Spectral Line VLBI

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Spectral Line Sources

- VLBI: High brightness temperatures
- Masers:
  - OH, H₂O, SiO, CH₃OH
  - Extra-galactic
    - OH, H₂O
- Extra-galactic HI absorption

Image courtesy of Lincoln Greenhill, Cfa VLBI Group
See also:
  - Hernández et al., 1999
  - Nature 406, 504
  - Miyoshi et al., 1999
  - Nature 400, 539
SiO masers in TX Cam

SiO masers in Orion BN/KL
Spectral Line Correlation

- Modern digital correlators intrinsically spectral line
- Spectral resolution function bandwidth & number of lags (or size of FFT)
- Maser components are very narrow
  → High spectral resolution is needed

- Galactic masers typically 1-20"
  → Short integration time (time smearing)
- Hanning smooth
- Scalar and vector averaging:
  → Scalar: broad lines
  → Vector: small synthesized beam

ATCA Data (6.7 GHz Methanol)  VLBI Data (12.2 GHz Methanol)
Calibration

- Basically the same as for continuum
- Estimate time-dependent continuum Tsys
- Estimate frequency delay and rate
- Also correct for bandpass

Assume time and frequency corrections are independent

Bandpass Calibration

- Need relatively strong continuum source
- Must observe at same frequency
- Can use auto-correlations, but cannot correct phase
- Cross-rat allows phase correction

- Need enough S/N on calibrator
- Need to fringe fit first

Amplitude Calibration

- Can do normal Tsys calibration
- Optionally, use auto correlations:
  - Gives very good results (in principle)
  - Corrects for pointing errors at telescope
  - Only gives relative calibration
    - Depends on amplitude calibration of template spectrum

Fringe Fitting

- Need to estimate residual delay and rate
- Residual rate seen as slope of phase in time (in both frequency and lag domain)
- Residual delay seen as shift in lag domain, so a slope of phase across the bandpass in the frequency domain
• Measure residual delay by measuring phase slope
• Only a couple of channels per feature for spectral line
  → Limited resolution, limited delay
• Continuum delay calibration must be observed every hour or so
• Residual rates obtained from a bright spectral feature

Doppler Correction
• Each station at different velocity
• Need to correct to standard rest frame
• Observe at fixed frequency
• Fringe rotation at correlator does some
• Further velocity correction in software
  → Application depends critically on design of correlator

Self-calibration
• Many separate components at different velocities and position
• Cannot selfcal data set as a whole
• Cannot run self cal on each frequency channel separately
• Selfcal strong (compact) feature and apply calibration to rest of channels
Continuum Subtraction

- No need for Galactic masers
- Do after all calibration for HI absorption
  → Image negative from to image
  → POSSM plots show as emission

Imaging

- Nothing special but...
  → Large maps with many frequency points
  yields large data cubes

Water masers in W49N


Fringe Rate Mapping

- Galactic masers sometimes large (>10")
  → Often many sources in beam
- Wide velocity width
  → Large data cube
- Use fringe rate mapping to find where
  emission is
- Also gives absolute position
- FRMRF in AIPS tricky to use
Scheduling

• Choose enough bandwidth for velocity coverage
• Calculate required spectral resolution (Allow for Hanning smoothing)
• Find correct velocity (and reference)
• Find close enough delay calibrator
• Choose a strong bandpass calibrator
• Turn off phasecal!
• Consider over sampling