Time-domain observations of stellar populations with TMT

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Outline

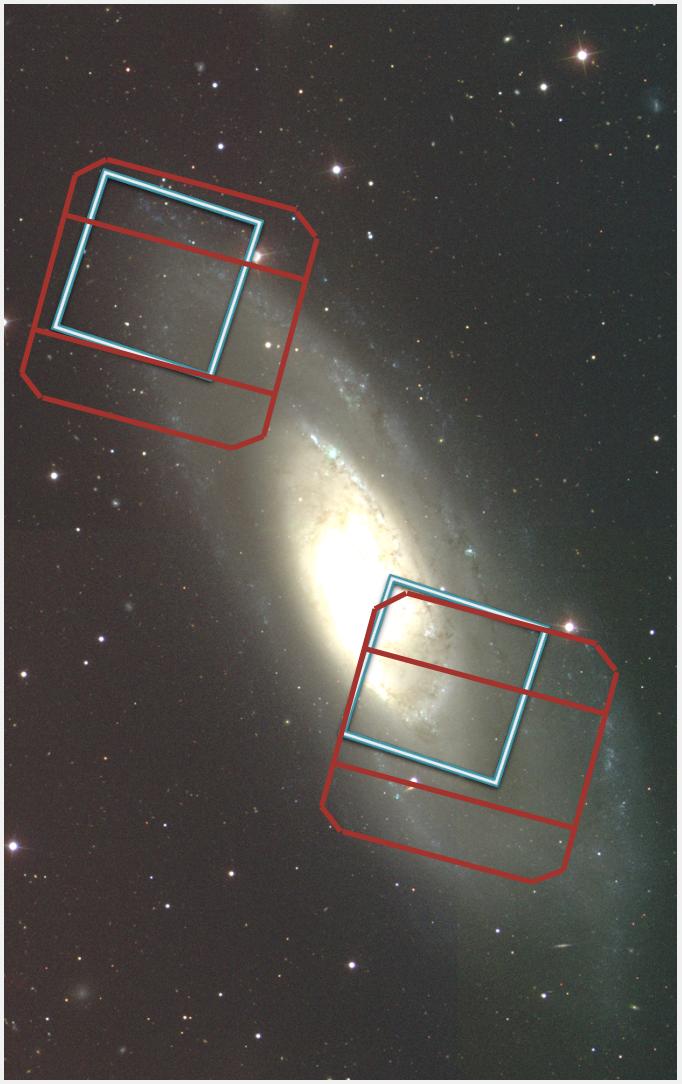
- **Current status & motivation**
- The landscape in 2022
- TMT observations of variable stars

Current status & motivation

- Cepheids
  - $0 \lesssim \log P \lesssim 2$; $-2 \lesssim M_I \lesssim -8$; $-3 \lesssim M_K \lesssim -9$
  - 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)
  - "Easily" observable with HST out to ~40 Mpc
  - Used to calibrate SNe Ia & determine H_0 to 3% (Riess, Macri+ 2011)

P-L RELATIONS IN MESSIER 106

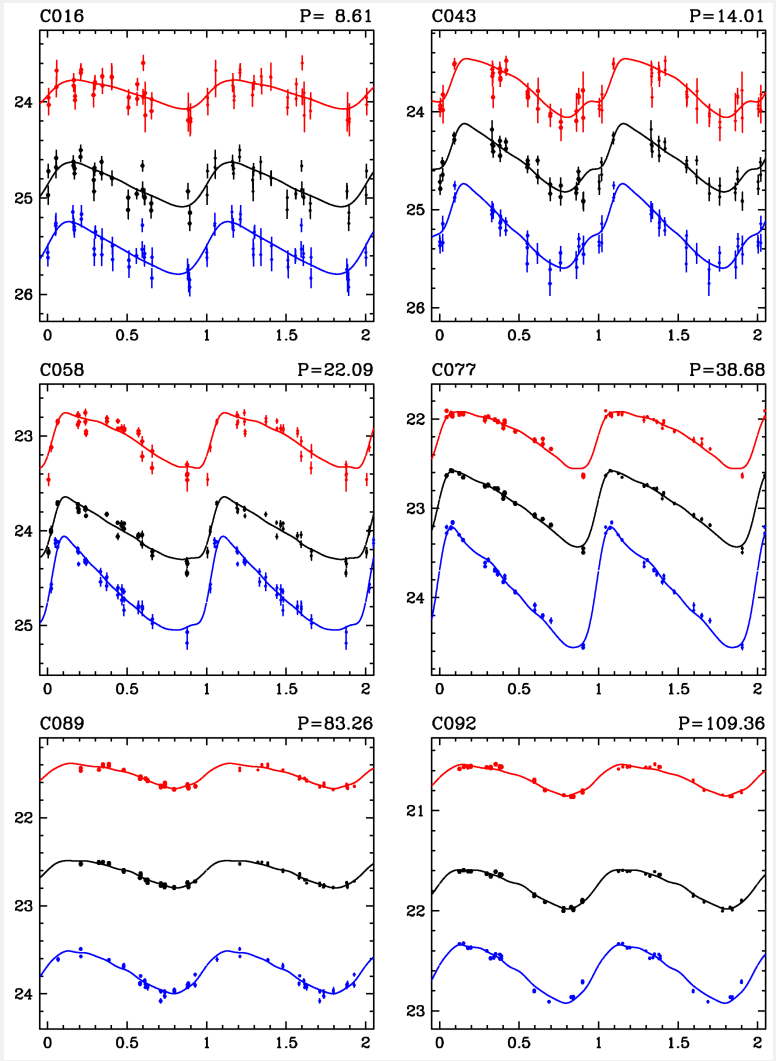
- Search for (rare) long-period Cepheids using Gemini North 8-m telescope
  - PhD Thesis of Samantha Hoffmann (Texas A&M)

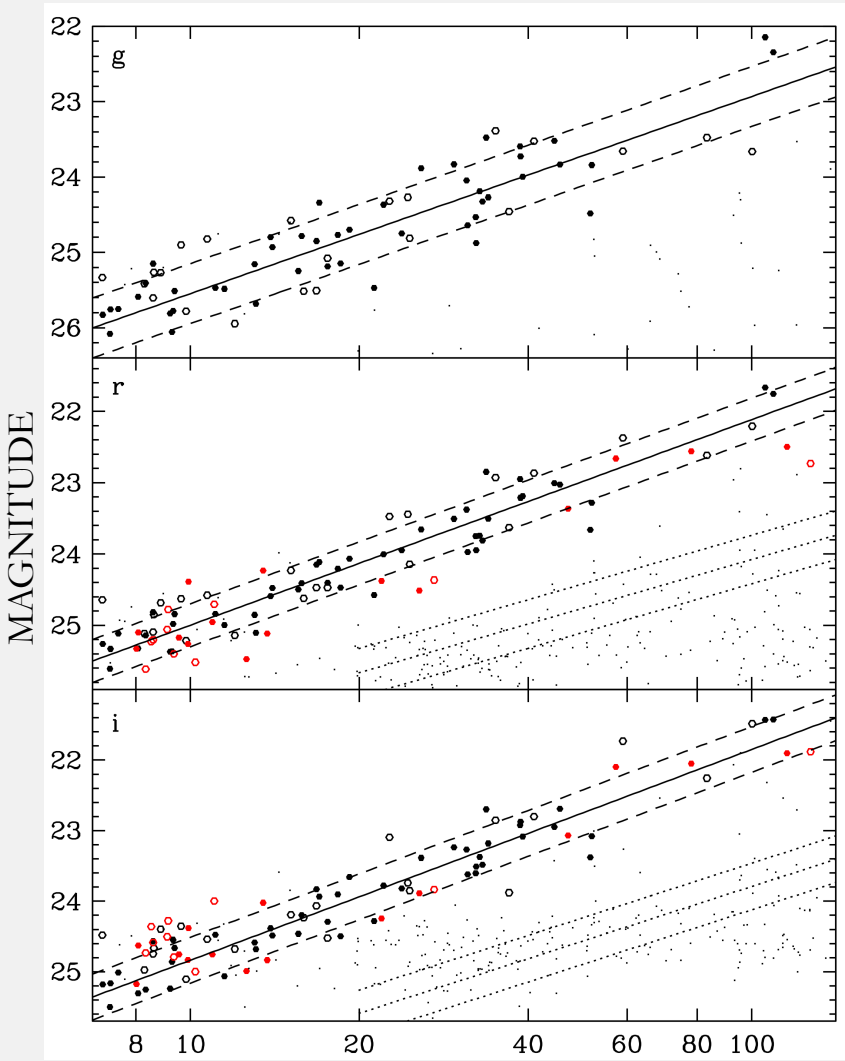


COLOR MOSAIC BASED ON SDSS IMAGES

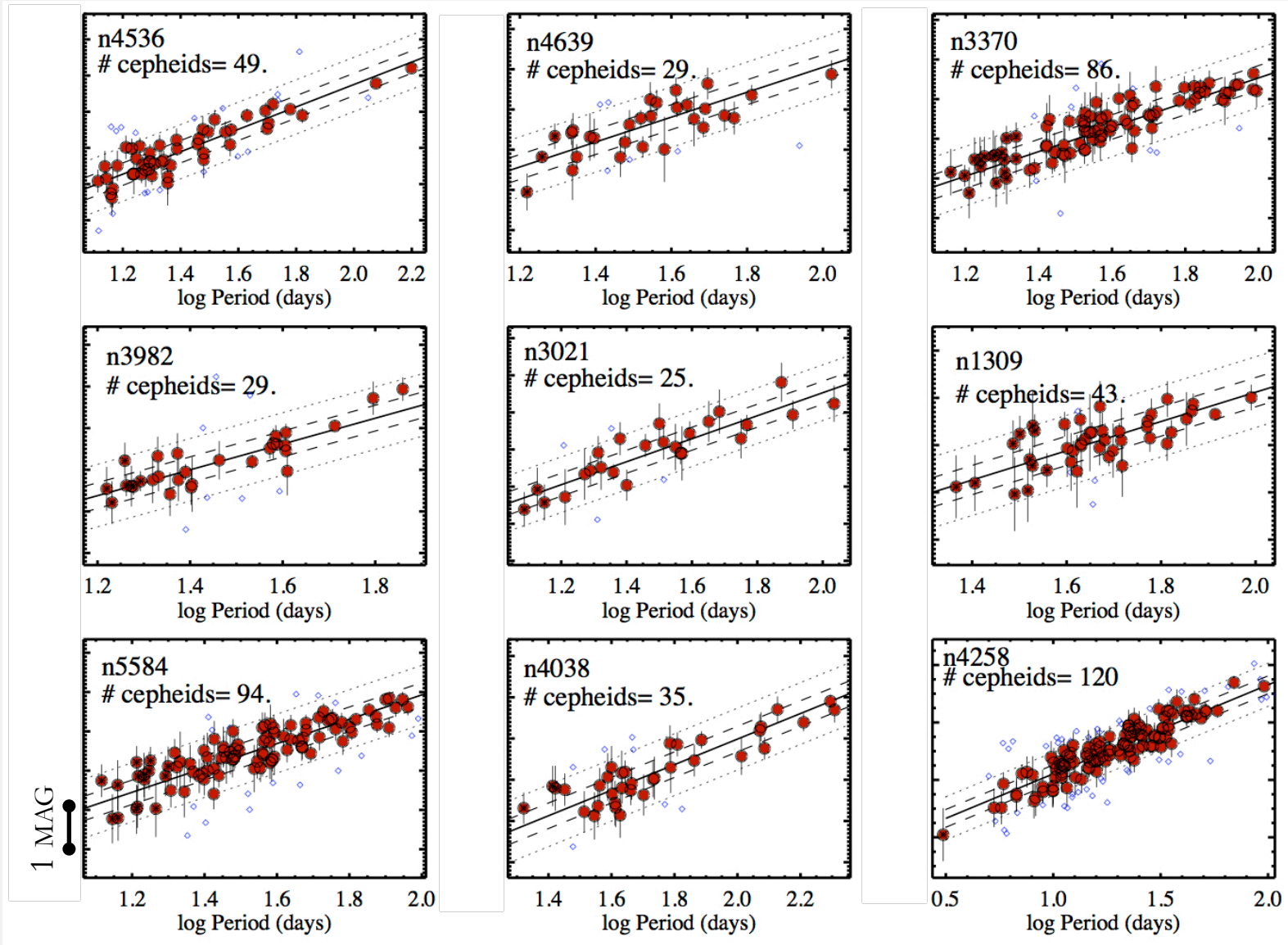
Cepheids in N4258 from Gemini

- 7.6 Mpc; 1200s/epoch/band, ~0.7” seeing (Hoffmann & Macri ‘15)





Cepheids to 40Mpc with HST



Riess, Macri+ (2011)

Cepheids to 40Mpc with HST

Riess, Macri+ (2011)

Current status & motivation

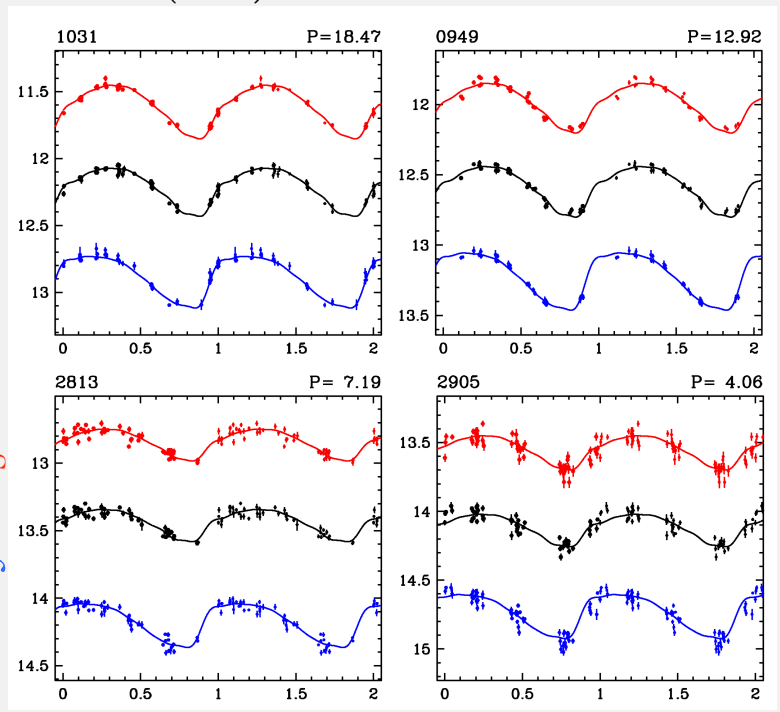
- RR Lyraes
  - $-0.7 \lesssim \log P \lesssim 0$; $0 \lesssim M_I, M_K \lesssim -1$
  - Old, low-mass stars: present in any galaxy type
  - Currently limited to M31 + Sculptor ($D \lesssim 2$ Mpc) w/HST (Contreras-Ramos+ '13; Rejkuba+ '11)

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

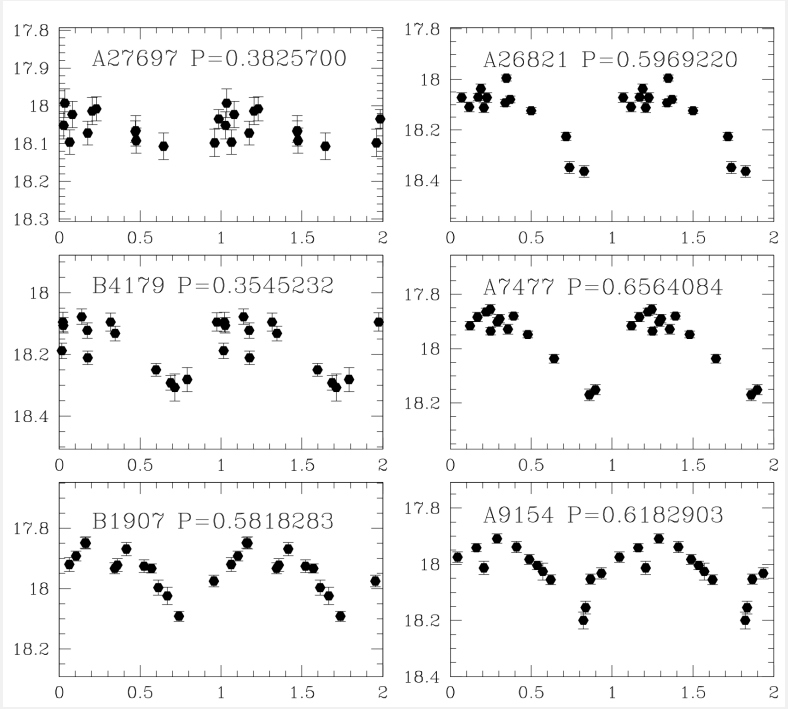
LMC-BASED CALIBRATIONS

- 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

MACRI+ (2015)

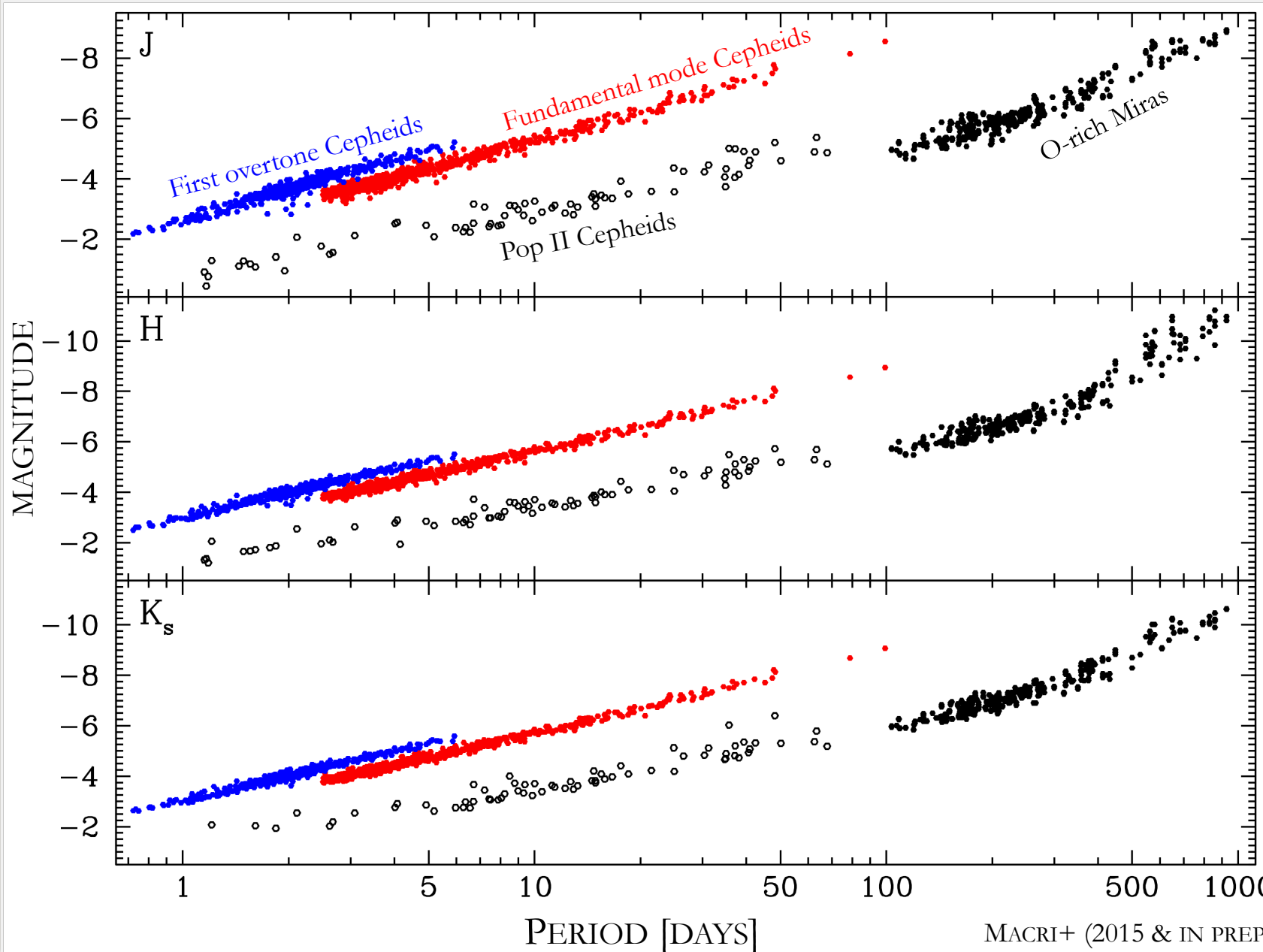


MURAVEVA+ (2015)



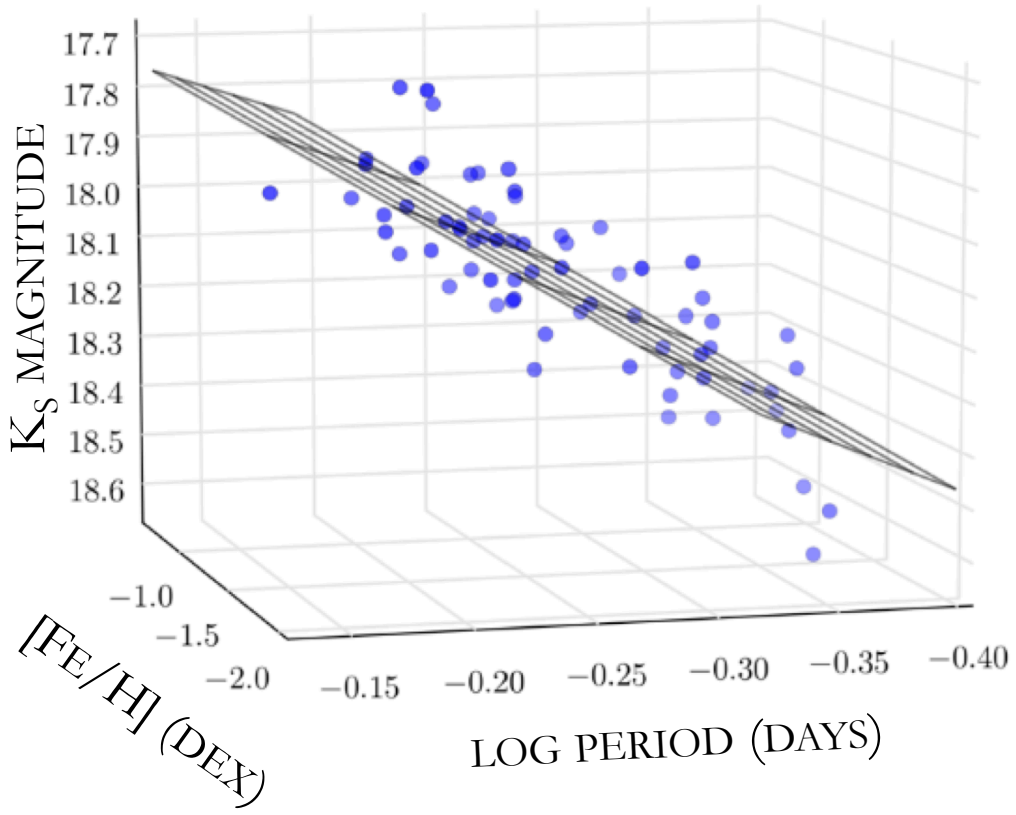
PHASE

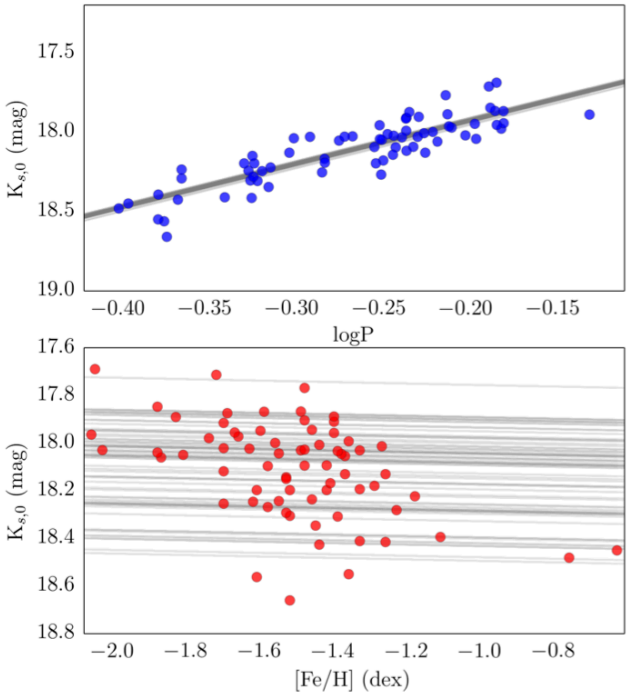
LMC-BASED CALIBRATIONS



MACRI+ (2015 & IN PREP.)

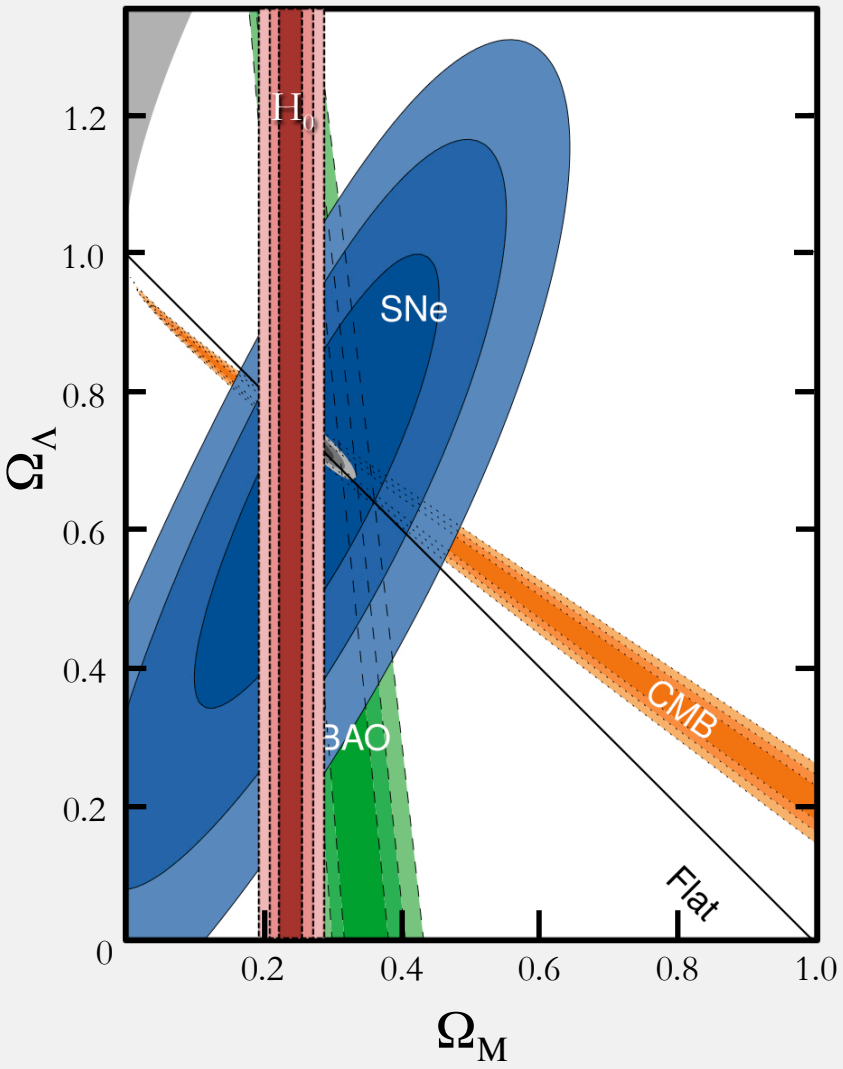
LMC-BASED CALIBRATIONS: RR LYRAES





MURAVEVA+ (2015)

Motivation: what is dark energy?



- Recent analysis based on:
  - SNe (Union2 sample)
  - WMAP-7 (Komatsu+2011)
  - BAO (Percival+ 2010)
  - H_0 (Riess+ 2011)
- Derived parameters:
  - $\Omega_\Lambda = 0.728 \pm 0.014$
  - $w = -1.003 \pm 0.093$
  - $\Omega_K = 0.002 \pm 0.006$
    (inflation: $\Omega_K < 10^{-5}$)

Suzuki+ (2012)

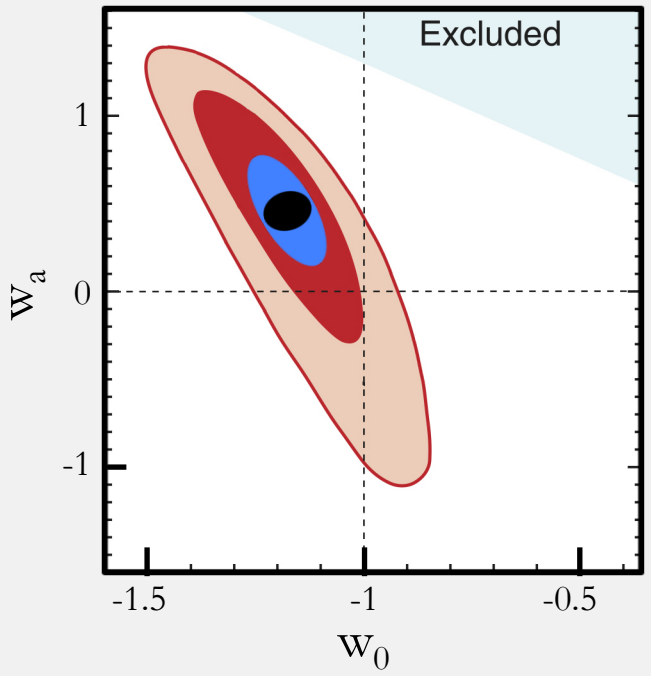
Constraining Dark Energy

- Equation of state of dark energy:

$$w = P/\rho c^2$$

$$w(a)=w_0+w_a(1-a)$$

Dark Energy Task Force Figure of Merit:
$[\sigma(w_0)\times\sigma(w_a)]^{-1}$

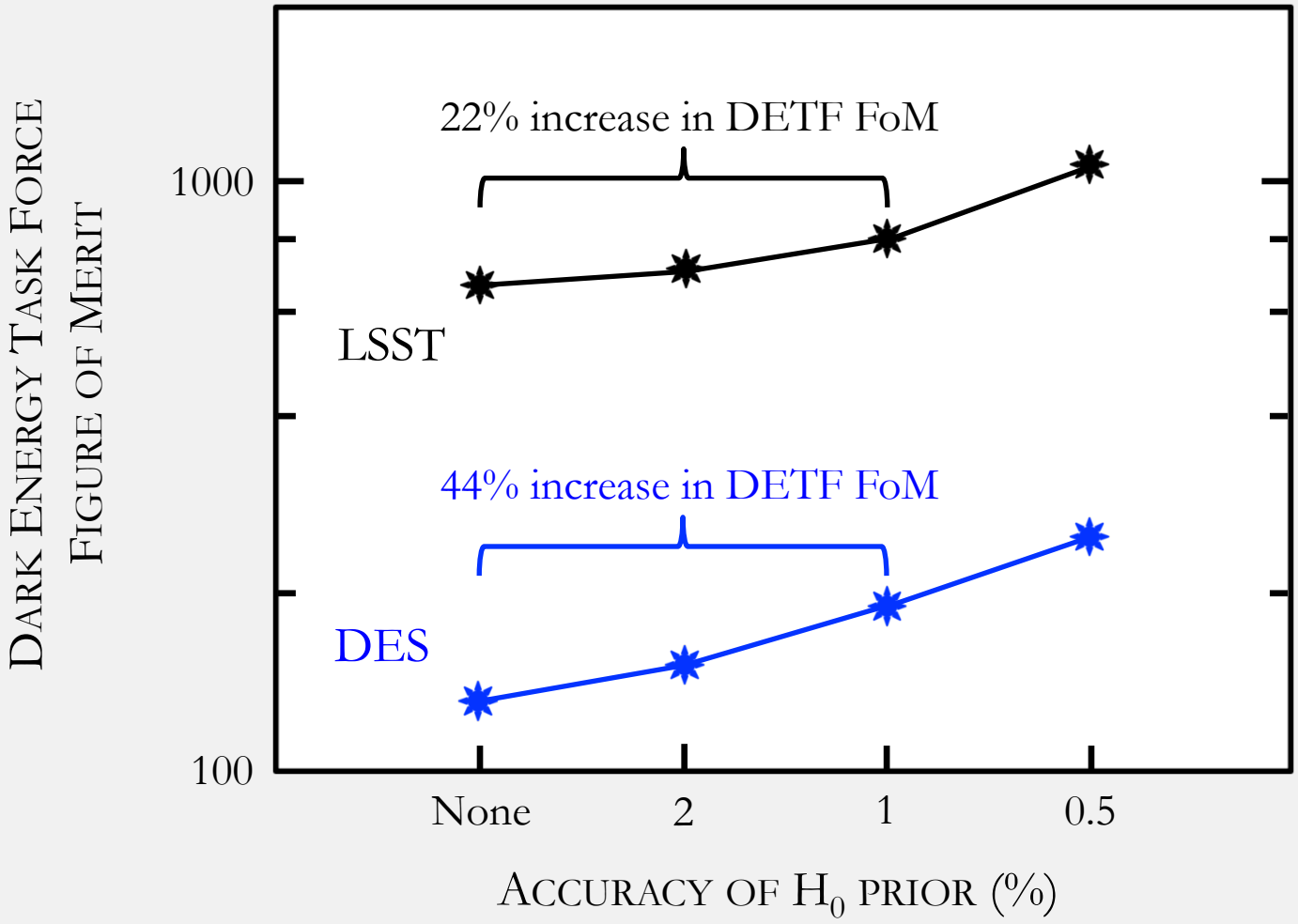


Coupled with additional priors (such as H_0)

- S12: w_0 ±0.09; w_a ±0.5
- DES: w_0 ±0.08; w_a ±0.3
- LSST: w_0 ±0.05; w_a ±0.1

Suzuki+ (2012)

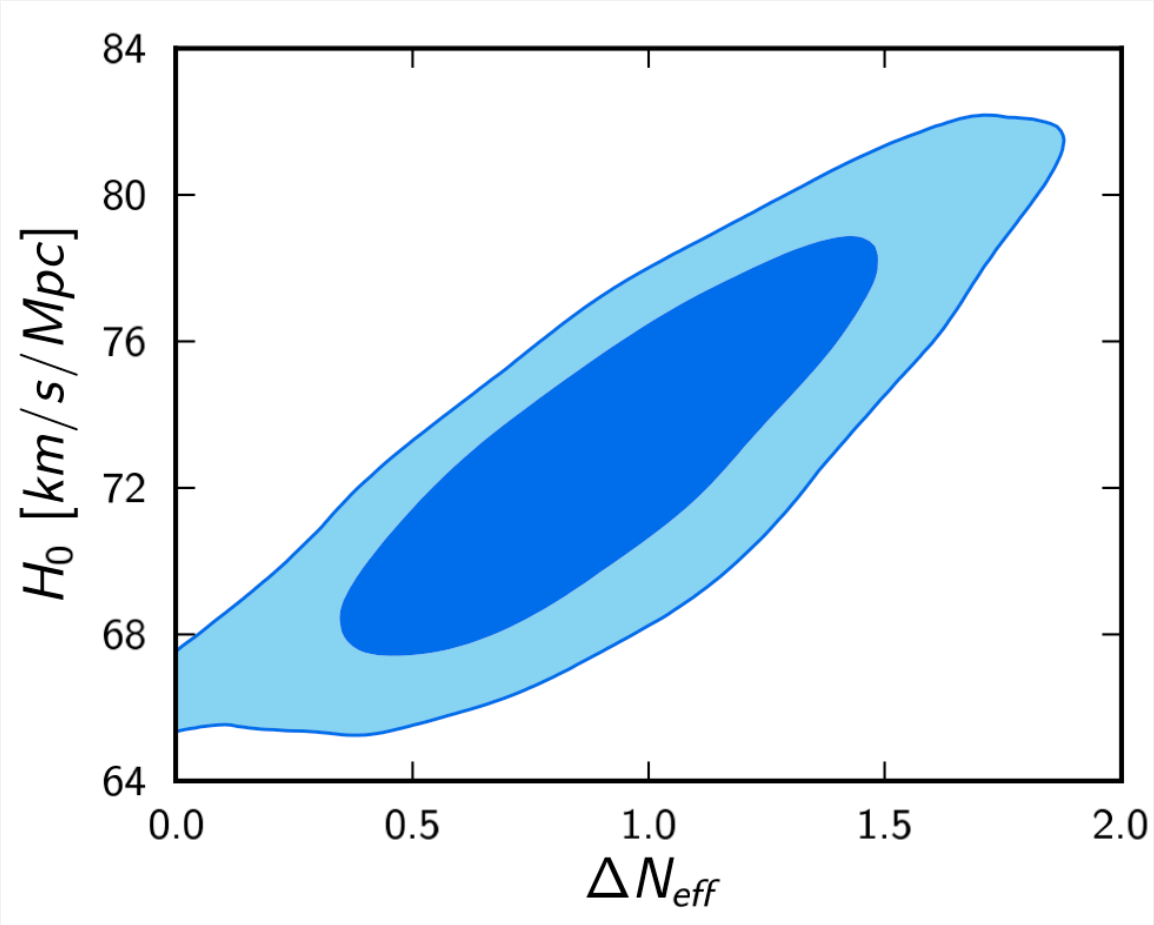
Motivation for further improvement in H_0



Based on Weinberg+ (2012)

Hints of "new physics"?

2.5σ "tension" between Planck results and local measurements of H0 can be alleviated by a sterile neutrino



Dvorkin+ (2014)

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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
  - First light!

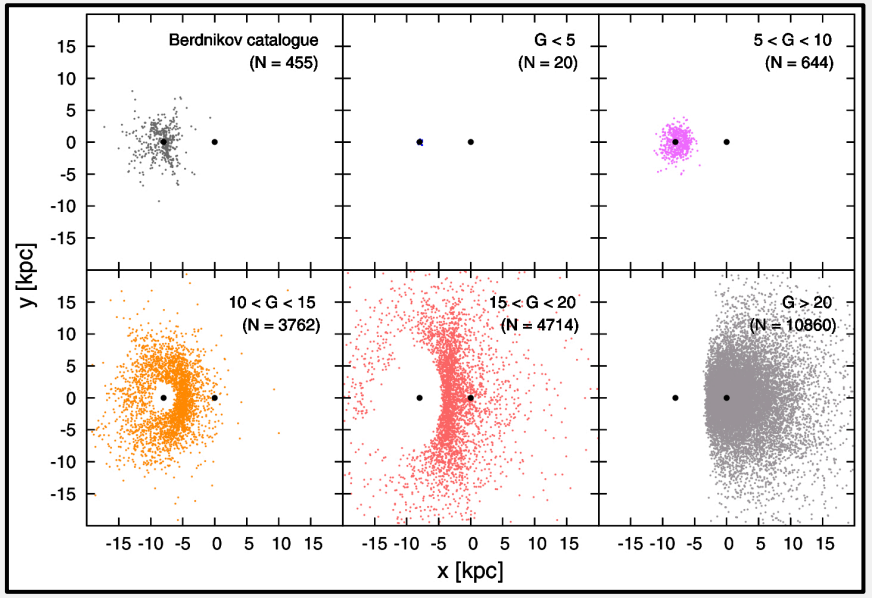
The Landscape in 2022

- Gaia
  - ~9,000 Galactic Cepheids; P-L zeropoint to 0.3-0.6%
- JWST
  - ~50 additional SNe Ia hosts to D~50 Mpc → H_0 to 1%
- LSST
  - Cepheids & Miras in ~80 Sp/Irr galaxies ($D \lesssim 10$ Mpc)
- TMT
  - First light!

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)

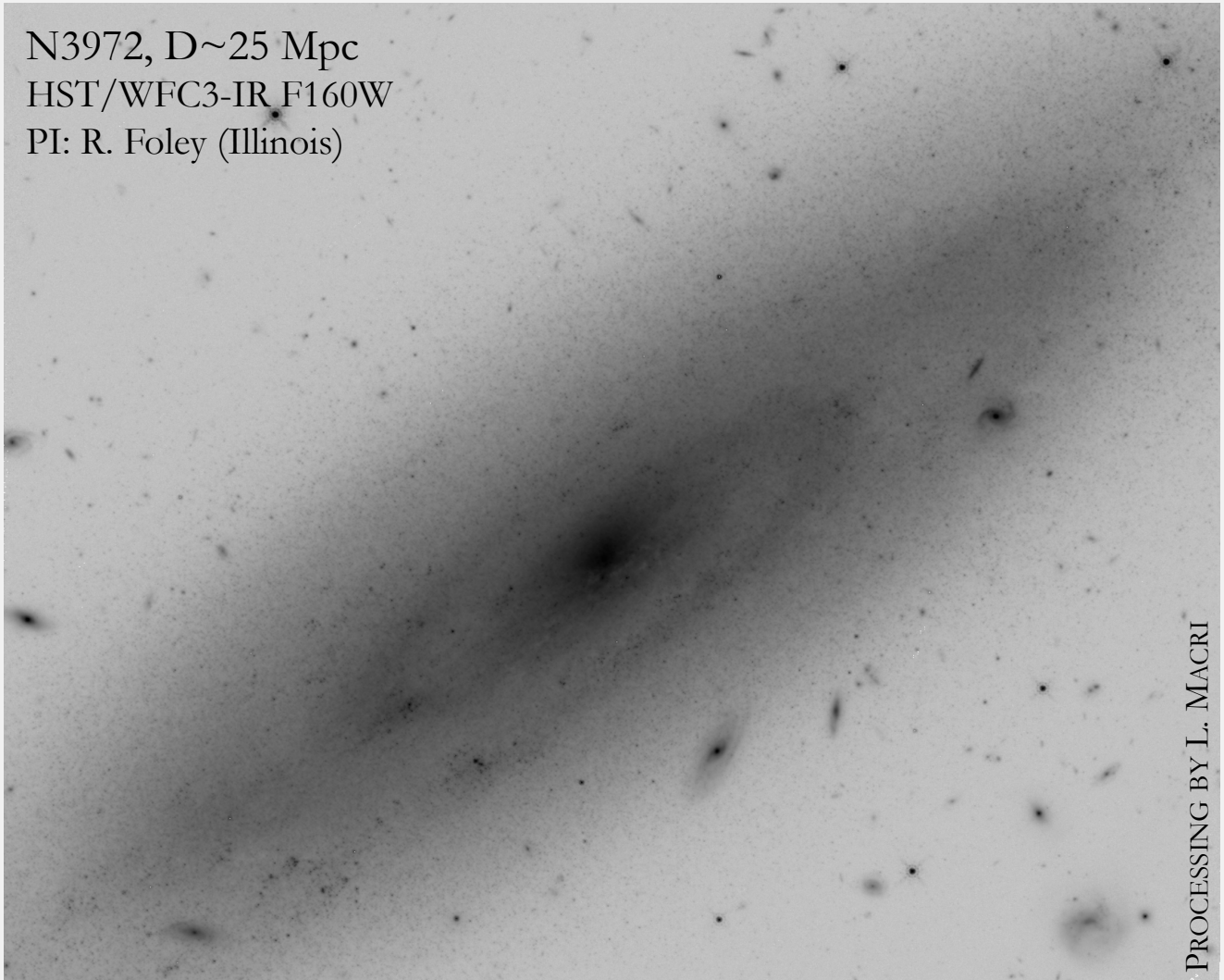
JWST OBSERVATIONS

- JWST+NIRCam improves over HST+WFC3
  - 4× finer sampling & 3× resolution
  - Similar FoVs (123” vs 130”)

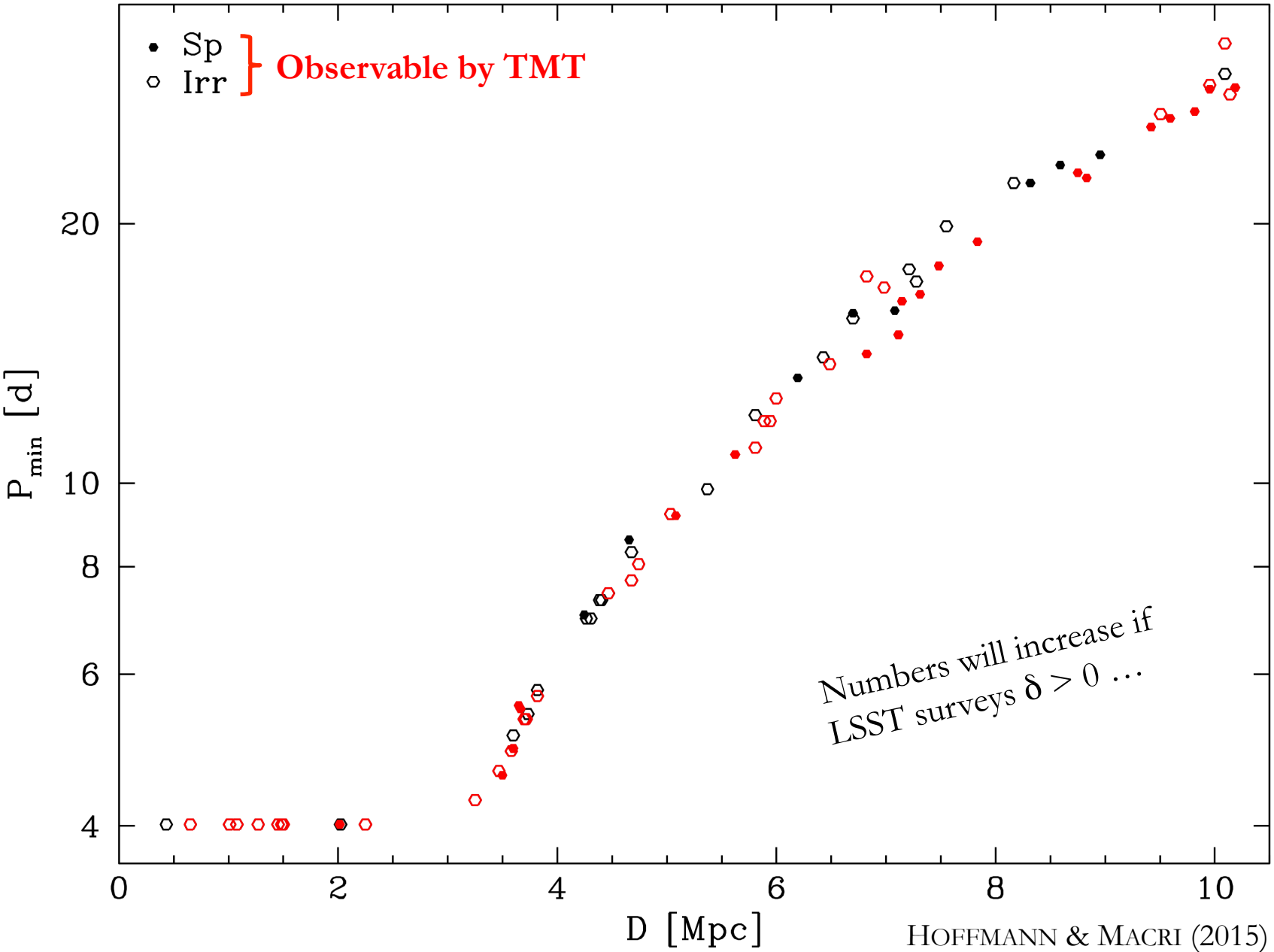
- But it’s still a modest aperture telescope…
  - 2hr, 1hr to SNR~10 for P=20d Cepheid @ 50 Mpc in J&K
  - At least 10 epochs needed to obtain periods

JWST OBSERVATIONS

- Imagine 4× finer sampling & 3× resolution…



LSST SENSITIVITY TO CEPHEIDS



HOFFMANN & MACRI (2015)

Outline

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TMT OBSERVATIONS

- TMT+IRIS improves over JWST+NIRCam
  - ~9× finer sampling, ~5× better resolution
    → greatly reduce impact of crowding & blending
- However, FoV considerably smaller…
  - 34” vs 123”
- But more than makes up for it in other ways:
  - 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-generation of 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…)