FAST RADIO BURSTS AND MAGNETARS

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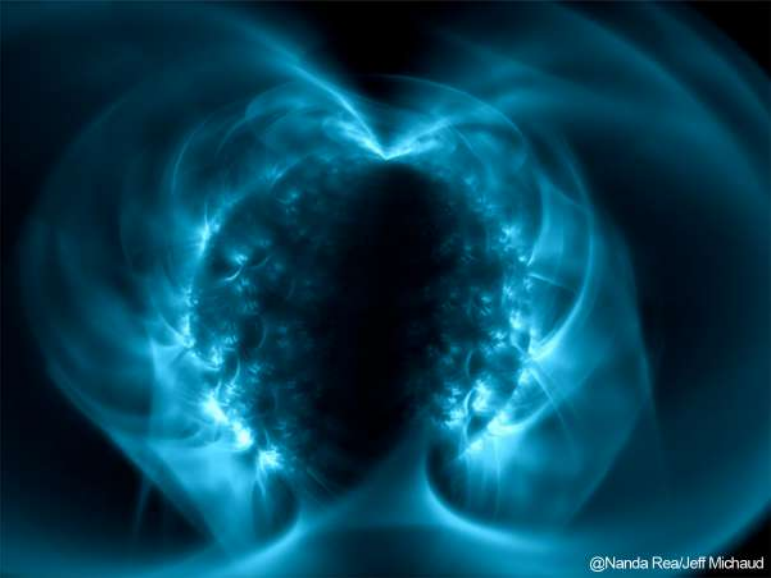
INAF – IASF MILANO

Hermes-SP/TP 1st Scientific Workshop

Astrophysics with CubeSats



Magnetars

Fast Radio Bursts

Neutron stars powered by magnetic energy

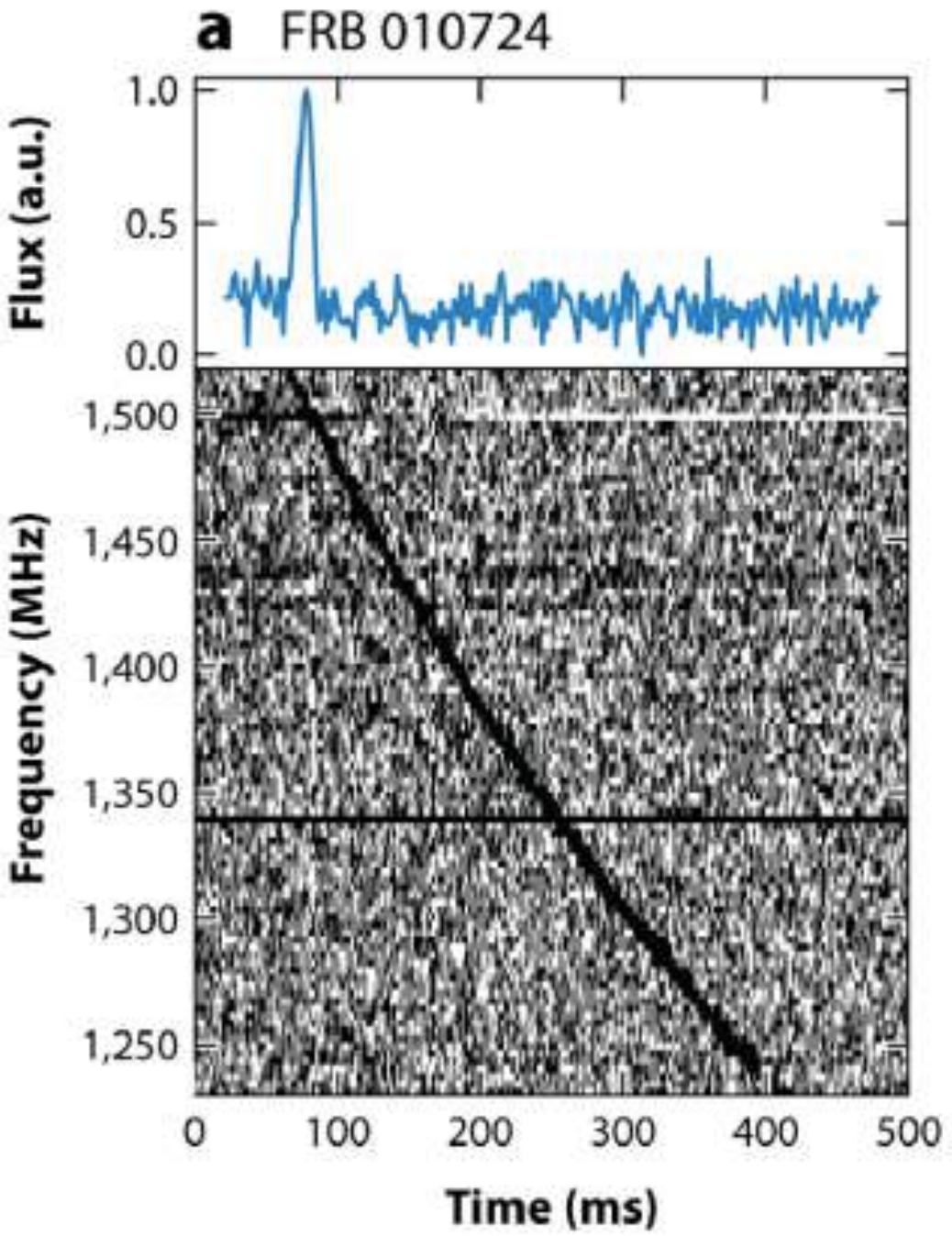
B ~$10^{15\text{-}16}$ G

the highest in the Universe !

?

Still a mystery

after ~20 yrs of observations



FAST RADIO BURSTS

Reviews: Cordes & Chatterjee 2019; Petroff+ 2019; Platts+ 2019; B. Zhang 2020

- Short (~ ms) and bright (~ 50 mJy – 100 Jy @ 0.4-8 GHz)
- Highly dispersed (DM > $DM_{Milky\ Way}$)
- No counterparts (a few host galaxies at z~0.03 – 0.5)
- A subset are repeating (2 periodic, 16 d and 157 d)
- high rate

  (>1000 per day in whole sky @ > 1 Jy ms → > 10^3 Gpc^{-3} yr^{-1})
- **Extragalactic, but unknown origin**

MAGNETARS

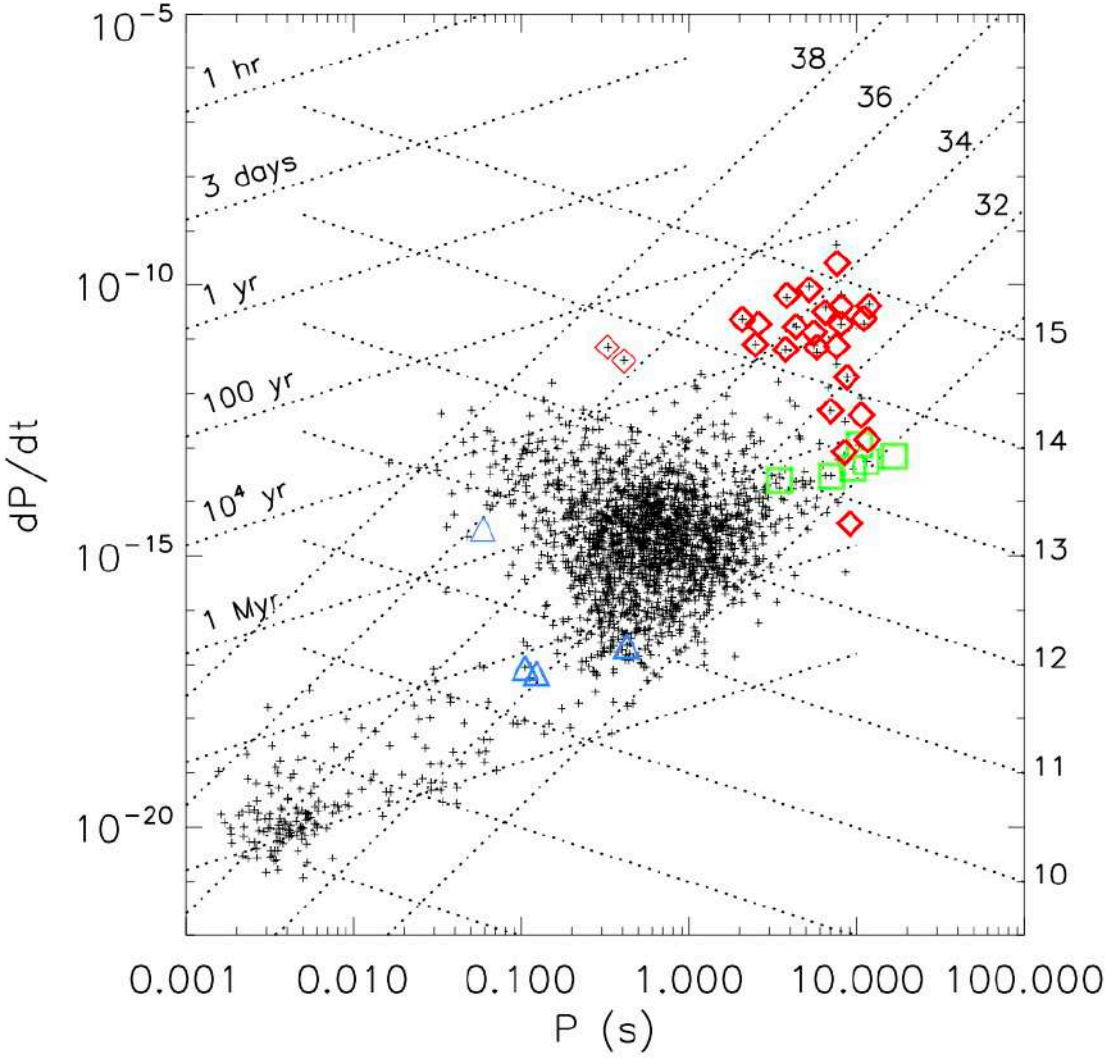
Reviews: Kaspi+Beloborodov 2017; Mereghetti+ 2015; Turolla+ 2015

- (Isolated) **neutron stars powered by magnetic energy** ($B \sim 10^{15\text{-}16}$ G)

- ~30 known in Milky Way and Magell.Clouds

- Slowly rotating ($P \sim 1\text{-}12$ s), fast spin-down ($dP/dt \sim 10^{-10} - 10^{-11}$ s/s)

- $dE_{rot}/dt \ll L_x \approx 10^{34}\text{-}10^{36}$ erg/s



MAGNETARS

- (Isolated) neutron stars powered by magnetic energy (B~$10^{15\text{-}16}$ G)

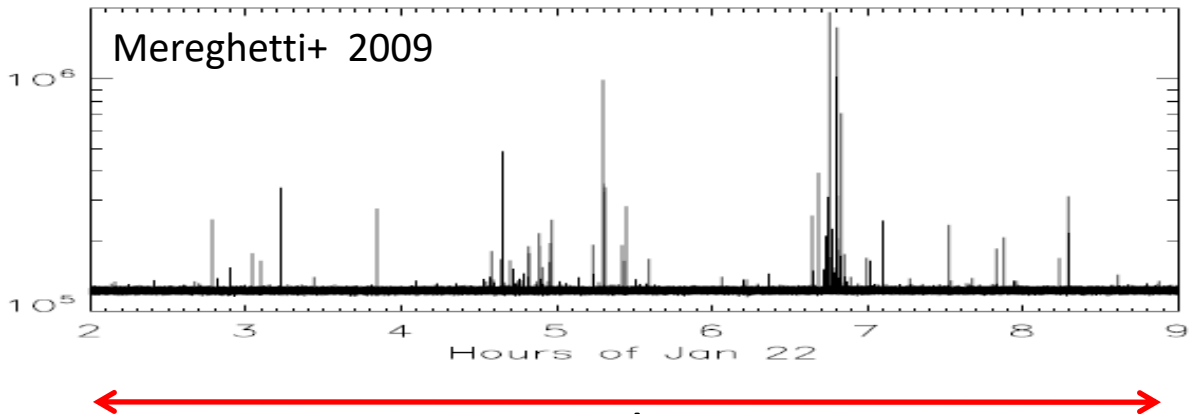
- ~30 known in Milky Way and Magell.Clouds

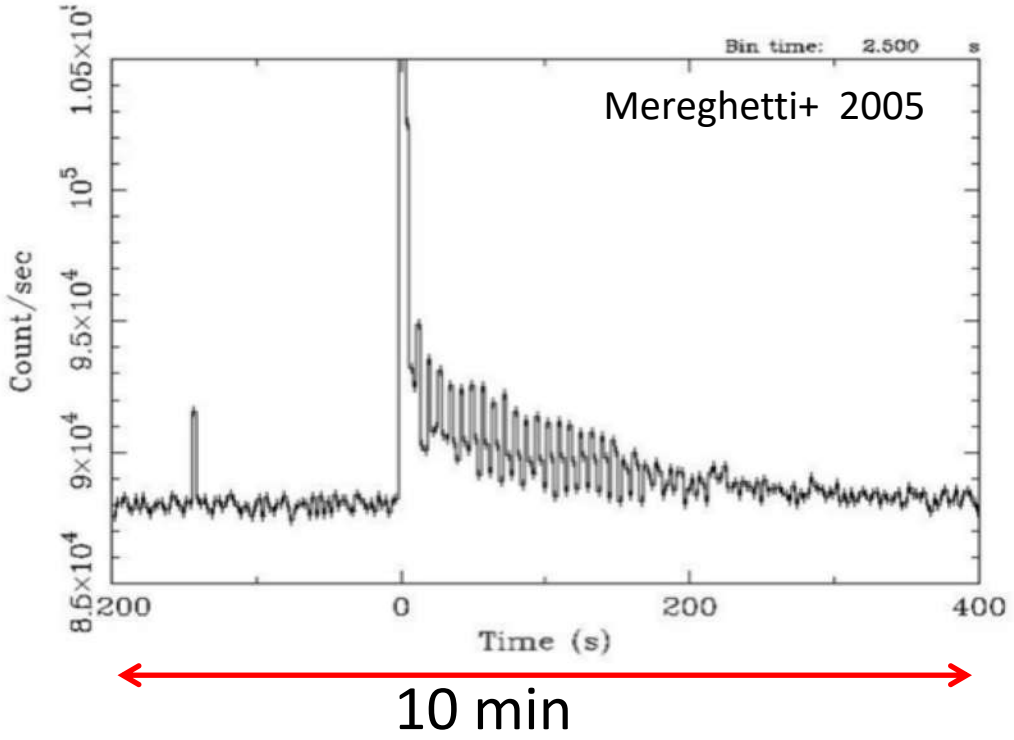
- Slowly rotating (P ~ 1-12 s), fast spin-down (dP/dt ~10^{-10} –10^{-11} s/s)

- $dE_{rot}/dt \ll L_x \approx 10^{34}\text{-}10^{36}$ erg/s

- **most are transients** ($L_{QUIESC} \approx 10^{32\text{-}33}$ erg/s)

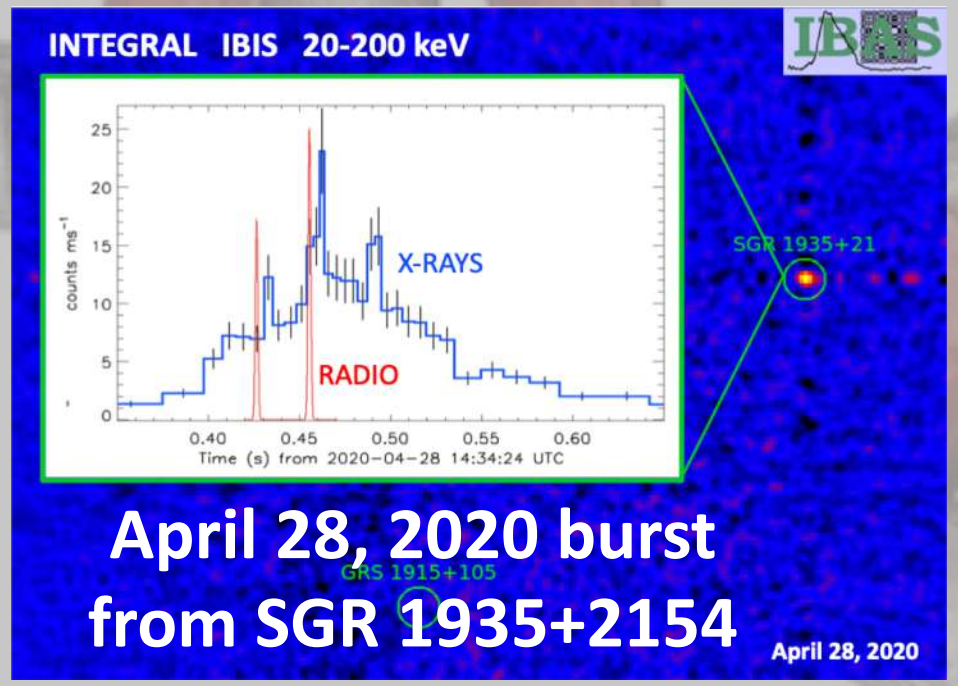
- **emit short hard X-ray bursts** (L ≈ $10^{38\text{-}43}$ erg/s) **and (rare) Giant Flares** (L ≈ $10^{44\text{-}47}$ erg/s)





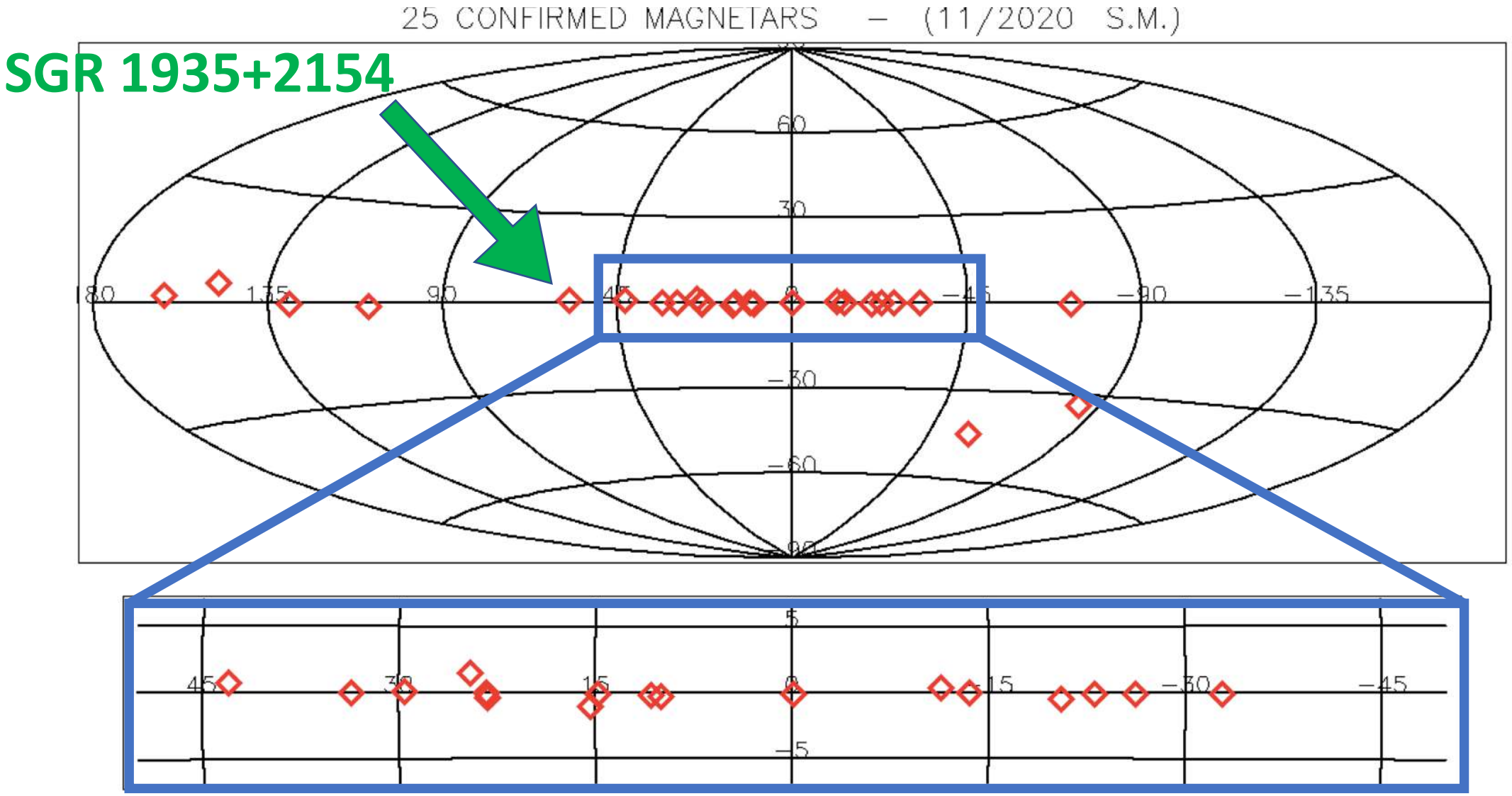
Magnetars

Fast Radio Bursts



First **observational** evidence for a connection

MAGNETARS POPULATION



SGR 1935+2154

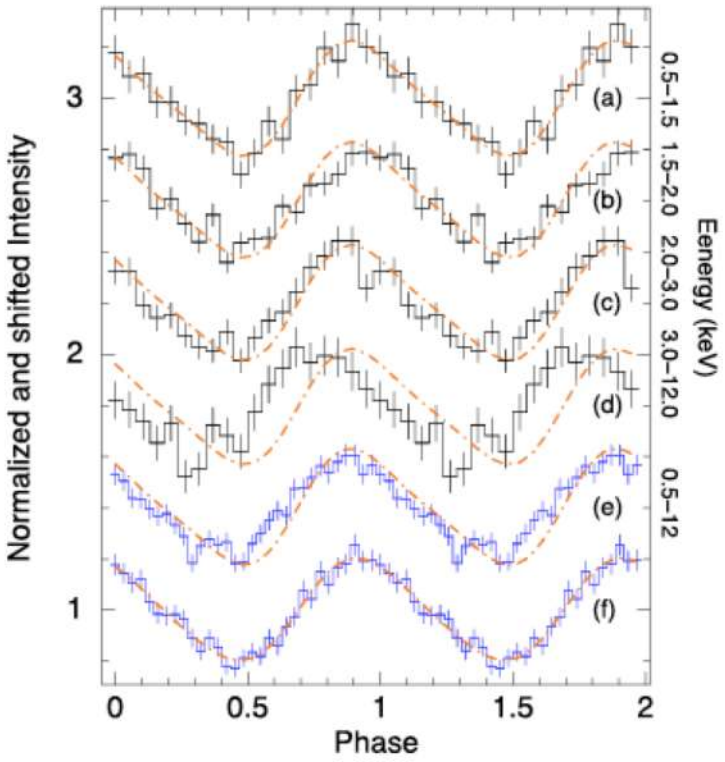
P = 3.24 s

B = 2.2 10^{14} Gauss

τ = 3600 years

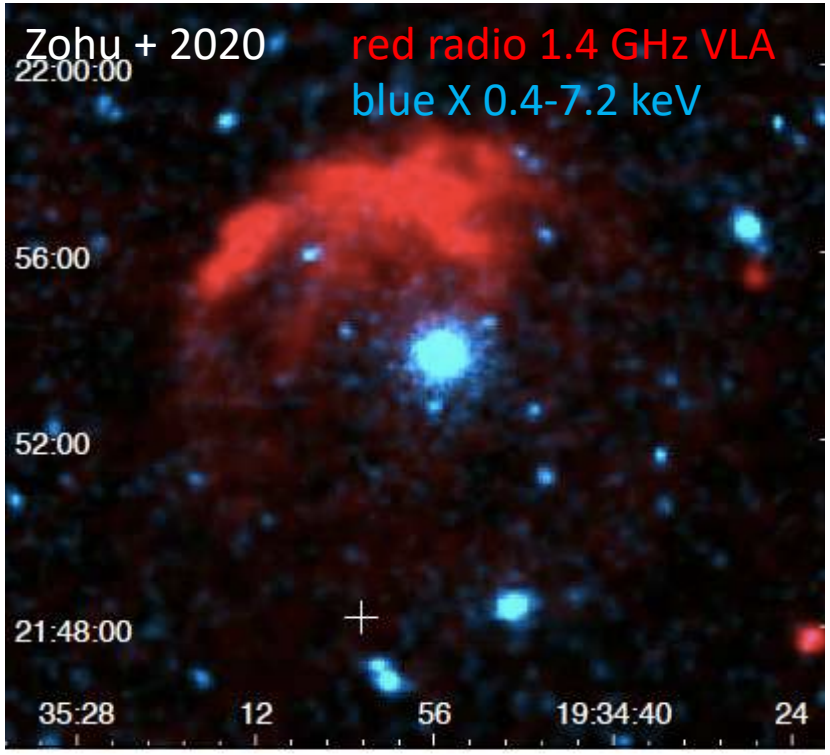
Spin-down lum. = 2 10^{34} erg/s

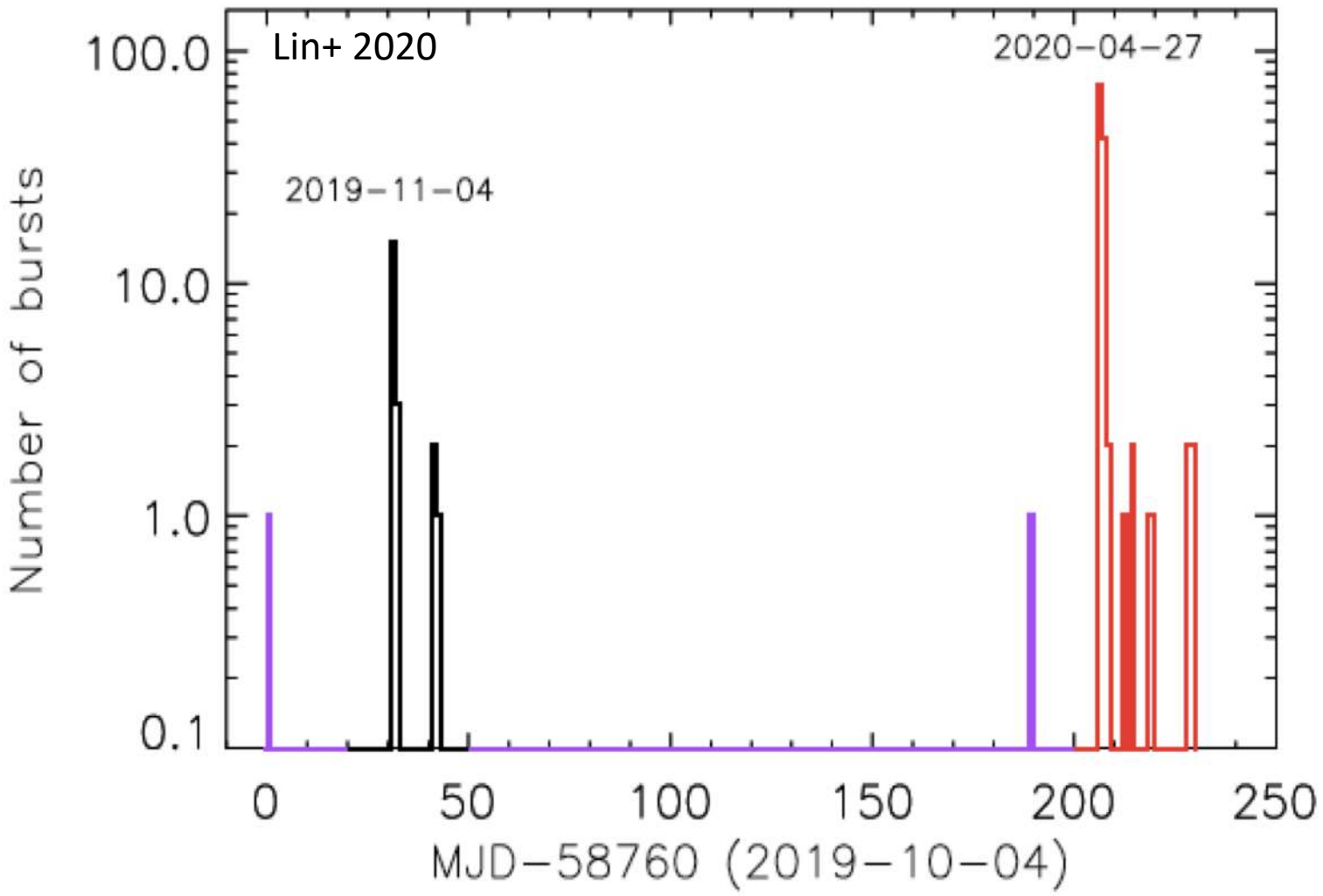
Israel+ 2016



Likely associated to SNR G57.2+0.8

Kothes+ 2018





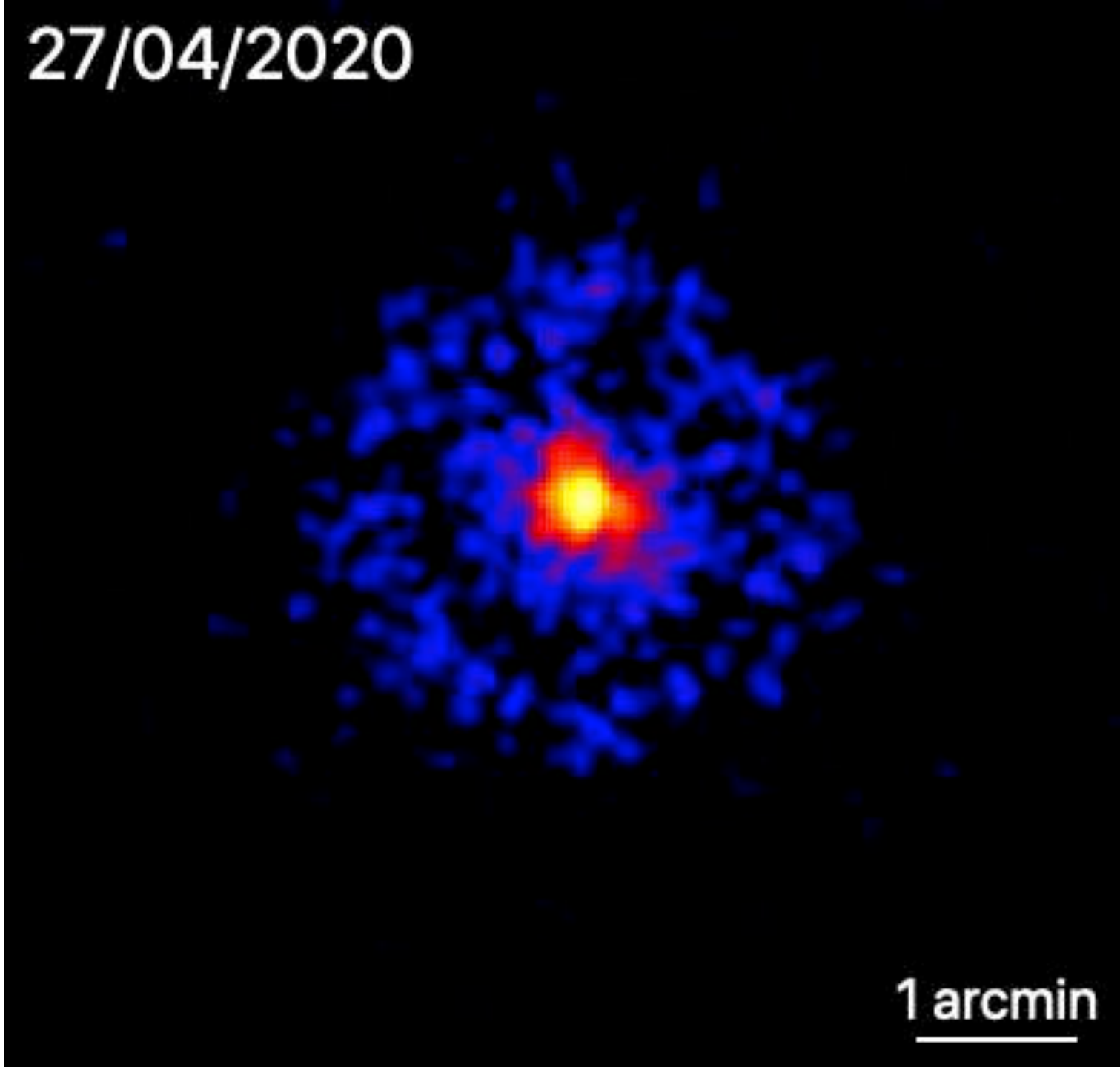
SGR 1935+2154 was very active in April 2020

→ observed by several X/gamma satellites

Swift / XRT detected a dust scattering X-ray ring on April 27, ~one hour after a ``burst forest''

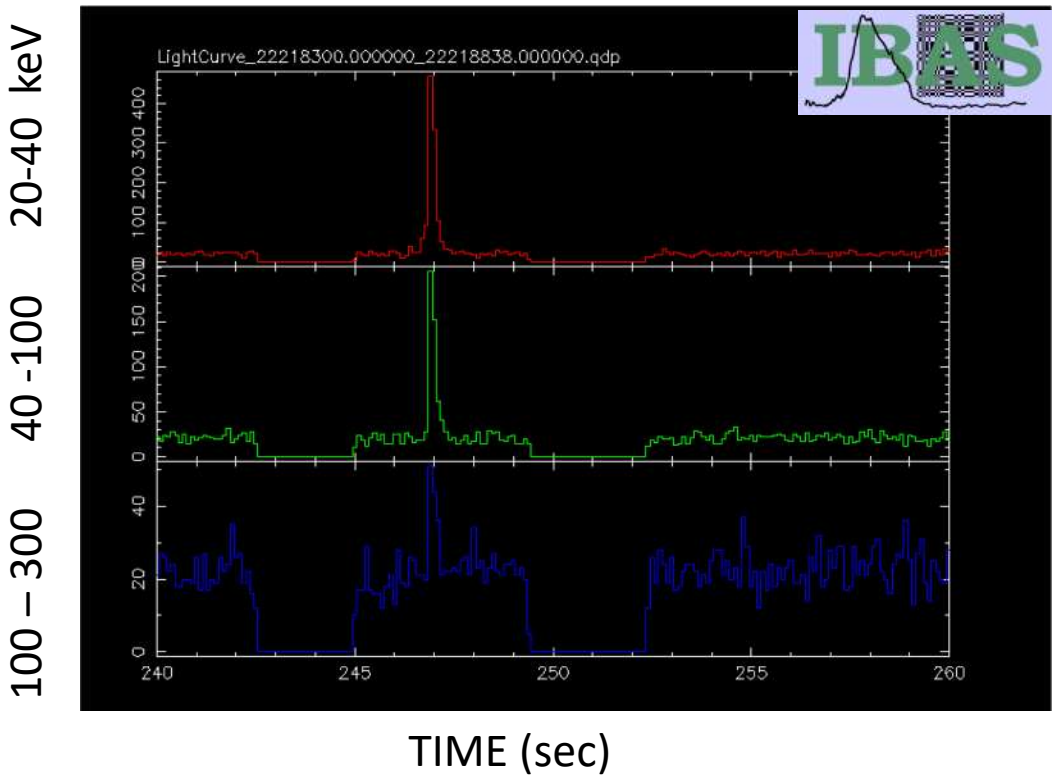
We used the ring angular expansion speed to constrain the magnetar distance

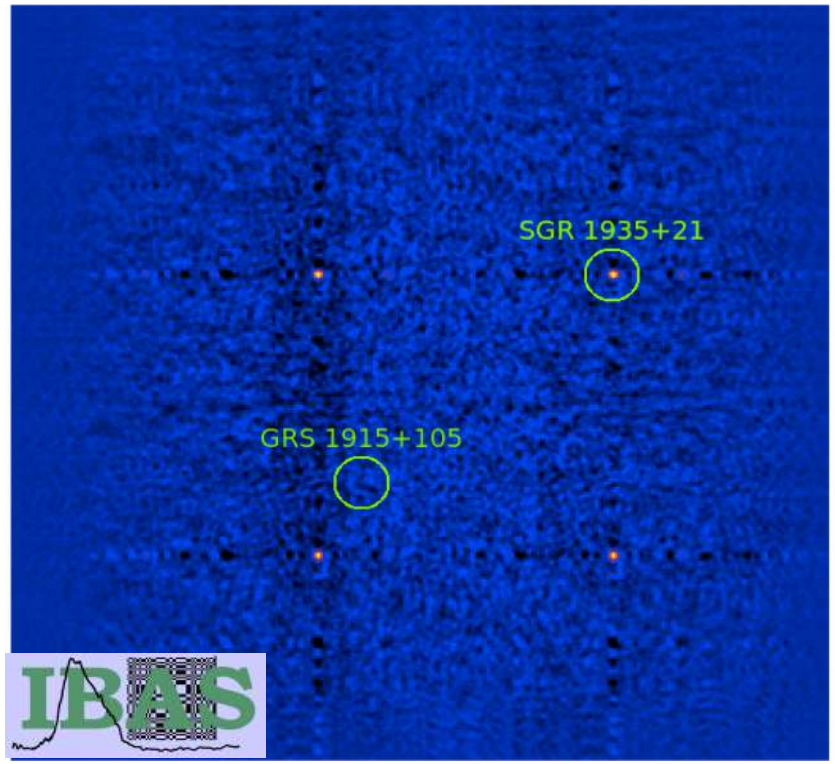
$$D_{SOURCE} = 4.4\,^{+2.8}_{-1.3}\ kpc$$



INTEGRAL Burst Alert System (IBAS) discovery

TIME OF PUBLICATION				
April 28	14:34:24	To	Burst from SGR 1935+2154	
	14:34:29	**To + 5 s**	**IBAS Alert sent, id. with SGR 1935+2154**	**GCN Notice 8611**

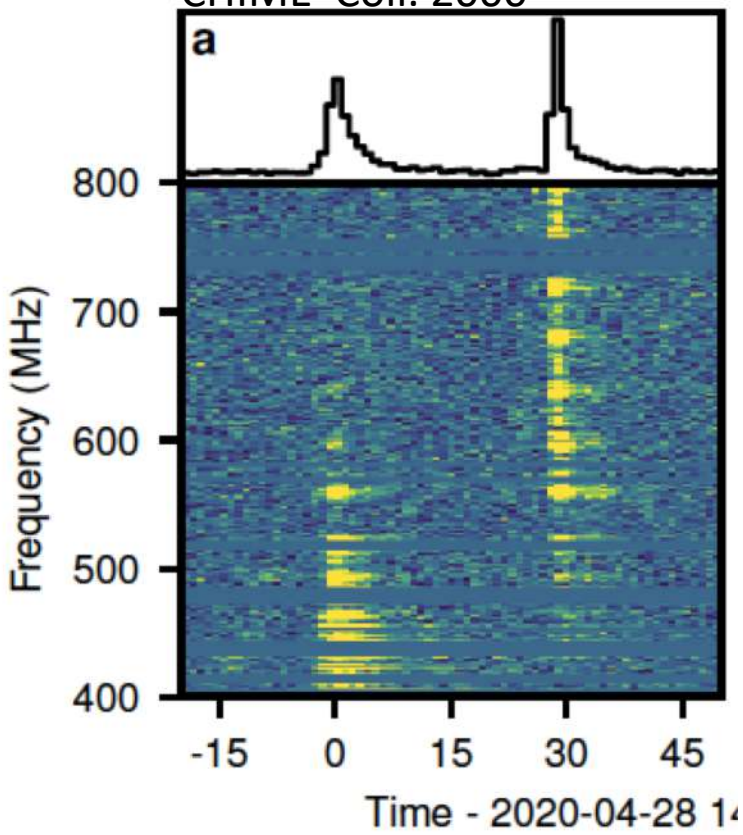




Detection in radio !

TIME OF PUBLICATION				
April 28	14:34:24	To	Burst from SGR 1935+2154	
	14:34:29	To + 5 s	IBAS Alert sent, id. with SGR 1935+2154	GCN Notice 8611
	20:45	**To + 6 hr**	**CHIME radio 400-800 MHz**	**Atel 13681**

CHIME Coll. 2000



400-800 MHz:
two pulses (0.6, 0.3 ms) separated by 29 ms

Fluence 480 and 220 kilo-Jansky ms

Localized with ~1 deg accuracy at position of SGR 1935+2154

Detection in radio independently confirmed !

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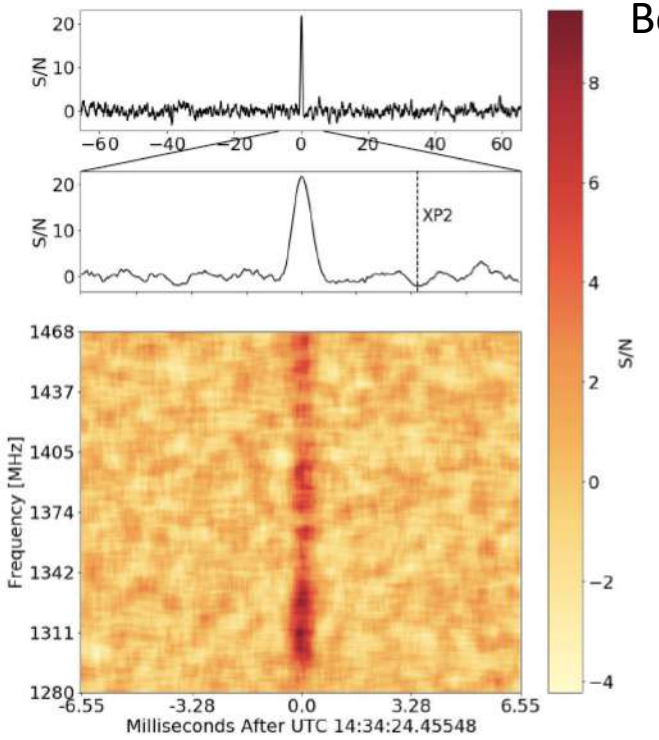
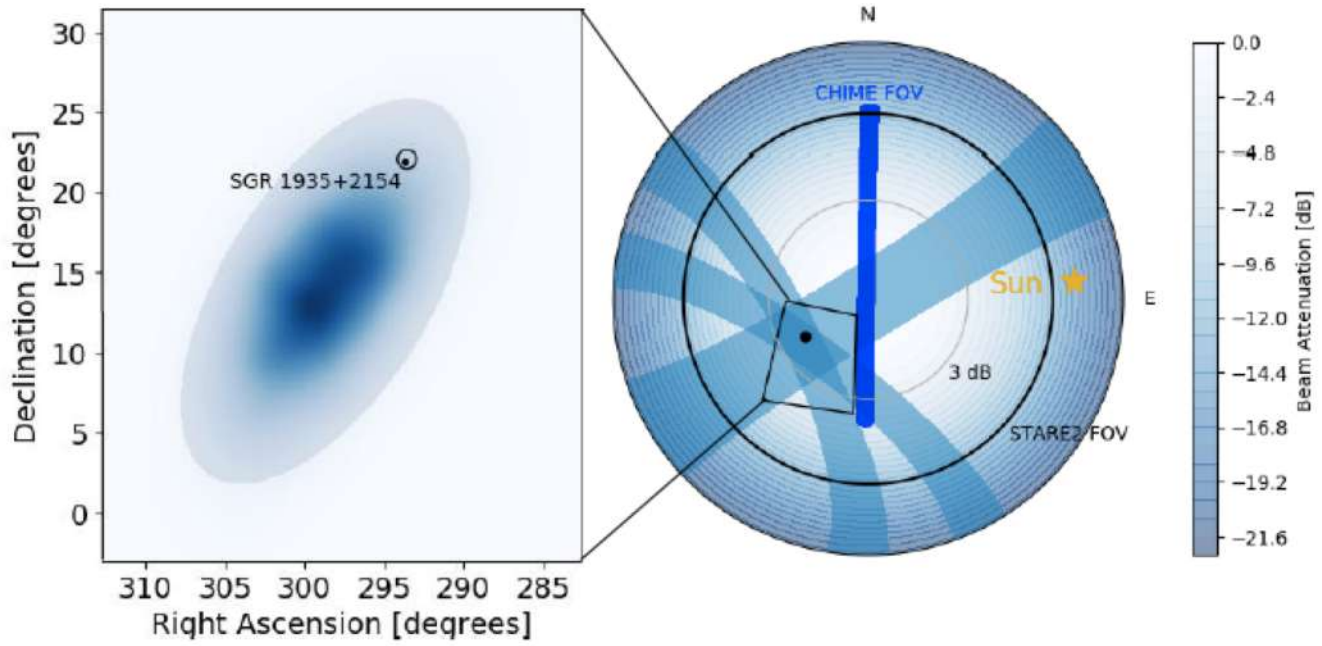
	20:45	To + 6 hr	CHIME radio 400-800 MHz	Atel 13681
April 29	03:04	**To + 12.5 hr**	**STARE 2 radio 1.4 GHz**	**Atel 13684**



Bochenek+ 2020

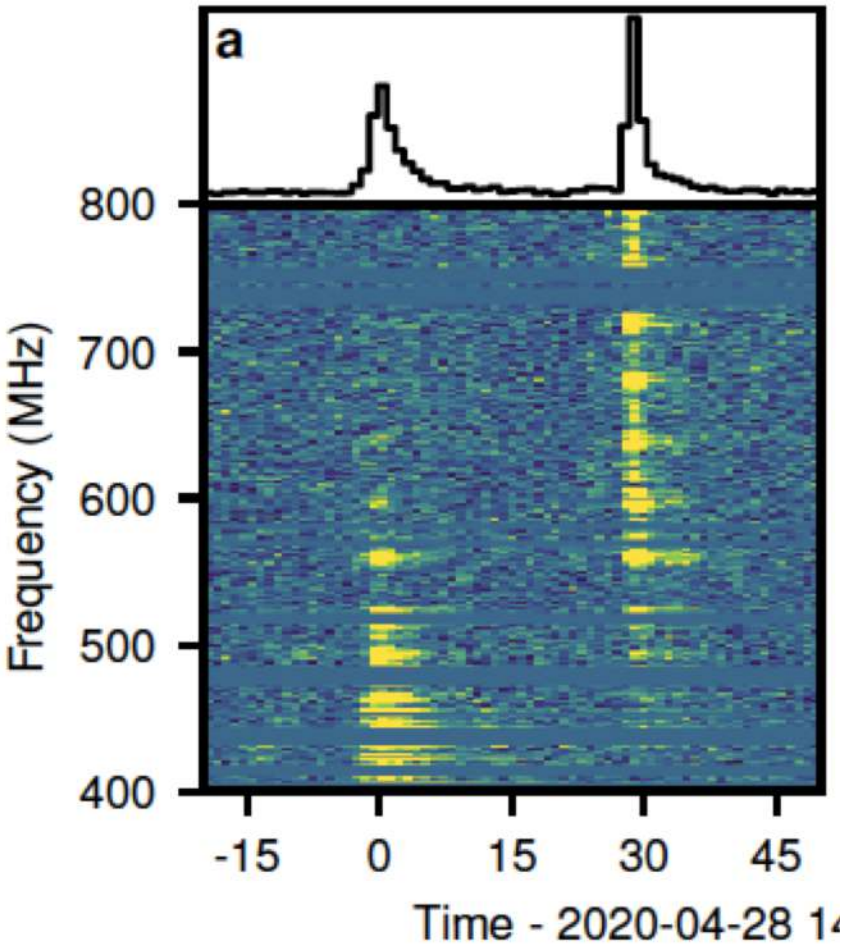


An ``FRB-like'' radio burst

CHIME 400-800 MHz:
two pulses (0.6, 0.3 ms) separated by 29 ms
Fluence 480 and 220 kilo-Jansky ms

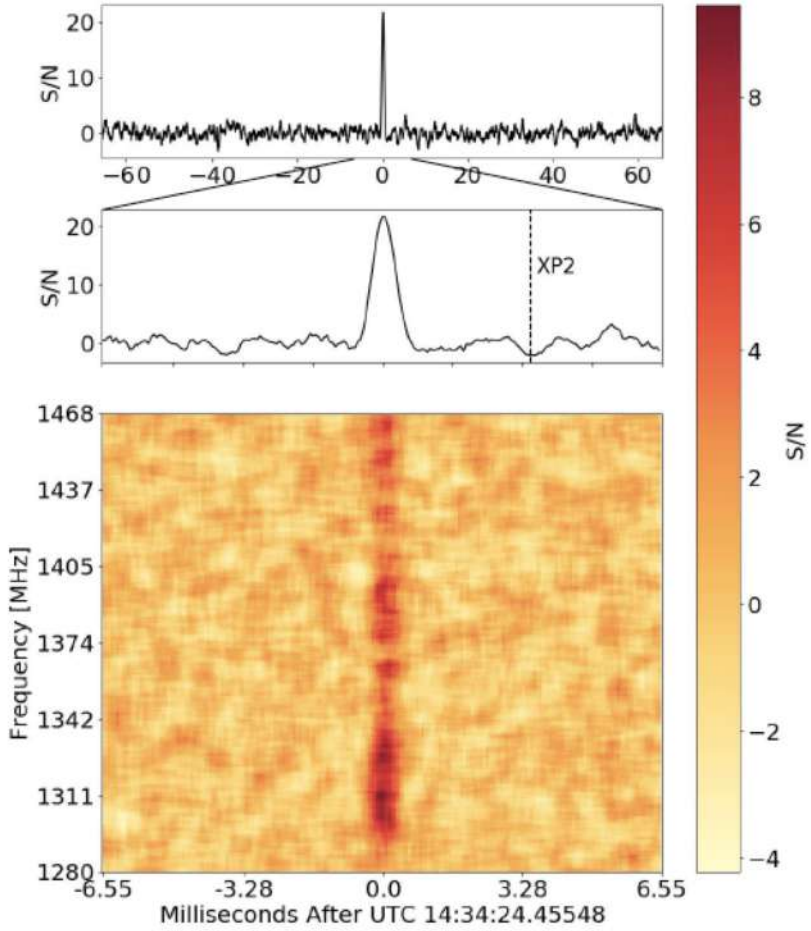
STARE2 1.4 GHz:
one pulse (= 2nd CHIME pulse)
Fluence 1.5 +/-0.3 Mega-Jansky ms

CHIME Collaboration 2020



DM = 332.7 pc/cm^3 < $DM_{Milky\ Way}$

E_{RADIO} ~ $10^{35\text{-}36}$ erg



bridging the gap

E_{RADIO} ~ $10^{35\text{-}36}$ erg

~ x 1000 higher than most energetic GALACTIC pulses

~ x 40 lower than least energetic FAST RADIO BURSTS

…and several other X-ray detections

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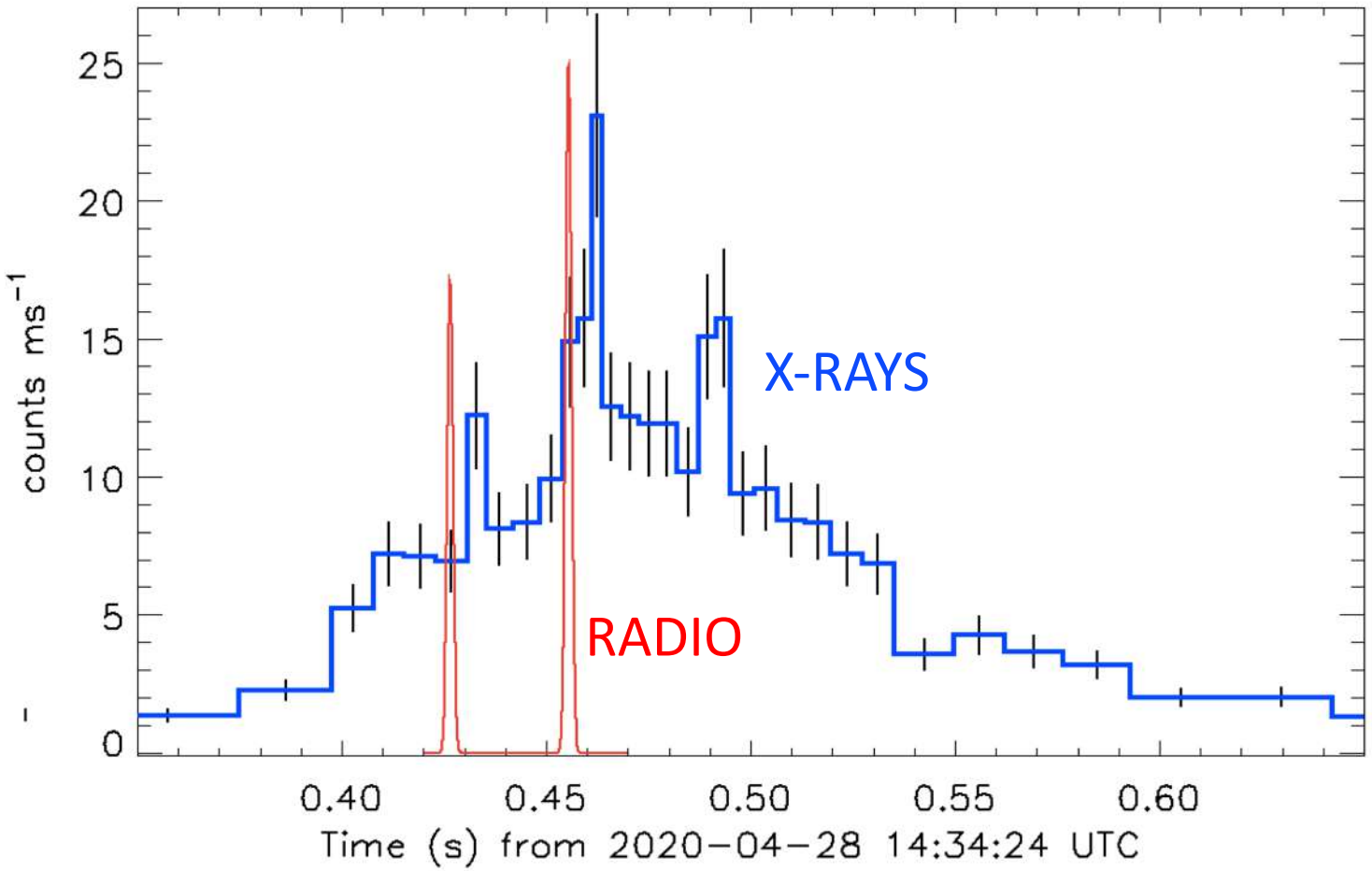
	20:45	To + 6 hr	CHIME radio 400-800 MHz	Atel 13681
April 29	03:04	To + 12.5 hr	STARE 2 radio 1.4 GHz	Atel 13684
	09:30:38	To + 19 hr	INTEGRAL	GCN Circ 27668
	10:53		INTEGRAL	Atel 13685
	11:05		**AGILE (no imaging)**	**Atel 13686**
	15:34:34	To + 1 day	**Konus-WIND (no imaging)**	**GCN Circ 27669**
	19:05		**Insight-XHMT**	**Atel 13687**

INTEGRAL 20-200 keV light curve

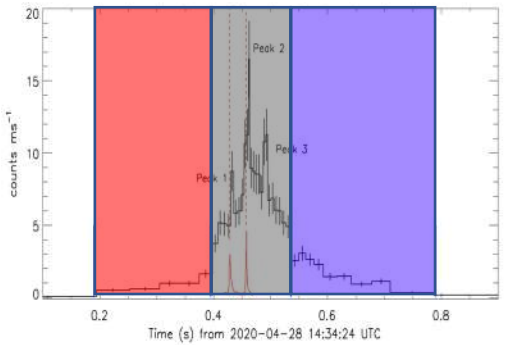


Broad X-ray pulse starts before the radio

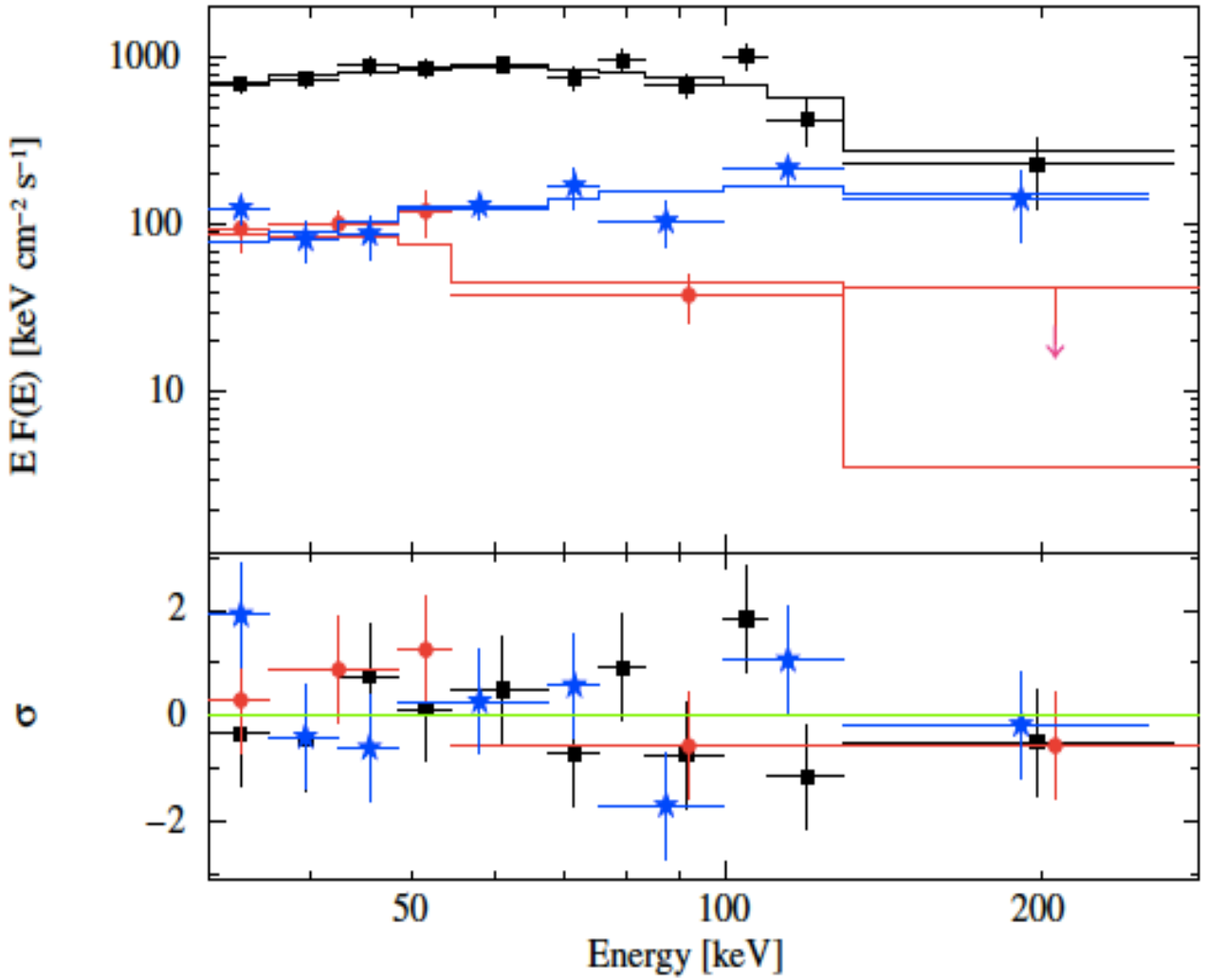
Narrow X-ray peaks with 6.5 +/- 1 ms lag wrt the radio

→ Hermes !

INTEGRAL SPECTRAL RESULTS



Mereghetti+ 2020



Exp. cut-off power law with soft-to-hard evolution

Phot.index = 0.62 +/- 0.2

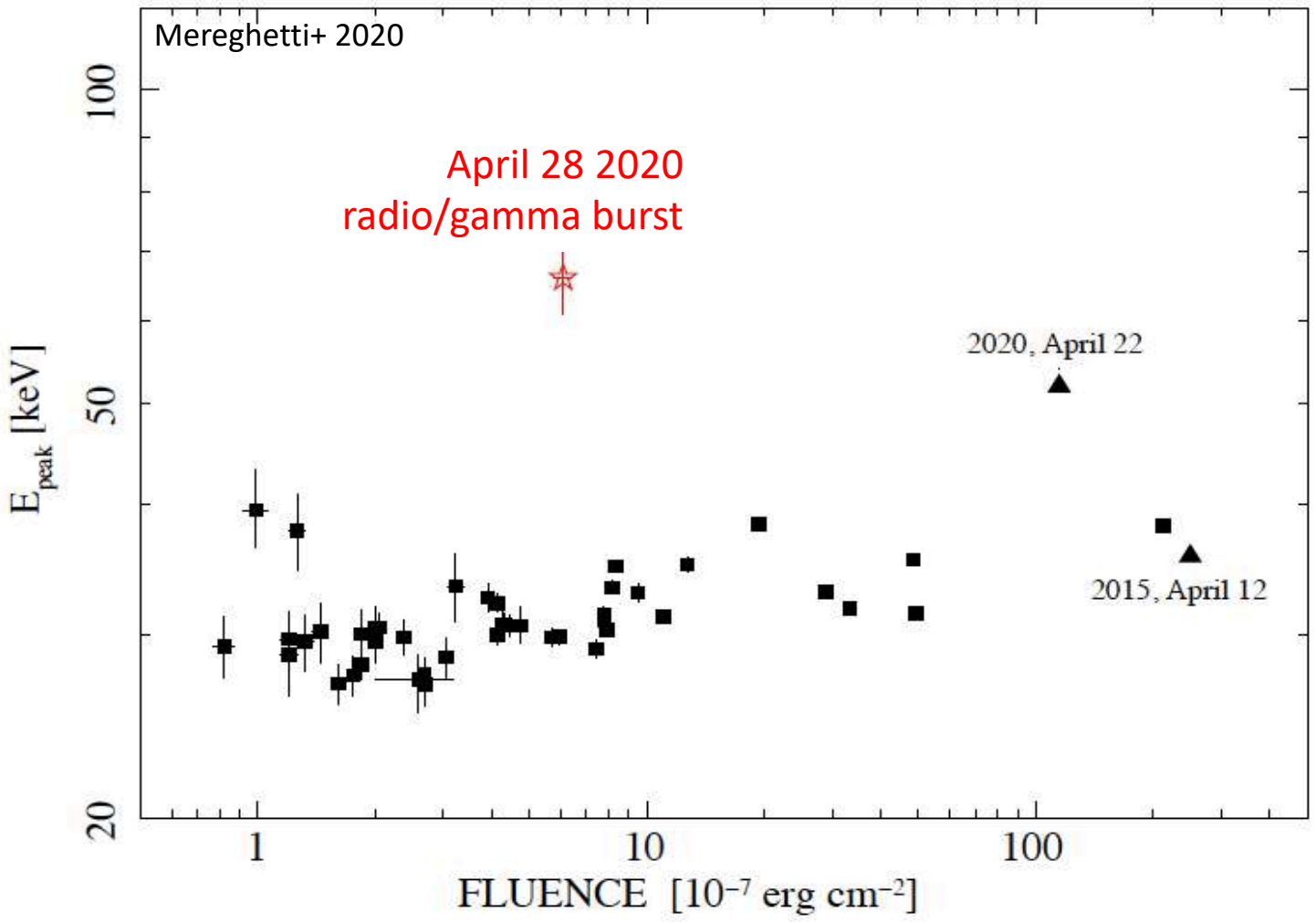
E_{peak} = 34 +/- 8 keV

E_{peak} = 60 +/- 5 keV

E_{peak} = 125 [-29, +50] keV

→E_{peak} increases with time

INTEGRAL SPECTRAL RESULTS



Peak luminosity ~ 10^{40} erg /s

isotropic energy emission
~ 1.4 10^{39} erg (@ 4.4 kpc)

Not particularly energetic but significantly harder than 'normal' bursts from SGR 1935+2154 (and other magnetars)

WHY SGR 1935 ?

A garden-variety magnetar (3.24 s, 2.2 10^{14} G, 3600 yrs)

5 outbursts since its discovery in 2014 (but quiescent for decades before)

…AND WHY ONLY THIS BURST ?

Standard X-ray fluence but spectrally harder than usual

Unusual light curve ? (slow rise, more structured)

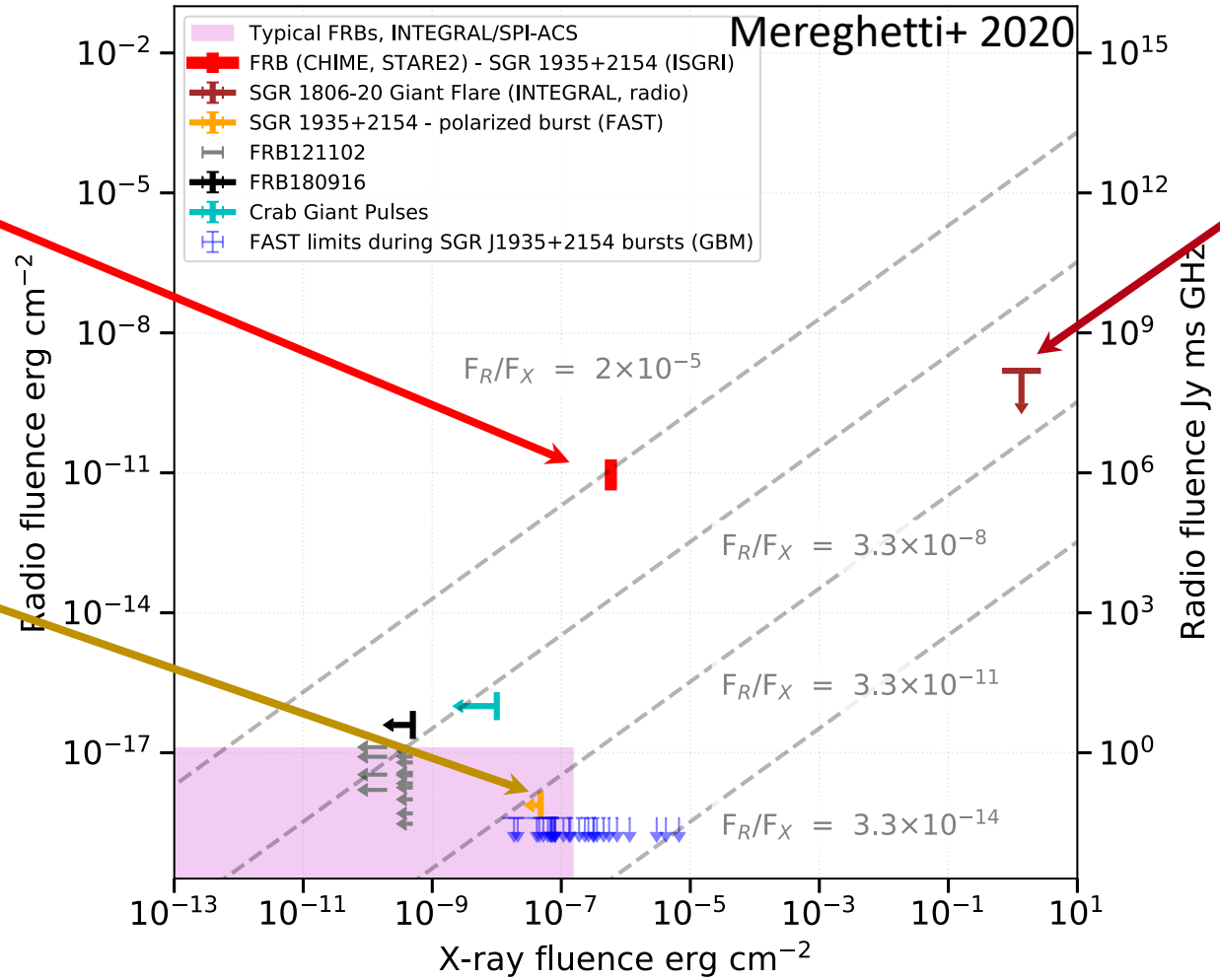
Not in the period of maximum activity (that occurred one day earlier)

RADIO versus X-RAY FLUENCE

SGR 1935
April 28
$F_R/F_X \sim 2\ 10^{-5}$

SGR 1935
FAST polarized
radio burst
$F_R/F_X \gtrsim 3\ 10^{-11}$

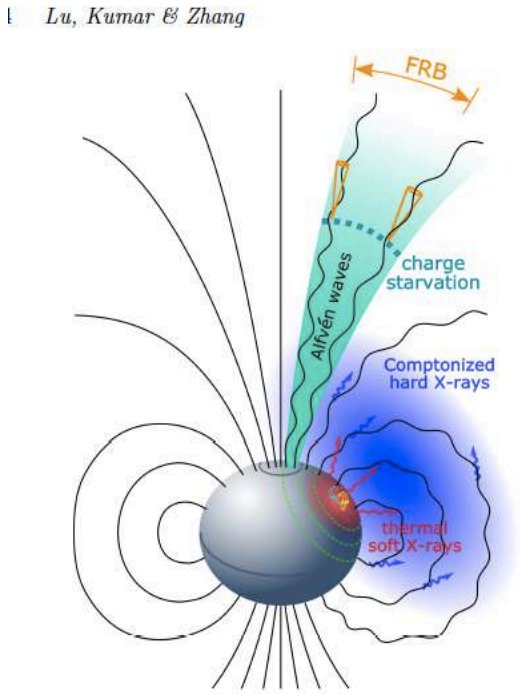
2004 Giant Flare
SGR 1806-20
$F_R/F_X \lesssim 10^{-9}$



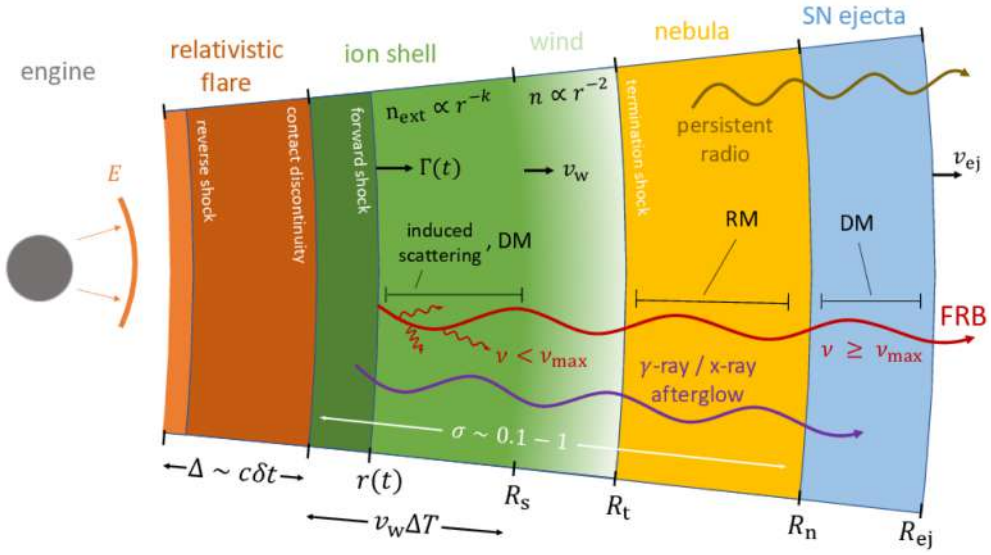
X-ray u.l. on extragalactic FRB not yet very constraining,
but RADIO u.l. on magnetars bursts and GF imply large range of F_R/F_X

TWO MAIN CLASSES OF FRB MODELS INVOLVING MAGNETARS

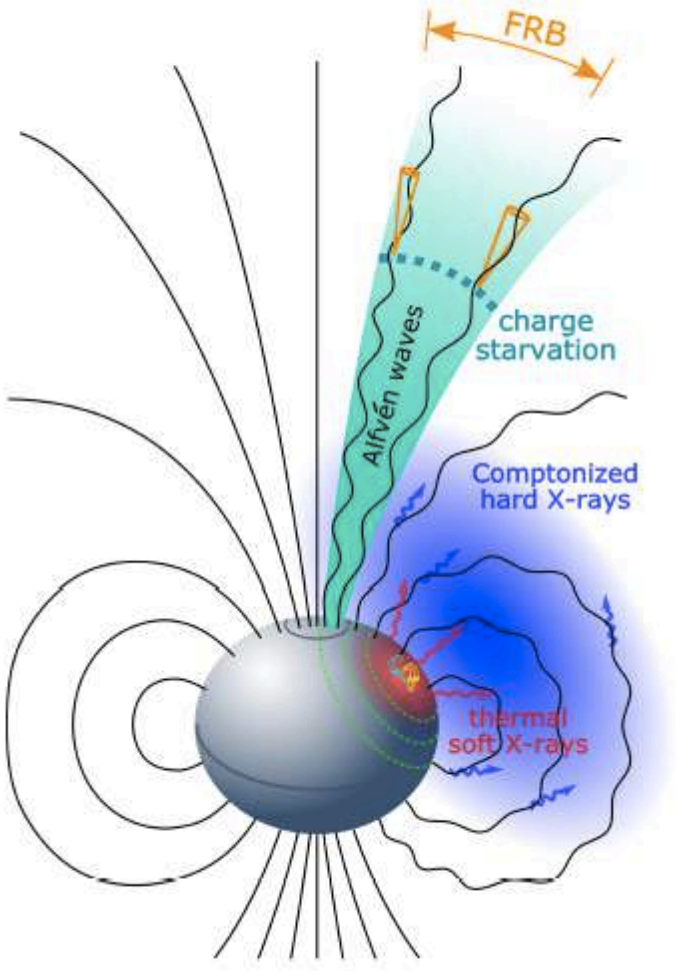
``PULSAR-LIKE''



``GRB-LIKE''



Most models originally developed considering Giant Flares, not 'normal' bursts

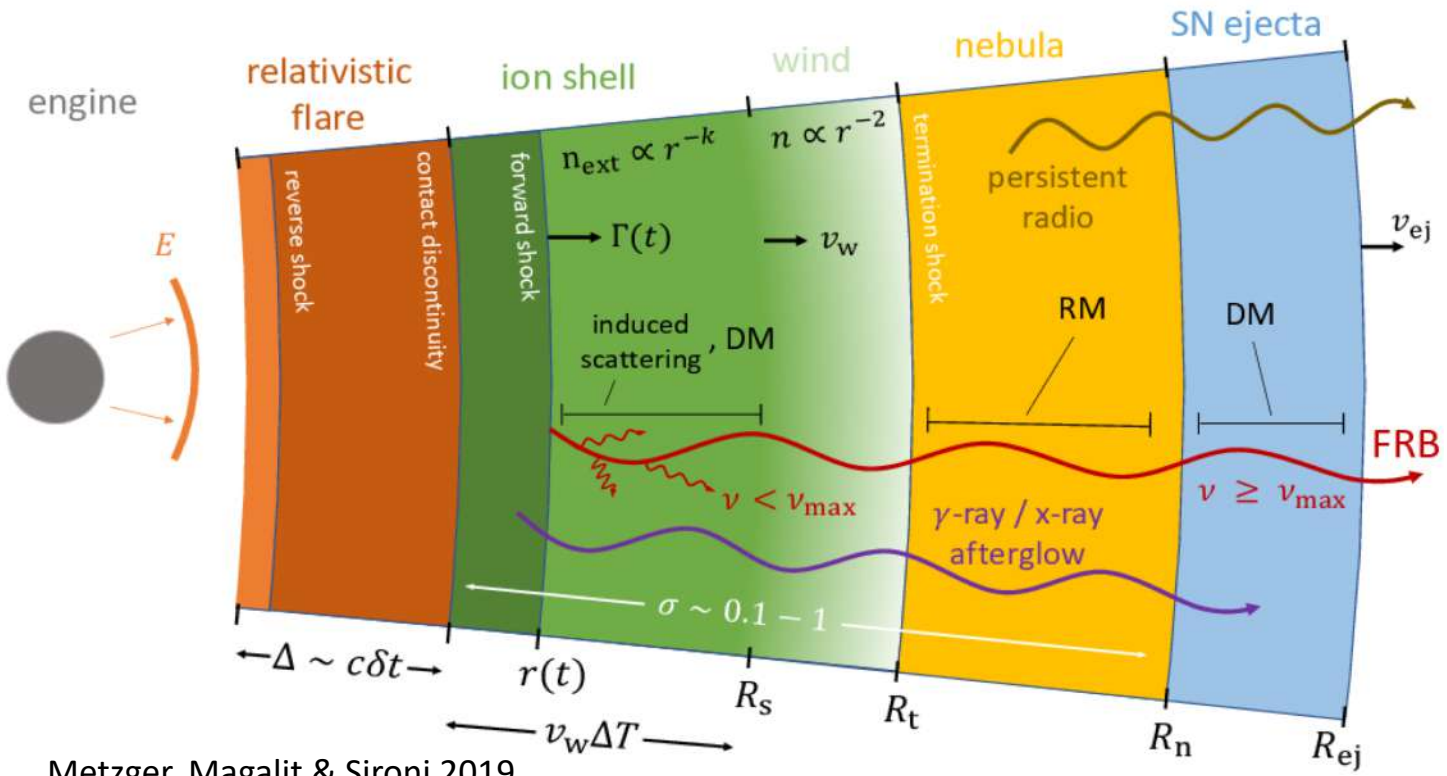


Both radio and in X-ray emission inside the NS magnetosphere

$R < R_{LC}$ (= 1.5 10^{10} cm for SGR1935)

[e.g., Pen & Connor 2015; Cordes & Wasserman 2016; Lyutikov + 2016; Kumar+ 2017; Zhang 2017; Lu & Kumar 2018; Yang & Zhang 2018; Kumar & Bosnjak 2020]

Emission in relativistic outflow interacting with surrounding medium at R ~$10^{13\text{-}15}$ cm >> R_{LC}



Metzger, Magalit & Sironi 2019

Collisionless shock in pre-existing pairs wind or slow barionic ejecta

Independent on nature of central engine

[e.g. Lyubarsky 2014; Waxman 2017; Beloborodov 2017, 2019; Metzger+ 2019; Margalit+ 2020]

First observational proof of a connection between magnetars and FRBs lends strong support to FRB models involving magnetars

Many questions remain…

- Can all FRB be explained by magnetars ?
- Are the magnetars in extragal. FRB different from Galactic ones?
- Why radio emission only from this particular burst ?
- How are the radio pulses generated by magnetars ?
- ….

…. but promising future ahead for HERMES !!