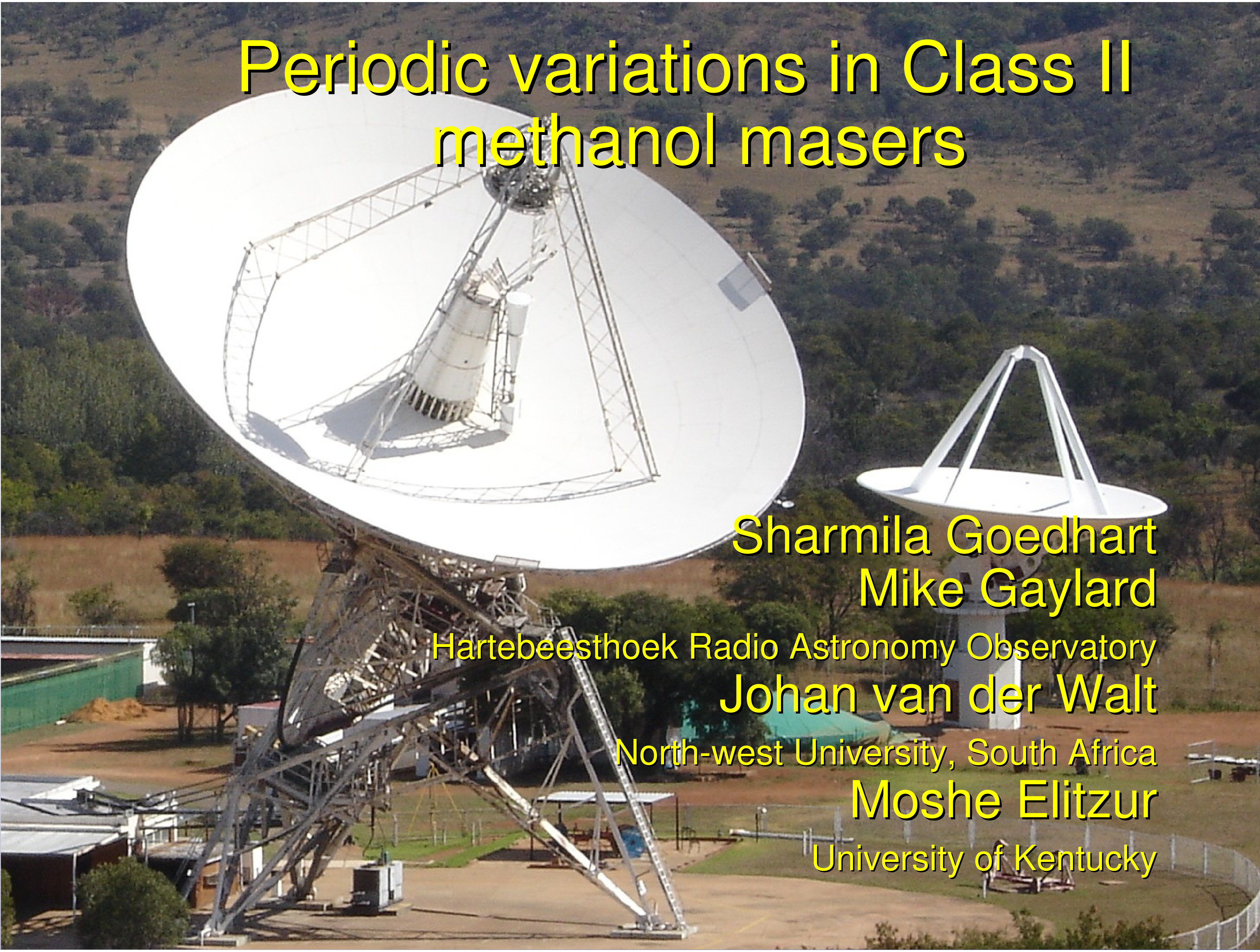

Periodic variations in Class II methanol masers

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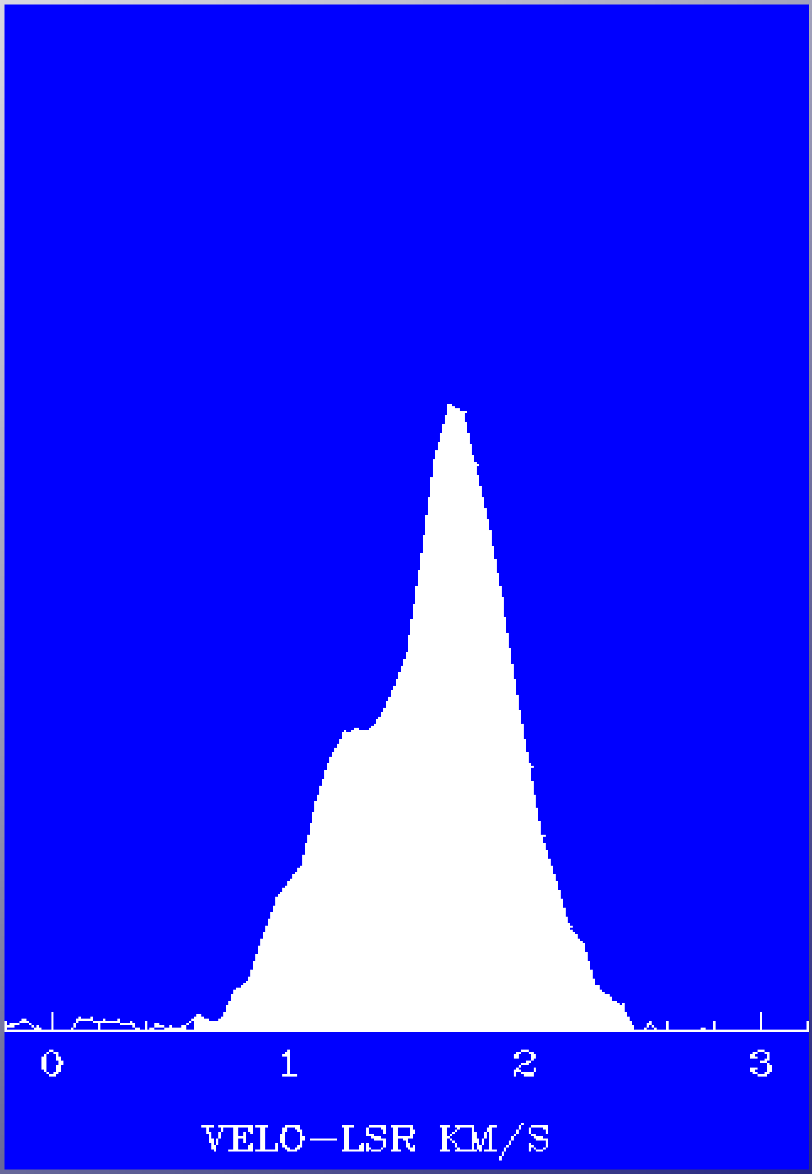
North-west University, South Africa
Moshe Elitzur
University of Kentucky

6.7 GHz methanol masers can be highly variable

G351.78-0.54 – variations over one year showing three cycles.



What can maser variability tell us about the process of high mass star formation?

Format

- Primarily presenting 6.7 GHz observations
- Where available, I will show 12.2 GHz observations
- 6 periodic sources
- G9.62+0.20 in greater detail: ARO observations @ 107 GHz, VLBA imaging @ 12 GHz
- List of suggestions for mechanisms

Observations at 6.7 GHz

with the 26-m Hartebeesthoek Telescope

- **Initial survey (Goedhart et al., 2004 MNRAS, 355,553):**
  - January 1999 --> April 2003
  - 54 sources
  - single polarisation (LCP)
  - 256-channel correlator at 0.32 or 0.64 MHz bandwidth

  Time-series plotted in blue

- Ongoing monitoring
  - ***New main reflecting surface, ~0.5mm rms (22 GHz available!)***
  - Rebuilt receiver in 2003, dual polarisation, LCP & RCP
  - new control computer & observing software
  - 1024 channels/pol correlator at 1 MHz bandwidth
  - 19 sources of interest

  Time-series plotted in black

Observations at 12.2 GHz

with the 26-m Hartebeesthoek Telescope

Most 12 GHz sources weak compared to 6.7 GHz – not always possible to achieve sufficient S/N for time-series analysis

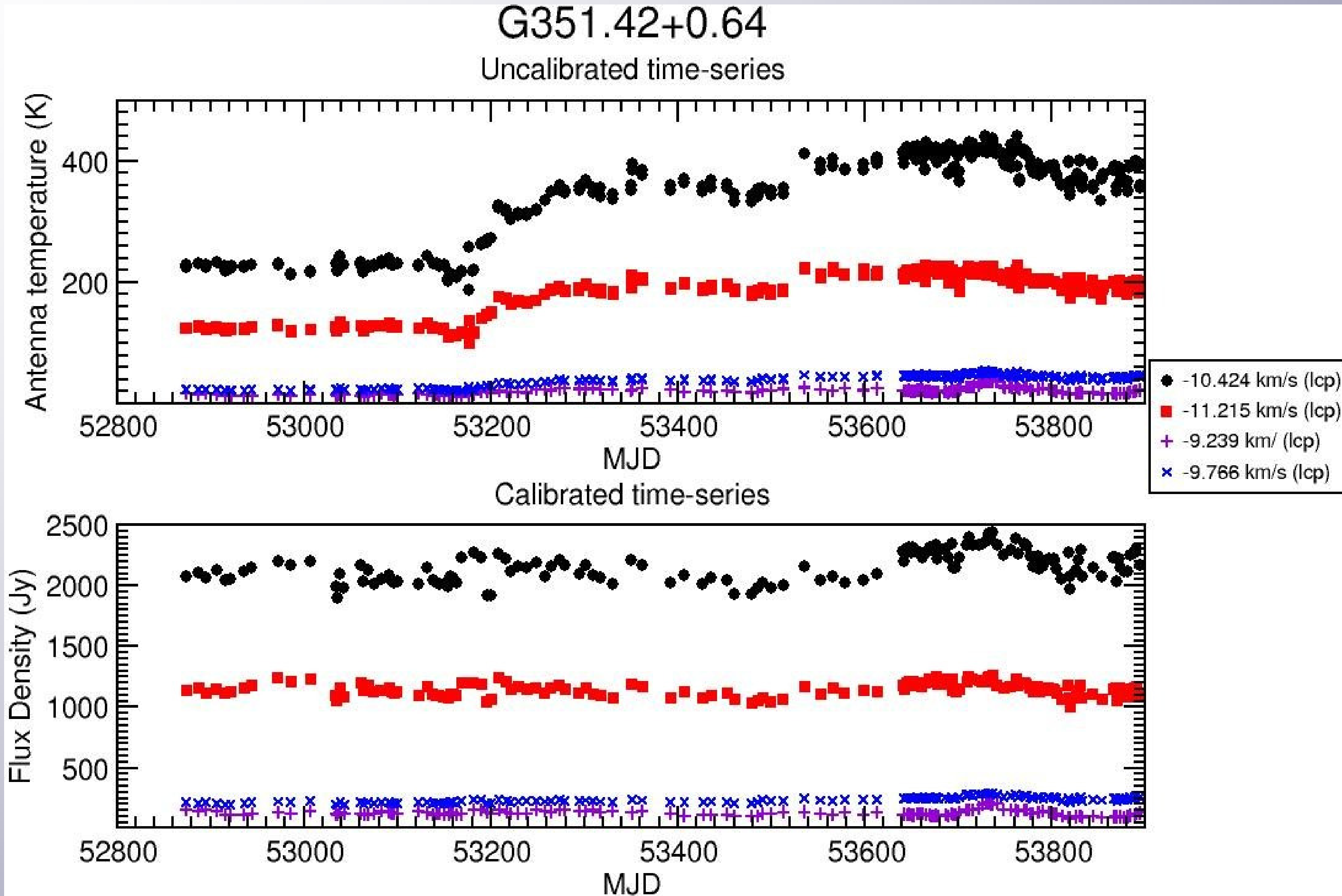
- Prior to surface upgrade, only monitoring strongest sources at 12 GHz (G9.62+0.20 shown)
- Similar observing parameters to 6.7 GHz

Time-series plotted in red

Amplitude calibration

- Continuum drift scans scheduled with each set of spectral line observations
- Hydra A, Virgo A & 3C123
- with pointing checks

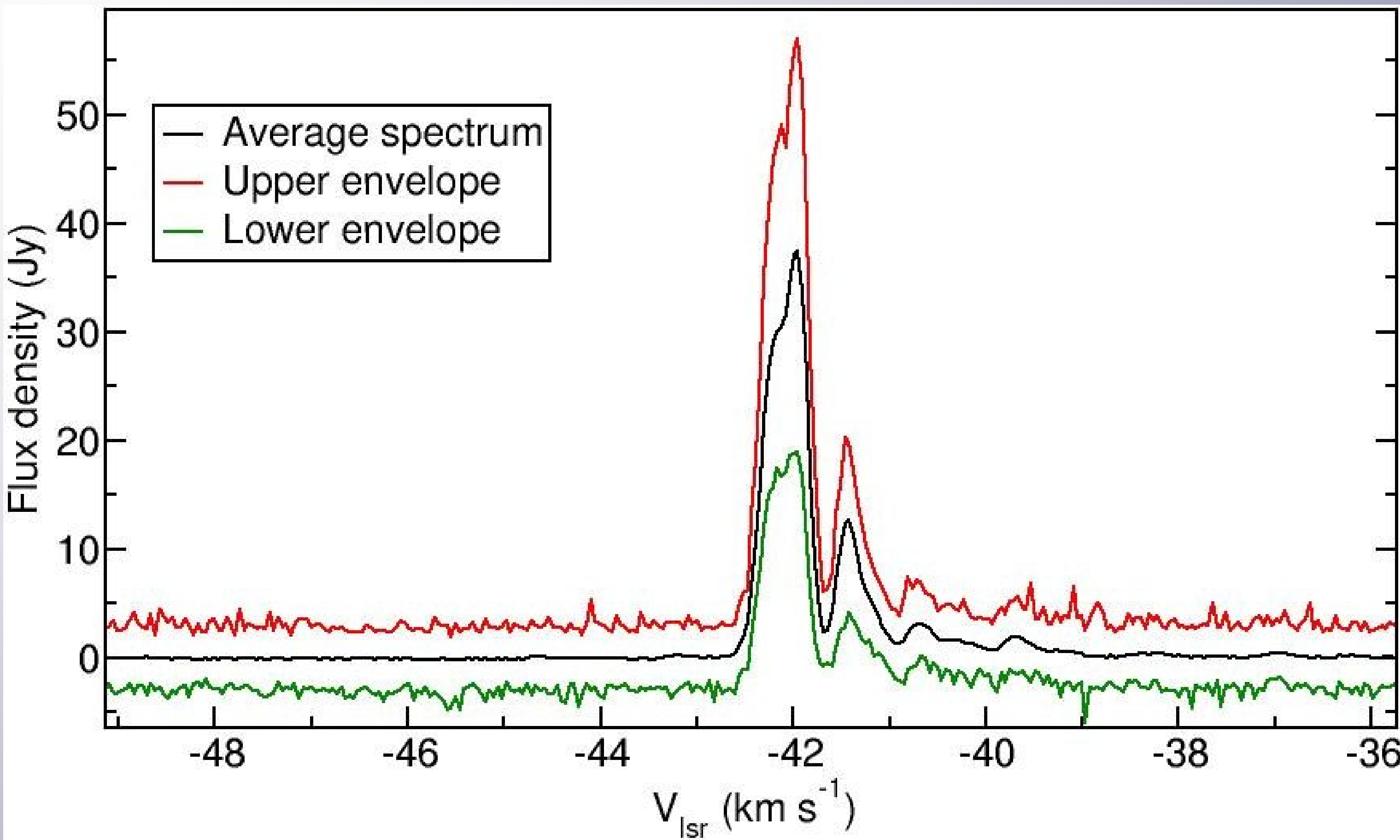
Comparison source at 6.7 GHz



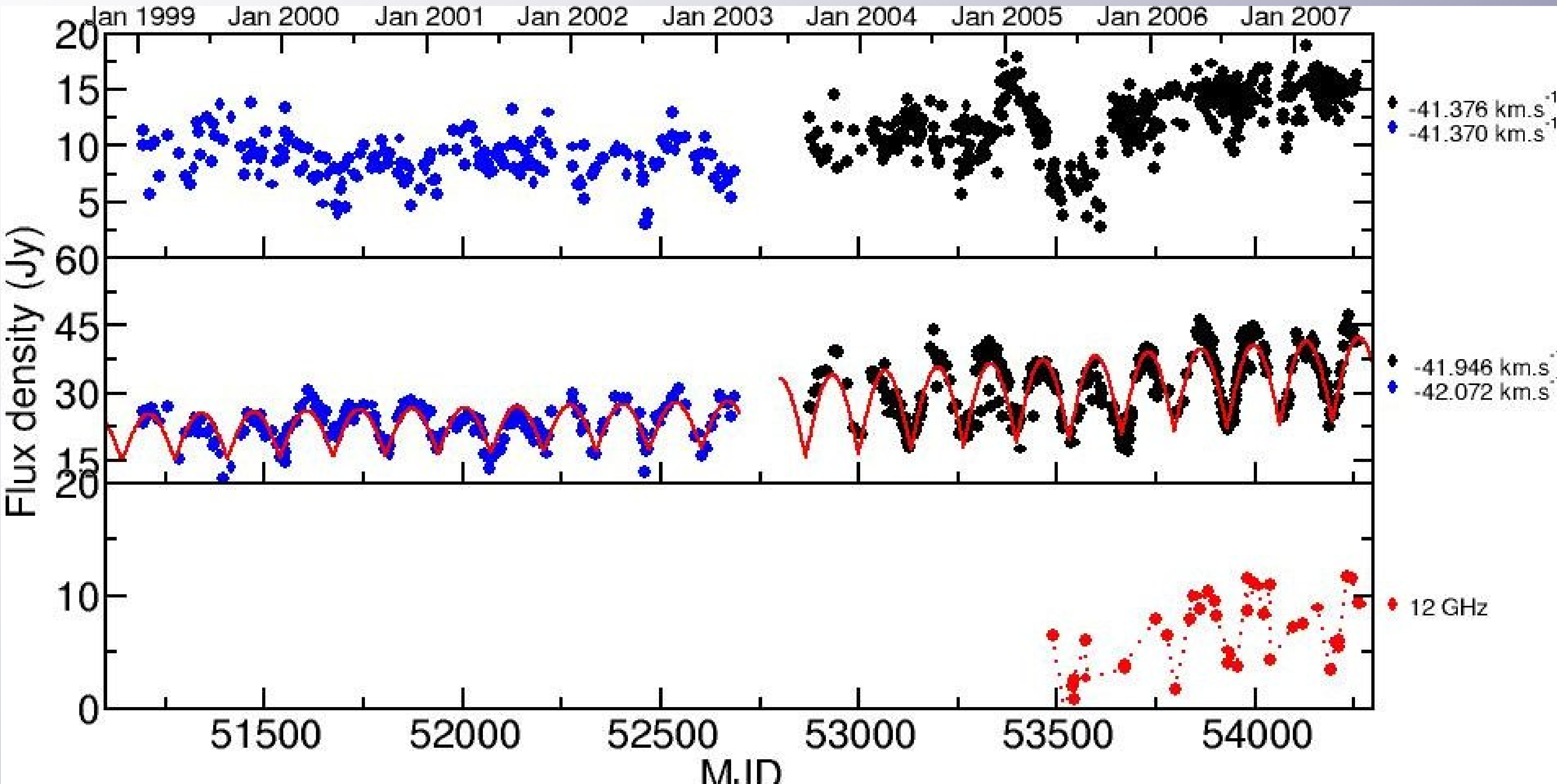
Period searches

- DFT (Period04 from the Delta Scuti network)
  - Lenz & Breger , 2005, Commun. Astroseismology 146, 53
  - only works well for sinusoidal curves or if cycle profiles repeat well
- Epoch-folding
  - Makes no assumption about shape of pulse
  - Sensitivity depends on test statistic and binning
  - Using Davies L statistic (1990,MNRAS, 244, 93)
  - works better for lots of cycles
- Sanity check – periods should be consistent between the two methods.

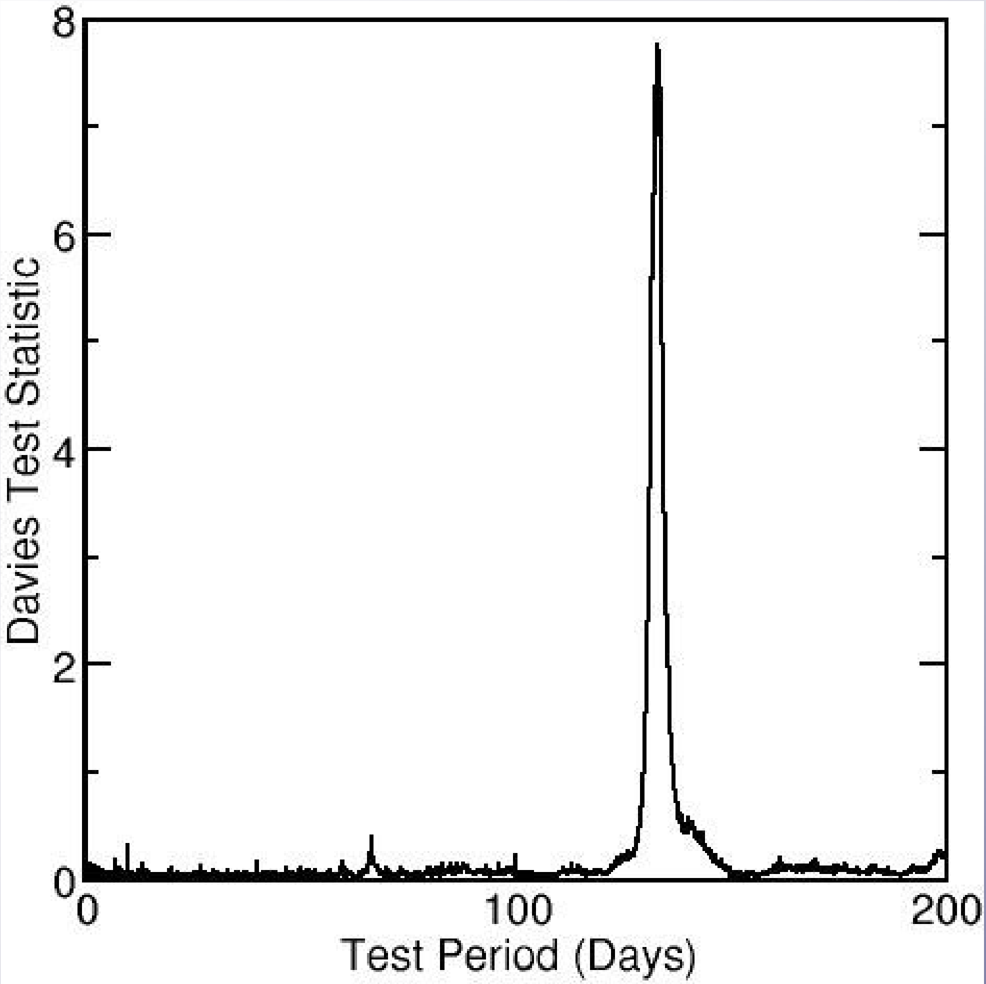
G338.93-0.06: Range of variation

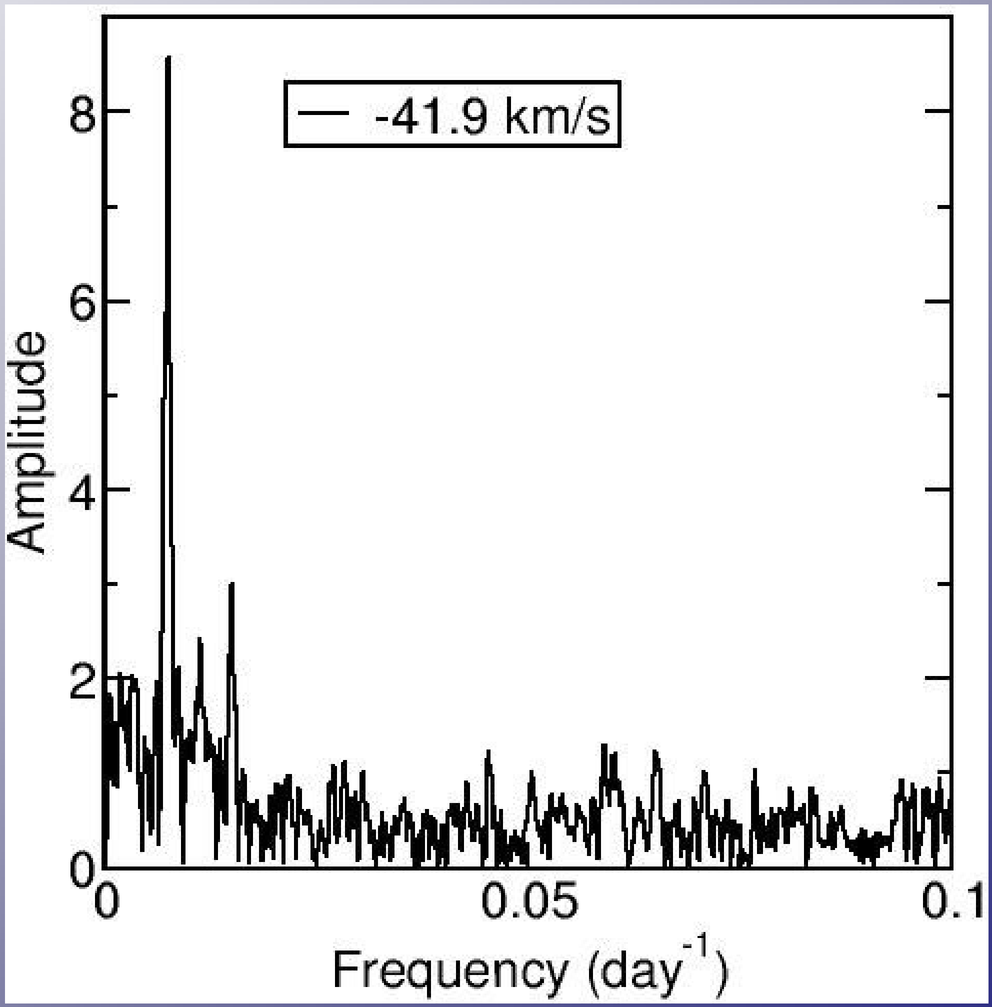


G338.93-0.06: Time-series



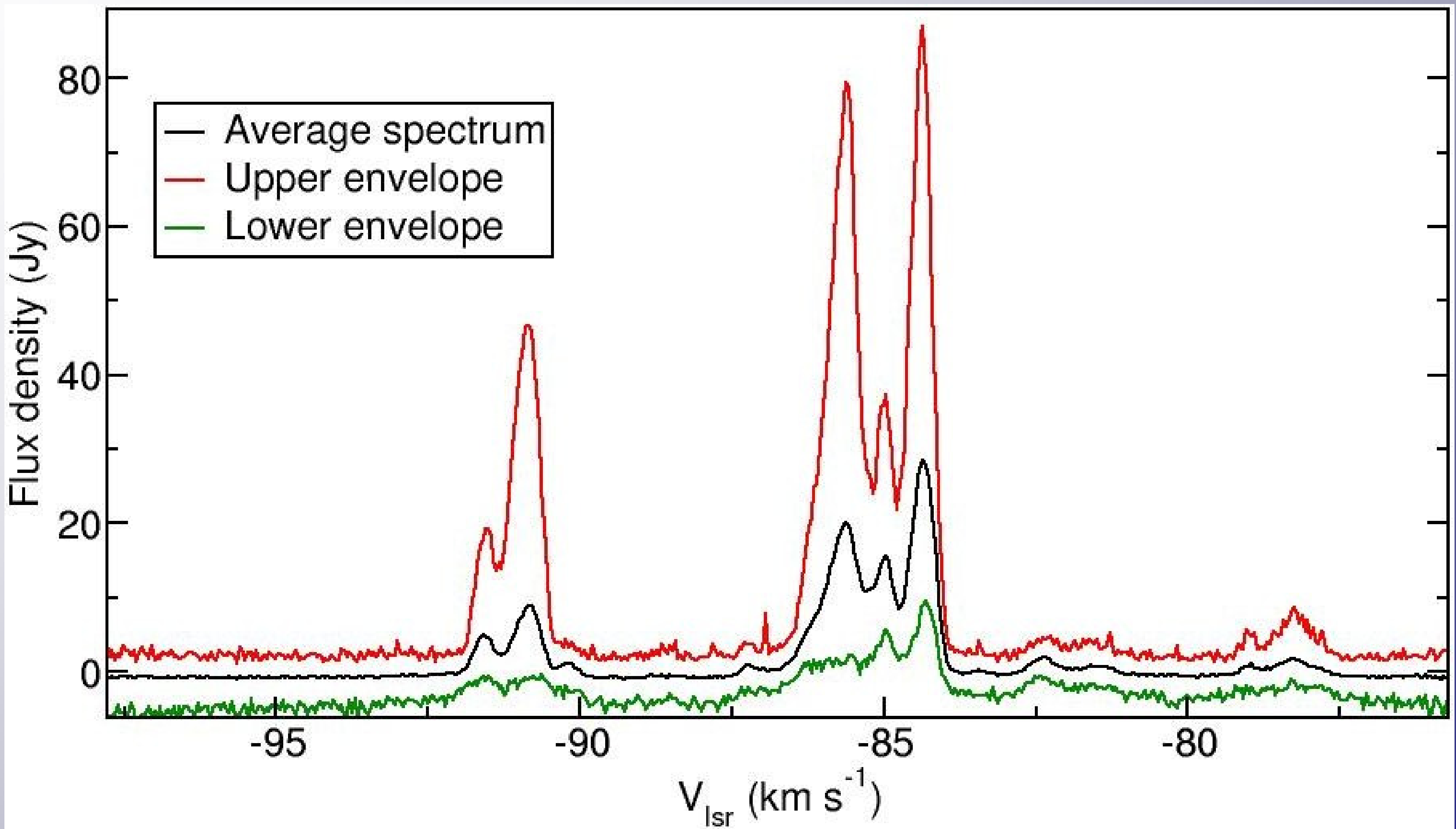
G338.93-0.06: Epoch-folding & Fourier Periodograms



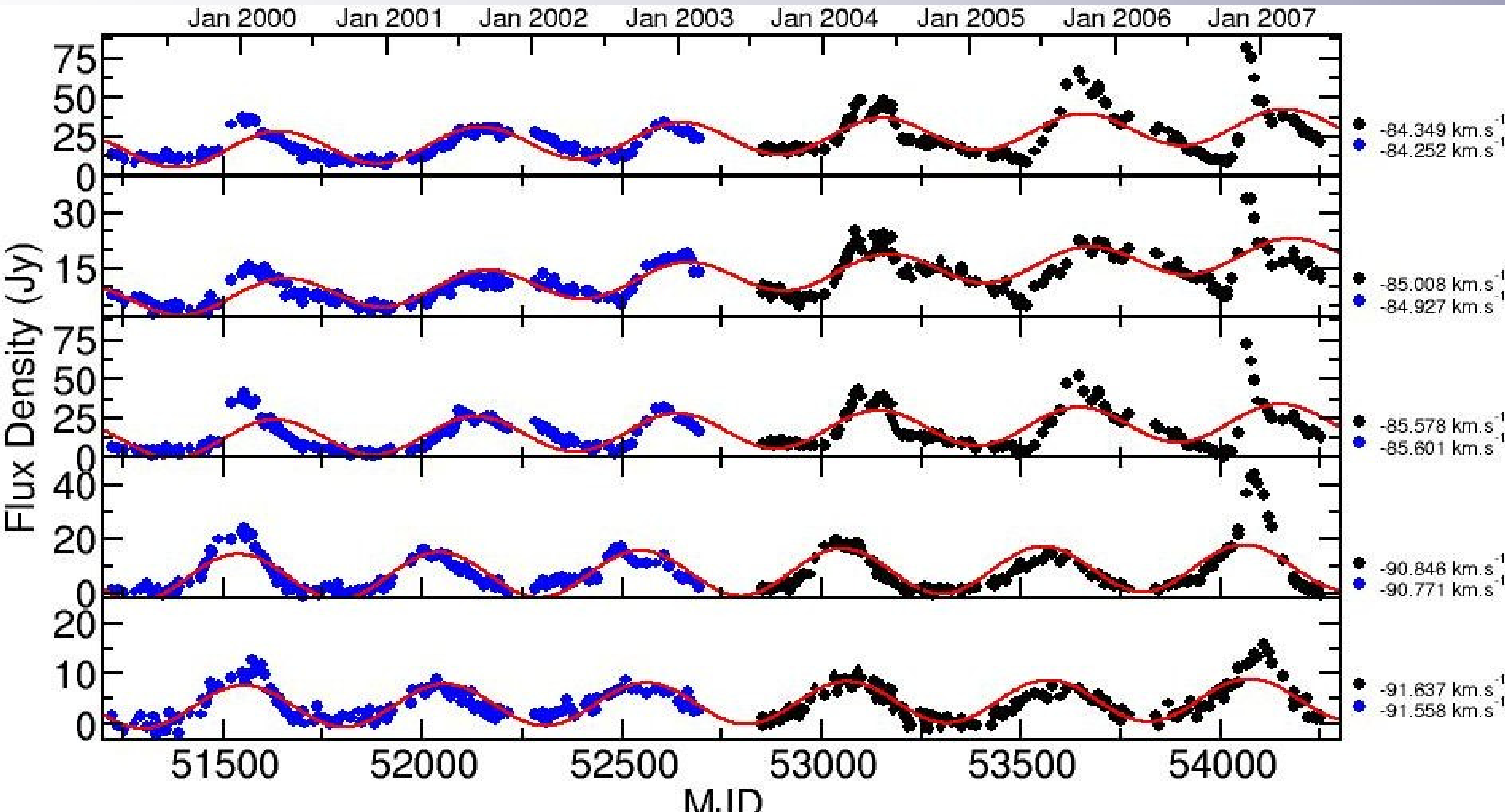


P = 133 days

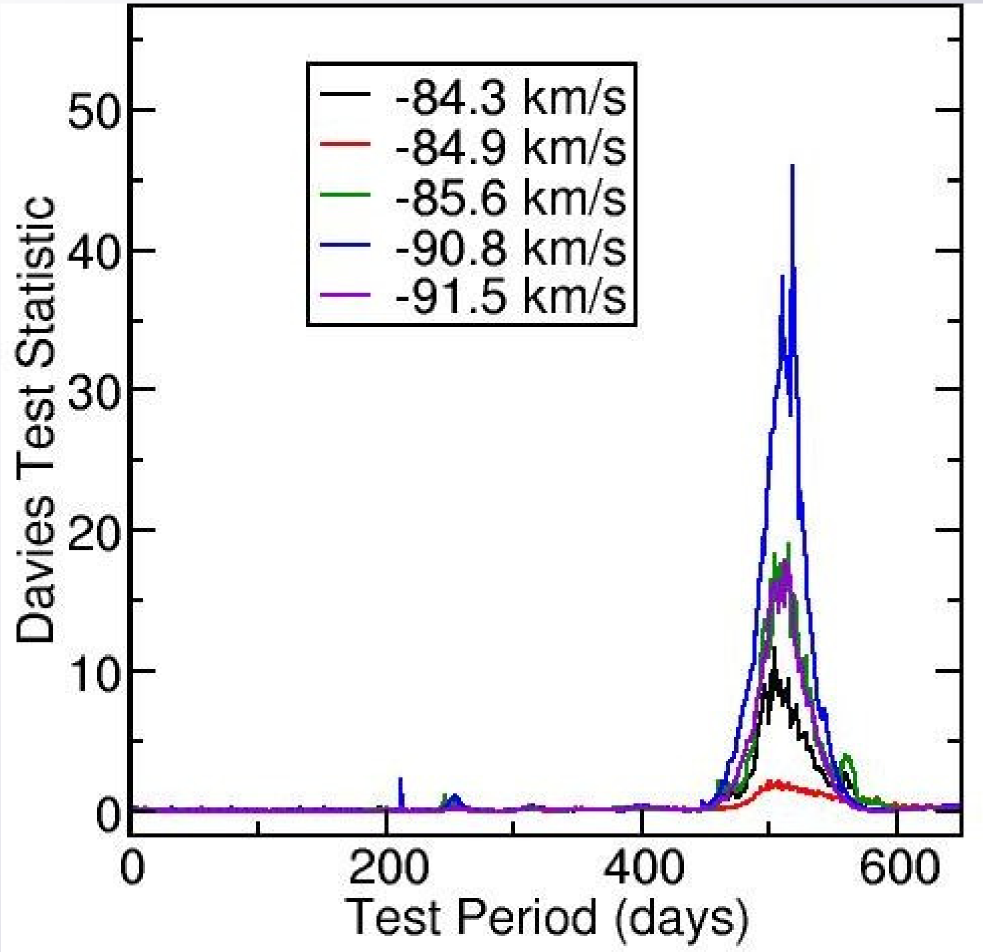
G331.13-0.24: Range of variation

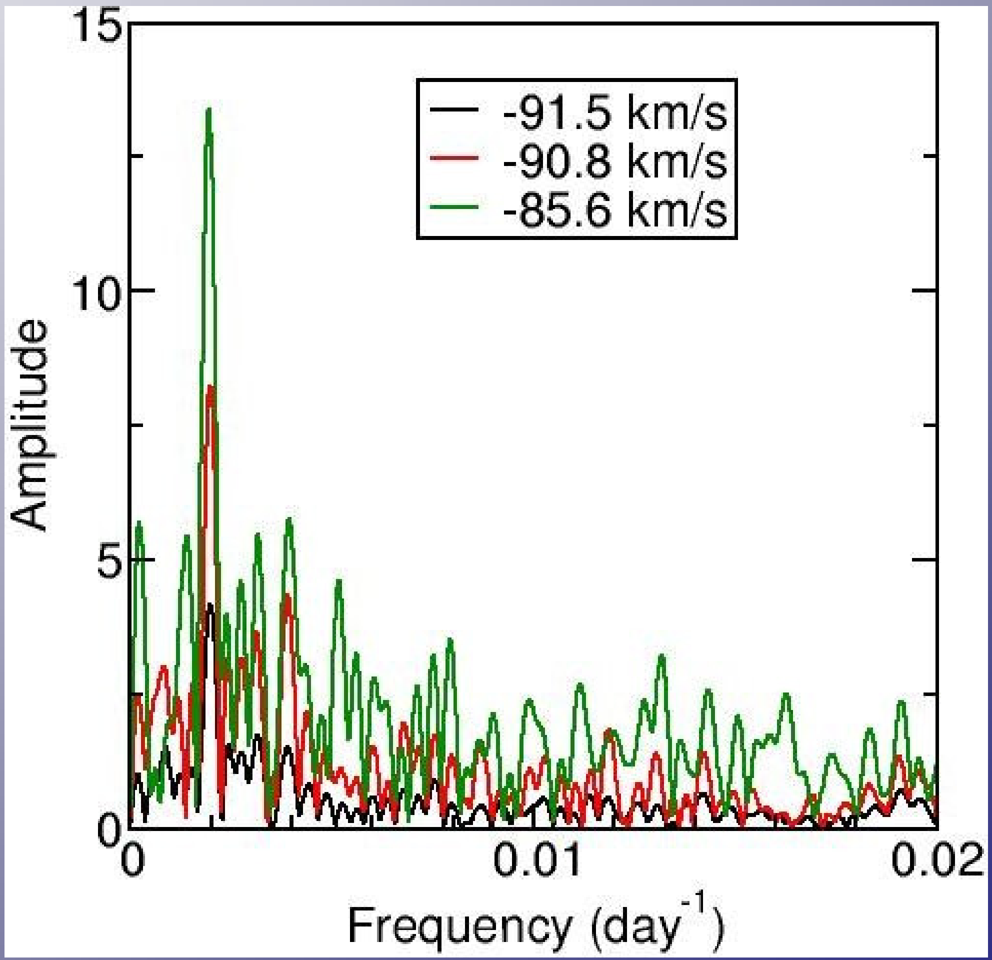


G331.13-0.24: Time-series



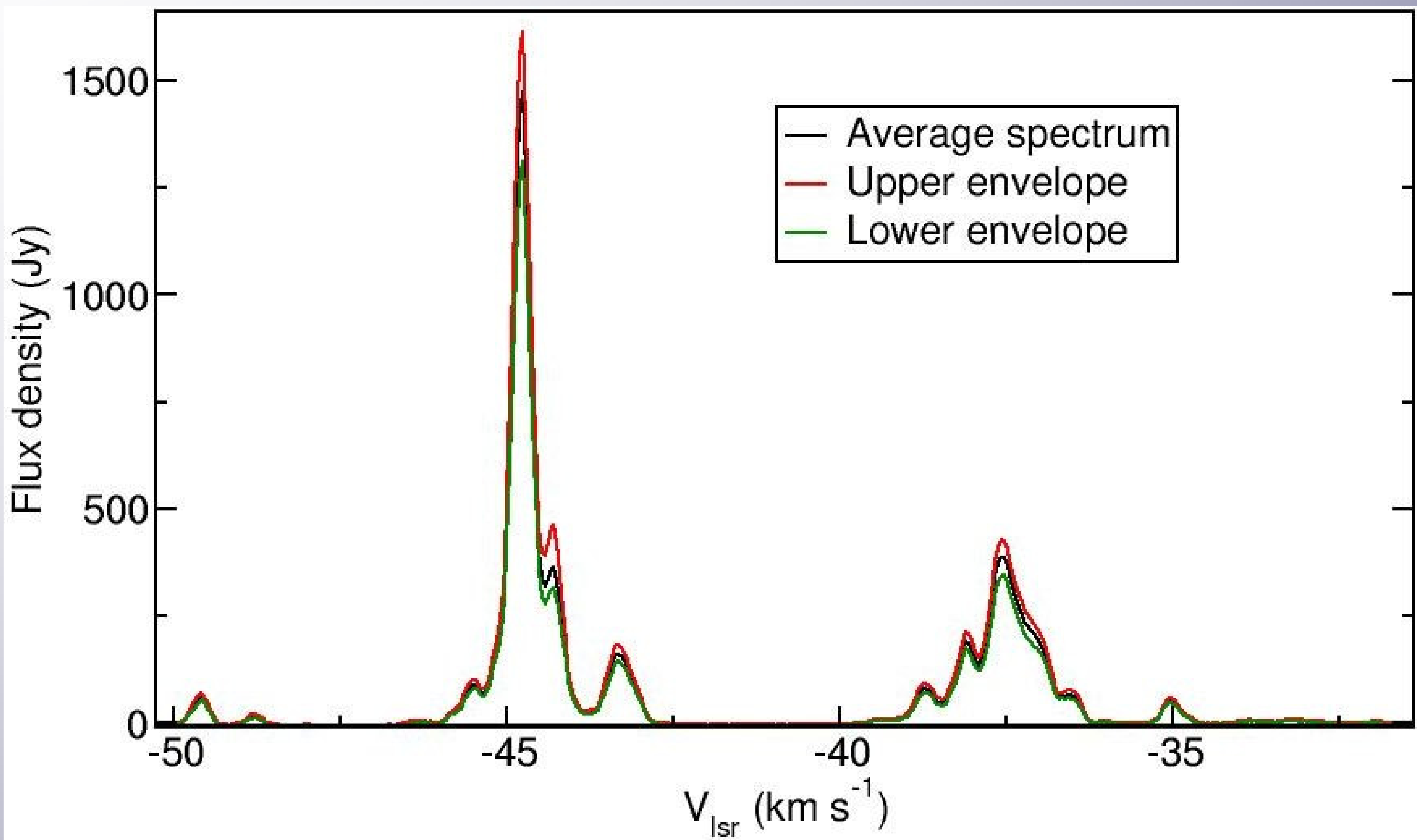
G331.13-0.24: Epoch-folding & Fourier Periodograms



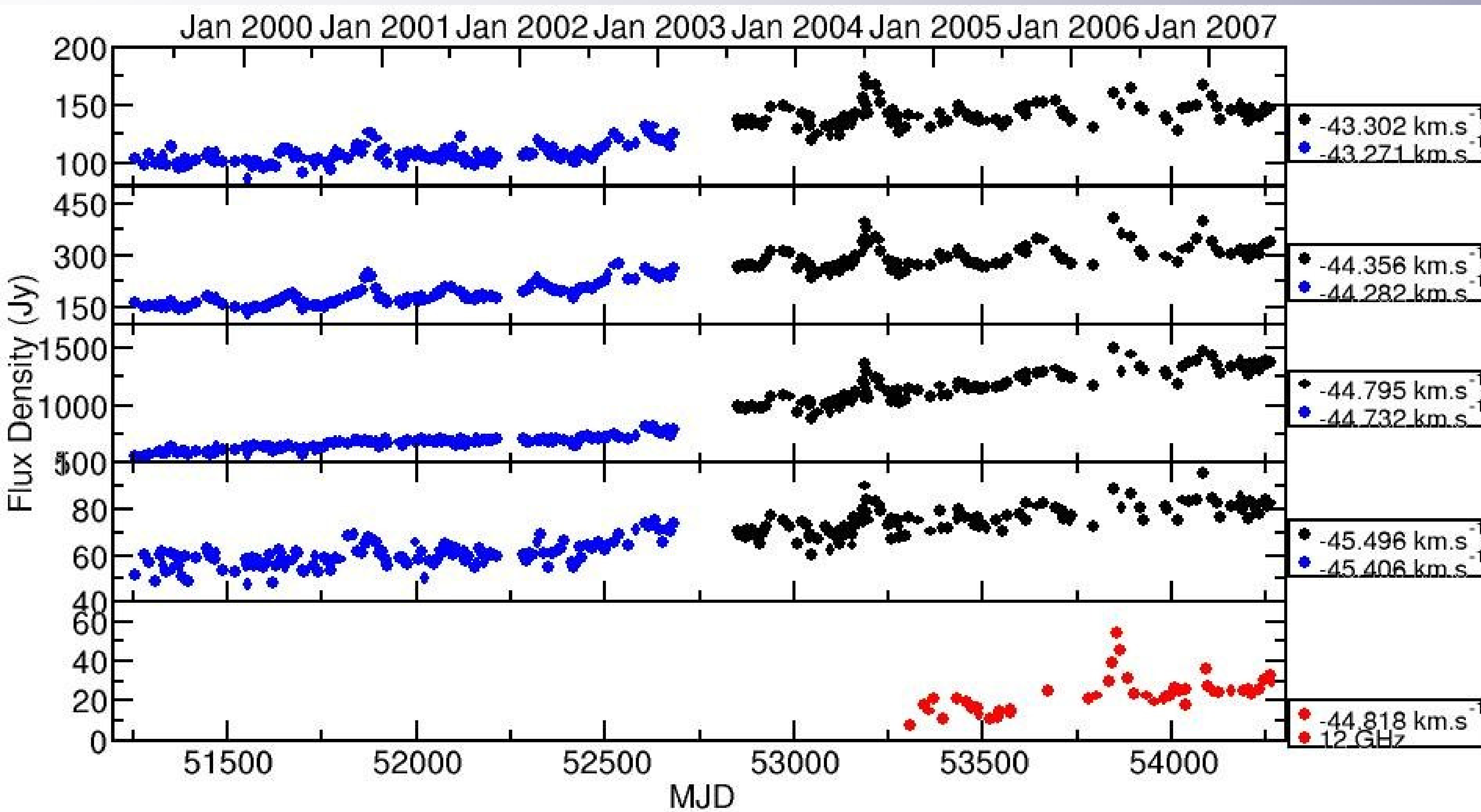


P = 504 days

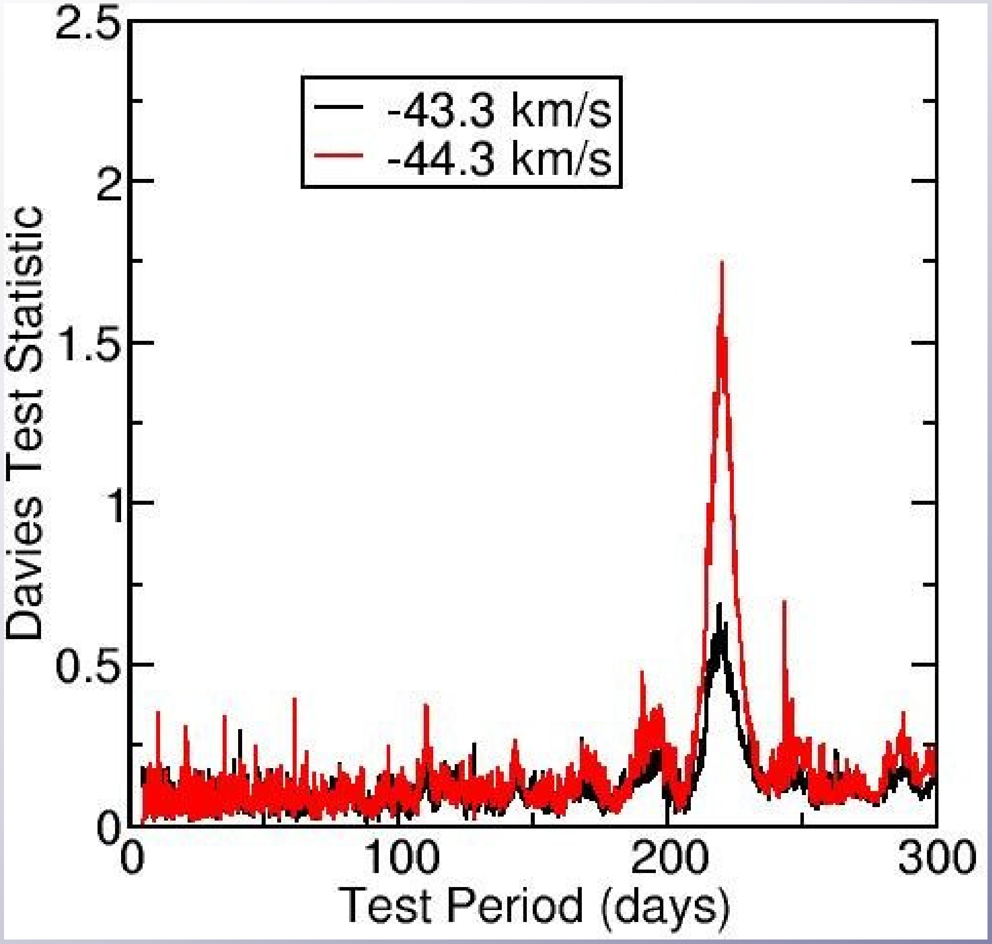
G328.24-0.55: Range of variation

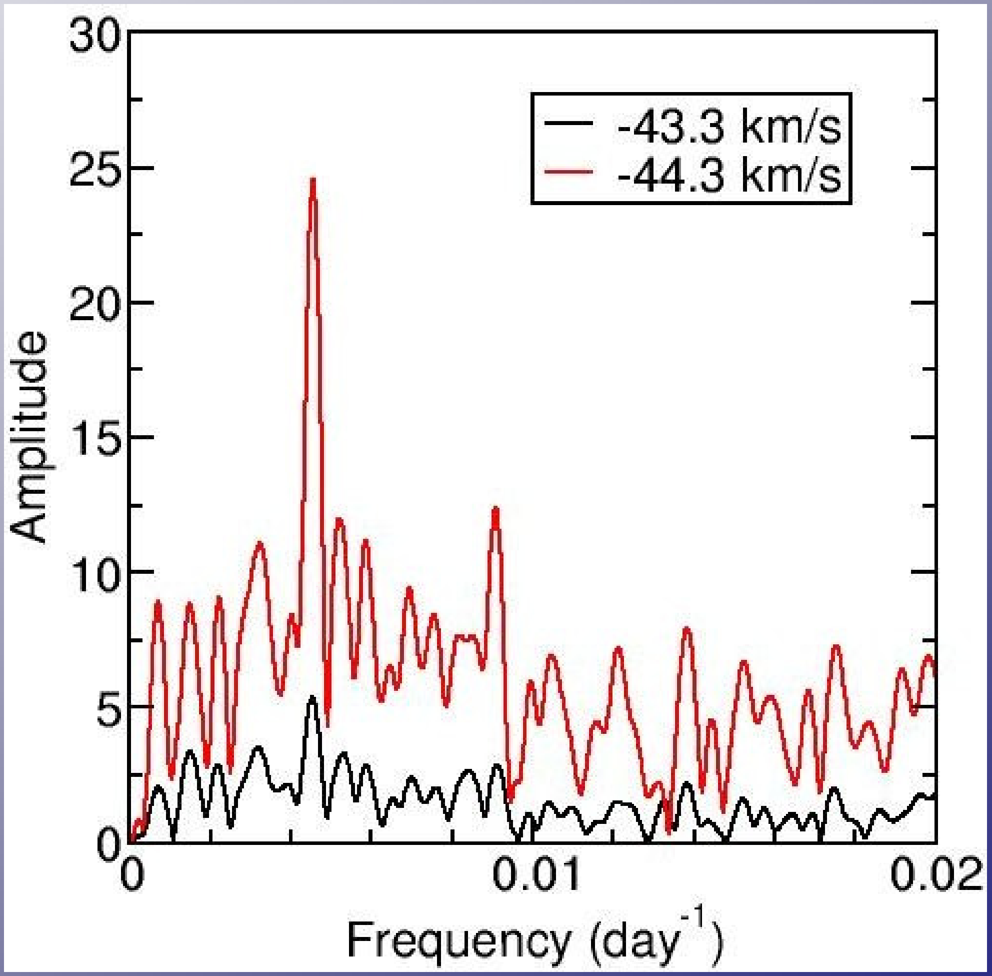


G328.24-0.55: Time-series



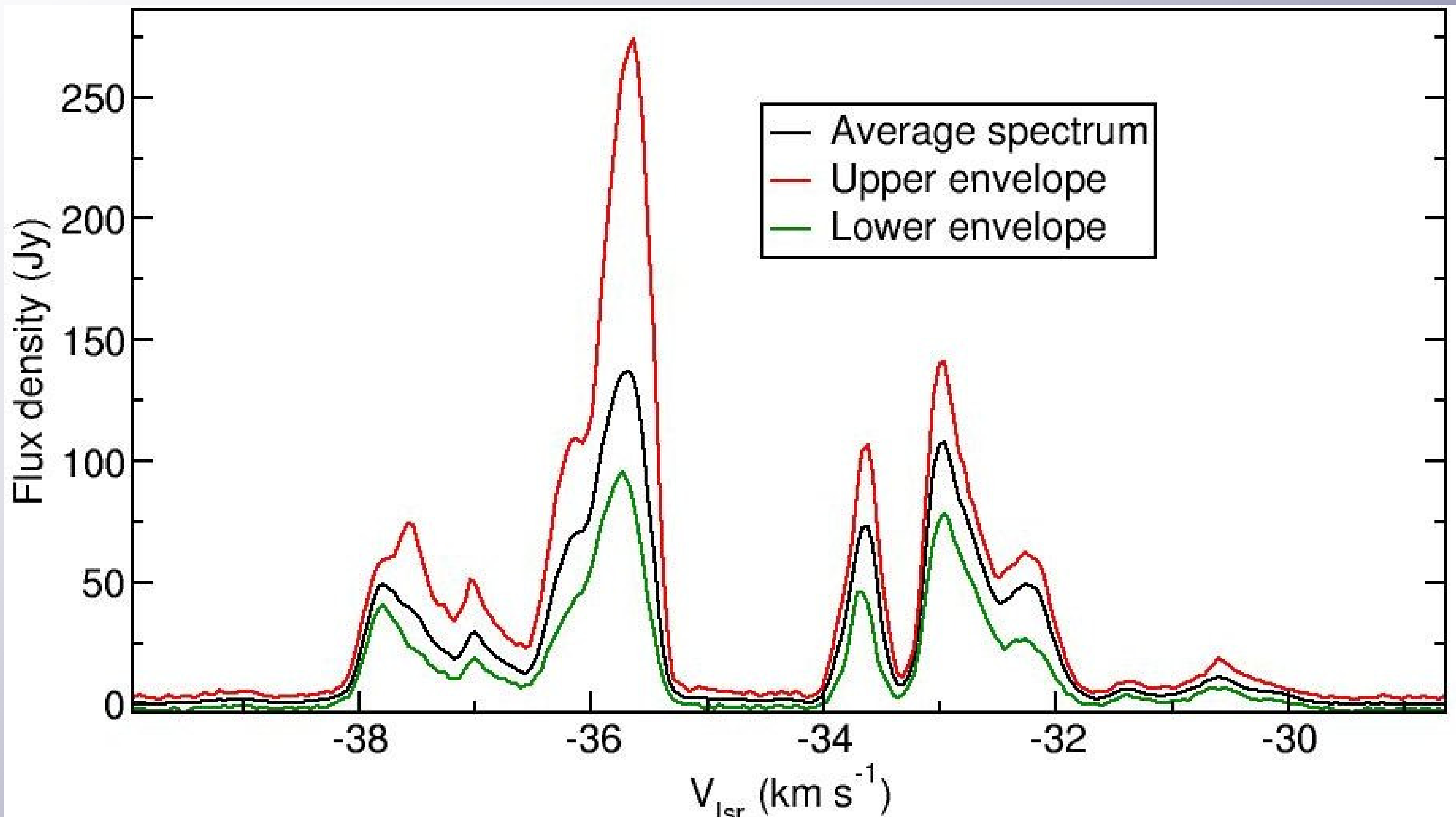
G328.24-0.55: Epoch-folding & Fourier Periodograms



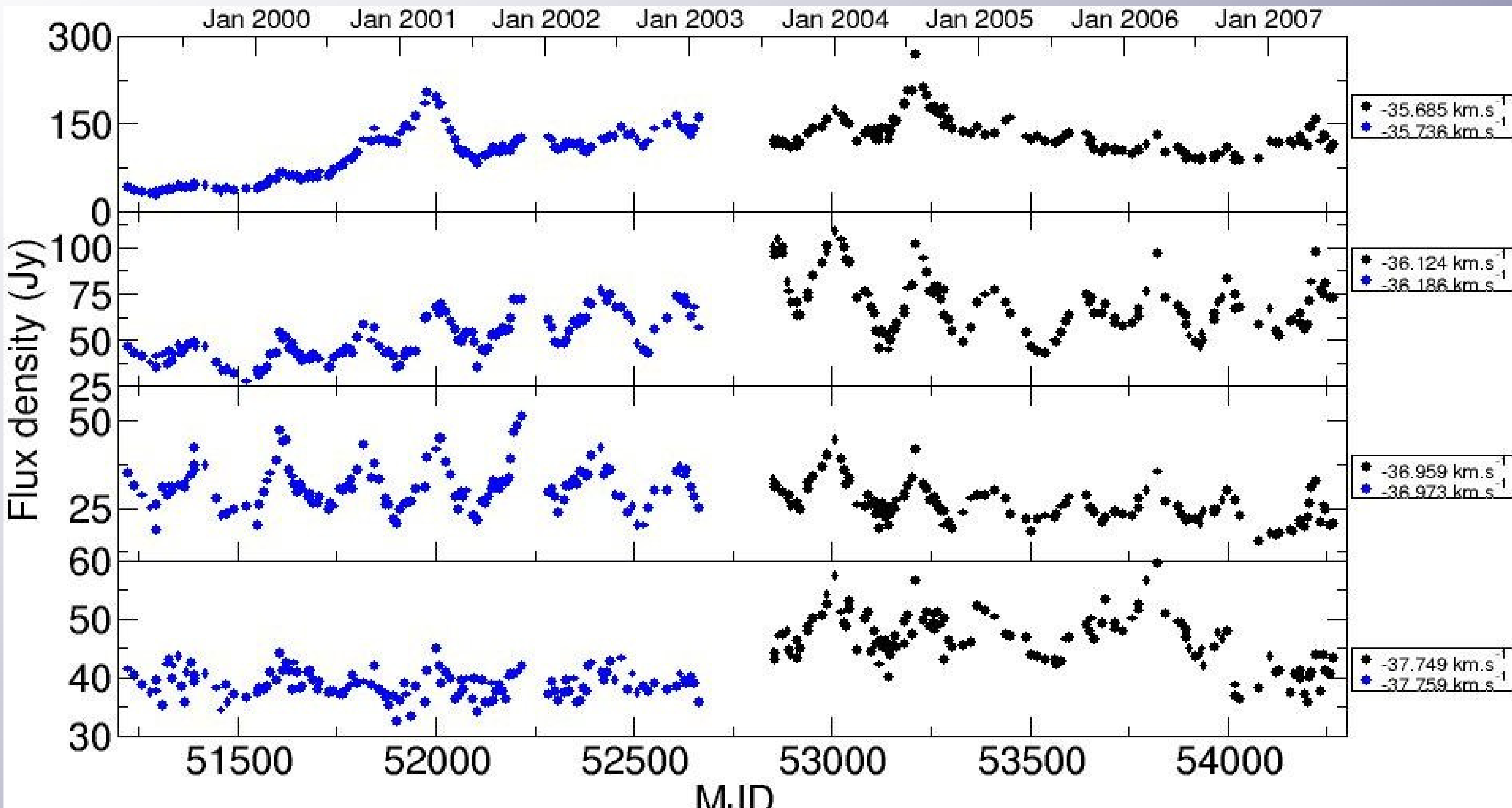


P = 220 days

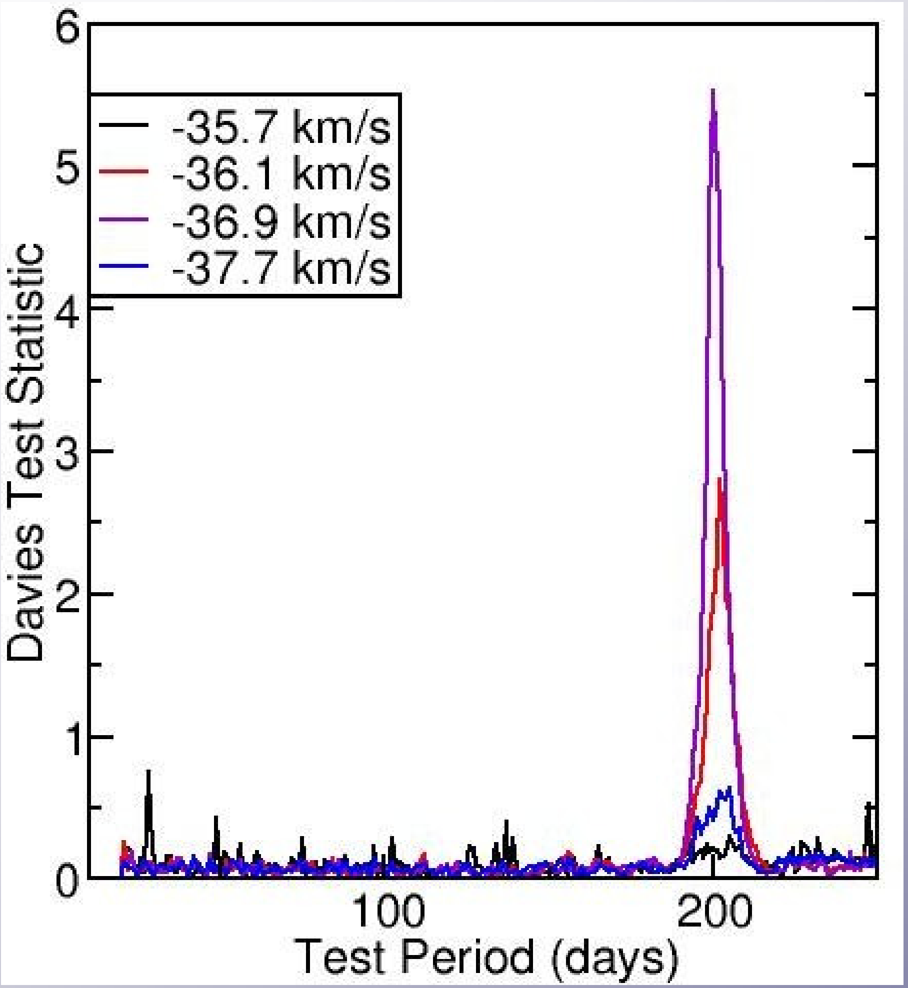
G339.62-0.12: Range of variation

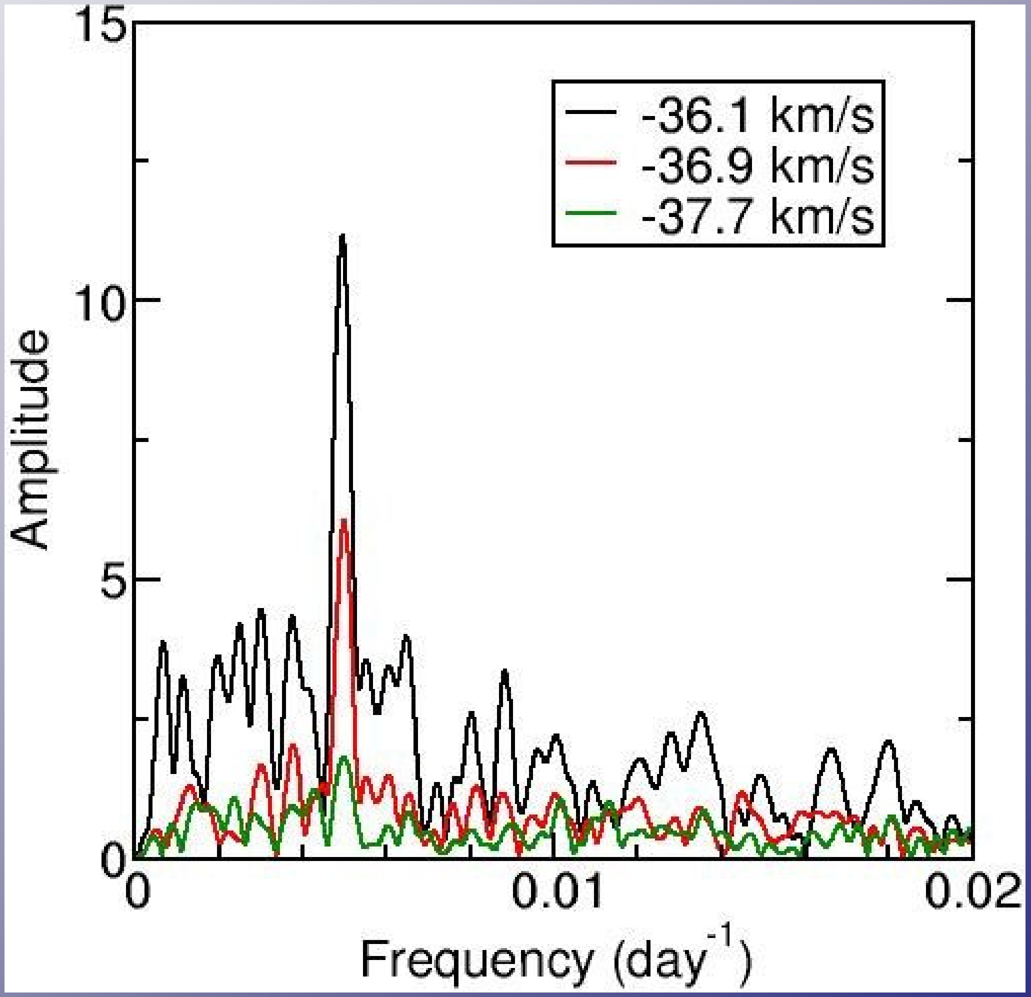


G339.62-0.12: Time-series



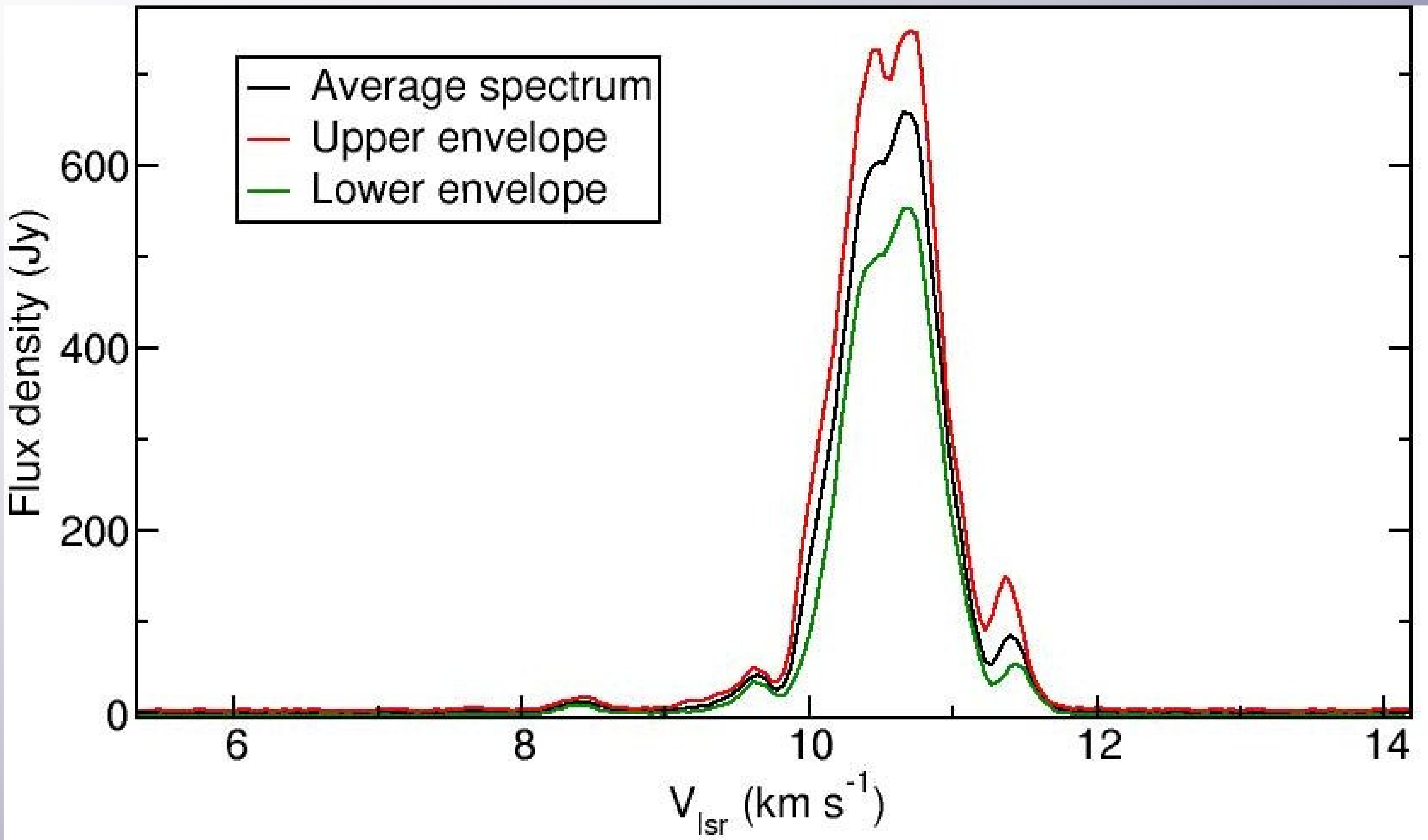
G339.62-0.12: Epoch-folding & Fourier periodograms



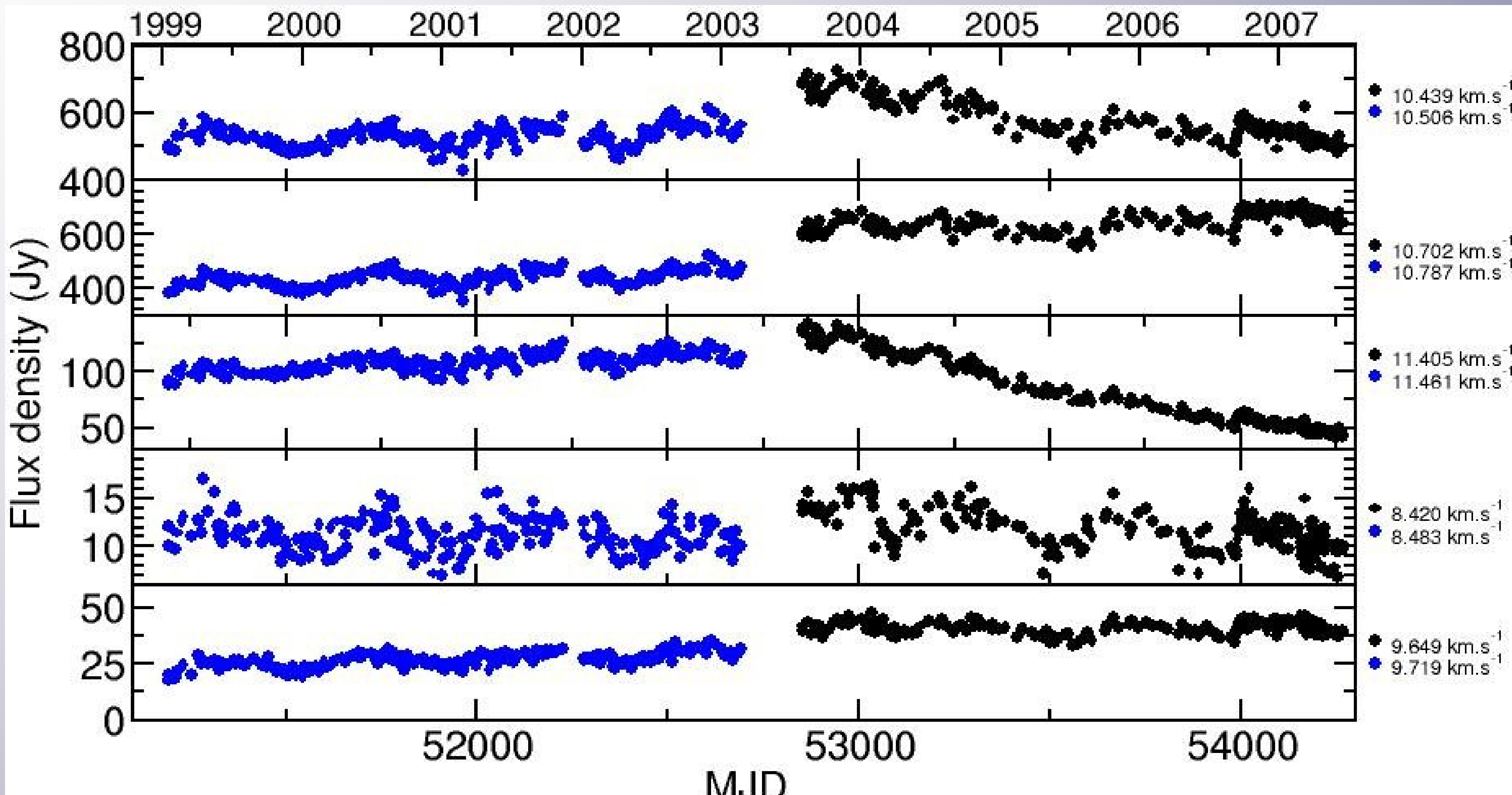


P = 201 days

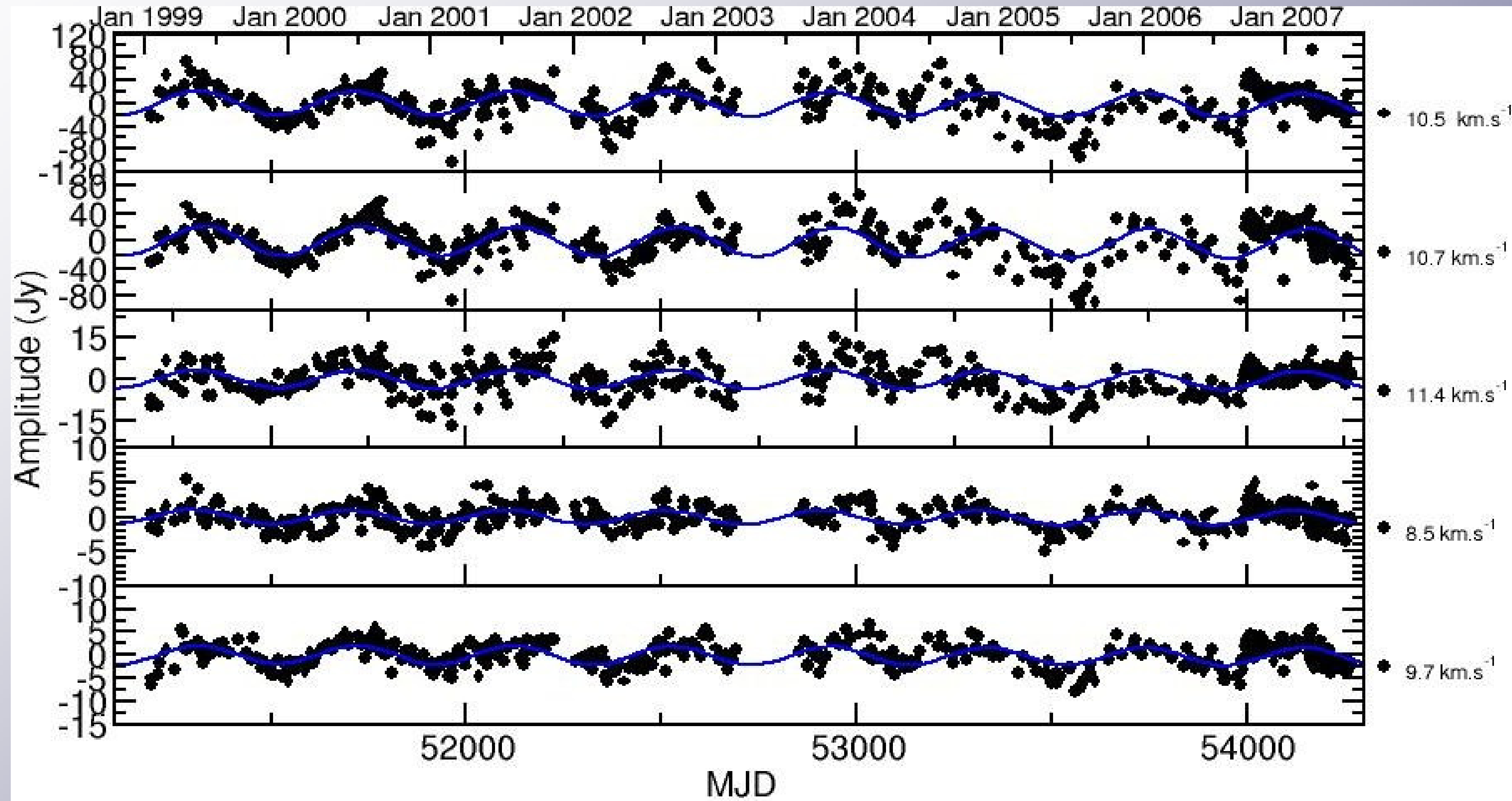
G188.95+0.89: Range of variation



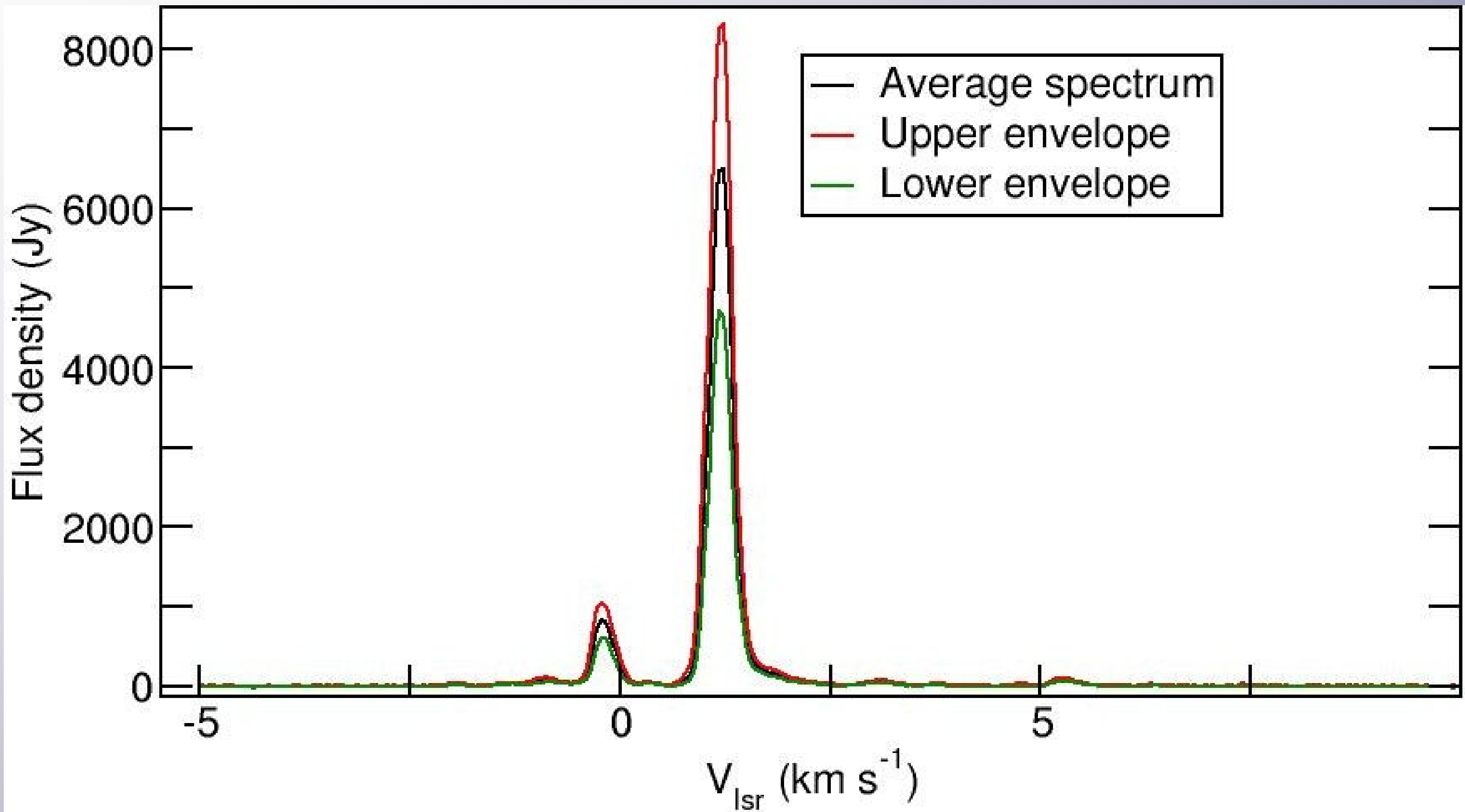
G188.95+0.89: Time-series



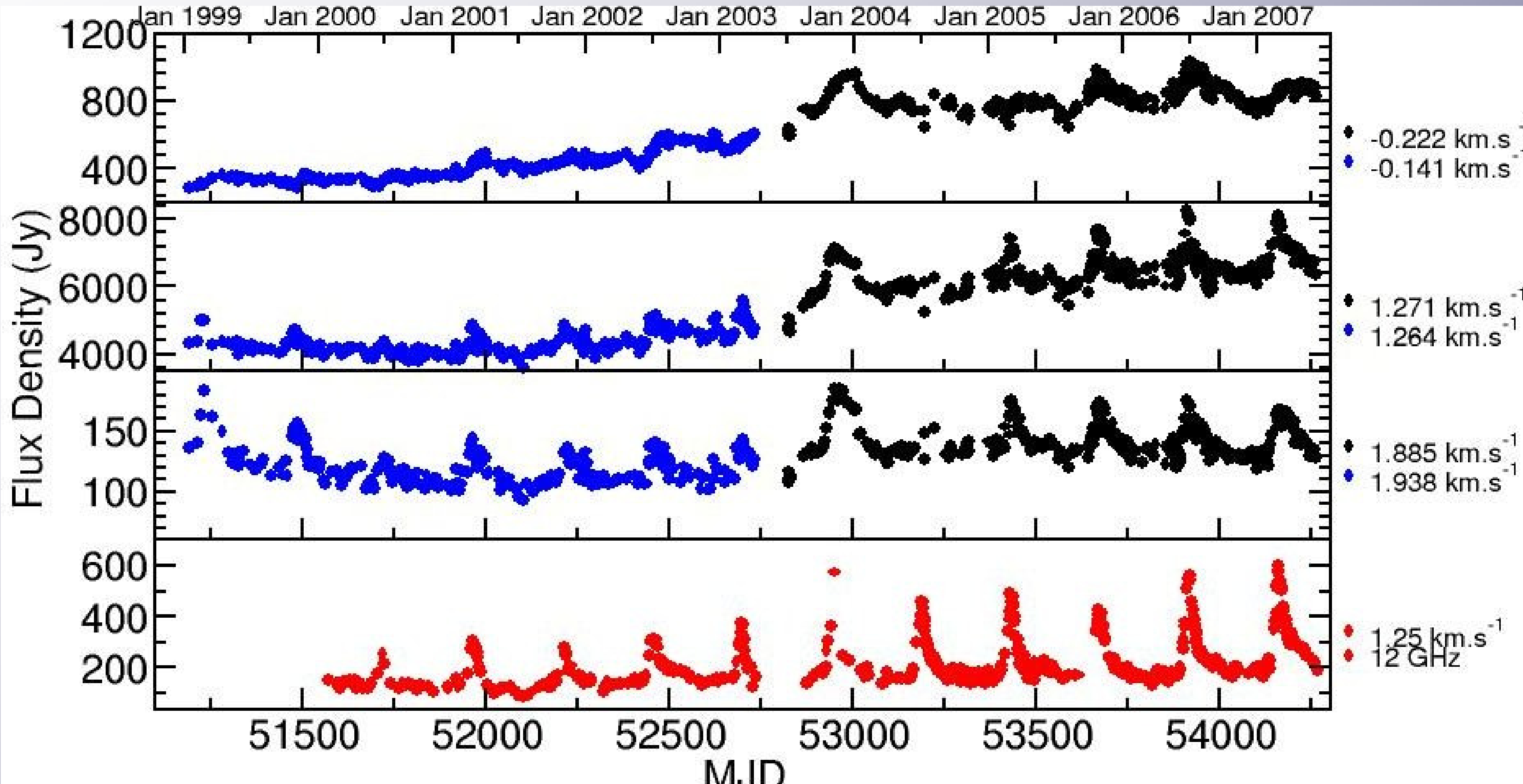
G188.95+0.89: Fits to detrended data



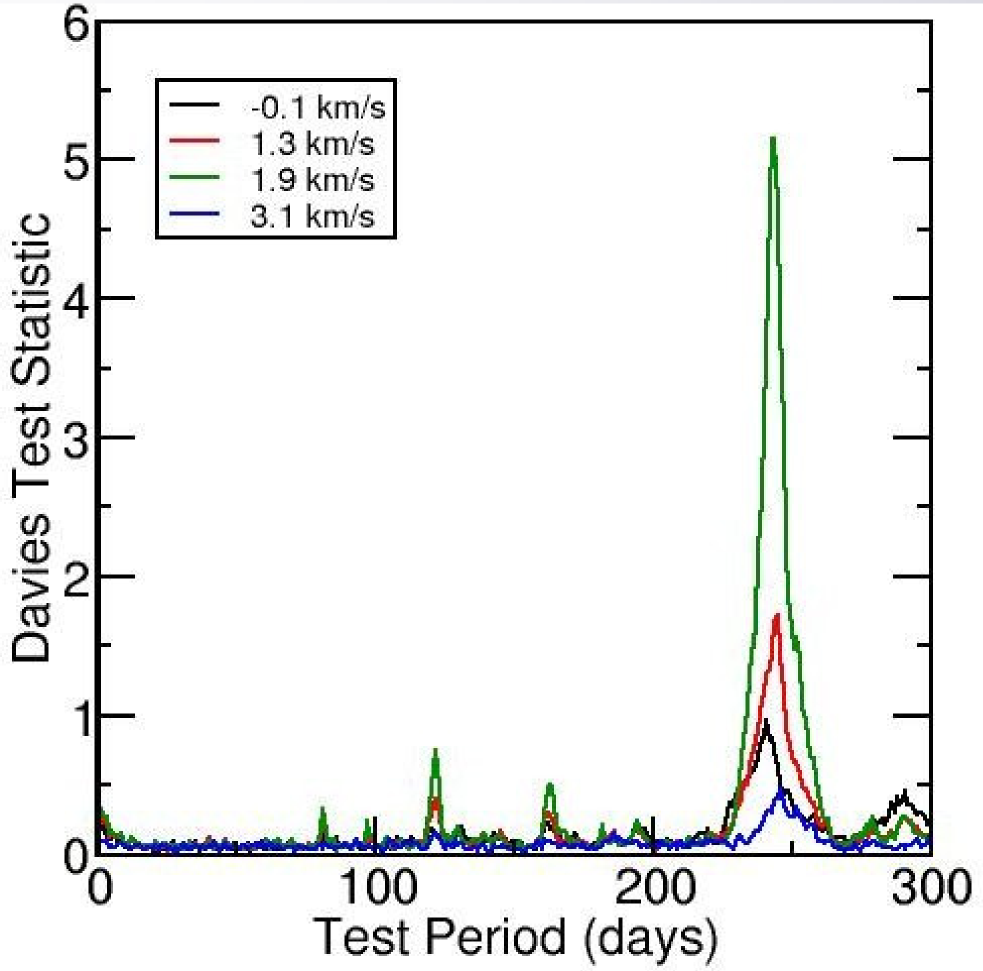
G9.62+0.20: Range of variation

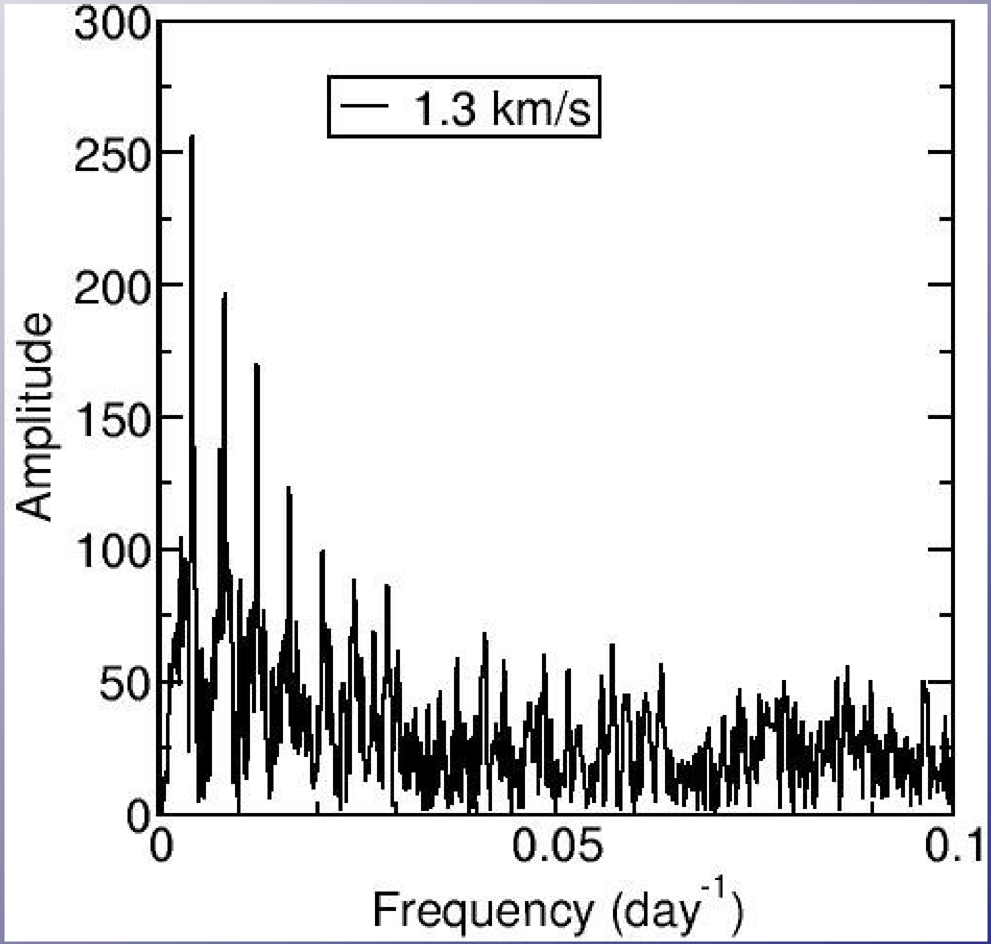


G9.62+0.20: Time-series



G9.62+0.20: Epoch-folding & Fourier periodograms





P = 244 days

So, what happens during a flare in G9.62+0.20?

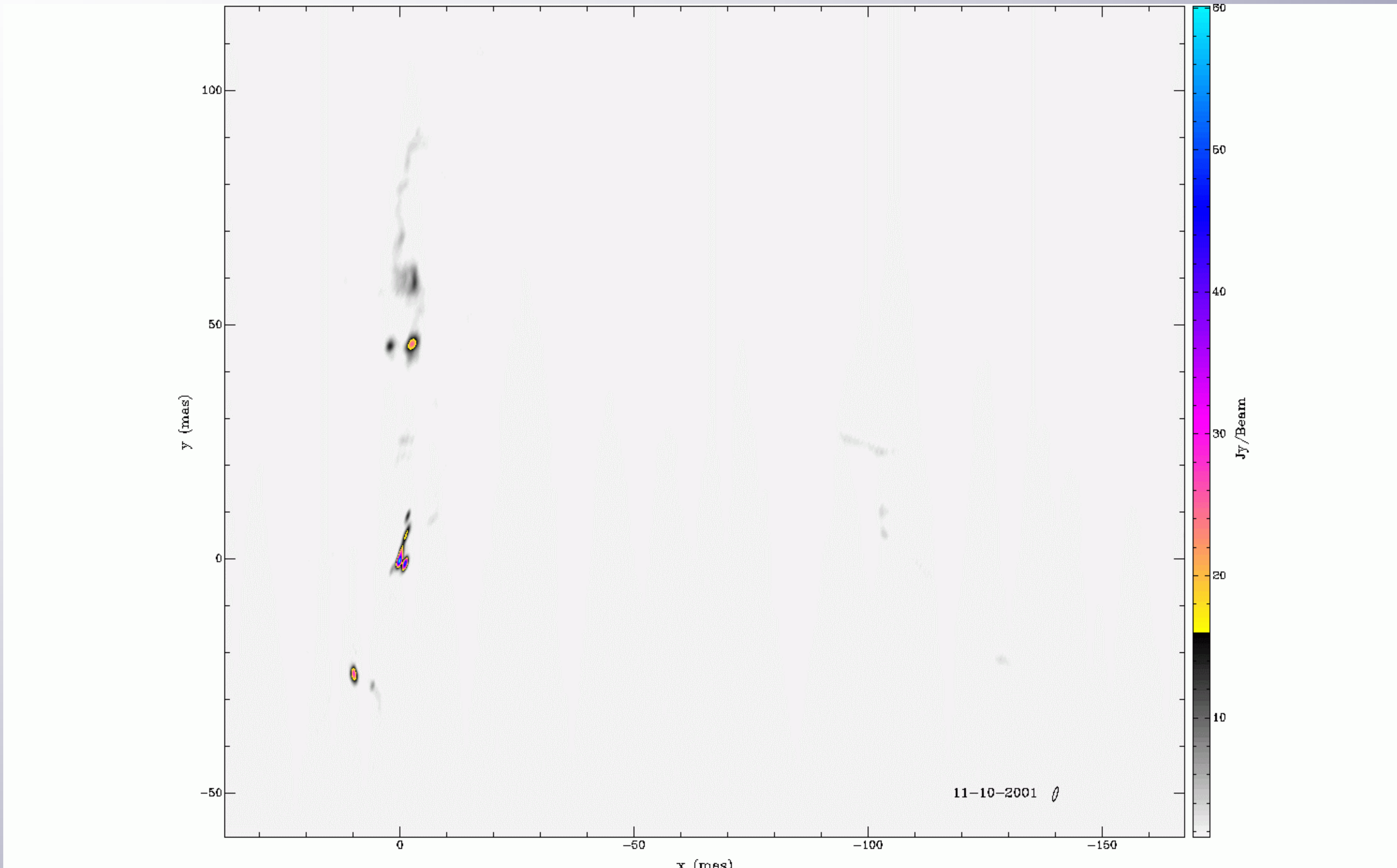
- Local effect or increase in incoming radiation?
- Do new spots appear?
- Is it a shock wave or some other disturbance passing through the masing regions?

VLBA observations of G9.62+0.20

- 7 observations during October – December 2001
- 6 hours integration time/observation
- 12.2 GHz

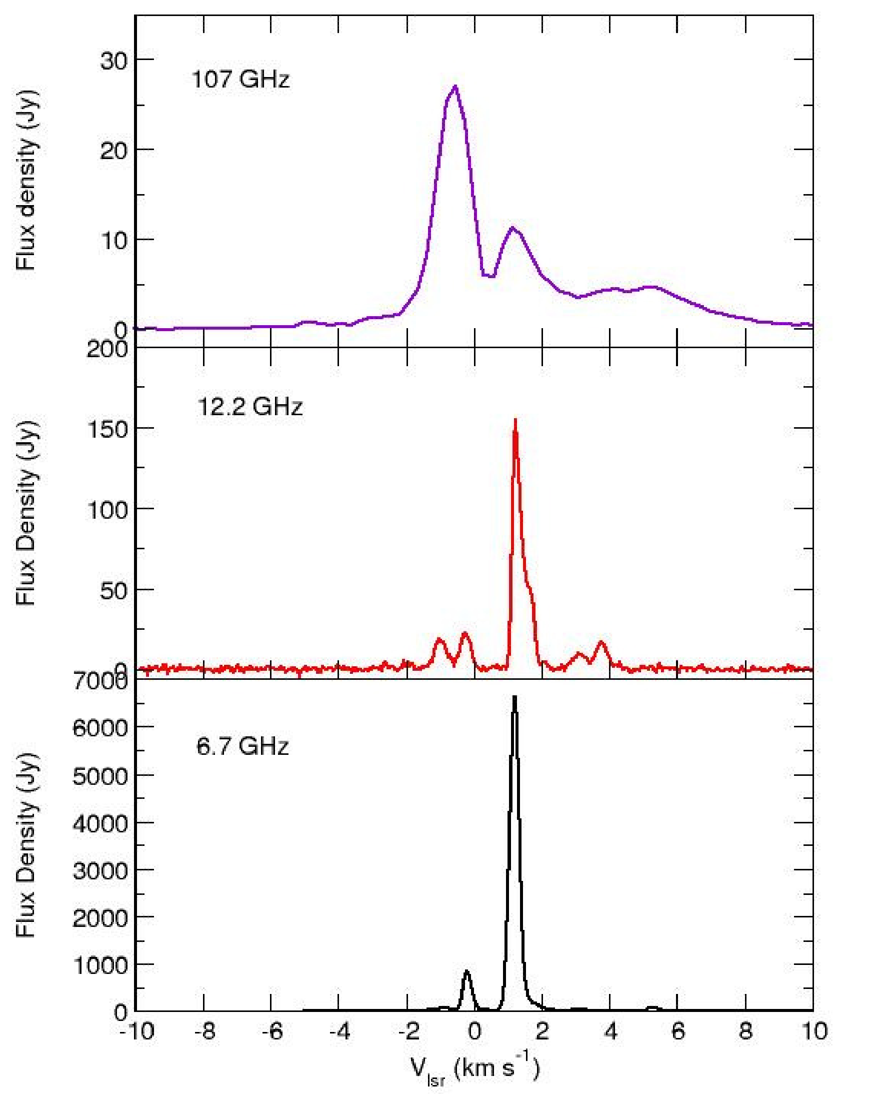
- Goedhart, Minier, Gaylard & van der Walt, 2005, MNRAS, 356, 839

G9.62+0.20 @ 12 GHz during a flare



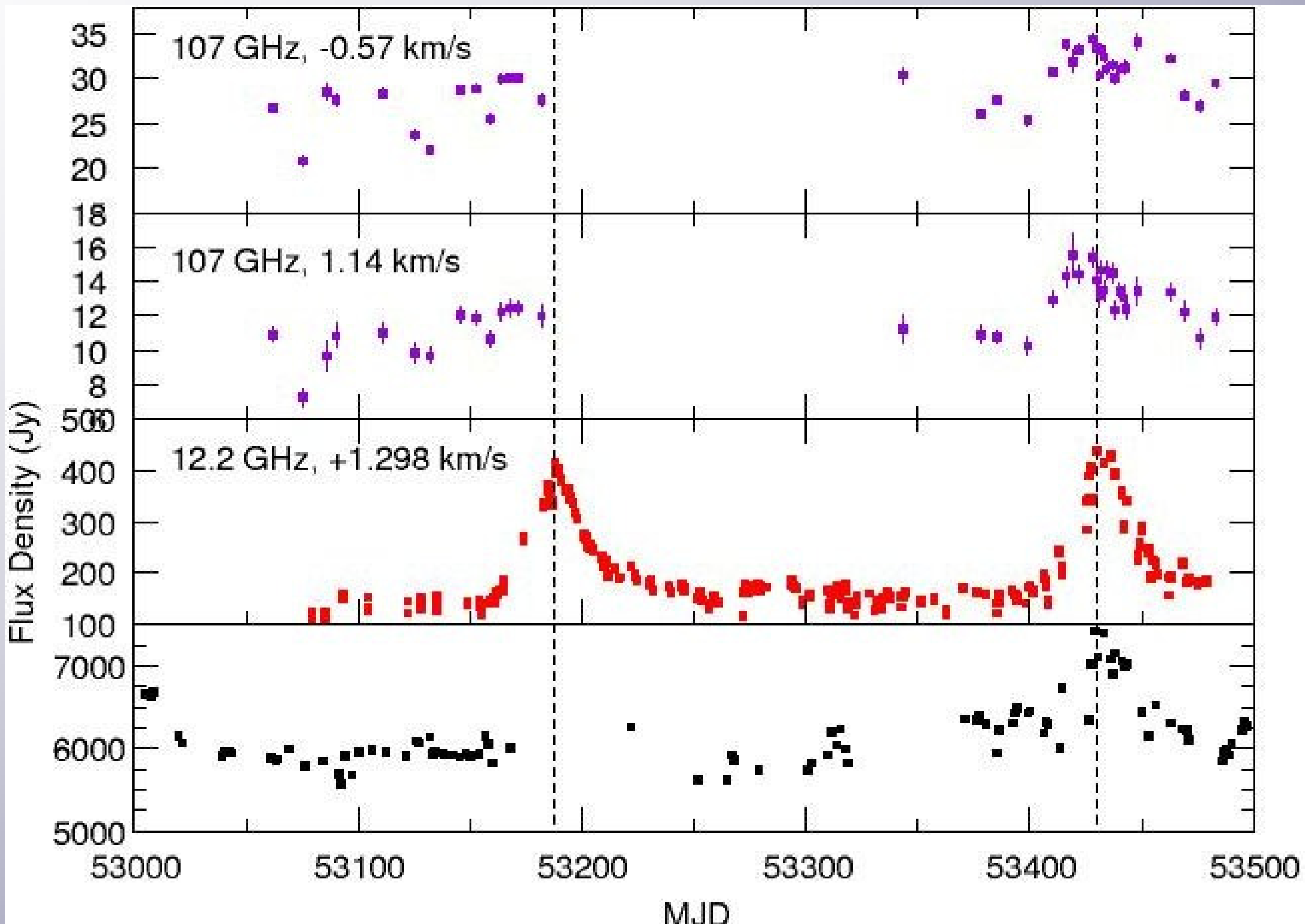
Available on-line at MNRAS

G9.62+0.20 @ 107 GHz



- ARO 12m telescope (Kitt Peak) – remote observing mode
- 03-12-2003 to 25-06-2004
- 14-01-2005 to 22-04-2005
- DR-21 used as calibrator

G9.62+0.20 @107, 12.2 & 6.7 GHz

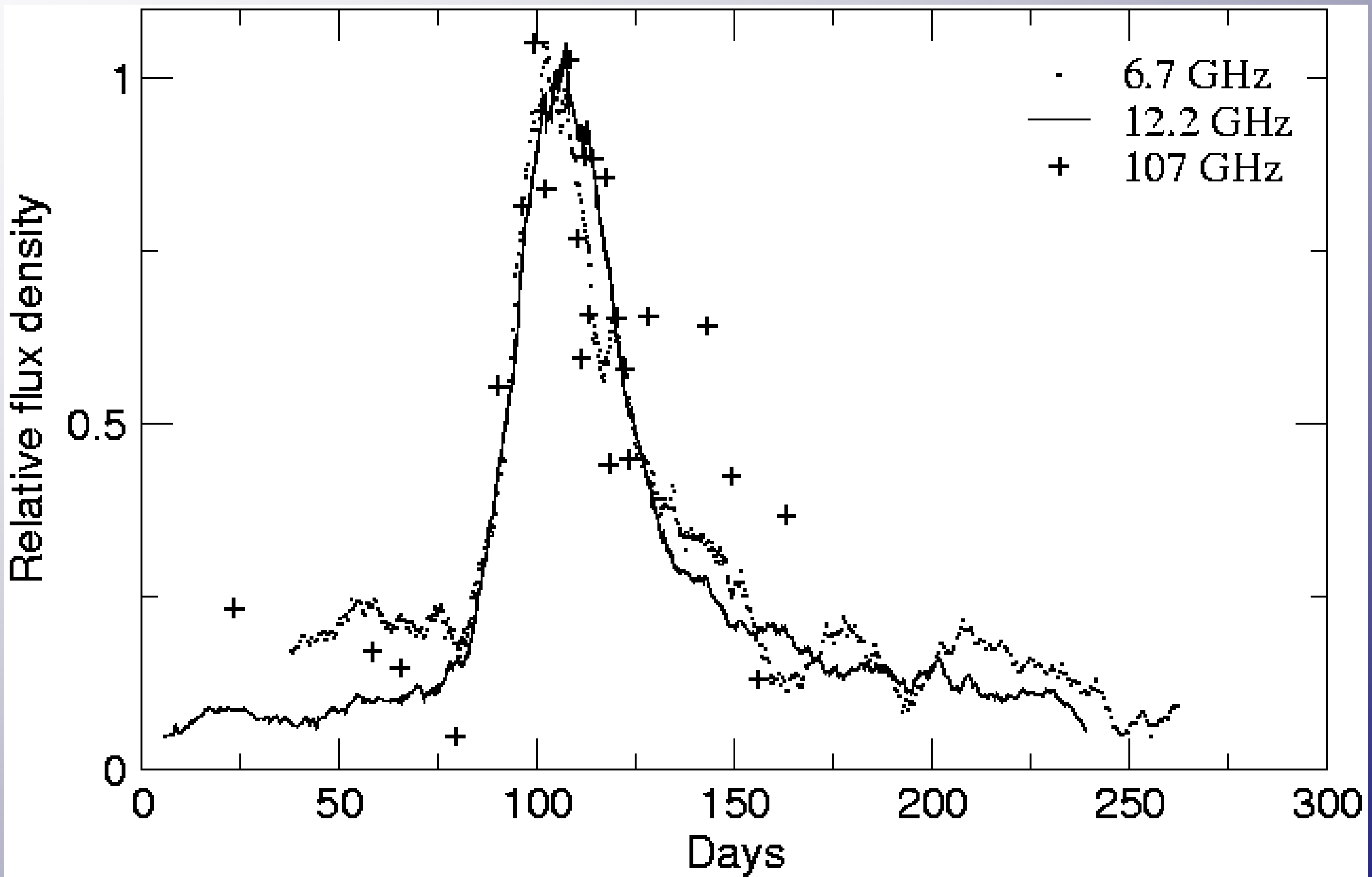


How to compare the different transitions?

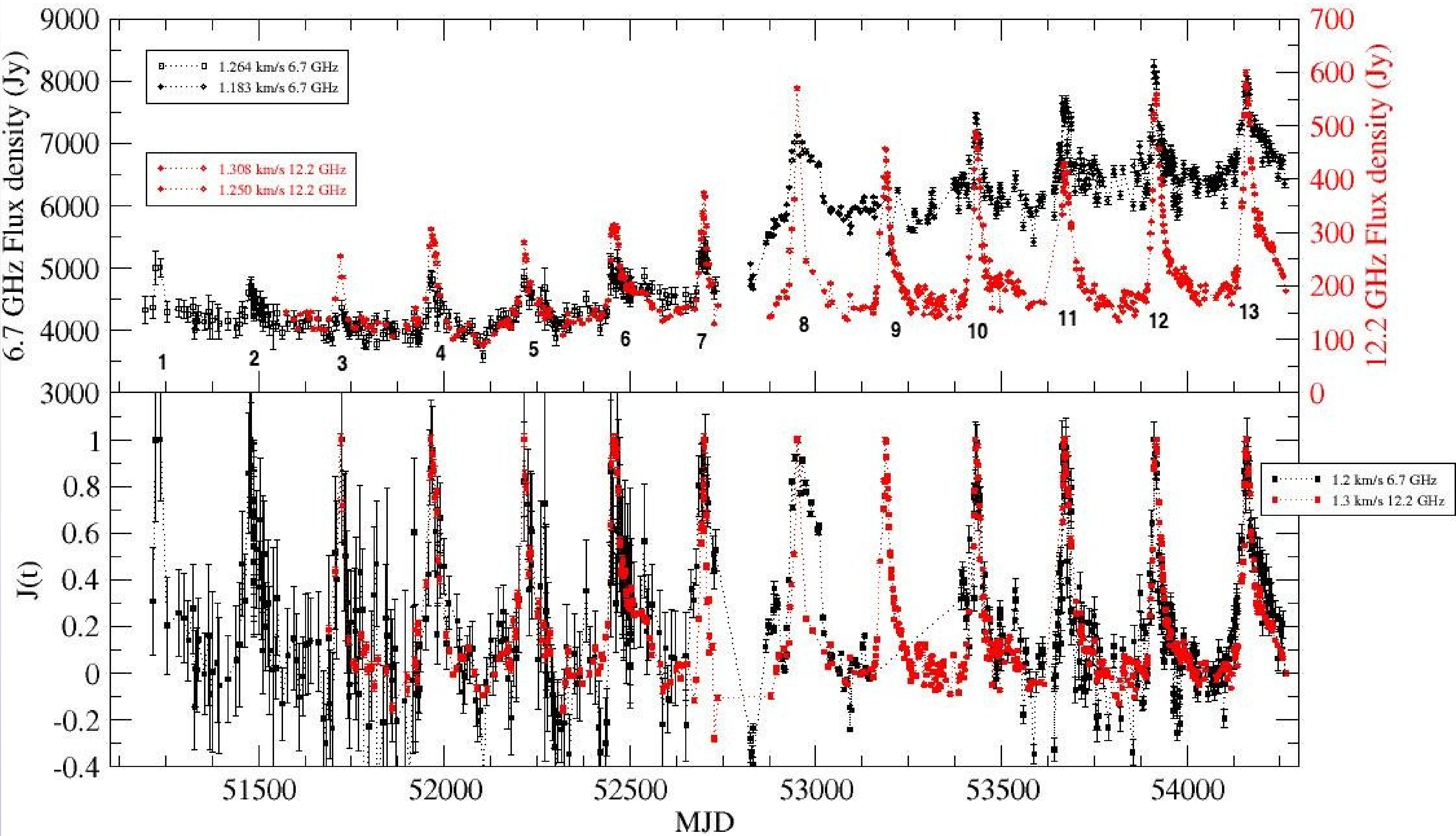
- Normalise the time-series, cycle by cycle:

$$J(t) = (I(t) - I_{min})/(I_{max} - I_{min})$$

Flare profiles @ 107, 12.2 & 6.7 GHz



G9.62+0.20 main peak time-series at 6.7 & 12.2 GHz



What does this tell us?

- Profiles vary slightly from flare to flare
- Both transitions react in the same manner at each flare even though the relative amplitudes are different
- Differing amplitudes can be due to changing conditions in the maser path.
- Easier to explain identical profiles by invoking changes in the continuum background

The masers are amplifying small changes in the background radiation

Causes of periodicity

- Rotating hot spots? Rotation periods ~ days
- Stellar pulsations? Beta Cep periods < 1 day
- Binary system?
  - Periods imply orbital radii between ~ 1 – 10 AU
  - Solid angles of eclipsing binaries probably too small
  - Maybe one or both stars still have an accretion disk?
  - Accretion from companion – cataclysmic variables

Causes of periodicity, cont.

- Precessing jets?
- Accretion disks?
  - gravitational instabilities
  - condensations
  - periodic mass dumps (binary)
    - UZ Tau E (Jensen et al, 2007)
- ???

Future work

- Maser models - Elitzur & Sobolev
- Observations - HII region variability
- Other tracers - find out more about the properties of these sources. Why are they special?

Questions

- Could the young star be pulsating? Why such long periods?