Science Strategy of NAOJ
:Cosmology

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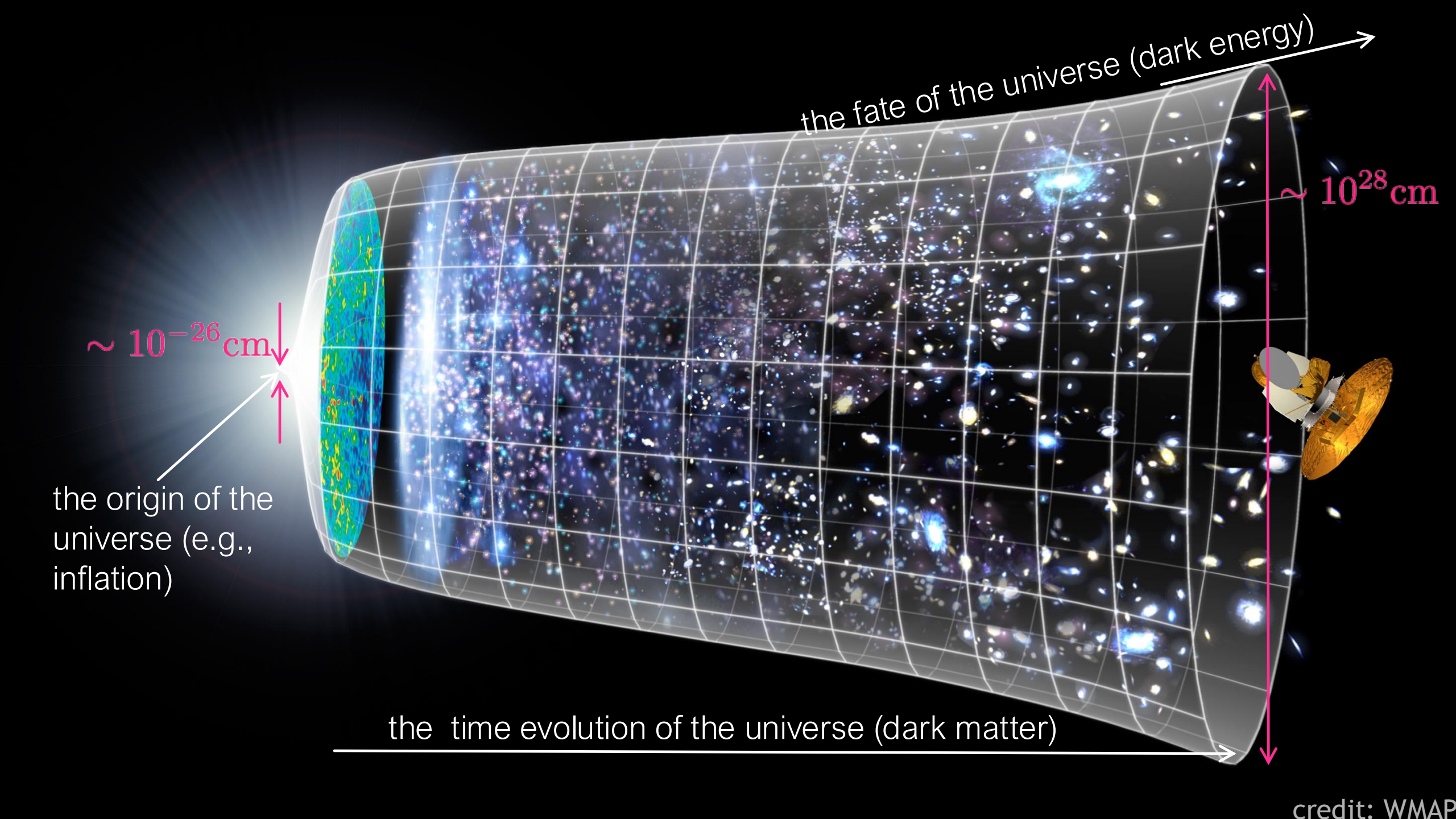
On behalf of Science Roadmap Committee of NAOJ

Current Trend in Observational Cosmology
世界的な観測的宇宙論の動向

- Ultimate Goal of Cosmology (当該分野の究極的な目的)
  - To elucidate the evolution of the Universe from its beginning (Big Bang) to the present-day by using all branches of mathematics and physics, as well as observational data
- Goals in Cosmology (当該分野の目標)
  - Understanding the origin and evolution of the universe – from its beginning (inflation) to the generation of matter and the formation of cosmic structures
  - Elucidating the constituents of the universe – including the generation of ordinary matter (baryon number), the nature of dark matter, and the nature of dark energy. In addition, the role of cosmic neutrinos in the formation of cosmic structures
  - Exploring physics beyond the standard model – including the physics of inflation, the nature of dark energy, and tests of modified gravity on cosmological scales


the fate of the universe (dark energy)
$\sim 10^{28}$cm
$\sim 10^{-26}$cm
the origin of the universe (e.g., inflation)
the time evolution of the universe (dark matter)
credit: WMAP

Current Status of Observational Cosmology
現在までの到達点

- Establishment of the standard cosmological model, namely the ΛCDM model through precise measurements of cosmic microwave background (CMB) anisotropies (e.g., WMAP and Planck), Type Ia supernovae (e.g., HST, Subaru), and wide-area galaxy surveys (e.g., SDSS, Subaru Hyper Suprime-Cam, Dark Energy Survey). The main ingredients of ΛCDM model are the initial conditions predicted by inflation, cold dark matter and Λ (or dark energy)
- The constituents of the universe – CMB photons, baryons found by the Big Bang nucleosynthesis (the Big Bang theory and data), dark matter (e.g., velocity dispersions of cluster galaxies and flat rotation curve), and dark energy (type-Ia supernovae, baryon acoustic oscillation and CMB)
- The interdisciplinary of cosmology – problems in cosmology can be addressed not only through cosmology and astronomy, but also through particle physics, high-energy physics, and both theoretical and observational approaches
- Subaru (HSC) has reached the forefront of cosmology

Future Trends
今後の世界的動向

- Stringent tests of the ΛCDM model – e.g., addressing the H0 tension and the S8 tension
- Exploring the physics of inflation – addressing the nature of primordial fluctuations that arise from quantum fluctuations and exploring primordial gravitational wave
- Unveiling the nature of dark matter – e.g., searching for signals from decaying and annihilating dark matter and addressing fuzzy dark matter and primordial black holes
- Exploring the nature of dark energy – addressing whether dark energy is dynamical (e.g., the recent DESI result)
- Testing gravity on cosmological scales
- Measurements of the neutrino mass

Science Strategy of NAOJ
国立天文台の科学戦略

Scientific Goals and Methods for “Galaxy Formation and Cosmic Evolution”
「宇宙論」の科学目標と手法

- Unraveling the origin and evolution of the universe
  宇宙の誕生と進化の解明
- Unveiling the nature of constituents of the universe
  宇宙を構成する基本的な要素の解明
- Exploring physics beyond the standard model
  自然の実験場としての新しい物理学を探る
- Ongoing and upcoming projects (projects being proposed)
  - Subaru, ESA Euclid, LSST (2026-), NASA Roman Space Telescope (2027-), SKA (203X-), JASMINE (203X-), GW experiments, TMT, …

Unraveling the origin and evolution of the universe
宇宙の誕生と進化の解明

- Stringent tests of the ΛCDM model
  - Addressing the S8-tension and the H0-tension. Measurements of cosmic expansion. Measurement of neutrino mass
  - Wide-area galaxy (including HI) surveys – (CMB), Subaru, 21cm survey
  - Standard candle (type-Ia supernova), standard ruler (BAO), and standard GW siren
  - Subaru, LSST, Roman, SKA, KAGRA, next-generation GW experiments
- Exploring the origin of inflation (exploring the evidence of inflation)
  - Measurement of primordial GW background
  - KAGRA, next-generation GW experiments, SKA

Unveiling the nature of constituents of the universe
宇宙を構成する基本的な要素の解明

- Unveiling the nature of dark matter
  - Microlensing to search for primordial black holes
  - Subaru, LSST, Roman, JASMINE
- Exploring the nature of dark energy
  - Standard ruler (BAO): Subaru, Roman, SKA
  - Standard candle and standard GW siren: LSST, Roman, KAGRA, next-generation GW experiment
- Direct measurement of cosmic acceleration
  - TMT

Exploring physics beyond the standard model
自然の実験場としての新しい物理学を探る

- Tests of gravity on cosmological scales (as an alternative explanation of present-day cosmic acceleration)
  - Wide-area galaxy surveys (redshift-space distortions): Subaru, Roman, SKA
- Exploring the physics of inflation
  - Measurements of the primordial power spectrum (e.g., spectral running index, features in the shapes). Primordial non-Gaussianity
  - Wide-area galaxy surveys: Subaru, Roman, SKA
- Exploring the time variation of physical constants (e.g., the fine-structure constant)
  - TMT, (Subaru)

Summary
まとめ

- Recent achievements enabled by Subaru HSC (and now PFS)
- “Big” and interdisciplinary scientific themes: the origin of the universe, the constituents of the universe (dark matter and dark energy), new physics beyond the standard model (physics at energy scales that cannot be achieved by terrestrial experiments)
- Many ongoing and upcoming experiments
  - Wide-area galaxy surveys: Subaru, Euclid, LSST, Roman Space Telescope, SKA
  - A new window using gravitational waves: standard sirens and the search for primordial gravitational waves on scales smaller than those probed by CMB
  - TMT: a direct measurement of cosmic acceleration and the search for time variation of physical constants (fine-structure constant)