AN FRB SENT ME A DM: MEASURING THE MILKY WAY'S PLASMA WITH CHIME/FRB

Amanda Cook, University of Toronto

on behalf of CHIME/FRB

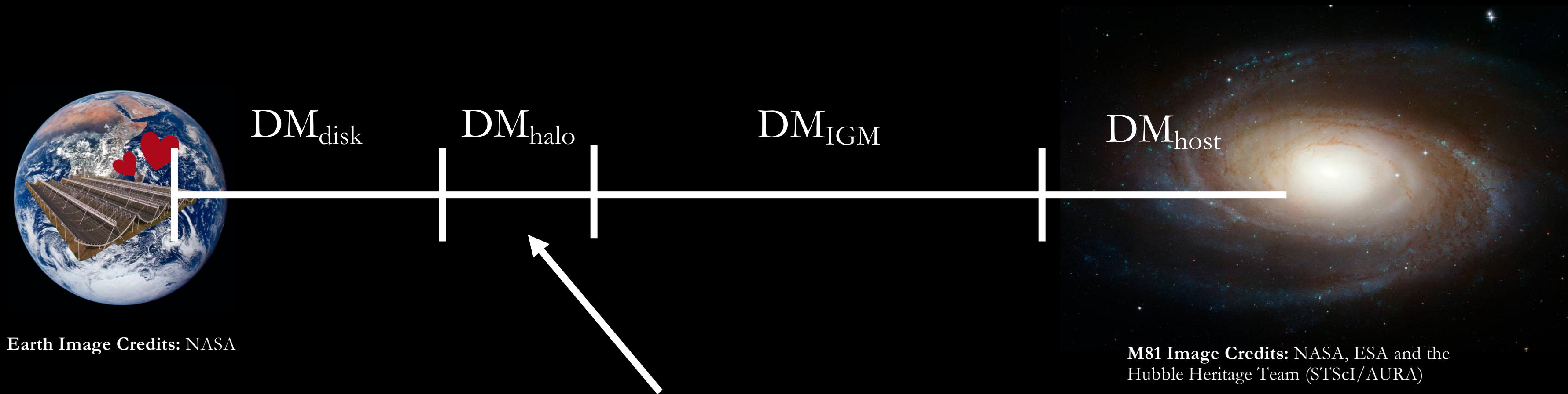
DM CONTRIBUTIONS

Earth Image Credits: NASA

M81 Image Credits: NASA, ESA and the Hubble Heritage Team (STScI/AURA)

$$\mathrm{DM} = \int_0^L n_e \, dl \propto \Delta t(\nu_1, \nu_2)$$

DM CONTRIBUTIONS



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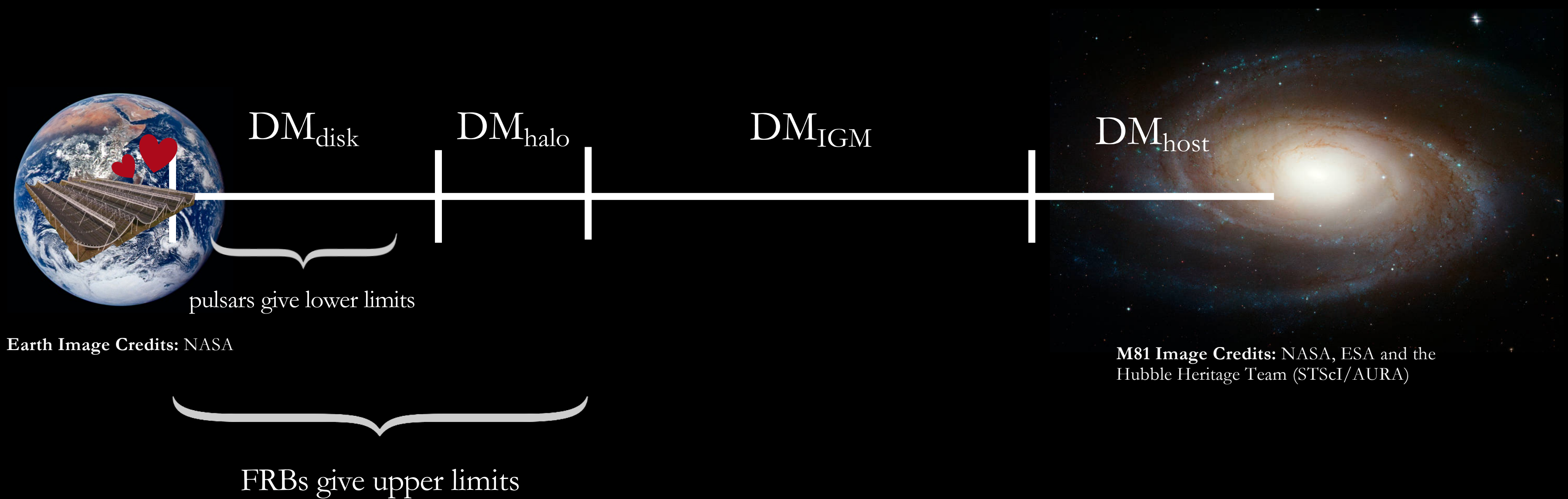
- too diffuse for direct imaging
- observables ⇨ total gas content is model-dependent
- DM_{halo} estimates span an order of magnitude (Keating & Pen 2020)
- implications for galactic formation theory
- DM_{halo} needed for FRB distance estimates

DM CONTRIBUTIONS



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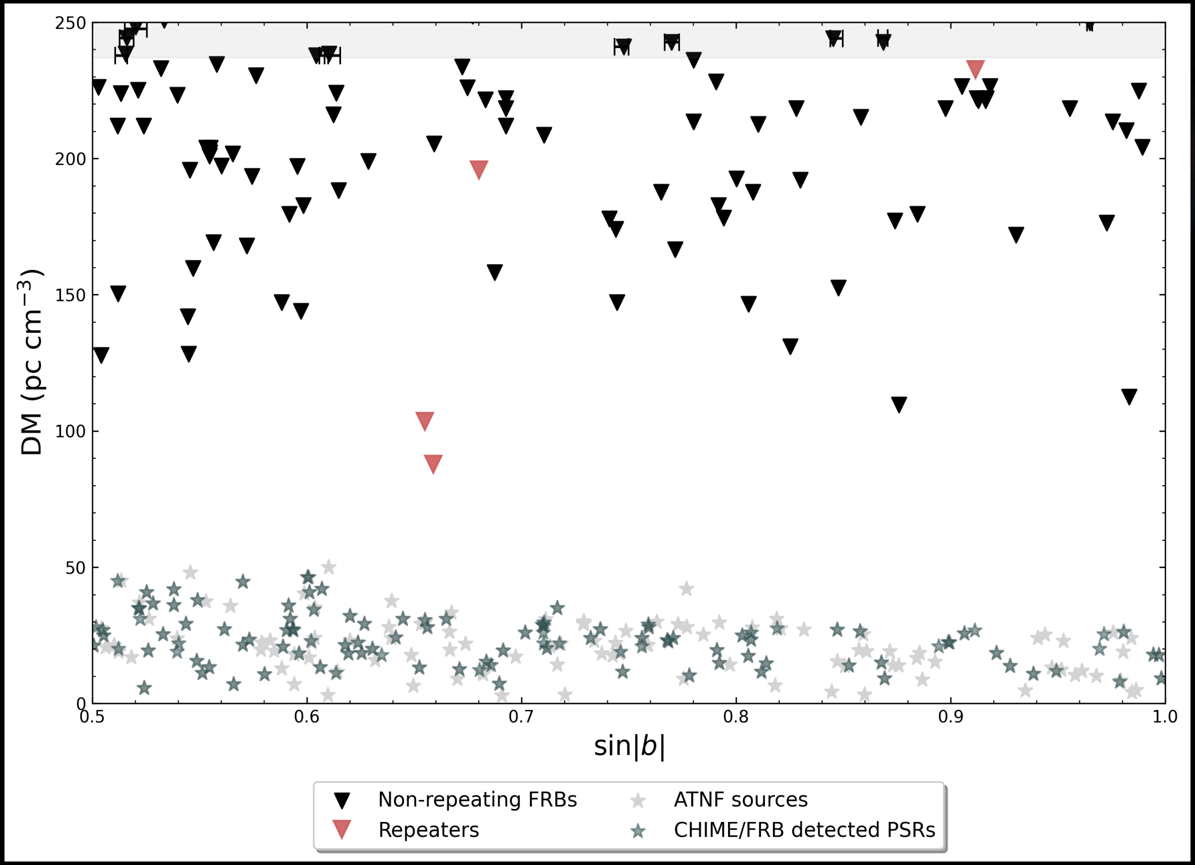
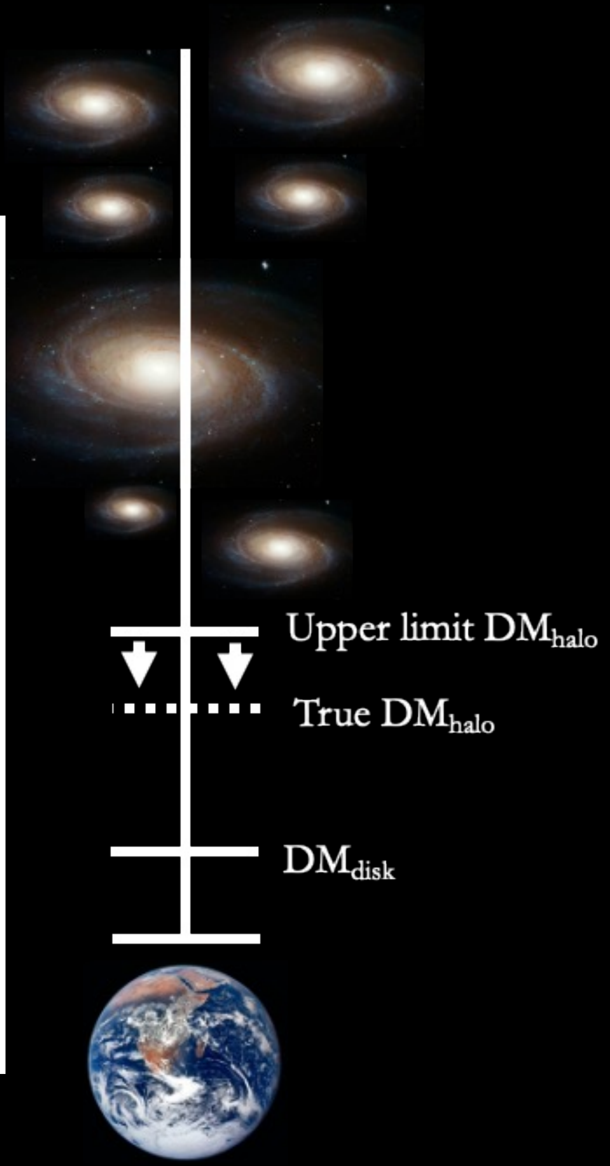
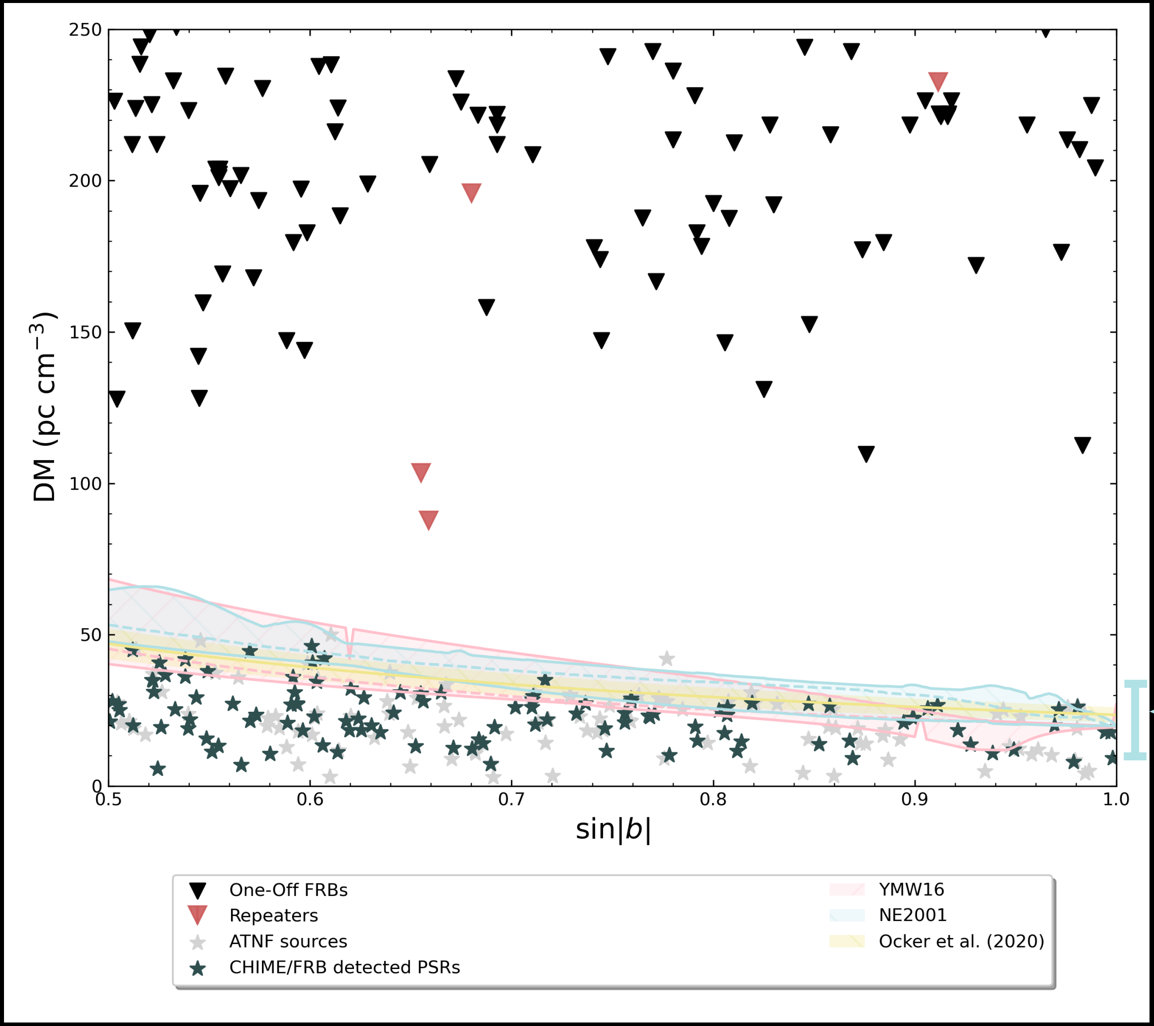
Subtracting the two constraints gives an upper limit on DM_{halo}

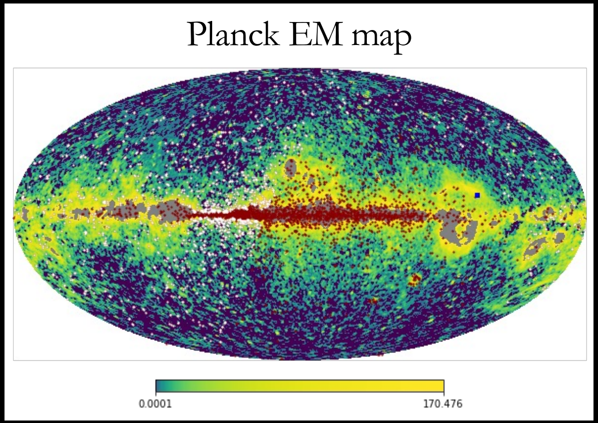
FRBS AND PULSARS





MW DISK MODELS



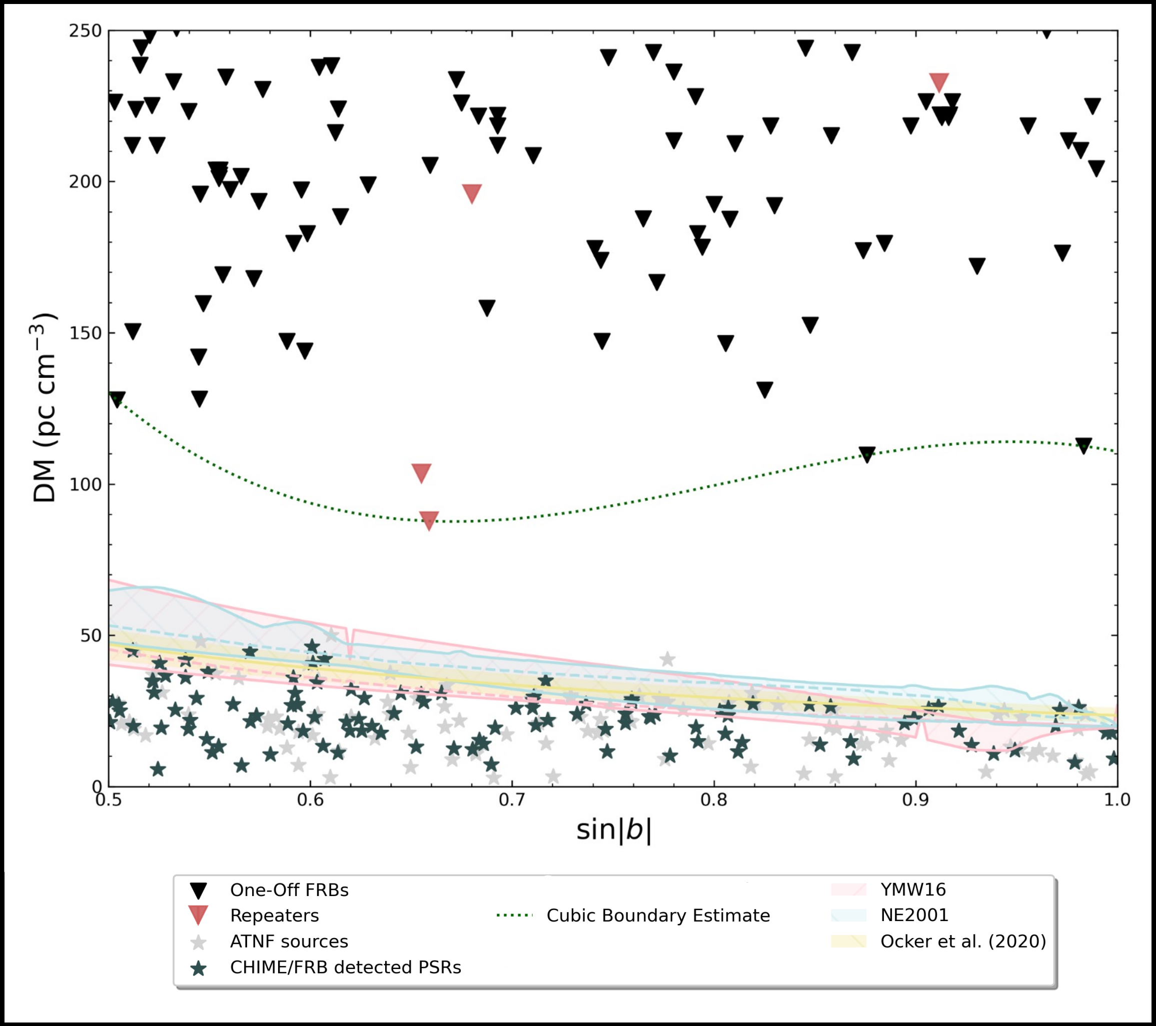


For each Galactic b, consider all l excluding:

- Dec. < -10 °
- lines of sight with high EM

Plot range of DM_{Gal} values

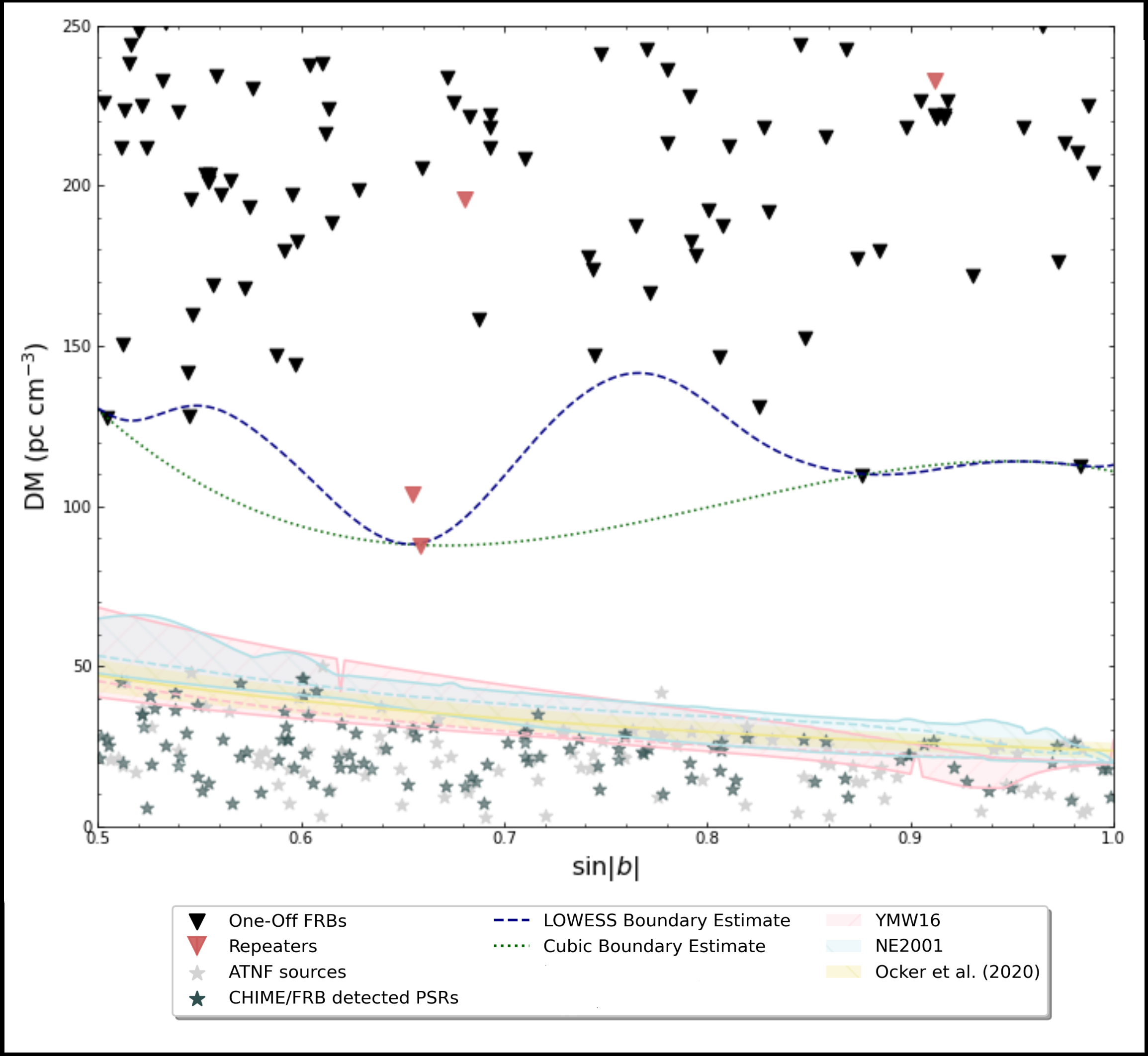
MW HALO MODELS



CUBIC BOUNDARY ESTIMATE

- Assumes polynomial form
- all FRB DMs must lie above curve
- maximize area from DM = 0 to boundary line

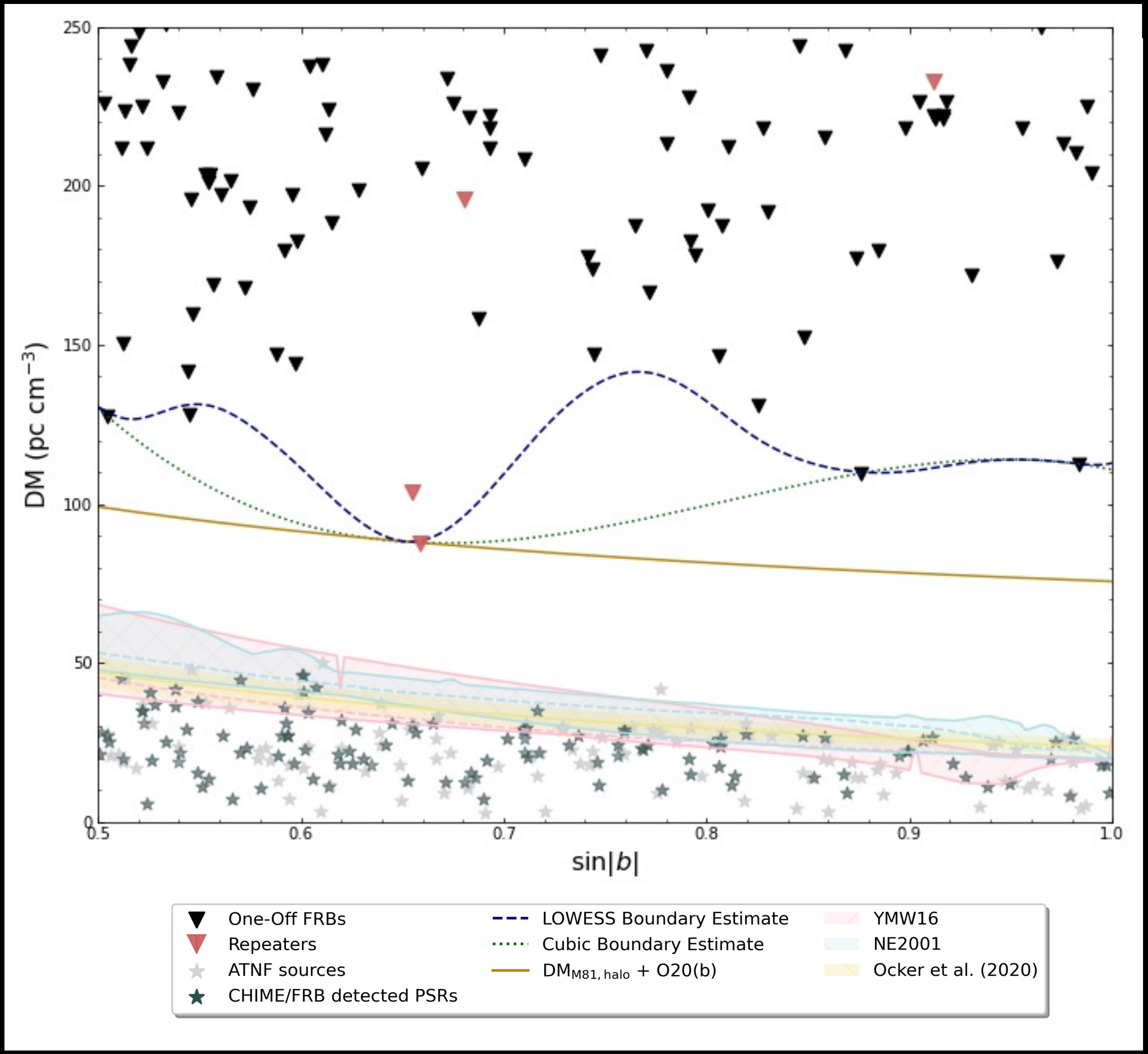
MW HALO MODELS



LOWESS BOUNDARY ESTIMATE

- ***LO**cally **WE**ighted **S**catterplot **S**moothing*
- DM value to fit at each *b* is defined as local (within 5 deg) FRB minimum
- polynomial degree 3,bandwidth = 0.55

MW HALO MODELS

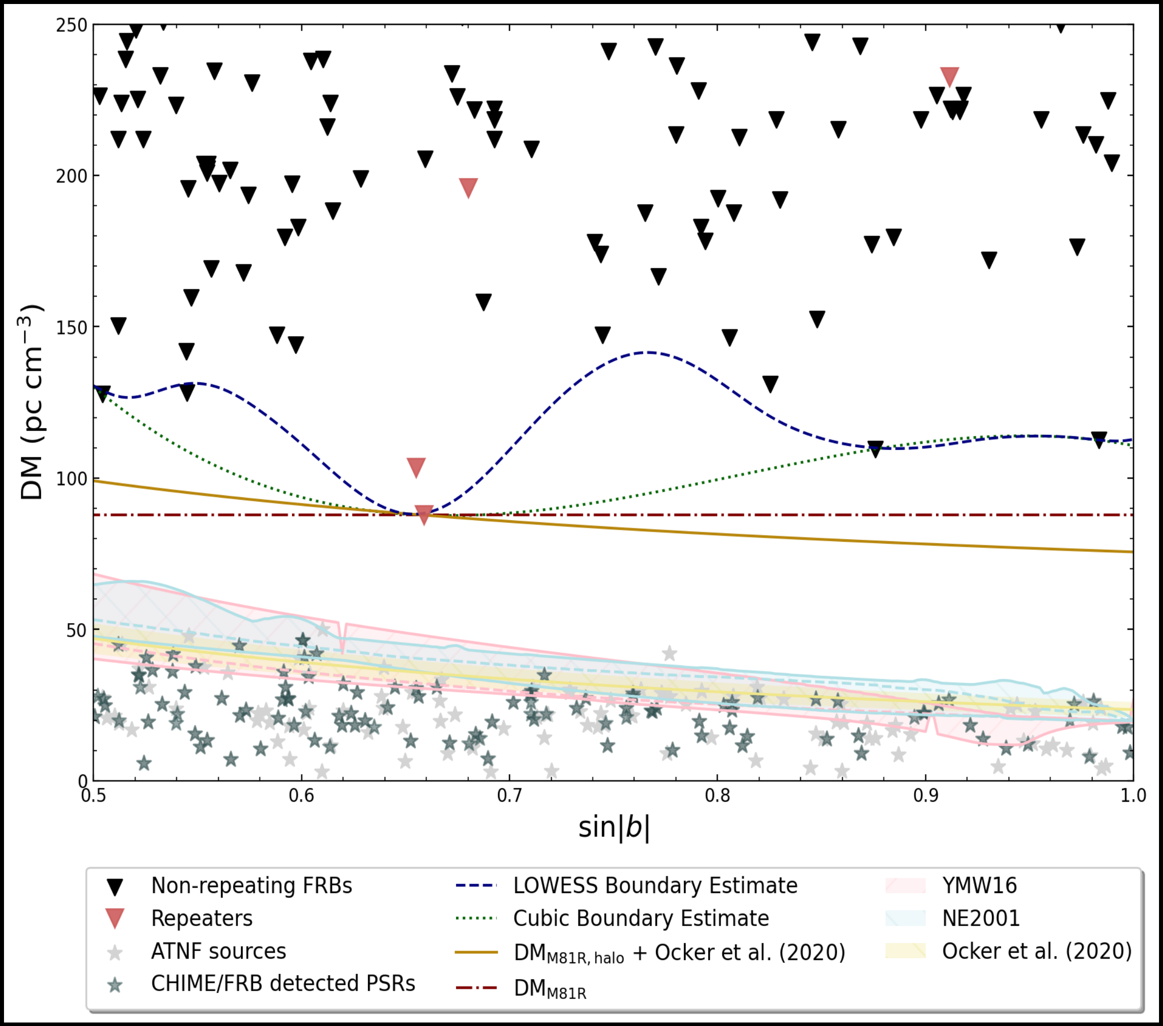


DM_{M81R} + O20(b)

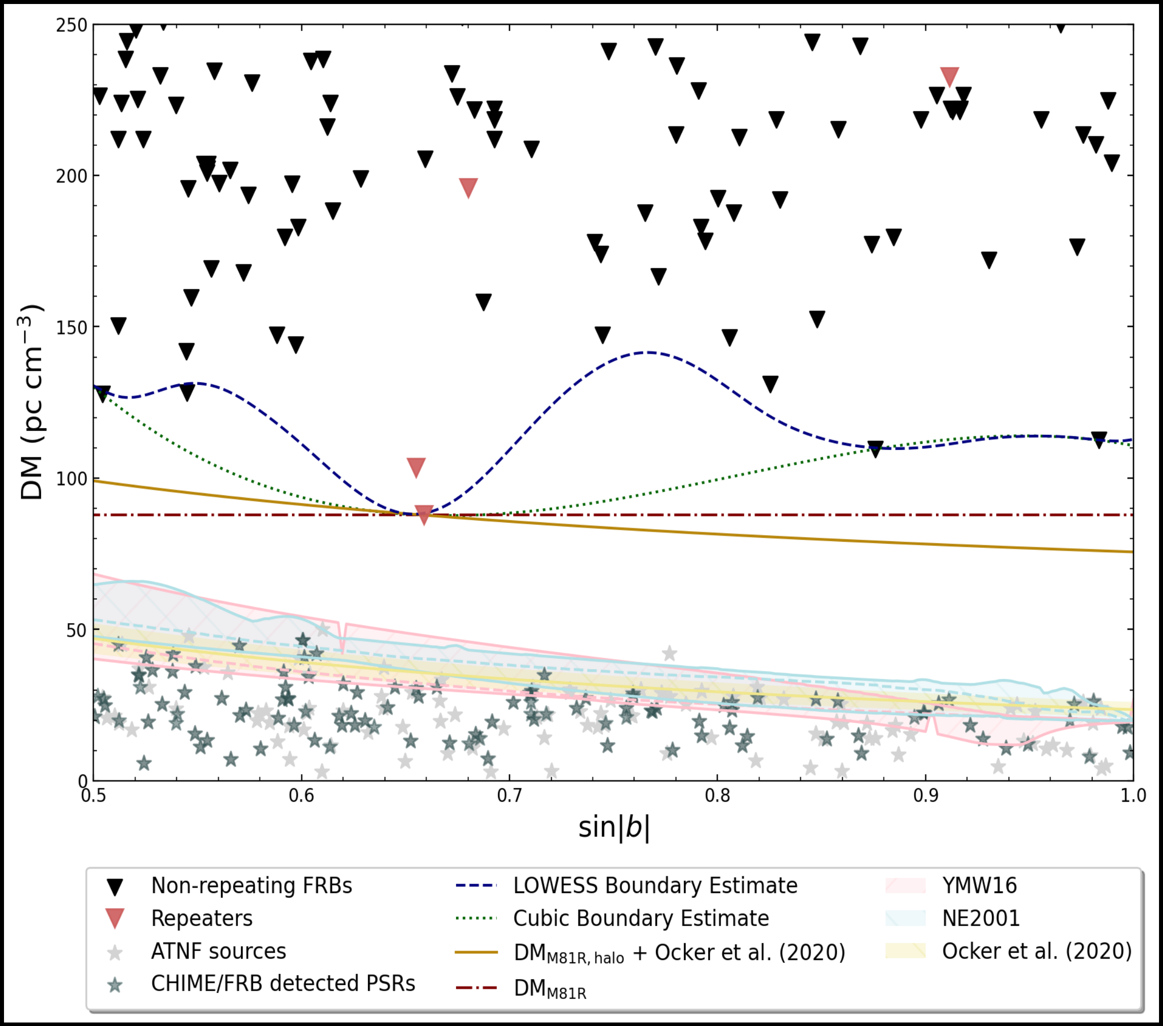
- use DM, *b* from FRB 20200120E
- Assume Ocker et al (2020) slab geometry for DM_{disk}
- Assume spherical symmetry of DM_{halo}

MW HALO MODELS

CONSTANT



MW HALO MODELS



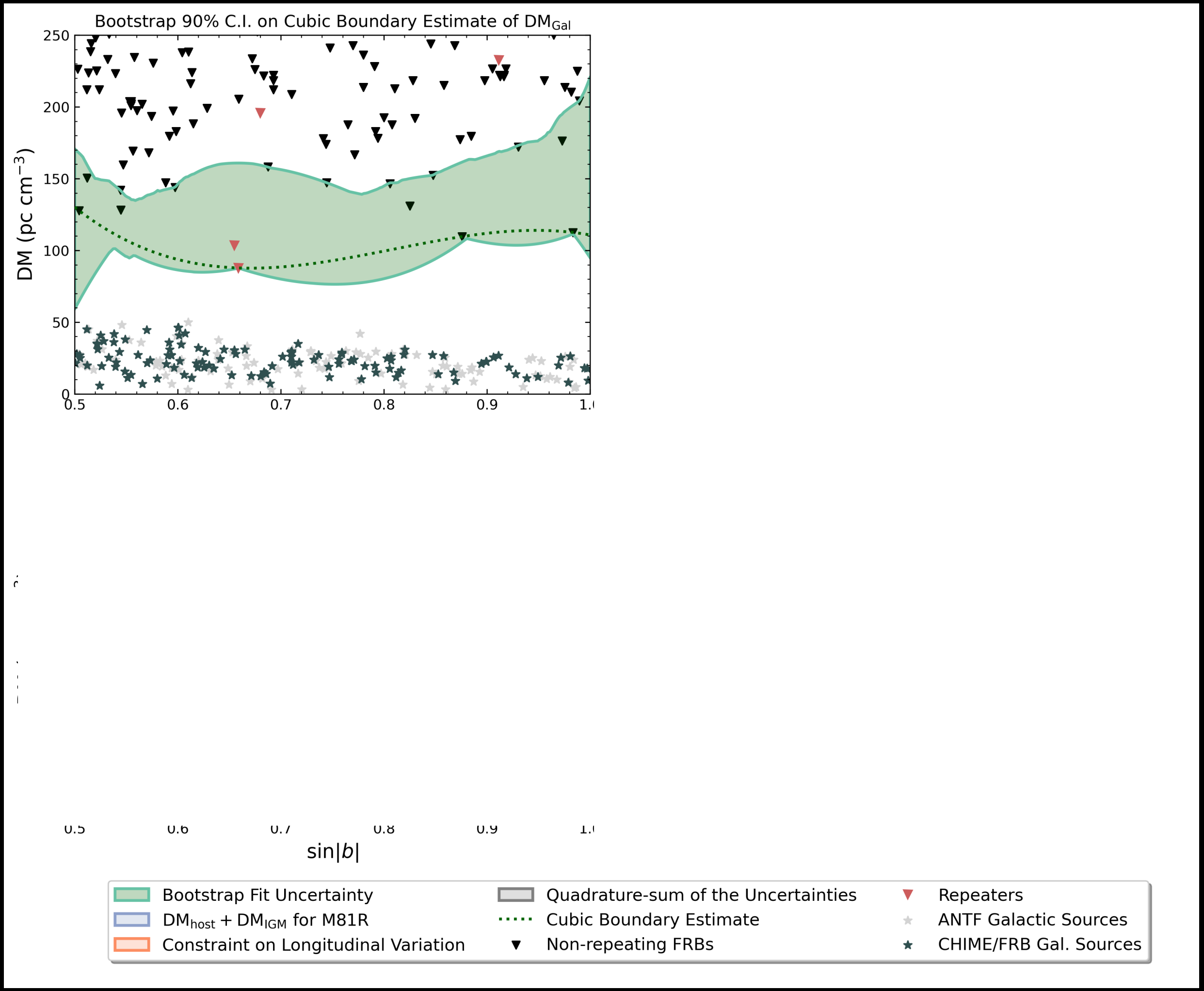
$DM_{MW} < 88$ - 141 pc cm^{-3}

$DM_{halo} < 52 – 111$ pc cm^{-3}

**Using Ocker et al (2020) to remove DM_{disk} gives DM_{halo} upper limits

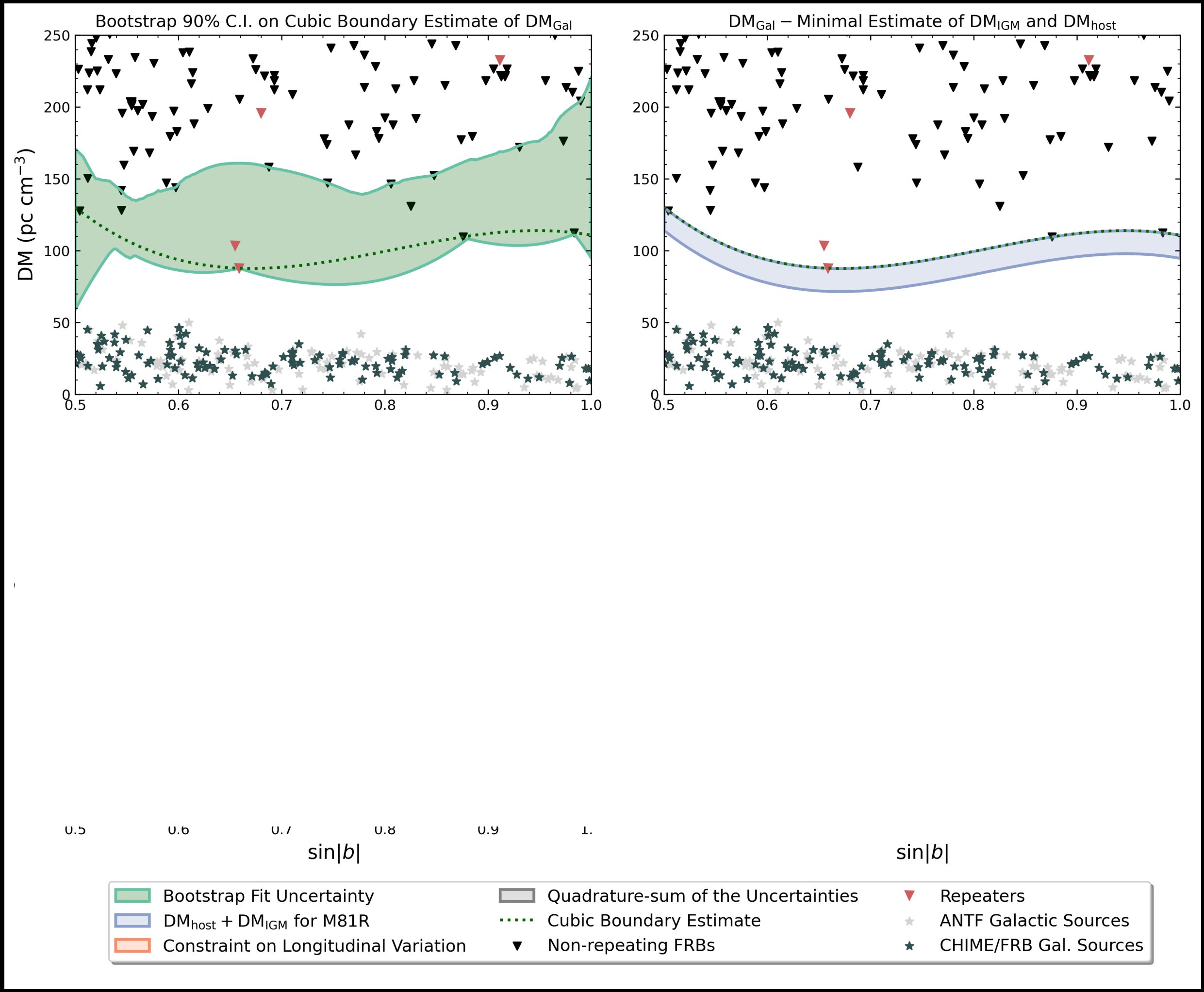
MODEL UNCERTAINTIES?

- Bootstrap ⇨ 90% confidence interval for fit



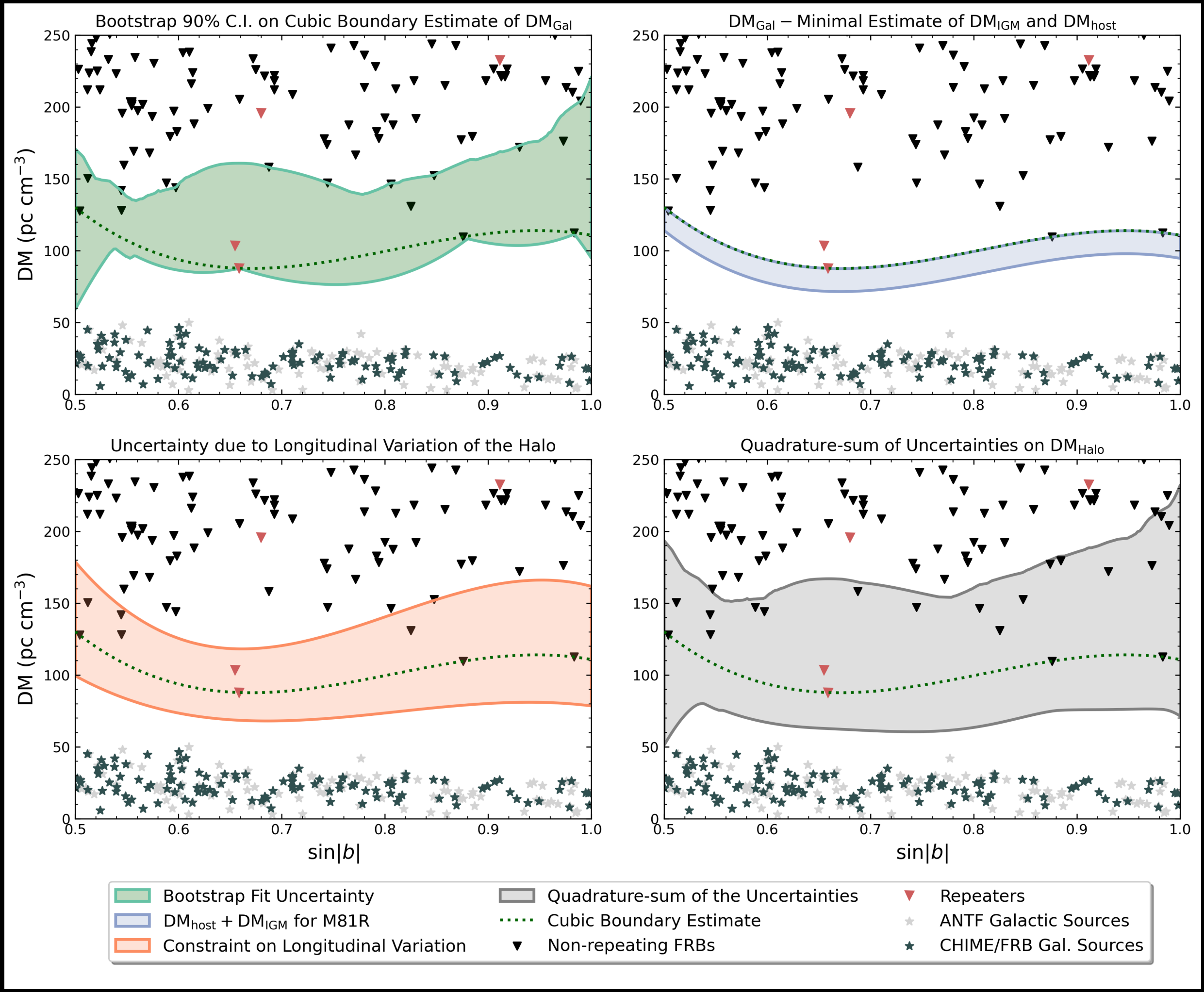
MODEL UNCERTAINTIES?

- Bootstrap ⇨ 90% confidence interval for fit
- Basic assumptions about DM_{host} (MW-like) and DM_{IGM} (Maquart relation) give estimate of isolated DM_{halo}



MODEL UNCERTAINTIES?

- Yamasaki & Totani (2020): scatter in the X-ray EM data ⇨ ~ 0.2 dex fluctuation of the MW halo DM over the whole sky
- Bootstrap ⇨ 90% confidence interval for fit
- Basic assumptions about DM_{host} (MW-like) and DM_{IGM} (Maquart relation) give estimate of isolated DM_{halo}



Joint Bayesian Analysis

Parameter	Symbol	Units	Prior
Host galaxy DM	$\mathrm{DM_{host}}$	pc cm^{-3}	log-normal($\mu_{\rm host} = 36.55, \sigma_{\rm host} = 1.27$)
MW WIM disk DM	$\mathrm{DM_{disk}}$	pc cm^{-3}	Normal($\mu_{\rm disk} = 23.5/\sin\|b\|$, $\sigma_{\rm disk} = 2.5/\sin\|b\|$)
Mean MW halo DM	$\mu_{\rm halo}$	pc cm^{-3}	Uniform(min = 0, max = DM)
MW halo DM std. deviation	$\sigma_{\rm halo}$	pc cm^{-3}	Uniform(min = 0, max = 0.4)
MW halo DM	$\mathrm{DM_{halo}}$	pc cm^{-3}	log-normal($\mu_{\rm halo}, \sigma_{\rm halo}$)
IGM DM	$\mathrm{DM_{IGM}}$	pc cm^{-3}	Equation 4 from Macquart et al. (2020)

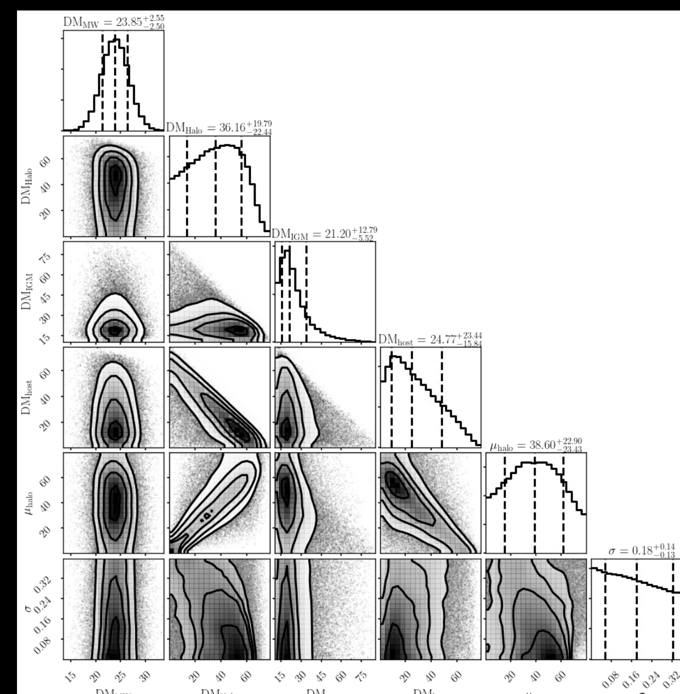
Assume:

1. Macquart (2020) $\mathrm{DM_{IGM}}$ prior
2. $\mathrm{DM_{host}}$ prior from IllustrisTNG's "FRB-like" galaxies at z=0.1 (Zhang et al 2020)
3. $\mathrm{DM_{disk}}$ from Ocker et al 2020
4. $\mathrm{DM_{halo}}$ distribution can be described using log-normal distribution

Four FRB sightlines with known redshift combined give mean MW halo DM estimate of

33^{+25}_{-22} pc cm^{-3}

Mohit Bhardwaj



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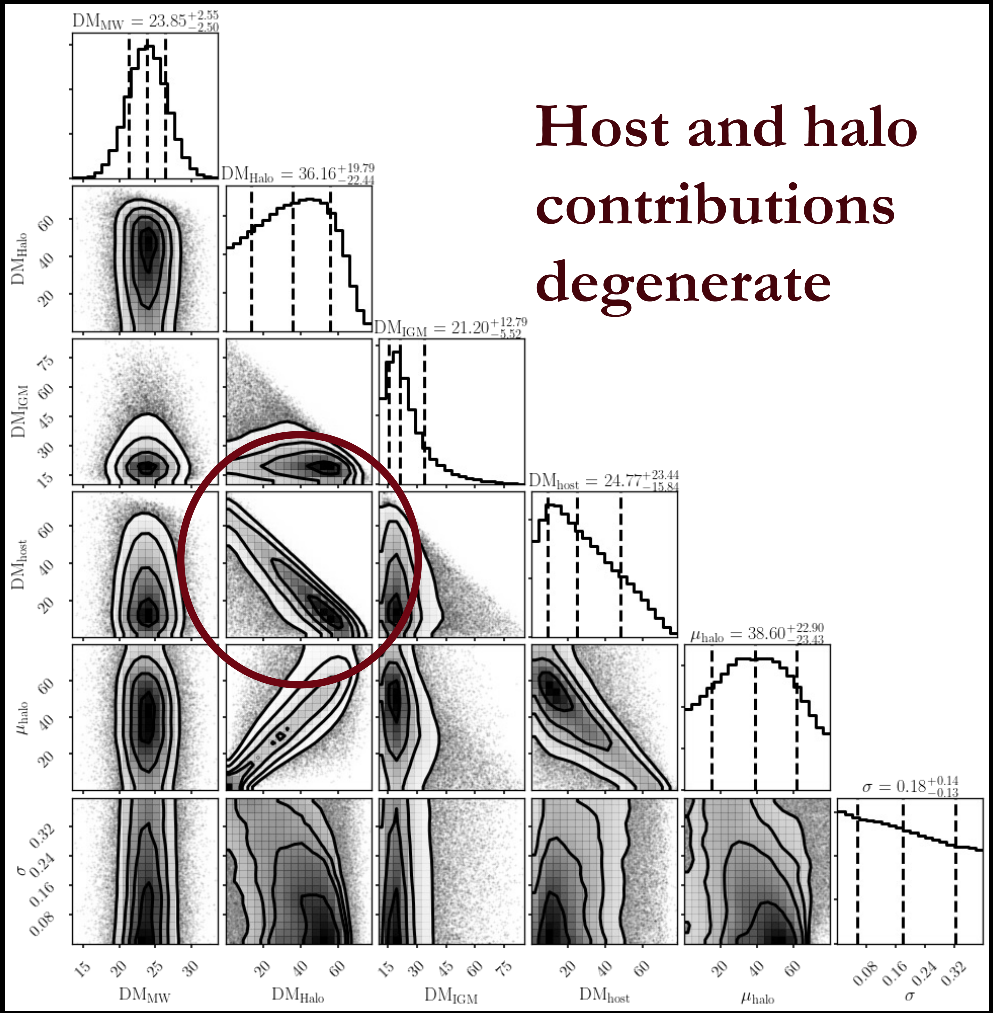
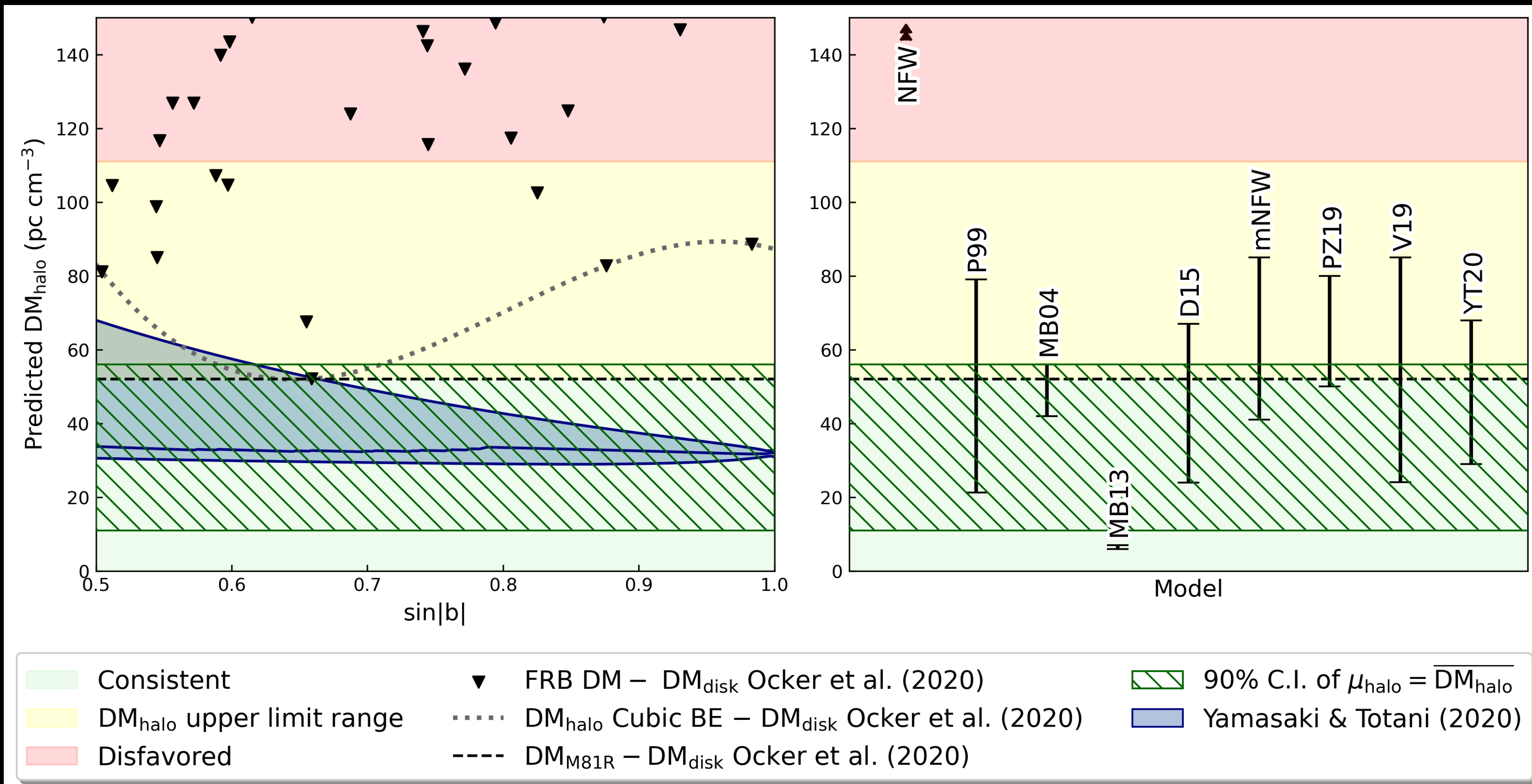


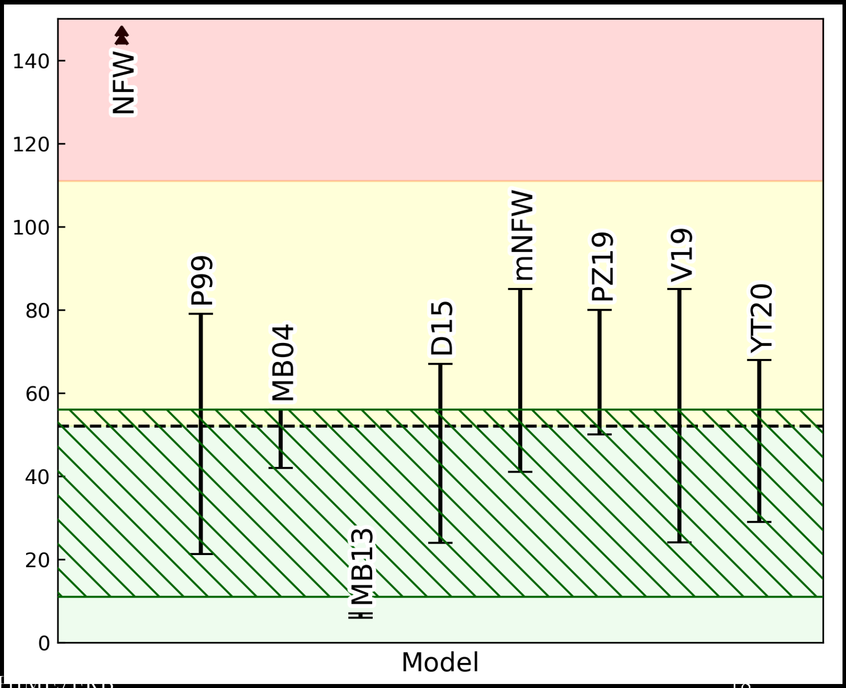
COMPARISON TO MODEL PREDICTIONS



COMPARISON TO MODEL PREDICTIONS

Summary:

- NFW profile inconsistent
- Higher mass (3.5×10^{12} $M_\odot$) scenario of most models ruled out
- Dolag et al (2015) cosmological simulation remains relevant
- MB13 low but possible if:
    1. MW halo is very clumpy (or)
    2. $DM_{M81\ halo}$ >> DM_{halo}
- Feedback processes substantial



CONCLUSIONS

- We present FRB derived constraints as a function of Galactic latitude for the plasma in the Galaxy and MW halo

- Observation based high-latitude constraints on
$$DM_{MW}(b) = DM_{halo} + DM_{disk} < 88 - 141 \text{ pc cm}^{-3}$$

- $DM_{halo}(b) < 52 – 111$ pc cm^{-3}

- $\mu(DM_{halo}) = 33^{+25}_{-22}$ pc cm^{-3}