TMT
THIRTY METER TELESCOPE

B04
Direct Detection of Cosmic Acceleration by TMT & High Dispersion Spectrograph
次世代超大型光学赤外線望遠鏡TMTと高分散分光器による宇宙の加速膨張の直接検証

TMT & Overview

Tomo Usuda (NAOJ / TMT-J Director)

B04 Members

- **PI（研究代表者）**

  Tomo Usuda（NAOJ TMT-J）

- **CoI（研究分担者）**

  Hajime Inaba（AIST）Optical Laser Frequency Comb

  Karoru Minoshima（UEC）Optical Laser Frequency Comb

  Takeshi Chiba（Nihon U）Direct detection of acceleration

  Toru Misawa（Shinshu U）Lyman-α forests IGM, Obs.

- **Collaborator（連携研究者）**

  Feng-Lei Hong（Yokohama Nat. U）Optical Laser Frequency Comb

  Nobunari Kashikawa（NAOJ）TMT instruments, IGM,

  Wako Aoki（NAOJ）TMT instruments, Obs.

  Atsuhi Onae（AIST）Optical Fiber Laser Frequency Comb

  Sho Ookubo（AIST）Optical Fiber Laser Frequency Comb

- **Others**

  Malte Shramm（AIST）Optical Fiber Laser Frequency Comb, Obs.,

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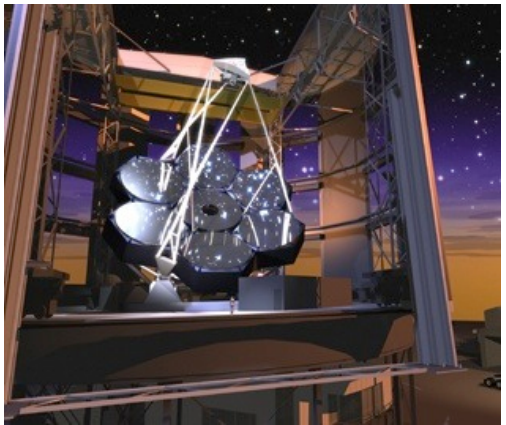
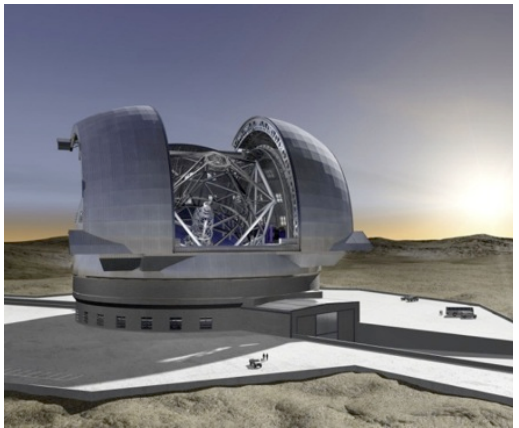
  Hajime Inaba（AIST）Optical Laser Frequency Comb
  Karoru Minoshima（UEC）Optical Laser Frequency Comb
  Takeshi Chiba（Nihon U）Direct detection of acceleration
  Toru Misawa（Shinshu U）Lyman-α forests IGM, Obs.
- **Optical Frequency combs and their applications**
  Feng-Lei Hong（Yokohama Nat. U）Optical Laser Frequency Comb
  Nobunari Kashikawa（NAOJ）TMT instruments, IGM,
  Wako Aoki（NAOJ）TMT instruments, Obs.
  Atsuhi Onae（AIST）Optical Fiber Laser Frequency Comb
- **Emerging age of precision spectroscopy in Astronomy using Laser Frequency Combs**
  Malte Shramm（AIST）Optical Fiber Laser Frequency Comb, Obs.,

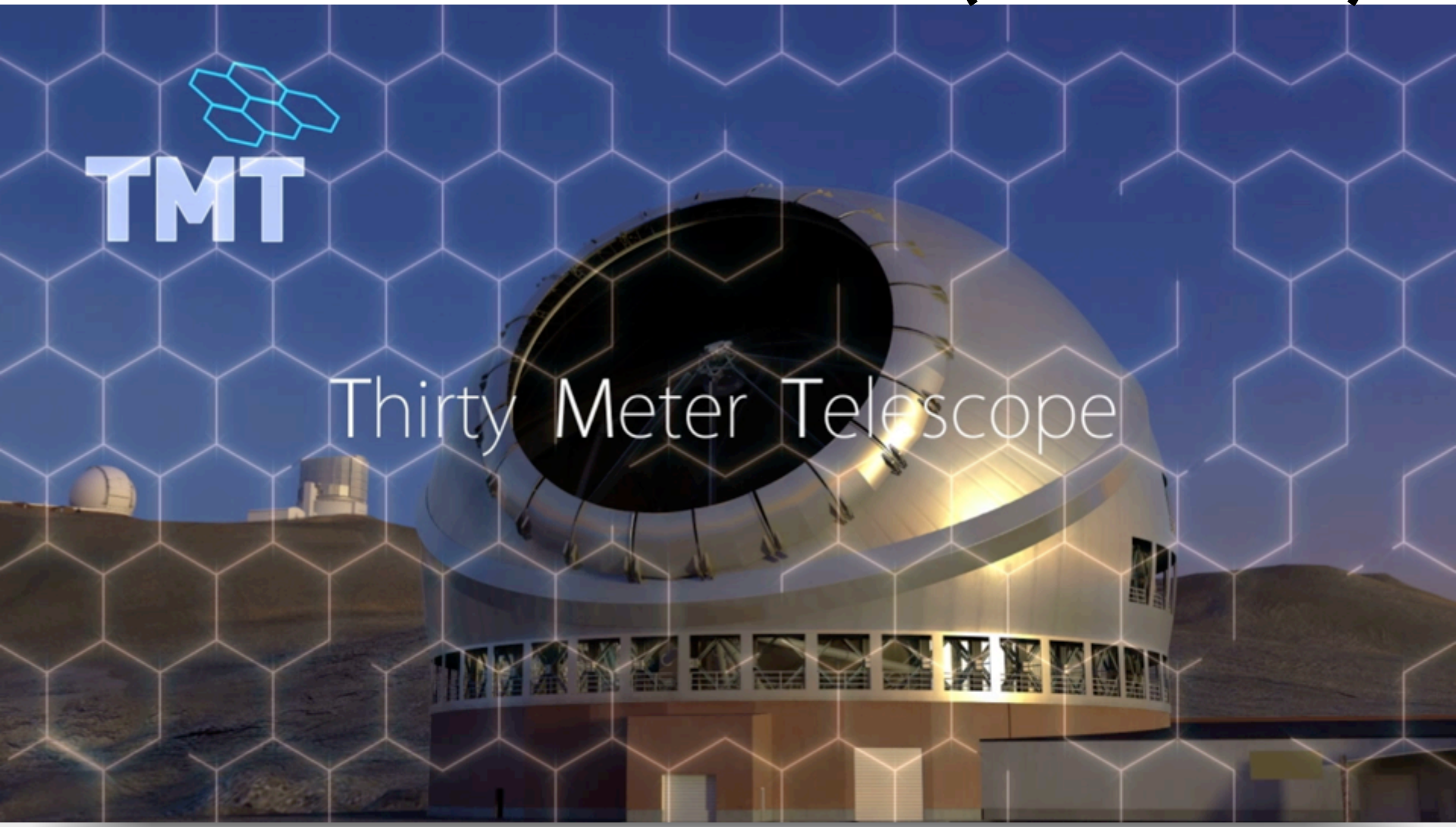
3 ELT projects in the world

Project	TMT (Thirty Meter Telescope)	GMT (Giant Magellan Telescope)	E-ELT (European-Extremely Large Telescope)
M1	30m	22m (8.4m x 7)	39m
Site	Hawaii, Mauna Kea (4,012m), North	Chile, Las Campanas (2,550m), South	Chile, Cerro Armazones (3,060m)
Budget	1,580M USD	1,100M USD (estimate)	2,000M USD (estimate)
Construction	2014～2024	2013～2021 (with 4 of 7 mirrors)	2014～2025
Member	Japan, USA (Caltech, UC, (AURA)), Canada, China, India	USA (Carnegie, Arizona, etc.), Australia, S.Korea, SaoPaolo)	ESO (including Brasil)





TMT on Mauna Kea (CG: 140 sec)



You can download the movie
http://tmt.nao.ac.jp/gallery/index.html

Members' contributions to TMT

Telescope

Enclosure

M2

M1 blank

M1 polish

30%

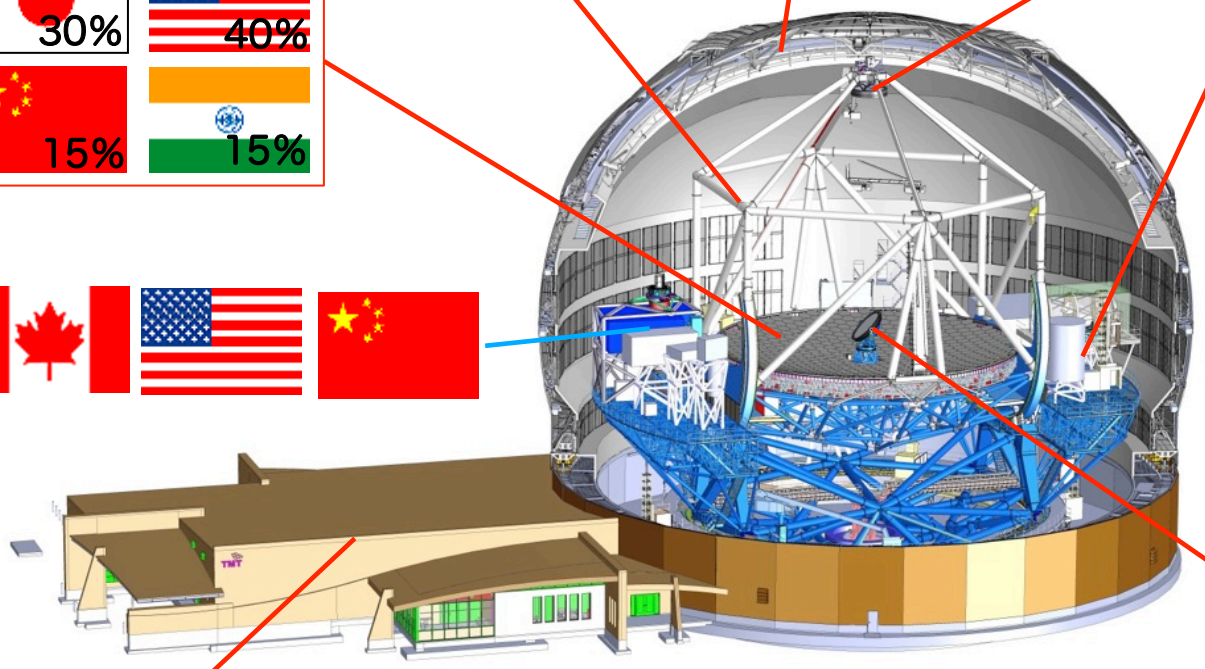
40%

15%

15%

Instruments

AO



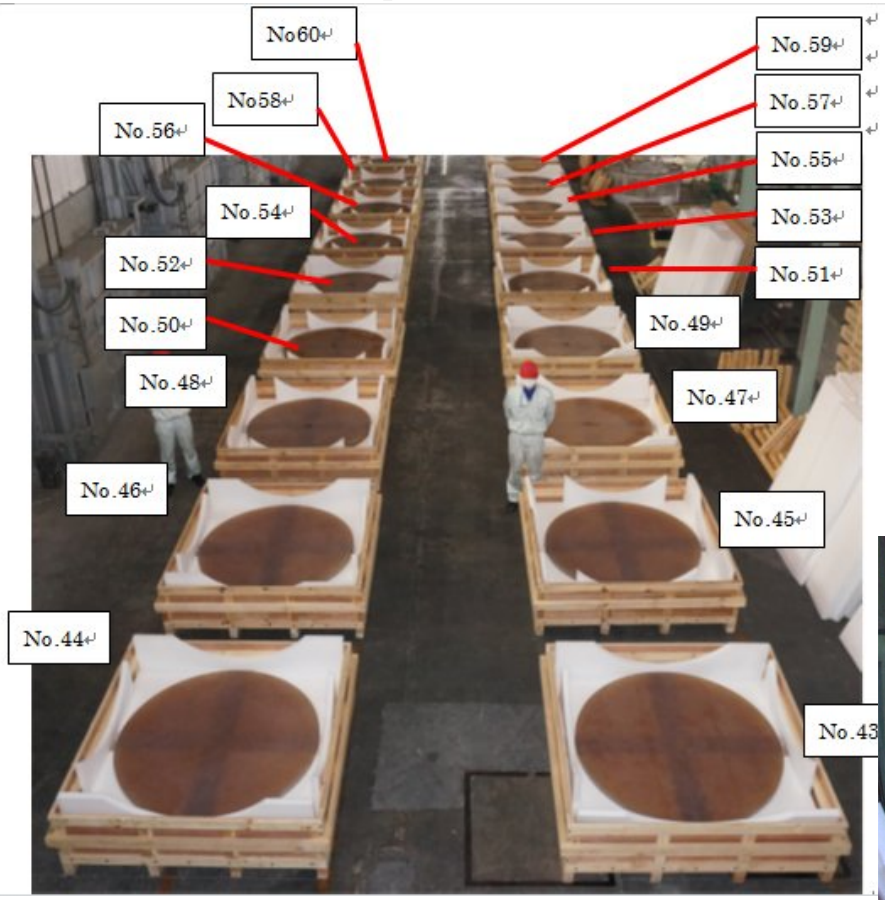
M3

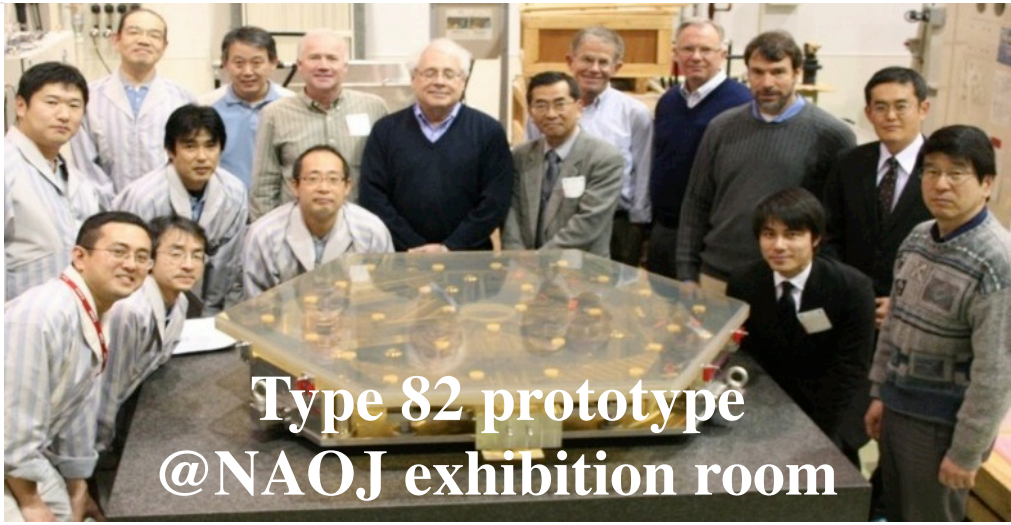
Facility

Control Systems
& Software

Providing M1 segment mirrors

- Prototype of M1 was made in 2013
- 99 plano-plano segment blanks by March 2015
- Mass production is on going





OHARA 株式会社 オハラ

Canon

TMT Science Instruments

Opt

- **WFOS** (Multi-Obj Spec) / no AO/GLAO
- **HROS** (High Spec Res) / no AO/GLAO

2nd gen. 2026~

NIR

- **IRIS** (IFU) / NFIRAOS
- **IRMS** (Multi-Obj Spec) / NFIRAOS
- **NIRES-Blue** (High Res J~K) / NFIRAOS
- **IRMOS** (Wide-field MO IFU) / MOAO
- **NIRES-Red** (High Res J~K) / MIR-AO
- **PFI** (Exoplanet finder) / ExAO

Early light 2024~

MIR

- **MICHI** (MIR Cam/Spec) / MIR-AO

3 pillars of science (theory)

4 approaches (expt, obs)

	[A01] Inflation Sasaki (Kyoto)	[A02] fluent. & struct. Takahashi (Tohoku)	[A03] Dark Energy Sugiyama (Nagoya)
[B01] CMB polariz. Hazumi (KEK)	ζ, r, n_s direct evidence	CMB lensing isocurv. m_ν, N_ν	cosmo. params CMB lensing
[B02] Subaru galaxy imaging Miyazaki(NAOJ)	Lensing → $b(k)$ $\rightarrow P_{\rm primod}(k)$	weak lensing m_ν non-std. DM	weak lensing SNe, γ
[B03] galaxy spectroscopy Takada(KIPMU)	primord. NG Ω_K, n_s, α_s	isocurv. DM in dSph gals. $P(k), m_\nu$	BAO, RSD $\Omega_{\rm de}(z), \gamma$
[B04] TMT Usuda (NAOJ)	(2) QED coupling (α) space time variation	(3) Lyman-α forests IGM	(1) Direct detection of acceleration

important observables at each intersection

B04 Objectives

- **3 Science topics**
  - **(1) Direct Detection of Cosmic Acceleration**「宇宙の加速膨張の直接測定」 **Chiba**
  - **(2) Constraining the spatial & temporal variation of the fine structure constant**「物理定数（微細構造定数、陽子・電子質量比）の時間変化に対する制限」**Chiba Misawa**
  - **(3) IGM tomography by QSOs & galaxies Absorption Lines**「銀河間物質の３次元構造の解明」**Misawa, Kashikawa**
- **R&D Plans for TMT High Dispersion Spectrograph**
  - **Develop Optical Laser Frequency Comb for very accurate / stable λ Calibrations** **Inaba, Minoshima, Hong, Onae, Ookubo, Shramm**
  - **Install the comb on Subaru HDS for on-site tests to know technical difficulties and establish the observation strategies for TMT** **Aoki, Misawa, Kashikawa**

(1) Direct Detection of Cosmic Acceleration

Future Universe?

What is Dark Energy?

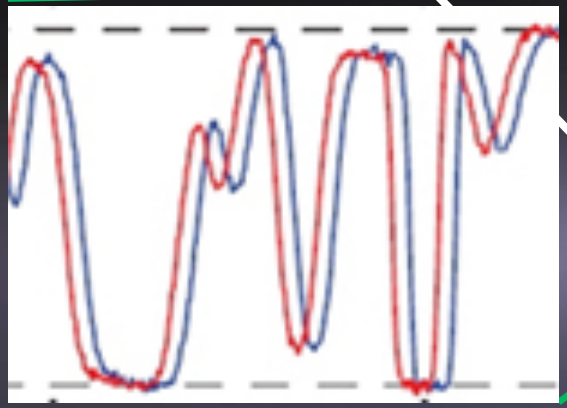
Universe after 10 yrs

Current Universe

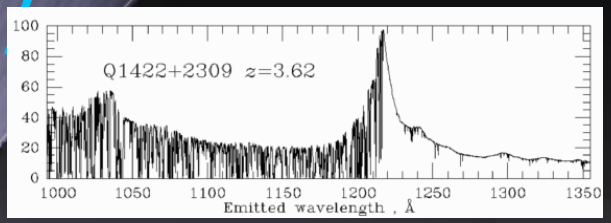
$$\dot{z} = (1+z)H_0 - H(z)$$

First direct detection of time variance toward same objects

Expanding Universe



Big Bang

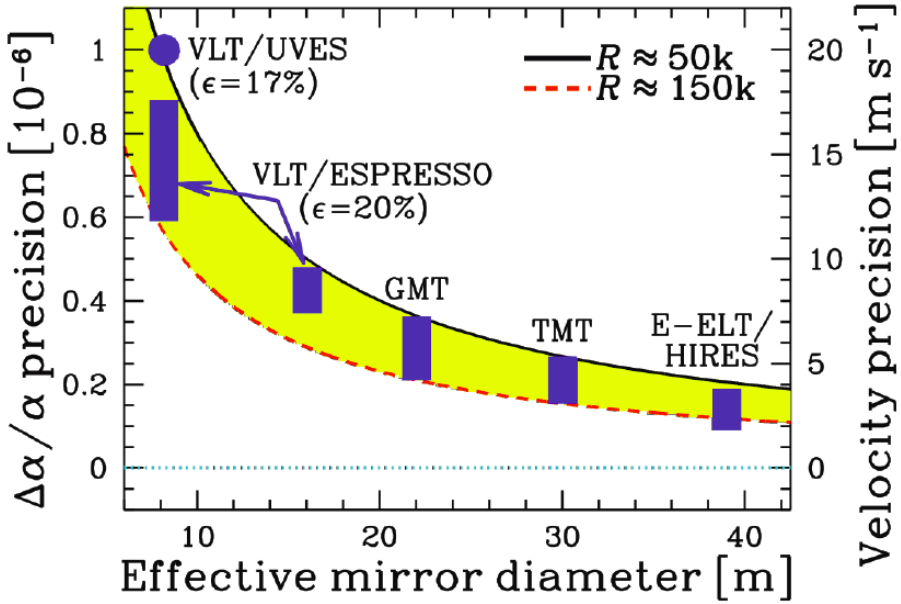


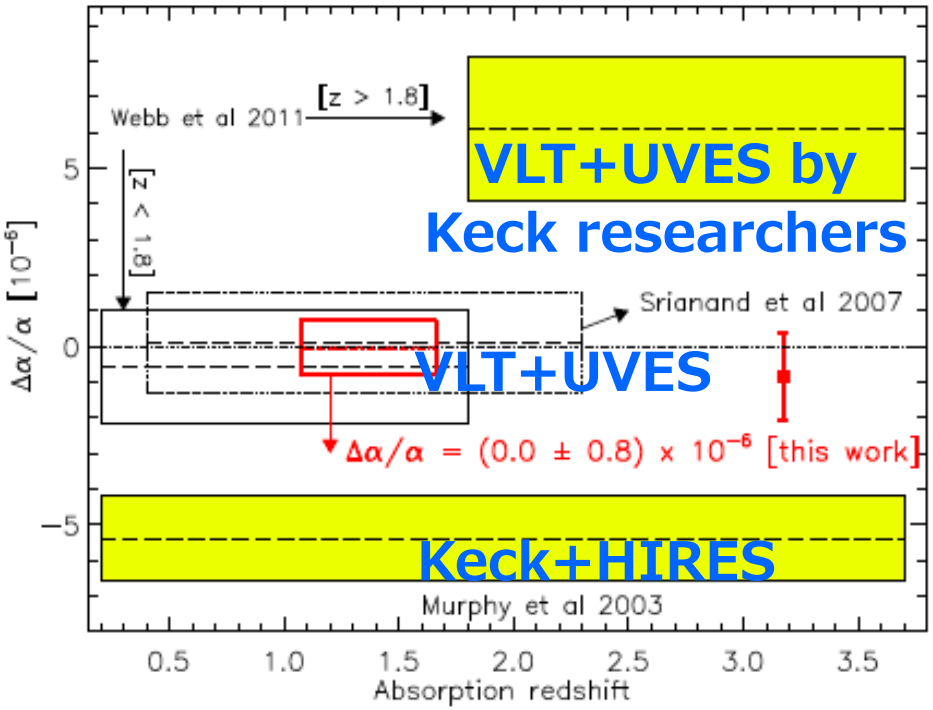
Very accurate measurements (6cm/s) of Lyman α absorption lines in ~10 years

- High S/N and R obs. for ~20 Lyα forests over >10 years
- Direct and model-independent measure of the expansion history

(2) Constraining the spatial & temporal variation of the fine structure constant

- **Fine structure constant** $\alpha \equiv 2\pi e^2 / hc$
- **FeII & ZnII lines in QSO absorptions are used for the constraint (λ difference ∝ α^2)**
- **Constrain in laboratory (yr^{-1})** $\Delta\alpha/\alpha = (-1.6 \pm 2.3) \times 10^{-17}$
- **Unsolved by observations with VLT & Keck**

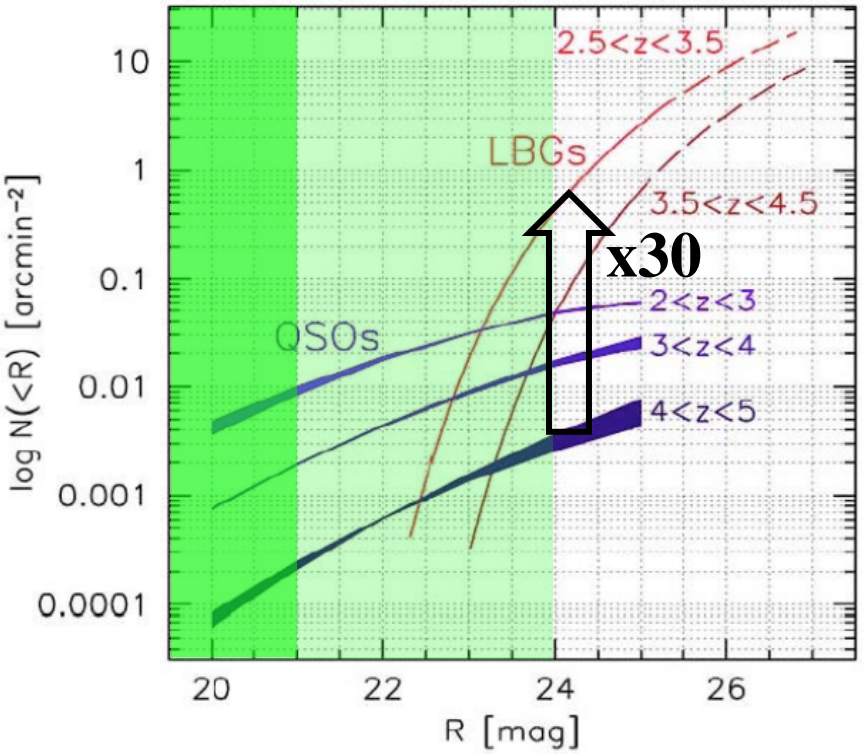


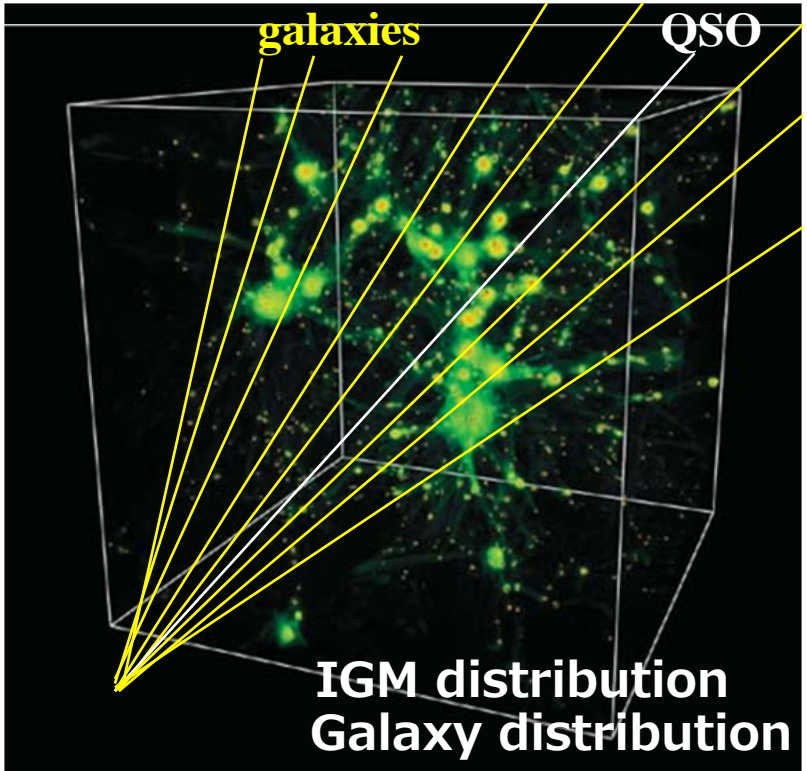


Rahmani+ 12

(3) IGM tomography

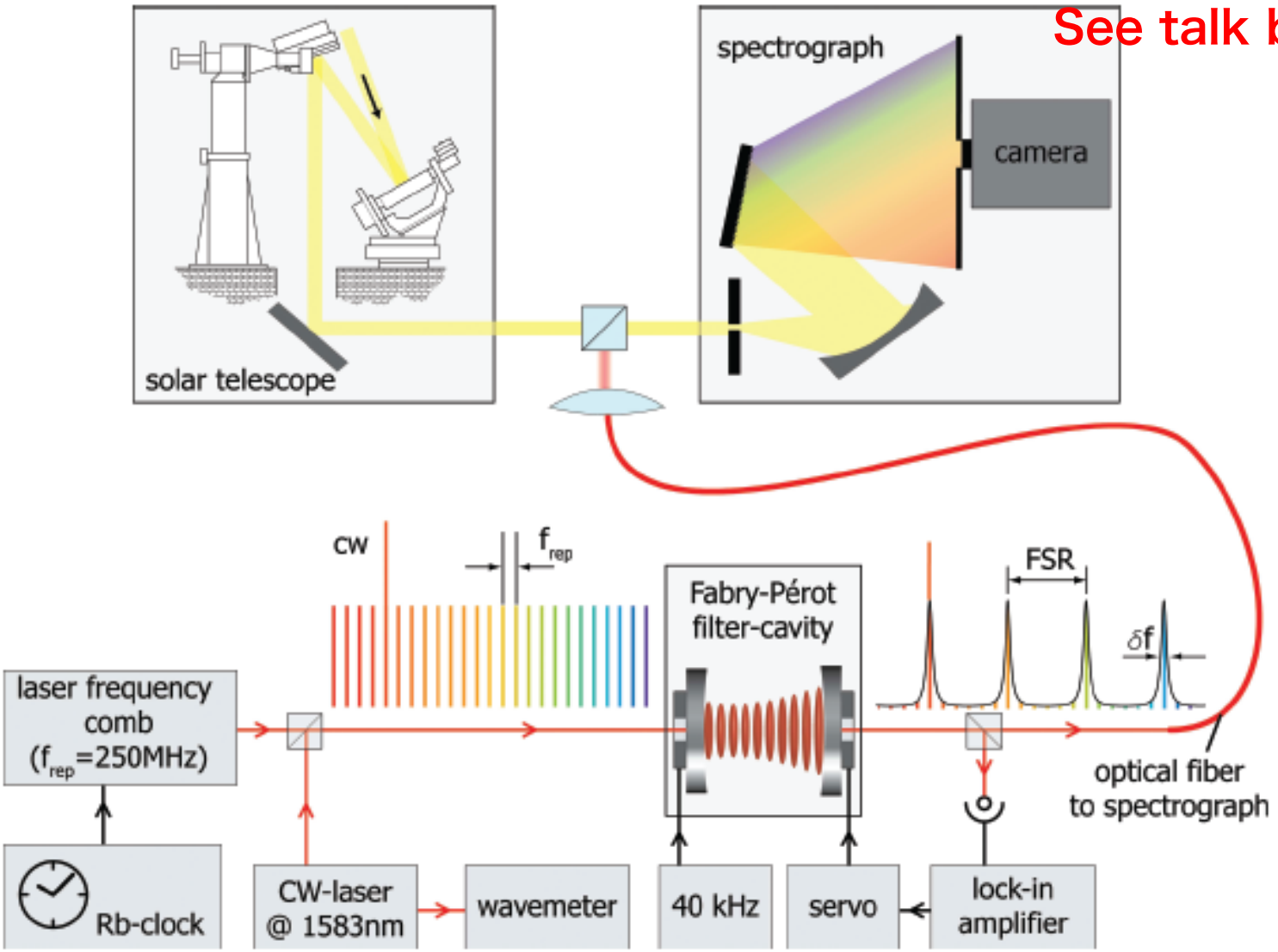
- Limiting mag ~24 with R=10,000
- Number density of galaxies is > QSO (2/arcmin^2)
- Enable to study physical and chemical properties (e.g, spatial distribution, kinematic pattern, chemical composition, ionization condition, volume density, and gas temperature) in d<300 kpc





Optical Laser Frequency Comb for very accurate λ calibrations

See talk by Hong



T. Steinmetz et al., Science 2008

Optical Laser Frequency Comb for very accurate λ calibrations

Wavelength (900~2,200 nm) See talk by Hong

Summary

- TMT on-site construction has started in 2014. Design and fabrication works are on going in the partner countries.
- 3 Science Topics:
  - (1) Direct Detection of Cosmic Acceleration
  - (2) Constraining the spatial & temporal variation of the fine structure constant
  - (3) IGM tomography by QSOs & galaxies Absorption Lines
- Technical R&D Plans
  - Develop Optical Laser Frequency Comb for very accurate / stable λ Calibrations
  - Install the comb on Subaru HDS for on-site tests to know technical difficulties and establish the observation strategies for TMT