Finding isolated stellar mass black holes with WFIRST

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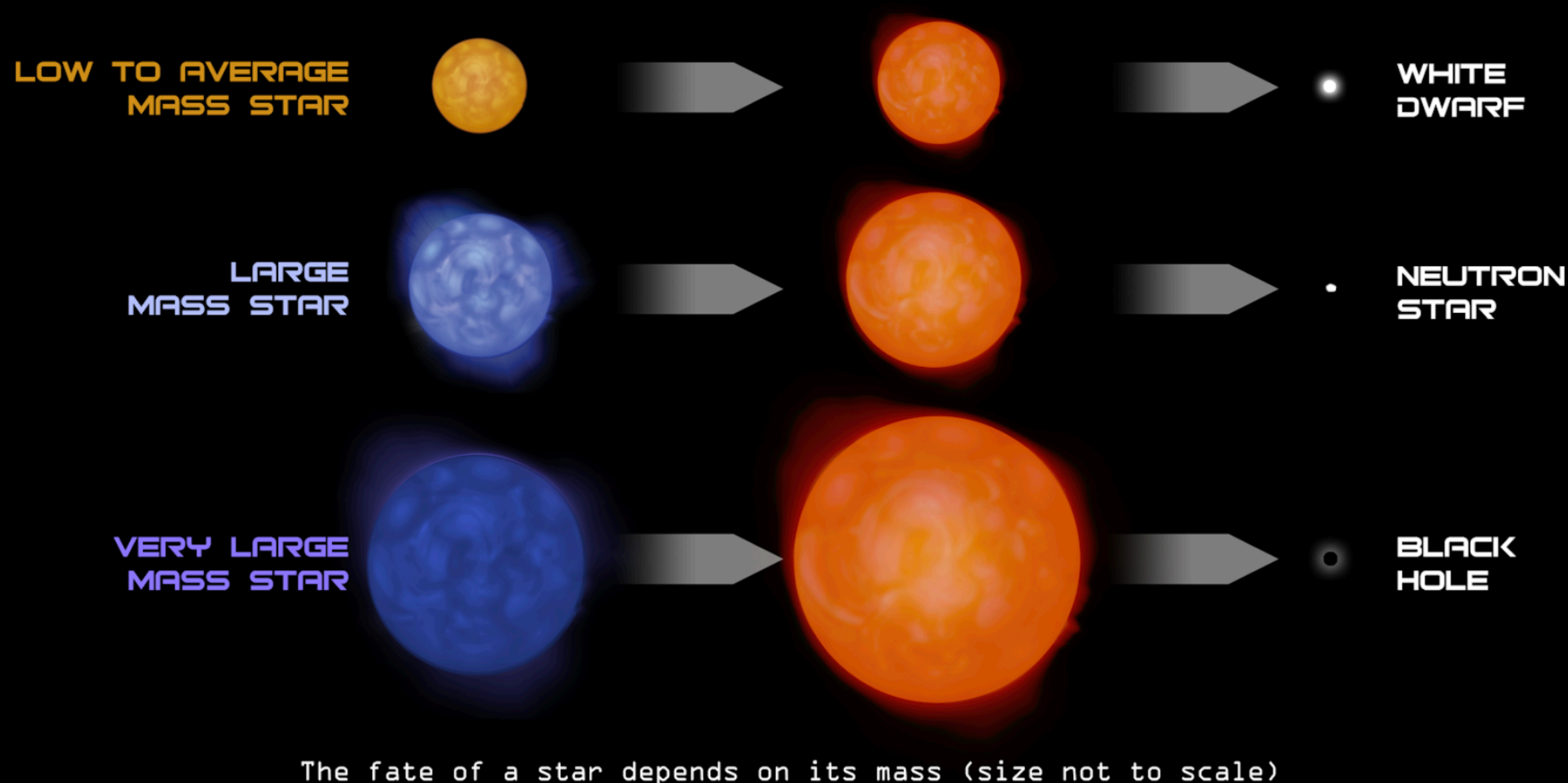
With Jessica Lu (UC Berkeley), Matthew Hosek Jr. (UCLA), William Dawson (LLNL), and Nathan Golovich (LLNL)

What happens when a star dies?

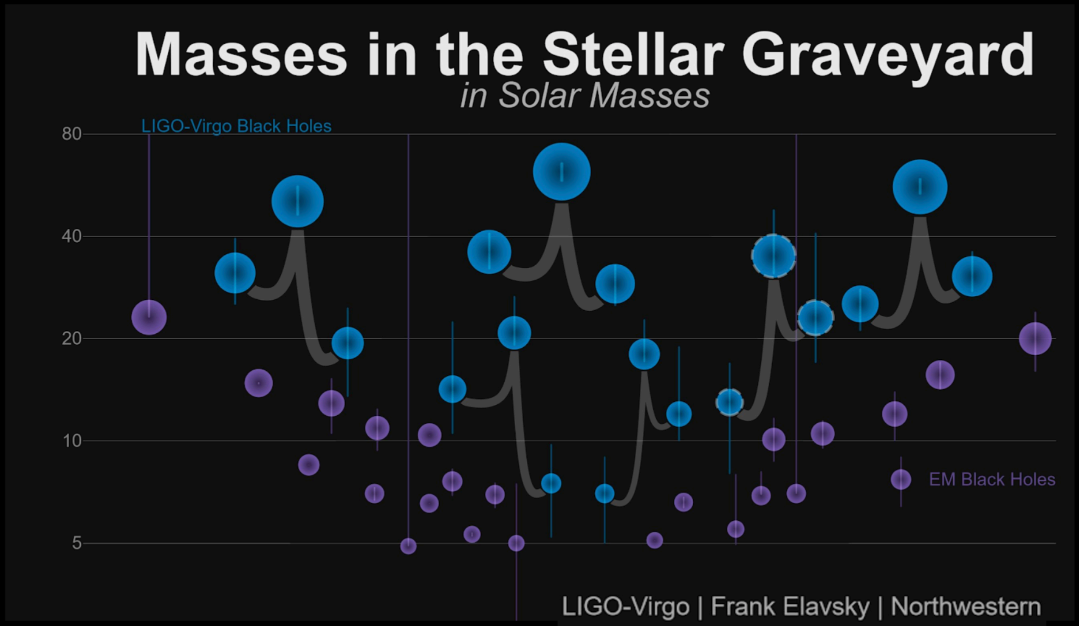


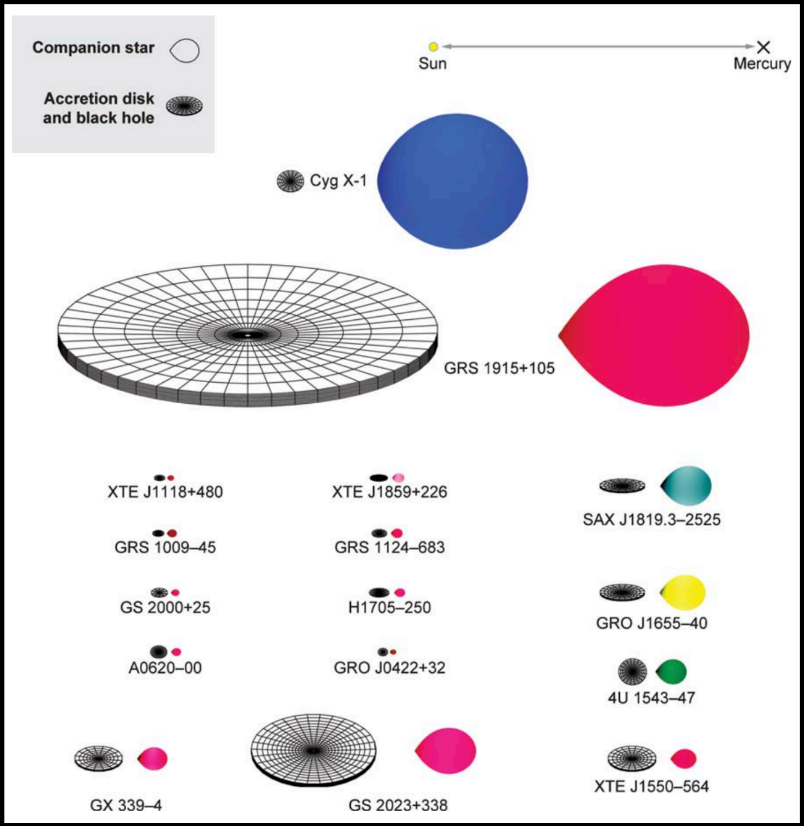
NASA/Chandra/Harvard

The fate of a star also depends on its metallicity, core structure, etc...
Stellar evolution is hard and not a solved problem

Where are the free-floating stellar mass black holes?

- Stellar mass BHs detected to date: ~2 dozen
- Predicted: 10^8 - 10^9 BHs in Milky Way (Agol & Kamionkowski 02, Timmes+96)

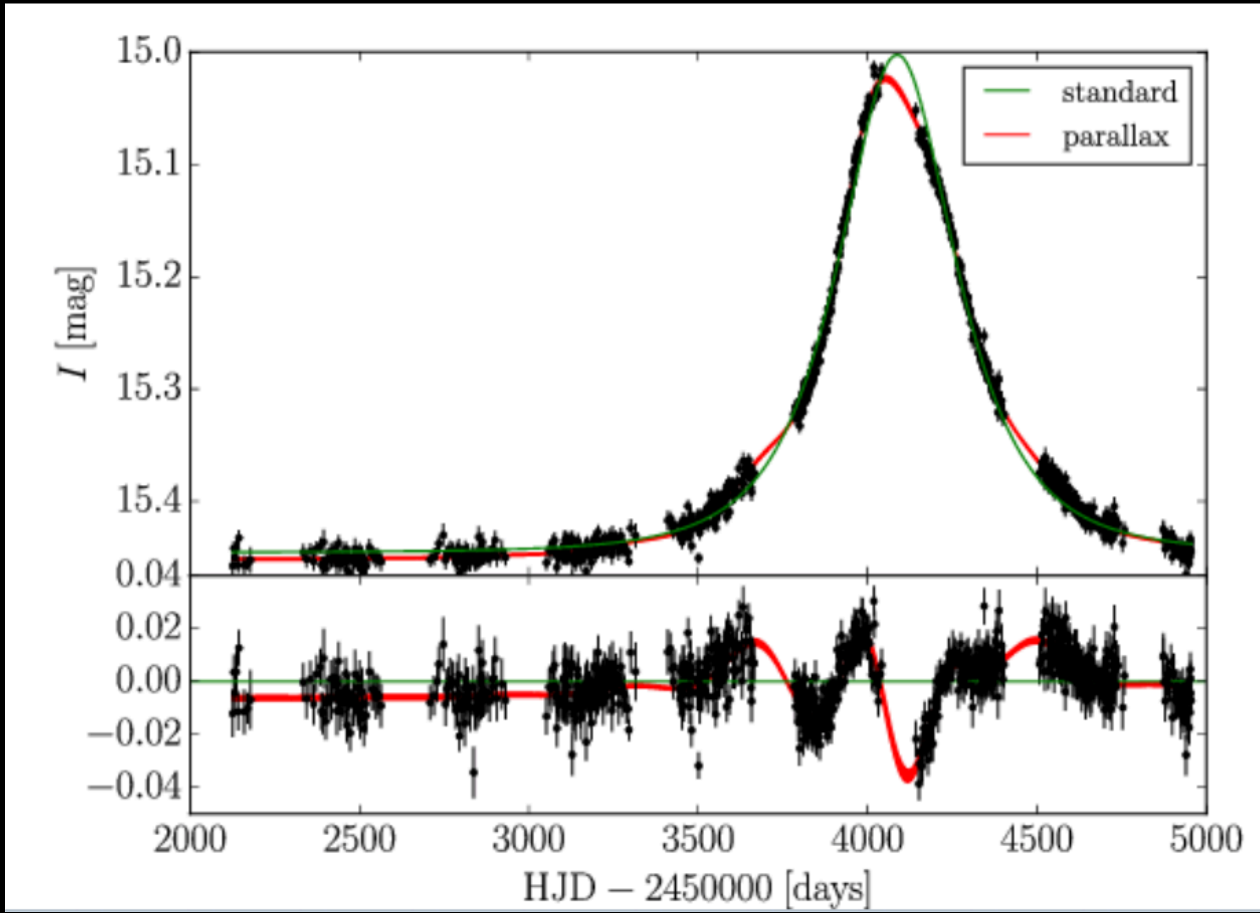




Remillard & McClintock 2006

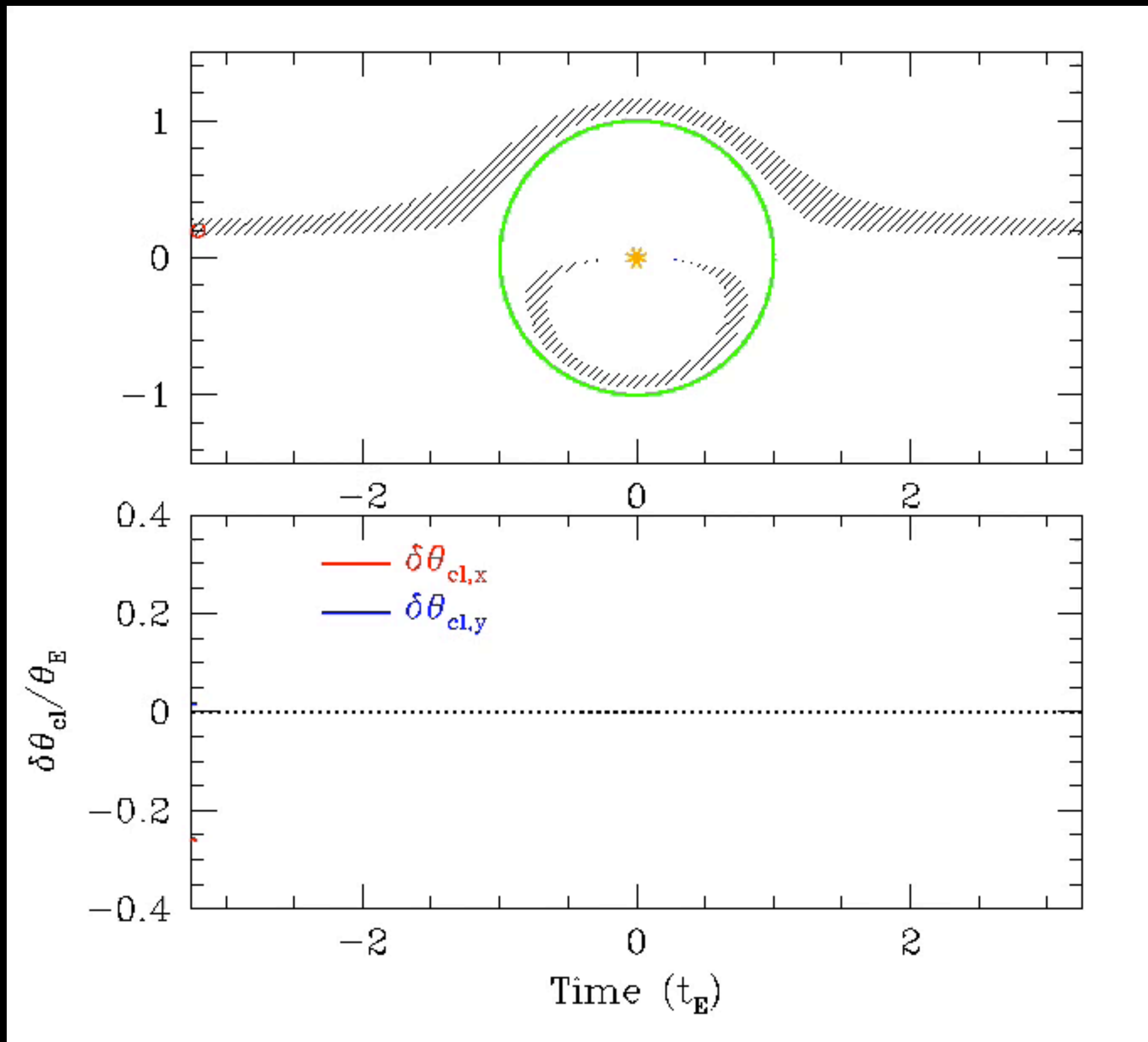
Photometric Microlensing

Microlens parallax: Earth moving around Sun produces asymmetry in light curve



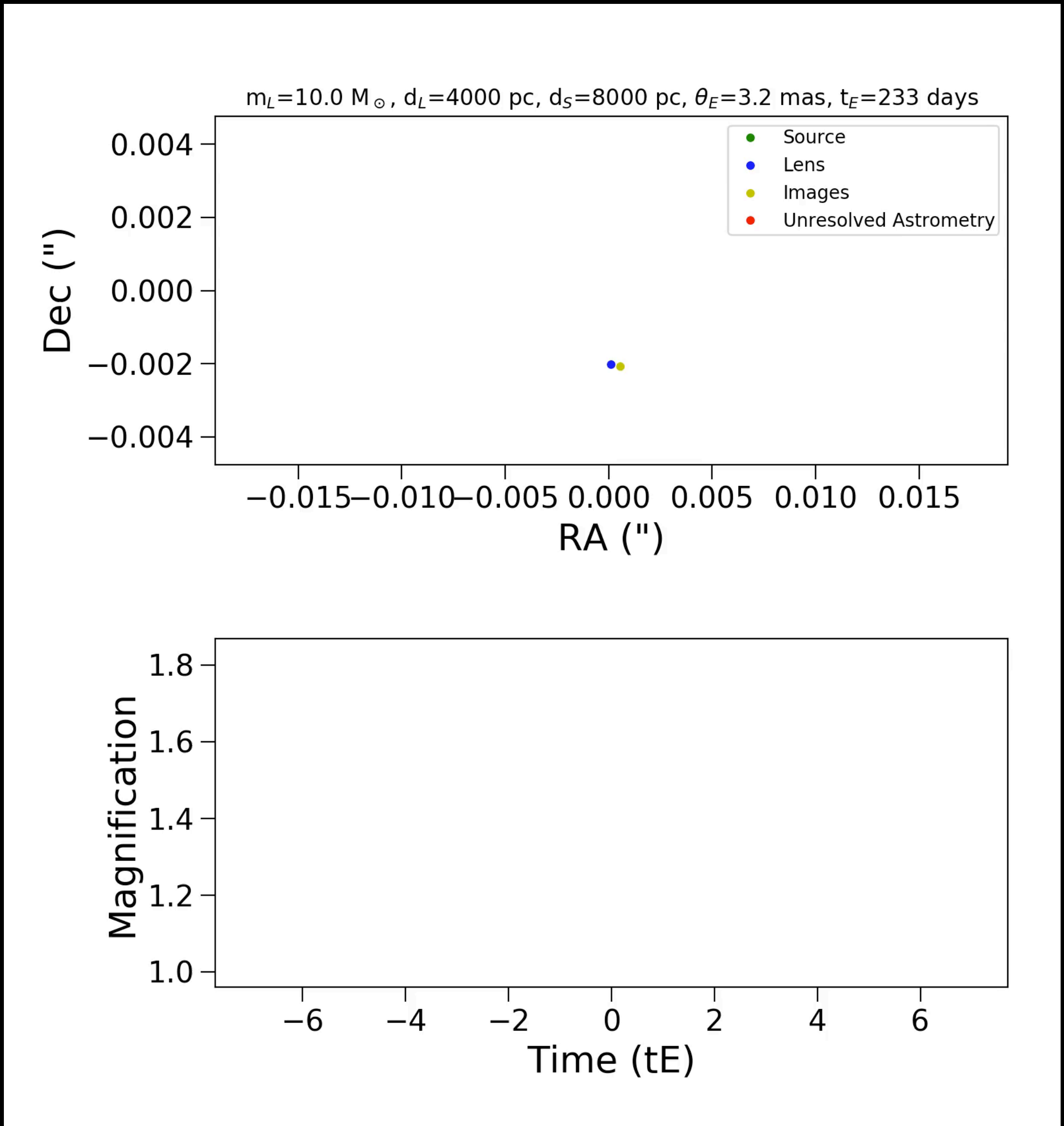
Wyrzykowski+16

Astrometric microlensing



B. S. Gaudi (OSU)

Astrometric microlensing



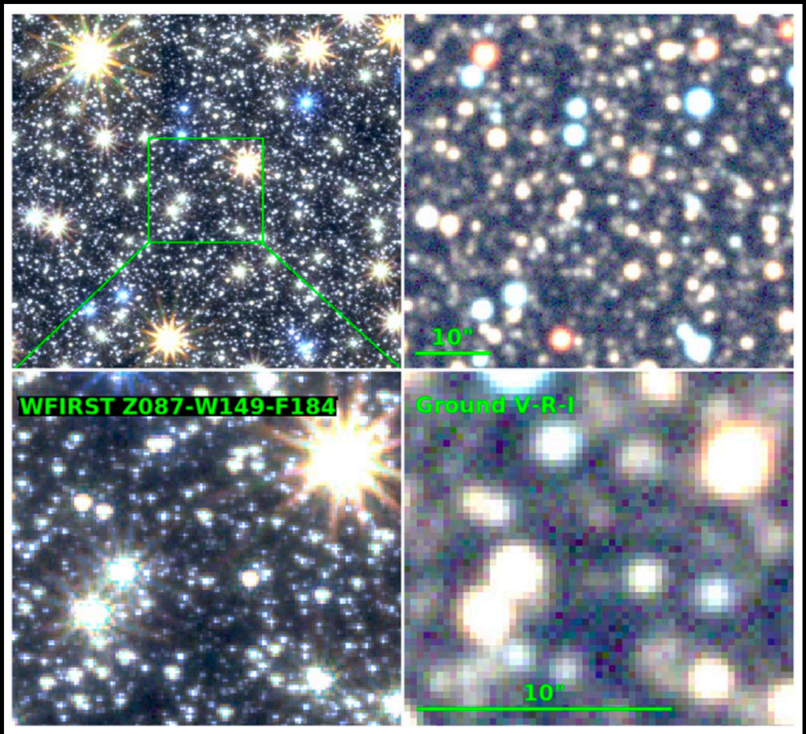
For 10 M$_\odot$ BH, max shift of 1.1 mas (c.f. 0.5 M$_\odot$ star, max shift of 0.25 mas)

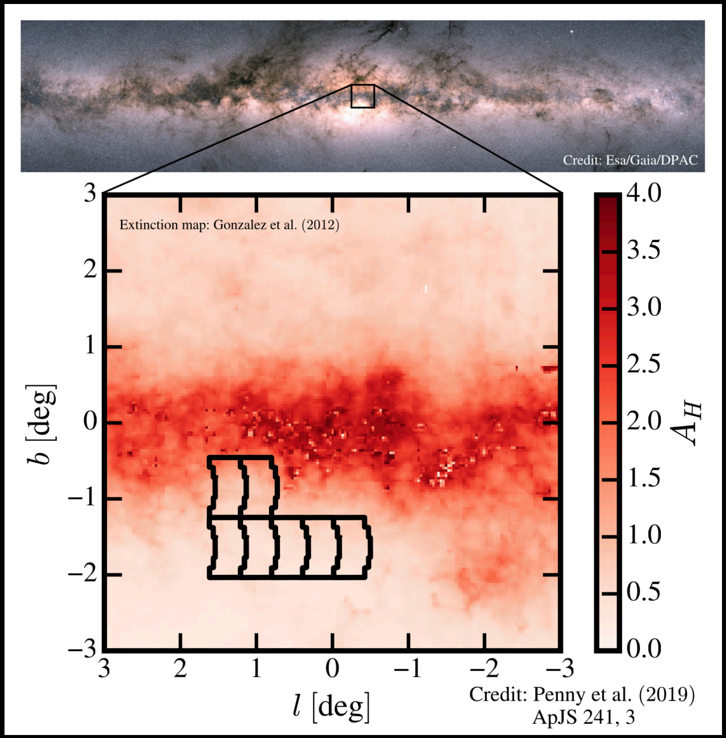
WFIRST astrometric precision: ~0.05 mas

Astrometry + Photometry → Lens mass

J. R. Lu (UC Berkeley)

How will WFIRST help find BHs?





Penny+19

Context	Estimated performance
Single-exposure precision	0.01 px; 1.1 mas
Typical guest-observer program (100 exposures of one field)	0.1 mas
Absolute astrometry accuracy	0.1 mas
Relative proper motions derived from High-Latitude Survey	25 μas yr^{-1}
Relative astrometry, Exoplanet MicroLensing Survey (per image)	1 mas
Relative astrometry, Exoplanet MicroLensing Survey (full survey)	3–10 μas
Spatial scanning, single scan	10 μas
Spatial scanning, multiple exposures	1 μas
Centering on diffraction spikes	10 μas

Sanderson+17

PopSyCLE (Population Synthesis for Compact object Lensing Events)

Besancon model (Robin+03, implementation Sharma+11)

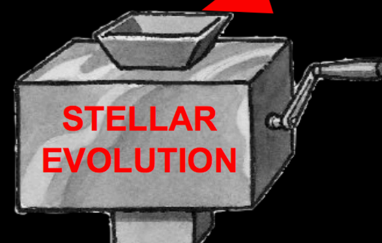
Stellar model of Milky Way

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

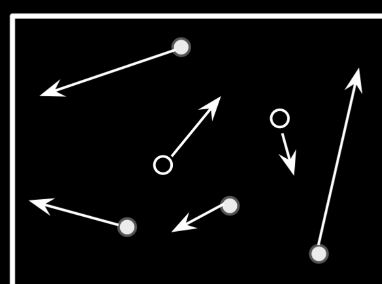
Select single-age subset of component

Stellar evolution: MIST models (Choi+16, Dotter 16, Paxton+11,13,15)

Initial-final mass relations: WD (Kalirai+08), BH/NS (Raithel+18, Sukhbold+16),

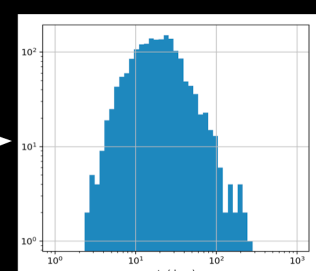


Compact objects with positions and velocities



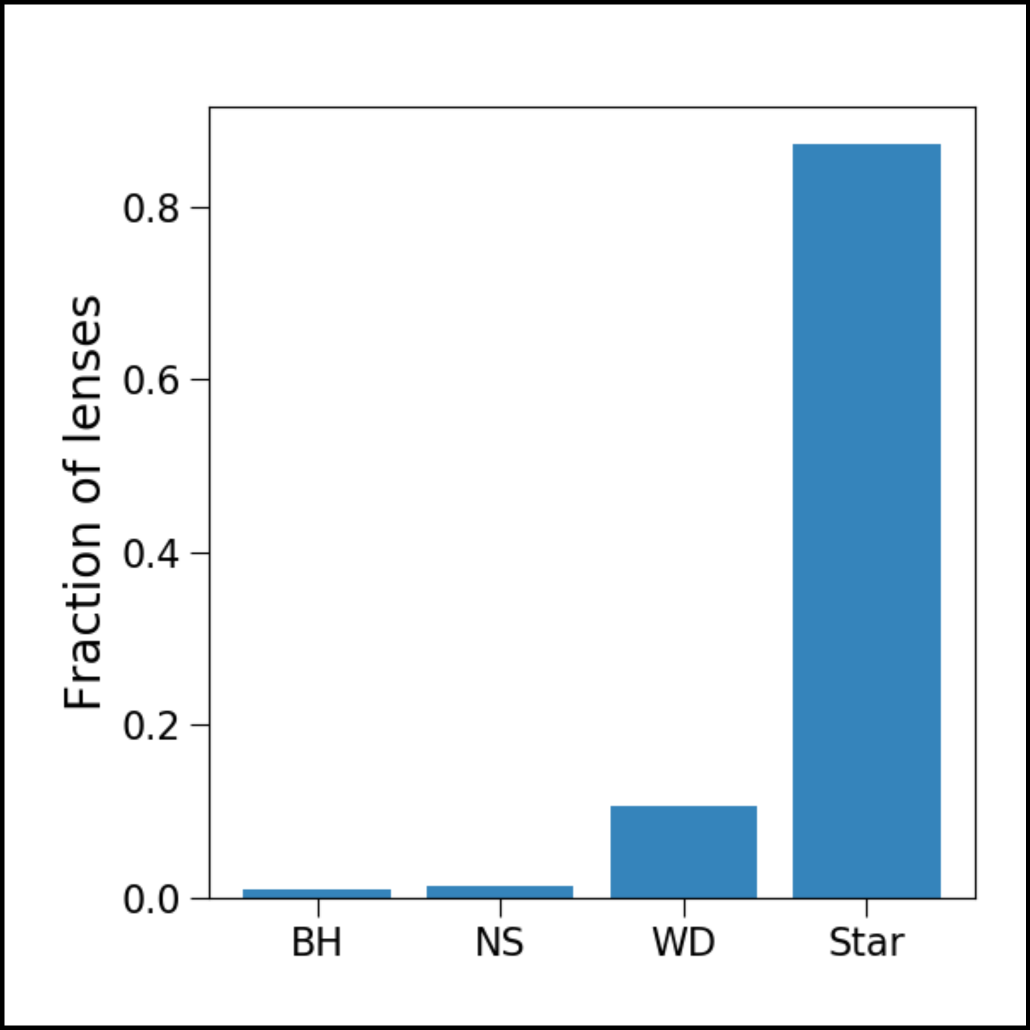
Simulated survey

Microlensing event parameters



NIR Extinction (Damineli+16)

How many lenses will be black holes?

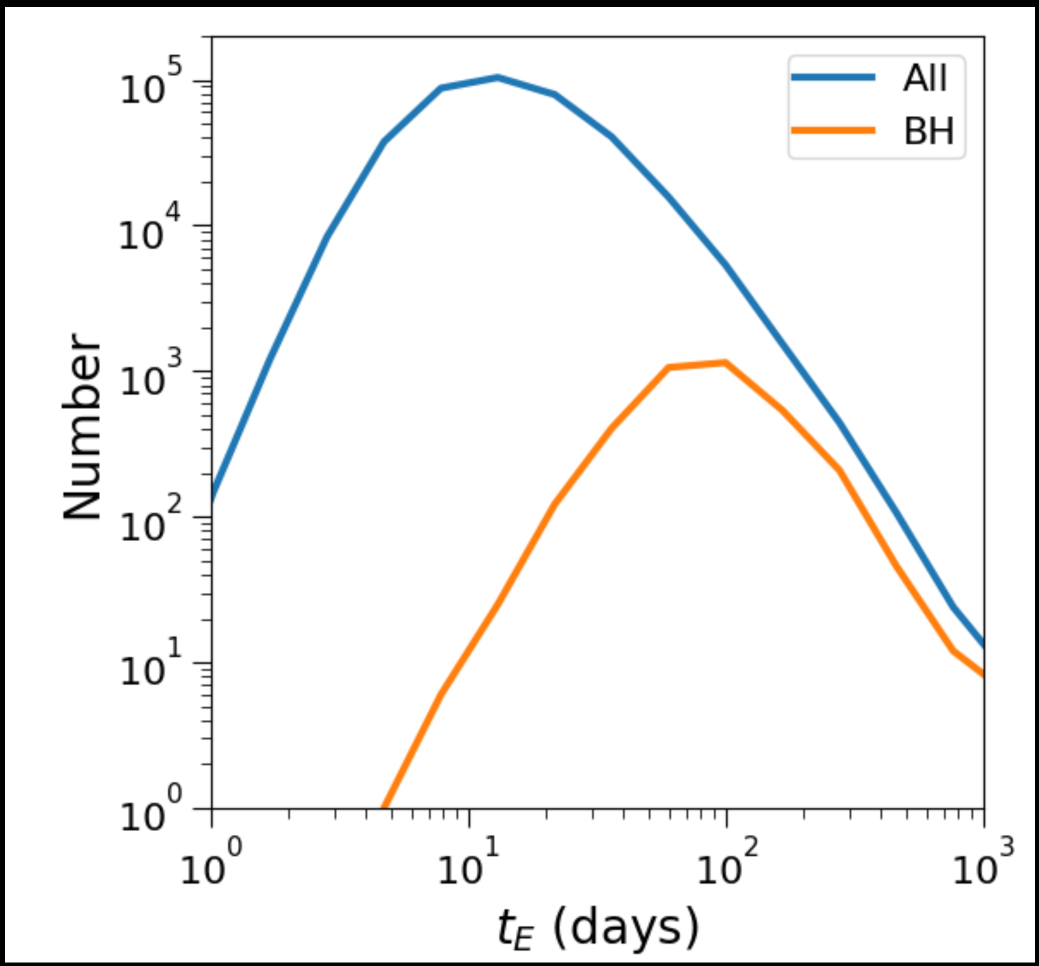


~0.1% of stellar objects are BHs

~1% of lenses are BHs

(Intrinsic) Einstein crossing time distribution

y-axis scaling is arbitrary

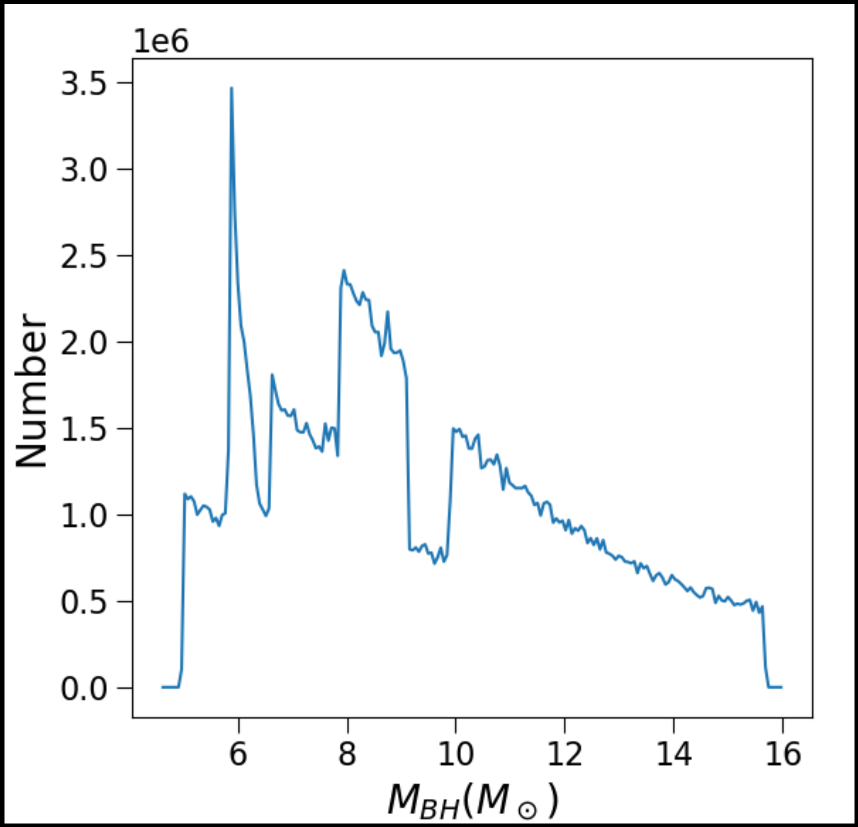


~33% of long (t_E > 100 day) events are BH

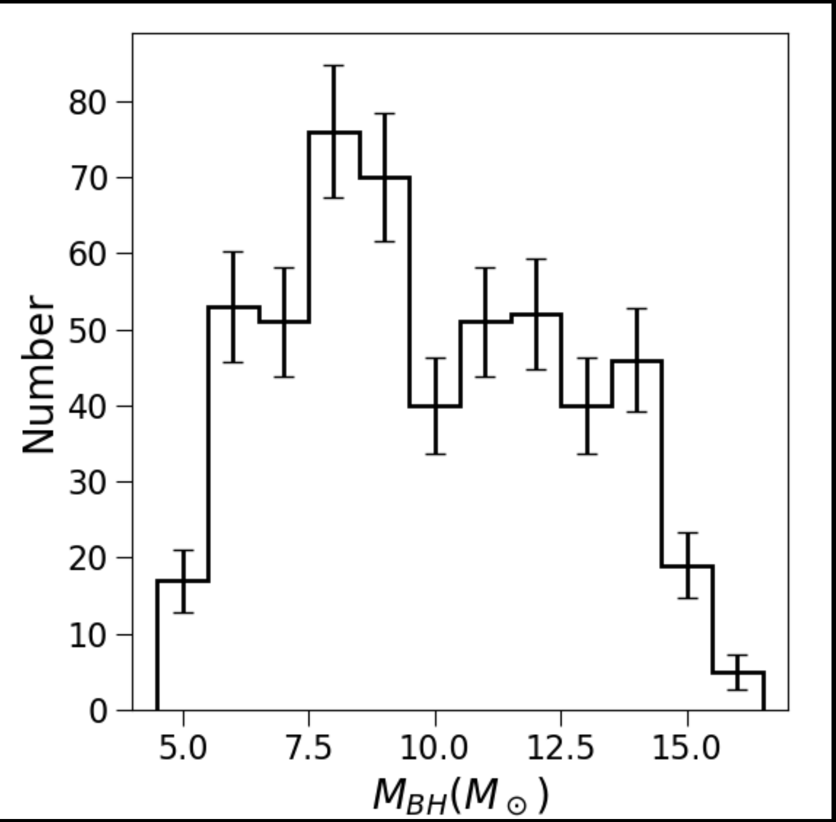
$$t_E \propto \sqrt{M_L}$$

O(100-1000) of BHs and NSs can have masses measured!

WFIRST can probe the Milky Way BH mass function

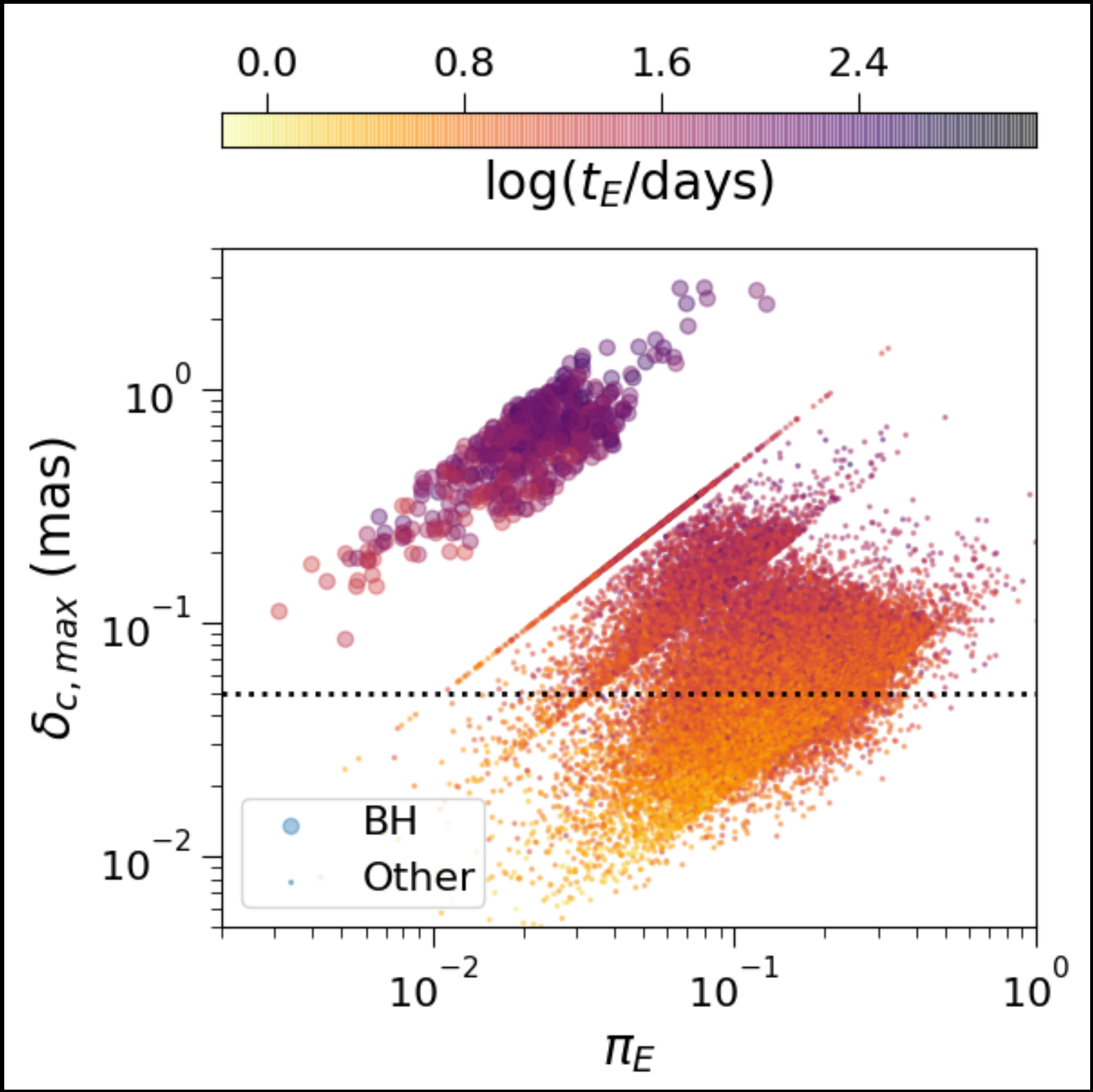


Underlying distribution (SFH + IFMR + IMF)



As detected by microlensing

Use microlens parallax + astrometric shift to confirm BH lens candidates

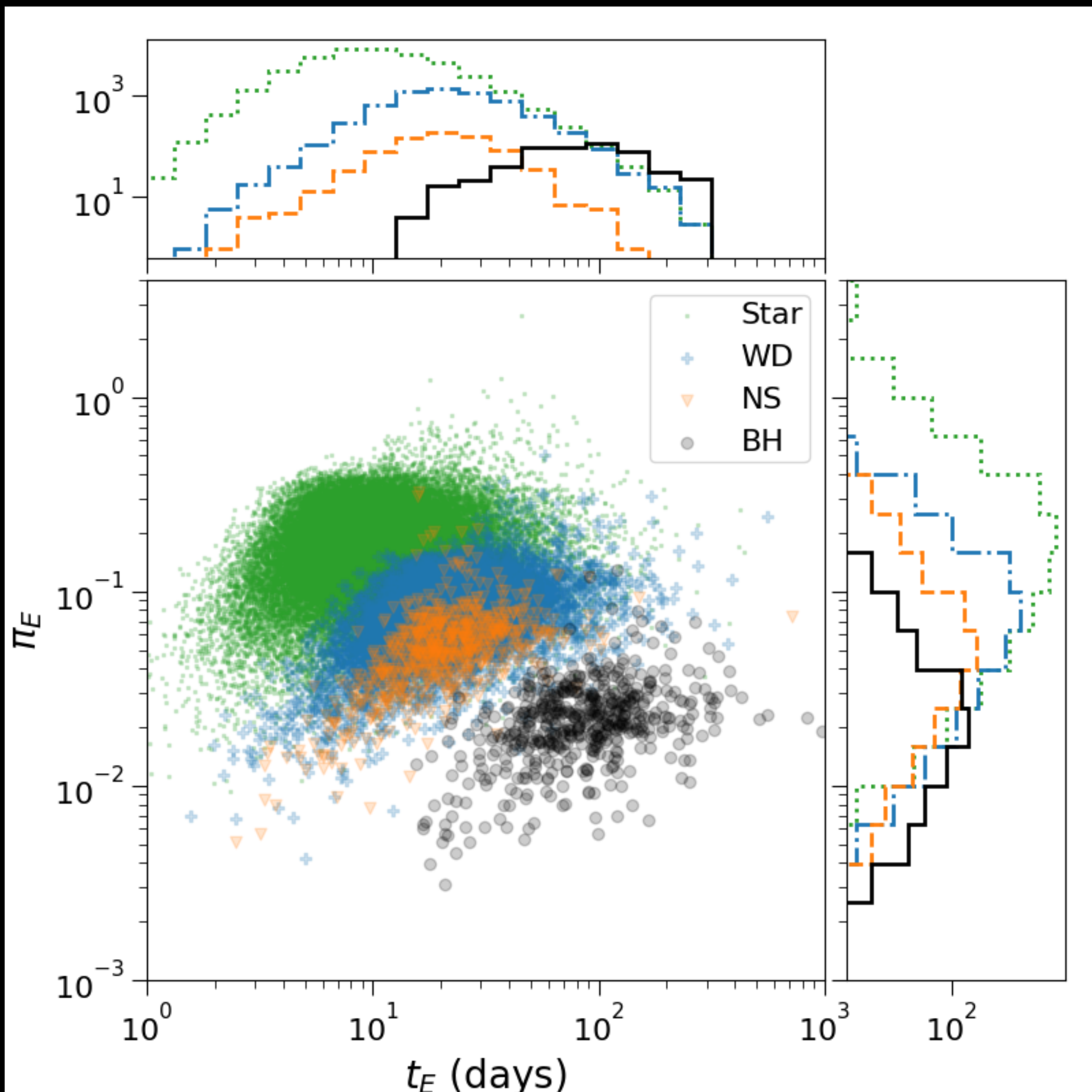


$$t_E \propto \sqrt{M_L}$$

$$\pi_E \propto \frac{1}{\sqrt{M_L}}$$

$$\delta_{c,max} \propto \sqrt{M_L}$$

Use Einstein crossing time + microlens parallax to confirm BH lens candidates



$$t_E \propto \sqrt{M_L}$$

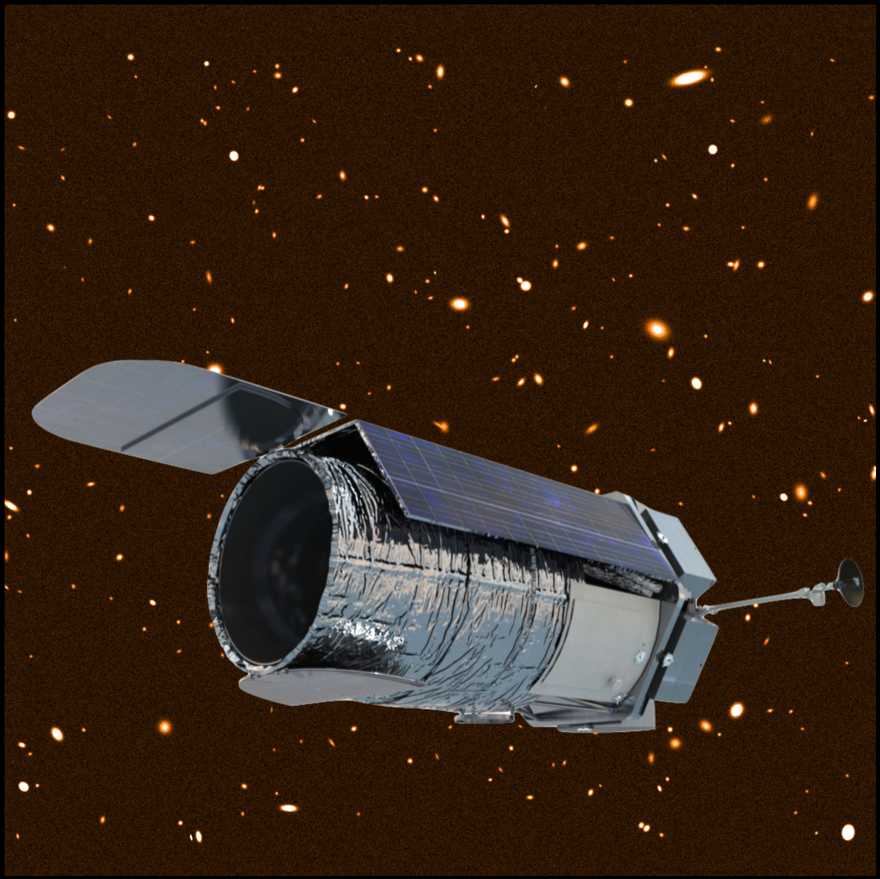
$$\pi_E \propto \frac{1}{\sqrt{M_L}}$$

What can you do with a large sample of BHs?

- Number of BHs in the Milky Way
- Construct the present-day BH mass function
    - Information about IMF, IFMR, SFH
- Probe BH formation channels and binary fraction
    - Stellar binaries? Two isolated BHs? Both? Neither?
- Constrain BH spatial and velocity distributions
    - Centrally concentrated due to dynamical friction? Supernova kicks?

Summary

- WFIRST microlensing survey will yield O(100-1000) BH masses (orders of magnitude more than possible with individual follow-up)
- Enabled by simultaneous photometry + astrometry
- Milky Way BH mass function and more!



wfirst.ipac.caltech.edu

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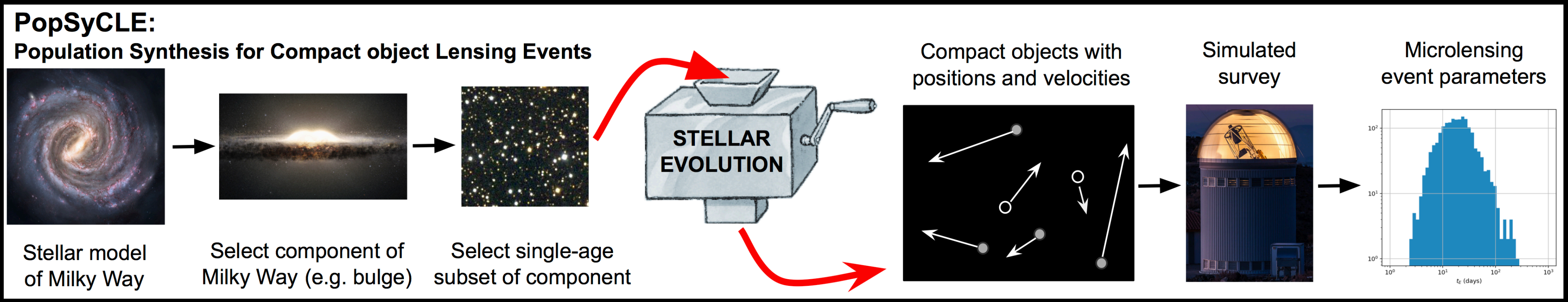
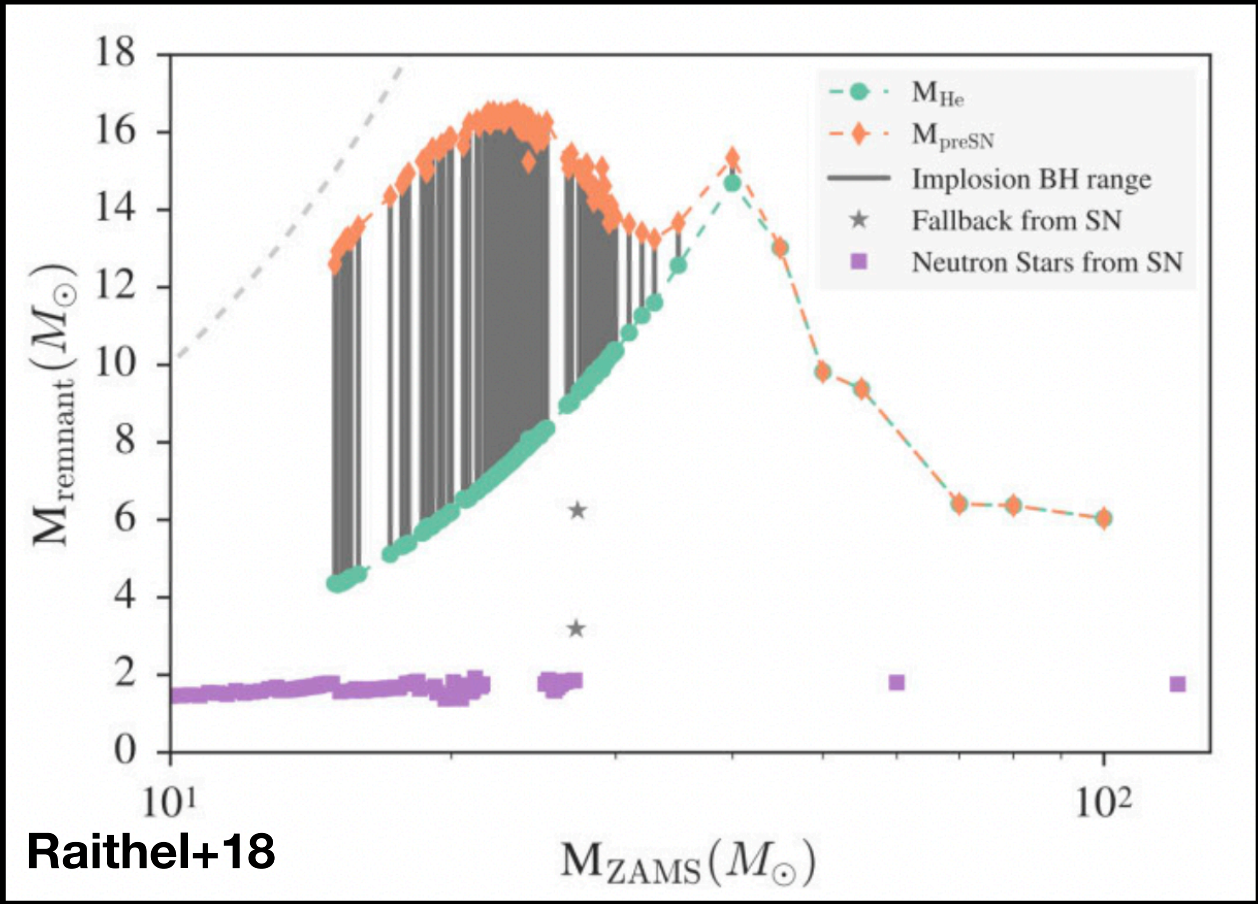
Extra Slides

PopSyCLE (Population Synthesis for Compact object Lensing Events)



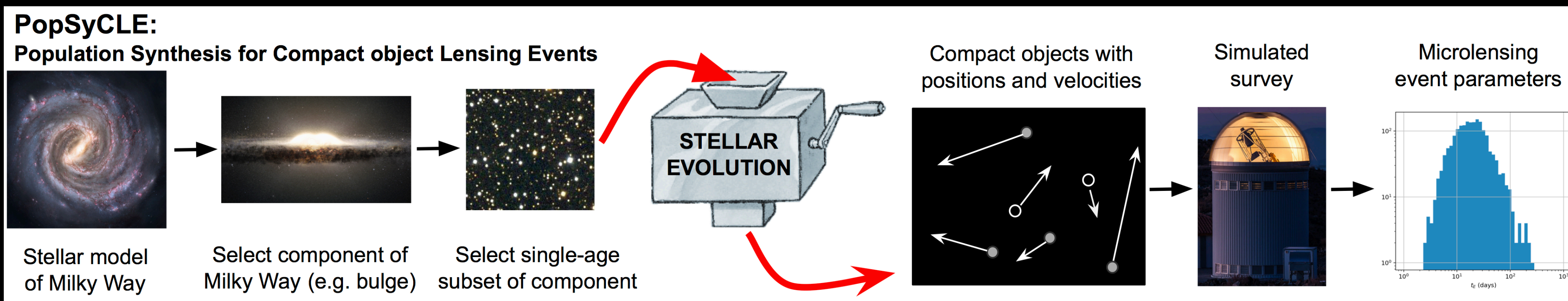
- Stellar model of the Milky Way: Galaxia (Sharma+11)
  - Implements Besancon model (Robin+03)
  - Stellar evolution: MIST (Choi+16, Dotter 16, Paxton+11,13,15)
- Initial-final mass relations for compact objects
  - BHs and NS: Raithel+18, Sukhbold+16
  - WDs: Kalirai+08
- Extinction law in the NIR (Damineli+16)

Initial-final mass relation, black holes + neutron stars

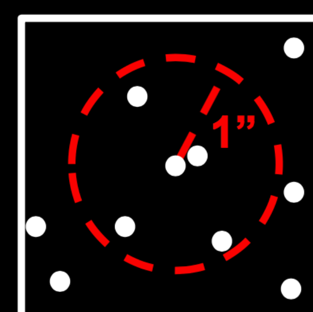


BH IFMR implemented probabilistically in PopSyCLE

PopSyCLE (Population Synthesis for Compact object Lensing Events)



- Event finding calculation
  - Find close approaches within survey window and calculate microlensing parameters
  - Estimate blending from neighbors within seeing disk
- Impose observational cuts/constraints
  - Event duration
  - Magnitude (of source + lens + neighbor stars)
  - Magnification amplitude
  - Blending



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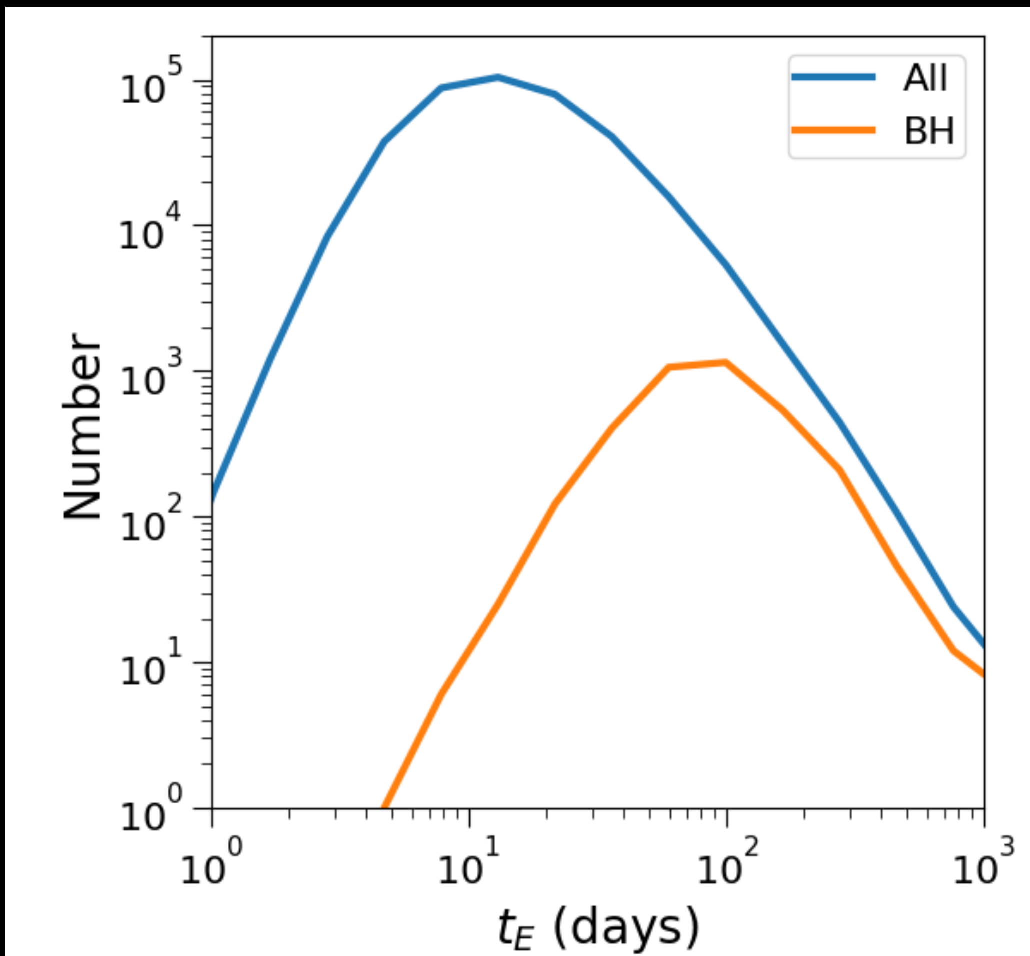

$$t_E \propto \sqrt{M_L}$$

O(100-1000) of BHs and NSs can have masses measured!

Assumptions:

1) 1000 day continuous survey
2) H < 26 (baseline)
3) ΔH > 0.1 mag
4) source flux fraction > 0.1
5) tE < 300 days