(Spectral Line) VLBI

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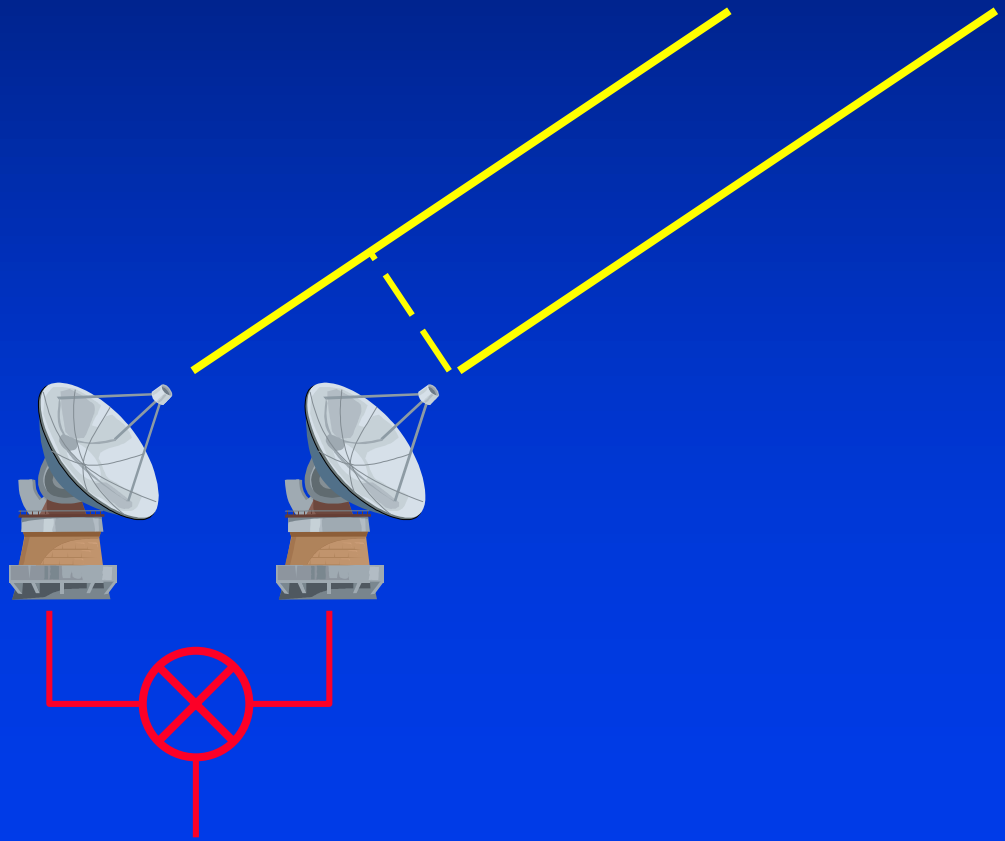
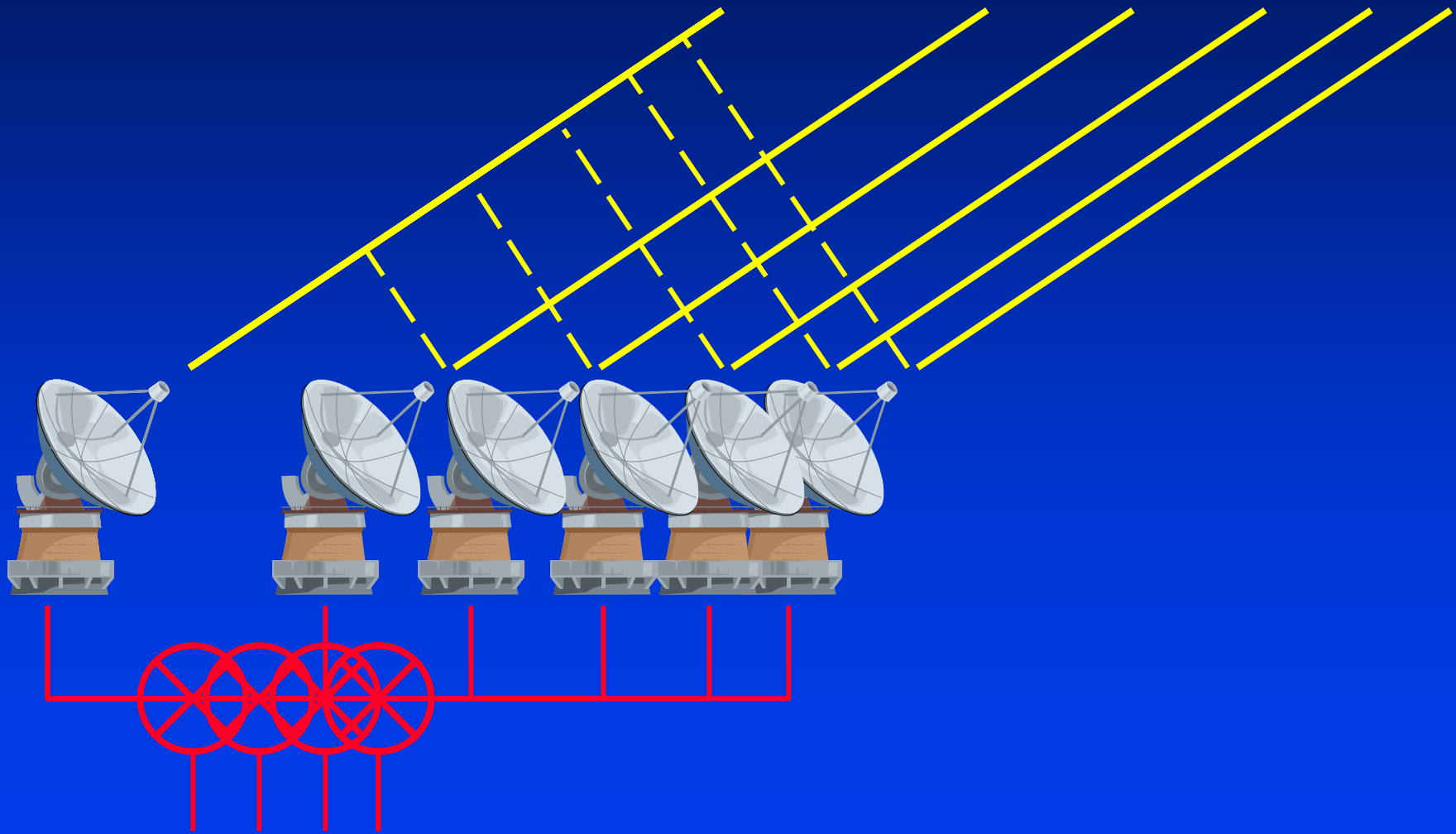
CSIRO ATNF

Quest for resolution

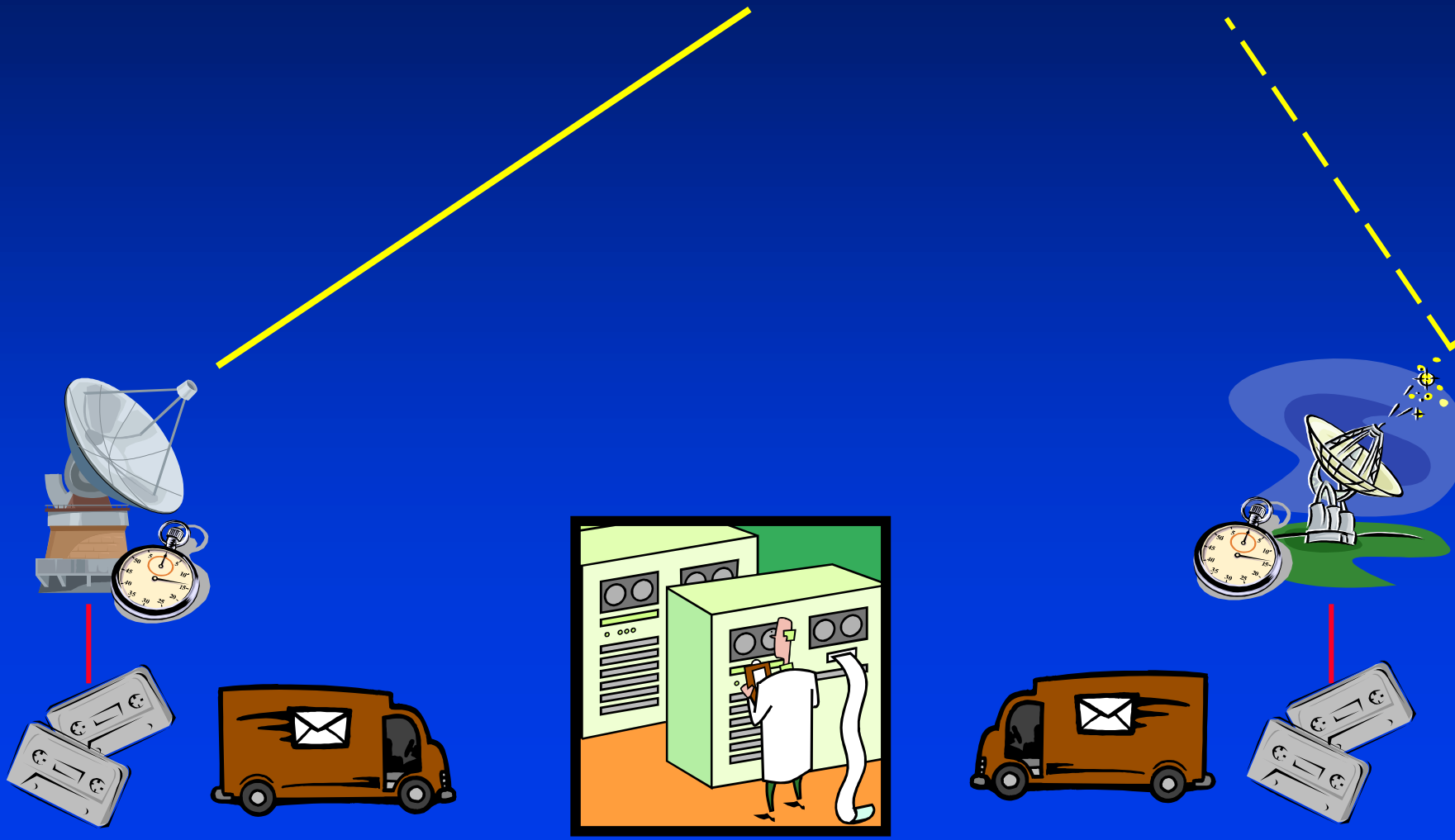
- Maximum resolution of an instrument is proportional to length of longest baseline



Quest for resolution



Quest for resolution



Resolution = Observing wavelength / Telescope diameter

Angular Resolution	Optical (5000A) Diameter	Optical (5000A) Instrument	Radio (4cm) Diameter	Radio (4cm) Instrument
1′	**2mm**	**Eye**	**140m**	**GBT+**
1″	**10cm**	**Amateur Telescope**	**6km**	**ATCA**
0.″05	**2m**	**HST**	**160km**	**MERLIN**
0.″001	**100m**	**Interferometer**	**8200km**	**VLBI**

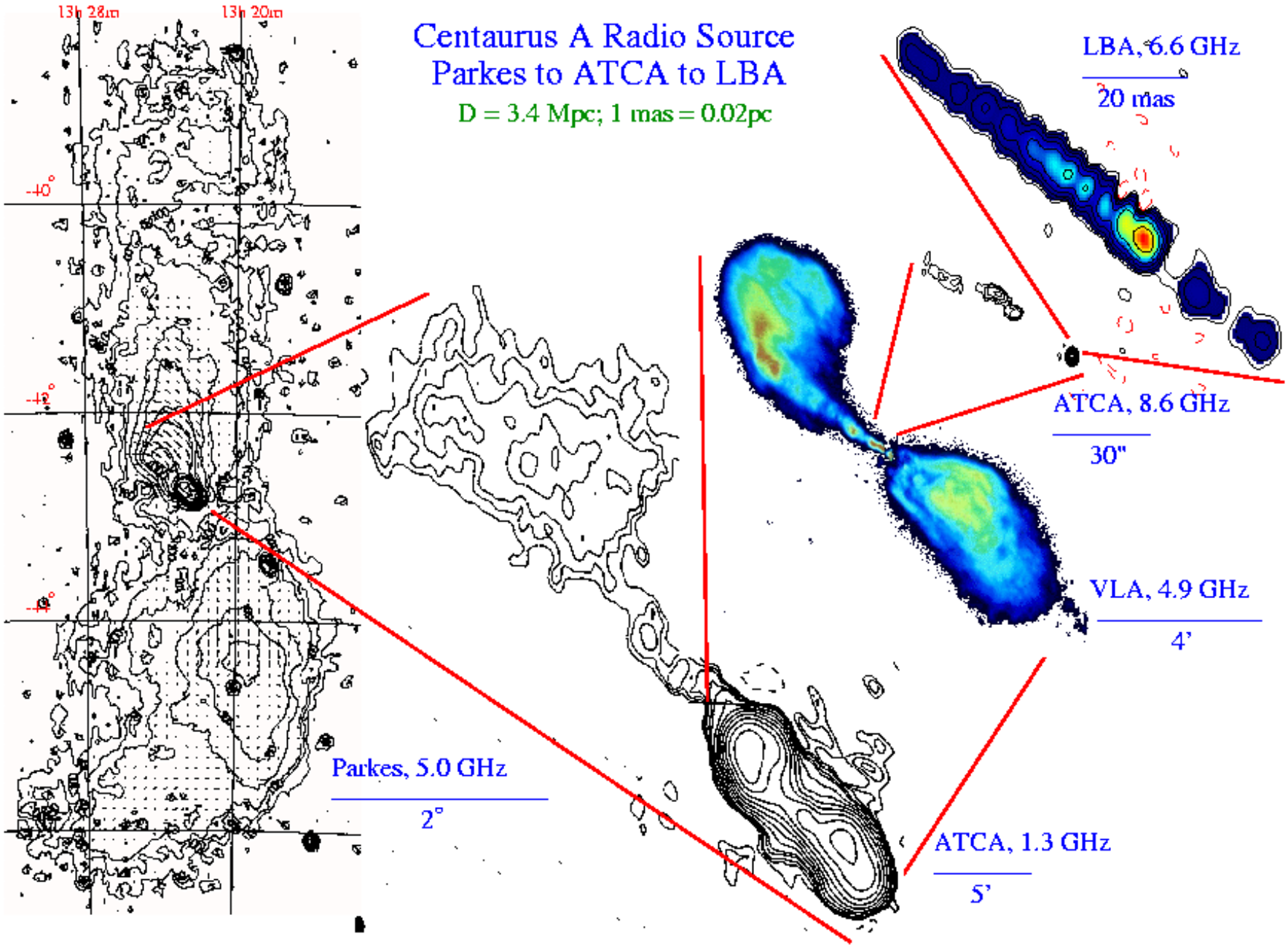
Atmosphere gives 1" limit without corrections which are easiest in radio

Jupiter and Io as seen from Earth

1 arcmin 1 arcsec 0.05 arcsec 0.001 arcsec

Simulated with Galileo photo

Courteous Craig Walker

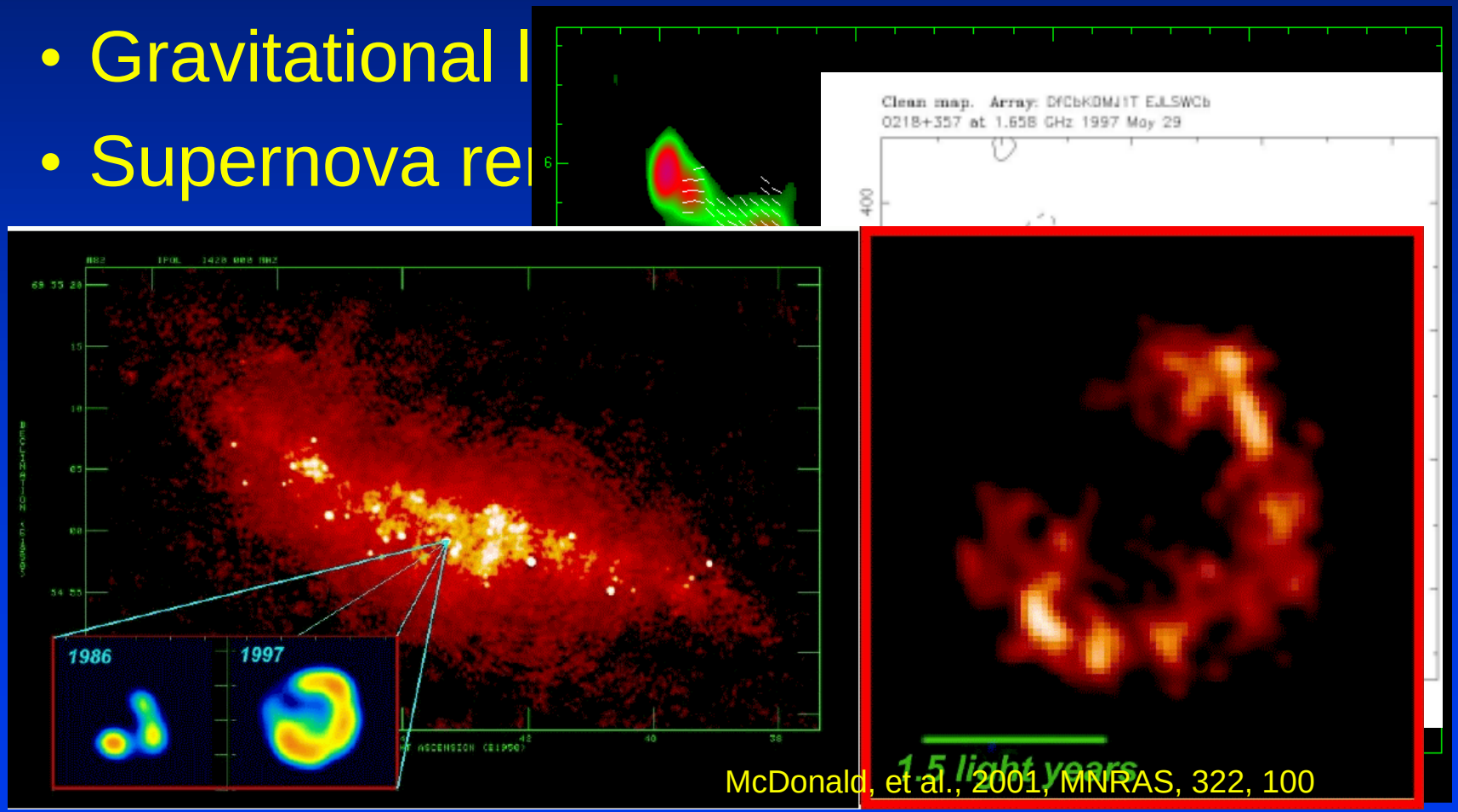

Centaurus A Radio Source
Parkes to ATCA to LBA
D = 3.4 Mpc; 1 mas = 0.02pc
13h 28m
13h 20m
-40°
-42°
-44°
Parkes, 5.0 GHz
2°
ATCA, 1.3 GHz
5'
VLA, 4.9 GHz
4'
ATCA, 8.6 GHz
30"
LBA, 6.6 GHz
20 mas

VLBI Targets

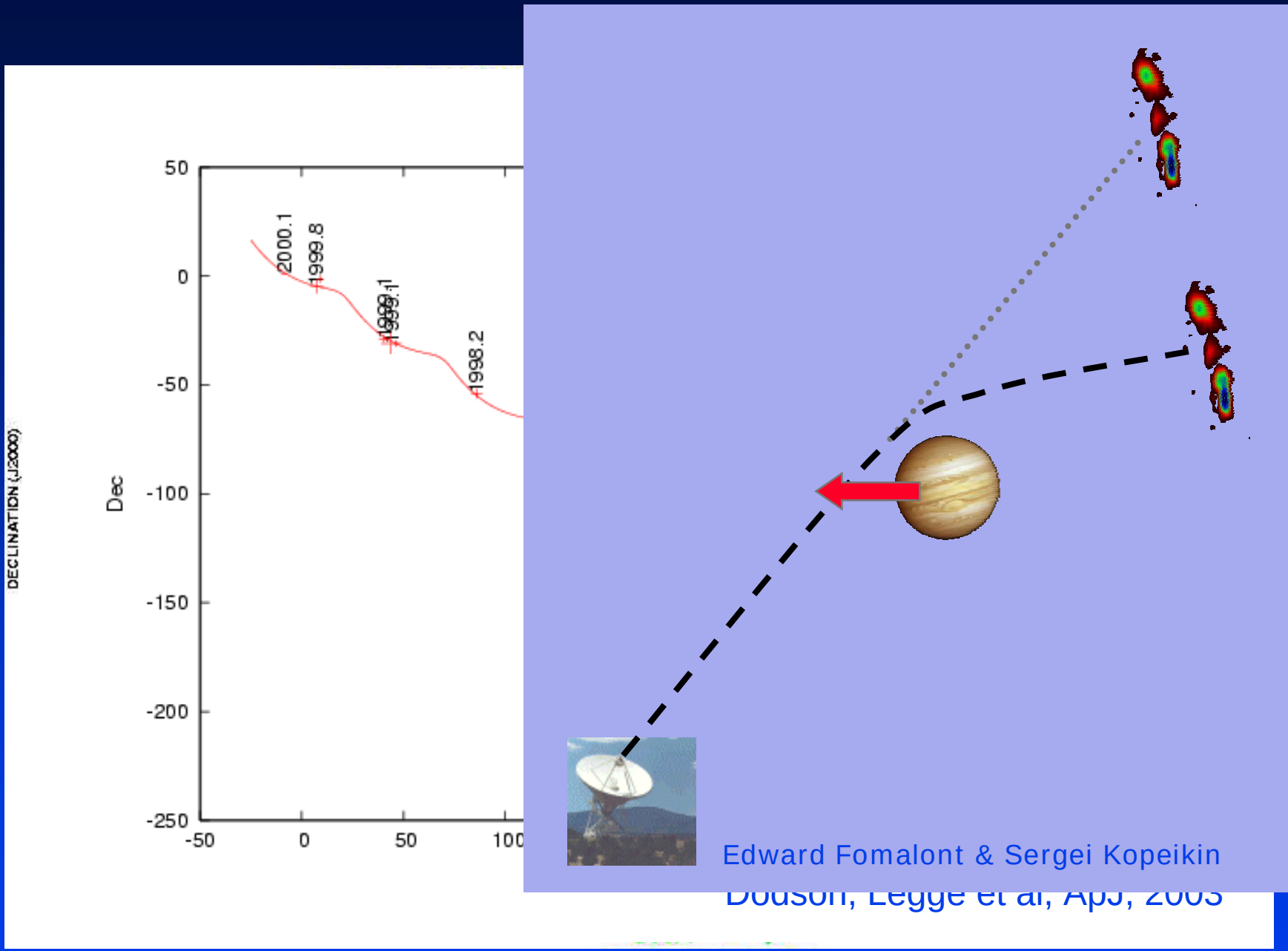
- VLBI is only sensitive to the most compact structure
- Need high brightness temperatures
  - $\rightarrow$ Compact and bright
  - $\rightarrow$ Plus physics to drive

Continuum Targets

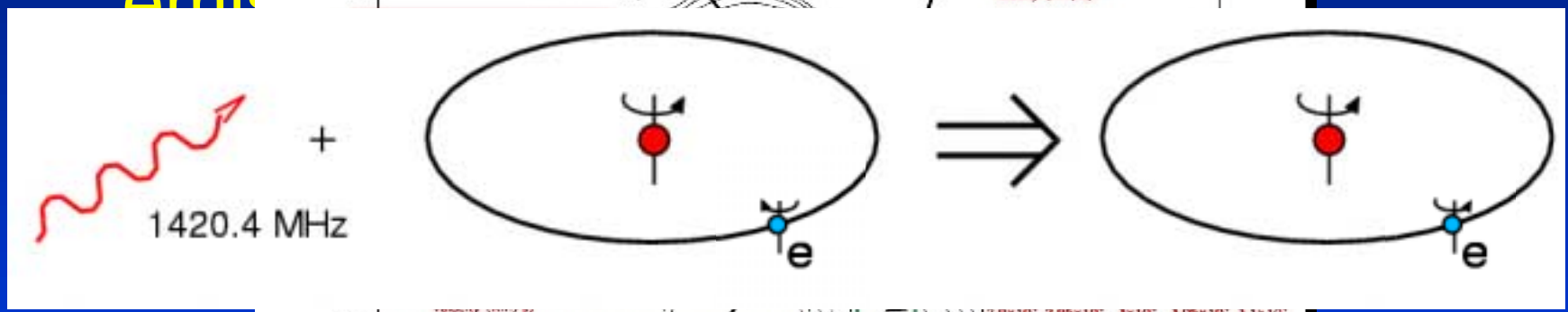
- Radiation from jets and cores in galaxies
- Gravitational l
- Supernova re



McDonald, et al., 2001, MNRAS, 322, 100


DECLINATION (J2000)
Dec
50
0
-50
-100
-150
-200
-250
-50
0
50
2000.1
1999.8
1998.2
Edward Fomalont & Sergei Kopeikin
Dodson, Legge et al, ApJ, 2003

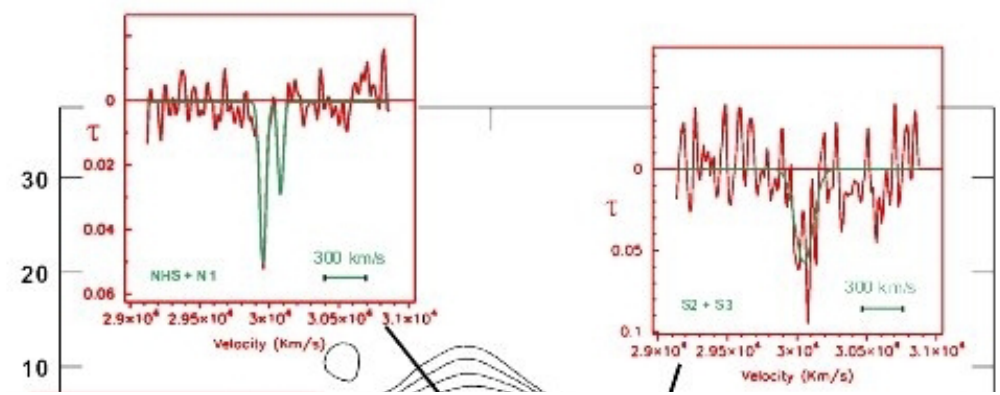
- Req
tem
emi

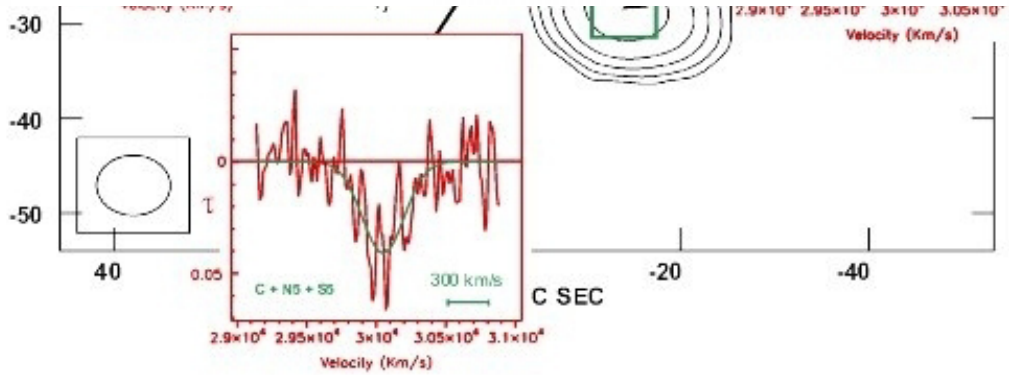


→ I

- Gala tion

HI Absorption Profiles toward 1946+708





Peck, Taylor & Conway 1999

VLBI arrays

- VLBA (Very Long Baseline Array)
  - → Dedicated US array of ten 25m telescopes
  - → 330 MHz – 90 GHz
- EVN (European VLBI Network)
  - → Formal collaboration of radio telescopes in Europe, Asia and South Africa
  - → ~15 telescopes 15m to 100m
  - → 330 MHz – 22/43 GHz

VLBI arrays

- LBA (Long Baseline Array)
  - → Parkes, Mopra, ATCA, Hobart, Ceduna and Tidbinbilla
  - → 1.4 GHz – 22 GHz
- APT (Asia Pacific Telescope
  - → LBA +
    - Hartebeesthoek (SA), Kokee Park (Hawaii)
    - Nobeyama and Kashima in Japan
    - Shanghai and Urumqi in China
- Global – EVN + VLBA
- Space VLBI: VSOP mission
- CMVA: US + European at 3mm

VLBI Correlation

- There are no fundamental difference in processing VLBI data
  - → Need to synchronise tapes
  - → Digital fringe rotation
- 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

VLBI Calibration

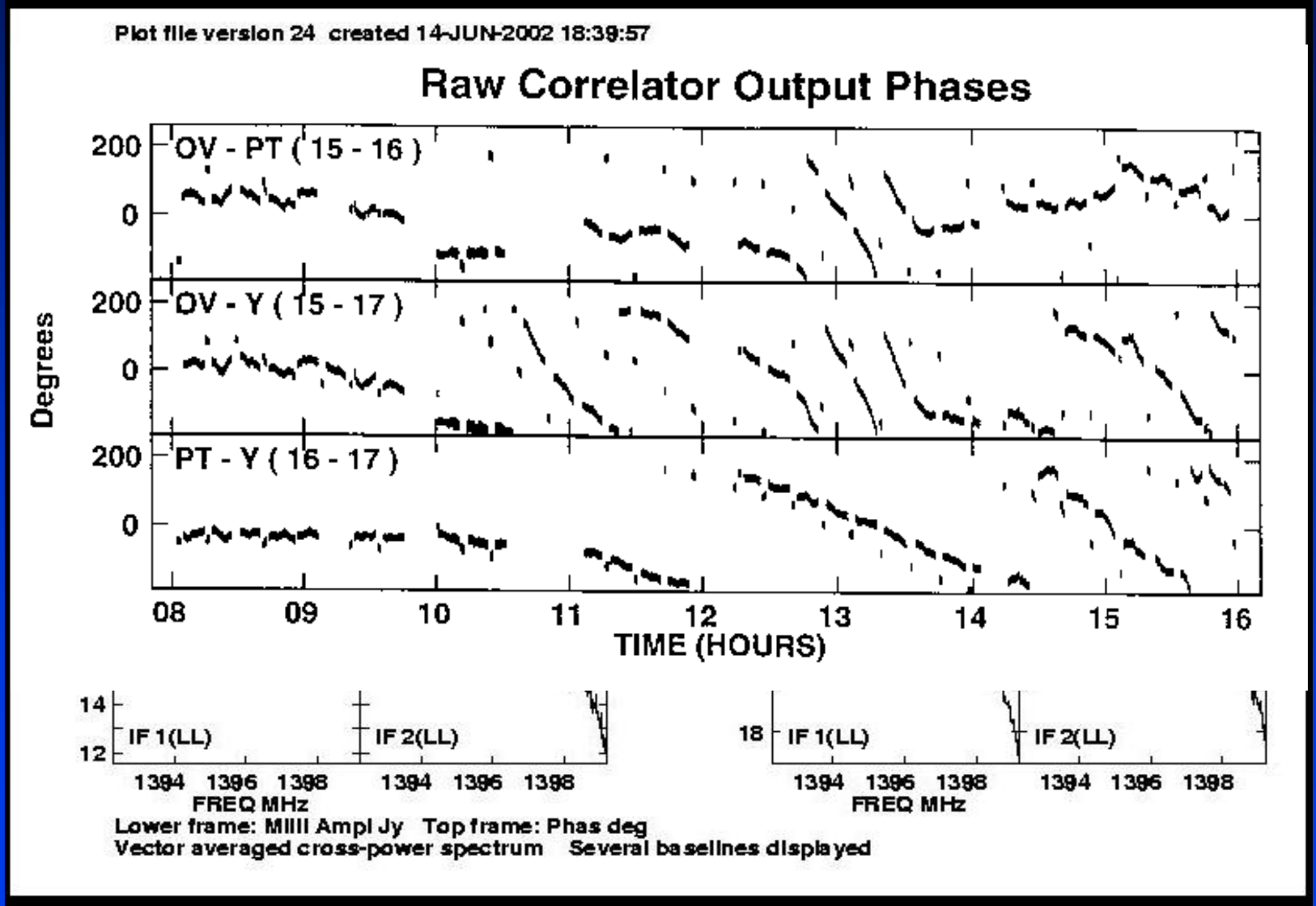
- Basically the same as for ATCA
  - → Estimate time dependent antenna gain
    - Tsys
    - Residual delay and rate
- Also correct for bandpass

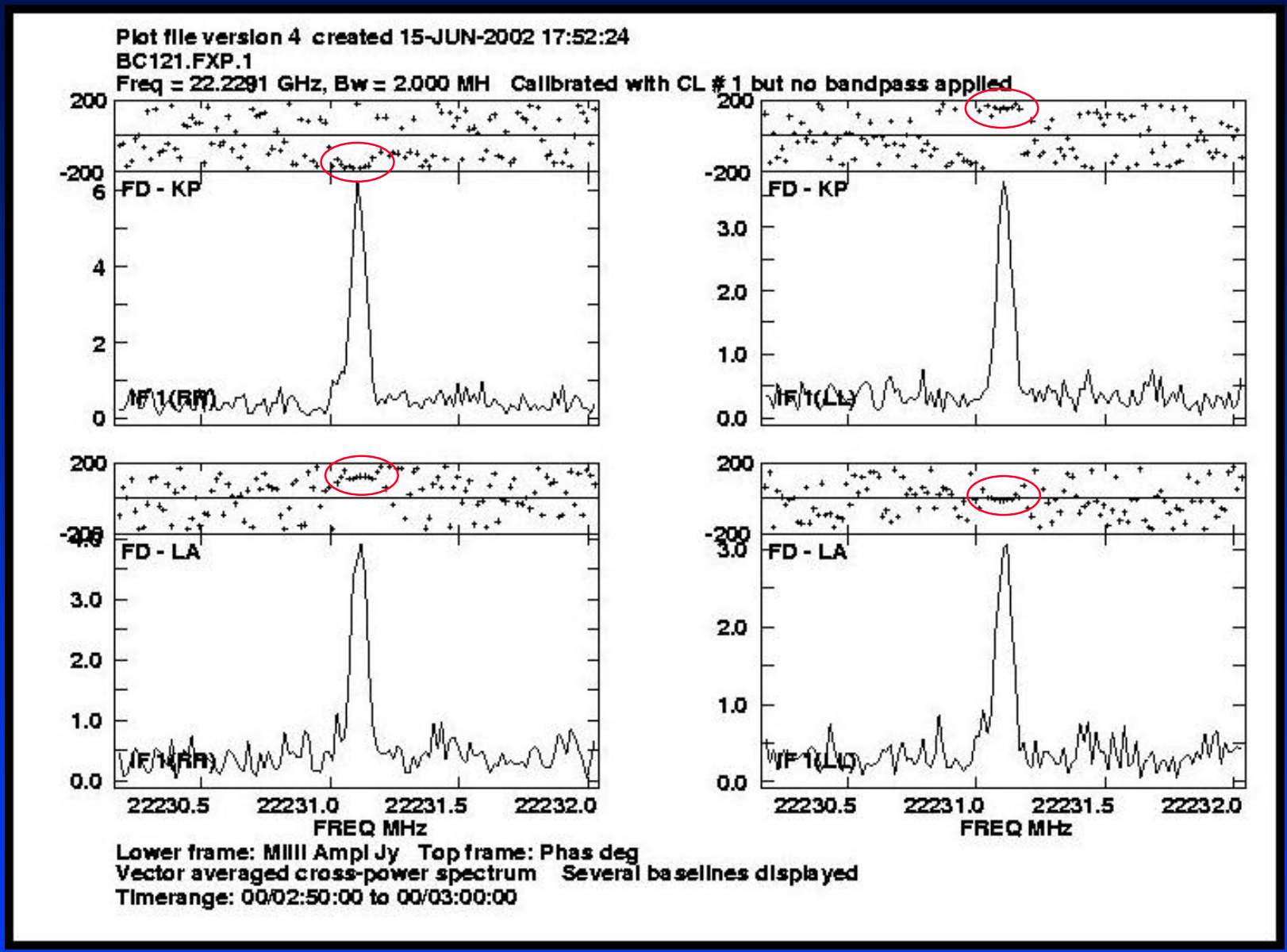
Assume time and frequency corrections are independent

Amplitude Calibration

- Usually use Tsys measurements
  - → No secondary calibrator
- For spectral line, 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
    - Fails on extended sources

Fringe Fitting




Plot file version 4 created 15-JUN-2002 17:52:24
BC121.FXP.1
Freq = 22.2291 GHz, Bw = 2.000 MH Calibrated with CL # 1 but no bandpass applied
FD - KP
IF 1 (RR)
IF 1 (LL)
FD - LA
IF 1 (RR)
IF 1 (LL)
200
-200
6
4
2
0
3.0
2.0
1.0
0.0
22230.5
22231.0
22231.5
22232.0
FREQ MHz
Lower frame: MIII Ampl Jy Top frame: Phas deg
Vector averaged cross-power spectrum Several baselines displayed
Timerange: 00/02:50:00 to 00/03:00:00

Phase referencing

- Can phase reference observations in a similar way to ATCA observations
  - → Need much shorter cycle time
- Fringe fit and then phase (& amplitude) selfcal calibrator – apply to target
- Image sources too weak to detect in coherence time
- Obtain accurate (relative) positions
- Need v. compact strong source close by
  - → Good catalogues in North, difficult for South

Bandpass Calibration

- Need relatively strong continuum source
- Must observe at same frequency
- Can use auto-correlations, but cannot correct phase
- Cross-corr allow phase correction
  - $\rightarrow$ Need enough S/N on calibrator
  - $\rightarrow$ Need to fringe fit first

Self-calibration

- As normal for continuum
  - $\rightarrow$ Beware poor UV coverage
- Spectral line,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

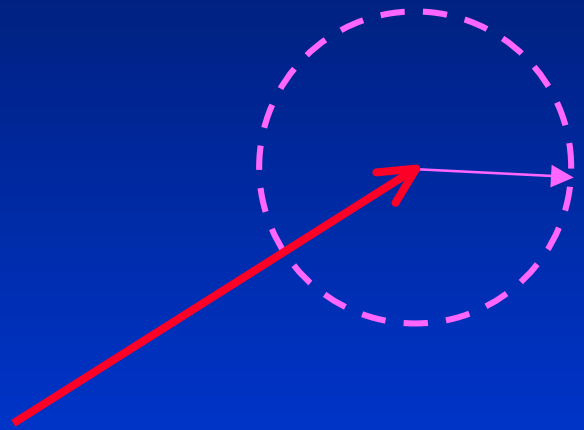
- No need for Galactic masers
- Do after all calibration for HI absorption
  - $\rightarrow$ Image negative hole in image
  - $\rightarrow$ POSSM/UVSPEC plots show as emission

Scalar/Vector Averaging

- Visibilities are complex vector + noise
- Estimate average:

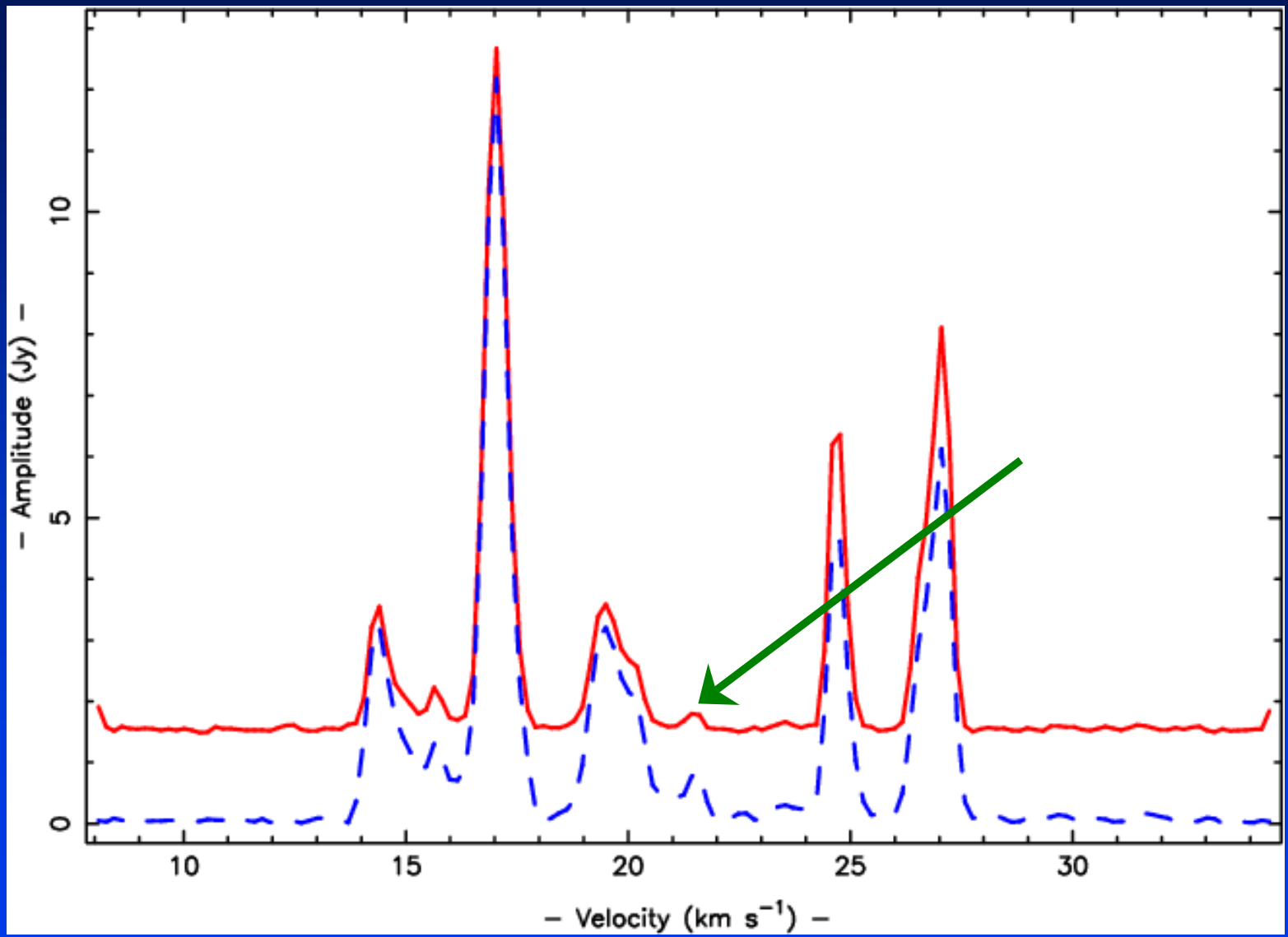
  $\rightarrow |\Sigma v|$ Vector

  $\rightarrow \Sigma |v|$ Scalar

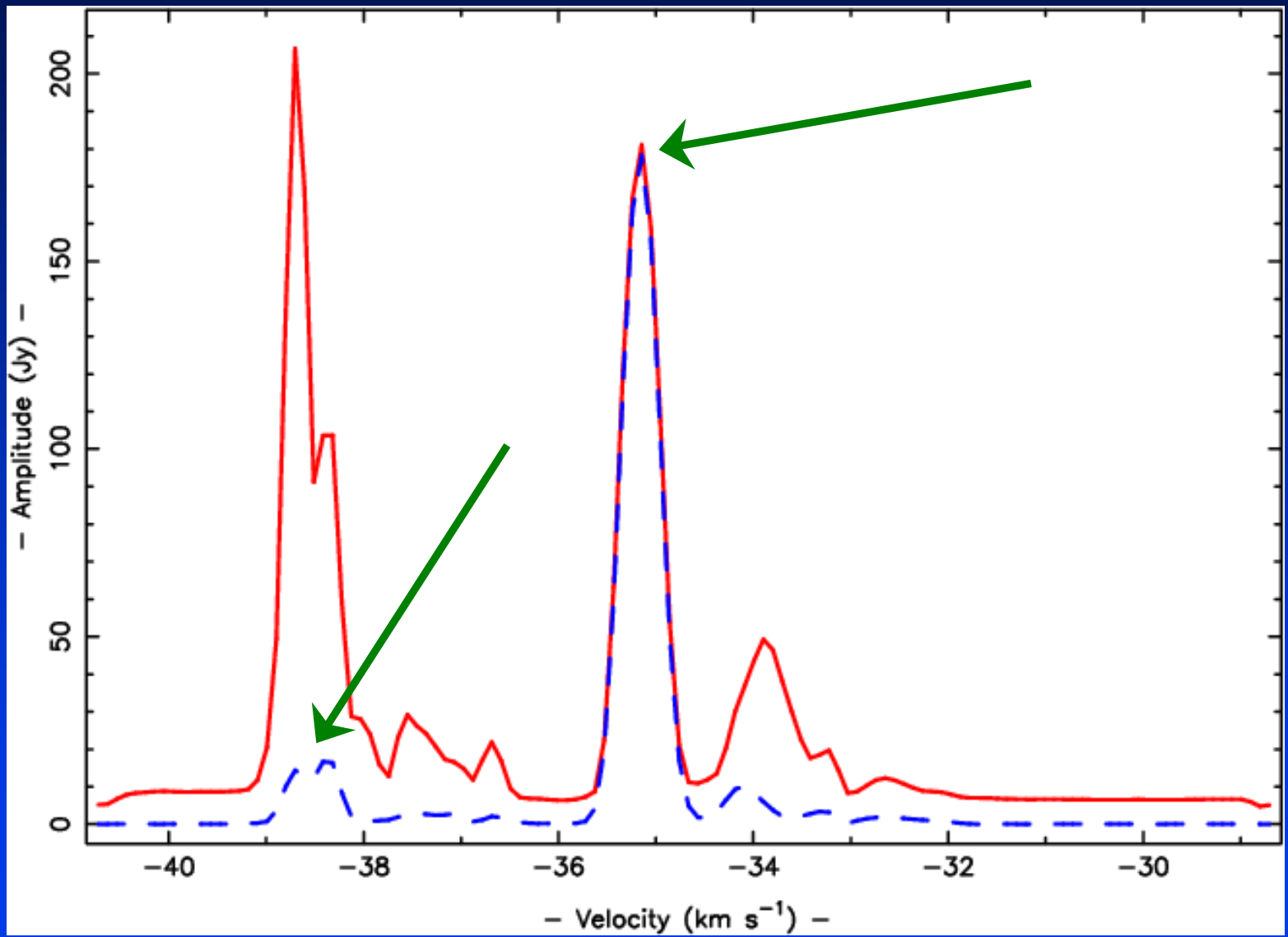


- Vector averaging sensitive to uncalibrated phases
- Scalar averaging noise bias

ATCA Data (6.7 GHz Methanol)



VLBI Data (12.2 GHz Methanol)



Imaging

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

Scheduling

- Observe a fringe finder
- If using tied ATCA include regular observation of strong compact calibrator
  $\rightarrow$ Calculate FOV of ATCA beam
- Seriously consider phase referencing
- Consult a local expert

Spectral Line Scheduling

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

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

- Ga… …10”)
- Wi…
- Us… …e em…
- Als…
- FR…