FRBs at the bottom

S. R. Kulkarni

Owens Valley Radio Observatory

California Institute of Technology

- The most incomprehensible thing about the world is that it is comprehensible – Albert Einstein

- I soon became convinced... that all the theorizing would be empty brain exercise and therefore a waste of time unless one first ascertained what the population of the universe really consists of – Fritz Zwicky

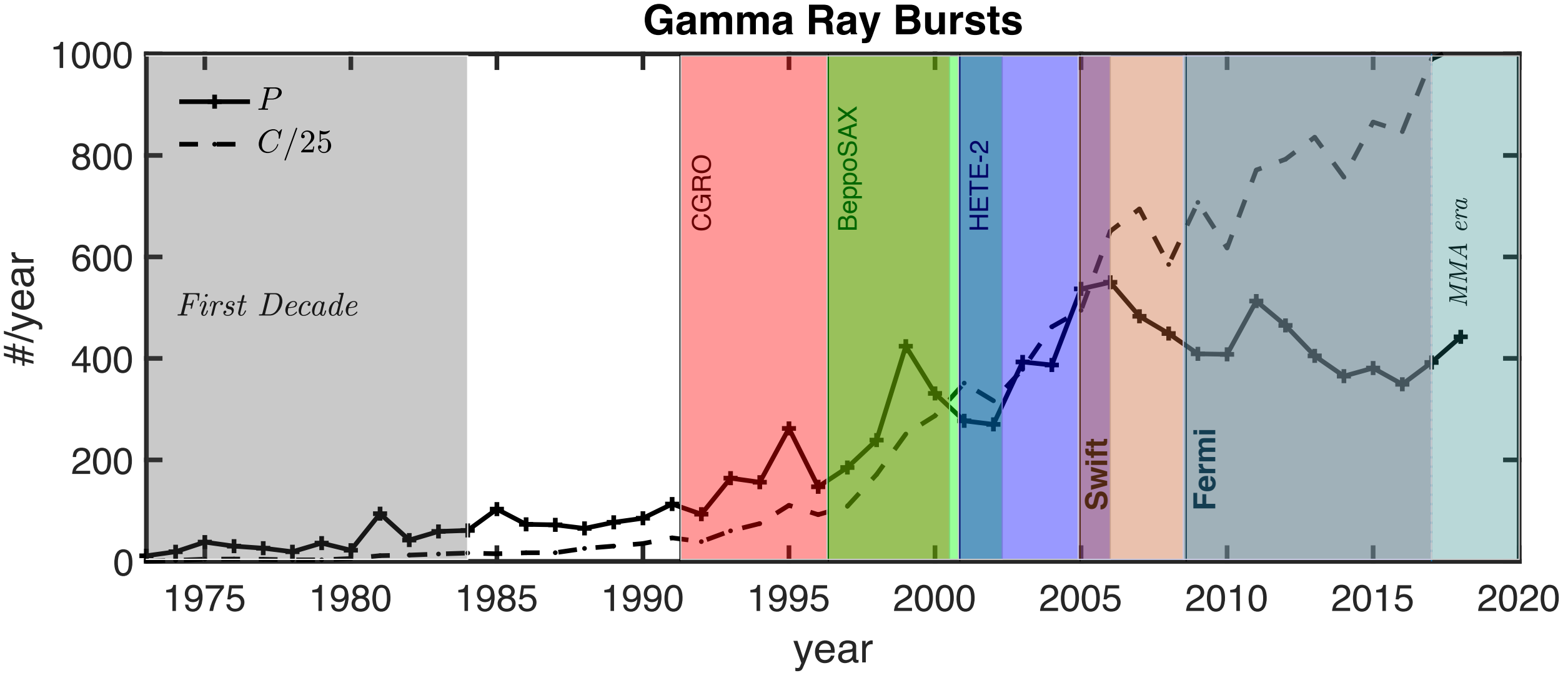
- There is something fascinating about some theoretical astrophysicists Some of them get such wholesale returns of conjecture out of such a trifling investment of fact – adapted from Mark Twain

I. DÉJÀ VU ALL OVER AGAIN: FROM GRBS TO FRBS

From gamma-ray bursts to fast radio bursts

The field of gamma-ray burst astronomy arguably went through three decades of growing pains before reaching maturity. What development lessons can be learned for the adolescent field of fast radio burst astronomy?

S. R. Kulkarni


Gamma Ray Bursts
1000
800
600
400
200
0
#/year
P
C/25
First Decade
CGRO
BeppoSAX
HETE-2
Swift
Fermi
MMA era
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
year

THEORIES OF γ-RAY BURSTS*

1975

M. Ruderman

Department of Physics
Columbia University
New York, New York 10027

INTRODUCTION

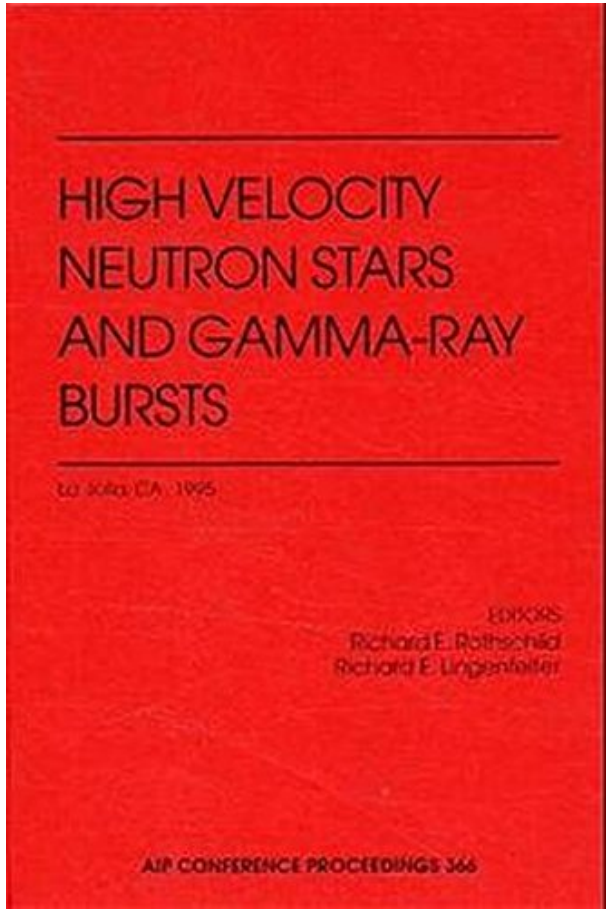
Most theoretical astrophysicists function well in only one or two normal modes. Therefore, we often tend to twist rather strenuously to convince ourselves and others that observations of new phenomena fit into our chosen specialties. As expected, there has been no lack of response by the theoretic community in suggesting an enormous variety of models for γ-ray bursts, such as the following: expanding supernovae shocks,[1,2] neutron star formation,[3] glitches,[2,4,6] neutron stars in close binaries,[7] black holes in binaries,[7,11] novae,[8] white holes,[9] flares on "normal" stars,[10,36] flares on flare stars,[X] flares on white dwarfs,[12,25] flares on neutron stars,[6,13] flares in close binaries,[7] nuclear explosions on white dwarfs,[8] comets on neutron stars,[14] Jupiter,[15] antimatter on conventional stars,[16] magnetic bottles and instabilities in the solar wind,[X] relativistic dust,[17] vacuum polarization instabilities near rotating charged black holes,[18] instabilities in pulsar magnetospheres,[13] and "ghouls."[27] (For theorists who may wish to enter this broad and growing field, I should point out that there are a considerable number of combinations, for example, comets of antimatter falling onto white holes, not yet claimed.)

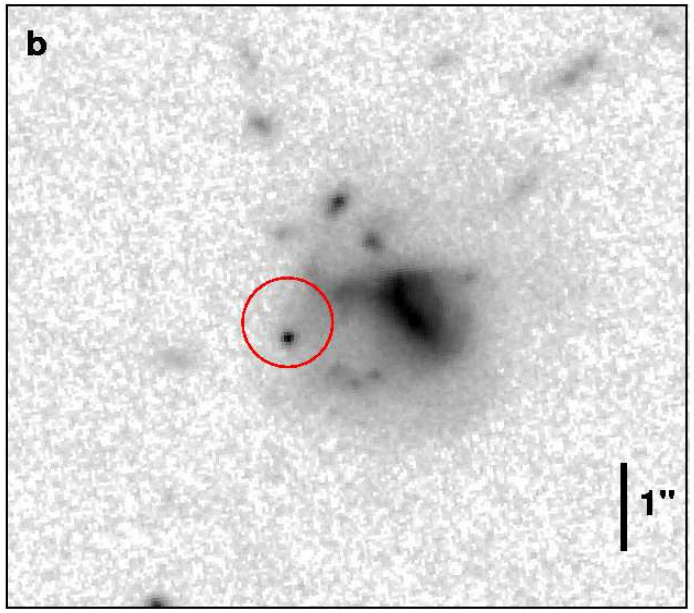
Various confrontations between models and observations and between models

Red Herrings, Wishful Thinking, Desperate theorists...

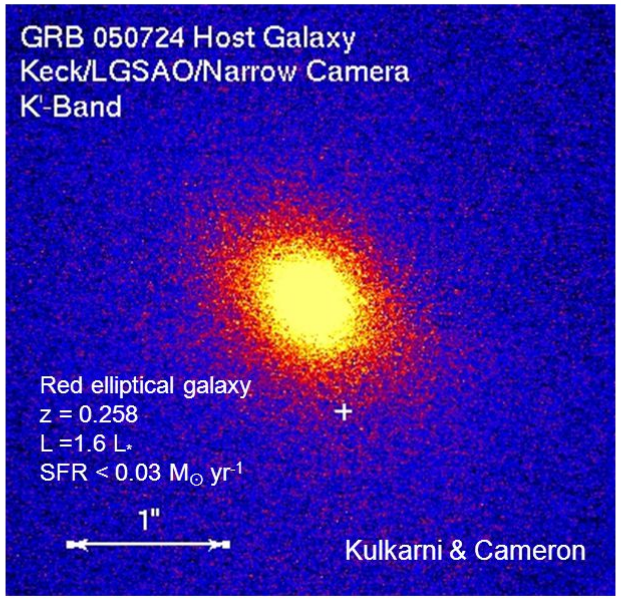
- Cyclotron lines
- Optical flashes (“Plate Defects”)
- The “no-host” problem

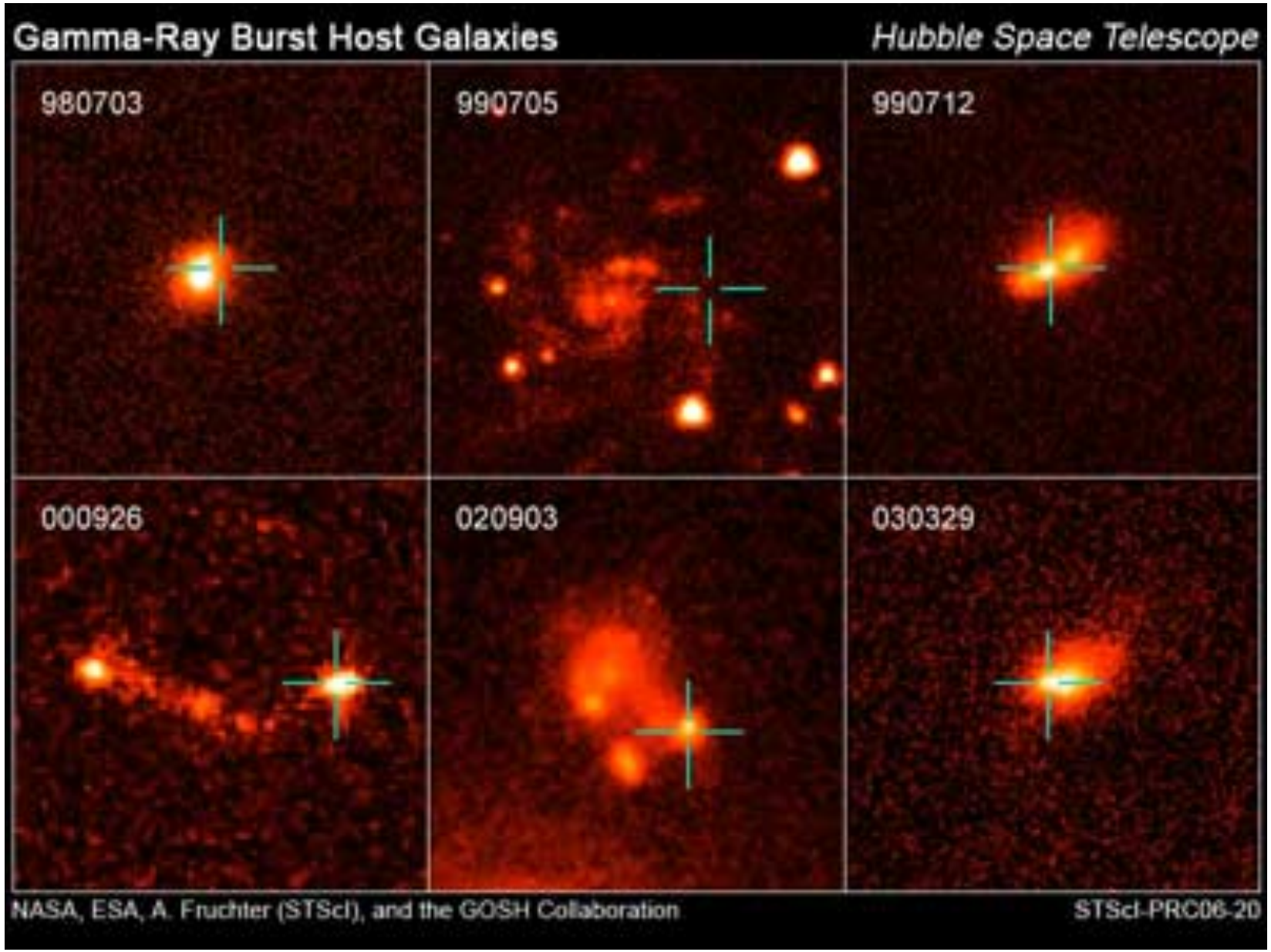
- The discovery of afterglow enabled localization and damped down speculative->crackpot GRB theories

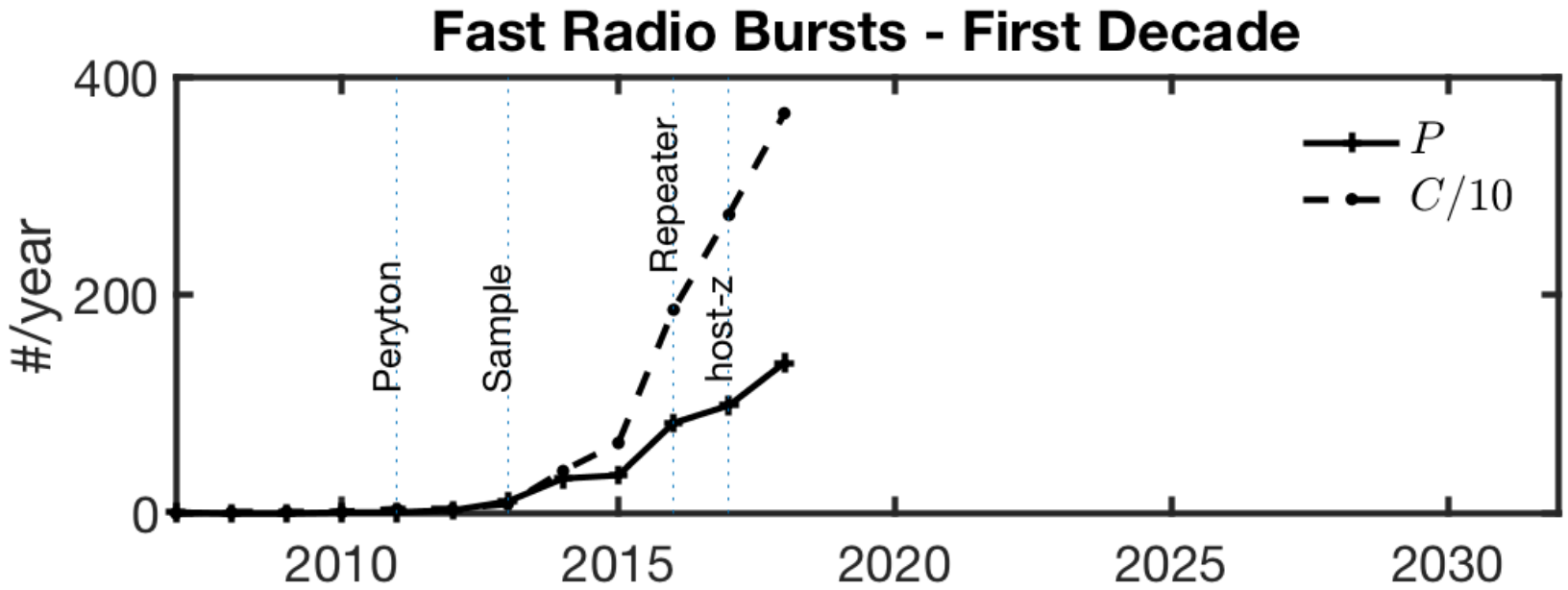


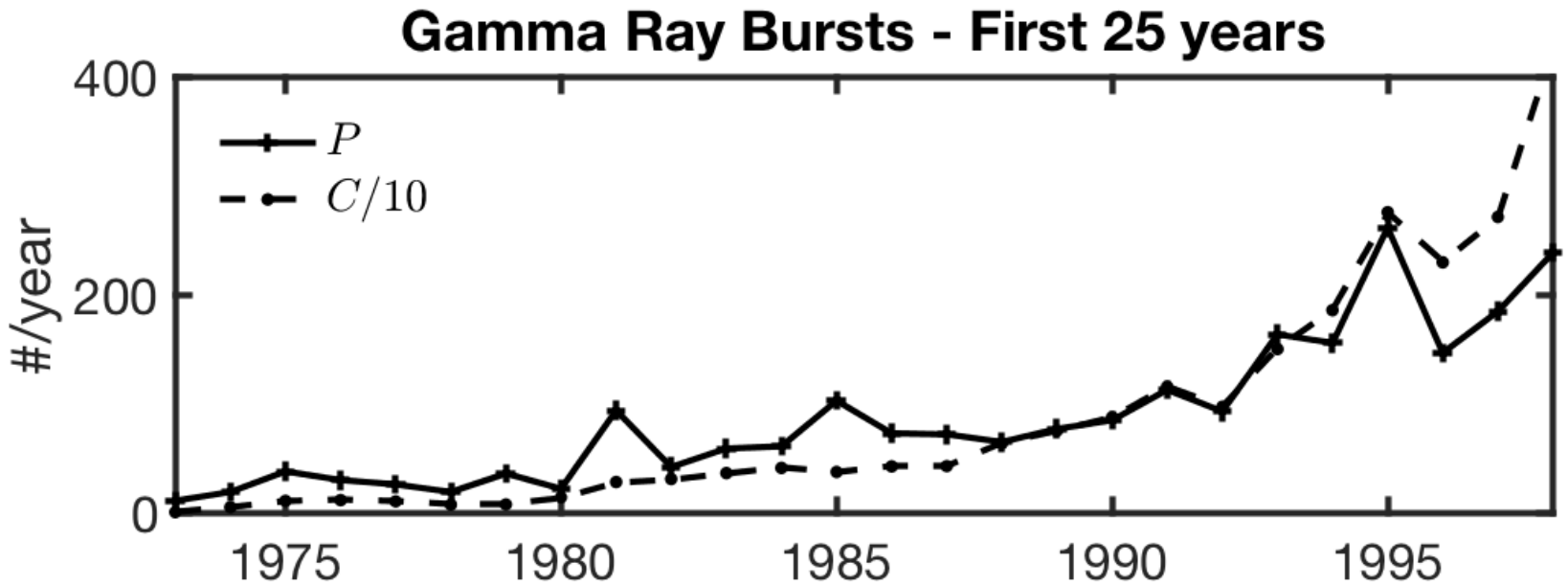


GRB 050724: Host Galaxy






Fast Radio Bursts - First Decade
400
200
0
#/year
Peryton
Sample
Repeater
host-z
P
$C/10$
2010
2015
2020
2025
2030


Gamma Ray Bursts - First 25 years
400
200
0
#/year
P
$C/10$
1975
1980
1985
1990
1995

FASTER PROGRESS BUT SOME THINGS HAVE REMAINED THE SAME

Log in

Main page | Discussion | Read | View source | View history | Search FRB Theory Wiki

Main Page

Hosted by the Institut Spatial de McGill – McGill Space Institute in collaboration with University of Cape Town – iYunivesithi yaseKapa – Universiteit van Kaapstad; University of KwaZulu-Natal – Inyuvesi YaKwaZulu-Natali

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Welcome to the FRB Theory Wiki!

This is a collaborative effort between theorists and astronomers to discuss and track theories and observations pertaining to fast radio bursts (FRBs). The field of FRBs is in its fairly nascent stages and theories are abound. It is getting hard to keep abreast of the latest ideas and observations. This wiki aims to do the following:

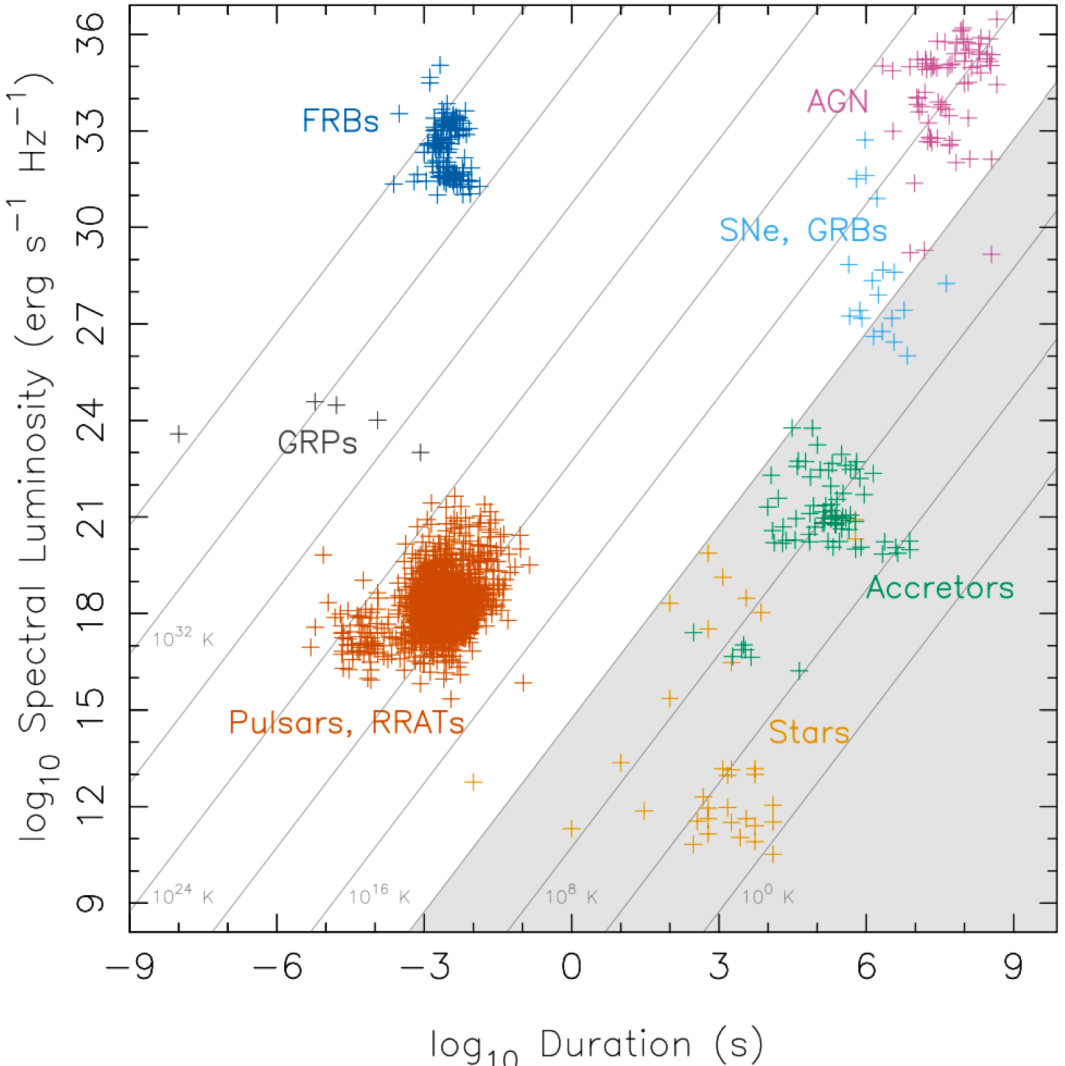
1. Track published FRB theories, their predictions in different wavebands, current observational constraints, and future tests

M2 Browing Heavy Machine Gun

A simple bow & arrow

SEARCH FOR GALACTIC FRBS

Are there Galactic FRBs?



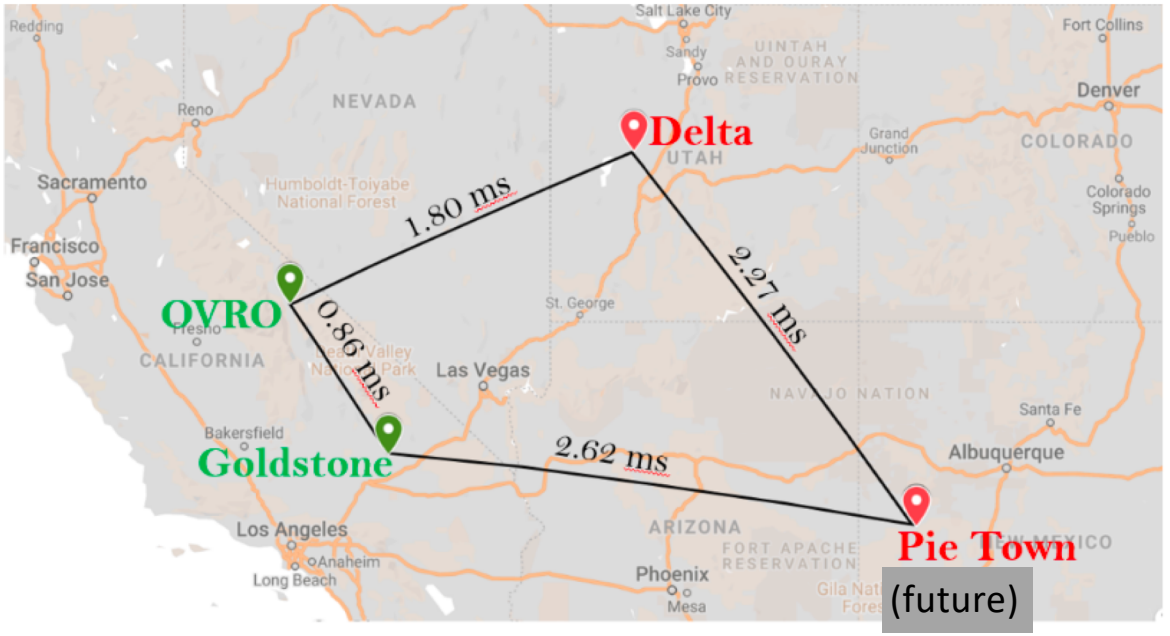
- 10^{31} erg/s/Hz corresponds to a 7 MJy-ms burst at 10 kpc.
- Detectable with a dipole!
- Detecting local FRBs requires an extrapolation of the energy distribution by 1-2 orders of magnitude.

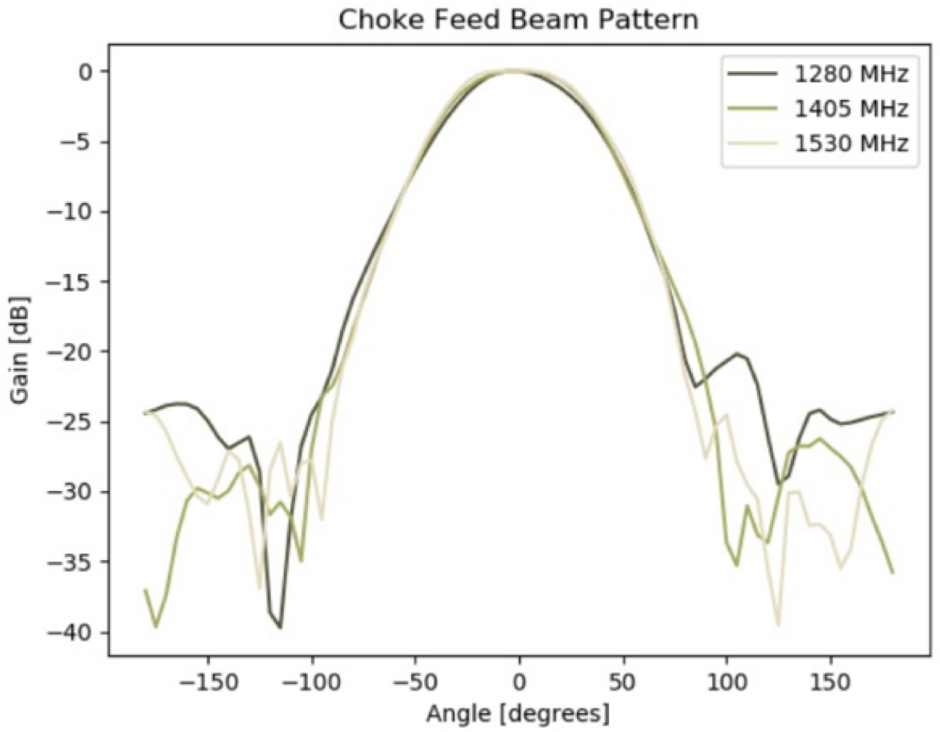
Chris Bochenek

STARE2

Sensitive to 0.3 MJy-ms FRBs at 1.4 GHz.

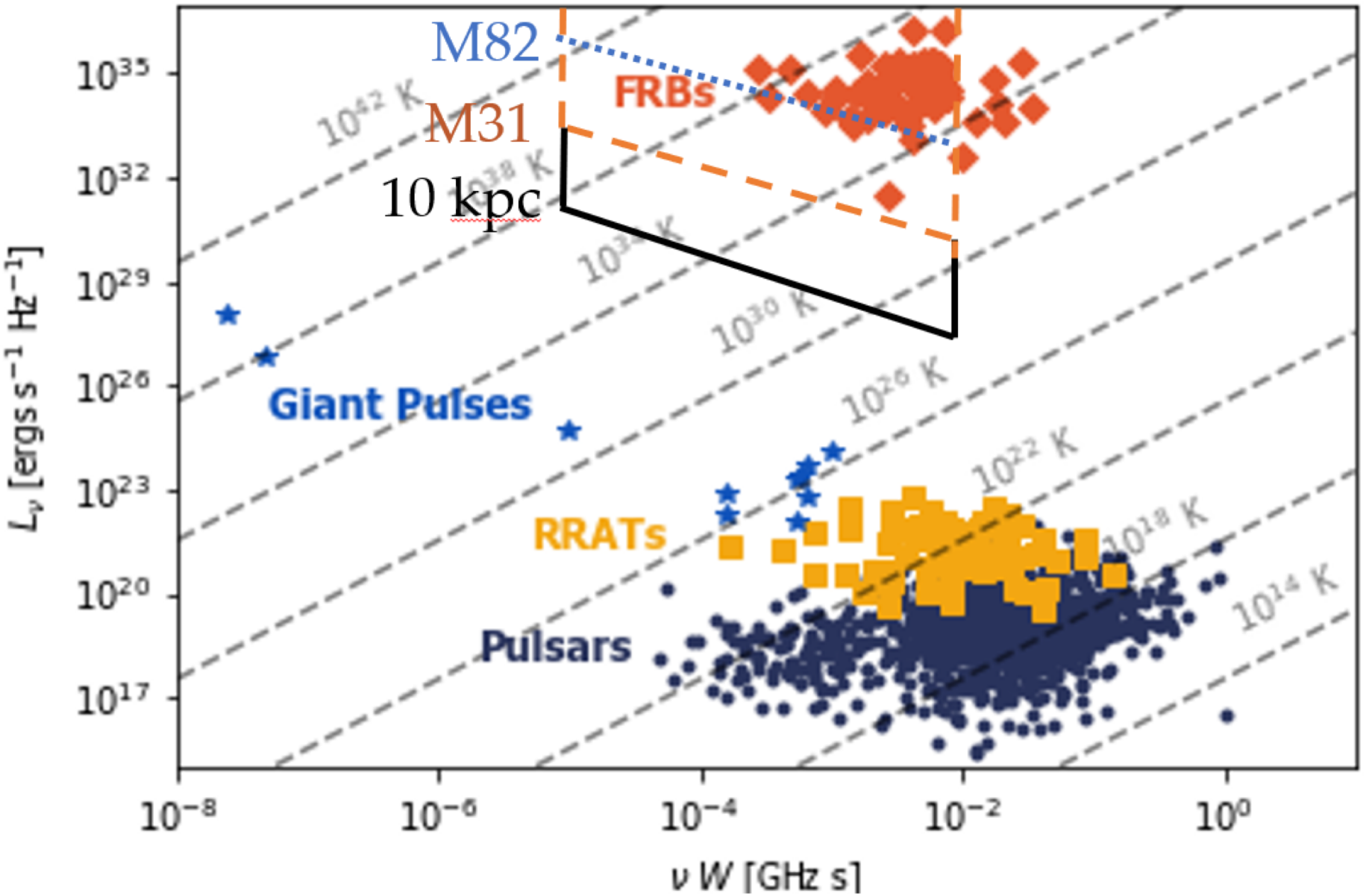
Bochenek, Kulkarni, Kocz, Ravi, McKenna, Belov (2020a)





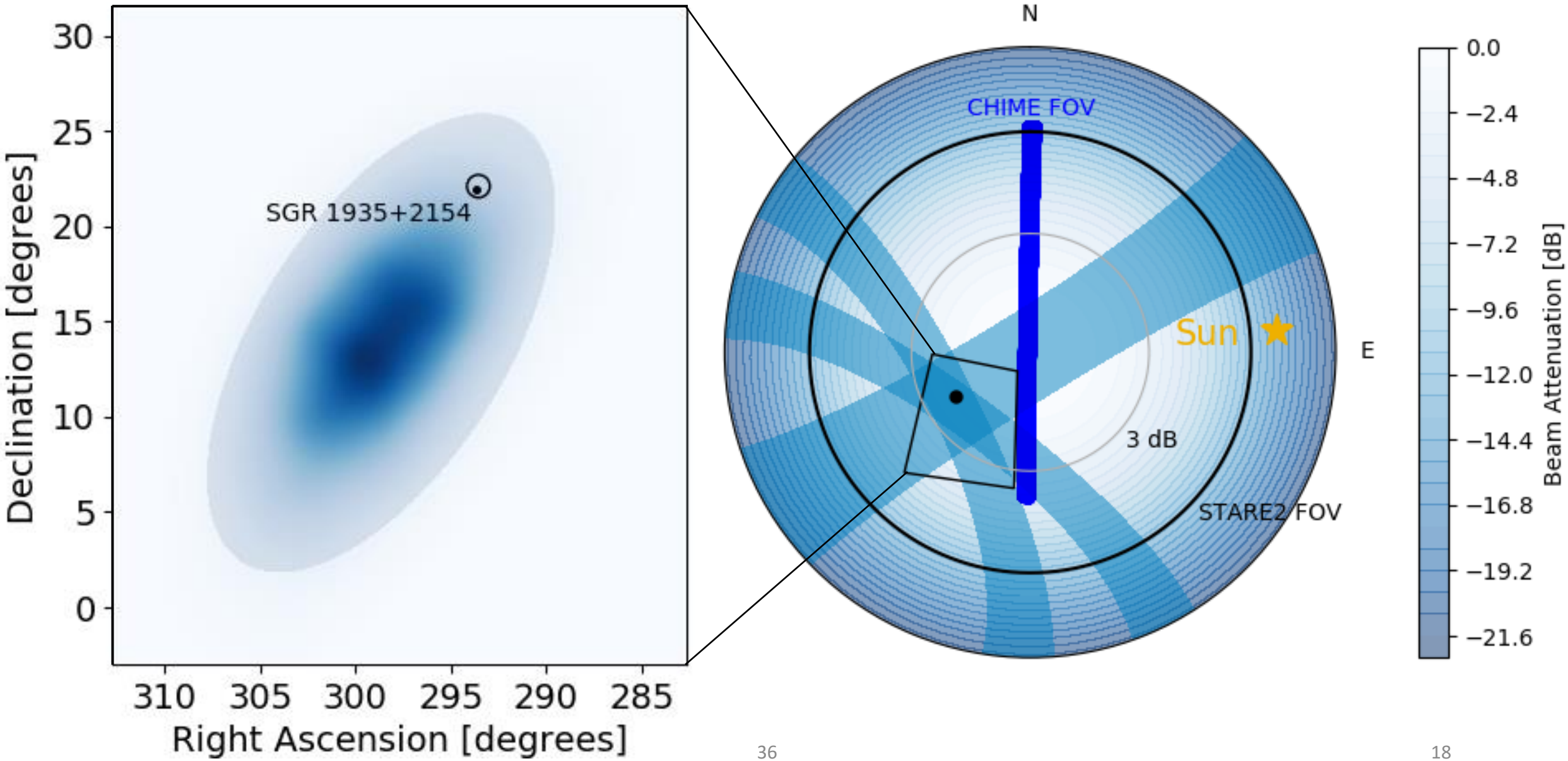
The receiver: end-to-end DSA-10 signal chain

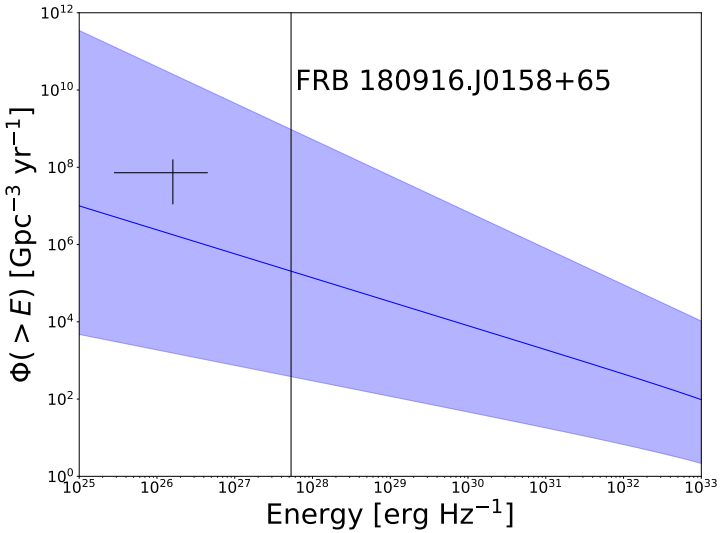
FWHM of beam is 70 degrees


M82
M31
10 kpc
FRBs
Giant Pulses
RRATs
Pulsars
10^{42} K
10^{38} K
10^{34} K
10^{30} K
10^{26} K
10^{22} K
10^{18} K
10^{14} K
10^{35}
10^{32}
10^{29}
10^{26}
10^{23}
10^{20}
10^{17}
L_ν [ergs s^{-1} Hz^{-1}]
10^{-8}
10^{-6}
10^{-4}
10^{-2}
10^{0}
νW [GHz s]

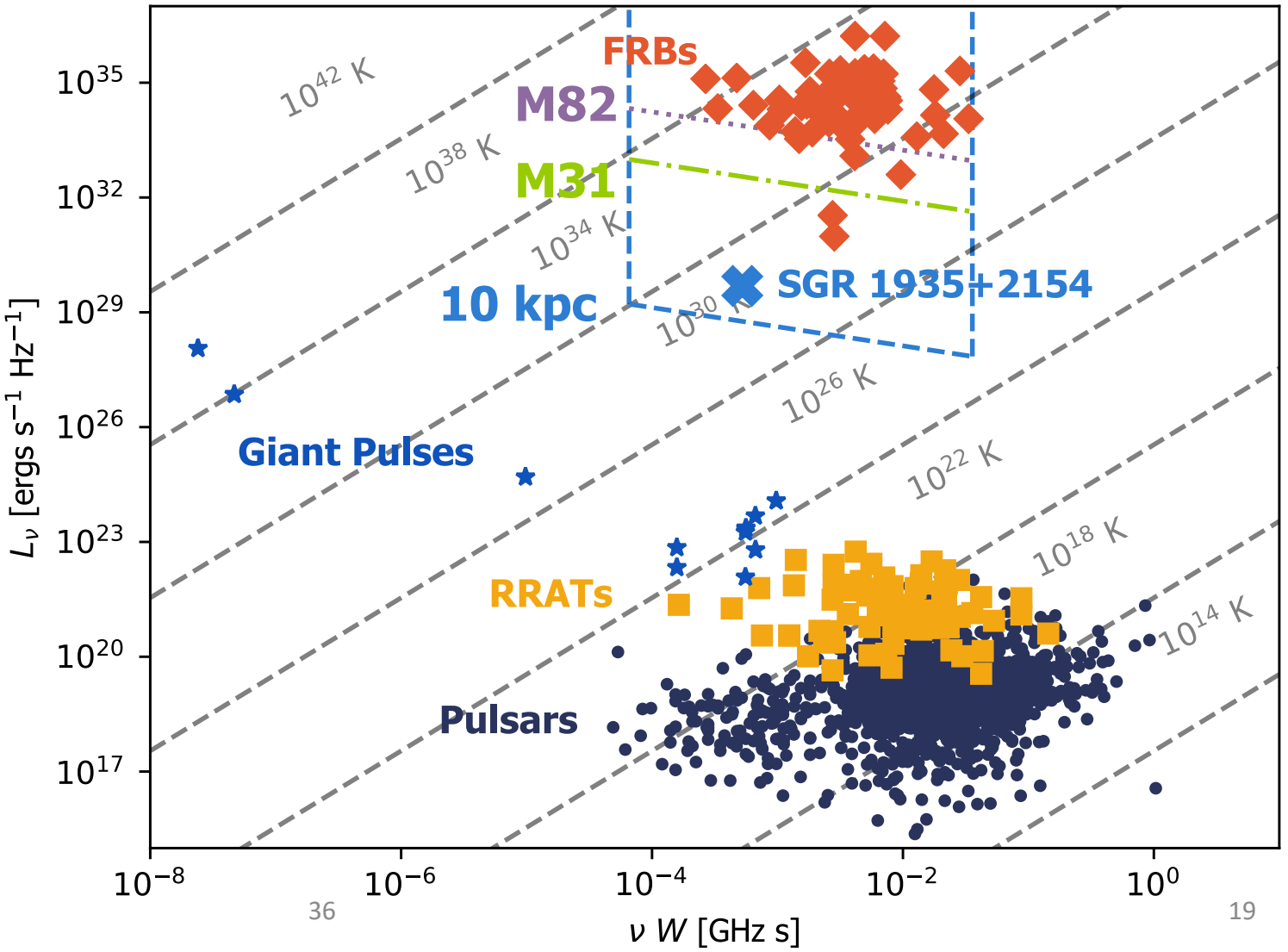
28 April 2020: An amazing day for FRBs

- On April 27, 2020, starting with Swift/BAT a “forest of bursts” were seen from SGR1935+2154
- CHIME detected and reported a dispersed burst with an estimated fluence of few kJy ms consistent with the SGR position
  - Revised upwards by a factor of 60 three weeks later
- STARE-2 detected 1.5×10^6 Jy burst
  - No flux correction since source present in our 70-degree primary beam
  - We suggested that this was sufficiently bright to belong to extra-galactic FRBs.
- X-ray missions (HXMT, Konus-WIND, Integral, AGILE and others) reported a hard burst coincident with the radio burst.


SGR 1935+2154
Declination [degrees]
Right Ascension [degrees]
30
25
20
15
10
5
0
310
305
300
295
290
285
N
E
CHIME FOV
STARE2 FOV
Sun
3 dB
Beam Attenuation [dB]
0.0
−2.4
−4.8
−7.2
−9.6
−12.0
−14.4
−16.8
−19.2
−21.6



Bochenek et al. 2020b



A (THEORY-THEOLOGY-FREE) SUMMARY OF FRBS

- FRBs are cosmological (leaving aside FRB 200428)

- Some FRBs are repeaters
  - The first repeater was embedded in a synchrotron nebula (plerion?) but this appears not to be universal
  - The simplest assumption is that all all FRBs are repeaters, albeit with a wide distribution of waiting times

- Leaving aside repeaters, the observed all-sky rate of FRBs do not support any catastrophic model
  - Do not waste time focusing on sci-fi phenomena (strings, black-hole batteries, evaporating primordial black holes, etc.)
  - Rushing off to work on minor contributors (e.g. GW events, AGN) without any observational clue is likely to be a waste time, as in GRB days

- The extant host galaxy sample and offsets show that FRBs follow ordinary core collapse events
  - So stop invoking exotic sub-types (e.g., SLSN) – until the data force you to do so

- A fraction of FRBs show scattering tails
- Of the localized FRBs, most FRBs do not show evidence for large local DM contribution
  - So most FRBs do not arise in plerions, very young SN or dense regions of ISM

- A low luminosity FRB is conclusively linked to a magnetar which is not particularly exceptional

FRBs at the bottom of the luminosity function

- Characterize the luminosity function of FRBs
  - Is most energy emitted at the high or low end of the luminosity function?
- What specific types of magnetar outbursts are associated with FRBs?
  - X-ray phenomenology is rich and confusing
- Localize FRBs in nearby galaxies
  - (Eventual) goal of locating FRB sites at the parsec scale

- We have giant radio pulses, RRATs and FRBs.
  - Is there any additional phenomena?
    - e.g, super-giant pulses, kilo Jy bursts bound from SGR 1935+2154
  - What , if any, is the connection between these three millisecond phenomena

- This motivates study of pulses and bursts in our Galaxy and nearby galaxies

GREx: A project to study nearest FRBs

- Milky Way & Nearby Galaxies
  - GREx (dipoles around the world)
- Galaxies in the local group galaxies
  - Use existing telescopes and keep staring!
- Nearest star-burst galaxies
  - Shift to 10 to 30 GHz and keep staring (10-m antennas will do)

GREX IS MADE POSSIBLE BY NEW TECHNOLOGY DEVELOPED FOR DSA-110

The 110-element Deep Synoptic Array (DSA-110)

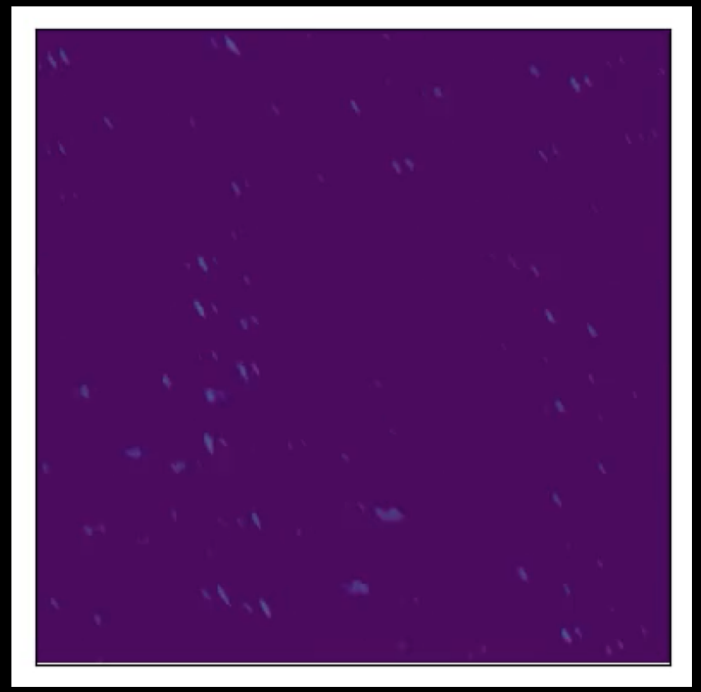
Vikram Ravi,
Caltech
With Gregg Hallinan
and the DSA team.

http://astro.caltech.edu/~vikram
https://www.deepsynoptic.org/

FRB 190523 localized with the DSA-10

131.072 micro-sec per frame, slowed down by a factor of 10,000.

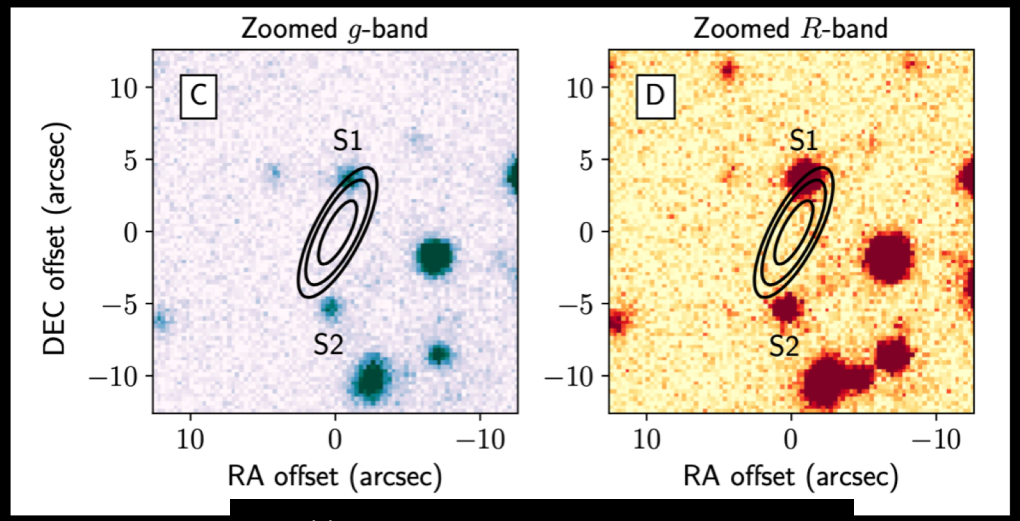
5’’ pixels.



0.5 deg

0.5 deg

Ravi+19



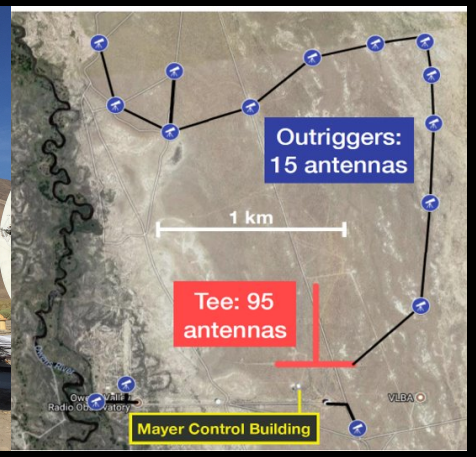
10^{11} solar mass host, z=0.66

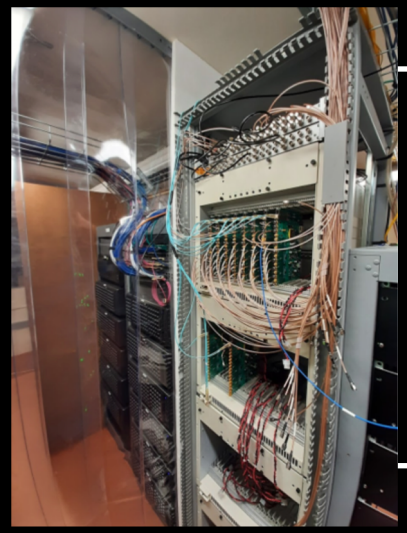
The DSA-110

https://www.deepsynoptic.org/

NSF MSIP (Hallinan, Ravi) - $5.3M - 2018-2024. <3'' localization. <60s alerts.

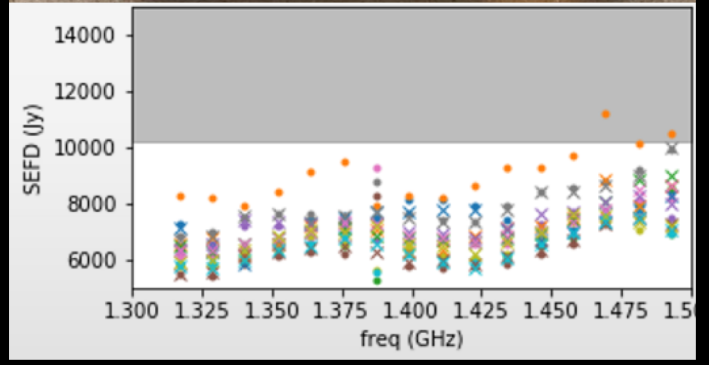
110 4.65-m dishes, elevation only. Custom RFoF transport. **Unit cost <$10k.**





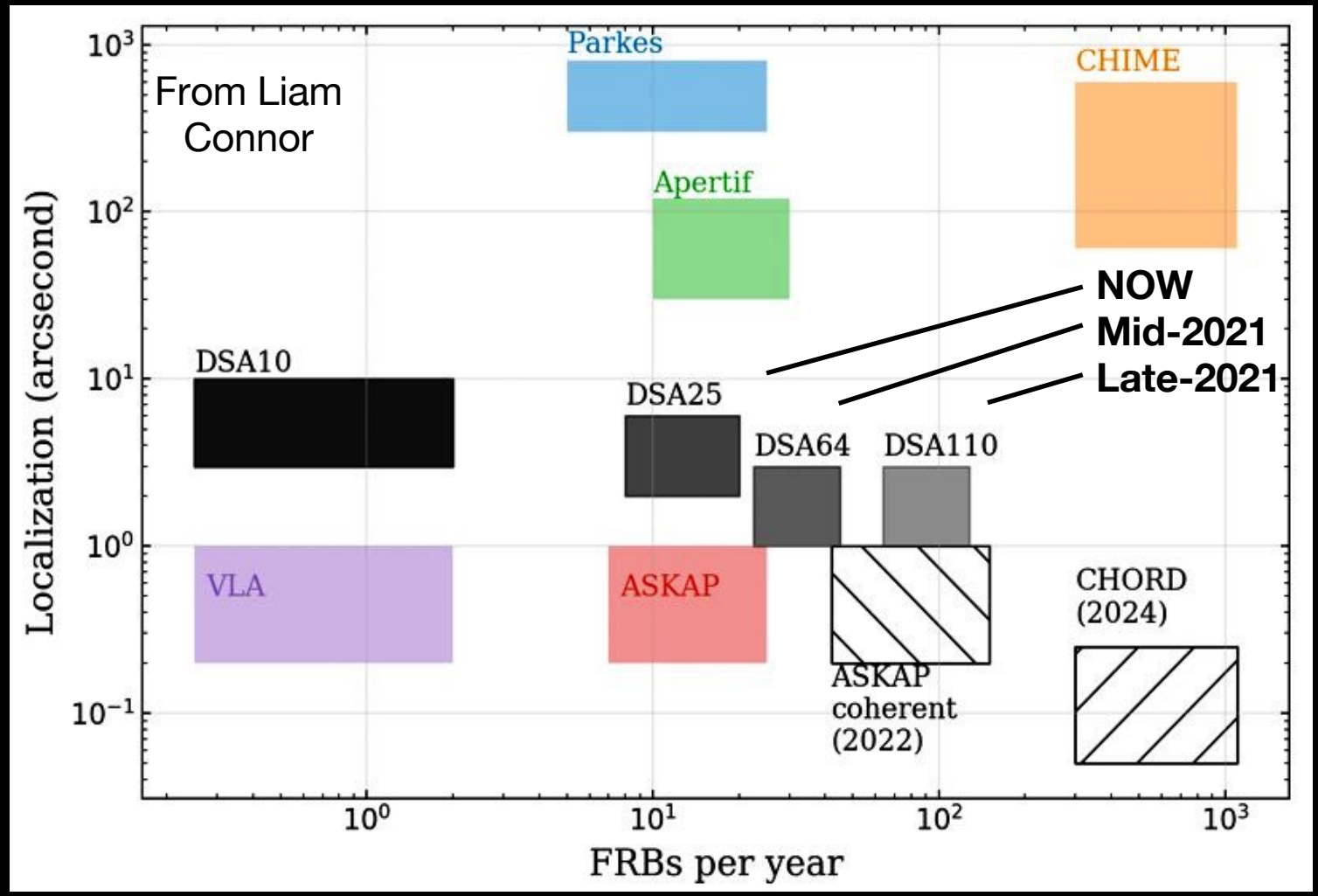
37 SNAP-1 FPGA boards + 24 dual 2080Ti GPU servers. Real time N^2 correlation and interferometric calibration, beam forming throughout primary beam, FRB searching, triggered storage of voltages.

1.28-1.53 GHz receivers. Custom "cakepan" feeds and **room-temp** LNAs (Weinreb & Shi 2020). **Tsys ~ 25K, aperture efficiency ~0.65.** Unit cost <$2k.



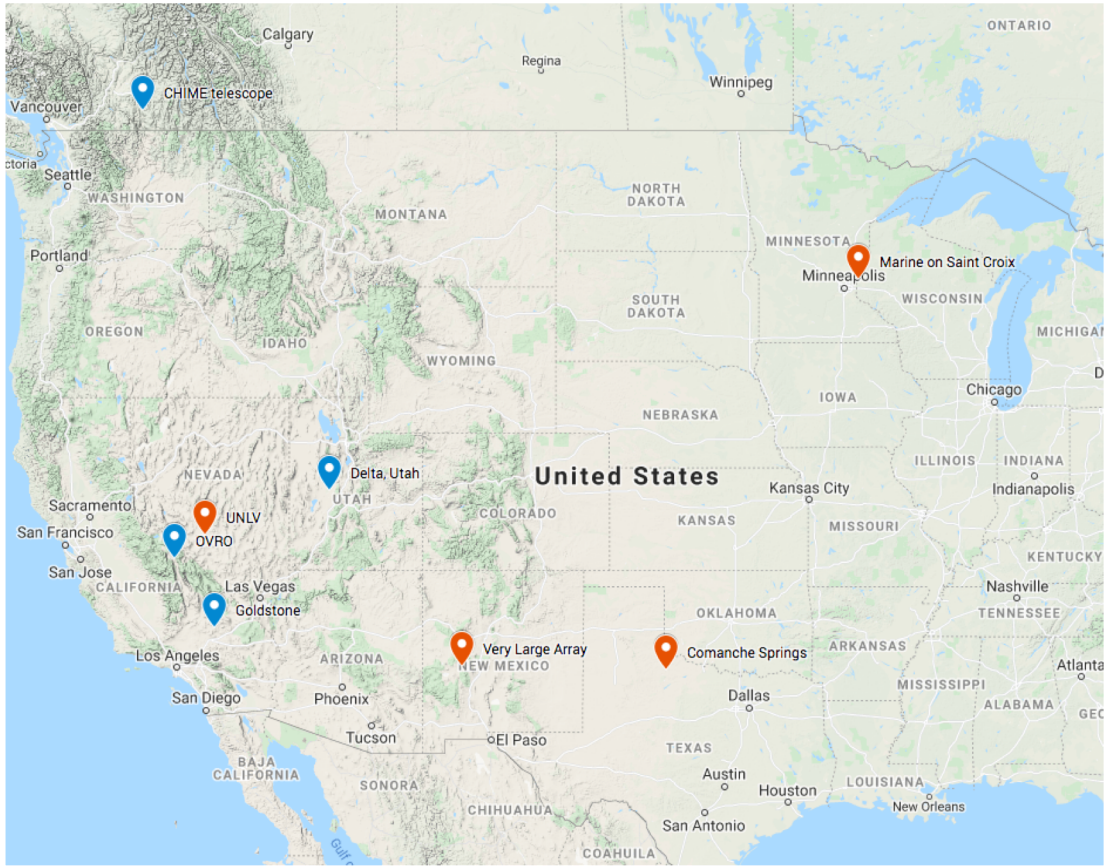
From Dana Simard

The FRB instrumentation landscape



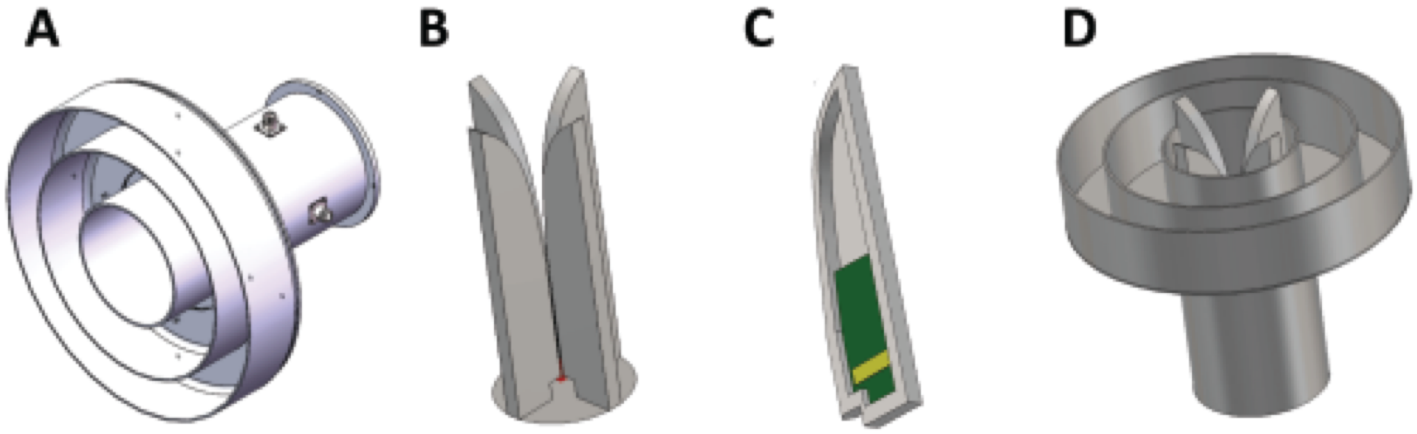
GALACTIC RADIO EXPLORER (GREX)

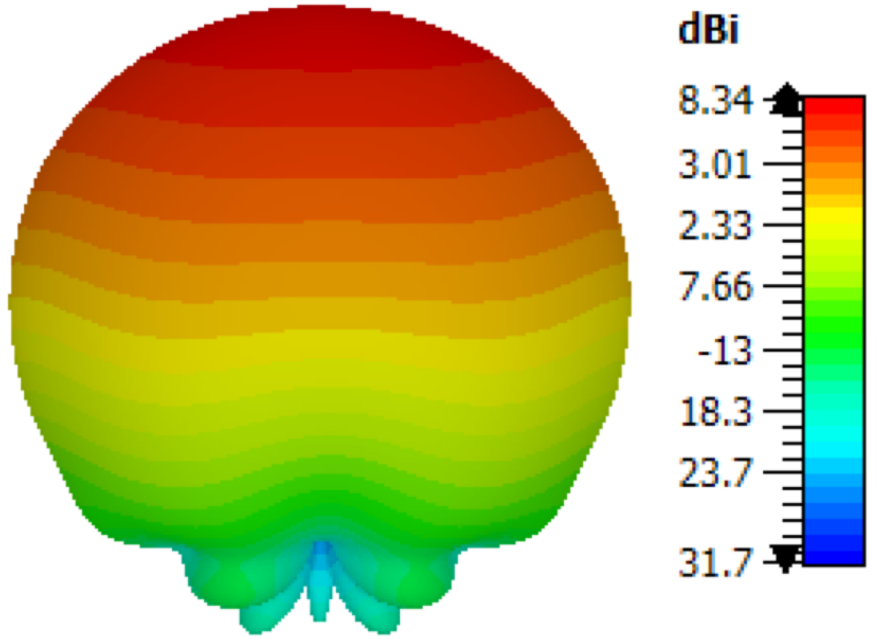
GREx Phase I



- Project Scientist:
  - Liam Connor, Post-doctoral Fellow
- Project Engineer:
  - Kiran Shila, Graduate Student in EE

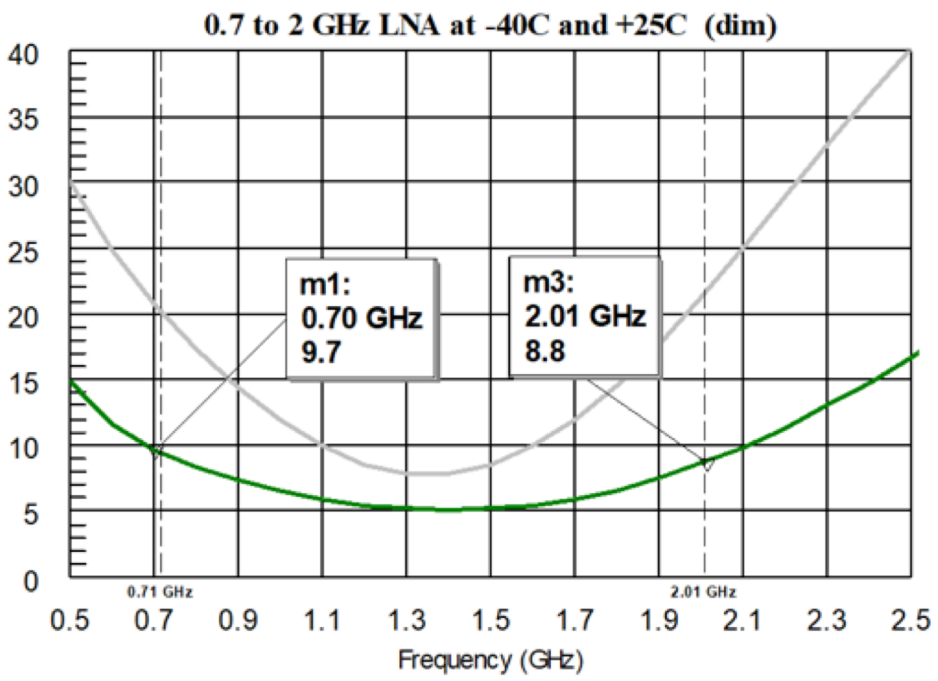
Wide-band feed

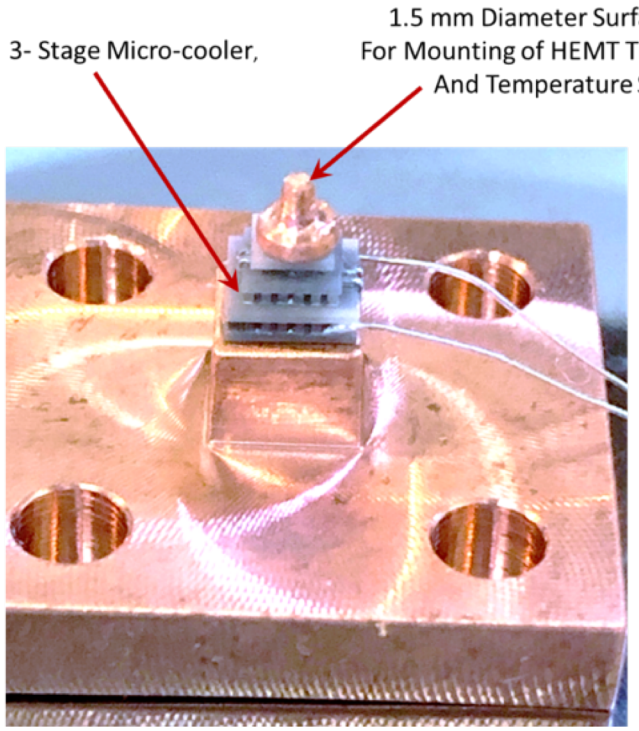


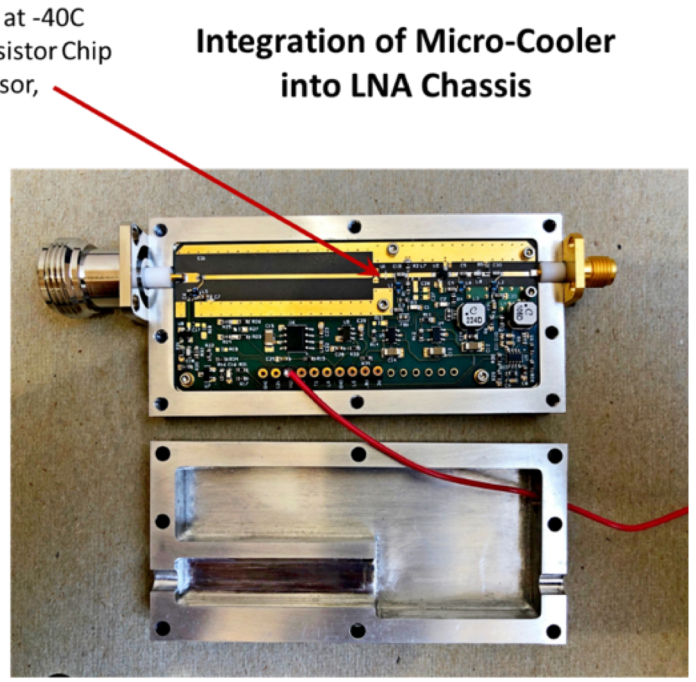


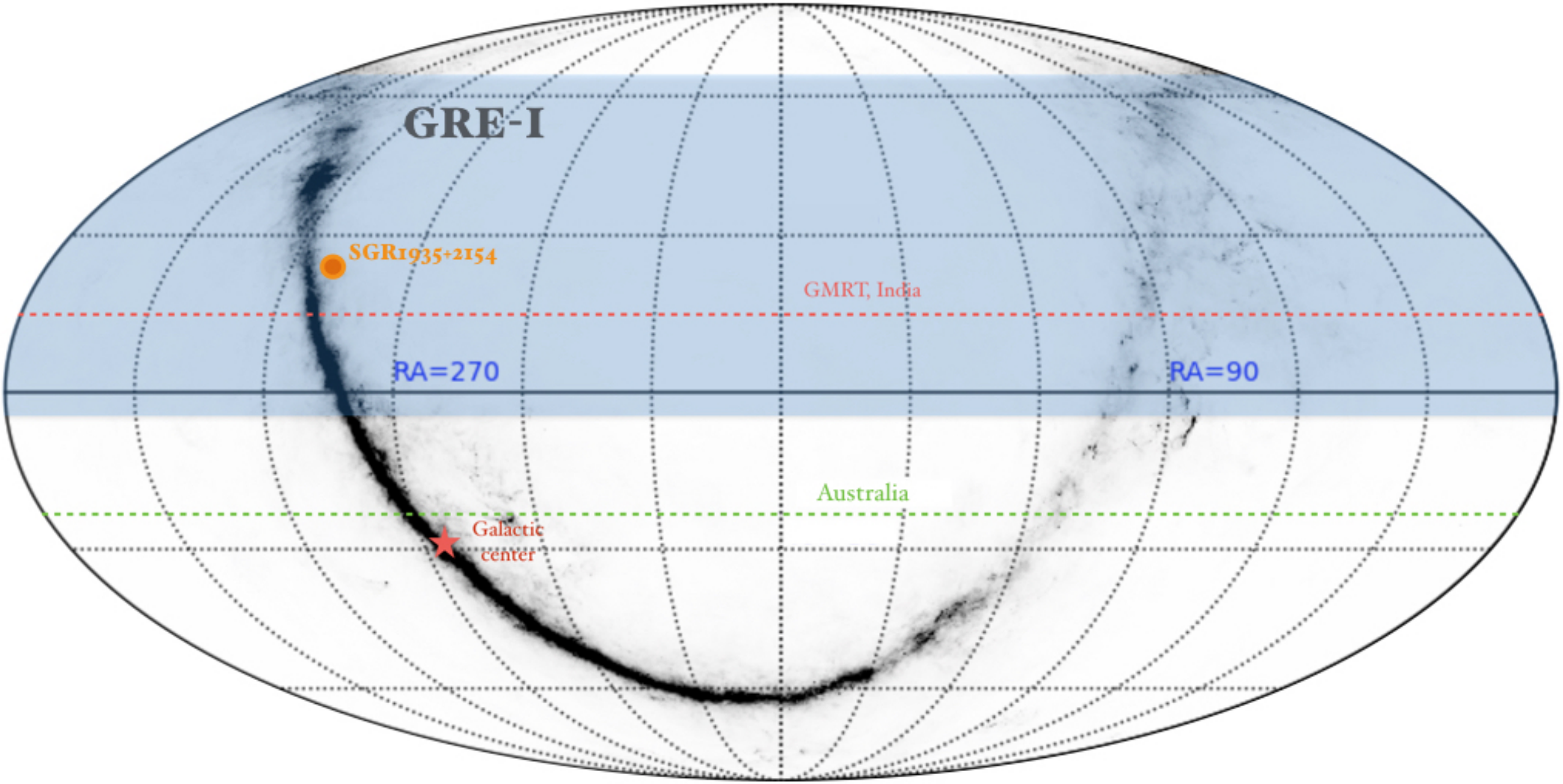
Beam Pattern

Room temperature low-noise amplifiers








GRE-I
SGR1935+2154
GMRT, India
RA=270
RA=90
Australia
Galactic
center


Marine on Saint Croix
Delta, Utah
Westerbork
GMRT, India
Canada
Mexico
Iceland
Finland
Sweden
Norway
United Kingdom
Poland
Germany
France
Spain
Italy
Ukraine
Russia
Kazakhstan
Mongolia
China
Japan
South Korea
Turkey
Iraq
Iran
Afghanistan
Pakistan
Thailand
Algeria
Libya
Egypt
Saudi Arabia
Mali
Niger
Sudan
Chad
Nigeria
Ethiopia
Kenya
DRC
Tanzania
Angola
Namibia
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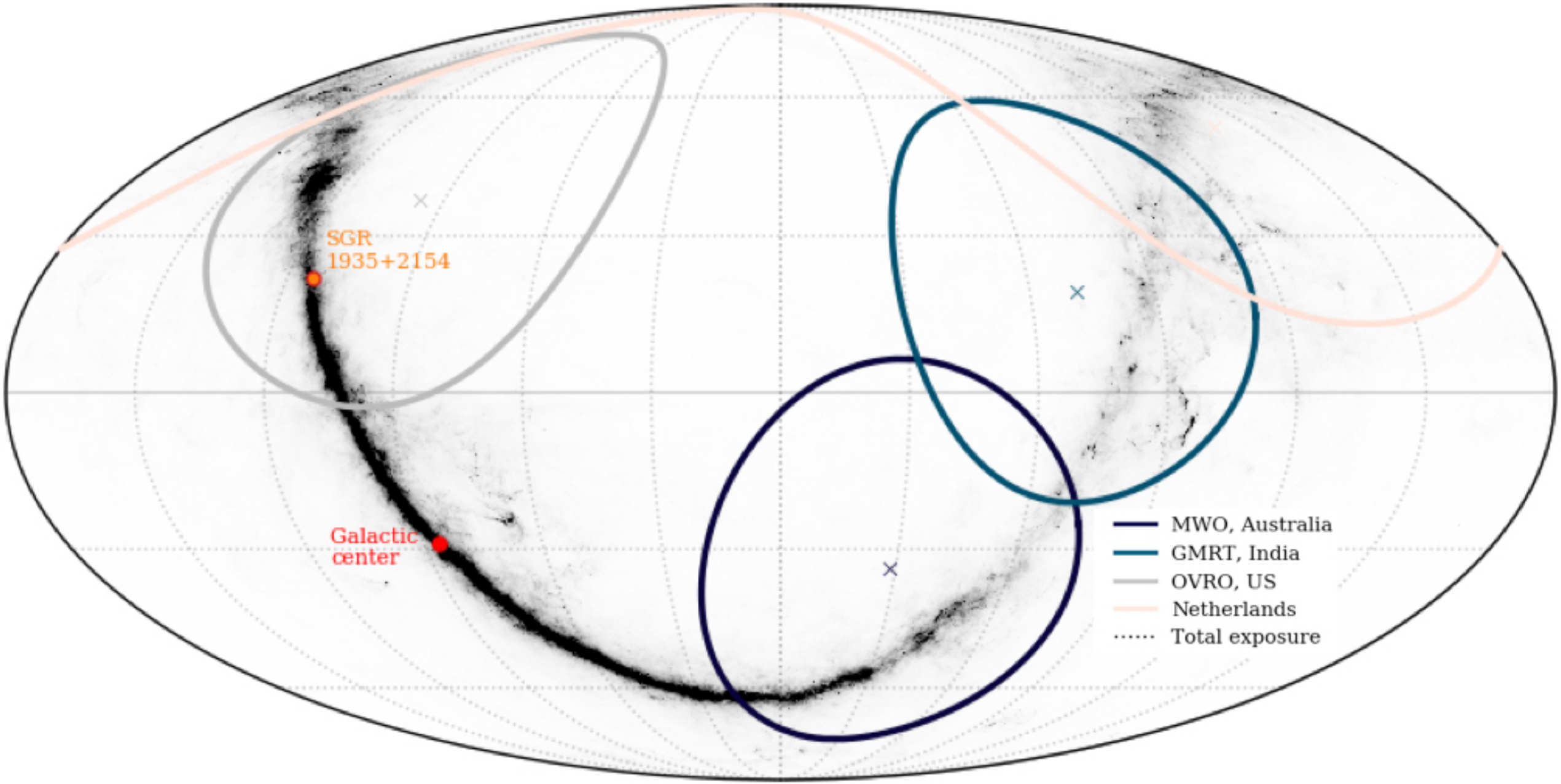
Madagascar
South Africa
Venezuela
Colombia
Brazil
Peru
Bolivia
Chile
Argentina
Indonesia
Australia


SGR
1935+2154
Galactic
center
MWO, Australia
GMRT, India
OVRO, US
Netherlands
Total exposure

36