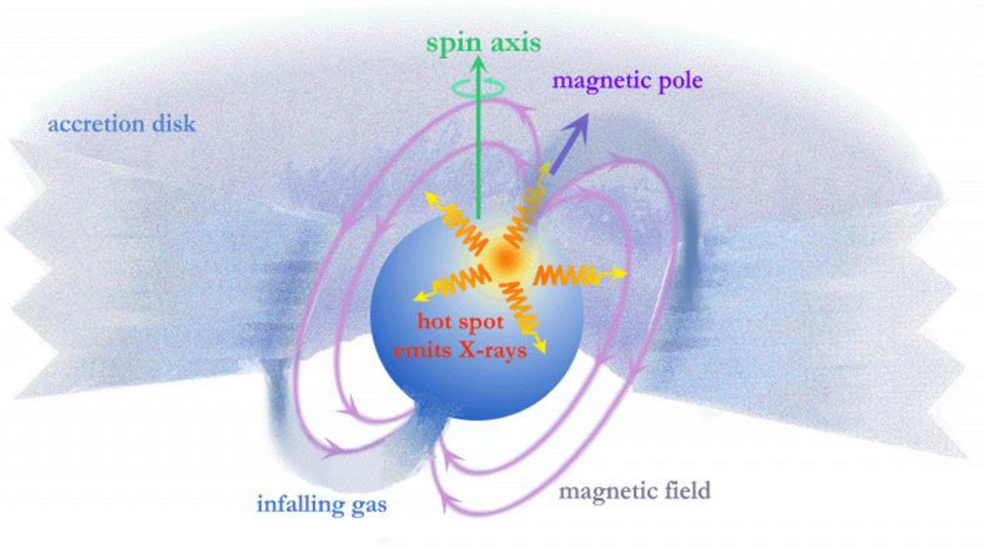
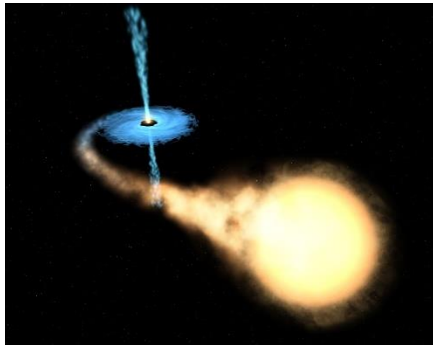
# Pulsars and Supernovae II

## 9. A PULSAR AND NEUTRON STAR MENAGERIE

X-ray pulsars
SGRs
AXPs
Magnetars
RRATS
GRBs

# X-ray pulsars



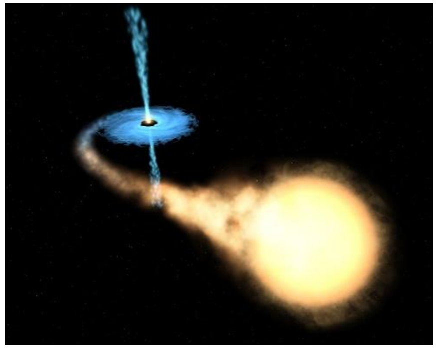
- We have seen how radio pulsars are powered by the rotational kinetic energy of the neutron star. X-ray pulsars are (mostly) powered by accretion from a binary companion:

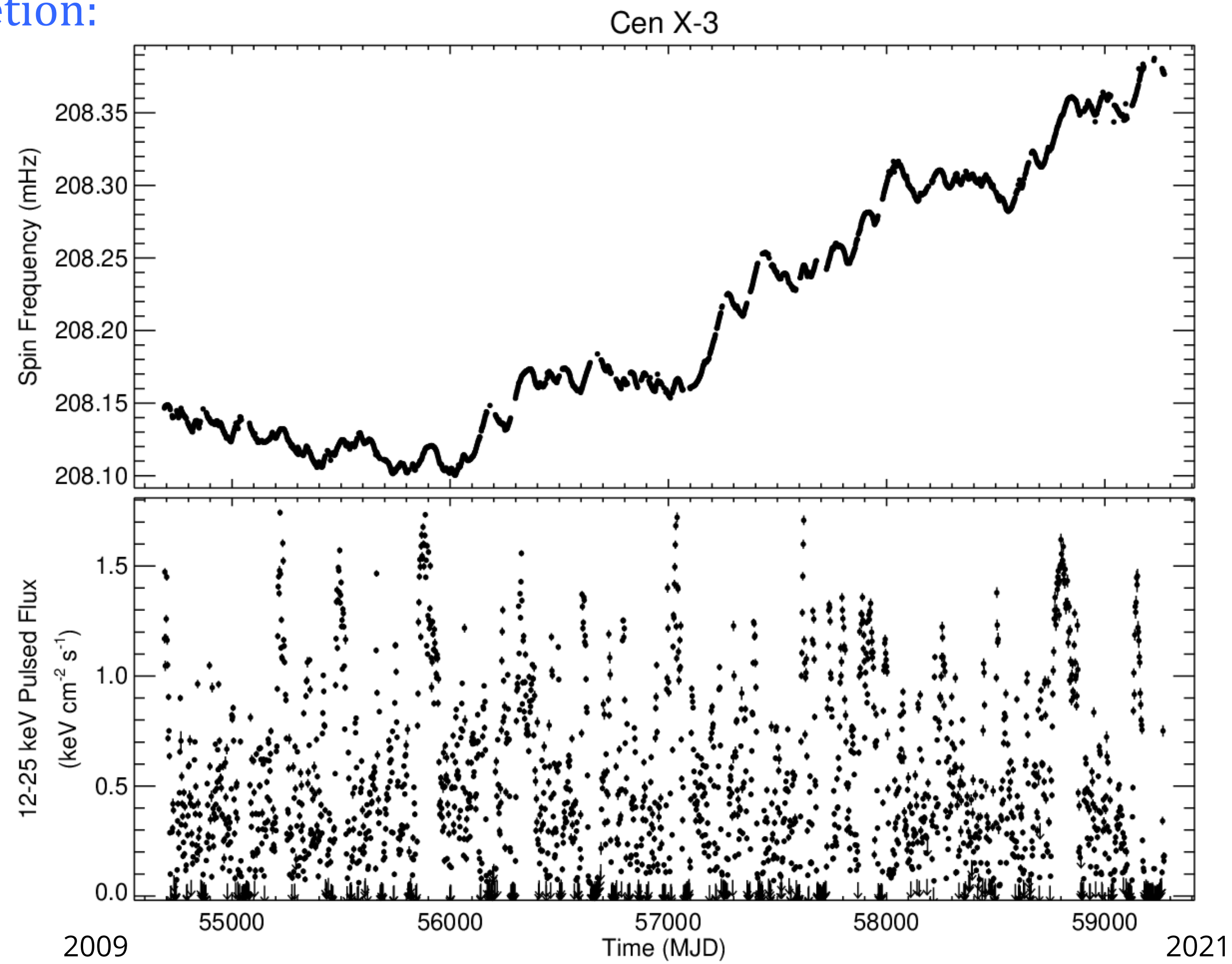
- In-falling gas is channelled onto the poles, where it impacts the surface at ~c causing (very) hotspots.
- This gas can come from:
  - Roche lobe overflow in an LMXB (e.g. Centaurus X-3, period 4.84 s, and with a measurable spin-up)
  - stellar wind capture, from a massive (OB) companion (e.g. the HMXB Vela X-1, spin period 283 s)
  - neutron star in a highly elliptical orbit around a Be star (gaseous disk). Pulsations only occur as the ns passes through the disk (e.g. HMXB 4U1145-619, with outbursts of 292 s-period X-ray pulses every 187d)

- Irregular in-fall can cause bursts of X-ray intensity and variations in the rotation rate, and if the rotation rate is too high, accretion is inhibited.

# X-ray pulsars

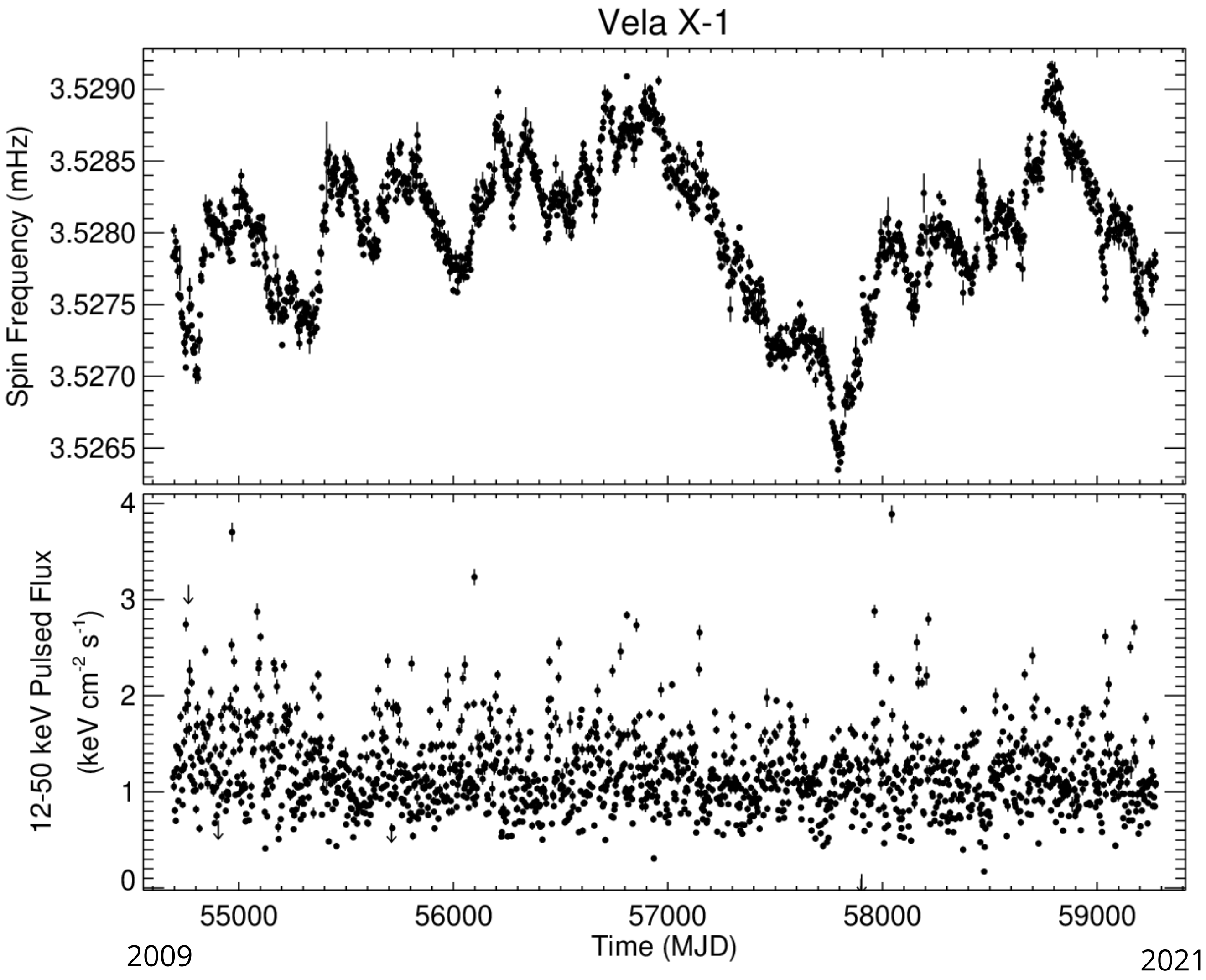
- Cen X-3: LMXB Roche lobe overflow (Fermi gamma ray burst data)
  - Spin-up due to accretion:



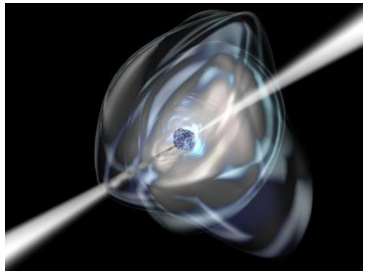


# X-ray pulsars

- Vela X-1: HMXB wind capture (Fermi gamma ray burst data)
  - Variable spin



# AXPs



- Not all X-ray pulsars are accretion- or rotation-powered. There are also anomalous X-ray pulsars (AXPs).

- Anomalous X-ray pulsars pulsate in X-rays but not in radio.

- Slow rotators: all have periods between 5 and 12 seconds, much the same as soft gamma ray repeaters (SGRs).

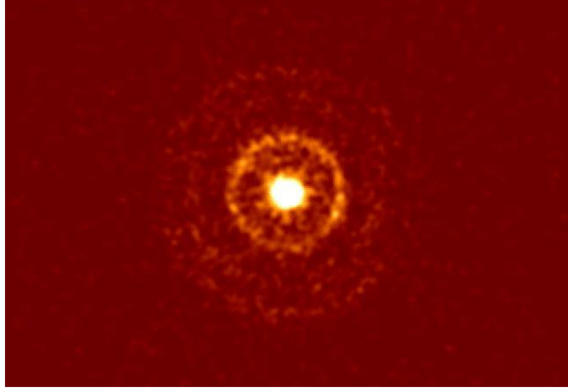
- Some show X-ray outbursts similar to SGRs (see later!)

- Their high spin-down rates indicate a magnetic field of $\sim 10^{13} – 10^{15}$ gauss ($10^9 – 10^{11}$ T). They are 'magnetars' (see later).

- The *anomaly* is the power source for the high X-ray luminosity, as these are not accreting. Seems likely it comes from the stored energy in the magnetic field.

- Only ~12 AXPs are known at present.

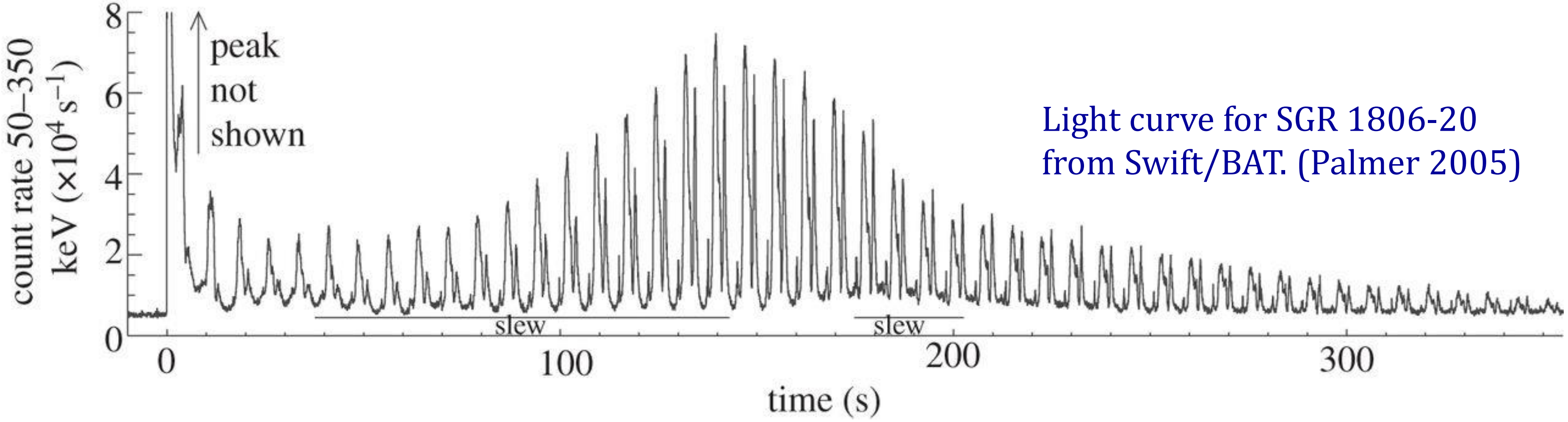
# SGRs



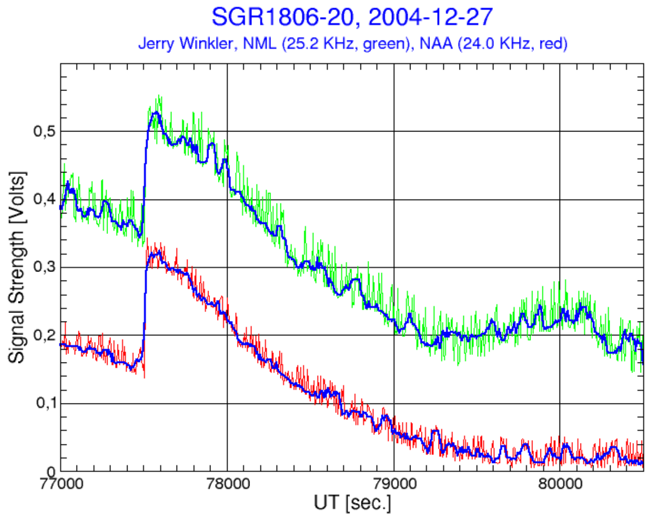
- Soft Gamma ray Repeaters.
- Look similar to GRBs, but lower energy gamma rays, and they repeat.
- Flare suddenly in gamma rays for a few minutes, showing periodic structure in the tail.
- Periodic structure probably traces the rotation of the neutron star. Periods are long (a few seconds).
- SGRs are also probably magnetars – a flare is the result of sudden magnetic reconfiguration in the neutron star (cf. solar flare) caused by the cracking of the strained crust in a starquake.
- SGRs show very high slowdown rates, revealed in successive bursts, consistent with magnetar-level magnetic fields.

# SGRs

7.5 s period



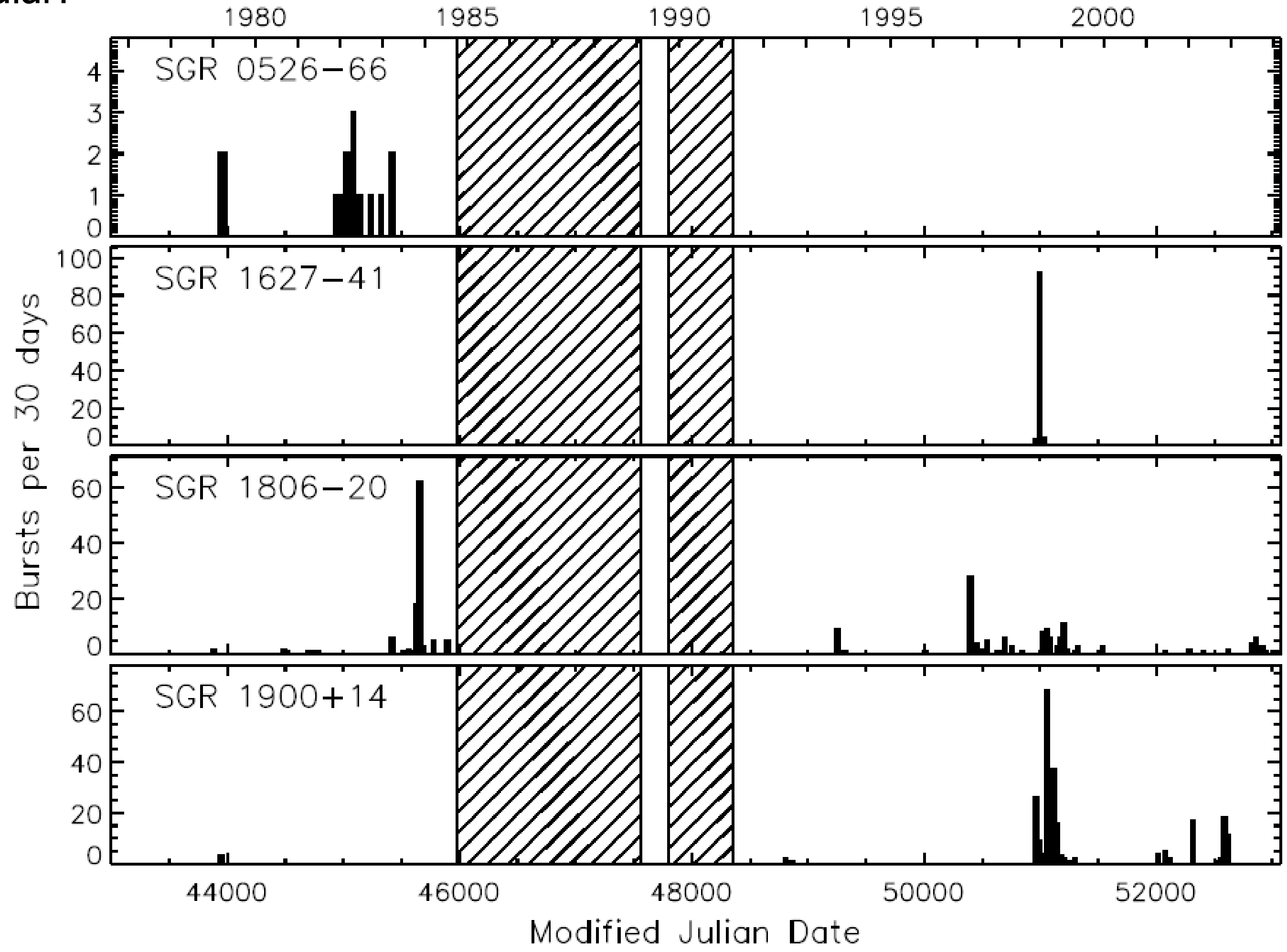

Light curve for SGR 1806-20 from Swift/BAT. (Palmer 2005)




- 14 kpc away but powerful enough to affect the Earth's ionosphere (radio propagation data)

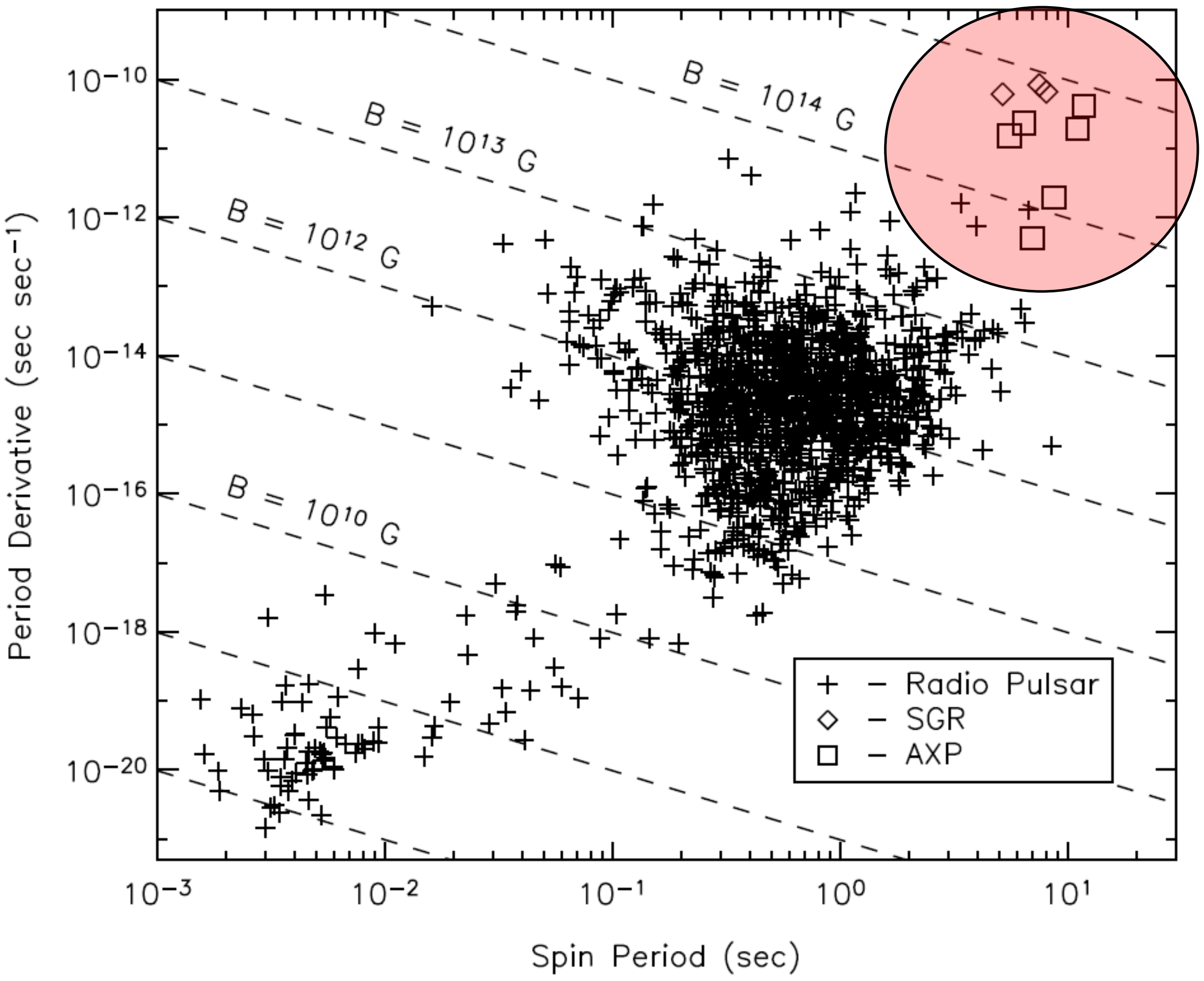
# SGRs – burst activity

Variable and irregular!




Woods & Thompson 2004

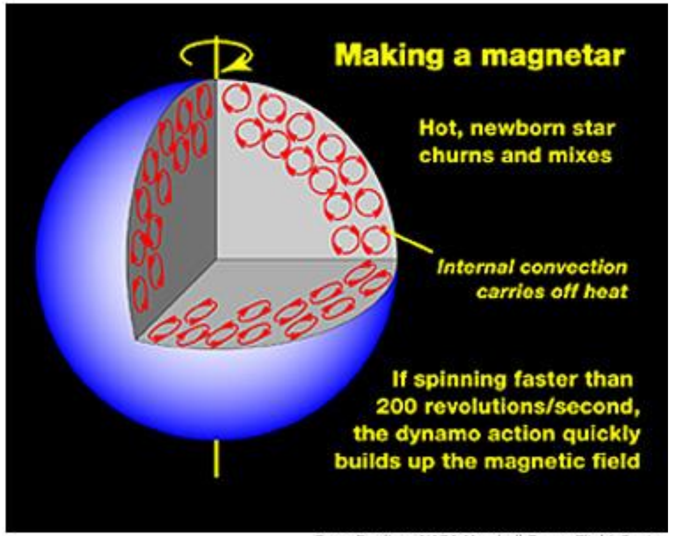
# SGRs and AXPs are similar…



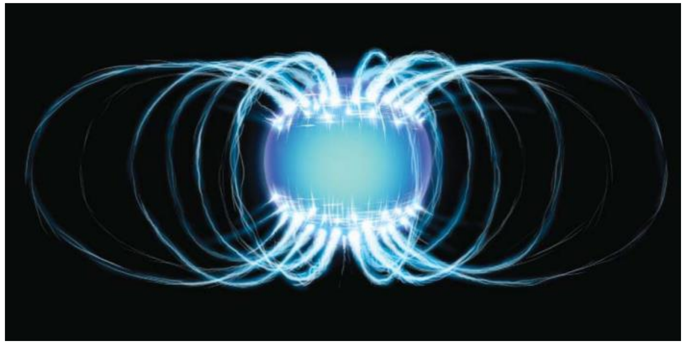

- long rotational periods
- large Pdot
- high magnetic fields

# ... They are MAGNETARS

- Newly born, very rapidly rotating neutrons stars may trigger an intense internal dynamo effect, increasing the star's magnetic field by factors of ~1000 ($B = 10^8$ tesla growing to $10^{11}$ tesla).
- This may not be rare when neutron stars are formed (10%?). The intense magnetic braking rapidly slows the star, but the superconducting core retains the field.
- Rotation rate slows from ~1000 Hz to ~300 Hz in ~10 s, electromagnetically dissipating 90% of its rotational energy, possibly generating a lot of the heavy element nucleosynthesis in the universe (r-process).
- Rapid braking leads to a short luminous life of ~$10^4$ years. A short life means we only know of about 24 (12 SGRs + 12 AXPs).
- Perhaps $10^7$ dead magnetars in the galaxy.

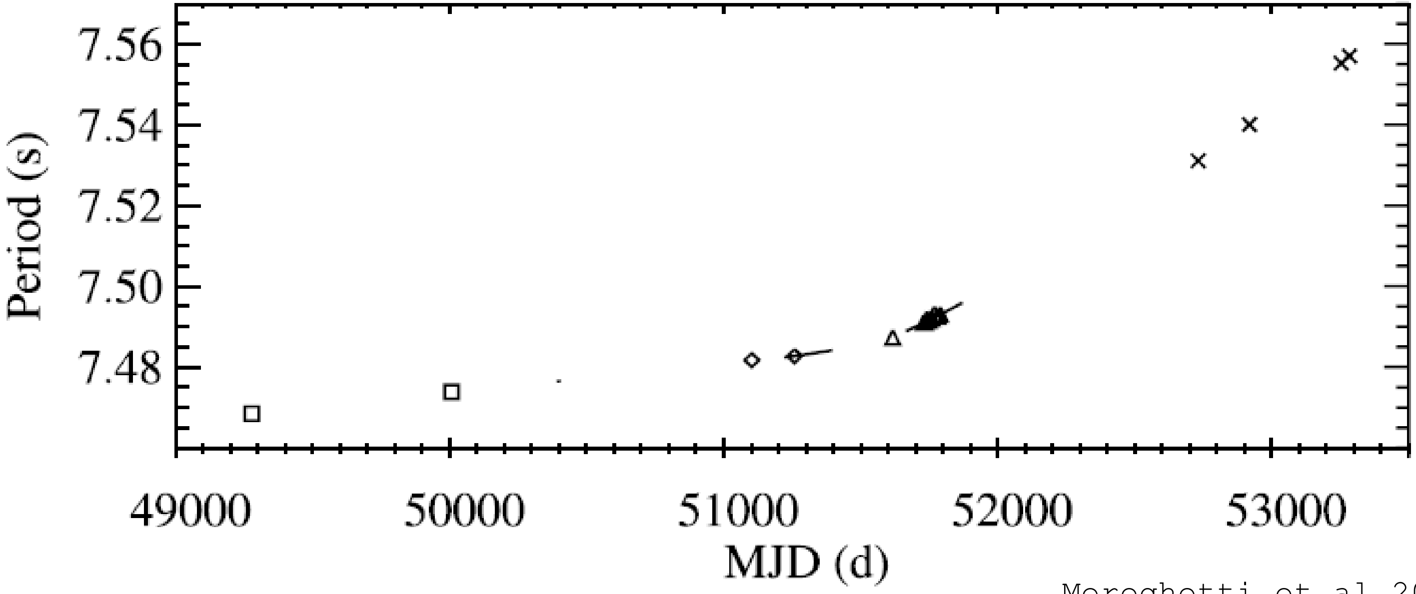


Dave Dooling, NASA Marshall Space Flight Center



# SGR1806-20 (again)

- An SGR magnetar with a large spin-down rate of $5.5 \times 10^{-10}$ s/s (radio pulsars spin-down $\sim 10^5$ times slower).

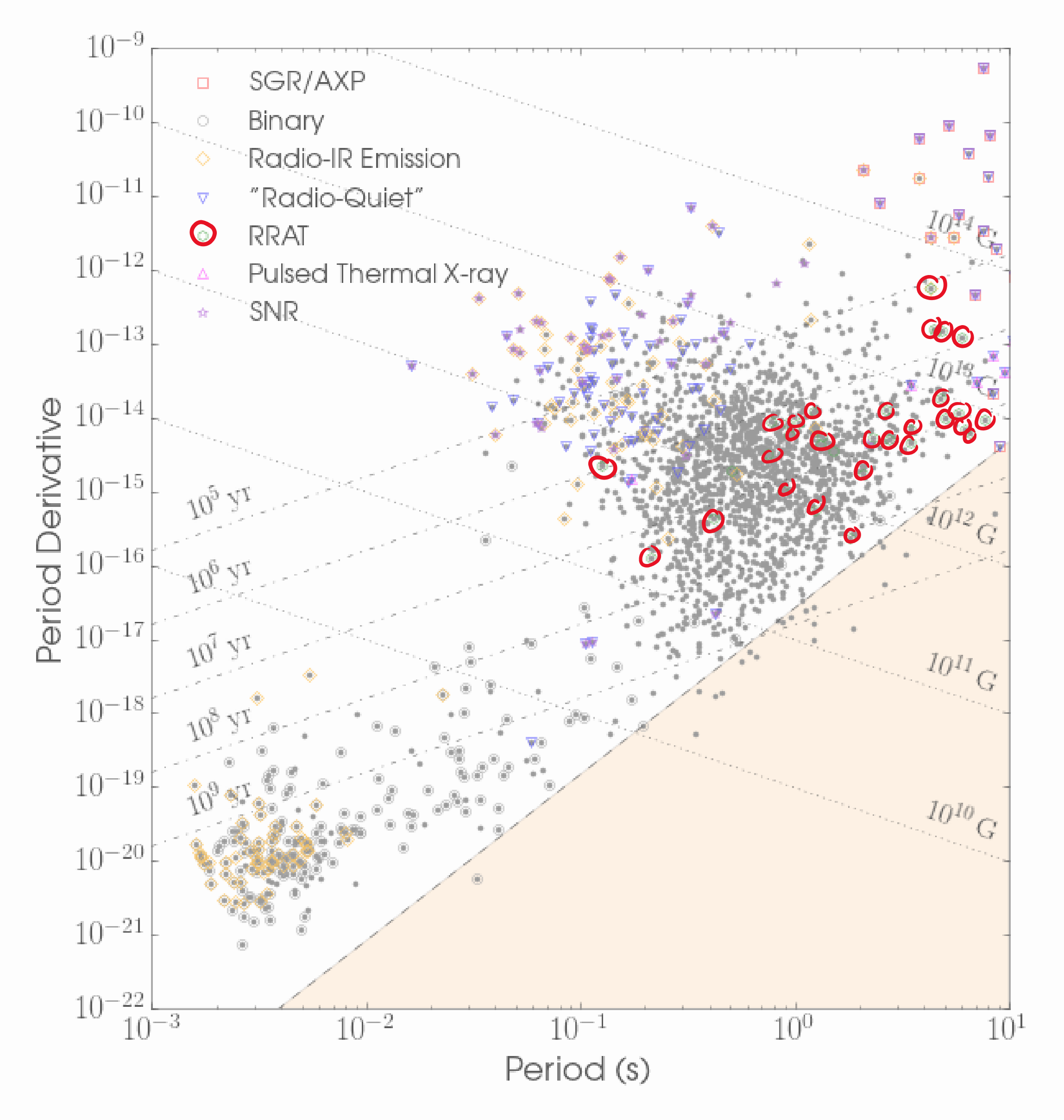



Mereghetti et al 2005

- This SGR has had several large outbursts and was responsible for the 27/12/2004 mega-burst ($\sim 10^{39}$ J).

# RRATs

- Rotating RAdio Transients.
- 11 RRATs in the discovery paper, now more than 100.
- Flashes last 2-30 ms, separated by 4 mins to 3 hours.
- Periods are hard to determine, but spin-downs indicate magnetic fields stronger than nearly all other radio pulsars.
- Maybe neutron stars that are not quite able to sustain radio emission, or maybe these are giant pulses from distant pulsars.



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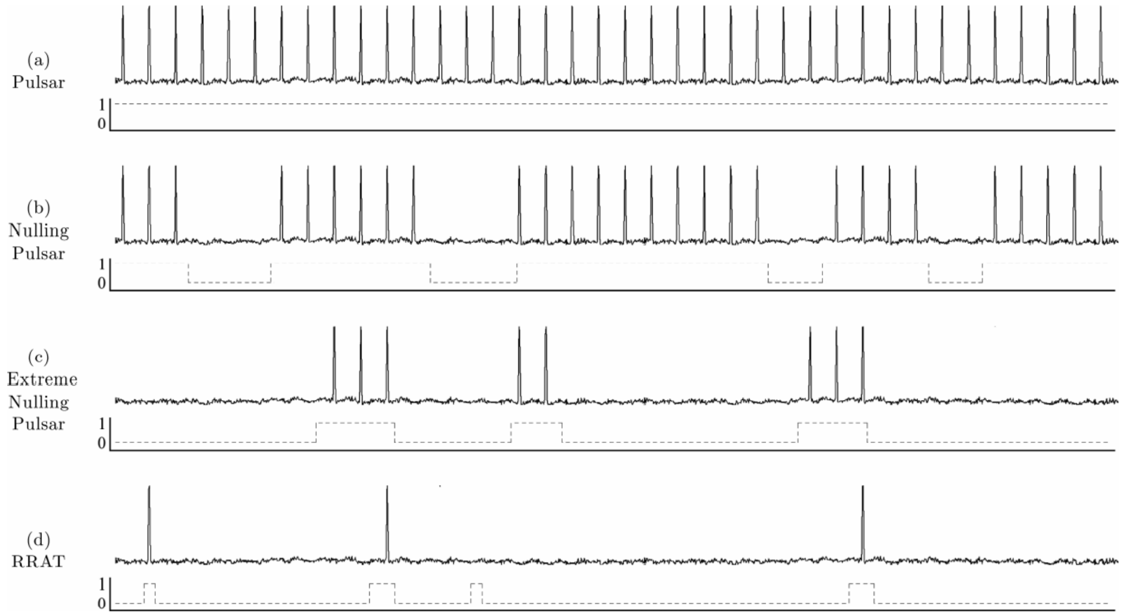
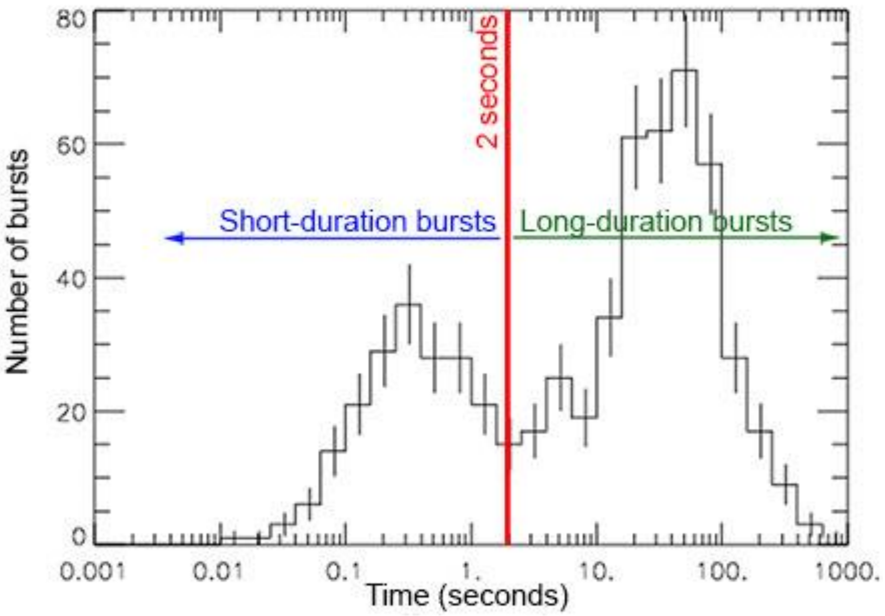
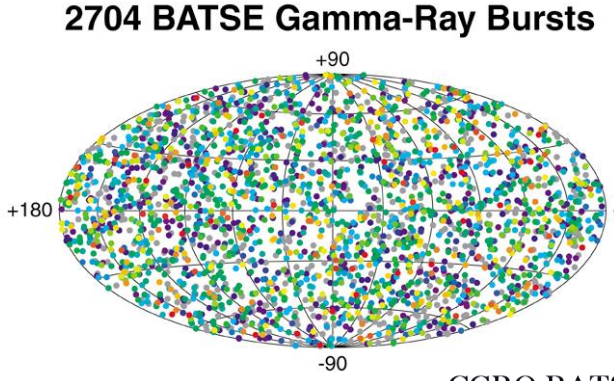


# What about GRBs?

- Gamma Ray Busts are transient sources of gamma rays that do not repeat. The gamma rays are also of higher energy ('harder') than those from SGRs.



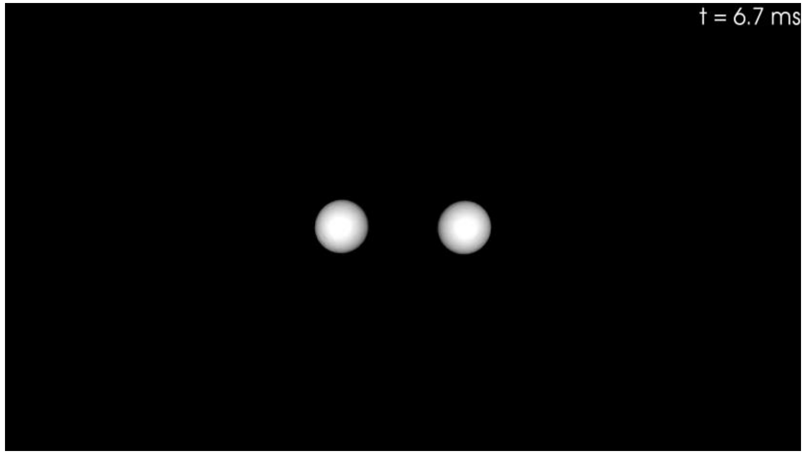

CGRO BATSE
Sky distribution
1991-2000

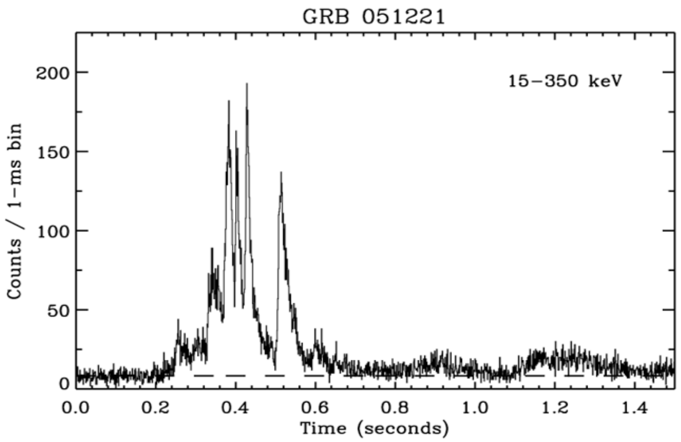
A uniform sky distribution

- Two types of GRB:
  - Short duration (<2 s). These are thought to be the final coalescence of a binary neutron star system, in a kilonova . Radiation is somewhat beamed (~10 degree beamwidth) and extragalactic (note that all SGRs are galactic), and the final product is almost certainly a black hole.
  - Long duration (>2 s) These are thought to be highly beamed emission from the collapse of a massive star to a black hole. We see a few a week – nothing much to do with this course!

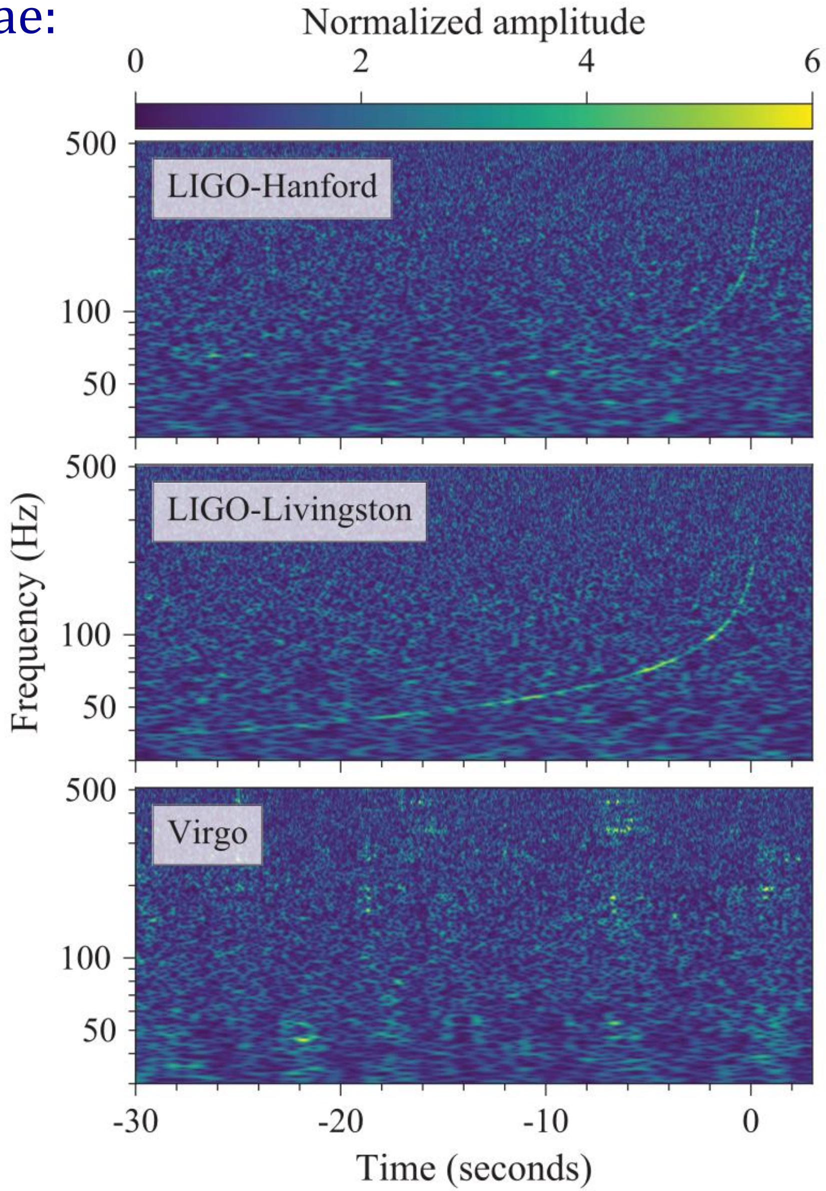
# Short duration GRBs

These are now know to be kilonovae:
the merger of two neutron stars

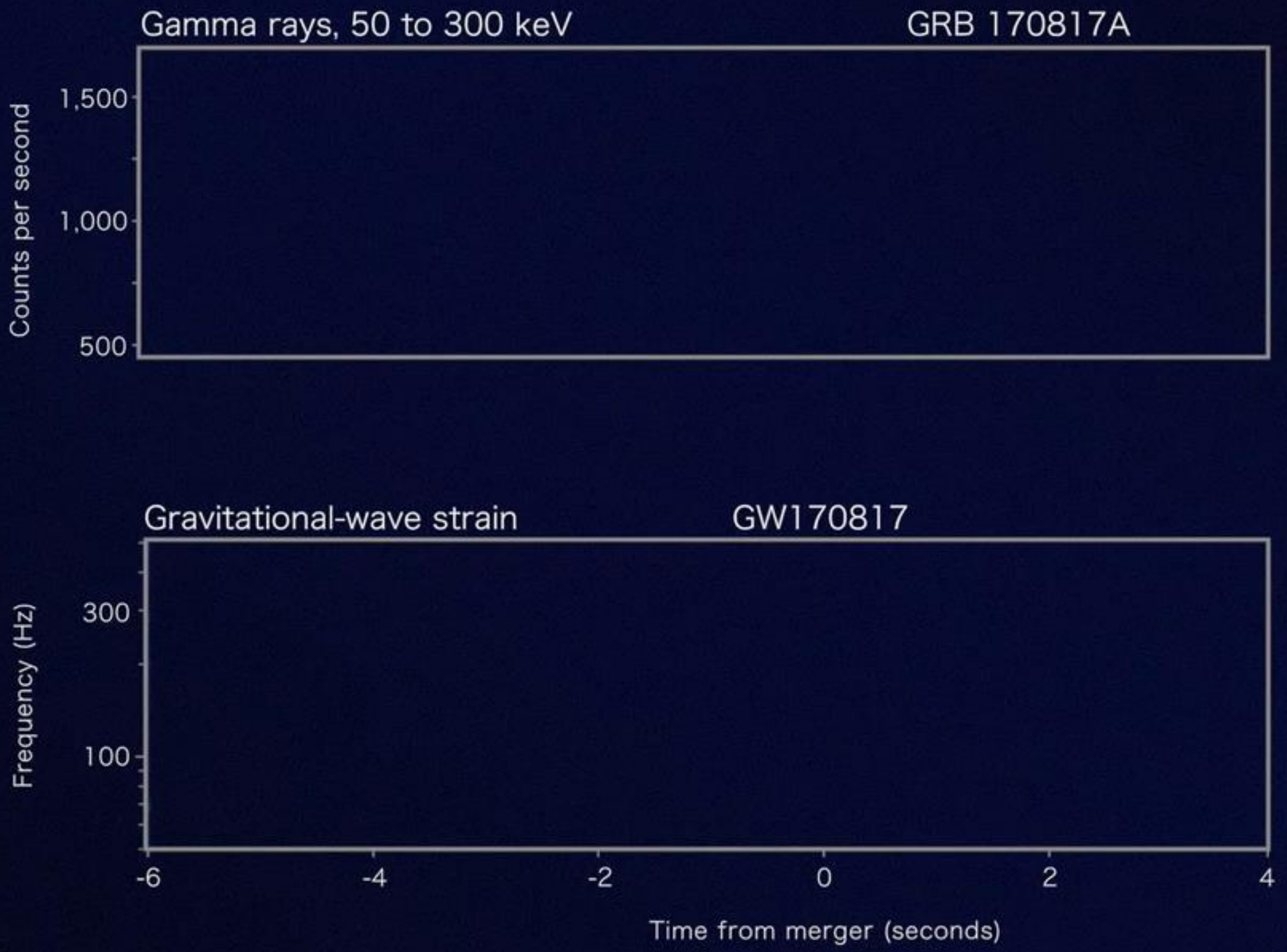



Swift satellite



Fermi


Gamma rays, 50 to 300 keV
GRB 170817A
Counts per second
1,500
1,000
500
Gravitational-wave strain
GW170817
Frequency (Hz)
300
100
-6
-4
-2
0
2
4
Time from merger (seconds)

LIGO