

Photometric Searches for Binaries & Multi-messenger Prospects

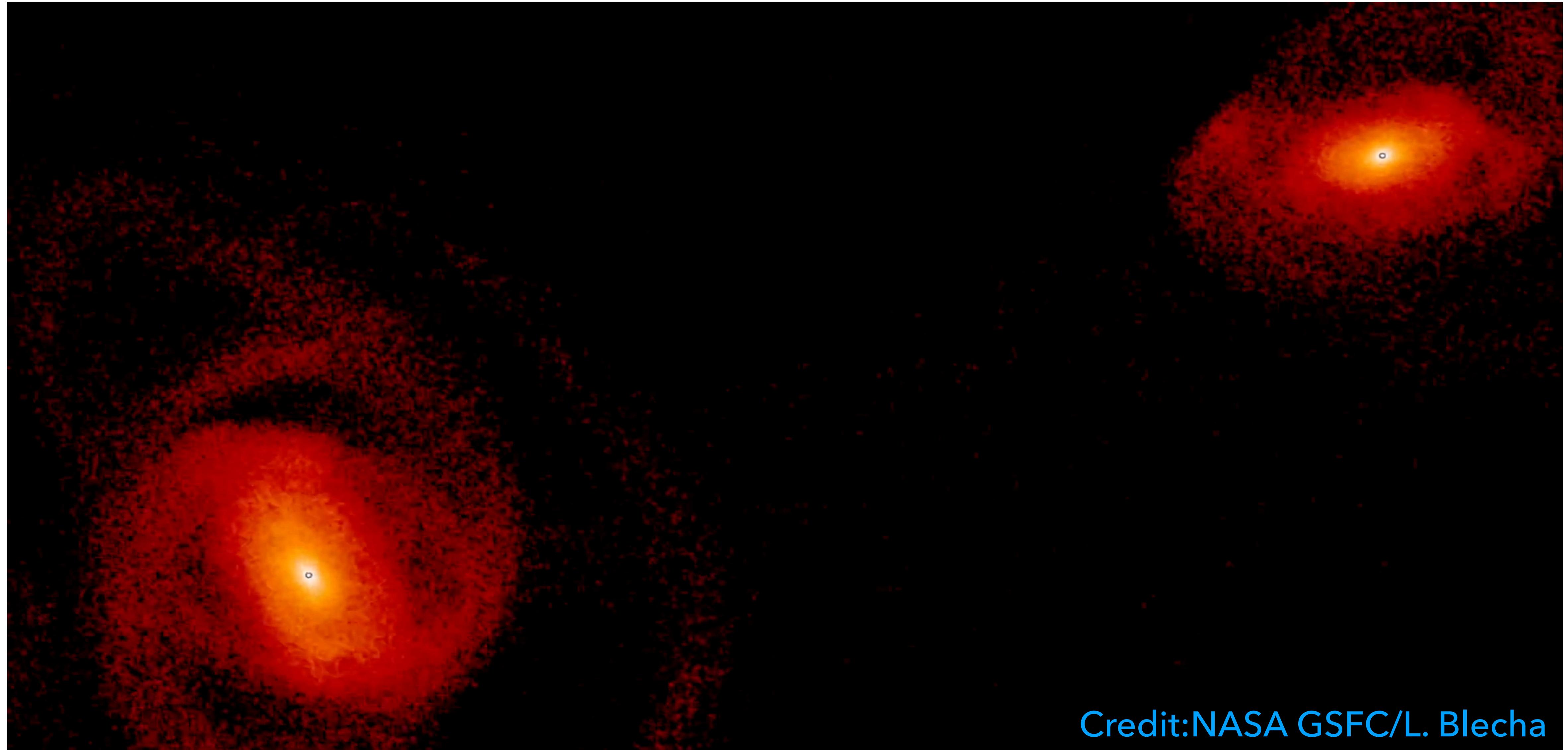
Maria Charisi
Washington State University
IA-FORTH/University of Crete



VIPER Summer School on GWs

July 12 2024

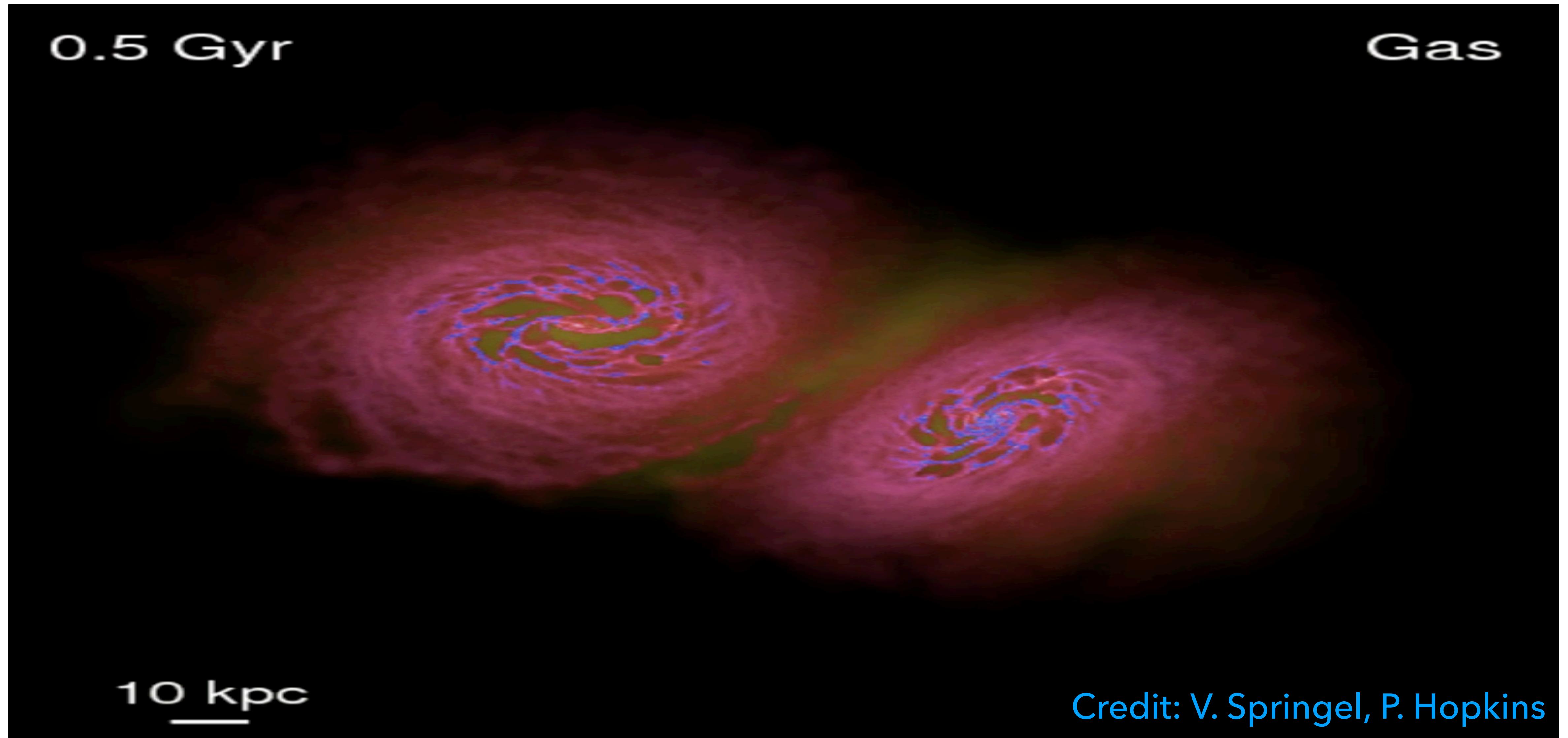
Supermassive Black Hole Binaries



Credit:NASA GSFC/L. Blecha

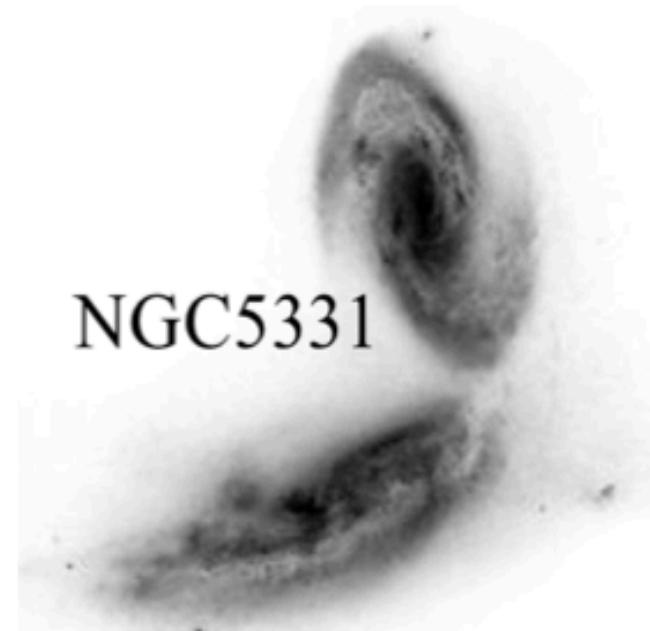
Binaries should be common as a result of frequent galaxy mergers.

Gas-rich Galaxy Mergers



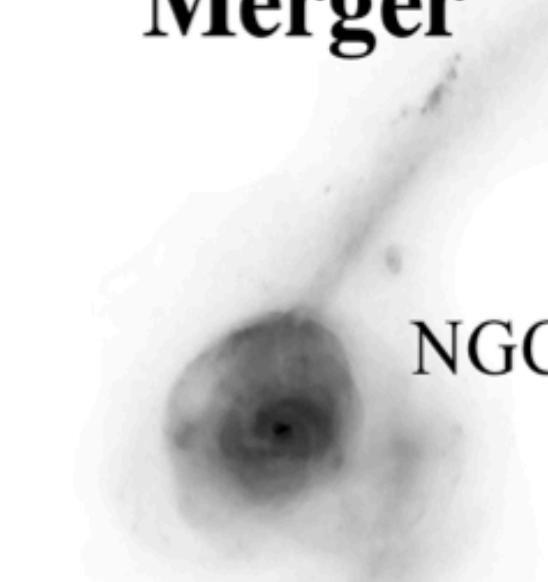
Binaries should produce bright electromagnetic emission.

Galaxy Merger



NGC 5331

Stellar Core Merger



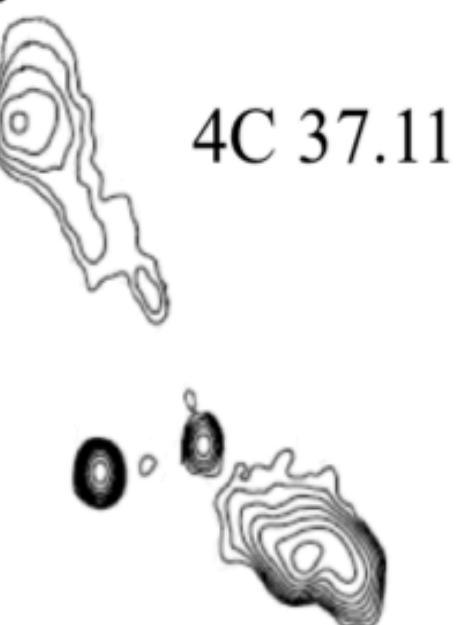
NGC 17

Dynamical friction drives massive objects to central positions

The Lifecycle of Binary Supermassive Black Holes

Dynamical friction less efficient as SMBHs form a binary.

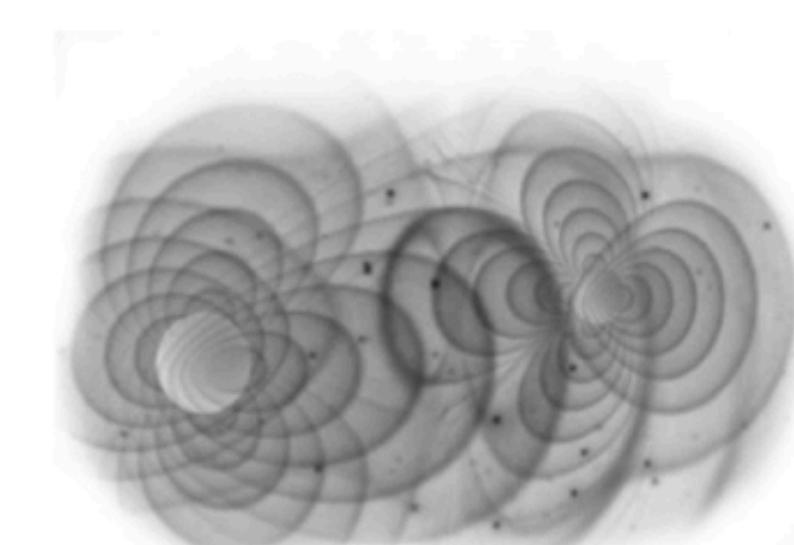
Binary Formation



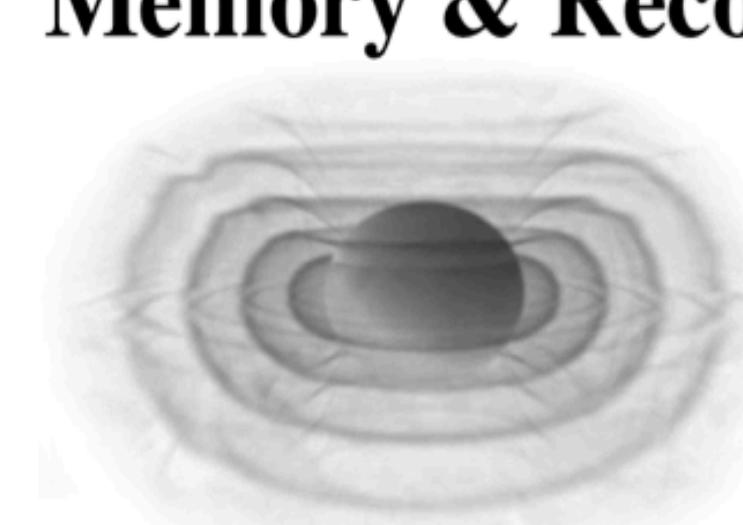
4C 37.11

Stellar and gas interactions may dominate binary inspiral?

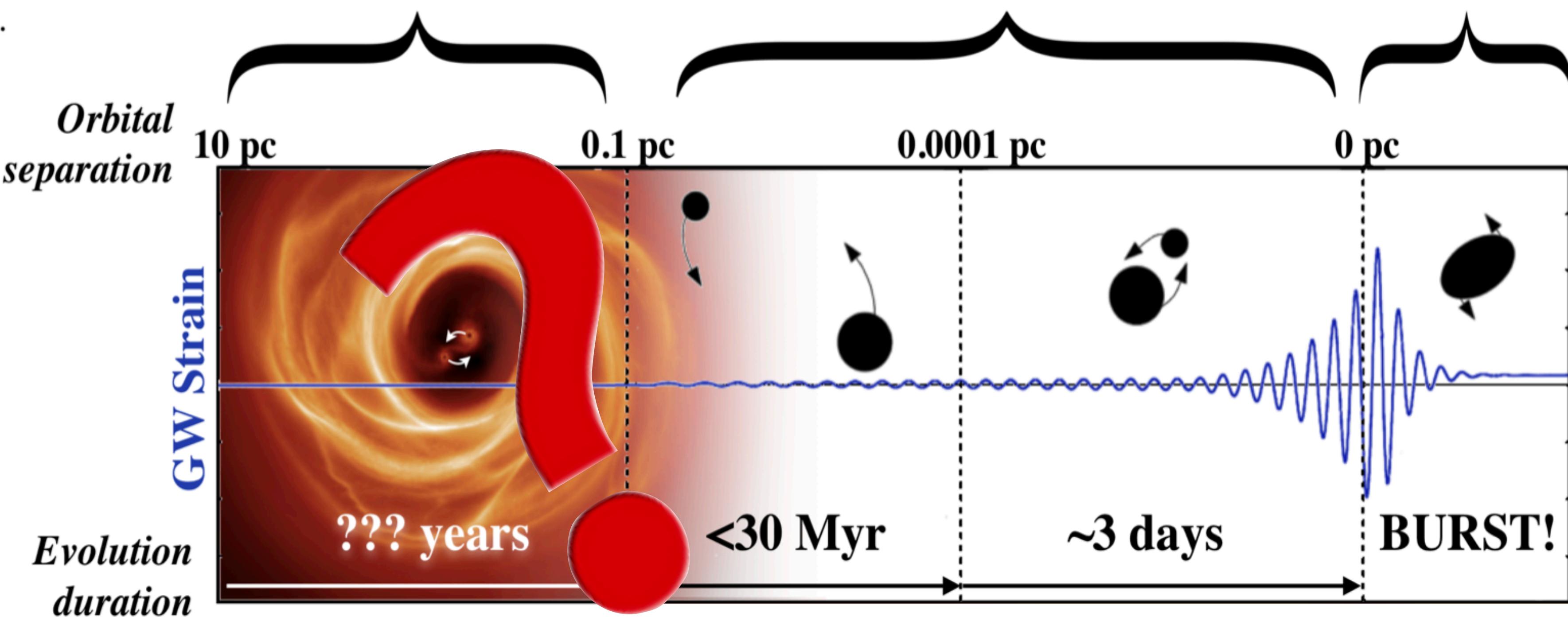
Continuous GWs



Coalescence, Memory & Recoil

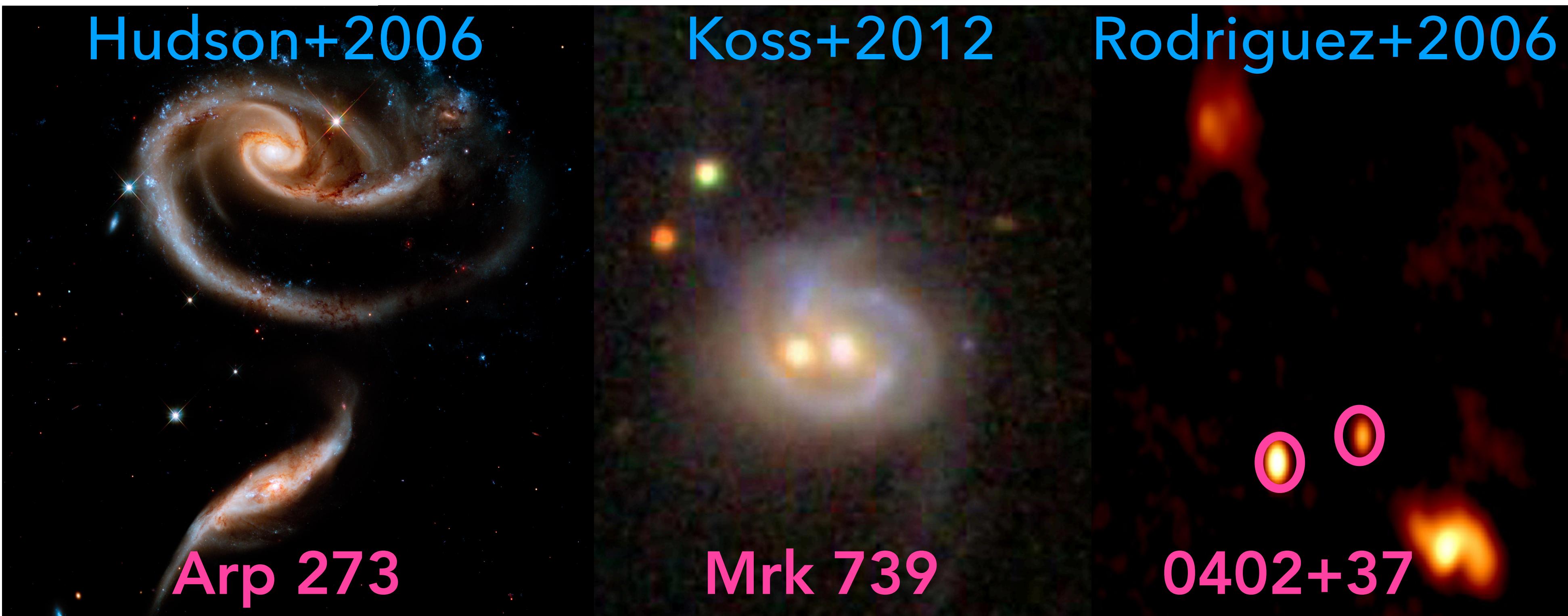


Post-coalescence system may experience gravitational recoil.



See review: Burke-Spolaor ^{incl.} Charisi+2019

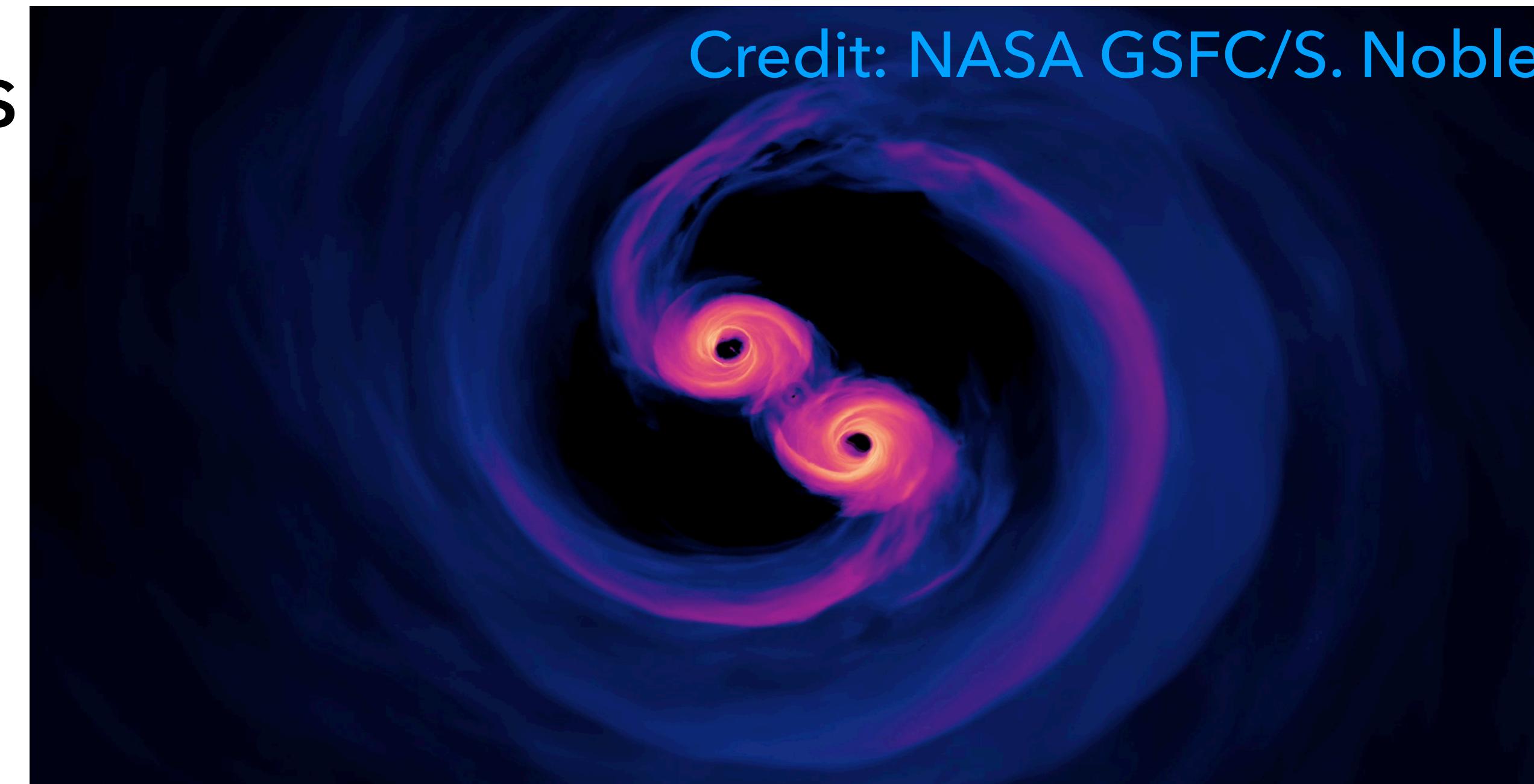
Observations



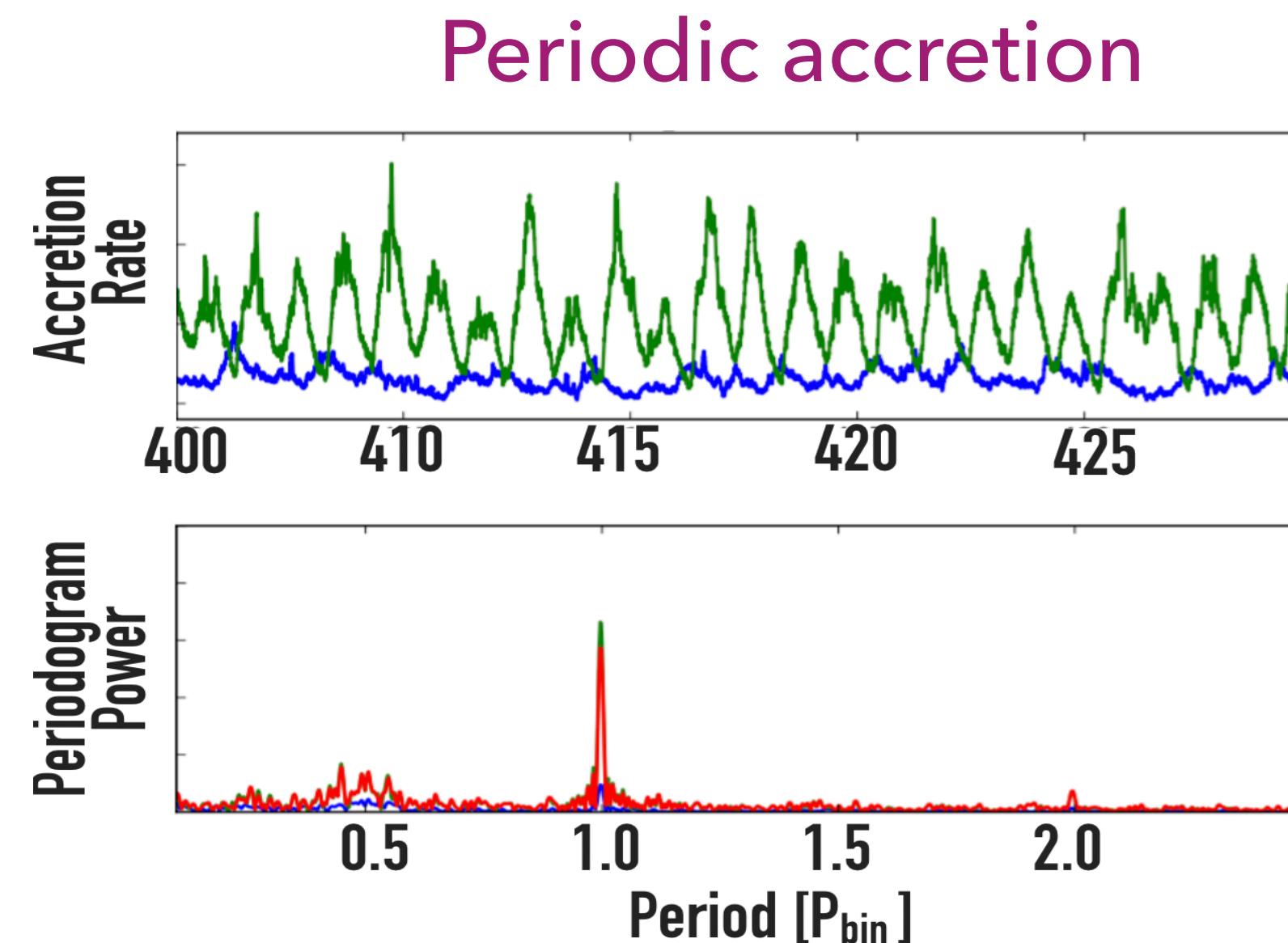
See review: De Rosa, incl. **Charisi+2019**

Quasars with periodic variability

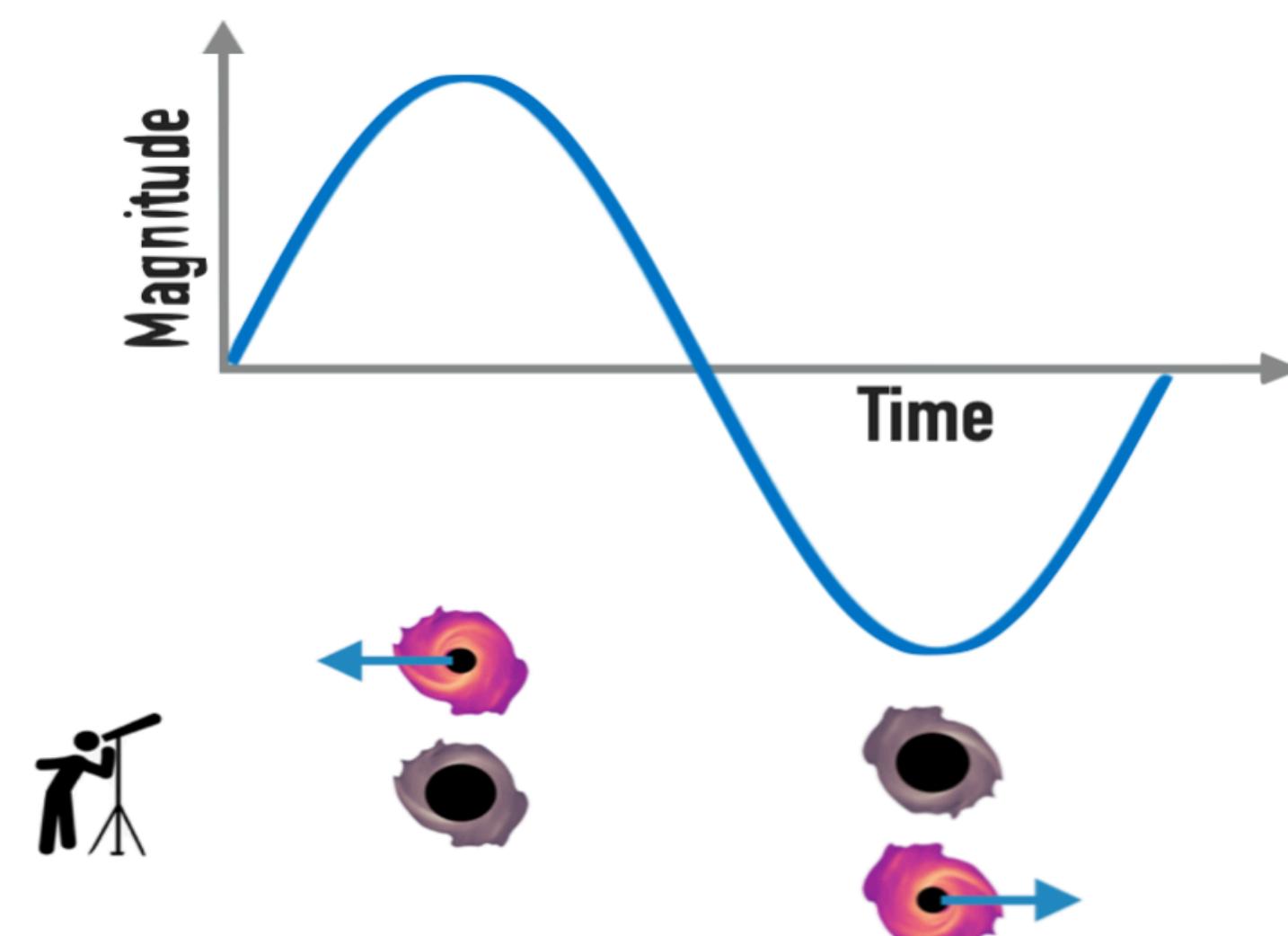
Some quasars
are activated
by mergers
→ prime
hosts for two
SMBHs.



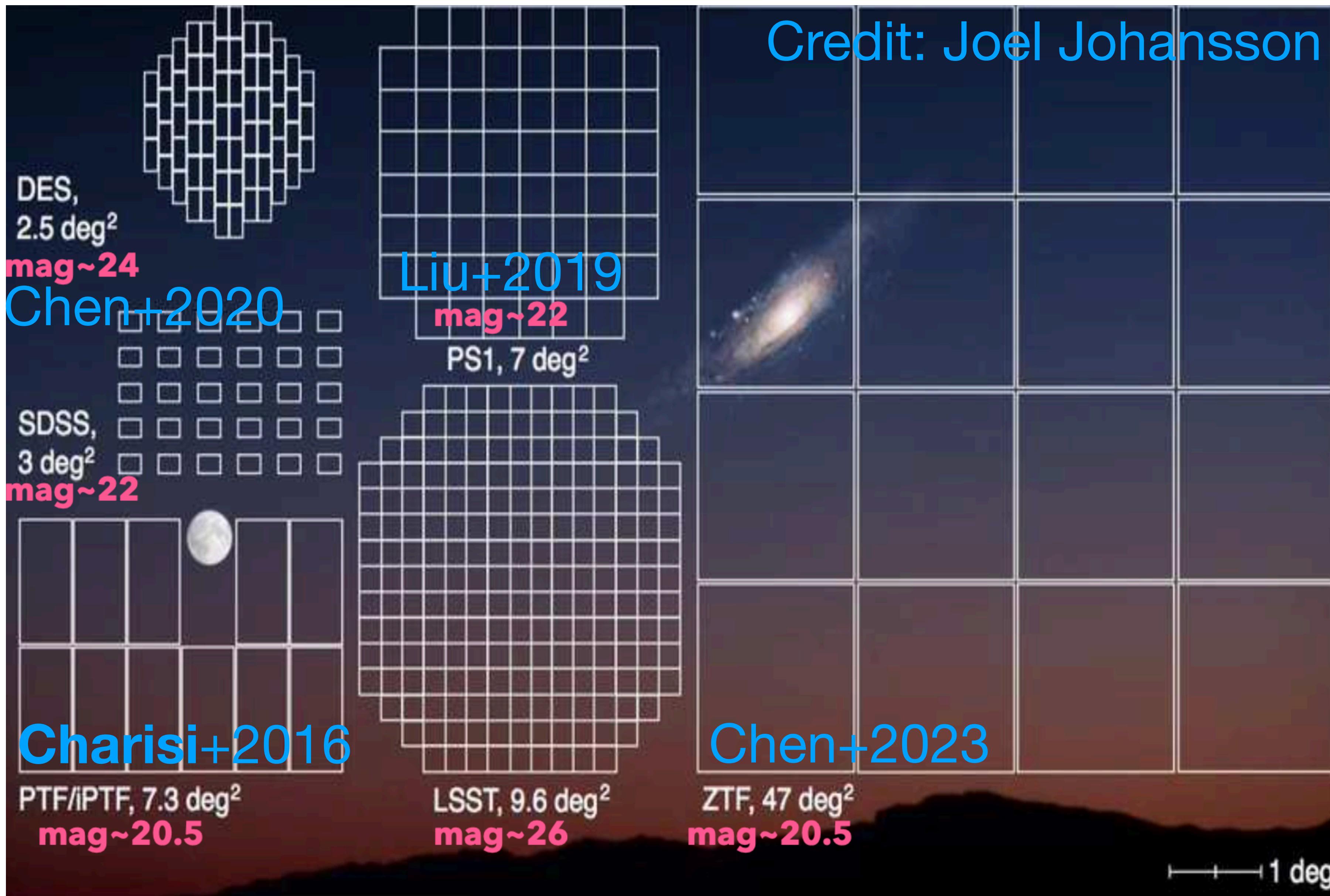
Binaries
produce
quasar-like
luminosities,
periodically
modulated.



Relativistic Doppler boost

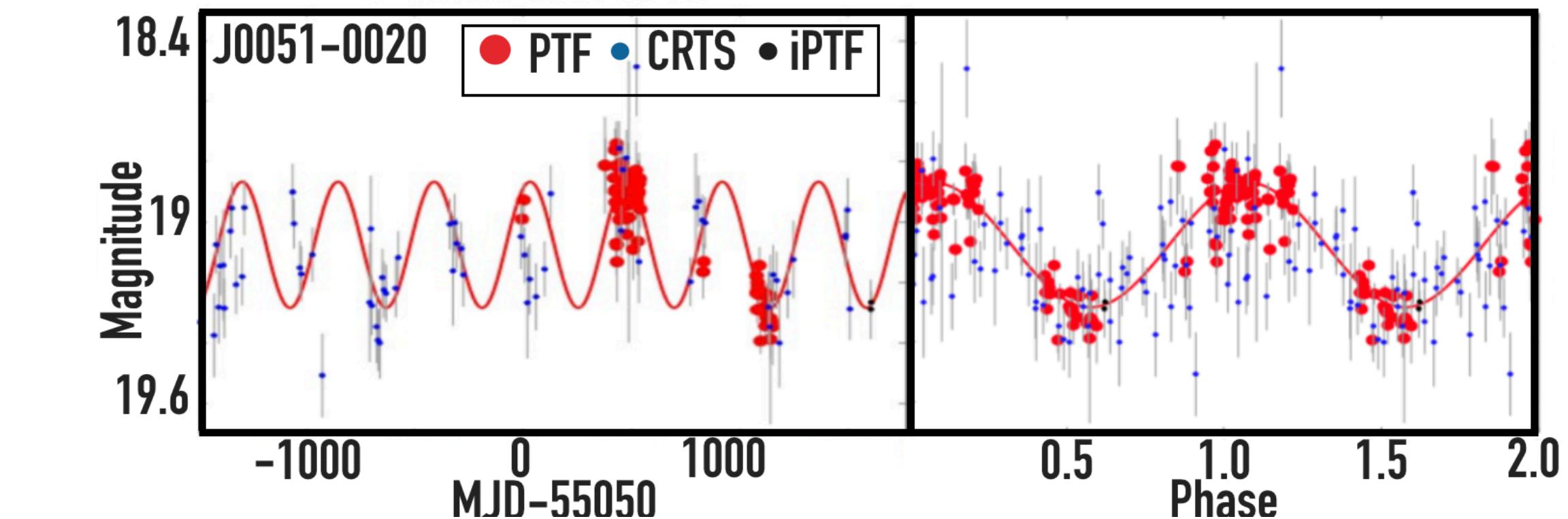
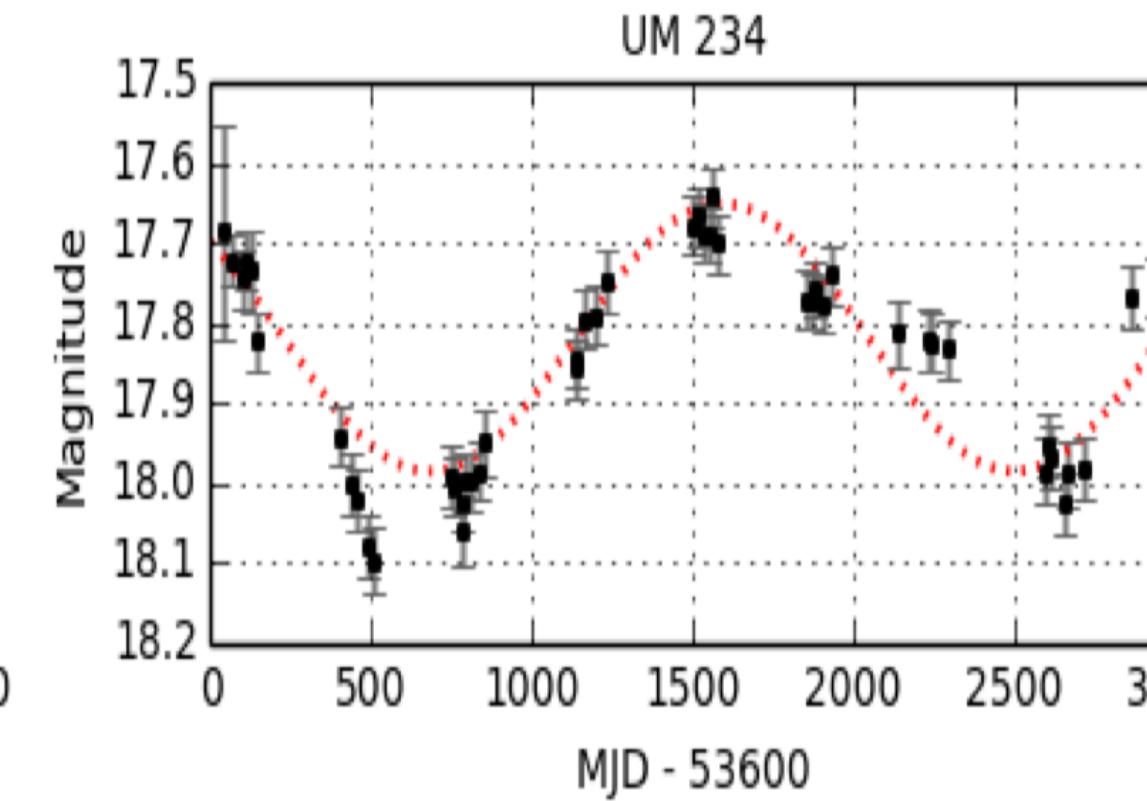
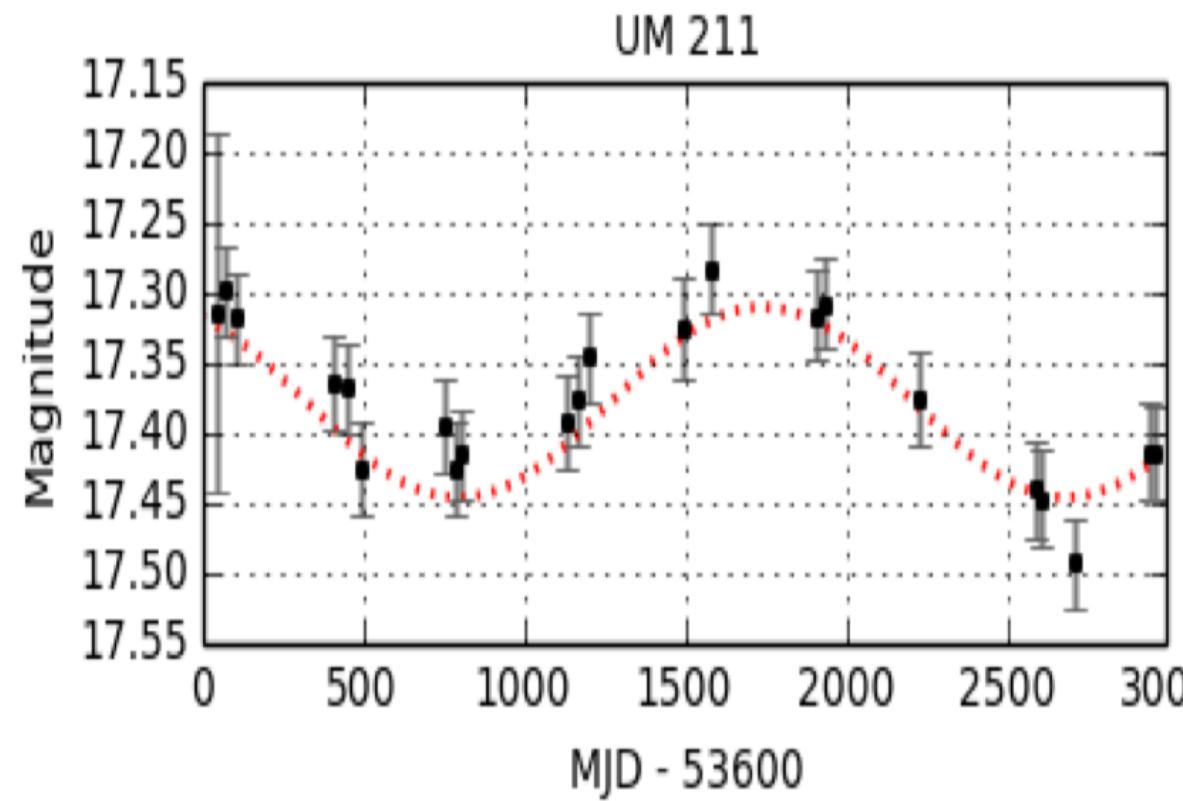


Time-domain Surveys



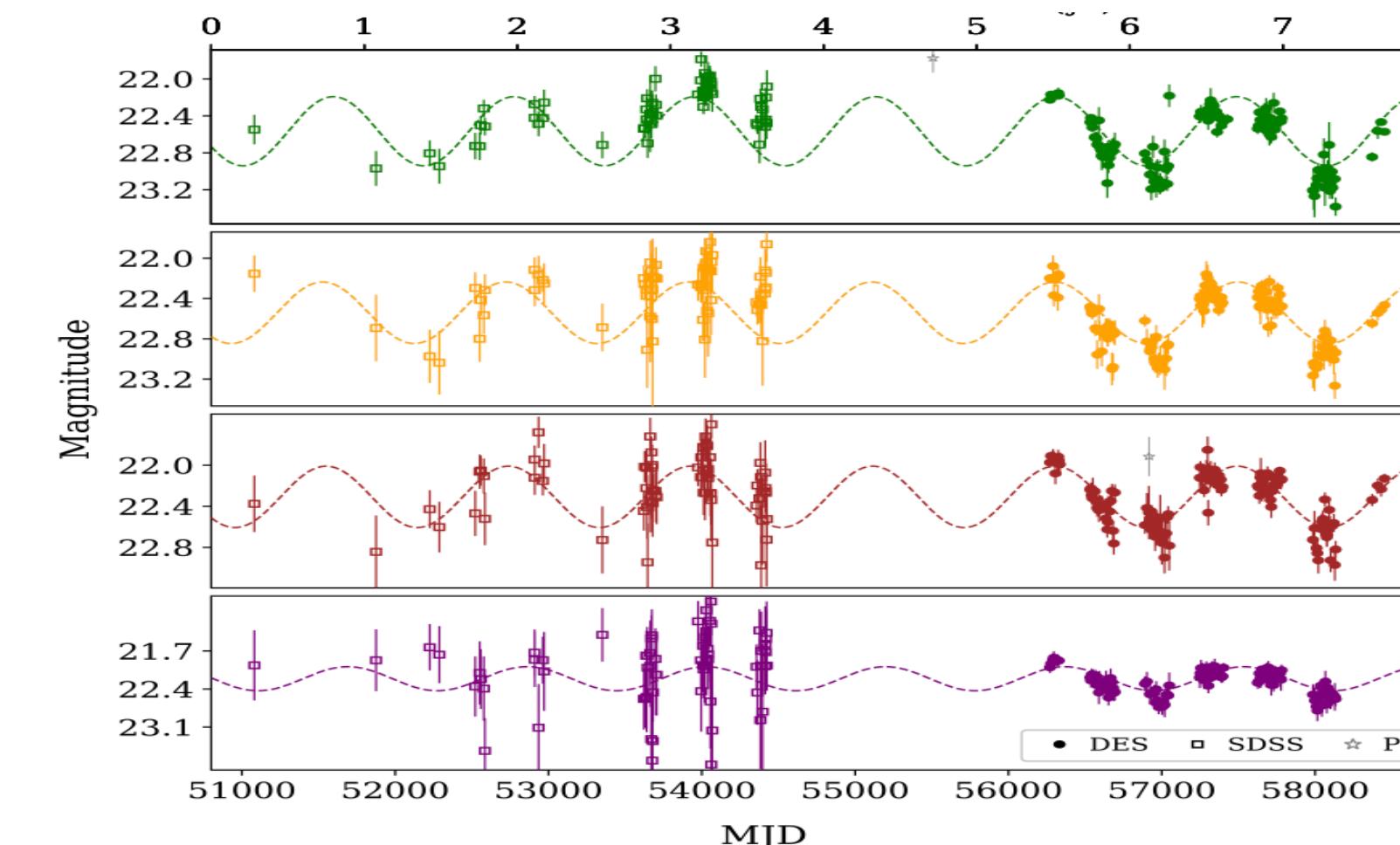
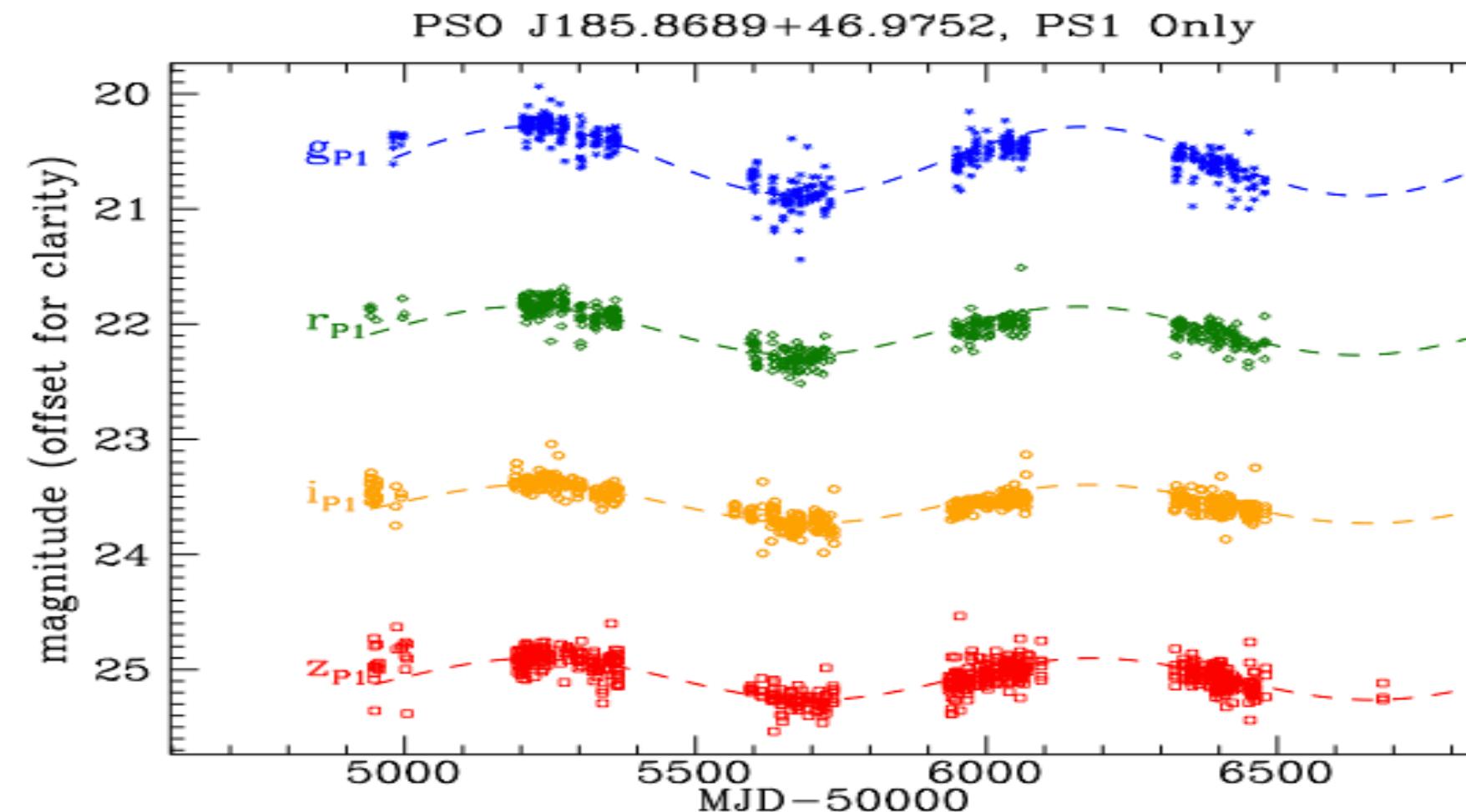
- Systematically scan the sky & record brightness evolution.
- Provided large samples to search for quasar periodicity.

Systematic Searches for Periodicity



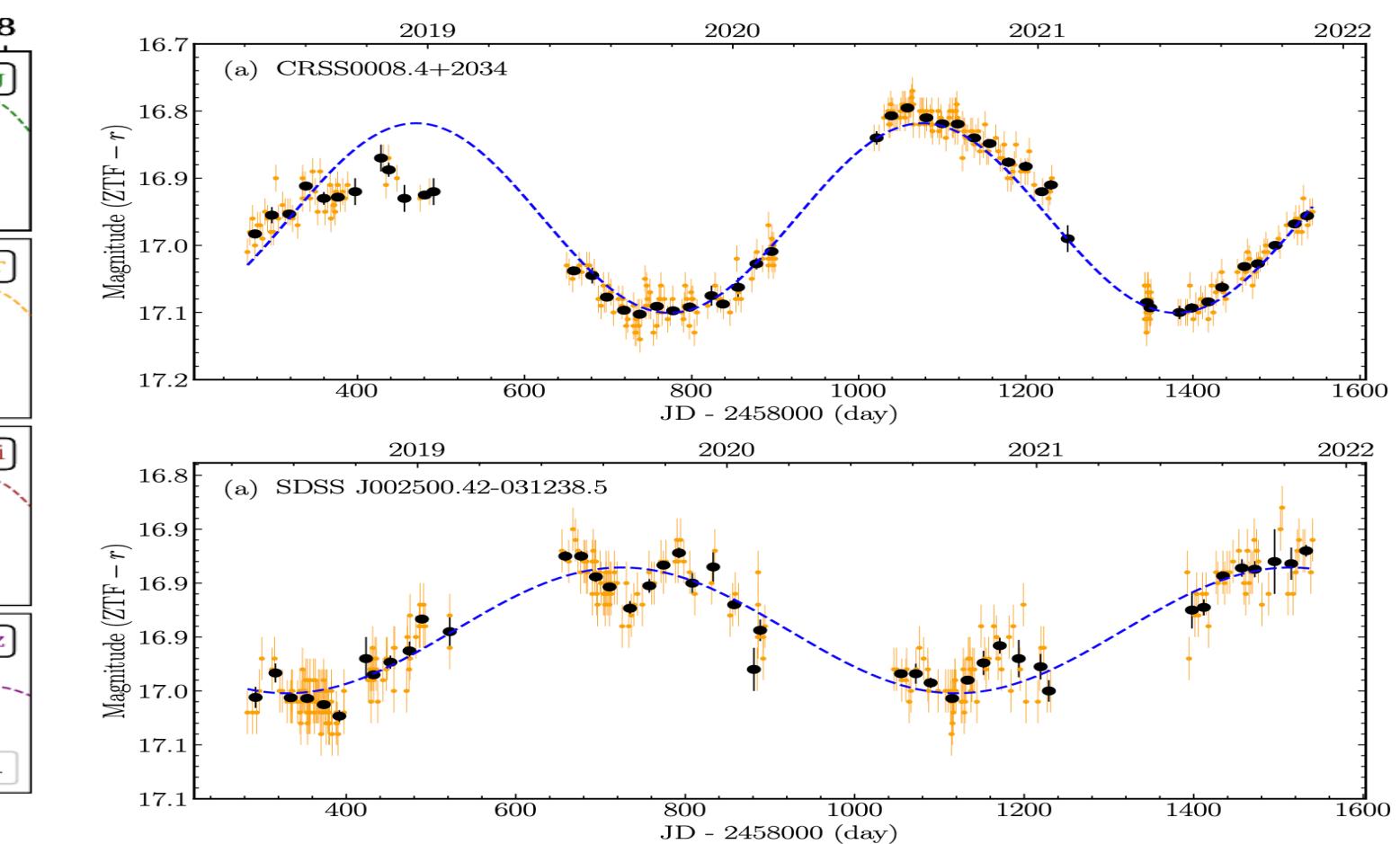
CRTS: 111 of 245,000
Graham+2015

PTF: 33 of 35,000
Charisi+2016



PanSTARRS: 1 of 9,000
Liu+2019

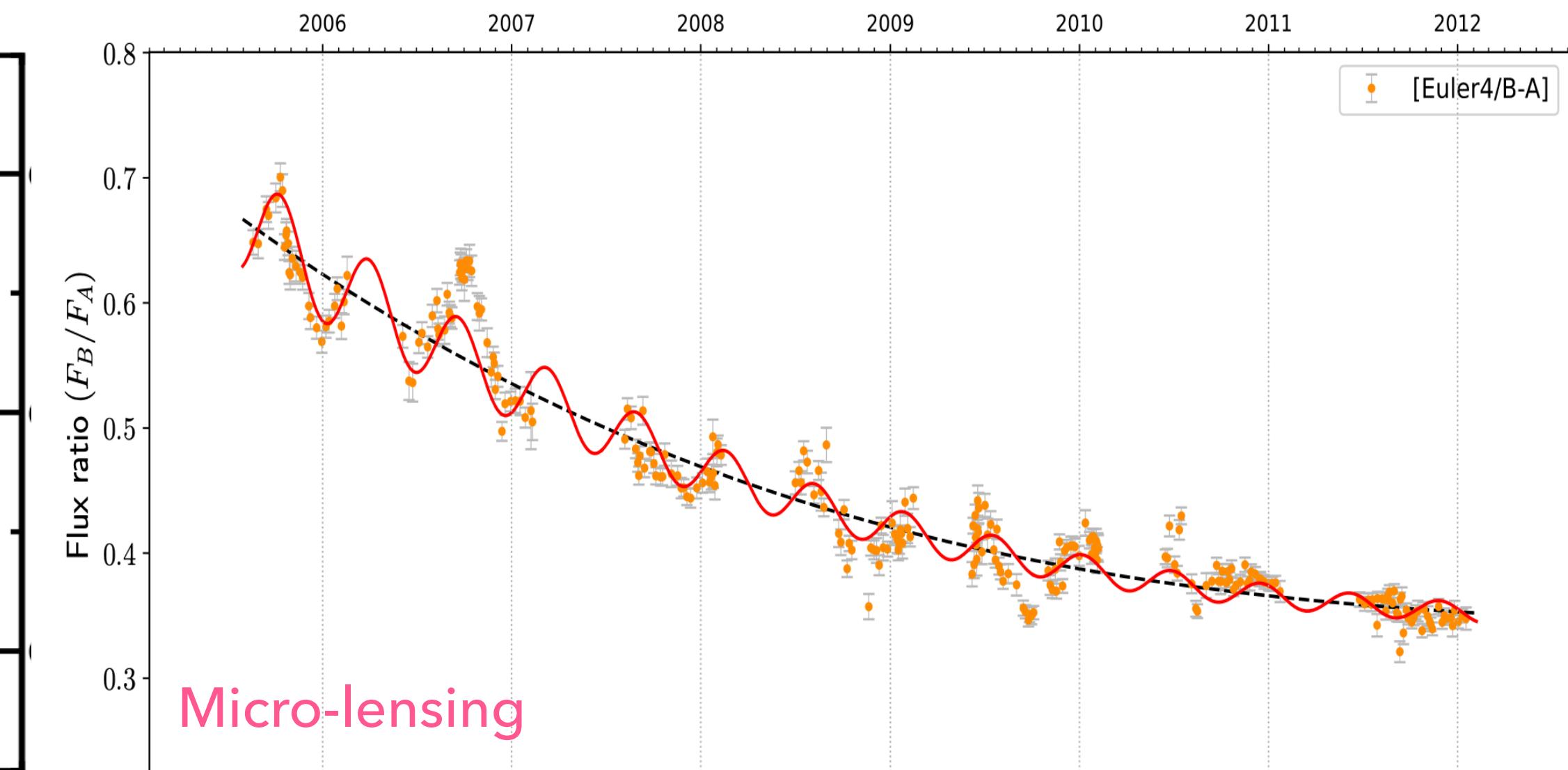
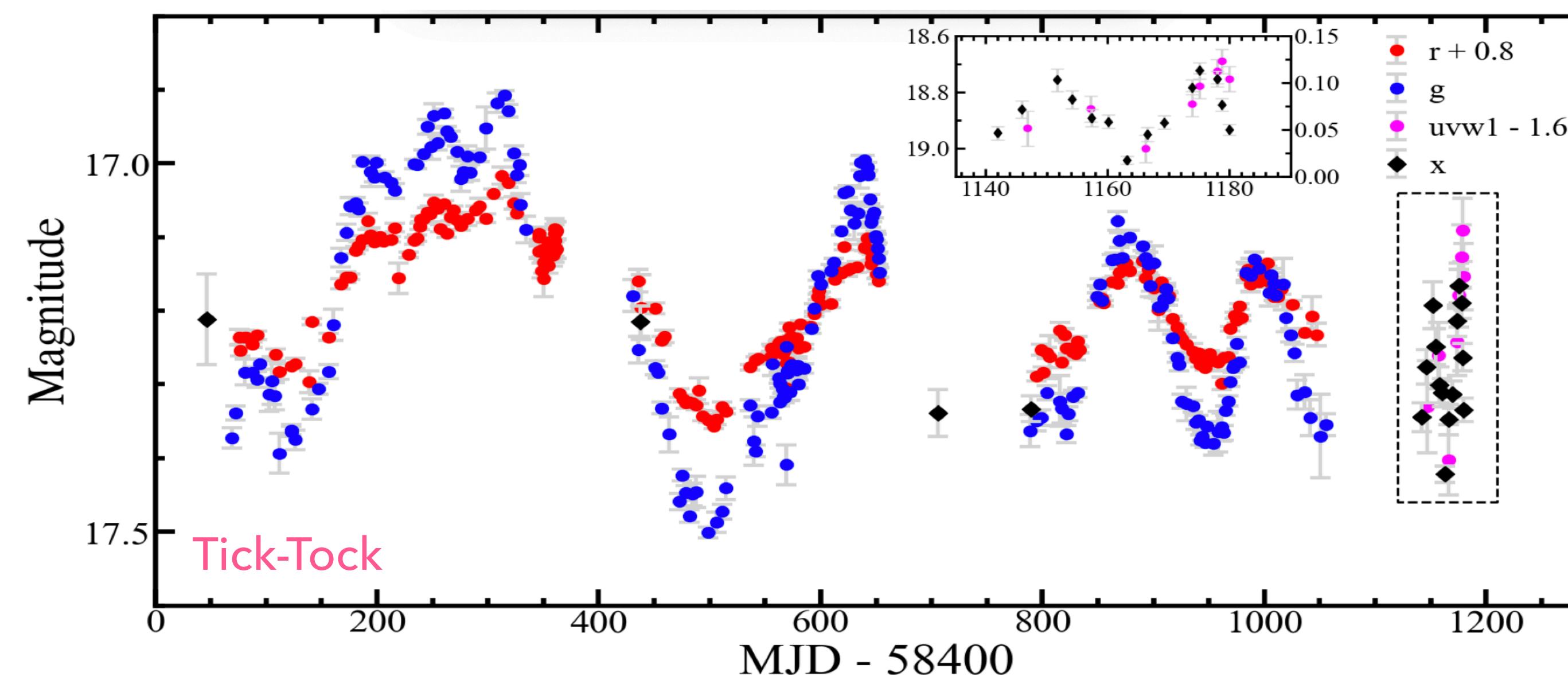
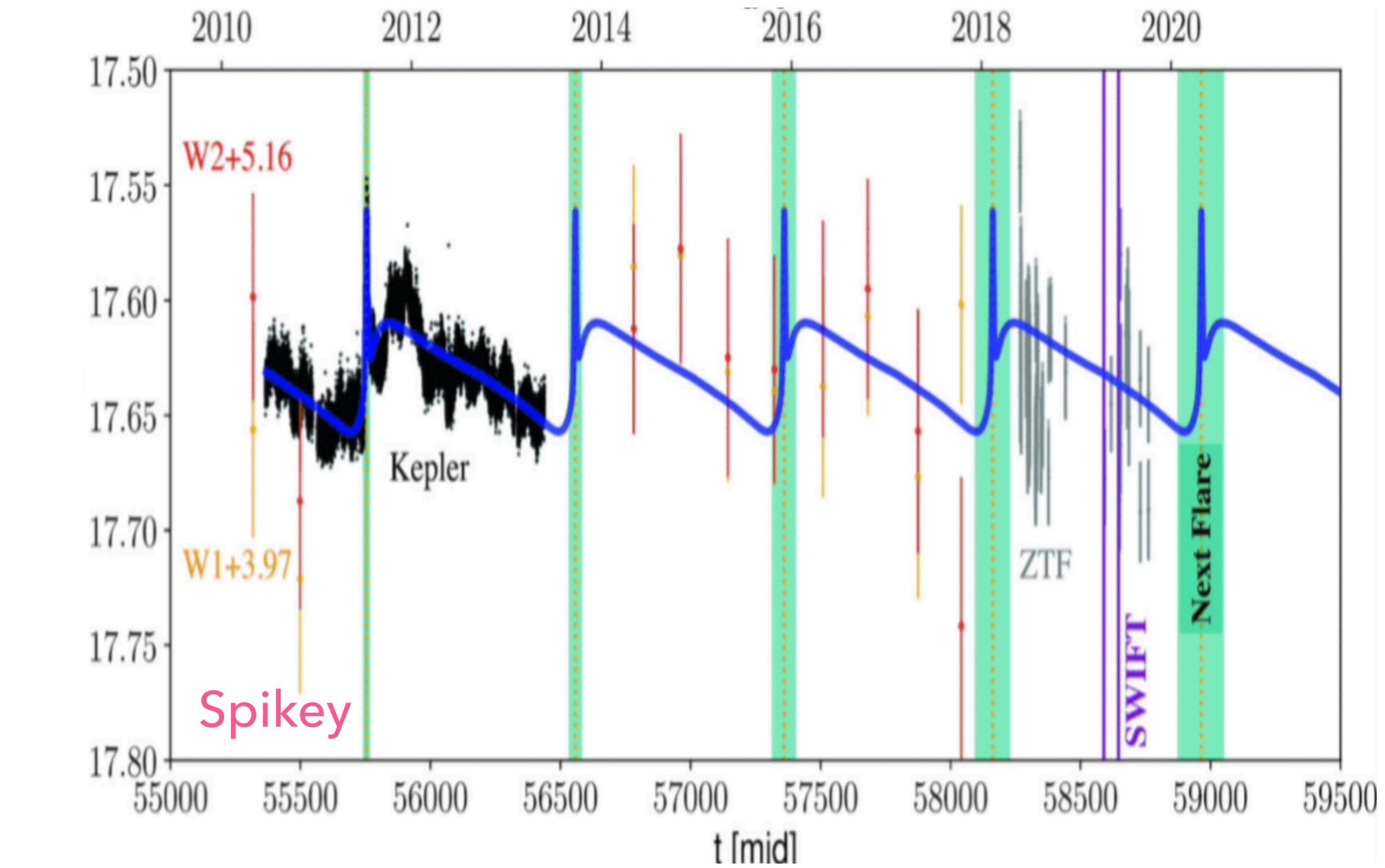
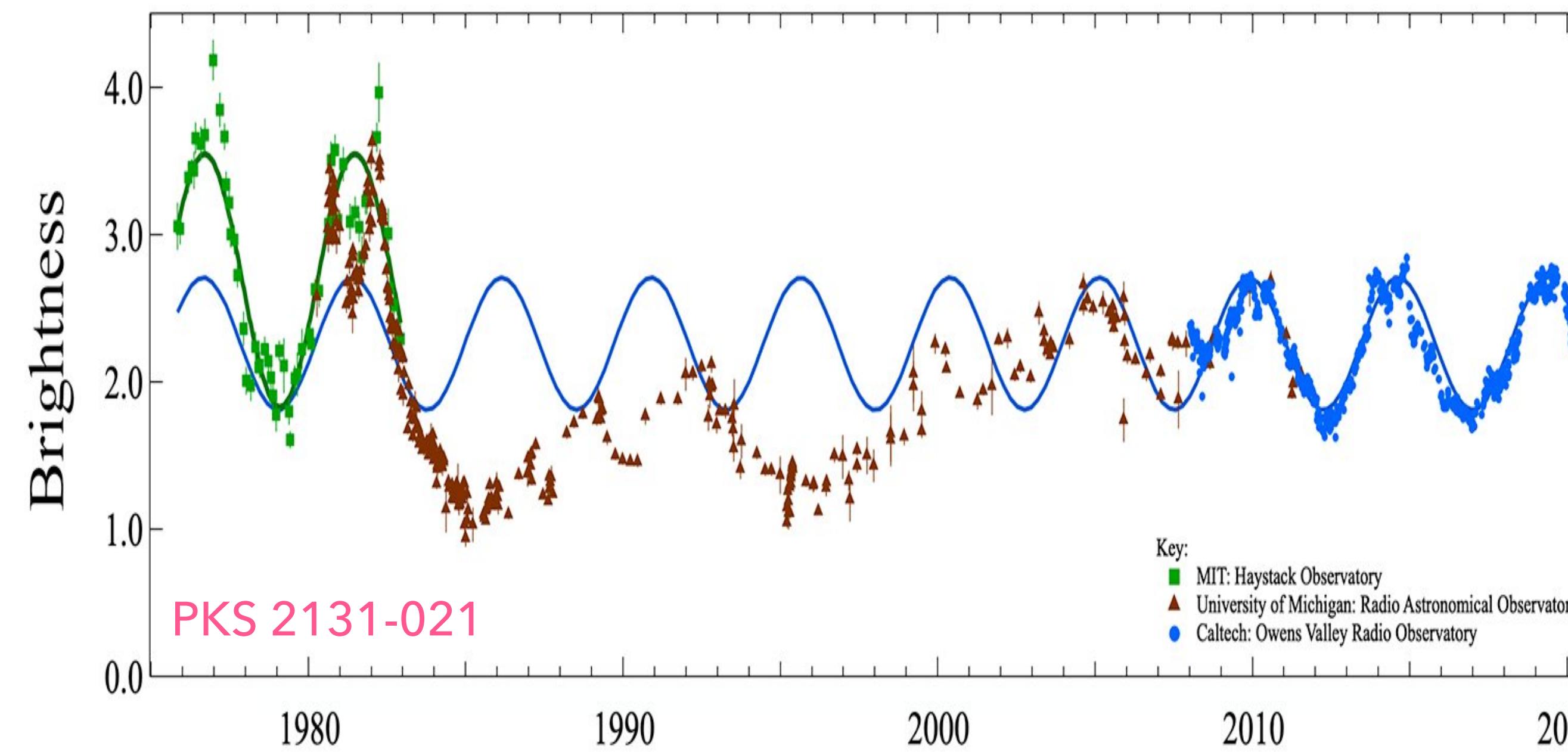
SDSS+DES: 5 of 625
Chen+2020



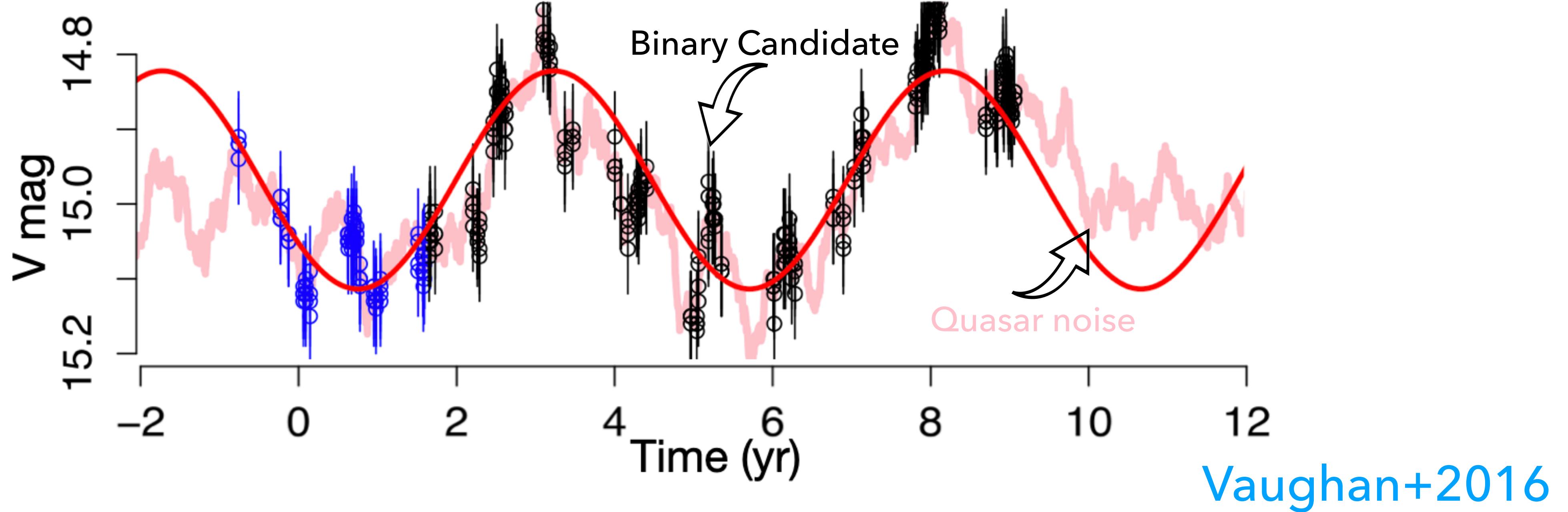
ZTF: 127 of 144,000
Chen+2023

~250 **Candidate** Supermassive BH binary systems.

Additional Candidates

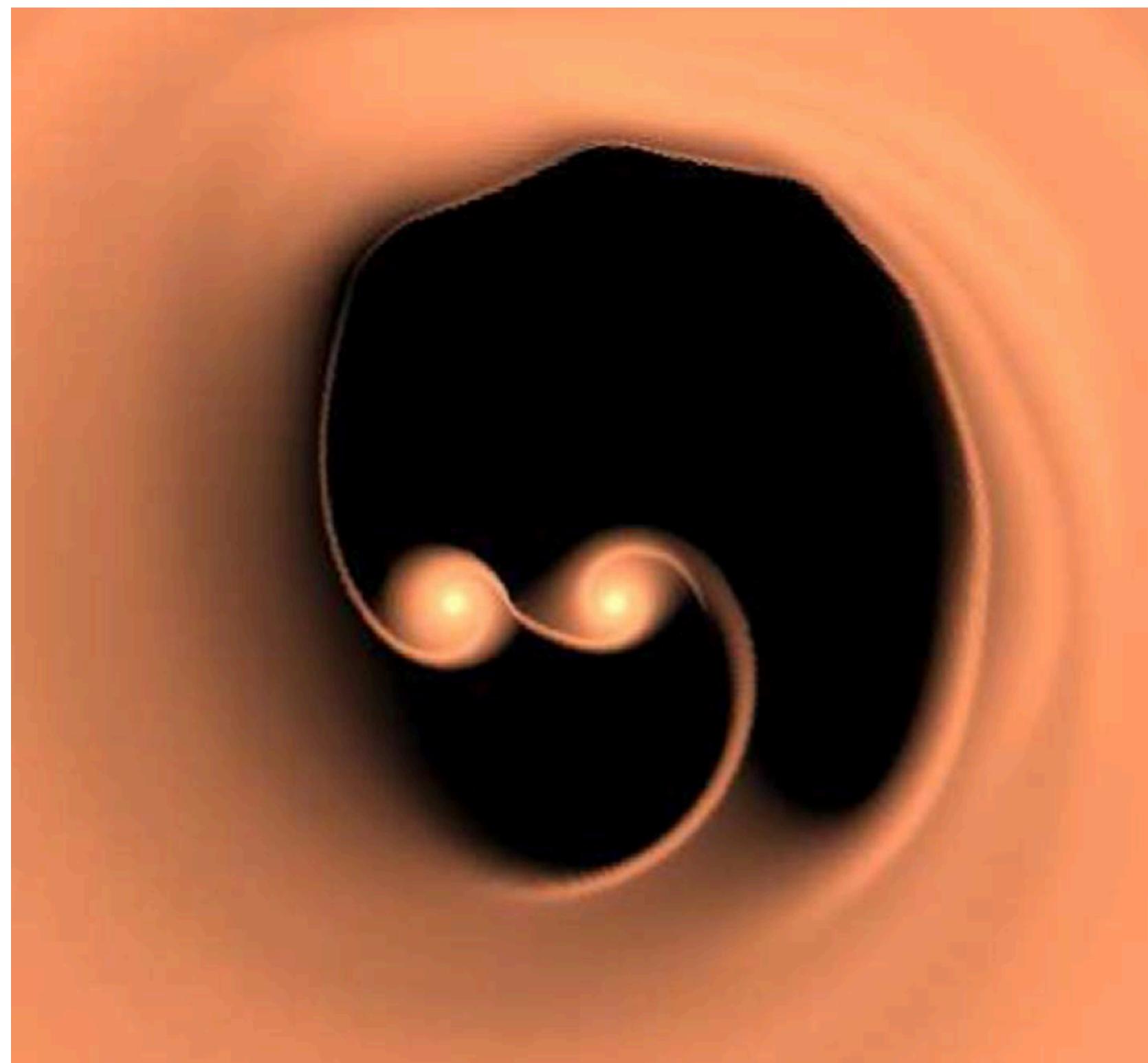


False Positives

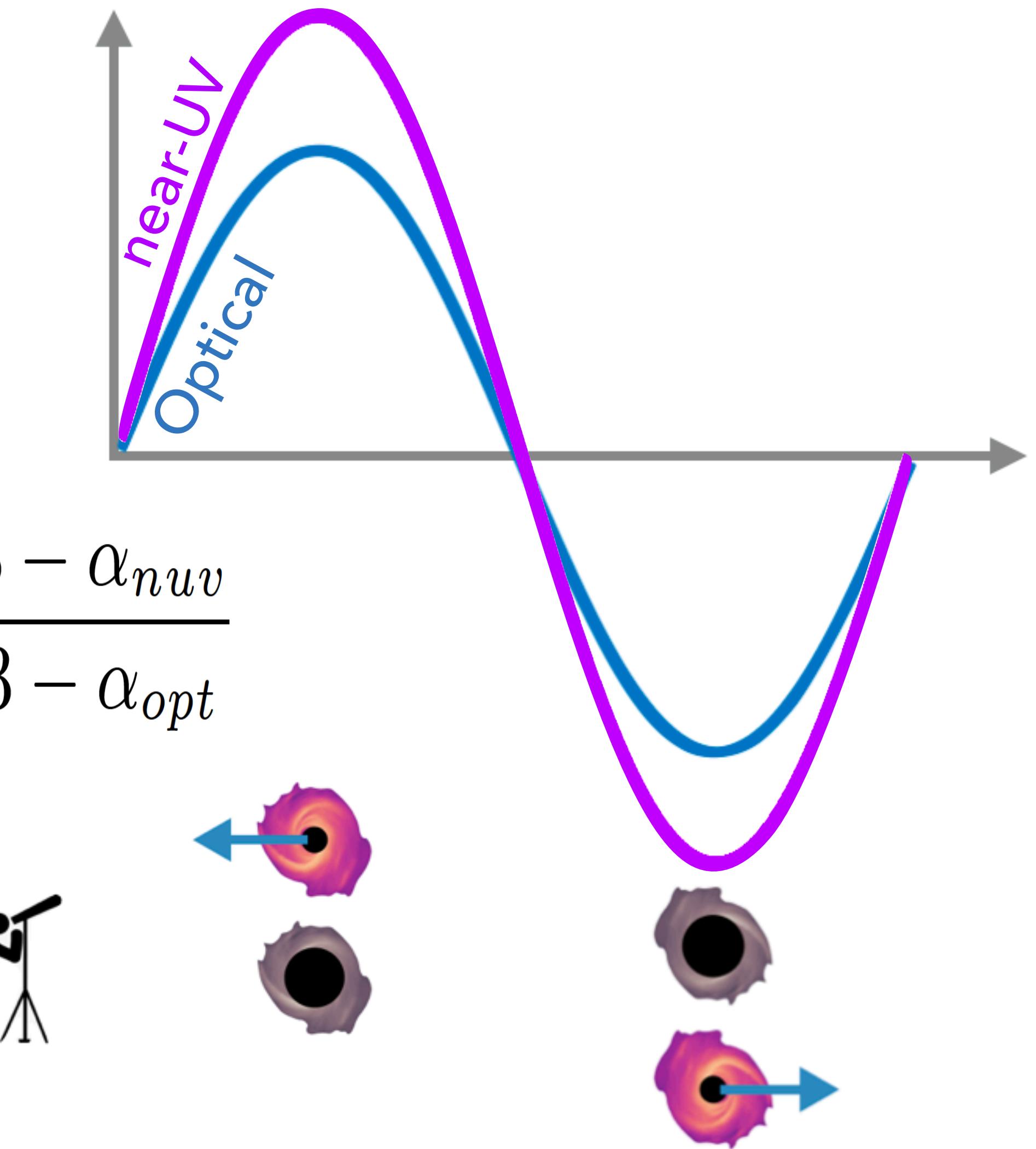


- Quasars show stochastic variability that mimics periodicity (+hinder the detection of real periodicity).
- Need long-term monitoring to observe many cycles of periodicity.
- Need better noise modeling (beyond the DRW).

Relativistic Doppler Boost

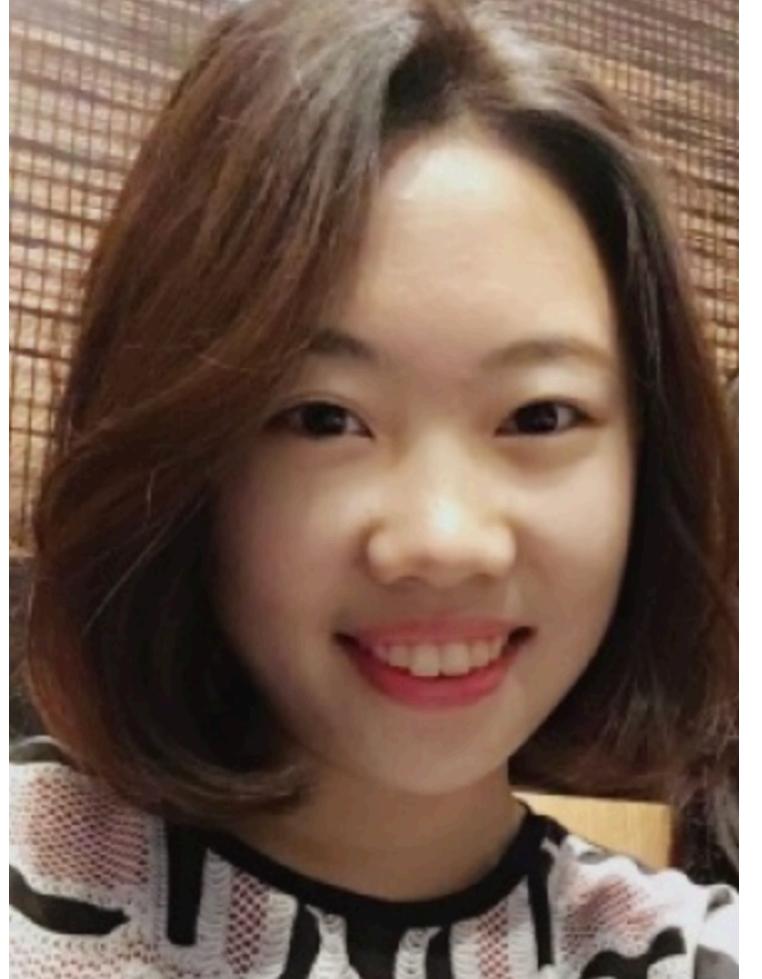


Duffell+2020

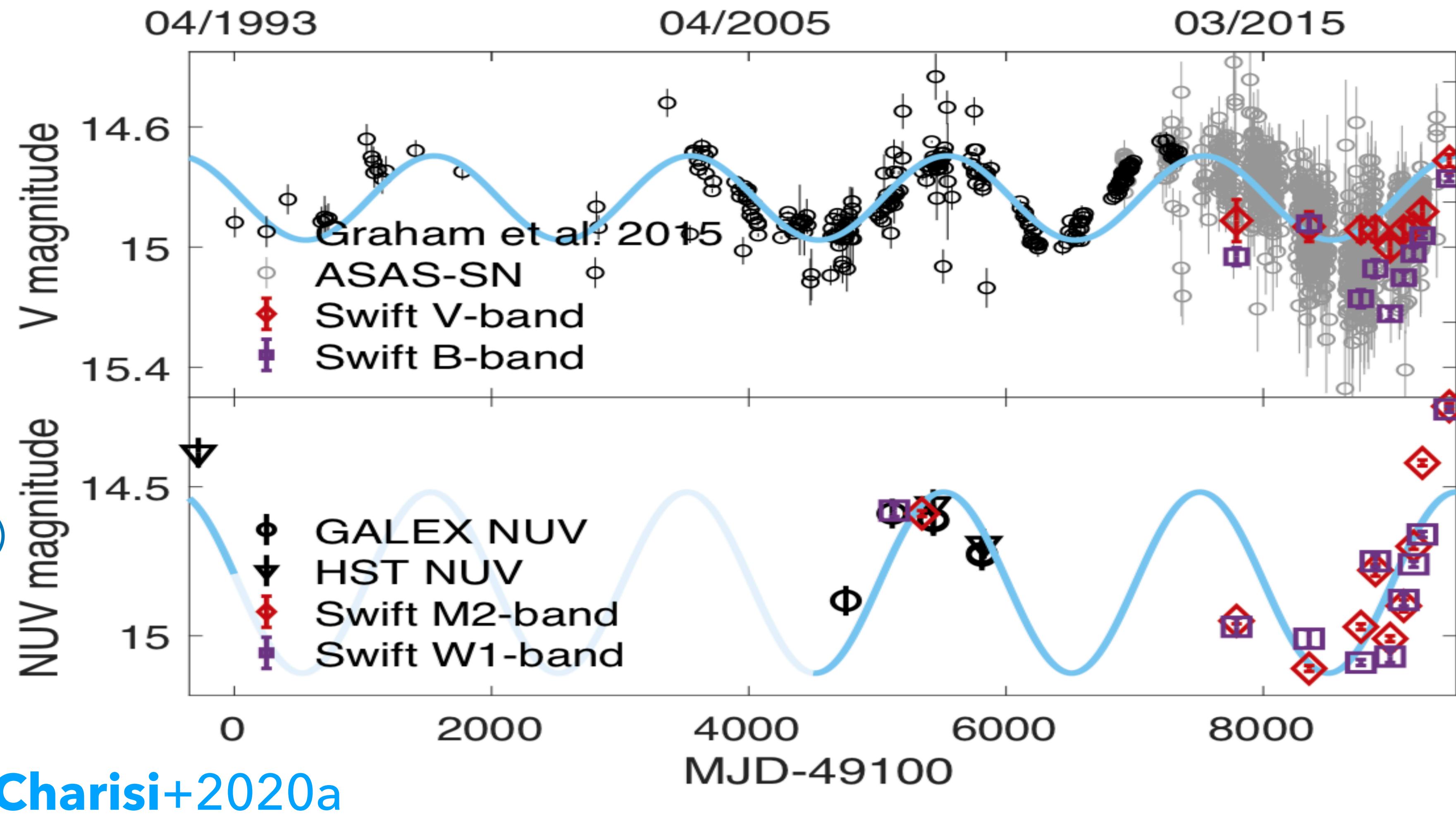


- Robust multi-wavelength prediction.
- Dominant for low-mass ratio binaries and relatively close to edge-on orbits.

Relativistic Doppler Boost PG1302-102

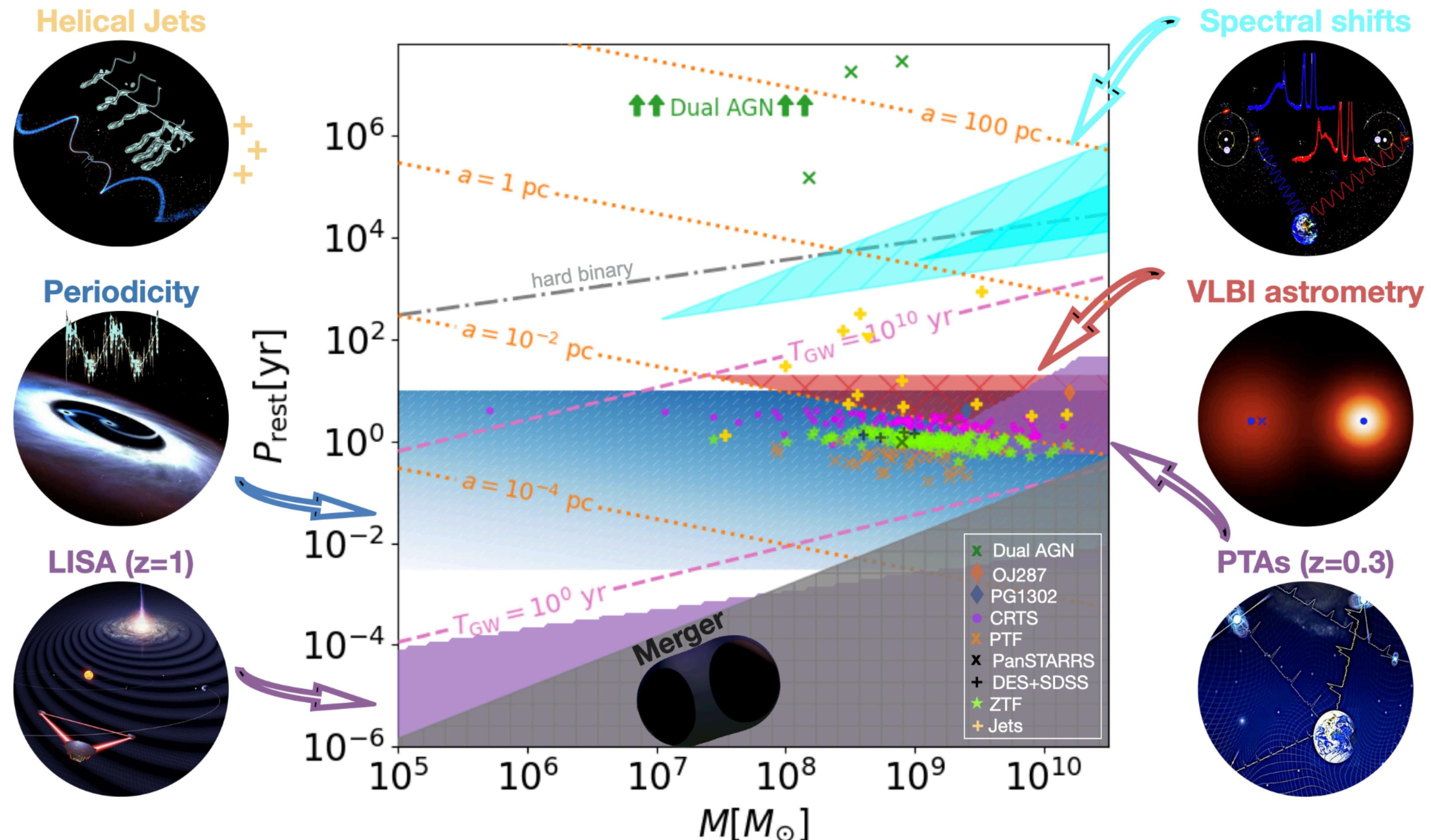


Chengcheng Xin
(PhD student at Columbia)



- PG1302-102 is consistent with Doppler boost variability
- Quasars have wavelength-dependent variability. [Xin, Charisi+2020b](#)

Search for additional signatures



See review: D'Orazio, Charisi, 2023

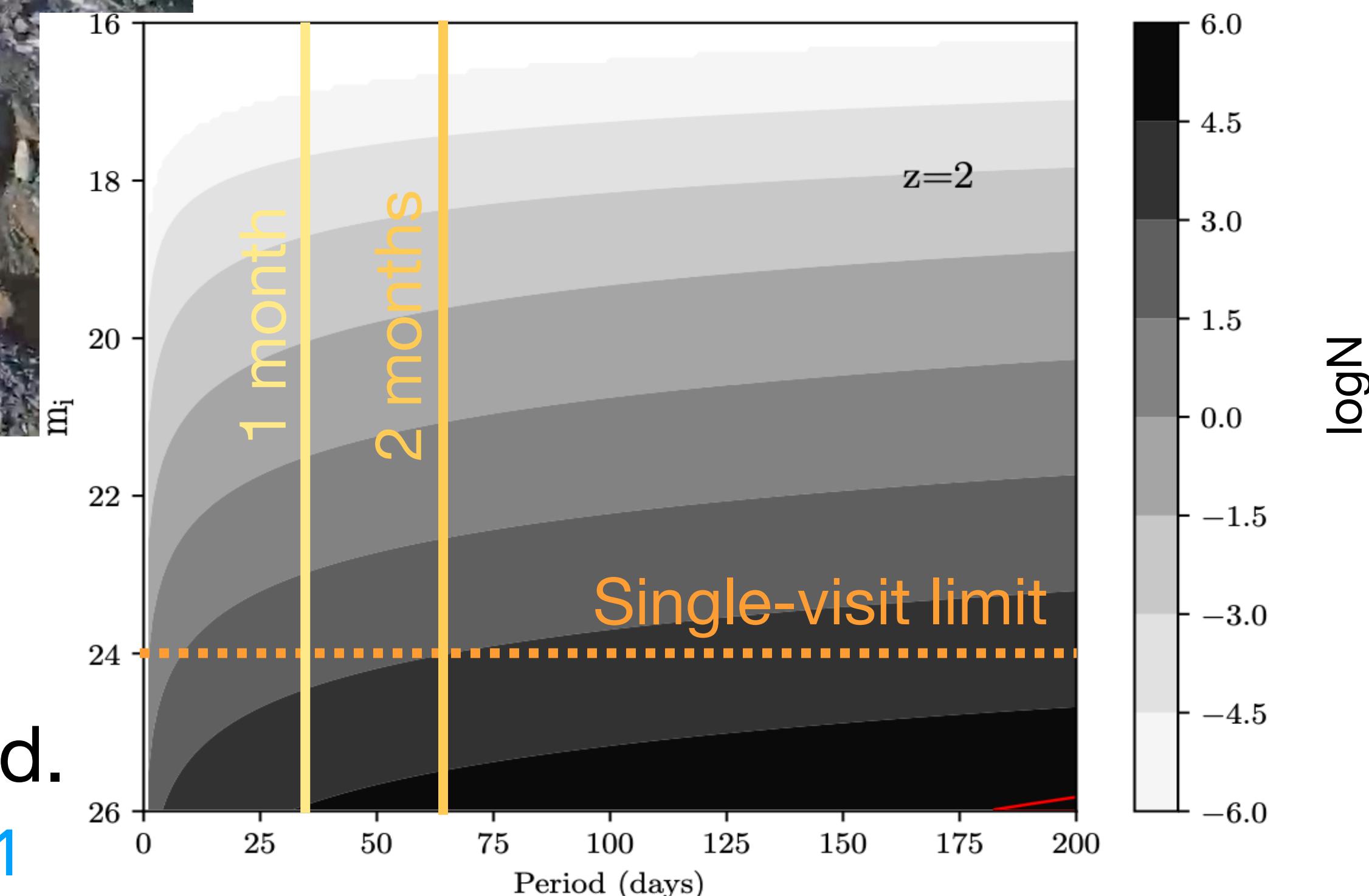
- Several candidates show multiple signatures, but signatures are not unique. Charisi+2015 Charisi+2018 Xin, Charisi+2020a,b

The future is bright!



Credit: LSST, Rubin Observatory

- High-quality data.
- Sample of quasars 2-3 orders of magnitude larger than current surveys.

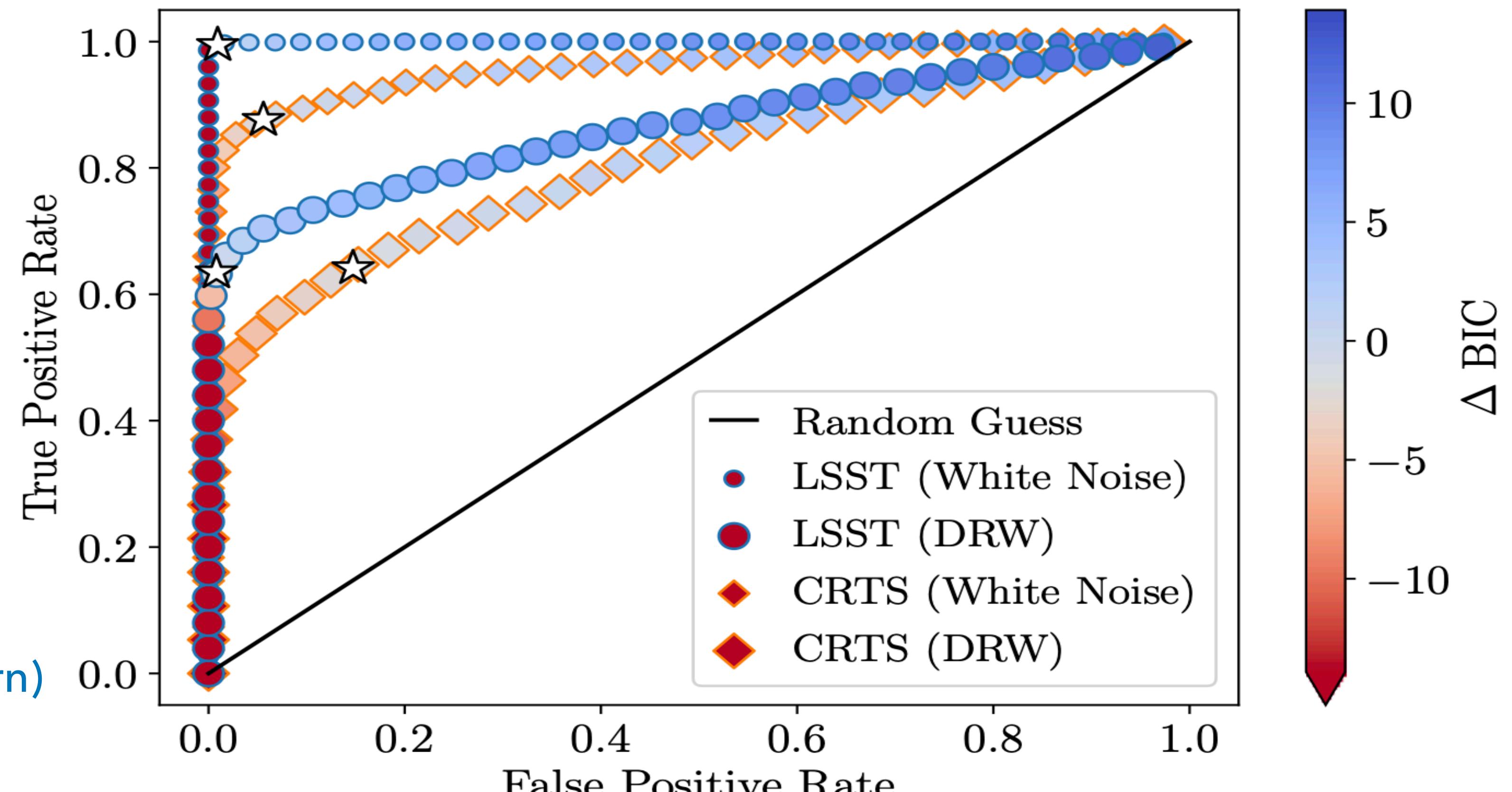


- Hundreds of short-period binaries are expected.

Binaries in LSST



Caitlin Witt
(PhD student at WVU
→ Postdoc at Northwestern)



Witt, Charisi+2022

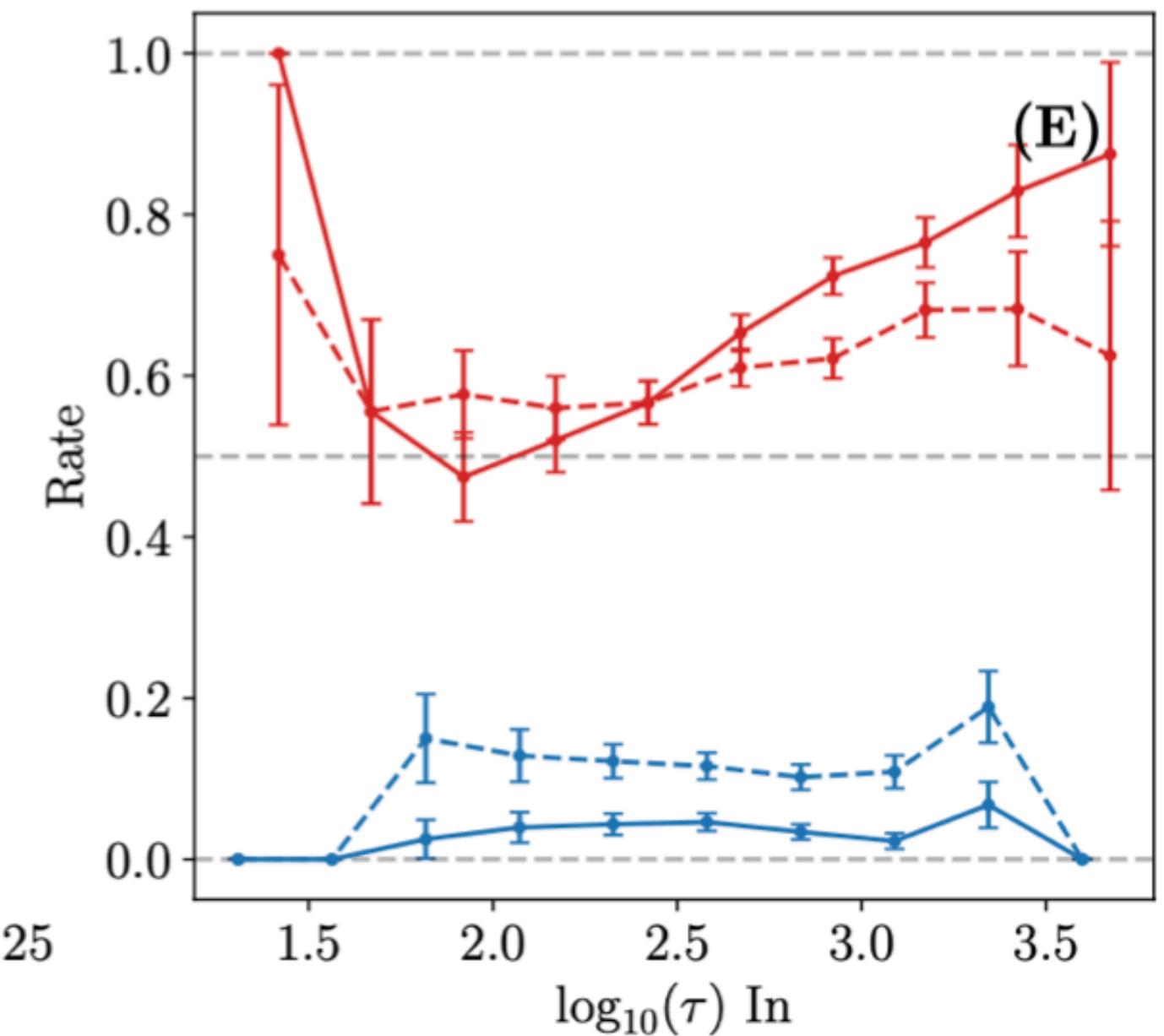
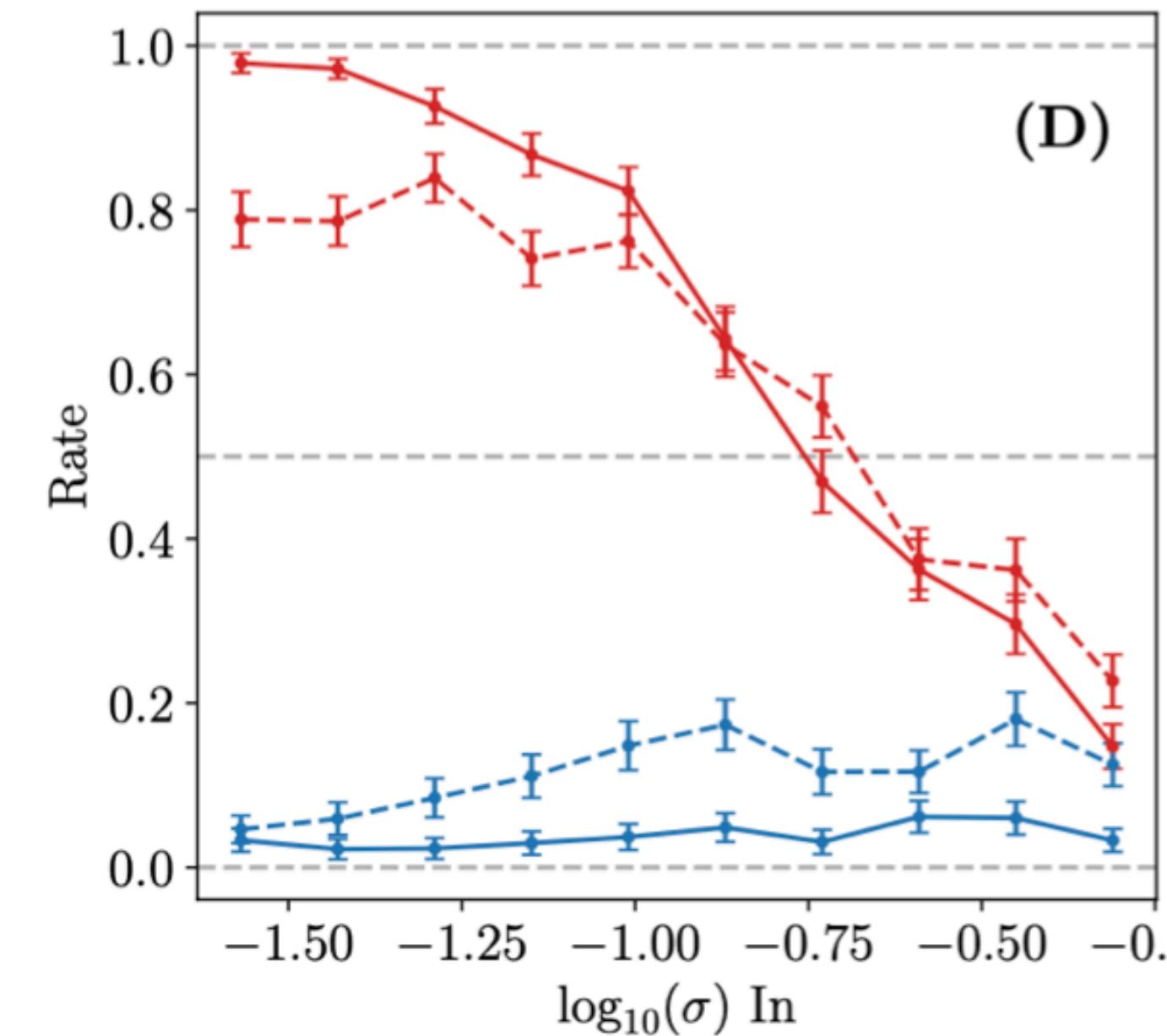
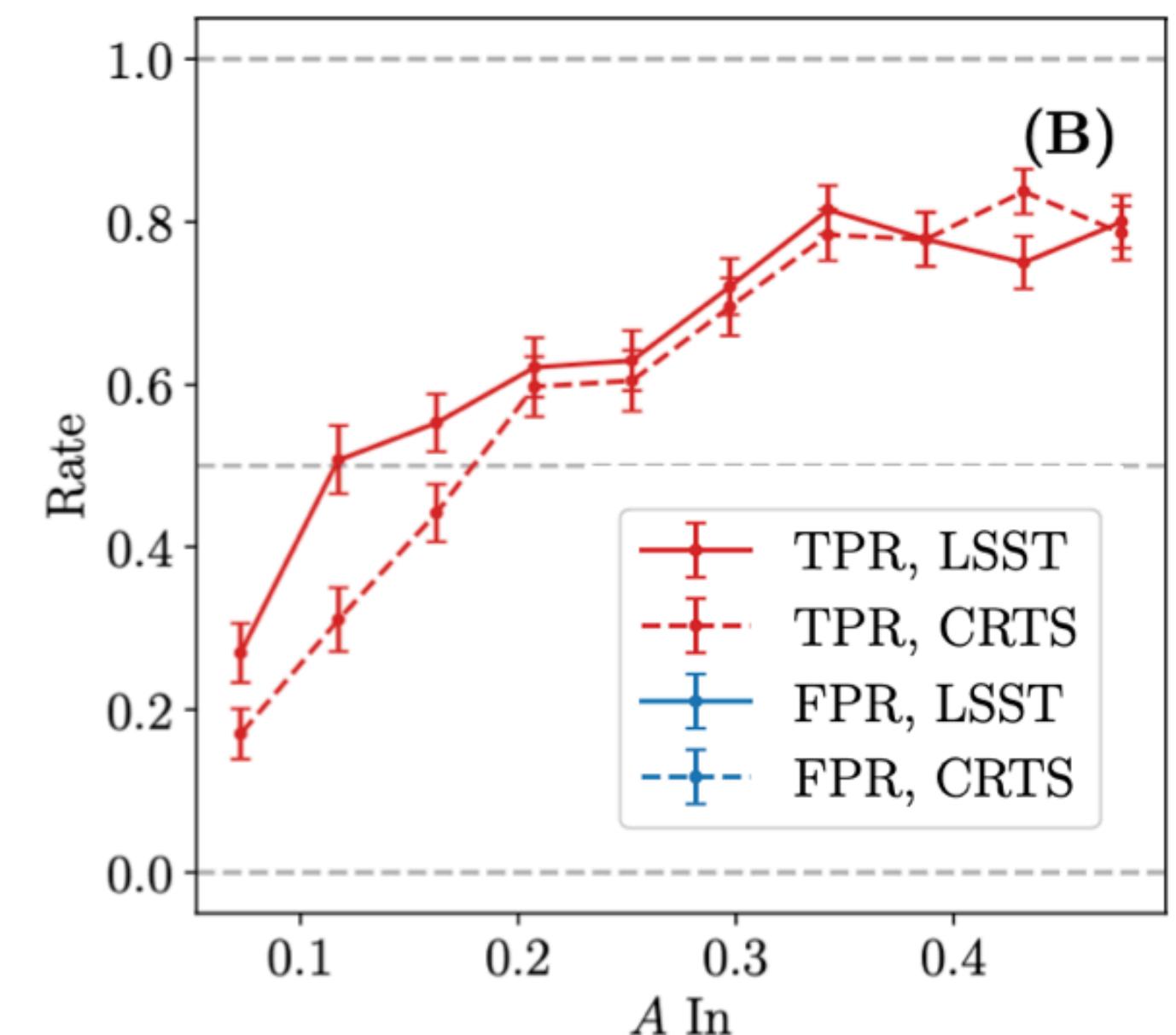
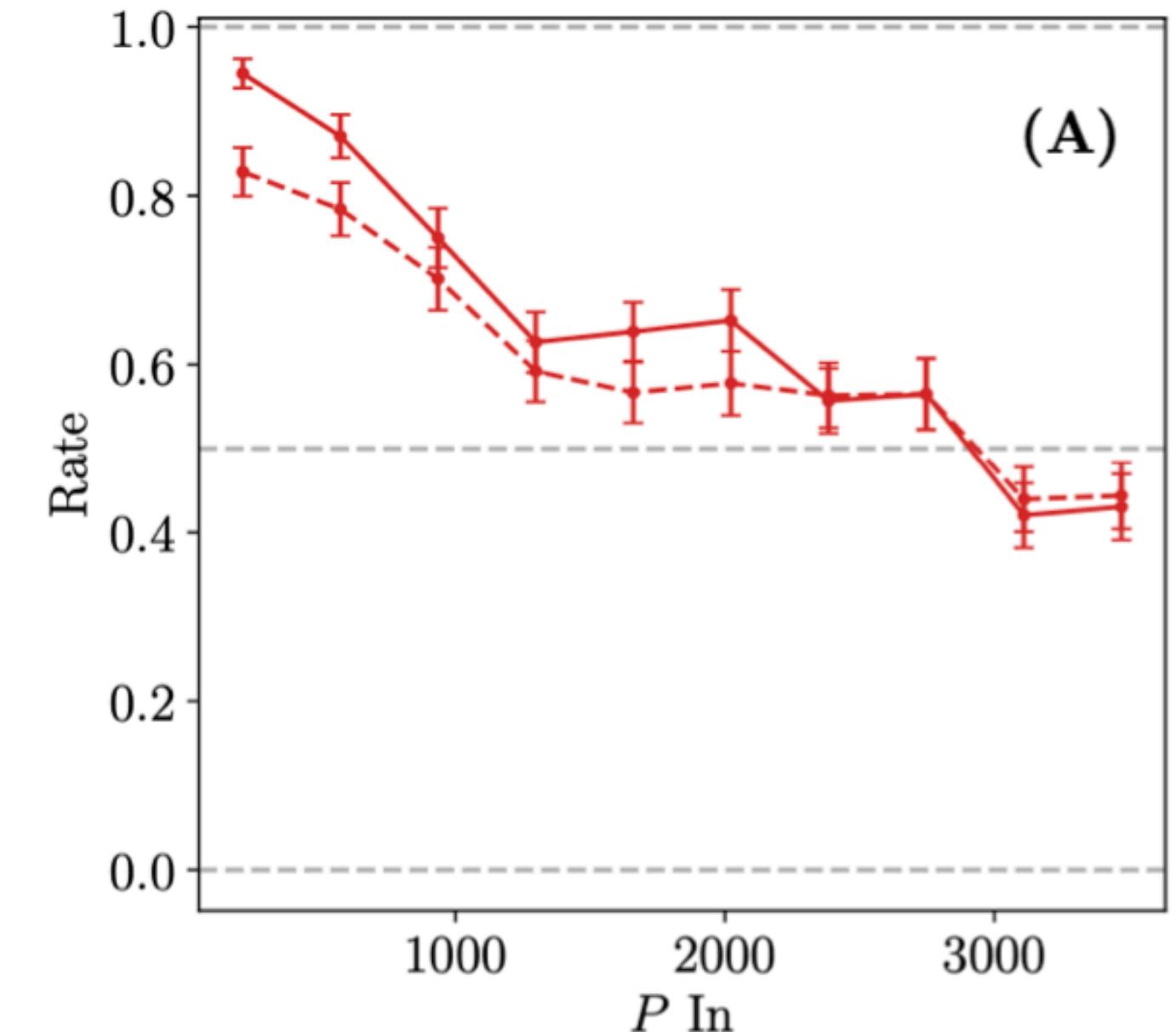
- LSST will provide very reliable binary candidates.
- Data volume is a major challenge.

Binaries in LSST

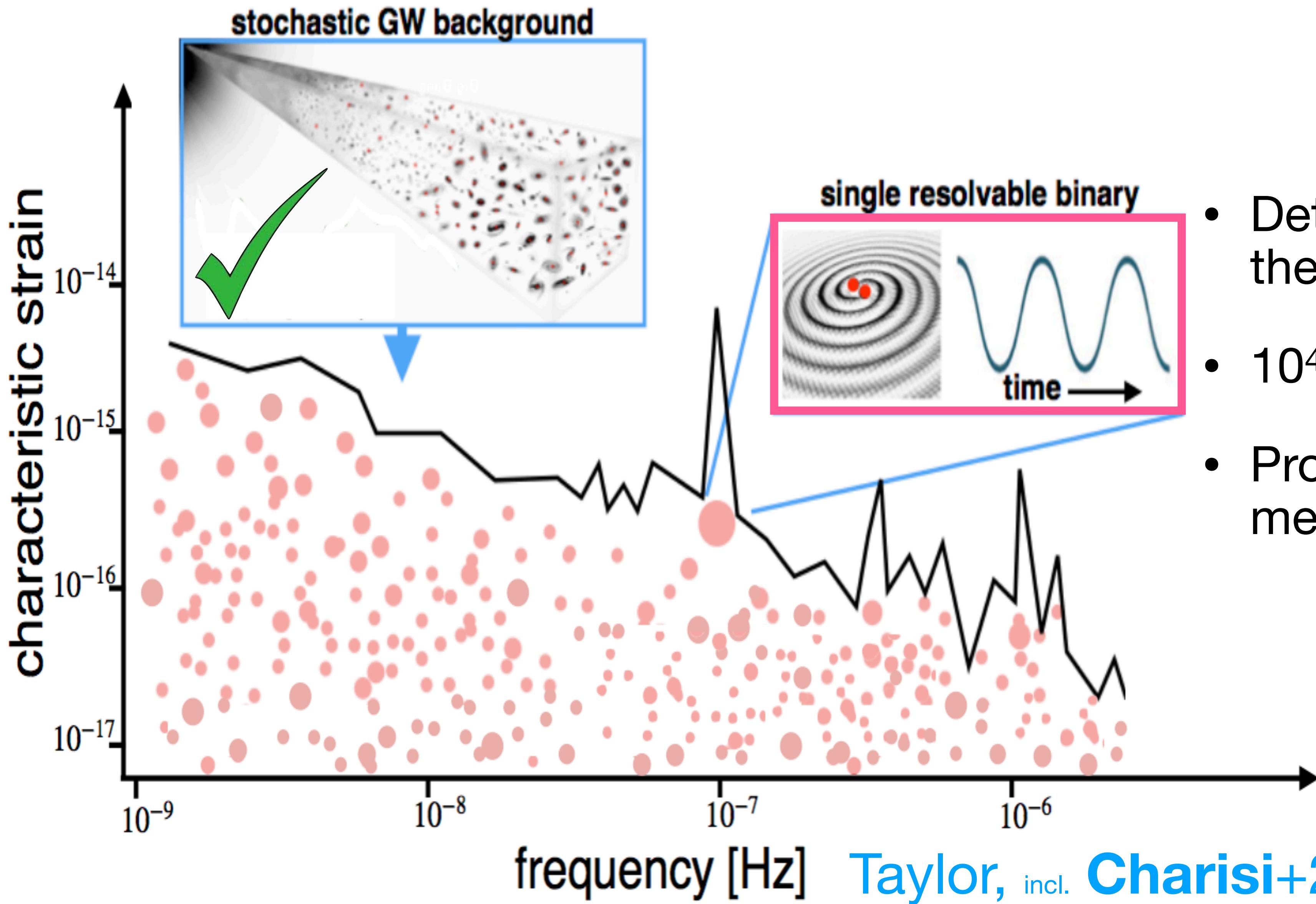


Caitlin Witt
(PhD student at WVU
→ Postdoc at Northwestern)

- Easier to detect short-period, high amplitude signals.



Individually Resolvable Binaries



- Detection → 3-5yrs after the background.
- 10^4 - 10^5 yr before merger.
- Promising sources for multi-messenger observations.

Taylor, incl. Charisi+2019

Multi-messenger Observations—WHY?

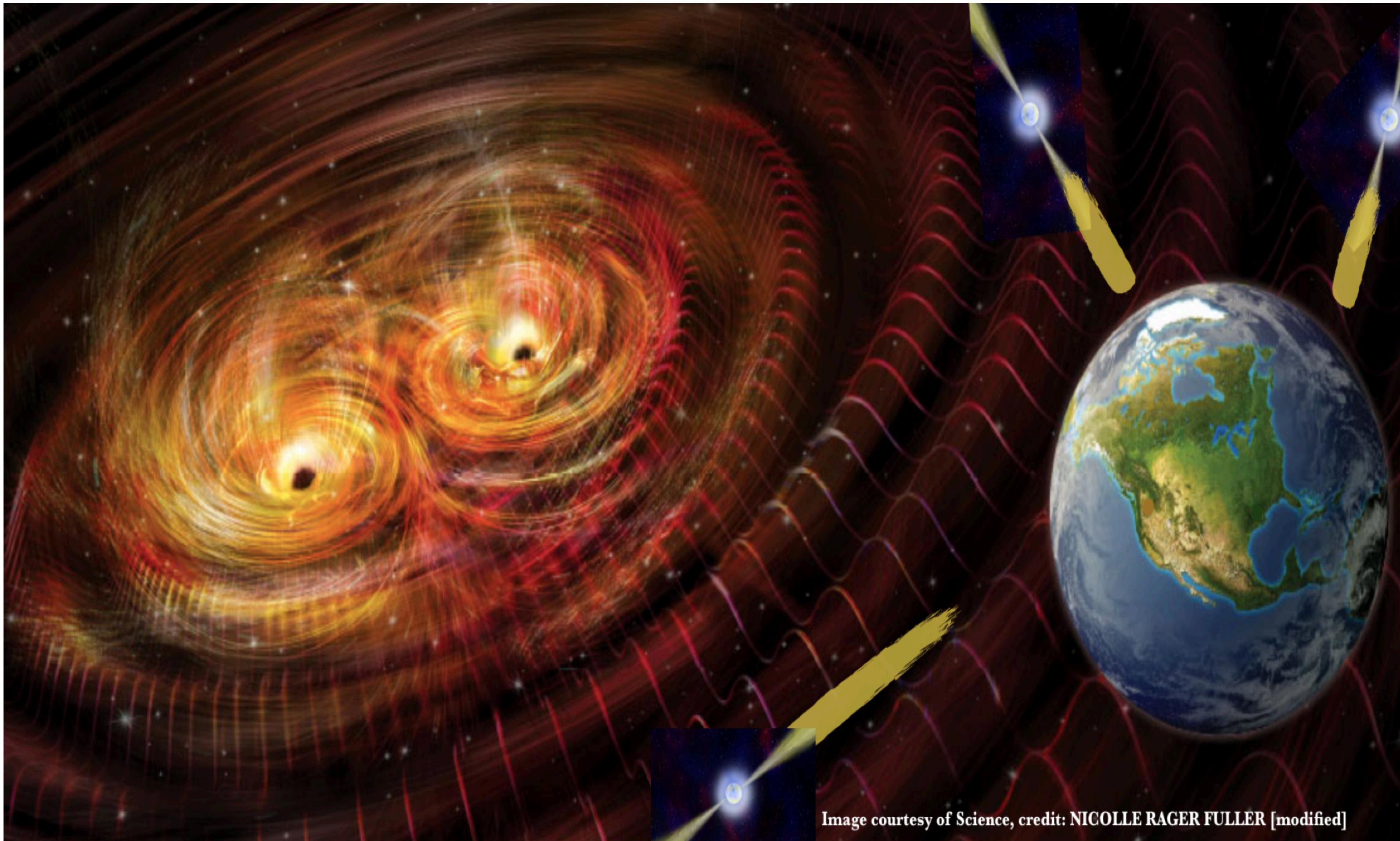
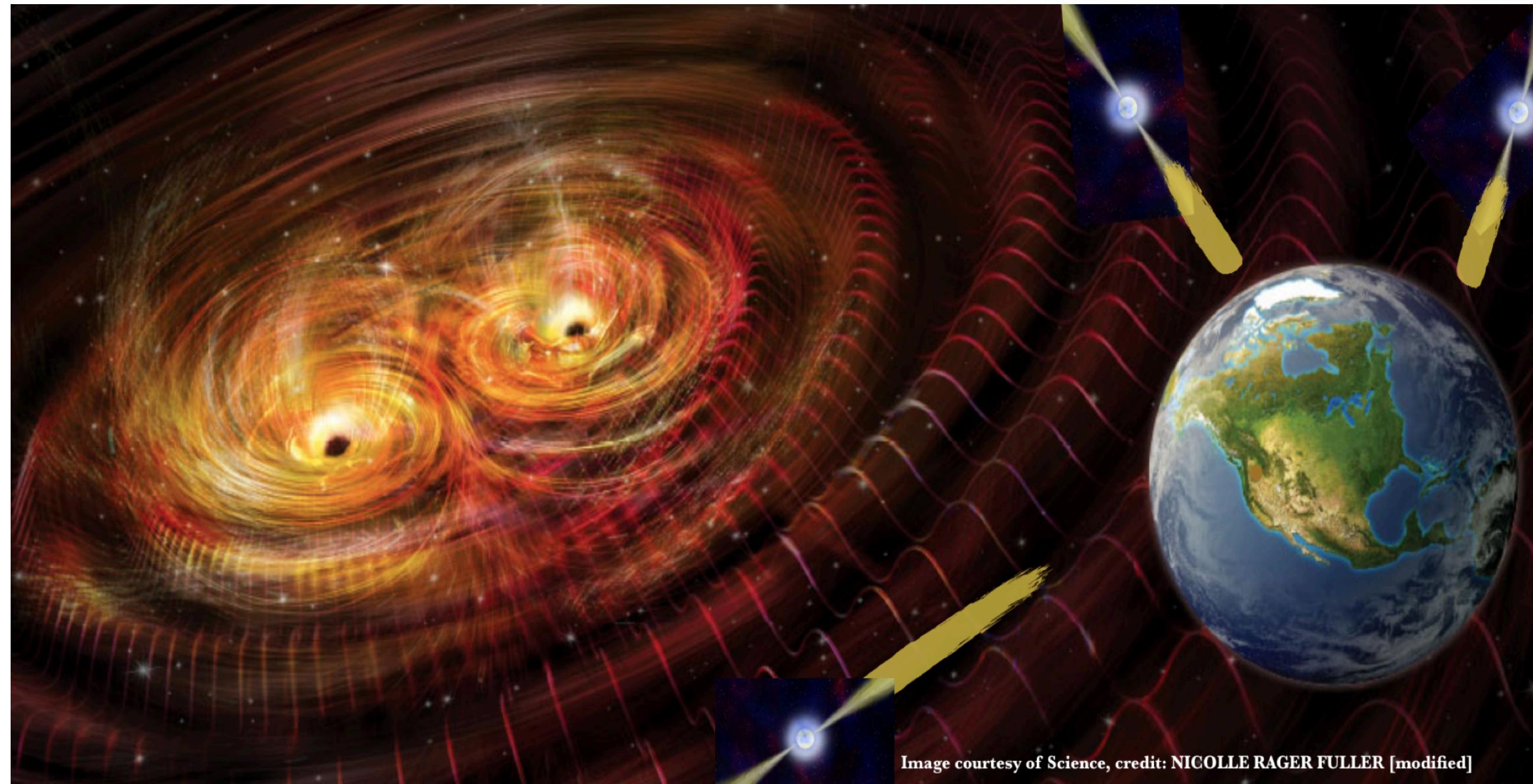


Image courtesy of Science, credit: NICOLLE RAGER FULLER [modified]

- GW observations probe the dynamics.
- EM observations probe the plasma.
- Combined (EM+GW): the most complete picture of binaries.

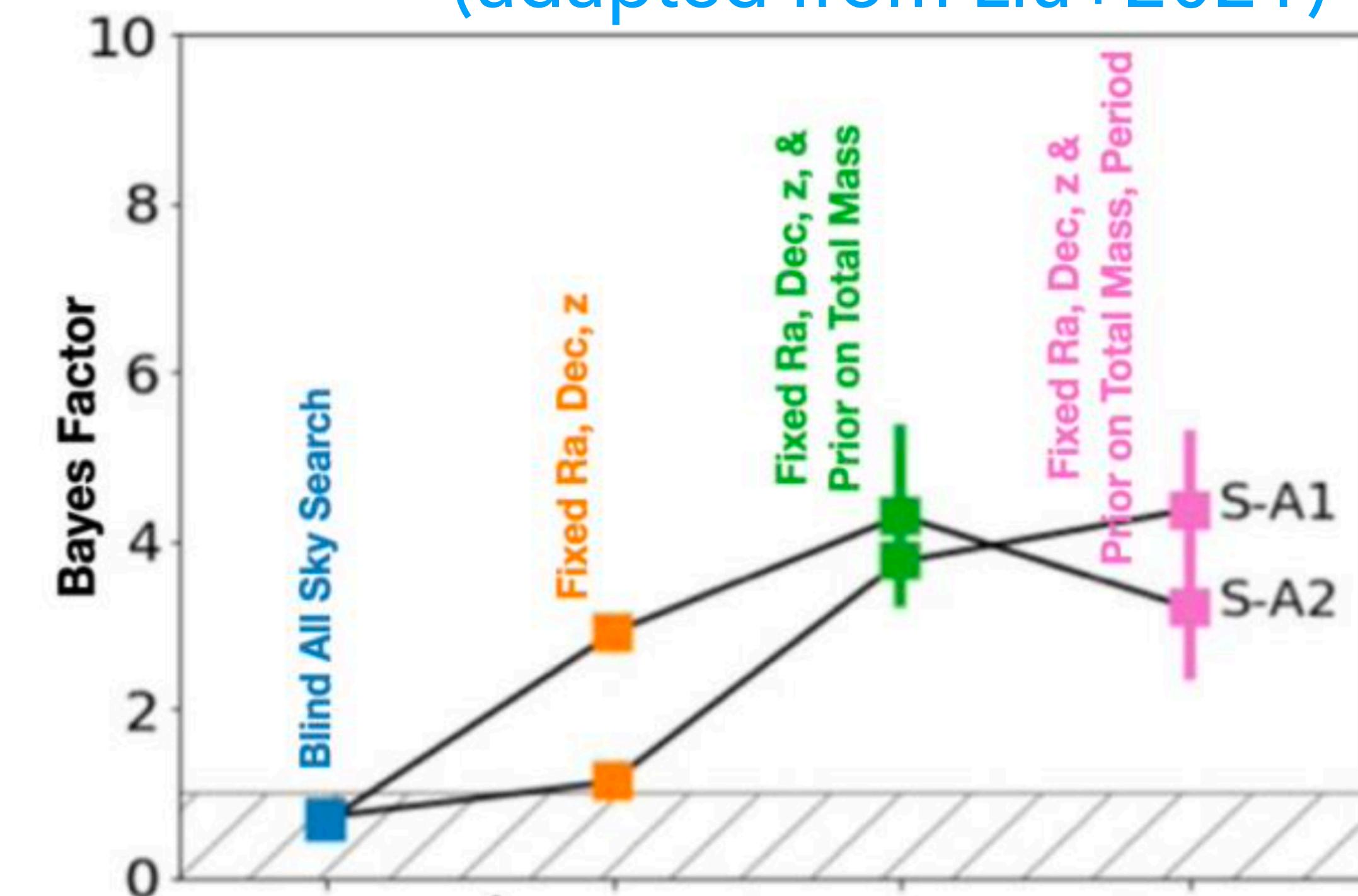
- Astro 2020 ranked multi-messenger and time-domain science as 1 of the 3 top science priorities.

Multi-messenger Observations



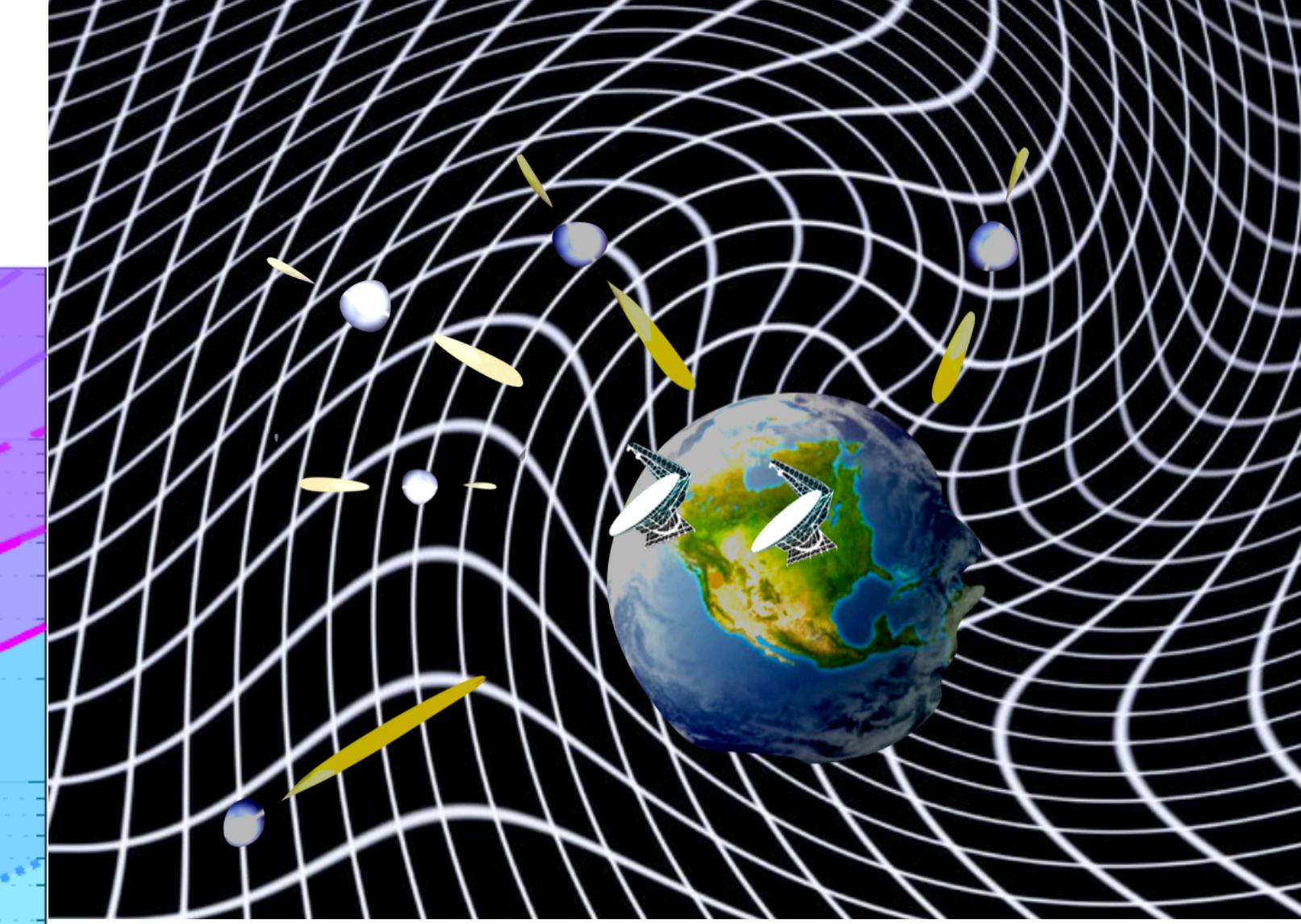
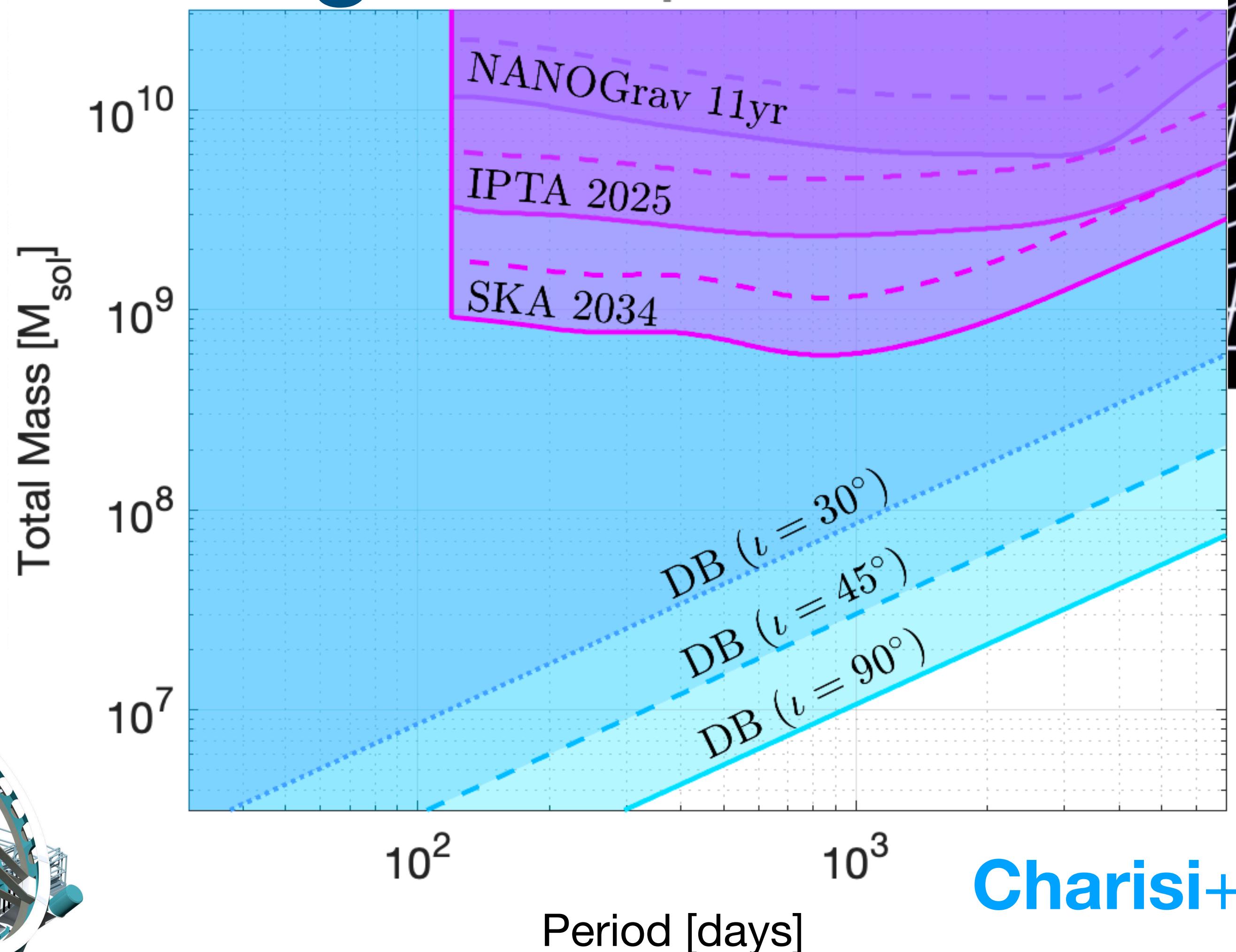
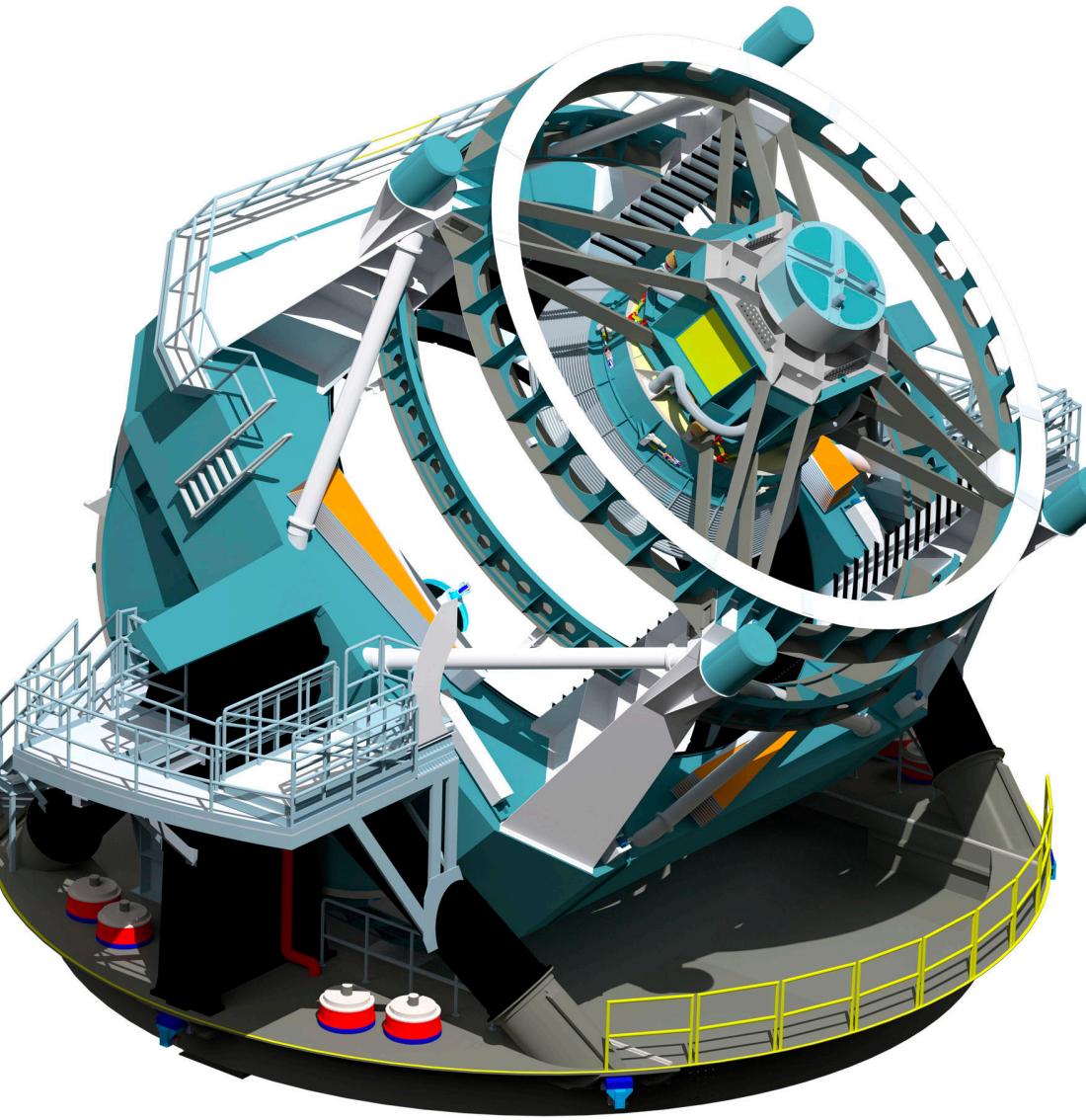
- Find GWs
- Find the host galaxy
- Find EM candidates
- Targeted search to find GWs

D'Orazio, Charisi, 2023
(adapted from Liu+2021)



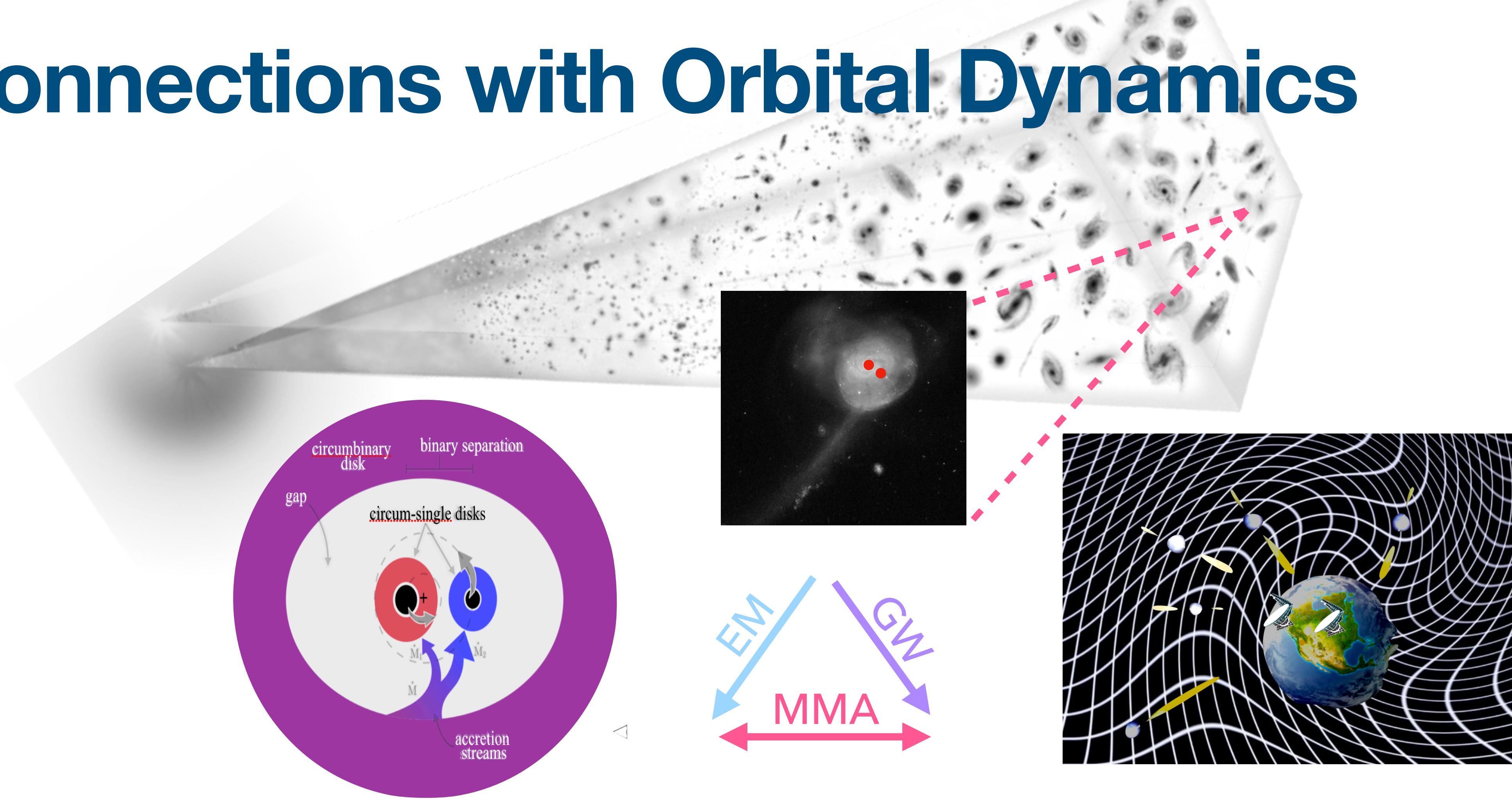
- PTA sensitivity increases with targeted searches.
- Caution is needed when targeting false positives.

Multi-messenger Binaries



- Time-domain surveys & PTAs probe the same population.
- Joint observations are possible for a variety of binaries.

Connections with Orbital Dynamics

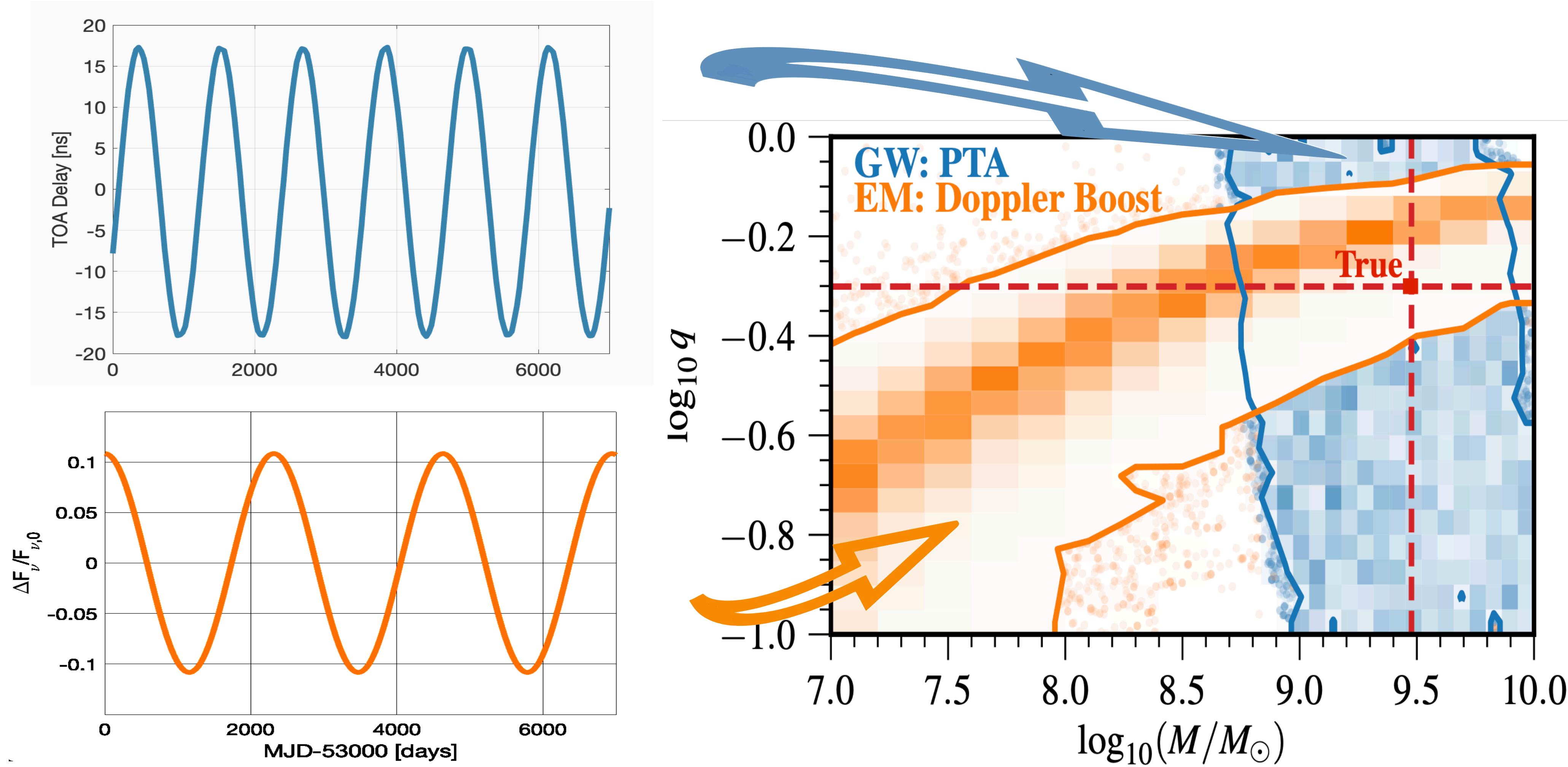


Model	Period	Amplitude	Phase
Doppler Boost	😊	😊	😐
Periodic Accretion ($q < 0.4$)	😊	😢	😢
Periodic Accretion ($q > 0.4$)	😐	😢	😢

- In the Doppler boost model, we can connect most of the parameters to the GW signal.

Charisi+2022

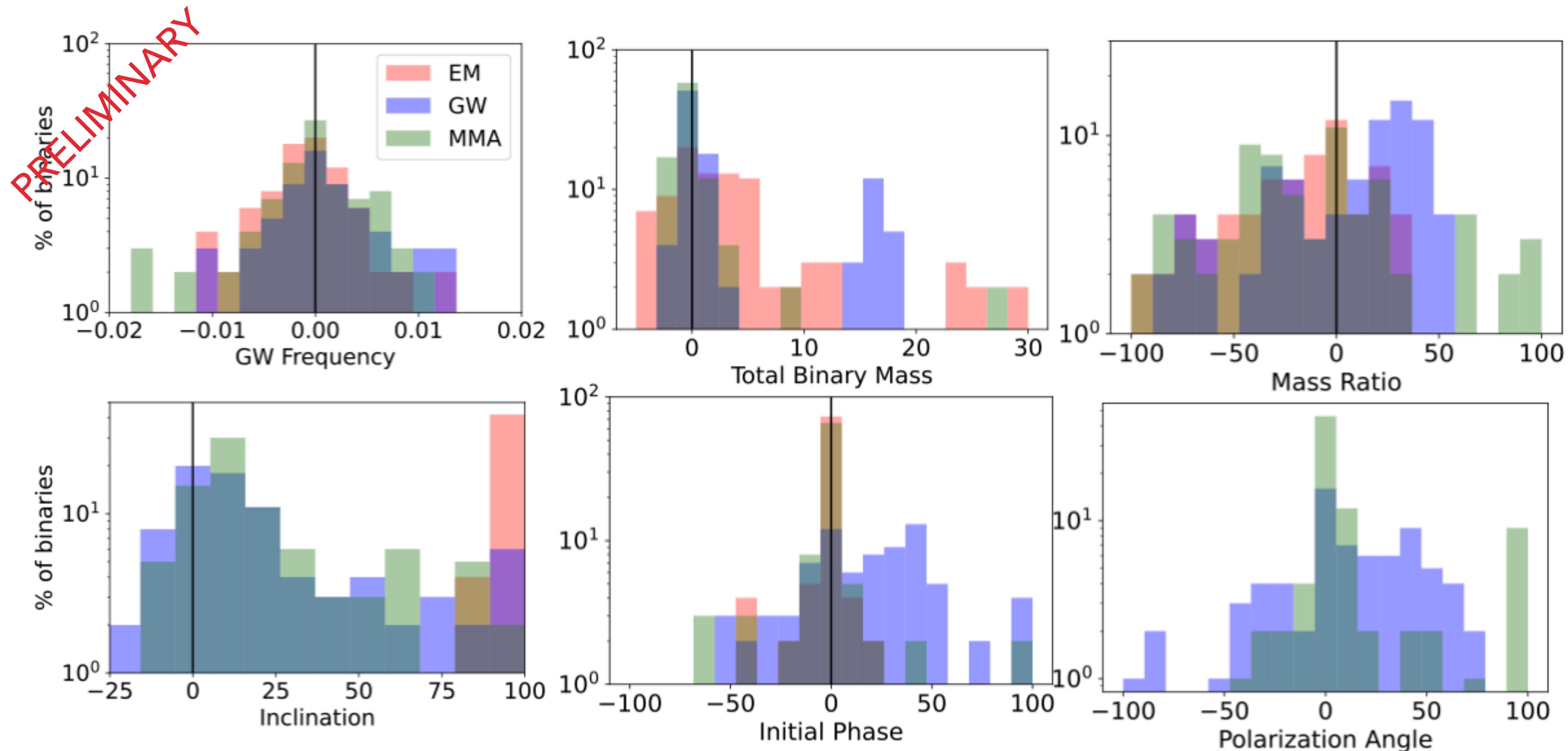
Multi-messenger observations



Charisi+in prep

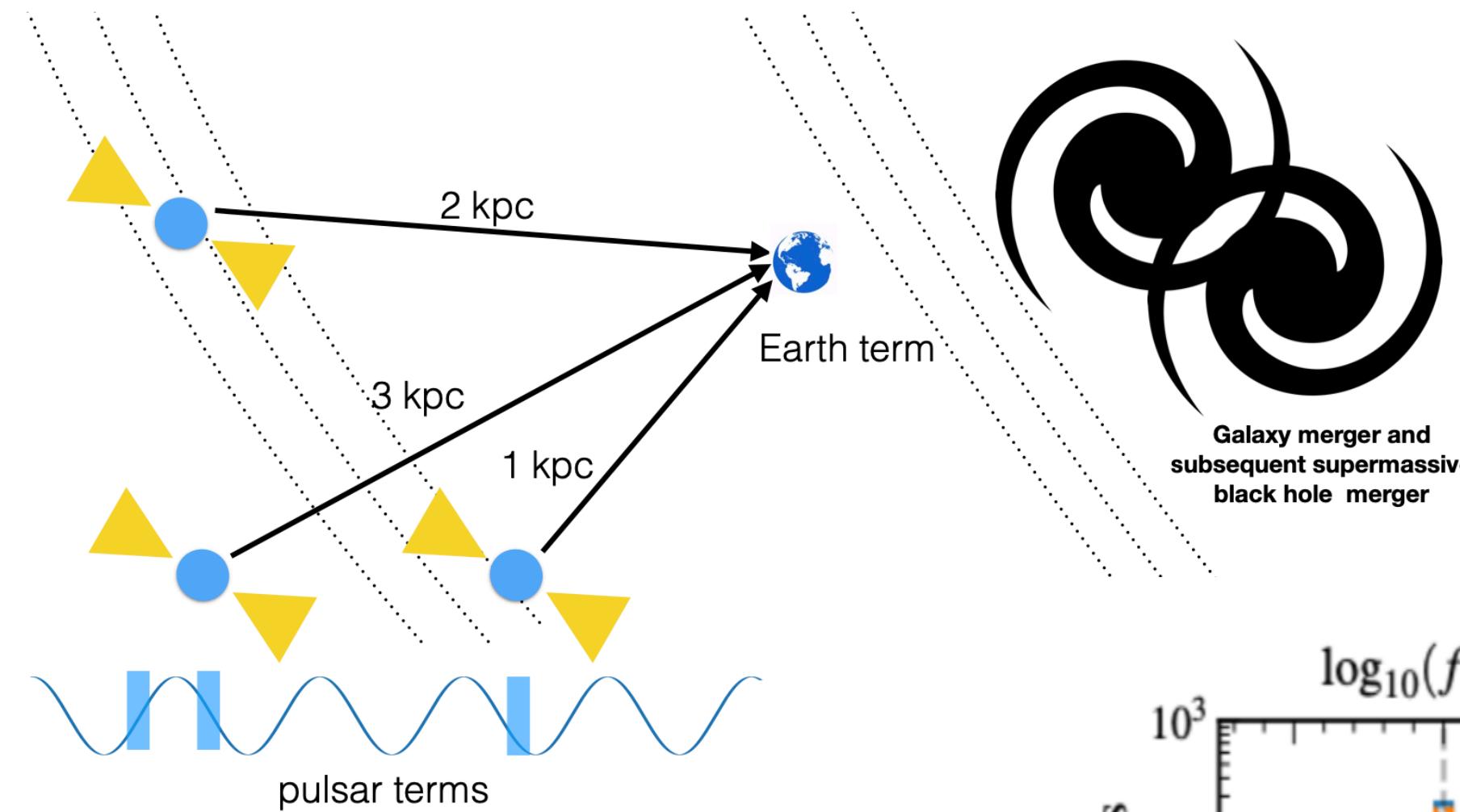
- EM and GW signals have different dependencies on different parameters.

Multi-messenger constraints



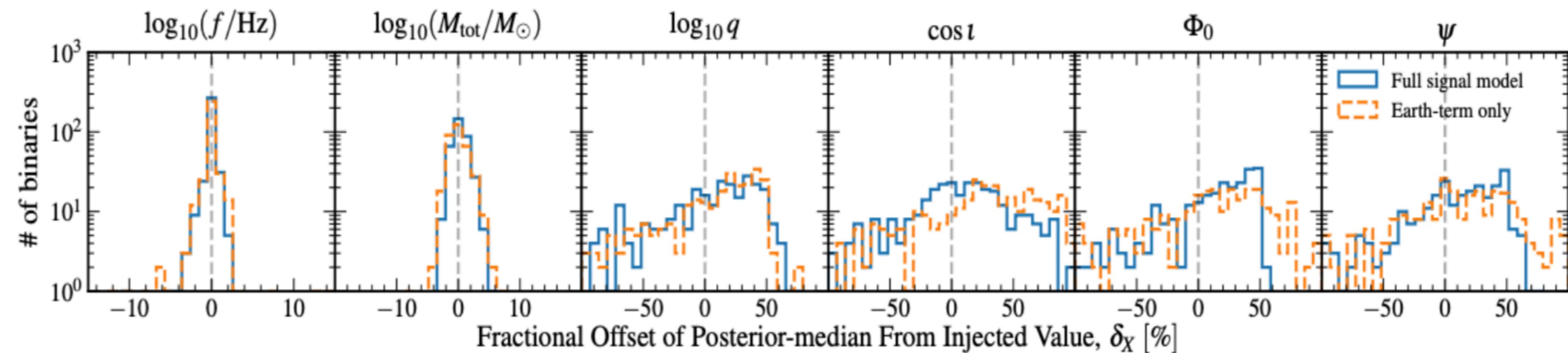
- Joint observations improve the parameter constraints. **Charisi+in prep**
- Better constraints than using EM priors.

Targeted Searches

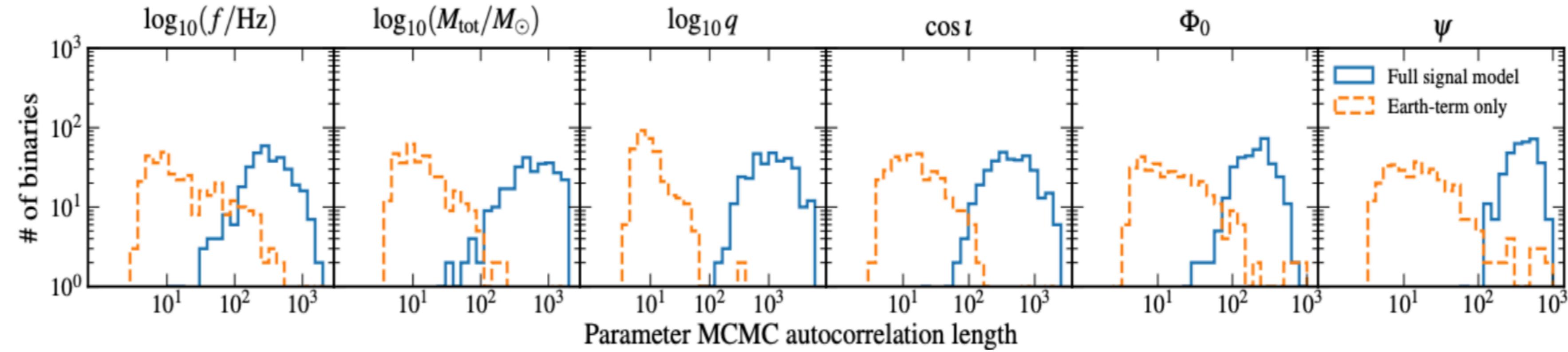


- PTA signal = Earth Term+ Pulsar Terms

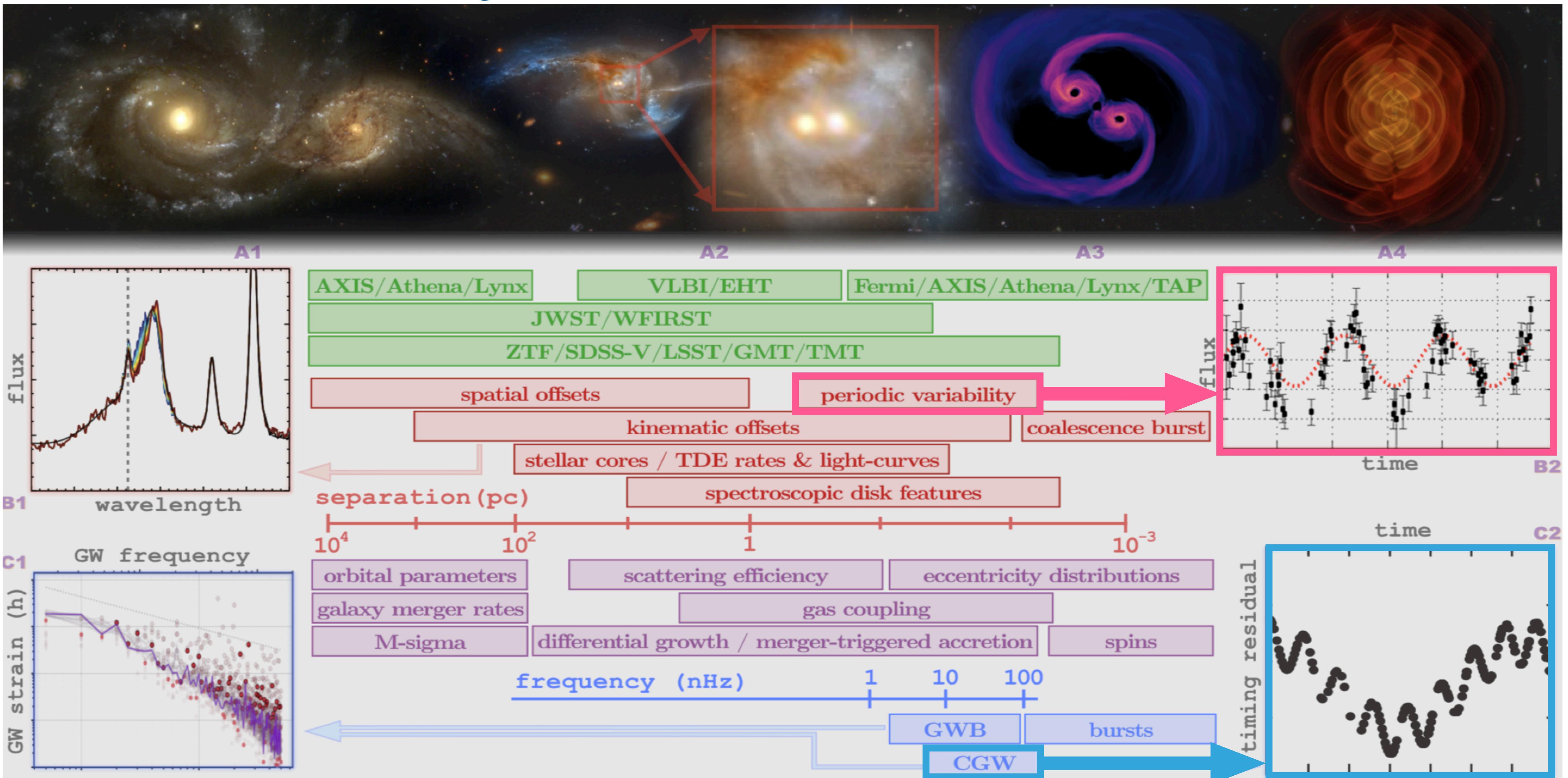
Charisi+2024



- In targeted searches, Earth term gives similar parameter constraints, but it is much faster.



Multi-messenger Observations with PTAs



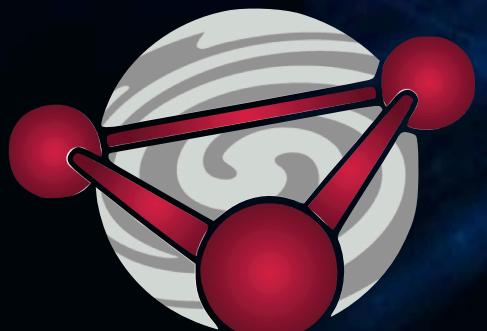
Summary

- Binaries can be identified as quasars with periodic variability. ~250 candidates, but hard to confirm.
- LSST will provide the best dataset for binary searches.
- Individually resolvable binaries should be detected soon after the background and are promising sources for multi-messenger observations.
- PTAs and time-domain surveys probe the same population of binaries. The common parameter space expands as PTA sensitivity improves.
- Multi-messenger searches provide better parameter estimates.
- Targeted searches can be much faster by omitting the pulsar term.

Photometric Searches for Binaries & Multi-messenger Prospects

THANK YOU!

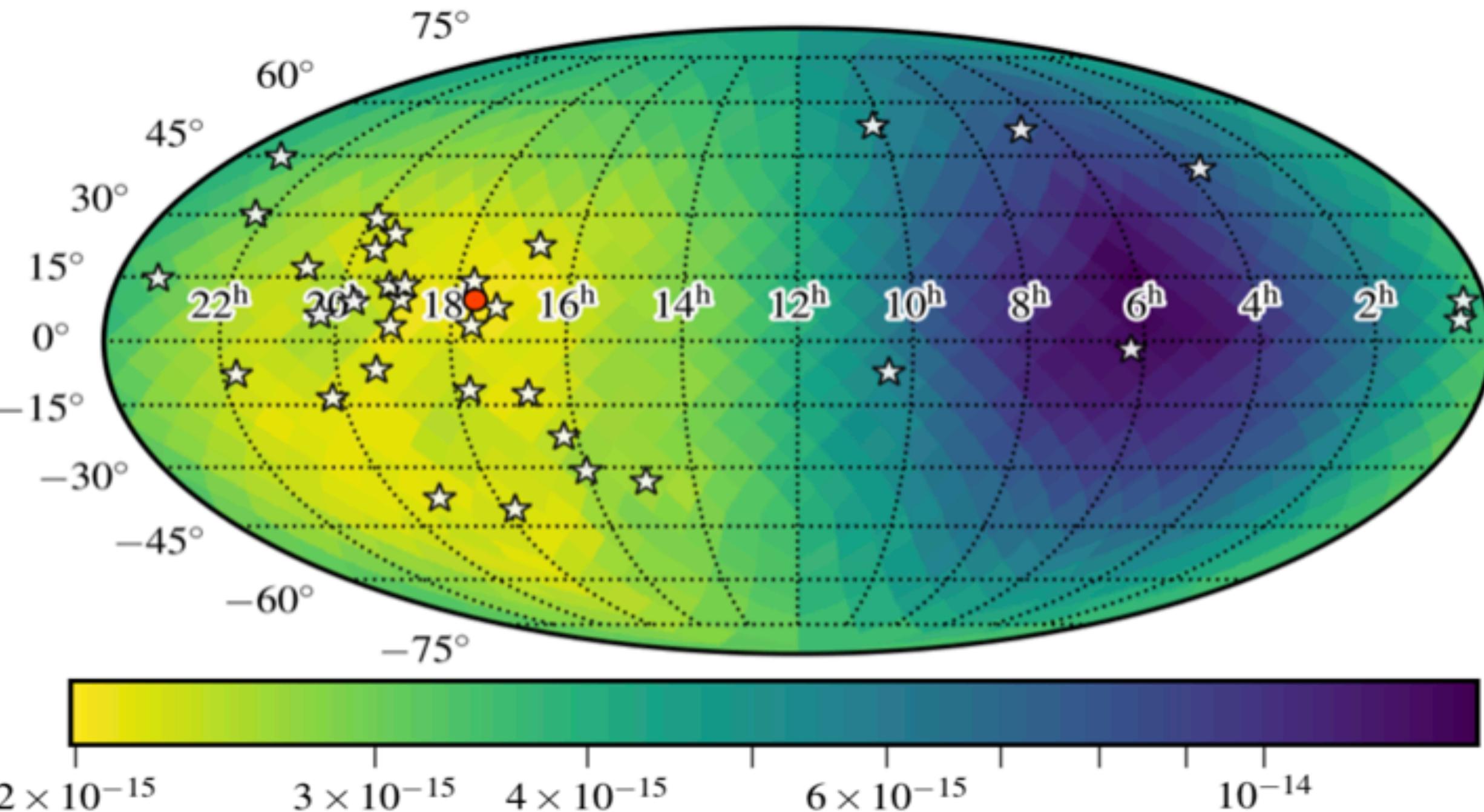
maria.charisi@wsu.edu



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Constraints on nearby galaxies



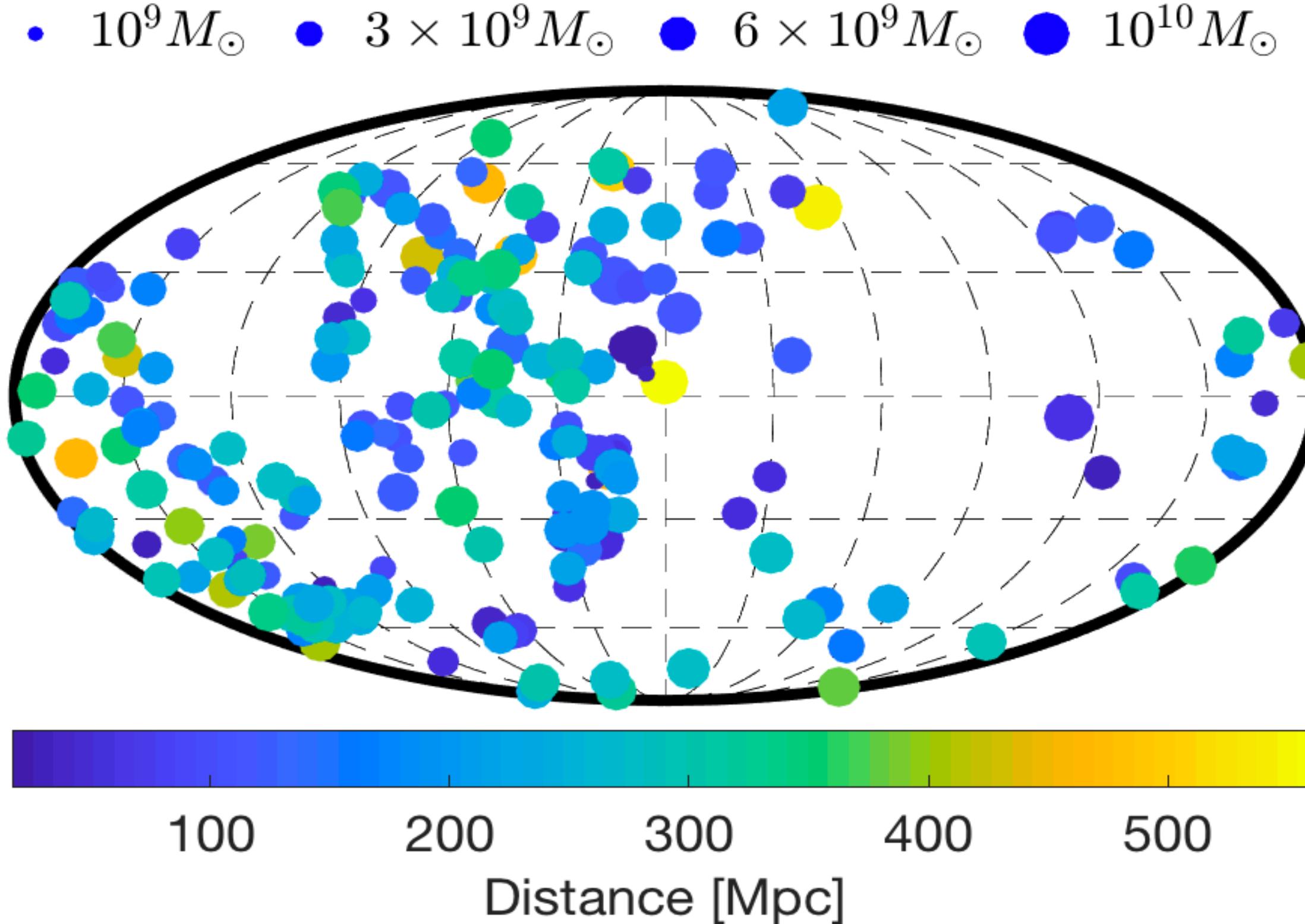
- Upper limits based on the NANOGrav 11yr dataset.

- Census of nearby massive galaxies.
- 45,000 galaxies enhanced with important quantities for GW detection.

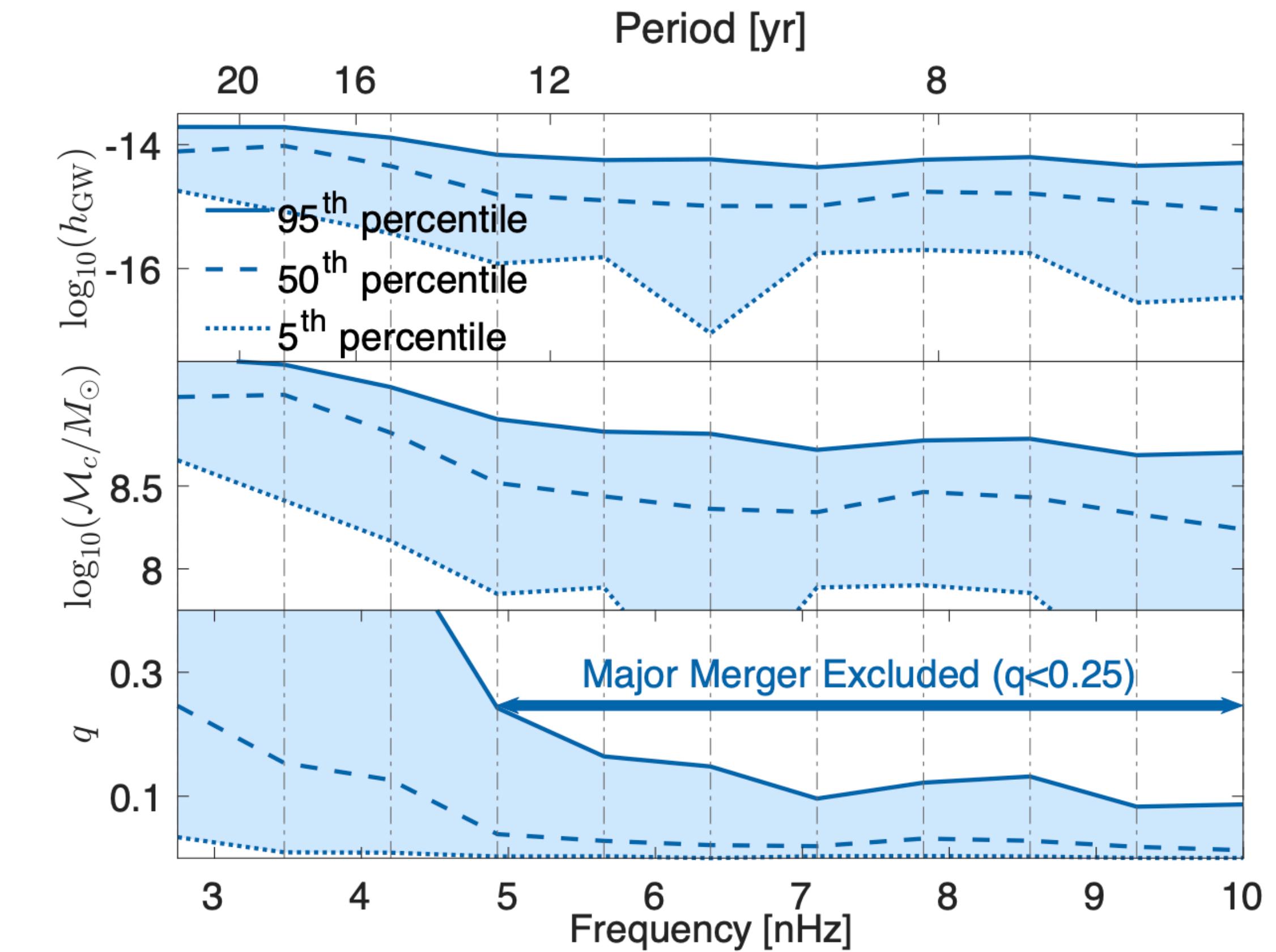
Aggarwal+2020

Arzoumanian+2021, *led by Charisi

Constraints on nearby galaxies



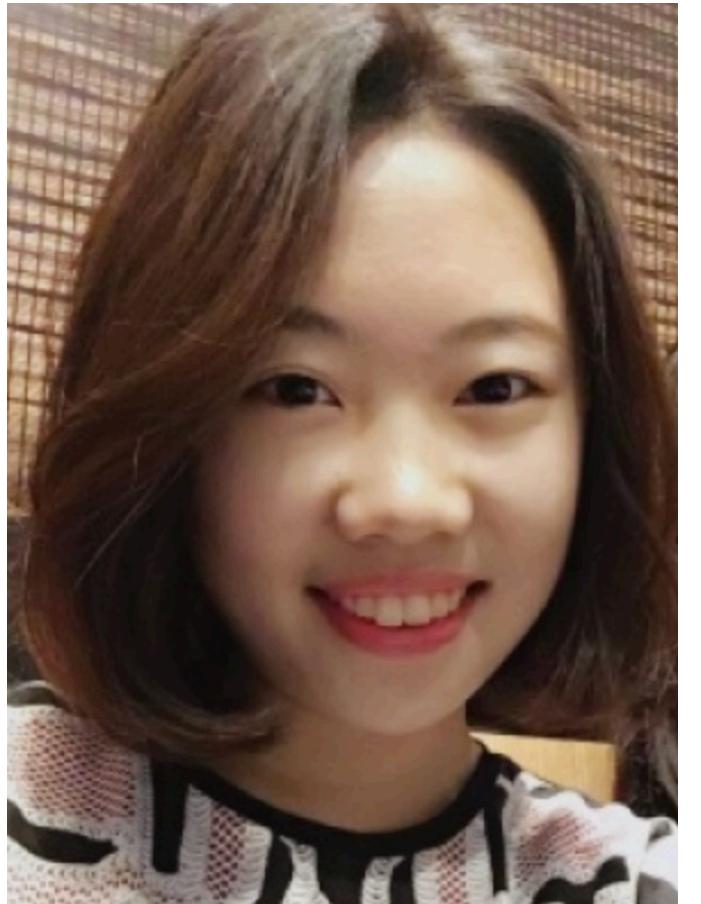
- 200 massive galaxies in the NANOGrav volume.



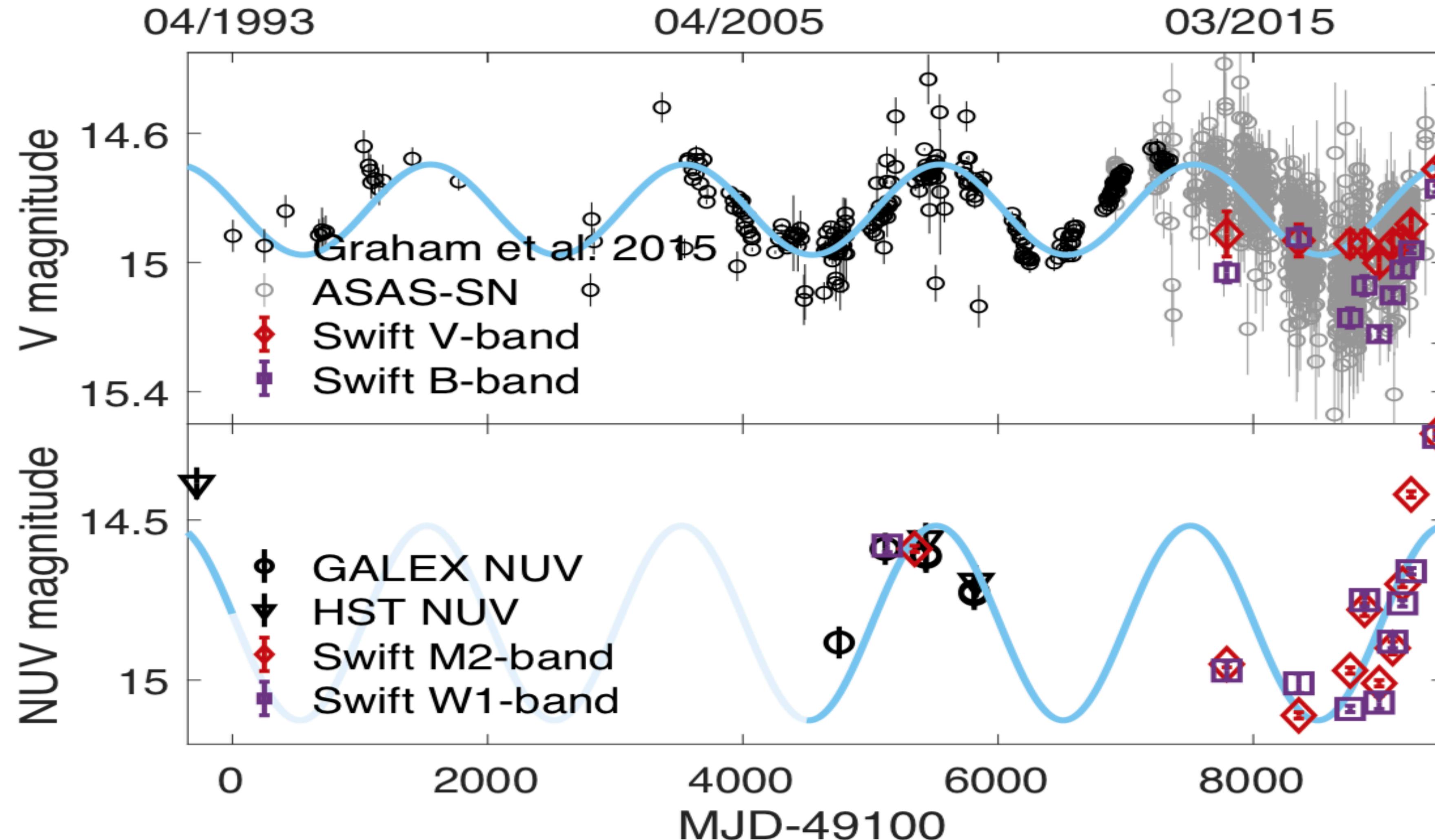
- Constraints on mass ratio comparable to Milky Way.

Doppler Boost for PG1302

Charisi (Science PI): Swift C13-C14



Chengcheng Xin
(UG at Columbia
→ grad student
at Columbia)



- PG1302 consistent with relativistic Doppler boost. Xin, Charisi+2020a
- Quasars have wavelength-dependent variability. Charisi+2018 Xin, Charisi+2020a