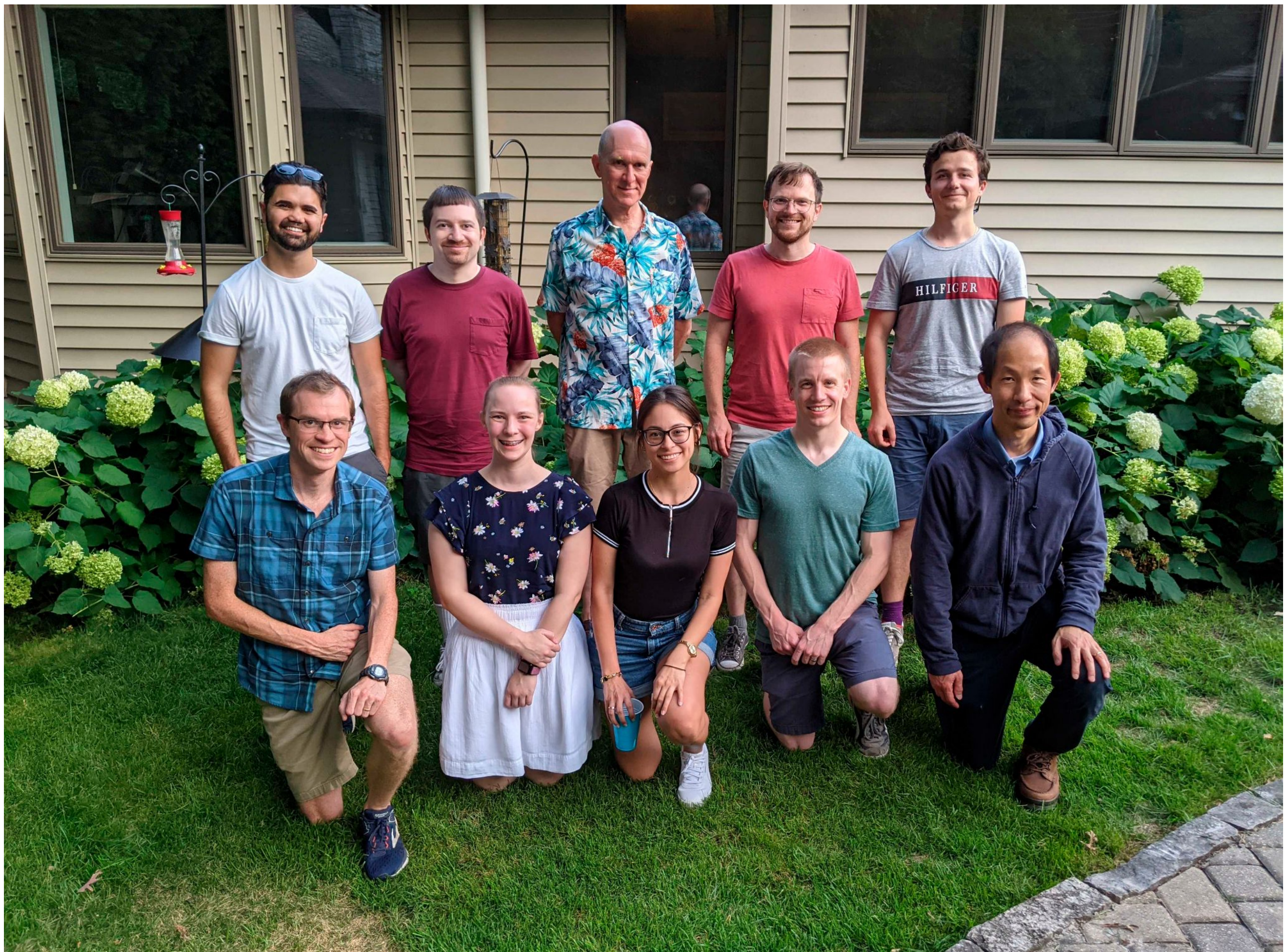
UW-Madison Cosmology & Astrophysics

physics.wisc.edu/research/#astro-comology-experiment
https://cosmology.physics.wisc.edu/



UW-Madison Cosmology & Astrophysics

Cosmology Theory Yang Bai, Baha Balantekin, Dan Chung, Gary Shiu

Observational & Computational Cosmology - Keith Bechtol & Peter Timbie & Moritz Münchmeyer

Plasma Astrophysics Alex Lazarian, Ellen Zweibel

Diffuse X-ray Astro & Detector Development - Dan McCammon

Neutrino Astronomy - Ice Cube Francis Halzen, Kael Hanson, Albrecht Karle, Justin Vandenbroucke, Ke Fang, Lu Lu

High Energy Cosmic Rays Justin Vandenbroucke, Lu Lu

Dark Matter Direct Detection Duncan Carlsmith

Solar & Supernova Neutrino Astrophysics Theory Baha Balantekin

Atmospheric Physics & Climate Susan Nossal

Plus **High Energy Physics** and a separate **Astronomy Department** with 12 faculty, 24 grad students, and a host of research possibilities.

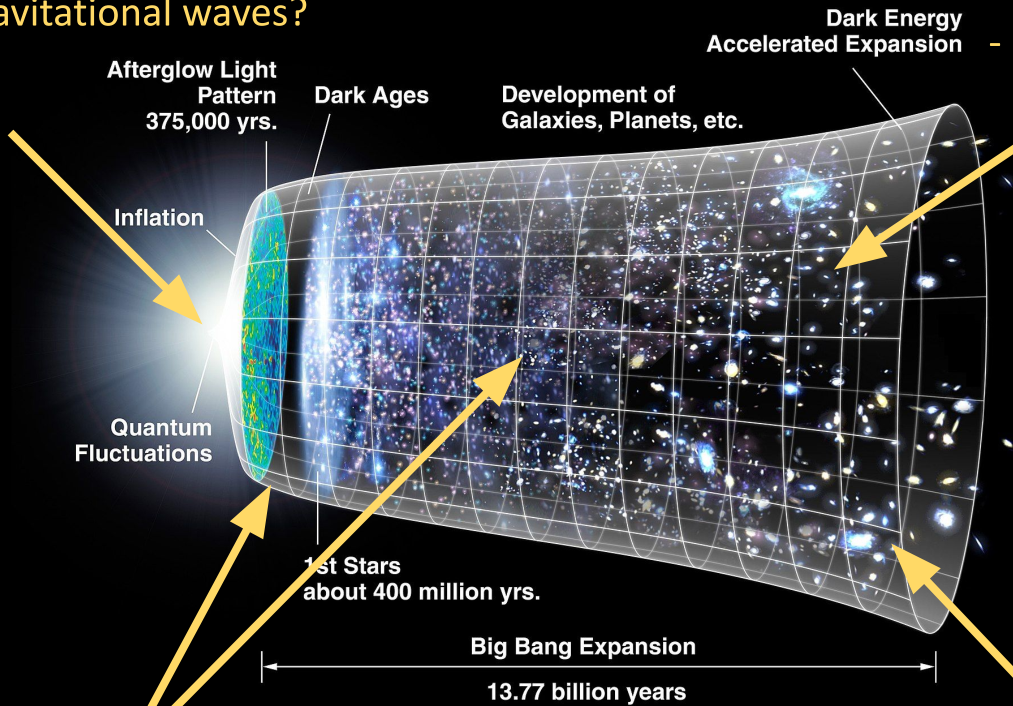
Cosmology

Inflation

- spectral index of fluctuations
- non-Gaussian fluctuations?
- inflationary gravitational waves?

Dark Energy

- expansion vs time
- growth of structure vs time
- is GR right on large scales?



Light relics/neutrinos

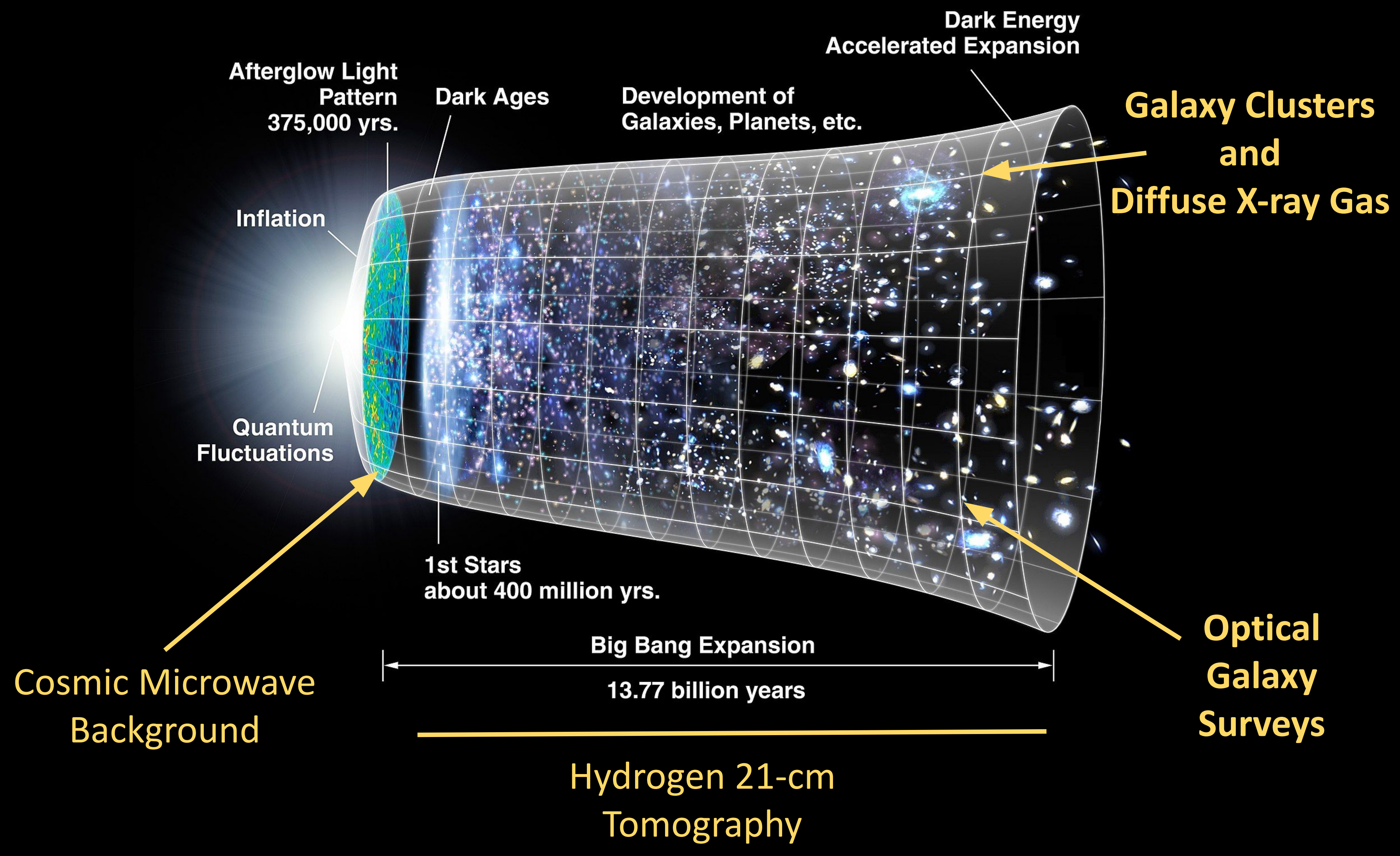
- affect growth of structure
- measure sum of neutrino masses Σm_ν
- measure number of light particles N_{eff}

Dark Matter

- small-scale structure
- particle vs. compact vs. wave-like dark matter
- non-gravitational couplings?

Observational Cosmology

we use the whole universe as our laboratory!



Peter Timbie

Making tomographic maps of the Universe using redshifted 21 cm line of neutral hydrogen gas

These 3D maps promise orders of magnitude more cosmic information than CMB maps.

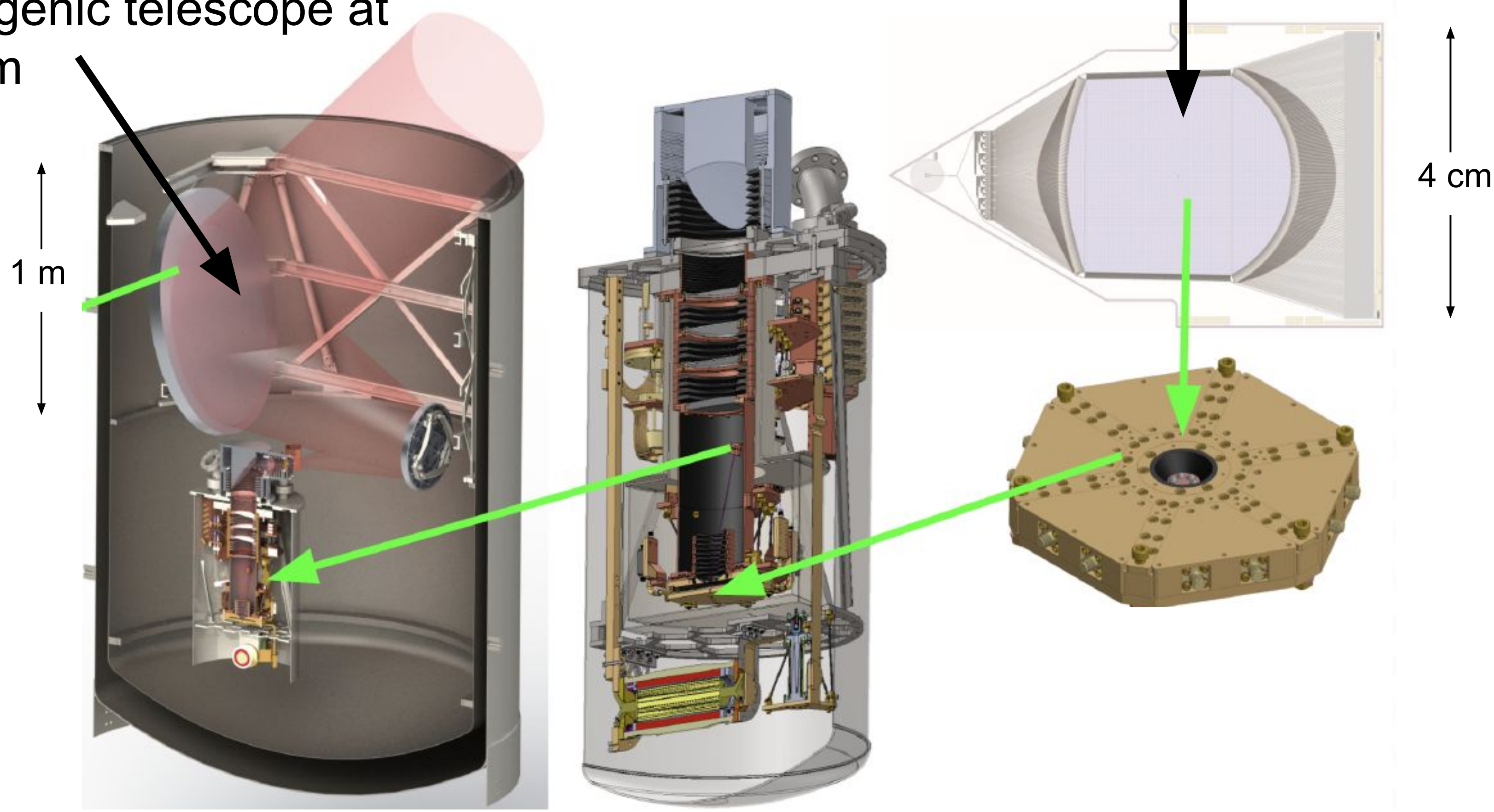
We are building the *Tianlai* radio interferometer in China:

- dedicated pathfinder for larger arrays
- dark energy
- detection of Fast Radio Bursts
- algorithm development for removing foregrounds

Using a similar technique with C+ lines: EXCLAIM!

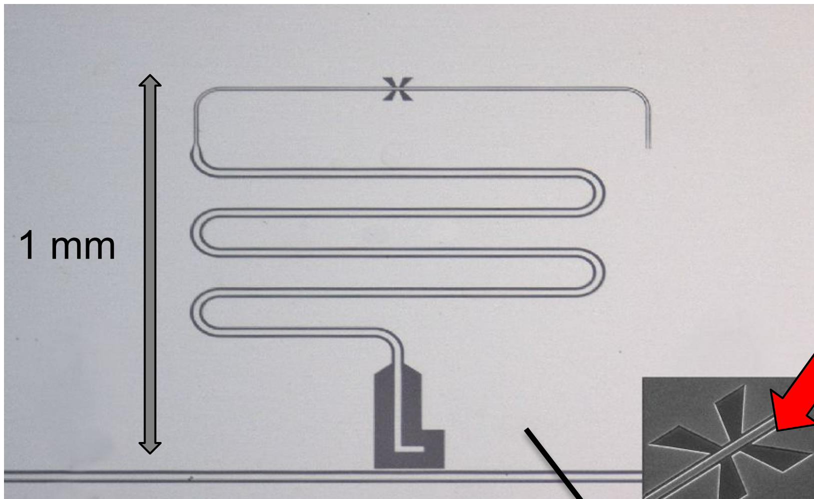
Superconducting spectrometer w/ kinetic inductance detectors (KIDs!)

Cryogenic telescope at 30 km

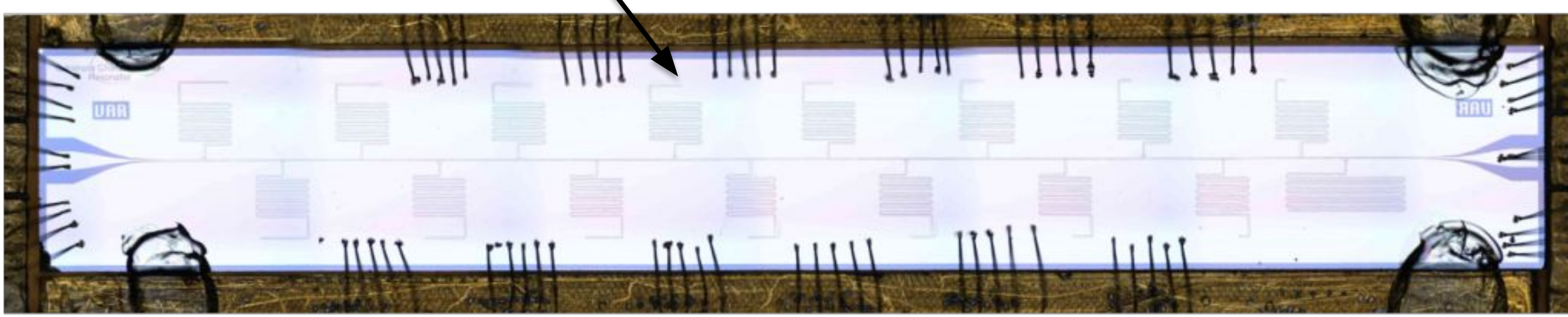


Kinetic Inductance Detectors (KIDs) for radio cosmology being fabricated at UW

Photons arrive here!



Hi – Q superconducting resonator & antenna

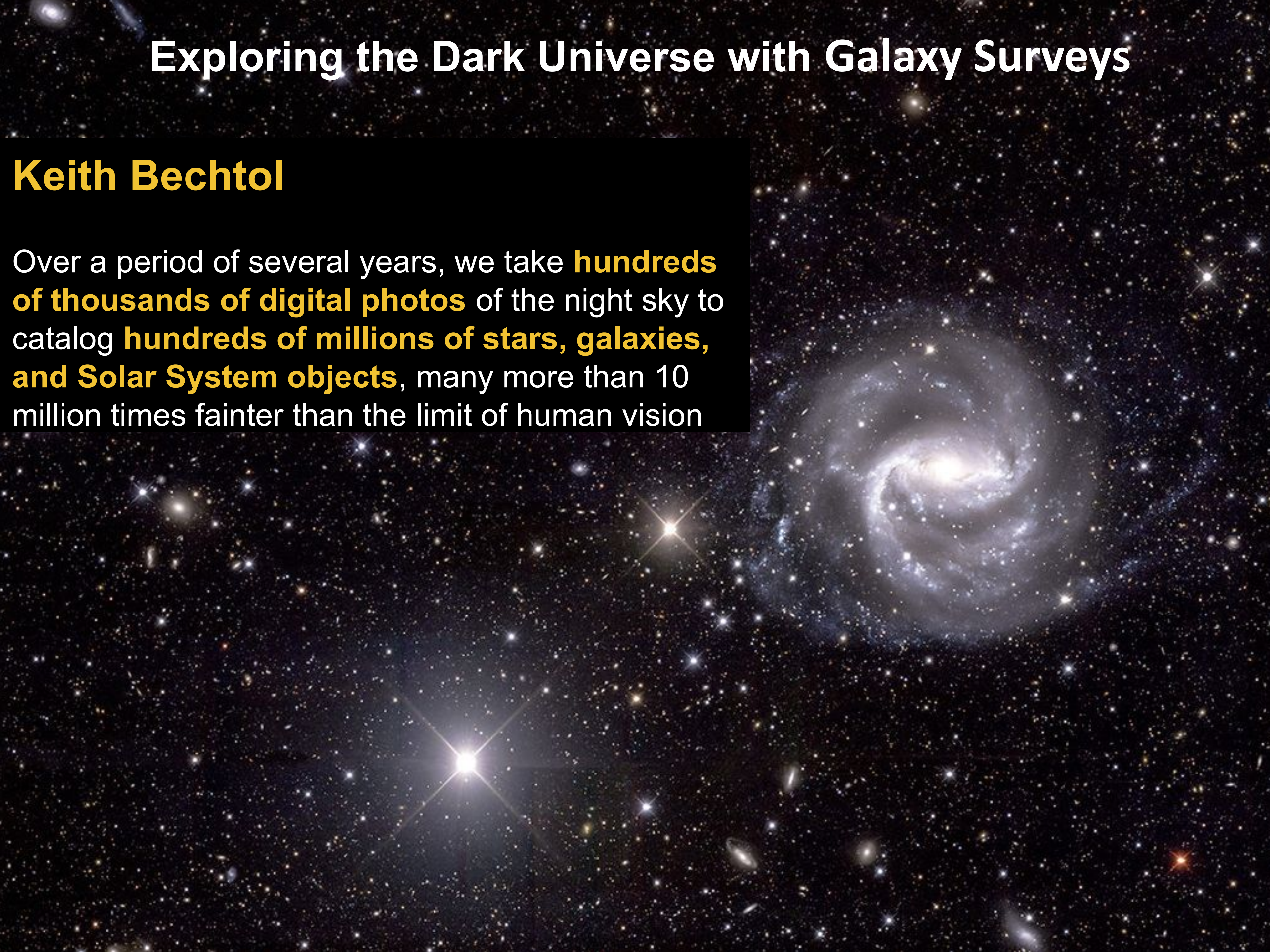


Keith Bechtol

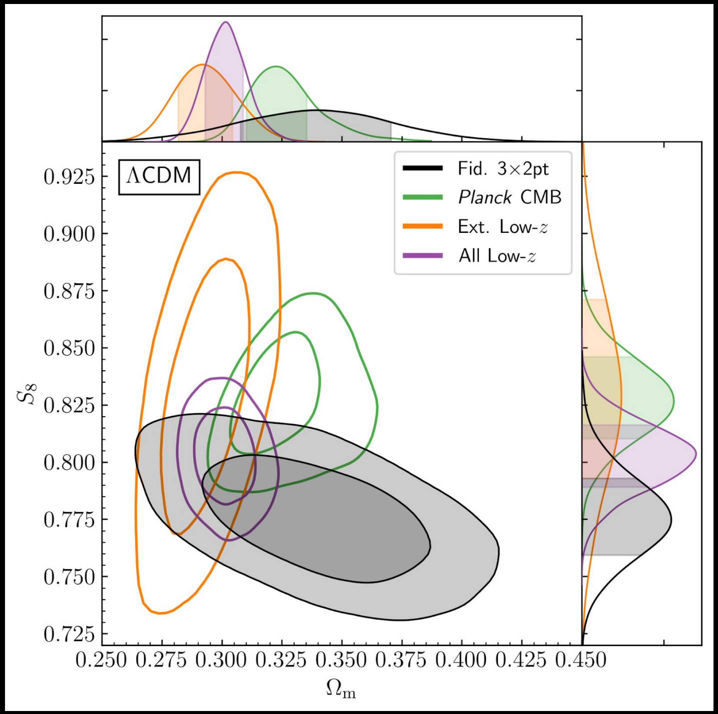
Exploring the Dark Universe with Galaxy Surveys

Keith Bechtol

Over a period of several years, we take **hundreds of thousands of digital photos** of the night sky to catalog **hundreds of millions of stars, galaxies, and Solar System objects**, many more than 10 million times fainter than the limit of human vision

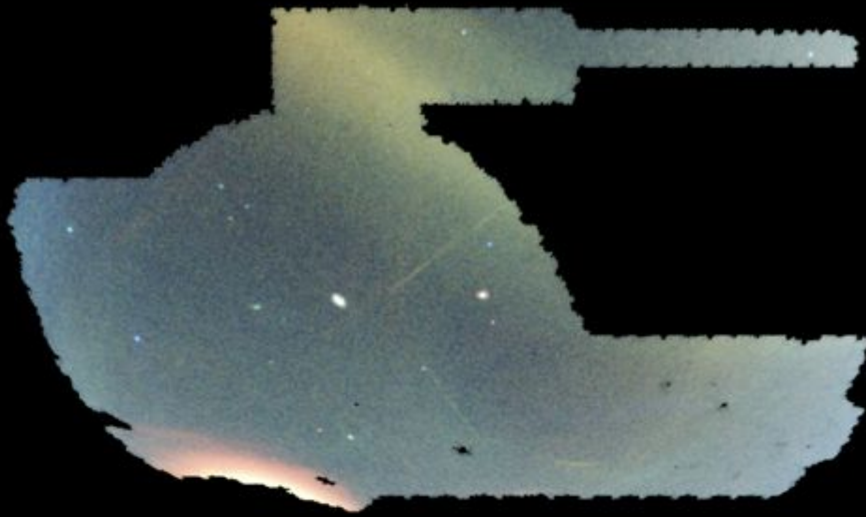


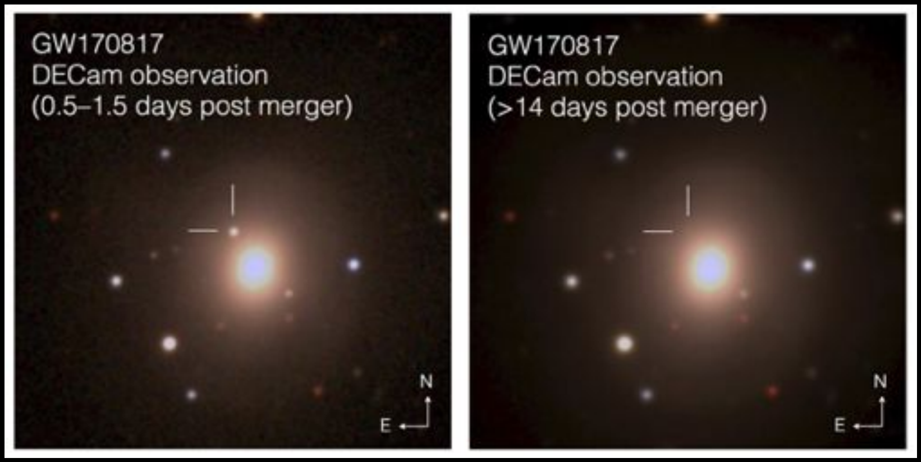
One Dataset: Many Science Opportunities



Cosmic expansion history and growth of structure using gravitational lensing, galaxy clustering, and supernovae

Mapping the distribution of dark matter within the Milky Way





Optical counterparts to gravitational wave and neutrino events

VERA C. RUBIN OBSERVATORY

Rubin Observatory / LSST will catalog more stars, galaxies, and Solar System objects in its first year than all previous astronomical surveys combined.

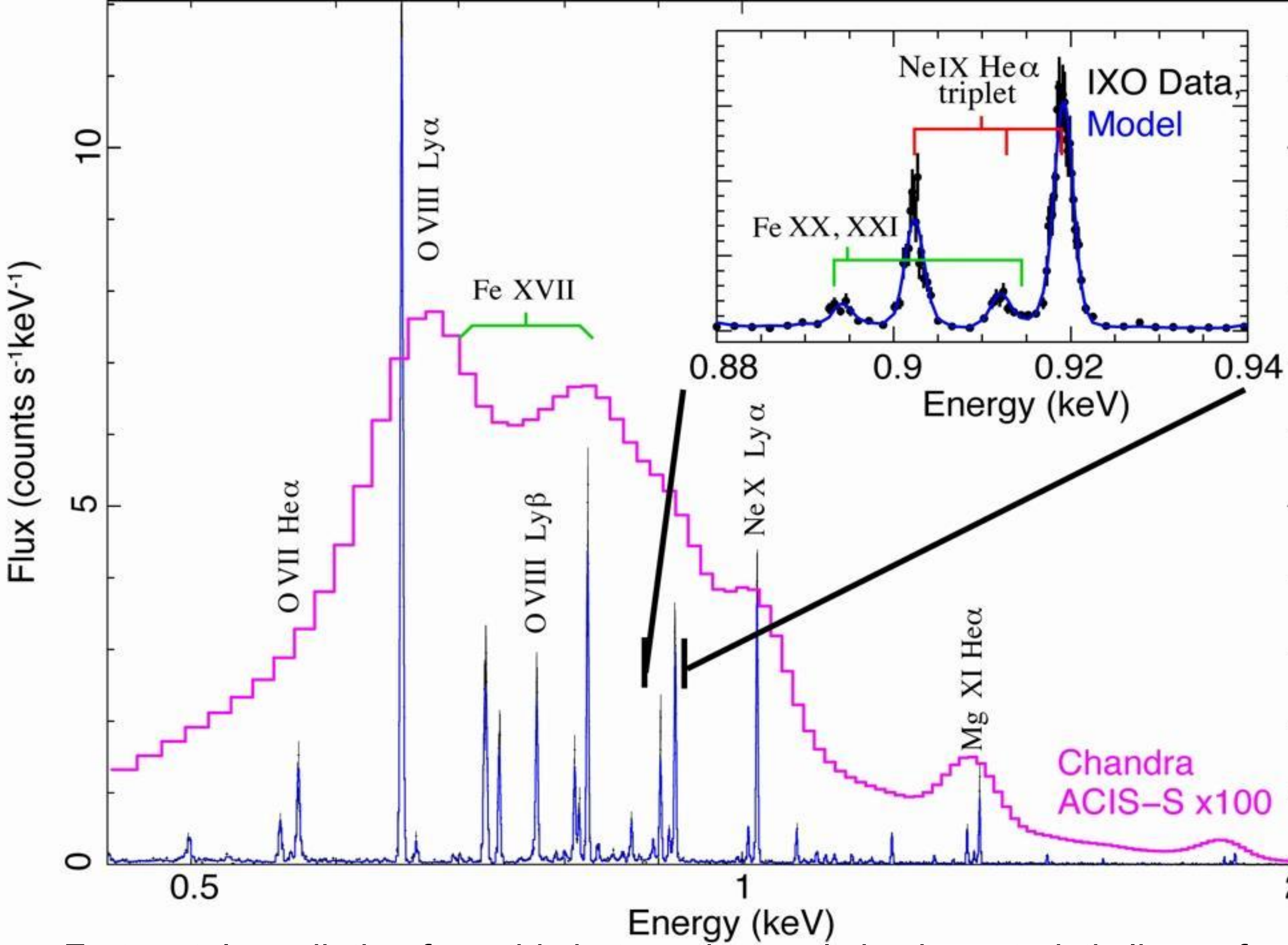
UW-Madison has a lead role in Rubin Observatory Commissioning and Science Validation

Dan McCammon

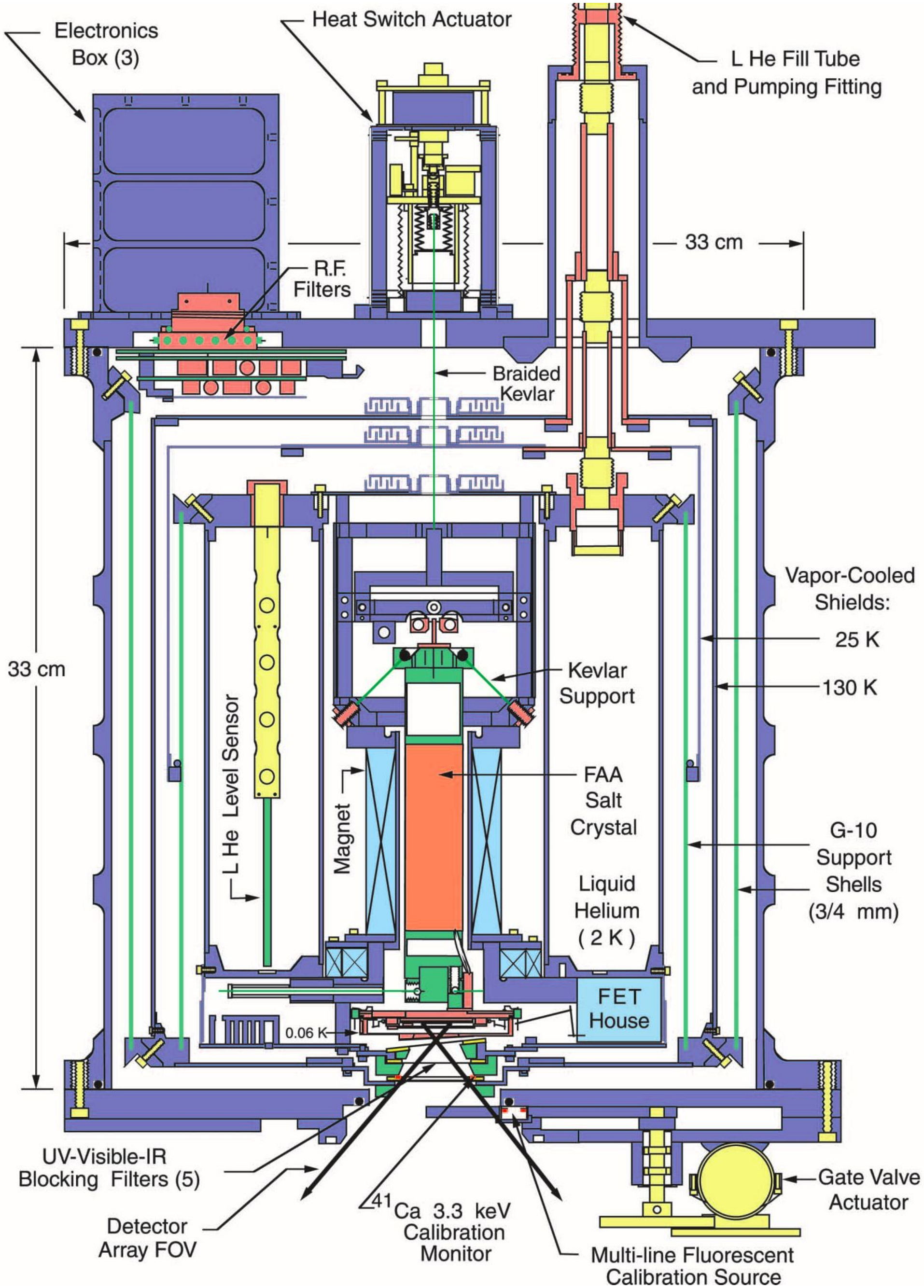
X-rays probe dark matter (and dark energy)

Dan McCammon

Most of the normal matter in the Universe is thought to be at $T>10^6$ K, where it only shows up in X-rays



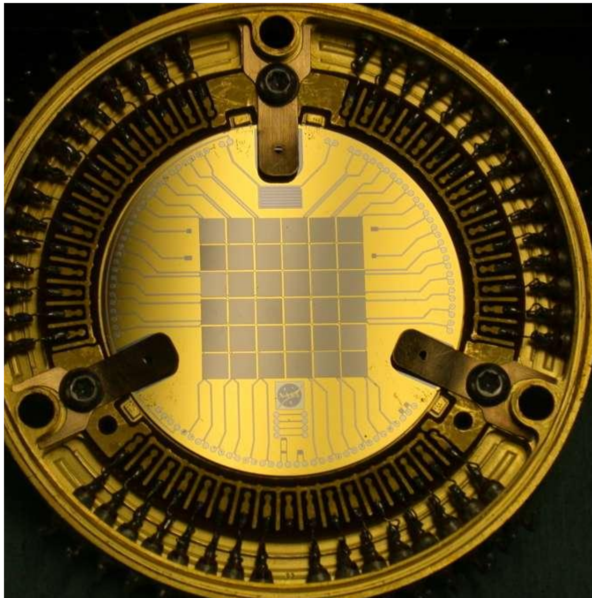
Fortunately, radiation from this hot gas is mostly in characteristic lines of many ions, providing detailed information on the state of the material. Unfortunately the CCD detectors universally used on current X-ray observatories don't have the spectral resolution needed to take advantage of this.

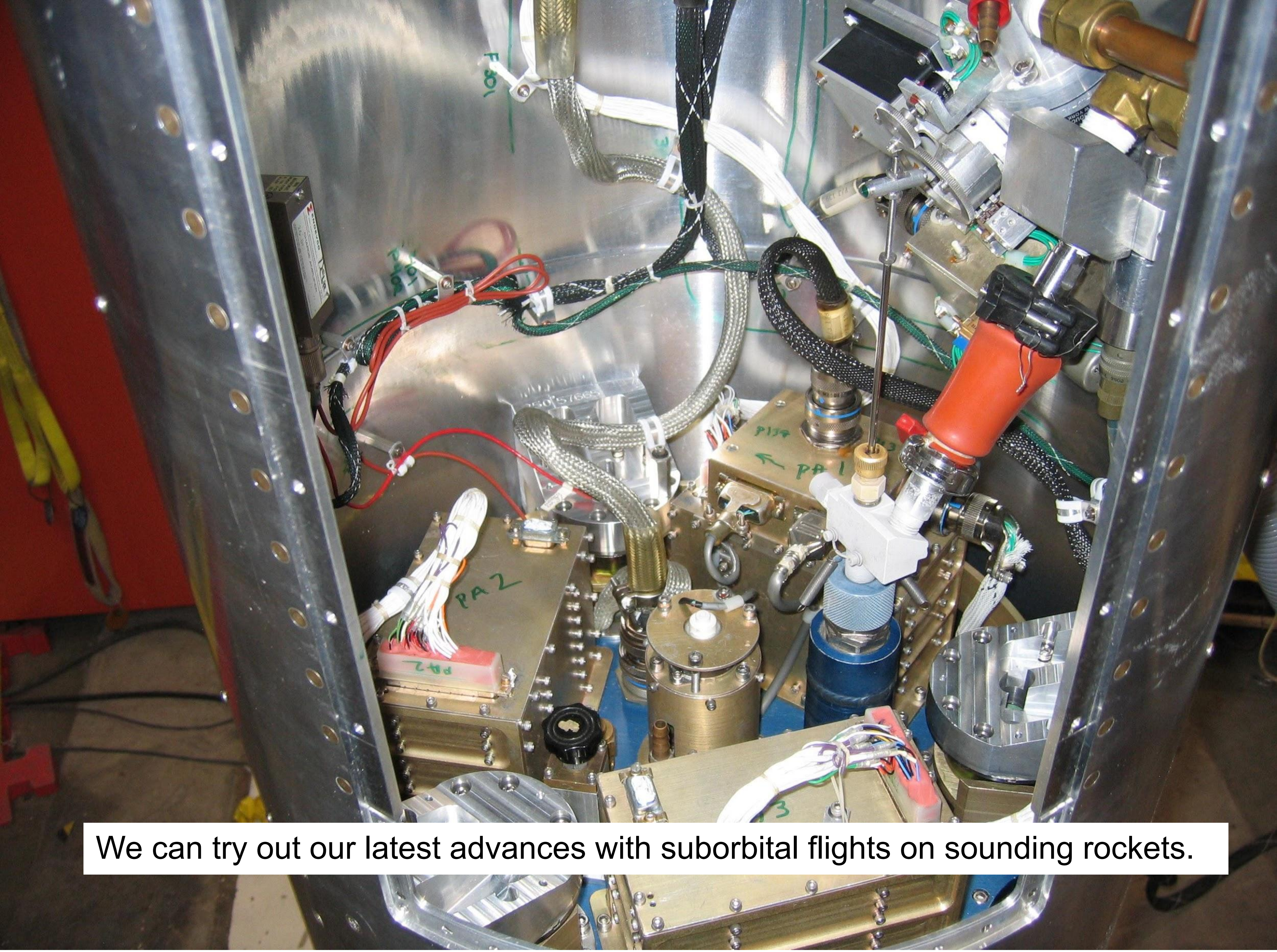


Problem is ionization statistics which limit energy resolution of even a theoretically perfect silicon solid state detector to about 120 eV for 6 keV X-rays. Solution is to do thermal calorimetry on individual photons to determine their energy.

Microcalorimeters operating at 50 mK with 5 eV resolution will be launched next year on the XRISM X-ray observatory.

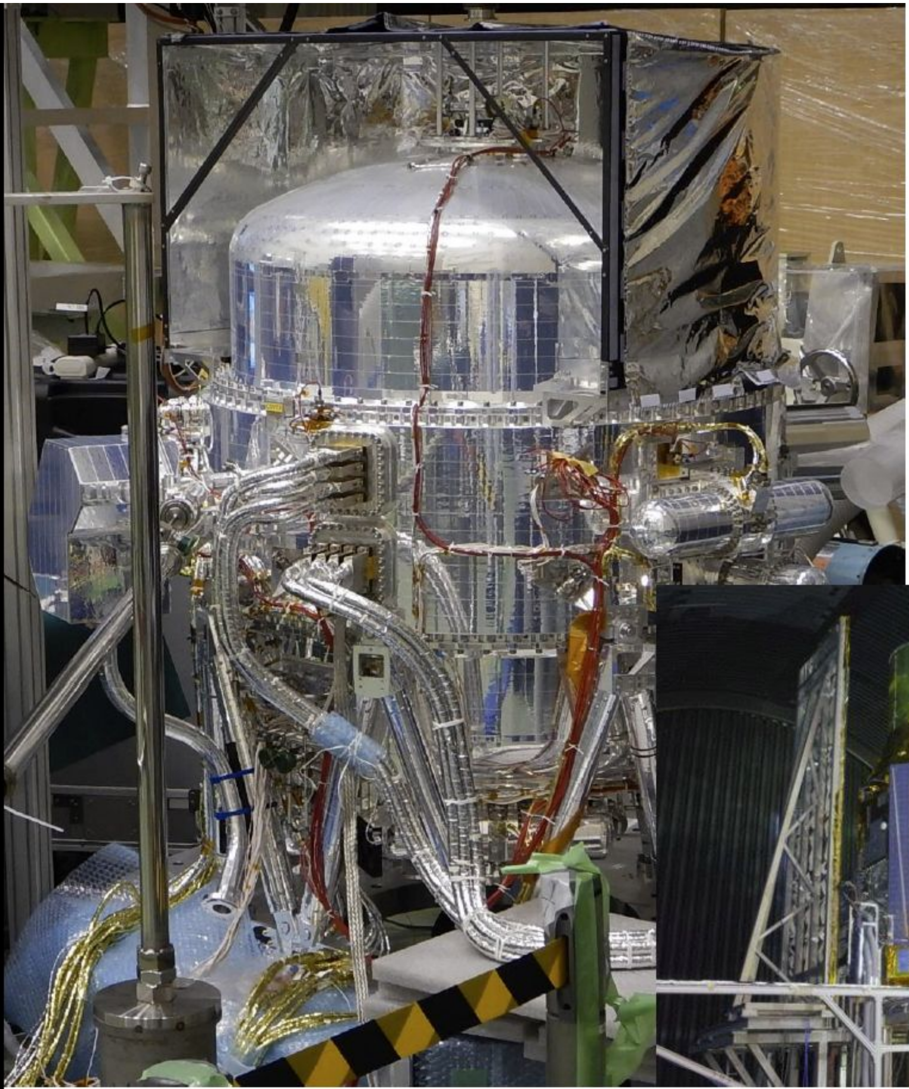
The best laboratory results are currently < 1 eV FWHM. We're trying to improve them still more!



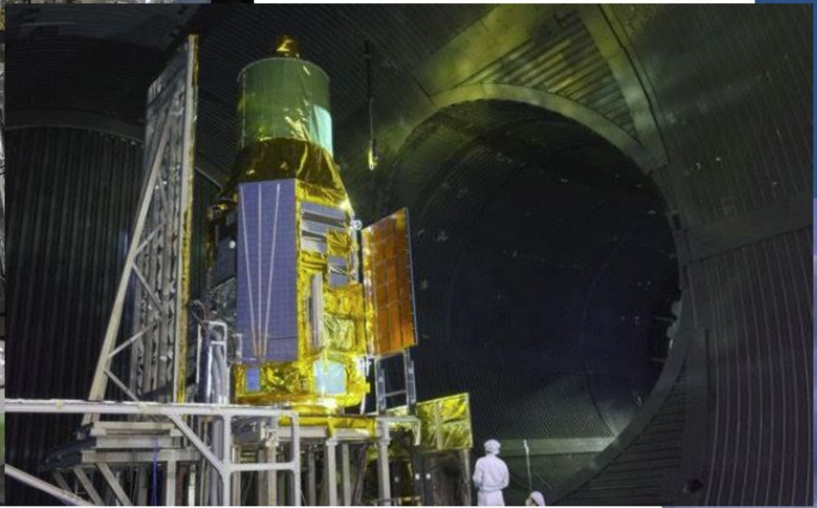


We can try out our latest advances with suborbital flights on sounding rockets.


Microcalorimeter instrument for the Astro-H/ Hitome X-ray Observatory



4 eV F.W.H.M.
resolution at 6000 eV.

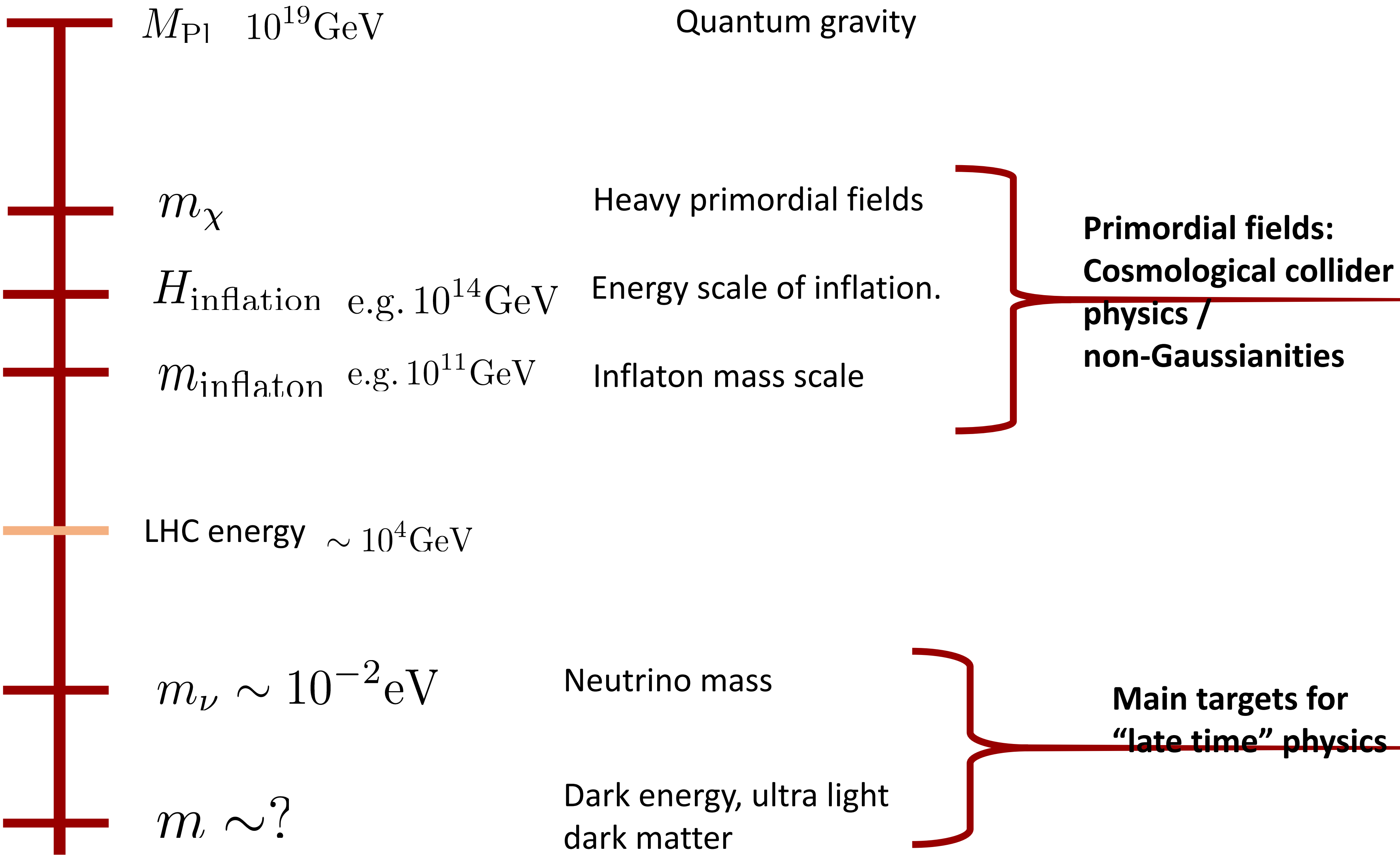


Goddard Space Flight Center / Wisconsin / JAXA Japan

(Unfortunately, Hitomi was broken after only 3 weeks in orbit, but we got two nice Nature papers and many others out of it. A replacement called XRISM is completed and being prepared for a launch early next year.)

Moritz Münchmeyer

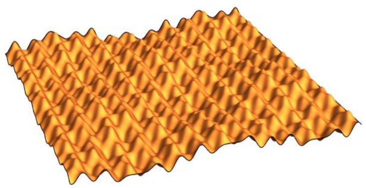
Energy scales probed by cosmology



Probing the fundamental physics of the early universe

The big bang was like a giant particle collider that set the initial conditions of the universe.

Primordial physics

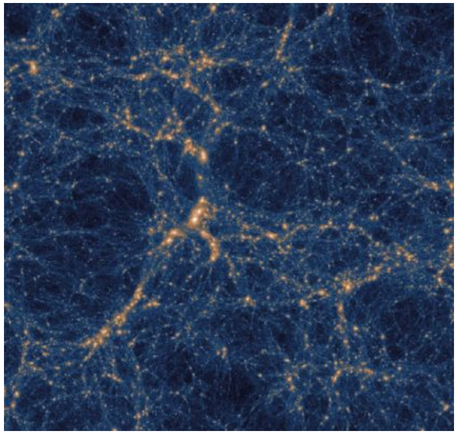


$\mathcal{L}_{\text{infl}}(\phi, g_{\mu\nu}, m_\chi..)$

Time evolution

Complicated astrophysics

Matter and radiation distribution today



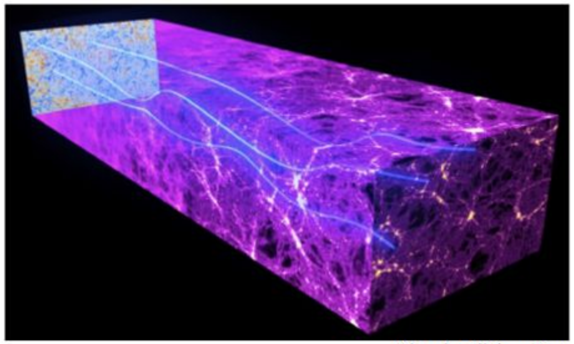
IllustrisTNG simulation

We develop **new theoretical and computational methods** to get from observations back to the initial conditions of the universe.

Example: Auto-differentiable effective physical models.

Methods for CMB-LSS cross correlation

Primary vs secondary anisotropies



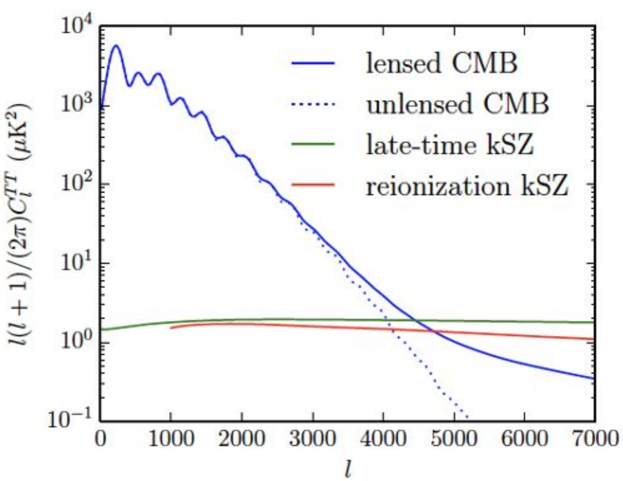
Planck collaboration

- Thompson scattering of CMB photons on free electrons

$$T_{kSZ}^{CMB} \sim \int dr \; \rho_e(r) \; v_r(r)$$

CMB temperature anisotropy — Electron density — Radial velocity

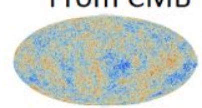
CMB power spectrum



Idea:

$$T_{kSZ}^{CMB} \sim \int dr \; \rho_e(r) \; v_r(r)$$

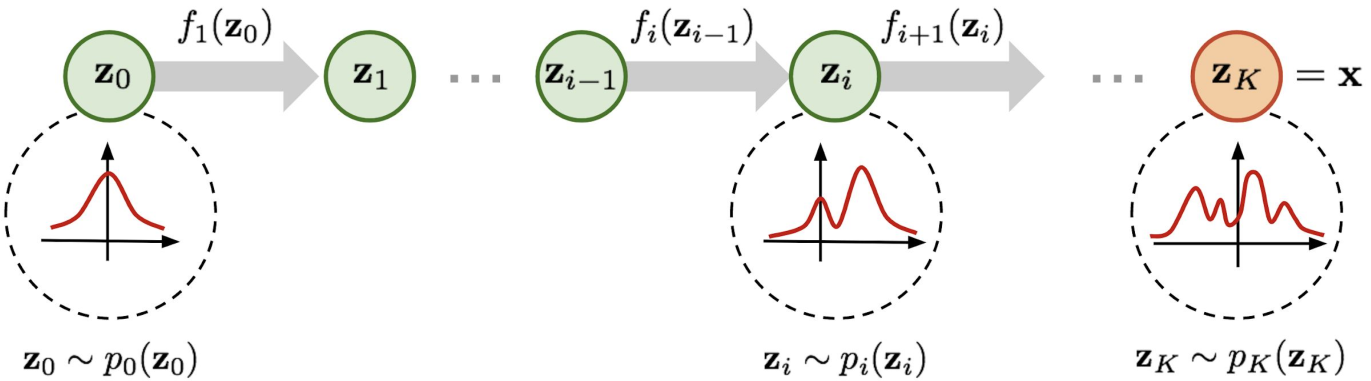
From CMB — From galaxy survey — Estimate!

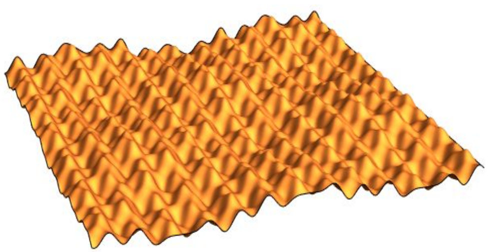


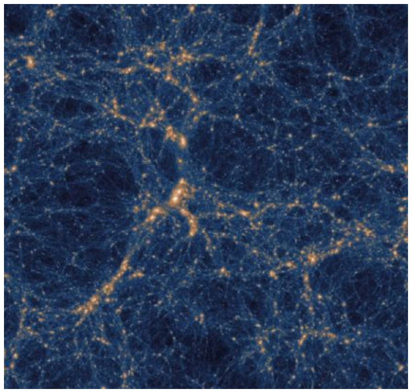
AI Initiative of the Physics Department

- Website: **ai.physics.wisc.edu**
- Main event: **Monthly Machine Learning and Physics seminar**, Wednesday at 11am in 5280 Chamberlin Hall.
- Alternating between local speakers and remote seminars.

Example: Normalizing Flows







Simple base distribution: initial gaussian fluctuations

Complicated target distribution: The late-time universe

Image credits: Lilian Weng, IllustrisTNG