Periodic variations in Class II 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?
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

G351.42+0.64
Uncalibrated time-series

Calibrated time-series

Antenna temperature (K)

Flux Density (Jy)

MJD
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
  - 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

\[ P = 220 \text{ days} \]
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

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:

\[ J(t) = \frac{I(t) - I_{\text{min}}}{I_{\text{max}} - I_{\text{min}}} \]
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?