Extracting Information From AGN Variability: A LSST AGN Collaboration Proposal

LSST AGN Science Collaboration Roadmap Development Meeting Grapevine, TX

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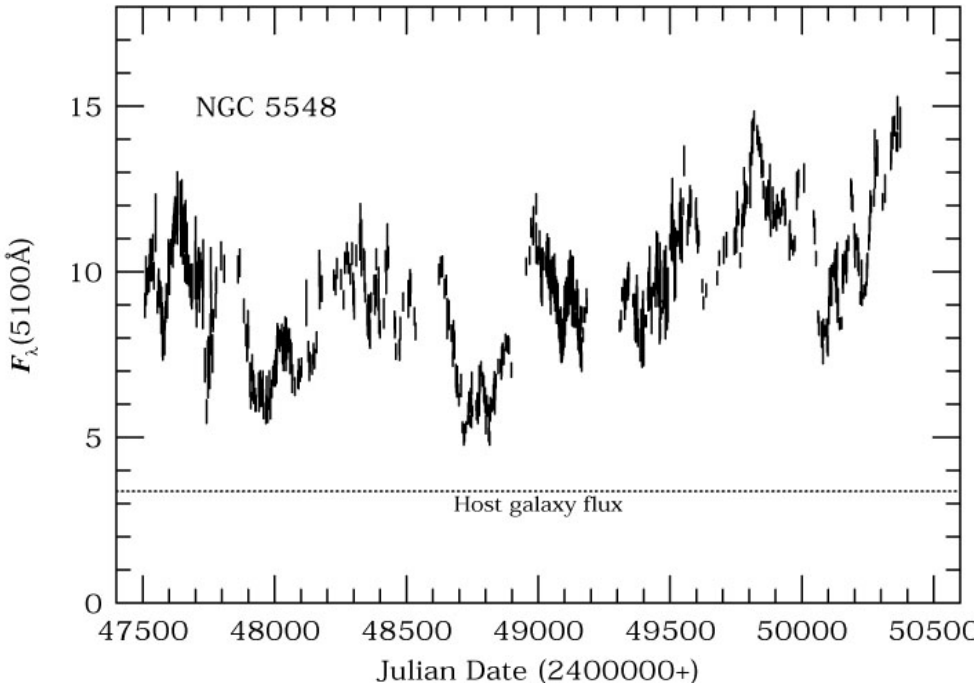
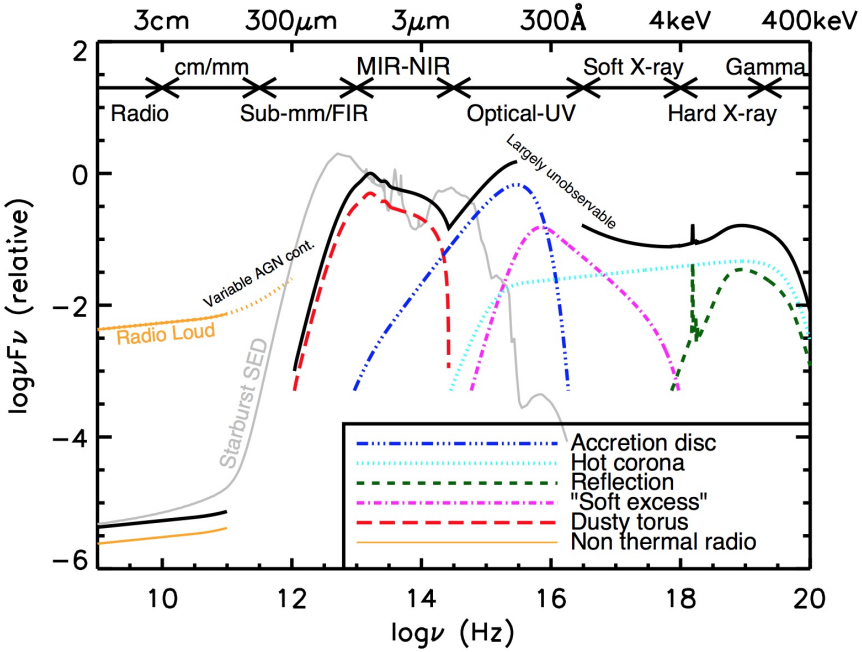
AGN Exhibit Rapid, Stochastic, Luminosity Variations (and we do not know why!)



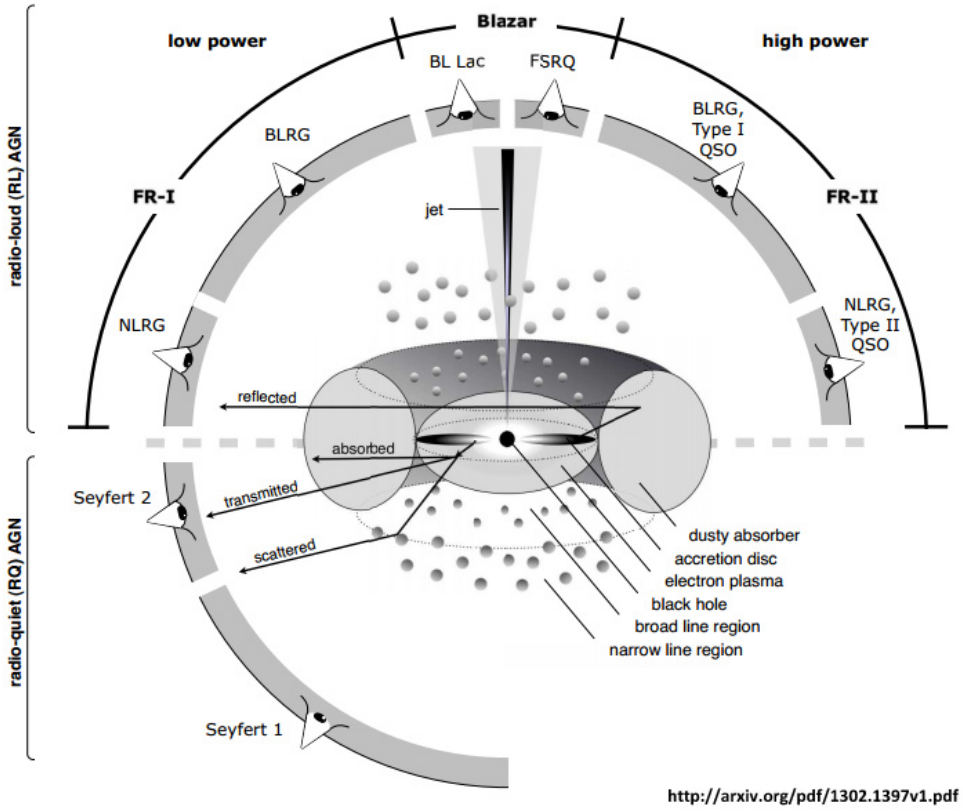
(Peterson et al. 1999)

- ~ 90 % vary (Sesar et al. 2007)
- Pan-spectral: shorter $\lambda \Rightarrow$ stronger variability
- Stochastic! (Peterson 1997)
- longer λ lag shorter λ

AGN Morphology: Continuum Variations → Origin in Accretion Disk

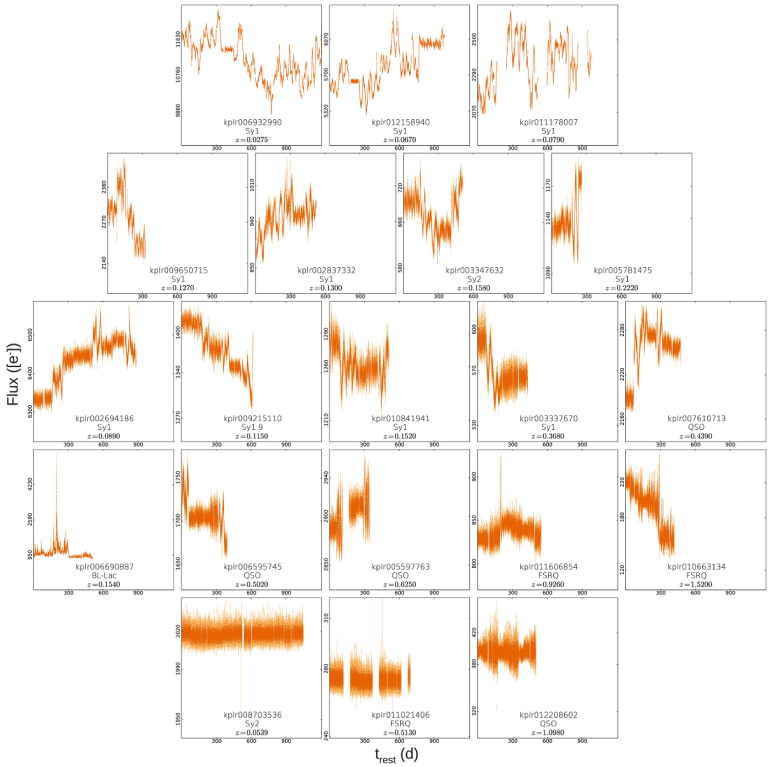


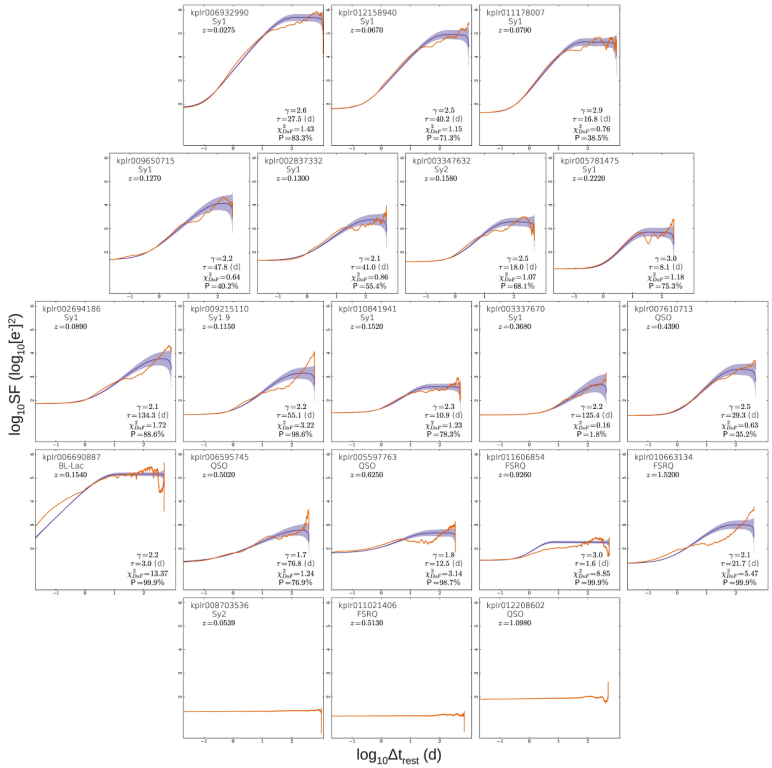
Chris Harrison



http://arxiv.org/pdf/1302.1397v1.pdf

AGN Show Complex Variability Behavior





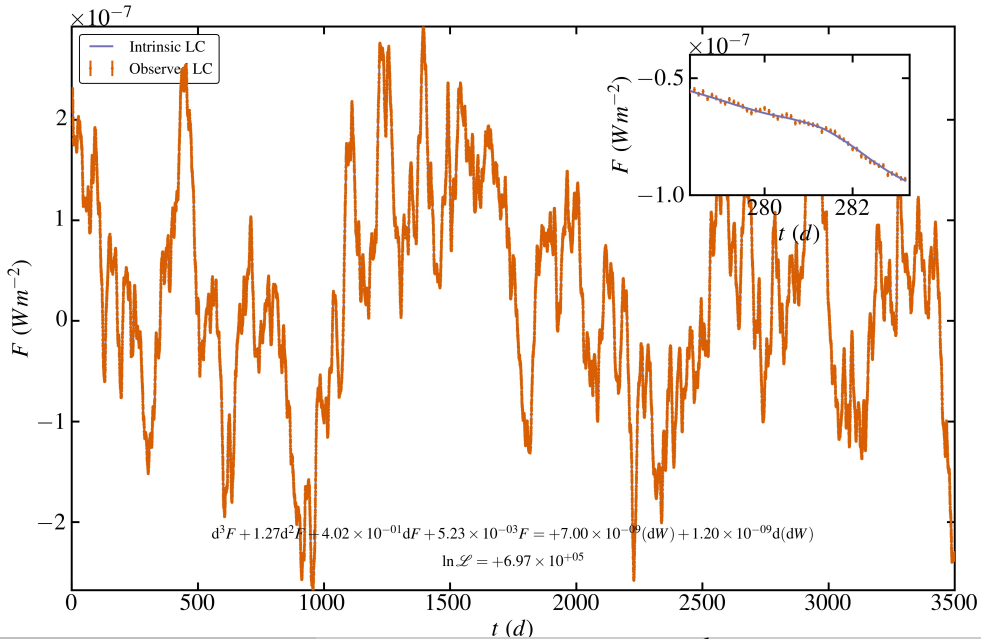
- $z \sim 0.02$-1.5
- $\delta t_{\rm rest} \sim$ 14-28 min
- $N \sim$ 16k-60k
- PSD index $-1.7 \sim -3.1$
- PSD model too simple
- Onset over $\sim$ 1 hr to $\sim$ 1 d

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

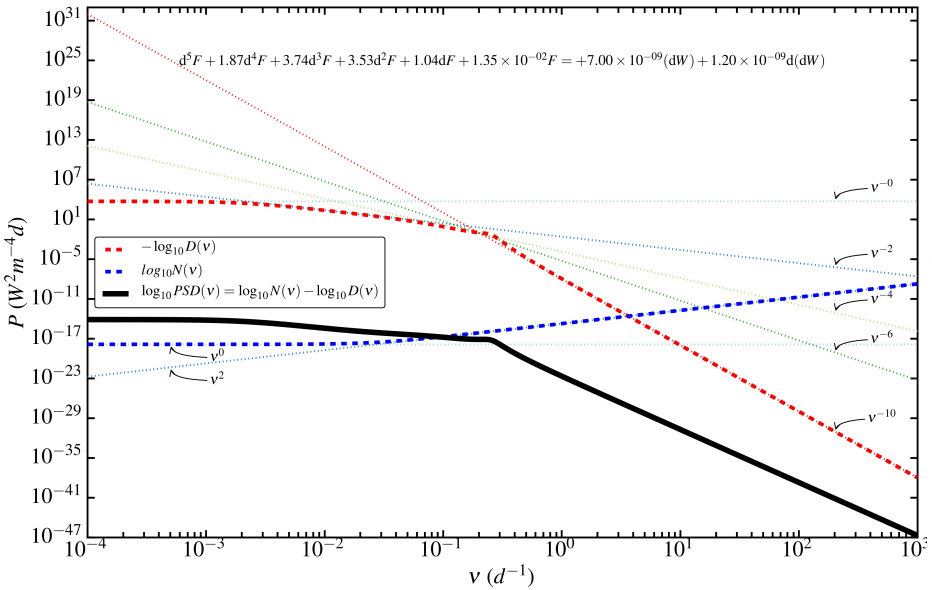
$$\mathrm{d}W \sim \mathcal{N}(0, \mathrm{d}t)$$

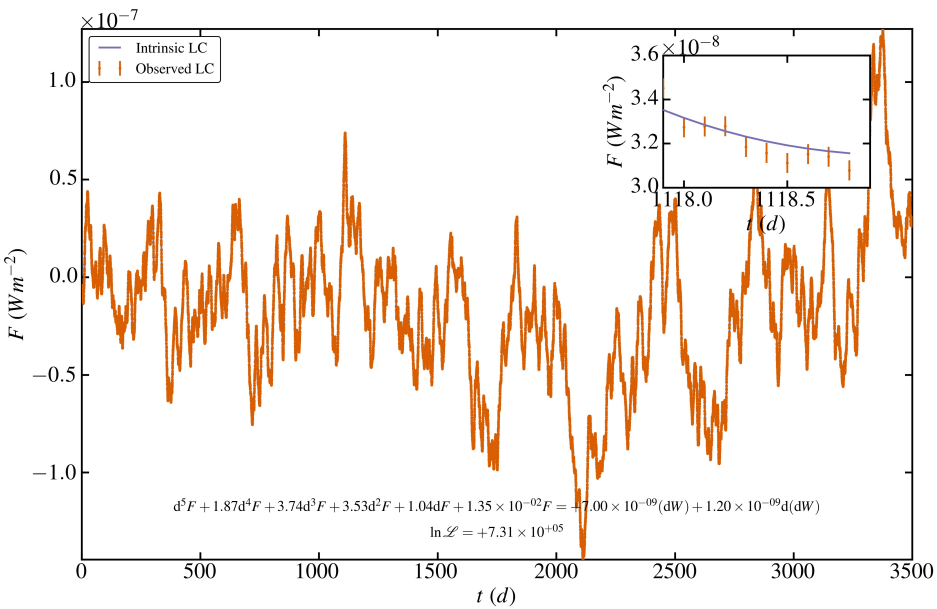
$$\mathrm{d}^p x + \alpha_1 \mathrm{d}^{p-1} x + \ldots + \alpha_{p-1} \mathrm{d}x + \alpha_p x = \beta_0 (\mathrm{d}W) + \ldots + \beta_q \mathrm{d}^q (\mathrm{d}W)$$

- Itō calculus Brockwell (2014); Davis (2002); Kelly et al. (2014)
- Drive linearized system with noise
- PSD is a ratio of even polynomials in frequency

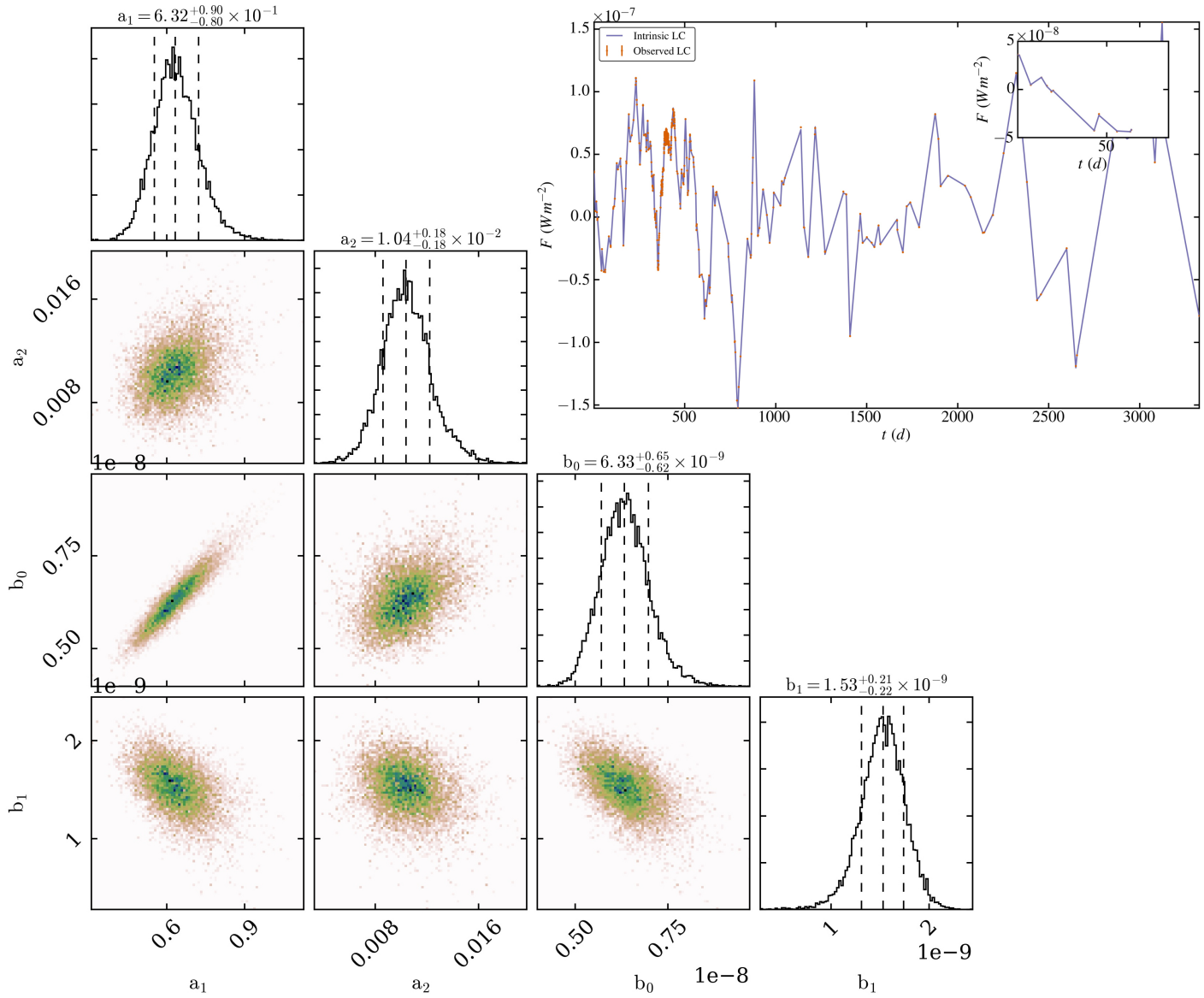


Power Spectral Density
Eg. C-ARMA(5,1)



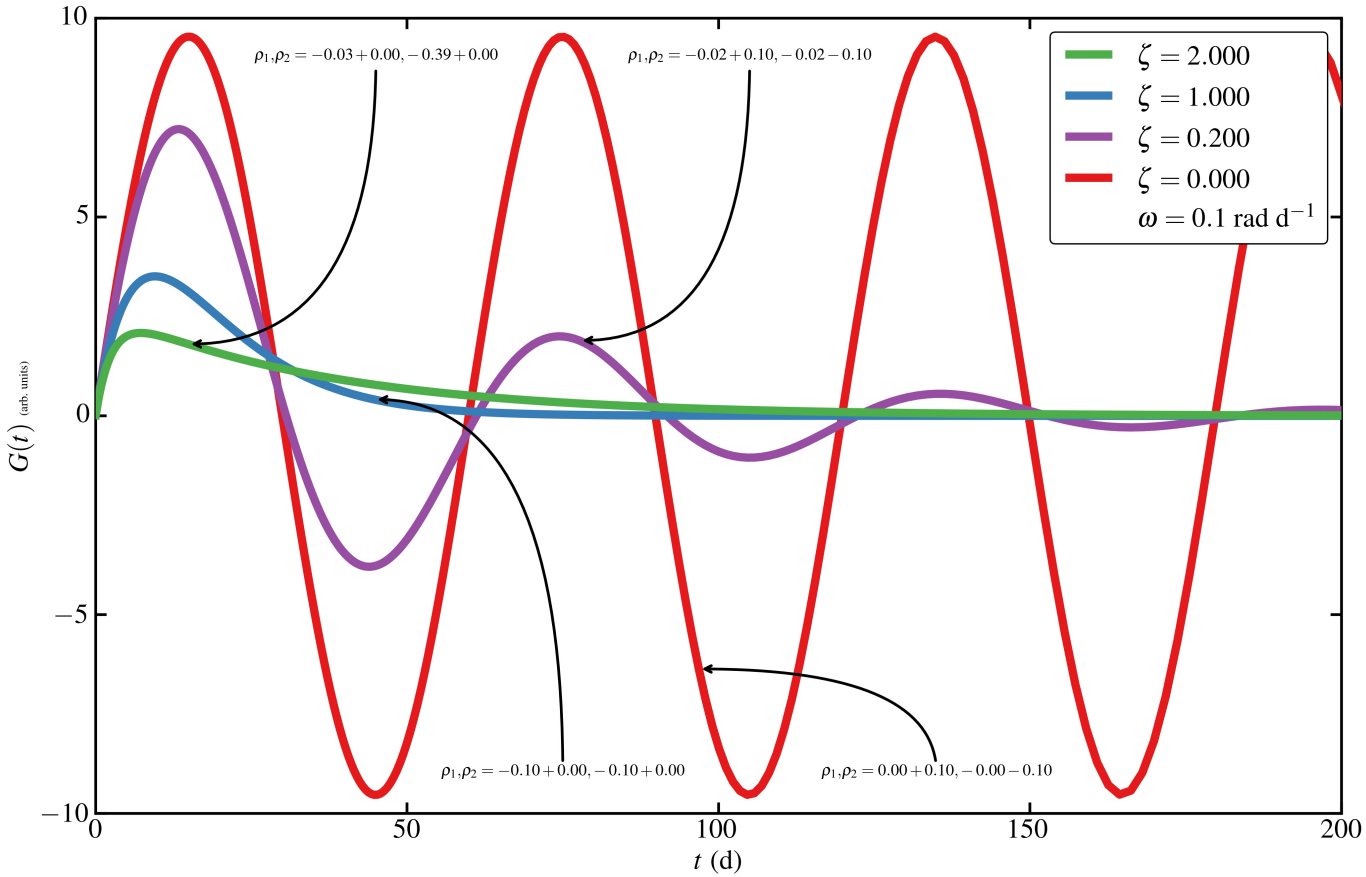


Confidence Interval Estimates

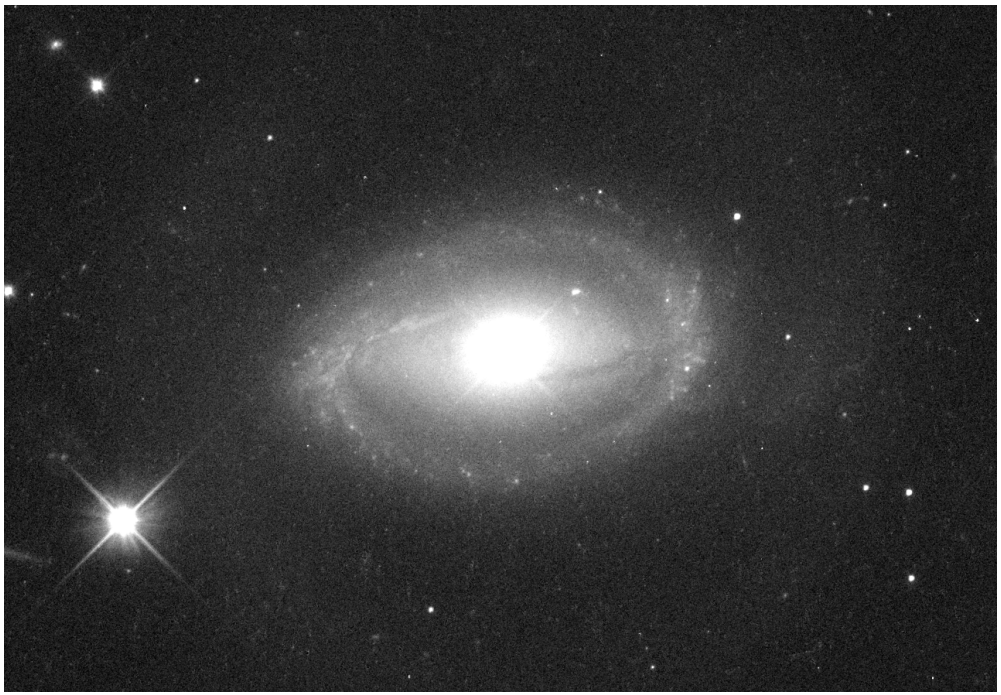


How to Interpret?: Green's Function of LHS (eg. C-ARMA(2,1)...)

$$\mathrm{d}^2G + 2\omega\zeta \mathrm{d}G + \omega^2 G = \delta(0)$$



Zw 229-15 (kplr006932990)

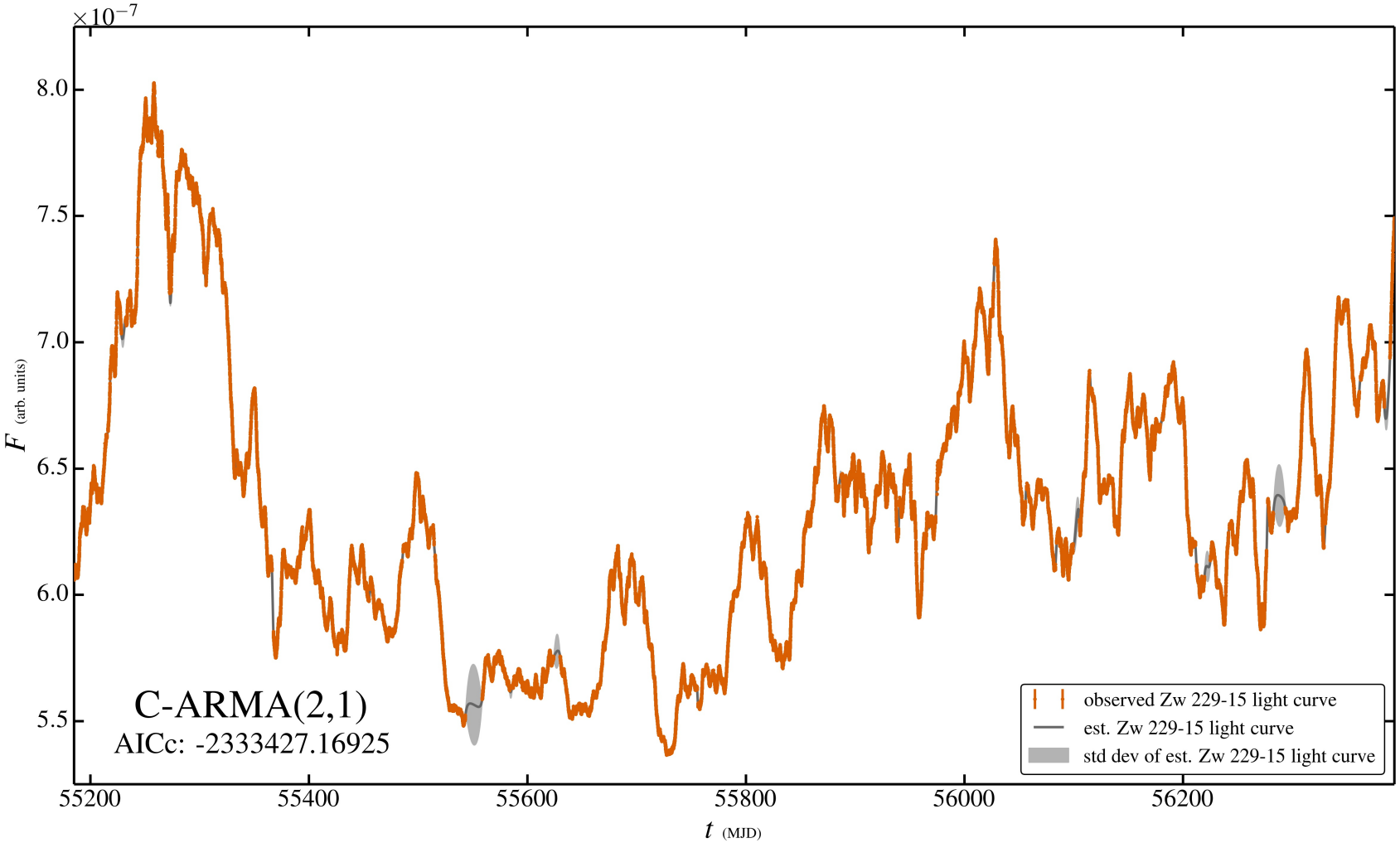


HST Image

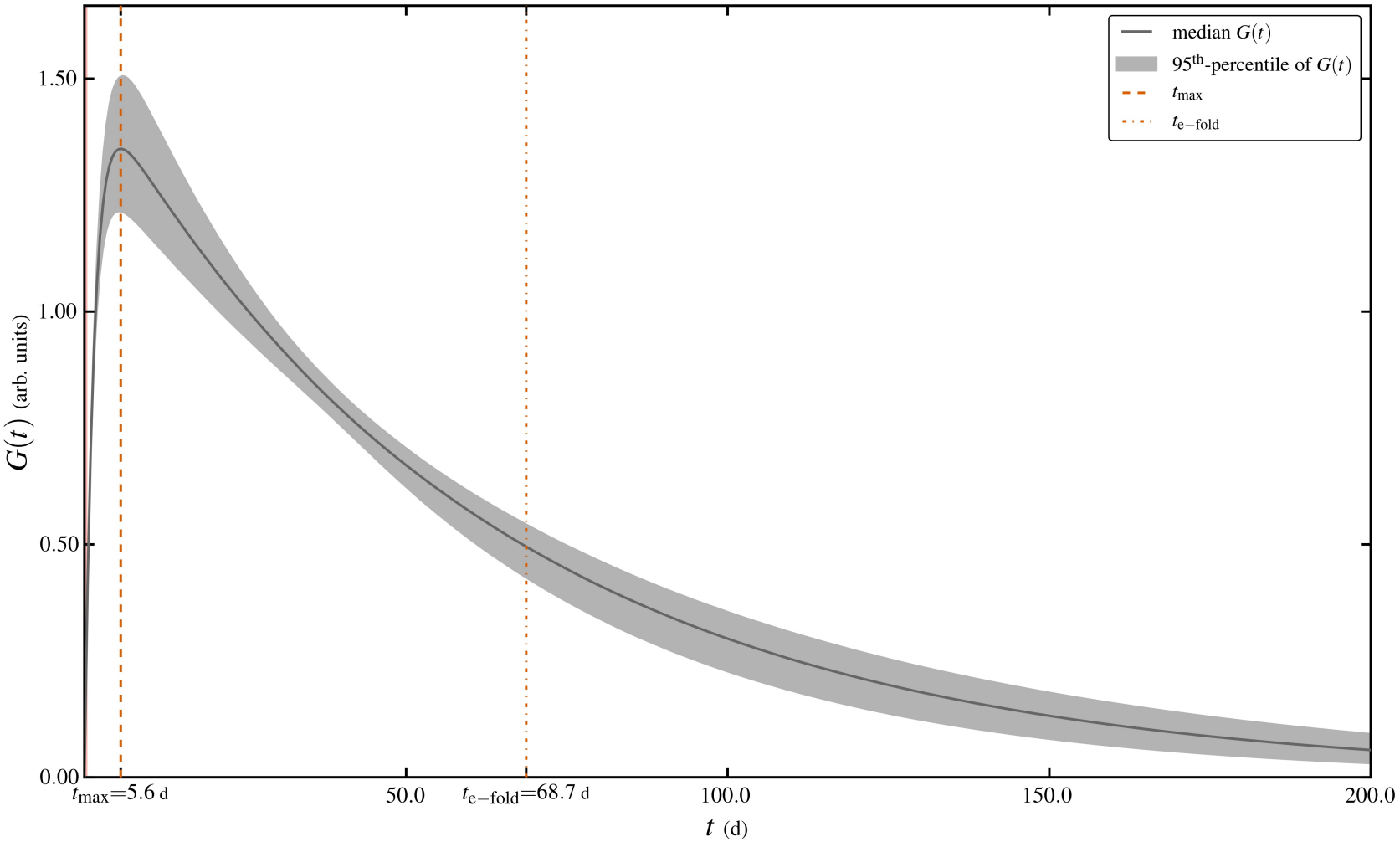
- Sy 1 in Lyra
- $\Delta T_{H\beta} = 3.86^{+0.69}_{-0.90}$ d
- mag 15.4
- $M_{BH} = 1.00^{+0.19}_{-0.24} \times 10^7 M_\odot$

(Barth et al. 2011)

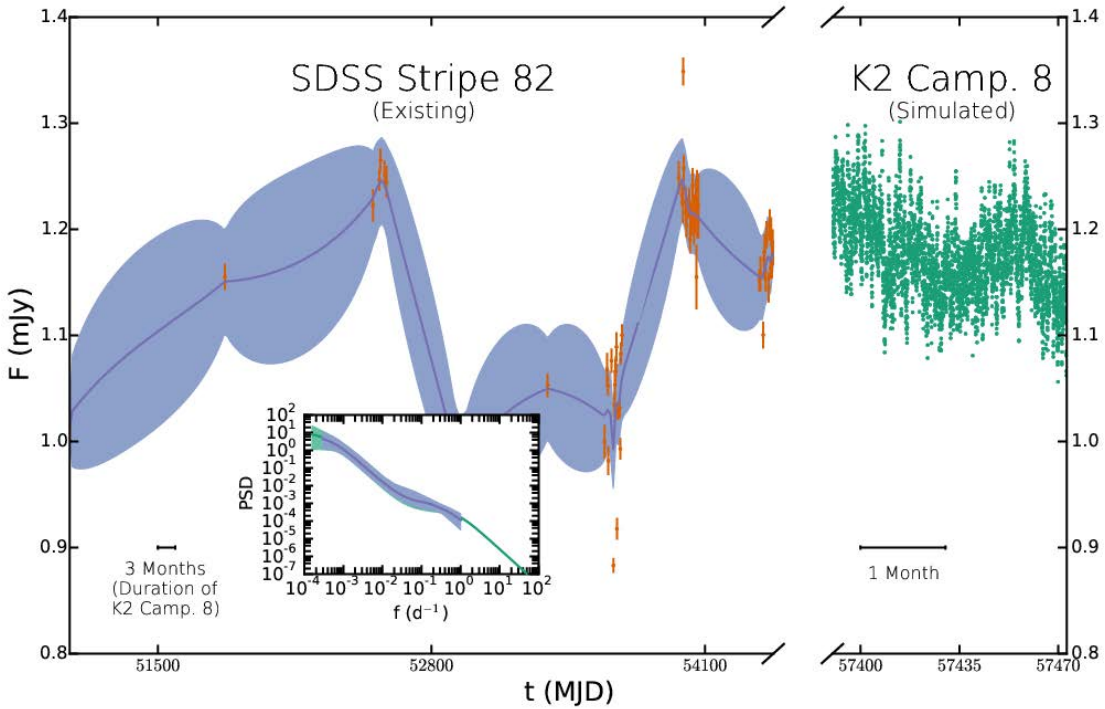
C-ARMA(2,1) model of Zw 229-15
Smoothed light curve



C-ARMA(2,1) model of Zw 229-15
Green's Function

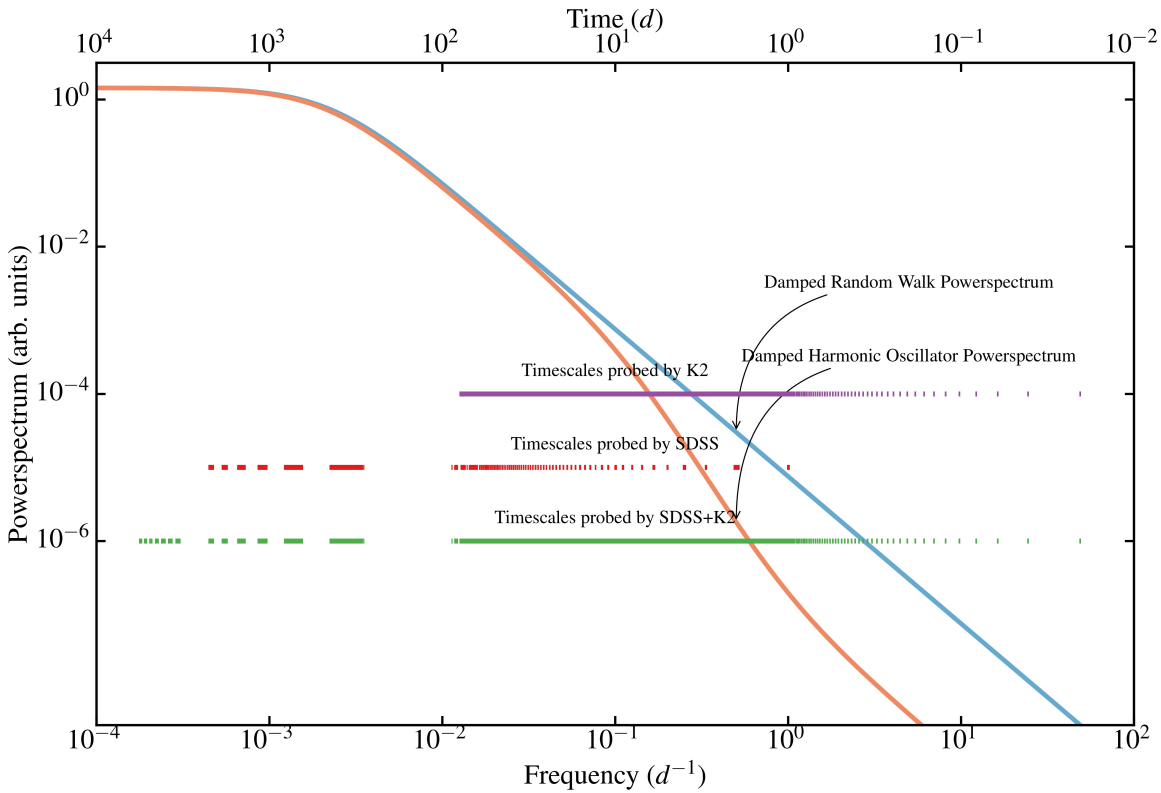


WiP: Power of SDSS+K2



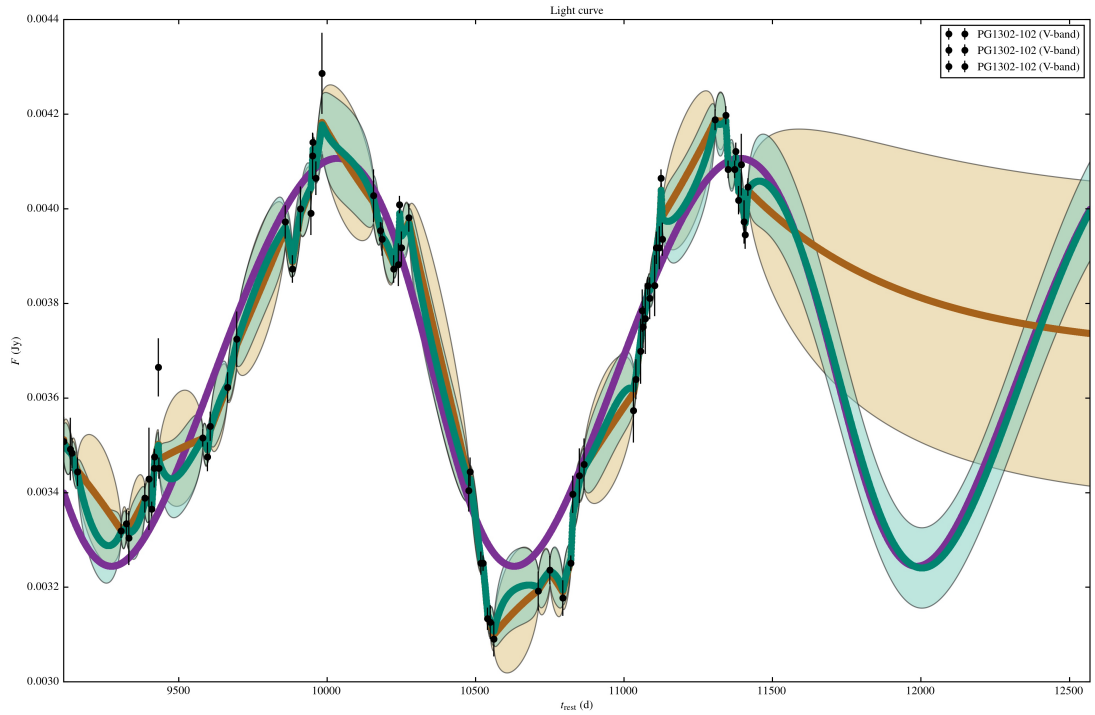
- Spectra required for good colorterms

WiP: K2 observations of Stripe 82 QSOs



- Prototype for LSST-DDF
- Can we use DASCH as well?

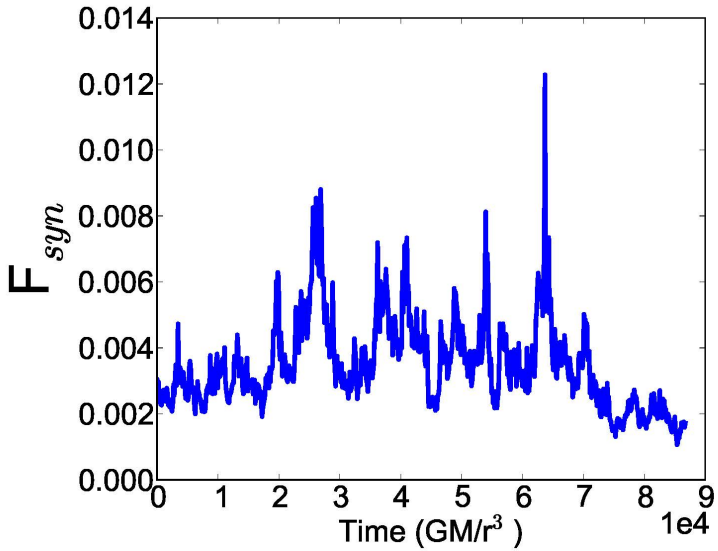
WiP: Is PG 1302-102 a Relativistically-Beamed Massive Black Hole Binary?



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

Work in Progress

- SDSS Stripe 82 + K2 QSO variability
  - Connection between AGN sub-type and variability
- Detection of binary-SMBH via variability
- Better time series models for exotic objects (blazars)
- Cadence and periodicity requirements of LSST
- Multi-wavelength variability
- Comparing simulations with observations
- Stationarity of AGN light curves



J. Drew Hogg

LSST Prep

- Learn as much as we can about the AGN in the DDF (we'll surely want spectra if nothing else).
- Determine single-band LSST sampling requirements (J. Moreno).
  - Will the WFD survey be useful?
  - Does adding DASCH & TESS help?
- Test applicability of C-ARMA models to large sample of AGN (J. Moreno, J. O'Brien, M. Graham & others).
  - Can we make a strong case for tweaking the WFD survey to make it more useful?
- Probe connections between varibility properties & physical properties (J. O'Brien)
  - Is variability a proxy for some other property?
- Develop models for multiplicative disturbances (for blazars etc..).
- Develop & test models for continuum-continuum variability.
  - How much does taking data non-simultaneously hurt us?

Armitage, P. J., & Reynolds, C. S. 2003, MNRAS, 341, 1041

Barth, A. J., Nguyen, M. L., Malkan, M. A., et al. 2011, ApJ, 732, 121

Belloni, T. M., & Stella, L. 2014, in Space Sciences Series of ISSI, Vol. 49, The Physics of Accretion onto Black Holes, ed. F. Maurizio, T. Belloni, P. Casella, M. Gilfanov, P. Jonker, & A. King (Springer), 43

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

Carini, M. T., & Ryle, W. T. 2012, ApJ, 749, 70

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

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

Edelson, R., & Malkan, M. 2012, ApJ, 751, 52

Emmanoulopoulos, D., McHardy, I. M., & Uttley, P. 2010, MNRAS, 404, 931

Hawley, J. F., & Krolik, J. H. 2002, ApJ, 566, 164

Janiuk, A., & Czerny, B. 2007, A&A, 466, 793

Kasliwal, V. P., Vogeley, M. S., & Richards, G. T. 2015, MNRAS, 451, 4328

Kelly, B. C., Bechtold, J., & Siemiginowska, A. 2009, ApJ, 698, 895

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

Lyubarskii, Y. E. 1997, MNRAS, 292, 679

McHardy, I. M., Papadakis, I. E., Uttley, P., Page, M. J., & Mason, K. O. 2004, MNRAS, 348, 783

Mushotzky, R. F., Edelson, R., Baumgartner, W., & Gandhi, P. 2011, ApJ, 743, L12

Nowak, M. A., & Wagoner, R. V. 1995, MNRAS, 274, 37

Peterson, B. M., Barth, A. J., Berlind, P., et al. 1999, ApJ, 510, 659

Peterson, Bradley, M. 1997, An Introduction to Active Galactic Nuclei (Cambridge University Press)

Poutanen, J., & Fabian, A. C. 1999, MNRAS, 306, L31

Sesar, B., Ivezić, Ž., Lupton, R. H., et al. 2007, AJ, 134, 2236

Shaya, E. J., Olling, R., & Mushotzky, R. 2015, ArXiv e-prints, arXiv:1507.08312 [astro-ph.HE]

Uttley, P., & Casella, P. 2014, in Space Sciences Series of ISSI, Vol. 49, The Physics of Accretion onto Black Holes, ed. F. Maurizio, T. Belloni, P. Casella, M. Gilfanov, P. Jonker, & A. King (Springer), 453

Uttley, P., McHardy, I. M., & Vaughan, S. 2005, MNRAS, 359, 345

Van Cleve, J. E., & Caldwell, D. A. 2009, Kepler Instrument Handbook, Tech. Rep. KSCI-19033, National Aeronautics and Space Administration, NASA Ames Research Center, Moffett Field, California

Wehrle, A. E., Wiita, P. J., Unwin, S. C., et al. 2013, ApJ, 773, 89