

Finding Free-Floating Black Holes

in Abundance with Roman

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“Ordinary” black holes are the fate of massive stars.

Stars with

$$M_{\odot} > 20\text{-}30 M_{\odot}$$

turn into black holes with

$$M_{\bullet} > 3 M_{\odot}$$

First predicted by theory

Michell 1784, Laplace 1799

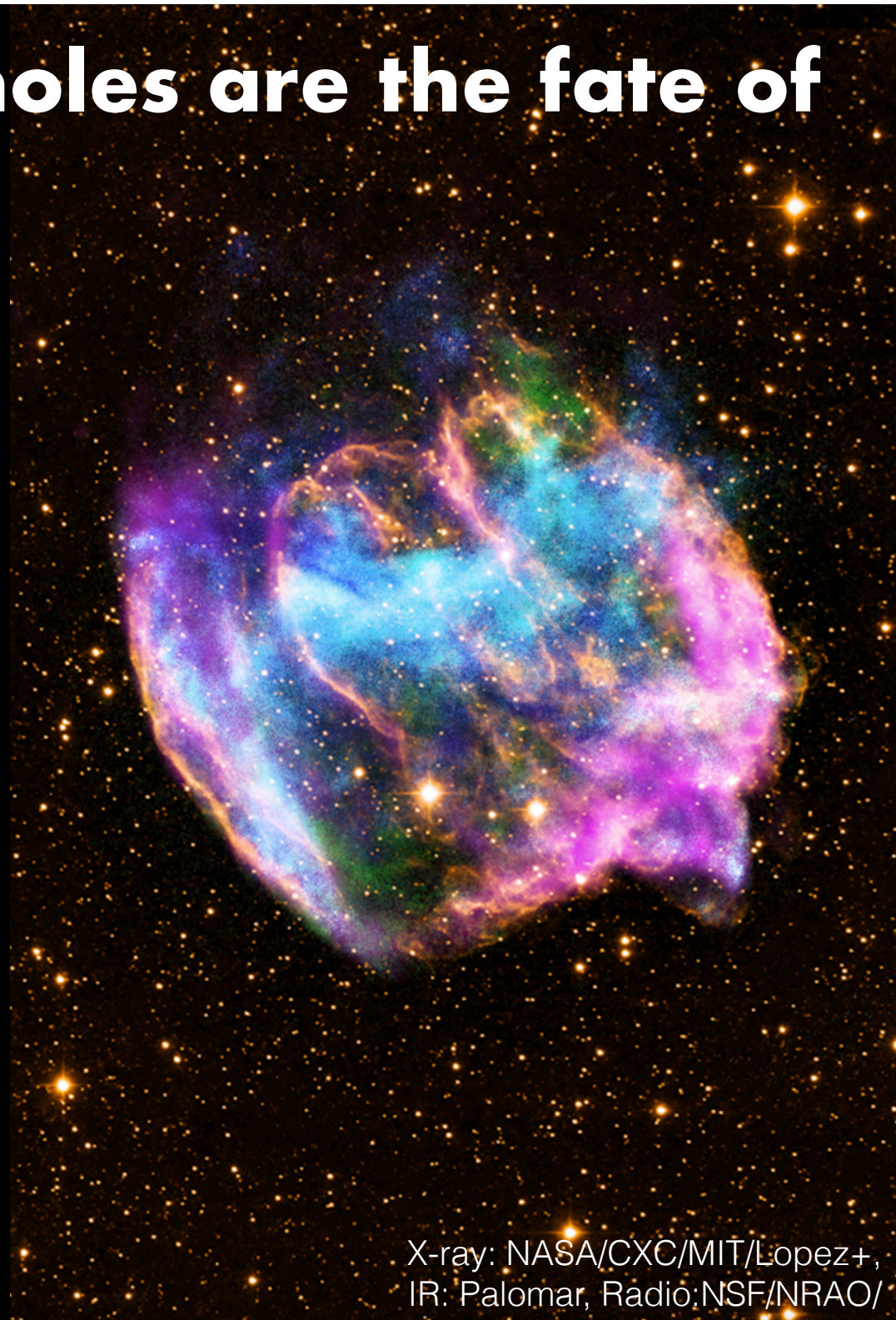
(see Montgomery+ 2009 for history)

Schwarzschild 1916, Droste 1916

$10^8 - 10^9$ stellar remnant black holes in the Milky Way

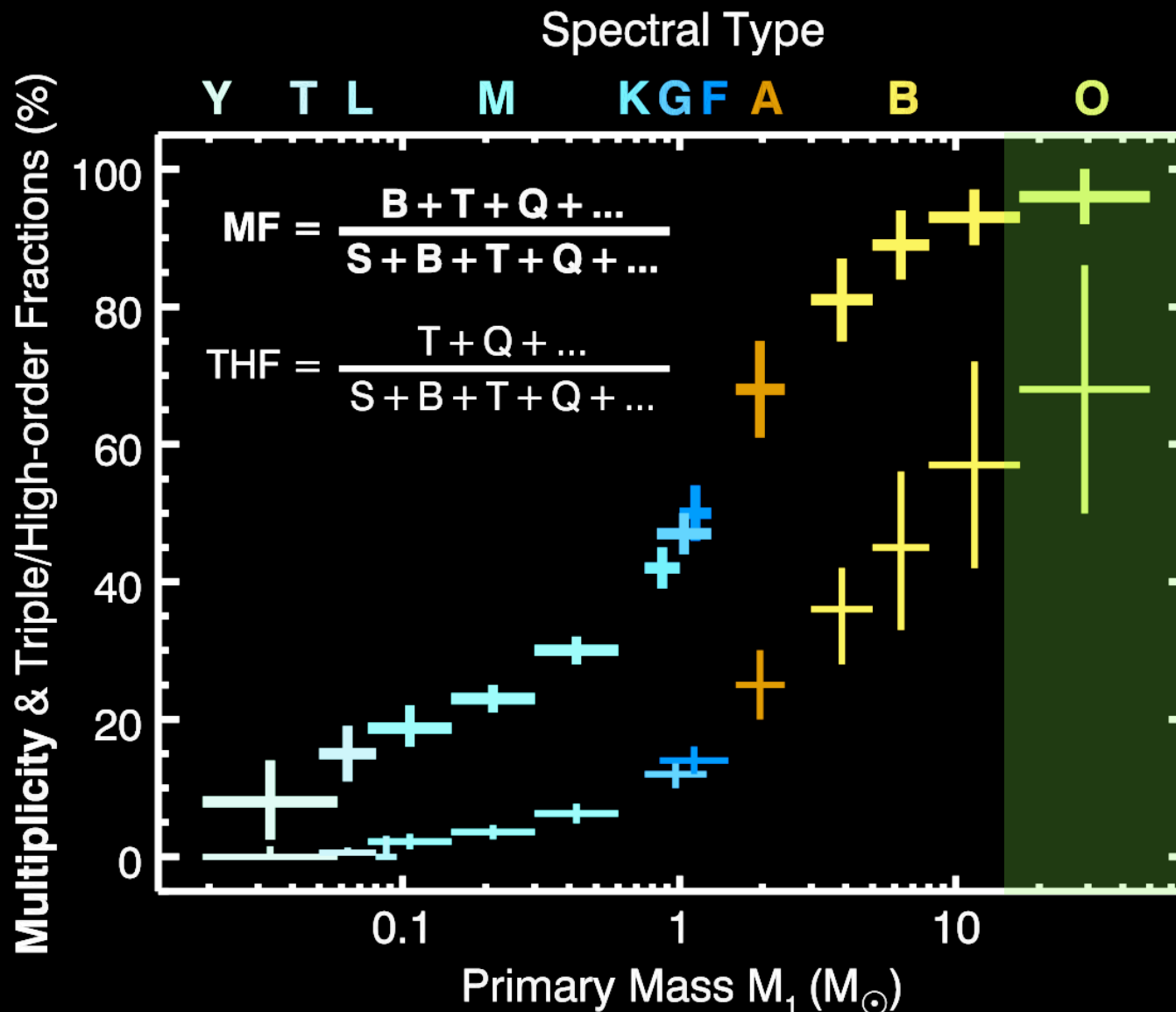
Gould 2000,

Agol and Kamiankowski 2002



X-ray: NASA/CXC/MIT/Lopez+,
IR: Palomar, Radio: NSF/NRAO/

Theory: BHs form from O-stars which are born in binary and triple systems.

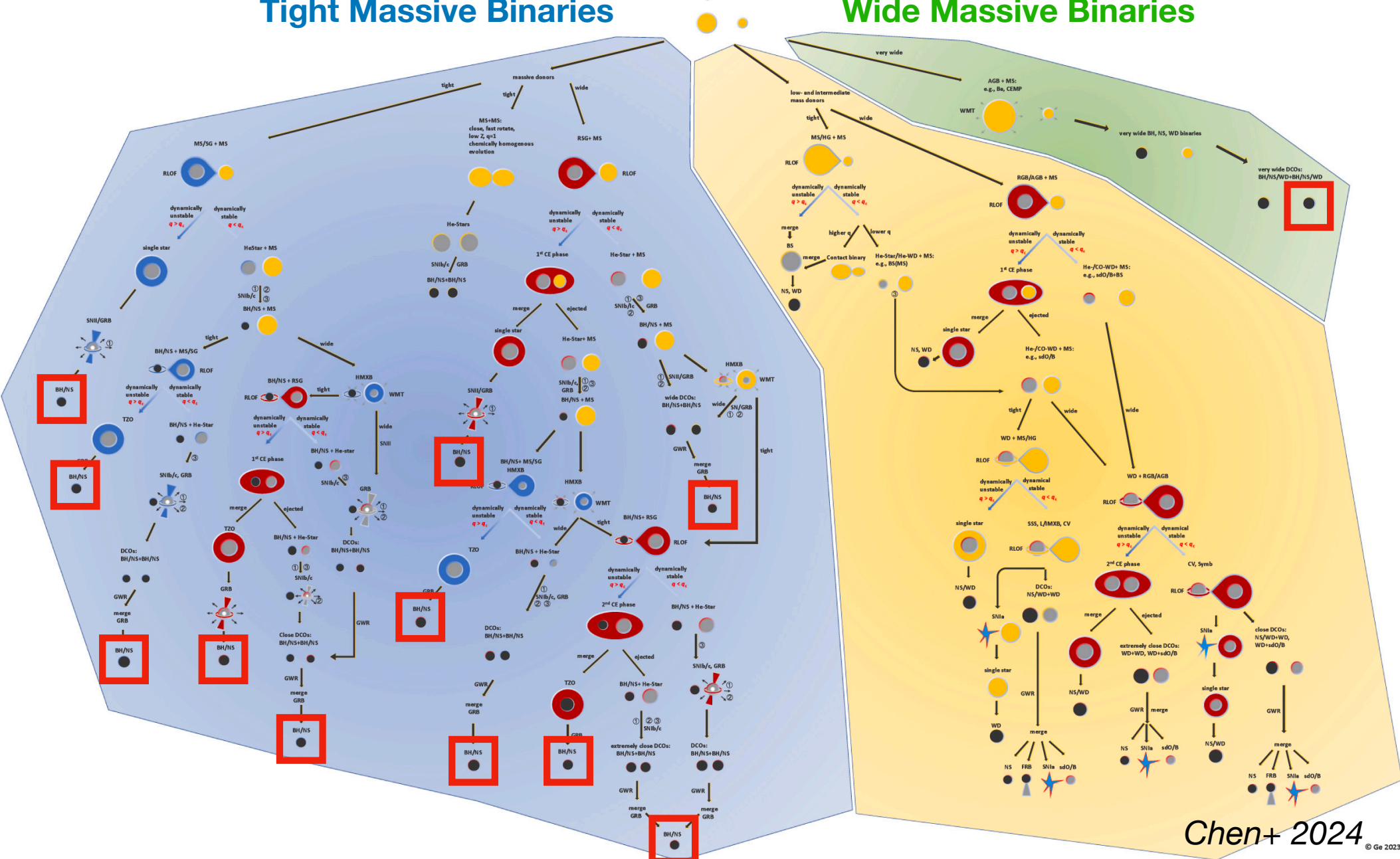


Theory: Evaporation, disruption, and mergers produce isolated BHs.



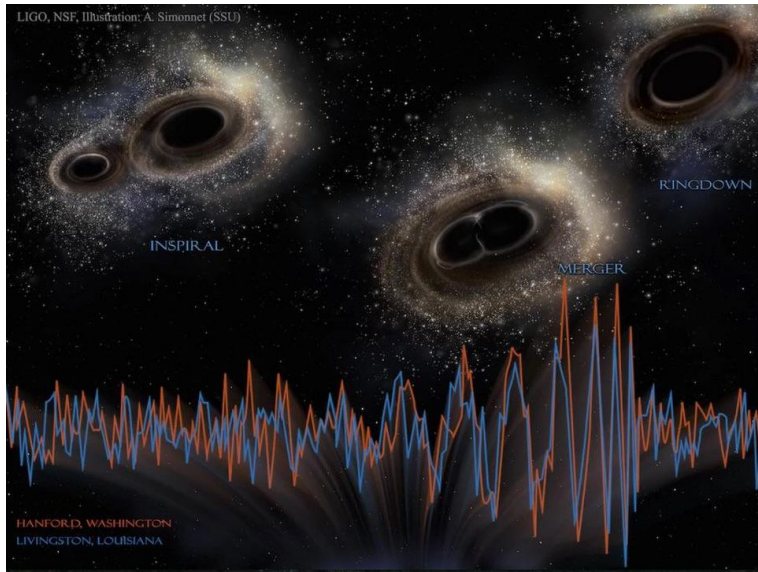
binary evolution

Wide Massive Binaries

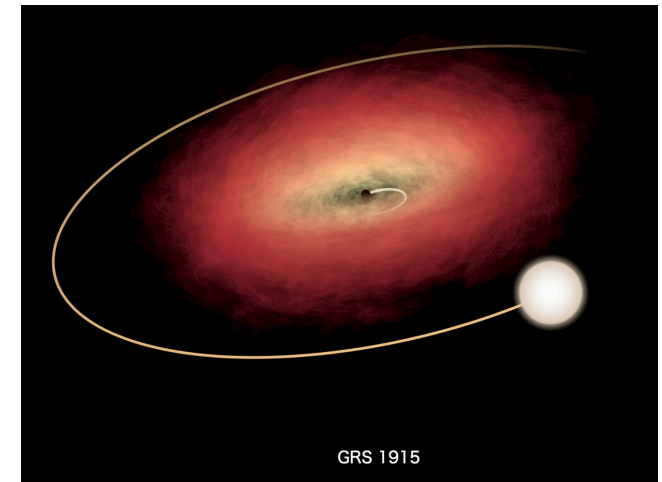


Observing BH Populations

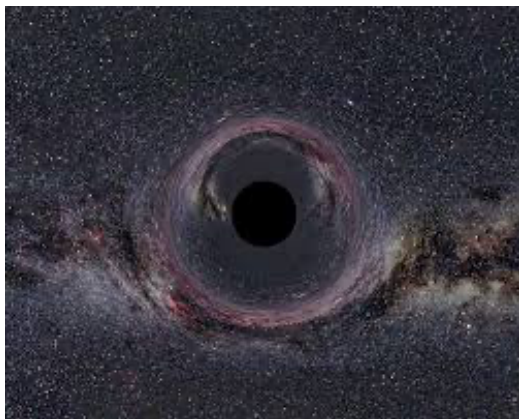
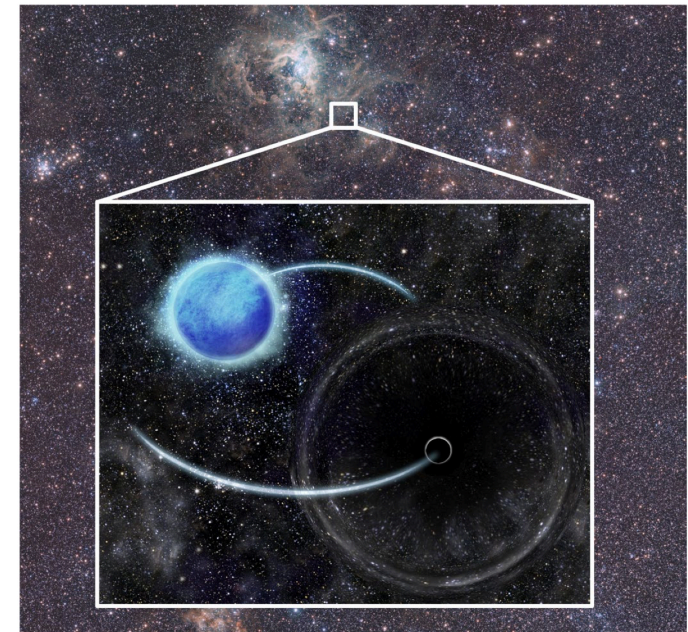
BH + BH Mergers
(>150)



Accreting X-ray
Binaries
(2 dozen)



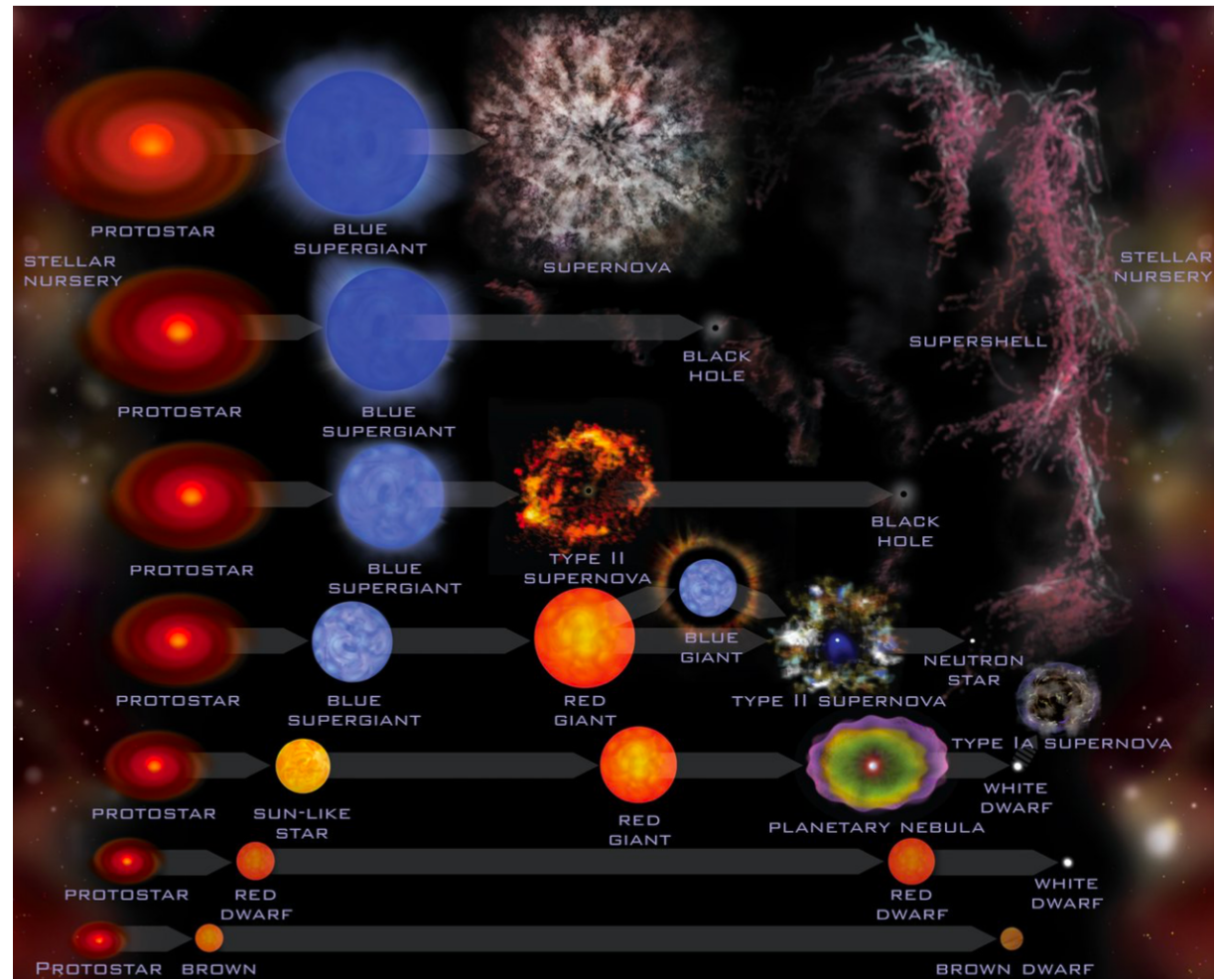
Non-Accreting
Star + BH
(few)

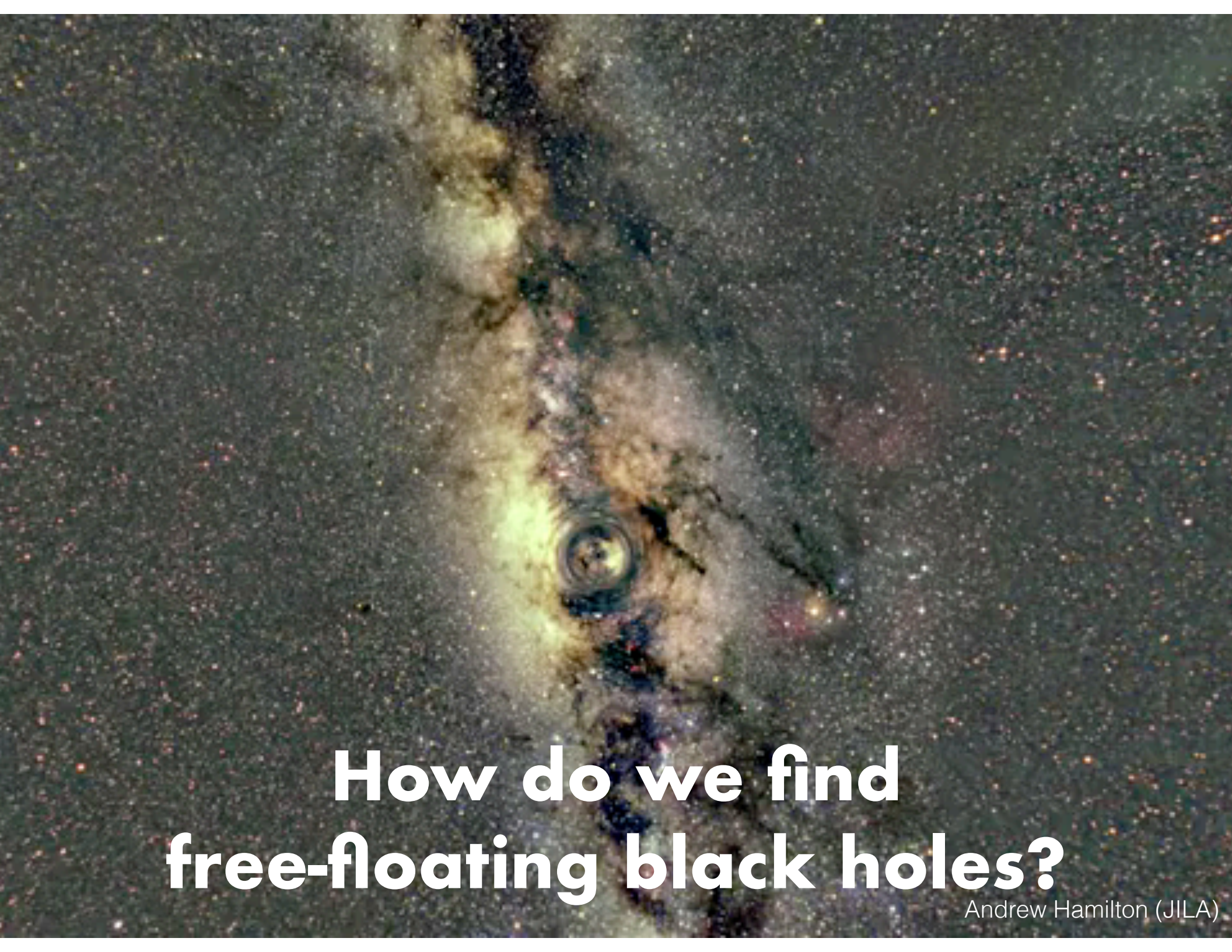


Isolated
(1)

The death and afterlife of stars is not fully understood.

- How many BHs are in the Milky Way?
- What is the black hole mass distribution?
- Do BHs get kicked during a supernova?
- How many BHs are in binaries and when will they merge?
- What stars turn into black holes?
- Do primordial black holes exist?

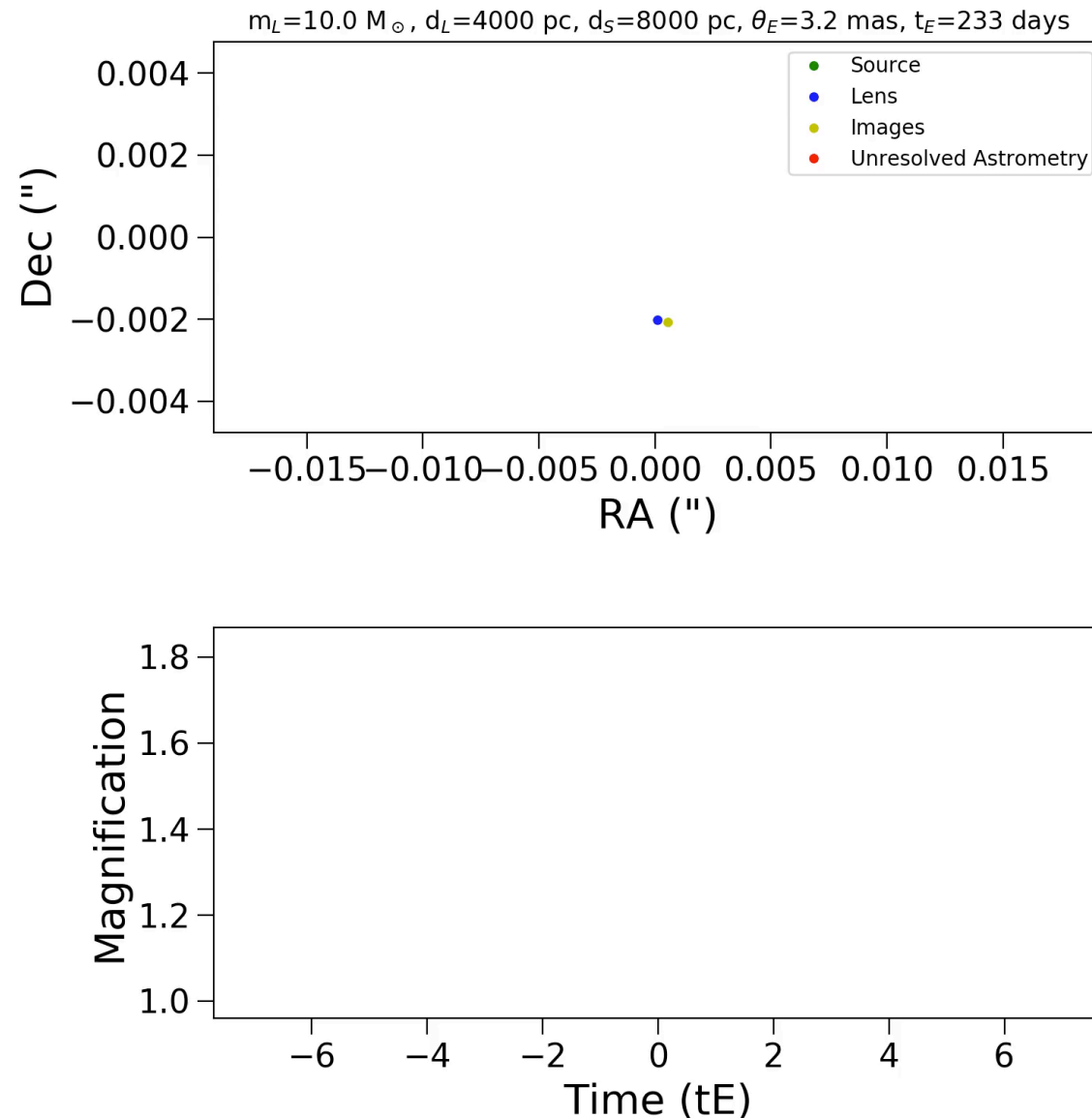




How do we find free-floating black holes?

Andrew Hamilton (JILA)

Star passing behind a black hole causes photometric and astrometric microlensing.



Typical BH:

$$\theta_E \sim \text{few mas}$$

Photometry:

$$t_E = \frac{\theta_E}{\mu_{rel}} \quad \pi_E = \frac{\pi_{rel}}{\theta_E}$$

Astrometric shift:

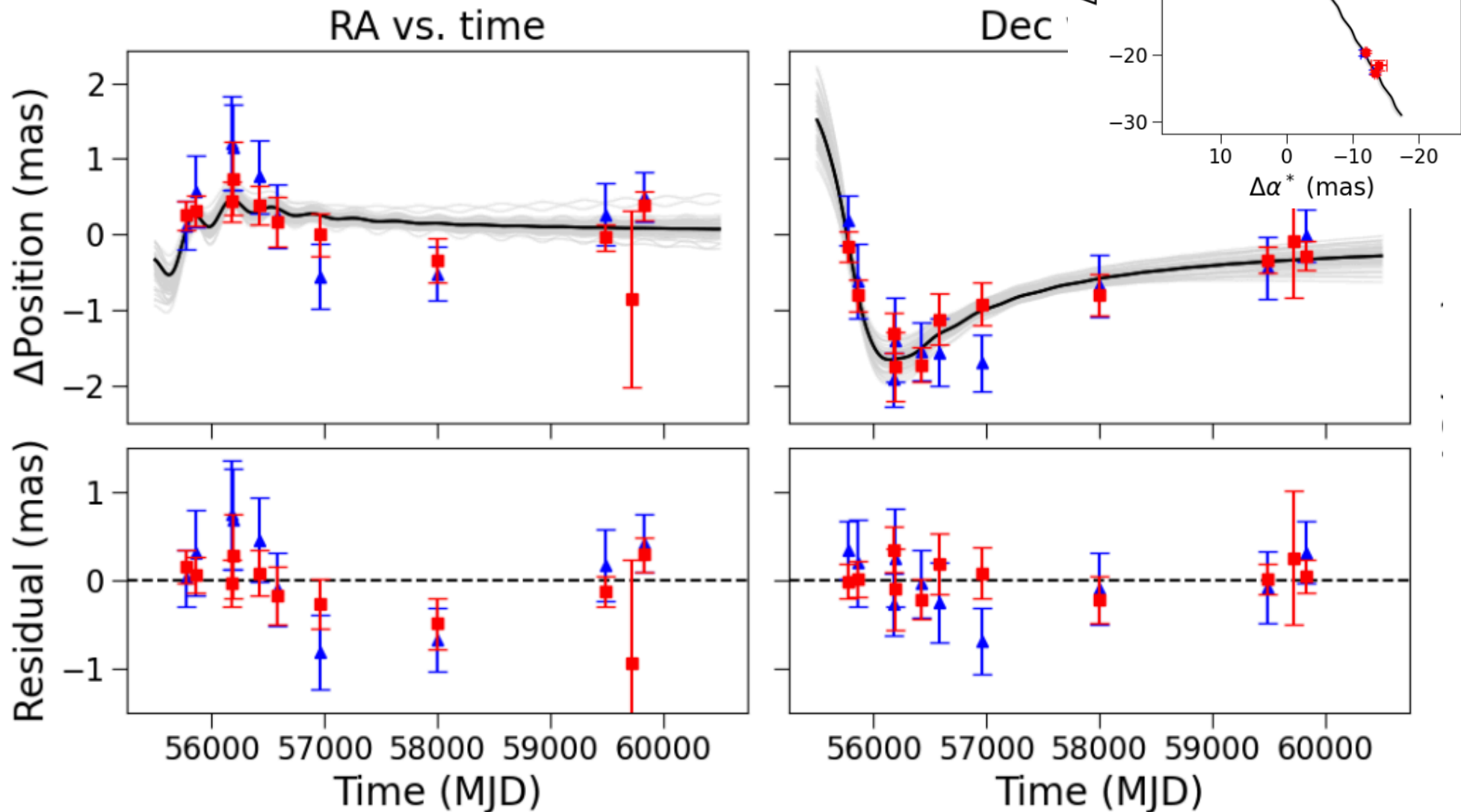
$$\delta_c(t) = \frac{\theta_E}{u(t)^2 + 2} u(t),$$

$$\text{max} \sim 0.35 \theta_E$$

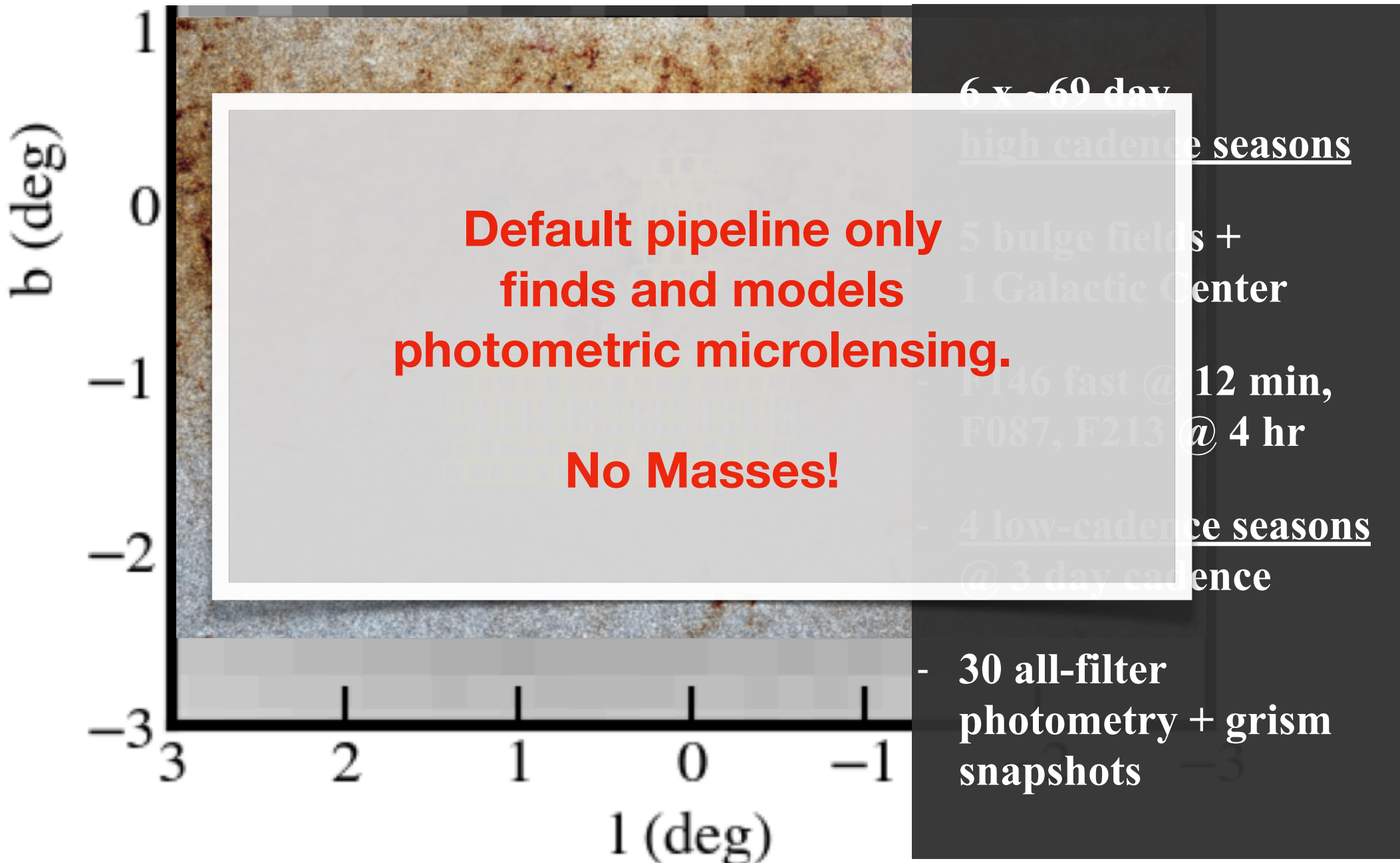
$$M = \frac{\theta_E}{\kappa \pi_E}$$

First isolated BH detected using astrometric microlensing:

$$M_{\text{BH}} = 6 \pm 1 M_{\text{sun}}$$



Roman's GBTDS is designed to find exoplanets via microlensing. But it will find black holes too!

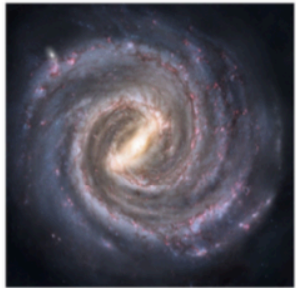


What compact objects will RGBTDS see?

Roman GBTDS Simulations with PopSyCLE.

PopSyCLE:

Population Synthesis for Compact object Lensing Events



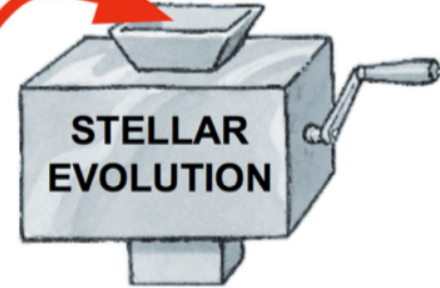
Stellar model of Milky Way



Select component of Milky Way (e.g. bulge)

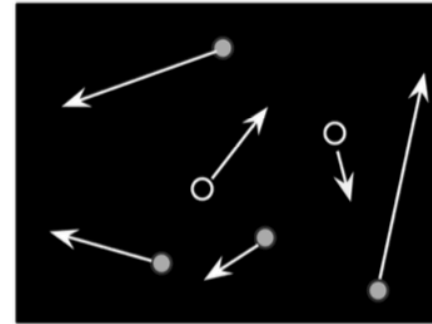


Select single-age subset of component



STELLAR EVOLUTION

Compact objects with positions and velocities



Includes:

- 1 billion “stars”
 - multiples
 - compact objects
- 30,000 microlensing events
- Generated lightcurves and astrometric trajectories

Caveats

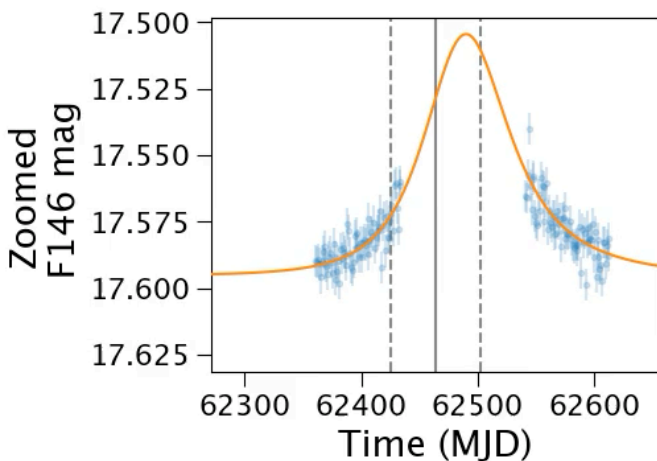
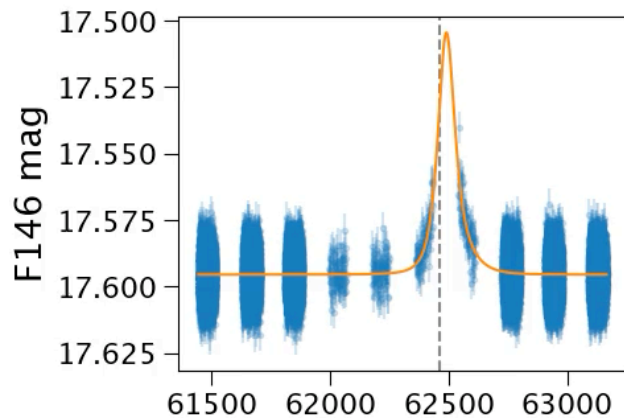
- No NSD, NSC
- No planets, brown dwarfs, binary evolution (yet)
- Too-high extinction towards center

*Lam+ 2020, Rose+ 2022,
Abrams+ 2025, Lu+ in prep*

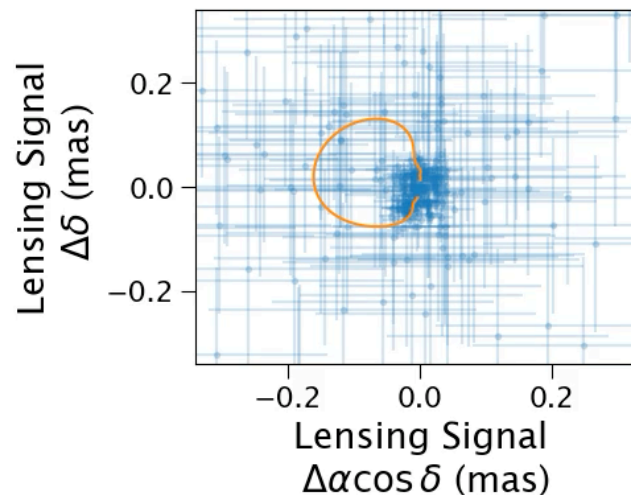
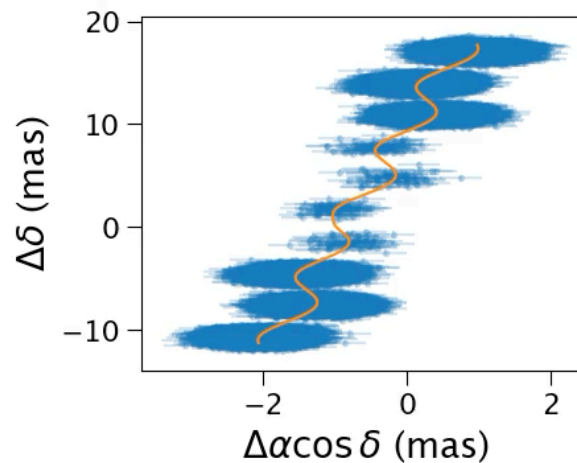
Example RGBTDS lightcurves and trajectories.

Photometry

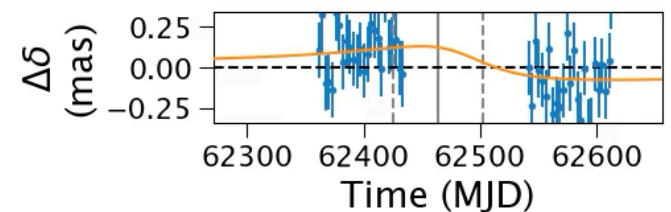
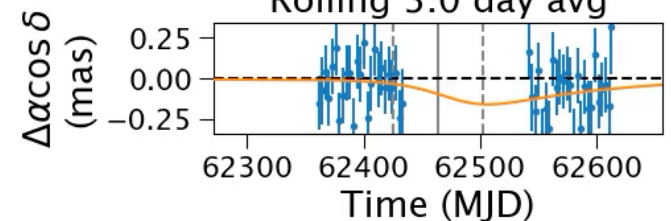
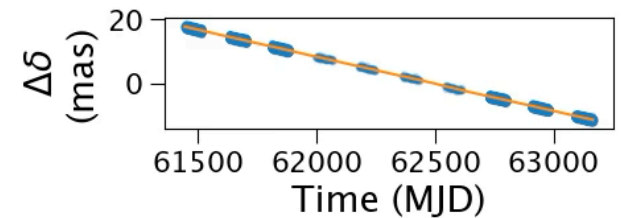
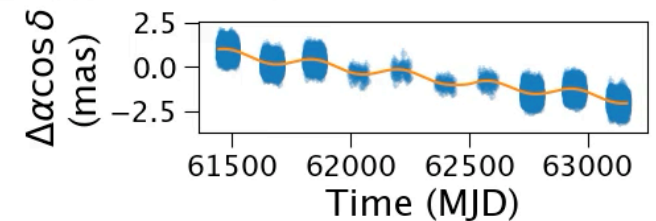
BSPL : $M_L=0.15$ Msun, $\pi_{\text{Rel}}=0.31$ mas, $\theta_E=0.6$ mas, $\mu_{\text{Rel}}=5.9$ mas/yr, $\text{sepS}=1.8$ mas $\text{fratioS}=\text{nan}$



On-Sky Astrometry



Astrometry Per Direction



Predicted Survey Statistics

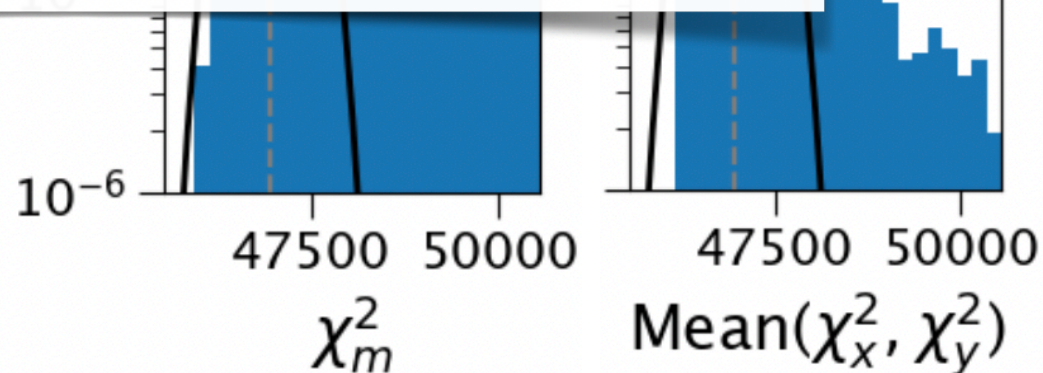
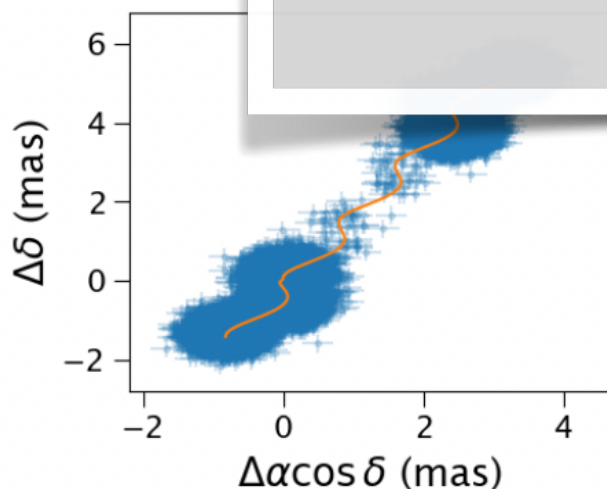
Number	Item
30,600	Events with $F146 < 24$ Vega, $u_0 < 2$, $\Delta m > 0.05$
12,500	Events with $N > 10$ points within $t_0 \pm t_E$

Fit all events with

- constant flux
- 5-parameter astrometric model
 - 2D position
 - 2D proper motion
 - parallax

>600 Photometric Events with Detectable Astrometry ($\chi^2 > 1000$)

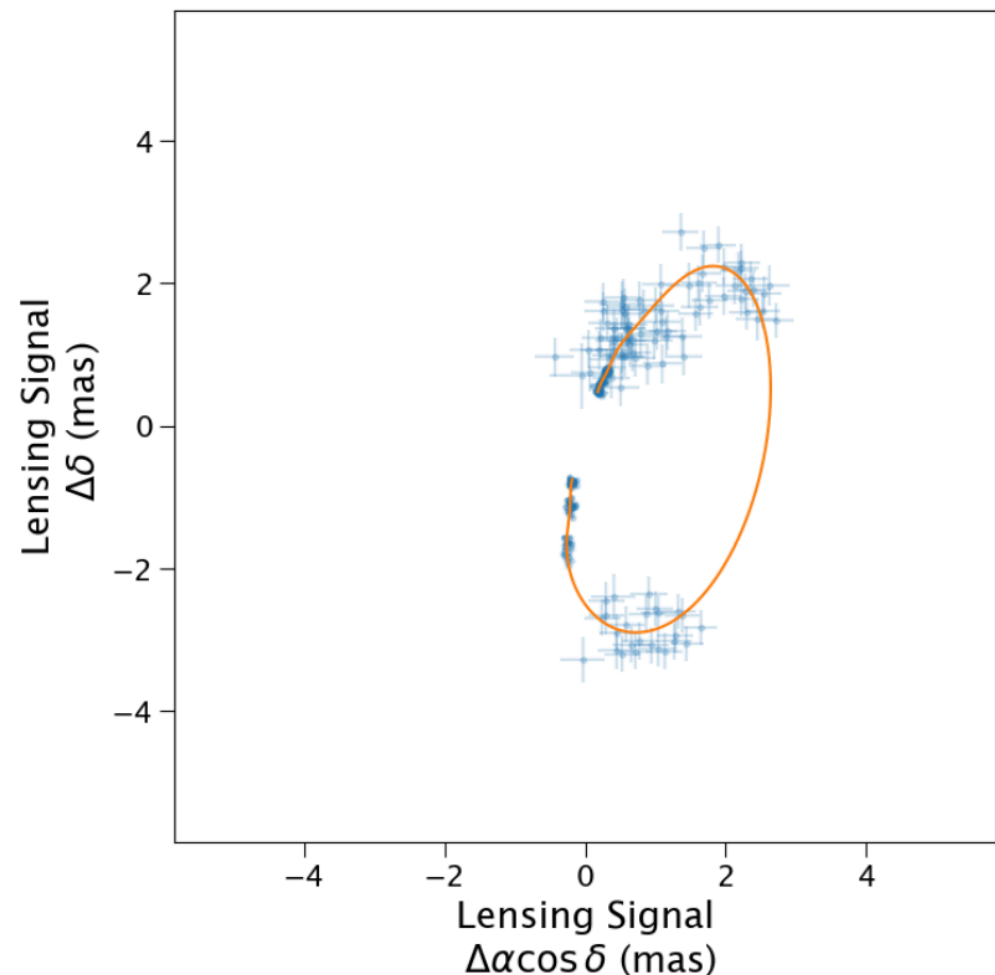
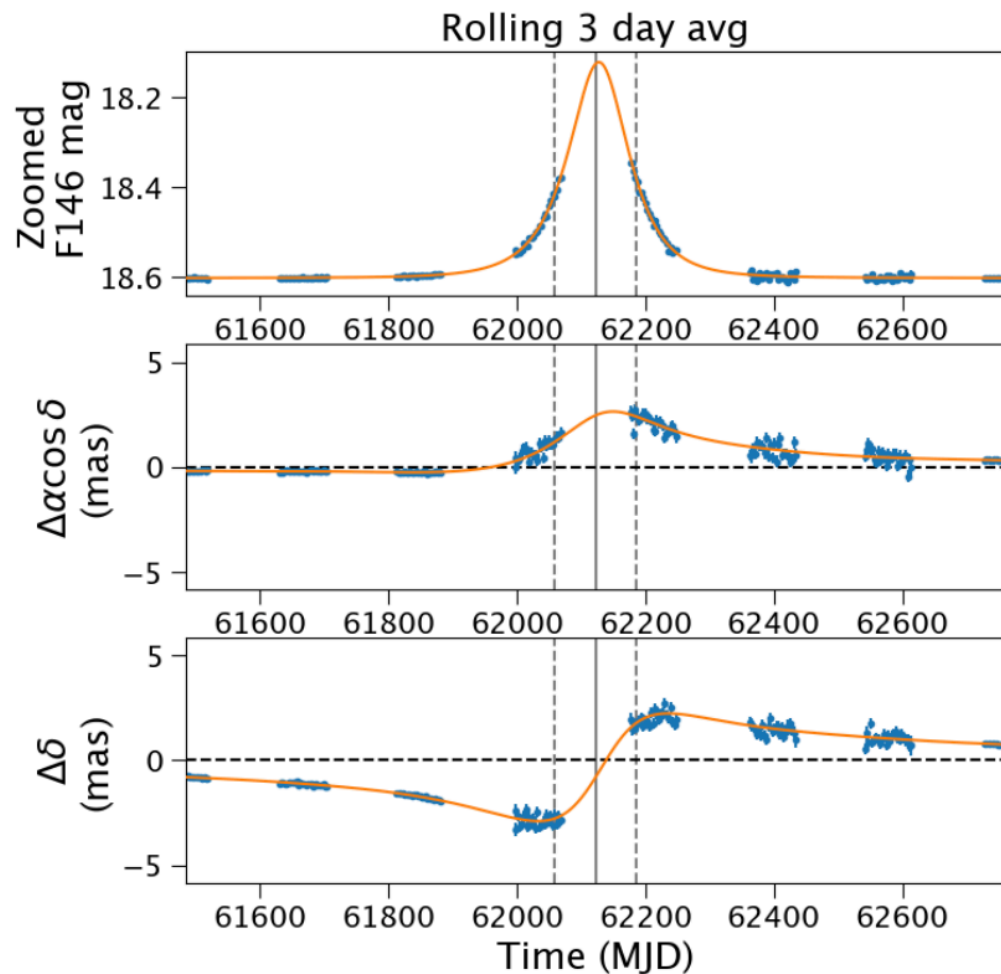
>1300 for $\chi^2 > 500$



Roman's GBTDS is great for finding isolated black holes via microlensing.

PSPL : $M_L = 12.30 \text{ M}_{\text{sun}}$, $\pi_{\text{Rel}} = 0.74 \text{ mas}$, $\theta_E = 8.6 \text{ mas}$,

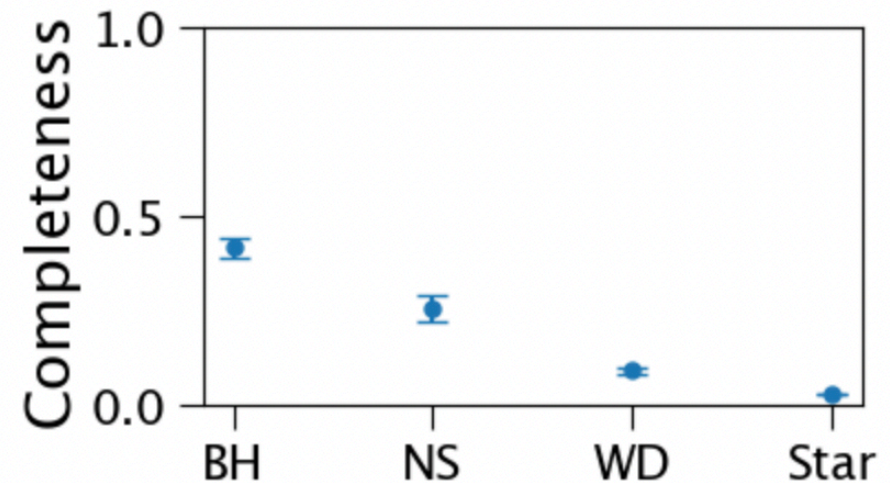
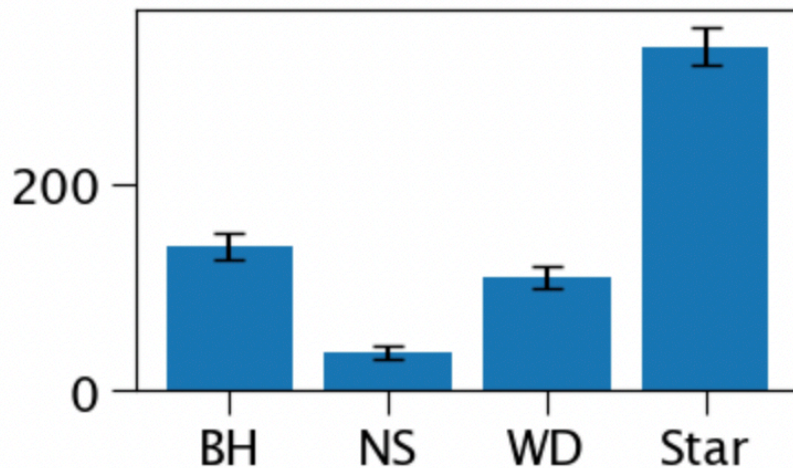
$\mu_{\text{Rel}} = 49.4 \text{ mas/yr}$, $\chi^2_p = 39086$, $\chi^2_a = 204484$



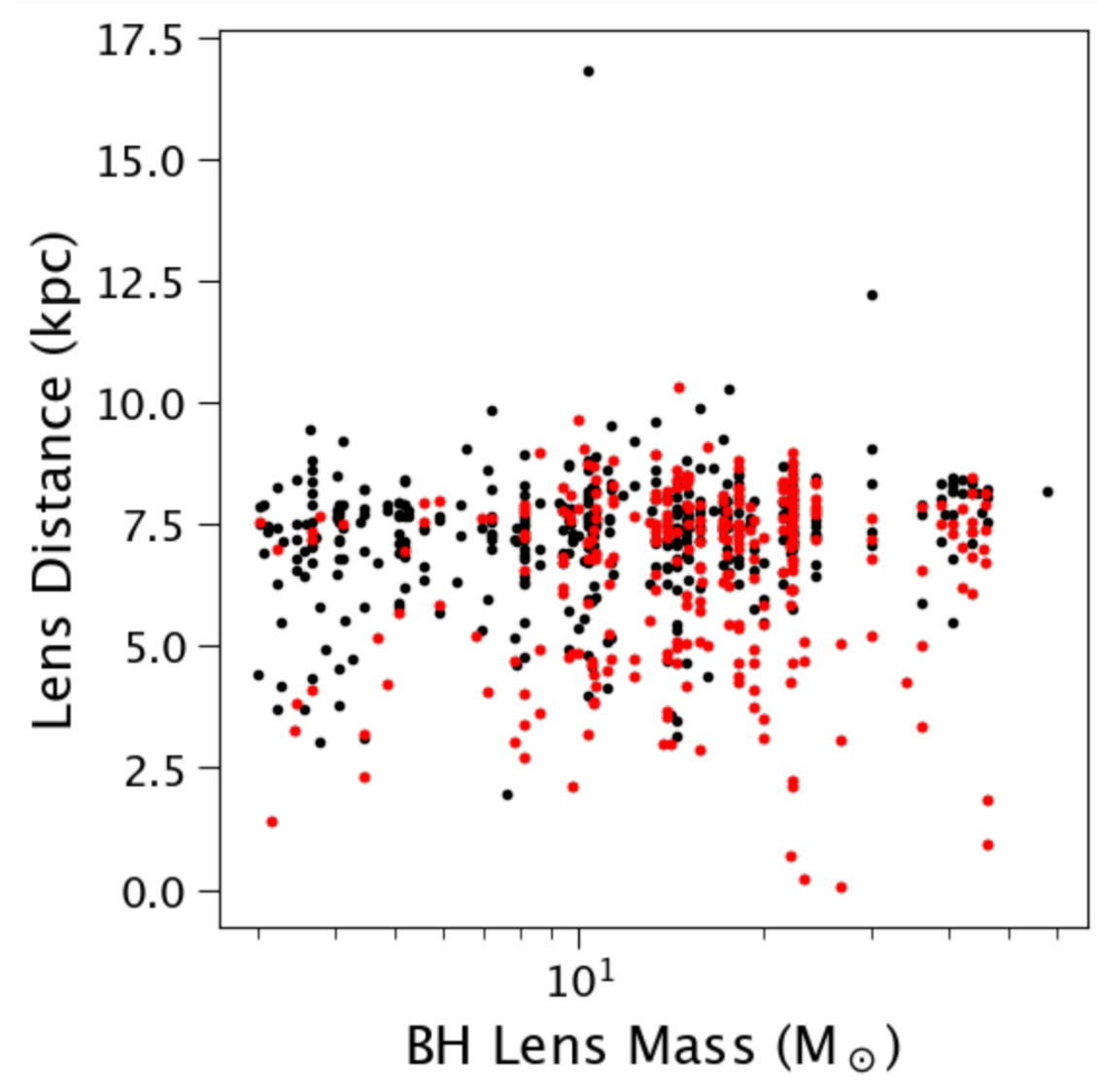
Roman will measure masses for over 100 black holes.

Lens Type	Detected	Undetected
Black Holes	139	195
Neutron Stars	37	109
White Dwarfs	109	1069
Stars	332	10,578

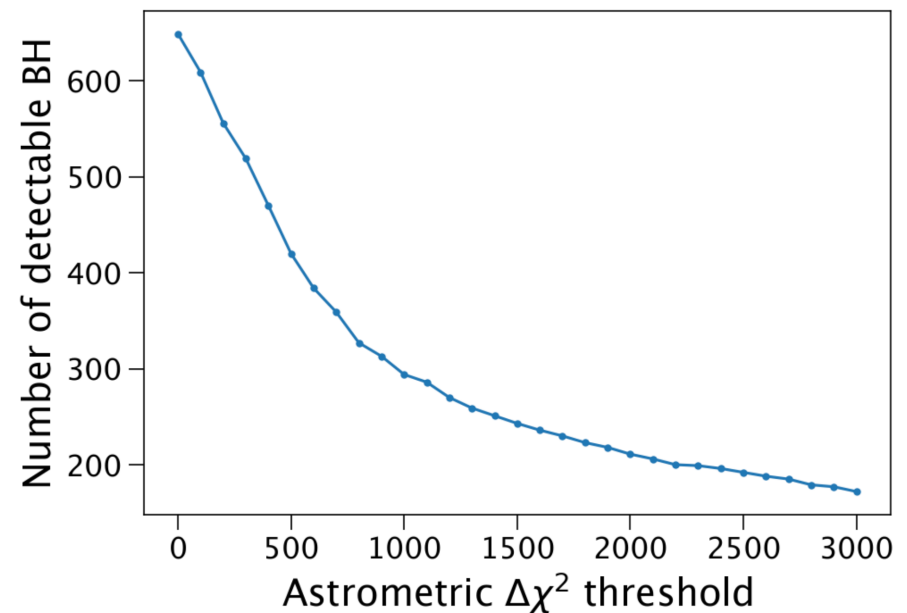
Events
Detected with
Astrometry



Photometric + astrometric microlensing is most sensitive to massive and close BHs.



Lower-mass black holes are detectable at lower significance.



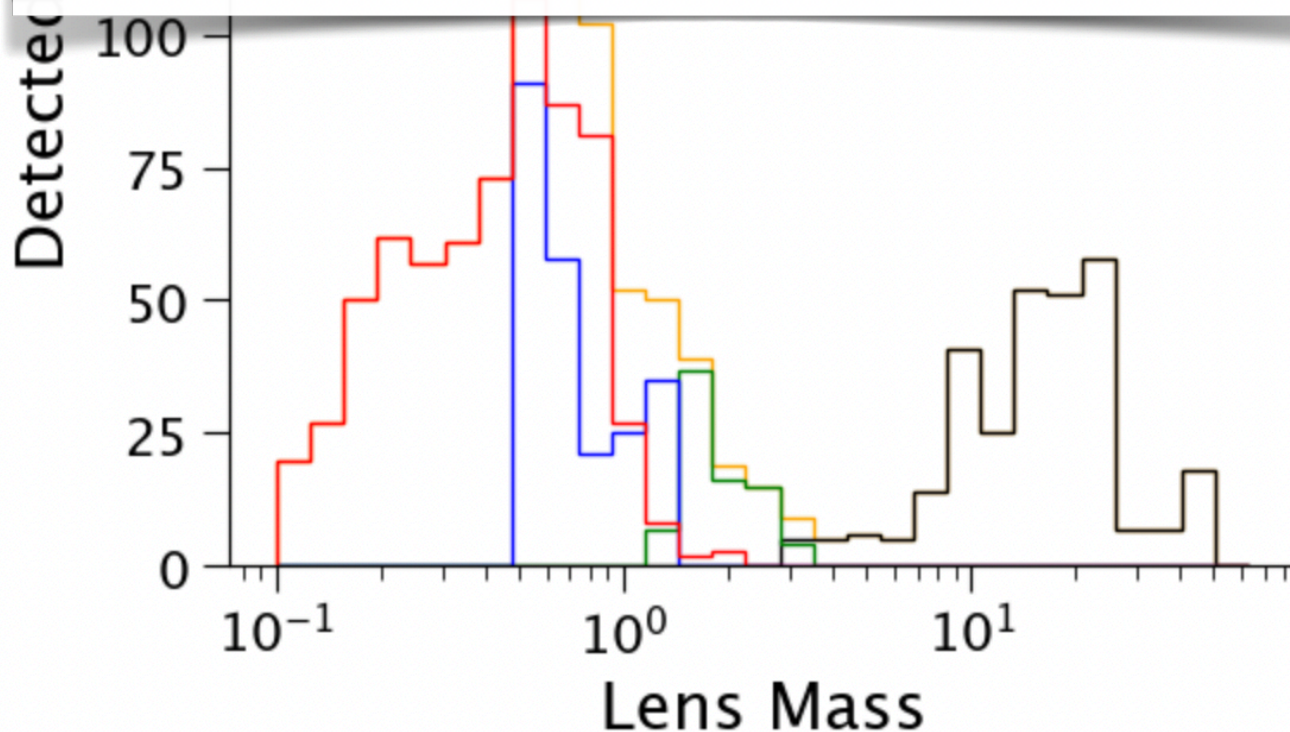
Roman's GBTDS is sensitive to binary systems in microlensing as well.

Lens Type	Single	Binary Lens	Binary Source	Binary Lens + Binary Source
Black Holes	88	14	33	4
Neutron Stars	22	0	16	0
White Dwarfs	29	46	9	25
Stars	172	50	72	39

In Progress:
Run PopSyCLE+COSMIC binary evolution.
Estimate classification uncertainty.

Resulting mass function of detectable events.

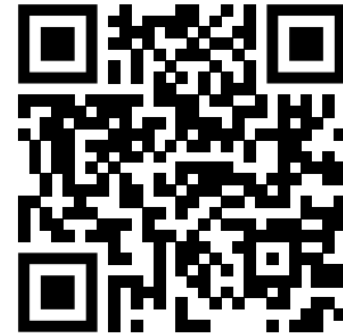
What follow-up do we need to confidently separate stars from WDs and NSs?



Raw (not completeness corrected).

Roman Science Collaboration

You are invited!



RSC Membership Benefits

Communication Tools

Slack Channels
Mailing Lists
Wiki
Calendar
GitHub

Science Groups

Exoplanets and Solar System
Milky Way and Stellar Astrophysics
Nearby Galaxies
Galaxy and Quasar Evolution
Cosmology
Explosive Transients

Events

Project Updates
Annual RSC Workshop
Hackathons
Workshops
(and more ... your idea here)

Code of Conduct

Publication Policy

Projects

Browsable List of Projects
(can request to join)
Project Teams Control Membership
Overlapping Projects Allowed

Black Holes

in the Milky Way with Roman

Team

Current μ Lab Members: **Macy Huston**, Charles-Antoine Claveau, Natasha Abrams, **Hannah Gulick**, Caitlin Begbie, Sage Remulla, Tianlin Lao, Ariana Abel, Jeff Chen, Madelyn Rahimi

Former μ Lab Members: **Dex Bhadra**, **Casey Lam**, **Sean Terry**, Michael Medford, Evan Sinukoff, Matt Hosek, Abby Schleich, Anette Brecko, Hunter Harling, Nijaid Arredondo, Sam Rose, Fatima Abdurrahman, Haynes Stephens, Shrihan Agarwal

and **RGES-PIT** and many more collaborators...



HEISING-SIMONS
FOUNDATION



Ethan Tweedie Photography