Pulsars

http://chandra.harvard.edu/resources/illustrations/neutronstars.html
Crab nebula in optical, X-ray

Image Credit: ESO VLT (optical), and Chandra (X-ray) – not to scale!
Pulse period, structure, and variability

Pulsar P-Pdot diagram

Populations:
• “Normal” pulsars, including youngest (Crab, Vela)
• millisecond pulsars, mostly in binaries (circles)
• magnetars

Lines:
• characteristic Spin-down age
• pole magnetic dipole field
• “deathline”

See: ANTF Pulsar catalog:

(From the Handbook of Pulsar Astronomy, by Lorimer and Kramer)
http://www.cv.nrao.edu/course/astr534/Pulsars.html
Goldreich-Julian pulsar model

• Electrons are trapped and accelerated along the magnetic field lines of the pulsar and emit synchrotron radiation.
• Magnetic field lines can’t close past the light cylinder ($v > c$). Open field lines induce toroidal B-fields and strong E-fields.
• Vacuum gaps / regions occur at the polar cap, the “slot gap”, and in the outer region close to the light cylinder.
• Vacuum gaps are filled with plasma, but its density is lower than the critical Goldreich-Julian density, where the magnetically induced electric field is saturated, and therefore electrons can be accelerated to very high energies.

Image: MAGIC Collaboration 2008
http://hera.ph1.uni-koeln.de/~heintzma/Sp_Art3/S701.htm
Indirect Evidence for GWs from Hulse-Taylor binary

- Binary pulsar PSR 1913 + 16
- Discovered in 1974
- Orbital parameters measured continuously measured over 30 years!
  - Only 7 kpc away
  - 8 hr period speeds up 35 sec from 1975-2005
  - Measured to ~50 msec accuracy
  - Deviation grows quadratically with time
  - Shortening of period $\Rightarrow$ orbital energy loss
  - Compact: negligible loss from friction, material flow
  - Beautiful agreement with GR prediction
  - Apparently, loss is due to GWs!
  - Nobel Prize, 1993
  - Merger in about 300M years (<< age of universe!)
  - GW emission will be strongest near the end – Coalescence of black holes!

\[ \text{Cumulative shift of periastron time (s)} \]

\[ \text{General Relativity prediction} \]

(Weisberg & Taylor, 2005)
Magnetars: SGRs and AXPs

<table>
<thead>
<tr>
<th>NAME</th>
<th>YEAR OF DISCOVERY</th>
<th>ROTATION PERIOD (seconds)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SGR 0526-66</td>
<td>1979</td>
<td>8.0</td>
</tr>
<tr>
<td>SGR 1900+14</td>
<td>1979</td>
<td>5.16</td>
</tr>
<tr>
<td>SGR 1806-20</td>
<td>1979</td>
<td>7.47</td>
</tr>
<tr>
<td>SGR 1801-23*</td>
<td>1997</td>
<td>?</td>
</tr>
<tr>
<td>SGR 1627-41</td>
<td>1998</td>
<td>?</td>
</tr>
<tr>
<td>AXP 1E 2259+586</td>
<td>1981</td>
<td>6.98</td>
</tr>
<tr>
<td>AXP 1E 1048-59†</td>
<td>1985</td>
<td>6.45</td>
</tr>
<tr>
<td>AXP 4U 0142+61</td>
<td>1993</td>
<td>8.69</td>
</tr>
<tr>
<td>AXP 1RXS 1708-40†</td>
<td>1997</td>
<td>11.0</td>
</tr>
<tr>
<td>AXP 1E 1841-045</td>
<td>1997</td>
<td>11.8</td>
</tr>
<tr>
<td>AXP AXJ1844-0258</td>
<td>1998</td>
<td>6.97</td>
</tr>
<tr>
<td>AXP CXJ0110-7211†</td>
<td>2002</td>
<td>5.44</td>
</tr>
</tbody>
</table>

* Not shown on map; location not known precisely
† Abbreviated name

Giant X-ray flare in August 1998 confirmed the existence of magnetars. It started with a spike of radiation lasting less than a second (left). Then came an extended train of pulses with a period of 5.16 seconds. This event was the most powerful outburst to come from the object, designated SGR 1900+14, since its discovery in 1979 (right).
5.16s pulsations from SGR giant flare
# McGill SGR/AXP Online Catalog

## Main Table

This catalog contains the current information available on 23 magnetars: 11 SGRs (7 confirmed, 4 candidates), and 12 AXPs (9 confirmed, 3 candidates). This site is maintained by the McGill Pulsar Group, and is a continual work-in-progress. You are free to use the information in this catalog in publications, however, we ask that you please refer to the url (http://www.physics.mcgill.ca/~pulsar/magnetar/main.html) in either the acknowledgements or a footnote.

- The data reflect the magnetars' persistent characteristics (with exceptions; see footnotes (c), (d) and (e)), rather than those observed during flare/burst periods.
- In cases where the property varies either with phase or time, or there exists multiple recently measured values, the entries are marked with an asterisk (*) and compiled separately in Table 2.
- Observations of optical/IR counterparts are listed in Table 3.

<table>
<thead>
<tr>
<th>Name</th>
<th>P</th>
<th>dP/dt</th>
<th>B_\text{surf}</th>
<th>dE/dt</th>
<th>Tau_e</th>
<th>N_H</th>
<th>BB Temp</th>
<th>PL Index</th>
<th>Unabs f_\text{e}</th>
<th>Distance</th>
<th>L_\text{\alpha}</th>
<th>Associ?</th>
<th>Opt/IR?</th>
<th>Bands?</th>
<th>Activity</th>
<th>RA, Dec</th>
</tr>
</thead>
<tbody>
<tr>
<td>SGR 0526-66</td>
<td>8.05442 (tem=09)</td>
<td>3.8(1) (tem=09)</td>
<td>5.6</td>
<td>2.9</td>
<td>3.4</td>
<td>0.46^{+0.07}_{-0.05}</td>
<td>...</td>
<td>3.27^{+0.07}_{-0.04}</td>
<td>...</td>
<td>0.48 (1.25 [1-10keV]) (tem-09)</td>
<td>50 (khp+04)</td>
<td>1.4</td>
<td>SNR N49, LMC, young star cluster? (khp+04)</td>
<td>no</td>
<td>H X</td>
<td>giant flare, bursts</td>
</tr>
<tr>
<td>SGR 1900+14</td>
<td>5.199877(7)^* (nnt=06)</td>
<td>9.2(4)^* (nnt=06)</td>
<td>7.0</td>
<td>26</td>
<td>0.90</td>
<td>2.12^{+0.8}_{-0.7}</td>
<td>0.47^{+0.1}_{-0.1}</td>
<td>1.9(1)^* (nnt=06)</td>
<td>4.8(2)^* (nnt=06)</td>
<td>12 - 15 (vhh=00)</td>
<td>0.83 - 1.3</td>
<td>maybe</td>
<td>H X</td>
<td>giant flare, bursts</td>
<td>19:07:14.33, 09:19:20.1 (kbb=99)</td>
<td></td>
</tr>
<tr>
<td>SGR 1806-20</td>
<td>7.60227(7)^* (nny=09)</td>
<td>75(4)^* (nny=09)</td>
<td>24</td>
<td>67</td>
<td>0.16</td>
<td>6.7^{+0.6}_{-0.7}</td>
<td>0.6^{+0.2}_{-0.1}</td>
<td>1.6^{+0.1}_{-0.1}</td>
<td>18 (ent=07)</td>
<td>...</td>
<td>8.7^{+1.8}_{-1.6} (bcck=08)</td>
<td>yes</td>
<td>H X</td>
<td>giant flare, bursts</td>
<td>18:09:39.329, -20:24:39.94 (kot=05)</td>
<td></td>
</tr>
<tr>
<td>SGR 1627-41</td>
<td>2.594578(6) (etm=09)</td>
<td>1.9(4) (etm=09)</td>
<td>2.2</td>
<td>43</td>
<td>2.2</td>
<td>10(2)^* (eiz=08)</td>
<td>...</td>
<td>3.3^{+0.6}_{-0.4}</td>
<td>...</td>
<td>11.0(3) (cdd=99)</td>
<td>...</td>
<td>0.025</td>
<td>SNR G337.0-0.1, CTB 33 (radio complex) (cdd=99)</td>
<td>no</td>
<td>H X</td>
<td>bursts</td>
</tr>
<tr>
<td>SGR 0501+4516(c)</td>
<td>5.76209653(3) (gpk=10)</td>
<td>0.582(3) (gpk=10)</td>
<td>1.9</td>
<td>1.2</td>
<td>1.6</td>
<td>0.89(8) (ern=09)</td>
<td>0.49(1) (ern=09)</td>
<td>2.8(1) (ern=09)</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>yes</td>
<td>X O</td>
<td>bursts</td>
<td>03:01:6.76, +45:16:33.92 (gpk=10)</td>
</tr>
<tr>
<td>SGR 0418+5729</td>
<td>9.07838827(4) (ret=10)</td>
<td>&lt;0.0006 (ret=10)</td>
<td>&lt;0.075</td>
<td>&lt;0.00032 &lt;24000</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>yes</td>
<td>X</td>
<td>bursts</td>
<td>04:18:33.667, +57:32:22.91 (vck=10)</td>
</tr>
<tr>
<td>SGR 1833-0832</td>
<td>7.565409(8) (gcl=10)</td>
<td>0.439(43) (gcl=10)</td>
<td>1.8</td>
<td>0.40</td>
<td>27</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>no</td>
<td>X</td>
<td>bursts</td>
<td>18:33:44.38, 08:31:07.71 (gcl=10)</td>
</tr>
<tr>
<td>Swift J1822.3-1606</td>
<td>8.43771968(6) (bkx+11)</td>
<td>0.0254(22) (bkx+11)</td>
<td>0.47</td>
<td>0.017</td>
<td>530</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>no</td>
<td>X</td>
<td>bursts</td>
<td>18:22:18.00, 16:04:26.8 (bkx=10)</td>
</tr>
<tr>
<td>Swift J1834.9-0844</td>
<td>2.4823018(1) (bkx=12)</td>
<td>0.79(12) (bkx=12)</td>
<td>1.4</td>
<td>21</td>
<td>4.9</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>4.0(2) (1b=07)</td>
<td>...</td>
<td>...</td>
<td>SNR W41? (kkp=12)</td>
<td>no</td>
<td>X</td>
<td>bursts</td>
<td>18:34:52.118, 08:45:56.02 (kek=12)</td>
</tr>
<tr>
<td>SGR 1801-23</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>...</td>
<td>bursts</td>
</tr>
</tbody>
</table>
TWO TYPES OF NEUTRON STARS

1. Most neutron stars are thought to begin as massive but otherwise ordinary stars, between eight and 20 times as heavy as the sun.

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

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

   Age: 0 to 10 seconds

   NEWBORN NEUTRON STAR

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

   Age: 0 to 10 seconds

   ORDINARY PULSAR

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

   Age: 0 to 10,000 years

   MAGNETAR

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.

   Age: 0 to 10 million years

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

   Age: above 10,000 years

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

   Age: above 10 million years

By Chryssa Kouveliotou, Robert C. Duncan and Christopher Thompson

38 SCIENTIFIC AMERICAN

COPYRIGHT 2003 SCIENTIFIC AMERICAN, INC.
Magnetar bursts

HOW MAGNETAR BURSTS HAPPEN

The magnetic field of the star is so strong that the rigid crust sometimes breaks and crumbles, releasing a huge surge of energy.

1. Most of the time the magnetar is quiet. But magnetic stresses are slowly building up.

2. At some point the solid crust is stressed beyond its limit. It fractures, probably into many small pieces.

3. This "starquake" creates a surging electric current, which decays and leaves behind a hot fireball.

4. The fireball cools by releasing x-rays from its surface. It evaporates in minutes or less.