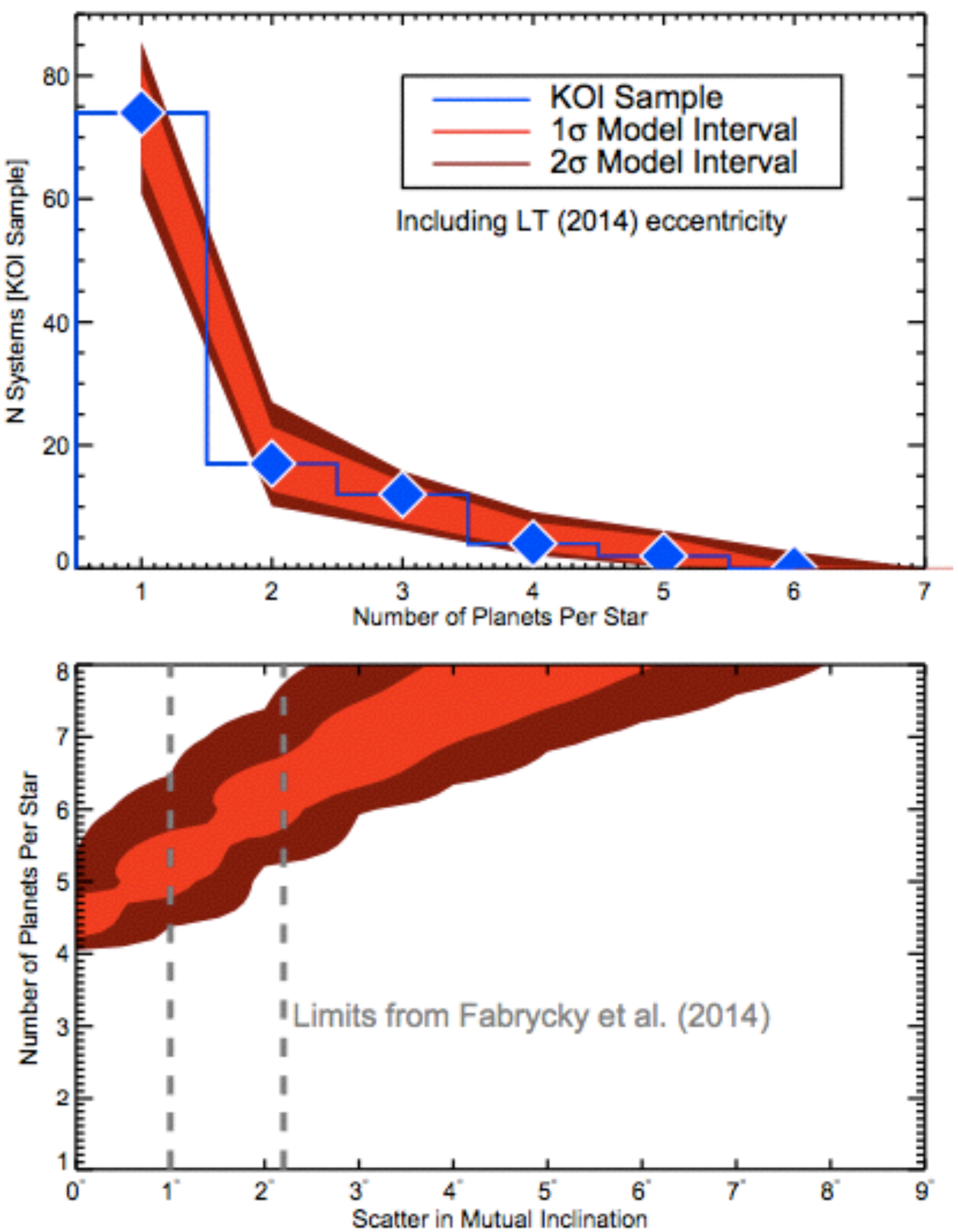


Ballard & Johnson (2016)

Mixture model for a dual population

Singles	Multis
slower stellar rotation rates	faster stellar rotation rates
farther from the Galactic plane	closer to the Galactic plane

The *Kepler* Dichotomy



Ballard & Johnson (2016)

Mixture model for a dual population

Older?	Younger?
slower stellar rotation rates	faster stellar rotation rates
farther from the Galactic plane	closer to the Galactic plane

Driving Questions

- How often do low-mass stars in the field exhibit extreme MIR excesses?
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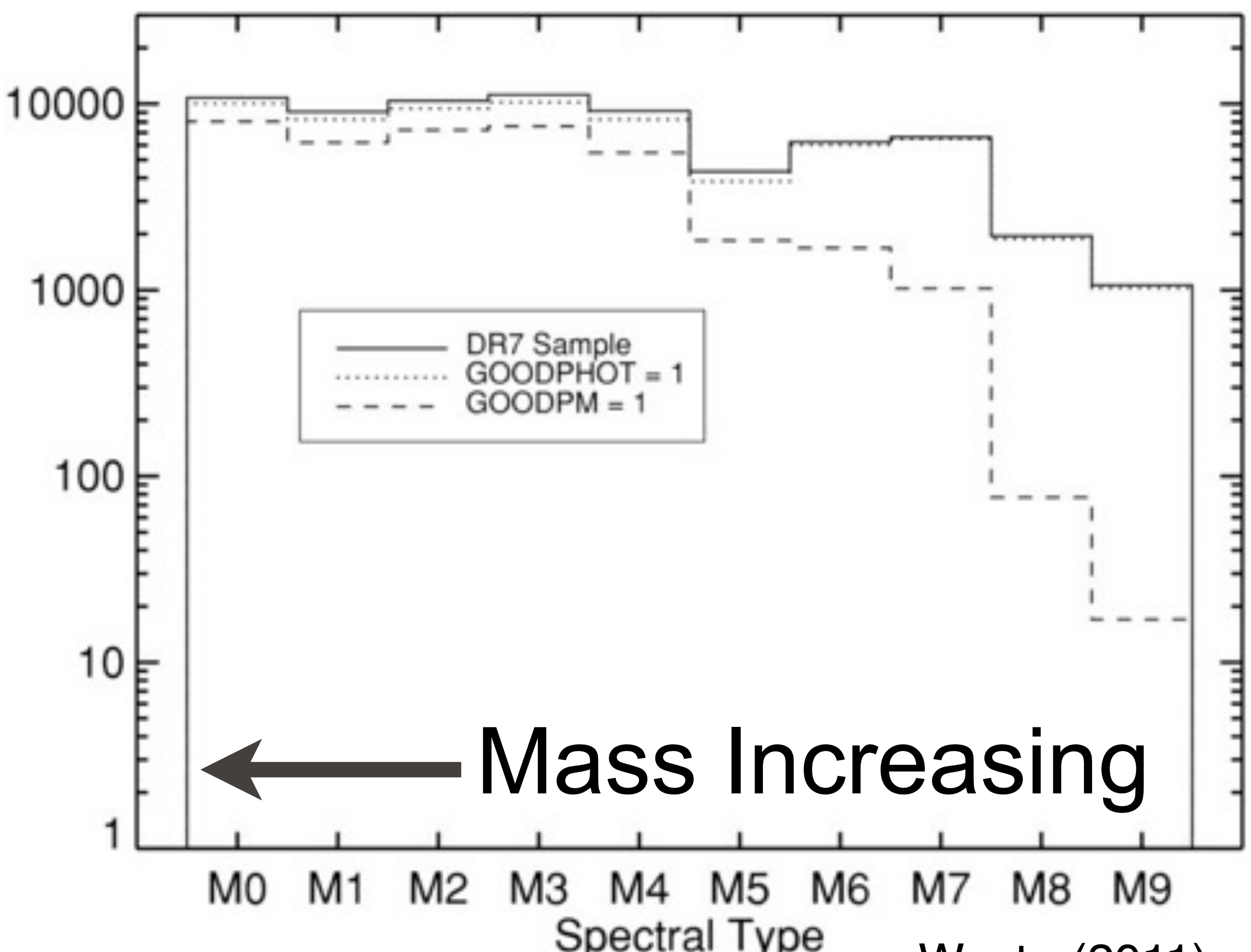
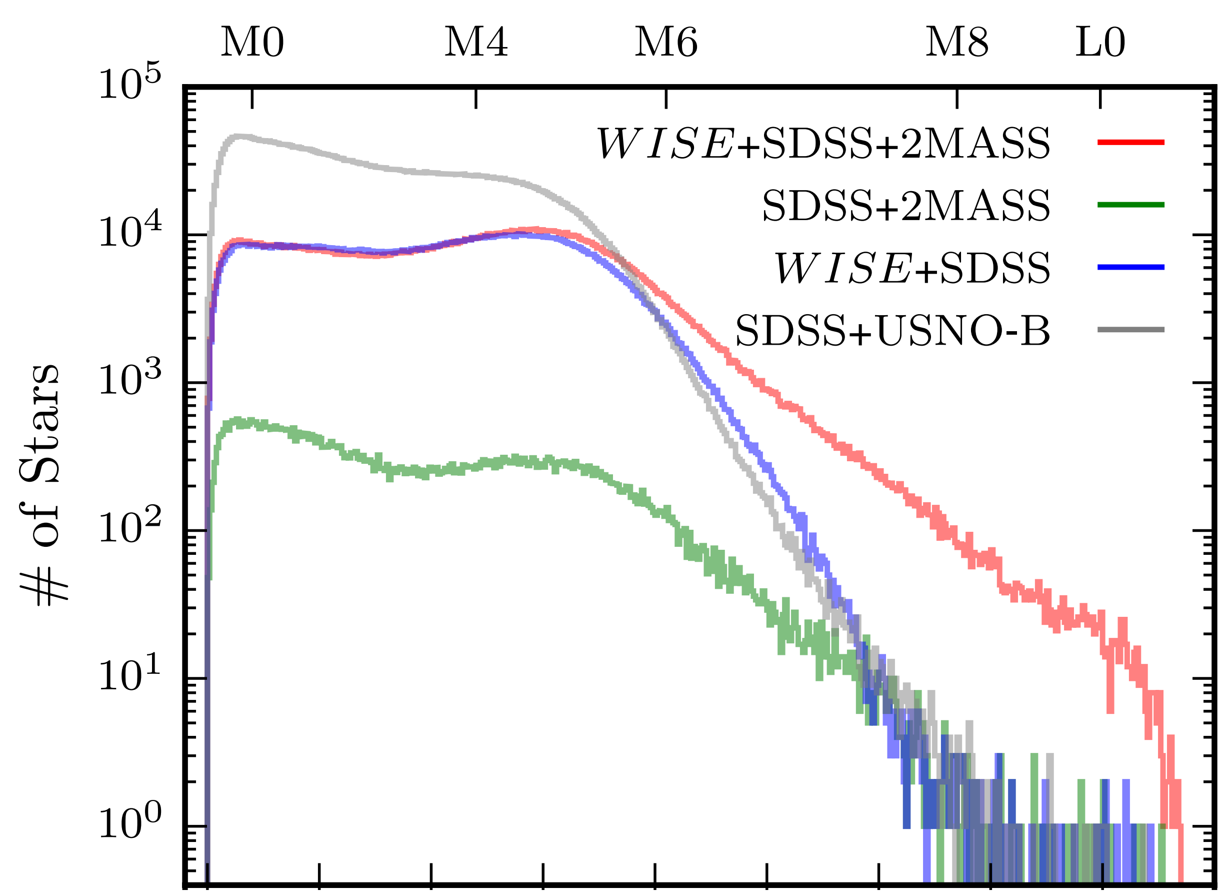
Using M Dwarfs

The spectroscopic sample



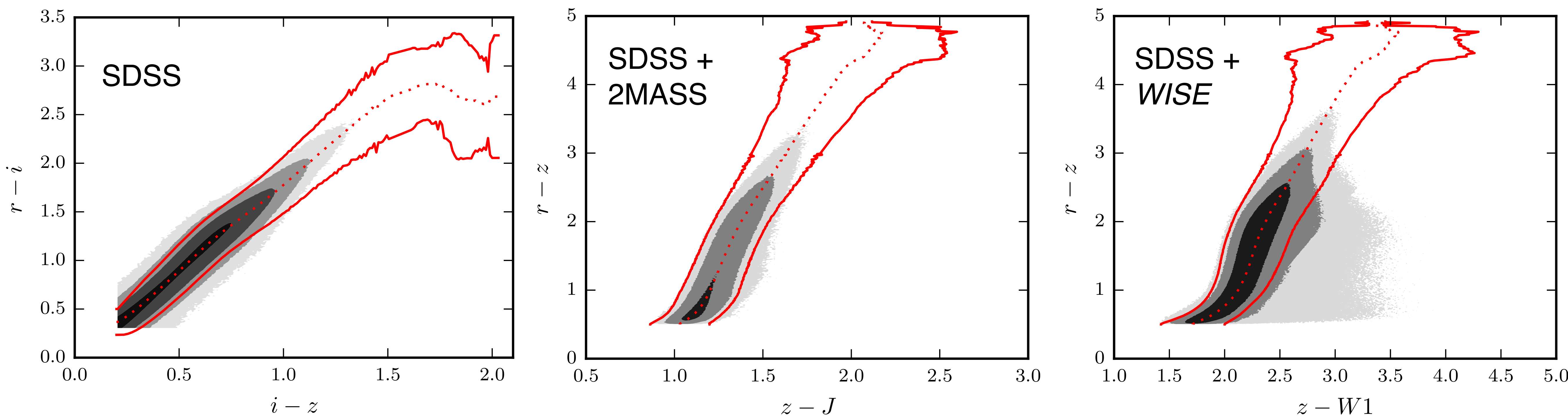
West+ (2011)

The photometric sample



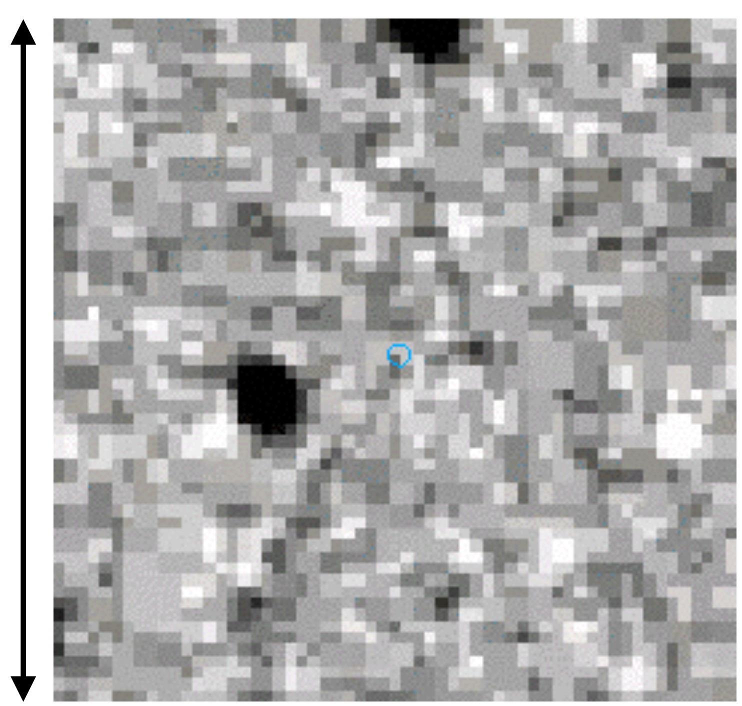
Theissen+ (2016)

Building the photometric sample
Motion Verified Red Stars (MoVeRS)



Theissen+ (2016)

1 arcminute



Building the photometric sample
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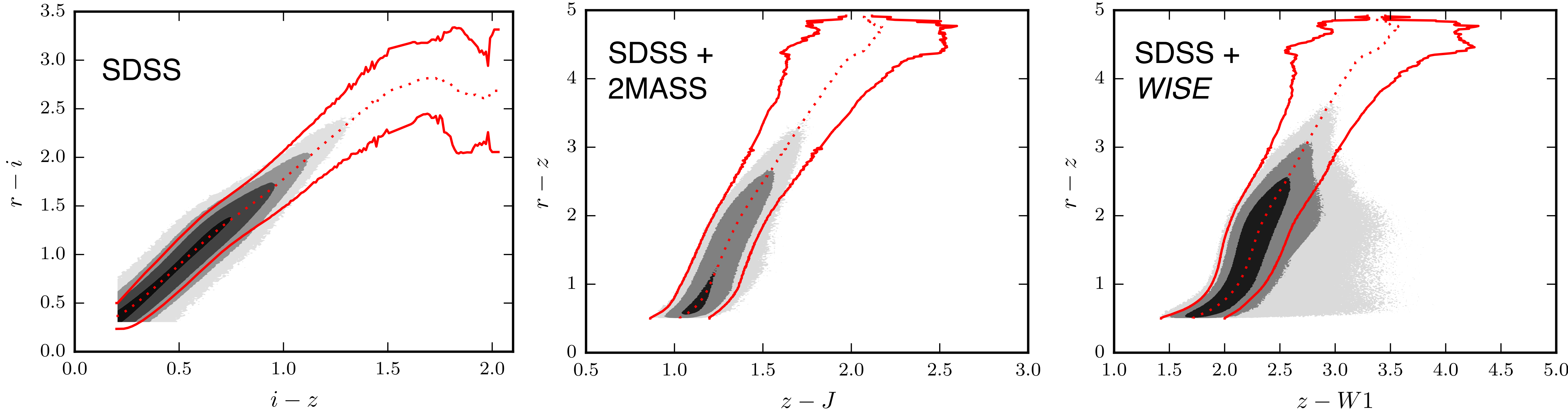
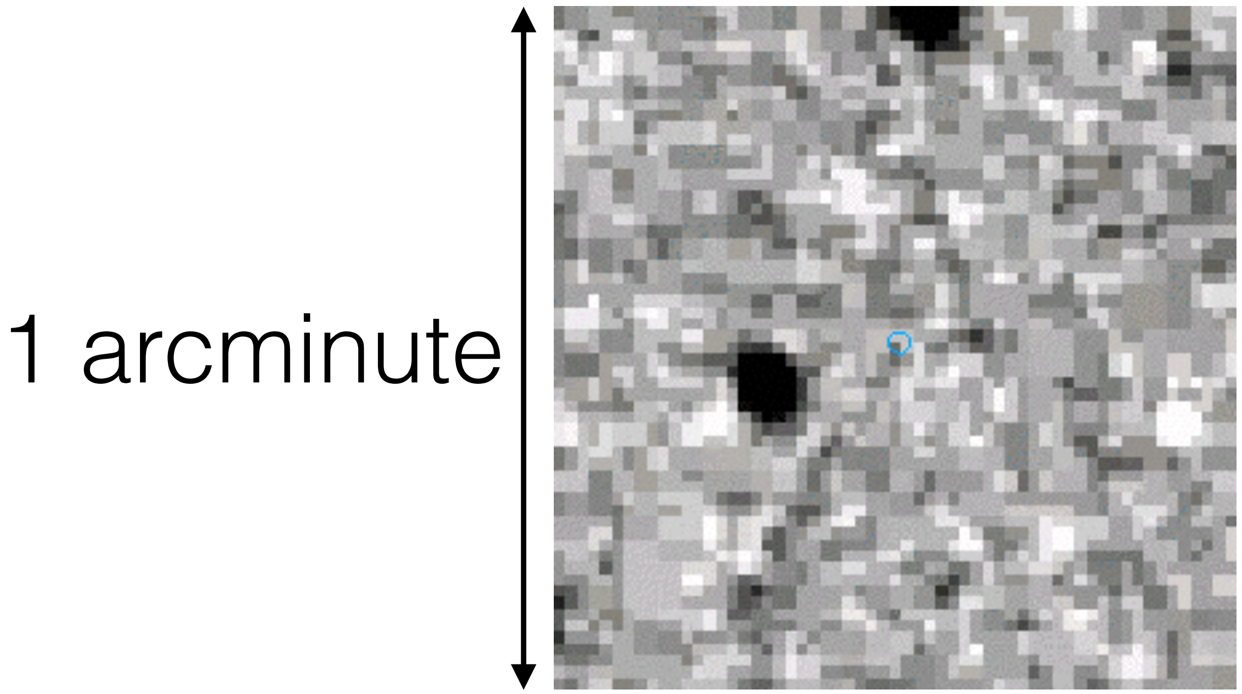
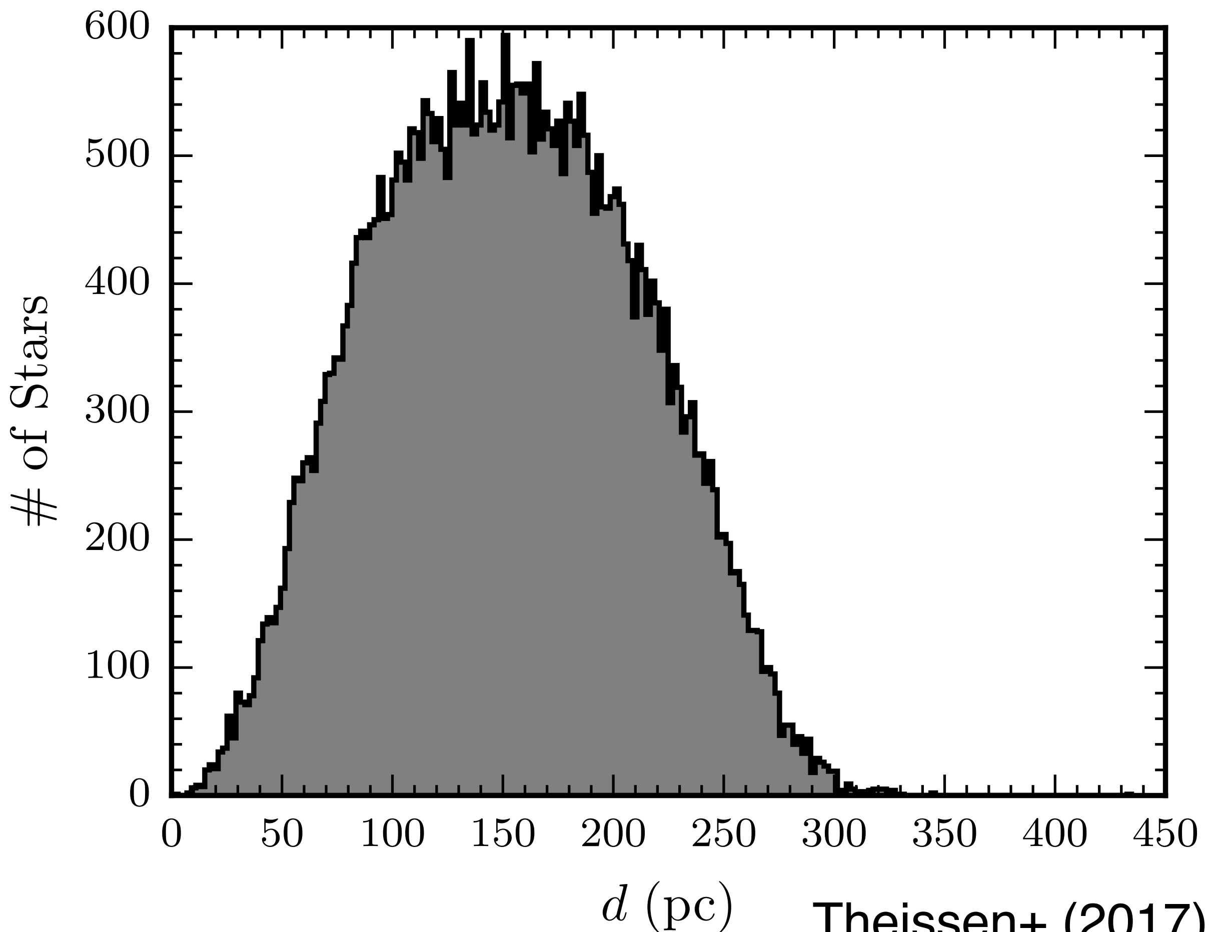


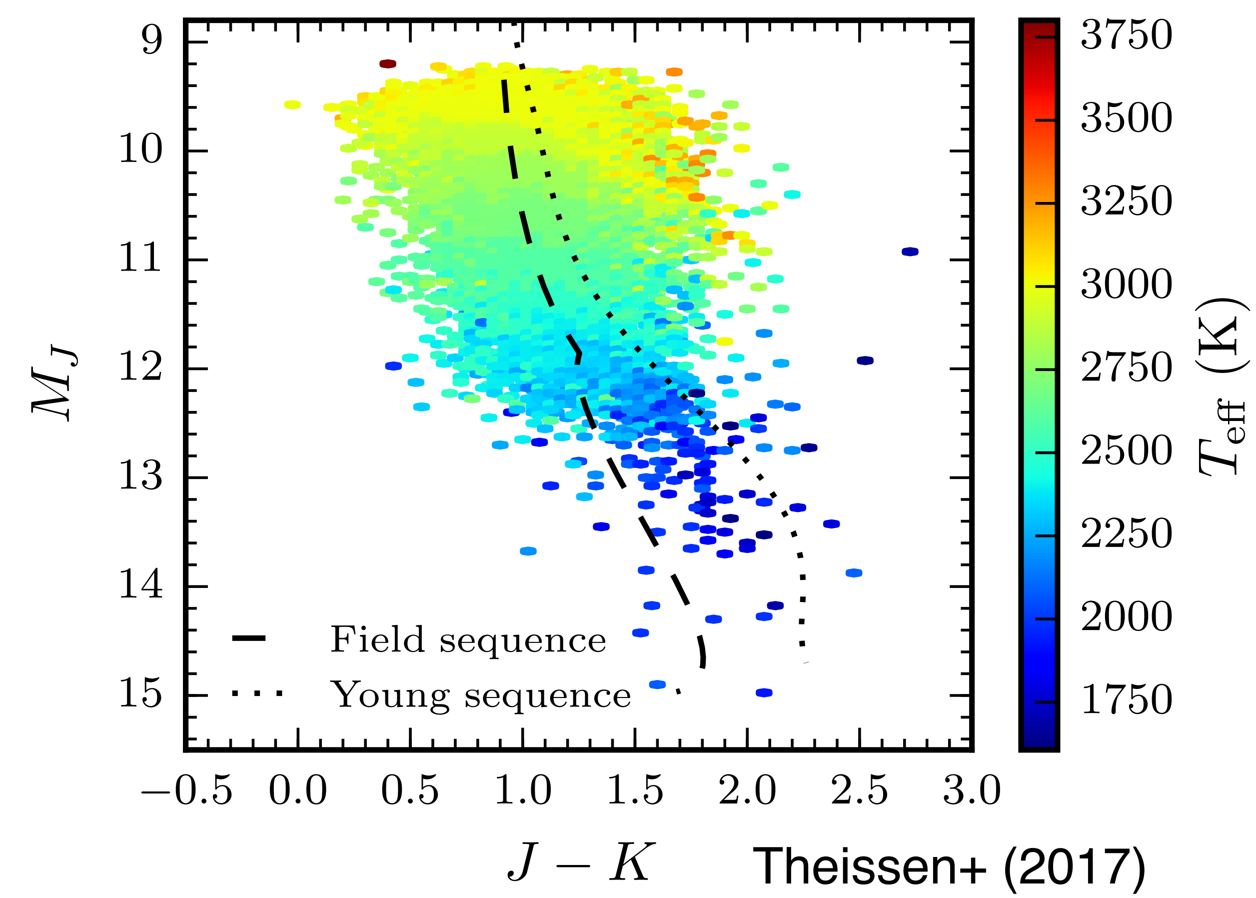
Theissen+ (2016)



…and the Late-Type Extension to MoVeRS (LaTE-MoVeRS)



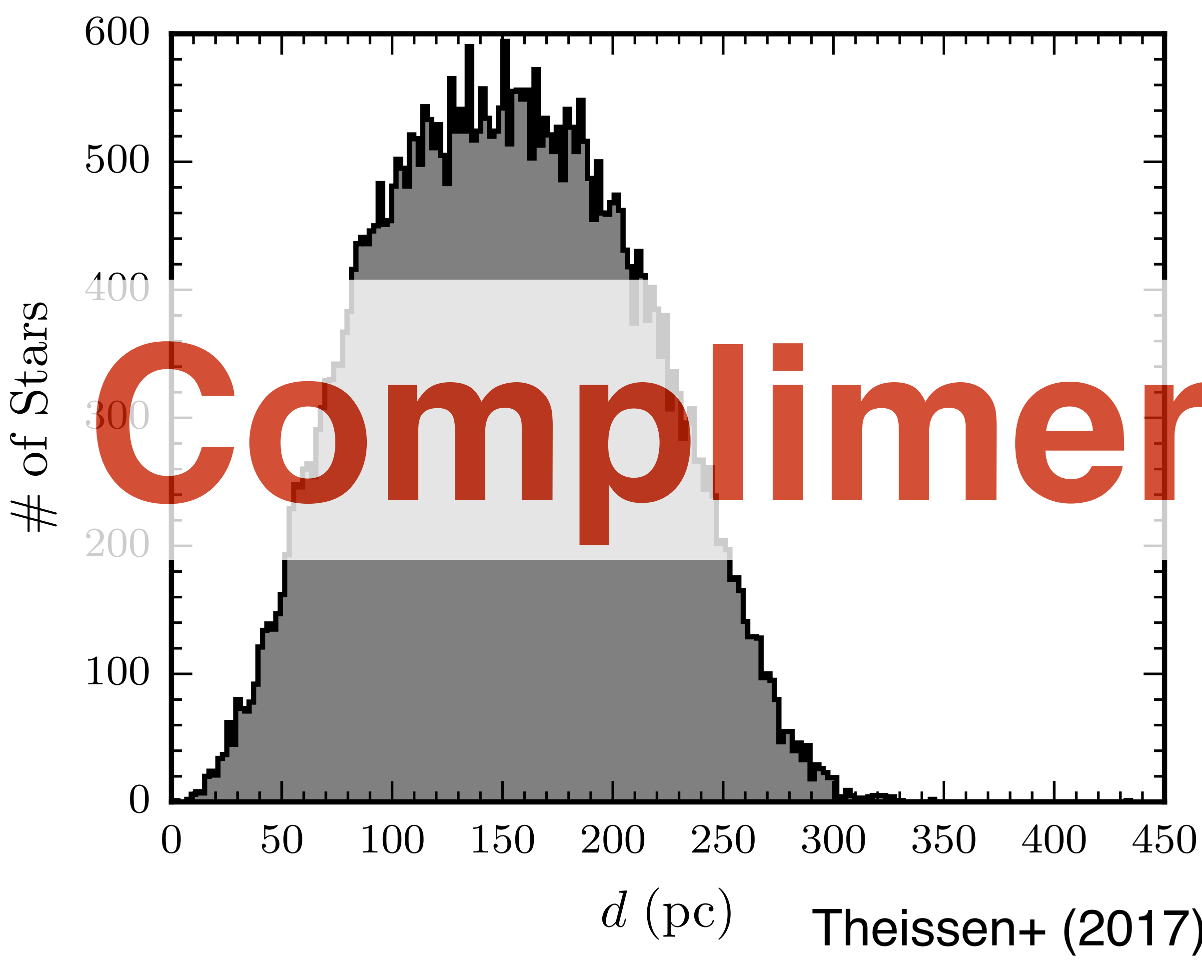
Theissen+ (2017)

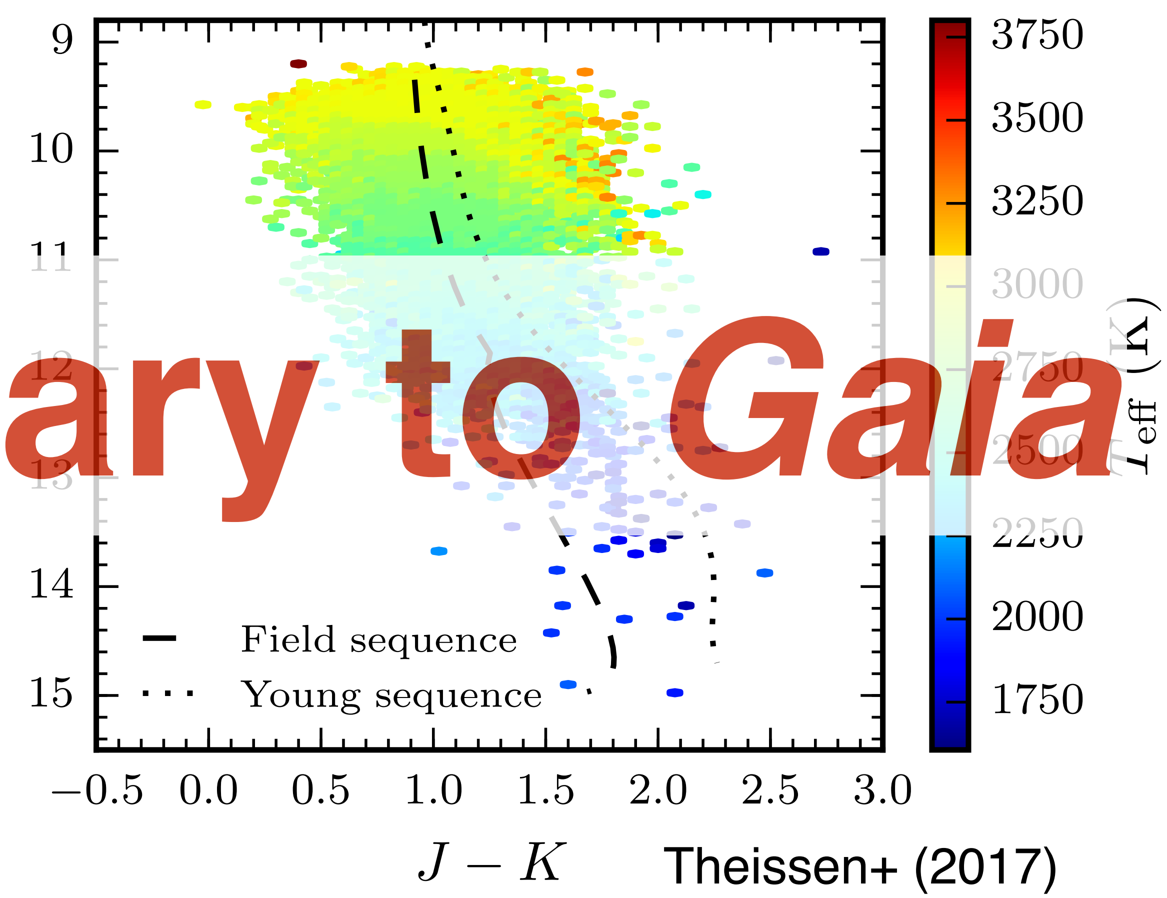


Theissen+ (2017)

~47,000 late-type objects with temperatures < 3800 K

…and the Late-Type Extension to MoVeRS (LaTE-MoVeRS)



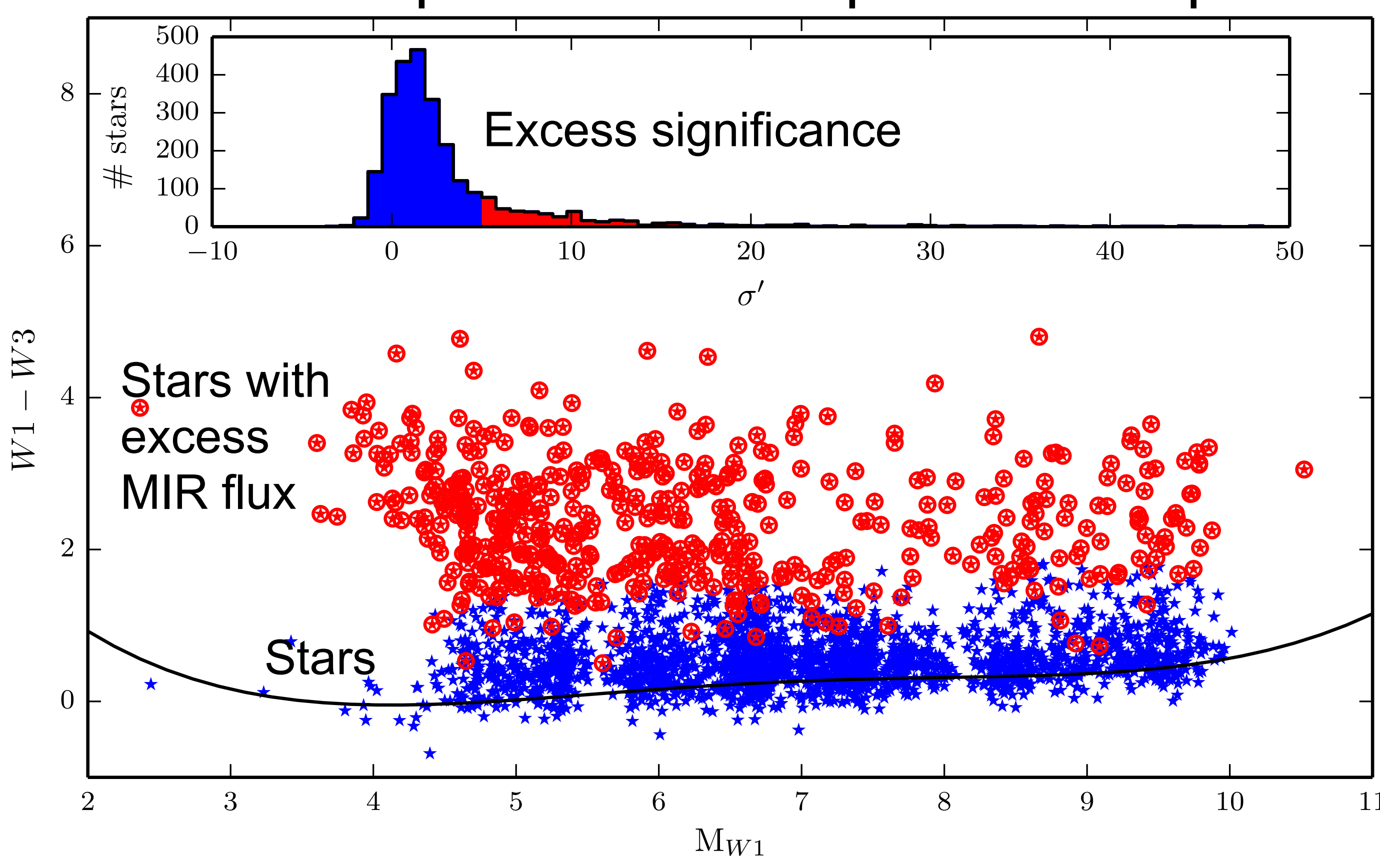


Complimentary to *Gaia*

~47,000 late-type objects with temperatures < 3800 K

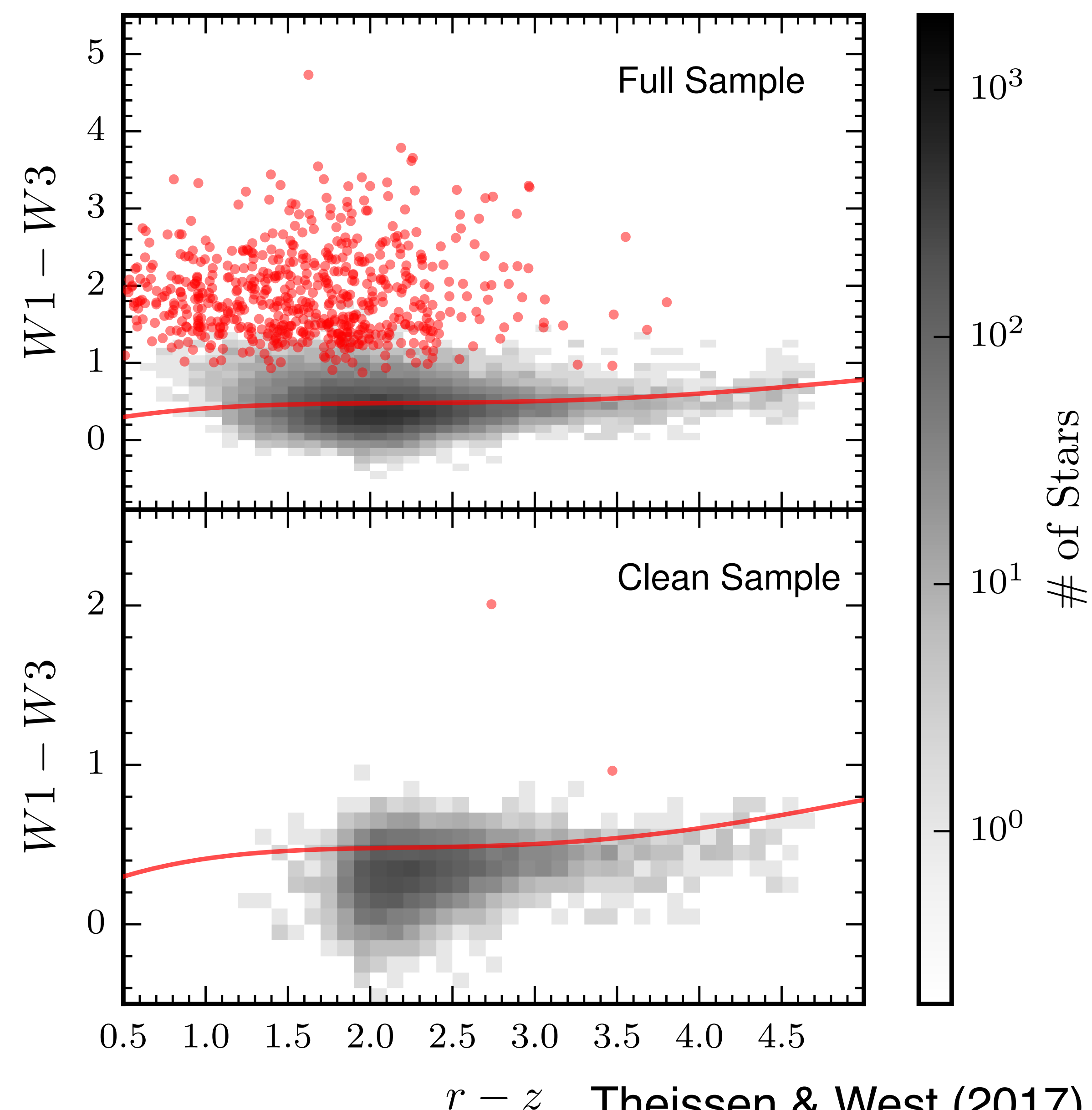
Selecting M Dwarfs with Excess MIR Flux

The spectroscopic sample



Theissen & West (2014)

The photometric sample

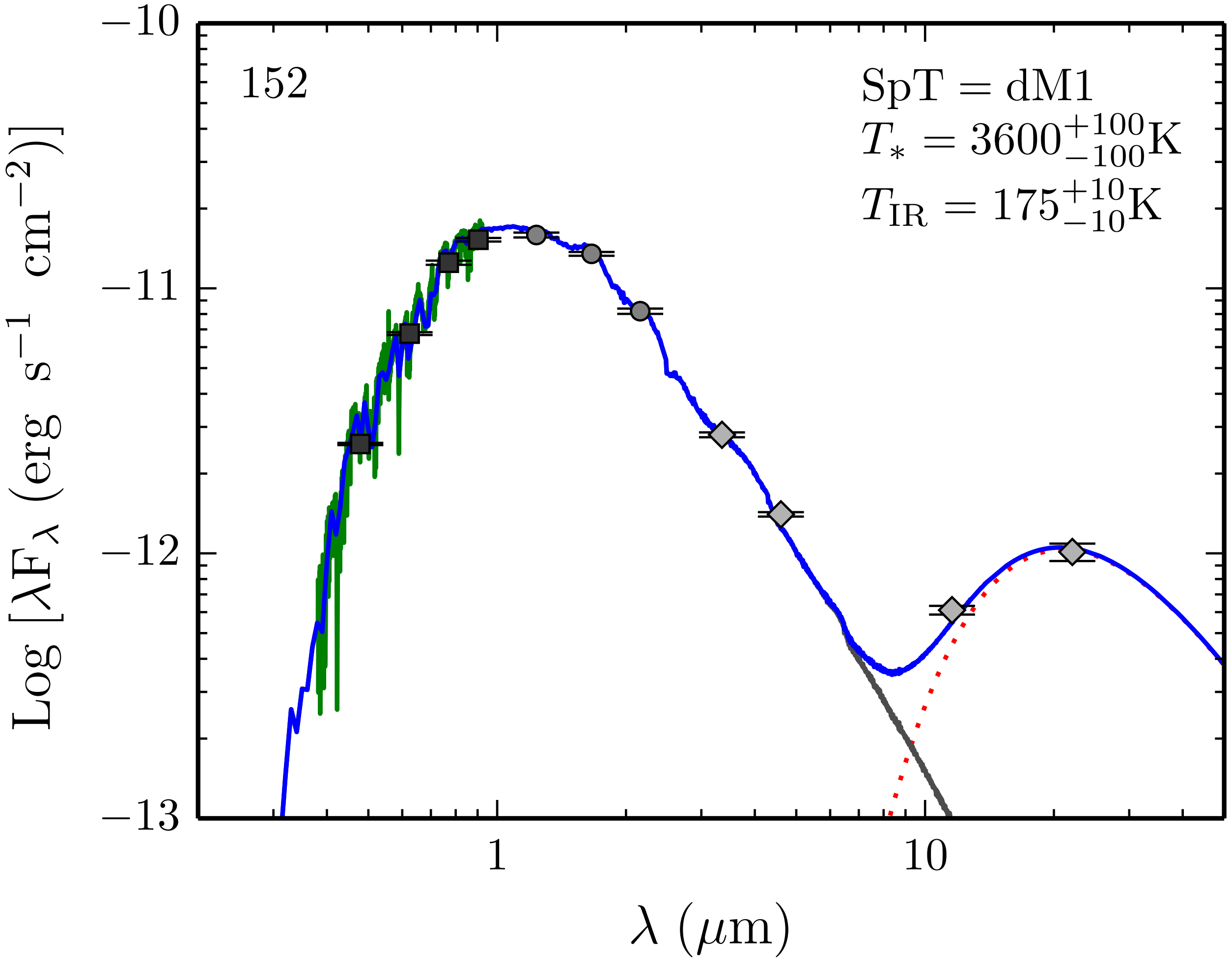


Theissen & West (2017)

Multiple criteria to select stars with excess MIR flux.

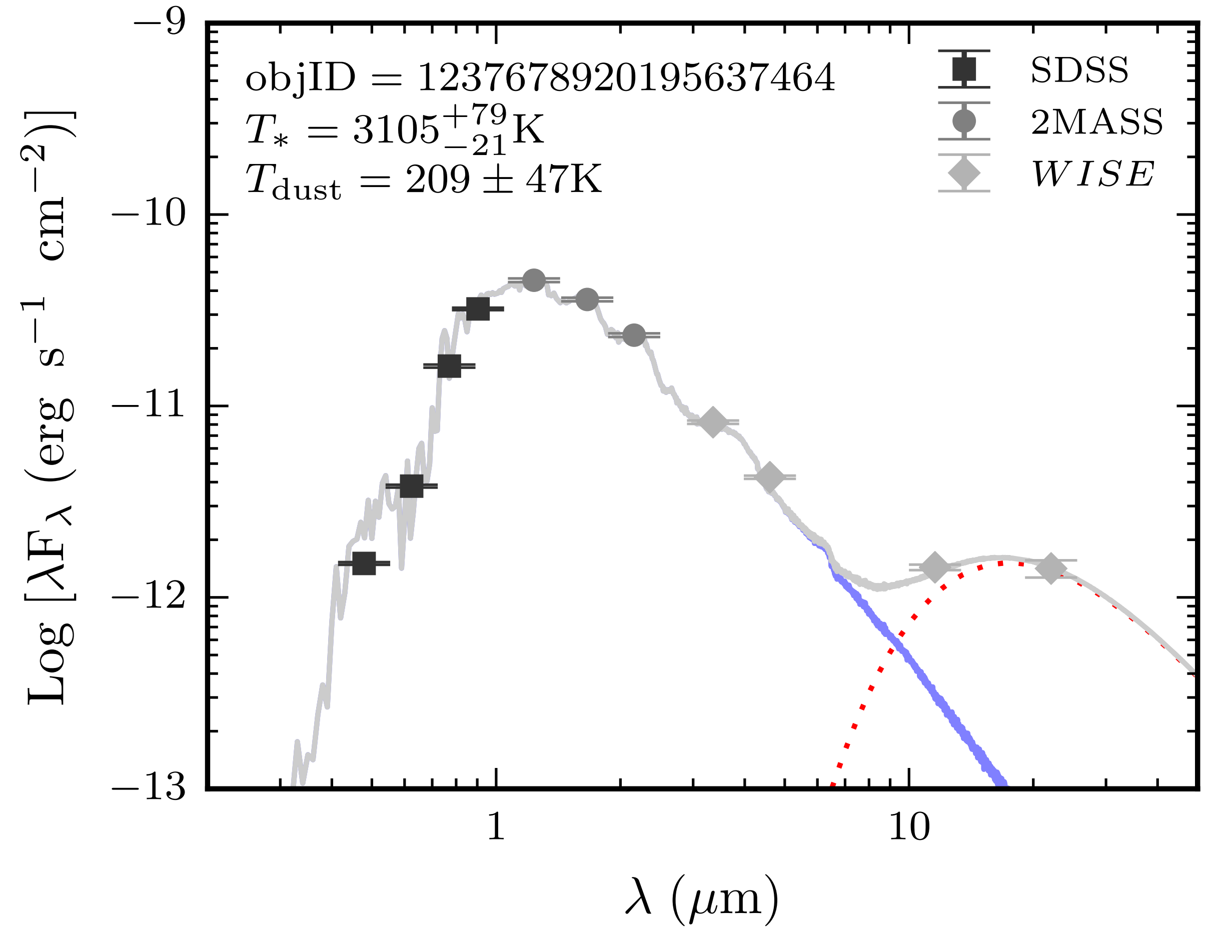
Spectral Energy Distributions for Extreme MIR Excesses

The spectroscopic sample



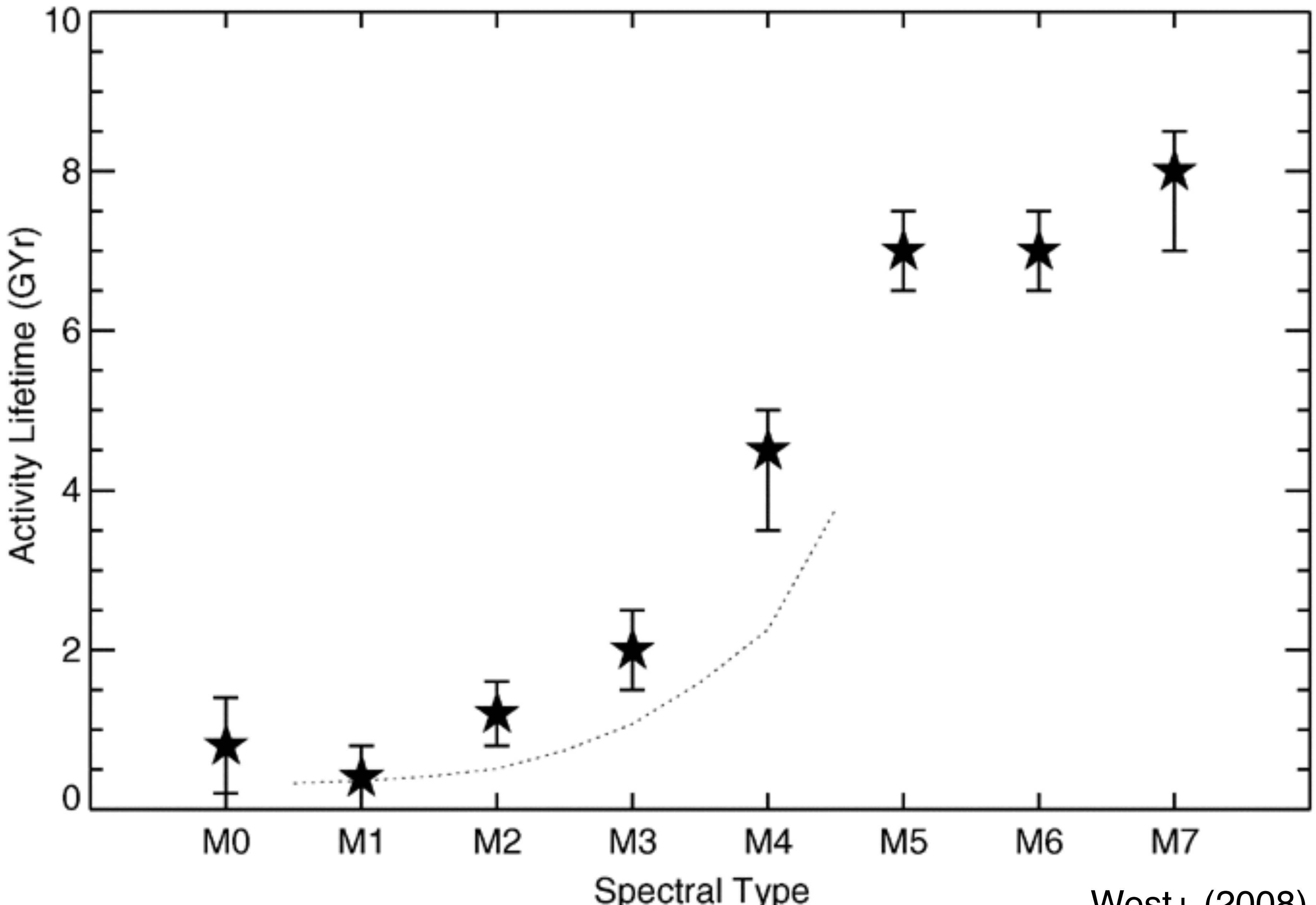
Theissen & West (2014)

The photometric sample



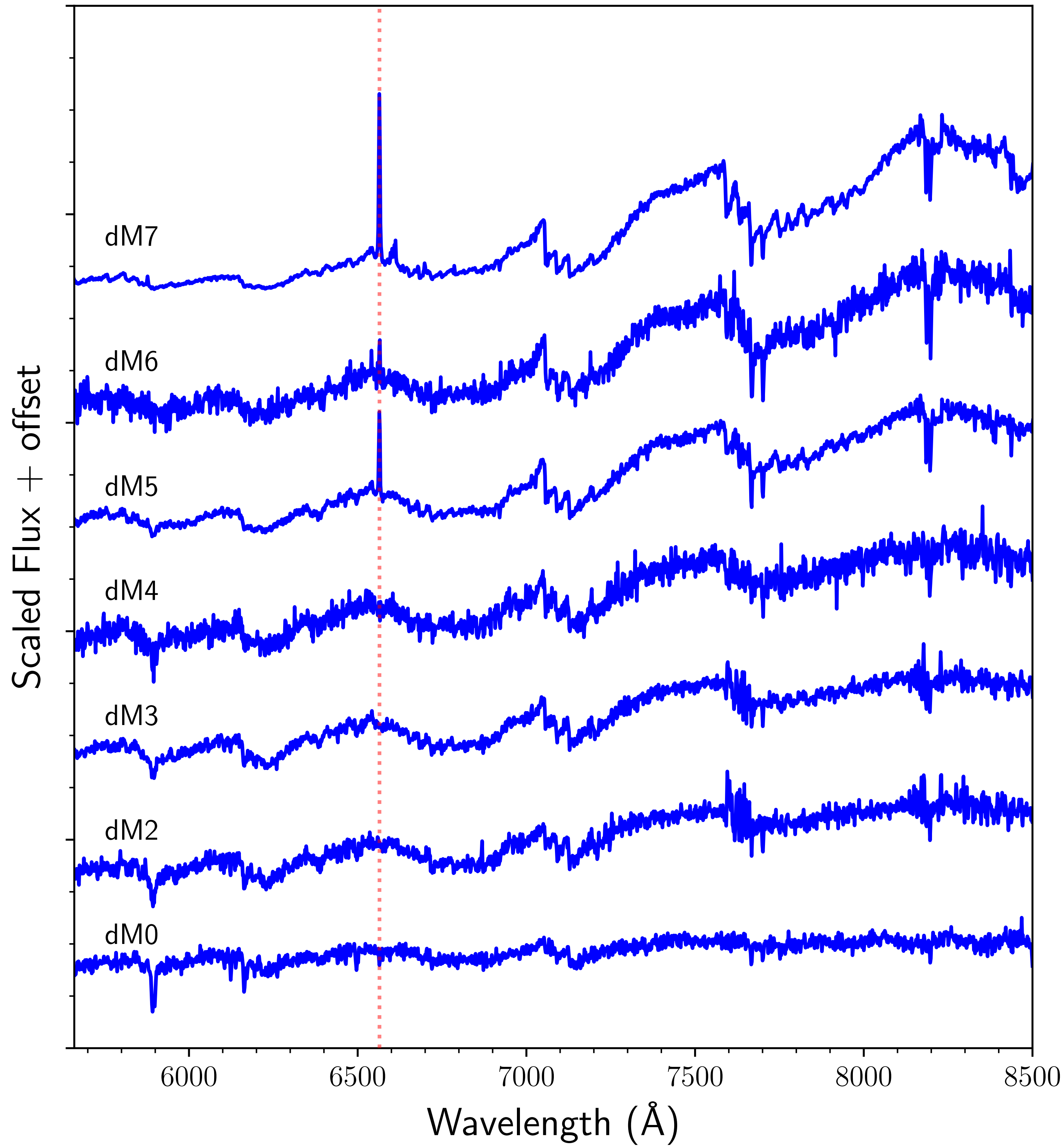
Theissen & West (2017)

Aging M Dwarfs: Hydrogen Emission aka “Activity”



West+ (2008)

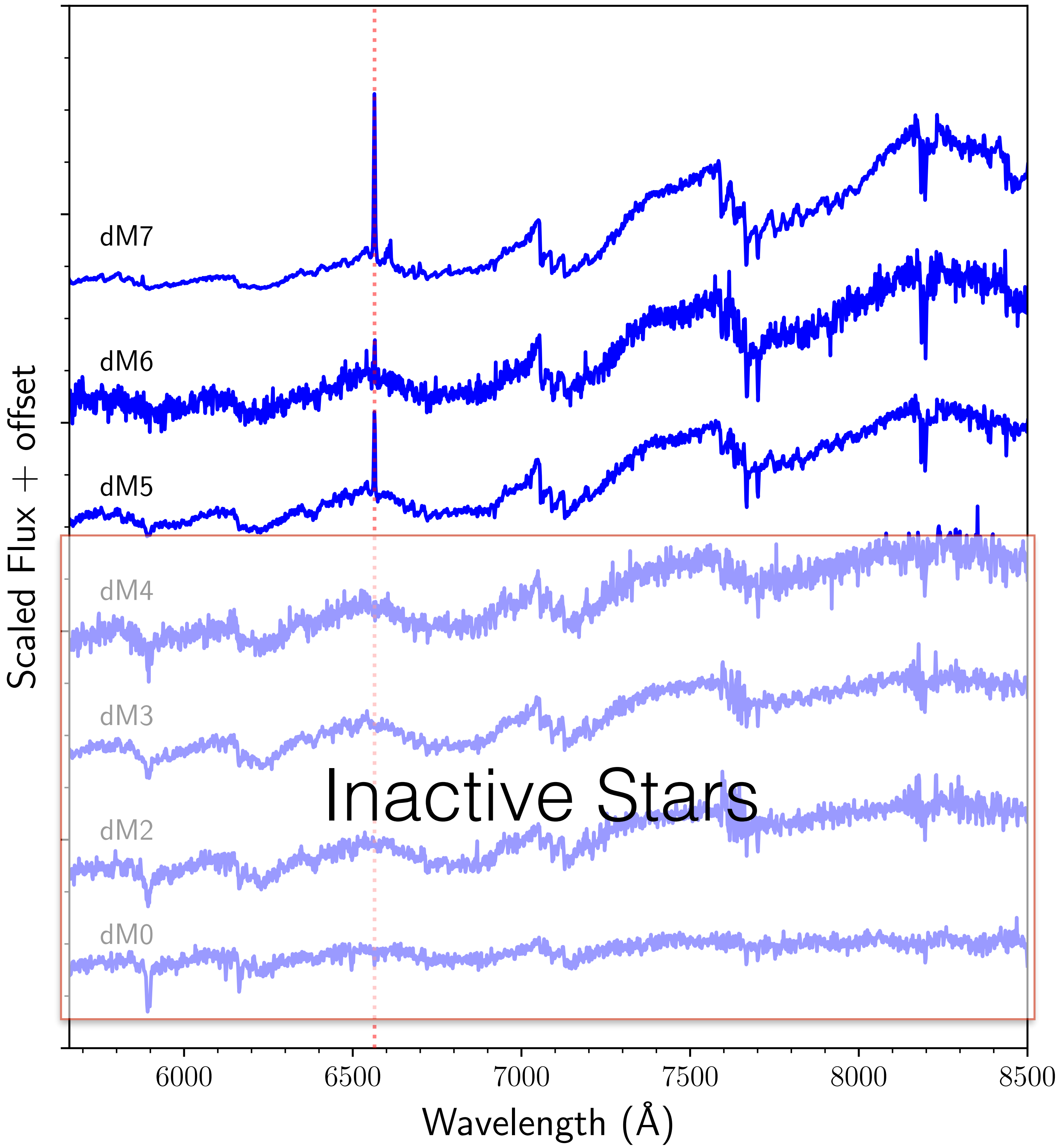
Hydrogen Emission



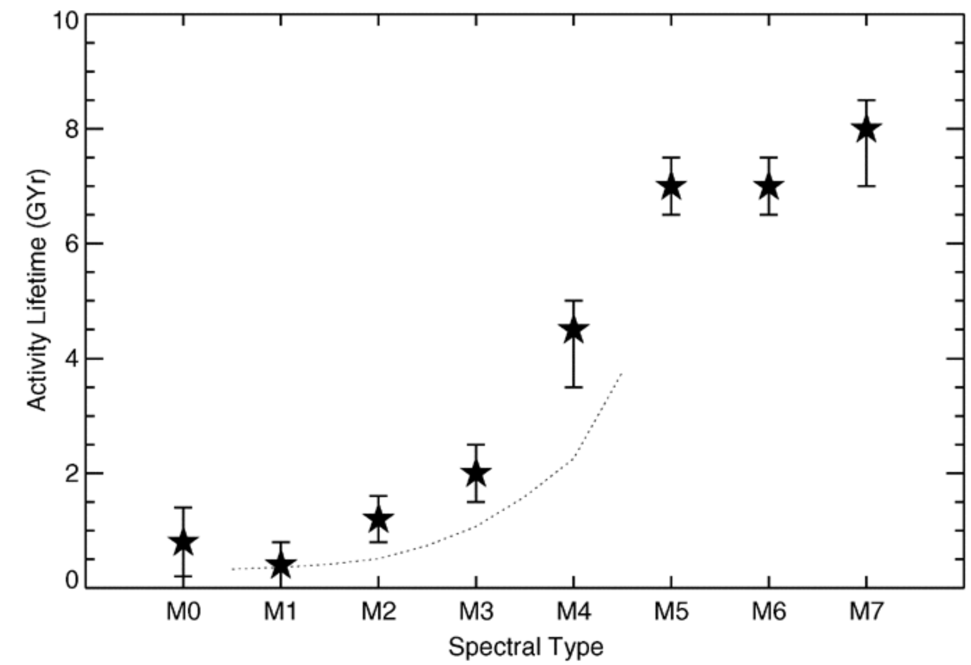
Adapted from Theissen & West (2017)

Obtained DCT (and SDSS) optical spectra of randomly selected stars.

Hydrogen Emission

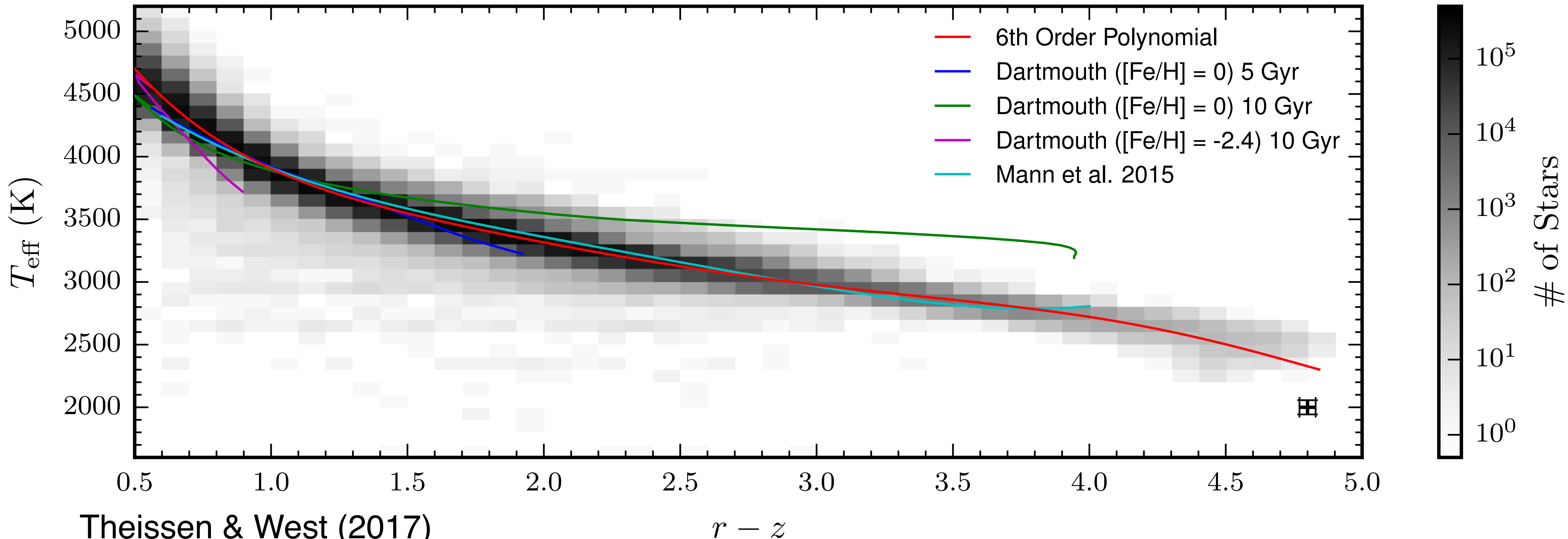


Adapted from Theissen & West (2017)



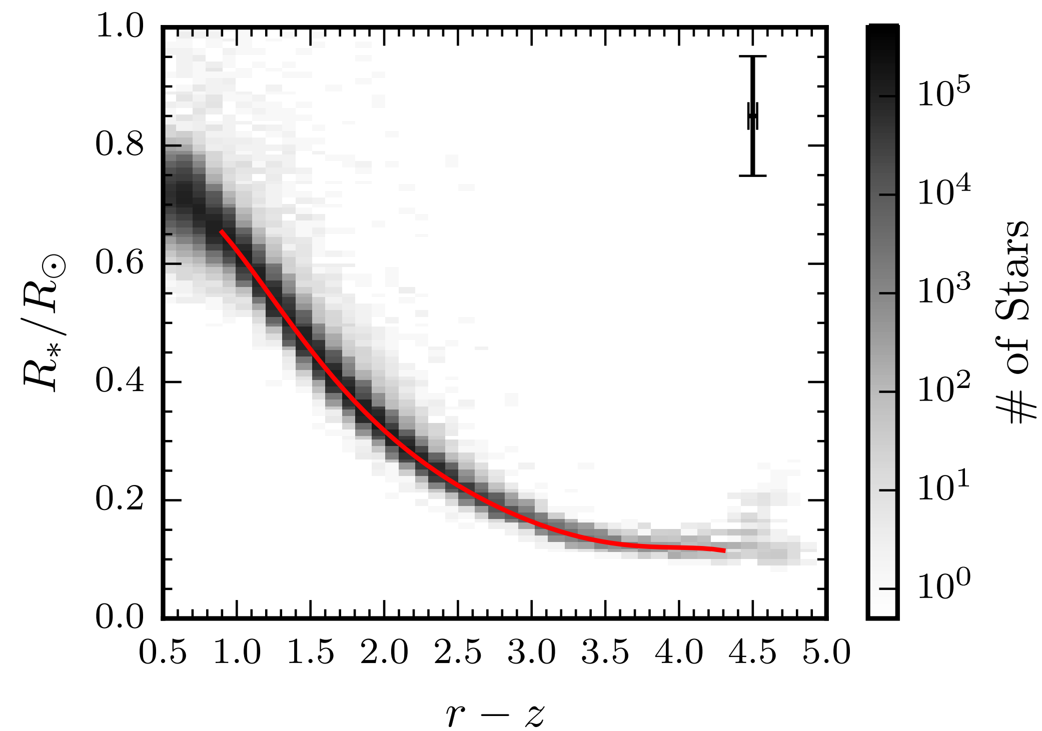
Stars later than M4 are inactive, indicating a field population likely older than a few billion years

Know Thy Star, Know Thy Disk



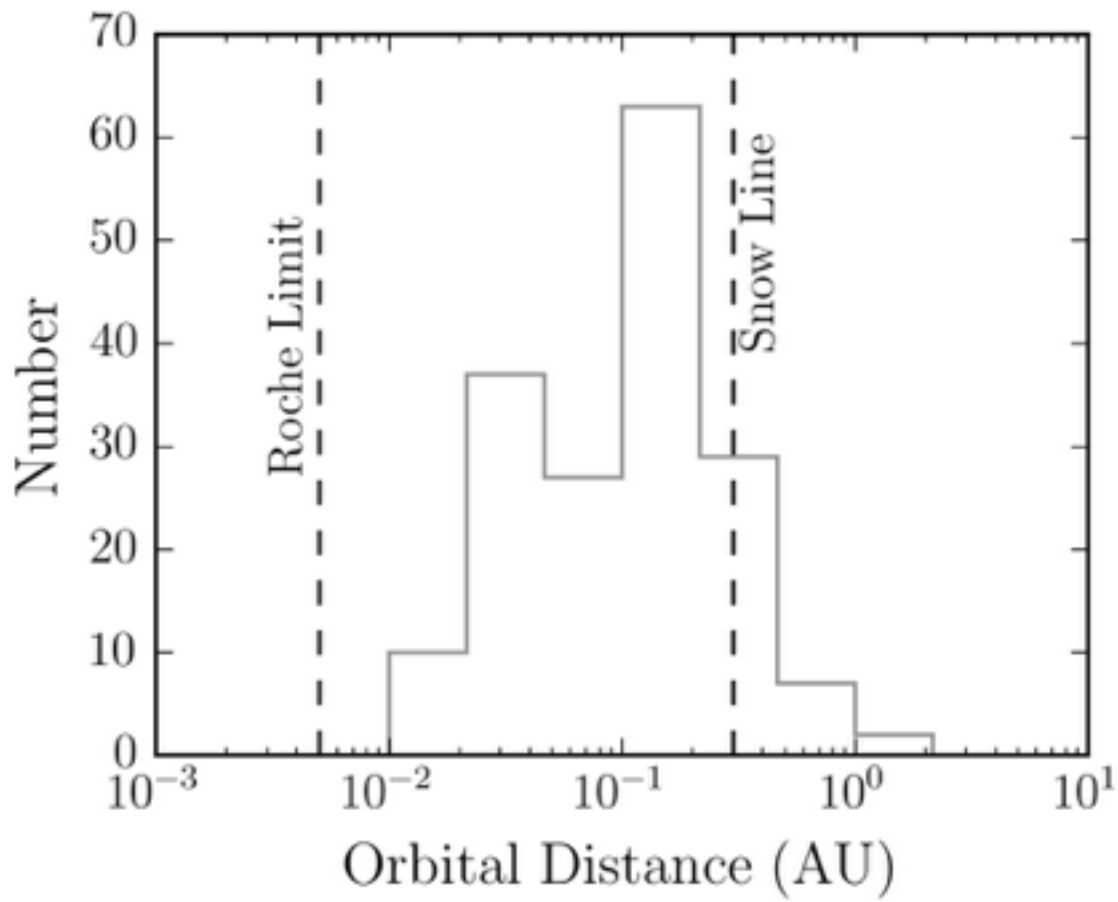
Theissen & West (2017)

Temperatures estimates from SED fits.
Radius estimates from SED fits + distances.



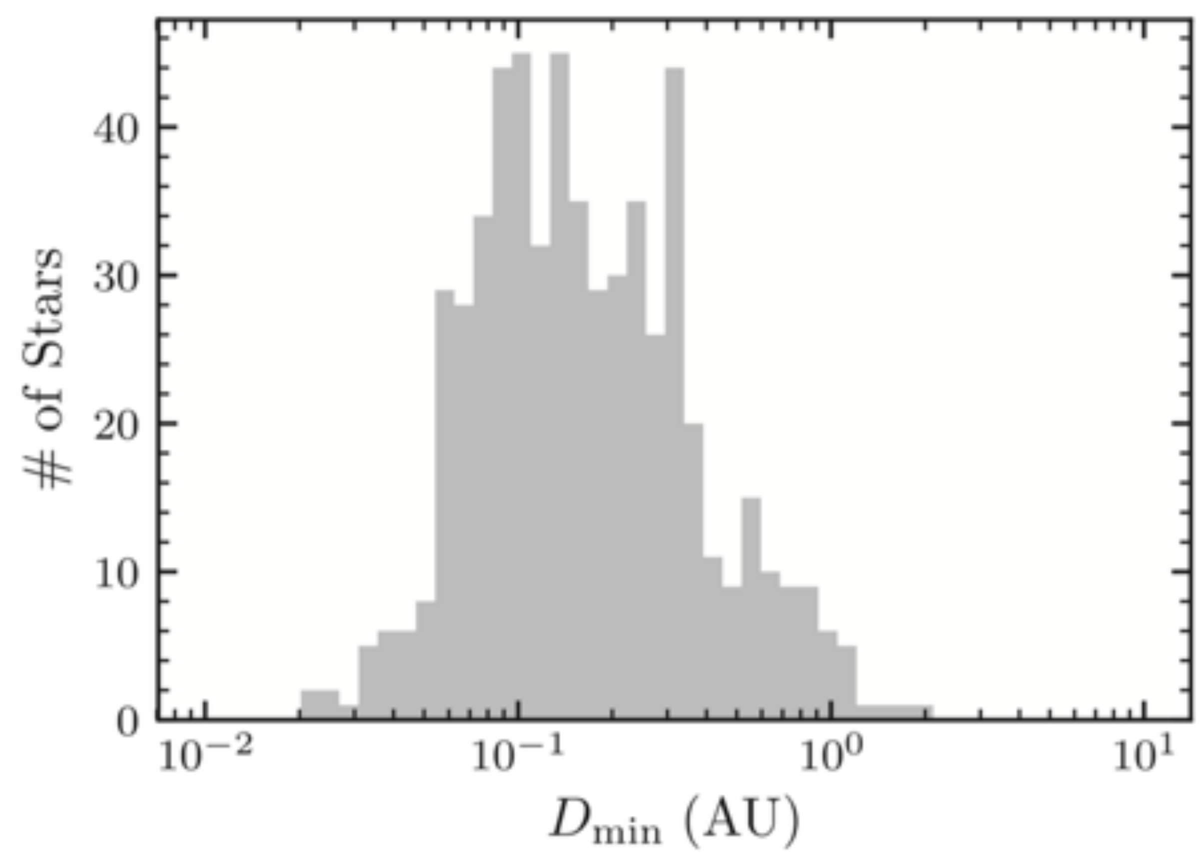
Know Thy Star, Know Thy Disk

The spectroscopic sample



Theissen & West (2014)

The photometric sample

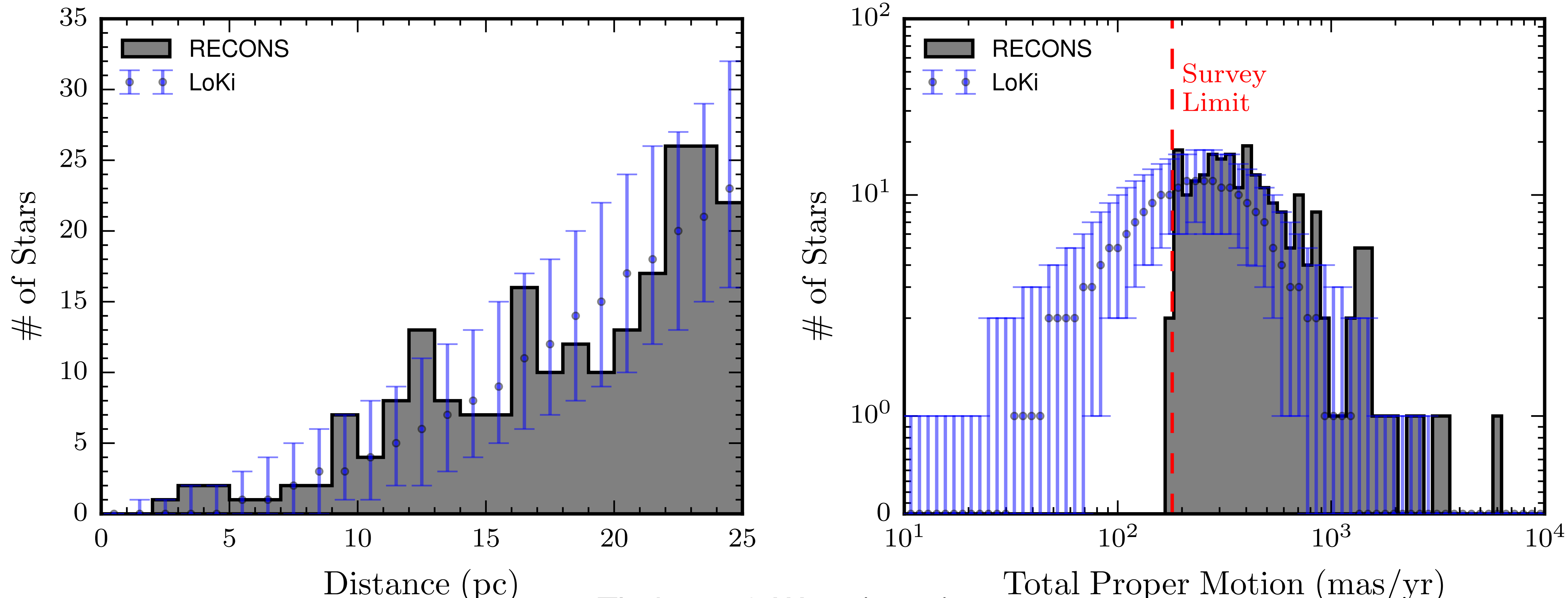


Theissen & West (2017)

Driving Questions

- How often do low-mass stars in the field exhibit extreme MIR excesses?
- What are the physical trends we observe for low-mass stars exhibiting extreme MIR excesses?
- Do binary systems exhibit extreme MIR excesses more often than single stars?

Model of the (Nearby) Galaxy

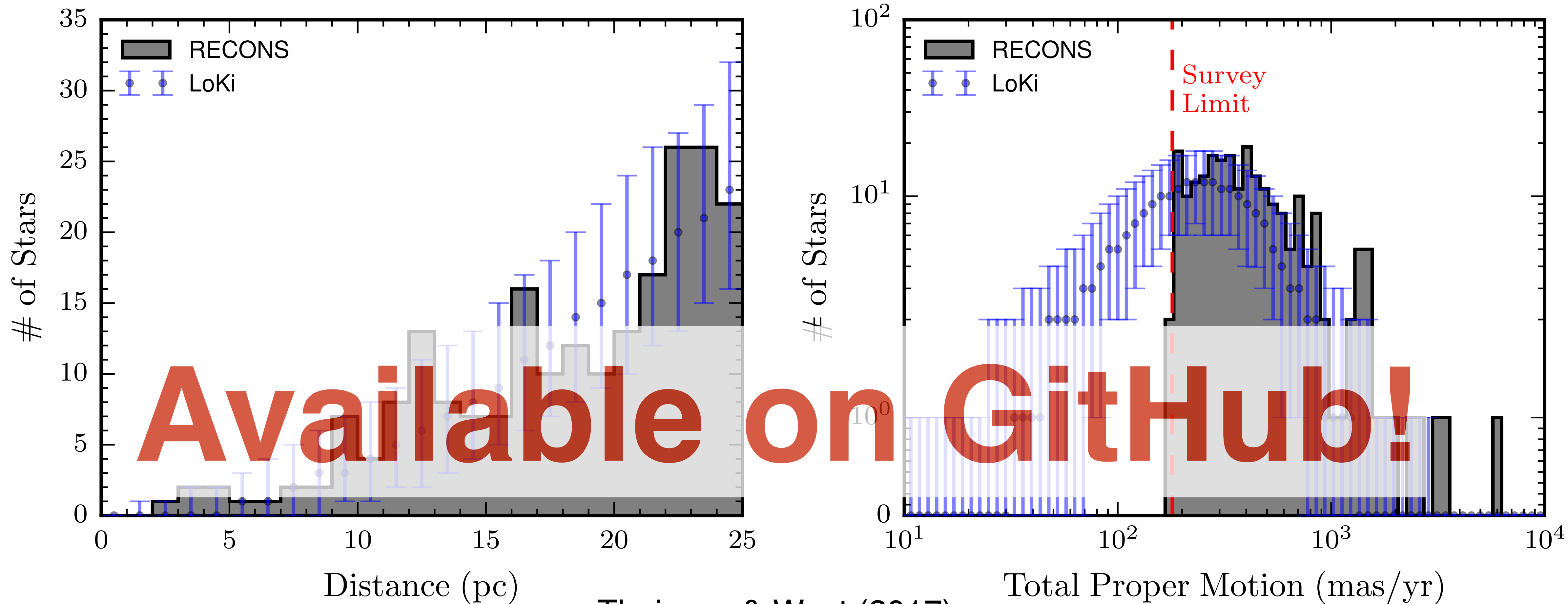


Theissen & West (2017)

Model of low-mass stars and their kinematics in our Galaxy

The Low-mass Kinematics model (*LoKi*)

Model of the (Nearby) Galaxy



Theissen & West (2017)

Model of low-mass stars and their kinematics in our Galaxy

The Low-mass Kinematics model (*LoKi*)

What percentage of low-mass field stars exhibit extreme MIR excesses?

~0.04% of low-mass stars exhibit extreme MIR excesses

What percentage of low-mass field stars exhibit extreme MIR excesses?

~0.04% of low-mass stars exhibit extreme MIR excesses

as compared to 0.0007% of solar-type stars (AFGK-spectral types)

Driving Questions

- How often do low-mass stars in the field exhibit extreme MIR excesses?
- What are the physical trends we observe for low-mass stars exhibiting extreme MIR excesses?
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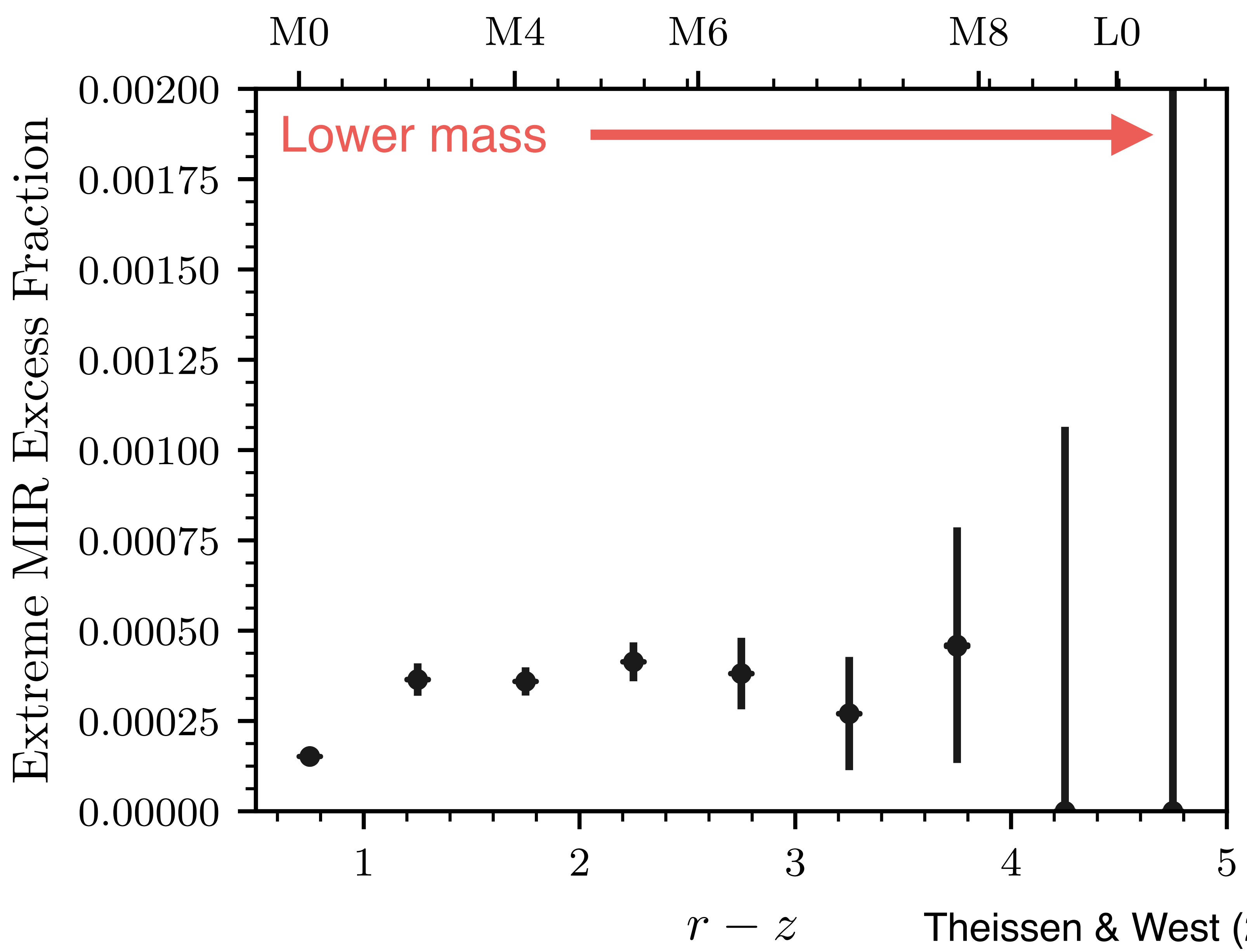
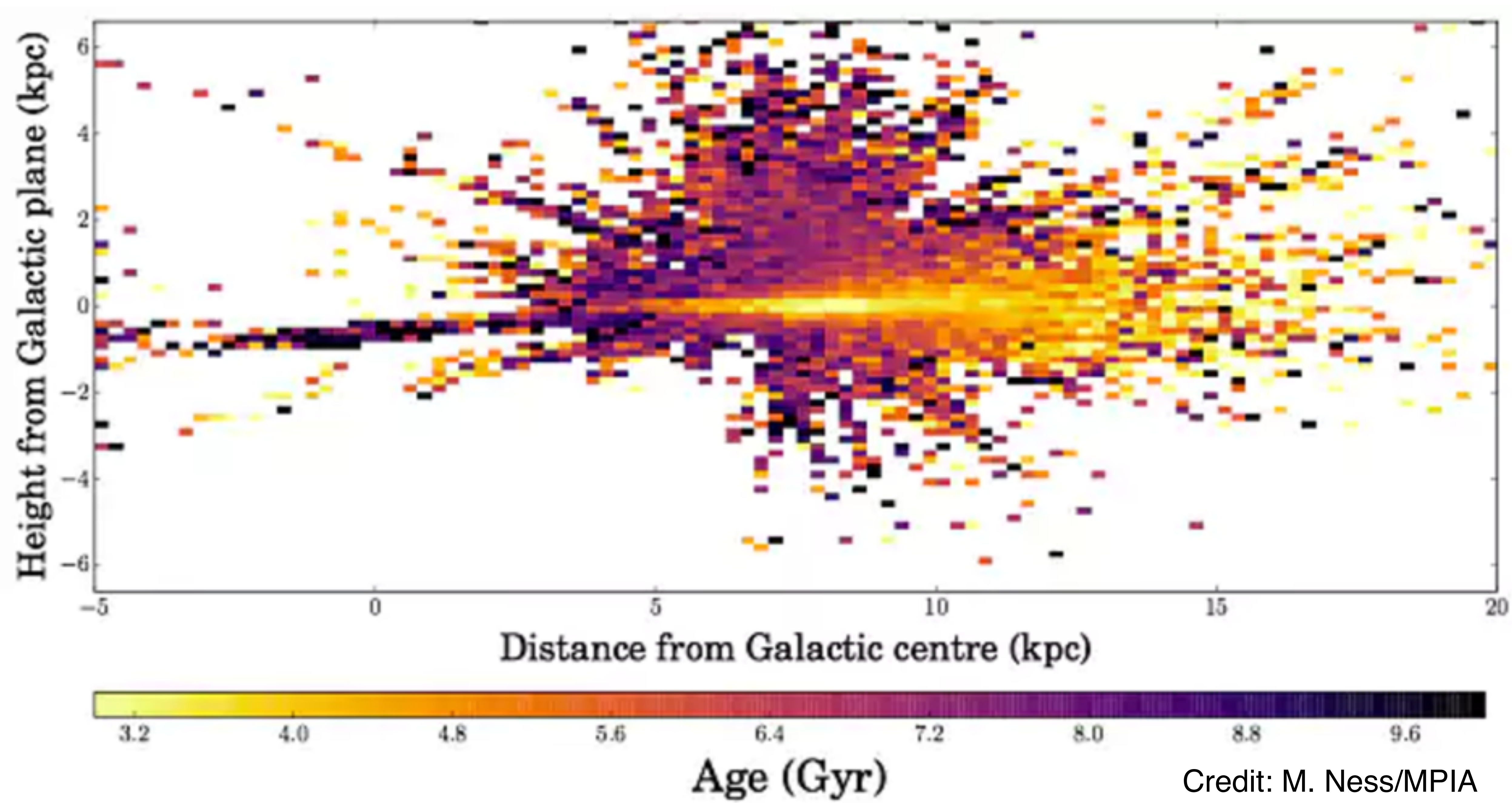
Is there a mass trend?



Theissen & West (2017)

There might be a slight trend with stellar mass, indicating lower-mass stars are more likely to host an extreme MIR excess

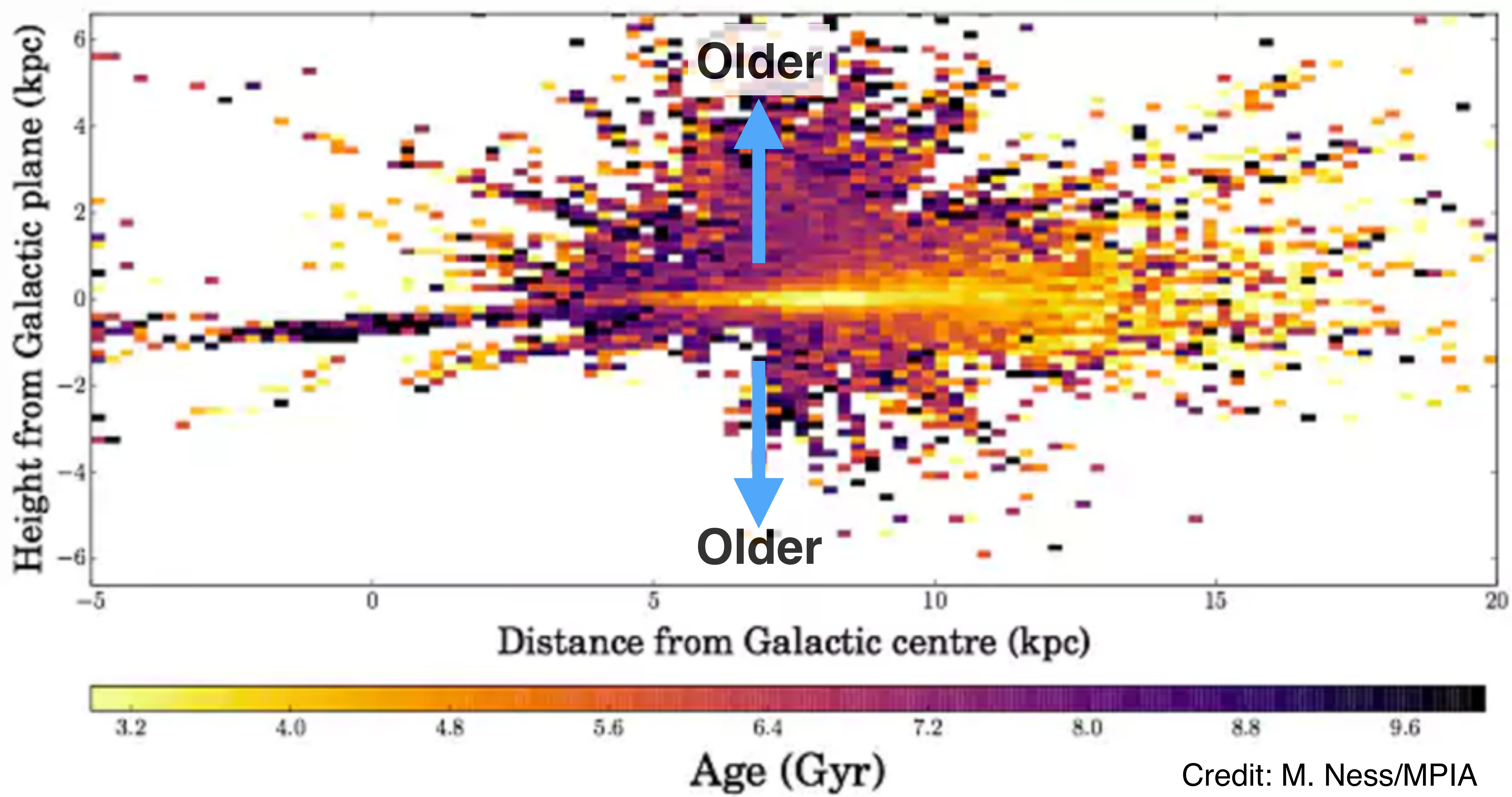
Is there an age trend?



Credit: M. Ness/MPIA

Stars further away from the Galactic plane are, on average, older

Is there an age trend?



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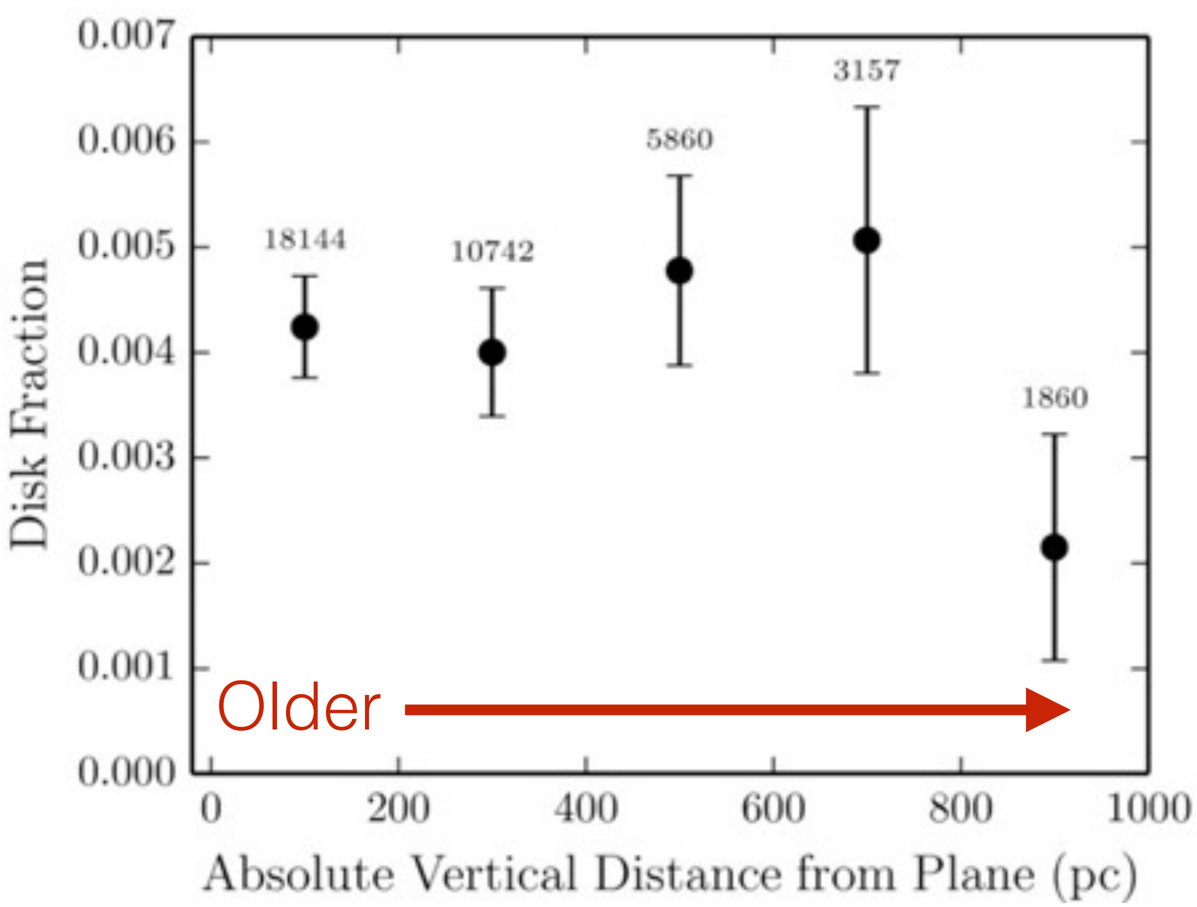
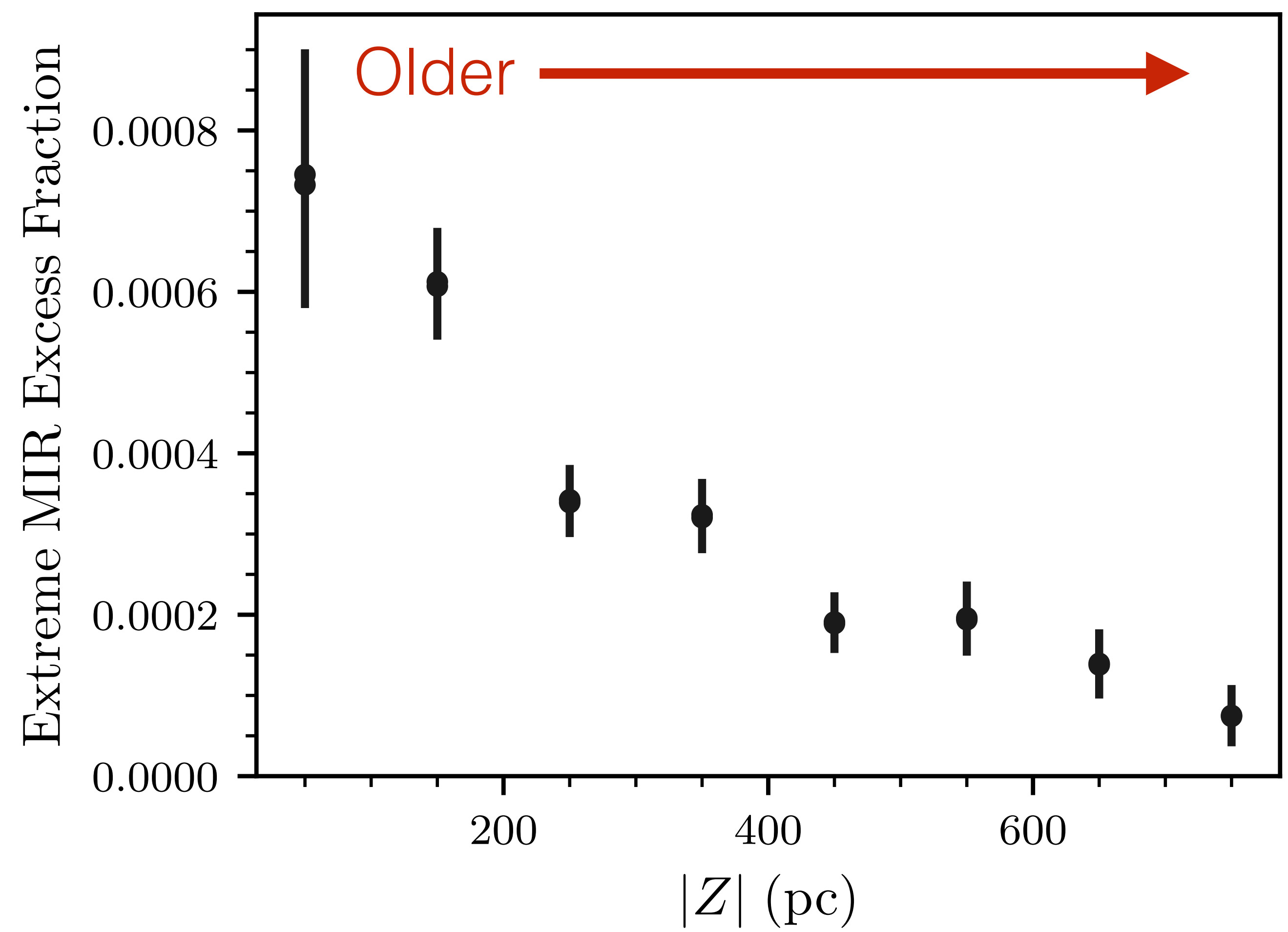
Is there an age trend?

The spectroscopic sample



Theissen & West (2014)

The photometric sample

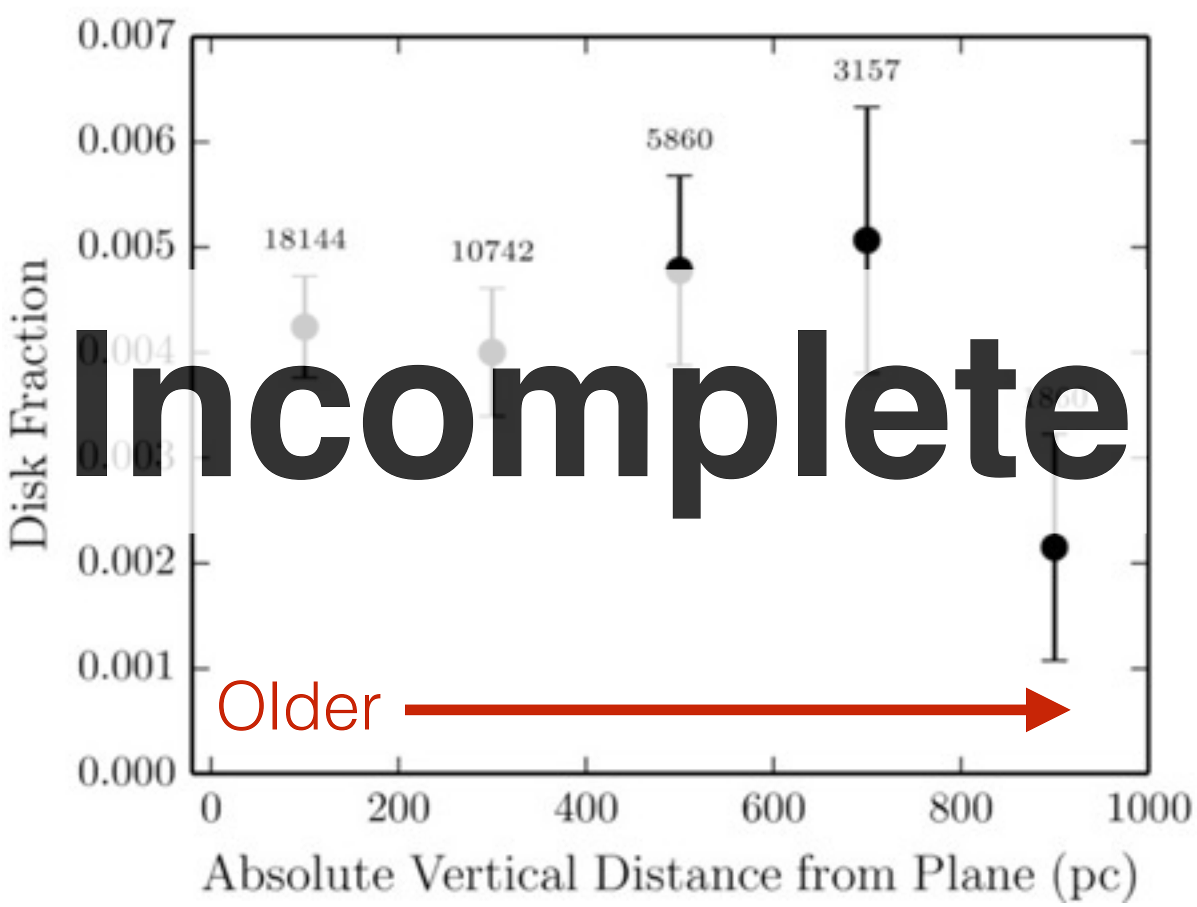


Theissen & West (2017)

$$\text{Fraction} = \frac{\text{\# stars w/ MIR excess}}{\text{Total \# stars}}$$

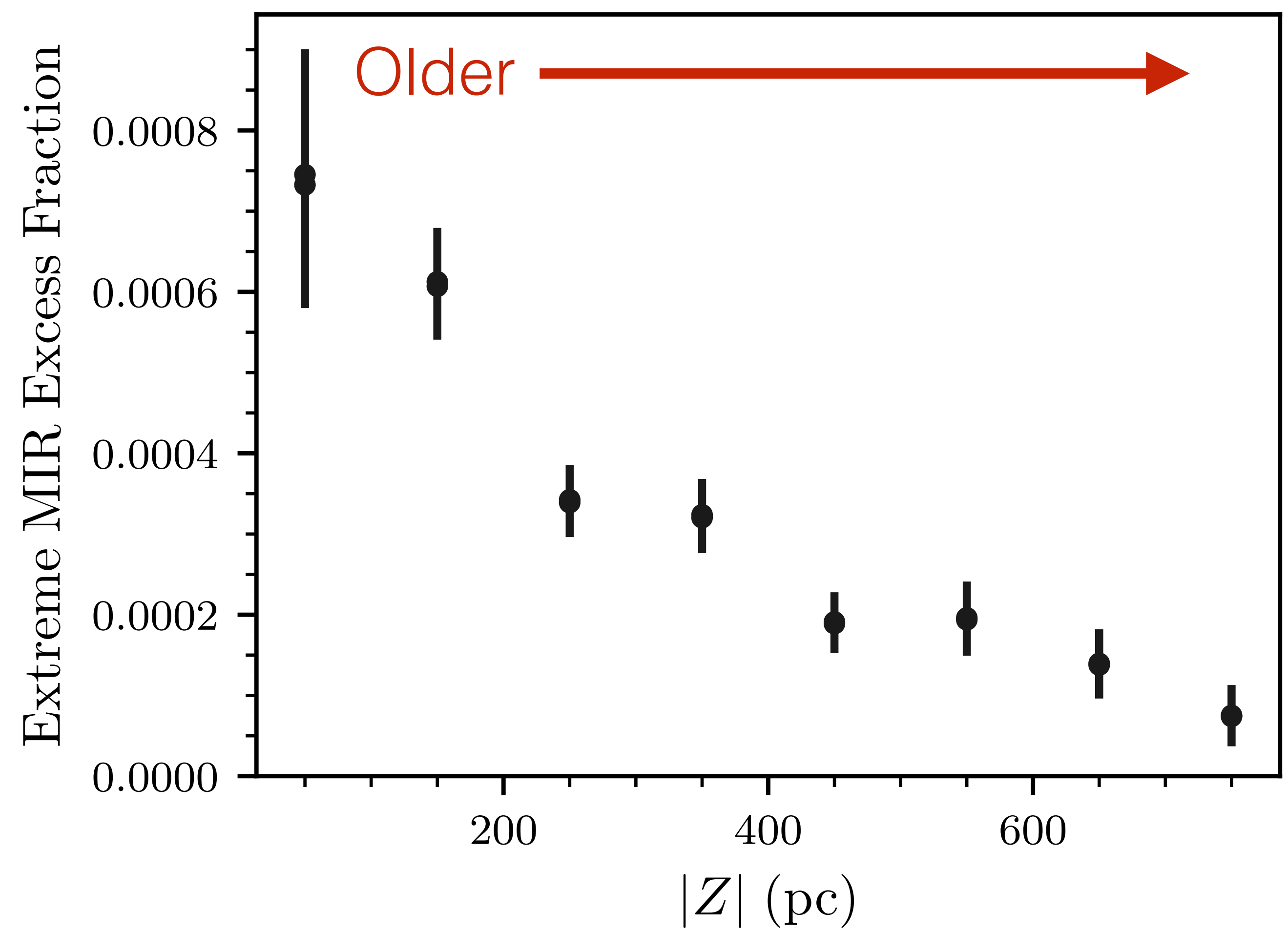
Is there an age trend?

The spectroscopic sample



Theissen & West (2014)

The photometric sample



Theissen & West (2017)

$$\text{Fraction} = \frac{\text{\# stars w/ MIR excess}}{\text{Total \# stars}}$$

Driving Questions

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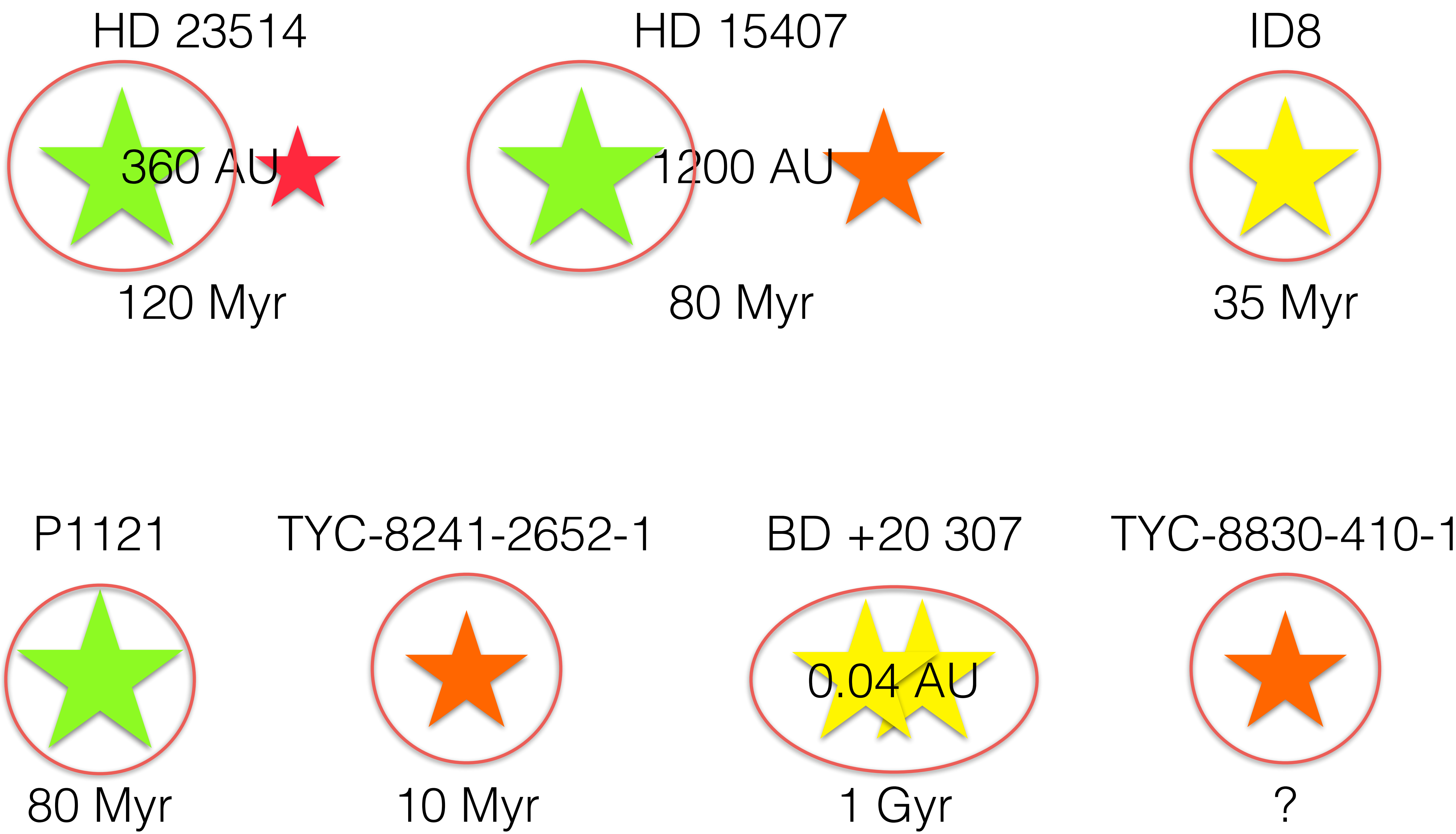
- What are the physical trends we observe for low-mass stars exhibiting extreme MIR excesses?
- Do binary systems exhibit extreme MIR excesses more often than single stars?

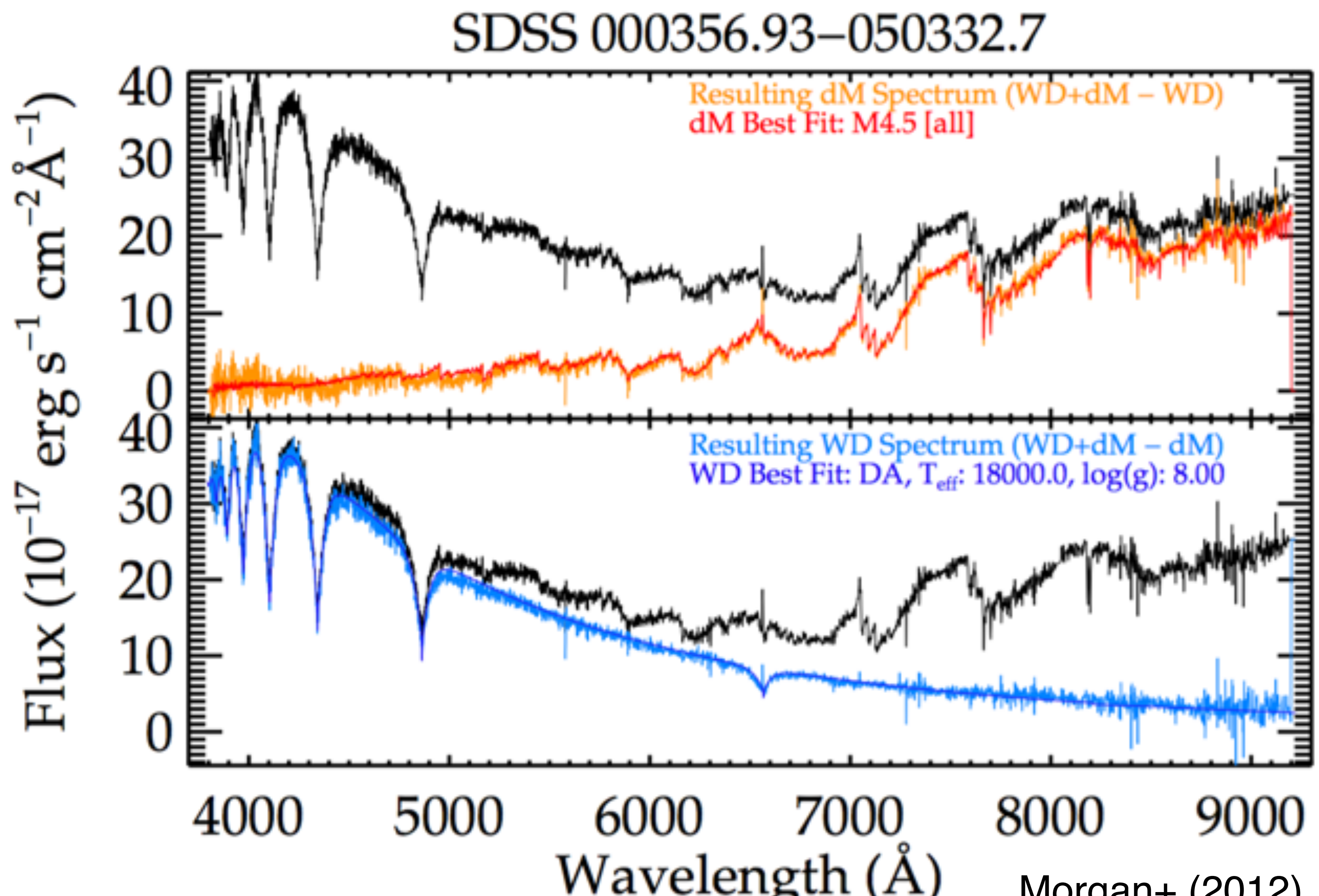
Seven systems currently known



White Dwarf + M Dwarf Binaries (WD+dM)

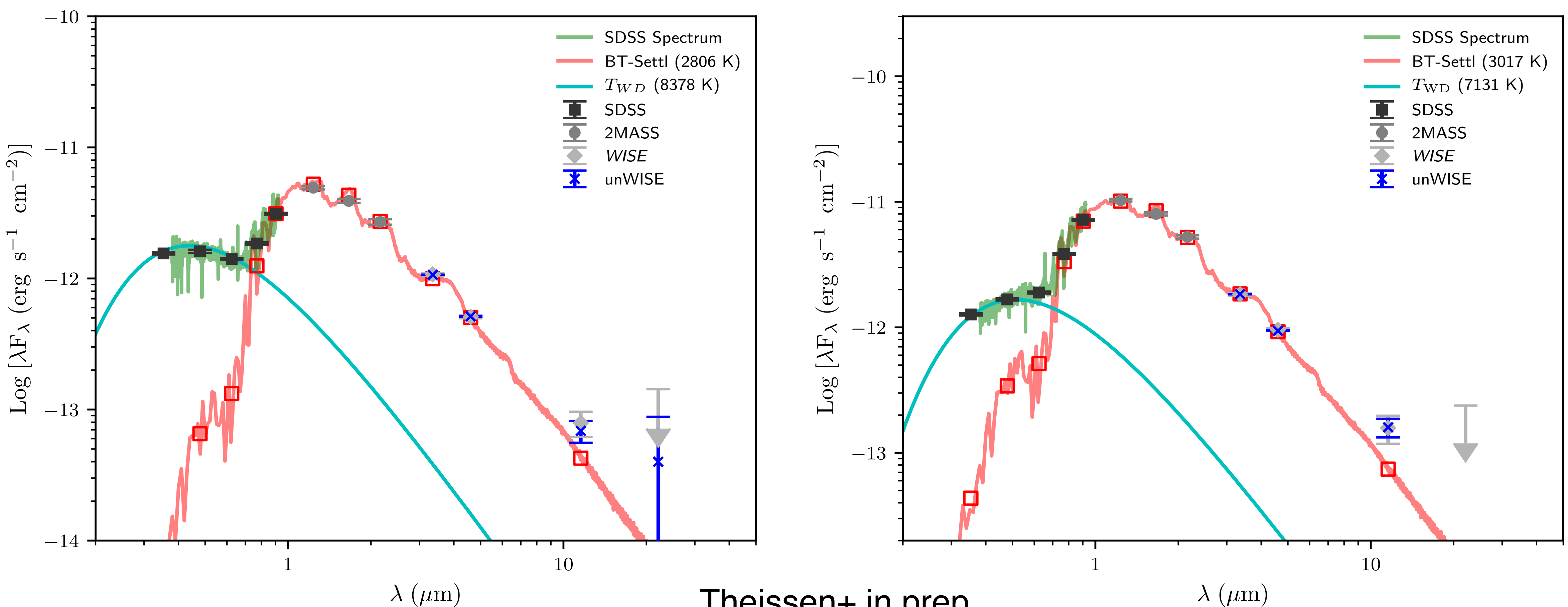
Similar luminosity binaries, but with different peaks in their spectral energy distributions.

Can be detected with low- to moderate-resolution spectra.



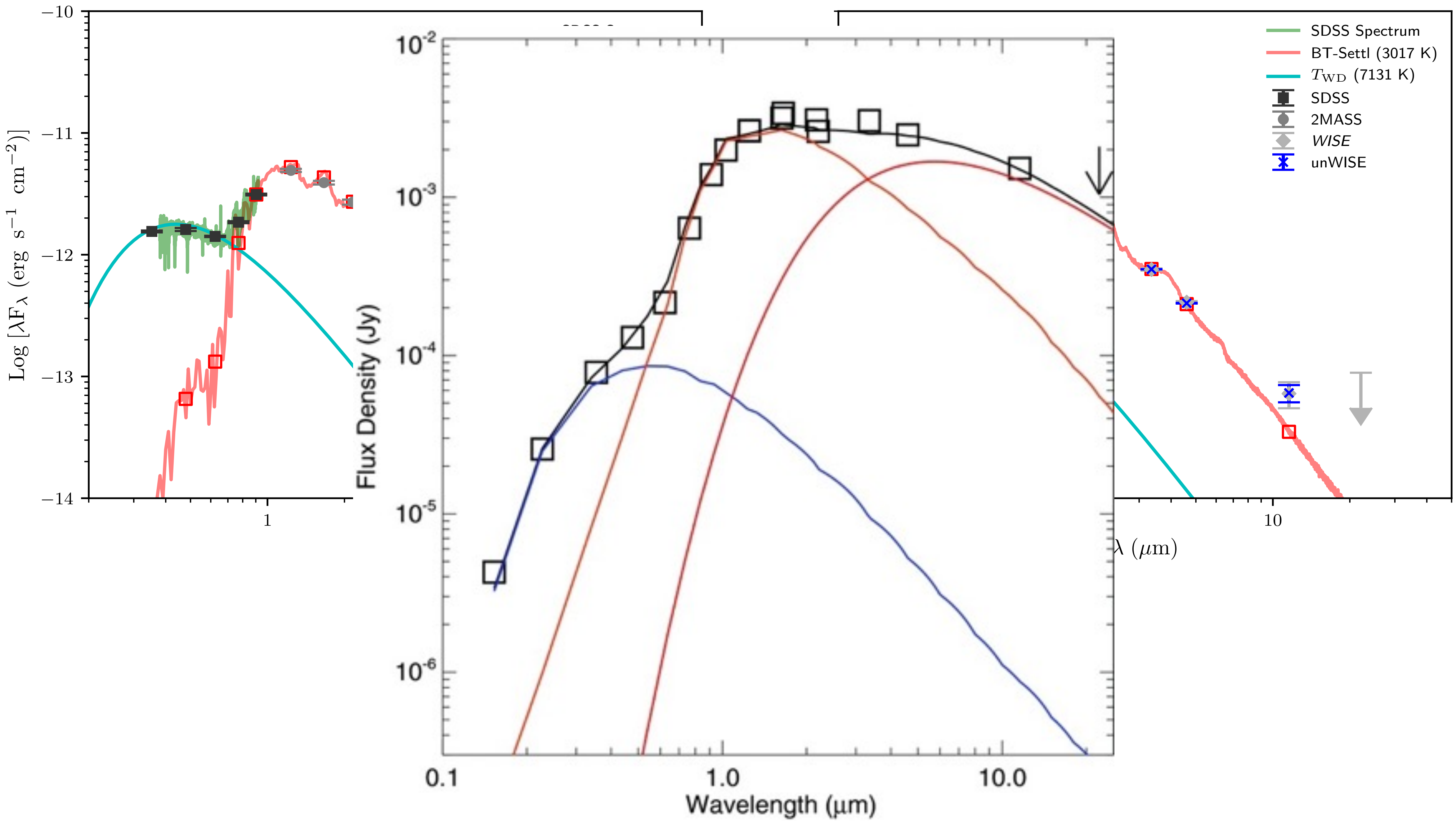
Morgan+ (2012)

Two Binaries Found



Theissen+ in prep.

Two Binaries Found
Plus One



Debes+ (2012)

What percentage of WD+dM systems exhibit extreme MIR excesses?

~0.04% of WD+dM systems exhibit extreme MIR excesses

What percentage of WD+dM systems exhibit extreme MIR excesses?

~0.04% of WD+dM systems exhibit extreme MIR excesses

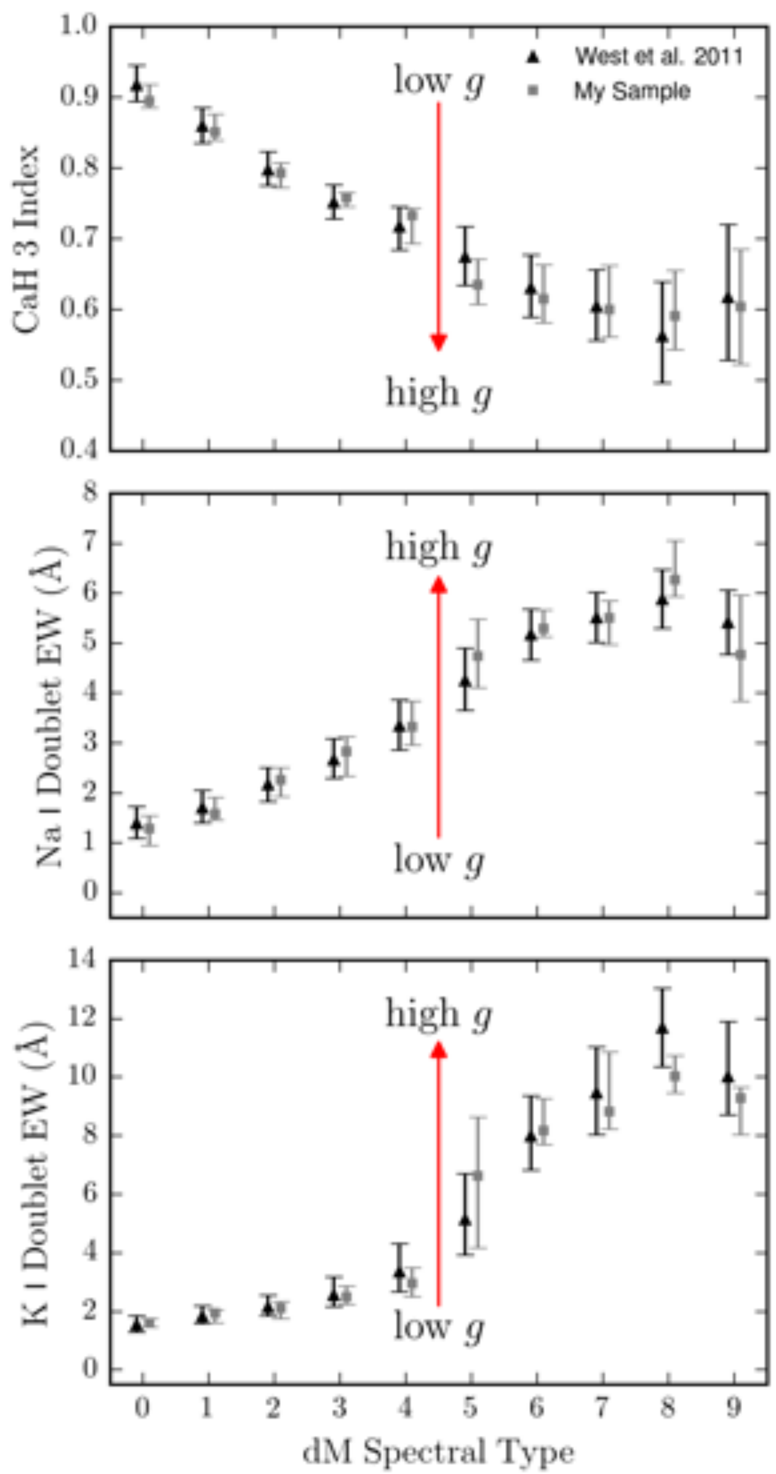
These are small number statistics with no way to account for completeness yet. More work is needed.

Conclusions

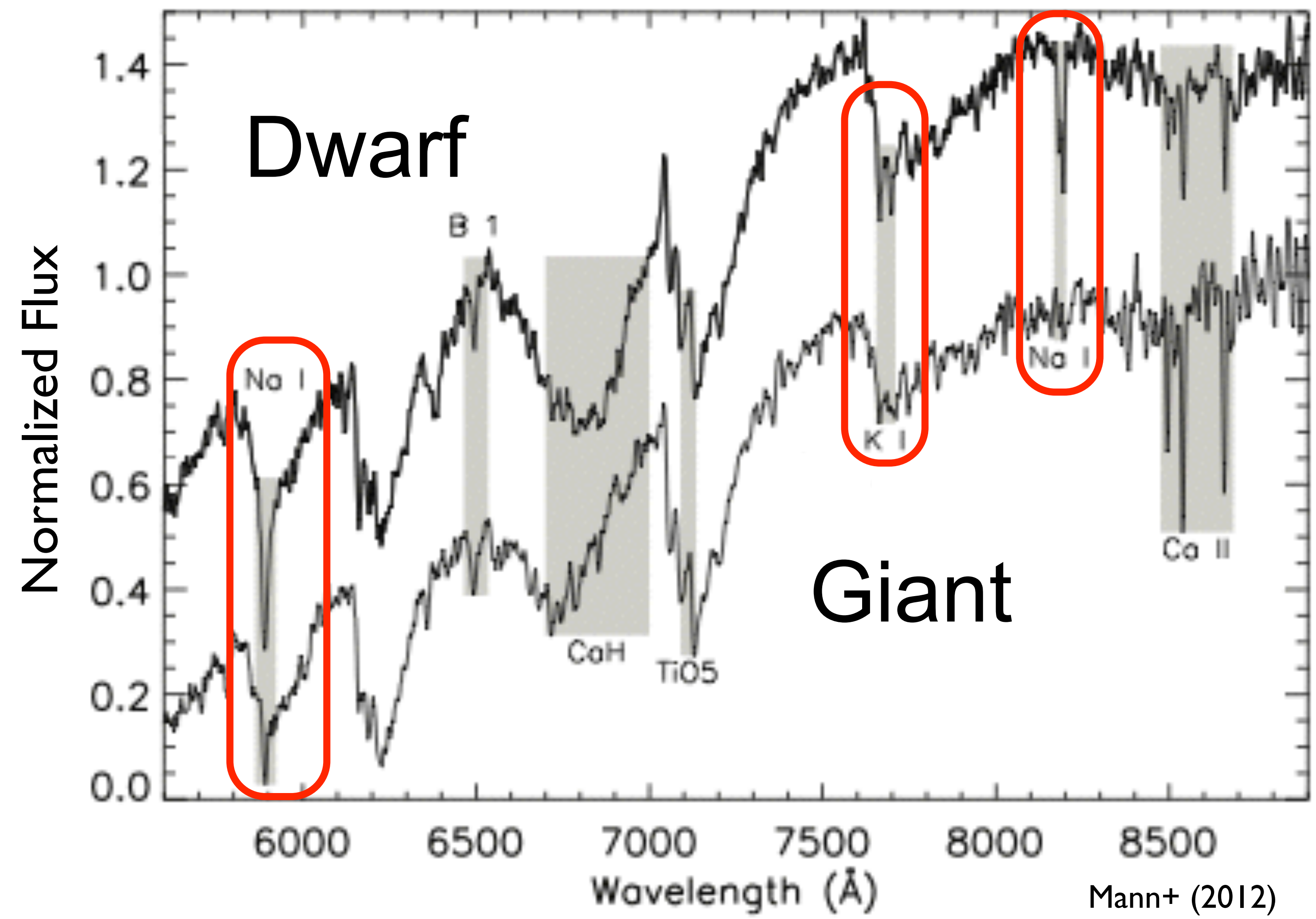
- **How often do low-mass stars in the field exhibit extreme excess MIR flux?**
  - Approximately 0.04% of low-mass field stars exhibit extreme MIR excesses (versus 0.0007% for solar-type stars).
- **What are the trends we observe for low-mass stars exhibiting extreme MIR excesses?**
  - An age trend is observed, with younger field stars exhibiting a higher incidence of extreme MIR excesses over older field populations
  - There may be a mass dependence, with lower-mass stars more likely to exhibit an extreme MIR excess.
- **Do binary systems exhibit extreme MIR excess more often than single stars?**
  - Using WD+dM systems, I find binaries typically host dust as often as single stars. Origins may be vastly different though.

Acknowledgements
(No one does it alone)

Aging SDSS M Dwarfs I: Surface Gravity

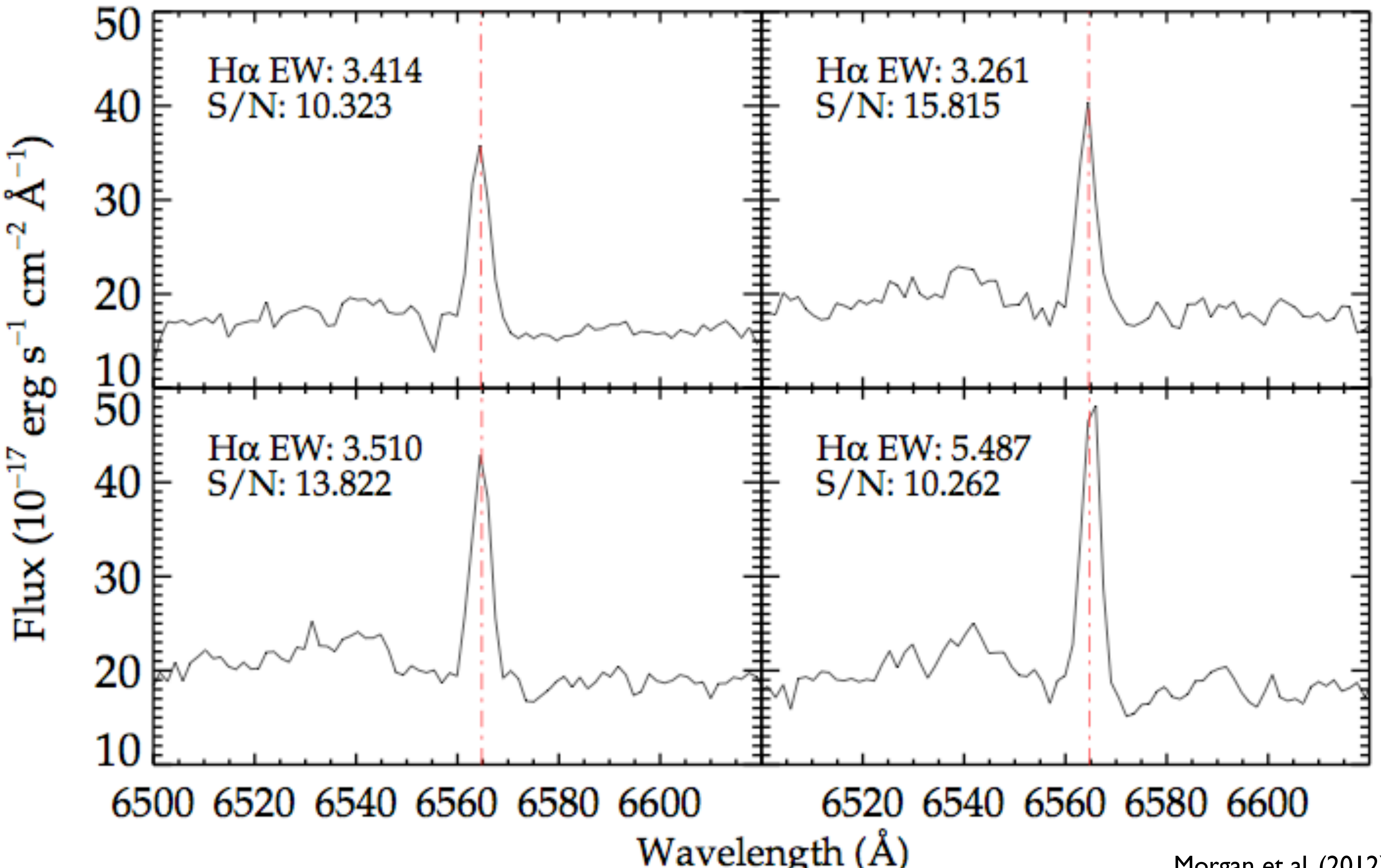


Theissen & West (2014)



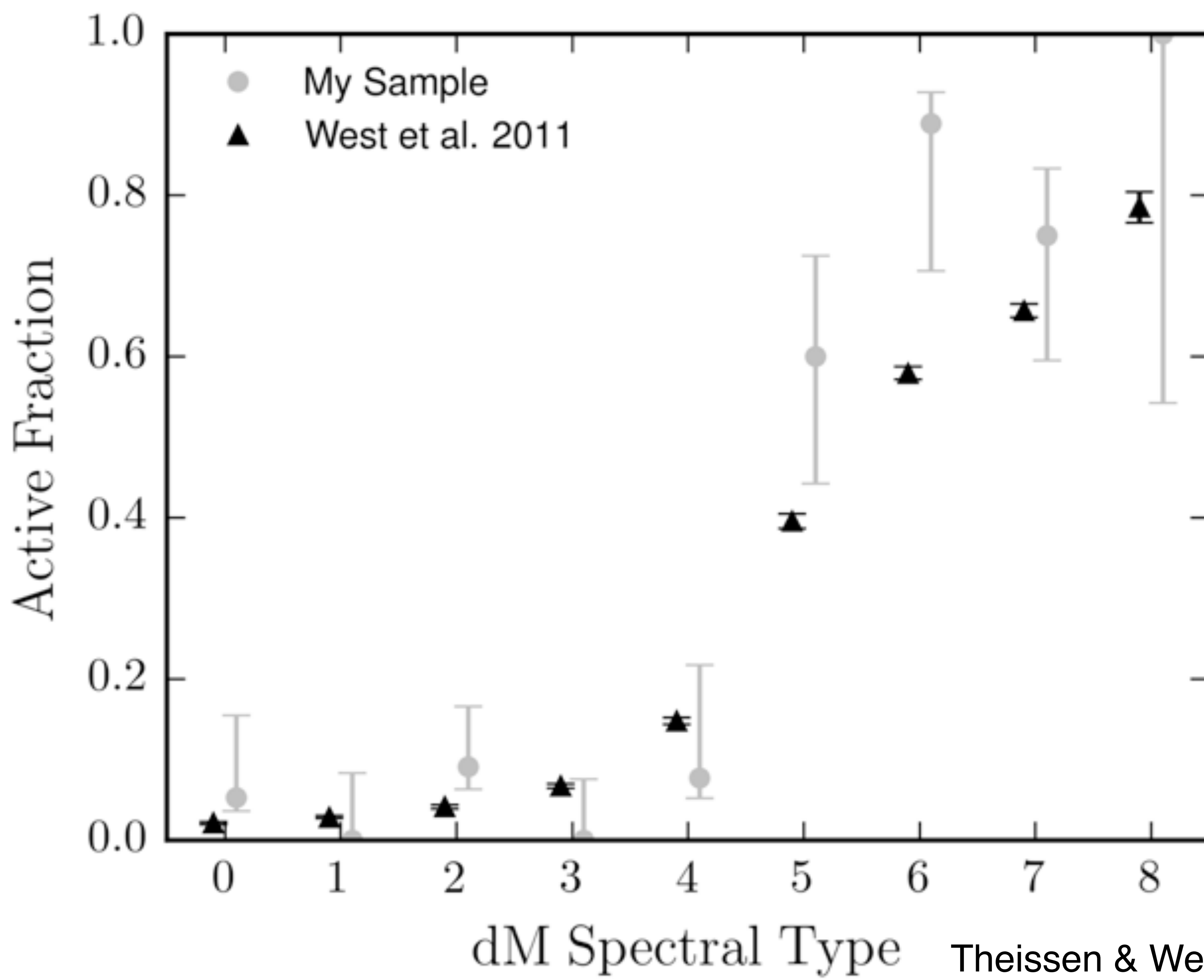
Mann+ (2012)

Aging SDSS M Dwarfs II: Hydrogen emission



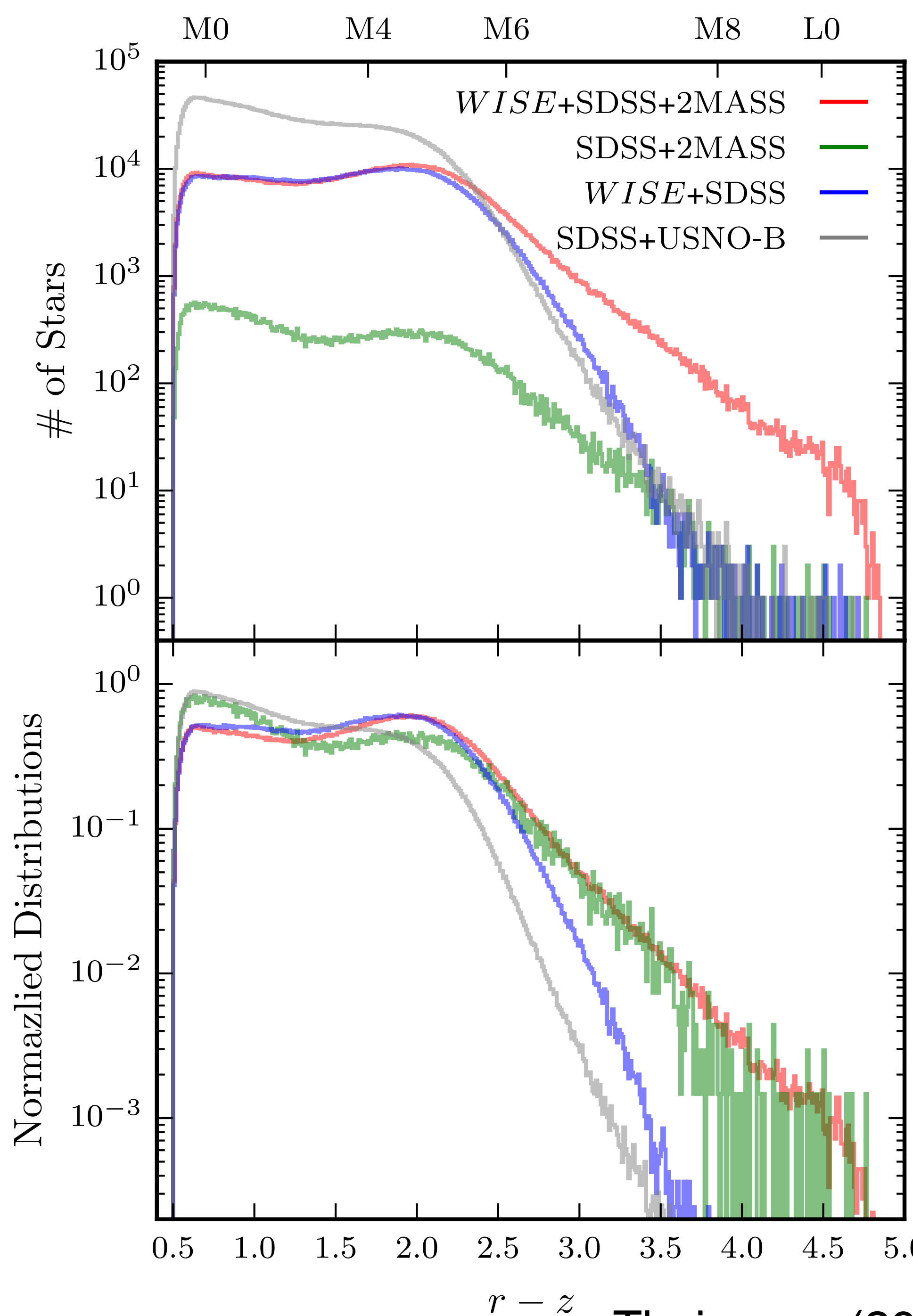
Morgan et al. (2012)

Aging SDSS M Dwarfs II: Hydrogen emission

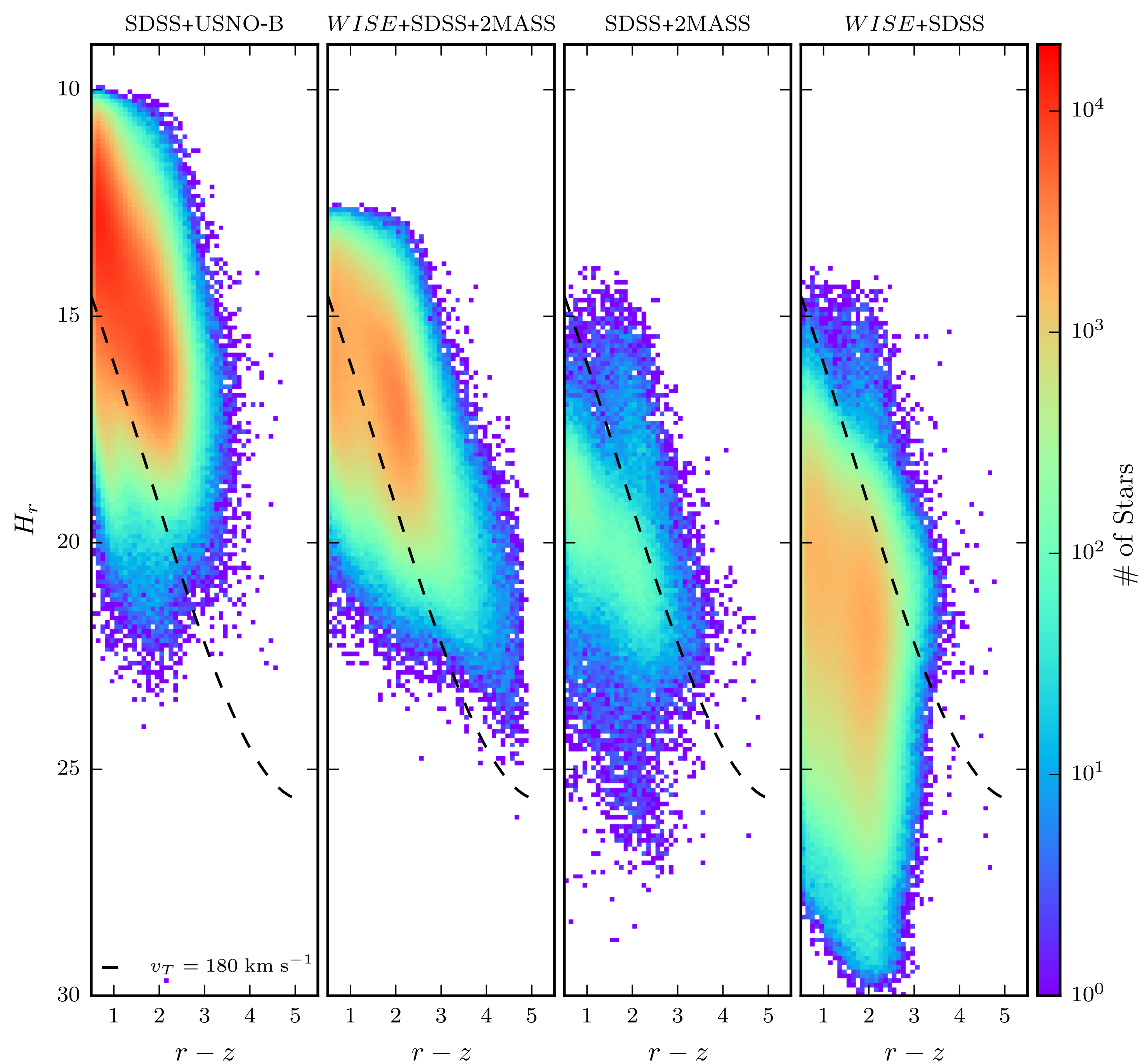


Theissen & West (2014)

Building the Photometric Sample
Motion Verified Red Stars (MoVeRS)

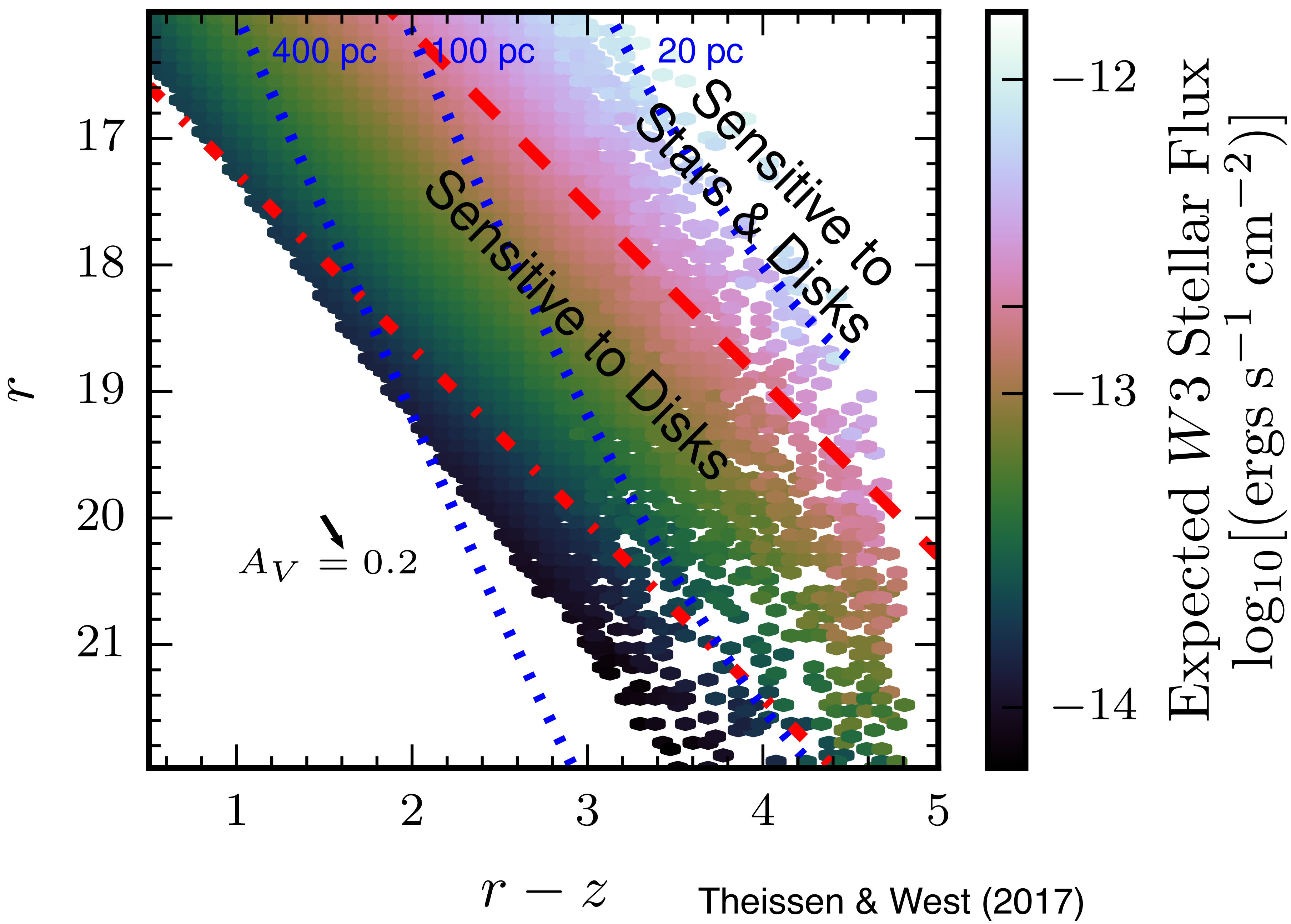


Theissen+ (2016,



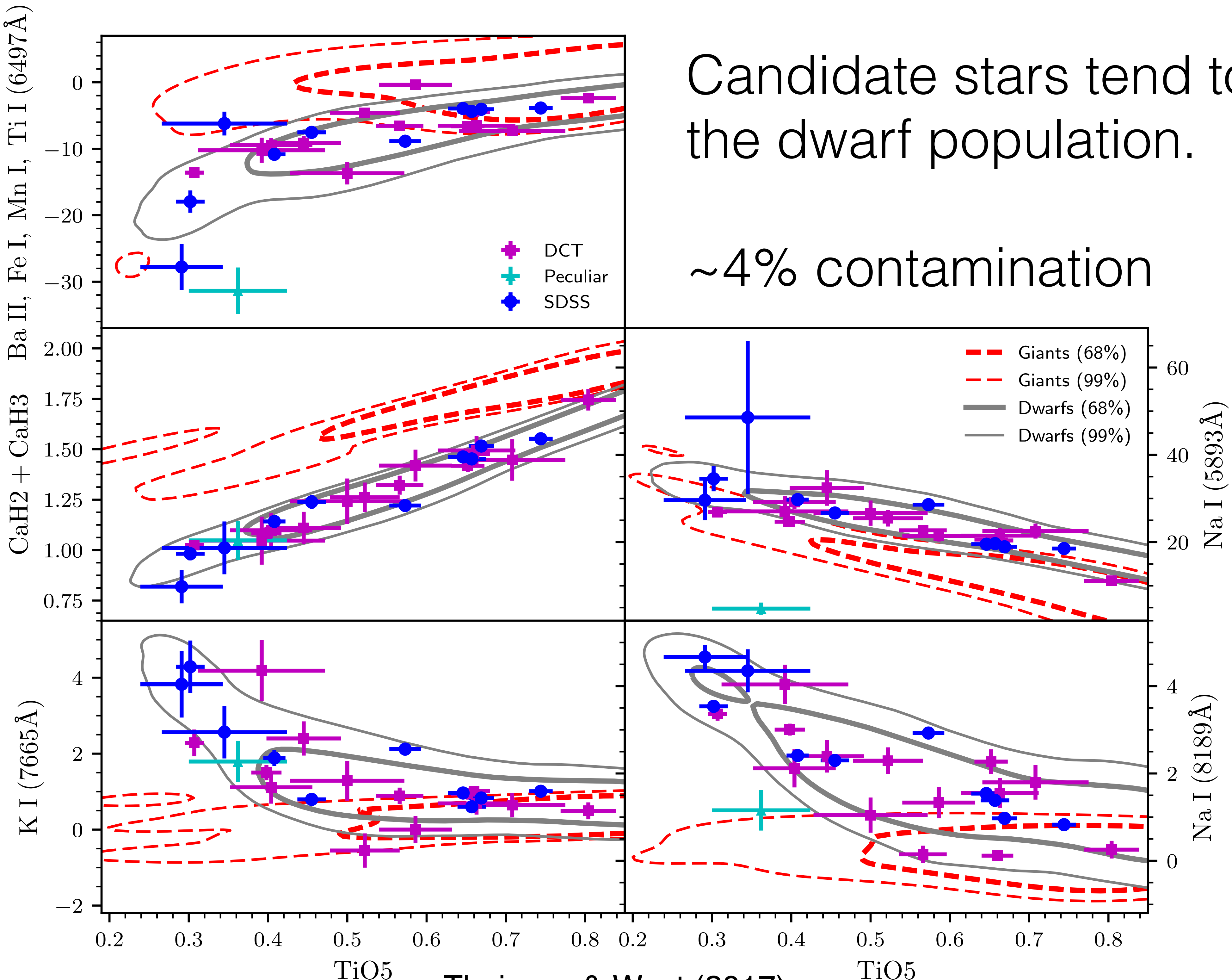
Theissen+ (2016)

Using MoVeRS: Defining the Sample



Theissen & West (2017)

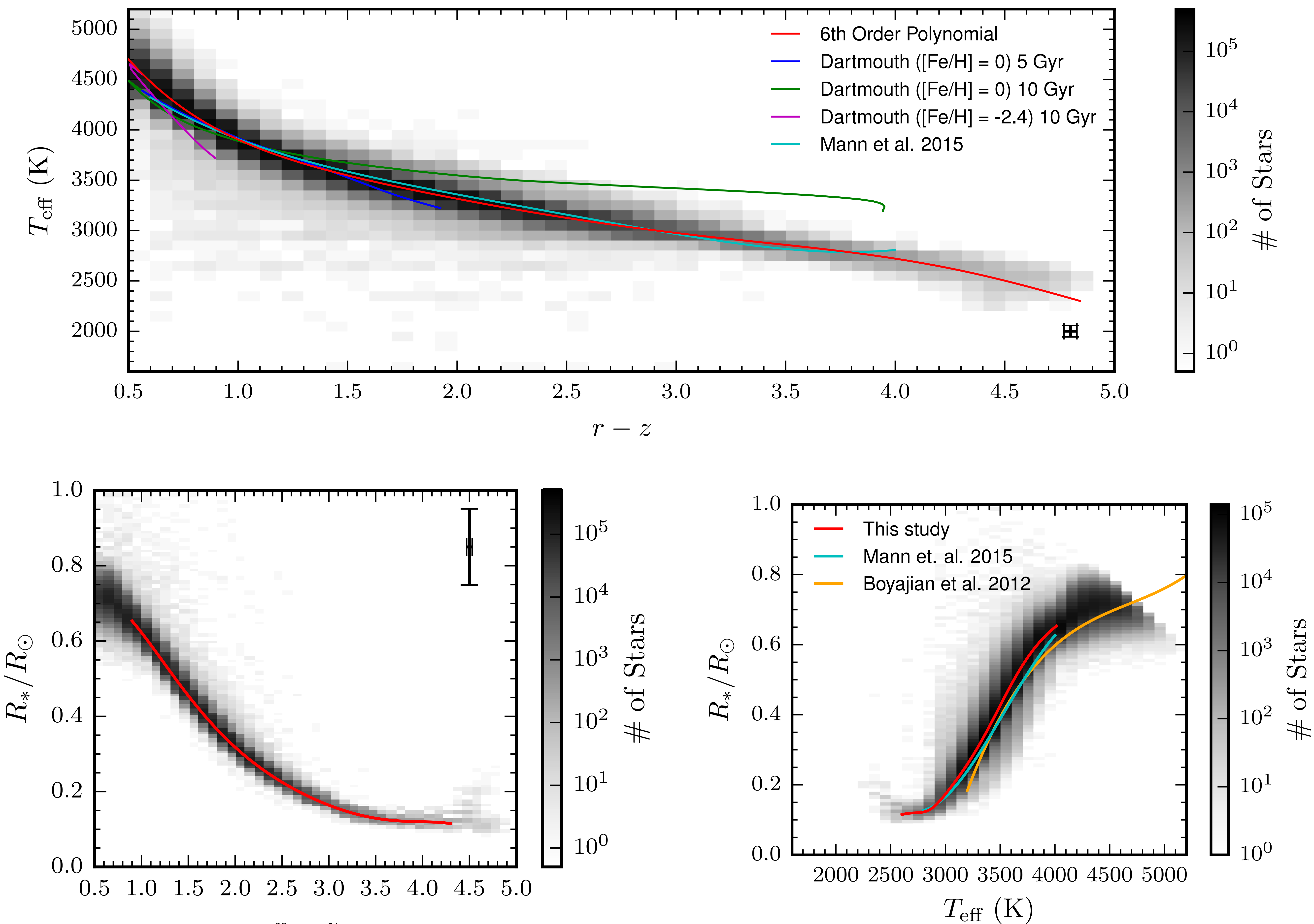
Contamination Rate? Giants verus Dwarfs



Candidate stars tend to follow the dwarf population.

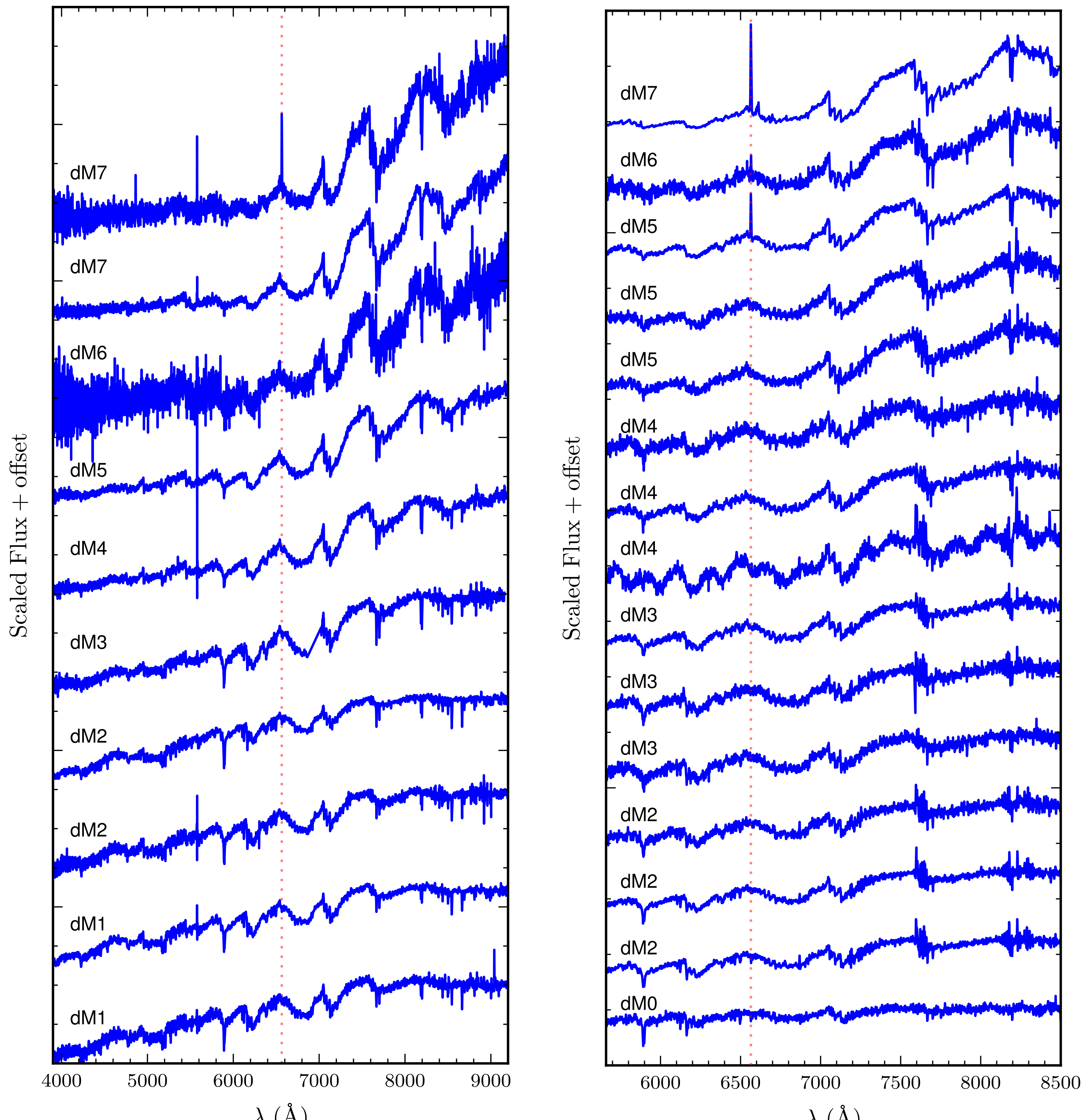
~4% contamination

Theissen & West (2017)



Theissen & West (2017)

Youth Tracers Part Deux

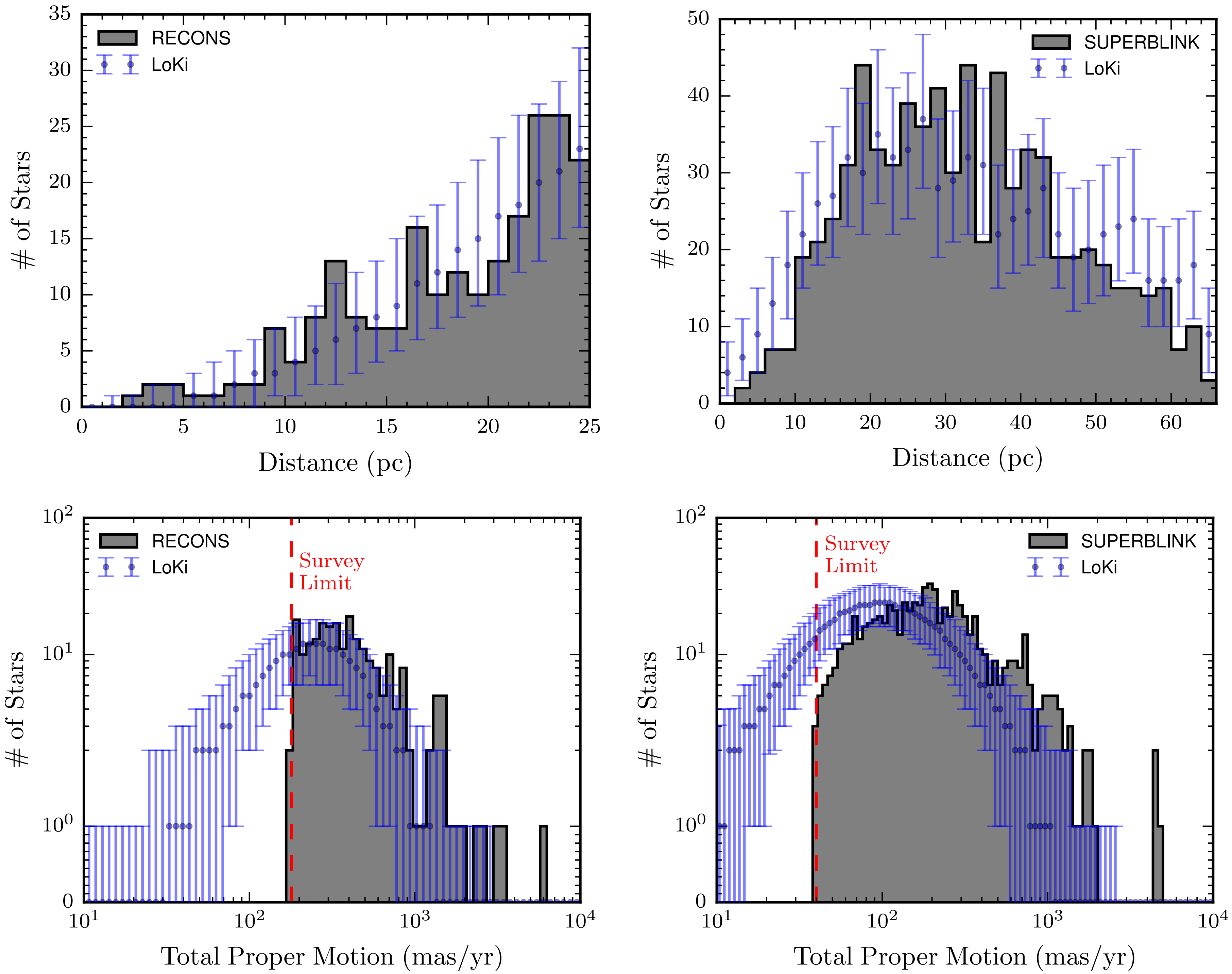


Theissen & West (2017)

Obtained SDSS and DCT optical spectra of randomly selected stars.

Stars are again consistent with the field population.

Model of the (Nearby) Galaxy

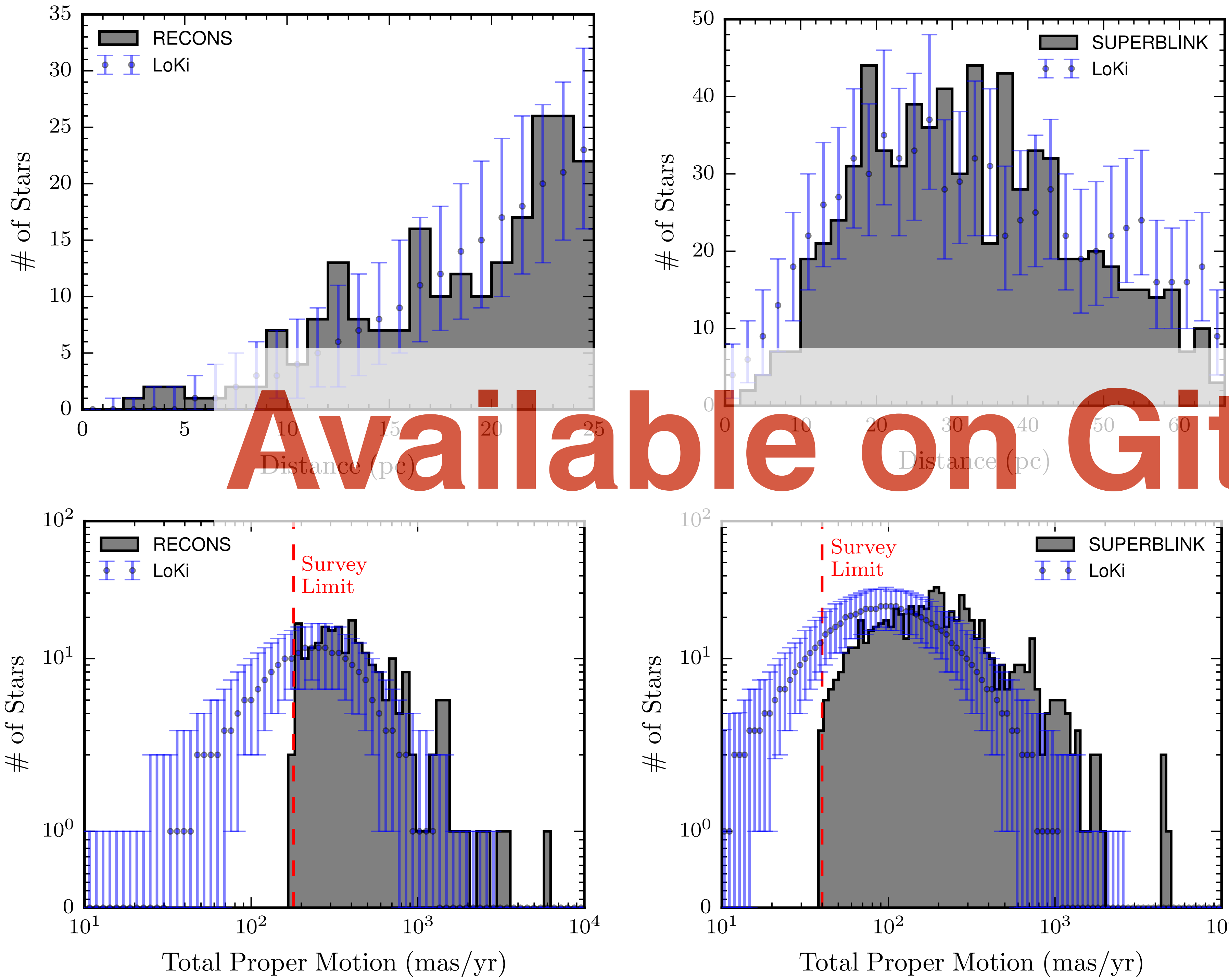


Theissen & West (2017)

Model of the low-mass stars and their kinematics in our Galaxy

The Low-mass Kinematics model (LoKi)

Model of the (Nearby) Galaxy



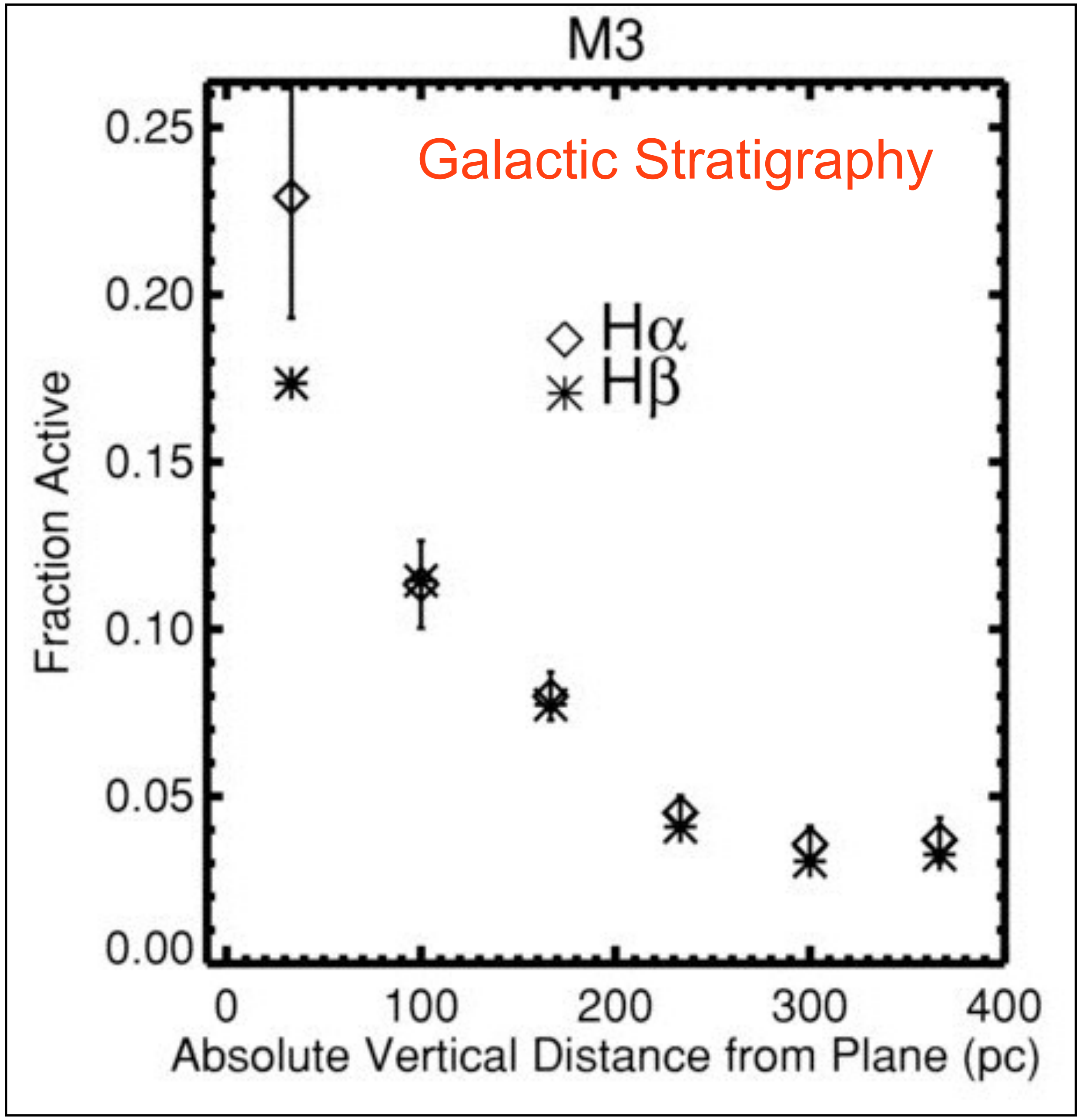
Model of the low-mass stars and their kinematics in our Galaxy

The Low-mass Kinematics model (LoKi)

Available on GitHub!

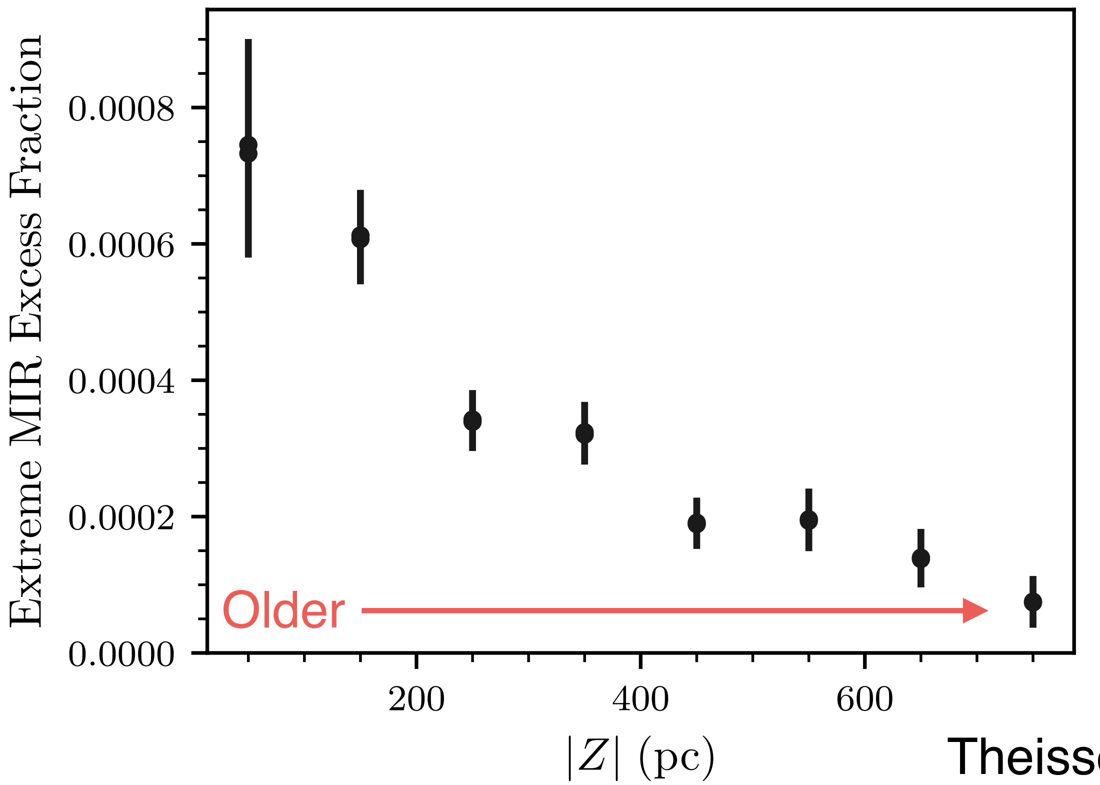
Theissen & West (2017)

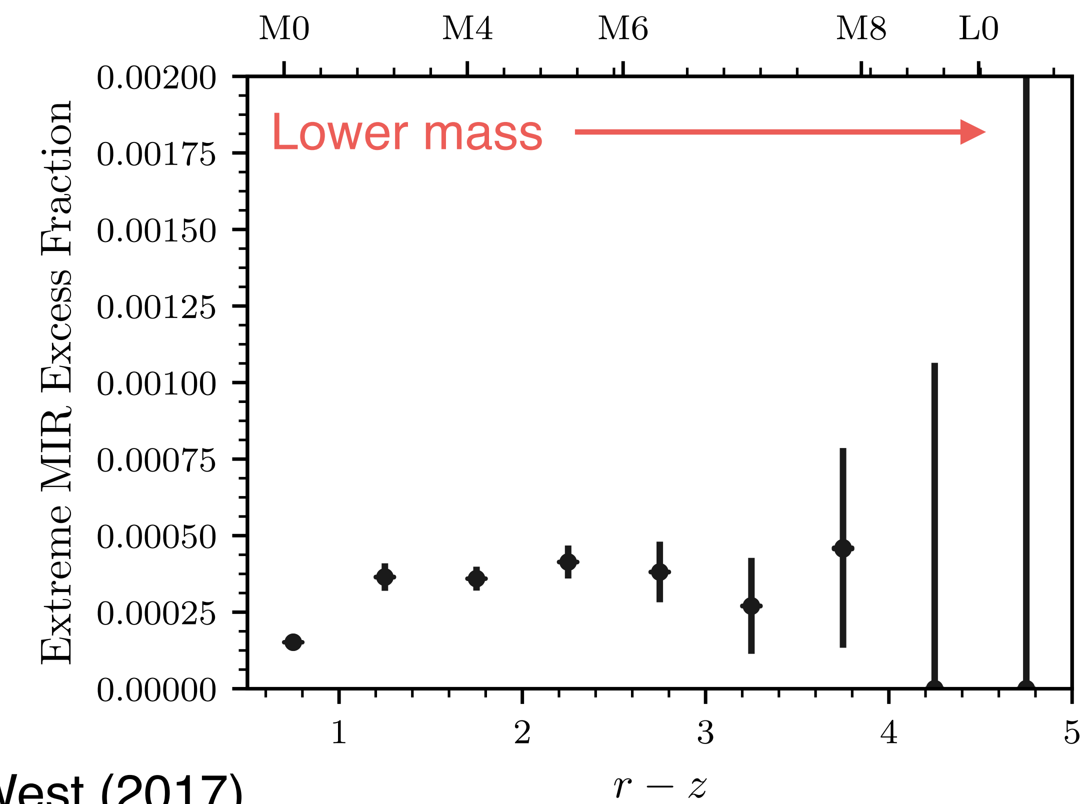
Is There an Age Effect?



Adapted from West et al. (2011)

What are the trends with MIR excesses?



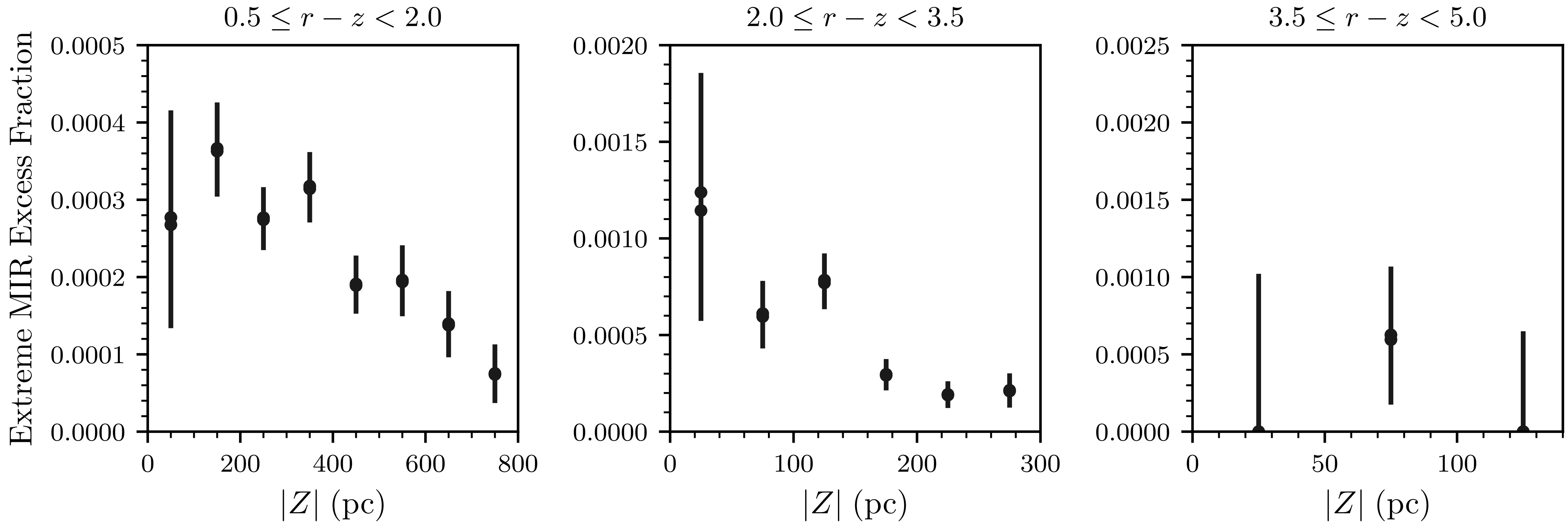


Theissen & West (2017)

Younger field stars are more likely to host an extreme MIR excess

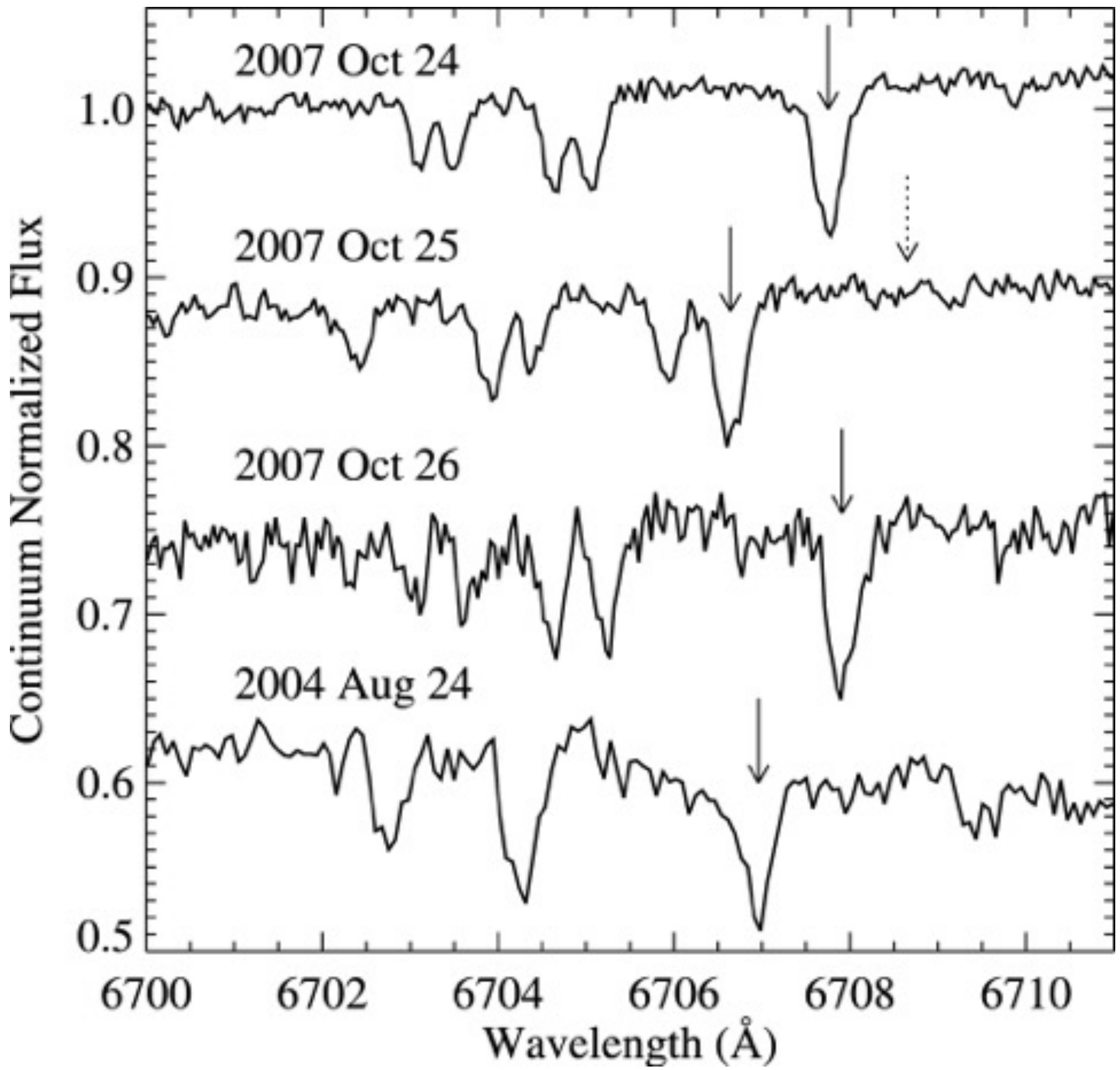
There might be a slight trend with stellar mass, indicating lower-mass stars are more likely to host an extreme MIR excess

What are the trends with MIR excesses?



Theissen & West (2017)

Locating Binaries

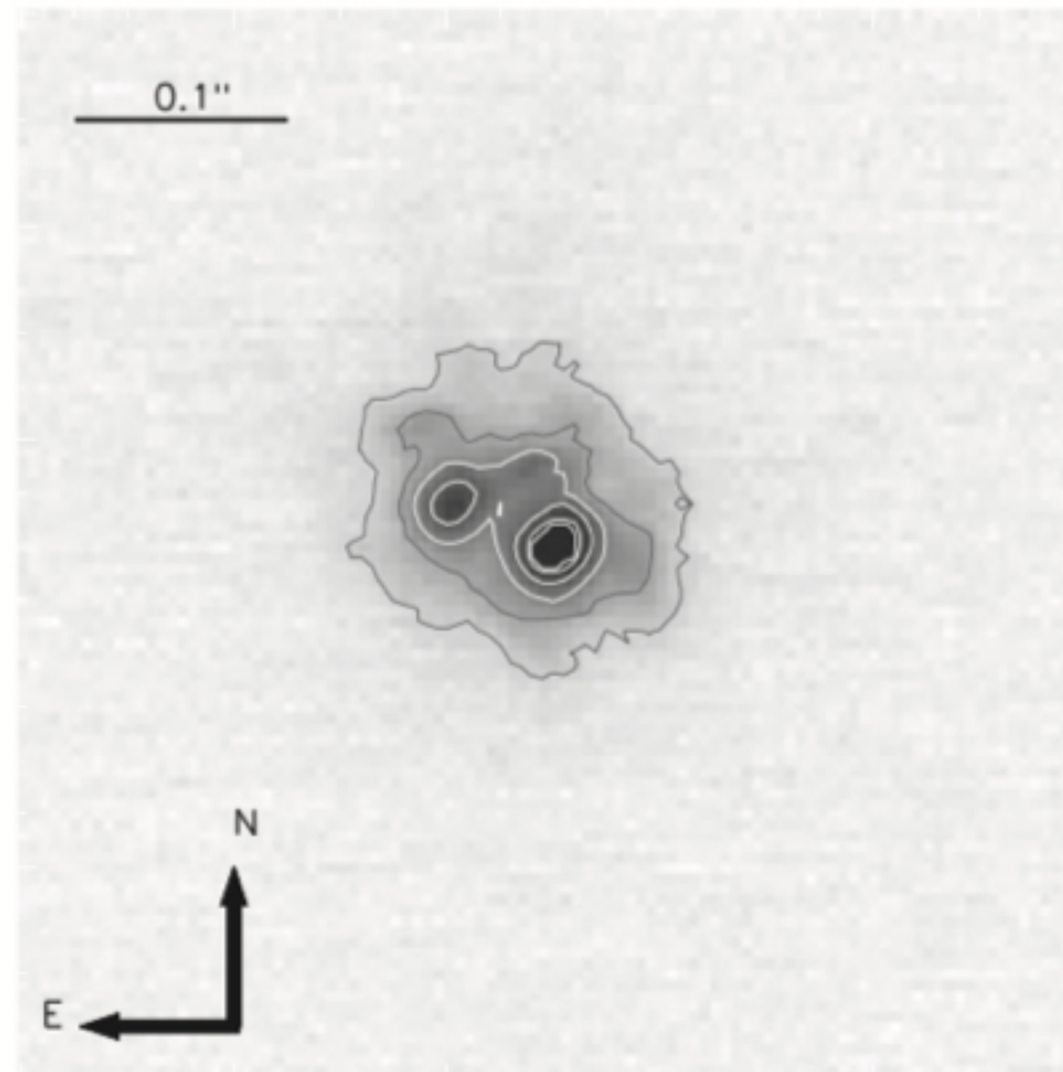


Weinberger (2008)

Very tight binaries require high-resolution spectroscopy (over multiple epochs) to find.

Locating Binaries

Intermediate separation binaries require high-resolution adaptive optics imaging

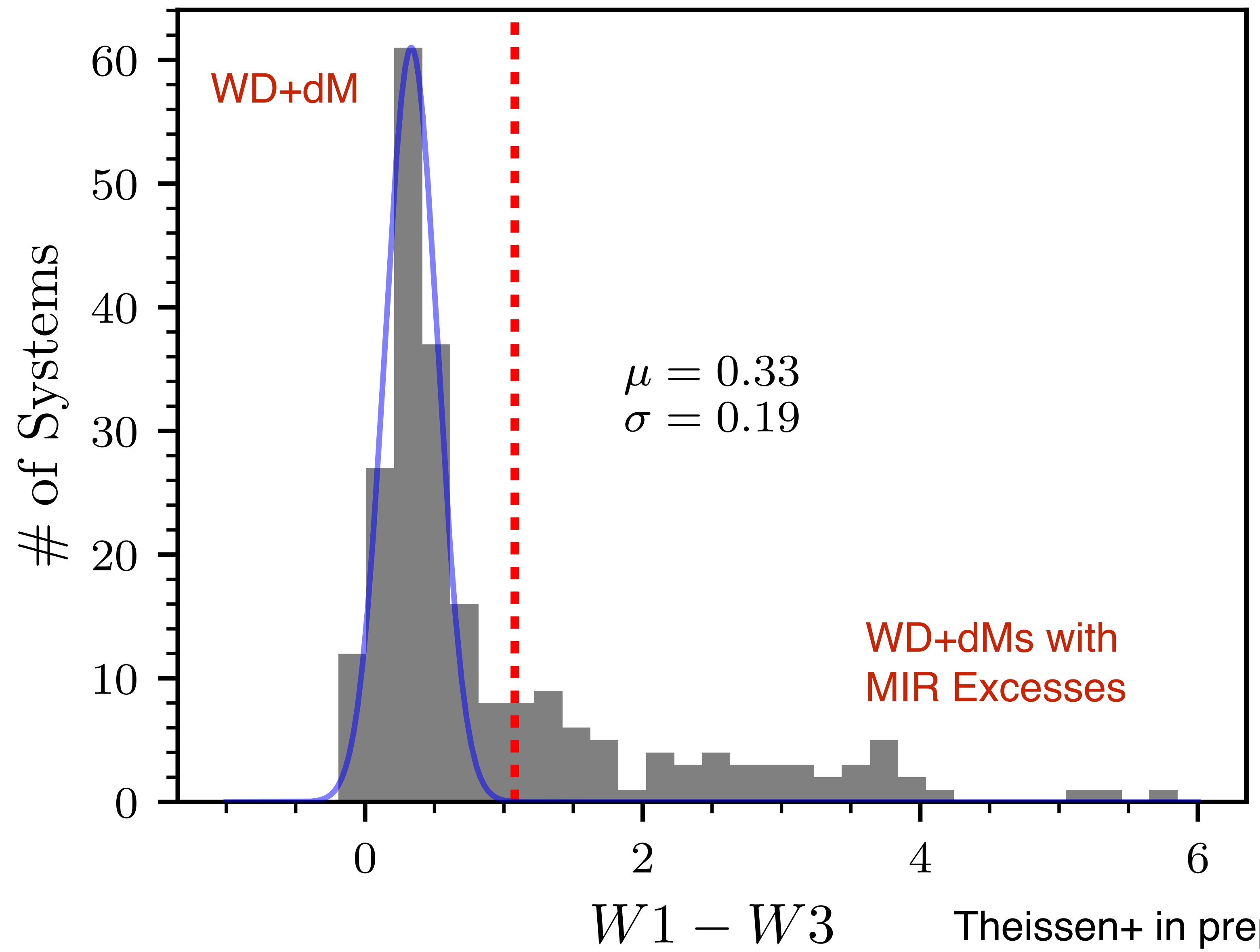


(i) *SDSS J2052-1609* K_s.

Bardalez-Gagliuffi+ (2015)

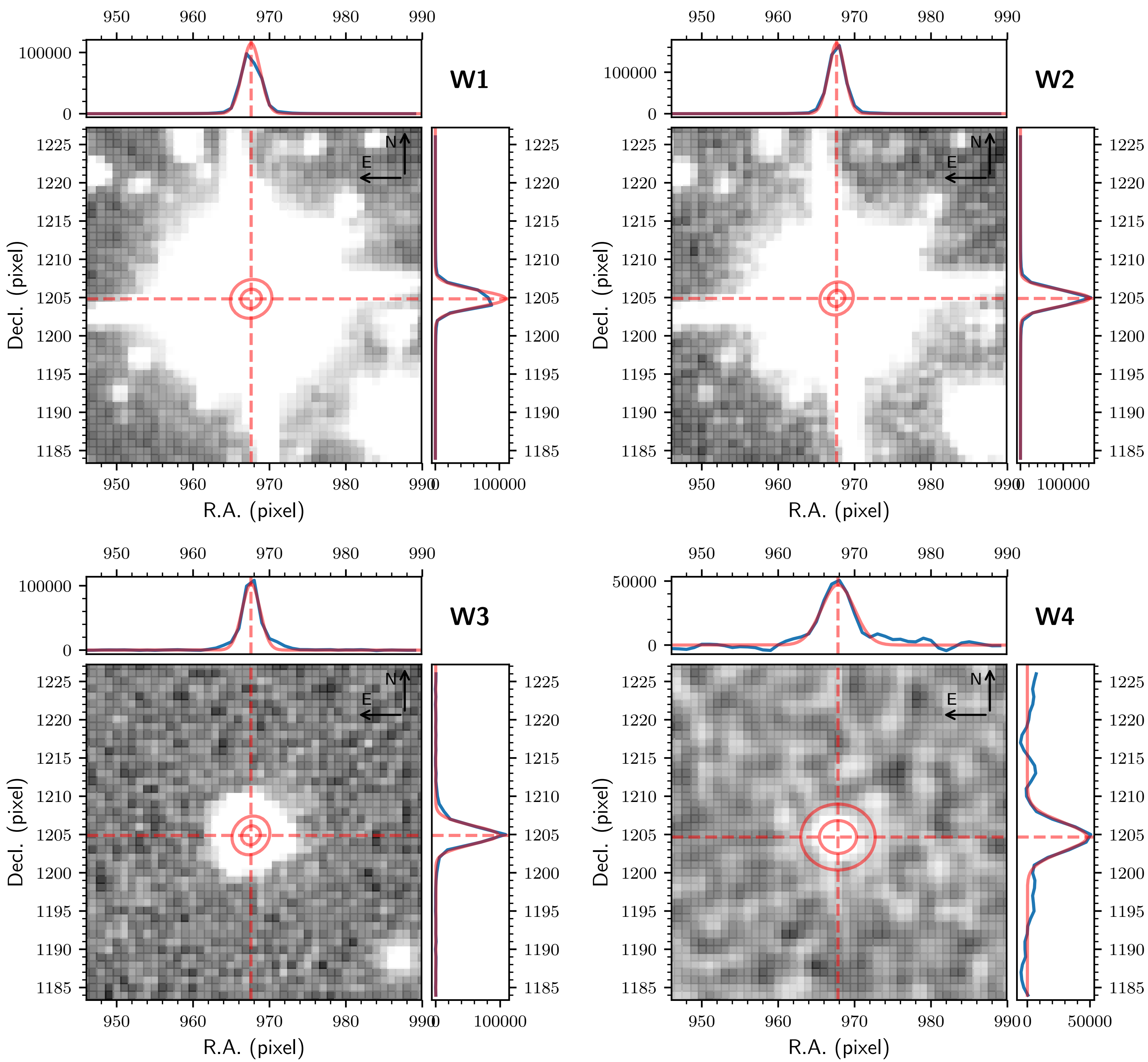
Current Samples with MIR Excesses

Using available samples, selected WD+dM systems with excess MIR flux



Theissen+ in prep.

A Tool for Measuring *WISE* Source Quality

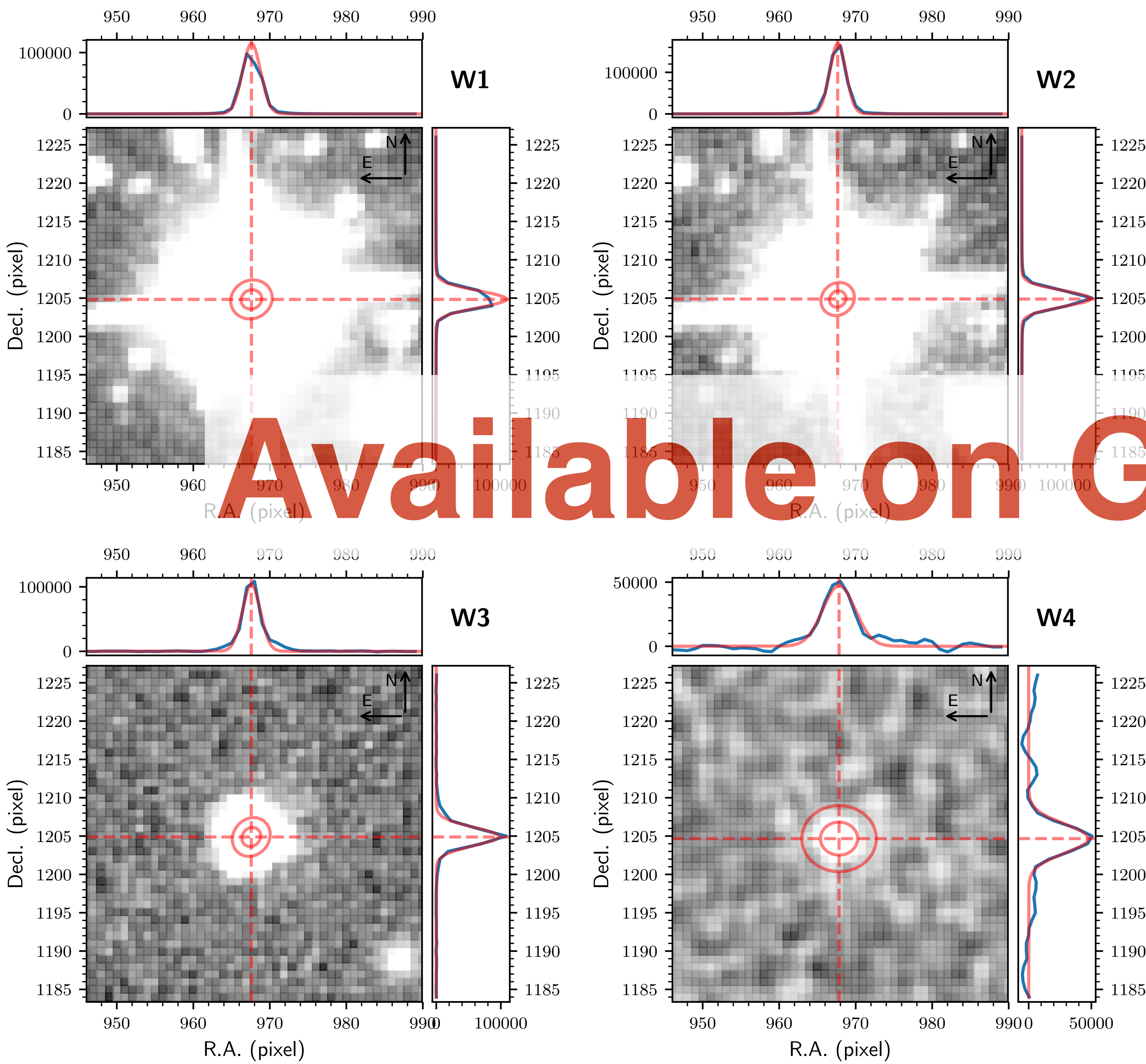


Theissen+ in prep.

A tool to measure source “roundness” and band-to-band correlation.

The unWISE Intrinsic Source Estimator for Sureness and Trustworthiness (*unWISEST*)

A Tool for Measuring *WISE* Source Quality



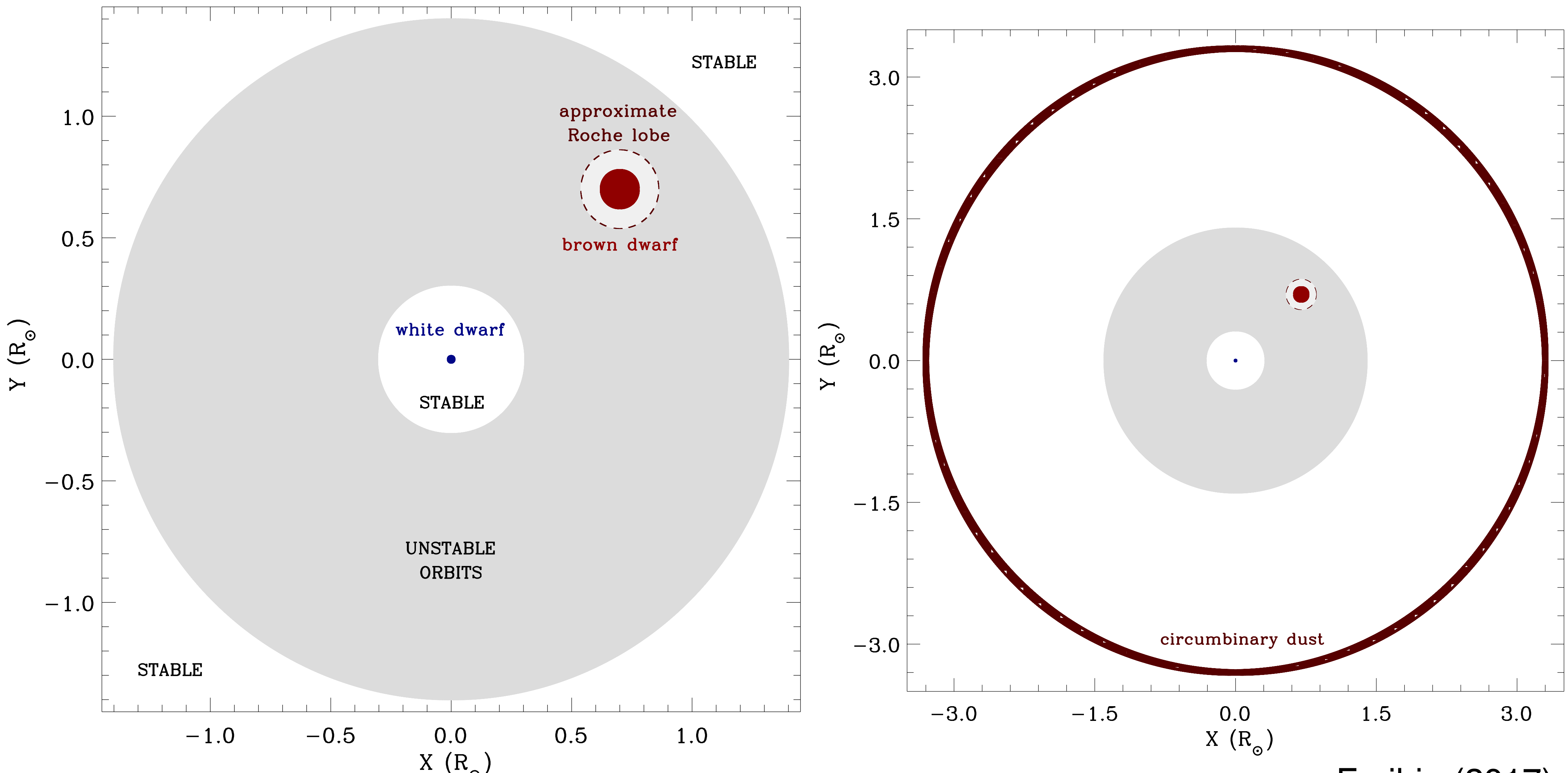
A tool to measure source "roundness" and band-to-band correlation.

Available on GitHub!

The unWISE Intrinsic Source Estimator for Sureness and Trustworthiness (*unWISEST*)

Theissen+ in prep.

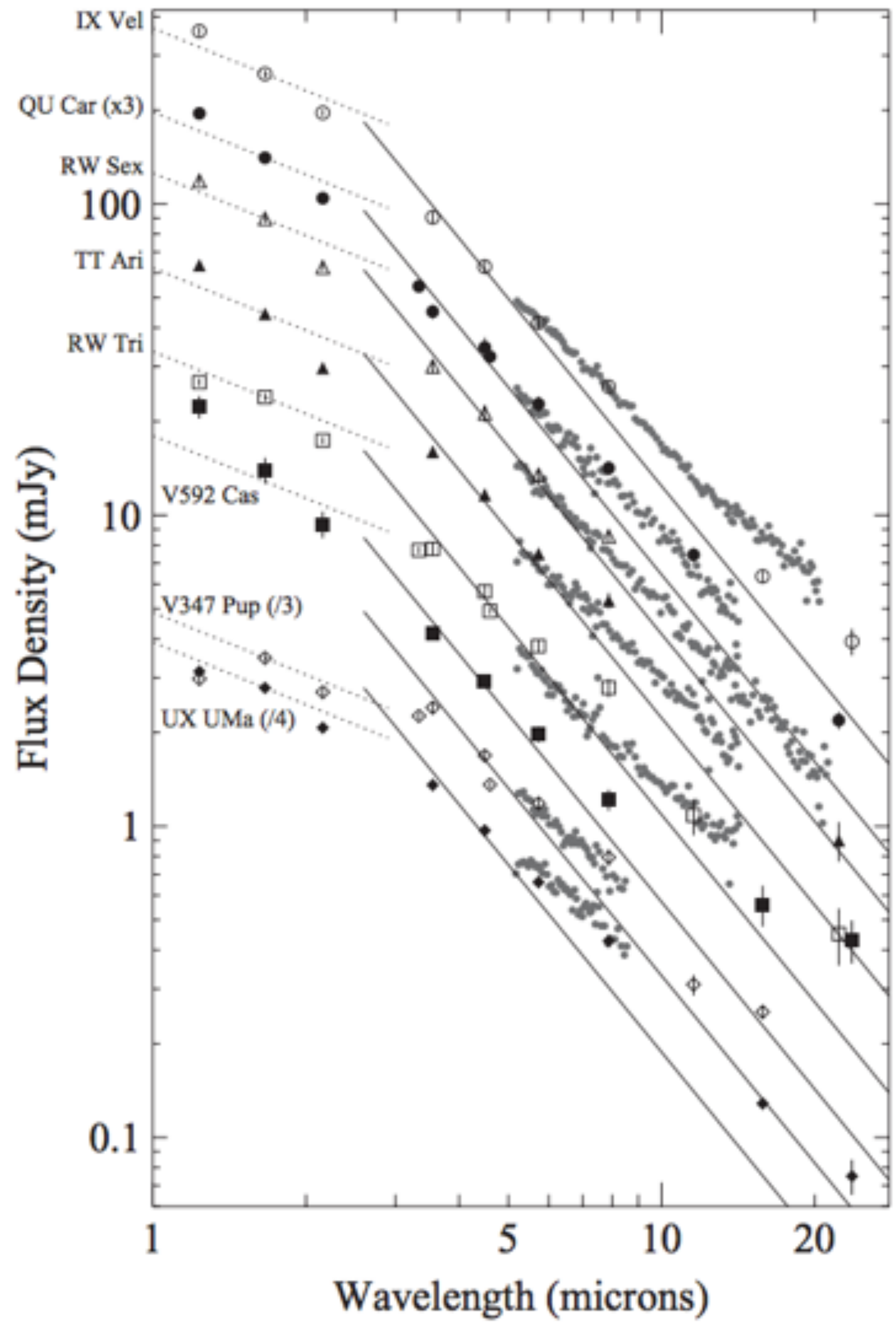
Circumbinary Dust



Farihi+ (2017)

Dust orbits both components of the binary

WD+dMs with Dust



Hoard (2013)

These are all *interacting* binaries