

Astronomy 353 (Spring 2008)



ASTROPHYSICS: From Black Holes to the First Stars (Lecture 15: Pulsars + Magnetars)

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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~5x10³¹ 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 velocity²

Pulsar lifecycle



Pulsars spin down, and disappear from view!

Magnetars = Extreme Pulsars Proposed by R. Duncan & C. Thompson (1992)



• hyper-strong magnetic fields: B~10¹¹ 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 ~10³⁹ J (Sun's energy release over 100,000 years)!

Magnetars and ``Normal Pulsars'':

à Why are they different?



200 revolutions/second, the dynamo action quickly builds up the magnetic field Amplify B-field via dynamo action!

 for dynamo to operate, need:
 rotation period (P)

convective turnover time ~ 10 ms



Magnetars and ``Normal Pulsars'':

Why are they different? à

TWO TYPES OF NEUTRON STARS

NEWBORN NEUTRON STAR -

Most neutron stars Lare thought to begin Lin a type II as massive but otherwise ordinary stars, between eight and 20 times as heavy as the sun.

Massive stars die supernova explosion, as the stellar core implodes into a dense ball of subatomic particles.

A: If the newborn neutron J star spins fast enough, it generates an intense magnetic field. Field lines inside the star get twisted.

: O to 10 seconds

B: If the newborn neutron J star spins slowly, its magnetic field, though strong by everyday standards, does not reach magnetar levels.

A: The magnetar settles 4 into neat layers, with twisted field lines inside and smooth lines outside. It might emit a narrow radio beam.



4^{B: The mature pulsar is} cooler than a magnetar of equal age. It emits a broad radio beam, which radio telescopes can readily detect.



A: The old magnetar has **O** cooled off, and much of its magnetism has decayed away. It emits very little energy.



B: The old pulsar has Cooled off and no longer emits a radio beam.



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Magnetars: Extreme magnetic fields!

(B ~ 10¹¹ T)

à Quantum-Electrodynamic (QED) effects kick in!



EXTREME MAGNETISM

MAGNETAR FIELDS wreak havoc with radiation and matter.

† VACUUM BIREFRINGENCE



Polarized light waves (*orange*) change speed and hence wavelength when they enter a very strong magnetic field (*black lines*).

PHOTON SPLITTING

In a related effect, x-rays freely split in two or merge together. This process is important in fields stronger than 10¹⁴ gauss.

SCATTERING SUPPRESSION





A light wave can glide past an electron (*black circle*) with little hindrance if the field prevents the electron from vibrating with the wave.

DISTORTION OF ATOMS

Fields above 10⁹ gauss squeeze electron orbitals into cigar shapes. In a 10¹⁴-gauss field, a hydrogen atom becomes 200 times narrower.



• 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>10¹¹ T à QED effects kick in!
- starquakes power giant flares
- observed as soft gamma repeaters (SGRs)