Is There A Distinction Between Periodic And Quasi-Periodic Class II Methanol Masers?

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A Neapolitan of Masers: Variability, Magnetism and VLBI

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Class II methanol masers

High mass stars are form in giant molecular clouds with high optiacal depth and are typically formed in clusters.

The two Class II methanol masers (6.7GHz and 12.2 GHz emission lines) are found in massive star forming regions and reside near ultra-compact ionised hydrogen (H II) region(e.g., Norris et al. 1993; Bartkiewicz et al. 2009; Sanna et al. 2010).

Monitoring these masers in the indirect way of studying the dynamics in massive star forming region.

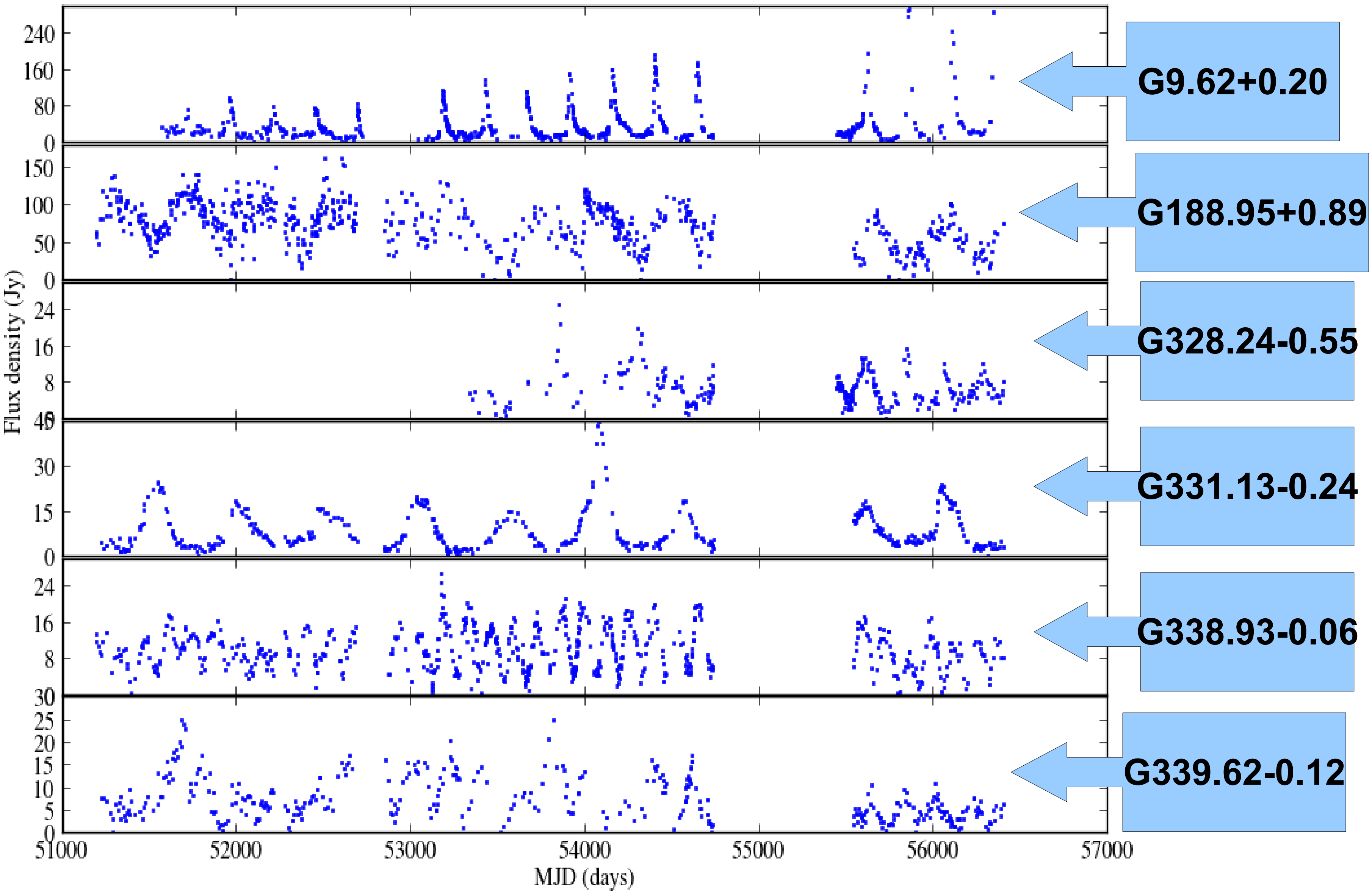
Class II methanol Masers

Goedhart et al. (2003) reported regular varying Class II methanol maser in some of massive star forming region (G9.621+0.196).

Since then, at least 900 methanol masers (6.7 GHz) had been observed (e.g., Pestalozzi et al. 2005; Caswell et al. 2011; Green et al. 2012), and Eleven have been reported to periodic or quasi-periodic (Goedhart et al. 2003, 2004 2007, 2009; Araya et al. 2010; Szymczak et al. 2011,Sanna et al. (2009); Xu et al. 2011; Green & McClure-Gri ths (2011); Reid et al. 2009A; Honma et al. 2007).

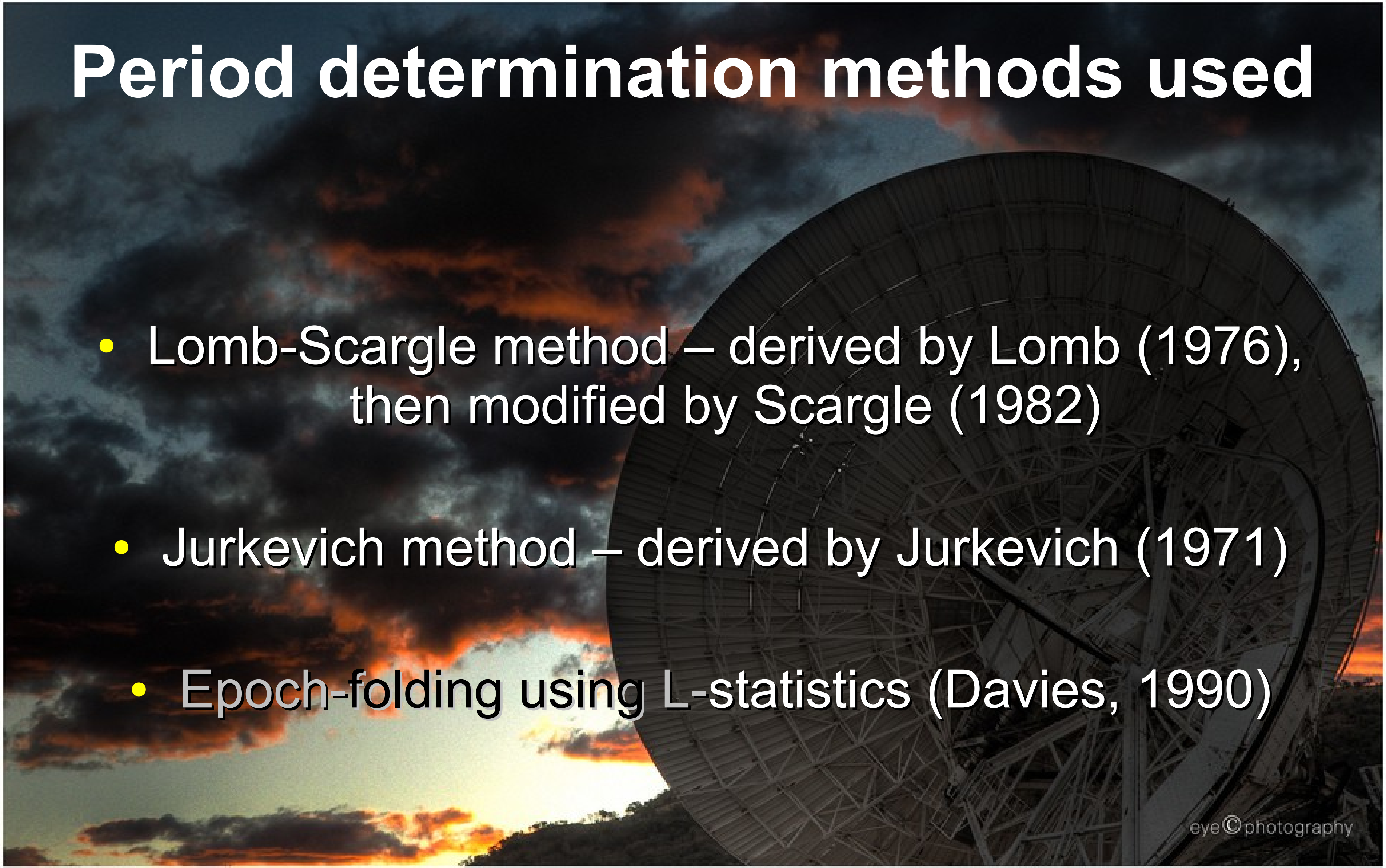
The periods range: 29 - 668 days.

Example of periodic or quasi-periodic class II methanol masers



Period determination methods used

- Lomb-Scargle method – derived by Lomb (1976), then modified by Scargle (1982)
- Jurkevich method – derived by Jurkevich (1971)
- Epoch-folding using L-statistics (Davies, 1990)



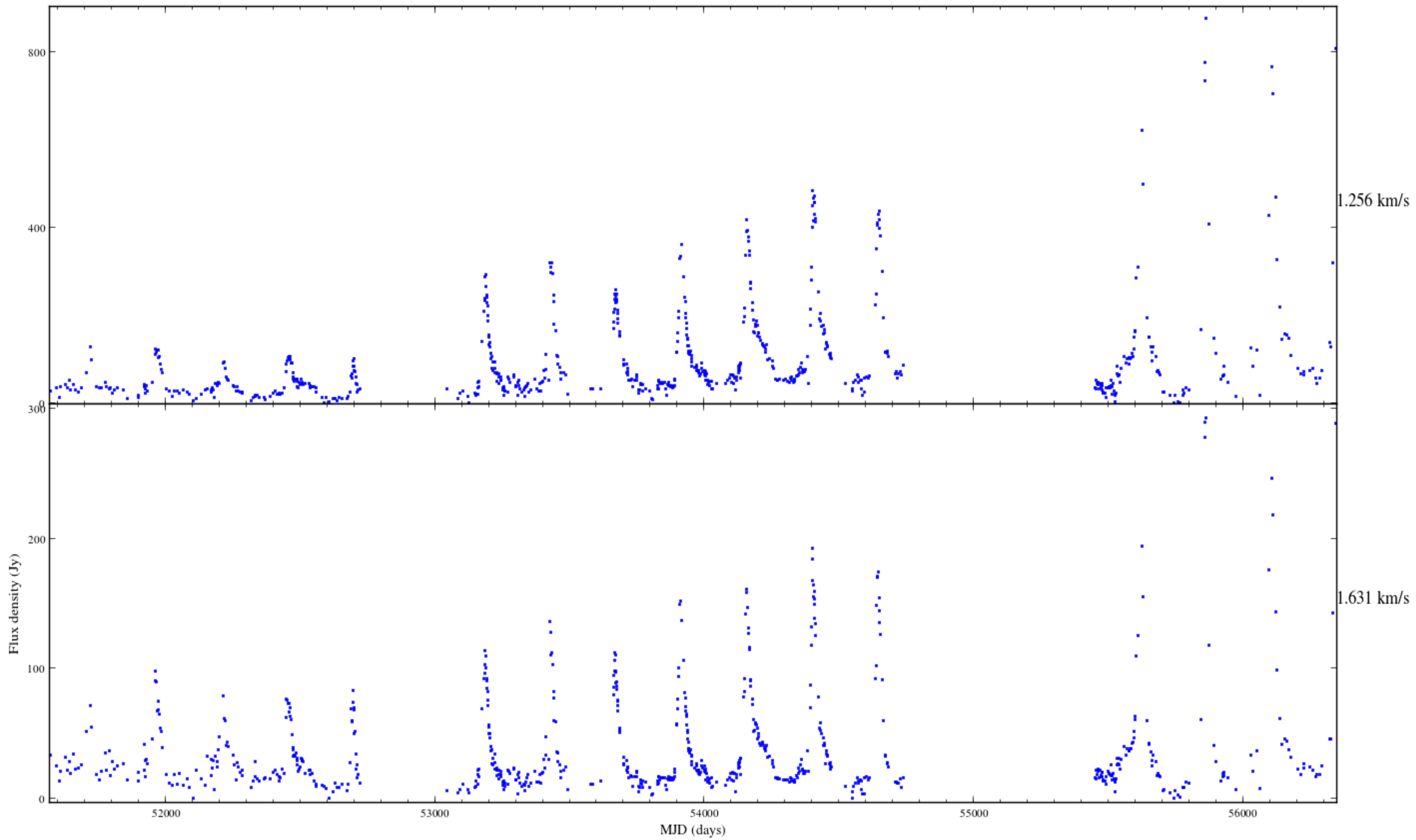
Lomb-Scargle method

This just a modified classical periodogram. Use false alarm probability statistics to test the significant of the determined period.

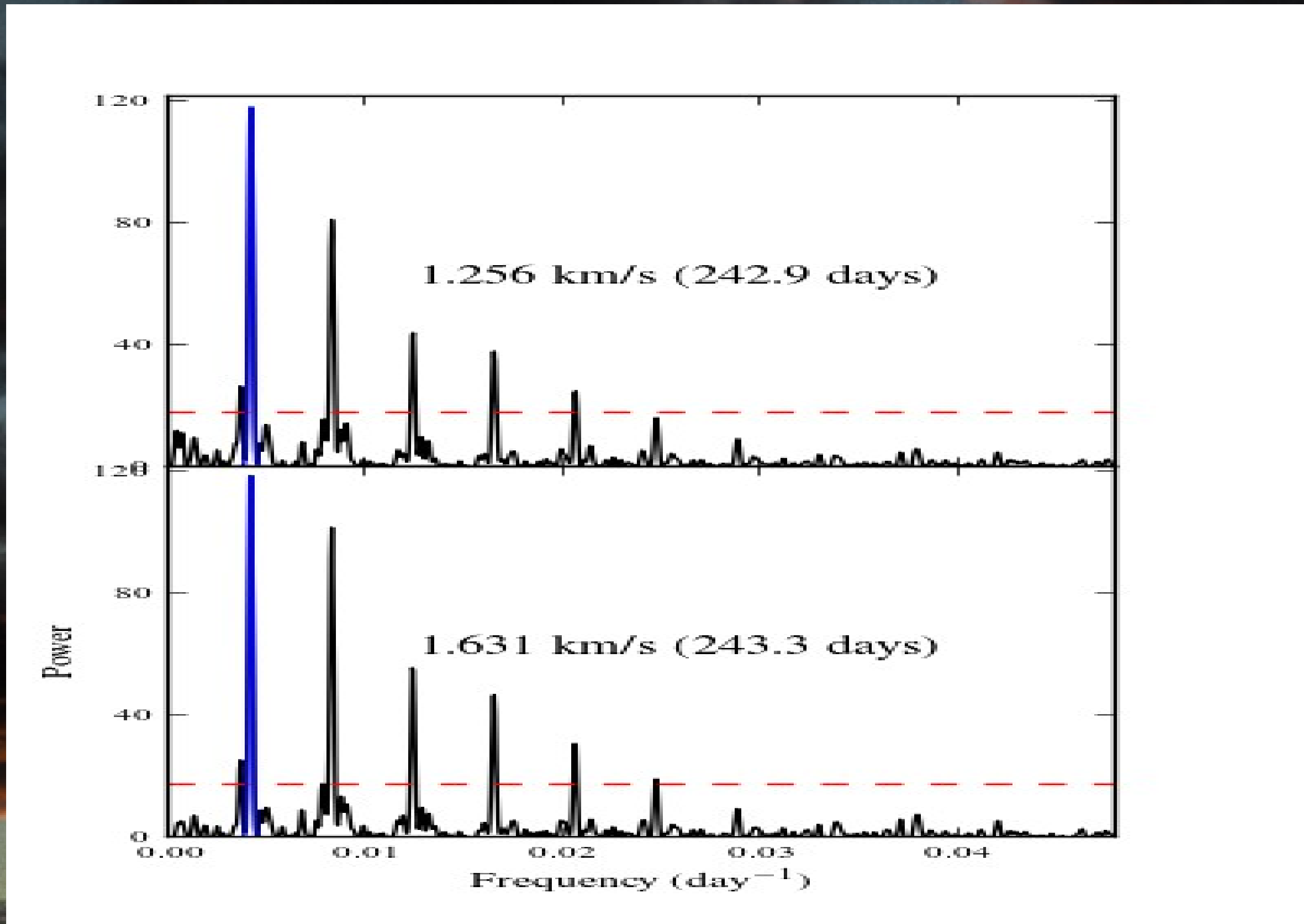
$$P_x(\omega) = \frac{1}{2}\left(\frac{\left[\sum_j X_j \cos\omega(t_j-\tau)\right]^2}{\sum_j \cos^2\omega(t_j-\tau)} + \frac{\left[\sum_j X_j \sin\omega(t_j-\tau)\right]^2}{\sum_j \sin^2\omega(t_j-\tau)}\right)$$

$$tan\,(2\omega\tau) = \frac{\sum_j sin2\omega t_j}{\sum_j cos2\omega t_j}$$

Lomb-Scargle applied to G9.62+0.20

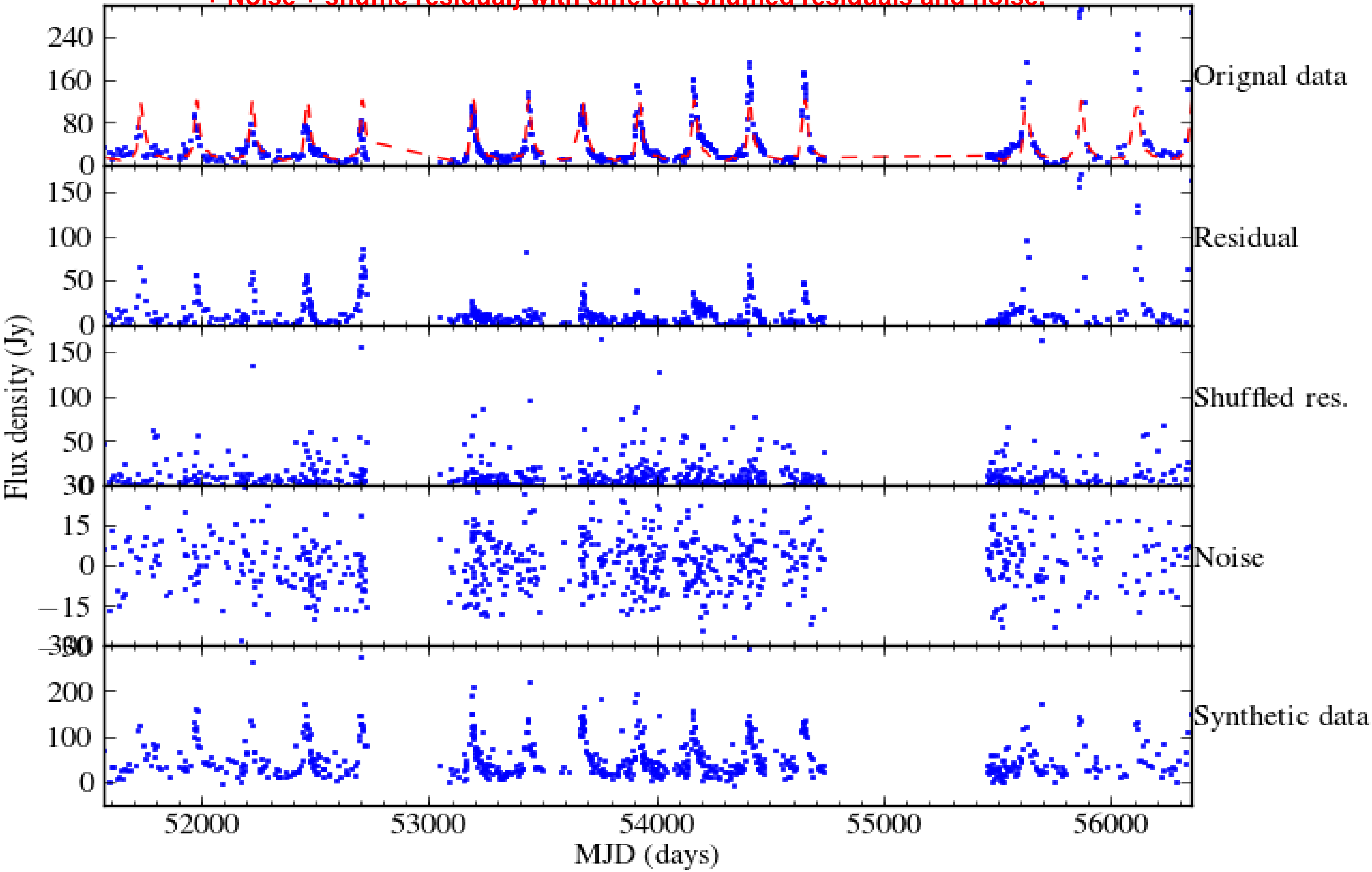


Lomb-Scargle Periodogram
(Red-dash line – significant test line)



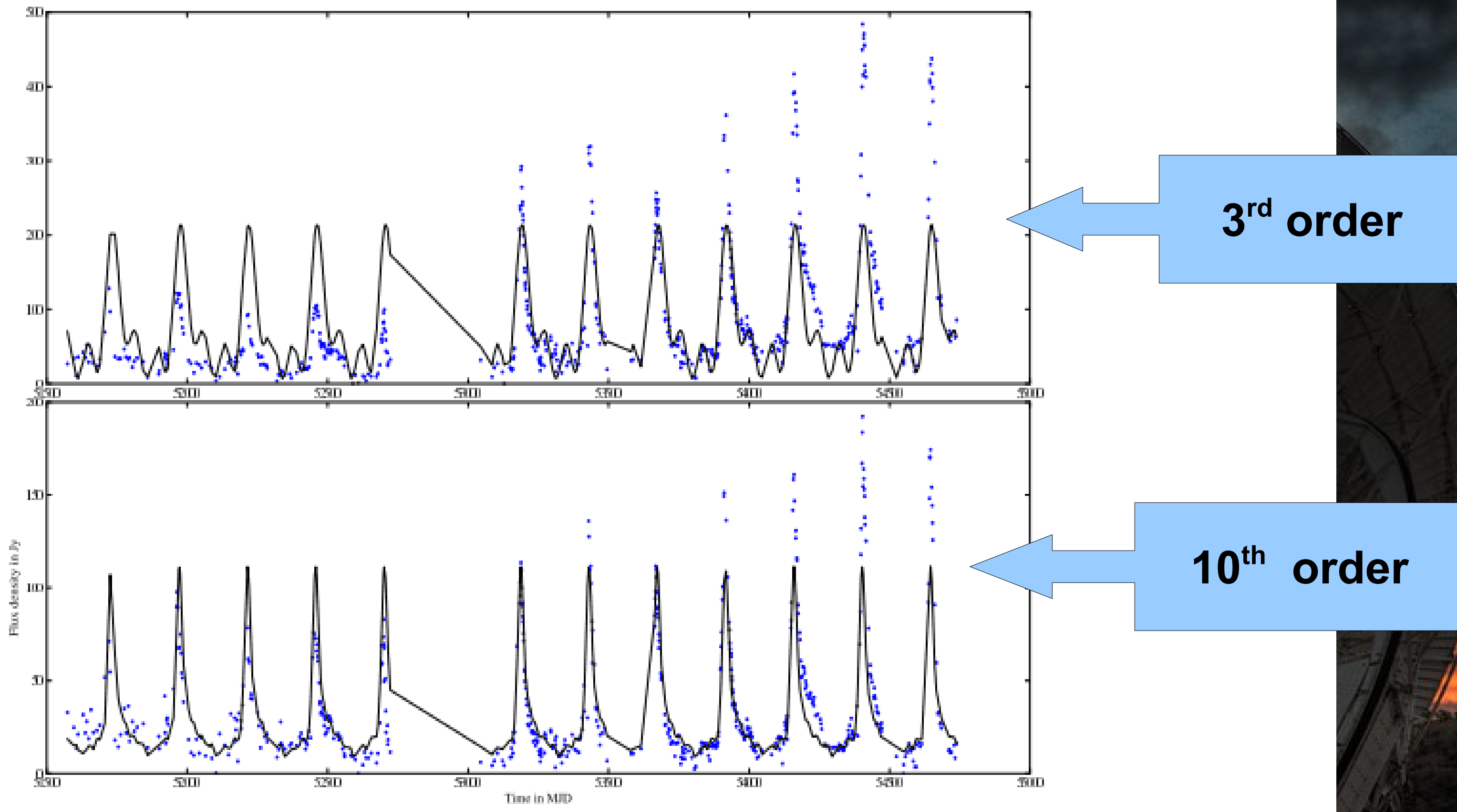
Monte Carlo simulation (Hakala et al. 2003)

Procedure: Fit Fourier series, shuffle residuals, create Noise. Create 1000 Synthetic time series {fitted Fourier series + Noise + shuffle residual} with different shuffled residuals and noise.



Monte Carlo simulation (Hakala et al. 2003)

(Example for the third and tenth order Fourier series fitted to G9.62-0.20 at 12 GHz)



Weighted mean of the harmonics improve the accuracy of the determine period (Gradari et al. 2009)

G9.62+0.20 (12GHz) 1.631 km/s

Peak one 243.1 +/- 0.6 days

Peak two: 121.5 +/- 0.2 days (2) 243.0 +/- 0.3 days

Peak three: 81.03 +/- 0.08 days (3) 243.1 +/- 0.2 days

Peak four: 60.76 +/- 0.05 days (4) 243.0 +/- 0.2 days

Peak five: 48.61 +/- 0.03 days (5) 243.0 +/- 0.2 days

Periods determine by Lomb-Scargle method

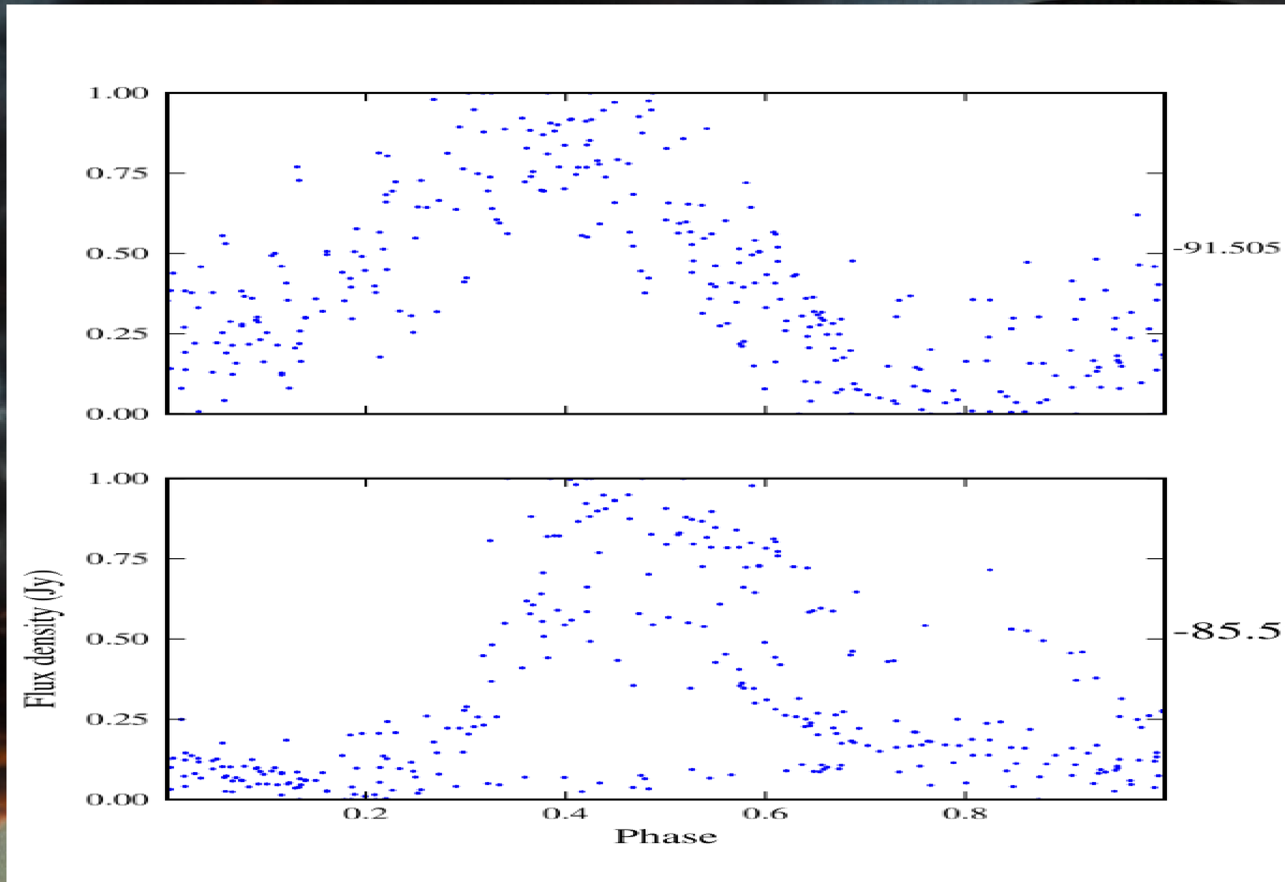
source	Period for MC Simulation (days)	Determined period (days)
G9.62+20	*243*	*243.05 (4)*
G12.89+0.49	*29*	*29.453 (5)*
G188.95+0.89	*400*	*394.1 (6)*
G328.24+0.55	*221*	*221.0 (3)*
G331.13-0.24	*510*	*511 (1)*
G338.93-0.06	*133*	*132.80 (6)*
G339.62-0.12	*200*	*200.1 (3)*

Jurkevich method

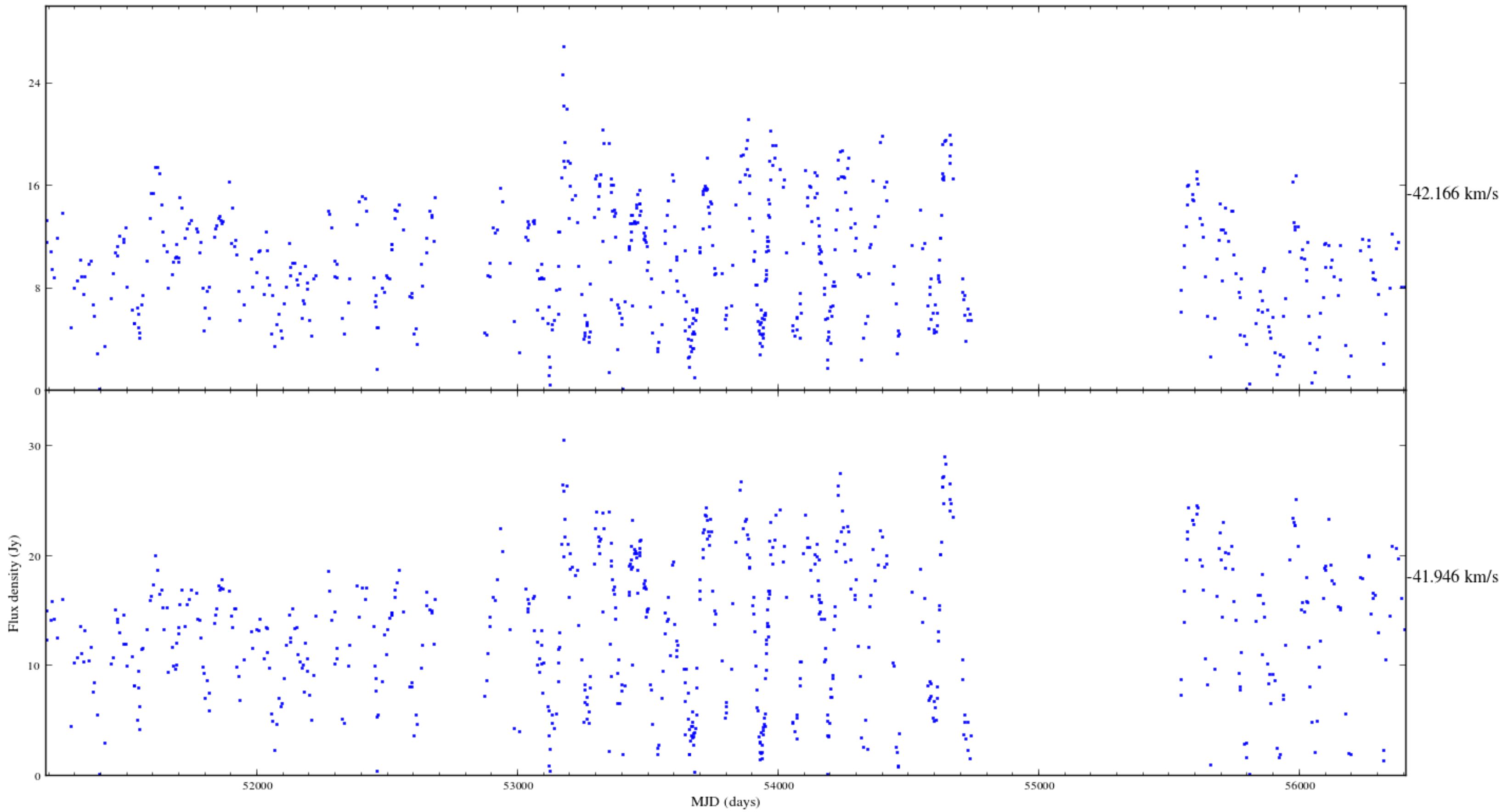
- It is based on the expected mean square deviation and it is less inclined to generate spurious periodicities than Fourier analysis (Fan et al. 1997)
- It folds the time series in bins (with a trial period), calculate the variance in each bin and sums all the variances across the bins (for each trial period).
- If the trial period is a true period, the sum of the variances across the bins will be absolute minimum.
- Kidger et al. (1992) used the minimum as the measure of time series periodicity.

$$f = \frac{1 - V_m^2}{V_m^2}$$

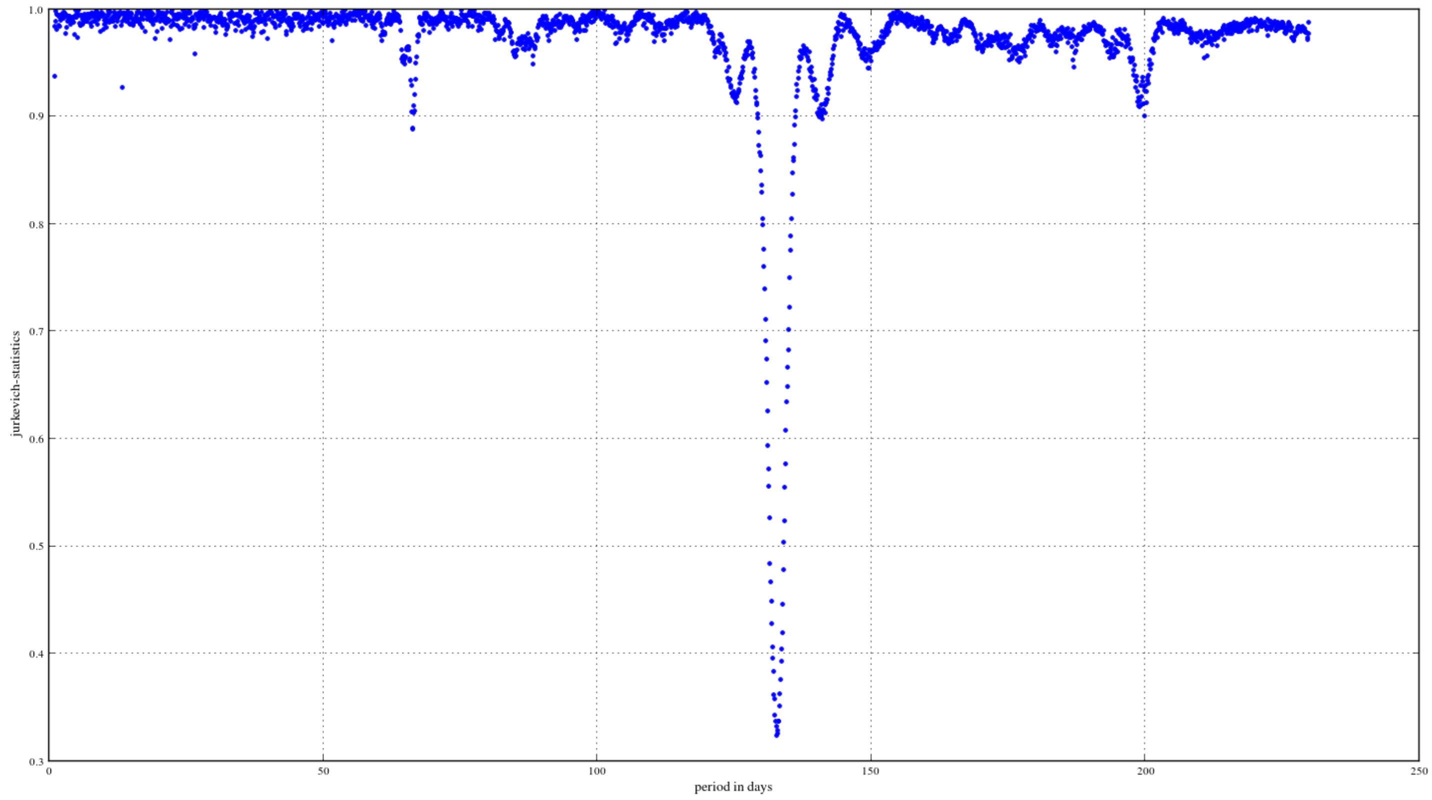
Example of the folded G331.13-0.24 time series



G338.93-0.06 at 6.7 GHz time series



Jurkevich method applied to G338.93-0.06



Periods determine by Jurkevich method

source	Period in days	Periodicity measure f (sum of varianceV^2)	
G9.62+20	***243 (2)***	**1.30 (0.46)**	**Periodic**
G12.89+0.49	***29.51 (7)***	**0.30 (0.77)**	**Periodic**
G188.95+0.89	**394 (7)**	**0.48 (0.68)**	**Periodic**
G328.24+0.55	**221 (2)**	**0.55 (0.64)**	**Periodic**
G331.13-0.24	**509 (10)**	**1.29 (0.44)**	**Periodic ?**
G338.93-0.06	**133 (1)**	**2.01 (0.33)**	**Periodic**
G339.62-0.12	**201 (3)**	**0.59 (0.63)**	**Periodic**

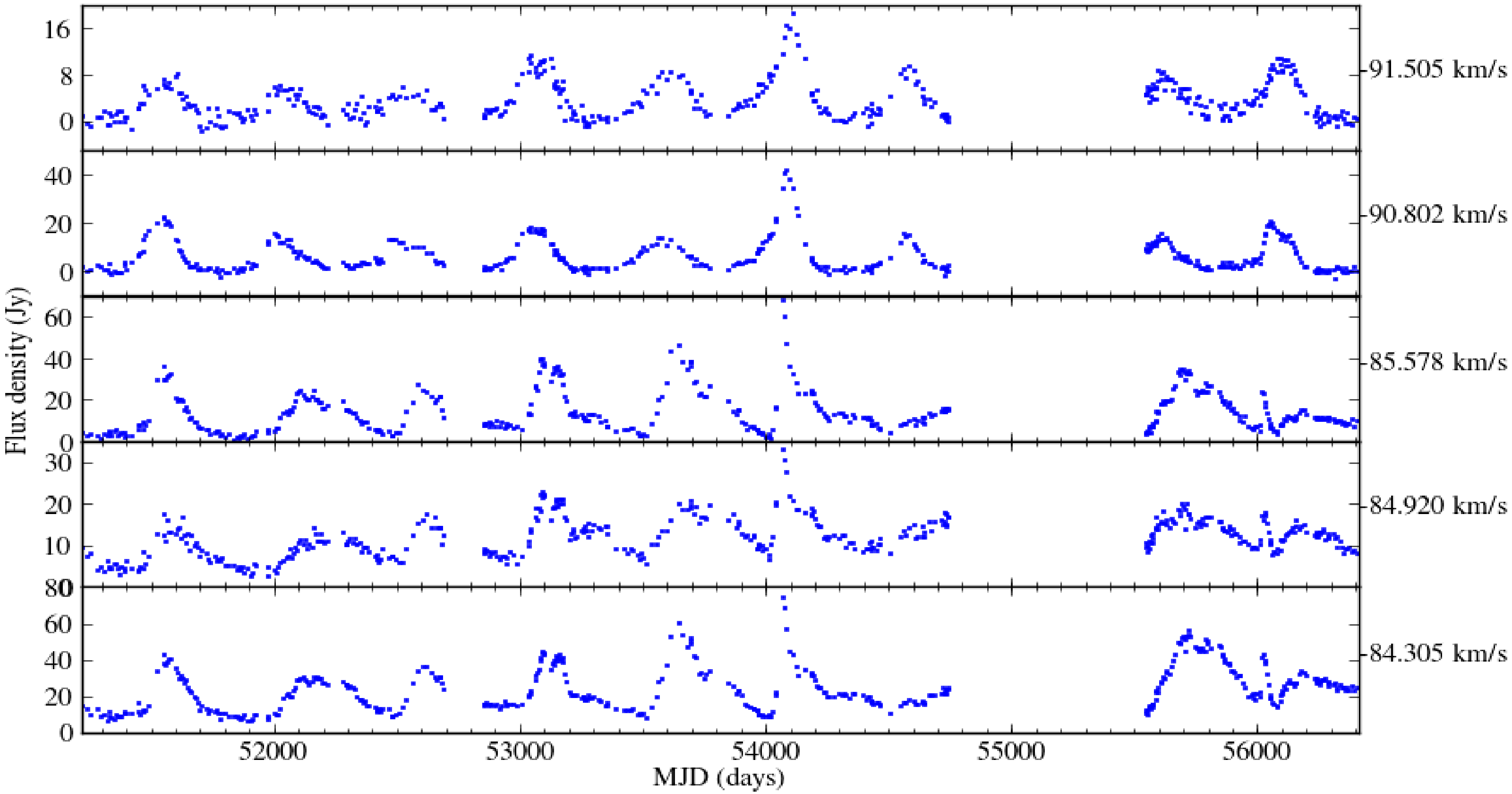
Epoch-folding using L-statistics

This method folds the time series like Jurkevich method,

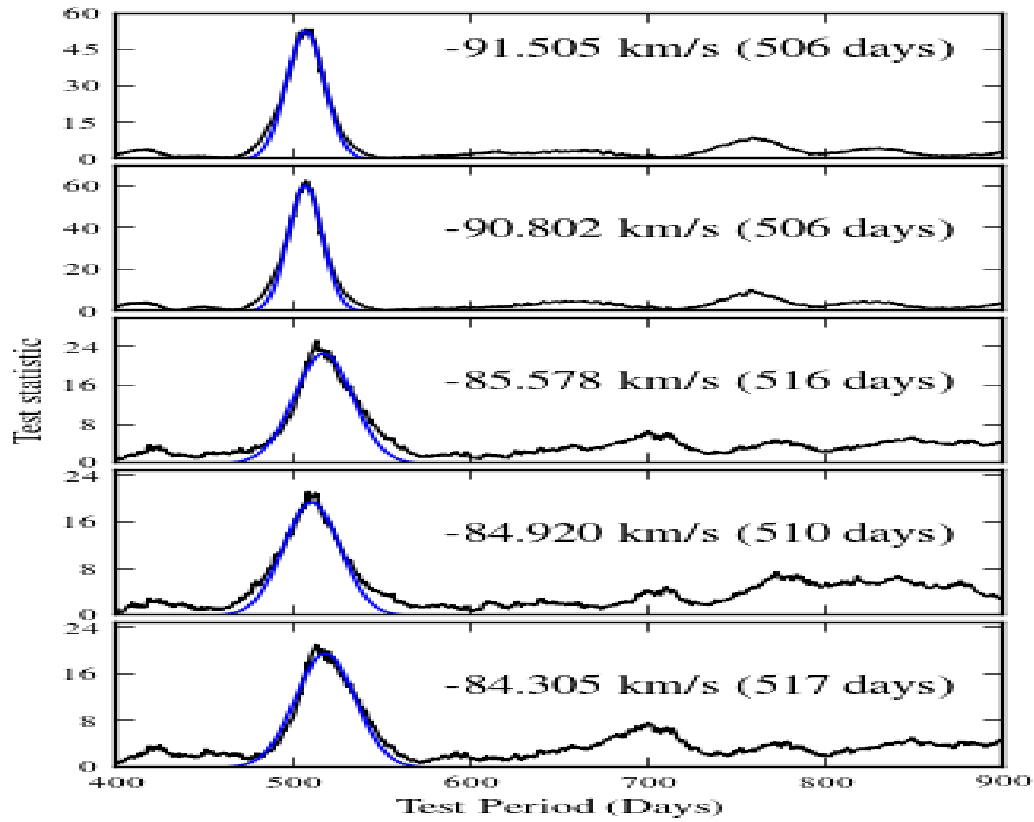
It determines the period using either Phase Dispersion Minimisation (Stellingwerf 1978) or Epochfolding but it tests the significancy of the period using L-statistics.

$$\left.\begin{aligned} L &= \frac{Q^2}{(M-1)\,\Theta^2}, \\ L &= \frac{(N-1)-(N-M)\,\Theta^2}{(M-1)\,\Theta^2}, \\ L &= \frac{(N-M)\,Q^2}{(M-1)\left[(N-1)-Q^2\right]}. \end{aligned}\right\}$$

G331.13-0.24 time series at 6.7 GHz



Epoch-folding using L-statistics applied for G331.13-0.24 time series at 6.7 GHz



Epoch-folding using L-statistics Results

source	Period in days
G9.62+20	243.2 (3)
G12.89+0.49	29.47 (4)
G188.95+0.89	395 (7)
G328.24+0.55	220.3 (6)
G331.13-0.24	509 (7)
G338.93-0.06	132.8 (9)
G339.62-0.12	200.1 (2)

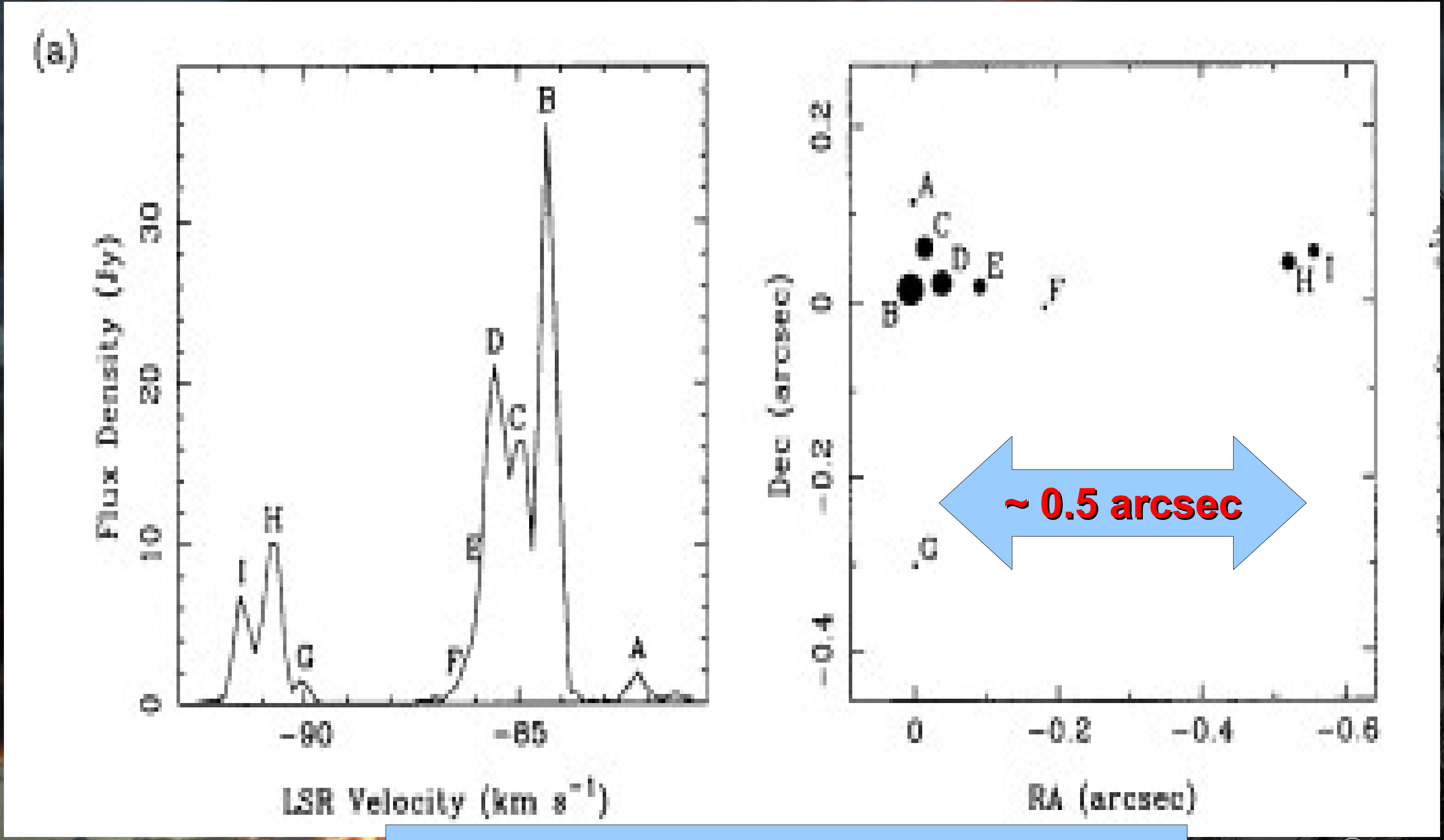
Comparing the methods

source	Lomb-scargle (days)	Epochfolding (days)	Jurkevich (days)	Best Approx. Period (days)
G9.62+20	*243.05 (4)*	243.2 (3)	*243(2)*	243.05 (4)
G12.89+0.49	29.453 (5)	29.47 (4)	29.51 (7)	29.453 (5)
G188.95+0.89	*394.1 (6)*	395 (7)	394 (7)	394.1 (6)
G328.24+0.55	221.0 (3)	220.3 (6)	221 (2)	220.9 (3)
G331.13-0.24	511 (1)	509 (7)	509 (10)	511 (1)
G338.93-0.06	132.80 (6)	132.8 (9)	133 (1)	132.80 (6)
G339.62-0.12	200.1 (3)	201 (2)	201 (3)	200.1 (3)

Summary

- All sources have been shown to be periodic.
- Using Jurkevich method: Kidger et al. (1992) proposed that if f >= 0.5 suggests there is a very strong periodicity and if f < 0.25 there is no periodicity, if periodic, it is a weak one.
- **But?** there is one source: G331.13-0.24.
- It should be quasi-periodic because one maser group is strongly periodic, and the other is quasi-periodic.

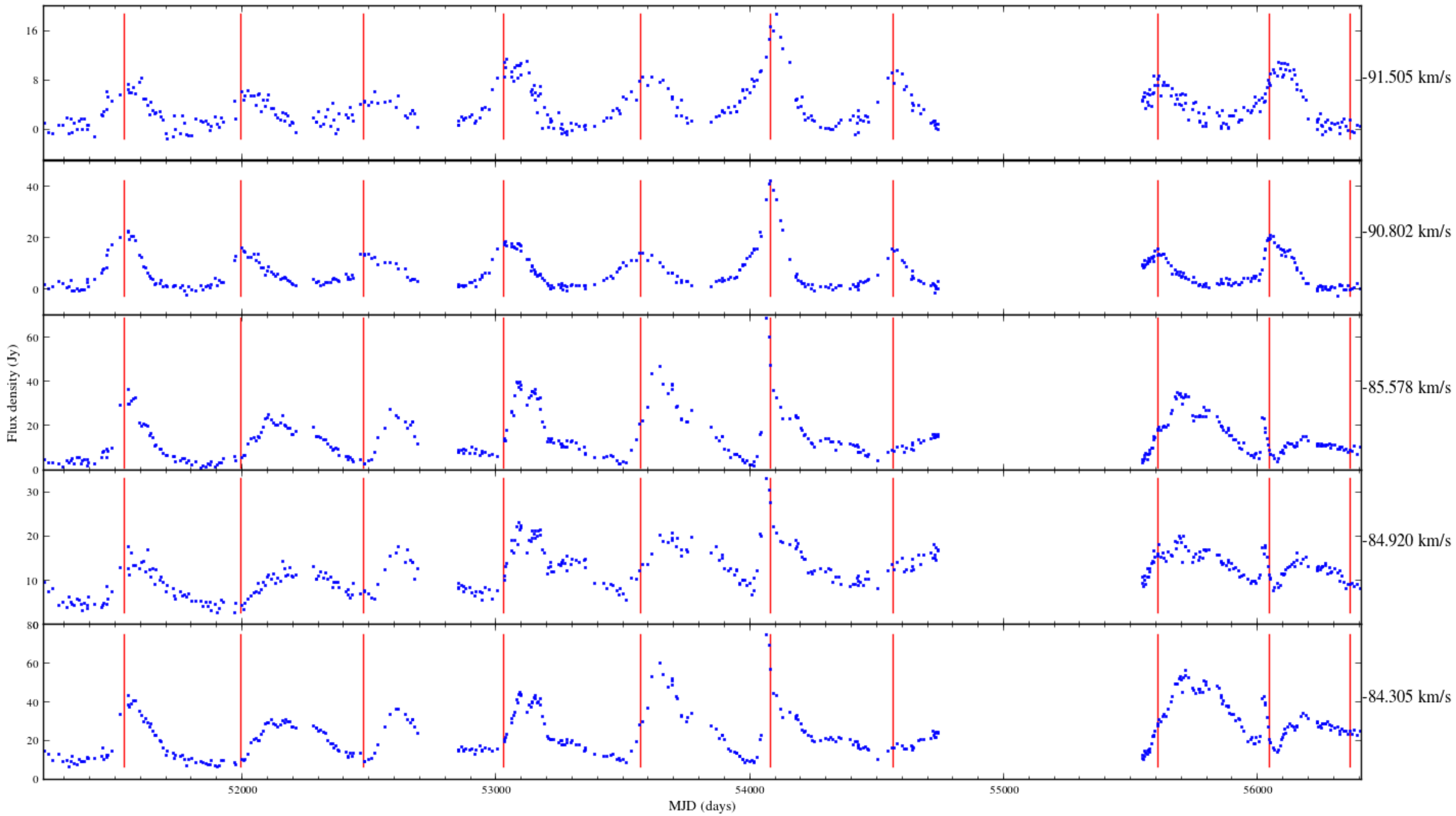
G331.13-0.24 maser spot map at 6.7 GHz

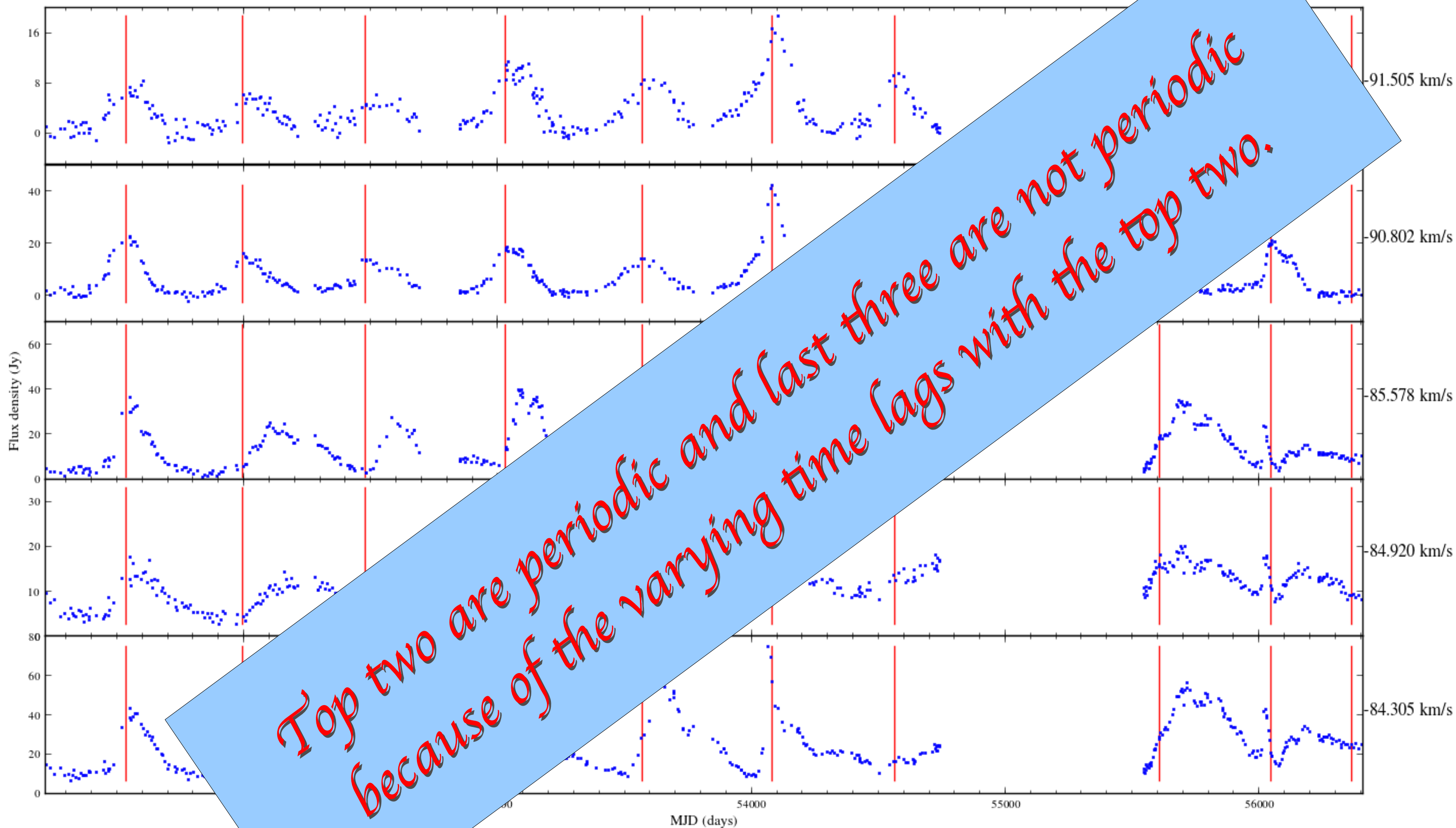


Phillips et al. (1998)

G331.13-0.24 time series

(Vertical lines prove that the bottom three time series have a varying time delay with the top two time series)





Top two are periodic and last three are not periodic because of the varying time lags with the top two.


The End
Thank you
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