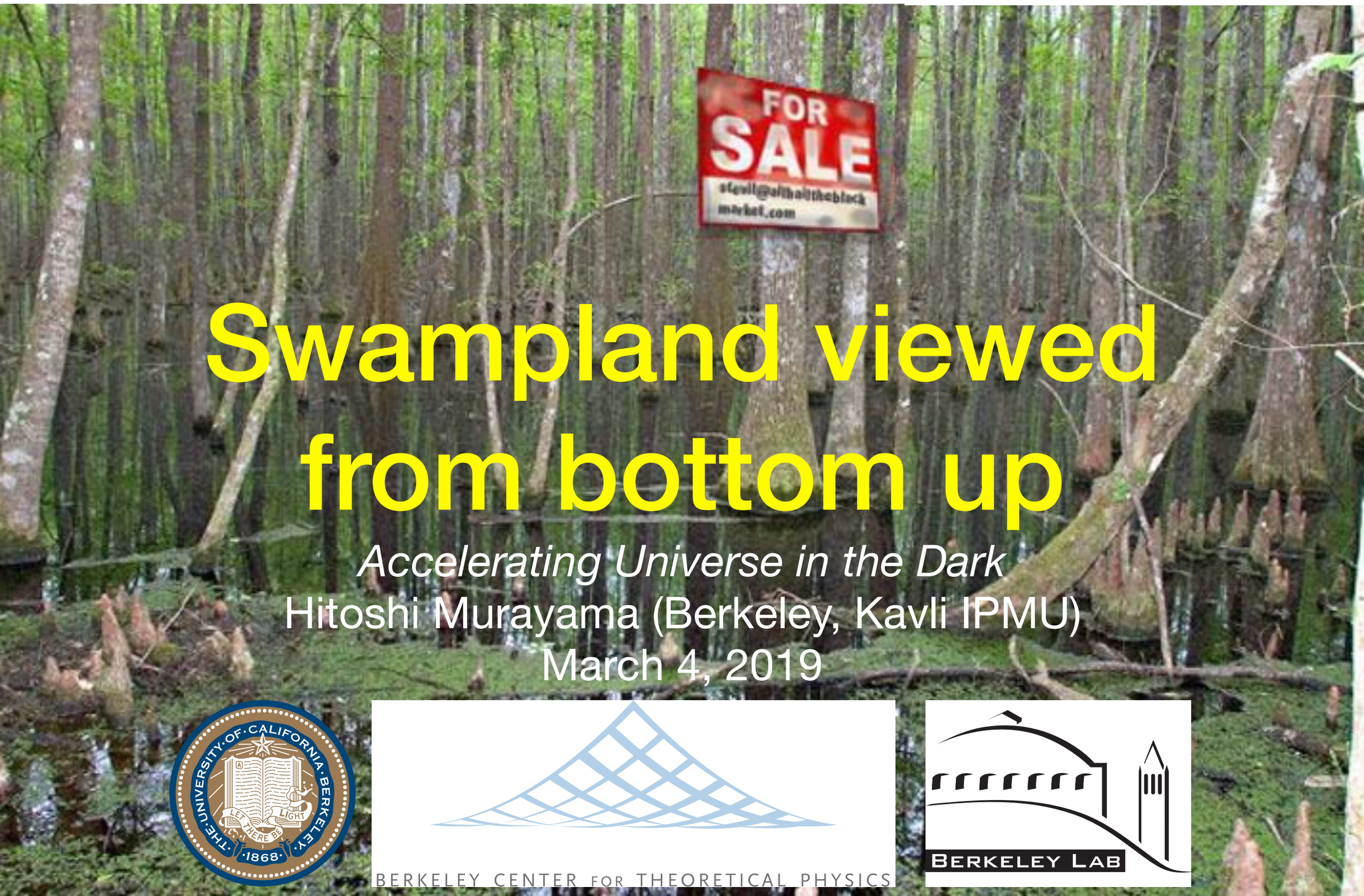
KAVLI IPMU INSTITUTE FOR THE PHYSICS AND MATHEMATICS OF THE UNIVERSE

東京大学 THE UNIVERSITY OF TOKYO



Swampland viewed from bottom up

Accelerating Universe in the Dark

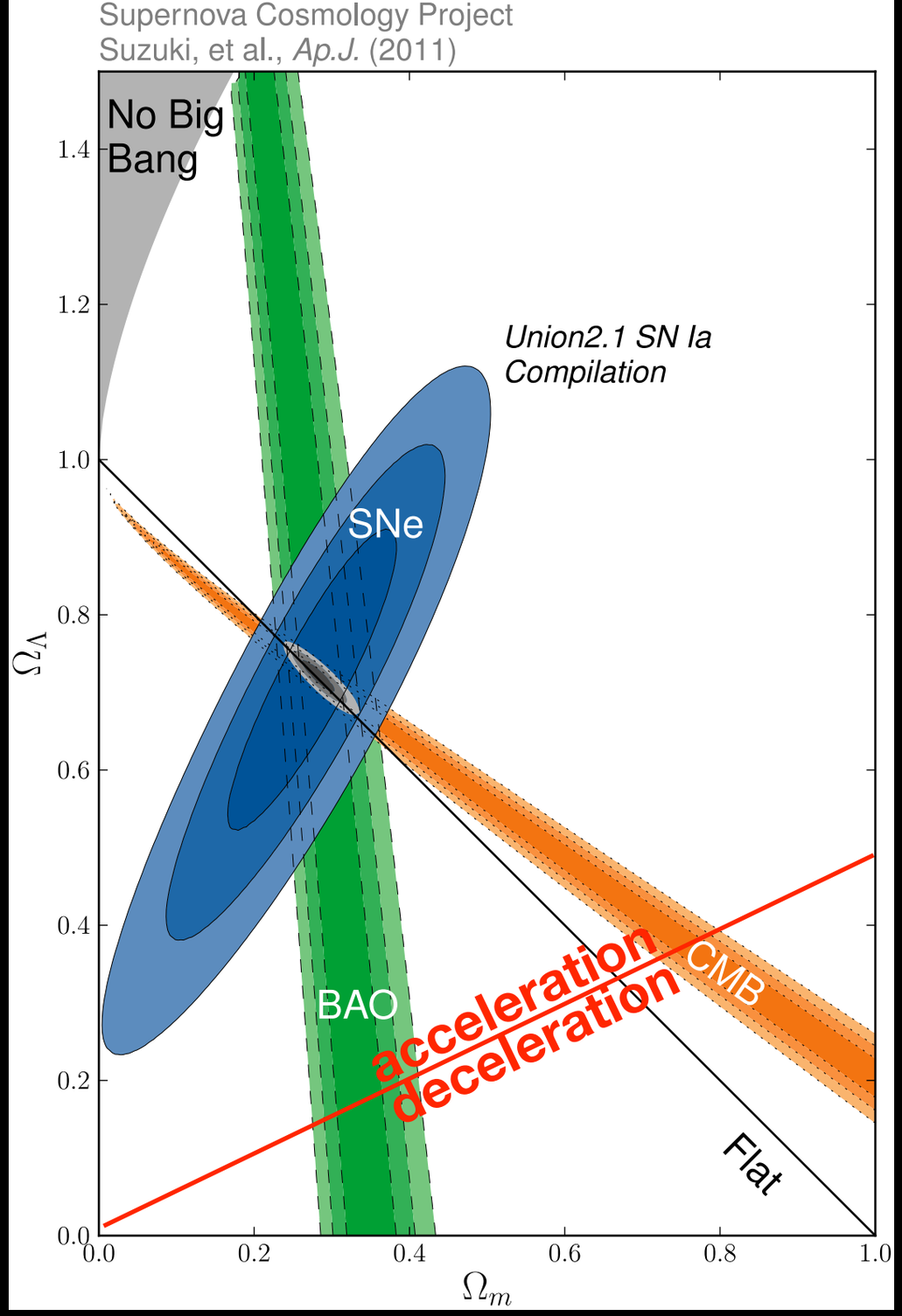
Hitoshi Murayama (Berkeley, Kavli IPMU)

March 4, 2019

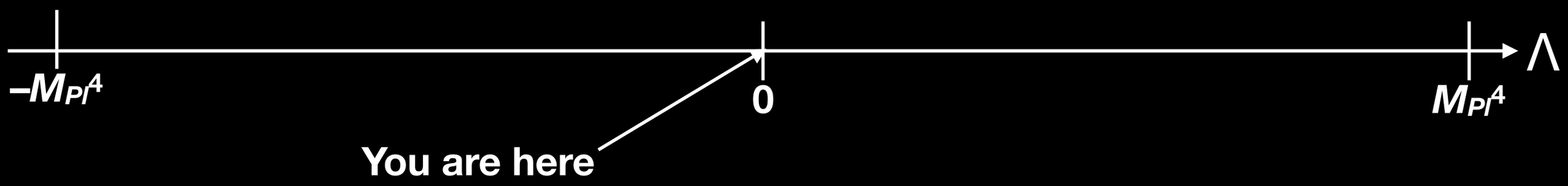
BERKELEY CENTER FOR THEORETICAL PHYSICS

BERKELEY LAB

Passed the Torch Oct 15, 2018



$\Lambda \approx 10^{-126}\ M_{Pl}^4$



Anthropic Principle? Multiverse?

Multiverse

NHK Show Cosmic Front NEXT

Melody Yang

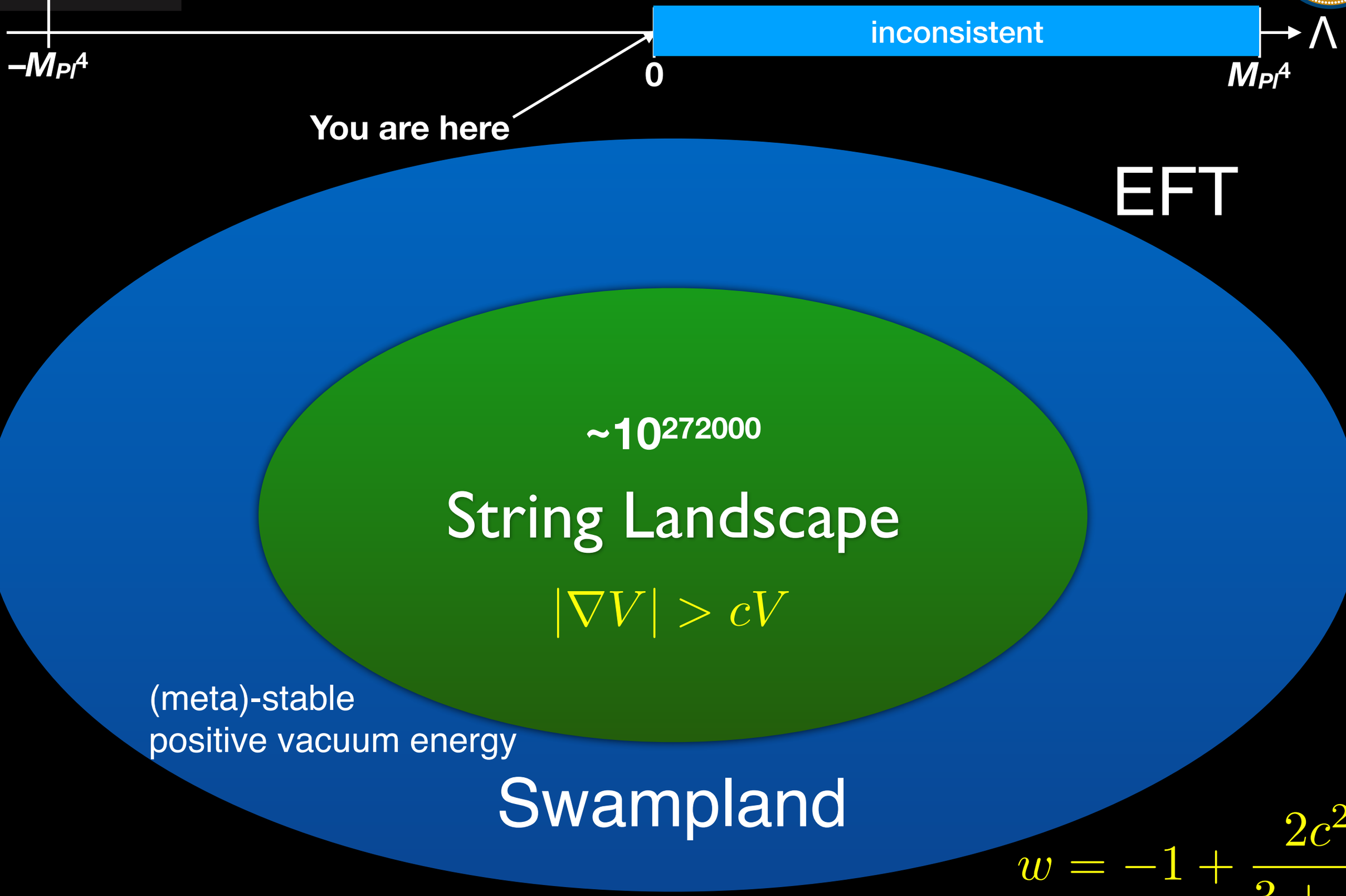
Multiverse

NHK Show Cosmic Front NEXT

Melody Yang

Beautiful Landscape

only Λ, nothing interesting with measuring *w!*



Obied, Ooguri, Spodyneiko, Vafa, arXiv:1806.08362

Nobody wa wampland

FOR SALE

w=0

Swampland viewed

from bottom up

"Quintessence"

- First "test" of swampland
  - *Is quintessence possible in supergravity?*
  - very difficult to keep flat potential for Q
  - SUSY broken > TeV
  - at the least, $m_{3/2} > (\mathrm{TeV}^2/M_{Pl}) \sim$ eV
    - *i*.e., vector mediation (Hook, HM)
  - more typically $m_{3/2} >$ TeV, 10^2 TeV (AMSB)
  - but we need $m_Q \sim H_0 \sim 10^{-33}$ eV
  - might mediate a long-range fifth force

Chien-I Chiang, HM, arXiv:1808.02279

shift symmetry

- incorporate into supergravity
- shift symmetry (monodromy) in Kähler
  - $Q \to Q + i\,\alpha$
  - $K(Q,Q^*) = K(Q+Q^*) \sim (Q+Q^*)^2/2$

$$V = e^K((K_i W + W_i)^* K^{-1\,j}_{\bar{i}} (K_j W + W_j) - 3|W|^2)$$
$$= |\not{W}_Q|^2 - 3m_{3/2}(W(Q) + W^*(Q))$$

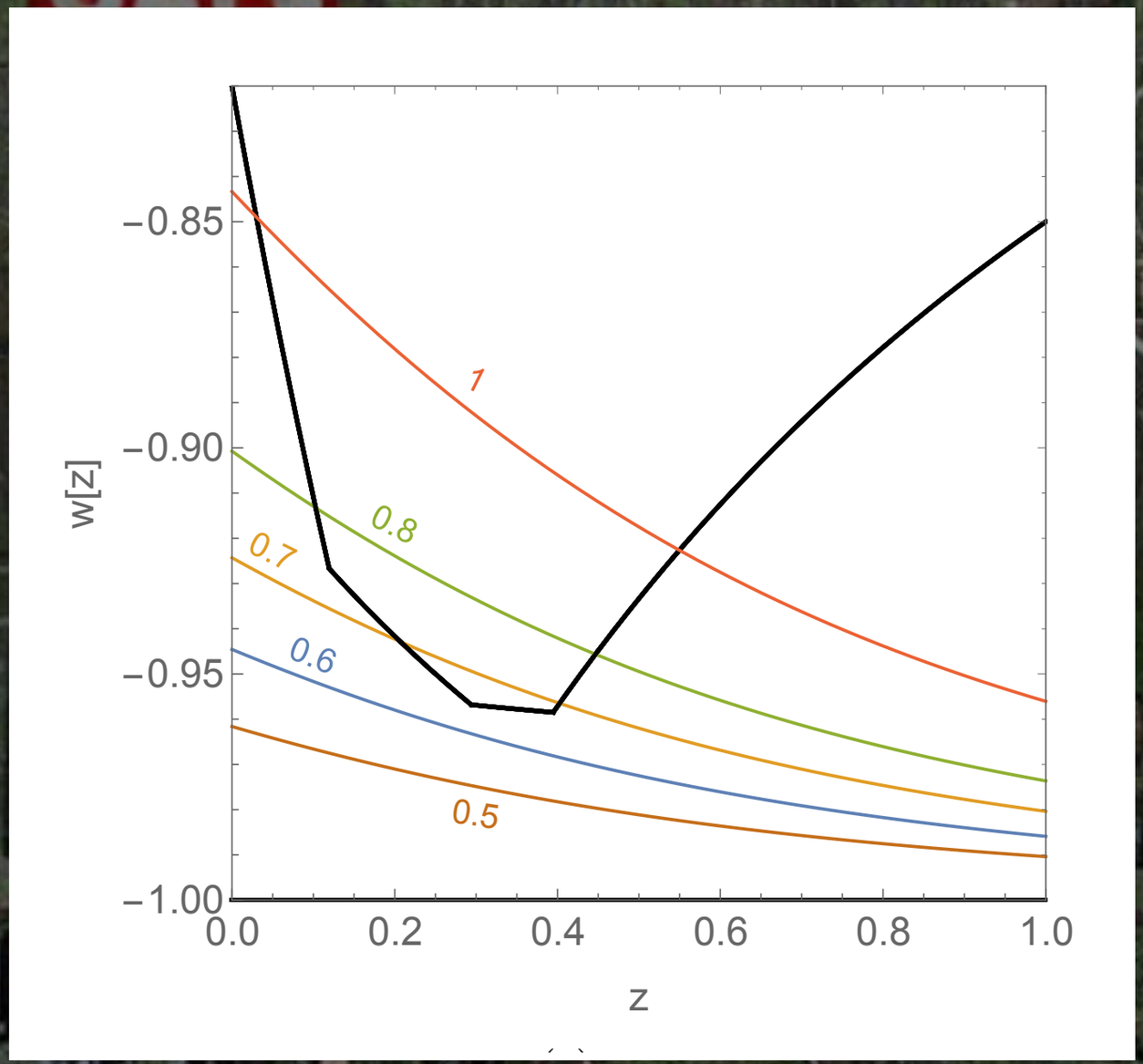
- need $m_{3/2} W(Q) \sim m_{3/2}\Lambda^3 \sim H_0^2$
- *any* potential can be lifted to supergravity
- also radiatively stable $\delta K \sim m_{3/2}^2 \Lambda^6$
  $\delta m_Q^2 \sim m_{3/2}^4 \Lambda^6$
- no fifth force through Q-Higgs mixing

Chien-I Chiang, HM, arXiv:1808.02279

Simplest model?

$$|\nabla V| > cV$$

- $V = V_0\, e^{\lambda Q}$, $\lambda > c > 0$
- observational constraints $c < \lambda < 0.6$
- (SNe, CMB, BAO)
- choose $W = V_0\, e^{i\lambda Q}$
- non-renormalization theorem protects W
- once it is set, it stays



Prateek Agrawala, Georges Obieda, Paul J. Steinhardt, Cumrun Vafa, arXiv:1806.09718

Chien-I Chiang, HM, arXiv:1808.02279

gravity M_{Pl}

SUSY breaking TeV

$$V = -3m_{3/2}(W(Q) + W^*(Q))$$
$$W(Q) = \Lambda^3 e^{-Q}$$

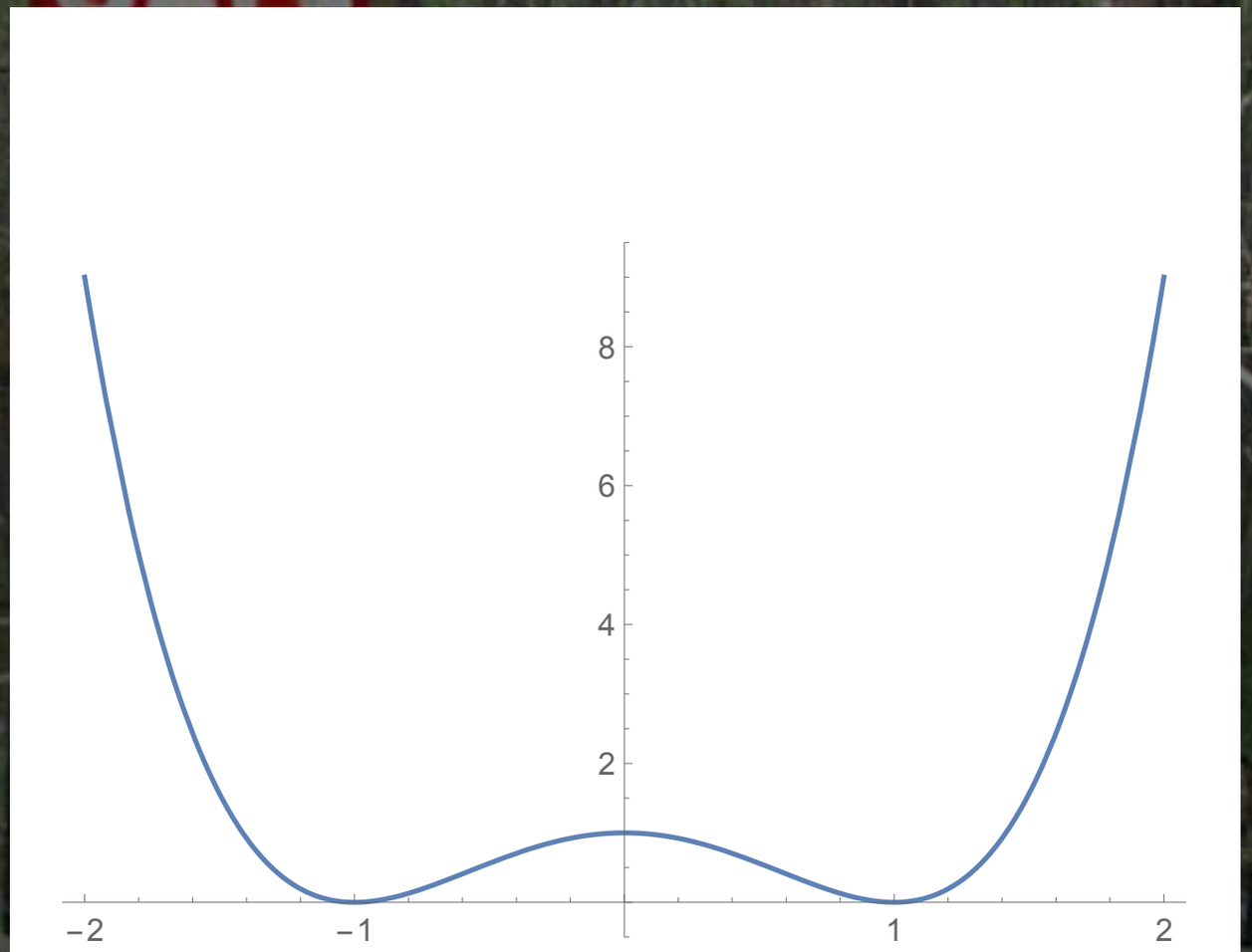
meV Q $m_{3/2} \sim \Lambda \sim \mathrm{TeV}^2/M_{Pl}$

Arkani-Hamed, Hall, Kolda, HM

Higgs

- Theorem:
- potential *V* of *H* and *S*
  - non-positive at all stationary points (minima or maxima)
  - there is a local minimum @ *V*=0 without flat direction
  - at least one more stationary point
  - *swampland!*

$$V = e^{-\lambda' Q} \lambda (H^\dagger H - v^2)^2$$



Exactly the same issue with GUTs!

Frederik Denef, Arthur Hebecker, and Timm Wrase, arXiv:1807.06581

HM, Masahito Yamazaki and Tsutomu T. Yanagida, arXiv:1809.00478

QCD

- QCD itself doesn't have scalar
- but low-energy theory is chiral Lagrangian of pions

$$V = \mu^3 \mathrm{Tr} MU$$

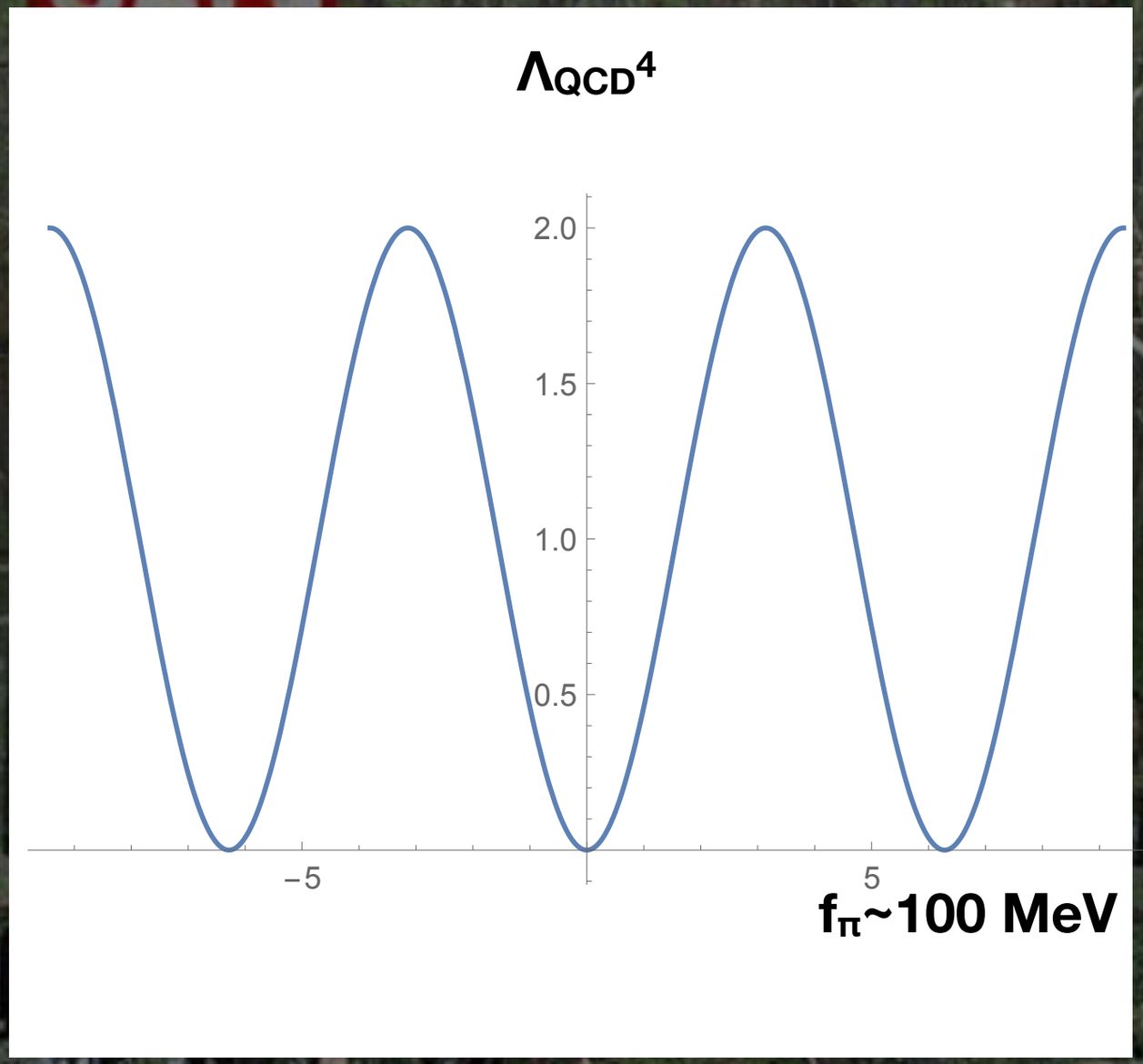
- coupling to quintessence?
- equivalence principle

$$M_f = y_f v \to M_f e^{-Q/f}$$

$$\frac{1}{g_s^2} \to \frac{1}{g_s^2} + \frac{Q}{f'}$$

$$\Lambda_{\mathrm{QCD}} \to \Lambda_{\mathrm{QCD}} e^{-(Q/f')}$$

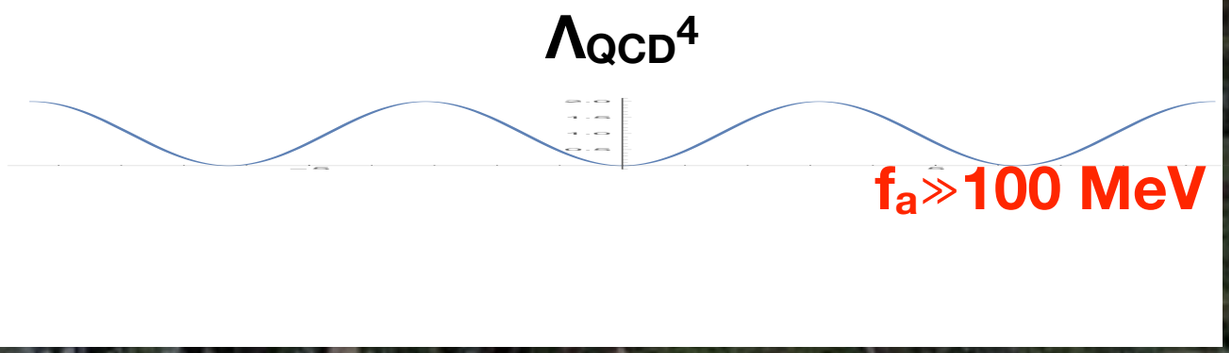
- but scalar force doesn't give correct relativistic effects
- can't be weaker than gravity because of WGC $f<M_{Pl}$



HM, Masahito Yamazaki and Tsutomu T. Yanagida, arXiv:1809.00478

QCD axion

- QCD axion also has local maxima
- can send maxima > M_{Pl}?
  - contradicts weak gravity conjecture $f_a < M_{Pl} / S_{inst}$
- coupling to quintessence?
  - Q couples to QCD, nucleons
  - fifth force constraints



Hitoshi Murayama, Masahito Yamazaki and Tsutomu T. Yanagida, arXiv:1809.00478

SUSY breaking

- Dynamical SUSY Breaking
- Intriligator-Seiberg-Shih (ISS) proposed simple models
- SUSY QCD with mass
- SUSY Breaking @ local minimum
- also excluded

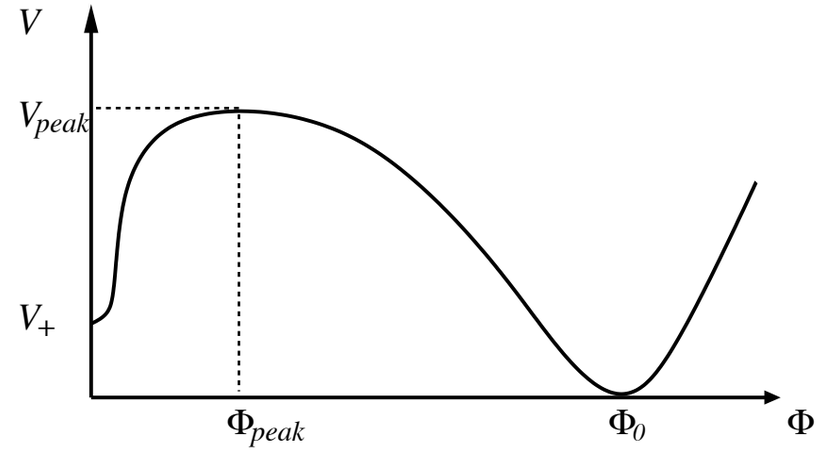


Figure 1: *The potential along the bounce trajectory. The peak is at* $\Phi_{peak} \sim \mu$ *and the supersymmetric minimum with vanishing potential is at large field* $\Phi_0 \sim \mu/\epsilon^{(N_f-3N)/(N_f-N)} \gg \mu$. *The values of the potential at the local minimum* V_+ *and at the peak* V_{peak} *are of order* μ^4.

HM, Masahito Yamazaki and Tsutomu T. Yanagida, arXiv:1809.00478

Inflation

$$|\nabla V| > cV$$

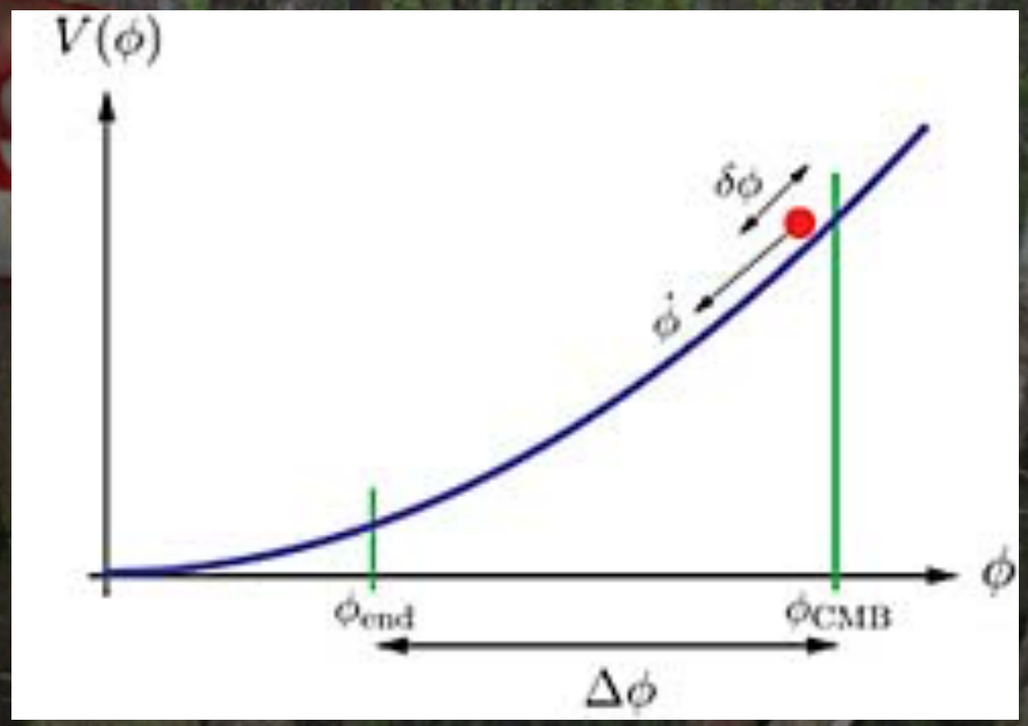
- seems to be inconsistent with the slow-roll condition

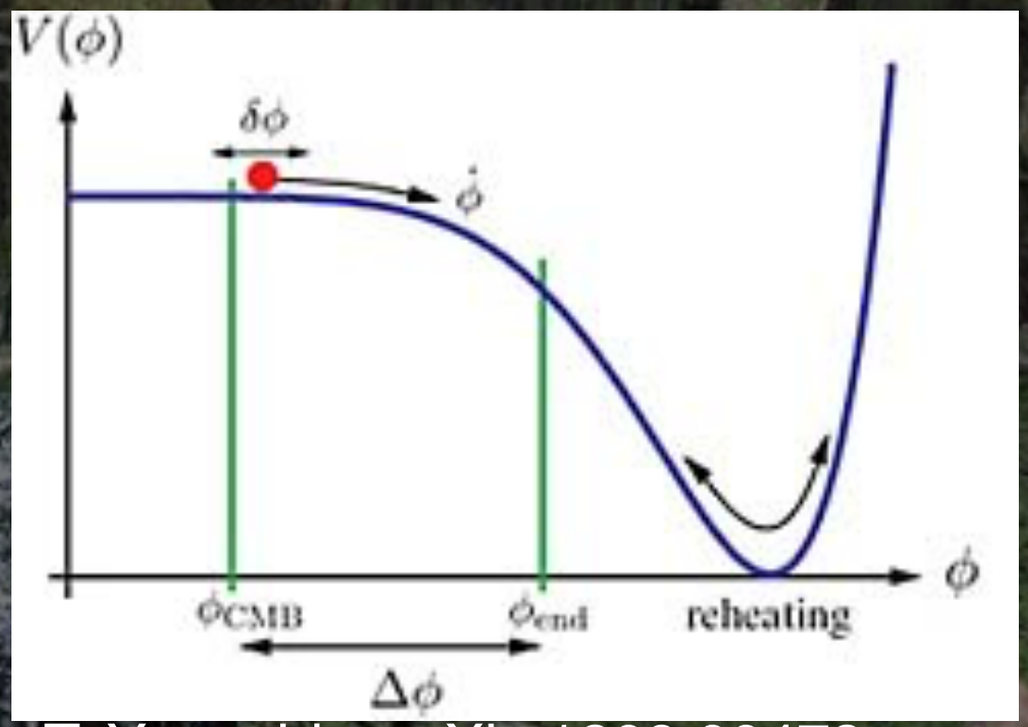
$$V' \ll \sqrt{3}V$$

  - one possible attitude: c=0.1~O(1)
  - can't expect $w \neq -1$
- "large field inflation" is in swampland
  - can't expect large tensor component

$$r \approx 8\left(\frac{d\phi}{dN}\right)^2$$

  - bad news for CMB S4, LiteBIRD





HM, Masahito Yamazaki and Tsutomu T. Yanagida, arXiv:1809.00478

too strong?

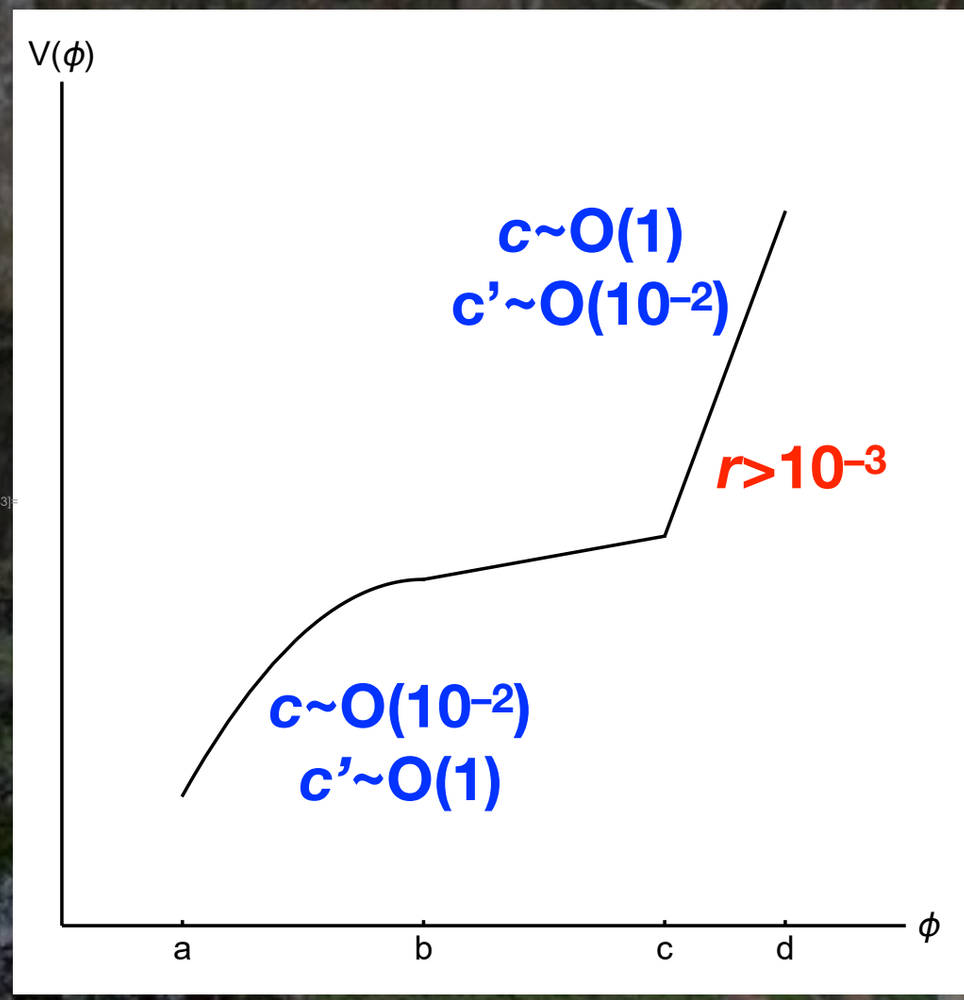
$$|\nabla V| > cV$$

- perhaps, the constraint is too strong?
- would local maxima be ok?
- Our suggestion:
  - $|\nabla V| > cV$ or $\nabla^2 V < 0$
  - $|\nabla V| > cV$ or $\nabla^2 V < c'V$

Ooguri, Palti, Shiu, Vafa, arXiv:1810.05506

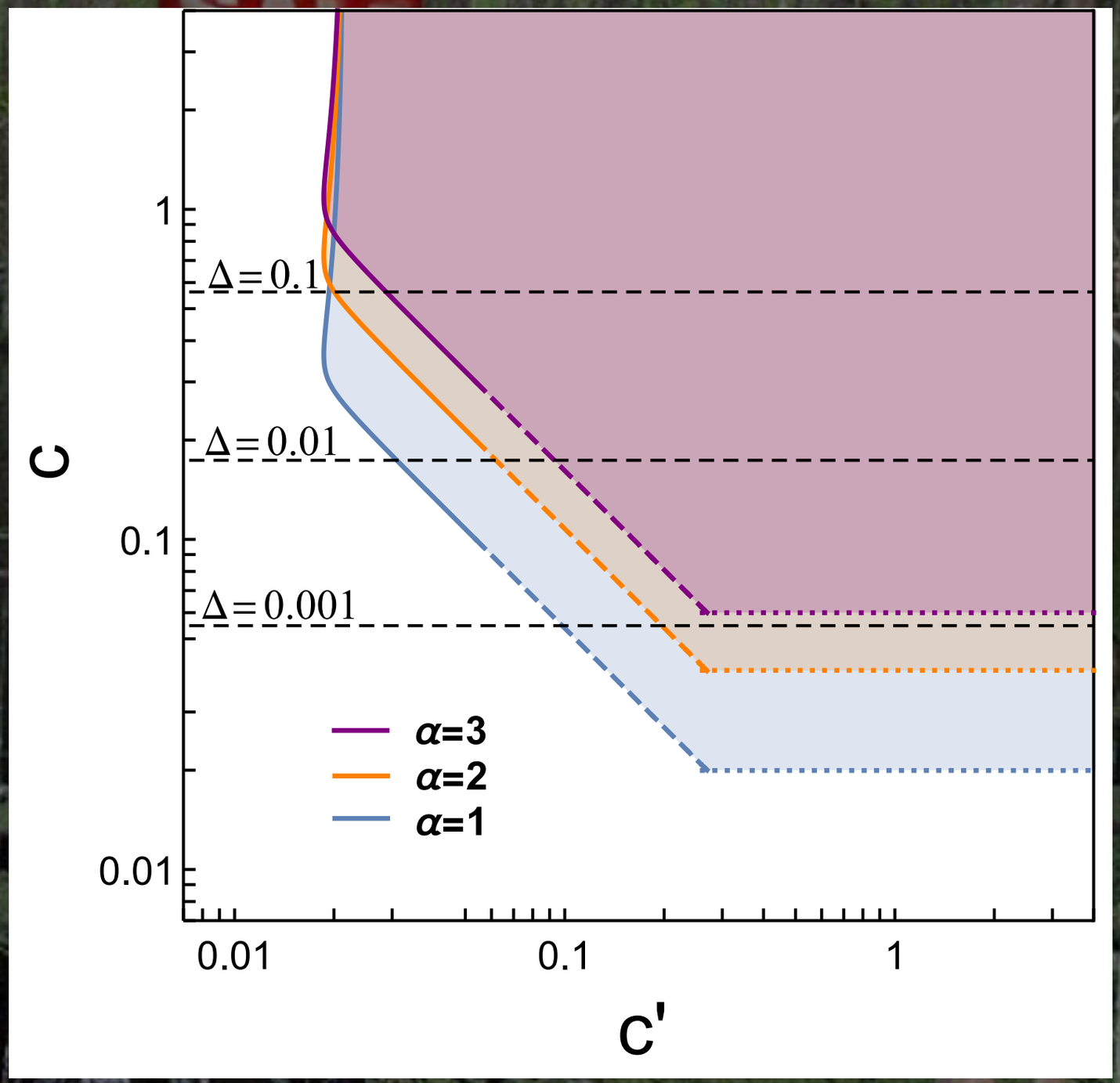
HM, Masahito Yamazaki and Tsutomu T. Yanagida, arXiv:1809.00478

Hope for w≠–1?



Is Inflation OK?

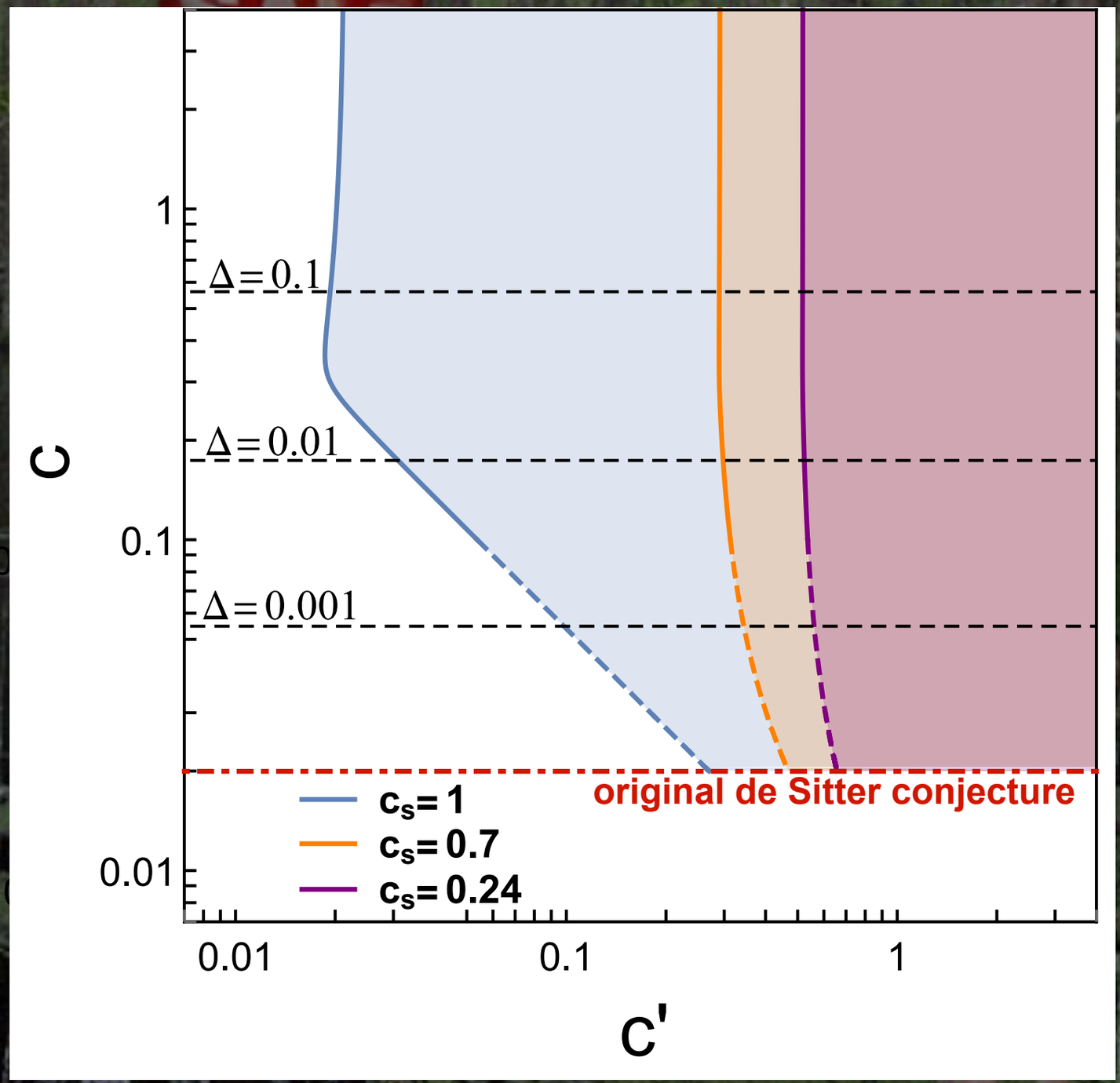
- Single-field inflation:
  - barely
  - still needs c or c’ < 0.1
  - can hope for
    $\Delta=1+w>0.1$
    but not necessary



Chien-I Chiang, Jacob Leedom, HM, arXiv:1811.01987

Is Inflation OK?

- Multi-field inflation:
  - type with centrifugal force
- If c_s~0.3, c, c'~O(1)
- Δ=1+w>0.1 quite natural



Chien-I Chiang, Jacob Leedom, HM, arXiv:1811.01987

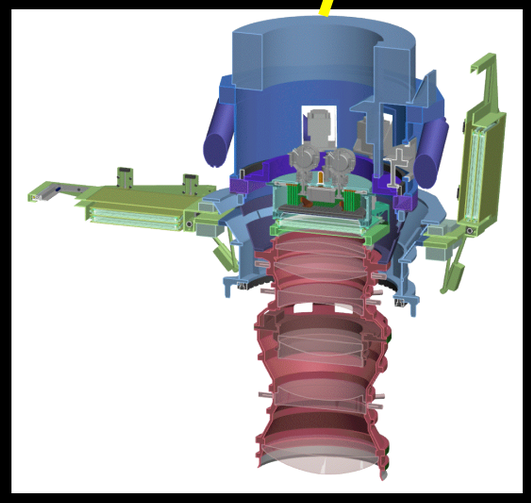
SuMIRe

Prime Focus Spectrograph

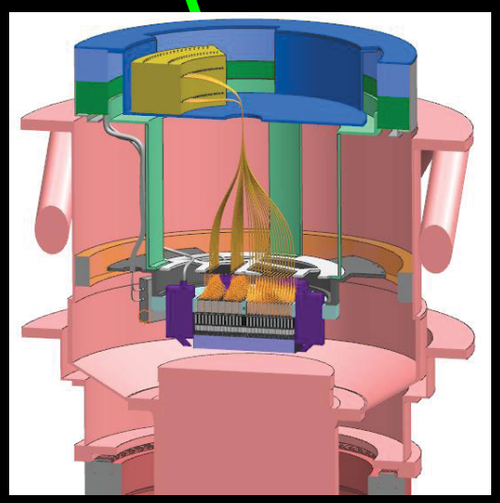
Subaru Measurement of Images and Redshifts

- one of the largest telescopes: 8.2m
- big field of view ~1.5°
- Imaging with Hyper Suprime-Cam (HSC)
  - 900M pixels
  - ~300M galaxy images
  - 2014–2019, 300 nights
- spectroscopy with PrimeFocusSpectrograph (PFS)
  - 2400 optical fibers
  - >1M redshifts
  - 2022–2026 300–360 nights?

Subaru



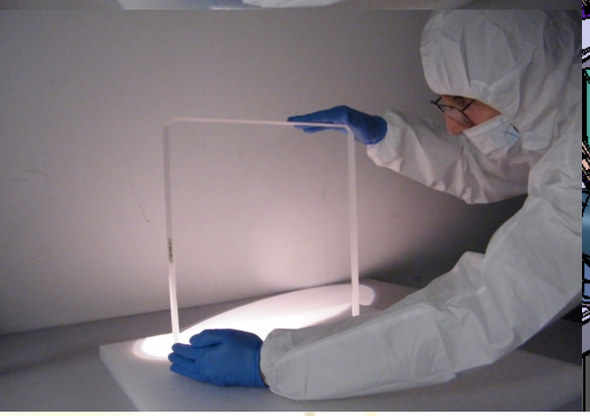
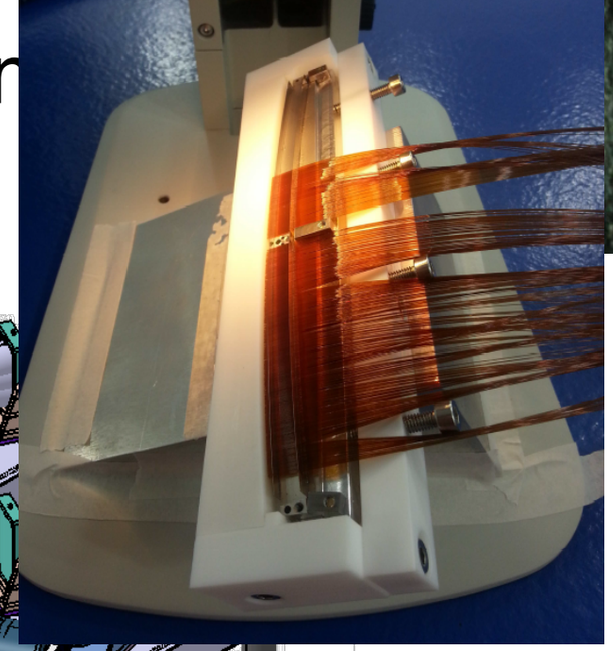
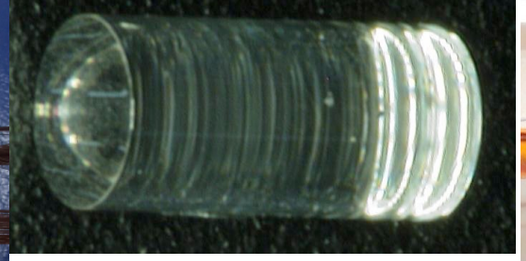
HSC

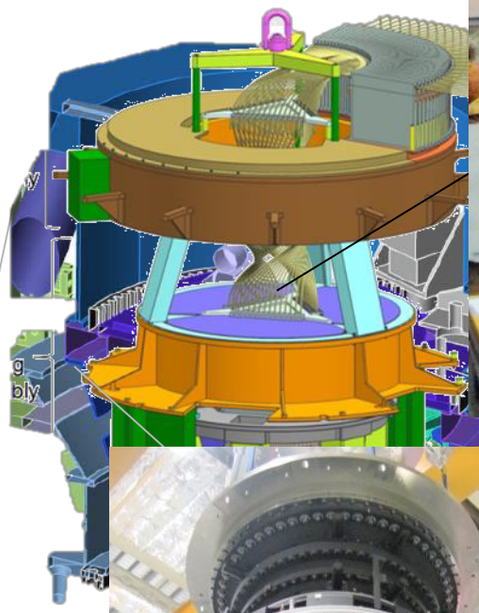


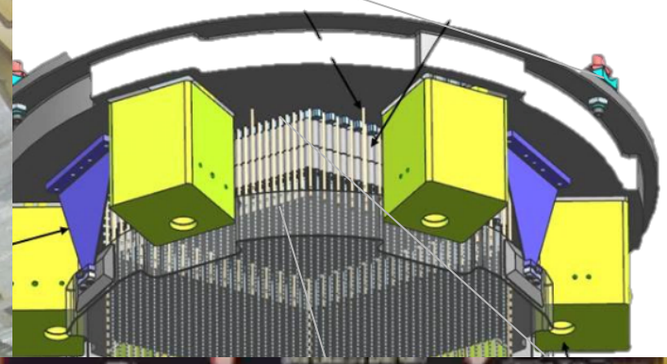
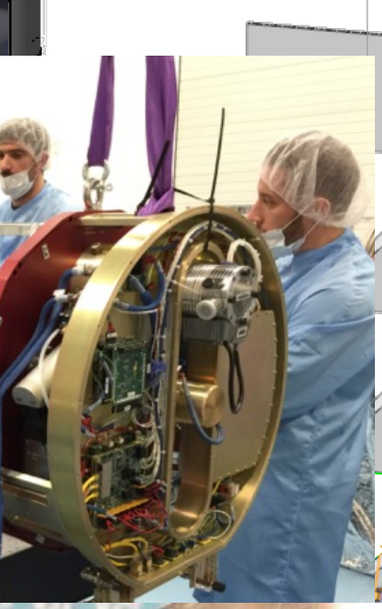
PFS

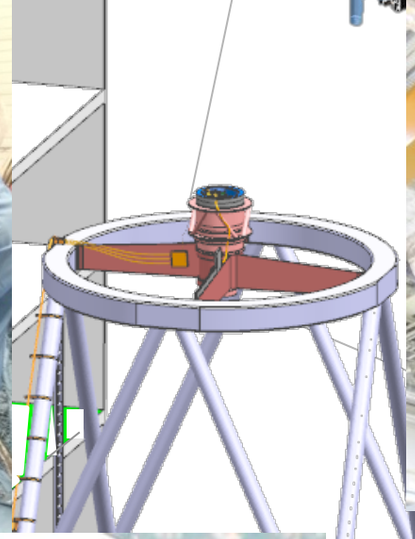
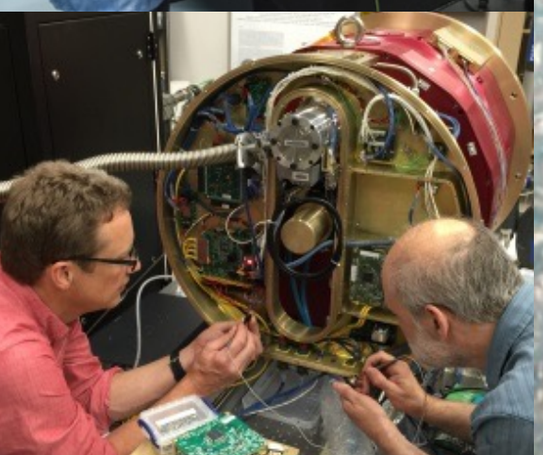
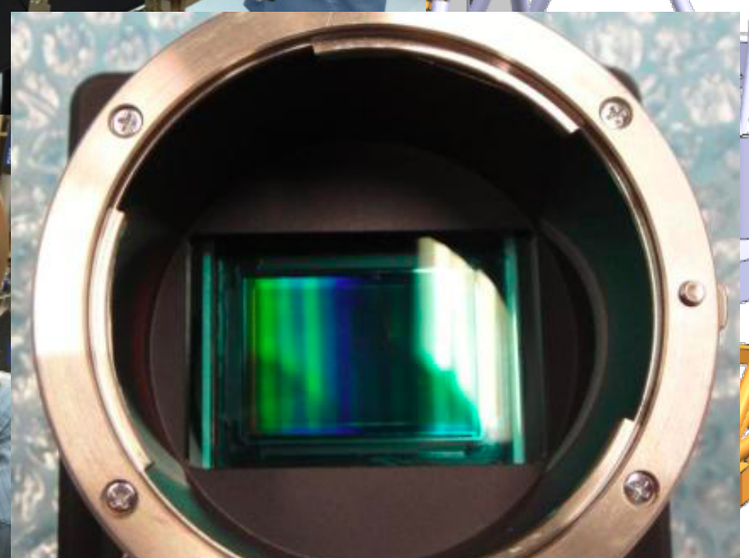
PFS 10th Collaboration Meeting in Shanghai

Dec 10-14, 2018

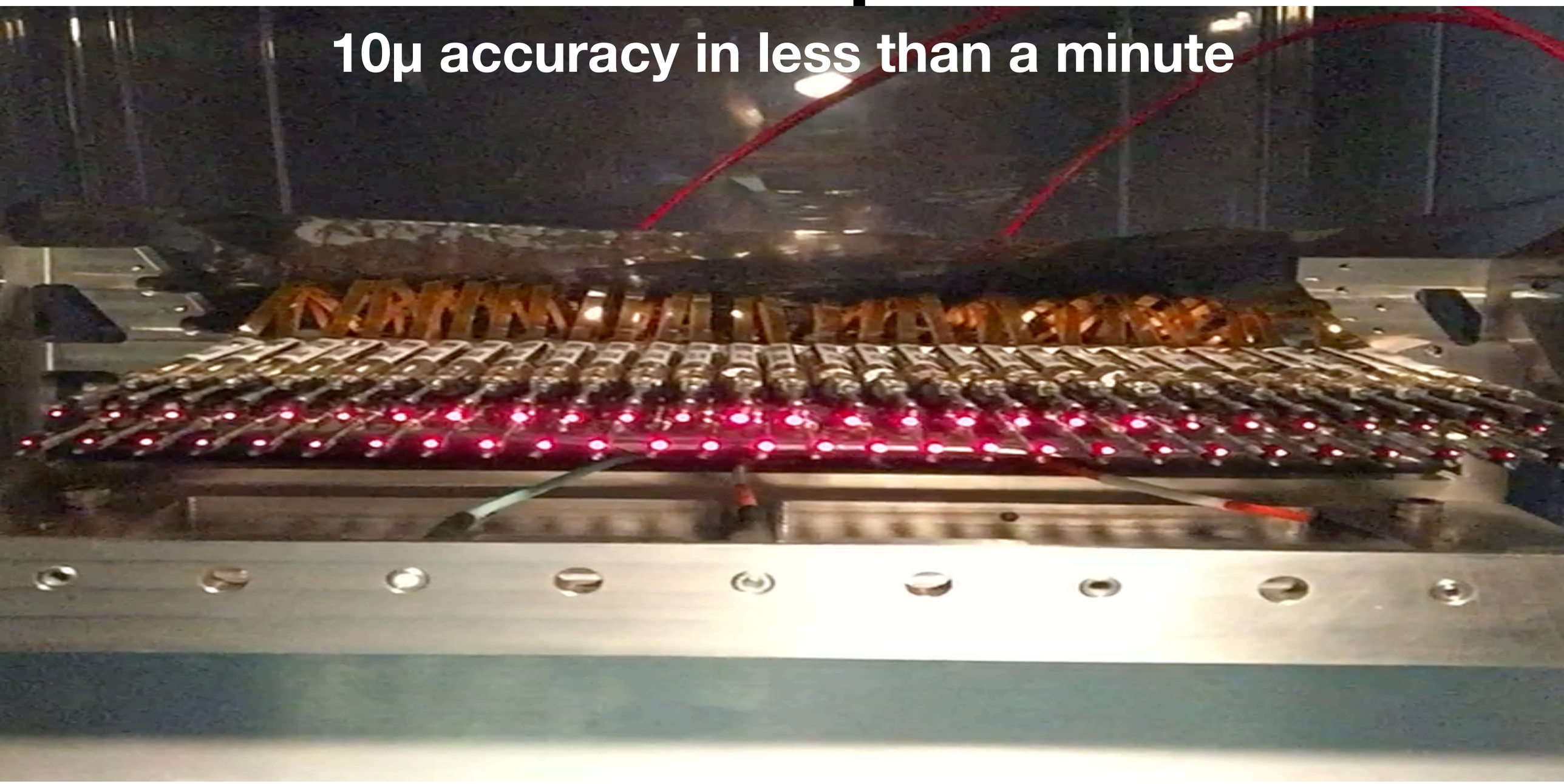







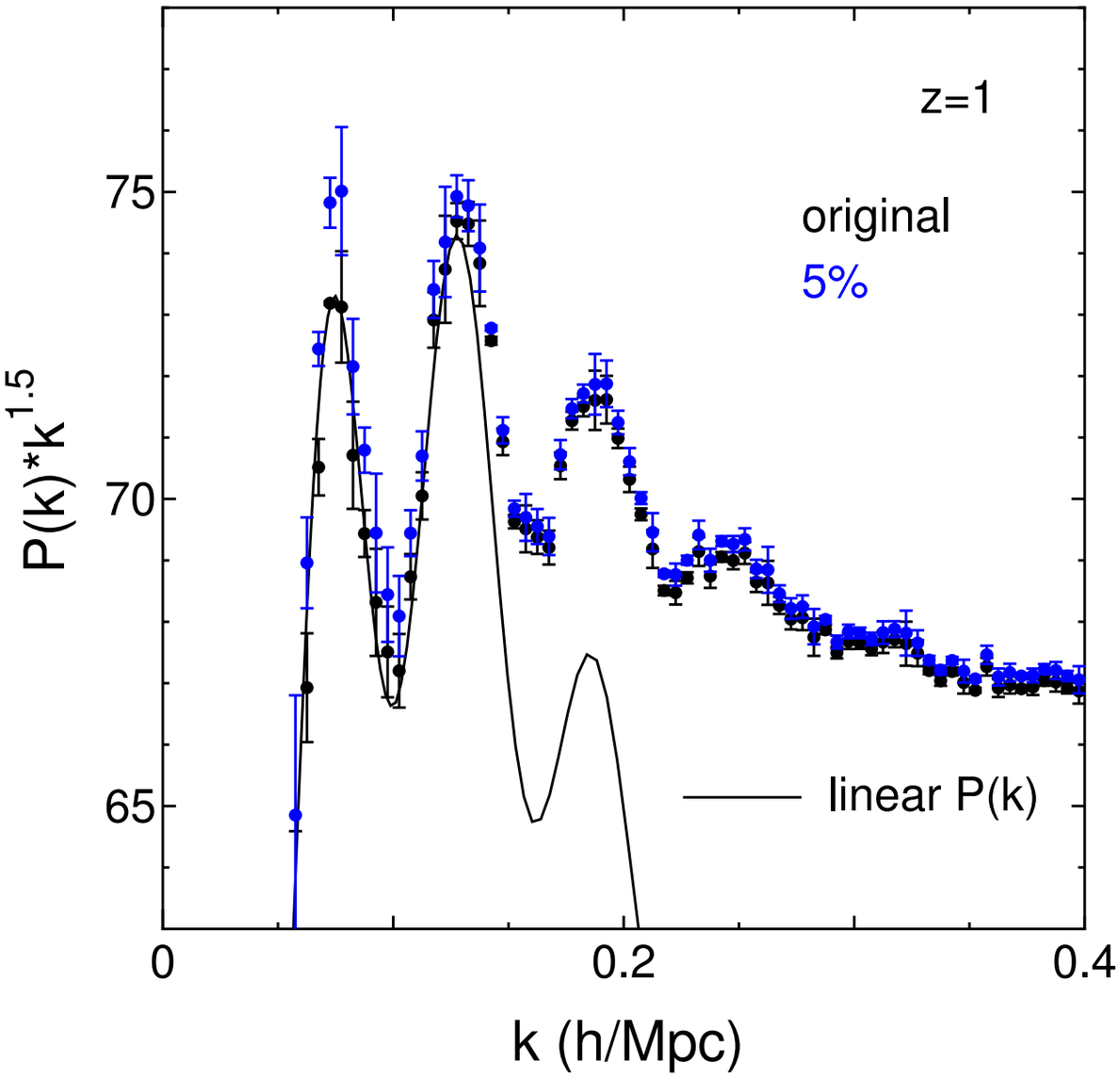




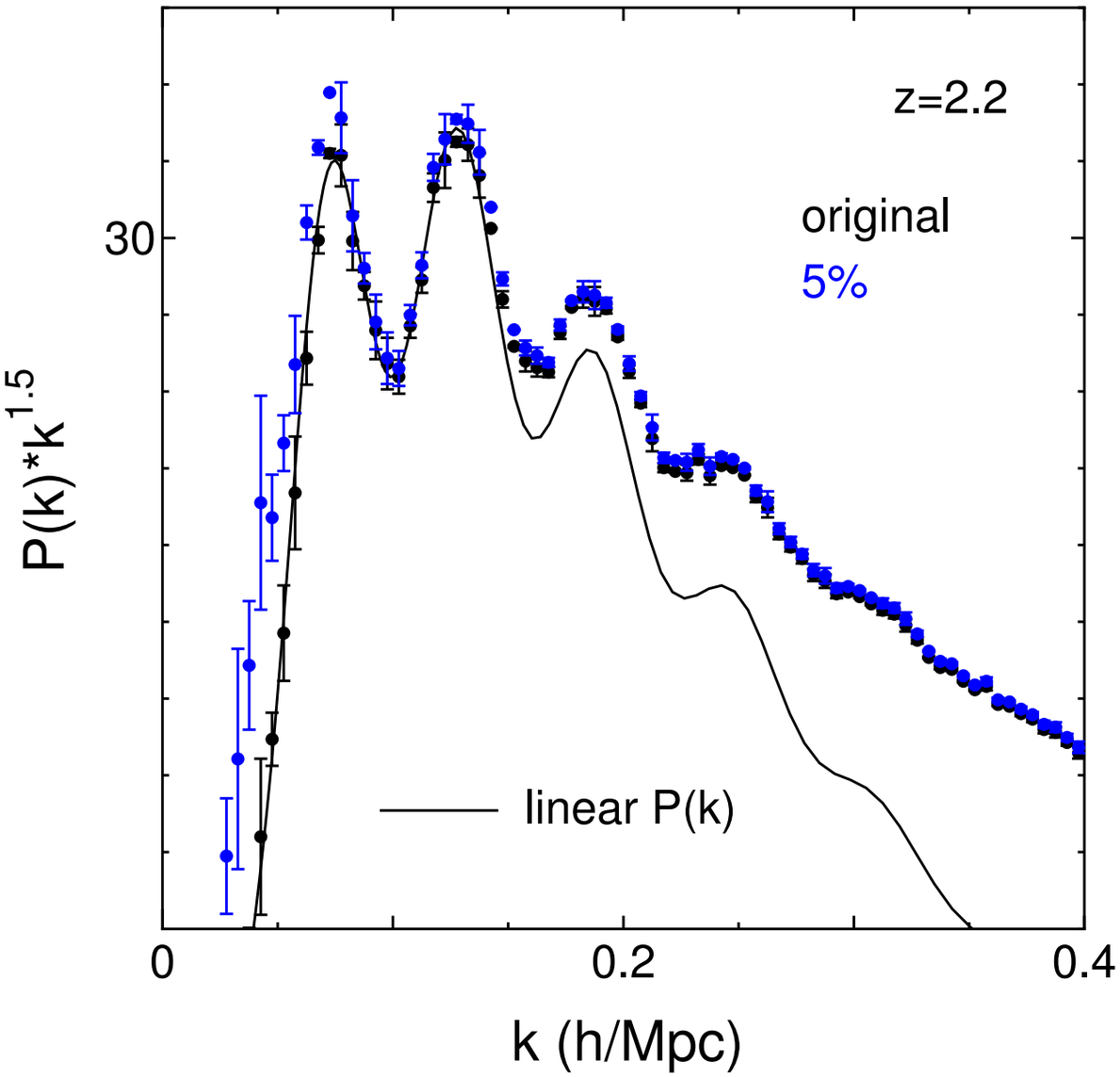

2550 Fiber Positioners "Cobra" all produced



co-developed with Caltech, NASA/JPL

Baryon Acoustic Oscillation

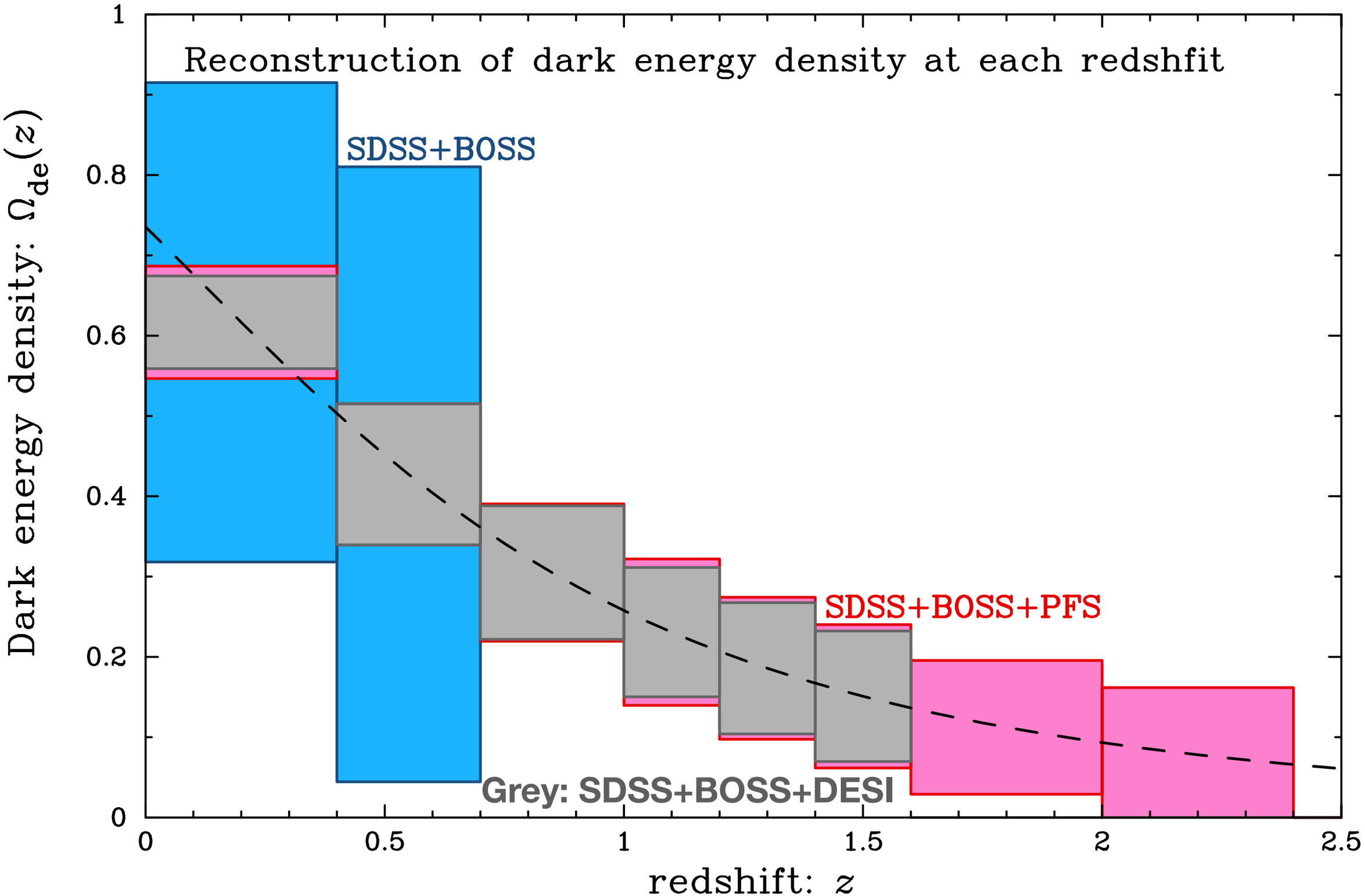




ELGs [OII], ~15 min exposure

Ruling out ΛCDM by mapping out time evolution of

Dark Energy Density



DASI
CBI
MAXIPOL
BOOMERanG
CAPMAP
WMAP-9yr
QUaD
QUIET-Q
QUIET-W
BICEP1-3yr
ACTPol
BKP
SPTpol
POLARBEAR

Lensing B-mode

Primordial B-mode
(r=0.01)

$l(l+1)C_l^{BB}/(2\pi)$ (μK^2)

Multipole Moment, ell

Figure courtesy of Dr. Chinone

DASI
CBI
MAXIPOL
BOOMERanG
CAPMAP
WMAP-9yr
QUaD
QUIET-Q
QUIET-W
BICEP1-3yr
ACTPol
BK14
SPTpol
POLARBEAR
Simons Array
LiteBIRD

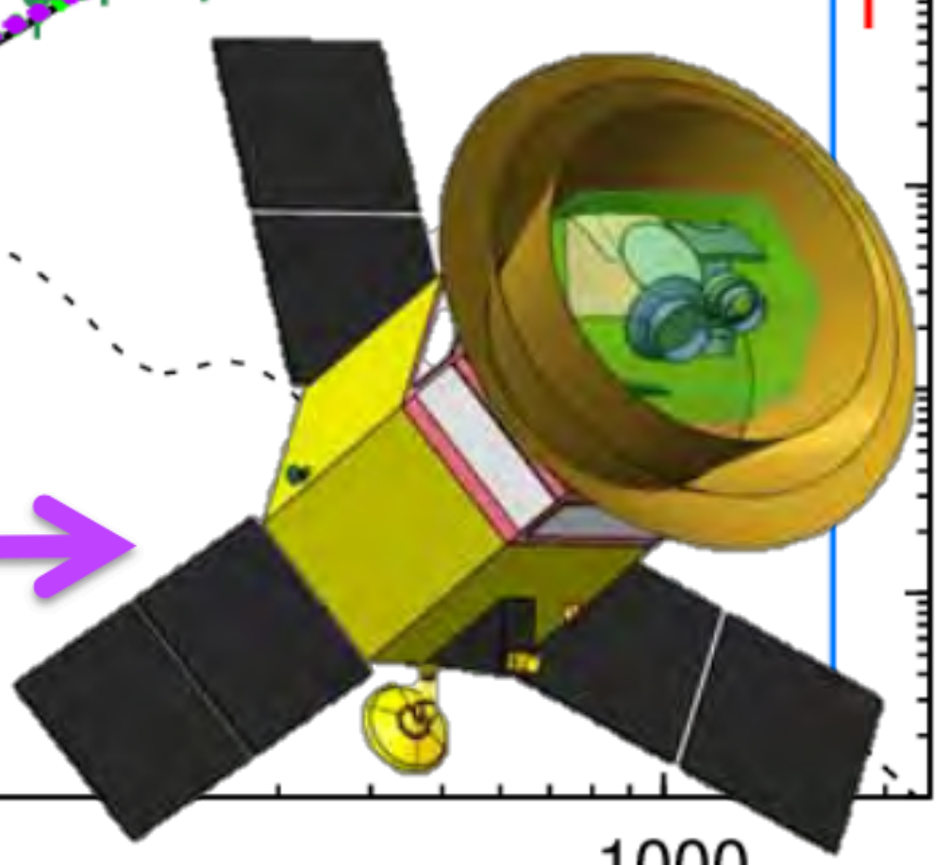
$l(l+1)C_l^{BB}/(2\pi)$ (μK^2)

10^2
10^1
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}

r=0.01

10
100
1000

LiteBIRD



downselect by JAXA 2019, expected launch ~2025

Swampland

EFT

String Landscape

$$|\nabla V| > cV$$

$$|\Delta\varphi| < M_{Pl}$$

(meta)-stable
positive vacuum energy

Swampland

$$w = -1 + \frac{2c^2}{3 + c^2}$$

swampland or not, measure *w* & *r*!