PHYSICS OF ACCRETION AND BINARY BLACK HOLES

Moving forward with high-cadence, band-filtered optical timing

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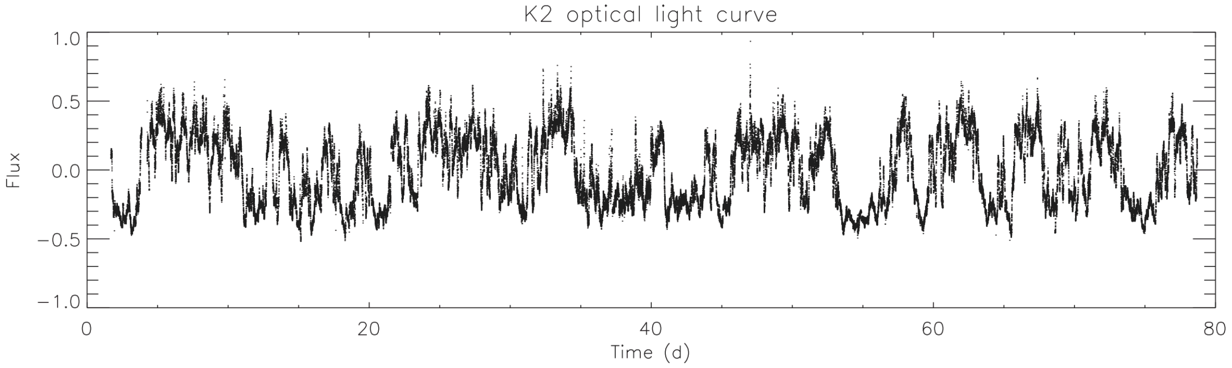
OPTICAL TIMING FROM SPACE: ACCRETION

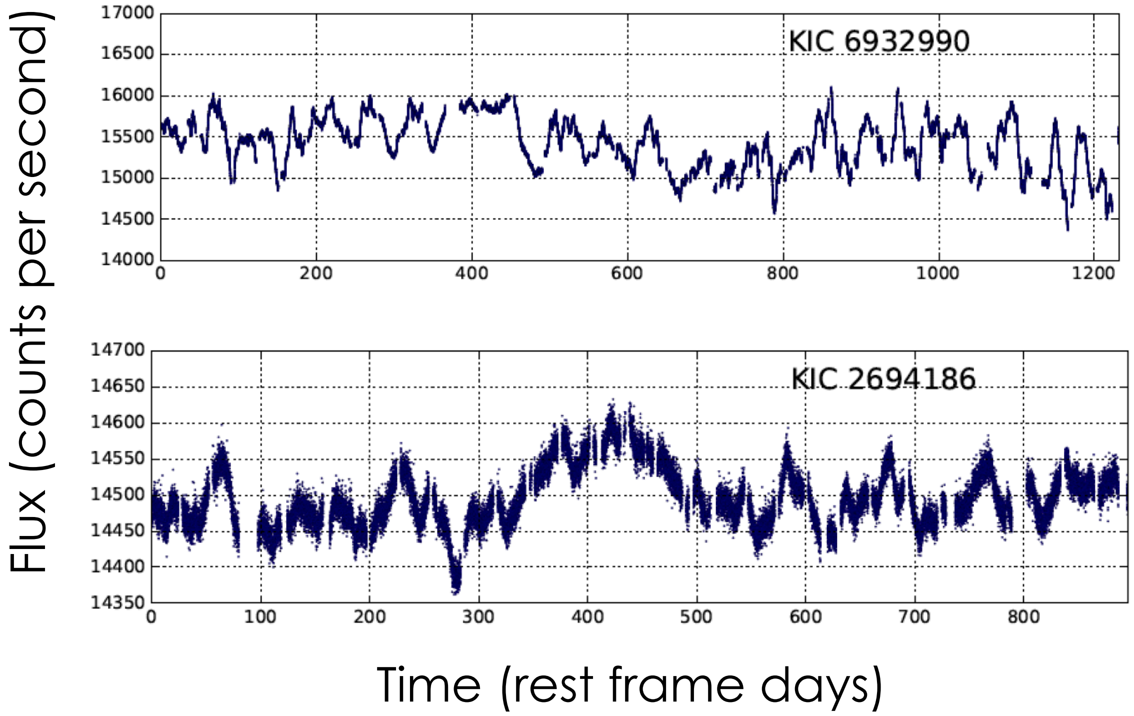
- Kepler/K2 and TESS provided sub-hour, virtually uninterrupted cadence for long time baselines at optical wavelengths, a totally new parameter space comparable to X-ray timing missions.

LMXB Sco X-1:



Hakala et al. (2015)

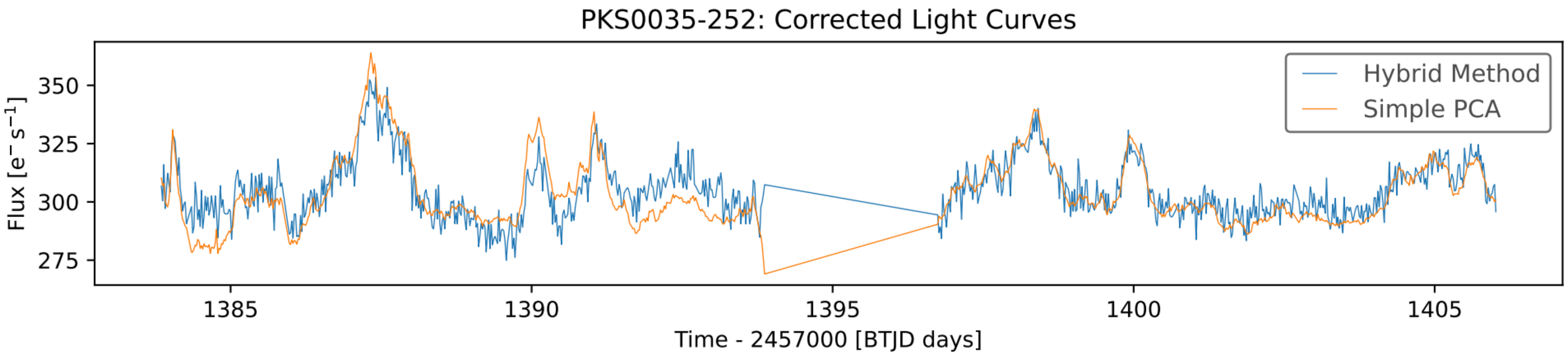
Seyfert 1 AGN:

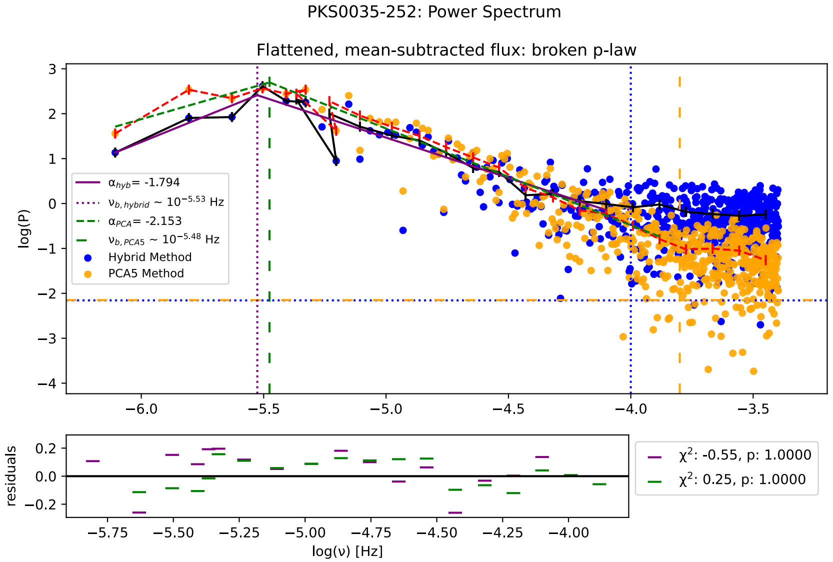


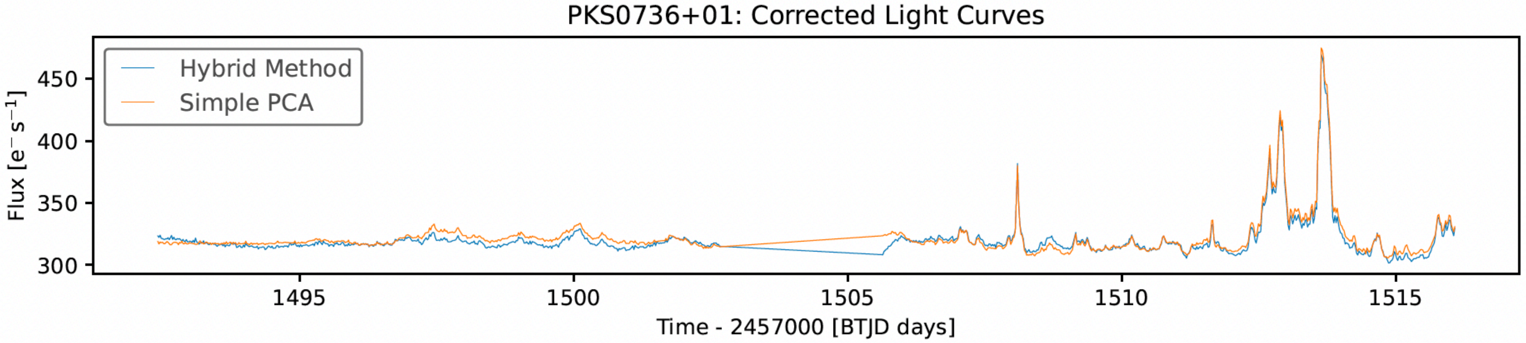
K. L. Smith et al. (2018a)

OPTICAL TIMING FROM SPACE: BLAZARS

Ryne Dingler

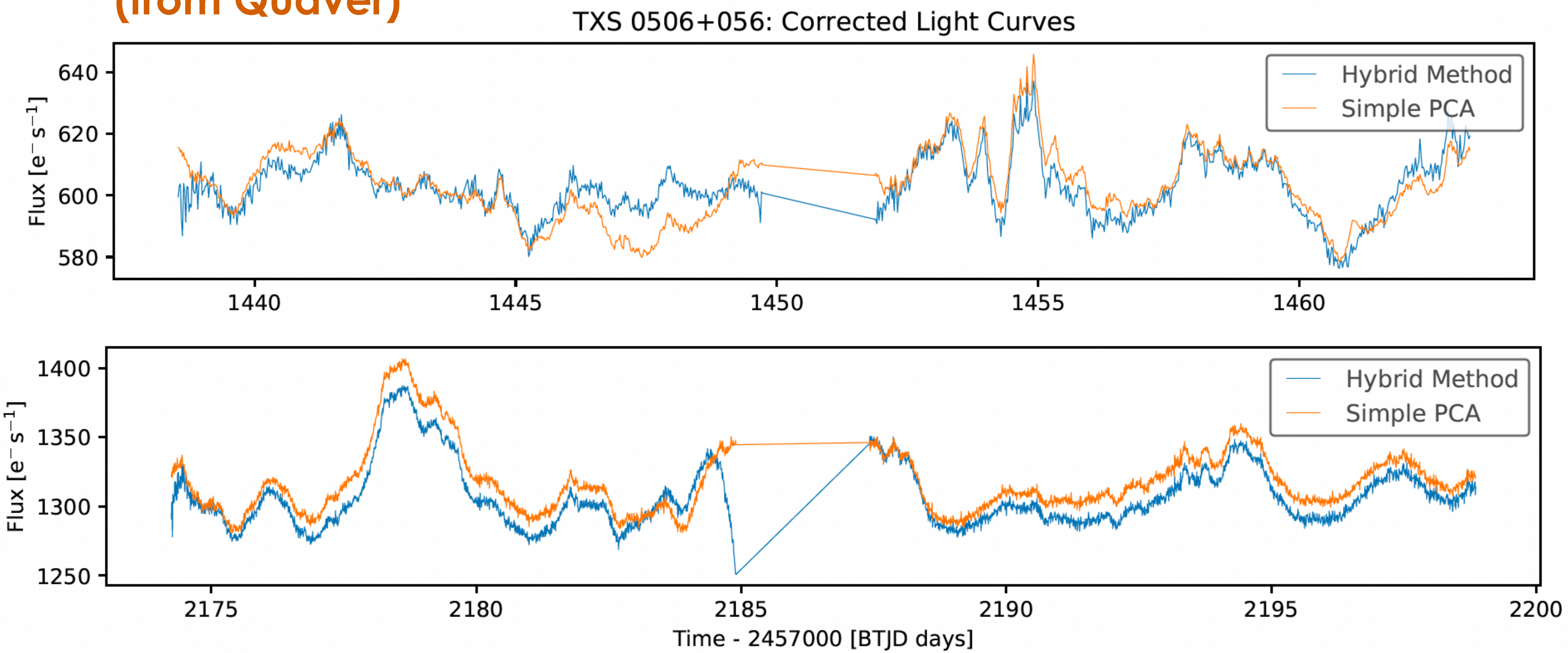




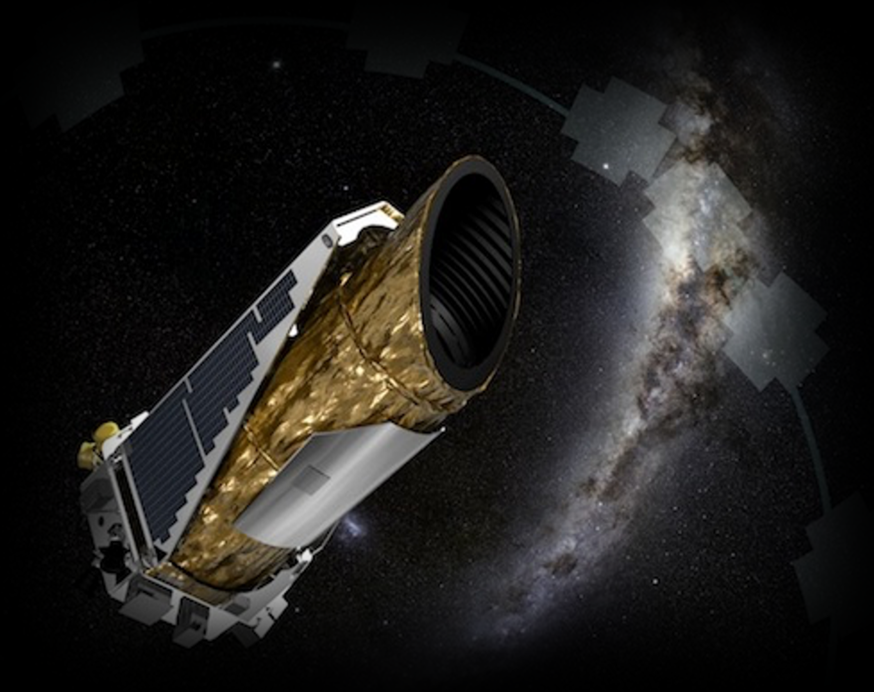


MULTI-BAND CAPABILITIES: BLAZARS

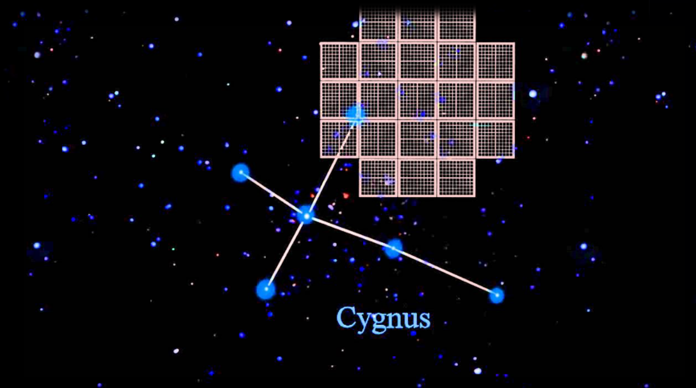
TESS Light Curves (from Quaver)

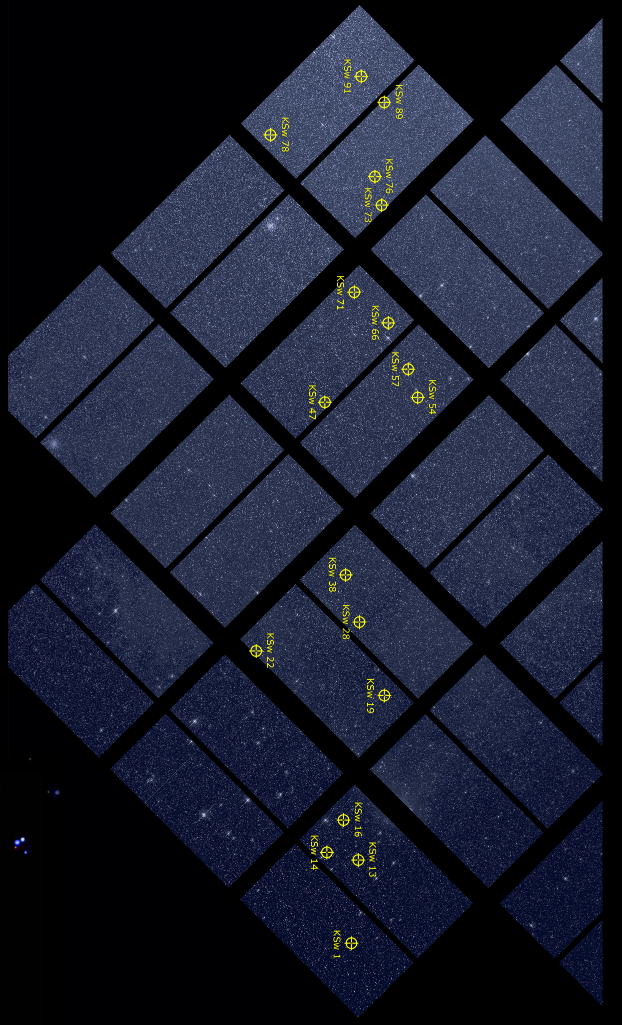


Kepler



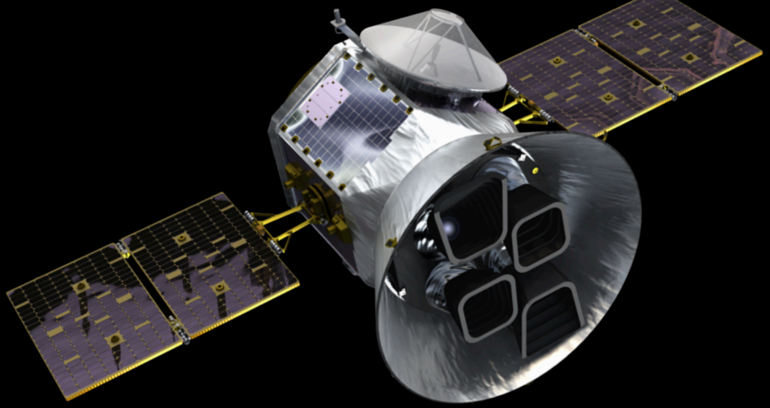
- Even sampling
- Long baselines
- Extreme photometric precision
- Very limited field of view

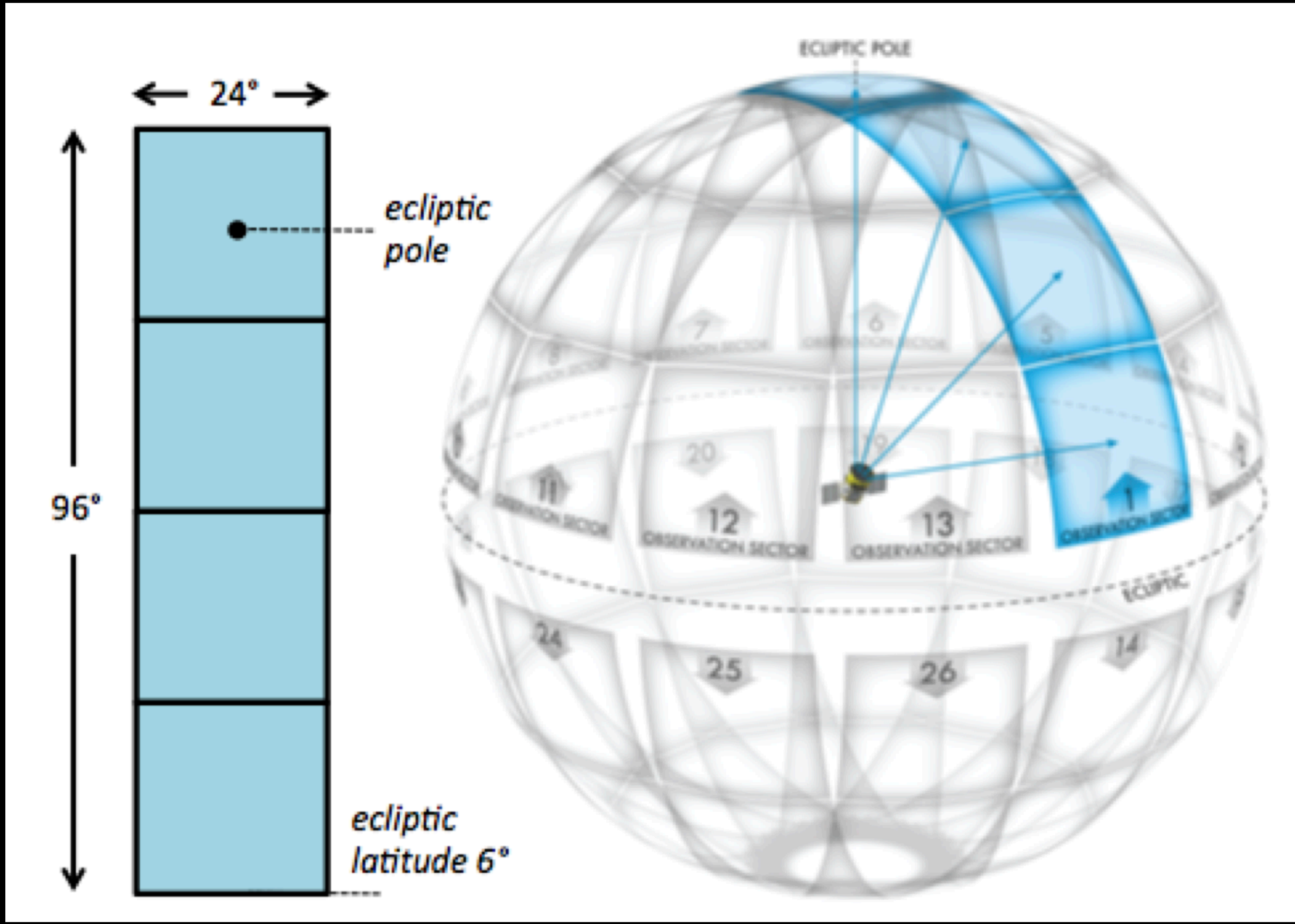




K.L. Smith et al. 2015

TESS

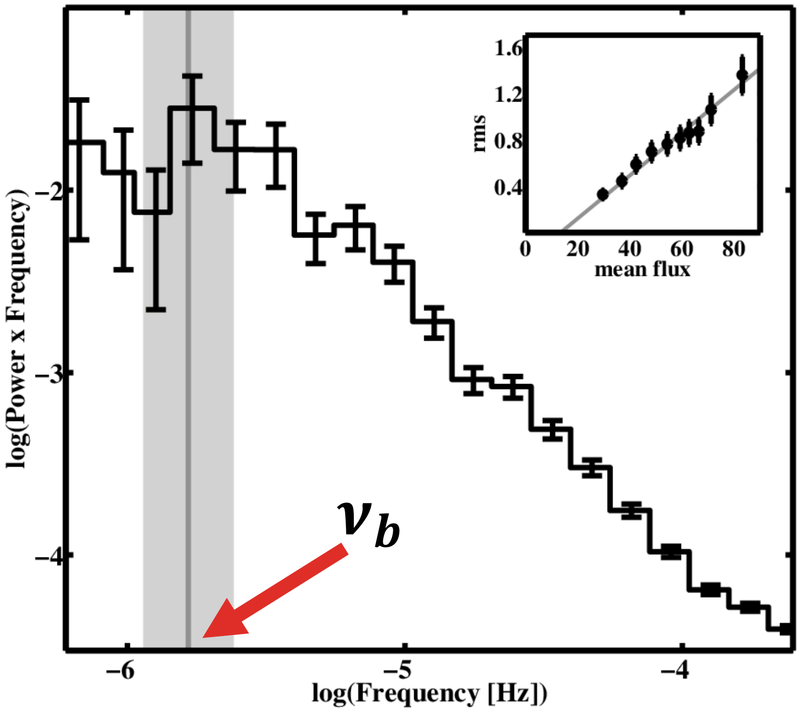


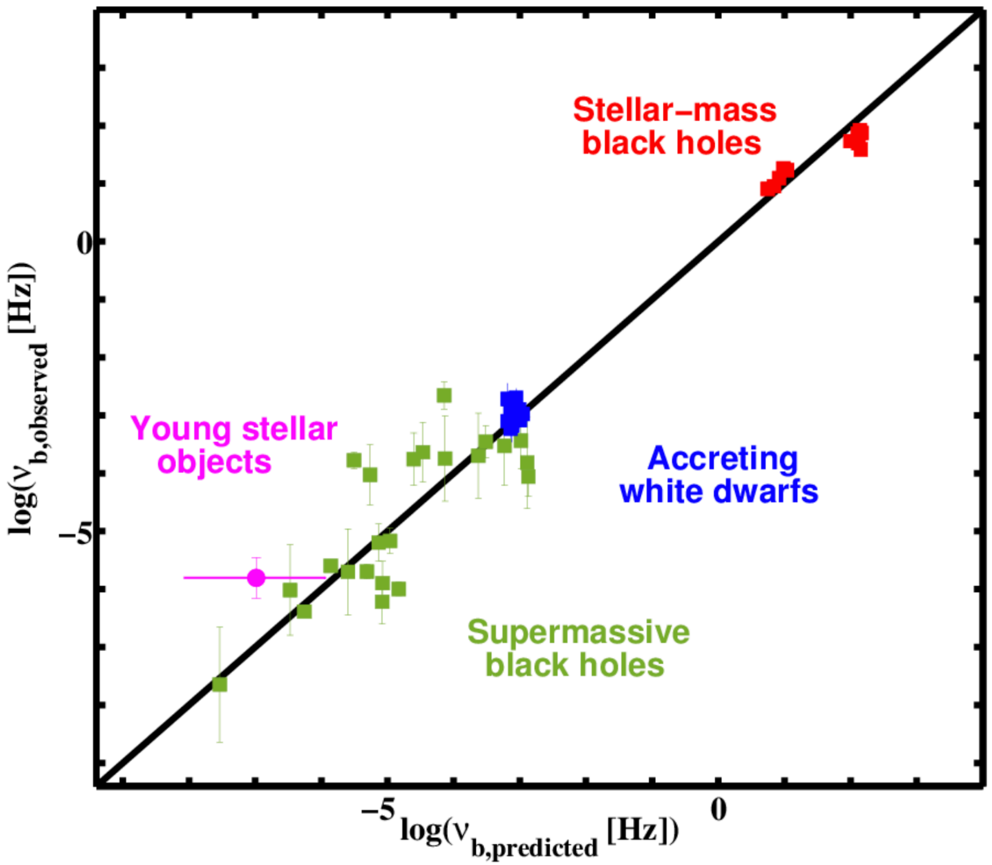

24°
96°
ecliptic
pole
ecliptic
latitude 6°
ECLIPTIC POLE
12
13
20
25
26
ECLIPTIC

IS ACCRETION MASS-AGNOSTIC?

Characteristic timescales match predictions from a scale-invariant model across many mass scales.

Power spectrum of a young stellar object:





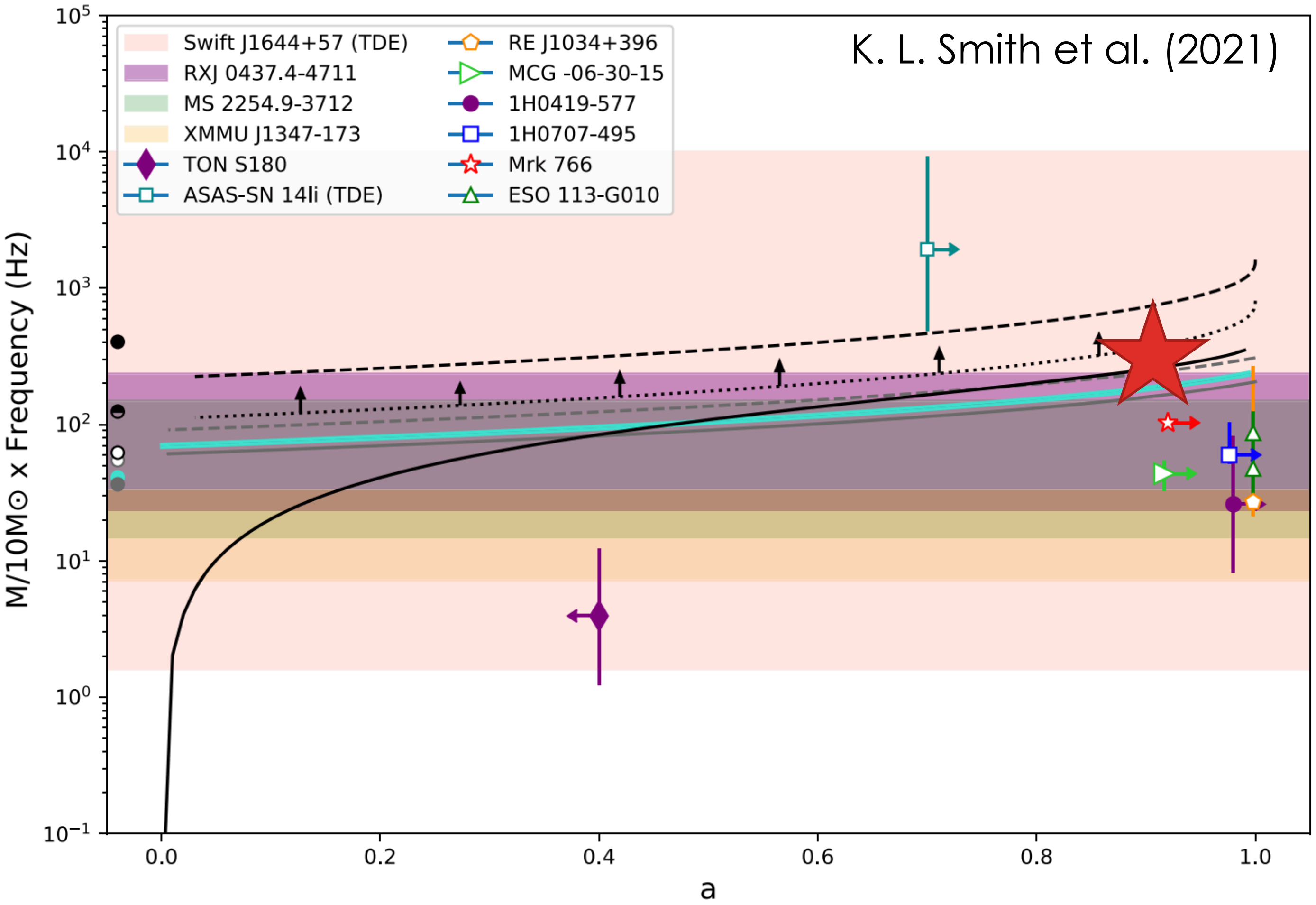
Scaringi et al. (2015)

BUT QUESTIONS REMAIN

- Quasi-periodic oscillations are common in X-ray binaries but rare in AGN, and occupy a different parameter space.

- Attempts to unify AGN with the X-ray binaries' hardness-intensity cycle are muddled.

QPO Frequency x Black Hole Mass



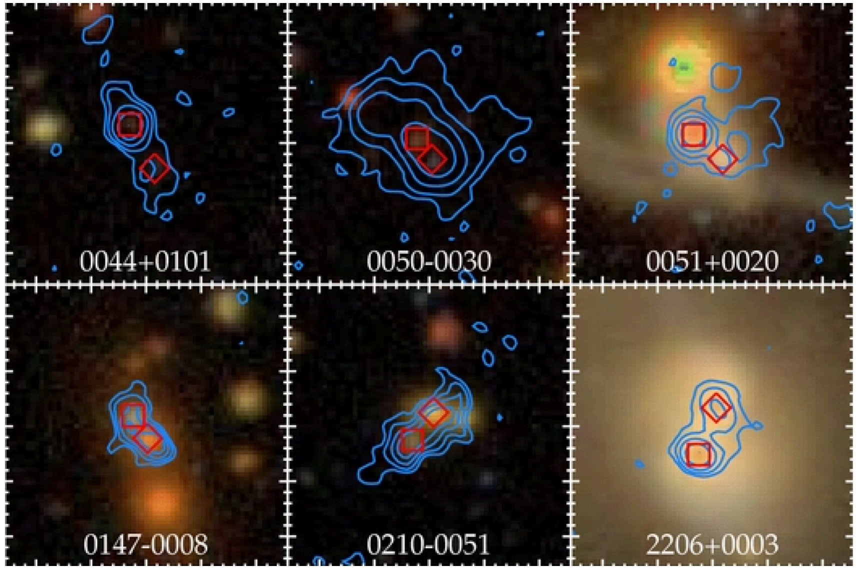
Black Hole Spin



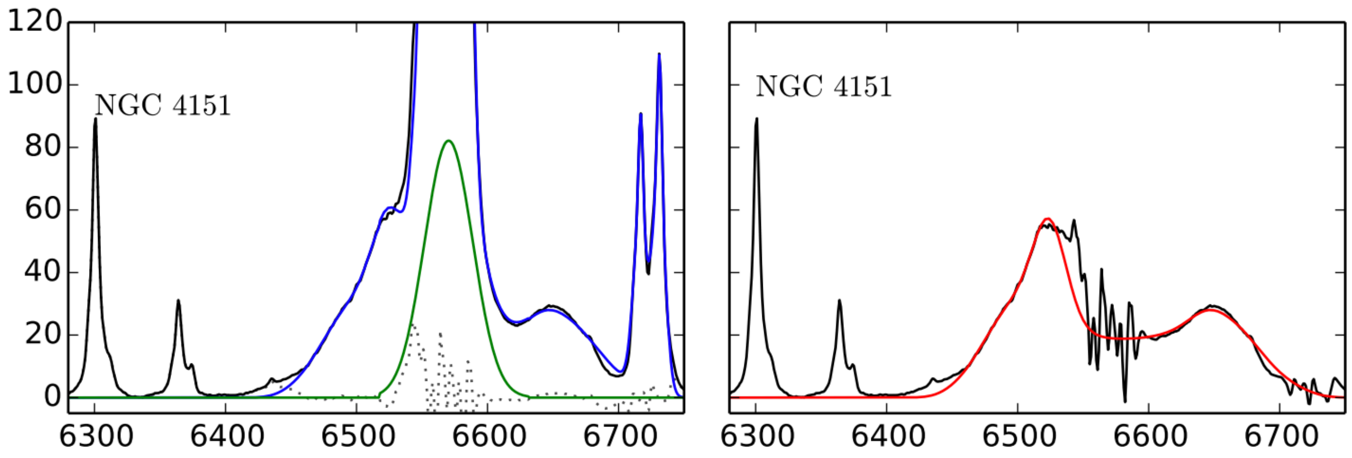




Binary massive black holes should be **everywhere.**

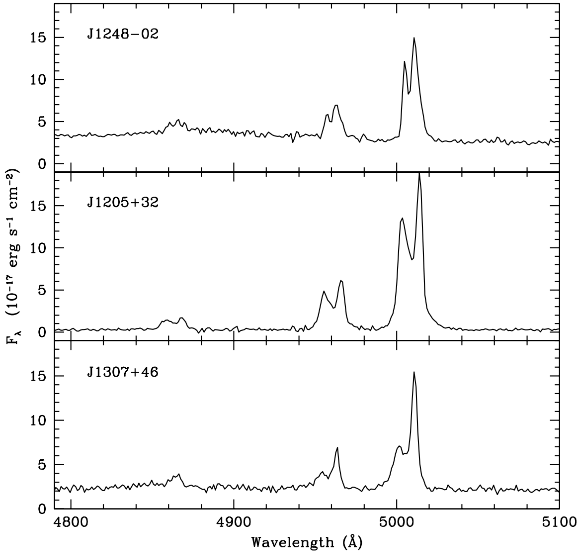


Fu et al. 2015

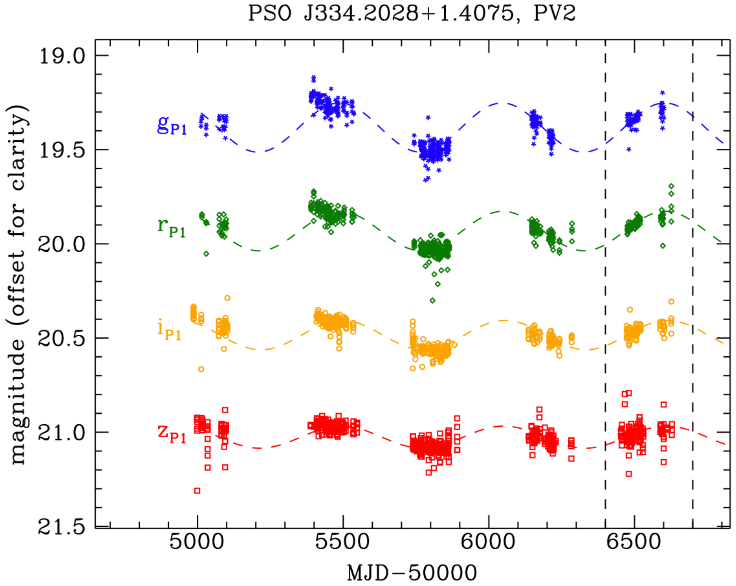


But they ***aren't.***

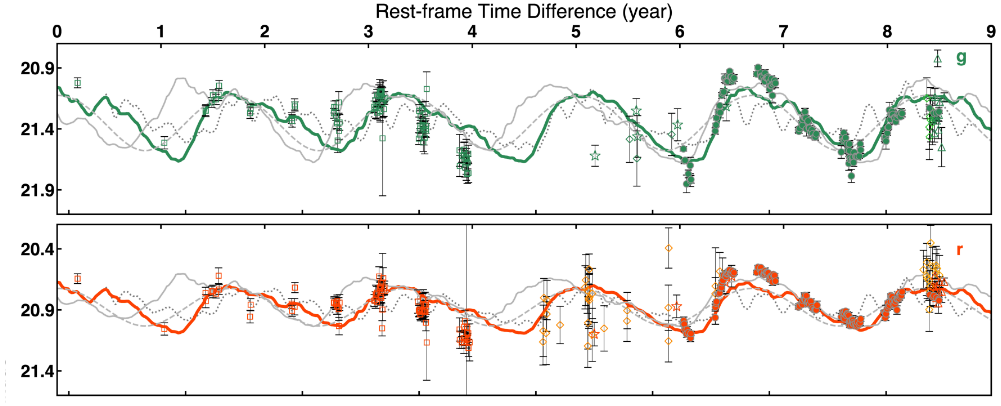
Storchi-Bergmann et al. 2016



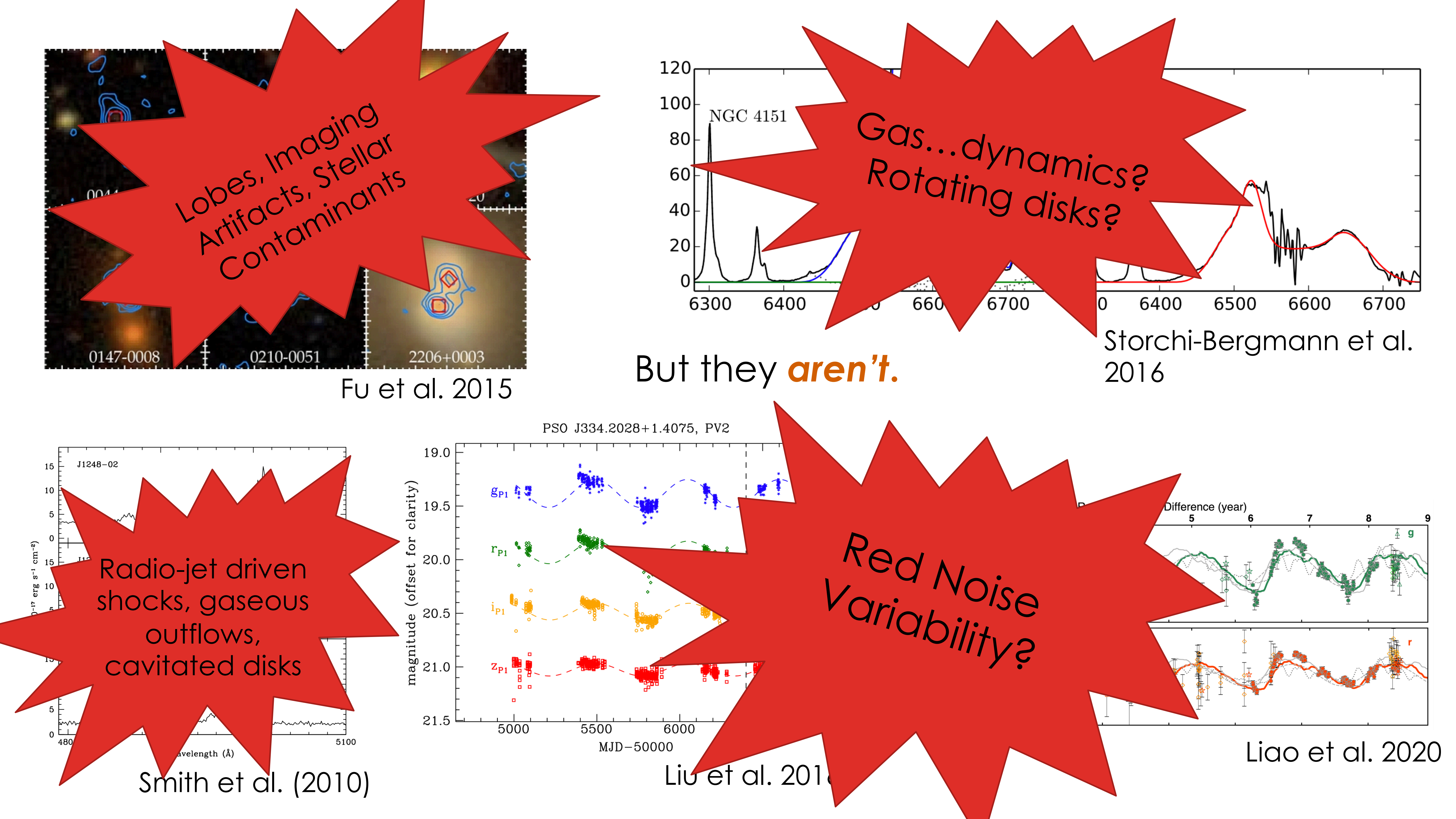
Smith et al. (2010)



Liu et al. 2016

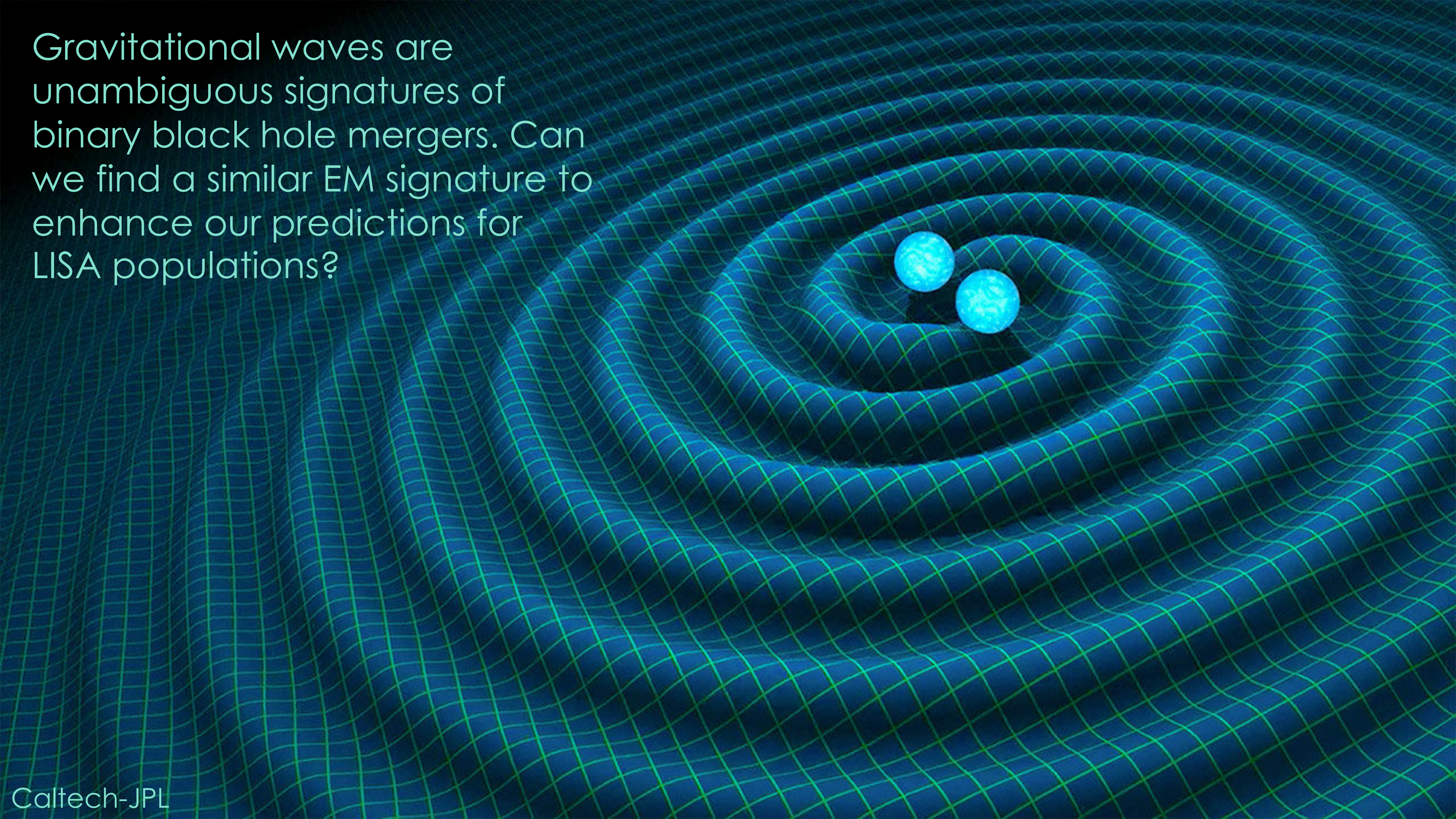


Liao et al. 2020

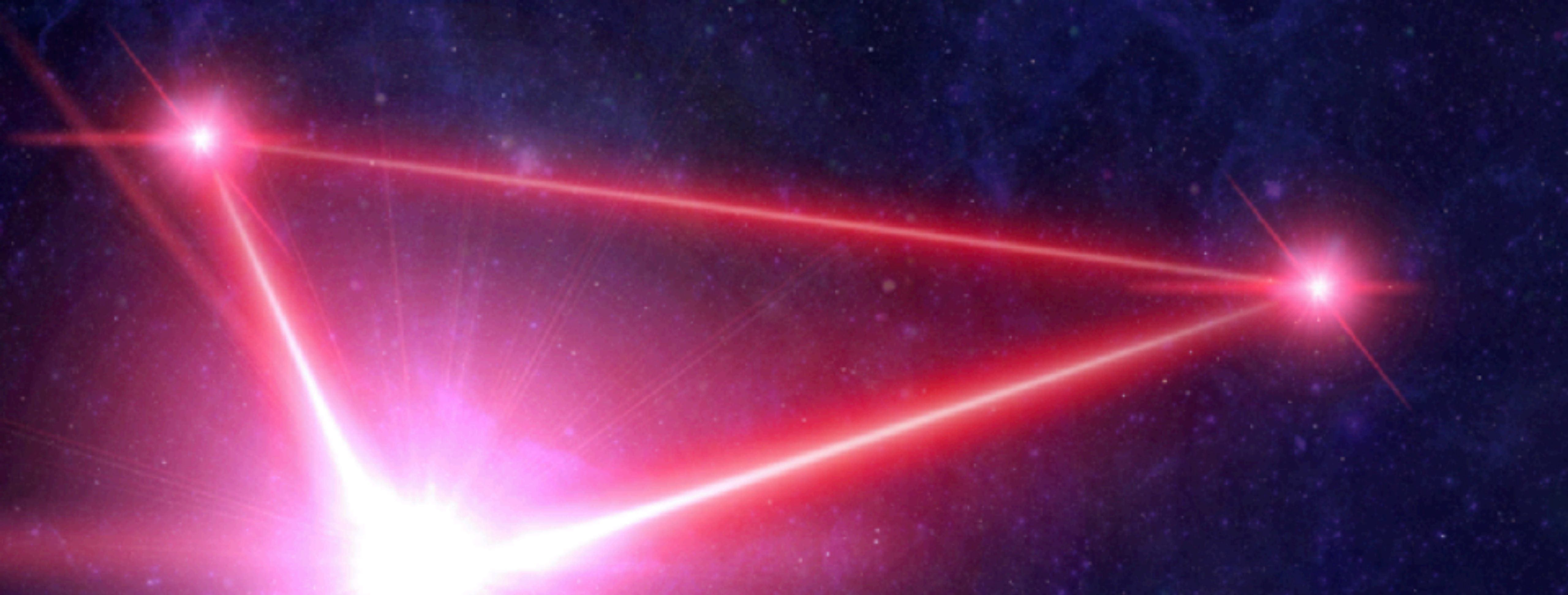


Lobes, Imaging Artifacts, Stellar Contaminants
0147-0008
0210-0051
2206+0003
Fu et al. 2015
NGC 4151
Gas…dynamics? Rotating disks?
Storchi-Bergmann et al. 2016
But they ***aren't.***
J1248-02
Radio-jet driven shocks, gaseous outflows, cavitated disks
Smith et al. (2010)
PSO J334.2028+1.4075, PV2
magnitude (offset for clarity)
MJD−50000
Red Noise Variability?
Liu et al. 201
Difference (year)
Liao et al. 2020

Gravitational waves are unambiguous signatures of binary black hole mergers. Can we find a similar EM signature to enhance our predictions for LISA populations?



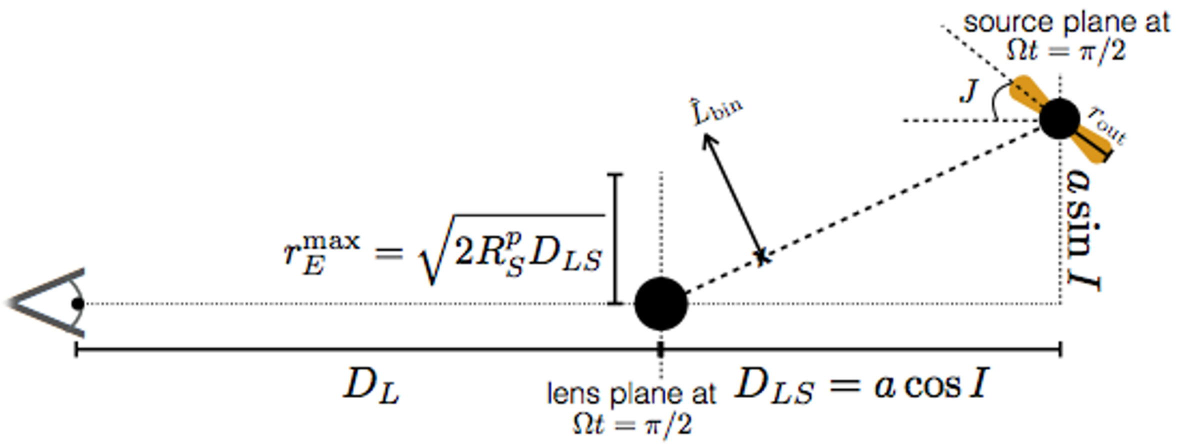
Caltech-JPL

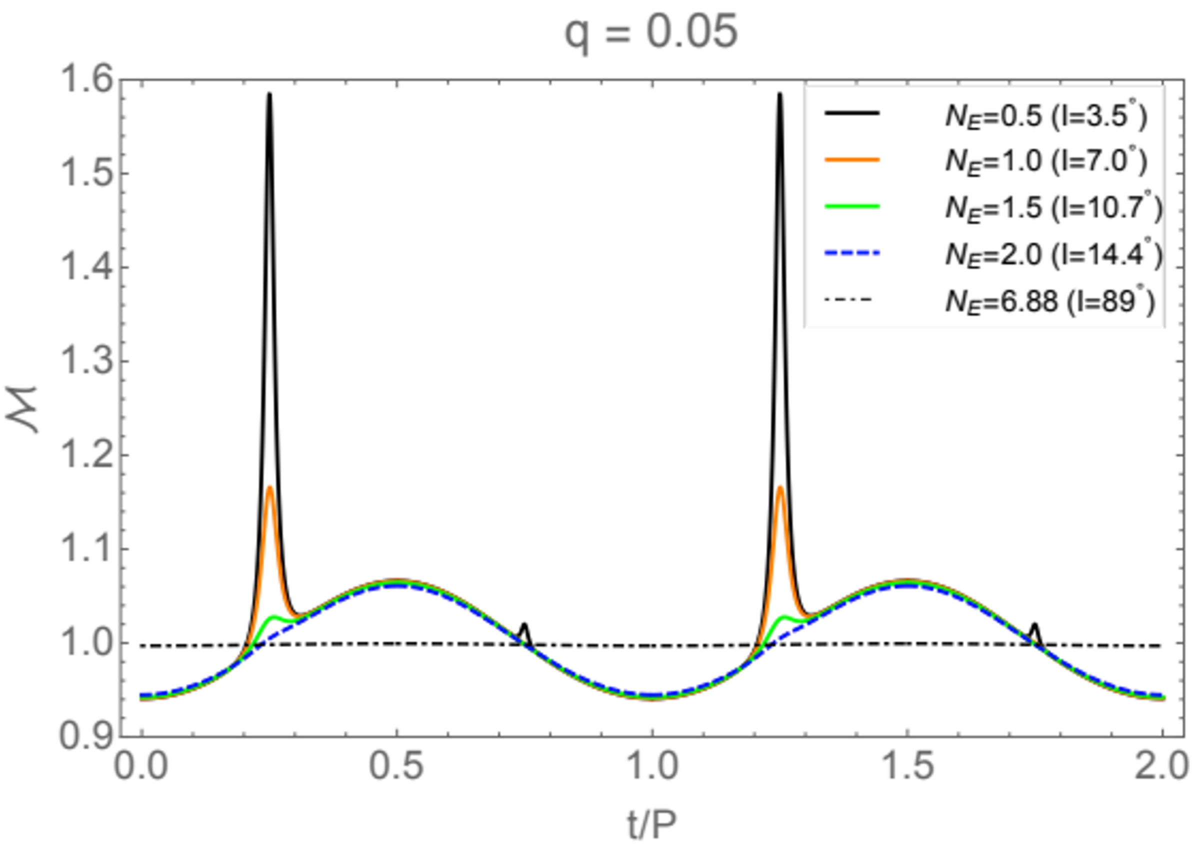


Variability, in many forms, promises to solidify and sharpen our census of supermassive black hole binaries in preparation for LISA's new window into Gravitational Waves.

NEW SEARCH METHODS FOR SUPERMASSIVE BINARIES

- Gravitational self-lensing flares

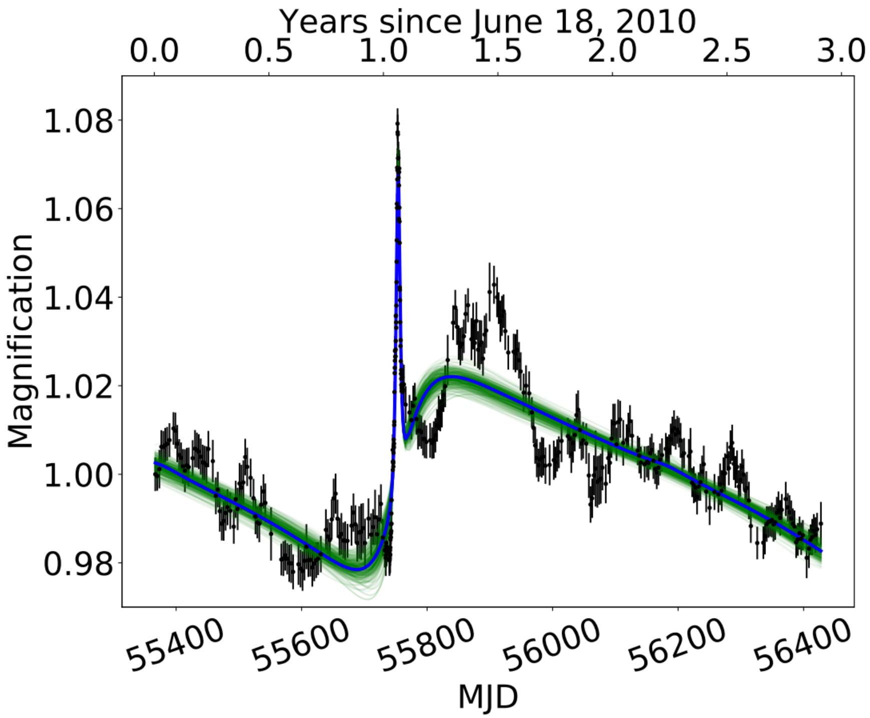


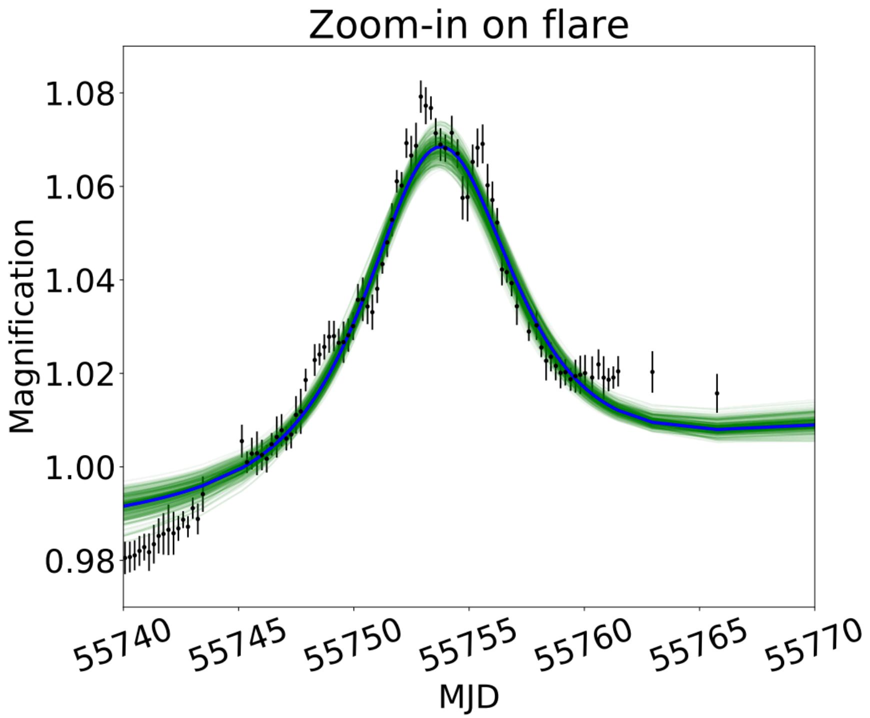


D'Orazio & Stefano (2018)

NEW SEARCH METHODS FOR SUPERMASSIVE BINARIES

- Gravitational self-lensing flares: a candidate from *Kepler*





Hu, D'Orazio, KL Smith + (2019)

MAJOR LIMITATIONS OF EXOPLANET-FOCUSED MISSIONS

- No color information
- Very poor spatial resolution
- Bright magnitude limits
- Lack of absolute calibrations / care for long-term systematics

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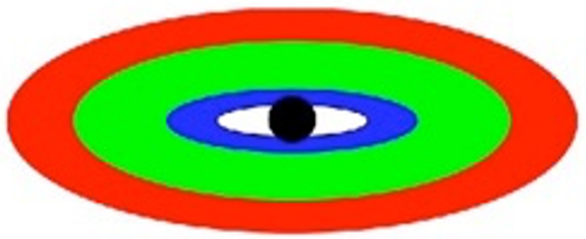
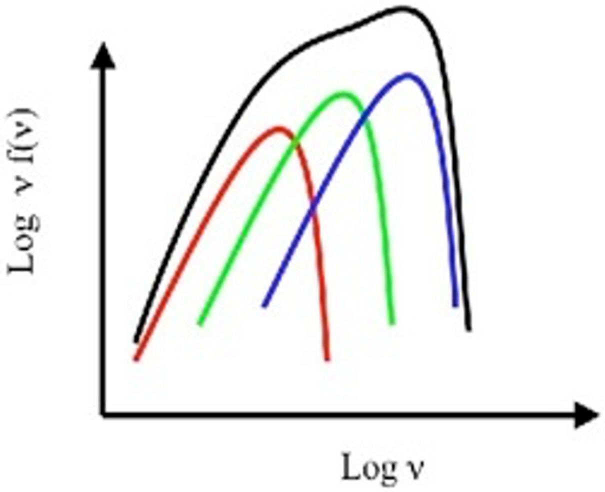
But these are a *really really big deal* too!

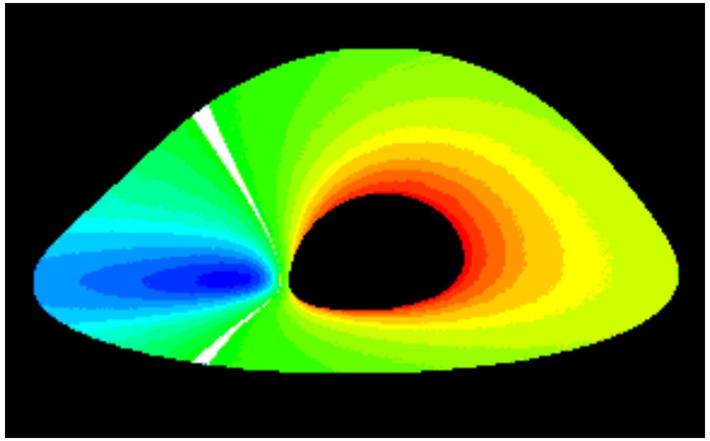
MULTI-BAND CAPABILITIES: ACCRETION

- Accretion disk physics: resolved reverberation in real-time



U. Alberta





Bromley (1995)

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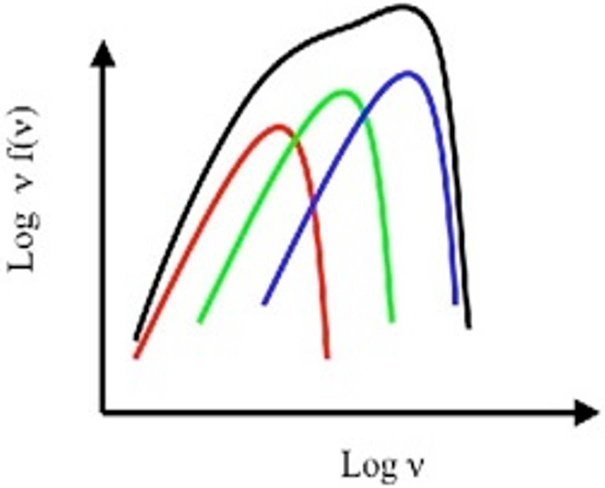
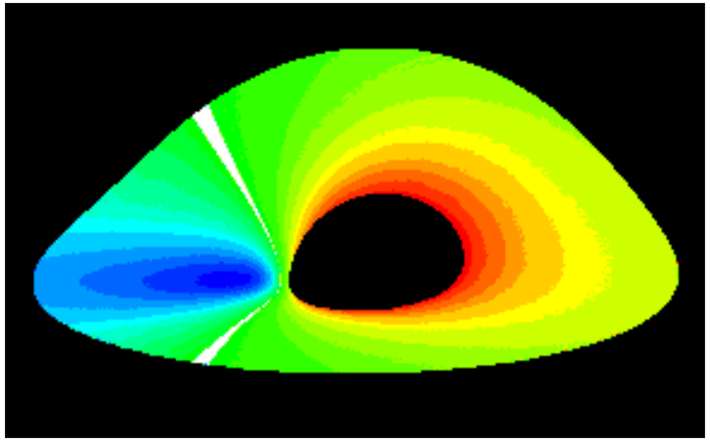
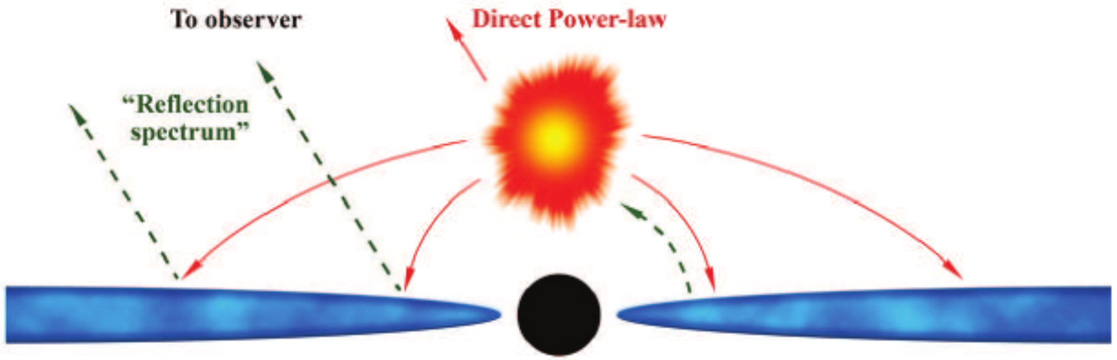
U. Alberta

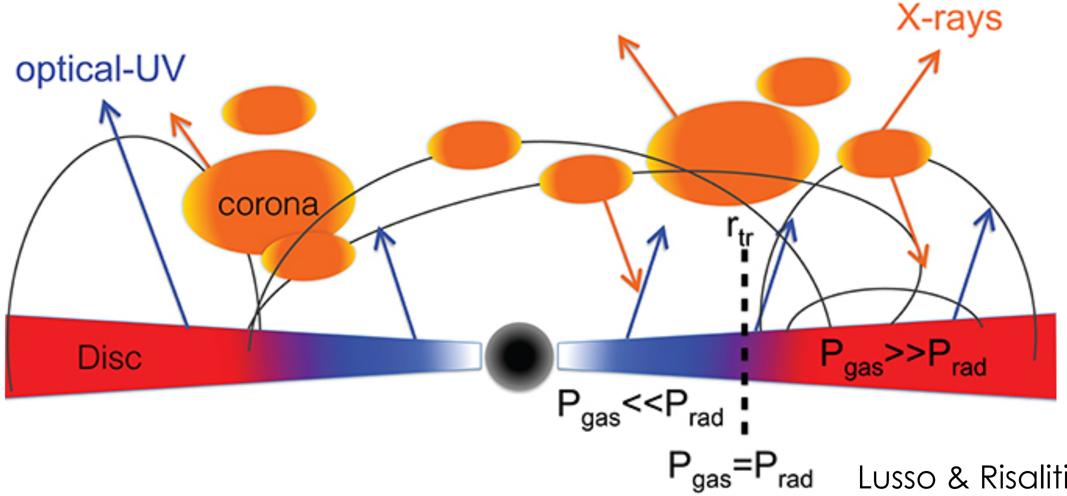




Bromley (1995)



Uttley et al. (2014)

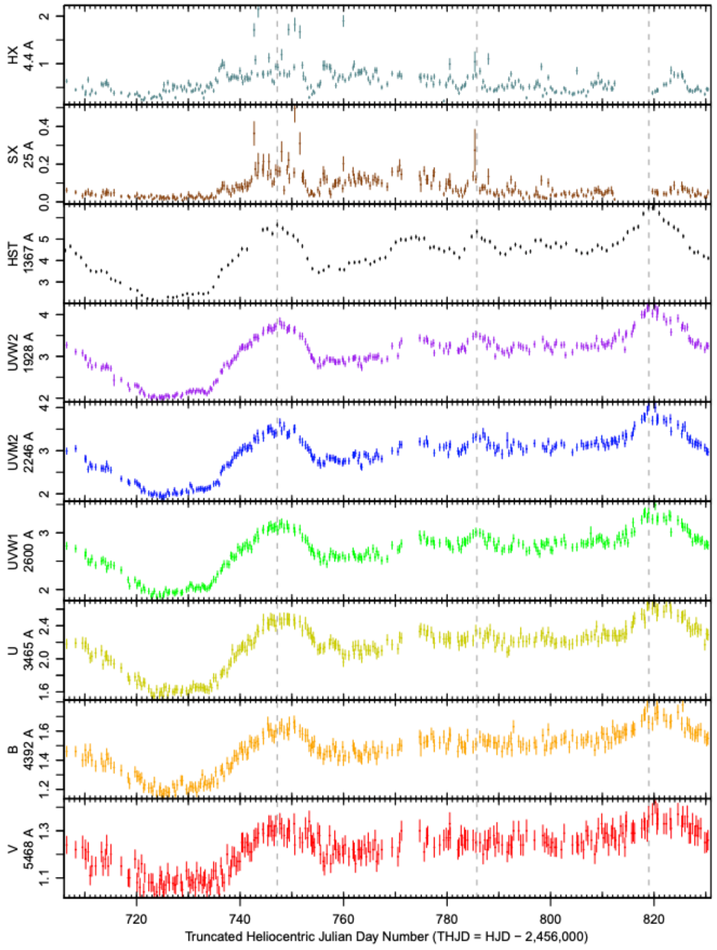


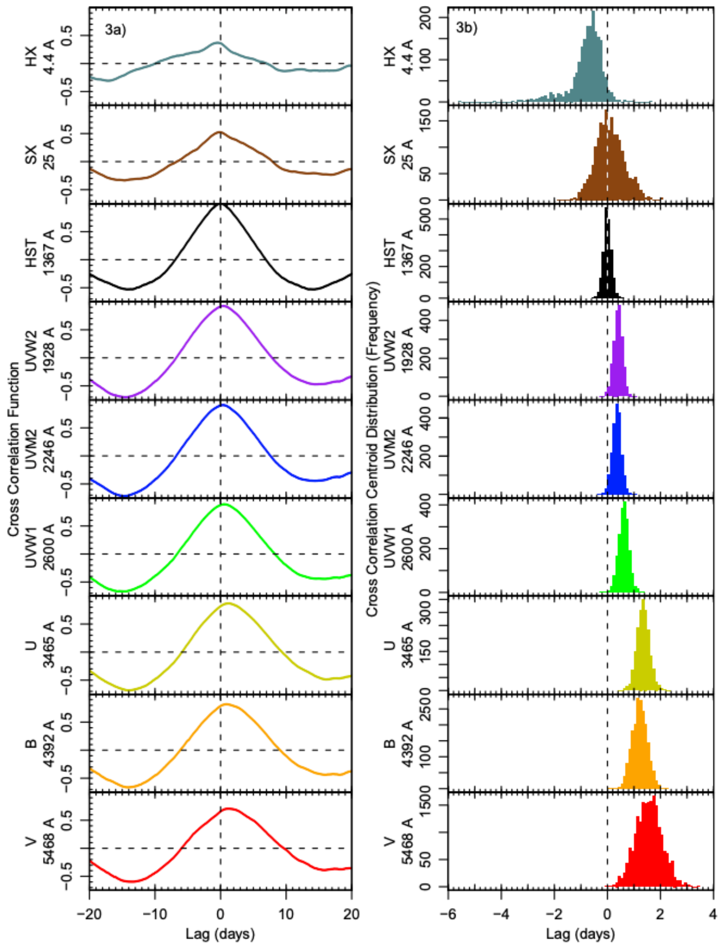
Lusso & Risaliti (2018)

MULTI-BAND CAPABILITIES: ACCRETION

- Accretion disk physics: resolved reverberation in real-time

Multi-band light curves of NGC 5548





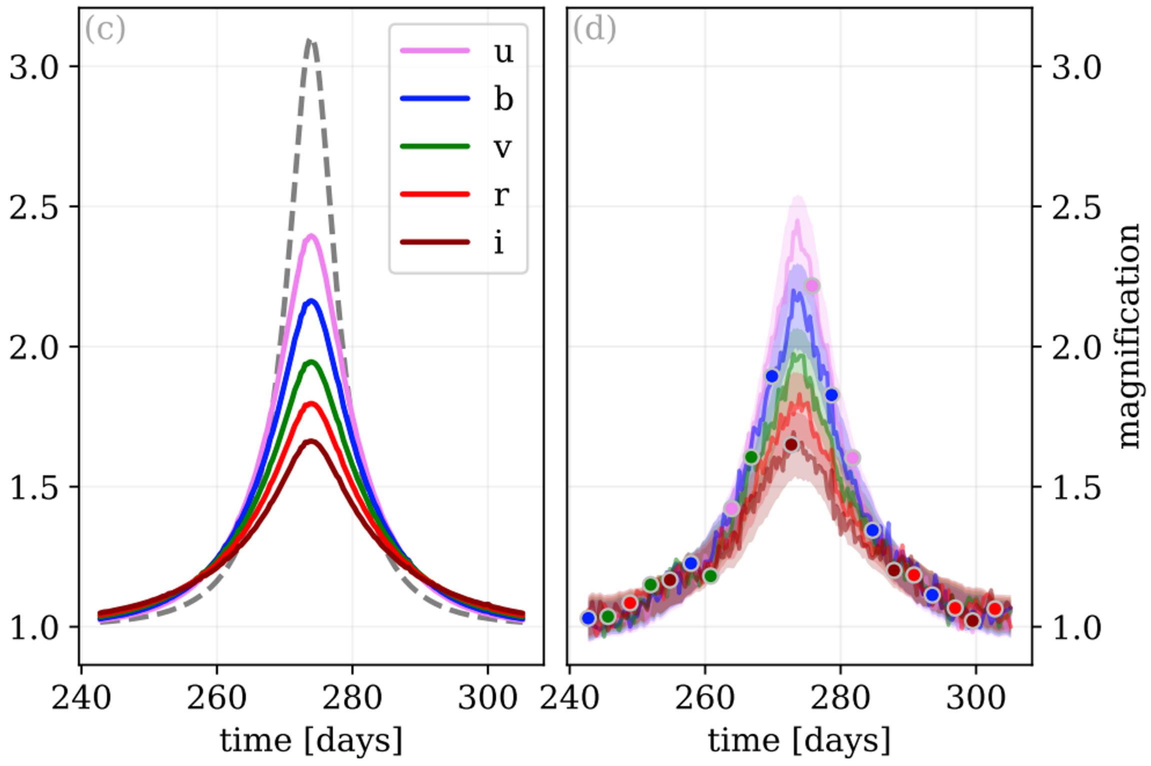
Cross-correlation lags by band in NGC 5548

Imagine doing this for thousands of AGN!

Edelson et al. (2015), part of AGN STORM

MULTI-BAND CAPABILITIES: BINARIES

- Large populations of binary AGN, with alignment and geometry information!



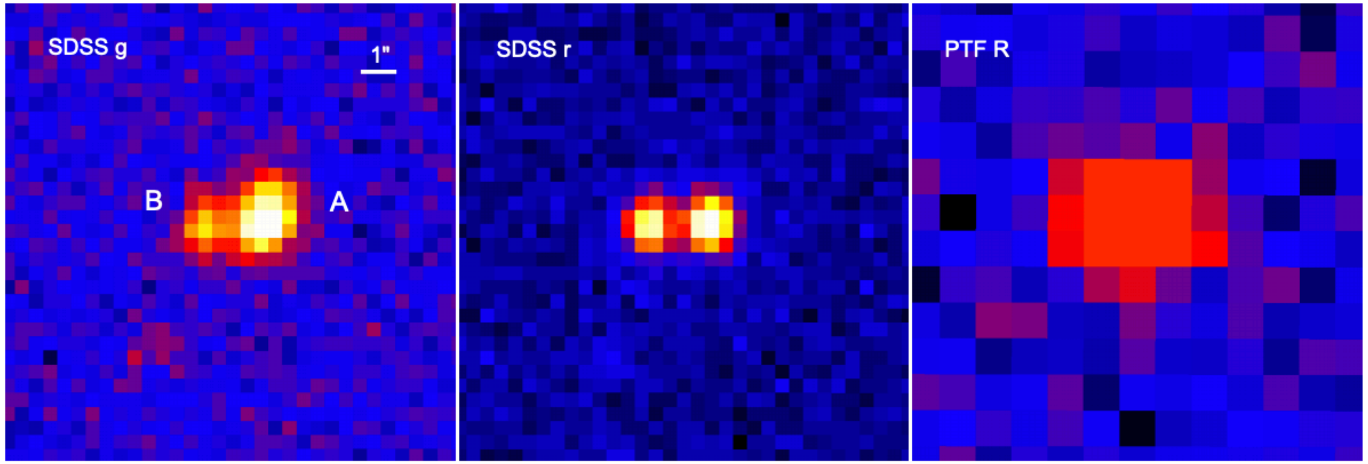
Kelley et al. (2021)

Expectations for a self-lensing binary flare based on a fiducial disk of blackbody annuli.

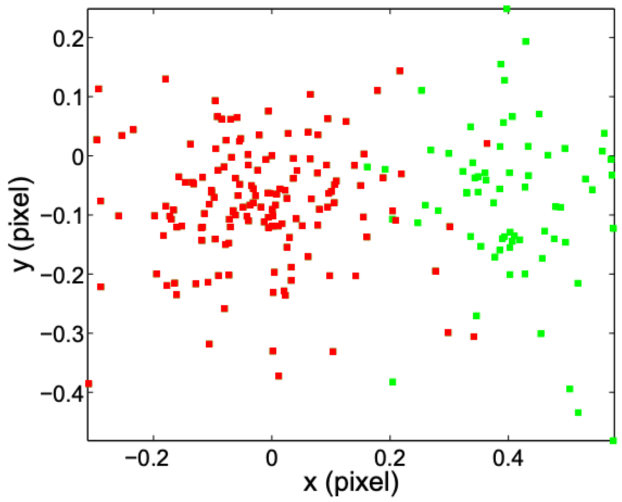
Very high time resolution also significantly increases the number of these short-term flares we can see, compared to Rubin cadences.

MULTI-BAND AND HIGH SPATIAL RESOLUTION

- Centroid shifts: another binary signature!
- As two accretion disks vary independently, the centroid position depends upon the waveband.



Complements the single-band *varstrometry* (Hwang+2020) technique by increasing detectability, including more binary sub-types.



Centroids of *R* vs *g* band

Liu 2016

The rapid, high-precision, uninterrupted cadence of optical exoplanet-hunting missions has revolutionized the time domain.

A high-energy focused timing mission that retains this cadence, but with

- multiple wavebands
- fainter magnitude limits
- higher spatial resolution
- absolute calibration

promises a colorful and dynamic future!

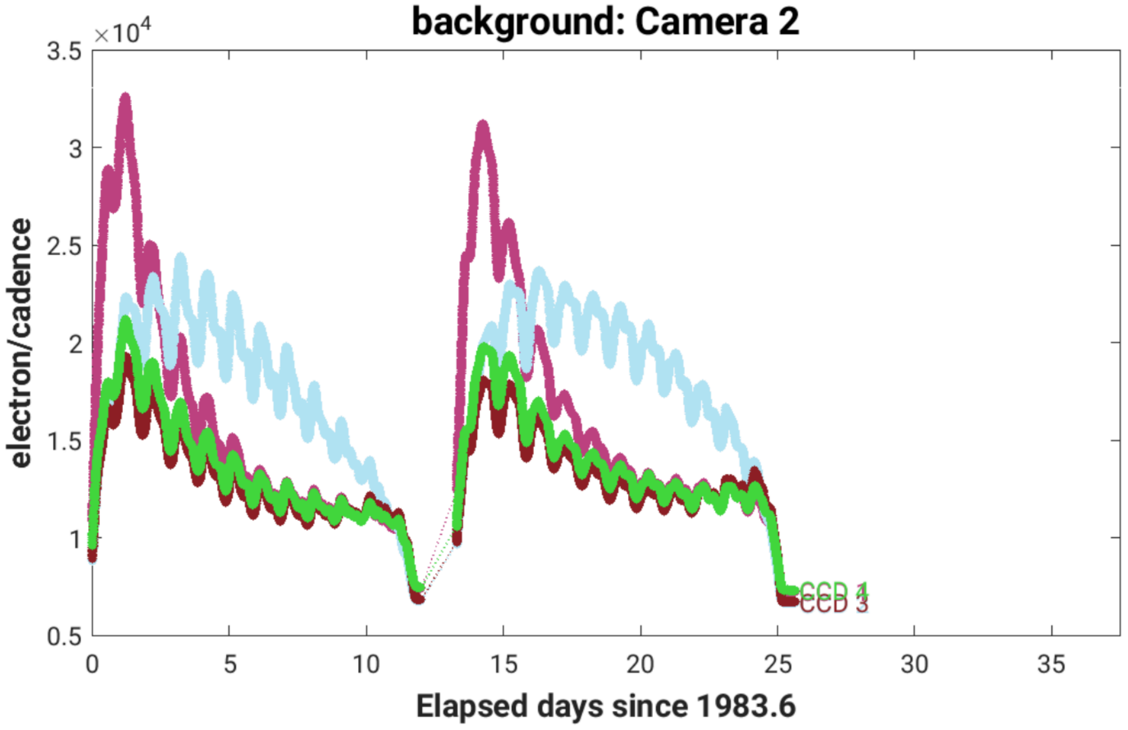
Thank you!

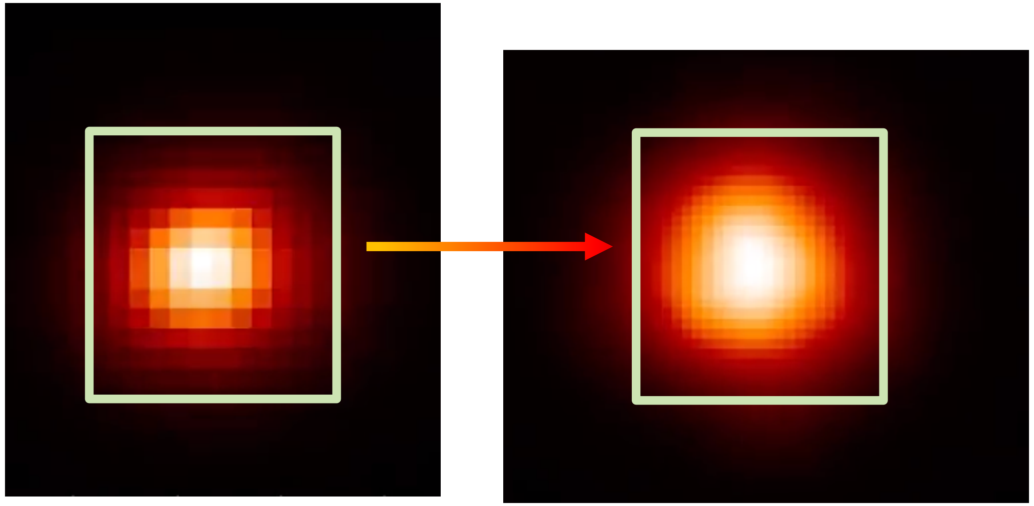
Systematics: TESS

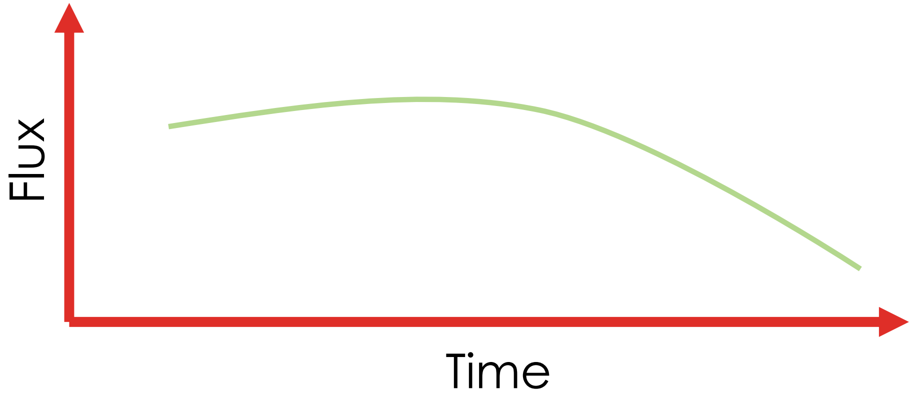
Repurposing spacecraft data: not an easy task!

Systematic dominate.

-Scattered light from the sun and moon
-Electronic noise
-Thermal fluctuations

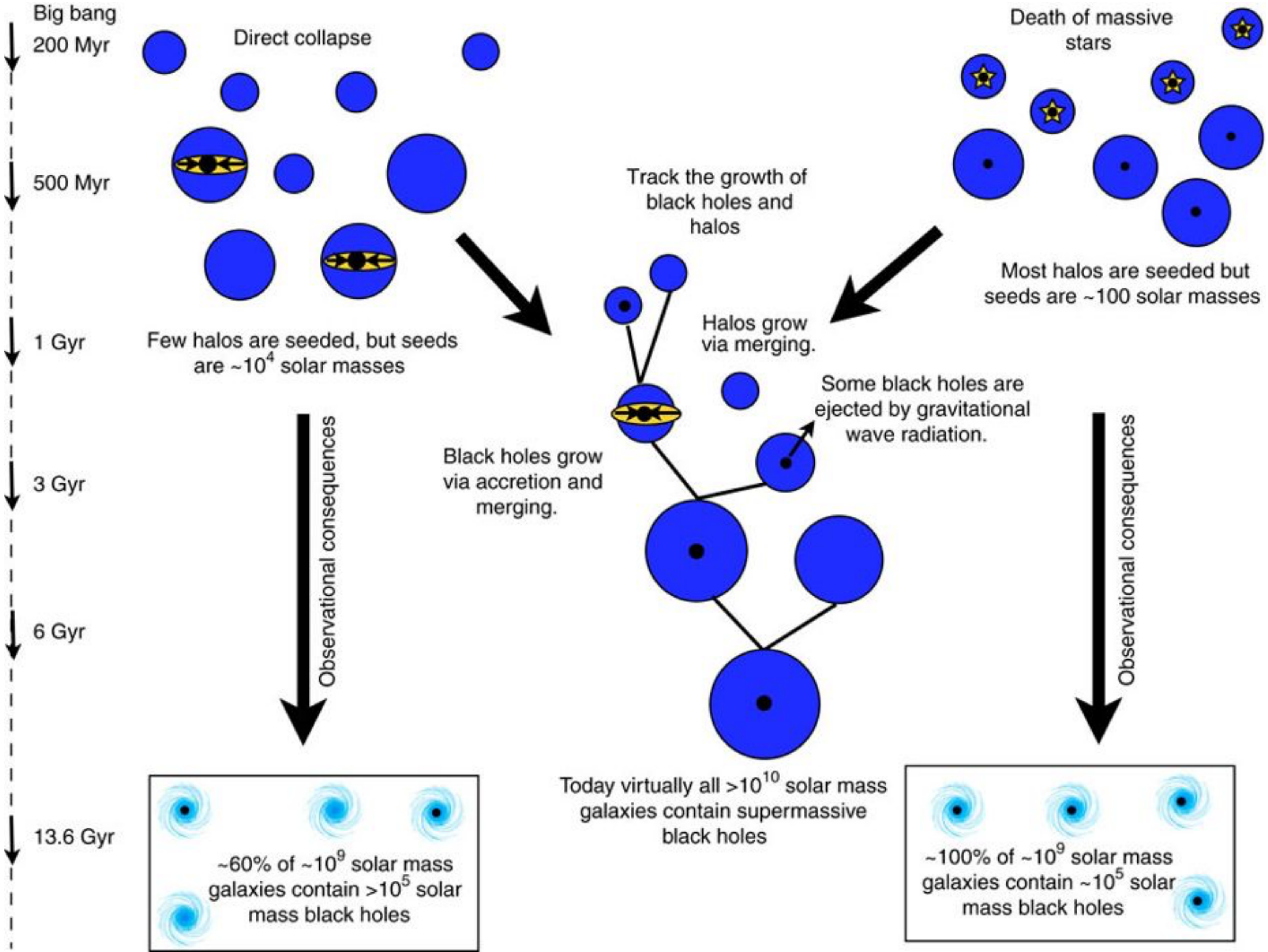






Detecting AGN in Dwarf Galaxies: Need to go fainter!

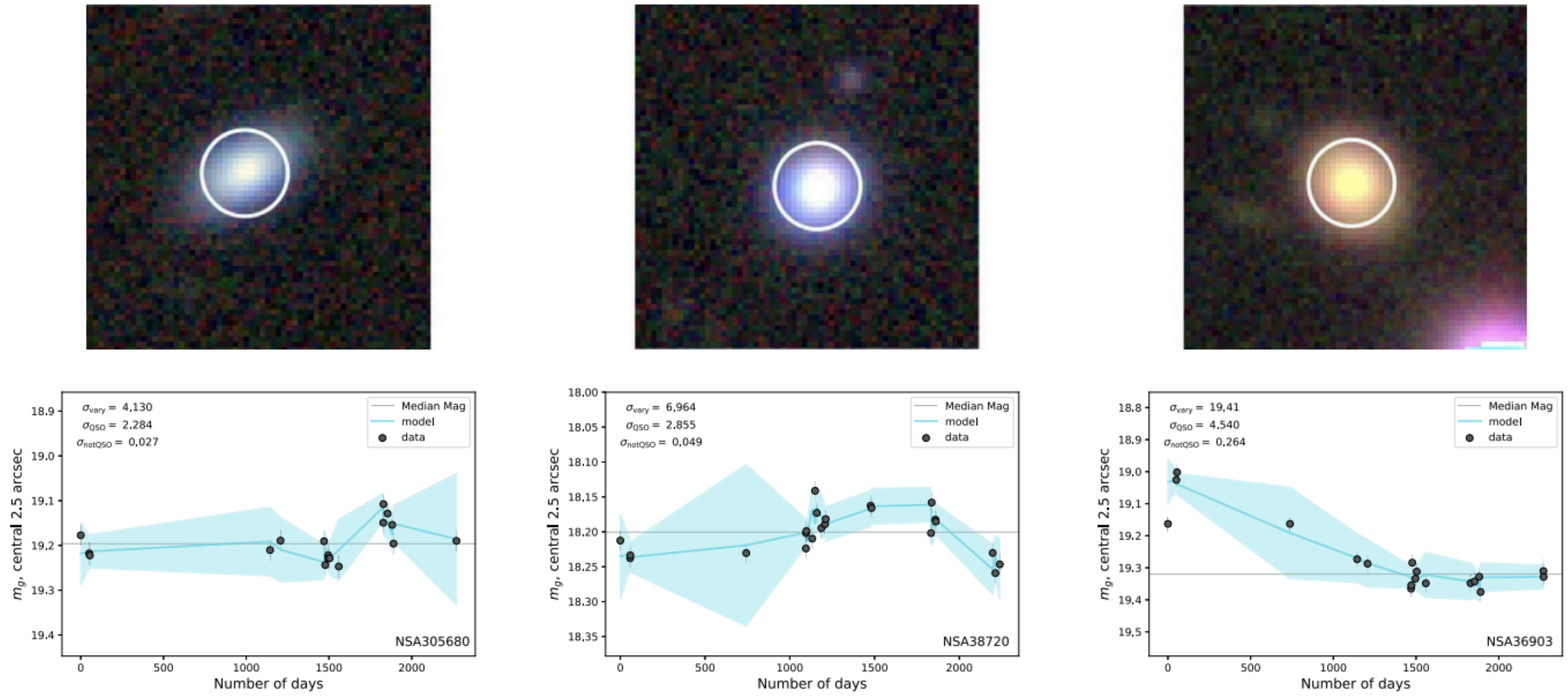
Detecting AGN in Dwarf Galaxies



Occupation Fraction of massive black holes in dwarf galaxies → seed mechanism of supermassive black holes.

Greene 2012

Detecting AGN in Dwarf Galaxies



Hint of lower occupation fraction in galaxies with $M < 10^{10}\ M_*$

Baldassare et al. 2018

QPOs: Different in Big and Small Black Holes?

High Frequency QPOs are stable → depend upon fixed BH gravitational field, rather than disk/coronal fluctuating properties?

↓

QPO frequencies "f" obey a relation: $\left(\frac{GM}{c^3}\right) \mathrm{f} = \mathrm{F}(\mathrm{a}, \mathrm{X})$

Dimensionless non-gravitational properties (e.g., accretion rate.)

spin

Smith et al. (2021)