First statistical evidence of cosmological baryonic fluctuation revealed by localized Fast Radio Bursts

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Introduction

The Missing Baryon Problem

30% of baryons are missing!

Astronomers think that they reside in the diffuse gas, which is very low-density, of the intergalactic medium (IGM) and undetectable.
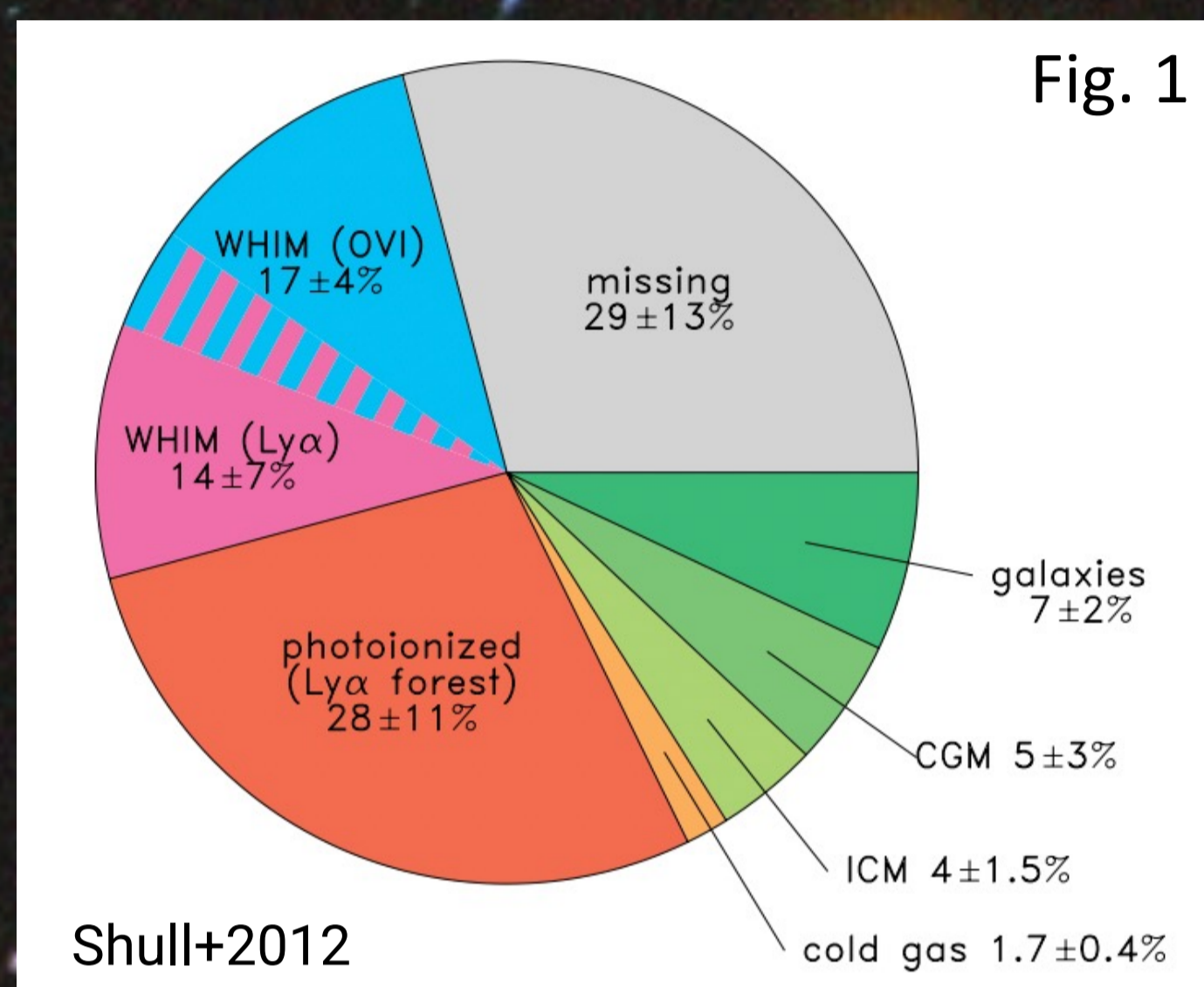

Fig. 1

Shull+2012

Fig. 1 shows the distribution of baryons in the universe

Solution: Dispersion Measure from Fast Radio Bursts (FRB)

What are FRBs?

1. Bright and millisecond duration transient
2. Most of them originated out of the Milky Way
3. ~30 are localized
4. Unique observable: Dispersion Measure (DM)

DM = Time lag of different frequencies
$\propto$ How many baryons are in line of sight
DM is mainly composed of 3 parts:

$$DM_{obs} = DM_{MW} + DM_{IGM} + \frac{DM_{host}}{(1+z)}$$

Observation · Milky Way · Intergalactic medium (IGM) · Host galaxy

DM - z relation

Significant amount of missing baryons reside in the IGM
The scatter of the data points relative to the theoretical predicted average DM_{IGM} could be caused by cosmological baryonic fluctuation
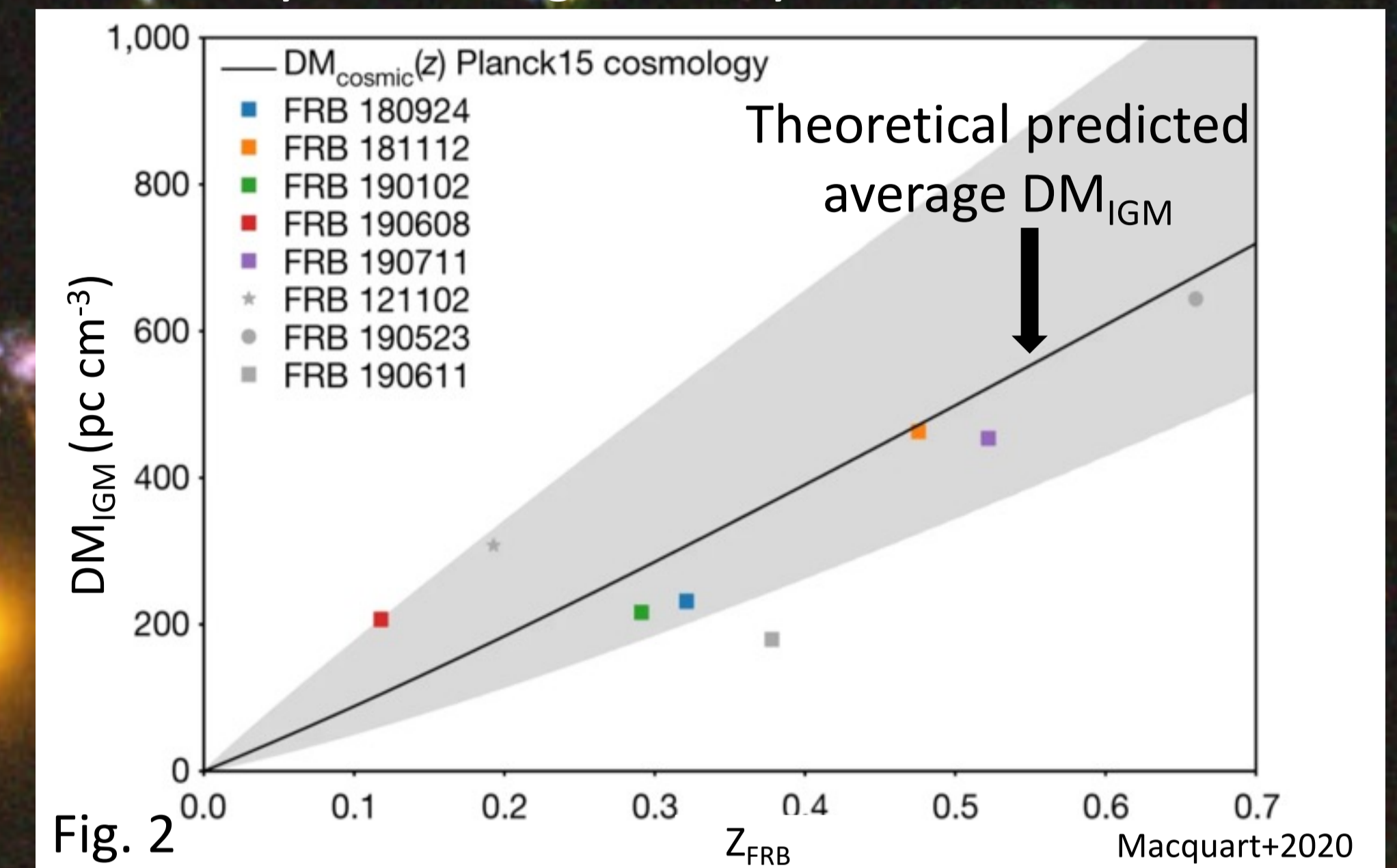

Theoretical predicted average DM_{IGM}

Fig. 2   Macquart+2020

Methods

How to improve DM_{IGM} estimation?

DM_{host} estimated by scattering time

Scattering time (τ)

Pulse broadening effect caused by multipath propagation in the turbulence of the plasma in the vicinity of where FRB emits (Fig. 3).
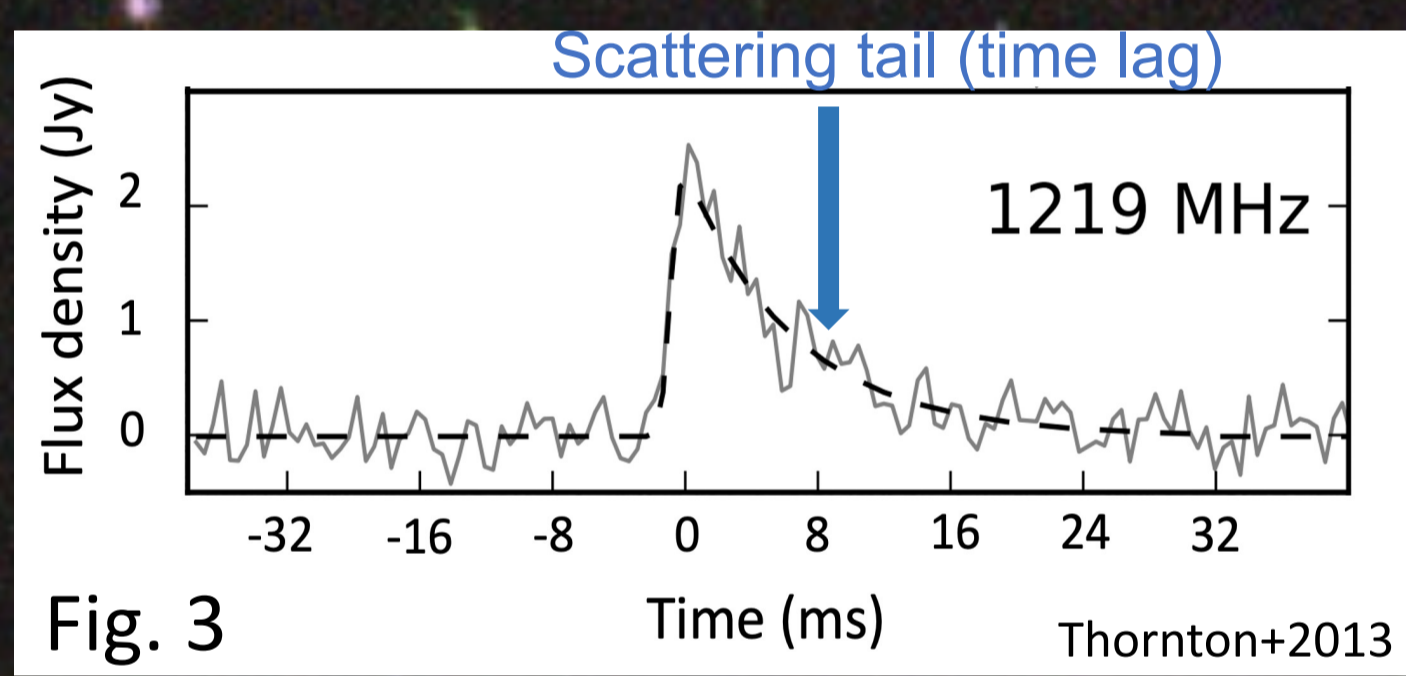
$$DM_{IGM} = DM_{obs} - DM_{MW} - \frac{DM_{host}}{(1+z)}$$

Observation · NE2001 model · Estimated by τ

DM_{host} can be estimated by scattering time from the empirical relation of the pulsar, assuming scattering only happens in the host galaxy (Fig. 4).

Scattering tail (time lag)
1219 MHz
Fig. 3   Thornton+2013

$\tau(DM) = 1.90 \times 10^{-7}ms\,DM^{1.5}(1 + 3.55 \times 10^{-5}DM^{3.0})$
$\sigma_{log\tau} = 0.76$
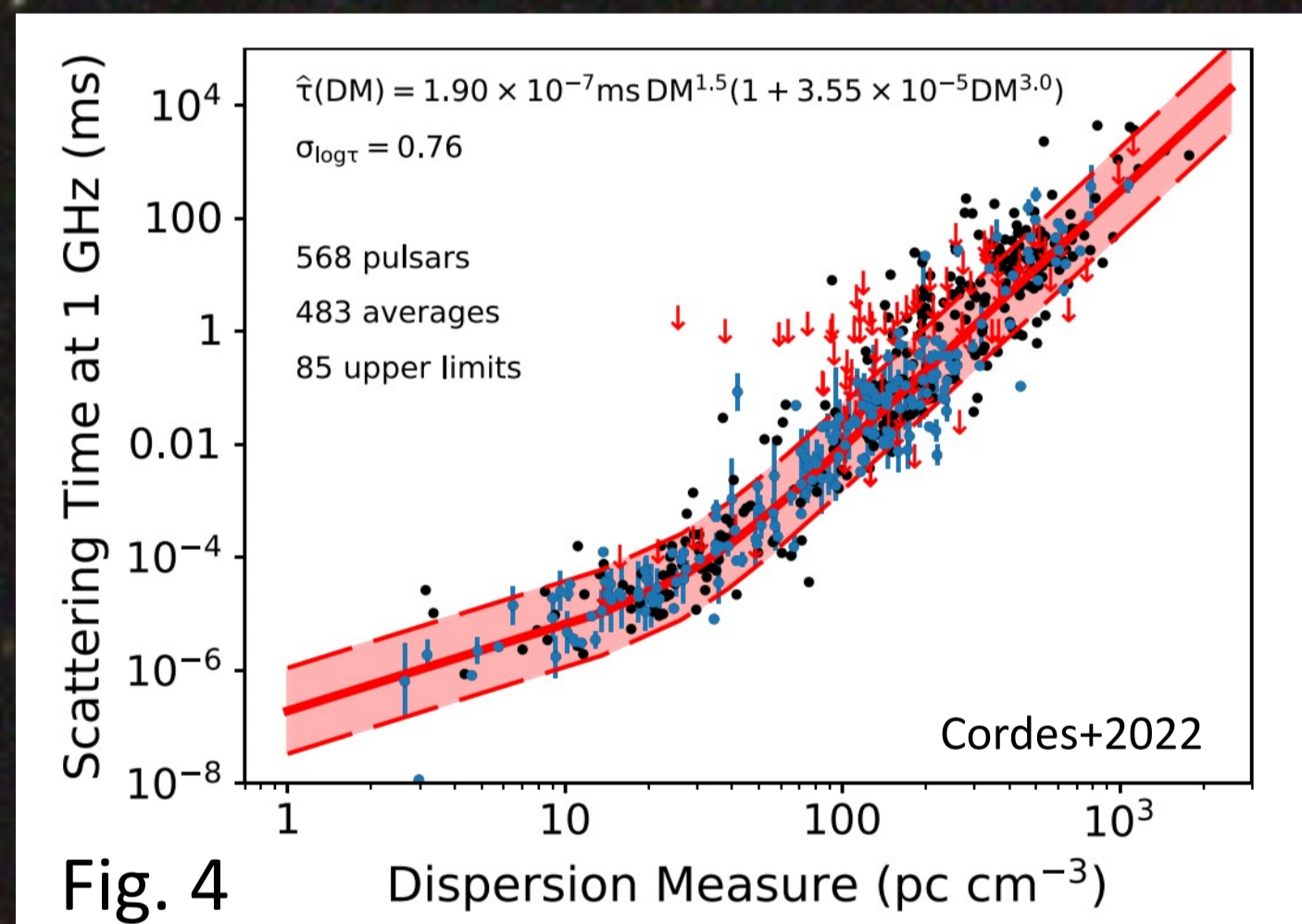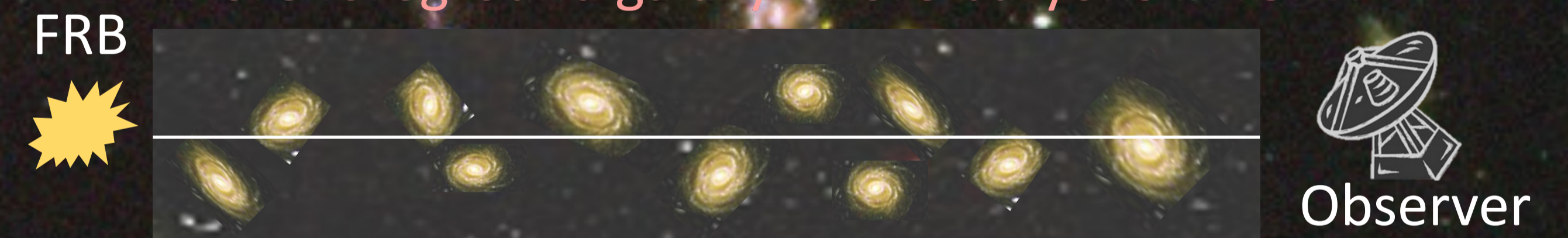568 pulsars
483 averages
85 upper limits
Fig. 4   Cordes+2022

How to quantify the fluctuation?

Count the foreground galaxies of FRBs within an aperture of radius of 1 Mpc! The radius is chosen by the typical halo size.

More foreground galaxy: More baryons in IGM?

FRB · Observer

Less foreground galaxy: Less baryons in IGM?

FRB · Observer

Results: First statistical evidence of cosmological baryonic fluctuation

DM-z relation with our sample

Red and blue data represent FRB encounters high ($\sigma > 0$) / low ($\sigma \leq 0$) foreground galaxy number density. Most of the red data points are above the theoretical predicted average DM_{IGM} and vice versa for the blue data points.
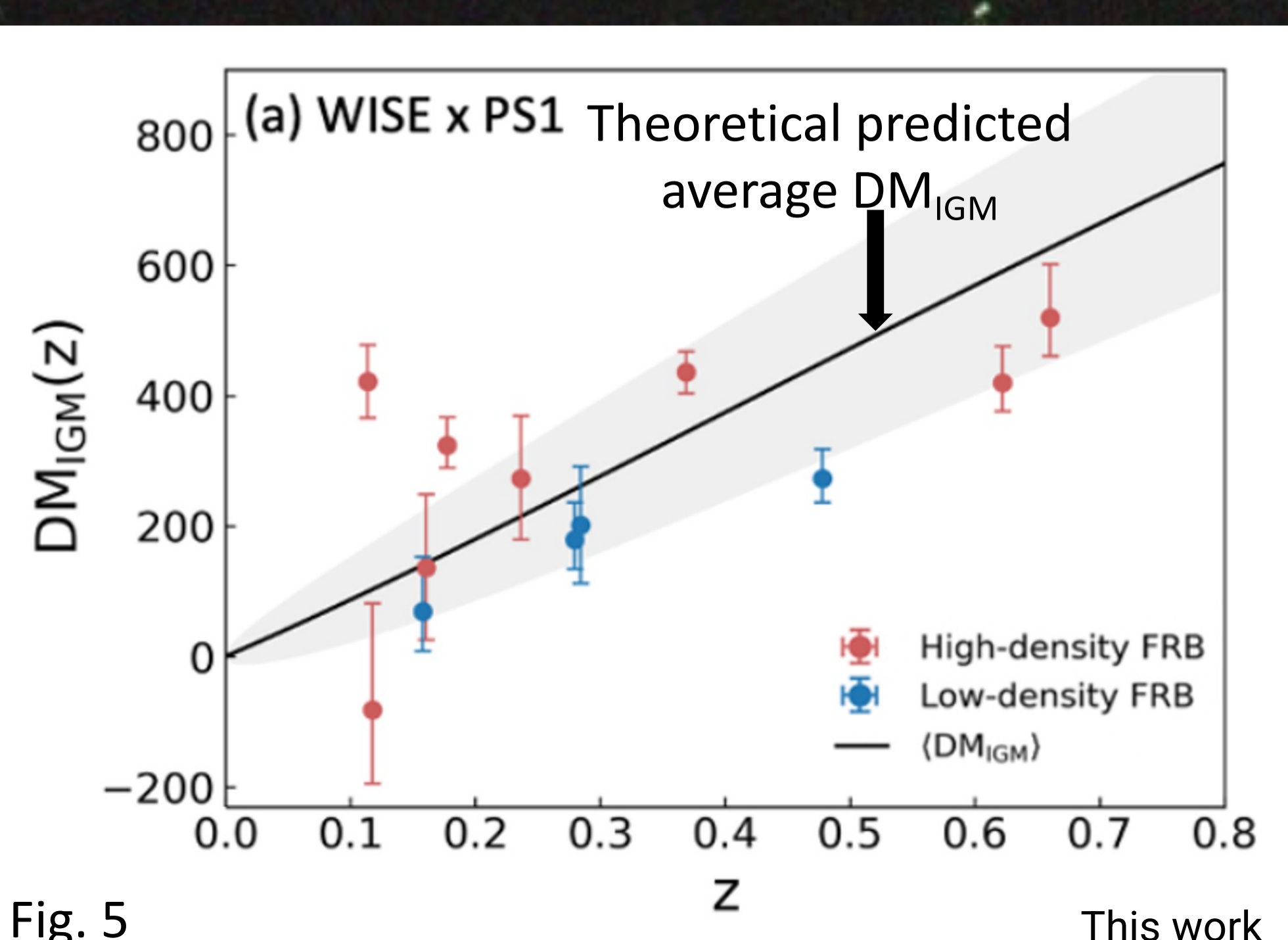

(a) WISE x PS1   Theoretical predicted average DM_{IGM}
High-density FRB
Low-density FRB
$\langle DM_{IGM} \rangle$
Fig. 5   This work

DM excess – galaxy density

DM excess increases with foreground galaxy number density with a statistical significance of p-value = 0.003 for the correlation in Fig.6

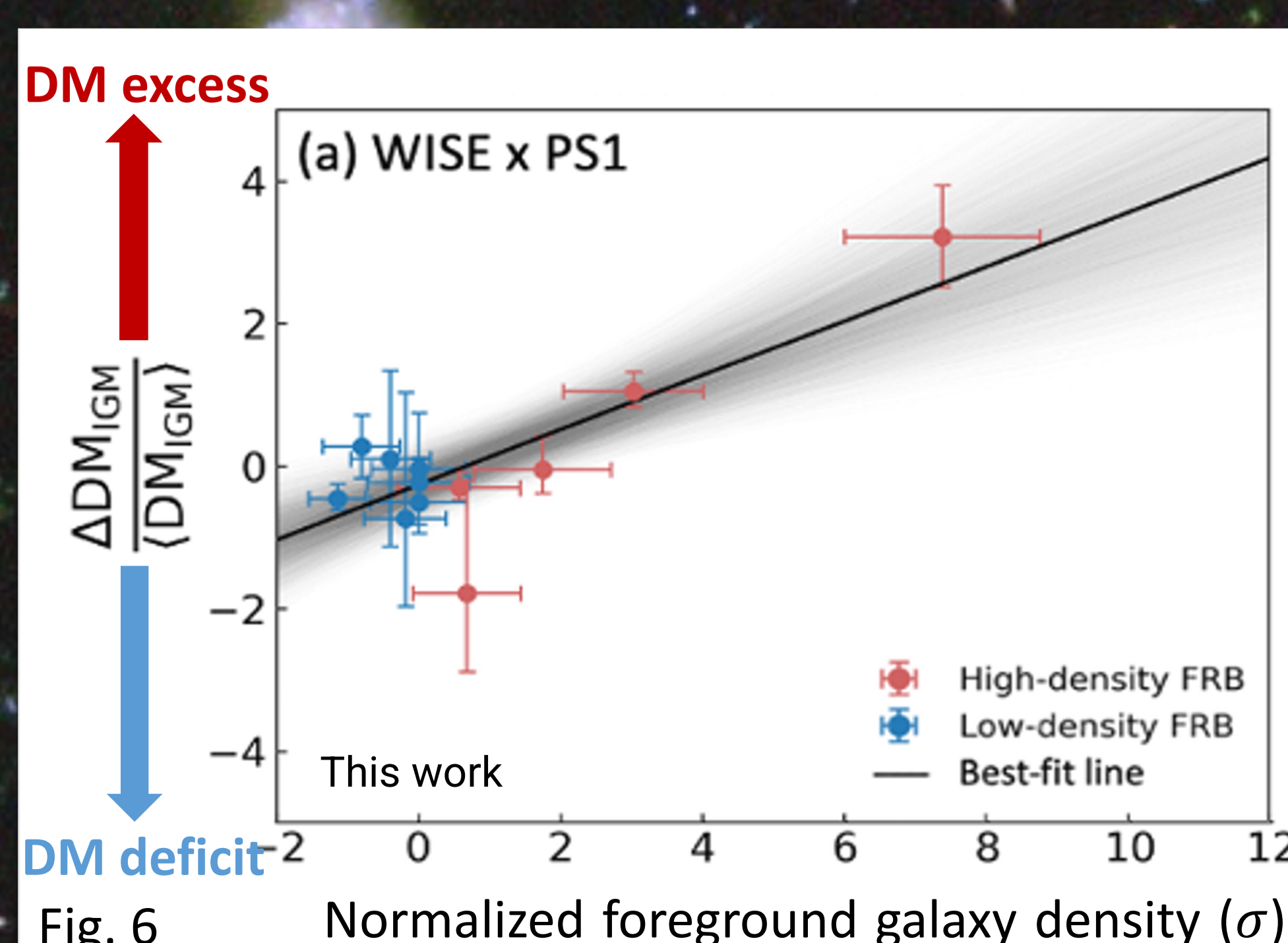-> **First statistical evidence of cosmological baryonic fluctuation**

DM excess
(a) WISE x PS1
High-density FRB
Low-density FRB
Best-fit line
This work
DM deficit
Fig. 6

Baryonic fluctuation scale

Using different radii to calculate galaxy density and test the p-value of the correlation (Fig.6). The correlation becomes less significant (higher p-values) when r > 1.5 Mpc, which indicates the **typical baryonic fluctuation scale of < 1.5 Mpc.** It is the first measurement of the baryonic fluctuation scale in IGM
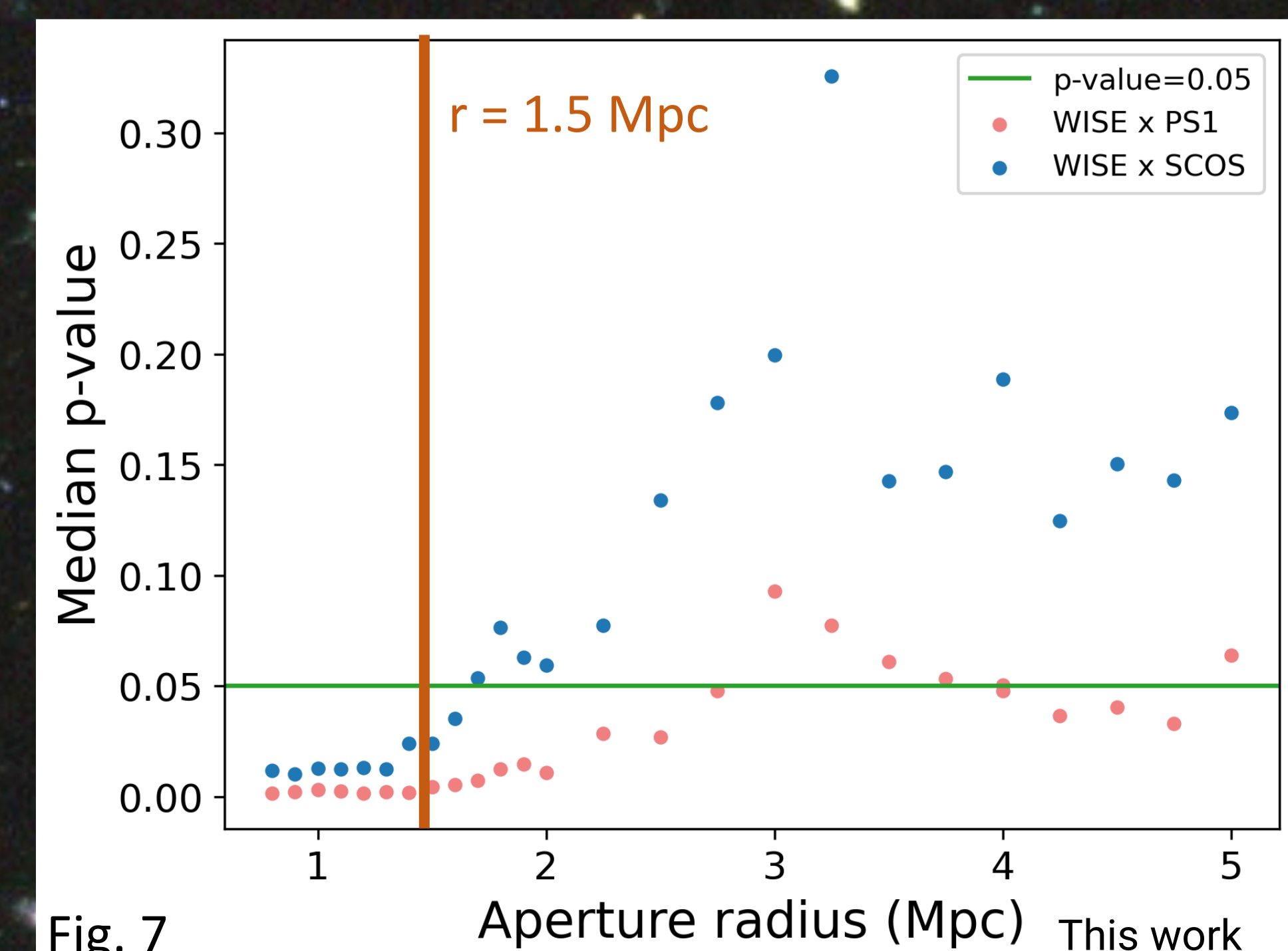

r = 1.5 Mpc
p-value=0.05
WISE x PS1
WISE x SCOS
Fig. 7   This work