Announcements

- Homework #7 due today, Nov 1
- Physics Demo Show tomorrow, Nov 2, 7pm
- Review on Monday, Nov 7 at 3:25pm
- Test #3 Next Tuesday, Nov 8

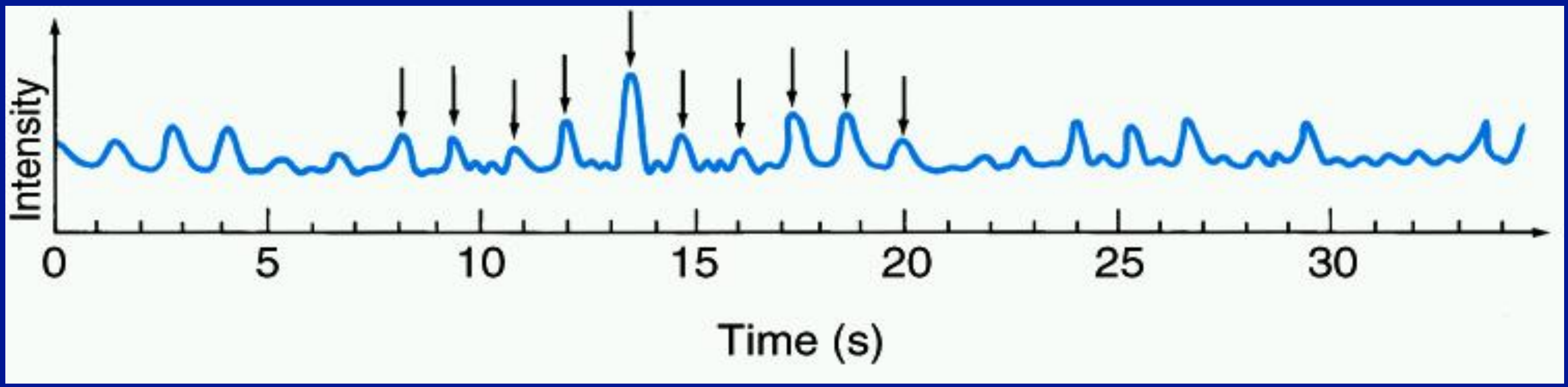
Final States of a Star

1. White Dwarf
   If initial star mass $< 8\ M_{Sun}$ or so.
   (and remember: Maximum WD mass is $1.4\ M_{Sun}$, radius is about that of the Earth)

2. Neutron Star
   If initial mass $> 8\ M_{Sun}$ and $< 25\ M_{Sun}$. Radius about 10 km

3. Black Hole
   If initial mass $> 25\ M_{Sun}$. Radius is zero

Pulsars



Discovery of LGM1 by Jocelyn Bell and Tony Hewish (Cambridge) in 1967. Nobel Prize to Hewish in 1974.

Pulse periods observed from 0.001 sec to 10 seconds - DEMO

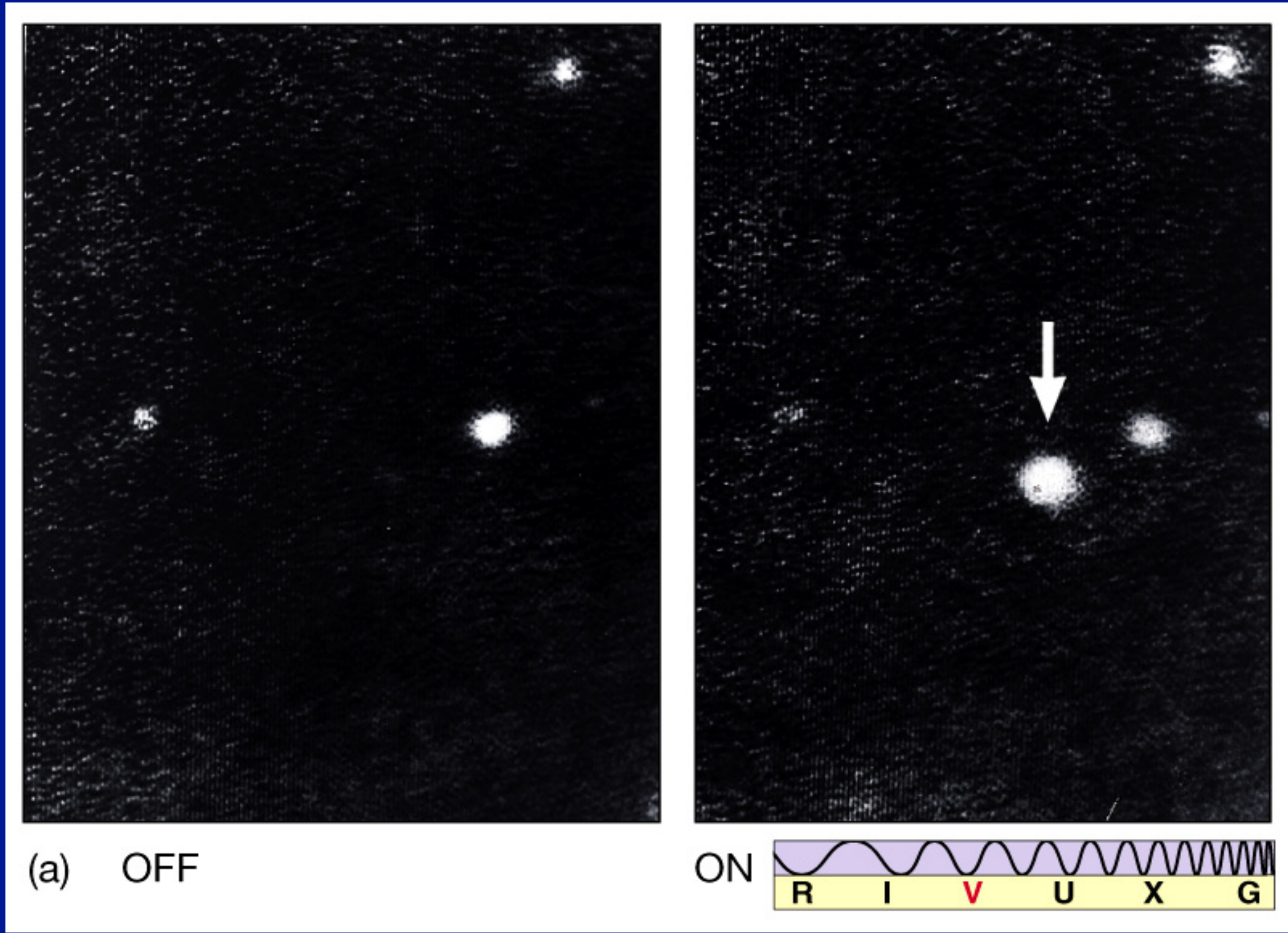
Explanation: "beamed" radiation from rapidly spinning neutron star.

Usually neutron stars are pulsars for 10^7 years after supernova.

Study the Universe, See the World

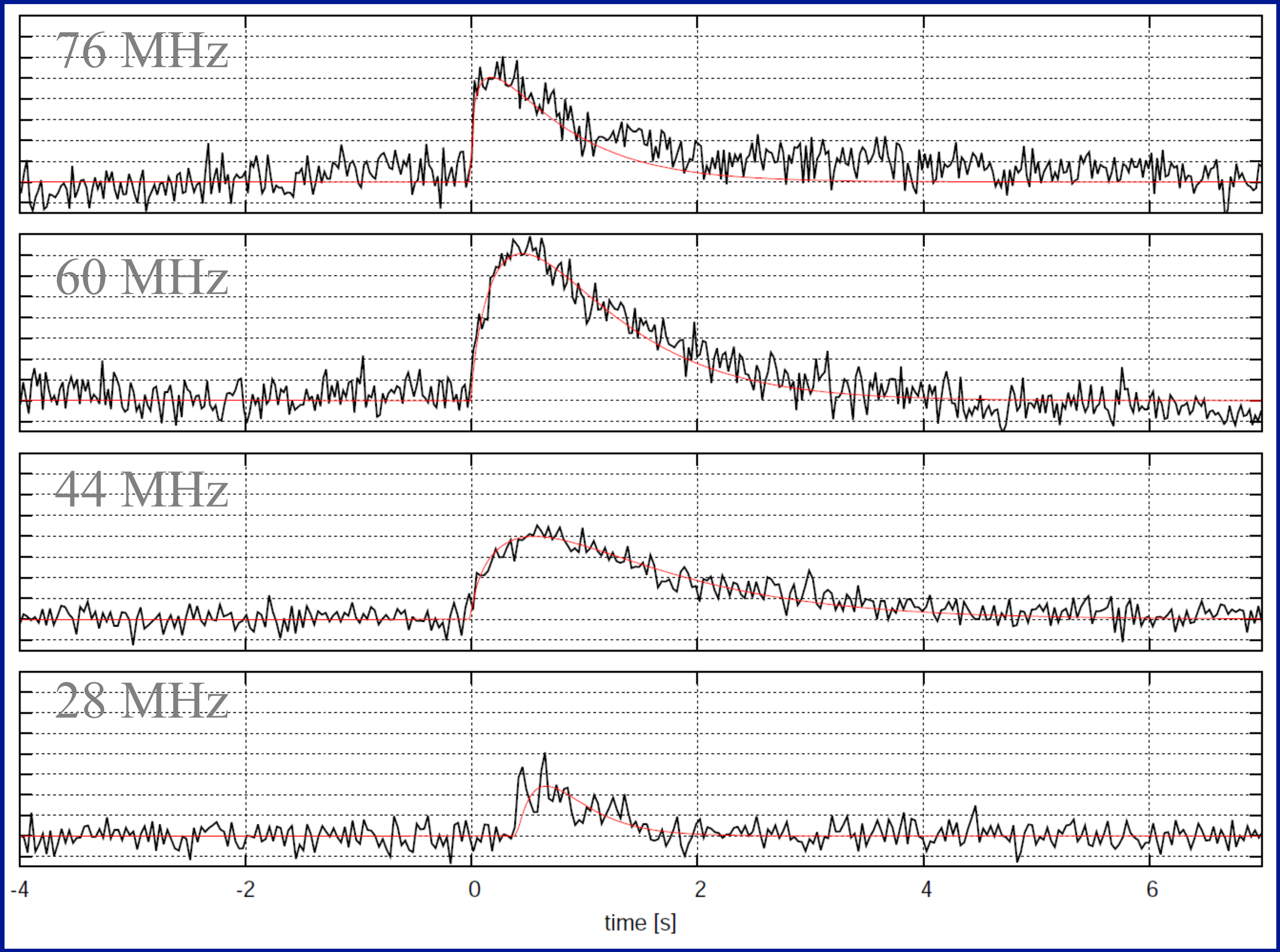
Jocelyn Bell and Alan Rogers at URSI-2011 meeting in Istanbul

The Crab Pulsar

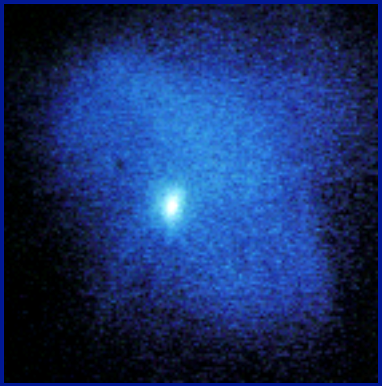


LWA Publication Highlights

Crab Giant Pulses
Ellingson et al. 2013



The Crab Pulsar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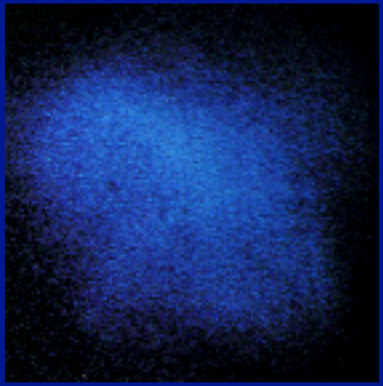
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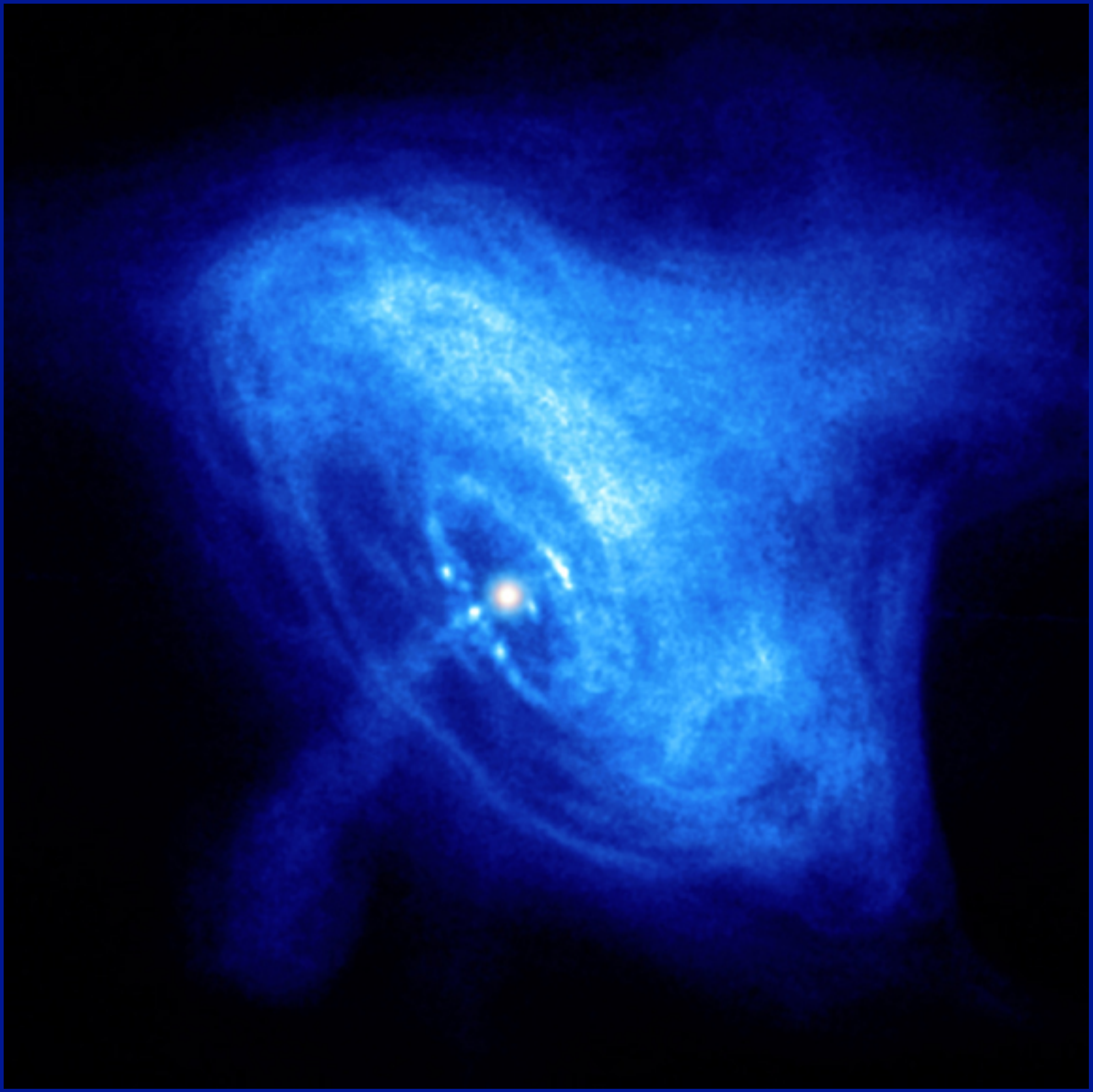
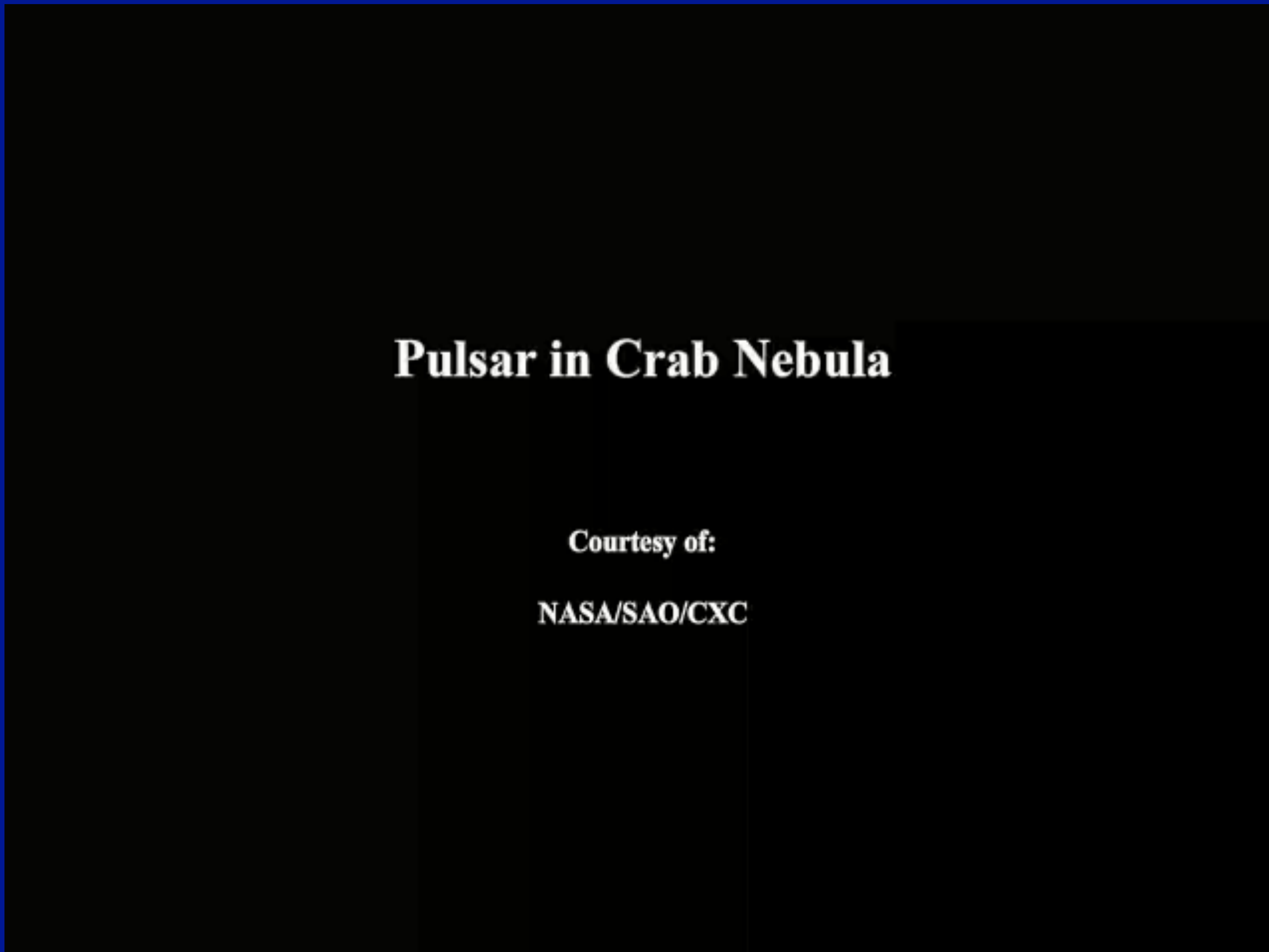


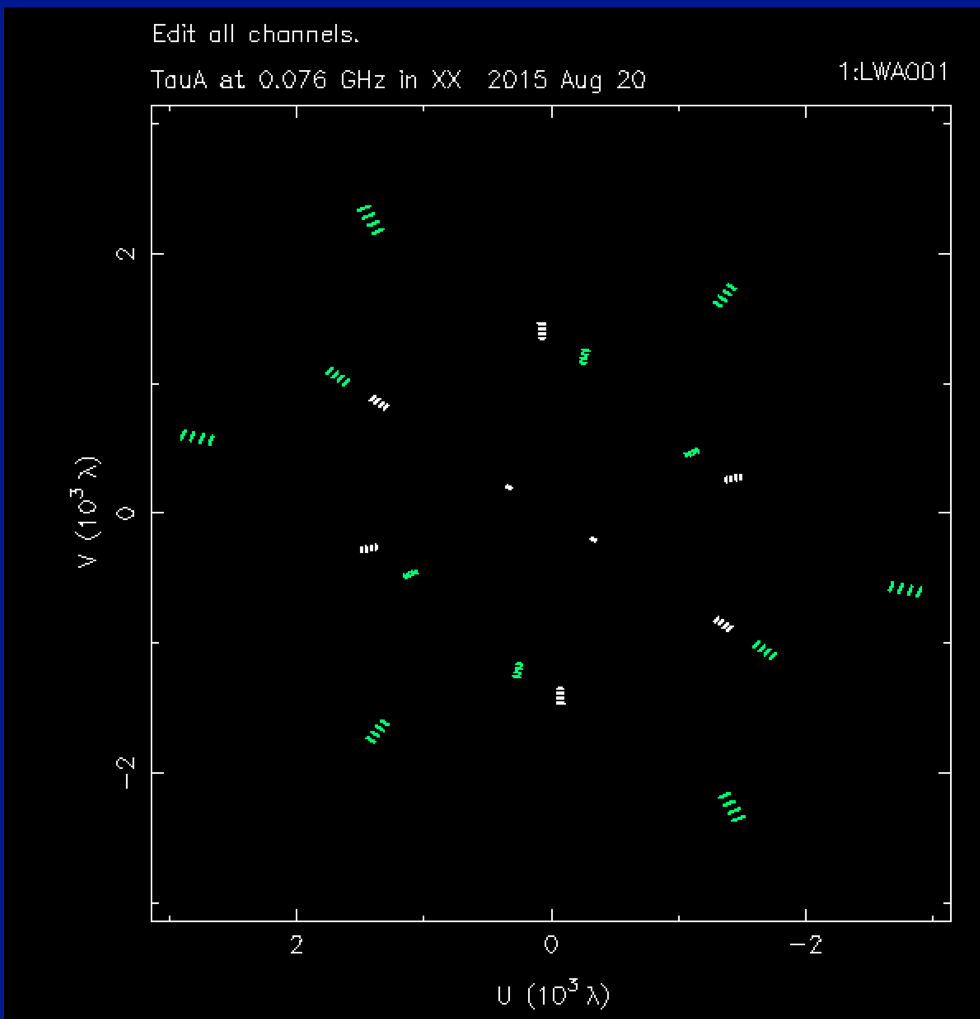
Chandra X-ray image

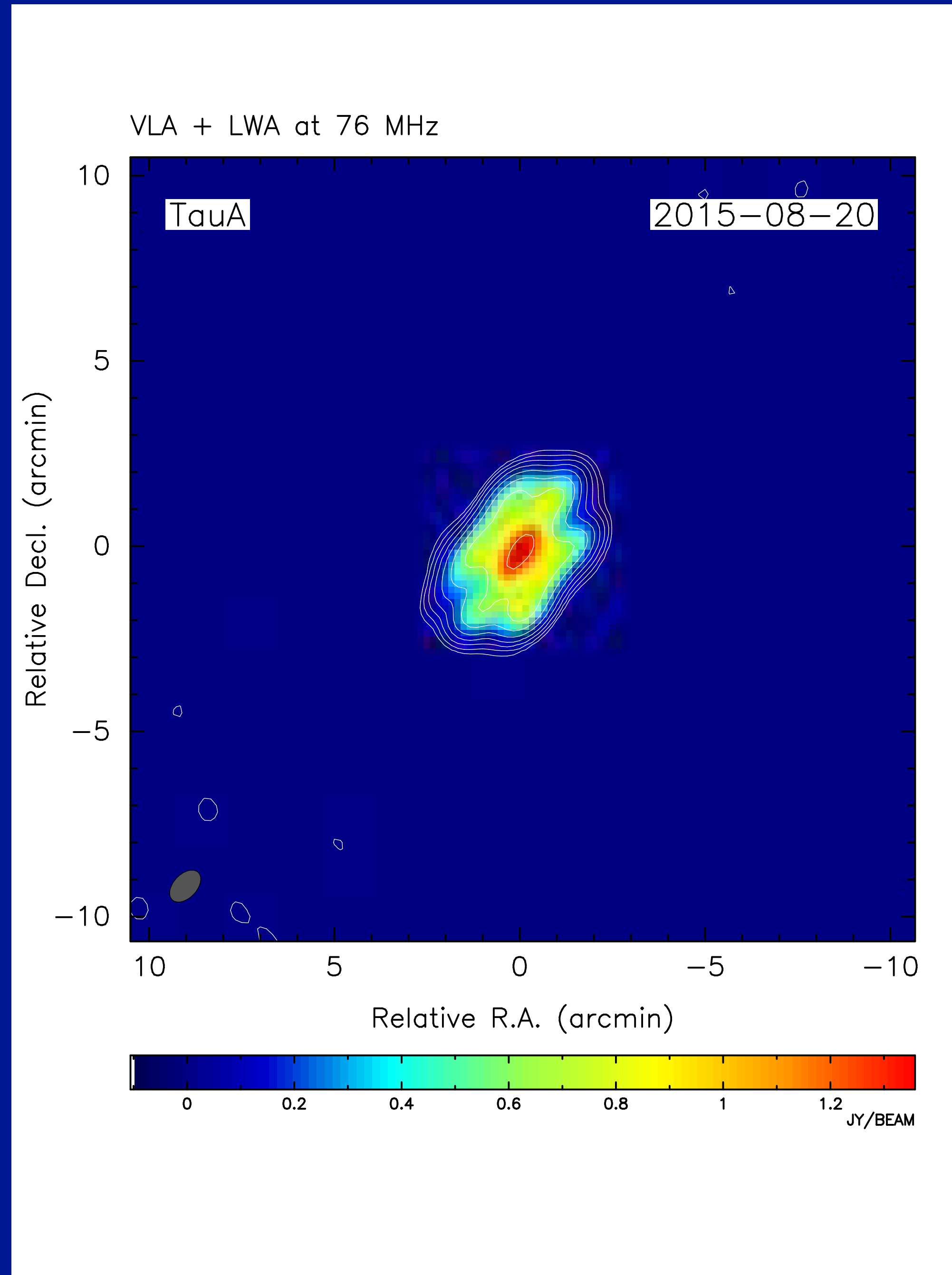
The Crab Pulsar



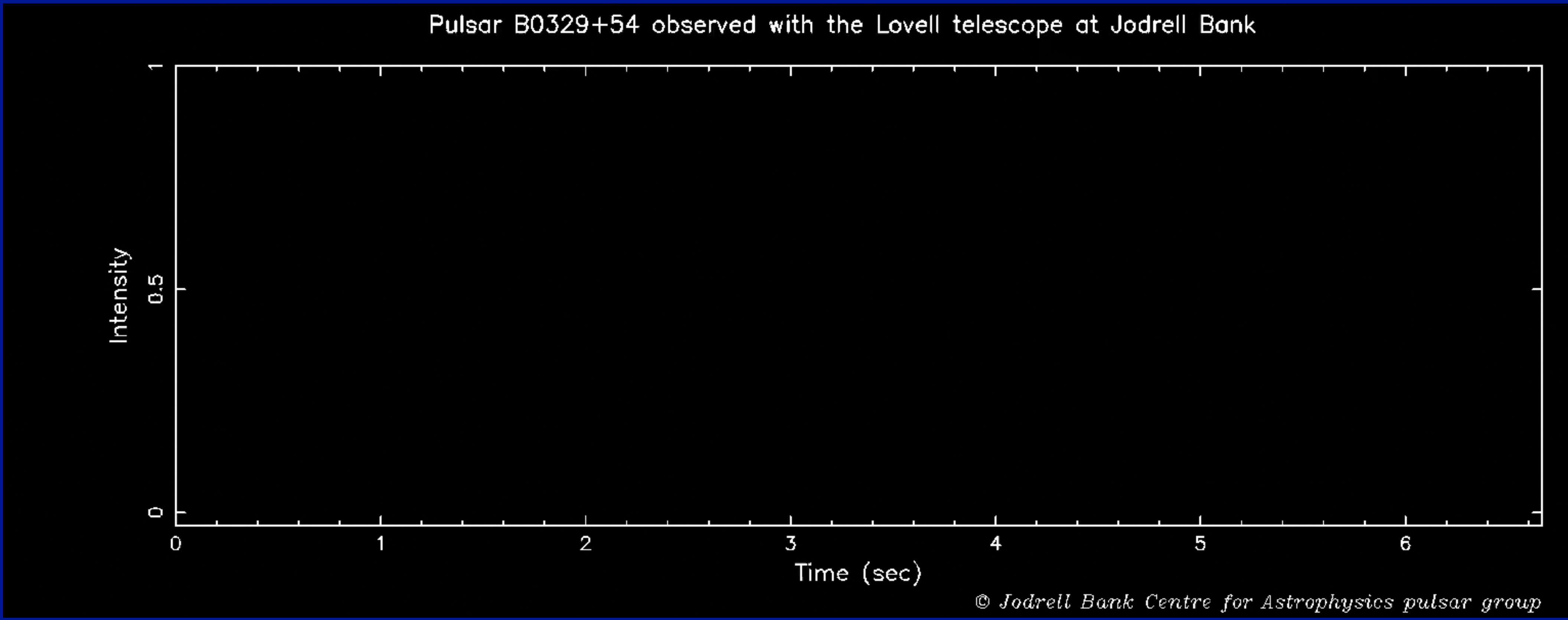
The expanded LWA (eLWA)

Crab pulsar nebula = Tau A



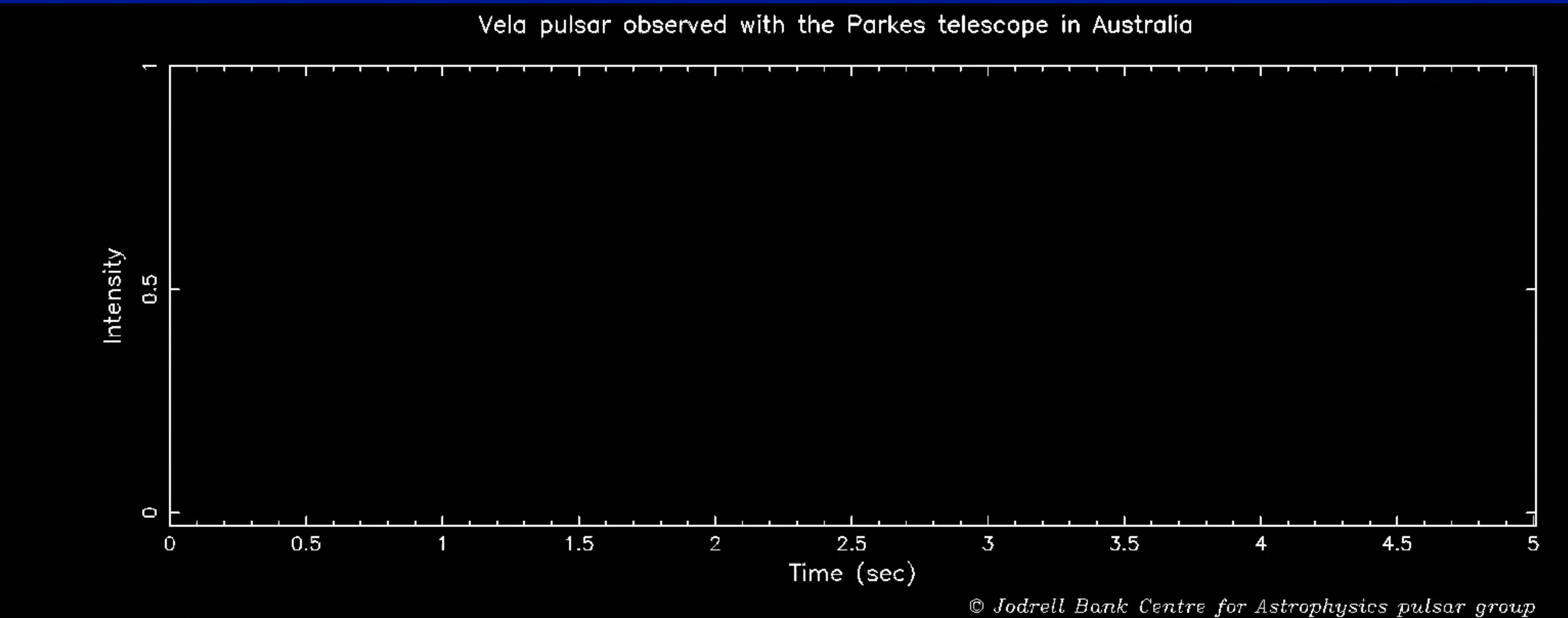


The Sound of Pulsars



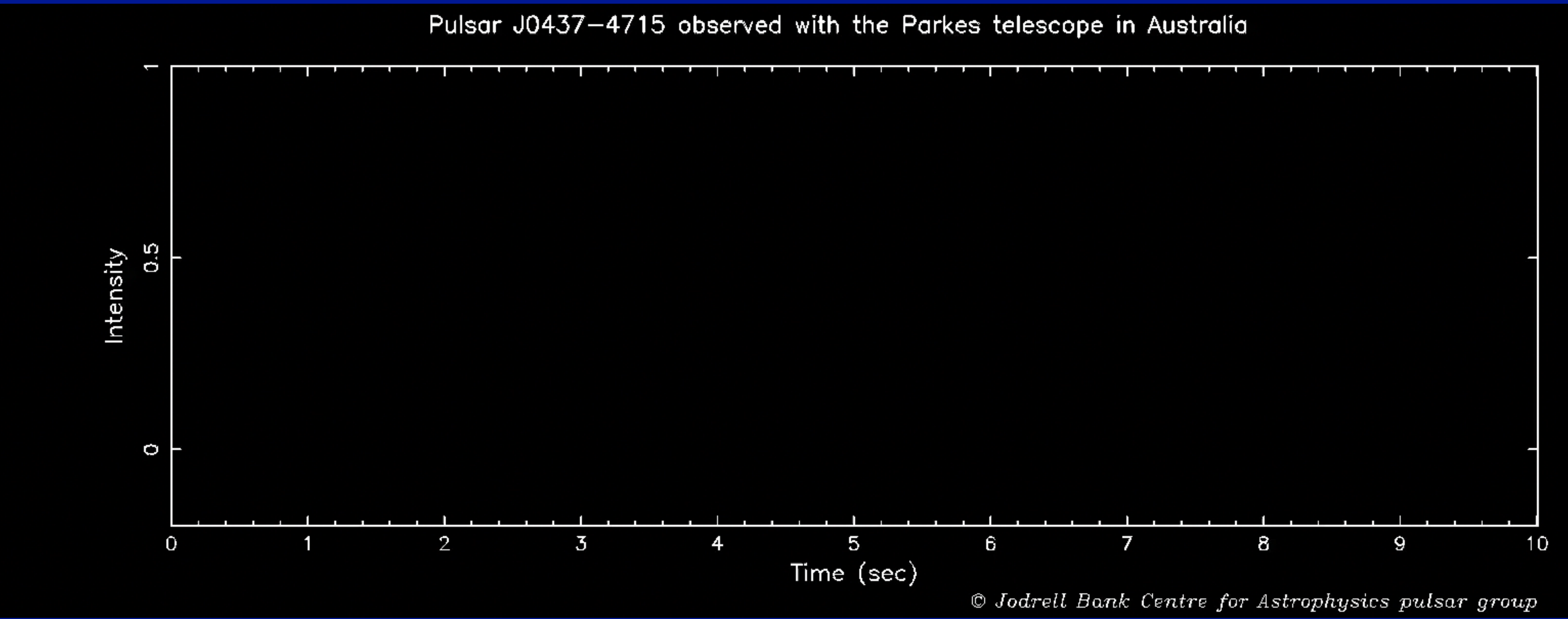
B0329+54, A bright pulsar with period 0.714520 sec

The Sound of Pulsars



Vela Pulsar, A young (age=10,000 years) pulsar with period 0.089 sec

The Sound of Pulsars

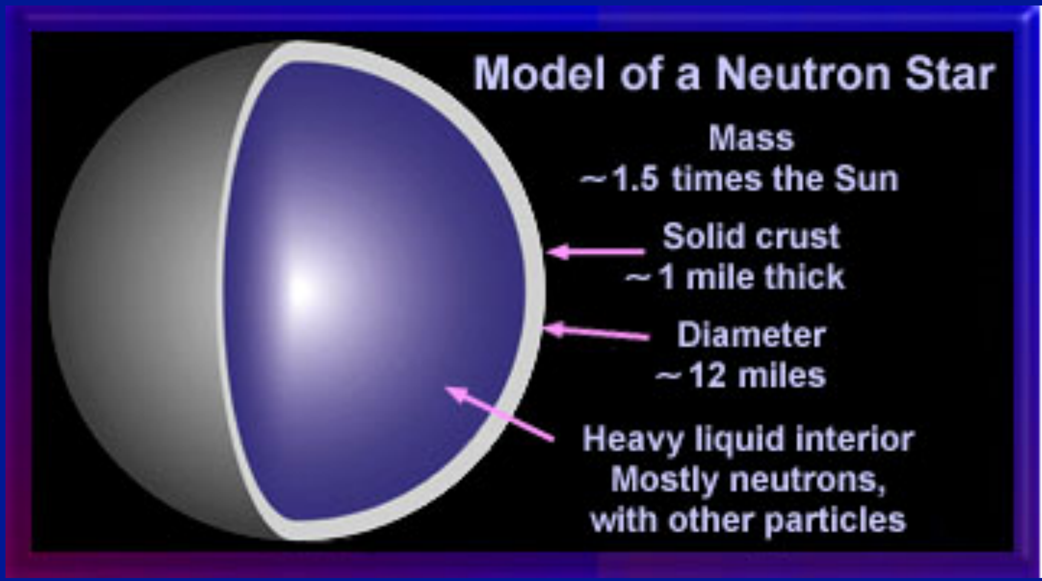


J0437-47 Pulsar, A millisecond (recycled) pulsar with period 0.005 sec

The Sound of Pulsars

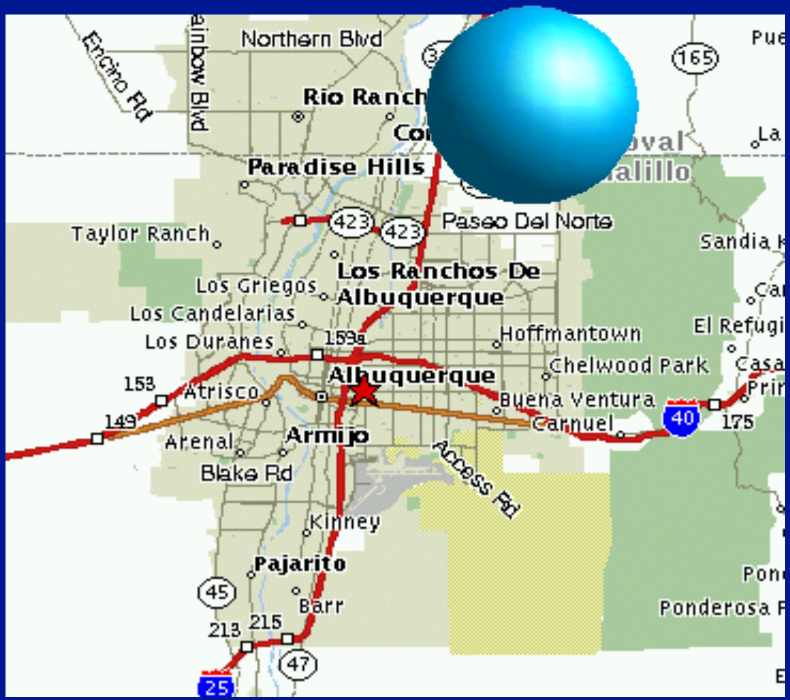
47 Tucanae, A globular cluster with 22 millisecond pulsars

Neutron Stars



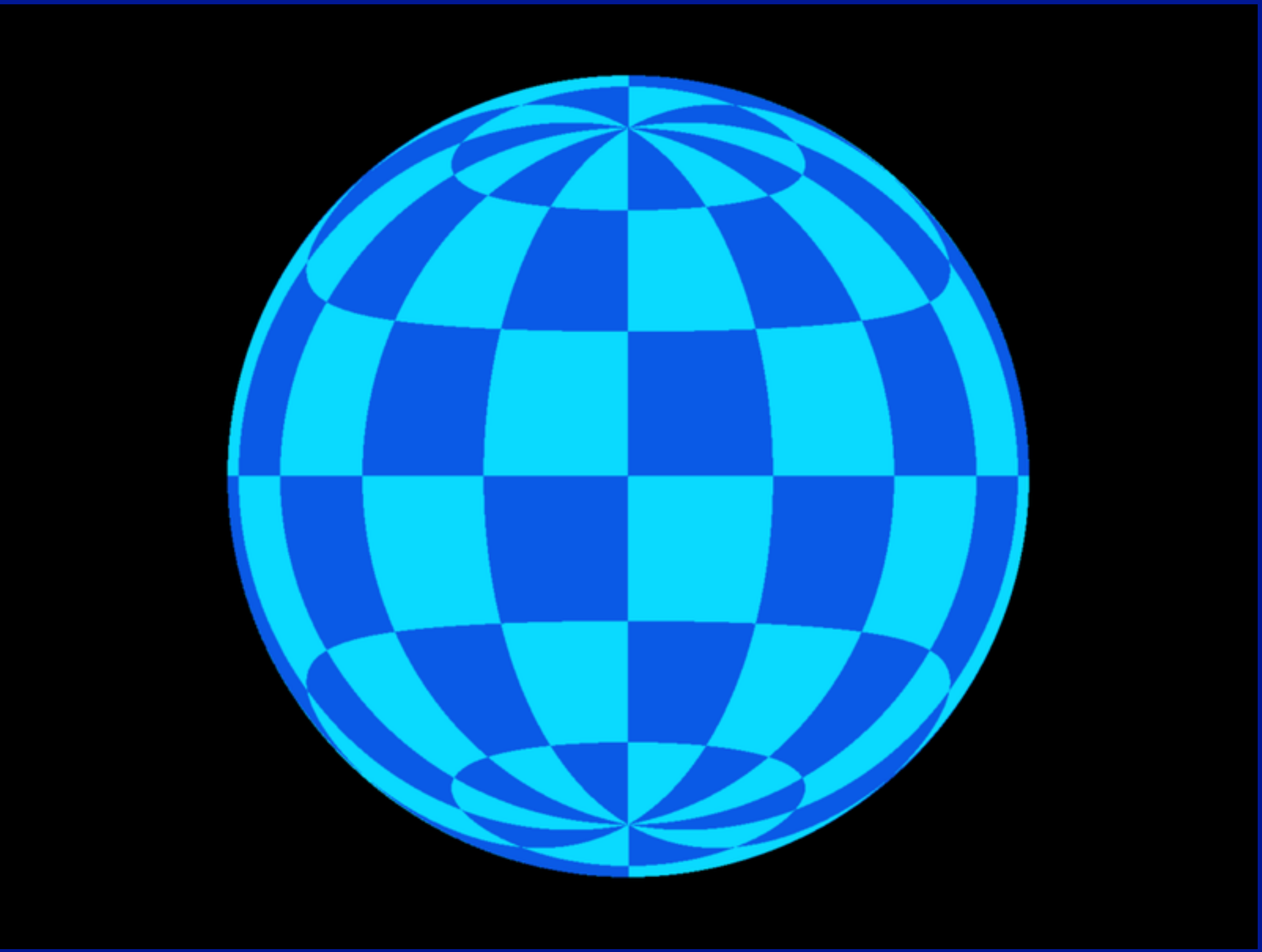
Leftover core from Type II supernova
- a tightly packed ball of neutrons.

Diameter: 20 km only!
Mass: 1.4 - 3(?) M_{Sun}
Density: 10^{14} g / cm^3 !
1 teaspoon = 1000 great pyramids
Surface gravity: 10^{12} higher
Escape velocity: 0.5c
Rotation rate: few to many times per second!!!
Magnetic field: 10^{12} x Earth's!

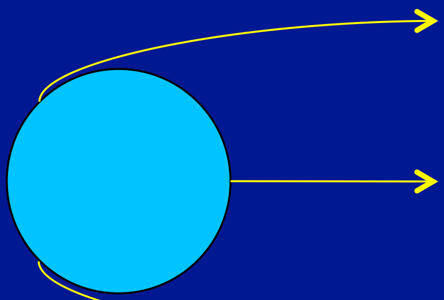


A neutron star over the Sandias?

General Relativistic deflection of light

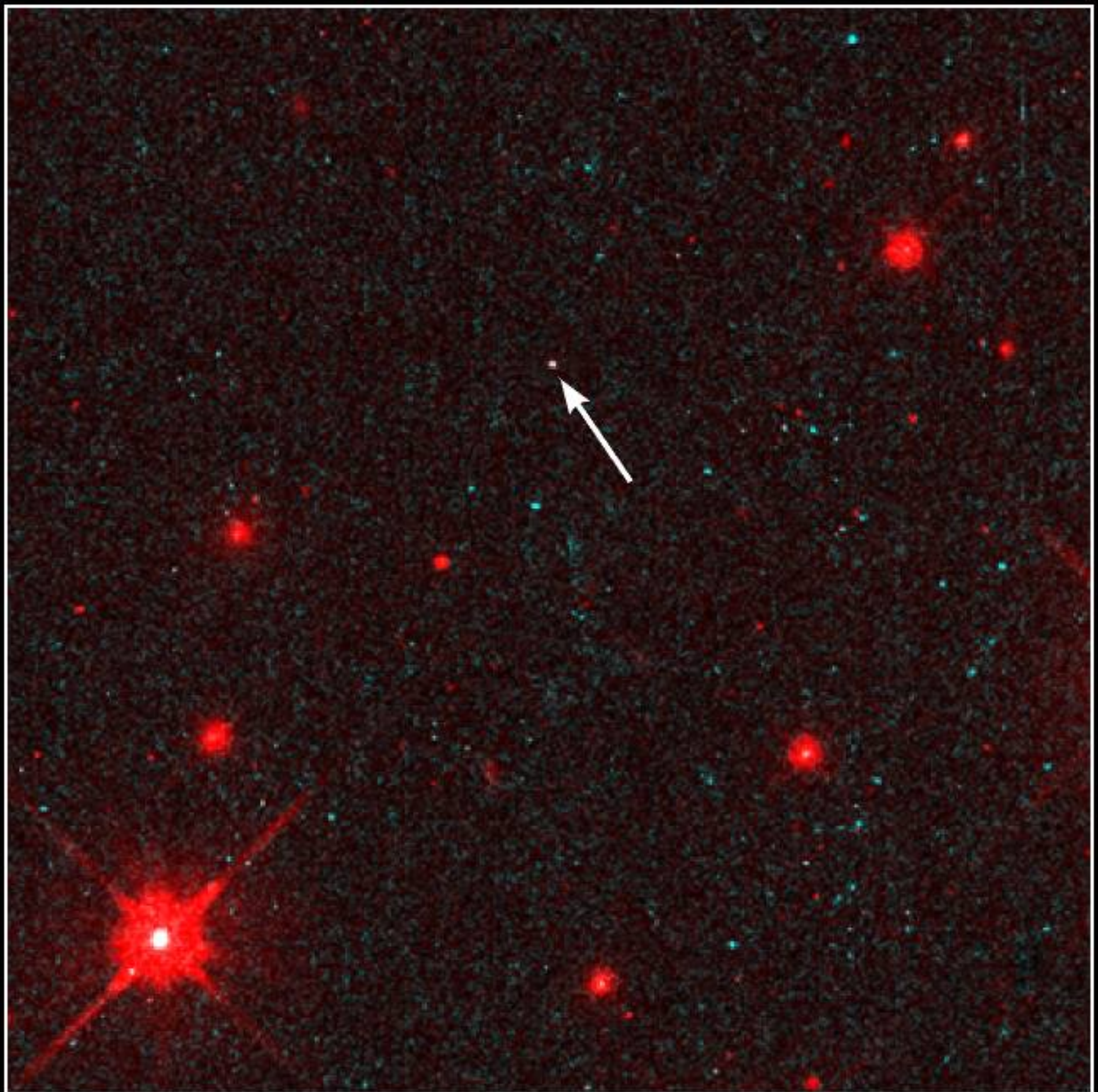


More than half the surface is visible at any one time!



Each square is 30 degrees x 30 degrees

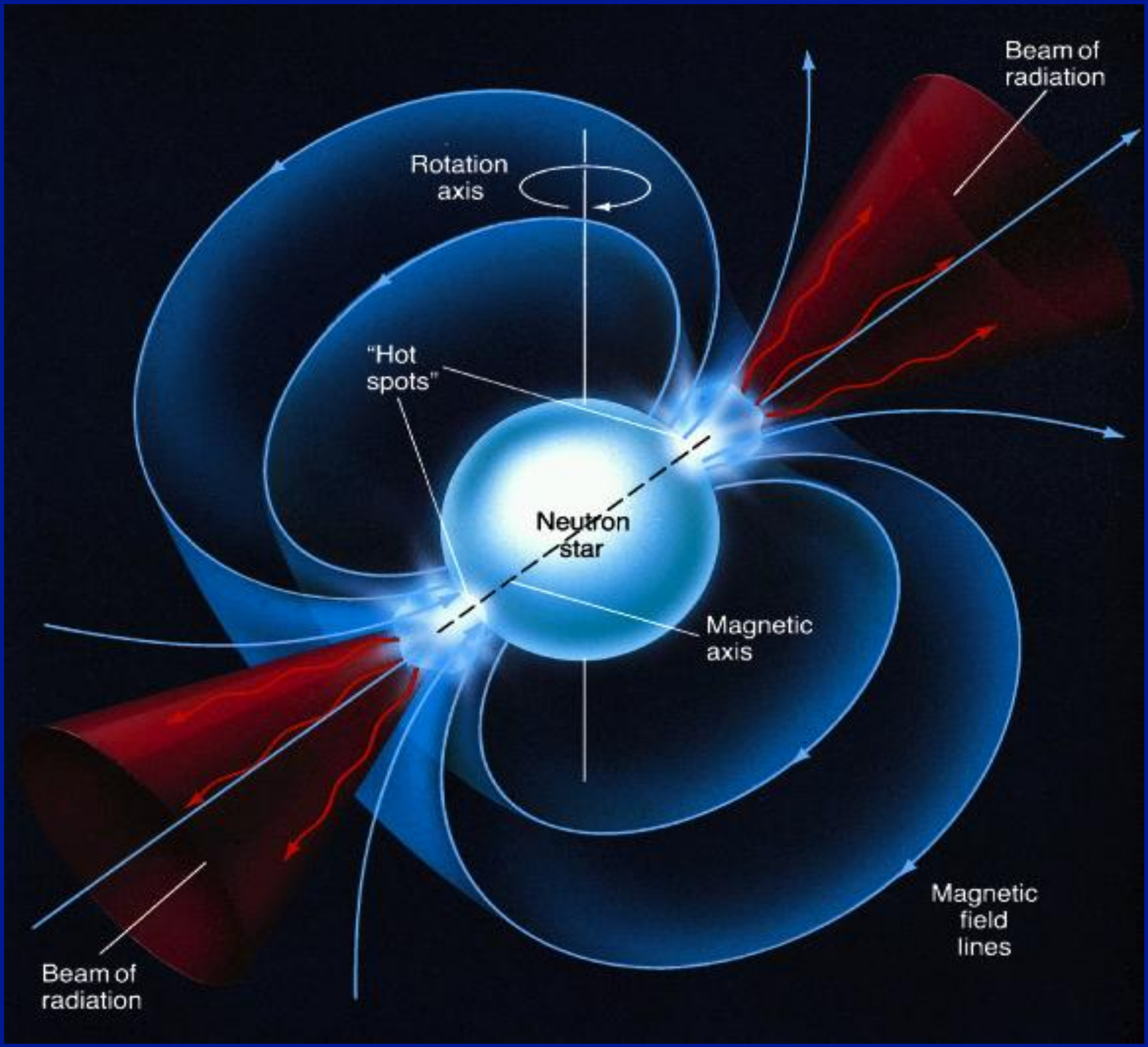
An Isolated Neutron Star



Isolated Neutron Star RX J185635-3754 HST • WFPC2
PRC97-32 • ST ScI OPO • September 25, 1997
F. Walter (State University of New York at Stony Brook) and NASA

T ~ 2 million K
Size ~ 30 km

The Lighthouse model of a pulsar



Pulsars are incredibly accurate clocks!

Example: period of the first discovered "millisecond pulsar" is:

$$P = 0.00155780644887275 \text{ sec}$$

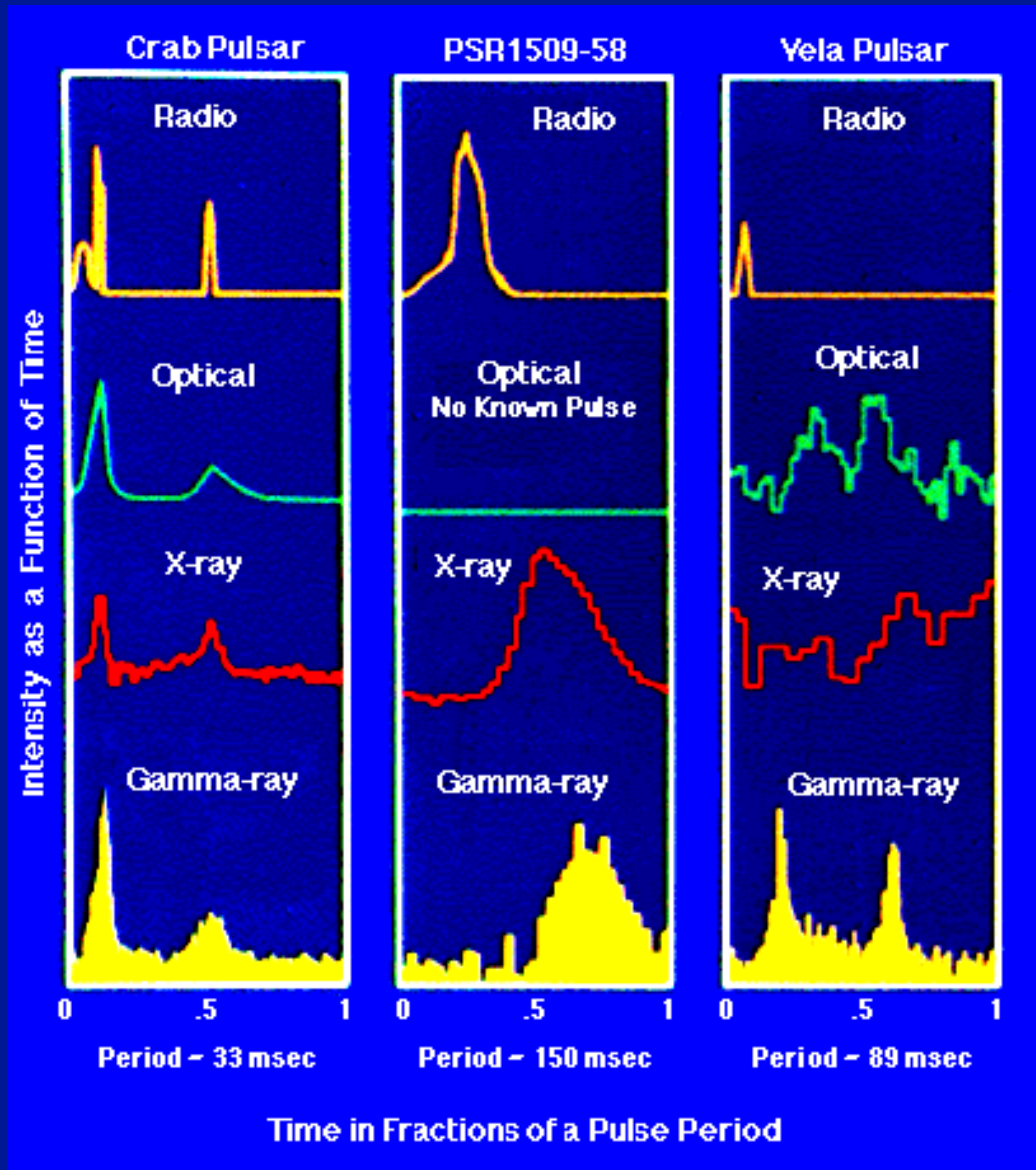
It is slowing down at a rate of

$$1.051054 \times 10^{-19} \text{ sec/sec}$$

The slowing-down rate is slowing down at a rate of:

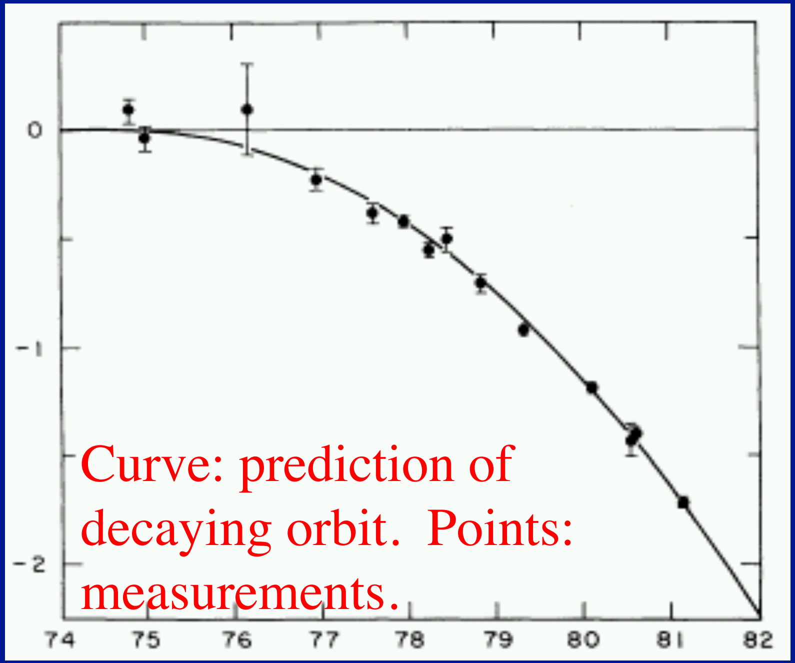
$$0.98 \times 10^{-31} \text{ /sec}$$

Multi-wavelength observations of Pulsars



Pulsar Exotica

Binary pulsars: two pulsars in orbit around each other.
Einstein predicted that binary orbits should "decay", i.e. the masses would spiral in towards each other, losing energy through "gravitational radiation". Confirmed by binary pulsar.



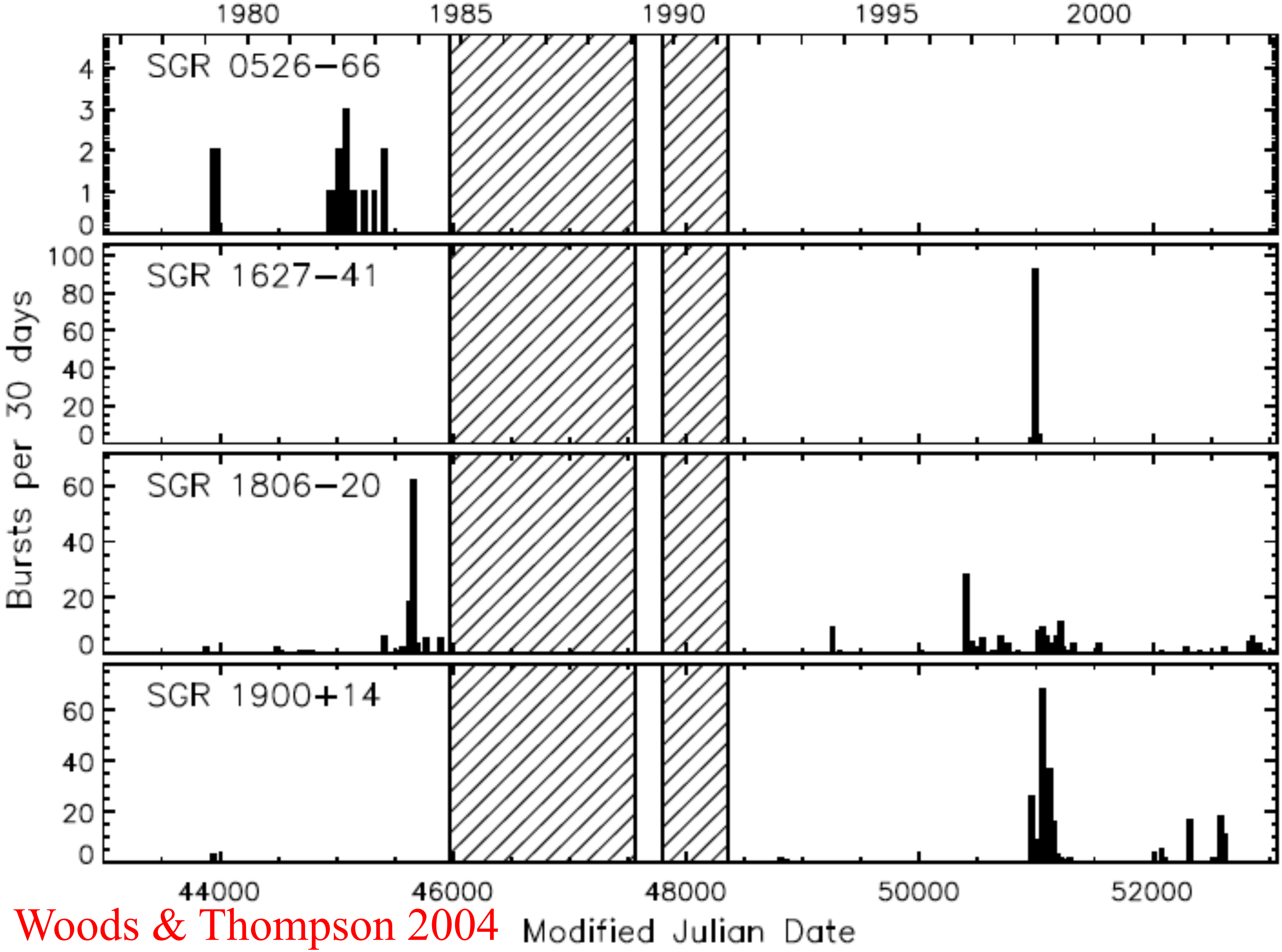
year

Planets around pulsars: A pulsar was found in 1992 to have three planets! Masses about 3 M_{Earth}, 1 M_{Earth}, and 1 M_{Moon} !

Millisecond pulsars: periods of 1 to a few msec. Probably accreted matter from a binary companion that made it spin faster.

Gamma-ray Bursts: some pulsars produce bursts of gamma-rays, called Soft Gamma-Ray Repeaters or SGRs

Time history of the 4 confirmed SGRs:

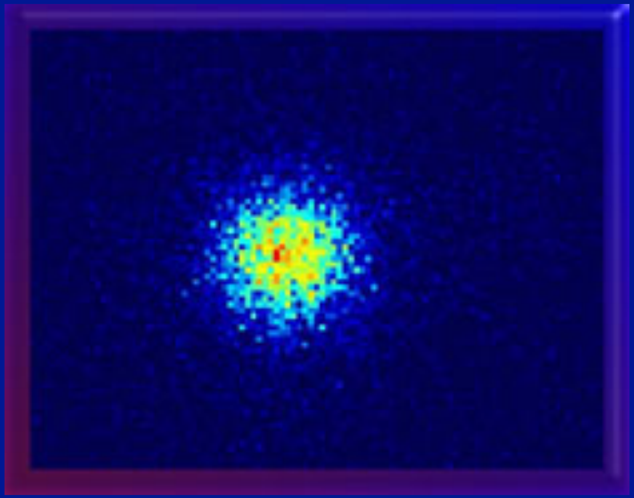


Woods & Thompson 2004

Soft Gamma-Ray Repeaters

E_{iso} ~ a few10^{44} erg in gamma-rays

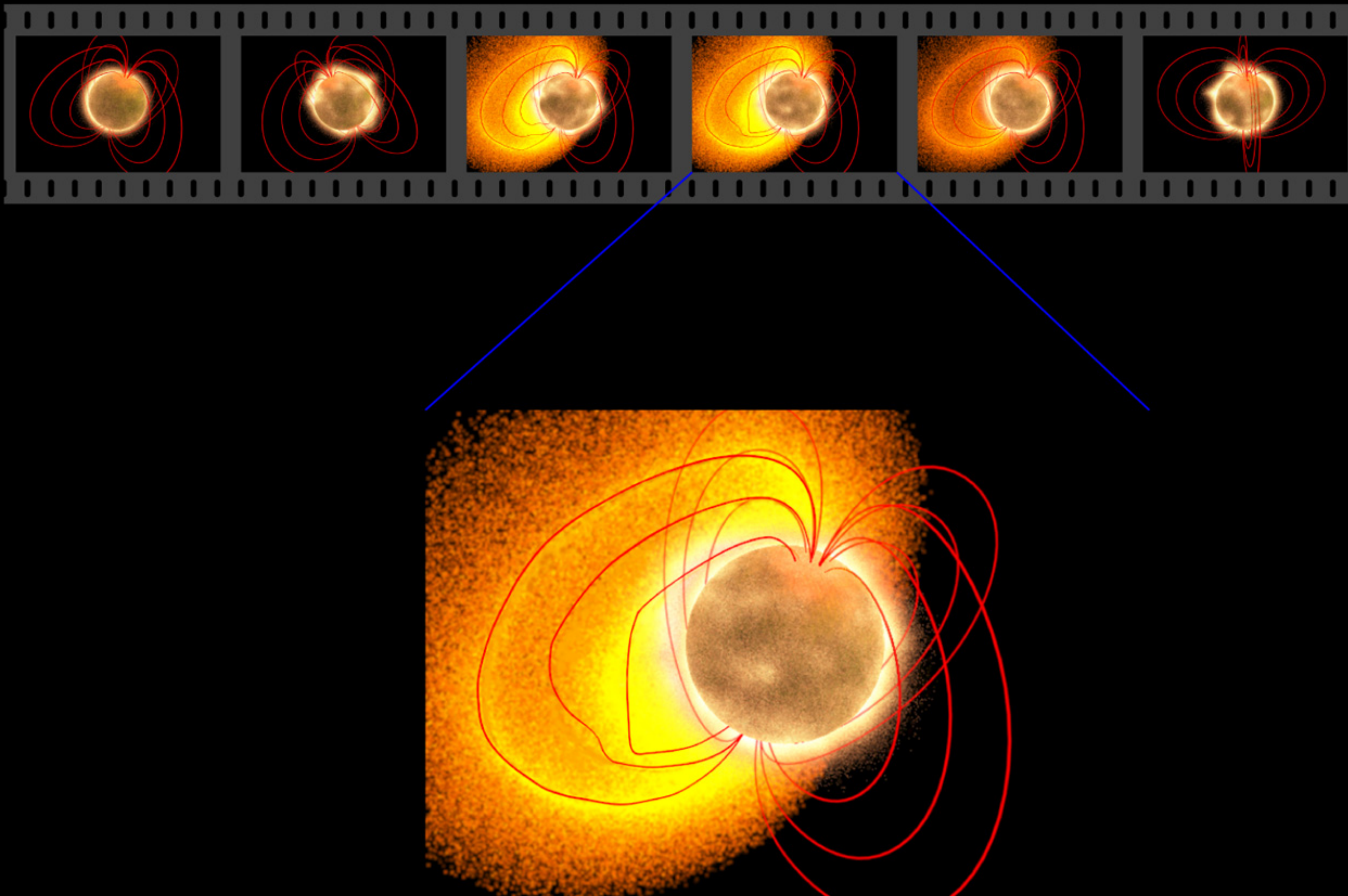
Where does this energy come from?



X-ray image

- Accretion? No sign of a disk
- Rotation? Not enough energy available
- Magnetic fields? Yes

Magnetar burst sequence



Clicker Question:

What is our basic model for a pulsar?

A: a rotating white dwarf

B: a rotating neutron star

C: a rotating black hole

D: an oscillating star

Clicker Question:

What is the diameter of a 2 M_{sun} neutron star?

A: 20 km

B: 2000 km

C: 14,000 km (size of the Earth)

D: 1,400,000 km (size of the Sun)

Clicker Question:

Which of the following is true about a binary pulsar system?

A: It will last forever.

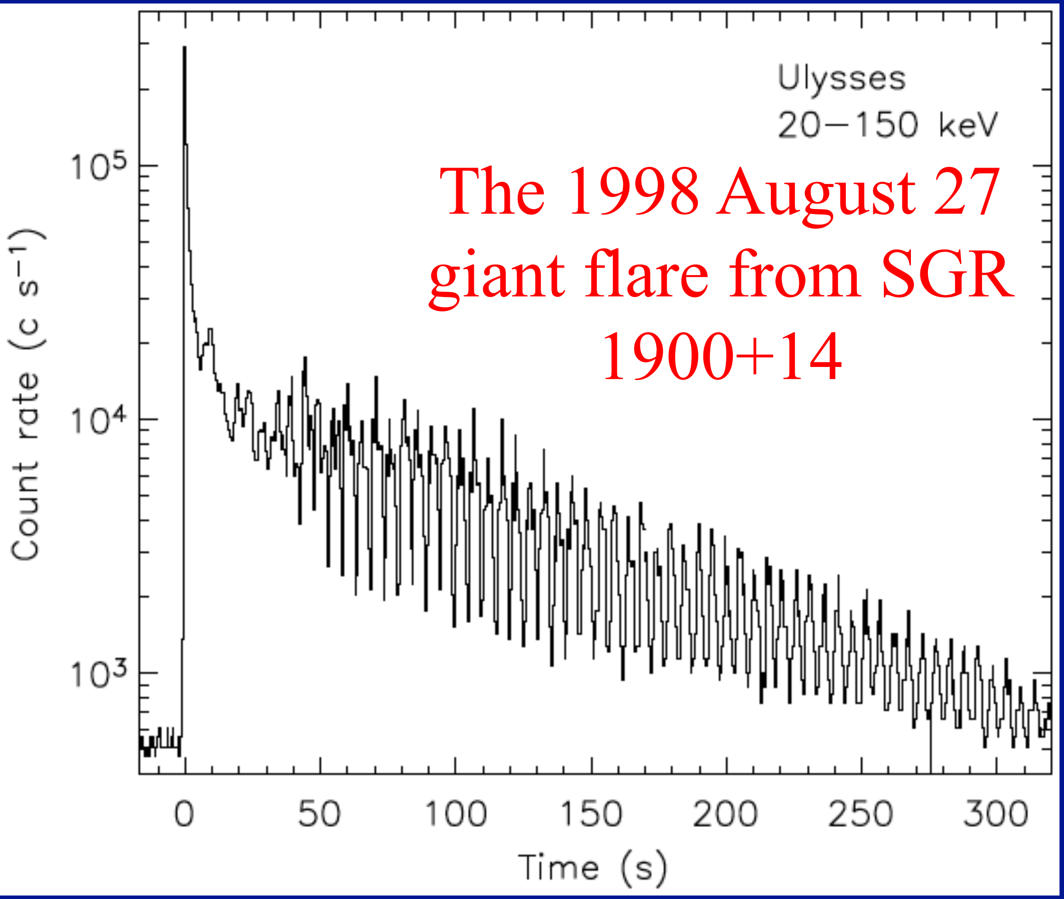
B: They can only be found in star forming regions

C: The total mass of the two pulsars must be more than 10 solar masses.

D: Each of the pulsars was produced by a massive star that exploded in a Supernova event.

Giant Flares from SGRs

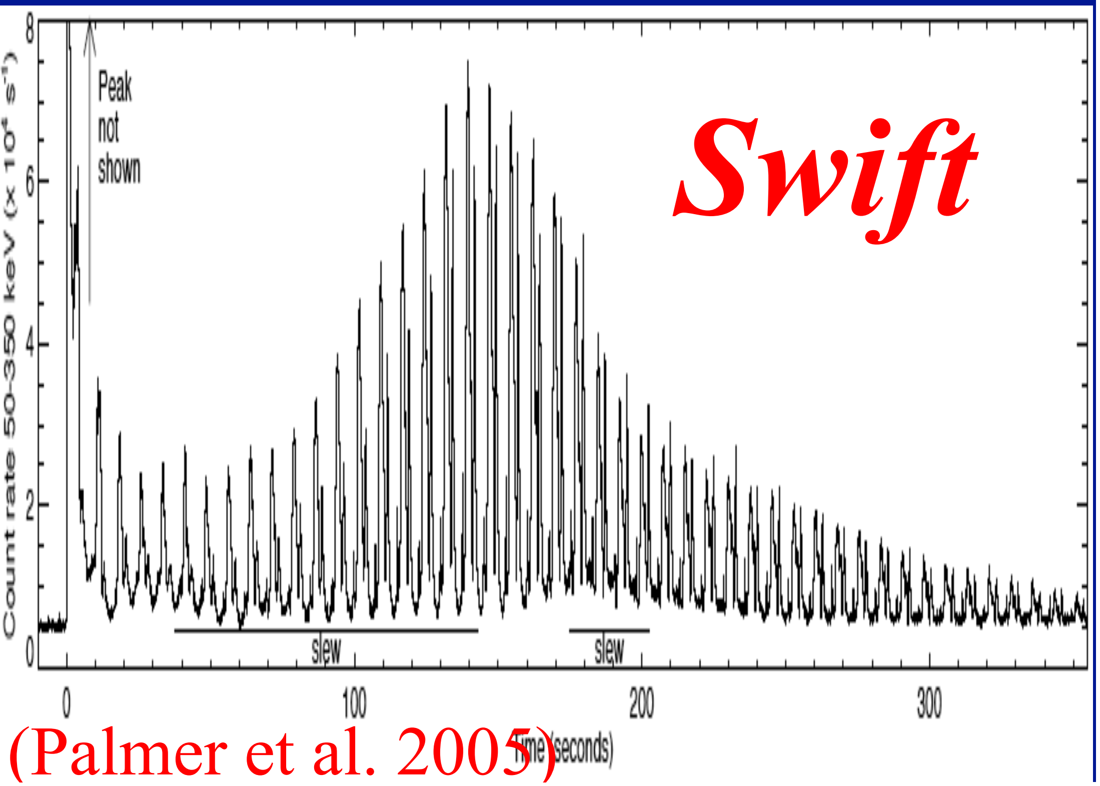
- Initial spike: **Δt** ~ 0.3 s , E_{iso} ~ a few10^{44} erg
  - hard spectrum
  - ~ ms rise time
- Pulsating tail
  - Lasts a few min.
  - Modulated at the NS rotation period
  - Softer spectrum



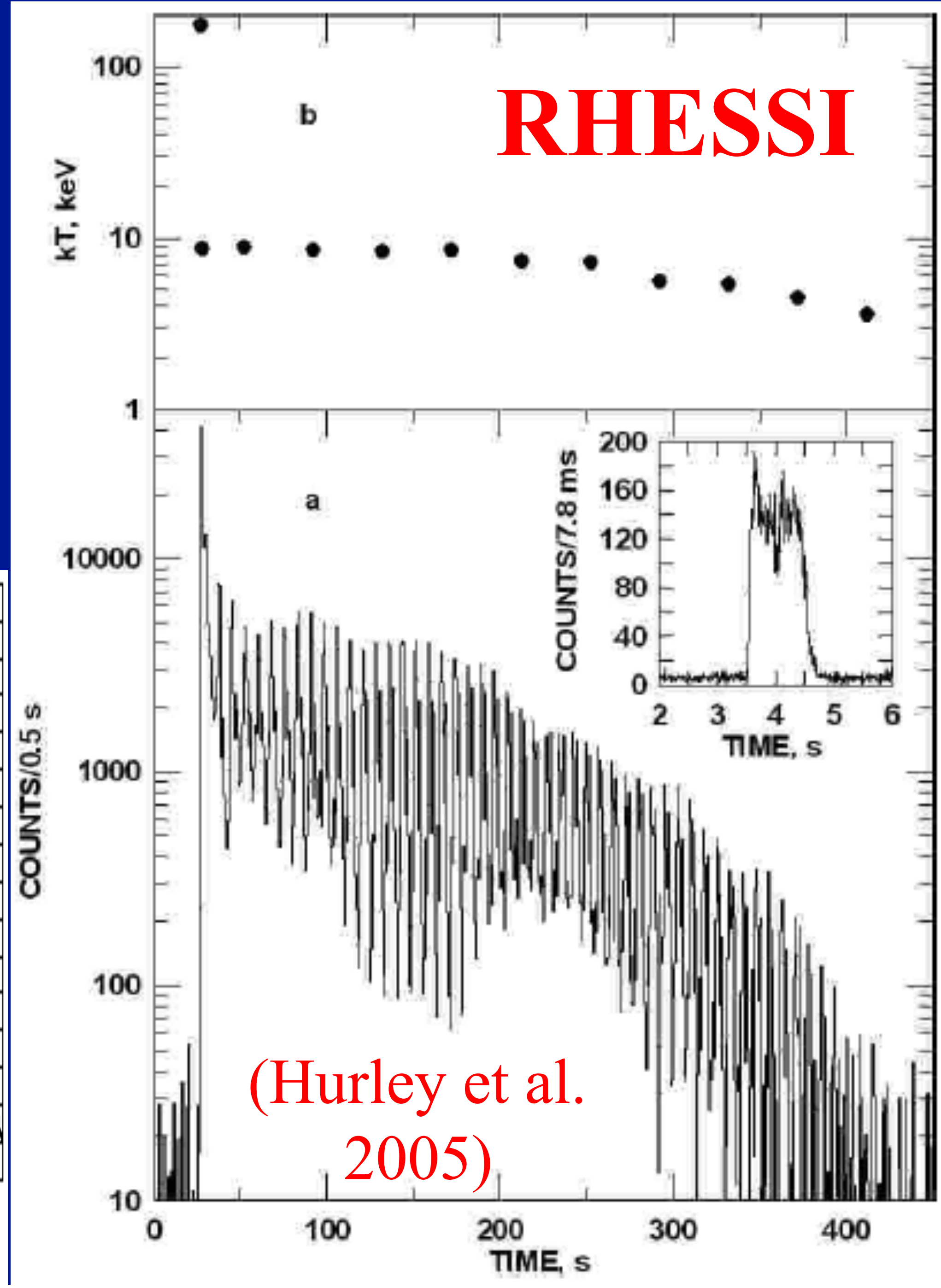
- Only 2 previous events ever recorded: in 1979 (SGR 0526-66 in LMC) & 1998 (SGR 1900-14)

The 2004 Dec. 27 Giant Flare

- was ~5^{o} from the sun
- It's distance ≈ 15 kpc
- $E_{iso} \sim 10^{46}$ erg

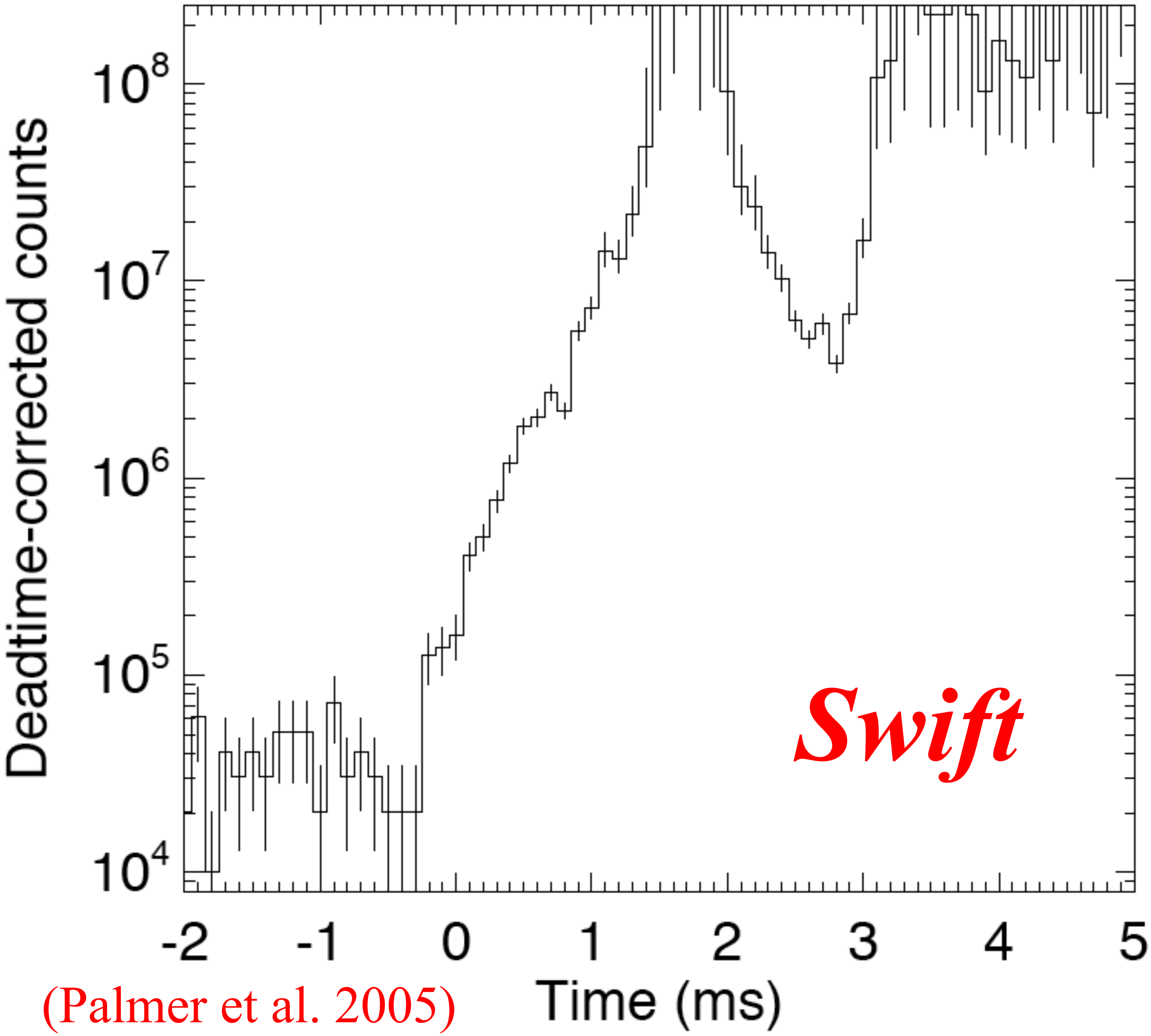


(Palmer et al. 2005)



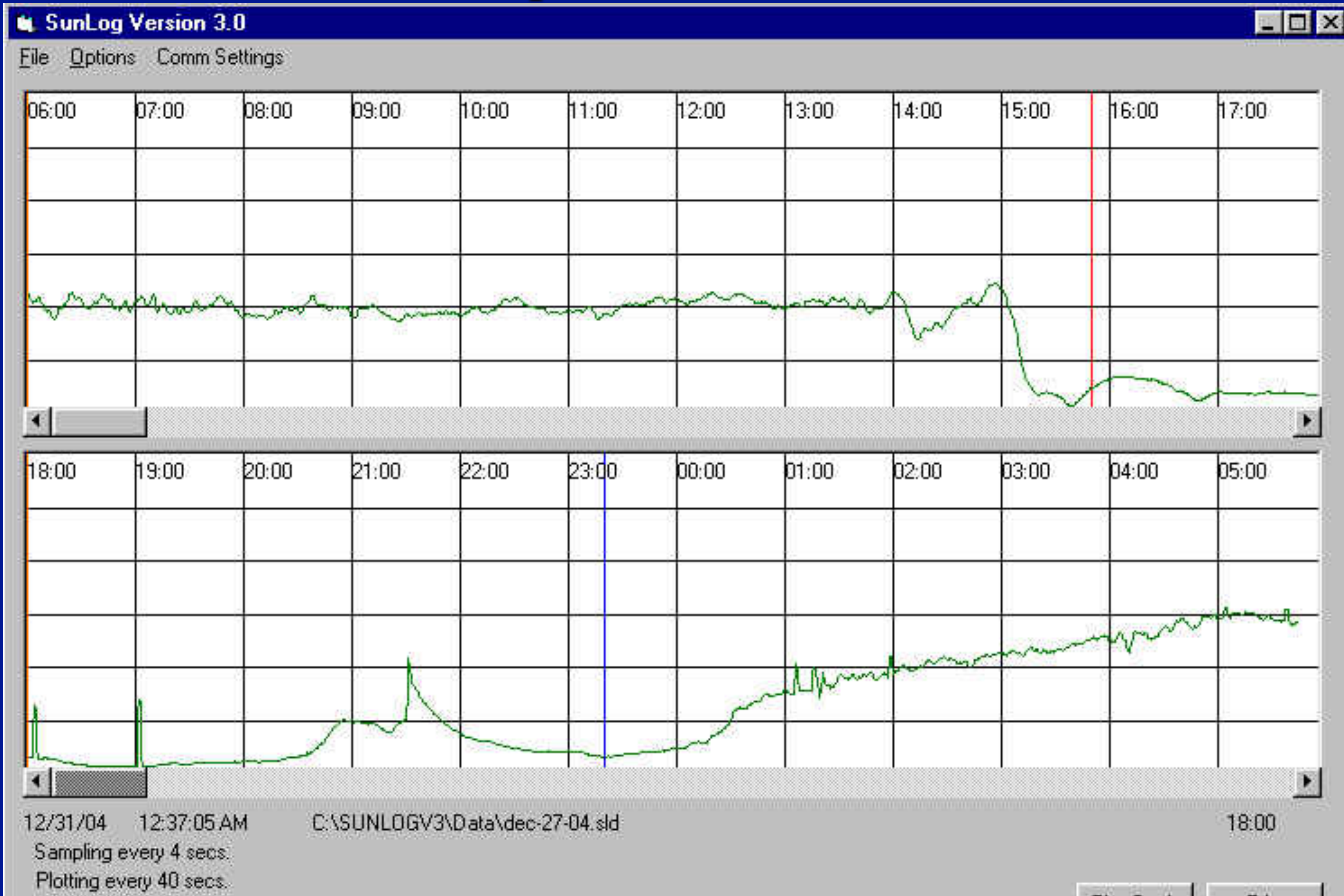
(Hurley et al. 2005)

Rise time: < 1 ms



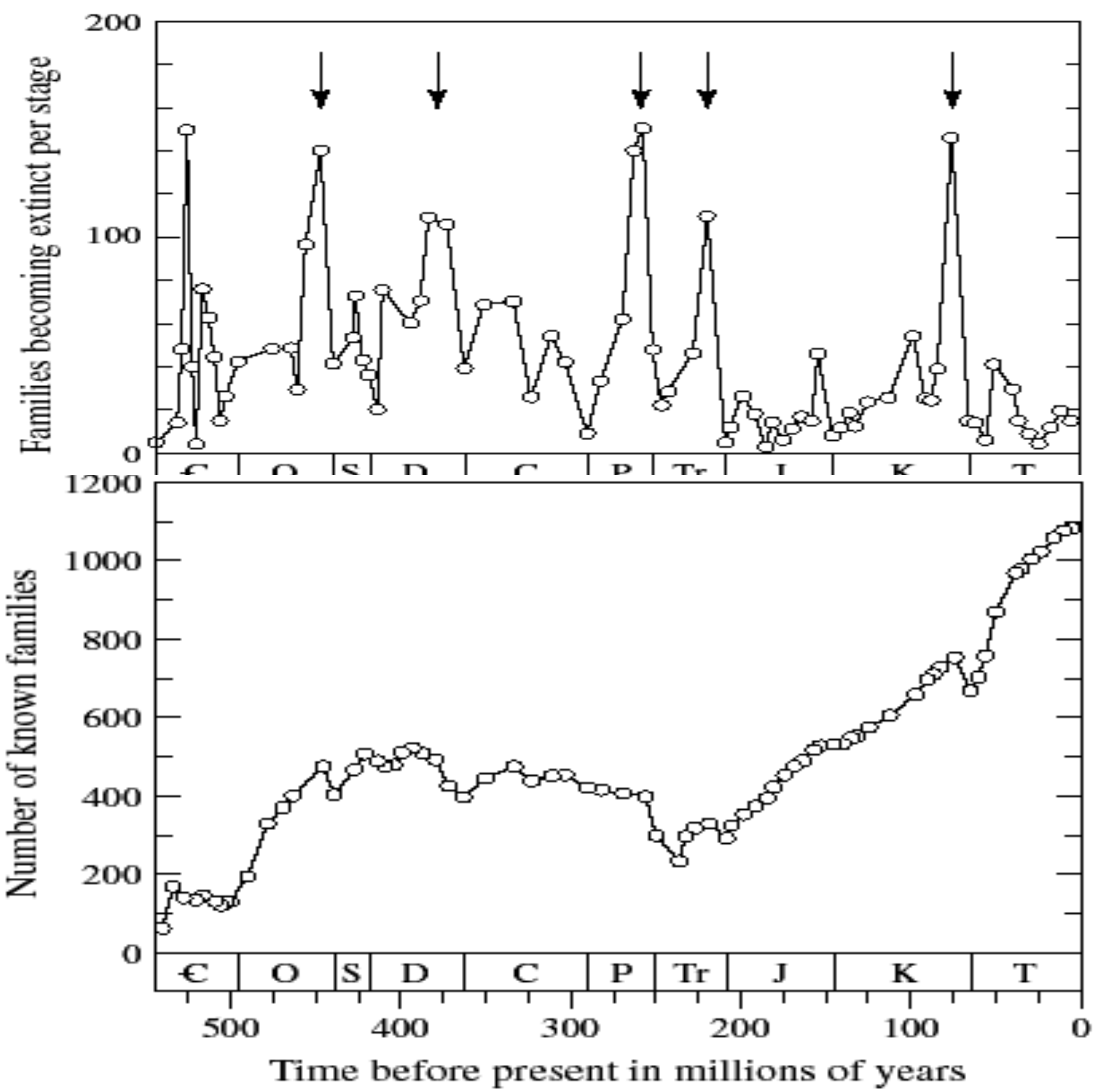
(Palmer et al. 2005)

Sudden Ionospheric Disturbance (SID)



Washington, USA to Alberta, CA Cambell et al. 2005

The Fossil Record is Marked by Mass Extinction Events

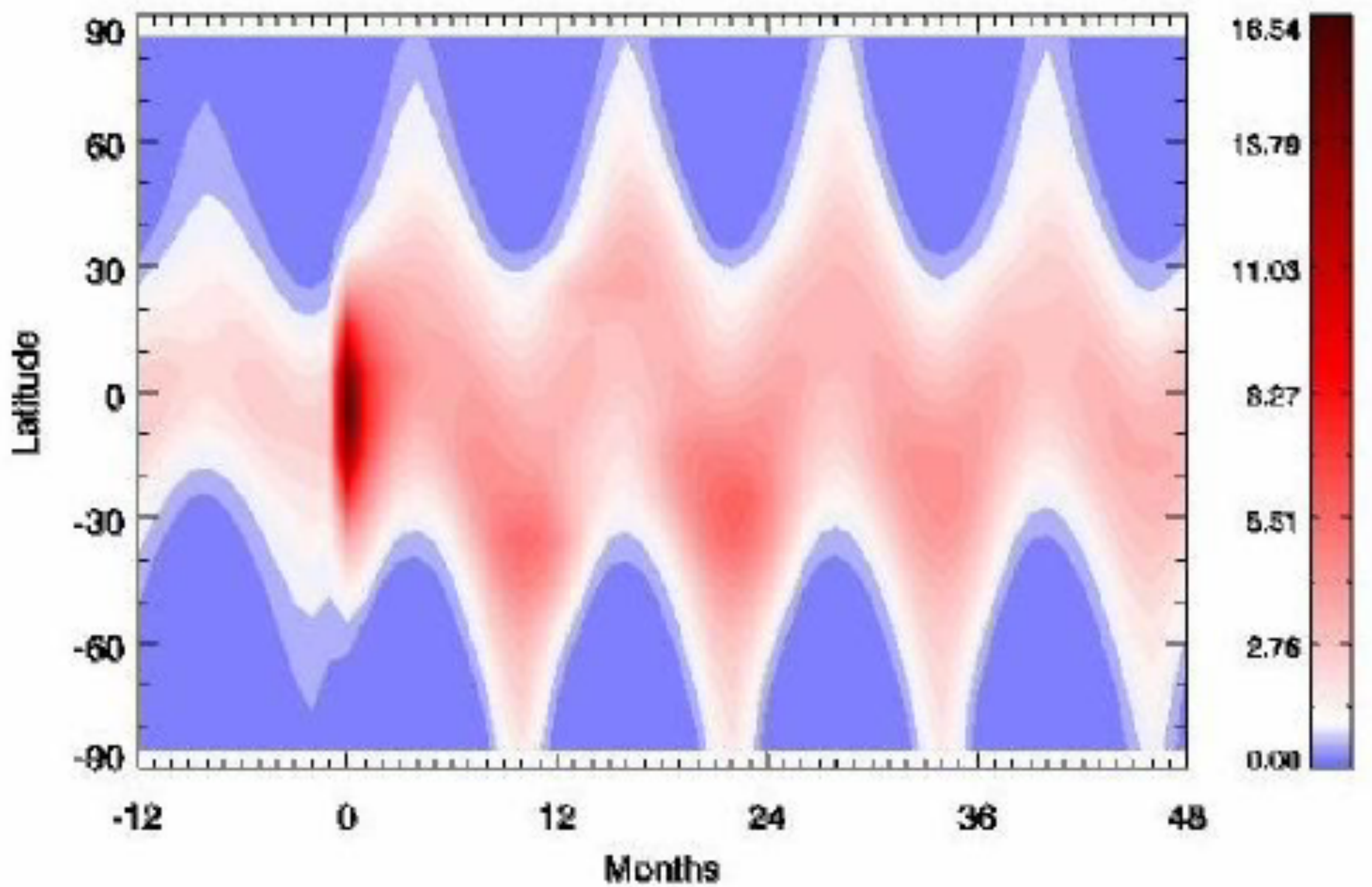


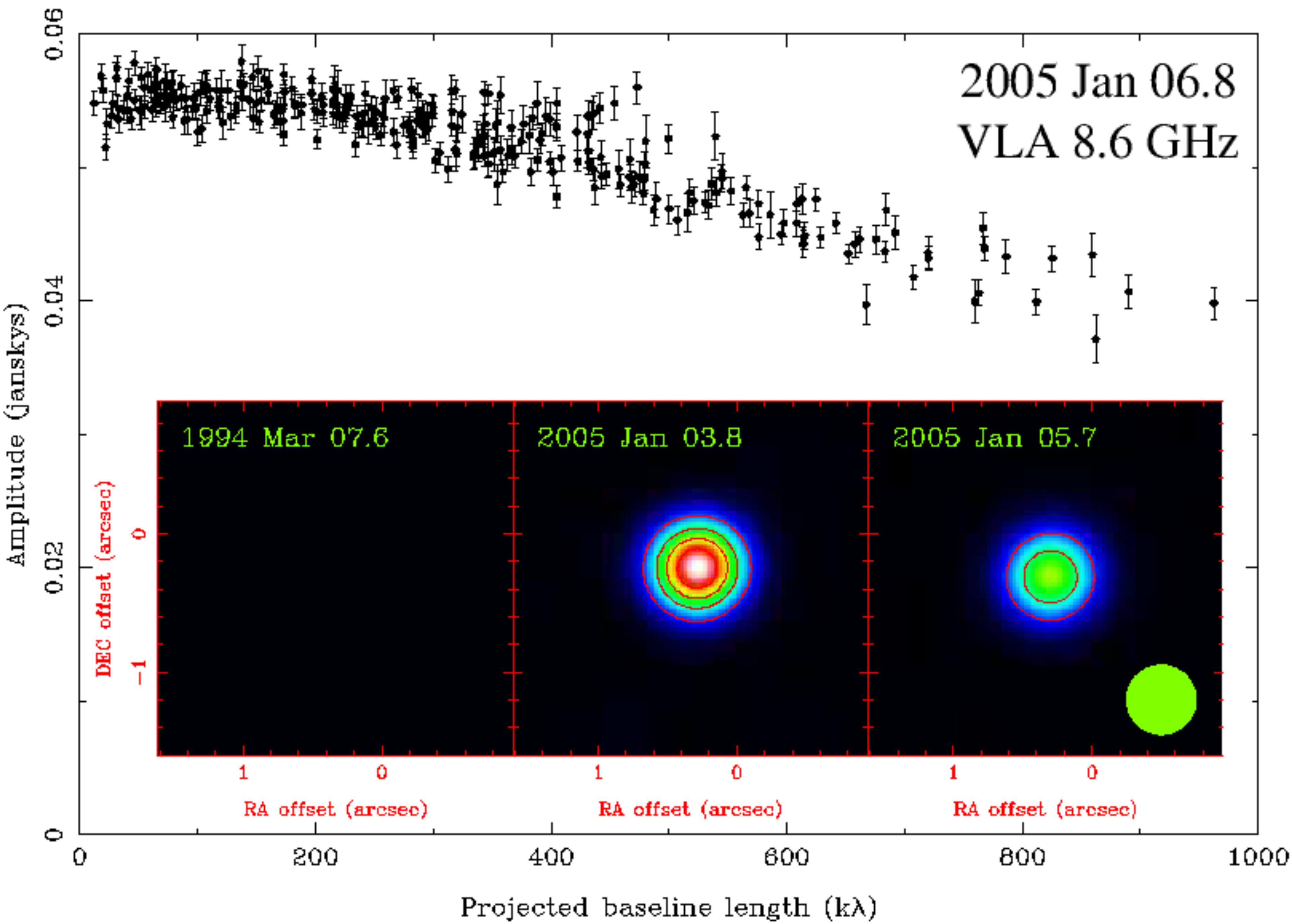
Extinction	Genus loss
End Ordovician	60%
End Devonian	57%
End Permian	82%
End Triassic	53%
End Cretaceous	47%

From Solé & Newman 2002

Effects of a nearby GRB on Earth

Melott et al. 2004

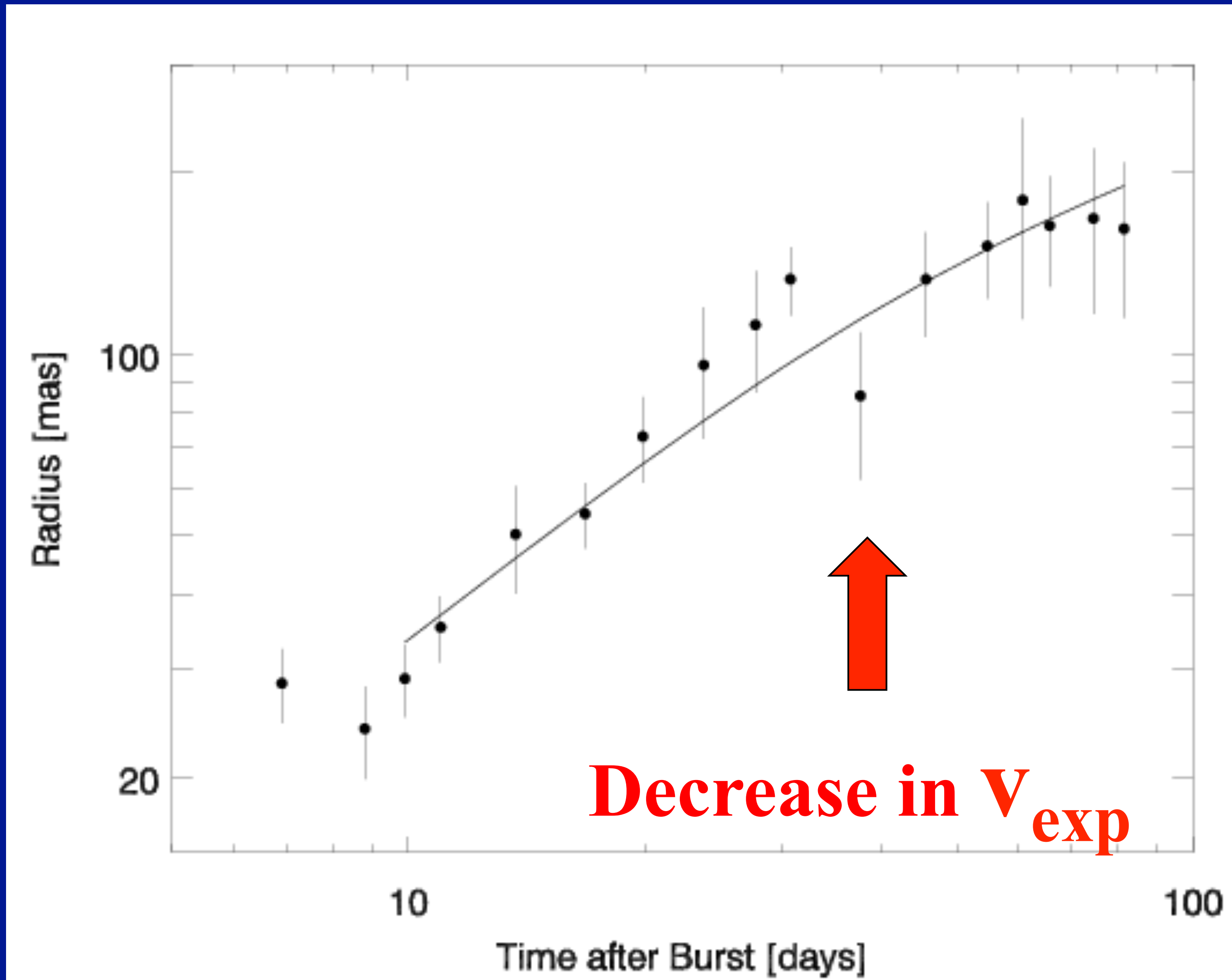




Gaensler et al 2005

Growth of the Radio Afterglow

Size at
t+7 days
10^{16} cm
(1000 AU)



VLA
8.5 GHz

Velocity to
t + 30 days
~ 0.8 c

Magnetar burst sequence

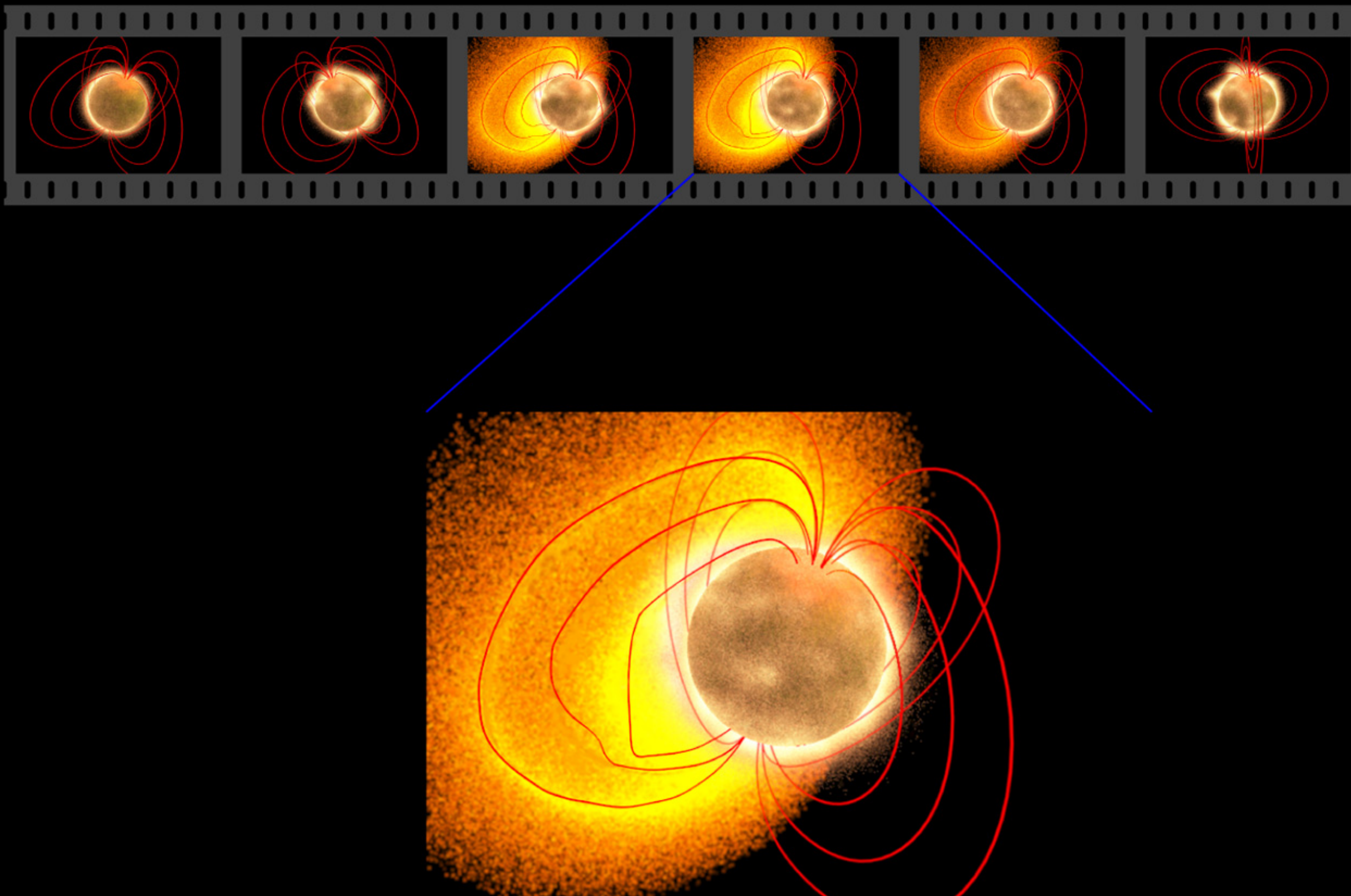
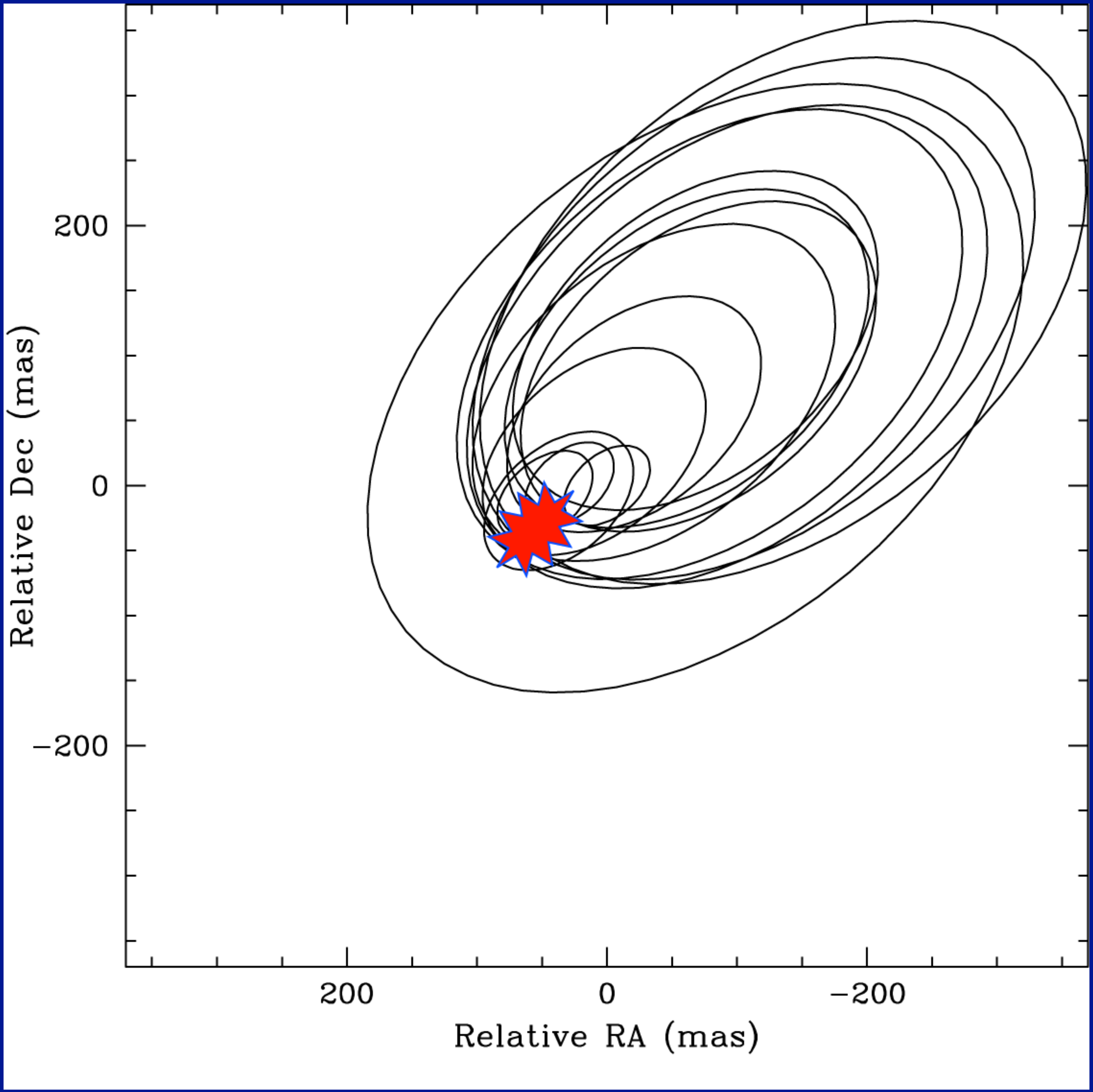


Image Evolution

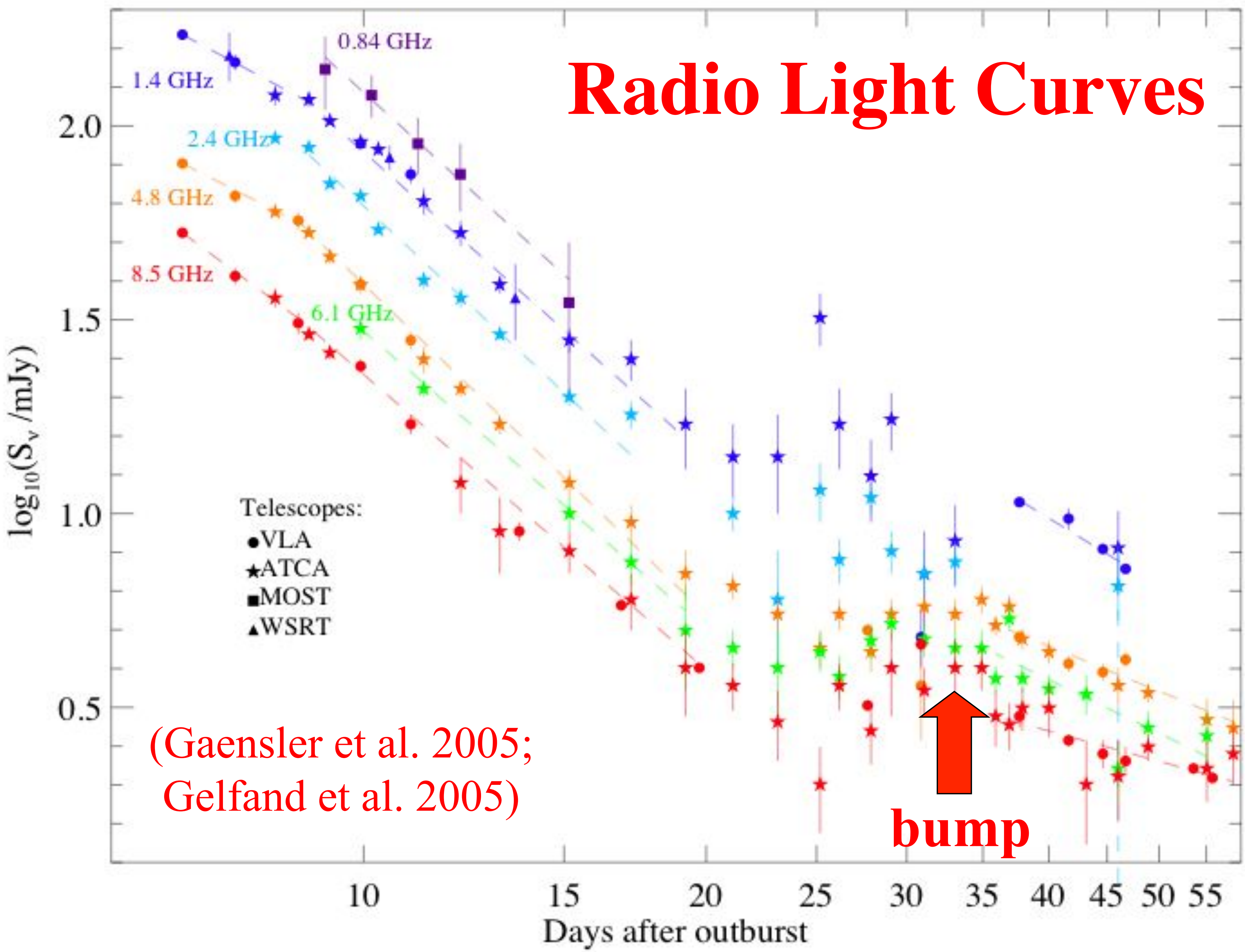
VLA 8.5 GHz

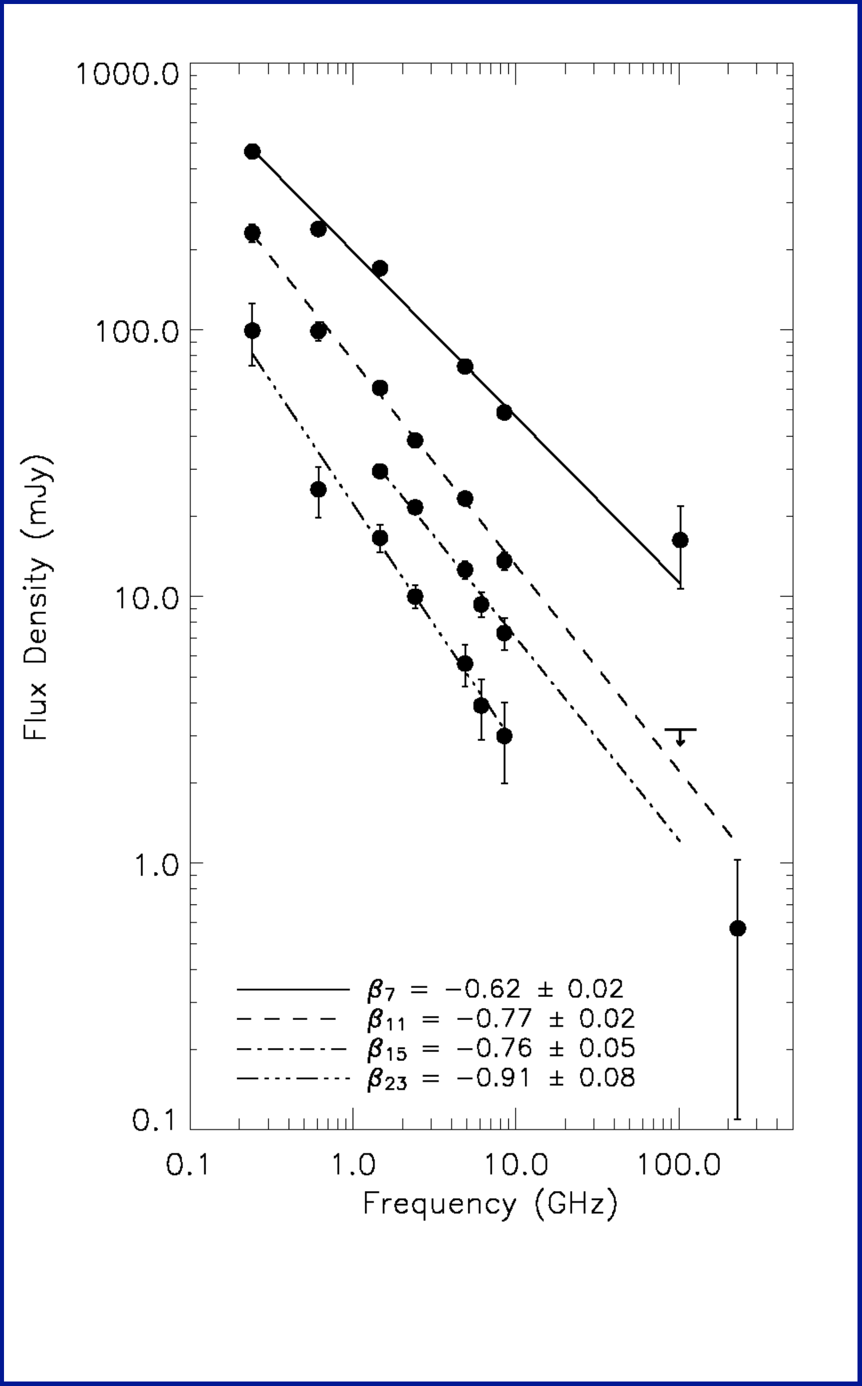
E ~ 10^45 ergs

One-sided (anisotropic) outflow



Taylor et al 2005


Radio Light Curves
0.84 GHz
1.4 GHz
2.4 GHz
4.8 GHz
8.5 GHz
6.1 GHz
Telescopes:
VLA
ATCA
MOST
WSRT
(Gaensler et al. 2005;
Gelfand et al. 2005)
bump
log10(Sv /mJy)
Days after outburst
2.0
1.5
1.0
0.5
10
15
20
25
30
35
40
45
50
55



Radio Afterglow has a Steep Spectrum ~ $\nu^{-0.6}$ at t+7 days down to 220 MHz

Flux > 1 Jy at early times and low frequencies.

From Cameron et al. 2005

Clicker Question:

The energy source for the repeated gamma-ray bursts (SGRs) from some neutron stars is what?

A: fusion of hydrogen on the surface

B: energy released by material accreting onto the surface.

C: the result of reconfigurations of the strong magnetic fields

D: changes in the rotation rate of the neutron star.

Clicker Question:

What happens to a neutron star that acquires a mass of more than 3 M_{sun}?

A: It will split into two or more neutron stars

B: It will explode and blow itself to bits

C: It will collapse to form a black hole

D: It will produce a type II supernova, leaving a single neutron star.

NS Merger Model for short GRBs

Mean redshift ~ 0.25 for short hard bursts (SHB)

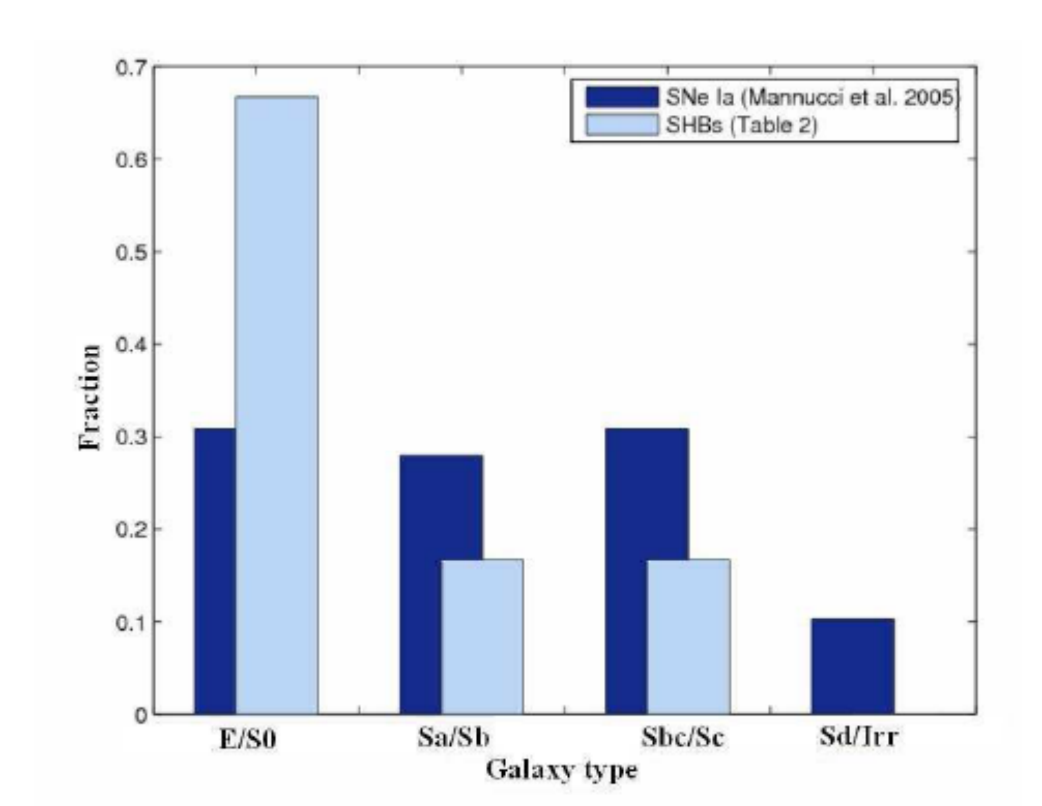
No supernova association expected

SHBs often found at outskirts of galaxy (implies large peculiar velocities)

SHBs found in

- Elliptical galaxies

- galaxies with low star formation rates



Neutron Star - Black Hole merger