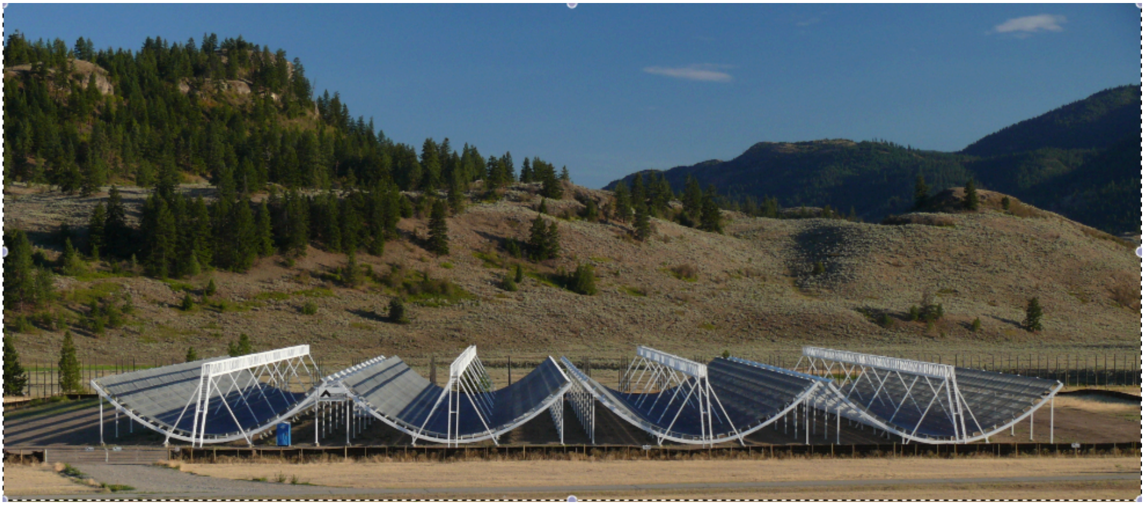
The beam calibration of CHIME

Meiling Deng

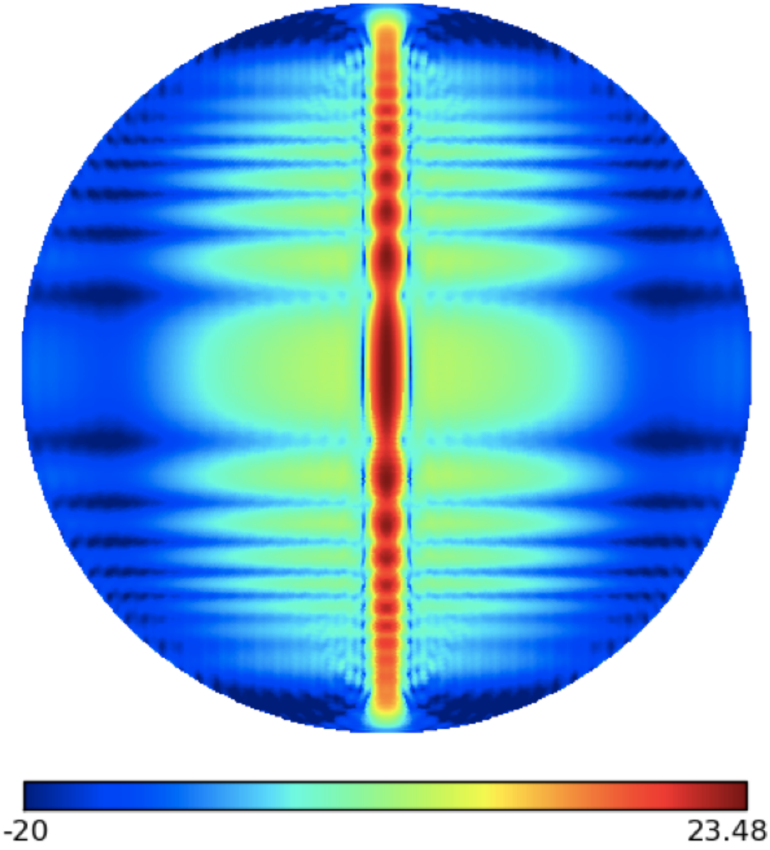
CHIME beam overview

Beam:

A 2D pattern describes telescope's sensitivity to signals from different directions on the sky



simulated CHIME beam at 651MHz [dB]



CHIME beam:

- Need to be calibrated to 0.1% to measure BAO
- Unusual (fan-shape beam, lots of structures)
- Huge volume of information: ~10^12

2048 (antennas) * 1024(frequency bins) * 400,000 (beam map pixels)

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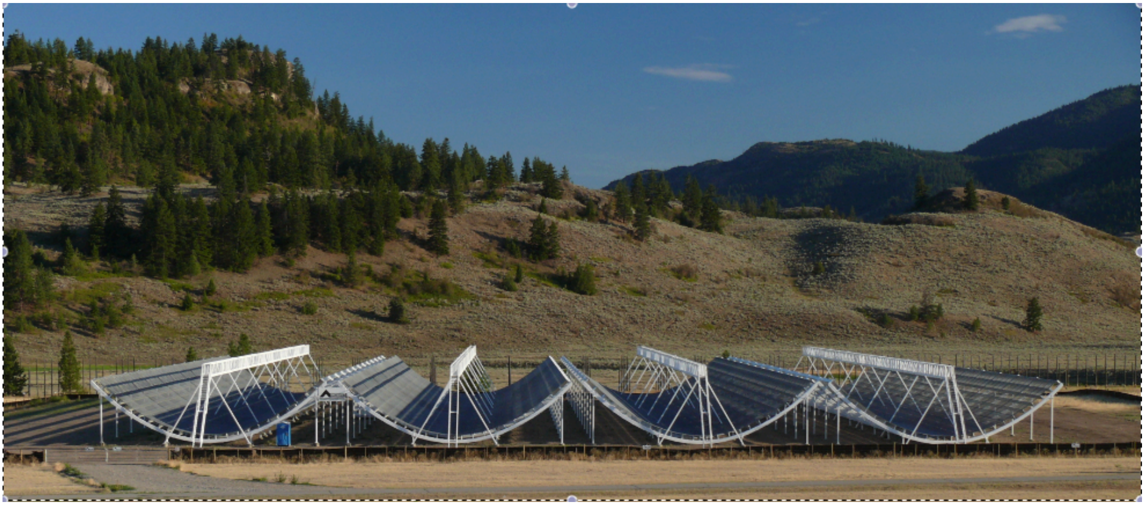

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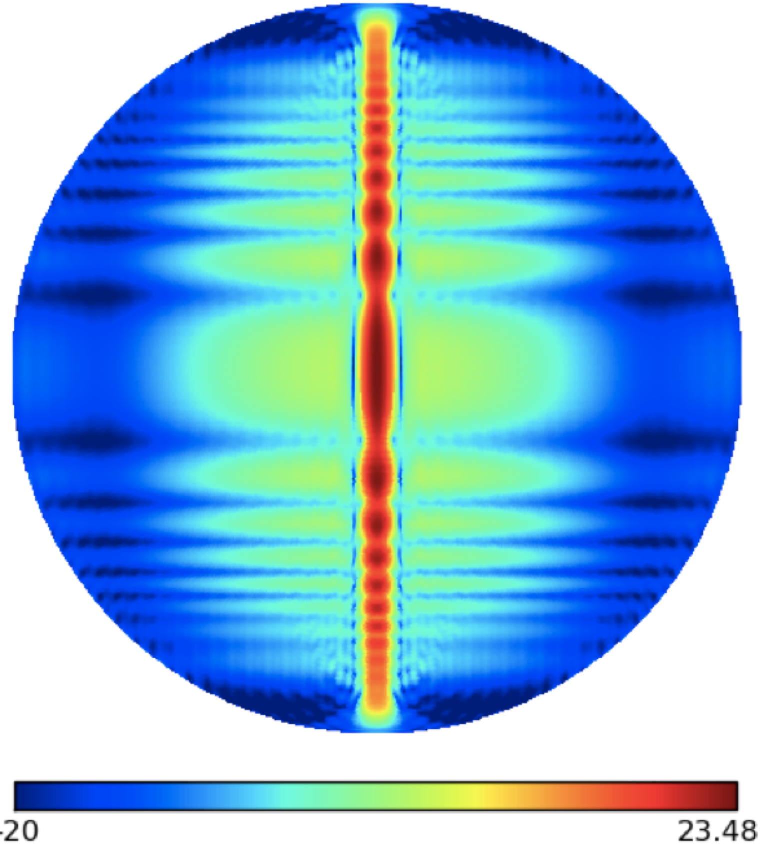

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On-going work: simulation and measurement

CHIME beam simulation

Two well-developed techniques

- **Methods of moments (MoM)** :
  - calculate the induced currents on metal from the incoming E/H field, for electrically big objects
- **Finite-Difference Time-Domain method (FDTD):**
  - meshes any 3D object and time domain with finite step size and solves Maxwell's equation at the the grid of those mesh, for electrically small objects

Challenging part for CHIME :

- 2e2*λ structure(reflector) with 5e-4* λ details
- Focal lines(amplifiers+ antenna array), cylindrical reflectors are entangling with each other
- No other CHIME-like experiments have done their beam calibration with such high accuracy requirement

My approaches:

FDTD

Build model as close as possible to reality,
simulate the whole thing with Compute Canada cluster
very computationally expensive

FDTD+MoM hybrid

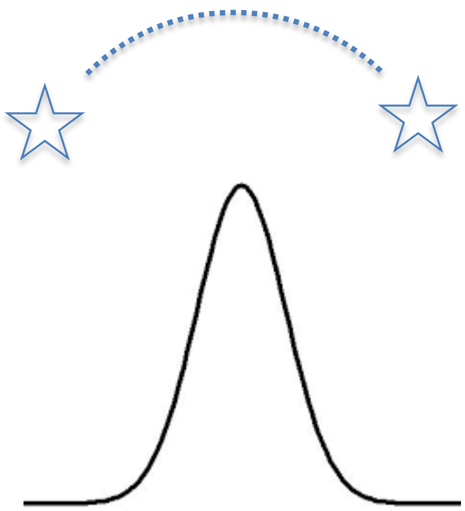
FDTD to model the focal line(fine details) and MoM to model the big reflector

The coupling between the reflector and focal line can't be well modelled

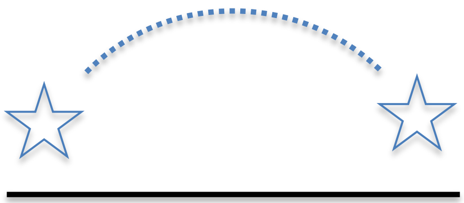
fitting basis functions

Use models as guide lines to develop sets of basis functions, and fit to the measured beam (which are partial)

Beam measurement: holography



Transit CHIME

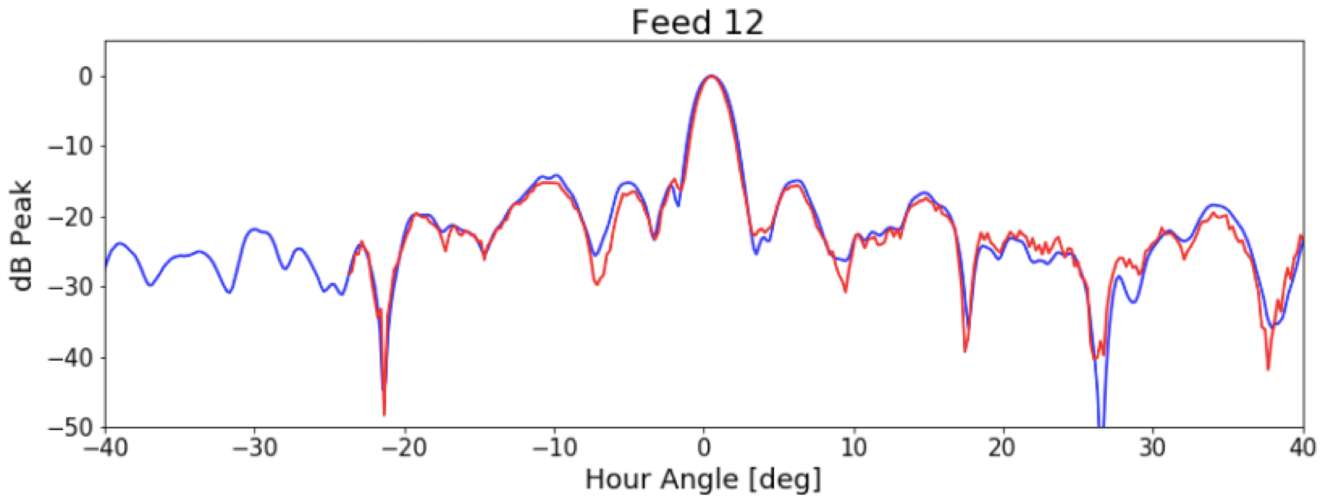


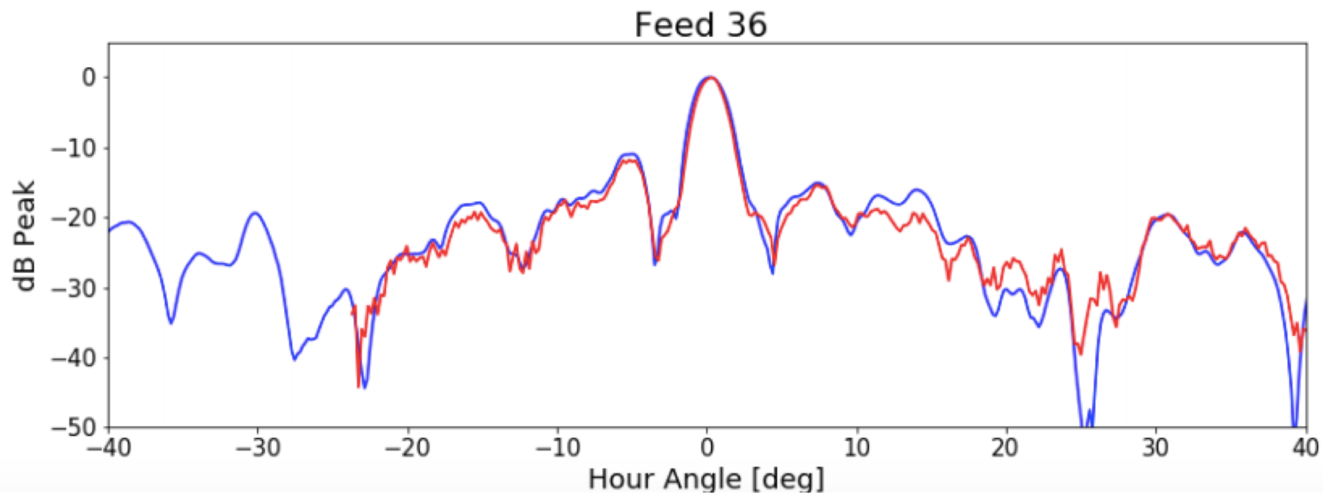
Tracking Galt

Radio source holography

We have been doing holography on bright radio sources (CasA, CygA, TauA, ..).

Beam measured with TauA holography (blue) are compared to beam measured with Sun (red)





They agree well with each other,

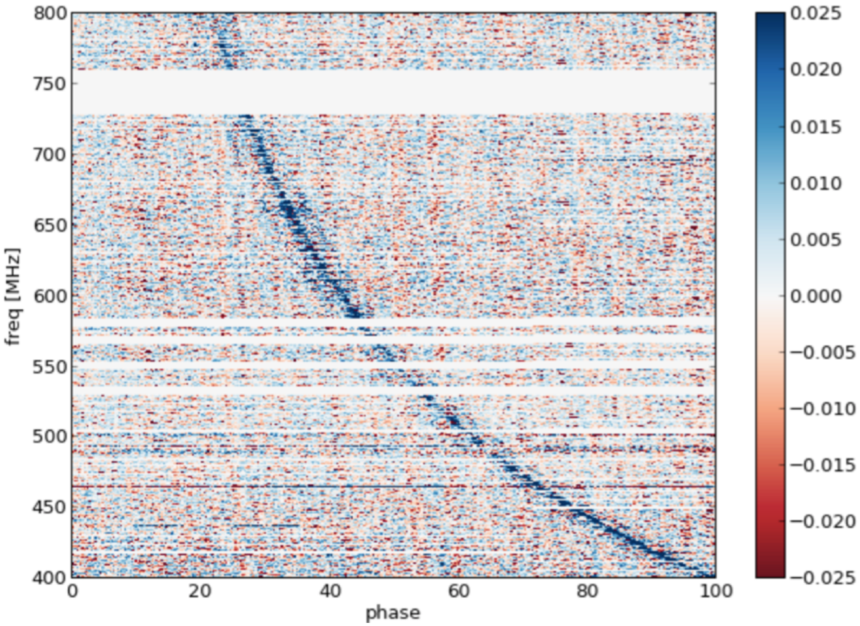
but we have very limited bright radio sources on the sky

Image credit: S. Siegal

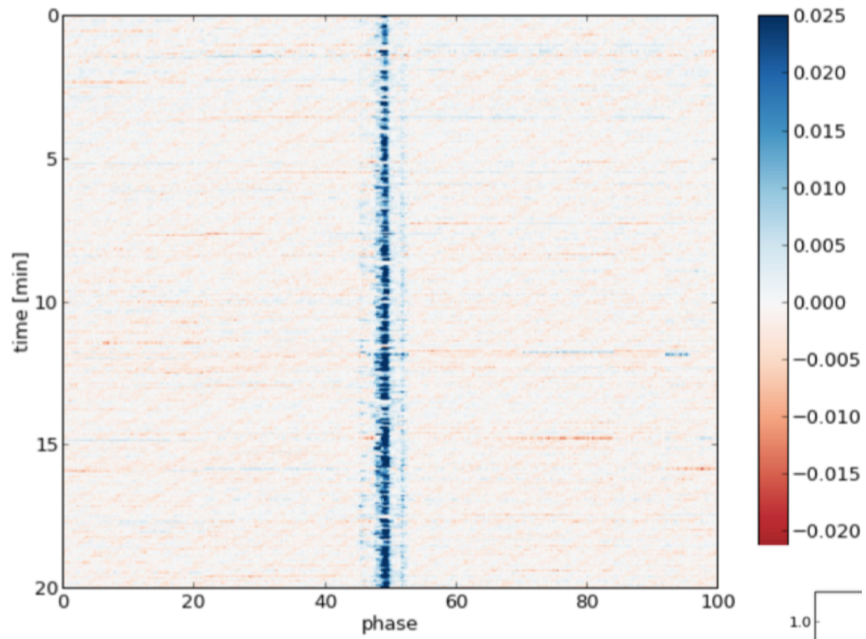
Pulsar Holography

There are a lot more pulsars can be used for CHIME beam holography

Pulse dispersed in galactic plasma



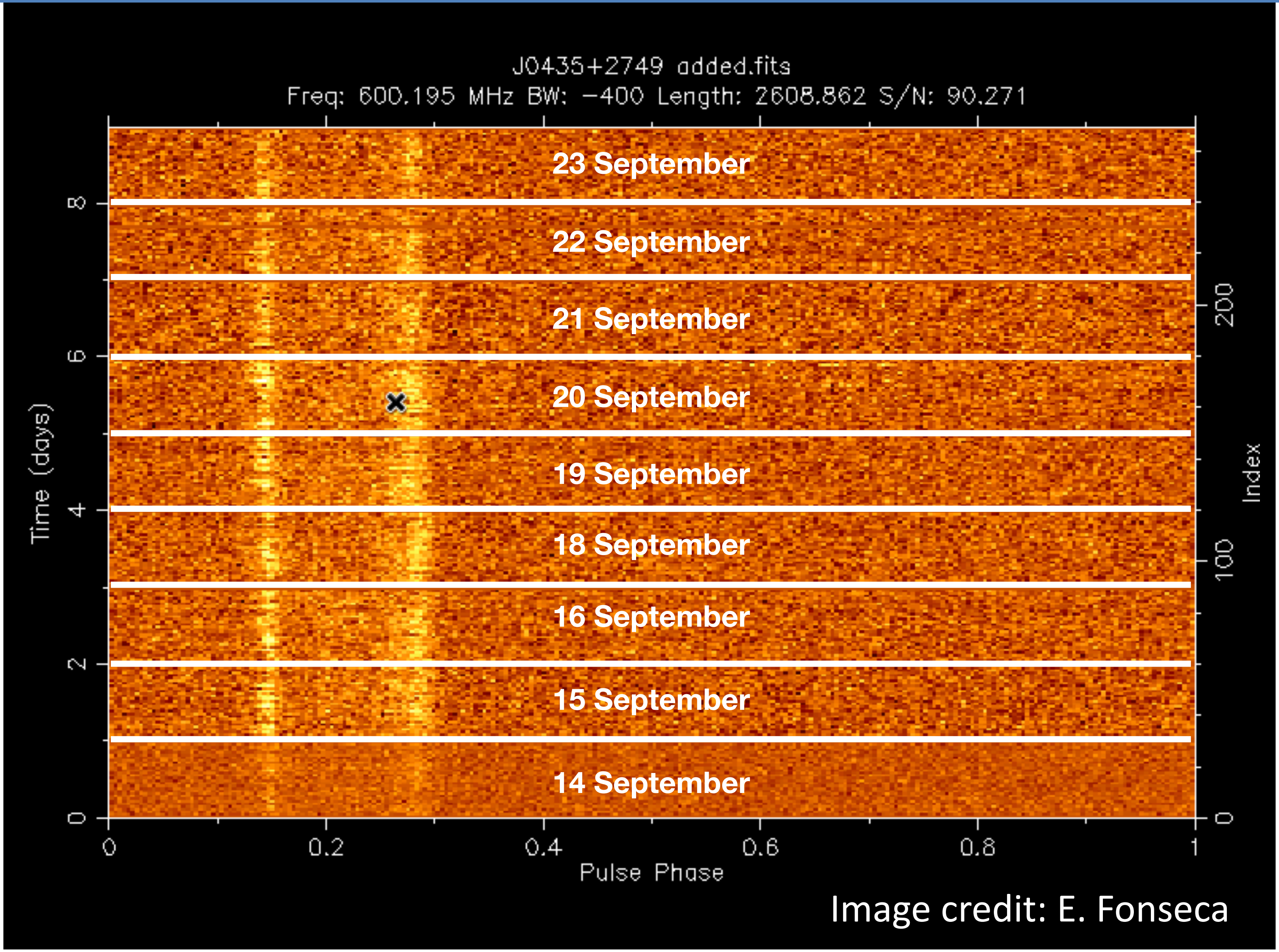
de-dispersed pulsar signal



an example of pulsar signal in CHIME pathfinder

Image credit: L. Conner

Pulsar Timing



We can use this to detect low-frequency gravitational waves!

Summary

- CHIME beam needs to be calibrated very accurately to remove the strong foreground contamination to measure the BAO.

- To address this very challenging task, we have been working on various simulation techniques and measurement methods.

- Pulsars, in addition to be used for beam holography measurement, can also be used to detect low-frequency gravitational waves.