# Beam Forming Optimisation for FRB Detection

Sacha Lévy, supervised by Dr. Cherry Ng and Dr. Paul Scholz.

## Objective

**What is the optimal beam configuration for the CHIME/FRB detection pipeline?**
We study the beamforming process to maximize the number of FRBs detected by CHIME. The telescope tiles its field of view with 1024 beams, yielding independent searchable data streams focused on particular sky locations [3]. Acting like pixels, these 1024 beams are distributed in 4 rows (East-West) of 256 focal points (North-South). Each beam's focal location is comprised within a ±60° range on the North-South axis, and has a fixed East-West inclination [1, 4]. We optimise this East-West angle for detecting a maximum of FRBs..

**What is CHIME?**

- Canadian Hydrogen Intensity Mapping Experiment (see figure 1).
- Static telescope, located in BC, Canada (see figure 2).
- Large 200 square degrees field of view.
- Broad frequency range covered (400 MHz to 800 MHz) [1].
- Has detected and published about 535 FRBs [2].
- The current default East-West beam offset is **0.4°**.

**What are Fast Radio Bursts (FRBs)?**

- Electromagnetic radio wave
- Distant origin (often extra-galactic)
- Repeating & non-repeating

The identification of high redshift FRBs could be used as new cosmological probes!

Figure 1: Picture of CHIME telescope.

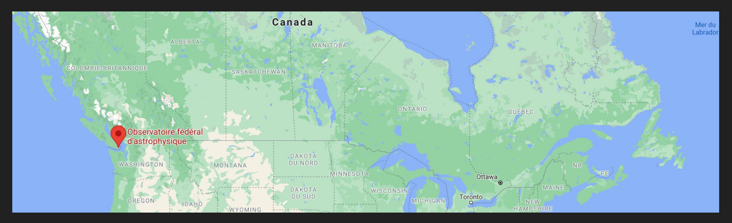

Figure 2: Map of North America showing CHIME's telescope location.

## Background

The **sky area covered** by the beams with **high sensitivity** is related to the number of **detected FRBs**. We select a sensitivity threshold and **study the sky area covered** when **changing the East-West inclination** of the beams.

- Begin by studying the **covered sky area with sensitivity above 0.5** (current beam spacing of 0.4° yields an intersection between East-West beam patterns at a sensitivity of 0.5).
- Retrieve sensitivity for 1600 fixed positions, 80 frequencies, 100 beam spacings, and 1024 beams,
- Compute union of area covered with sensitivity higher than 0.5 across all beams.
- Beam spacing yielding **largest covered area is 0.4°** (see red points in figure 4).)

## Experiment

- Ideally, **compare** multiple **beam spacings in production**, but:
  - **Too expensive** computationally for current infrastructure.
  - **Cannot afford to stop** production pipeline.
- Thus, use knowledge on FRB populations to **run simulations**.
- We generate FRBs for different configurations of the beam model (changing the East-West inclination), and compare the number of detected signals.

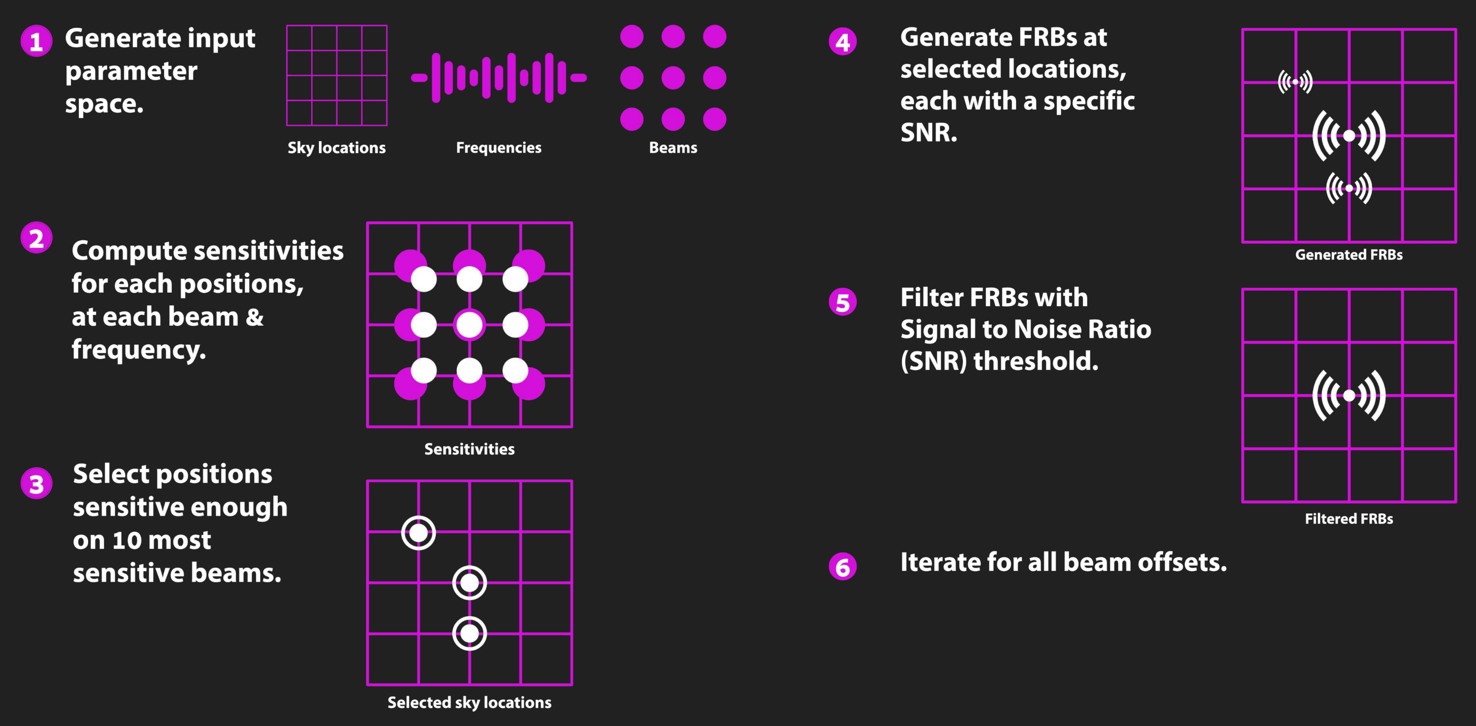


Figure 3: CHIME/FRB simulation process.

**Experiment Setting**

- We repeat our simulation with multiple independent FRB populations to obtain statistically significant results.
- Overall, the experiment is run with the following input space sizes:
  - 100 independent FRB populations.
  - 100 fixed East-West beam spacings (linearly spaced, ranging from 0° to 2°).
  - 6400 random positions (ranging from -60° to 60° on the North-South axis, and -6° to 6° on the East-West axis).
  - 256 fixed frequencies (sampled from CHIME/FRB's 1024 production frequencies, linearly spaced between 400 MHz and 800 MHz).
  - 1024 beams.
  - $10^5$ generated FRBs.
- See figure 3 for simulation process with FRB population.

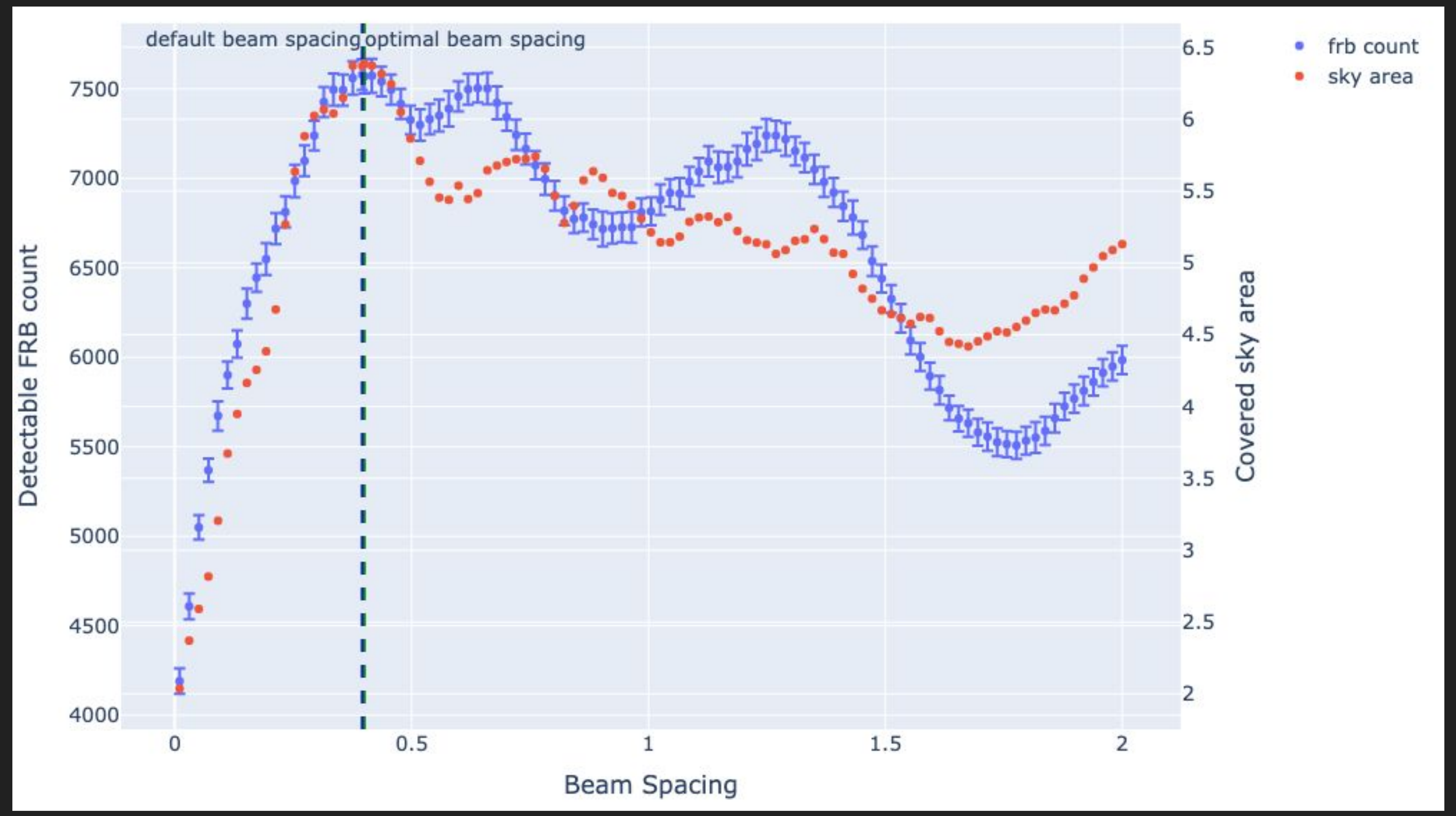


Figure 4: Mean detectable FRB count per beam spacing averaged over FRB populations (in blue). Covered sky area above sensitivity threshold of 0.5 per beam spacing (in red).

## Results

- We observe in figure 4 a similar pattern in covered sky area above sensitivity threshold and simulated detectable FRB count (1 identical maximum, 2 similar local maxima).
- **Optimal** beam spacing coincides with current beam spacing: **0.4**°.
- 2 local maxima at 0.67° and 1.35° (see Figure 4).
- The standard deviation on the FRB detection count is contained within ±2% of the mean.
- Beams closer to middle indexes on North South axis detect more FRBs than beams on the extremes (close to index 0 and 255), as expected (see Figure 5).

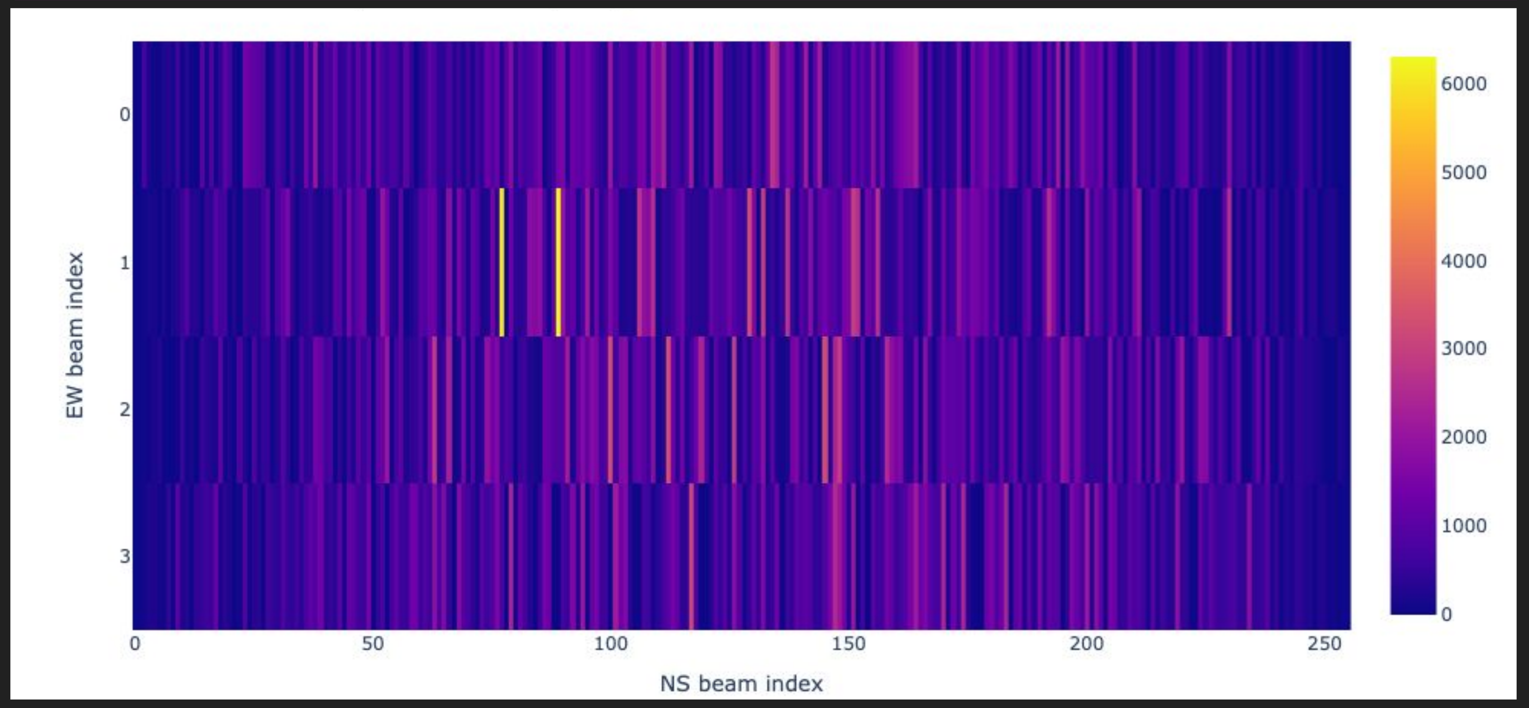


Figure 5: Simulated FRB detection pattern on beam map (color is associated to detection count).

## Conclusion

- We conclude that the **current East-West beam offset theoretically maximizes the number of detected FRBs**.
- **Caveats:**
  - The simulation is built on detected FRB signals with the current beam spacing. It is possible the results were implicitly bias to favor this configuration.
- **Future work:**
  - Explore different FRB population spectral parameters to validate beam spacing optimality.
  - Test alternative local maxima performances in production.

## References


1. Amiri, M., et al. "The CHIME fast radio burst project: system overview." *The Astrophysical Journal* 863.1 (2018): 48.
2. Amiri, Mandana, et al. "The First CHIME/FRB Fast Radio Burst Catalog." *arXiv preprint arXiv:2106.04352* (2021).
3. Condon, James J. and Ransom, Scott M.. "3. Radio Telescopes and Radiometers". *Essential Radio Astronomy*, Princeton: Princeton University Press, 2016, pp. 64-140. https://doi.org/10.1515/9781400881161-004
4. Ng, Cherry, et al. "CHIME FRB: An application of FFT beamforming for a radio telescope." *2017 XXXIInd General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS)*. IEEE, 2017.