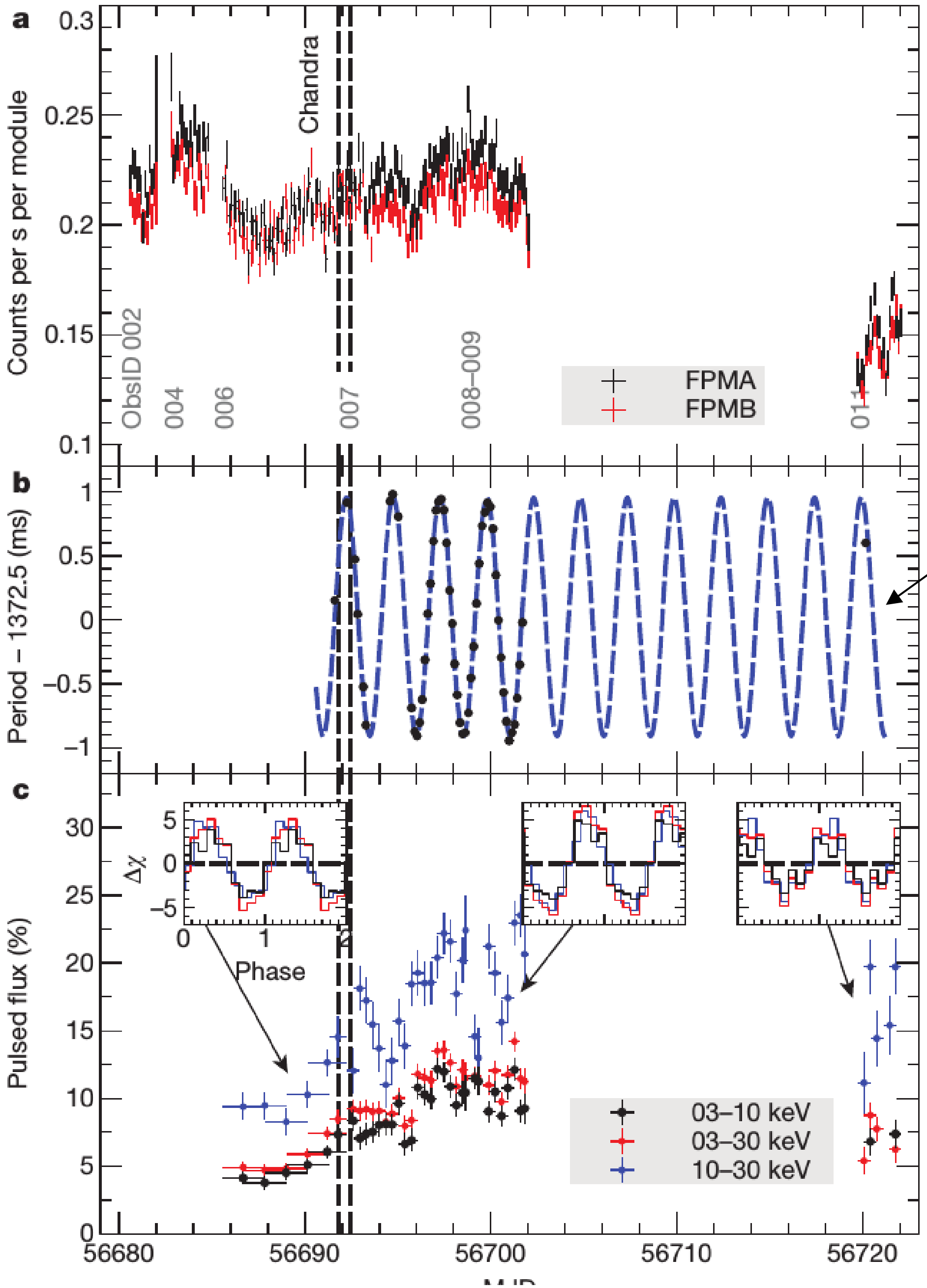
# Ultraluminous X-ray pulsar: accreting magnetar?

H. Tong ( 仝号 )
2015.5
Xinjiang Astronomical Observatory, Chinese Academy of Sciences

Homepage: www.escience.cn/people/tonghao



Bachetti et al. 2014

In one ultraluminous X-ray source
10^40 erg s^-1

Pulsation (1.37 s) modulated
By the orbital motion (2.5 day)

# Content

# History of pulsars

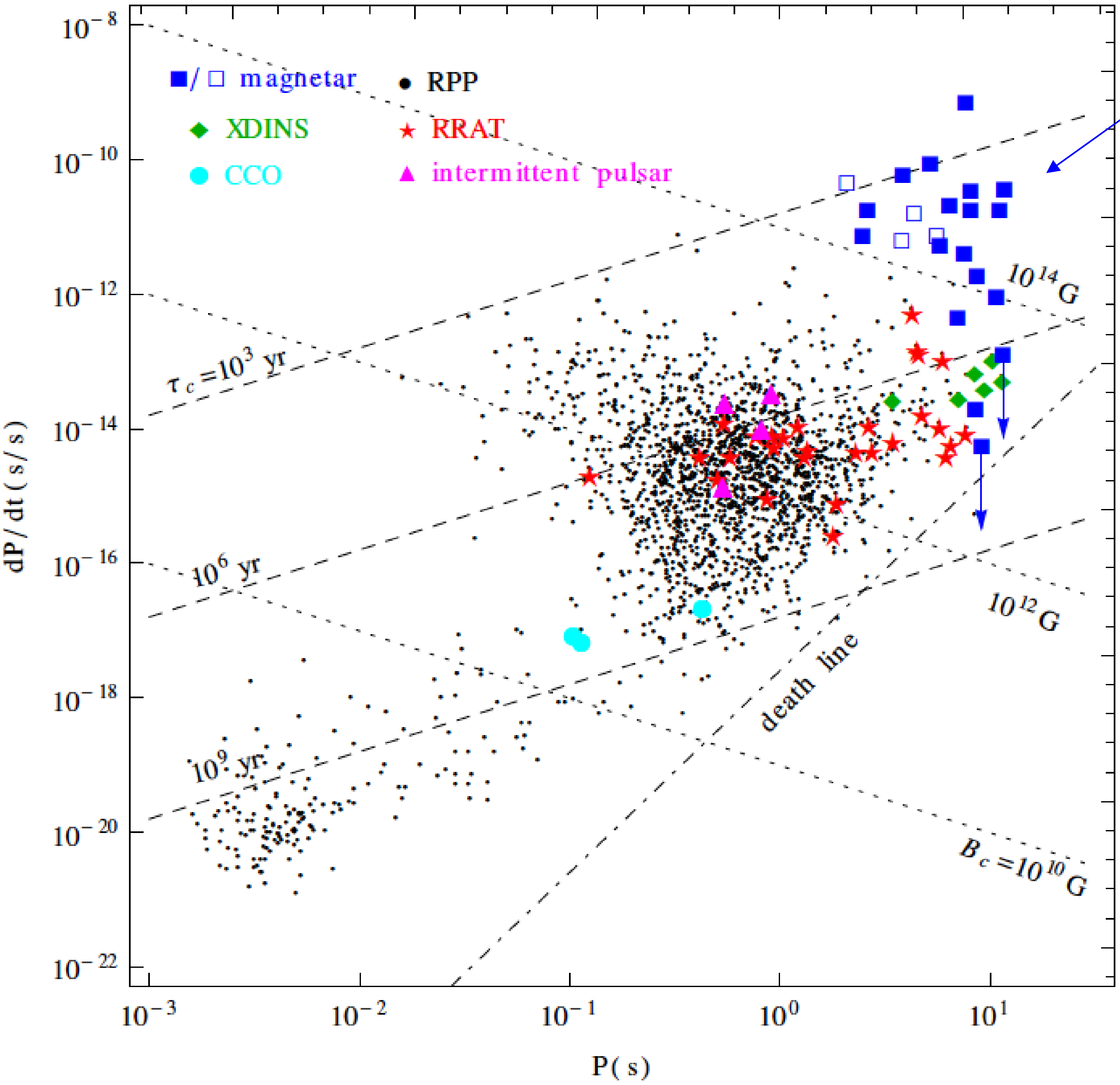
- 1967: discovery of pulsars (Hewish, Bell et al.)
- ~1970: X-ray pulsars (accreting neutron stars in binary systems, Giacconi et al.)
- 1982: millisecond pulsars (Backer et al. )
  Recycled neutron stars via low mass X-ray binaries
- 1990s: magnetar (Thompson/Duncan, Kouveliotou et al.)

Where are accreting magnetars?

# X-ray pulsars

1. Rotation-powered X-ray pulsars (Crab, Vela)
2. Accretion-powered X-ray pulsars (accreting NSs in XRBs)
3. Magnetars (AXPs/SGRs, neutron stars powered by their magnetic energy)
4. Thermal-powered X-ray pulsars (XDINSs, CCOs etc)

**Observational appearances of accreting magnetars?**

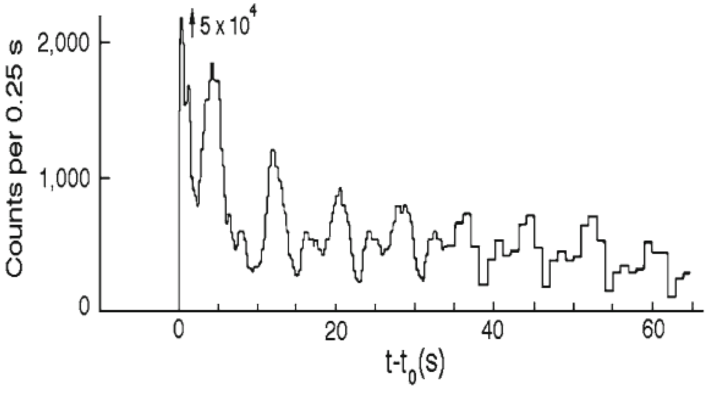


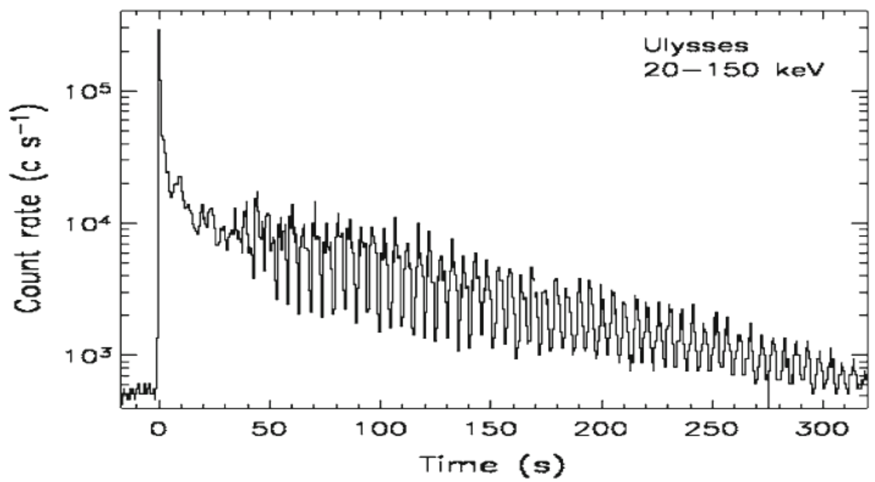
Magnetars
my favorite!

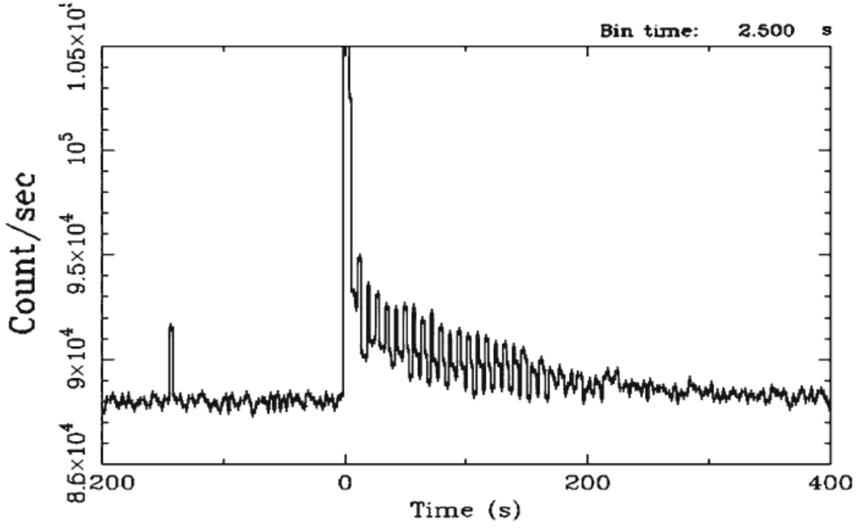
Tong & Wang 2014

# Traditional magnetar model (Mereghetti 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)







Giant flares of magnetars (Mereghetti 2008):
1. Spike+pulsating tail (hundreds of seconds)

2. 10^4 times super-Eddington during the tail (10^42 erg s^-1)

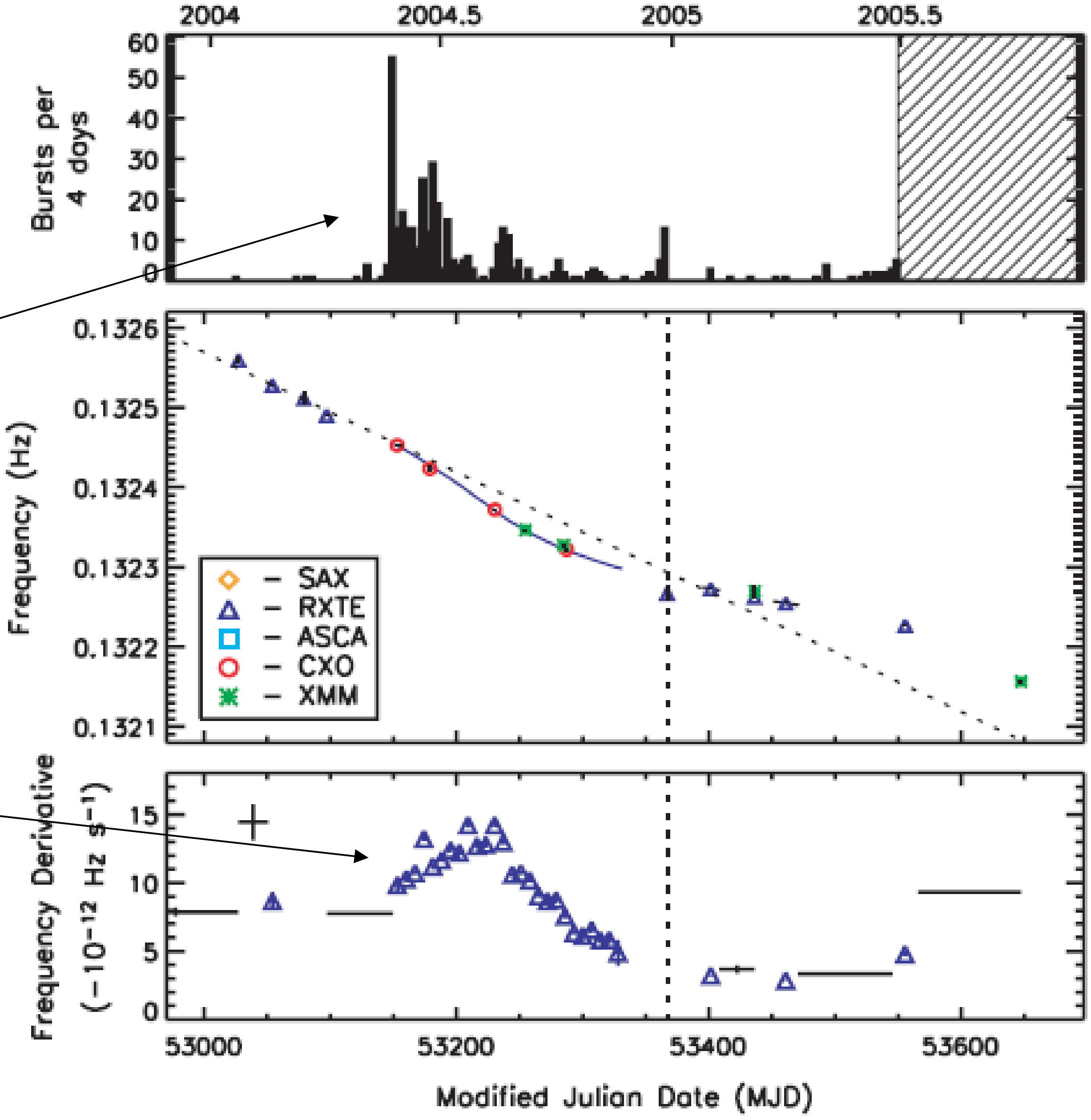
Explanation: 10^15 G magnetic field as the energy power and cause of super-Eddington luminosity

## Restless magnetars:

Woods+ 2007

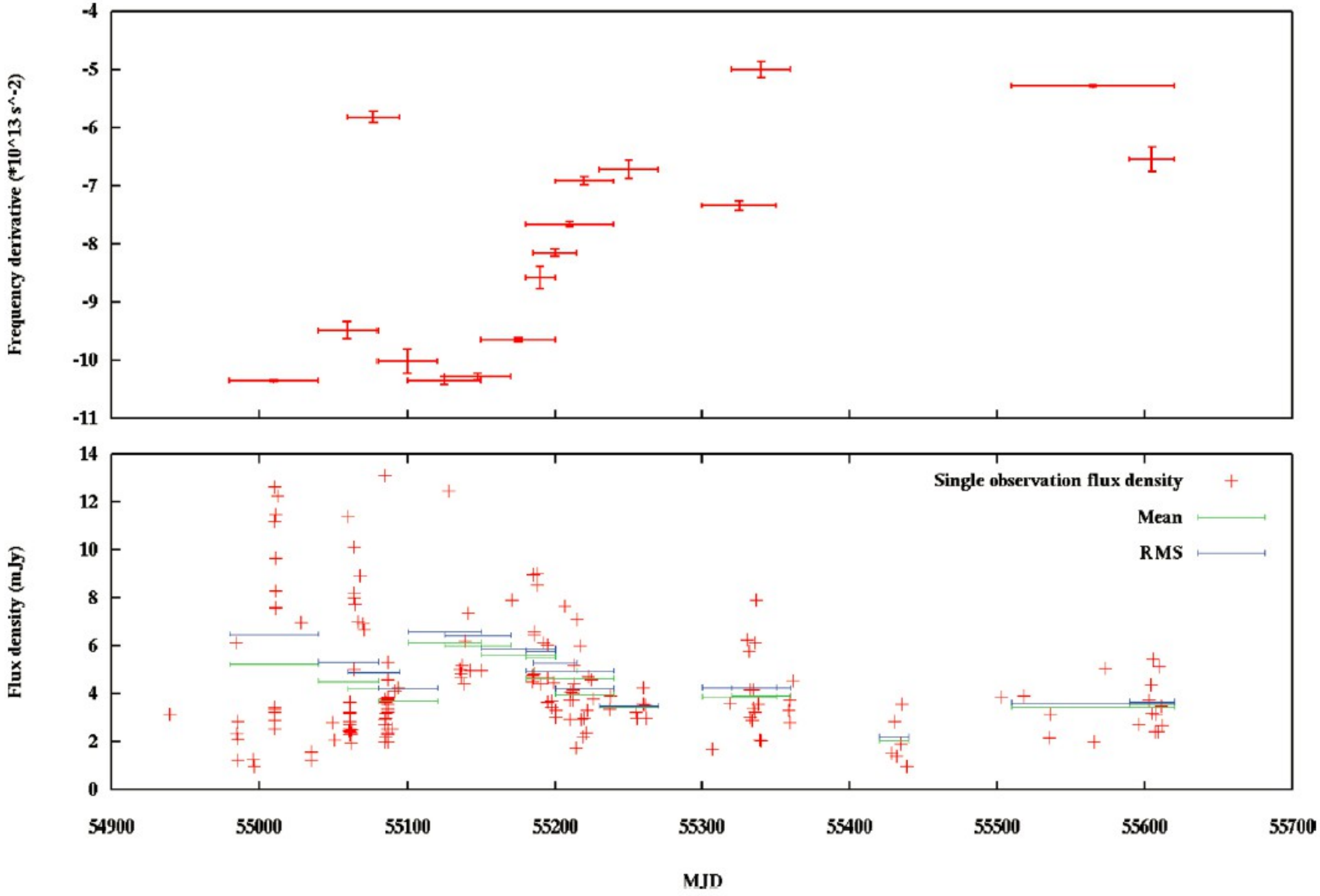
bursts

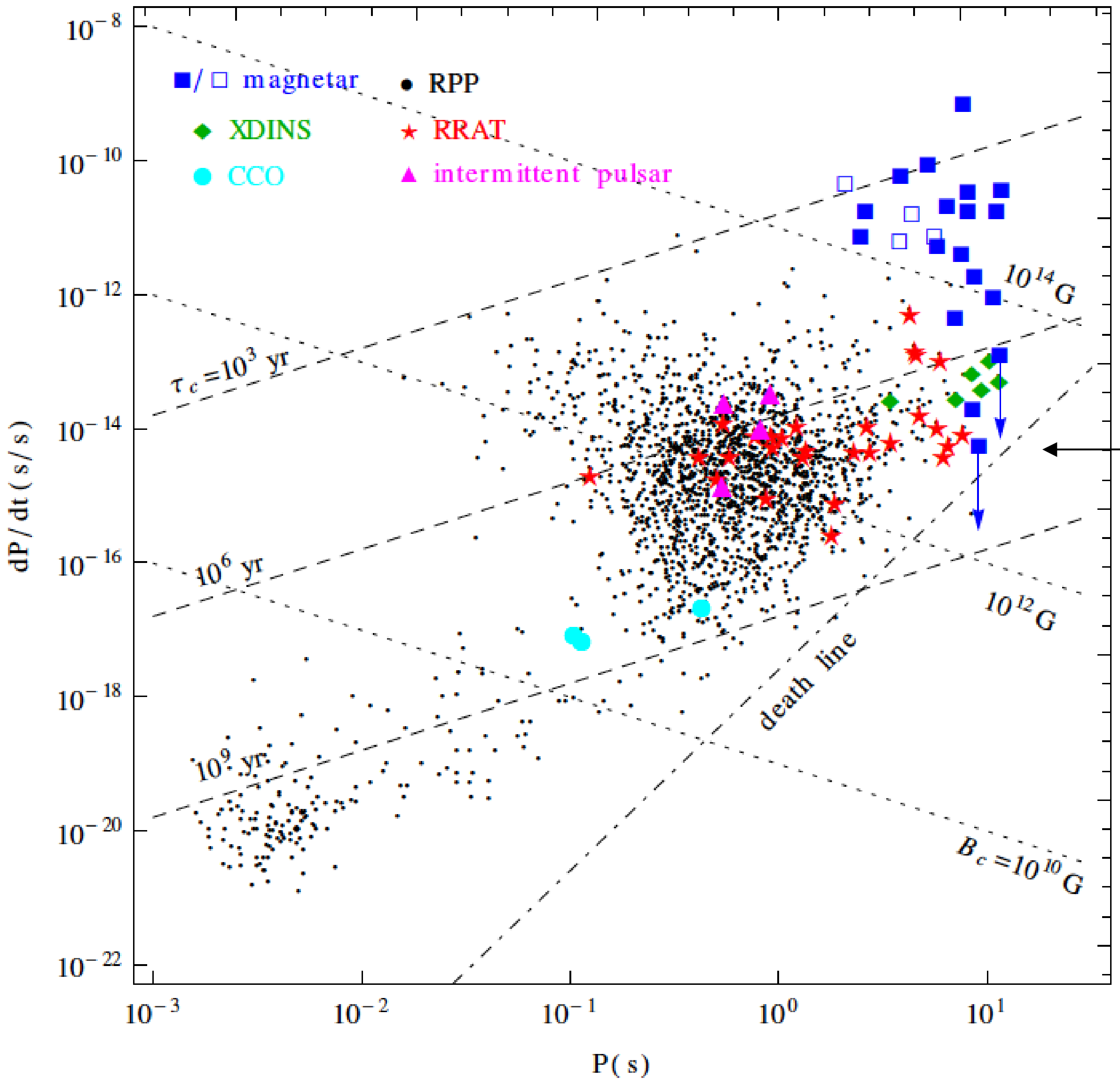
A period of enhanced spindown



# Restless magnetars

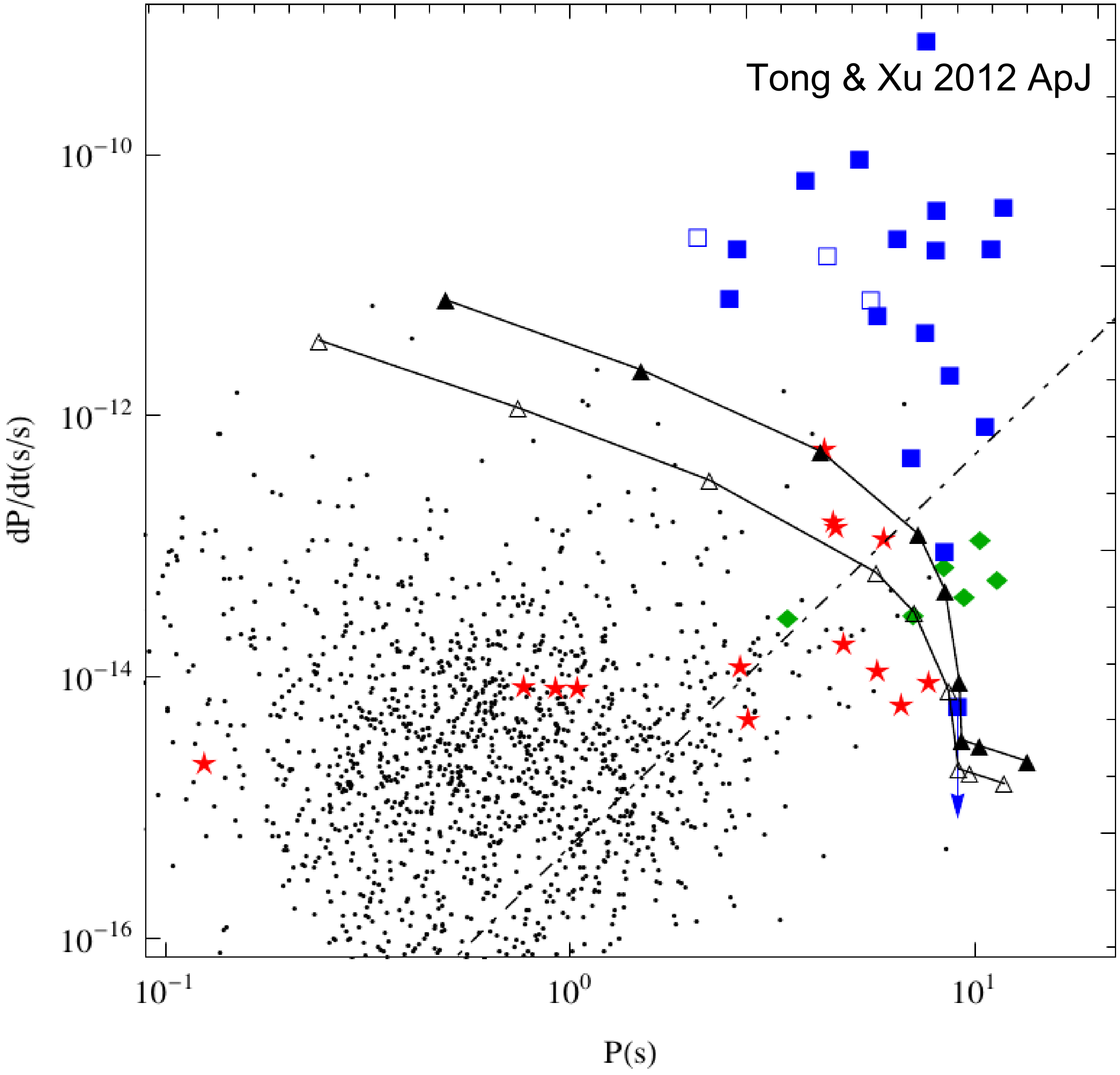
# **PSR J1622-4950** (Levin+ 2012)





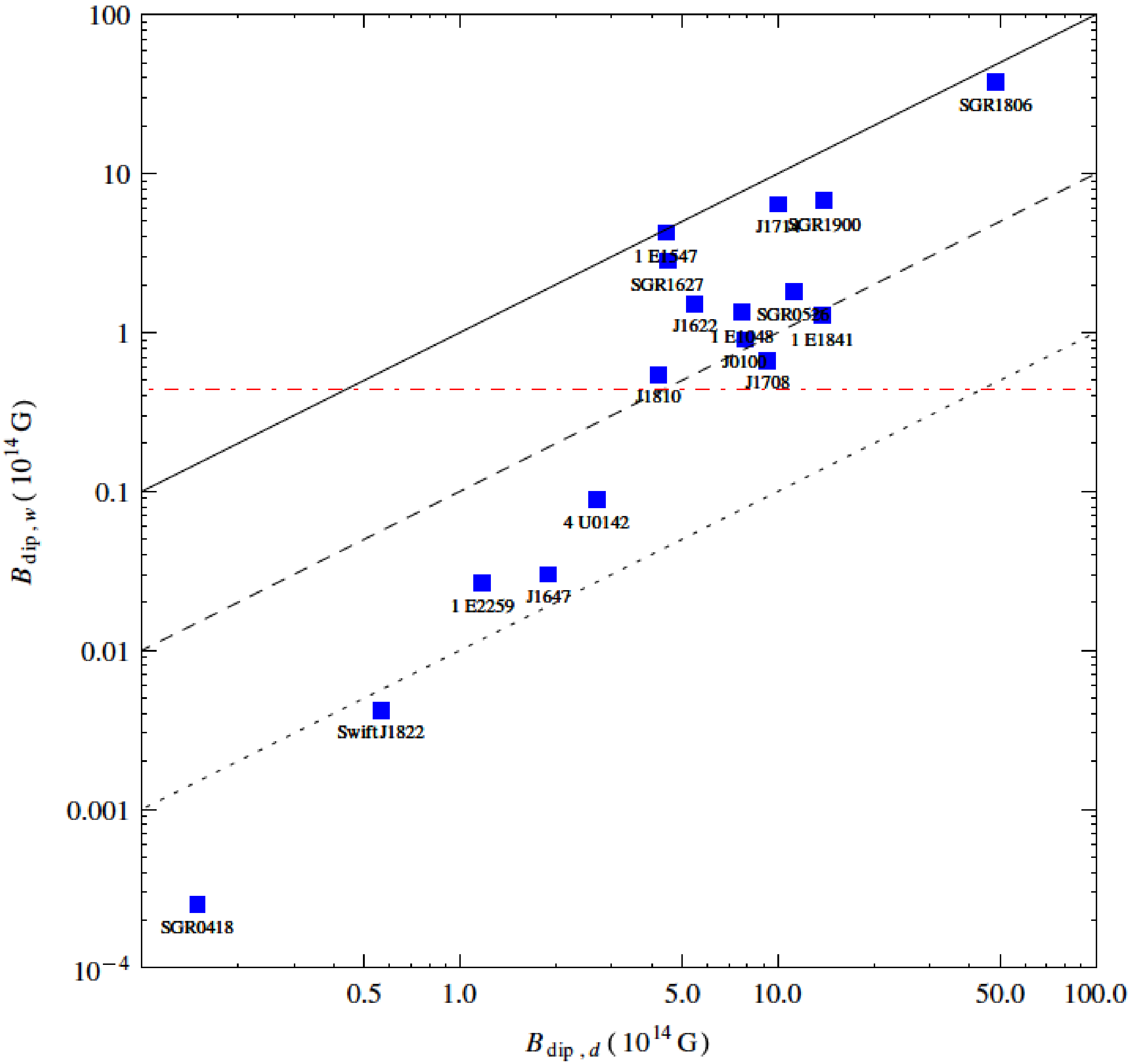
**Low magnetic field magnetar**
Bdip=7.5*10^12 G
(Rea et al. 2010, 2012;
Zhou et al. 2014)

# Timing and explanations: evolution?

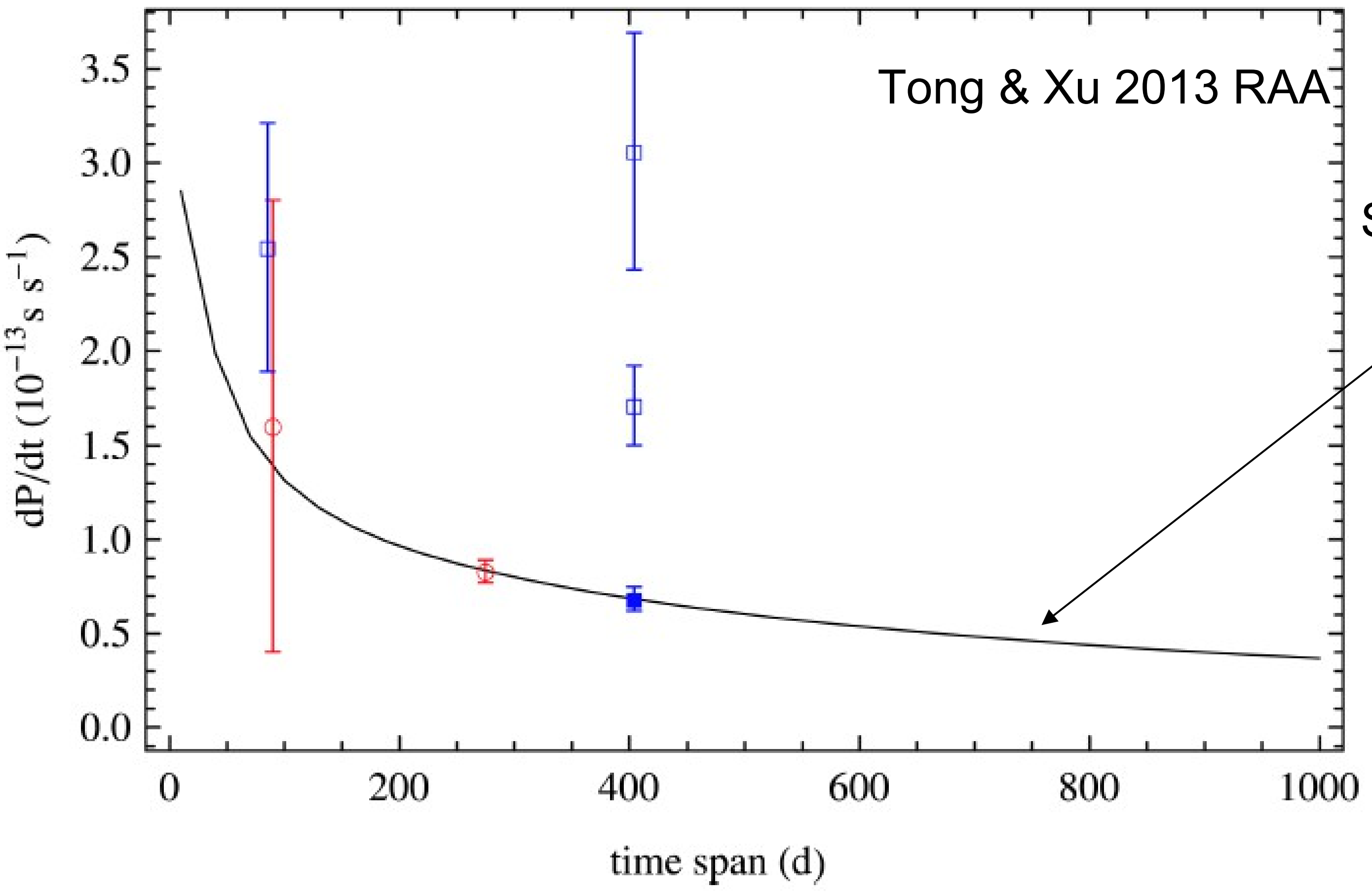


Tong & Xu 2012 ApJ

# Wind braking of magnetars: low-B for many magnetars
Tong et al. 2013 ApJ



# Decreasing Pdot for the second low-B magnetar

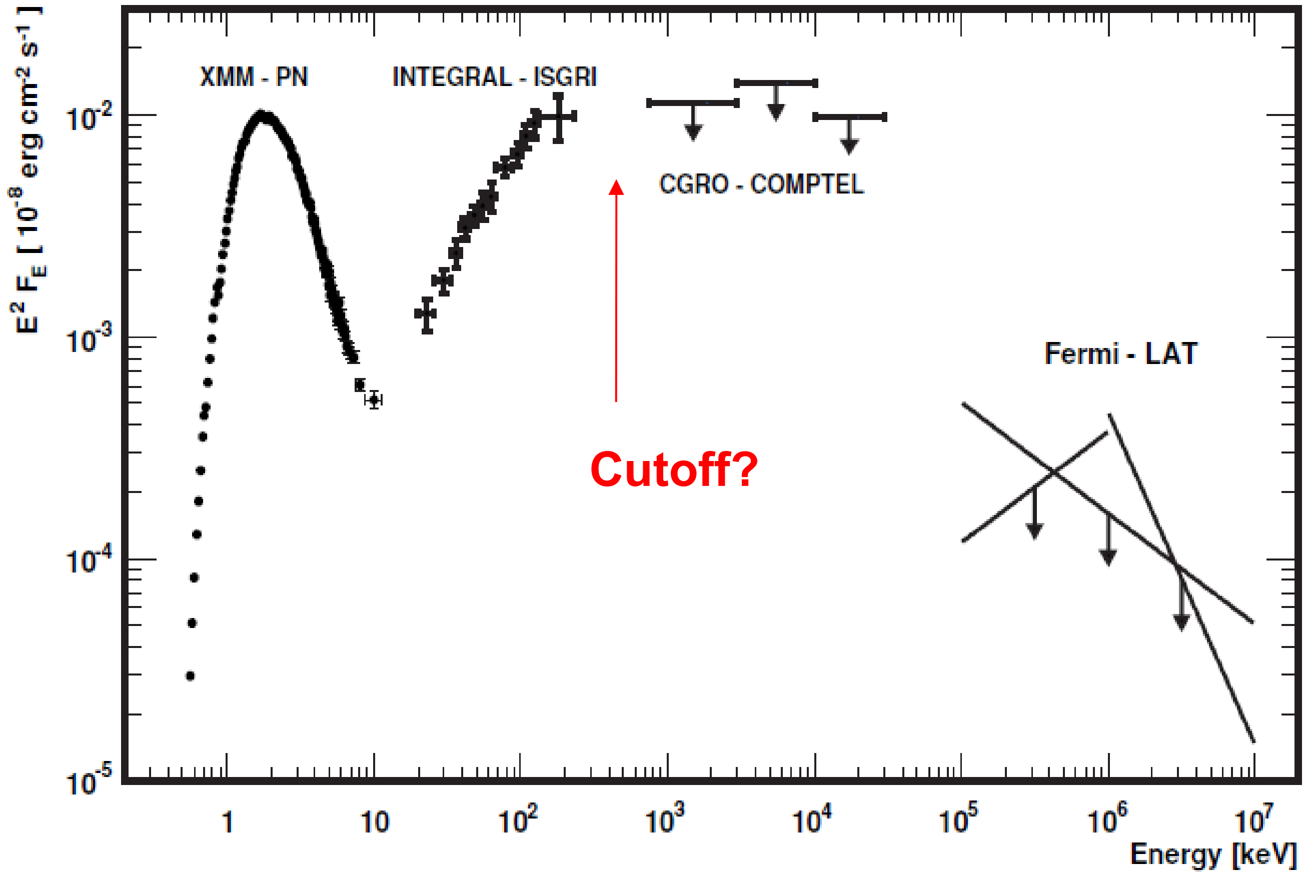


Tong & Xu 2013 RAA

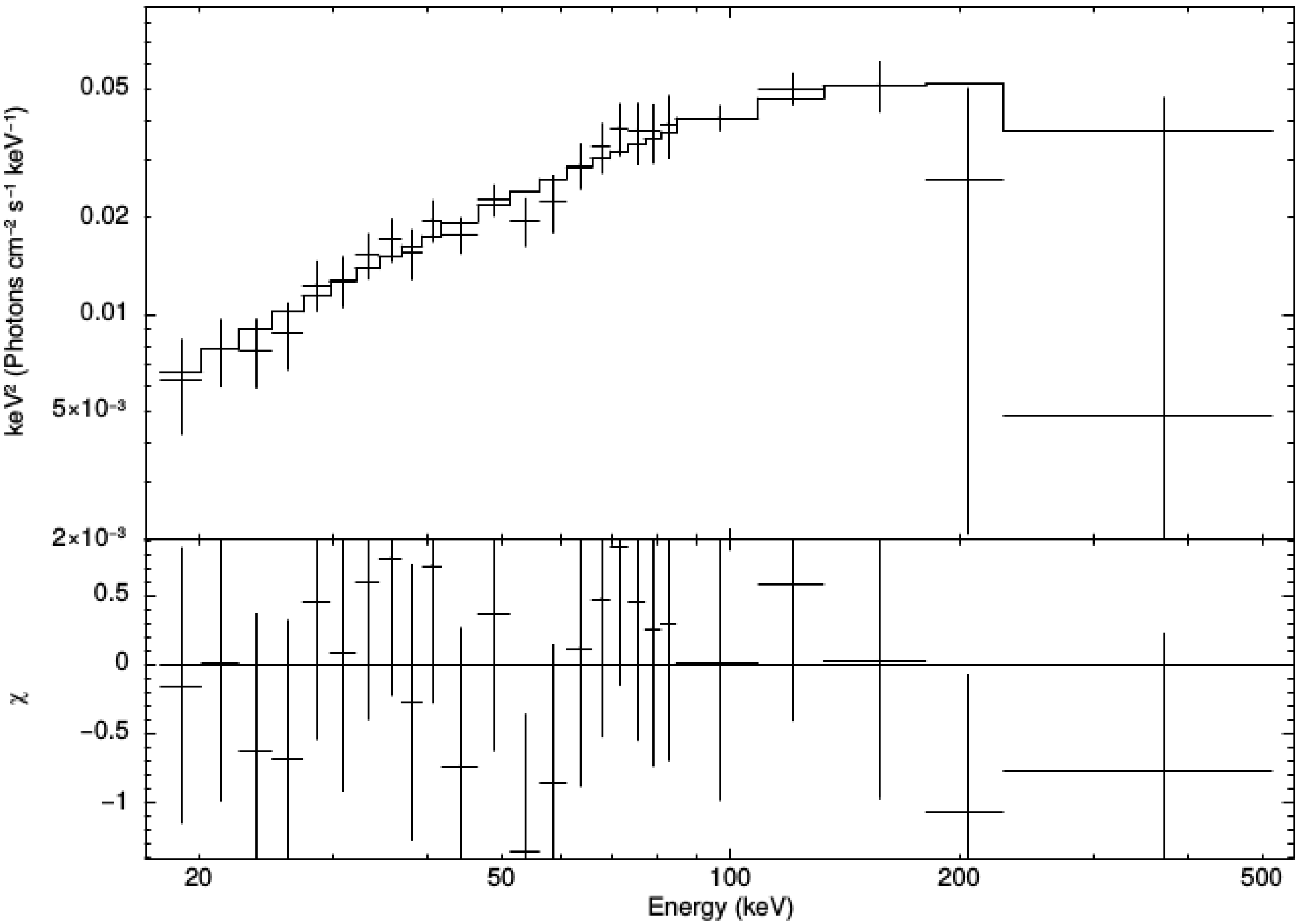
Scholz+ 2014

# Spectra of magnetars

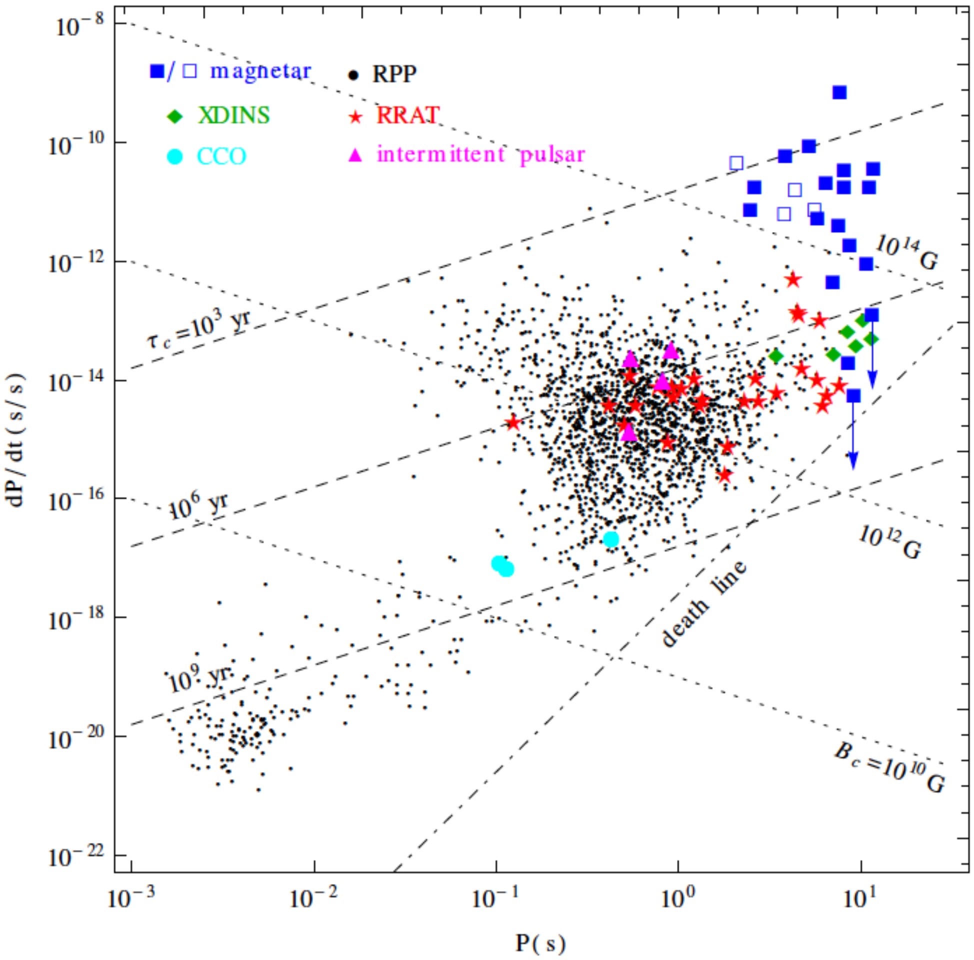
## (Abdo et al. 2010)



# Cuttoff at ~130keV for 4U 0142+61 (Wang, Tong, Guo 2014 RAA; 9 years Integral data)



Conclusion: ultra-relativistic models can be ruled out!



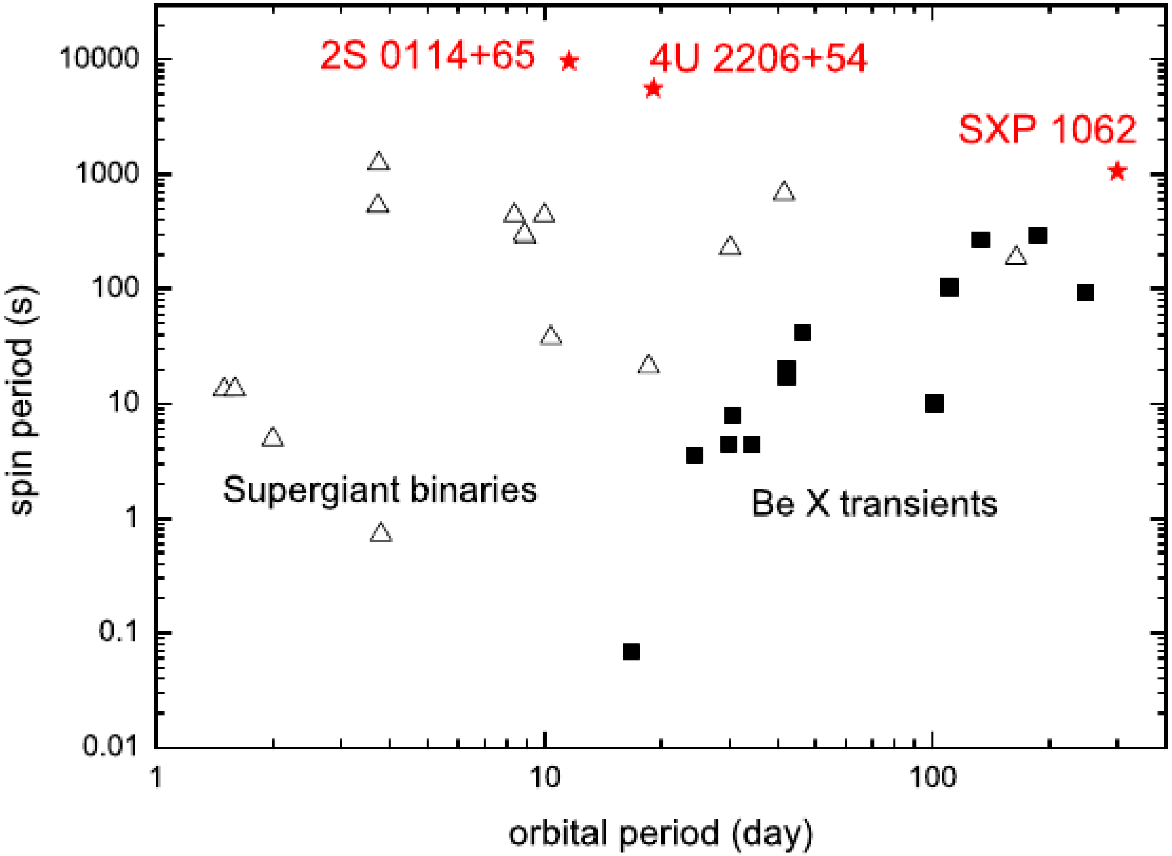
The key difference between magnetars and rotation-powered pulsars:
**multipole magnetic field!**

Not their positions on the P-Pdot diagram (determined by the magnetospheric torque)

Evidence for strong multipole field in accreting systems (Tong & Wang 2014):
1. magnetar burst
2. hard X-ray tail
3. ...

# Super slow X-ray pulsar may not be accreting magnetars
# (Tong & Wang 2014)

Super slow X-ray pulsars in HMXBs



# Ultraluminous X-ray sources

## (Feng & Soria 2011)

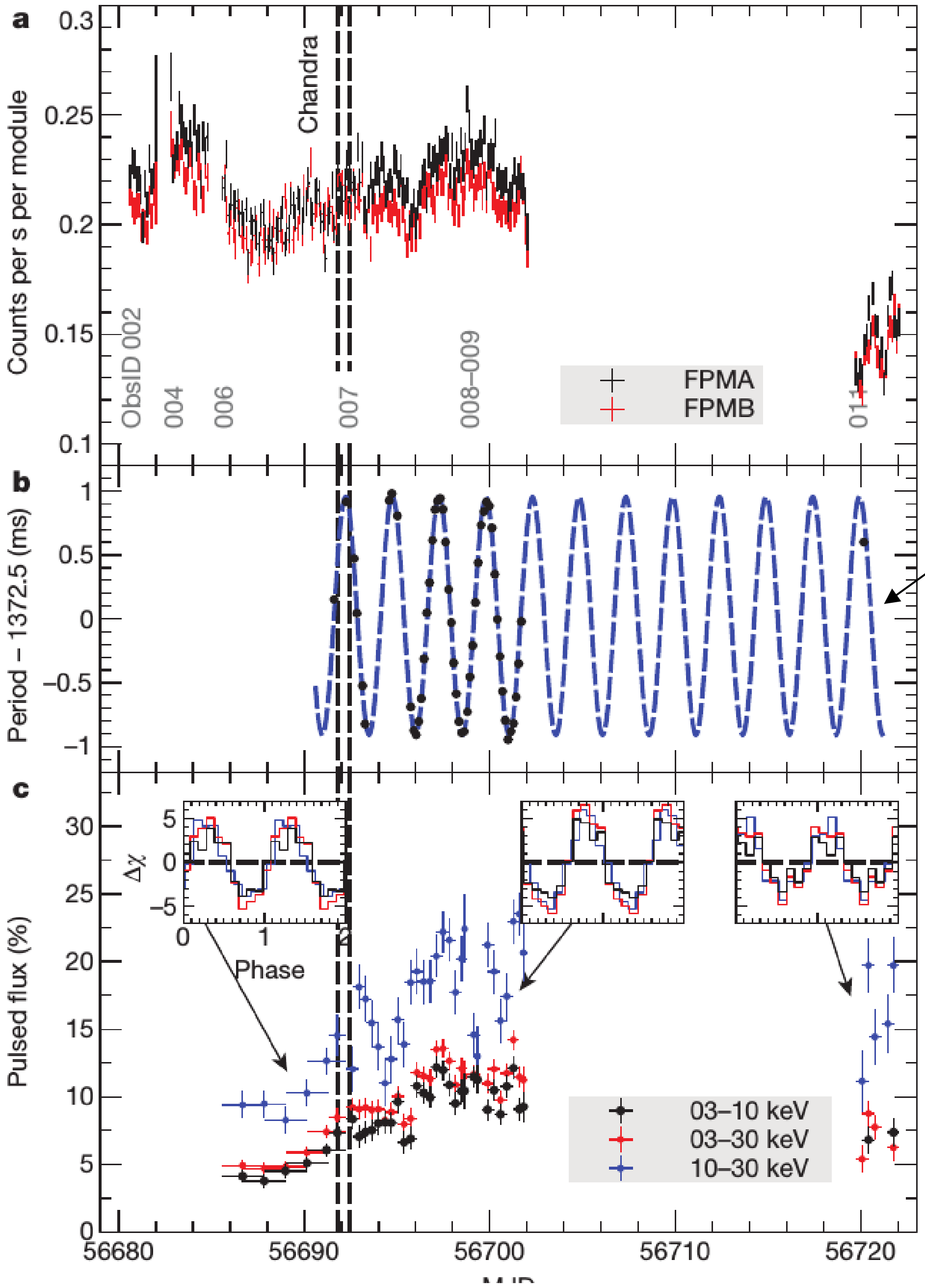
- X-ray point sources offset from the nuclei of nearby galaxies
- Lx=10^39-10^41 erg s^-1
- Intermediate mass black hole (100-10000 Msun) or super-Eddington accreting stellar mass black hole  
  or ...

LETTER

doi:10.1038/nature13791

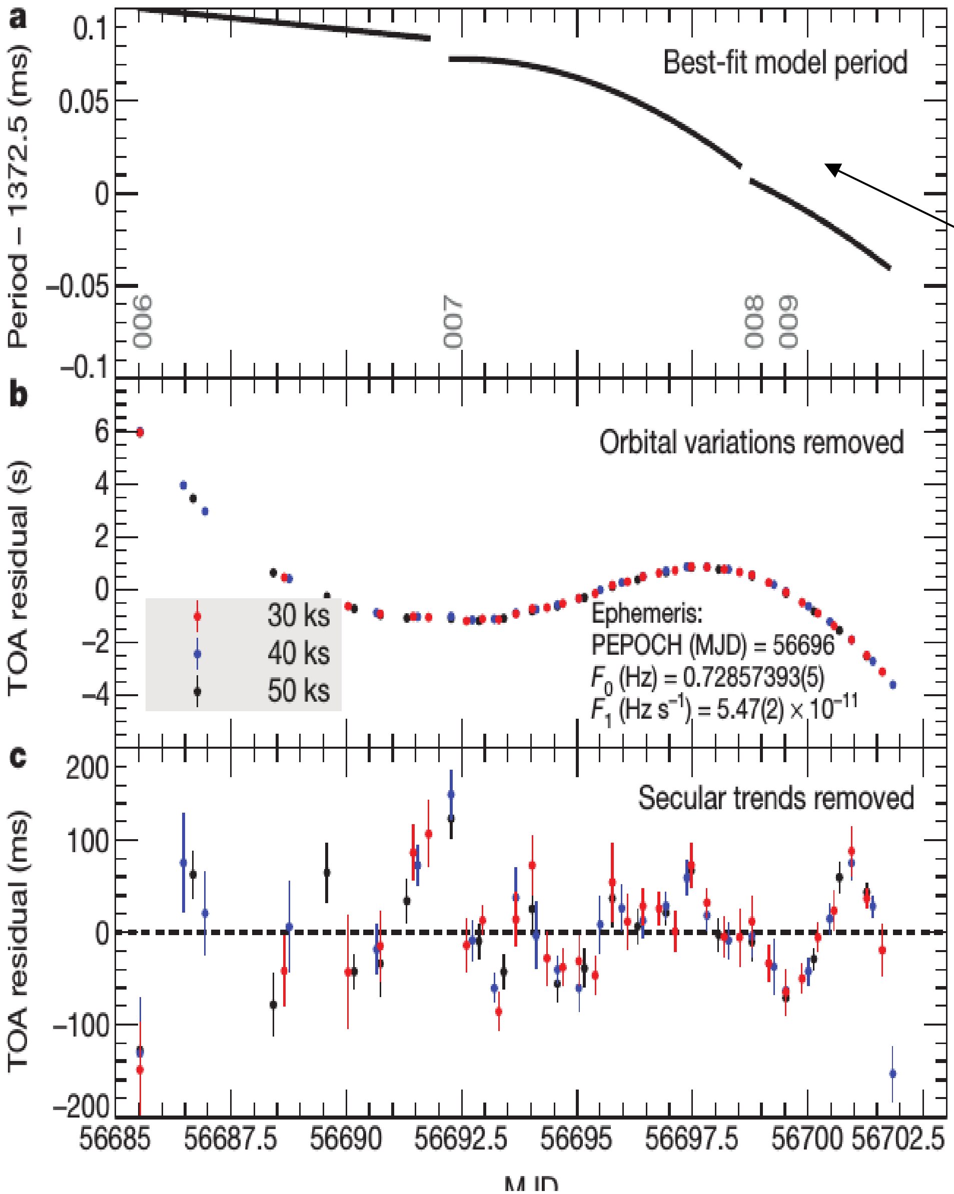
# An ultraluminous X-ray source powered by an accreting neutron star

M. Bachetti[1,2], F. A. Harrison[3], D. J. Walton[3], B. W. Grefenstette[3], D. Chakrabarty[4], F. Fürst[3], D. Barret[1,2], A. Beloborodov[5], S. E. Boggs[6], F. E. Christensen[7], W. W. Craig[8], A. C. Fabian[9], C. J. Hailey[10], A. Hornschemeier[11], V. Kaspi[12], S. R. Kulkarni[3], T. Maccarone[13], J. M. Miller[14], V. Rana[3], D. Stern[15], S. P. Tendulkar[3], J. Tomsick[6], N. A. Webb[1,2] & W. W. Zhang[11]



Bachetti et al. 2014

Pulsation (1.37 s) modulated
By the orbital motion (2.5 day)



Bachetti et al. 2014

The neutron star is spinning up!
Pdot=-2*10^-10
Typical accretion-power X-ray pulsars

Problem & Difficulity:
How to explain the super-Eddington luminosity (10^40 erg s^-1) and spin-up rate?

Accreting magnetar

# Models: accreting magnetar

- Observation: Bachetti et al. (arXiv:1410.3590)

1. Eksi et al. (arXiv:1410.5205): accreting magnetar, smaller torque during accretion equilibrium
2. Lyutikov (1410.8745): accreting magnetar, smaller torque due to super-Eddington accretion
3. Tong (1411.3168): accreting low magnetic field magnetar
4. Christodoulou et al. (1411.5434): accreting normal neutron star
5. Dall'Osso et al. (1412.1834): accreting magnetar
6. Guo et al.: massive pulsars (GR responsible for the super Eddington luminosity)
7. Fragos et al. (1501.02679), Shao & Li (1502.03905): formation

# Accreting low magnetic field magnetar

- Aged magnetars are more like to be low magnetic field magnetars (10^6 yrs old; consistent with population synthesis)
- Super-Eddington luminosity due to the presence of strong multipole field (e.g.,10^14 G)
- Rotational behaviors due to the interaction of much lower dipole field (10^12 G) with the accretion flow

# Discussion

- M82 X-2 may be the counterpart of this ultraluminous X-ray pulsar.

1. Wide luminosity range 10^37-10^40 erg s^-1 (Feng et al. 2007; Kong et al. 2007): due to switches between accretion phase and propeller phase
2. A disk component (at 4.1 sigma level, Feng et al. 2010):
   - temperature (0.17+-0.03 keV) vs. 0.15 keV(theory), inner
   - disk radius (3.5+3.0-1.9)*10^9 cm vs. 7.5*10^7 cm (theory)
   - future more accurate observations may contrain current models

# Discussion

3. Theoretical period range: 0.1-10^3 seconds for accreting magnetars. In search of these periodic signals, the orbital effect must be taken into consideration.
4. Three observational signatures of accreting magnetars (effect of multipole field): (1) magnetar-like burst; (2) A hard X-ray tail (>100keV); (3) ultraluminous X-ray pulsar.

# Summary

- Ultraluminous X-ray pulsar as accreting magnetars

1. Magnetar strength multipole field (10^14 G)--> super-Eddington luminosity
2. Lower large scale dipole field (10^12 G) determines the interaction between accretion flow and central neutron star--> timing behaviors
3. Possible transient counterpart: switches between accretion phase and propeller phase
4. Wide theoretical period range
5. Three observational signatures of accreting magnetars

**The hard X-ray modulation telescope (HXMT) may contribute on these aspects**