Measuring the Hubble constant with next-generation galaxy surveys

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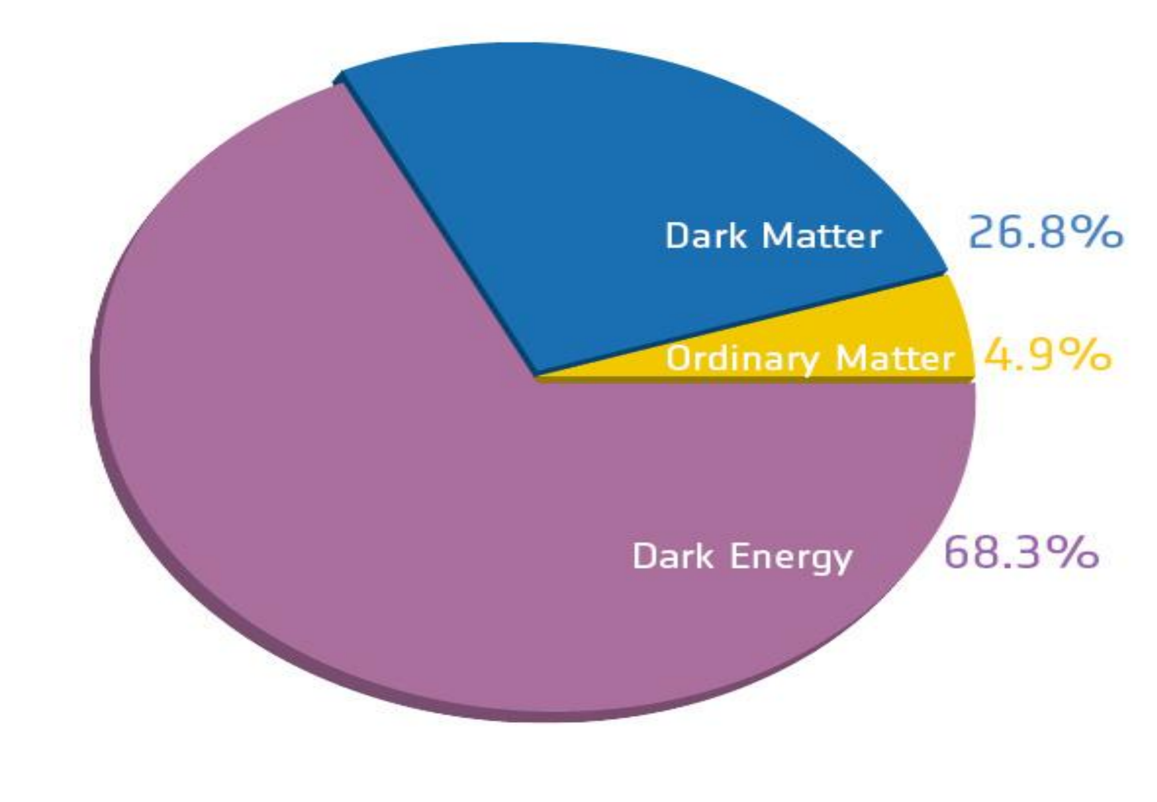
Outline

- The concordance model of Cosmology
- The trouble with Hubble
- Measuring Hubble Constant with next-generation surveys
- Results and conclusions

The concordance model of Cosmology

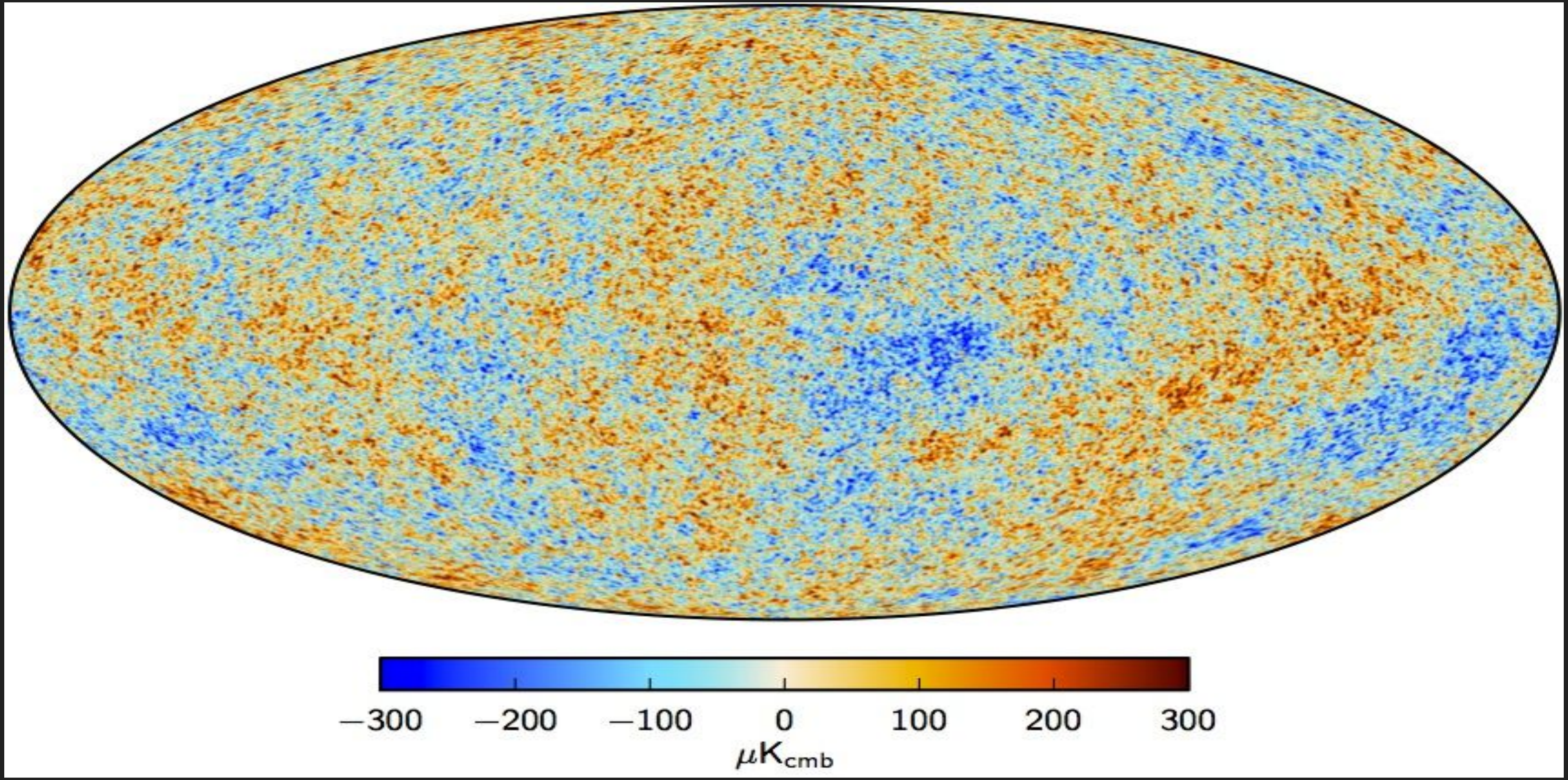


Credits: Planck Collaboration

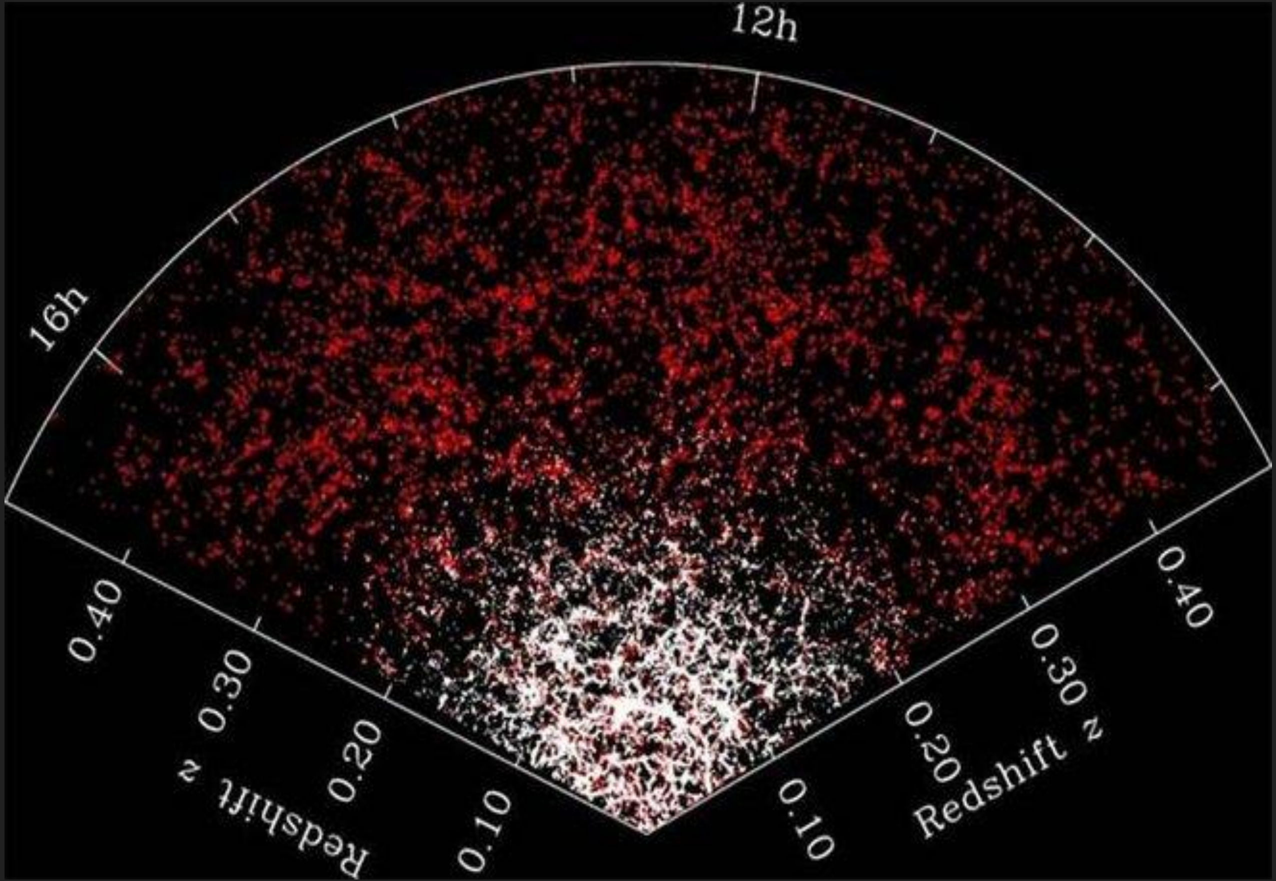
What is dark matter?

What is dark energy?

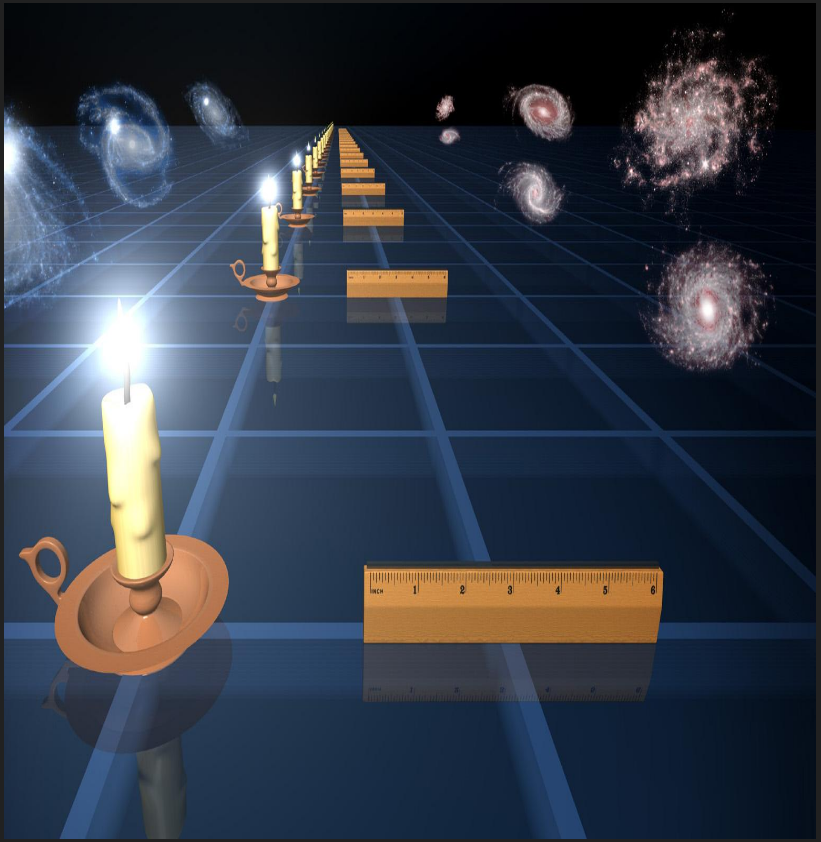
The Cosmic Microwave Background (CMB)

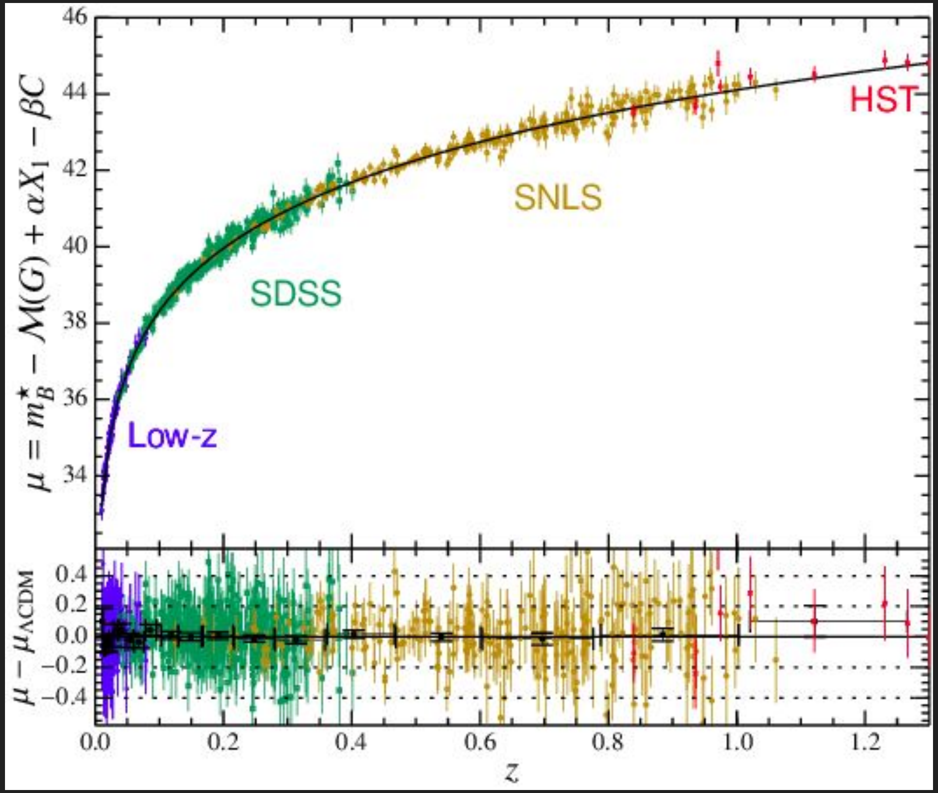


The galaxy distribution in the large-scale structure of the Universe



The distance to Type Ia Supernovae (SNe)





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What’s going on???

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2019 status: Planck 2018 measured H0 = 67.36 \pm 0.54 km/s/Mpc, and updated SN distance ladder gave H0 = 74.03 \pm 1.42 km/s/Mpc
=> $\sim 4.4\sigma$ tension!

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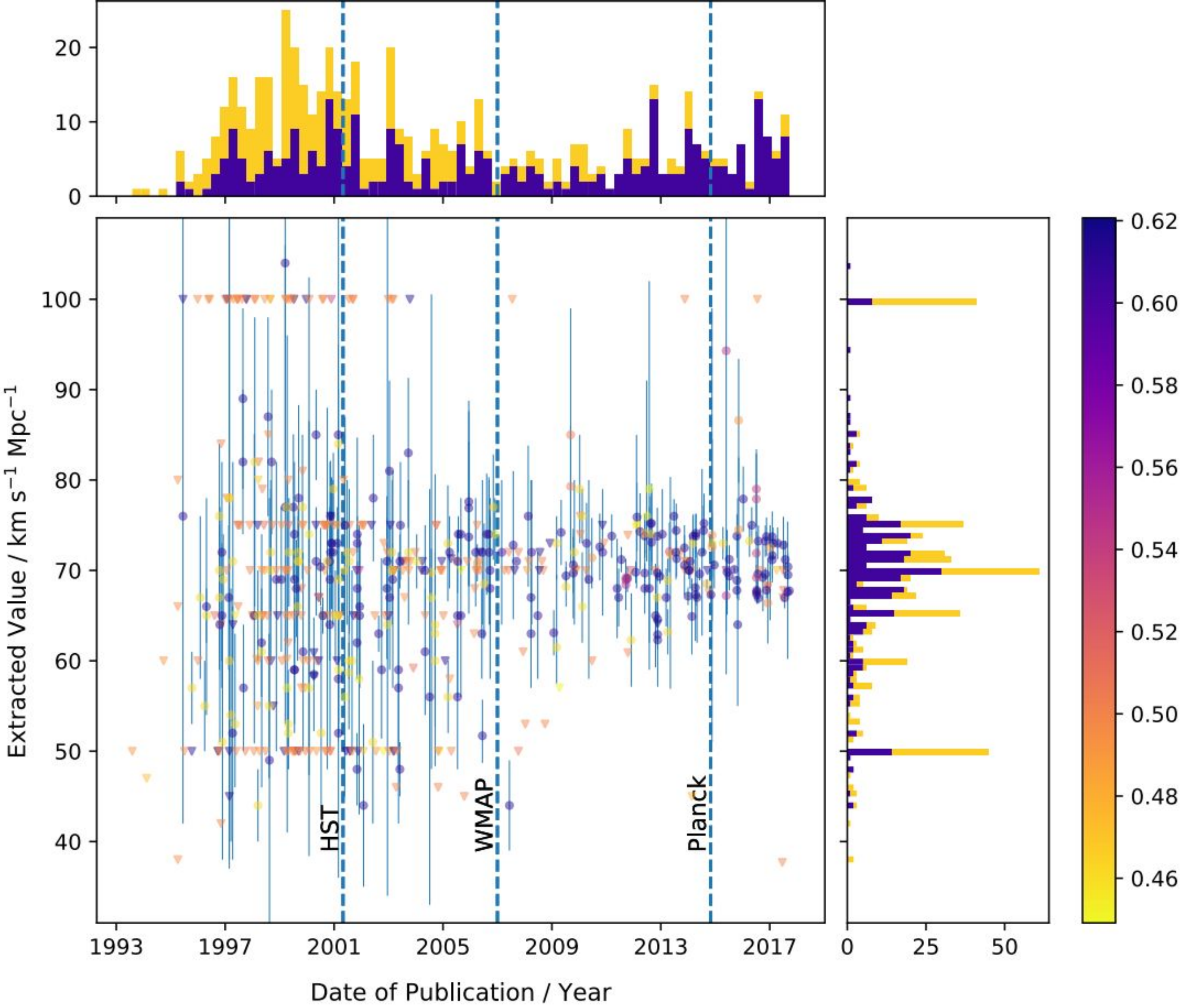
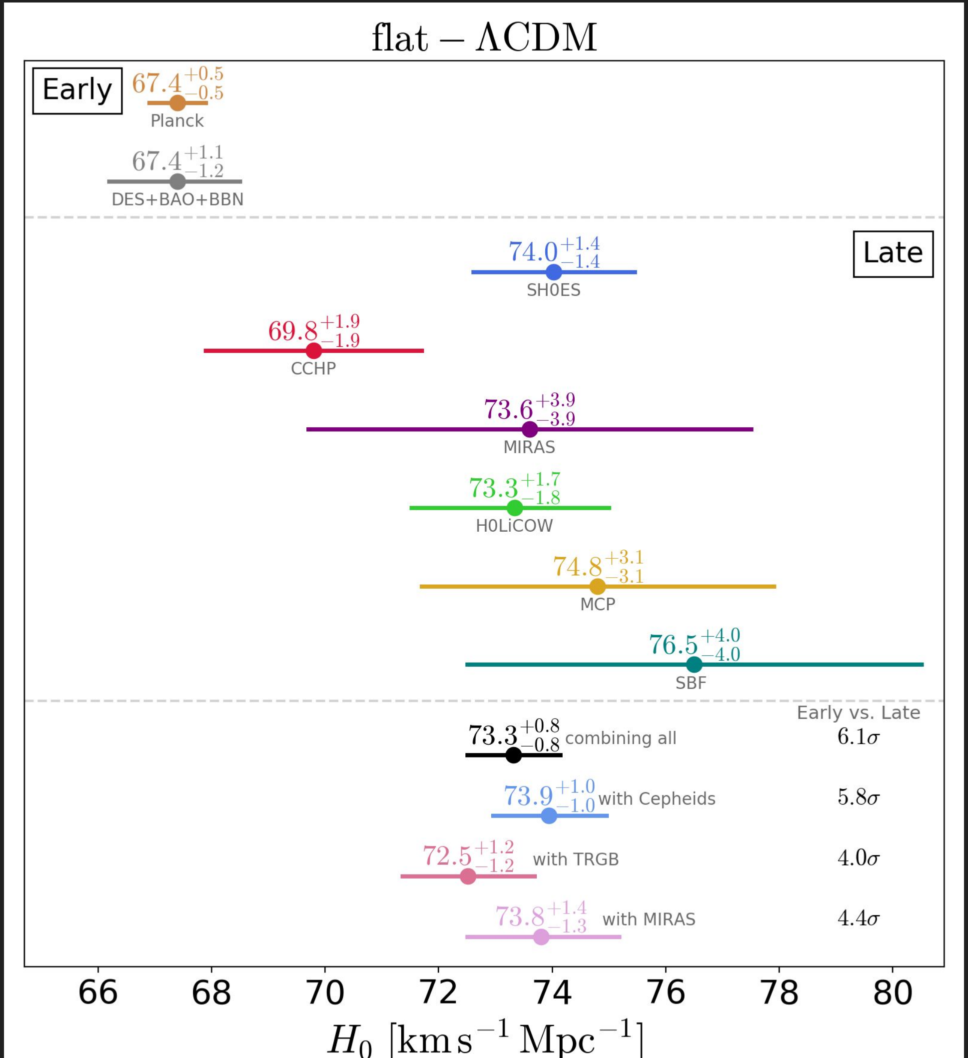
New measurements from strongly lensed quasars and TRGBs distance ladder only cast further doubts.



Crossland et al. 2019, arXiv:1902.00027



Credits: Verde et al

arXiv:1907.10625

The H0 tension is persisting now for more than 6 years and no compelling solution has appeared so far.

What can we do?

- Focus on model building of early- or late-Universe
- Focus on recalibration of the distance ladder
- Focus on forecasting errors from future surveys

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This work

- How well can we measure H0 with future redshift surveys like SKA and Euclid?
- Model-independent approach using Gaussian processes - tells H0 regardless of the cosmological model assumed
- If we can measure H0 down to a few per cent, we can tell early- and late-Universe H0 values apart at ~5sigma. But can we?

The Hubble constant tension with next generation galaxy surveys

Carlos A. P. Bengaly, Chris Clarkson, Roy Maartens

(Submitted on 13 Aug 2019)

The rate at which the universe is expanding today is a fundamental parameter in cosmology which governs our understanding of structure formation and dark energy. However, current measurements of the Hubble constant, H_0, show a significant tension ($\sim 4-6\sigma$) between early- and late-Universe observations. There are ongoing efforts to check the diverse observational results and also to investigate possible theoretical ways to resolve the tension~-- which could point to radical extensions of the standard model. Here we demonstrate the potential of next-generation spectroscopic galaxy surveys to shed light on the Hubble constant tension. Surveys such as those with Euclid and the Square Kilometre Array (SKA) are expected to reach sub-percent precision on Baryon Acoustic Oscillation (BAO) measurements of the Hubble parameter, with a combined redshift coverage of $0.1 < z < 3$. This wide redshift range, together with the high precision and low level of systematics in BAO measurements, mean that these surveys will provide independent and tight constraints on $H(z)$. These $H(z)$ measurements can be extrapolated to $z = 0$ to provide constraints on H_0, which can be model independent if we use non-parametric regression. To this end we use Gaussian processes and we find that Euclid-like surveys can reach $\sim$3\% precision on H_0, with SKA-like intensity mapping surveys reaching $\sim$2\%. When we combine the low-redshift SKA-like Band 2 survey with either its high-redshift Band 1 counterpart, or with the non-overlapping Euclid-like survey, the precision is predicted to be close to 1\% with 40 $H(z)$ data points. This would be sufficient to rule out the current early- or late-Universe measurements at a $\sim 5\sigma$ level.

Work Outline

- Simulate H(z) data following Euclid- and SKA-like (B1 and B2) surveys, with uncertainties taken from SKA1 red book (arxiv:1811.02743)

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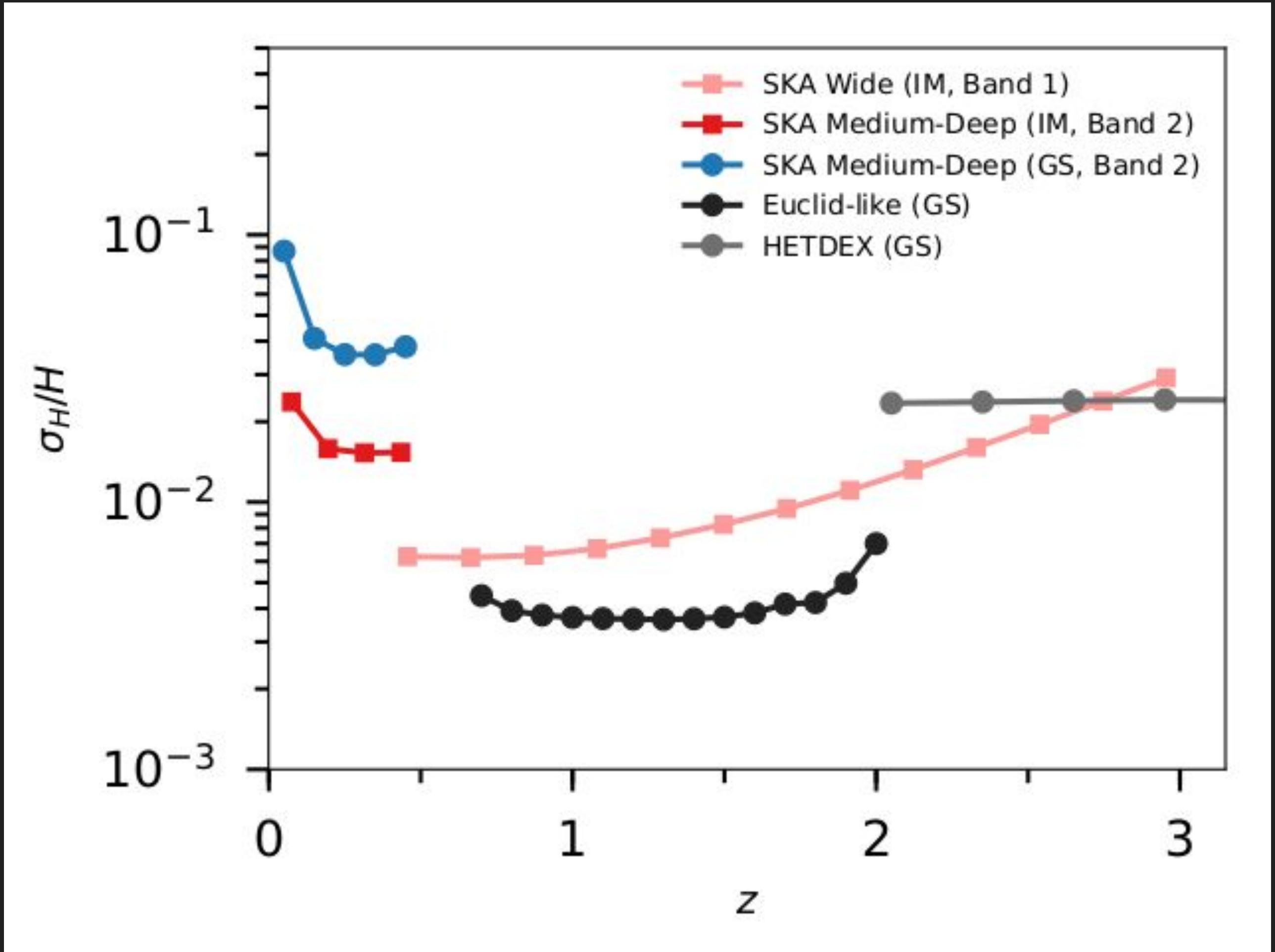
- Fiducial model based on Planck 2018 flat LCDM best-fit

- Rather than forecasting H0 uncertainty using eg Fisher Matrix, we perform a non-parametric regression over the H(z) data points all the way to H(z=0) using Gaussian Processes GaPP code
  http://www.acgc.uct.ac.za/~seikel/GAPP/index.html
  Seikel, Clarkson & Smith JCAP 1206 (2012) 036



Credits: SKA1 red book Arxiv:1811.02743

Note: we fit a polynomal curve through sigH/H to get the H(z) uncertainty at a given redshift.

The method

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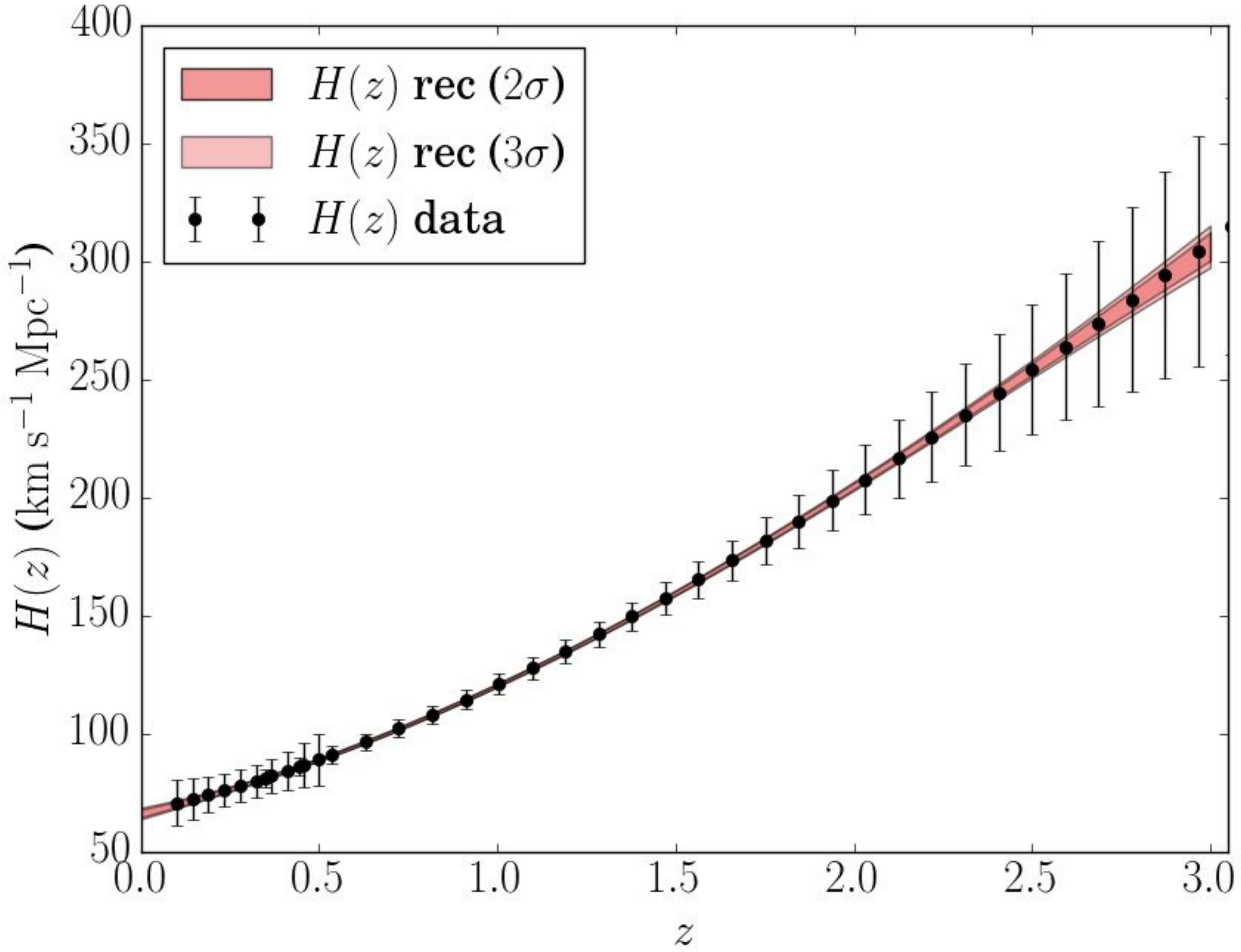
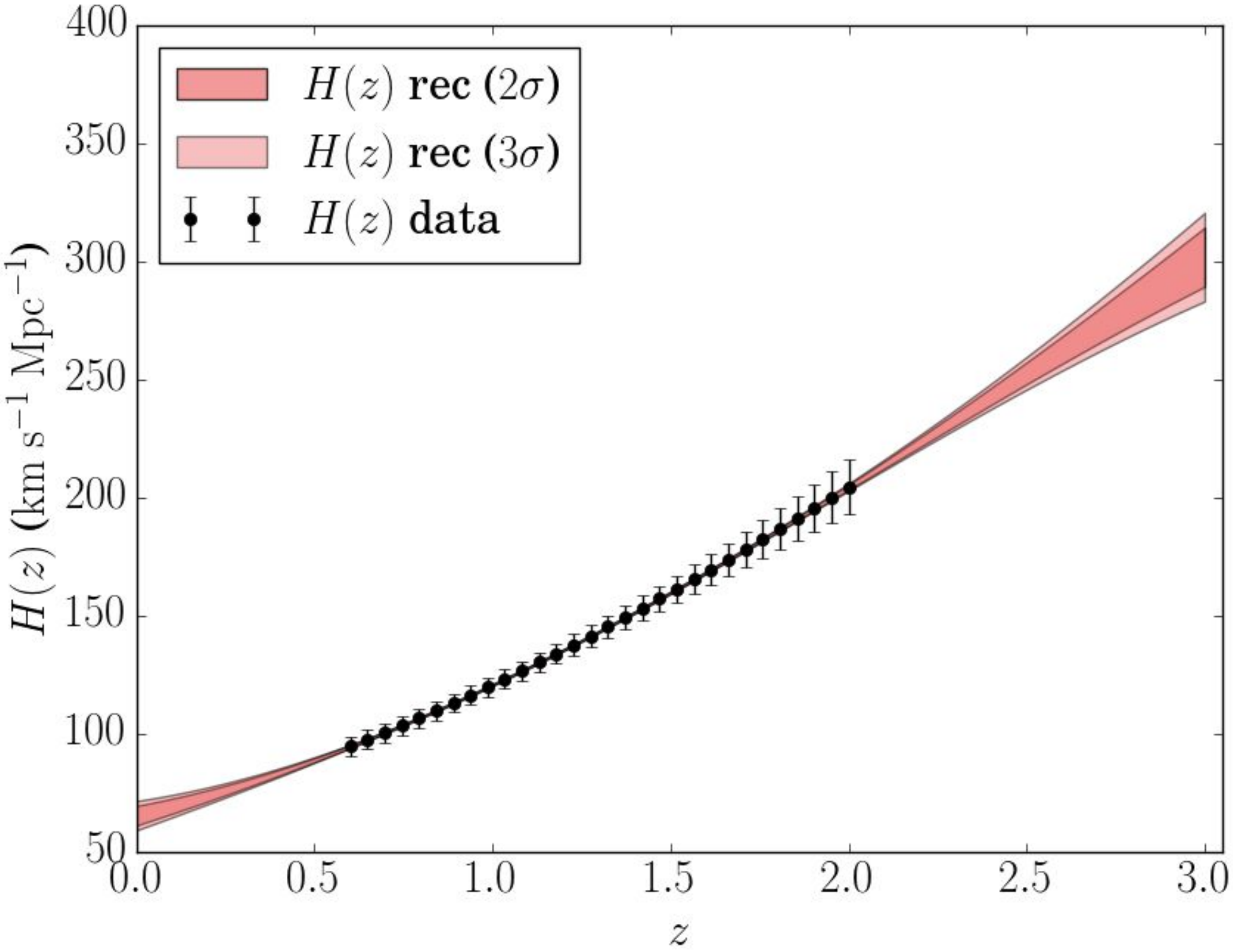
- We will look for a function that best describes the data, and then extrapolate it to other redshift ranges. A model-independent approach

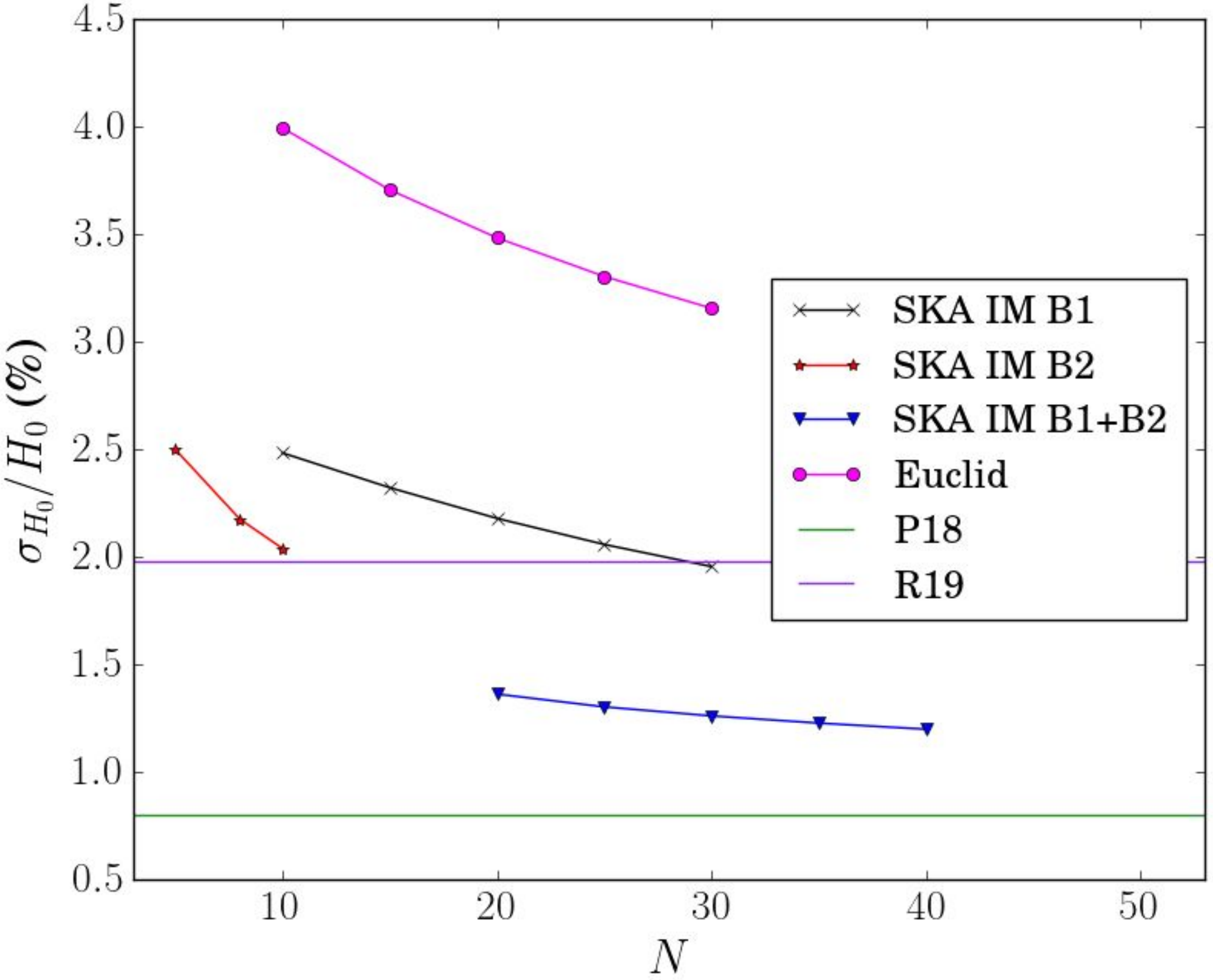
Results

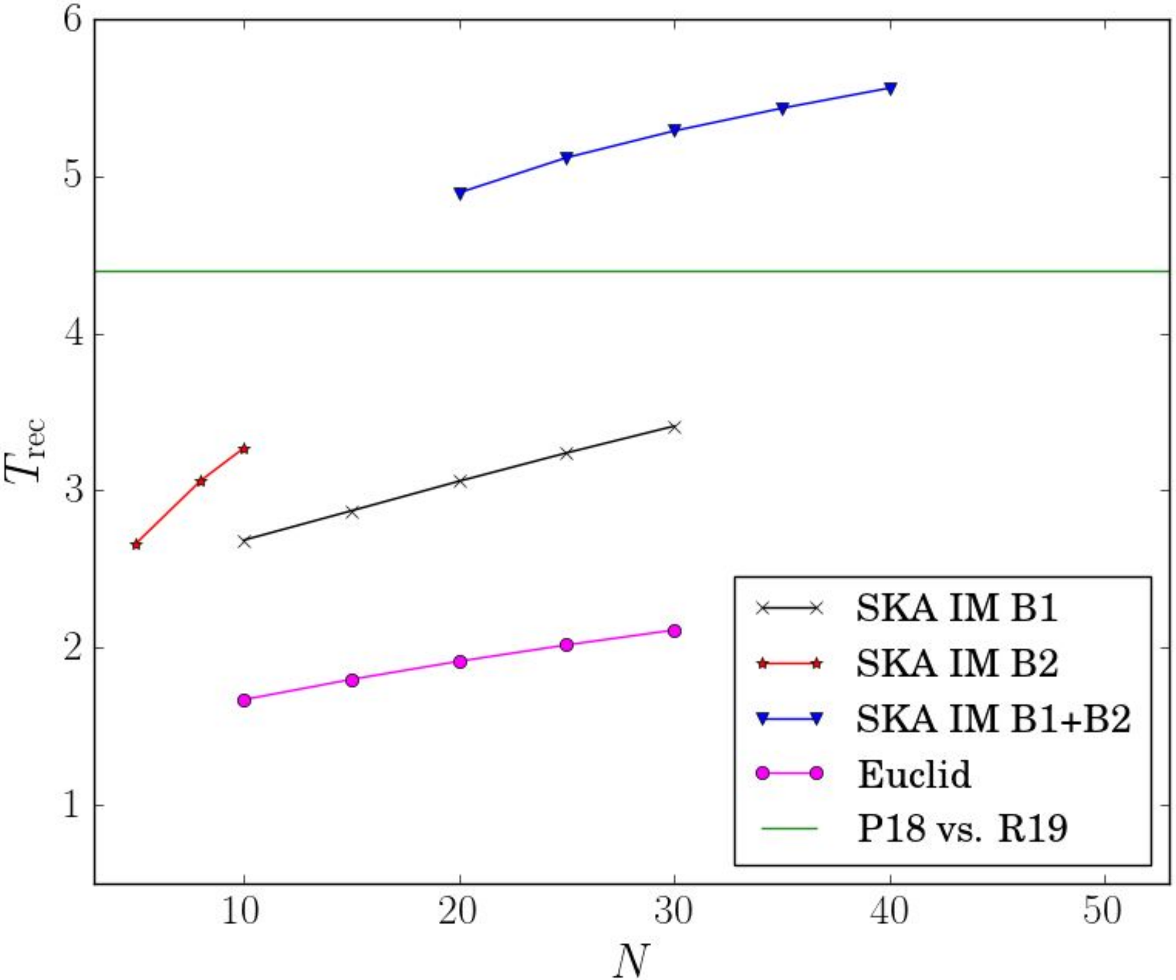


Note: Error bars x 6



Note: Error bars x 10


4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
σ_{H_0}/H_0 (%)
10
20
30
40
50
N
SKA IM B1
SKA IM B2
SKA IM B1+B2
Euclid
P18
R19



$T_{\rm rec}$
N
SKA IM B1
SKA IM B2
SKA IM B1+B2
Euclid
P18 vs. R19

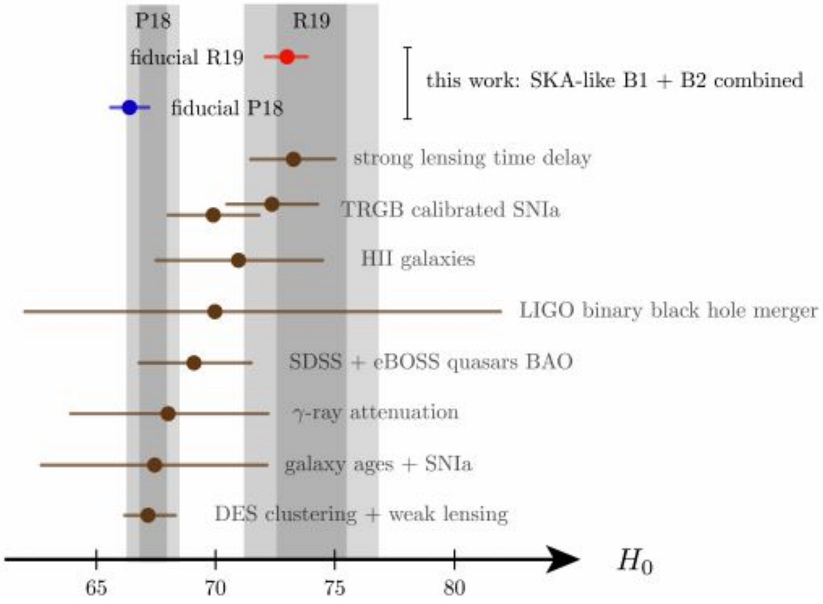


FIG. 3. Compilation of H_0 measurements, with 1σ error bars, shown against 1σ (darker) and 2σ (lighter) error bands for P18 (left) and R19 (right). From bottom to top: DES clustering + weak lensing [37]; galaxy ages + SNIa [19]; γ-ray attenuation [35]; SDSS + eBOSS quasars BAO (direct estimate of H_0) [18]; LIGO binary black hole merger GW170817 [39]; HII galaxies [36]; TRGB calibrated SNIa [7, 8]; strong lensing time delay [6]. Our GP-reconstructed estimates for SKA-like B1+B2 combined are: (fiducial P18, in blue) and (fiducial R19, in red), where the dots indicate the reconstructed $H_0^{\rm P18}$ and $H_0^{\rm R19}$.

Conclusions

- Using a non-parametric analysis, we find that Euclid- (SKA B1)-like surveys will measure H0 at 3% (2%) precision. Combining 20+10 data points of SKA-like B1+B2 improves it to ~1% level.
  Note: Similar results were obtained for Euclid-like + B2

- These results do not depend on any cosmological model, or assumptions about the Gaussian Process kernel etc.

- Future redshift surveys will be able to tell the two conflicting H0 values apart at ~5sigma level - thus showing possible directions to solve this tension

THANKS!

OBRIGADO!

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- **Gaussian Processes (GP):** "A Gaussian Process is a collection of random variables, any finite number of which have (consistent) joint gaussian distributions"

- In other words: GP consists on a **distribution of functions** rather than a **distribution of values**

$$k(x^* x) = \sigma_f^2 \exp\left[\frac{(x - x^*)^2}{2I^2}\right]$$

$$f(x) \sim \mathrm{GP}(\mu(x), k(x^*, x))$$

$$k(x^* x) = \sigma_f^2 \frac{2^{1-\nu}}{\Gamma(\nu)} \left[\frac{\sqrt{2\nu(x - x*)^2}}{I}\right]^{\nu} \mathcal{K}_\nu \left(\frac{\sqrt{2\nu(x - x*)^2}}{I}\right)$$