

Cosmology with CHROMOS:
Cosmic Higher Resolution Origins
Multi-Object Spectroscopy
---Transforming Our Understanding of the Universe

Yun Wang (Caltech/IPAC), for the CHROMOS team

September 1, 2026

Answering Fundamental Questions Takes Decades

Astro2020 Major Science Questions on Cosmology

C-Q1. What set the Hot Big Bang in motion?

C-Q2. What are the properties of dark matter and the dark sector?

C-Q3: What physics drives the cosmic expansion and large-scale evolution of the universe?

C-Q3a. The Physics of Cosmic Acceleration

C-Q3b. The Properties of Neutrinos

C-Q3c. End-to-End Tests of Cosmology

C-Q4. How will measurements of gravitational waves reshape our cosmological view?

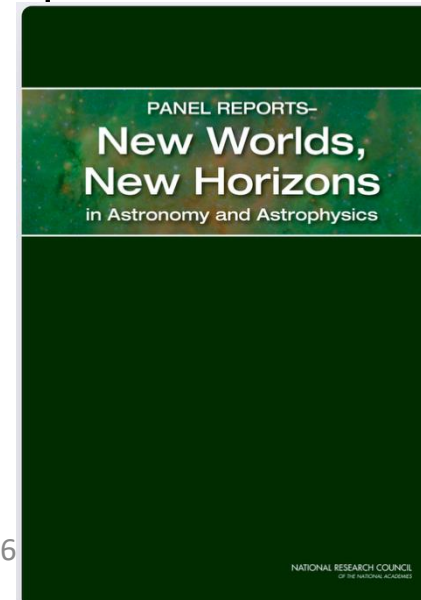
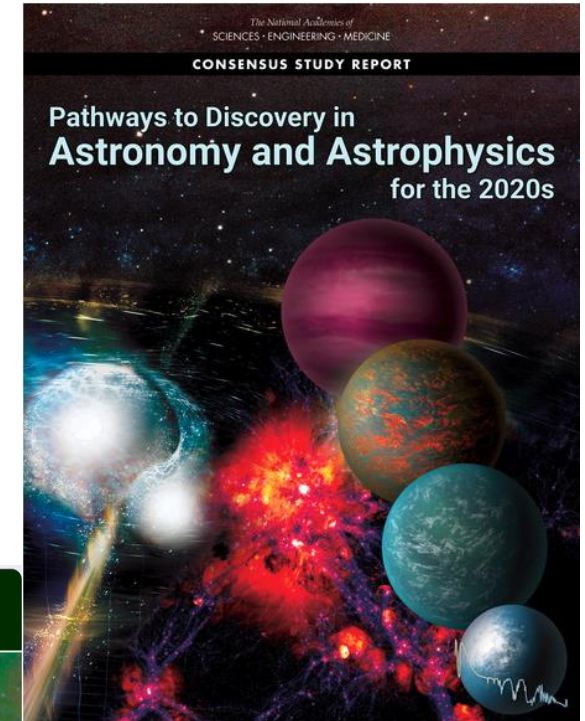
Astro2010 Cosmology & Fundamental Physics Major Questions:

CFP 1. How did the universe begin?

CFP 2. Why is the universe accelerating?

CFP 3. What is dark matter?

CFP 4. What are the properties of neutrinos?



All Astro2010 major cosmology questions remain for Astro2020

Key Science Questions in the Coming Decades

Cosmology (*Yun Wang's talk*)

1. What is the physics of cosmic inflation?
2. What causes the observed cosmic acceleration?
3. What is sum of neutrino masses?

Exoplanets (*Tom Greene's talk*)

1. What are the compositions of sub-Saturn exoplanets, and how did they form?
2. What causes departures from equilibrium chemistry?

Galaxy Evolution (*Andreas Faisst's talk*)

1. What are the physical drivers of large-scale structure evolution and how do they affect galaxies within it?
2. How do super-massive black holes form, how is growth coupled with host galaxies, how do they vary with time?

Milky Way Science (*Lynne Hillenbrand's poster*)

1. What stellar populations are in the inner Galaxy?
2. What are star-formation rates & initial mass functions of Galactic star clusters?
3. What ionization conditions exist in Galactic HII zones?

CHROMOS Mission Concept

- Telescope aperture: 2m diameter
- FoV: 0.7 deg^2
- Wavelength range: $1.25\text{-}5\mu\text{m}$
- Total throughput: ~ 0.25
- 4 identical spectrographs $1.25\text{-}5\mu\text{m}$ (blue channel $1.25\text{-}2.5\mu\text{m}$, red channel $2.5\text{-}5\mu\text{m}$)
- 8 H4RG detectors (2 per spectrograph)
- 1 imager (guiding/calibration)
- Spectroscopic resolution: $R = 1000$ (cleanly separate $\text{H}\alpha$ & NII)
- Spectroscopic multiplex: $> 16,000$ (30 micron pixel next-generation Digital Micro-mirror Device)
- DMD micro-mirror scale: $0.75'' \times 0.75''$, Detector pixel scale: $0.375''$
- Pointing stability: $< 0.02''$ RMS (exoplanet science driven)
- Orbit: L2
- Cost: $\sim \$1.2\text{B}$ (scaling 1.5m ATLAS Probe to 2m)



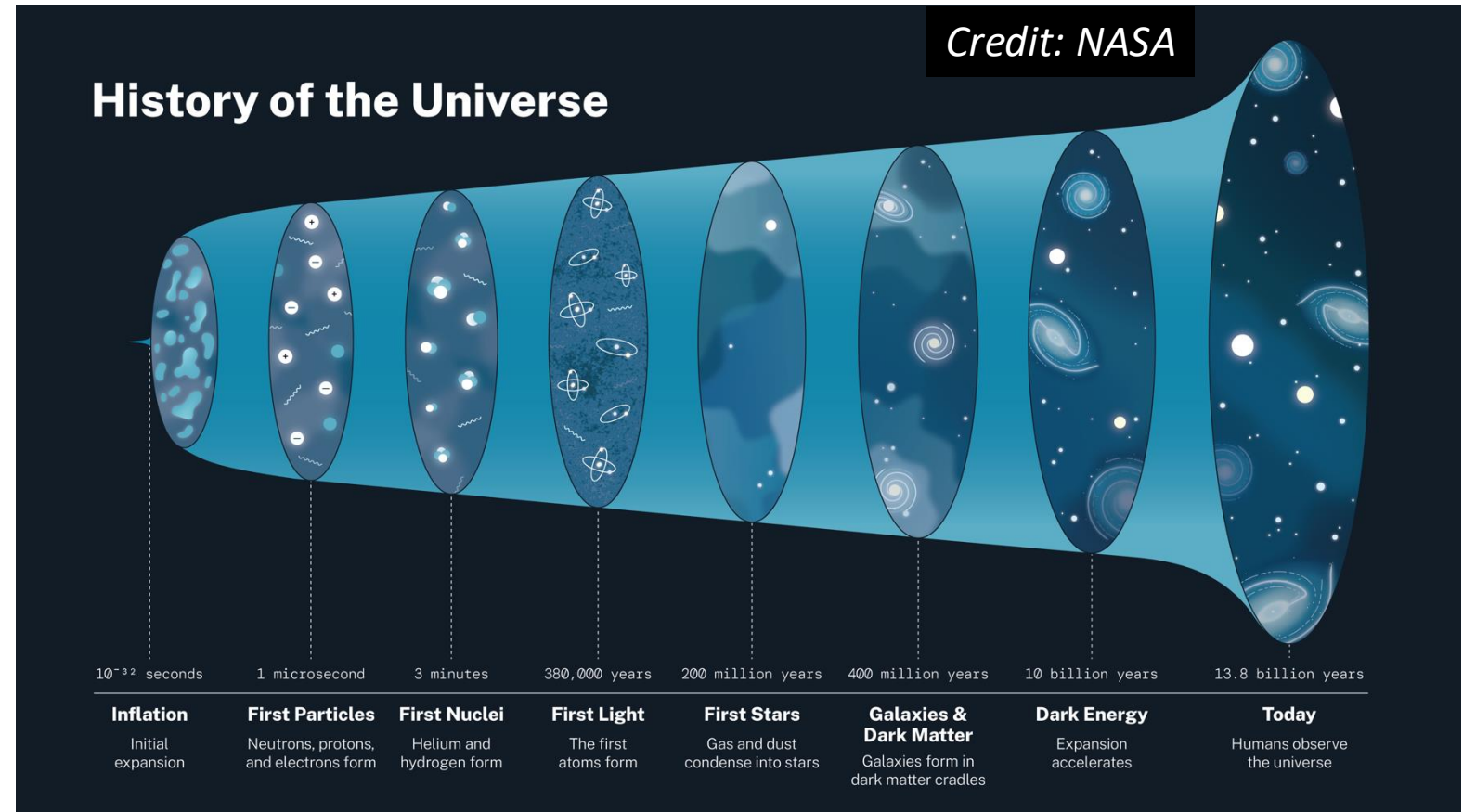
CHROMOS thermal design leverages & is much simpler than that of PRIMA

*Mission implementation talk: Greg Wirth (BAE)
September 2, 1:42pm, "UV Optical IR" session

CHROMOS Science Goals in Cosmology

Illuminating the Physics of Cosmic Origins and Evolution

1. Discover how cosmic inflation seeded large-scale structure in the Universe.
2. Unveil the physics of cosmic acceleration.
3. Measure the sum of neutrino masses.

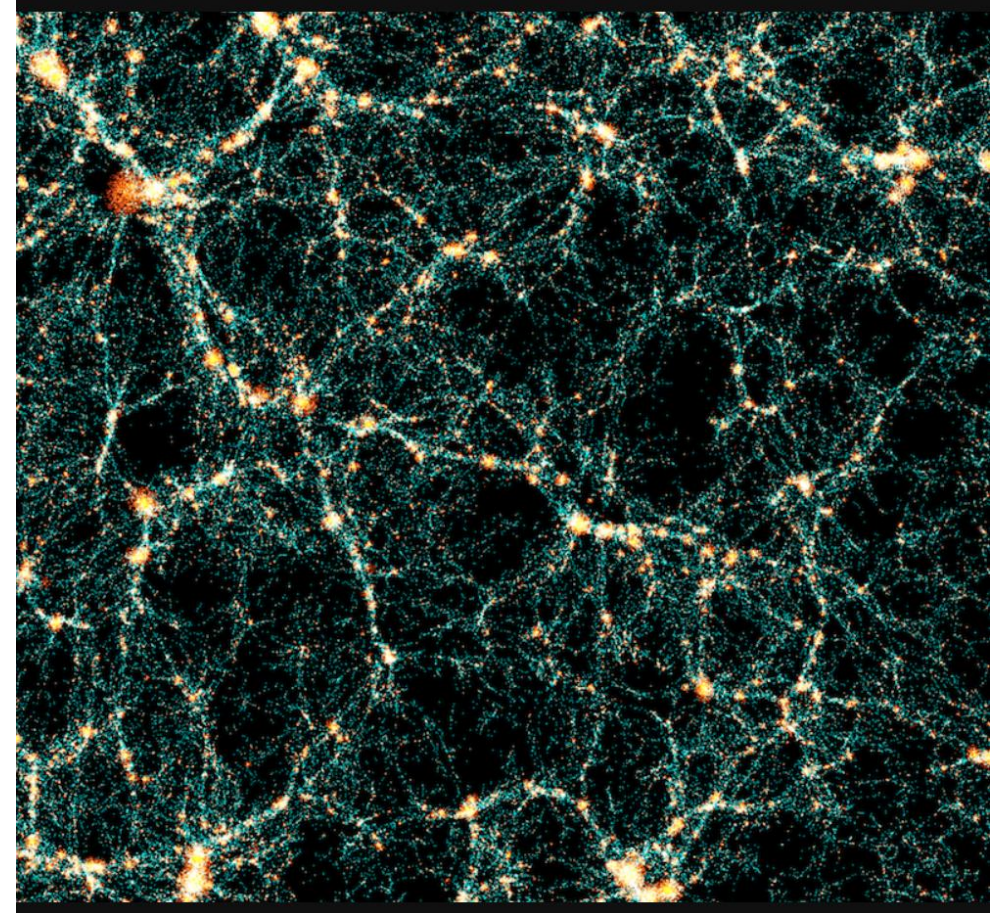


CHROMOS Science Objectives in Cosmology

1. Measure primordial non-Gaussianity parameter $f_{\text{NL,loc}} = 1$ at $> 5\sigma$ to discover whether primordial inflation was driven by a single field or multiple fields
2. Measure cosmic expansion history and large-scale structure evolution to sufficient accuracy & precision to differentiate different models for late time cosmic acceleration
3. Measure the sum of neutrino masses at $> 10\sigma$ (a precision of $< 0.006\text{eV}$)

CHROMOS traces 3D cosmic large-scale structure in unprecedented detail over a huge cosmic volume of 1000 cubic gigaparsecs, 14000 deg^2 at $z=1$ to 9, with 1 billion $\text{H}\alpha$, [OIII], [OII] emission line galaxies.

Observing time: < 3 years (inc. 20% overhead)



Virtual universe detail from Euclid Flagship simulation.

CHROMOS Addresses 2 out of 4 Astro2020 Major Science Questions on Cosmology

CHROMOS addresses all major science questions in cosmology from Astro2020 except for those on dark matter & gravitational waves

C-Q1: What set the Hot Big Bang in motion?

C-Q1a. Primordial Gravitational Waves

C-Q1b. Non-Gaussianity of the Large-Scale Structure of the Universe

C-Q1c. The Initial Power Spectrum of Density Fluctuations

- CHROMOS definitively test inflationary physics (single/multiple fields)

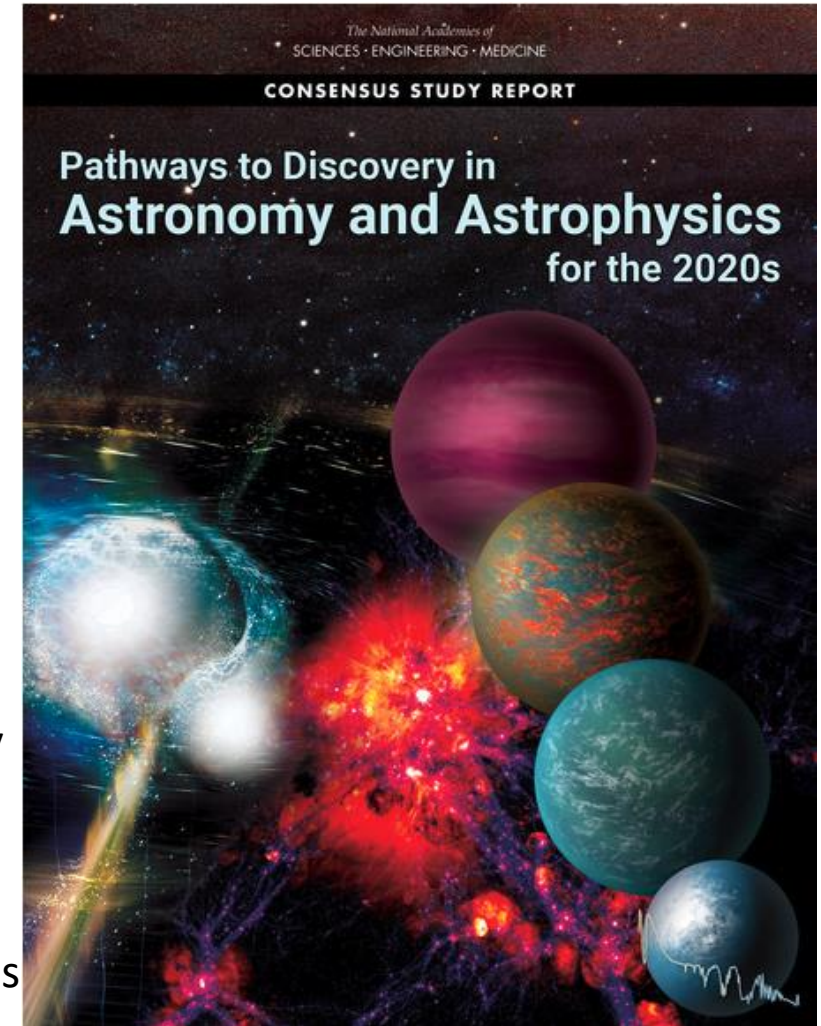
C-Q3: What physics drives the cosmic expansion and large-scale evolution of the universe?

C-Q3a. The Physics of Cosmic Acceleration

C-Q3b. The Properties of Neutrinos

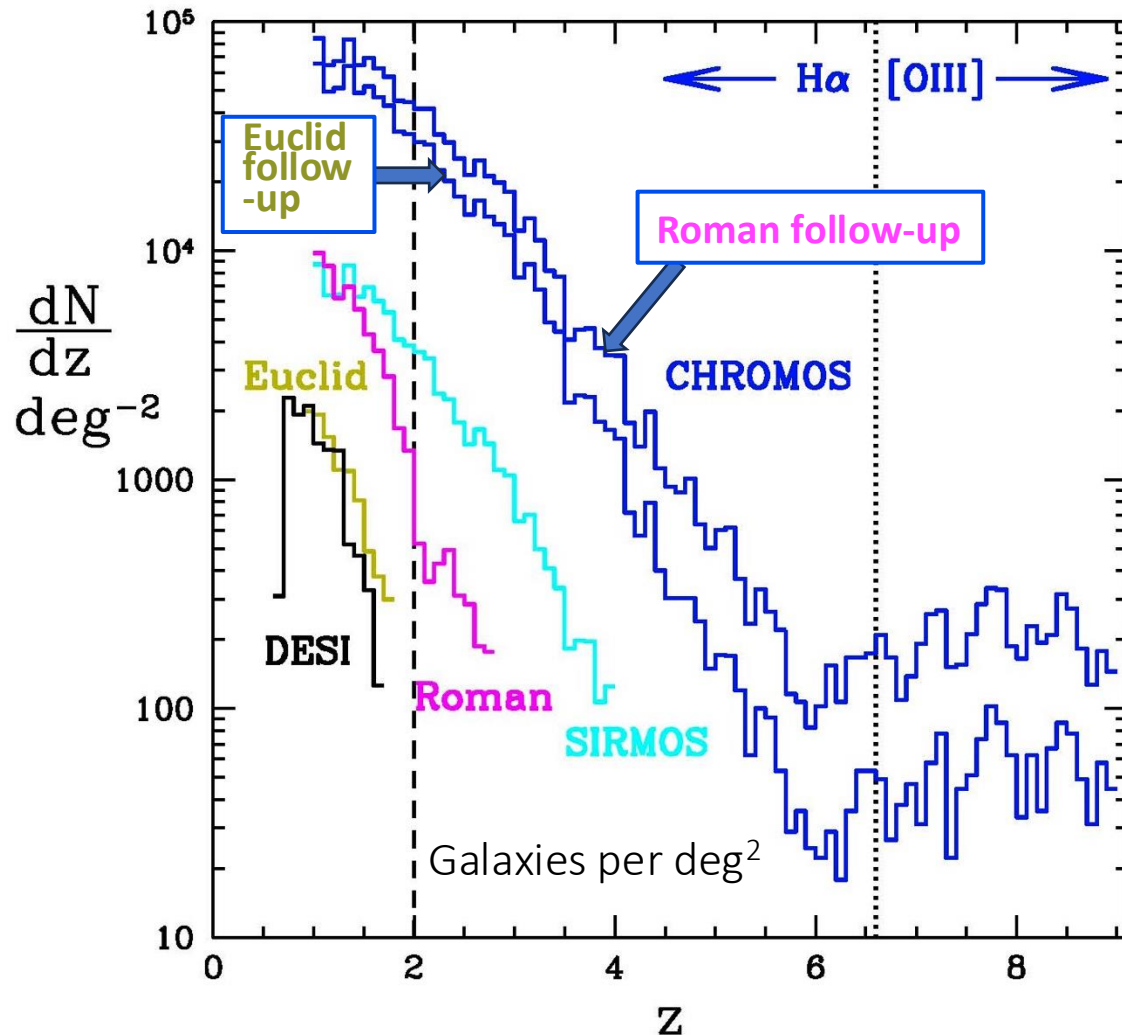
C-Q3c. End-to-End Tests of Cosmology

- CHROMOS makes definitive measurement of cosmic expansion history and growth history of large-scale structure to illuminate the nature of the observed cosmic acceleration (i.e., dark energy).
- These observations provide an end-to-end test of the standard cosmological model & measure the properties and masses of neutrinos



CHROMOS: Mapping the Universe Beyond

--- the spectroscopic follow-up mission to Roman and Euclid



The higher the number density of galaxies (and the smaller their redshift errors) used to trace cosmic large-scale structure, the more detailed we are mapping the Universe in 3D and obtaining cosmological information.

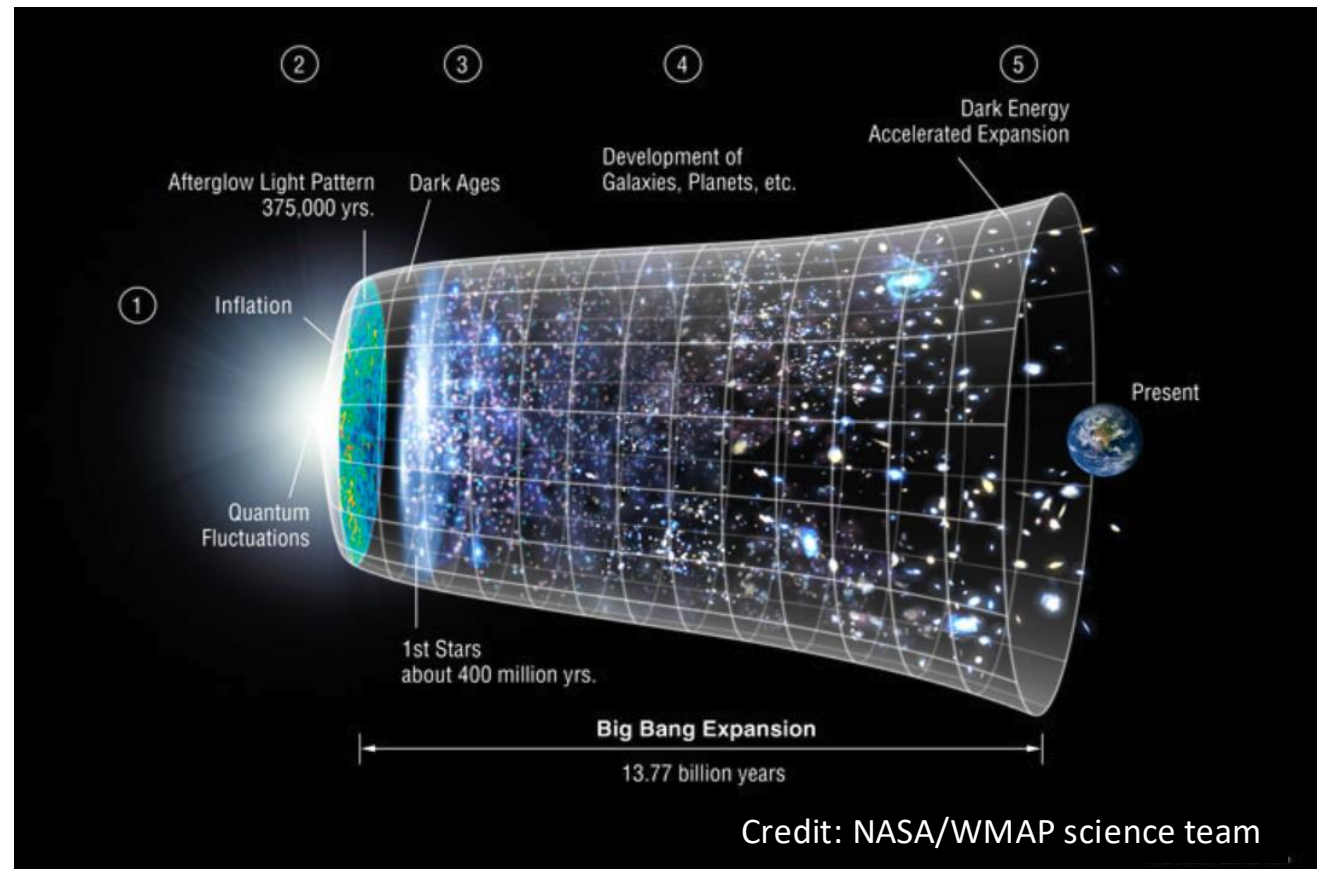
	$\sigma_z/(1+z)$	Method
Euclid/Roman	~ 0.001	Slitless grism
DESI	~ 0.0001	Slits via fibers
SIRMOS/CHROMOS	~ 0.0001	Slits via DMD

CHROMOS has the unique capability to map the Universe at $1 < z < 9^*$ in sufficient detail to measure fundamental physics with tight control of systematic errors. (** dN/dz uncertain at $z \gtrsim 5$ due to scarce data*)

Probing Inflationary Physics: Constrain Primordial Non-Gaussianity

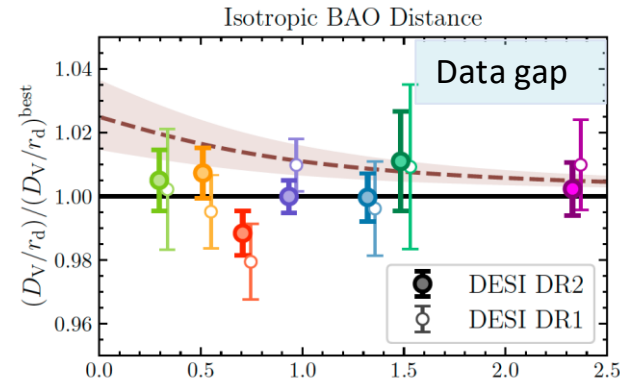
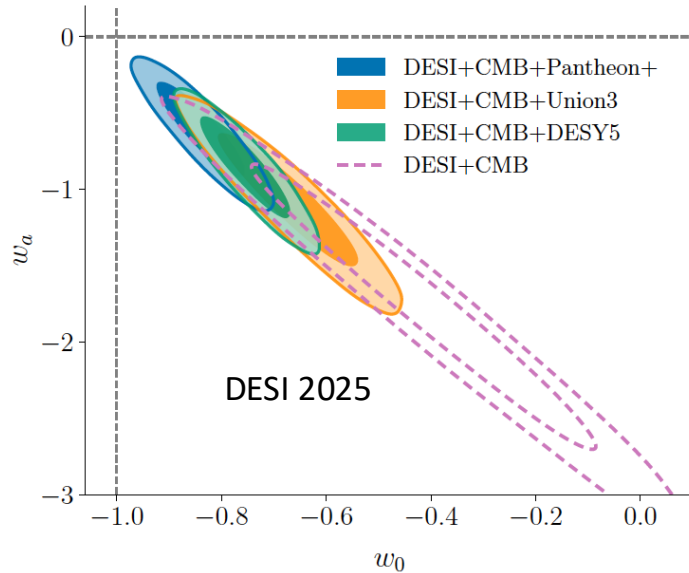
Astro2020 Major Science Question C-Q1: What set the Hot Big Bang in motion?
CHROMOS addresses this by definitively test single-field inflation.

- Cosmic large-scale structure was seeded by quantum fluctuations produced during inflation at $t \sim 10^{-34}s$
- Primordial gravitational potential arising after inflation: $\Phi = \varphi + f_{NL}(\varphi^2 - \langle \varphi^2 \rangle)$
 φ : Gaussian random field
 f_{NL} : “local” non-Gaussianity parameter
- The simplest inflation models involve a single field, and predict $f_{NL} \ll 1$.
- A detection of $f_{NL} > 1$ rules out the class of single-field inflation models.
- **Astro2020: measures $f_{NL}=1$ at $\geq 5\sigma$**
- Current & planned measurements of $f_{NL}=1$: 0.2σ (Planck), 2σ (SPHEREx)
- **CHROMOS measures $f_{NL}=1$ at 7σ .**

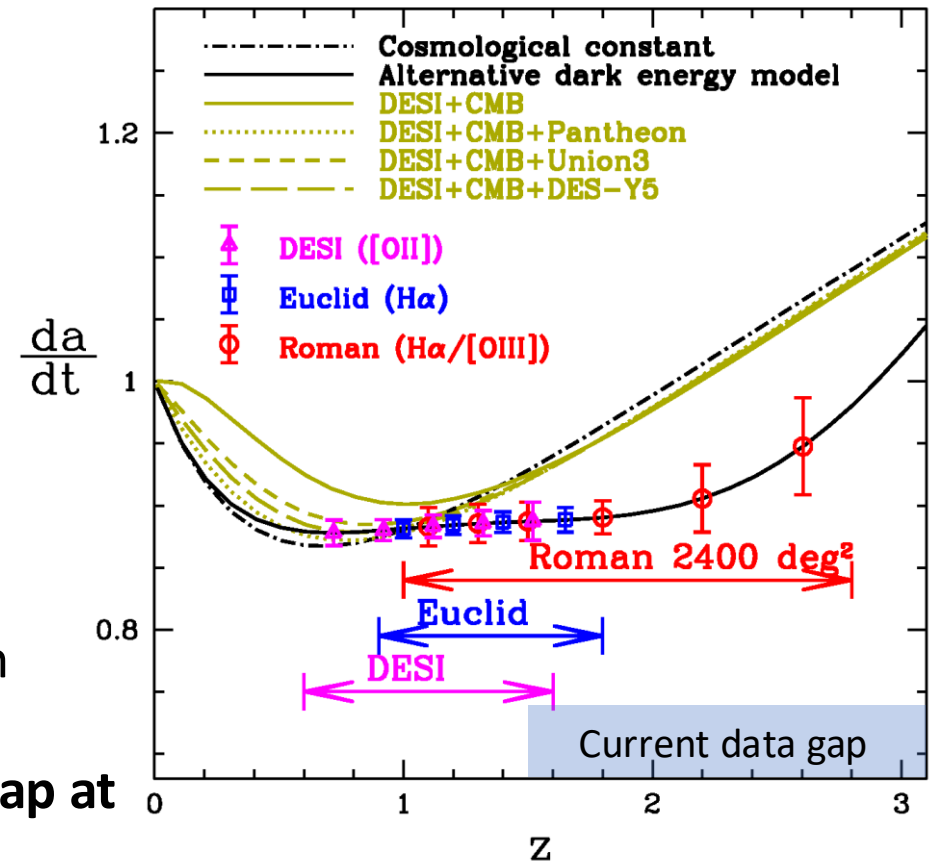


Current & Planned Dark Energy Measurements

DESI+ data give 3σ evidence for dynamic DE, but assuming $w_x(z) = w_0 + w_a(1-a)$.
 All best fit models have $w_0 + w_a < -1$: DE density $\propto (1+z)^{3(1+w_0+w_a)} \rightarrow 0$ at high z , in data gap!



Note current data gap: $1.5 < z < 3$
 (with a single BAO measurement at $z \sim 2.3$ from Ly α)



- Need model-independent dark energy measurements!
- Euclid could confirm DESI results on DE density variation with time.
- Roman will measure DE at higher z , filling in the data gap at $2 < z < 3$, to explore beyond $w_0 w_a$ models

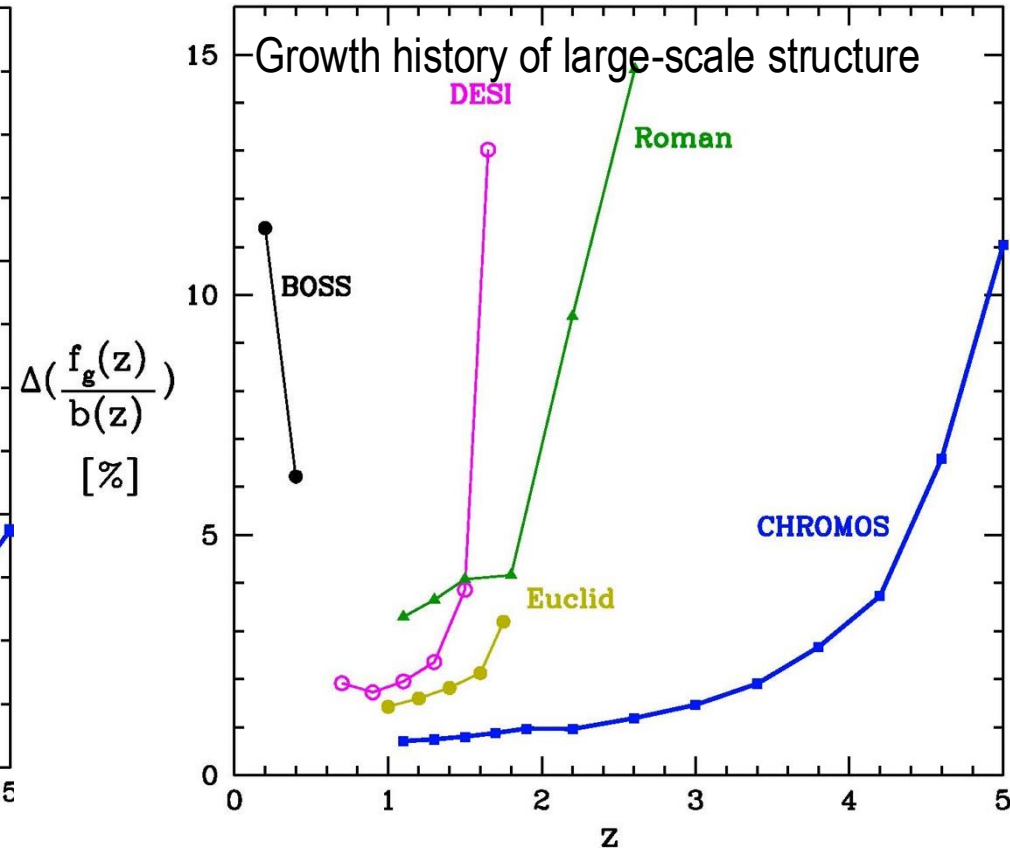
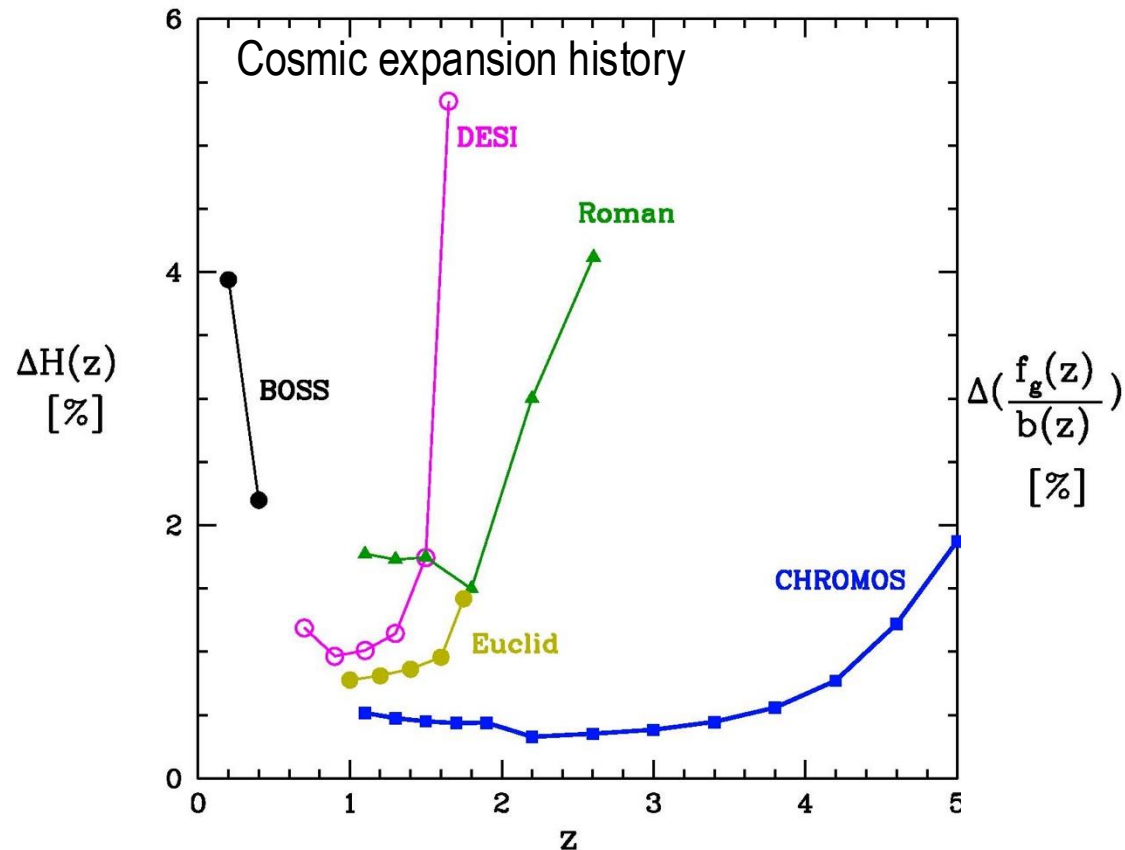
* $a(t)$: cosmic scale factor, z : redshift (proxy for t)

CHROMOS Illuminates Physics of Dark Energy

Astro2020 Major Science Question C-Q3:

What physics drives the cosmic expansion and large-scale evolution of the universe?

CHROMOS addresses this by measuring cosmic expansion history $H(z)$ & growth history of large-scale structure $f_g(z)$, to discover whether dark energy is an unknown energy component (e.g., a cosmological constant), or the modification of General Relativity.



Ultra-conservative estimates assuming 2pt statistics only

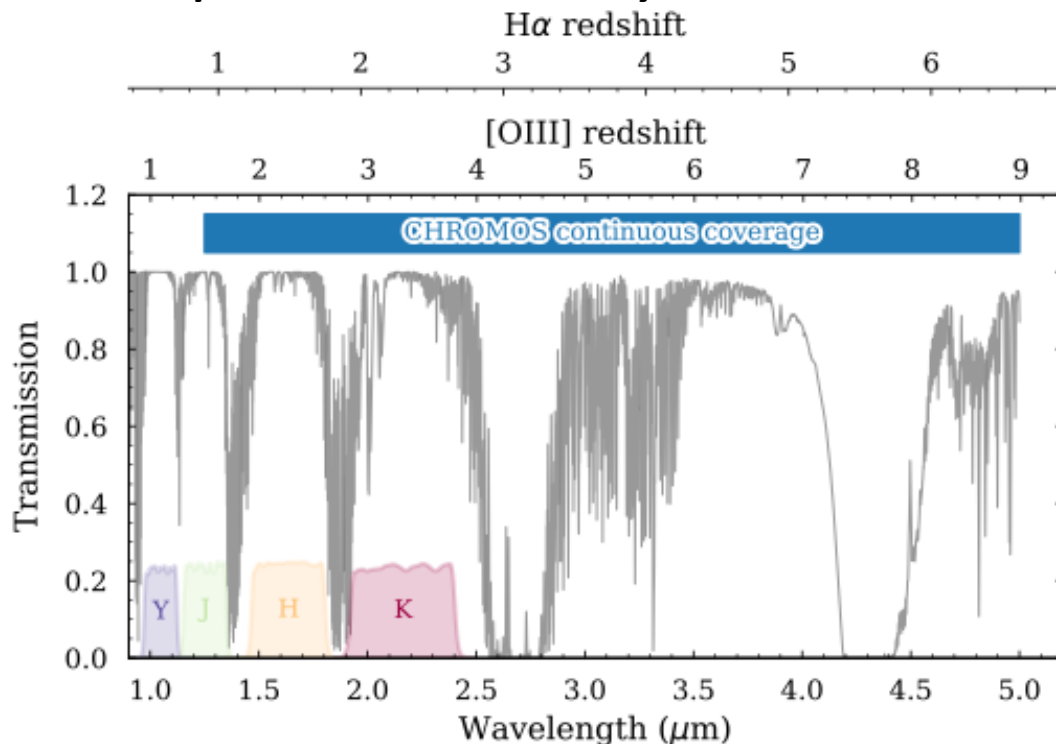
Forecast limited to $z < 5$ since dN/dz at $5 < z < 9$ has large uncertainty due to insufficient current data.

CHROMOS Cosmology Requires a Space Platform

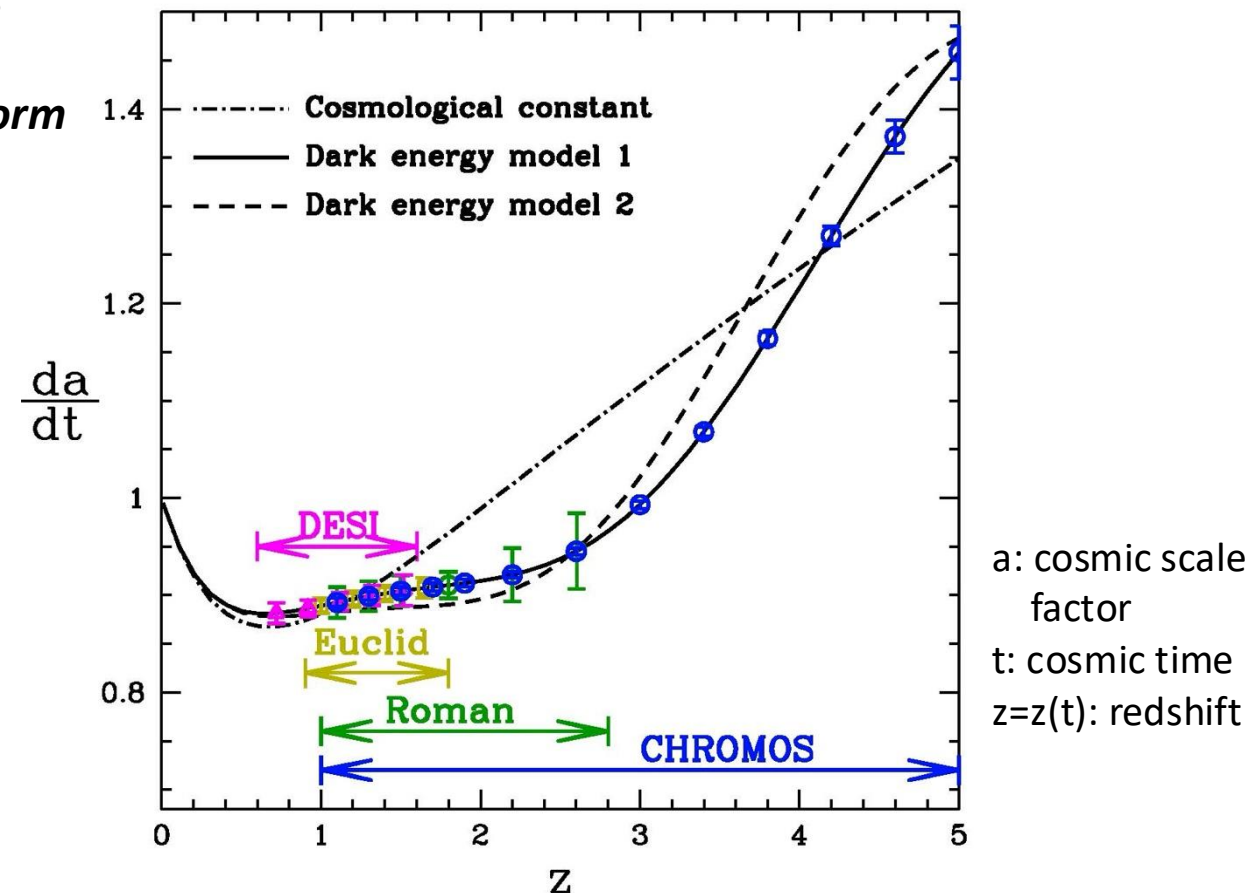
CHROMOS science is beyond the reach & capability of current & future ground-based projects

- Precision cosmology at $1 < z < 9$ requires homogeneous samples with continuous wavelength coverage at 1.1-5 μm
- Ground-based observatories: significant wavelength gaps at $\lambda > 1.1 \mu\text{m}$ (low atmospheric transmission):
 - Missing half of wavelength/redshift coverage
 - The other half severely contaminated by sky lines

CHROMOS science requires accurate measurement of large-scale fluctuations, which requires a space platform to provide the consistency in observations.

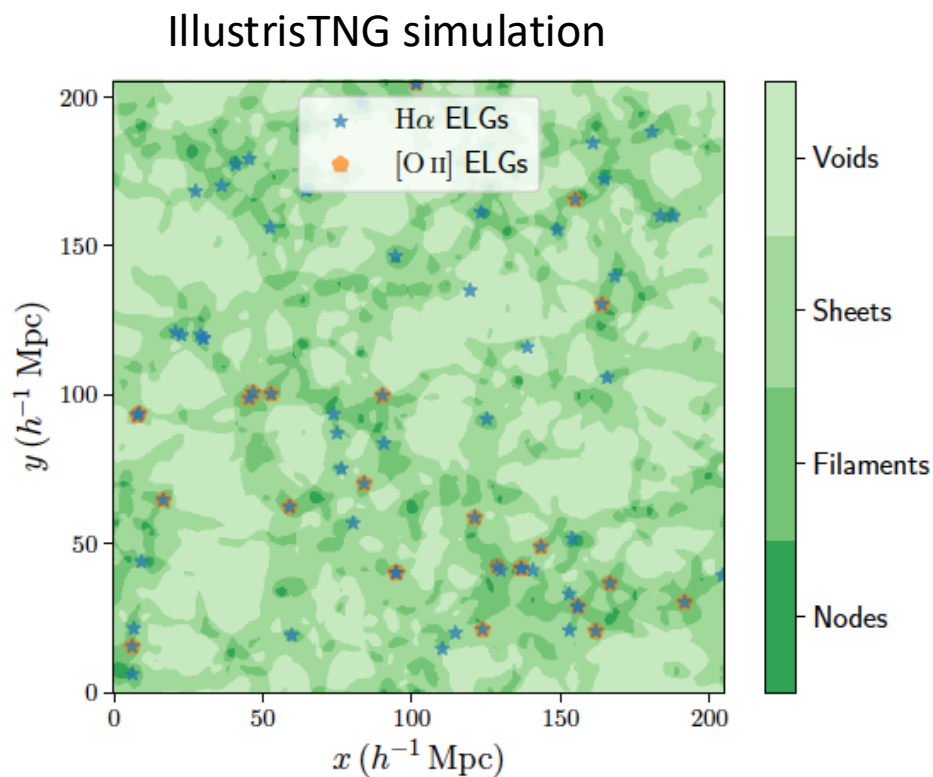


Measurement of the cosmic expansion rate: a capability metric

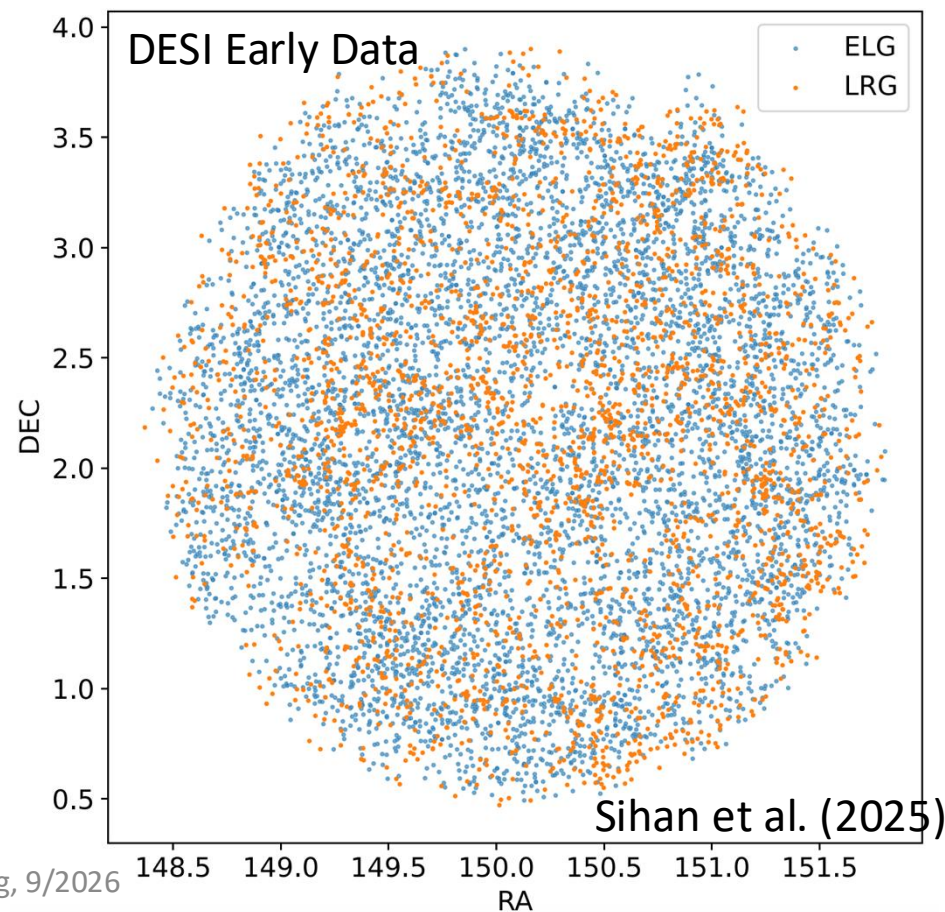


Mapping the Universe in 3D Using ELGs

- Emission Line Galaxies (ELGs) have been demonstrated to be the best tracer of large-scale structure:
 - High resolution cosmological N-body simulations show ELGs trace the cosmic web, inc. filaments & knots
 - Most passive galaxies reside in dense, high-mass environments like galaxy groups & clusters (cosmic web knots)
 - Early DESI data show that ELGs (higher density) trace large-scale structure better than passive galaxies (lower density)
- CHROMOS maps a huge cosmic volume ($\sim 1,000 \text{ Gpc}^3$) using 1 billion $\text{H}\alpha$ and $[\text{O II}]$ ELGs over $14,000 \text{ deg}^2$ at $1 < z < 9$ via slit spectroscopy, beyond the capability of Euclid/Roman slitless spectroscopy



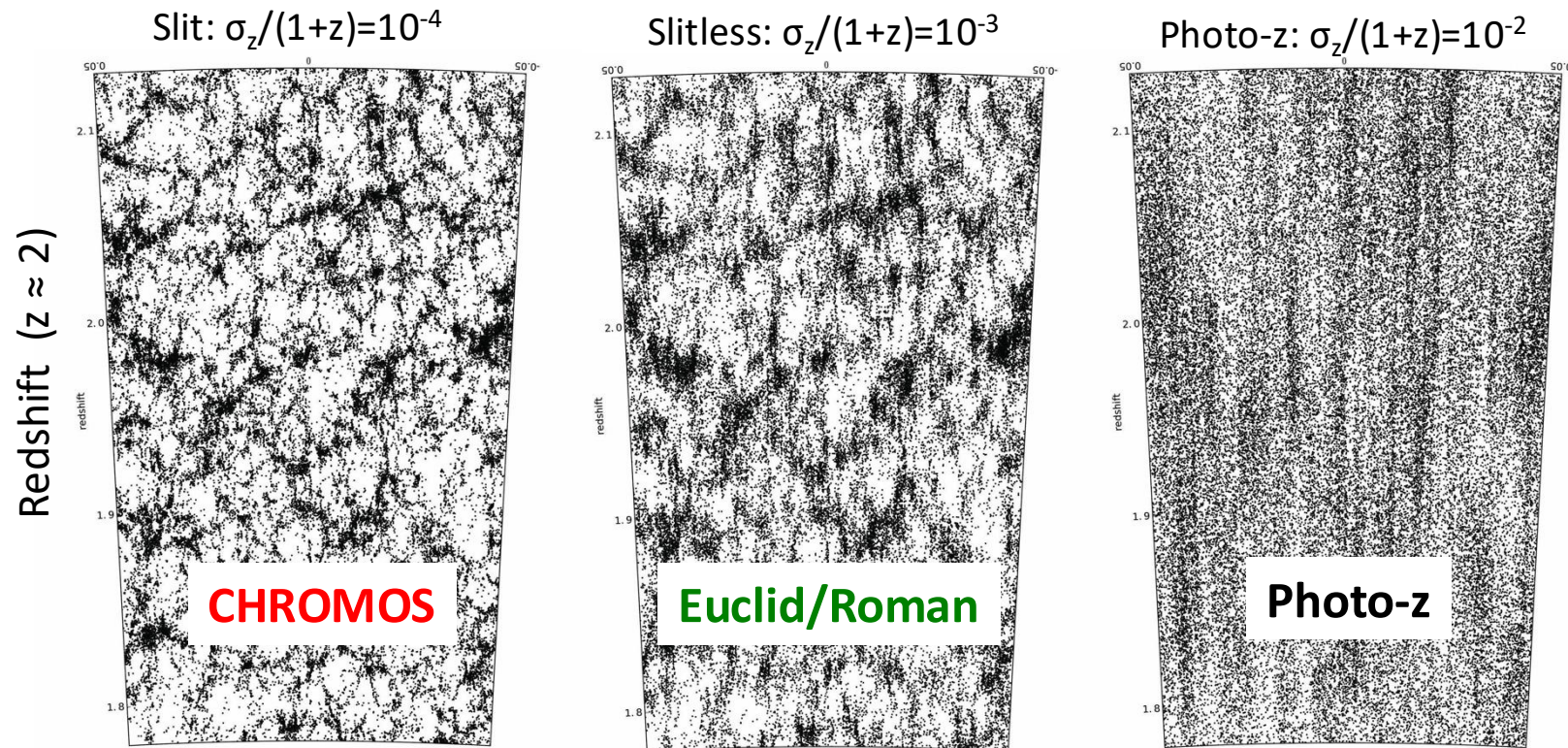
Osato & Okumura (2022)



Sihan et al. (2025)

Why Slit Spectroscopy?

- Reduce background → Increase spectroscopic SNR
- Remove systematic errors from slitless spectroscopy (spectral overlap & line misidentification)
- Enable high spectral resolution to trace the cosmic web with sufficient fidelity to place galaxies into their environmental context



Angular position in radians

Yun Wang, 9/2026

(Figures by Alvaro Orsi)

CHROMOS: Unique Capability for Cosmological Discoveries

Wide Survey Mode	<i>CHROMOS</i>	<i>Roman</i>	<i>SPHEREx</i>	<i>Euclid</i>	<i>JWST</i> *	<i>HST</i>
Slit spectroscopy	Yes	No	No	No	Yes	No
Spectral resolution	1000	461	41, 35, 110, 130	380	1000, 2700	130
Wavelength (μm)	1.25-5	1-1.91	0.75-5	1.25-1.85	1-5	0.8-1.7
Redshift range Δz	1-9 H α /[OIII]	1-2.85 H α /[OIII]	$z < 2$ (6.2" pixels)	0.9-1.8 H α	0.5-9 H α /[OIII]	0.2-1.6 H α
Redshift error σ_z	0.0002	0.001	0.1	0.001	0.0002	0.002
Magnitude cut	H<24.5 (25)	H<24.5	H<20	H<24	N/A	N/A
Survey depth (erg/s/cm ²)	7(5) $\times 10^{-18}$ / 3.5(2.4) $\times 10^{-18}$ (5 σ)	1.5 $\times 10^{-16}$ (5 σ)	3 $\times 10^{-15}$, 6 $\times 10^{-16}$ @1, 4 μm (3 σ)	2 $\times 10^{-16}$ (3.5 σ)	3.5 $\times 10^{-19}$ (10 σ)	5 $\times 10^{-17}$ (5 σ)
Survey area (deg ²)	~14,000 (2000)	~2,400	~28,000	~14,000	< 1	< 0.2
Survey Volume (Gpc ³)	1,000	44	111@z=1, 426@z=2	121	0.084/deg ²	0.0058/deg ²
FOV (deg ²)	0.463	0.28	39.6	0.55	0.0034	0.00147
Survey efficiency e**	~1	~1	~1	~1	~0.0167	~1
Telescope aperture (m)	2	2.4	0.2	1.2	6.6	2.4
Launch date	~2036	~2026	2025	2023	2021	1990
Measuring $f_{\text{NL,loc}}=1$	7 σ	< 0.5 σ	2 σ	< 0.5 σ	N/A	N/A
FoM=D ² •FoV• Δz •10 ⁻³ e/ σ_z	74	2.98	0.016-0.032	0.71	0.105	0.006

*The $f_{\text{NL,loc}}=1$ signal increases as larger scales are probed, but its degeneracy with galaxy bias & cosmological parameters can only be broken by probing down to small scales. Only CHROMOS does both to achieve >5 σ . Current best result: 0.2 σ (Planck). **Slew and settle time $t_{ss} \leq 60\text{s}$: e=1, else e=60s/ t_{ss}

† JWST covers the entire redshift range of CHROMOS, but CHROMOS survey will take > 100 years on JWST (due to long set-up times)!

CHROMOS ASTRA Team

- **PI:** Yun Wang (Caltech/IPAC)
- **Instrument Scientist:** Massimo Robberto (JHU/STScI)
- **Industry Lead:** Gregory Wirth (BAE)
- **Scientific Advisory Committee:** Mark Dickinson (Noirlab), Thomas Greene (Caltech/IPAC), Jeffrey Kruk (GSFC), Will Percival (Canada), Joshua Schlieder (GSFC)
- **Cosmology Science Leads:** Nikhil Padmanabhan (Yale), Lado Samushia (Kansas State)
- **Exoplanet Science Lead:** Thomas Greene (Caltech/IPAC)
- **Galaxy Evolution Science Leads:** Andreas Faisst (Caltech/IPAC), Jeyhan Kartaltepe (RIT)
- **Milky Way Science Lead:** Lynne Hillenbrand (Caltech)
- **Instrument Working Group:** Robert Content (AAO), Jon Lawrence (AAO), Gregory Mosby (GSFC), Zoran Ninkov (RIT), Jack Piotrowski (JHU), Steve Smee (JHU)
- **Cosmology Science Work Group:** Florian Beutler, Samuel Brieden (UK), Kyle Finner (Caltech/IPAC), Andrew Hearin (ANL), Cullan Howlett (Australia), Alvise Raccanelli (Italy), Jason Rhodes (JPL), Shun Saito (Missouri S & T), Hee-Jong Seo (Ohio Univ), Zachary Slepian (Univ of Florida), Francesco Spezzati (Caltech/IPAC)
- **Galaxy Evolution Science Working Group:** Lee Armus (Caltech/IPAC), Andrew Benson (Carnegie), Micol Bolzonella (Italy), Jarle Brinchmann (Portugal), Emanuele Daddi (France), Ken Osato (Japan), Casey Papovich (Texas A&M), Lucia Pozzetti (Italy)

Summary

- CHROMOS maps the Universe in 3D over a cosmic volume of ~ 1000 cubic gigaparsecs using ~ 1 billion galaxies with $H\alpha$ /[OIII] emission lines (optimal for tracing cosmic large-scale structure) at $1 < z < 9$, with tight systematics control, to **address 2 Major Questions in Cosmology from Astr2020: C-Q1, C-Q3**
- **Primary Science Goals in Cosmology:**
 - 1. Discover how cosmic inflation seeded large-scale structure in the Universe** Primordial non-Gaussianity constraint $\sigma(f_{NL}) = 0.14$ (7σ measurement of $f_{NL,loc}=1$) to differentiate single & multi-field inflation models [Best current constraints: $\sigma(f_{NL,loc}) \sim 5.1$ from Planck]
 - 2. Differentiating dark energy & modification of general relativity as the cause for the observed cosmic acceleration** $\Delta H(z) \sim 0.5\%$ in 10 redshift bins at $1 < z < 4$, $\Delta H(z) \lesssim 0.7\text{-}6\%$ in 12 redshift bins at $4 < z < 9$ [No accurate current measurements at $z > 2$]
 - 3. Advancing fundamental physics: $\sigma(\sum m_\nu) < 0.002$ eV ($> 30\sigma$ measurement) [Upper limits only now]**
- **CHROMOS leverages Euclid photometric data to accomplish flagship science on an ASTRA mission ($\sim \$1B$)**
- CHROMOS cosmology science case requires accurate measurement of large-scale fluctuations, which requires a space platform to provide the consistency in observations.
- **CHROMOS benefits from ongoing work on SIRMOS (MIDEX concept) and earlier work on ATLAS Probe. It has the capability to transform our understanding of the universe, and should enter the ASTRA incubation now.**