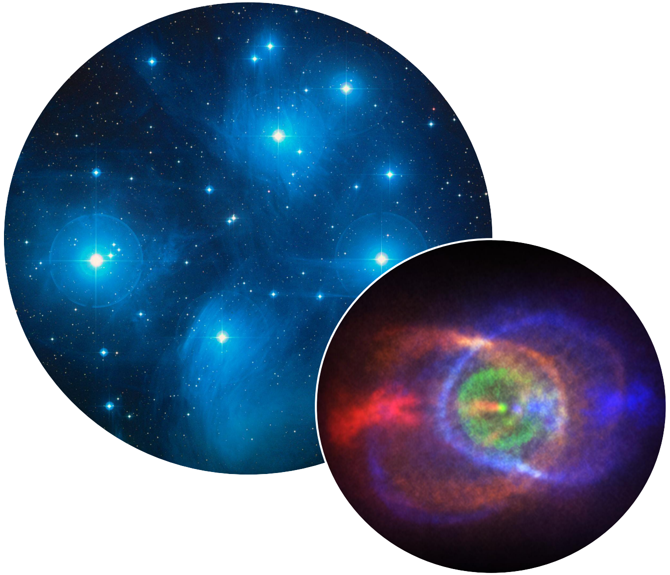
David A. Dunlap Department of Astronomy & Astrophysics
UNIVERSITY OF TORONTO

From Clusters to Common Envelopes

The first catalogue of candidate white dwarf main sequence binaries in open star clusters



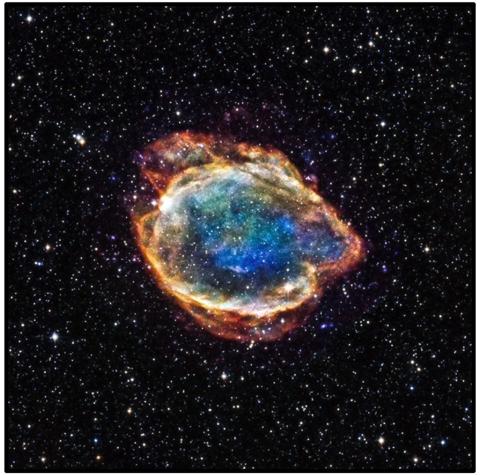
Steffani Grondin
University of Toronto

MODEST-24 (August 21, 2024)

Collaborators: Maria Drout, Jeremy Webb, Joshua Speagle, Ryan Chornock, Phil Muirhead, Jason Nordhaus

Close binary systems with a WD are the progenitors of a variety of astrophysical transients:

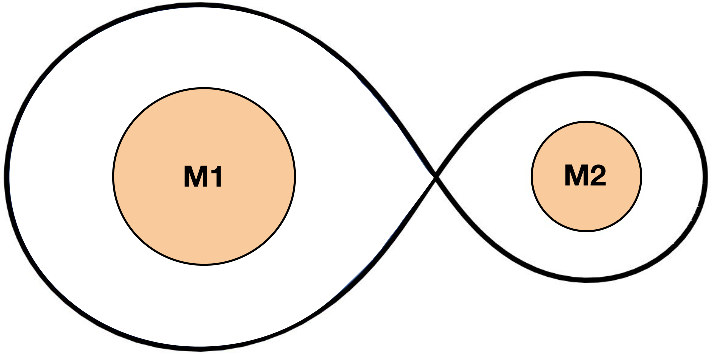
- Cataclysmic variables
- Low-mass x-ray binaries
- Type Ia supernovae
- Mergers → gravitational waves



SN Ia remnant G299.2-2.9
(NASA/CXC/U.Texas/S. Post et al./2MASS/UMass/IPAC-Caltech)

To produce a short-period binary, at least one common envelope phase is usually required.

e.g. formation of a close white dwarf + main-sequence binary



Main Sequence + Main Sequence Binary

(M1 > M2)

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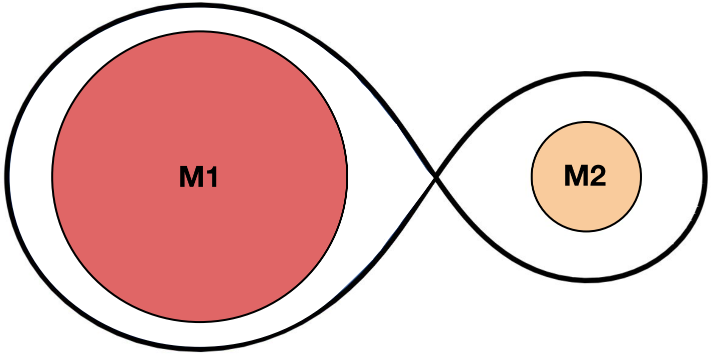

AGB + Main Sequence Binary

(M1 >> M2)

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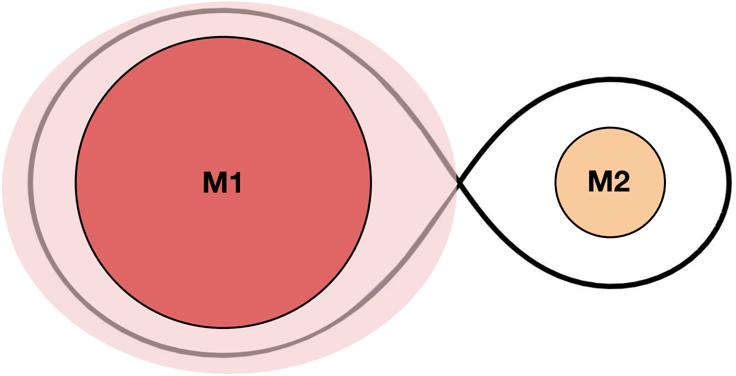

AGB + Main Sequence Binary

(AGB's Roche Lobe filled)

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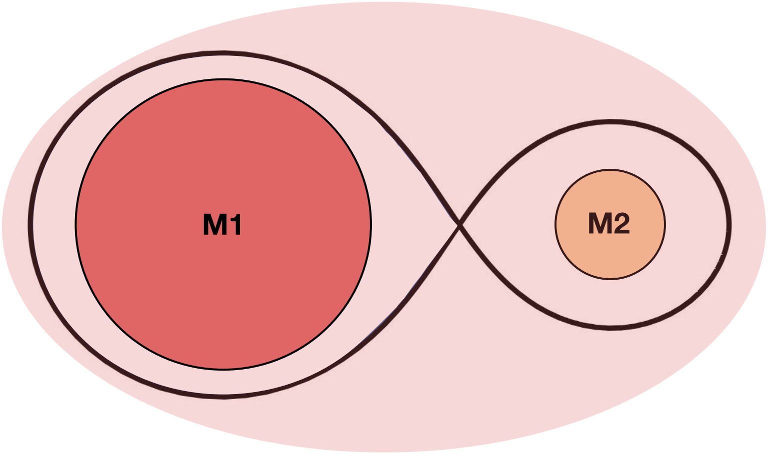

AGB + Main Sequence in Common Envelope

(RLOF; M1 and M2 orbit inside a CE)

To produce a short-period binary, at least one **common envelope phase** is usually required.

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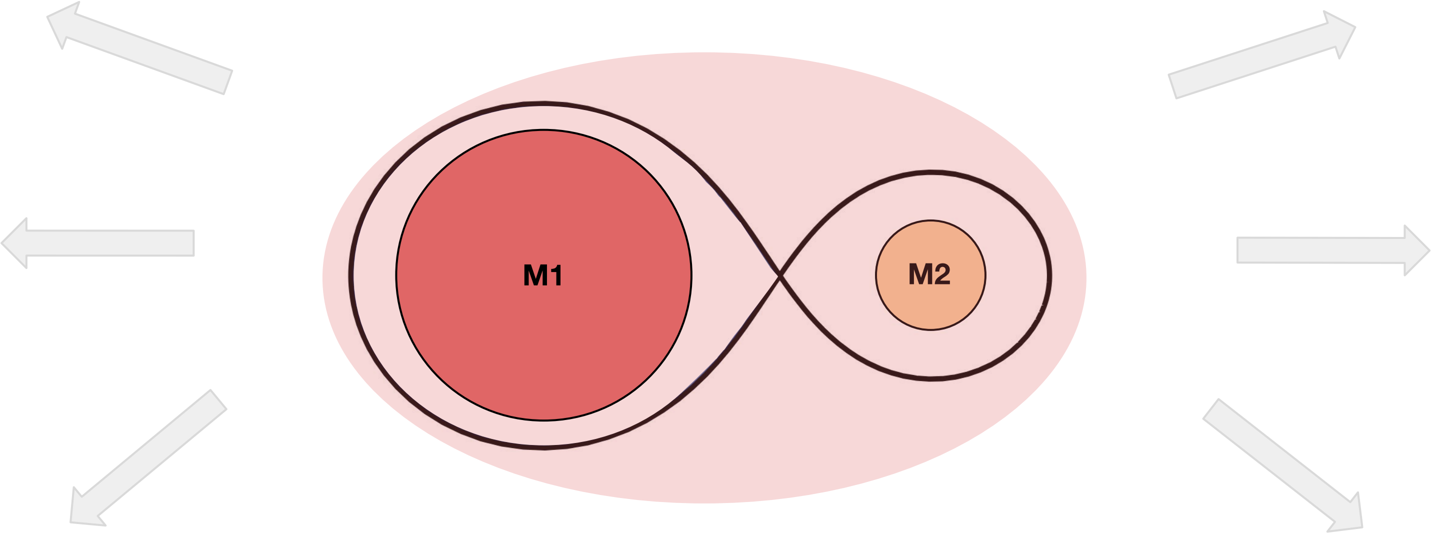

AGB + Main Sequence in Common Envelope
(Energy from in-spiral → envelope; CE ejected)

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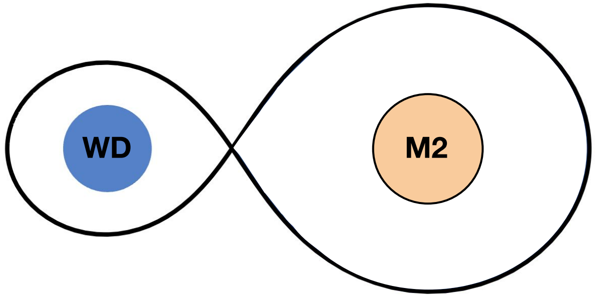


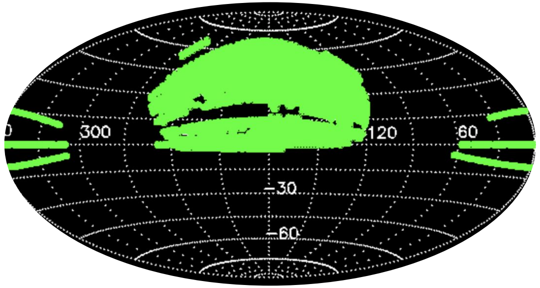
White Dwarf + Main Sequence Post-CE Binary

P ~ hours – days

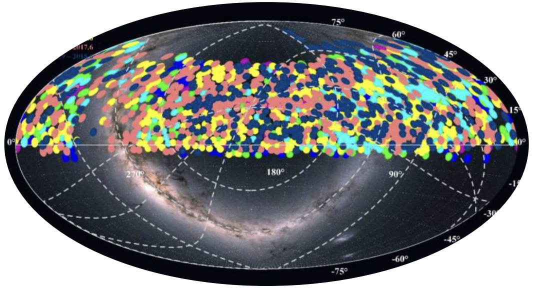
(Parsons et al. 2021)

Large multi-wavelength surveys have yielded the discovery of thousands of white dwarf + main-sequence binaries.

SDSS



e.g. Rebassa-Mansergas+ (2010, 2016), Inight+ (2023)

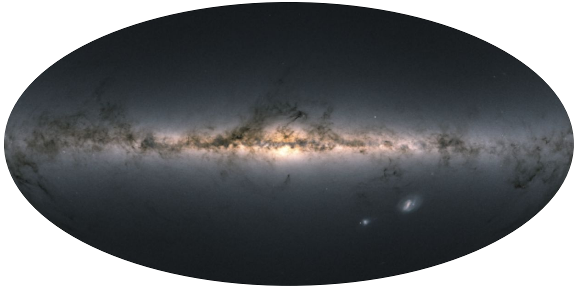


LAMOST

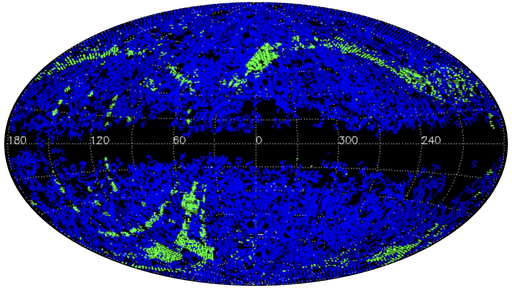
e.g. Ren+ (2014), Parsons+ (2016)

Large multi-wavelength surveys have yielded the discovery of **thousands of white dwarf + main-sequence binaries.**

Gaia



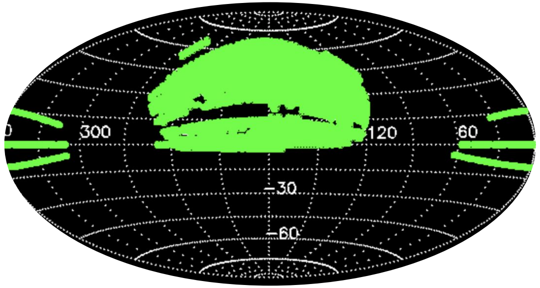
e.g. Rebassa-Mansergas+ (2021)



GALEX

e.g. Nayak+ (2023), Jackim+ (2024)

SDSS



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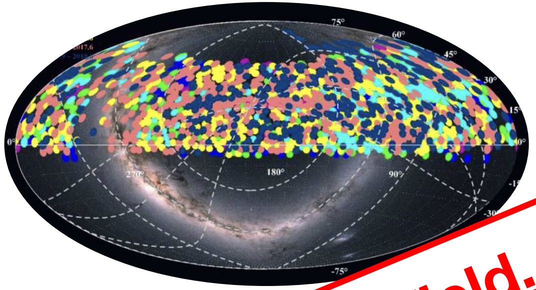


e.g. Ren+ (201…

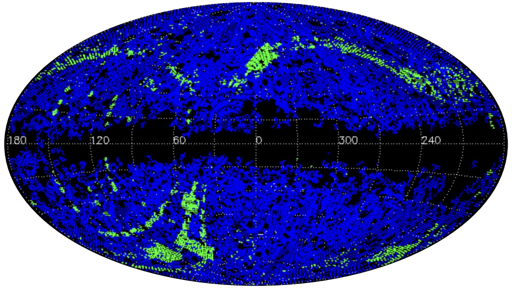
Large multi-wavelength survey… …ed the discovery of **thousands of white d… …n-sequence binaries.**

All of these binaries are located in the field.

Gaia

e.g. Rebassa-Mansergas+ (2021)

GALEX



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(extra information to probe the evolutionary history)

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Despite their utility, there are only two confirmed WD+MS post-CE binaries associated with a cluster.

V471 Tau: e.g. Young & Capps 1971, Muirhead+ 2023
HZ9: e.g. Stauffer 1987, Muirhead+ (incl. **Grondin**) 2024, submitted

The Goal:

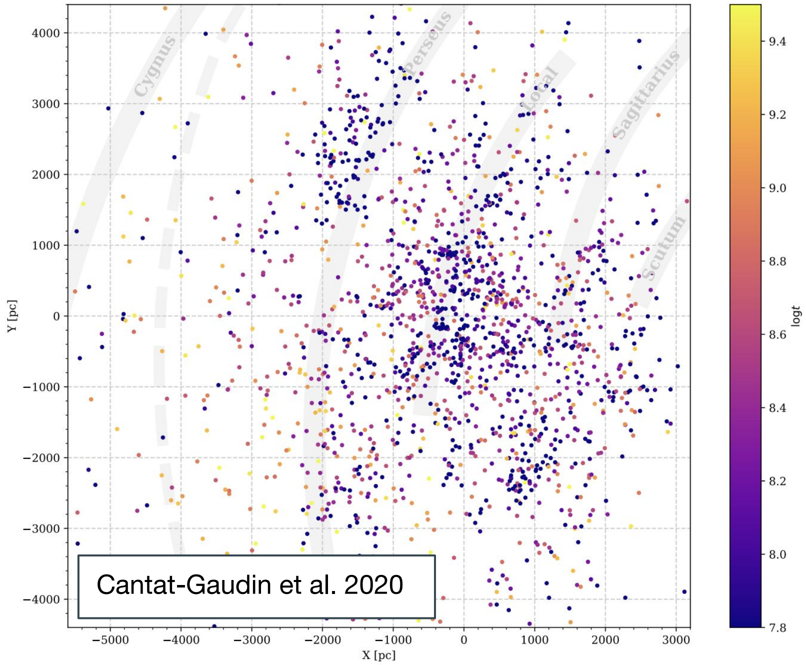
Perform the first systematic search for WD+MS binaries in hundreds of Milky Way open clusters.

STEP 1: Select a sample of well-constrained open clusters to search.

Important considerations for clusters:

1. **Have a reported age > 50 Myr**: searching for clusters in Cantat-Gaudin et al. (2020) with turnoff masses ~ $1.5 - 8M_{\odot}$ (AGB radius expansion + WDs have formed)
2. **Declination > -30 deg:** griz data from Pan-STARRS1 with *Gaia* DR3 and 2MASS
3. **Distance < ~1.5kpc:** within a distance with reliable parallaxes/suitable for follow-up

Full sample: 299 Galactic OCs!



Grondin+ 2024b

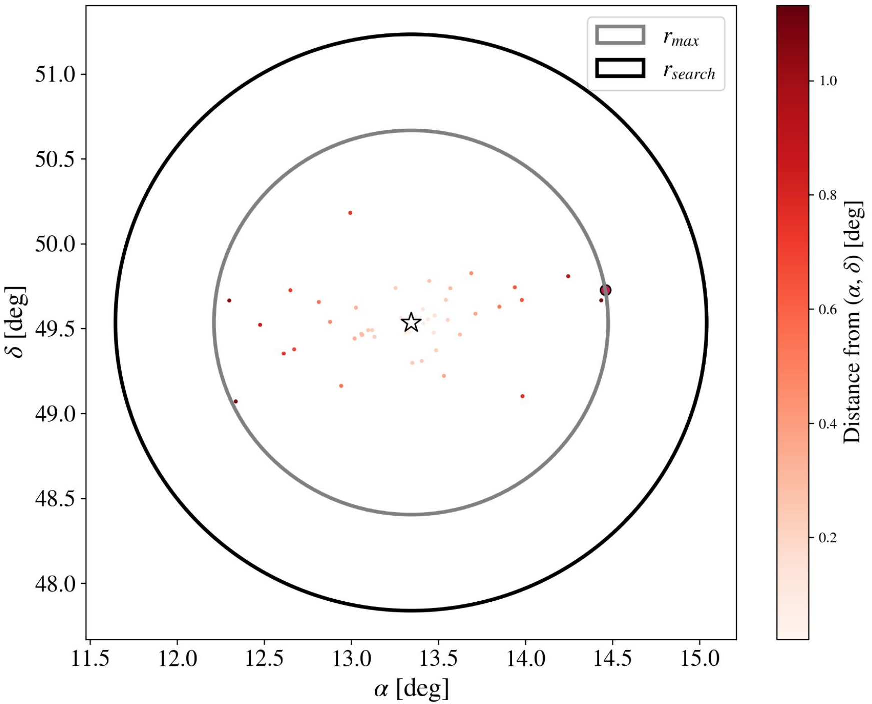
STEP 2: Select Gaia stellar samples based on broad kinematic constraints.

How?

1. Search for stars either within a radius:
   a. of **50pc** from the cluster centre.
   b. **30% farther** than the furthest high-probability cluster member in the Cantat-Gaudin+ 2020 catalogue

2. Stellar kinematics must fall within a range of 30% beyond the minimum and maximum *Gaia* OC proper motion and parallax.

3. Full kinematics are explored afterwards.



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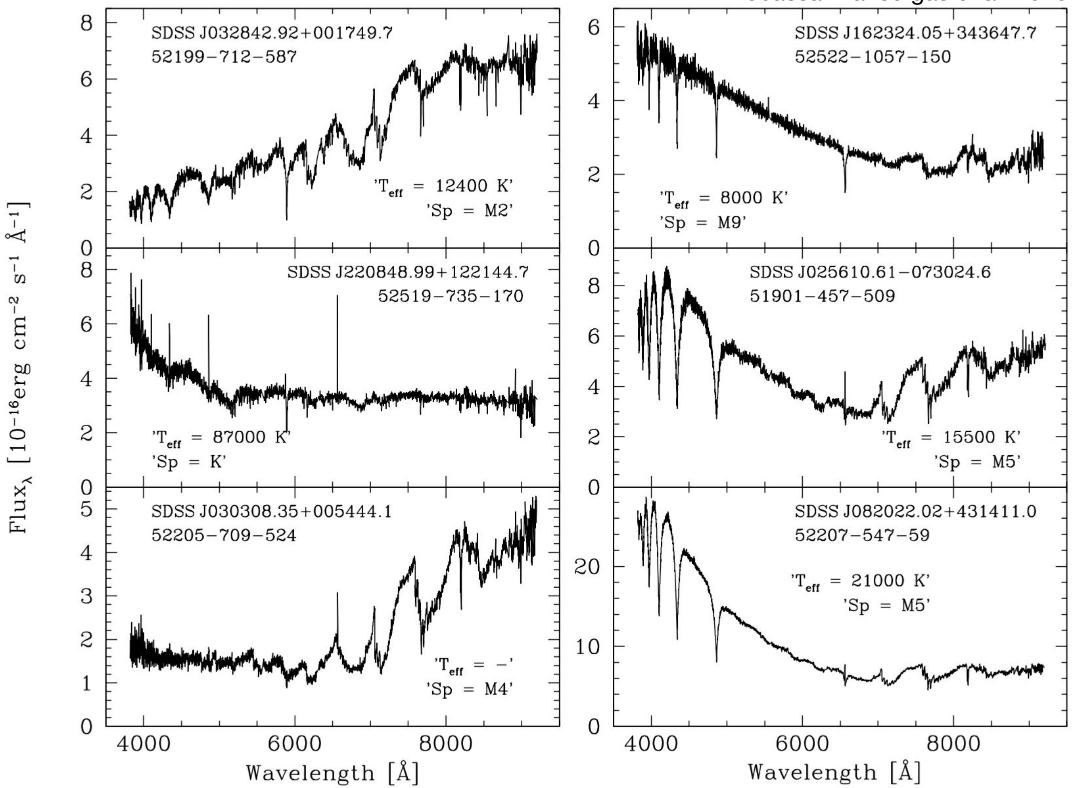
STEP 3: Cross-match the *Gaia* DR3 data.

Rebassa-Mansergas et al. 2010



WD+MS binaries have unique colour combinations due to the presence of a **cool low-mass MS star** and **hot WD.**

→ Hunt for WD+MS binaries using multi-band photometry.

- **2MASS (J, Ks)**
- **Pan-STARRS1 (g,r,i,z)**

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STEP 4: Develop a support vector machine (SVM) to identify systems.

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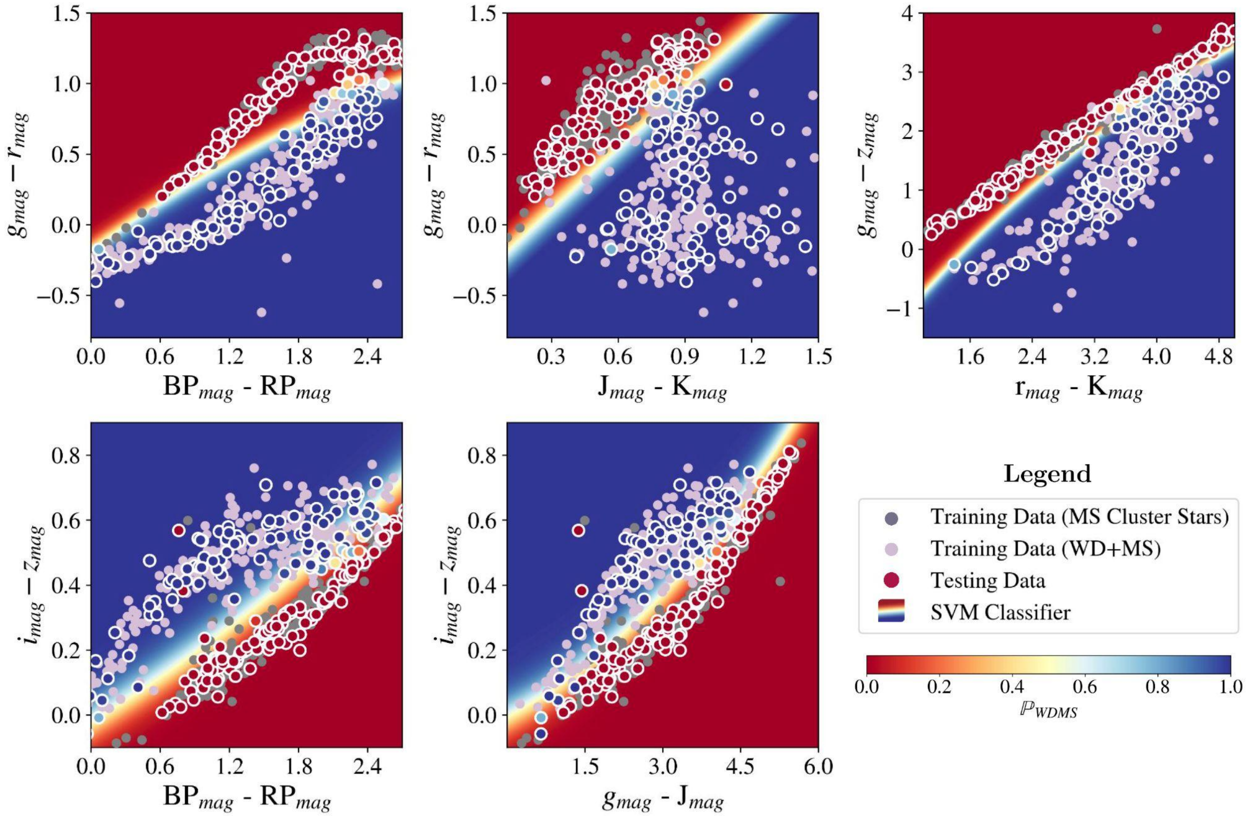

Grondin+ 2024b

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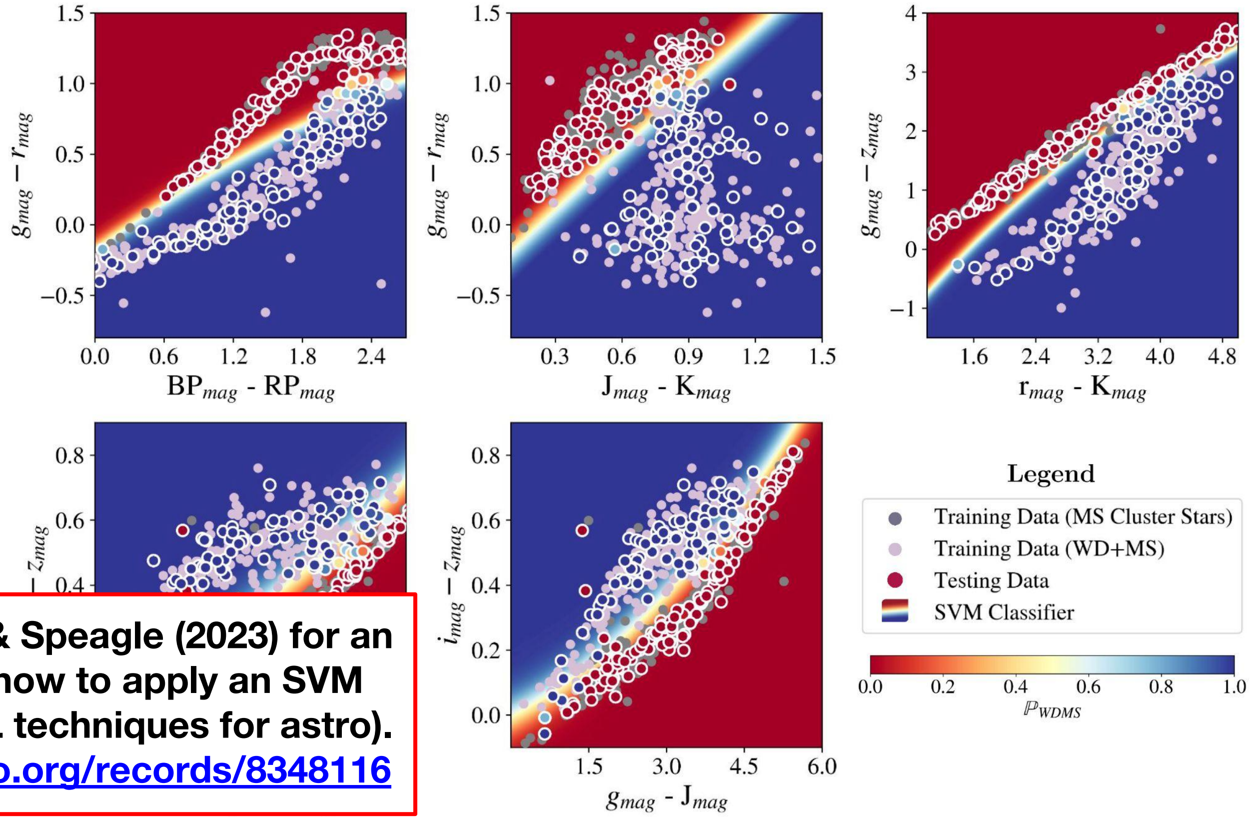

See Grondin & Speagle (2023) for an example of how to apply an SVM (and other ML techniques for astro).
https://zenodo.org/records/8348116

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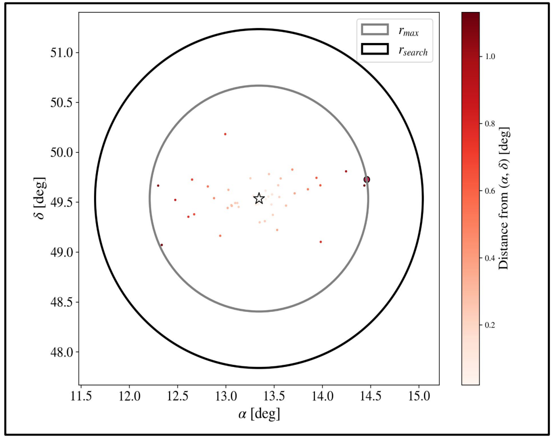
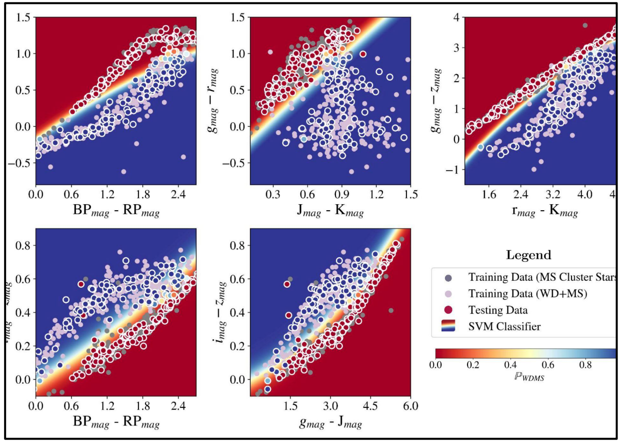
Create cleaned + cross-matched stellar samples and run through SVM for all clusters.

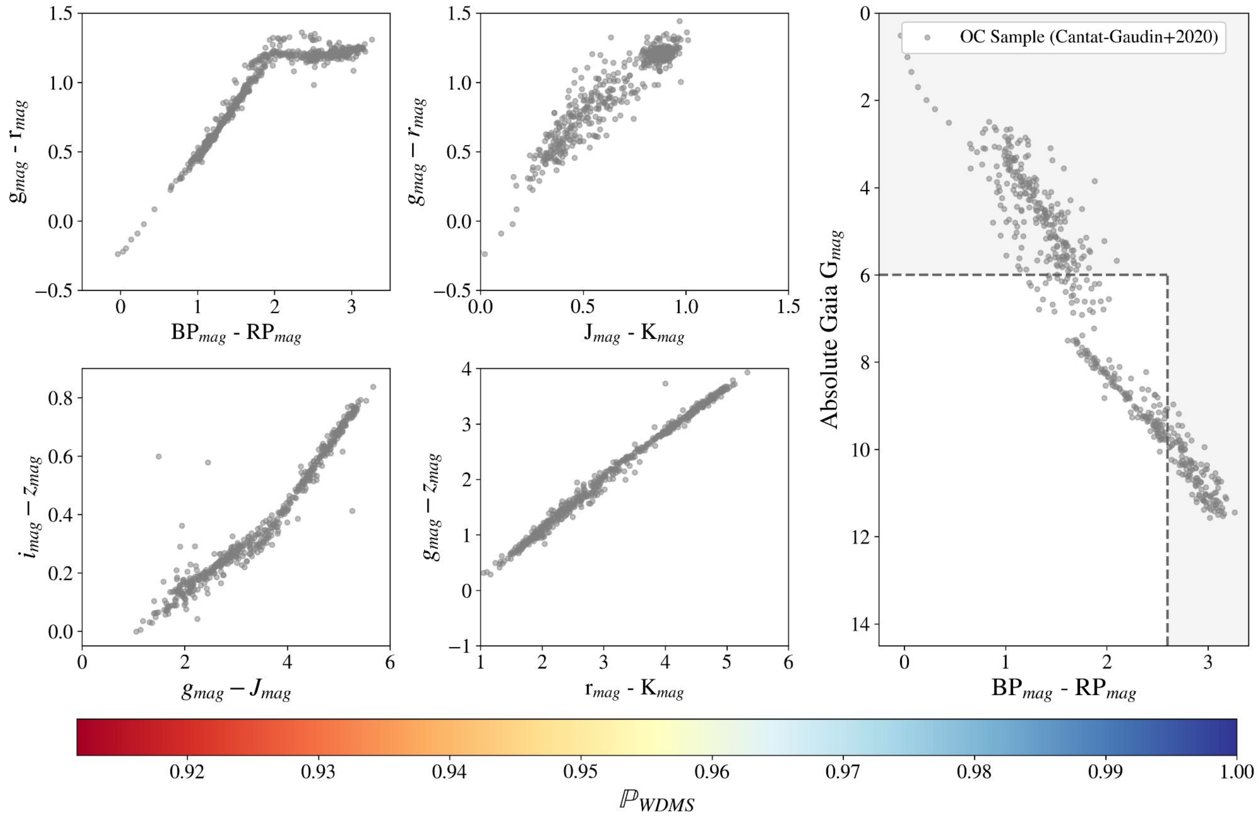




× **299 clusters**

Grondin+ 2024b

We search 299 open clusters for WD+MS binaries using our SVM.



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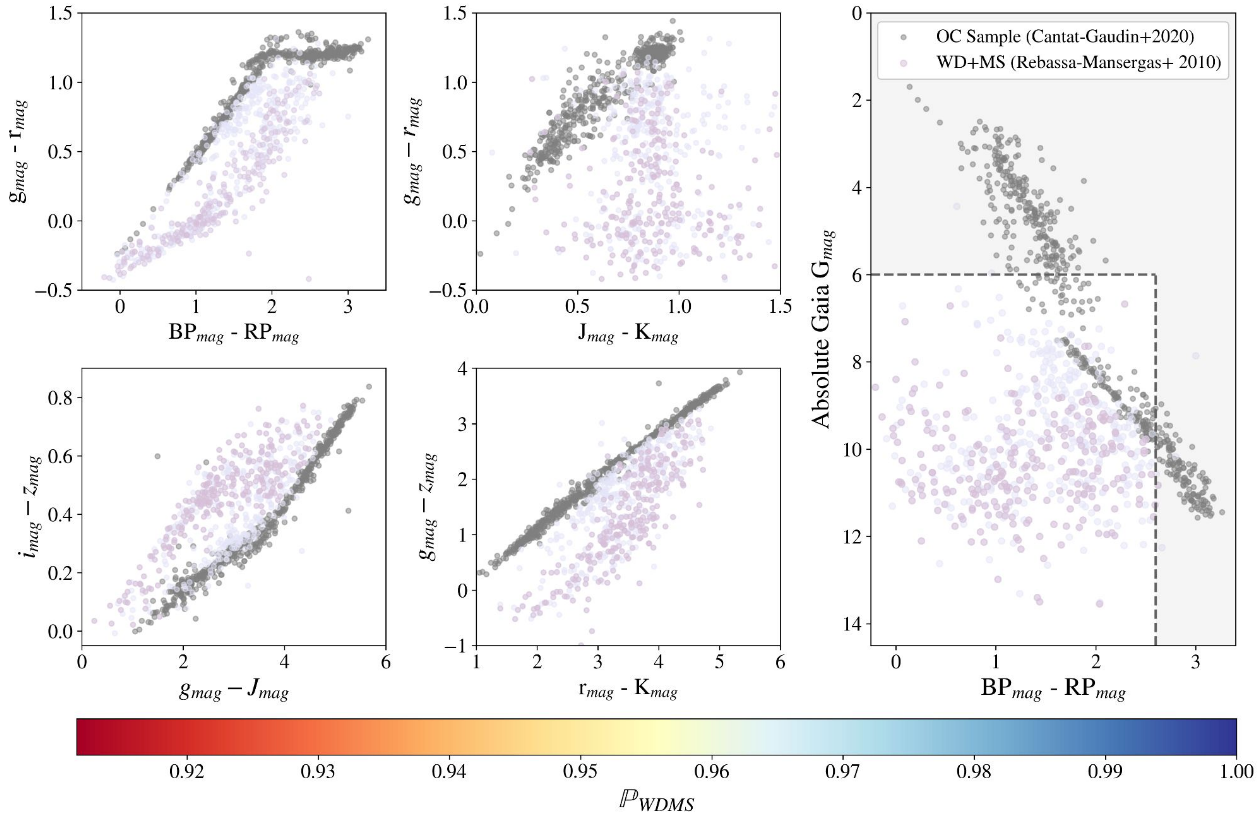
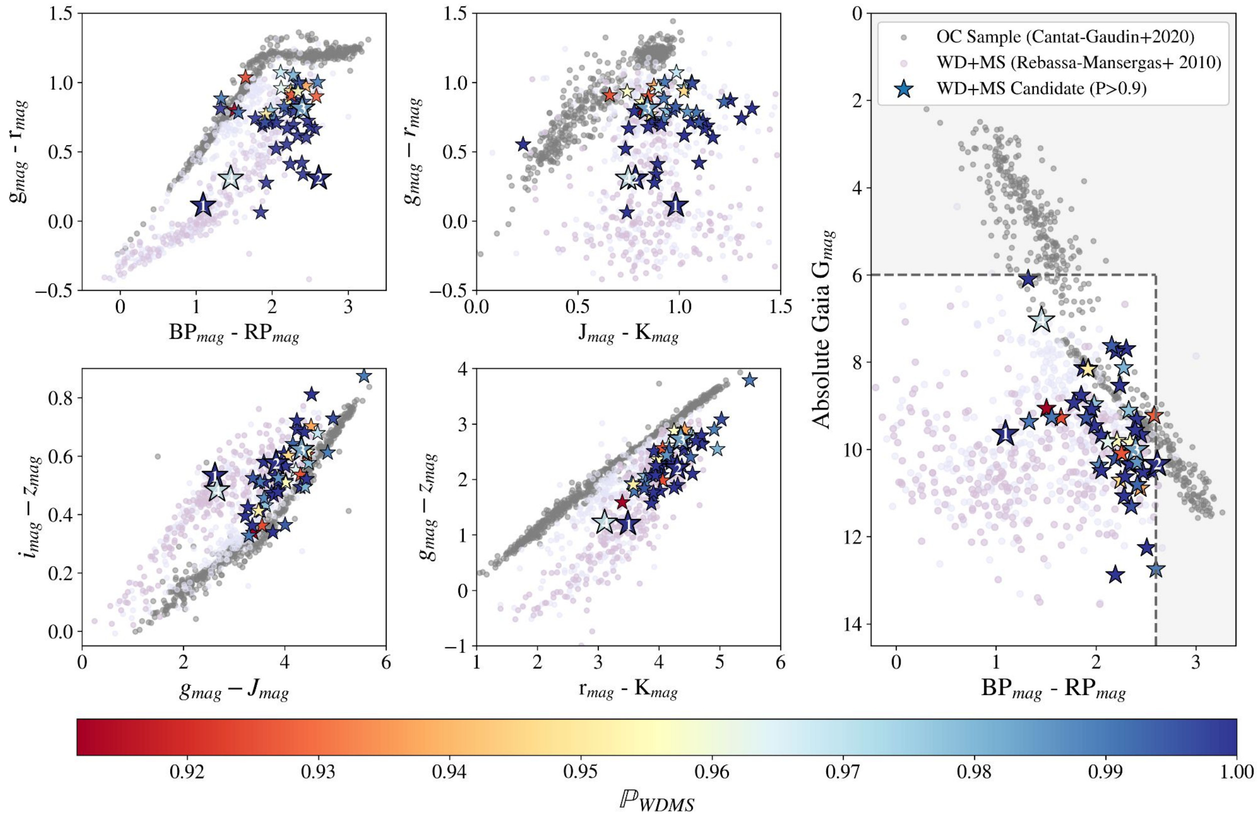


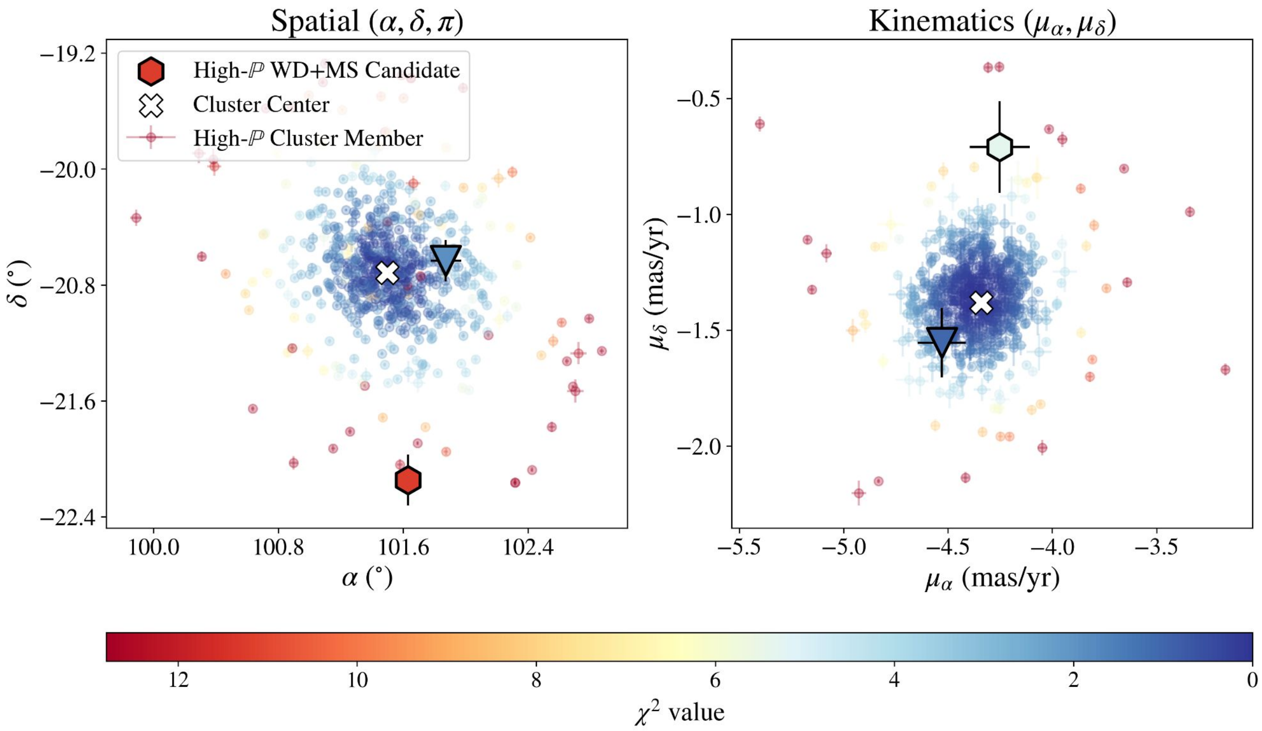
Grondin+ 2024b

Our high-probability candidate catalogue: 52 systems above P>0.9.



Grondin+ 2024b

We perform a χ^2 analysis to determine the degree of spatial and kinematic cluster association for each candidate.



$$\chi^2 = (\vec{\mu} - \vec{X})^T C_*^{-1} (\vec{\mu} - \vec{X}) \quad \vec{\mu} = [\alpha,\, \delta,\, \pi] \;\; \vec{\mu} = [\mu_\alpha,\, \mu_\delta]$$

Grondin+ 2024b

Follow-up **spectroscopy** reveals a range of properties.

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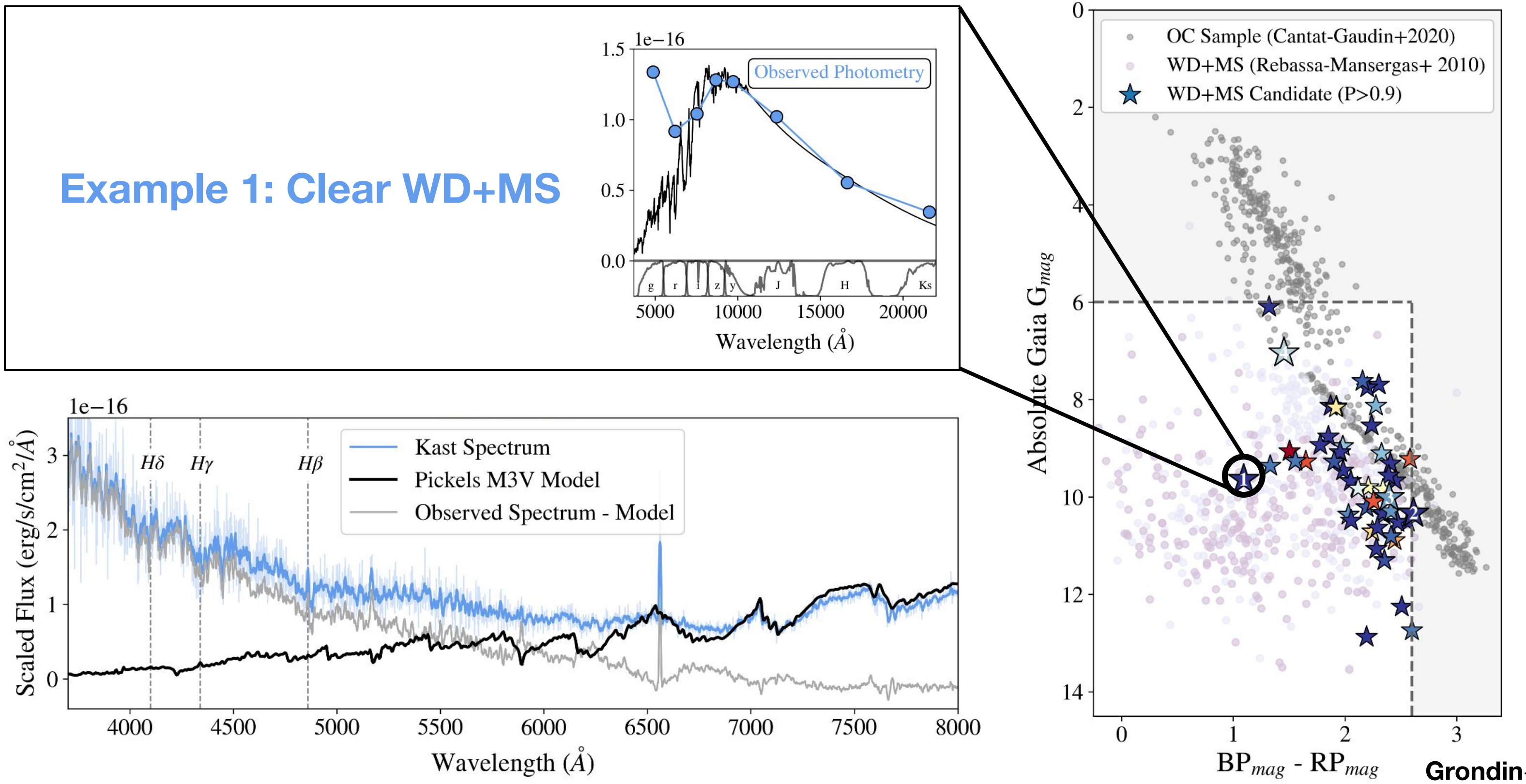
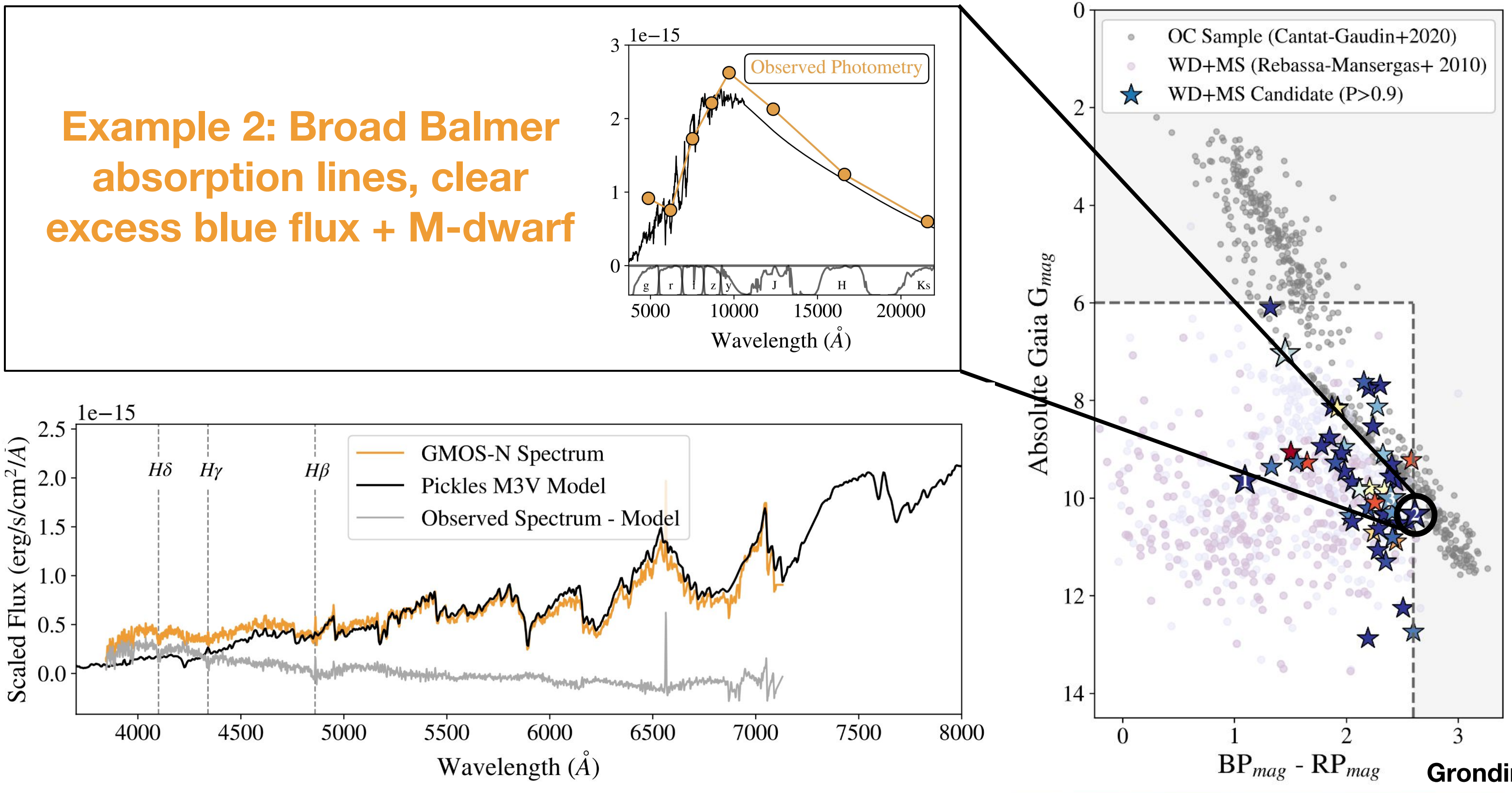


Grondin+ 2024b

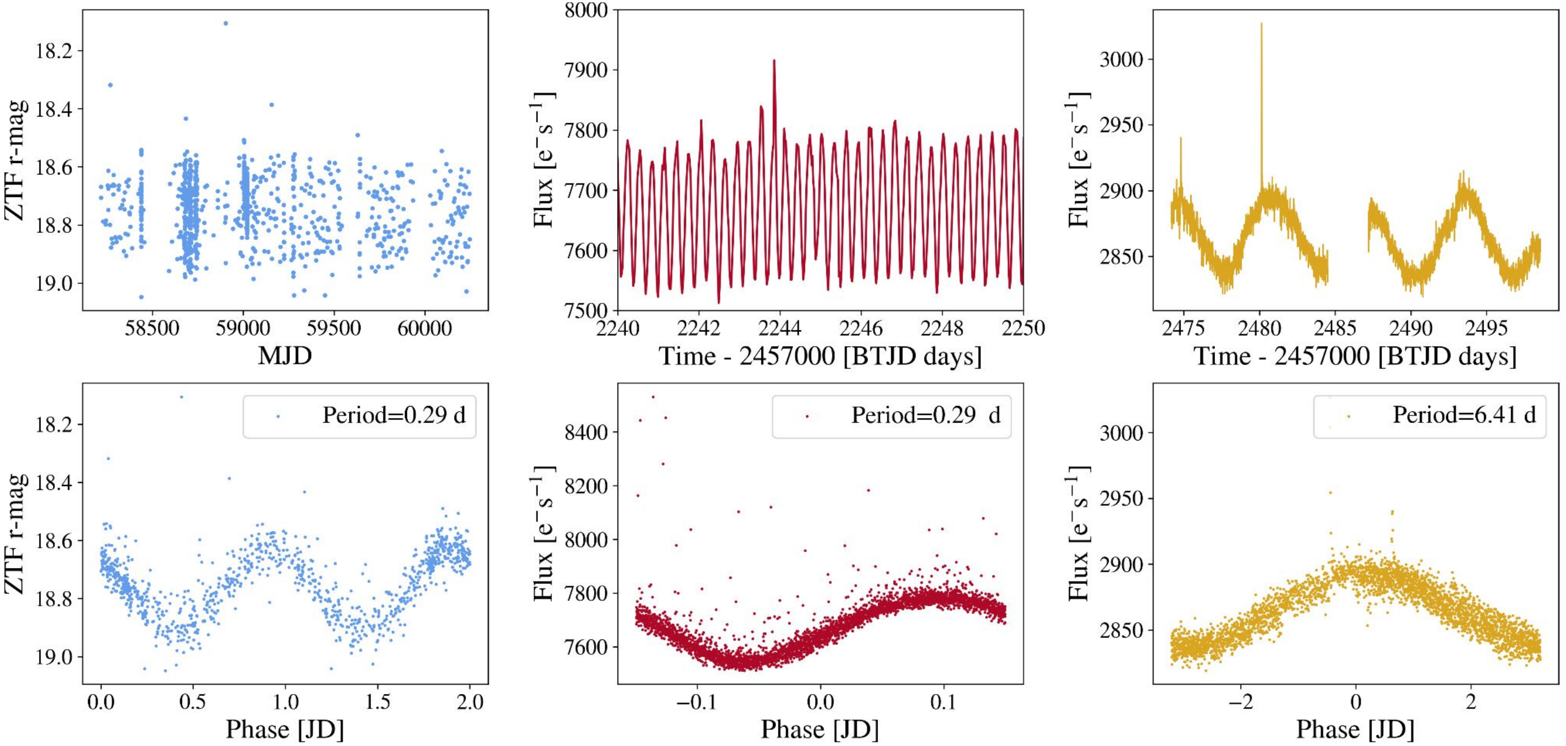
Follow-up spectroscopy reveals a range of properties.

Example 2: Broad Balmer absorption lines, clear excess blue flux + M-dwarf



Grondin+ 2024b

Clear and regular (short period) variability is observed in ZTF, K2 and TESS data.



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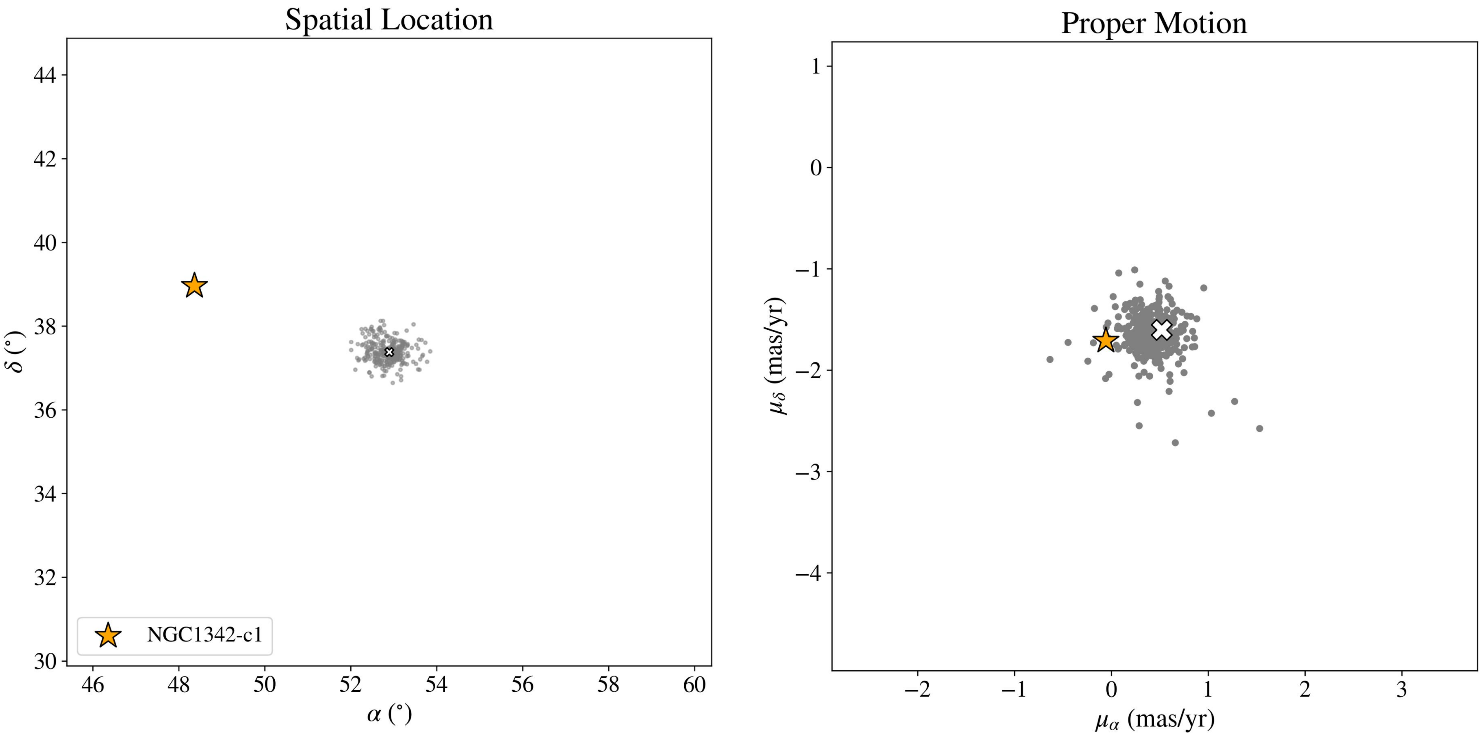

Grondin+ 2024b

There is an observed deficit of WDs in clusters.

e.g. Richer et al. (incl. **Grondin**) 2020

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Possible through natal kicks!

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Dynamics: **interactions with other cluster stars can eject binaries and single stars.**

e.g. through 3-body encounters

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Once a star/binary escapes a cluster, how do you trace it back?

Simulate high-N parameter spaces for extra-tidal stars/binaries ejected from clusters.

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`Corespray`
Grondin+ 2023

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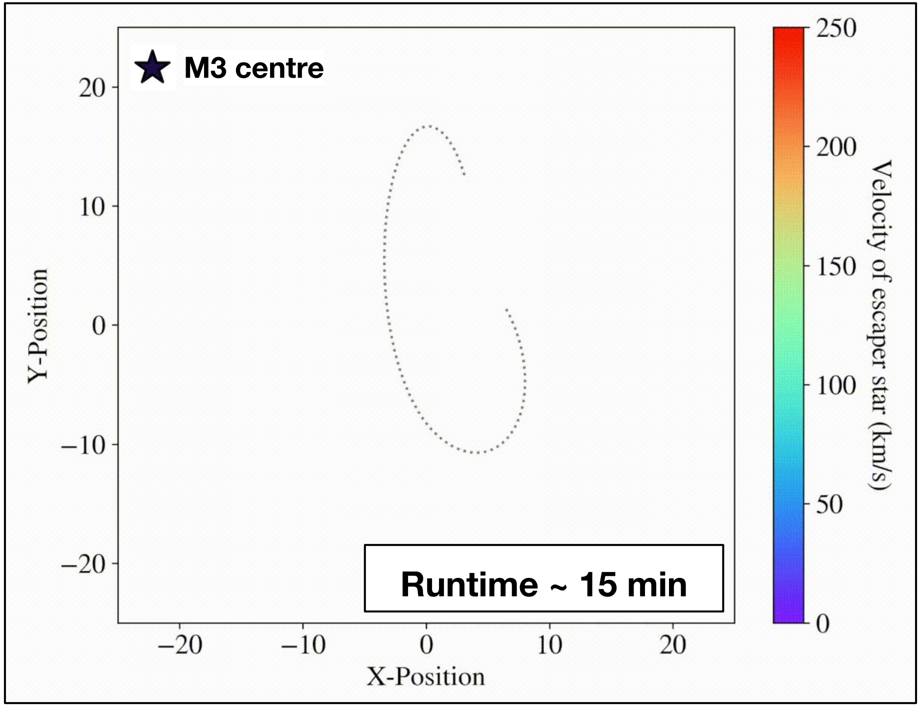
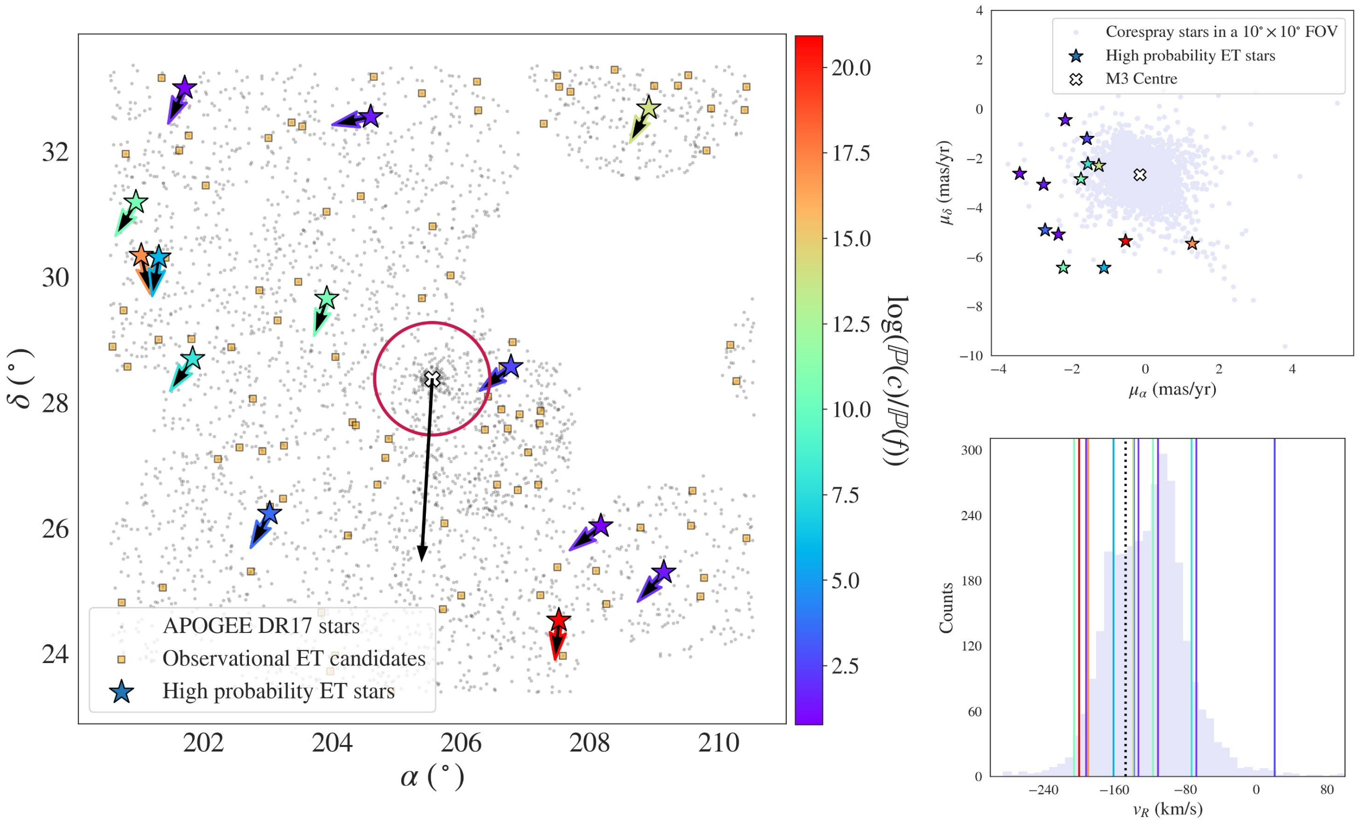
Grondin+ 2023



Simulate:

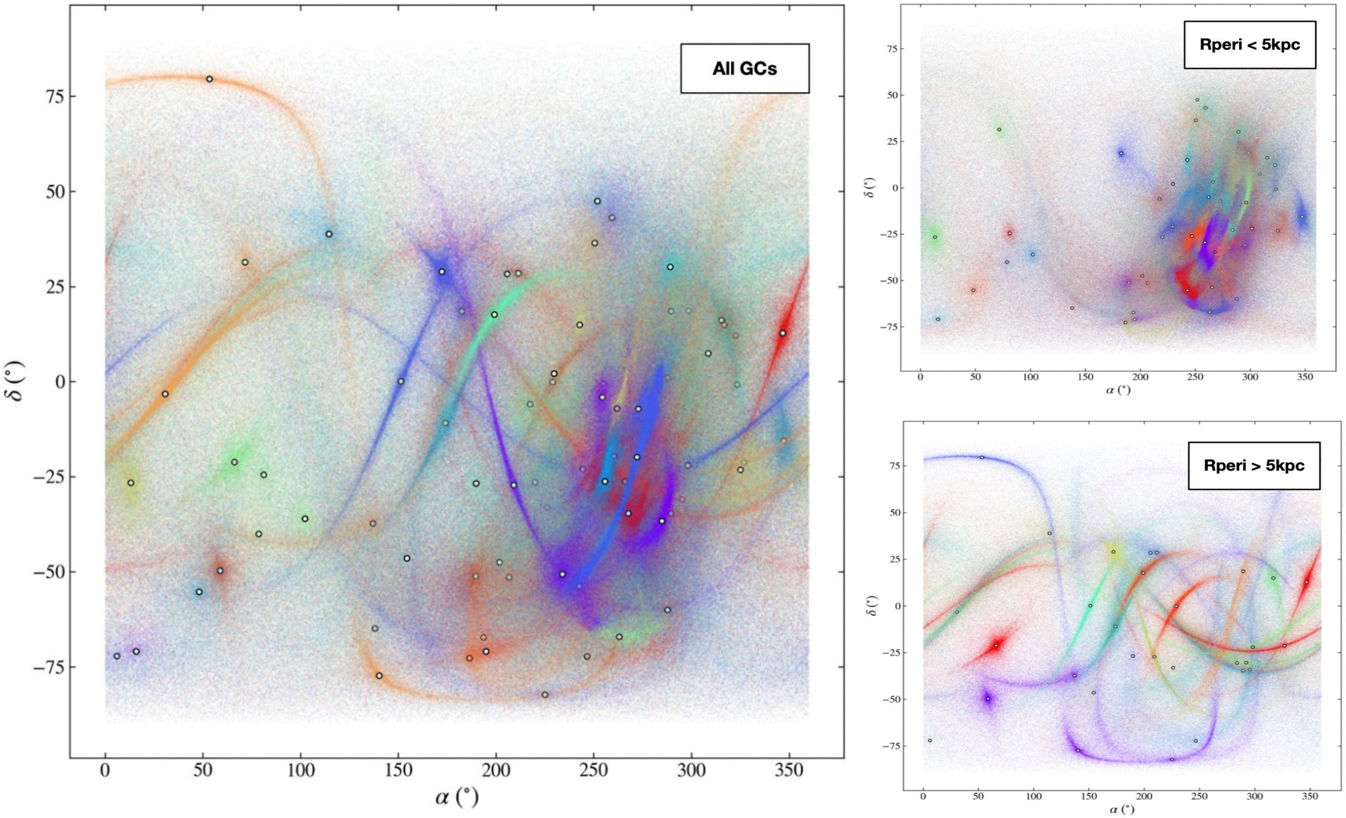
- Spatial position
- Distance
- Proper motion
- Velocities
- etc.

Example: chemical tagging and `Corespray` identified 10 new extra-tidal stars of the GC M3.



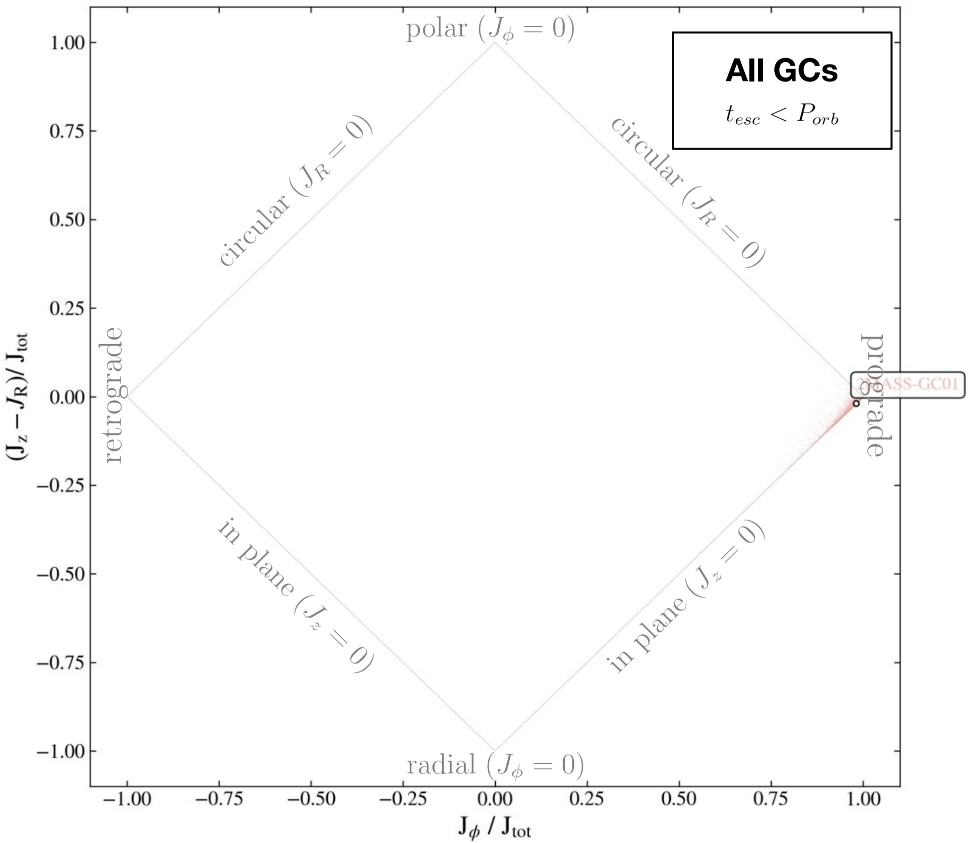
Grondin+ 2023

We apply this method to simulate ejected stars/binaries of all Milky Way clusters.



Grondin+ 2024a

Actions of each GC are ~unique, acting as useful parameters to identify escaped cluster members.



Based on Myeong+ 2019
& Vasiliev 2019

Grondin+ 2024a

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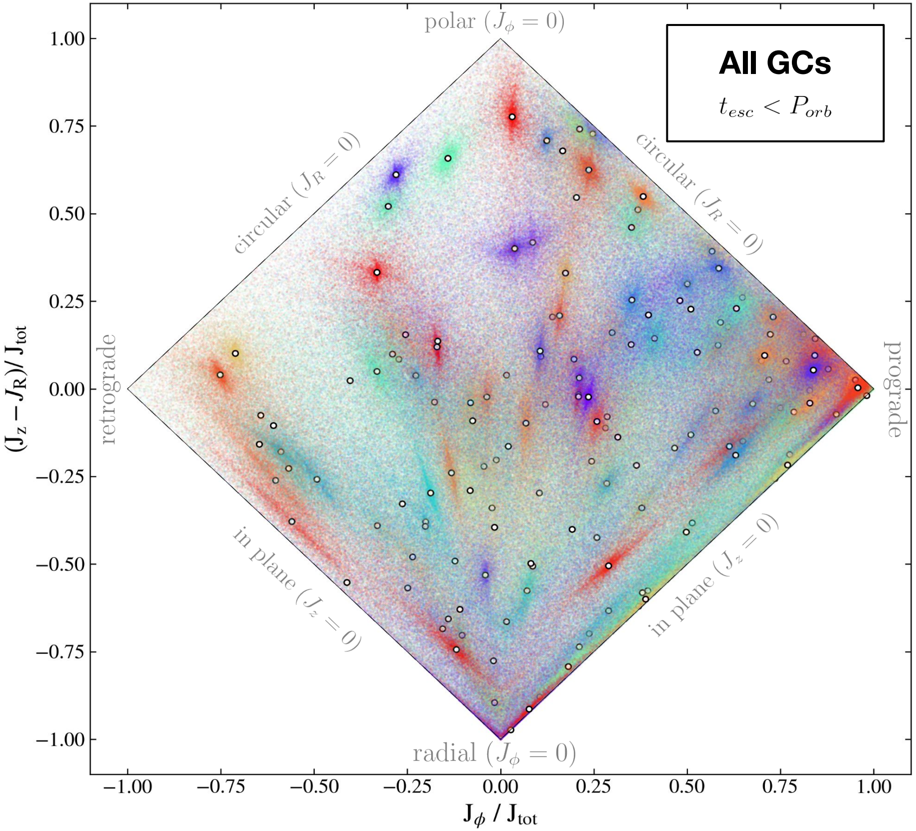

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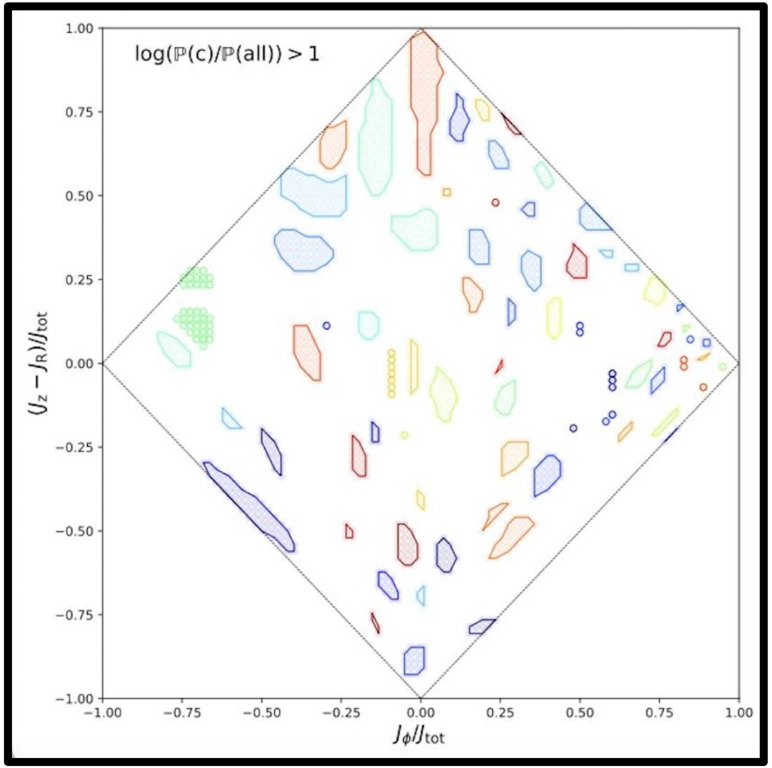
Grondin+ 2024a

Application: Hundreds of observed extra-tidal stars traced back to ~25 clusters.

Comparing chemistry and kinematics of simulated ejected stars to observed systems in Gaia and APOGEE.

Ryan Wang (UofT undergraduate)



Grondin, Wang et al. in prep.

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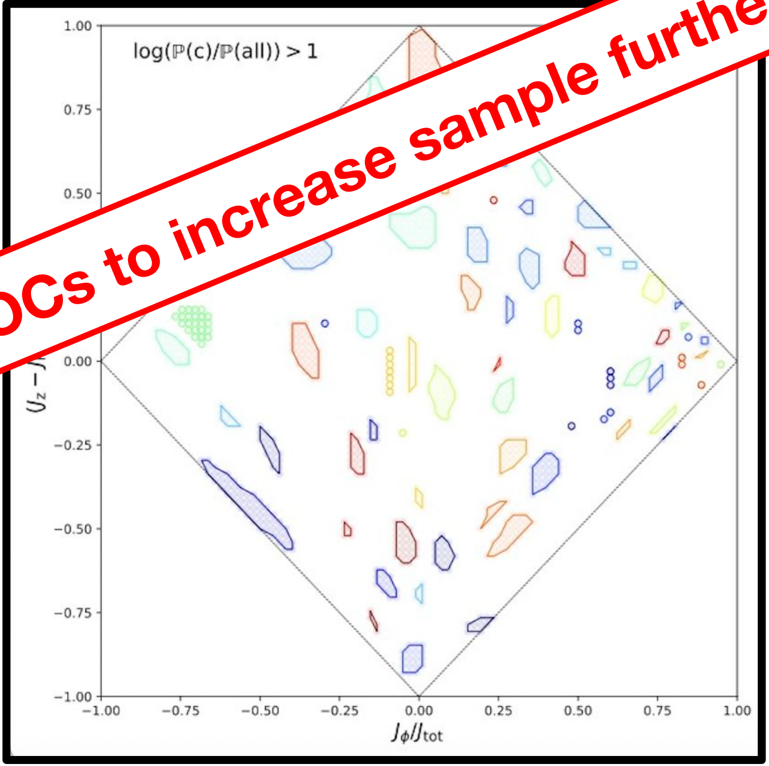

Repeat for WD+MS binaries in OCs to increase sample further!

Grondin, Wang et al. in prep.

New catalogue of WD+MS binaries in OCs

- A **detailed characterization** (masses, orbital solutions, etc.) of a subset of our WD+MS candidate binaries in clusters is **currently underway.**
- Once a larger sample of post-CE WD+MS binaries in clusters is confirmed, we can measure pre-CE masses → **one-to-one mapping between initial/final masses of CE systems.**

Grondin+ 2024b: arXiv: 2407.04775

Extra-tidal/escaped stars and binaries

- **Associating field post-CE binaries with clusters** could greatly increase the number of benchmark post-CE systems with ages → novel insights into one of the most **uncertain phases of binary evolution.**
- **Extending `Corespray` to open clusters.**
- **For `Corespray` applications, see talks by Fraser Evans (hypervelocity stars) and Alonso Herrera (single+binary runaways) tomorrow!**

Grondin+ 2023: arXiv.org/2207.11263
Grondin+ 2024a: arXiv.org/2310.09331

I am applying for postdoc positions this fall!
Please come talk to me about potential avenues for collaboration. :)