Periodic variations in 6.7 GHz methanol masers

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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?
Observations at 6.7 GHz
with the 26-m Hartbeesthoek 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

• **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
Amplitude calibration

- Continuum drift scans scheduled with each set of spectral line observations
- Hydra A, Virgo A & 3C123
- with pointing checks
Some periodic maser candidates
G338.93-0.06: Range of variation
G338.93-0.06: Time-series
G338.93-0.06: Epoch-folding & Fourier Periodograms

P = 133 days
G338.93-0.06: Time-series folded modulo 133 days
G331.13-0.24: Averaged spectrum
G331.13-0.24: Time-series
G331.13-0.24: Epoch-folding & Fourier Periodograms

\[ P = 504 \text{ days} \]
G331.13-0.24: Sinusoid fits, P=504d
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
G9.62+0.20: Range of variation
G9.62+0.20: Time-series
G9.62+0.20: Epoch-folding & Fourier periodograms

P = 244 days
G188.95+0.89: Range of variation
G188.95+0.89: Time-series
G188.95+0.89: Sinusoidal fits with $P=404$ days
So, what happens during a flare?

- 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

G9.62+0.20 @ 12 GHz during a flare

Available on-line at MNRAS
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)
• ???
Summary

- 8 year time-series
- Six (five?) periodic maser candidates
- Period range: 133d – 504d
- Varying amplitudes & durations in flares but start times the same
- Behaviour may evolve over time
Outlook

• Lots of work to do!
• We need a time-dependent maser model
• Can we distinguish between possibilities of a binary system, precessing jet or accretion disk?
• Radiative transfer calculations – cause of disturbance at a few AU but masers at 100s – 1000s AU