Extreme Quasar Variability

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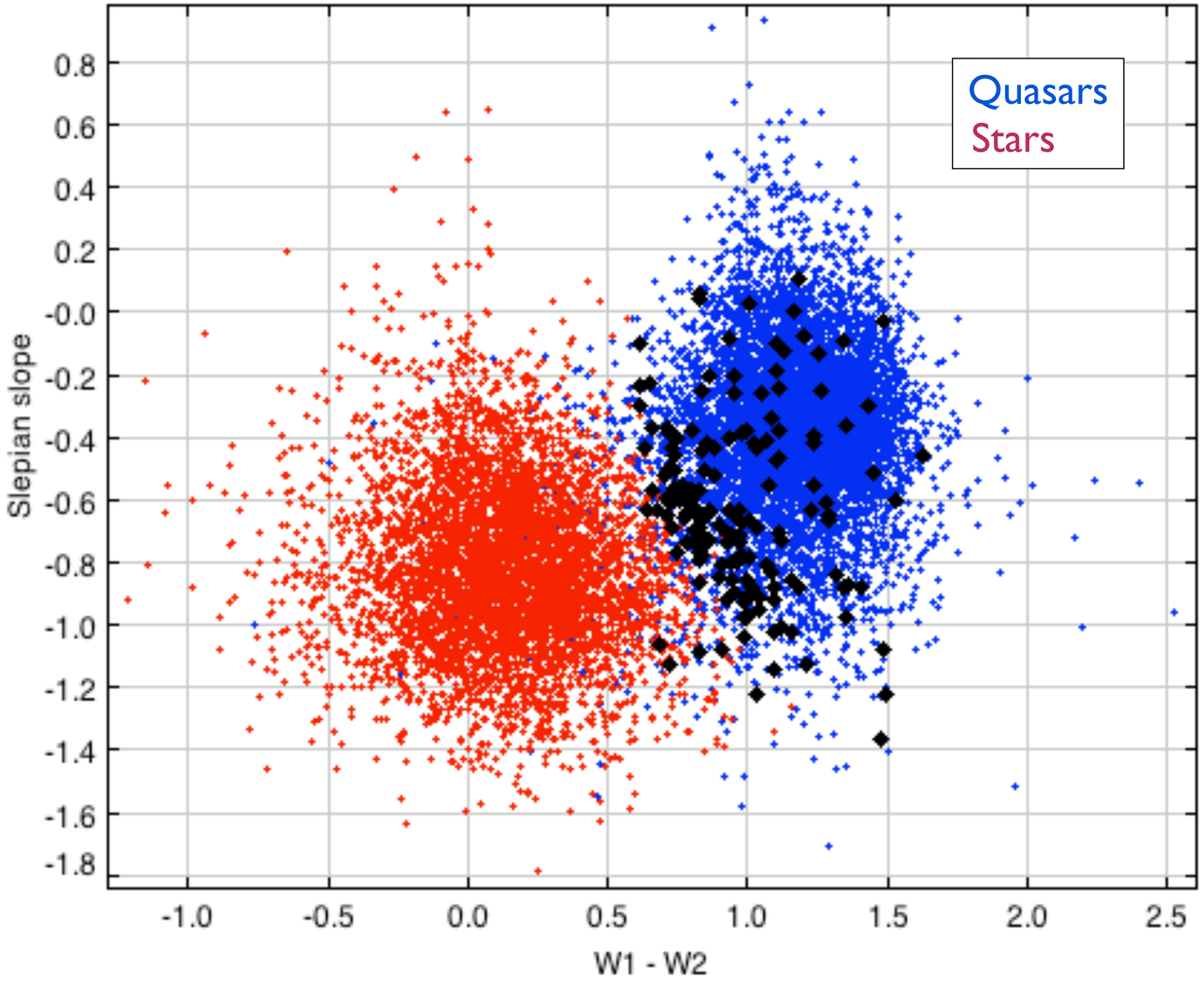
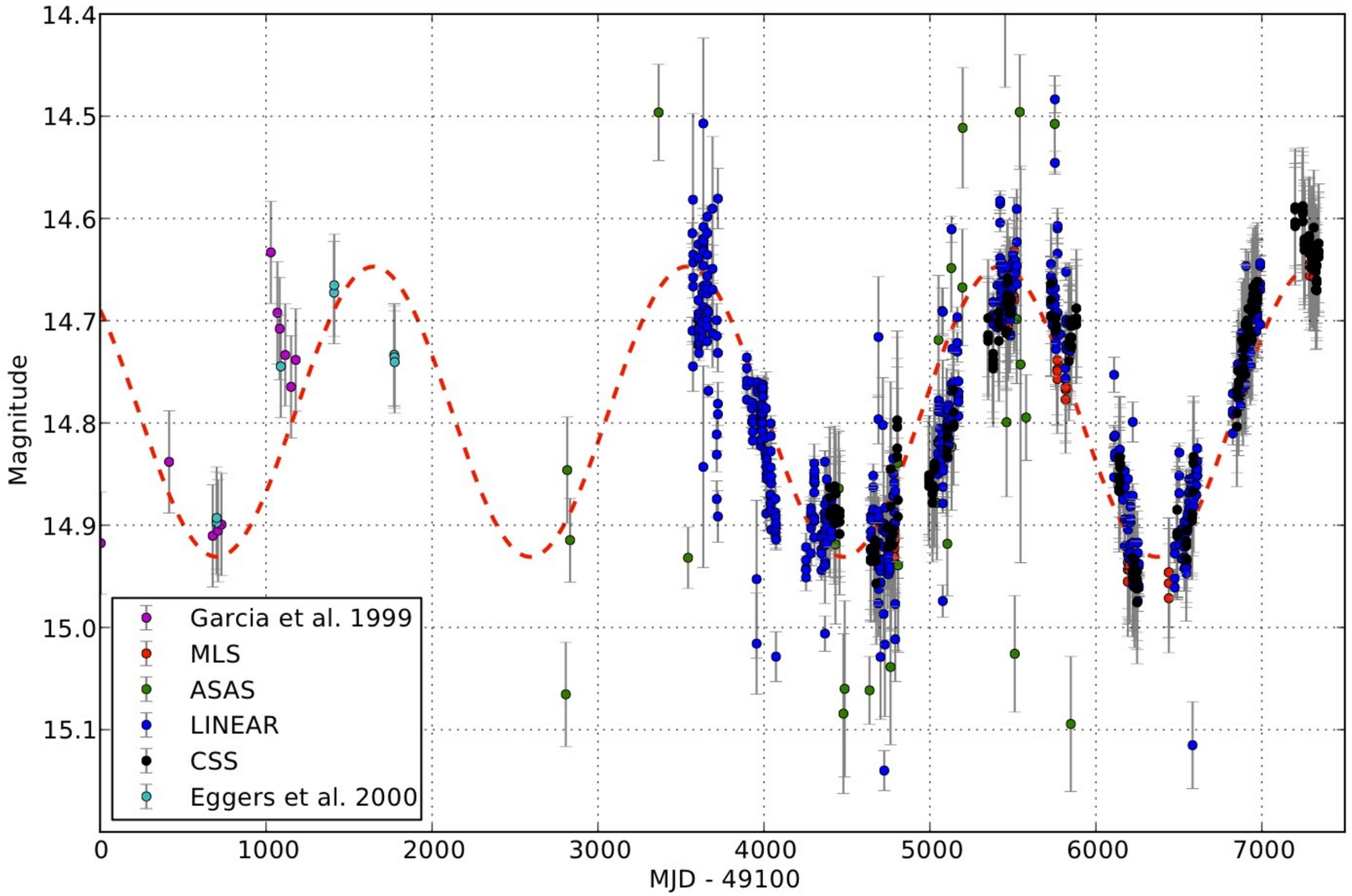
Matthew J. Graham (California Institute of Technology)



- quasars can be distinguished from Galactic stars based on their optical light curves
- quasar light curves well-described by a "damped random walk"

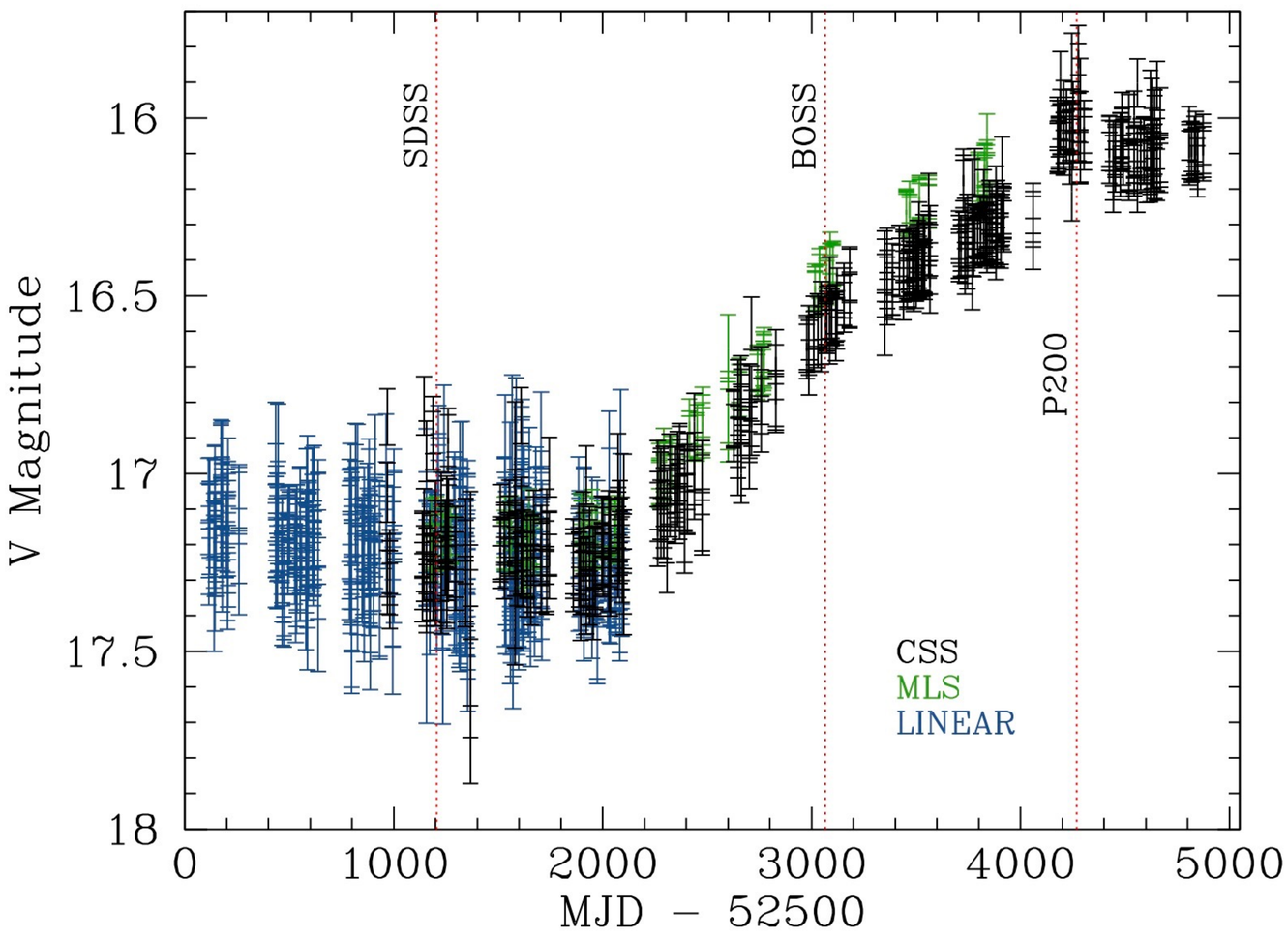
Graham, et al. 2014, ApJ, 439, 703

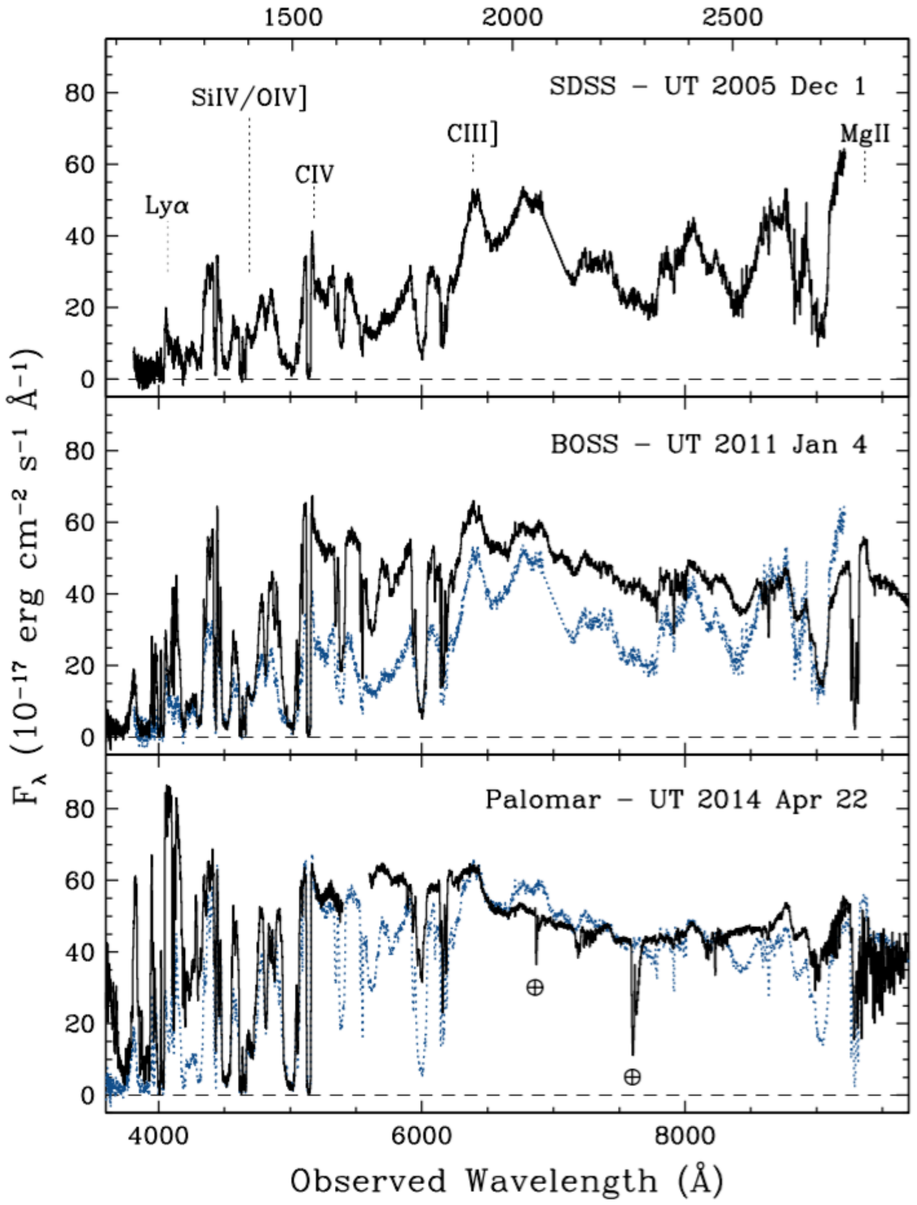
PG 1302-105



- **Extreme Activity I:** periodic quasars
- binary supermassive black holes???

Graham, Djorgovski, Stern et al. 2015, Nature, 518, 74
Graham, Djorgovski, Stern et al. 2015, MNRAS, 453, 1562

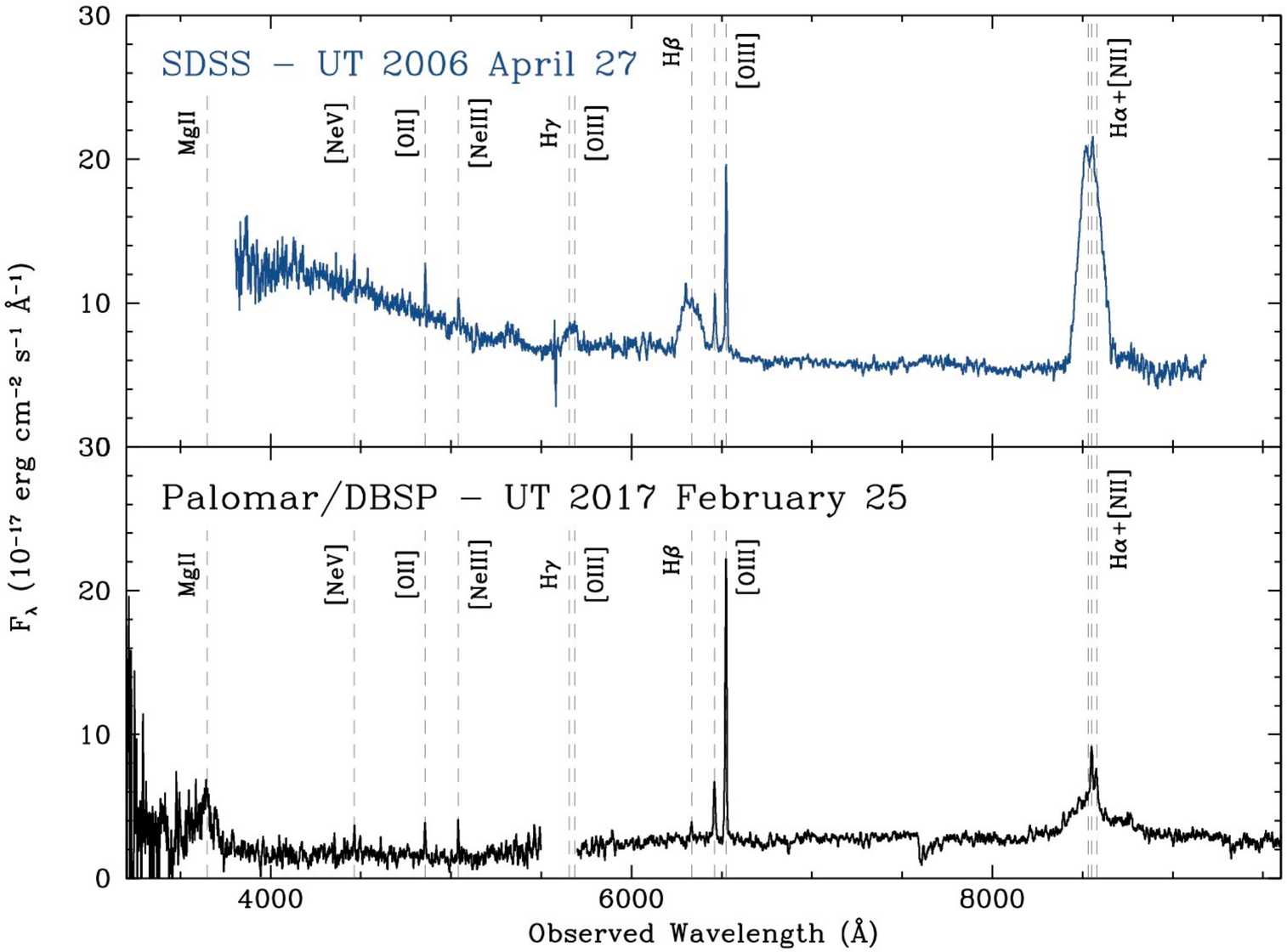




only ~1/10,000 quasars should show this much optical variability based on DRW model

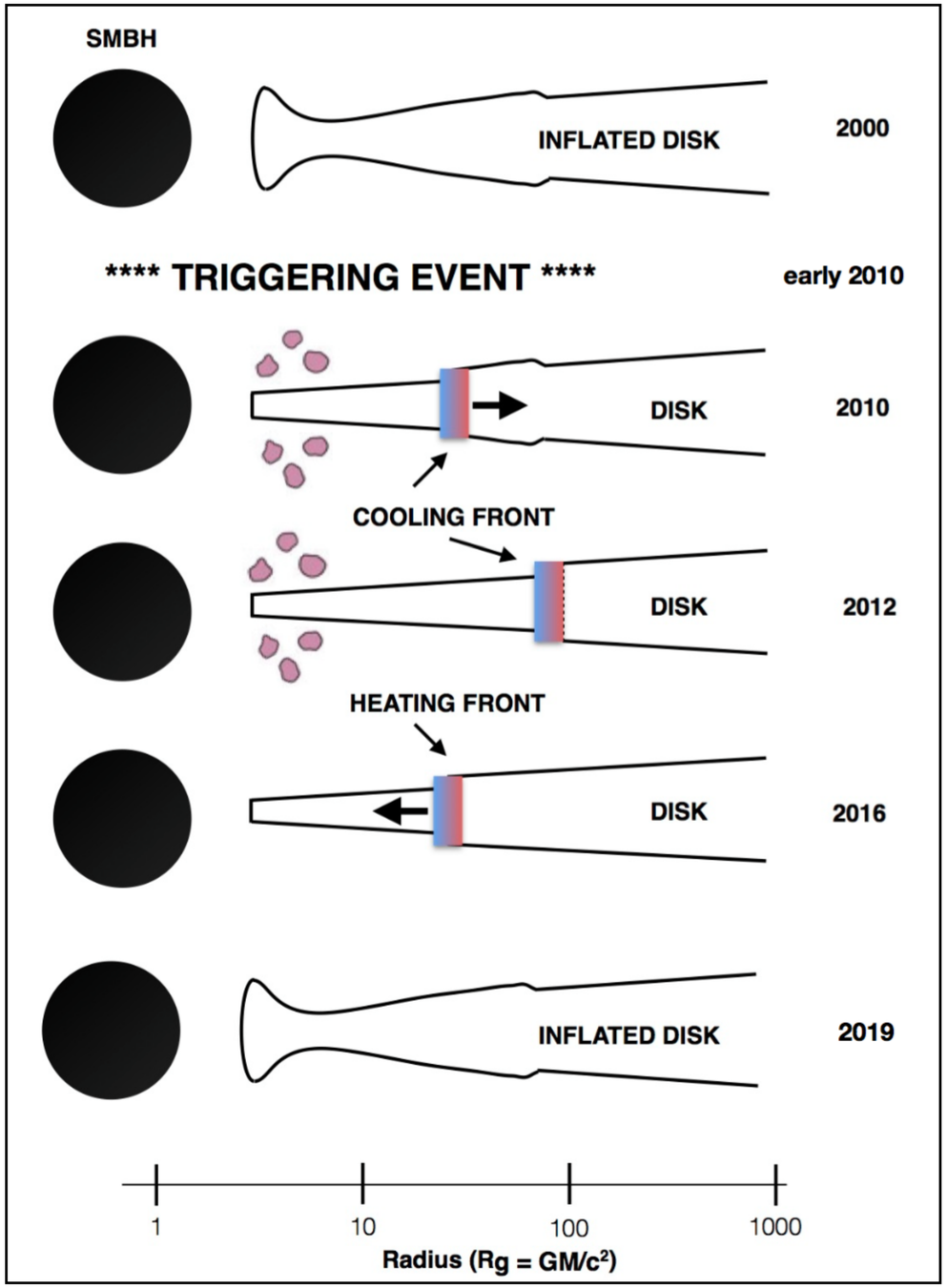
- **Extreme Activity 2:** changing look/changing state quasars (step function lightcurve)
- e.g., FeLoBAL turning into a normal BAL quasar over a decade

Stern et al. 2017, ApJ, 839, 2



- **Extreme Activity 2:** changing look/changing state quasars (step function lightcurve)
- e.g., WISE-selected changing state quasars

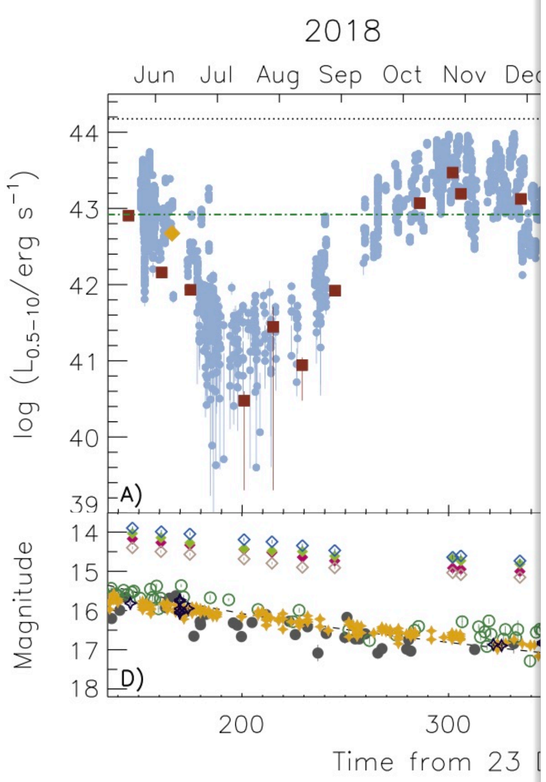
Stern et al. 2018, ApJ, 684, 27
Ross et al. 2018. MNRAS, 480, 4468

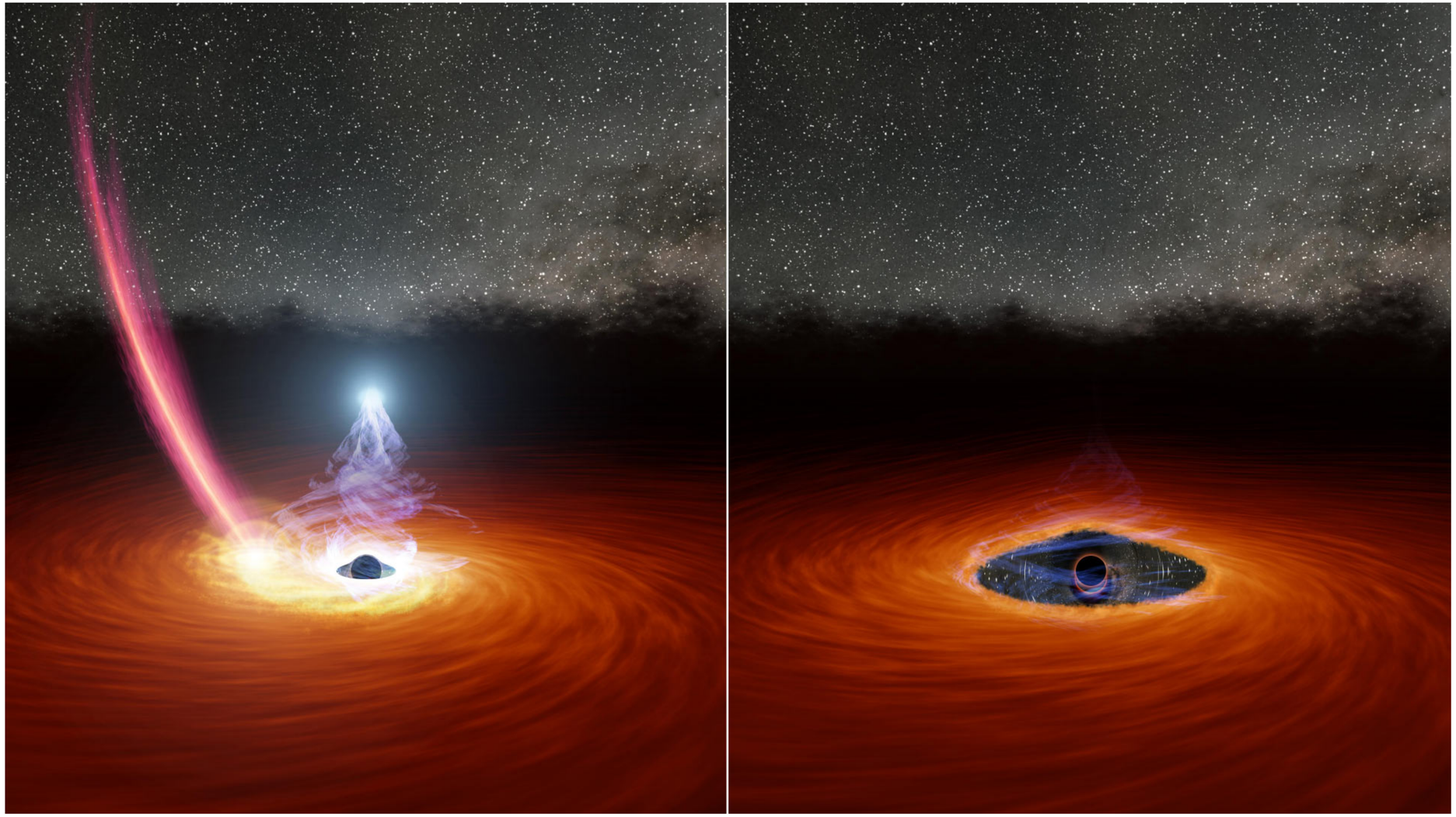


Stern et al. 2018, ApJ, 684, 27
Ross et al. 2018.MNRAS, 480, 4468

- **Extreme Activity 3:** Tidal Disruption Events in AGN

IES 1927+65





Ricci, et al. 2020, ApJL, 898, L1

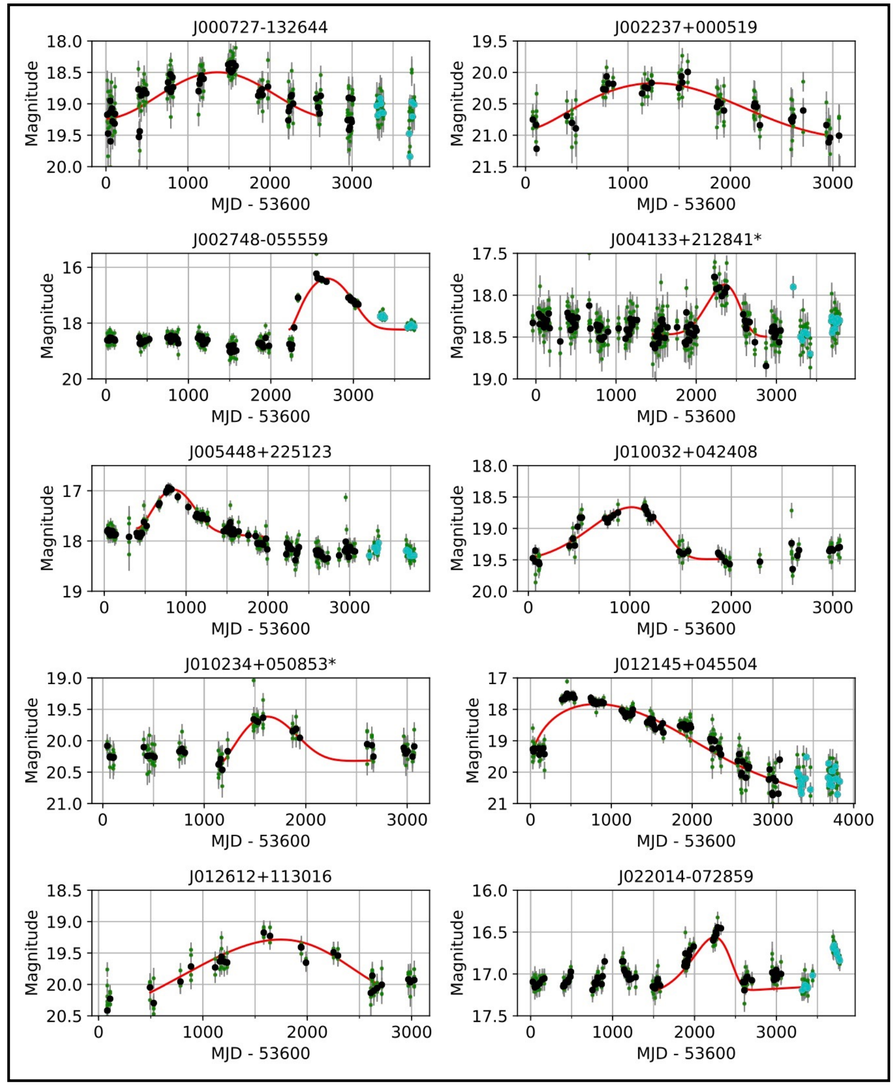
GraL Collaboration

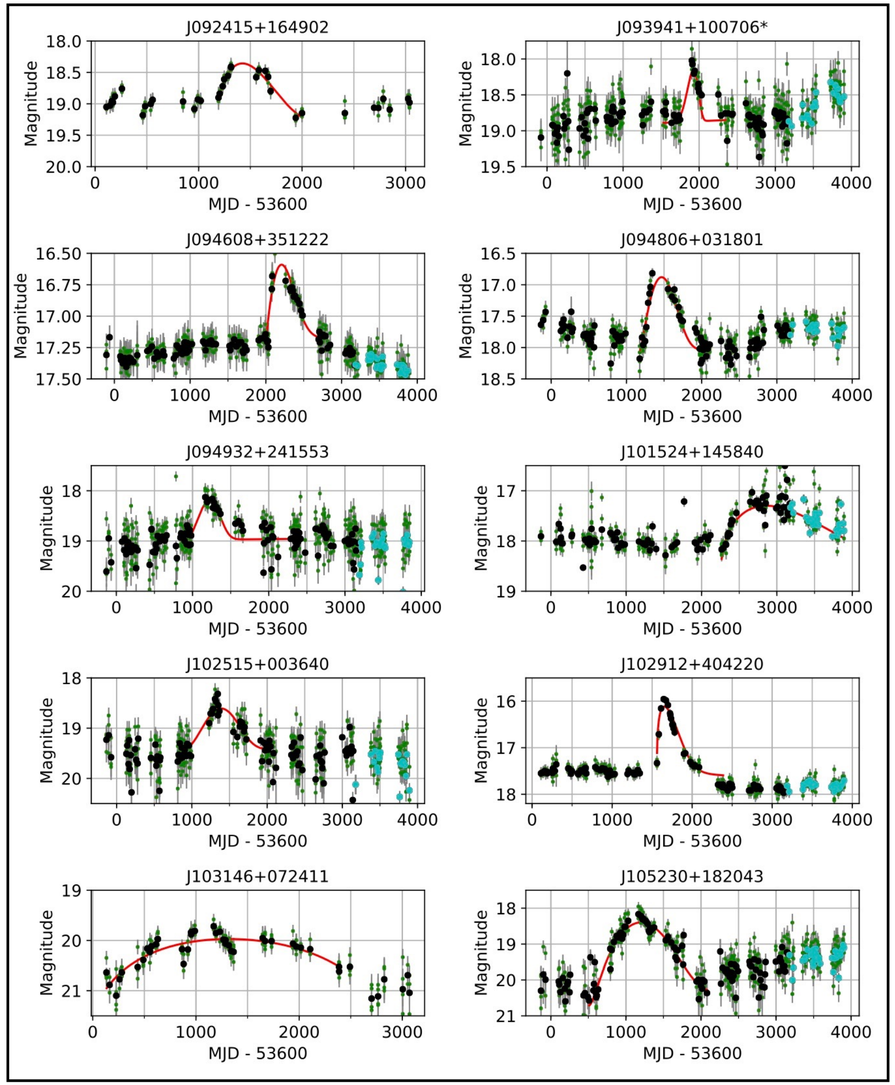
Alberto Krone-Martins (UC-Irvine)

S.G. Djorgovski (Caltech)

- **Extreme Activity 4:** Strong Gravitational Lenses

Stern et al. 2021, ApJ, 921, 42





- **Extreme Activity 5:** AGN flares
- obviously diverse flare morphologies = diverse physics

Graham, Djorgovski, Drake, Stern et al. 2017; MNRAS, 470, 4112
Drake, Djorgovski, Graham, Stern et al. 2019; MNRAS, 482, 98

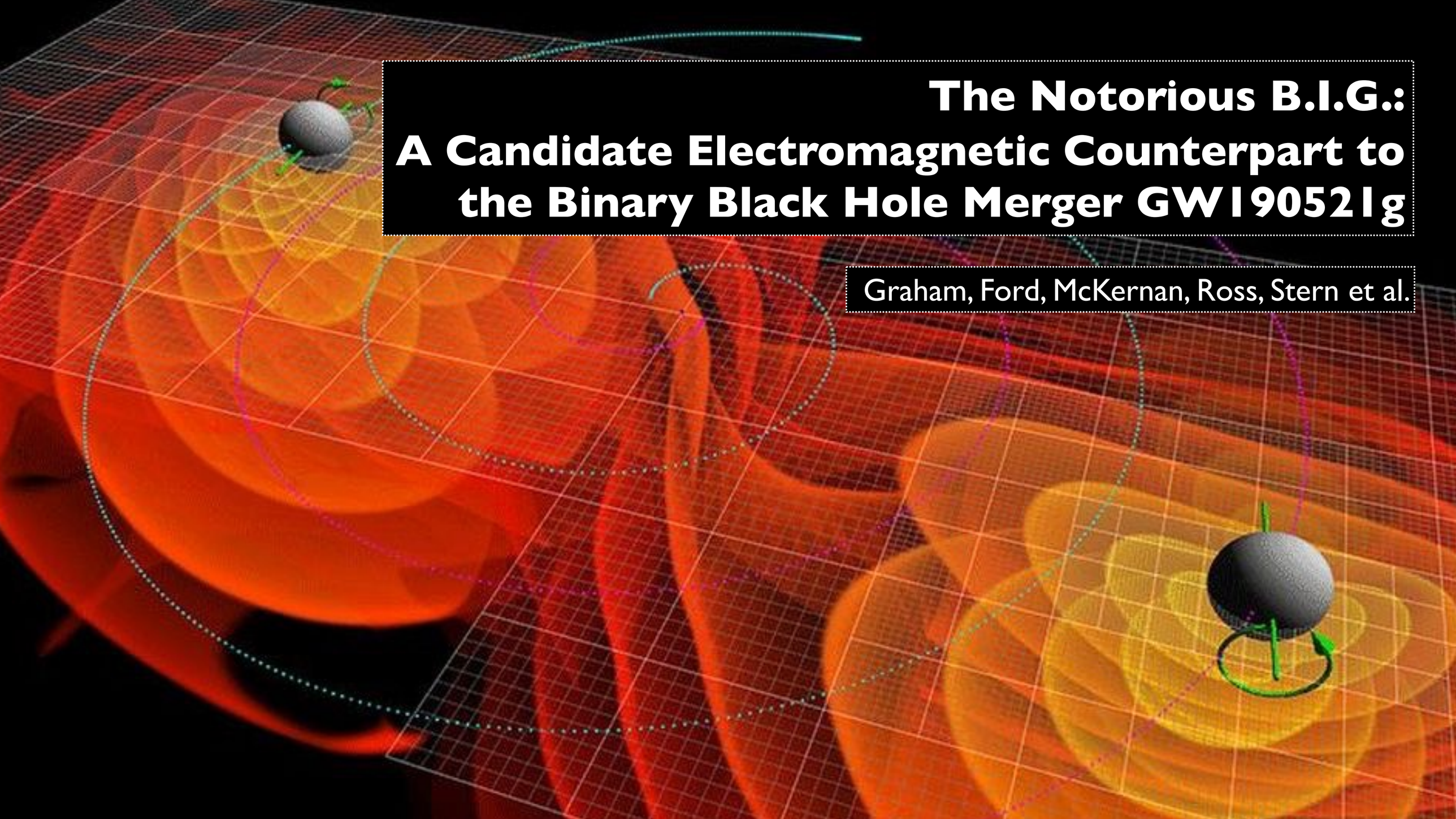
THE ASTROPHYSICAL JOURNAL LETTERS

Ram-pressure Stripping of a Kicked Hill Sphere: Prompt Electromagnetic Emission from the Merger of Stellar Mass Black Holes in an AGN Accretion Disk

B. McKernan[1,2,3], K. E. S. Ford[1,2,3], I. Bartos[4], M. J. Graham[5], W. Lyra[6,7], S. Marka[8], Z. Marka[8], N. P. Ross[9], D. Stern[7], and Y. Yang[4]

Published 2019 October 17 •

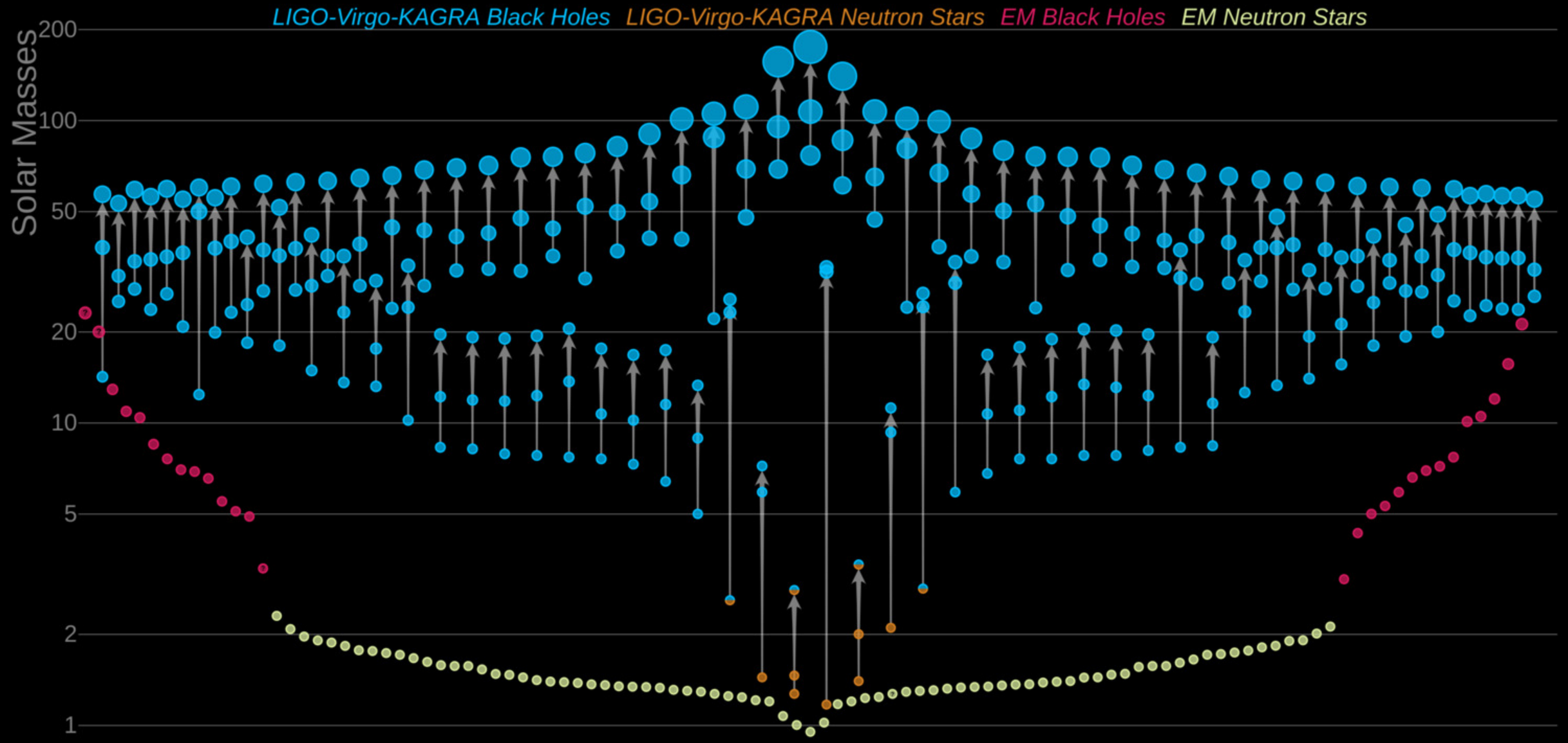
The Astrophysical Journal Letters, Volume 884, Number 2



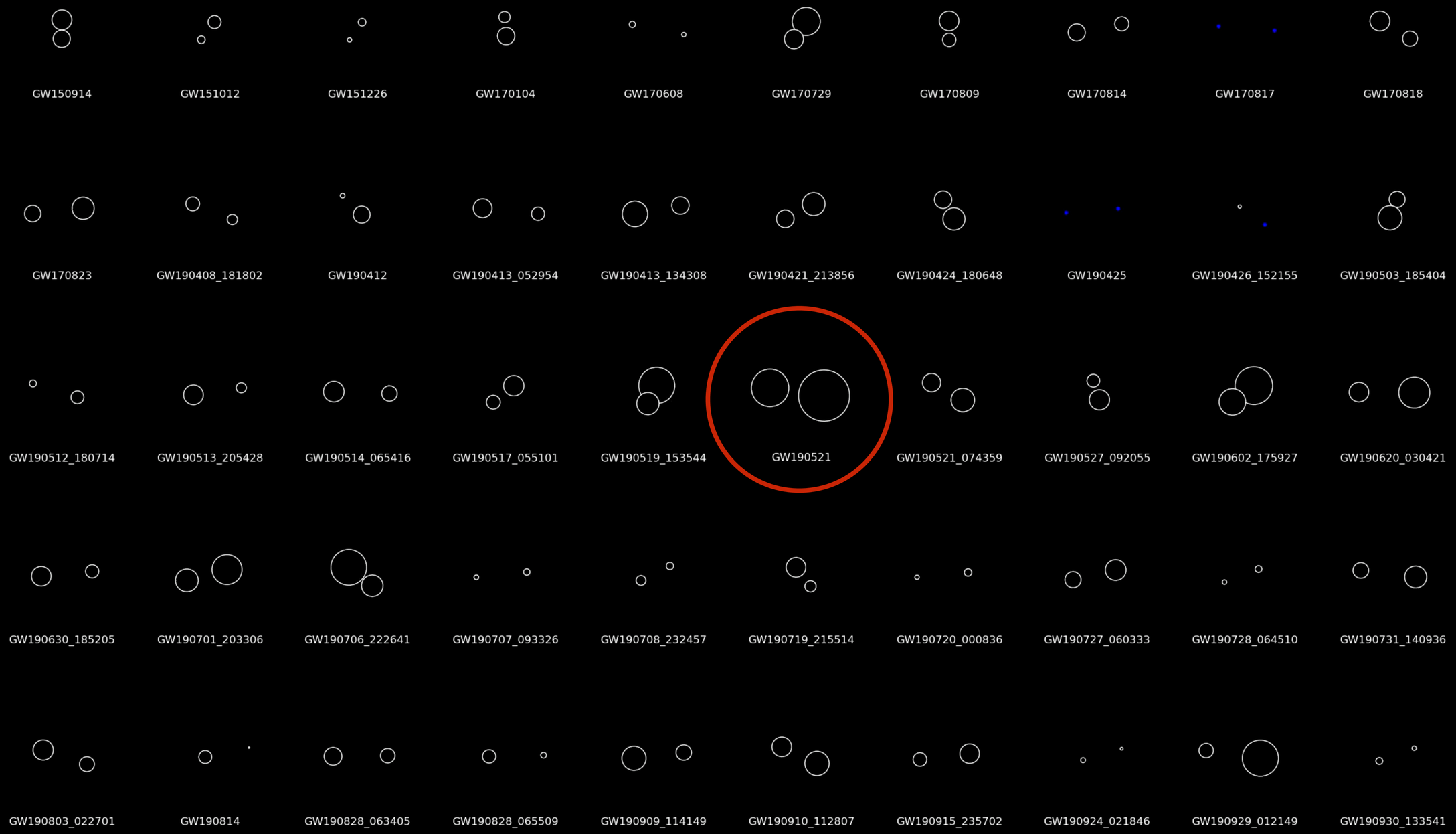
The Notorious B.I.G.: A Candidate Electromagnetic Counterpart to the Binary Black Hole Merger GW190521g

Graham, Ford, McKernan, Ross, Stern et al.

Masses in the Stellar Graveyard

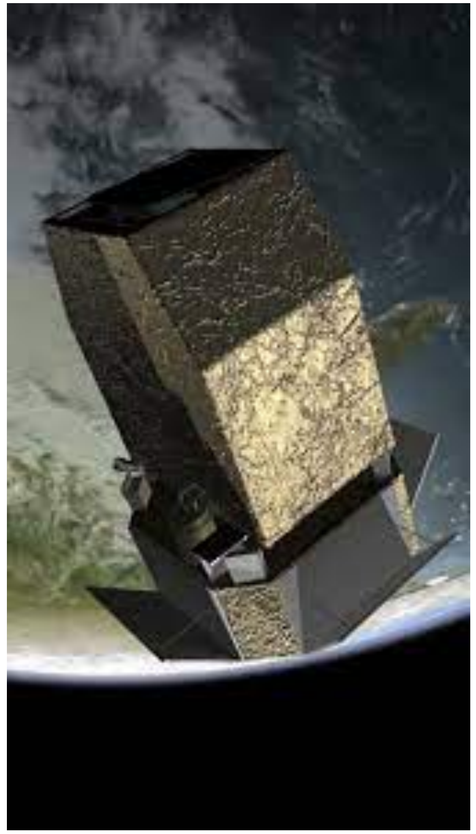


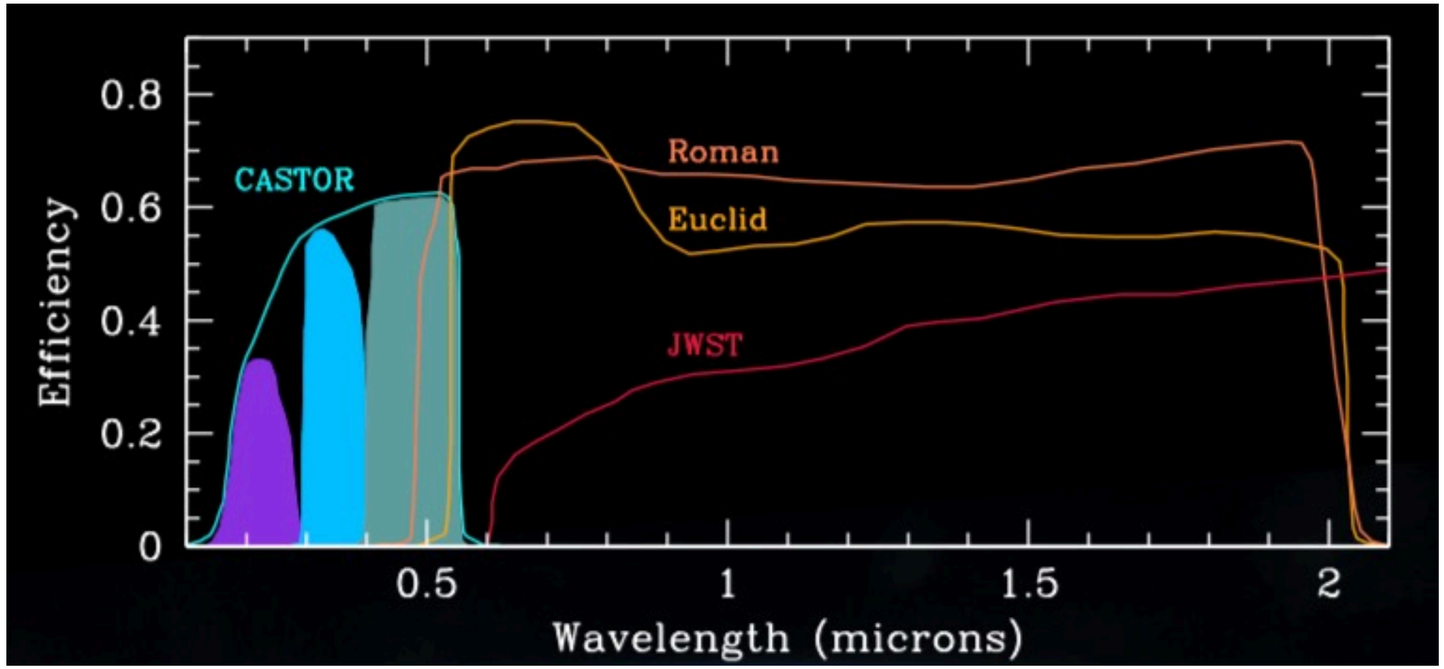
LIGO-Virgo-KAGRA | Aaron Geller | Northwestern



Zoheyr Doctor / CIERA / LIGO-Virgo Collaboration

CASTOR: the Cosmological Advanced Survey Telescope for Optical and ultraviolet Research

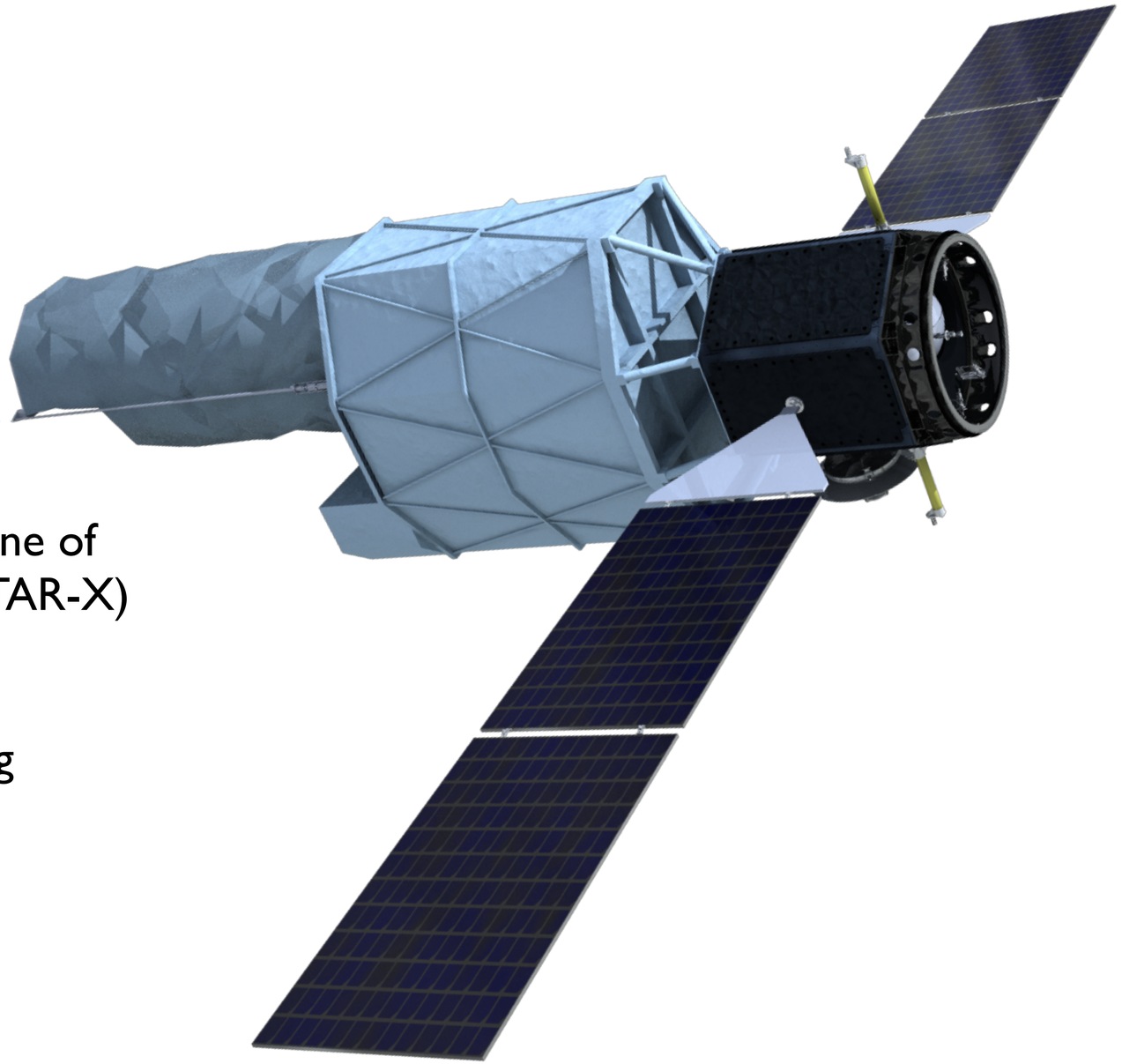




- 1-meter unobscured aperture
- wide field-of-view (0.61° × 0.38°; FWHM = 0.15″)
- 3-band imaging + spectroscopy
- planned launch in ~2027
- broad science, from exoplanets to cosmology
- 8 science working groups, including both Time Domain Astrophysics and AGN
- planned wide-field blind time-domain legacy survey, as well as targeted time-domain follow-up of AGN

https://www.castormission.org/

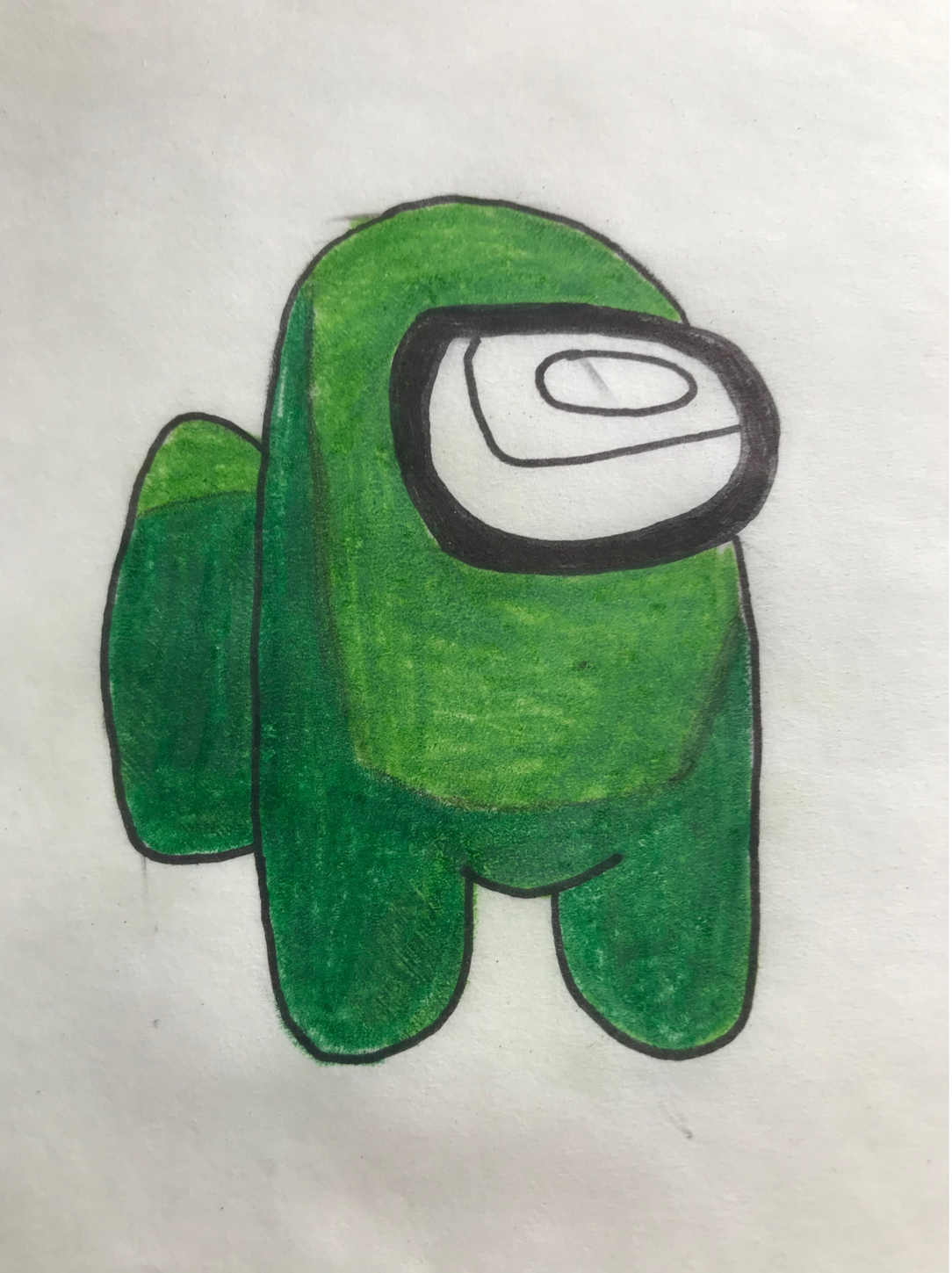
UVEX: Ultraviolet Explorer



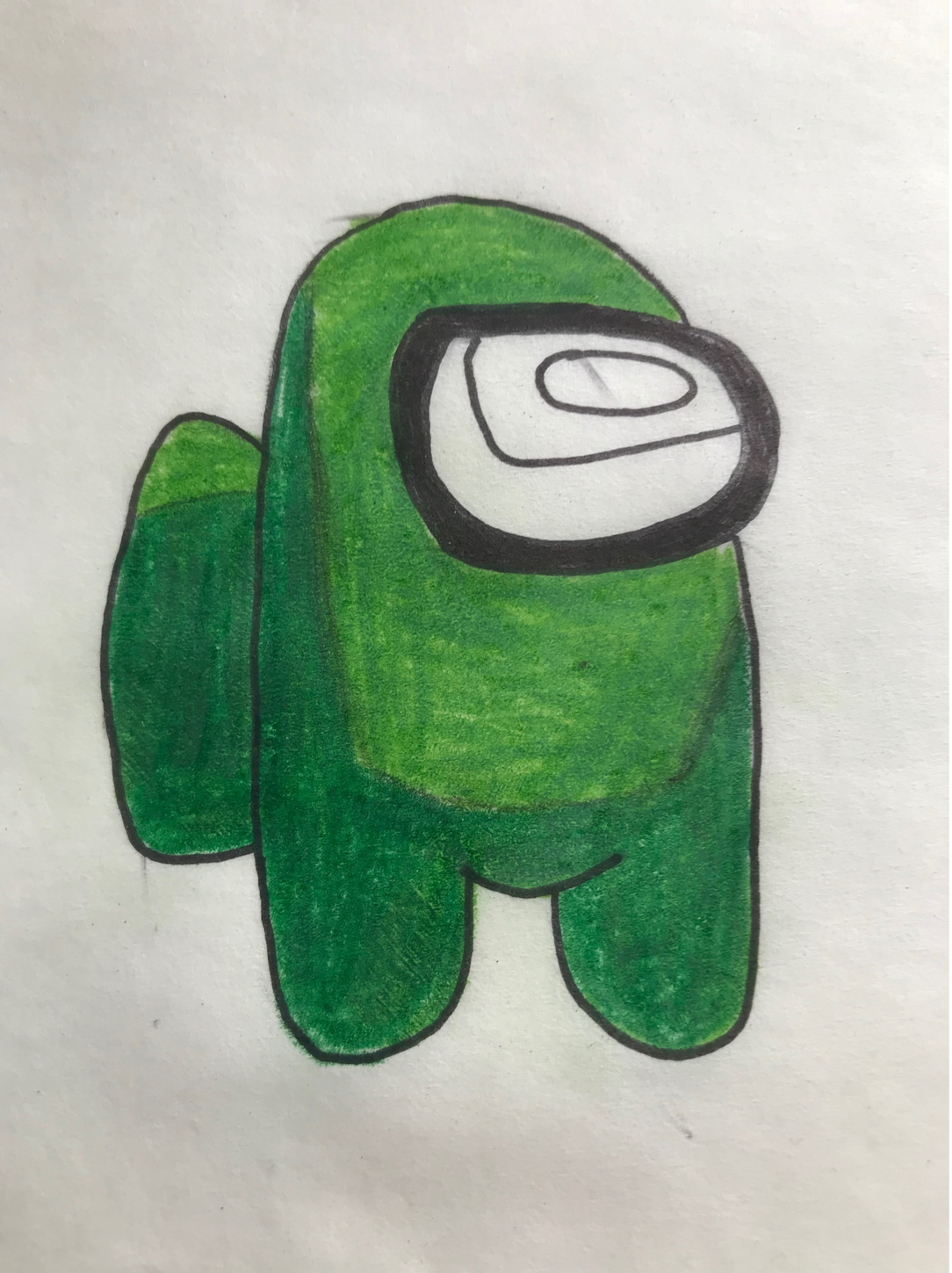
- submitted to 2021 NASA MIDEX opportunity, and one of two missions selected for a Phase A study (along w/ STAR-X)
- PI: Fiona Harrison (Caltech)
- Project Scientist: Brian Grefenstette (Caltech)
- will do a multiple-cadence, all-sky UV survey, reaching 50-100x deeper than GALEX

- 75 cm effective aperture
- wide field-of-view (3.5° × 3.5°)
- FWHM ≤ 2.25″
- 2-band imaging (NUV + FUV) + longslit spectroscopy
- if selected, planned launch in ~2028

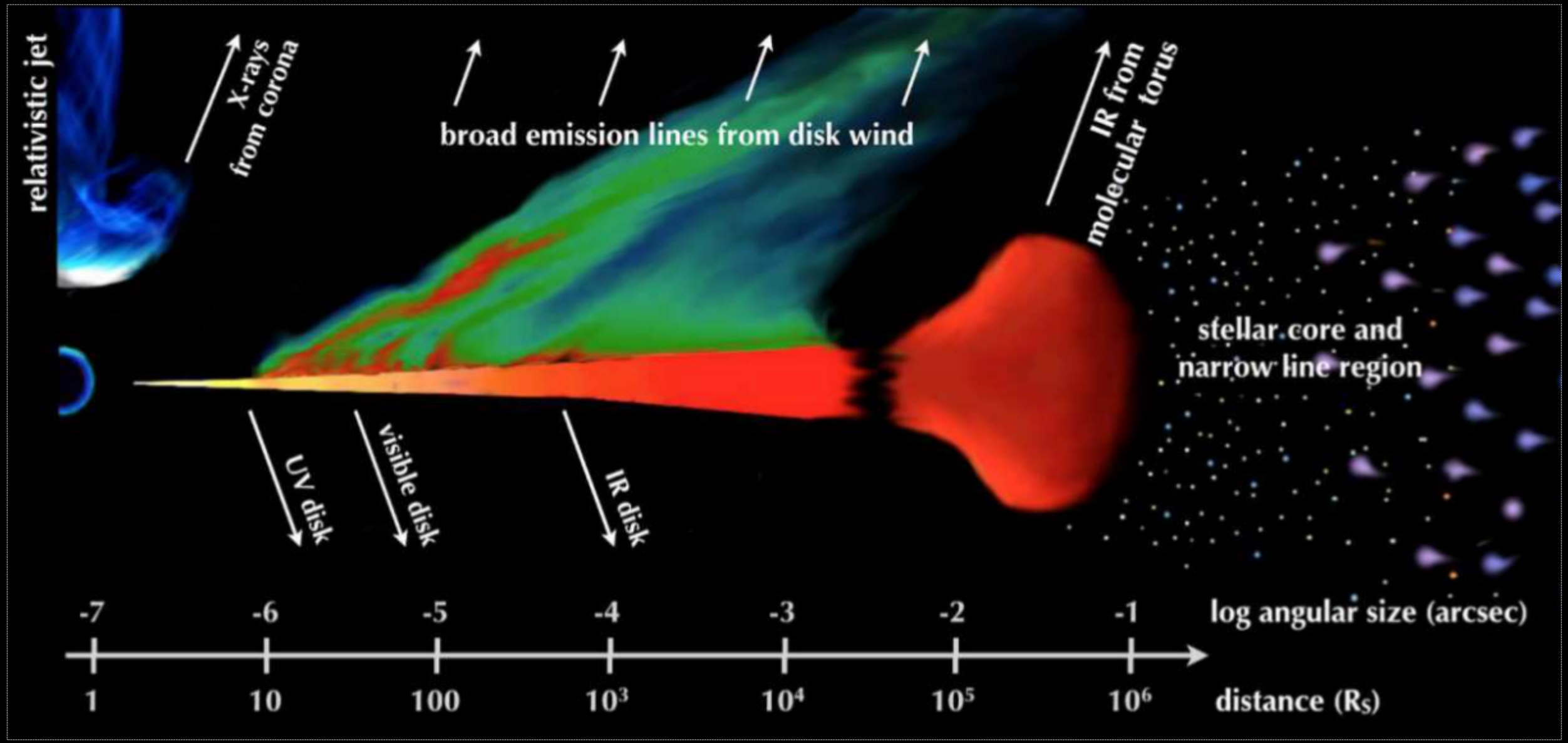
https://arxiv.org/abs/2111.15608



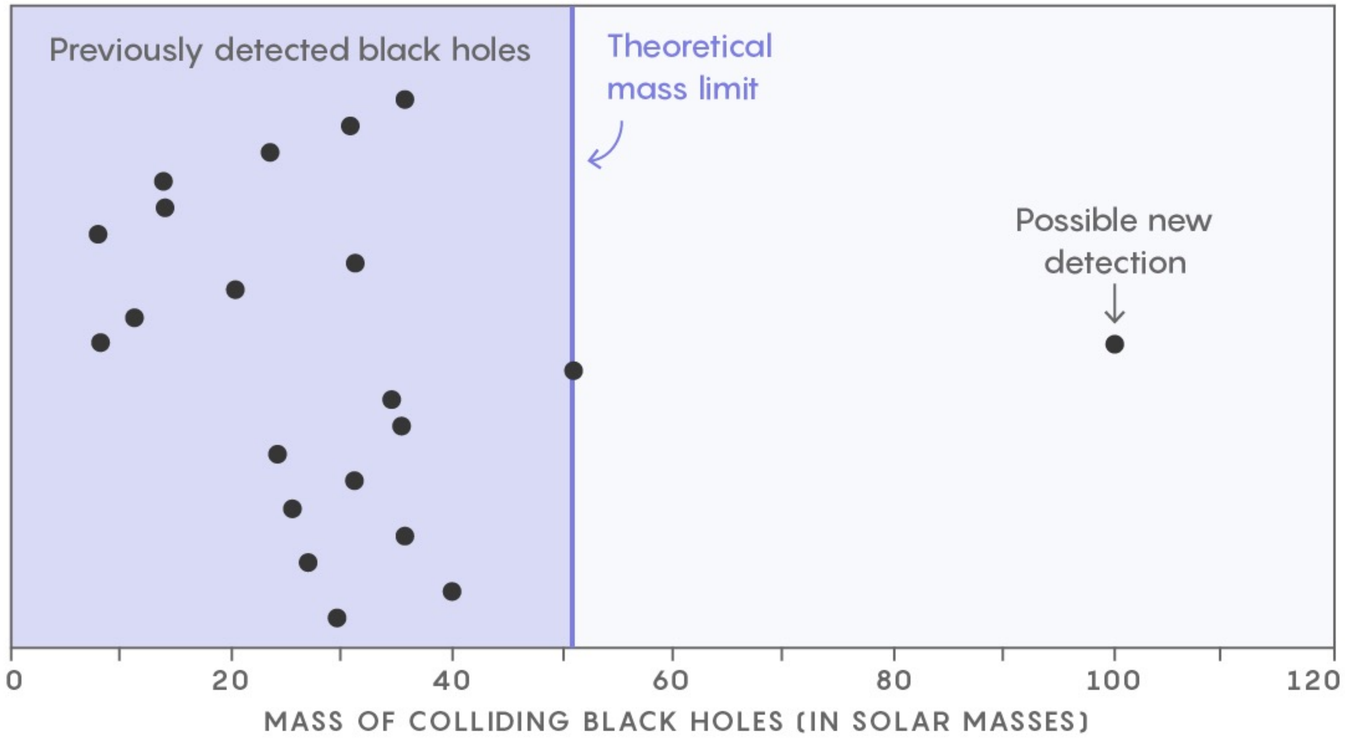
THE END

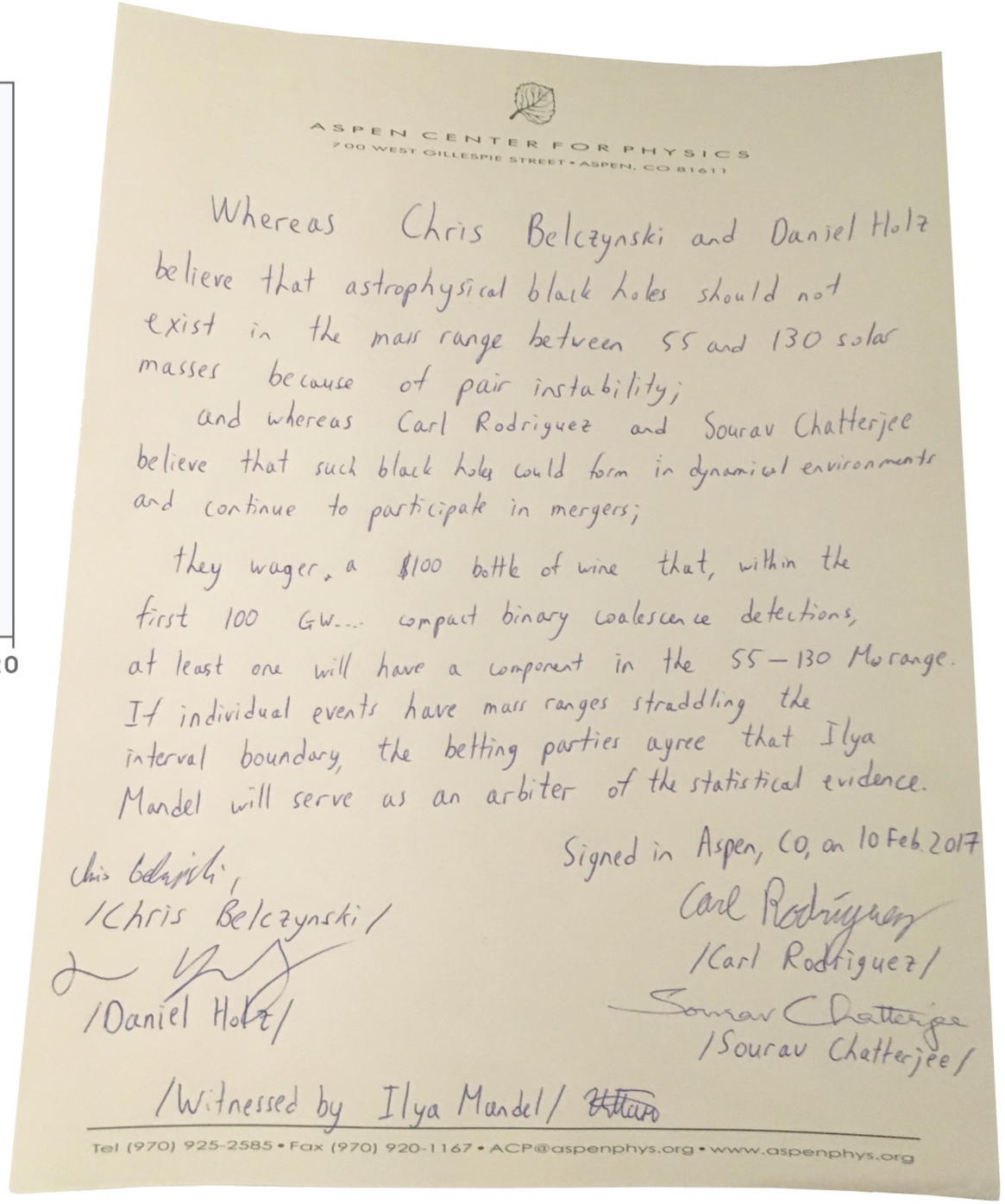


BACK-UP SLIDES


relativistic jet
X-rays from corona
broad emission lines from disk wind
IR from molecular torus
stellar core and narrow line region
UV disk
visible disk
IR disk
-7
-6
-5
-4
-3
-2
-1
log angular size (arcsec)
1
10
100
10³
10⁴
10⁵
10⁶
distance (Rs)

A Black Hole Over the Limit





ASPEN CENTER FOR PHYSICS
700 WEST GILLESPIE STREET • ASPEN, CO 81611

Whereas Chris Belczynski and Daniel Holz believe that astrophysical black holes should not exist in the mass range between 55 and 130 solar masses because of pair instability;

and whereas Carl Rodriguez and Sourav Chatterjee believe that such black holes could form in dynamical environments and continue to participate in mergers;

they wager, a $100 bottle of wine that, within the first 100 GW-... compact binary coalescence detections, at least one will have a component in the 55–130 $M_\odot$ range. If individual events have mass ranges straddling the interval boundary, the betting parties agree that Ilya Mandel will serve as an arbiter of the statistical evidence.

Signed in Aspen, CO, on 10 Feb. 2017

Chris Belczynski,
/Chris Belczynski/

/Daniel Holz/

Carl Rodriguez
/Carl Rodriguez/

Sourav Chatterjee
/Sourav Chatterjee/

/Witnessed by Ilya Mandel/

Tel (970) 925-2585 • Fax (970) 920-1167 • ACP@aspenphys.org • www.aspenphys.org

Potential false positives:

AGN variability: Analyzed light curves of 2.5 million WISE-selected AGN from Assef et al. (2018) with ZTF coverage, looking for flares. Find 393 events. Comparison with damped random walk (DRW) model to ZTF light curves and identifying sources where flare is strong preferred over regular quasar variability drops this number to 13. So probability of a linear light curve with a well-detected >20 day flare is ~5e-6.

Look elsewhere effect: Looked at longer term CRTS light curves for all 3255 AGN within GW 190521g area, and Monte Carlo'd their light curves (1000x per AGN), assuming DRW model, with ZTF sampling. Find just 5 comparable flares, without visual inspection. So O(0.5%) likelihood of chance event.

Supernova: Rejected given the timescale (too short for a SN) and uniform color over time (SNe vary in color as they evolve).

Microlensing: Rejected given the level of magnification, expected years-long event, not weeks.

Tidal disruption event (TDE): Rejected; doesn't match luminosities and GW signal.

Predictions:

EMGW from binary BH mergers: Preferentially should be detected for more massive BHs. Would be good if O4+ include (crude) BH masses.

Off-center flare: If got spectra soon enough, expect signatures from non-uniform illumination of the BLR.

Return to the disk: Expect BH to return to the disk, assuming typical kicks. So more BHL emission in ~1.5 years.

Working on longer, more detailed paper(s) including full GW event sample and more details on the predicted light curves.

Assuming a cosmology, can get constraints on orientation of the BBH merger (= AGN orientation). Or, if you're more bold, assuming AGN orientation, get cosmology.

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