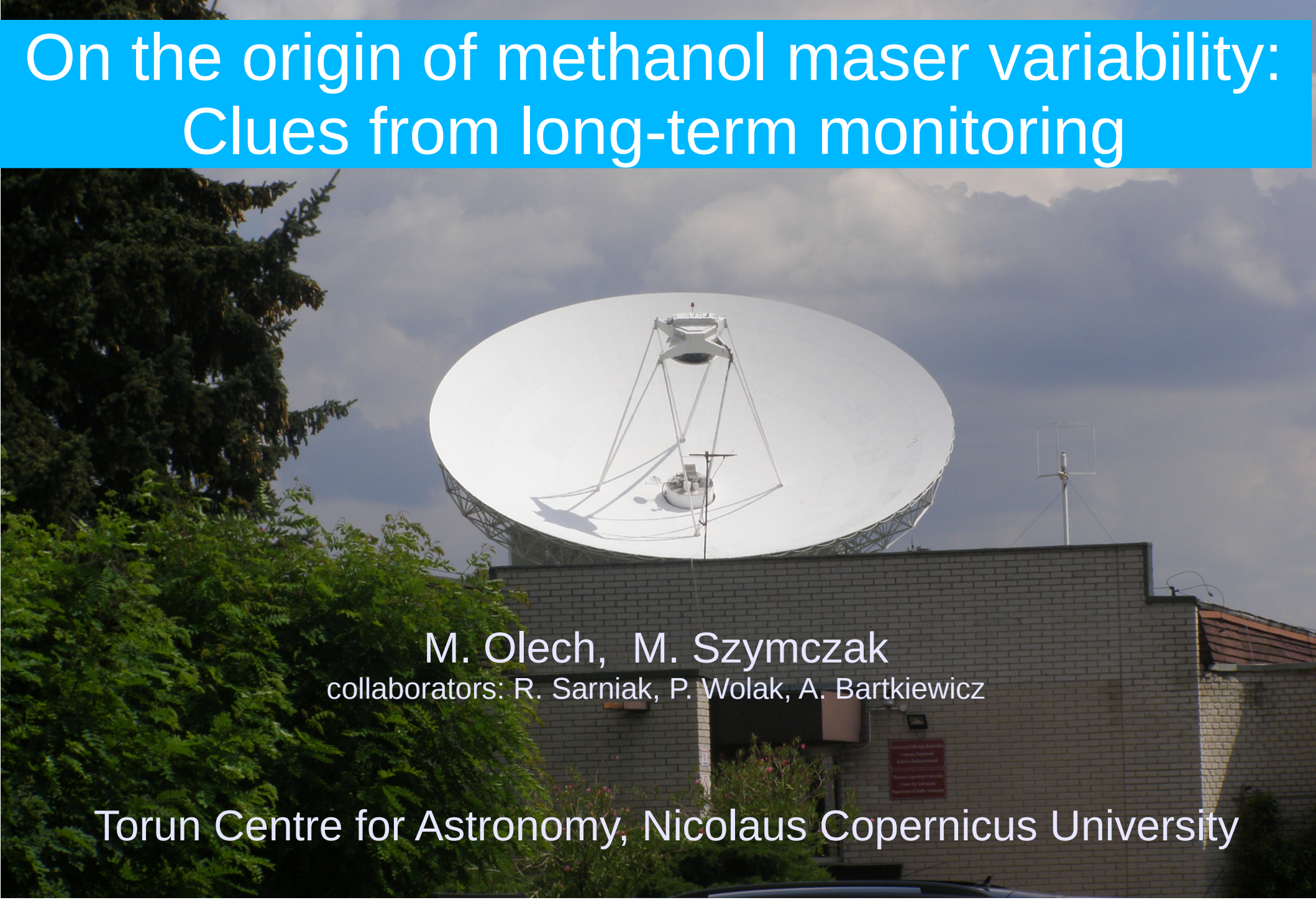
On the origin of methanol maser variability: Clues from long-term monitoring



M. Olech, M. Szymczak
collaborators: R. Sarniak, P. Wolak, A. Bartkiewicz

Torun Centre for Astronomy, Nicolaus Copernicus University

Overview

- Introduction (context and motivation of the monitoring)
- Methods (sample, observing with the Torun 32m radio telescope, variability measures)
- Monitoring results (variability statistics, diversity of variability patterns, bursts, periodicity)
- Comparison with previous studies (variability measures and luminosity relations, causes of variability)
- Summary and conclusion (maser features with low luminosity tend to be more variable than those with high luminosity, infrared photons trigger outburst activity)

Introduction:
previous studies

Early facts on the variability of 6.7GHz methanol masers:

- searching for new sources – 245 sources observed on 4-5 occasions over ~1.5 yr (Caswell+ 1995)

- the largest variability survey (Goedhart+ 2004) – 54 targets observed over 4.3 yr (daily or 2-4 observations per month)

- individual sources:
  - → flare activity of G351.78-0.54 (MacLeod & Gaylard 1996)
  - → episodic and short (<6 d) bursts of only one feature in G33.641-0.228 (Fujisawa+ 2014)
  - → synchronized and anti-correlated variations of features in Cep A (Sugiyama+ 2008)

Introduction:
context and aims

- MMB survey (e.g. Breen+ 2015) + other surveys: >1000 masers
- Causes of variability not fully understood; changes in T_{bg} or τ ?

$$T_{bm}(t) = T_{bg}(t)e^{-\tau(t)} \quad \text{but} \quad \tau \propto (\Delta P/\Gamma)(n/\Delta\Phi)L,$$

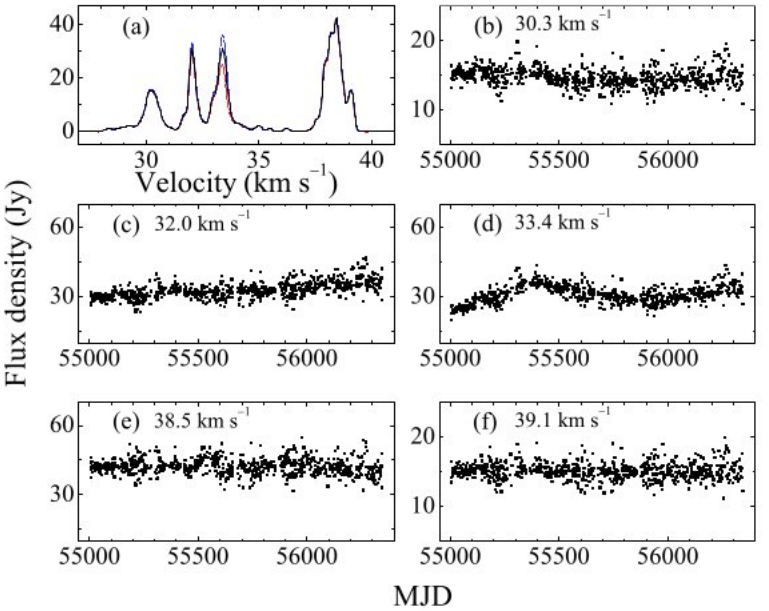
ΔP is the net pump rate, Γ is the collisional dumping rate of the maser levels,
n is the number density of the molecule, $\Delta\Phi$ is the line profile width
L is the amplification path

- Several suggestions/explanations:
  - changes in the maser path length or pump rate (Caswell+ 1995)
  - effect of turbulence (Sobolev+ 1998)
  - changes in pump rate triggered by accretion events (Caratti o Garatti+ 2017, Moscadelli+ 2017)
  - magnetic energy release (Fujisawa+ 2014)

Methods:
observing characteristics

- 32m dish
- FWHM 5.8 arcmin at 6.7GHz
- pointing errors of 25arcsec
- system noise ~250-350Jy (30-40K)
- 3σ survey sensitivity of ~0.8Jy
- spectral resolution of 0.09kms^{-1}

G32.74-0.07

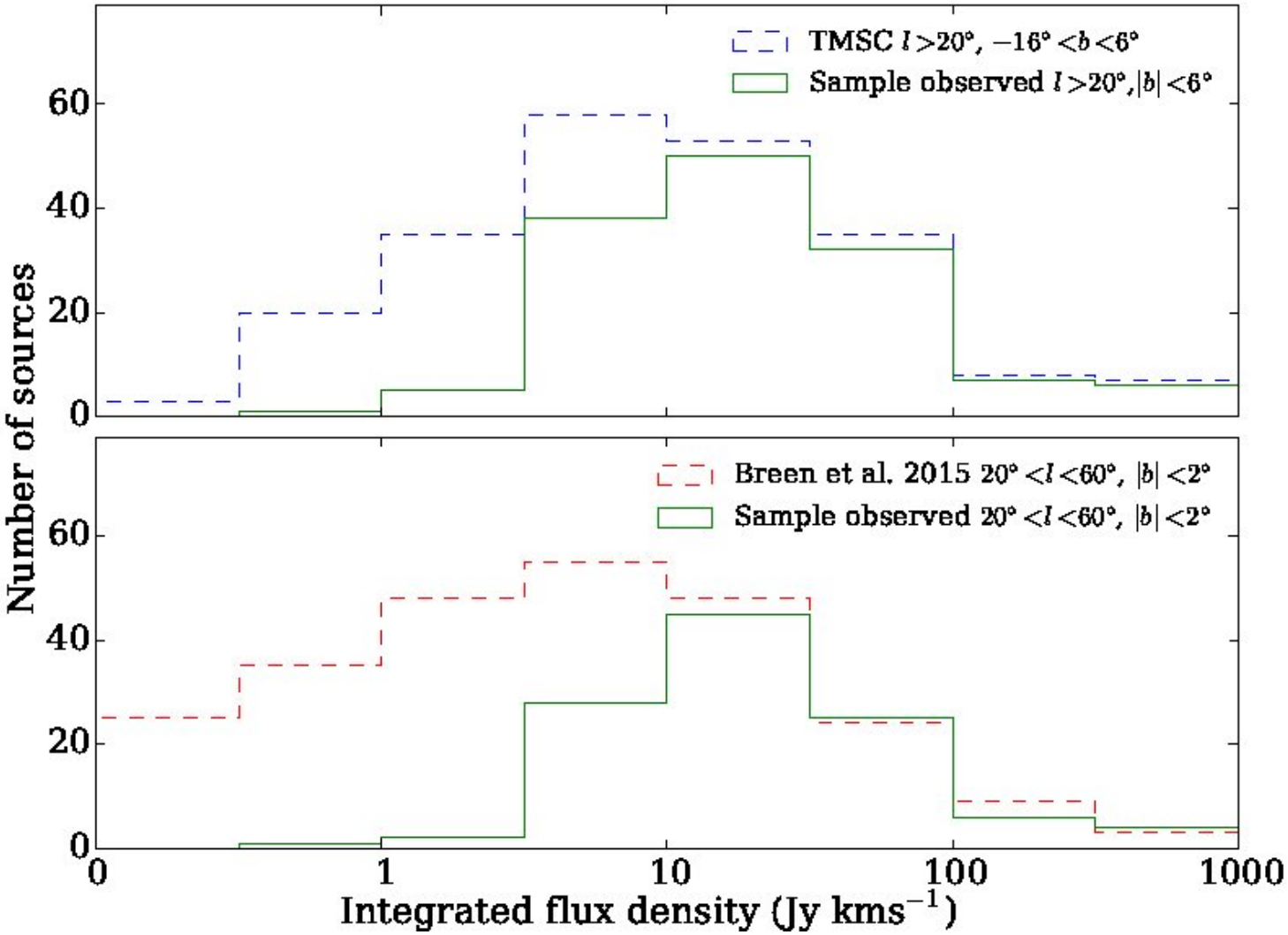


- 06/2009 – 02/2013
- observations at least once a month before 2010 October then highly variable targets observed at irregular intervals of 5-10 d, circumpolar objects observed 3-4 times a week over the entire monitoring

- variability threshold ~10% (G32.74-0.07 as secondary calibrator)

Methods:
sample

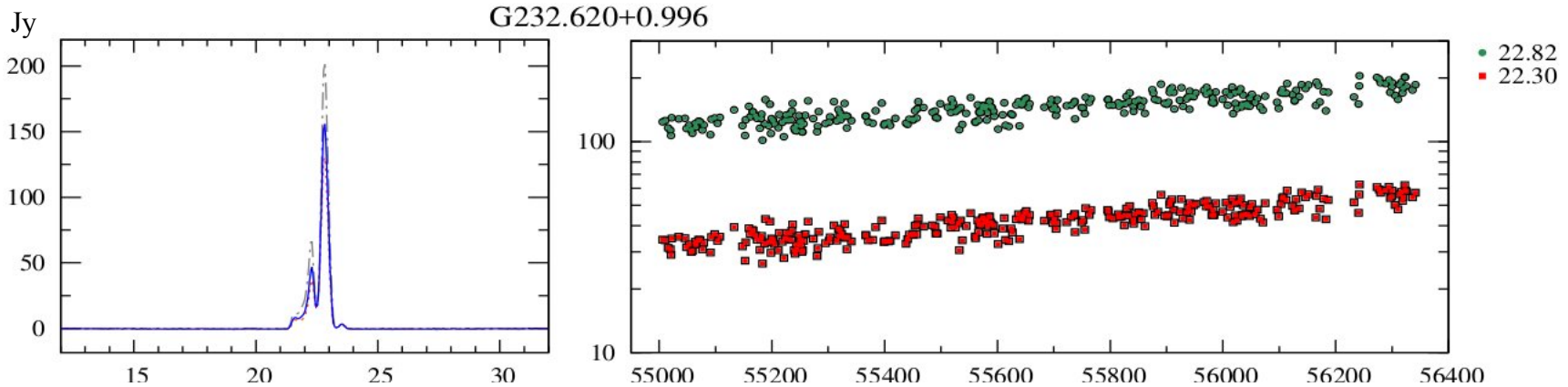
139 star-forming sites (169 sources) with peak 6.7 GHz flux density >5 Jy, Dec > −11° from the Torun Methanol Source Catalogue (TMSC, Szymczak+ 2012)



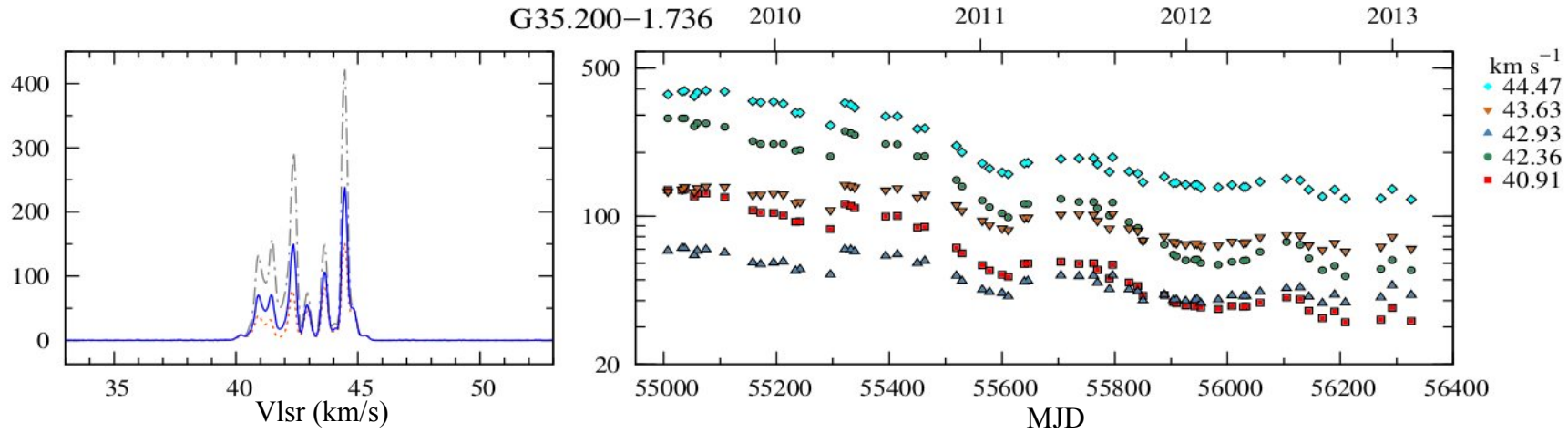
Monitoring results:

patterns (1)

monotonic rise



modulated decay



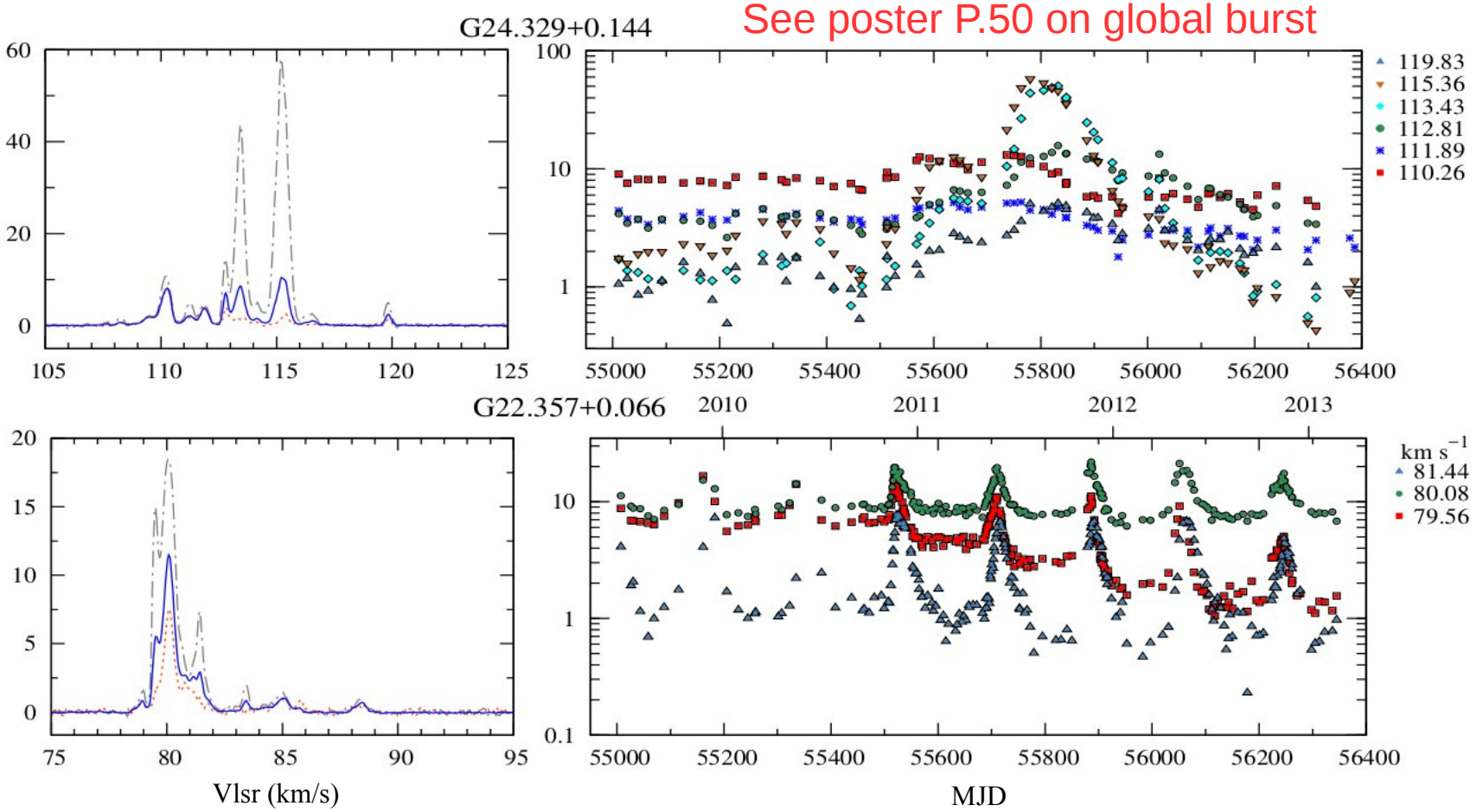
Monitoring results:

patterns (2)

See poster P.50 on global burst

burst

periodic

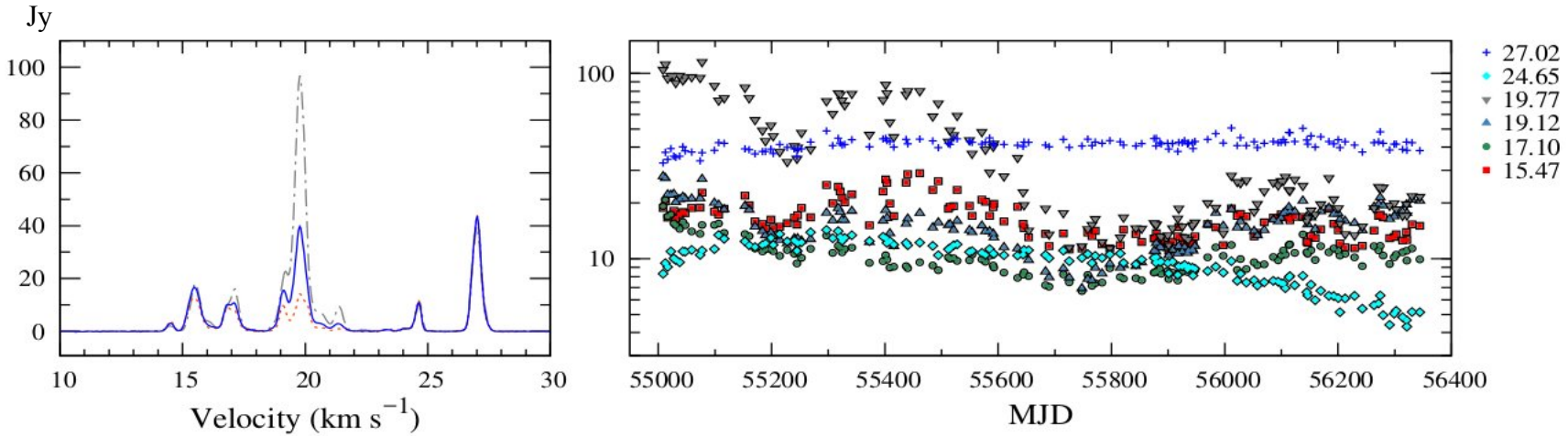


See poster P.44 on monitoring and search for periodic masers

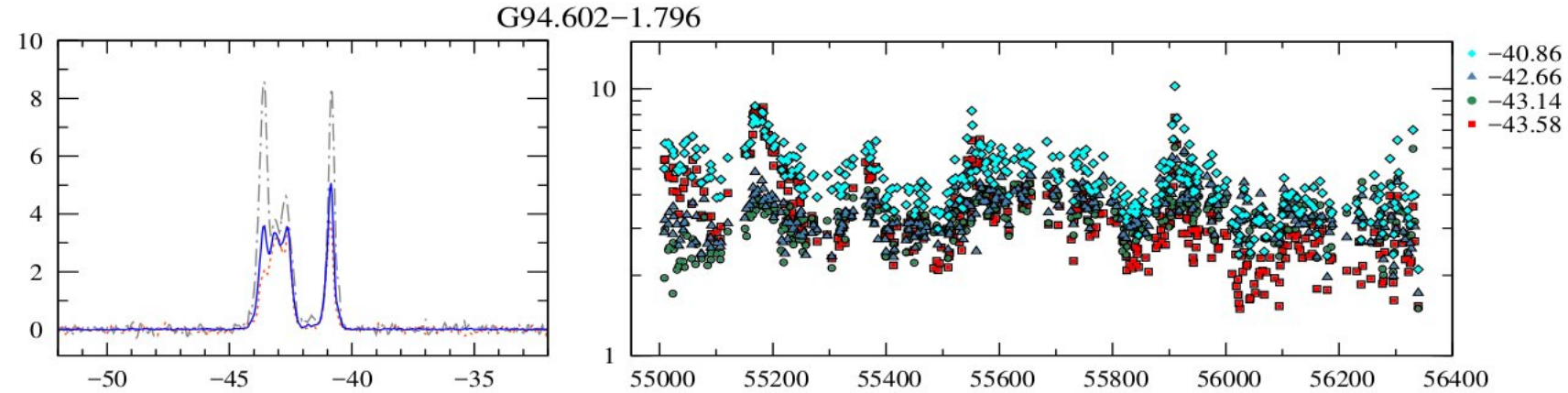
Monitoring results:

patterns (3)

complex

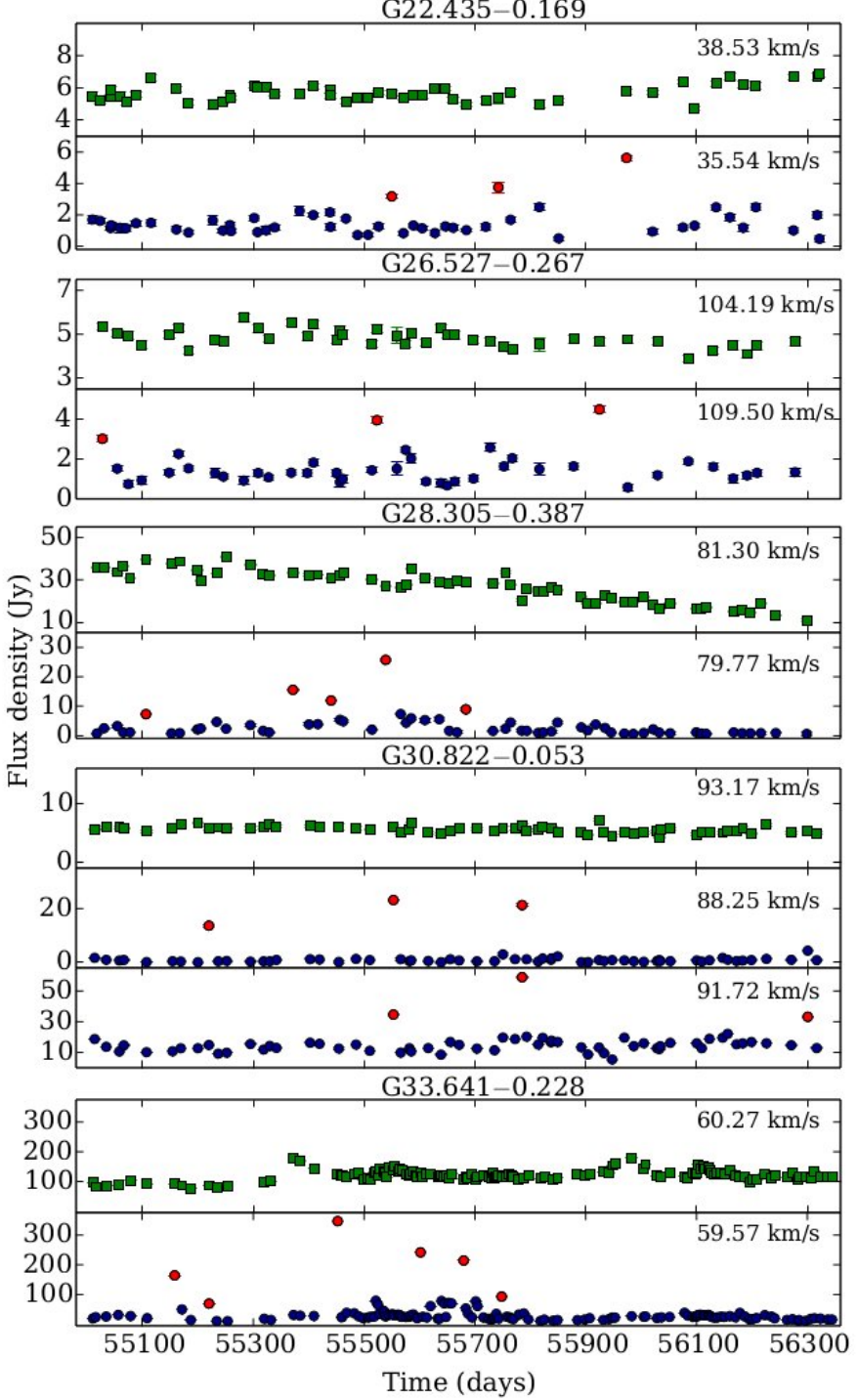


quasi-periodic

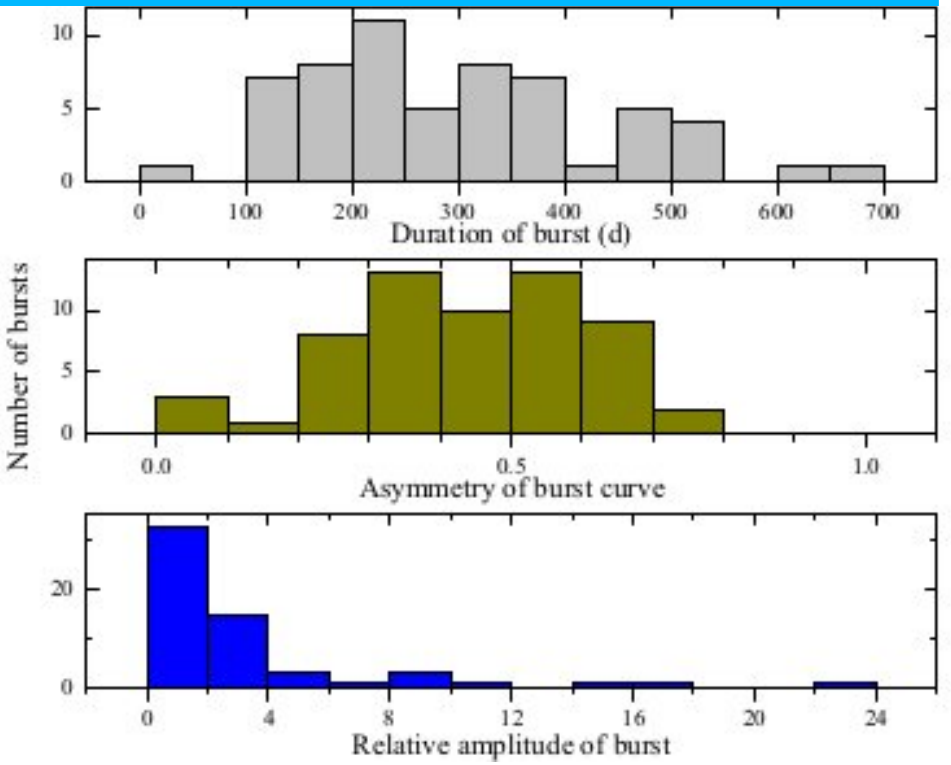


Monitoring results:
short-lived bursts

- Large and rapid flux density enhancements of individual features
- Seen as outliers in the light curves
- Relative amplitude
  $2 < (S_{max}-S_{min})/S_{min} < 90$
- Shorter than 5-7 d
- For G33.64 typical rise and fall times of one and five days, respectively (Fujisawa+ 2014)

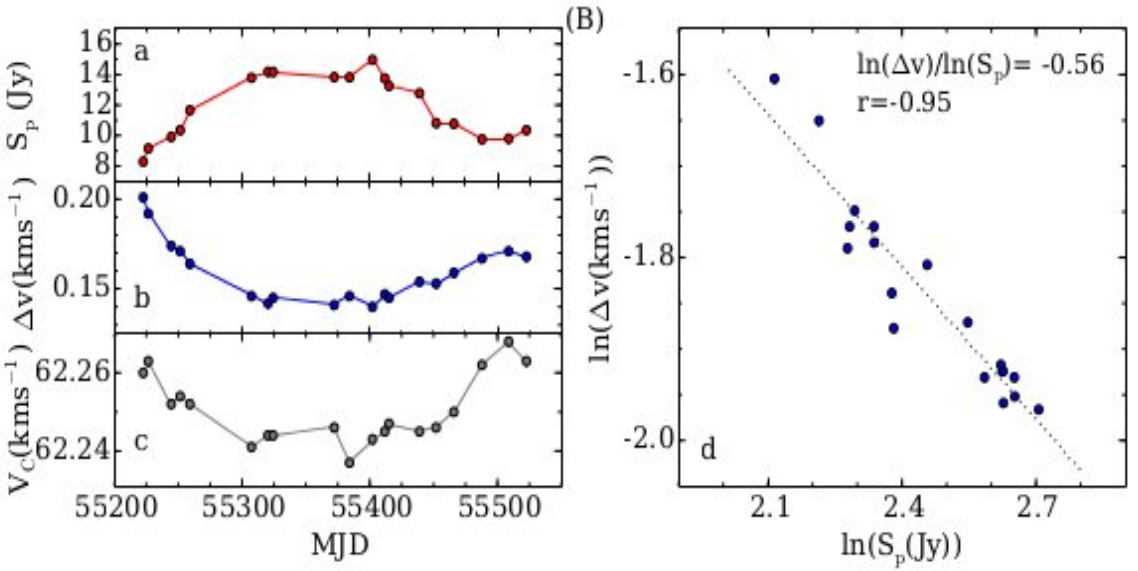


Monitoring results:
long-lived bursts



- 19 objects with long bursts of one or more features with the relative amplitude >0.4

- the line-width – flux density anti-correlation observed for a few bursts (expected for unsaturated amplification)



Monitoring results:

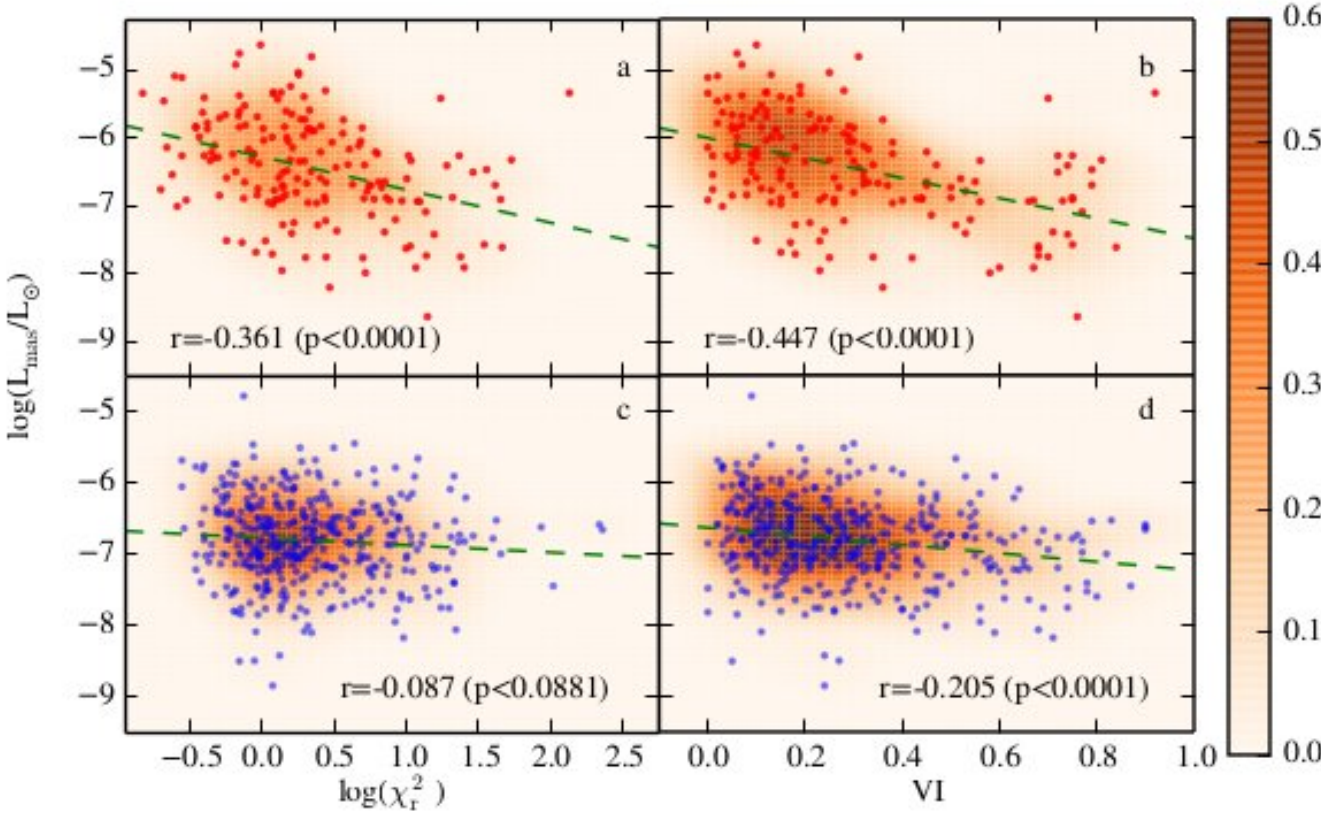
variability measures and maser luminosity

- Measures of variability

$$\chi^2_r = \frac{1}{N-1}\sum_{i=1}^{N}\left(\frac{S_i - \overline{S}}{\sigma_i}\right)^2$$

$$VI = \frac{(S_{max} - \sigma_{max}) - (S_{min} + \sigma_{min})}{(S_{max} - \sigma_{max}) + (S_{min} + \sigma_{min})}$$

(a-b) trigonometric distances
(c-d) kinematic distances

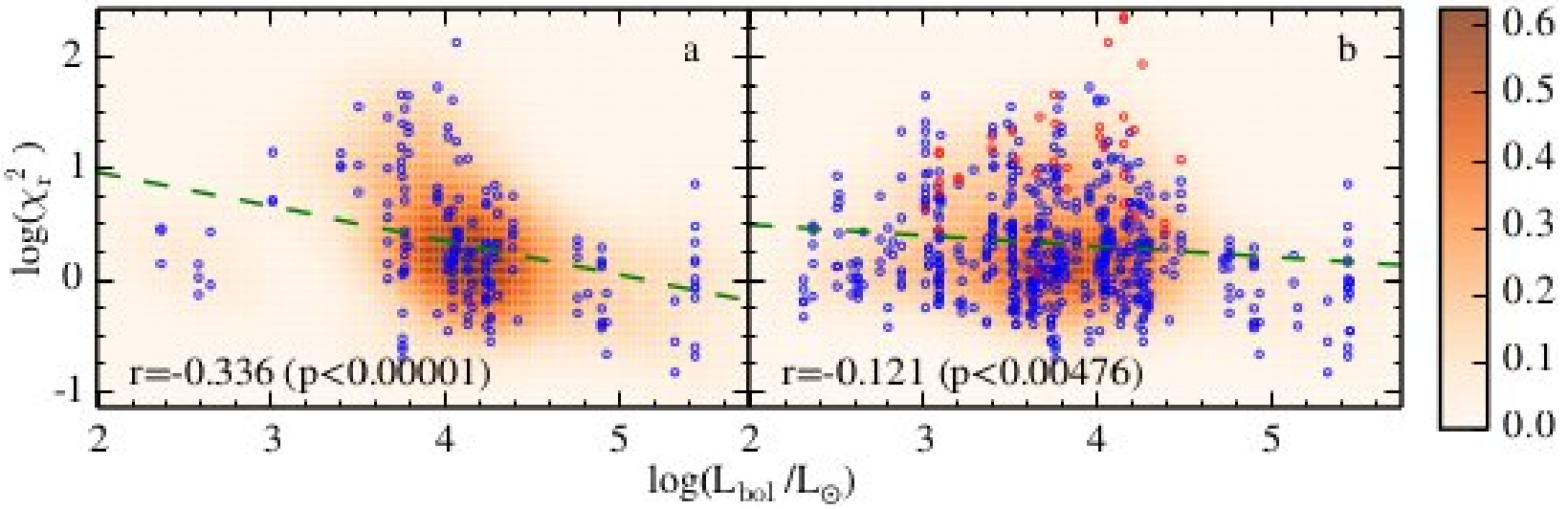


- Features of low luminosity tend to be more variable than those of high luminosity

Monitoring results:

variability measures and bolometric luminosity

- Bolometric luminosity of exciting star (up to 33 bands from 3.4mm to 1.1mm, Robitaille+ 2007 SED fitter)



(a) trigonometric distances
(b) kinematic distances

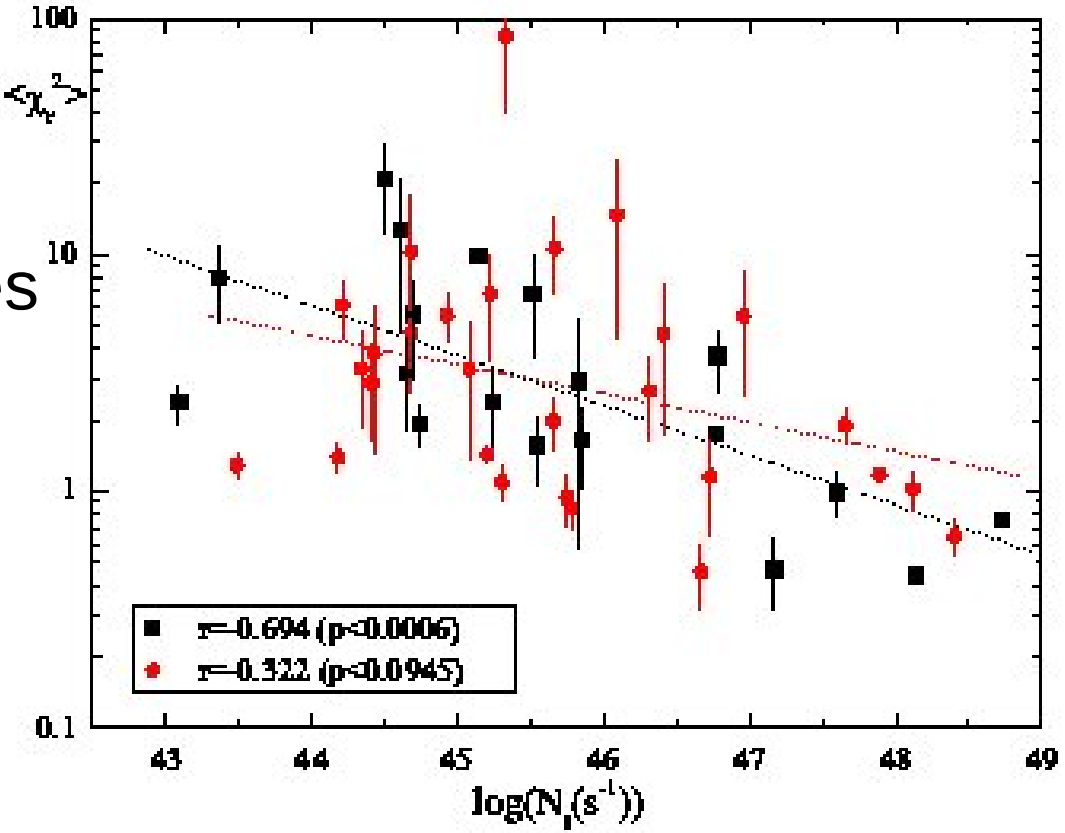
- Variability of maser features tend to increase for sources powered by less luminous MYSOs

Monitoring results:

variability measures and bolometric luminosity

- 48 methanol masers with radio continuum emission (<3”, Hu+ 2016) – Lyman flux determined.

- More luminous massive stars would excite methanol molecules more efficiently over a larger region than less luminous stars; the pump rate would be higher and the path of maser amplification would be longer.



Summary:

- 3.7 yr montoring observations of 169 methanol masers
- ~80% per cent of the sources show variations greater than 10% in at least one features on time-scales of ~1month to a few years
- Diverse variability patterns, including 9 periodic sources
- Bursts (a week - several months) in ~17% of the sources
- A general trend: low luminosity features are more variables than high luminosity features.
- Maser luminosity - bolometric luminosity and Lyman flux, confirmed for the sub-sample of sources with trigonometric distances.