国際SKA宇宙論グループの活動とサイエンスブックの進捗について

SKA-Japan サイエンスワークショップ 2026/4/3

箕田鉄兵 (清華大学)

現状整理と本講演の目的

- 現状：日本からcosmology sessionへの寄稿なし
  1. 他のsession (EoRなど)に執筆参加
  2. Science Book EoIの締切以降にいくつか関連研究がある
     (伊東さん・長倉さん・大黒さん・新居さん・成瀬さん・Wildanさん・直川さんetc.)
  3. 他の班とも協力してSV, KSP を狙いたい

- **今日のトーク内容：**

  国際SKA cosmology 関連研究の情報共有
  Update from AASKA 2015 and RedBook 2018?

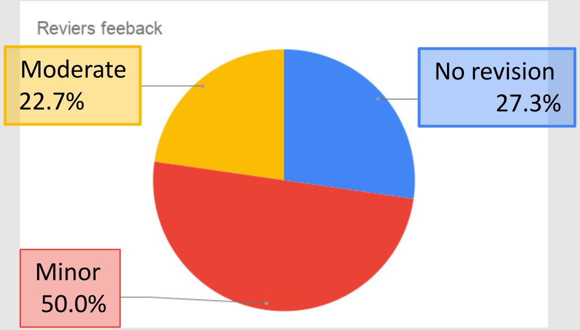
SKAサイエンスブック(国際版)

- 2015 SKA science book (AASKA, white book)
  - 18のchapter (BAO, RSD, HI survey, weak lensing, …)
- SKA1 Redbook 2018
- 2024 November SWG meeting at Nice

  > 次回は今年の夏頃に開催？

SKAサイエンスブック(国際版)

- 一昨日（4/1）にcosmology SWG zoom meetingがあった
- 2026 Science book (AASKA II, AA4)
  - MeerKATなど先行機の観測結果を反映
  - チャプターがより細分化、18→22に (ex. Intensity Mappingは1→ 6)
  - 新しいサイエンステーマが追加
  - 近年の先行機や他波長観測とのシナジーによるアップデート



2015 Cosmology Chapter

- Overview
- Galaxy clusters
- Weak lensing (2)
- Continuum
- HI simulations
- HI galaxies
- BAO
- RSD
- Intensity mapping
- Topology
- Foreground
- Beyond (2)
- Largest scales
- Cross-correlation
- Real time cosmology
- Stacking

2026 Cosmology Chapter

- Overview
- Galaxy clusters
- Weak lensing (2)
- Continuum
- HI simulations

- ~~HI galaxies~~
- ~~BAO~~
- ~~RSD~~

竹内さん(銀河進化)

2つにまとまる：
Tully-Fisher HI galaxy
Cosmology from HI galaxy

再構成：
Dipole
Gravity
Inflation

- ~~Intensity mapping~~
- ~~Topology~~
- ~~Foreground~~
- ~~Beyond (2)~~
- ~~Largest scales~~
- ~~Cross-correlation~~
- ~~Real time cosmology~~
- ~~Stack~~

島袋さん(再電離)

細分化、6つに：
Cosmology from IM
Statistics beyond 2pt
Late time with SKA-mid
Systematics&Foregrounds
IM with Pathfinders
IM with MeerKAT

細分化、2つに：
GW synergy, multi-IM

高橋さん(パルサー)

新たに追加：
Nx2pt, On-the-Fly, FRBs, particle DM

2026 Cosmology Chapter

- Overview
- Galaxy clusters
- Weak lensing (2)
- Continuum
- HI simulations
- ~~HI galaxies~~
- ~~BAO~~
- ~~RSD~~

2つにまとまる：
Tully-Fisher HI galaxy
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Dipole
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- ~~Intensity mapping~~
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新たに追加：
Nx2pt, On-the-Fly, **FRBs**, particle DM

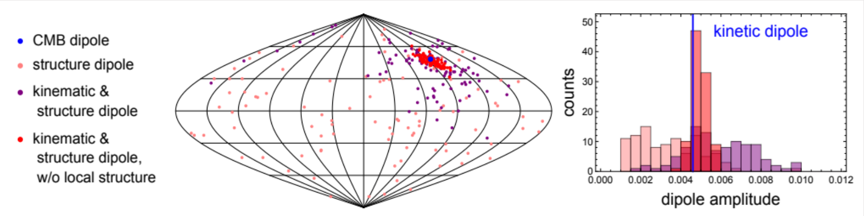
Dipole

- 2015では簡単な言及があった (ISW, relativistic effect)
- Red Book ではsimulation が議論
- 今回は独立した章が提出
- 先行機の観測によって議論が活発に

Cosmology on the Largest Scales with the SKA

Stefano Camera*,[a] Alvise Raccanelli,[bcd] Philip Bull,[e] Daniele Bertacca,[f] Xuelei Chen,[g] Pedro G. Ferreira,[h] Martin Kunz,[ij] Roy Maartens,[fk] Yi Mao,[l] Mário G. Santos,[fma] Paul R. Shapiro,[n] Matteo Viel[op] and Yidong Xu[g]

The study of the Universe on ultra-large scales is one of the major science cases for the Square Kilometre Array (SKA). The SKA will be able to probe a vast volume of the cosmos, thus representing a unique instrument, amongst next-generation cosmological experiments, for scrutinising the Universe's properties on the largest cosmic scales. Probing cosmic structures on extremely large scales will have many advantages. For instance, the growth of perturbations is well understood for those modes, since it falls fully within the linear régime. Also, such scales are unaffected by the poorly understood feedback of baryonic physics. On ultra-large cosmic scales, two key effects become significant: primordial non-Gaussianity and relativistic corrections to cosmological observables. Moreover, if late-time acceleration is driven not by dark energy but by modifications to general relativity, then such modifications should become apparent near and above the horizon scale. As a result, the SKA is forecast to deliver transformational constraints on non-Gaussianity and to probe gravity on super-horizon scales for the first time.



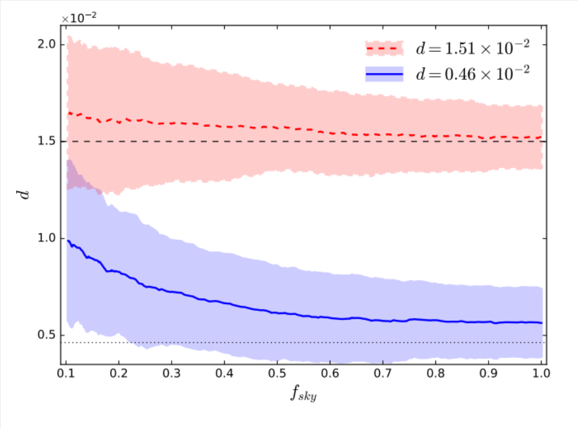
Camera et al. (AASKA) 2015, RedBook 2018

Dipole

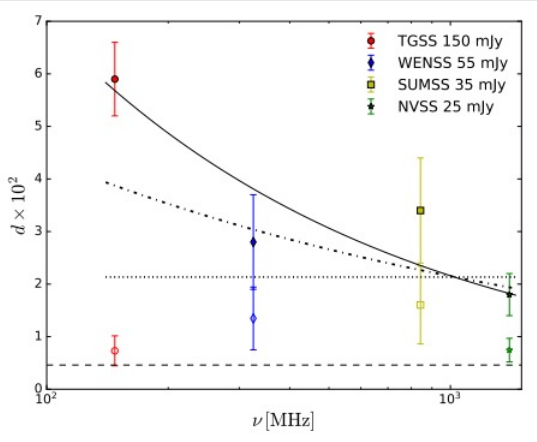
(Siewert et al. 2021)
NVSSなどのデータを使って、dipole の推定を行った

	2017	1997	2003	1998
	TGSS-ADR1	WENSS	SUMSS	NVSS
instrument	GMRT	WRST	MOST	VLA
latitude	19° 05′ 48″ N	52° 54′ 53″ N	53° 22′ 15″ S	34° 04′ 43″ N
central frequency	147. MHz	325. MHz	843. MHz	1.4 GHz
sky coverage	$DEC > -53$ deg	$DEC > 30$ deg	$DEC \leq -30$ deg	$DEC > -40$ deg
sky area	11.24 sr	3.10 sr	2.47 sr	10.32 sr
sky fraction	0.89	0.25	0.20	0.82
limit flux density	25 mJy	15 mJy	6/10 mJy	2.5 mJy
source density	5.7×10^4 sr^{-1}	7×10^4 sr^{-1}	8.6×10^4 sr^{-1}	17.2×10^4 sr^{-1}
resolution	$25'' \times 25''$	$54'' \times 54''/\sin(DEC)$	$45'' \times 45''/\cos(DEC)$	$45'' \times 45''$
number of objects	640 017	229 420	210 412	1 773 484

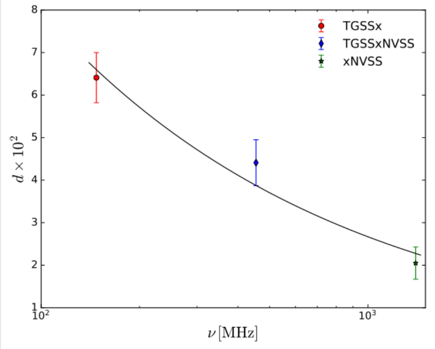
解析に用いたサーベイデータの詳細



観測のSky fractionと、dipole amplitudeの測定誤差の関係 (simulation結果)



$A = 2.16 \times 10^{-2}, m = -0.51, \chi^2/\text{dof} = 1.23$



$$d_{\text{fit}}(\nu) = A(\nu/1\ \text{GHz})^m$$
$$A = (2.67 \pm 0.70) \times 10^{-2}$$
$$m = -0.47 \pm 0.16$$
$$\chi^2/\text{dof} = 1.44$$

Dipole

(Siewert et al. 2021)
NVSSなどのデータを使って、dipole の推定を行った

- **CMB dipole と大きさに不一致**
  宇宙原理：等方性の破れ？
  局所性など、その他の物理？
  バイアス？系統誤差？
  > cross-correlation
- **周波数依存性の謎**

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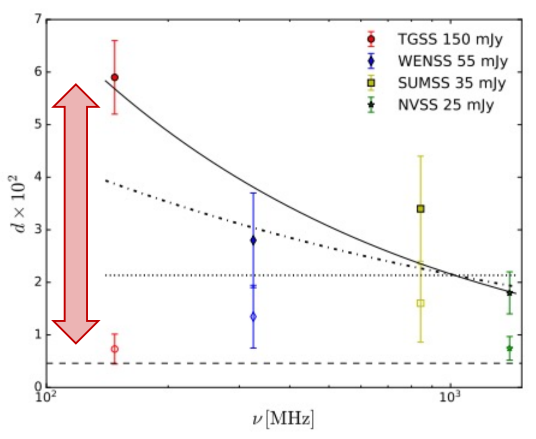

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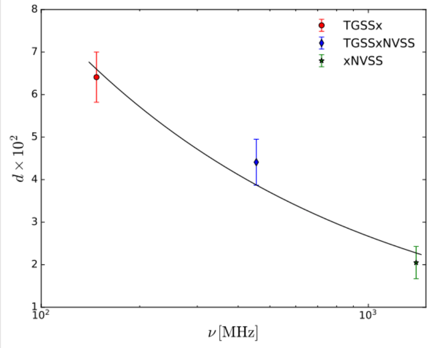

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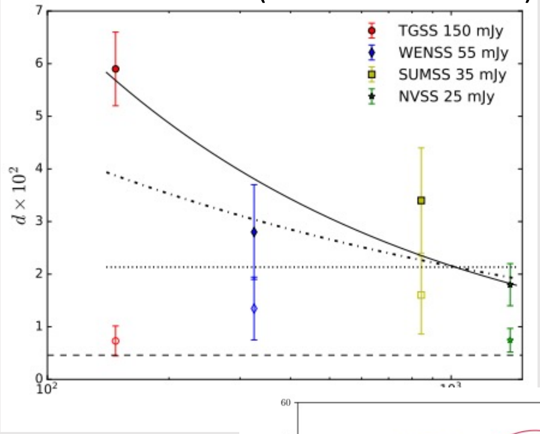
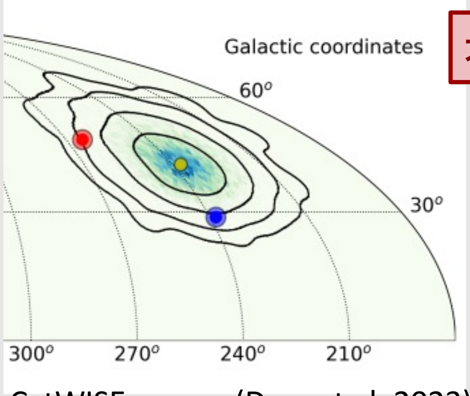
$$\chi^2/\mathrm{dof} = 1.44$$

Dipole

大きさだけでなく、方向も若干のずれ？

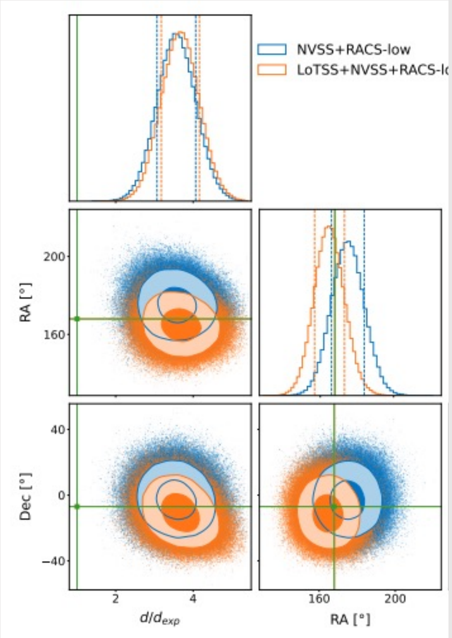
(Siewert et al. 2021)

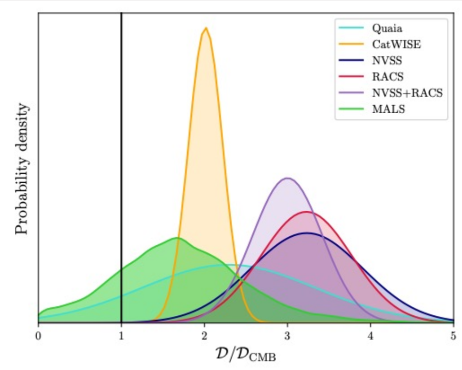


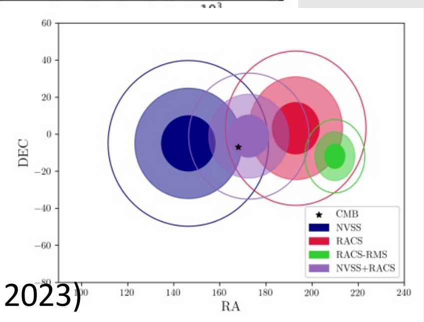


CatWISE quasar (Dam et al. 2023)
赤：Planck, 青： Secrest 2021

5.4 sigma discrepancy from CMB!
LOFAR (LoTSS-DR2, Bohme et al. 2025)







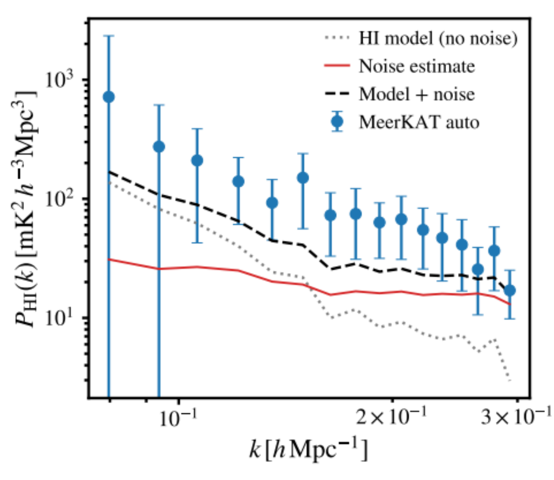
VLA and ASKAP
(NVSS+RACS,
Wagenveld et al. 2023)

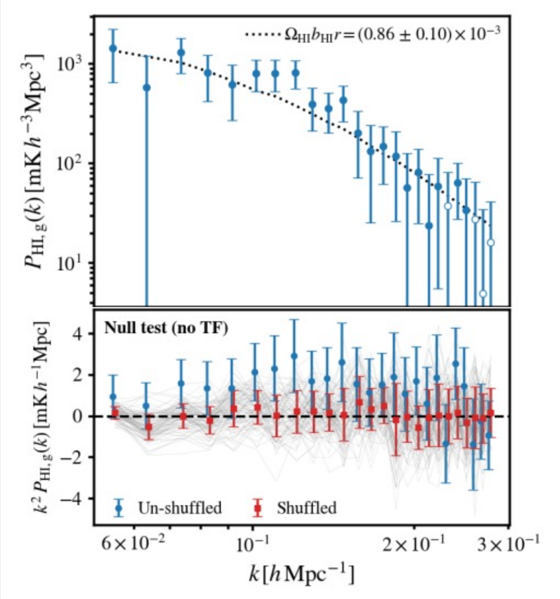
MeerKAT absorption line survey
(MALS, Wagenveld et al. 2023)

HI intensity mapping

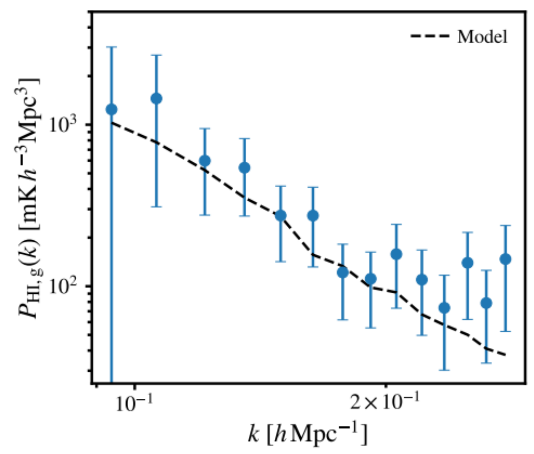
- **2015年の予測**: single dishを用いたIMの実現可能性や前景放射除去の理論的検討が中心
- **2026年**: 6本の論文に分割
  - Single dish mode / Precursors によるIM / Pathfinders によるIM
  - systematics, component separation の新たな手法
  - 高次統計量の議論 (bispectrum, l-1 norm, marked PS, 1-pt, …)

HI intensity mapping with MeerKAT



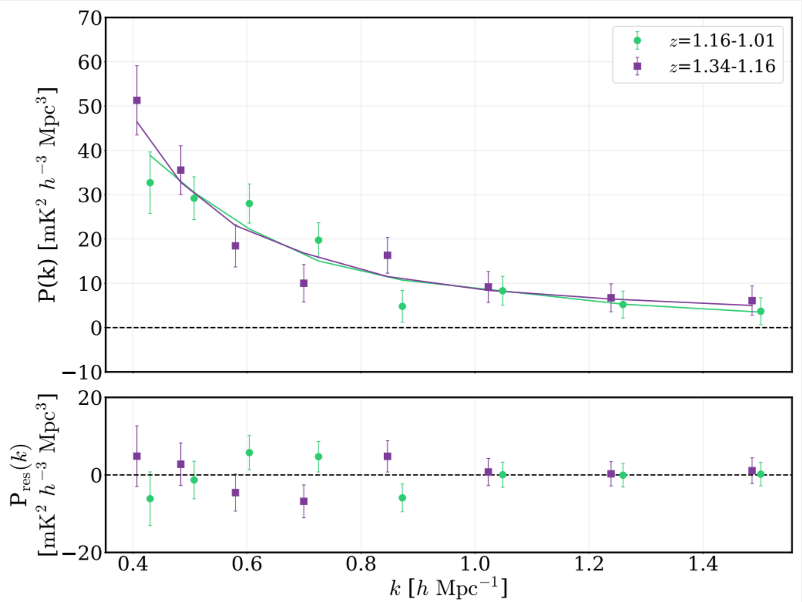


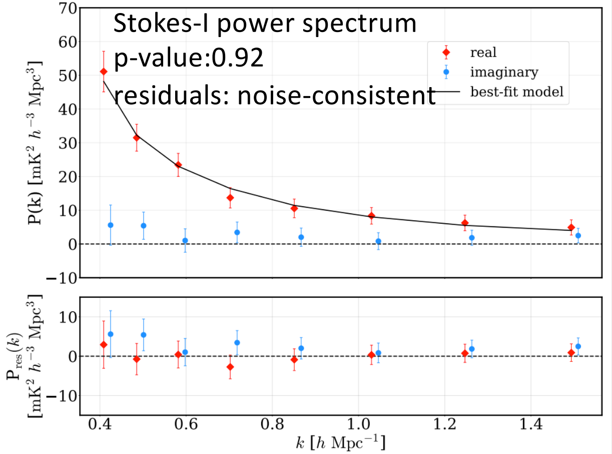
auto-correlation MeerKLASS
cross-correlation
MeerKLASS IM x GAMA
at $0.39 < z < 0.46$
236 deg2, 63 hours, 64 dishes
(single-dish mode)
(Barberi-Squarotti et al. 2023)

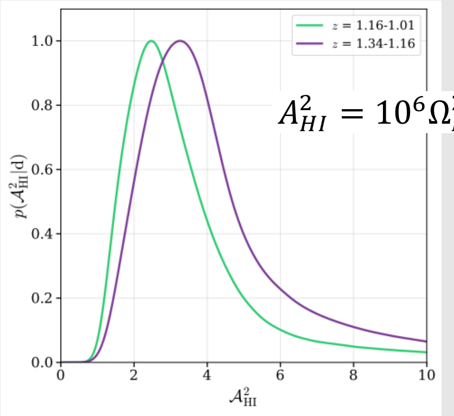


7.7 sigma detection of cross-correlation.
MeerKAT IM x WiggleZ, $0.400 < z < 0.459$
(Cunnington et al. 2023)

HI intensity mapping with CHIME



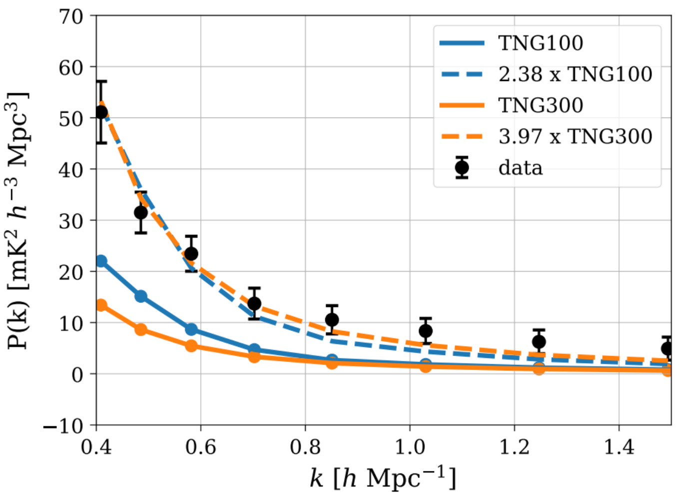




$$A_{HI}^2 = 10^6 \Omega_{HI}^2 (b_{HI}^2 + \langle f\mu^2 \rangle)^2$$

Total detection significance: 12.4 sigma
CHIME 94 nights (Amiri et al. 2025)

HI intensity mappi



arXiv > astro-ph > arXiv:2603.25680v1

Astrophysics > Cosmology and Nongalactic Astrophysics

[Submitted on 26 Mar 2026]

Interpretation of 21 cm Auto Power Spectrum Measure Hydrogen Intensity Mapping Experiment

CHIME Collaboration, Mandana Amiri, Kevin Bandura, Arnab Chakraborty, Zhuo Yu B Halpern, Gary Hinshaw, Albin Joseph, Nolan Kruger, Joshua MacEachern, Kiyoshi W. Pinsonneault-Marotte, Alex Reda, Shabbir Shaikh, Seth R. Siegel, Yukari Uchibori, Keith Vanderlinde, Haochen Wang, Dallas Wulf

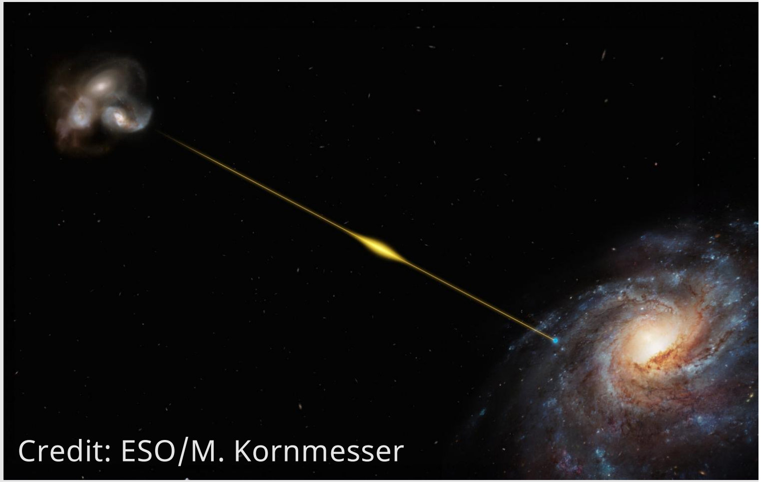
Observations with the Canadian Hydrogen Intensity Mapping Experiment (CHIME) have been used to measure the 21 cm intensity mapping auto power spectrum, at $z \sim 1$, over a frequency range from 608.2 MHz to 707.8 MHz at wavenumbers $0.4\ h\,\mathrm{Mpc}^{-1} \lesssim k \lesssim 1.5\ h\,\mathrm{Mpc}^{-1}$. In this paper, we present the results of two different approaches to interpreting this measurement. In the first approach, we use a parametric power spectrum model to constrain an amplitude parameter, defined as $\mathcal{A}_{\mathrm{HI}}^2 \equiv 10^6 \Omega_{\mathrm{HI}}^2 (b_{\mathrm{HI}}^2 + \langle f\mu^2 \rangle)^2$, where Ω_{HI} is the cosmological density parameter for atomic hydrogen (HI), b_{HI} is the linear bias for HI, and $\langle f\mu^2 \rangle$ incorporates the dominant large-scale impact of redshift-space distortions on the angle-averaged power spectrum. Imposing an additional prior on either Ω_{HI} or b_{HI}, based on values in the literature, allows us to break the pairwise degeneracy between those two parameters. In the second approach, we compare CHIME's measurement with predictions for the power spectrum of HI from the IllustrisTNG simulations, finding that the measurement disagrees with the TNG100 run at 3.1σ and the TNG300 run at 4.0σ. This disagreement is most likely attributable to the strength of nonlinear redshift-space clustering of HI in the simulations, rather than the total abundance of HI, and invites further investigation of the physical processes in the simulations that determine the behavior of HI at nonlinear scales. These results exemplify the ability of 21 cm intensity mapping to provide astrophysical information using measurements at nonlinear scales.

Fast Radio Bursts cosmology

- 全天で1日に1000件以上発生と想定
- SKAでは1日10-100件検出が予想
- Dispersion measure の測定

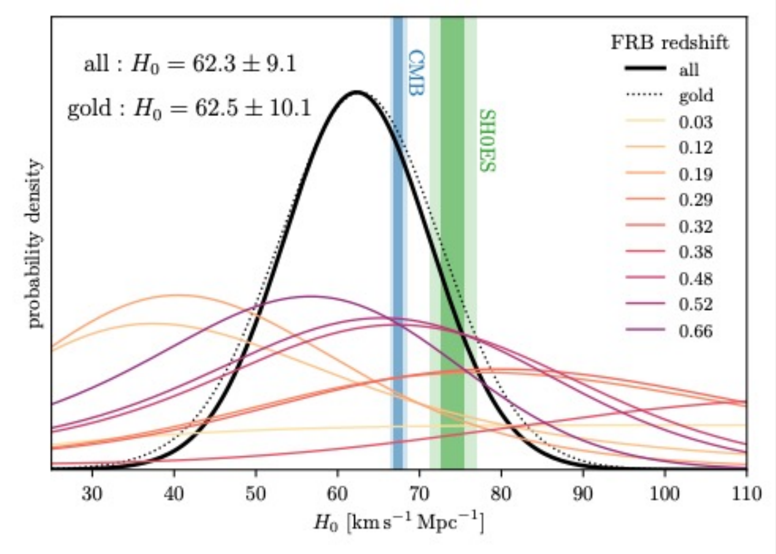
  宇宙のバリオン分布

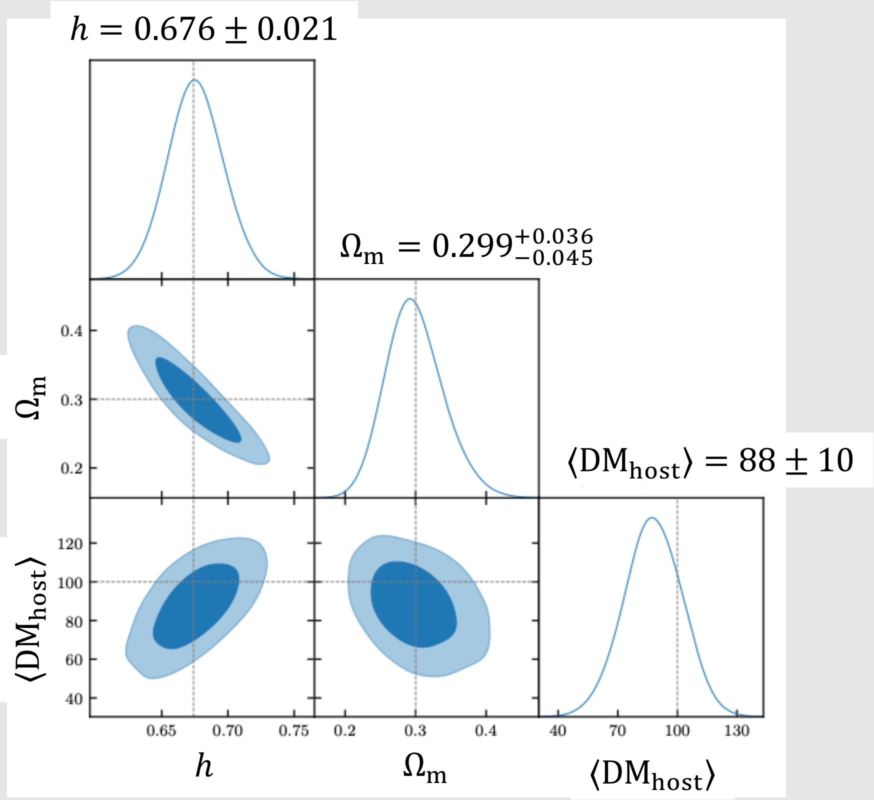
  再電離の歴史



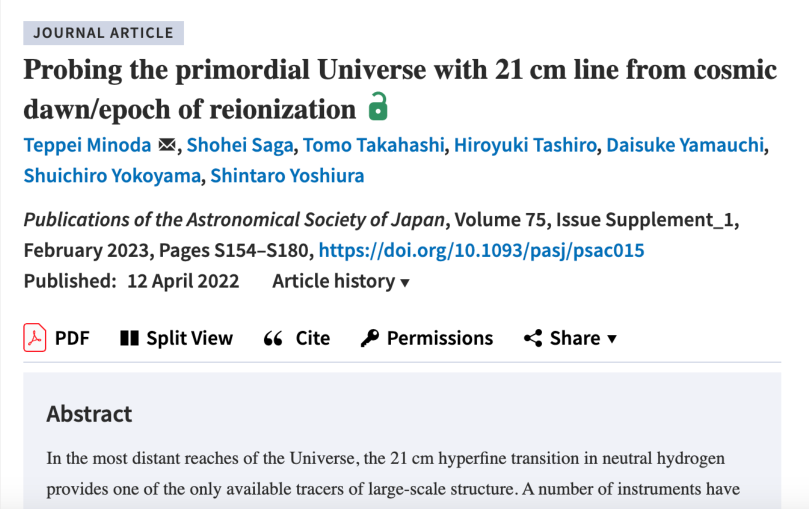
$$\Delta t \propto \frac{\mathrm{DM}}{\nu^2}, \qquad \mathrm{DM} = \int n_{\mathrm{e}} dl$$

Fast Radio Bursts cosmology





(左) 9 identified FRBs ASKAP
(右) Expected constrant from 500 sample
(Hagstotz et al. 2022)



JOURNAL ARTICLE

Probing the primordial Universe with 21 cm line from cosmic dawn/epoch of reionization

Teppei Minoda, Shohei Saga, Tomo Takahashi, Hiroyuki Tashiro, Daisuke Yamauchi, Shuichiro Yokoyama, Shintaro Yoshiura

Publications of the Astronomical Society of Japan, Volume 75, Issue Supplement_1, February 2023, Pages S154–S180, https://doi.org/10.1093/pasj/psac015

Published: 12 April 2022 Article history ▾

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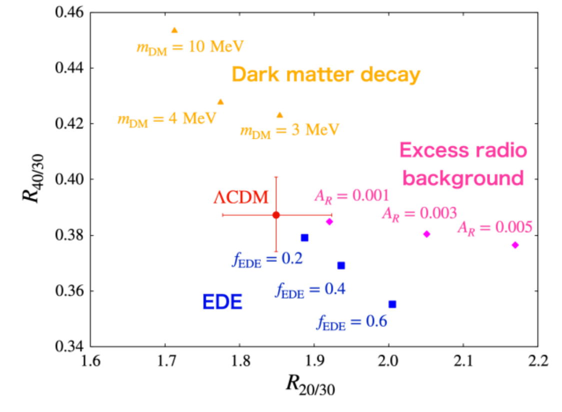
Abstract

In the most distant reaches of the Universe, the 21 cm hyperfine transition in neutral hydrogen provides one of the only available tracers of large-scale structure. A number of instruments have

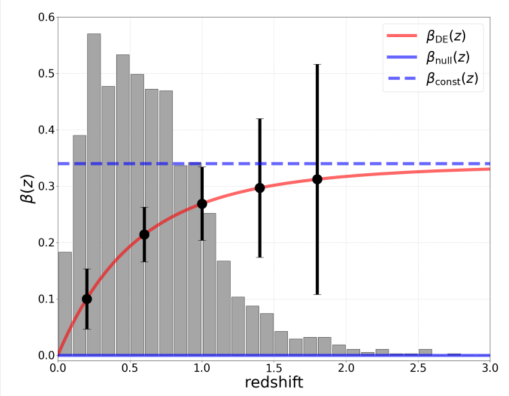
A new observable to test cosmological models from 21-cm global signal in the Dark Ages (Okamatsu+ 2024)



Published a review article for cosmology science of SKA-JP (Minoda+ 2023)

Topics:

- Inflation models and power spectrum
- Isocurvature perturbations
- Primordial non-Gaussianities
- Primordial magnetic fields



Forecasted error bar of the cosmic birefringence from LOFAR (Naokawa 2026)

Cosmology Chapter 一覧

- Dipole
- Cluster lensing
- Weak lensing (2)
- Intensity mapping (6)
- Continuum Auto-correlations
- Nx2pt cosmology
- HI simulations

- HI galaxies (2)
- Beyond (2)
- Particle dark m
- Fast radio burs
- Gravitational w
- Line intensity m
- On-the-fly map

日本が狙うサイエンス:
- 原始非ガウス性
- ダークエネルギーモデル
- 初期パワースペクトル
- ニュートリノ質量
- 原始磁場
- ミッシングバリオン
- HIバイアス

(出典： 日本版サイエンスブック2020)

今年は新たな項目を加えてアップデート(予定)