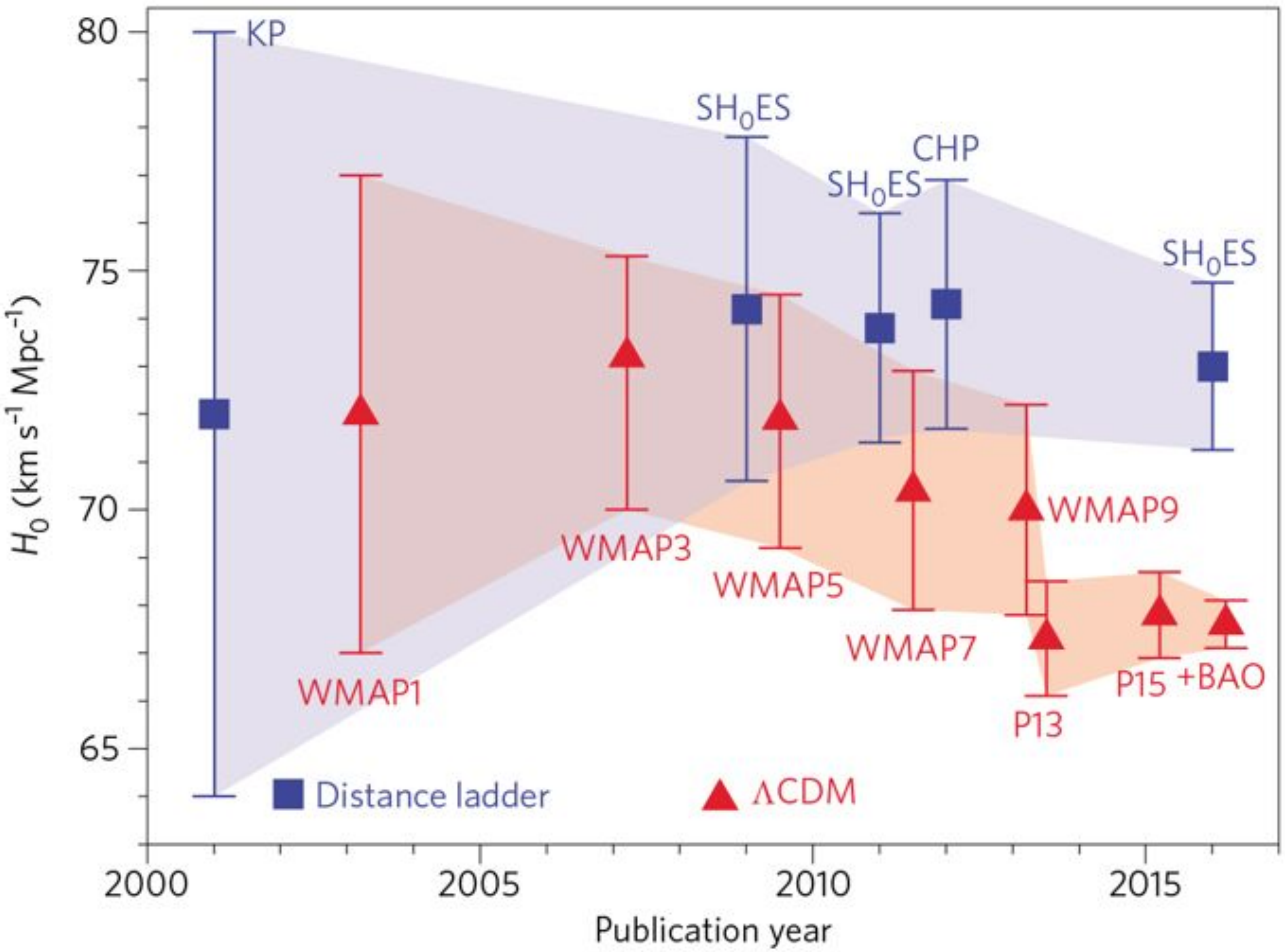
哈勃危机简介

胡彬 （北师大）

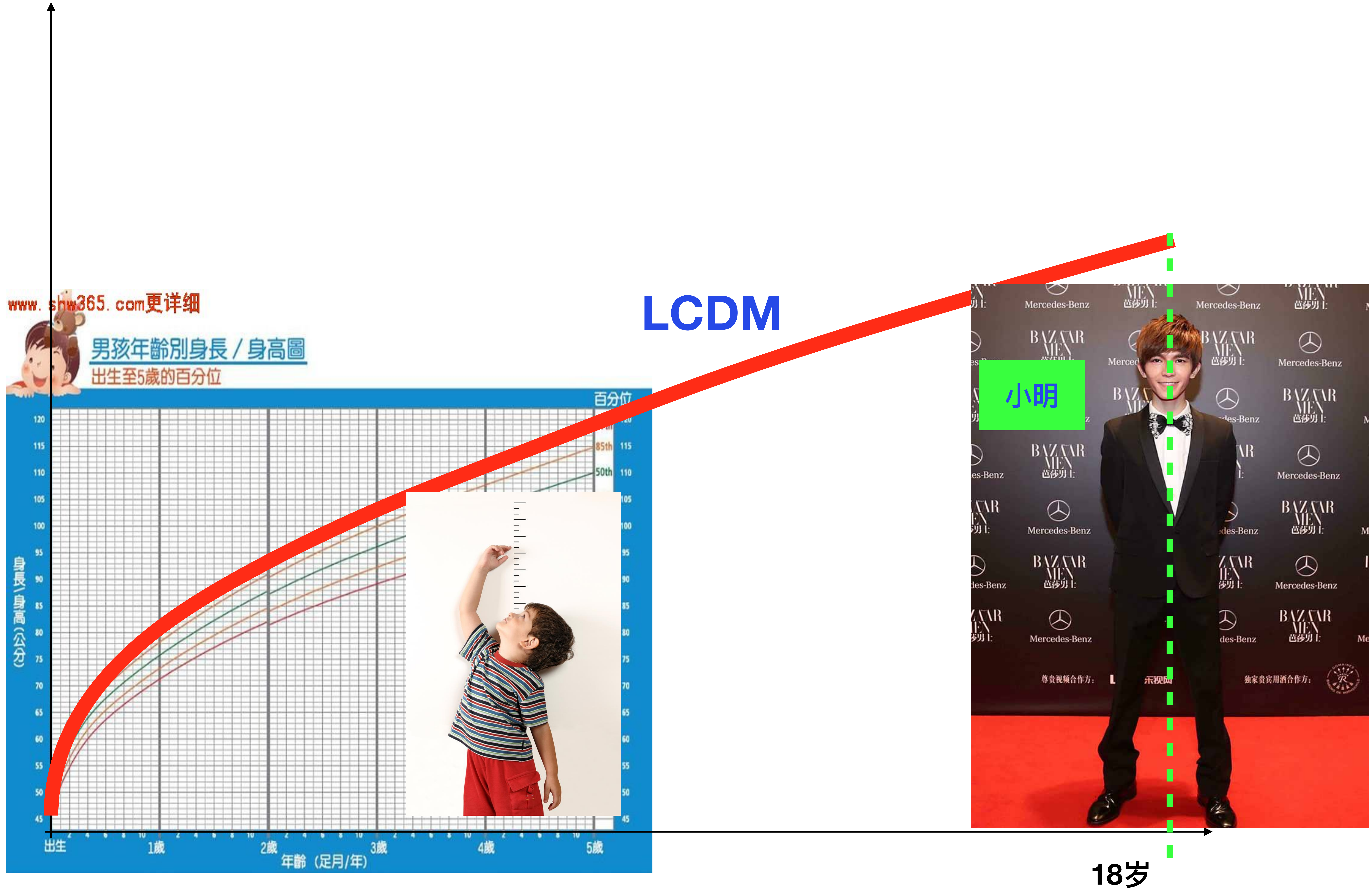
中科大彭桓武高能基础理论研究中心 2023/4月

- 距离阶梯
- BBO+BAO
- 距离红移对欧关系
- H0LiCOW
- Hubble tension的直接原因/Neff
- 早期暗能量
- Cephied vs TRGB
- GW sirens
- AdS-EDE

A 3.7σ tension



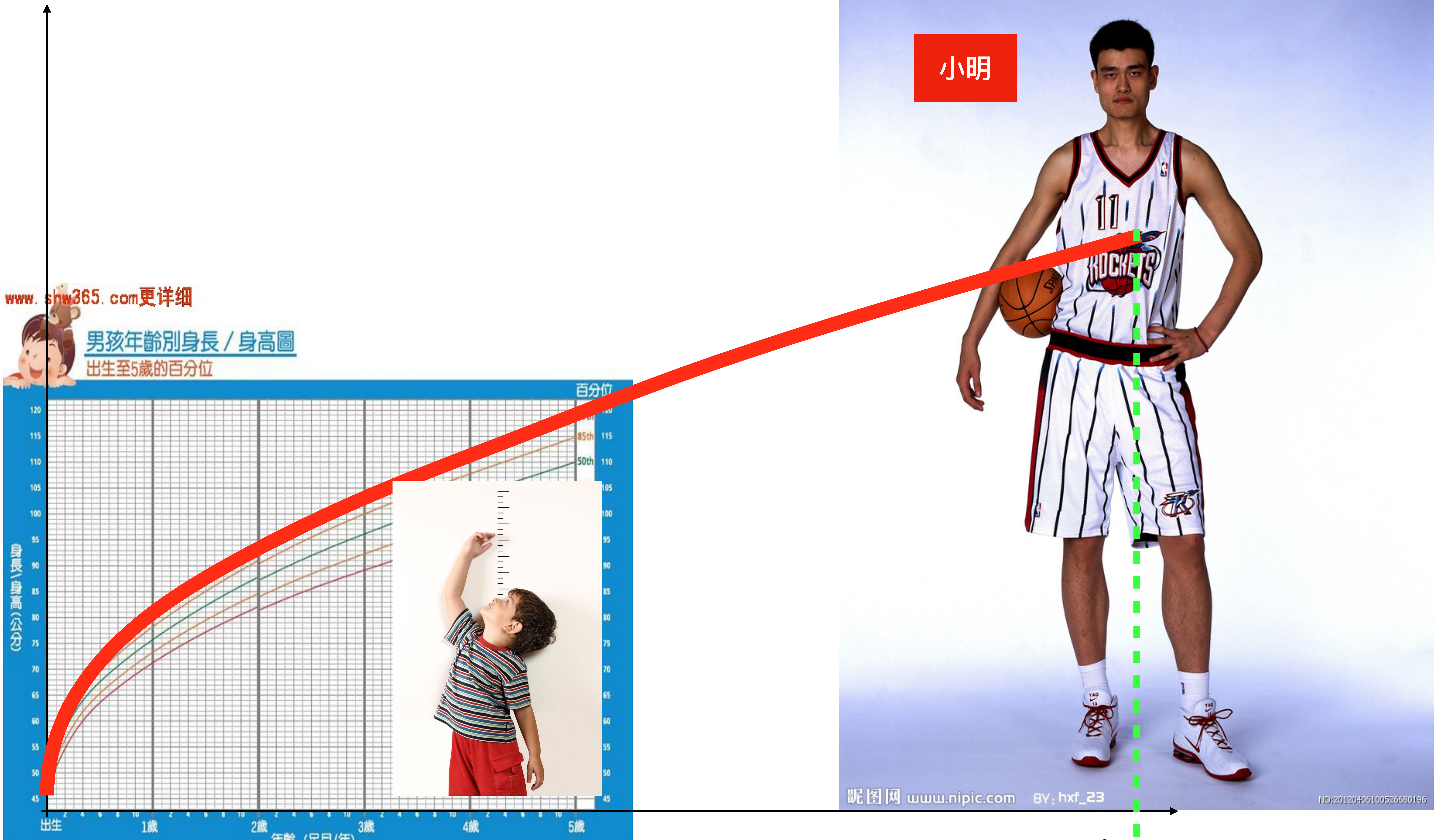
[Freedman, Nature 2017]


www.shw365.com更详细
男孩年齡別身長／身高圖
出生至5歲的百分位
百分位
85th
50th
身長／身高(公分)
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
出生
1歲
2歲
3歲
4歲
5歲
年齡（足月/年）
小明

LCDM

18岁

CMB

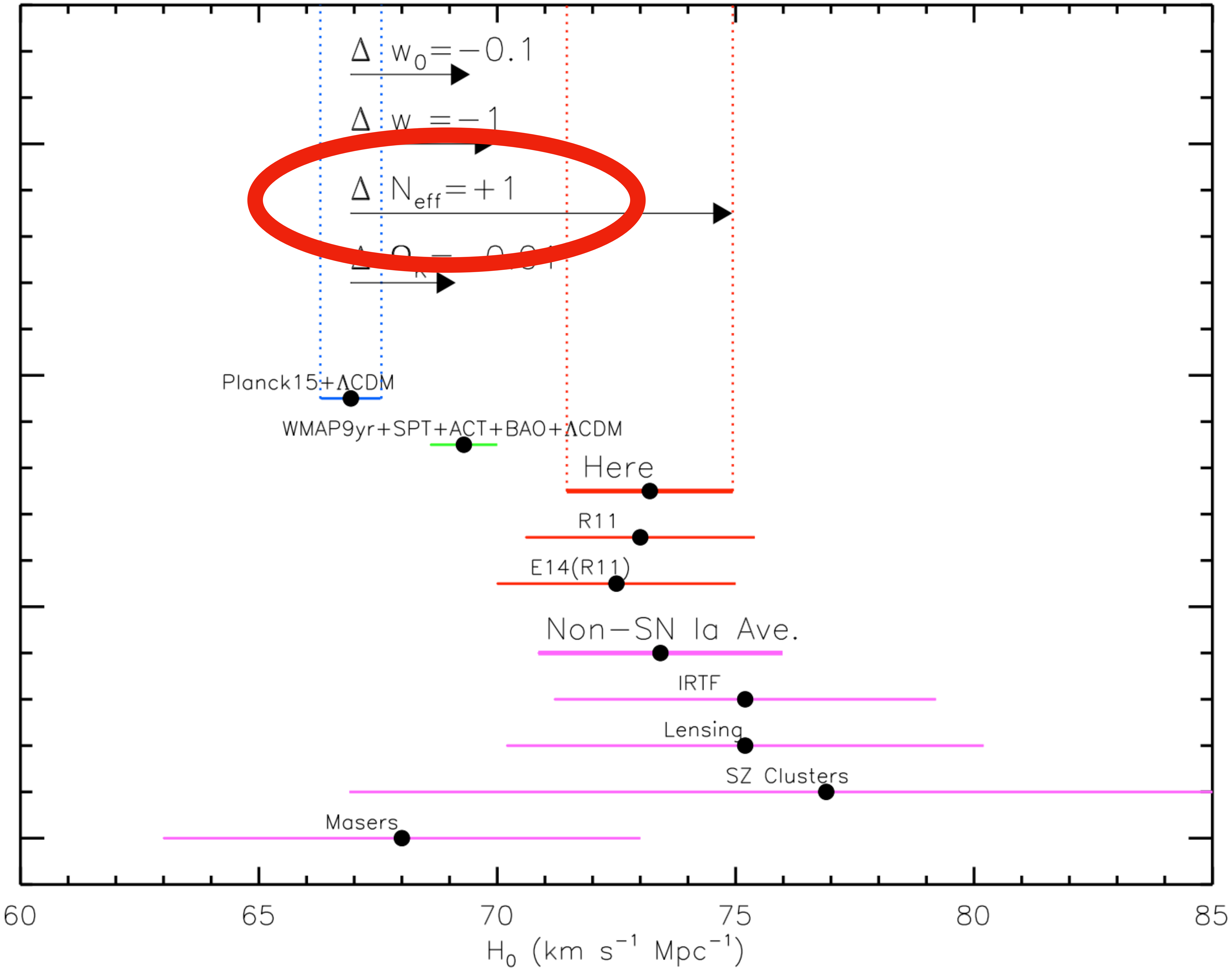


18岁

CMB

SNe Ia

[Riess et. al. 2016]



可观测宇宙半径：
14Gpc

$$\mathbf{L} \not\longleftrightarrow \frac{1}{H_0}$$

共动距离

$$\chi = \frac{c}{H_0}\int_{z1}^{z0}\frac{dz}{E(z)}; E^2(z) = \Omega_{m,0}(1+z)^3 + \Omega_{r,0}(1+z)^4 + \Omega_{\Lambda,0}$$

宇宙的全局坐标时

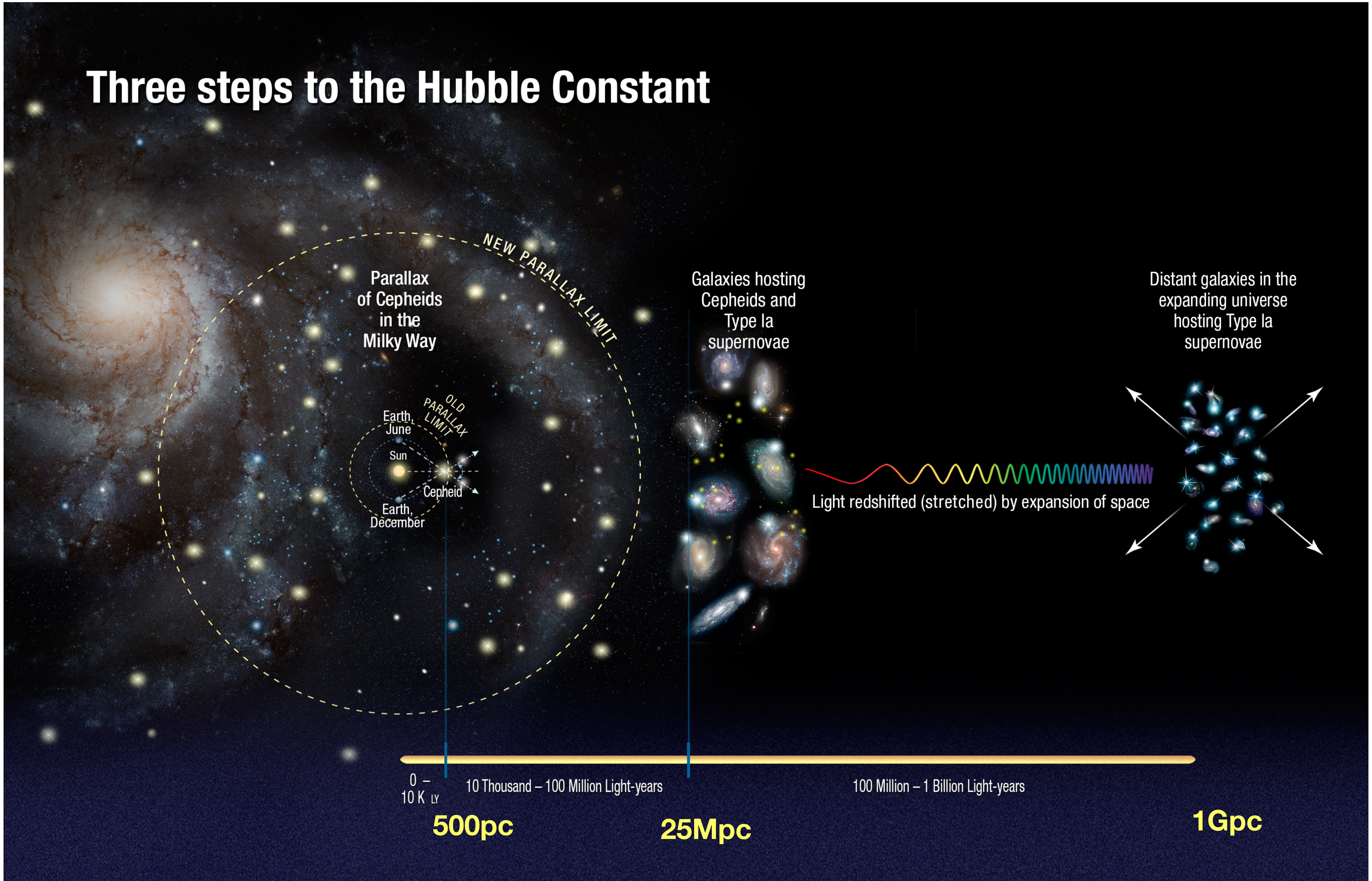
$$t = \frac{c}{H_0}\int_{z1}^{z0}\frac{dz}{E(z)(1+z)}$$

宇宙膨胀率（速度）

$$H(t) = \frac{\dot{a}}{a}(t)$$

速度越快，到达指定距离（L）就时间越短；时间越短，宇宙能够膨胀的半径就越小。

Cosmic Distance Ladder



1) find Cepheid in WM & LMC, using parallex measurement calibrate Cepheid

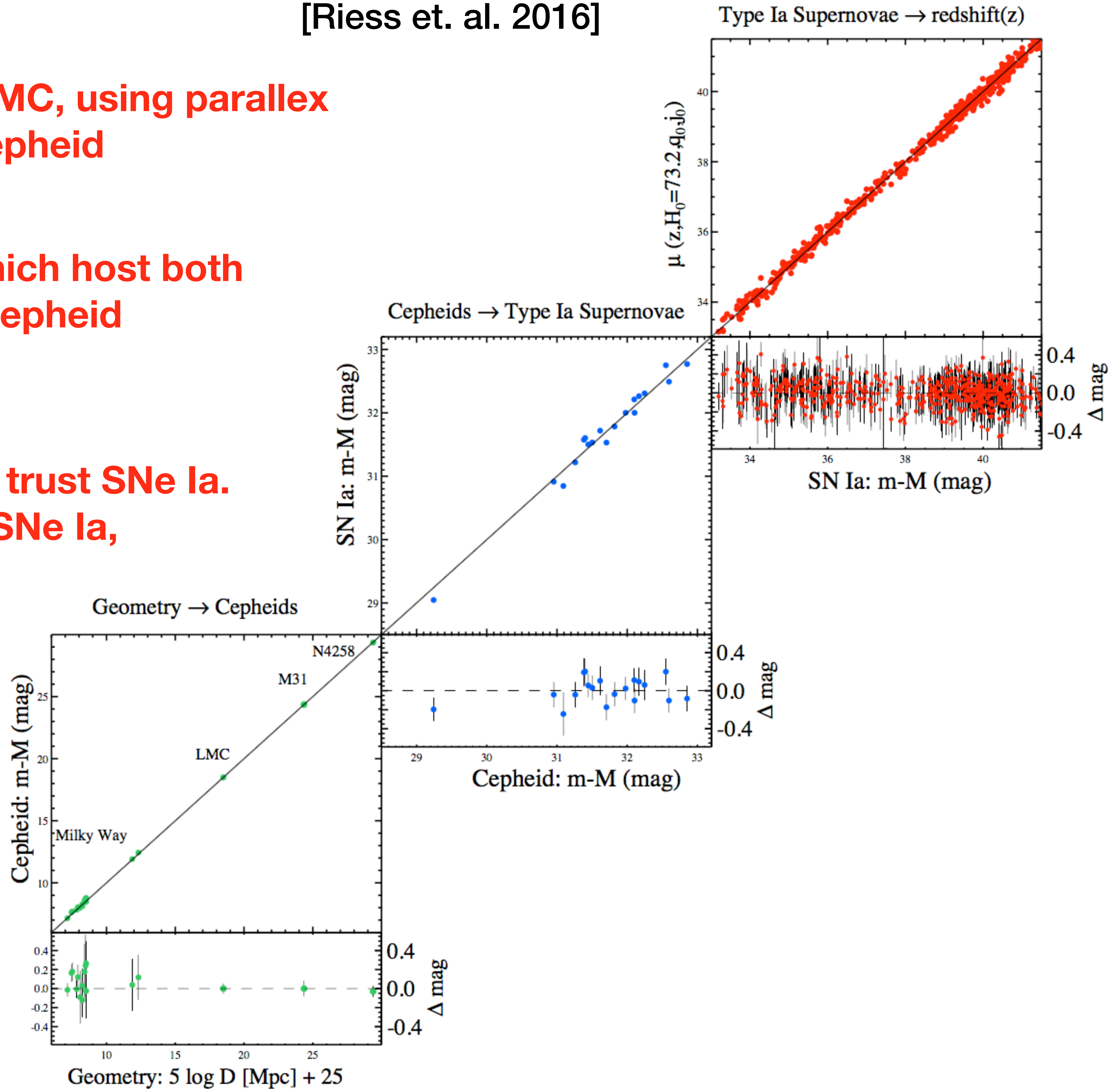
2) find nearby galaxies, which host both SNe Ia & Cepheid, using Cepheid calibrate SNe Ia.

3) After the 1) & 2), we can trust SNe Ia. Search for further distant SNe Ia, measure H0

3种距离测量方法：

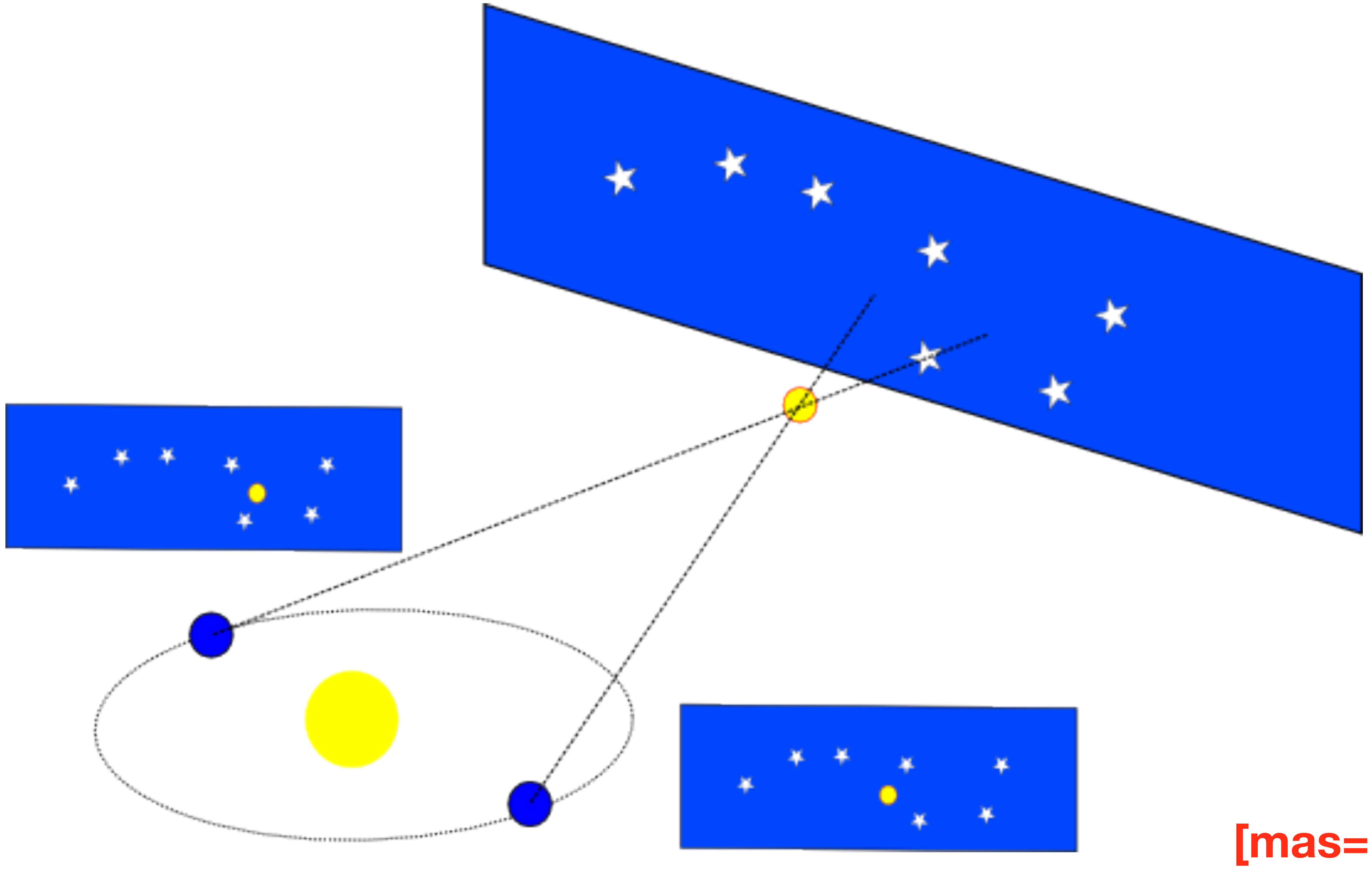
1. 三角视差法（纯几何）
2. 灶父变星的周光关系
3. 超新星的光变曲线

[Riess et. al. 2016]



Cosmic Distance Ladder

1. 三角视差法测距

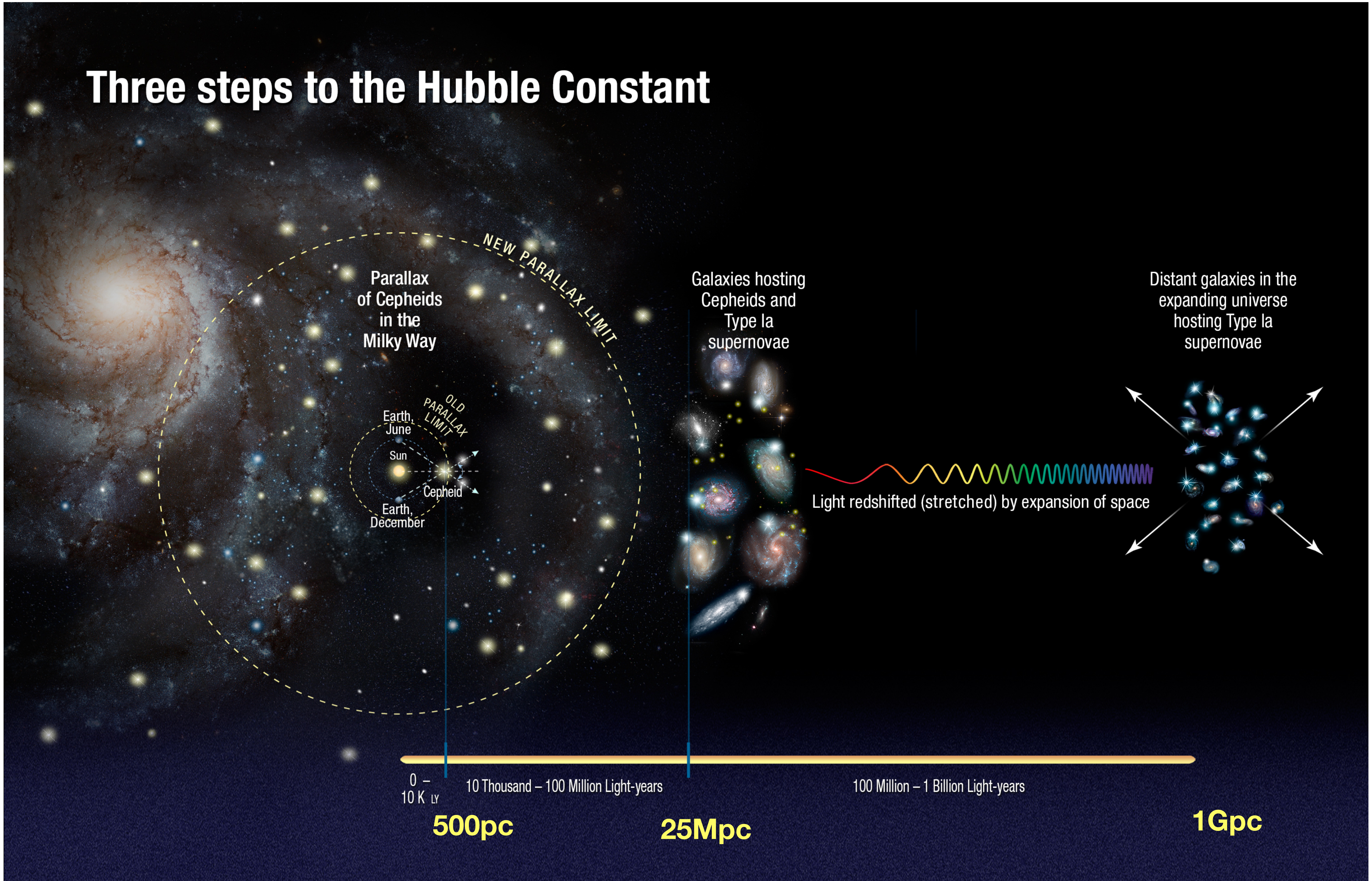


[mas=milli-arcsec]

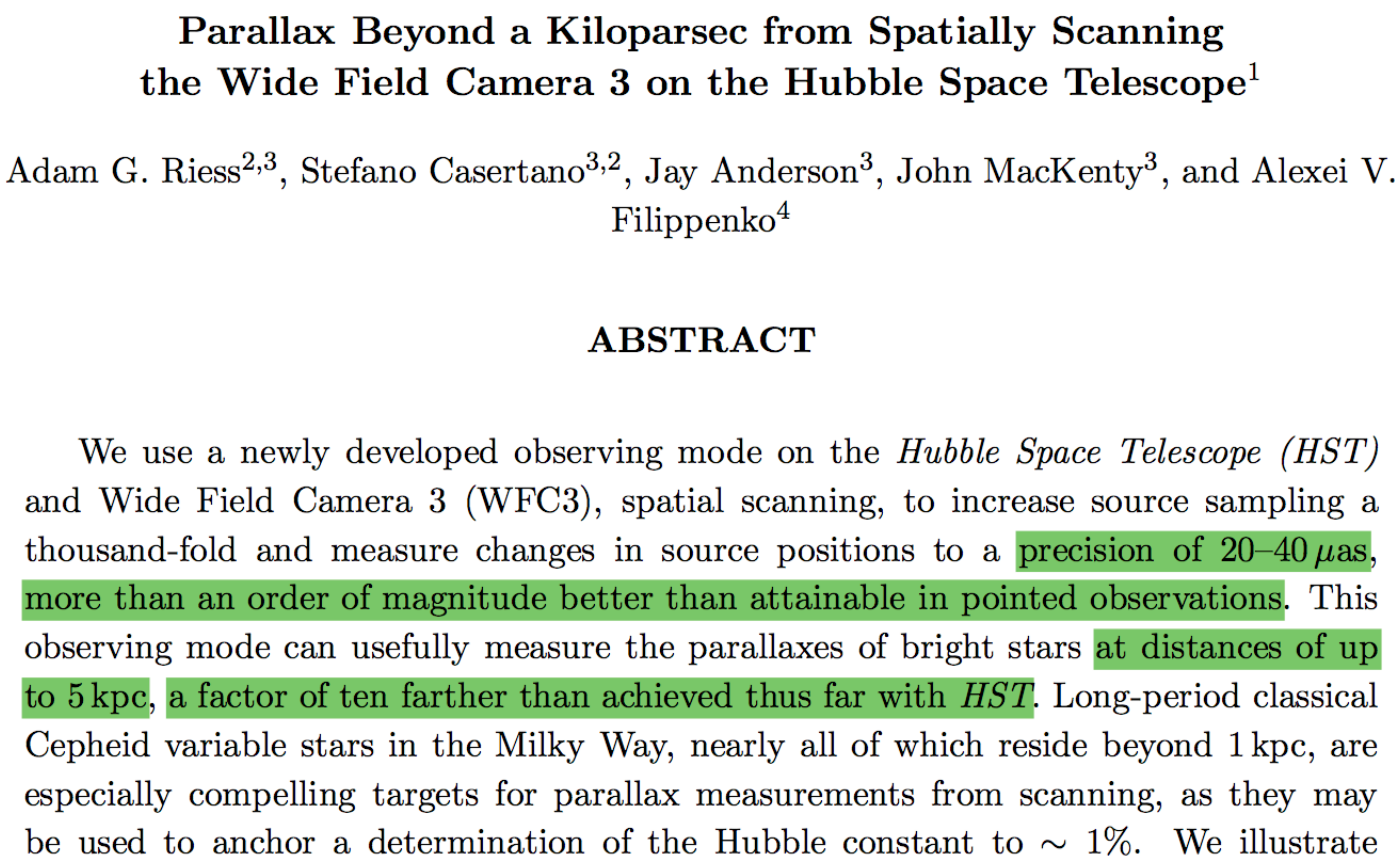
- Even the nearest known Cepheid has a parallax of **<u>only a few mas</u>**, requiring sub-mas measurements
- The most precise previous measurements of stellar parallax came from the Fine Guidance Sensor (FGS) on HST, which can measure relative astrometry to a typical precision of ~ 0.2–0.3 mas
- Unfortunately, only two of these have P ≥ 10 days, the lower end of the period range of those measurable at the typical distances of SN Ia hosts.

(too near!)

Cosmic Distance Ladder



paper-I, 2014



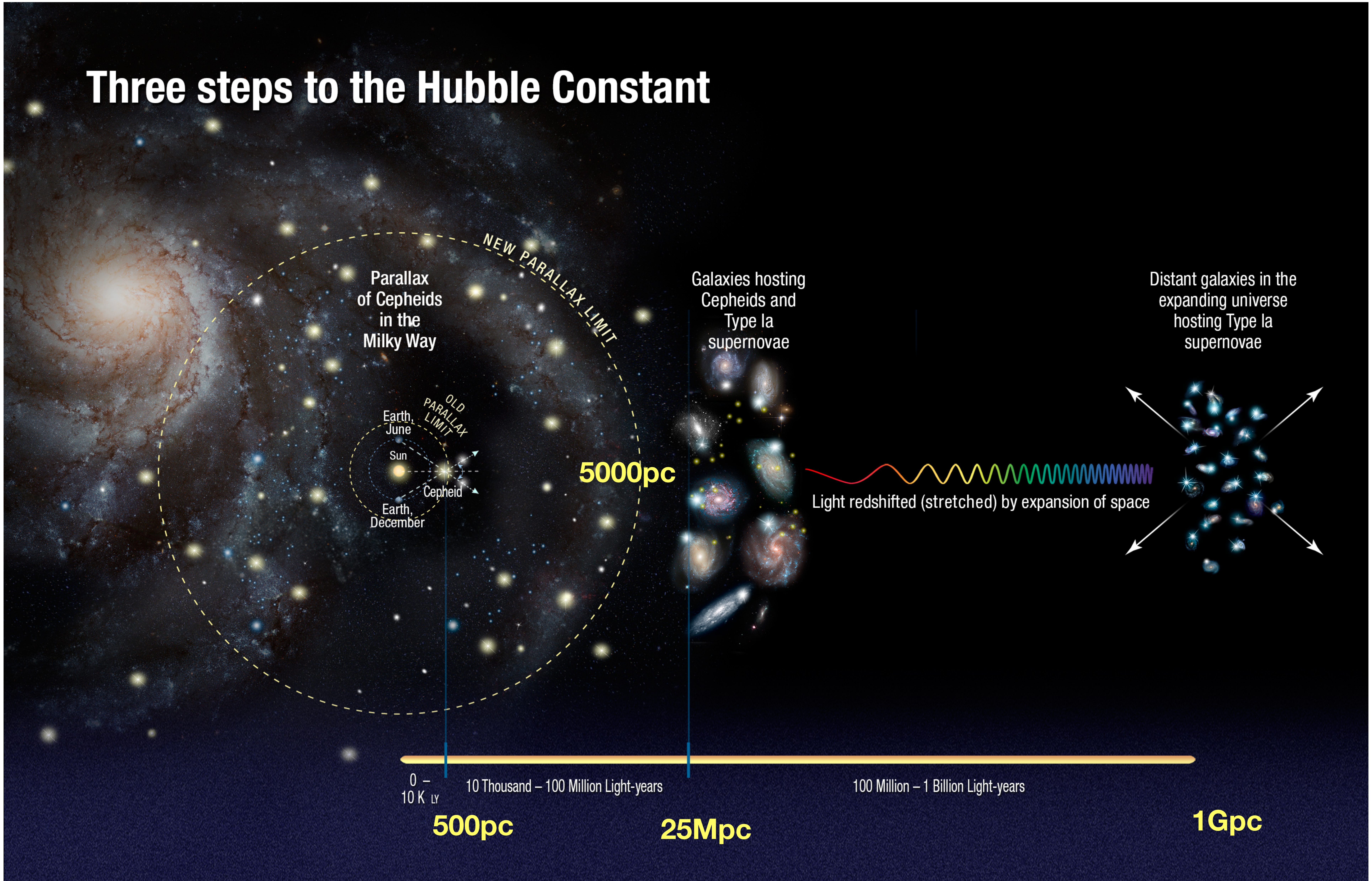
Parallax Beyond a Kiloparsec from Spatially Scanning the Wide Field Camera 3 on the Hubble Space Telescope[1]

Adam G. Riess[2,3], Stefano Casertano[3,2], Jay Anderson[3], John MacKenty[3], and Alexei V. Filippenko[4]

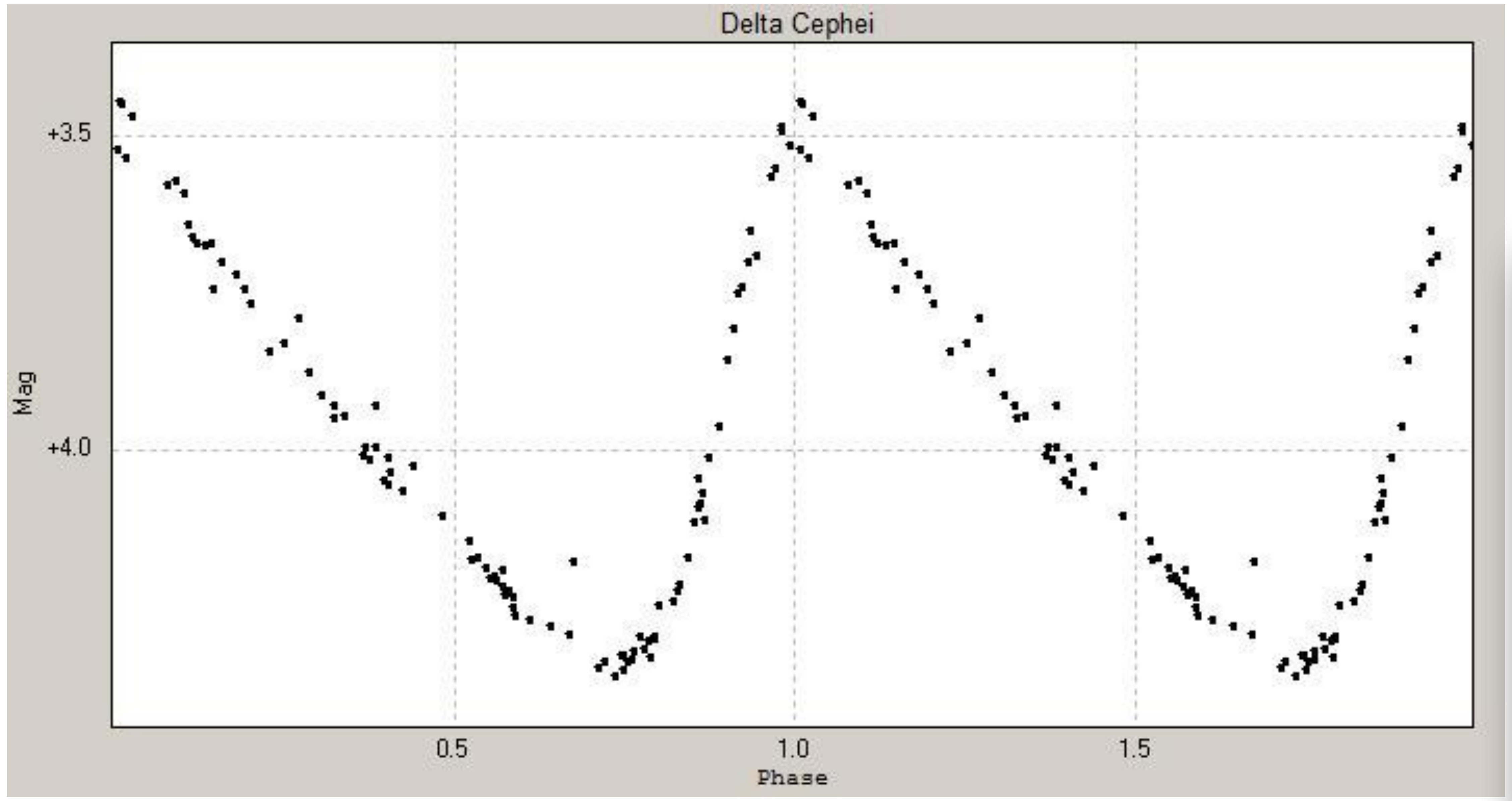
ABSTRACT

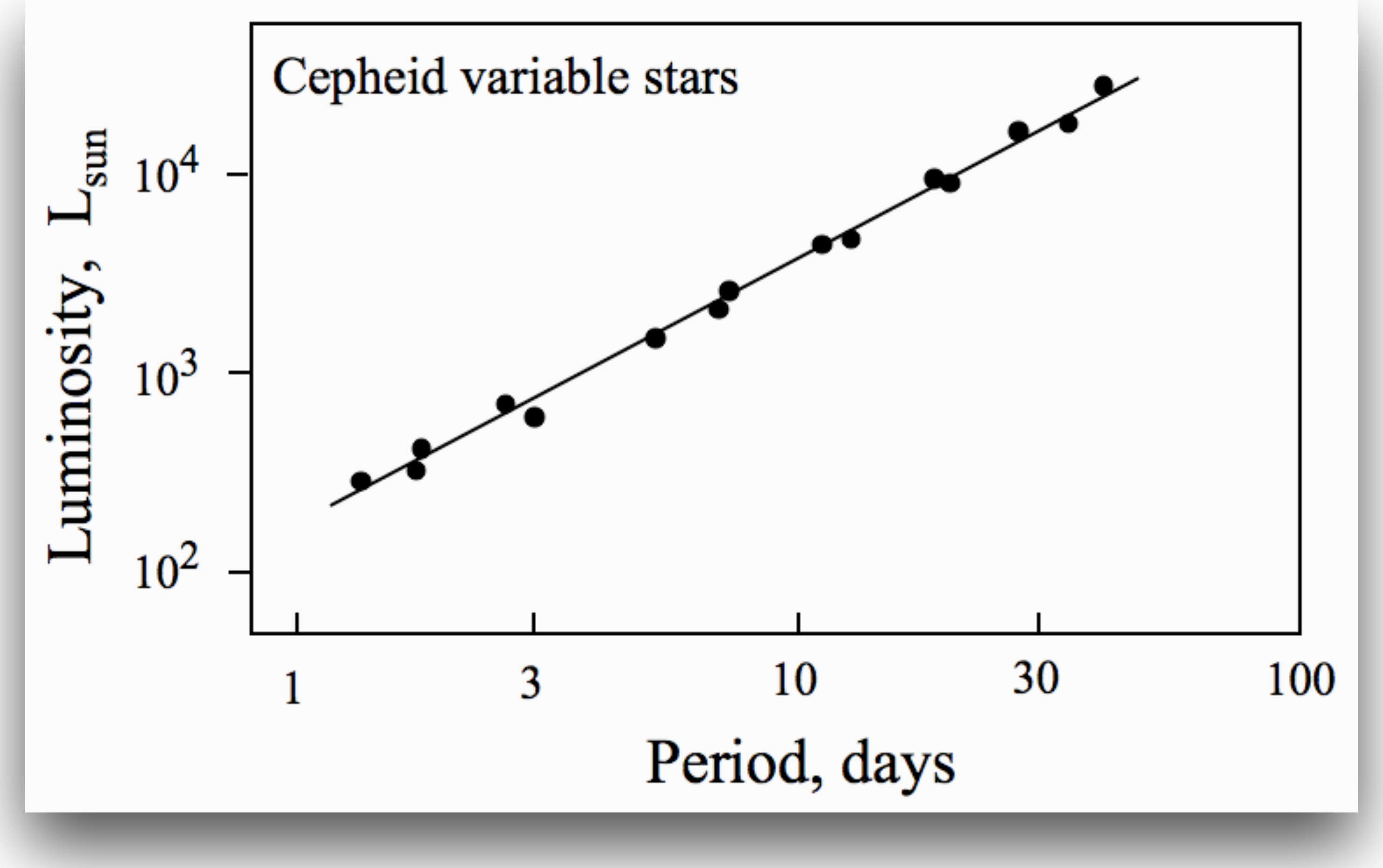
We use a newly developed observing mode on the *Hubble Space Telescope (HST)* and Wide Field Camera 3 (WFC3), spatial scanning, to increase source sampling a thousand-fold and measure changes in source positions to a precision of 20–40 μas, more than an order of magnitude better than attainable in pointed observations. This observing mode can usefully measure the parallaxes of bright stars at distances of up to 5 kpc, a factor of ten farther than achieved thus far with *HST*. Long-period classical Cepheid variable stars in the Milky Way, nearly all of which reside beyond 1 kpc, are especially compelling targets for parallax measurements from scanning, as they may be used to anchor a determination of the Hubble constant to $\sim 1\%$. We illustrate

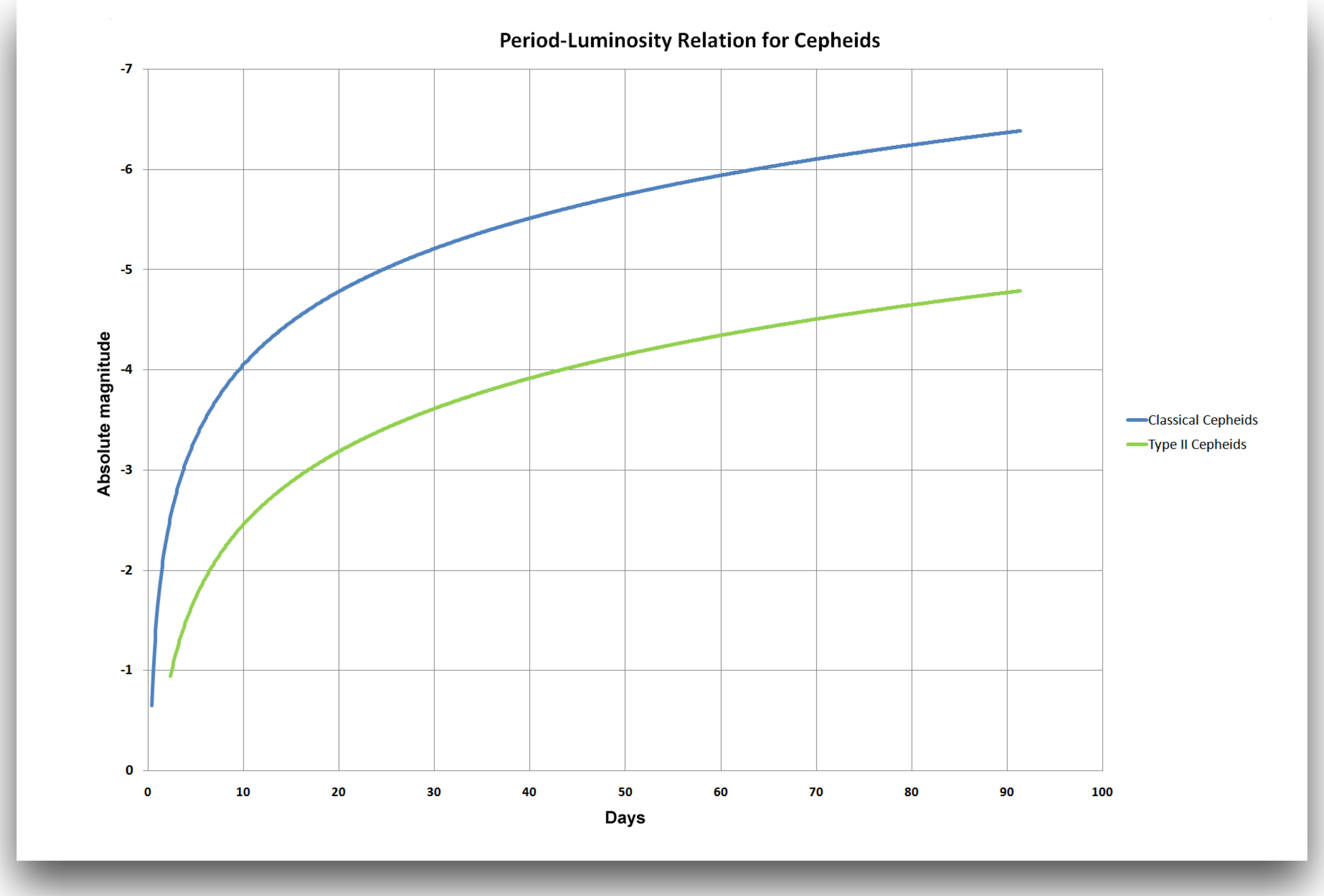
Cosmic Distance Ladder



2. 灶父变星 / 周光关系 [P-L relation]

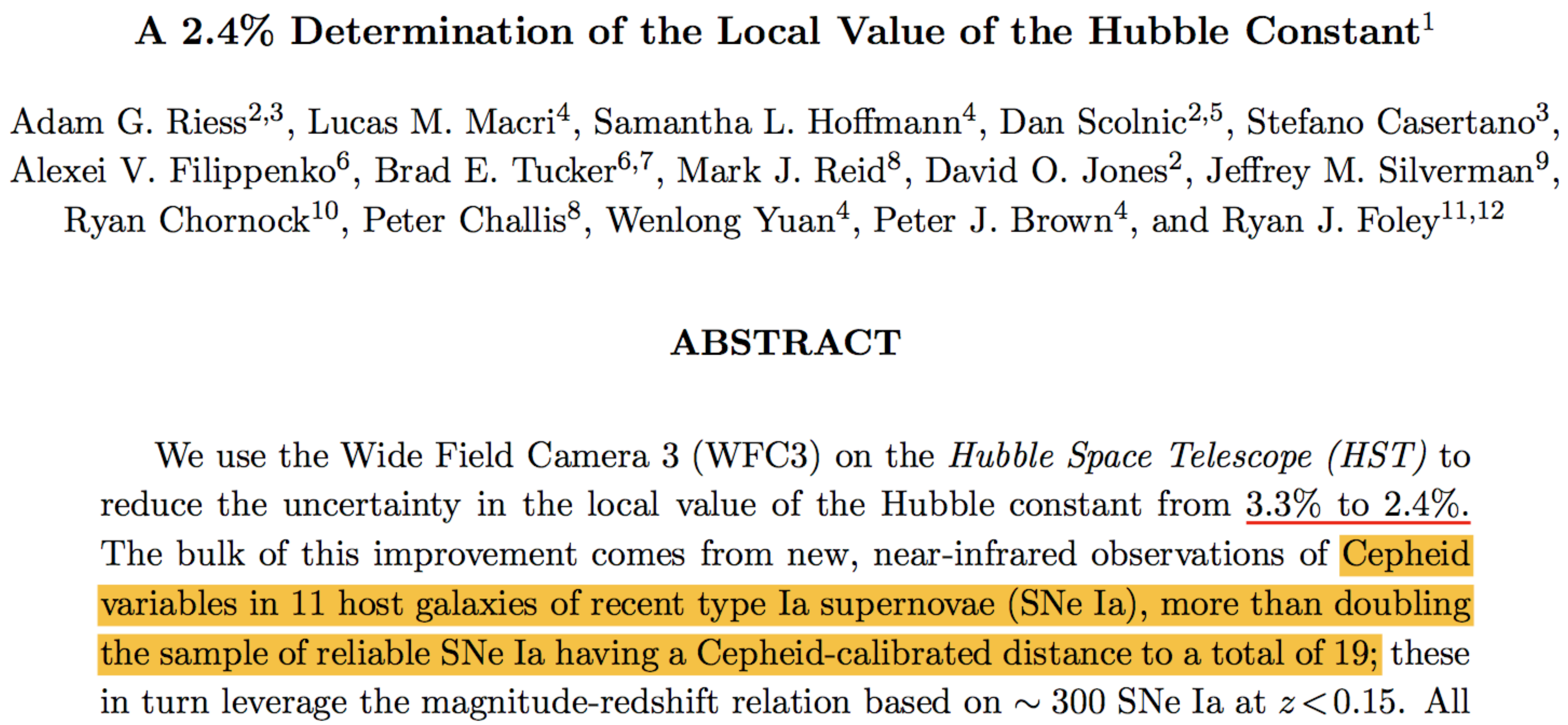






- **To produce a meaningful measurement (SNR ≈ 10) of the parallax of P > 10 day Cepheids, nearly all of which have D > 2 kpc, it is necessary to reach an astrometric precision of ~ 30 μas for individual epochs of MW Cepheids.**

paper-II, 2016



A 2.4% Determination of the Local Value of the Hubble Constant[1]

Adam G. Riess[2,3], Lucas M. Macri[4], Samantha L. Hoffmann[4], Dan Scolnic[2,5], Stefano Casertano[3], Alexei V. Filippenko[6], Brad E. Tucker[6,7], Mark J. Reid[8], David O. Jones[2], Jeffrey M. Silverman[9], Ryan Chornock[10], Peter Challis[8], Wenlong Yuan[4], Peter J. Brown[4], and Ryan J. Foley[11,12]

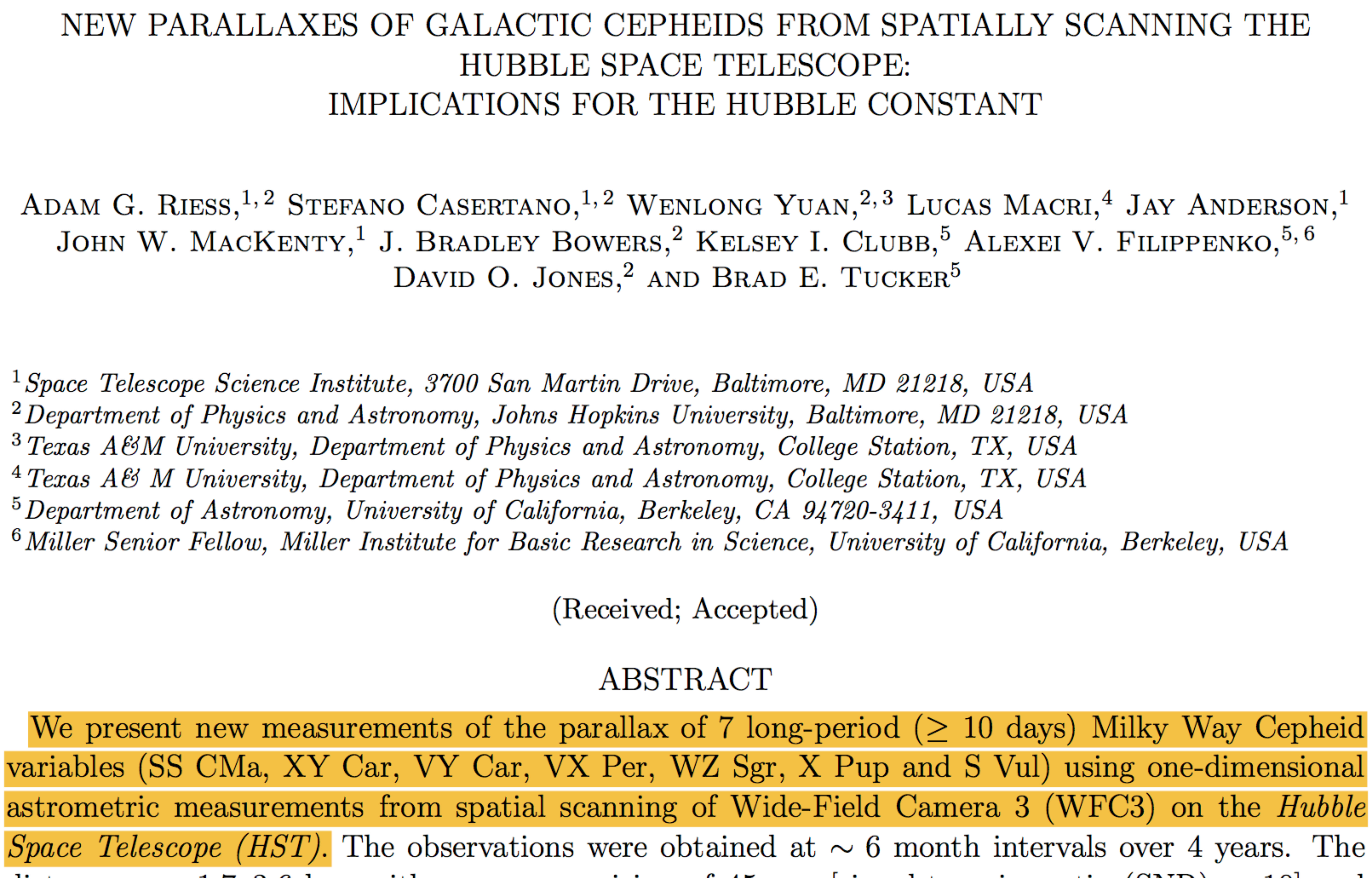
ABSTRACT

We use the Wide Field Camera 3 (WFC3) on the *Hubble Space Telescope (HST)* to reduce the uncertainty in the local value of the Hubble constant from 3.3% to 2.4%. The bulk of this improvement comes from new, near-infrared observations of Cepheid variables in 11 host galaxies of recent type Ia supernovae (SNe Ia), more than doubling the sample of reliable SNe Ia having a Cepheid-calibrated distance to a total of 19; these in turn leverage the magnitude-redshift relation based on ~ 300 SNe Ia at $z < 0.15$. All

11/19

paper-III, 2018a [7 WM cepheids] [2.4%->2.3%]

[3.7\sigma in tension with Planck]



NEW PARALLAXES OF GALACTIC CEPHEIDS FROM SPATIALLY SCANNING THE HUBBLE SPACE TELESCOPE: IMPLICATIONS FOR THE HUBBLE CONSTANT

Adam G. Riess,[1,2] Stefano Casertano,[1,2] Wenlong Yuan,[2,3] Lucas Macri,[4] Jay Anderson,[1]
John W. MacKenty,[1] J. Bradley Bowers,[2] Kelsey I. Clubb,[5] Alexei V. Filippenko,[5,6]
David O. Jones,[2] and Brad E. Tucker[5]

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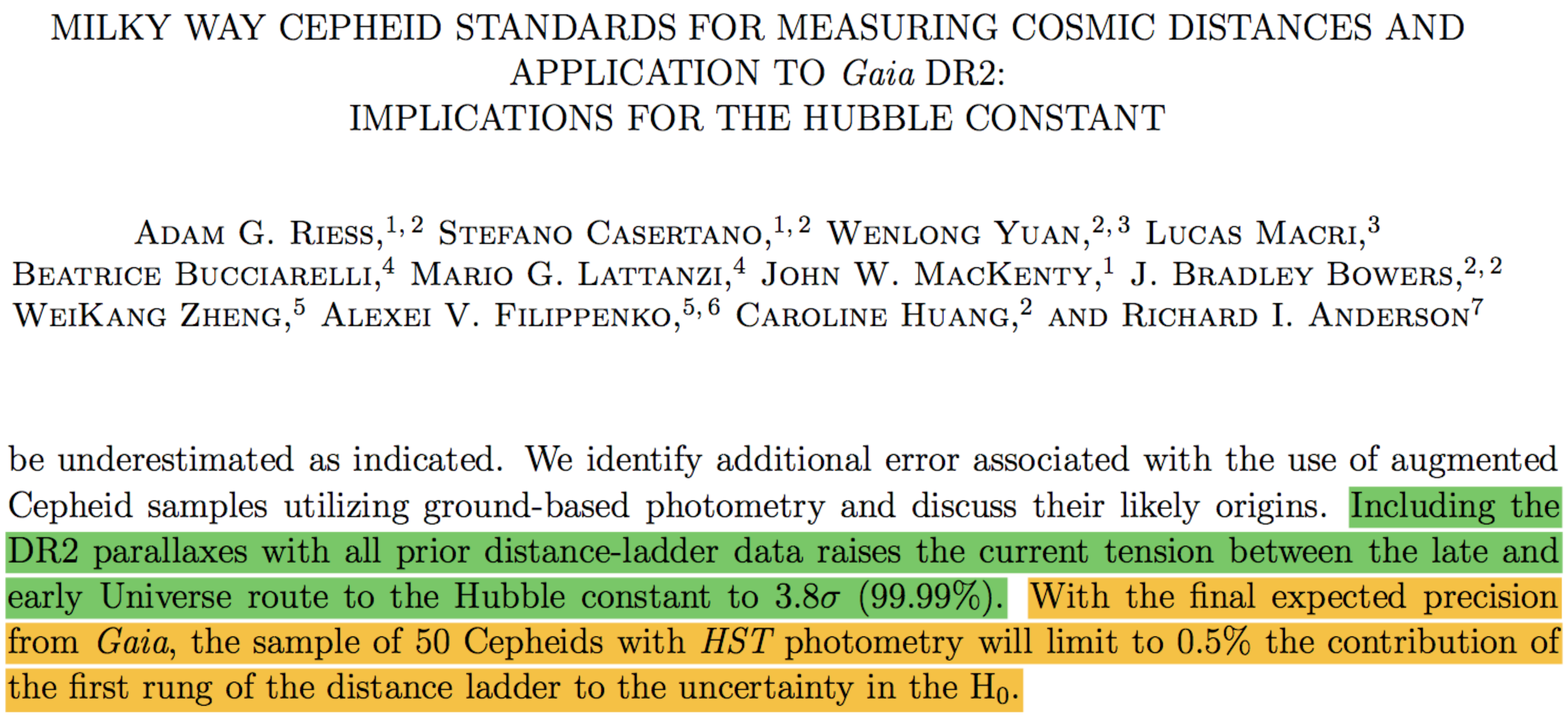
(Received; Accepted)

ABSTRACT

We present new measurements of the parallax of 7 long-period ($\geq$ 10 days) Milky Way Cepheid variables (SS CMa, XY Car, VY Car, VX Per, WZ Sgr, X Pup and S Vul) using one-dimensional astrometric measurements from spatial scanning of Wide-Field Camera 3 (WFC3) on the *Hubble Space Telescope (HST)*. The observations were obtained at $\sim$ 6 month intervals over 4 years. The

paper-IV, 2018b **[+Gaia DR2]** **[3.8\sigma in tension with Planck]**



MILKY WAY CEPHEID STANDARDS FOR MEASURING COSMIC DISTANCES AND APPLICATION TO *Gaia* DR2: IMPLICATIONS FOR THE HUBBLE CONSTANT

Adam G. Riess,[1,2] Stefano Casertano,[1,2] Wenlong Yuan,[2,3] Lucas Macri,[3]
Beatrice Bucciarelli,[4] Mario G. Lattanzi,[4] John W. MacKenty,[1] J. Bradley Bowers,[2,2]
WeiKang Zheng,[5] Alexei V. Filippenko,[5,6] Caroline Huang,[2] and Richard I. Anderson[7]

be underestimated as indicated. We identify additional error associated with the use of augmented Cepheid samples utilizing ground-based photometry and discuss their likely origins. Including the DR2 parallaxes with all prior distance-ladder data raises the current tension between the late and early Universe route to the Hubble constant to 3.8σ (99.99%). With the final expected precision from *Gaia*, the sample of 50 Cepheids with *HST* photometry will limit to 0.5% the contribution of the first rung of the distance ladder to the uncertainty in the H_0.

3. SNe Ia

$$\mu = m - M = 5\log_{10}(d_L) + 25$$

$$\mu_0 = m_V^0 - M_V^0 = 5\log\frac{cz}{H_0}\left\{1+\frac{1}{2}\left[1-q_0\right]z-\frac{1}{6}\left[1-q_0-3q_0^2+j_0\right]z^2+O(z^3)\right\}+25,$$

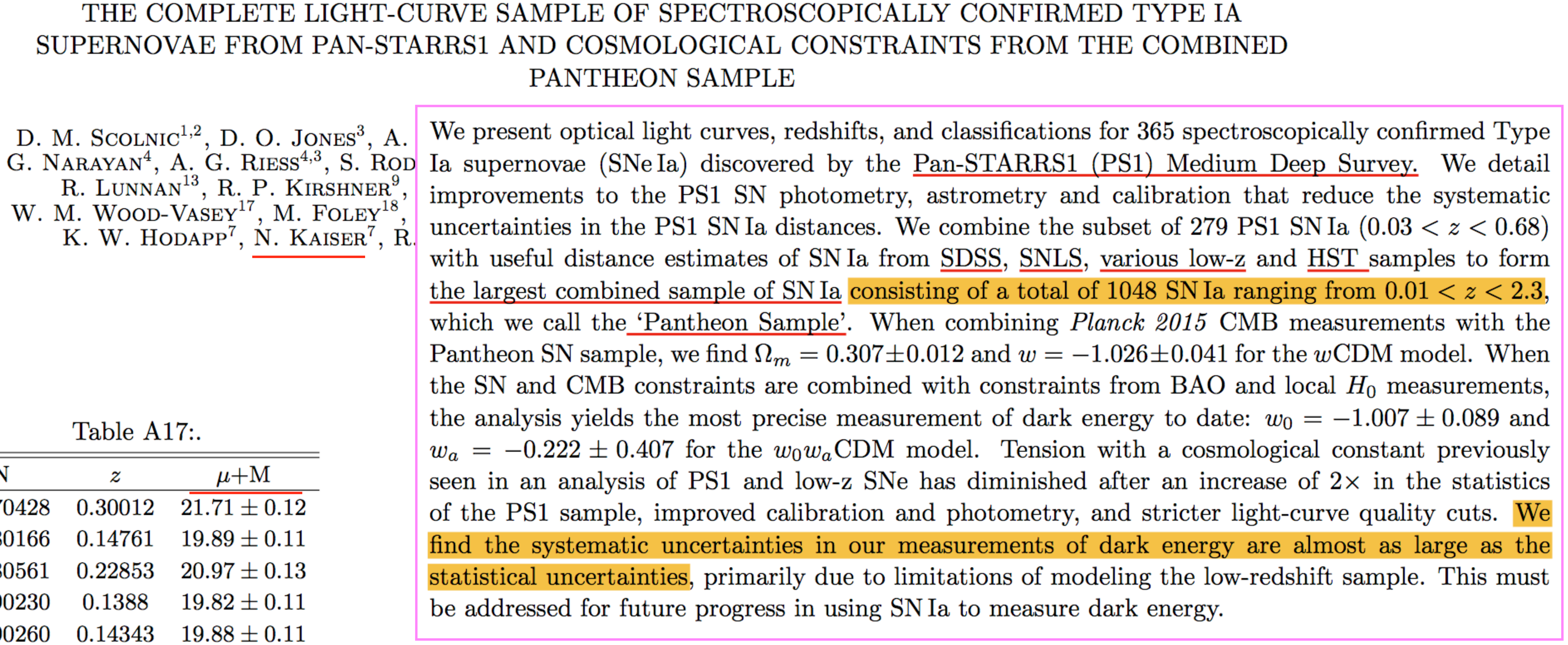
$$\boxed{\underbrace{\log cz\left\{1+\frac{1}{2}\left[1-q_0\right]z-\frac{1}{6}\left[1-q_0-3q_0^2+j_0\right]z^2+O(z^3)\right\}-0.2m_V^0}_{\equiv a_v}=\log H_0-0.2\,M_V^0-5,}$$

a_v only depends on the **relative** distance (i.e. expansion history),

is free of absolute distance (i.e. **free of H_0**) !

The absolute magnitude M_V is completely degenerate with H_0!

e.g. Pantheon data compilation

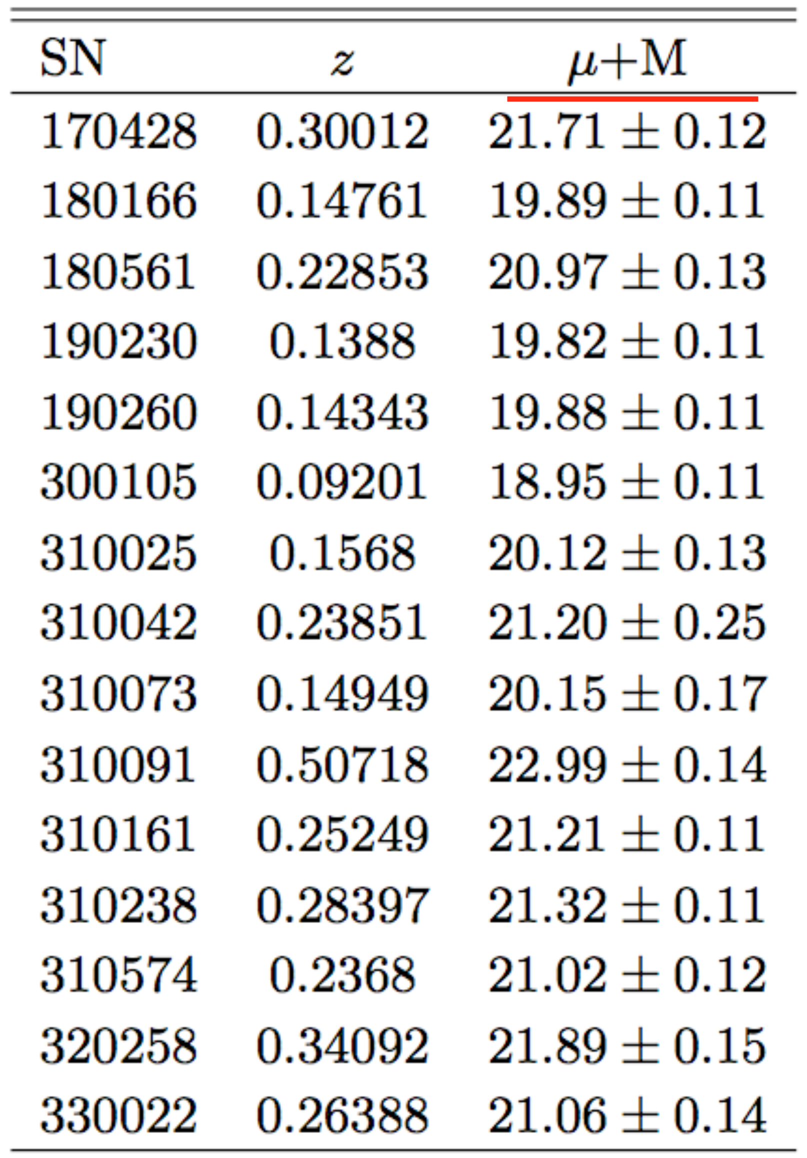


THE COMPLETE LIGHT-CURVE SAMPLE OF SPECTROSCOPICALLY CONFIRMED TYPE IA SUPERNOVAE FROM PAN-STARRS1 AND COSMOLOGICAL CONSTRAINTS FROM THE COMBINED PANTHEON SAMPLE

D. M. Scolnic[1,2], D. O. Jones[3], A.
G. Narayan[4], A. G. Riess[4,3], S. Rod
R. Lunnan[13], R. P. Kirshner[9],
W. M. Wood-Vasey[17], M. Foley[18],
K. W. Hodapp[7], N. Kaiser[7], R.

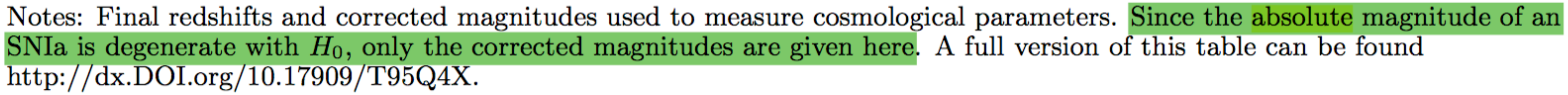
We present optical light curves, redshifts, and classifications for 365 spectroscopically confirmed Type Ia supernovae (SNe Ia) discovered by the Pan-STARRS1 (PS1) Medium Deep Survey. We detail improvements to the PS1 SN photometry, astrometry and calibration that reduce the systematic uncertainties in the PS1 SN Ia distances. We combine the subset of 279 PS1 SN Ia ($0.03 < z < 0.68$) with useful distance estimates of SN Ia from SDSS, SNLS, various low-z and HST samples to form the largest combined sample of SN Ia consisting of a total of 1048 SN Ia ranging from $0.01 < z < 2.3$, which we call the 'Pantheon Sample'. When combining *Planck 2015* CMB measurements with the Pantheon SN sample, we find $\Omega_m = 0.307 \pm 0.012$ and $w = -1.026 \pm 0.041$ for the wCDM model. When the SN and CMB constraints are combined with constraints from BAO and local H_0 measurements, the analysis yields the most precise measurement of dark energy to date: $w_0 = -1.007 \pm 0.089$ and $w_a = -0.222 \pm 0.407$ for the w_0w_aCDM model. Tension with a cosmological constant previously seen in an analysis of PS1 and low-z SNe has diminished after an increase of 2× in the statistics of the PS1 sample, improved calibration and photometry, and stricter light-curve quality cuts. We find the systematic uncertainties in our measurements of dark energy are almost as large as the statistical uncertainties, primarily due to limitations of modeling the low-redshift sample. This must be addressed for future progress in using SN Ia to measure dark energy.

Table A17:.



SN	z	μ+M
170428	0.30012	21.71 ± 0.12
180166	0.14761	19.89 ± 0.11
180561	0.22853	20.97 ± 0.13
190230	0.1388	19.82 ± 0.11
190260	0.14343	19.88 ± 0.11
300105	0.09201	18.95 ± 0.11
310025	0.1568	20.12 ± 0.13
310042	0.23851	21.20 ± 0.25
310073	0.14949	20.15 ± 0.17
310091	0.50718	22.99 ± 0.14
310161	0.25249	21.21 ± 0.11
310238	0.28397	21.32 ± 0.11
310574	0.2368	21.02 ± 0.12
320258	0.34092	21.89 ± 0.15
330022	0.26388	21.06 ± 0.14

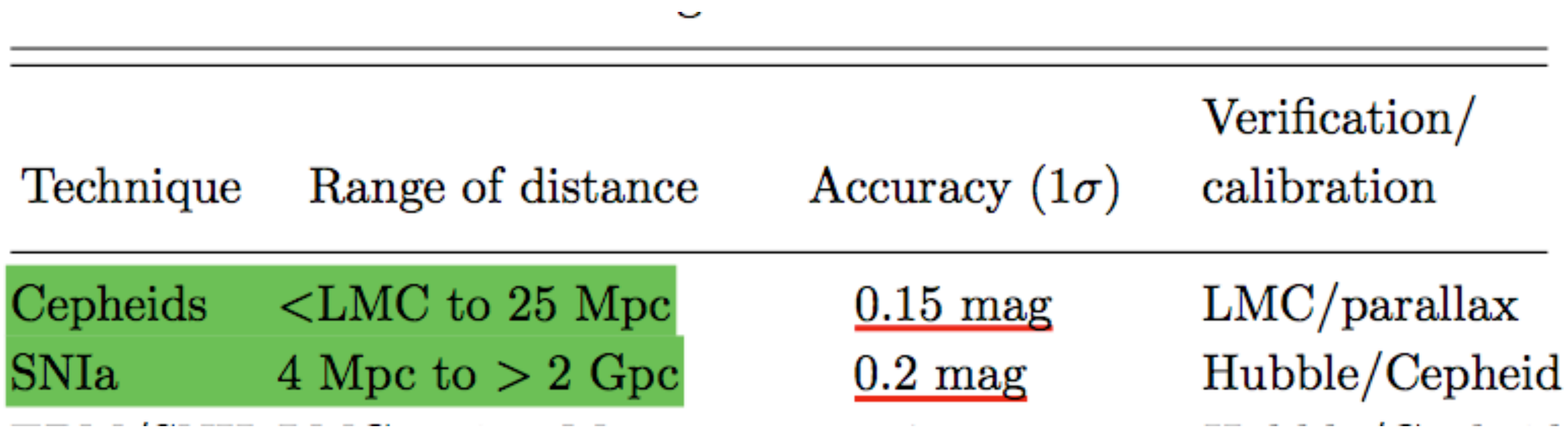
Different data sets using different absolute magnitude calibration, hence can not trust neither of them. Hence, only use the relative distance indicator, e.g. **PANTHEON data compilation can only constrain EoS!**



Notes: Final redshifts and corrected magnitudes used to measure cosmological parameters. Since the absolute magnitude of an SNIa is degenerate with H_0, only the corrected magnitudes are given here. A full version of this table can be found http://dx.DOI.org/10.17909/T95Q4X.

$$\mu = 5\log_{10}(d_L/pc) - 5$$

0.1 mag uncertainty -> 5% d_L uncertainty

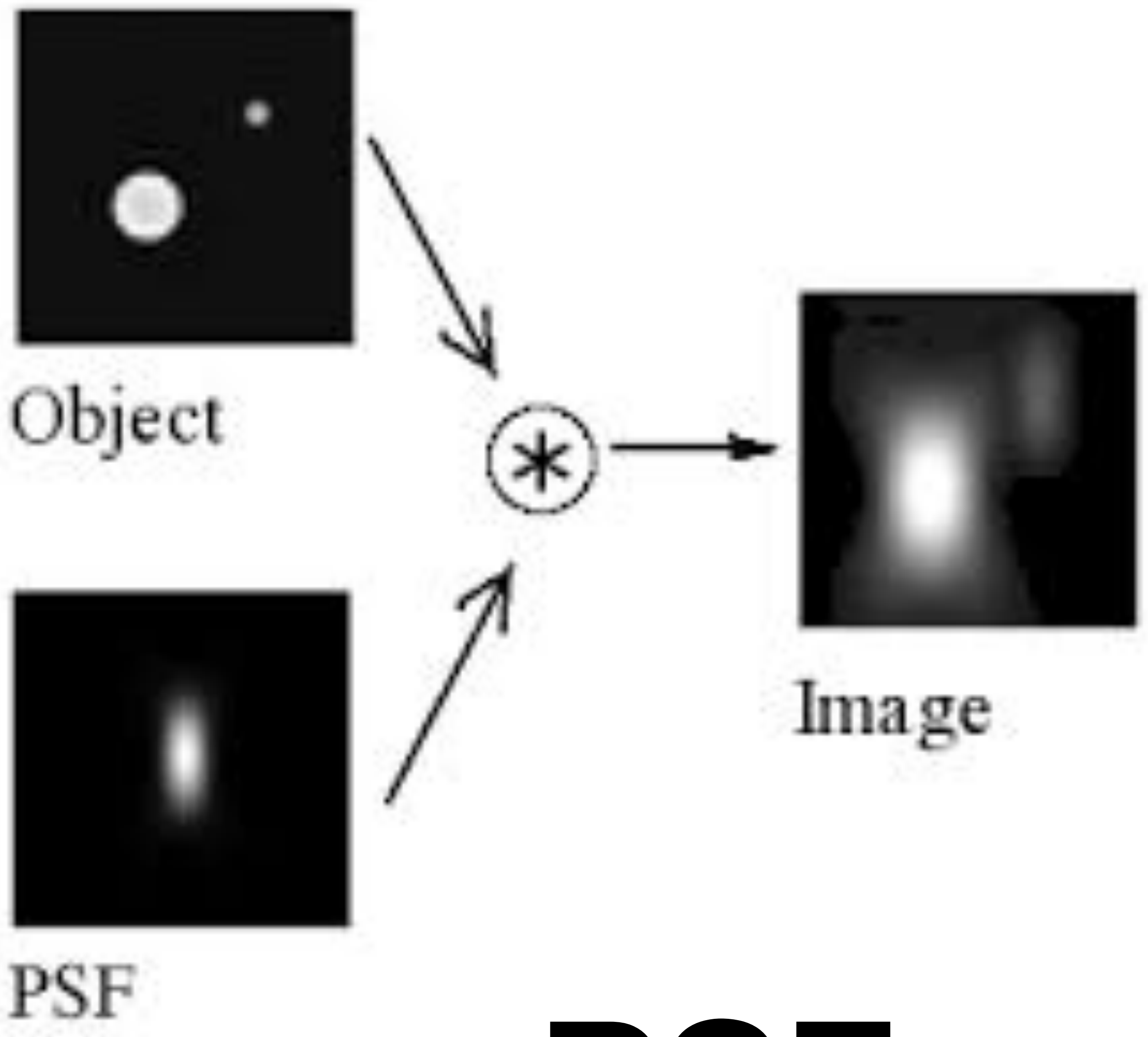


Technique	Range of distance	Accuracy (1σ)	Verification/ calibration
Cepheids	<LMC to 25 Mpc	0.15 mag	LMC/parallax
SNIa	4 Mpc to $>$ 2 Gpc	0.2 mag	Hubble/Cepheid

single SNe Ia 10% uncertainty in distance measurement!

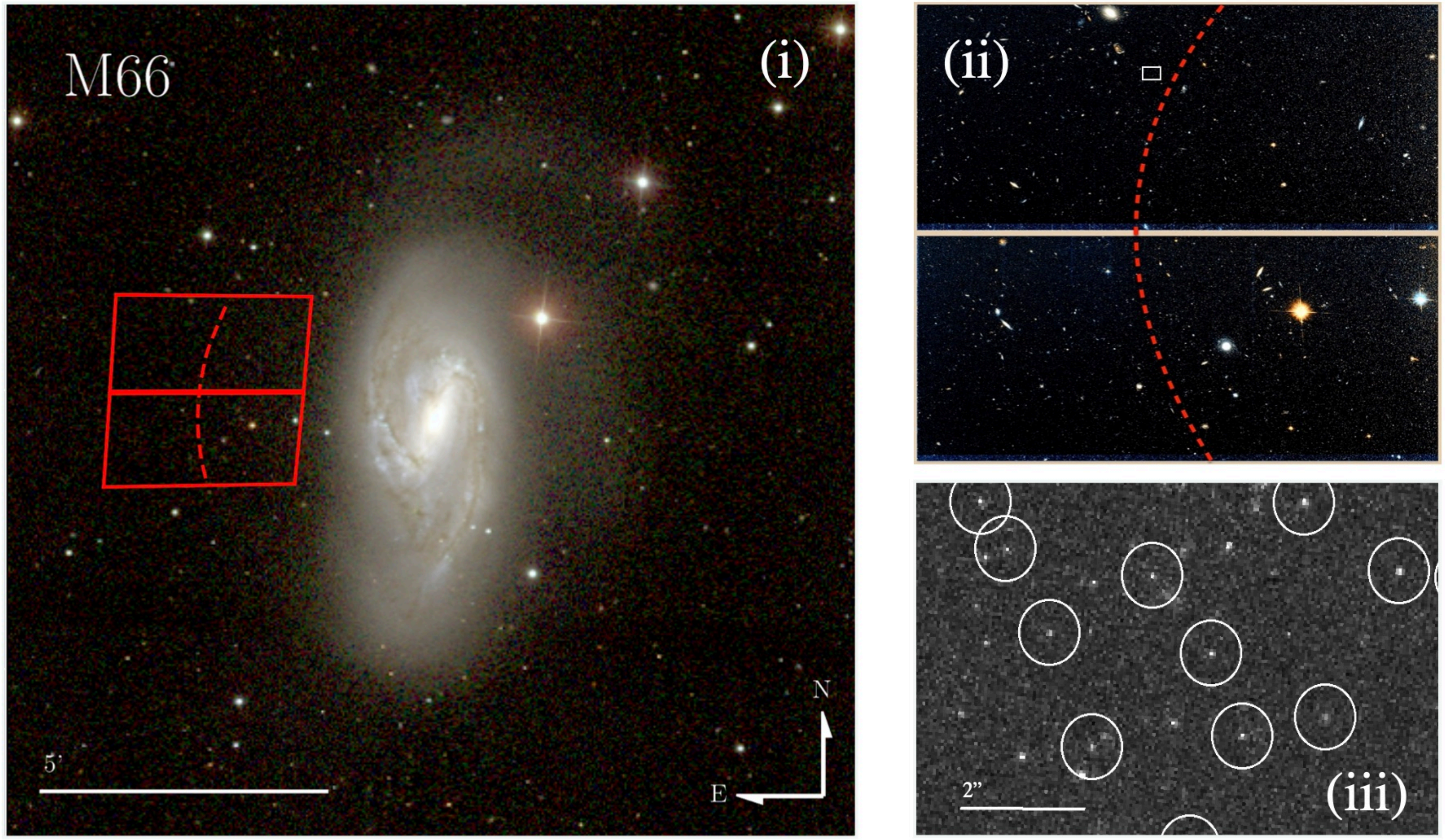
主要误差

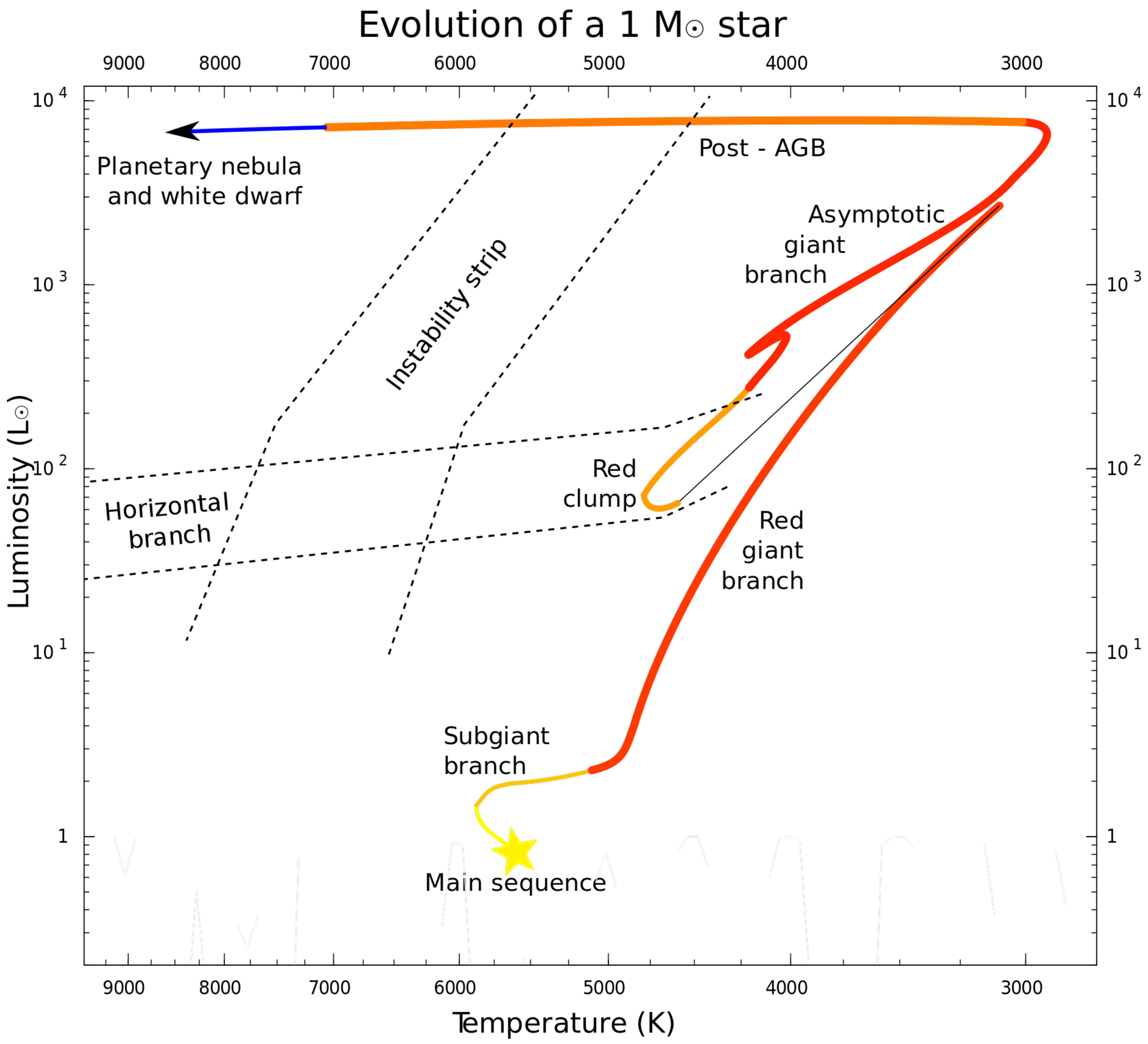
1. blending (混光)

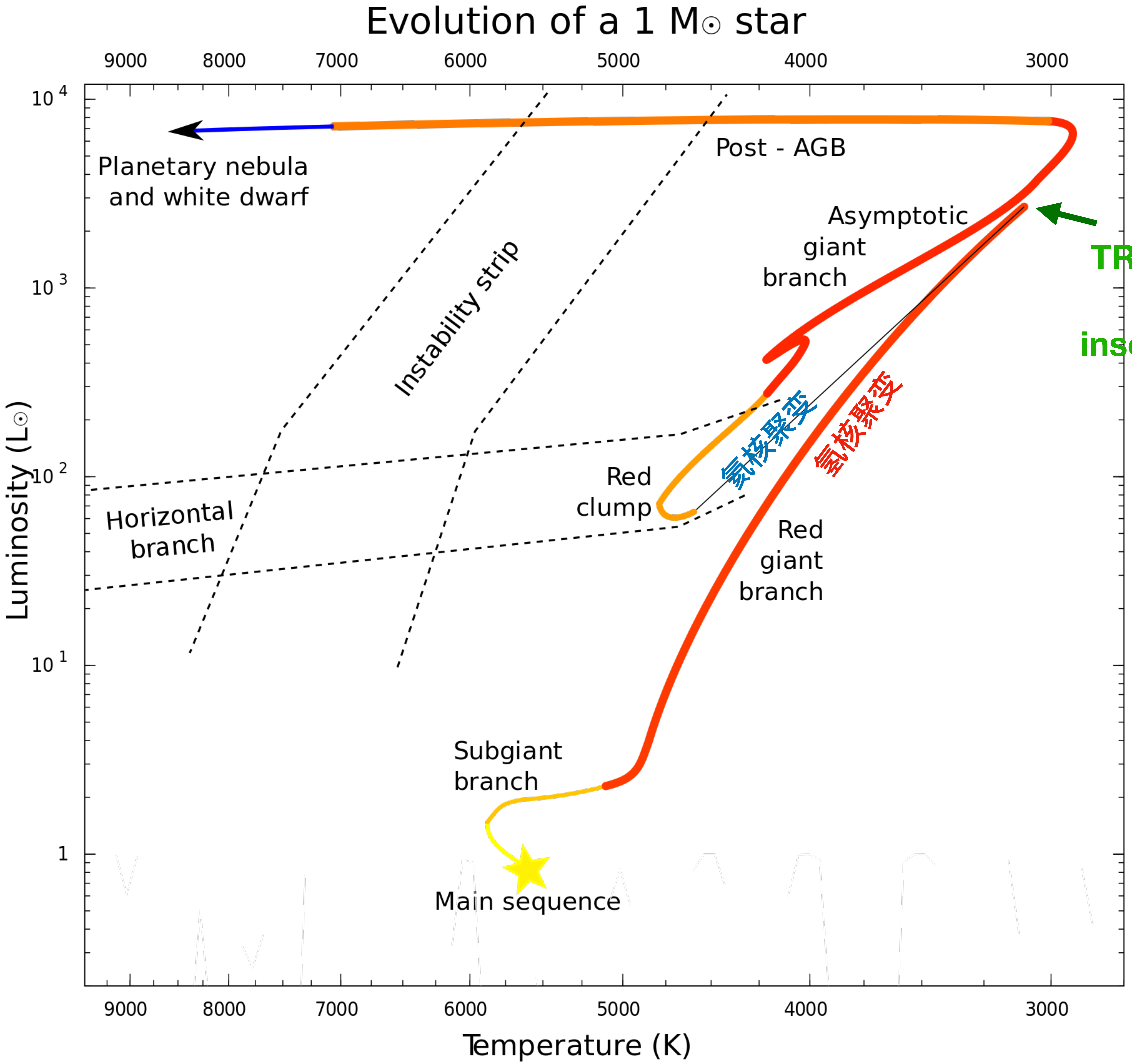


PSF

TRGB

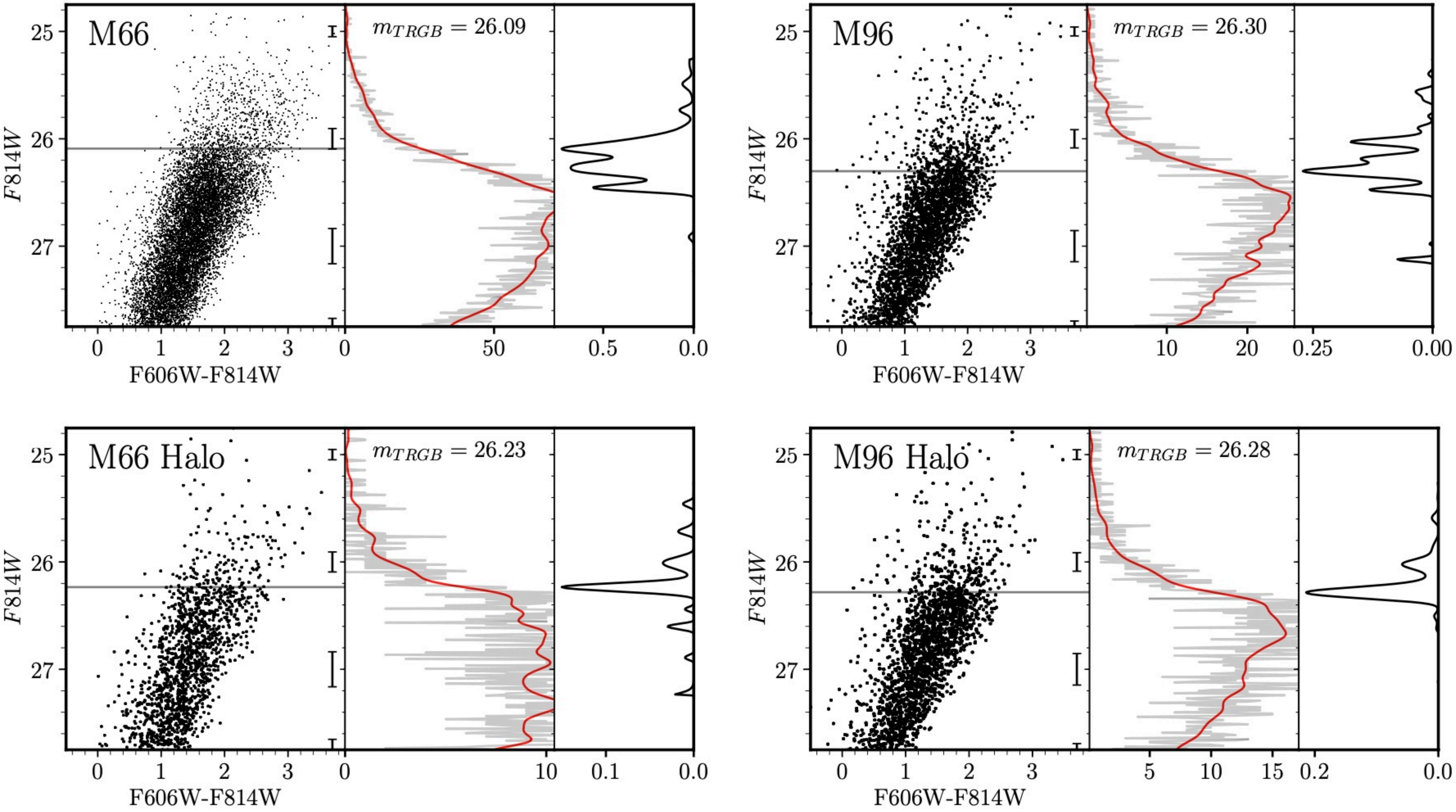

M66
(i)
5'
N
E
(ii)
(iii)
2"

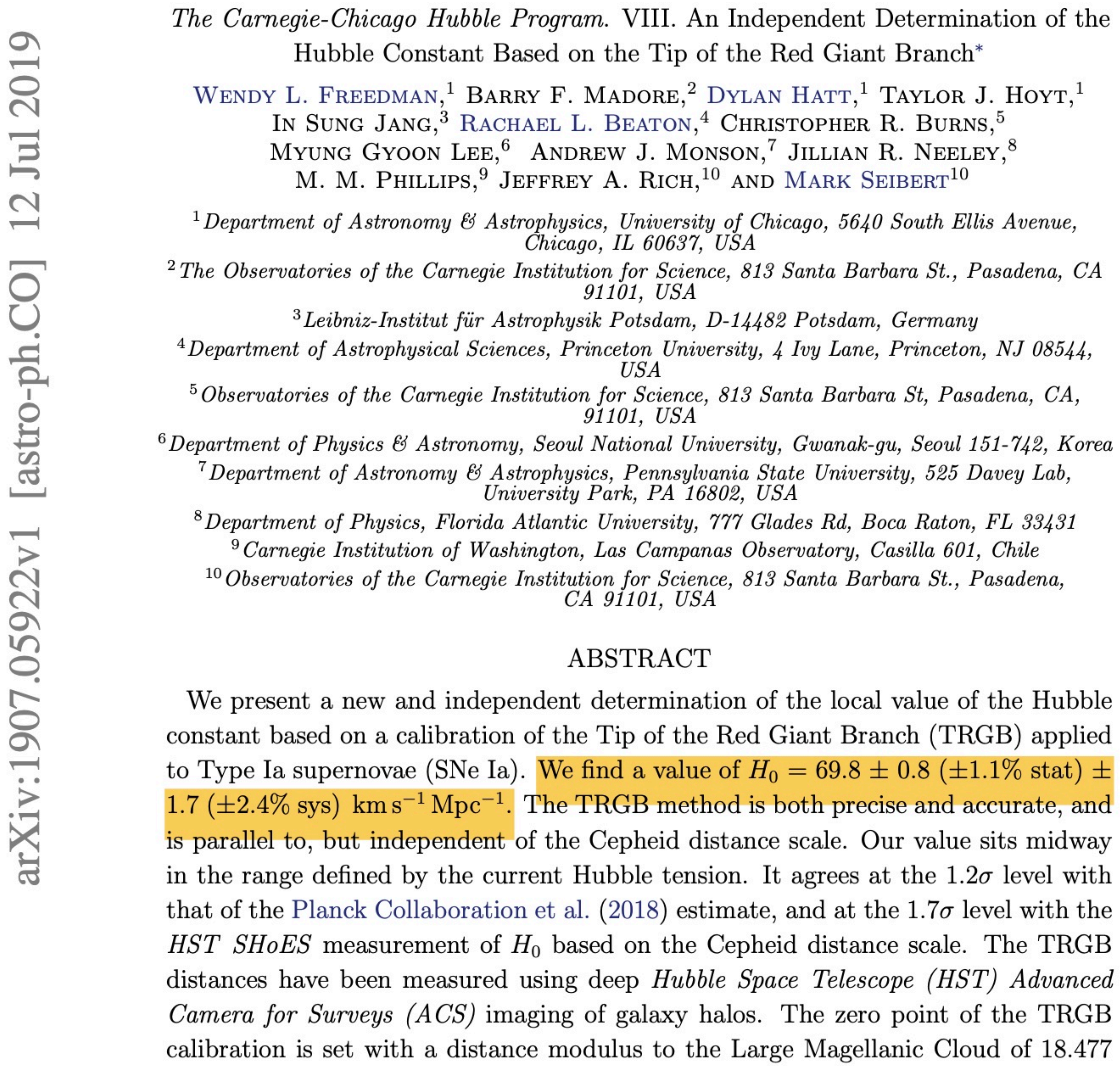

Evolution of a 1 M☉ star
9000
8000
7000
6000
5000
4000
3000
10 4
10 3
10 2
10 1
1
Luminosity (L☉)
Temperature (K)
Planetary nebula
and white dwarf
Post - AGB
Asymptotic
giant
branch
Instability strip
Horizontal
branch
Red
clump
Red
giant
branch
Subgiant
branch
Main sequence



TRGB （helium flash）

Standard candle:
insensitive to metallicity
mass, etc.


M66
$m_{TRGB} = 26.09$
M96
$m_{TRGB} = 26.30$
M66 Halo
$m_{TRGB} = 26.23$
M96 Halo
$m_{TRGB} = 26.28$
$F814W$
F606W-F814W
25
26
27
0
1
2
3
50
0.5
0.0
10
20
0.25
0.00
0.1
5
15
0.2



The Carnegie-Chicago Hubble Program. VIII. An Independent Determination of the Hubble Constant Based on the Tip of the Red Giant Branch*

Wendy L. Freedman,[1] Barry F. Madore,[2] Dylan Hatt,[1] Taylor J. Hoyt,[1]
In Sung Jang,[3] Rachael L. Beaton,[4] Christopher R. Burns,[5]
Myung Gyoon Lee,[6] Andrew J. Monson,[7] Jillian R. Neeley,[8]
M. M. Phillips,[9] Jeffrey A. Rich,[10] and Mark Seibert[10]

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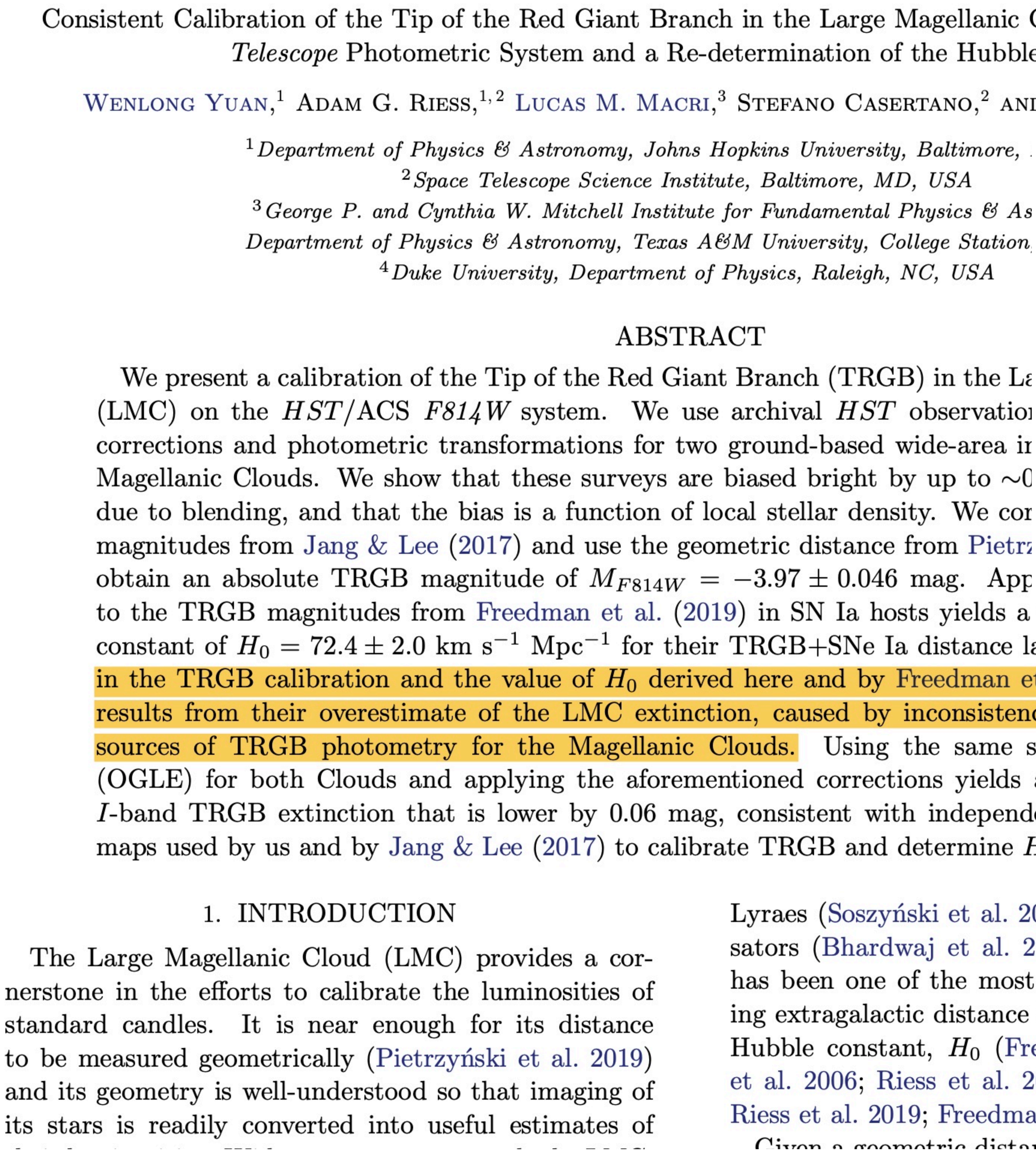
ABSTRACT

We present a new and independent determination of the local value of the Hubble constant based on a calibration of the Tip of the Red Giant Branch (TRGB) applied to Type Ia supernovae (SNe Ia). We find a value of $H_0 = 69.8 \pm 0.8$ ($\pm 1.1\%$ stat) $\pm$ 1.7 ($\pm 2.4\%$ sys) $\mathrm{km\,s^{-1}\,Mpc^{-1}}$. The TRGB method is both precise and accurate, and is parallel to, but independent of the Cepheid distance scale. Our value sits midway in the range defined by the current Hubble tension. It agrees at the 1.2σ level with that of the Planck Collaboration et al. (2018) estimate, and at the 1.7σ level with the *HST SHoES* measurement of H_0 based on the Cepheid distance scale. The TRGB distances have been measured using deep *Hubble Space Telescope (HST) Advanced Camera for Surveys (ACS)* imaging of galaxy halos. The zero point of the TRGB calibration is set with a distance modulus to the Large Magellanic Cloud of 18.477



Consistent Calibration of the Tip of the Red Giant Branch in the Large Magellanic Cloud on the *Hubble Space Telescope* Photometric System and a Re-determination of the Hubble Constant

Wenlong Yuan,[1] Adam G. Riess,[1,2] Lucas M. Macri,[3] Stefano Casertano,[2] and Daniel M. Scolnic[4]

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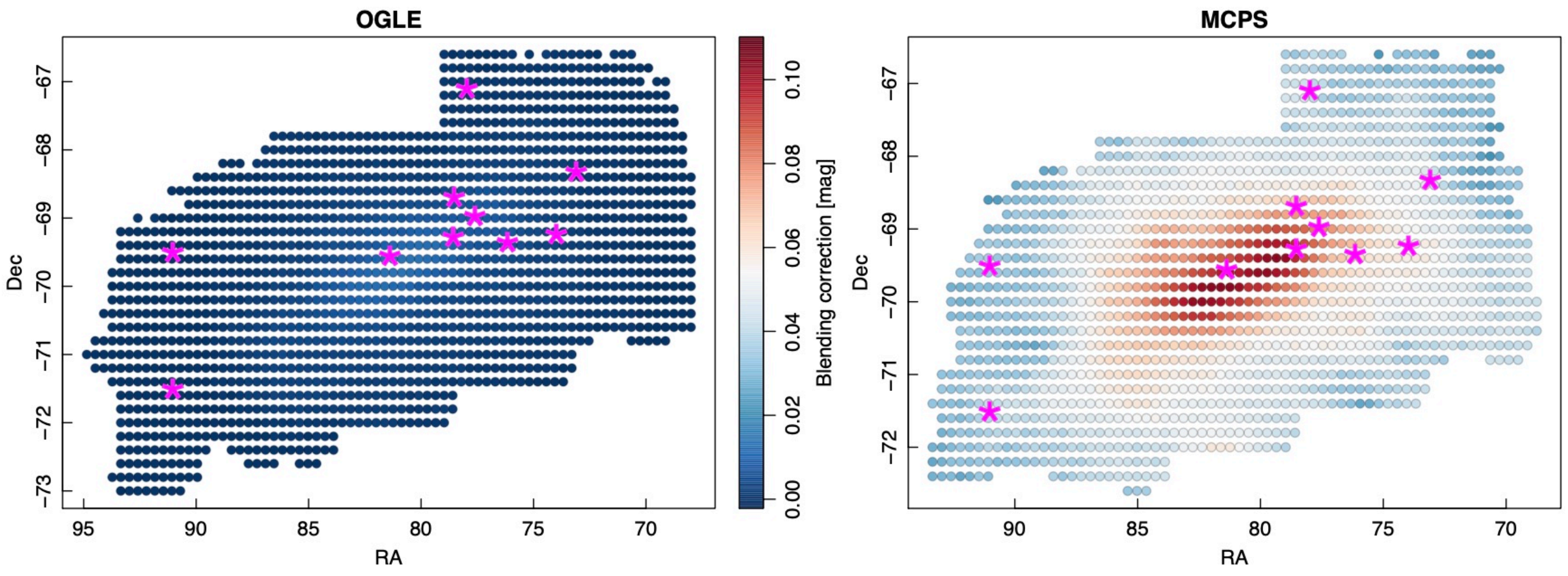
ABSTRACT

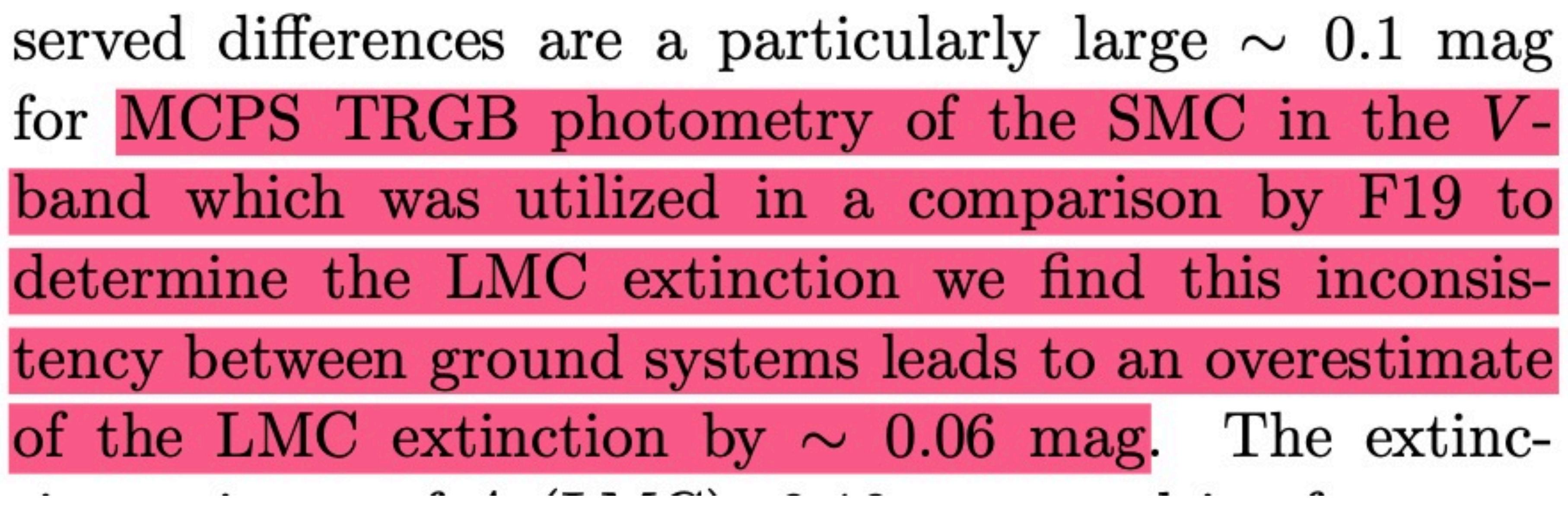
We present a calibration of the Tip of the Red Giant Branch (TRGB) in the La (LMC) on the *HST*/ACS *F814W* system. We use archival *HST* observatio corrections and photometric transformations for two ground-based wide-area ir Magellanic Clouds. We show that these surveys are biased bright by up to ∼0 due to blending, and that the bias is a function of local stellar density. We cor magnitudes from Jang & Lee (2017) and use the geometric distance from Pietrz obtain an absolute TRGB magnitude of $M_{F814W} = -3.97 \pm 0.046$ mag. App to the TRGB magnitudes from Freedman et al. (2019) in SN Ia hosts yields a value for the Hubble constant of $H_0 = 72.4 \pm 2.0$ km s^{-1} Mpc^{-1} for their TRGB+SNe Ia distance ladder. The difference in the TRGB calibration and the value of H_0 derived here and by Freedman et al. (2019) primarily results from their overestimate of the LMC extinction, caused by inconsistencies in their different sources of TRGB photometry for the Magellanic Clouds. Using the same source of photometry (OGLE) for both Clouds and applying the aforementioned corrections yields a value for the LMC *I*-band TRGB extinction that is lower by 0.06 mag, consistent with independent OGLE reddening maps used by us and by Jang & Lee (2017) to calibrate TRGB and determine H_0.

1. INTRODUCTION

The Large Magellanic Cloud (LMC) provides a cornerstone in the efforts to calibrate the luminosities of standard candles. It is near enough for its distance to be measured geometrically (Pietrzyński et al. 2019) and its geometry is well-understood so that imaging of its stars is readily converted into useful estimates of Lyraes (Soszyński et al. 2009b), and Population II pulsators (Bhardwaj et al. 2017). As a result, the LMC has been one of the most critical anchors for calibrating extragalactic distance indicators and measuring the Hubble constant, H_0 (Freedman et al. 2001; Sandage et al. 2006; Riess et al. 2011, 2016; Jang & Lee 2017; Riess et al. 2019; Freedman et al. 2019).

Given a geometric distance measurement to the LMC





served differences are a particularly large ∼ 0.1 mag for MCPS TRGB photometry of the SMC in the *V*-band which was utilized in a comparison by F19 to determine the LMC extinction we find this inconsistency between ground systems leads to an overestimate of the LMC extinction by ∼ 0.06 mag. The extinc-

2. Cepheid metallicity

The Hubble Tension Revisited: Additional Local Distance Ladder Uncertainties

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United Kingdom

ABSTRACT

In a recent paper, we investigated possible systematic uncertainties related to the Cepheid color-luminosity calibration method and their influence on the tension between the Hubble constant as inferred from distances to Type Ia supernovae and the cosmic microwave background as measured with the Planck satellite. Here, we study the impact of other sources of uncertainty in the supernova distance ladder, including Cepheid temperature and metallicity variations, supernova magnitudes and GAIA parallax distances. Using Cepheid data in 19 Type Ia supernova host galaxies from Riess et al. (2016), anchor data from Riess et al. (2016, 2019, 2021) and a set of re-calibrated Milky Way Cepheid distances, we obtain $H_0 = 71.9 \pm 2.2$ km/s/Mpc, 2.0 σ from the Planck value. Excluding Cepheids with estimated color excesses $\hat{E}(\mathrm{V-I}) = 0.15$ mag to mitigate the impact of the Cepheid color-luminosity calibration, the inferred Hubble constant is $H_0 = 68.1 \pm 2.6$ km/s/Mpc, removing the tension with the Planck value.

Keywords: Cepheid distance (217), Hubble constant (758), Type Ia supernovae (1728), Interstellar dust extinction (837)

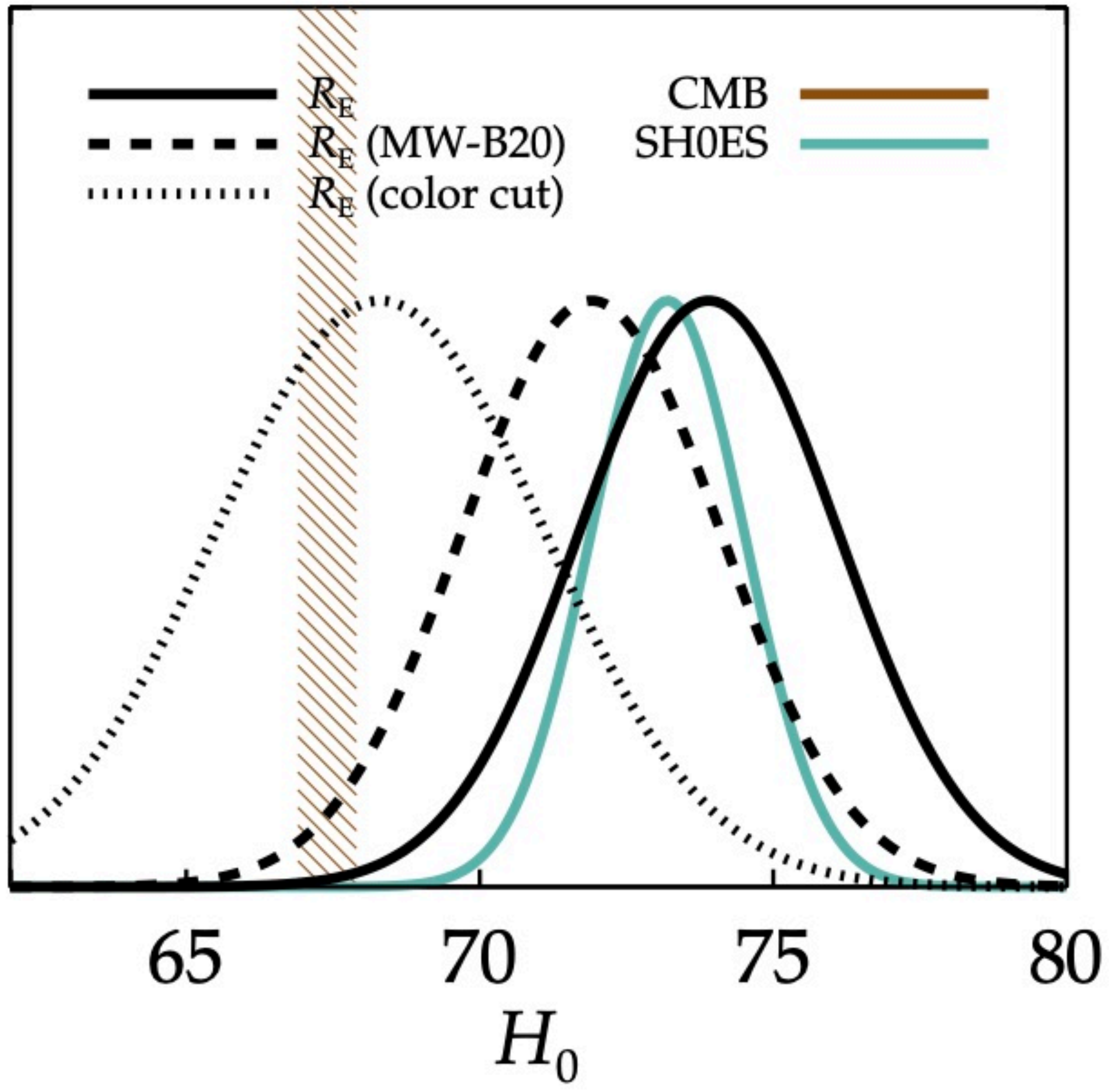
1. INTRODUCTION

Cepheid stars are crucial in building up the distance ladder to Type Ia supernovae (SNIa) when estimating the Hubble constant H_0. To be used as standard candles, Cepheids need to be calibrated with respect to fact that

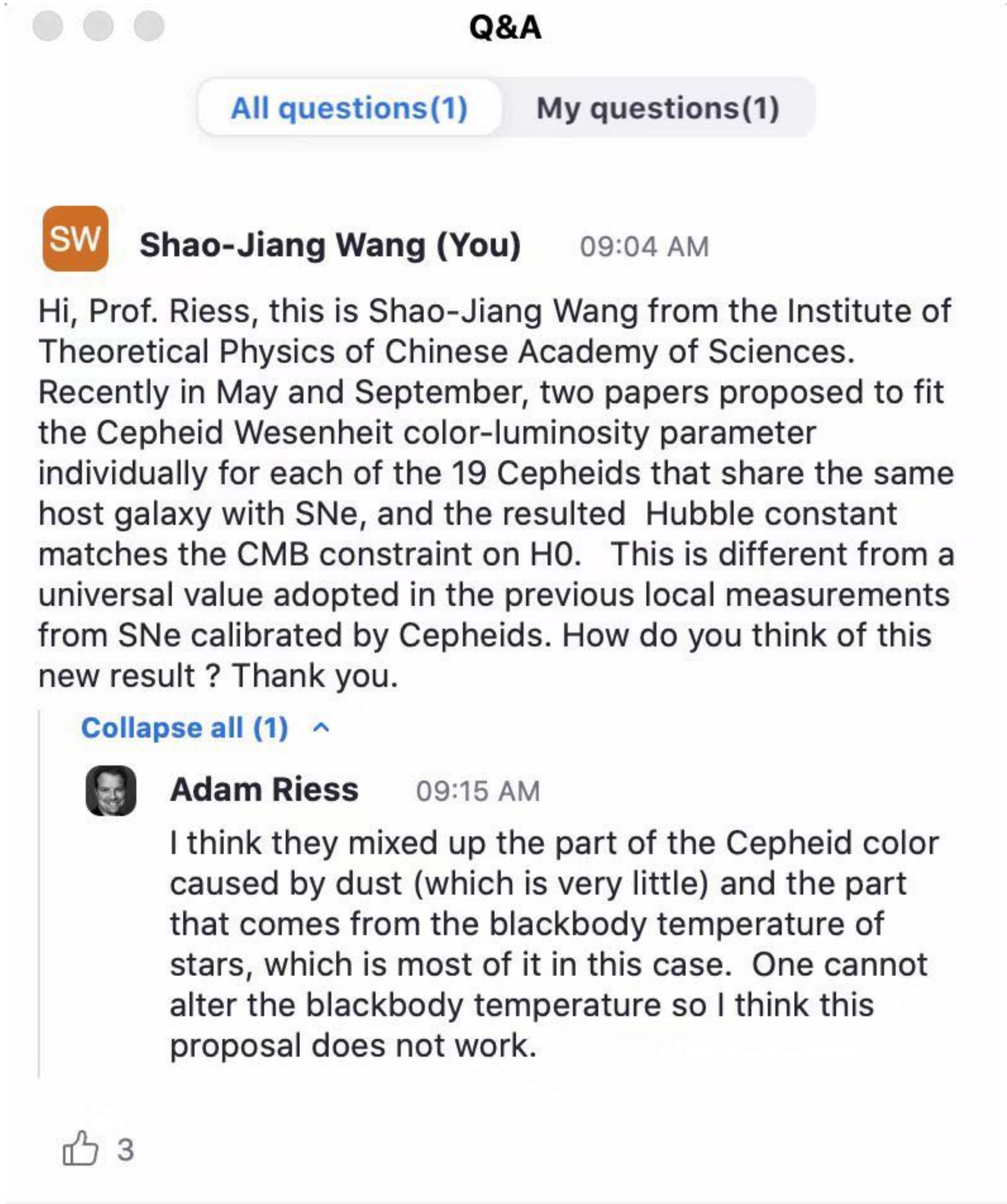
- long period Cepheids are brighter,

(Pejcha & Kochanek 2012). Given the difficulty in separating these effects, Cepheids are usually calibrated using a phenomenological approach where a parameter, R, corrects for both dust and intrinsic variations (Madore 1982). The correction can be applied to observed colors, as by the SH0ES team in e.g. Riess et al. (2016), or estimated color excesses, as in Follin & Knox (2018), derived by subtracting a model for the mean

$$m^{\mathrm{W}}_{\mathrm{H},j} = \mu_j + M^{\mathrm{W}}_{\mathrm{H}} + b_{\mathrm{W}}[\mathrm{P}]_j + Z_{\mathrm{W}}[\mathrm{M/H}]_j.$$



remove Cepheids for which dust extinction is expected to dominate the observed color excess, $\hat{E}(\mathrm{V-I}) > 0.15$ mag, we obtain $H_0 = 68.1 \pm 2.6$.



Shao-Jiang Wang (You) 09:04 AM

Hi, Prof. Riess, this is Shao-Jiang Wang from the Institute of Theoretical Physics of Chinese Academy of Sciences. Recently in May and September, two papers proposed to fit the Cepheid Wesenheit color-luminosity parameter individually for each of the 19 Cepheids that share the same host galaxy with SNe, and the resulted Hubble constant matches the CMB constraint on H0. This is different from a universal value adopted in the previous local measurements from SNe calibrated by Cepheids. How do you think of this new result ? Thank you.

Adam Riess 09:15 AM

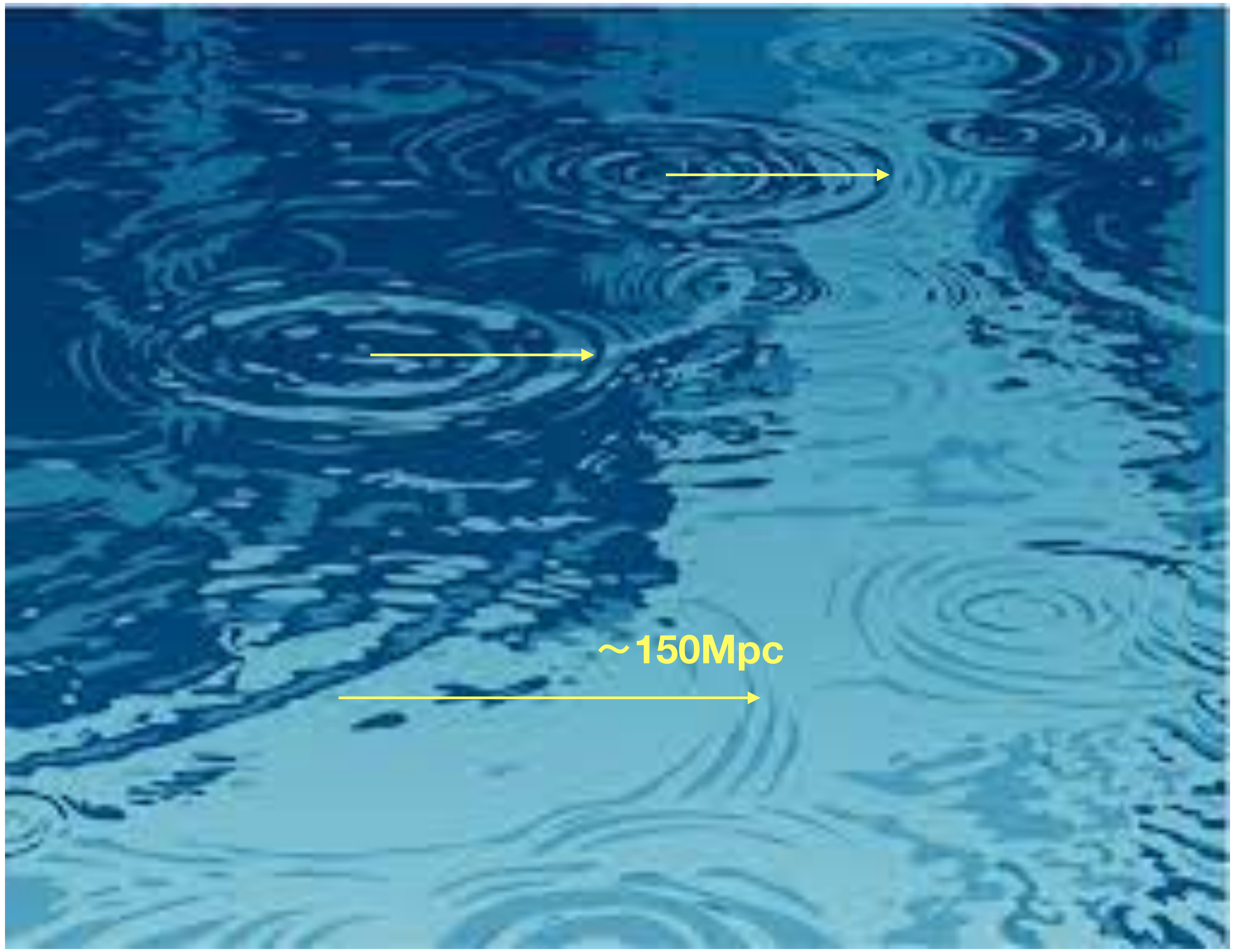
I think they mixed up the part of the Cepheid color caused by dust (which is very little) and the part that comes from the blackbody temperature of stars, which is most of it in this case. One cannot alter the blackbody temperature so I think this proposal does not work.

我的看法：SH0ES基本靠谱，
LCDM需要修正

第三方检验

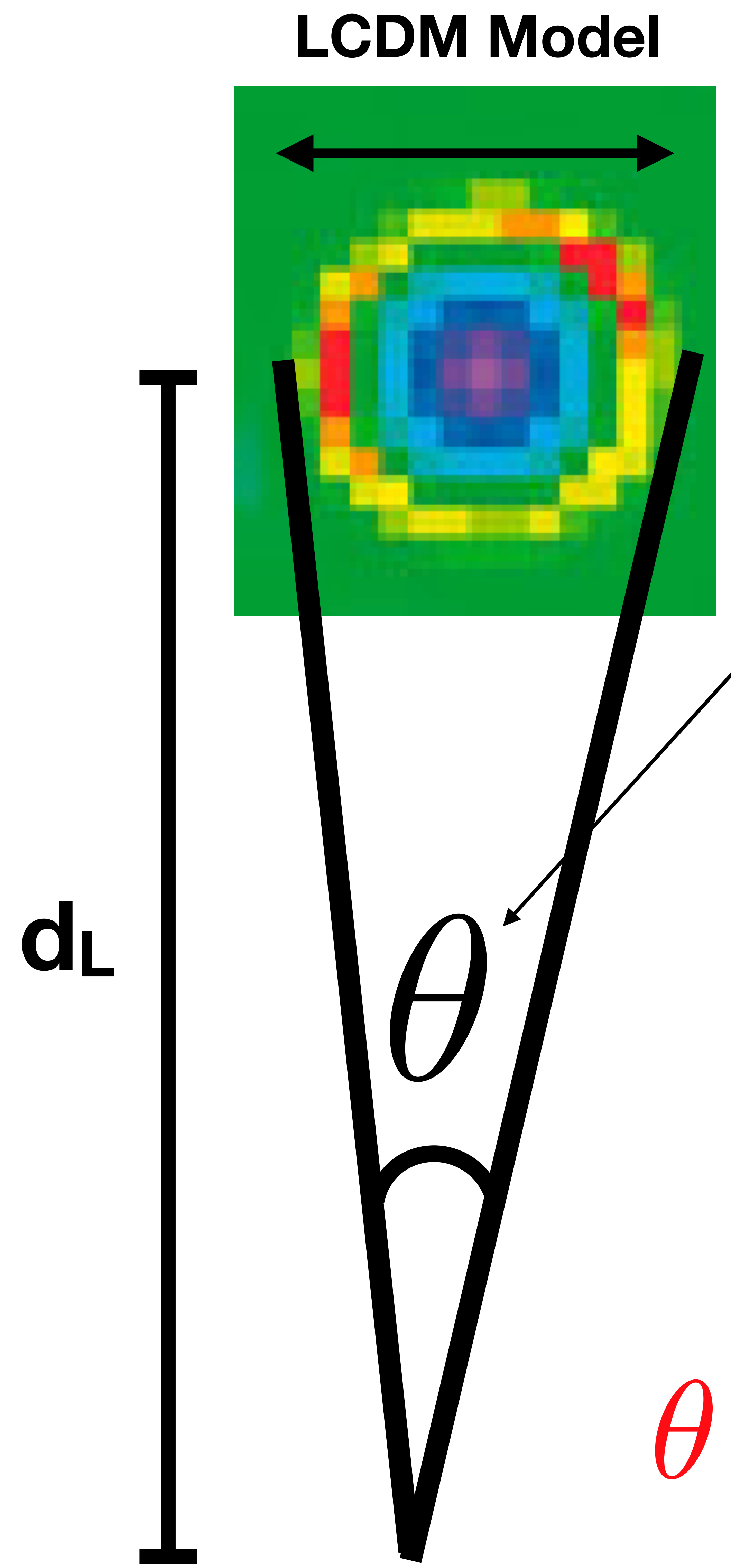
引力向内；热压向外

BAO：宇宙早期等离子体热汤中声学振动的基频波所传播的尺度



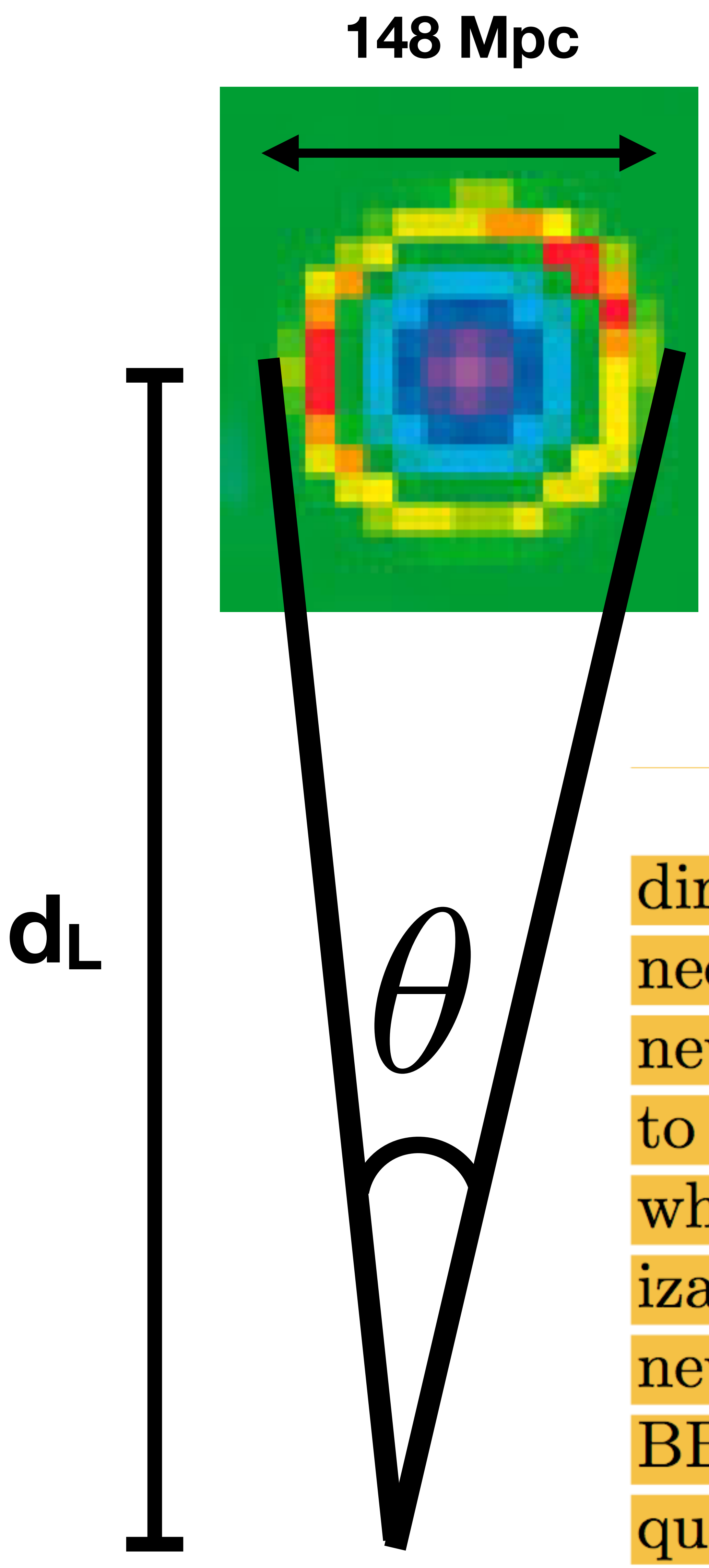
CMB/BAO

CMB/BAO 并不直接测量H_0！其测量的是再复合时期的声学视界的张角



H_0 from CMB/BAO=

θ measurement + LCDM



Model independent $H(z)$ reconstruction using the cosmic inverse distance ladder

[1806.06781]

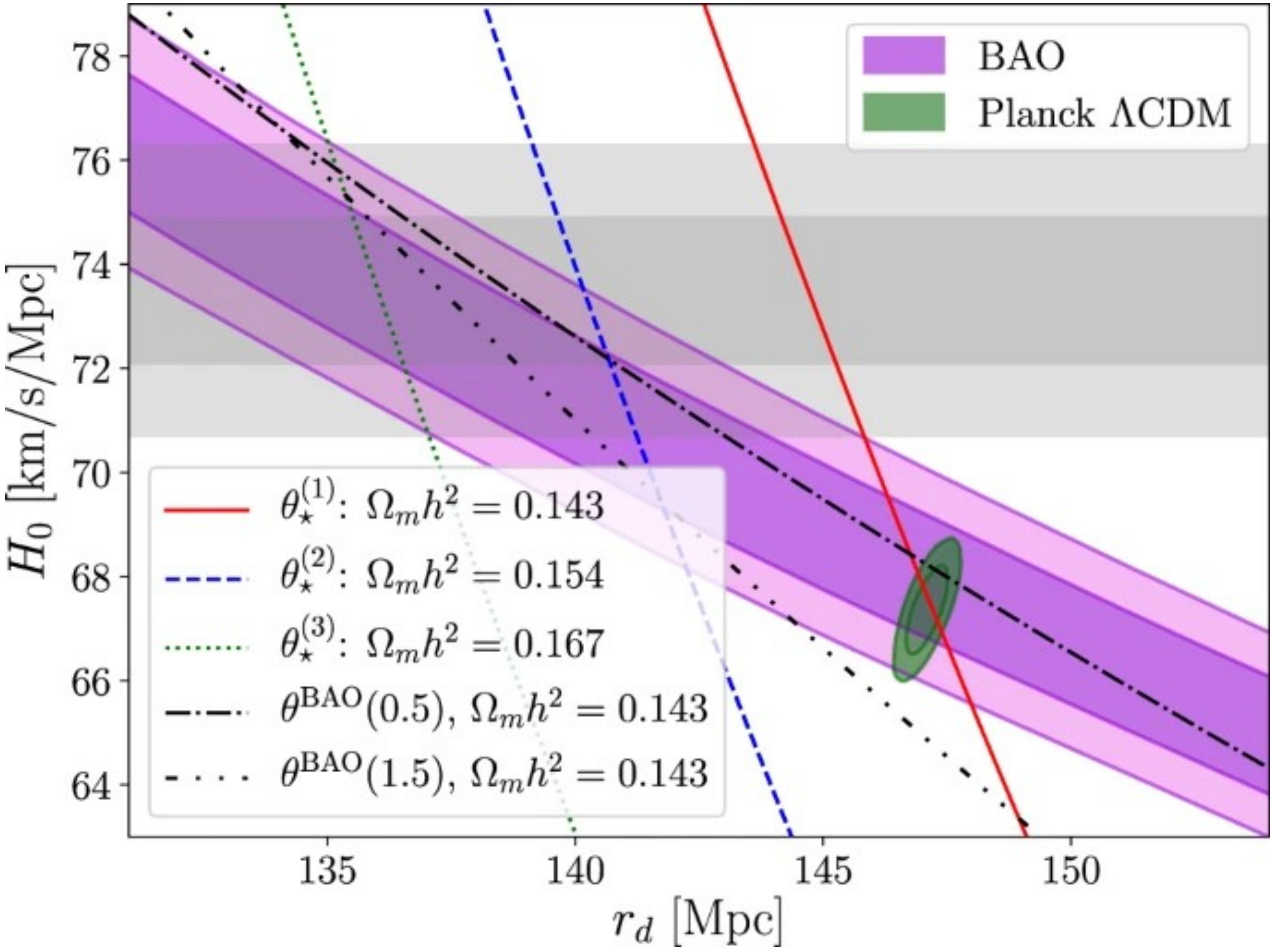
Pablo Lemos*, Elizabeth Lee, George Efstathiou, Steven Gratton
Kavli Institute for Cosmology Cambridge and Institute of Astronomy, Madingley Road, Cambridge, CB3 OHA.

If the tension between the CMB estimates of H_0 and direct measurements is a signature of new physics, then we need to introduce new physics in the early Universe. This new physics must lower the sound horizon by about 9% (i.e. to about 135 Mpc) compared to the values used in this paper while preserving the structure of the temperature and polarization power spectra measured by CMB experiments. This new physics also needs to preserve the consistency between BBN and observed abundances of light elements. These requirements pose interesting challenges for theorists.

BAO本身不能给予H0以很好地限制（测量张角）；需要通过重子过程确定绝对的横向尺度后，方可给出。

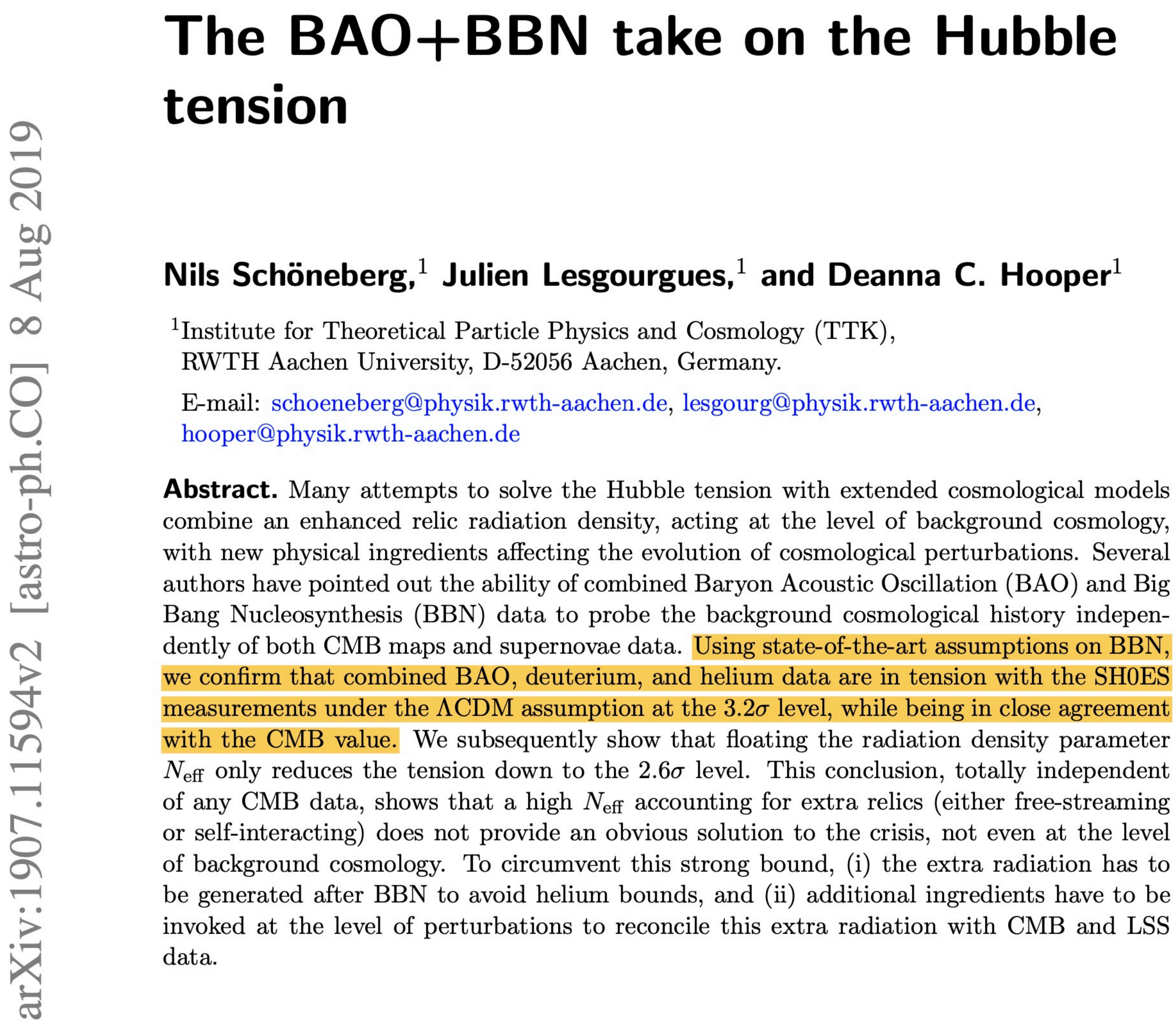
（CMB，BBN）

$$(\Omega_b, \Omega_m, H_0)$$



BAO+BBN（原初氘、氦丰度）/独立于CMB的测量结果

$$(\Omega_b, \Omega_m, H_0)$$



The BAO+BBN take on the Hubble tension

Nils Schöneberg,[1] **Julien Lesgourgues,**[1] **and Deanna C. Hooper**[1]

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hooper@physik.rwth-aachen.de

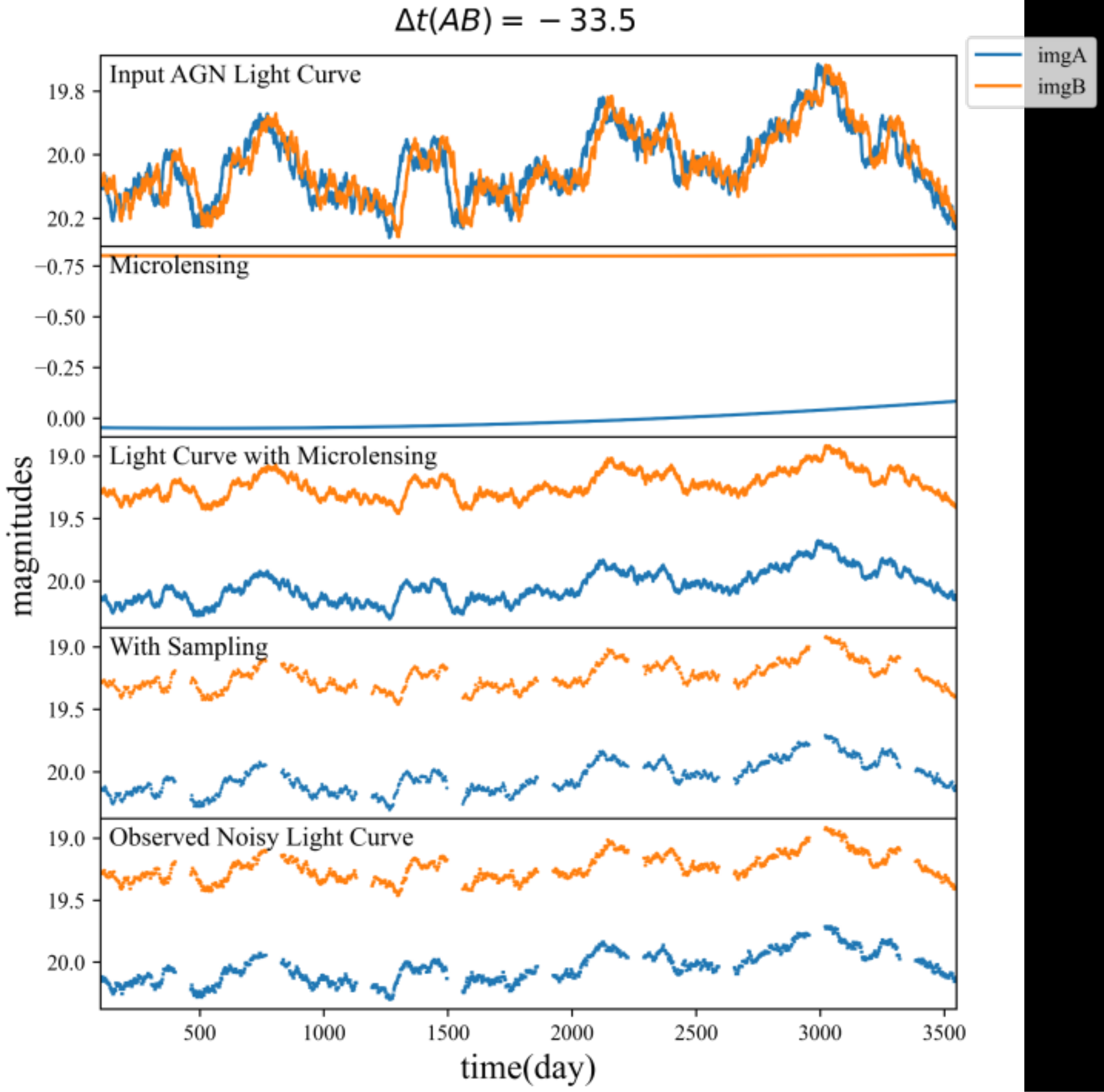
Abstract. Many attempts to solve the Hubble tension with extended cosmological models combine an enhanced relic radiation density, acting at the level of background cosmology, with new physical ingredients affecting the evolution of cosmological perturbations. Several authors have pointed out the ability of combined Baryon Acoustic Oscillation (BAO) and Big Bang Nucleosynthesis (BBN) data to probe the background cosmological history independently of both CMB maps and supernovae data. Using state-of-the-art assumptions on BBN, we confirm that combined BAO, deuterium, and helium data are in tension with the SH0ES measurements under the ΛCDM assumption at the 3.2σ level, while being in close agreement with the CMB value. We subsequently show that floating the radiation density parameter $N_{\rm eff}$ only reduces the tension down to the 2.6σ level. This conclusion, totally independent of any CMB data, shows that a high $N_{\rm eff}$ accounting for extra relics (either free-streaming or self-interacting) does not provide an obvious solution to the crisis, not even at the level of background cosmology. To circumvent this strong bound, (i) the extra radiation has to be generated after BBN to avoid helium bounds, and (ii) additional ingredients have to be invoked at the level of perturbations to reconcile this extra radiation with CMB and LSS data.

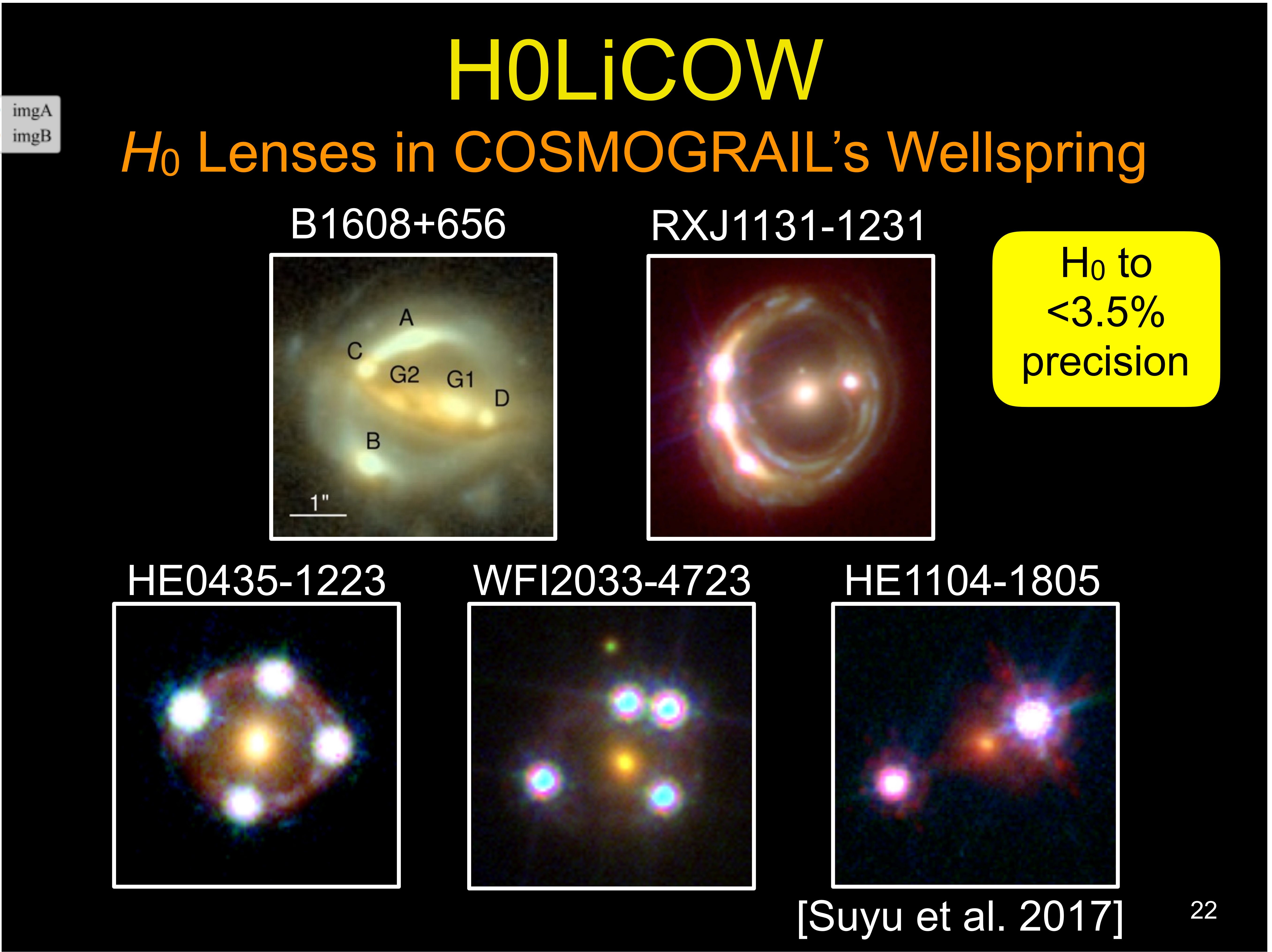
H0LiCOW

$$\Delta t = \frac{1}{c} D_L \Psi_{\text{Fermat}} \qquad D_L \propto \frac{1}{H_0}$$

multi images w 5% uncertainty

time delay
w 2% uncertainty




H0LiCOW

H_0 Lenses in COSMOGRAIL's Wellspring

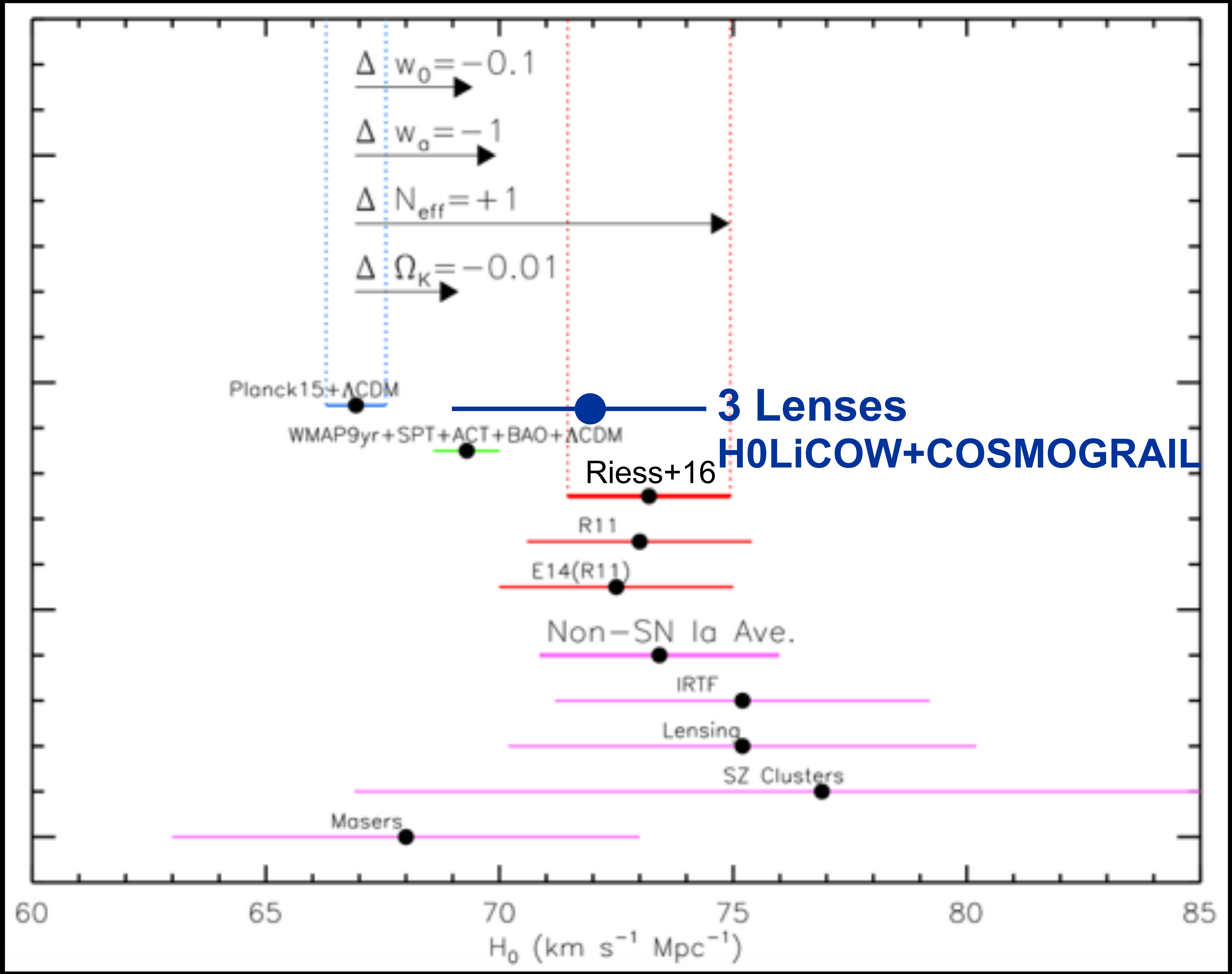
B1608+656
RXJ1131-1231
HE0435-1223
WFI2033-4723
HE1104-1805

H_0 to
<3.5%
precision

[Suyu et al. 2017]

22

H_0 with 3 Lenses



[Riess et al. 2016]

哈勃危机的中国方案


全球安全倡议：破解安全困境的中国方案
The Global Security Initiative: China's Proposal for Solving Security Challenges
Organizer: China Public Diplomacy Association
Sponsors: Chongyang Institute for Financial Studies, Renmin University of China(RDCY)
Institute for Global Cooperation and Understanding, Peking University
Supported by: Ministry of Foreign Affairs of the People's Republic of China
2023年2月21日
中国 · 北京
February 21, 2023
Beijing, China
LANTING FORUM
蓝厅论坛
AP

减小声视界r_s

$$r_s = \int_{z_*}^{\infty} \frac{c_s}{H(z)} dz$$

在recombination时期之前增加总能量

- 修改z_*（->光子退耦温度）=> 热力学过程
- 修改$c_s^2 \equiv [3(1+R)]^{-1}$
- 修改$H^2(z > z_*) = \frac{8\pi G}{3}\rho(z)$
  - G => 修改引力
  - ρ => 新能量组分

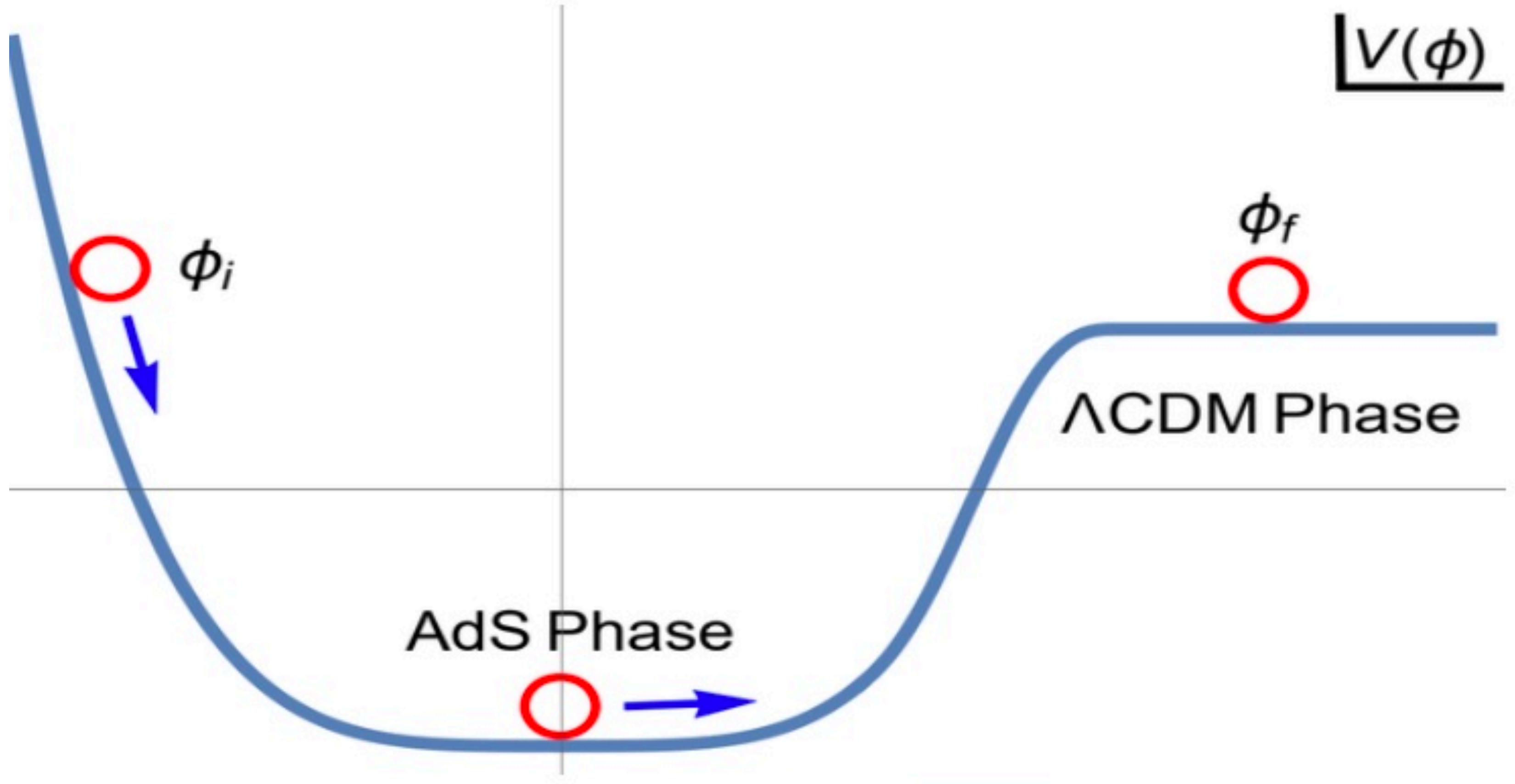
[credit: 叶根 (朴云松)]

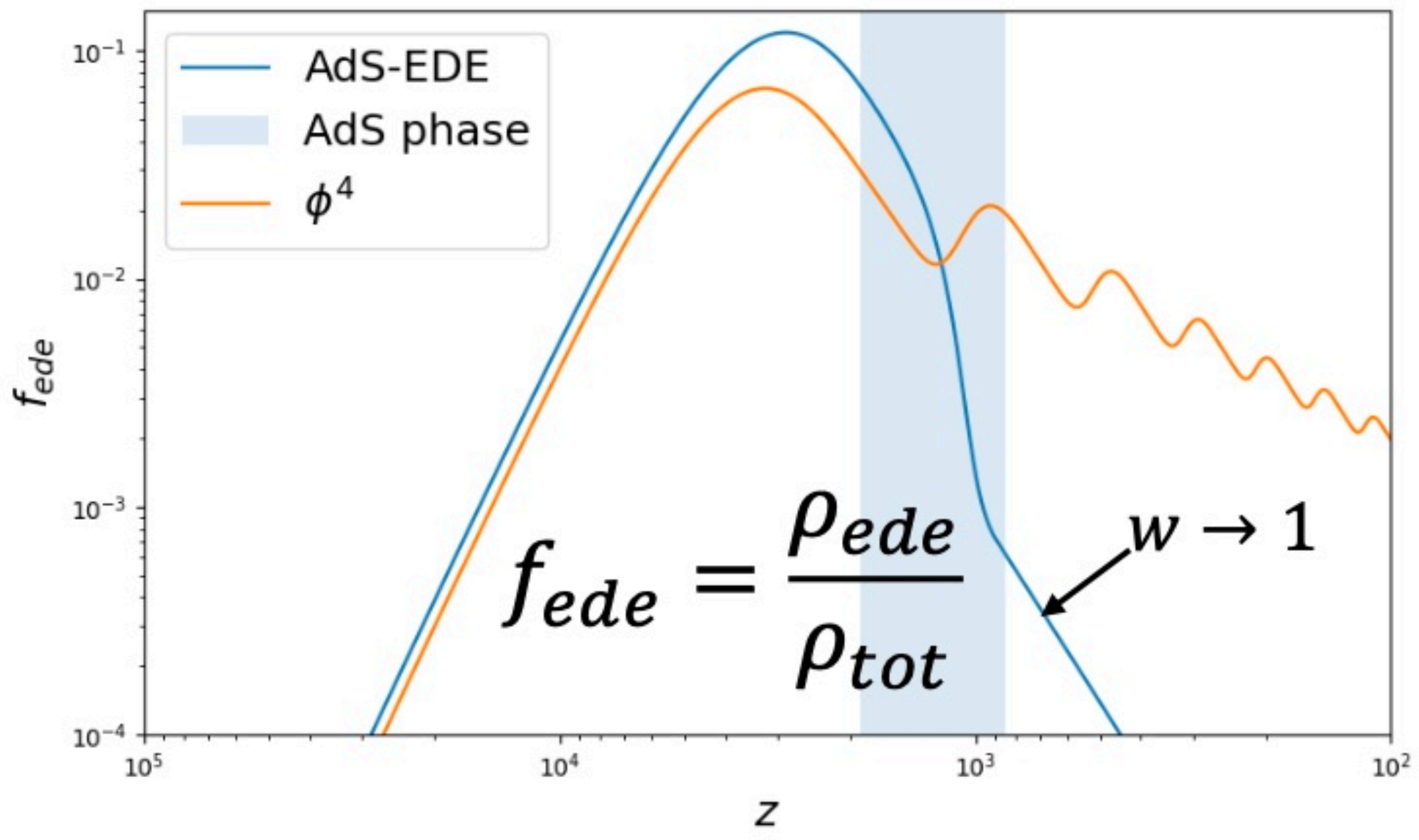
AdS-EDE的好处在于：AdS相中，EDE组分衰减够快。所以早期可以产生很多而不残留！

Phys.Rev.D 101 (2020) 8, 083507

AdS-EDE

University of Chinese Academy of Sciences





- 优化EDE核心机制

$$w = \frac{P}{\rho} = \frac{\dot{\phi}^2/2 - V}{\dot{\phi}^2/2 + V}$$

- 动能主导 $w \rightarrow 1$
- 滚动势($w \rightarrow 1$)提升微小

(Lin M.X., Benevento G., Hu W. and Raveri M., Phys.Rev.D 100 (2019) 6, 063542)

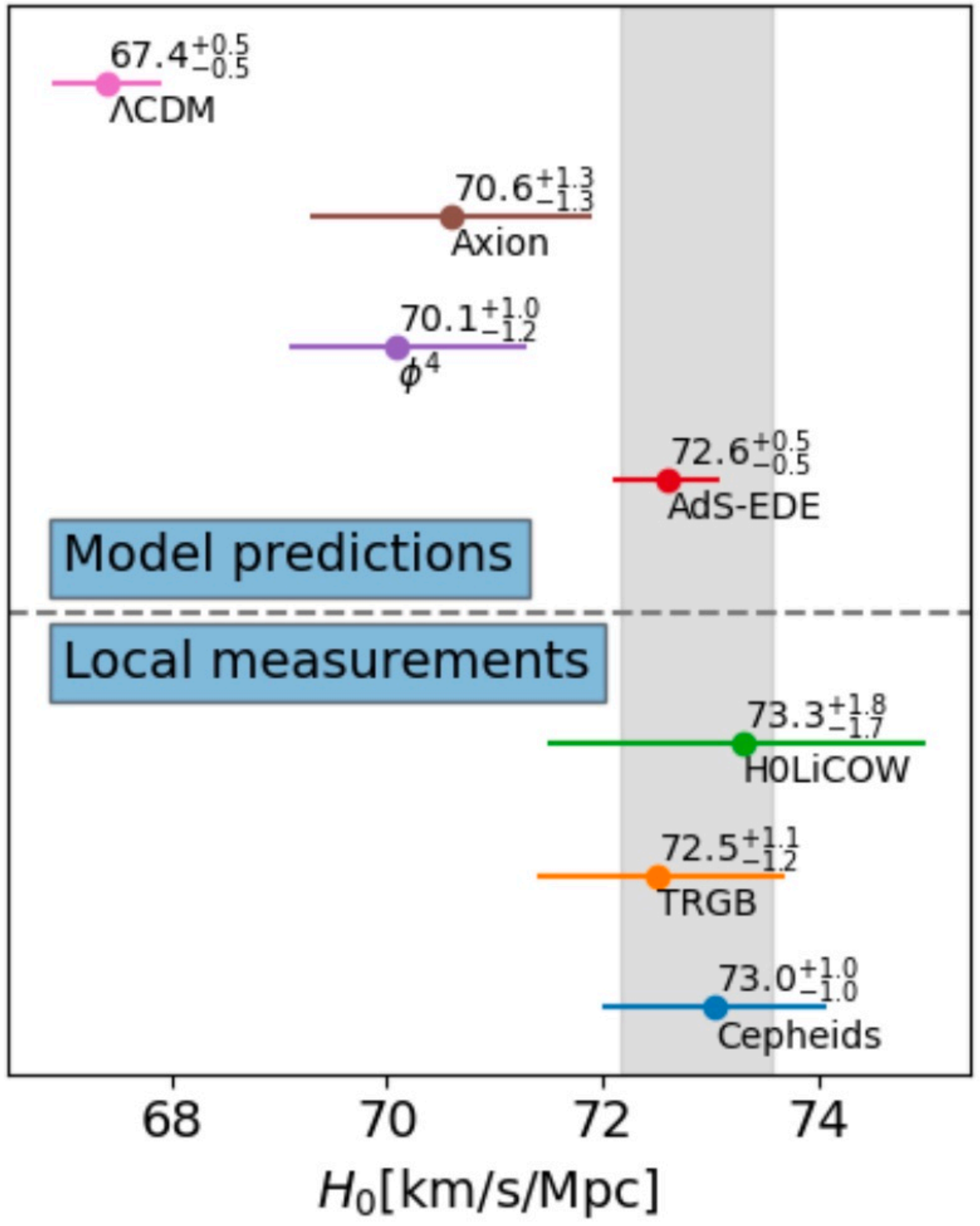
- AdS (V<0) $w > 1$

[credit: 叶根 (朴云松)]

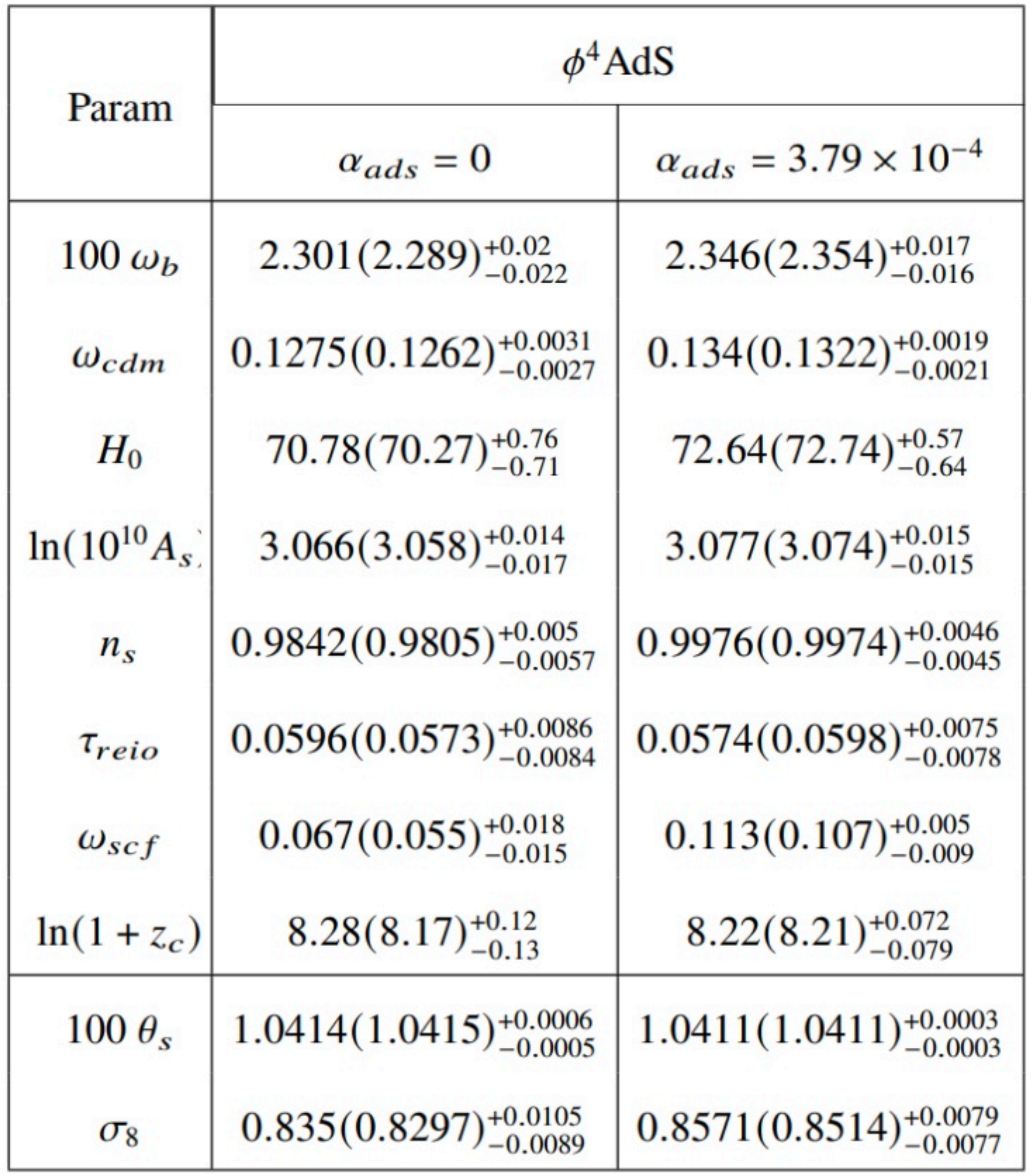
Phys.Rev.D 101 (2020) 8, 083507

AdS-EDE：结果

$$\{\omega_c, \omega_b, H_0, \tau_{rei}, \ln 10^{10} A_s, n_s, \ln(1+z_c), f_{ede}\}$$



- Planck18+BAO+SNIa+R19



Param	ϕ^4AdS	
	$\alpha_{ads} = 0$	$\alpha_{ads} = 3.79 \times 10^{-4}$
$100\,\omega_b$	$2.301(2.289)^{+0.02}_{-0.022}$	$2.346(2.354)^{+0.017}_{-0.016}$
ω_{cdm}	$0.1275(0.1262)^{+0.0031}_{-0.0027}$	$0.134(0.1322)^{+0.0019}_{-0.0021}$
H_0	$70.78(70.27)^{+0.76}_{-0.71}$	$72.64(72.74)^{+0.57}_{-0.64}$
$\ln(10^{10}A_s$	$3.066(3.058)^{+0.014}_{-0.017}$	$3.077(3.074)^{+0.015}_{-0.015}$
n_s	$0.9842(0.9805)^{+0.005}_{-0.0057}$	$0.9976(0.9974)^{+0.0046}_{-0.0045}$
τ_{reio}	$0.0596(0.0573)^{+0.0086}_{-0.0084}$	$0.0574(0.0598)^{+0.0075}_{-0.0078}$
ω_{scf}	$0.067(0.055)^{+0.018}_{-0.015}$	$0.113(0.107)^{+0.005}_{-0.009}$
$\ln(1+z_c)$	$8.28(8.17)^{+0.12}_{-0.13}$	$8.22(8.21)^{+0.072}_{-0.079}$
$100\,\theta_s$	$1.0414(1.0415)^{+0.0006}_{-0.0005}$	$1.0411(1.0411)^{+0.0003}_{-0.0003}$
σ_8	$0.835(0.8297)^{+0.0105}_{-0.0089}$	$0.8571(0.8514)^{+0.0079}_{-0.0077}$

[credit: 叶根 (朴云松)]