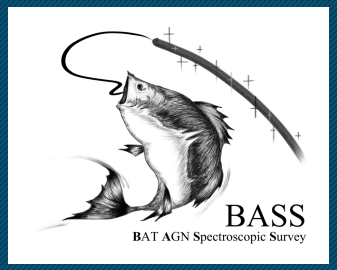


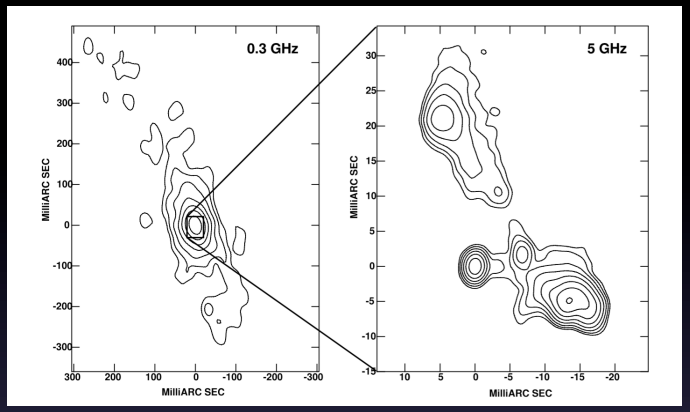
Variability Signatures of Supermassive Black Hole Binaries in BAT

Tingting Liu

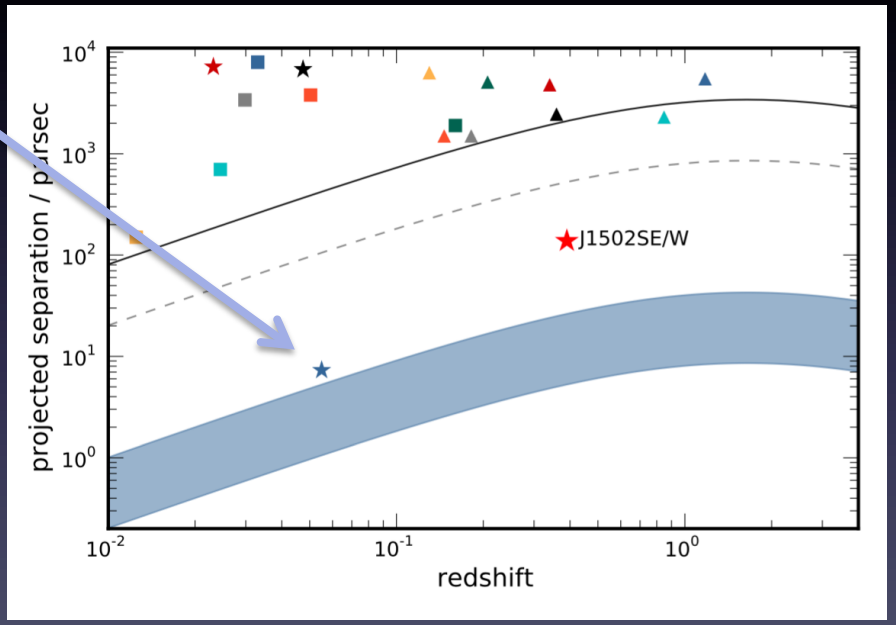
University of Wisconsin – Milwaukee

Slack Channel: #bat_variability

Supermassive black hole binaries (SMBHBs)

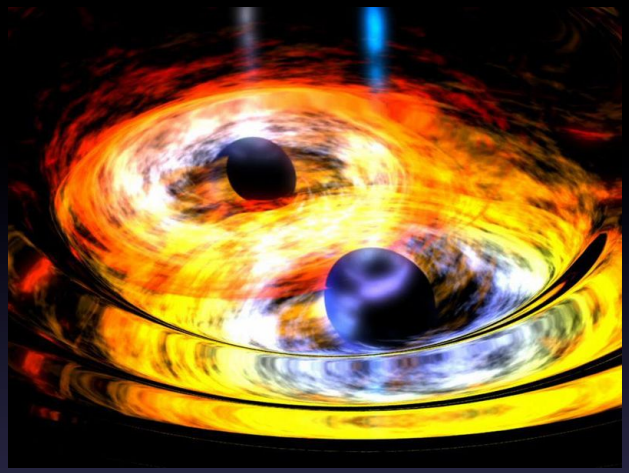


Closest resolved SMBHB
(CSO 0402+379; Rodriguez+2006)
a = 7 pc

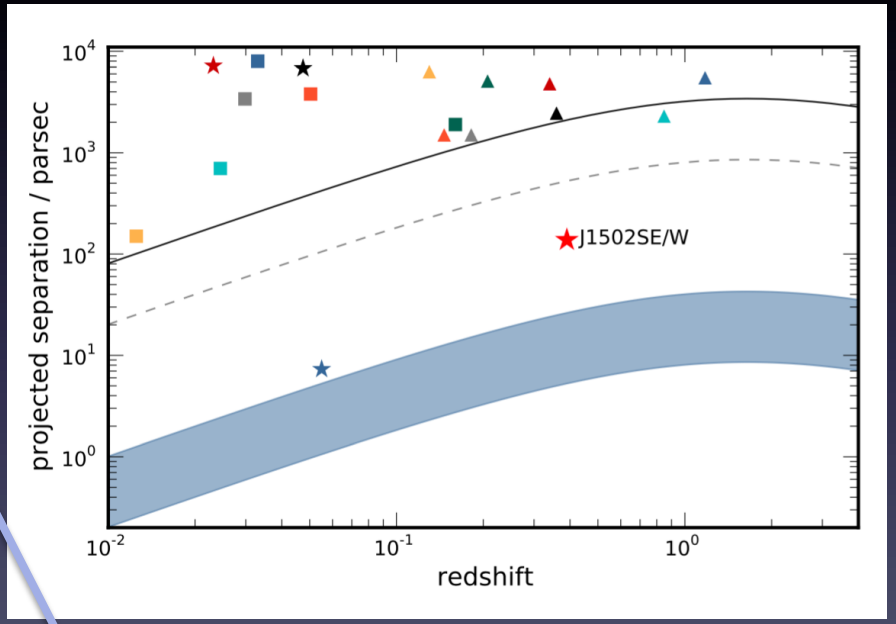


Deane et al. (2014)

Supermassive black hole binaries (SMBHBs)



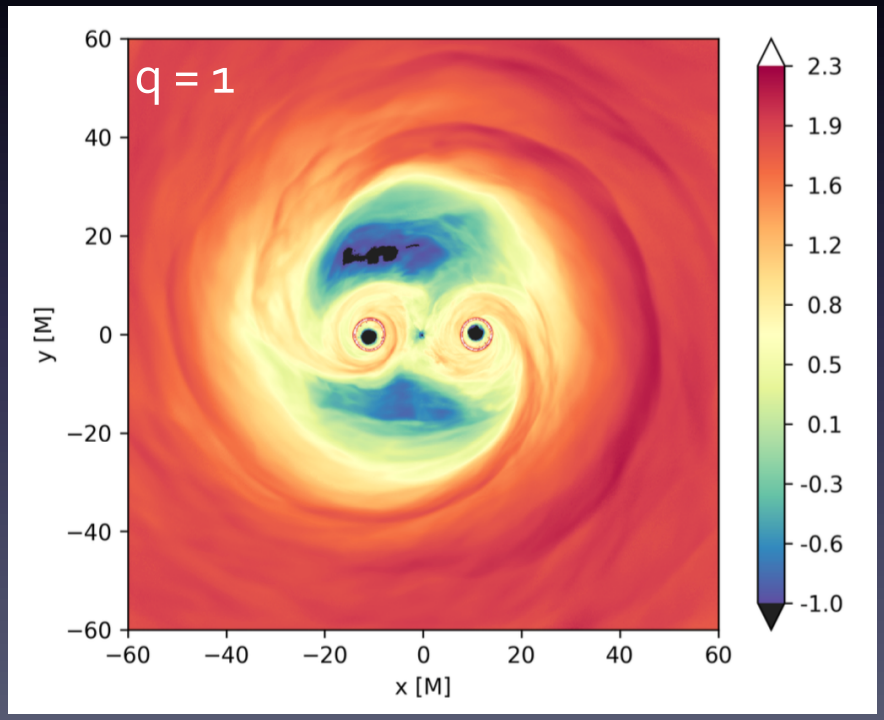
a ~ 0.001 – 0.01 pc
orbital timescale ~ years



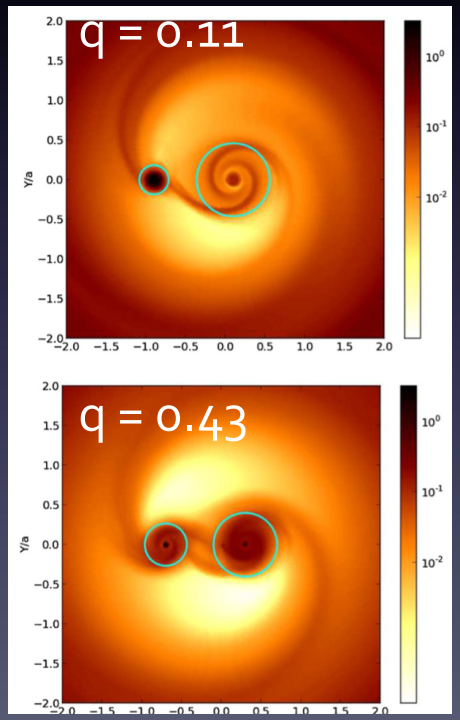
Deane et al. (2014)

Periodically varying AGN as SMBHB candidates

- Predictions (optical/UV)
  - Cavity forms in the circumbinary disk
  - Matter crosses cavity through streams



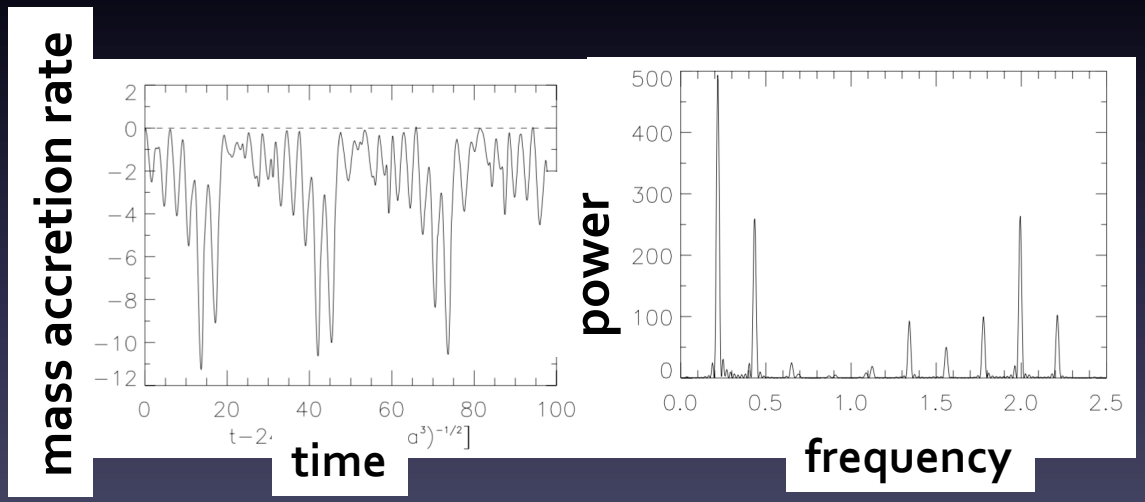
d'Ascoli et al. (2018)



Farris et al. (2014)

Periodically varying AGN as SMBHB candidates

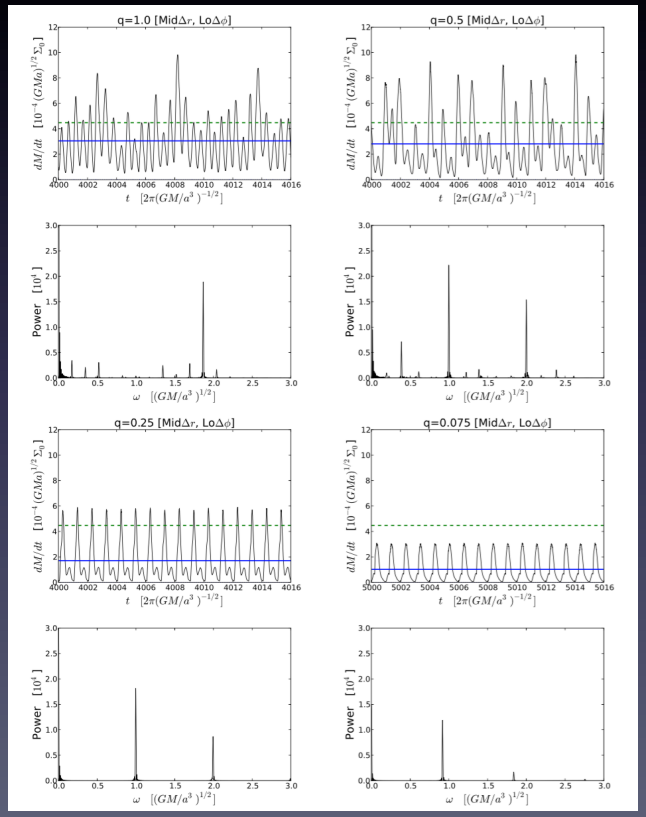
- Predictions (optical/UV)
  - Mass accretion rate onto the binary is strongly modulated on the ~orbital period
  - For various mass ratios



MacFadyen & Milosavljevic (2008)

q = 1

q = 0.1 - 1

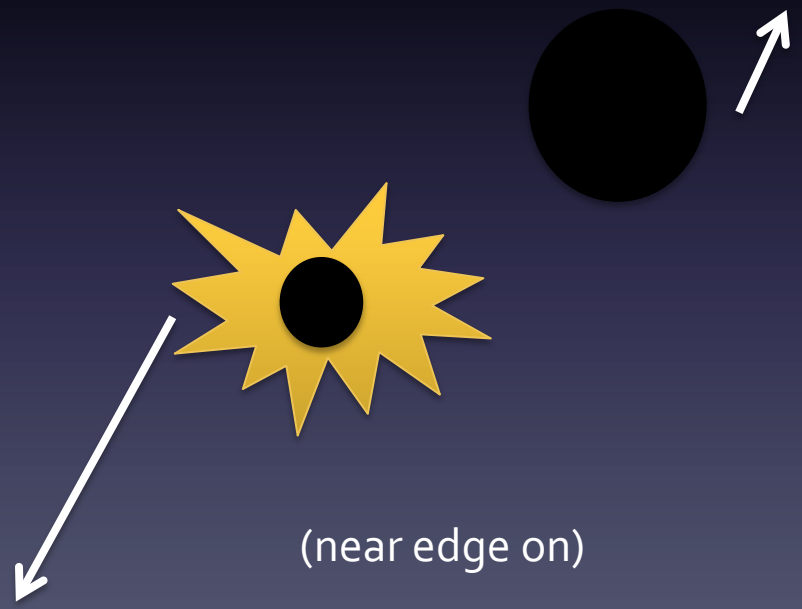


D'Orazio et al. (2013)

See also: Shi et al. (2012); Roedig et al. (2012); Noble et al. (2012); D'Orazio et al. (2013); Farris et al. (2014); Gold et al. (2014) …

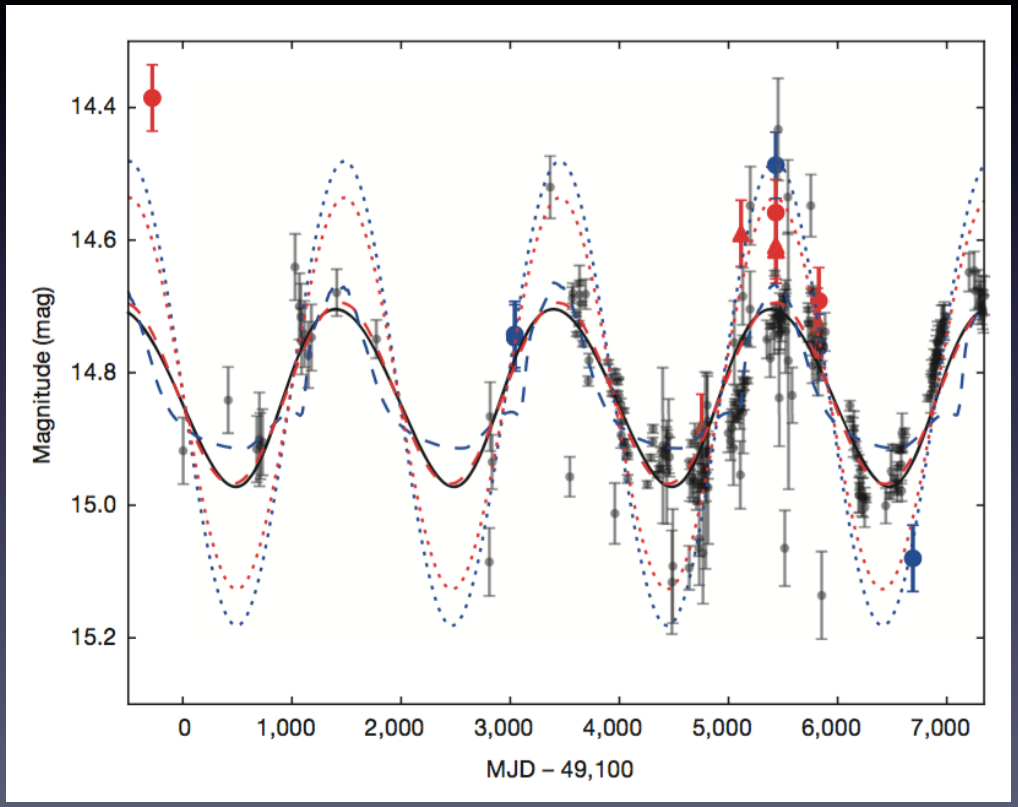
Periodically varying AGN as SMBHB candidates

- Predictions (optical/UV)
  - Relativistic Doppler boosting



(near edge on)

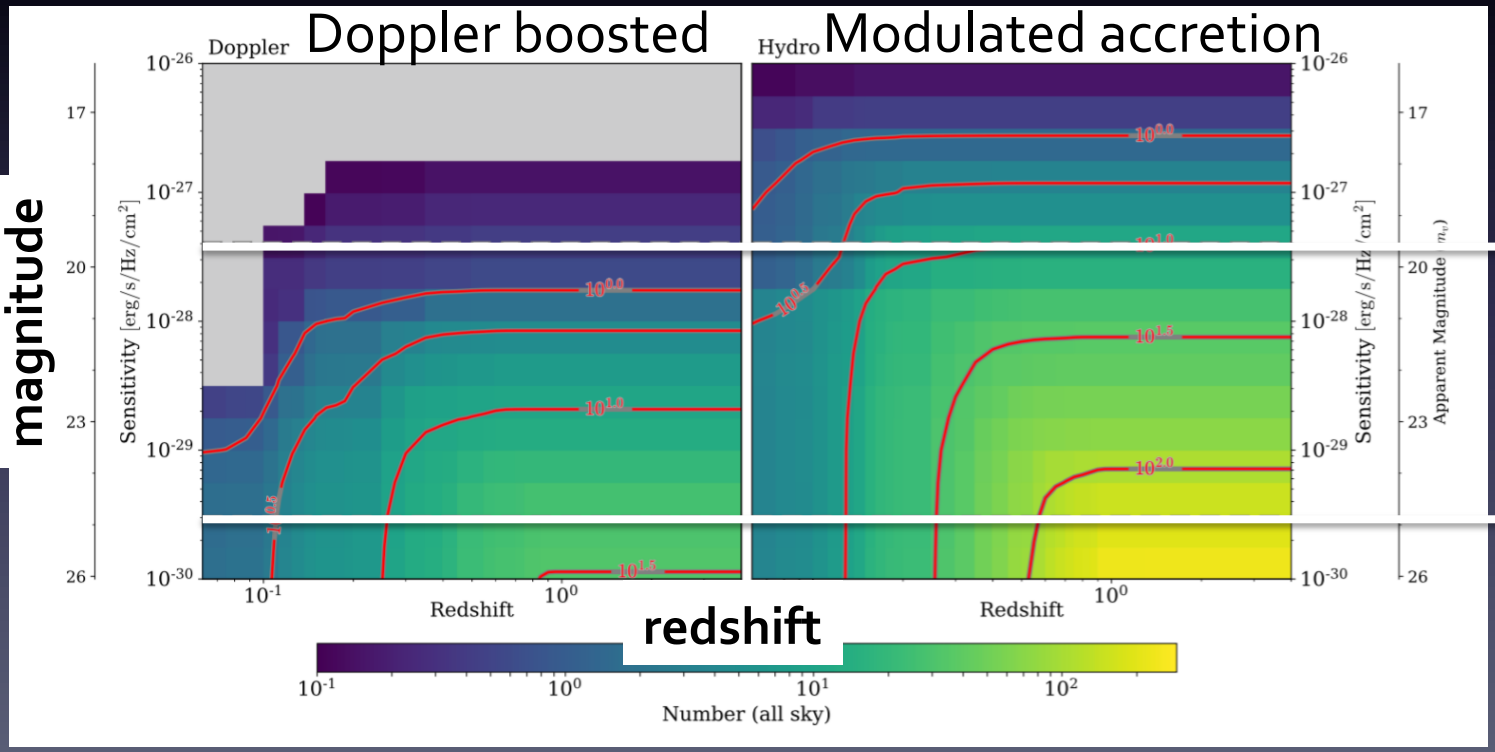
PG 1302-102 (Graham+2015b)



D'Orazio et al. (2015)

Periodically varying AGN as SMBHB candidates

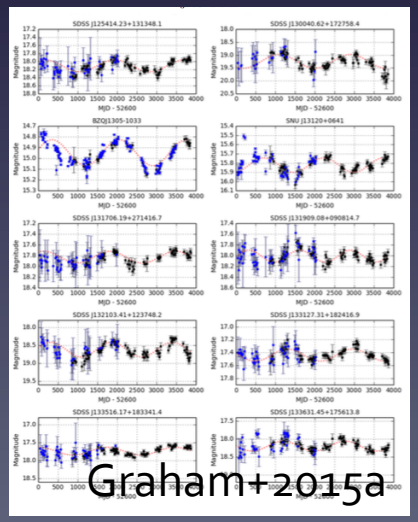
- Detectability in a time domain survey (full sky)
  - ~10 with CRTS sensitivity
  - ~100 with LSST sensitivity

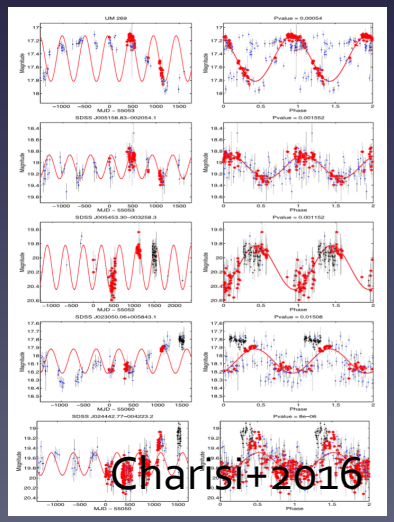


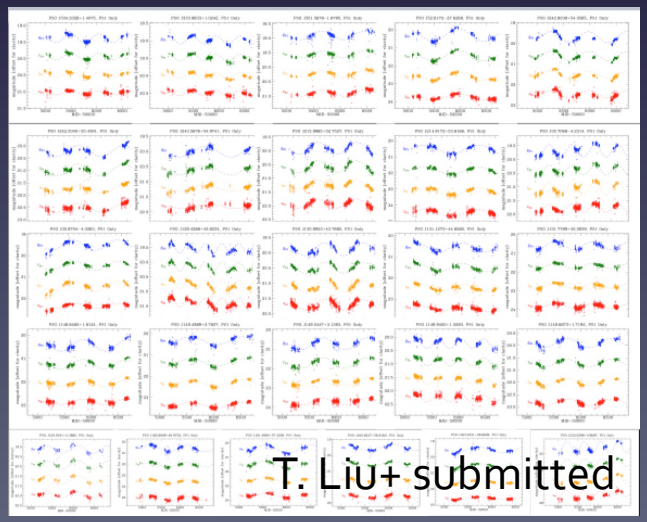
Kelley et al. (2018)

Periodically varying AGN as SMBHB candidates

- Systematic search in a time domain survey
  - Graham+2015a;2015b
    - 111 candidates from ~243,500 quasars in CRTS
  - Charisi+2016
    - 33 candidates from ~35,000 quasars in PTF
  - T. Liu+2015;2016;2018 (submitted)
    - 1 statistically significant candidate from ~9000 quasars from PS1 MDS


Graham+2015a


Charisi+2016


T. Liu+ submitted

Periodically varying AGN as SMBHB candidates

- Systematic search in a time domain survey
  - Graham+2015a;2015b
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    - 1 statistically significant candidate from ~9000 quasars from PS1 MDS
- Detection rates
  - ~1 binary per 1000 quasars out to z~1 (Graham+; Charisi+)
  - ~1 binary per 10^4 quasar out to z~2 (T. Liu+)

Rates may be too high

Periodically varying AGN as SMBHB candidates

- Systematic search in a time domain survey
  - Graham+2015a;2015b
    - 111 candidates from ~243,500 quasars in CRTS
  - Charisi+2016
    - 33 candidates from ~35,000 quasars in PTF
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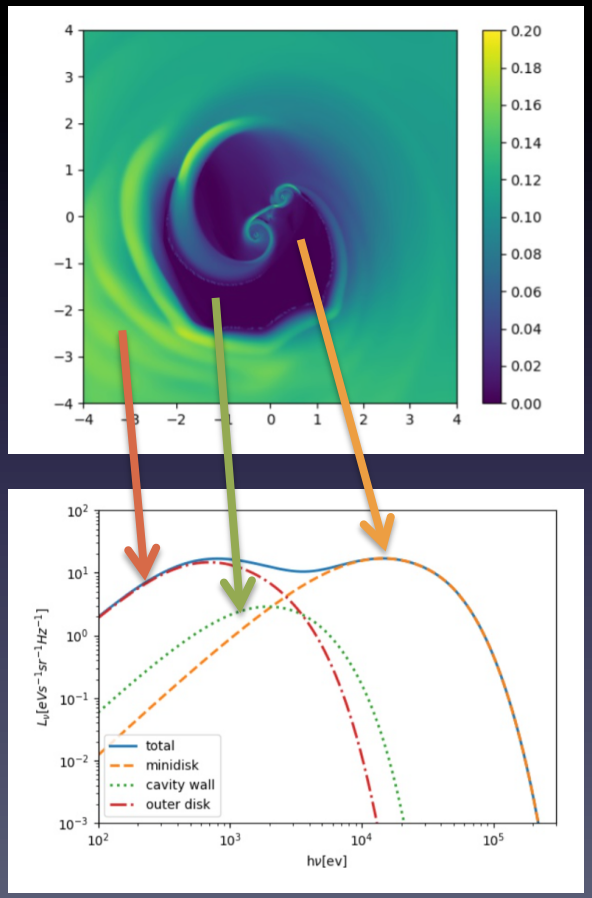
- Detection rates
  - ~1 binary per 1000 quasars out to z~1 (Graham+; Charisi+)
  - ~1 binary per 10^4 quasar out to z~2 (T. Liu+)
- ZTF, LSST…

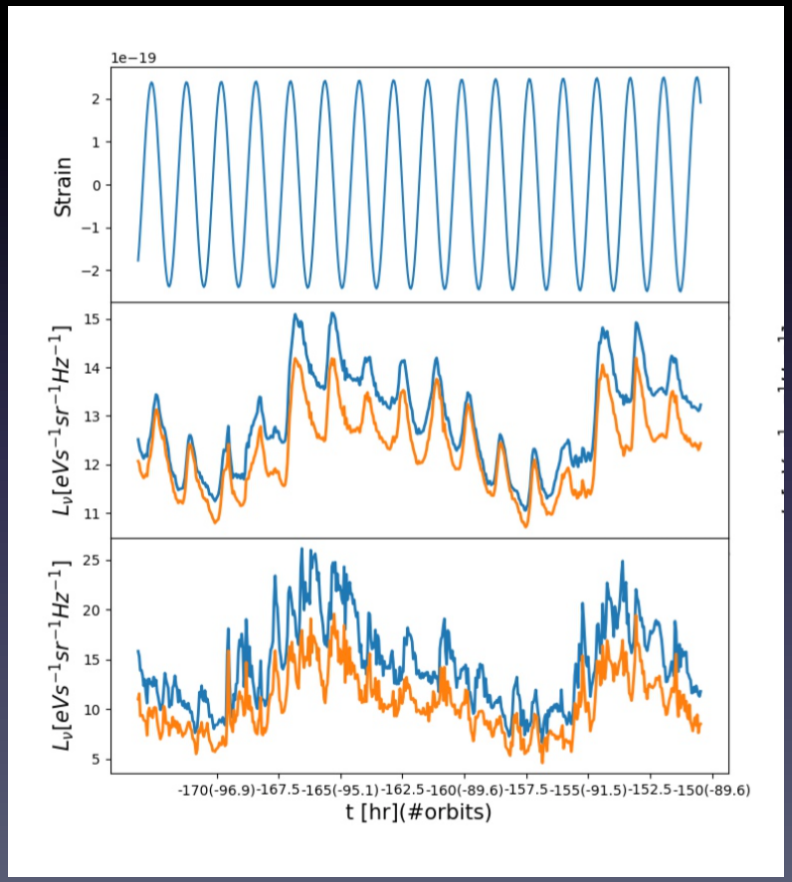
Why look in the X-rays?

- We haven't looked in the X-rays
- Predicted X-ray periodicity

Periodically varying AGN as SMBHB candidates

- Predictions (X-rays)
  - Gas flung outward and periodically hitting the cavity wall





GW strain (edge on)

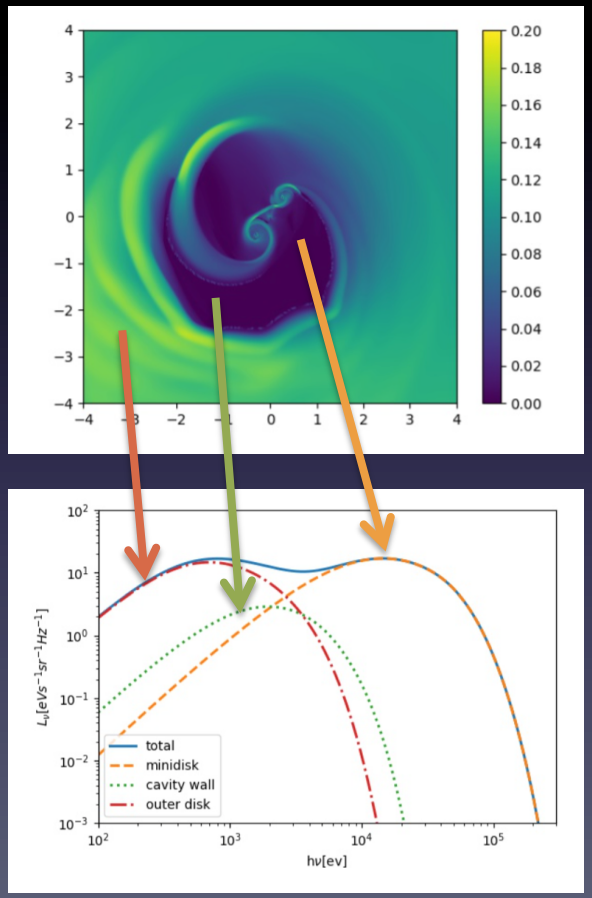
2 keV light curve (blue)

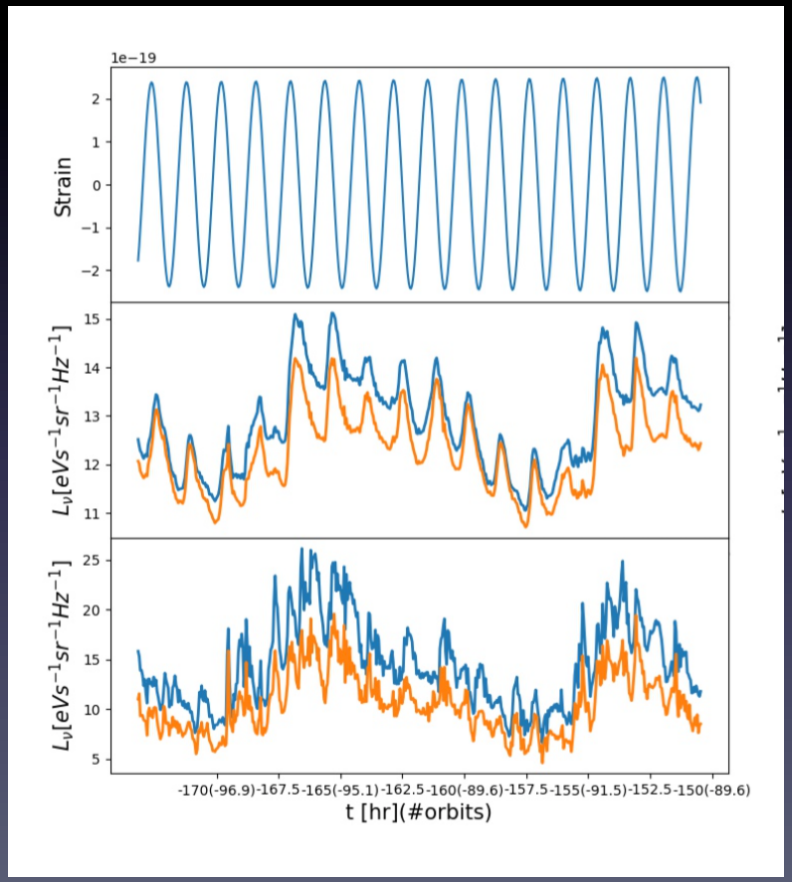
10 keV light curve (blue)

Tang+2018

Periodically varying AGN as SMBHB candidates

- Predictions (X-rays)
  - +Relativistic Doppler boosting





GW strain (edge on)

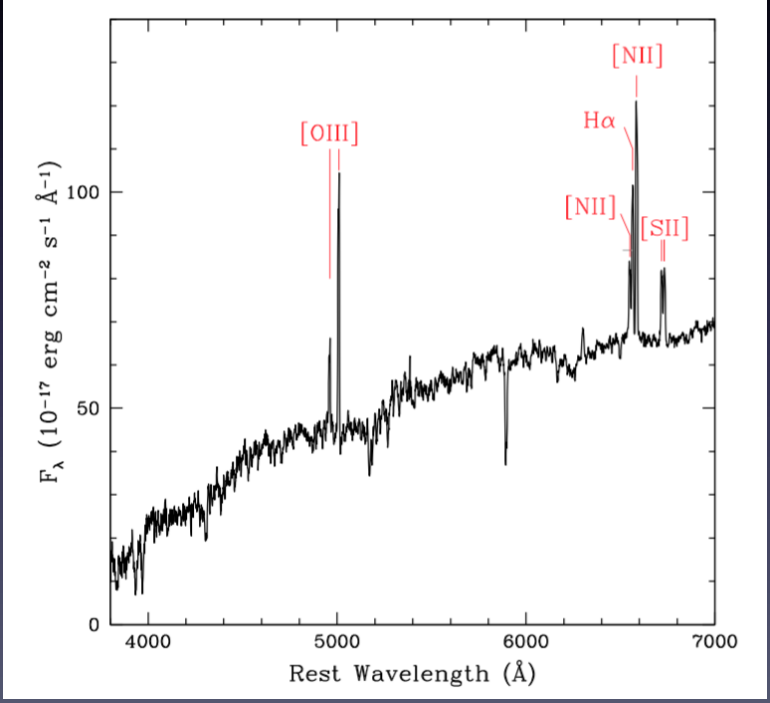
2 keV light curve (orange)

10 keV light curve (orange)

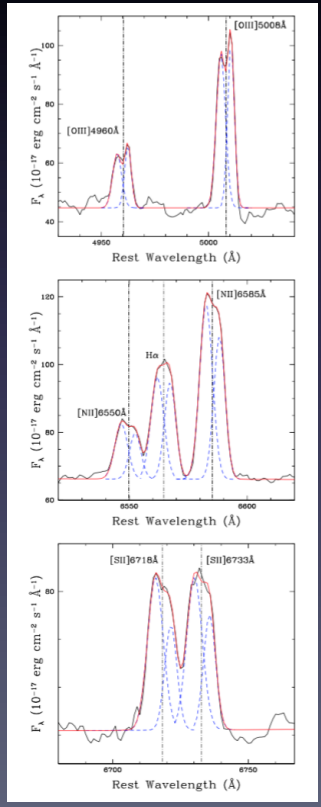
Tang+2018

Periodically varying AGN as SMBHB candidates

- An SMBHB in MCG+11-11-032?
  - Seyfert 2 galaxy at z = 0.0362
  - Double peaked narrow lines (dual AGN candidate)

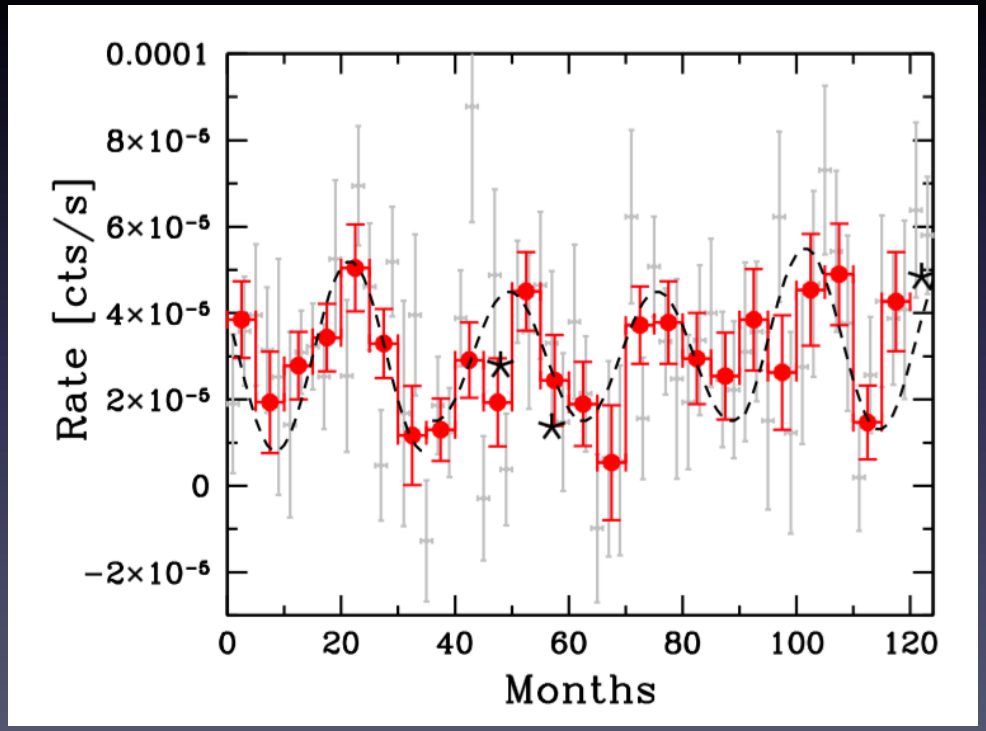


Severgnini+2018



Periodically varying AGN as SMBHB candidates

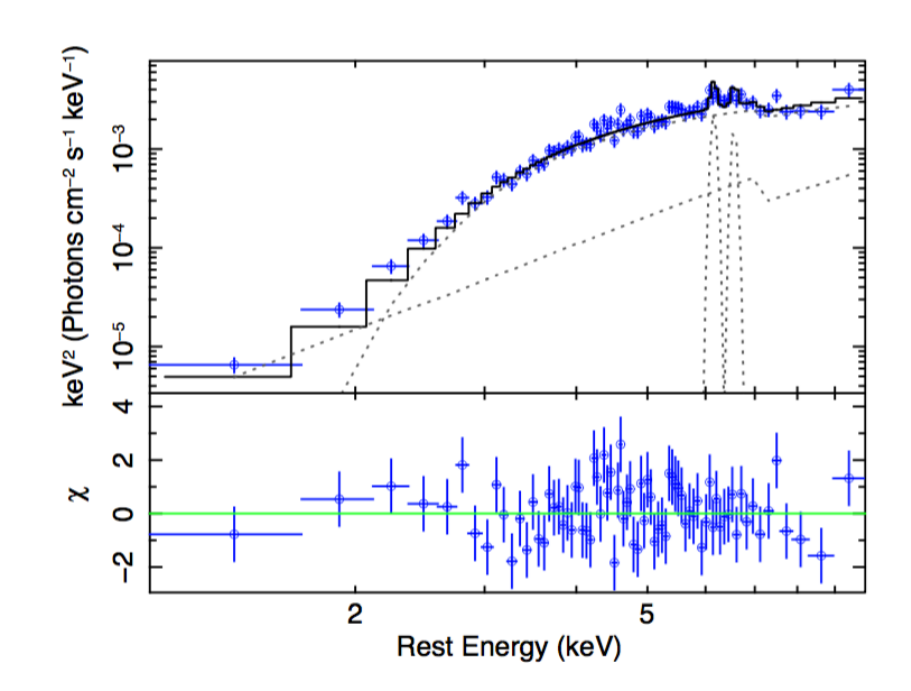
- An SMBHB in MCG+11-11-032?
  - (Quasi-)periodic BAT light curve?
    - P = 25 months ➔ orbital velocity ~ 0.06c



Severgnini+2018

Periodically varying AGN as SMBHB candidates

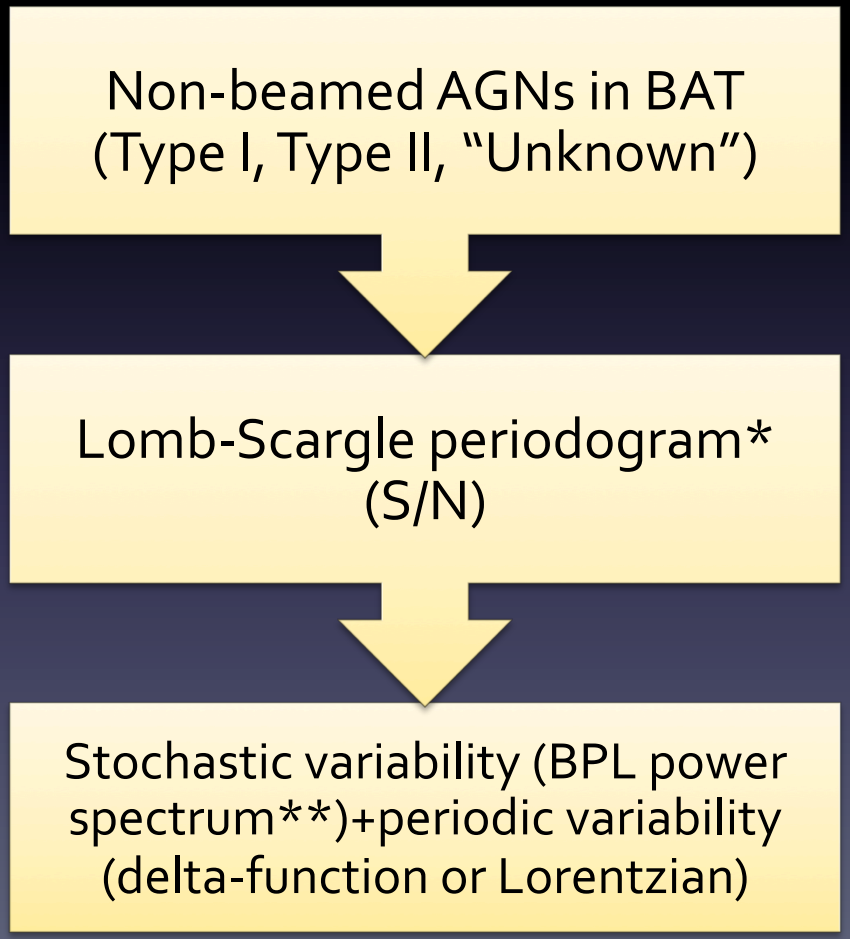
- An SMBHB in MCG+11-11-032?
  - Double Fe Kα?
    - ΔE = 0.4 keV ➔ orbital velocity ~ 0.06c

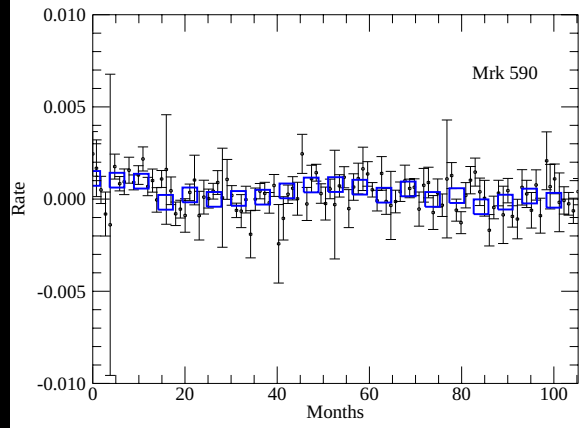


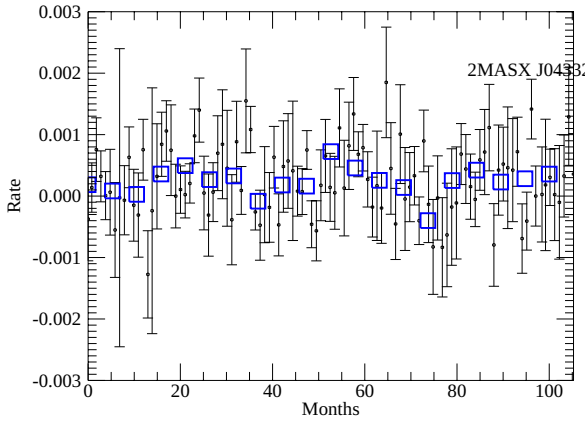
Severgnini+2018

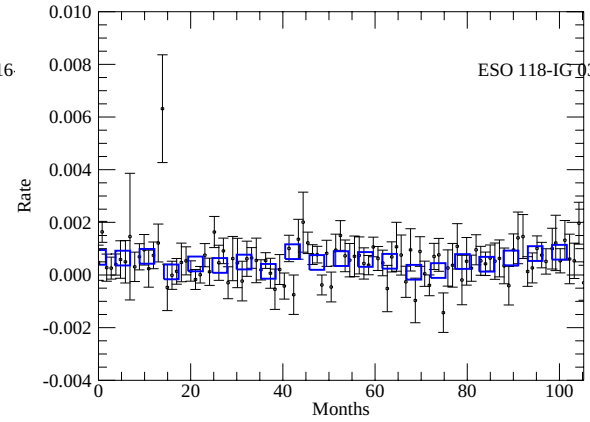
Periodically varying AGN as SMBHB candidates

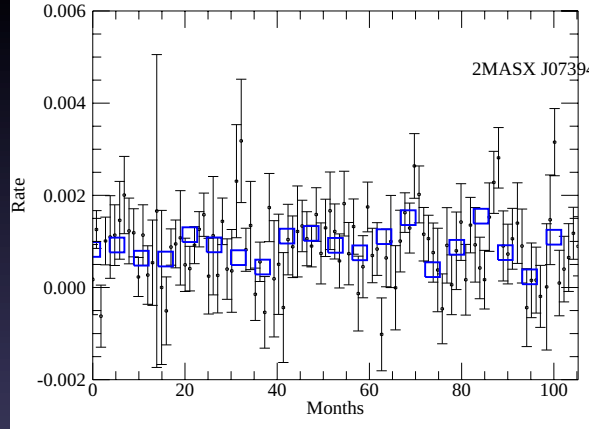
- A systematic search in the 105-month BAT catalog

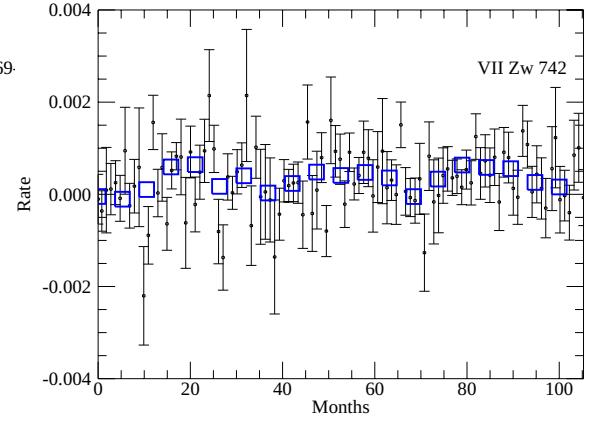


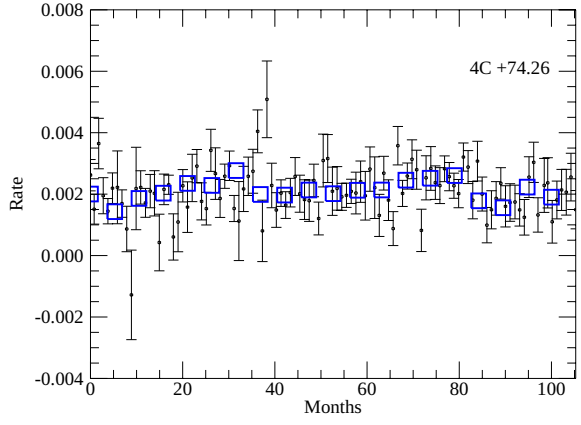

Mrk 590
Rate
Months

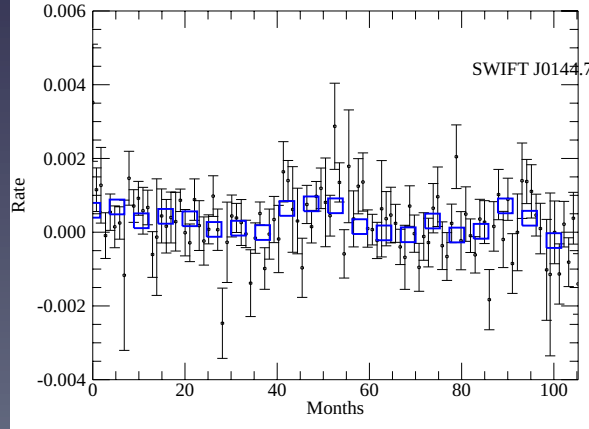

2MASX J04332716
Rate
Months

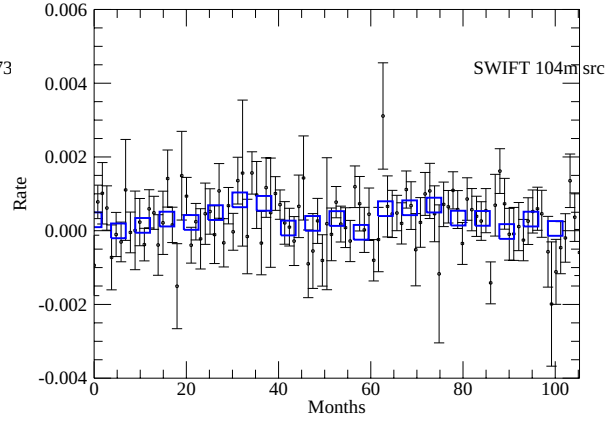

ESO 118-IG 033 NE
Rate
Months

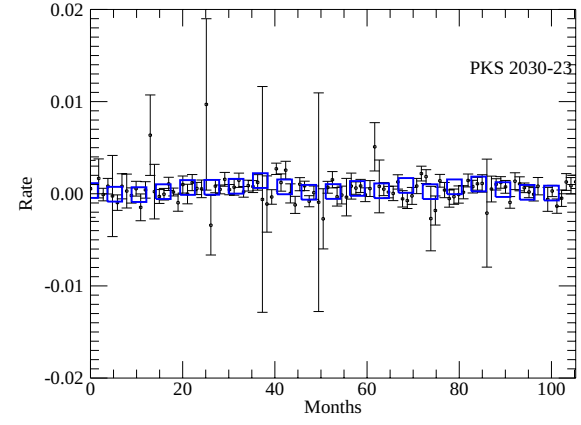

2MASX J07394469
Rate
Months


VII Zw 742
Rate
Months


4C +74.26
Rate
Months

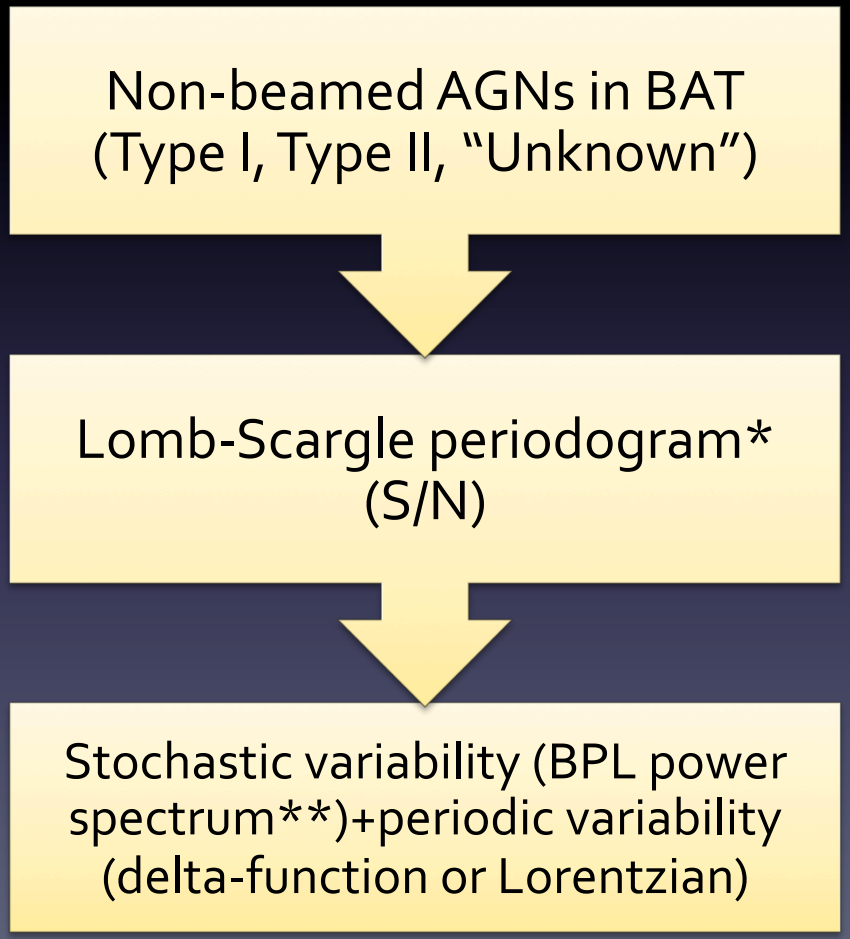

SWIFT J0144.7-273
Rate
Months


SWIFT 104m src
Rate
Months


PKS 2030-23
Rate
Months

Periodically varying AGN as SMBHB candidates

- A systematic search in the 105-month BAT catalog



*Treat it as evenly–sampled?

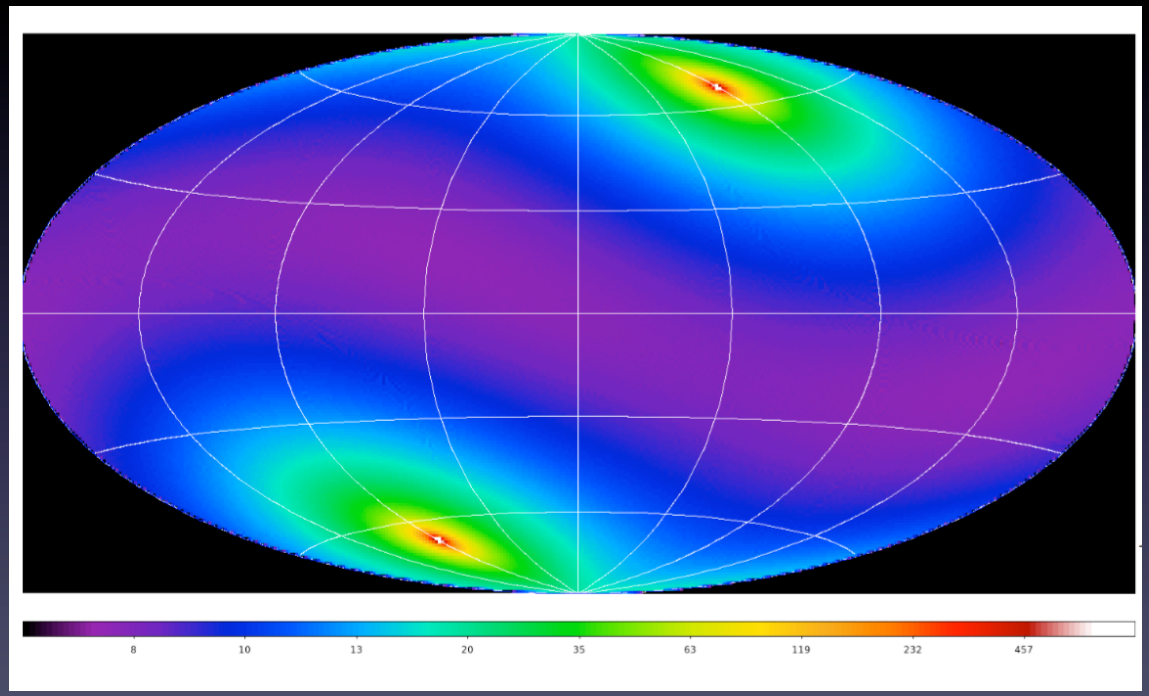
** Fix PSD slopes α_{hi}=-2, α_{lo} = -1?
Measure from full sample?

Why look in the X-rays?

- We haven't looked in the X-rays
- Predicted X-ray periodicity
- Upcoming X-ray surveys

Upcoming X-ray surveys

- eROSITA (2019)
  - Survey the full sky eight times in four years
  - >30 visits in the ~1000 deg^2 area around the poles



Merloni+2012

- TAP/WFI (late 2020s/early 2030s)