Photometric Determination of Main-Sequence Binaries (with Gaia)

Alex Wallace

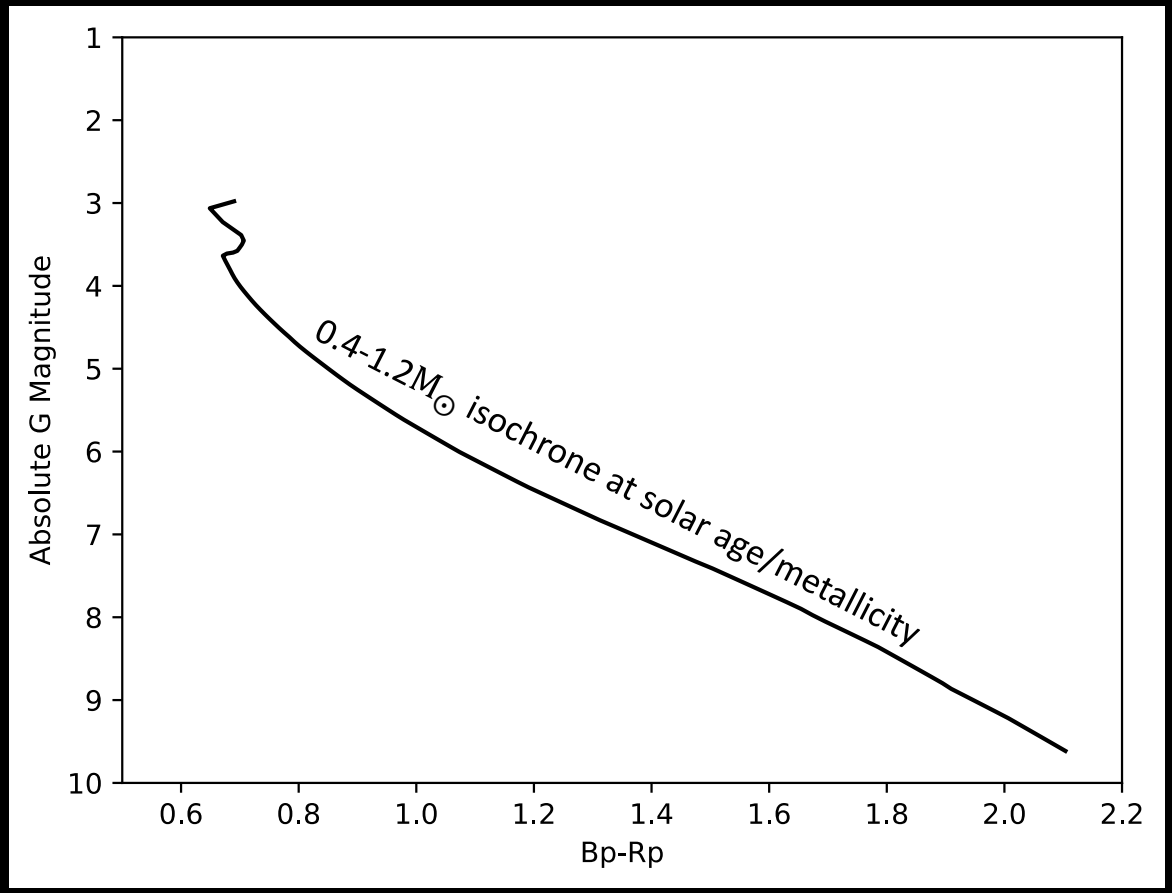
(with Andrew Casey)

Overall Goals

- Use Gaia photometry to constrain astrophysical parameters of a star
- Determine whether it is hosting an unresolved companion
- If there is a companion, calculate the mass ratio
- Calculate binary fractions

Astrophysical Parameters on the H-R Diagram

Mass



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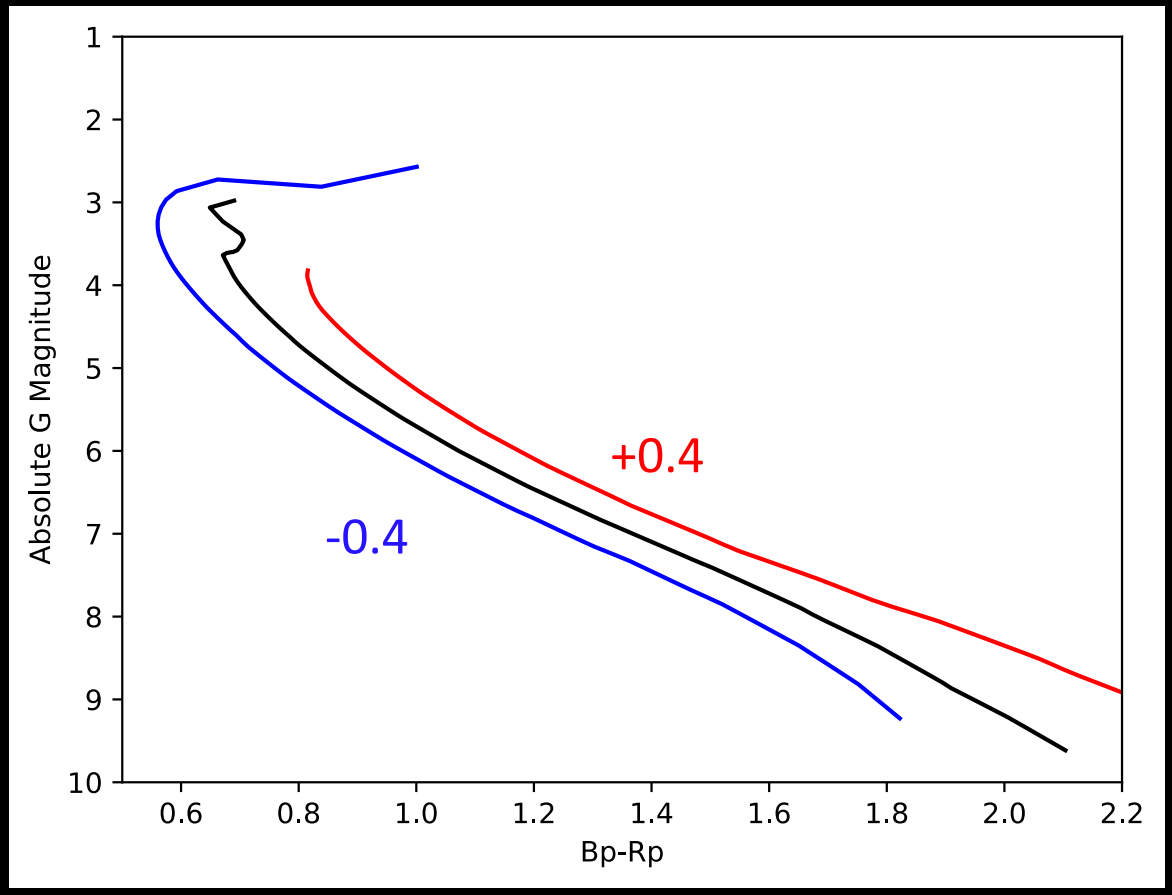
Astrophysical Parameters on the H-R Diagram

[Fe/H]



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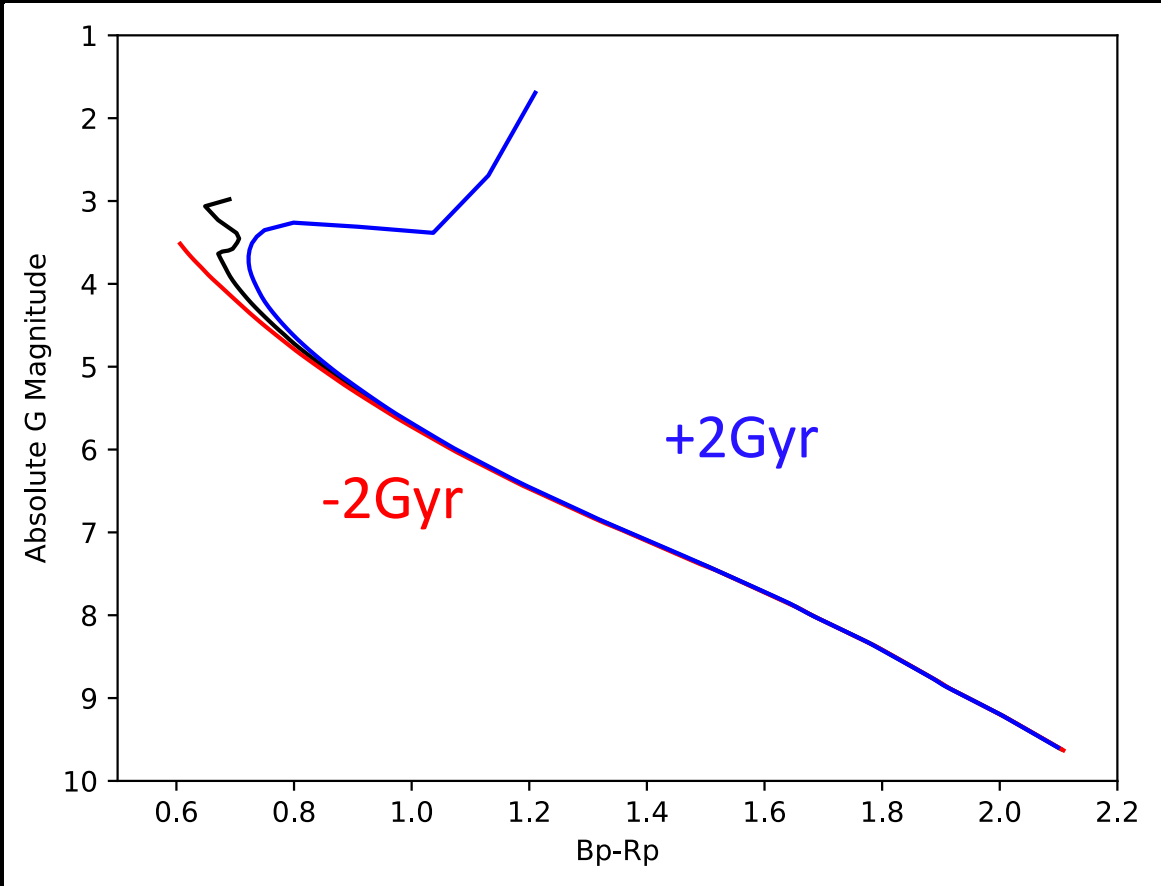
Astrophysical Parameters on the H-R Diagram

Age



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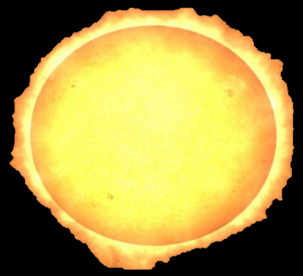
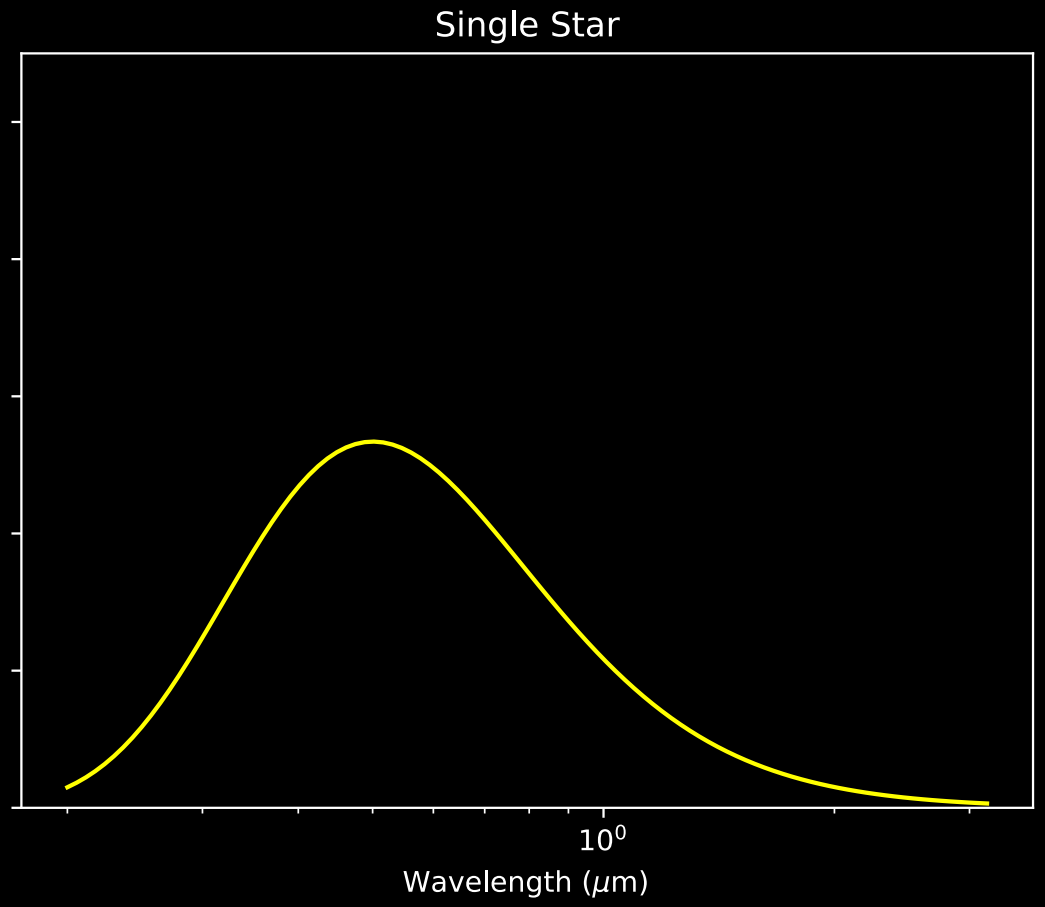
Binaries

- What about mass ratio?

Combination of Light





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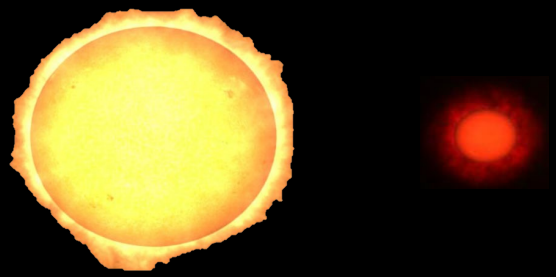
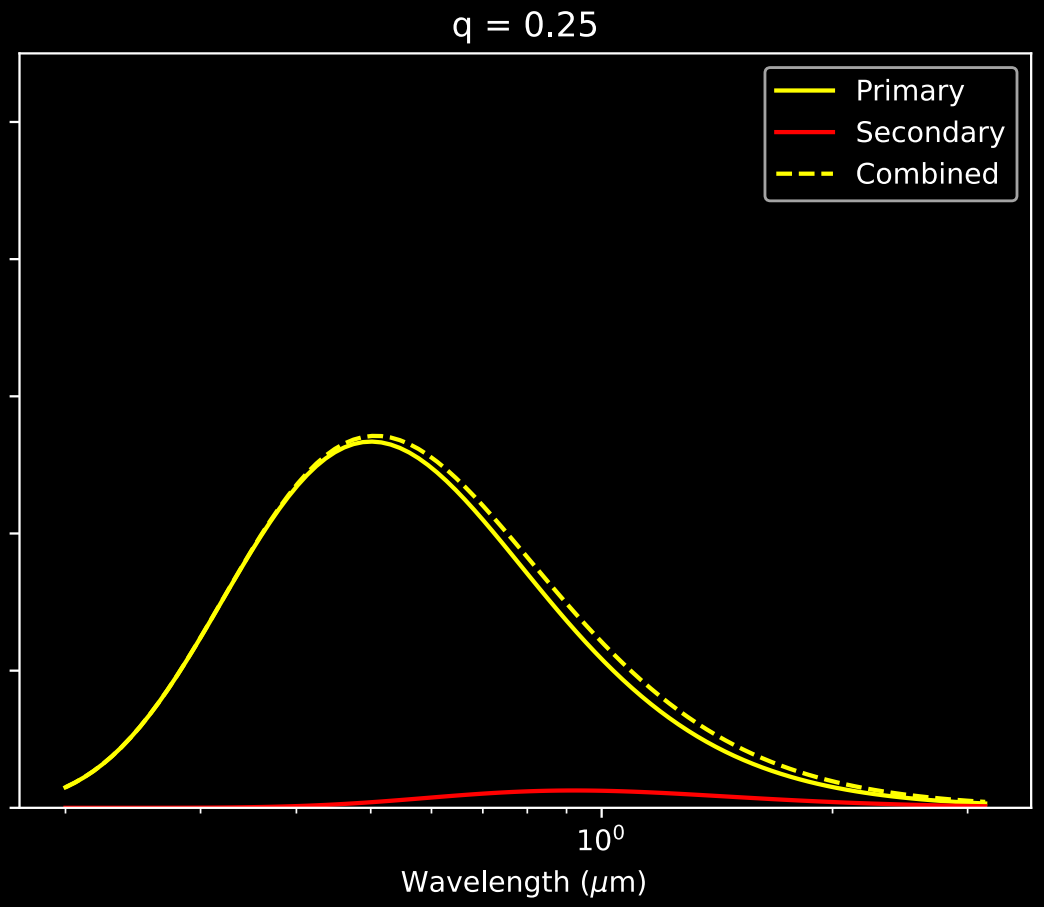
Combination of Light





- We receive light contribution from both stars

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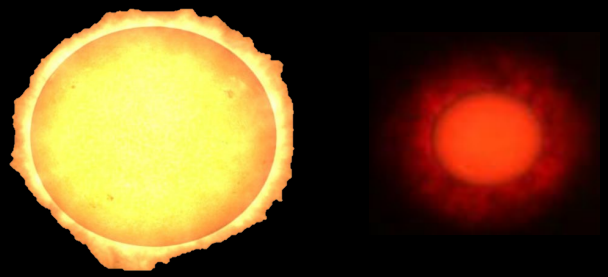
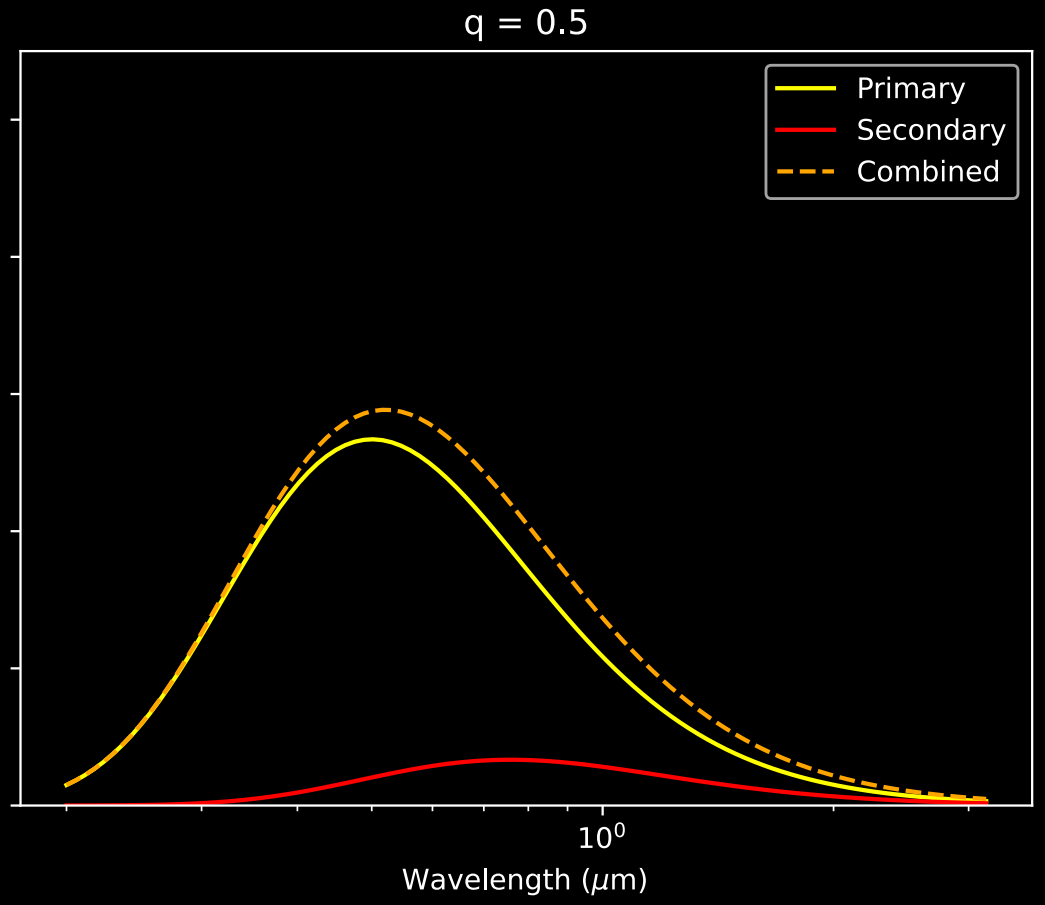
Combination of Light





- We receive light contribution from both stars

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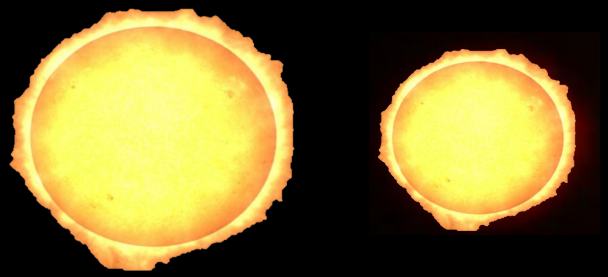
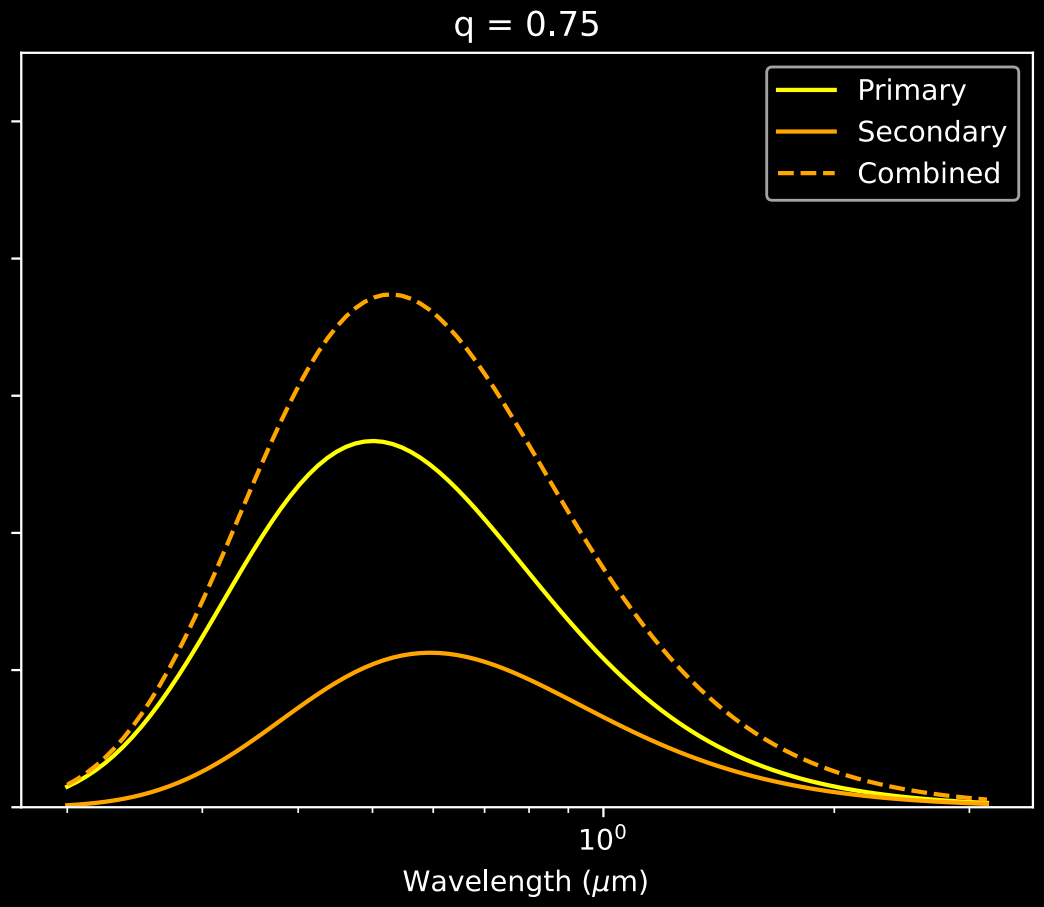
Combination of Light





- We receive light contribution from both stars

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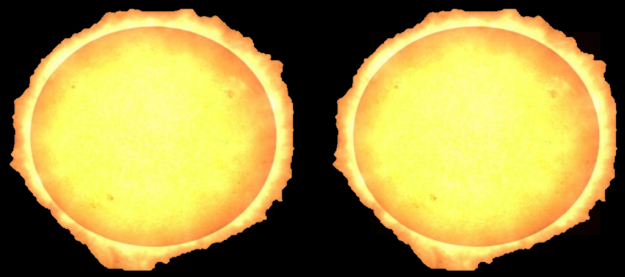
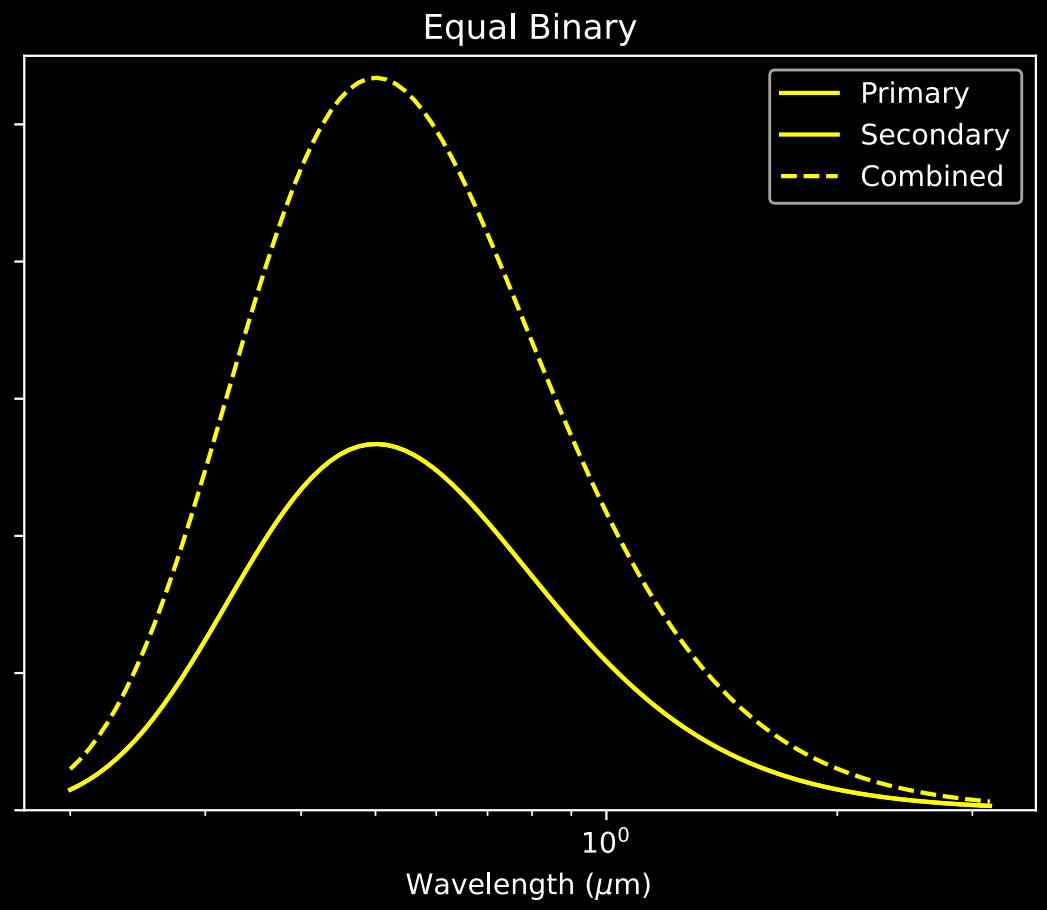
Combination of Light





- We receive light contribution from both stars

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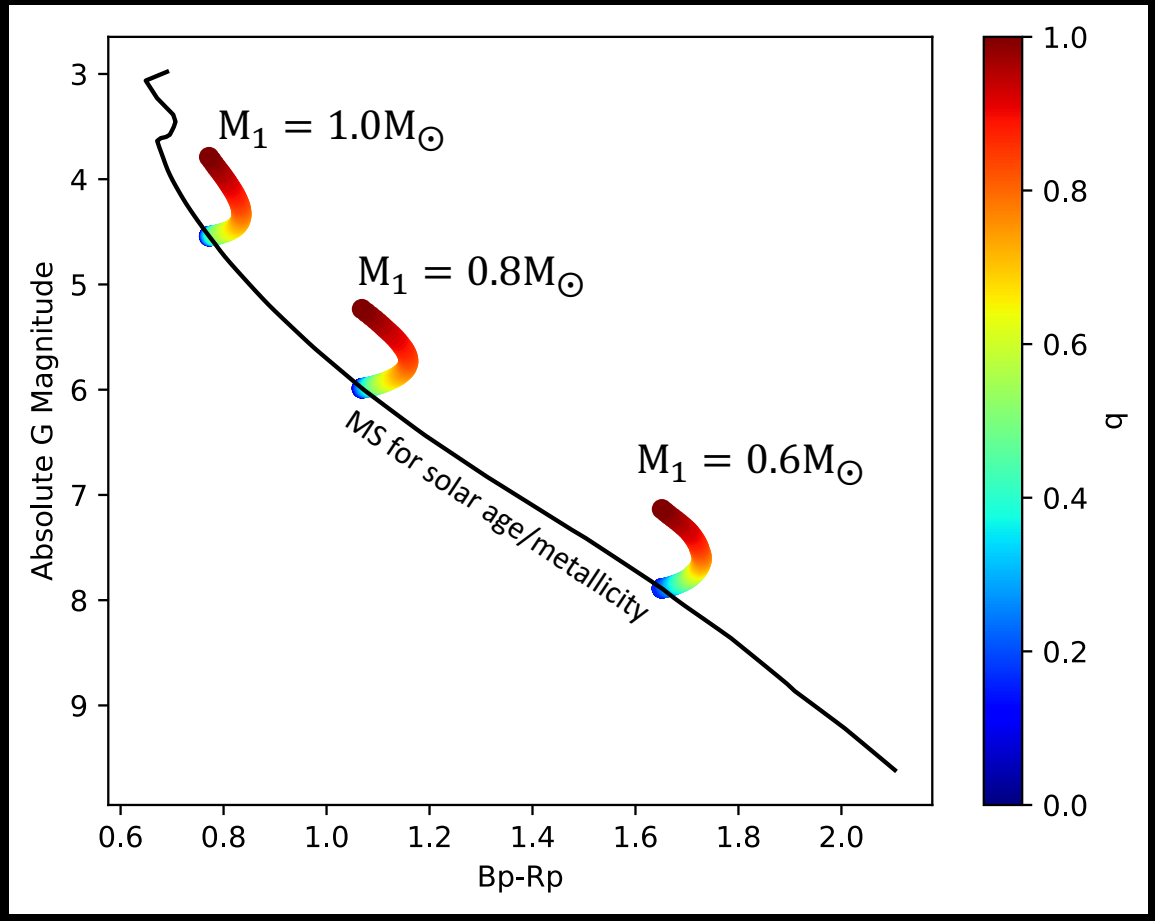
Binaries on the H-R Diagram



- Low-Medium q: Redder and brighter
- Equal binary: ~0.75 mag brighter than single star

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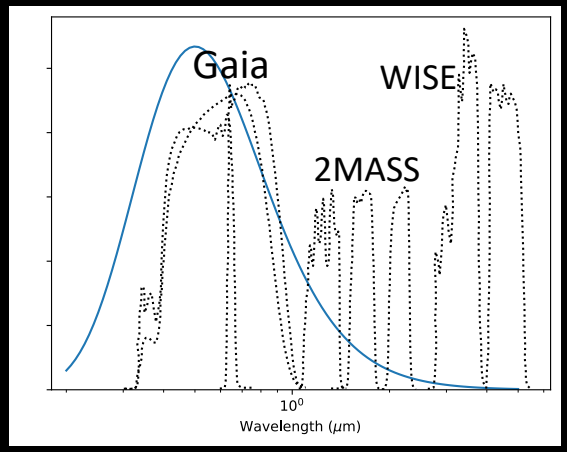
Our Simulations

M_1
q
[Fe/H]
τ

`isochrones`

Simulation



Magnitudes

Want to get from here

Bp
G
Rp
J
H
Ks
W_1
W_2
π

to here

M_1
q
[Fe/H]
τ
d

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Simulation-based Inference (SBI)

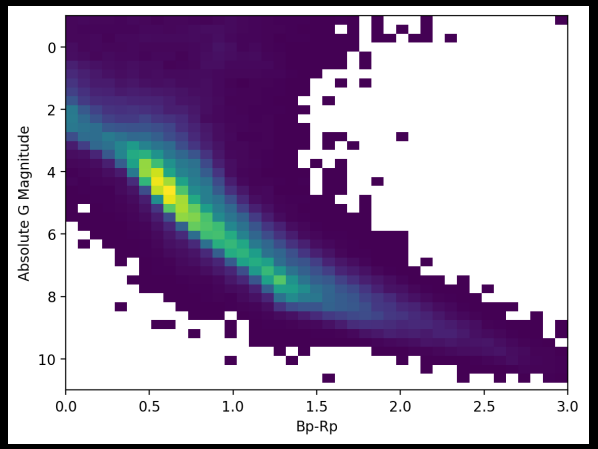
Start with many simulations

M_1
q
[Fe/H]
τ
d

θ → x

Bp
G
Rp
J
H
Ks
W_1
W_2
π

Set of magnitudes, parallaxes



→ Maximize probability $P(\theta|x)$

Sample many times to produce posterior distribution

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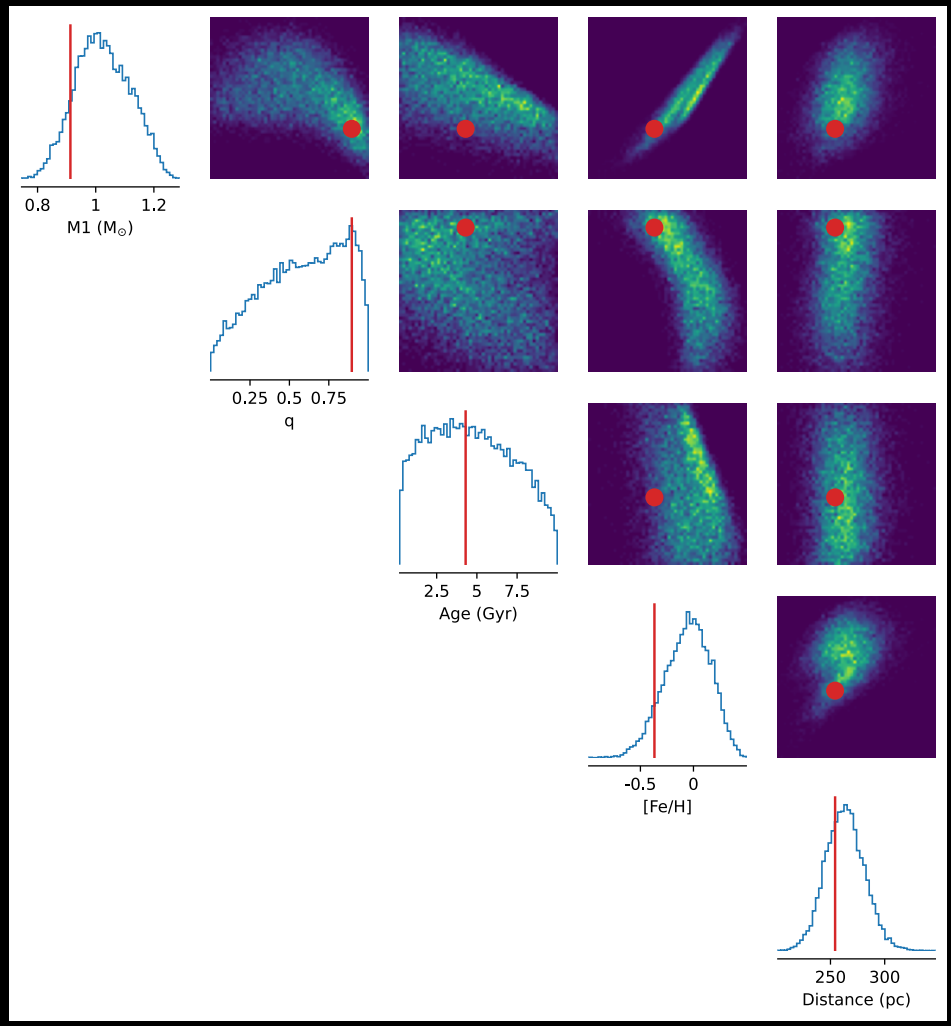
Injection and Recovery

- Simulate sets of θ to produce x
- Run SBI on x to recover θ
- Compare median θ with simulations



- Example posterior distributions of 5 parameters
- Simulated values marked in red

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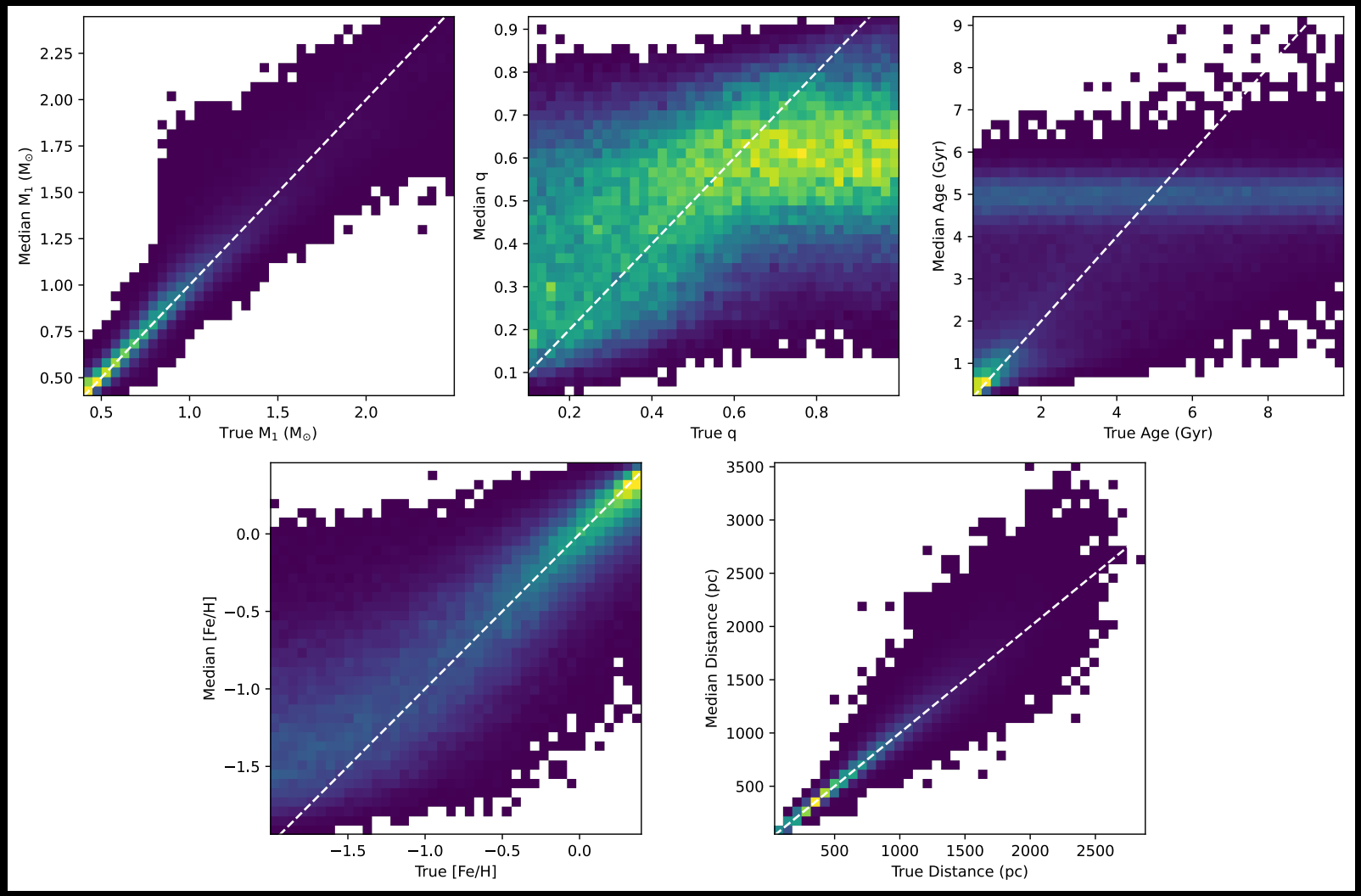
How did we do overall?



Comparison histograms between true values and medians

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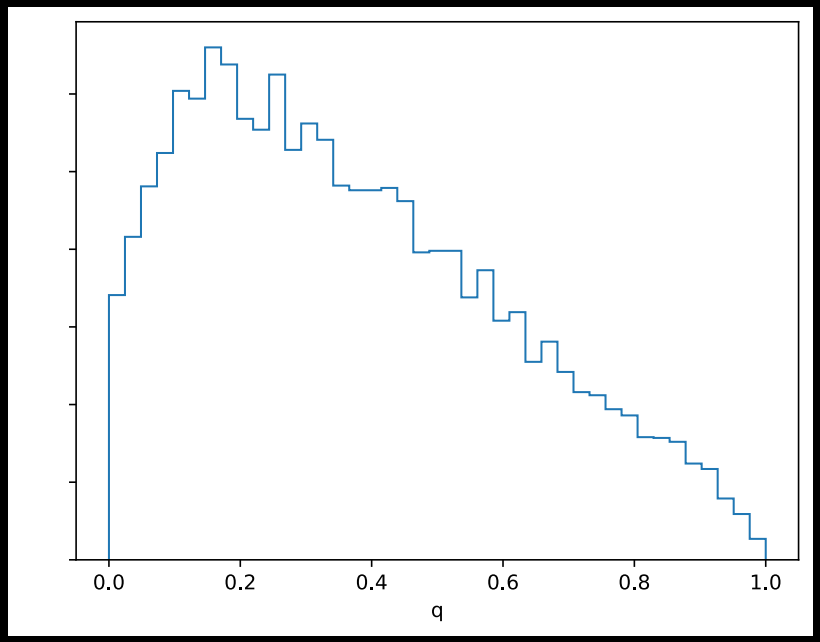
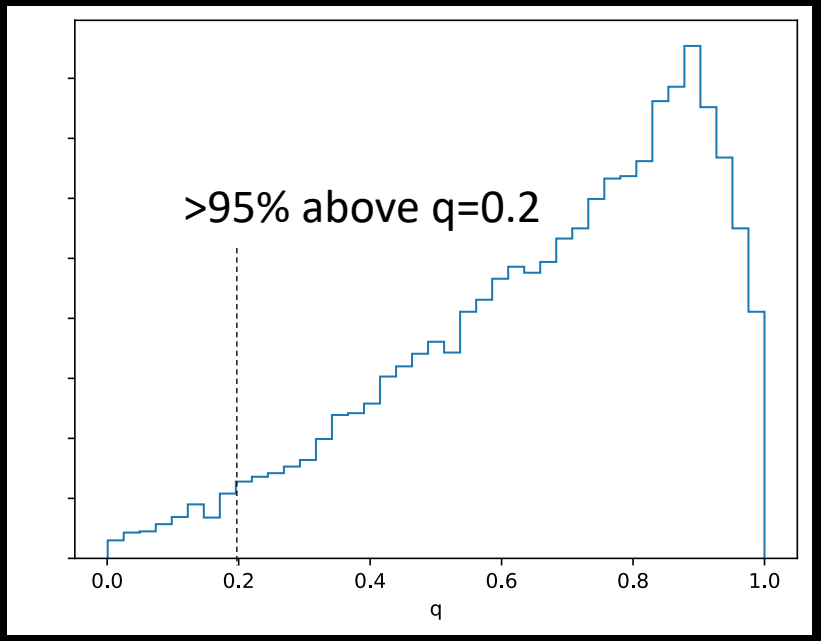
Binary Fraction

- What qualifies as a binary?



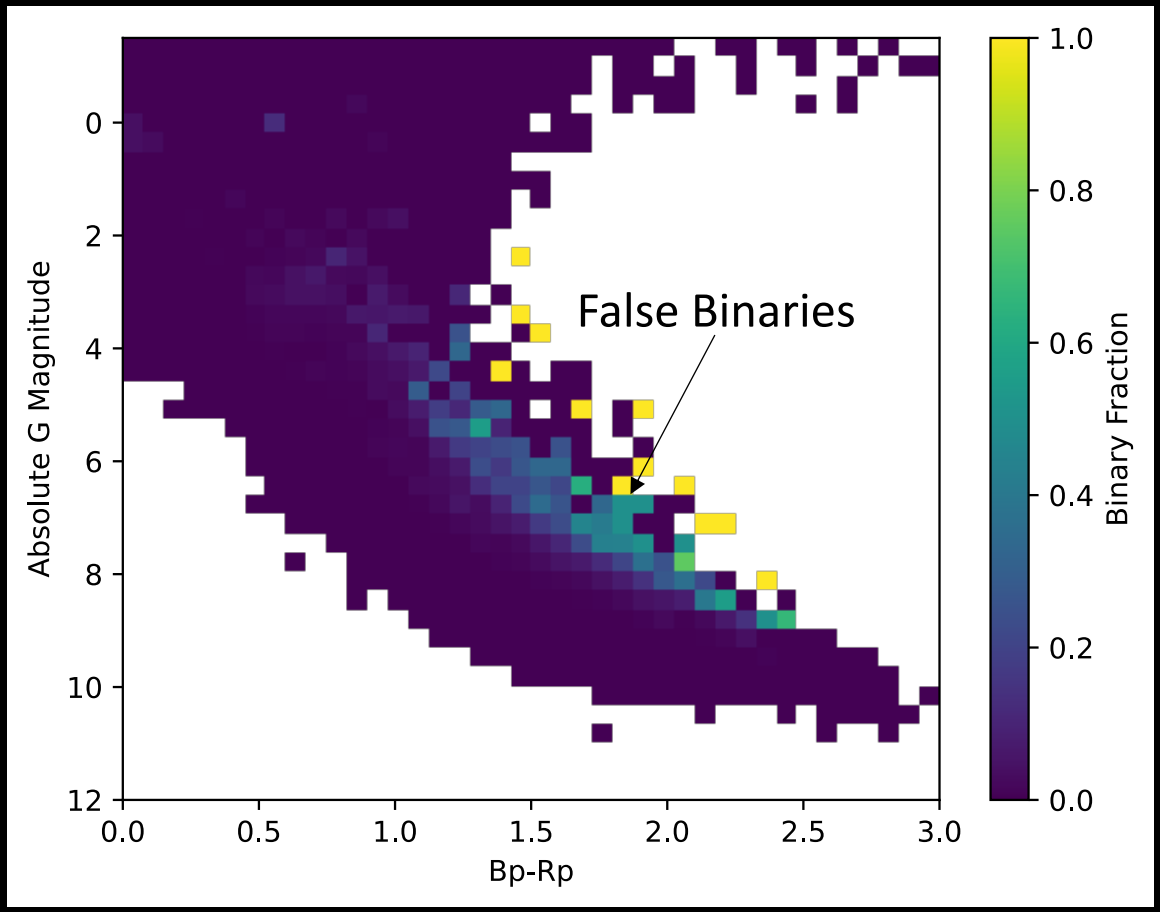
What we consider a single star



What we consider a binary

Both simulated with q=0

Where does our method fail?



100,000 stars simulated with q=0

(all single stars)

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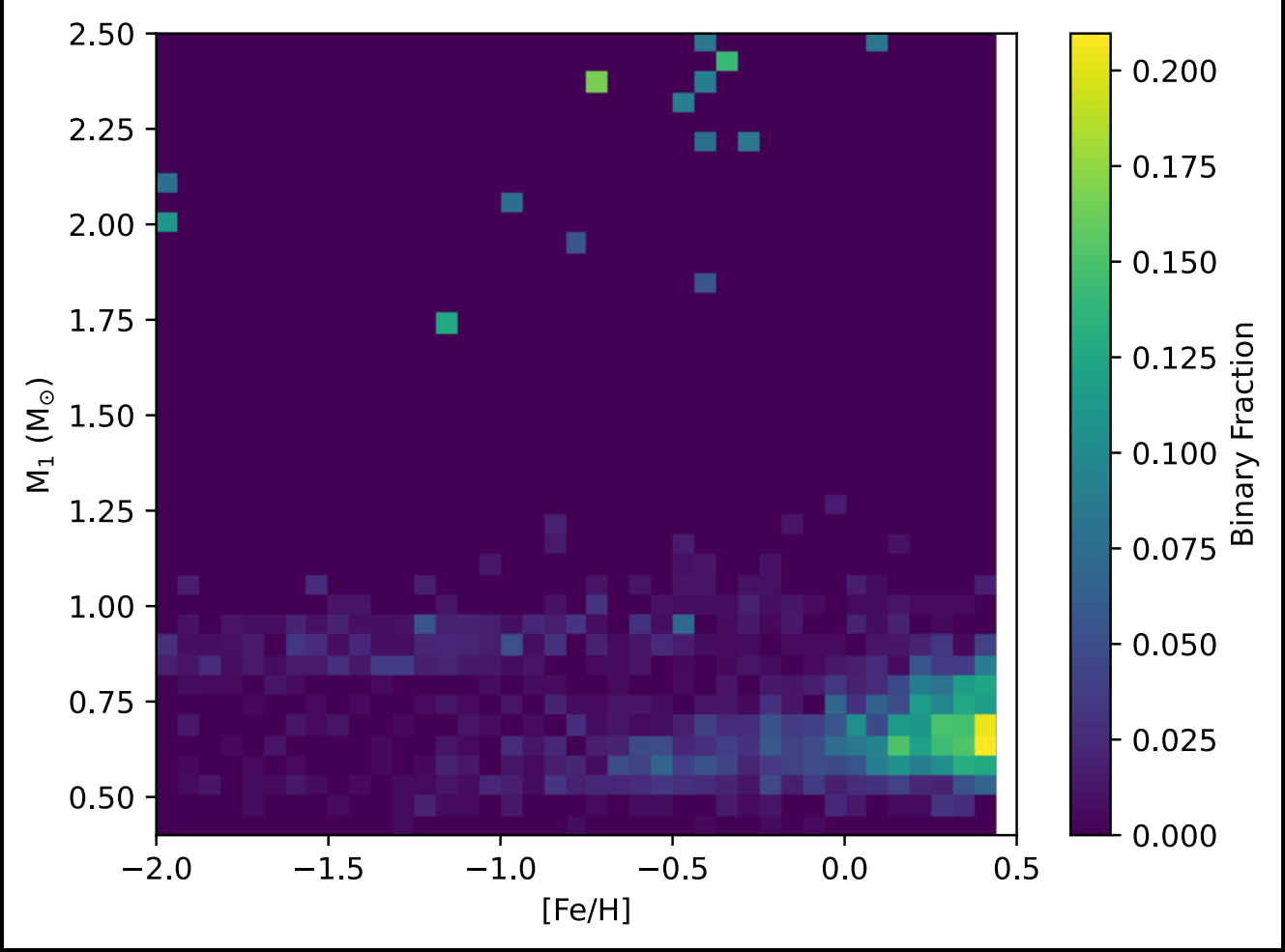
Where does our method fail?



High mass or low mass/high [Fe/H] can be mistaken for binaries

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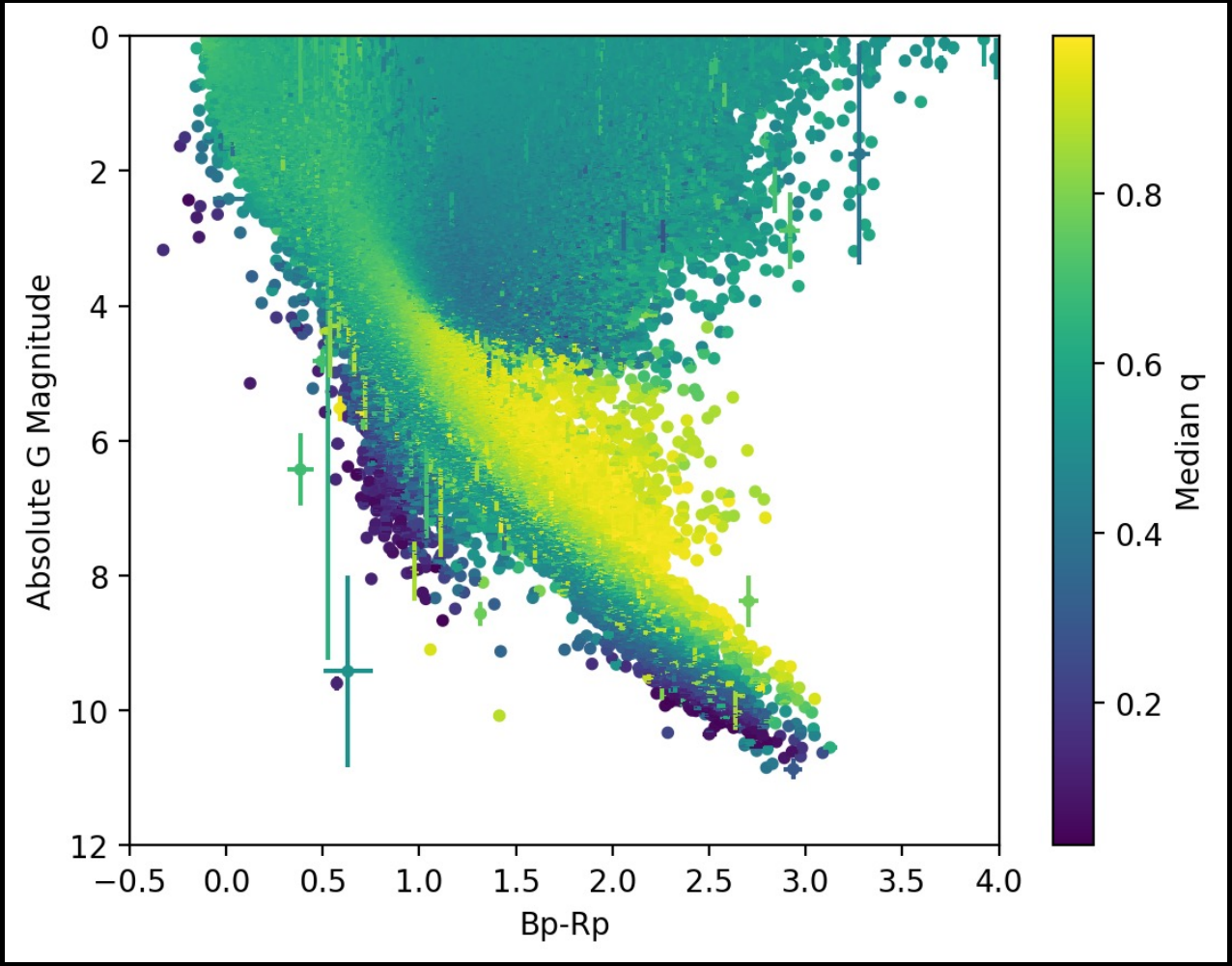
Results with real data

Spectroscopic survey of stars in the Milky Way to trace the history of the galaxy

Results with real data



~700,000 sources from GALAH survey

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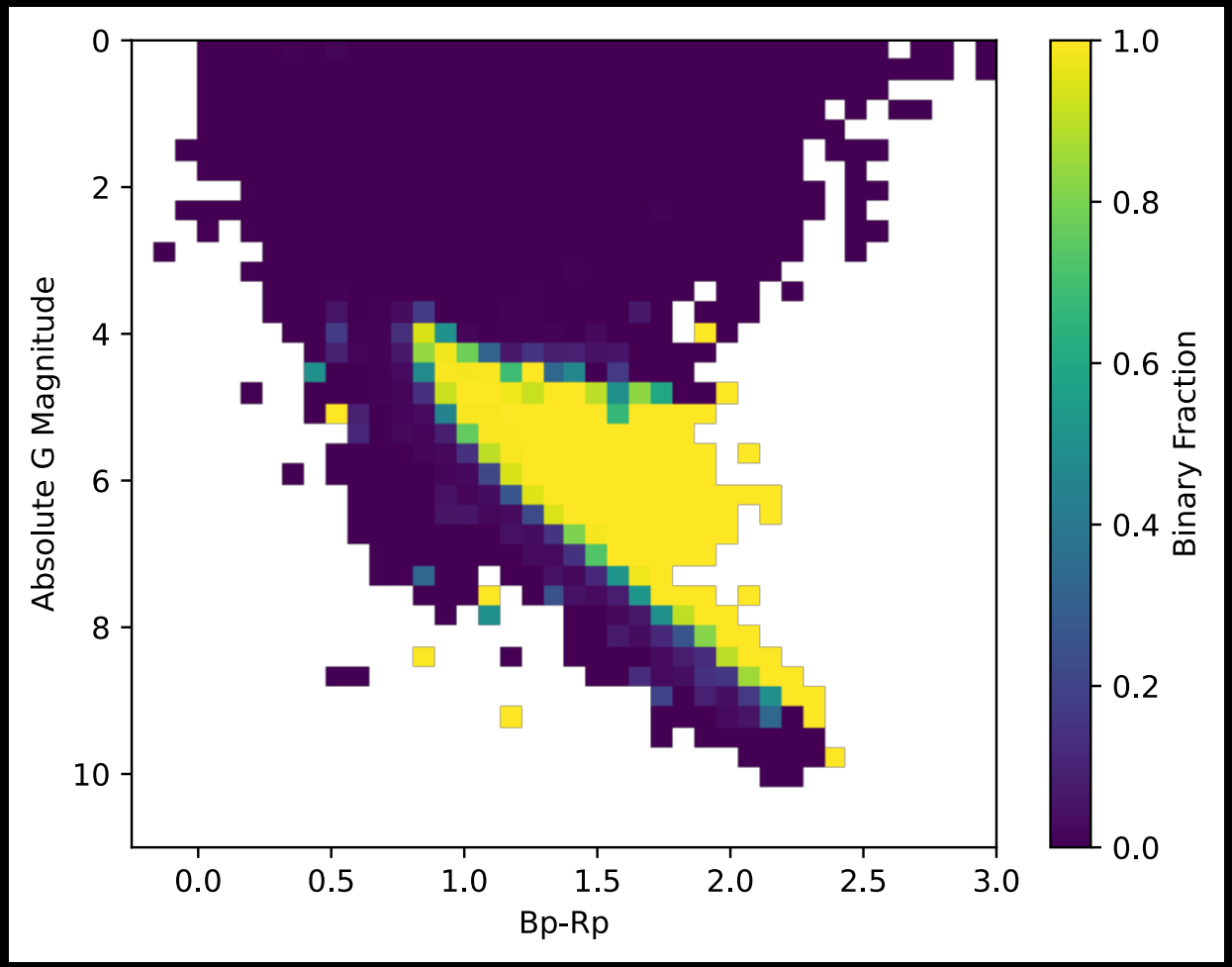
Binary Fraction of GALAH Sample



Clear binary ‘region’

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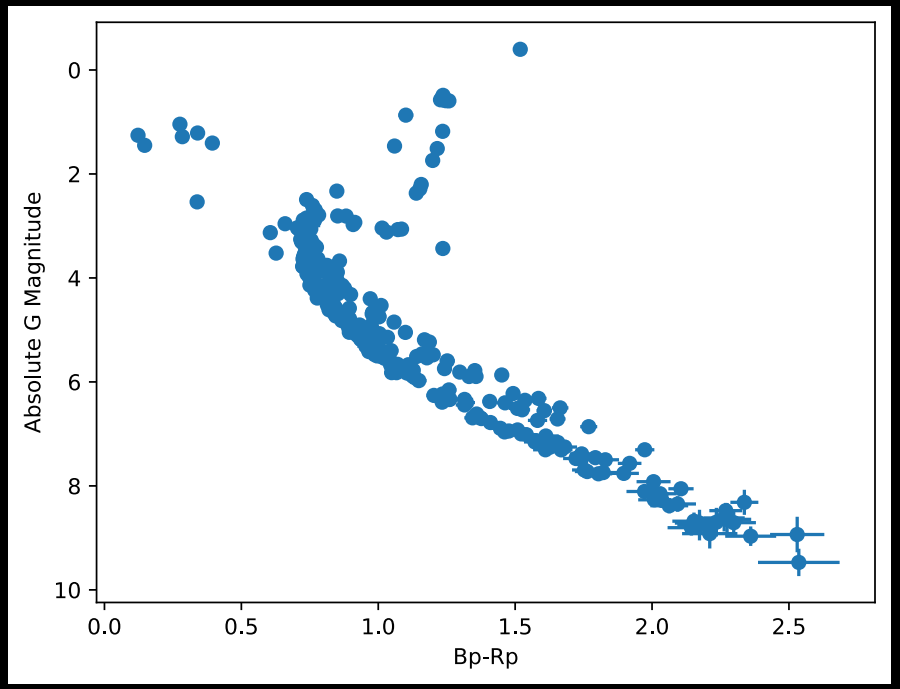
What if we already know something about the star?

Open cluster M67

- Well studied
- Many Sun-like stars



H-R Diagram of M67, using Gaia parallax and magnitudes

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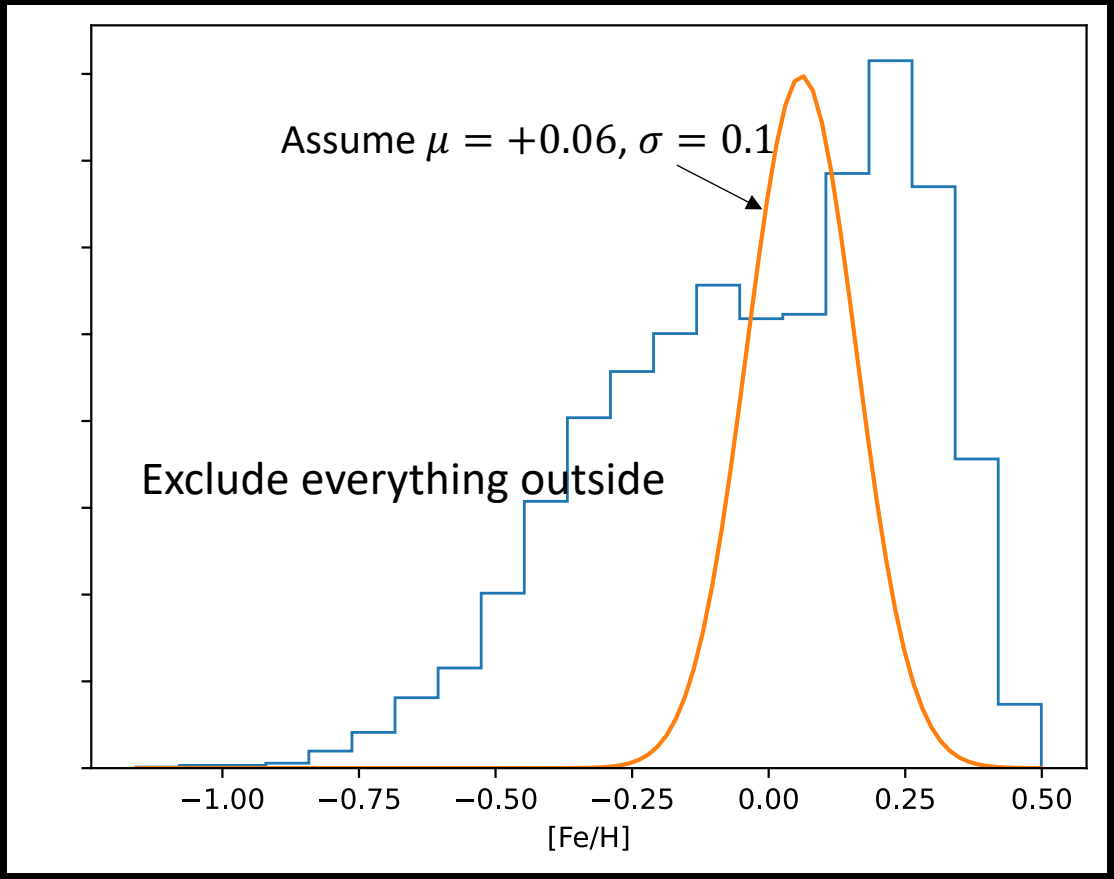
Forced metallicity distribution

We can constrain [Fe/H] based on previous studies of M67



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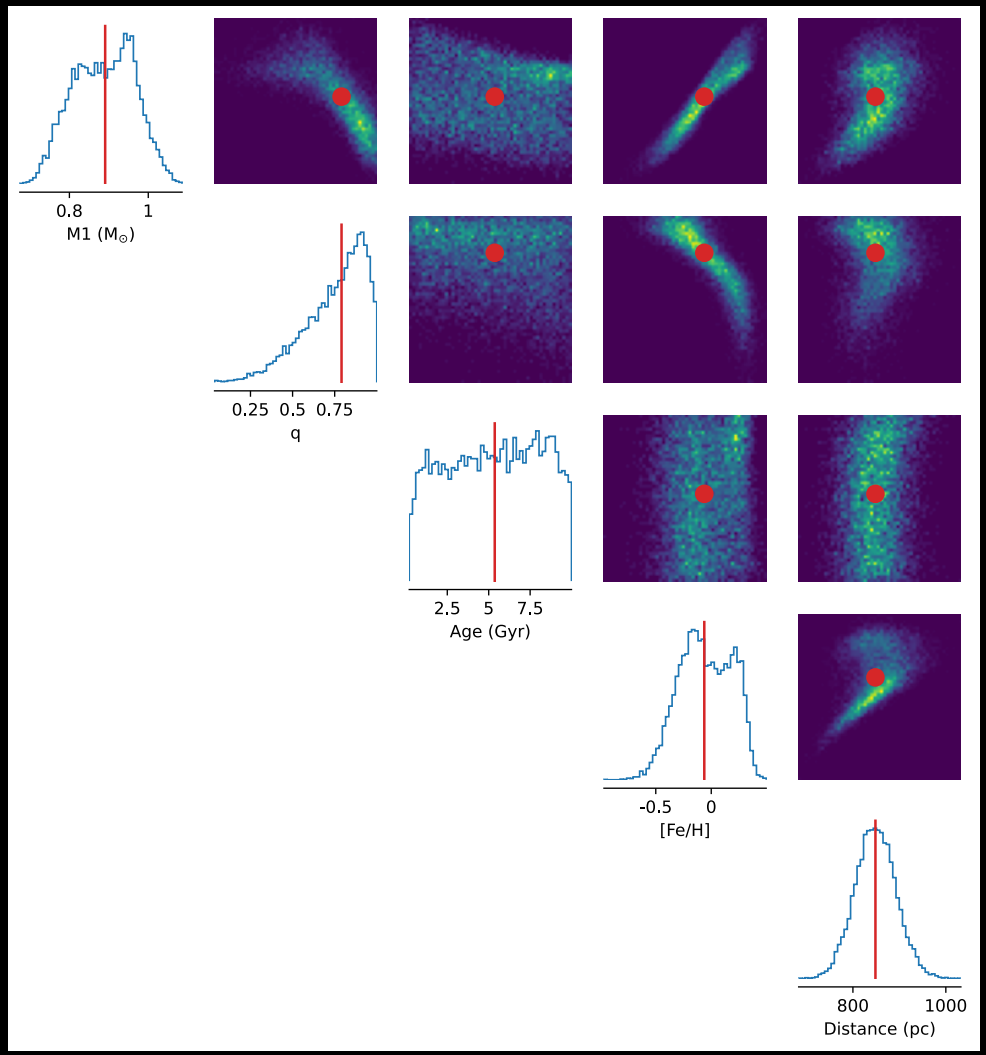
Effect on distributions

Original



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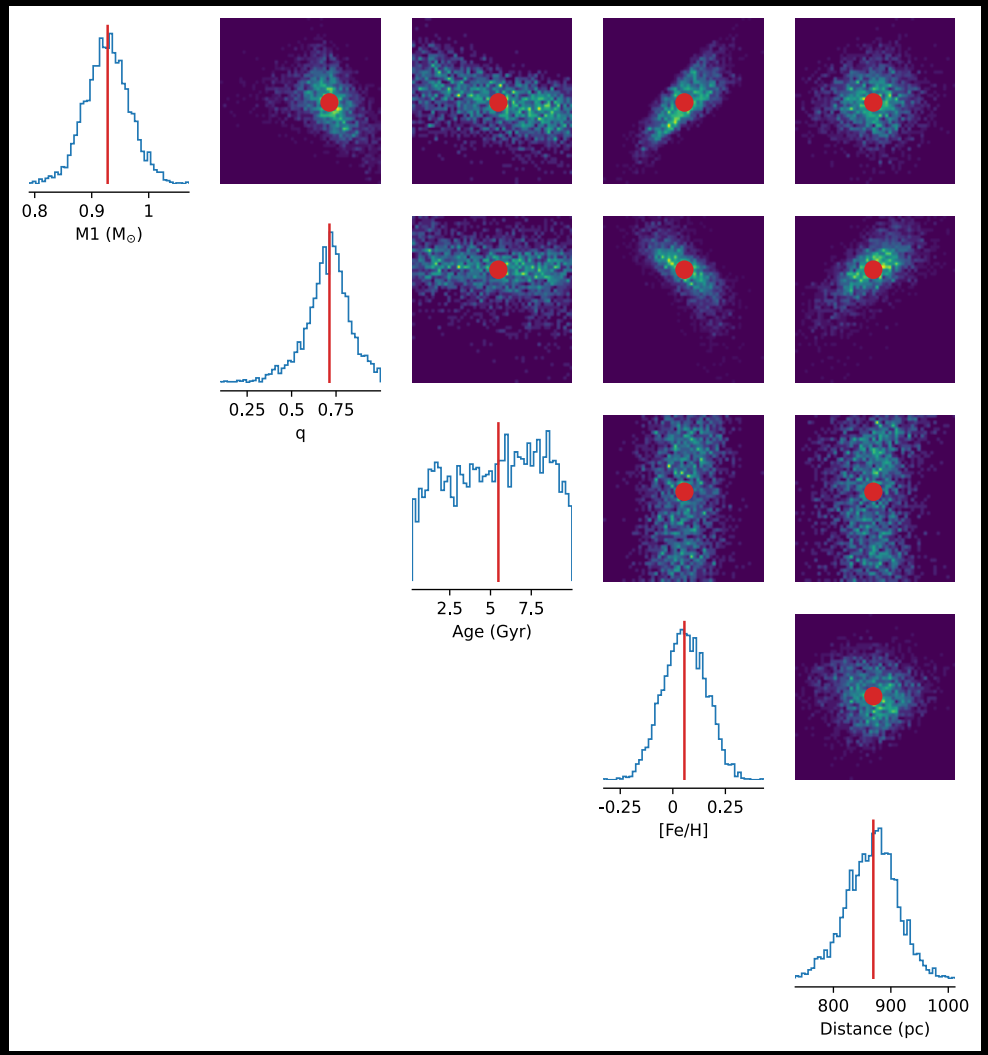
Effect on distributions

New [Fe/H] Distribution

Masses are now better constrained



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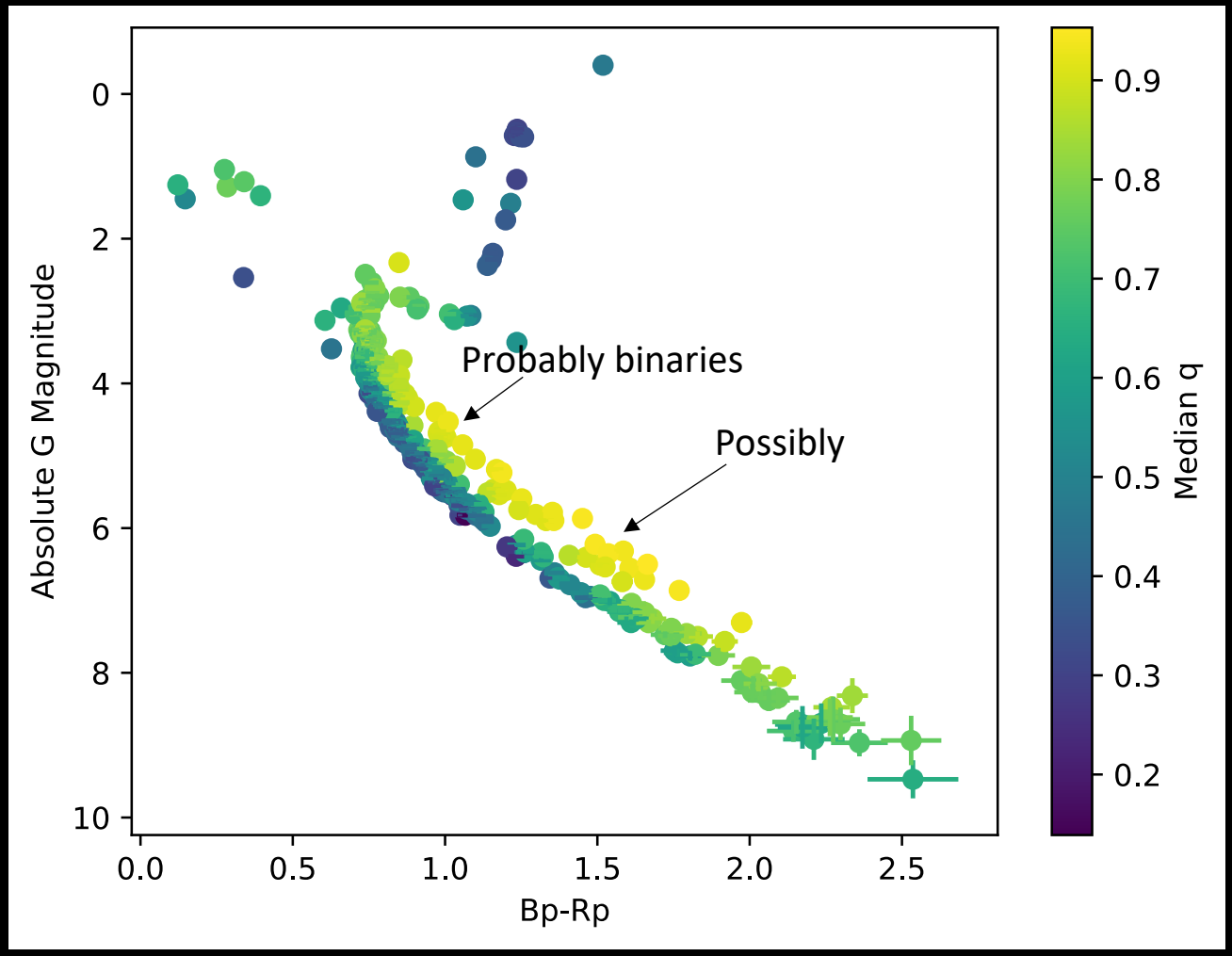
M67 H-R Diagram



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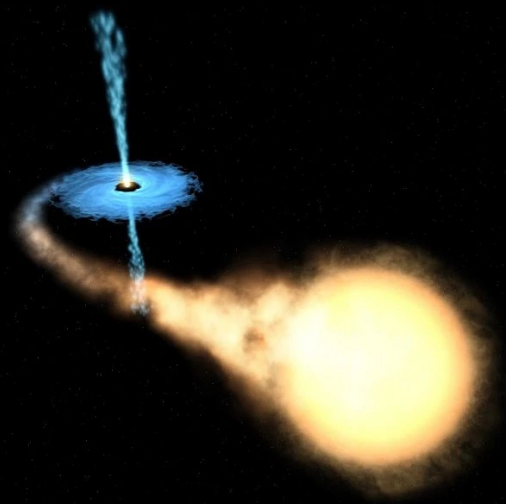
Limitations & ongoing work



- Currently constrained to the main sequence
- We don’t consider possible stellar interaction (ongoing work)
- We are not considering systems of more than 2 stars
- Only the beginning: planning to combine with RV and astrometry to produce a single tool for identifying companions

Thank You

Alex Wallace