MULTI-MESSENGER OBSERVATIONS OF SUPERMASSIVE BH BINARIES +THEIR GW BACKGROUND

MARIA CHARISI

(VIDA FELLOW)

VANDERBILT UNIVERSITY

LSST AGN Science Collaboration

INTERNATIONAL PULSAR TIMING ARRAY IPTA

NANOGrav Physics Frontiers Center

The restless nature of AGN:10 years later

Naples, June 29 2023

A NEW WINDOW ONTO THE GW UNIVERSE

[37] arXiv:2306.16213 [pdf, other]

The NANOGrav 15-year Data Set: Evidence for a Gravitational-Wave Background

Gabriella Agazie, Akash Anumarlapudi, Anne M. Archibald, Zaven Arzoumanian, Paul T. Baker, Bence Becsy, Laura Blecha, Adam Brazier, Paul R. Brook, Sarah Burke-Spolaor, Rand Burnette, Robin Case, Maria Charisi, Shami Chatterjee, Katerina Chatziioannou, Belinda D. Cheeseboro, Siyuan Chen, Tyler Cohen, James M. Cordes, Neil J. Cornish, Fronefield Crawford, H. Thankful Cromartie, Kathryn Crowter, Curt J. Cutler, Megan E. DeCesar, Dallas DeGan, Paul B. Demorest, Heling Deng, Timothy Dolch, Brendan Drachler, Justin A. Ellis,

[38] arXiv:2306.16214 [pdf, other]

The second data release from the European Pulsar Timing Array III. Search for gravitational wave signals

J. Antoniadis, P. Arumugam, S. Arumugam, S. Babak, M. Bagchi, A.-S. Bak Nielsen, C. G. Bassa, A. Bathula, A. Berthereau, M. Bonetti, E. Bortolas, P. R. Brook, M. Burgay, R. N. Caballero, A. Chalumeau, D. J. Champion, S. Chanlaridis, S. Chen, I. Cognard, S. Dandapat, D. Deb, S. Desai, G. Desvignes, N. Dhanda-Batra, C. Dwivedi, M. Falxa, R. D. Ferdman, A. Franchini, J. R. Gair, B. Goncharov, A. Gopakumar, E. Graikou, J.-M. Grießmeier, L. Guillemot, Y. J. Guo, Y. Gupta, S. Hisano, H. Hu, F. Iraci, D. Izquierdo-Villalba, J. Jang, J. Jawor, G.

[39] arXiv:2306.16215 [pdf, other]

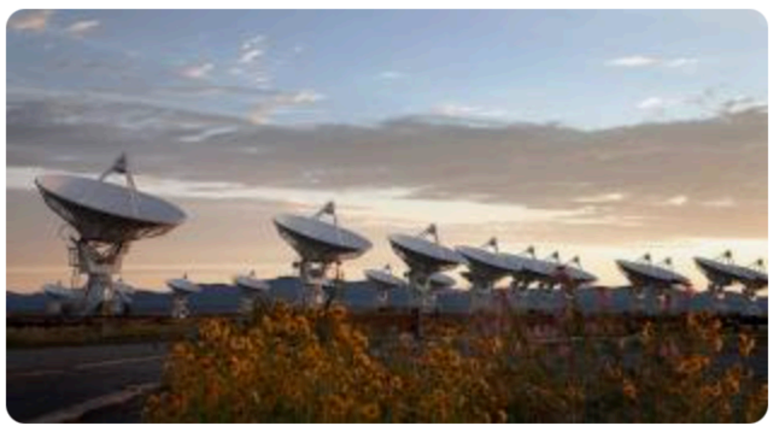
Search for an isotropic gravitational-wave background with the Parkes Pulsar Timing Array

Daniel J. Reardon, Andrew Zic, Ryan M. Shannon, George B. Hobbs, Matthew Bailes, Valentina Di Marco, Agastya Kapur, Axl F. Rogers, Eric Thrane, Jacob Askew, N. D. Ramesh Bhat, Andrew Cameron, Małgorzata Curyło, William A. Coles, Shi Dai, Boris Goncharov, Matthew Kerr, Atharva Kulkarni, Yuri Levin, Marcus E. Lower, Richard N. Manchester, Rami Mandow, Matthew T. Miles, Rowina S. Nathan, Stefan Osłowski, Christopher J. Russell, Renée Spiewak, Songbo Zhang, Xing-Jiang Zhu

[40] arXiv:2306.16216 [pdf, other]

Searching for the nano-Hertz stochastic gravitational wave background with the Chinese Pulsar Timing Array Data Release I

Heng Xu, Siyuan Chen, Yanjun Guo, Jinchen Jiang, Bojun Wang, Jiangwei Xu, Zihan Xue, R. Nicolas Caballero, Jianping Yuan, Yonghua Xu, Jingbo Wang, Longfei Hao, Jingtao Luo, Kejia Lee, Jinlin Han, Peng Jiang, Zhiqiang Shen, Min Wang, Na Wang, Renxin Xu, Xiangping Wu, Richard Manchester, Lei Qian, Xin Guan, Menglin Huang, Chun Sun, Yan Zhu



The New York Times

The Cosmos Is Thrumming With Gravitational Waves, Astronomers Find

8 hours ago

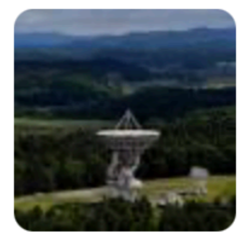
Jet Propulsion Laboratory

15 Years of Radio Data Reveals Evidence of Space-Time Murmur

8 hours ago

The Washington Post

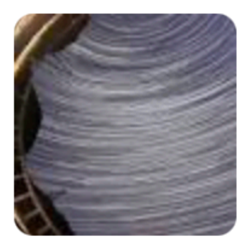
Astronomers announce major discovery about gravitational waves



5 hours ago

Nature

Monster gravitational waves spotted for first time



8 hours ago

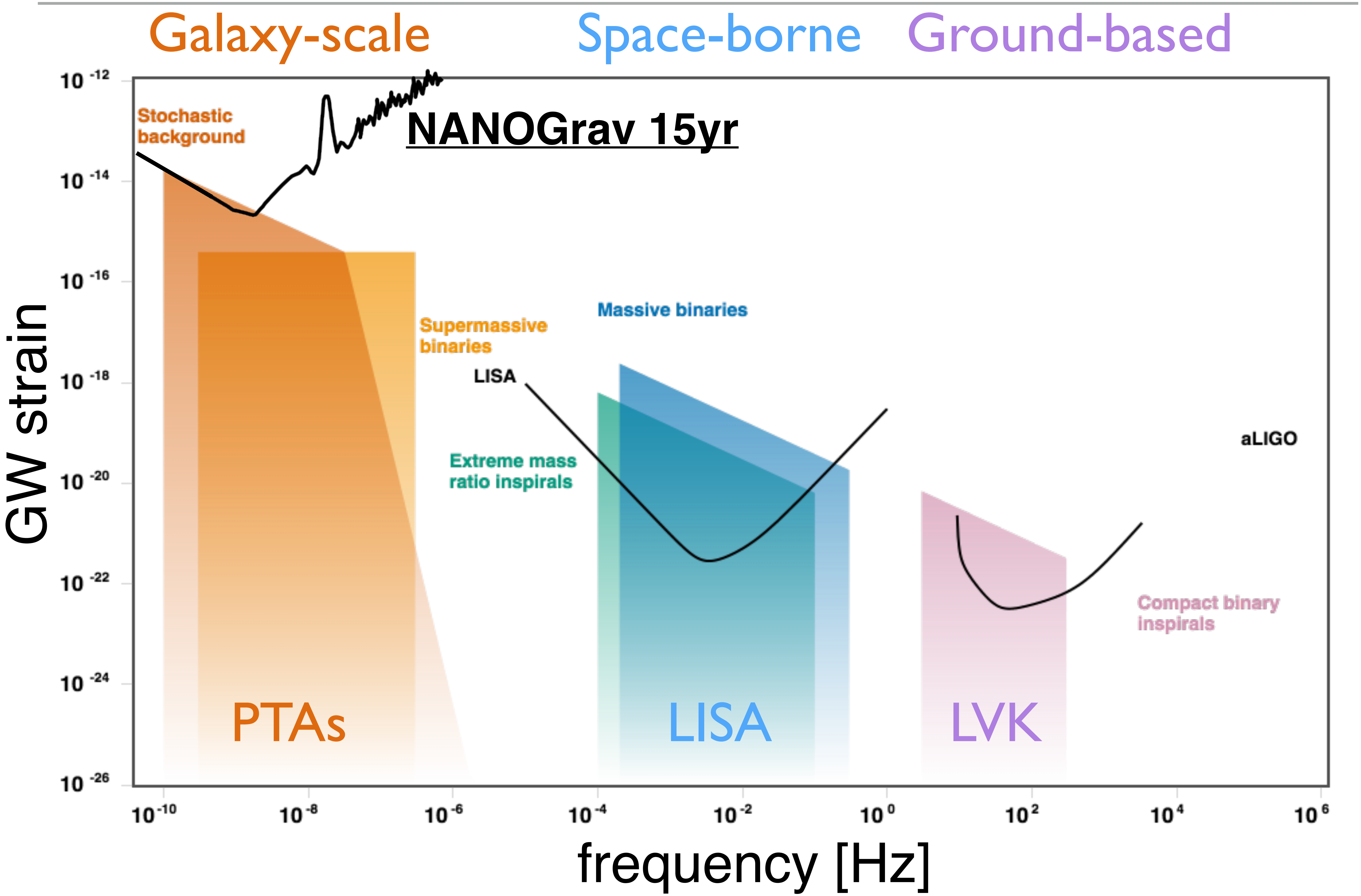
Quanta Magazine

An Enormous Gravity 'Hum' Moves Through the Universe

8 hours ago

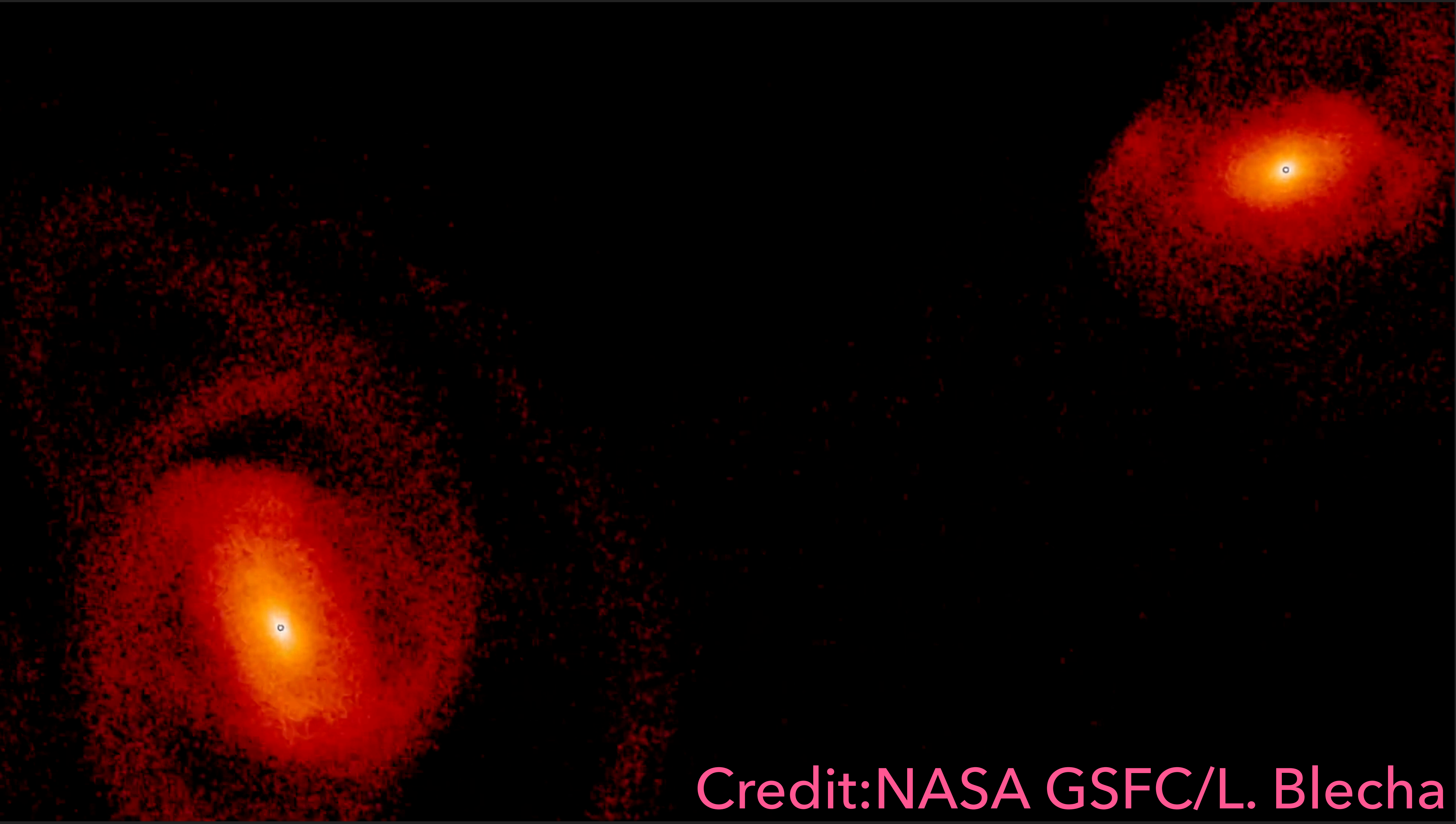
- Press event today at 7pm!!!
- Evidence for GW background.
- Found by all major PTAs.

GW SPECTRUM



Credit: Moore, Cole, Berry (2014) *[modified]*

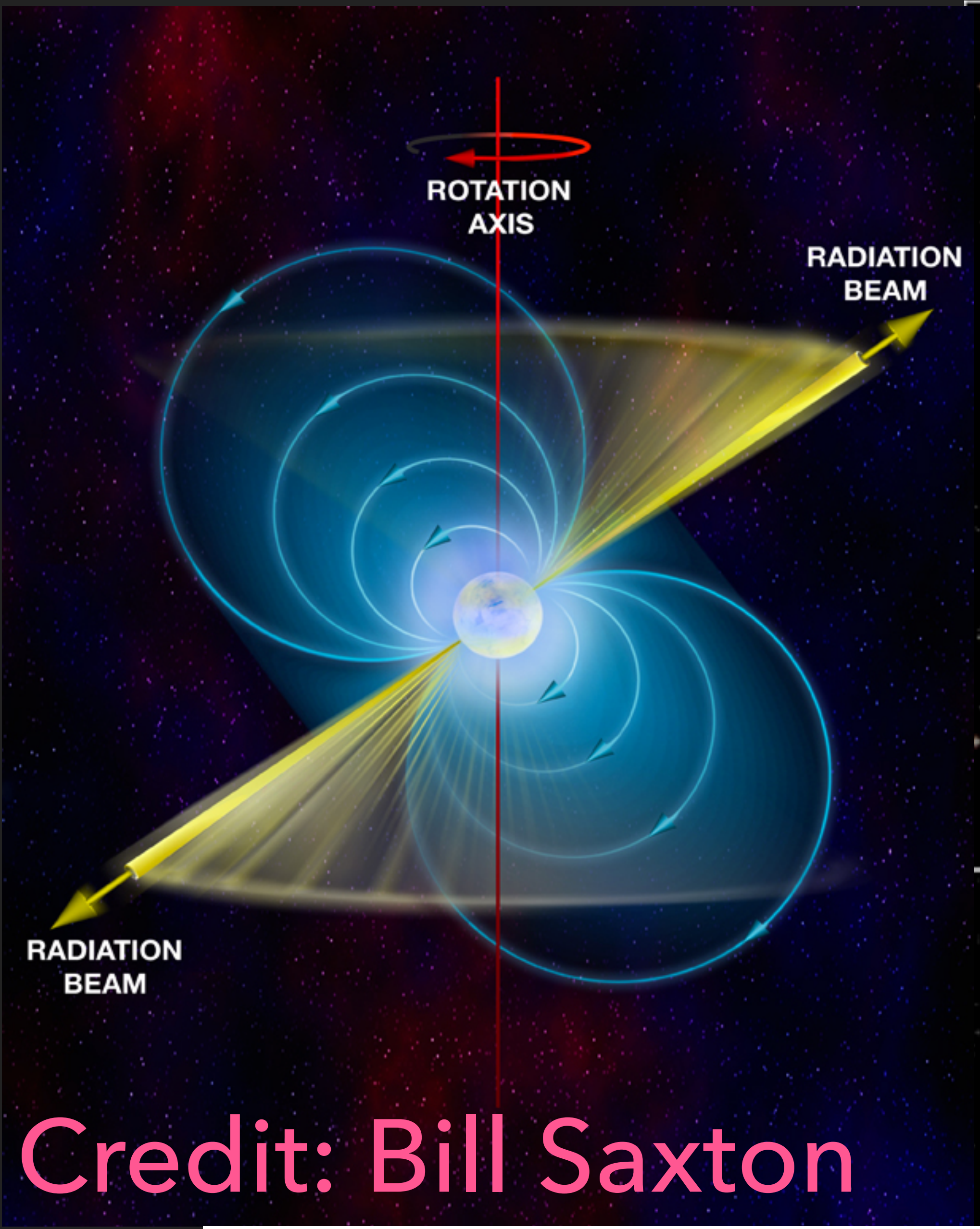
GALAXY MERGERS

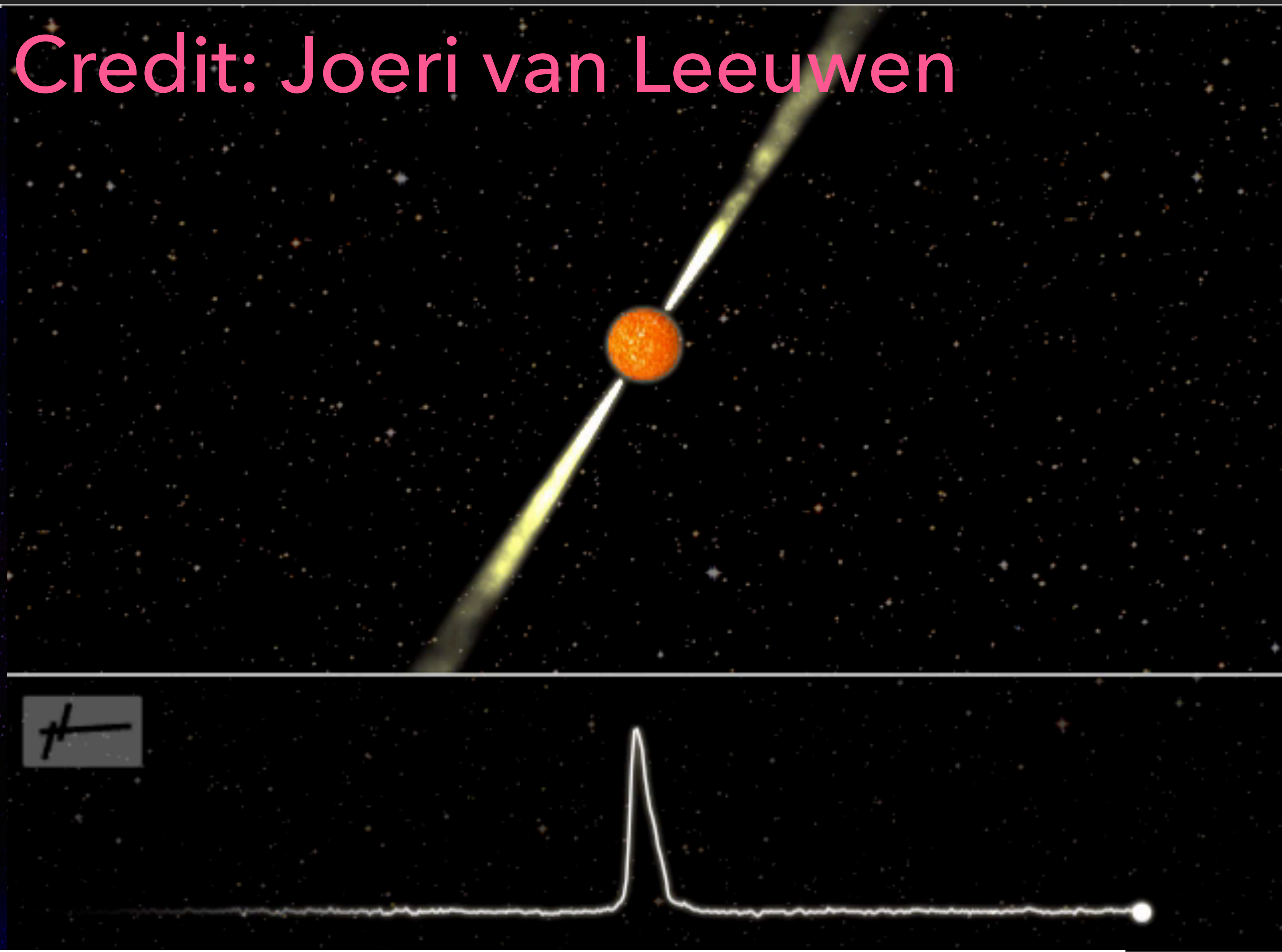


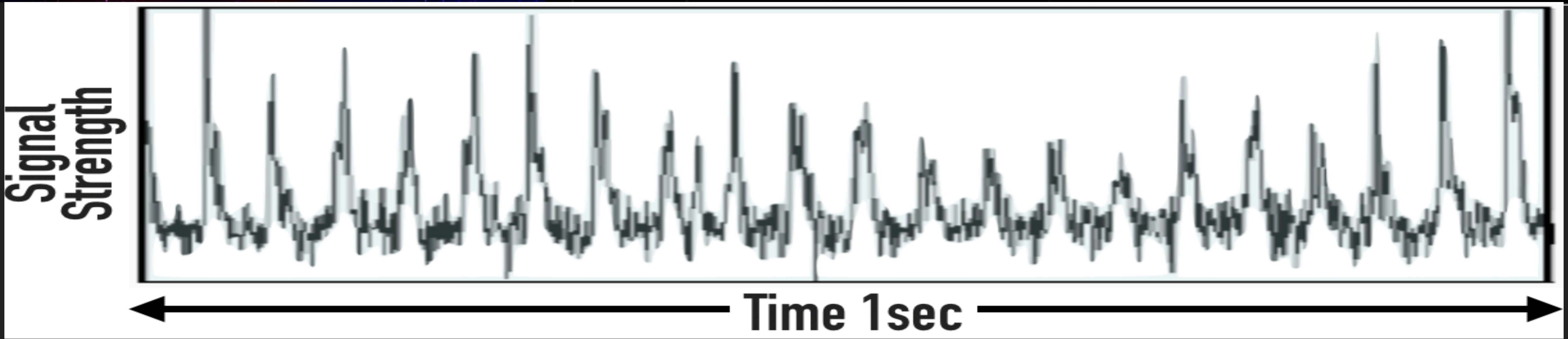
- SMBHBs should be fairly common.

STRONG SOURCES OF GRAVITATIONAL WAVES

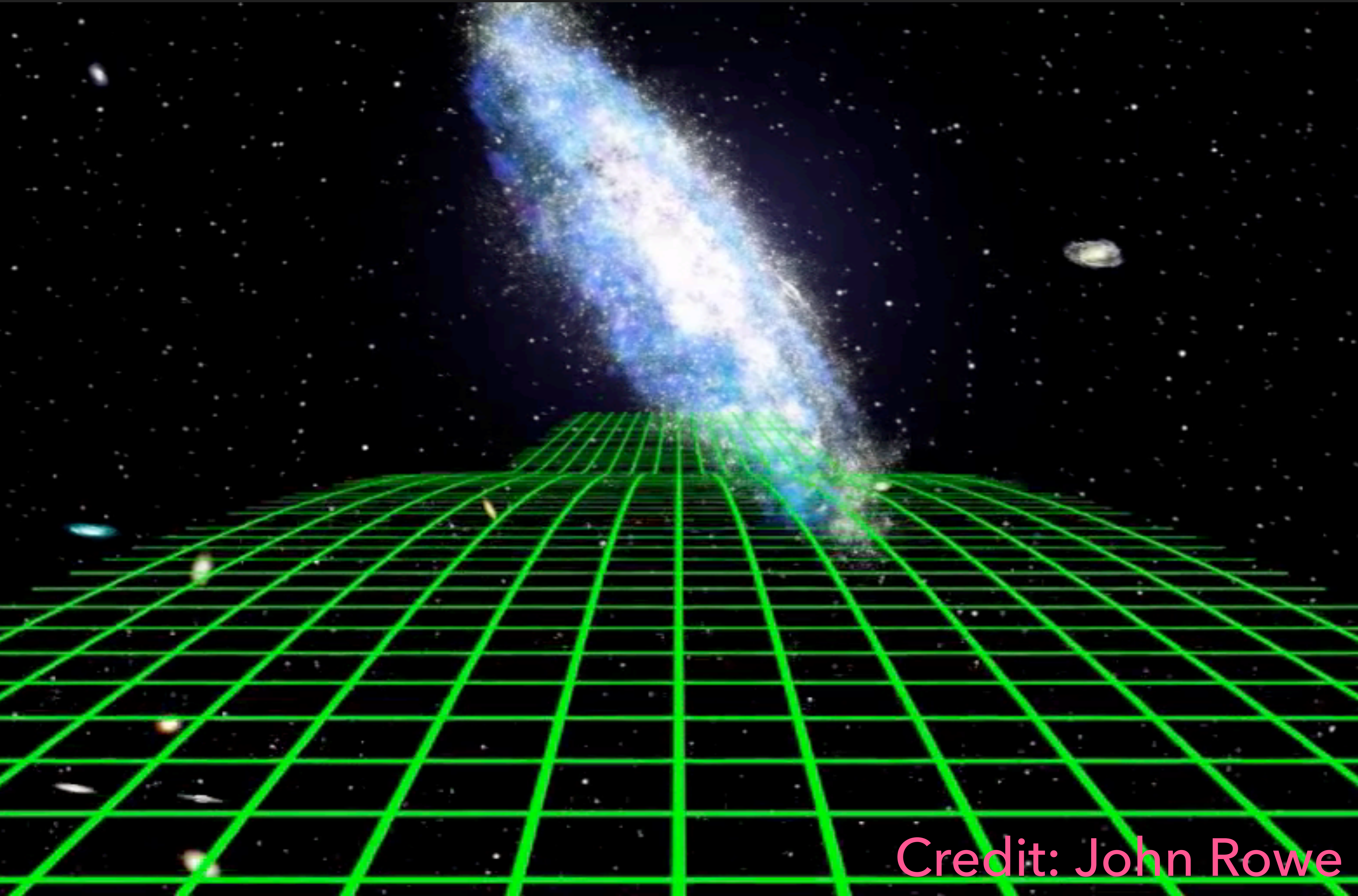
MILLISECOND PULSARS





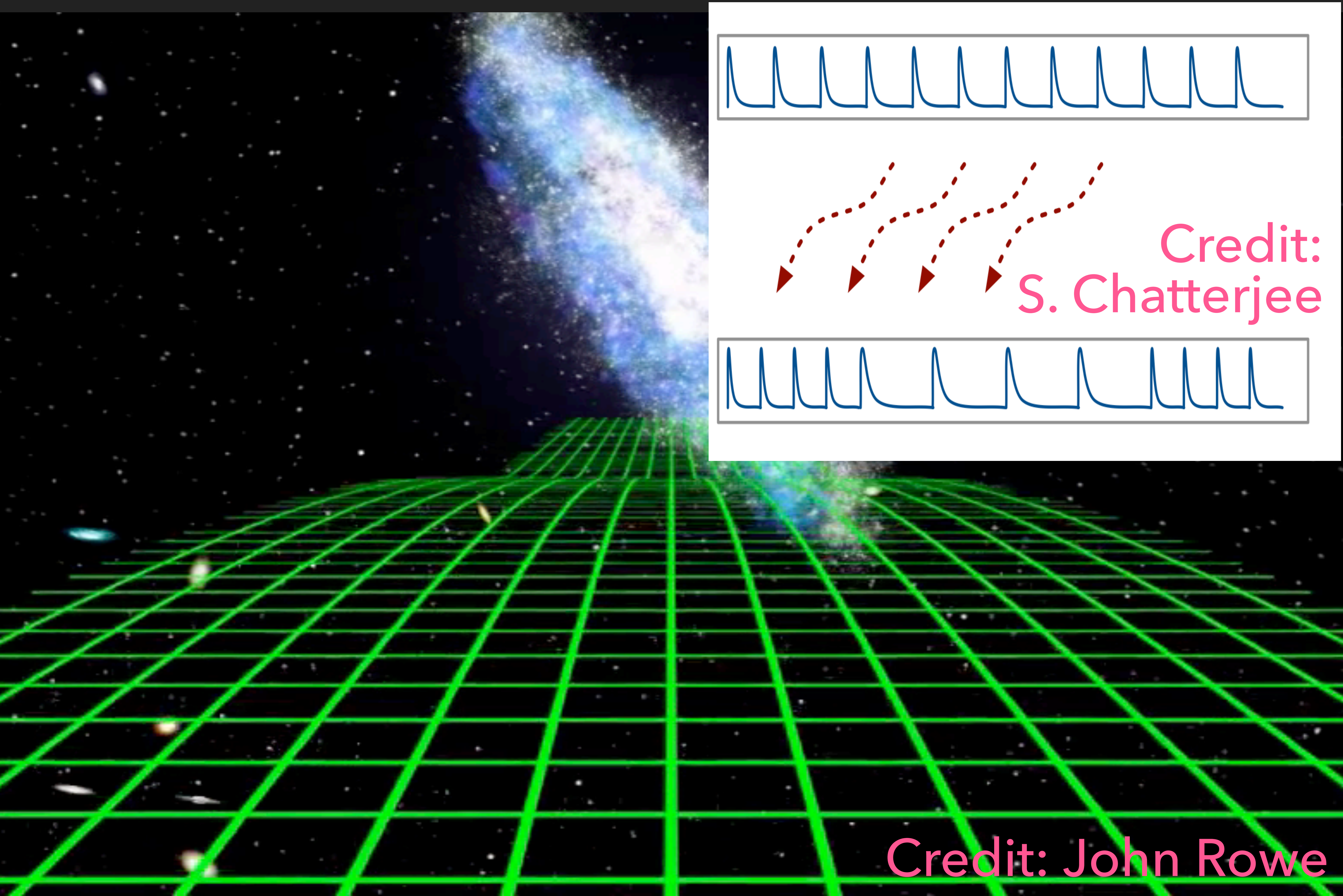


PULSAR TIMING ARRAYS

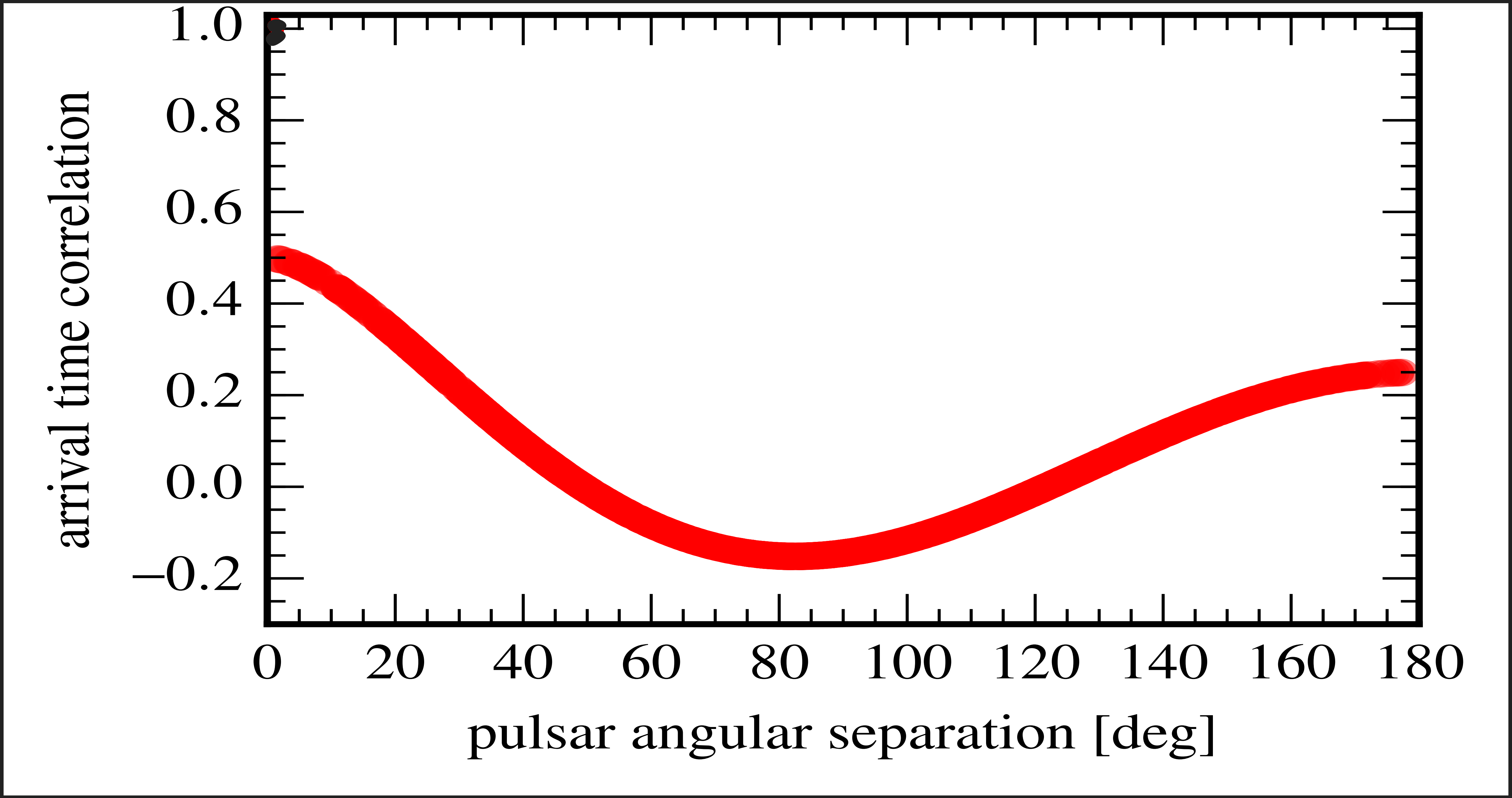


Credit: John Rowe

PULSAR TIMING ARRAYS

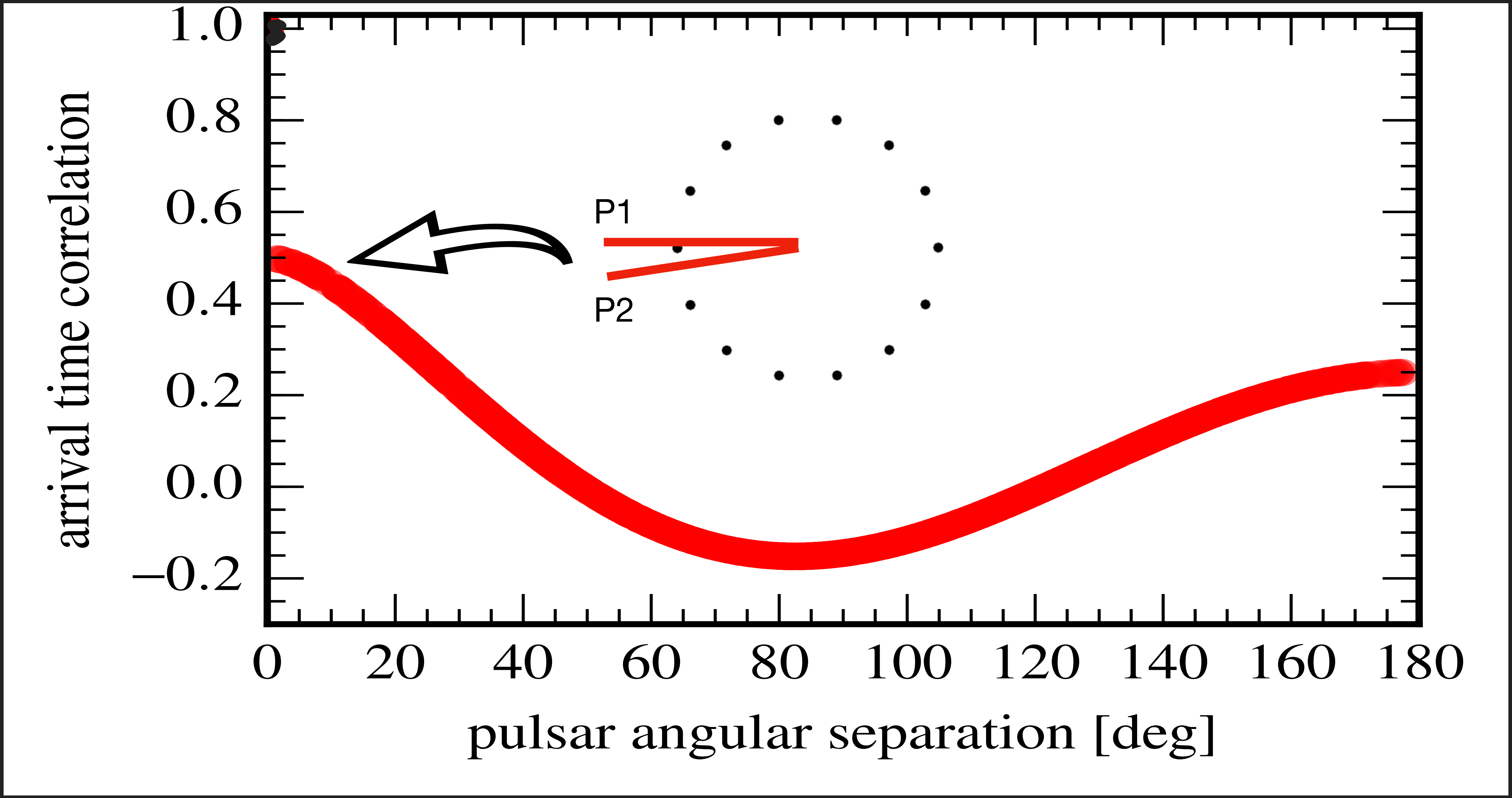


INTER-PULSAR CORRELATIONS



- Signal detected in many pulsars.
- Signal is spatially correlated with a characteristic quadrupolar pattern (Hellings-Downs curve).

INTER-PULSAR CORRELATIONS



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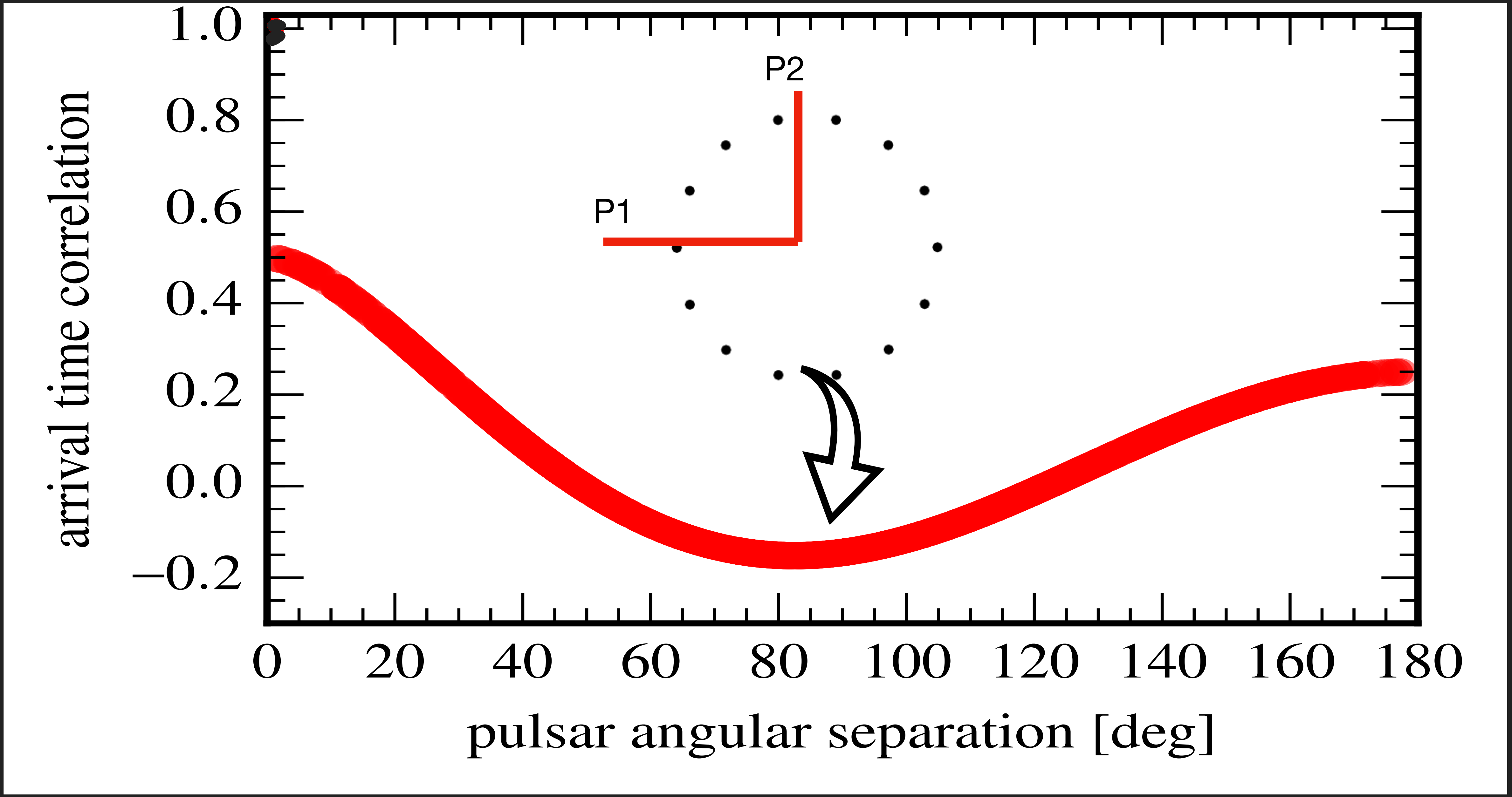

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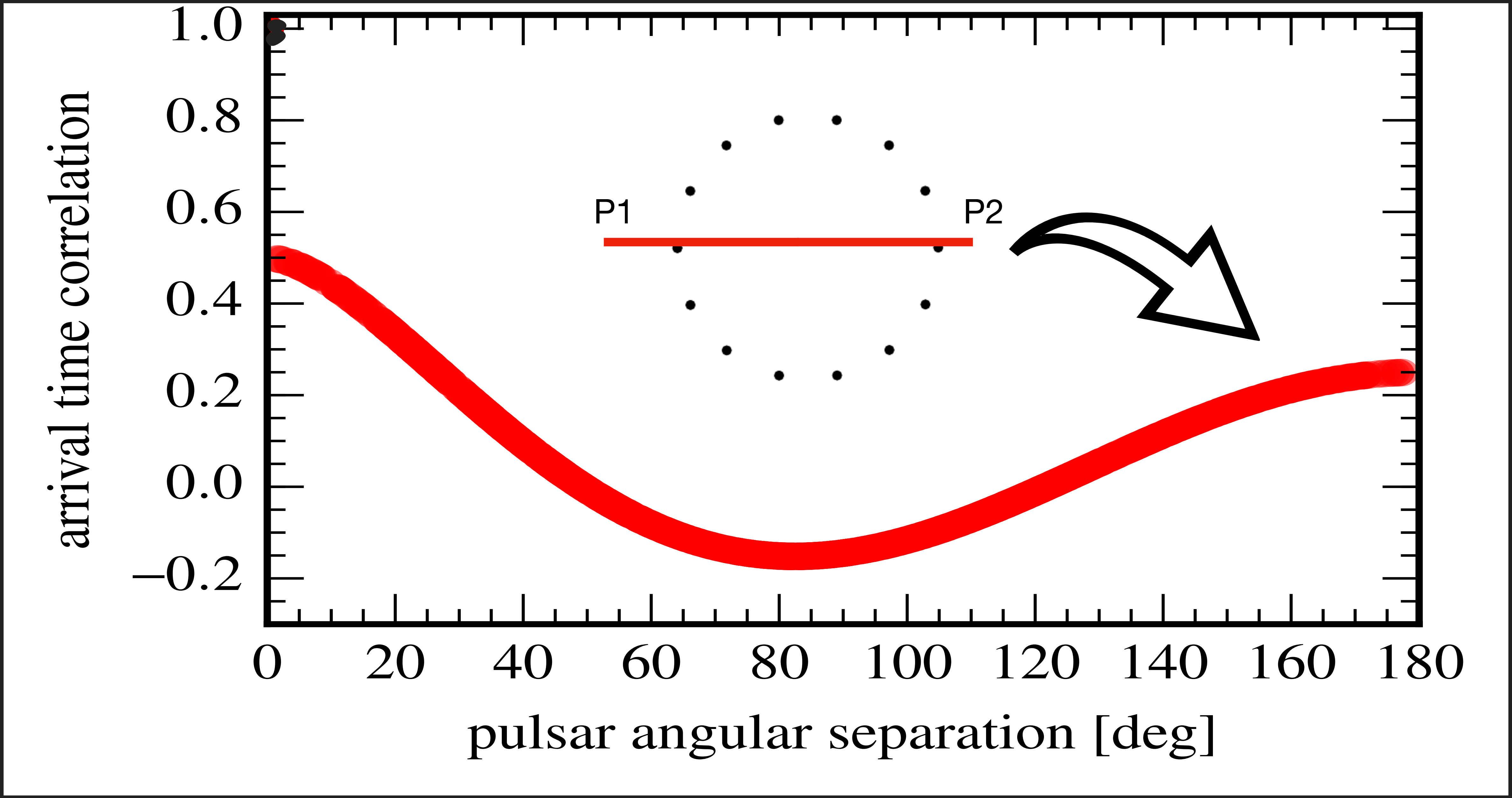
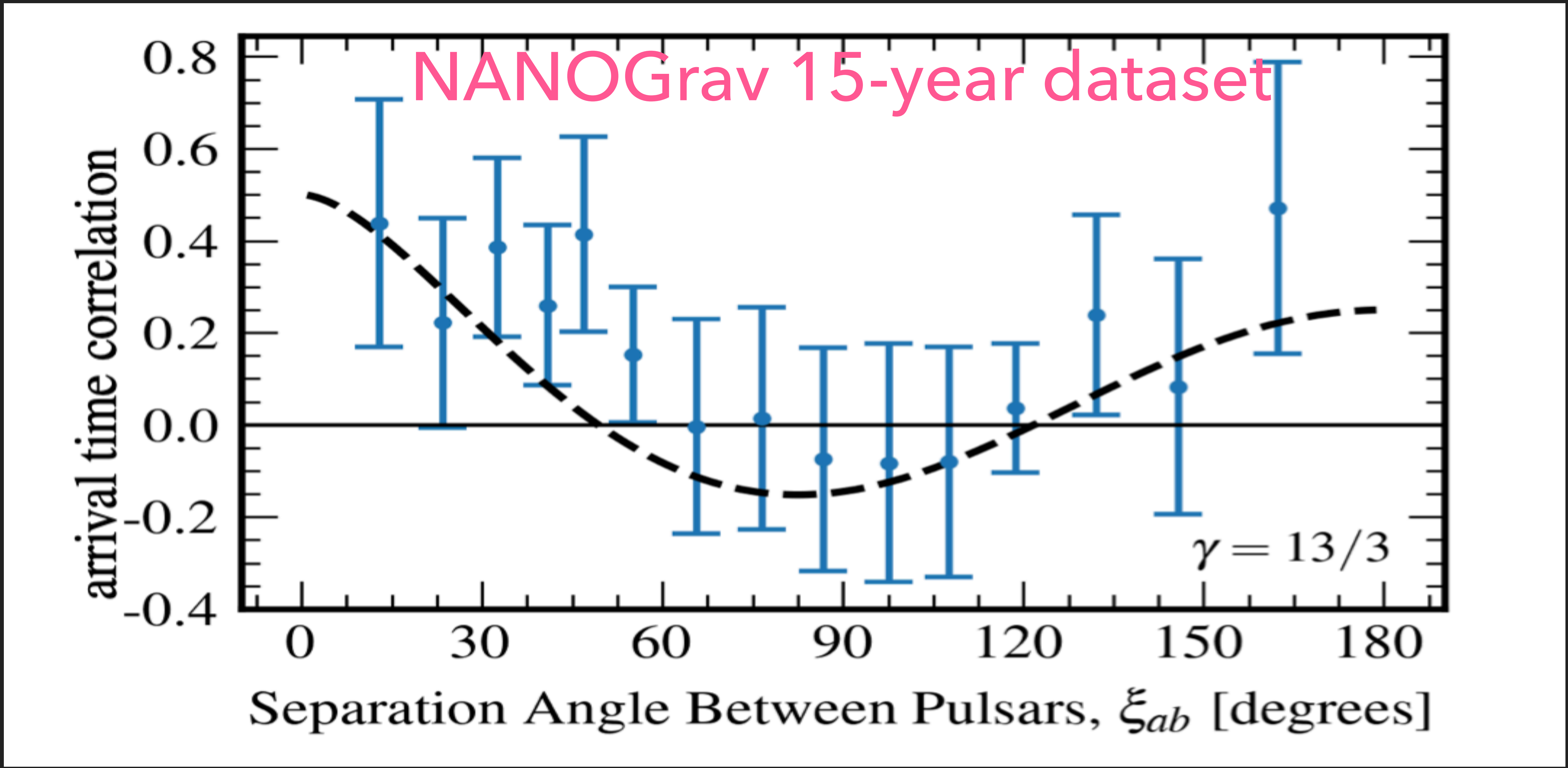
INTER-PULSAR CORRELATIONS



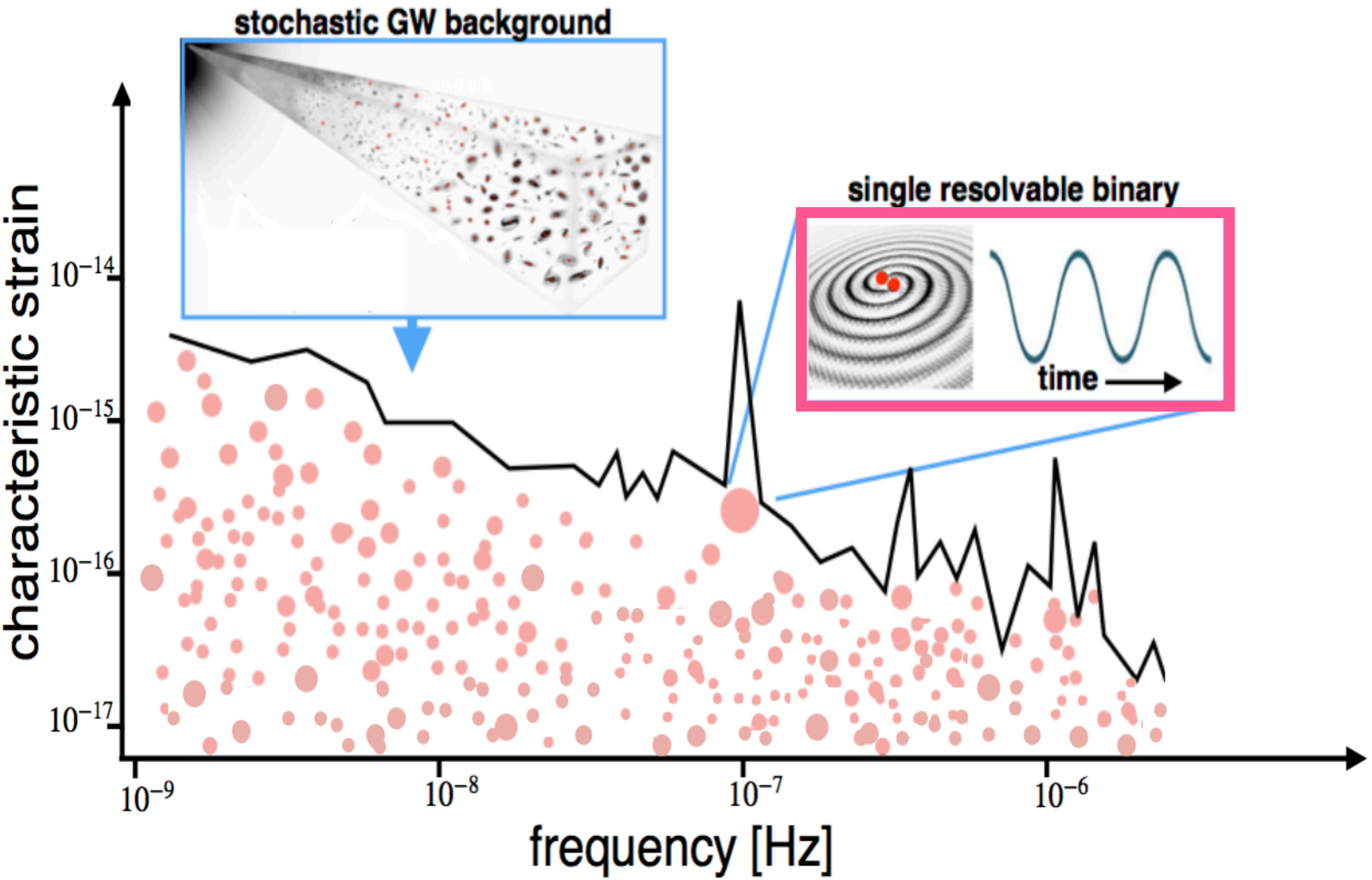
- Signal detected in many pulsars.
- Signal is spatially correlated with a characteristic quadrupolar pattern (Hellings-Downs curve).

PTAS FIRST-LIGHT

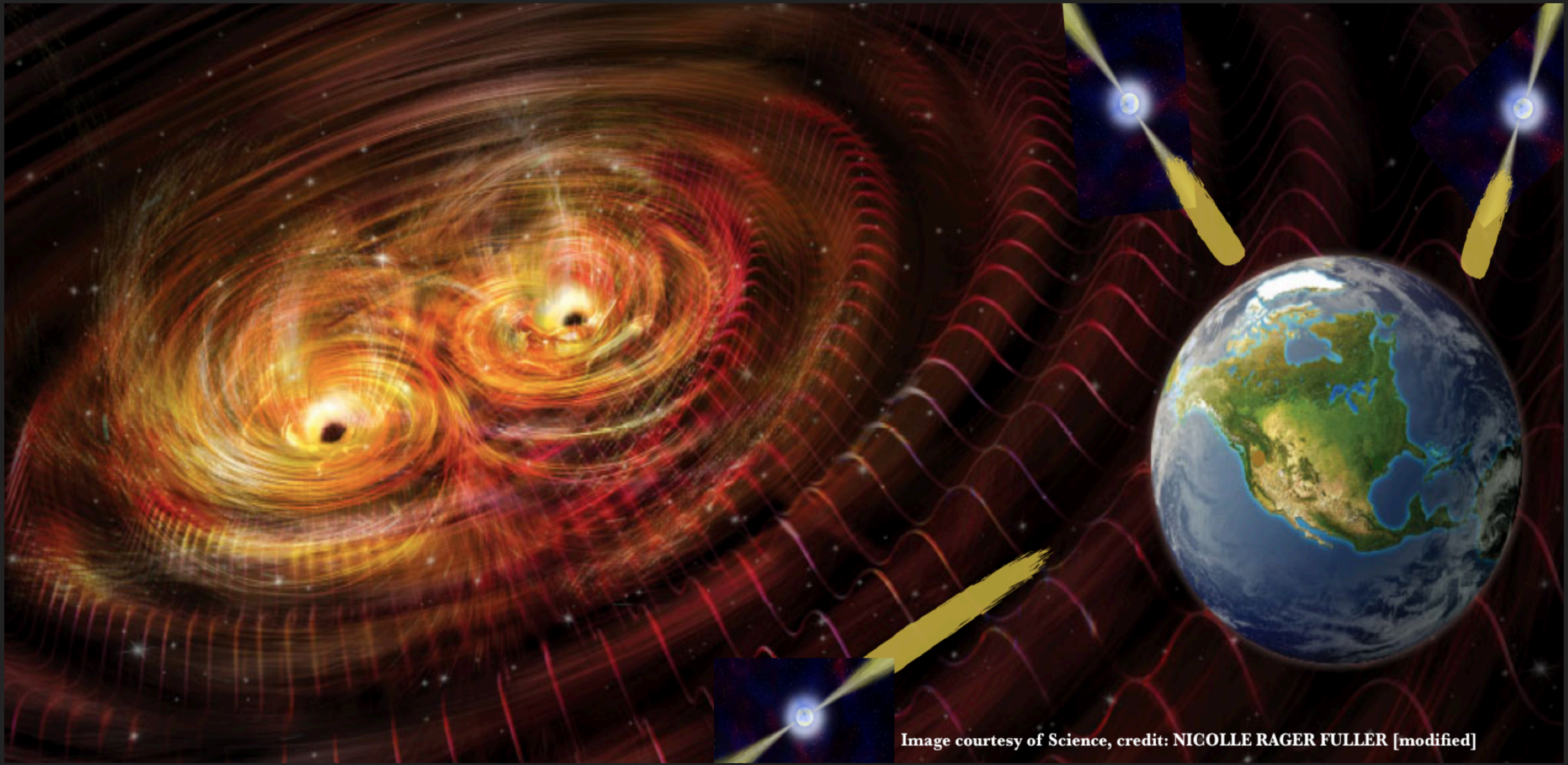


- Characteristic correlation pattern found with significance 3.5-4sigma.
- Consistent with SMBH binaries.

INDIVIDUALLY RESOLVED BINARIES

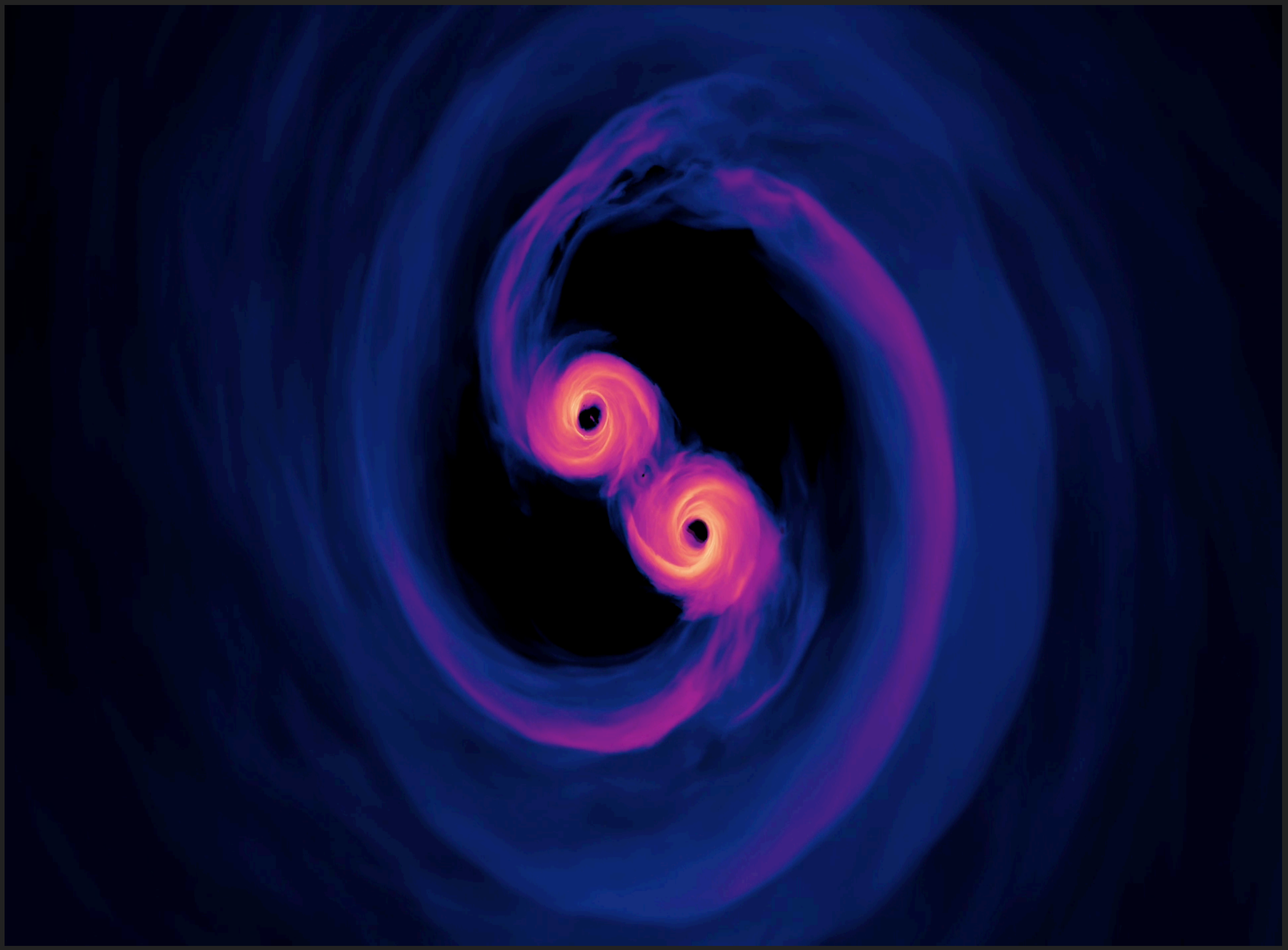


MULTI-MESSENGER OBSERVATIONS



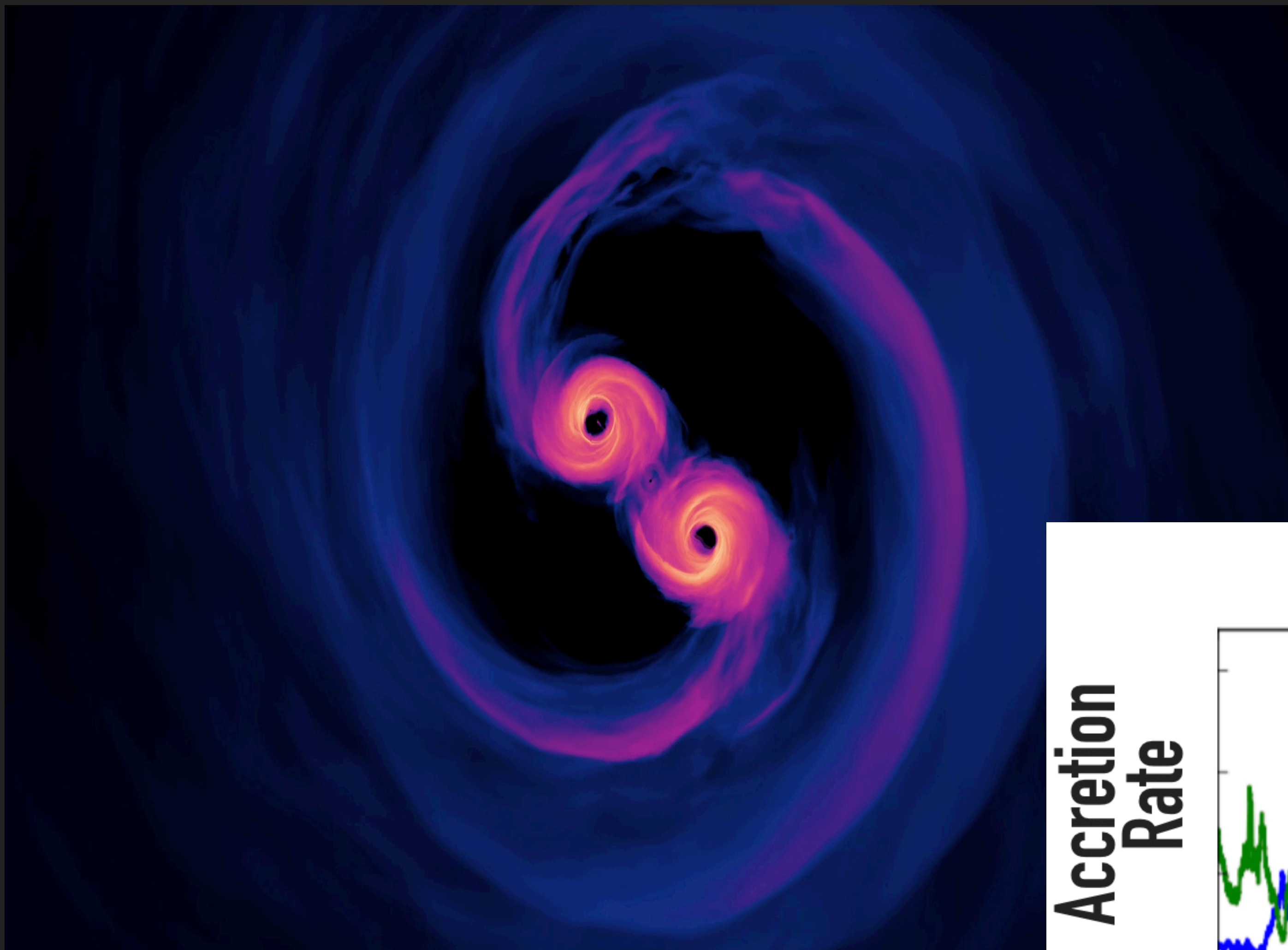
- GWs probe dynamics.
- EM obs. probe interaction with gas.
- Multi-messenger obs. provide the most complete picture.

QUASARS WITH PERIODIC VARIABILITY



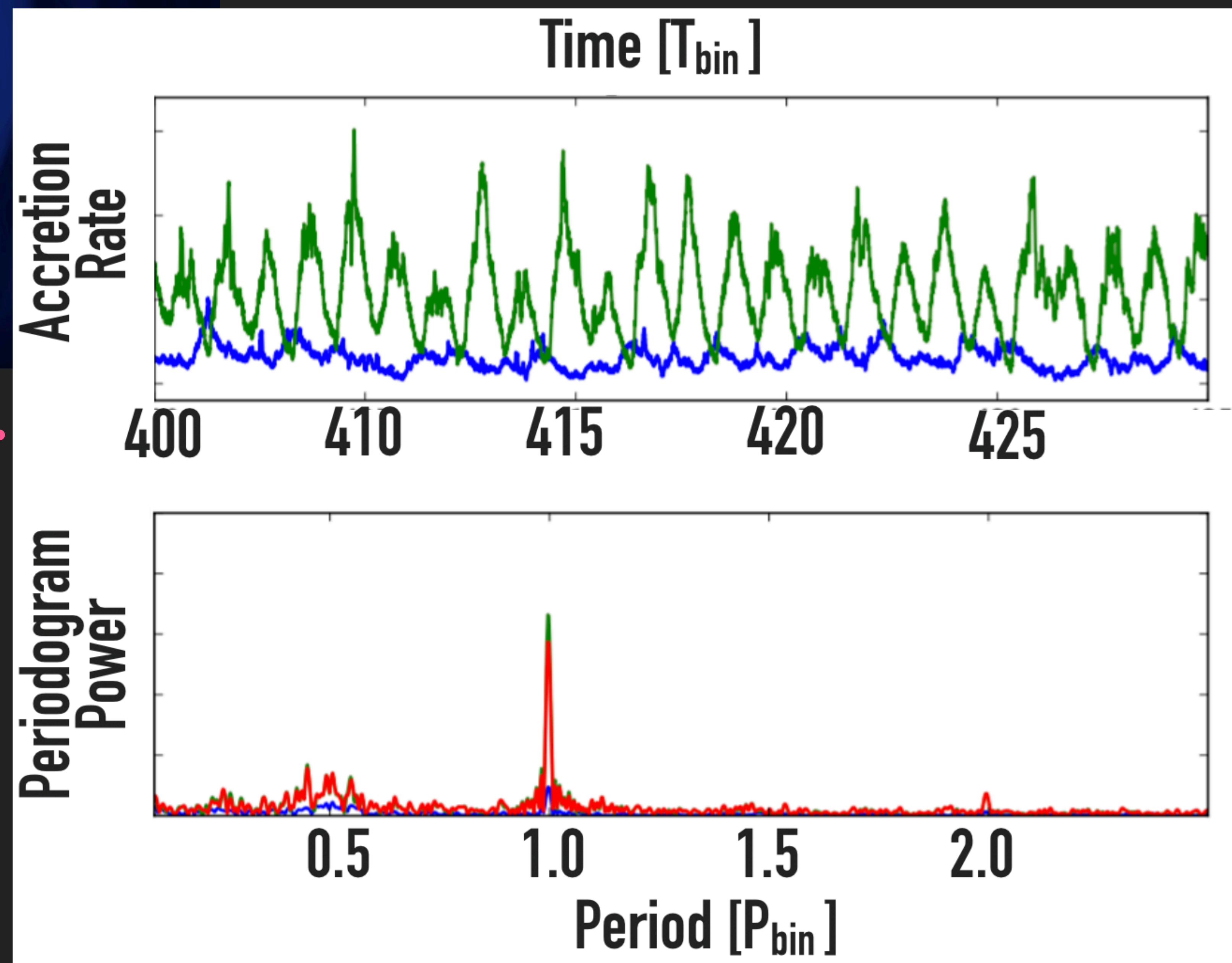
Credit: NASA GSFC/S. Noble

QUASARS WITH PERIODIC VARIABILITY



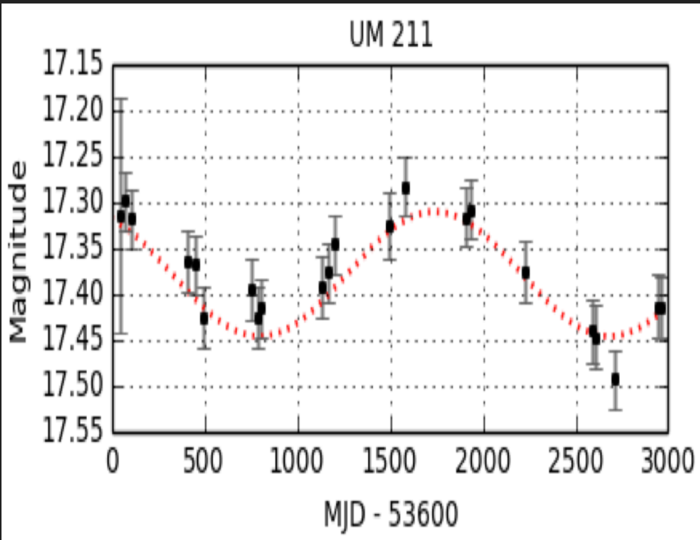
Credit: NASA GSFC/S.

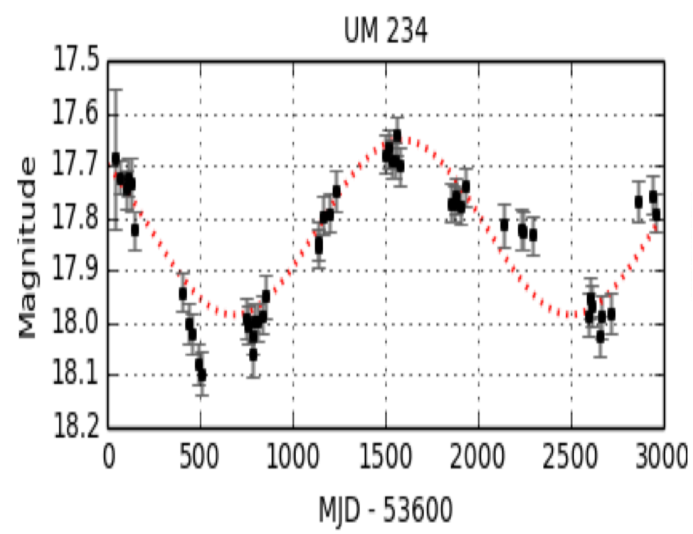
- Bright emission
- Periodic variability

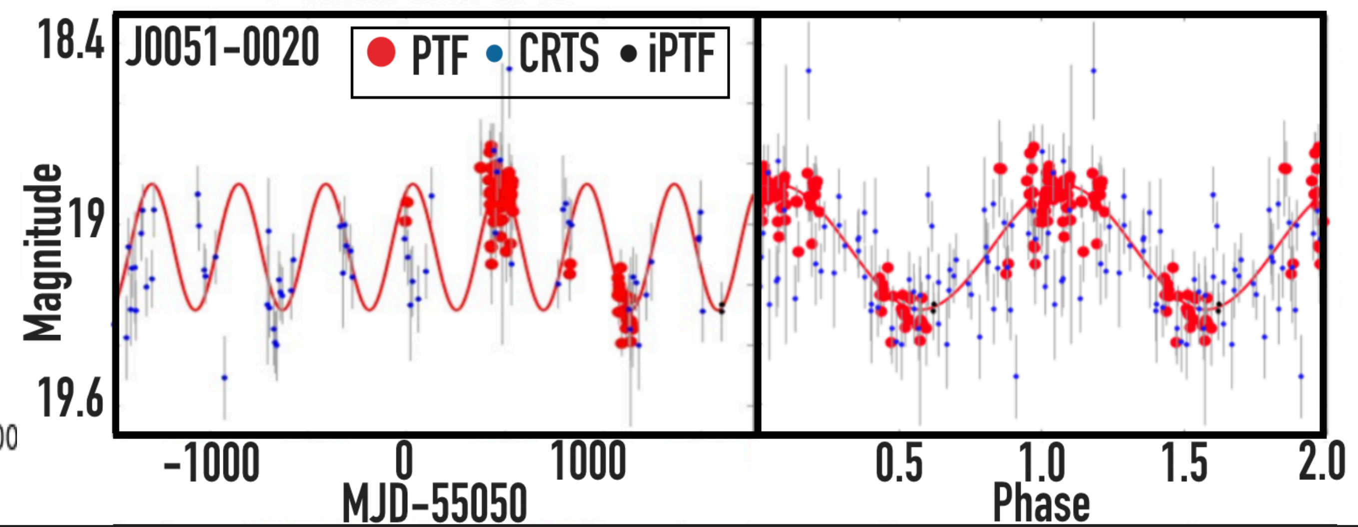


- Slow evolution
- Binaries should be common.

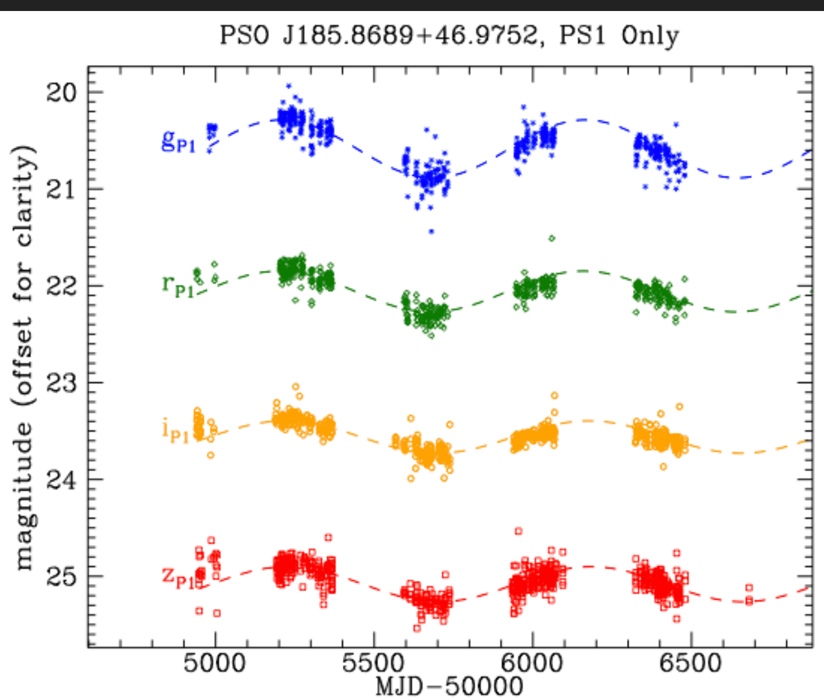
SYSTEMATIC SEARCHES

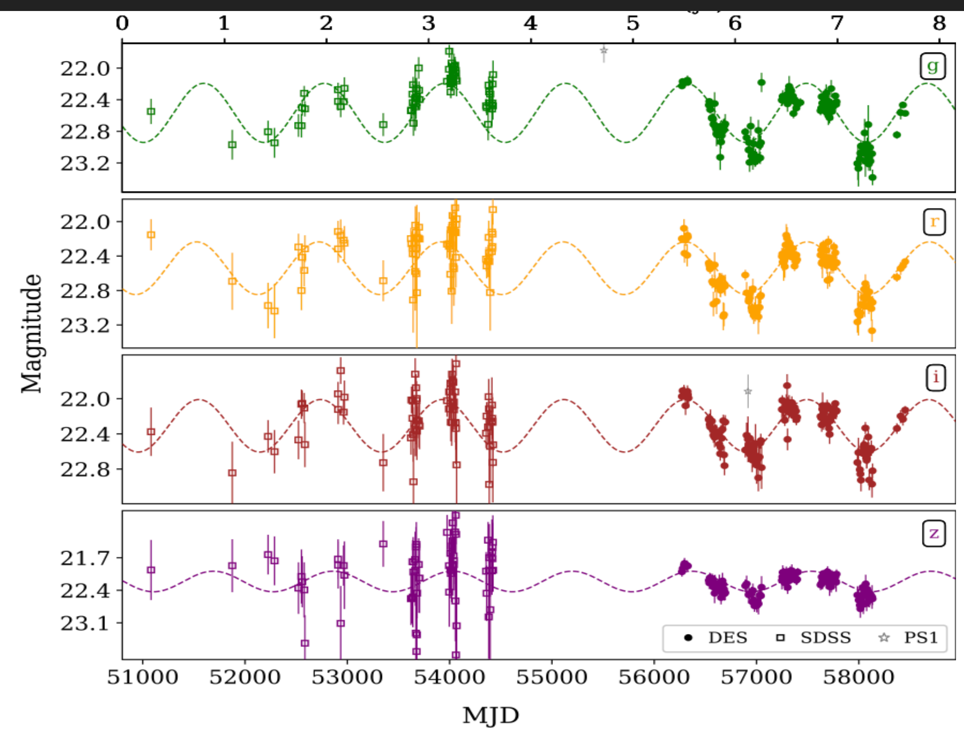


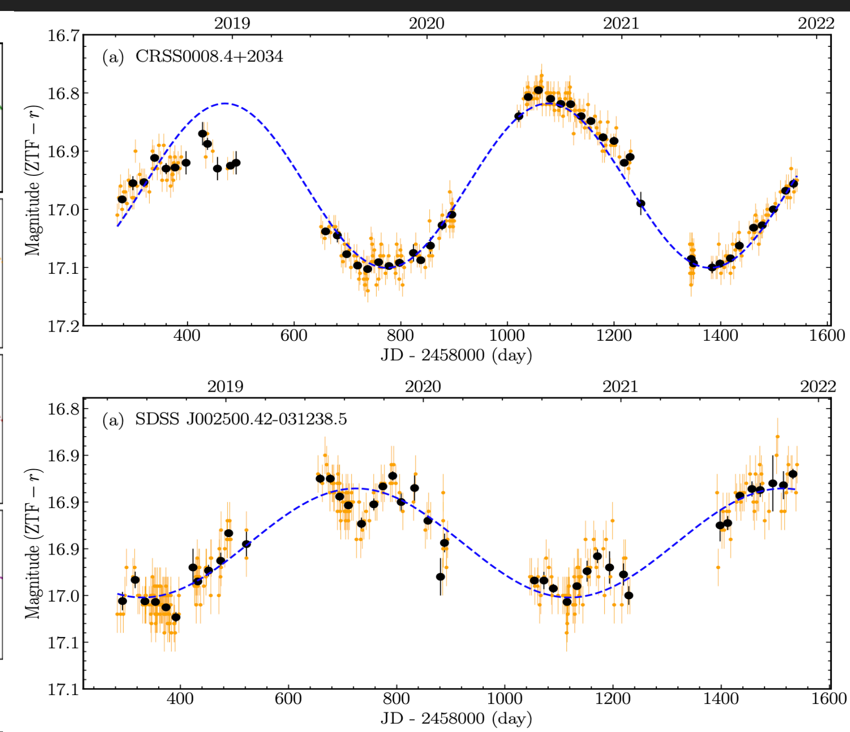




- CRTS: 111 of 245,000 Graham+2015
- PTF: 33 of 35,000 **Charisi**+2016



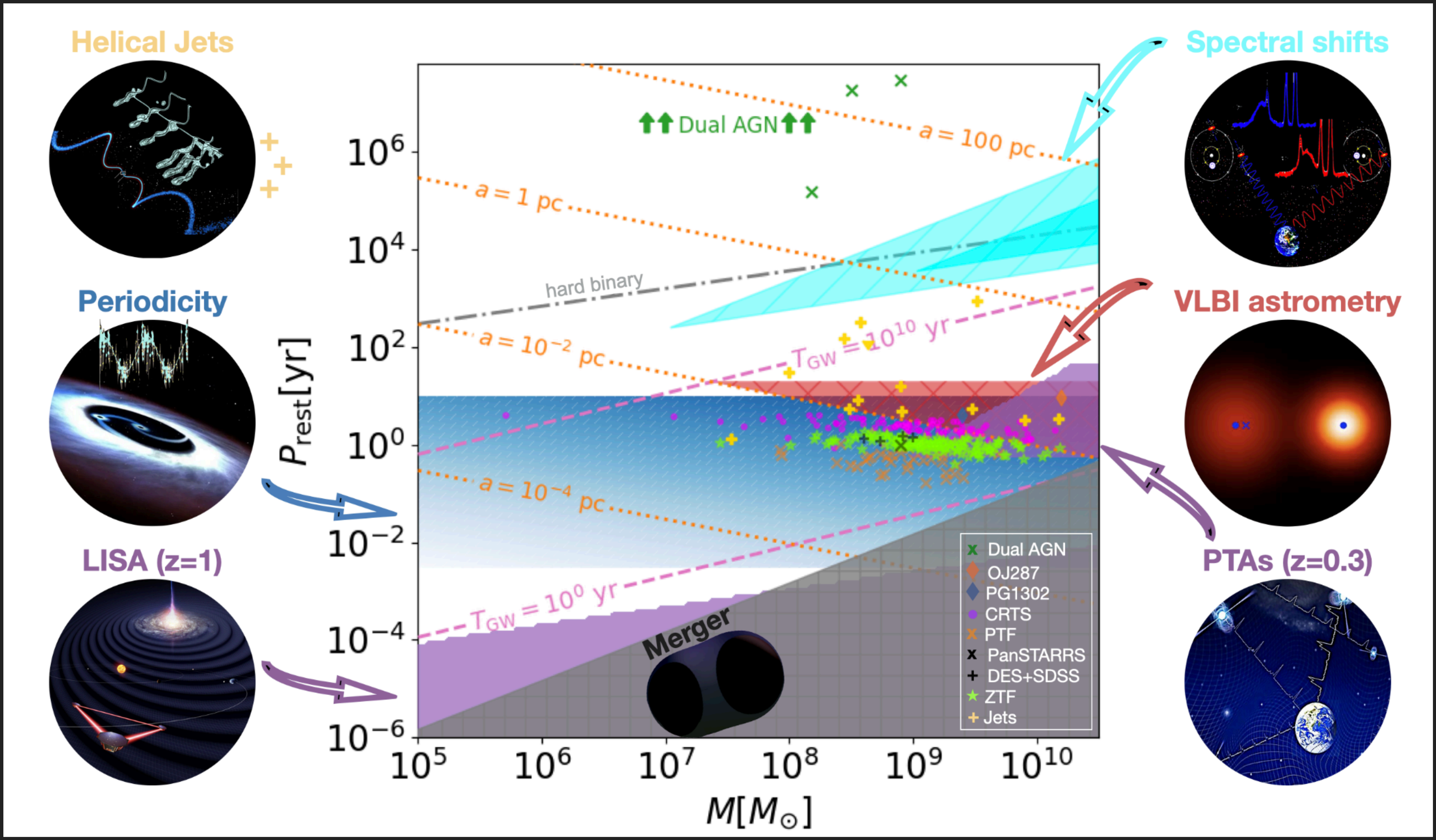




- PanSTARRS: 1 of 9,000 Liu+2019
- DES: 5 of 625 Chen+2020
- ZTF: 117 of 144000 Chen+2022

~250 **Candidate** Supermassive Black Holes.

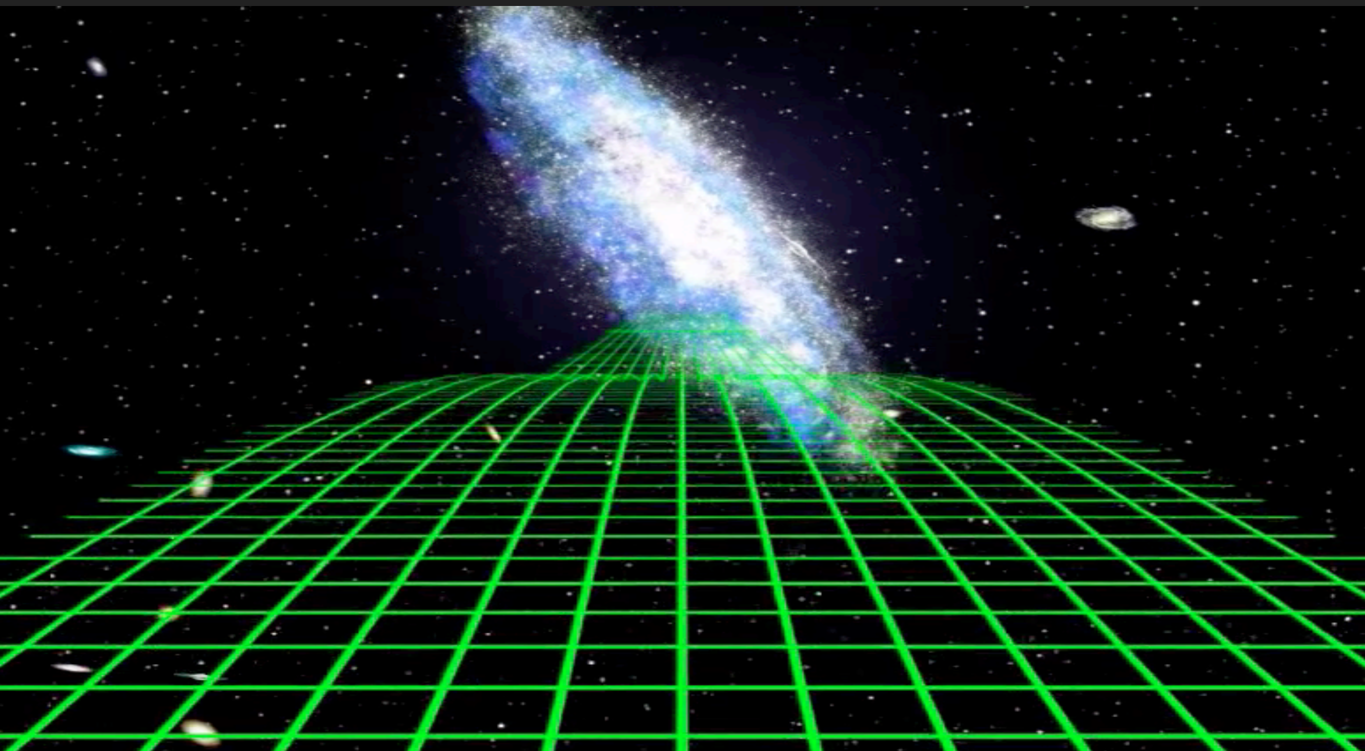
ADDITIONAL SIGNATURES

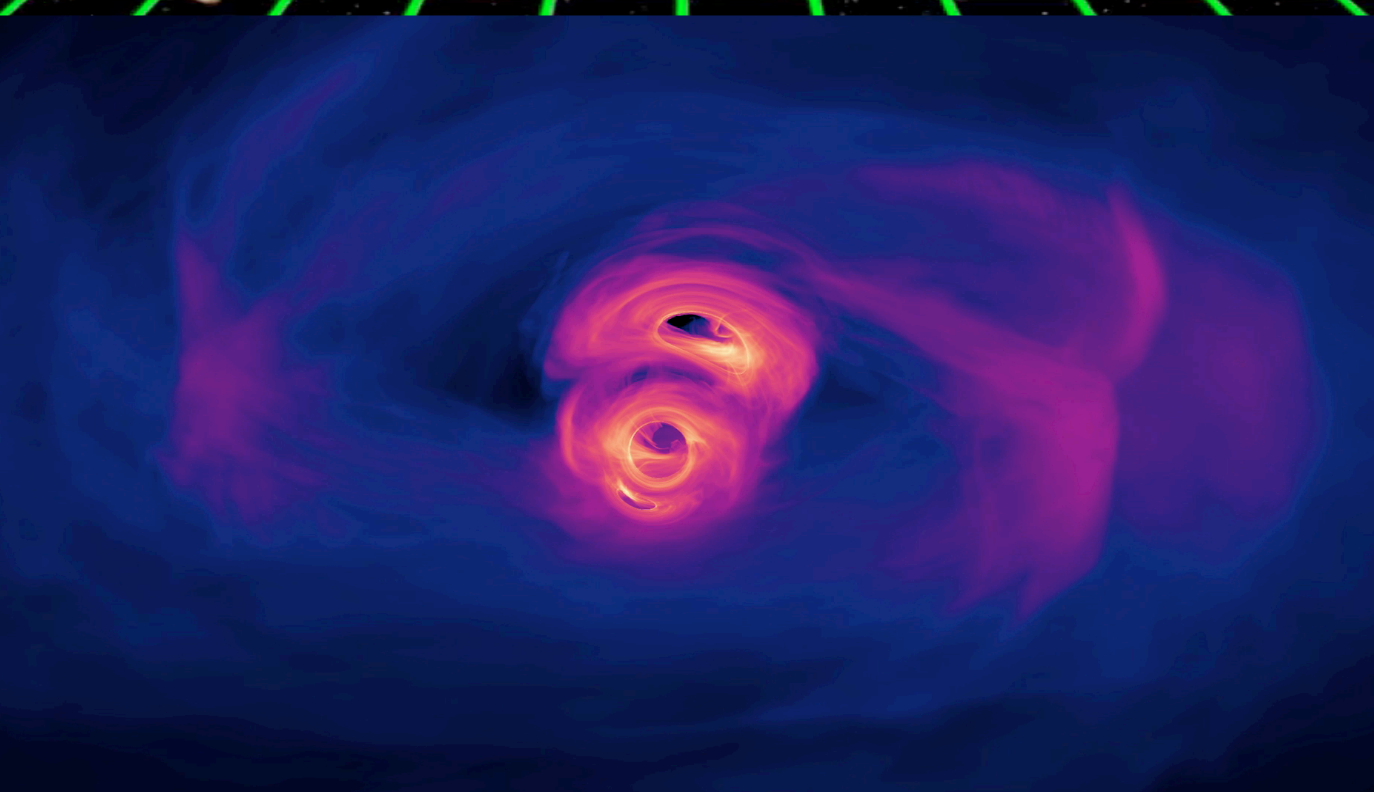


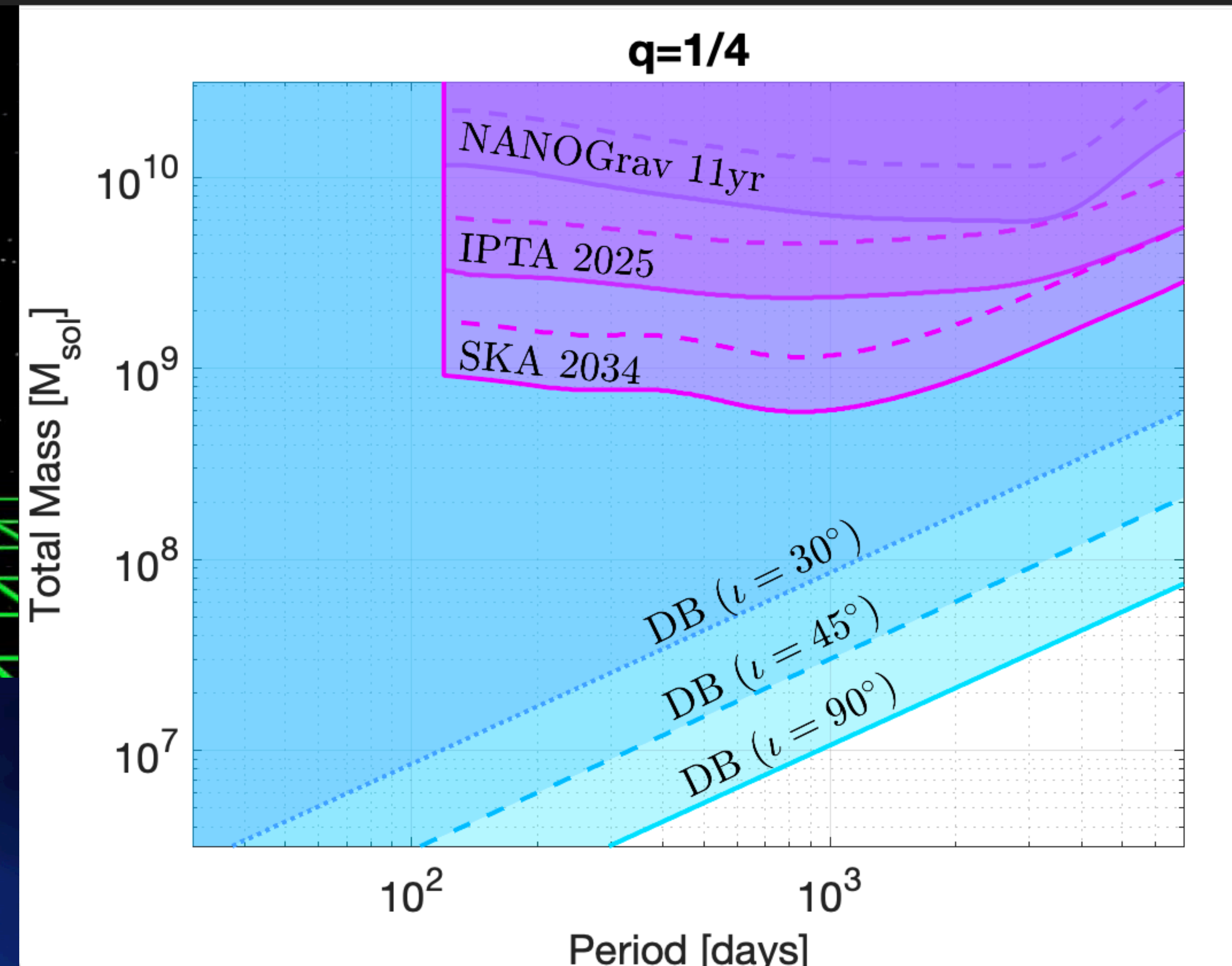
See review: D'Orazio, **Charisi**+2023

- Several candidates show multiple signatures.
- Challenging to distinguish them from quasar variability.

MULTI-MESSENGER OBSERVATIONS



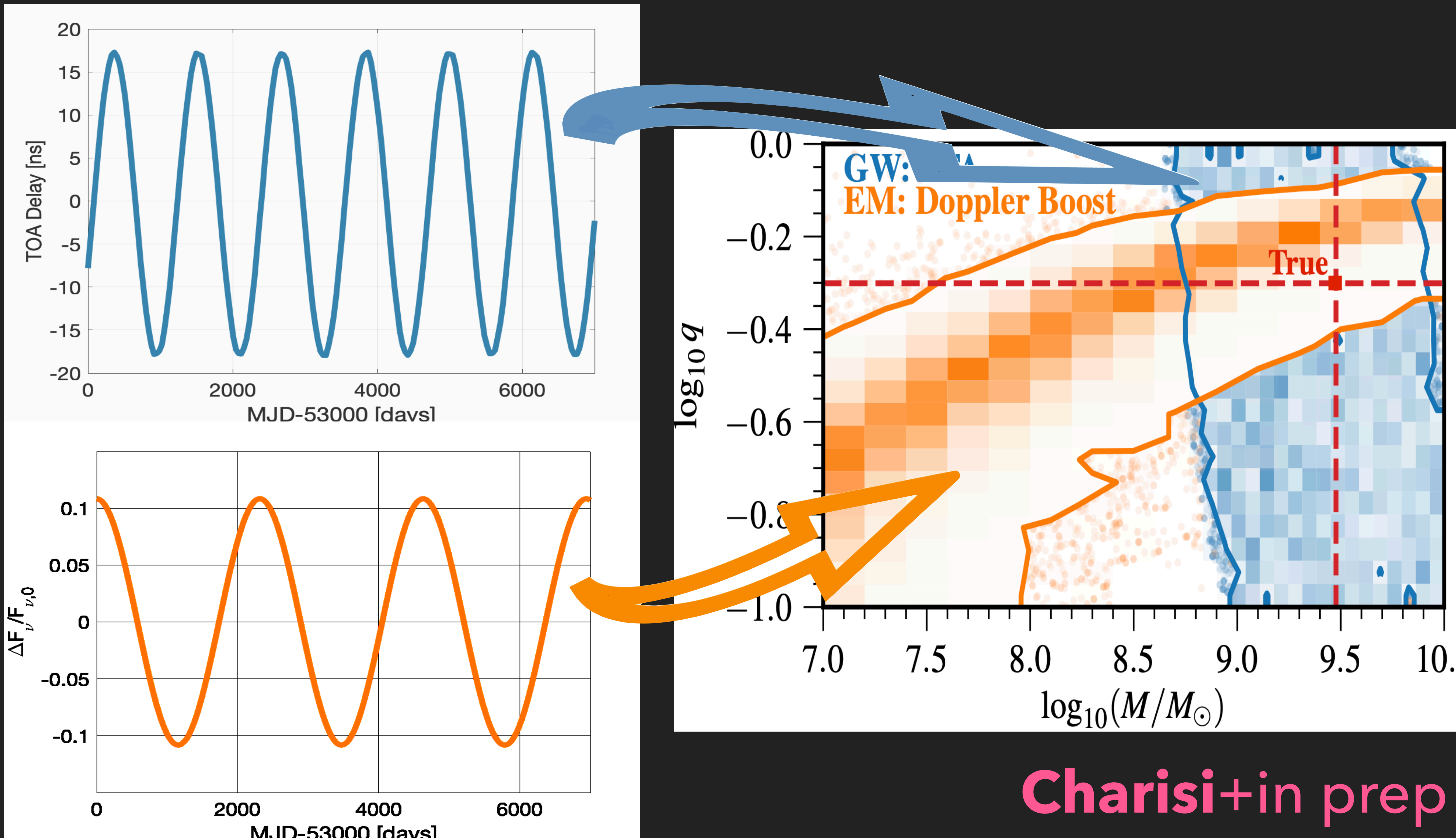




- PTAs and EM surveys probe the same binaries

Charisi+2022

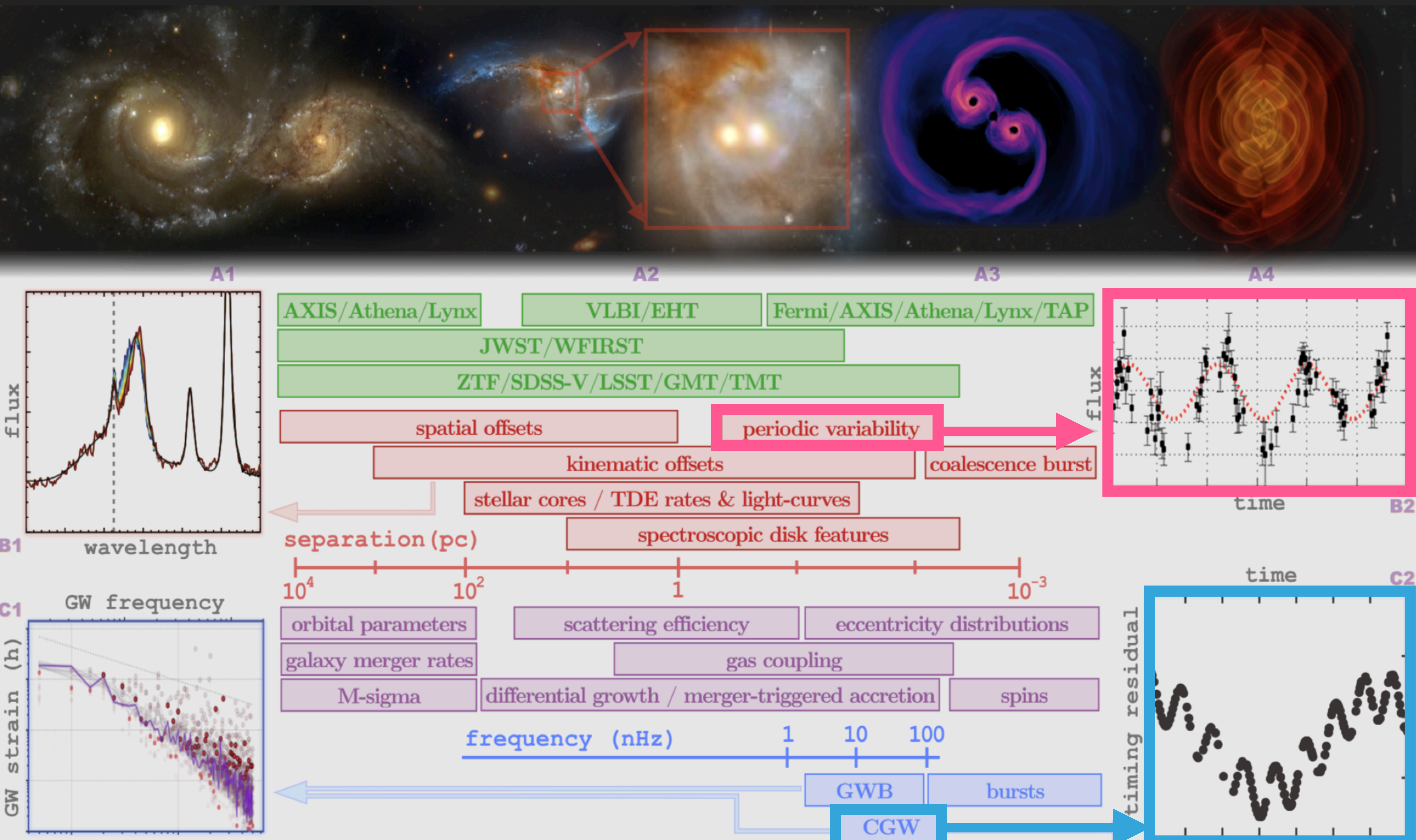
MULTI-MESSENGER OBSERVATIONS



Charisi+in prep

- Pipeline to jointly analyze EM+GW data.

MORE MULTI-MESSENGER SIGNATURES

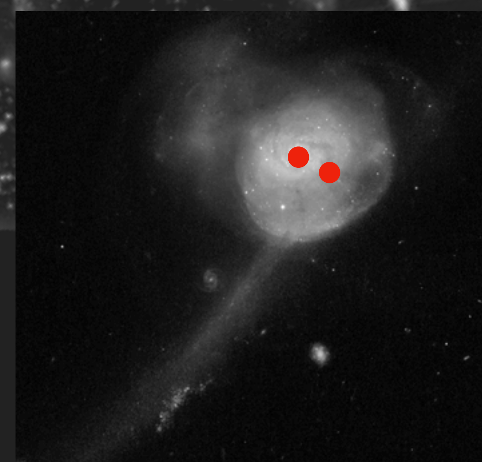


Kelley, **Charisi**+2019

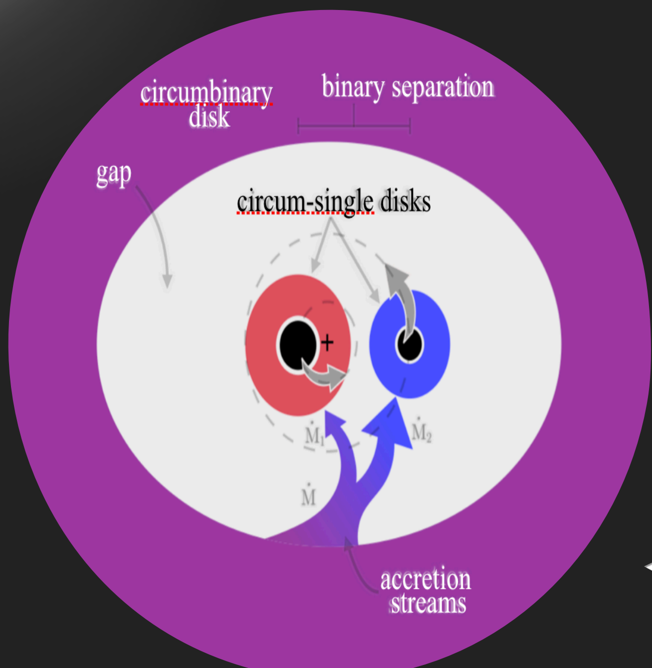
SUMMARY

- PTAs have found the first evidence of the GW background.
- PTAs soon will detect GWs from individually resolved binaries.
- SMBH Binaries produce bright EM emission and are promising sources of multi-messenger observations.
- ~250 candidates identified as quasars with periodic variability.
- Confirming the binary nature of quasar candidates is challenging.

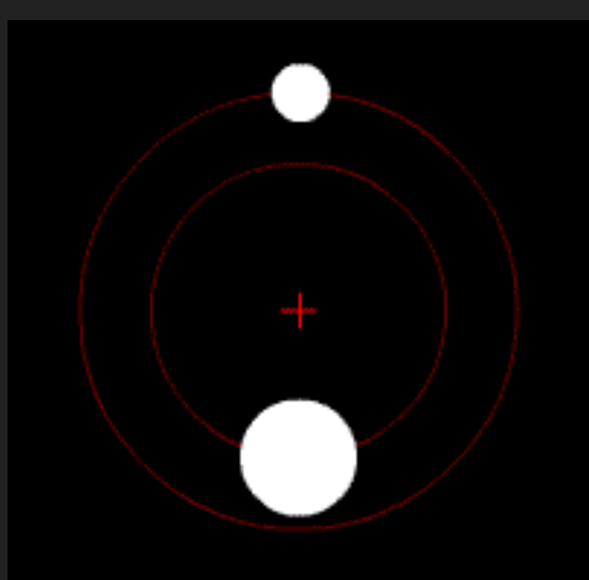
CONNECTIONS WITH ORBITAL DYNAMICS



Charisi+2022

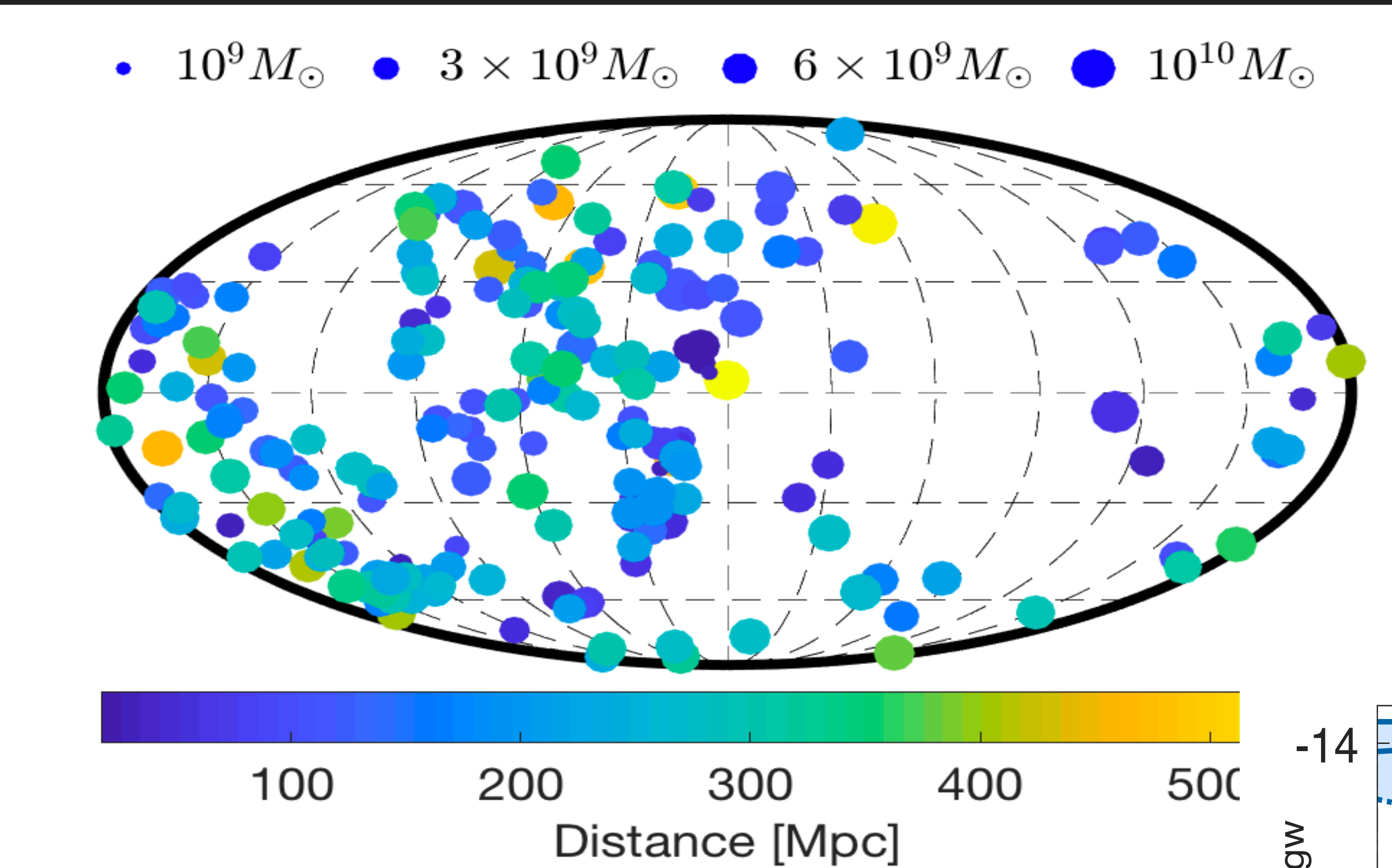


- PTAs and EM surveys probe the same binaries

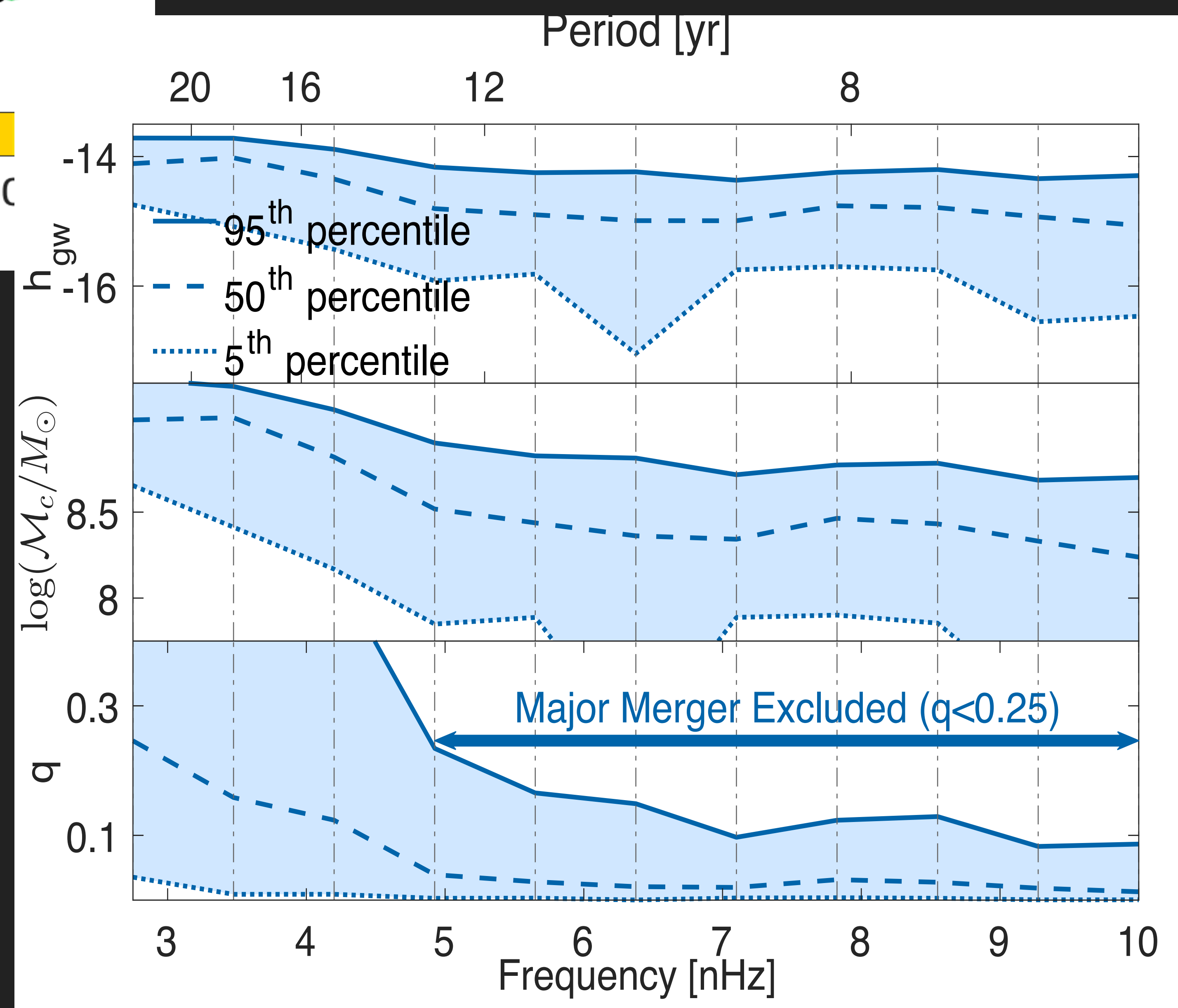


Model	Period	Phase	Amplitude
Circular (q>0.4) Periodic Accretion	😐	☹	☹
Circular (q<0.4) Periodic Accretion	☺	☹	☹
Circular Doppler Boost	☺	☺	☺

CONSTRAINTS ON LOCAL GALAXIES



- ~200 galaxies within NANOGrav volume.



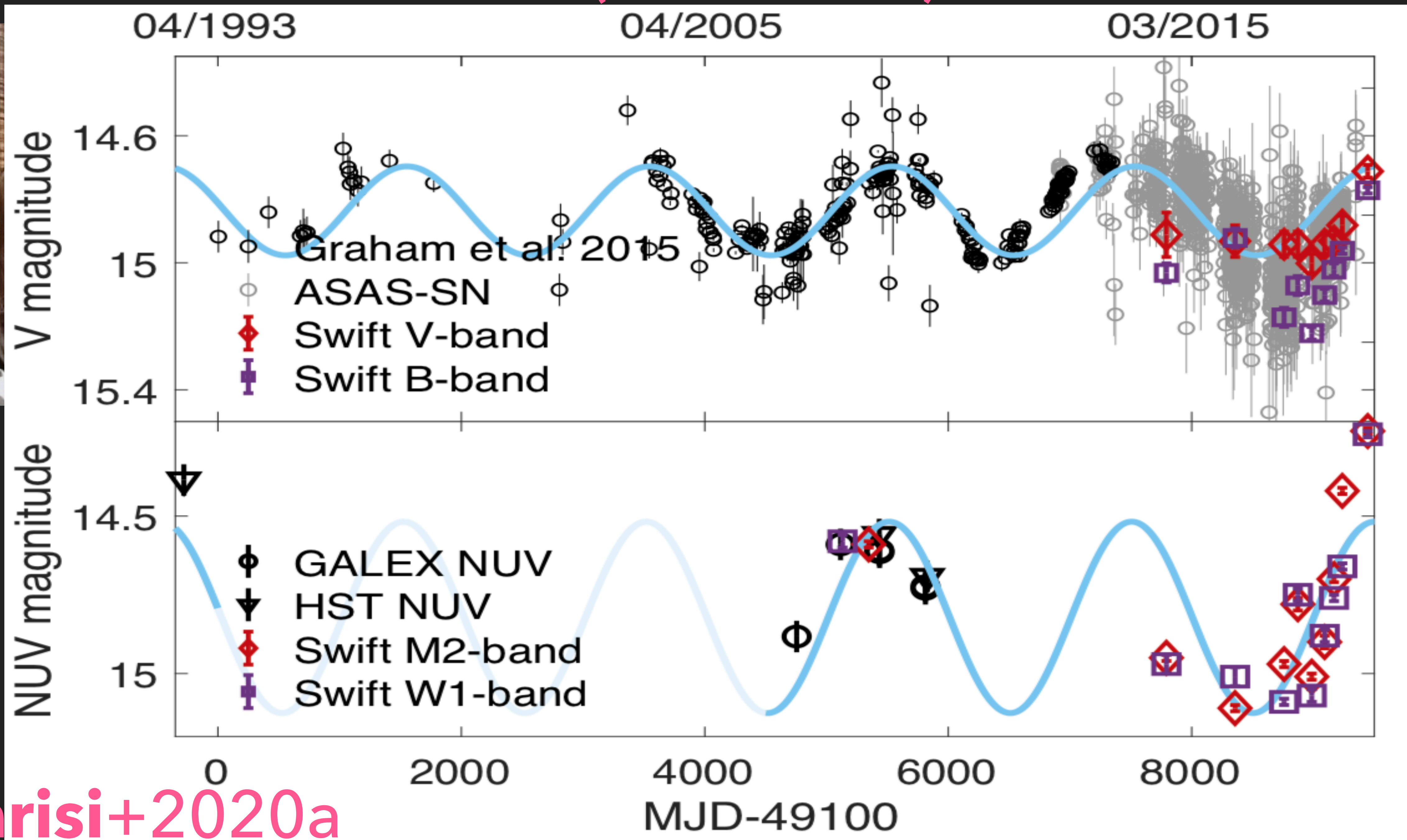
- Constraints on mass ratio comparable to Milky Way.

Arzoumanian+2021 (*led by **Charisi**)

DOPPLER BOOST-PG1302

Charisi (Science PI): Swift C13-C14

Chengcheng Xin (undergraduate at Columbia)



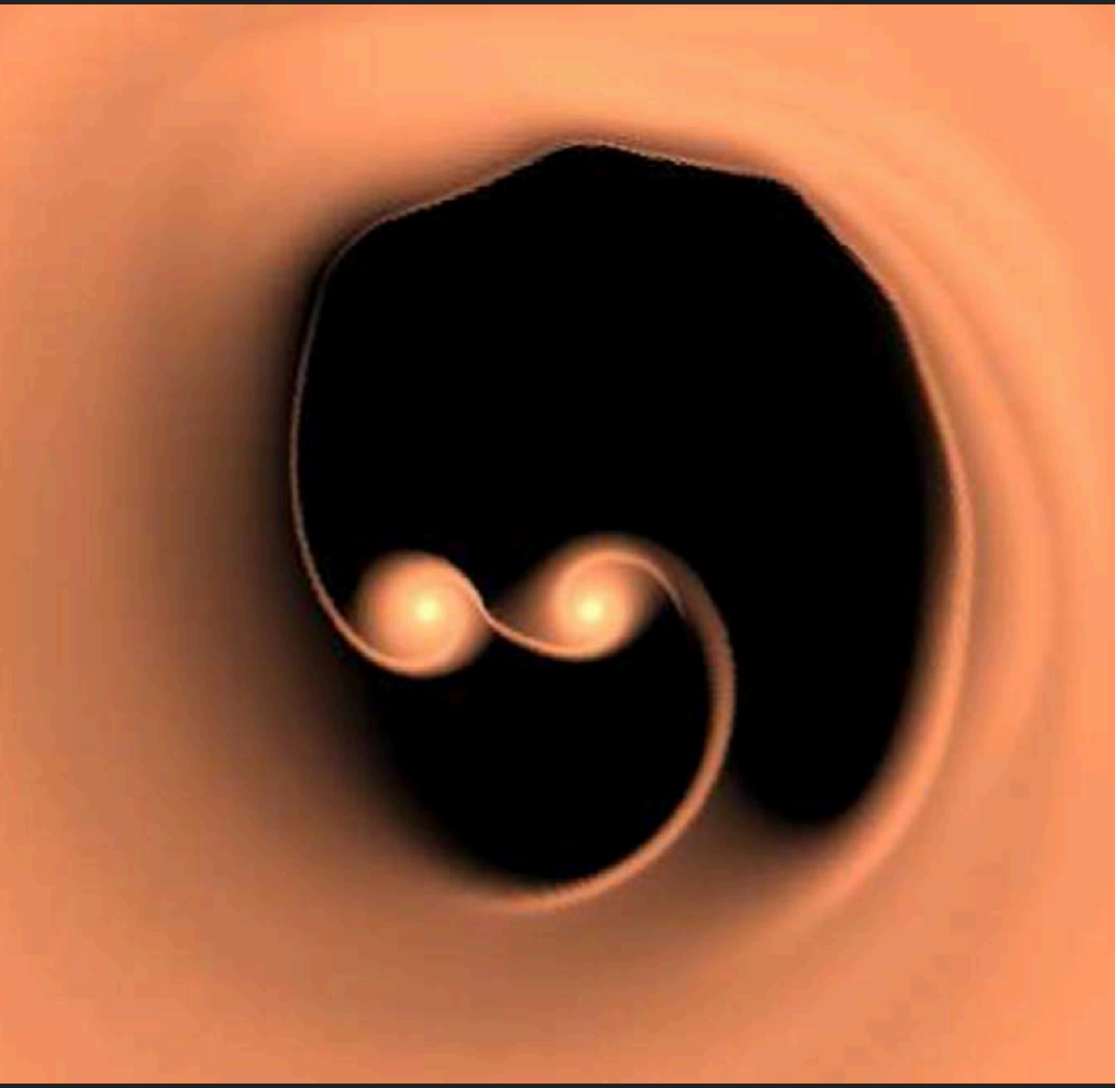
Xin, **Charisi**+2020a

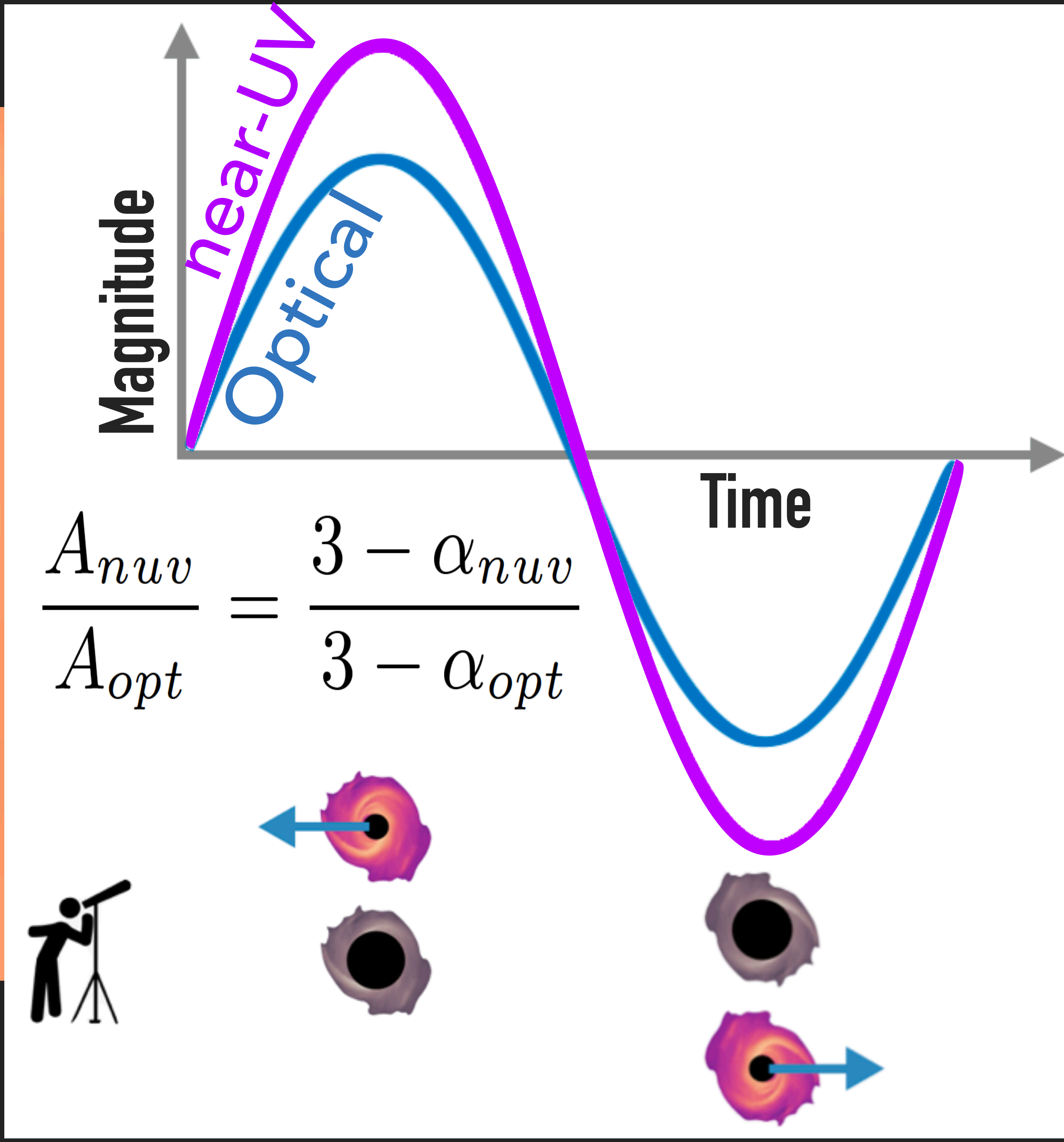
- PG1302 is consistent with Doppler boost.
- Quasars have wavelength-dependent variability.

Charisi+2018

RELATIVISTIC DOPPLER BOOST

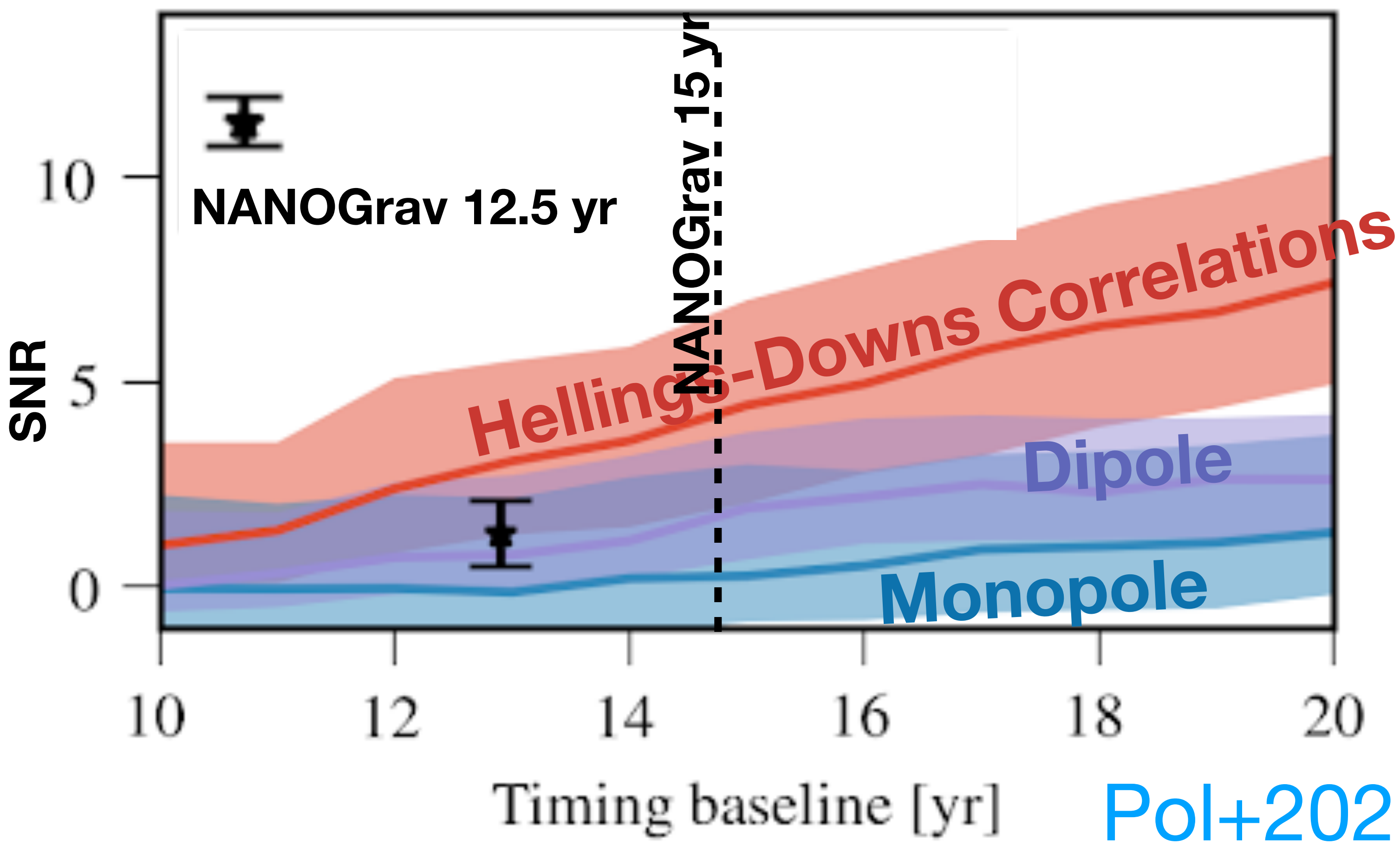
Duffell+2020





- Robust multi-wavelength prediction.

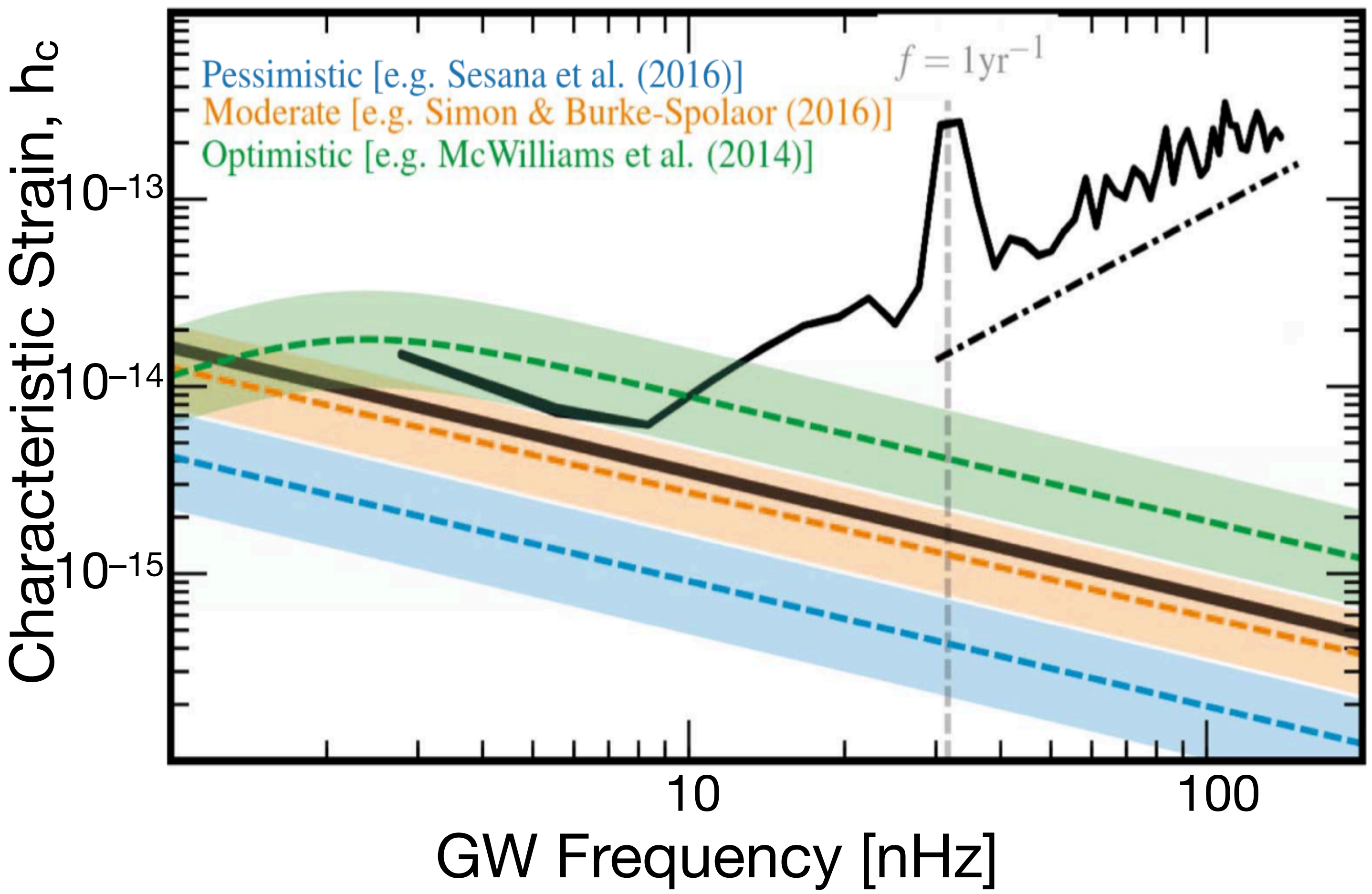
Time to Detection



Pol+2021

- If NANOGrav detected the first hints of the GW background, correlations should be detectable in the 15yr dataset.
- Data already collected & analysis is ongoing.

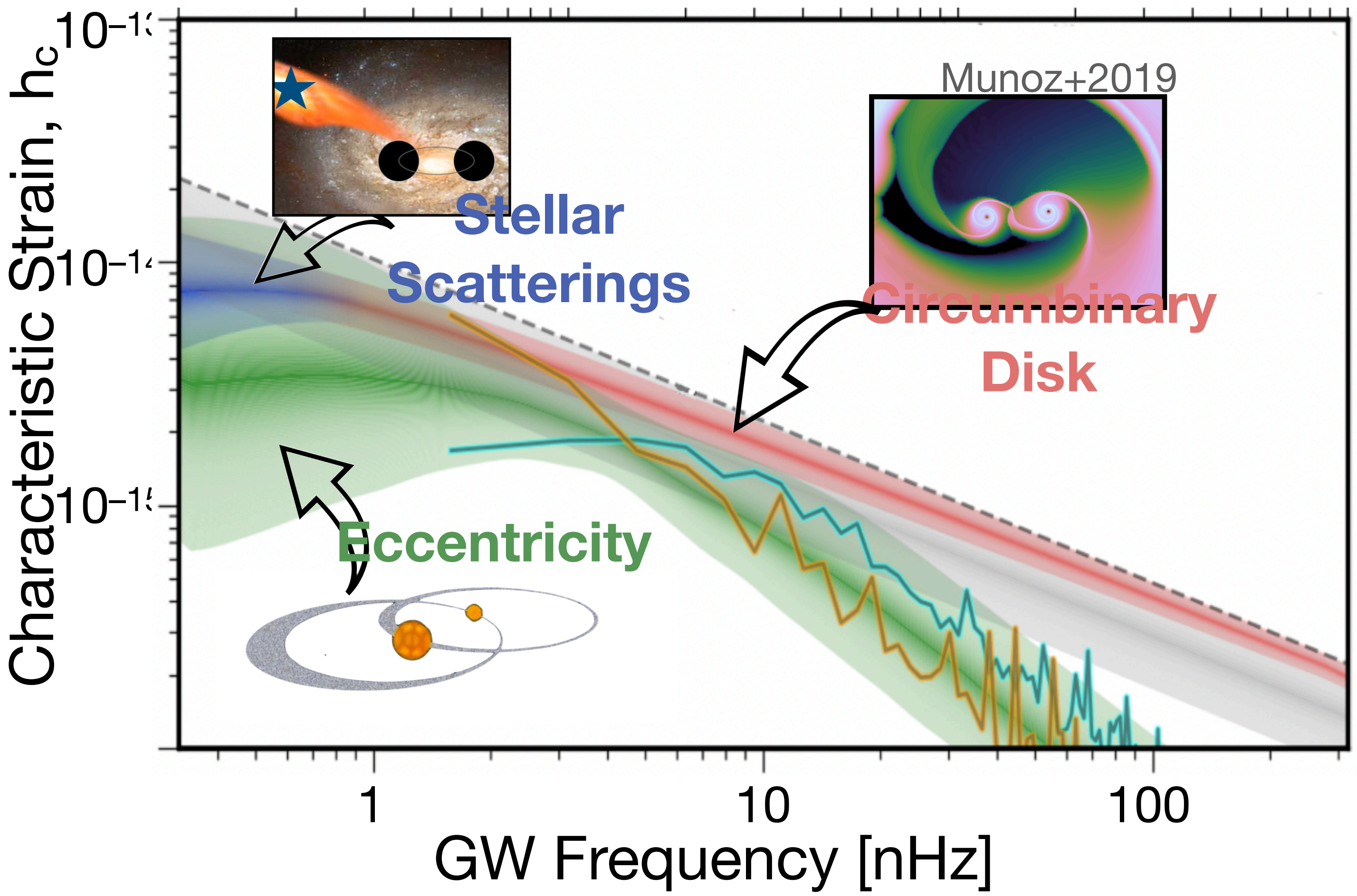
Astrophysics with the GW background



Arzoumanian+2018

- $$h_c = A_{\mathrm{GWB}} \left(\frac{f_{\mathrm{GW}}}{\mathrm{yr}^{-1}} \right)^{-2/3}$$
- GW amplitude depends on:
  - Galaxy merger rate
  - Efficiency of binary formation
  - BH mass function

Astrophysics with the GW background



Burke-Spolaor incl. **Charisi**+2019

- GW spectrum depends on:
  - Interactions with environment (e.g., stars or gas)
  - Eccentricity