ORIGIN OF THE GAMMA-RAY EMISSION IN AGN JETS: THE CASE OF 3C 279

by Sebastian Kiehlmann

Metsähovi Radio Observatory
School of Electrical Engineering
Aalto University

MAX-PLANCK-GESELLSCHAFT

Aalto University
School of Electrical
Engineering

Photometry:

- 140 individual light curves
- 26 combined light curves
  from radio to gamma-rays
  with time sampling: 1-36 days

Preliminary results

3C 279

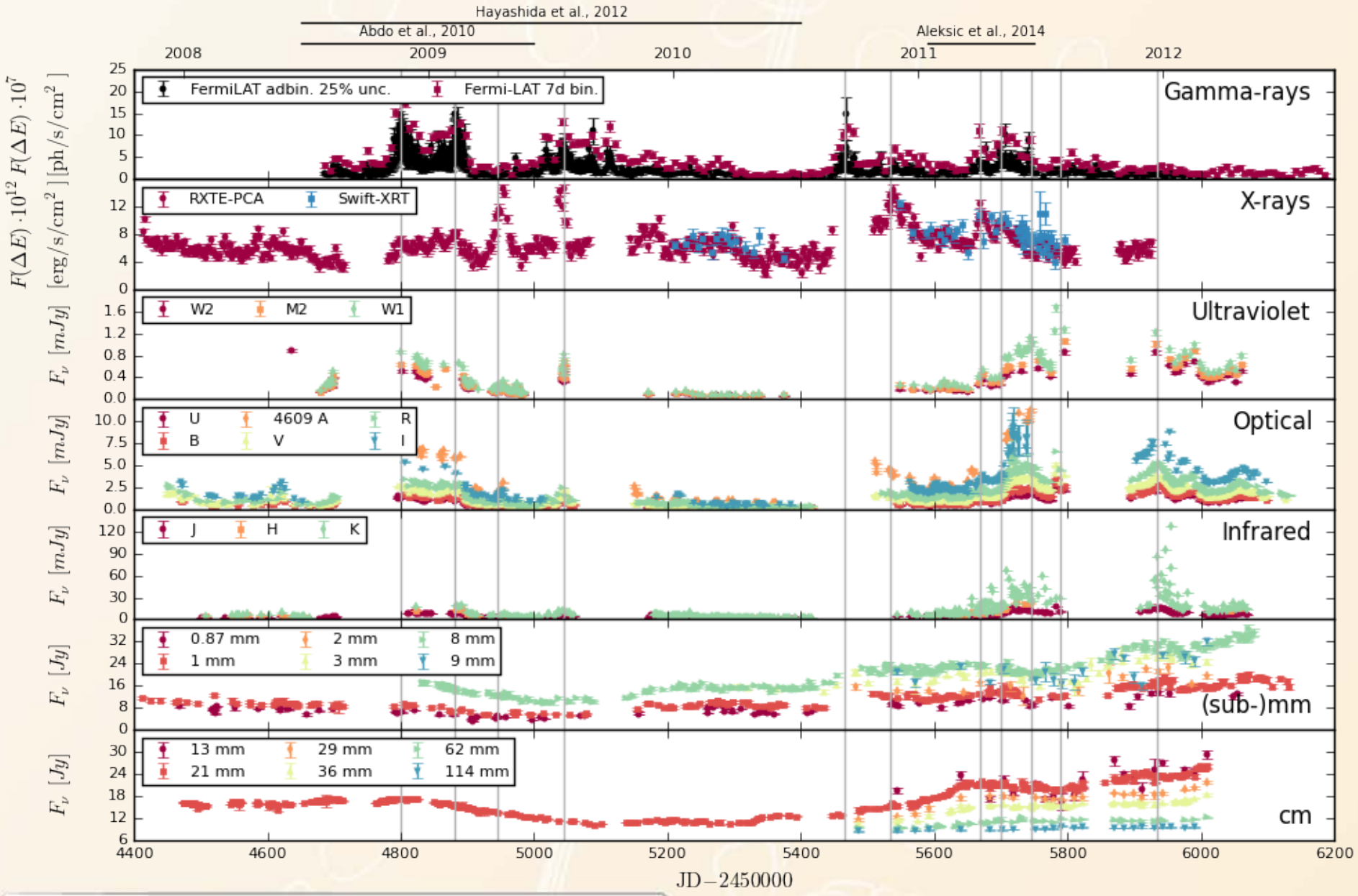
Polarimetry:

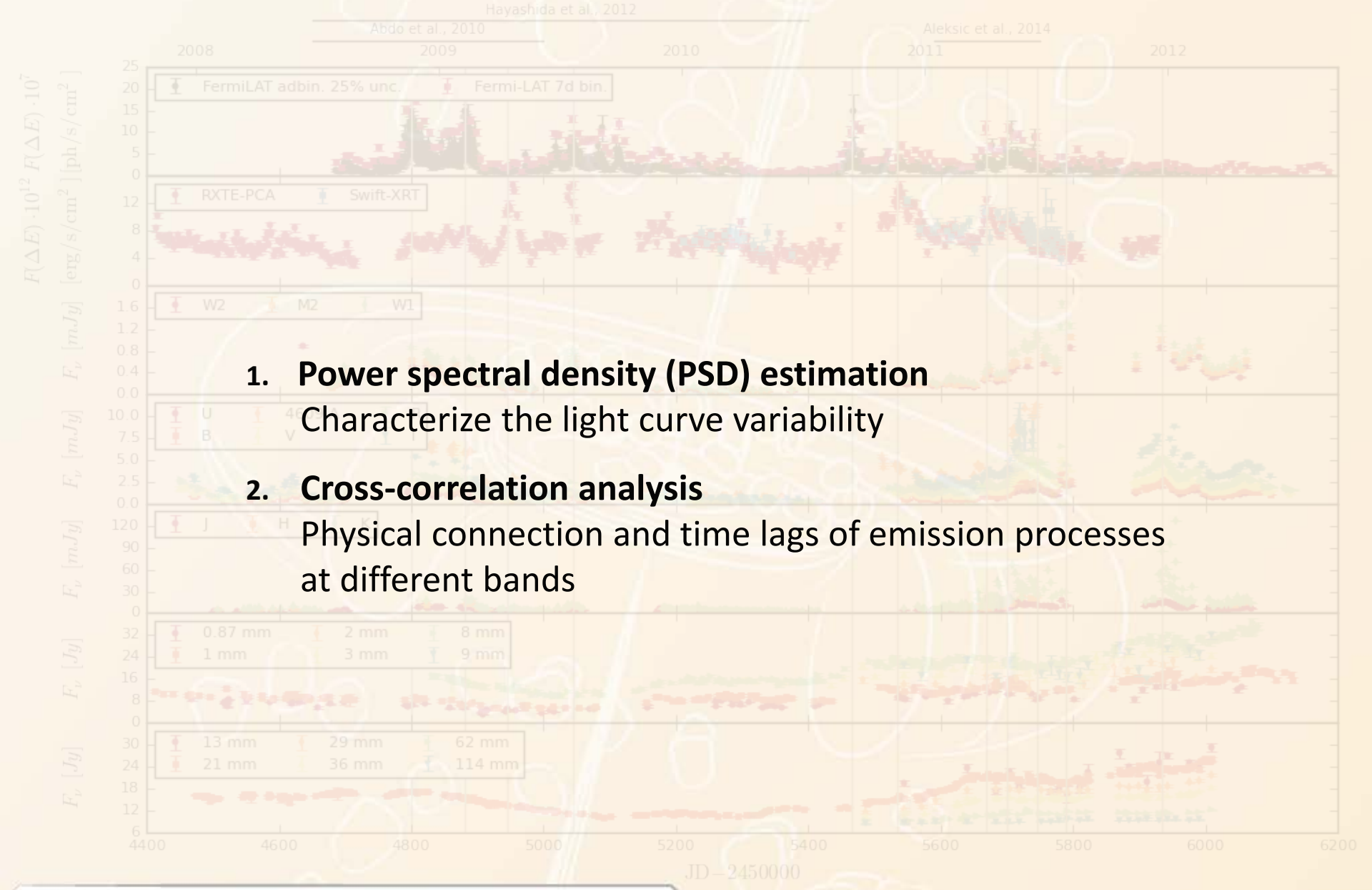
- 9 optical polarization curves
- 5 mm, cm polarization curves

Kiehlmann et al., 2016, A&A, 590, A10

VLBI:

- 18 epochs, 2010-2012
- 5, 8, 15, 24, 43, 86 GHz


Hayashida et al., 2012
Abdo et al., 2010
Aleksic et al., 2014
2008
2009
2010
2011
2012
FermiLAT adbin. 25% unc.
Fermi-LAT 7d bin.
Gamma-rays
RXTE-PCA
Swift-XRT
X-rays
W2
M2
W1
Ultraviolet
U
B
4609 A
V
R
I
Optical
J
H
K
Infrared
0.87 mm
1 mm
2 mm
3 mm
8 mm
9 mm
(sub-)mm
13 mm
21 mm
29 mm
36 mm
62 mm
114 mm
cm
$F(\Delta E)\cdot 10^{12}\ F(\Delta E)\cdot 10^{7}$ [erg/s/cm^2] [ph/s/cm^2]
F_ν [mJy]
F_ν [Jy]
JD−2450000

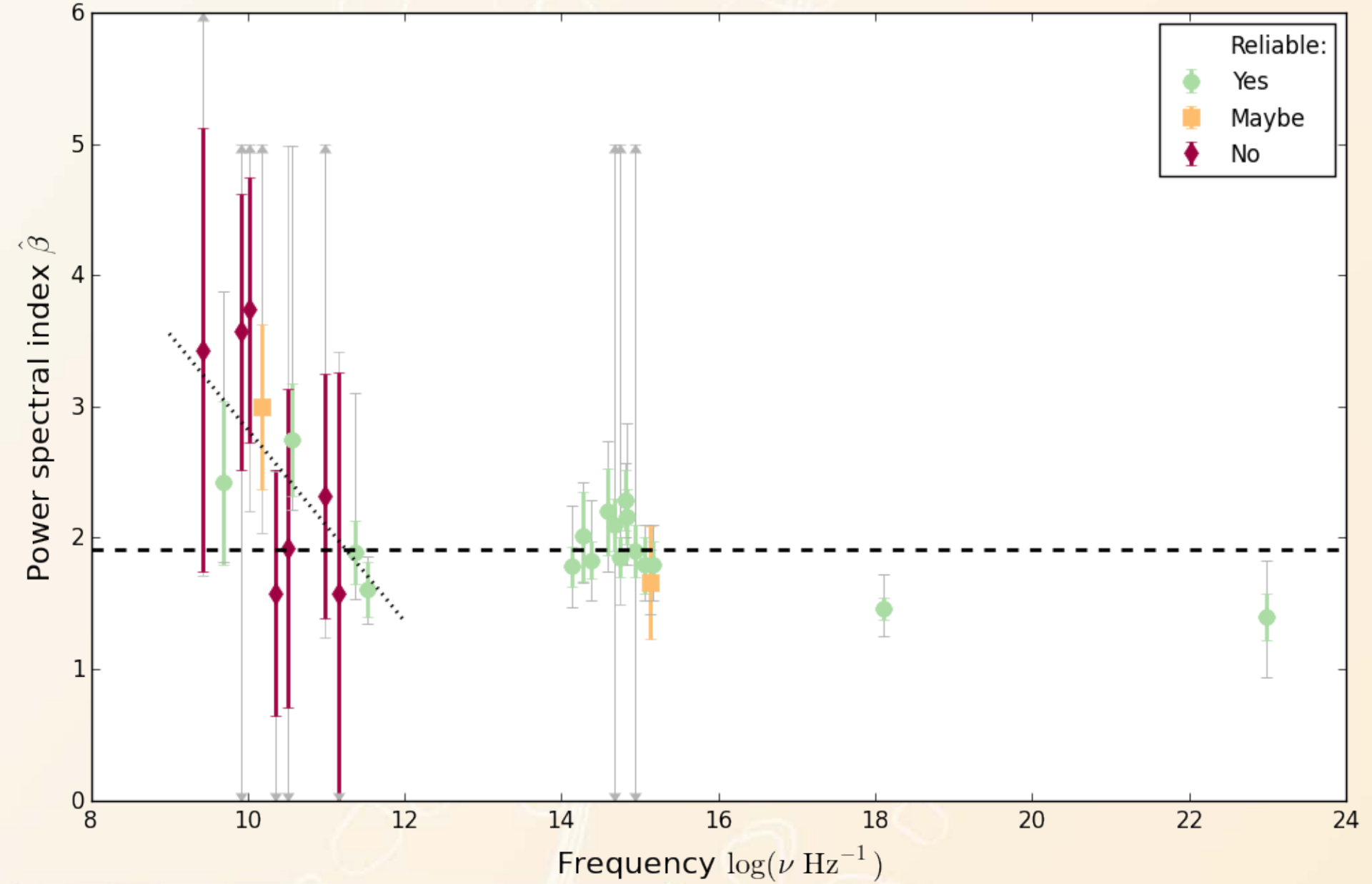


1. **Power spectral density (PSD) estimation**
   Characterize the light curve variability
2. **Cross-correlation analysis**
   Physical connection and time lags of emission processes at different bands

Power Spectral Density (PSD) estimation of the light curve variability

Assumption: red noise process $P(\upsilon) \propto \upsilon^{-\beta}$

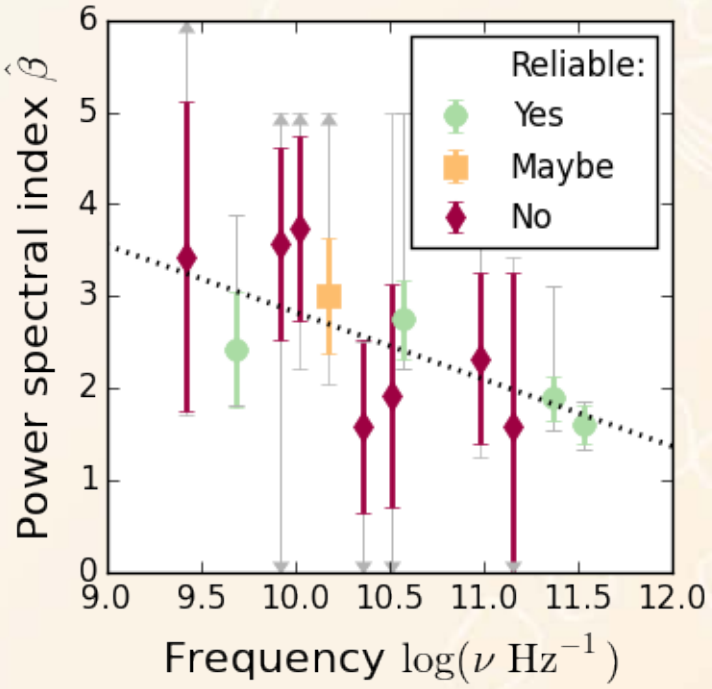
Method: *Uttley et al., 2002*

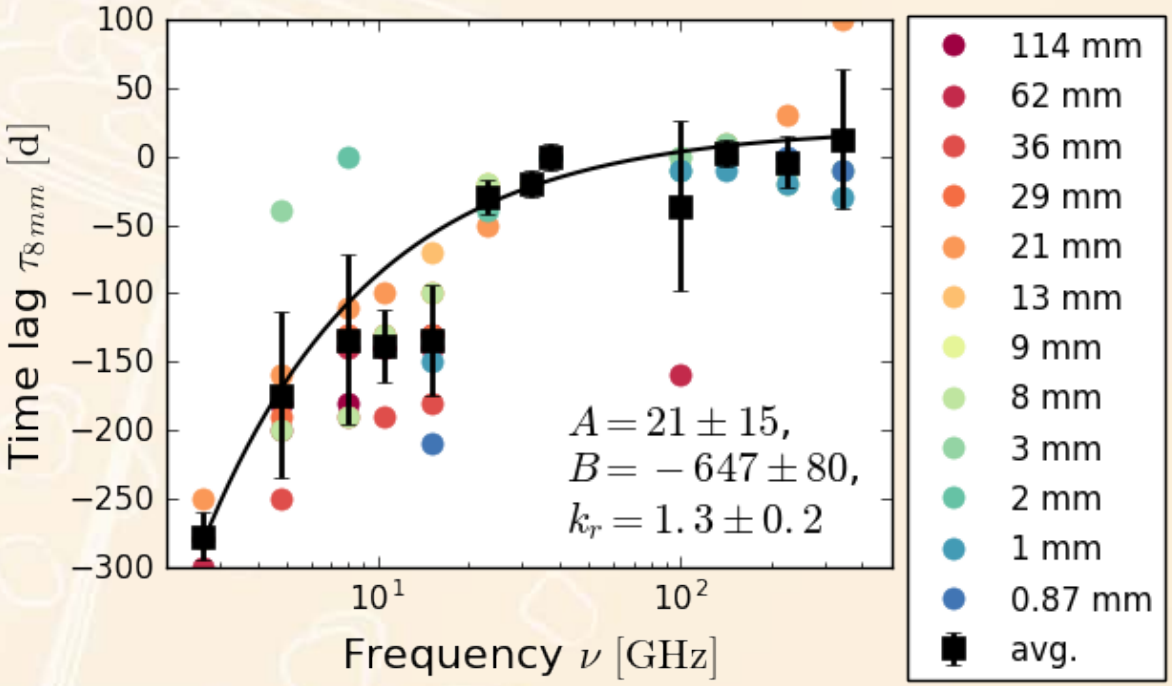

Reliable:
Yes
Maybe
No
Power spectral index $\hat{\beta}$
Frequency $\log(\nu\ \mathrm{Hz}^{-1})$
0
1
2
3
4
5
6
8
10
12
14
16
18
20
22
24

Radio PSDs and time lags:

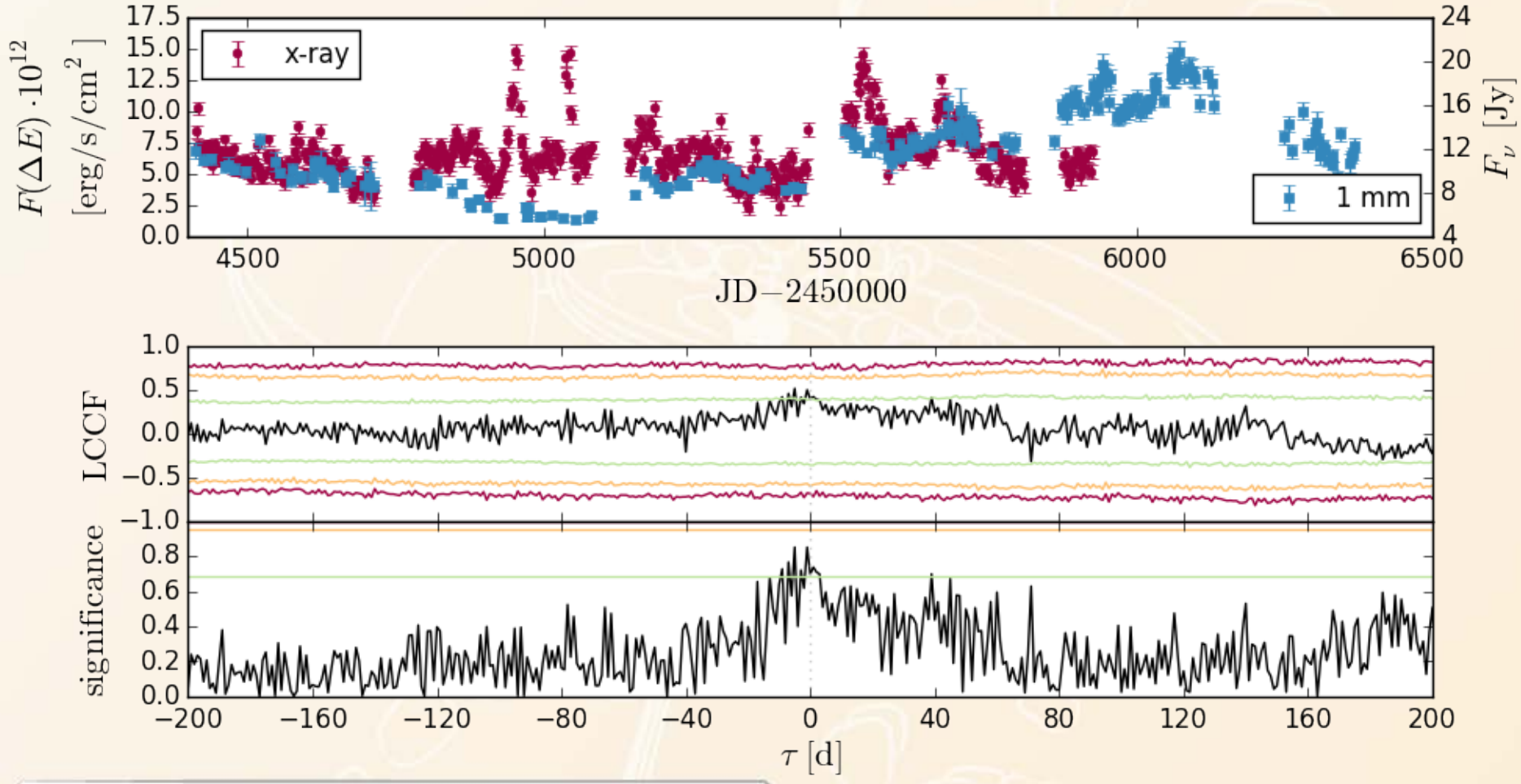
Lower frequency – larger emission region

- Synchrotron Self-Absorption (SSA):
  Fuhrmann et al., 2014, based on VLBI core shift
  $\tau = A + B \cdot \nu^{-1/k_r} \rightarrow k_r = 1.3 \pm 0.2$
  Consistent with self-absorbed, conical jet in equipartition ($k_r = 1$)





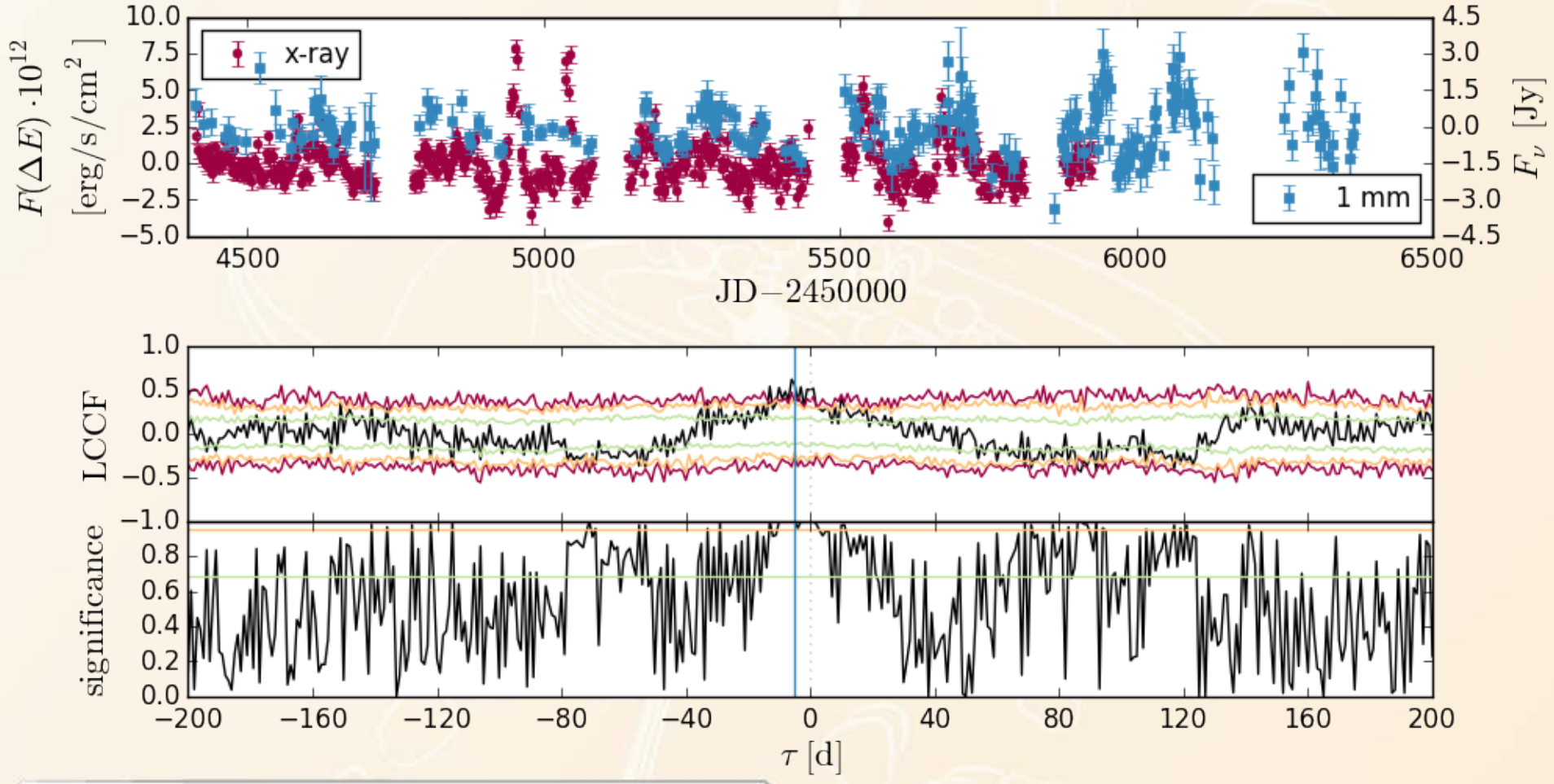
X-ray vs. 1 mm variability correlation:

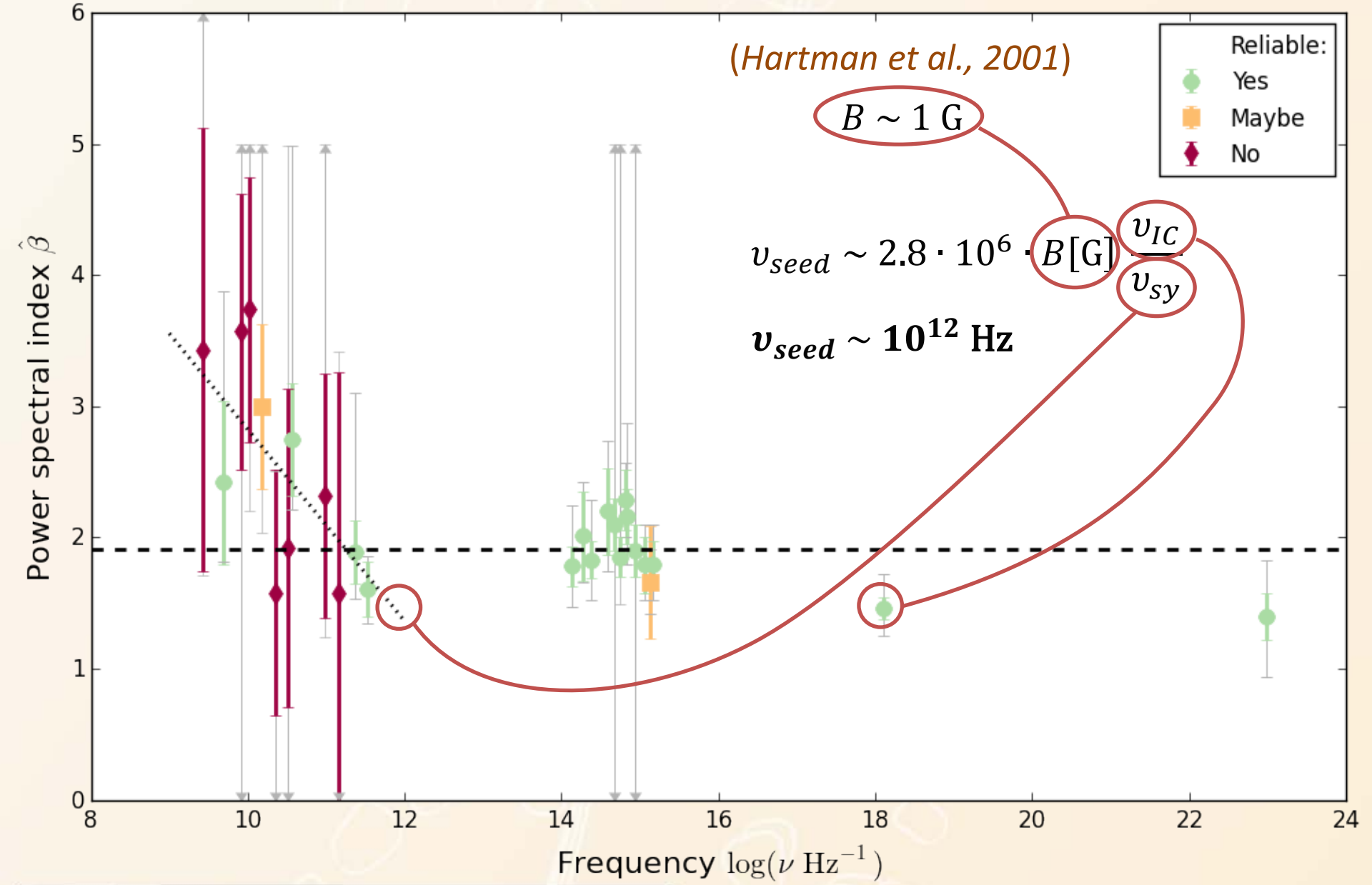


Short term X-ray vs. 1 mm variability correlation:

Light curves de-trended with a Hann window of 300 days width

Time lag $\tau = -6 \pm 11$ days with significance 1

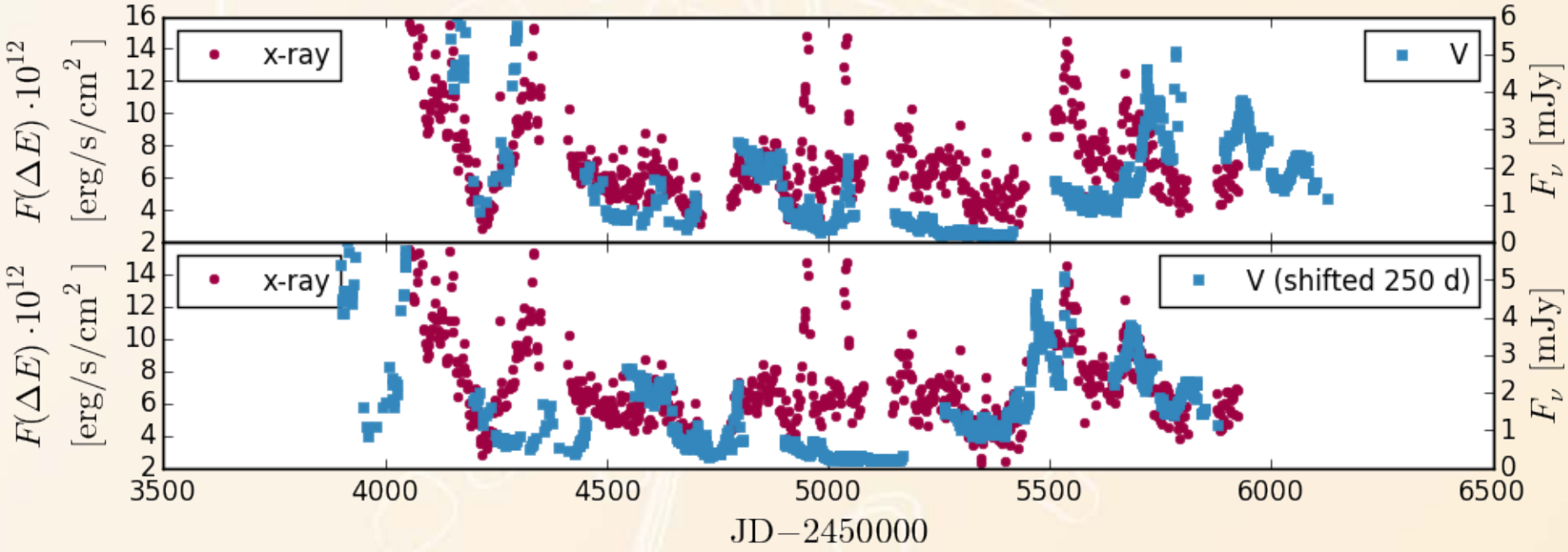



(Hartman et al., 2001)
$B \sim 1\,\mathrm{G}$
$\upsilon_{seed} \sim 2.8 \cdot 10^6 \cdot B[\mathrm{G}] \frac{\upsilon_{IC}}{\upsilon_{sy}}$
$\boldsymbol{\upsilon_{seed} \sim 10^{12}\ \mathrm{Hz}}$
Reliable:
Yes
Maybe
No
Power spectral index $\hat{\beta}$
Frequency $\log(\nu\ \mathrm{Hz}^{-1})$
0
1
2
3
4
5
6
8
10
12
14
16
18
20
22
24

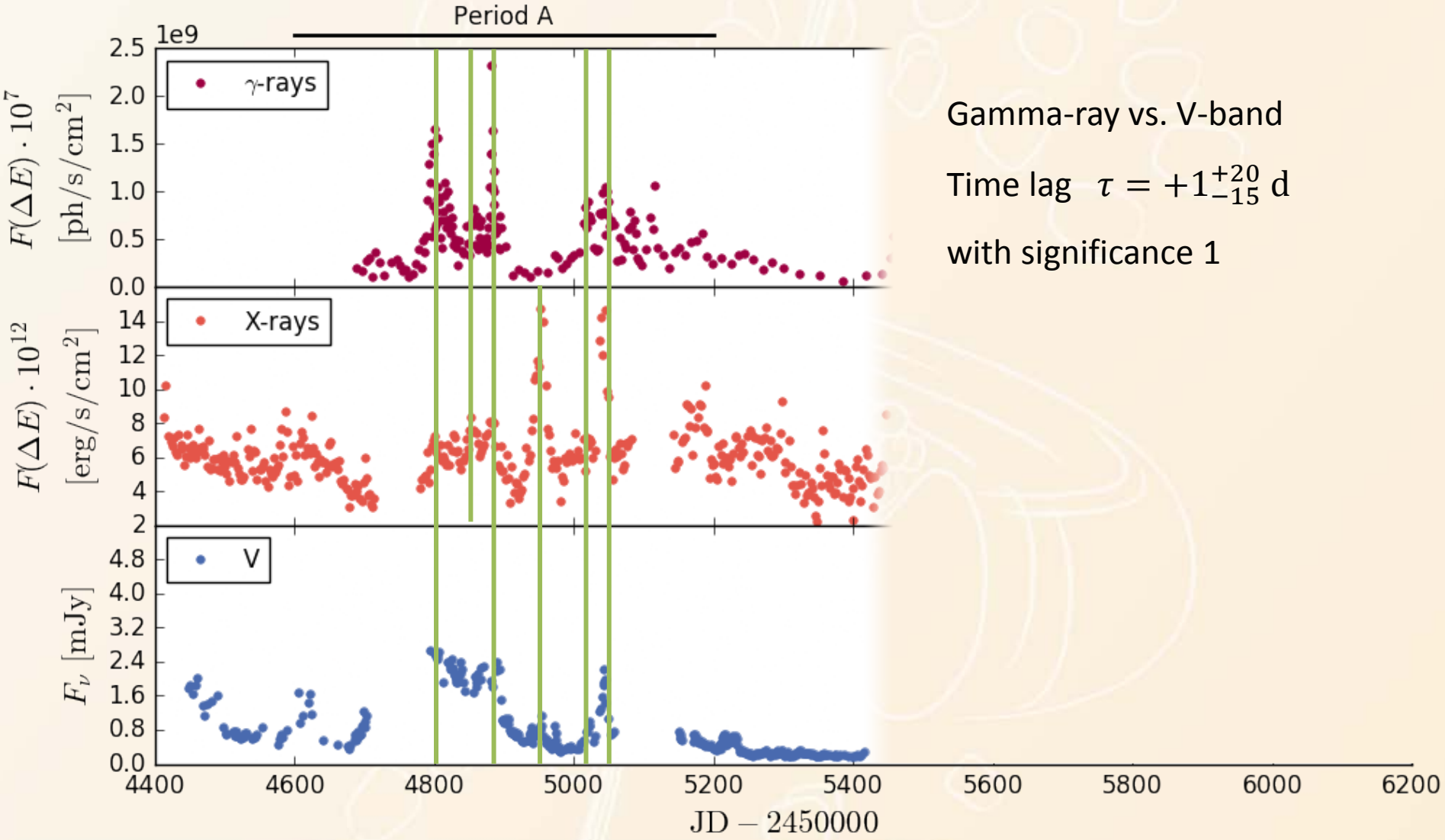
V-band vs. low frequencies:

	21 mm	8 mm	1 mm	0.87 mm
V lagging:	60^{+28}_{-61} d	255^{+30}_{-47} d	270^{+30}_{-63} d	250^{+45}_{-100} d
Significance:	0.94	0.98	0.99	0.99

V-band vs. X-rays:



Gamma-ray correlations:



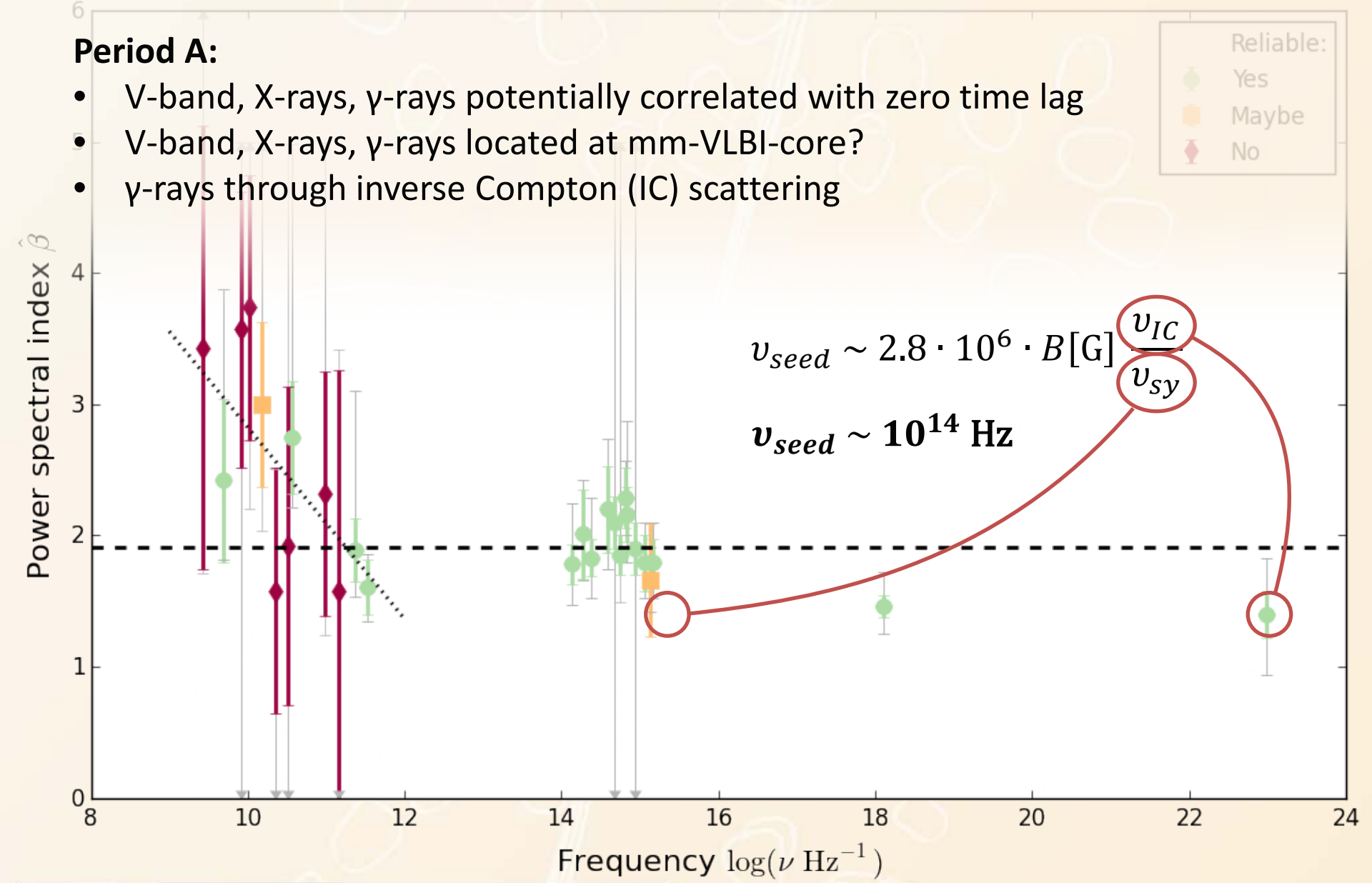
Gamma-ray vs. V-band

Time lag $\tau = +1^{+20}_{-15}$ d

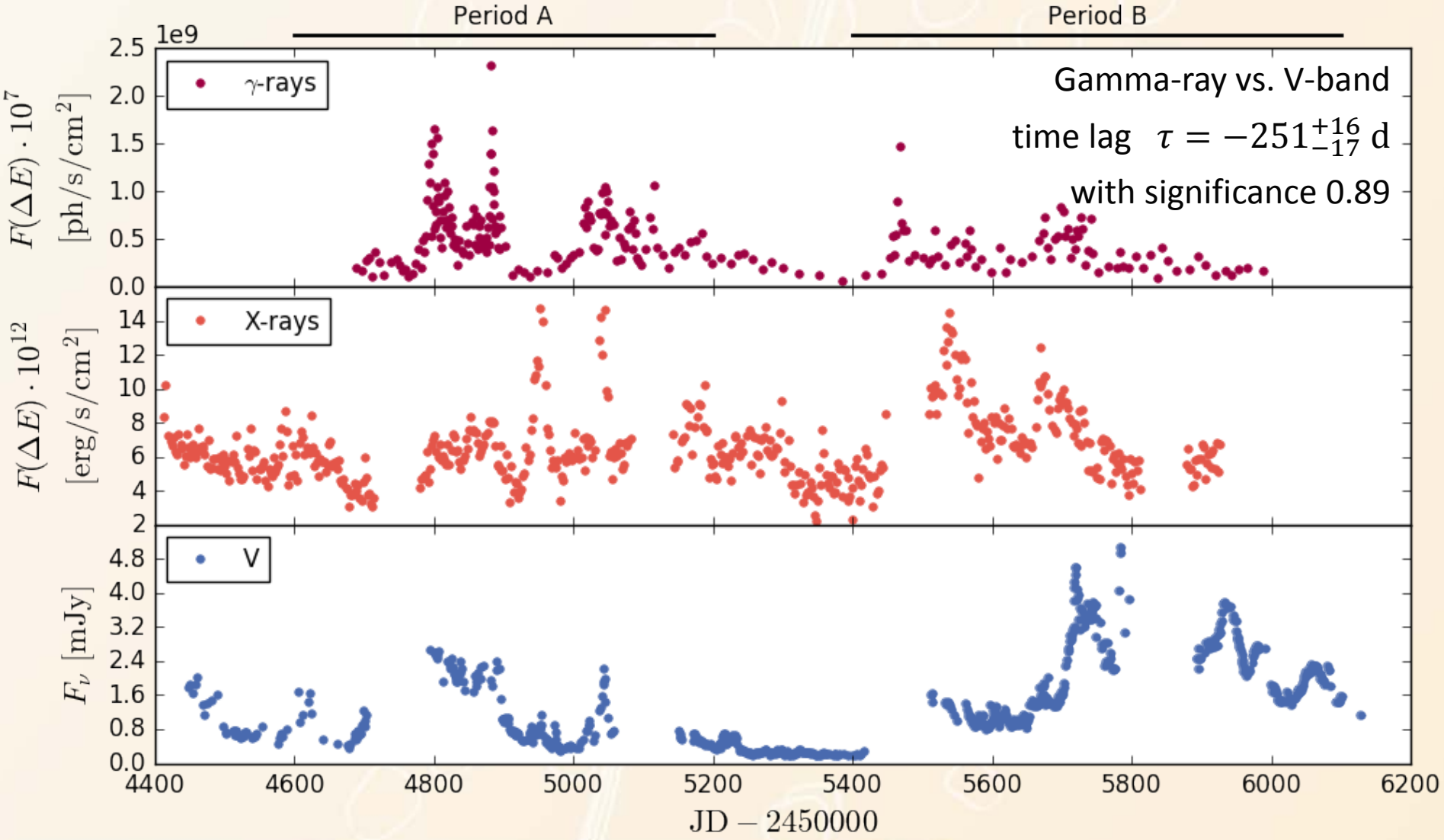
with significance 1

Period A:

- V-band, X-rays, γ-rays potentially correlated with zero time lag
- V-band, X-rays, γ-rays located at mm-VLBI-core?
- γ-rays through inverse Compton (IC) scattering



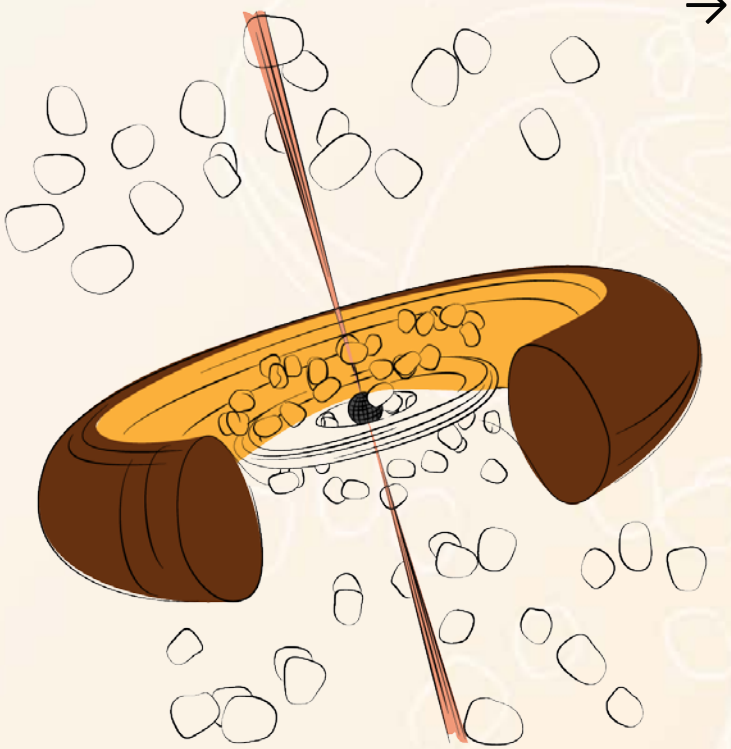
Gamma-ray correlations:



The Quasar Movie Project

Photometry data of 3C 279
Extremely well-sampled in time and frequency

Power spectral densities and **cross-correlation analysis** of 26 light curves



→ X-rays:
- Partially at mm-VLBI-core
- Synchrotron self-Compton (SSC)
- Multiple emission sites?

→ Gamma-rays:
- At mm-VLBI-core?
- External Compton – Dust Torus

→ V-band :
- Changing and
- Extreme time lag?!

Special thanks to the QMP collaborators:

T. Savolainen (PI), S. G. Jorstad, F. Schinzel, K. V. Sokolovski, I. Agudo, M. Aller, I. Berdnikov, V. Chavushyan, L. Fuhrmann, M. Gurwell, R. Itoh, J. Heidt, Y. Y. Kovalev, T. Krajci, O. Kurtanidze, A. Lähteenmäki , V. M. Larionov , J. León-Tavares, A. P. Marscher, K. Nilson, A. Sadun, P. S. Smith, the AAVSO, the Yale SMARTS project and all the observers.

The Quasar Movie Project

Acknowledgements:

S.K. was supported for this research through a stipend from the International Max Planck Research School (IMPRS) for Astronomy and Astrophysics at the Max Planck Institute for Radio Astronomy in cooperation with the Universities of Bonn and Cologne. T.S. was partly supported by the Academy of Finland project 274477. The research at Boston University was partly funded by NASA Fermi GI grant NNX11AQ03G. K.V.S. is partly supported by the Russian Foundation for Basic Research grants 13-02-12103 and 14-02-31789. N.G.B. was supported by the RFBR grant 12-02-01237a. E.B., M.S. and D.H. thank financial support from UNAM DGAPA-PAPIIT through grant IN116211-3. I.A. acknowledges support by a Ramon y Cajal grant of the Spanish Ministry of Economy and Competitiveness (MINECO). The research at the IAA-CSIC and the MAPCAT program are supported by the Spanish Ministry of Economy and Competitiveness and the Regional Government of Andalucía (Spain) through grants AYA2010-14844, AYA2013-40825-P, and P09-FQM-4784. The Calar Alto Observatory is jointly operated by the Max-Planck-Institut für Astronomie and the Instituto de Astrofísica de Andalucía-CSIC. Data from the Steward Observatory spectropolarimetric monitoring project were used. This program is supported by Fermi Guest Investigator grants NNX08AW56G, NNX09AU10G, NNX12AO93G, and NNX14AQ58G. St.Petersburg University team acknowledges support from Russian RFBR grant 15-02-00949 and St.Petersburg University research grant 6.38.335.2015. The Abastumani team acknowledges financial support of the project FR/638/6-320/12 by the Shota Rustaveli National Science Foundation under contract 31/77. We acknowledge the photometric observations from the AAVSO International Database contributed by observers worldwide and used in this research. This research has made use of up-to-date SMARTS optical/near-infrared light curves that are available at http://www.astro.yale.edu/smarts/glast/ (2012ApJ...756...13B). We acknowledge the contributions of Y. Y. Kovalev to the Quasar Movie Project.

MAX-PLANCK-GESELLSCHAFT

Aalto University
School of Electrical
Engineering