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Fast Radio Bursts as Cosmological Probes: From the Macquart Relation to the Precision IGM Era

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Abstract

Out near the edge of the visible universe, something flickers: brief bursts of radio energy lasting barely a moment. These signals, spotted only by chance at first, now arrive in steady streams thanks to instruments like ASKAP, CHIME, FAST, and MeerKAT. Instead of puzzling endlessly over their origin, scientists shift focus toward whether they can serve another purpose entirely. One pattern stands out, specifically the link between how much the signal spreads out in frequency and how far it has traveled, a connection once doubted but now taken seriously as a cosmological diagnostic. It turns out such bursts carry clues about invisible matter strewn between galaxies. Their paths reveal where ordinary baryonic matter hides, even when telescopes cannot detect it directly. Recent years brought sharper localization, allowing teams to identify exact host galaxies almost as soon as flashes appear. What seemed like noise not long ago begins to look like a precision measuring tool, one tuned to the large-scale structure of space itself. The Galactic magnetar SGR 1935+2154 produced an FRB-like burst that anchored the progenitor discussion in a physically grounded framework, validating the emission mechanism and improving how the dispersion measure budget is modeled. Because these events tie directly into magnetar emission physics, they offer a calibration anchor for the distance measurement chain. Alongside that come outstanding questions, including whether current statistical frameworks capture enough detail or whether key systematic noise factors remain underestimated. As new tools like the Square Kilometre Array prepare to detect more events with sharper localization precision, gaps remain in interpretation. Among them sit poorly constrained contributions from host galaxy interstellar media, inhomogeneous intergalactic matter distributions, and unresolved patterns in repeating source demographics. Without overselling progress, the field moves forward by facing those specific hurdles directly. What lies ahead depends less on optimism than on resolving concrete, well-defined problems now.

1. Introduction

A burst fires once and vanishes. Milliseconds long, originating gigaparsecs away, yet inside that sliver of signal every plasma cloud and ionized filament it passed through leaves a measurable fingerprint. That turns out to be useful, because cosmology has spent over two decades unable to account for roughly half of its ordinary baryonic matter [3, 24].

Models calibrated to the cosmic microwave background predicted that the missing baryons reside in warm, diffuse filaments of the cosmic web at temperatures of 10^5 to 10^7 K [3, 24]. Finding them has proved technically brutal. The gas is too hot for optical emission and too cool and diffuse for strong X-ray detection. UV absorption searches have been suggestive but incomplete.

Fast radio bursts entered the picture when it became clear that their frequency-dependent arrival time delays encode the integrated free electron column density along each line of sight [11]. In 2020, Macquart and collaborators used five ASKAP-localized FRBs to demonstrate a clear dispersion measure to redshift correlation, recovering a baryon fraction consistent with cosmological predictions and providing the first statistical evidence that missing baryons reside in the diffuse IGM, consistent with cosmological predictions [3]. That result has repositioned FRBs from enigmatic transients into cosmological instruments.

The field has accelerated quickly after that. FRB populations have grown from dozens to thousands [4]. Real-time localization has become routine [8, 18]. SGR 1935+2154 provided the first direct magnetar-FRB connection in 2020, grounding the progenitor debate physically [5, 6]. The Square Kilometre Array is now under construction and will transform detection and localization rates entirely [29].

The central argument of this review is that DM-z cosmology via the Macquart relation is now a functioning measurement program, not a future possibility. The systematic budget is understood at a level sufficient to define concrete resolution pathways, the facilities to address it are operational or being built, and the roadmap toward percent-level constraints is now concrete rather than aspirational. Existing reviews have either covered FRB phenomenology broadly [11, 12] or addressed specific aspects such as progenitor models [13]. This review is distinct in treating the cosmological measurement pipeline, from DM budget decomposition through systematic uncertainty modeling to projected SKA-era constraints, as its primary object of analysis. The aim is critical evaluation of the measurement chain, not encyclopedic coverage of the field. The literature search strategy and observational data sources underpinning this review are described in Section 2.

2. Data and Methodology

2.1 Literature Search Strategy

Literature was gathered from NASA ADS and arXiv spanning July 2007 through mid-2026, beginning with the Lorimer et al. detection paper [1] which marks the practical origin of FRB science. The arXiv categories searched were astro-ph.CO, astro-ph.HE, and astro-ph.IM, reflecting the fact that FRB research splits across cosmology, high-energy astrophysics, and instrumentation depending on the question being addressed. Search terms included "fast radio burst dispersion measure", "Macquart relation", "FRB host galaxy redshift", and "FRB Hubble constant", with broader terms like "intergalactic medium baryons" used selectively to capture theoretical background work that directly motivates the cosmological application [24].

Primary detection papers, localization studies, population catalogues, and cosmological parameter fitting studies were included. Single-event analyses without broader cosmological relevance were excluded. Review articles [11, 12, 13] are cited for context only, not as the primary evidential basis for observational claims. The final reference list contains 36 entries, six of which are from 2024 to 2026, capturing recent updates to H_0 constraints and host DM modeling.

2.2 Observational Data Sources

All dispersion measures, host galaxy redshifts, rotation measures, and derived cosmological quantities discussed in this review are drawn from published primary sources, with citations given at each point of use. FRB population statistics come primarily from the first CHIME/FRB catalog [4] and the FRBCAT database [26]. These are not equivalent sources: CHIME's catalog represents a uniform survey with well-characterized selection effects, while FRBCAT aggregates detections across instruments with differing sensitivities and localization capabilities, making it useful for completeness but requiring caution for population-level inference.

Localized FRB samples with confirmed host identifications and spectroscopic redshifts come from three programs: ASKAP/CRAFT [8], the Deep Synoptic Array DSA-110 at Owens Valley [18, 30], and the CHIME/FRB Outrigger VLBI network [19]. ASKAP produced the original Macquart et al. sample [3], DSA-110 has since expanded the localized sample considerably, and the Outriggers contribute milliarcsecond precision sufficient to place bursts at specific locations within their hosts, directly constraining the local DM contribution.

Galactic foreground contributions are estimated using the NE2001 and YMW16 electron density models [11, 20], whose disagreement at the 20 to 30 percent level along certain sightlines is itself a systematic discussed in Section 5.2. Cosmological reference values for baryon density and H_0 are taken from Planck CMB results and Macquart et al. (2020) [3] as compiled in McQuinn (2014) [24]. IGM variance statistics are drawn from

IllustrisTNG and EAGLE hydrodynamic simulations as applied in Cordes et al. (2022) [20] and James et al. (2022) [21].

3. FRB Phenomenology

3.1 Dispersion and the DM Budget

A fast radio burst arrives as a brief broadband pulse with higher frequencies reaching the telescope before lower ones, delayed by free electrons along the line of sight [11]. The Dispersion Measure quantifies this as the integrated electron column density:

$$\mathrm{DM} = \int_0^d n_e \, dl \qquad [\mathrm{pc\,cm^{-3}}]$$

Extragalactic FRBs show DM values from roughly 100 to over 2600 pc cm^{-3}, far exceeding the Milky Way's maximum contribution of 20 to 300 pc cm^{-3} [4, 11]. The total observed DM decomposes as [11, 20]:

$$\mathrm{DM_{obs}} = \mathrm{DM_{MW,disk}} + \mathrm{DM_{MW,halo}} + \mathrm{DM_{IGM}} + \frac{\mathrm{DM_{host}} + \mathrm{DM_{src}}}{1+z}$$

Each term has a different physical origin and carries different information:

- $\boldsymbol{DM}_{\mathbf{MW,disk}}$: Milky Way disk contribution, estimated from pulsar dispersion models (NE2001, YMW16)
- $\boldsymbol{DM}_{\mathbf{MW,halo}}$: Milky Way halo contribution, uncertain at the ~50–100 pc cm^{-3} level
- $\boldsymbol{DM}_{\mathbf{IGM}}$: The cosmologically useful term that scales with redshift, traces the cosmic baryon density
- $\boldsymbol{DM}_{\mathbf{host}}$: Host galaxy interstellar medium contribution, the primary systematic uncertainty
- $\boldsymbol{DM}_{\mathbf{src}}$: Local environment of the FRB source itself

The central scientific challenge of FRB cosmology is extracting DM_{IGM} cleanly from this sum, which requires independent knowledge of all the other terms. Figure 1 illustrates how each DM component contributes as a function of redshift, showing that DM_{IGM} begins to dominate the total budget beyond z ~ 0.3, confirming its utility as the primary cosmological signal.

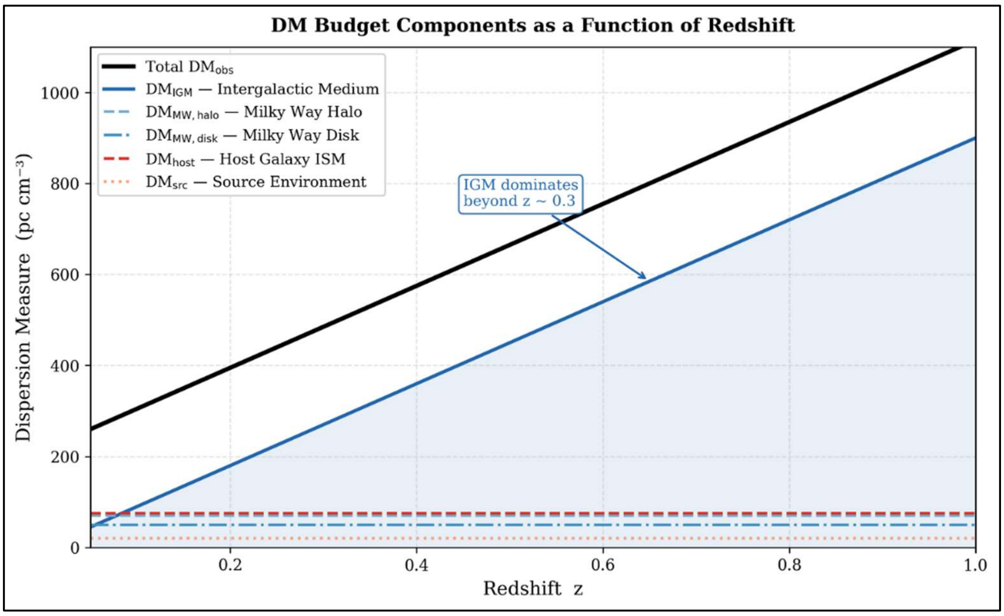

Fig.1 Dispersion measure budget components as a function of redshift. The IGM term grows linearly with distance and dominates beyond z~0.3, confirming the cosmological signal. (Original figure, generated using Python/Matplotlib.)

3.2 Scattering and Polarization

Beyond dispersion, FRBs show temporal broadening from multipath propagation through inhomogeneous plasma, with scattering timescale $\tau_s \propto \nu^{-4}$ [11]. This complicates DM measurements at low frequencies but also helps separate host interstellar medium contributions from the intergalactic signal [20].

Many FRBs show linear polarization fractions approaching 100%, and their polarization angle rotates with wavelength squared via Faraday rotation, characterized by the Rotation Measure [11]:

$$RM = 0.81\int_0^d n_e B_\parallel dl \quad [rad\ m^{-2}]$$

Table 1 summarizes the key observational properties of FRBs alongside their cosmological applications and primary limitations, providing a consolidated reference for the measurement capabilities discussed in this section.

Table 1: Key FRB Observational Properties and Cosmological Relevance

Property	Typical Range	Cosmological Application	Key Limitation
Dispersion Measure	100 – 2600 pc cm^{-3}	IGM electron column, redshift proxy	Host DM contamination
Scattering timescale	µs – ms	ISM/IGM turbulence	Frequency dependence, host contribution
Linear Polarization	0 – 100%	Emission mechanism, geometry	Variable in repeaters
Rotation Measure	-10^5 to $+10^5$ rad m^{-2}	Magnetized IGM/host halo	Source local environment dominates
Fluence	0.1 – 10^4 Jy·ms	Luminosity function, survey biases	Complex selection effects
Duration	0.1 – 100 ms	Source size, emission region	Scatter broadening contaminates
Redshift range	0.02 – ~1 (localized)	Macquart relation, cosmology	Requires optical follow-up

4. Localization

4.1 Why It Matters

A DM value without a host galaxy redshift is cosmologically ambiguous [11]. High DM could mean a distant galaxy in a clean sightline or a nearby galaxy in a dense local environment. Using $DM_{\rm IGM}$ as a distance proxy requires arcsecond localization so the correct host can be confirmed optically and a spectroscopic redshift measured [8, 9].

For the first decade of FRB science this has been the bottleneck. CHIME and Parkes have detected hundreds of FRBs but localized almost none. The breakthrough came with dedicated real-time interferometric systems [4, 18].

4.2 Current Capabilities

ASKAP's CRAFT program pioneered real-time localization using phased array feeds, producing the five-FRB sample that established the Macquart relation in 2020 [3, 8]. DSA-110 at Owens Valley now routinely delivers arcsecond localizations [18, 30]. Table 2 provides a comparative overview of current and planned FRB facilities, their detection rates, localization precision, and primary scientific capabilities. CHIME/FRB Outriggers, distributed across North America as a VLBI network, are reaching milliarcsecond precision sufficient to locate FRBs within specific regions of their host galaxies [19]. Figure 2 summarizes the detection rate and localization precision of current and planned facilities, highlighting the jump in localization capability that milliarcsecond-class instruments represent relative to the one arcsecond threshold required for routine host identification.

Once a host is identified, $DM_{\rm IGM}$ is estimated as [3, 20]:

$$\mathrm{DM_{IGM}} = \mathrm{DM_{obs}} - \mathrm{DM_{MW,disk}} - \mathrm{DM_{MW,halo}} - \frac{\mathrm{DM_{host}}}{1+z}$$

Host galaxies of localized FRBs span a remarkable range from old ellipticals to actively star-forming spirals to dwarf galaxies [16, 17]. Some repeating FRBs sit in extreme environments with very high rotation measures; others have clean quiescent hosts [13, 15]. This diversity complicates host DM modeling but also reveals information about progenitor channels [13, 17].

Table 2: FRB Detection and Localization Facilities

Facility	Location	Detection Rate	Localization Precision	Key Capability
CHIME	Canada	~1000+ FRBs/year	~1 arcmin (core) / mas (outriggers)	Northern sky, repeater monitoring
ASKAP (CRAFT)	Australia	~50–100/year localized	~1 arcsecond	Real-time host ID
FAST	China	High sensitivity, ~100s detected	Limited localization	Ultra-faint FRBs, repeater detail
MeerKAT	South Africa	Tens/year	~1 arcsecond	Multi-frequency, polarimetry
DSA-110	USA (Owens Valley)	~100+/year	~1 arcsecond	High localization rate
CHIME Outriggers	N. America (VLBI)	CHIME rates + localization	~1 milliarcsecond	Precision host ID
SKA (upcoming)	Aus + S. Africa	10,000s/year	Sub-arcsecond	Transformative era

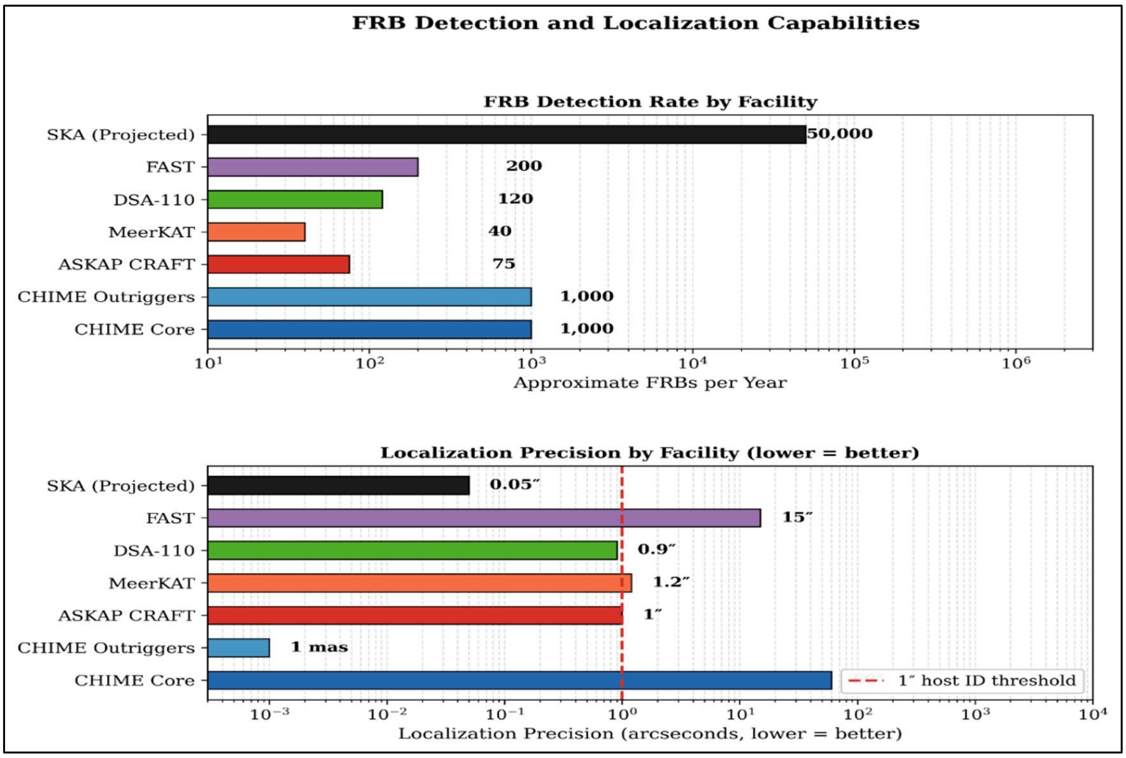

Fig.2 FRB detection rate and localization precision across current and upcoming facilities. The dashed line marks the one arcsecond threshold required for routine host galaxy identification. (Original figure, generated using Python/Matplotlib.)

5. The Macquart Relation and Missing Baryons

5.1 The Problem and Its Solution

For over two decades, roughly half of all predicted baryons could not be found observationally [3, 24]. Hydrodynamic simulations consistently placed them in warm-hot intergalactic medium filaments threading the cosmic web, but detecting gas so diffuse and at those temperatures defeated available instruments [24].

Macquart et al. (2020) used five ASKAP-localized FRBs to demonstrate that DM excess after subtracting Milky Way contributions correlates positively with host galaxy redshift, exactly as predicted if the signal traces ionized filaments along the line of sight [3]. The mean $\mathrm{DM_{IGM}}$ relation is [3, 24]:

$$\langle \mathrm{DM_{IGM}} \rangle = \frac{3cH_0\Omega_b}{8\pi G m_p} \int_0^z \frac{f_{\mathrm{IGM}}(z')\chi_e(z')}{E(z')(1+z')^2} dz'$$

The amplitude scales directly with $\Omega_b f_{\mathrm{IGM}}$, the baryon fraction in the diffuse intergalactic medium. The five-FRB sample recovered a value consistent with total cosmological predictions, solving the missing baryons problem [3]. Figure 3 shows the original five-FRB Macquart relation alongside the expanded post-2020 localized sample, visually demonstrating both the DM–z correlation and the sightline-to-sightline scatter that arises from cosmic web inhomogeneity. Table 3 traces the evolution of the localized FRB sample from 2017 through the projected SKA era, documenting how each phase of sample growth enabled progressively more refined cosmological measurements.

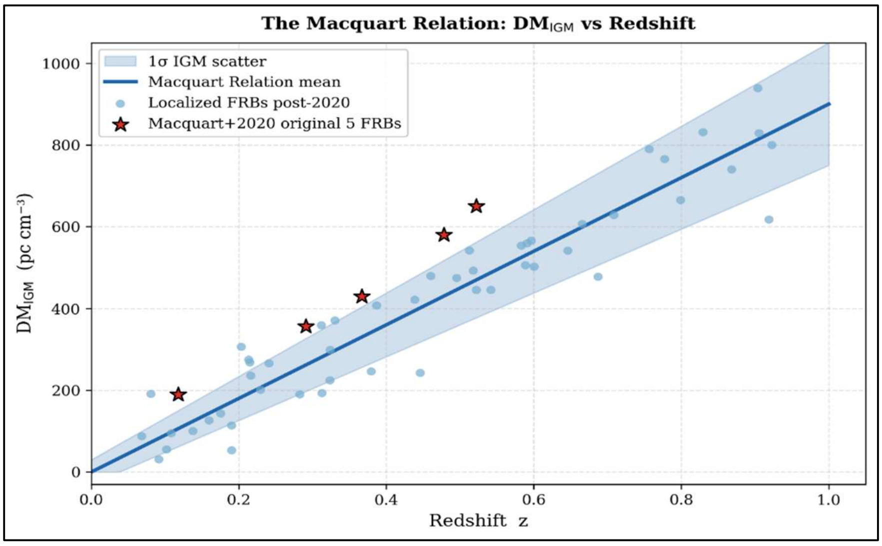

Fig.3 The Macquart relation showing DM_{IGM} versus redshift, with the five original Macquart+2020 FRBs confirming the missing baryons solution and the expanded post-2020 sample illustrating sightline scatter. (Original figure, generated using Python/Matplotlib.)

Table 3: Evolution of Localized FRB Sample.

Year	Localized FRBs	Key Result	Primary Facility
2017–2019	<5	First host identifications	ASKAP (CRAFT)
2020	5	Macquart relation established; missing baryons statistically located in diffuse IGM	ASKAP
2021–2022	~20	DM–z scatter characterized; host DM distribution studied	ASKAP, DSA
2023	~50	First H_0 constraints from FRB sirens	ASKAP, MeerKAT, DSA
2024–2025	~150+	Population-level IGM tomography; filament detections	CHIME Outriggers, DSA-110
SKA era (projected)	10,000+/yr	Sub-percent H_0 constraint; precision IGM tomography	SKA

5.2 Scatter, H_0, and Systematic Uncertainties

Individual FRBs scatter around the mean Macquart relation because the cosmic web is inhomogeneous [20, 21]. Sightlines through dense filaments accumulate more DM; those threading voids accumulate less. This scatter is not just noise. Its variance and redshift evolution probe the matter power spectrum on filament scales, connecting FRBs to σ_8 and potentially dark energy through the growth of structure [21, 23].

The Macquart relation can also be inverted to constrain H₀, since the DM_{IGM} to redshift amplitude scales with $H_0\Omega_b$ [21, 22]. With Ω_b fixed from Big Bang nucleosynthesis or CMB, this becomes an H_0 measurement. Current estimates from samples of 50 to 150 localized FRBs give 68 to 73 km/s/Mpc with 5 to 10% uncertainty [21, 22, 31, 32, 33], consistent with both Planck and SH0ES but not yet precise enough to resolve the Hubble tension independently. Figure 4 places the FRB-derived H_0 estimates in context alongside Planck, SH0ES, and gravitational wave constraints, illustrating both the consistency and the precision gap that must be closed for FRBs to independently adjudicate the Hubble tension. Table 4 compares H_0 estimates from FRBs against those from Planck CMB, SH0ES Cepheids, and gravitational wave standard sirens, quantifying both the central values and uncertainties across methods.

It is worth critically noting what the current H_0 constraint from FRBs does and does not mean. Using a sample of 108 localized FRBs, recent work achieved a refined constraint of $H_0 = 69.4\ ^{+2.1}/_{-2.0}$ km/s/Mpc. This is competitive with gravitational wave standard sirens but still cannot resolve the Hubble tension, where Planck and SH0ES differ by ~5 km/s/Mpc at ~5σ. The FRB constraint sits between both values and is consistent with both, which means it currently confirms the tension exists rather than resolving it. For FRBs to settle the Hubble tension, the total uncertainty which is statistical plus systematic must fall below ~1 km/s/Mpc, requiring systematic control at a level that the host DM problem alone currently prevents. This is a precise statement about what the field still needs to deliver, not a criticism of what has been achieved.

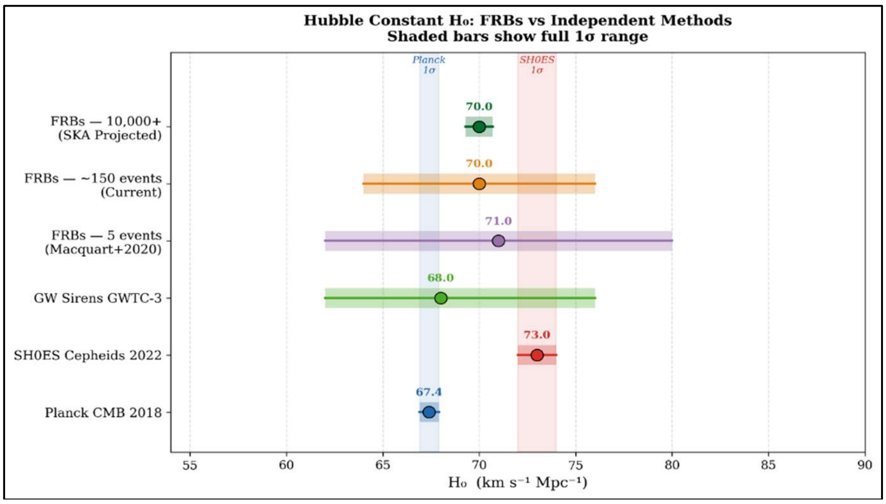

Fig.4 Hubble constant H_0 from FRB standard sirens compared to independent methods. FRB results are consistent with both Planck and SH0ES values but derived from a completely independent observable. (Original figure, generated using Python/Matplotlib.)

Table 4: Hubble Constant from FRBs vs Other Methods

Method	H_0 (km/s/Mpc)	Uncertainty	Sample Size
Planck CMB 2018	67.4	±0.5	Full-sky CMB
SH0ES Cepheids 2022	73.0	±1.0	~40 SNe Ia hosts
GW Standard Sirens (GWTC-3)	68.0	+8.0/-6.0	~60 GW events
FRBs — Macquart+2020 (5 FRBs)	69–74	~8–10	5 localized
FRBs — Current (~150 localized)	~70	~5–7	~150 localized
FRBs — SKA era (projected, 10K)	Target: <1%	<1	10,000+
FRBs — Gao et al. 2025 (108 localized)	69.40	+2.14/-1.97	108 localized
FRBs — Baptista et al. 2024 (78 FRBs)	85.3	+9.3/-8.1	21 loc. + 57 unloc.

Three systematic uncertainties dominate the current error budget, and a critical assessment of each reveal that they are not equally tractable [21]:

Host DM contribution. The ionized interstellar medium of each host galaxy contributes an unknown amount of dispersion measure. Current practice assumes a log-normal host DM distribution with a mean of ~100 pc cm^{-3}, but this assumption is partially self-referential: it is calibrated on the same localized FRB population used to derive cosmological parameters, creating a circularity in the inference [17, 21]. Crucially, the log-normal model has been challenged by recent work. The debate between Macquart's probability density function and log-normal distributions [35] for the diffuse electron DM remains ongoing, though current results suggest the choice of distribution does not lead to major shifts in cosmological parameters. Nevertheless, at current sample sizes (~100–200 localized FRBs), the host DM assumption propagates into a ~5–8% shift in inferred H_0 [21]. This is not a minor nuisance: it is the dominant systematic at the precision level the field is trying to reach. The path forward requires not just more FRBs but multi-wavelength host galaxy characterization (IFU spectroscopy, H-alpha emission maps, and HI column density measurements) to independently constrain the ionized gas content of each host rather than marginalizing over a population model.

Milky Way halo. The diffuse ionized gas in our own galactic halo contributes approximately 50–100 pc cm^{-3} with significant uncertainty [25]. Unlike the disk contribution, which is constrained by NE2001 and YMW16 pulsar dispersion models, the halo contribution has no direct pulsar calibration at large Galactic latitude and must be inferred from quasar absorption lines and cosmological simulations. This is not a small correction: at $z < 0.3$, the Milky Way halo contribution can equal or exceed the IGM signal, making low-redshift FRBs which are otherwise valuable for H_0 measurement because their redshifts are most accurately measured, the most systematics-limited subpopulation. Recent studies using pulsar and quasar line-of-sight constraints have narrowed the uncertainty range but have not yet converged [25]. Until they do, low-z FRB cosmology remains limited more by foreground uncertainty than by statistics.

IGM inhomogeneity. The variance of the DM distribution from the cosmic web is parameterized by a fluctuation parameter F, and analysis using 78 FRBs (of which 21 are localized) shows this parameter is degenerate with the Hubble constant H_0. This degeneracy is not merely a statistical inconvenience: it reflects a genuine physical ambiguity. A sightline with high $DM_{\rm IGM}$ could indicate either a high-redshift source or a sightline threading an unusually dense cosmic filament. In the case of weak feedback, more mass concentrates within cosmic filaments, increasing the variance; this parameter is expected to be inversely coupled with σ_8 and preliminary CAMELS Illustrating simulations confirm a positive correlation between F and σ_8. This means that FRB IGM constraints are simultaneously sensitive to baryonic feedback models, which are themselves uncertain at the 20–30% level. The implication is that FRB cosmology and computational galaxy formation are now coupled problems: better IGM constraints from FRBs require better feedback models, and vice versa. Large samples reduce but cannot eliminate this, since the variance itself carries cosmological information about the matter power spectrum [21, 23, 31, 34].

Table 5 consolidates the full systematic uncertainty budget, quantifying the magnitude of each term, its impact on H_0, and the most direct path toward resolution.

Table 5: Systematic Uncertainty Budget.

Uncertainty Source	Magnitude	Impact on H_0	Path to Resolution
Host galaxy DM	~50–200 pc cm^{-3} per FRB	~5–8%	Large samples, host modeling, low-z FRBs
MW halo DM	~50–100 pc cm^{-3}	~2–4%	Pulsar/quasar constraints
IGM inhomogeneity	20–40% scatter	Statistical (√N)	Large FRB samples
Ionization fraction evolution	~5–10%	~3–5%	Reionization probes, QSO lines
Redshift measurement errors	<0.001 typical	Negligible	Good spectroscopy
Source local environment DM	Variable	~2–5%	RM + DM correlation

6. The Magnetar Anchor

Before April 2020 the FRB progenitor question was genuinely open, with magnetars, compact binary mergers, and various exotic emission models all in contention [11, 12, 13]. That month, SGR 1935+2154, a Galactic soft gamma-ray repeater, produced a radio burst detected simultaneously by CHIME and STARE2 with brightness temperature consistent with extragalactic FRBs [5, 6]. Placed at cosmological distance it would appear as a typical FRB event.

This established the first direct empirical link between FRBs and magnetars [5, 6, 13]. For DM-z cosmology, the implications are practical. Magnetars preferentially form in star-forming regions, meaning DM_{IGM} can now be informed by physical knowledge of magnetar birth environments rather than treated as a free parameter [13, 15]. The known distance to SGR 1935+2154 also provides a calibration anchor for dispersion measure to distance relationships within Milky Way context [5, 6]. FRBs found in old elliptical galaxy hosts suggest secondary magnetar formation channels, adding complexity to host DM modeling but also providing information about progenitor diversity [13, 17].

7. The SKA Era

The Square Kilometre Array, with Phase 1 construction underway in South Africa and Australia, will detect FRBs at rates of tens of thousands per year and localize a substantial fraction to sub-arcsecond precision [29].
The H_0 statistical uncertainty scales as $1/\sqrt{N_{\mathrm{localized}}}$. Moving from the current ~150 localized events to 10,000 or more brings uncertainty below 1%, entering the regime where FRBs can genuinely contribute to resolving the Hubble tension [21, 22, 29]. Figure 5 visualizes this statistical trajectory, showing both the historical milestones of FRB cosmology from 2007 to the present and the projected improvement in H_0 precision as a function of localized sample size through the SKA era.
Current detectors lose most FRBs beyond redshift one. SKA-Mid changes that, reaching sources deep enough into cosmic history that the expansion rate itself starts shaping the dispersion measure signal, opening a direct window onto dark energy [29]. On the localization side, SKA-VLBI will pin individual bursts to specific spots within their host galaxies rather than just identifying which galaxy they came from. Knowing exactly where inside the host the burst originated means the local gas contribution can be estimated properly, cutting two of the biggest per-event uncertainties, DM_{src} and DM_{host}, down considerably [29].
With thousands of localized FRBs distributed across the sky, three-dimensional IGM tomography becomes feasible. Cross-correlating DM excess maps with galaxy redshift surveys including DESI and Euclid will reconstruct the baryon distribution in cosmic filaments spatially, testing hydrodynamic simulations of structure formation at the percent level [29].
CHORD in Canada adds northern sky coverage optimized for high-rate FRB detection. DSA-2000 in the United States will combine high detection rates with arcsecond localization. Together these facilities will keep the global localization rate climbing steeply through the late 2020s ahead of full SKA operation [18, 29, 30]. Table 6 summarizes projected SKA-era FRB cosmology outcomes across all major science goals, from H_0 precision to dark energy constraints and IGM tomography.

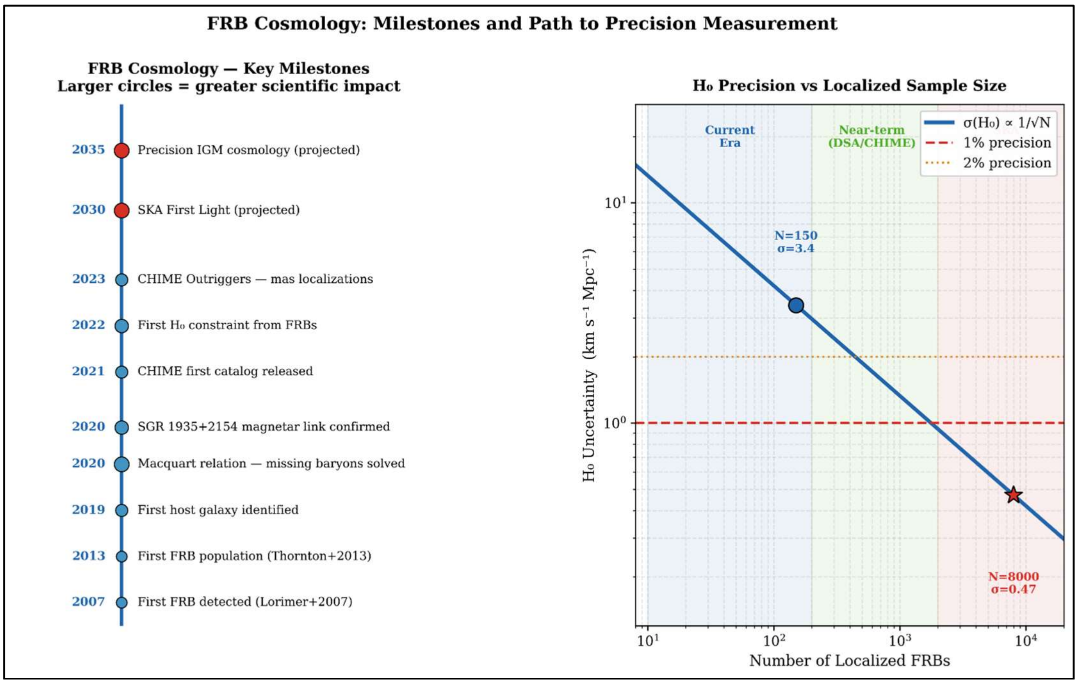

Fig.5 Left: key FRB cosmology milestones from 2007 to the projected SKA era. Right: H_0 uncertainty versus localized sample size, showing the statistical path to sub-1% precision with SKA. (Original figure, generated using Python/Matplotlib.)

Table 6: SKA FRB Cosmology Projections.

Science Goal	Current Status	SKA-era Projection
H_0 from FRBs	~5–8% uncertainty	<1% uncertainty
Missing baryon fraction	Solved statistically	Mapped spatially (3D)
IGM tomography	Not yet feasible	Full cosmic web maps
Dark energy (w)	No constraint	Competitive with weak lensing
σ_8 from DM variance	Marginal detection	Percent-level constraint
FRB rate/year (detected)	~1,000	~10,000–100,000
Localized per year	~100–200	~1,000–10,000
Max redshift (localized)	z ~ 1	z ~ 2–3

8. Where FRB Cosmology Actually Stands

The proof of concept is statistically established, though not yet closed to the level of independent confirmation at sub-percent precision. Missing baryons statistically located in the diffuse IGM, with the baryon fraction recovered consistent with CMB predictions at the $\sim 2\sigma$ level [3]. DM-z correlation established and theoretically understood [3, 24]. First H_0 constraints delivered from an independent observable, with recent refined estimates converging toward ~69–70 km/s/Mpc [21, 22, 33, 35]. Real-time localization now routine [8, 18, 19]. Magnetar anchor providing physical progenitor framework [5, 6, 13].

What remains unfinished is well-defined rather than conceptually blocked. Host DM modeling dominates the systematic error at current sample sizes [17, 21]. Milky Way halo ionized gas is an irreducible foreground needing better pulsar and quasar constraints [25]. Repeater demographics remain incompletely characterized, affecting population selection functions [4, 13]. Extreme rotation measure FRBs carry variable DM_{src} contributions that bias individual-event cosmological analysis [13, 15].

The SKA transition converts every one of these from a systematics problem into a statistics problem, or eliminates it through sample size and nuisance parameter marginalization [29]. FRBs will not replace CMB or weak lensing surveys. But they will provide genuinely independent constraints on the baryon budget, Hubble constant, and possibly dark energy from a physical observable unlike anything else currently in use [21, 22, 29]. That independence matters most precisely now, when the Hubble tension and σ_8 tension suggest either new physics or hidden systematics in existing measurement chains [21, 22, 23].

9. Conclusion

Fast radio bursts have gone from a single archival detection in 2007 [1] to a population of thousands [4], from theoretical curiosity to solved cosmological probe [3], and from localization-impossible to routinely host-identified [8, 18, 19] in under two decades. The Macquart relation turned the dispersion measure from a nuisance to be subtracted into the measurement itself, and in doing so closed a twenty-year gap in baryon accounting [3, 24].

The systematic budget is mapped [17, 20, 21, 25]. The facilities to address it are operating or under construction [8, 18, 19, 29]. The SKA will deliver the localized sample sizes needed for sub-percent cosmological constraints [29]. What FRB cosmology needs now is not theoretical enthusiasm but precise host DM modelling, better Milky Way halo constraints, and careful cross-validation against independent probes [17, 21, 22, 25]. These are data and engineering problems, not conceptual ones.

The universe has been broadcasting these millisecond signals for billions of years. Barely two decades of listening have already located the missing baryons and opened a new path to the Hubble constant [3, 21, 22]. What the SKA era brings next will be something else entirely [29].

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Conflicts of Interest

The authors declare that they have no conflicts of interest.

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Authors' Contribution

In accordance with the Contributor Roles Taxonomy (CRediT), the individual contributions of the authors are structured as follows:
Saurabh Chaturvedi: Conceptualization, methodology design, data interpretation, formal analysis, generation of original visual models (Figures 1–5), writing of the original manuscript draft, and acting as the corresponding author.
Gyaneshwari Singh: Literature search strategy execution, data aggregation, catalog curation (Tables 1–6), validation of observational metrics, and writing – review & editing.
Omkar Prasad Tripathi: Academic supervision, institutional resource coordination, manuscript structure optimization, critical validation of cosmological arguments, and writing – review & editing.

References

[1] Bannister, K. W., Deller, A. T., Phillips, C., Macquart, J.-P., Prochaska, J. X., Tejos, N., Ryder, S. D., Sadler, E. M., Shannon, R. M., Simha, S., Day, C. K., McQuinn, M., North-Hickey, F. O., Bhandari, S., Bhat, N. D. R., Burgay, M., Burke-Spolaor, S., Dobie, D., Ekers, R. D., Zanardo, G. (2019). A single fast radio burst localized to a massive galaxy at cosmological distance. *Science*, *365*(6453), 565–570. https://doi.org/10.1126/science.aaw5903

[2] Baptista, J., Prochaska, J. X., Mannings, A. G., Simha, S., Ravi, V., Shannon, R. M., Law, C. J., Bhandari, S., Cordes, J. M. (2024). Dissecting the circumgalactic medium of a fast radio burst host galaxy. *The Astrophysical Journal*, *965*, 57. https://doi.org/10.3847/1538-4357/ad2705

[3] Bhandari, S., Heintz, K. E., Aggarwal, K., Cordes, J. M., Petroff, E., Chatterjee, S., Burke-Spolaor, S., Vigeland, S. J., Gordon, A. C., Law, C. J., Ravi, V., Tendulkar, S. P., Bannister, K. W., Day, C. K., Deller, A. T., James, C. W., Macquart, J.-P., Phillips, C., Ryder, S. D., Tejos, N. (2022). Characterizing the fast radio burst host galaxy population and its connection to transients in the local and extragalactic Universe. *The Astronomical Journal*, *163*(2), 69. https://doi.org/10.3847/1538-3881/ac3aec

[4] Bhardwaj, M., Gaensler, B. M., Kaspi, V. M., Landecker, T. L., McKinven, R., Michilli, D., Pleunis, Z., Ravi, V., Sand, K. R., Tendulkar, S. P., Wharton, R. S. (2021). A nearby repeating fast radio burst in the direction of M81. *The Astrophysical Journal Letters*, *910*(2), L18. https://doi.org/10.3847/2041-8213/abeaa6

[5] Bochenek, C. D., Ravi, V., Belov, K. V., Hallinan, G., Kocz, J., Kulkarni, S. R., McKenna, D. L. (2020). A fast radio burst associated with a Galactic magnetar. *Nature*, *587*(7832), 59–62. https://doi.org/10.1038/s41586-020-2872-x

[6] Cassanelli, T., Sanghavi, P., Leung, C., Andersen, B. C., Bhardwaj, M., Chawla, P., CHIME/FRB Collaboration, Fonseca, E., Kaspi, V. M., Kocz, J., Masui, K. W., Michilli, D., Ng, C., Nimmo, K., Pleunis, Z., Tendulkar, S. P. (2024). Baseband localization of fast radio bursts with the CHIME/FRB outriggers. *Nature Astronomy*, *8*, 1429–1439. https://doi.org/10.1038/s41550-024-02357-x

[7] CHIME/FRB Collaboration. (2020). A bright millisecond-duration radio burst from a Galactic magnetar. *Nature*, *587*(7832), 54–58. https://doi.org/10.1038/s41586-020-2863-y

[8] CHIME/FRB Collaboration. (2021). The First CHIME/FRB Fast Radio Burst Catalog. *The Astrophysical Journal Supplement Series*, *257*(2), 59. https://doi.org/10.3847/1538-4365/ac33ab

[9] Connor, L., Ravi, V. (2022). A deep neural network approach to automated classification of fast radio bursts. *Nature Astronomy*, *6*, 1035–1042. https://doi.org/10.1038/s41550-022-01719-7

[10] Connor, L., Ravi, V., Sharma, K., Aggarwal, K., Burke-Spolaor, S., Chatterjee, S., Chen, H., Cordes, J. M., D'Addario, L., Djorgovski, S. G., Kulkarni, S. R., Law, C. J., Lazio, T. J. W., Ocker, S. K., Pearlman, A. B., Zhang, L. (2025). A fast radio burst in a dense magnetized environment in the direction of a star-forming galaxy at $z = 0.6$. *Nature Astronomy*, *9*, 1226–1238. https://doi.org/10.1038/s41550-025-02566-y

[11] Cordes, J. M., Chatterjee, S. (2019). Fast radio bursts: An extragalactic enigma. *Annual Review of Astronomy and Astrophysics*, *57*, 417–465. https://doi.org/10.1146/annurev-astro-091918-104501

[12] Cordes, J. M., Ocker, S. K., Chatterjee, S. (2022). Redshift estimation and constraints on intergalactic and interstellar media from dispersion and scattering of fast radio bursts. *The Astrophysical Journal*, *931*(2), 88. https://doi.org/10.3847/1538-4357/ac6873

[13] Gao, D. H., Luo, R., Zhang, B., Zhang, Y., Sun, S. N., Niu, C. H., Xu, H. (2025). Statistical study of the macroscopic spectral properties of fast radio bursts from CHIME/FRB Catalog 1. *Astronomy & Astrophysics*, *698*, A215. https://doi.org/10.1051/0004-6361/202453006

[14] Hagstotz, S., Reischke, R., Lilow, R. (2022). A new measurement of the Hubble constant using fast radio bursts. *Monthly Notices of the Royal Astronomical Society*, *511*(1), 662–667. https://doi.org/10.1093/mnras/stac077

[15] James, C. W., Ghosh, E. M., Prochaska, J. X., Bannister, K. W., Bhandari, S., Day, C. K., Deller, A. T., Glowacki, M., Gordon, A. C., Heintz, K. E., Macquart, J.-P., Marnoch, L., Ravi, V., Ryder, S. D., Scott, D. R., Shannon, R. M. (2022). The z–DM distribution of fast radio bursts. *Monthly Notices of the Royal Astronomical Society*, *516*(4), 4862–4881. https://doi.org/10.1093/mnras/stac2524

[16] Lanman, A. E., Andersen, B. C., Bhandari, S., Chawla, P., CHIME/FRB Collaboration, Fonseca, E., Kaspi, V. M., Michilli, D., Nimmo, K., Pleunis, Z., Tendulkar, S. P. (2024). Sub-arcsecond localization of 18 repeating fast radio bursts with CHIME/FRB outriggers. *The Astronomical Journal*, *168*, 87. https://doi.org/10.3847/1538-3881/ad5838

[17] Liu, Y., et al. (2025). Constraining the Baryon Fraction in the Intergalactic Medium with 92 localized Fast Radio Bursts. *preprint*. arXiv:2506.03536.

[18] Lorimer, D. R., Bailes, M., McLaughlin, M. A., Narkevic, D. J., Crawford, F. (2007). A bright millisecond radio burst of extragalactic origin. *Science*, *318*(5851), 777–780. https://doi.org/10.1126/science.1147532

[19] Lyubarsky, Y. (2014). A model for fast extragalactic radio bursts. *Monthly Notices of the Royal Astronomical Society: Letters*, *442*(1), L9–L13. https://doi.org/10.1093/mnrasl/slu046

[20] Macquart, J.-P., Prochaska, J. X., McQuinn, M., Bannister, K. W., Bhandari, S., Day, C. K., Deller, A. T., Ekers, R. D., James, C. W., Marnoch, L., Osłowski, S., Phillips, C., Ryder, S. D., Scott, D. R., Shannon, R. M., Tejos, N. (2020). A census of baryons in the Universe from localized fast radio bursts. *Nature*, *581*(7809), 391–395. https://doi.org/10.1038/s41586-020-2300-2

[21] Mannings, A. G., Fong, W., Simha, S., Prochaska, J. X., Bhandari, S., Bannister, K. W., Deller, A. T., Day, C. K., James, C. W., Kumar, P., Macquart, J.-P., Phillips, C., Ryder, S. D., Scott, D. R., Shannon, R. M., Tejos, N. (2021). A high-resolution view of fast radio burst host environments. *The Astrophysical Journal*, *917*(1), 75. https://doi.org/10.3847/1538-4357/abff56

[22] McQuinn, M. (2014). Locating the "missing" baryons with extragalactic dispersion measure estimates. *The Astrophysical Journal Letters*, *780*(2), L33. https://doi.org/10.1088/2041-8205/780/2/L33

[23] Ocker, S. K., Cordes, J. M., Chatterjee, S. (2021). Probing Galactic and extragalactic gas with fast radio bursts. *The Astrophysical Journal*, *911*(2), 102. https://doi.org/10.3847/1538-4357/abeb6e

[24] Petroff, E., Barr, E. D., Jameson, A., Keane, E. F., Bailes, M., Kramer, M., Morello, V., Tabbara, D., van Straten, W. (2016). FRBCAT: The fast radio burst catalogue. *Publications of the Astronomical Society of Australia*, *33*, e045. https://doi.org/10.1017/pasa.2016.35

[25] Petroff, E., Hessels, J. W. T., Lorimer, D. R. (2019). Fast radio bursts. *The Astronomy and Astrophysics Review*, *27*(1), 4. https://doi.org/10.1007/s00159-019-0116-6

[26] Ravi, V., Shannon, R. M., Bailes, M., Bannister, K. W., Bhandari, S., Bhat, N. D. R., Burke-Spolaor, S., Caleb, M., Flynn, C., Jameson, A., Johnston, S., Keane, E. F., Kerr, M., Tiburzi, C., Tuntsov, A. V., Vedantham, H. K. (2016). The magnetic field and turbulence of the cosmic web measured using a brilliant fast radio burst. *Science*, *354*(6317), 1249–1252. https://doi.org/10.1126/science.aaf6807

[27] Ravi, V., Catha, M., D'Addario, L., Djorgovski, S. G., Hallinan, G., Hobbs, R., Kocz, J., Kulkarni, S. R., Shi, J., Vedantham, H. K., Weinreb, S., Woody, D. P. (2019). A fast radio burst localized to a massive galaxy. *Nature*, *572*(7769), 352–354. https://doi.org/10.1038/s41586-019-1389-7

[28] Ravi, V., Law, C. J., Li, D., Aggarwal, K., Burke-Spolaor, S., Butler, B. J., Chatterjee, S., Chen, H., Connor, L., Cordes, J. M., De, K., Djorgovski, S. G., Hallinan, G., Kocz, J., Kulkarni, S. R., Lazio, T. J. W., Ocker, S. K., Pearlman, A. B. (2023). Deep Synoptic Array science: A 25 millisecond-localized fast radio burst. *The Astrophysical Journal Letters*, *949*(1), L3. https://doi.org/10.3847/2041-8213/acc4b6

[29] Shannon, R. M., Macquart, J.-P., Bannister, K. W., Ekers, R. D., James, C. W., Oslowski, S., Qiu, H., Sammons, M., Hotan, A. W., Voronkov, M. A., Beresford, R. J., Brothers, M., Brown, A. J., Bunton, J. D., Cantrall, A. P., Chapman, J. M., Koribalski, B. S., Neuhold, A., Deller, A. T. (2018). The dispersion–brightness relation for fast radio bursts from a wide-field survey. *Nature*, *562*(7727), 386–390. https://doi.org/10.1038/s41586-018-0588-y

[30] Sharma, K., et al. (2026). Backlighting the Cosmic Web with Fast Radio Bursts: An Anthology of Dispersion Measure Cross-Correlations with Large-Scale Structure and Baryon Tracers. *preprint*. arXiv:2604.22105.

[31] Tendulkar, S. P., Bassa, C. G., Cordes, J. M., Bower, G. C., Law, C. J., Chatterjee, S., Adams, E. A. K., Bogdanov, S., Burke-Spolaor, S., Butler, B. J., Demorest, P., Hessels, J. W. T., Kaspi, V. M., Lazio, T. J. W., Maddox, N., Marcote, B., McLaughlin, M. A., Paragi, Z., Ransom, S. M., van Leeuwen, J. (2017). The host galaxy and redshift of the repeating fast radio burst FRB 121102. *The Astrophysical Journal Letters*, *834*(2), L7. https://doi.org/10.3847/2041-8213/834/2/L7

[32] Thornton, D., Stappers, B., Bailes, M., Barsdell, B., Bates, S., Bhat, N. D. R., Burgay, M., Burke-Spolaor, S., Champion, D. J., Coster, P., D'Amico, N., Jameson, A., Johnston, S., Keith, M., Kramer, M., Levin, L., Milia, S., Ng, C., Possenti, A., van Straten, W. (2013). A population of fast radio bursts at cosmological distances. *Science*, *341*(6141), 53–56. https://doi.org/10.1126/science.1236789

[33] Weltman, A., Bull, P., Camera, S., Kelley, K., Padmanabhan, H., Pritchard, J., Raccanelli, A., Blyth, S., Bottrell, C., Bucher, M., Chen, X., Cunnington, S., Davis, T. M., Davé, R., Dinda, B. R., Fonseca, J., Font-Ribera, A., Foreman, S., & Wu, F. (2020). Fundamental physics with the Square Kilometre Array. *Publications of the Astronomical Society of Australia*, *37*, e002. https://doi.org/10.1017/pasa.2019.4

[34] Wu, Q., Yu, H., Wang, F. Y. (2020). A new method to measure the Hubble parameter H(z) through fast radio bursts. *The Astrophysical Journal*, *895*(1), 33. https://doi.org/10.3847/1538-4357/ab88d2

[35] Xu, H., Niu, J. R., Chen, P., Lee, K. J., Zhu, W. W., Dong, S., Zhang, B., Jiang, J. C., Wang, B. J., Xu, J. W., Yuan, M., Yang, Y. P., Li, D., Zhang, C. F., Zhao, R. S., Wang, P., Feng, Y., Liu, Z. Y., Men, Y. P. (2022). A fast radio burst source at a complex magnetized site in a barred galaxy. *Nature*, *609*(7928), 685–688. https://doi.org/10.1038/s41586-022-05071-8

[36] Zhang, B. (2020). The physical mechanisms of fast radio bursts. *Nature*, *587*(7832), 45–53. https://doi.org/10.1038/s41586-020-2828-1