Optical Variability Signatures from Massive Black Hole Binaries

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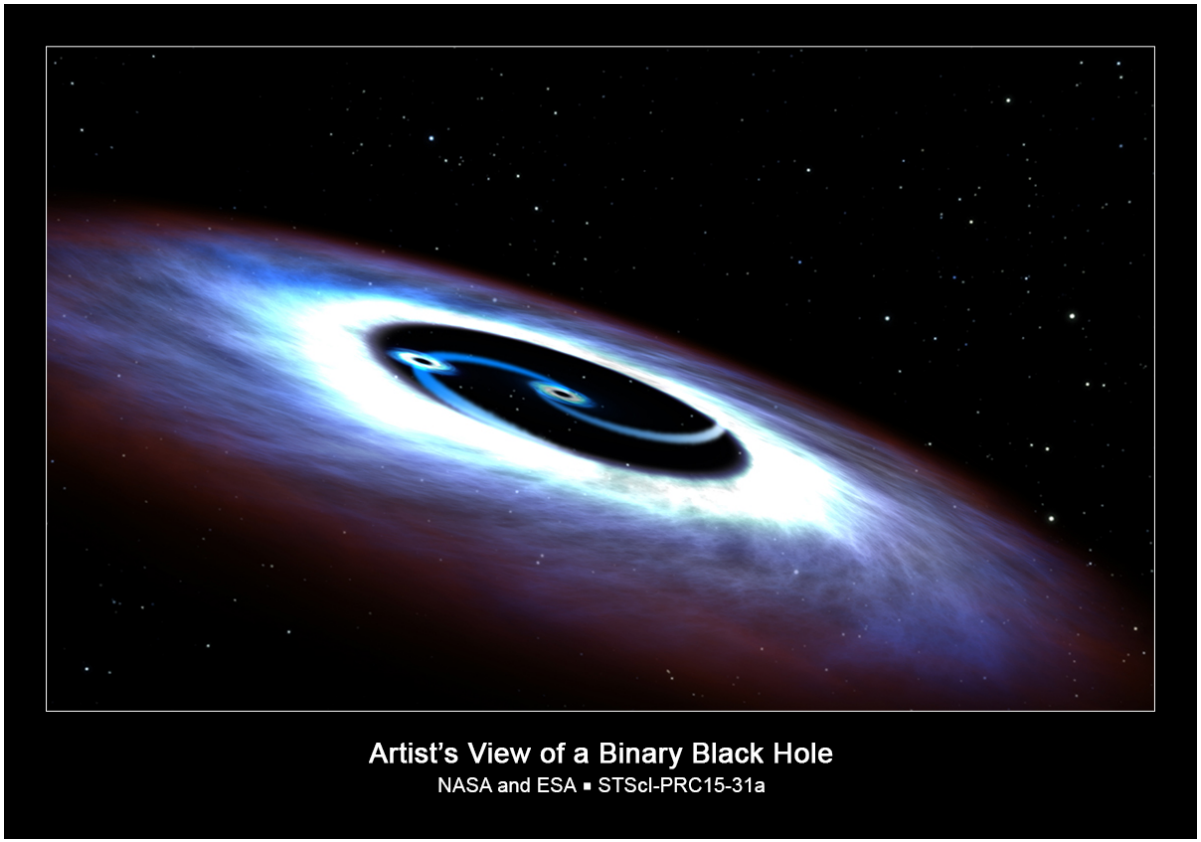
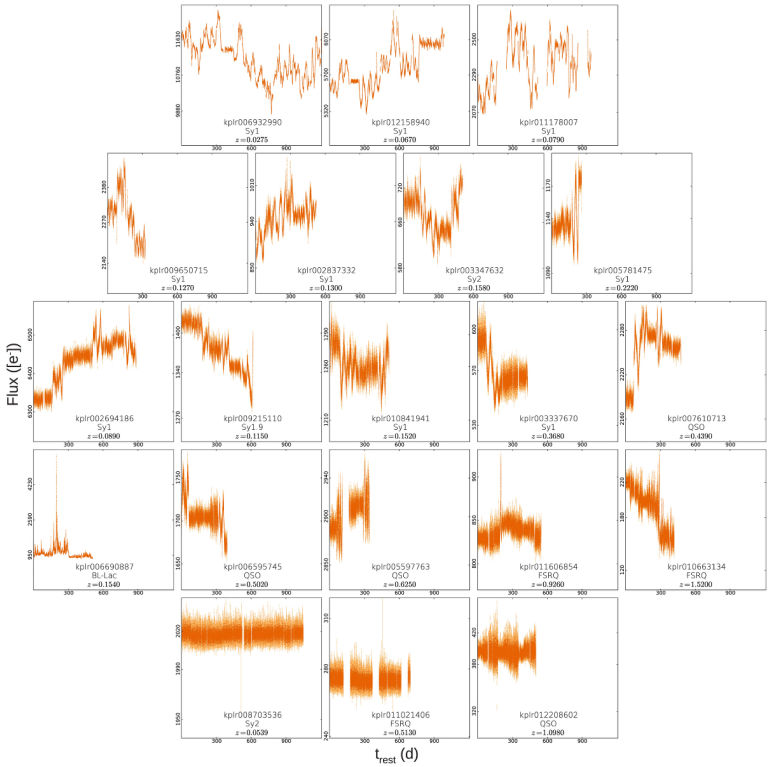
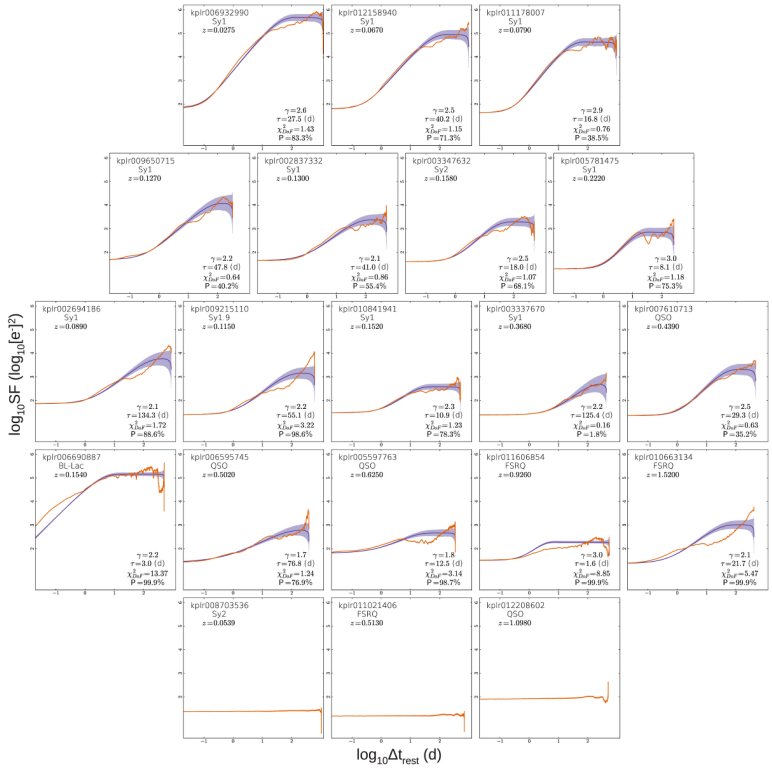
Galaxy Mergers $\Longrightarrow$ Massive Black Hole Binaries (MBHB)



- Shen & Loeb (2010)
- Colpi (2014)
- D'Orazio et al. (2013)
- D'Orazio et al. (2015)

AGN Show Complex Variability Behavior





- $z \sim 0.02$-1.5
- $\delta t_{\rm rest} \sim 14$-$28$ min
- $N \sim 16$k-60k

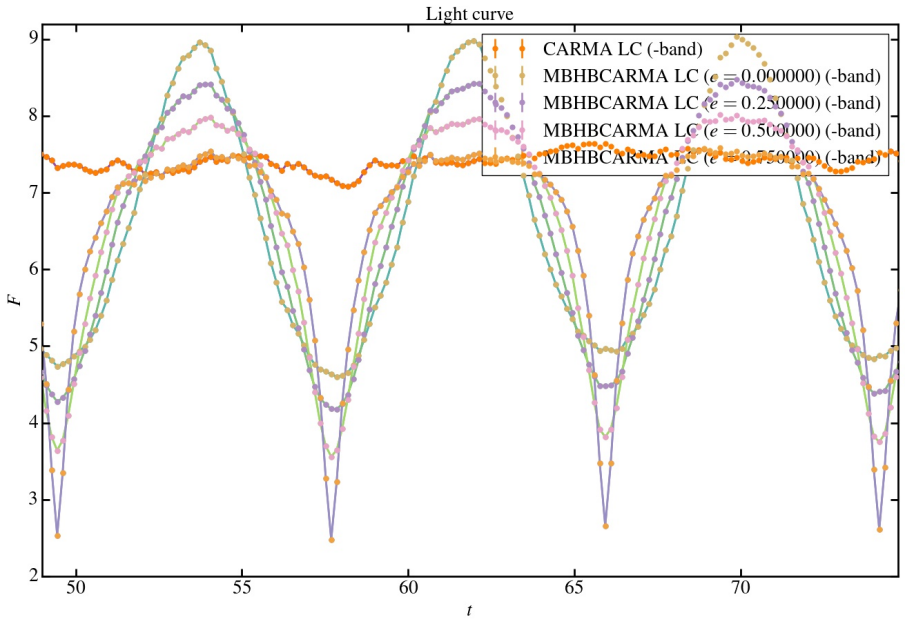
- PSD index $-1.7 \sim -3.1$
- PSD model too simple
- Onset over ~ 1 hr to ~ 1 d

Continuous-time AutoRegressive Moving Average (C-ARMA) Processes

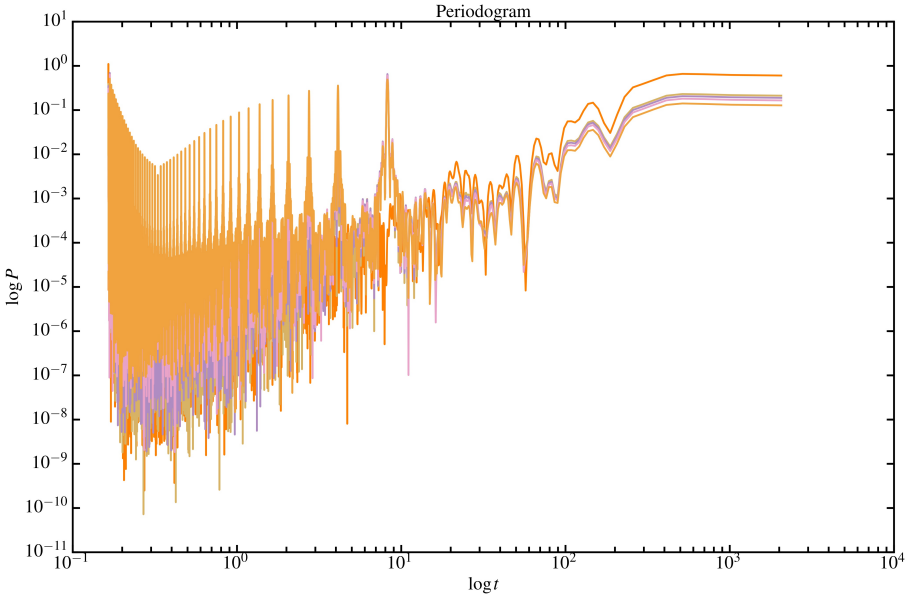
$$\mathrm{d}W \sim \mathcal{N}(0, \mathrm{d}t)$$

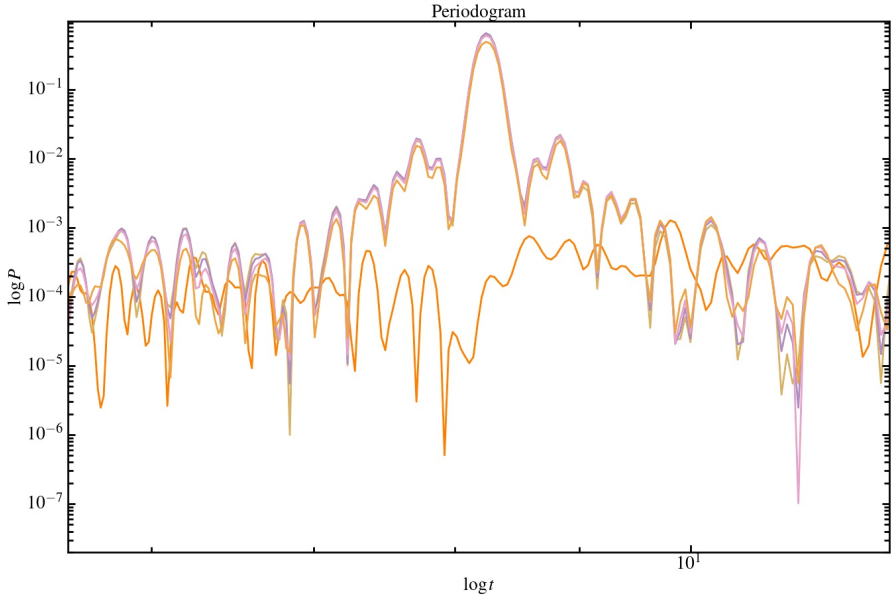
$$\mathrm{d}^p x + \alpha_1 \mathrm{d}^{p-1} x + \ldots + \alpha_{p-1} \mathrm{d}x + \alpha_p x = \beta_0 (\mathrm{d}W) + \ldots + \beta_q \mathrm{d}^q (\mathrm{d}W)$$

- Itō calculus Davis (2002); Brockwell (2014); Kelly et al. (2014); Kasliwal et al. (2016)
- Drive linearized system with noise
- PSD is a ratio of even polynomials in frequency
- Modulate C-ARMA with relativistic beaming factor!
- Now available in kālī!



Effect on PSD

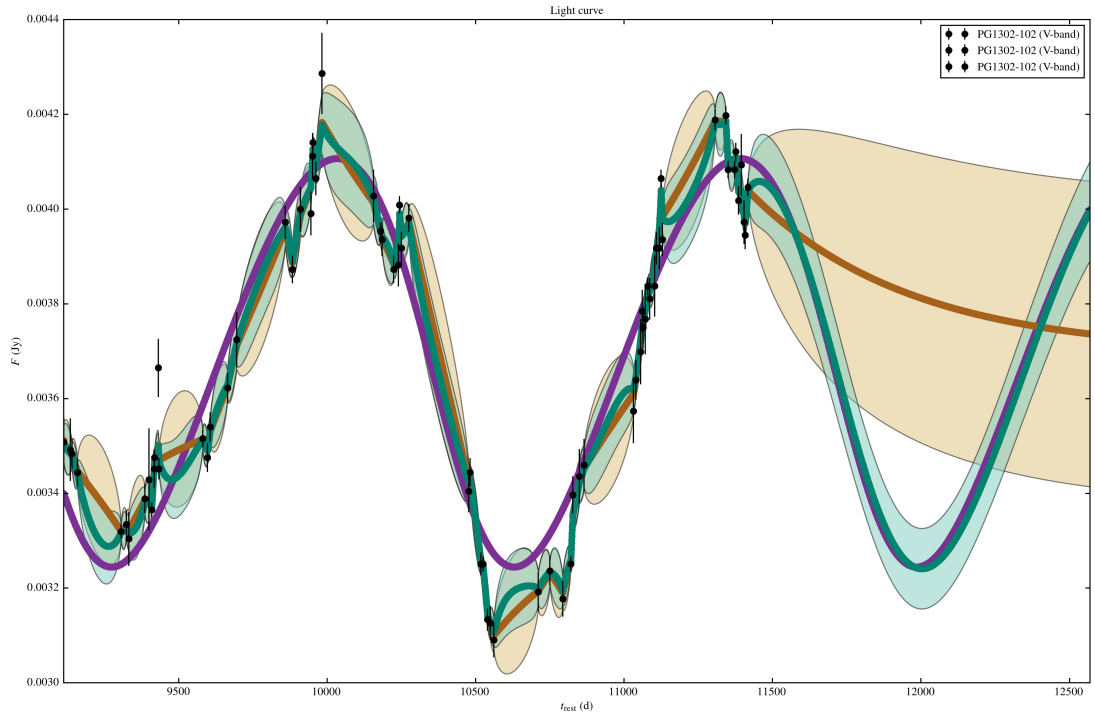




- $a_1 = 10^{-4}$ pc
- $a_2 = 10^{-4}$ pc
- $T = 8.25$ d
- e ranges from 0.0 to 0.75

- $M_{12} = 138.68 \times 10^6 M_\odot$
- $\Omega = 0.0$ degree
- $i = 90.0$ degree

Massive Black Hole Binary Fit for PG 1302-102



- $a_1 \sim 6.8 \times 10^{-3}$ pc
- $a_2 \sim 1.1 \times 10^{-2}$ pc
- $T \sim 1343$ d
- $M_{12} \sim 4.05 \times 10^9 M_\odot$
- $M_2/M_1 \sim 0.66$
- $e \sim 0.077$

Brockwell, P. 2014, Ann. Inst. Stat. Math., 66, 647

Colpi, M. 2014, Space Sci. Rev., 183, 189

Davis, J. H. 2002, Foundations of Deterministic and Stochastic Control (Birkhäuser)

D'Orazio, D. J., Haiman, Z., & MacFadyen, A. 2013, MNRAS, 436, 2997

D'Orazio, D. J., Haiman, Z., & Schiminovich, D. 2015, Nature, 525, 351

Kasliwal, V. P., Vogeley, M. S., & Richards, G. T. 2016, arXiv:1607.04299, submitted to MNRAS.

Kelly, B. C., Becker, A. C., Sobolewska, M., Siemiginowska, A., & Uttley, P. 2014, ApJ, 788, 33

Shen, Y., & Loeb, A. 2010, ApJ, 725, 249