

A population of periodic quasars from PTF as Supermassive Black Hole Binary Candidates

Maria Charisi

Columbia University

*I. Bartos, Z. Haiman, A. M. Price-Whelan, M. J. Graham, E.
C. Bellm, R. R. Laher, S. Marka*

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Supermassive Black Hole Binaries (SMBHBs)



Image Credit: ESO

- SMBHBs at sub-pc separations should be common.
- Embedded in gas-rich environments.
- Periodic variability of AGN could indicate binaries.
- Sources of low-frequency gravitational waves.

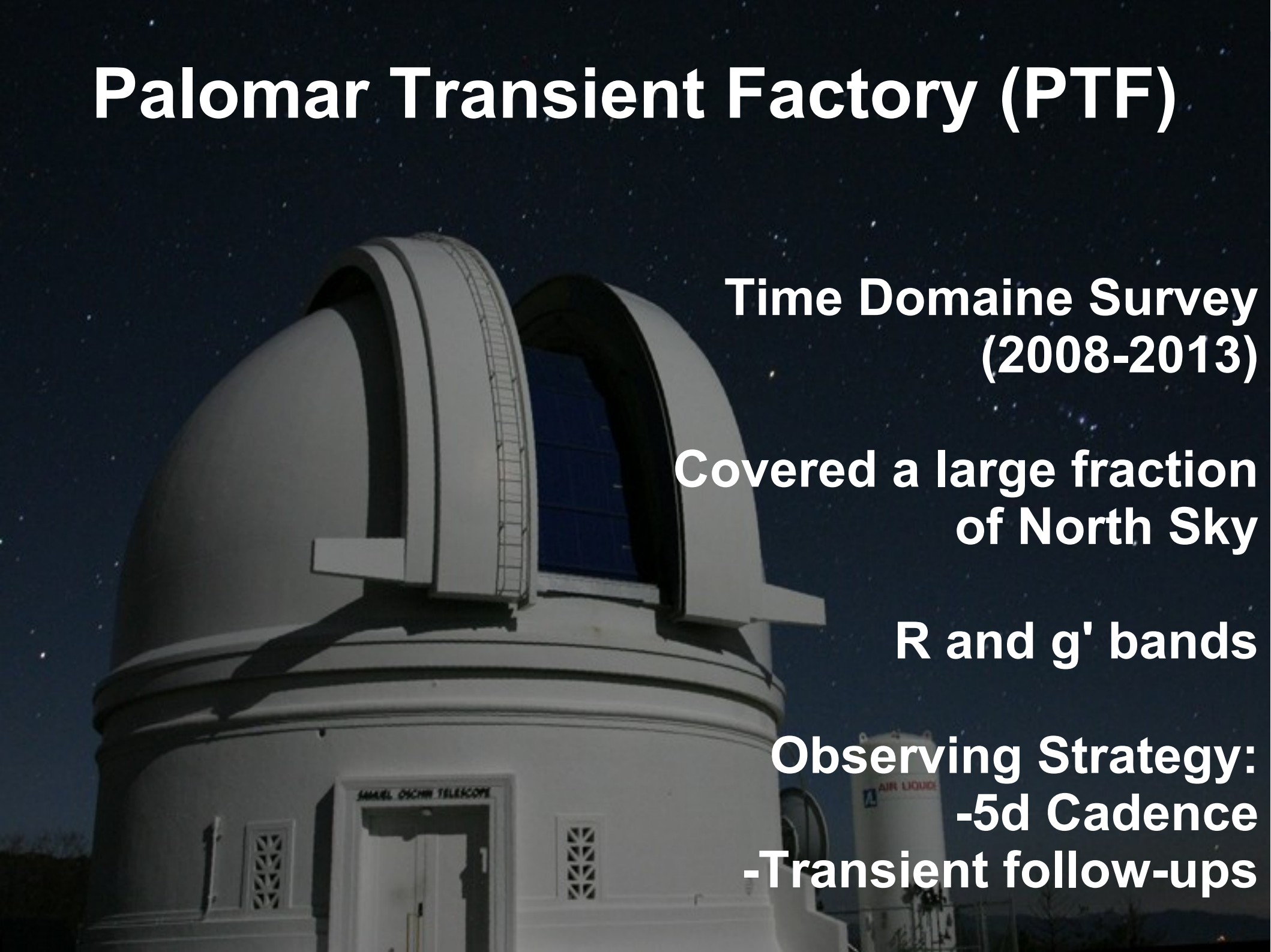
Palomar Transient Factory (PTF)

**Time Domain Survey
(2008-2013)**

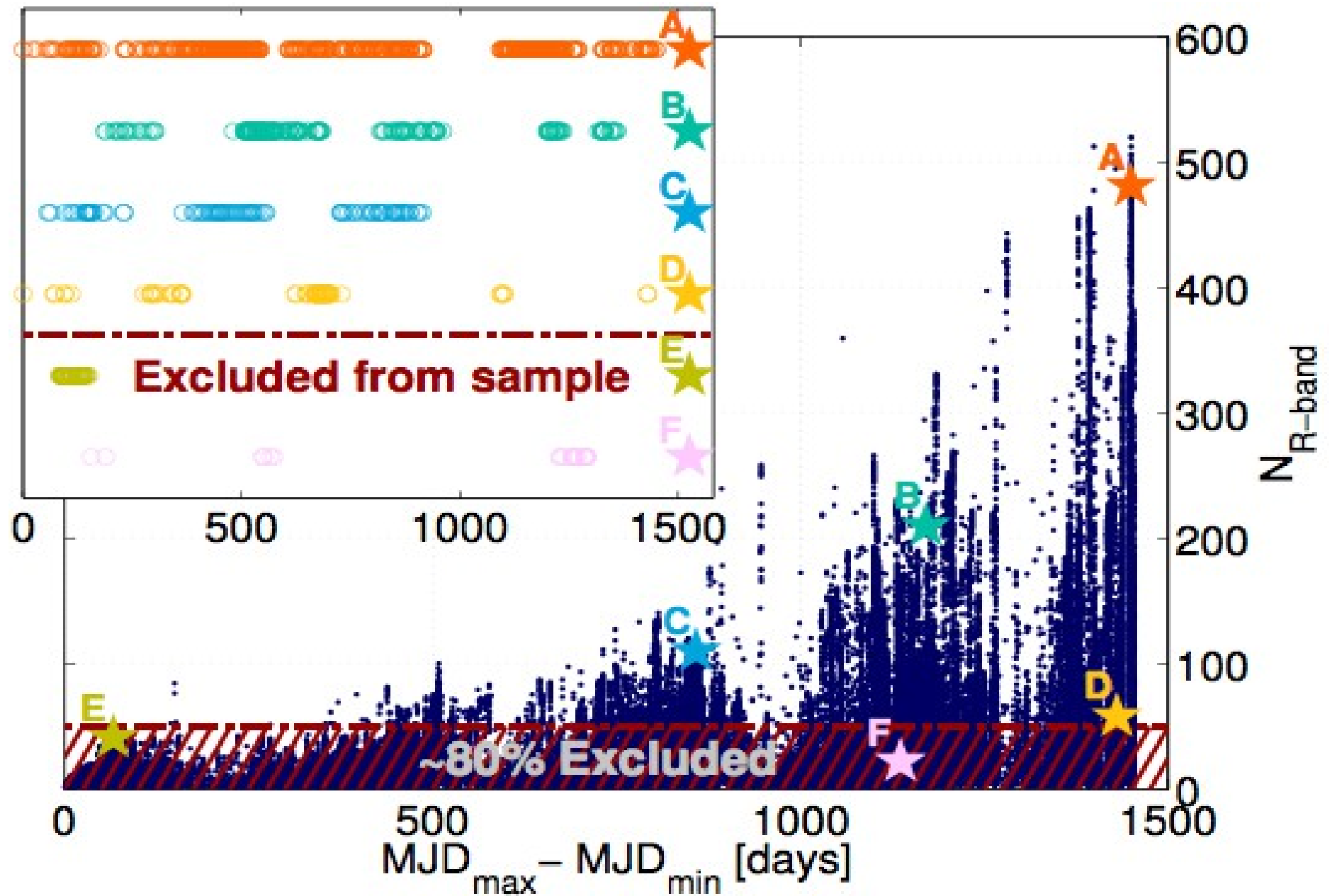
**Covered a large fraction
of North Sky**

R and g' bands

**Observing Strategy:
-5d Cadence
-Transient follow-ups**

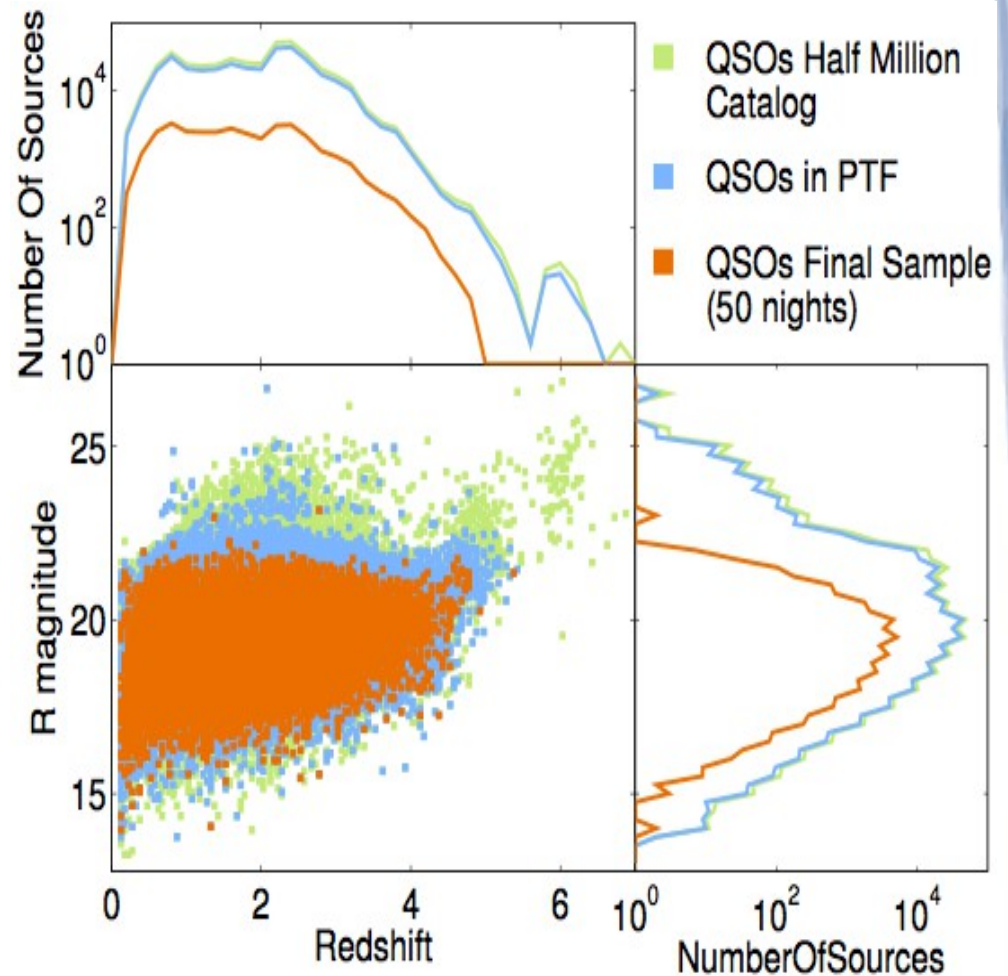
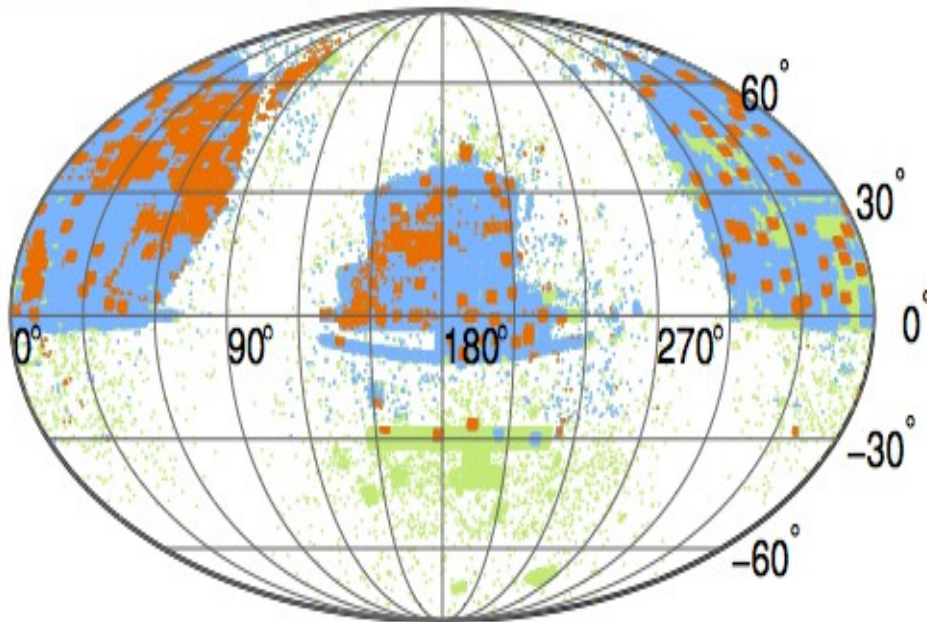


PTF Light Curves



Quasar Sample

- QSOs Half Million Catalog
- QSOs in PTF
- QSOs Final Sample (50 nights)



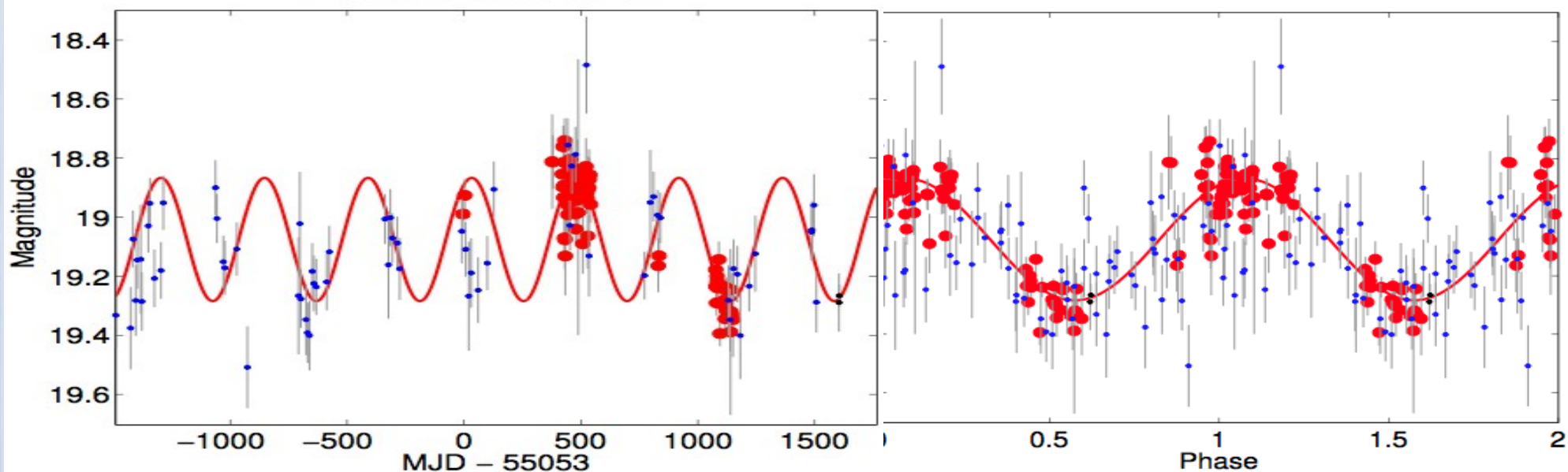
- QSOs Half Million Catalog: ~425k
- QSOs in PTF: ~280k
- QSOs Final Sample: ~35k

Statistical Search

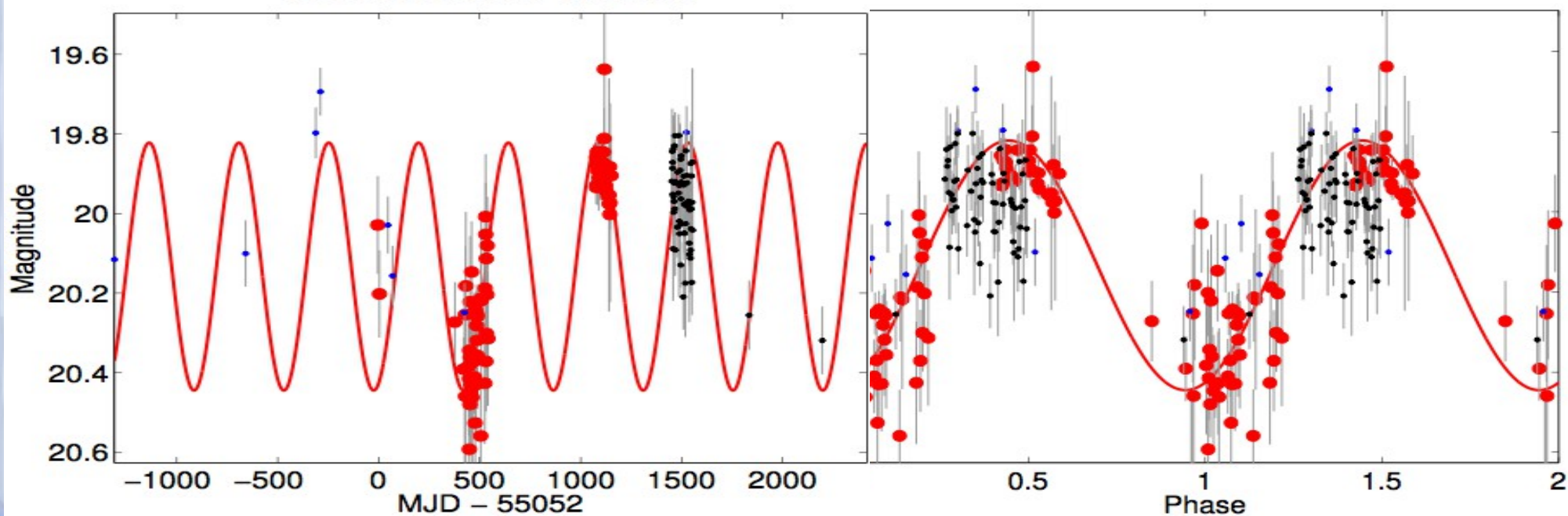
- Lomb-Scargle periodogram
- Quasar variability described as Damped Random Walk
- Analyzed each quasar individually
- Assigned significance simulating mock time series and taking into account all the trial factors
- Required 1.5 cycles within PTF baseline

QSOs with Significant Periodicity

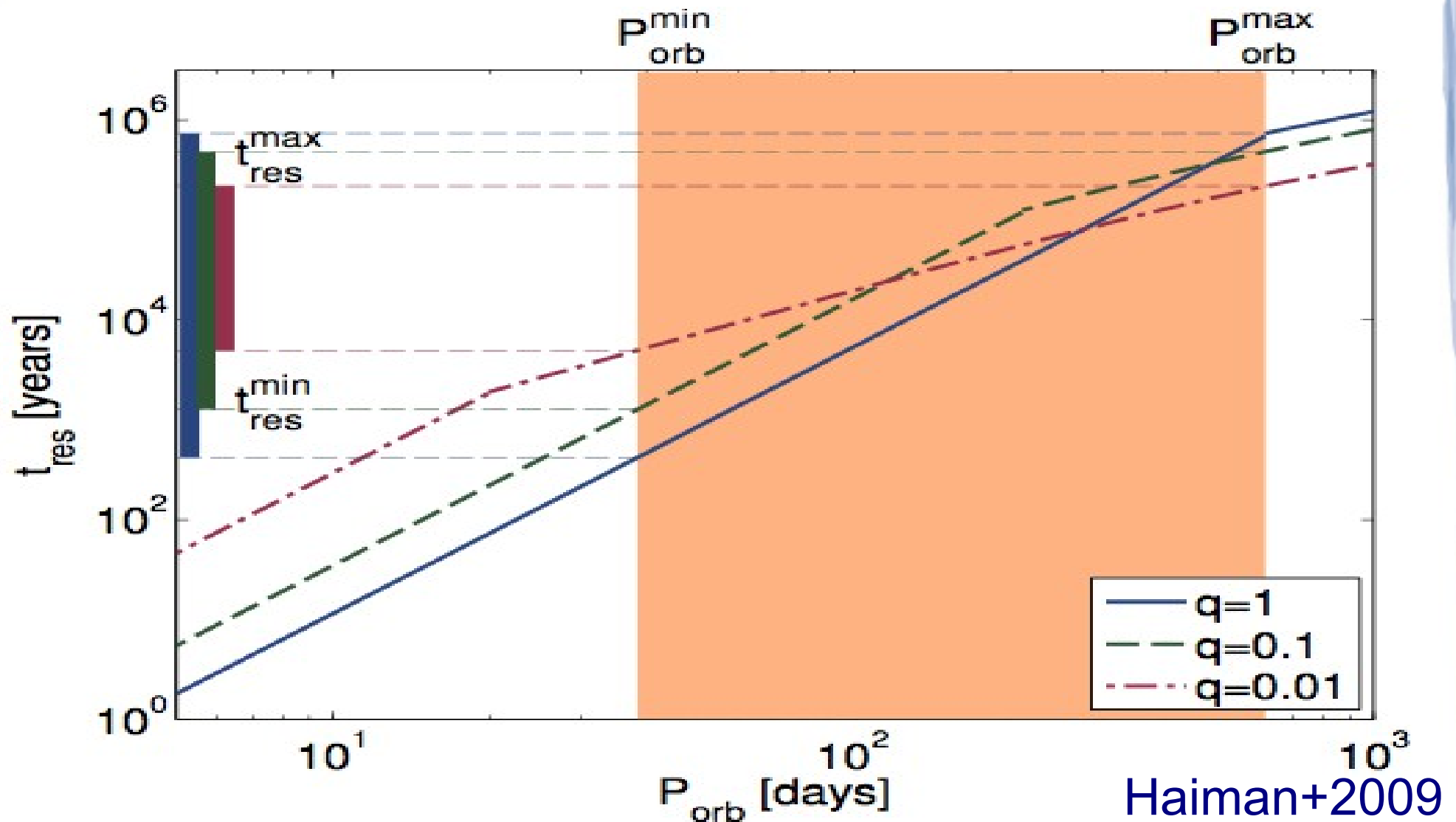
SDSS J005158.83-002054.1



SDSS J005453.30-003258.3

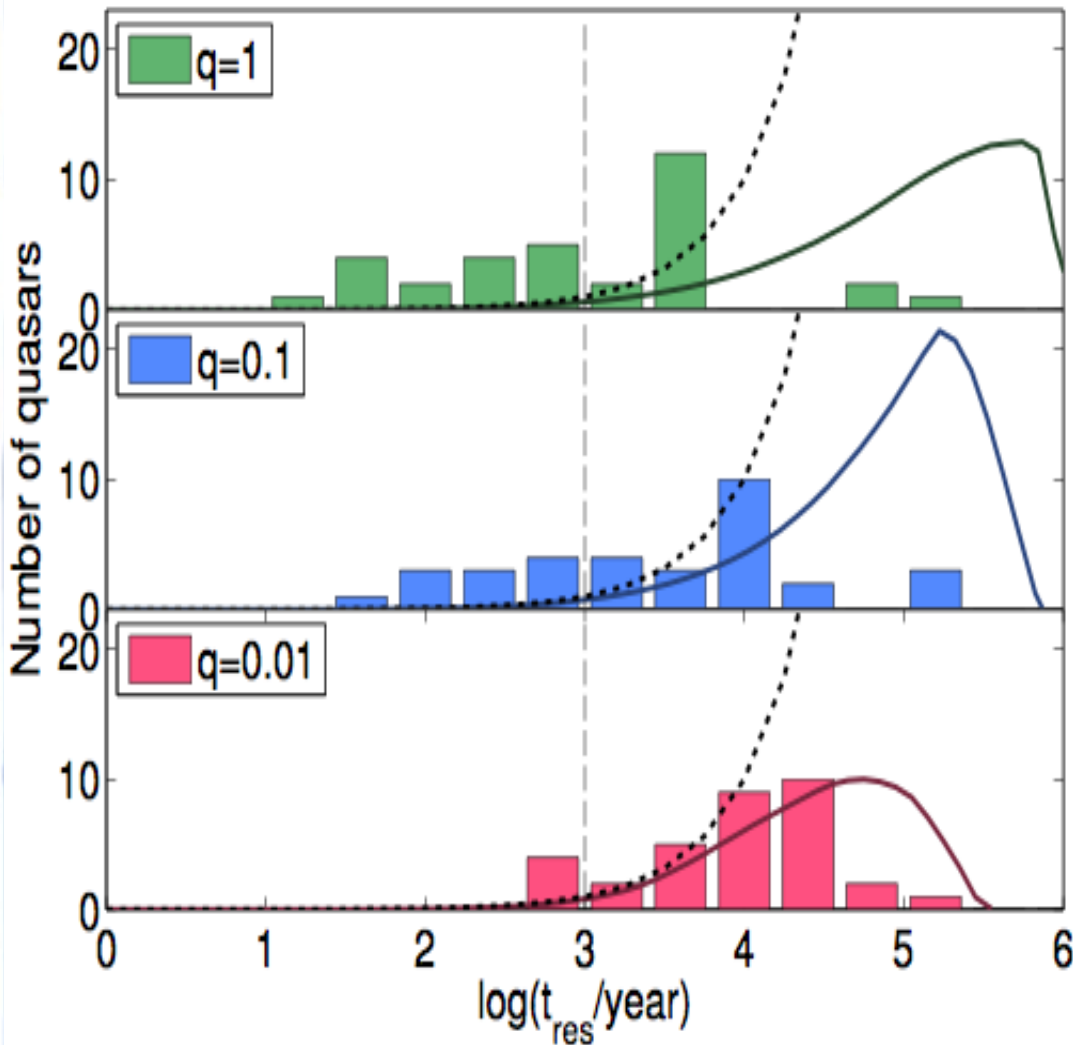


SMBHB Candidates



Residence Time: time binary spends at specific orbital separation/period

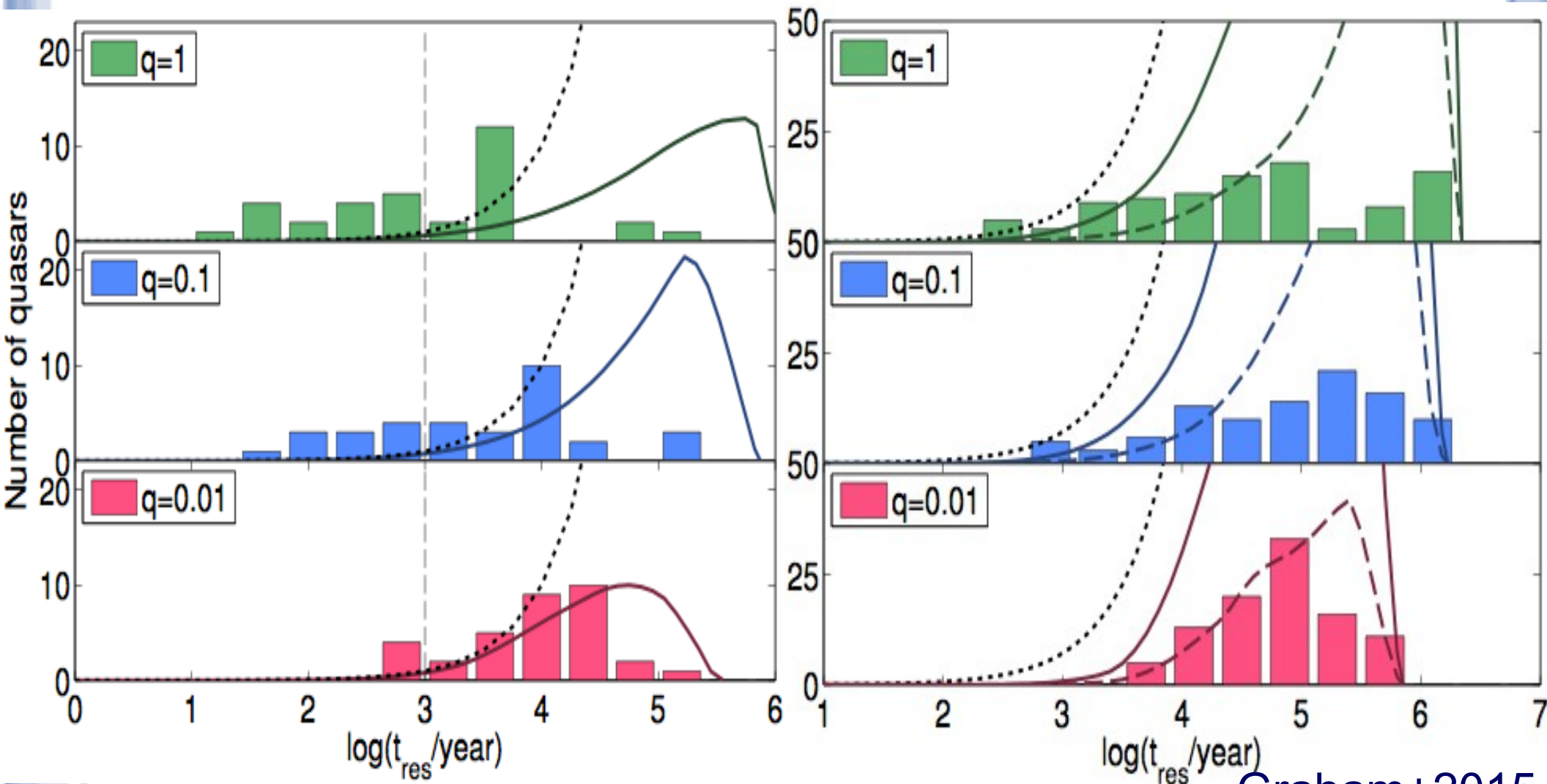
Population of SMBHBs



- **OJ 287** $q \sim 0.01$
(Valtonen+2012)
- **PG 1302** $q < 0.05$
(D'Orazio+2015)
- **Mrk 231** $q = 0.026$
(Yan+ 2015)
- **J0159+0105** $0.05 < q < 0.8$
(Zheng 2016)
- Merger trees at moderate redshift $q < 0.1$

Unequal-mass binaries preferred!

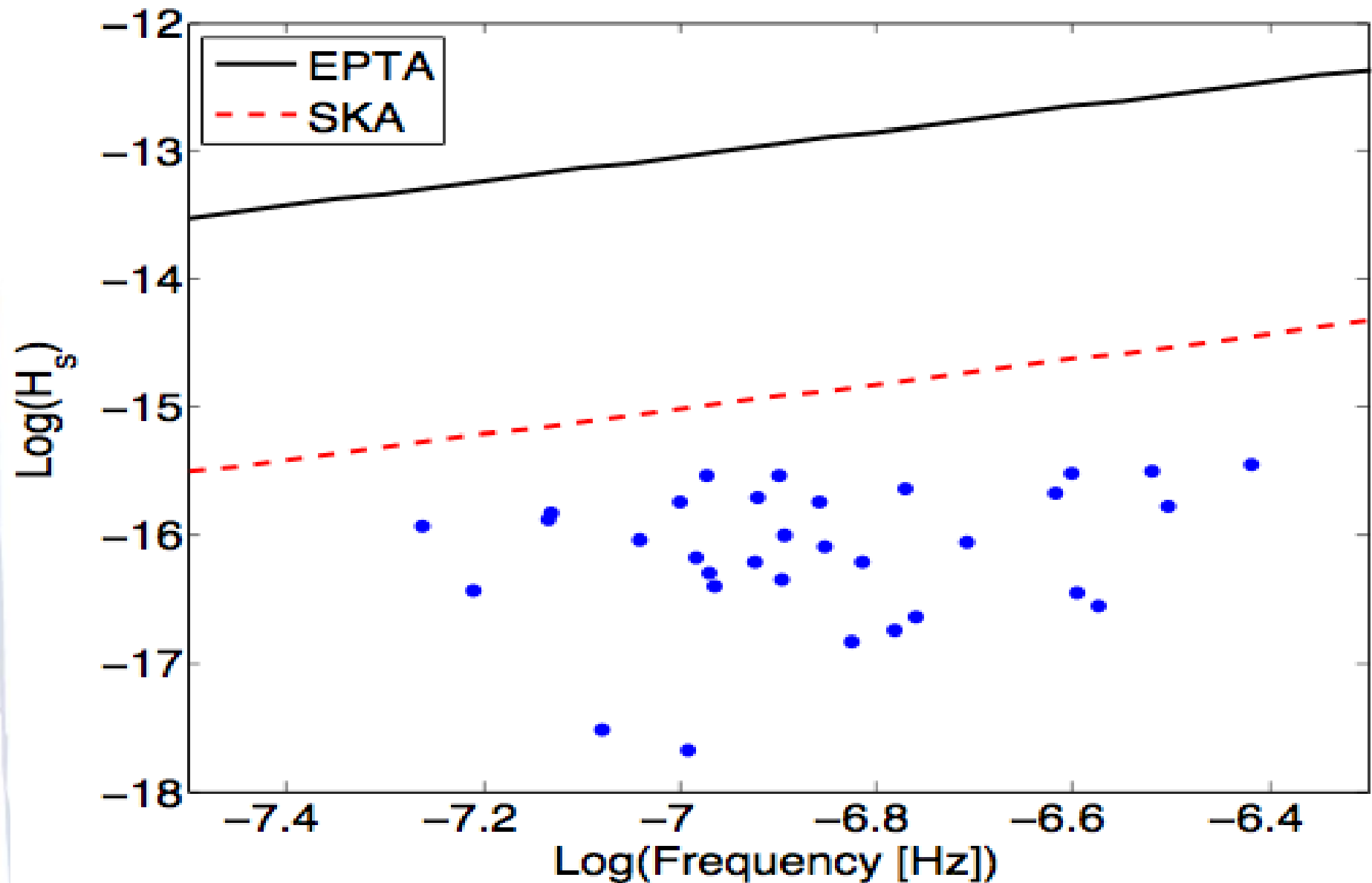
Population of SMBHBs



Graham+2015

Unequal-mass binaries preferred!

Pulsar Timing Arrays



- GW Background?

Summary

- Large statistical search for periodicity in 35k QSOs from PTF.
- 33 QSOs with significant periodicity (short periods and faint magnitudes).
- Milli-pc SMBHB candidates.
- Population of unequal-mass SMBHB.
- Charisi+2016, arXiv:1604.01020