2020年代の宇宙論・構造形成

高田昌広（班長）
大栗真宗（サブリーダー）

班員：浜名崇(NAOJ), 樽家篤史(京大), 齊藤俊(IPMU), 宮武広直(Princeton/IPMU), 奥村哲平(IPMU), 日影千秋(IPMU), 高橋龍一(弘前大), 西澤淳(名大), 鮫島 寛明 (京産大)

LSC LIGO Scientific Collaboration

Feb 11, 2016
Press Release from NSF

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MEDIA ADVISORY

For Immediate Release: Monday, February 8, 2016

THURSDAY: SCIENTISTS TO PROVIDE UPDATE ON THE SEARCH FOR GRAVITATIONAL WAVES

100 years after Einstein predicted the existence of gravitational waves, the National Science Foundation gathers scientists from Caltech, MIT and the LIGO Scientific Collaboration to update the scientific community on efforts to detect them.

(Washington, DC) -- Journalists are invited to join the National Science Foundation as it brings together the scientists from Caltech, MIT and the LIGO Scientific Collaboration (LSC) this Thursday at 10:30 a.m. at the National Press Club for a status report on the effort to detect gravitational waves - or ripples in the fabric of spacetime - using the Laser Interferometer Gravitational-wave Observatory (LIGO).

This year marks the 100th anniversary of the first publication of Albert Einstein's prediction of the existence of gravitational waves. With interest in this topic piqued by the centennial, the group will discuss their ongoing efforts to observe gravitational waves.

LIGO, a system of two identical detectors carefully constructed to detect incredibly tiny vibrations from passing gravitational waves, was conceived and built by MIT and Caltech researchers, funded by the National Science Foundation, with significant contributions from other U.S. and international partners. The twin detectors are located in Livingston, Louisiana, and Hanford, Washington. Research and analysis of data from the detectors is carried out by a global group of scientists, including the LSC, which includes the GEO600 Collaboration, and the VIRGO Collaboration.

For additional background about the project, you may be interested in these websites:

- LIGO Lab: https://ligo.caltech.edu/ (Observatories: Livingston | Hanford)
- Advanced LIGO: https://www.advancedligo.mit.edu/
- LIGO Scientific Collaboration: http://www.ligo.org/
- LIGO Partner Experiments and Collaborations: http://www.ligo.org/partners.php

WHEN:

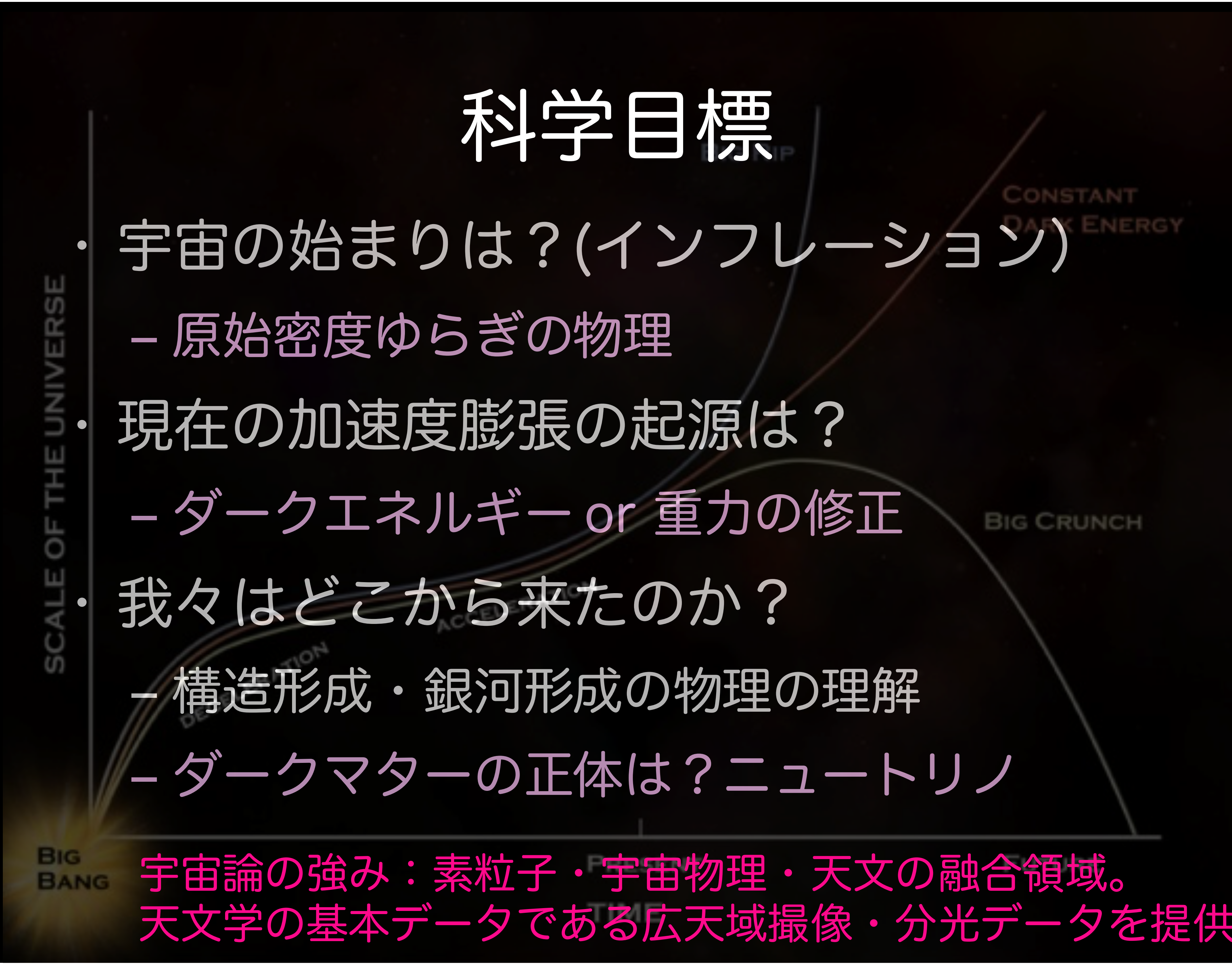
Thursday, Feb. 11, 2016
10:30 AM US EST

March 4, 5@NAOJ
HSC時間軸天文学
ブレインストーミング研究会

科学目標

- 宇宙の始まりは？(インフレーション)
  - 原始密度ゆらぎの物理
- 現在の加速度膨張の起源は？
  - ダークエネルギー or 重力の修正
- 我々はどこから来たのか？
  - 構造形成・銀河形成の物理の理解
  - ダークマターの正体は？ニュートリノ

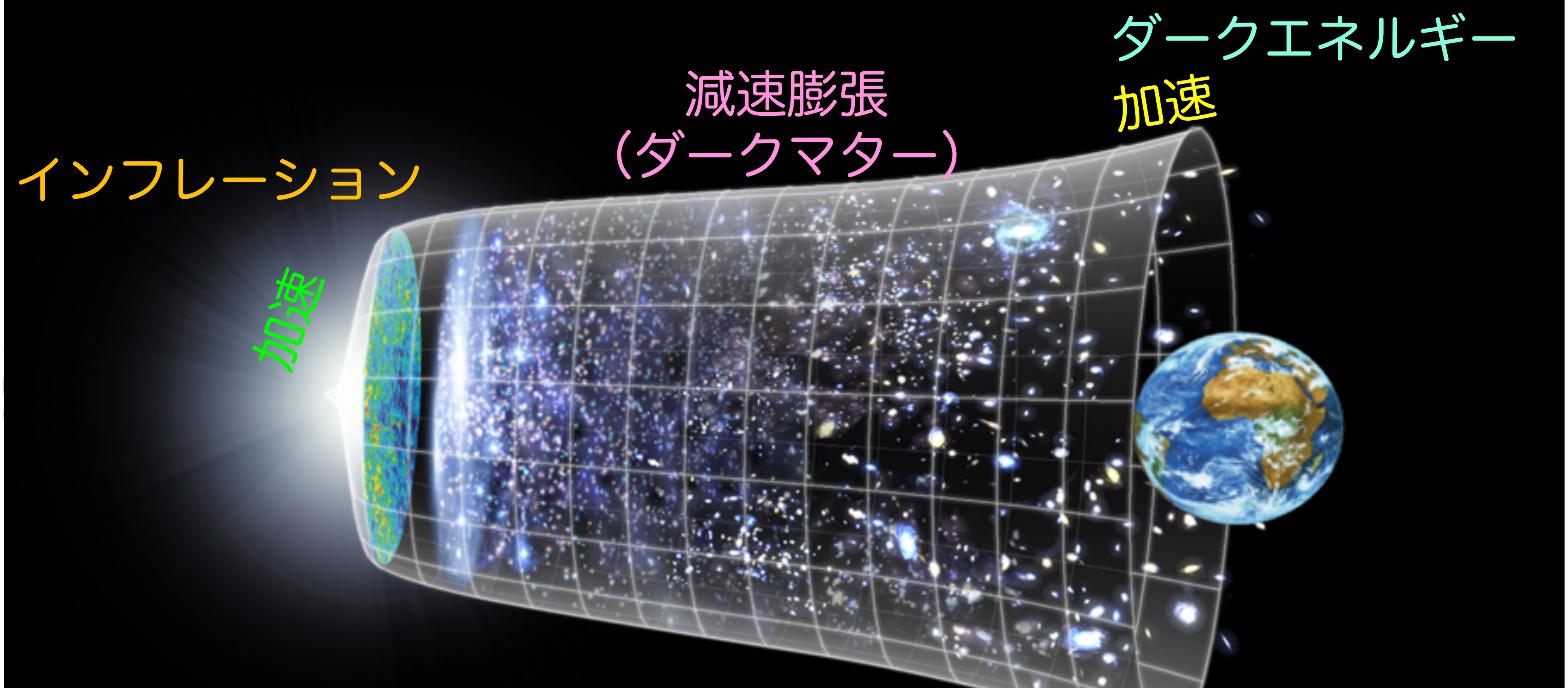
宇宙論の強み：素粒子・宇宙物理・天文の融合領域。
天文学の基本データである広天域撮像・分光データを提供

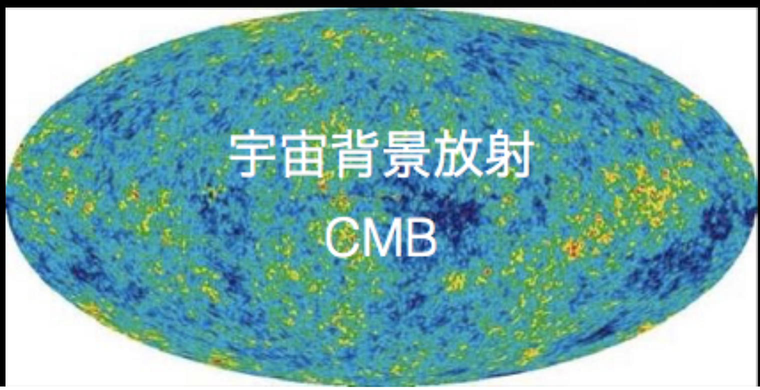


これまでの議論のポイント

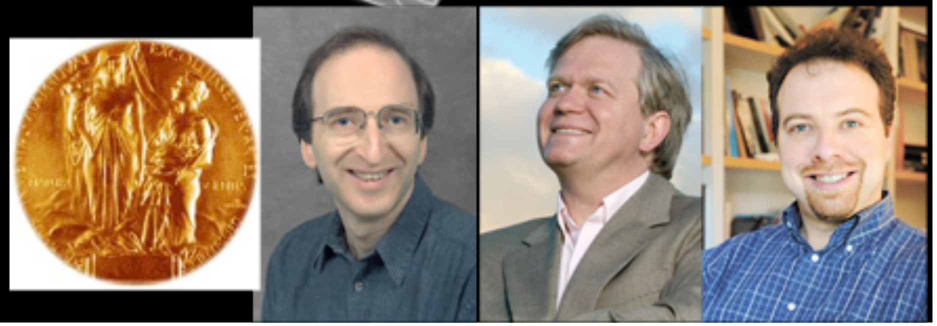
- サイエンスの重要性
- サイエンス⇒手段・手法
- 独自性：可視光・赤外の観測でしかできない計画か？
- サイエンスの発展性、他の分野との相乗効果は？
- 実現可能性は？
- 国際情勢、国際競争力は？

宇宙膨張の変遷

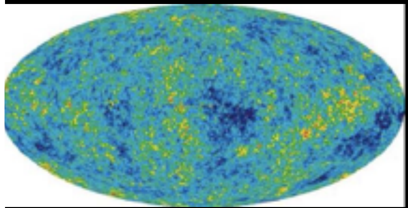




2011年ノーベル物理学賞

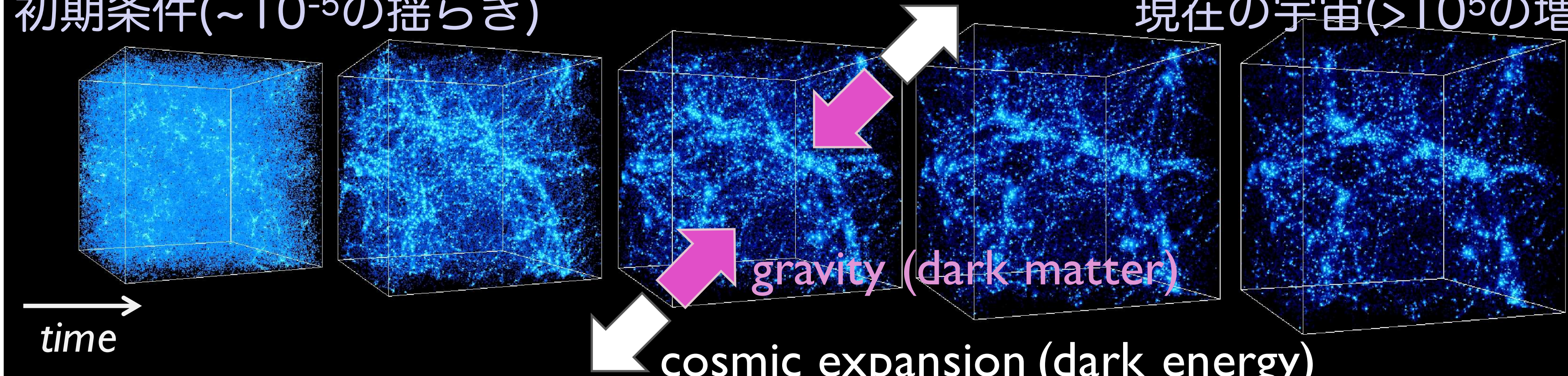


宇宙の構造形成

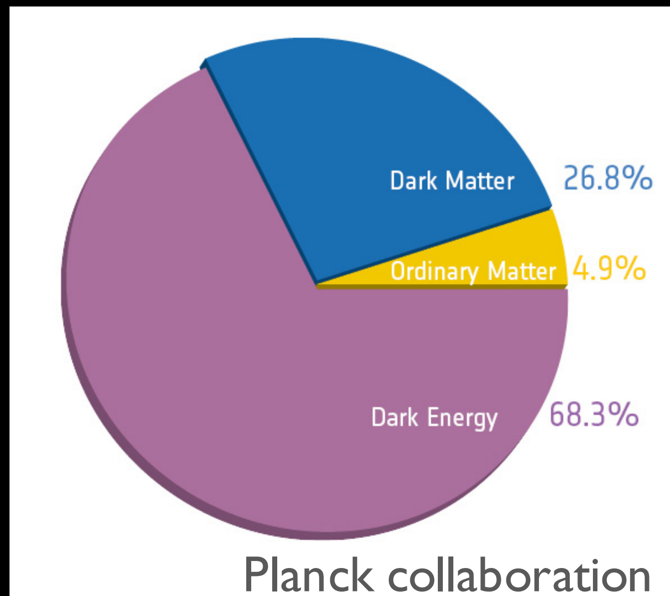


初期条件(~10^{-5}の揺らぎ)

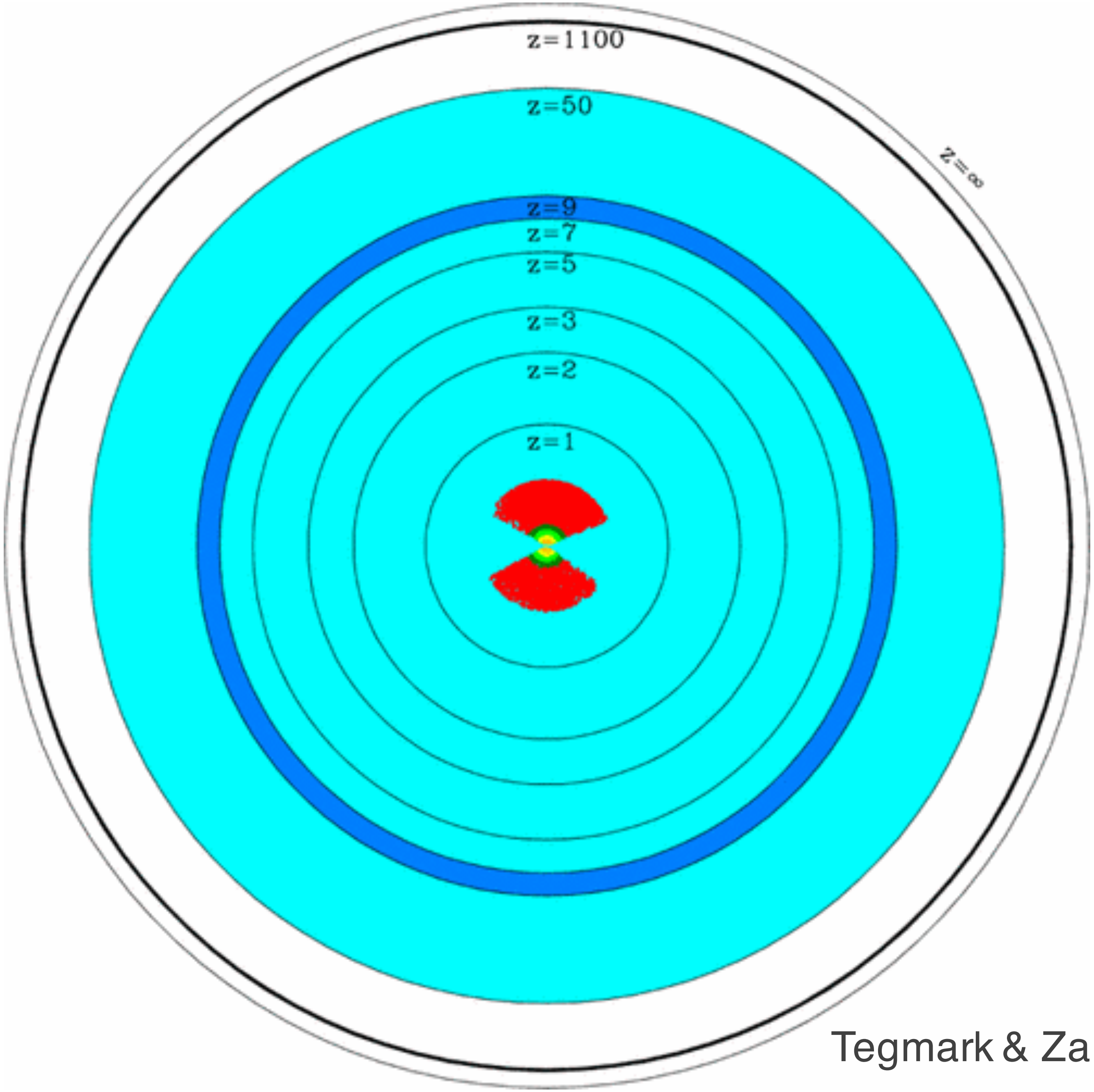
現在の宇宙(>10^5の増幅)



- The present-day large-scale structure arises from a gravitational amplification of the tiny perturbations in the early universe
- Assume Cold Dark Matter (CDM) for unknown source of gravity – cold, massive & collision-less
- LCDM = current standard model
- Gravity (DM) vs. Cosmic expansion (DE)



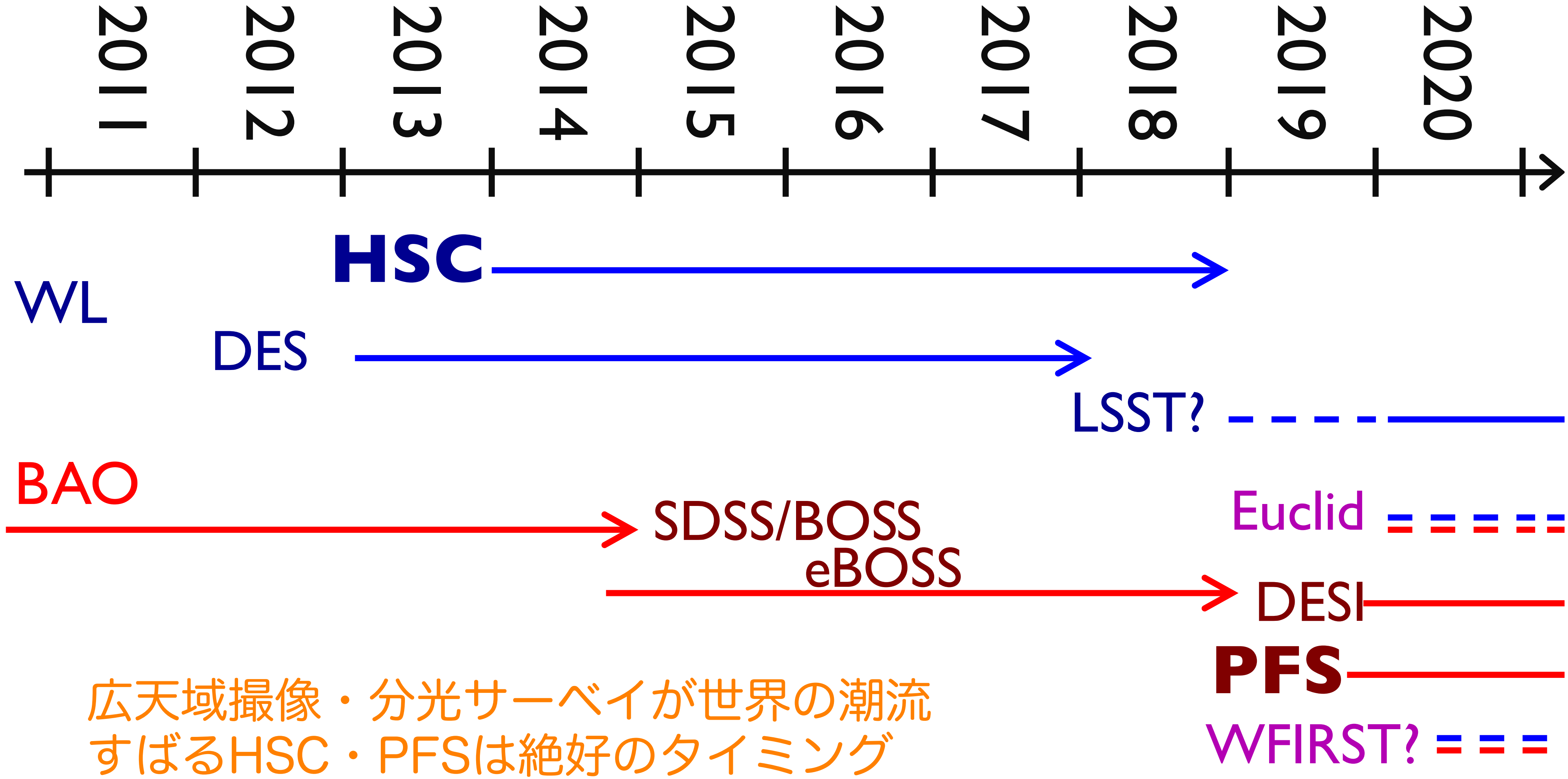
宇宙論に必要なサーベイ



Tegmark & Zaldarriaga 09

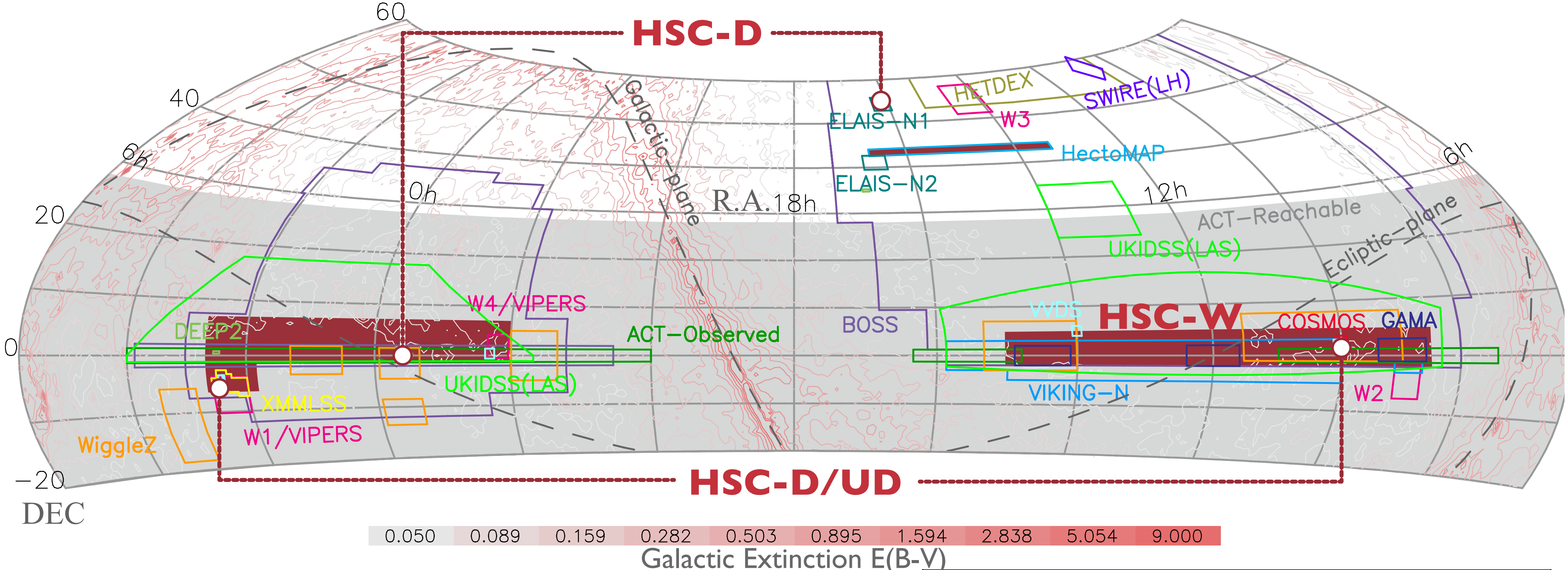
- 広天域の銀河（銀河間ガス）のイメージング・分光サーベイ
- CMB = 晴れ上がりの2次元の情報
- 銀河サーベイ＝3次元の情報 （圧倒的な情報量）
- 銀河→ダークマター→理論と比較
- 銀河バイアス、ガス物理の不定性

国際情勢、国際競争力

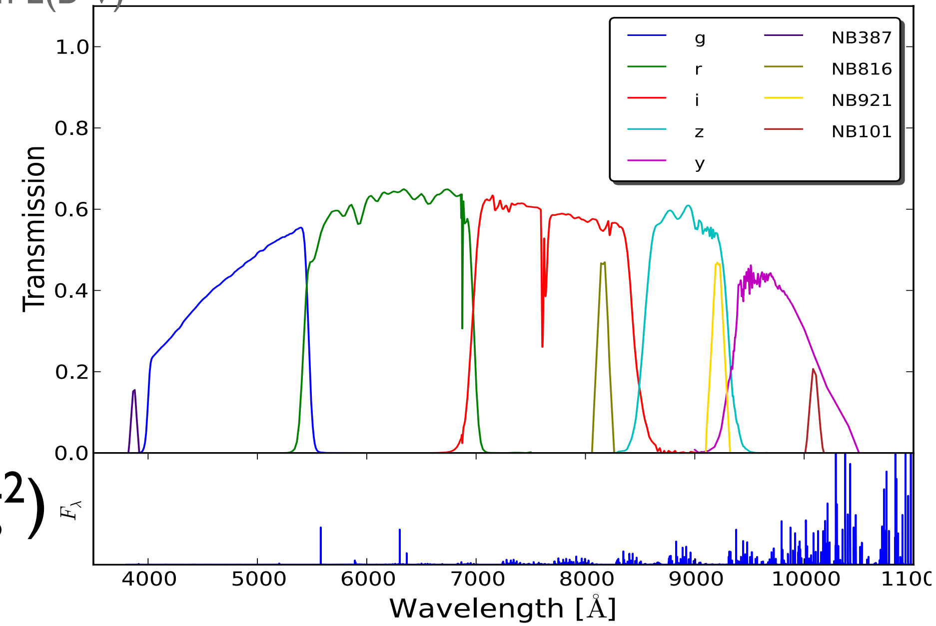


広天域撮像・分光サーベイが世界の潮流
すばるHSC・PFSは絶好のタイミング
2020年代の宇宙論をリード

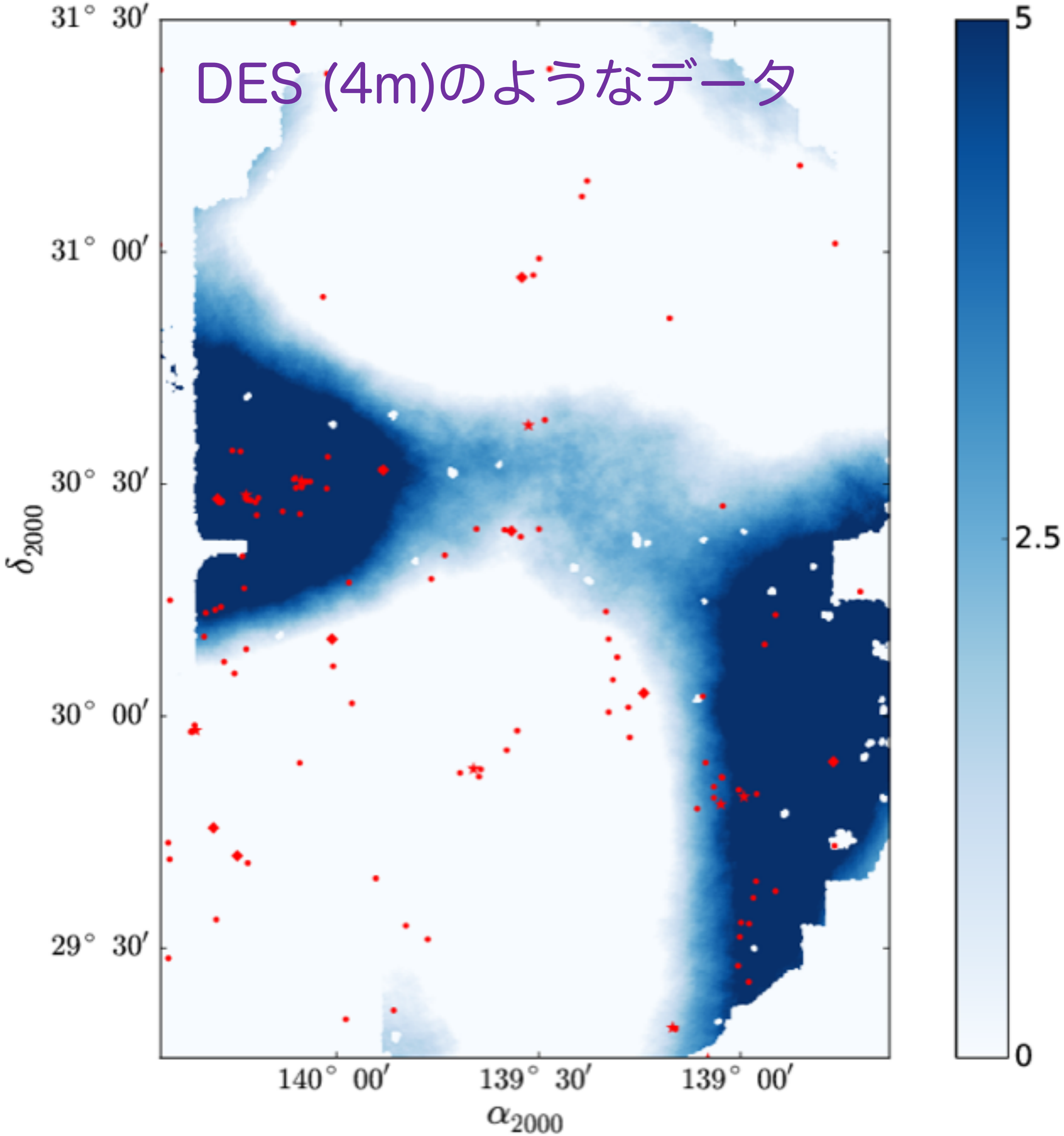
HSC SSP Survey (PI: S. Miyazaki)



- 2014 – 2019 (so far 21 nights)
- Three survey layers
  - Wide (i~26, grizy, 1400 deg^2)
  - Deep (i~27, grizy+NBs, 28 deg^2)
  - Ultra-D (i~28, grizy+NBs, 3.5 deg^2)



Miyazaki et al. 15; HSC is working!

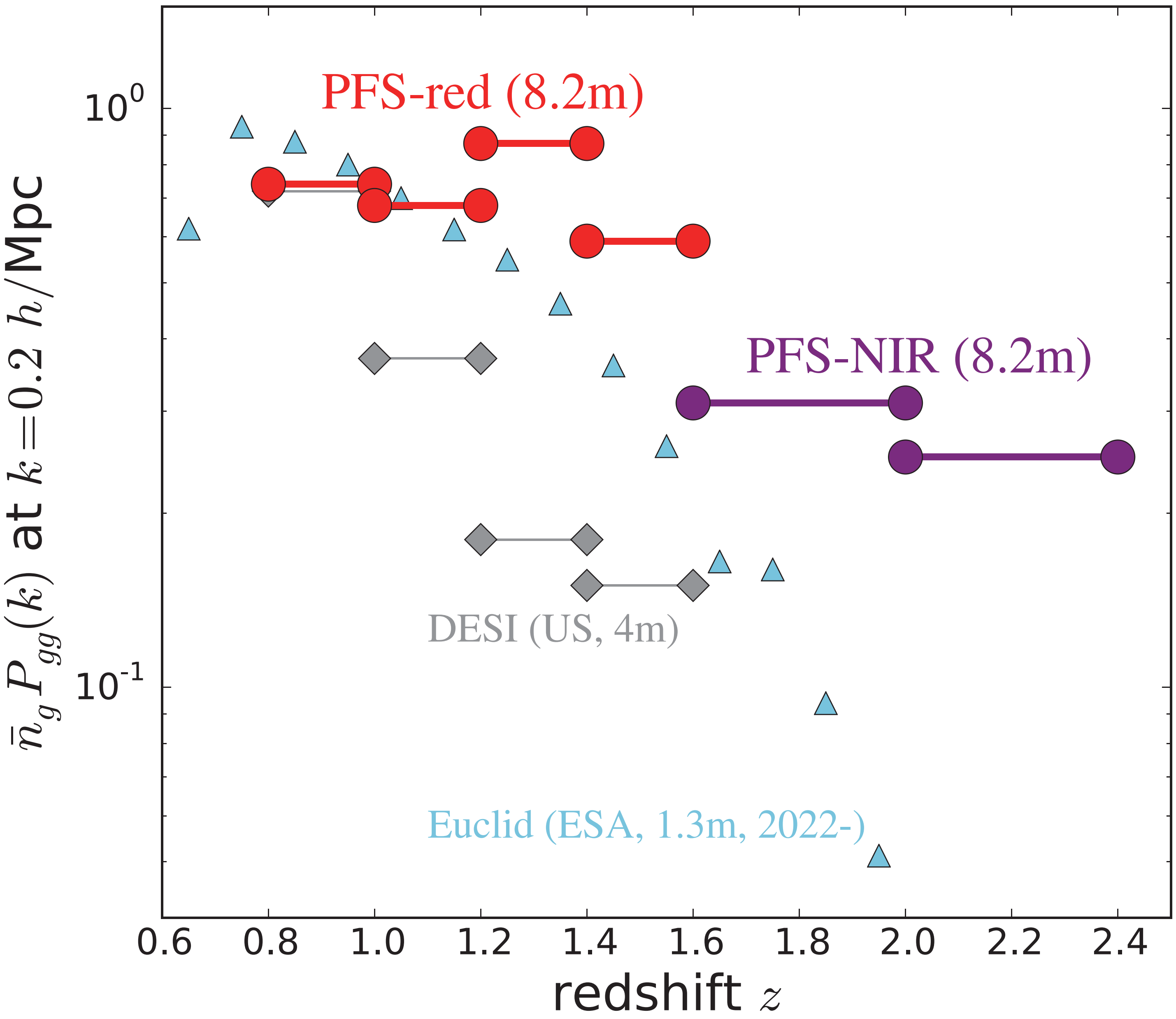


方銀河像の重力効果測
から復元したダークマ
ーの地図 (Miyazaki+
pJ 2015)

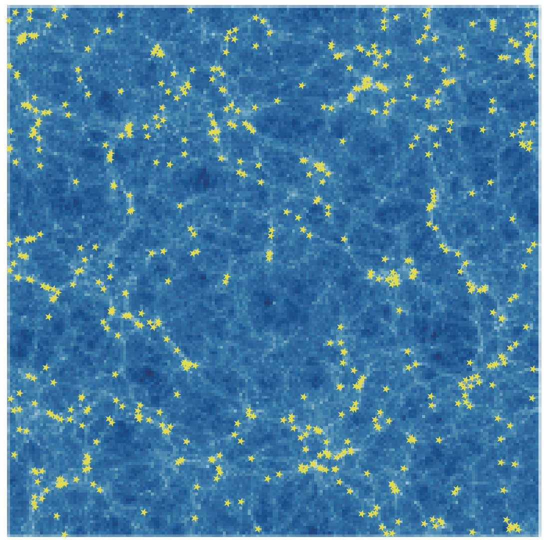
：シャープな結像性能

Power of PFS

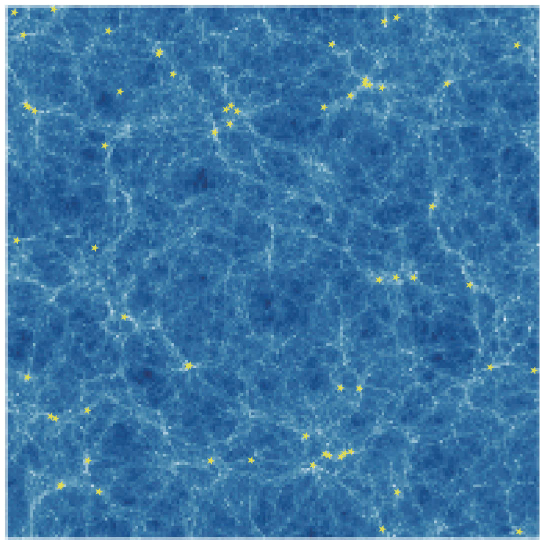
Best datasets at z>1… before WFIRST (NASA:2025-)



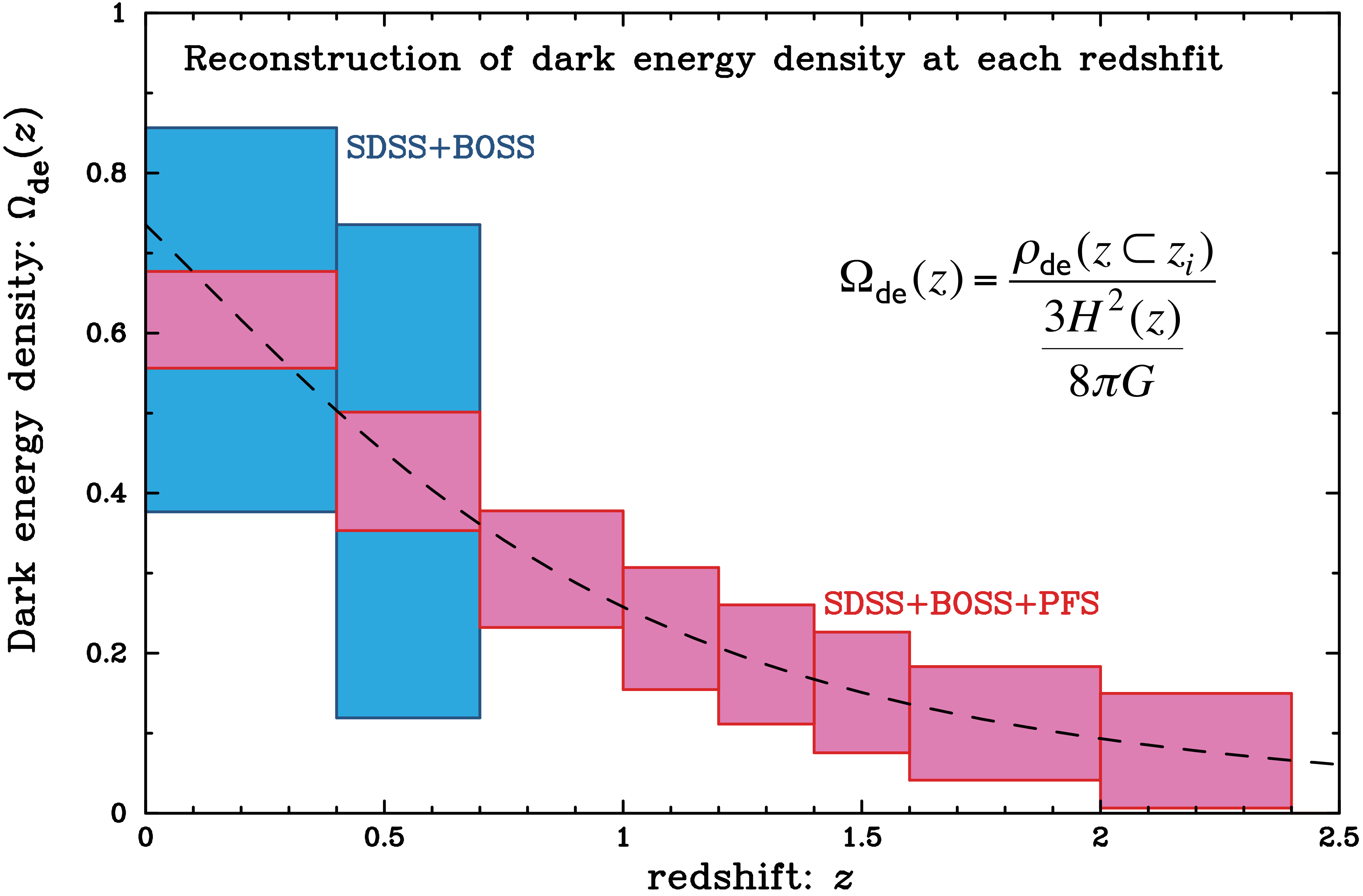
PFS (8.2m) for z~1.5 slice



4m-class tel.



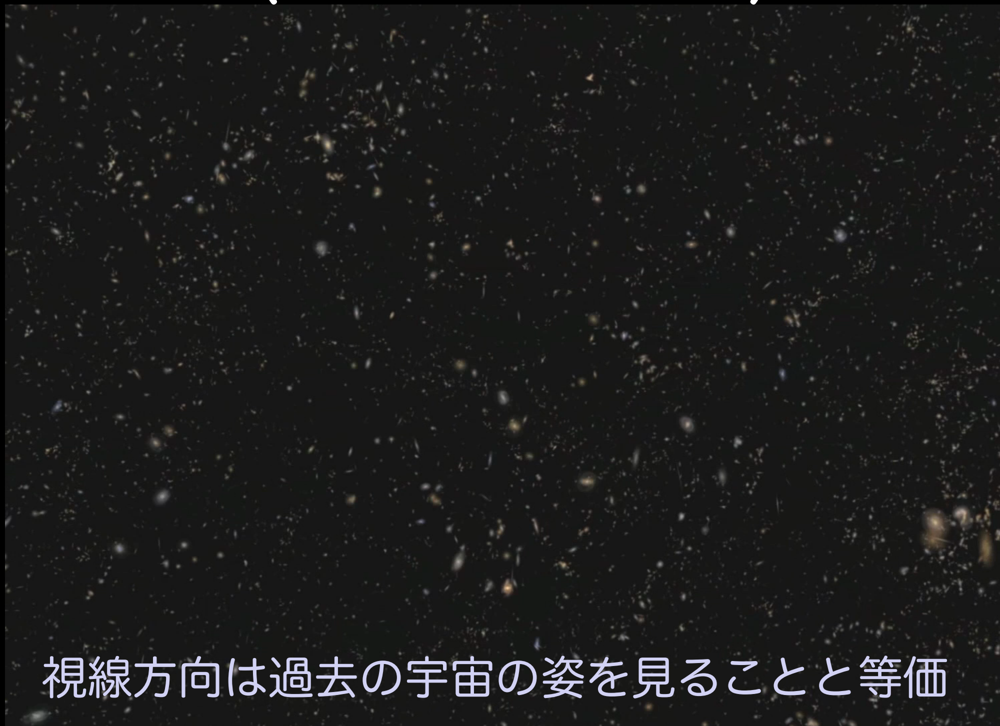
Model-independent DE reconstruction

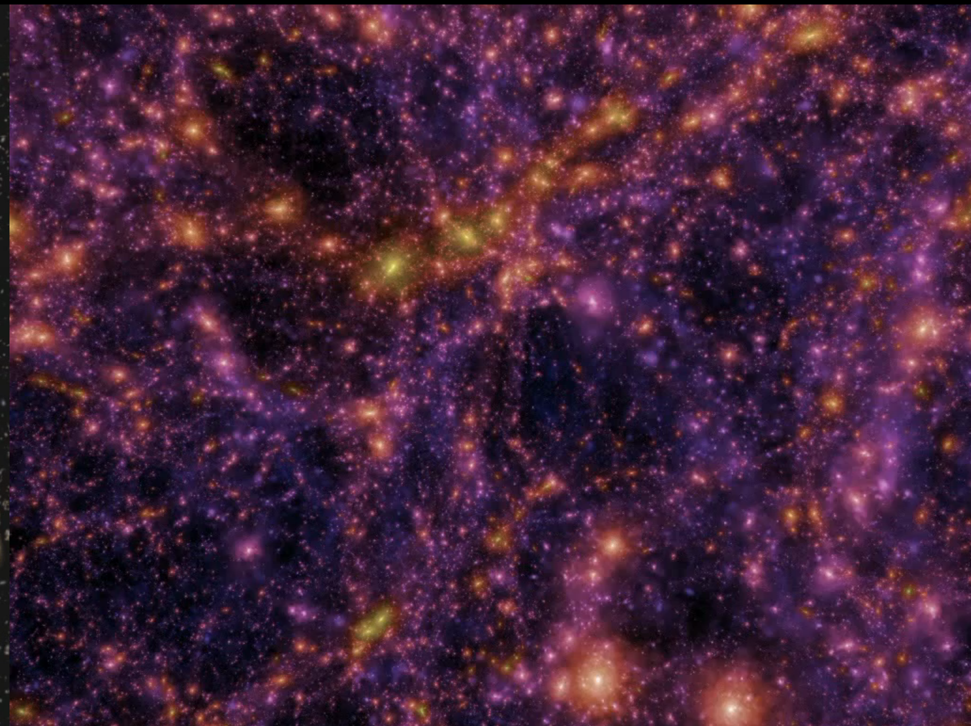


銀河の3次元地図による宇宙論

広天域銀河イメージング＋分光
(現時点のデータ)

シミュレーション
（ダークマターの分布）



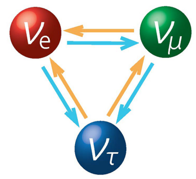


すばる観測と理論モデルを直接的に比較し、宇宙の加速膨張、重力理論を検証　（銀河の分布とダークマターの分布の関係を観測的に解決）

Neutrinos

Prof. Takaaki Kajita (ICRR/IPMU)

Neutrinos = Japanese nat'l particles



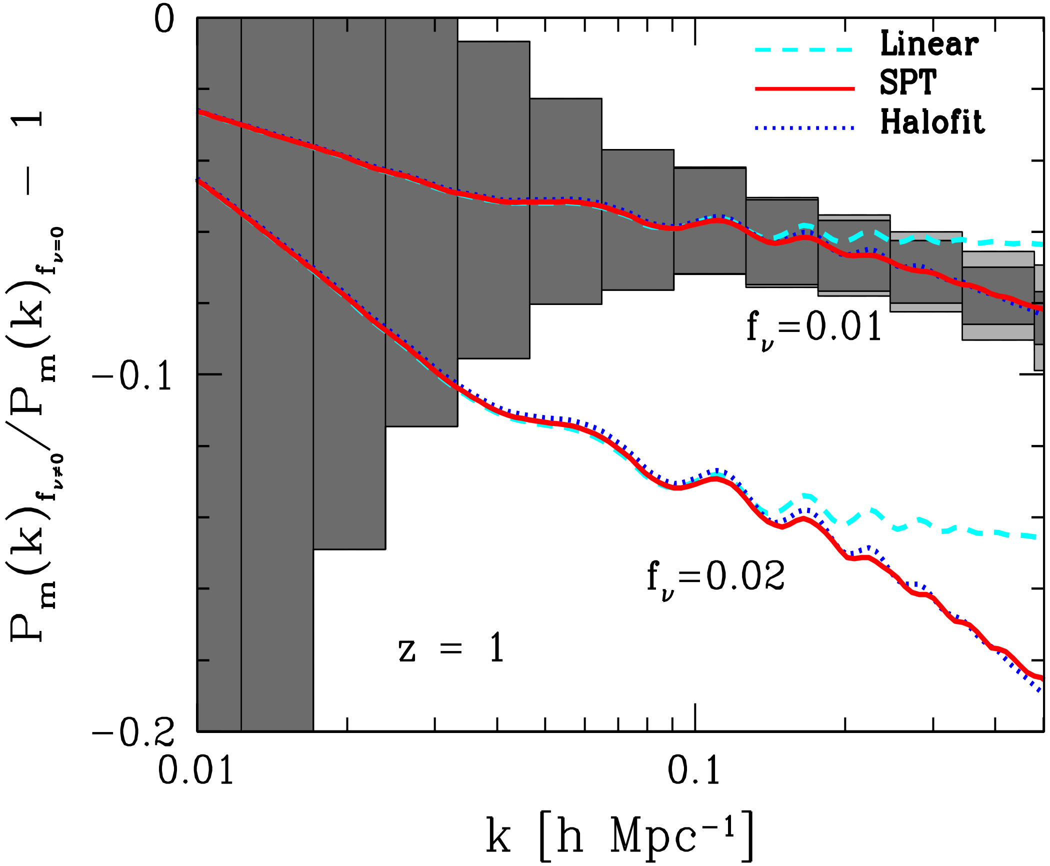
$$\begin{bmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{bmatrix}=\begin{bmatrix}U_{e1} & U_{e2} & U_{e3}\\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3}\\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3}\end{bmatrix}\begin{bmatrix}\nu_1\\ \nu_2\\ \nu_3\end{bmatrix}.$$

$$U=\begin{bmatrix}c_{12}c_{13} & s_{12}c_{13} & s_{13}e^{-i\delta}\\ -s_{12}c_{23}-c_{12}s_{23}s_{13}e^{i\delta} & c_{12}c_{23}-s_{12}s_{23}s_{13}e^{i\delta} & s_{23}c_{13}\\ s_{12}s_{23}-c_{12}c_{23}s_{13}e^{i\delta} & -c_{12}s_{23}-s_{12}c_{23}s_{13}e^{i\delta} & c_{23}c_{13}\end{bmatrix}$$

- Atmospheric neutrino oscillation $\Delta m^2_{31}, \sin^2\theta_{23}$:
  Super-K (1998), K2K
- Solar neutrino oscillation $\Delta m^2_{21}, \sin^2\theta_{21}$:
  SNO, KamLAND
- CP-violation phase $\delta_{\rm CP}, \sin^2\theta_{31}$: T2K hint, Hyper-K
- Mass hierarchy (sign of Δm^2): hopefully T2K (within 5yrs)
- Neutrino mass m_ν : hopefully KamLAND-Zen or PFS *has to measure the neutrino mass*
- *Then all neutrino parameters will be measured by Jp-experiments*

Weighing neutrino mass with PFS

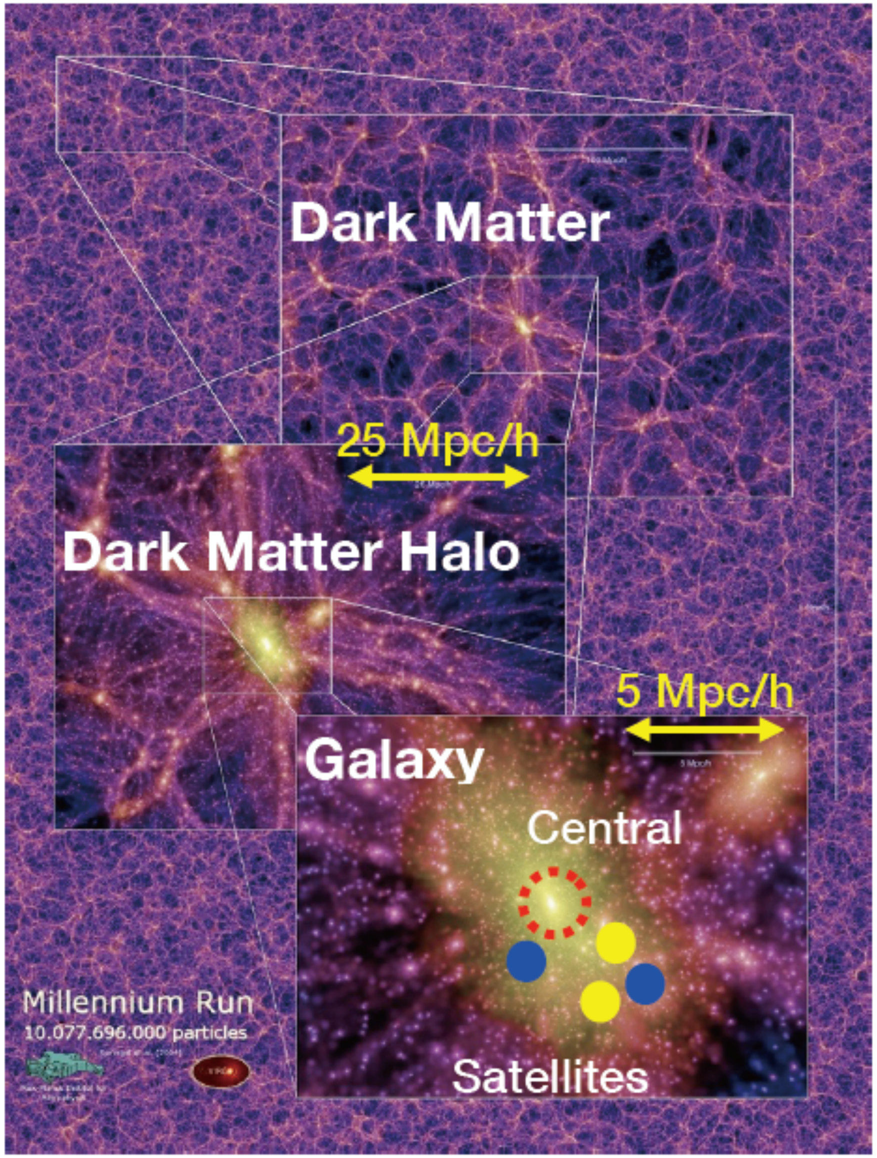
Saito, MT, Taruya 09



- Neutrinos suppress the growth of large-scale structure
- More linear regime at higher redshift
- A higher sampling density of galaxies enables to use up to higher k
- Takada et al. (2014): PFS alone gives $\sigma(m_\nu)$~0.13eV (conservative)
- Further improvement expected
  - Higher-order correlations
  - HSC lensing
  - CMB lensing
- *Goal*: a detection of neutrino mass rather than upper limit: $\sigma(m_\nu)$~0.03eV, then at least 2sigma detection of neutrino mass and discriminate the mass hierarchy

Halo-galaxy connection

Galaxies in the Large-Scale Structure



[Textbook: Mo, van den Bosch, White (2010)]

How galaxies spatially gather?
= **3D Galaxy Clustering**

LARGE Scale O(10-100Mpc)
trace the DM distribution
- ruled by Gravity

Small Scale O(0.1-1Mpc)
galaxy distribution within a virial radii of a DM halo
- Gravity + Baryon physics

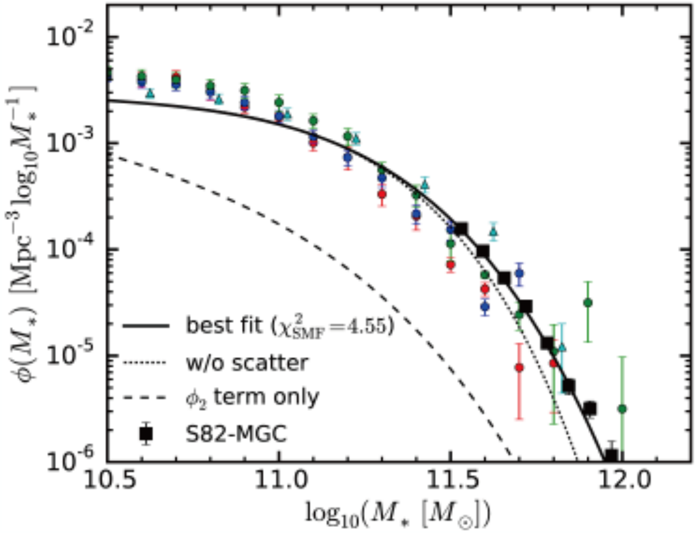
Saito et al. 15

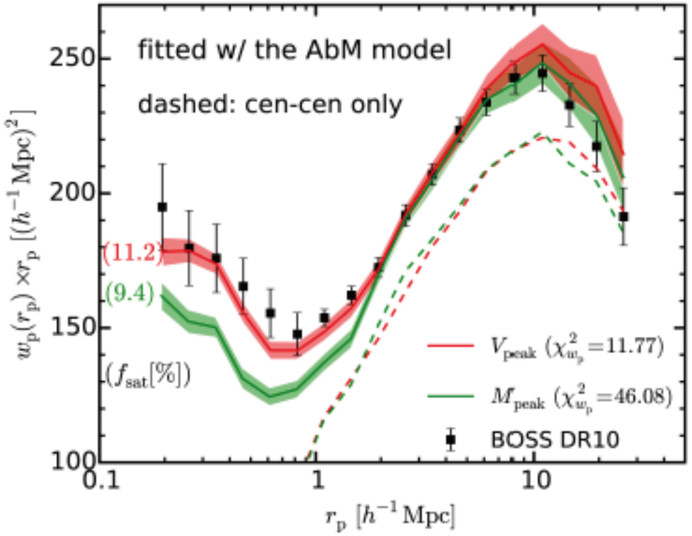
Result

SS, Leauthaud+ (2015)

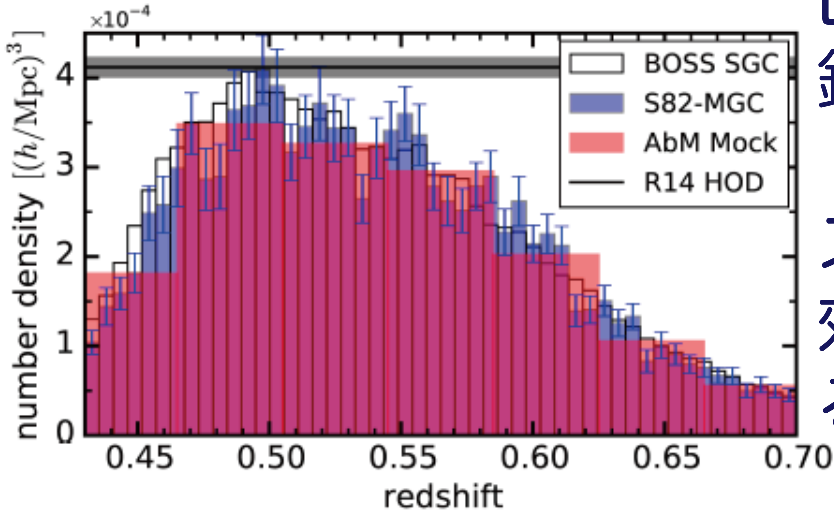
$$\sigma(\log M_* | V_{\rm peak}) = 0.1$$

- can simultaneously explain SMF & w_p





- explain dN/dz by design



DMハローだけで銀河の統計的特性（質量関数、クラスタリング、環境効果）を説明できるか？

2020年代に必要なサーベイ

- 宇宙の初期条件の物理
  - (信号は？）原始非ガウス性、原始パワースペクトル、宇宙の曲率
  - (データは？）広天域銀河分光サーベイ（+イメージング)
  - (計画は？）PFS, HSC, DESI, Euclid, WFIRST
- 現宇宙の加速膨張の物理
  - ダークエネルギーの状態方程式、重力レンズ、BAO、ダークマターの分布、宇宙膨張の直接測定、AGN反響マッピング
  - 広天域銀河イメージング(高結像性能)＋分光サーベイ、TMTによる高分解能分光
  - HSC, PFS, DESI, LSST, Euclid, WFIRST, TMT
- 構造形成・銀河形成の物理の理解、ダークマターの正体
  - 銀河・DM分布の関係（クラスタリング、Abundance Matching)、ニュートリノ質量、銀河間ガスマッピング
  - 広天域銀河イメージング(高結像性能)＋分光、TMT分光、多波長データ
  - HSC, PFS, DESI, LSST, Euclid, WFIRST, TMT