All Sky Transient Radio Array (ASTRA)

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NCRA • TIFR

RRI

CIFAR

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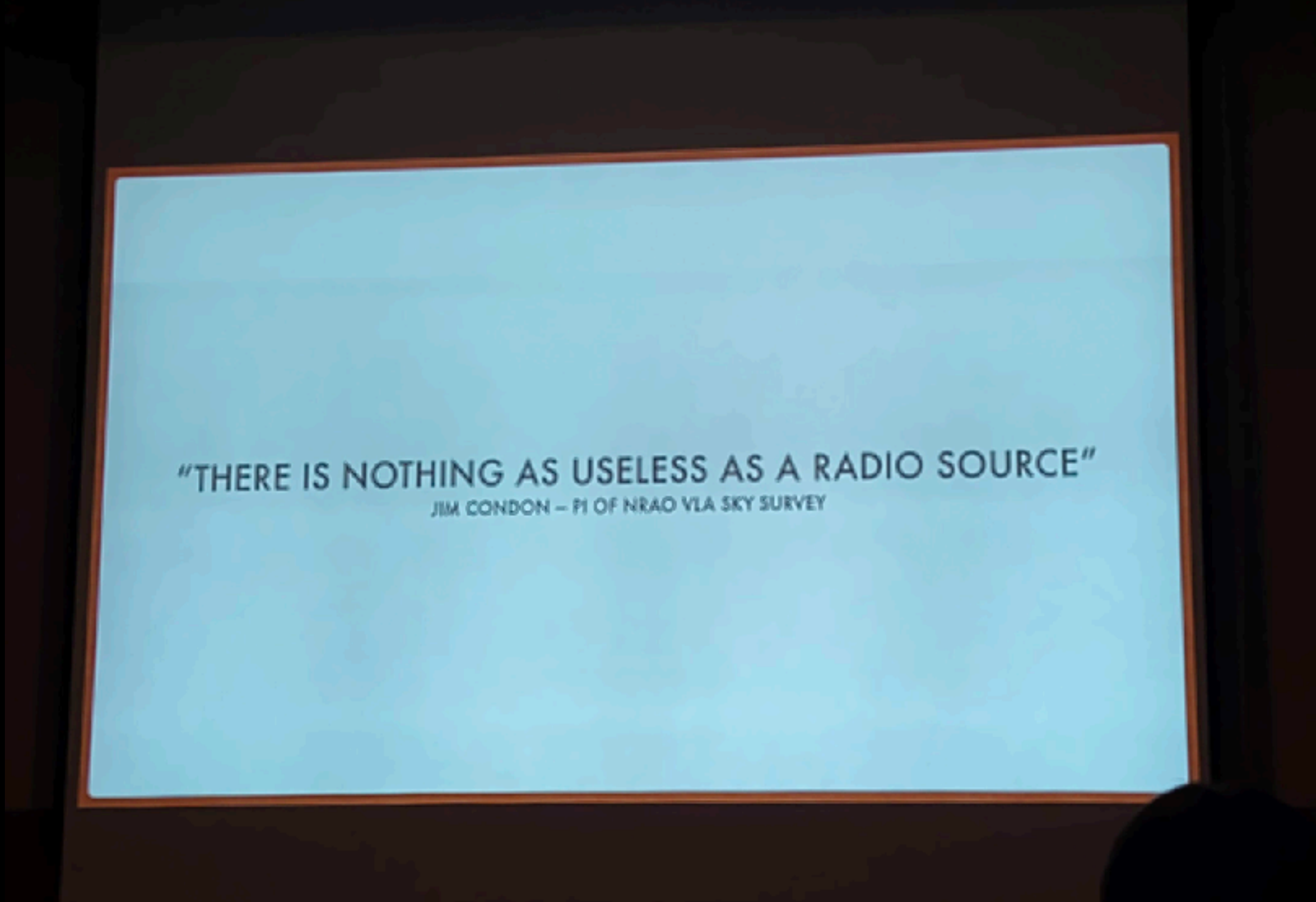
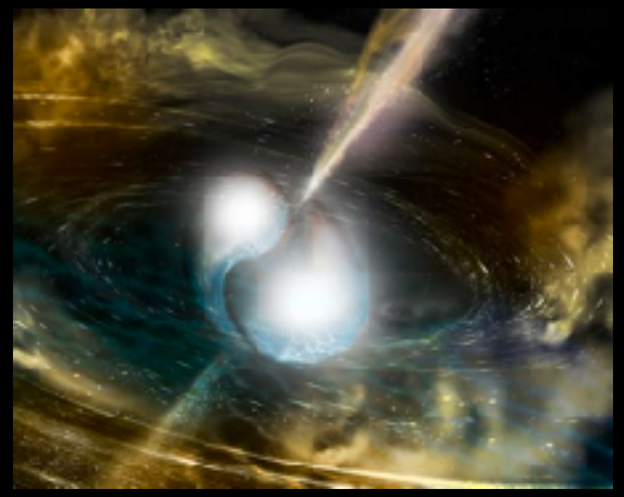
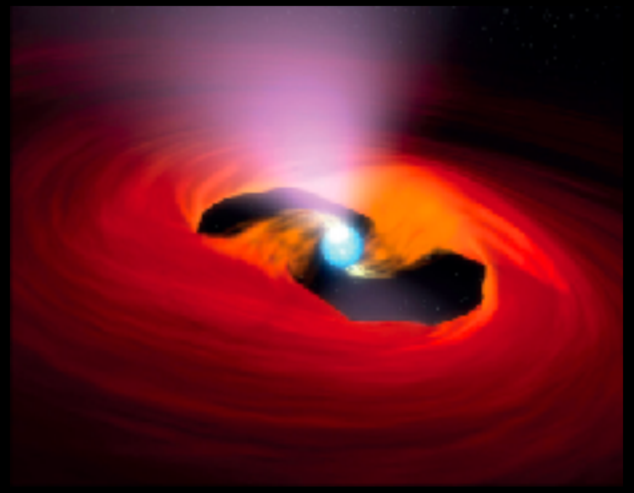
Brightest and Nearest FRBs

- Radio telescopes are too darn sensitive
  - Detect almost any cosmic blip
  - Not very discerning
- Need more information about the emission processes
  - Multi-wavelength/multi-messenger (MWMM) inputs are crucial
- Links different transients together



C. Law, quoting J. Condon, IAUGA Busan (2022)





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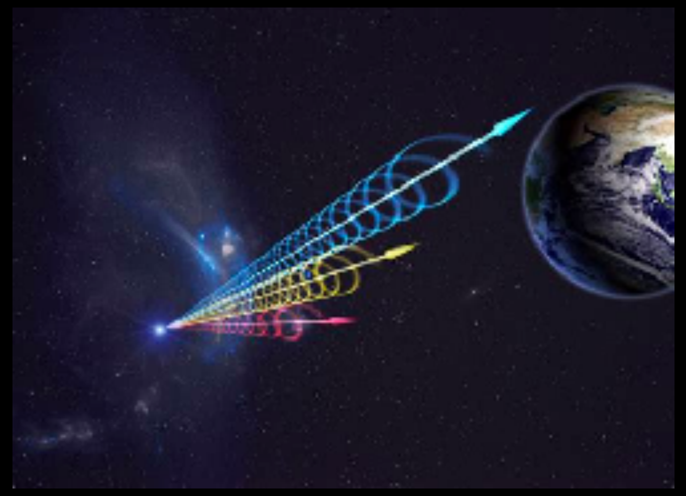
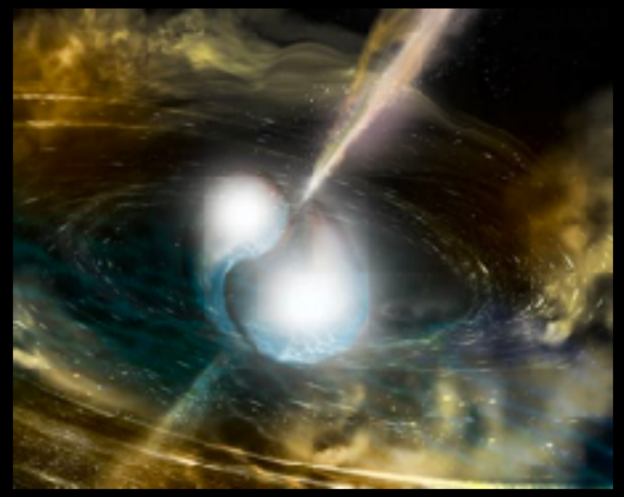
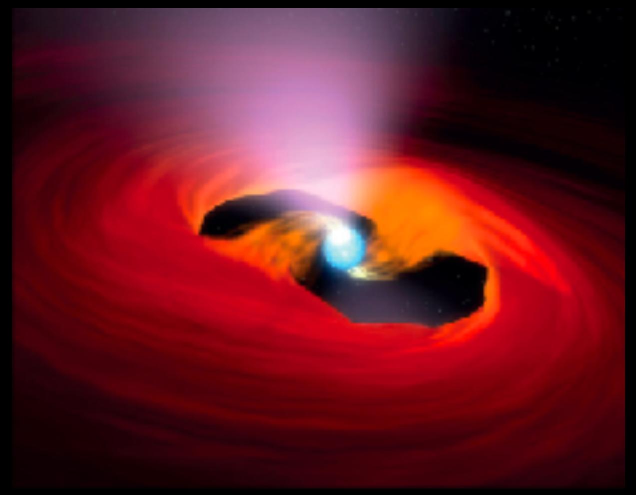
10^{41-44} ergs << 10^{51-52} ergs



Observed Rates

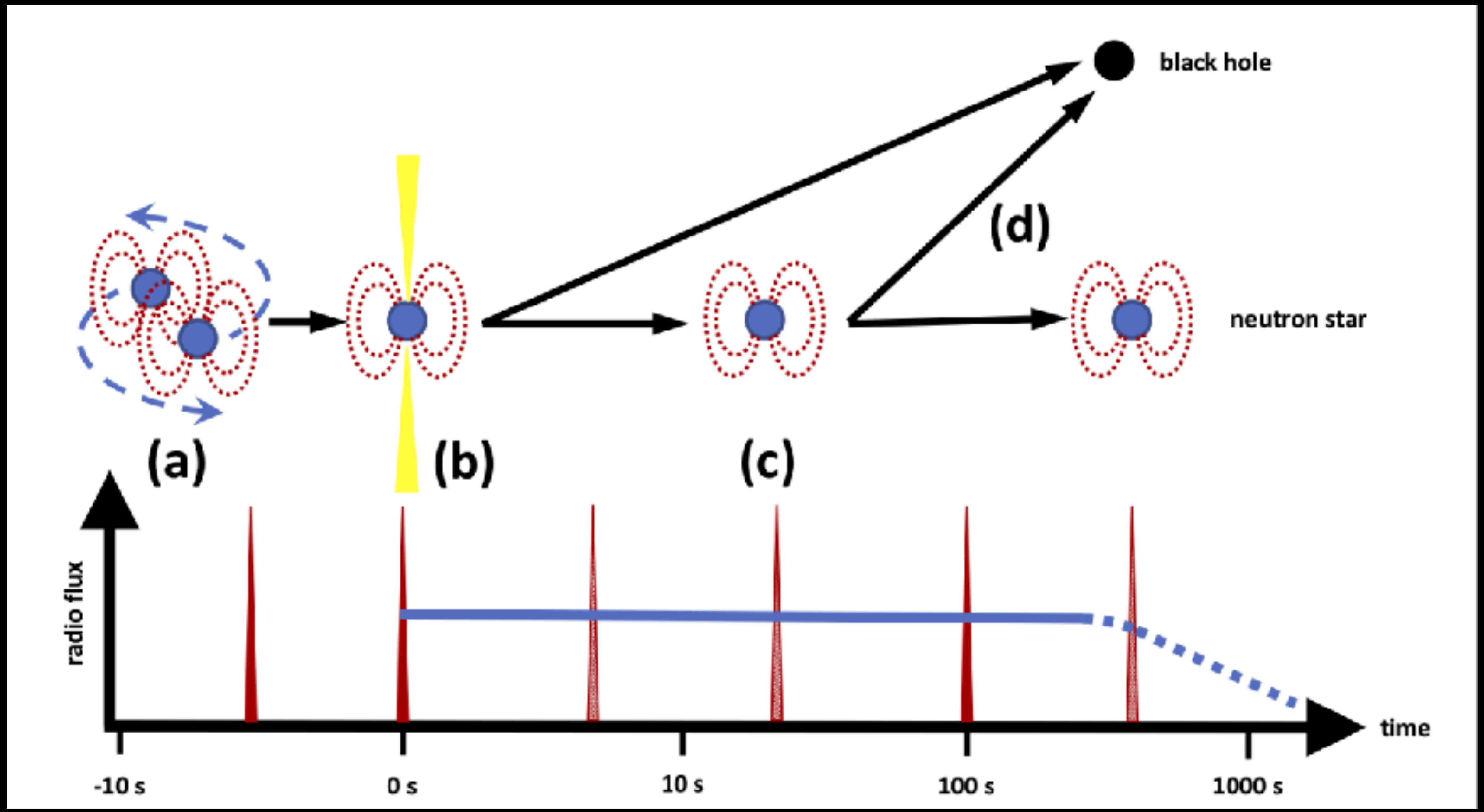
FRBs	10^3/day
GRBs	1/day
Galactic Magnetar flares	~1/day (clustered in space and time)
Binary NS mergers	1/year (will change in O5)
ULX/HMXB outbursts	10/year

There are far too many FRBs in the sky

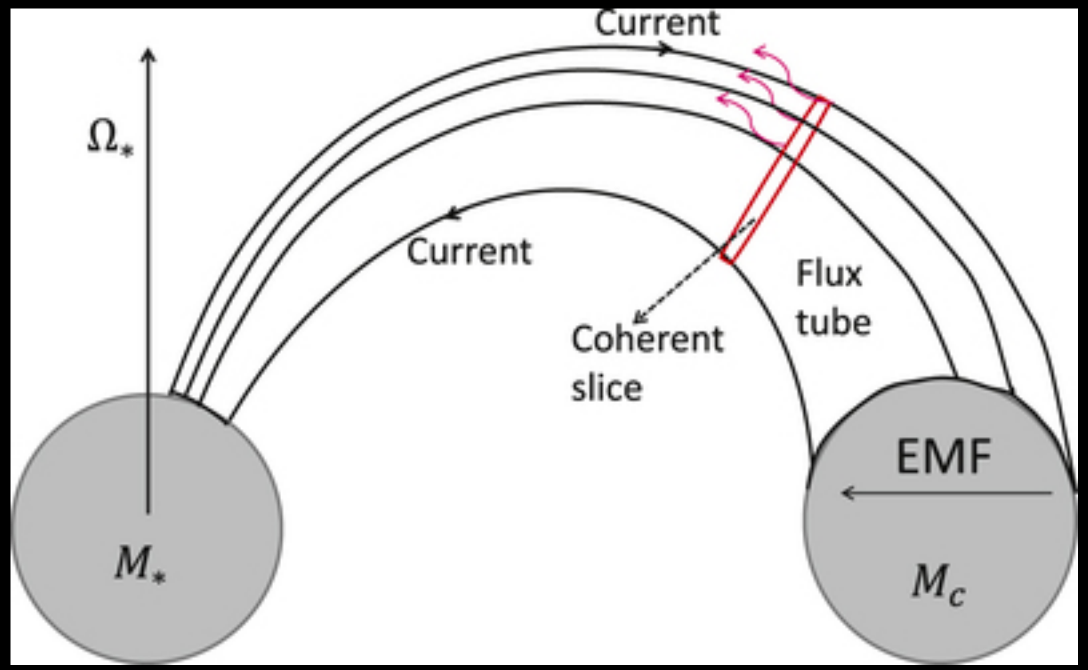
Few FRBs will be associated with other detectable transients

X-rays/Gamma-rays

- Multiple models for FRB - short GRB connection
  - Inspiral phase, Actual merger, Post merger



Rowlinson et al (2019)



Wang et al (2016)

Hansen & Lyutikov (2001; few second timescales),
Pshirkov & Postnov (2010; radio precursors),
Totani (2013), Zhang (2014),
Ravi & Lasky (2014), Flack & Rezolla (2014), Most et al (2018) — post merger
Wang et al (2016; inspiral phase),
Mingarelli et al (2014), Liu et al (2016) — NS-BH mergers
Sridhar & Metzger (2021; nearly pre-merger)

With apologies for incompleteness

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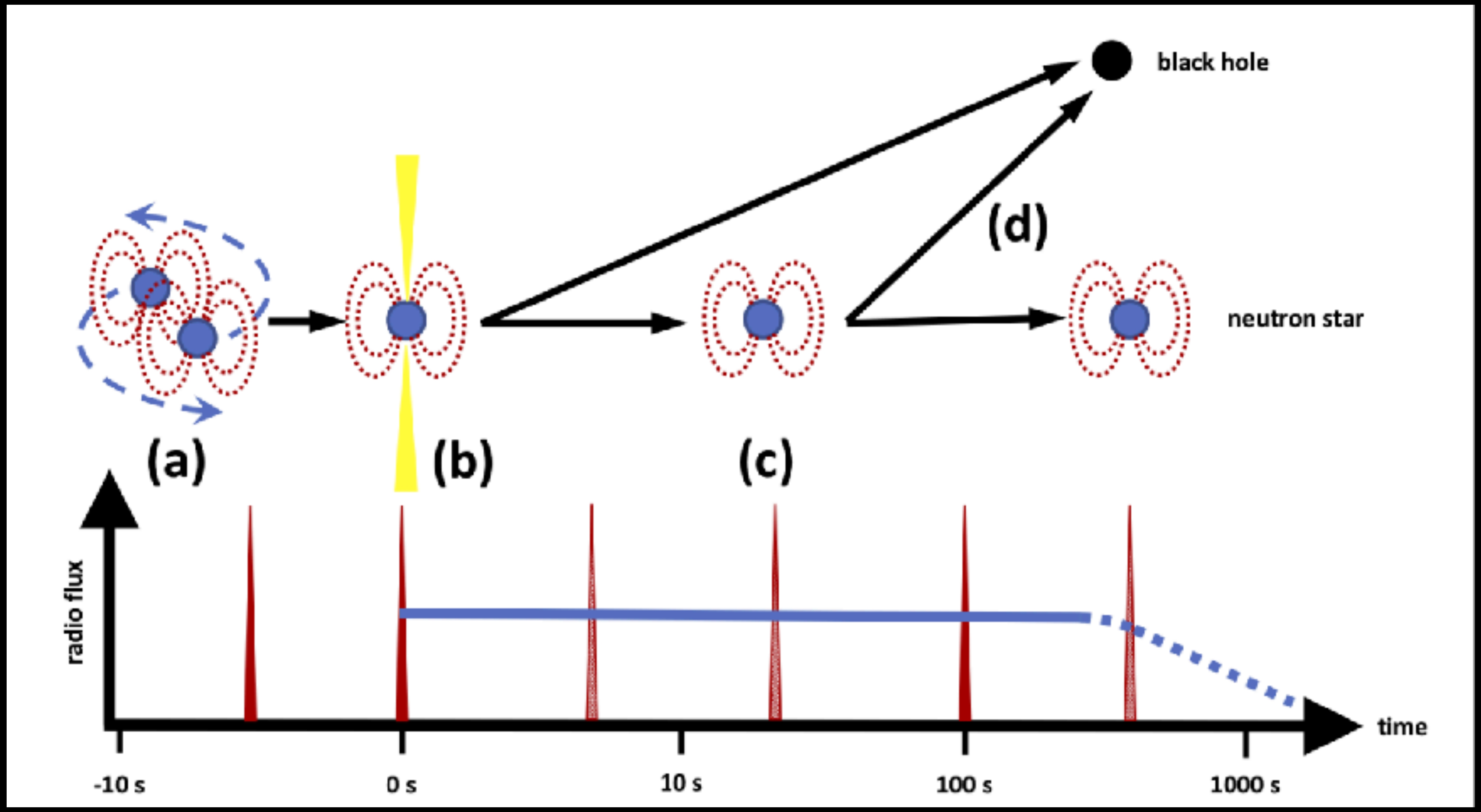

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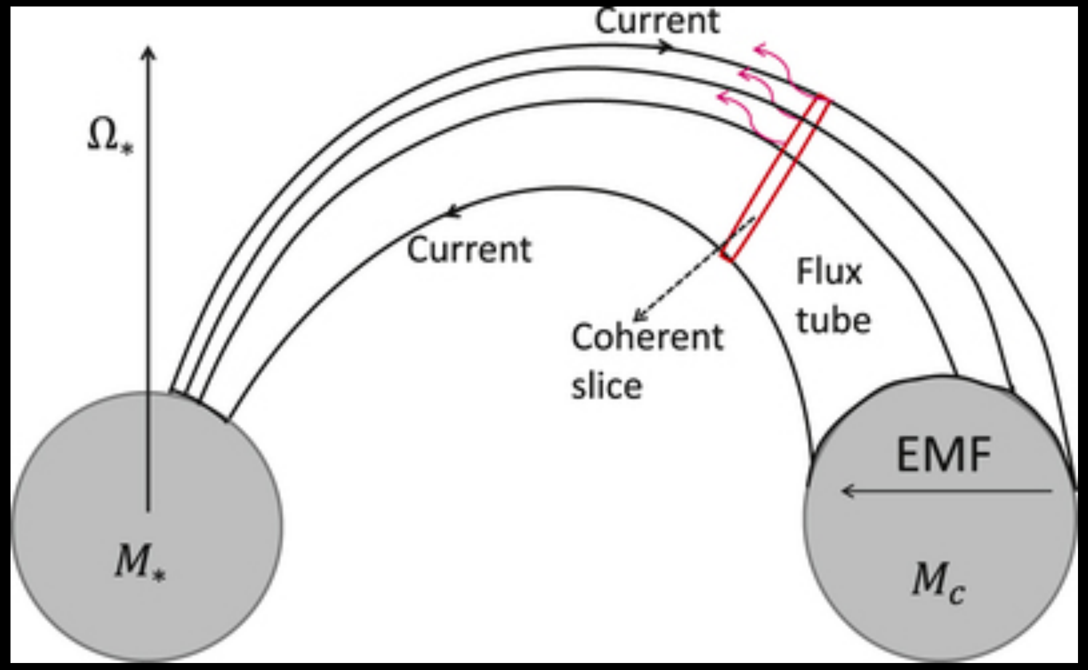

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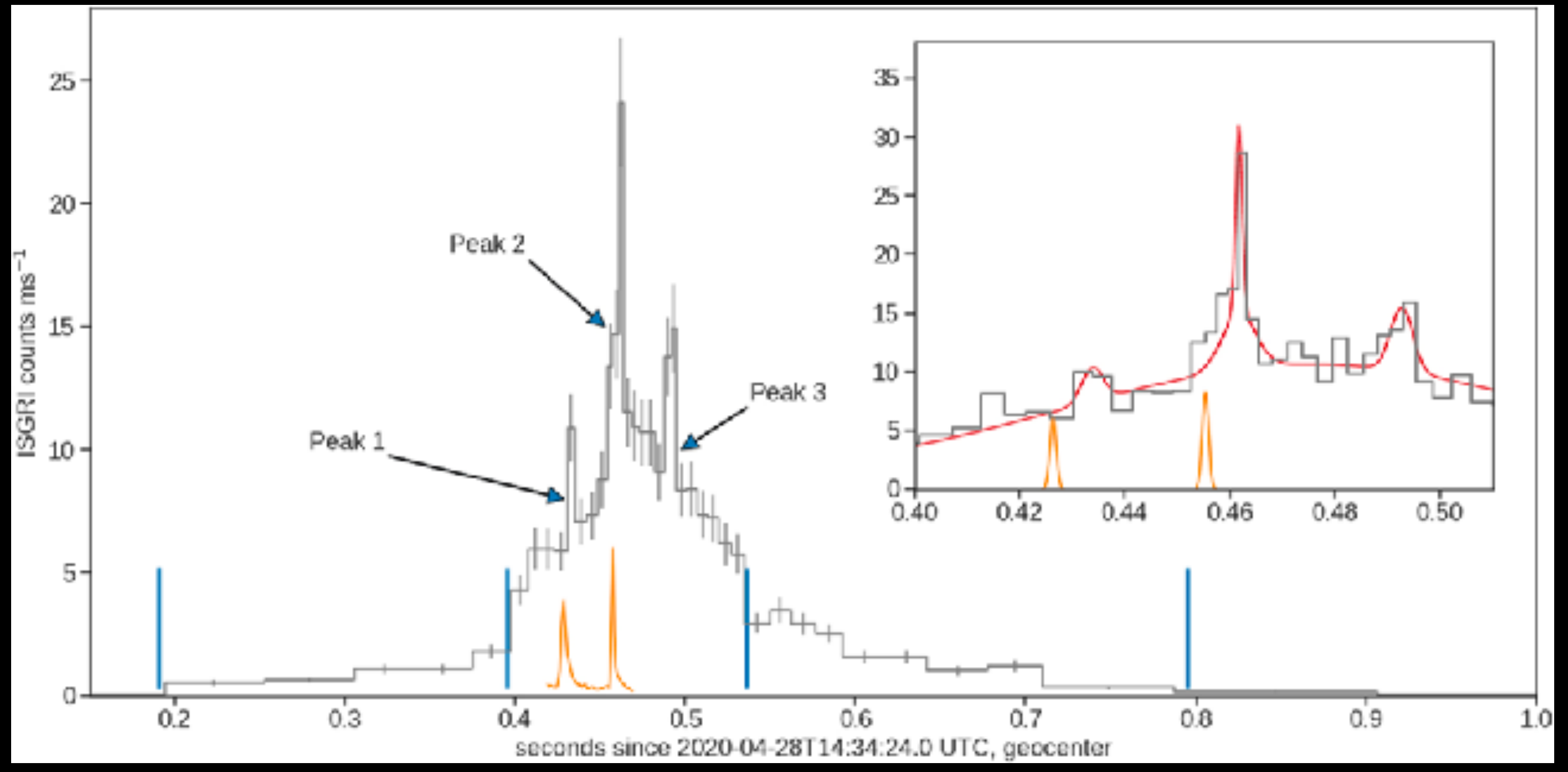
Take away message:
Lots of different models about when and how FRBs can form — before, during, or after BNS/NSBH mergers.

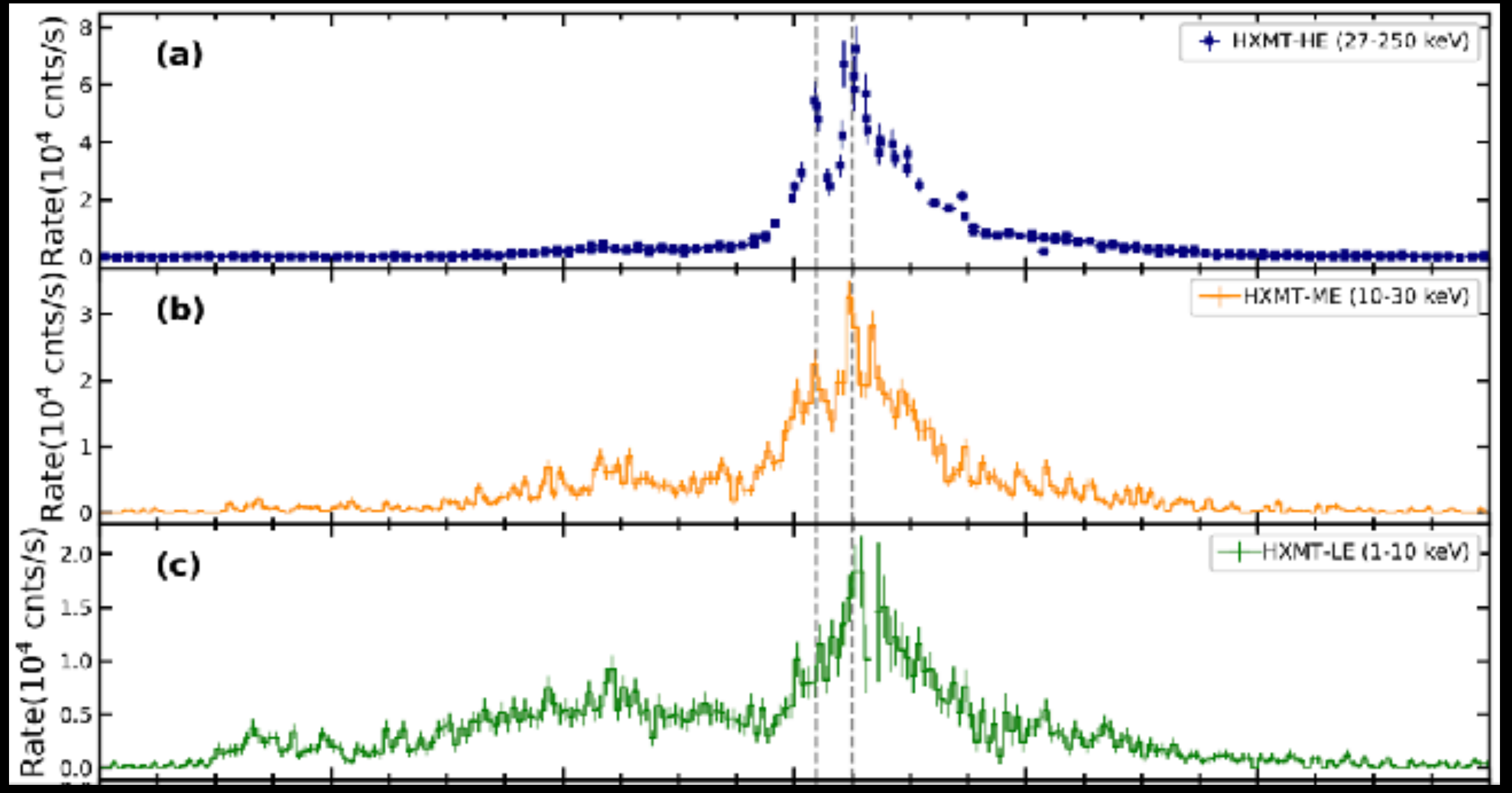
With apologies for incompleteness

X-rays/Gamma-rays

- Magnetar flares
  - SGR 1935 + 2154
  - Multi-peaked radio and X-ray profiles
  - X-ray comes after radio
  - BUT — many other X-ray bursts w/o radio (CHIME/FRB Coll 2020, Lin et al 2020)
  - Many radio bursts w/o X-ray (CHIME/FRB Coll. 2020, Kirsten et al 2020)



Mereghetti et al (2020)



Li et al (2020)

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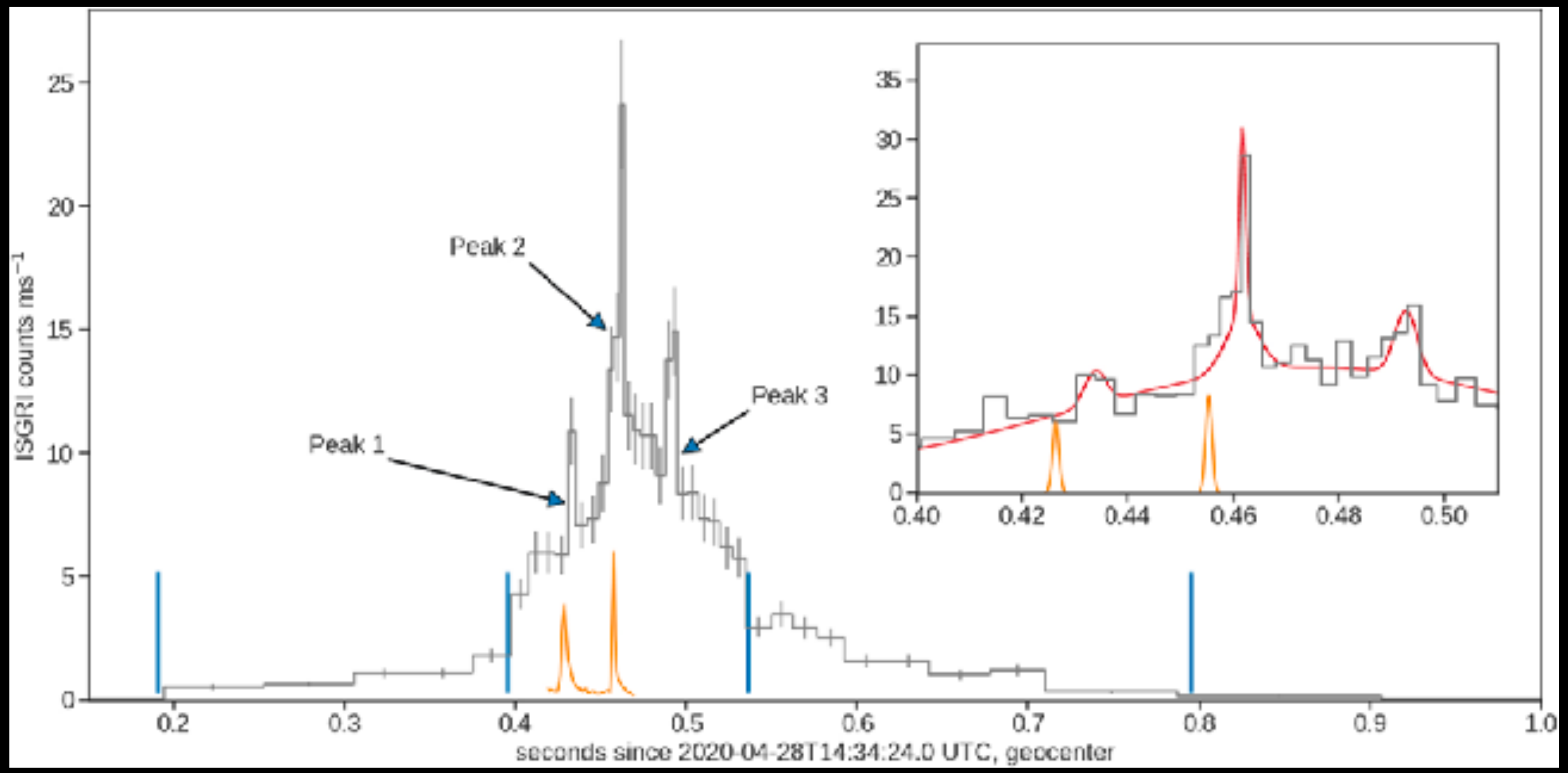

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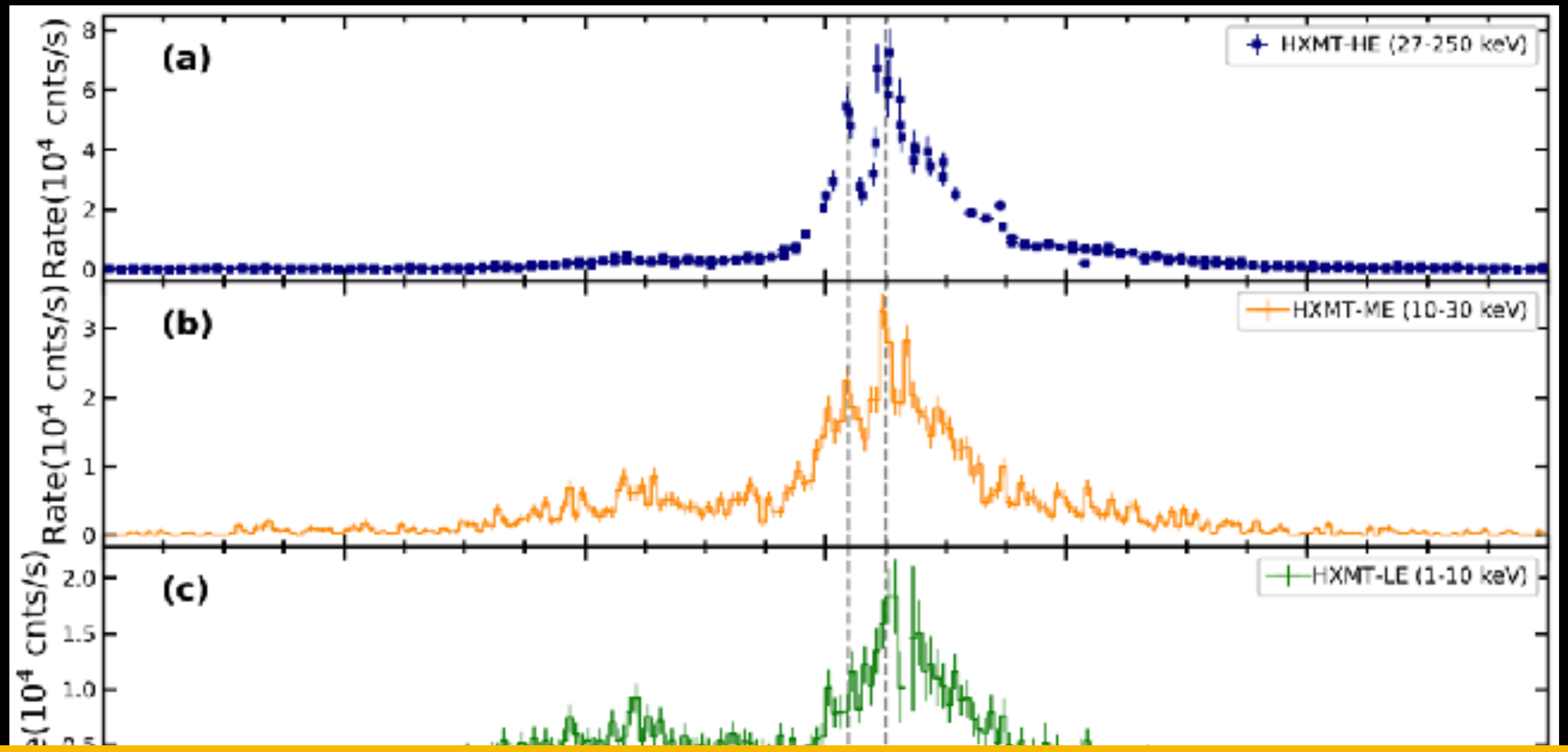
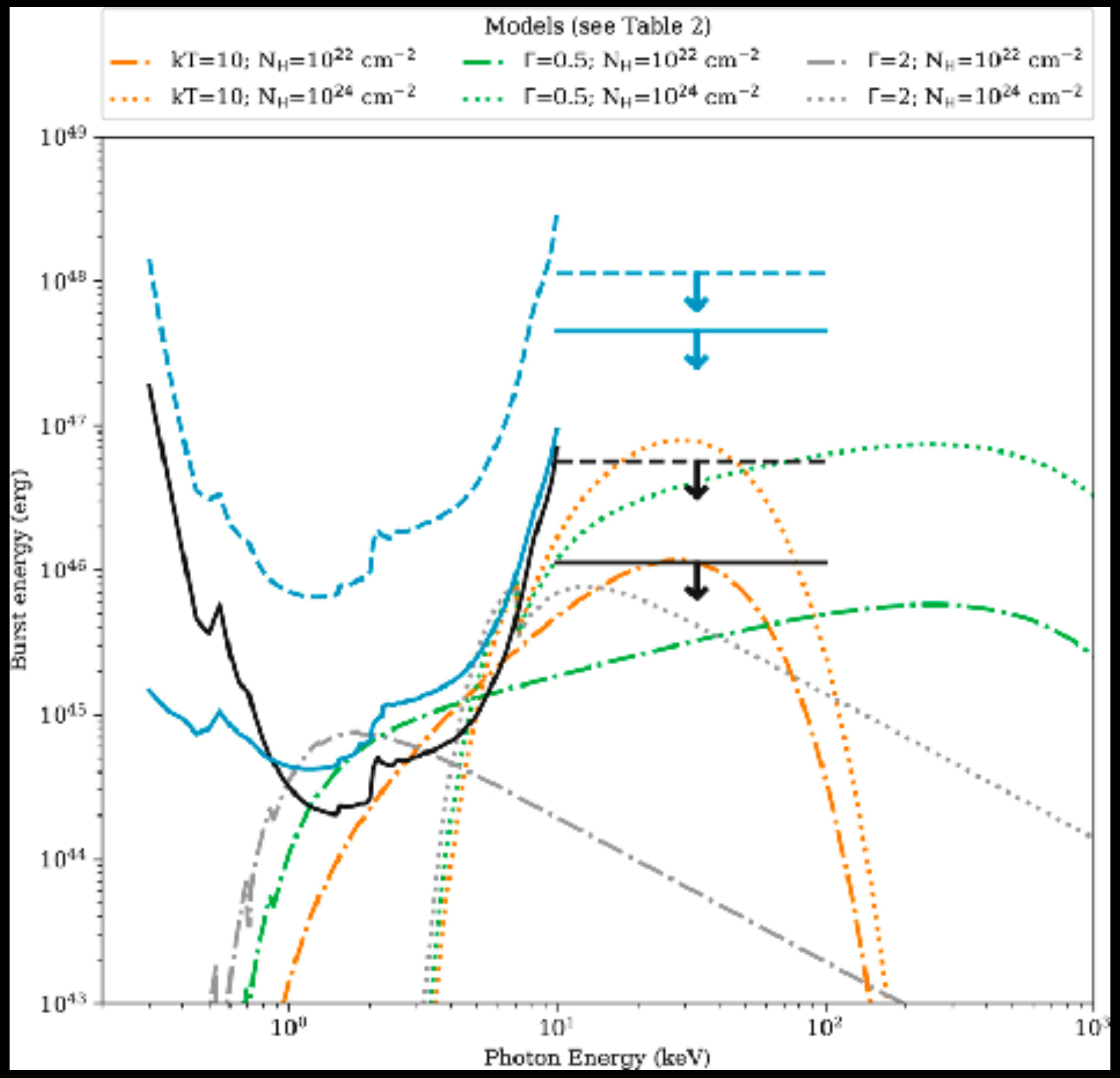


These coincident detections are key to emission mechanisms — but are RARE

Repeater - X-ray Connection

- For repeaters, focused observations are possible
- Simultaneous radio, X-ray also done: Scholz et al (2021) for FRB 20180916B, Scholz et al (2017; FRB 20121102A)
- Fluence limits of ~ 10^{-10}–10^{-9} erg/cm^2
- At 150 Mpc (R3), energy < 10^{45} erg (>> FRB energy)



Scholz et al (2021)

SGR 1806-20 Giant Flare: 10^{47} erg,
SGR 1935+2154 burst: 10^{39} erg (both isotropic)

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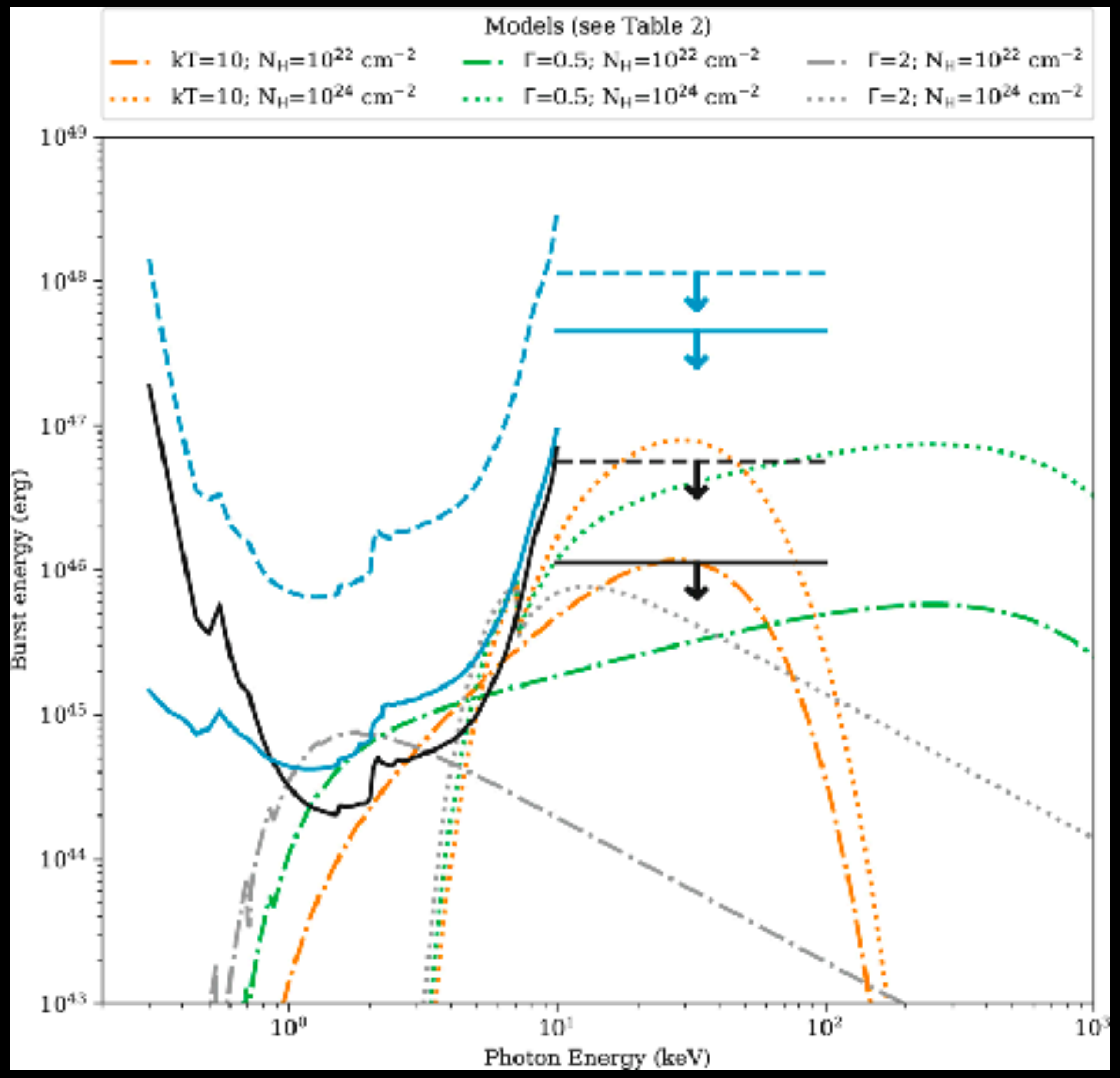

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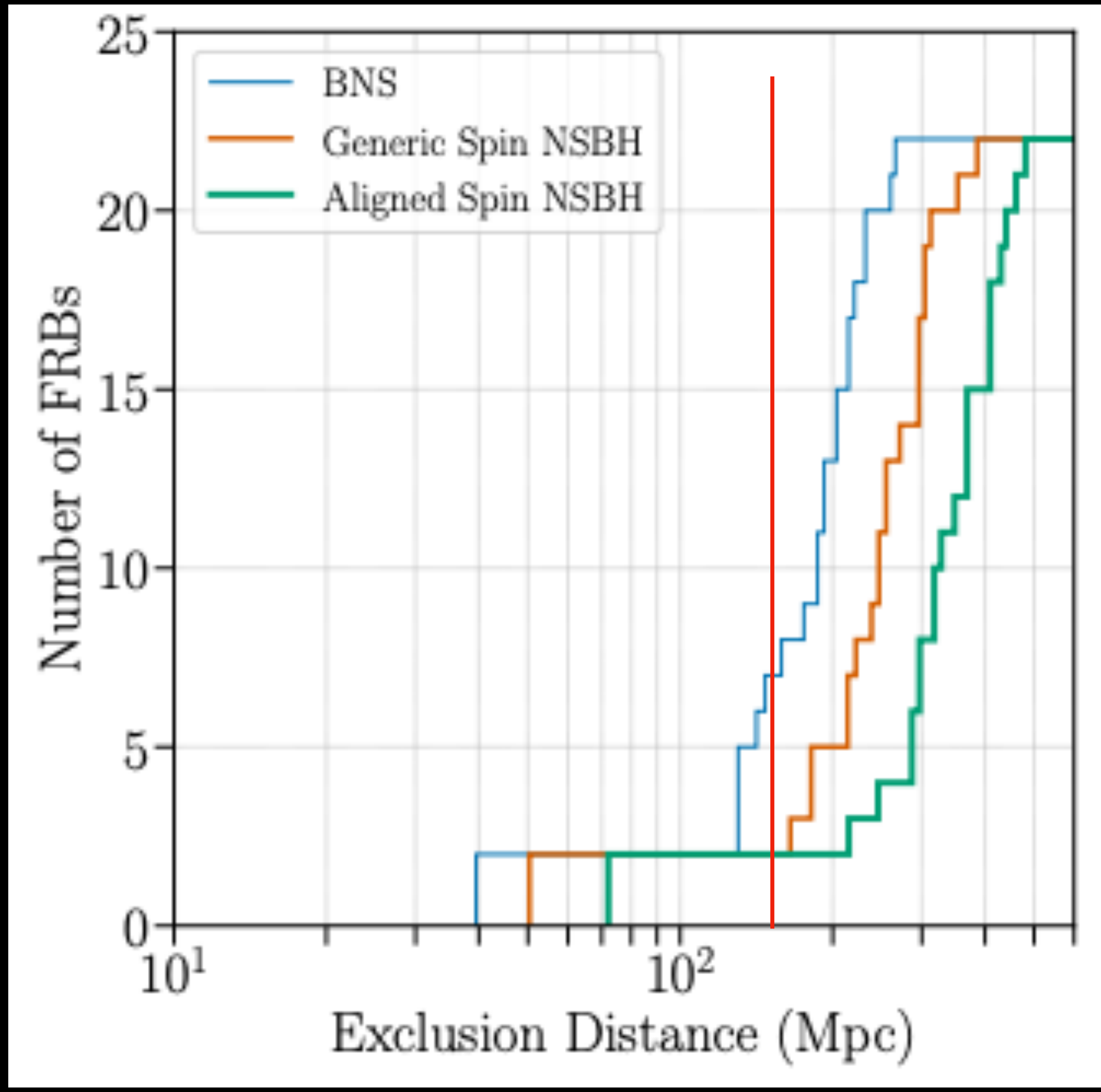
Need nearby repeaters to improve constraints

Gravitational Waves

- Current limits on BNS-like mergers at the CHIME/FRB catalog 1
  Search range = (–600 s, +120 s)
- Modeled + unmodeled searches
- Future runs will be more sensitive — more likelihood of detections



LVK + CHIME/FRB Collaborations (2022)

Sensitivity Horizons

- LIGO/VIRGO/KAGRA —> BNS merger horizon: ~200 Mpc
- Detectable giant-flare horizon: 100 Mpc
- Rate of FRBs within this horizon — ~ 1–10 per wk (typical energy scale)
    - BUT in the entire sky (42000 sq deg!)

- Counterparts are rare —focus on the brightest and nearest FRBs
- Needs larger FoV surveys, coordinated observations
- More sensitive X-ray telescopes
- Be more inclusive in finding FRBs

ASTRA

All Sky Transient Radio Array

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Let FRBs fall into ChASMs

CoHerent All-Sky Monitors HT Liam

- We need extremely wide FoV monitors to find nearest FRBs
- Same phase space as STARE2, GREx, BURSTT (Lin et al 2022)
- 400-800 MHz analog, 100 MHz digital, 3+ stations, 700 signal chains, 300s voltage buffer for external + internal triggers

Let FRBs fall into ChASMs

CoHerent All-Sky Monitors HT Liam

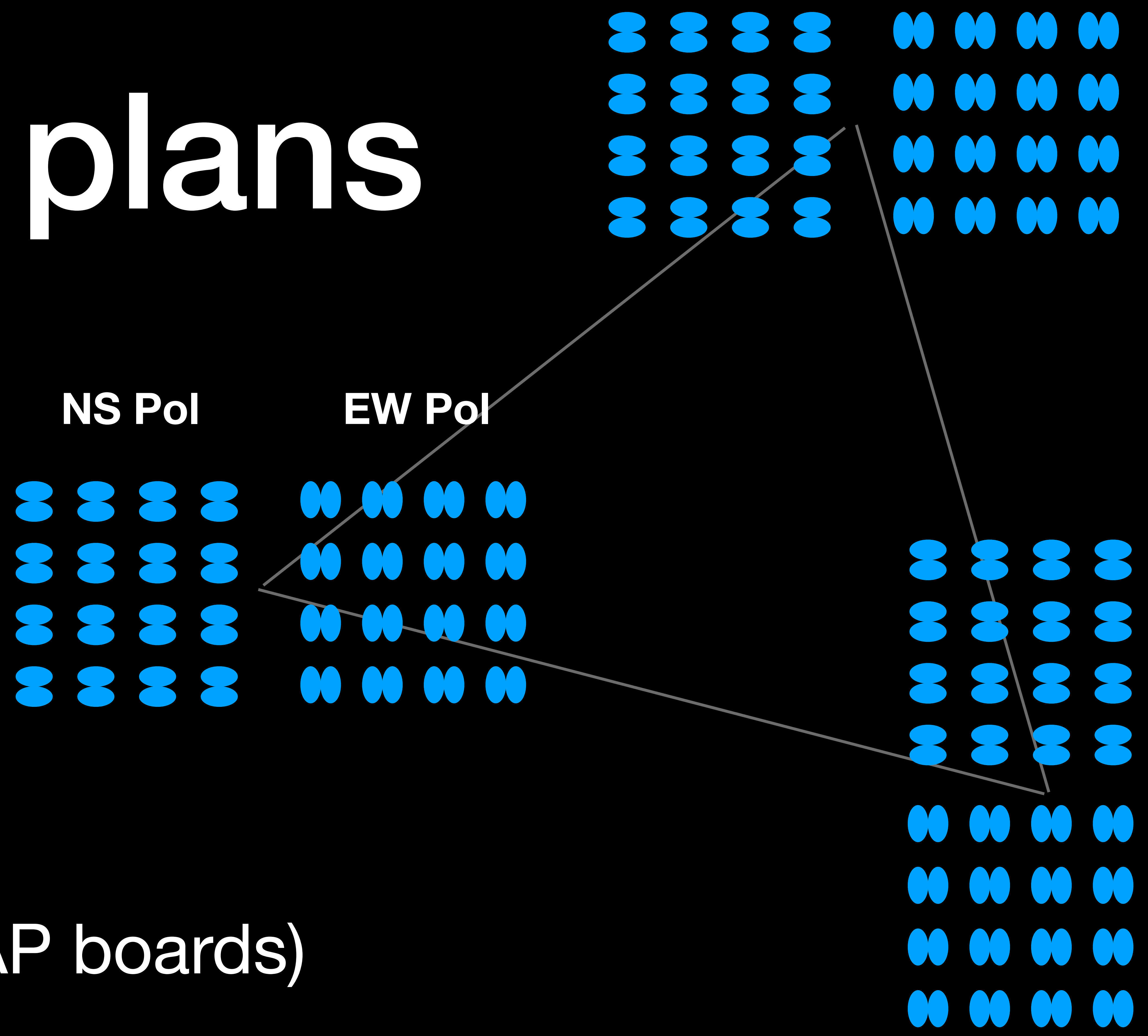
- We nee
- Same p
- 400-80 ains,
  300s vo

Parameter	Goal	Requirement
Instantaneous Field of View	15,000 $deg.^2$	10,000 $deg.^2$
Localization (10-σ burst)	0.1″	1″
Incoherent Beam Sensitivity (5-σ)	500 Jy-ms	700 Jy-ms
Coherent Beam Sensitivity (5-σ)	10 Jy-ms	30 Jy-ms
Voltage Data Buffer	5 min	1 min

Table 1: Summary of System Parameters

Science plans

- 3 stations (more later)
- 2 layouts of single polzn dipoles in a grid
- Analog systems designed for 400-800 MHz
- Digital systems designed for 100 MHz (SNAP boards)
- 300s voltage buffer for external + internal triggers
  - Trigger on alerts from LVK, Fermi, Daksha (next talk)



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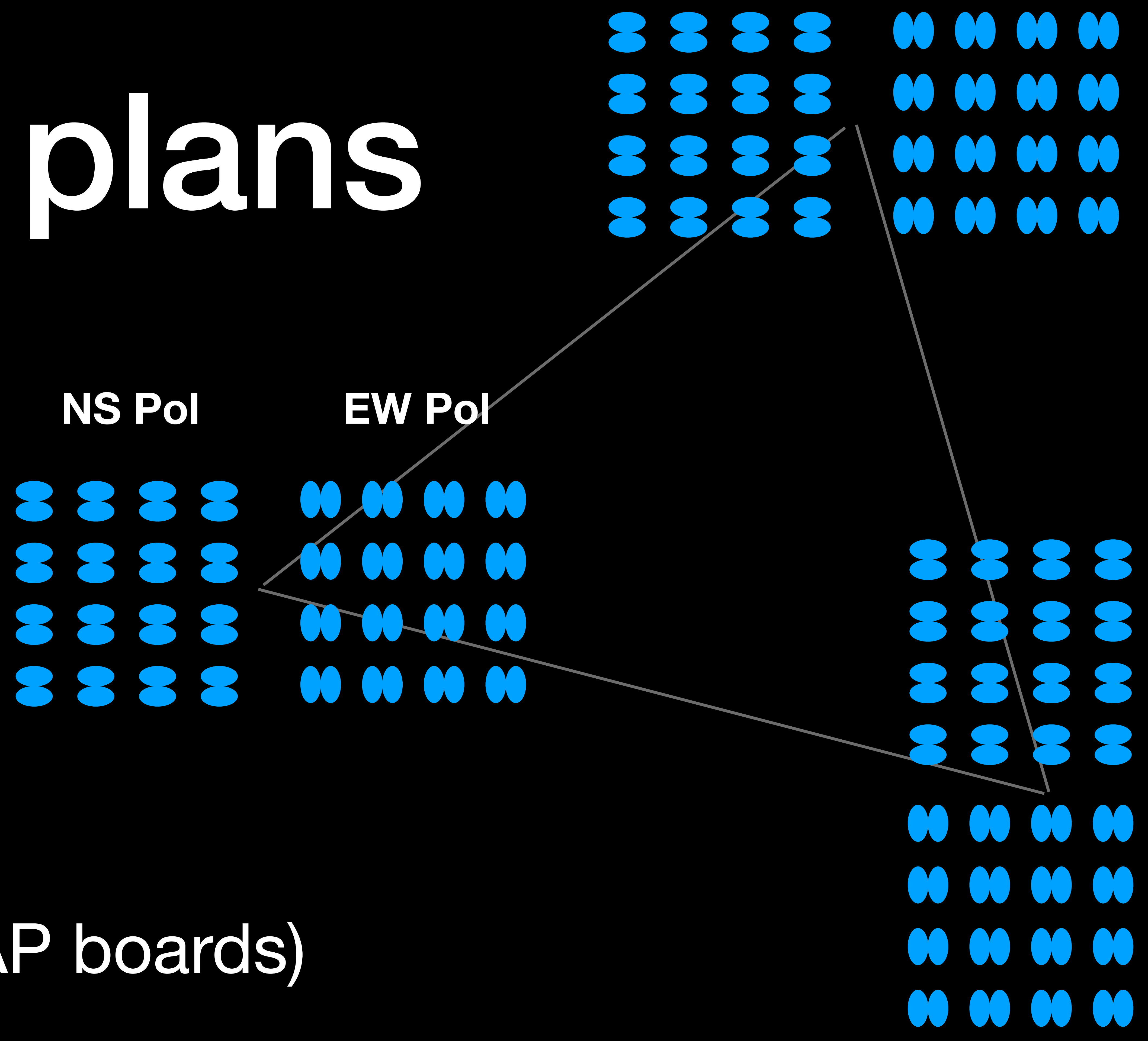

Specifically required due to the uncertainty in BNS prompt emission models

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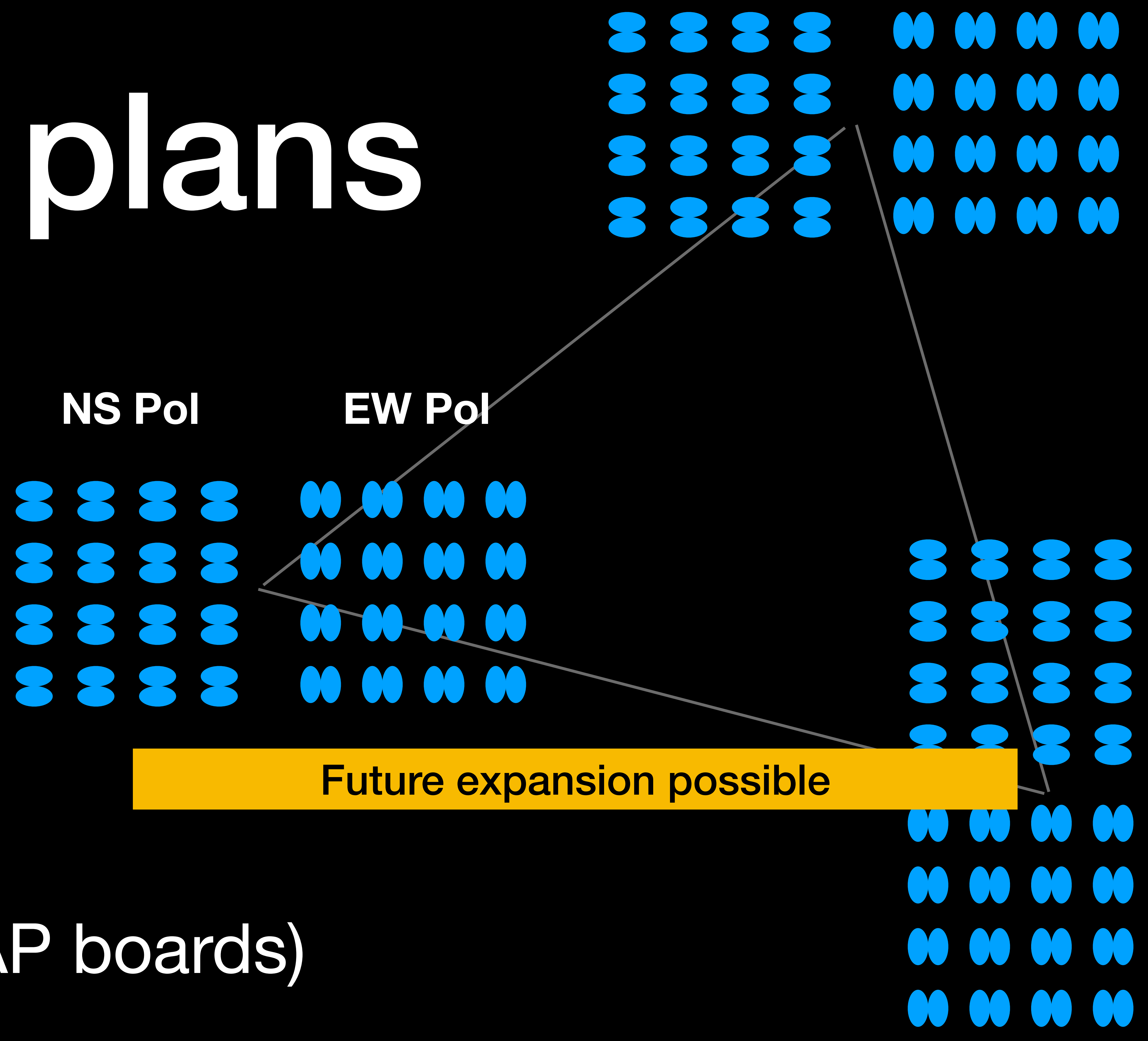

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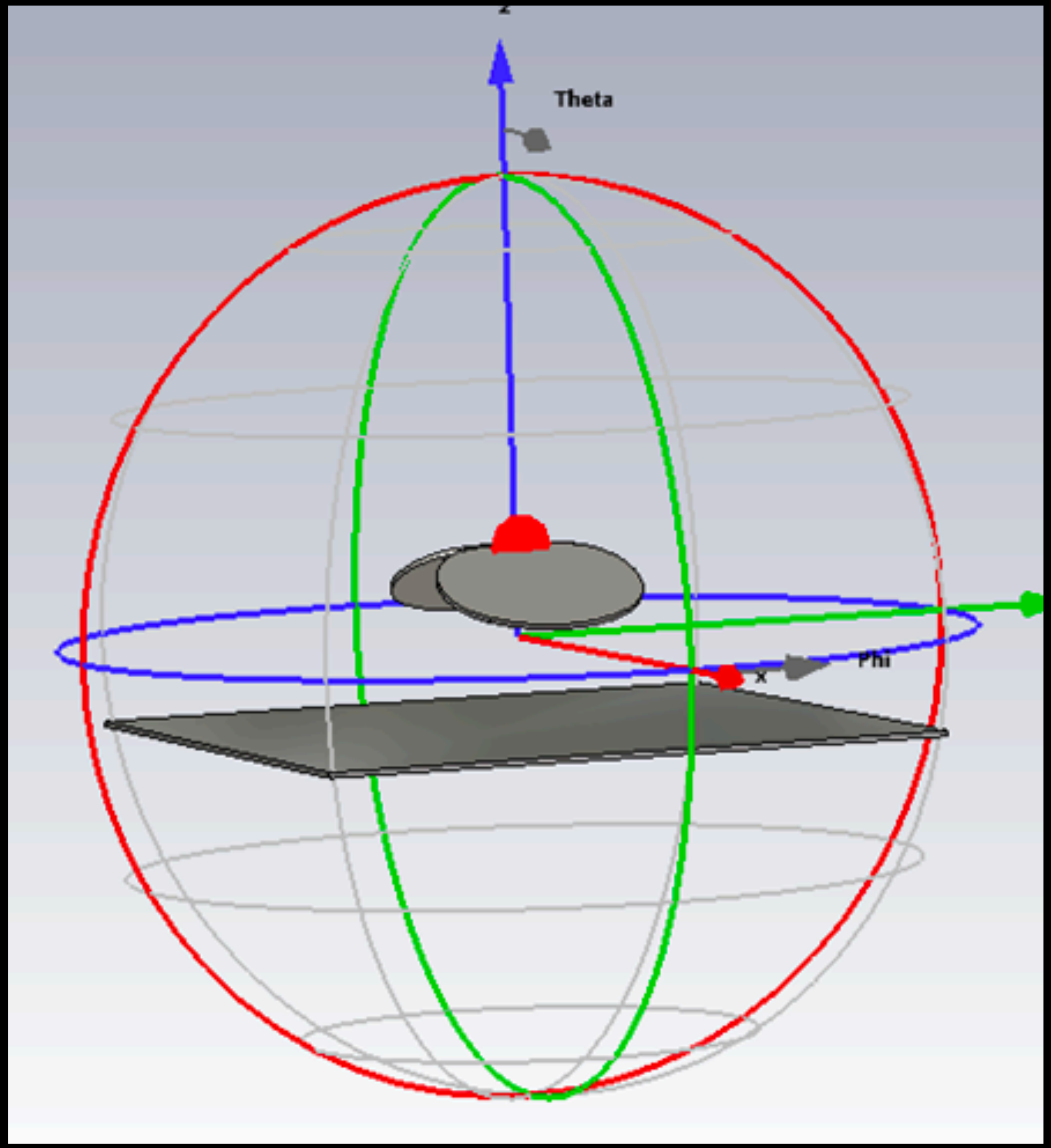
Feed Design

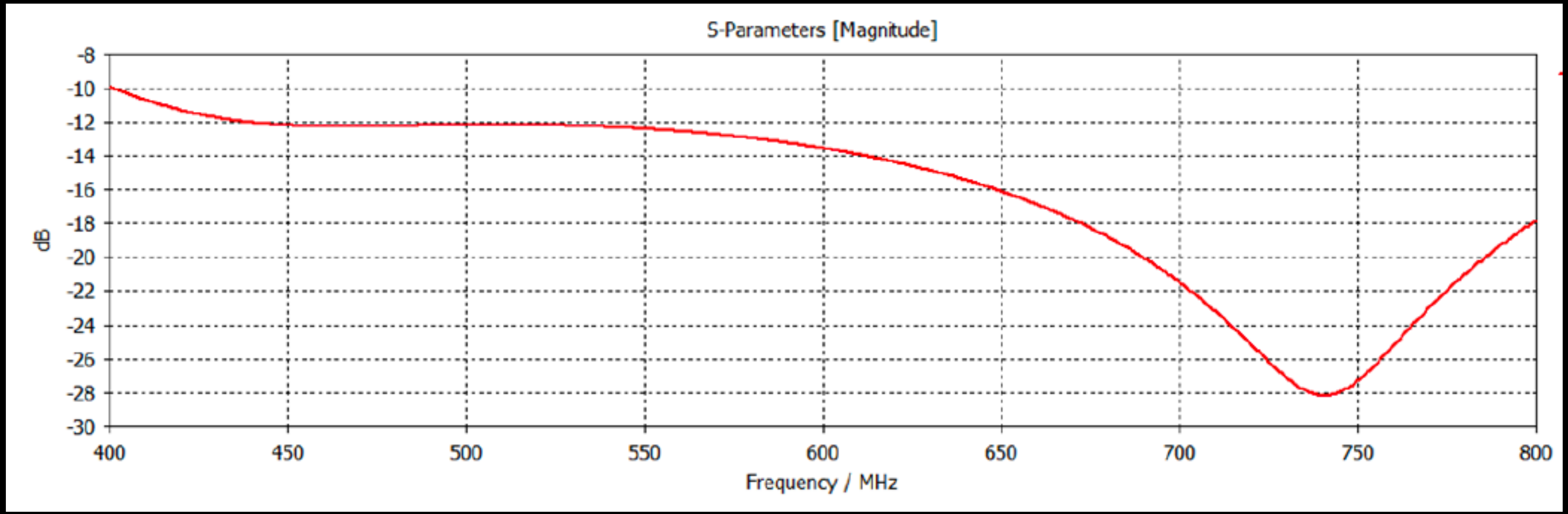


400-800 MHz feed design (by Nipun Ghangas)

- Based on the CHIME design, but single polarization, much wider FoV
- Two downward tilted aluminium sheet ~13 cm wide petals

Half power beam widths (deg)

Phi	400 MHz	600 MHz	800 MHz
0	69	66	121
90	83	92	135



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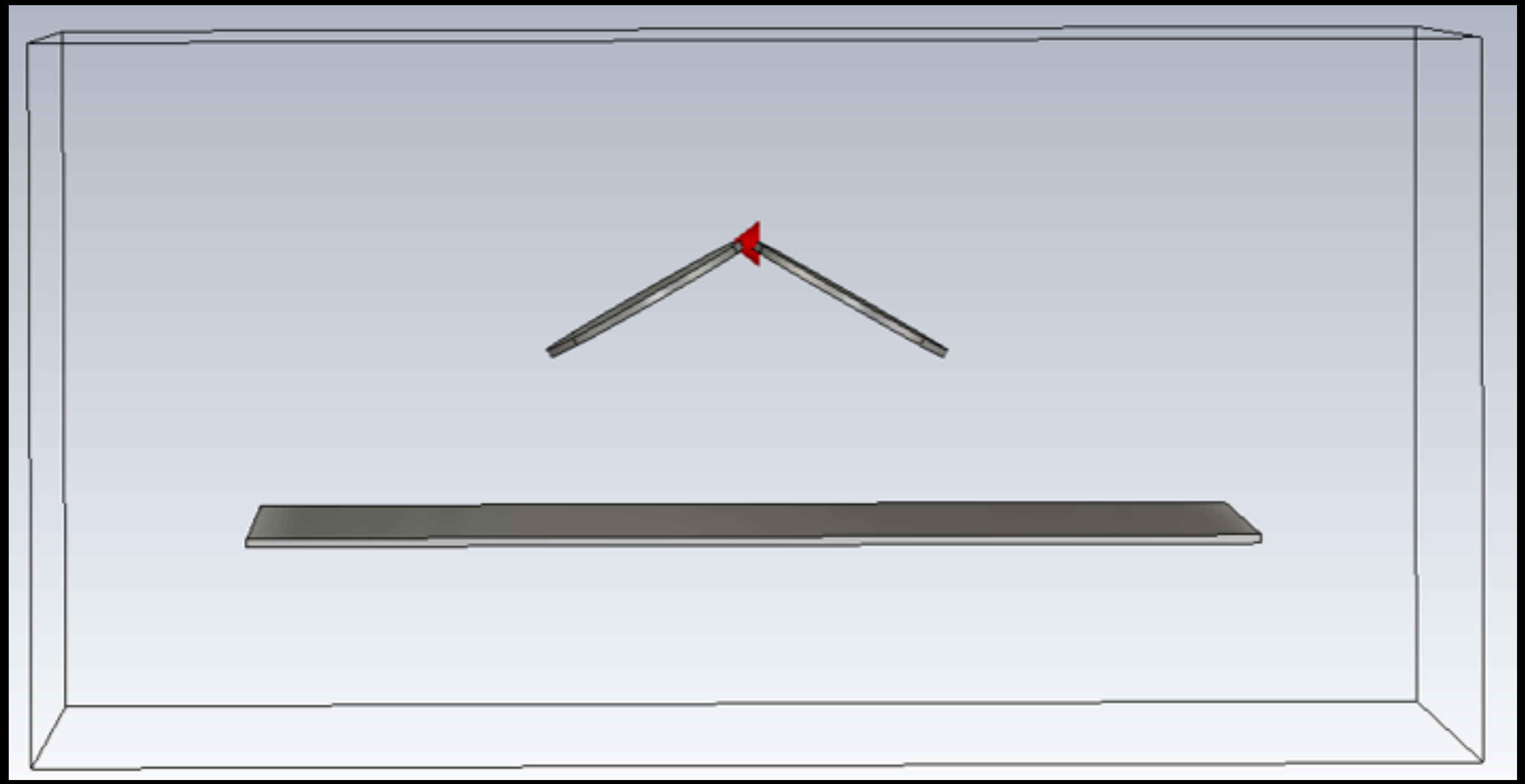

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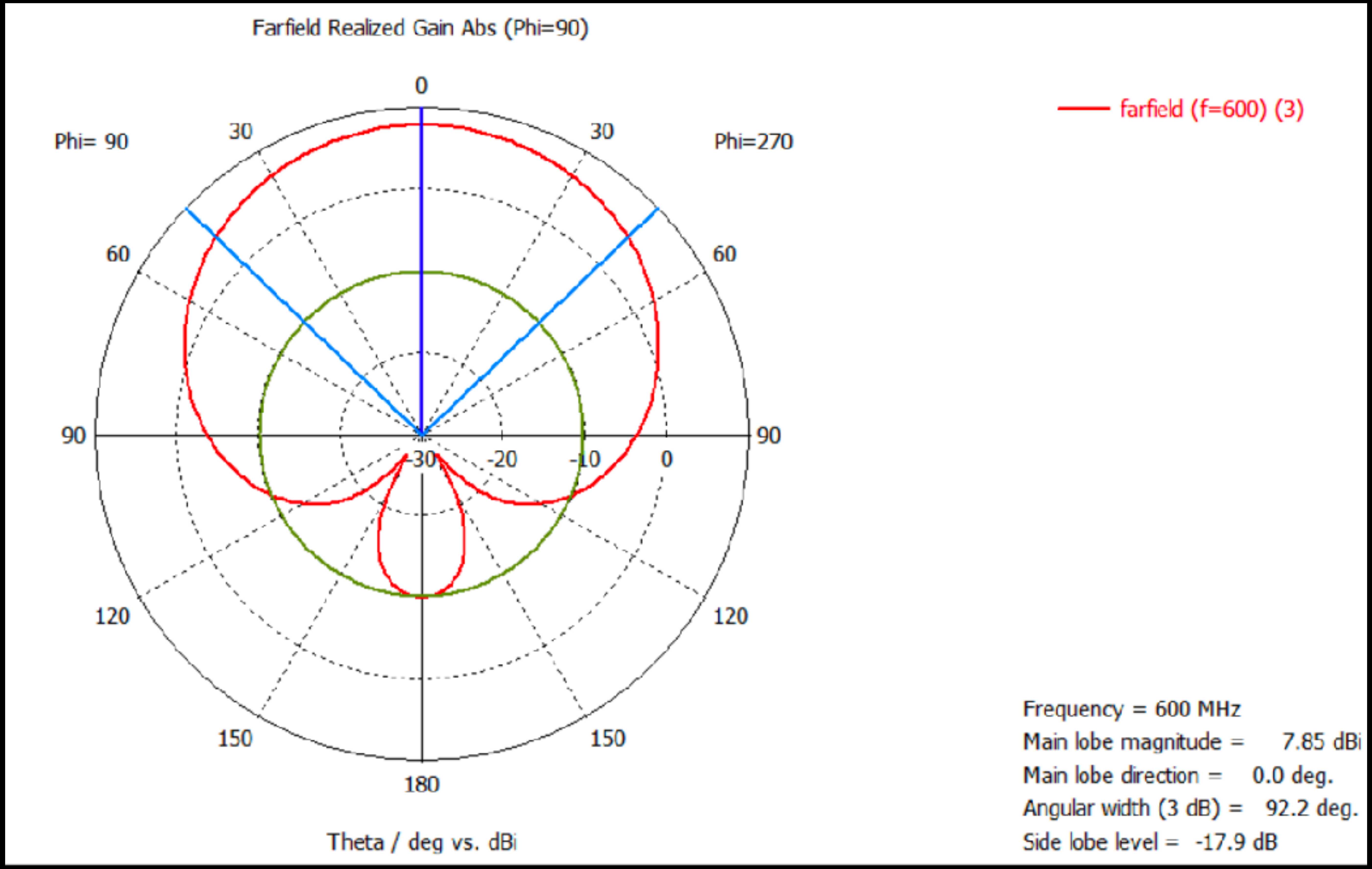
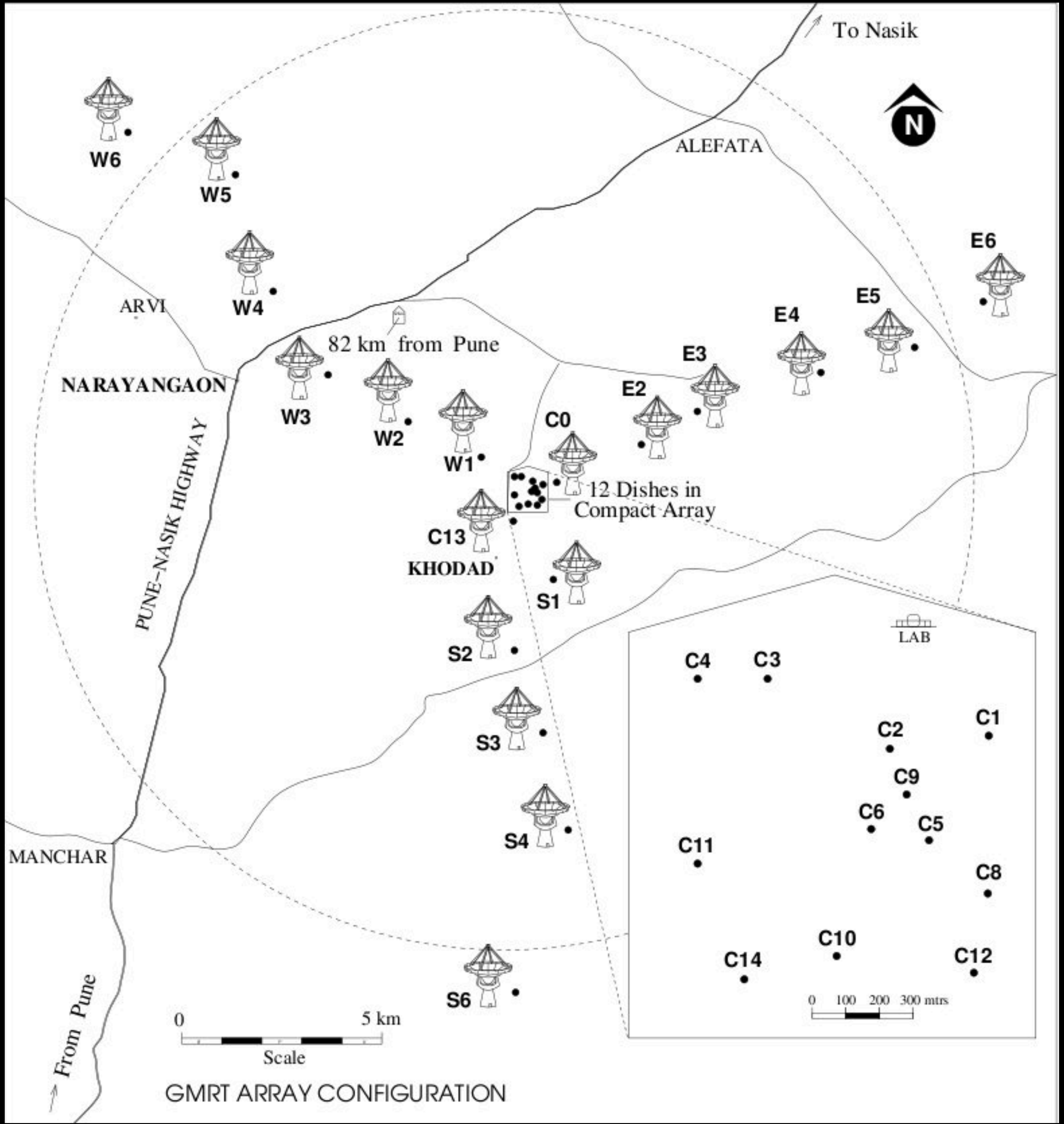
- Beam pattern at 600 MHz



Medium Baseline Locations

- GMRT array
- Fiber optics and power to each pad
- Maser at correlator building
- Some empty pads
- ~20 km baselines



Long Baseline Locations

- GMRT — ORT: 900 km
- GMRT — GBO: 700 km
- Ooty — GBO: 250 km

Each location is a radio observatory and has a hydrogen maser

Digital systems

- Each station searches for bursts separately
- Low threshold detections are shared and compared
- Originally only in incoherent beam
  - Upon detection, freeze buffers, transfer data and correlate offline
- In future, FFT beam forming

Plans

- Field testing of feeds and analog chain (GMRT Band 3)
- 16 element array (early 2023)
- Scale up to larger size through 2023

ASTRA Summary

- ASTRA: Designed for detecting the brightest and nearest radio transients
- Counterparts of BNS mergers, Galactic FRBs, local magnetar flares
- Large voltage buffer to dump the last 5 minutes of sky
- Pilot array in development