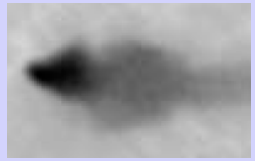


CHRISTOPHER HALES

4th Year Physics Honours Talk

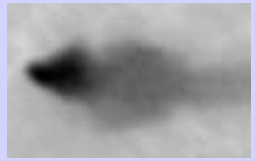
12th October 2007

Cosmic Forensics: A Study of the Pulsar Wind Nebula G359.23-0.82, "The Mouse"

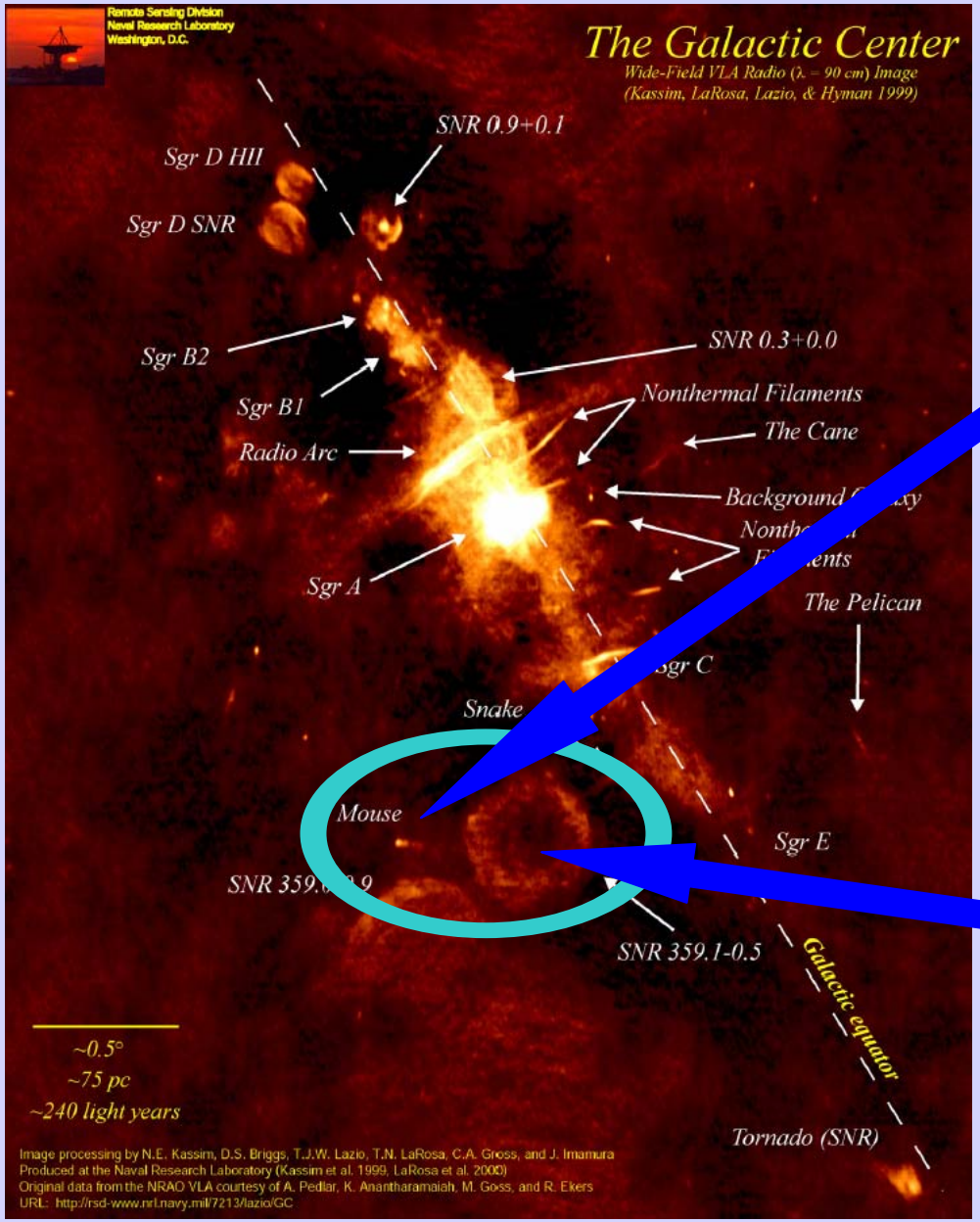
Supervisor: Prof. Bryan Gaensler

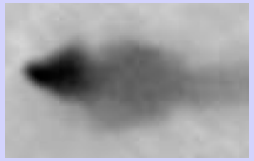
Associate Supervisor: Dr Shami Chatterjee

Opening Statements



- Case Background
  - Pulsars, Pulsar Wind Nebulae and The Mouse
- Fingerprinting: Collecting the Evidence
  - Reduction of Data from The Very Large Array (VLA)
- Ballistics: Where is the Mouse Going?
  - Derivative Maps and Kinematics
- Recreating the Scene of the Crime
  - Origin of the Mouse? Future?
- Closing Arguments



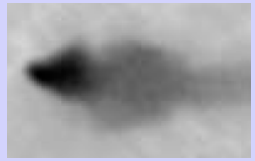


Mouse

Associated Supernova Remnant?

http://rsd-www.nrl.navy.mil/7213/lazio/GC

Pulsars and Pulsar Wind Nebulae

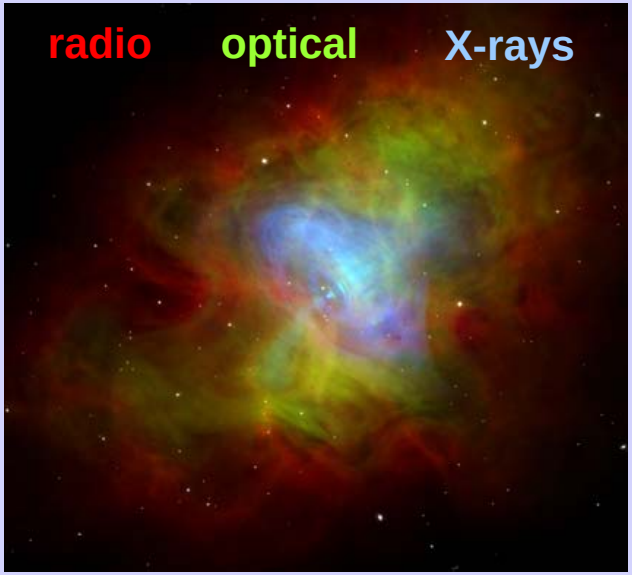


- Pulsars are magnetised rotating neutron stars

$$\dot{E} = \frac{d}{dt}\left(\tfrac{1}{2} I\omega\right) = I\omega\dot{\omega}$$

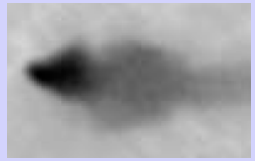
- Get pulsar wind nebula (PWN) from interaction of shocked ambient particles with magnetised wind

NASA / CXC



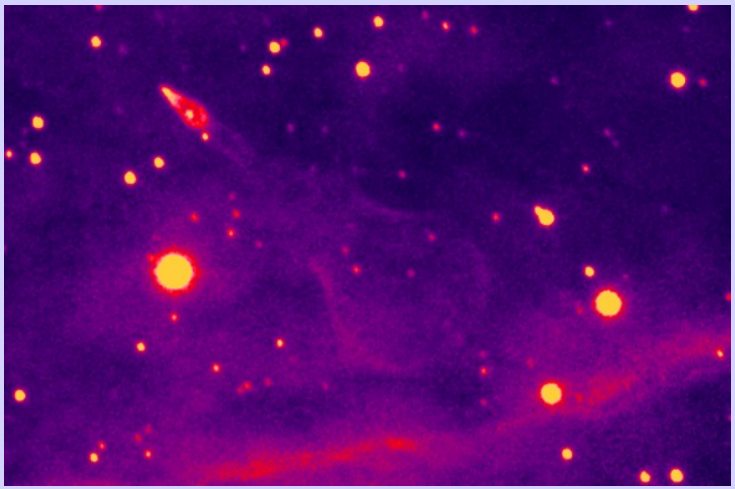
Crab Nebula (Hester et al. 2002)

Bow Shock PWNe

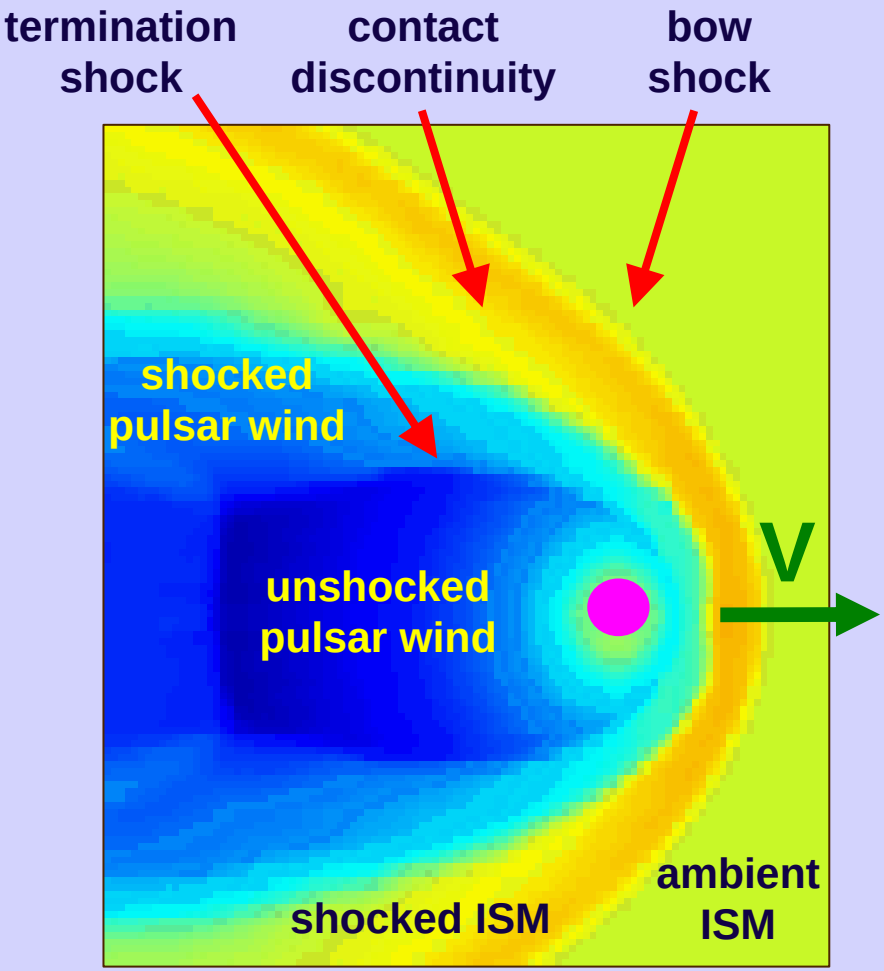


- Natal kicks from supernova (SN) explosion

$$V_{birth} \approx 300 - 1000 \text{ km/s}$$

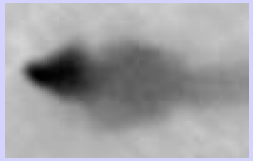


Guitar Nebula (Chatterjee & Cordes 2002)



3D hydrodynamic simulation
(Vigelius, Gaensler et al. 2007)

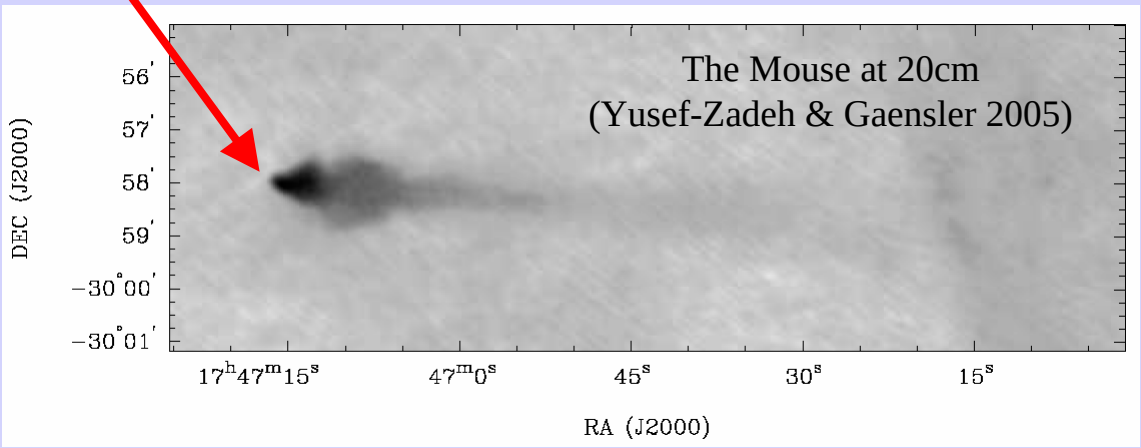
The Mouse



- First radio observation in 1987 (Yusef-Zadeh & Bally 1987)
- X-ray detection in 1994 (Predehl & Kulkarni 1995)
- Internal pulsar J1747-2958 discovered in 2002 (Camilo et al. 2002)

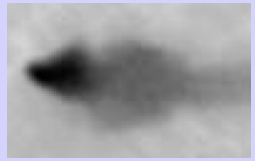
$$P = 98.8\,\text{ms}$$

$$\dot{P} = 6.14\times10^{-14}\ \text{s/s}$$



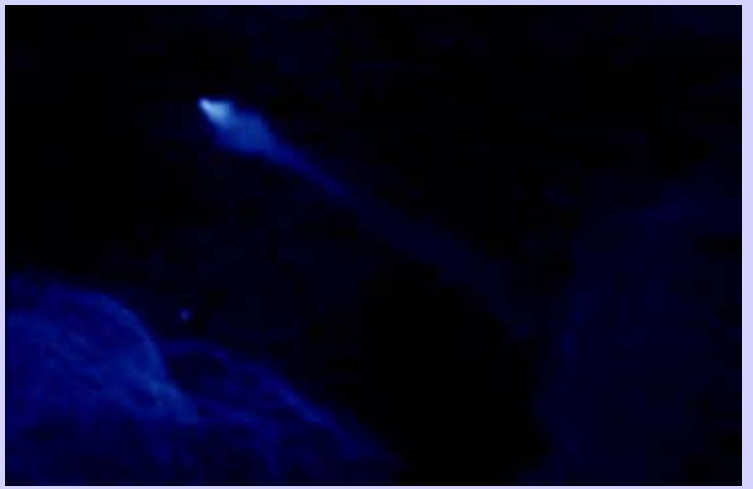
$$\tau_c = \frac{P}{2\dot{P}} = 25.5\,\text{kyr} \qquad \dot{E} = 2.5\times10^{36}\ \text{ergs/s} \qquad B = 2.5\times10^{12}\ \text{G}$$

The Arraignment

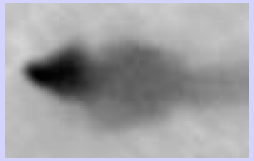


- Where is the Mouse going?
- Can we get an independent age estimate?
- Can we learn about the ISM?
- Associated with nearby SNR?

The Mouse:
Radio → X-Ray/Radio → X-Ray

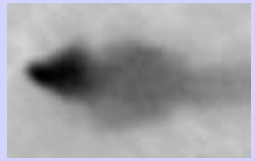


http://chandra.harvard.edu/press/04_releases/press_092304.html



FINGERPRINTING:
COLLECTING THE EVIDENCE

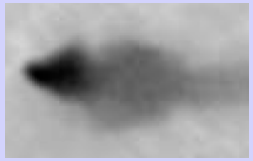
Reduction of VLA Data

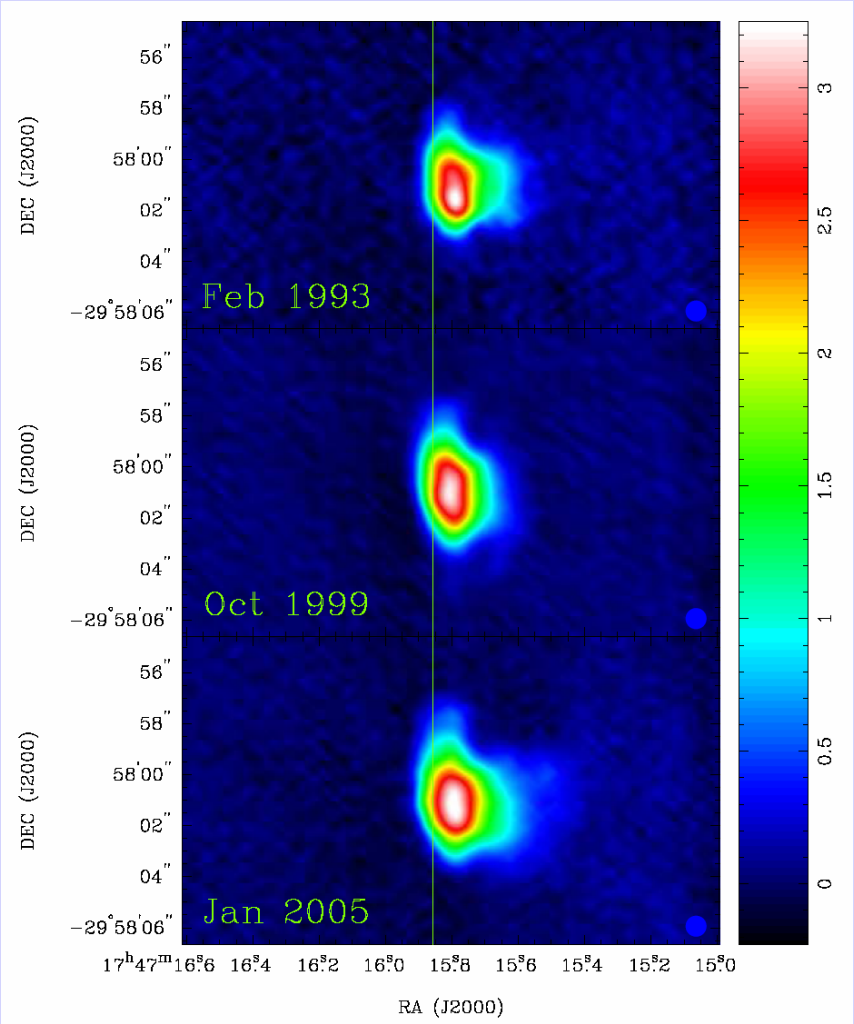


- Similar observations using hybrid BnA configuration at 1993, 1999 and 2005 epochs
- Observing frequency of 8.5 GHz
- Raw data edited, calibrated, imaged, and smoothed to uniform resolution

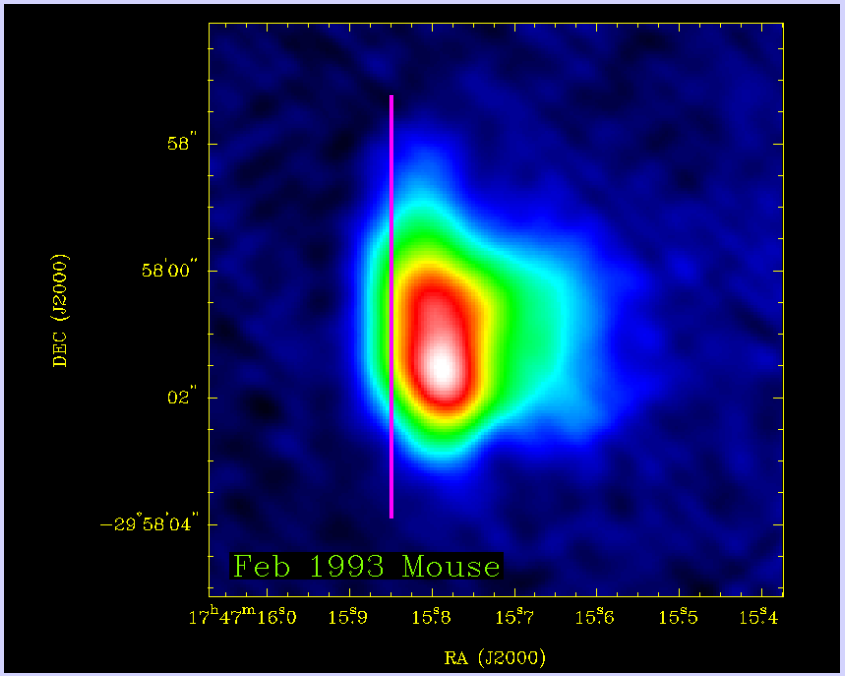
The Very Large Array (VLA)
http://www.vla.nrao.edu/

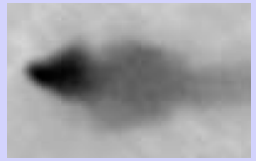
Comparison of Epochs





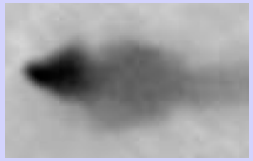
- 1999 data has poorer spatial frequency coverage

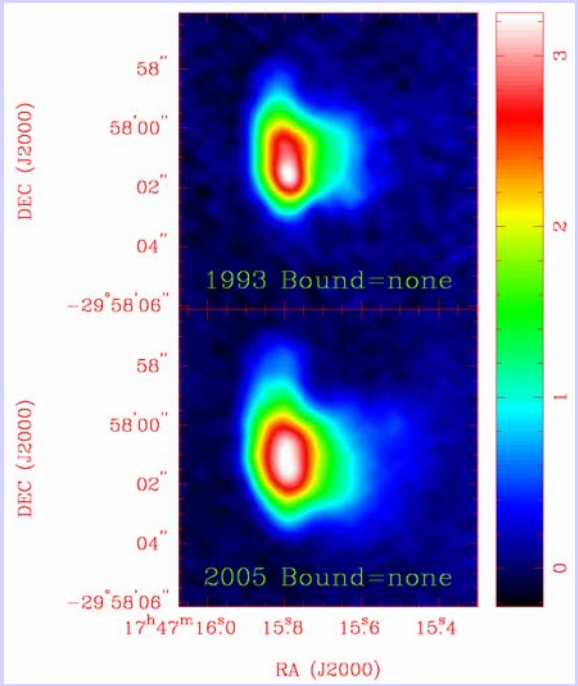


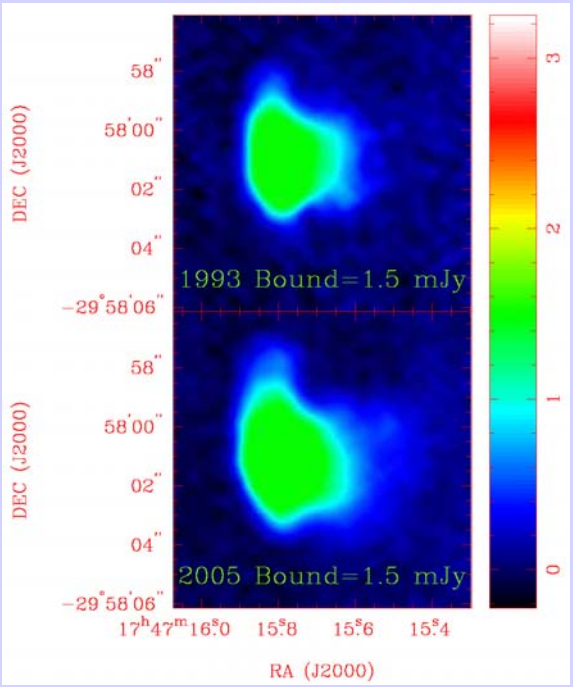


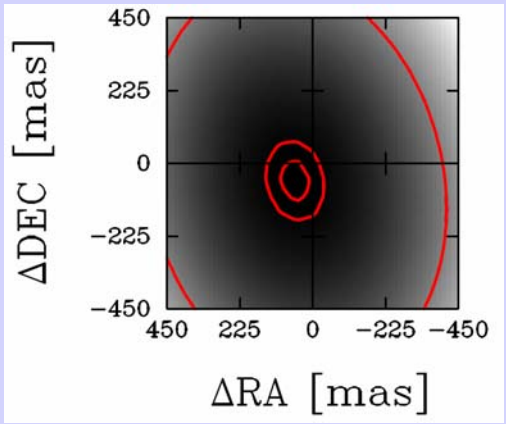
Ballistics:
Where is the Mouse Going?

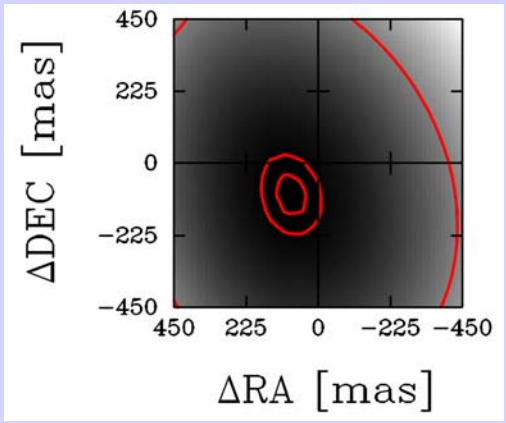
Morphology Evolution



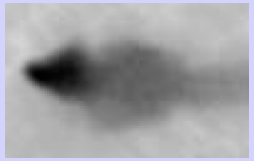


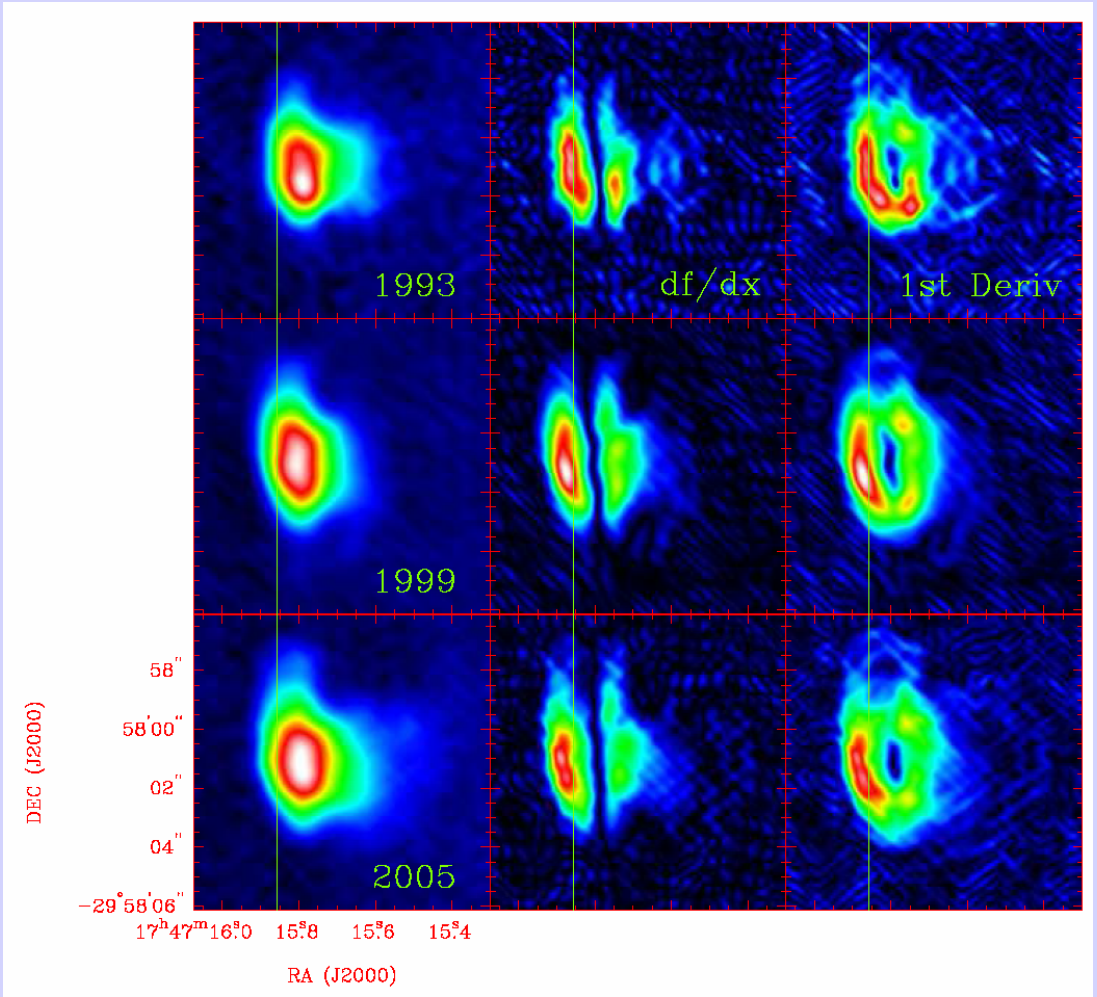


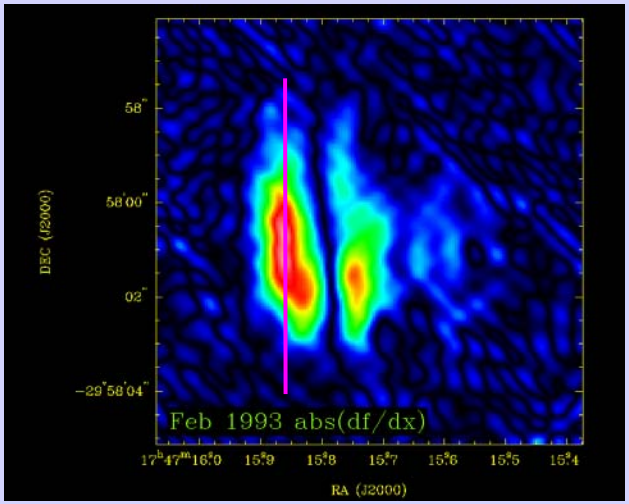




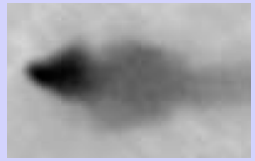
Derivative Maps

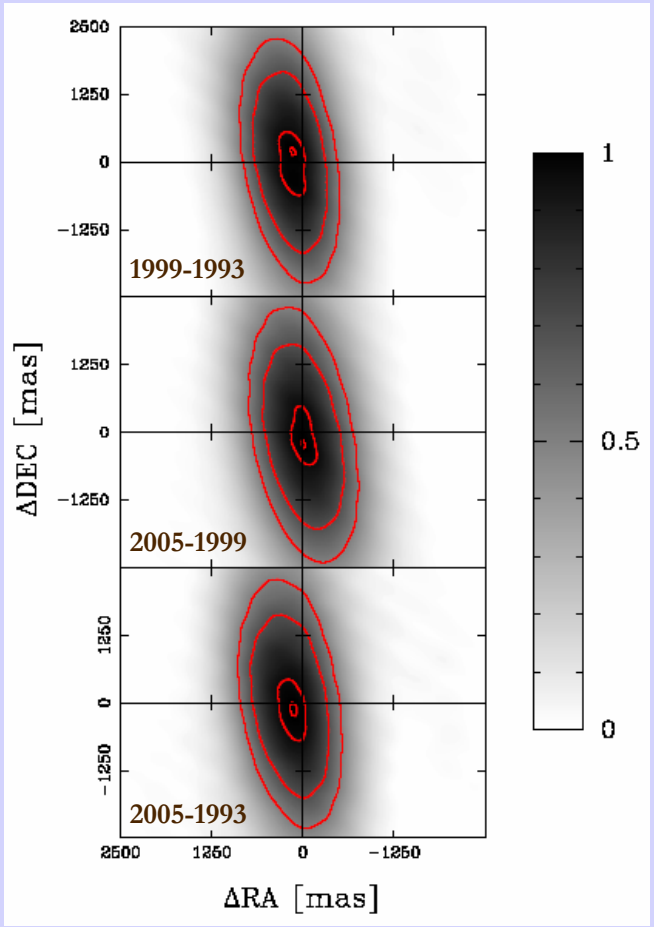






KINEMATICS



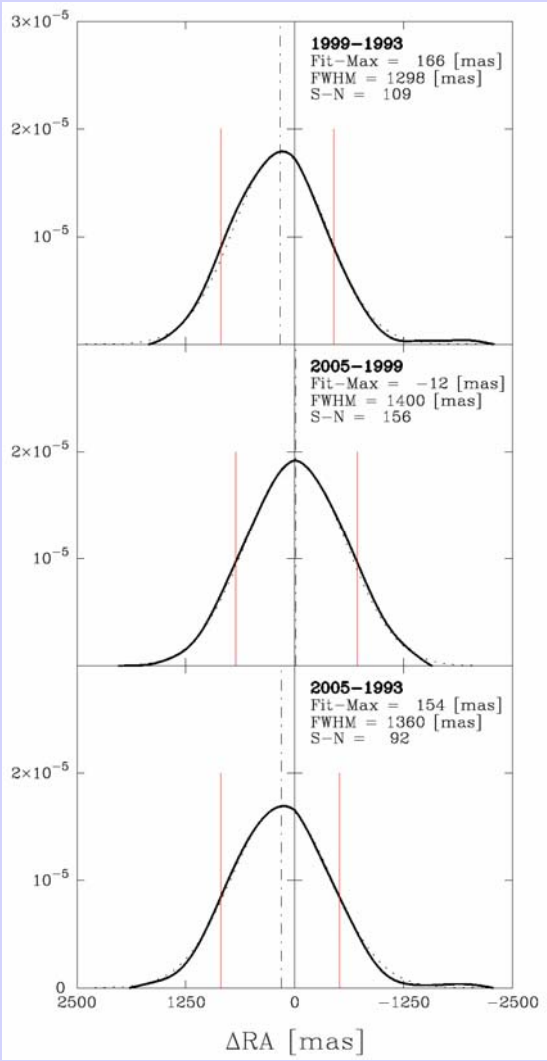


Only 2005-1993 used:

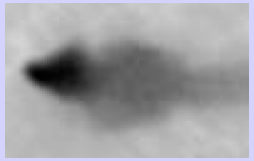
$$\mu = 12.9 \pm 3.2 \text{ mas yr}^{-1}$$

For $d = 5$ kpc:

$$V_{\perp} = 305 \pm 75 \text{ km s}^{-1}$$

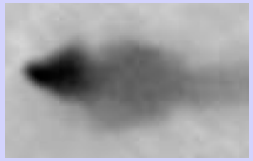


Compares well with NS velocity distribution



Recreating the Scene of the Crime

In Situ ISM Measurement



- Ram pressure balance with pulsar wind:

$$\frac{\dot{E}}{4\pi(r)^2 c} = 1.37 n_0 m_H V^2 = 1.37 n_0 m_H M^2 c_s^2$$

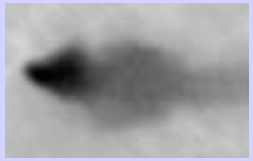
- Combine to estimate proper motion:

$$d = 5 d_5 \text{ kpc} \qquad V = \frac{305}{\sqrt{n_0 d_5}} \text{ km/s} \qquad \mu = \frac{V}{5 d_5} = \frac{13}{\sqrt{n_0 d_5^2}} \text{ mas/yr}$$

- Using detected proper motion and $4 \le d \le 6$ kpc:

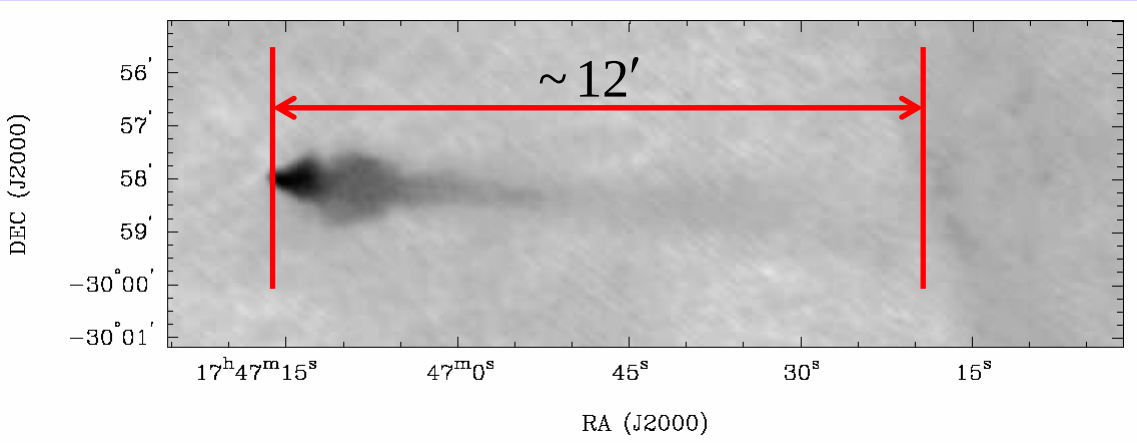
$$0.5 \le n_0 \le 2.5 \text{ cm}^{-3} \qquad M \approx 60 \text{ !!}$$

Age Estimate For J1747-2958



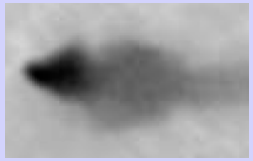
- Lower bound from distance travelled along tail: ~50kyr

$$t > \tau_c = 25.5\,\mathrm{kyr}$$

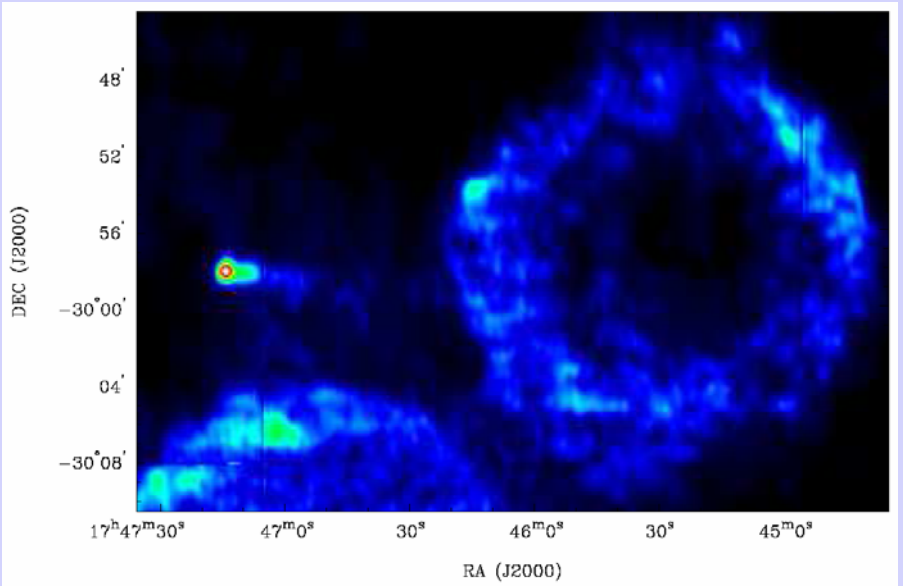


The Mouse at 20cm
(Yusef-Zadeh & Gaensler 2005)

Association with SNR G359.1-0.5?

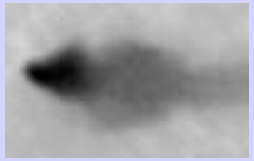


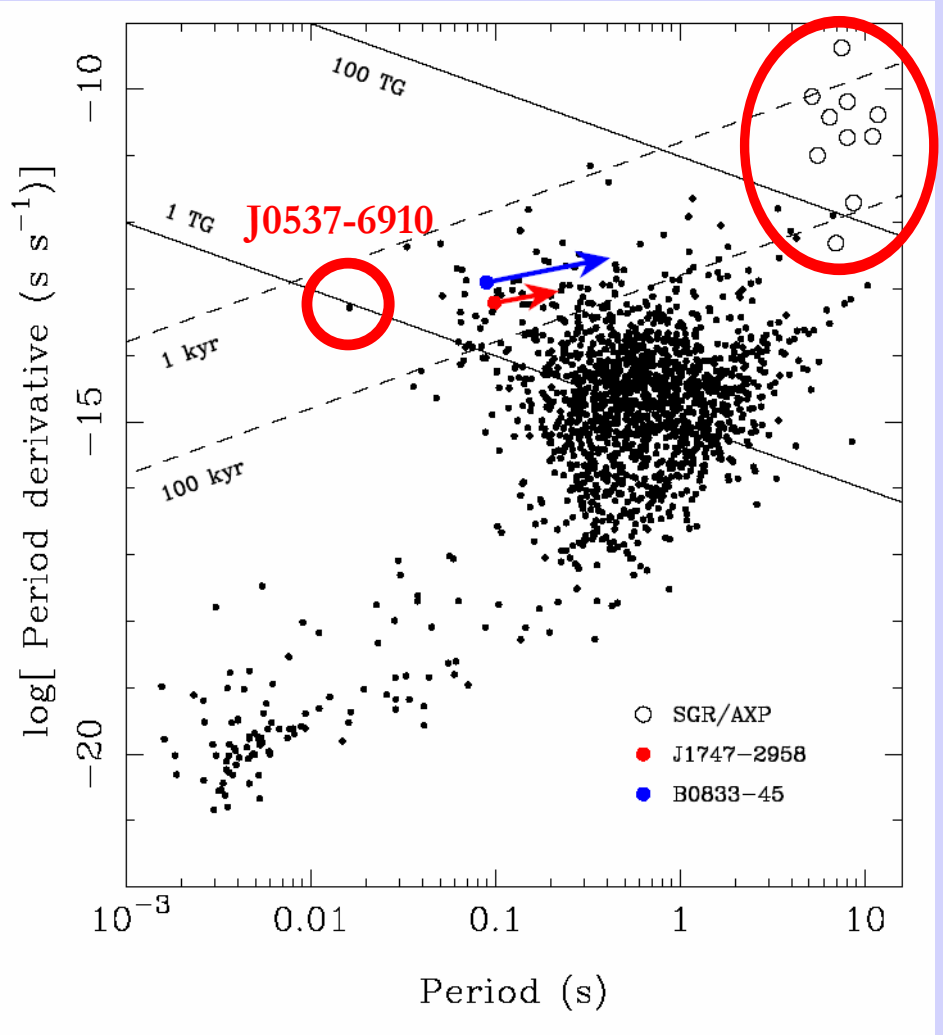
- Compare proper motion with SNR evolution
- Using previous density and distance: ~90 kyr to cross SNR shell
- Total age of pulsar ≈ 55 + 90 = 140 kyr
- But do not see SNR of correct size (too small)



http://rsd-www.nrl.navy.mil/7213/lazio/GC

Future Evolution of J1747-2958?



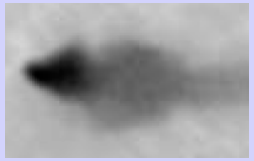


$$\dot{\omega} = -K\omega^n$$

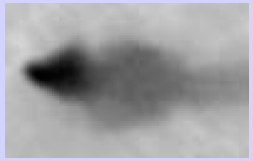
- B increasing
- Similarity to Vela
- Will the Mouse become an exotic magnetar?

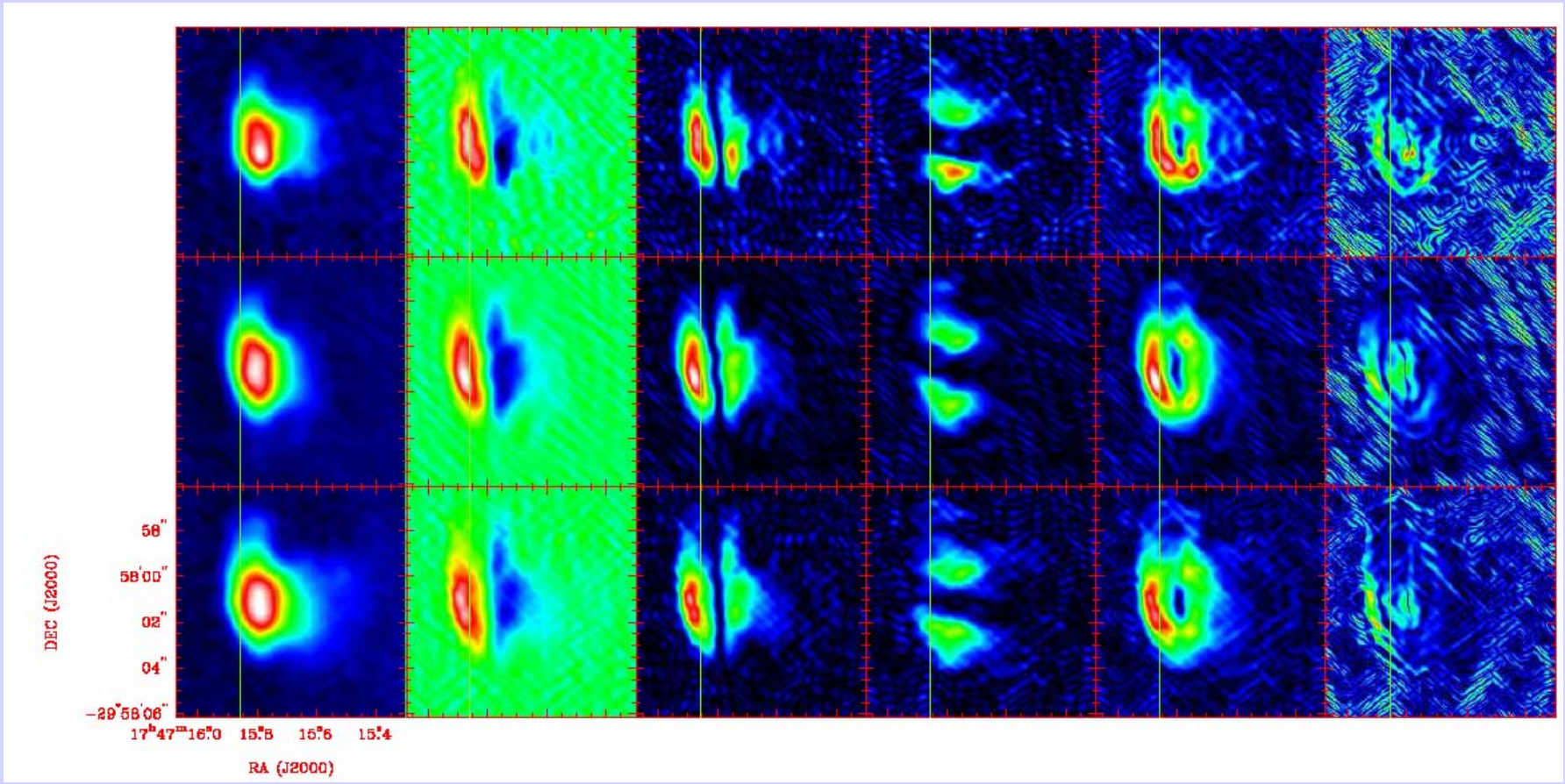
Using data from:
http://www.atnf.csiro.au/research/pulsar/psrcat/

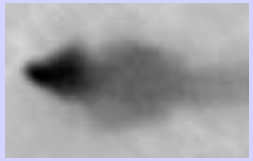
Closing Arguments

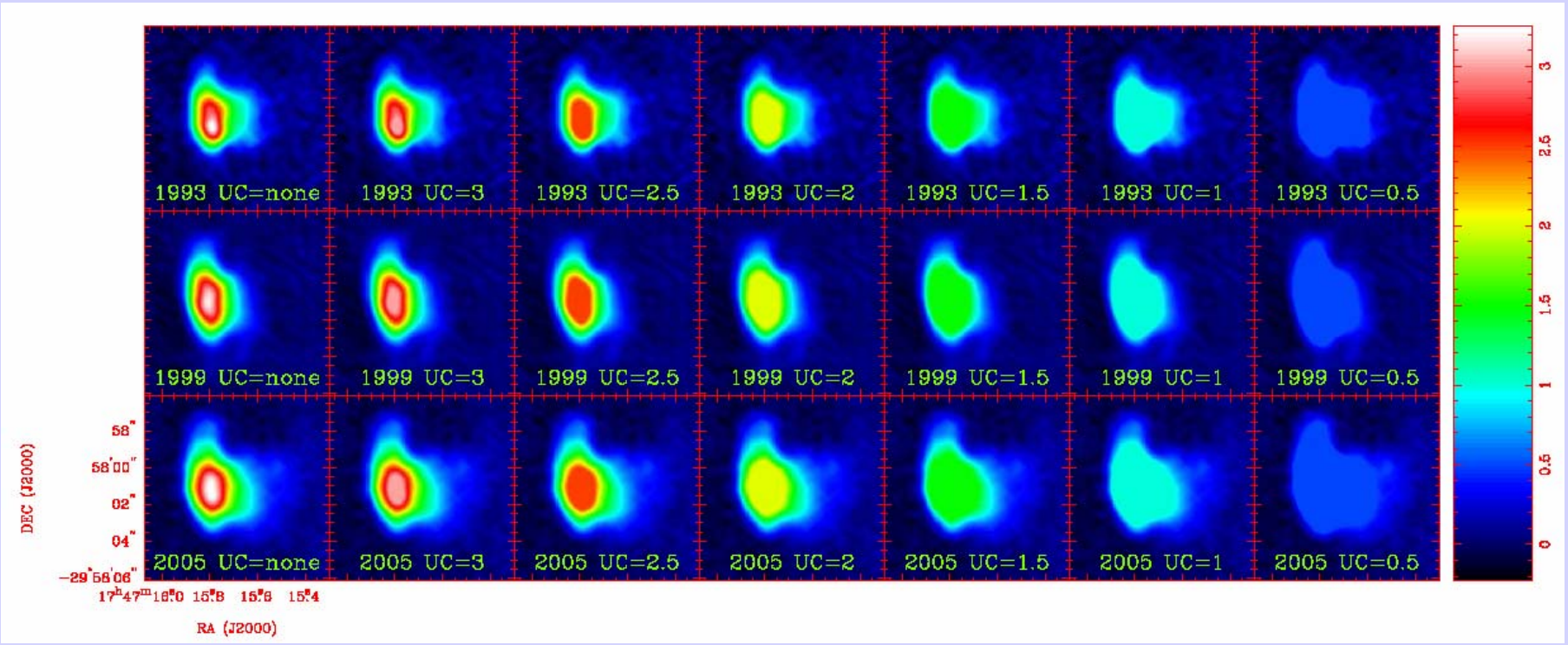


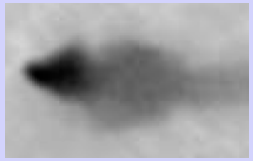
- Velocity consistent with neutron star population
  - First time a proper motion has been calculated for this object
- In situ measurement of ISM density from 16 kly away!
- Unlikely association with SNR G359.1-0.5
- Lower limit on age $t \geq 140\ \mathrm{kyr} \approx 5\tau_c$
- Magnetic field growing
  - Mouse evolving into a magnetar?
- *All of this from a proper motion measurement!*

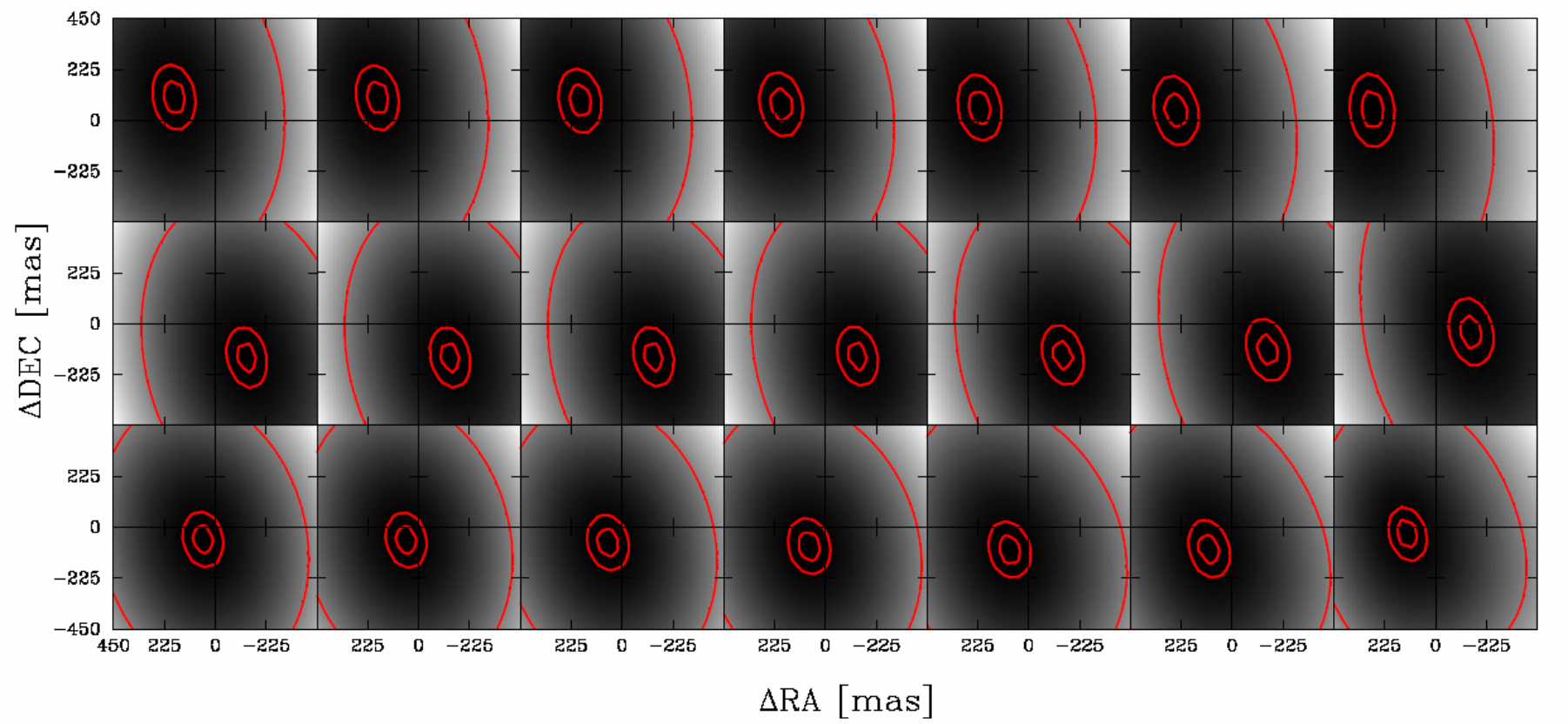


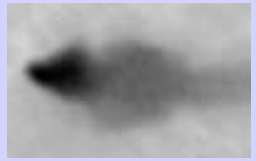

58"
58'00"
02"
04"
-29°58'06"
DEC (J2000)
17h47m16s.0
15s.8
15s.6
15s.4
RA (J2000)

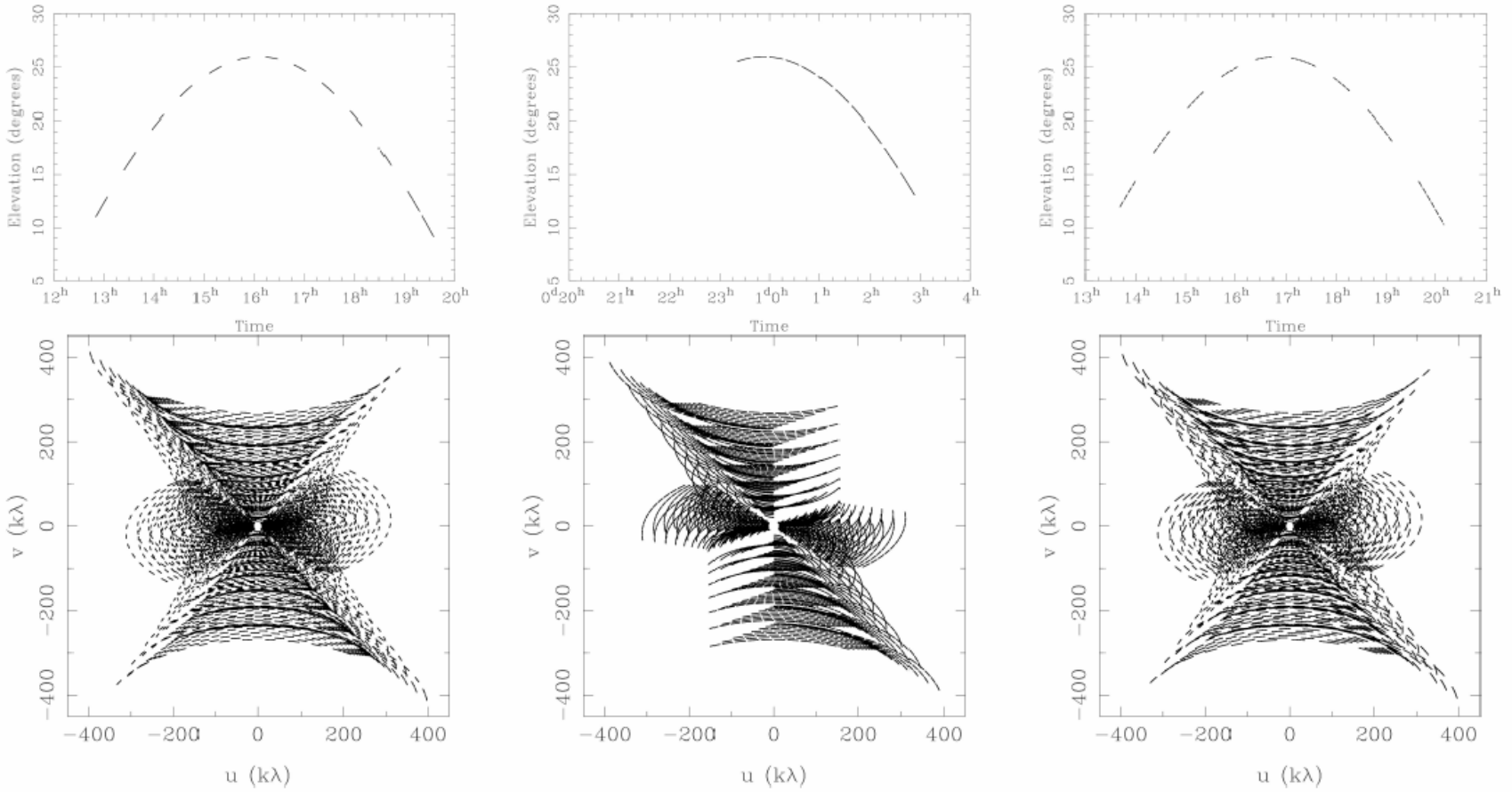


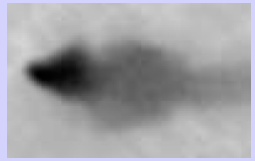

1993 UC=none
1993 UC=3
1993 UC=2.5
1993 UC=2
1993 UC=1.5
1993 UC=1
1993 UC=0.5
1999 UC=none
1999 UC=3
1999 UC=2.5
1999 UC=2
1999 UC=1.5
1999 UC=1
1999 UC=0.5
2005 UC=none
2005 UC=3
2005 UC=2.5
2005 UC=2
2005 UC=1.5
2005 UC=1
2005 UC=0.5
DEC (J2000)
58"
58'00"
02"
04"
−29°58'06"
17h47m16s.0 15s.8 15s.6 15s.4
RA (J2000)
0
0.5
1
1.5
2
2.5
3

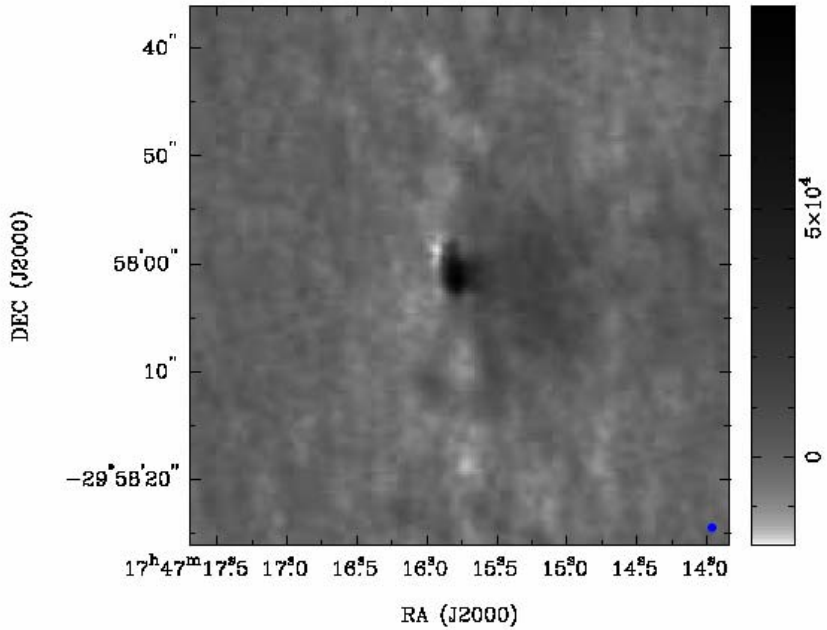


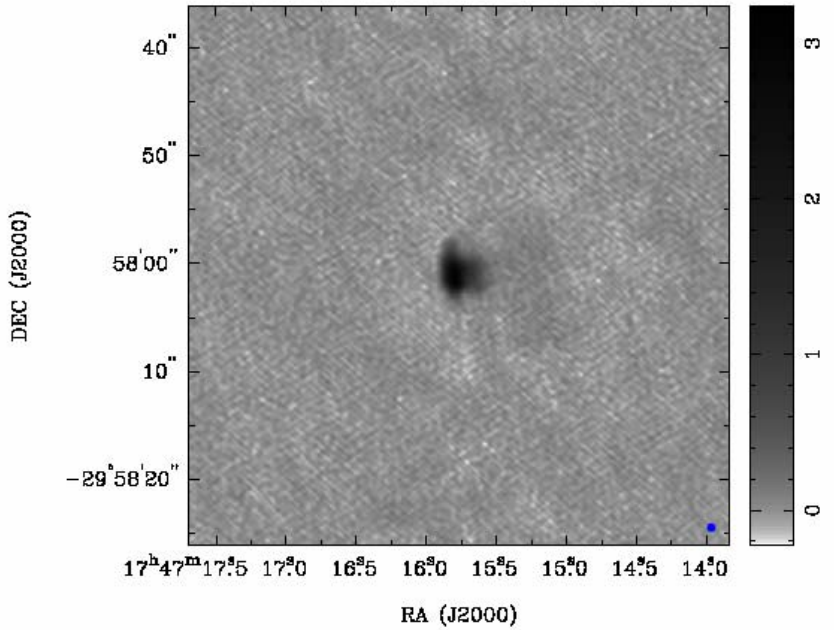

450
225
0
−225
ΔDEC [mas]
450 225 0 −225
ΔRA [mas]

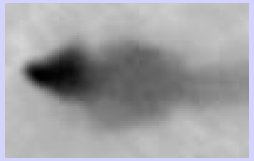


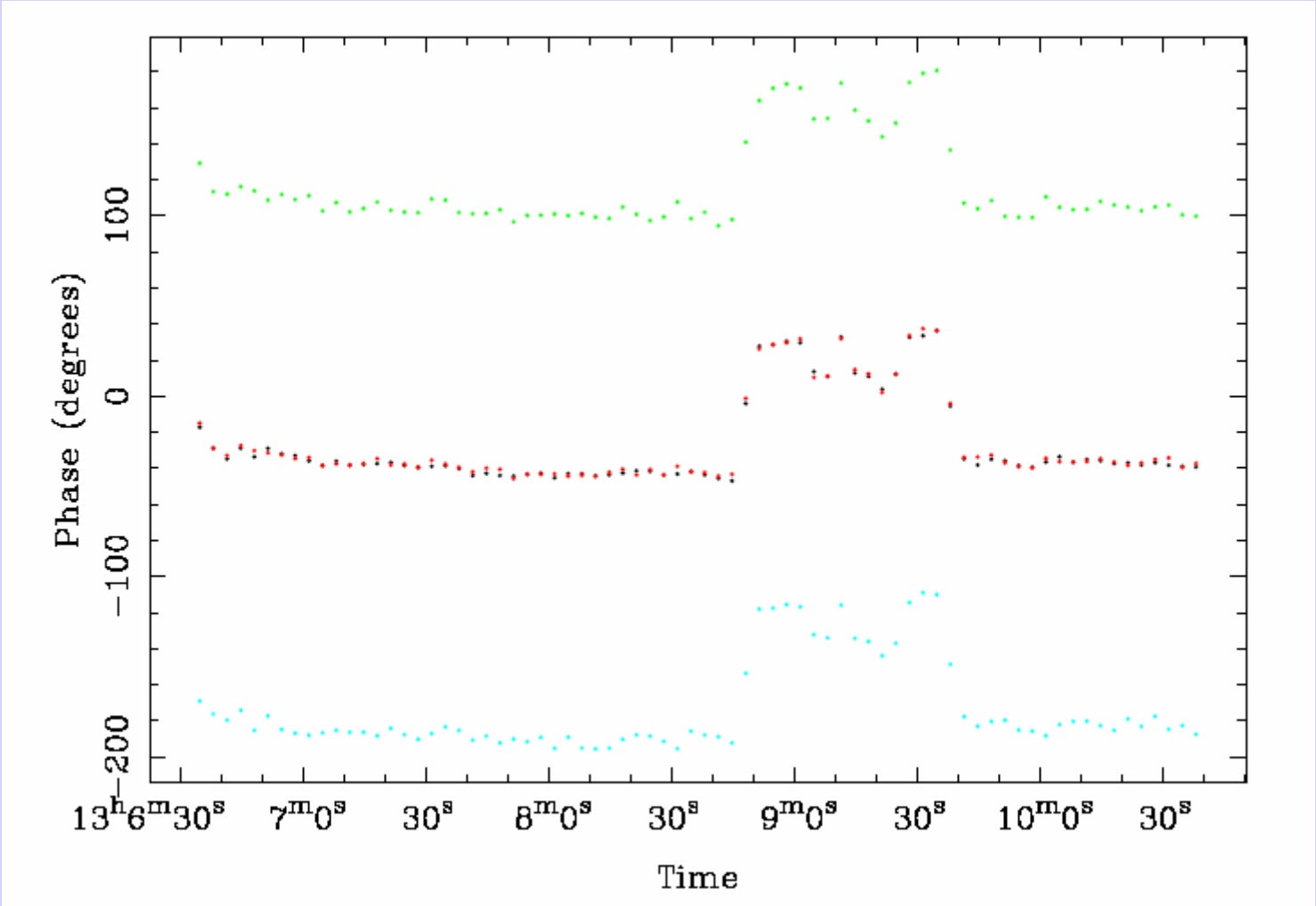

Elevation (degrees)
Time
v (kλ)
u (kλ)

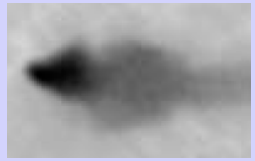



40"
50"
58'00"
10"
−29°58'20"
DEC (J2000)
17h47m17.5 17.0 16.5 16.0 15.5 15.0 14.5 14.0
RA (J2000)
5×10^4
0

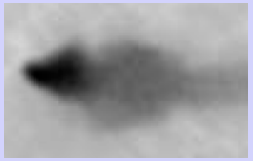

40"
50"
58'00"
10"
−29°58'20"
DEC (J2000)
17h47m17.5 17.0 16.5 16.0 15.5 15.0 14.5 14.0
RA (J2000)
3
2
1
0

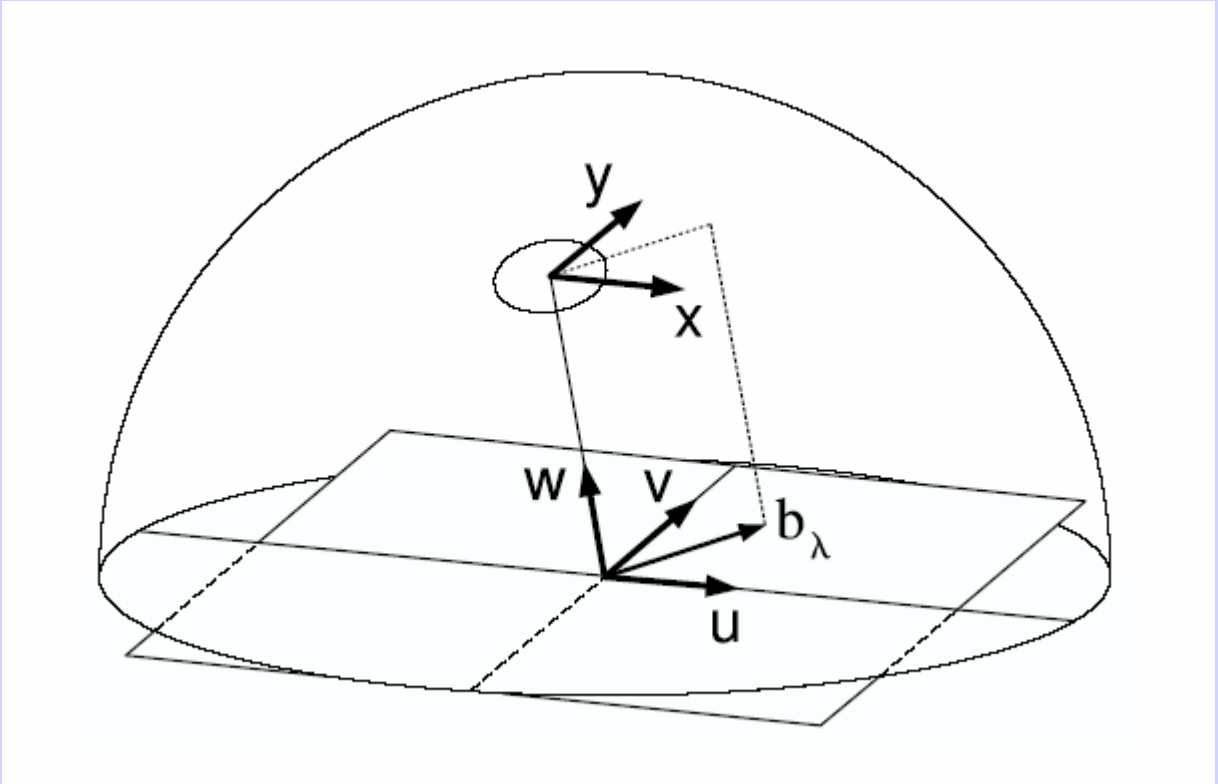



Phase (degrees)
100
0
−100
−200
13h6m30s
7m0s
30s
8m0s
30s
9m0s
30s
10m0s
30s
Time



	Epoch 1	**Epoch 2**	**Epoch 3**
Date Observed	02 Feb 1993	08 Oct 1999	22 Jan 2005
Array Configuration	BnA	BnA	BnA
Antennas Available	27	27	25
Centre Frequency (GHz)	8.44	8.44	8.46
Bandwidth (MHz)	62.5	100	100
Polarisation Information	RR,LL	RR,LL,RL,LR	RR,LL,RL,LR
On-Source Observation Time (h)	3.12	2.98	2.72
Secondary Calibrator Reference Interval ($\sim$m)	15	17	4




y
x
w
v
b_λ
u