PROSPECTS FOR THE EXTRAGALACTIC DISTANCE SCALE WITH TMT

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OUTLINE

Motivation

- Current status of the Extragalactic Distance Scale
- The landscape in 2022
- Possible TMT programs

MOTIVATION: WHAT IS THE NATURE OF DARK ENERGY?





BASED ON WEINBERG+ (2012)

"NEW PHYSICS" BEYOND ACDM?

- 3.3σ tension between <u>predictions</u> from *Planck*. (ΛCDM) and local <u>measurements</u> of H₀ may be a hint of additional relativistic species in early Universe
- "Dark radiation" is parameterized as an increase in N_{eff}



DVORKIN+ (2014); RIESS+ (2016)

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CURRENT STATUS

• Cepheids

- $\circ~0 \lesssim log~P(d) \lesssim 2$; -2 $\lesssim M_I \lesssim$ -8 ; -3 $\lesssim M_K \lesssim$ -9
- Best method to estimate distances for moderately-inclined galaxies with recent star formation
- Can be efficiently discovered using 8-m telescopes out to ~10 Mpc (Fassnaugh+'15; Hoffmann & Macri '15)
- $\circ\,$ "Easily" observable with HST out to ${\sim}50~{\rm Mpc}$
- Used to calibrate SNe Ia & determine H₀ to 2.4% (Riess, Macri+ 2016)

CEPHEIDS TO 40MPC WITH HST

- Cepheids in 19 hosts of modern SNe Ia + 4 calibrators
- >1500 with homogeneous HST photometry
 - +800 with ground-based observations



PERIOD (DAYS)

RIESS, MACRI+ (2016)

CEPHEIDS TO 40MPC WITH HST



RIESS, MACRI + (2016)

CURRENT STATUS

• RR Lyraes

- -0.7 $\lesssim \log P(d) \lesssim 0$; 0 $\lesssim M_{I},\!M_{K} \lesssim$ -1
- Old, low-mass stars: present in any galaxy type
- Currently limited to M31 + Sculptor (D ≤2 Mpc) w/HST (Contreras-Ramos+ '13; Rejkuba+ '11)

• Miras

- $2 \leq \log P(d) \leq 3$; $-6 \leq M_K \leq -11$
- Low/Intermediate-mass stars: present in any galaxy type
- Currently limited to Local Group + Cen A (D ≤4 Mpc) (Javadi+ '11; Rejkuba+ '03)

LMC-BASED CALIBRATIONS

- All variable types can be absolutely calibrated in LMC
 - Distance to 2% via eclipsing binaries (Pietrzynski+'13)
 - Discovered by OGLE surveys (Soszynski+ '08ab, '09ab)
 - NIR light curves from LMCNISS, VMC, others



LMC-BASED CALIBRATIONS







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THE LANDSCAPE IN 2022

• Gaia

• Final data release (astrometry, photometry, RVs)

• JWST

• Cycle 4(?) under way

• LSST

• Start of survey operations

• TMT

• T-5 years and counting...



THE LANDSCAPE IN 2022

• Gaia

• ~9,000 Galactic Cepheids; P-L zeropoint to 0.3-0.6%

• JWST

• ~50 additional SNe Ia hosts to D~50 Mpc \rightarrow H₀ to 1%

• LSST

 $\circ\,$ Cepheids & Miras in ~80 Sp/Irr galaxies (D $\lesssim 10$ Mpc)

• TMT

• T-5 years and counting...

GAIA DISCOVERY OF & PARALLAXES TO MILKY WAY CEPHEIDS BY 2022

Cepheid population of Milky Way:
 N_{TOT}~ 20,000; N_{Gaia}~ 9,000

- Uncertainty in Period-Luminosity relation parameters:
 - Slope: 0.1-0.2%
 - Zeropoint: 0.3-0.6%
 - Range reflects uncertainties due to dust corrections



WINDMARK, LINDEGREN & HOBBS (2011)

JWST'OBSERVATIONS

- JWST+NIRCam improves over HST+WFC3
 - 4× finer sampling & 3× resolution
 - Similar FoVs (123" vs 130")
- But it's still a modest aperture telescope...
 - 3hr to SNR~10 for P=20d Cepheid @ 50 Mpc in J+K
 - At least 10 epochs needed to obtain periods

JWST'OBSERVATIONS

• Imagine 4× finer sampling & 3× resolution...



LSST SENSITIVITY TO CEPHEIDS



LSST SENSITIVITY TO MIRAS?

- Newly developed Gaussianprocess periodogram is very successful at detecting Miras using sparse, noisy datasets and providing robust period estimates [example: M33]
- Bodes well for searches with better-quality LSST data!
- NIR followup critical for accurate distances, population studies



YUAN, MACRI+ (IN PREP)

OUTLINE

✓ Motivation

✓ Current status of the Extragalactic Distance Scale

 \checkmark The landscape in 2022

Possible TMT programs

TMT OBSERVATIONS

- TMT+IRIS improves over JWST+NIRCam
 - ~9× finer sampling, ~5× better resolution
 → greatly reduce impact of crowding & blending
- FoV considerably smaller...
 - 34" vs 123"
 - But much larger aperture!
 - 5, 15 min to SNR~10 for P=20d Cepheid @ 50 Mpc in J&K
 - 1, 2 hr for same object @ 100 Mpc



POSSIBLE TMT PROGRAMS

- Follow-up imaging of JWST/NIRCam fields
 - Single epoch @ higher angular resolution to mitigate crowding issues
- New Cepheid distances to objects of interest
 - Hosts of rare/interesting objects from ZTF/LSST for which precise luminosity calibration is desired
 - Next-gen bulge luminosity vs. black hole mass relations
 - Photometric calibration with 8-m observations
- Study of Mira populations in different environments
 Follow-up LSST discoveries (2025 and beyond)
- RR Lyrae in Virgo? (massive investment of time...)