Dim Isolated Neutron Stars, Cooling and Energy Dissipation

Ages of DINs and Cooling
Warming the Old: Post cooling energy dissipation,
Energy dissipation due to dipole spindown, ordinary and magnetar fields
Energy dissipation due to torques from a fallback disk
Numbers and Ages
Relations with other isolated neutron star populations
Disks, higher multipole fields and activity of the neutron star-

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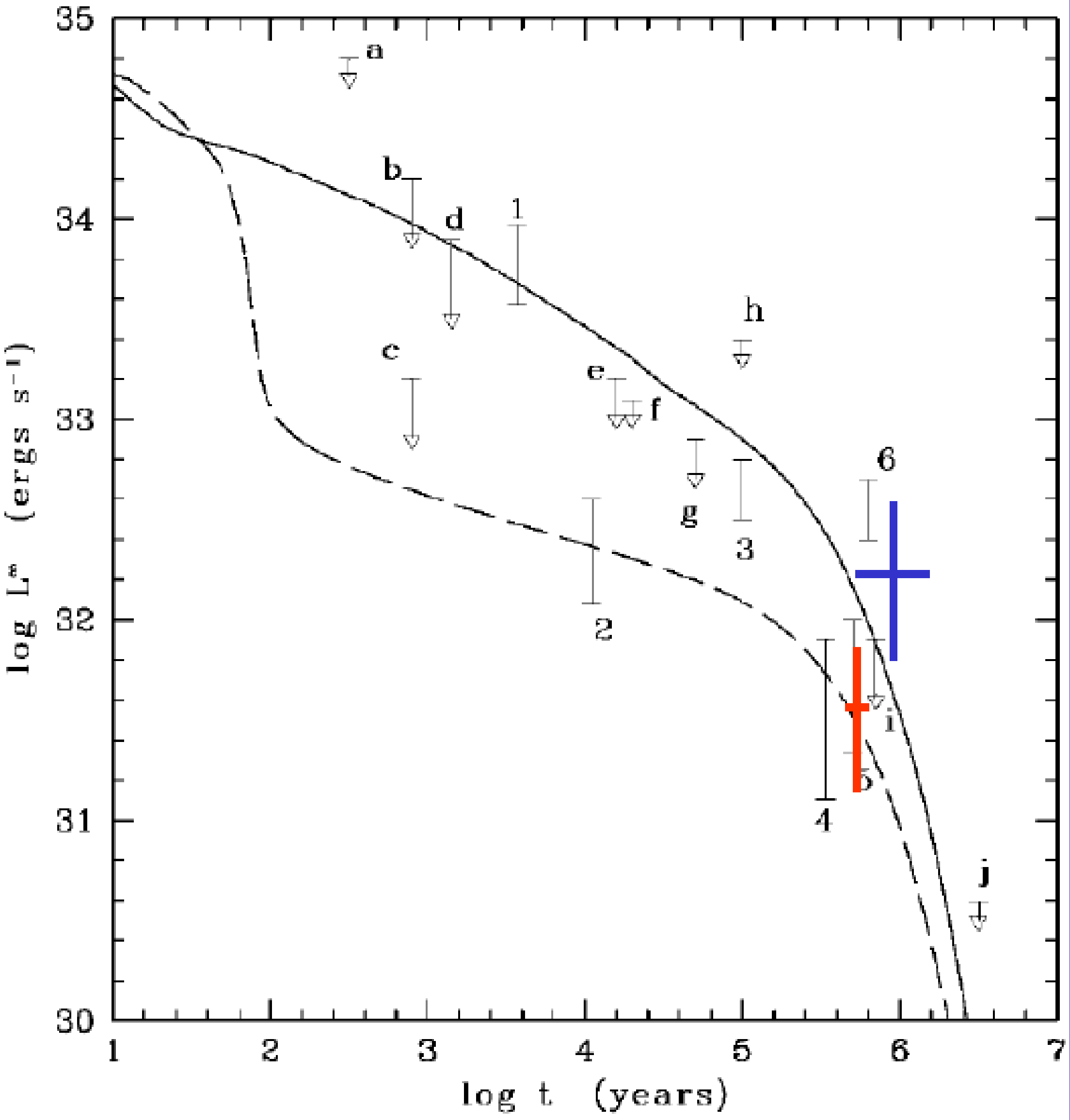


Standard cooling curves show a sharp drop in luminosity, down from about 10^{32} ergs s^{-1}, at an age of 10^{6} years. This reflects the transition from photon to neutrino cooling. (Tsuruta et al. 2002; points added: RX J 1856.5-3754, RX J 0720.4-3125 (Pavlov, Zavlin, Sanwal 2003, Haberl 2005 and refs).

All “magnificent” seven ROSAT detected sources are consistent with “thermal” luminosities of the order of 10^{31} - 10^{32} ergs s^{-1}.

The one source, with a parallax distance determination and kinematic age, RX J1856.5-3754 has luminosity 3 10^{31} ergs s^{-1} at distance 120 pc.

RXJ1856.5-3754 and RX J 0720.4-3125 spectra can be fit with two blackbodies to cover X-ray and optical data. This is probably an indicative representation of the actual temperature modulation due to the magnetic fields. Moreover, the soft to hard luminosity ratio is the same, 0.5, in both sources, possibly indicating similar physics on the surface.

The soft blackbody seems to cover the entire neutron star surface. This suggests that the entire surface luminosity is of order 10^{31} - 10^{32} ergs s^{-1}.

Are luminosities of 10^{31} – 10^{32} ergs s^{-1} standard? Why?

Ages:

RX J1856.5-3754:	5 10^5 yr	(kinematic)
RX J0720.4-3754:	9.5 +/- 4 10^5 yr	(P/(2Pdot))
RX J1308.8+2127:	> 1.8 10^5 yr	(P/(2Pdot))
RX J0806.4-4123:	> 10^5 yr	(P/(2Pdot))
RX J0420.0-5022:	> 6000 yr	(P/(2Pdot))

Why do we not detect a few at age 10^5 yr and luminosity 10^{33} ergs s^{-1} ?

Well, their space density is only 10 times less than the density of the 10^6 yr olds. The detectable volume may not be significantly larger than it is for the 10^6 olds- the detected neighbourhood being limited by absorption.

Expect an even larger number of older DINs, say at age 3 10^6 yrs ? But cooling luminosity drops sharply →effective temperature shifted to softer energies → more severe absorption.

In any case, 7 is a small number to see these statistical effects.

What else can happen after the initial 10^6 yrs of cooling?

Reheating by energy dissipation:

$$L_{diss} = J \mid d\,\Omega / dt \mid$$

J is a parameter of the neutron star inner crust, of the order of 10^{43} erg s and $d\,\Omega / dt$ is the spindown rate due to the external torque on the neutron star.

Torque options:

Rotating magnetic dipole

Torques from a fallback disk.

Magnetic Dipole Braking:

$$d\,\Omega / dt = -\,2/3\,\mu^{2}\ \ \Omega^{3} / c^{3}$$

which yields the time dependence:

$$|\,d\,\Omega / dt\,| = 4\ \ 10^{-13}\ s^{-2}\ \ t_6^{\,-3/2}\ \ I_{45}^{\,1/2}\,\mu_{30}^{\,-1}$$

(t_6 is the age in units of 10^6 yrs, I_{45} the star's moment of inertia (gm cm^2)

The expected energy dissipation rate is

$$L_{diss} = 4\ \ 10^{30}\ t_6^{\,-3/2}\ \ I_{45}^{\,1/2}\,\mu_{30}^{\,-1}\ \text{ergs s}^{-1}$$

Torques from a fallback disk near rotational equilibrium with the neutron star:

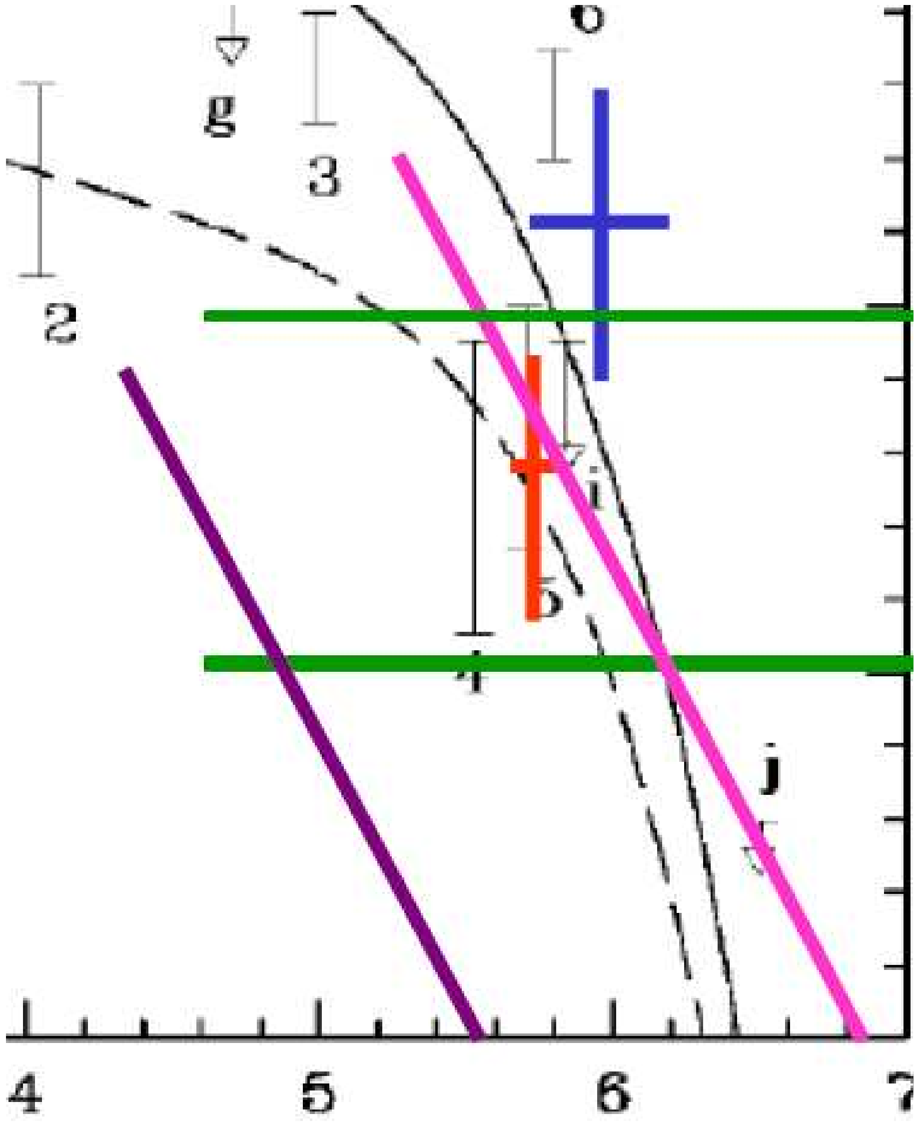
$$I \mid d\Omega / dt \mid \sim (\mu^2 / r_A{}^3) (\Omega - \Omega_{eq})/ \Omega_{eq} \sim (\mu^2 / r_{co}{}^3) (\Omega - \Omega_{eq})/ \Omega_{eq}$$

$$\sim (\mu^2 /GM) \Omega^2 (\Omega - \Omega_{eq})/ \Omega_{eq}$$

which gives the energy dissipation rate estimate

$$L_{diss} \sim J / I (\mu^2 /GM) \Omega^2 < (\Omega - \Omega_{eq})/ \Omega_{eq} >$$
$$\sim 10^{31} \mu_{30}{}^2 \Omega^{\,2} (M/M_{sun})^{-1} \text{ ergs s}^{-1} ,$$
taking $< (\Omega - \Omega_{eq})/ \Omega_{eq} > \sim 0.1$ (cf spread of DIN periods).

Disks surviving beyond 10^6 yrs would keep most DINs (the oldest and most abundant) at luminosities of $10^{31} – 10^{32}$ ergs s $^{-1}$



<u>Energy dissipation rates:</u> log L $_{\rm diss}$ (ergs s^{-1}) vs log t (yrs)

Dipole spindown, Magnetar dipole spindown,

Disk torques near equilibrium

At typical separations of say 150 pc, these young objects must make up a galactic plane population of about 10 000. Their age (duration of the cooling epoch at $L > 10^{32}$ erg s^{-1}) is 10^{6} yrs . The rate of formation is of the order of 10^{-2} yr^{-1} .

The Dim Isolated Neutron stars make up a substantial fraction of the supernova rate: they are a very abundant population of young neutron stars, comparable to isolated radio pulsars (and possibly RRATS).

Dipole magnetic fields inferred from dP/dt and P , as well as surface fields inferred from absorption features from proton cyclotron lines are about $6\ 10^{13}$ G: of the order of or above the quantum critical field, and only an order of magnitude less than the inferred dipole magnetic fields of AXPs and SGRs.

Periods are clustered in the same special narrow range as AXPs and SGRs, for 5 DINs observed periods range from 3.45 s to 11.37 s (Haberl 2005)

All these classes of objects are in the upper right hand part of the P-Pdot diagram. All are close to but above the death line for radio pulsars. They share the P-Pdot neighbourhood with the high dipole field radio pulsars. So why do the DINs (AXPs and SGRs also) not function as radio pulsars?

This is more of a question for the DINs as their inferred dipole surface fields are of the same order as the highest dipole field radio pulsars: the AXPs and SGRs might short out the pair creation in the polar cap more easily by virtue of fields that are one order of magnitude larger than those of the radio pulsars.

Now there is a new enigma: RRATS- close to same corner of P-Pdot diagram; similar with ordinary radio pulsars in that their bursting activity keeps to the rotation period of the neutron star. RRATS also may be similar to AXPs and SGRs in that they burst, though in the radio.

What distinguishes between the different classes might be the presence or absence, and nature of a fallback disk around the neutron star.

Radio pulsar population synthesis – high dipole B only in the tail of the distribution (Faucher-Giguere & Kaspi 2005).

This is a natural third initial parameter, in addition to the initial rotation period and magnetic moment(s) at birth of the neutron star (Alpar 2001)

This is also a natural way to account for period clustering.

A disk has been detected around the AXP 0142+ 61!
Wang, Chakrabarty & Kaplan 2006

This is an active gas disk, consistent with all far and near IR and optical data, at A_v = 3.5 (Ertan et al. 2006, Ertan & Caliskan 2006).

dM/dt history of the disk determines the equilibrium period to which the star approaches asymptotically.

For B = 10^{12} - 10^{13} , a relatively wide range of dM/dt gives a narrow range of equilibrium periods:

P_{eq} scales with | dM/dt | $^{-4/7}$.

An interesting example: if the dipole magnetic field on the surface is the quantum critical field, and dM/dt is Eddington, this leads to equilibrium periods of about 12 s.

All this, life time of fallback disks depends on torque models.
(Ekşi & Alpar; Ekşi, Narayan & Hernquist)

Most numerous, after the no-disk radio pulsars, must be the very small- light mass disk cases, where the disk would have a long lifetime. These are the DINs.

Low Mdot, 10^{12} G dipole B

All the good things about the magnetar model: strength of the magnetic field in the neutron star surface and crust:

What if the surface magnetar fields are concentrated in the higher multipole, and the dipole field on the surface is of order or less than the quantum critical field?

Evolution of magnetic fields in neutron stars, large magnetic stresses pushing on and breaking crust- Thompson and Duncan, Ruderman- local, higher multipole structure must exist in the surface field.

A speculation: when the quantum critical field is reached on the surface, leading to pair creation, near surface currents and surface heating, magnetic structure in the higher multipoles will be amplified, at the expense of the dipole (global) surface field, which might saturate neartthereby be limited to a value near the quantum critical field?

Surface multipole fields: Zane & Turolla 2005, Zane this conference;

Reconnection and higher multipoles in magnetars: changes in pulse shape after flares- Tiengo;

Gaensler- this conference- mention for RRATs - multipole starspots reactivating dead radio pulsars?

Lyne- this conference- braking indices less than 3, pulsars move up in P-P_{dot} diagram.

The typical distance scales for the interaction of matter (disk) with field : the Alfven radii for multipole fields:

While the disk is mostly stopped at the (dipole!) Alfven radius, part of the plasma inflow and angular momentum will set up a total field pattern ithe magnetosphere, matching dynamically the surface multipole composition of the field and conditions imposed by the inflow of matter and angular momentum.