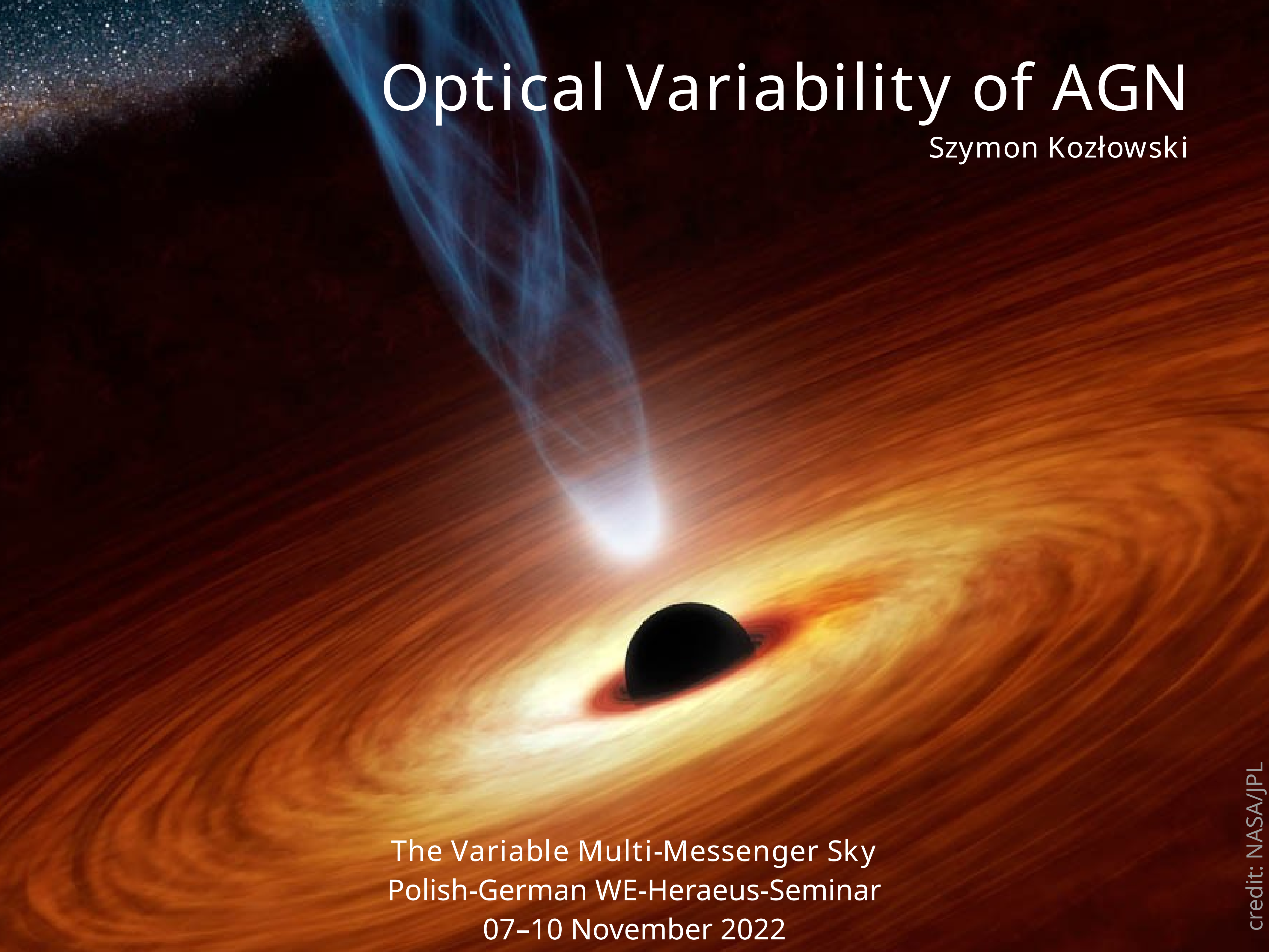
Optical Variability of AGN

Szymon Kozłowski

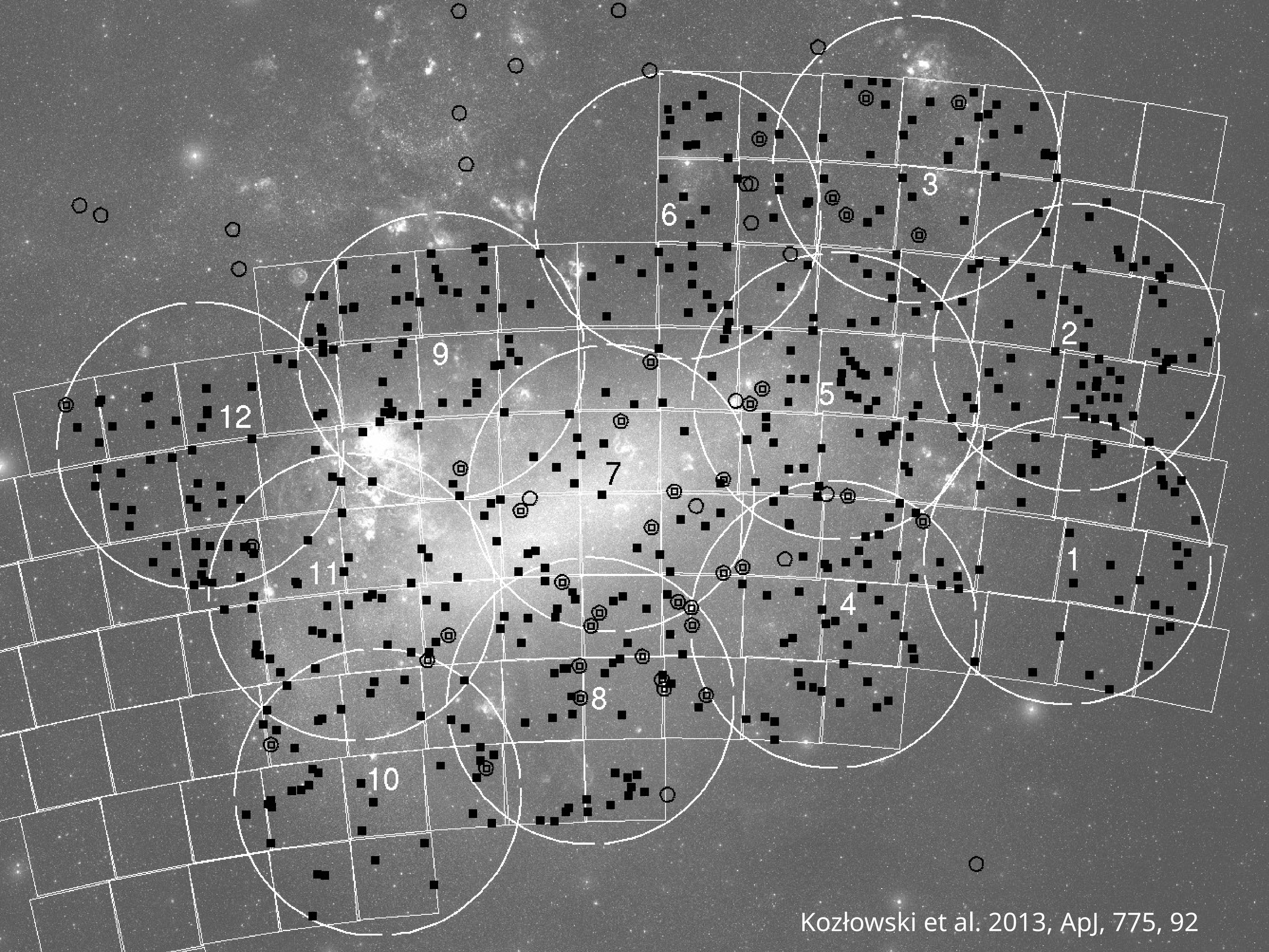


The Variable Multi-Messenger Sky
Polish-German WE-Heraeus-Seminar
07–10 November 2022

credit: NASA/JPL

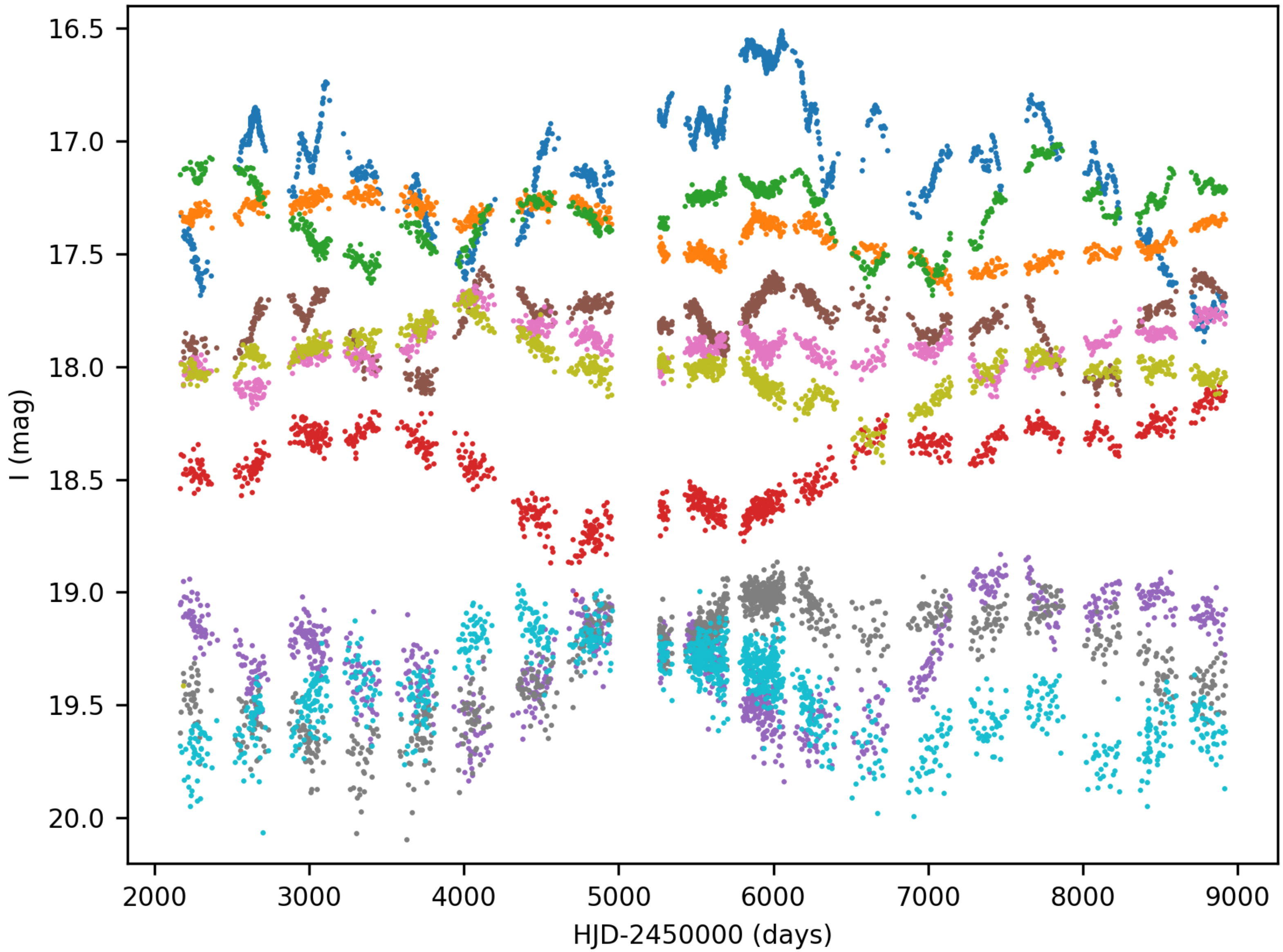
Optical Gravitational Lensing Experiment (OGLE)

Udalski et al. 2015, Acta Astronomica, 65, 1

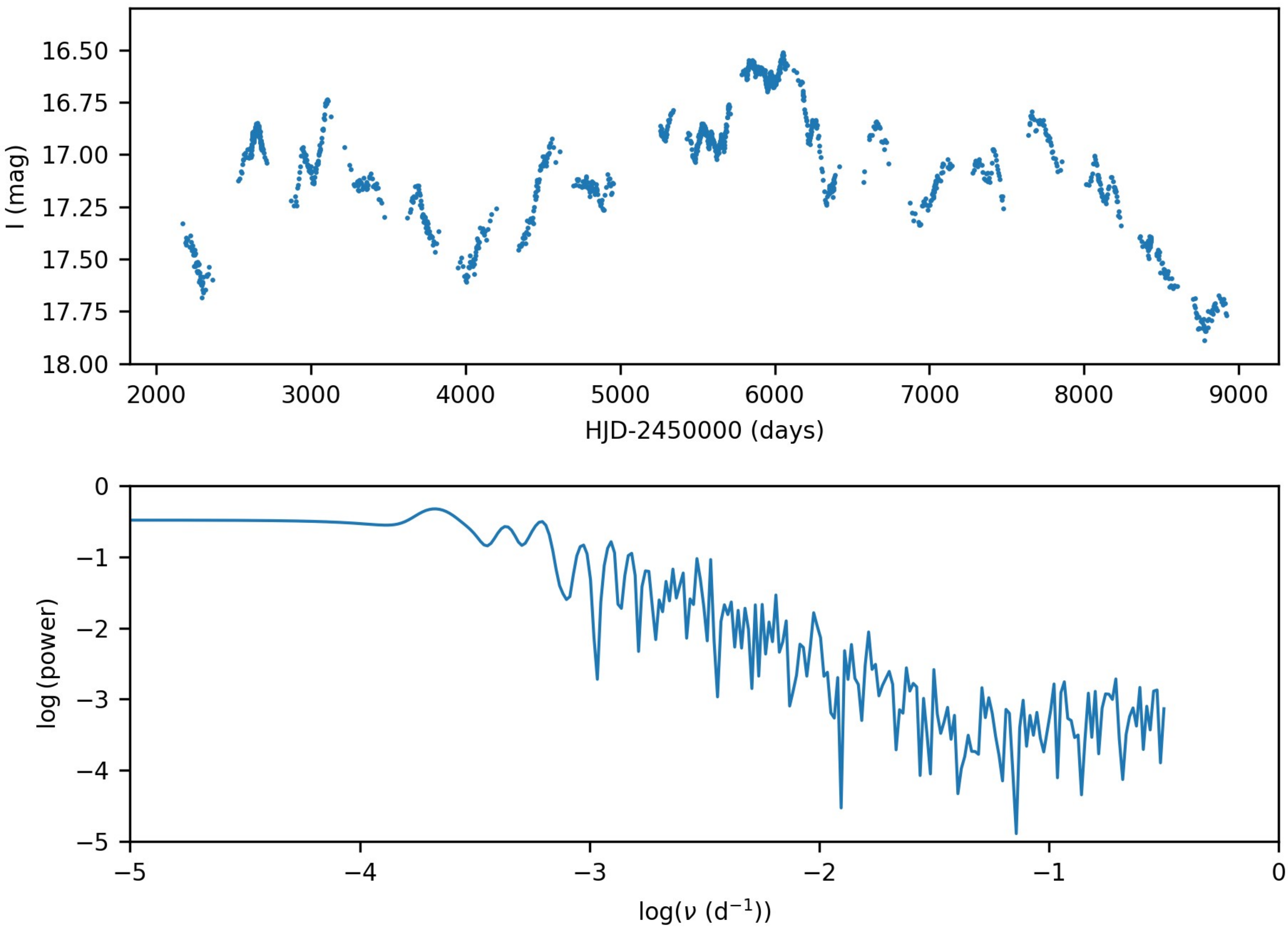


Kozłowski et al. 2013, ApJ, 775, 92

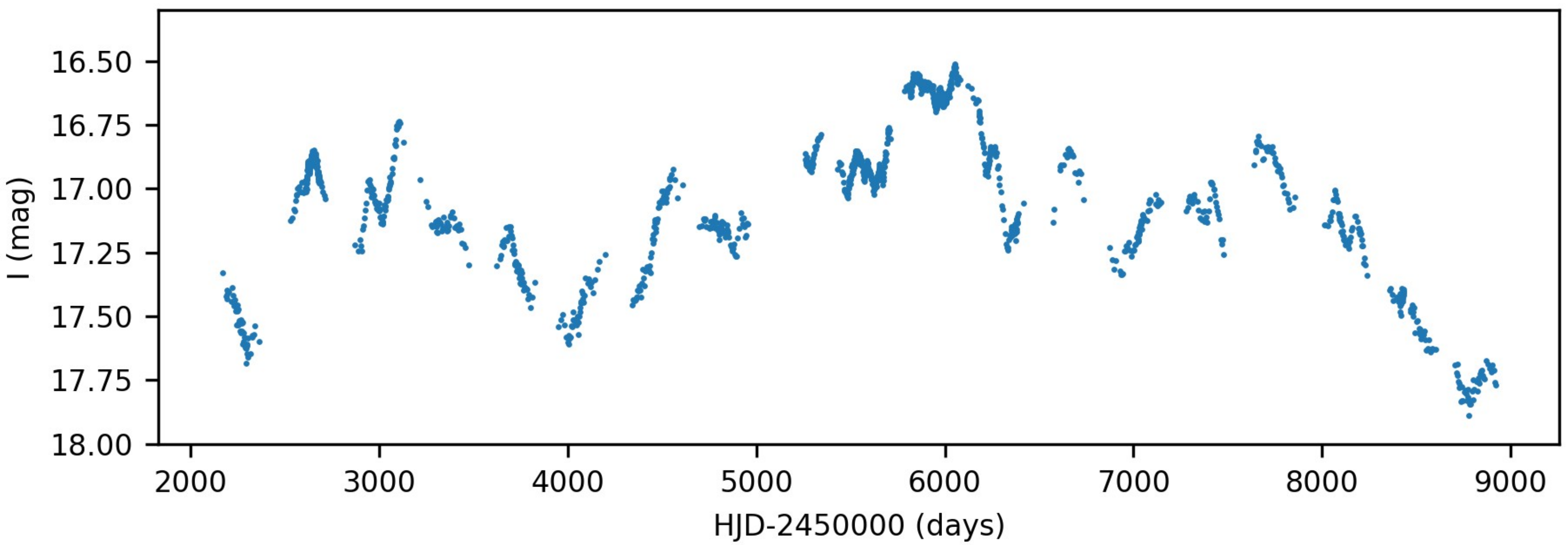
AGN Variability in OGLE

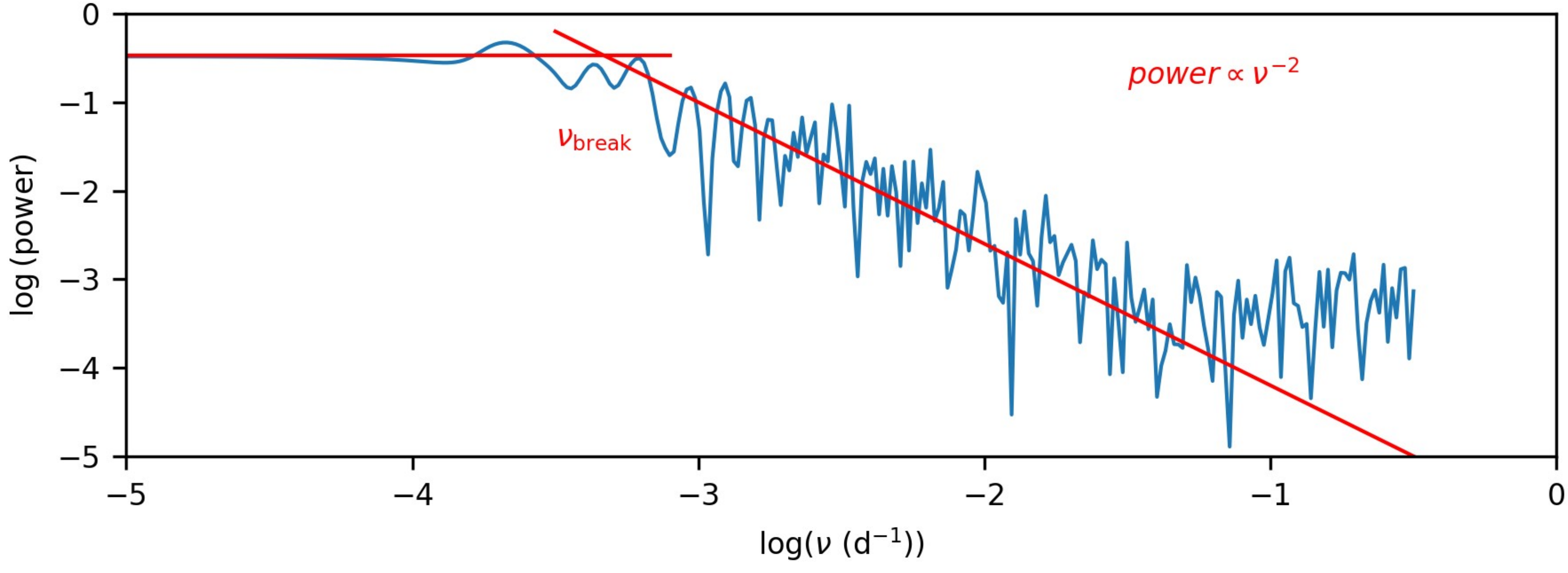


Non-periodic Objects

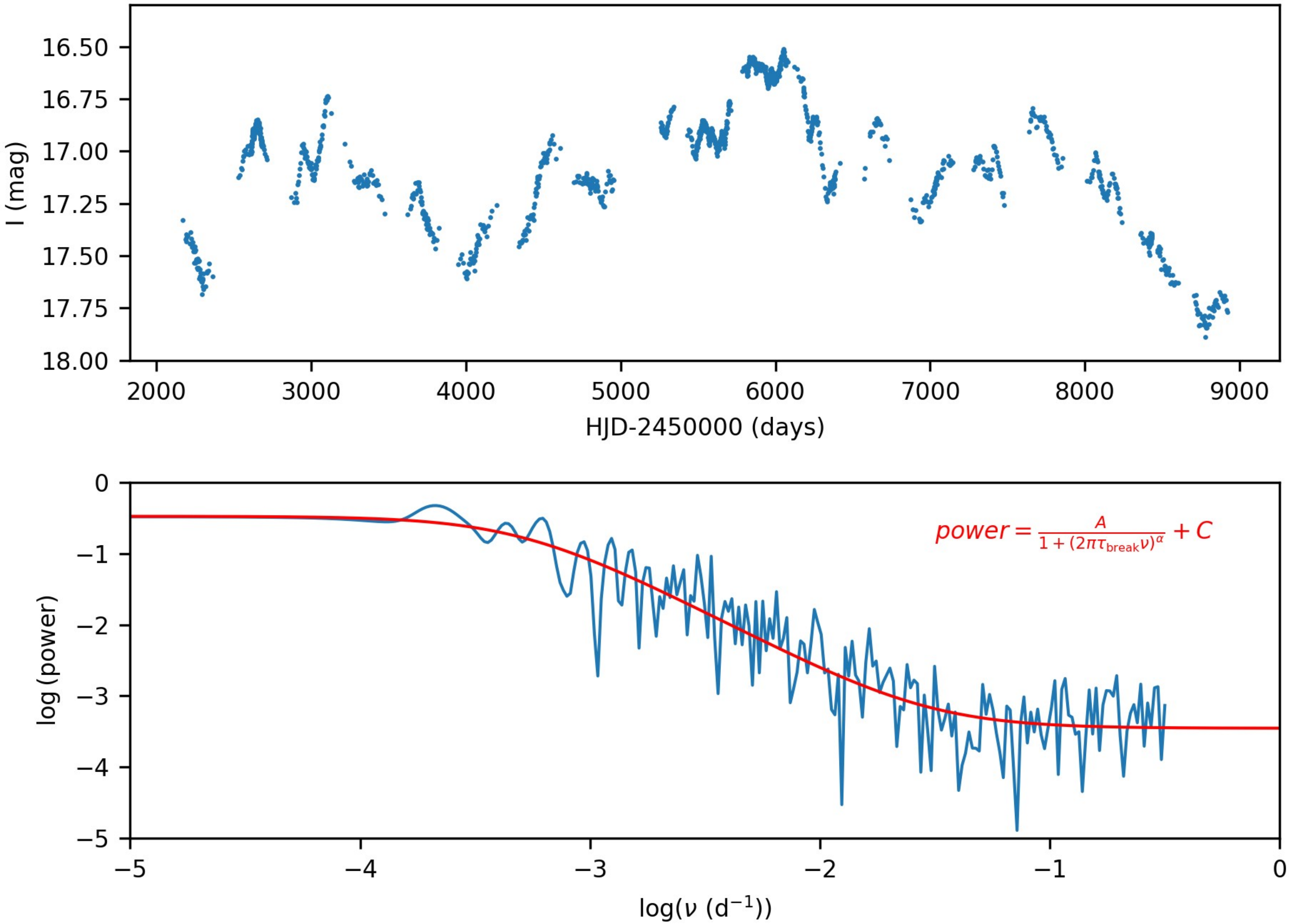


Non-periodic Objects

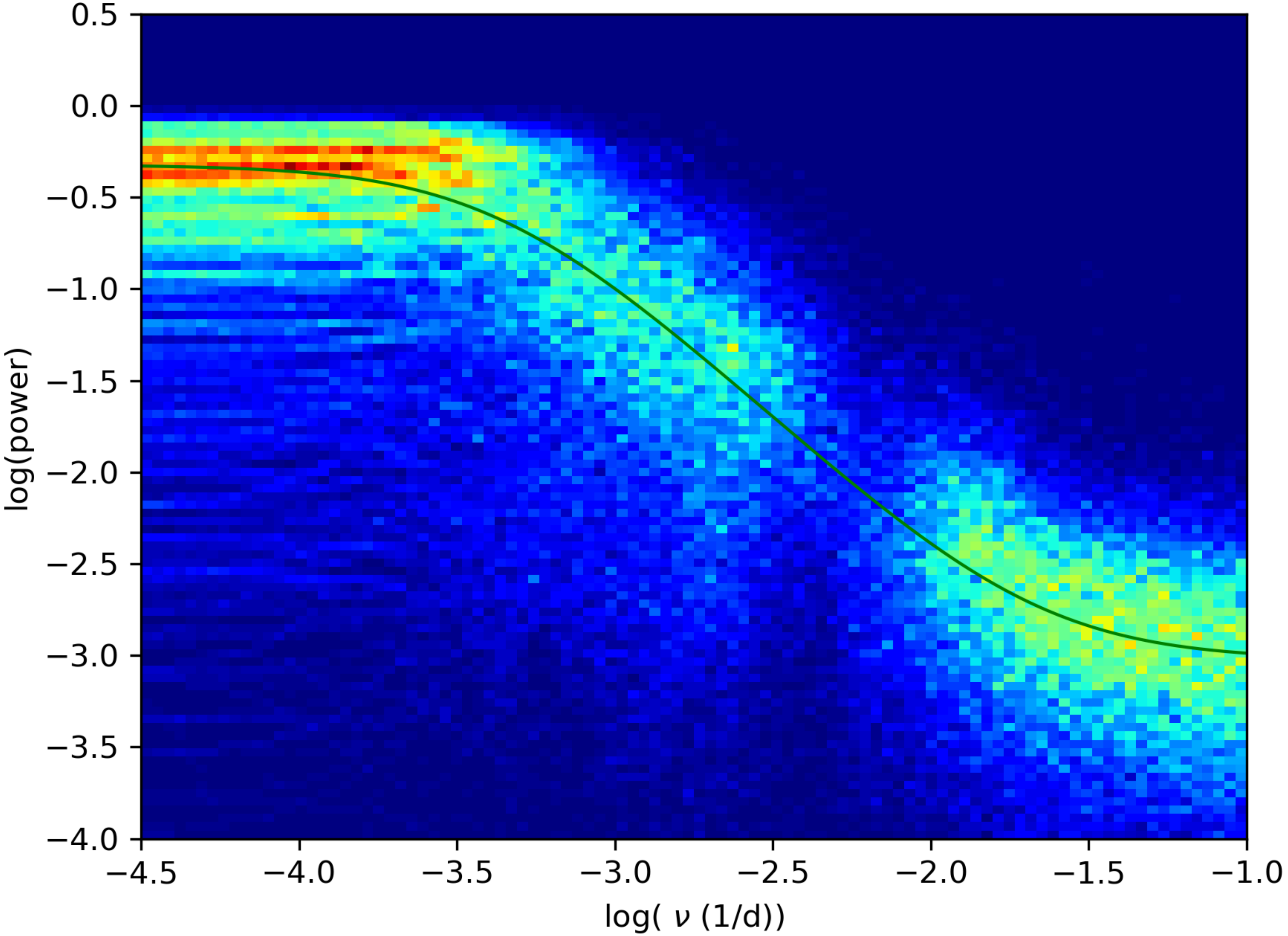




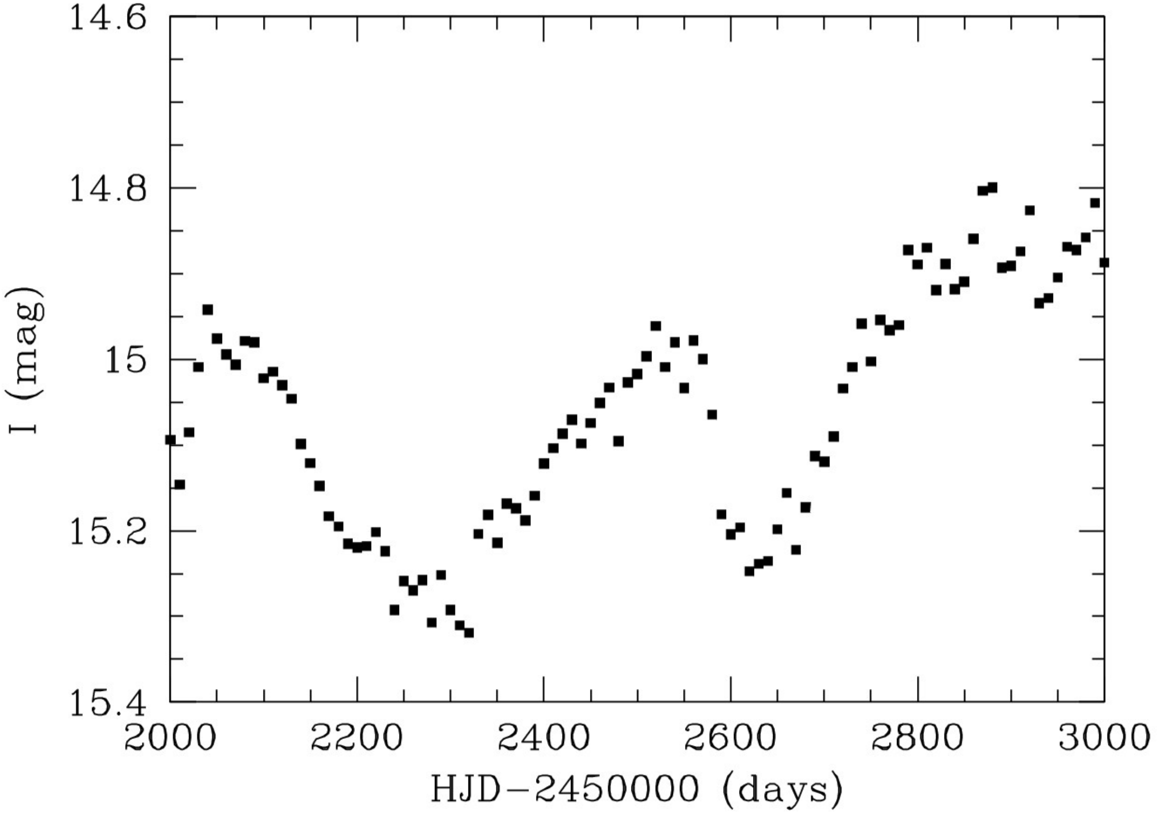
Non-periodic Objects

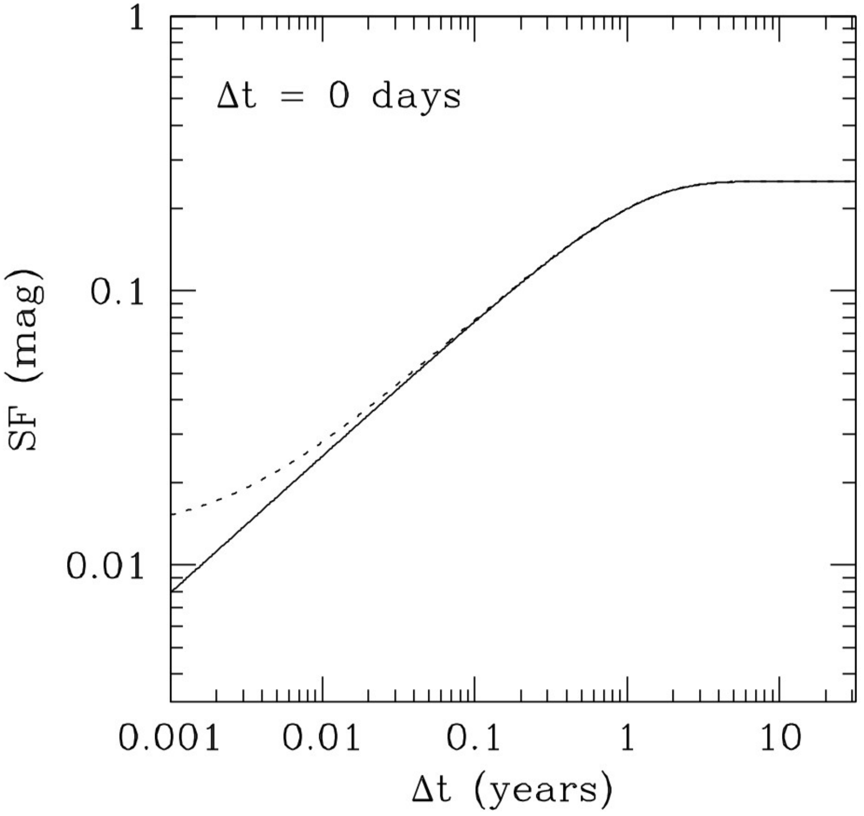


Power spectrum: OGLE-III + OGLE-IV



Structure Function





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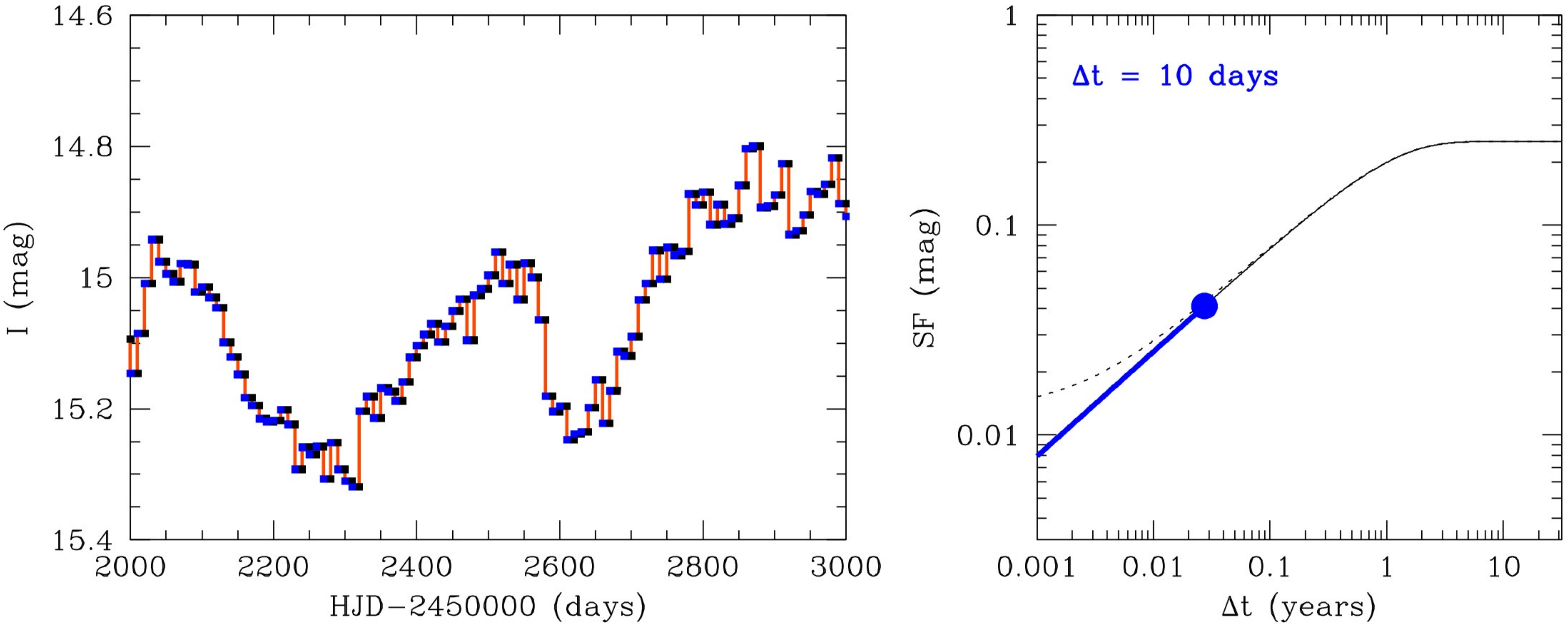

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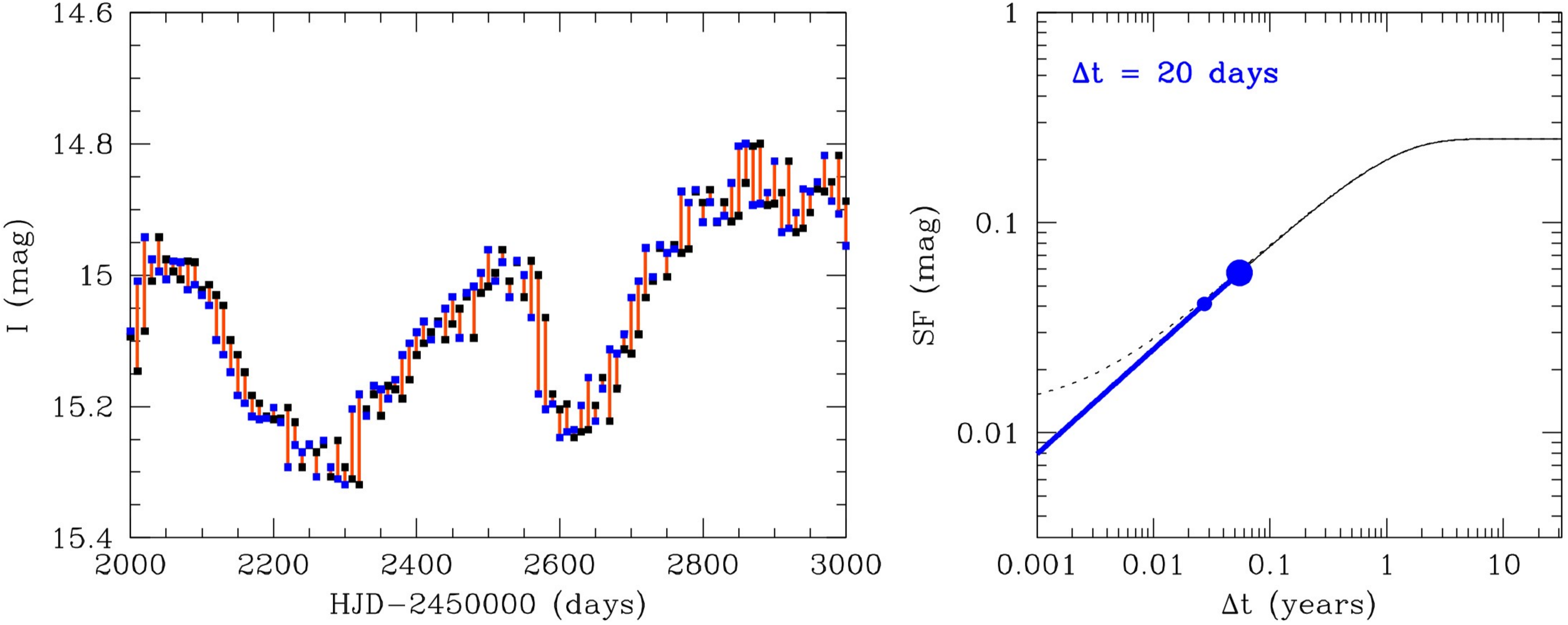

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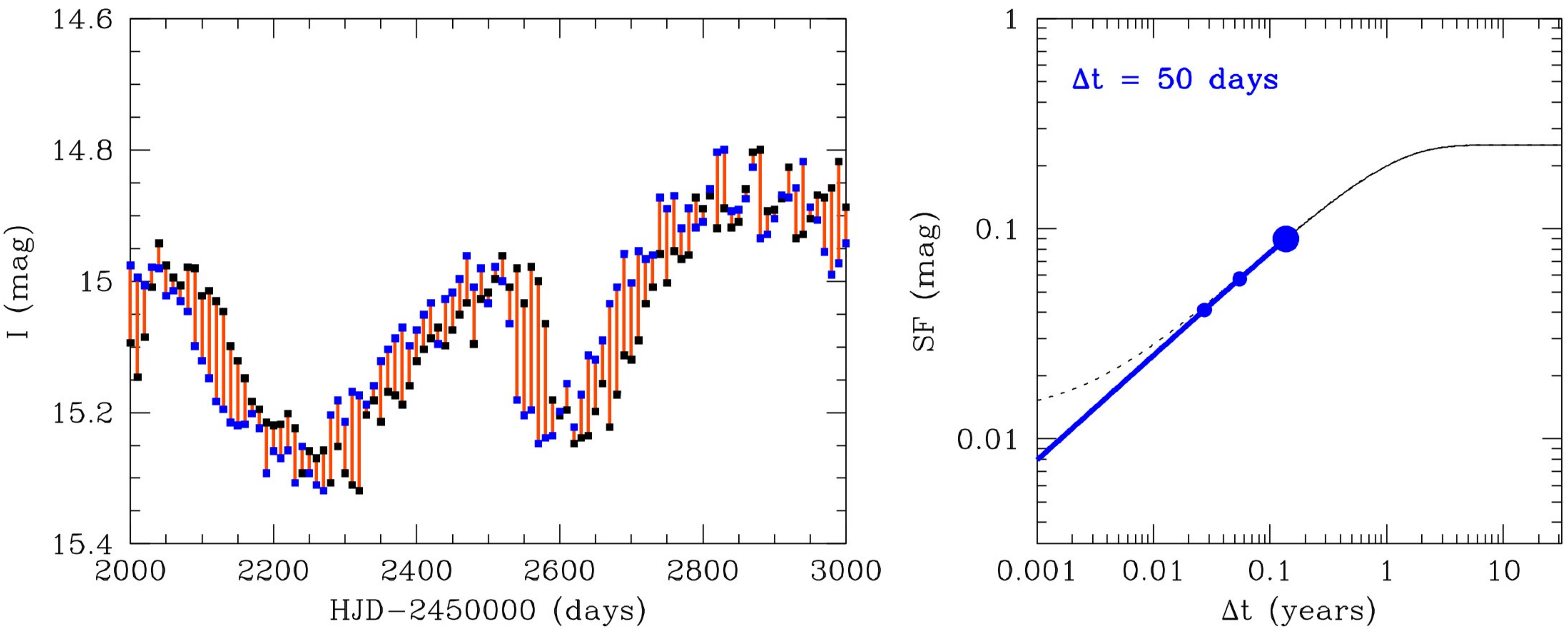

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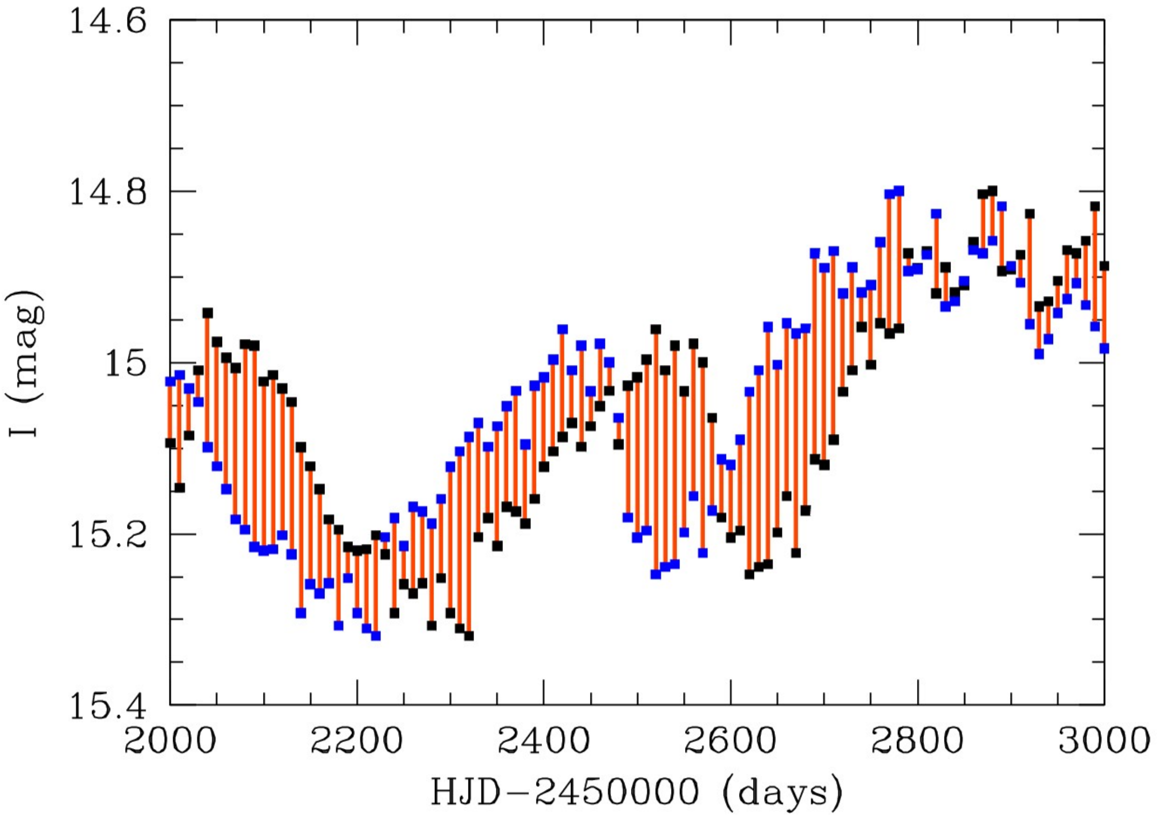

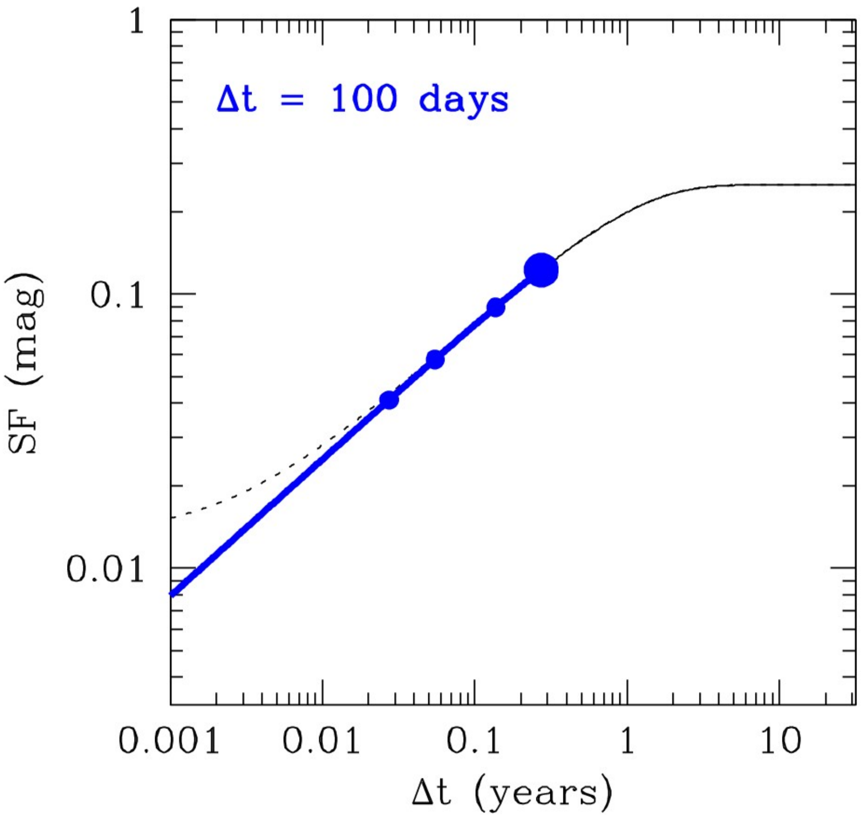

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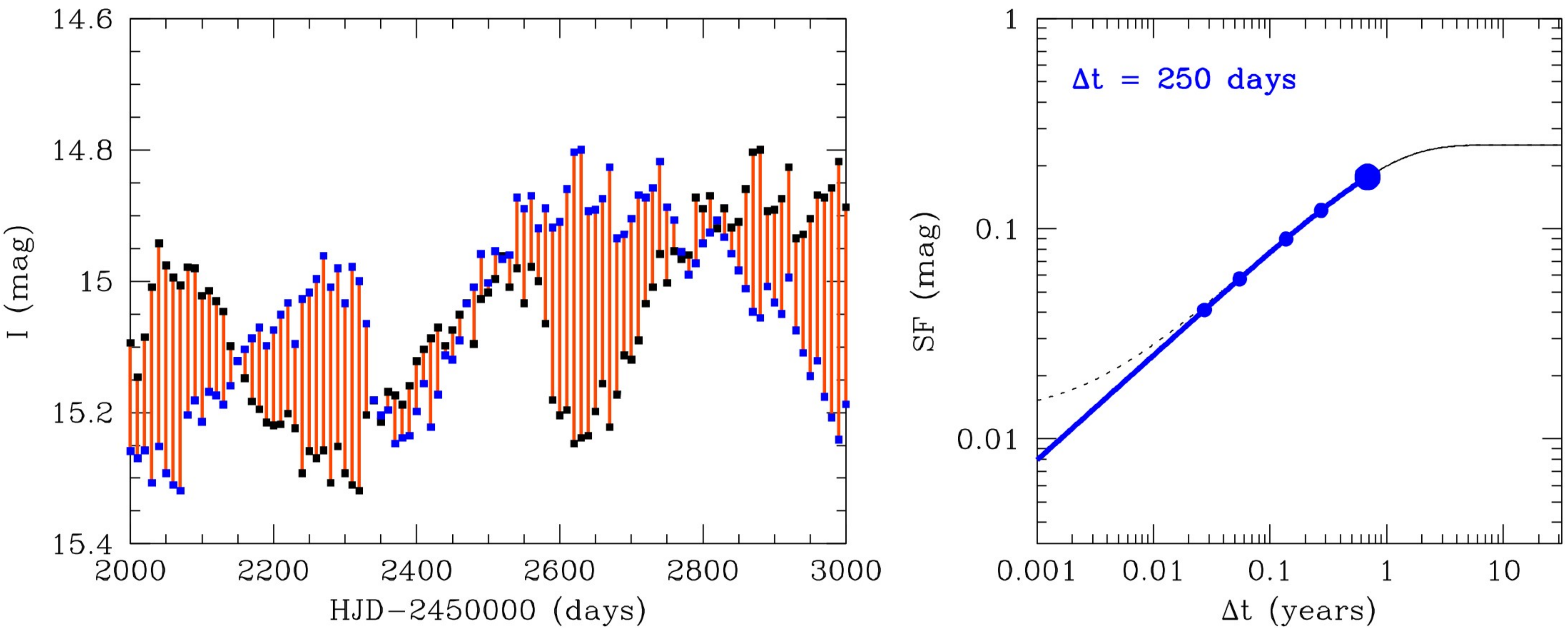

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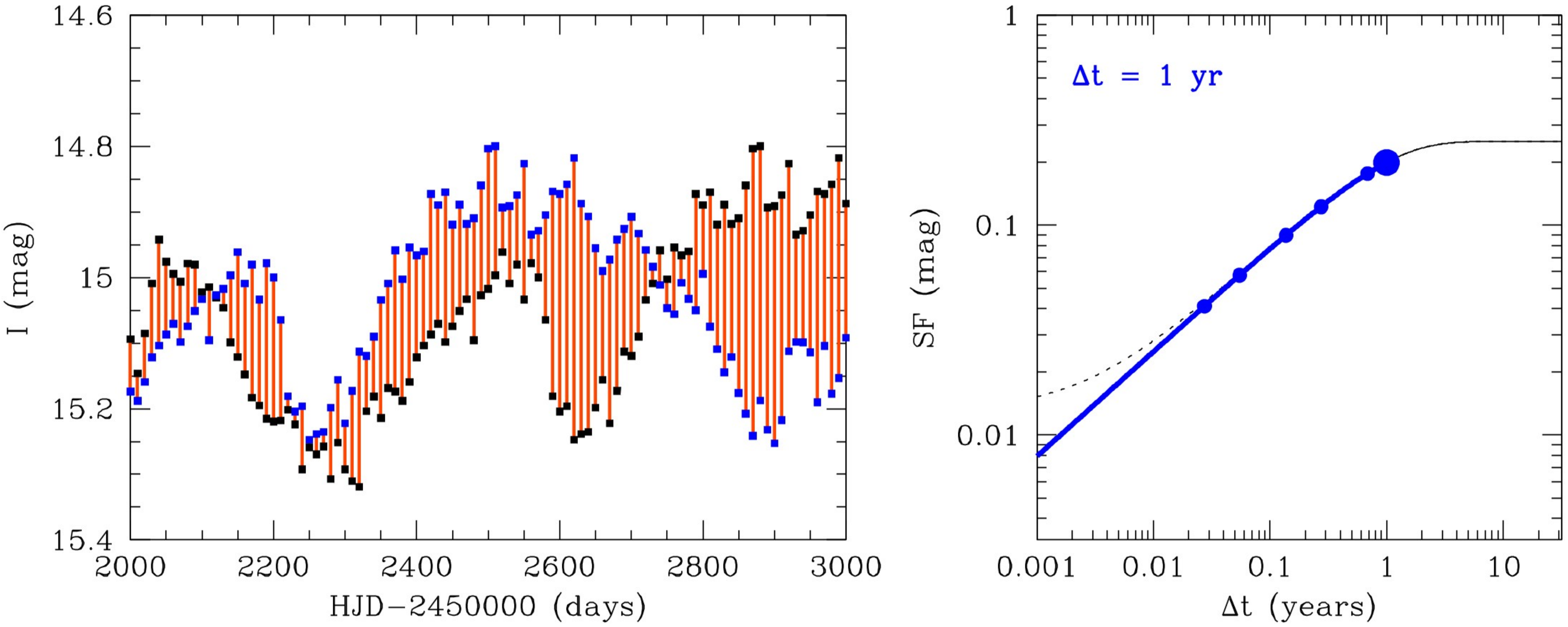

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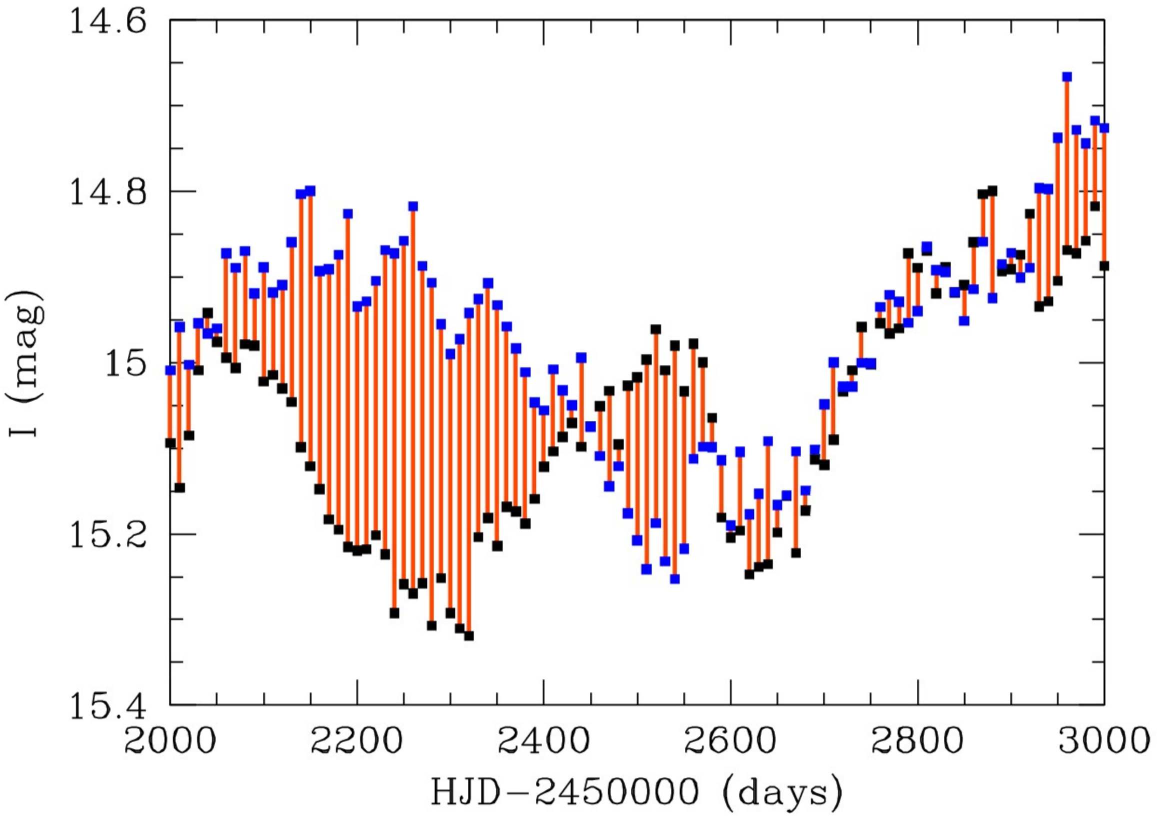

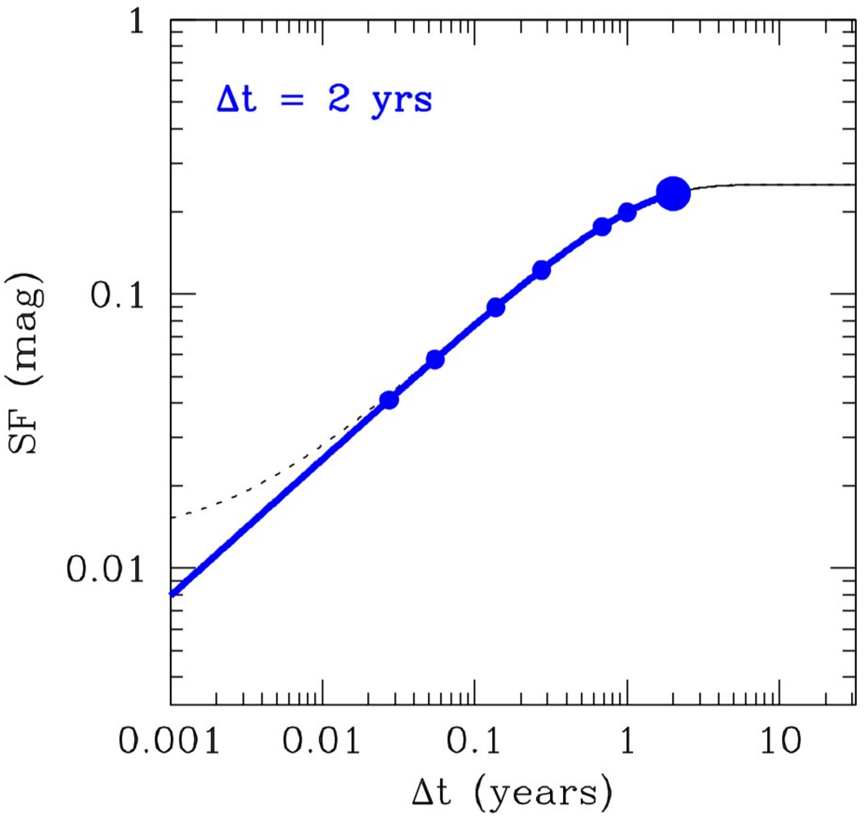

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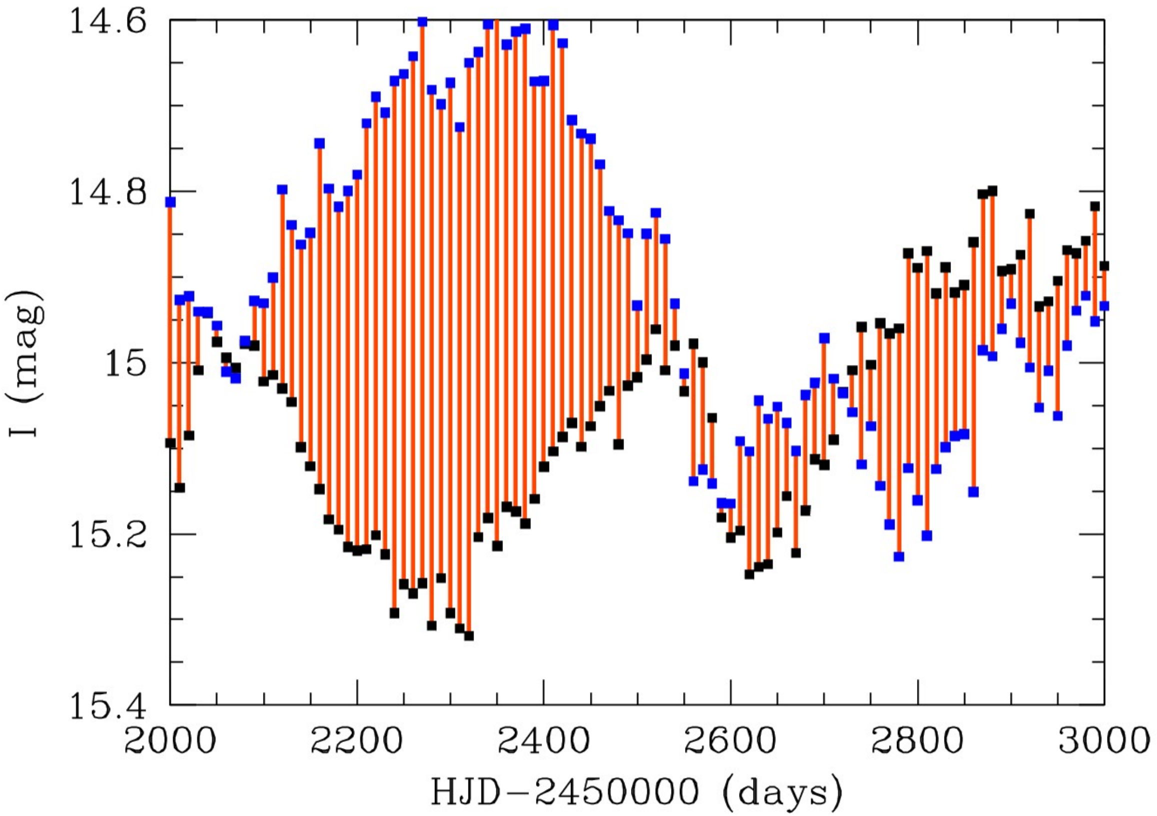
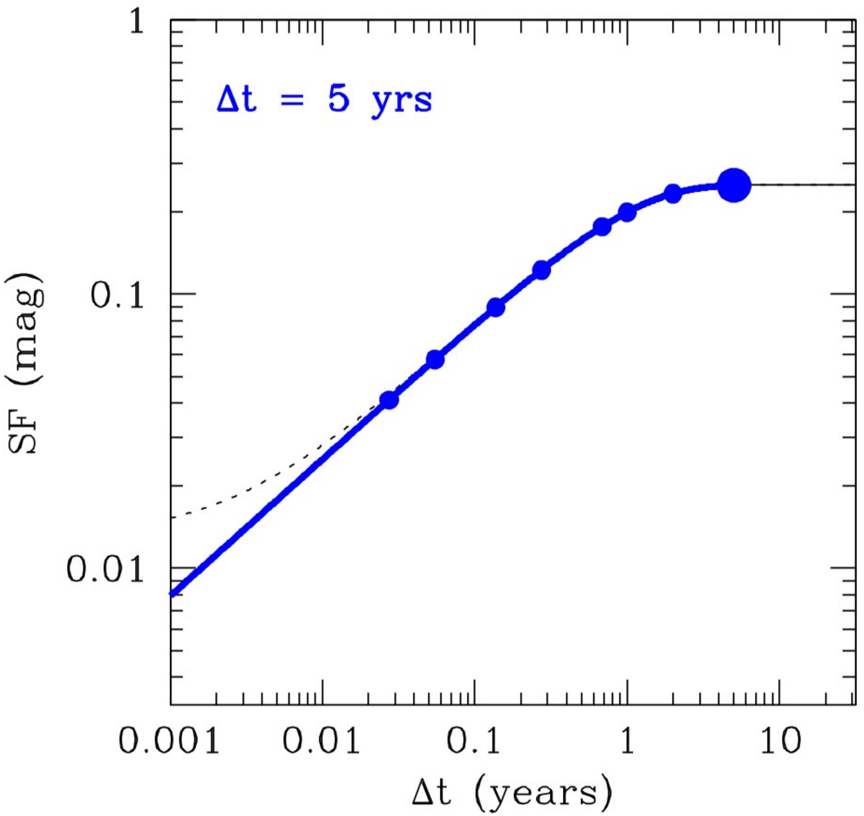




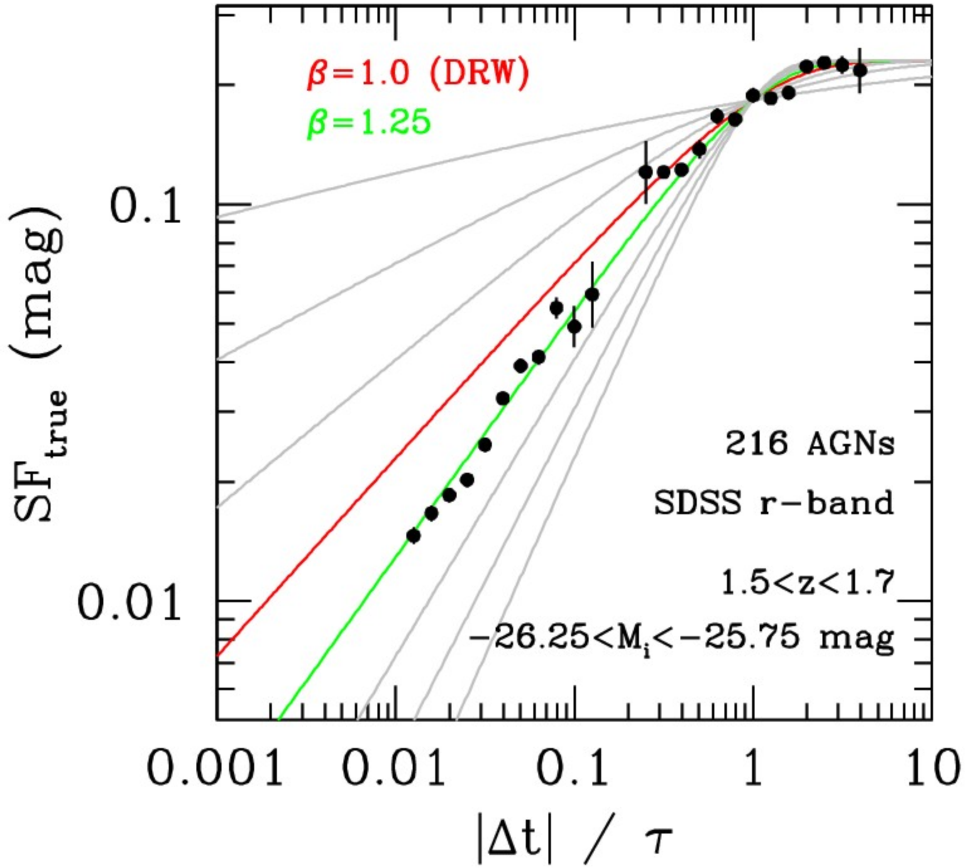
Structure Function

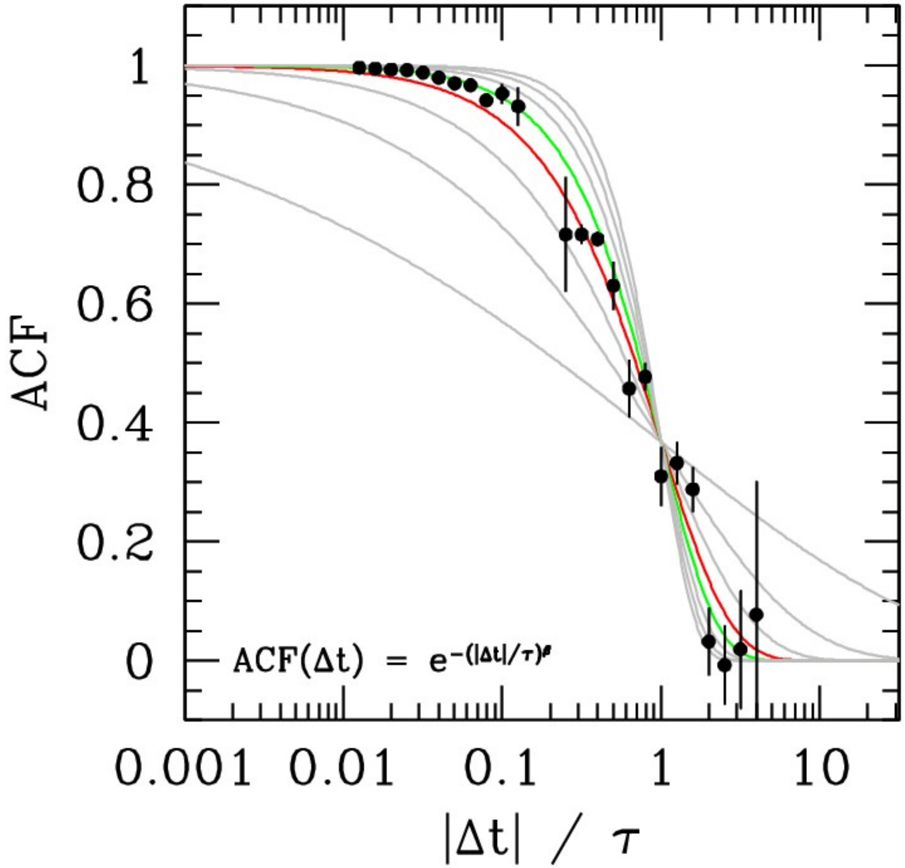
$$\operatorname{cov}(y_i, y_j) \equiv \operatorname{var}(y_i) - V(y_i, y_j)$$

$$V(y_i, y_j) = \frac{1}{2}\langle (y_i - y_j)^2 \rangle$$

$$SF = \sqrt{2V}$$

Structure Function and ACF

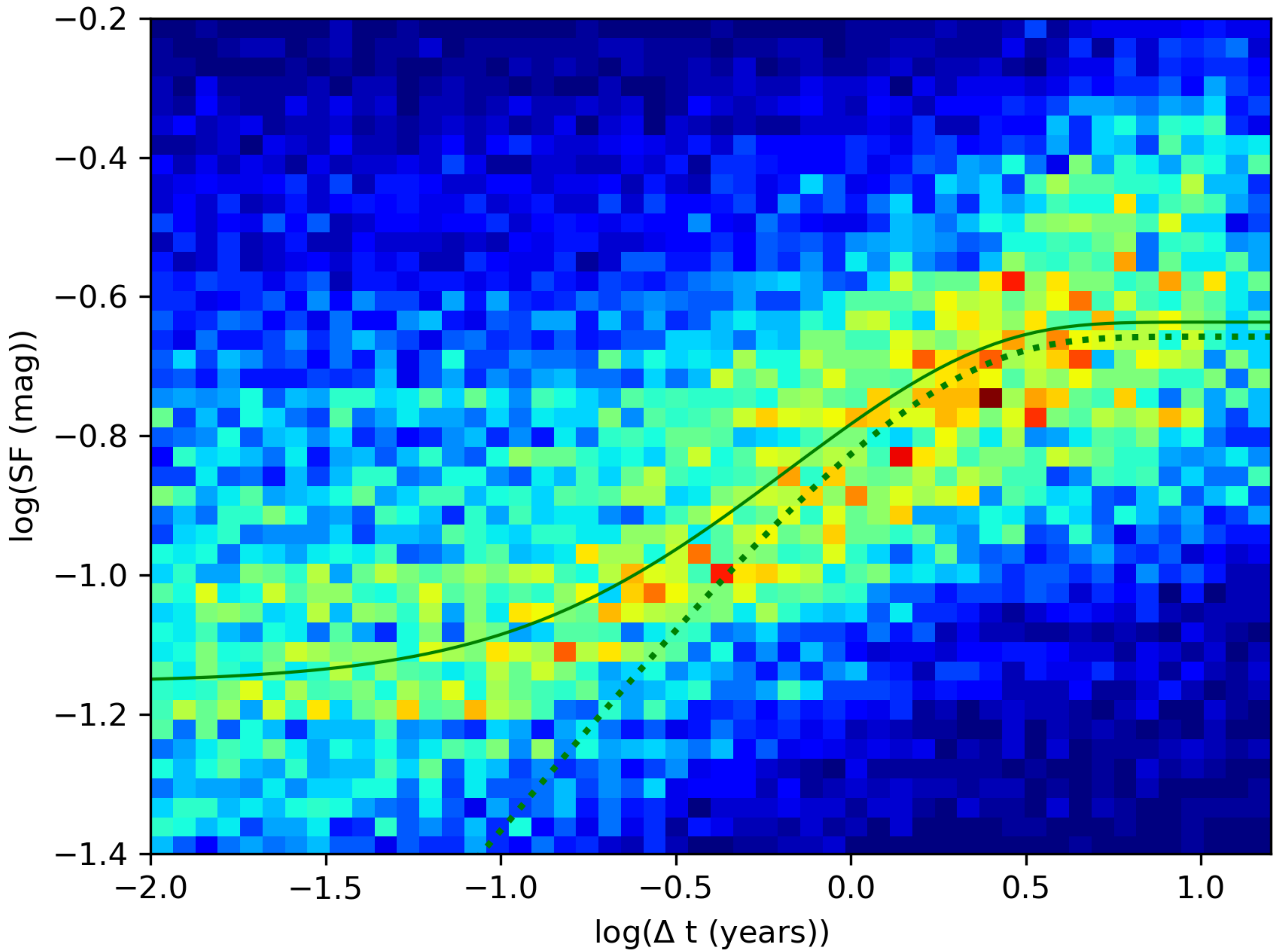




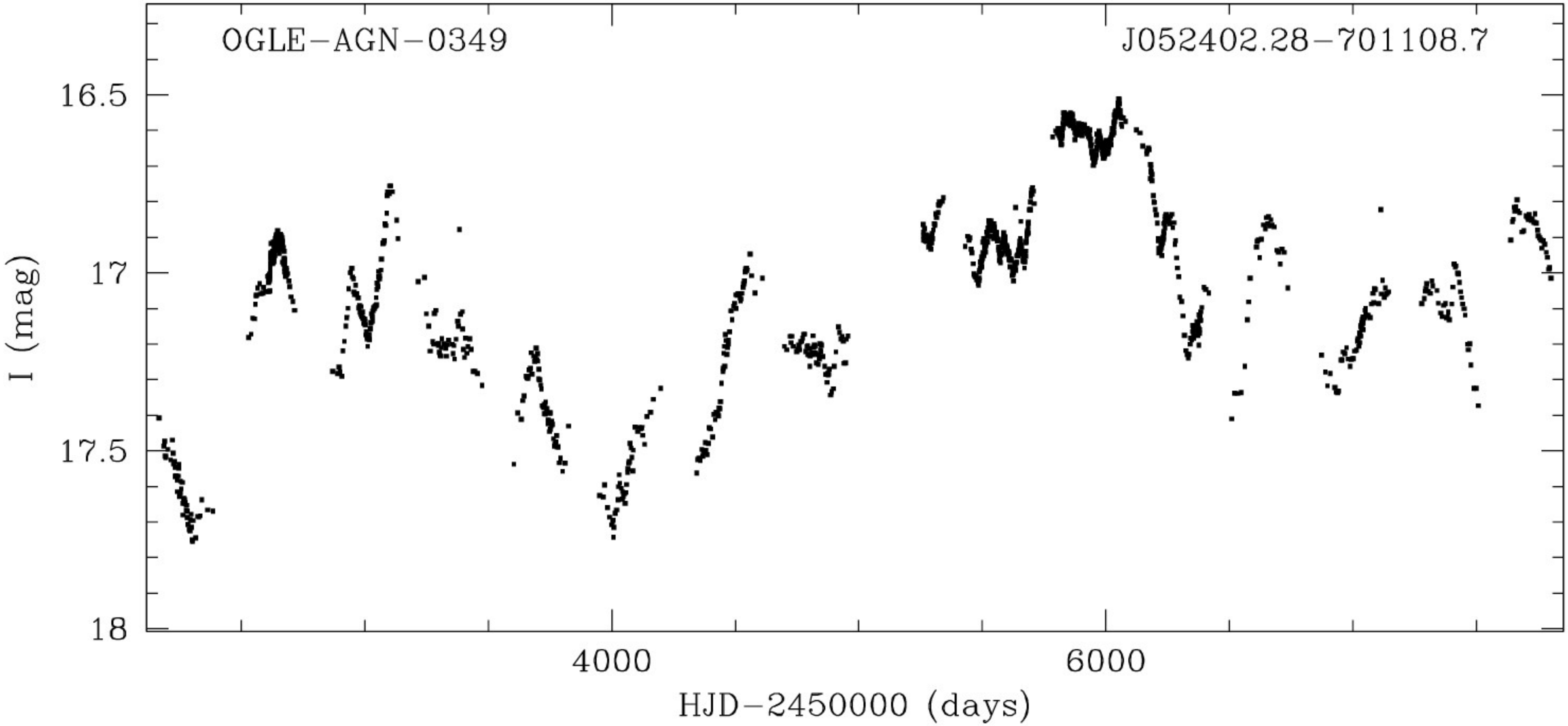
$$\mathrm{SF} = \sqrt{\mathrm{SF}_{\infty}^{2}\,(1 - \mathrm{ACF}) + 2\sigma_n^2}$$

$$\mathrm{ACF} = e^{-\left(\frac{|\Delta t|}{\tau}\right)^{\beta}}$$

Structure Function: OGLE-III + OGLE-IV



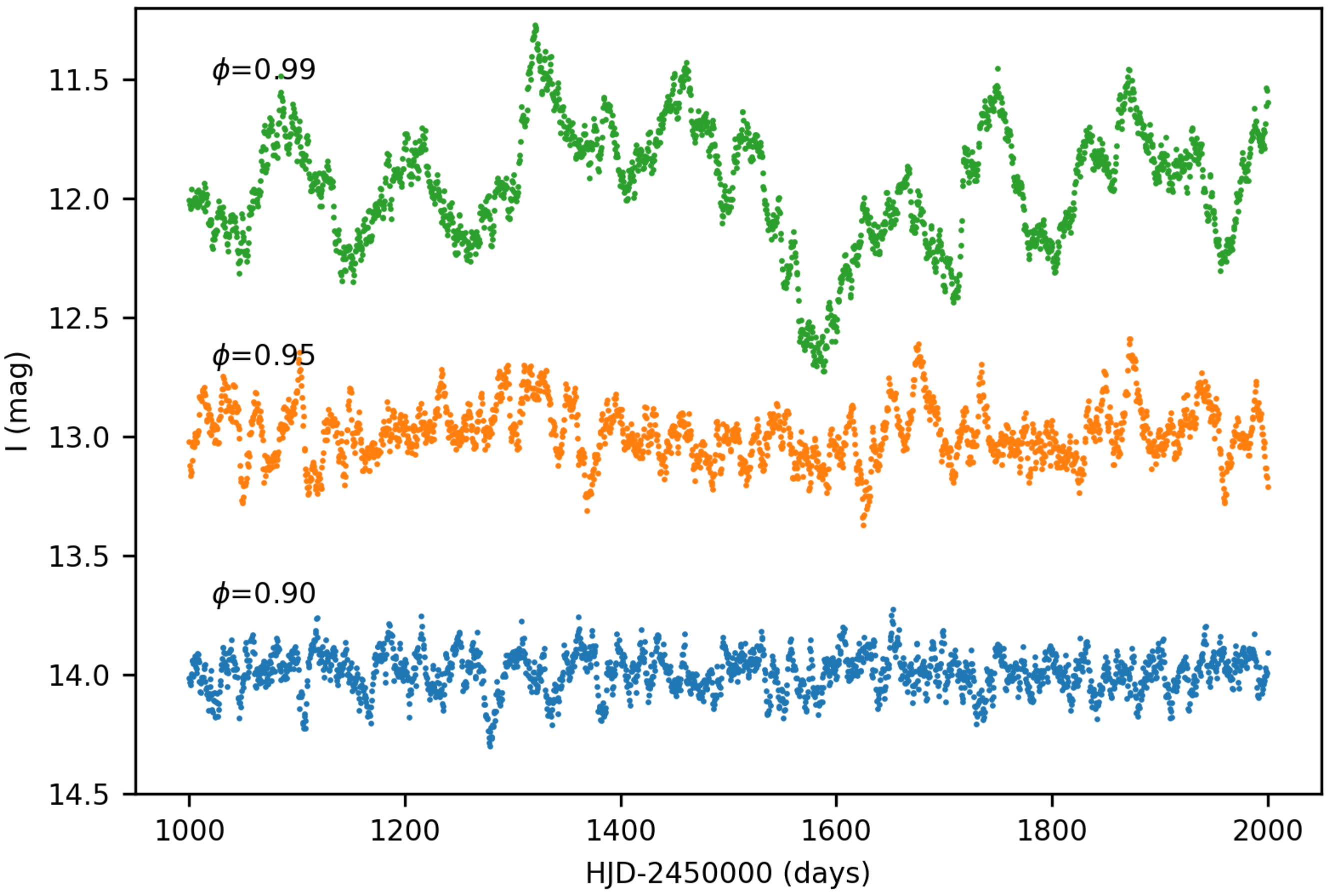
Light Curve Modeling



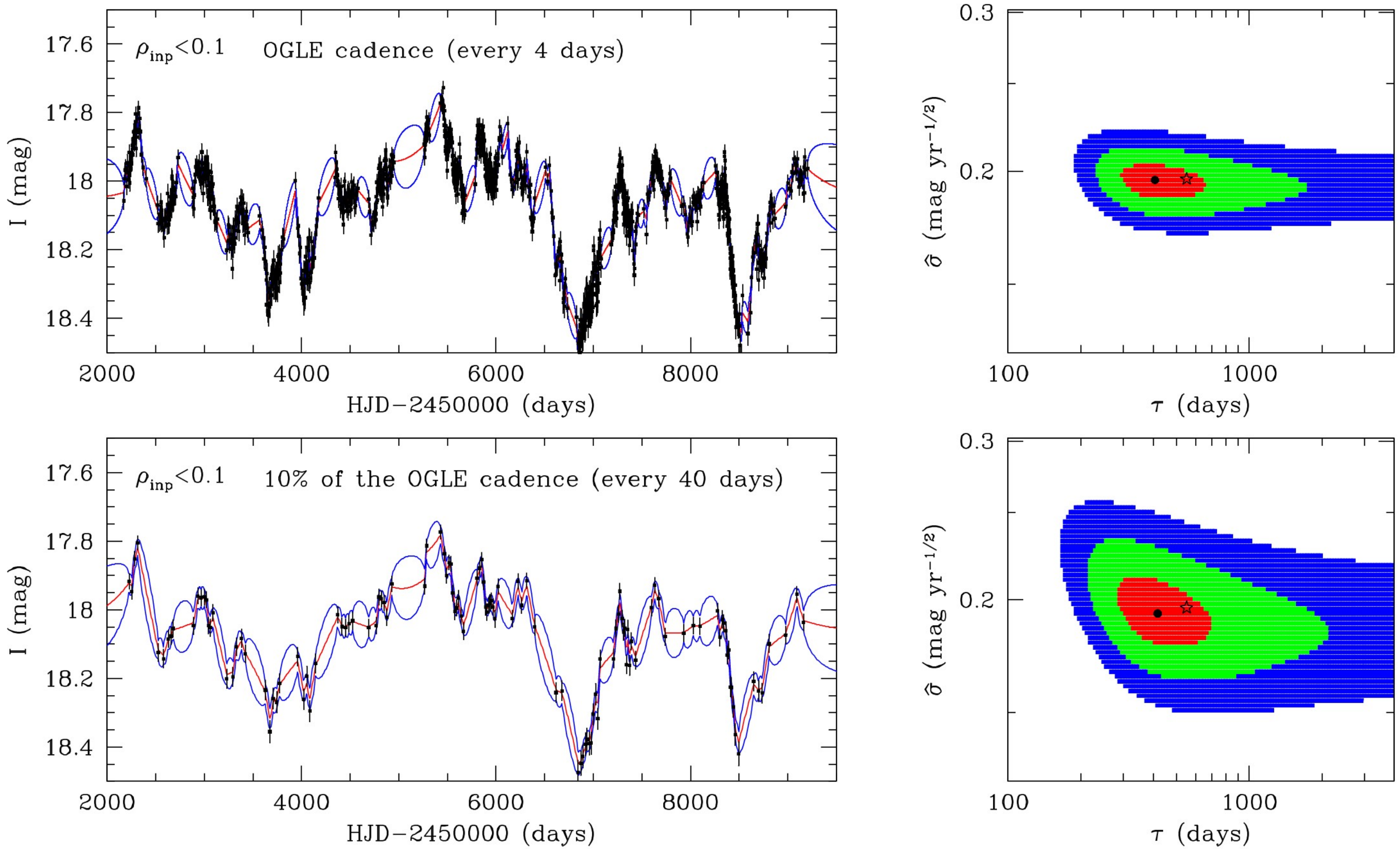
Auto Regressive (AR) models

$$x_i = \mu + \phi_1 x_{i-1} + \epsilon_i, \qquad (1)$$

where ϕ_1 is the auto-regressive or “lag” coefficient that indicates how closely tied future values are to past values and where ϵ_i represents a source of noise.



Damped Random Walk (DRW)



Kozłowski 2017, A&A, 597, 128

(C)ARMA models

$$x_i = \mu + \phi_1 x_{i-1} + \epsilon_i, \quad (1)$$

where ϕ_1 is the auto-regressive or "lag" coefficient that indicates how closely tied future values are to past values and where ϵ_i represents a source of noise.

The general notation for a p_{th}-order AR process is

$$x_i = \mu + \sum_1^p \phi_p x_{i-p} + \epsilon_i. \quad (2)$$

For example, in an AR($p = 2$) process, the state of the system depends on two lag terms (and thus has two timescales):

$$x_i = \mu + \phi_1 x_{i-1} + \phi_2 x_{i-2} + \epsilon_i. \quad (3)$$

Stochastic Modeling Handbook for Optical AGN Variability: Moreno et al. 2019, PASP, 131, 063001

(C)ARMA models

Moving Average (MA) models:

$$x_i = \epsilon_i + \theta_1 \epsilon_{i-1}. \quad (4)$$

In the simplest MA process (order 1 with $\theta_1 \neq 0$), the system depends not only on the current shock, but also the previous one.

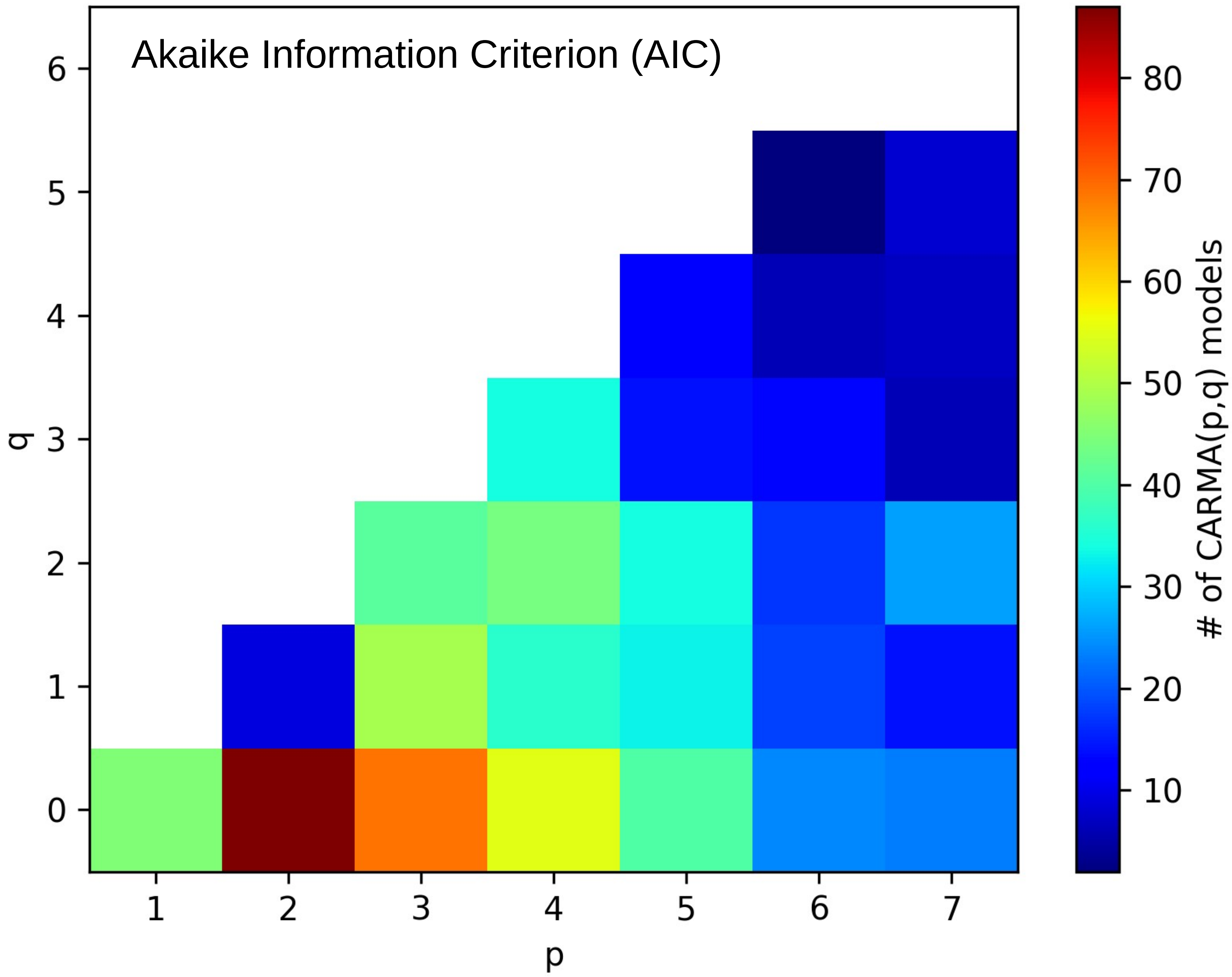
$$x_i = \sum_1^q \theta_q \epsilon_{i-q} + \epsilon_i.$$

CARMA model: p+q+1 parameters and q < p

$$x_i = \mu + \sum_1^p \phi_p x_{i-p} + \sum_1^q \theta_q \epsilon_{i-q} + \epsilon_i$$

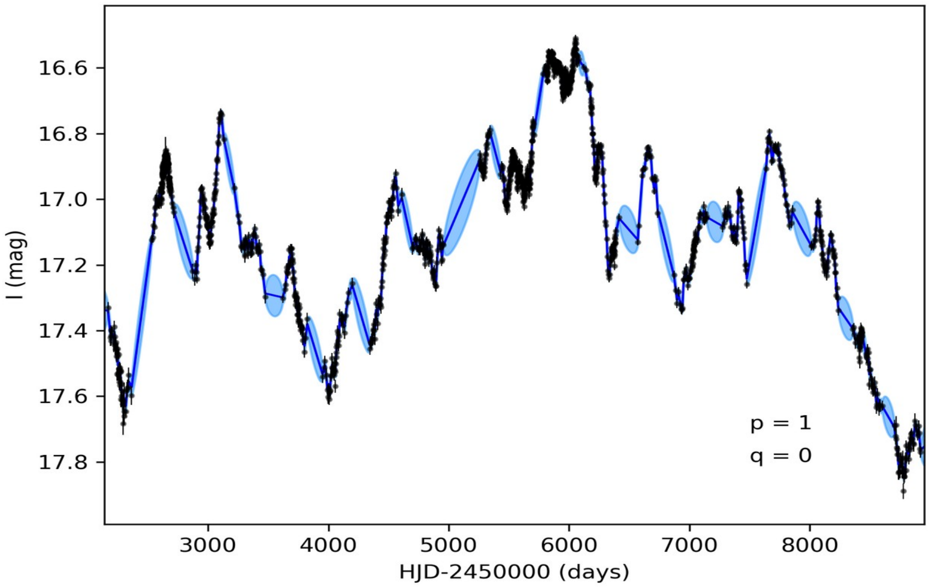
Stochastic Modeling Handbook for Optical AGN Variability: Moreno et al. 2019, PASP, 131, 063001

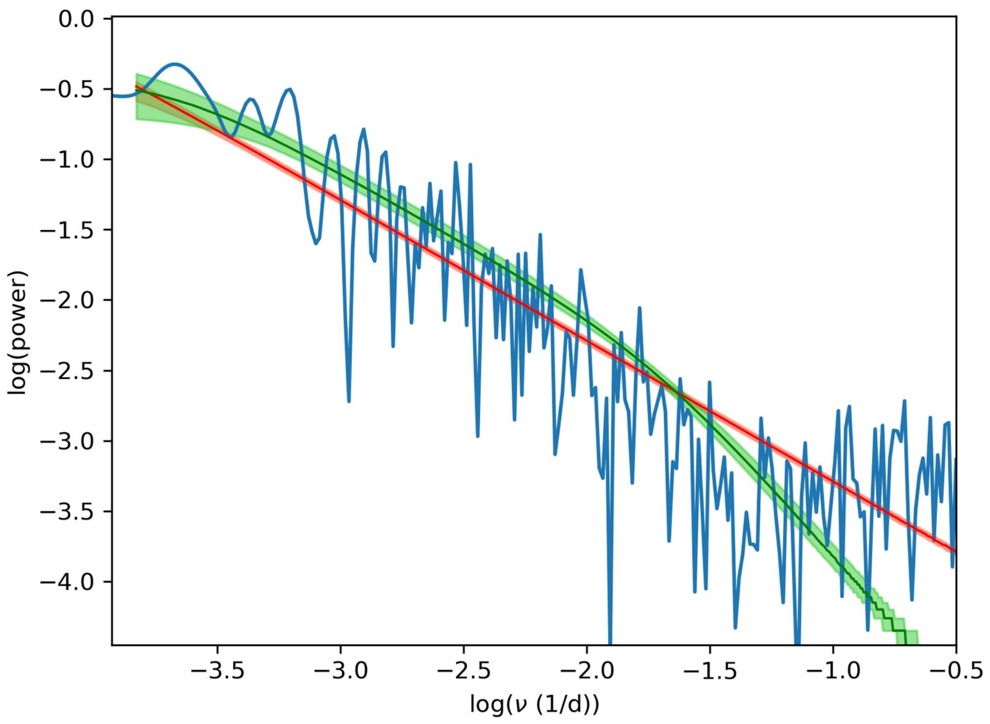
CARMA: OGLE-III + OGLE-IV

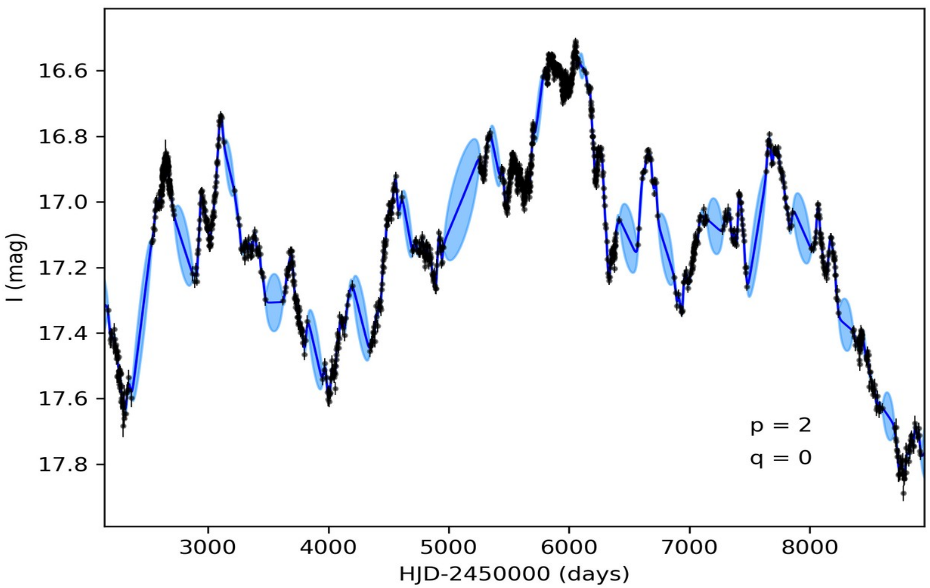


CARMA code: Kelly et al. 2014, ApJ, 788, 33

CARMA: OGLE-III + OGLE-IV







Thank you!

Revisiting Stochastic Variability of AGNs with Structure Functions
Kozłowski Szymon, 2016, The Astrophysical Journal, 826, 118

A degeneracy in DRW modelling of AGN light curves
Kozłowski Szymon, 2016, MNRAS, 459, 2787

Limitations on the recovery of the true AGN variability parameters using damped random walk modeling
Kozłowski Szymon, 2017, A&A, 597, 128

A Method to Measure the Unbiased Decorrelation Timescale of the AGN Variable Signal from Structure Functions
Kozłowski Szymon, 2017, The Astrophysical Journal, 835, 250

A Survey Length for AGN Variability Studies
Kozłowski Szymon, 2021, Acta Astronomica, 71, 103