Simultaneous X-ray and Radio observations of FRB 121102

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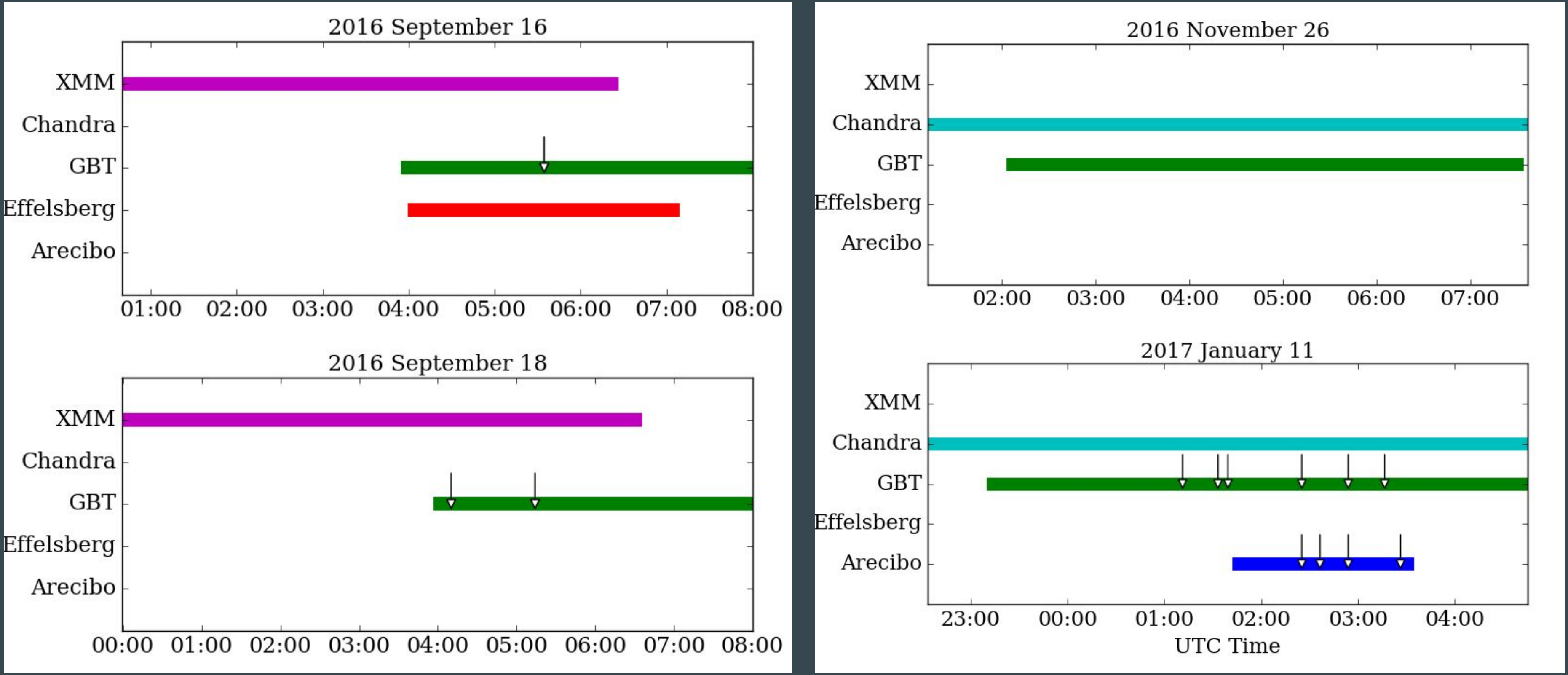
Repeater

- Repeats episodically
- Had a large episode in Aug-Sept 2016
  - Resulted in localization! (Shami's talk)
- Host is a low-metallicity dwarf galaxy at z=0.193 → D_L= 972 Mpc
- FRB 121102 in star forming region (Shriharsh's talk)

We undertook an X-ray project (see : *Scholz et al. 2017, arxiv:1705.07824)*

- GBT and XMM DDT time for simultaneous X-ray and Radio observations during Aug-Sept 2016 activity
- Joint Chandra/GBT program during Chandra Cycle 18 (Jan-Dec 2017)

Schedule


2016 September 16
XMM
Chandra
GBT
Effelsberg
Arecibo
01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00
2016 September 18
XMM
Chandra
GBT
Effelsberg
Arecibo
00:00 01:00 02:00 03:00 04:00 05:00 06:00 07:00 08:00
2016 November 26
XMM
Chandra
GBT
Effelsberg
Arecibo
02:00 03:00 04:00 05:00 06:00 07:00
2017 January 11
XMM
Chandra
GBT
Effelsberg
Arecibo
23:00 00:00 01:00 02:00 03:00 04:00
UTC Time

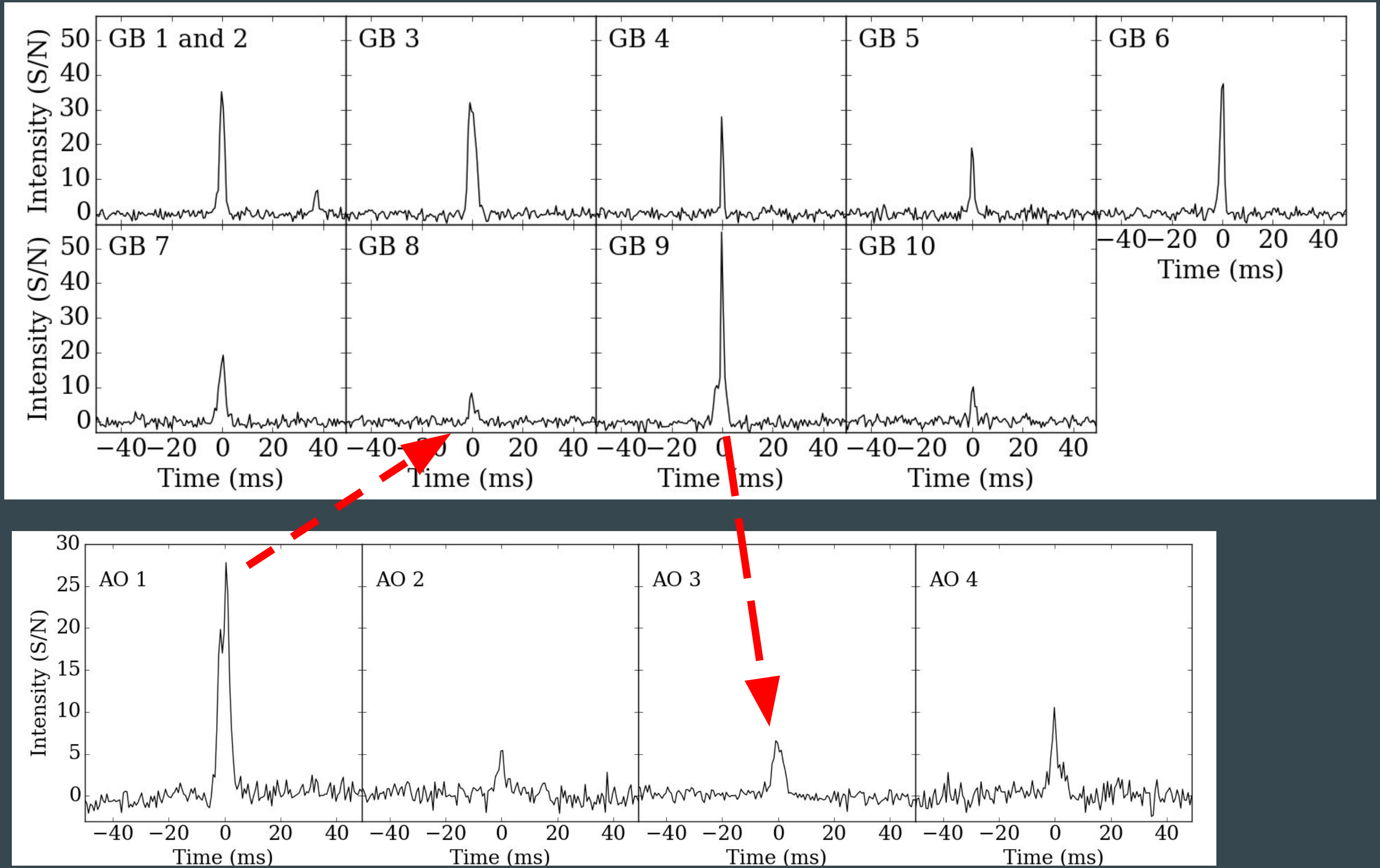
Radio Bursts

12 bursts

2 AO-GBT co-detections

GBT at 2 GHz

AO at 1.4 GHz

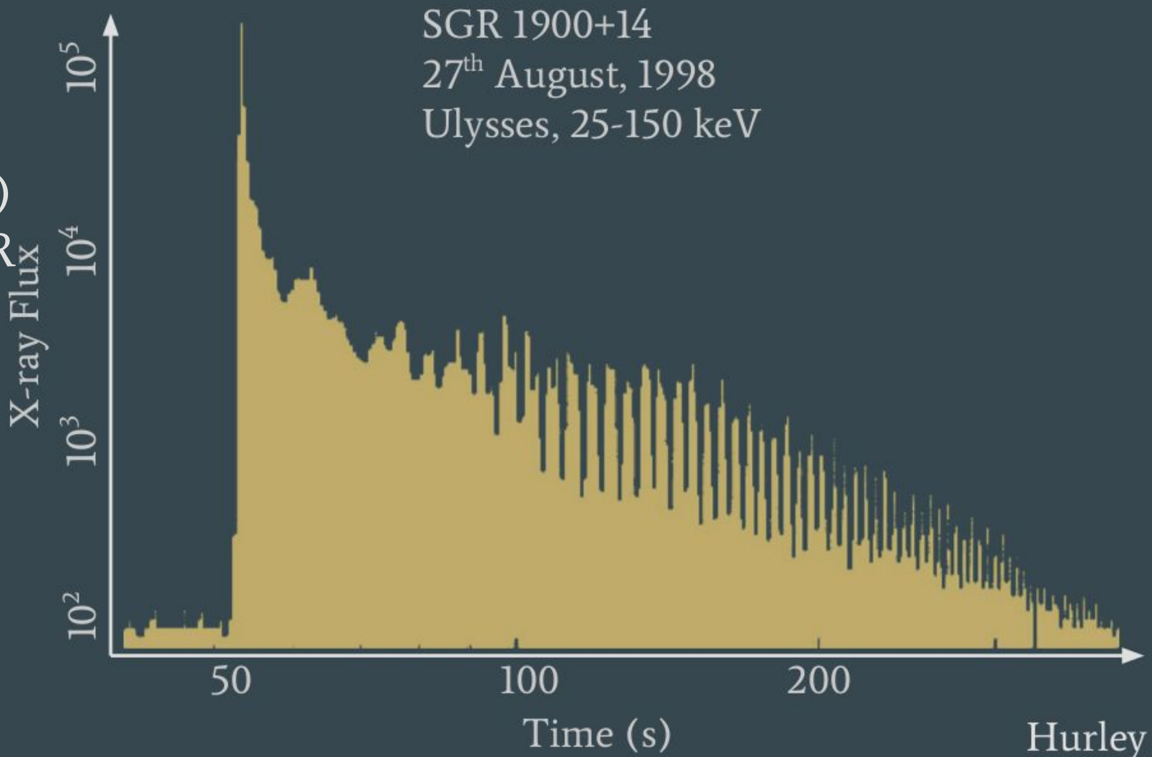


What do we expect to see?

Magnetar giant flare?

Brightest GF released **10^{47} erg/s** (c.f. ~10^{40} FRB) at peak in **~100 ms**. (SGR 1806-20)

At 972 Mpc, would expect 0.5-10 keV (Chandra/XMM) peak flux of:
~**5×10^{-11} erg/cm^2/s**



Hurley et al. 1999

Why X-ray bursts from magnetars?

- Galactic magnetars show short duration X-ray bursts similar in timescale of FRBs (milliseconds-seconds)
  - Though most are not as luminous as the onset of a giant flare
- Galaxies like host may preferentially form young magnetars in SLSNe and LGRBs
  - Note: not necessarily the *same* magnetars, just both powered by magnetic field...
- Other high-energy events, e.g. GRBs, ruled out because of repeating nature.
- Several theory papers arguing that FRBs can come from magnetar giant flares:
  - Katz 2016, Lyutikov 2017, Beloborodov 2017, Lyubarsky 2014

What do we expect to see?

Persistent source?

Crab nebula at 972 Mpc:

~1 x 10^{-19} erg/s/cm^2

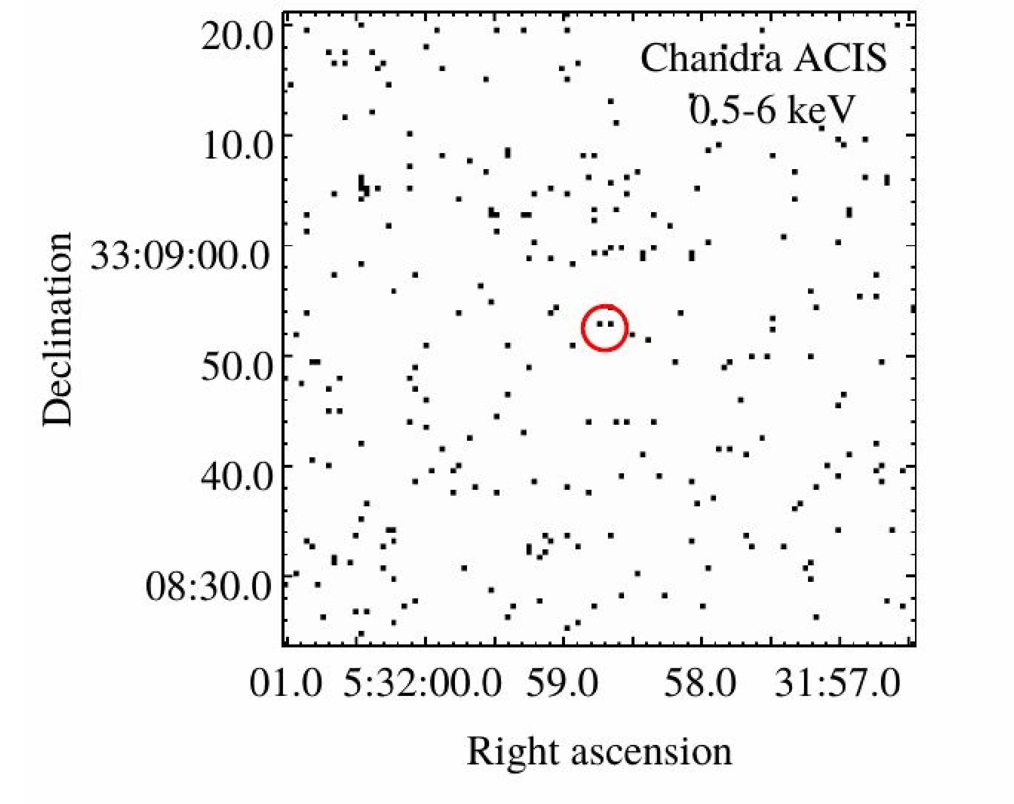
But: There is ~200 μJy persistent radio source at positions of FRB 121102 (Chatterjee et al. 2017)

Same L_X/L_R ratio as Crab:

→ ~ 5 x 10^{-14} erg/s/cm^2 "scaled" Crab

Image Credit: NASA

What did we see?



Zero counts at time of radio bursts

Number of total X-ray counts consistent with background

(Note: XMM image not shown)

Scholz et al. 2017, arxiv:1705.07824

Limits on burst emission

Model independent X-ray fluence limit in erg/cm^2

Telescope	Single burst during radio burst	Stacked during all radio bursts	At any time during observation
Chandra	$5x10^{-10}$	$3x10^{-11}$ (12 bursts)	$1x10^{-9}$
XMM/Newton	$2x10^{-10}$		$5x10^{-10}$
Fermi	$1x10^{-8}$	$4x10^{-9}$ (4 bursts)	-

In Bands:

0.5-10 keV

10-100 keV

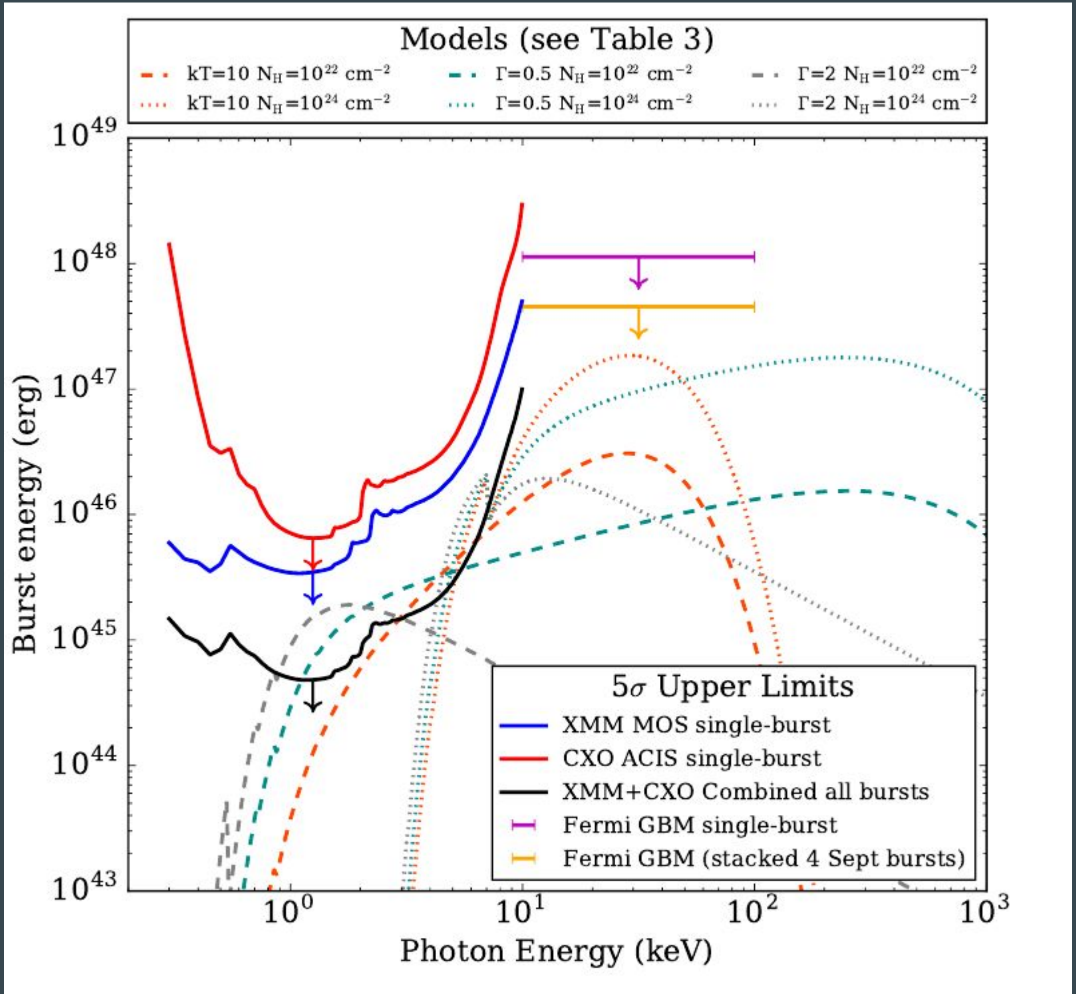
Compare to:

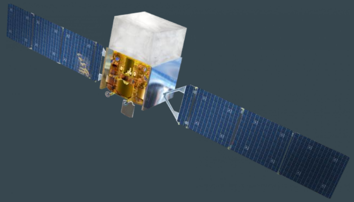
SGR 1806-20-like giant flare: ~$5x10^{-12}$ erg/cm^2 0.5-10 keV fluence
GRB-like event (for scale): 10^{50} erg/s in 1s → $1x10^{-6}$ erg/cm^2 fluence

Limits

Chandra

XMM/Newton





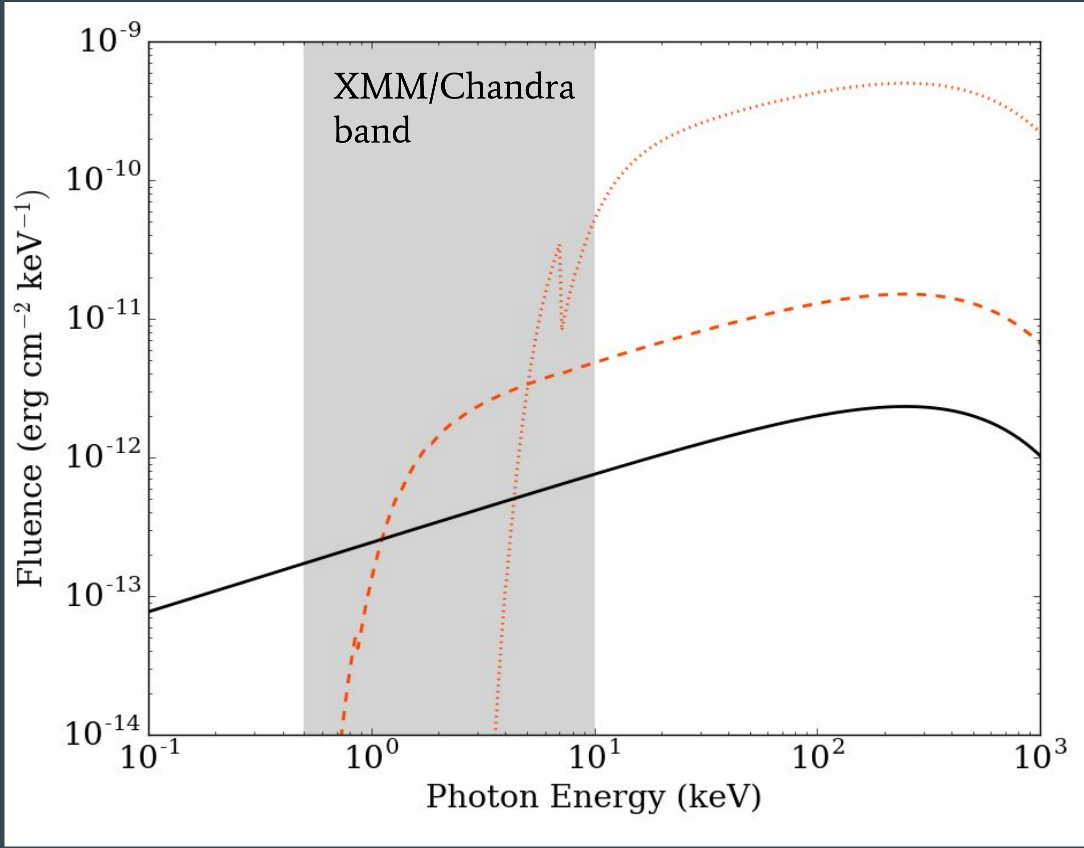
Fermi

All Models: Normalized by 0.5-10 keV fluence limit

Scholz et al. 2017, arxiv:1705.07824

How do these limits compare to what's expected?

SGR 1806-20 flare ~1 order of magnitude fainter than limit.



From 0.5-10 keV Limit
Giant Flare spectrum with

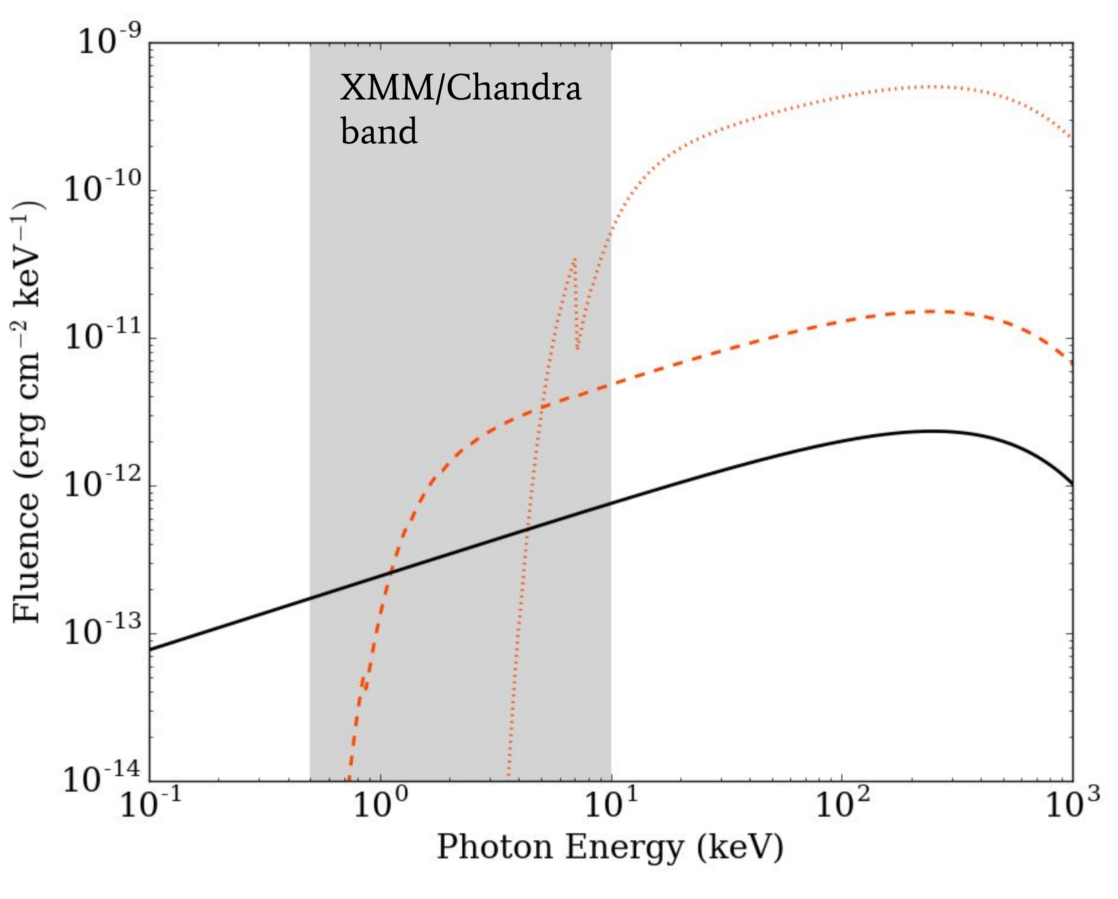
log(nH)=22 (---)
log(nH)=24 (...)

at limited Fluence

SGR 1806-20
giant flare at 972 Mpc with N_H=0

Caveats

Absorption can hide source flux in soft X-rays (i.e. <10 keV)



From 0.5-10 keV Limit
Giant Flare spectrum with

log(nH)=22 (---)
log(nH)=24 (...)

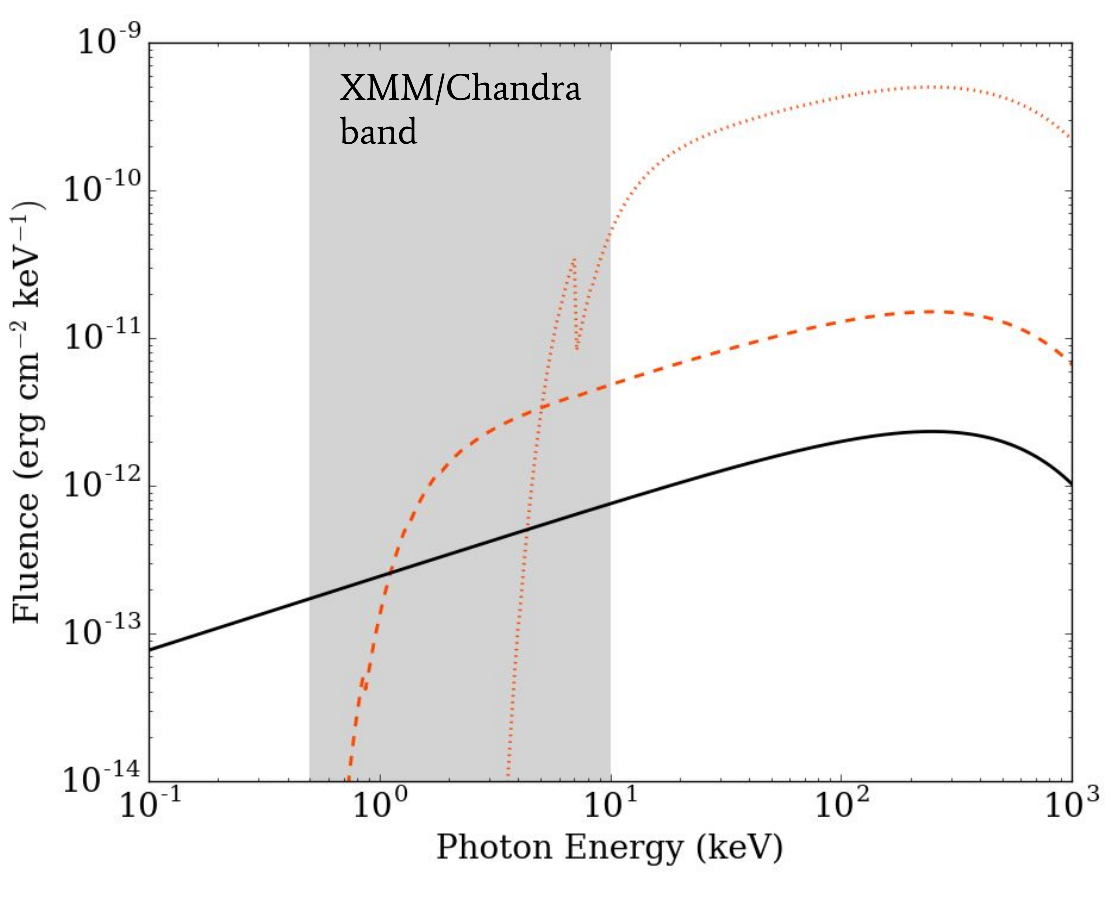
at limited Fluence

SGR 1806-20 giant flare at 972 Mpc with N_H=0

Caveats

X-ray Bursts are hard

Emit majority of X-ray energy outside of 0.5-10 keV



From 0.5-10 keV Limit
Giant Flare spectrum with

log(nH)=22 (---)
log(nH)=24 (...)

at limited Fluence

SGR 1806-20 giant flare at 972 Mpc with N_H=0

Caveats

More:

Lensing

Beaming

Actual L_R lower than measured.

So for a fixed L_X/L_R, expected L_X goes down

Limit on persistent emission

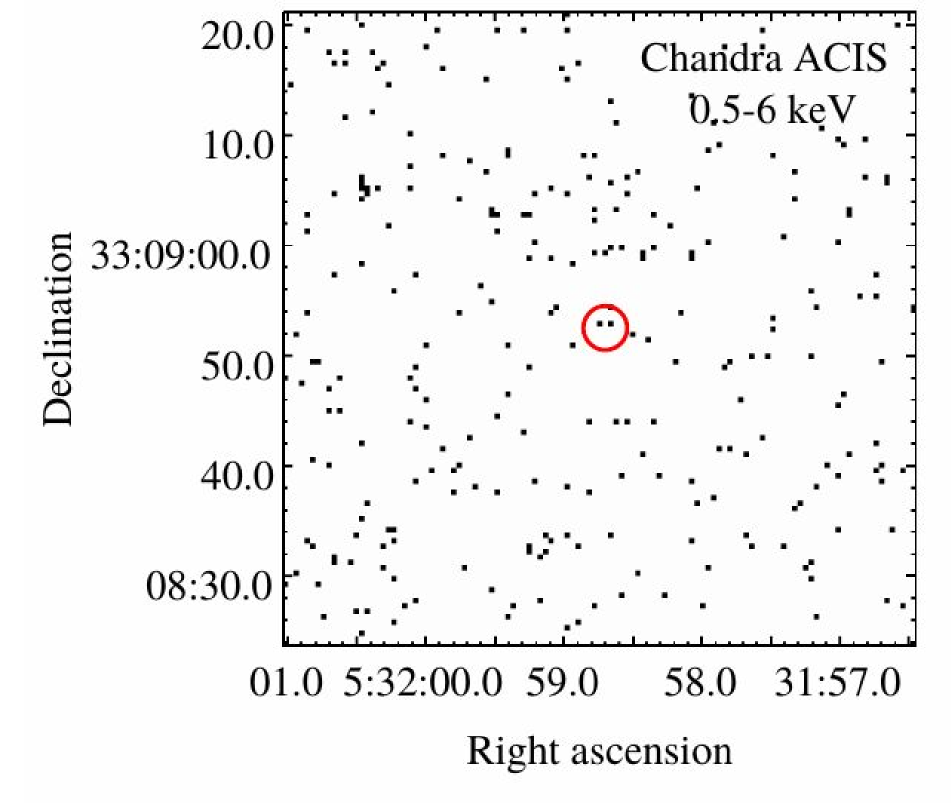
5-sigma 0.5-6 keV limit on persistent flux:

4 x 10^{-15} erg s^{-1} cm^{-2}

Compare to:

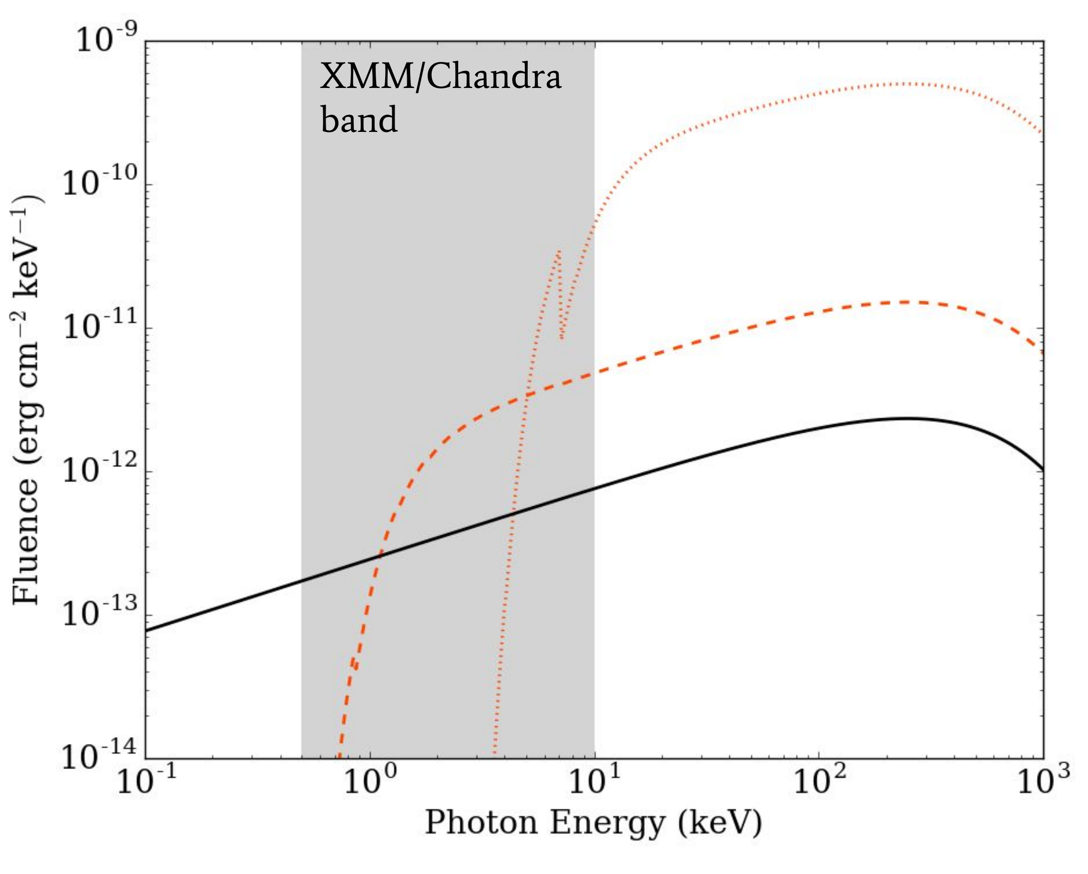
Crab at 972 Mpc: **~1 x 10^{-19} erg/s/cm^2**

"Scaled" Crab: **~5 x 10^{-14} erg/s/cm^2**



Scholz et al. 2017, arxiv:1705.07824

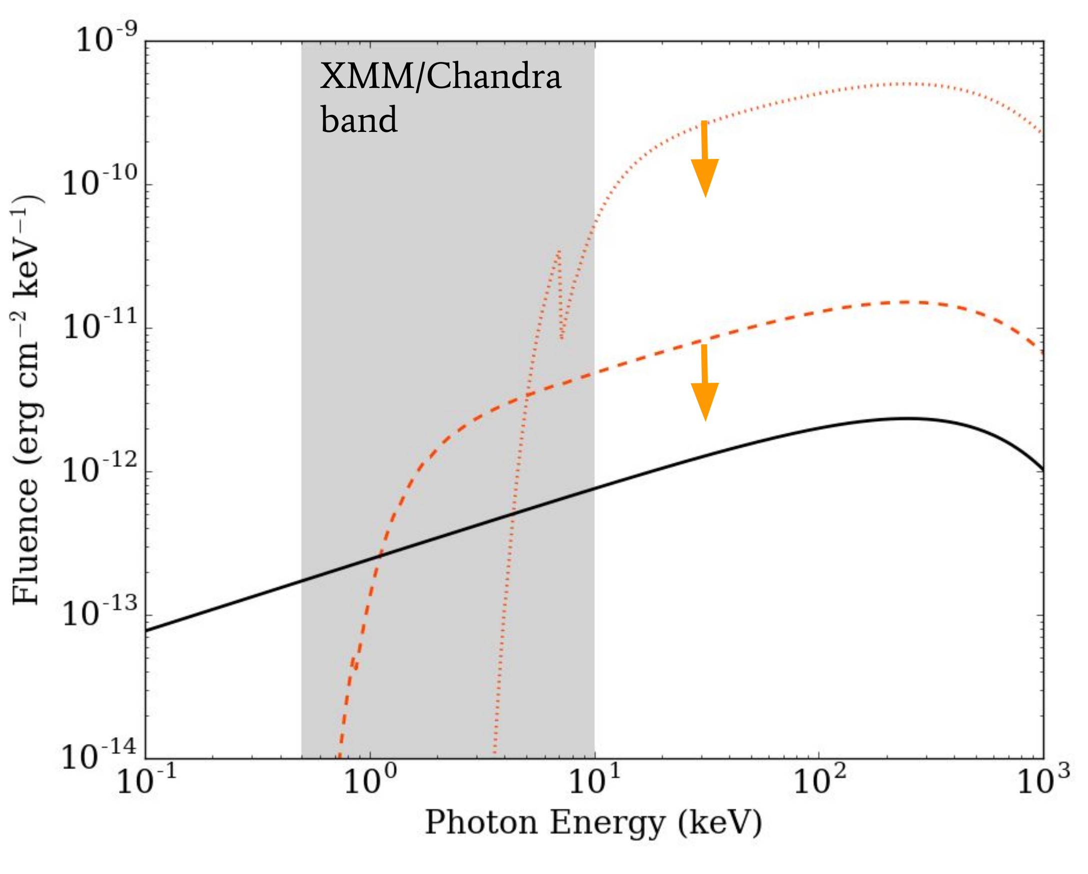
How would we ever see something?



Limits on giant flare spectral model from FRB 121102 emitted at times of radio bursts

Expected from SGR 1806-20 at FRB 121102 distance ("maximal" magnetar activity)

How would we ever see something?



A few ways:

- **Go deeper**

How?

Bigger telescope

- 10 years away?

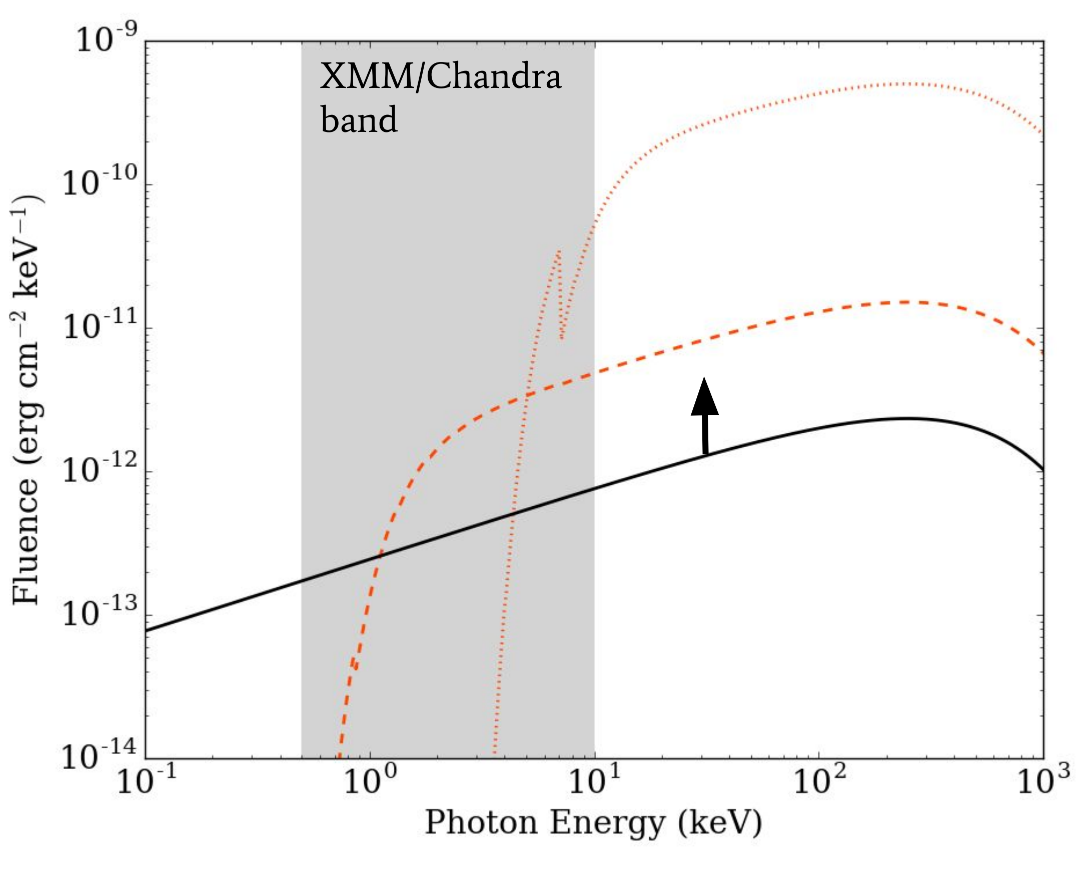
Longer integration

- doesn't work with bursts!

More radio bursts

- OK. But only under assumption that X-ray is emitted with every radio burst...

How would we ever see something?



A few ways:

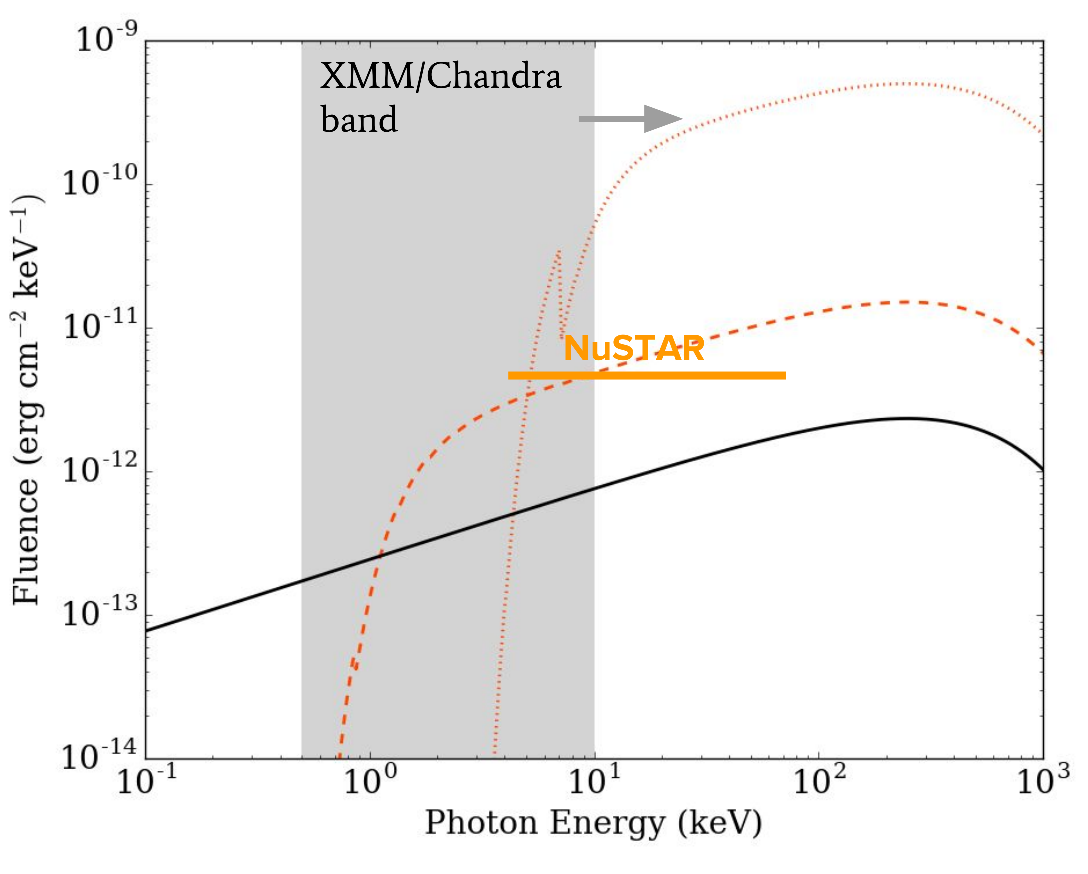
- Go deeper
- **Observe brighter sources**

How?

Close-by repeating FRB!

But less volume -> Lower rates...

How would we ever see something?

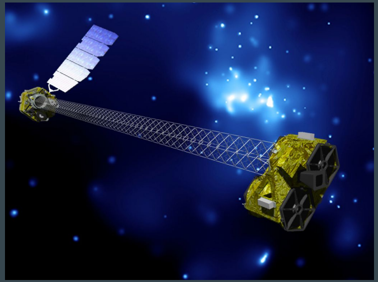


A few ways:

- Go deeper
- Observe brighter sources
- **Look at higher energies**

How?

Hard X-ray / gamma-ray telescopes:
NuSTAR, ASTROSAT



When would we expect to see something?

What if magnetar giant flare at every burst (optimistic)?

- Can detect SGR 1806-20-like giant flare with Chandra/XMM at < 300 Mpc.
- Assume current FRB rate estimates are probing up to z=1
- 300 Mpc leads to 10^{-4}x the volume

→ 10^{-4} times the total rate for FRBs

Given total CHIME rate of ~10 per day in z<1 volume:

→ 0.3 FRBs (D<300Mpc) per year

But assumptions: handful in a few years with CHIME

When would we expect to see something?

Given:

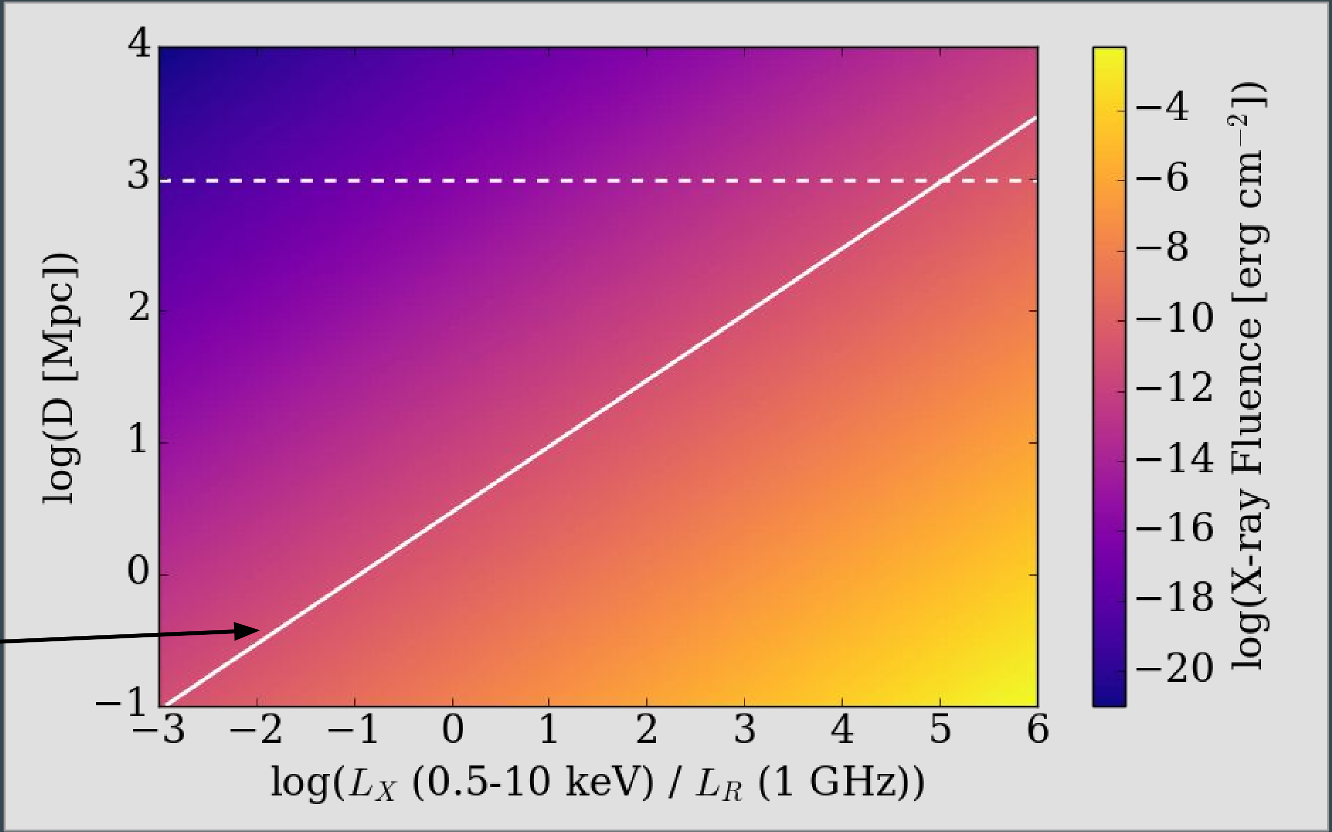
Fixed $E_{FRB} = 10^{40}$ erg

Ratio between X-ray and radio luminosities, (L_X/L_R)

Distance, D

What is X-ray fluence? Is it detectable?

Chandra/XMM burst limit



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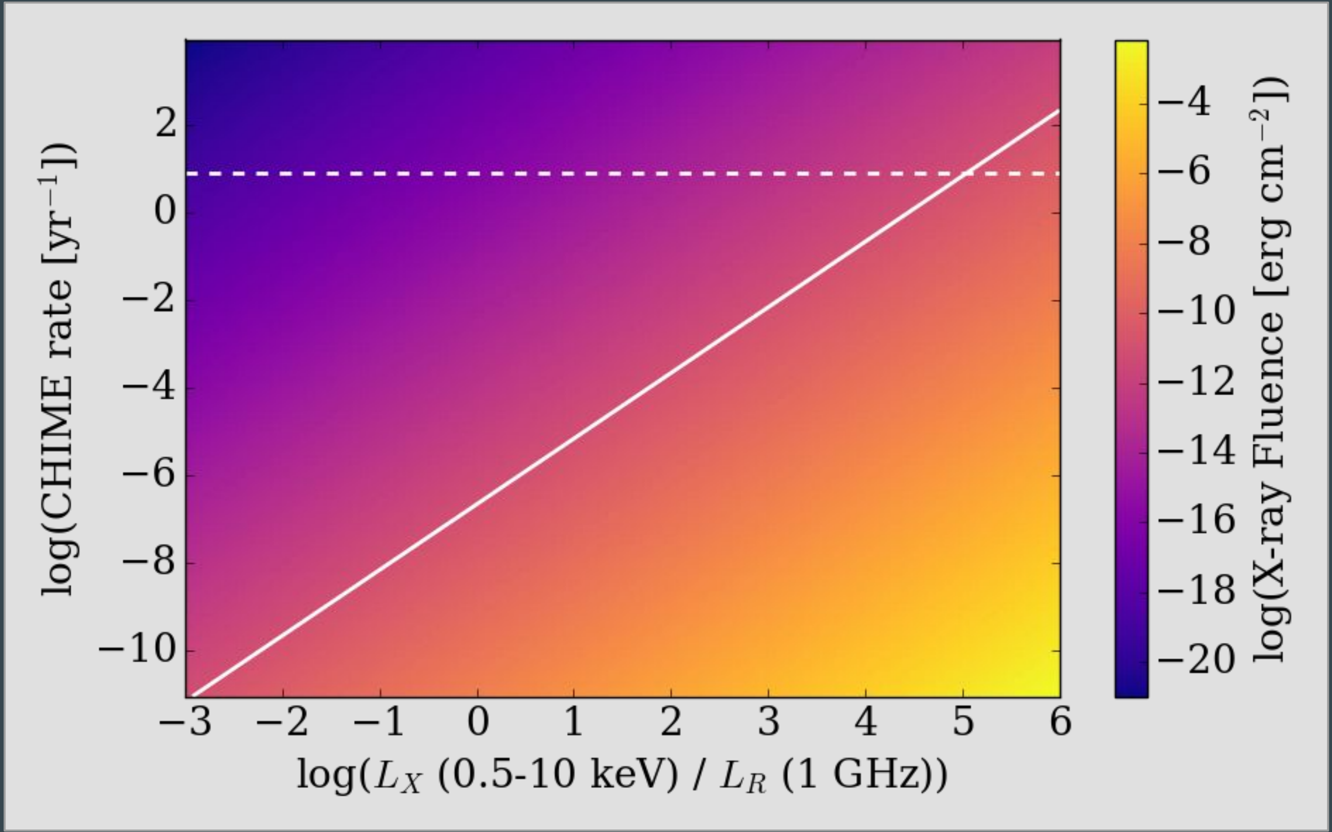
Distance, D

What is X-ray fluence? Is it detectable?

What is the CHIME rate within that volume?



Summary

Persistent X-rays: We place a 0.5-10 keV limit of 4×10^{-15} erg s^{-1} cm^{-2}. Rules out an (mildly-absorbed) super-Crab powering 200 μJy persistent radio source.

Bursts: We place deepest limits to date on X-ray emission at the time of radio bursts from FRB 121102.

For X-ray bursts to be detectable, the X-ray counterparts must be much brighter than the radio bursts.

If all FRBs have magnetar GF counterparts and all FRBs repeat, CHIME should discover 0.3 sources per year with detectable X-ray counterparts.

If X-rays fainter, mileage varies.

Statistics

Nice clean statistics when you have 0 counts and 0 background:

$$P = \lambda^N e^{-\lambda}/N!$$

For confidence level CL and N=0, limit in counts is:

$$\lambda_{lim} = -\ln(1-CL)$$

Independent of duration until background no longer negligible or counts detected in duration “window”.

So, **Fluence** [erg cm^{-2}] (not flux) is natural value for limit.