Fast Radio Bursts and Cosmology

Steffen Hagstotz
with Robert Reischke & Robert Lilow

IPMU
20 I 5 I 2021

Overview

1. Fast Radio Burst cosmology
2. Dispersion measure correlations
3. FRB distance scale and the Hubble parameter

Overview

1. **Fast Radio Burst cosmology**
2. Dispersion measure correlations
3. FRB distance scale and the Hubble parameter

Fast Radio Bursts

- Mechanism unknown
- First discovered in archival data 2007
- Short (~ms), bright (~Jy) radio transients
- Frequencies 300 Mhz - 8 Ghz
- Extragalactic
- About 100 known events, soon several 1000s
- Some events are repeating

Proposed Mechanisms

A Living Theory Catalogue for Fast Radio Bursts

E. Platts[a,*], A. Weltman[a], A. Walters[b,c], S. P. Tendulkar[d], J.E.B. Gordin[a], S. Kandhai[a]

arXiv 1810.05836

www.frbtheorycat.org

Main Page

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2 Contributing to the Wiki
  2.1 Rules and Guidelines
3 Summary Table

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Neutron stars? Mergers? AGN?

Article | Published: 04 November 2020

A bright millisecond-duration radio burst from a Galactic magnetar

The CHIME/FRB Collaboration

Nature **587**, 54–58(2020) | Cite this article

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1 Welcome to t

Fast Radio Bursts from Extragalactic Light Sails

Manasvi Lingam, Abraham Loeb

We examine the possibility that Fast Radio Bursts (FRBs) originate from the activity of extragalactic civilizations. Our analysis shows that beams used for powering large light sails could yield parameters that are consistent with FRBs. The characteristic diameter of the beam emitter is estimated through a combination of energetic and engineering constraints, and both approaches intriguingly yield a similar result which is on the scale of a large rocky planet. Moreover, the optimal frequency for powering the light sail is shown to be similar to the detected FRB frequencies. These `coincidences' lend some credence to the possibility that FRBs might be artificial in origin. Other relevant quantities, such as the characteristic mass of the light sail, and the angular velocity of the beam, are also derived. By using the FRB occurrence rate, we infer upper bounds on the rate of FRBs from extragalactic civilizations in a typical galaxy. The possibility of detecting fainter signals is briefly discussed, and the wait time for an exceptionally bright FRB event in the Milky Way is estimated.

November 2020

A bright millisecond-duration radio burst from a Galactic magnetar

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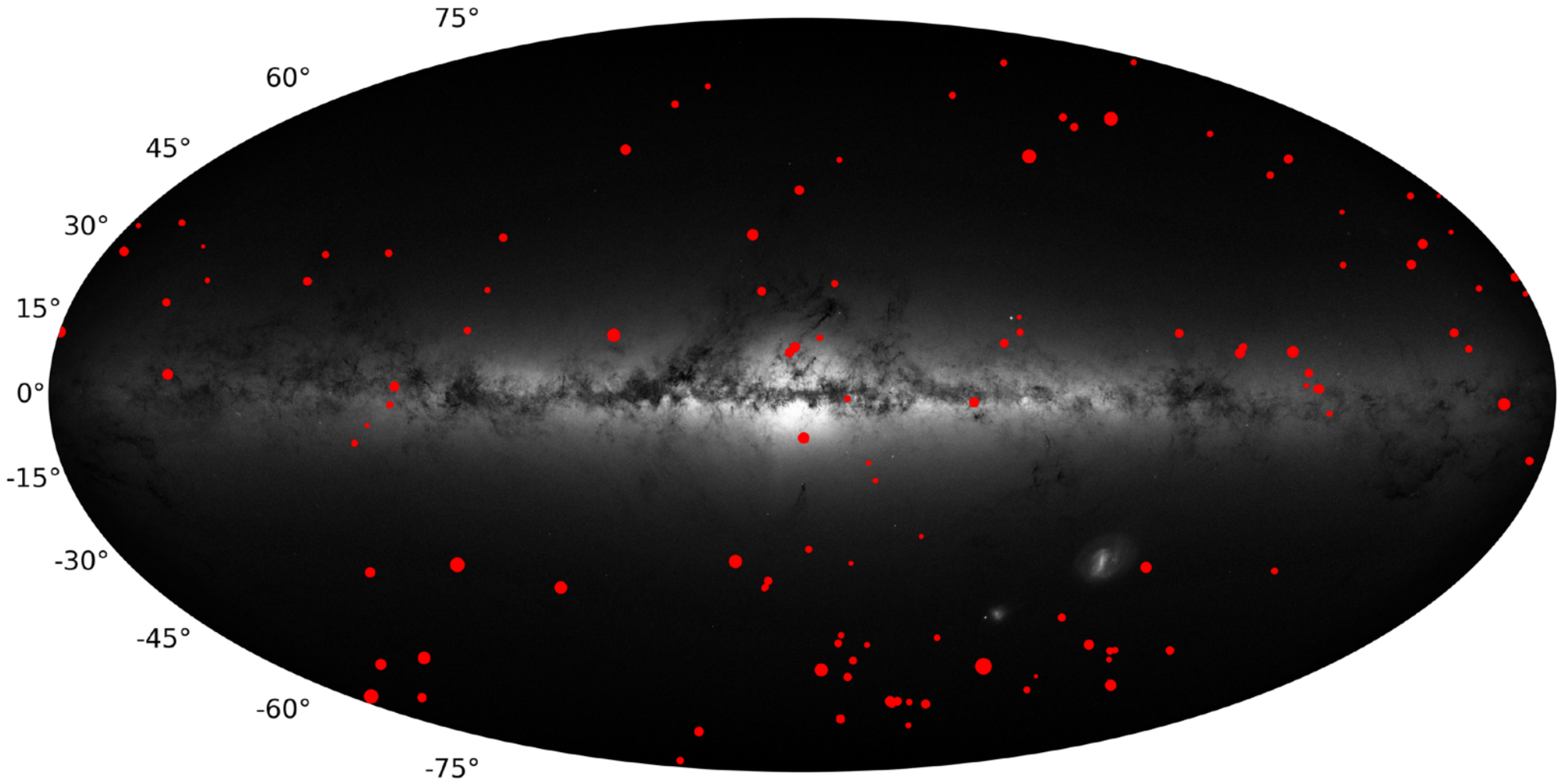
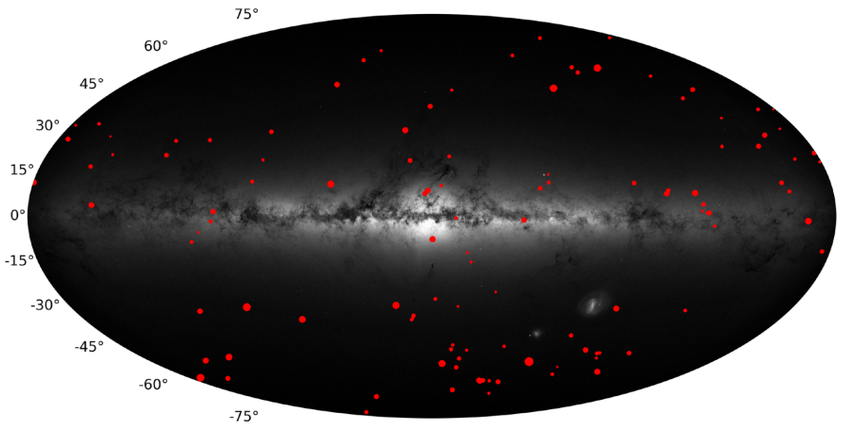
Known FRBs



Events uncorrelated with the Milky Way

Known FRBs

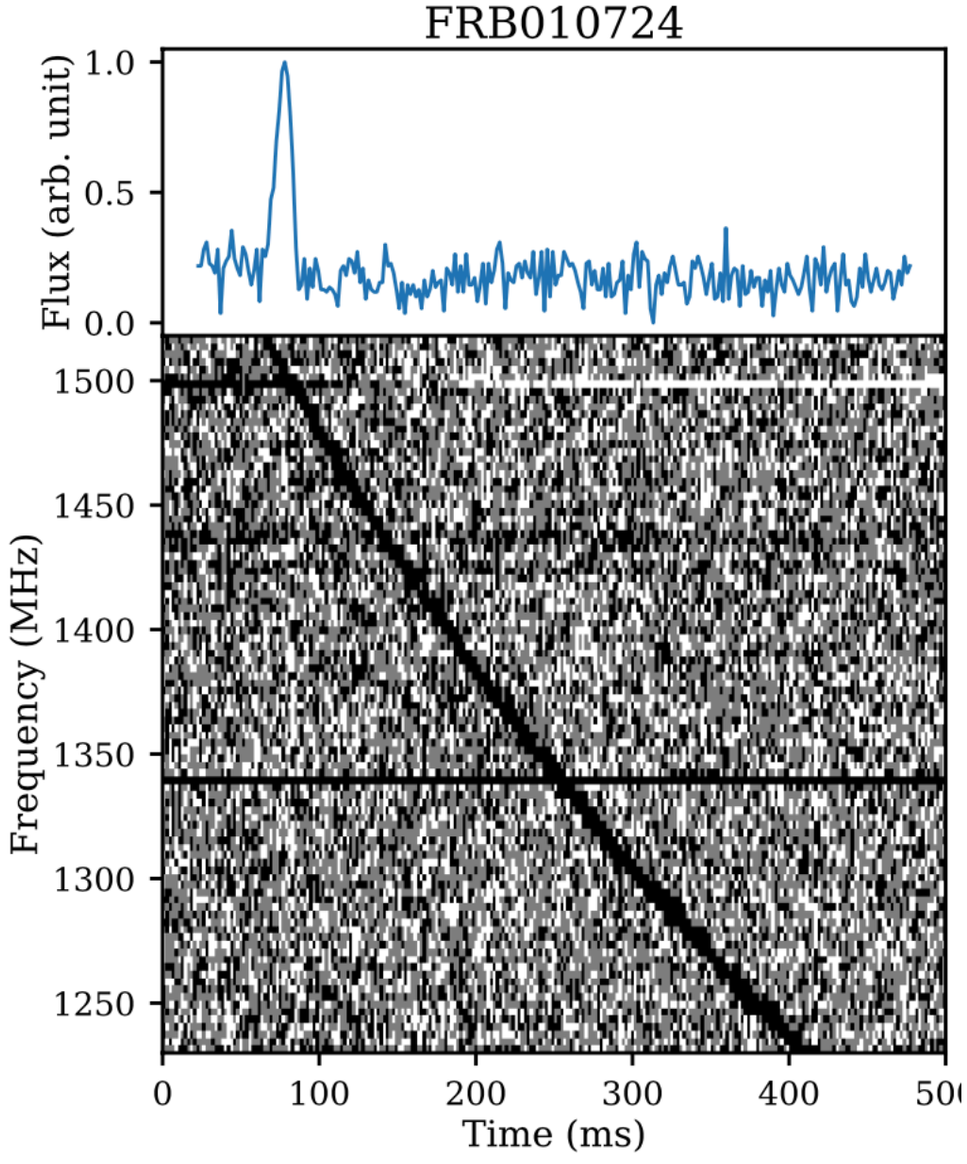


- Until now: detections mostly incidental
- Expect rates of $10^3 - 10^4$ / sky / night
- Now: dedicated searches ongoing

CHIME

ASKAP

Dispersion measure



- Radio signals undergo dispersion
- Pulse delay $\Delta t \sim \nu^{-2}$
- Depends on integrated electrons along LoS

$$\mathrm{DM} = \int \frac{n_e}{1+z} \mathrm{d}l$$

Lorimer et al 2007
Cordes & Chatterjee 2019

Dispersion measure

$$\mathrm{DM_{tot}}(z) = \mathrm{DM_{MW}} + \mathrm{DM_{LSS}}(z) + \mathrm{DM_{host}}(z)$$

LSS

Milky Way models

Can be checked with Pulsars

Quite accurate!

Host halo models

Depends on galaxy types?

Location of FRBs?

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Location of FRBs?

Redshift scaling:

const.

$$\propto \int^{z} \frac{1+z'}{E(z')} \mathrm{d}z' \quad \propto \frac{1}{1+z}$$

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Statistics can tell contributions apart

Dispersion measure

Dispersion measure has several contribution:

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Density field

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Ionisation history

Density field

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Baryon fraction

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Distance measure
Need redshifts

Baryon fraction
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Nature, volume 581, 391–395(2020)

Article

A census of baryons in the Universe from localized fast radio bursts

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Overview

1. Fast Radio Burst cosmology
2. **Dispersion measure correlations**
3. FRB distance scale and the Hubble parameter

FRB statistics

Redshifts in general not known: consider angular clustering

Correlate FRBs

$$C_\ell = \langle \delta_\ell^{\mathrm{FRB}} \, \delta_{\ell'}^{\mathrm{FRB}} \rangle$$

Sparse, noisy distances, shot-noise dominated

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signal >> noise

Because $\mathrm{DM}_{\rm LSS}(z) \gg \mathrm{DM}_{\rm host}$

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Super weak lensing*

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***(but still sparse)**

signal >> noise

Because $\mathrm{DM}_{\rm LSS}(z) \gg \mathrm{DM}_{\rm host}$

FRB statistics

Correlate dispersion measure

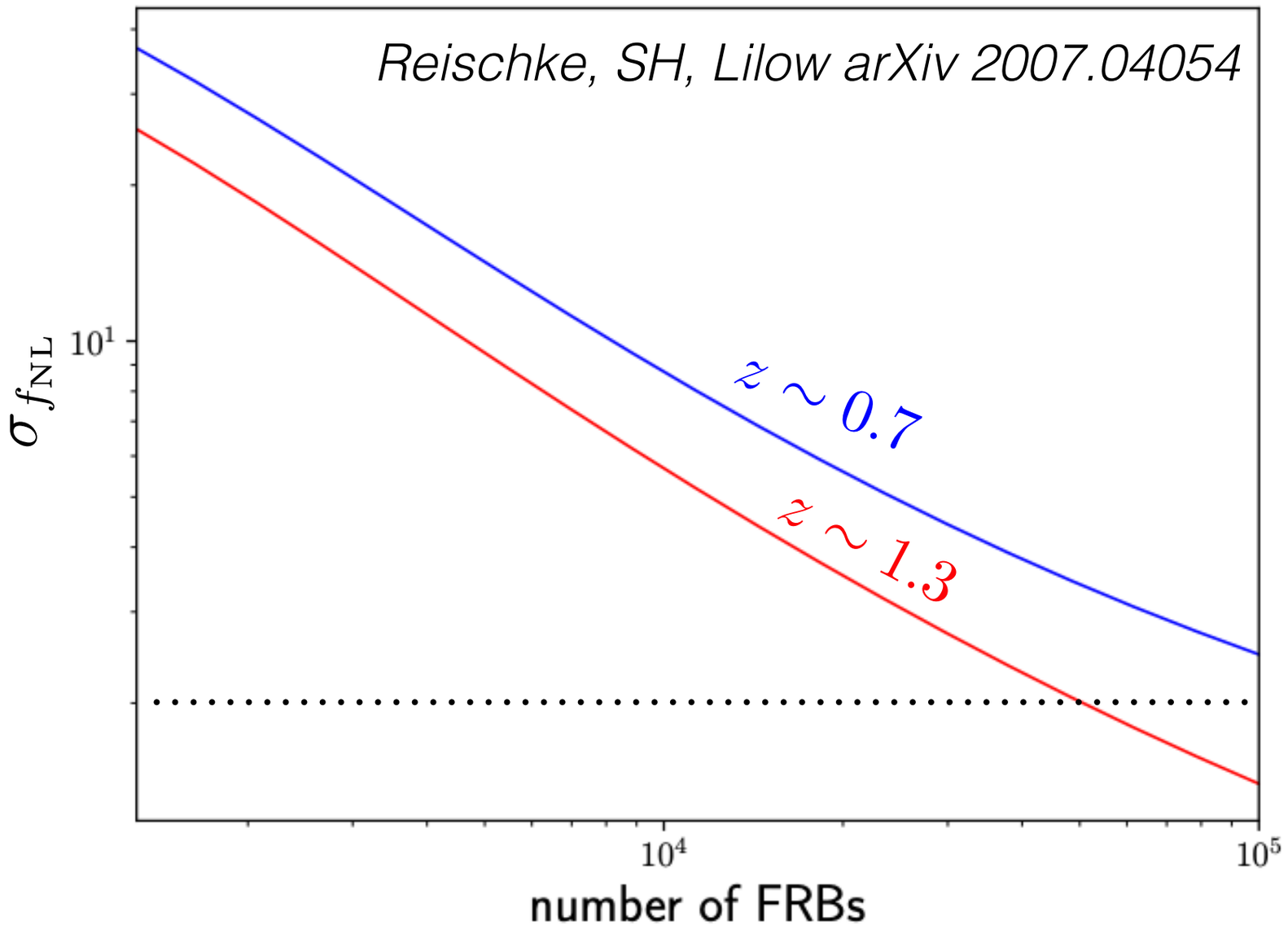
$$C_\ell = \langle \mathrm{DM}_\ell \, \mathrm{DM}_{\ell'} \rangle$$

Great for signals on large scales!

- DM correlations - Masui & Sigurdson (1506.01704)
- Cross-correlations with galaxy surveys - Rafiei-Ravandi, Smith & Masui (1912.09520)
- Primordial non-Gaussianity - Reischke, SH, Lilow (2007.04054)
- Shapiro delay tests of GR - Reischke, SH, Lilow (2102.11554)
- …

Primordial Non-Gaussianity

FRBs could cover large volumes faster than galaxy surveys



- Tomographic $C_\ell^{\rm DM}$ analysis without host ID
- Competitive limits if we get ~1000 events/night

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Equivalence principle tests

Reischke, SH, Lilow arXiv 2102.11554

- True observable: time delay between frequency arrival $\Delta t = \Delta t_{\rm DM} + \Delta t_{\rm grav}$

- Shapiro delay

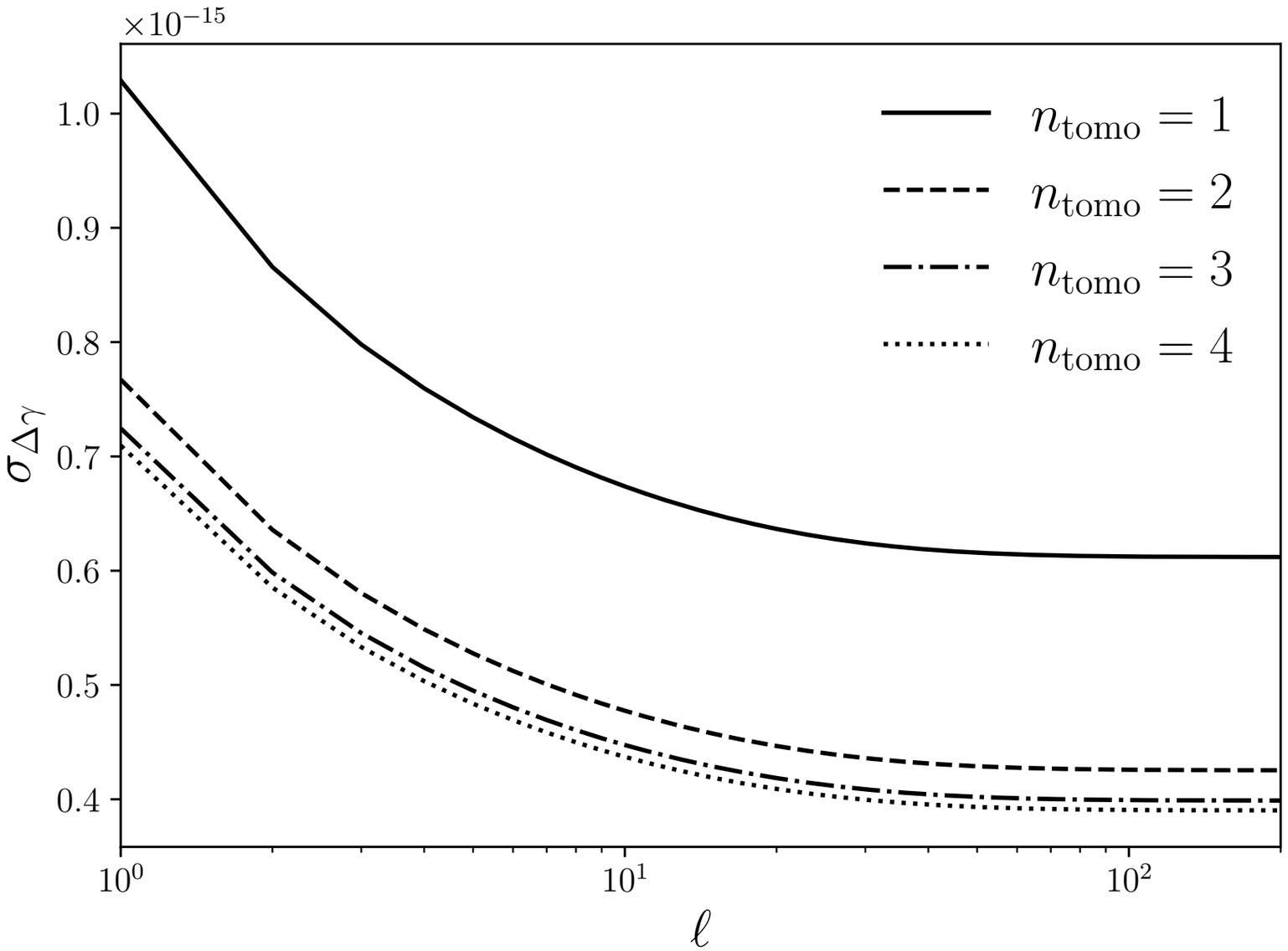
Possible frequency dependence

$$\Delta t_{\rm grav} = \frac{\Delta\gamma}{c^3}\int {\rm d}\chi a(\chi)\phi(\hat{\boldsymbol{x}}\chi)$$

- Can imprint additional correlations when interpreted as DM signal

Equivalence principle tests

Reischke, SH, Lilow arXiv 2102.11554



- Events ~ms, line of sight ~Gpc
- Any $\Delta\gamma$ would completely dominate the correlation signal

Overview

1. Fast Radio Burst cosmology
2. Dispersion measure correlations
3. **FRB distance scale and the Hubble parameter**

Distance scales

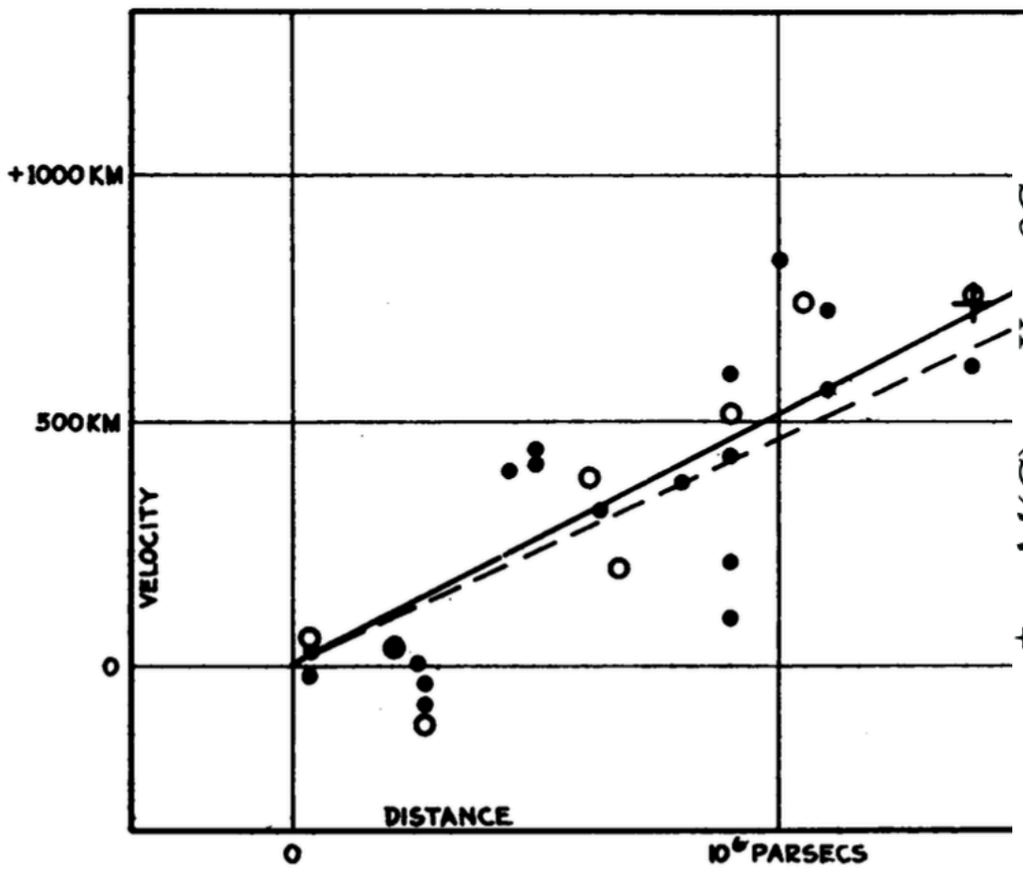
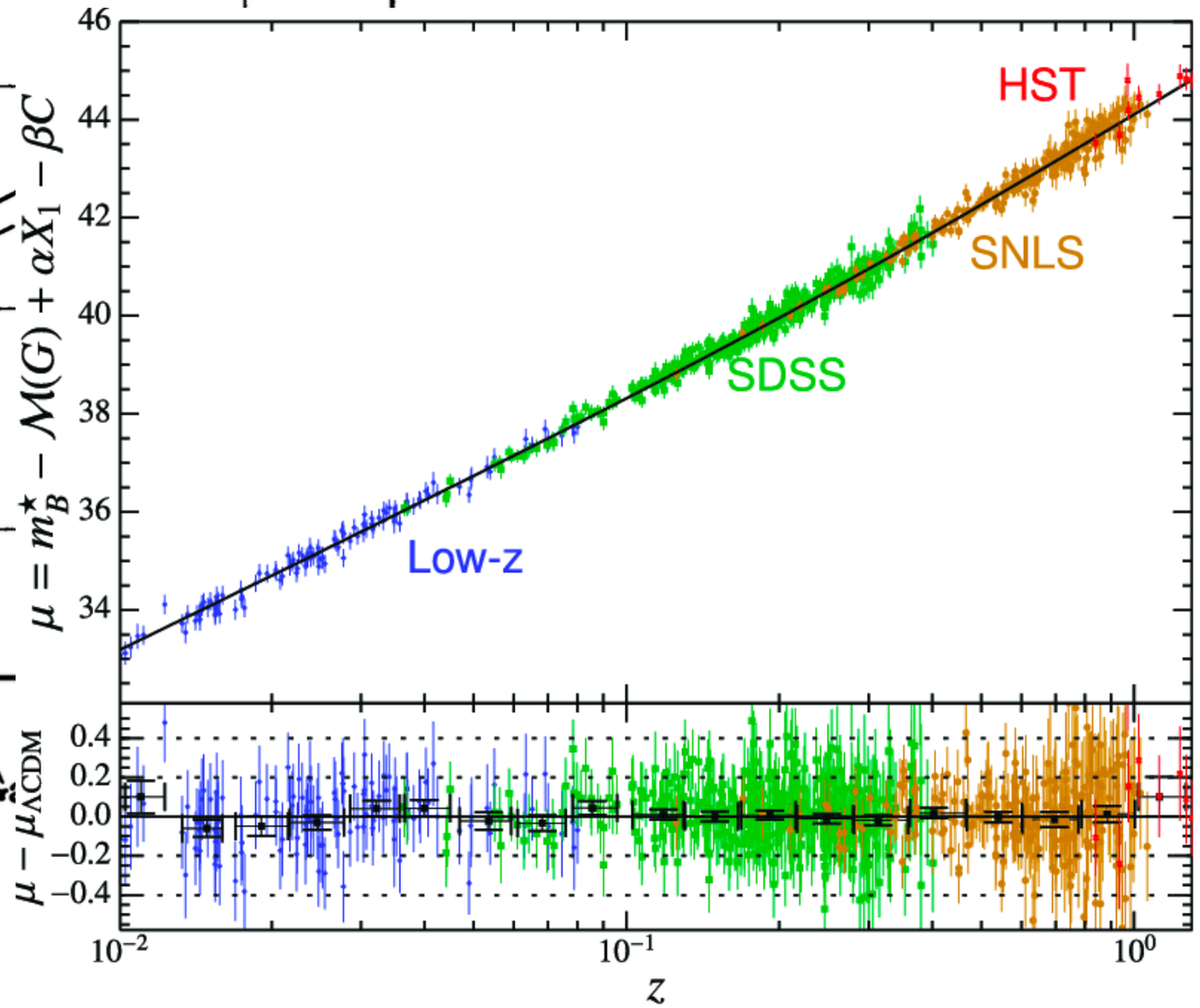


FIGURE 1

Velocity-Distance Relation among Extra-G



Bahcall 2015

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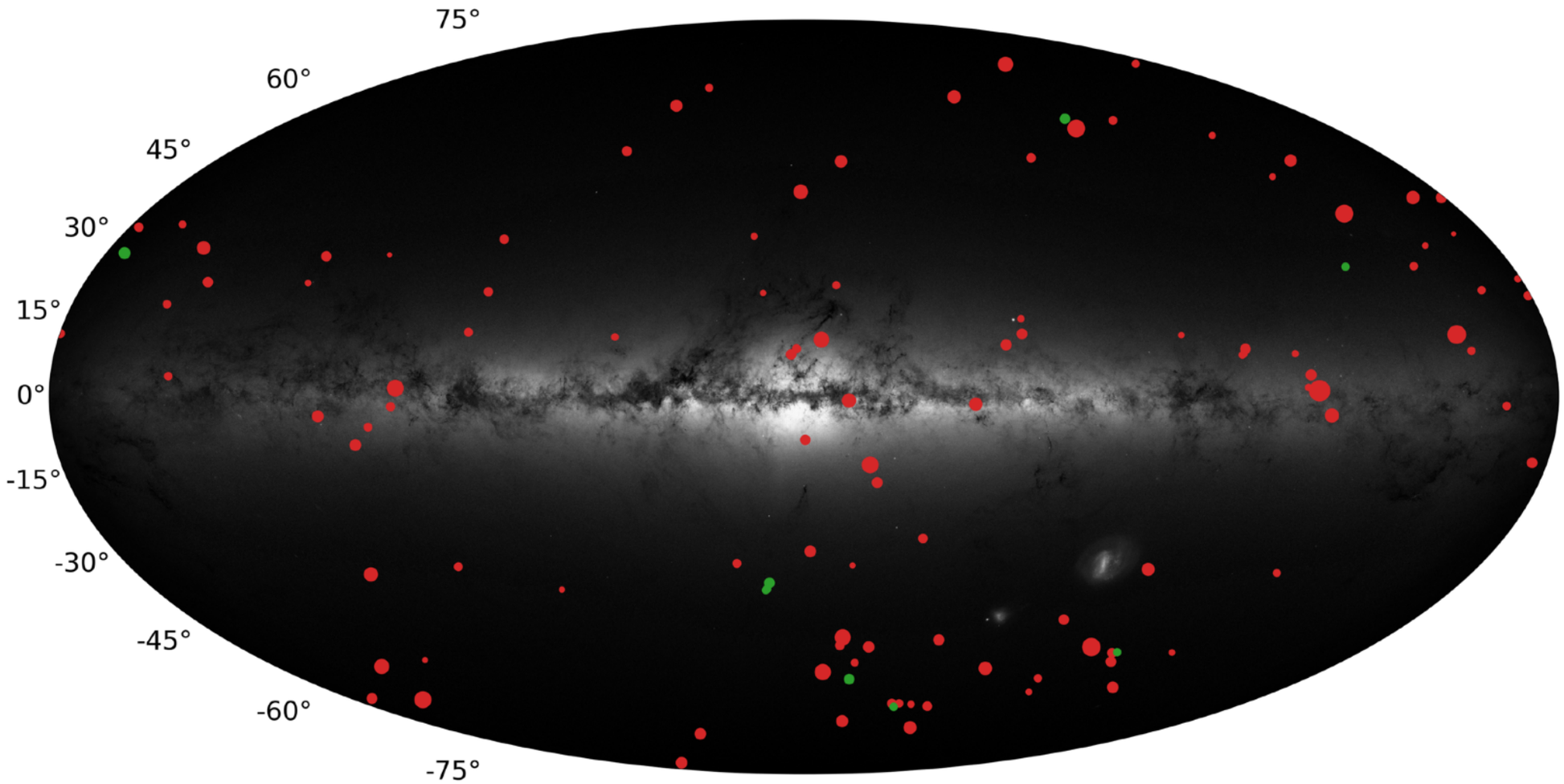
FRB distance scale

Mean LSS dispersion

$$< \mathrm{DM_{LSS}} > (z) = \frac{3\Omega_\mathrm{b} H_0}{8\pi G m_\mathrm{P}} \chi_\mathrm{e} f_\mathrm{IGM} \int^z \frac{1+z'}{E(z')} \mathrm{d}z'$$

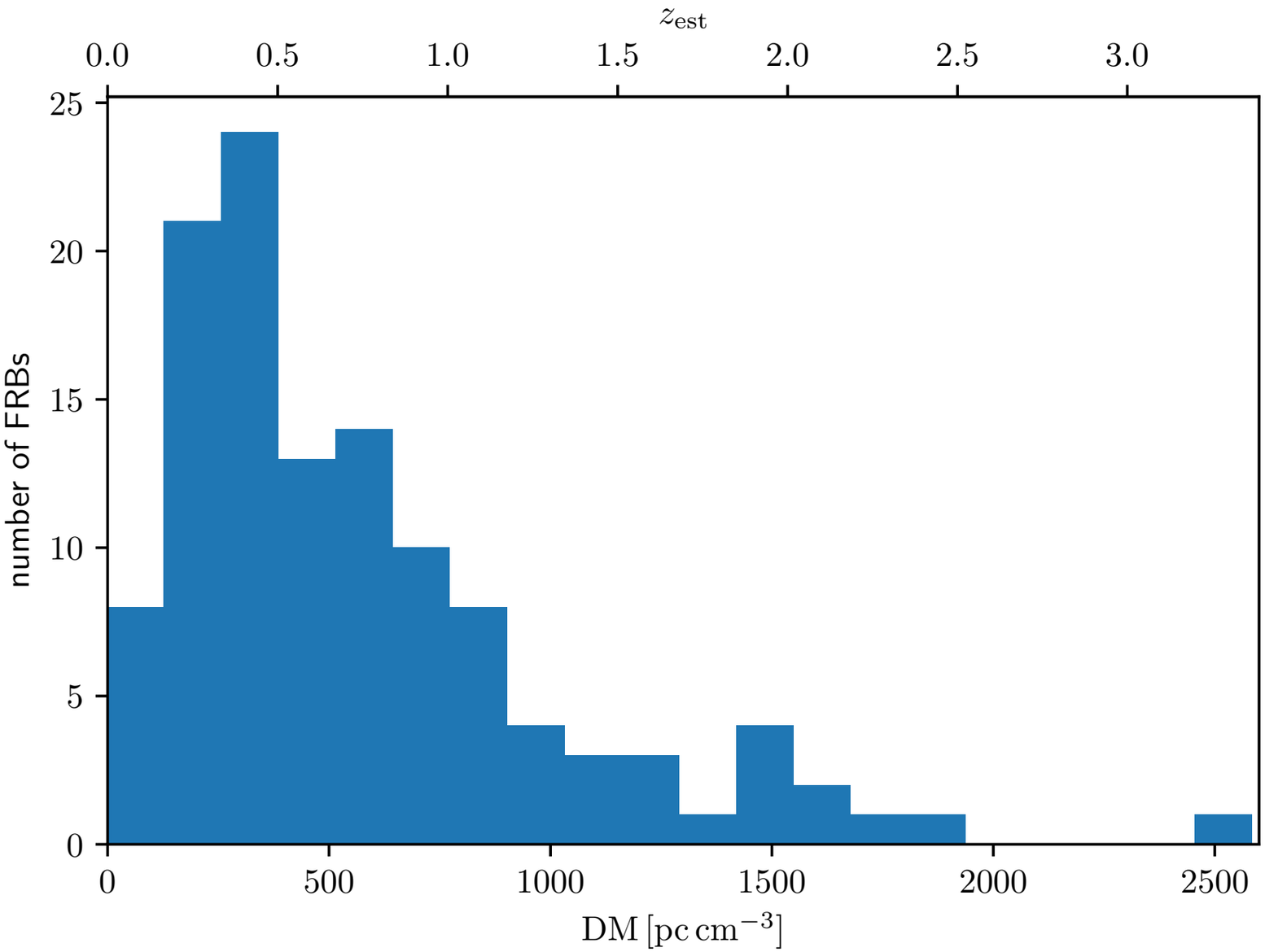
- Slope of relation gives Hubble constant
- Perfect degeneracy at the background level
- Combine with prior on baryon density (CMB or BBN)

Known FRBs



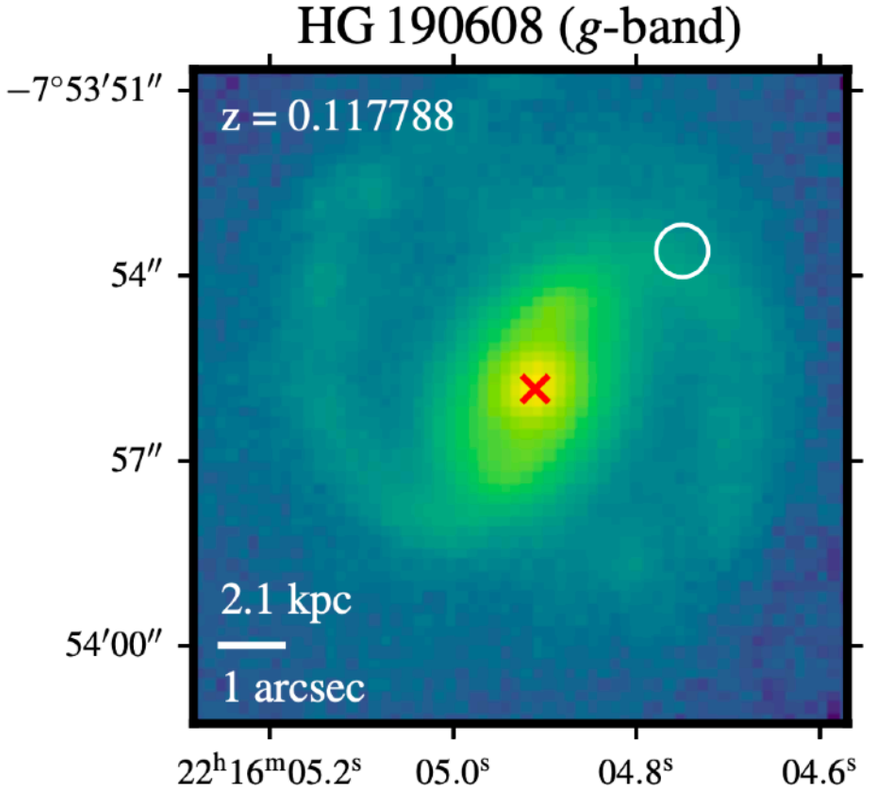
118 events known, 9 with redshift

Known FRBs



- True FRB population not well known
- Detections up to z~2 possible
- Maybe beyond? Reionisation studies?

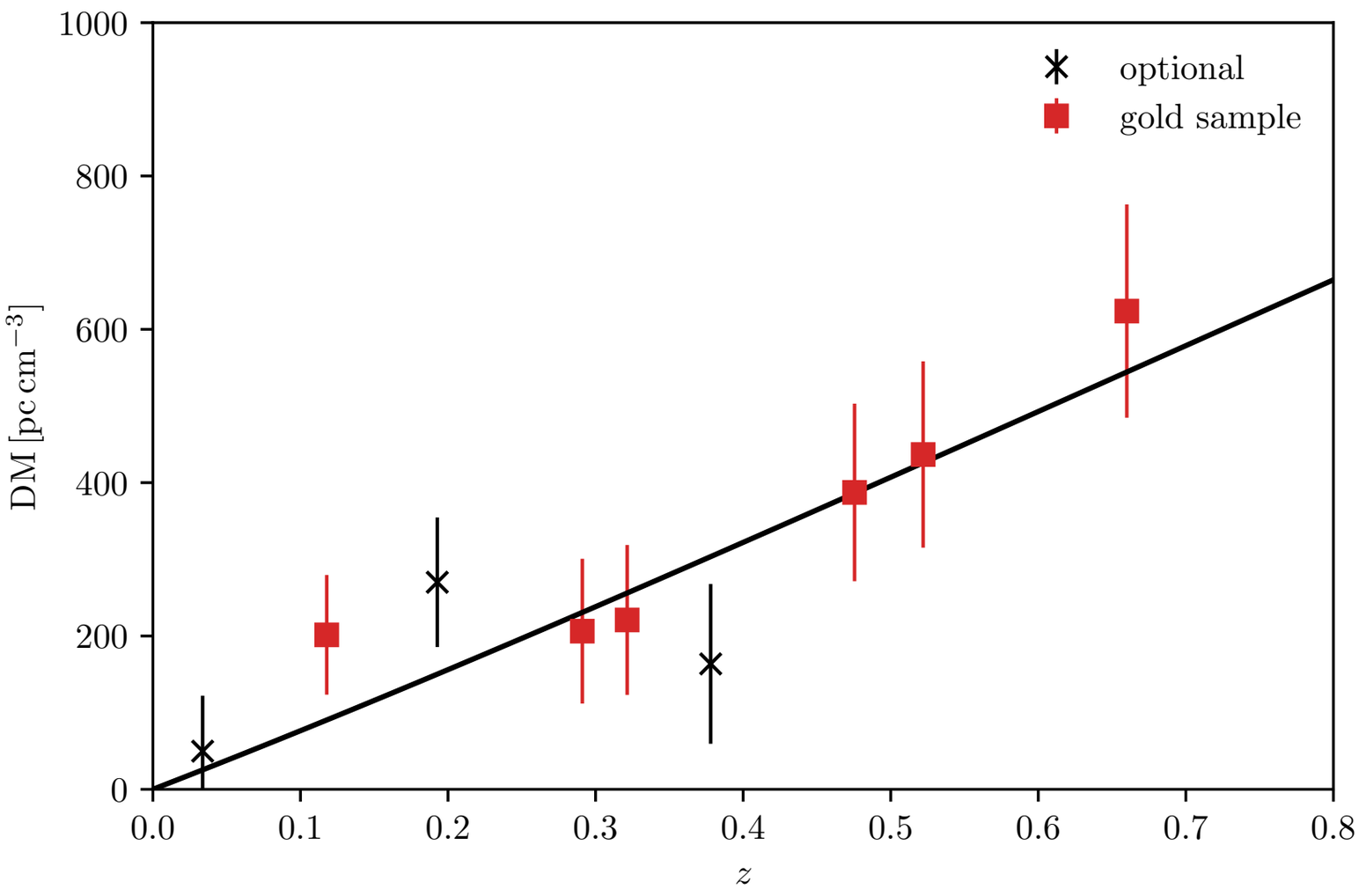
Host ID



VLT + ASKAP (Macquart et al 2020)

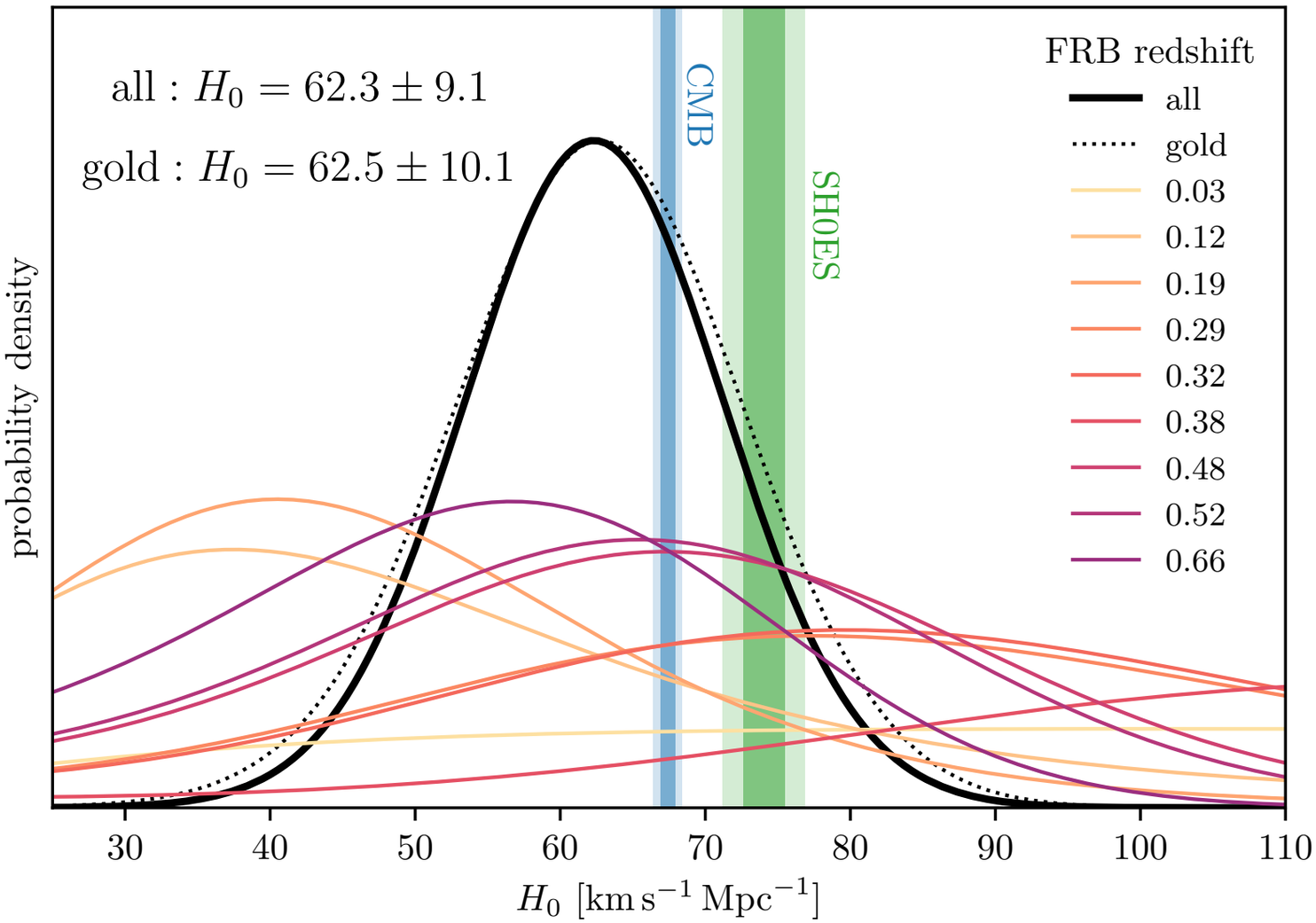
- Dedicated FRB searches from radio arrays
- Long baselines, excellent angular resolution
- Optical follow-up allows host ID and redshift

FRB distance scale



- Compile DM-z diagram similar to SNe Ia
- Absolute calibration via subtraction of host & MW DM
- Additional “gold sample” of high quality events

Hubble constant



Events at large z most important

Uncertainty in host DM dominates error

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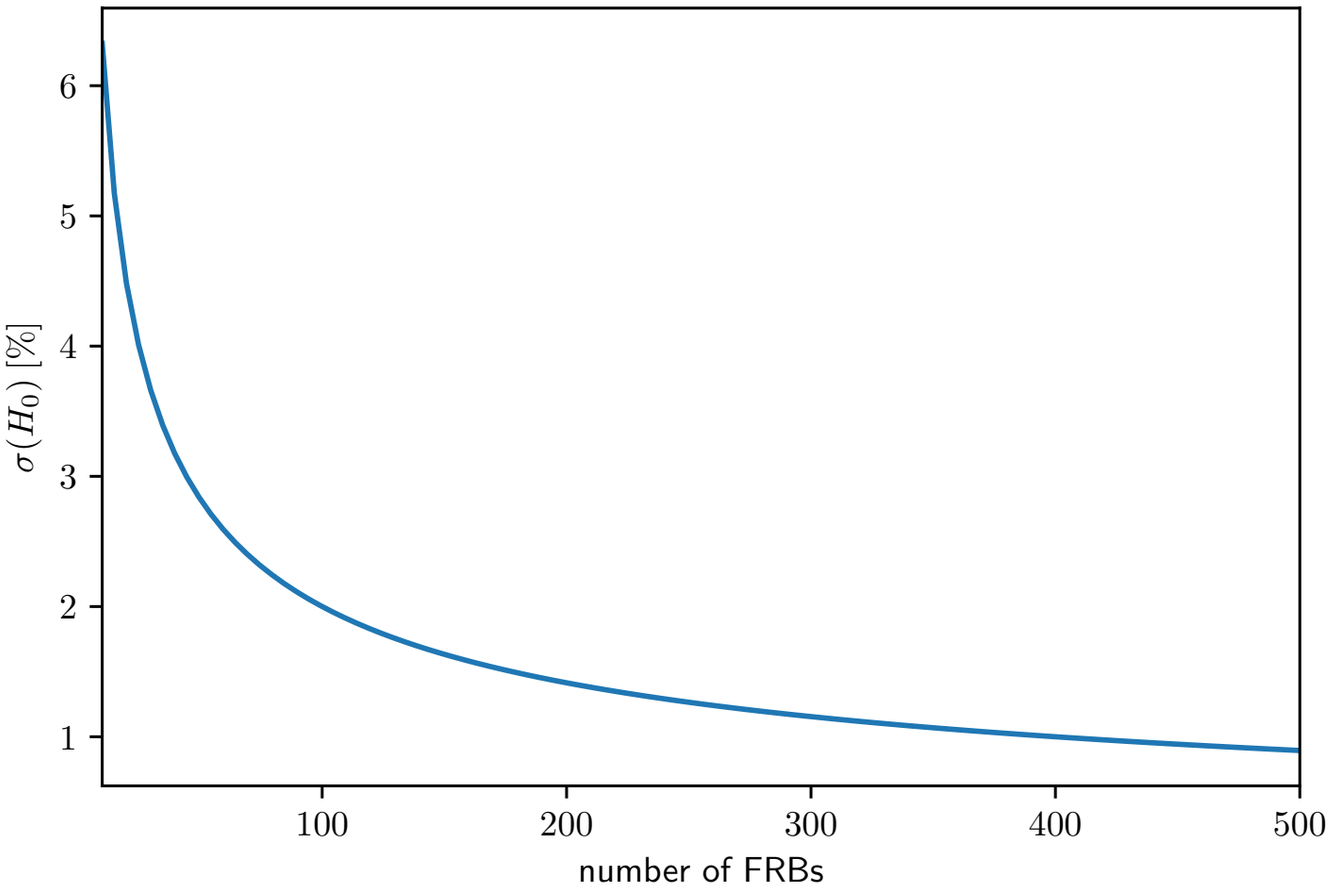
The Future

When can FRBs be competitive?



- A few hundred events with host ID get to ~1% precision
- Can we relax some assumptions with larger samples?

Dispersion measure

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LSS

Milky Way models
Can be checked with Pulsars
Quite accurate!

Host halo models
Depends on galaxy types?
Location of FRBs?

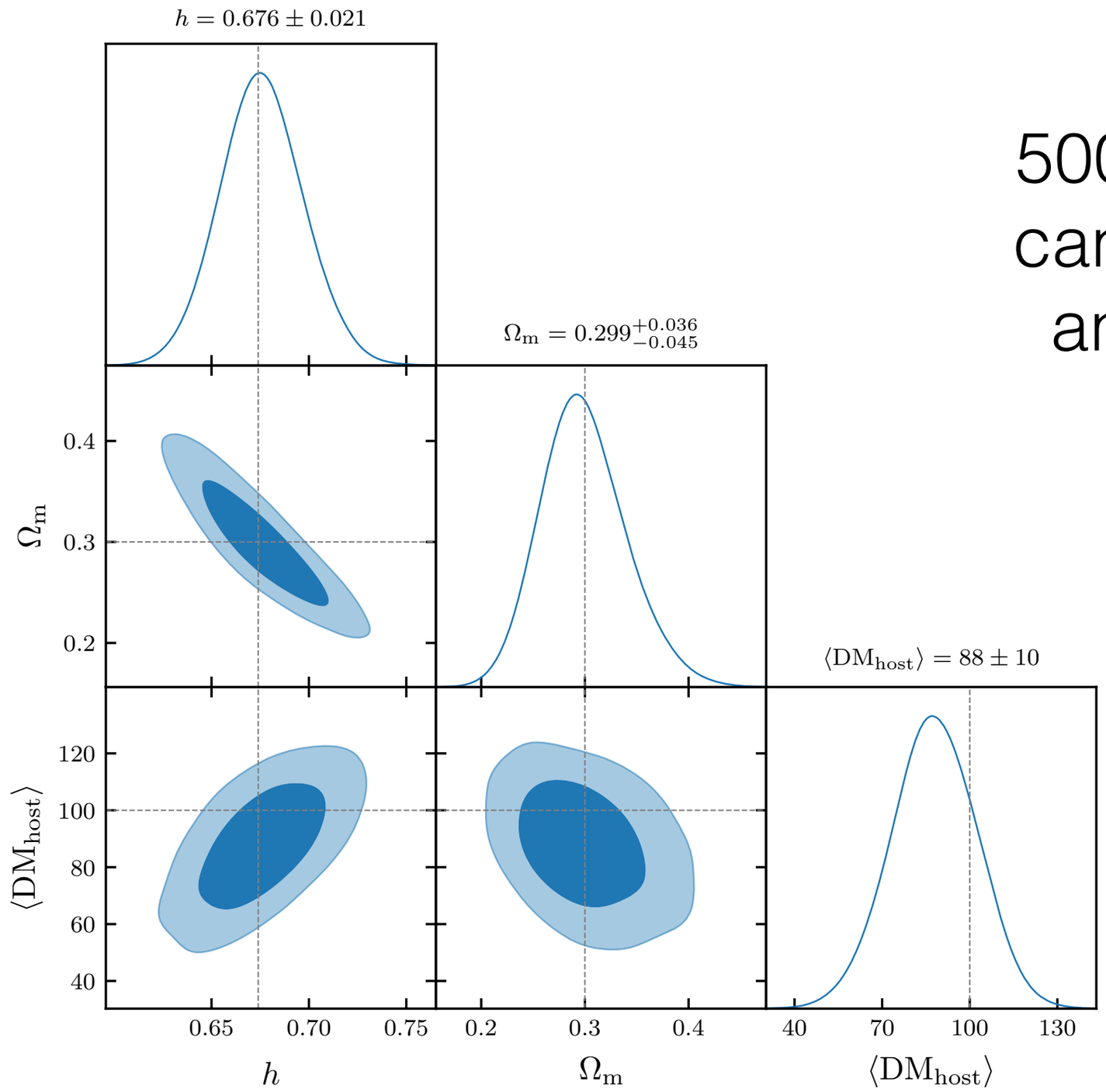
Redshift scaling:

const.

$$\propto \int^{z} \frac{1+z'}{E(z')} \mathrm{d}z' \quad \propto \frac{1}{1+z}$$

Statistics can tell contributions apart

Forecast



500 events with host ID can determine host DM and Hubble constant simultaneously

Available soon!

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Summary

- Mechanism of the bursts unknown

- FRBs can provide independent* measurement of the Hubble constant $H_0 = 62.3 \pm 9.1$

- Currently limited by statistics, many more events are coming from CHIME/ASKAP/HIRAX

- FRBs can do many more things for cosmology!

  Primordial non-Gaussianity (Reischke, SH, Lilow 2020)

  Equivalence principle (Reischke, SH, Lilow 2021)