Title: Studying Fast Radio Bursts with the HIRAX Telescope

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Abstract: <span style="font-size:9.0pt;font-family:"Arial",sans-serif;
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EN-CA;mso-fareast-language:EN-CA;mso-bidi-language:AR-SA">Fast Radio Bursts are mysterious radio flashes that appear to have extragalactic origin. The inferred isotropic brightness temperature for these events can exceed 10^34 K. Discovered in 2006, only about 25 have been reported to date. I will give a short summary of the these events then explain how a new generation of dense radio arrays will dramatically improve our understanding of these burst. The HIRAX telescope in South Africa will detect about 10 FRBs per day and will localize these events with sub-arcsecond precision. A next generation of packed array could detect one every minute, allowing tomography of the ionized universe.

# Fast Radio Bursts and HIRAX

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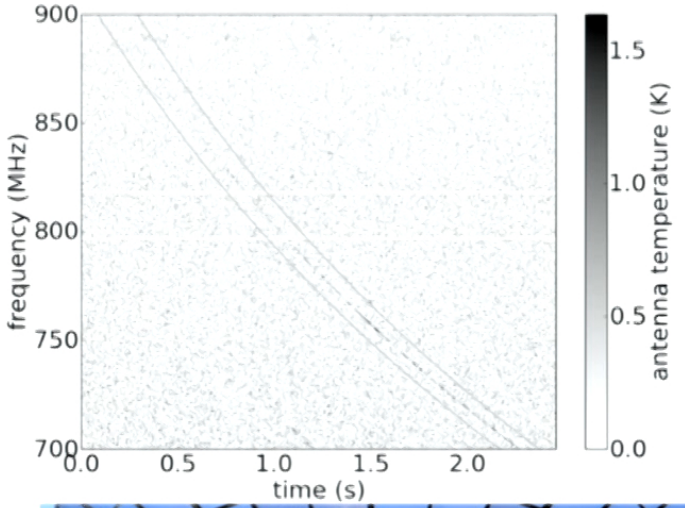
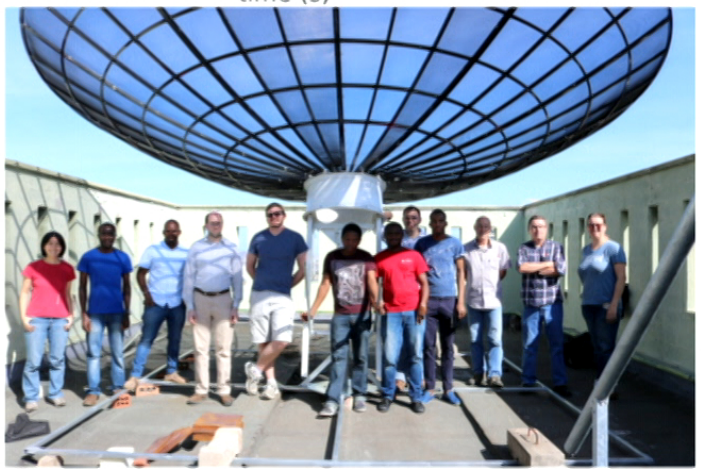



FRB 110523



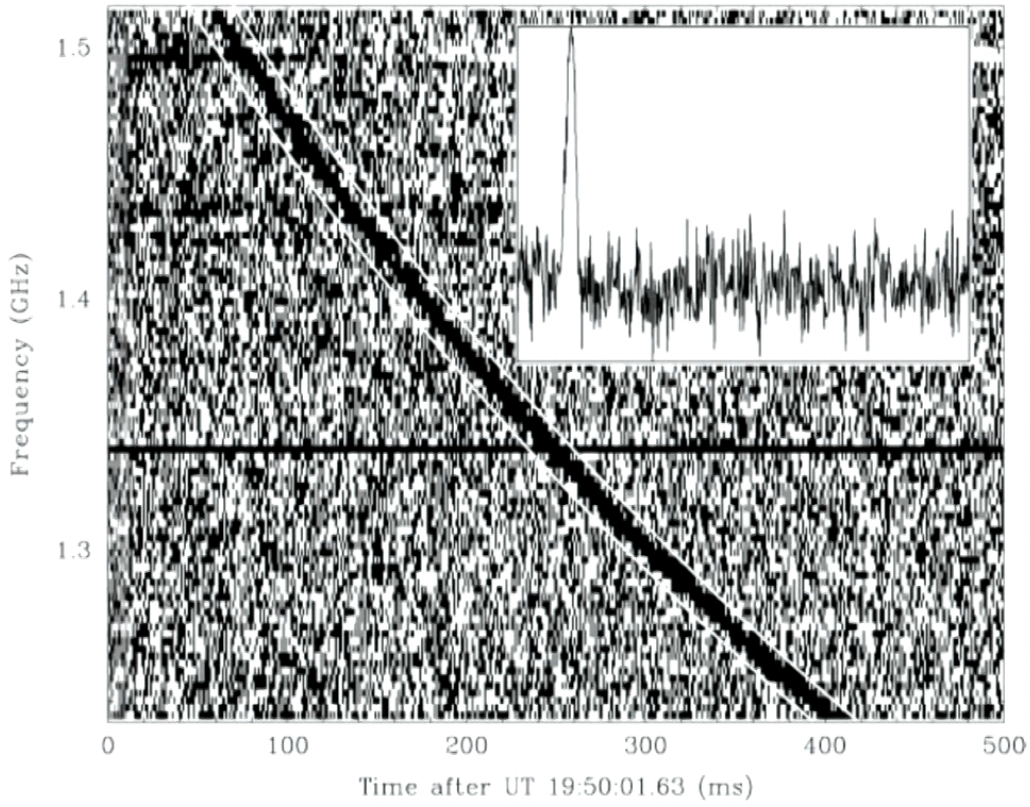
First HIRAX
Six-Meter Dish
Built at CMU, now at
Durban SA

# Fast Radio Bursts

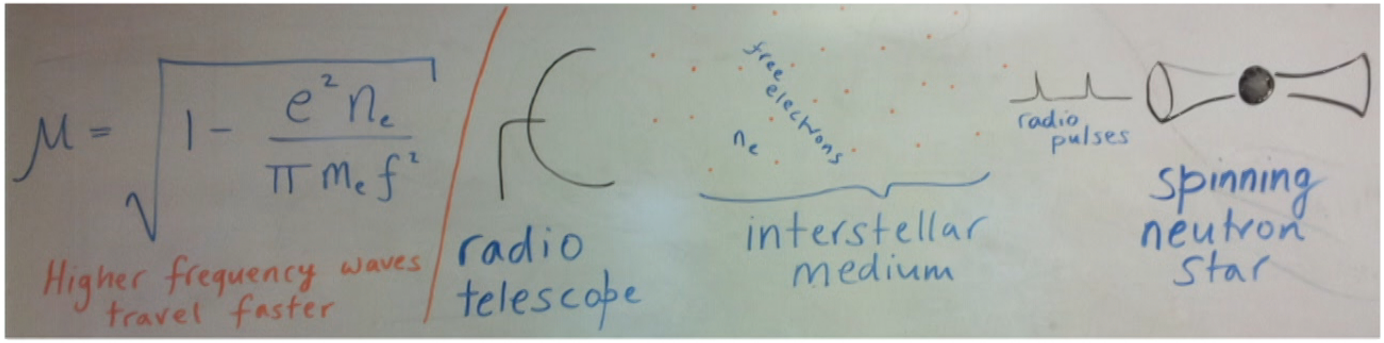
- Published Bursts (~25)
  - Probably Extra-galactic with z = 0.2-1
  - Inferred isotropic brightness temperature 10^35 K
- Proposed Source Models…many wild ideas
- Our GBT Data used to find FRB 110523
  - Polarization and Faraday Rotation
  - Scattering
  - Source has substantial local material
- Repeating FRB 121102 localized via VLBI. Coincident with small galaxy at z = 0.2
- HIRAX, (and Tianlai, CHIME) will pin down the FRB sources and provide 10 events per day.

# The Lorimer Burst (2006)

- Found in a pulsar search of archived data from Parkes



# Dispersion: delay increases with wavelength due to cold electron gas




T_delay (ms) = 4.15 DM ν−2 (GHz)

DM = integrated neD in pc cm−3

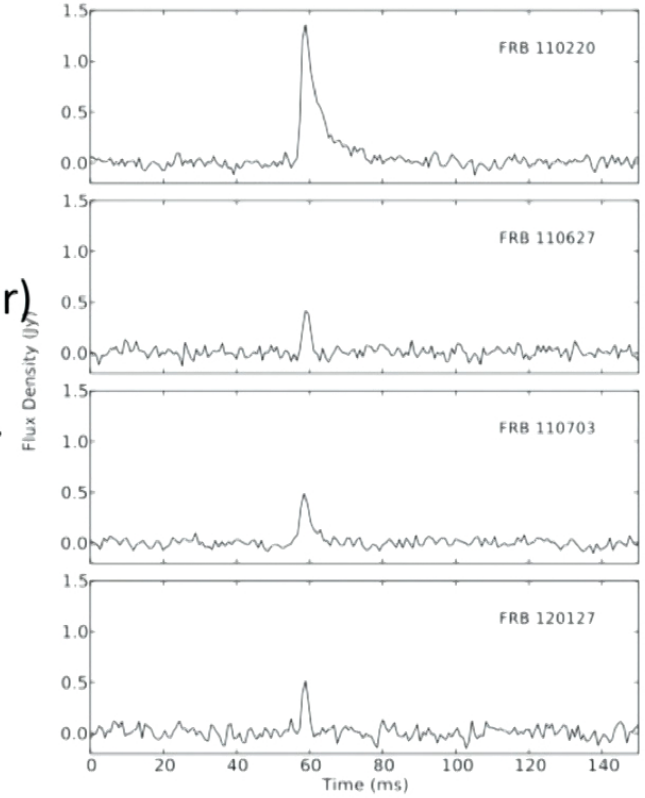
Typical pulsar DM: 50
Typical FRB DM: 500

# Seen with only one beam of the Parkes Multibeam receiver

- Dispersion much too large to be explained by Milky Way electrons.
- If Dispersion comes from IGM source is at cosmological distance z~0.5

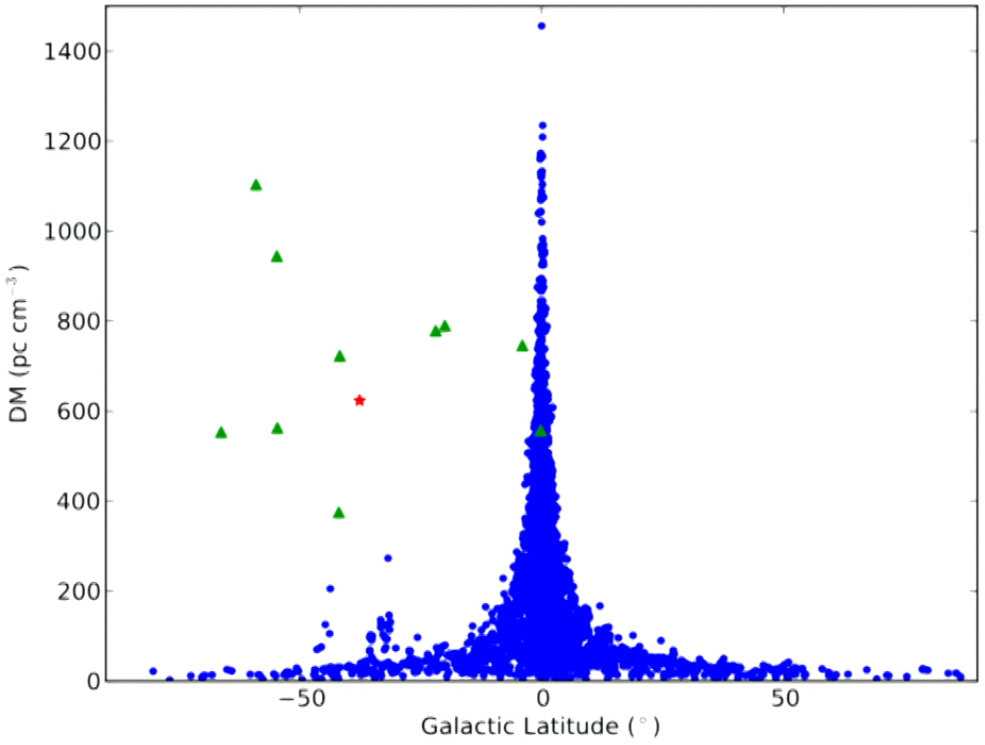
# Characteristics of Fast Radio Bursts

-Peak Flux ~ 1-100 Jansky
-Highly dispersed
-Pulse width few ms
-Most do not repeat
-One FRB (121102) repeats (more later)
-15% have scattering tail
-Typical Location precision: 15 arcmin.
-Not concentrated in Galactic plane
-Rate ~ 5000 sky^-1 day^-1
-detected with Parkes, GBT,
Arecibo, MOST
-Only one counterpart clearly identified at other wavelengths




Thornton etal 2013

# FRB sources are very likely outside of the Milky Way




Blue: pulsar
Green: FRB
Red: FRB110523

# 2010-15: Confusion due to false positives at Parkes (Microwave oven)

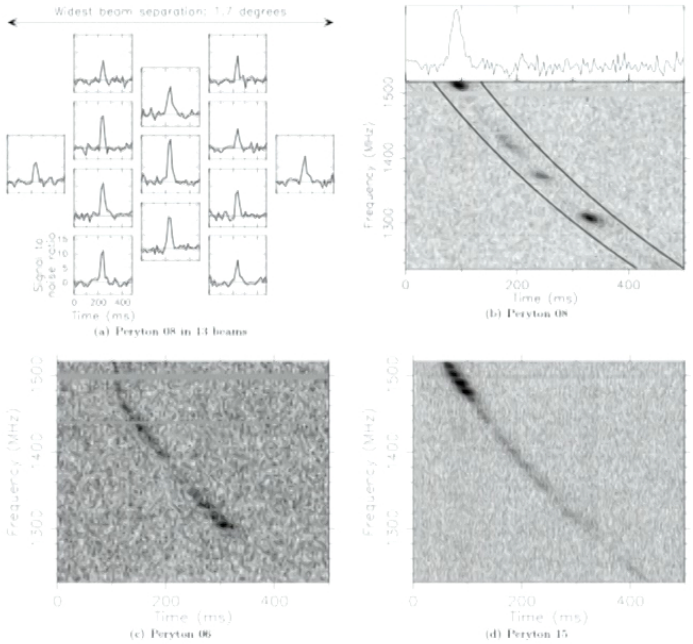
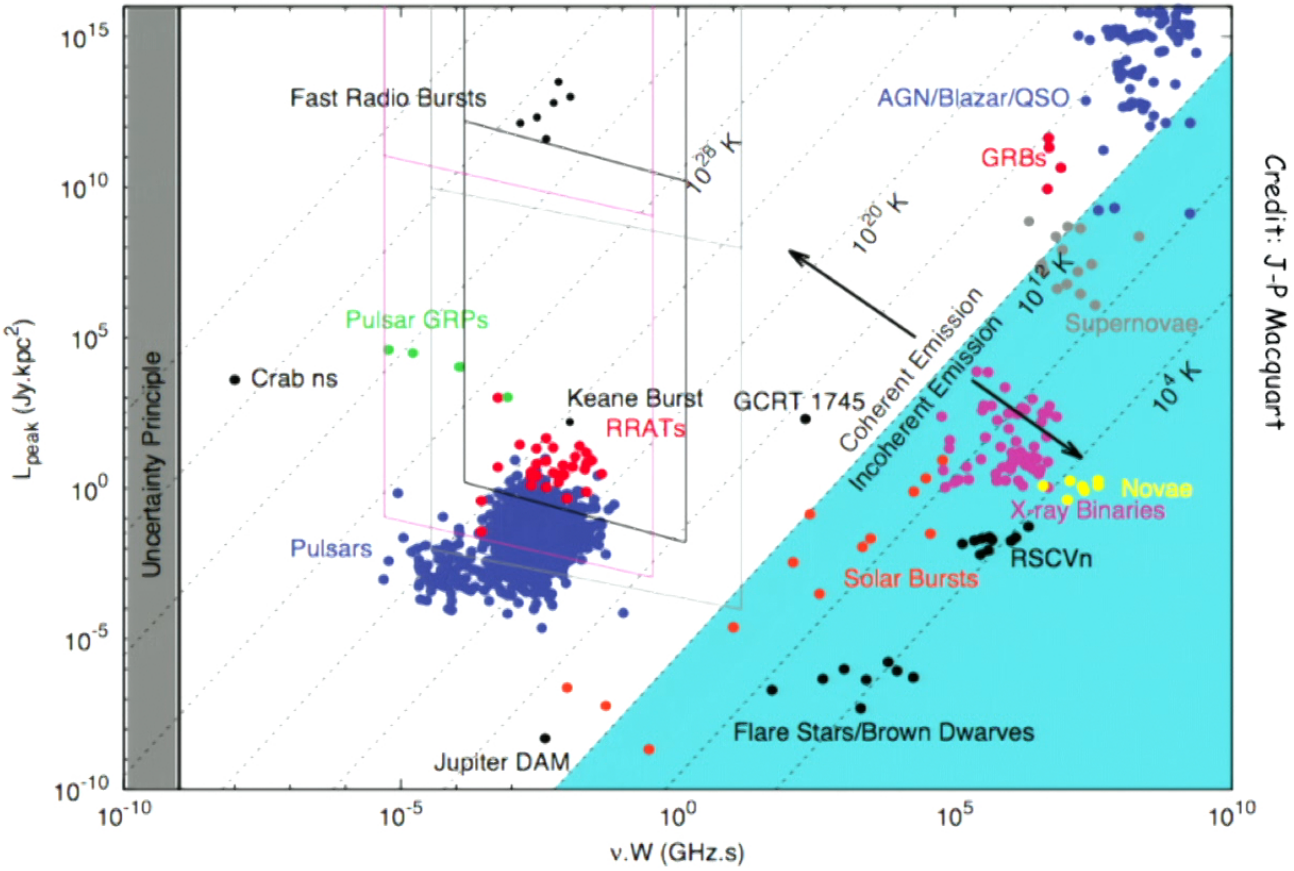


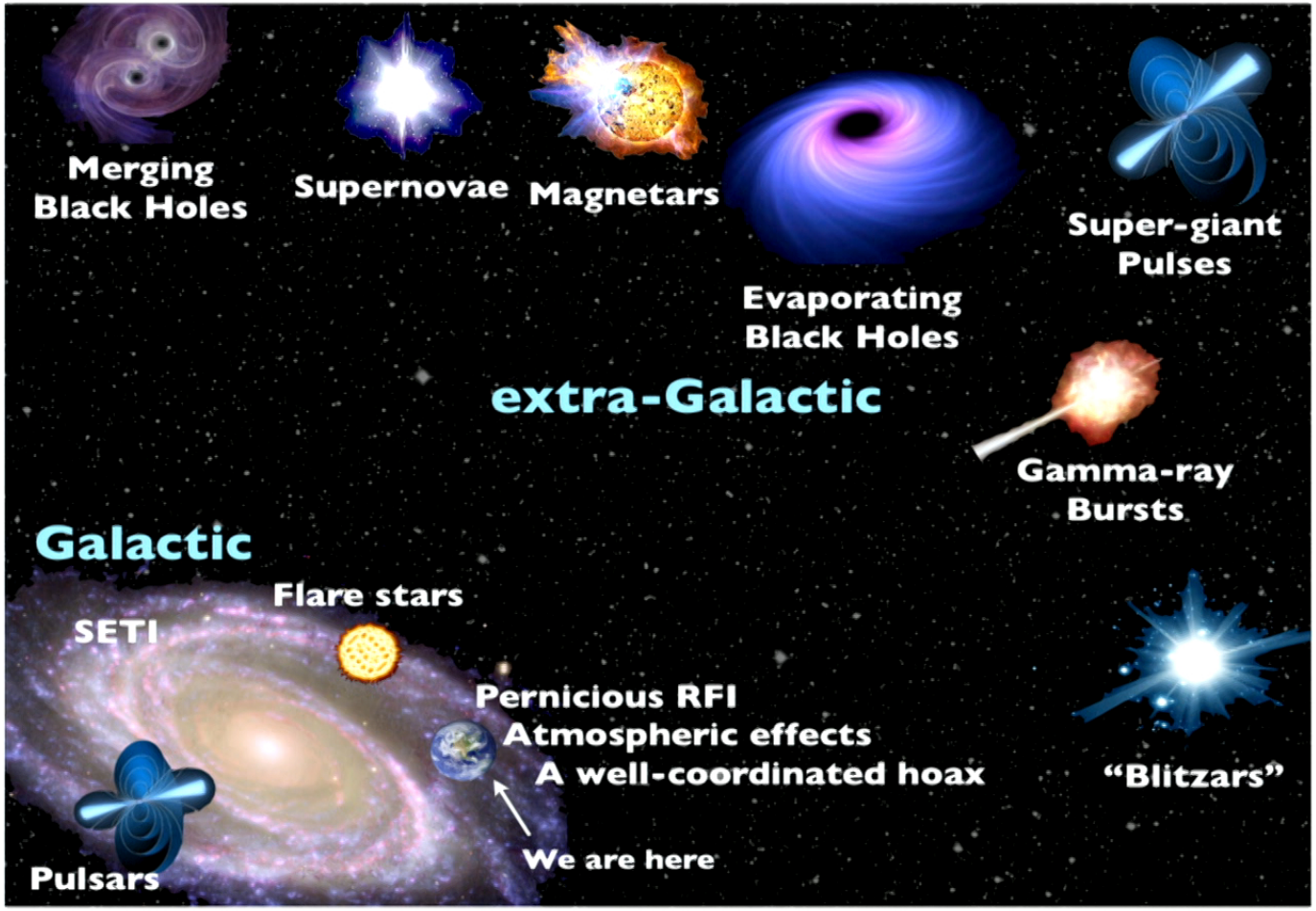

Fig. 1.— Spectrograms and time series for several detections. **(b,c,d)** Data from the 13 beams have been summed to enhance the signal. Frequency channels with known interference have been blanked. **(a)**. De-dispersed time series showing Peryton 08 in the 13-beam multibeam receiver as the beams are distributed on the sky. **(b)** De-dispersed time series and spectrogram of Peryton 08. The black lines trace the best-fit dispersive delay for this detection. **(c,d)** Spectrograms of Peryton 06 and 15, respectively.

# If FRB are at z~1 they have exceptional brightness temperature




Black: Parkes; Pink: SKA1-lo; Grey: SKA1-mid

# FRB proposed models



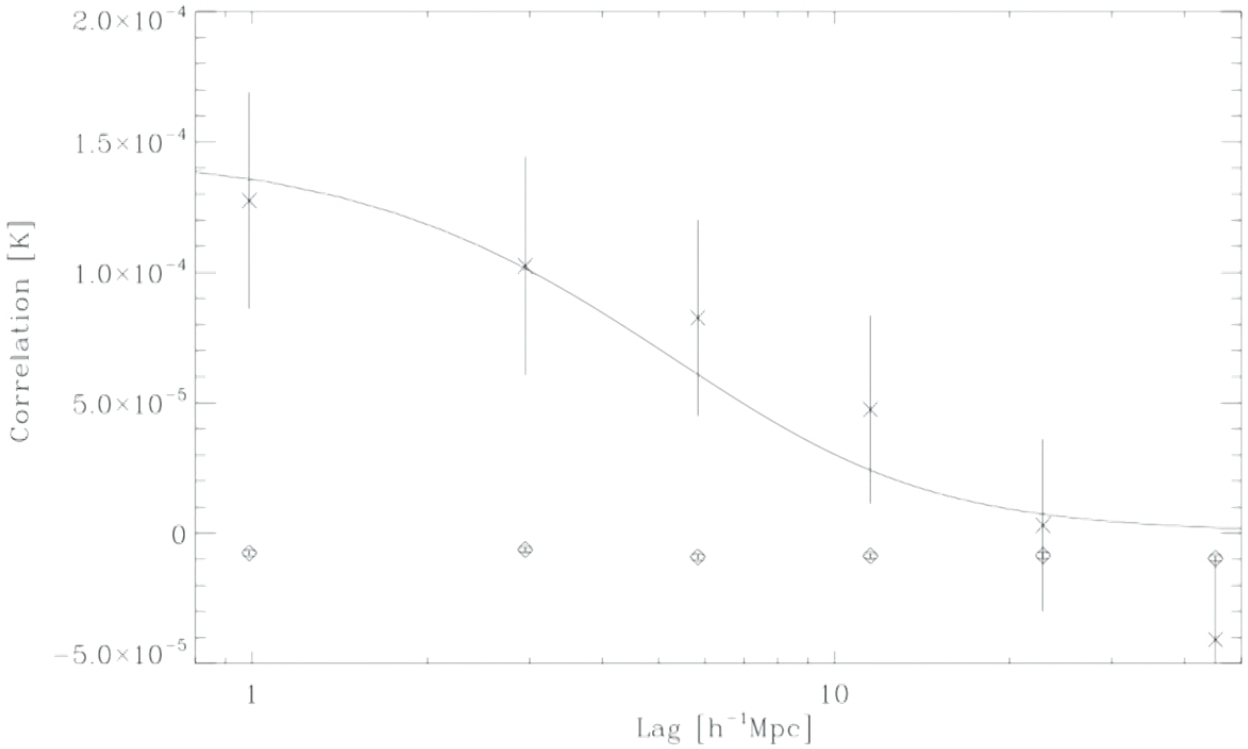

Slide by J Hessels

# 21-cm Intensity Mapping with the Green Bank Telescope West Virginia

- 650 Hours
- Frequency 700 to 900 MHz\
- Spectra recorded every 1.024 ms
- 15 arcminute angular resolution

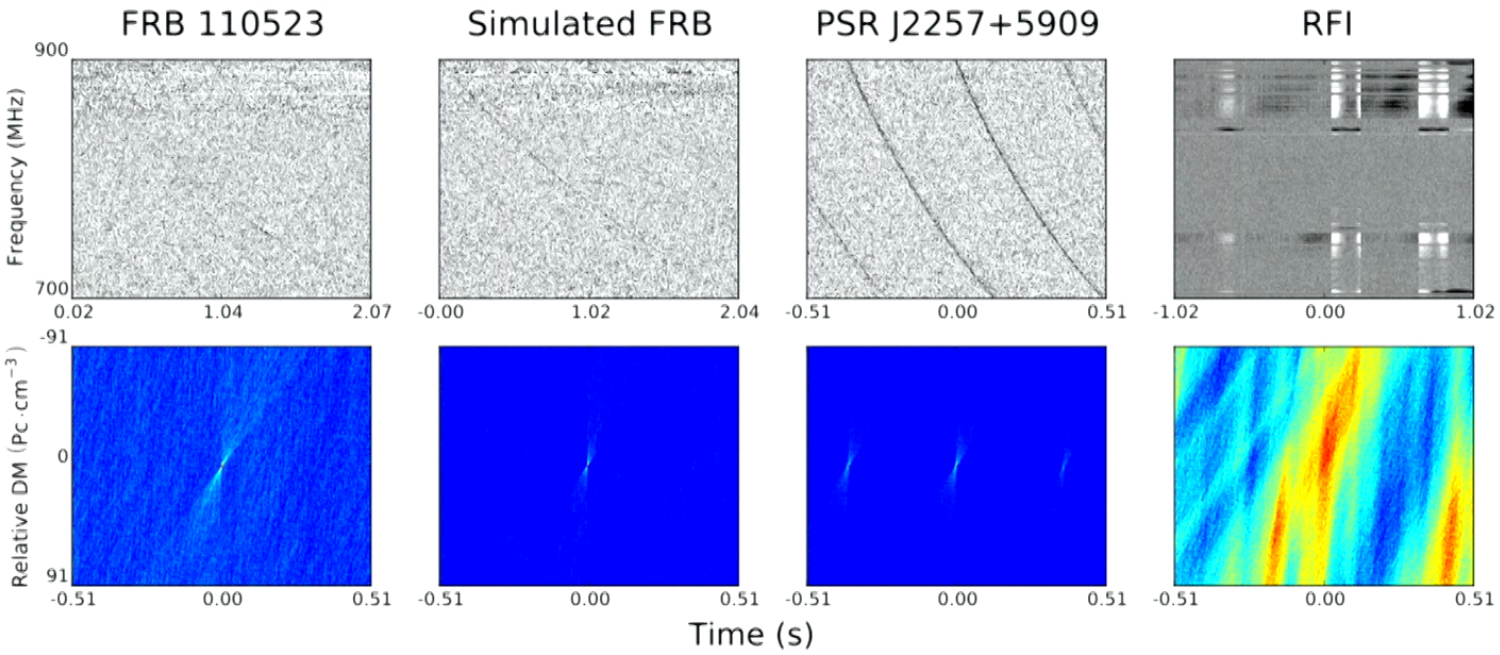
- We decided to search this data for FRBs

# 21cm – DEEP2 cross correlation




Chang, Pen, Bandura, JP, Nature 466, 463 (2010)

# We (mostly J. Sievers) developed a new de-dispersion method

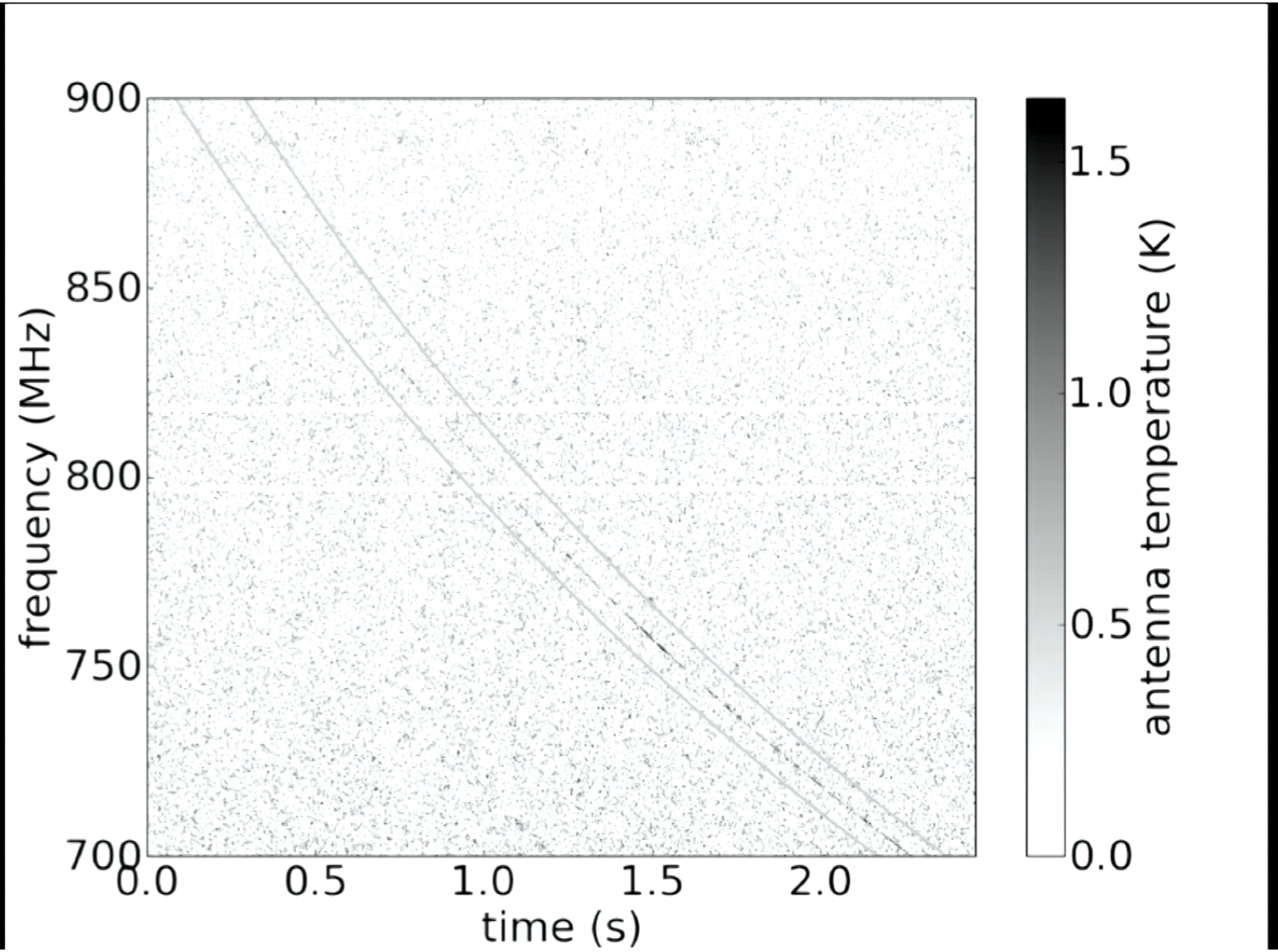


# HH Lin (CMU Grad Student) searched over 6000 candidate events and found FRB 110523 !

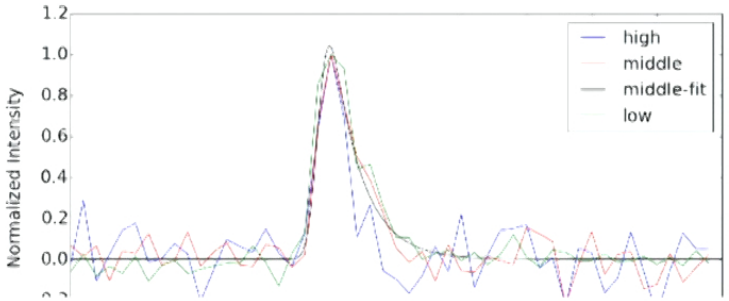
**Dense magnetized plasma associated with a fast radio burst**

Kiyoshi Masui[1,2], Hsiu-Hsien Lin[3], Jonathan Sievers[4,5], Christopher J. Anderson[6], Tzu-Ching Chang[7], Xuelei Chen[8,9], Apratim Ganguly[10], Miranda Jarvis[11], Cheng-Yu Kuo[12,7], Yi-Chao Li[8], Yu-Wei Liao[7], Maura McLaughlin[13], Ue-Li Pen[14,2,15], Jeffrey B. Peterson[3], Alexander Roman[3], Peter T. Timbie[6], Tabitha Voytek[4,3] & Jaswant K. Yadav[16]

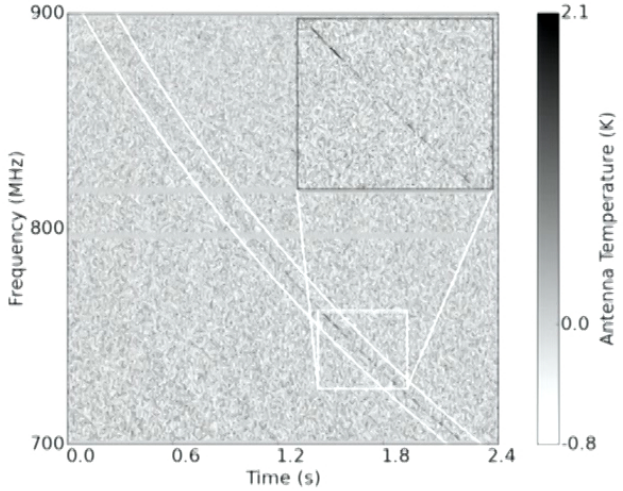
Nature, Dec.2015


900
850
800
750
700
frequency (MHz)
0.0
0.5
1.0
1.5
2.0
time (s)
1.5
1.0
0.5
0.0
antenna temperature (K)

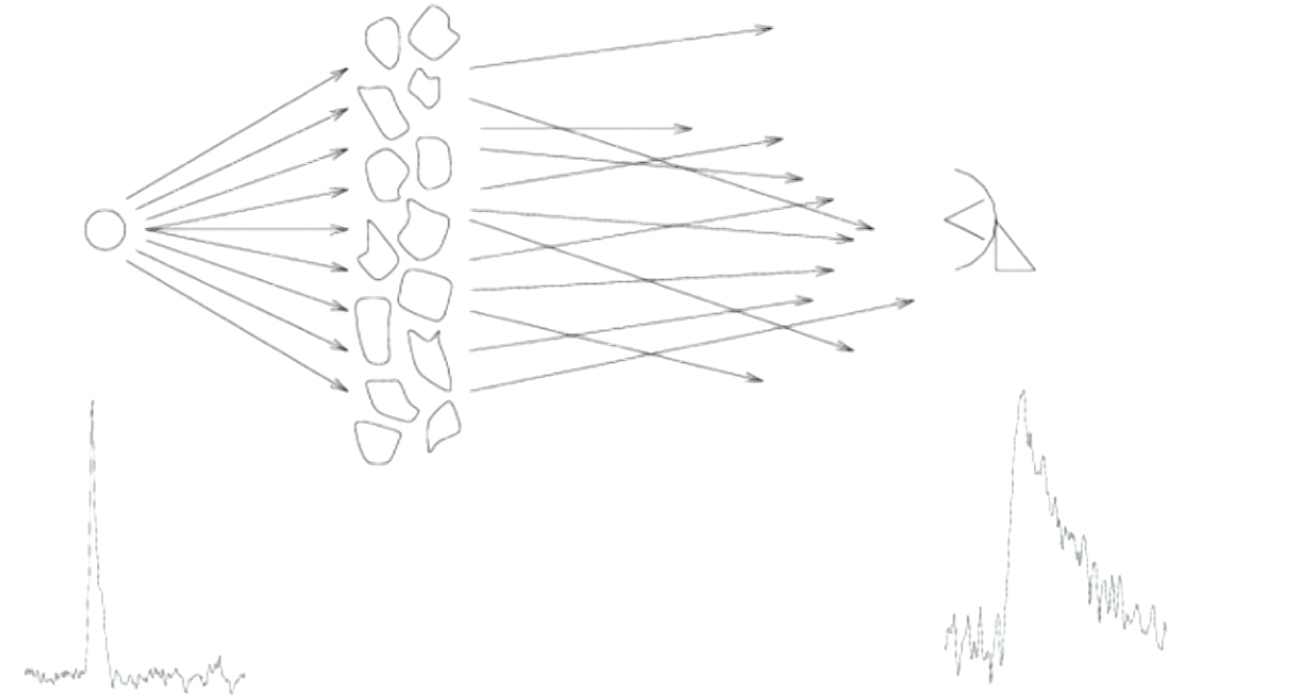
# Scattering and Scintillation detected




Scattering



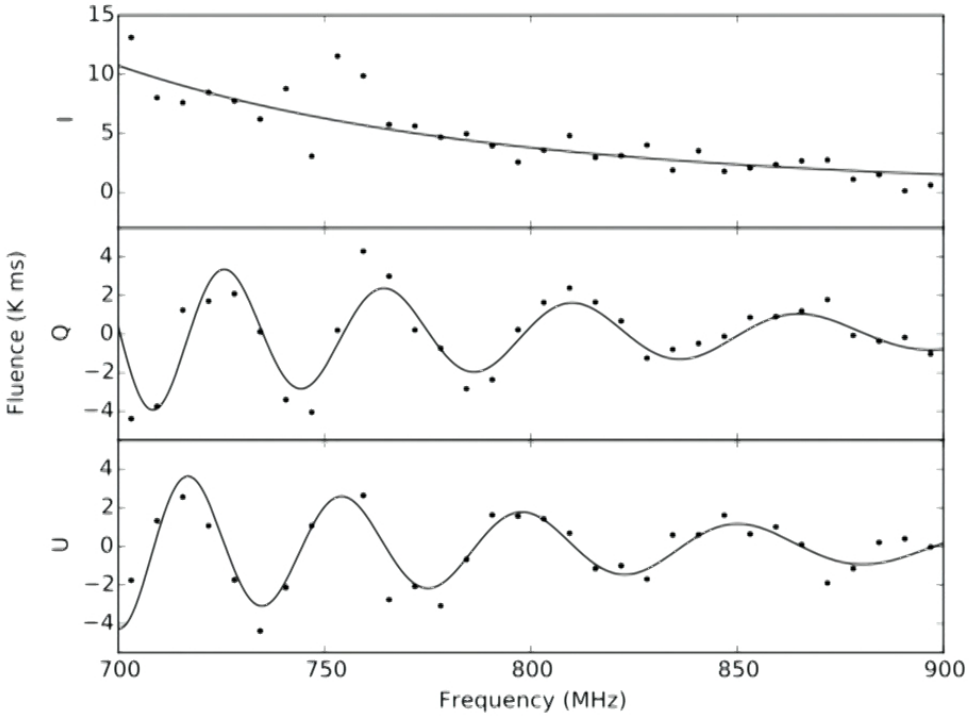

Scintillation



Emitted Pulse

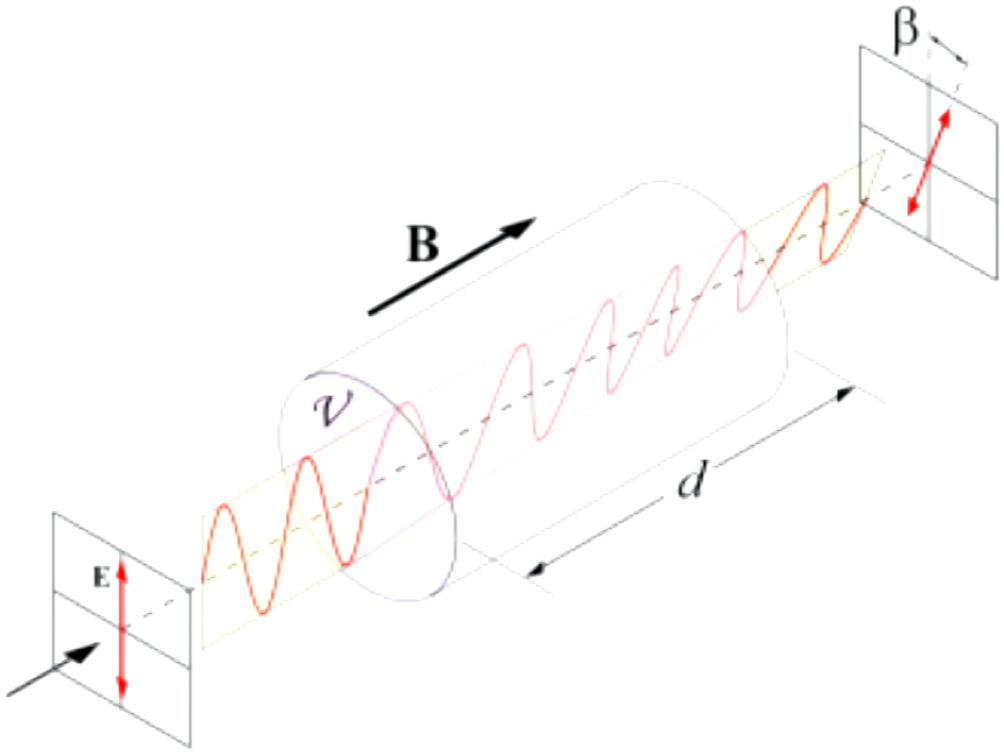
Detected Pulse

# Faraday rotation also detected




Magnetization is ten times
As much as Milky Way and IGM
Can explain

# Faraday effect measures B along line of site



# FRB 110523 summary

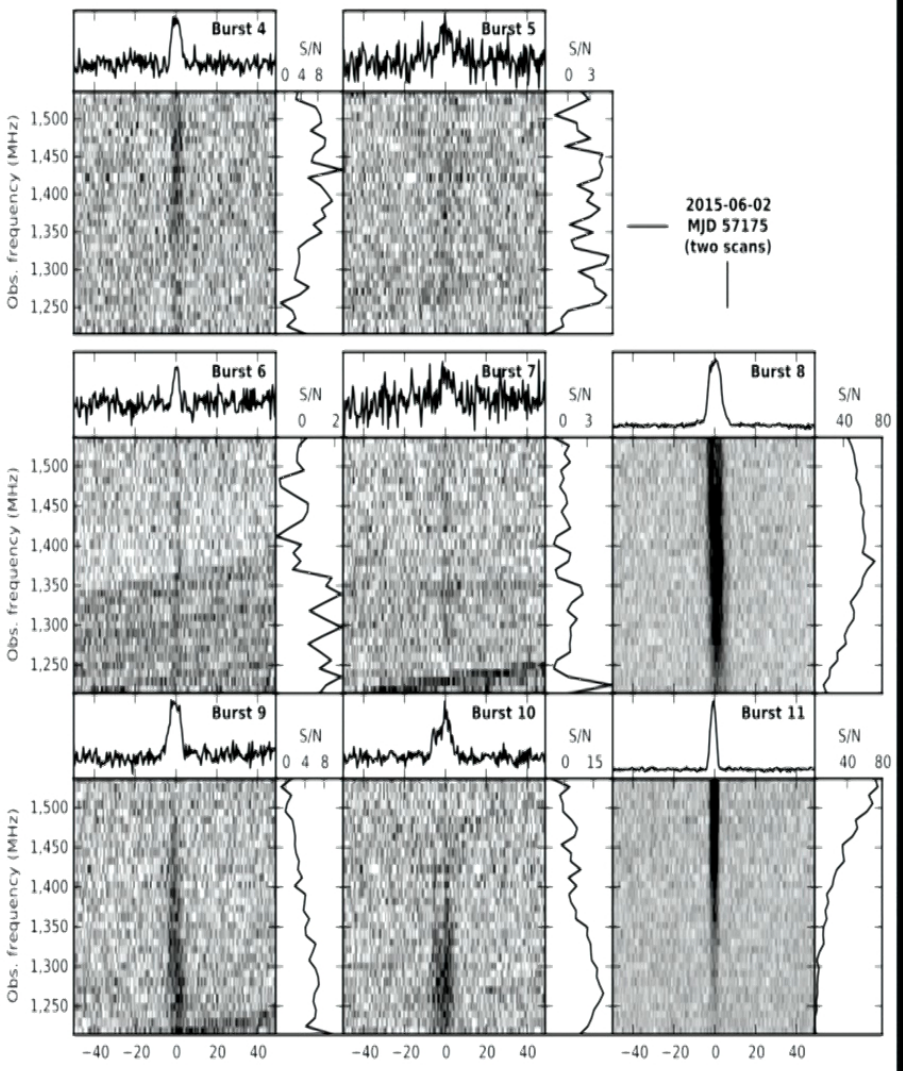
- First FRB found with Green Bank Telescope
- First found outside 1.5GHz band
- First with linear polarization
- First with scintillation
- Dispersion spectral index -1.998(3) {-2.0 exp.}
- Scattering spectral index -3.6(1.4) {-4 exp.}
- High Rotation Measure points to extragalactic source

# FRB 121102: It repeats!

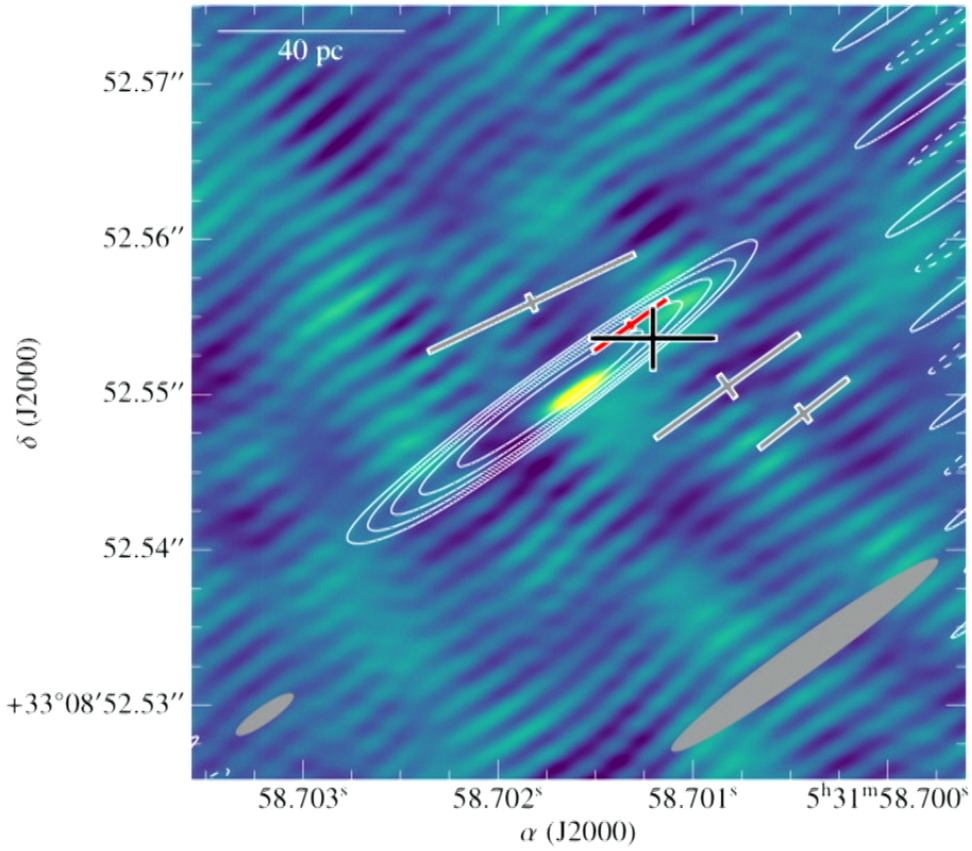
Not periodic.

This one is not a Supernova

There may be more then one type of FRB source.

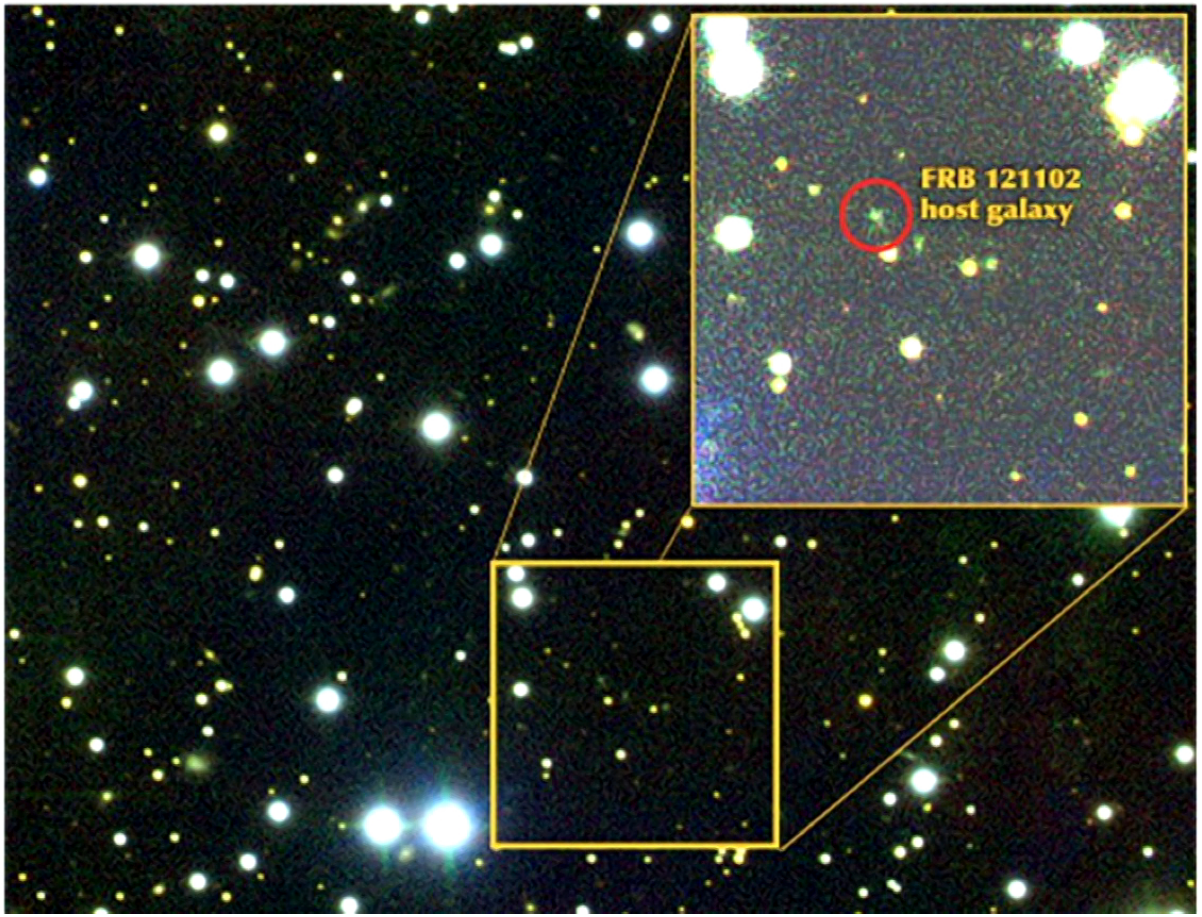


# Several pulses detected and localized with VLA and EVN



# Coincident with dwarf galaxy at z = 0.2

Gemini Optical Image



# Possible uses of FRBs

- Understand emission physics
- Map (3d) the intergalactic ionized gas
- Probe missing baryons
- Use the spatial power spectrum for cosmology (BAO, shape, bias, Redshift space distortions, nongaussianity)
- Study turbulence in IGM using scattering
- Measure the intergalactic B-field
- Probe population vs redshift
- Trigger for Gravitational Wave events
- Constrain the mass of the photon (10^-14 eV)

# Next steps for our group :

-- Use dense-packed interferometers to find and study FRBs

- Tainlai -- Xin Jiang, China
- HIRAX – SKA site, South Africa

-- Set up drift scan interferometer array:

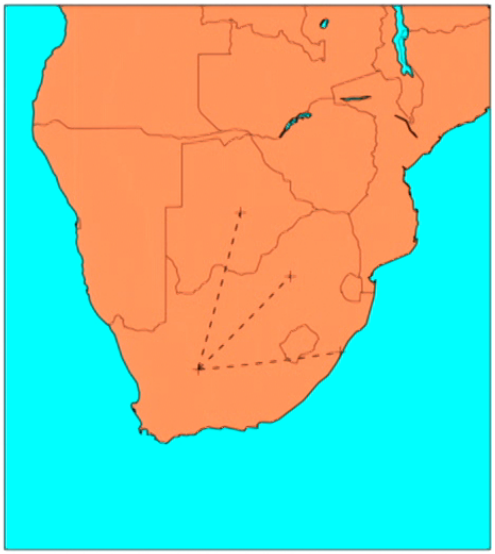
– ARO, 140 ft, CHIME will give milli-arc-second positions

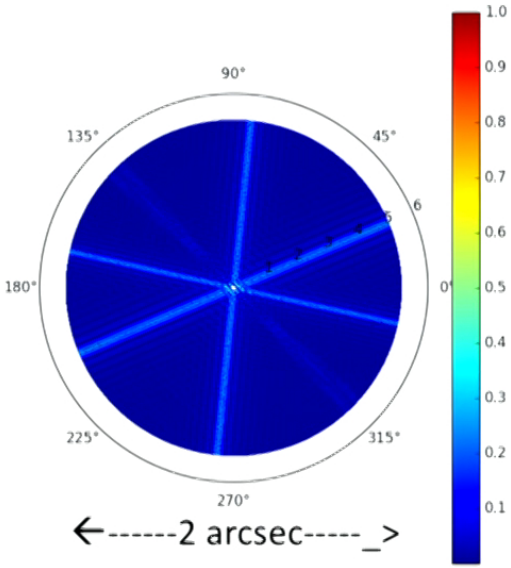
# HIRAX

- 1024 close-packed 6m dishes at Karoo site.
- Dishes tilt N/S by hand
- Construction funding on its way (~$7M USD).

CMU dish arrived Durban July 2015.


# 1) HIRAX with three 8-dish Outriggers will sharply localize Fast Radio Bursts

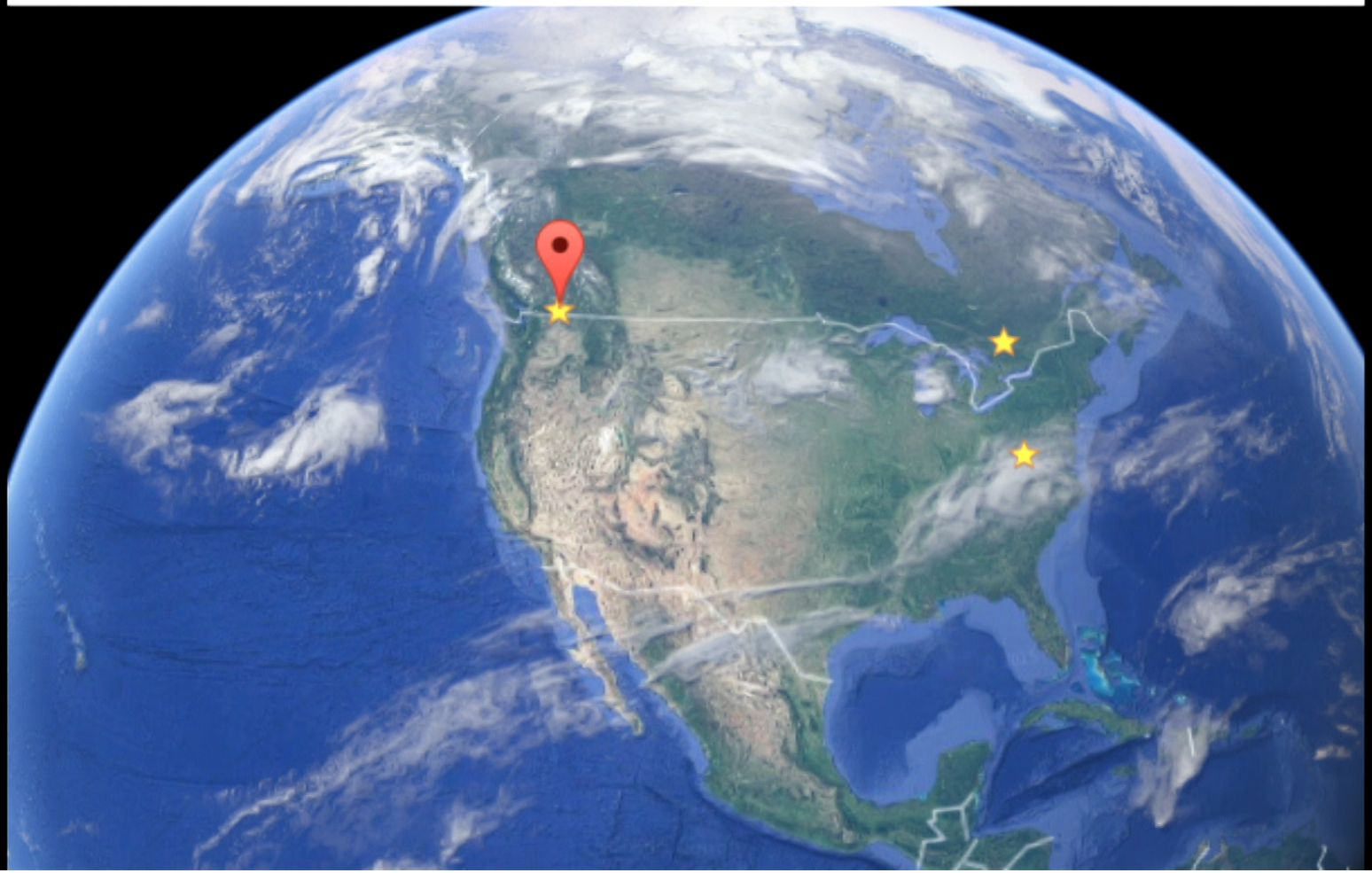




# CHIME in Canada

- Four Cylinders with 1000 dual-pol feeds
- Construction funded ($9MUSD) and proceeding
- Pathfinder currently in operation
- CMU built first prototype IM cylinder telescope
- FRB observations begin fall 2017

CHIME, Algonquin RO, Green Bank 40 foot form an FRB interferomter.



# Conclusions

- FRBs appear to be extragalactic
- They may have inferred isotropic brightness temp 10^34 K
- How can that be achieved?
- Dense Interferometers like Tianlai, CHIME and HIRAX will detect and localize 10 FRB per day.
- HIRAX will use outriggers to give sub-arcsec positions
- These galaxy IDs will allow determination of redshifts and searches for other emission e.g. supernova remnant synchrotron emission, stacked gamma flux, etc.