

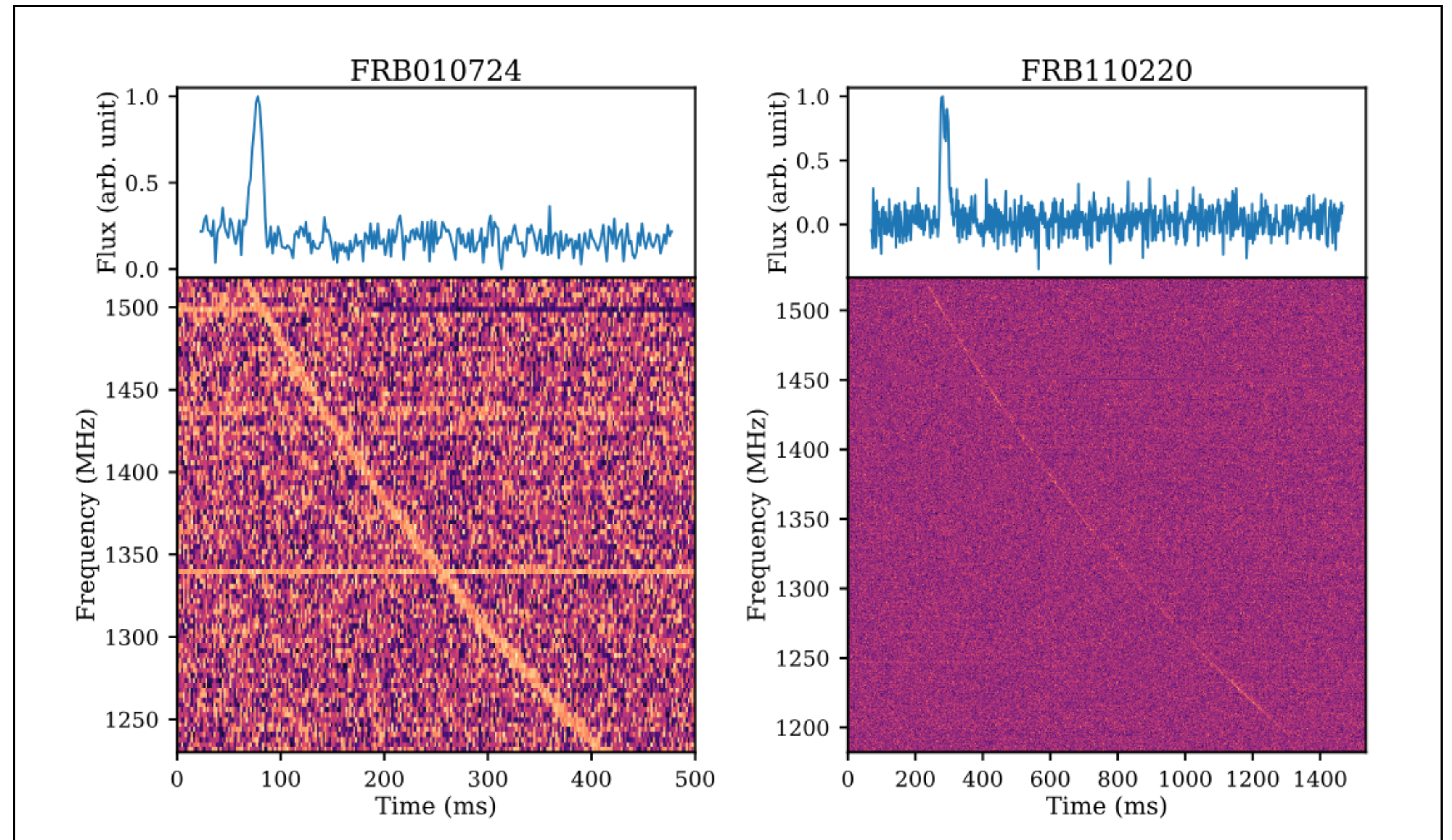
A Deep-Learning-Based FRB Population Simulation : Zero Order Model

Shruti Bhatporia, Christo Venter, Marlie Davel, Randle Rabe, Jéferson Fortunato, Ben Opperman, Amanda Weltman, Stefan Lotz



Fast Radio Bursts

- Millisecond-duration high-energy
 - $< 50\text{ms}$
 - $> 30\text{ Jy}$
- Extragalactic



[Lorimer et al. 2007](#)

[Thornton et al. 2013](#)

Fast Radio Bursts

FRB Newsletter Volume 07, Issue 9 — September 2026

Total FRB count: 4500+

Repeaters: 124

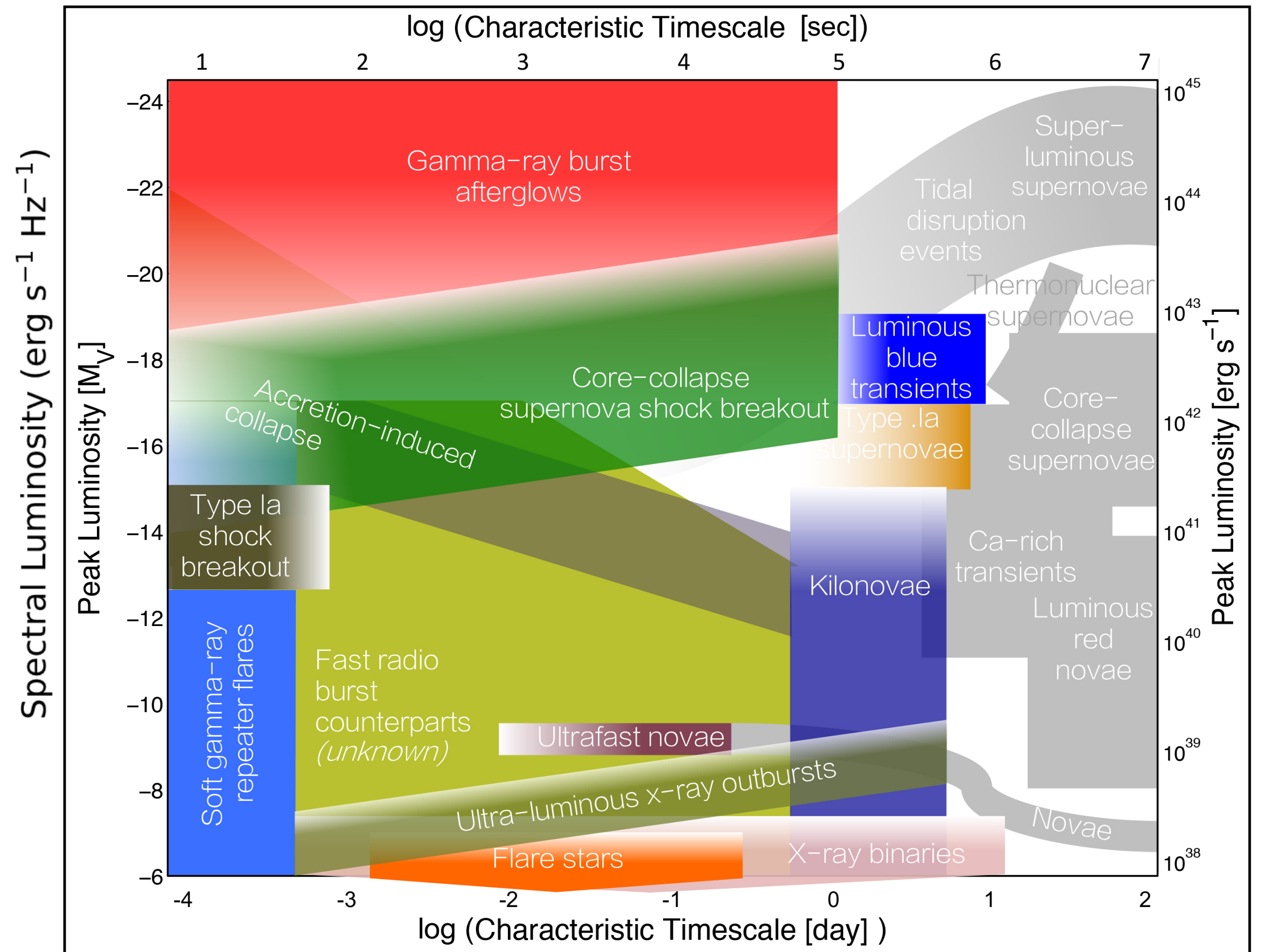
Host galaxies: 139 (20 new)

[TNS FRB Search](#)

Progenitor Models for FRBs

- Extragalactic sources – cosmological?

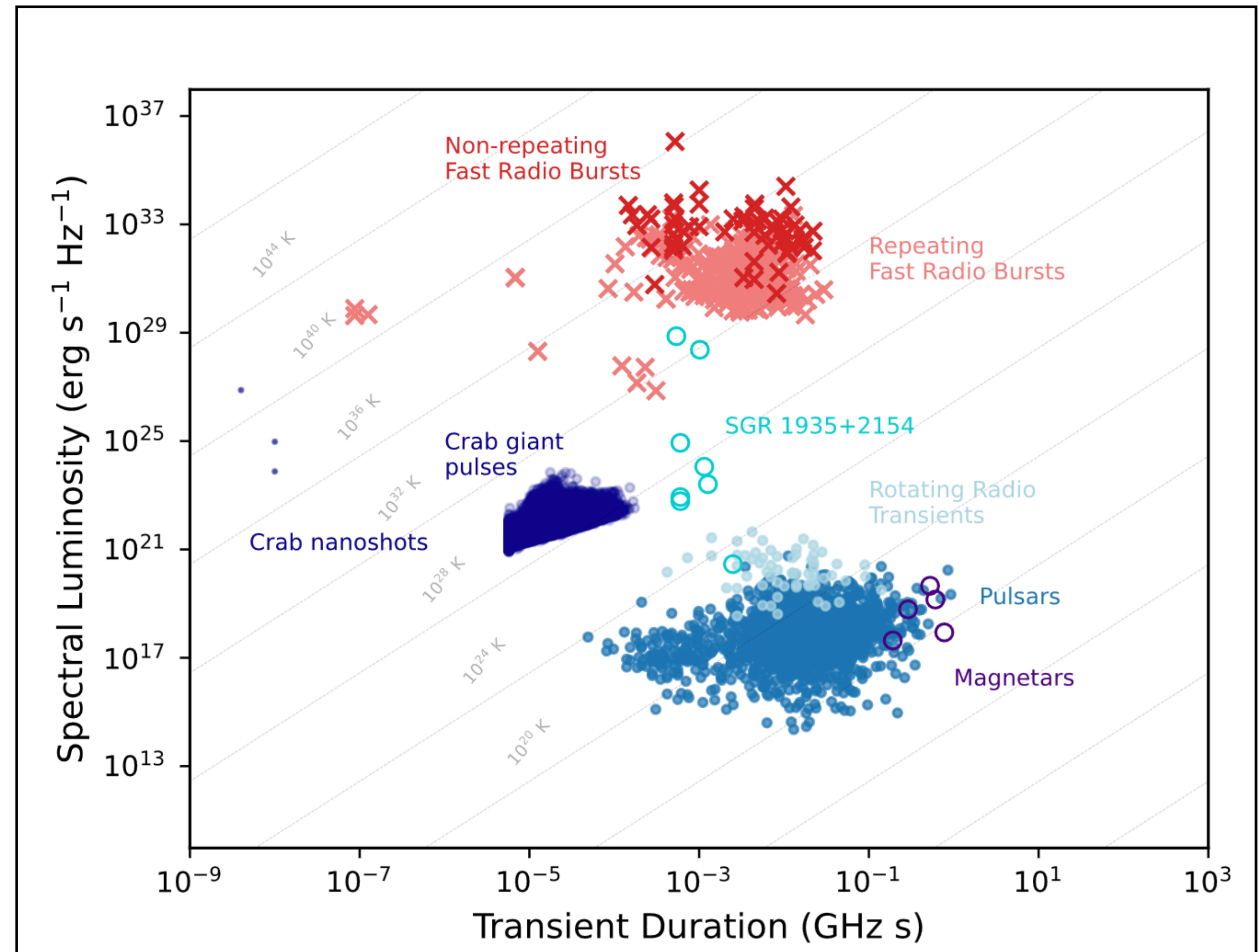
- Soft Gamma Repeater giant flares (Popov & Postnov 2007).
- Collapsing supra-massive NS (Falcke & Rezzolla 2013).
- Bright, rare, Crab-like giant pulses from extragalactic pulsars (Cordes & Wasserman 2016)
- Merging white dwarfs (Kashiyama et al. 2013).
- Merging neutron stars (Hansen & Lyutikov 2001)
- Pulsar planets – Alfvén wings (Mottez & Zarka 2014).
- ... etc. etc. etc.



[David et al 2021](#)

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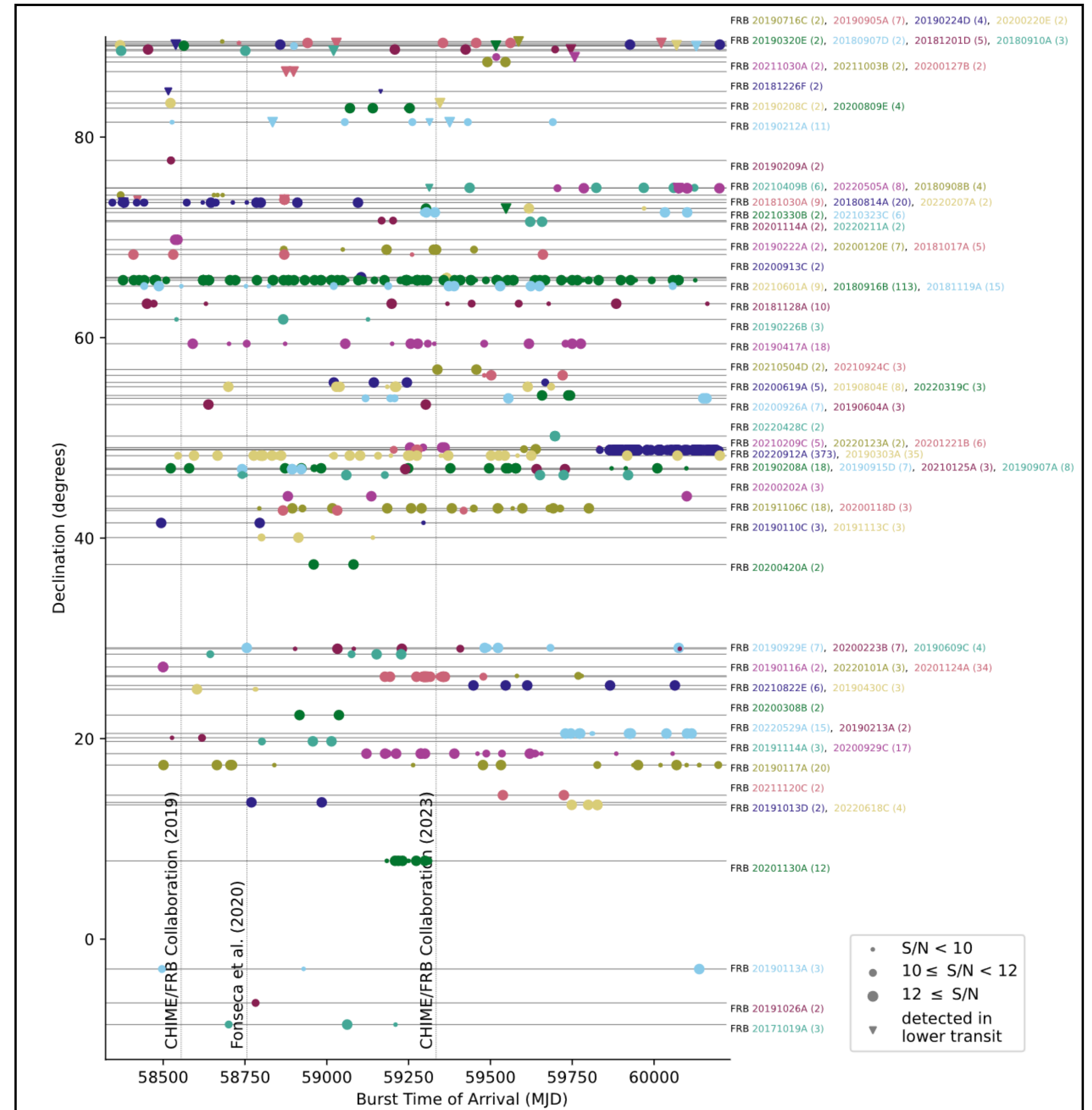


[Curtin et al. 2026](#)

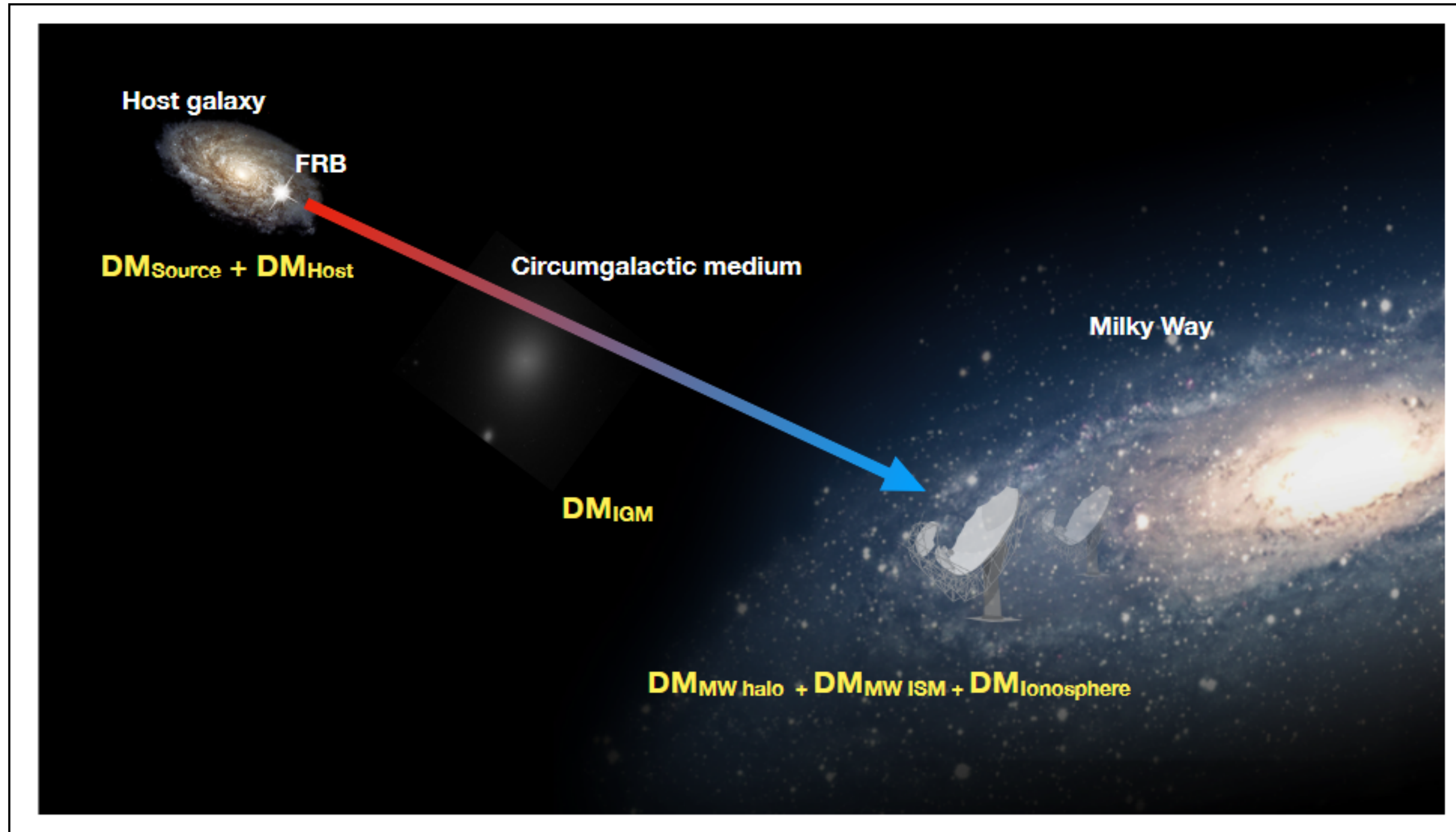
Repeater FRBs

- **Highly Active Repeaters:** Some sources show extreme activity with dozens or hundreds of detected bursts.
 - Examples labeled on the right include **FRB 20190123A**, which boasts a massive **373** recorded bursts, and **FRB 20180916B** with **113** bursts (represented by dense horizontal tracks of green and light blue dots).
- **Low Activity/Sparse Repeaters:** Many sources are listed with very few recorded events—often just 2, 3, or 4 bursts over the entire multi-year monitoring period (e.g., FRB 20200420A with only 2 bursts)

[Cook et al 2026](#)



Placement of FRBs



DM-z Relation

$$DM_{total} = DM_{MW,ISM} + DM_{MW,Halo} + DM_{IGM} + DM_{Host}$$

$$\langle DM_{IGM}(z) \rangle = \frac{3cH_0\Omega_b f_{IGM}}{8\pi Gm_p} \int_0^z \frac{\chi(z')(1+z')}{E(z')} dz'$$

$$E(z) = \left[(1+z)^3 \Omega_m + f(z) \Omega_{DE} + (1+z)^2 \Omega_k \right]^{\frac{1}{2}}$$

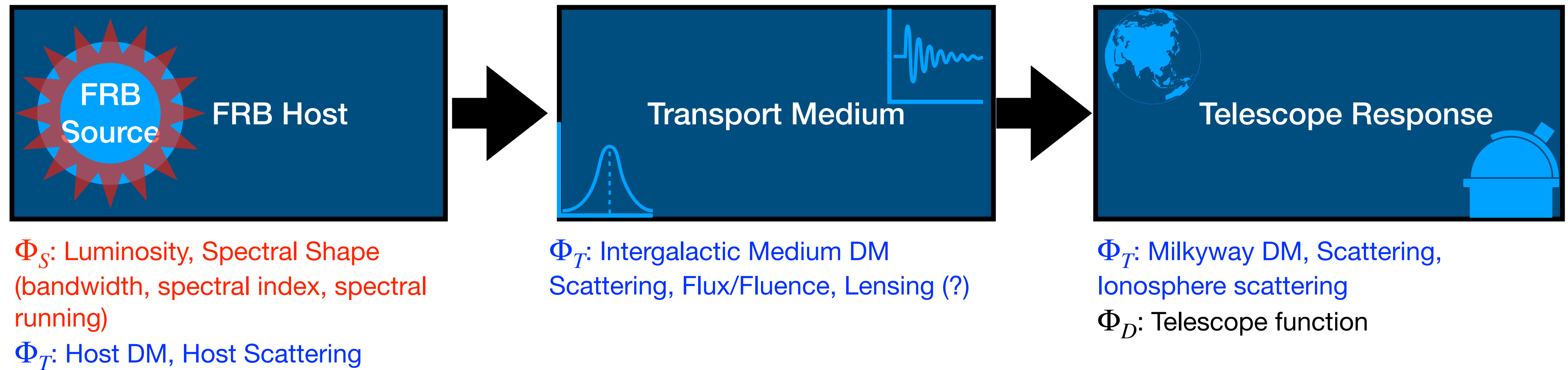
$$\chi(z) = Y_H \chi_{e,H}(z) + \frac{1}{2} Y_p \chi_{e,He}(z)$$

$$f(z) = \exp \left[3 \int_0^z \frac{1+w(z'')}{1+z''} dz'' \right]$$

*IGM is homogenous

FRB-SIM Methodology and ZOM

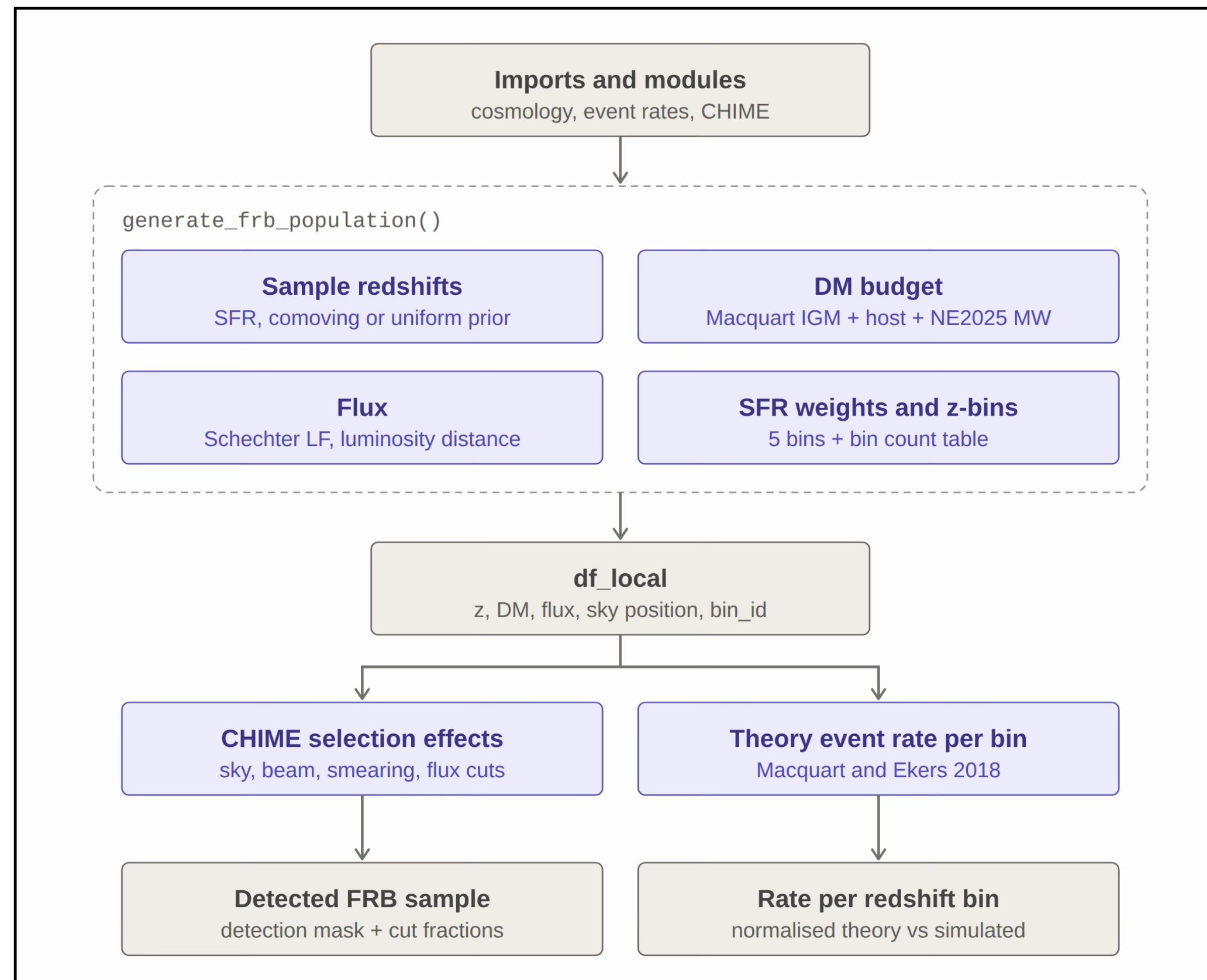
- **Have a Generic FRB simulation:** Constrain the intrinsic **FRB population** responsible for detections by telescopes like MeerKAT and CHIME.
- **FRBpoppy** (Gardenier et al 2019)
- **The 3-Step Pipeline:** (1) Cosmic Population (2) Photon Transport (3) Telescope Response.
- **The Computational Challenge**
 - These simulations are computationally expensive, limiting exhaustive parameter space searches
 - **Solution:** Develop a **Deep Learning (ML) surrogate model** to drastically accelerate runtimes
- **Phased Approach & Validation**
 - 1.Zero-Order Model (ZOM):** Build a fast, simplified population synthesis model with a **1:1 input/output architecture** matching FRBpoppy.
 - 2.Proof-of-Concept:** Use ZOM to constrain setup for surrogate model (e.g., which parameters to freeze, parameter ranges, etc.); build physics intuition so we can interpret eventual results.
 - 3.The Switch:** Deploy the verified ML pipeline onto the full FRBpoppy framework.
 - 4.Comparative Analysis:** Evaluate the constraining power and output accuracy of ZOM vs. **FRBpoppy**.



Deep-Learning-Based FRB Populations Simulation

Why?

Current Status: ZOM

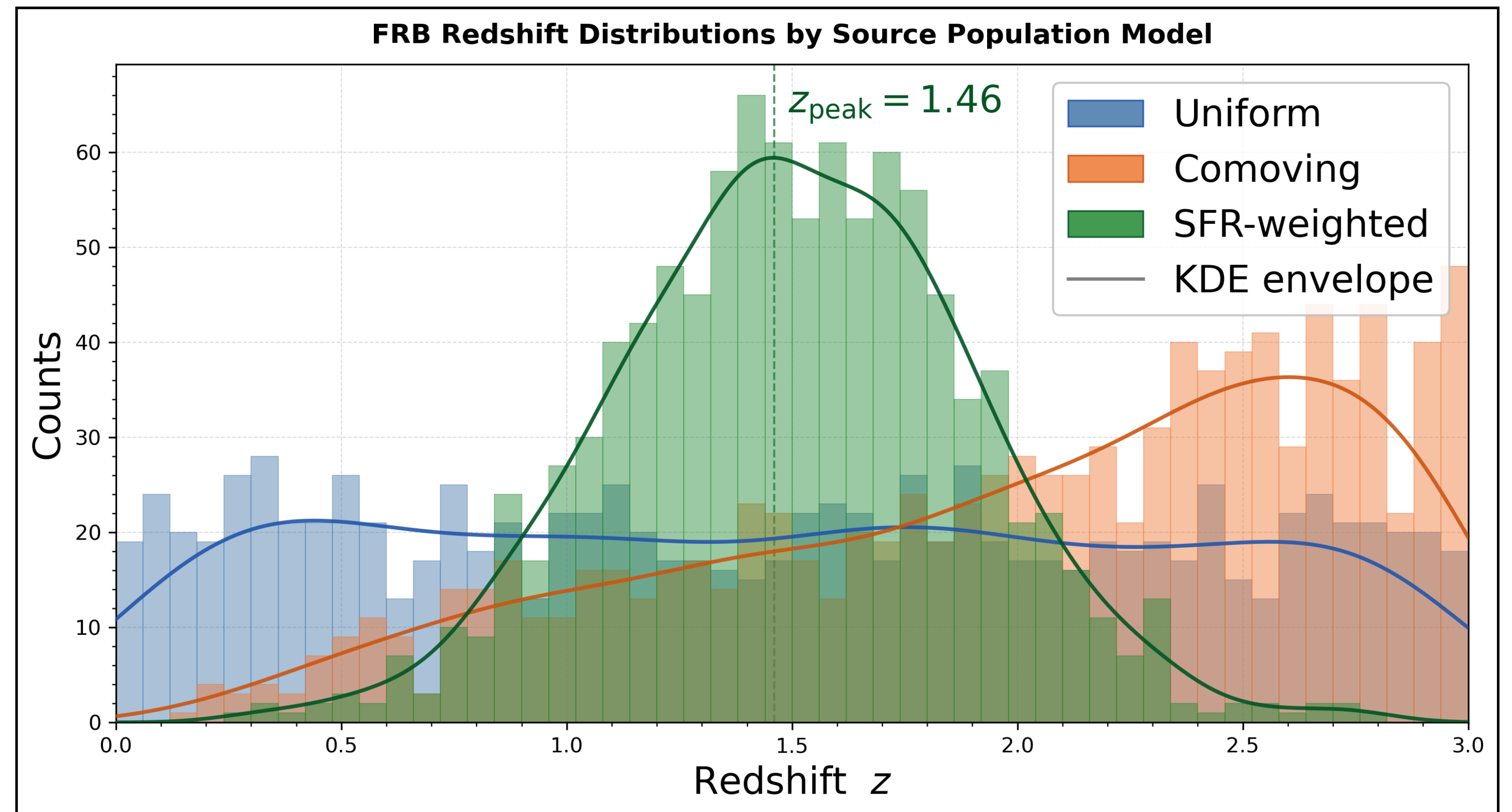


- Machine Learning Speedups
- Speeding up isotropic measurements?
- Parametric Search?

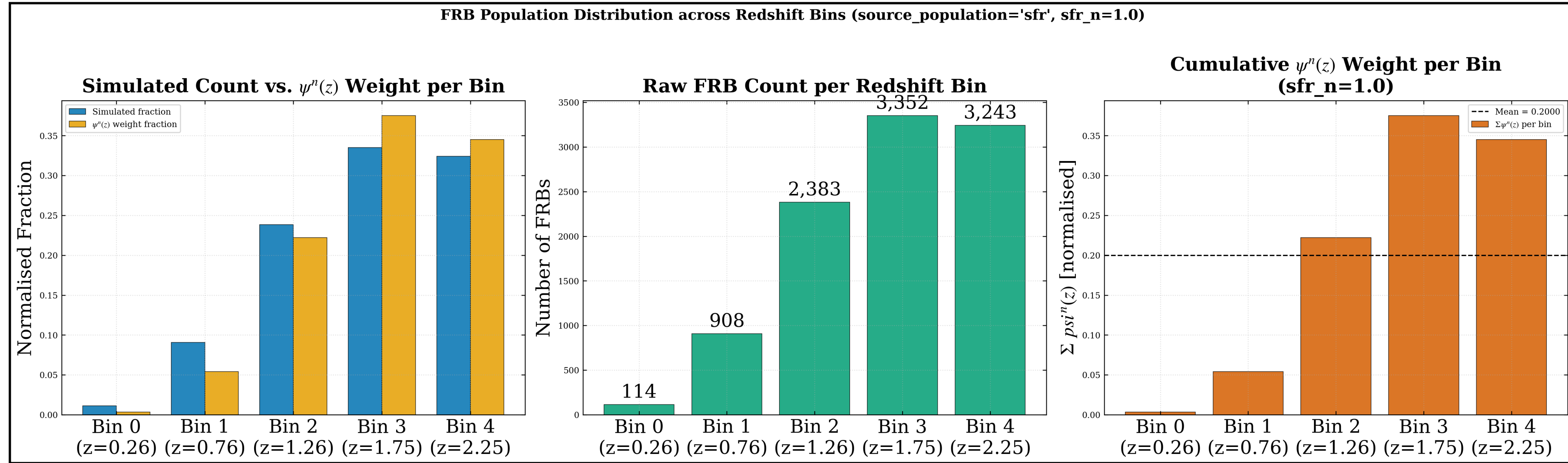
Cosmic Population Setup

- **Source Generation Engine:**
 $\mathbf{X}_i = [z_i, \text{RA}_i, \text{Dec}_i, L_i]$ Tracks non-homogeneous spatial Poisson birthrates following global cosmic star-formation history via Madau & Dickinson (2014):

$$\psi(z) \propto \frac{(1+z)^{2.7}}{1 + [(1+z)/2.9]^{5.6}}$$



FRB Event Rate

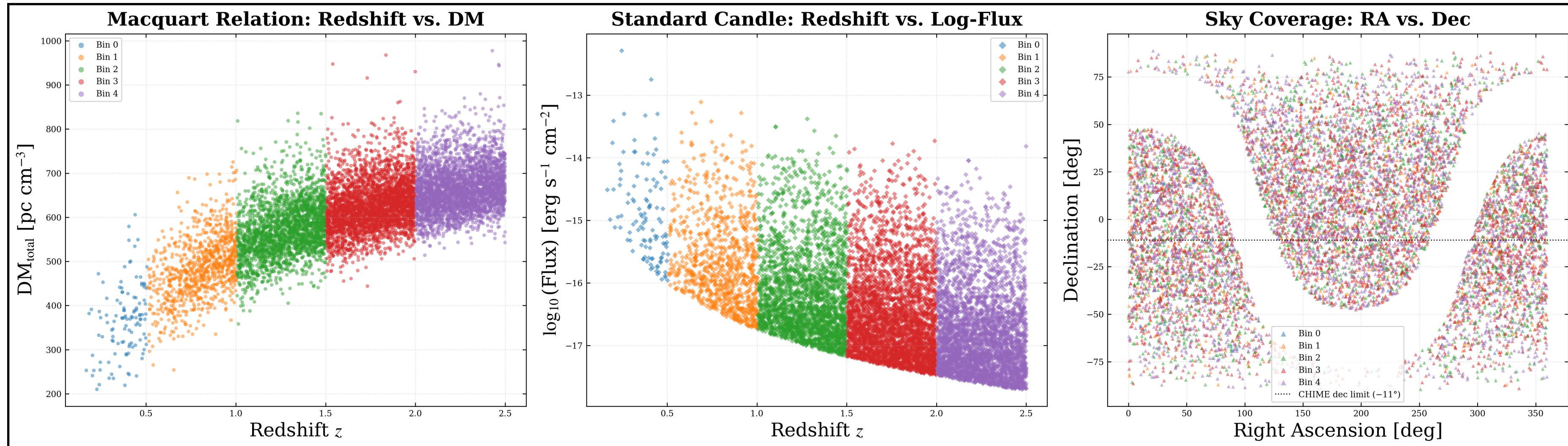


- **Fluence-Limited Selection Rate:** The differential event rate $\frac{dR_F}{dz}$ given a limiting survey fluence threshold F_0 is:

$$\frac{dR_F}{dz} = 4\pi D_H D_M^4(z) \frac{(1+z)^{\alpha-1}}{E(z)} \psi^n(z) g(F_0, z)$$

where $g(F_0, z)$ is the completeness fraction over the burst energy power law $\theta_E \propto E^{-\gamma}$, Following (Macquart & Ekers (2018))

Source Distribution



- **Transport Plasma Medium:** Maps spatial properties to the continuous target matrix $\mathbf{y}_i = [\log_{10} S_{\text{observed},i}, DM_{\text{total},i}]$. Total dispersion combines its plasma components:

$$DM_{\text{total}} = DM_{\text{MW}}(b) + DM_{\text{Halo}} + DM_{\text{IGM}}(z) + DM_{\text{Host}}$$

- **Schechter Luminosity Function**

$$\Phi(L) dL = \phi^* \left(\frac{L}{L^*} \right)^\alpha \exp \left(-\frac{L}{L^*} \right) d \left(\frac{L}{L^*} \right)$$

CHIME/FRB Selection Effects

- **Geometric Horizon Cutoff:** Prevents detection below CHIME's southern horizon:

$$\text{Mask}_{\text{Horiz}} = 1 \text{ if } \delta_i \geq -11.0^\circ$$

- **Dispersion Smearing: Broadening:** Δt_{smear} must not exceed the processing window (100 ms):

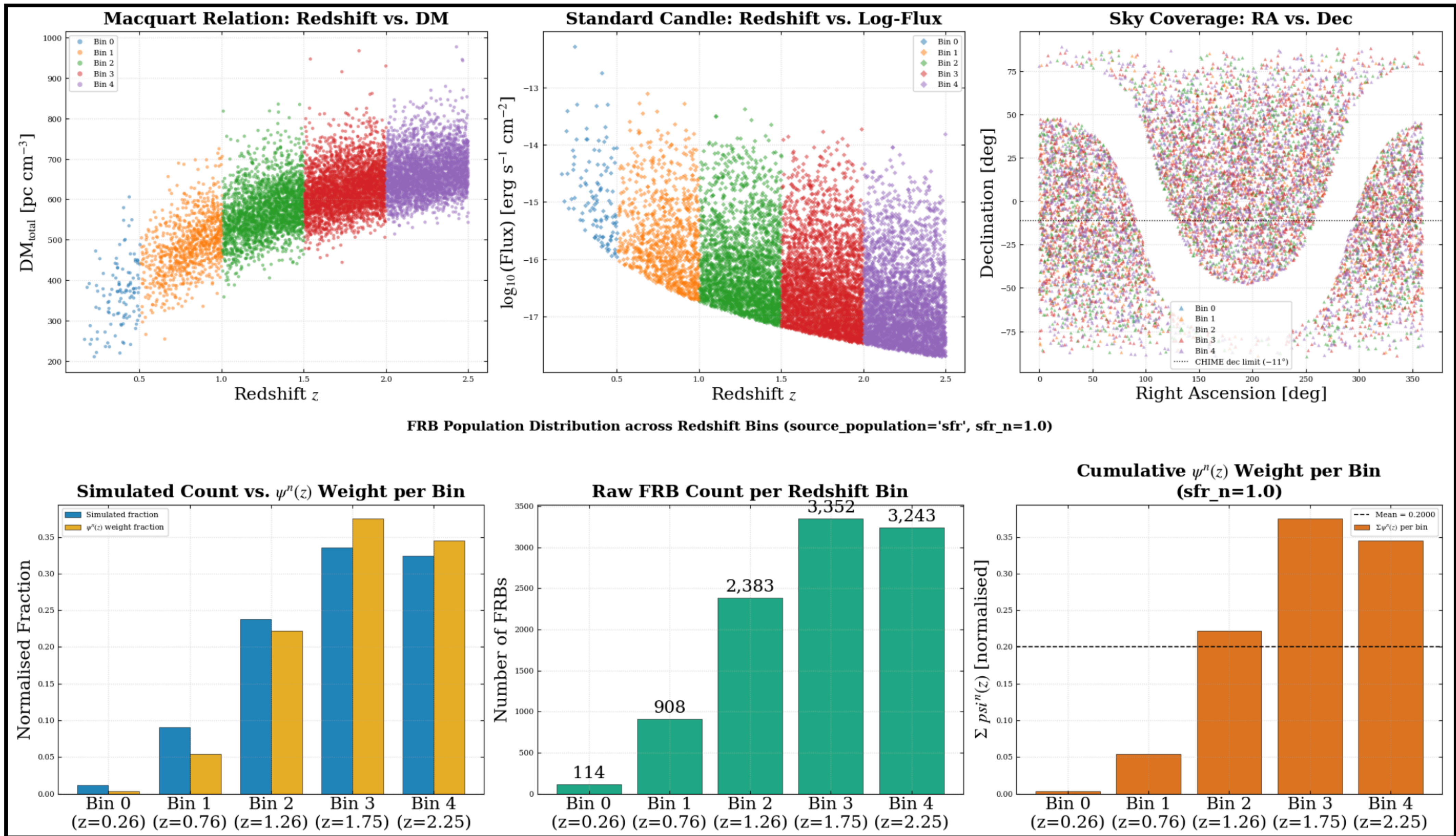
$$\Delta t_{\text{smear}} \approx 8.3 \times 10^{-3} \cdot DM \cdot \frac{\Delta \nu_{\text{chan}}}{\nu_{\text{mid}}^3}$$

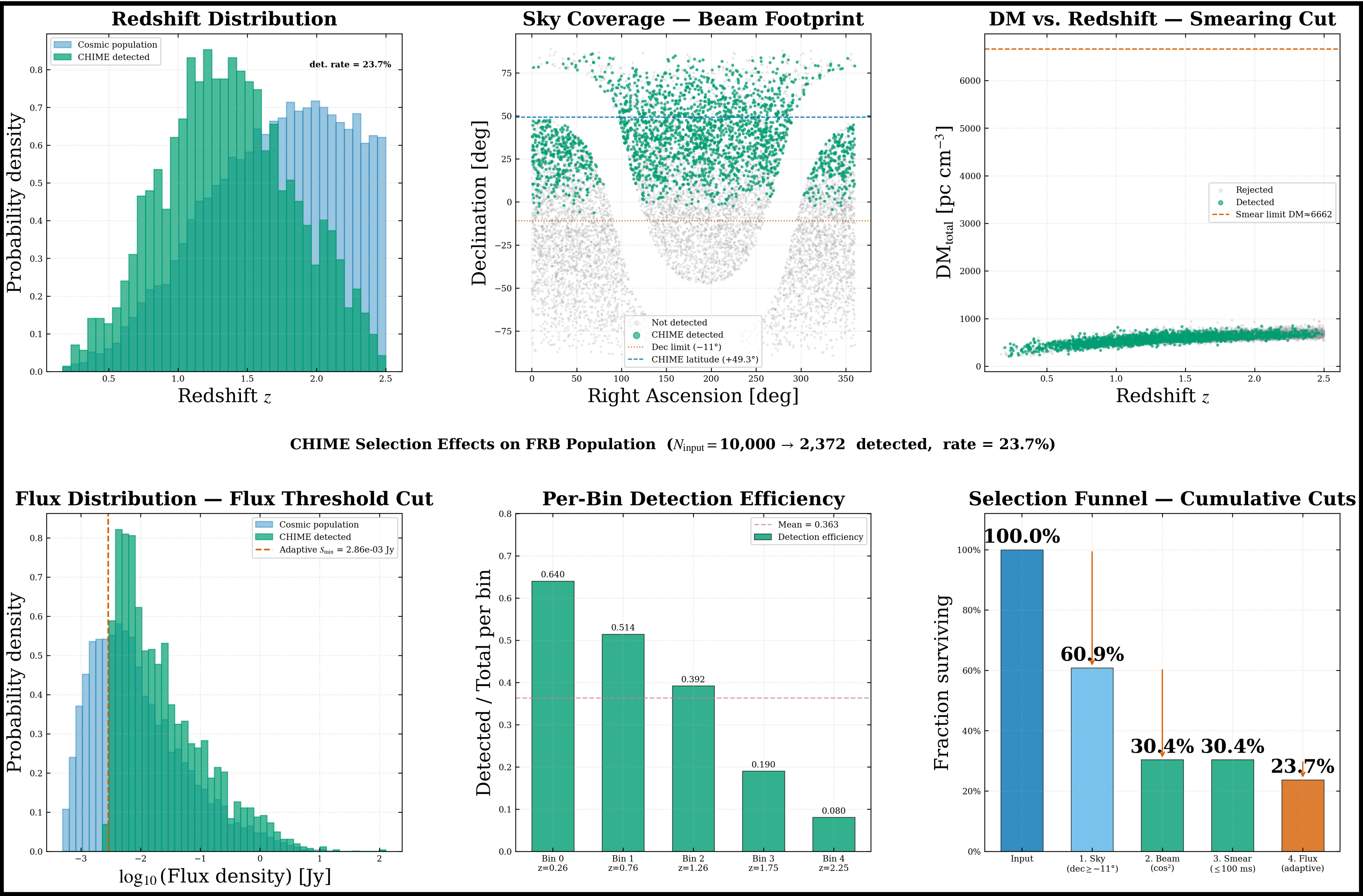
- **Primary Beam Response:** Projected sensitivity $B(\delta_i)$ via a cosine-squared model:

$$B(\delta_i) = \cos^2 \left(\frac{\pi}{2} \cdot \frac{|\delta_i - 49.3^\circ|}{60^\circ} \right)$$

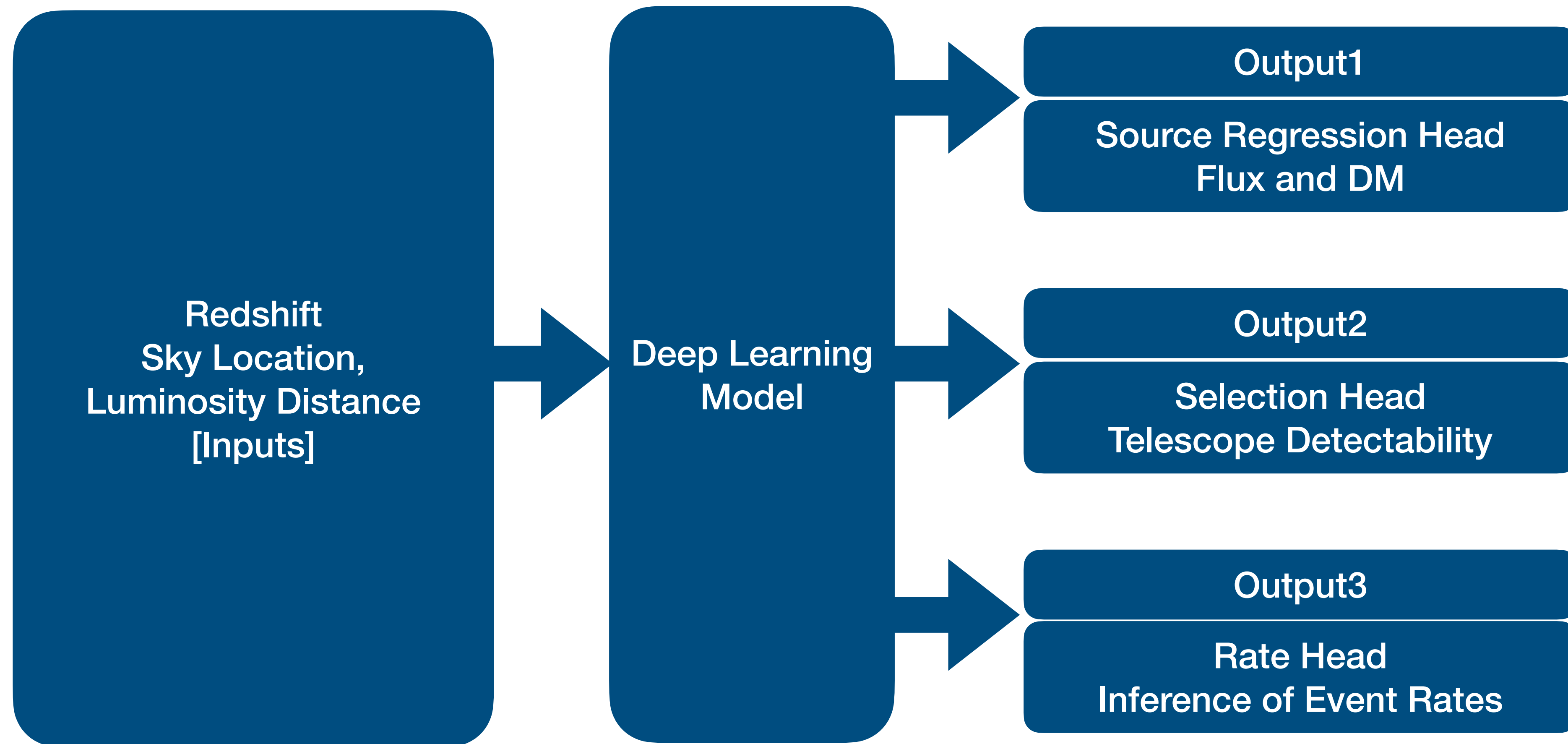
- **Flux Sensitivity:** Observed flux must clear the baseline threshold of 0.05 Jy:

$$\text{Mask}_{\text{Flux}} = 1 \text{ if } \log_{10} S_{\text{obs}} \geq \log_{10}(0.05)$$





Current Machine Learning Setup



Future Outlook

- **Progenitor Modelling**
 - Integrate actual **burst profiles** and emission geometries into the population synthesis.
 - Test population metrics under the explicit assumption of a **magnetar progenitor engine**.
- Comparison of MeerKAT and CHIME/FRB rates

Thank you!