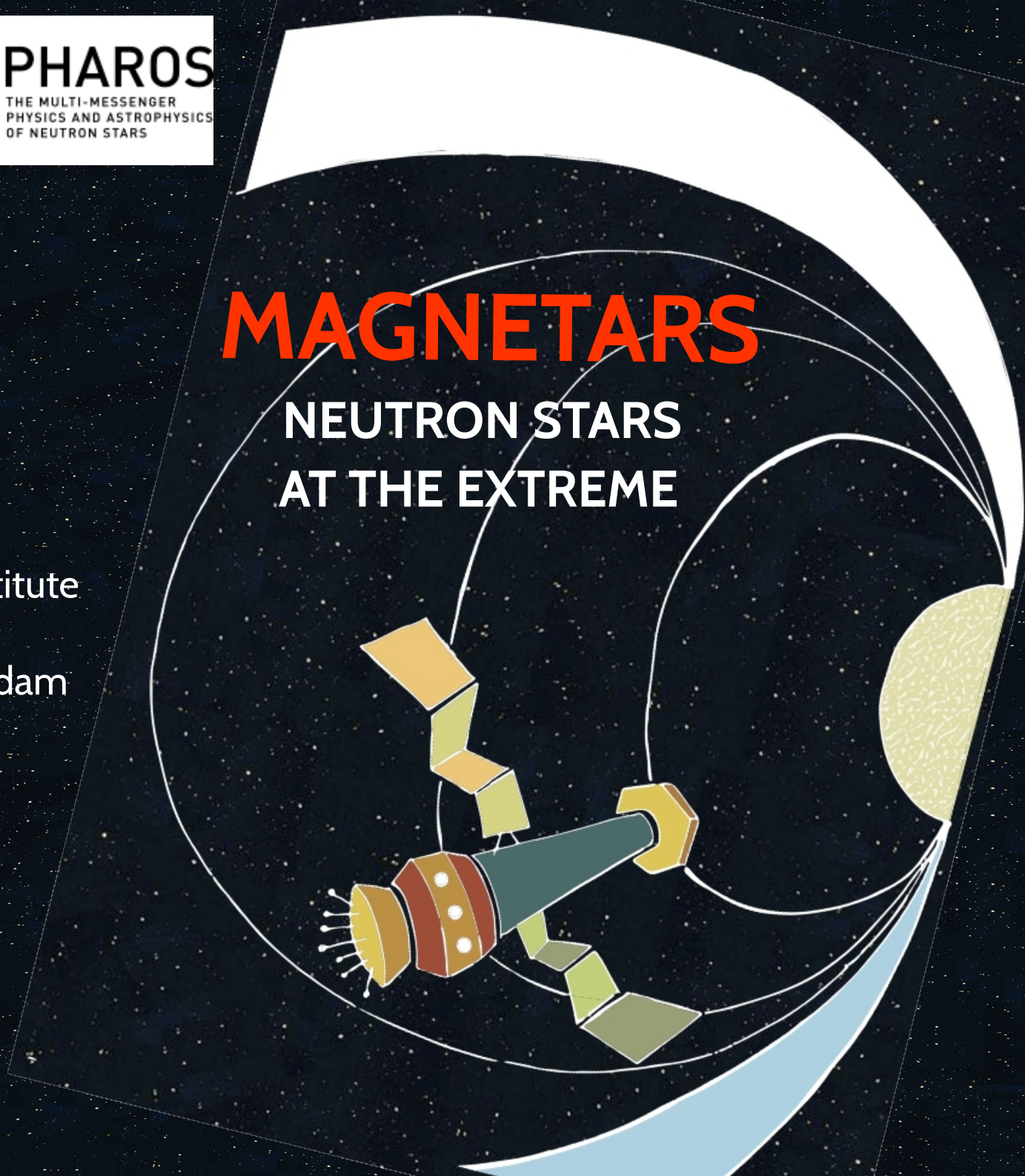
PHAROS
THE MULTI-MESSENGER PHYSICS AND ASTROPHYSICS OF NEUTRON STARS

MAGNETARS

NEUTRON STARS AT THE EXTREME



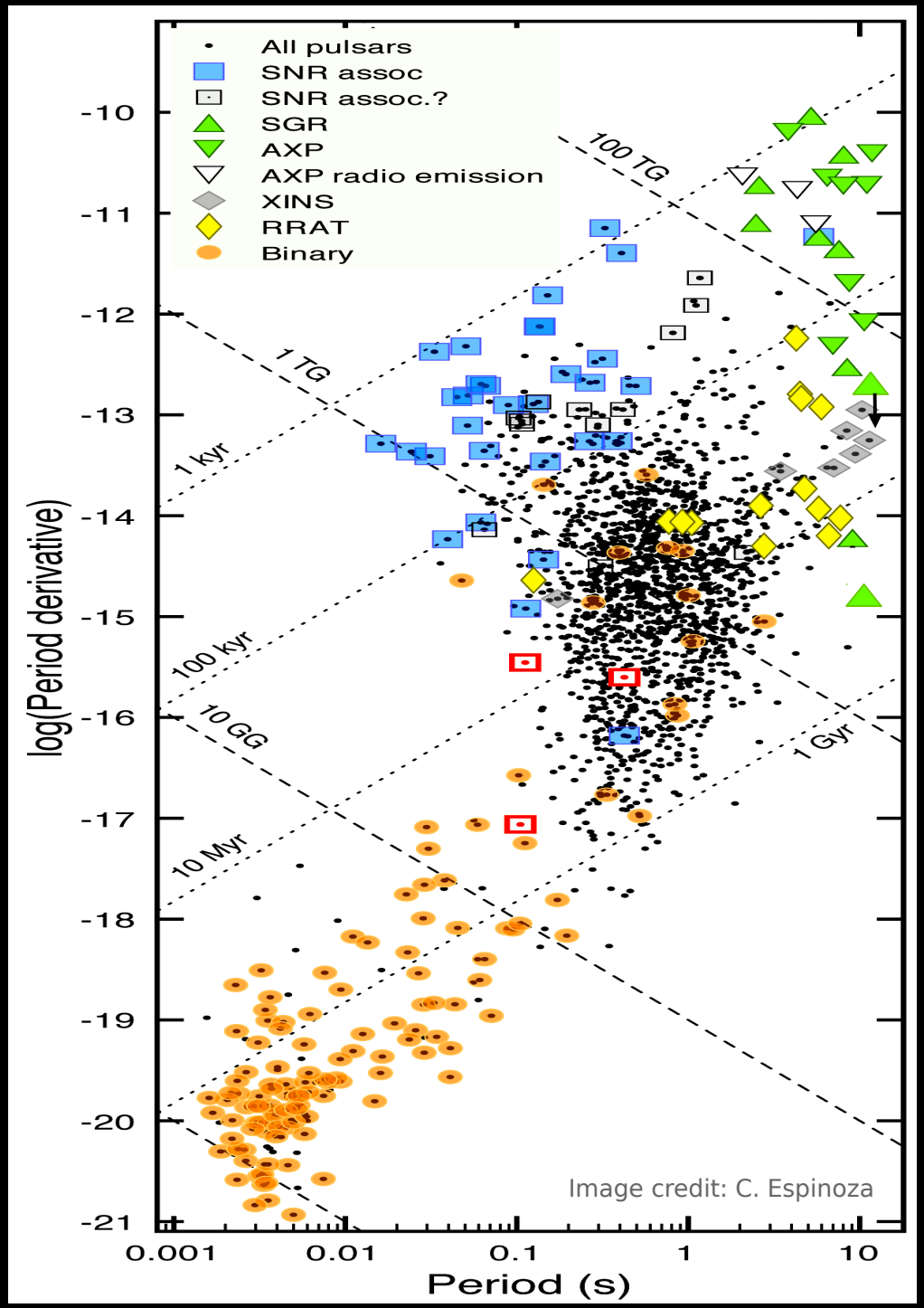
Alice Borghese

Anton Pannekoek Institute
for Astronomy
University of Amsterdam

ANTON PANNEKOEK INSTITUTE

INTEGRAL looks AHEAD to Multi-Messenger Astrophysics

The neutron star zoo

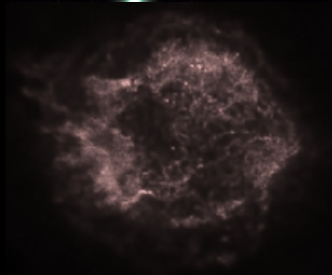


Magnetars: B-powered

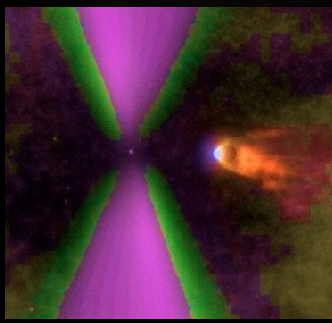
XDINS: kT-powered

Pulsars: rotation-powered

CCOs: kT-powered

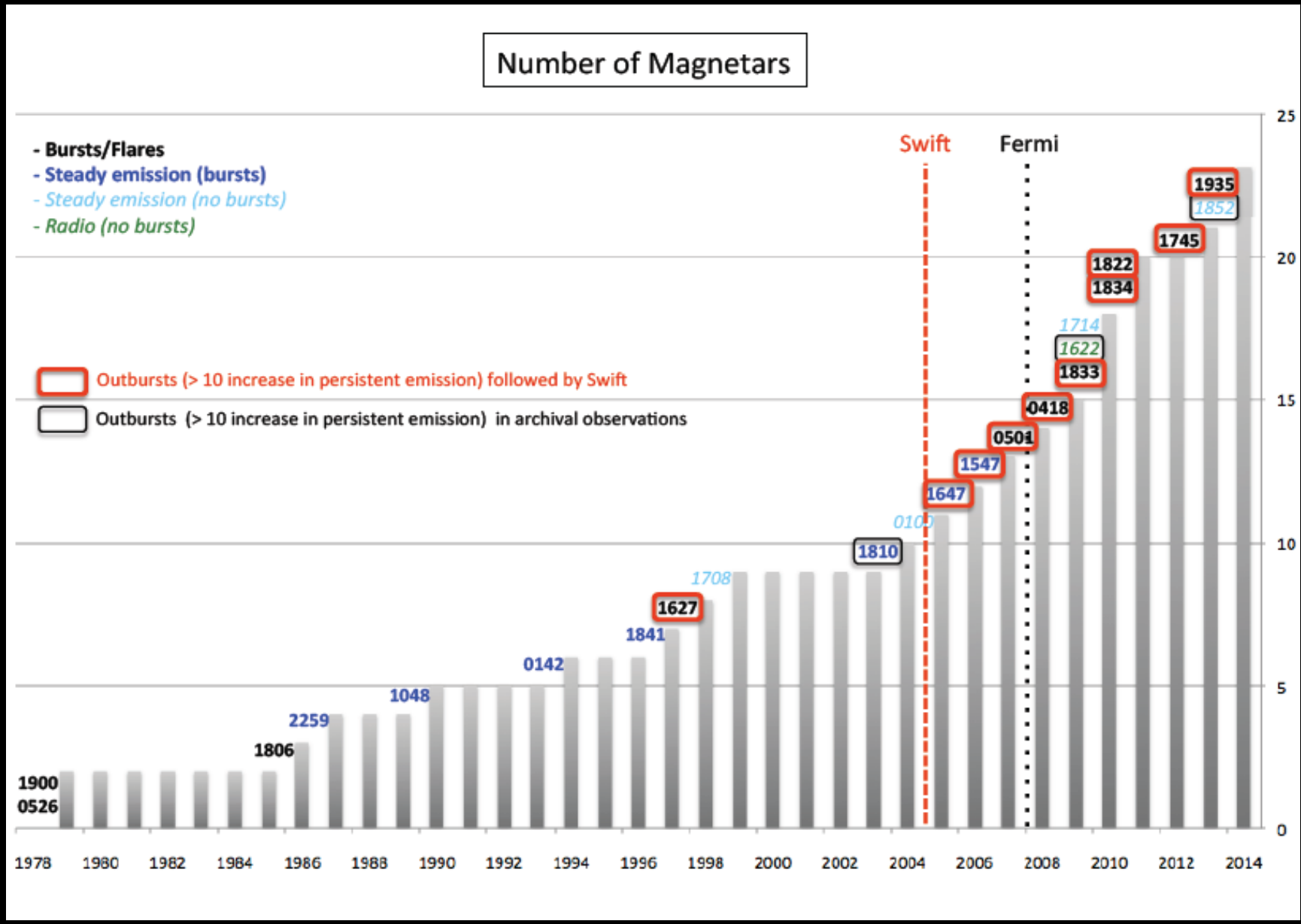


MSPs recylced in binaries: rotation-powered



Magnetars: observational properties

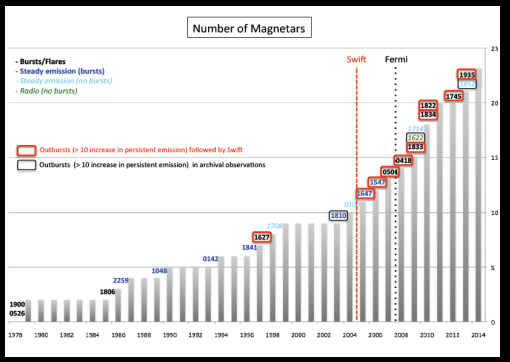
23 confirmed magnetars + 6 candidates



Olausen & Kaspi 2014

Magnetars: observational properties

23 confirmed magnetars



X-ray luminosity ($L_x \sim 10^{31}$ - 10^{36} erg s^{-1}) generally larger than the rotational energy loss rate

Dipolar magnetic fields $B_{dip} \sim 10^{13}$ – 10^{15} G

Rotating with $P \sim 0.3$ – 12 s

For reviews Turolla et al. 2015; Kaspi & Beloborodov 2017; Esposito et al. 2018

Magnetars: observational properties

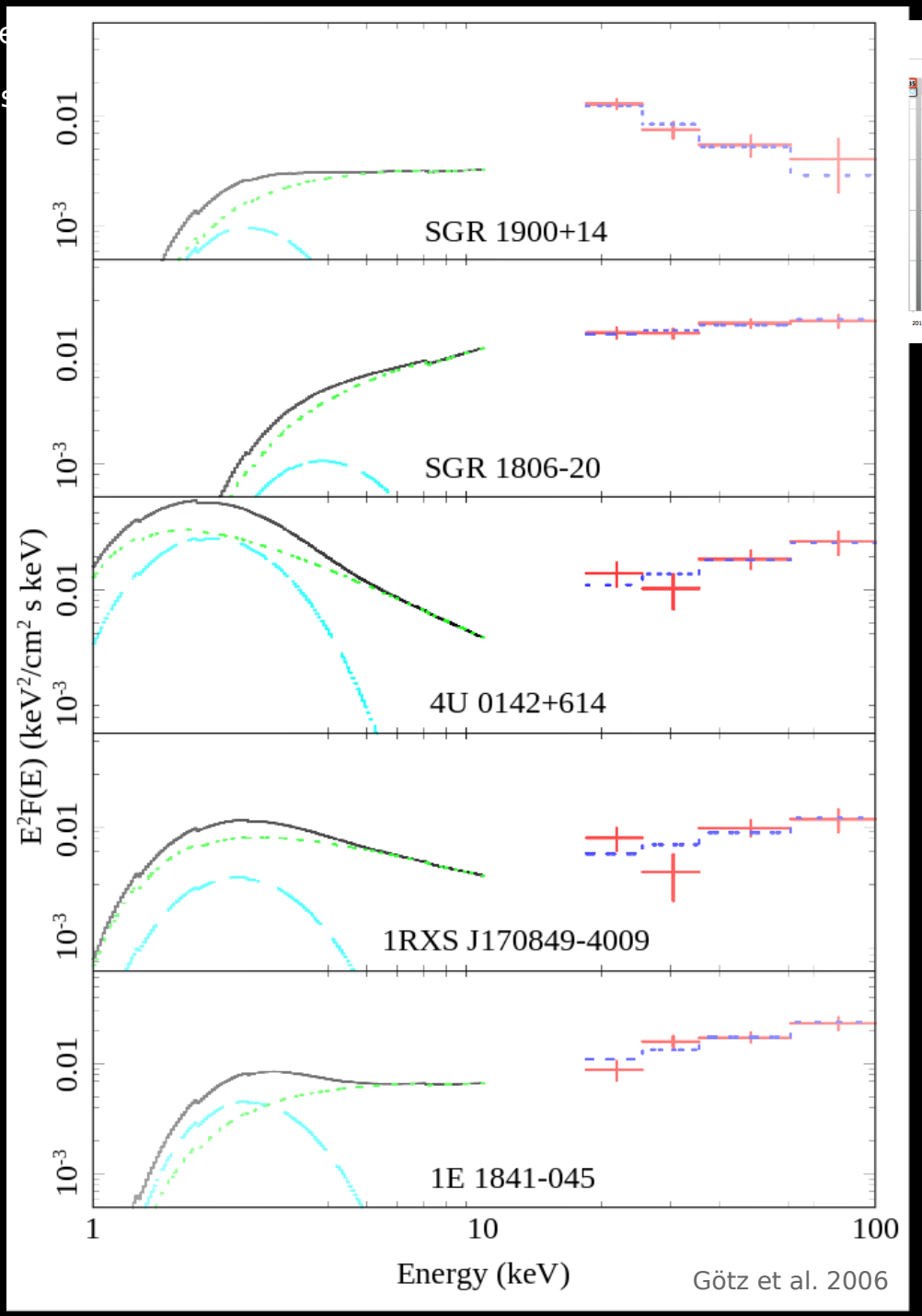
23 confirmed magnetars with X-ray luminosity $L_x \sim 10^{31}$ - 10^{36} e

X-ray luminosity generally larger than the rotational energy los

Dipolar magnetic fields $B_{dip} \sim 10^{13}$ – 10^{15} G

Rotating with $P \sim 0.3$ – 12 s

Broadband spectra
0.5 – 100 keV
soft thermal + hard non-thermal
spectral components



Götz et al. 2006

Magnetars: flaring activity (timescale: sec – min)

GIANT FLARES

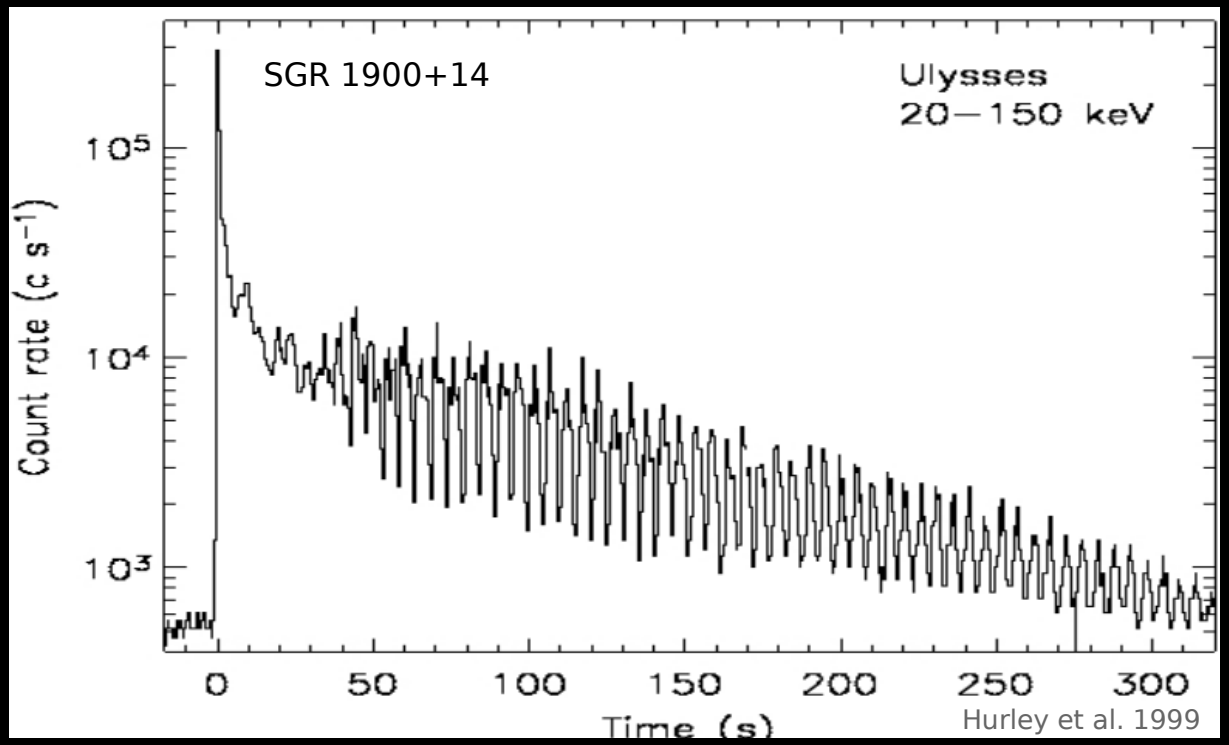
rare events

$L_x > 10^{44}$ erg s^{-1}

initial spike with a hard spectrum

+

long pulsating tail modulated at the NS spin period



Magnetars: flaring activity (timescale: sec – min)

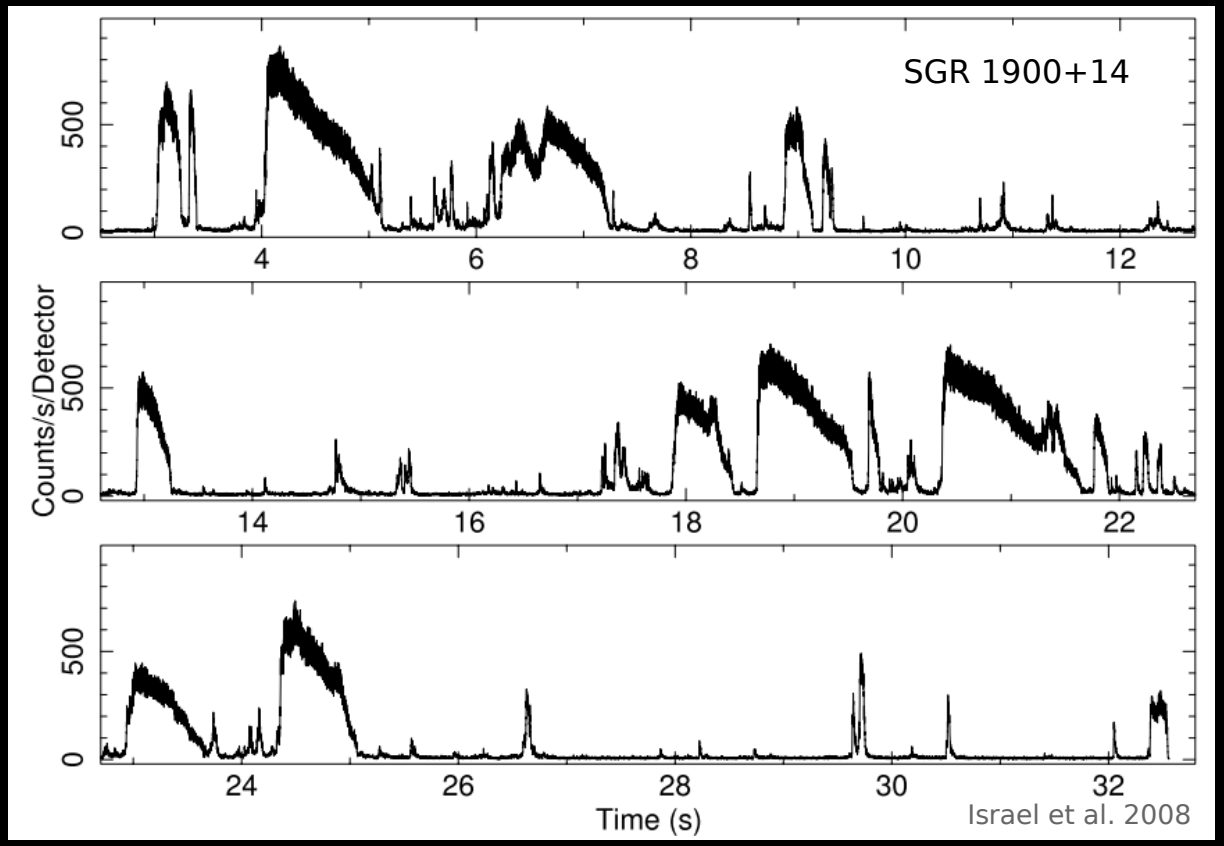
INTERMEDIATE BURSTS

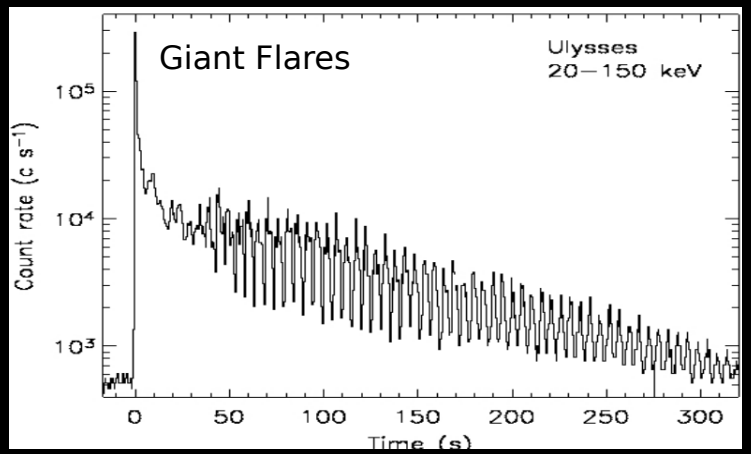
duration ~ 1 – 40 s

$L_{peak} \sim 10^{41} - 10^{43}$ erg s^{-1}

abrupt onset

thermal spectra





Magnetars: flaring activity (timescale: sec – min)

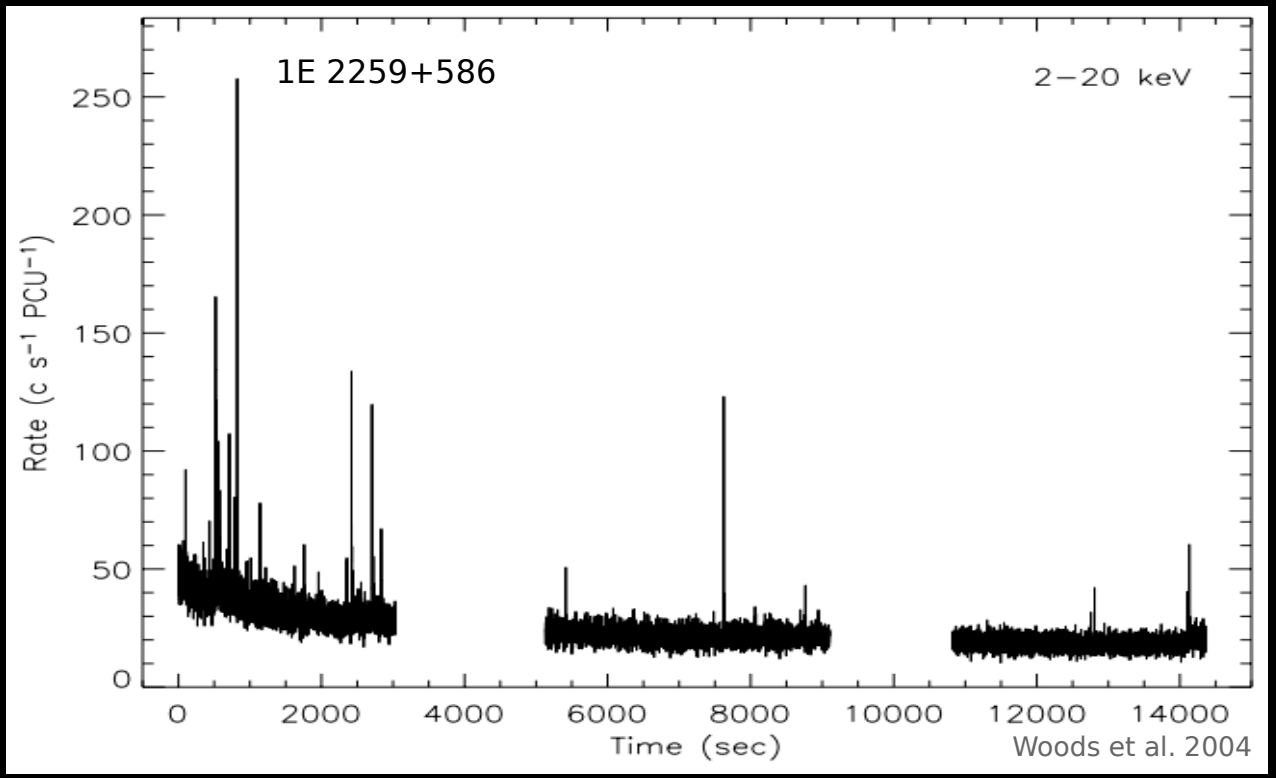
SHORT BURSTS

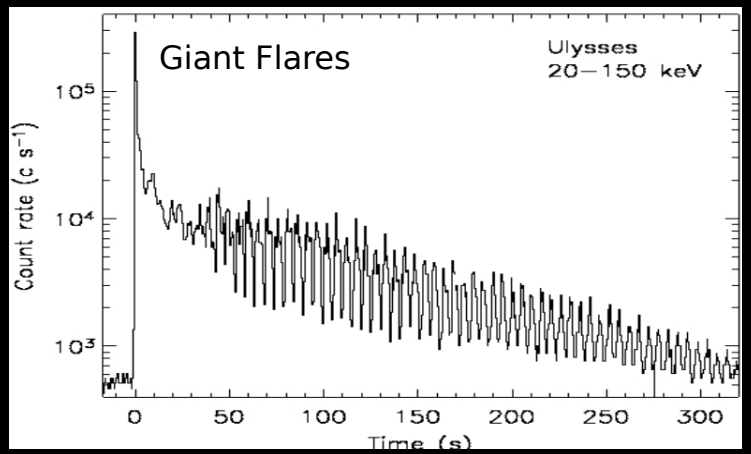
Duration ~ 0.01 – 1 s

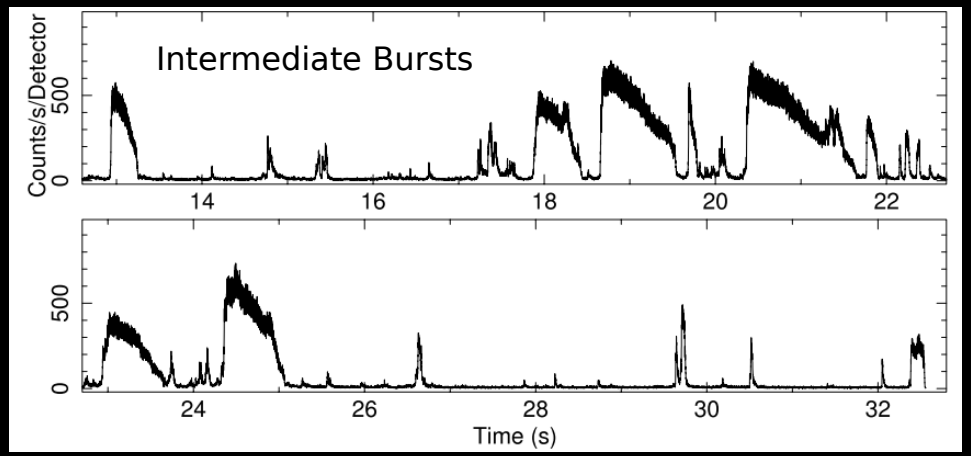
$L_{peak} \sim 10^{39} - 10^{41}$ erg s^{-1}

sporadically or storm

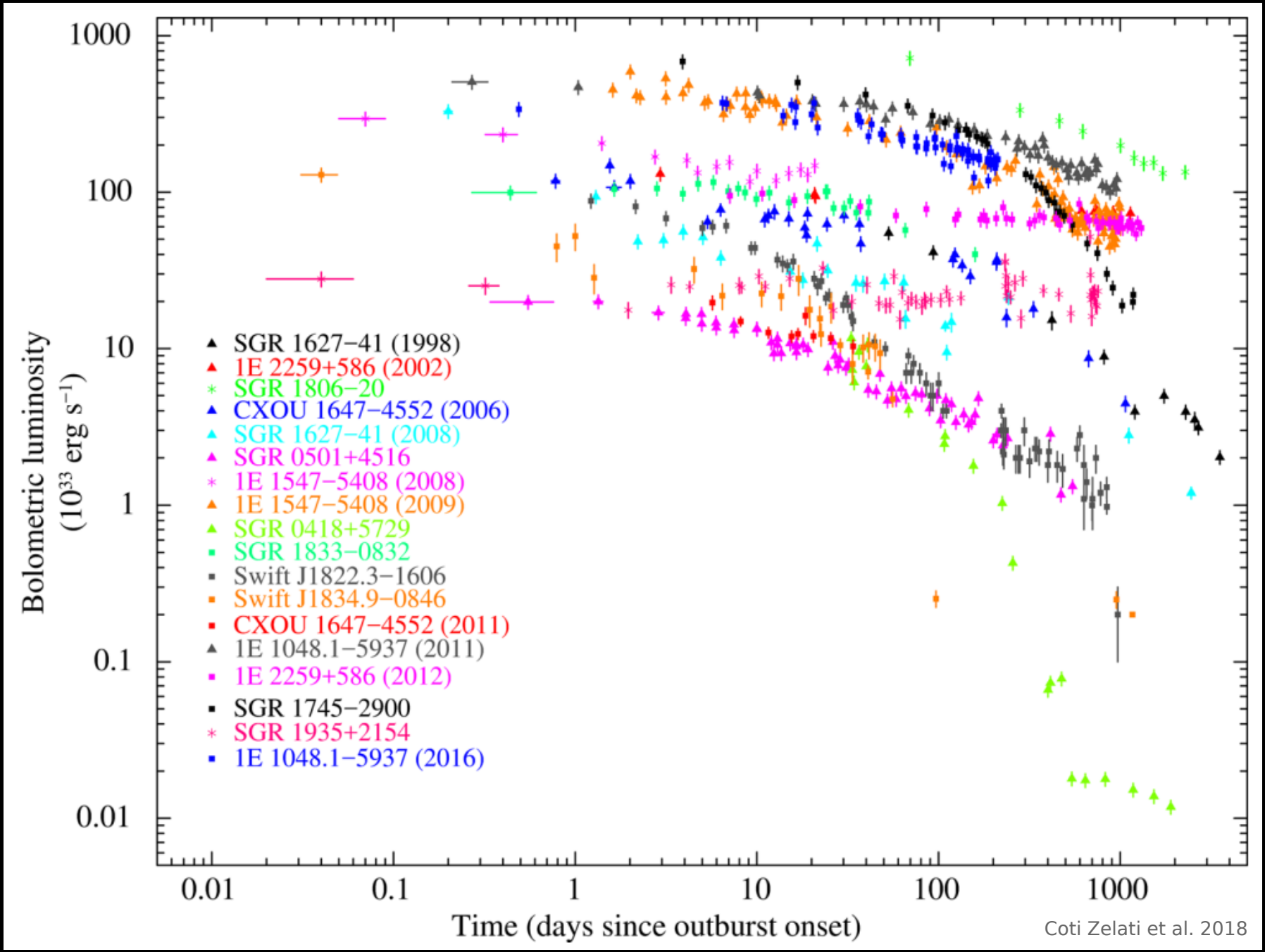
thermal spectra





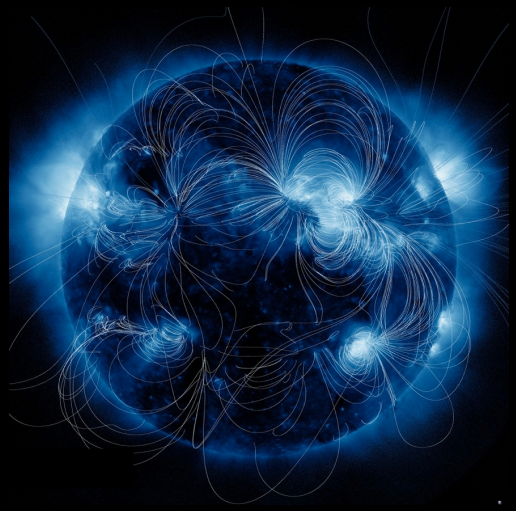


Magnetars: outbursts (timescale: months – years)



Magnetars: outburst mechanisms

Internal source of heat



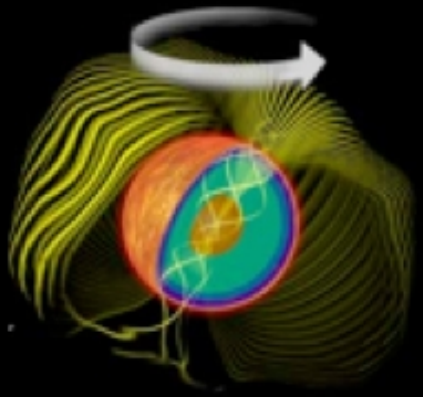
Magnetic stresses in localized regions of the crust

Plastic flows convert magnetic energy into heat

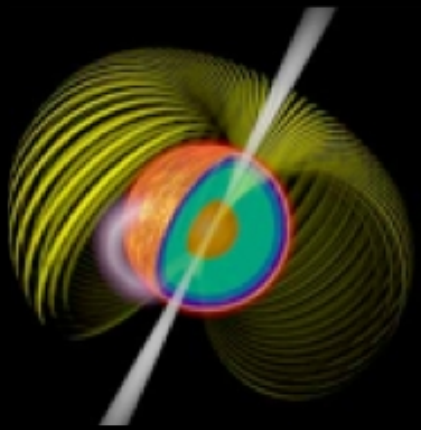
Heat conducted up and radiated

External source of heat

Magnetar



Normal Pulsar

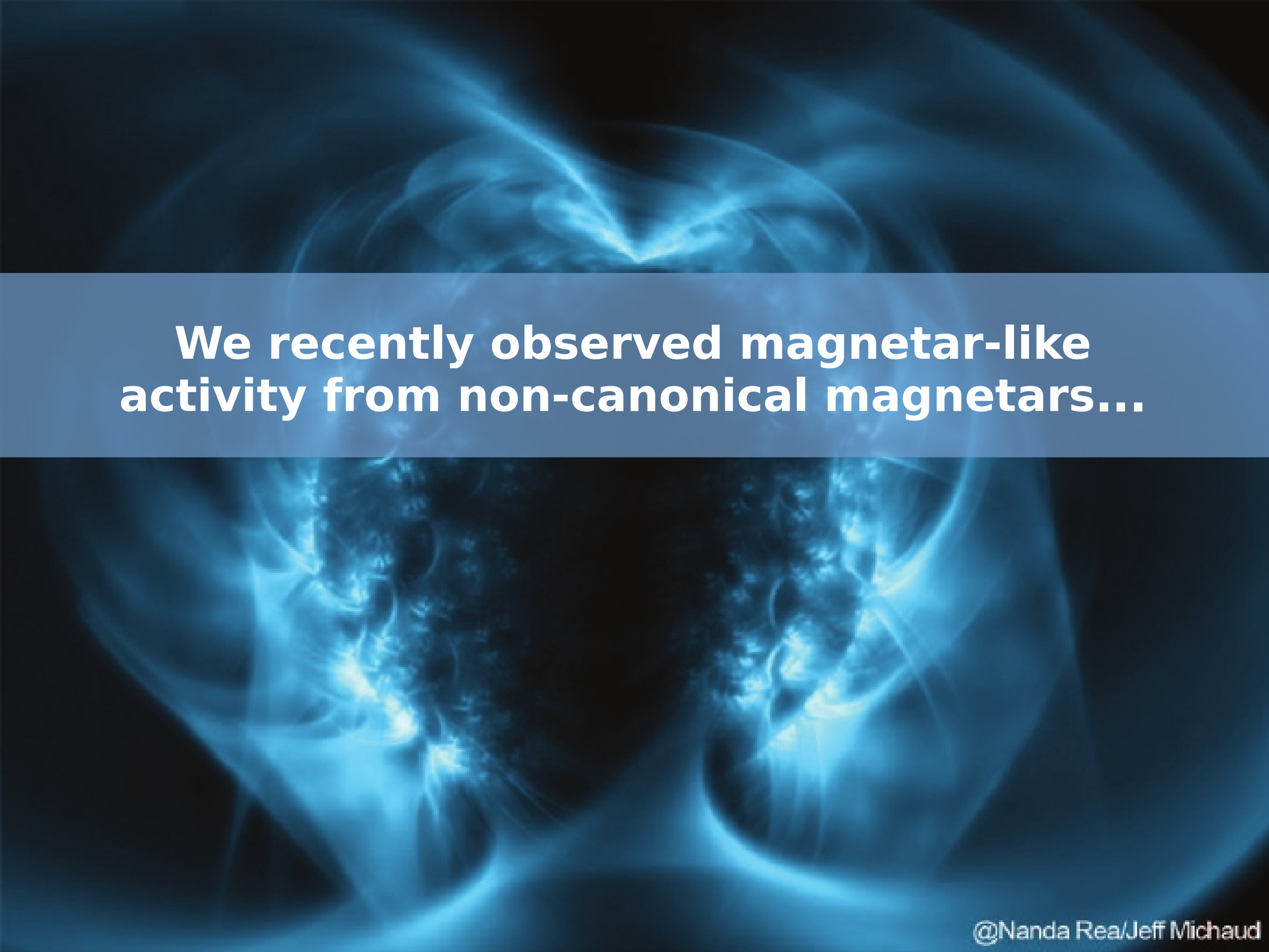


Crustal displacements twist up the external *B*-field

Returning currents hit and heat the magnetar surface

Bundle dissipates as the the energy supply from the star interior decreases

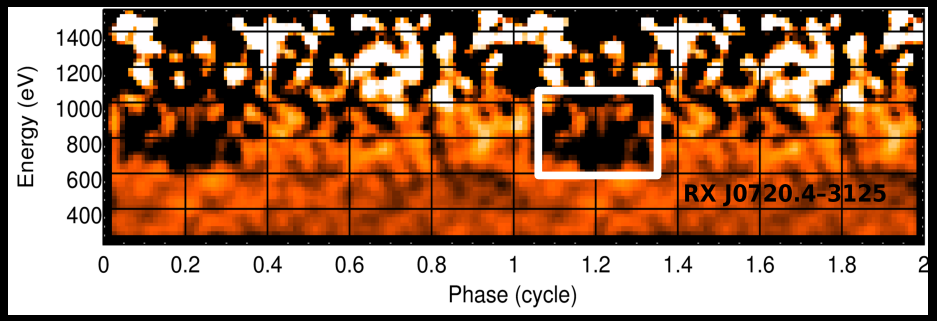
Nobili, Turolla & Zane 2008a,b; Beloborodov 2009; Pons & Rea 2012; Parfrey et al. 2013; Beloborodov & Levin 2014; Beloborodov & Li 2016; Li et al. 2016; Li et al. 2018

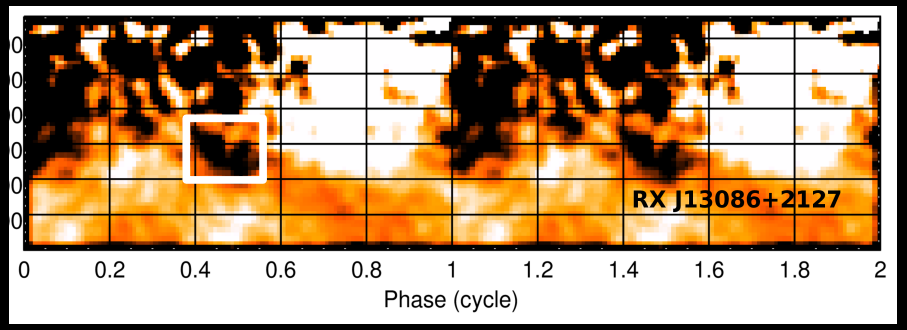

We recently observed magnetar-like activity from non-canonical magnetars...
@Nanda Rea/Jeff Michaud

Not only magnetars: X-ray Dim Isolated Neutron Stars

Radio-quiet, nearby, thermally emitting INSs with $P \sim 3$ – 11 s and $B_{dip} \sim 10^{13}$ G

Narrow phase-dependent absorption features





Borghese et al. 2015, 2017

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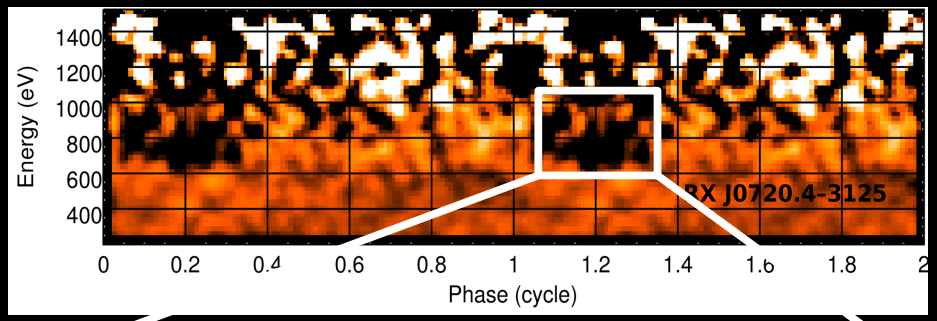

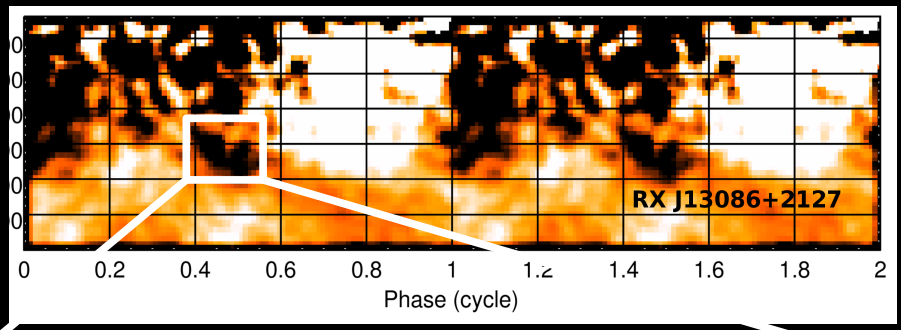

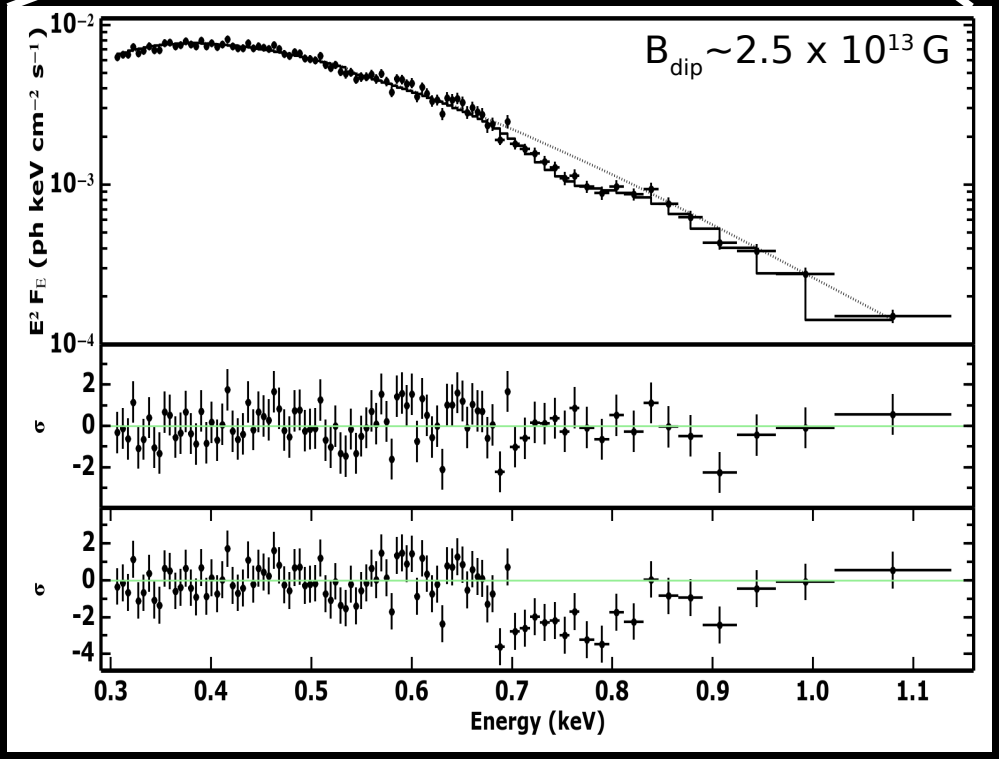

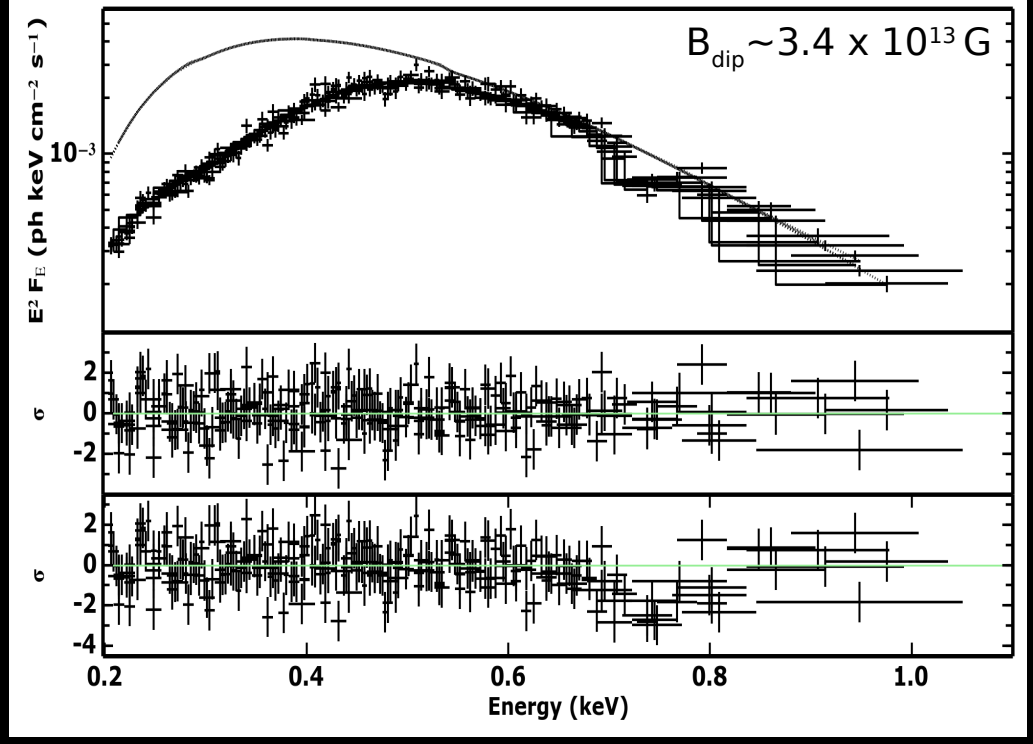

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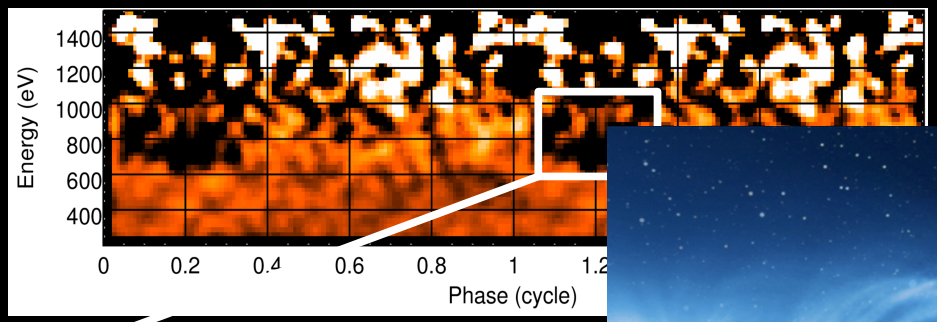
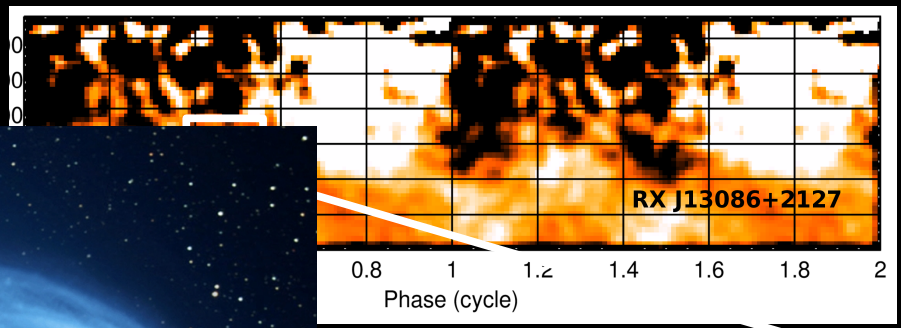
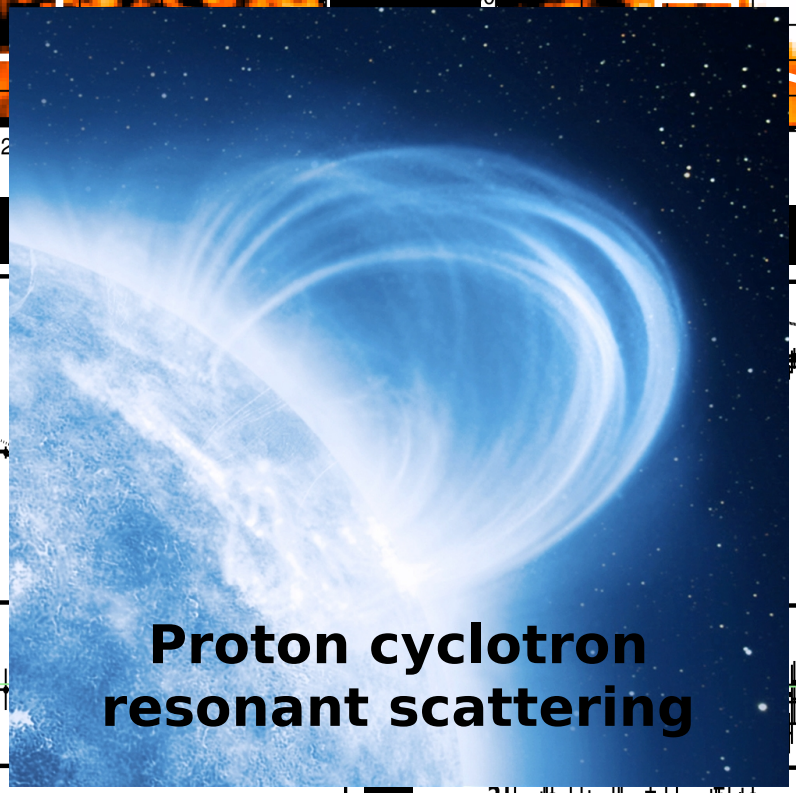
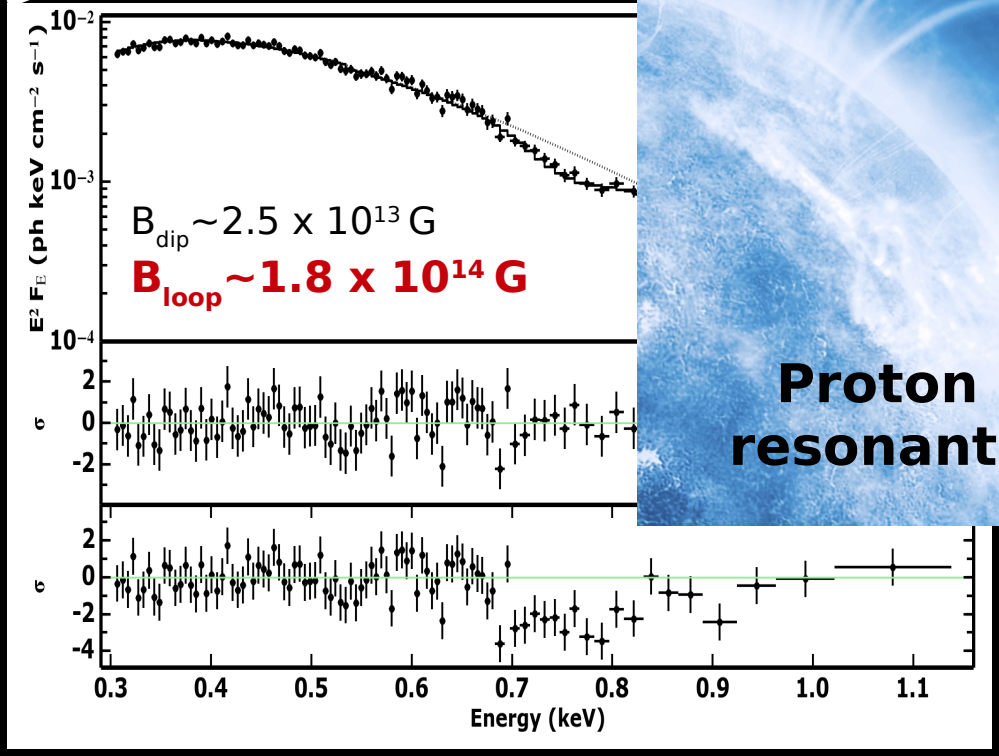
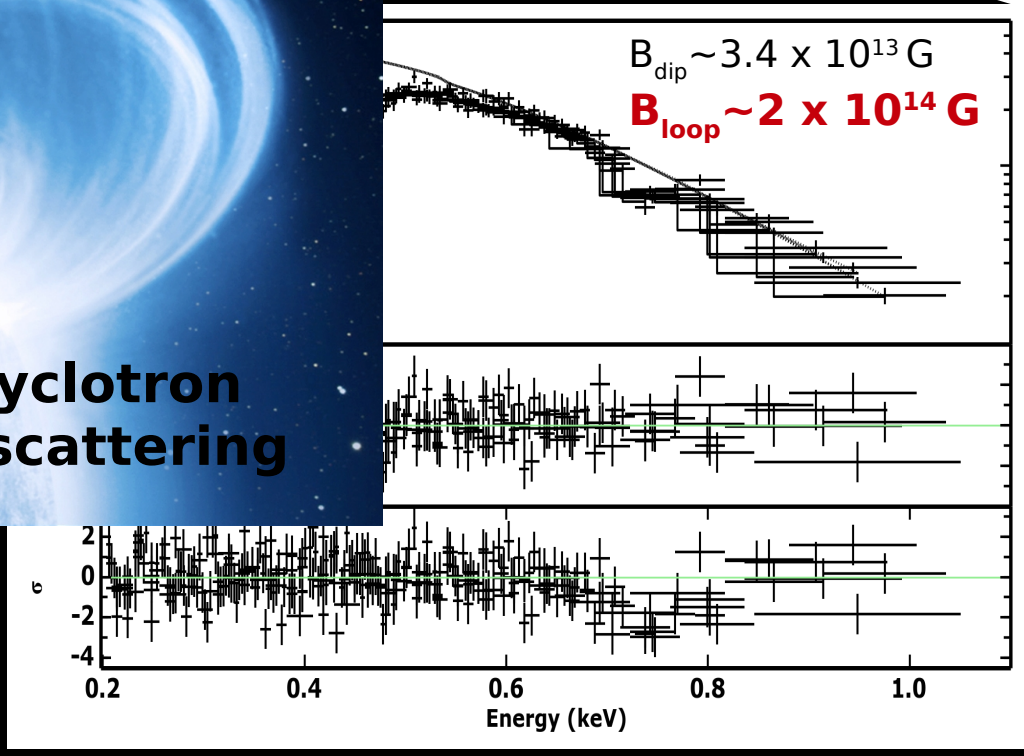






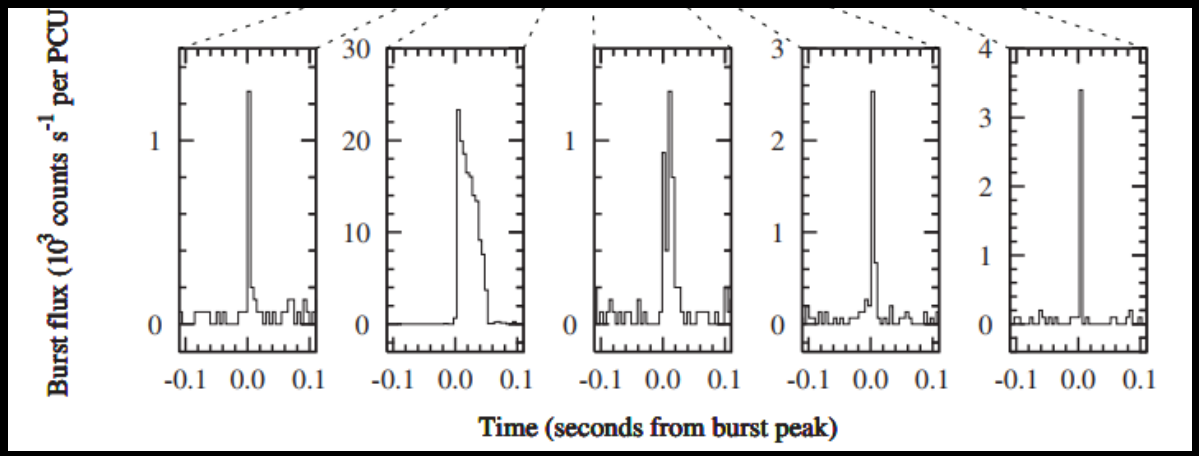


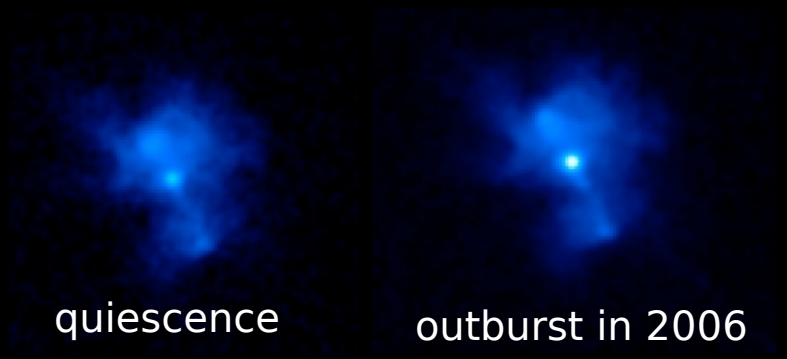


Borghese et al. 2015, 2017

PSR J1846-0258

at the center of the SNR Kes75 with $B_{dip} \sim 5 \times 10^{13}$ G





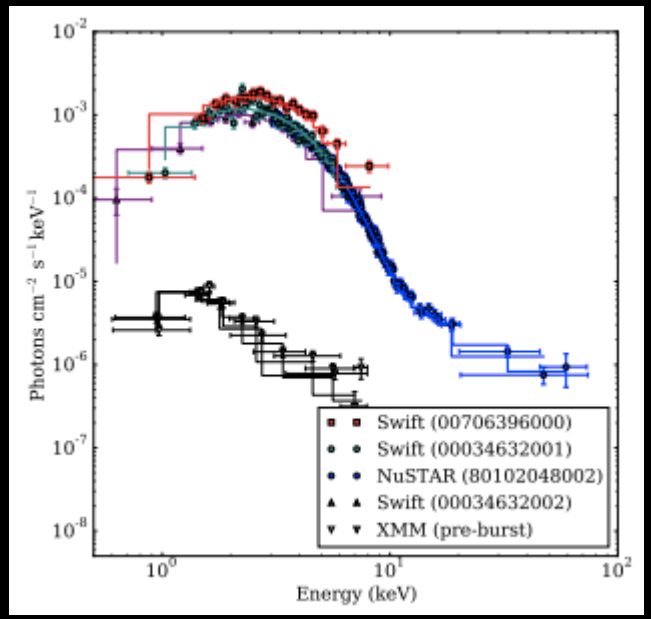
quiescence outburst in 2006

Gavriil et al. 2008; Kumar & Safi-Harb 2008

PSR J1119-6127

with $B_{dip} \sim 4 \times 10^{13}$ G

outburst in 2016

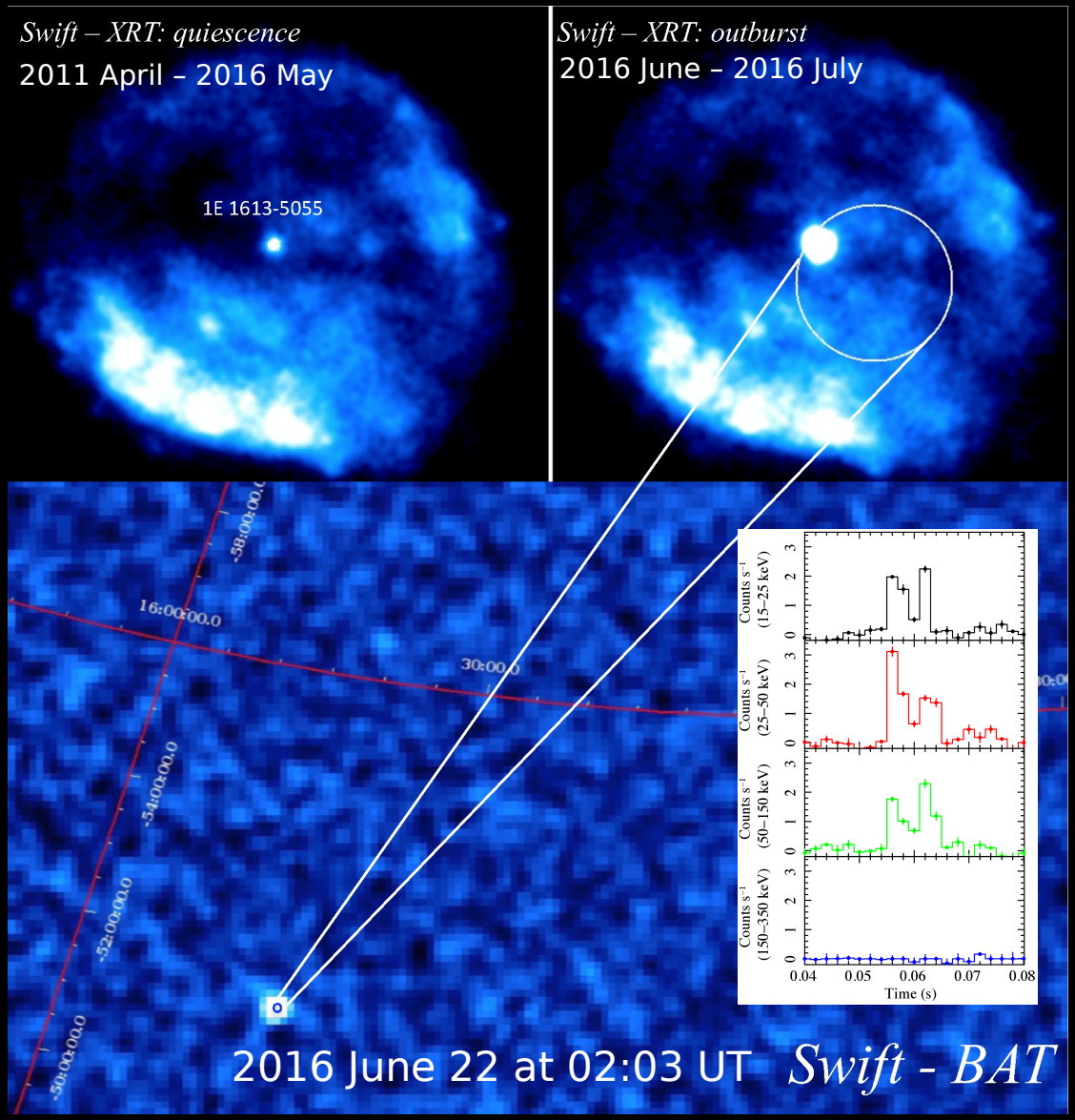


Archibald et al. 2016, 2017; Gogus et al. 2008

Not only magnetars: the strangest known pulsar

1E 161348-5055

at the center of the SNR RCW103 with $P \sim 6.67$ h



Rea, Borghese et al. 2016; D'Aì et al. 2016; Borghese et al. 2018

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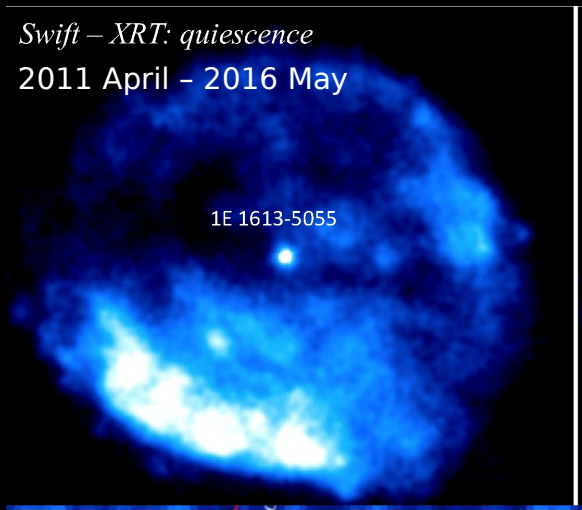
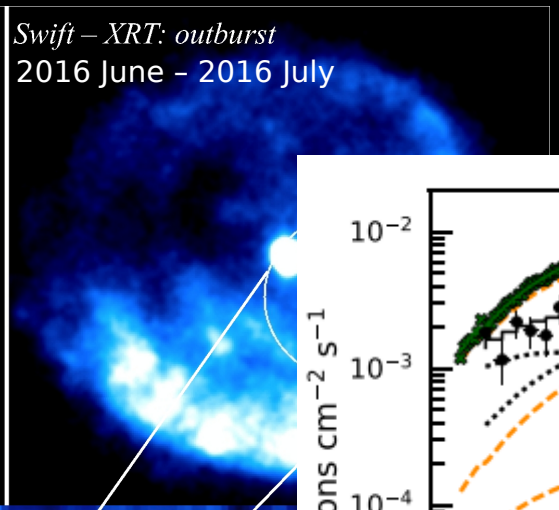
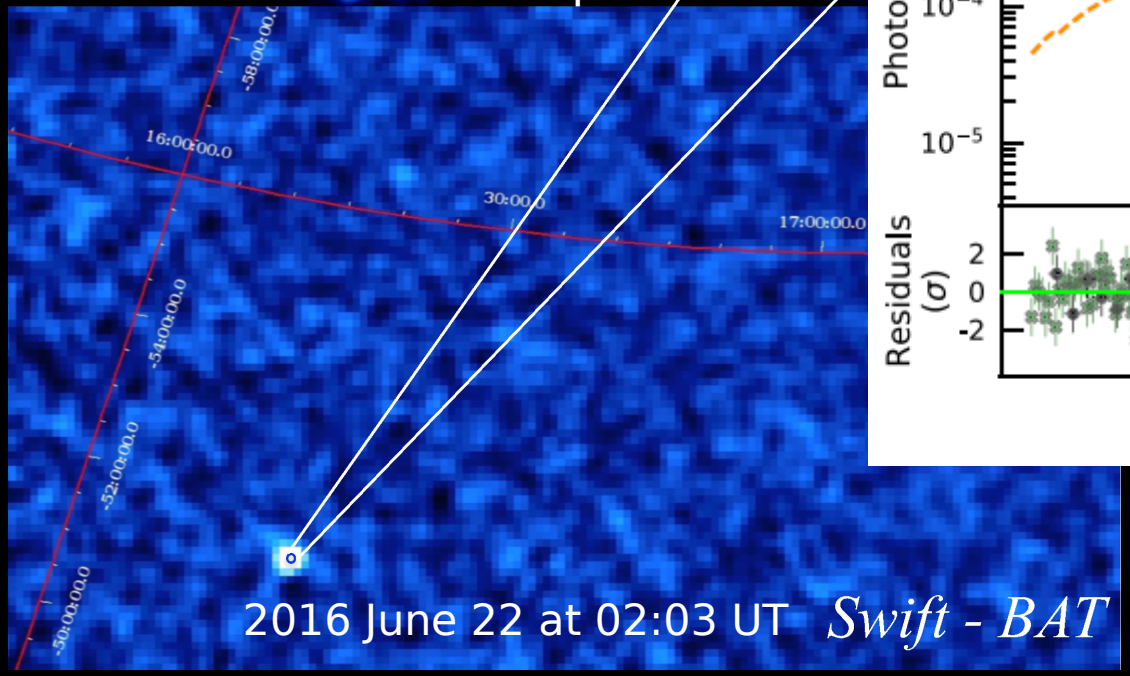
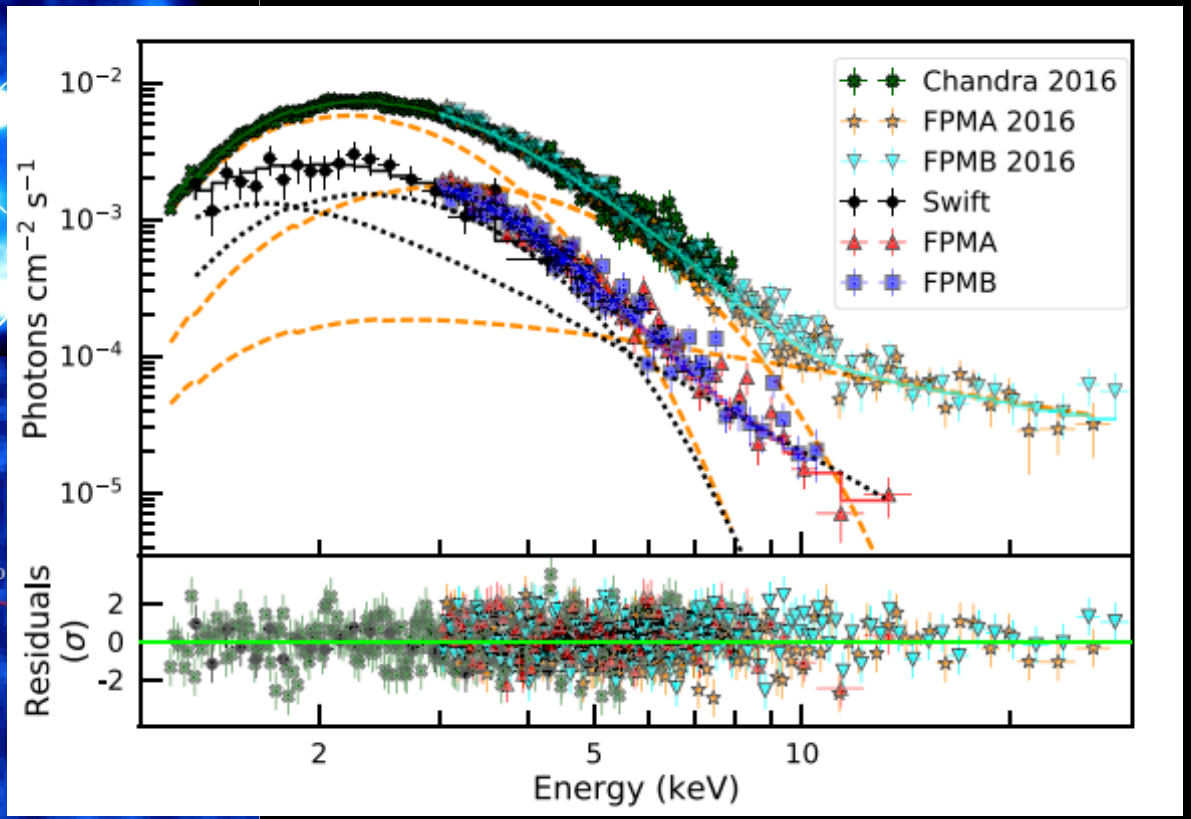
Swift – XRT: quiescence
2011 April – 2016 May



Swift – XRT: outburst
2016 June – 2016 July







Rea, Borghese et al. 2016; D'Aì et al. 2016; Borghese et al. 2018

Magnetar Outburst Online Catalog – MOOC

23 outbursts from 14 magnetars + 2 high-*B* RPPS + CCO in RCW 103

1100 X-ray observations (12 Ms) from 1998 to 2017

Coti Zelati et al. 2017
Magnetar Outburst Online Catalog
http://magnetars.ice.csic.es/

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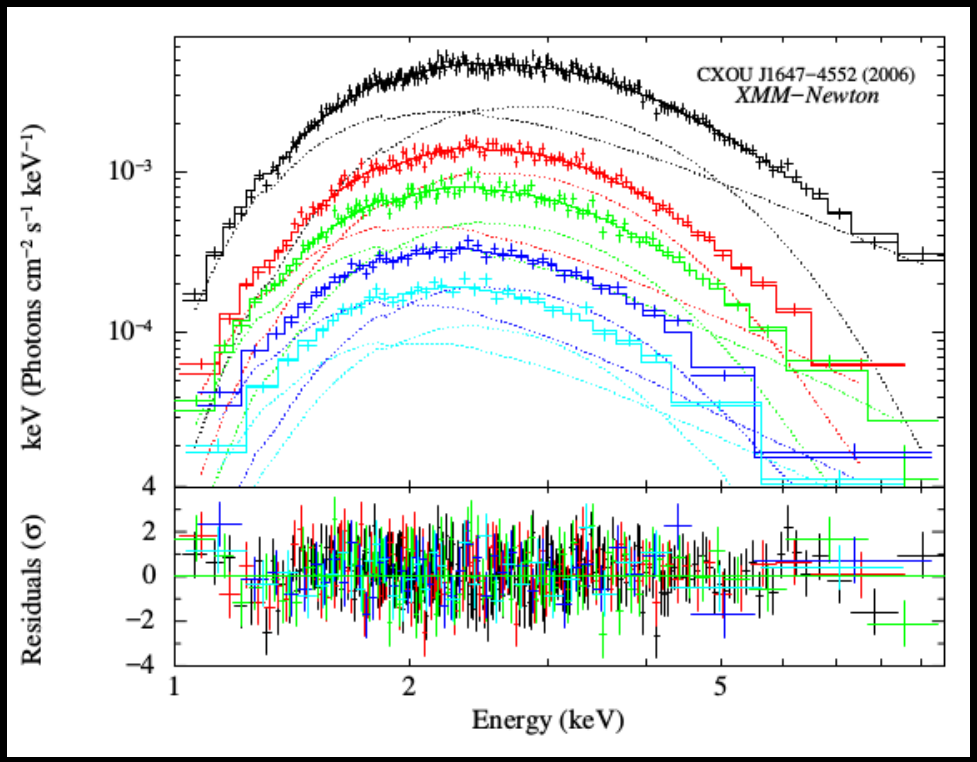

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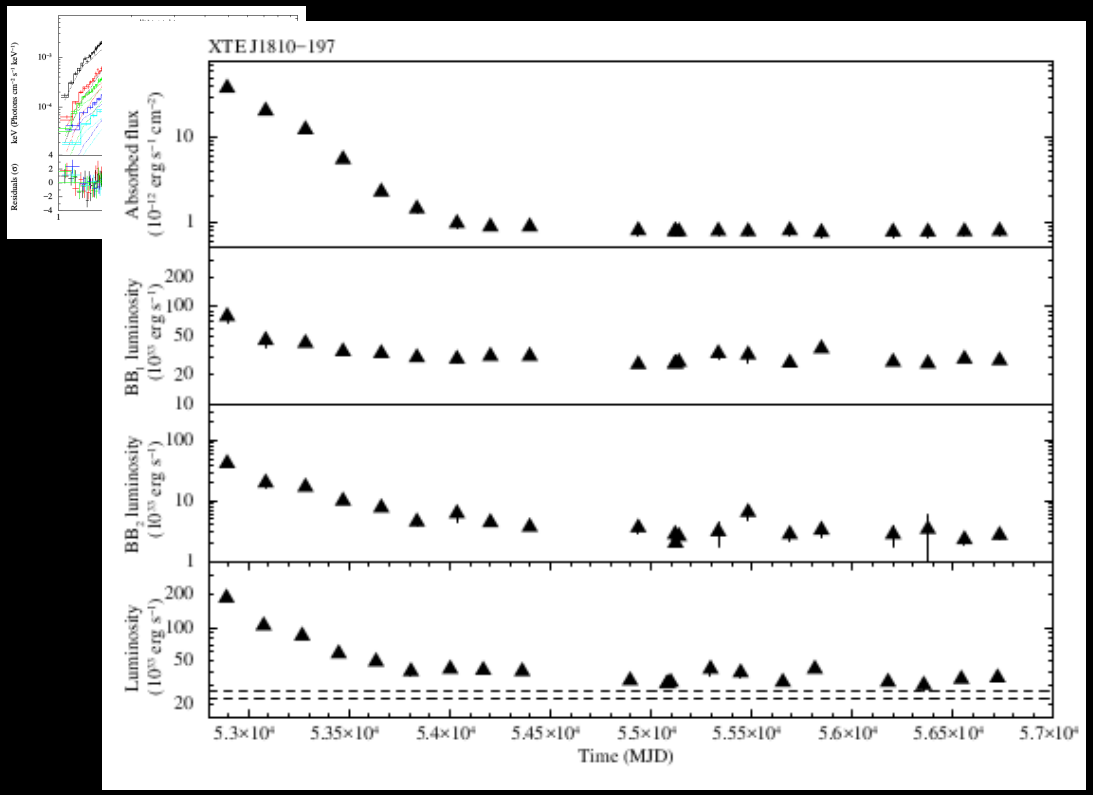

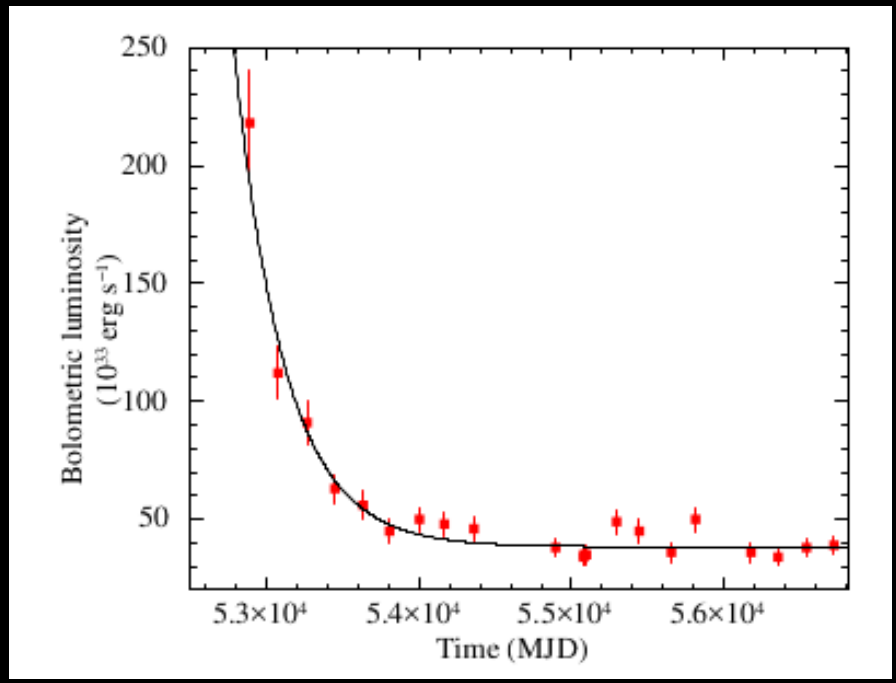

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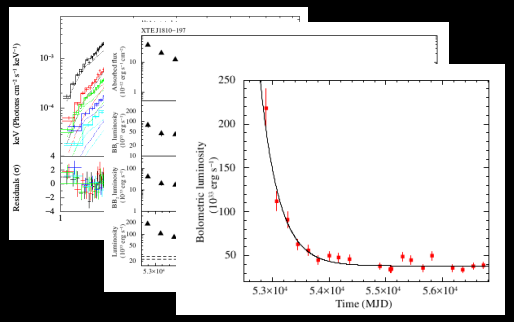

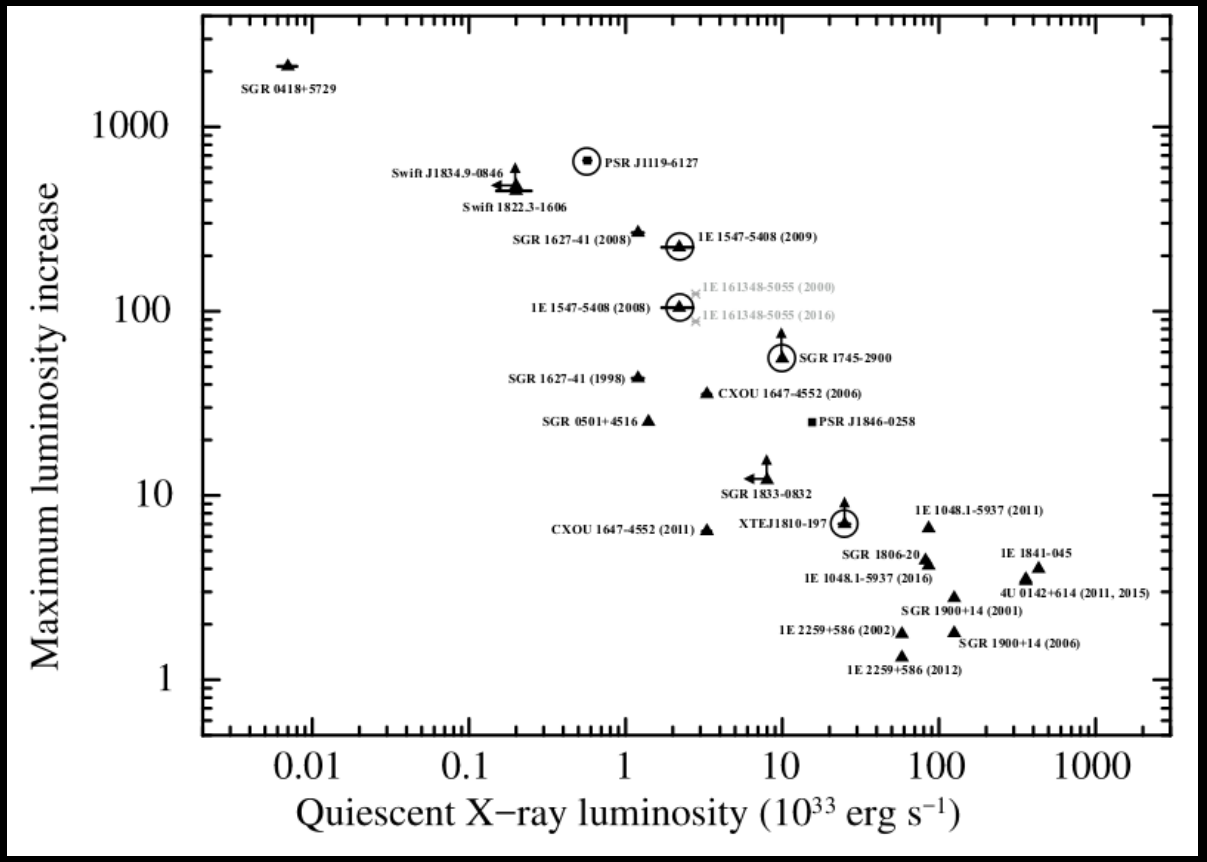

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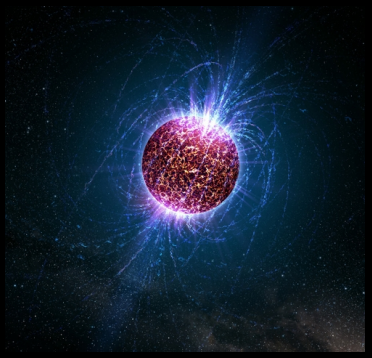
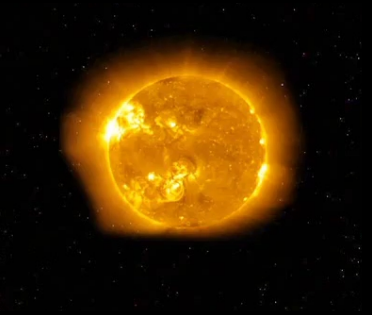
Conclusions



Magnetars are unique laboratories to study the effect on matter embedded in extreme magnetic fields.

The intense follow-up of magnetar-like bursts/outbursts is giving new key discovery.



Magnetar-like activity occurs in isolated neutron stars with a wide range of magnetic field much wider than previously thought.