Astronomy 353

(Spring 2008)

ASTROPHYSICS: From Black Holes to the First Stars

(Lecture 15: Pulsars + Magnetars)

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TA: Jarrett Johnson

The University of Texas at Austin

Pulsars: Discovery (by serendipity)

Jocelyn Bell

Cambridge (England): Radio antenna array

Discovery

- Hewish & Bell 1967

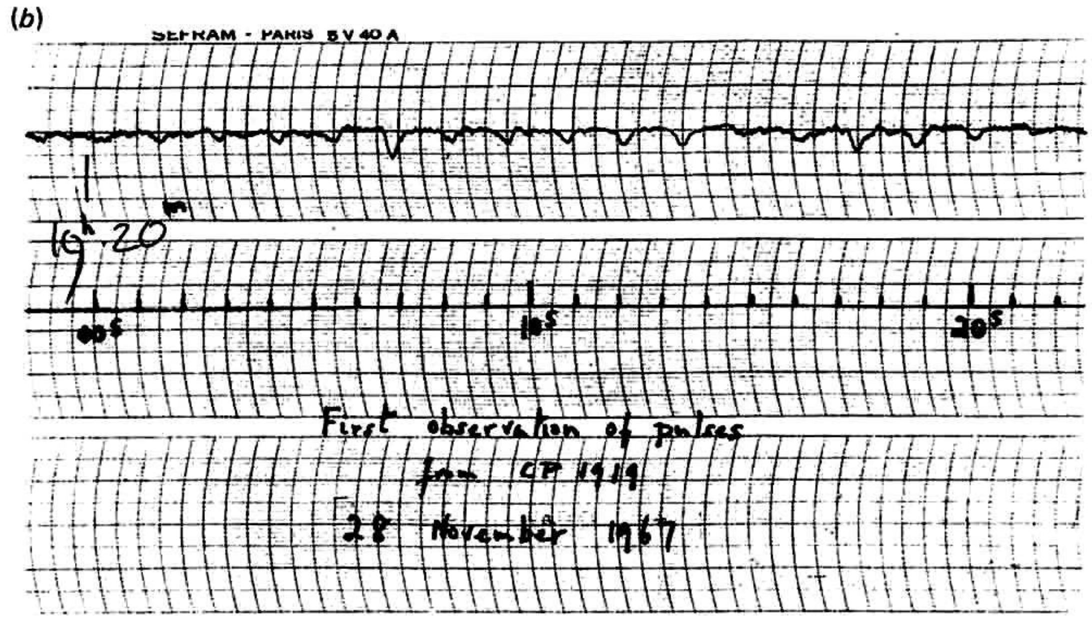
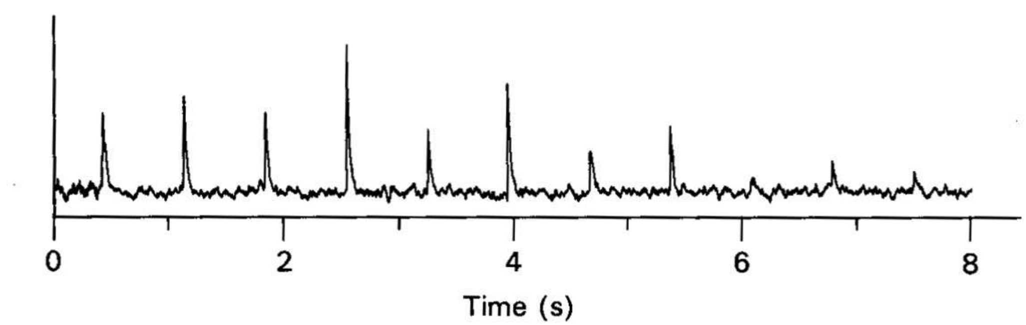
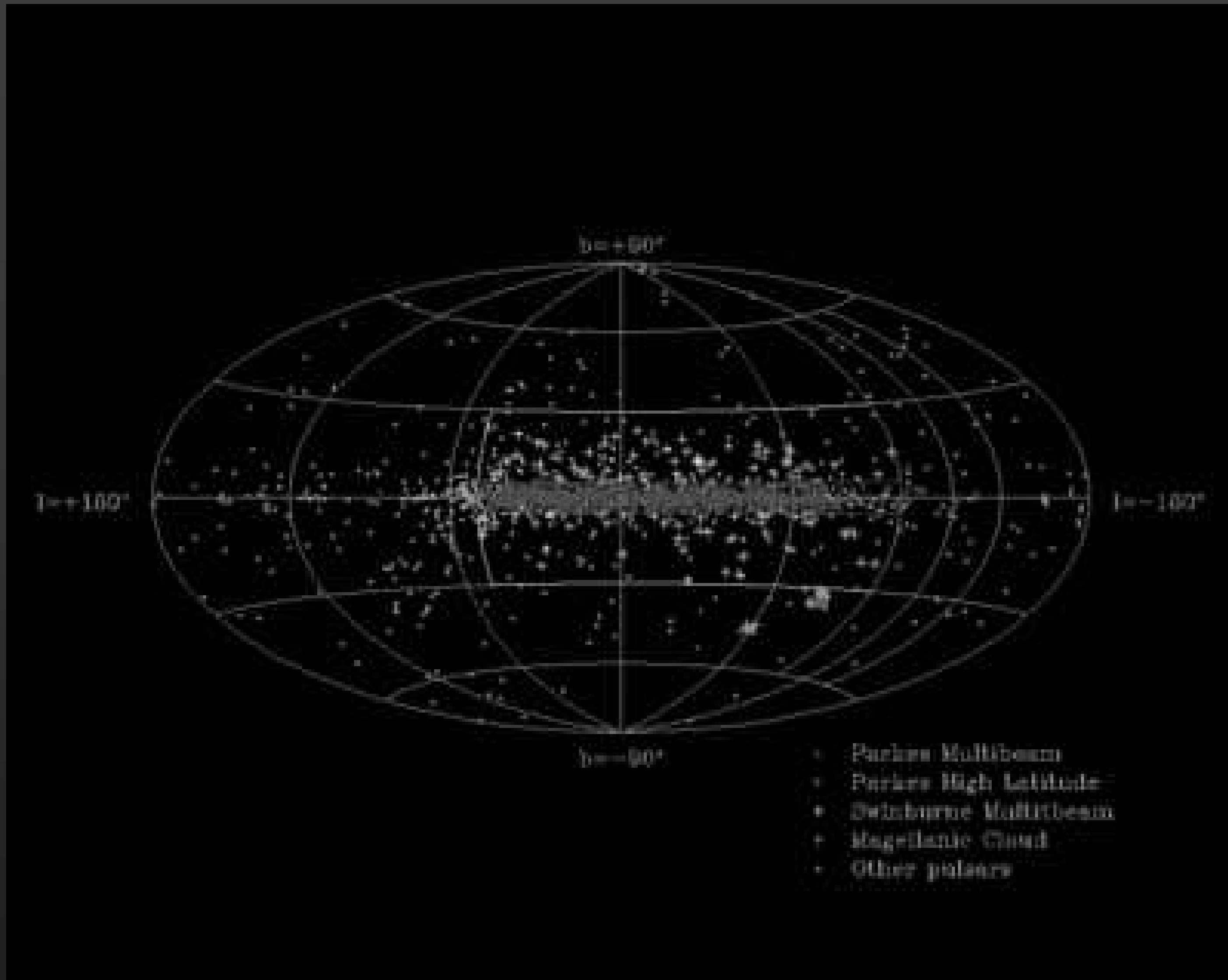


Fig. 1.1. Discovery observations of the first pulsar. (a) The first recording of PSR B1919+21; the signal resembled the radio interference also seen on this chart: (b) Fast chart recording showing individual pulses as downward deflections of the trace (Hewish *et al.* 1968).



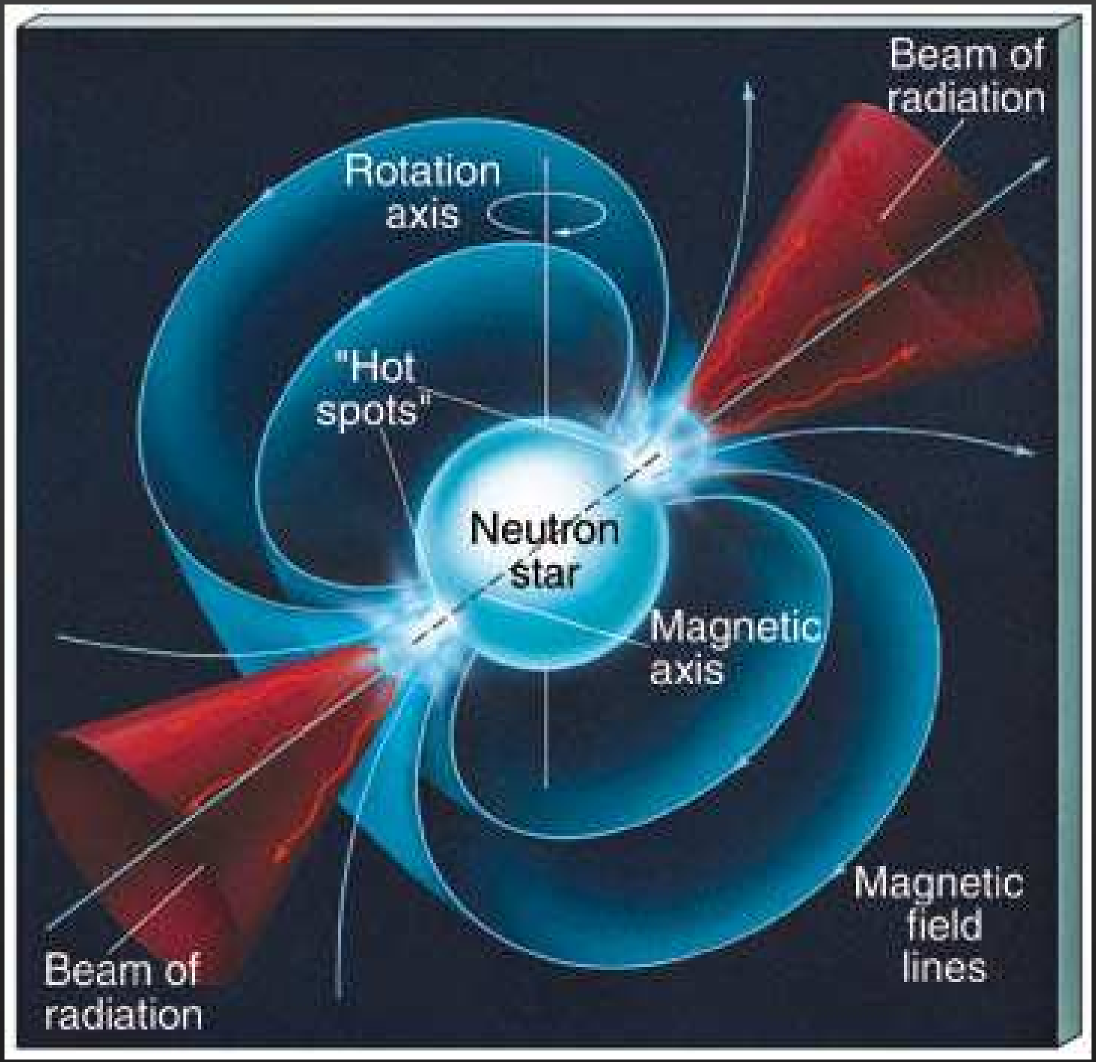
1-3 Chart record of individual pulses from one of the first pulsars discovered, PSR 0329 + 54. They were recorded at a frequency of 410 MHz and with an instrumental time constant of 20 ms. The pulses occur at regular intervals of about 0.714 s.

Radio pulsars: Where are they located?



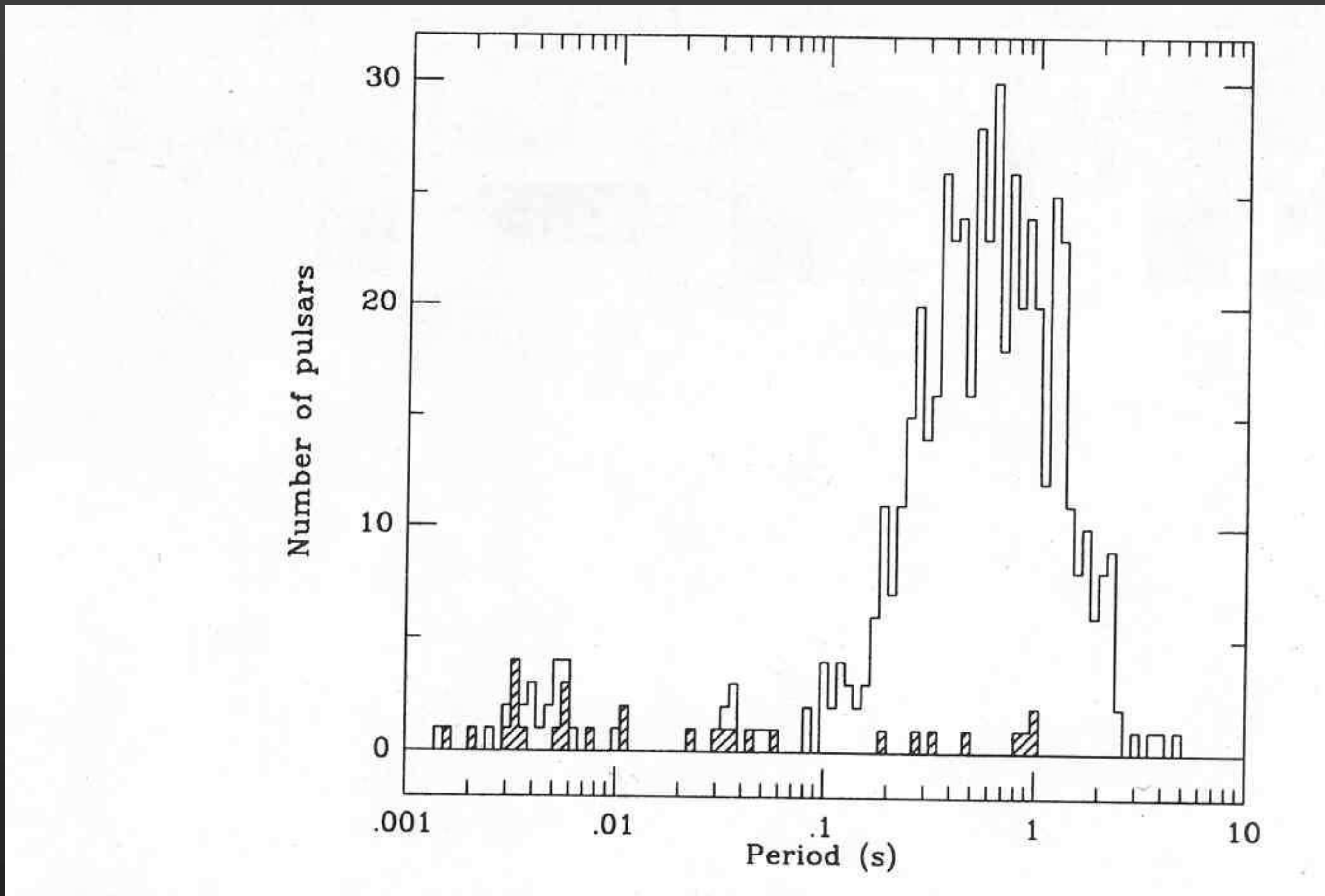
A: Preferentially in disk of our Galaxy!

Big Question: What ARE pulsars?



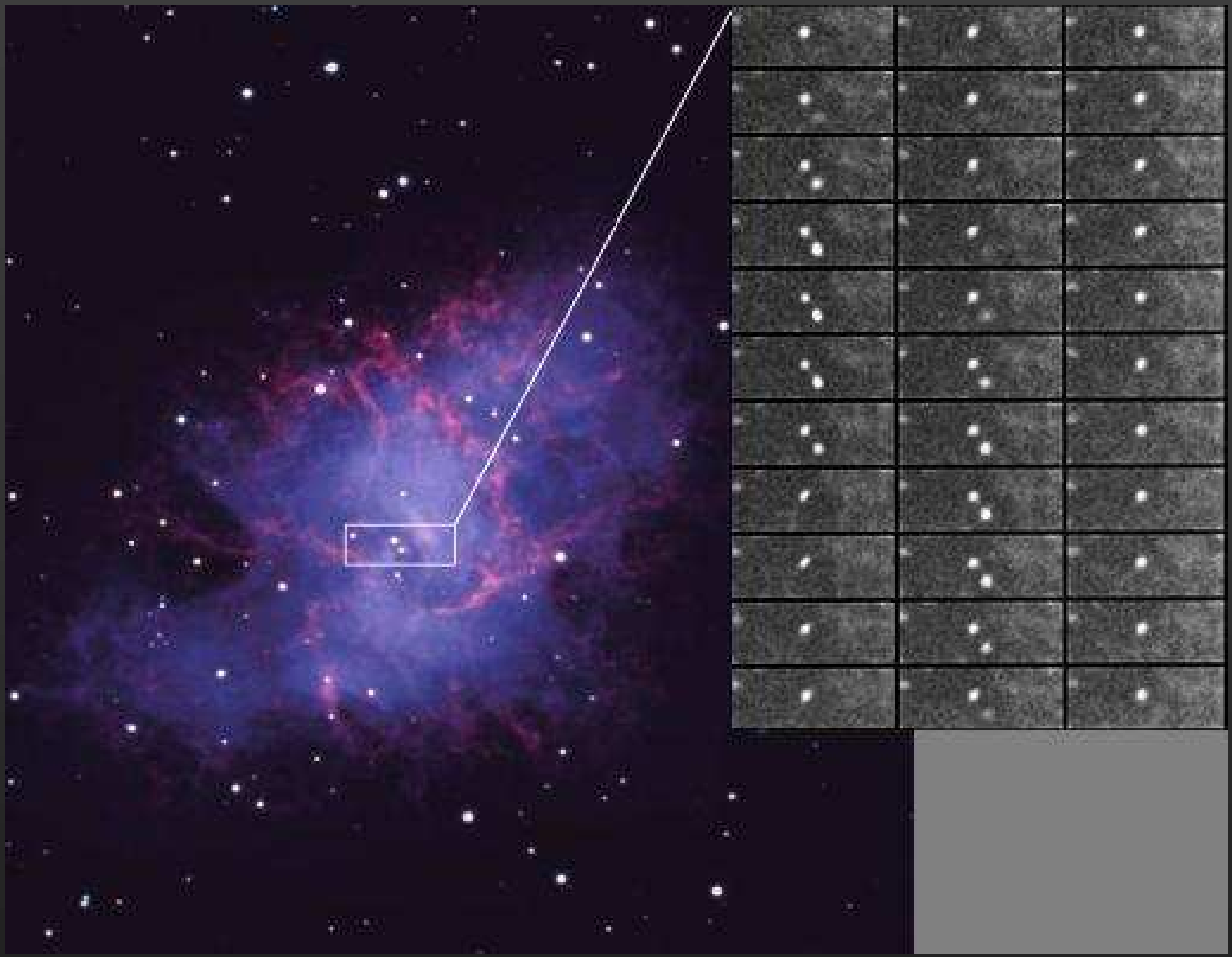
A: Rotating, highly magnetized neutron stars!

Observed Pulsar Periods



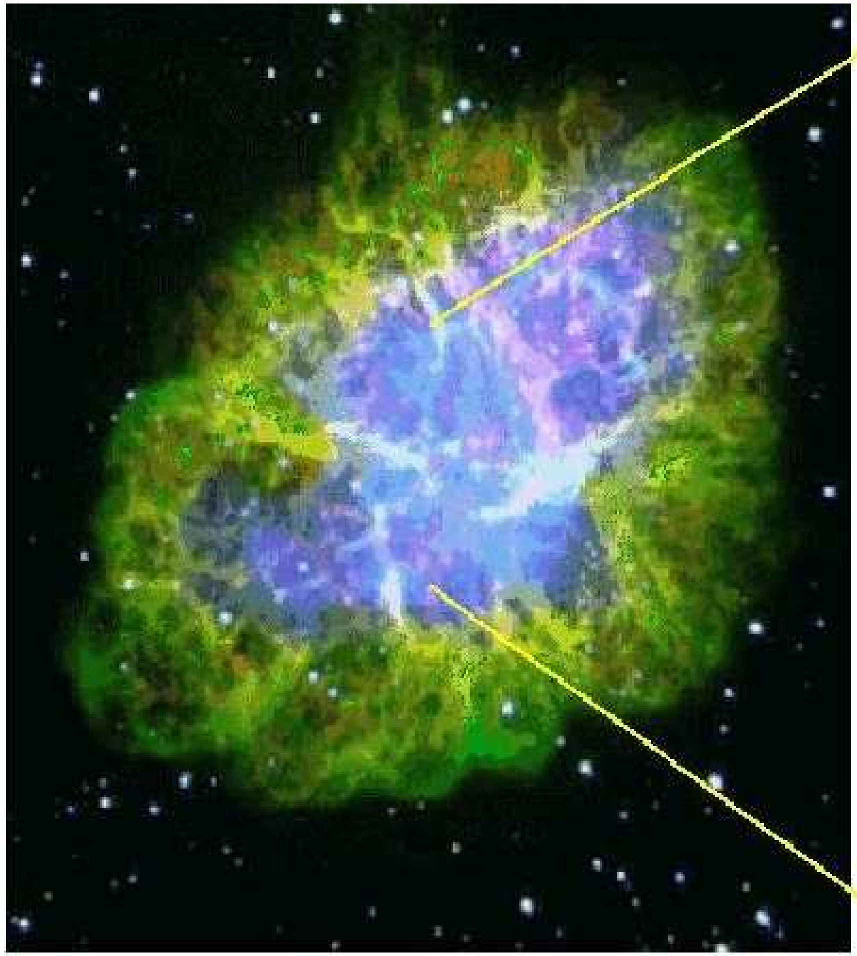
- Average period ~ 0.8 s

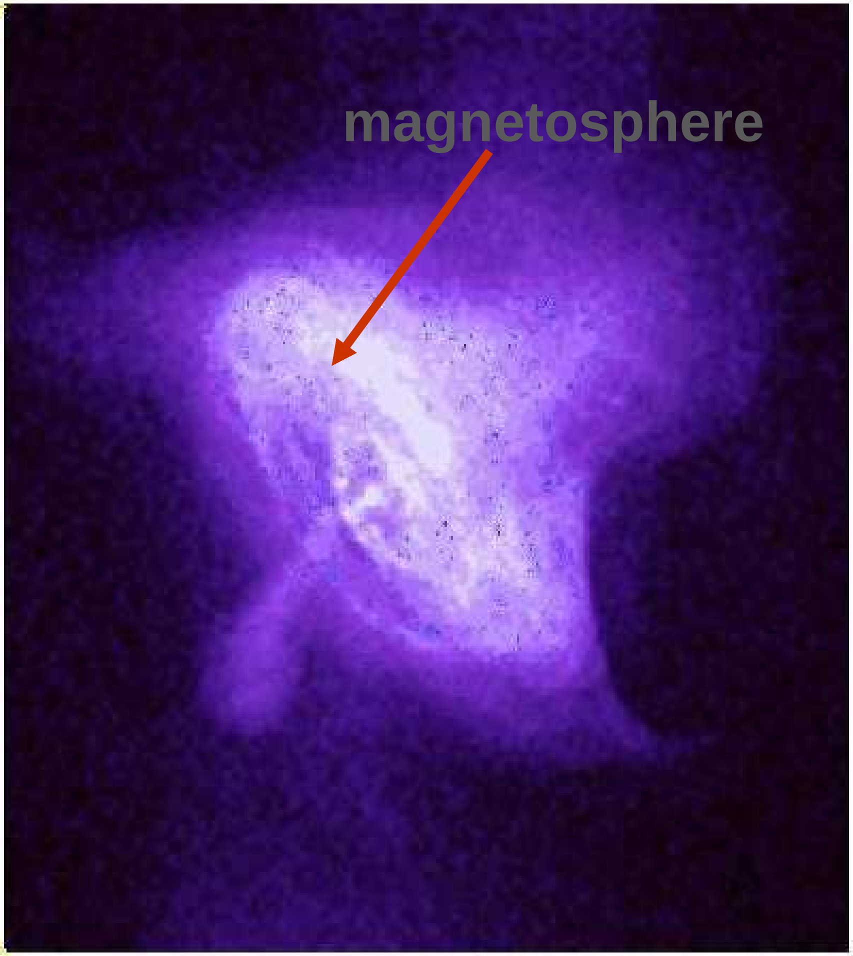
The Crab pulsar



• Period P=33 ms

The Crab pulsar





optical

X-ray
(Chandra Observatory)

The Crab pulsar

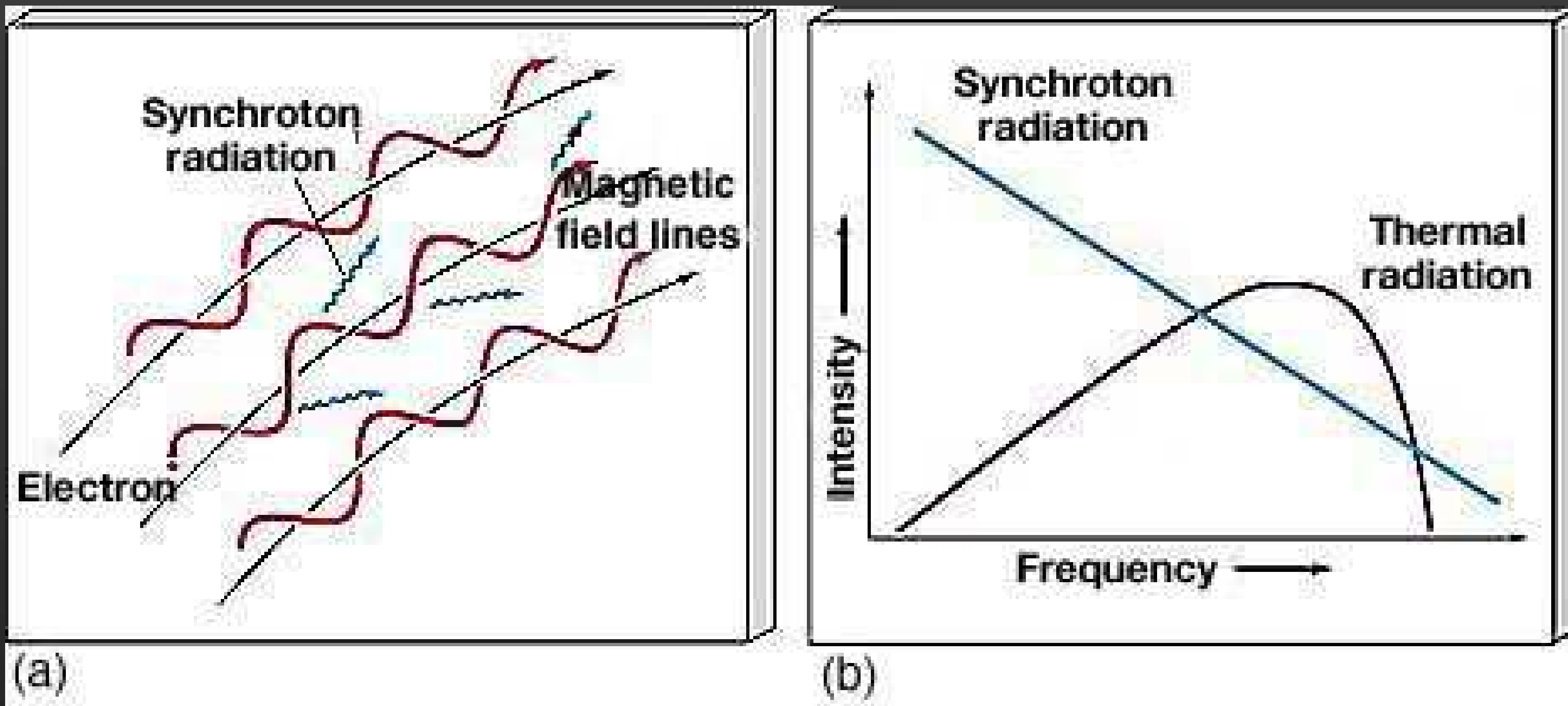
Synchrotron radiation

- Radiation power from nebula: $L \sim 5 \times 10^{31}$ W

(~100,000 solar luminosities)

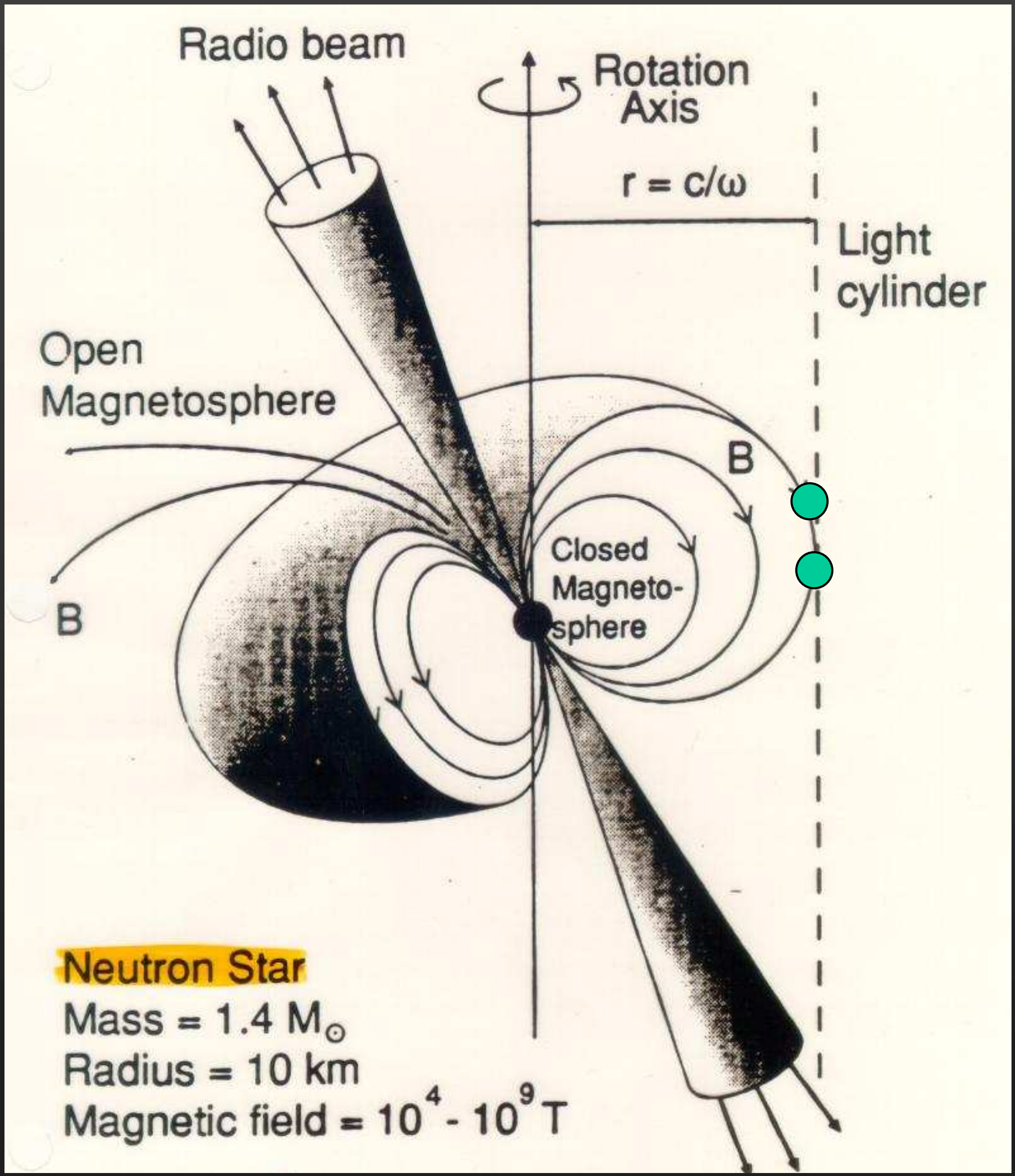
Synchrotron radiation

(non-thermal radiation = non-blackbody)



- relativistic electrons spiral around ("are accelerated by") strong magnetic field lines

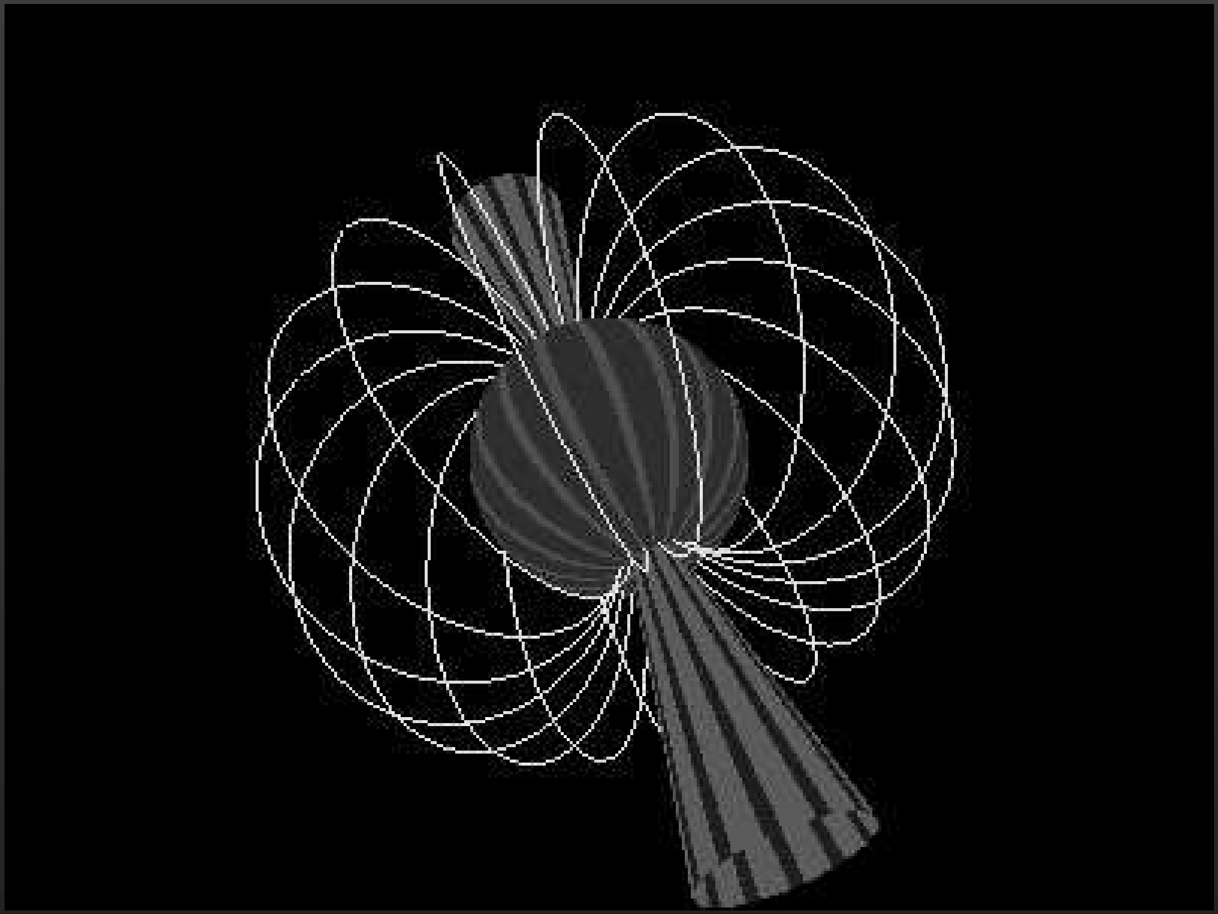
Q: Where do relativistic particles come from?



- v=omega x radius
- v~c at radius r=c/omega

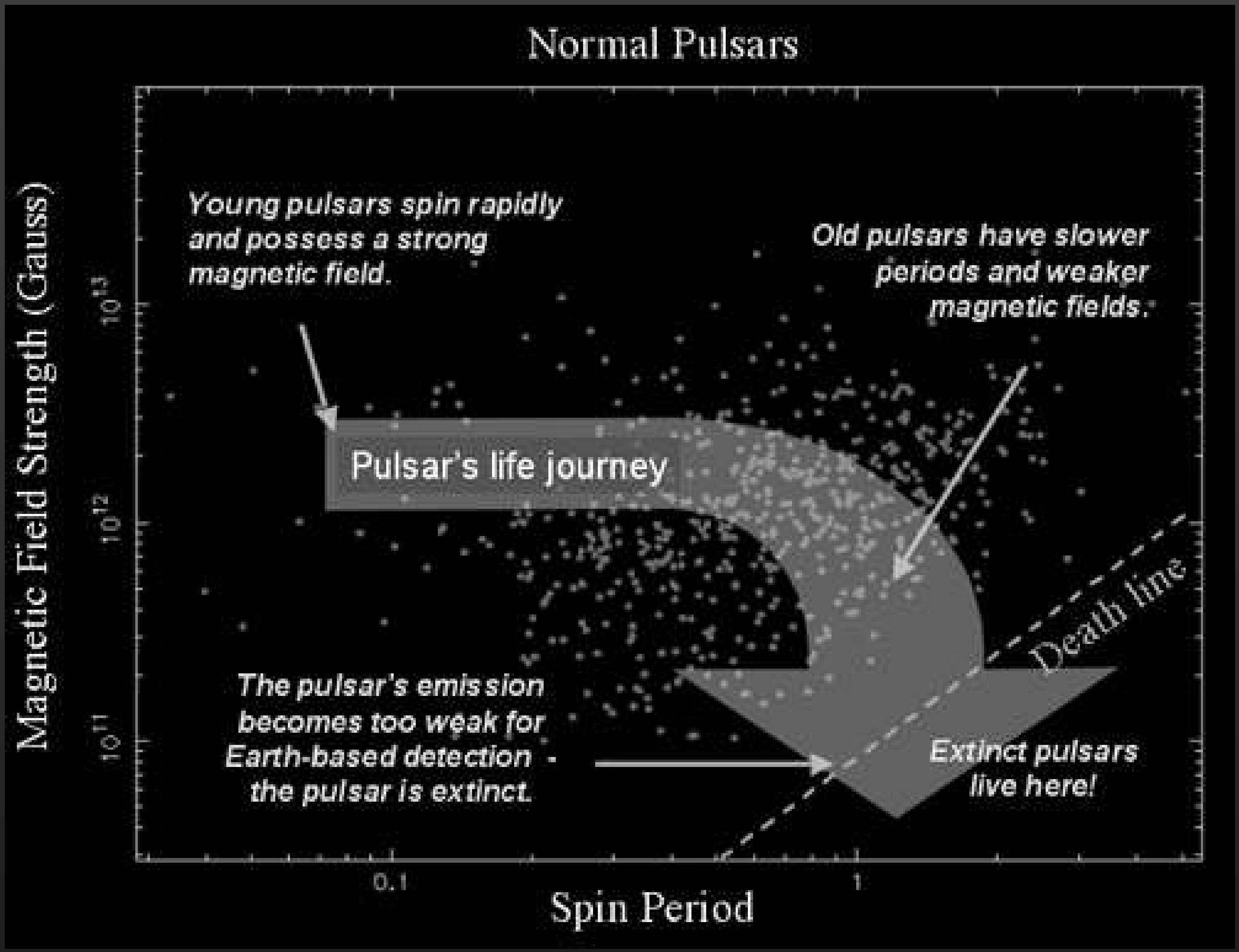
à Light cylinder

Pulsar energy source: Rotation



- E_{rot}=1/2 Moment of inertia x angular velocity^{2}

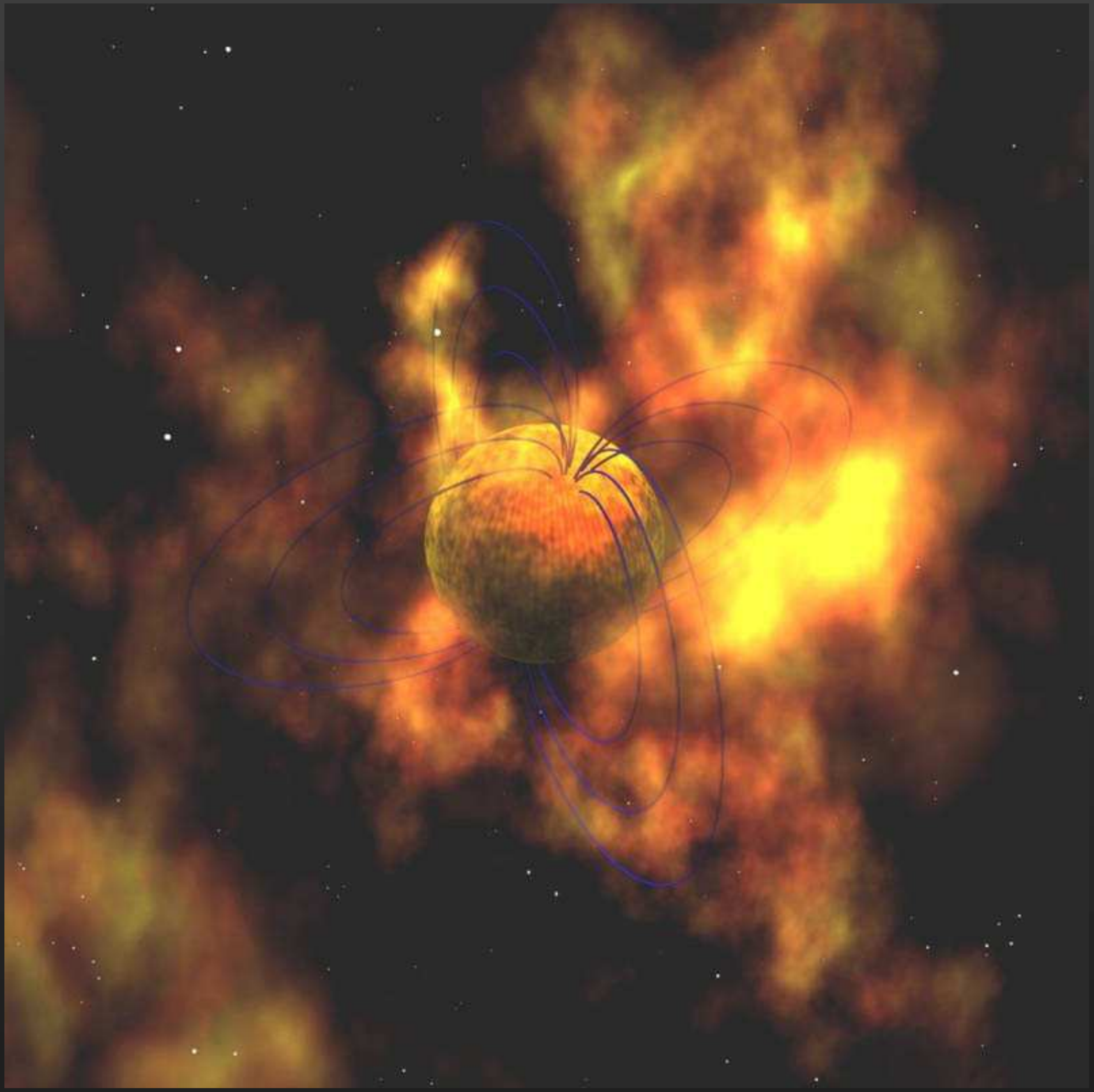
Pulsar lifecycle



- Pulsars spin down, and disappear from view!

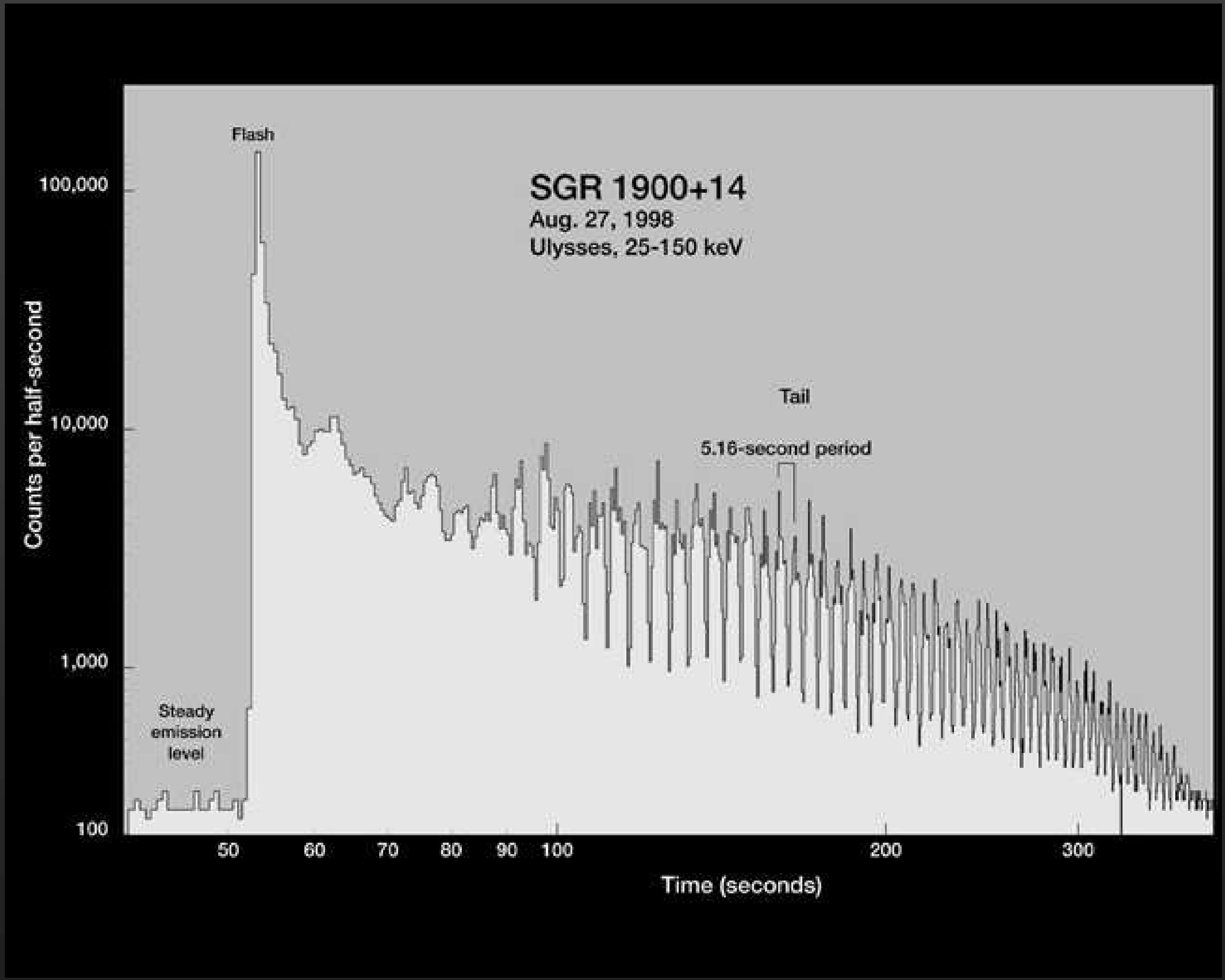
Magnetars = Extreme Pulsars

- Proposed by R. Duncan & C. Thompson (1992)



- hyper-strong magnetic fields: B~10^{11} T

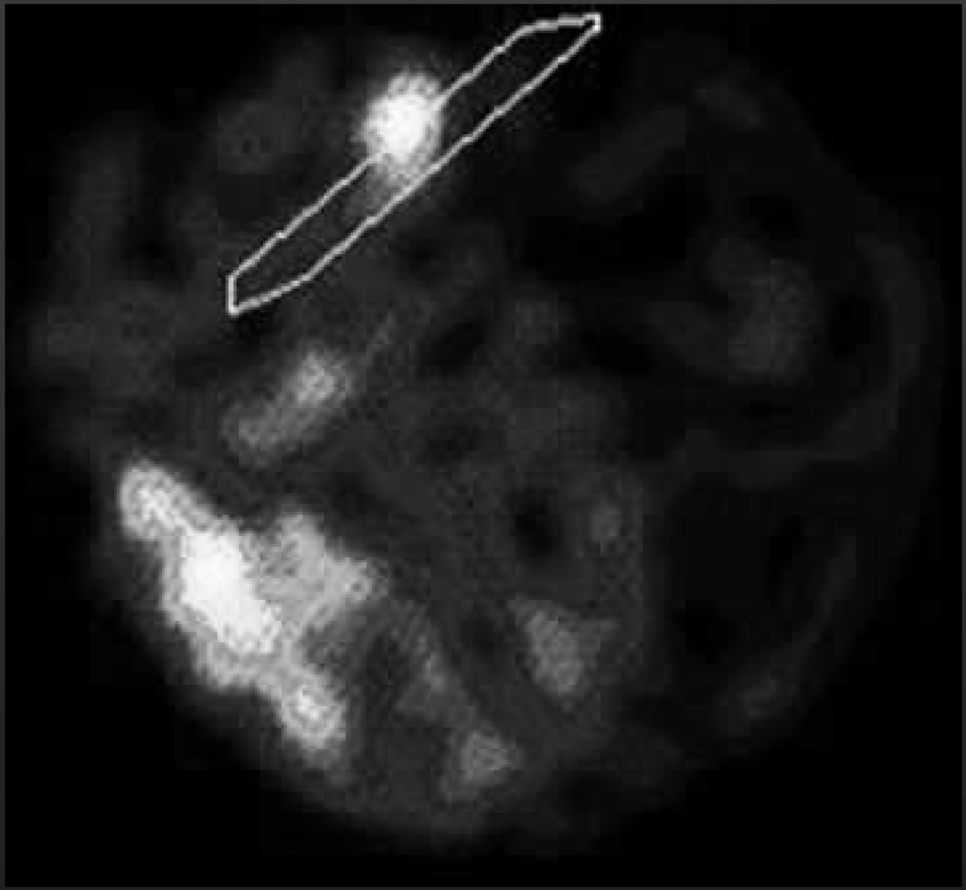
Magnetars: Discovery (again by serendipity)

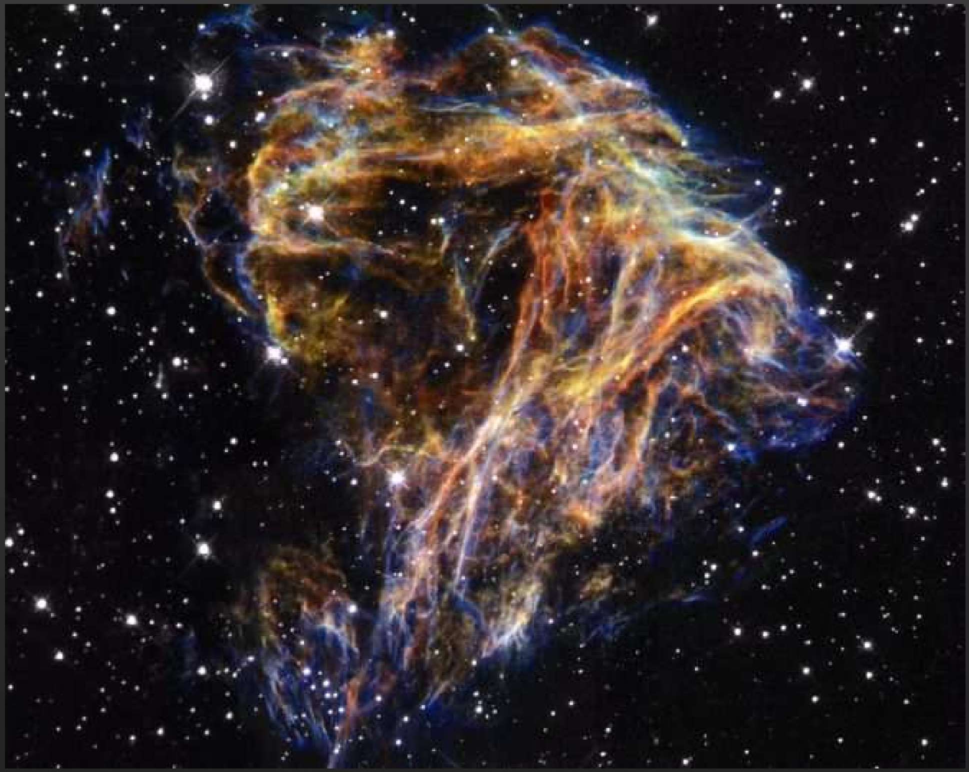


- Soft gamma repeaters (SGRs): extremely bright, but relatively slow rotation (periods of few s)!

Association of SGRs with Supernova remnants

X-ray (ROSAT) | optical (HST)

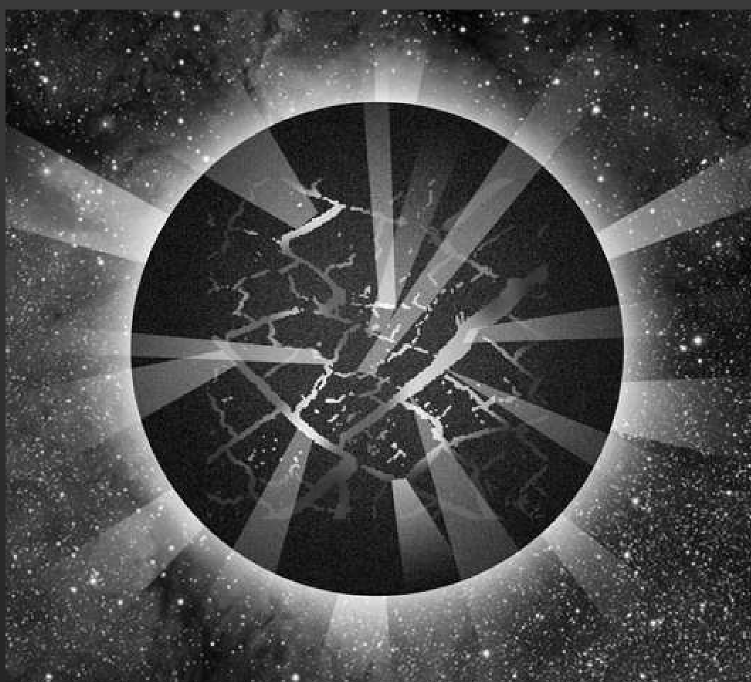


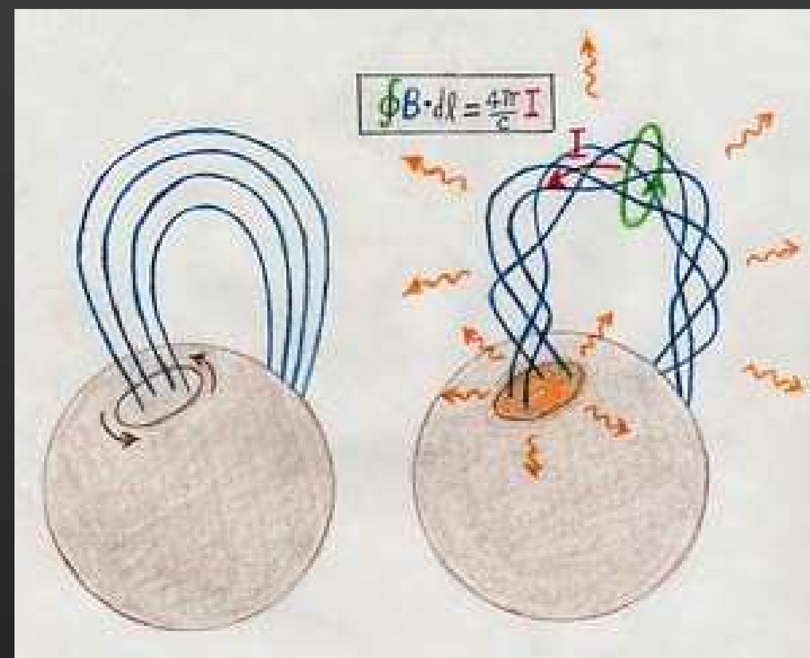


- SGR 0526-66 (``March 5th event'' in 1979) à coincident with young SNR N49 in the LMC!

Origin of Giant X-ray Flares

à a `starquake' in Neutron Star crust

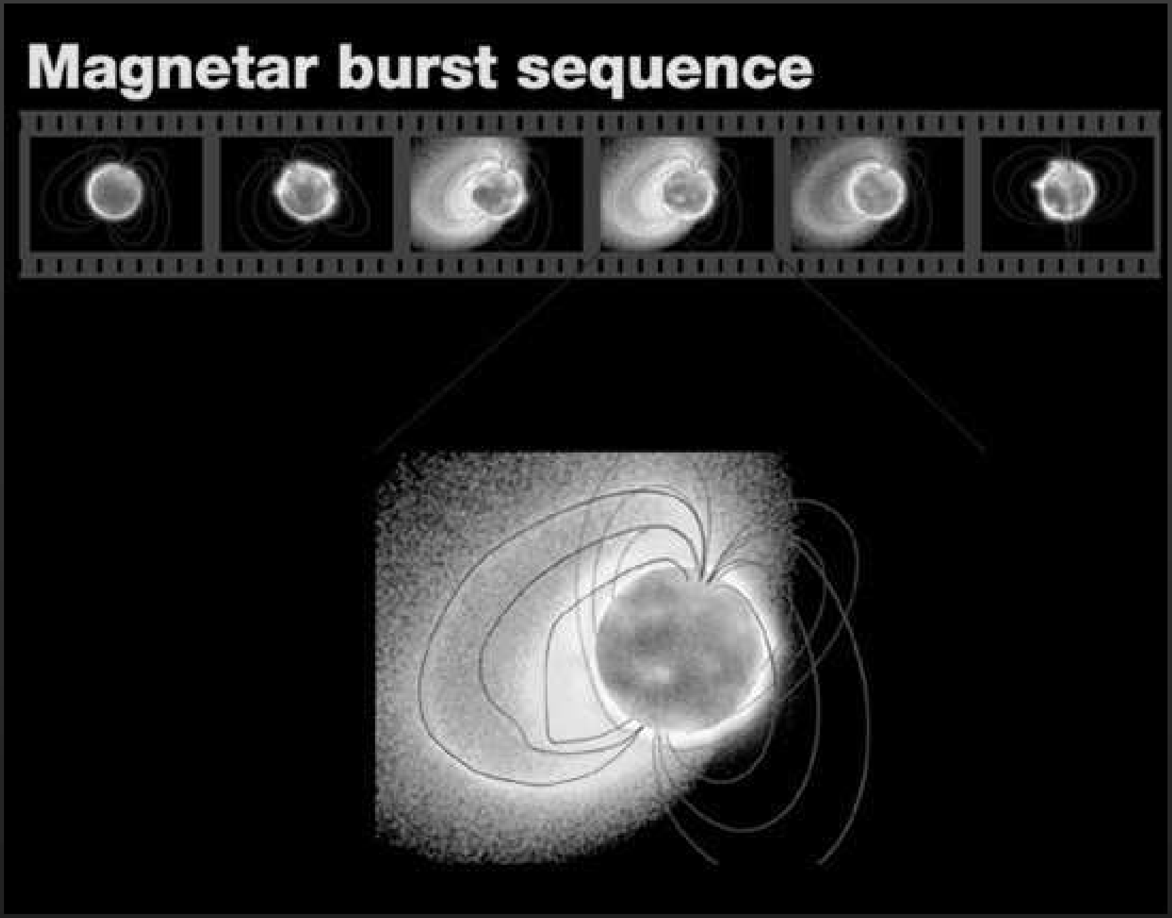




- starquake twists B-field à huge release of magnetic energy!

Origin of Giant X-ray Flares

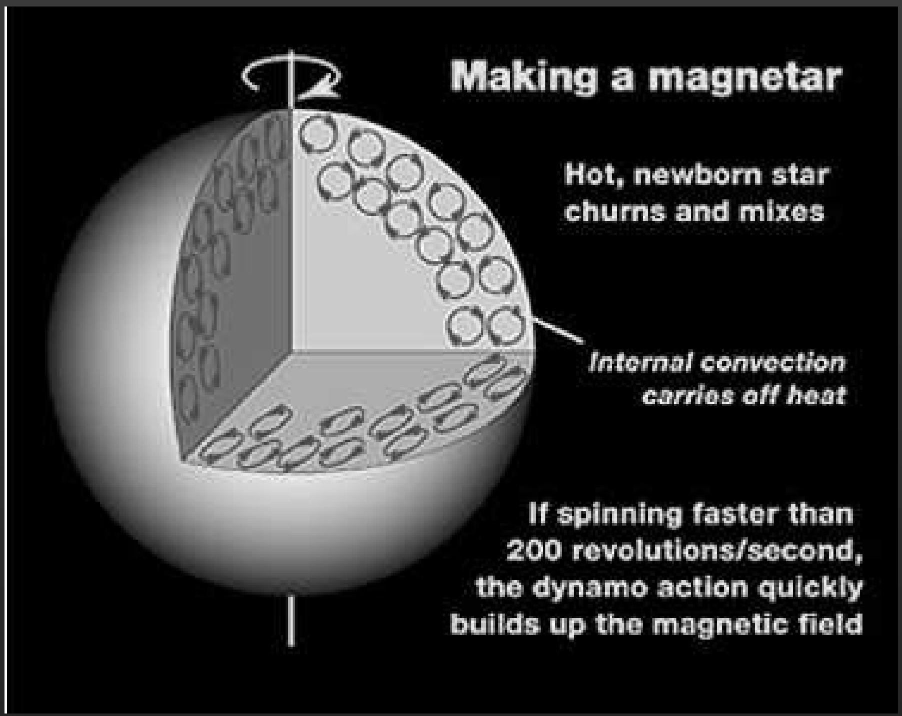
à a `starquake' in Neutron Star crust



• brief (few minutes) burst of $\sim 10^{39}$ J (Sun's energy release over 100,000 years)!

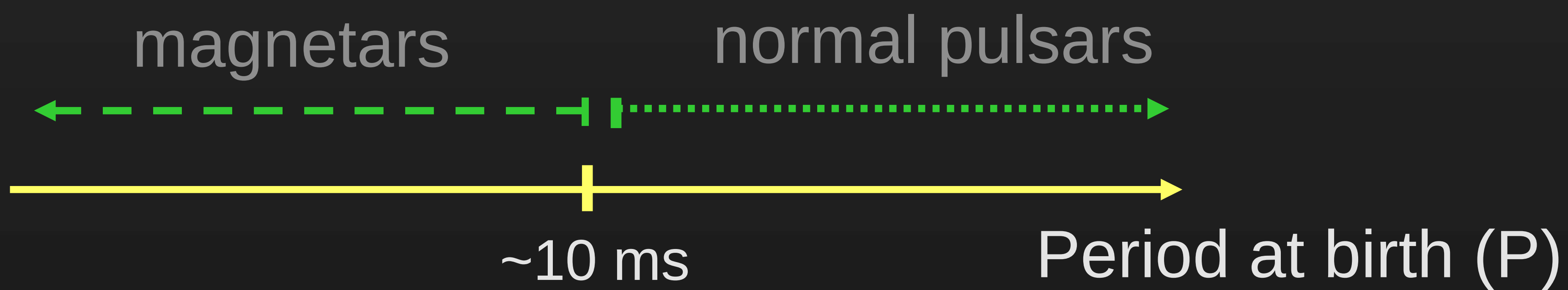
Magnetars and ``Normal Pulsars'':

à Why are they different?



- Amplify B-field via dynamo action!
- for dynamo to operate, need:

rotation period (P) < convective turnover time ~ 10 ms



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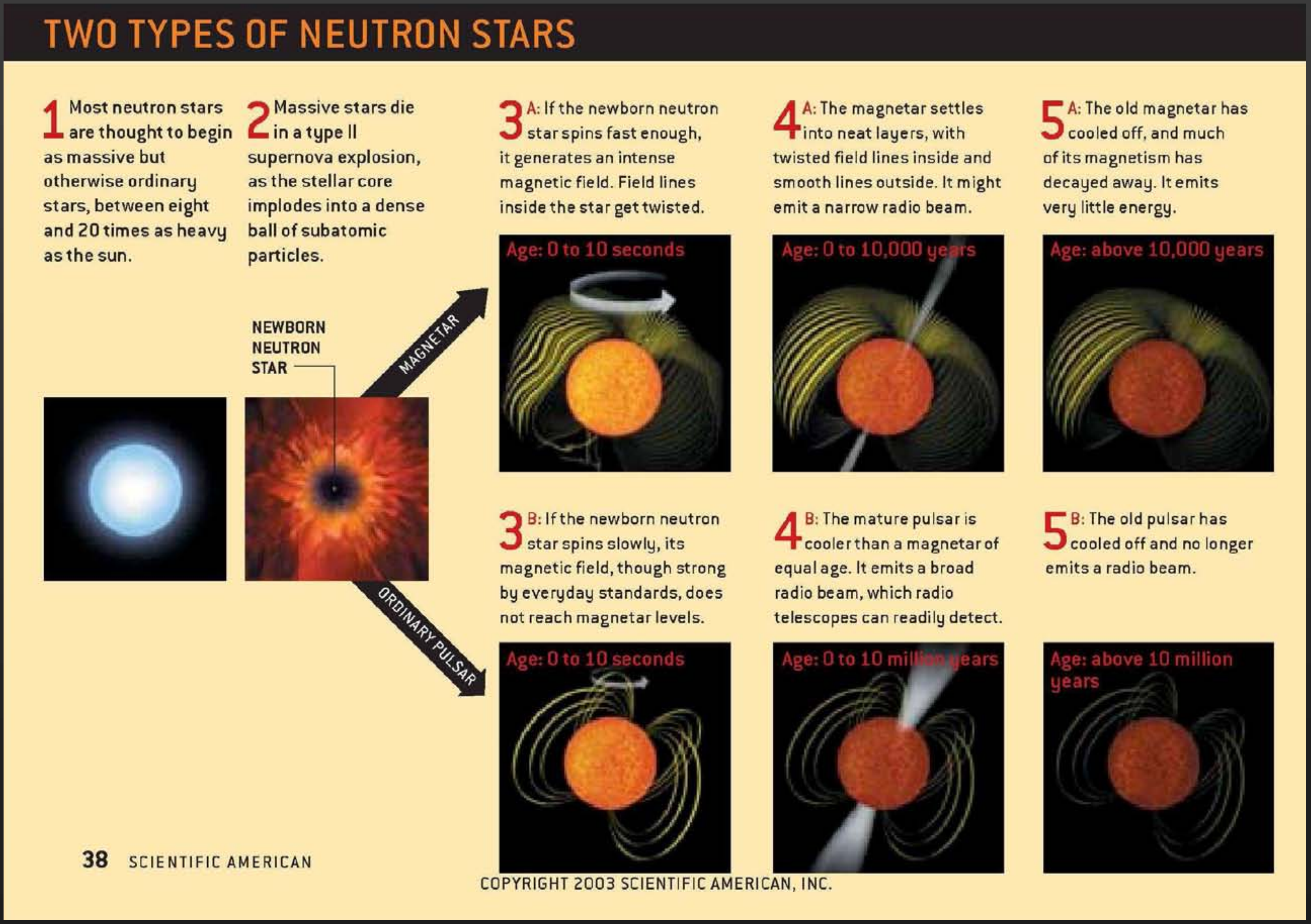
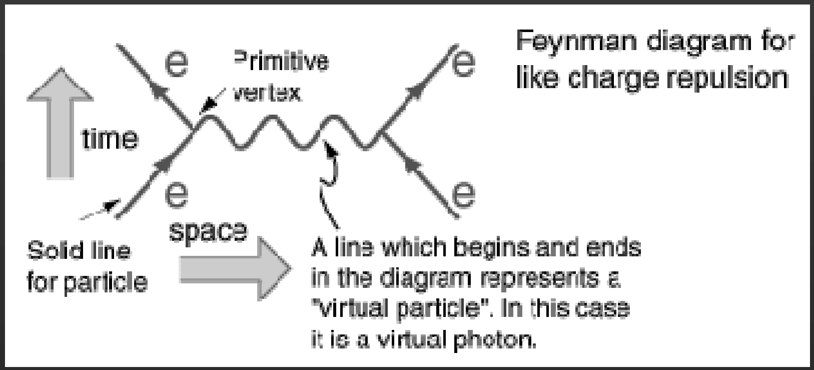
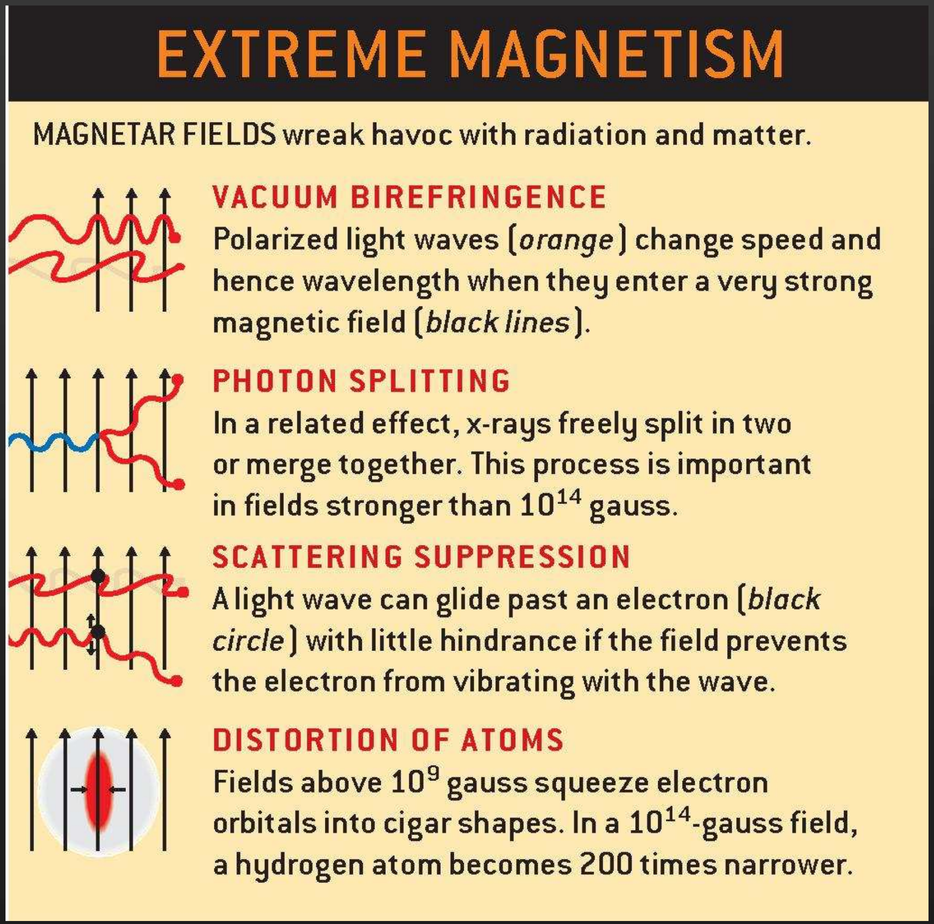


Magnetars: Extreme magnetic fields!

(B ~ 10^{11} T)

à Quantum-Electrodynamic (QED) effects kick in!





Summary:

- Pulsars:
  - **rotating, highly magnetized neutron stars**

  - **rotational energy replaces losses due to radiation**

- Special Case: Crab Nebula (SN remnant, AD 1054)
  - **very bright source of synchrotron radiation**

  - **pulses detected in: radio, optical, X-ray**
    à **young pulsar!**

- Magnetars:

- rotating, hyper-magnetized neutron stars

- active for only ~10,000 years!

- B>10^{11} T à **QED effects kick in!**

- starquakes power giant flares

- observed as *soft gamma repeaters* (SGRs)