

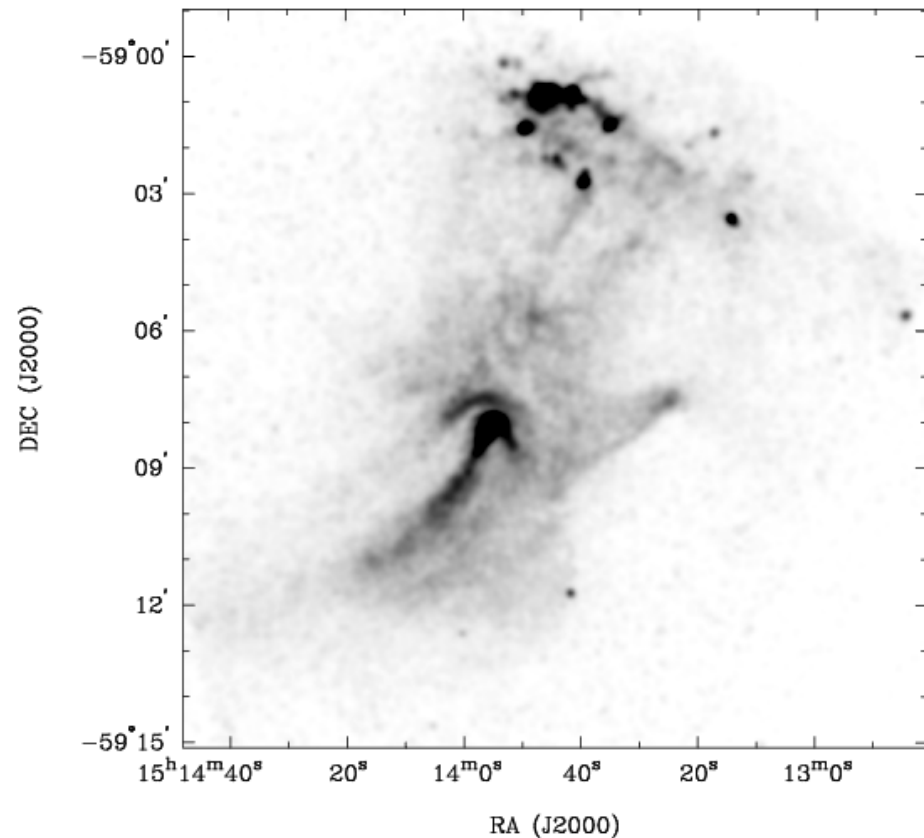
Time Variability in the X-ray Nebula and Jet Powered by PSR B1509-58

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Outline

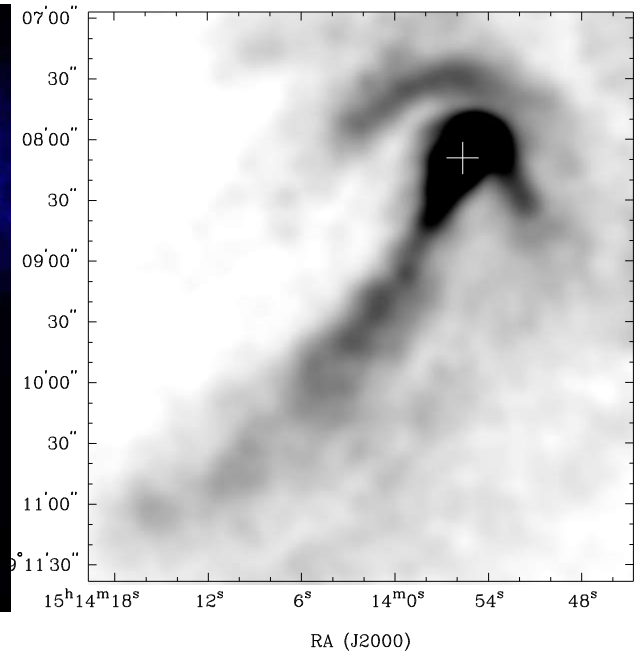
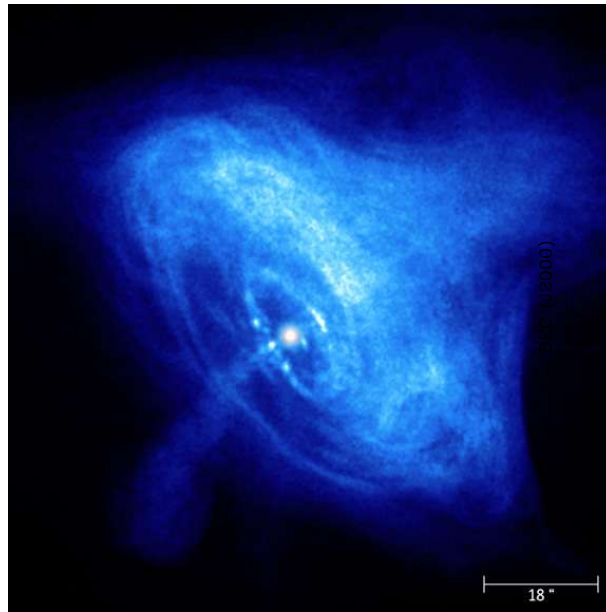
Part I: Review of selected PWNe morphology

- Crab, Vela, B1509
- multiband correlations

Part II: X-ray motions/variability in B1509

- comparison to Crab, Vela
- interpretation of observations – cartoons

Part I: PWNe Morphology Review



Vela

$P=89$ ms

$D=0.3$ kpc

$t_c=11000$ yrs

$\dot{E}=7 \times 10^{36}$ erg/s

$B=3 \times 10^{12}$ G

Crab

$P=33$ ms

$D=2$ kpc

$t_c=1240$ yrs

$\dot{E}=5 \times 10^{38}$ erg/s

$B=3 \times 10^{12}$ G

PSR B1509-58

$P=150$ ms

$D=5.2$ kpc

$t_c=1700$ yrs

$\dot{E}=2 \times 10^{37}$ erg/s

$B=2 \times 10^{13}$ G

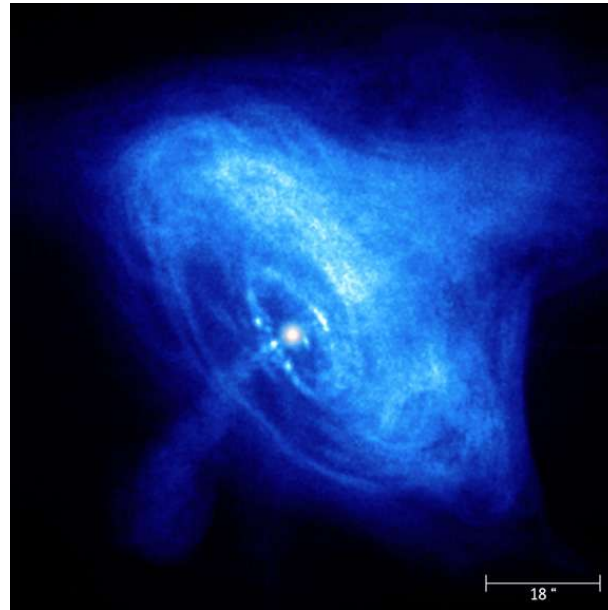
Jets, Torii, Wisps



Vela

jet length=0.15 pc

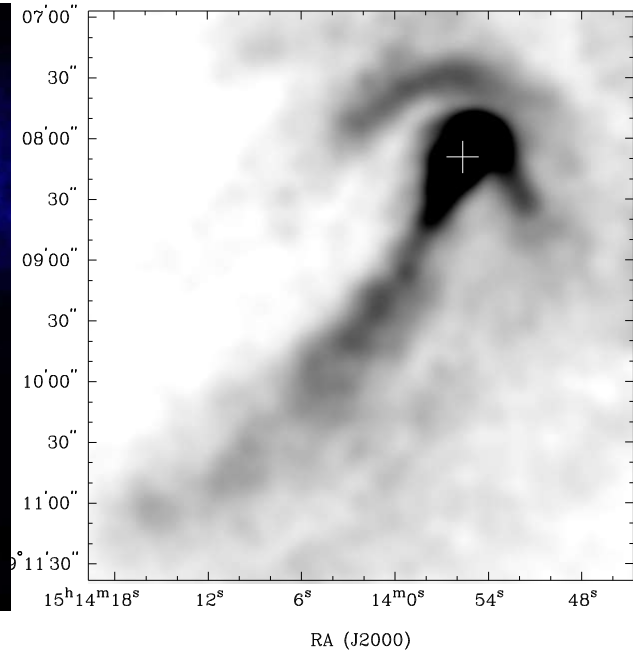
jet width=0.01 pc



Crab

Jet length=0.5 pc

Jet width=0.1 pc



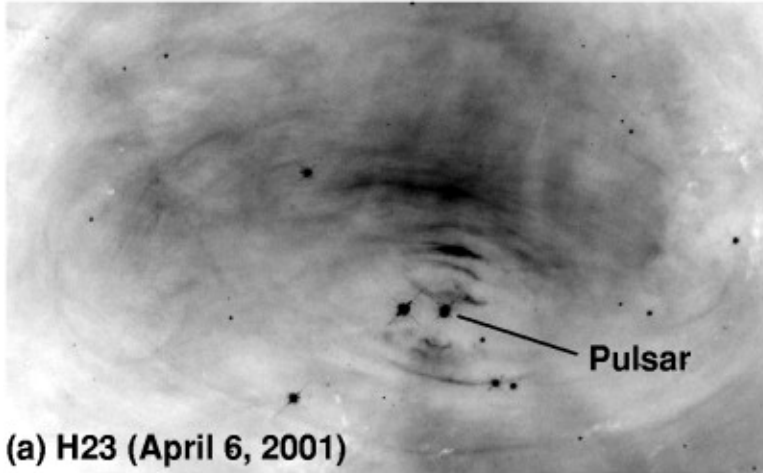
PSR B1509-58

Jet length=12 pc

Jet width=0.5 pc

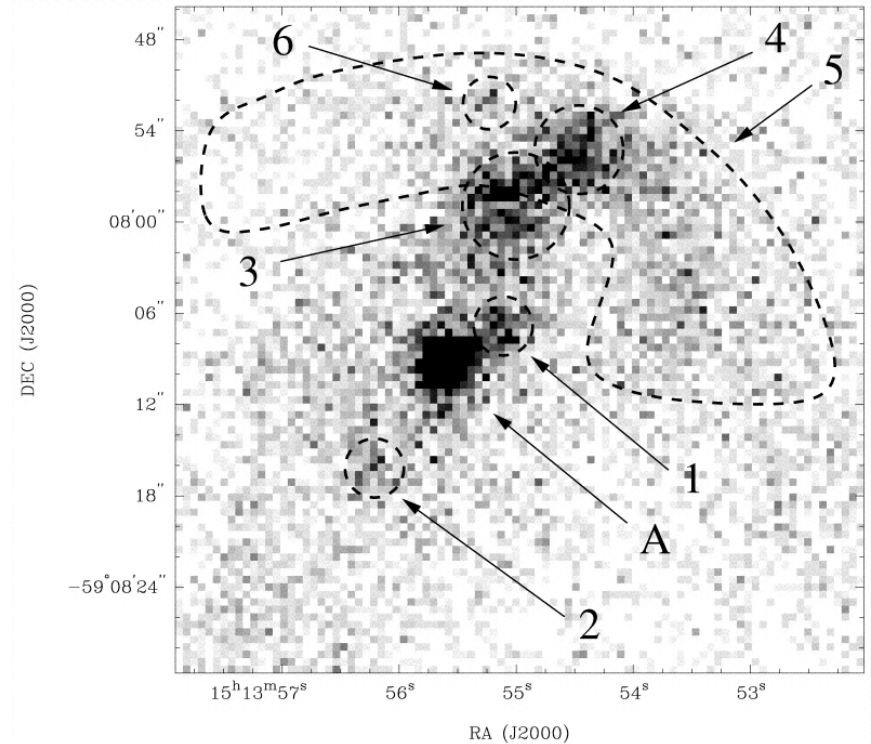
Many features brighter on one side than on other – Doppler boosting

Sprite, Knots



Crab HST

Hester et al 2002



B1509 Chandra

Gaensler et al 2002

Multiband Associations Complicated

Crab

- Jet – visible in optical and X-rays – not radio
- Wisps – visible in optical, X-rays, radio
 - some optical /X-ray correlations with varying brightness ratios (Hester et al 2002)
 - radio correlations to optical rare (Bietenholz et al 2004)
- Sprite – visible in optical and X-rays

B1509

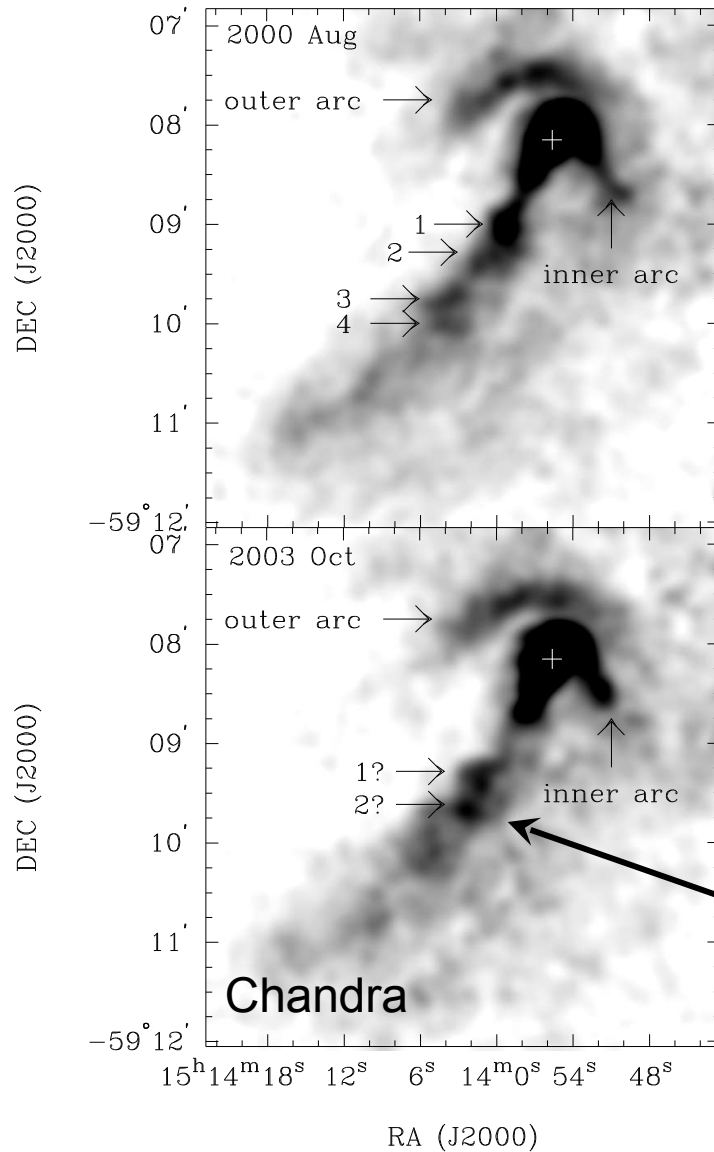
- Jet – X-rays only, reduced radio emission (Gaensler et al 2002)
- Torii – X-rays, polarized radio
- Knots – X-rays only

Part II: B1509 X-ray Variations

Using *ROSAT* and *Chandra* data –
identify changes on timescales of
6 months to 12 years

- Motion along jet
- Brightening/Fading of jet
- Bending of jet
- Small knot variability
- Will not discuss torus/wisp variability here

Clump/Knot Motions along Jet



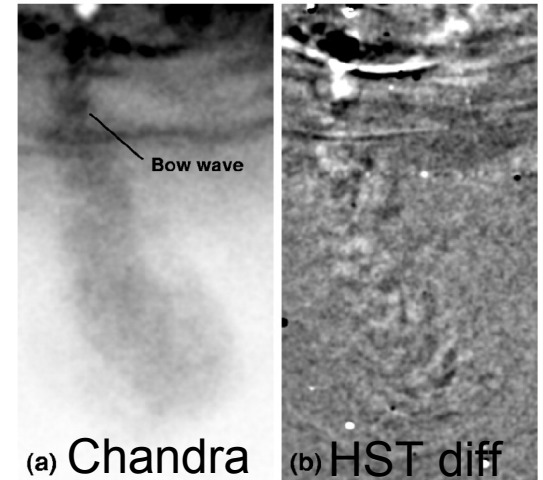
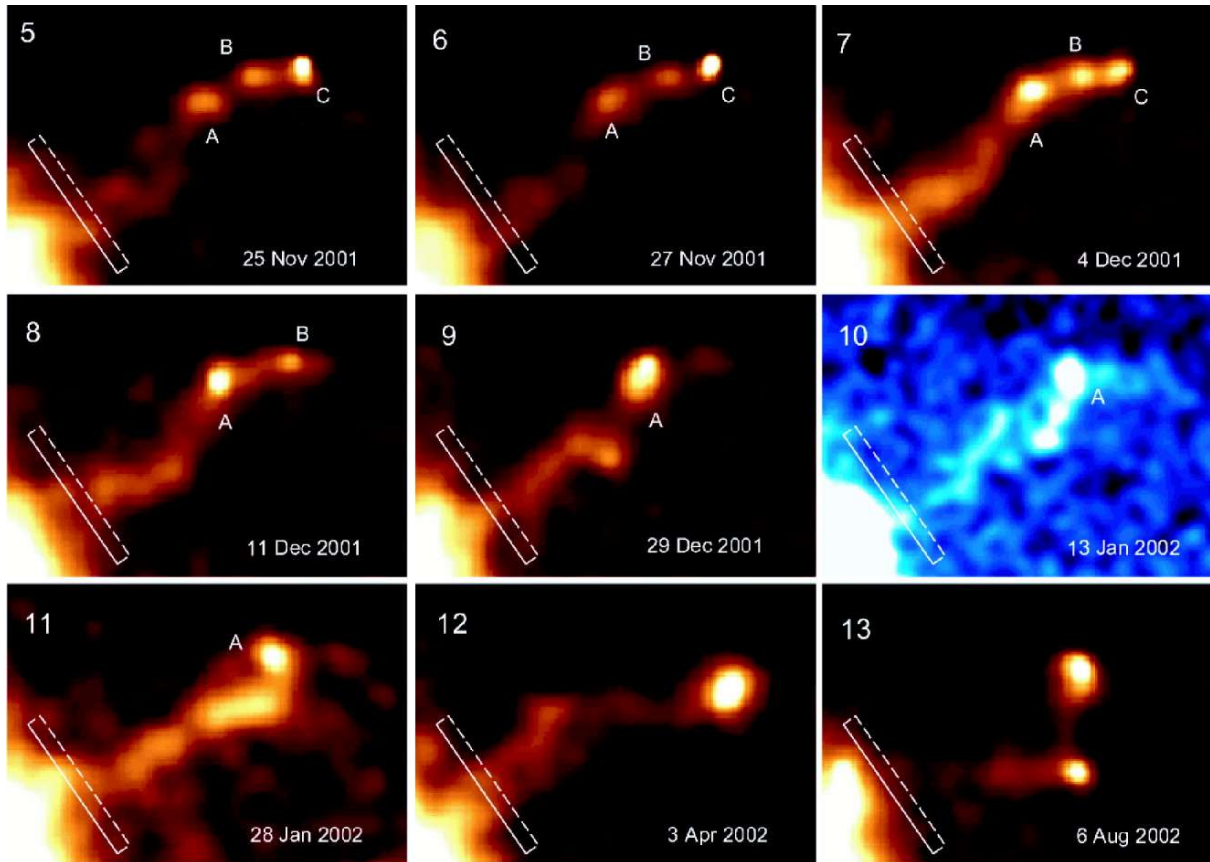
$v=0.5c$
 $dt=3\text{yrs}$
 $d_{\text{clump1}}=3\text{ pc}$

Clumps move
outward and fade

RA (J2000)

URJA, Banff 13 Jul 2005

Clump/Knot Motions along Jet

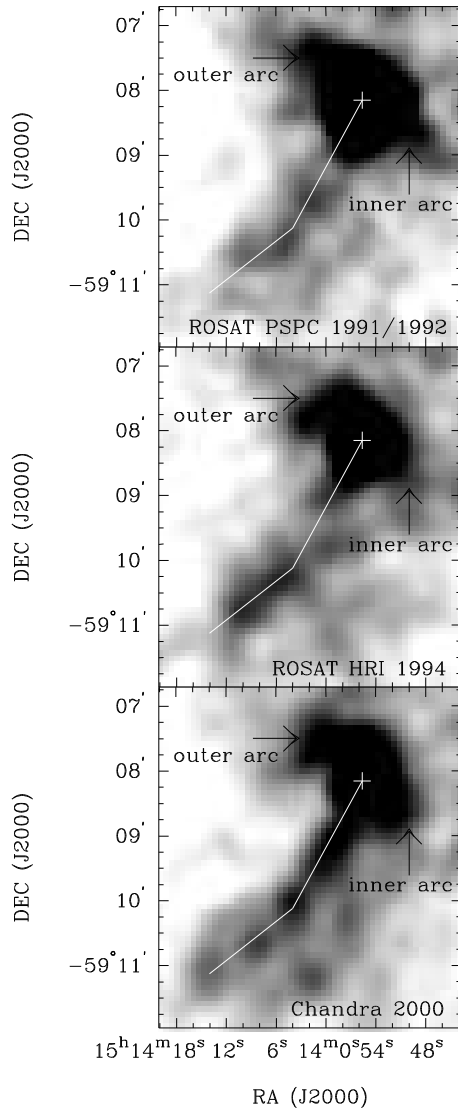


$v=0.4c$
 $dt=109$ days
Hester et al 2002

$v=0.3-0.7c$
 $d_{\text{blobA}} = 0.1$ pc
Pavlov et al 2003

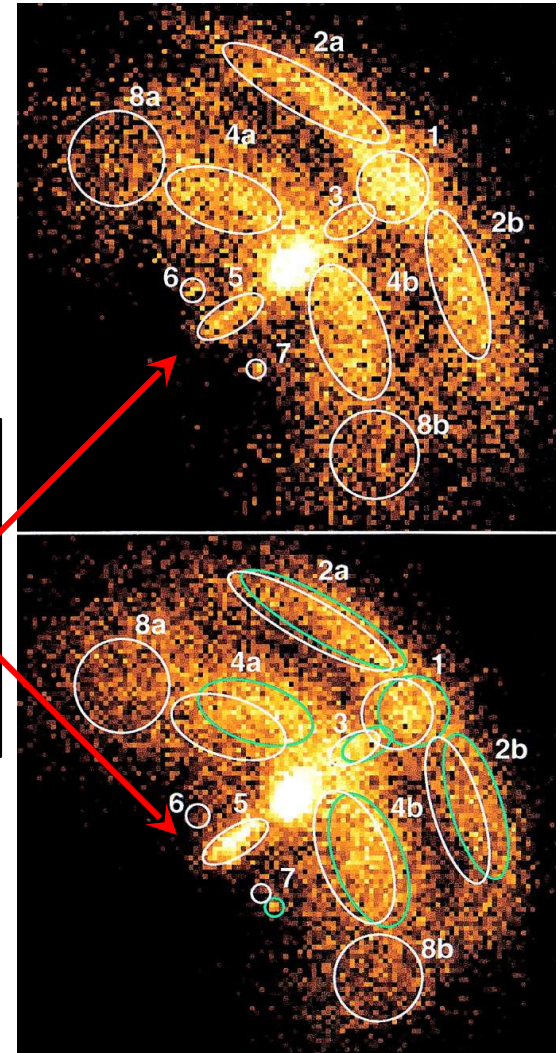
Clumps move
outward and
fade

Brightening/Fading of Jet

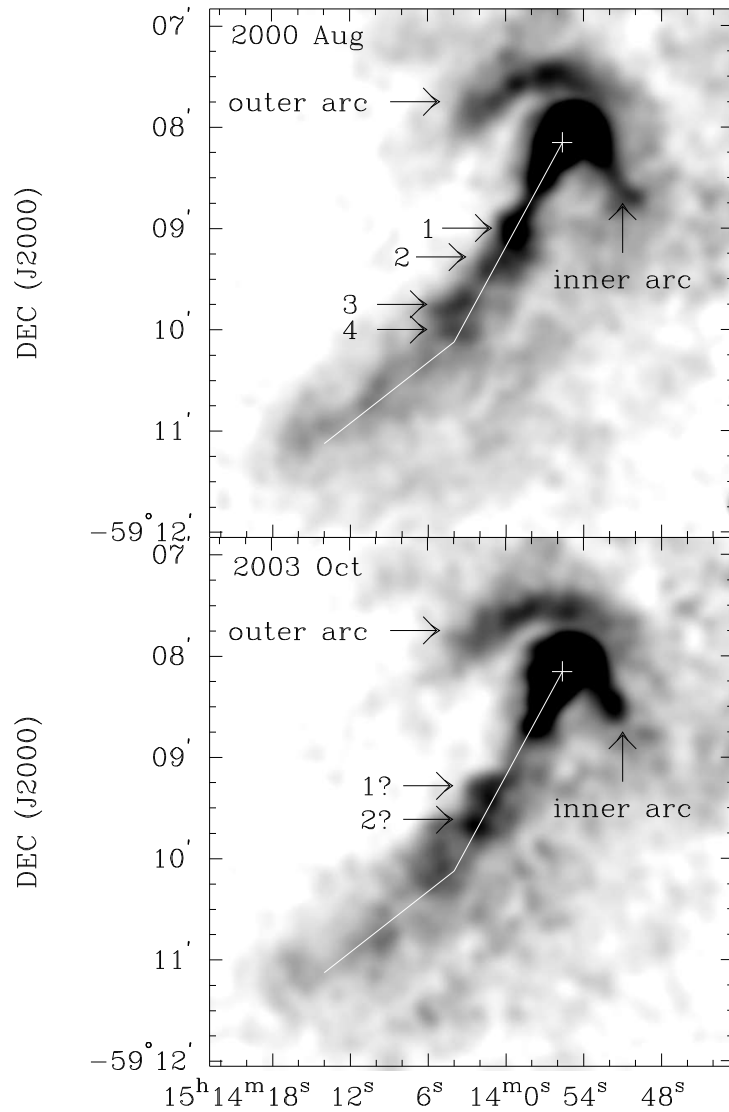


Jet has
"turned on"
over 9 yrs
30% change

Jet has
brightened in
7 months
Pavlov et al 2001

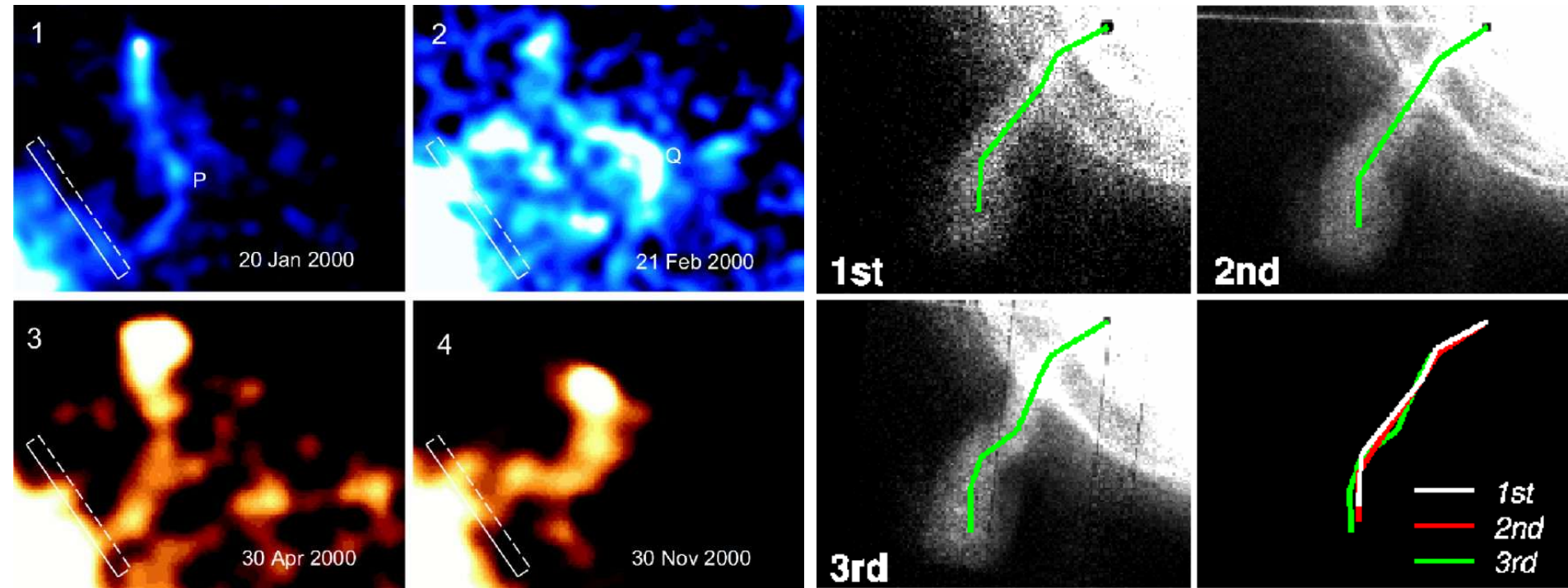


Kinking/Bending of Jet



Bent jet – but no obvious changes in bend between epochs (3 years)

Kinking/Bending of Jet

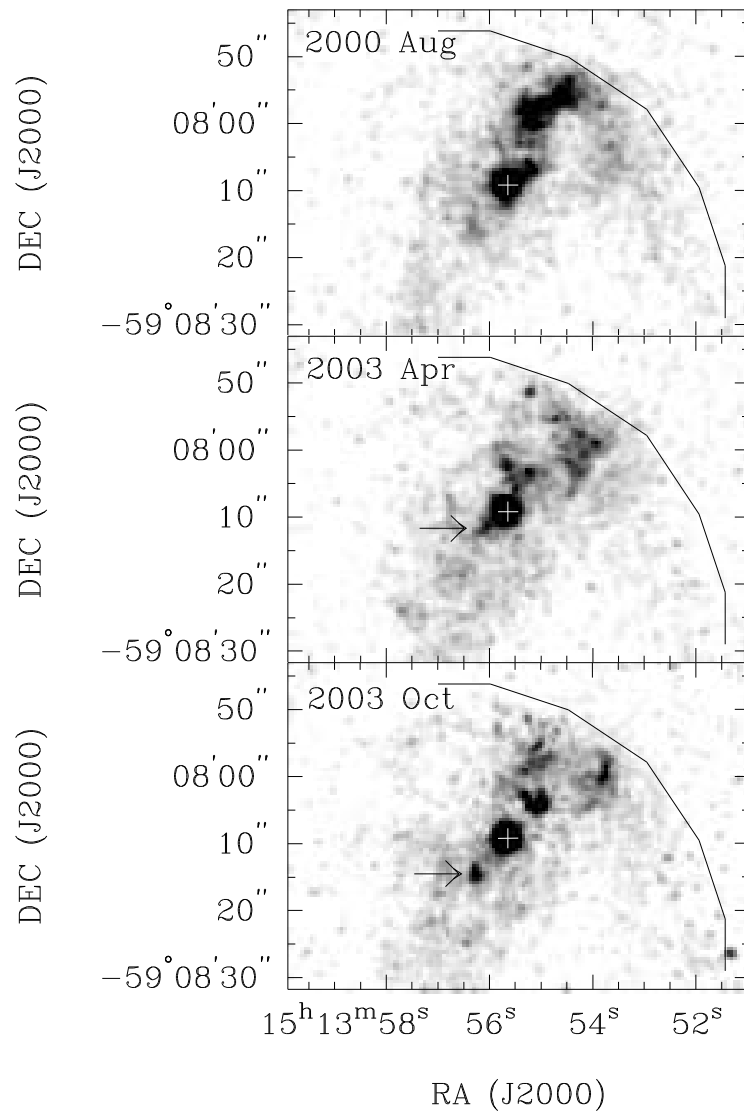


Vela
Minimum $dt=10$ days
Pavlov et al 2003

Crab
Minimum $dt=1.6$ yrs
Mori et al 2004

Changes observed in Crab/Vela, not in B1509!

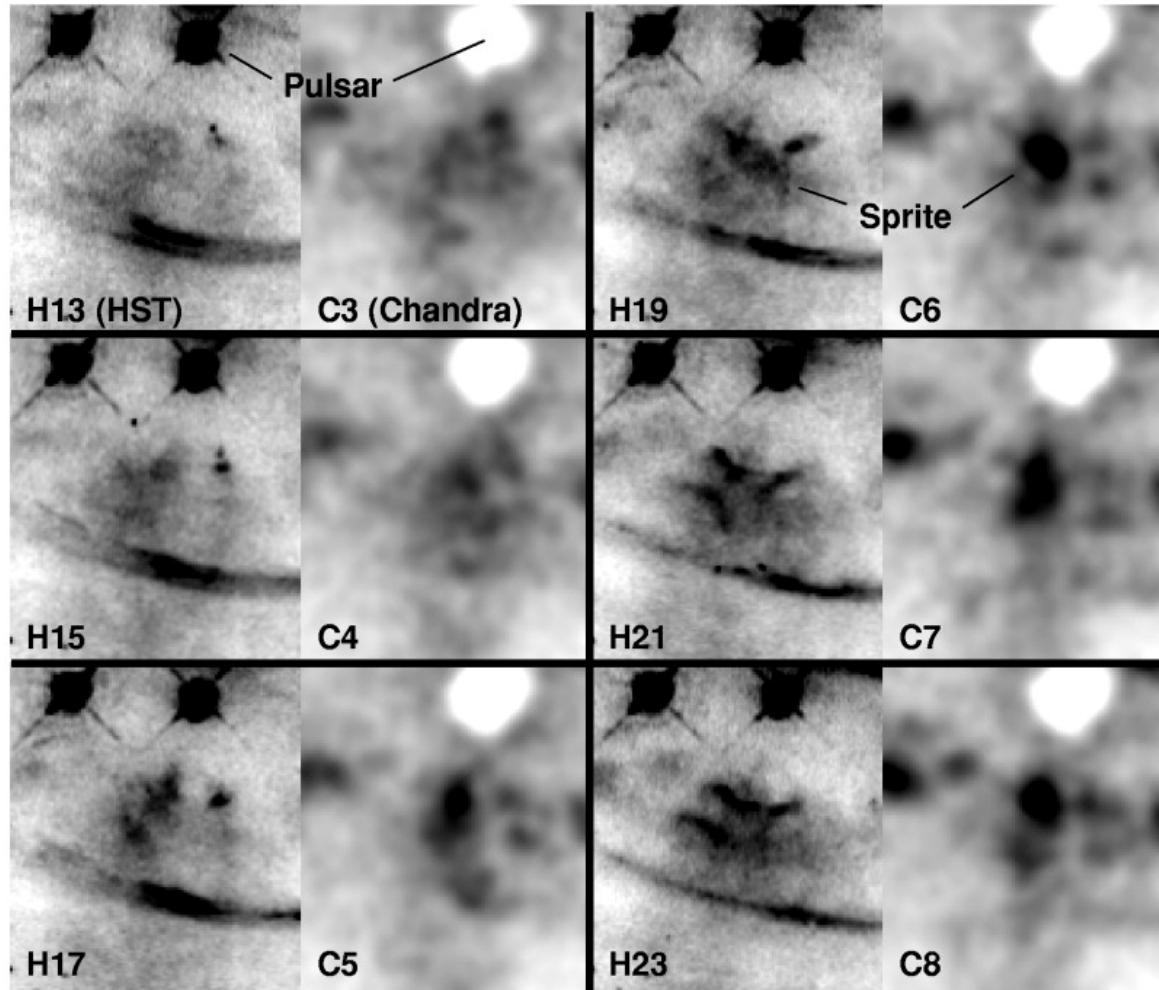
Small Knot Changes



Dramatic Changes!

If knot to south is moving, $v=0.6c$

Crab Sprite Changes Dramatically!



44 days between adjacent images

Hester et al 2002

Observations Summary

Jet

motion of clumps along jet with velocity similar to Crab/Vela

30% brightening – brightening observed in Vela

no new bending observed – new bending observed in
Crab/Vela

Stunning changes in small knots near pulsar – perhaps similar to
Crab sprite

Interpretations - Cartoons

Jet

Sausage and Kink instabilities in magnetically confined pinched jet flow – get bending and relativistically moving clumps (Pavlov 2003)

timescales proportional to width of jet (Alfven speed crossing time)

For B1509, $T_A \approx 2.5$ years – why no new bending?

Cannot get jet brightening by material flowing along jet because it would take 80 years for material moving at $0.5c$ to travel length of jet – could pinch instability account for brightening?

Interpretations - Cartoons

Small knots

Crab sprite attributed to unstable, quasi-stationary shock in jet (Hester et al 2002)

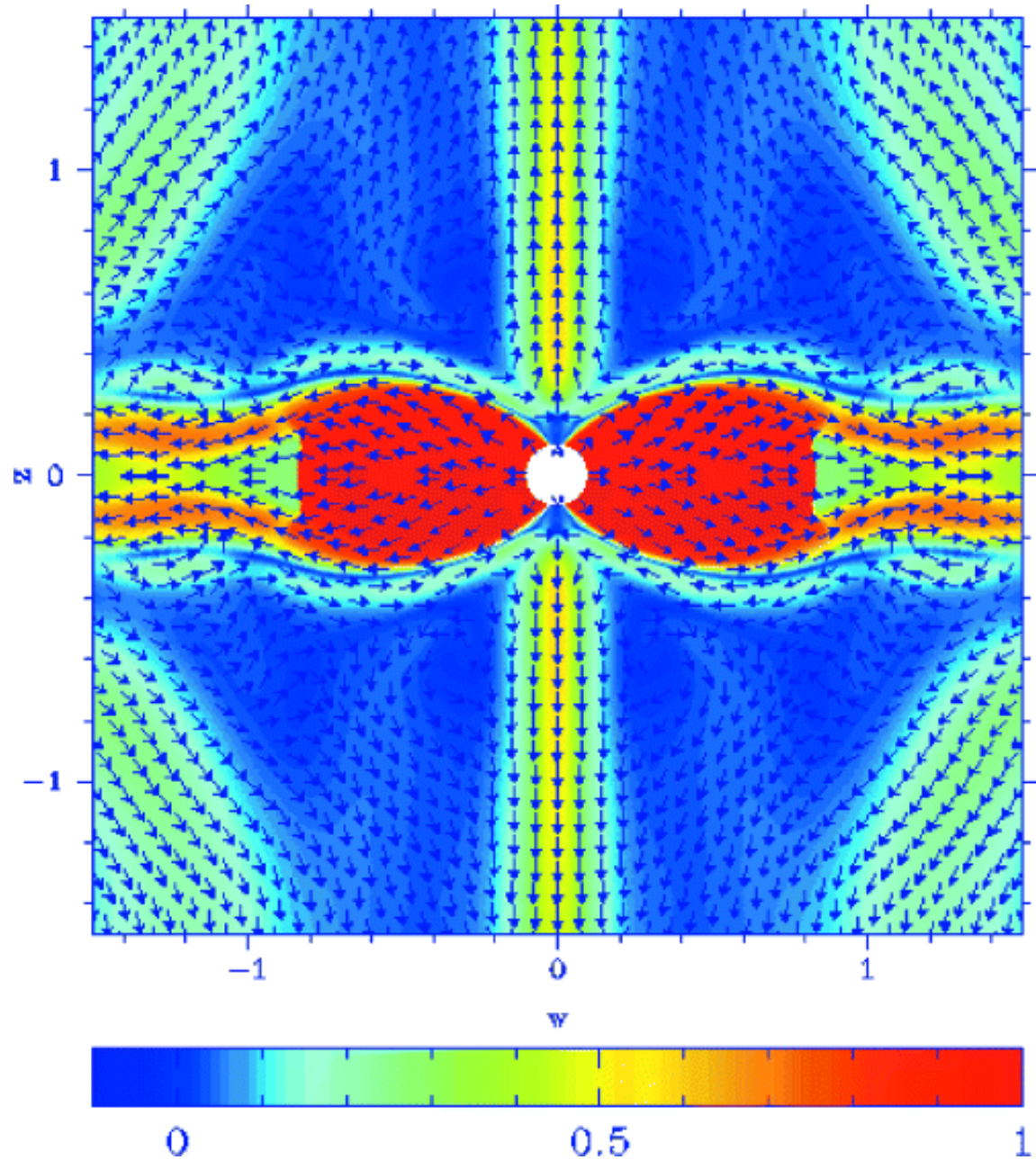
But consider relativistic MHD (Komissarov & Lyubarsky 2003,2004, Del Zanna et al 2004)

Converging turbulent relativistic flow at base of receding jet may be Doppler boosted

results in transient features – “weather”

(N. Bucciantini)

Kommissarov &
Lyubarsky 2003



URJA, Banff 13 Jul 2005