Probing the polarization characteristics of SS433 on milliarcsecond scales

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Outline of the talk:

SS433 as a microquasar

The binary system and the precessing jets
The known VLBI structure; motivation for further research

Circular Polarization in microquasars and SS433

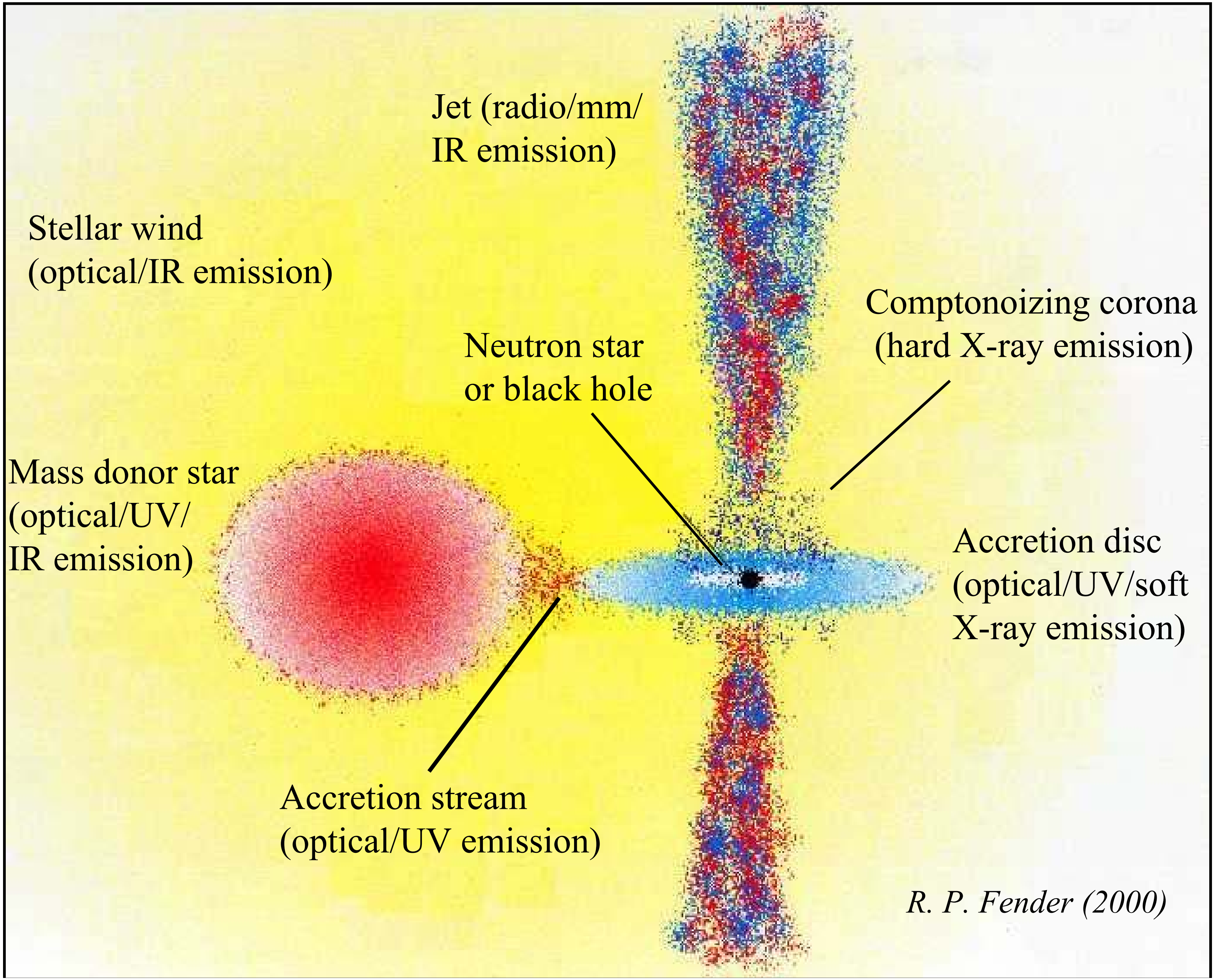
CP mechanisms
CP observations in microquasars and SS433

Global VLBI Observations

CP detection with VLBI, data processing issues
Expected CP errors from large D-terms

Early results

Stokes I map of SS433, kinematic modeling of the source
Polarization properties

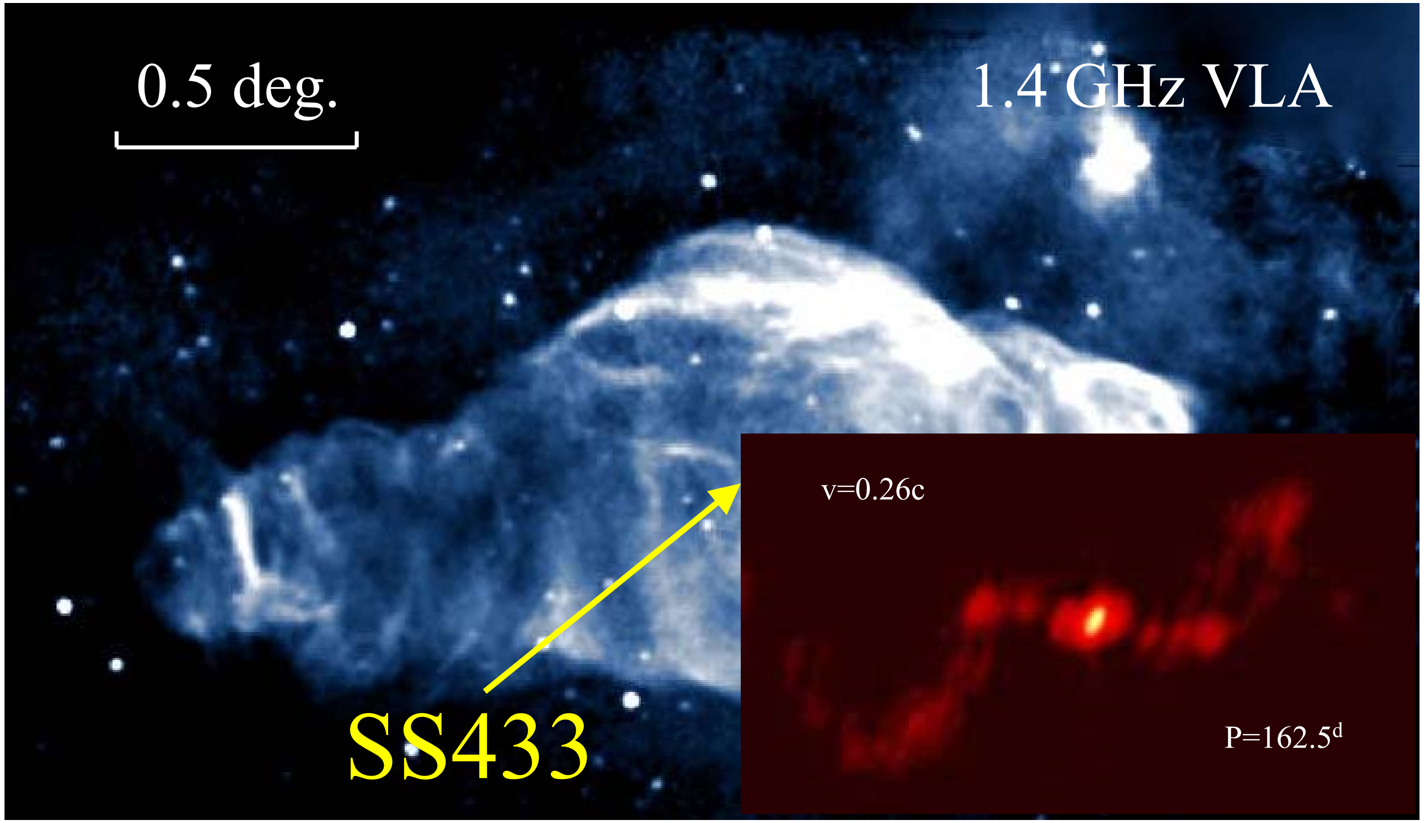

Jet (radio/mm/
IR emission)
Stellar wind
(optical/IR emission)
Comptonoizing corona
(hard X-ray emission)
Neutron star
or black hole
Mass donor star
(optical/UV/
IR emission)
Accretion disc
(optical/UV/soft
X-ray emission)
Accretion stream
(optical/UV emission)
R. P. Fender (2000)

SS433: the first Galactic radio-jet system

- Strong, Hα spectral lines (*Stephenson, Sandaluek 1977*)
- Eclipsing binary, V1343 Aql, m_v=14 mg (*Kholopov et al. 1981*)
- Related radio and X-ray sources
- Spectral lines at unusual frequencies (*Margon et al. 1979*)
- Doppler-shifted Balmer and HeI lines (*Fabian, Rees 1979, Milgrom 1979*)
- "moving lines", between -30000 and +50000 km/s, P~164 days (*Margon 1979b*)

- MERLIN: elongated structure on 1" scales (*Spencer 1979*)
- EVN: compact VLBI structure, ~10 mas (*Schilizzi et al. 1979*)
- VLA: precessing beams (*Hjellming, Johnston 1981*)

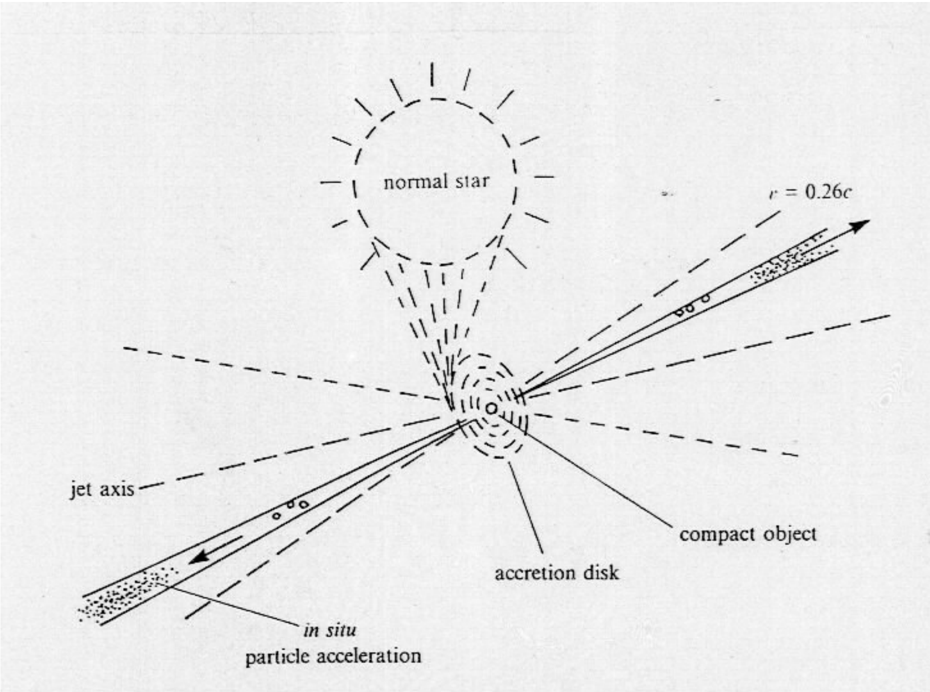
W50 supernova remnant



*Dubner et al. (1998), Astron J. **116**, 1842*

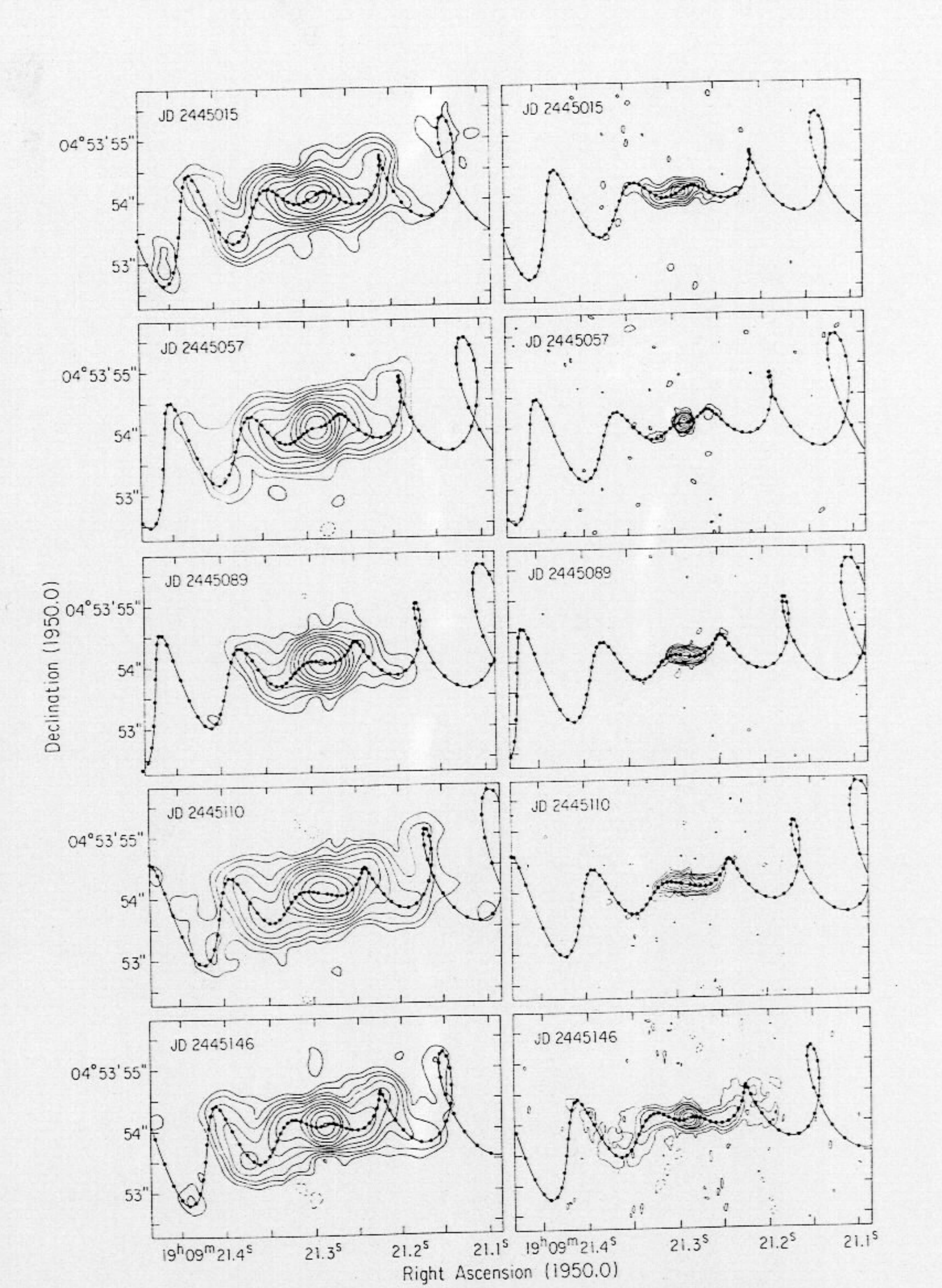
The binary stellar system:

- O, B, or WR normal star, about 10 $M_\odot$ or larger
- Black hole or neutron star, $M_{compact}/M_\star$~0,25 (estimate)
- 4×10^{12} cm (0,27 AU) (*Brinkmann, Kawai, Matsuok 1989*)
- 13.081 day orbital period (*Kemp et al. 1986*)



Hjellming, Johnston (1986)

- $dM/dt = 10^{-5}–10^{-4}\ M_\odot$ /yr
  (*van den Heuvel 1981*)
- $L_{bol} = 10^{39} – 10^{40}$ erg/s
  (e.g. *Wagner 1986*)
- $L_X = 10^{36}$ erg/s
  (*Kotani et al. 1996*)
- $L_{kin} = 2\times10^{39}$ erg/s
  (*e.g. Watson et al. 1986*)

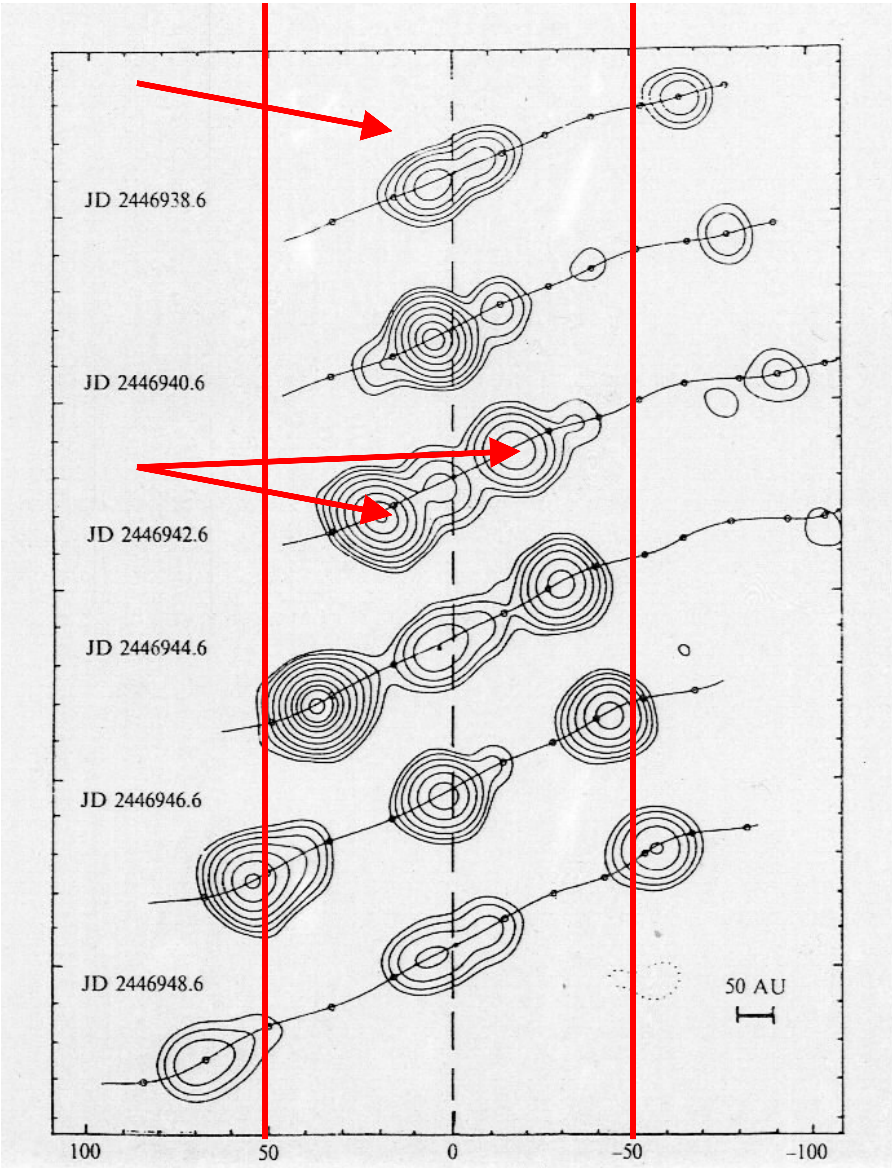


Hjellming, Johnston (1985)

Kinematic model parameters

- inclination (*Margon, Anderson 1989*):
  $i = 78{,}83° \pm 0{,}10°$
- prec. cone half opening angle (*Margon, Anderson 1989*):
  $\theta = 19{,}85° \pm 0{,}17°$
- prec. cone axis projected PA (*Hjellming, Johnston 1981*):
  $\chi = 100° \pm 2°$
- sense of precession (*Hjellming, Johnston 1981*):
  $s = -1$
- jet velocity (*Margon, Anderson 1989*):
  $v_{jet} = 0{,}2602 \pm 0{,}0013$ c
- prec. period (*Margon, Anderson 1989*):
  $P_{164} = 162{,}5 \pm 0{,}03$ nap
- prec. phase = 0.0 at (*Vermeulen 1989*):
  t_{164} = JD $2443588{,}03 \pm 0{,}3$

EVN, 5 GHz



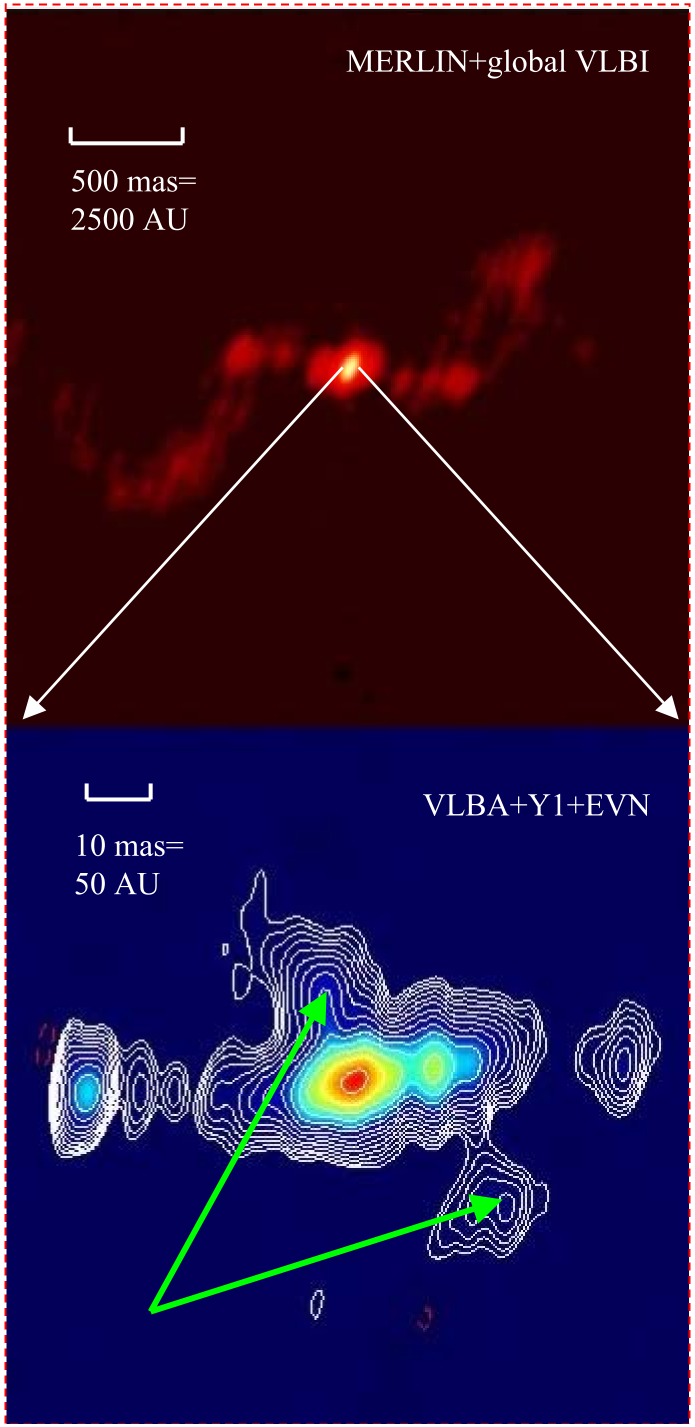
Vermeulen et al. (1993)

The radio structure of SS433 on mas scales, as seen with the EVN.

D = 5 kpc ⇨ 0,001” = 5 AU

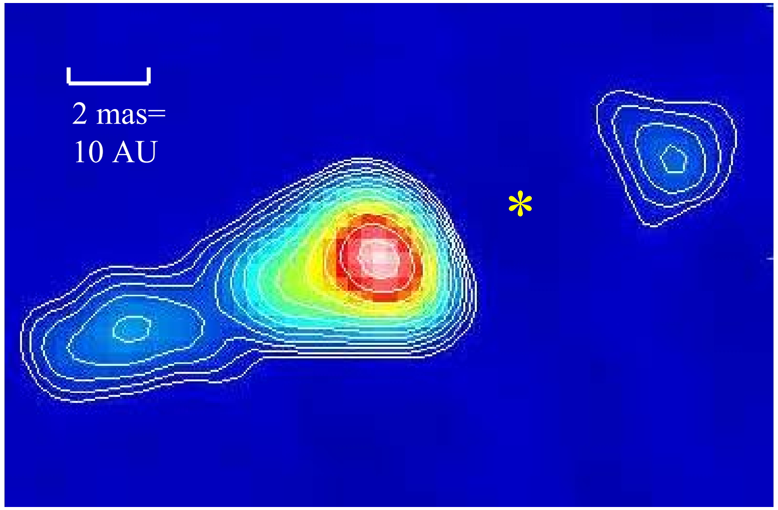
- elongated radio core-jet
- radio plasmons ejected from time to time
- brightening zone

The precessing beams of SS433 at 1.6 GHz . MERLIN and global VLBI, 1998 June 6.



Full resolution global VLBI image showing the recently discovered equatorial radio components.

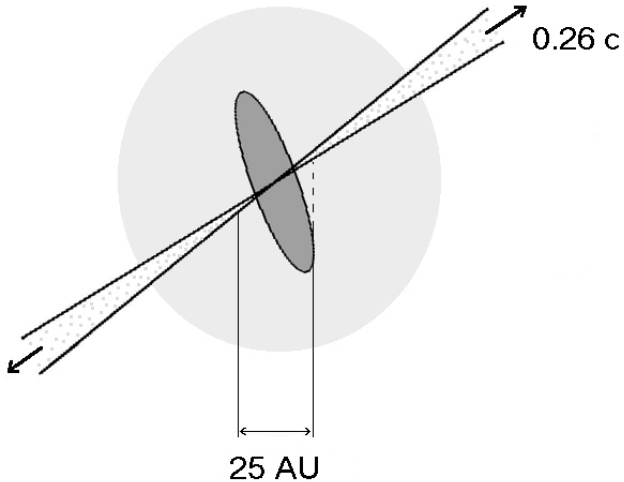
Paragi, Fejes, Vermeulen et al. (2000)



The highest resolution VLBI image to date. VLBA, 22 GHz, 1998 June 16.

Z. Paragi, PhD thesis

Interpretation: an ionized disk surrounds the system. Can be an equatorial outflow.



Paragi, Vermeulen, Fejes et al. (1999), Astron. Astrophys. ***348****, 910*

The radio structure is well established – what is still interesting in this source?

- production and collimation of jets
- electron acceleration place and mechanism
- jet composition (e^-e^+ vs. e^-p^+)
- the low and high energy cutoffs in the electron population

Some of these questions can be addressed with polarization observations, especially interesting is the circularly polarized component of the emission.

Some possible circular polarization (CP) emission mechanisms:

- Synchrotron radiation
  - order of $1/\gamma$ (*Legg and Westford 1968*)
  - $m_{cp} \propto \nu^{-1/2}$, i.e. steep fractional polarization
- Gyro-synchrotron radiation
  - requires low energy electrons, γ~30 or lower
  - may result in very high fractional polarization (up to 70%)
  - very steep spectrum (*Spencer and McCormick 2003*)
- Faraday conversion (LP => CP)
  - m_{cp} spectrum is steep with spectral indeces ranging from –1 (*Pacholczyk 1973*) to –3 (*Kennett and Melrose 1998*) , depending on the plasma properties

CP observations in microquasars (ATCA, MERLIN, WSRT)

GRS 1915+105 (*Fender et al. 2003*)

– ATCA and MERLIN observations in 2001
– correlated stokes I and V changes
– negative stokes V, 0–2 mJy (m_{cp} ~0.3%)

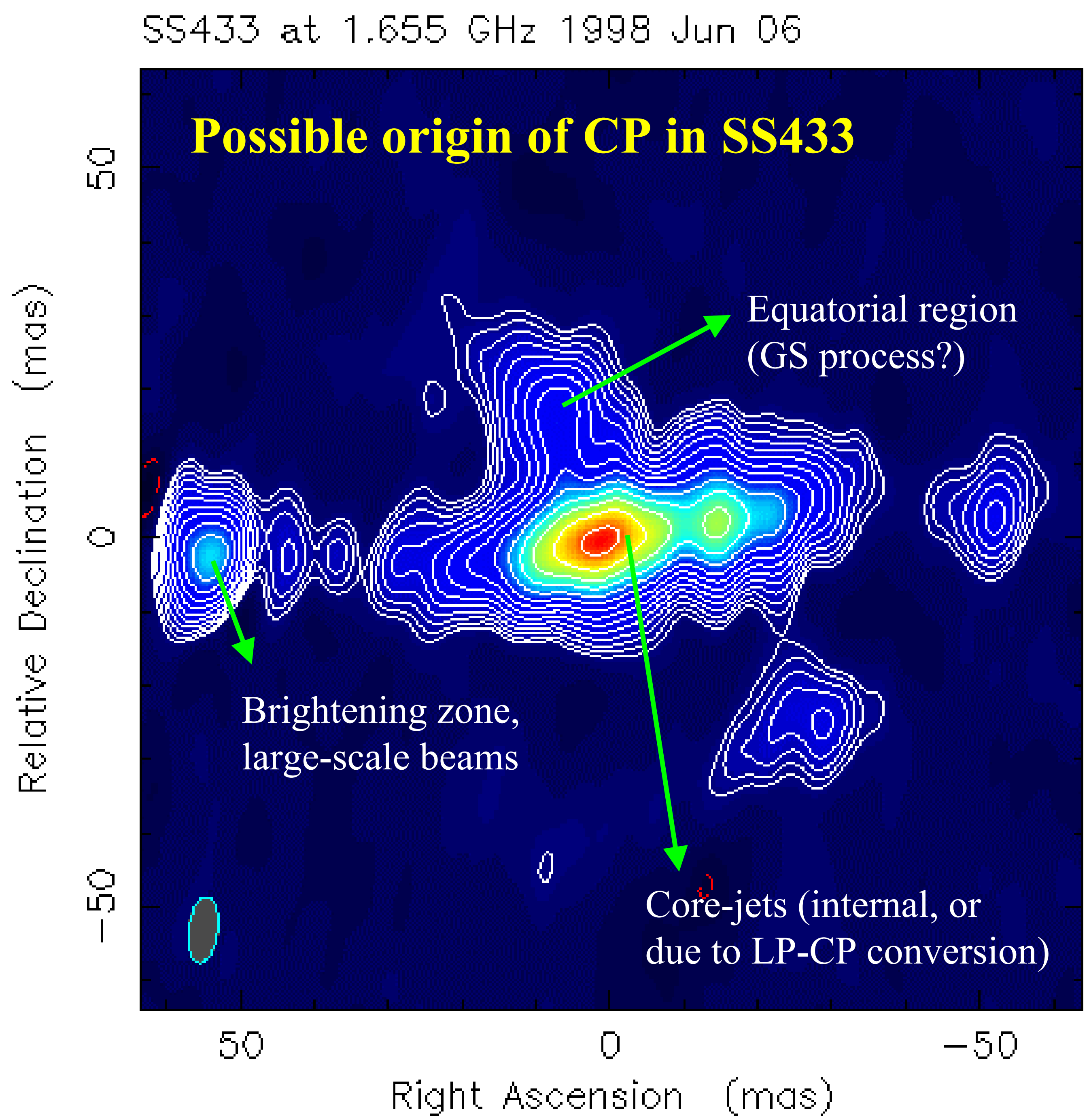
GRO J1655-40 (*Macquart et al. 2002*)

– m_{cp} ~0.2%

SS433

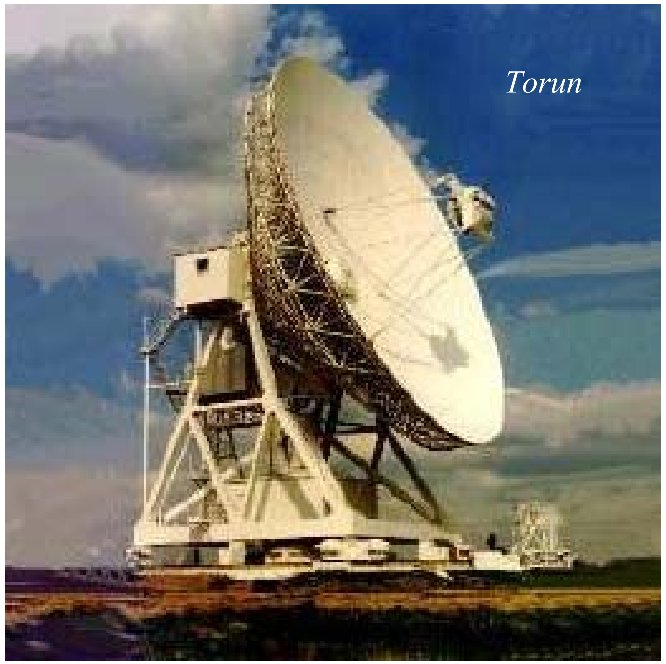
– ATCA observations on 20 May 1999. (*Fender et al. 2000*)
– significant CP detected, up to 5 mJy (m_{cp} ~0.1–0.8%)
– observed spectrum was steep ($\alpha = -0.9 \pm 0.1$)
– sign change detected in 2000 (*Spencer et al. 2003*)

Fractional CP cannot be determined. VLBI observations needed!


SS433 at 1.655 GHz 1998 Jun 06
Possible origin of CP in SS433
Equatorial region
(GS process?)
Brightening zone,
large-scale beams
Core-jets (internal, or
due to LP-CP conversion)
50
0
−50
Relative Declination (mas)
50
0
−50
Right Ascension (mas)

Global VLBI observations on 29 May 2003

- MERLIN (only very short time)
- Western EVN



- The full VLBA
- The Green Bank Telescope
- A single dish of the VLA

Major steps of data processing

- A-priori amplitude calibration
- fringe-fitting
- cross-hand fringe-fritting
- D-term calibration (OQ208)
- R-L gain calibration (3C345, OQ208, NRAO512, J1832+1357, J2002+4725)

  (Homan and Wardle 1999)

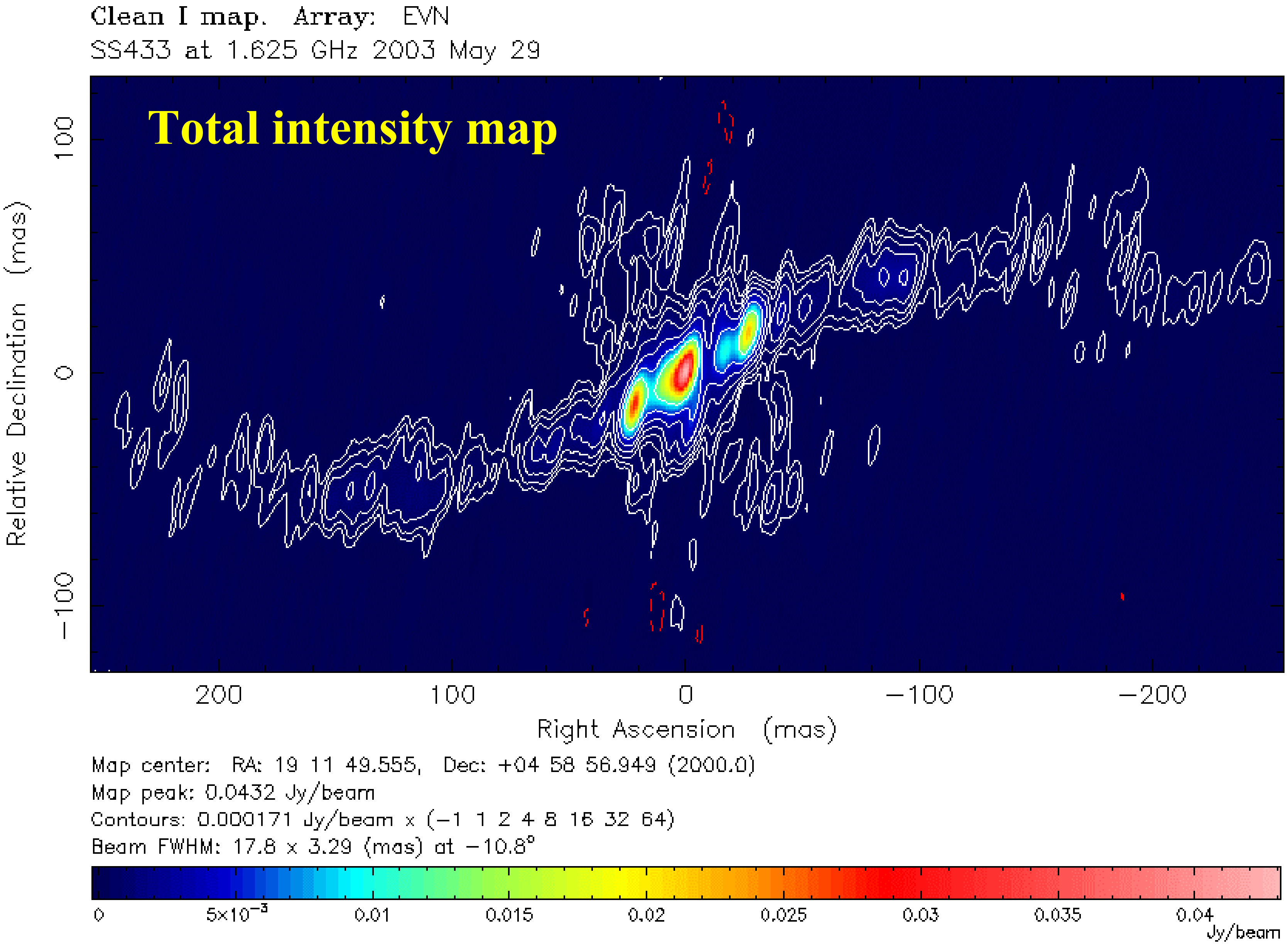
On average, the CP contribution of the calibrators will cancel. Any sources showing significant CP with respect to the others are excluded form the calibration process.

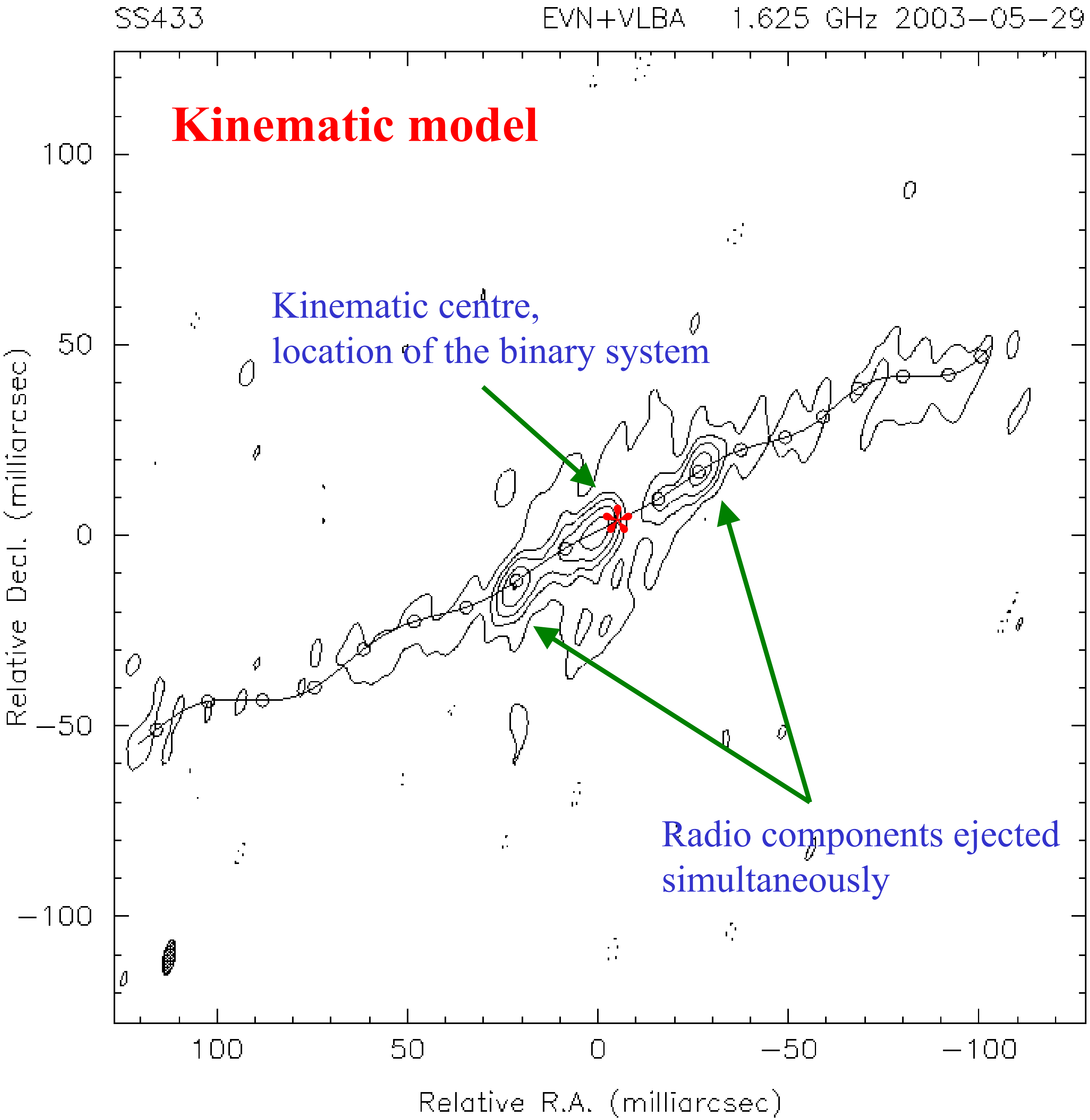
Current status of the calibration

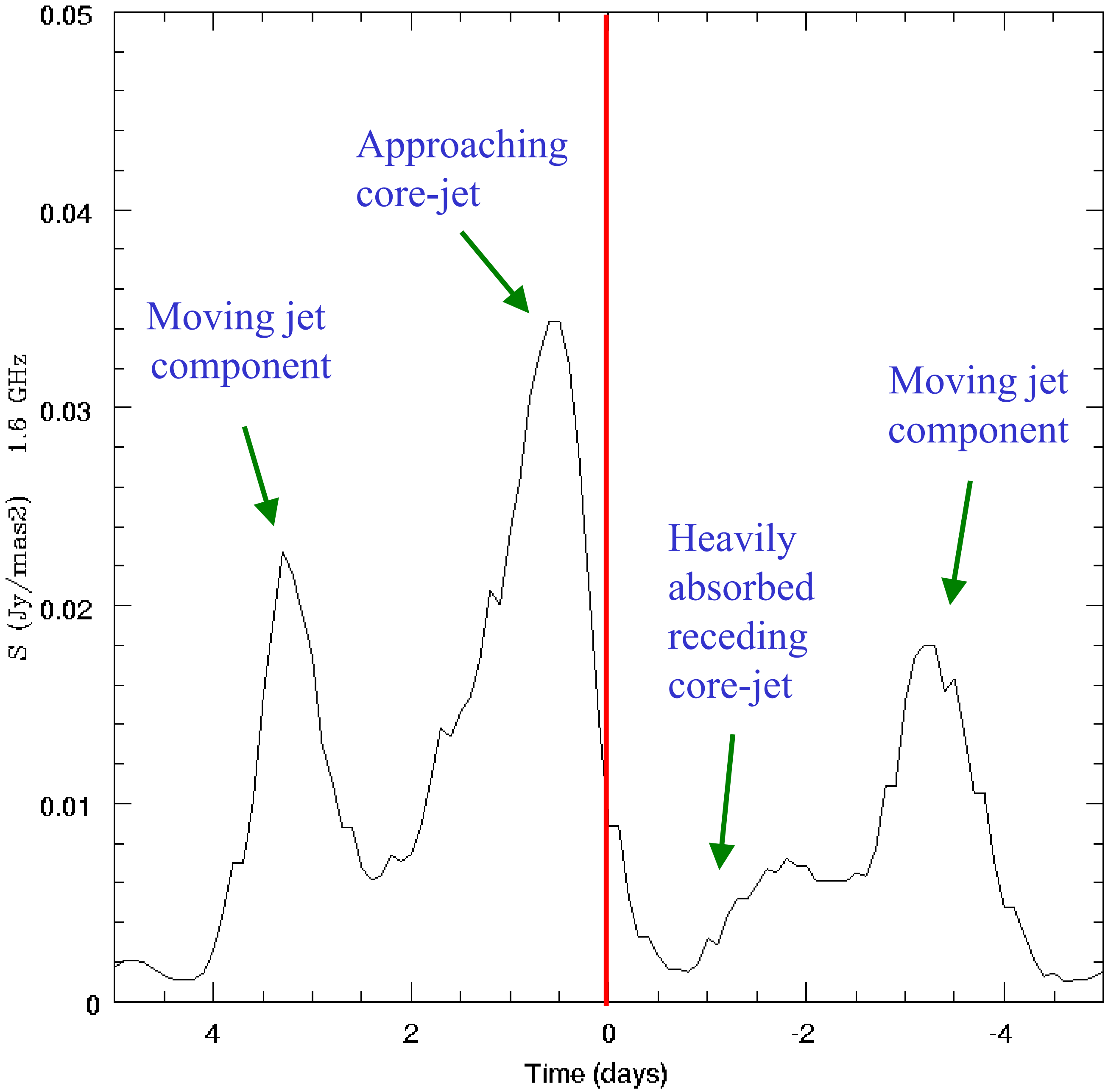
- stokes I map was produced
- polarization leakage D-terms were determined
- some stations seem to have variable D-terms (Gb, Wb)
- the effect of the D-term errors (<1%) is expected to be at levels of 0.01% in CP calibration

- zero-V self-calibration test carried out
- R-L gain calibration preliminary results
- some EVN stations (Mc,Tr) and the VLA had very high, sometimes variable R-L gain offset

Here come the maps…


Clean I map. Array: EVN
SS433 at 1.625 GHz 2003 May 29
Total intensity map
Relative Declination (mas)
100
0
−100
200
100
0
−100
−200
Right Ascension (mas)
Map center: RA: 19 11 49.555, Dec: +04 58 56.949 (2000.0)
Map peak: 0.0432 Jy/beam
Contours: 0.000171 Jy/beam x (−1 1 2 4 8 16 32 64)
Beam FWHM: 17.8 x 3.29 (mas) at −10.8°
0
5×10−3
0.01
0.015
0.02
0.025
0.03
0.035
0.04
Jy/beam


SS433
EVN+VLBA 1.625 GHz 2003–05–29
Kinematic model
Kinematic centre,
location of the binary system
Radio components ejected
simultaneously
Relative Decl. (milliarcsec)
Relative R.A. (milliarcsec)
100
50
0
−50
−100


0.05
0.04
0.03
0.02
0.01
0
S (Jy/mas2) 1.6 GHz
4
2
0
-2
-4
Time (days)
Approaching
core-jet
Moving jet
component
Heavily
absorbed
receding
core-jet
Moving jet
component

No linear polarization observed on mas scales.

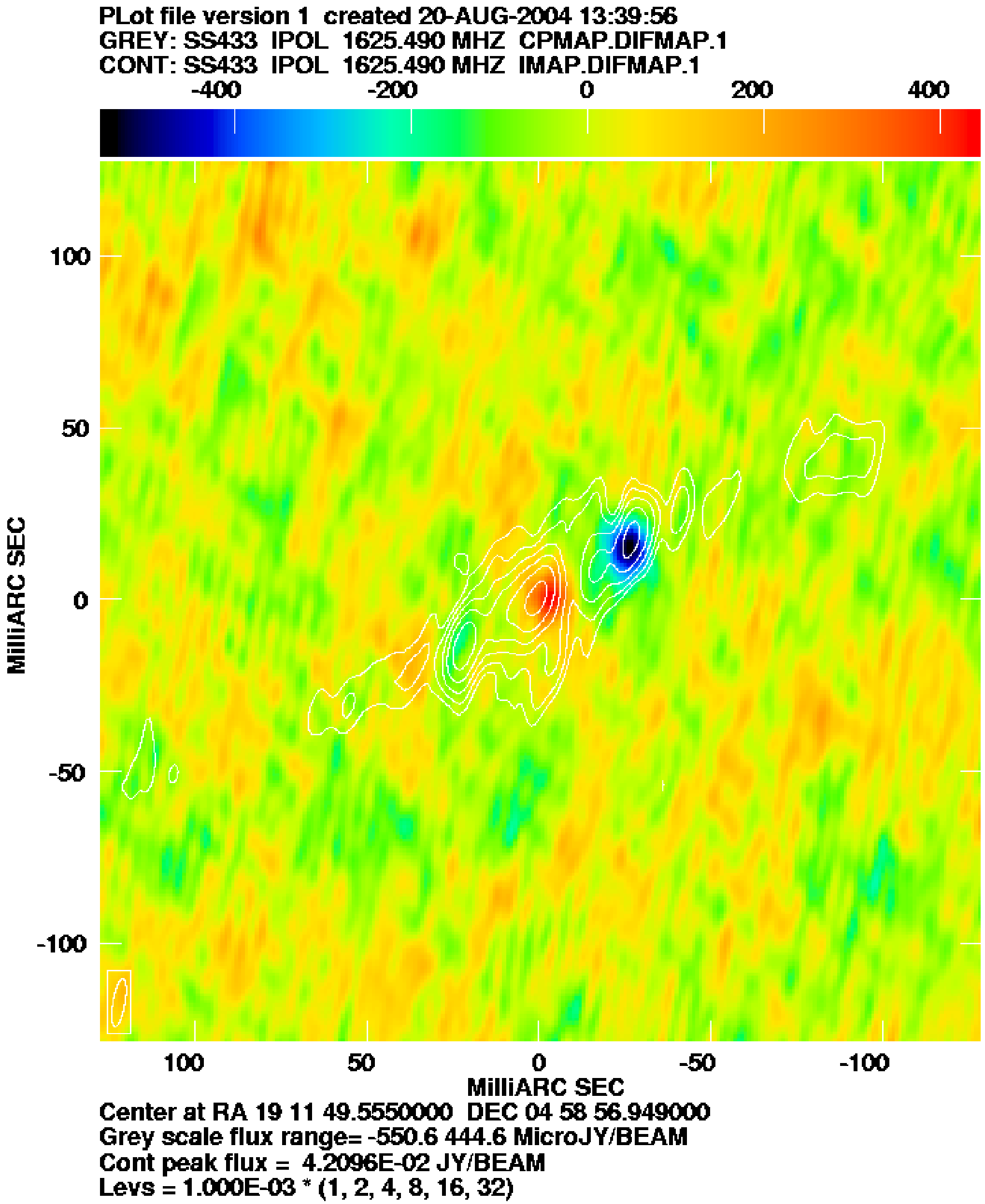
Fractional LP upper limit is about 0.5% in the approaching core-jet (in agreement with *Paragi et al. 1999*).

Could be due to Faraday depolarization in the equatorial region, or within the jets

There is no evidence for high levels of CP from zero-V self-calibration.

If emission was GS in the equatorial region, this might produce high levels of fractional CP (*Spencer and McCormick 2003*)

This could show up even after self-calibrating the data assuming no CP in the source. There is no evidence for GS in the equatorial region.



Preliminary CP results

- Negative CP related to the receding core-jet (about 6 sigma; off the peak intensity in stokes I)
- Weak positive CP associated with the approaching core-jet (about 4 sigma; off the peak intensity in stokes I)
- This detection of CP in the core region of SS433 must be further confirmed.