中國科學院新疆天文台
XINJIANG ASTRONOMICAL OBSERVATORY, CAS

Talk for SMFNS2013

Dipole magnetic field of magnetars: the effect of magnetar wind

H. Tong

Xinjiang Astronomical Observatory

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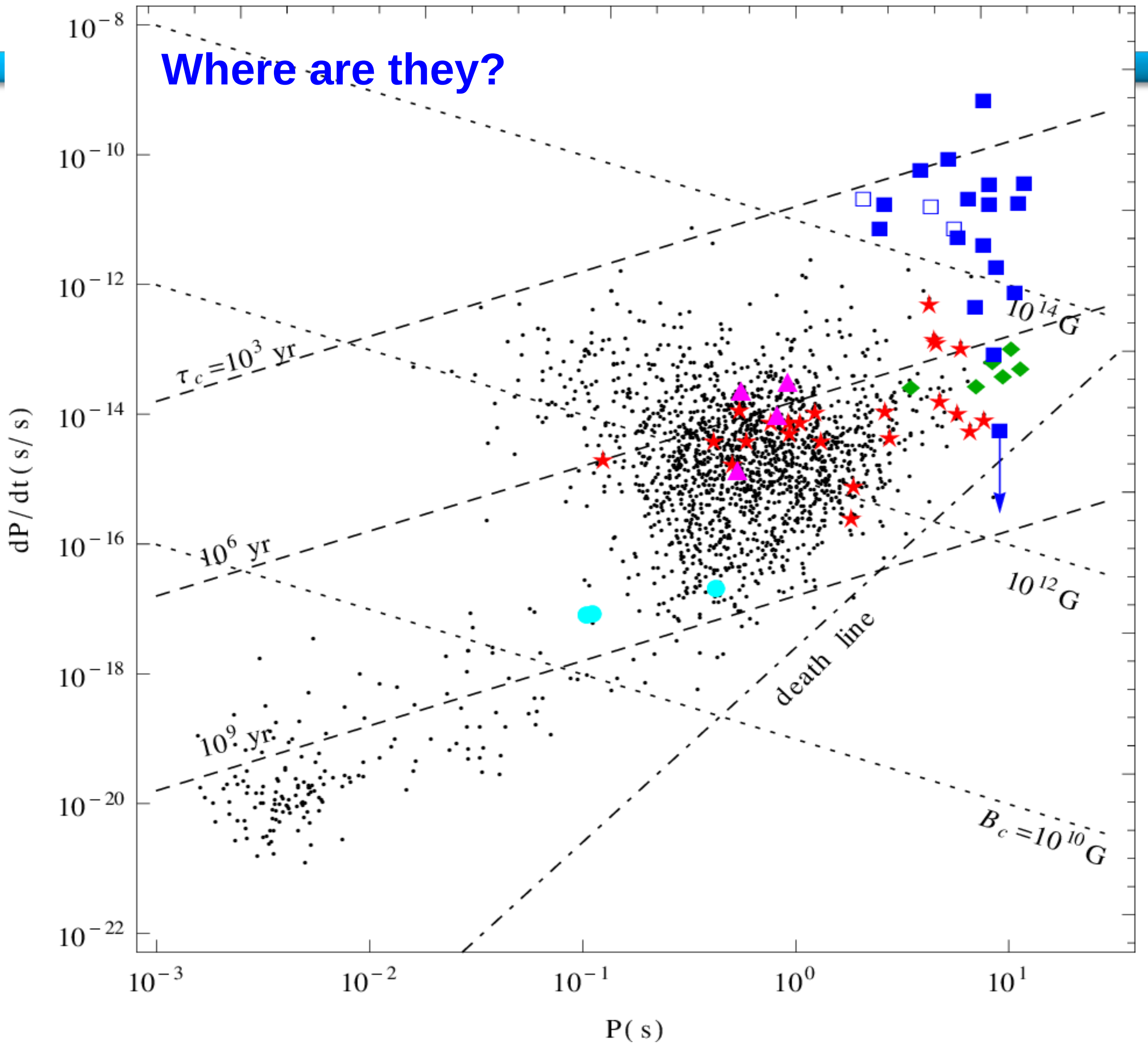
Outline

1. Introduction
2. Existence of a particle wind
3. Rotational energy loss rate
4. Wind braking of magnetars
5. Conclusions

Where are they?



Traditional magnetar model (2008)

- Magnetar =
  1. young NS (SNR & MSC)
  2. $B_{dip} > B_{QED} = 4.4\times10^{13}$ G (braking)
  3. $B_{mul} = 10^{14}$ -10^{15} G (burst and super-Eddington luminosity and persistent emission)

A brief history of magnetars

- 1979: giant flare of SGR 0526-66
- 1986: soft gamma repeaters
- 1992: “magnetars”
- 1998: Timing of SGR 1806-20
  giant flare of SGR 1900+14
- 2004: giant flare of SGR 1806-20
- 2006: multiwave era
- 2010: non-detection in Fermi-LAT;
  low magnetic field SGR (B<7.5*10^12 G)

Failed predictions

1. SNe more energetic (2006)
2. A larger kick velocity (2007)
3. Radio emissions (2006)
4. High-energy gamma-ray detectable by Fermi/LAT (2010)
5. $B>B_{QED}$ (2010)
6. Always a large L_x ($L_x>E_{dot}$): transients & HBPSRs
7. Precession: No

Then …

1. Alternative origin of strong-B
2. Alternative mechanisms in the magnetar domain: wind braking of magnetars
(Tong, Xu, Song & Qiao 2013, ApJ)
3. Alternative models of AXPs/SGRs

Challenges to magnetic dipole braking of magnetars

1. SNe more energetic (Vink & Kuiper 2006; Dall'Osso+ 2009)
2. Non-detection in Fermi observations (Sasmaz Mus & Gogus 2010; Abdo+ 2010; Tong+ 2010, 2011)
3. Low-B SGRs (Rea+ 2010, 2012)
4. HBPSRs (Ng & Kaspi 2010; Pons & Perna 2011)

Why wind braking?

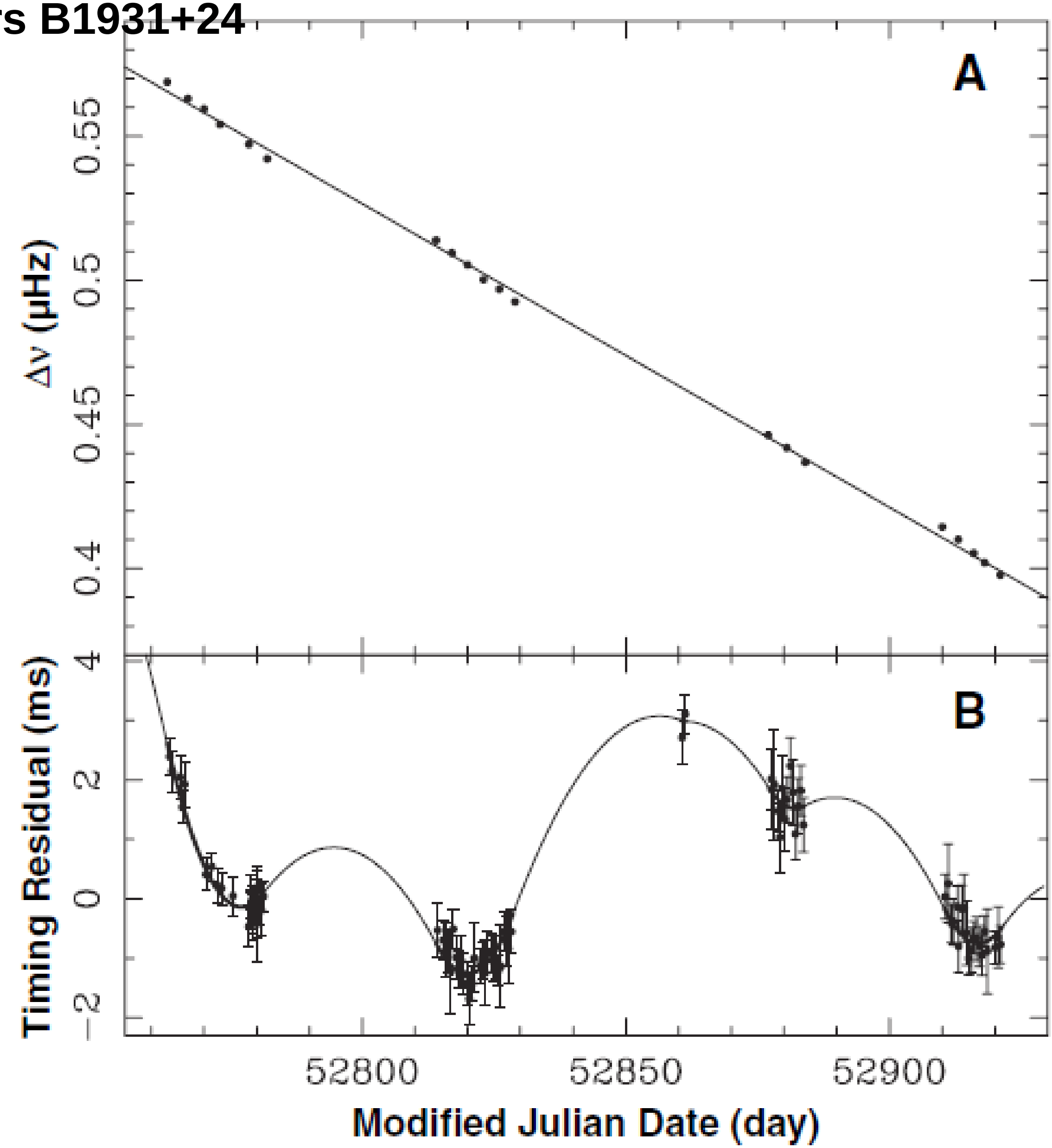
- magnetism-powered: $L_x >> E_{dot}$
- A particle wind $E_p \sim L_x >> E_{dot}$ (strong wind case & magnetism-powered)
- Lower dipole field (Harding+ 1999; Thompson+ 2000)

"Magnetic dipole braking" of normal pulsars

- Rotational energy: magnetic dipole radiation+particle wind (rotation-powered)
- Effects: higher order modifications, e.g. braking index (Michel 1969; Manchester 1985; Xu & Qiao 2001; Contopoulos & Spitkovsky 2006; Wang+ 2012)
  timing noise (Lyne+ 2010; Liu+ 2011)
  +a rotation-powered PWN
- Exist: intermittent pulsars (Kramer+ 2006; Camilo+ 2012)

Intermittent pulsars B1931+24

(Kramer+ 2006)



Magnetic dipole braking is only a pedagogical model!

- Rotating dipole in vaccum!
- Only as first order approximation to the real case
- Normal pulsars braked down by a rotation-powered particle wind

Existence of a particle wind in magnetars

1. Varying period derivative
2. Higher level of timing noise (compared with HBPSRs)
3. Magnetism-powered PWN
   a) Correlation between L_{pwn} and L_x
   b) Higher L_{pwn}/E_{dot}

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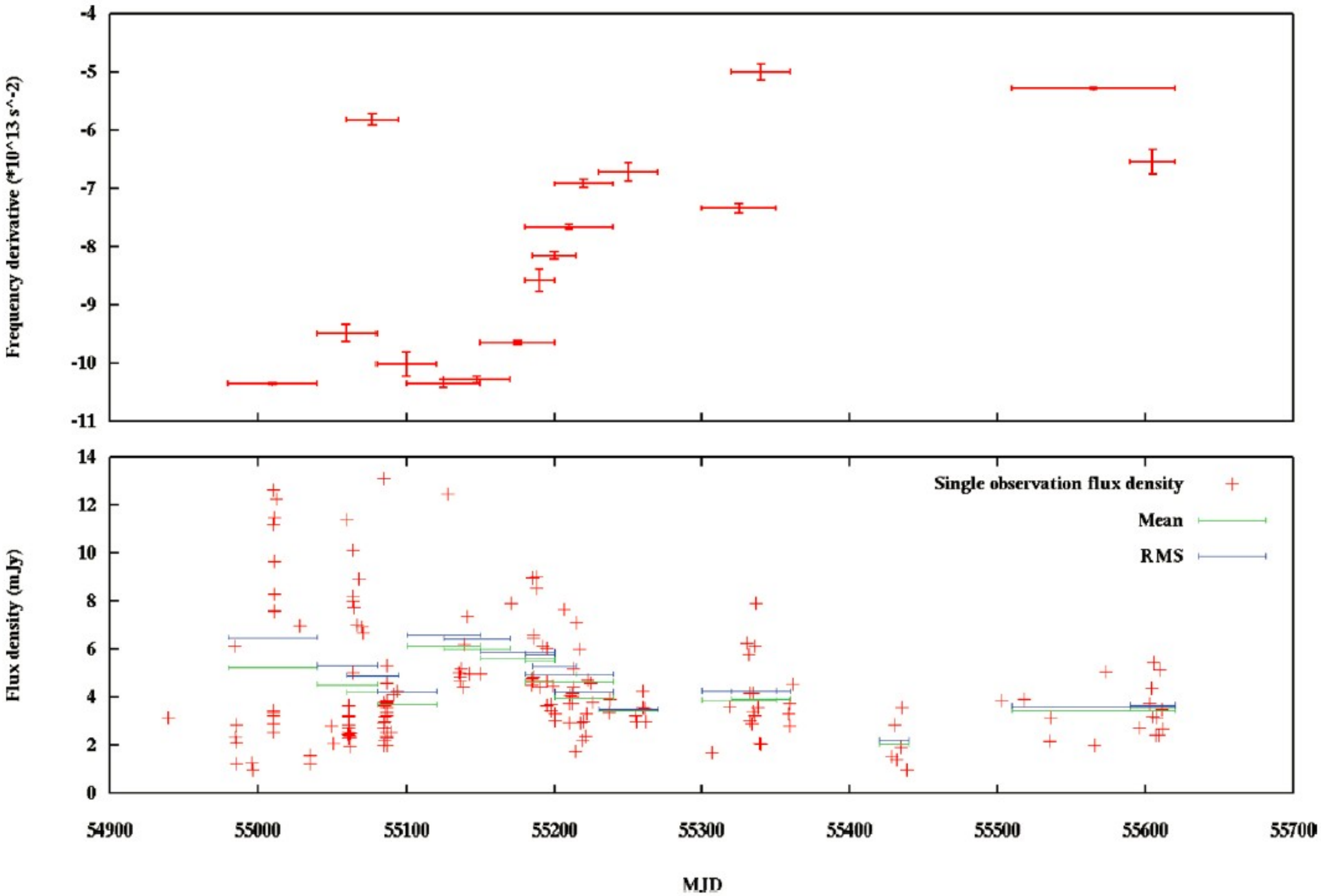
PSR J1622-4950

(Levin+ 2012)



Rotational energy loss rate

- In summary

$$\dot{E}_{\rm w} = \dot{E}_{\rm d}\left(\frac{L_{\rm p}}{\dot{E}_{\rm d}}\right)^{1/2} = \dot{E}_{\rm d}^{1/2} L_{\rm p}^{1/2}$$

- Magnetism-powered particle wind
- When L_p >> $E_{dot,}$ a much lower magnetic field (plus higher order effects, magnetar case)

Observational effects of wind braking of magnetars

- Main aspects

1. Dipole magnetic field
2. Acceleration potential
3. Spin down evolution and age
4. Braking index
5. Duty cycles

- Discussions

1. A decaying particle wind
2. The presence of fallback disk
3. Spin down evolution of newly born magnetars
4. Magnetism-powered pulsar wind nebula

Dipole magnetic field (1): magnetic dipole braking

$$-\dot{E}_{\rm rot} = \dot{E}_{\rm d} = \frac{B_0^2 r_0^6 \Omega^4}{6c^3}$$

$$B_0 = 6.4 \times 10^{19} \sqrt{P\dot{P}}\,{\rm G} = 6.4 \times 10^{14} \left(\frac{P}{10\,{\rm s}} \frac{\dot{P}}{10^{-11}} \right)^{1/2} {\rm G}$$

Polar magnetic field

Dipole magnetic field (2): wind braking

$$-\dot{E}_{\rm rot} = \dot{E}_{\rm w} = \dot{E}_{\rm d}^{1/2} L_{\rm p}^{1/2}$$

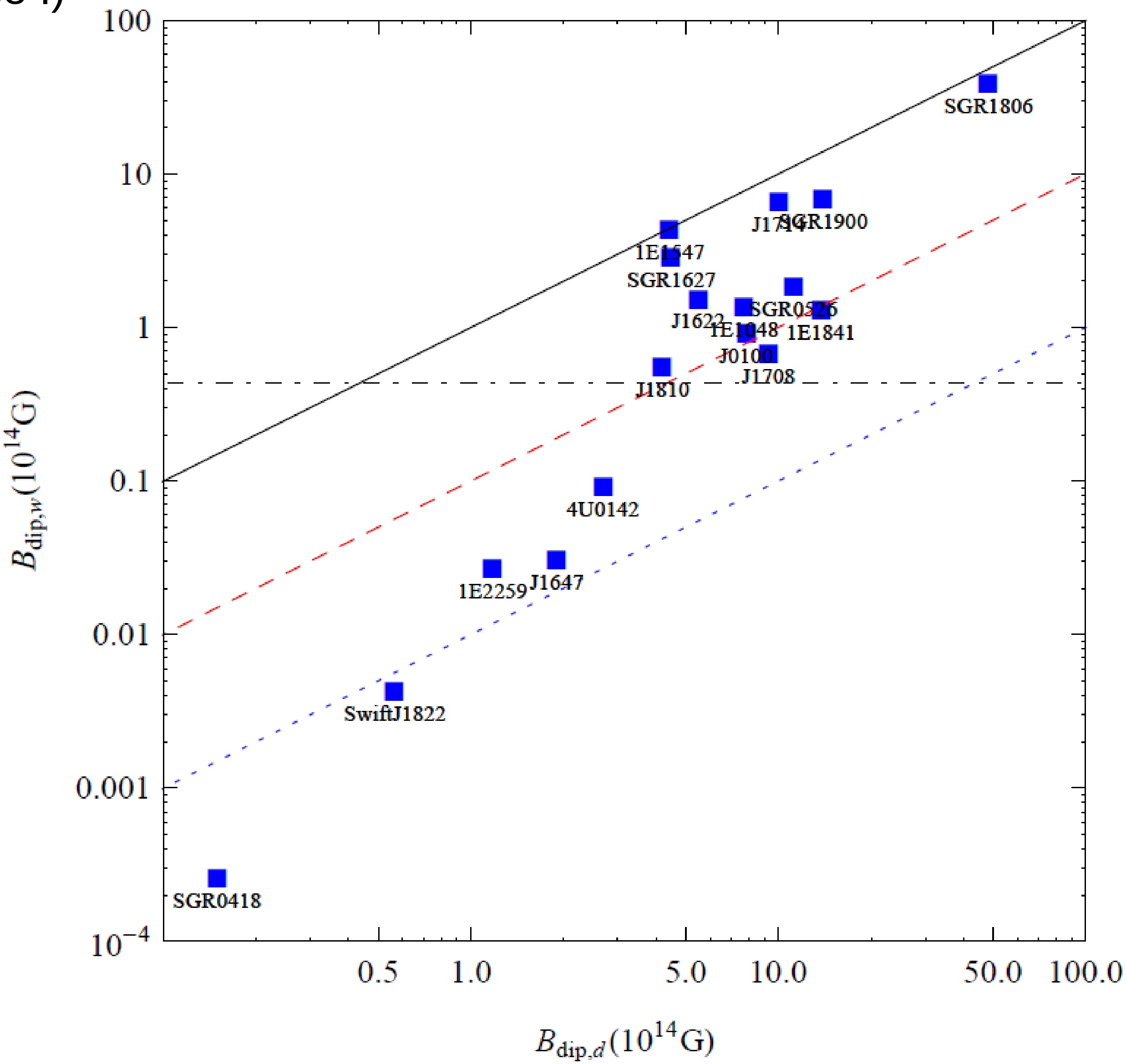
$$B_0 = 4.0 \times 10^{25} \frac{\dot{P}}{P} L_{\rm p,35}^{-1/2}\,{\rm G} = 4.0 \times 10^{13} \frac{\dot{P}/10^{-11}}{P/10\,{\rm s}} L_{\rm p,35}^{-1/2}\,{\rm G}$$

Dipole magnetic field in the case of wind braking

Dipole magnetic field (3)

- In the case of wind braking:
  1. Typical Bdip 10 times lower
  2. Magnetar=NS+strong multipole field
  3. Multipole field responsible for: bursts, persistent emissions, and braking (through a particle wind)

Dipole B (case I)



Dipole magnetic field in the case of wind braking: summary (1)

1. B_{dip} 10 times lower than the magnetic dipole braking case
   - Magnetar SNe energetics will be of normal value
2. B_{dip} from 10^{12}-10^{15} G
   - A strong dipole field is no longer required
3. Several sources with B_{dip} from 10^{13}-10^{14} G
   - They will become XDINSs naturally
4. More sources with $B_{dip} < 4.4\times10^{13}$ G
   - Low-B magnetars are not unusual

Dipole magnetic field in the case of wind braking: summary (2)

- For a given magnetar
  1. Variation of wind luminosity → variation of Pdot

$$\dot{P} \propto L_{\rm p}^{1/2}$$

  2. Magnetar=NS+strong multipole field
     (a higher level of timing noise)
     HBPSR=NS+strong dipole field
     (no magnetar-like activities, except PSR J1846-0258)

Braking index (1)

Definition: $$\dot{\Omega} = -(\mathrm{constant})\Omega^n$$

n=3 for magnetic dipole braking

n=1 for wind braking

↑

$$-I\Omega\dot{\Omega} = \left(\frac{B_0^2 r_0^6 \Omega^4}{6c^3}\right)^{1/2} L_{\mathrm{p}}^{1/2}$$

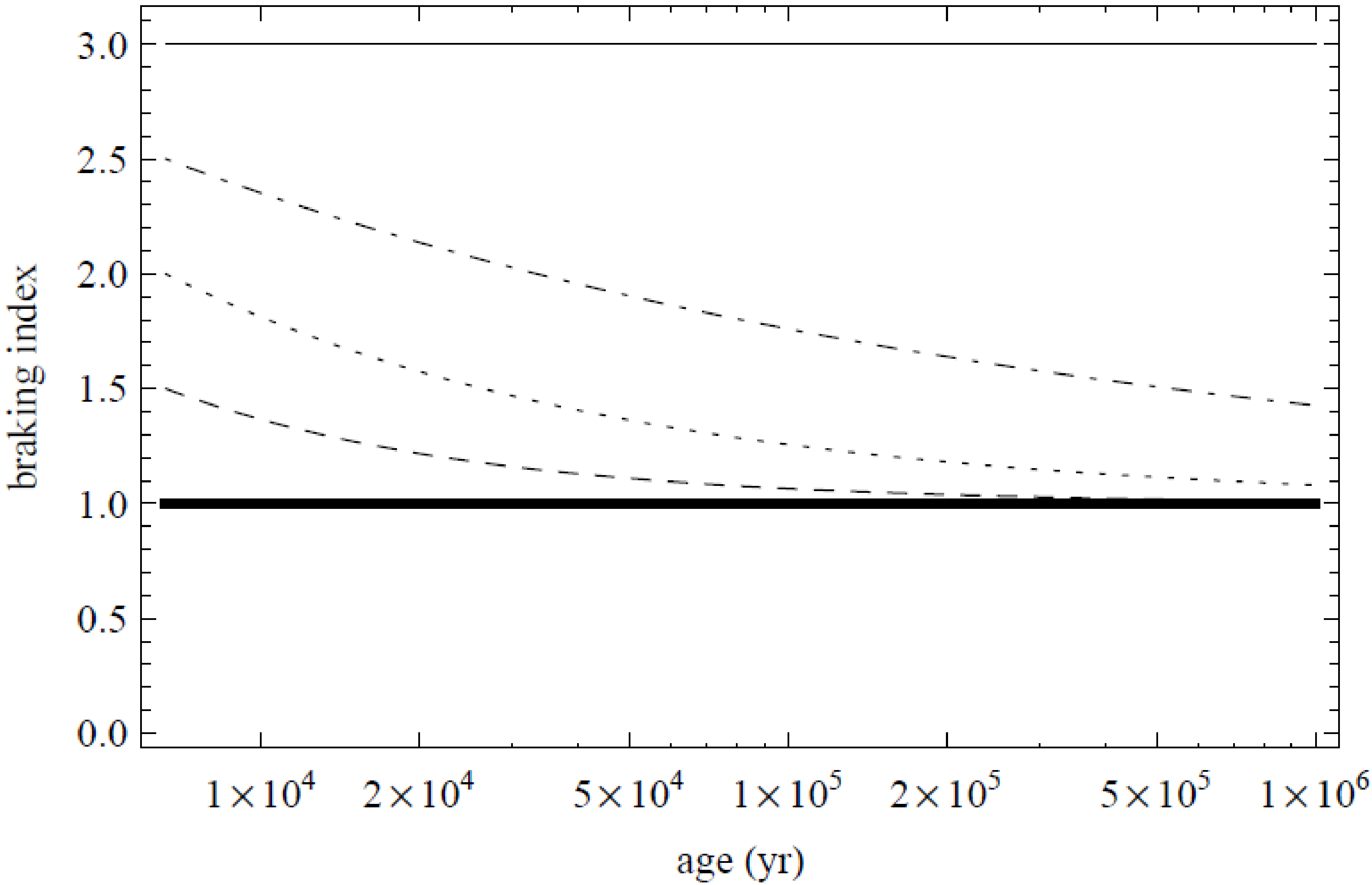
Braking index (2): a decaying particle wind

A decaying particle wind:

$$L_{\rm p}(t) = L_{\rm p,0}\left(\frac{t}{t_{\rm D}}\right)^{-\alpha},\ 0 \le \alpha \le 2$$

Braking index as a function of age

For AXP 4U 0142+61



Magnetism-powered PWN

- Magnetism-powered:

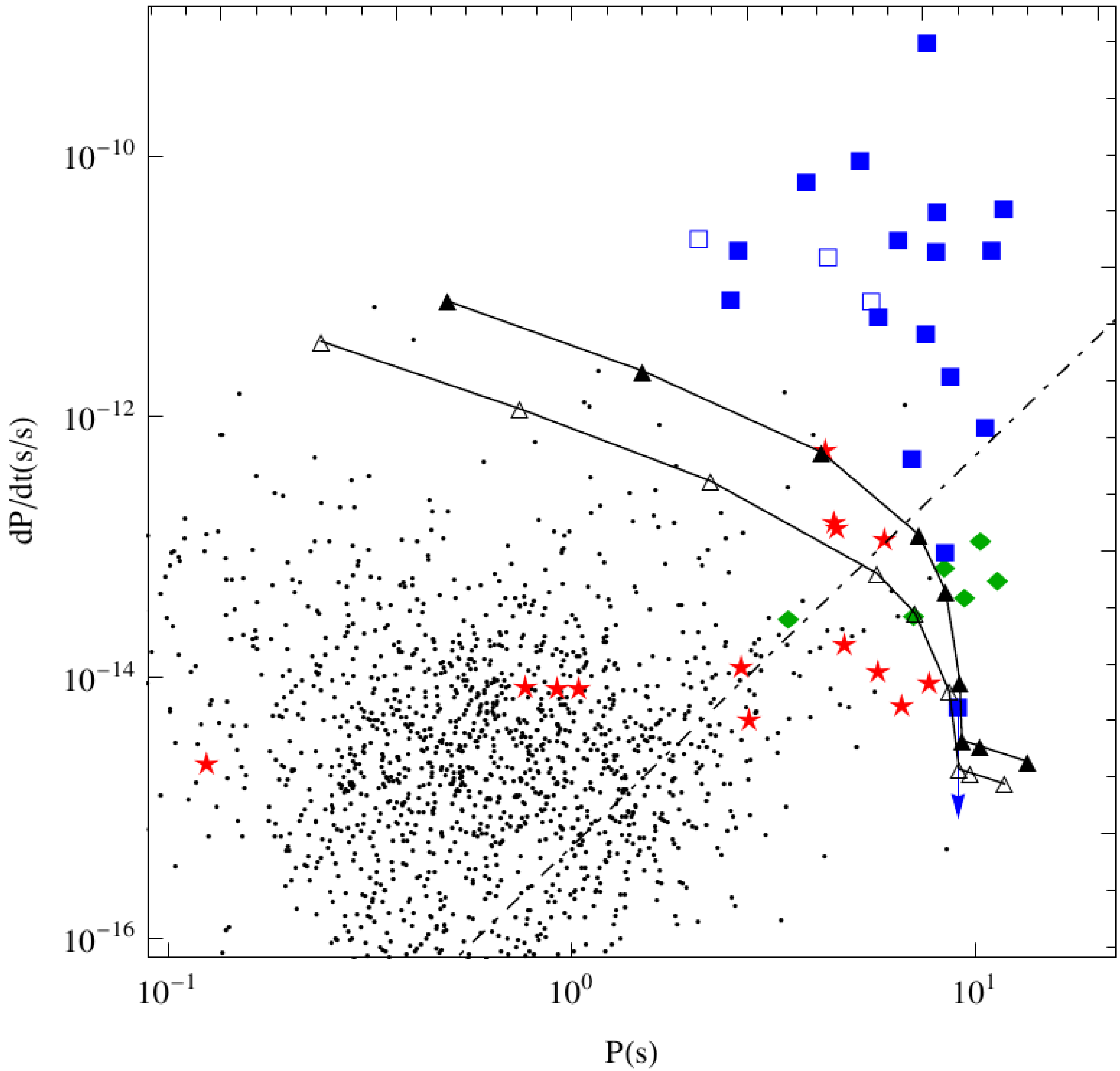
1. L_{pwn} correlated with L_X
   - For 1E 1547.0-5408 (Vink & Bamba 2009; Olausen+ 2011)
2. $L_{\rm pwn} > -\dot{E}_{\rm rot}$: may be hard to achieve for young magnetars
3. A high conversion efficiency
   - For RRAT J1819-1458 (Rea+ 2009) L_{pwn}/E_{dot}=0.2 (1% for rotation-powered PWNe)

Conclusions (1)

1. Wind braking:
   - Wind-aided spin down
   - A lower surface dipole field
   - Magnetars=NS+strong multipole field
2. Explain challenging observations of magnetars
   a) Their SNe energies are of normal value
   b) Non-detection of magnetars by Fermi-LAT
   c) The problem of low-B SGRs
   d) The relation between magnetars and HBPSRs
   e) A decreasing Pdot during magnetar outburst
3. Low luminosity mangetars more likely to have radio emissons
4. Two predictions
   – A magentism-powered PWN
   – A braking index n<3

Conclusions (2): subsequent developments

1. Magnetism-powered pulsar wind nebula around SGR Swift J1834.9-0846 (Younes et al. 2012)
2. A braking index smaller than 3 (Tendulkar et al. 2012)
3. Geometrical effect during wind braking: small inclination angle--> higher B for SGR 0418+5729 (Tong & Xu 2012)


dP/dt(s/s)
10^{-10}
10^{-12}
10^{-14}
10^{-16}
10^{-1}
10^{0}
10^{1}
P(s)

A paradigm shift in the future

- FAST: more radio-loud magnetars, HBPSRs, intermittent pulsars ...
- “Pulsars are magnetic dipole braking”

↓

Pulsars are wind braking