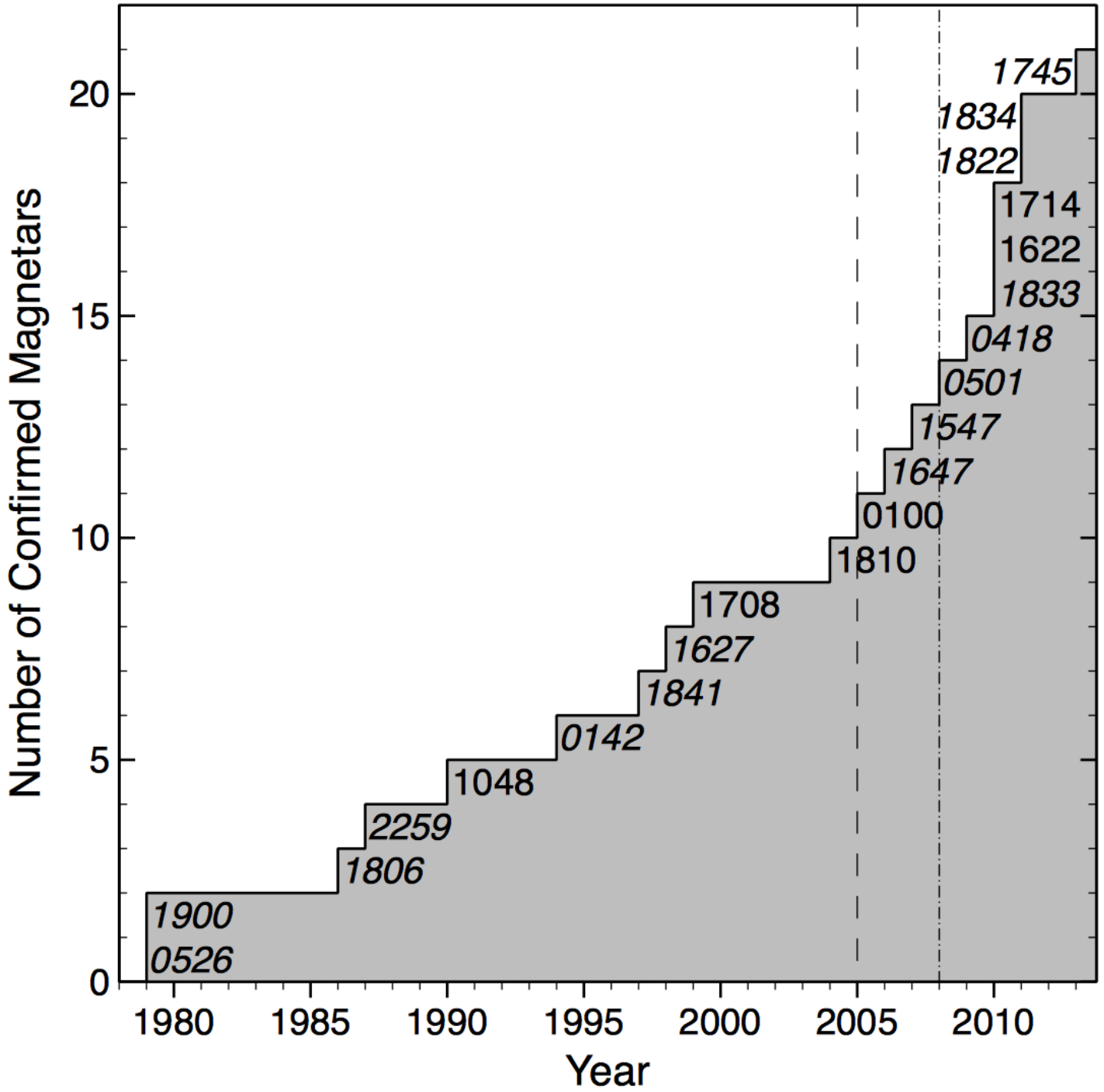
Magnetar Magnetospheres

Andrei Beloborodov

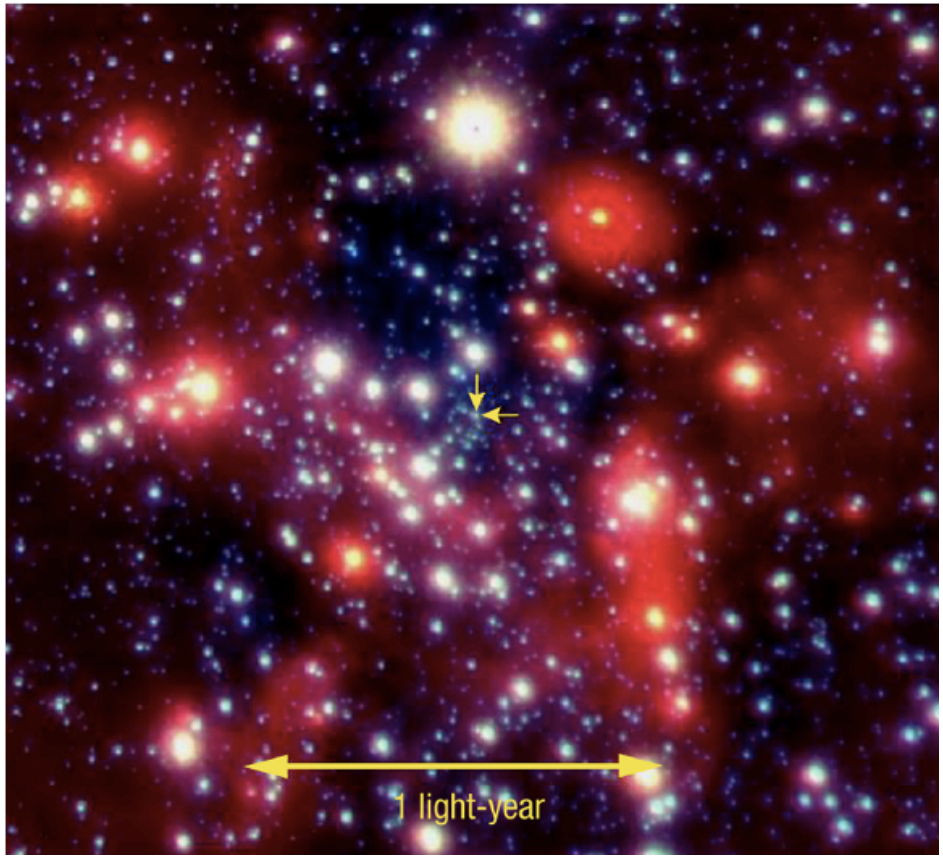
Columbia University

Romain Hascoet, Indrek Vurm

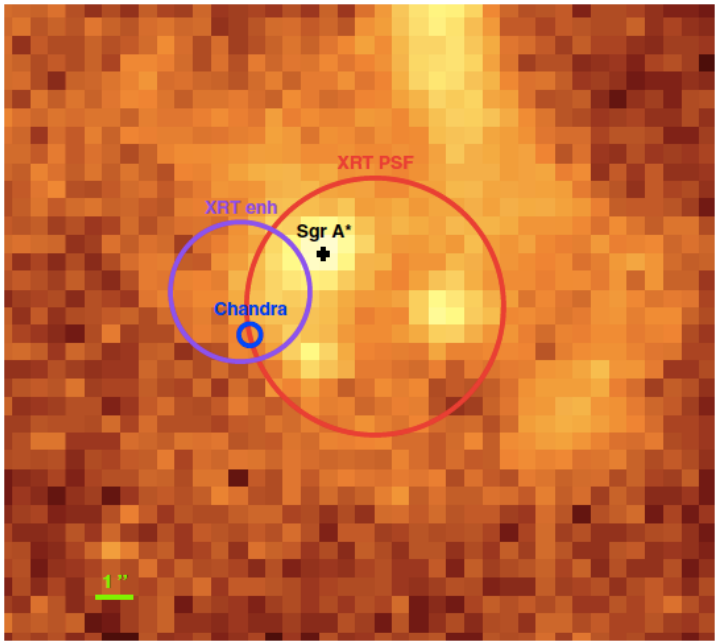
+ NuSTAR team


Number of Confirmed Magnetars
Year
0
5
10
15
20
1980
1985
1990
1995
2000
2005
2010
1900
0526
2259
1806
1048
0142
1841
1627
1708
1810
0100
1647
1547
0501
0418
1833
1622
1714
1822
1834
1745

Discovery of a magnetar in the Galactic Center

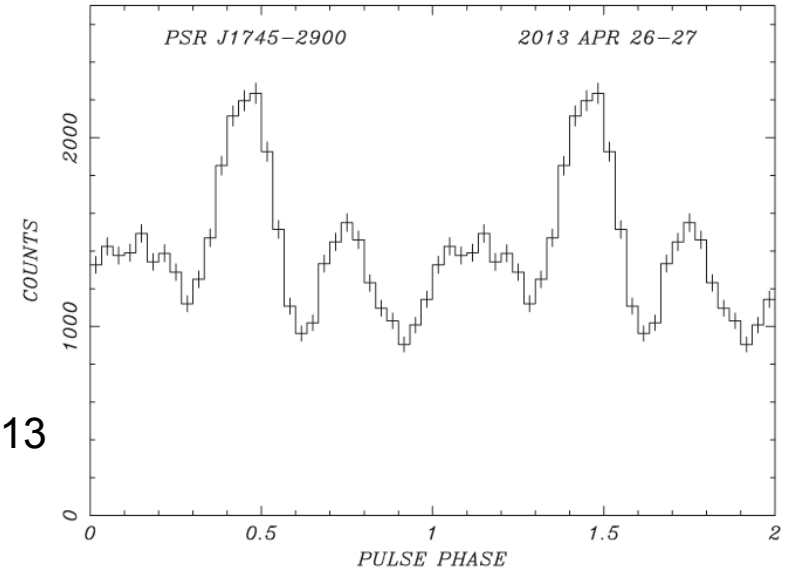


Genzel et al. (2003)



Kennea et al. 2013; Rea et al. 2013

NuSTAR
Mori et al. 2013



Discovery of a magnetar in the Galactic Center

$P = 3.76$ s

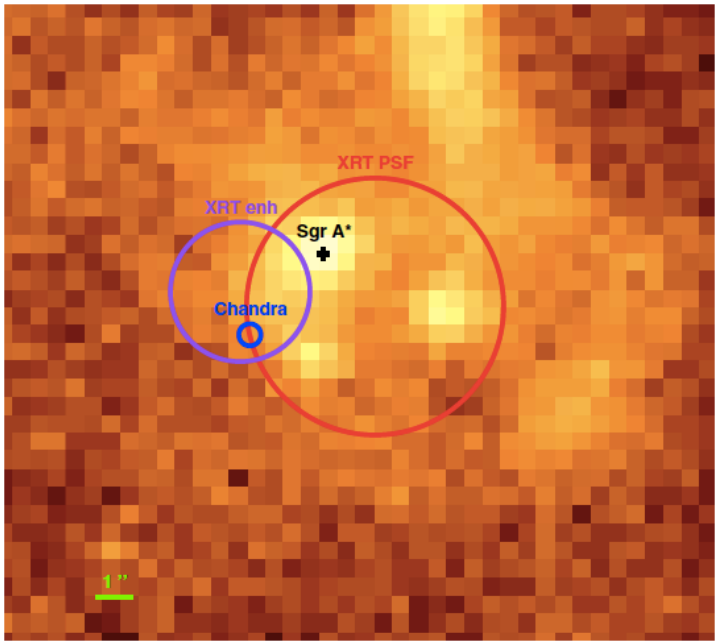
$\dot{P} = (6.8 \pm 1.5) \times 10^{-12}$

$B \sim 2 \times 10^{14}$ G

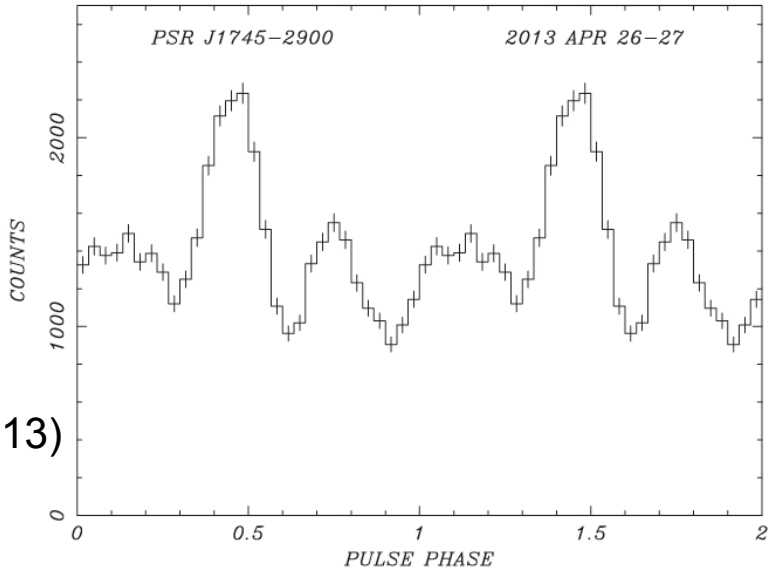
$kT \approx 1$ keV

d ≈ 8 kpc

$L \approx 3 \times 10^{35}$ erg s^{-1}

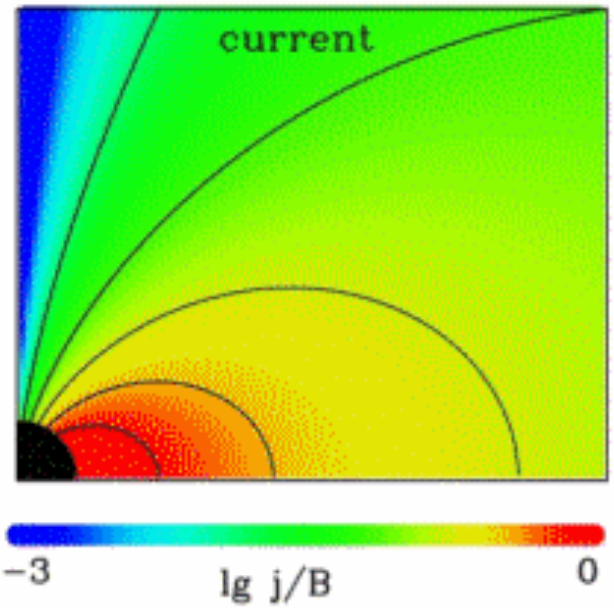


Kennea et al. 2013; Rea et al. 2013

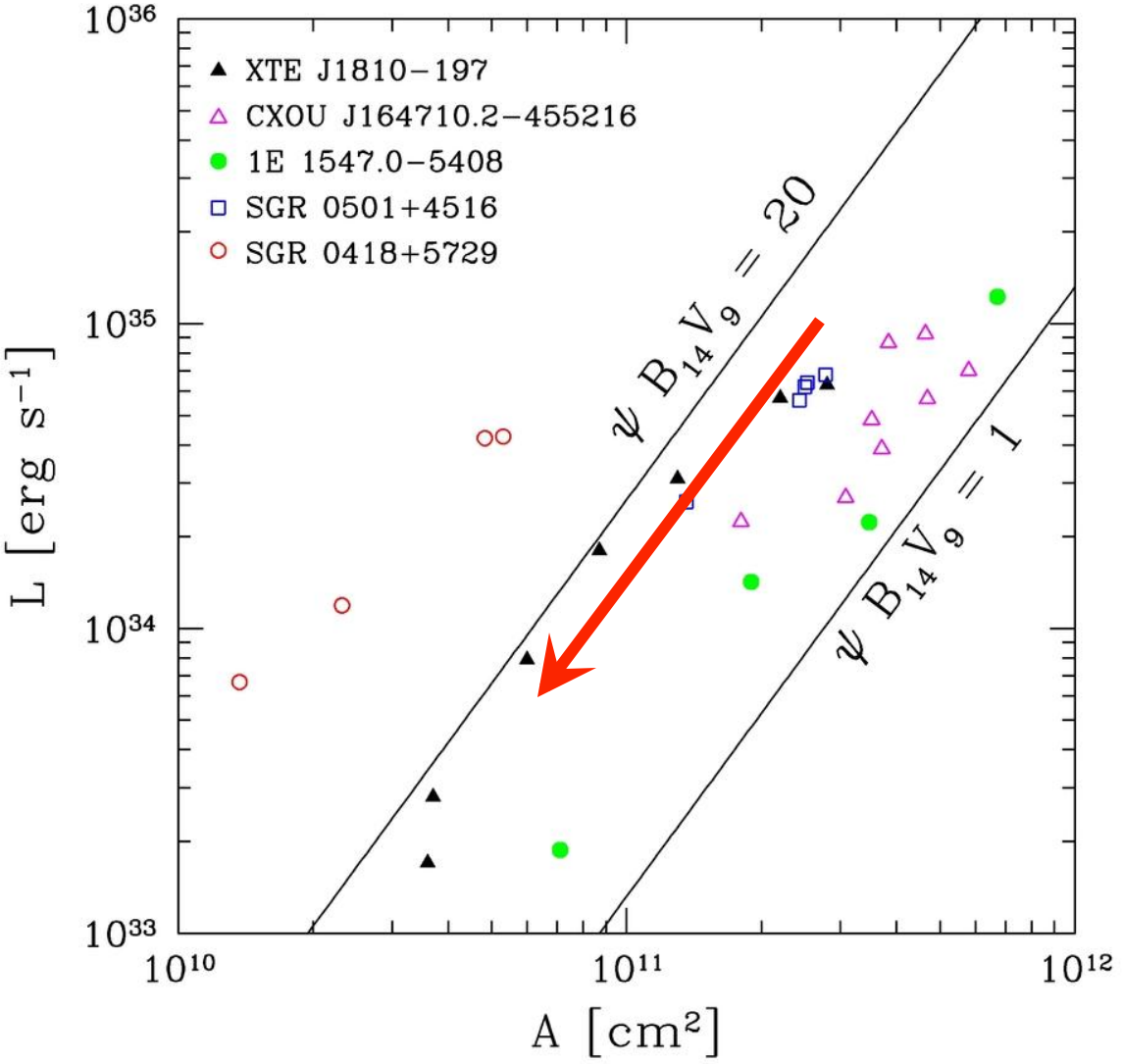


NuSTAR
Mori et al. (2013)

Post-outburst evolution (untwisting)

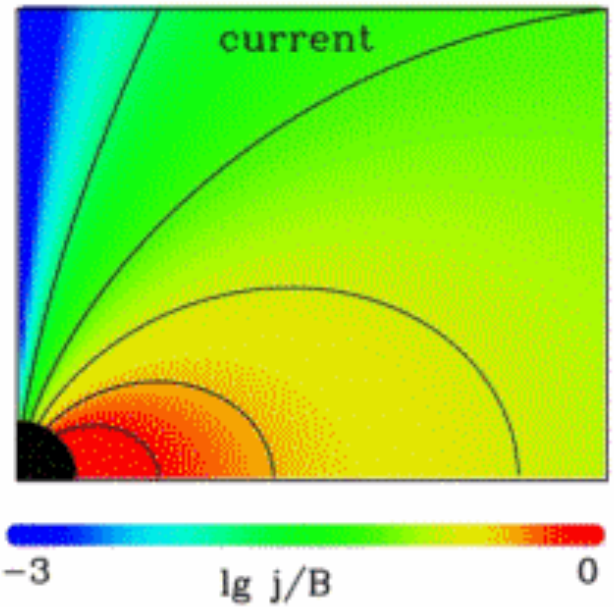


$$t_{\rm ev} \approx 0.4 \;\; \Phi_{10}^{-1} \; B_{14} \; A_{12} \quad \text{yr}$$

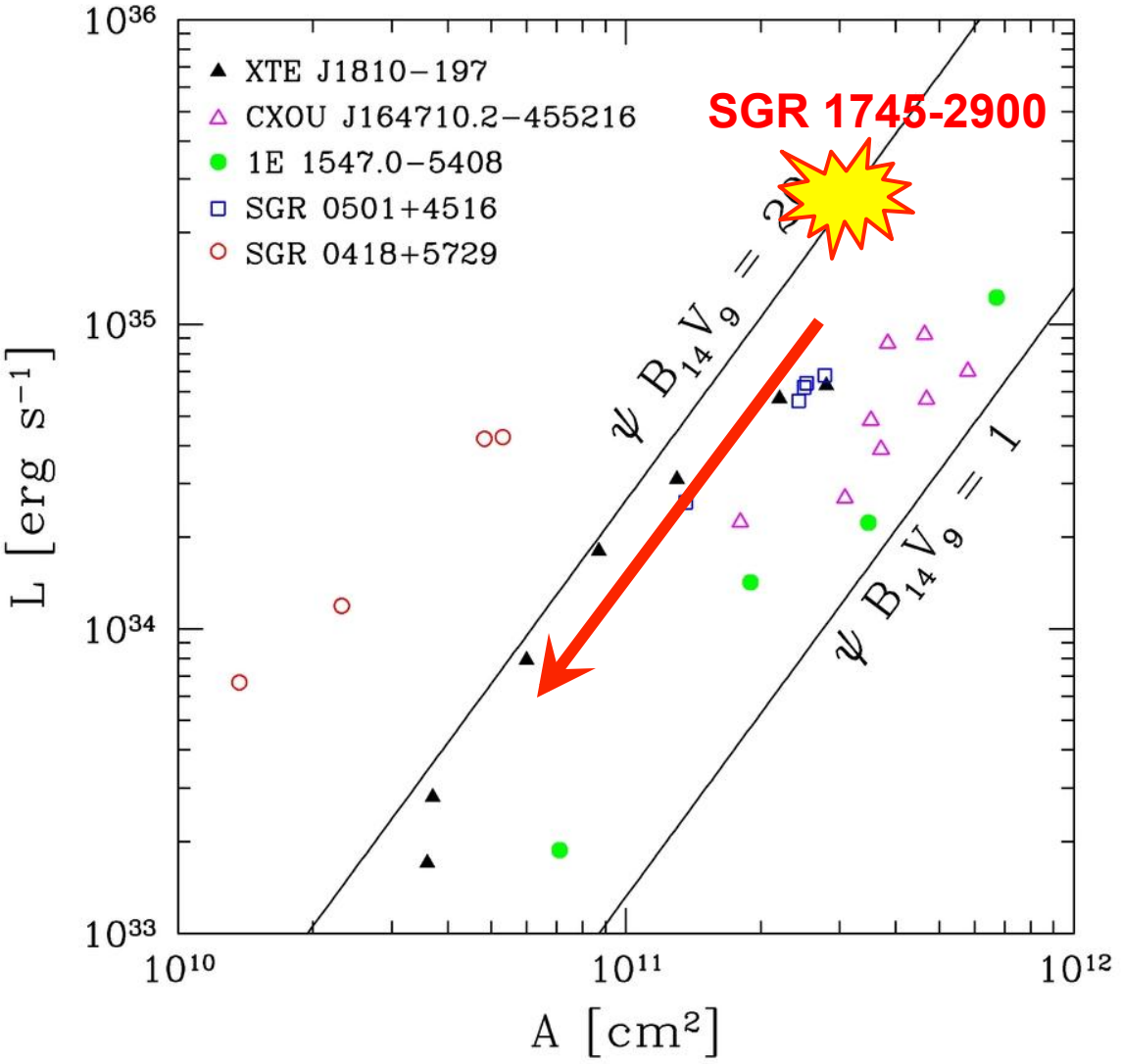


Beloborodov (2009)

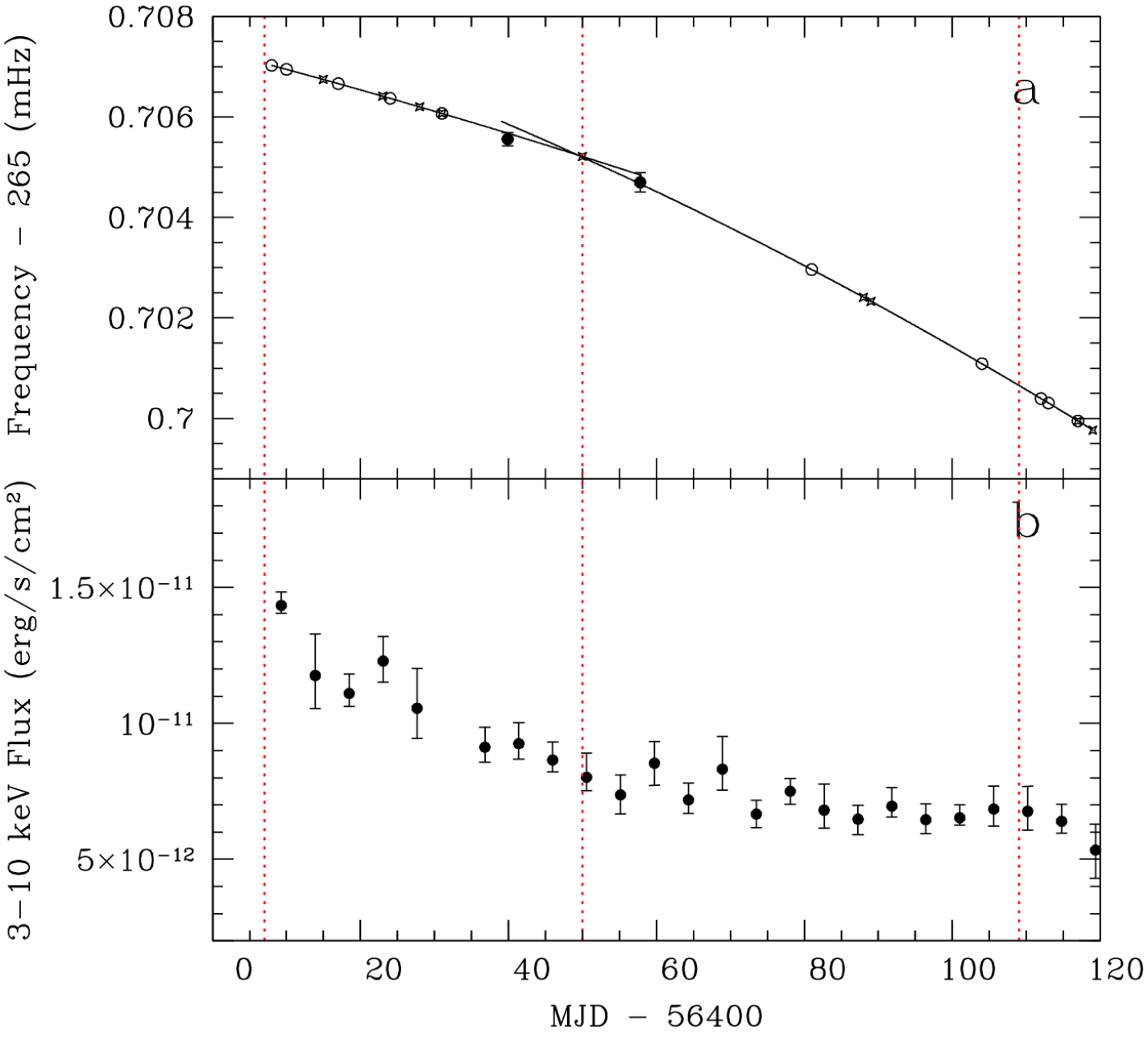
Post-outburst evolution (untwisting)



$$t_{\rm ev} \approx 0.4 \;\; \Phi_{10}^{-1} \; B_{14} \; A_{12} \quad \text{yr}$$

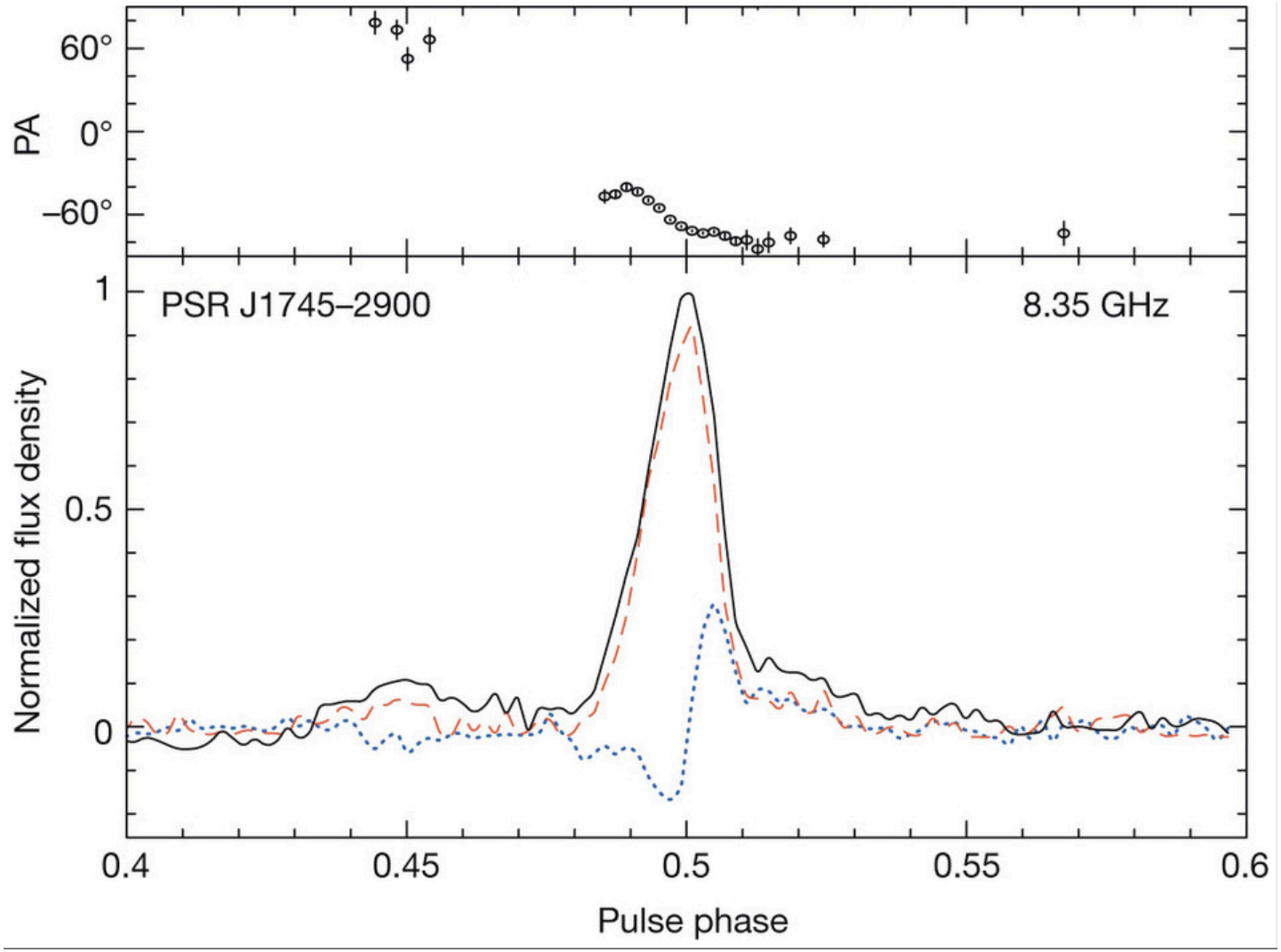


Beloborodov (2009)

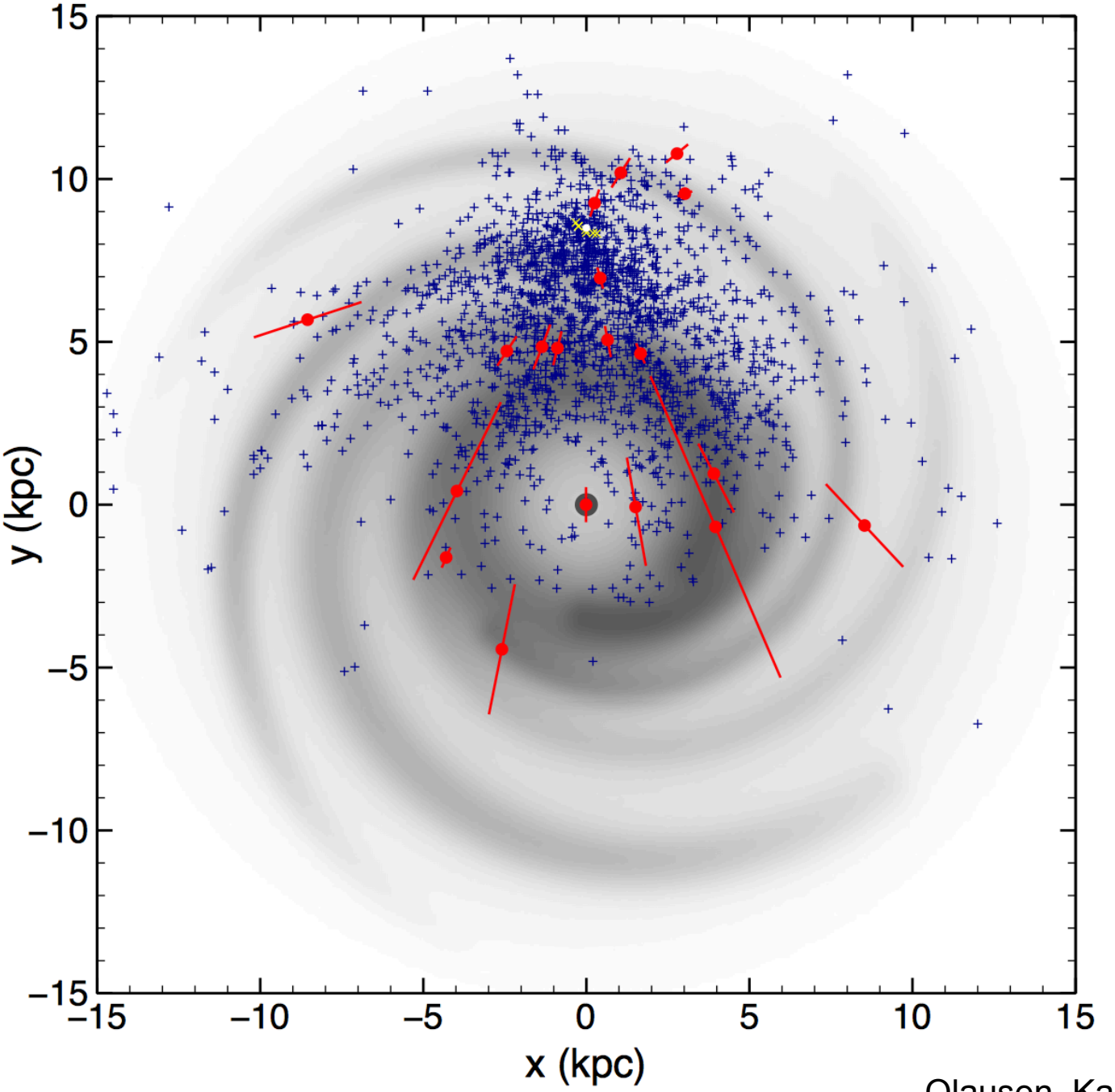


Kaspi et al., submitted to ApJ

Radio pulsations



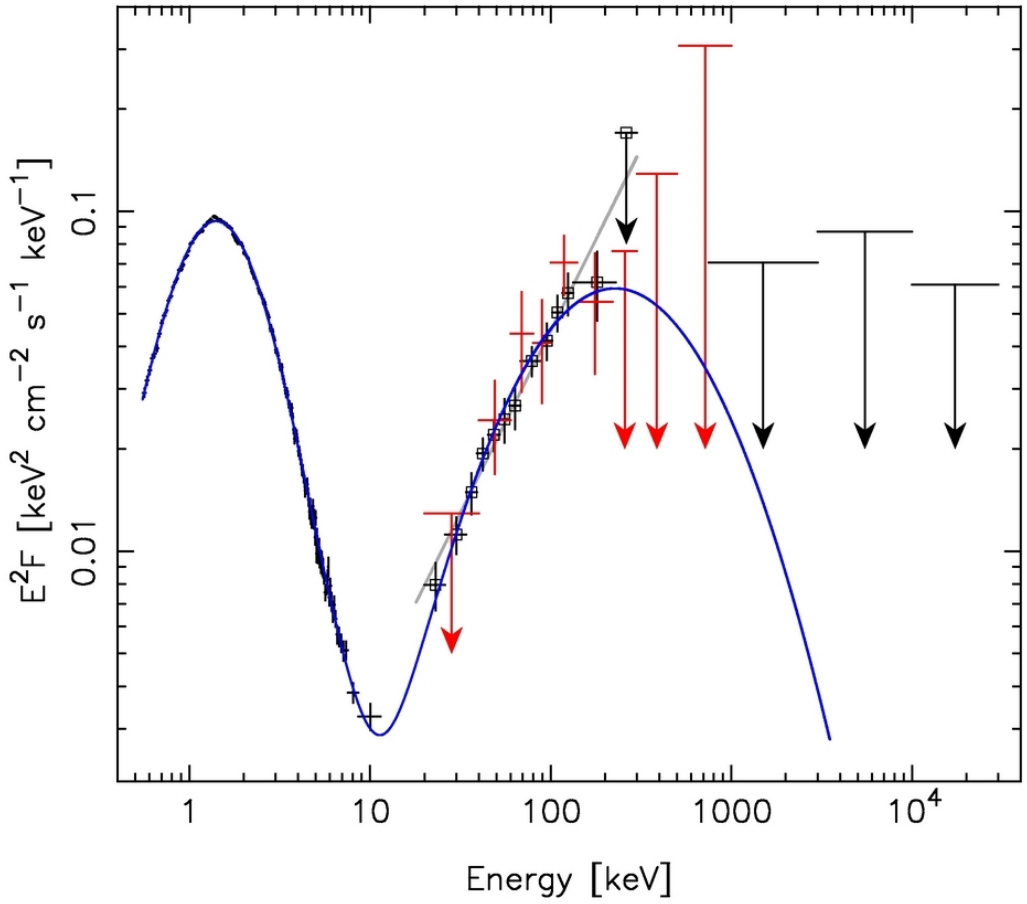
Effelsberg telescope Eatough et al. (2013)

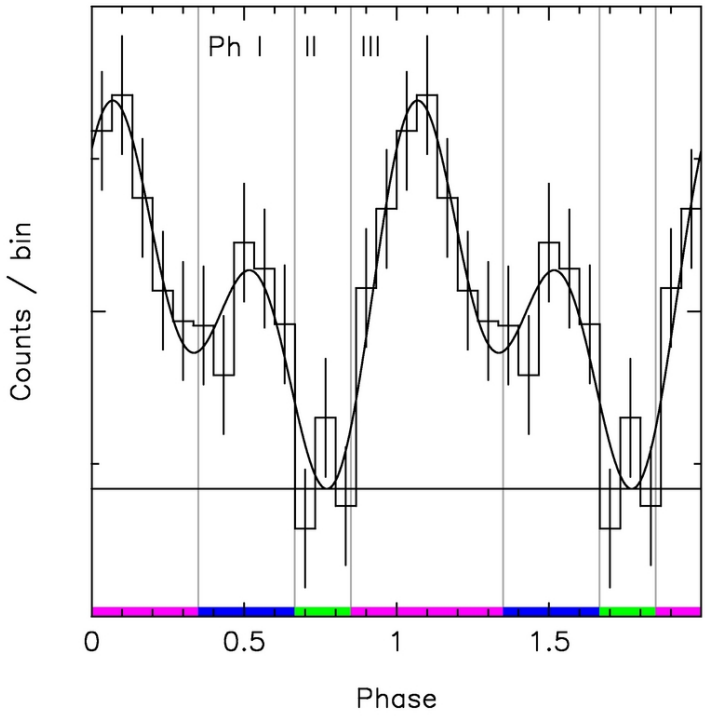


Olausen, Kaspi (2013)

Hard X-ray emission

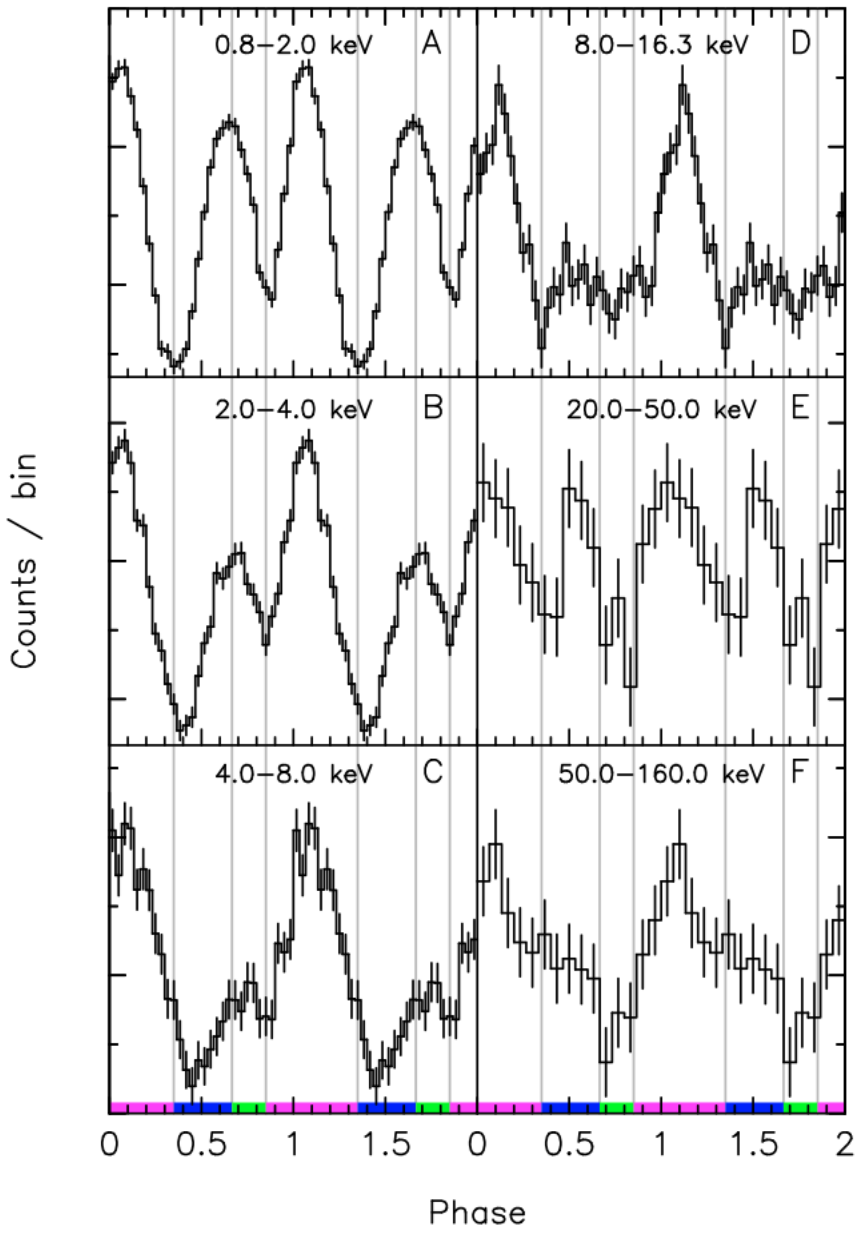
AXP 4U 0142+61

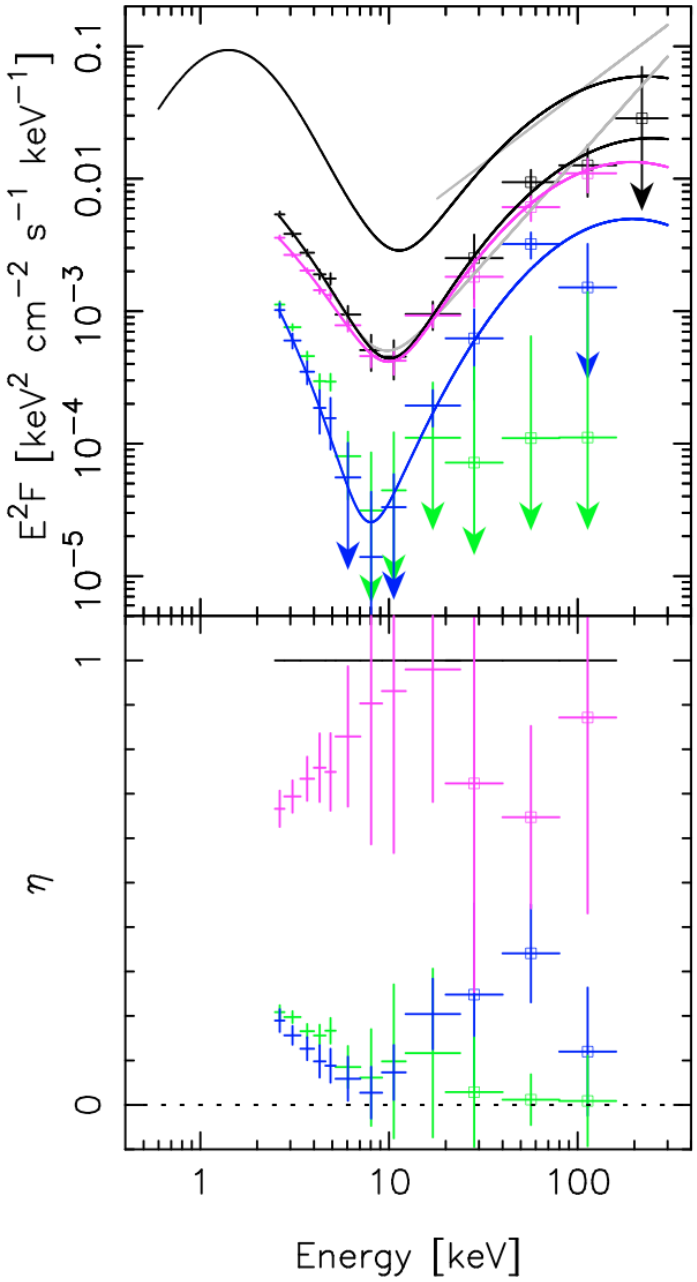




Den Hartog et al. (2008)

AXP 4U 0142+61





Den Hartog et al. (2008)

Magnetospheric plasma

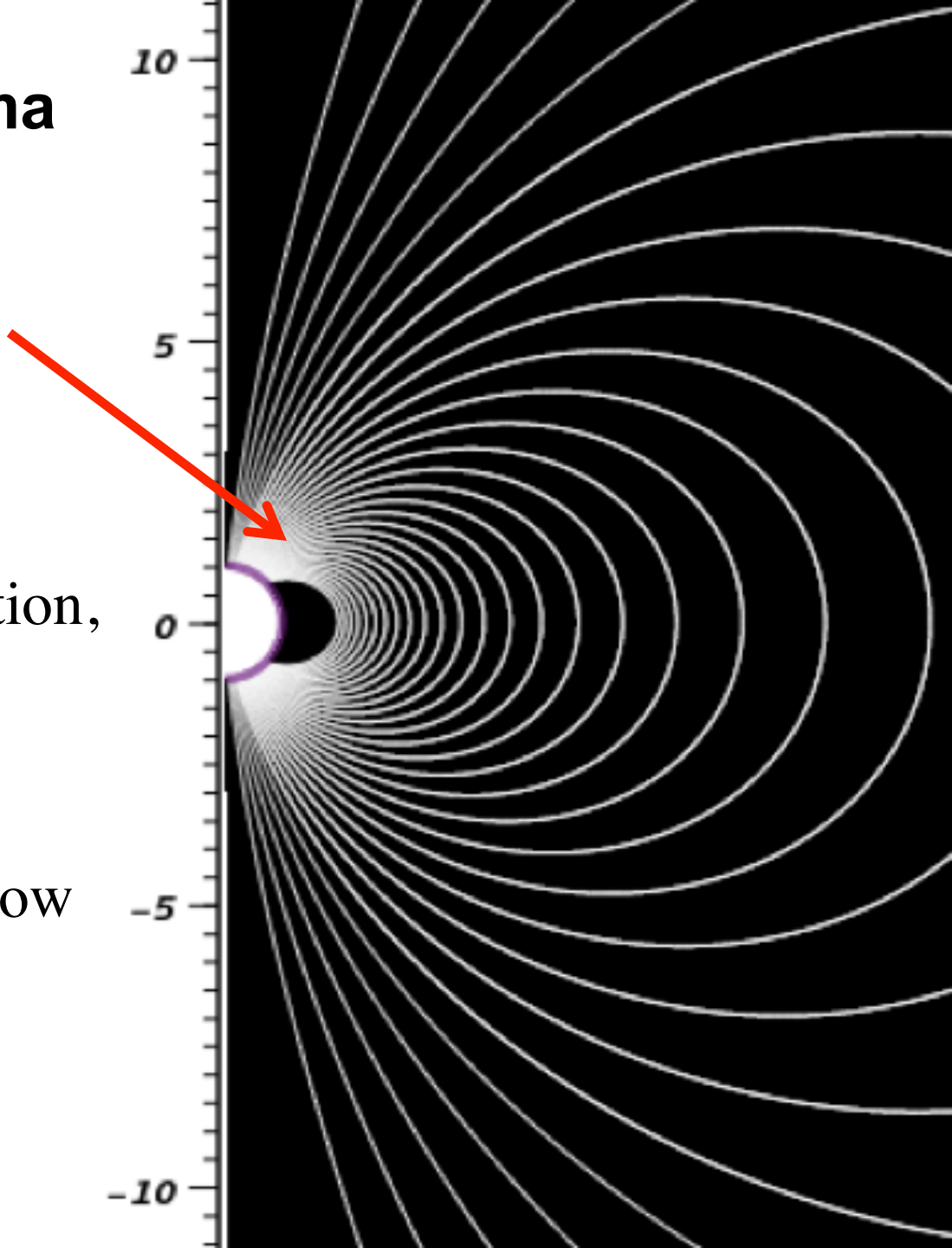
discharge: e^+, e^- injection,

$$L_{\pm} \sim I\Phi \sim 10^{36} \text{ erg s}^{-1}$$

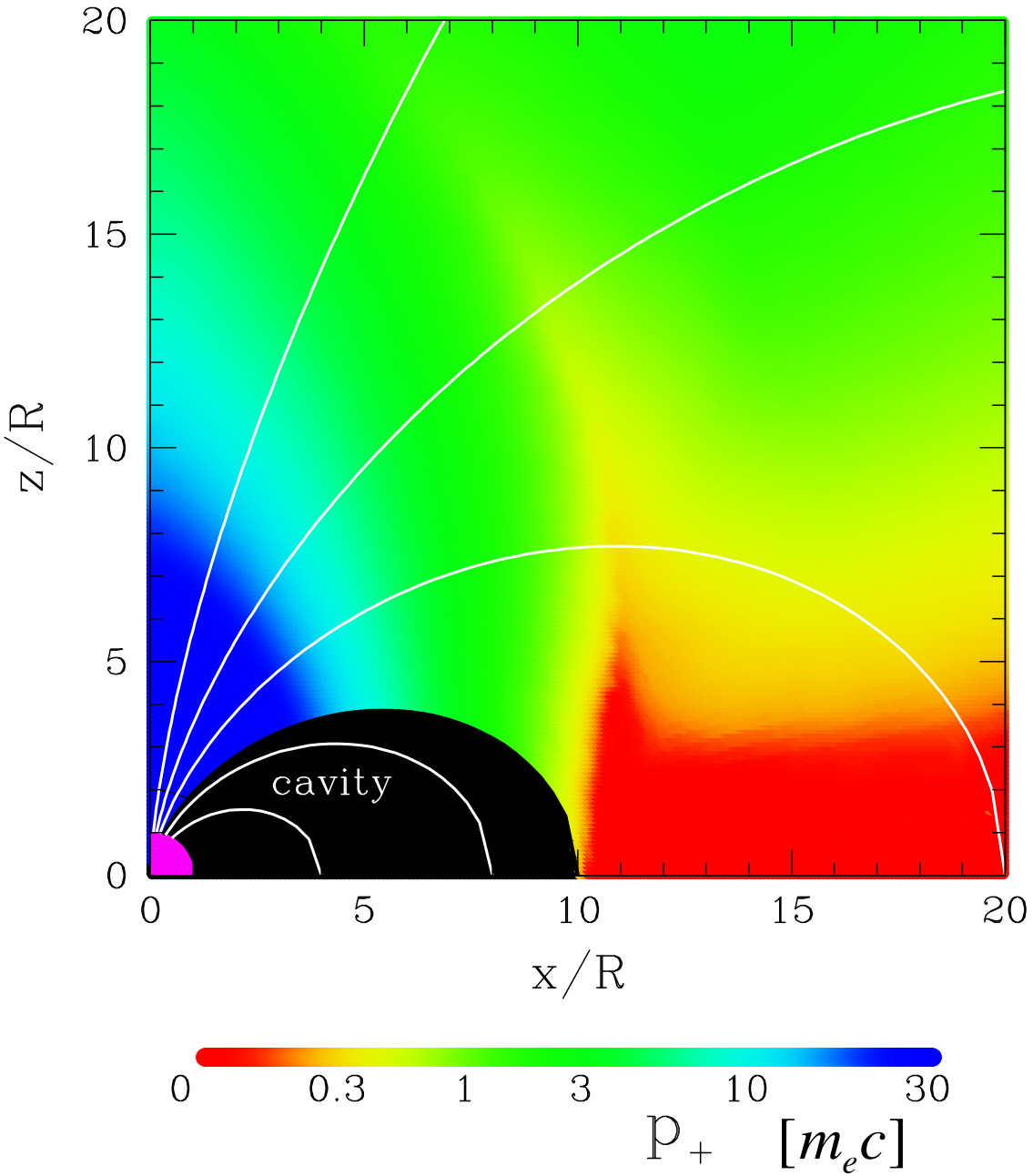
the star emits thermal radiation,

$$L \sim 10^{35} \text{ erg s}^{-1}$$

radiation controls the $e^{\pm}$ flow



solution

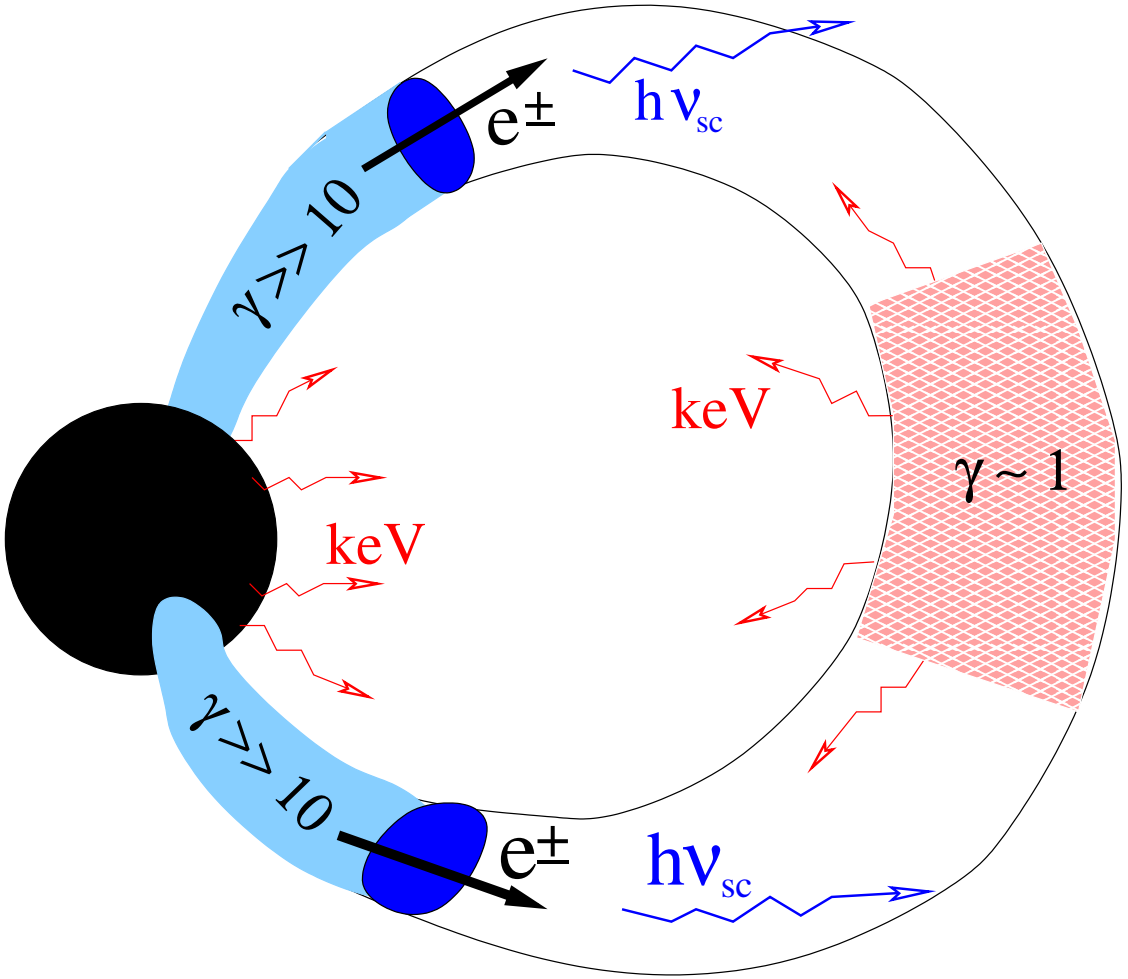


$B_{\rm pole} = 10^{15}$ G

$kT = 0.3$ keV

(star)

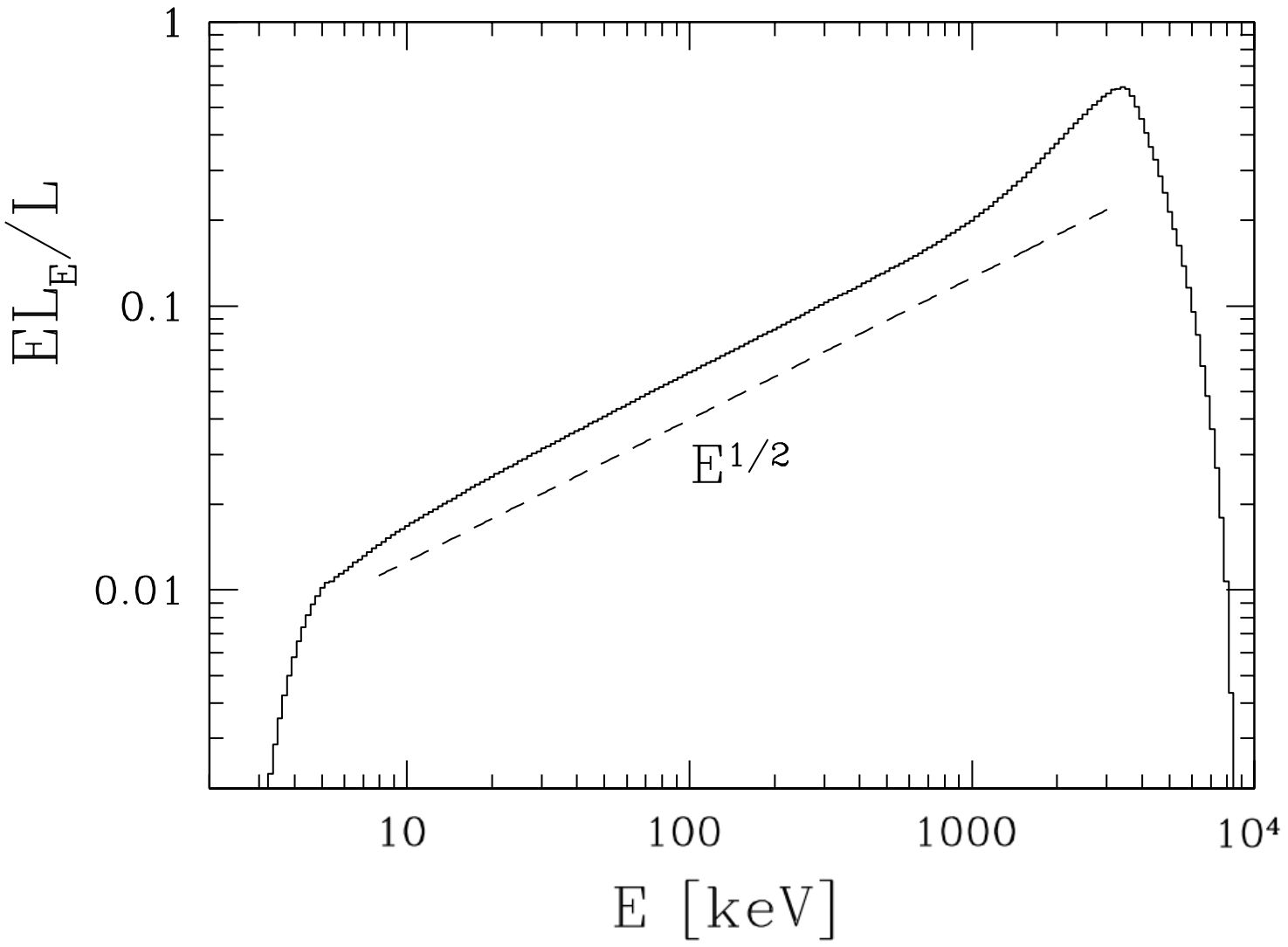
Beloborodov (2013)



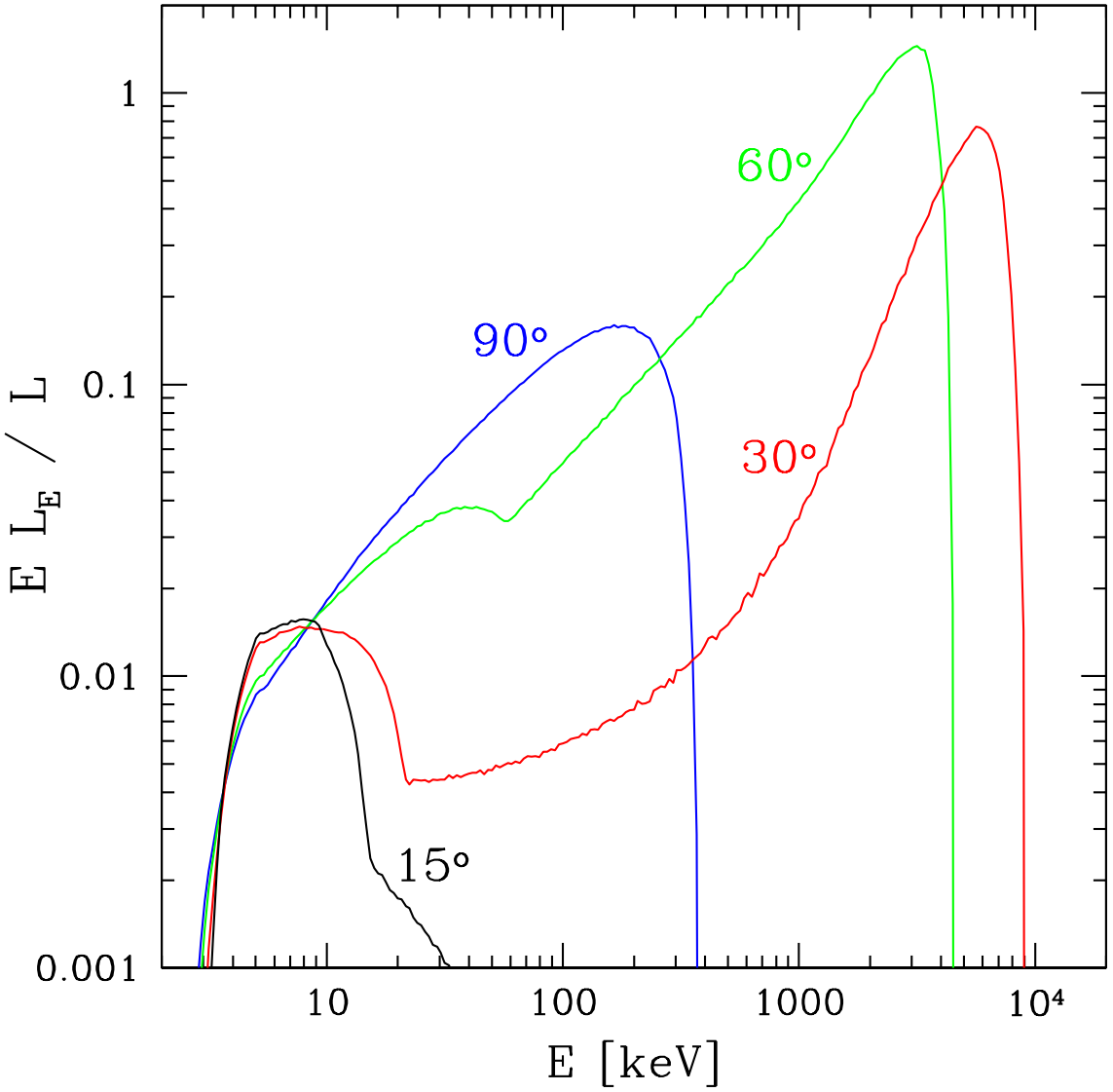
$$L_{\rm ann} \sim 0.1L$$

$$\gamma \approx 100\,\frac{B}{B_Q}, \qquad \text{radiative zone:}\quad B < \frac{B_Q}{4} \approx 10^{13}\ \text{G}$$

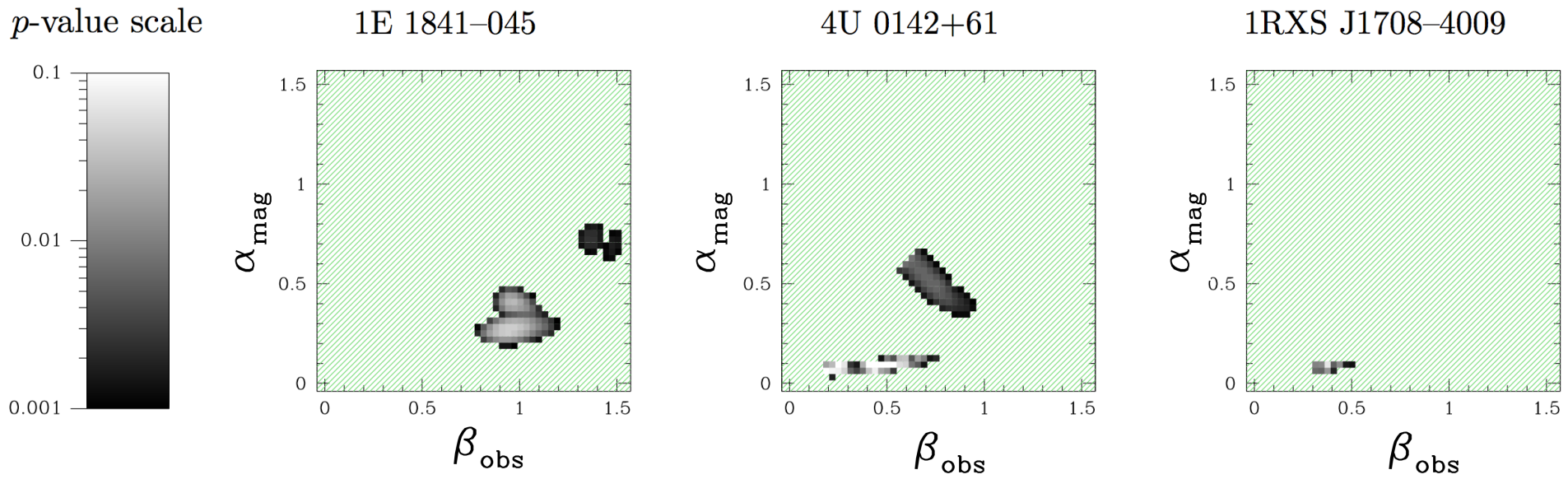
Spectrum radiated by the decelerating outflow



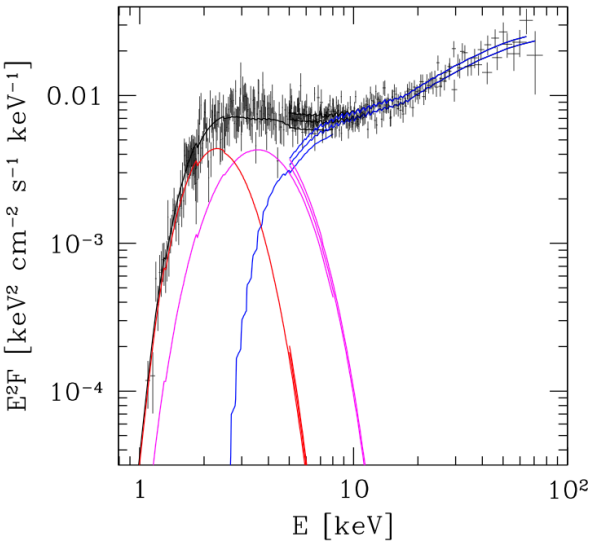
Spectrum variation with inclination



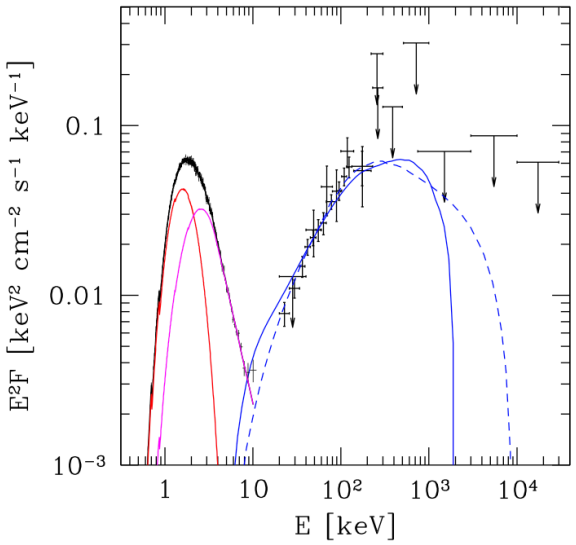
Observational test: phase resolved spectra



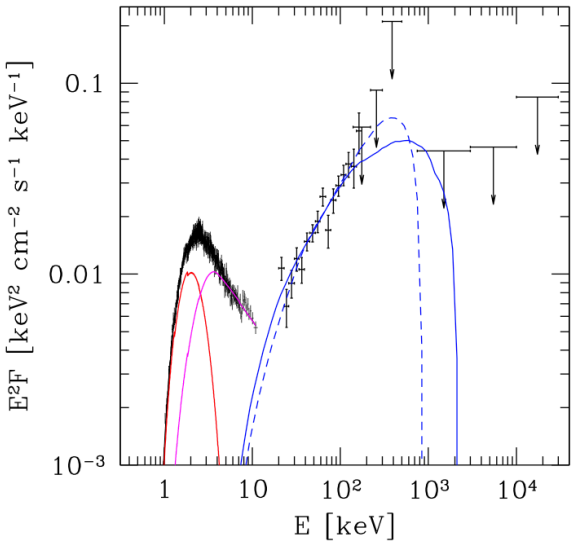
1E 1841–045

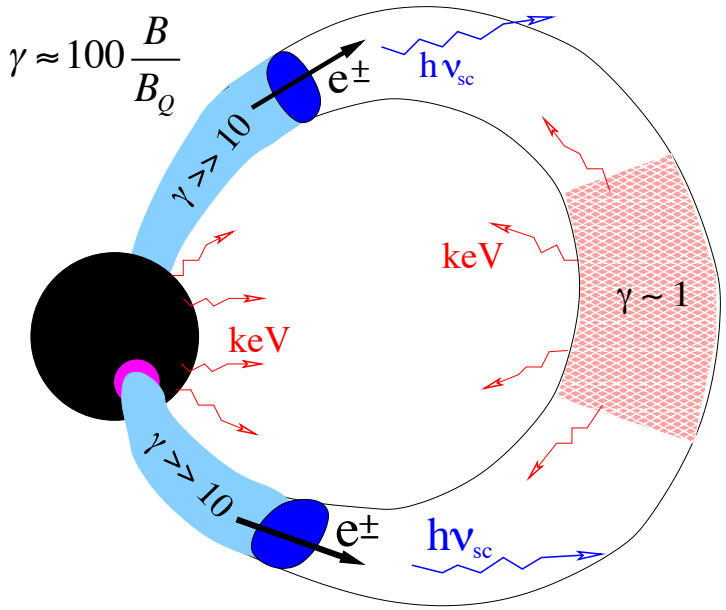


4U 0142+61



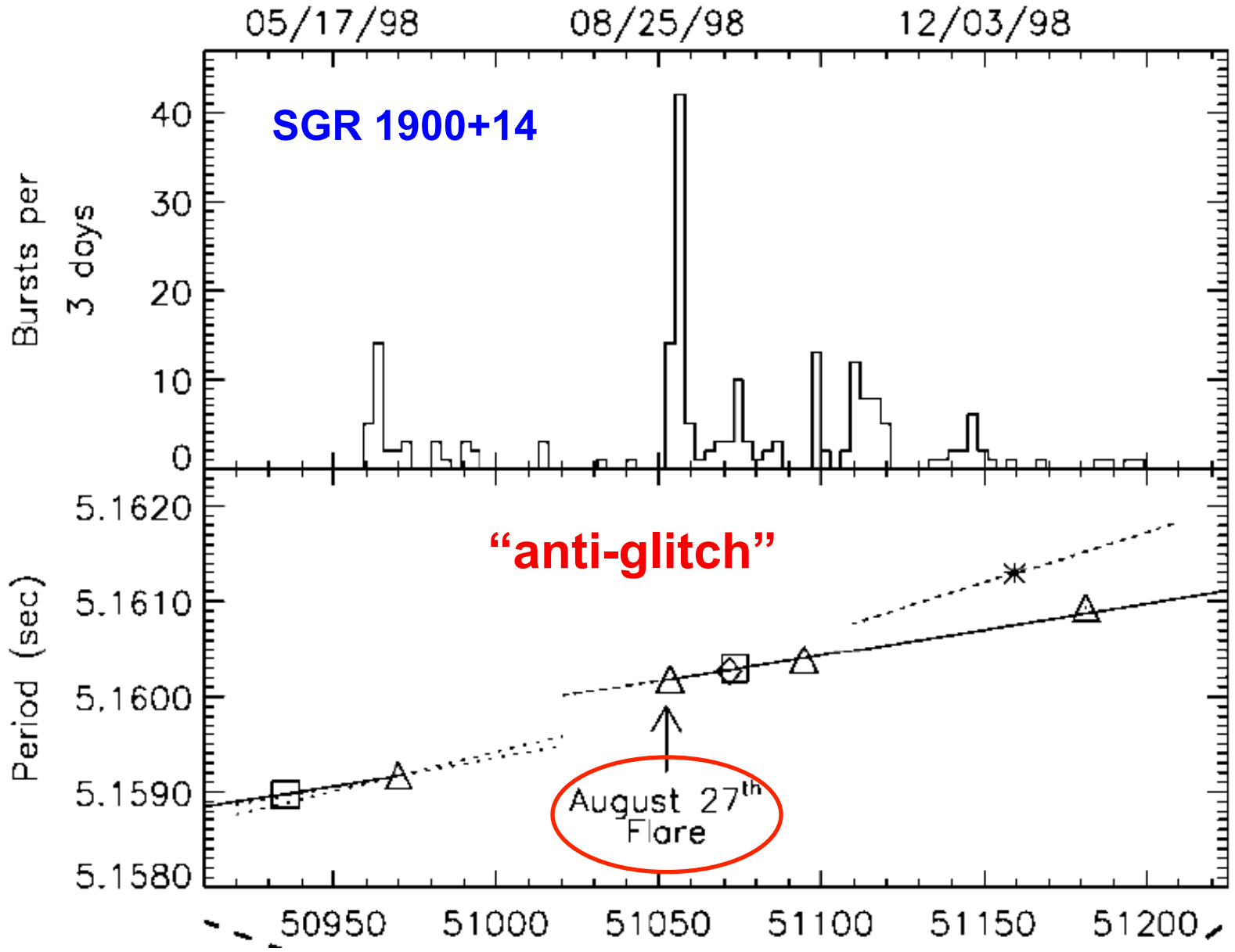
1RXS J1708–4009





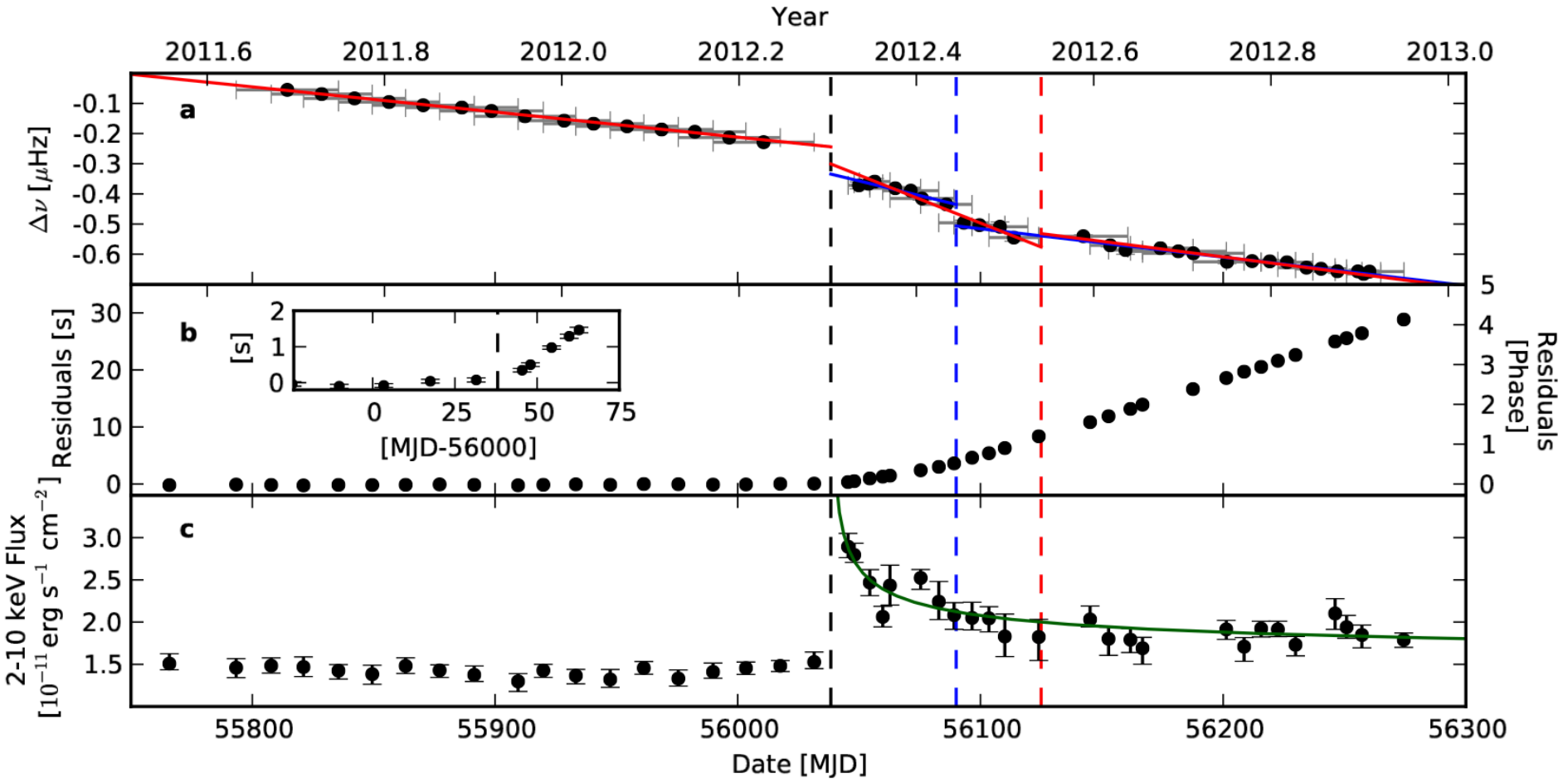
An et al. 2013
Hascoet, AB, den Hartog 2014

Anti-glitches



Woods et al. (1999)

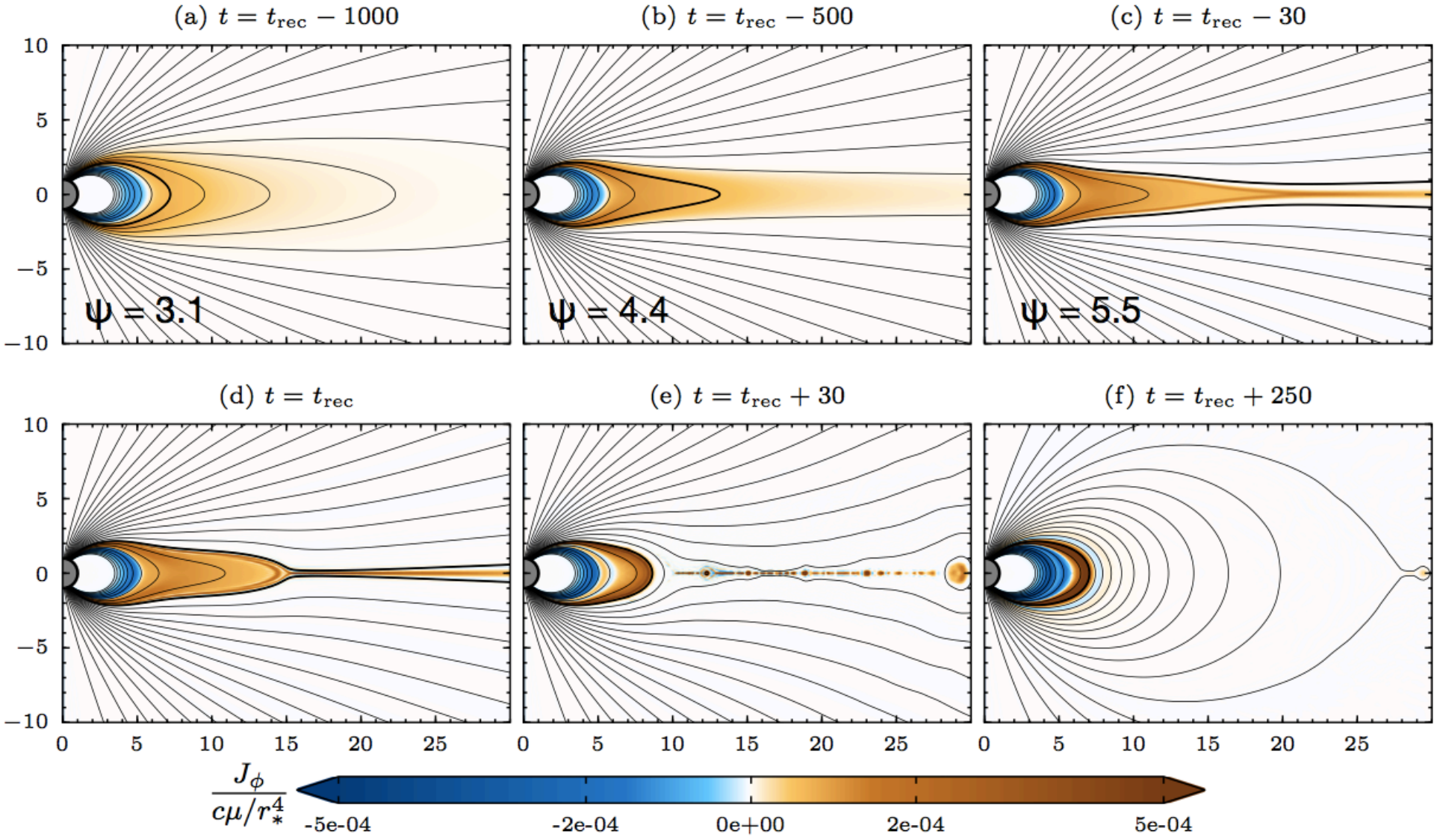
Anti-glitch in 1E 2259+586



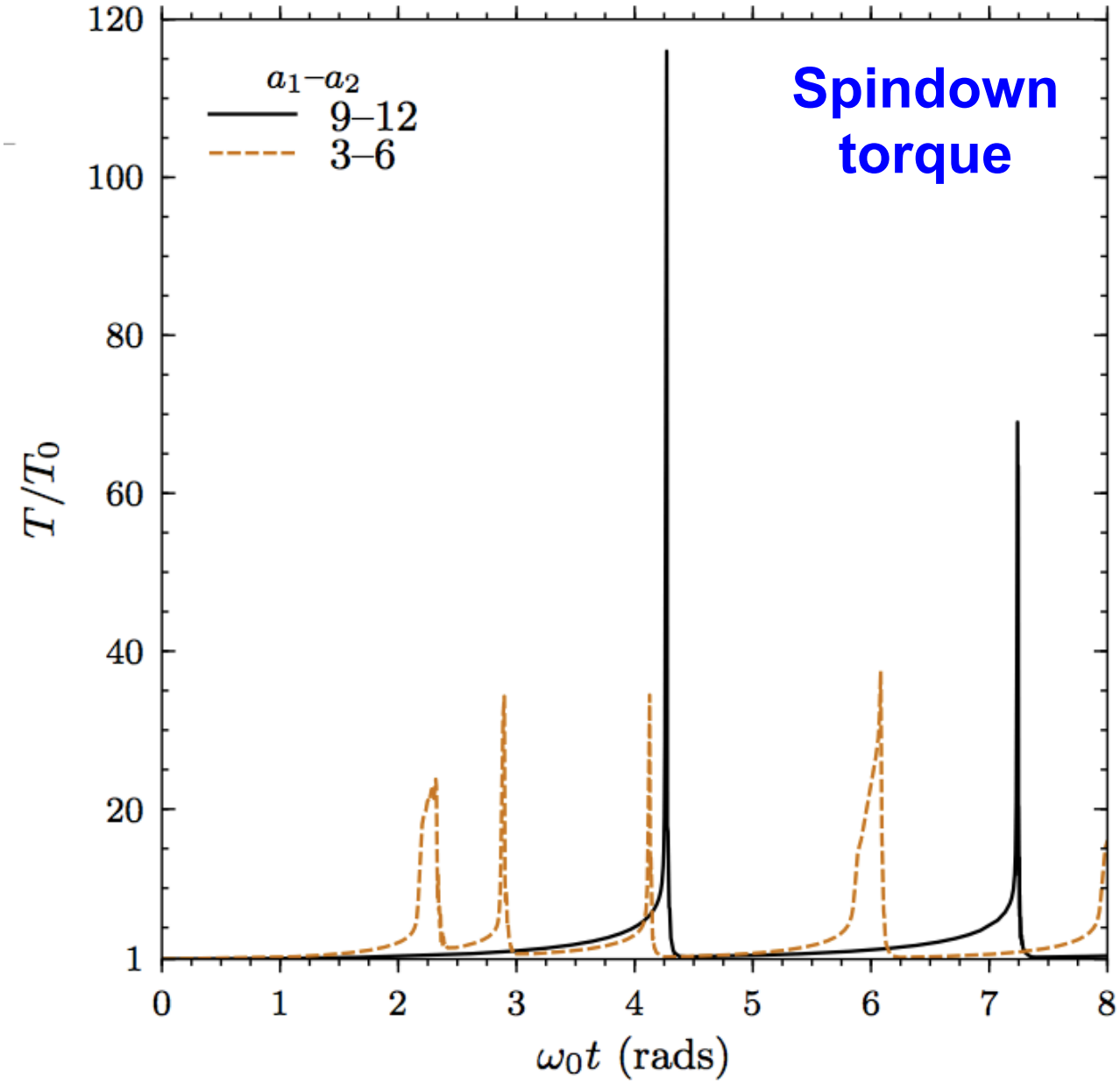
$$\Delta\nu/\nu = -1.44(6) \times 10^{-6}$$

Archibald et al. (2013)

Loss of magnetic equilibrium and reconnection



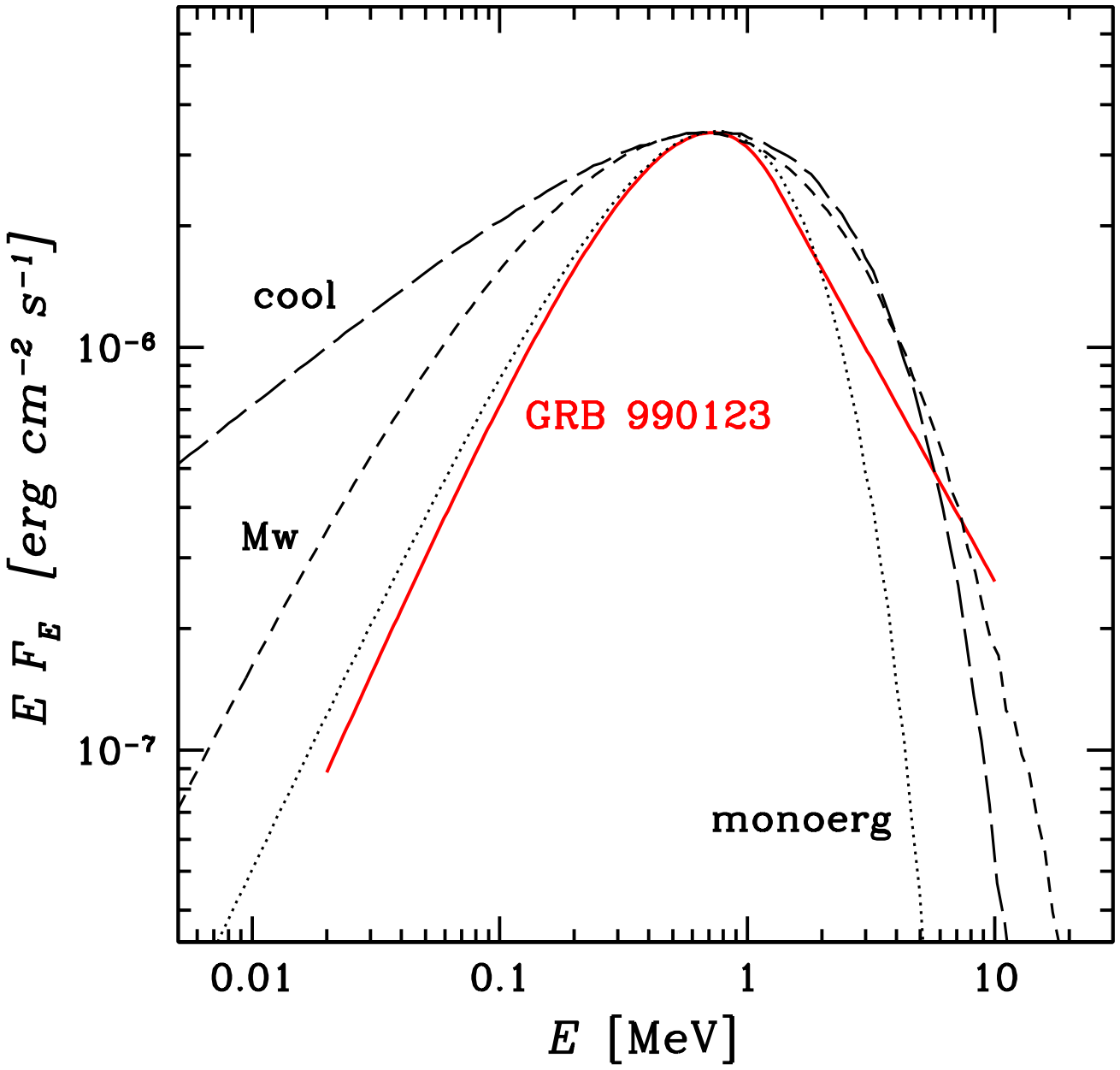
Parfrey et al. (2012; 2013)

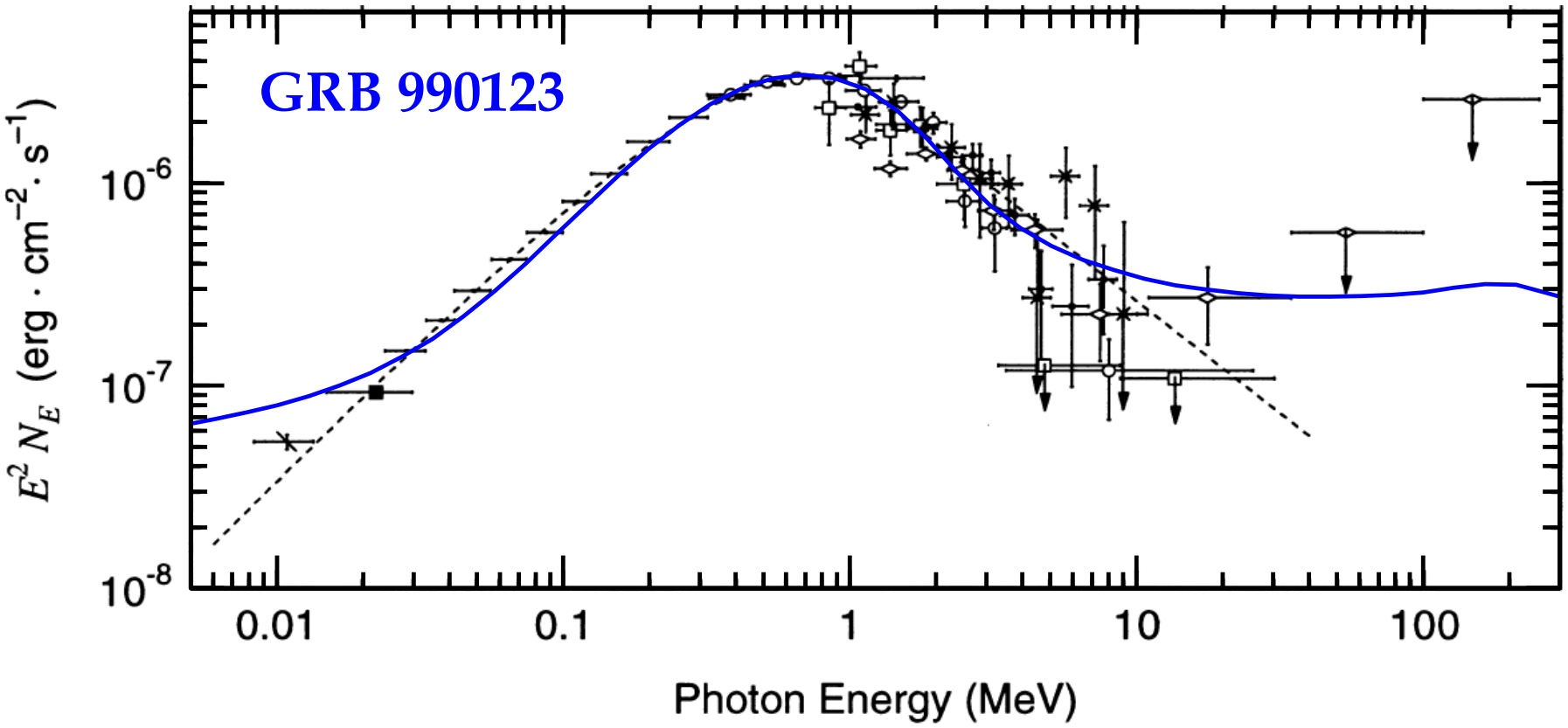

Spindown torque
a_1–a_2
9–12
3–6
T/T_0
$\omega_0 t$ (rads)
120
100
80
60
40
20
1
0
1
2
3
4
5
6
7
8

GRBs

Prompt emission

Synchrotron models



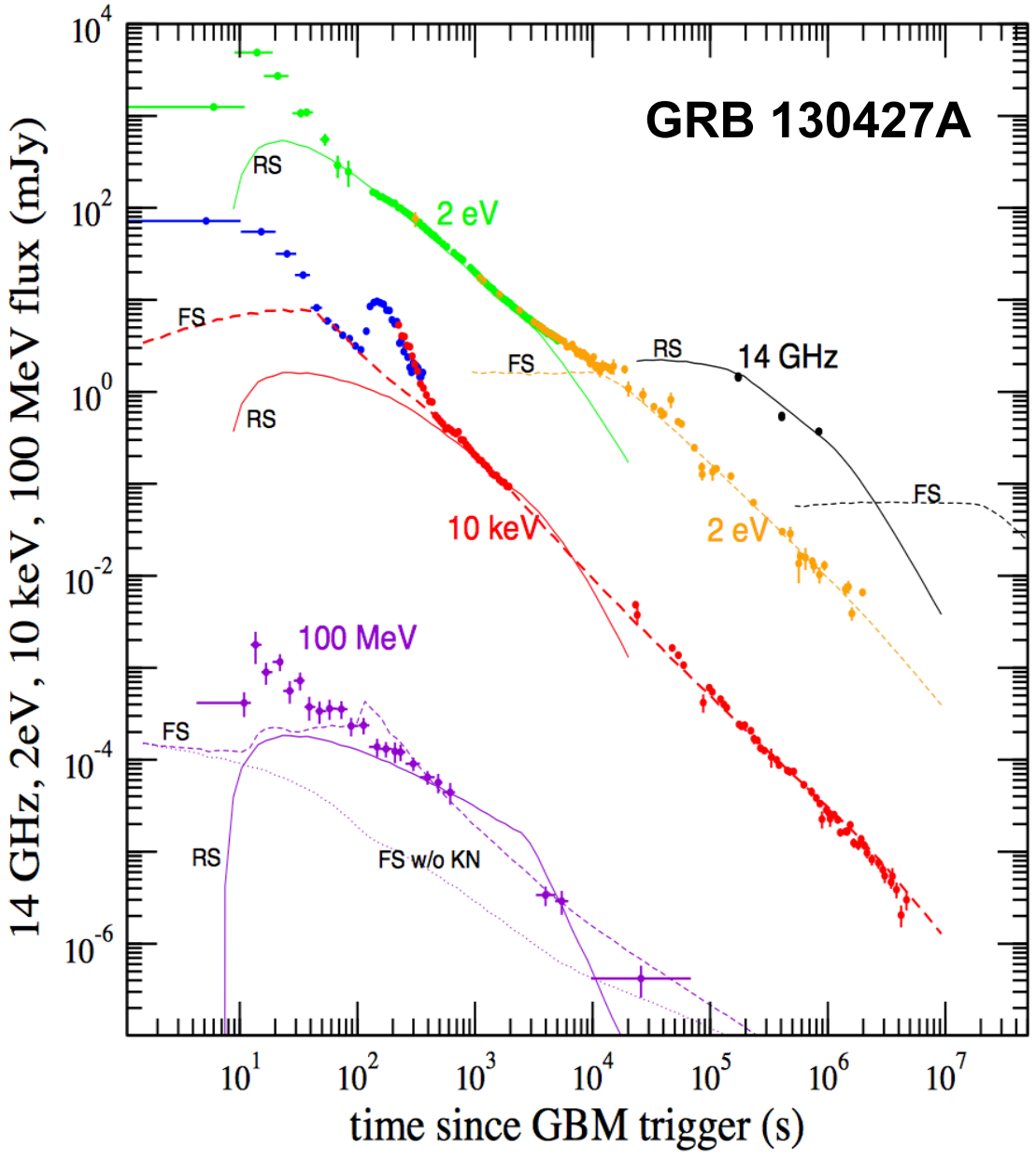


$$L_{\rm JET} = 3\times10^{53}\ {\rm erg\ s^{-1}} \qquad \eta = 1000 \qquad \varepsilon_B = 0.005$$

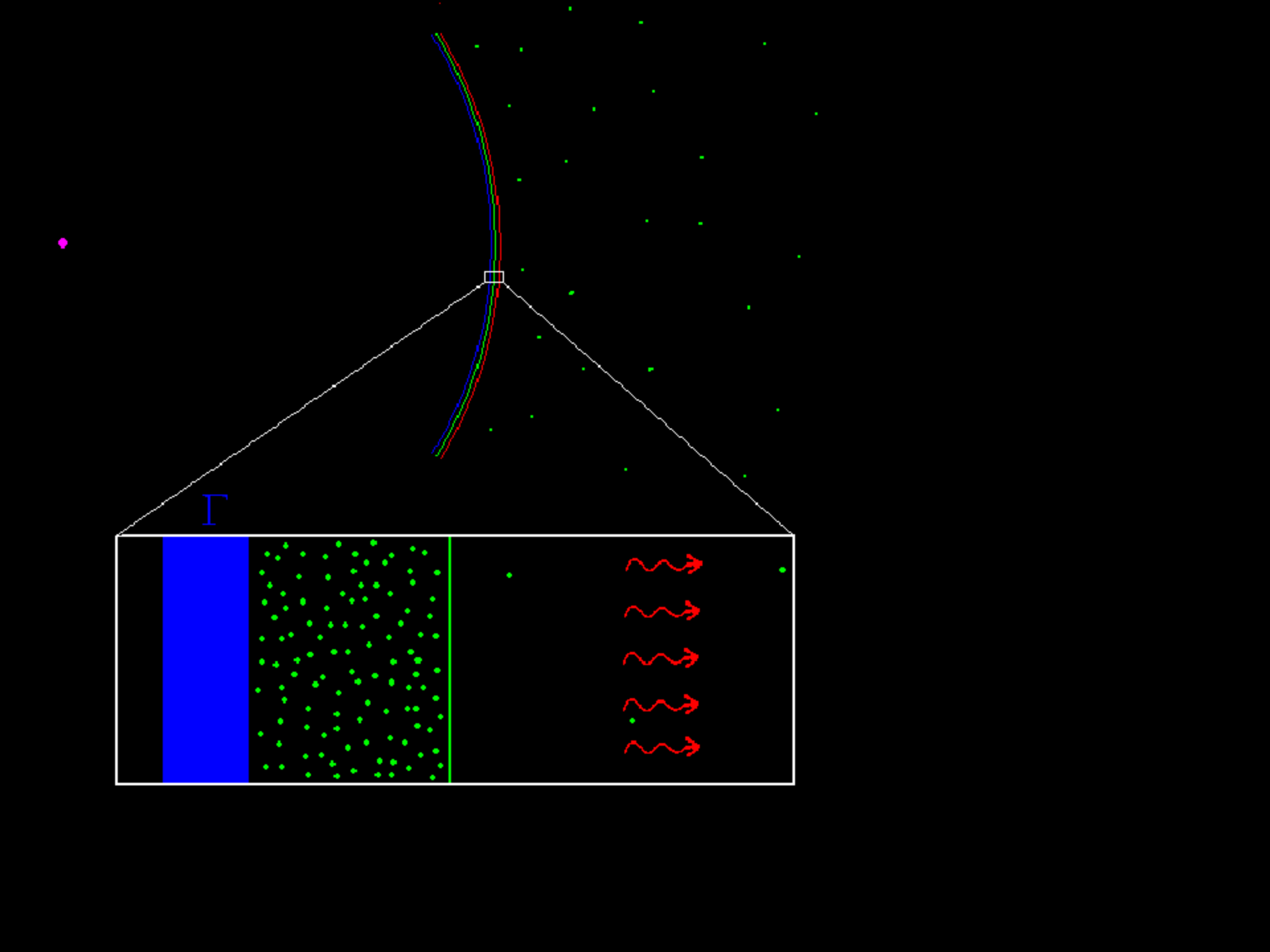
Vurm, Beloborodov, in preparation

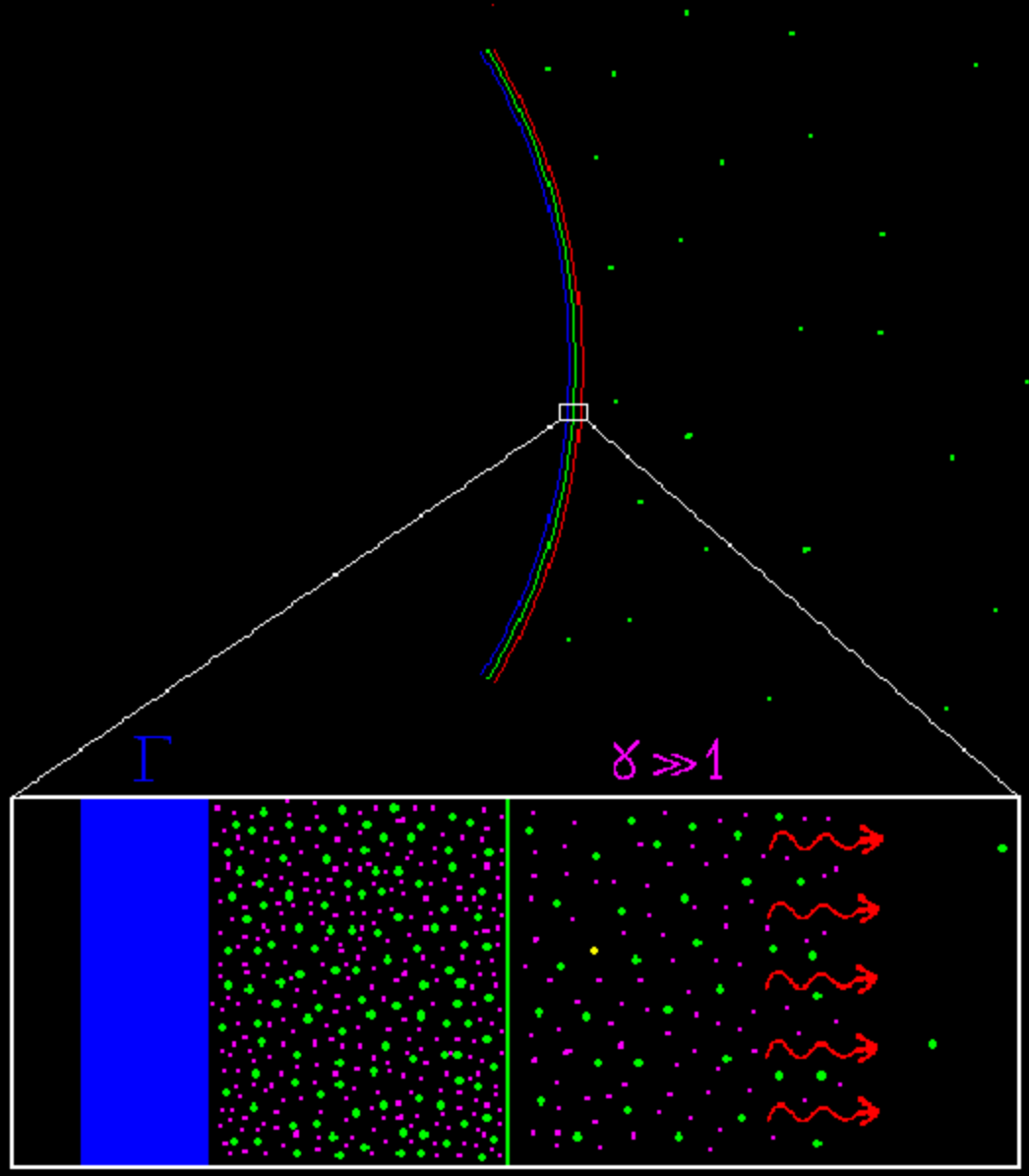
GeV flash

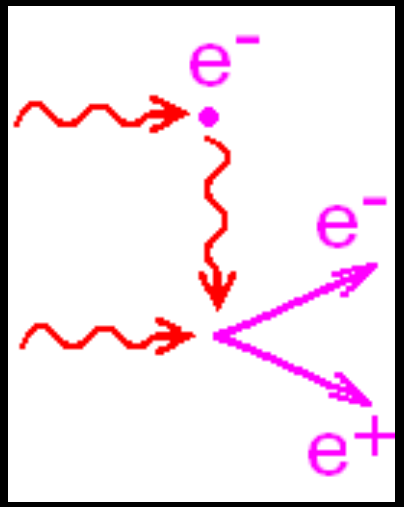
Emission from blast wave

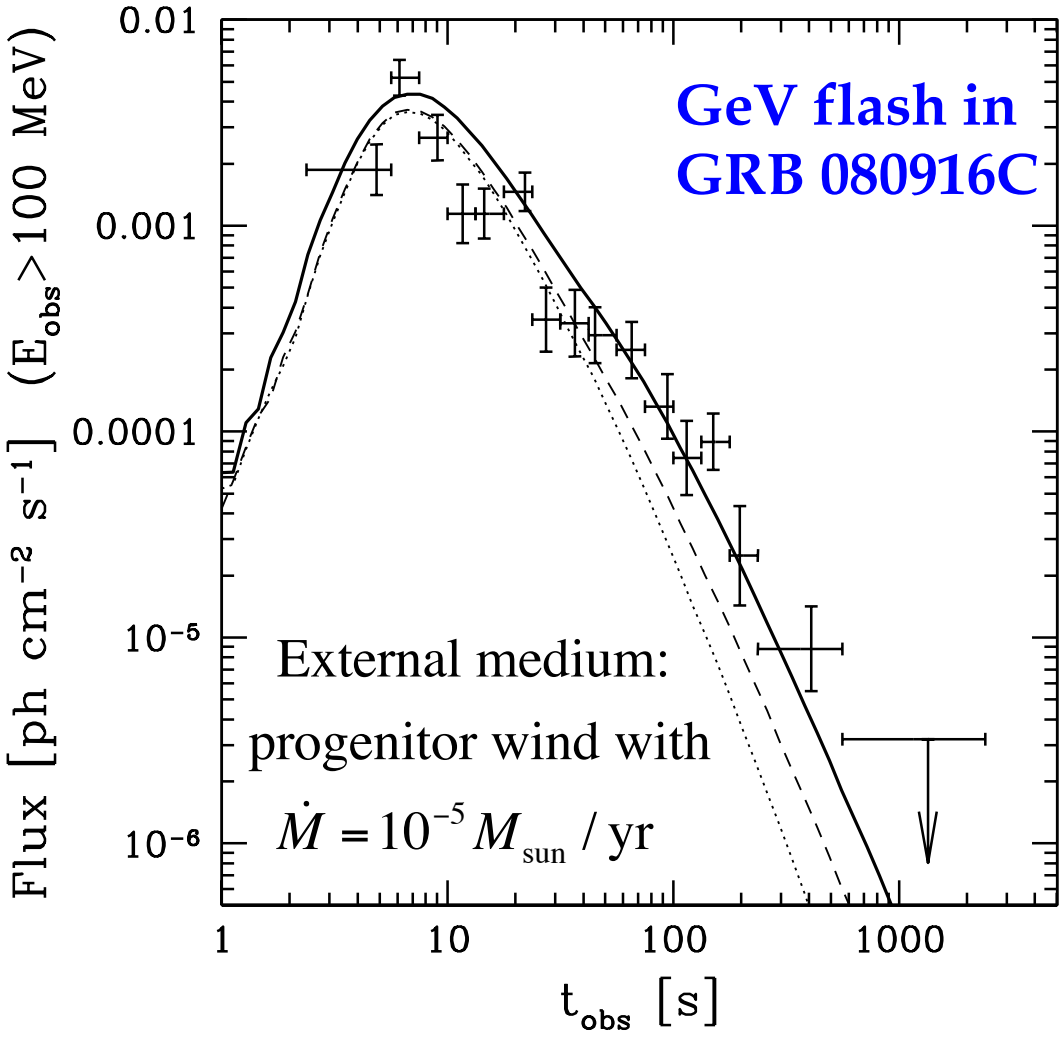


Panaitescu et al. (2013)


Γ


Γ
γ ≫ 1


e⁻
e⁻
e⁺



Beloborodov, Hascoet, Vurm (2013)

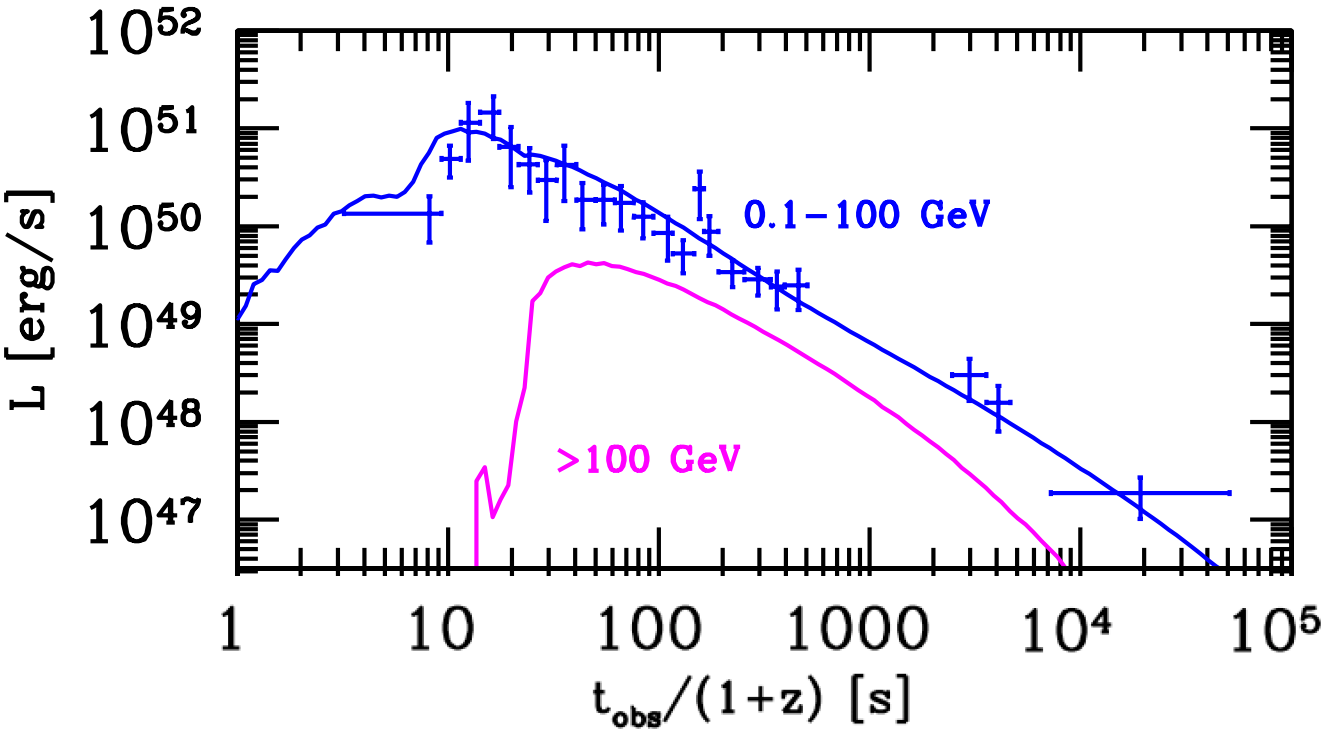
+ prediction of optical flash

detected!

GRB 130427A

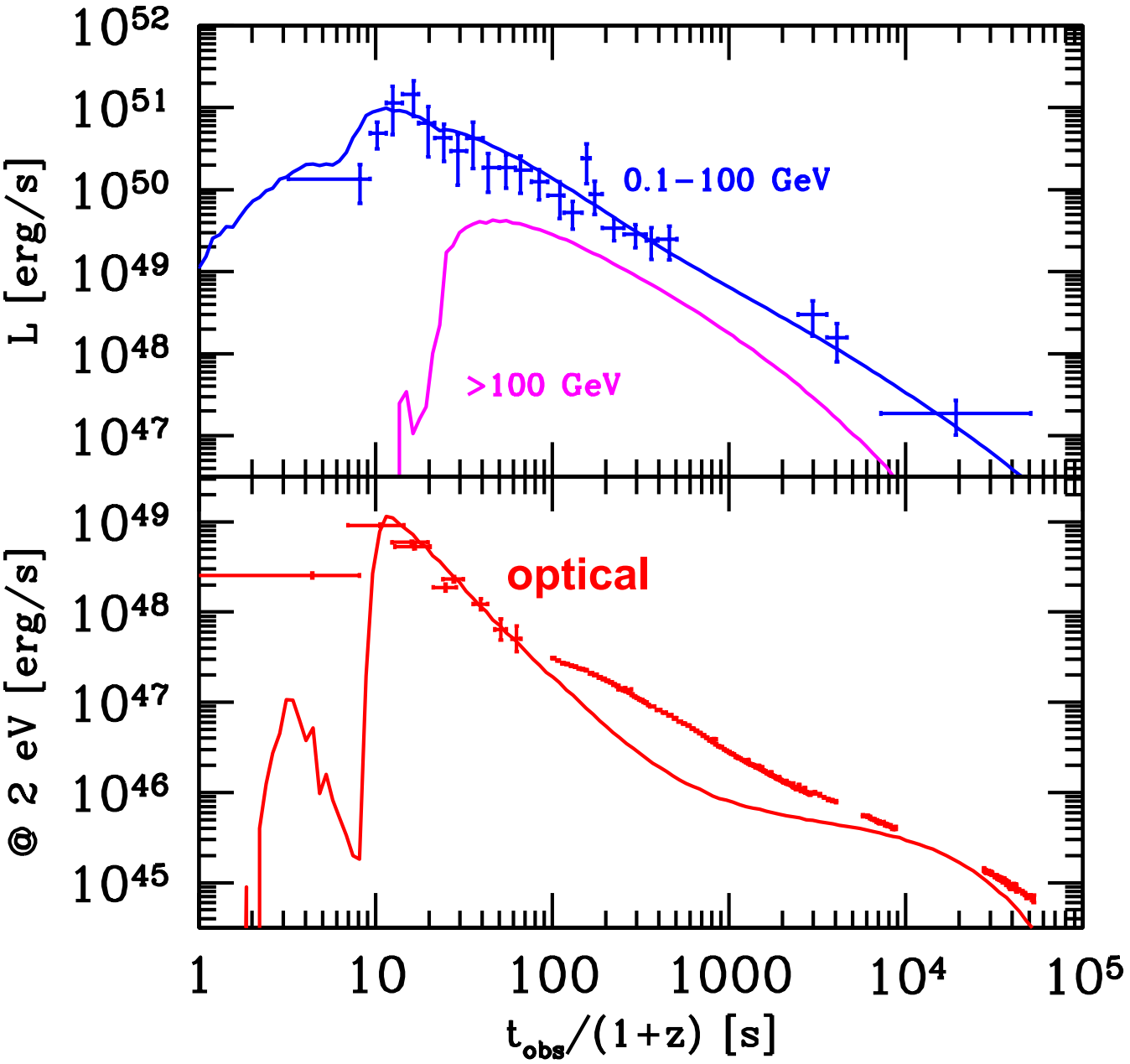
Vestrand et al. (2013)

Ackermann et al. (2013)



External medium:
progenitor wind with
$\dot{M} \sim 10^{-6} M_{sun} / yr$

Vurm, Hascoet, AB,
in preparation



External medium:
progenitor wind with
$\dot{M} \sim 10^{-6} M_{sun} / yr$

Vurm, Hascoet, AB,
in preparation