The Mira Distance Ladder

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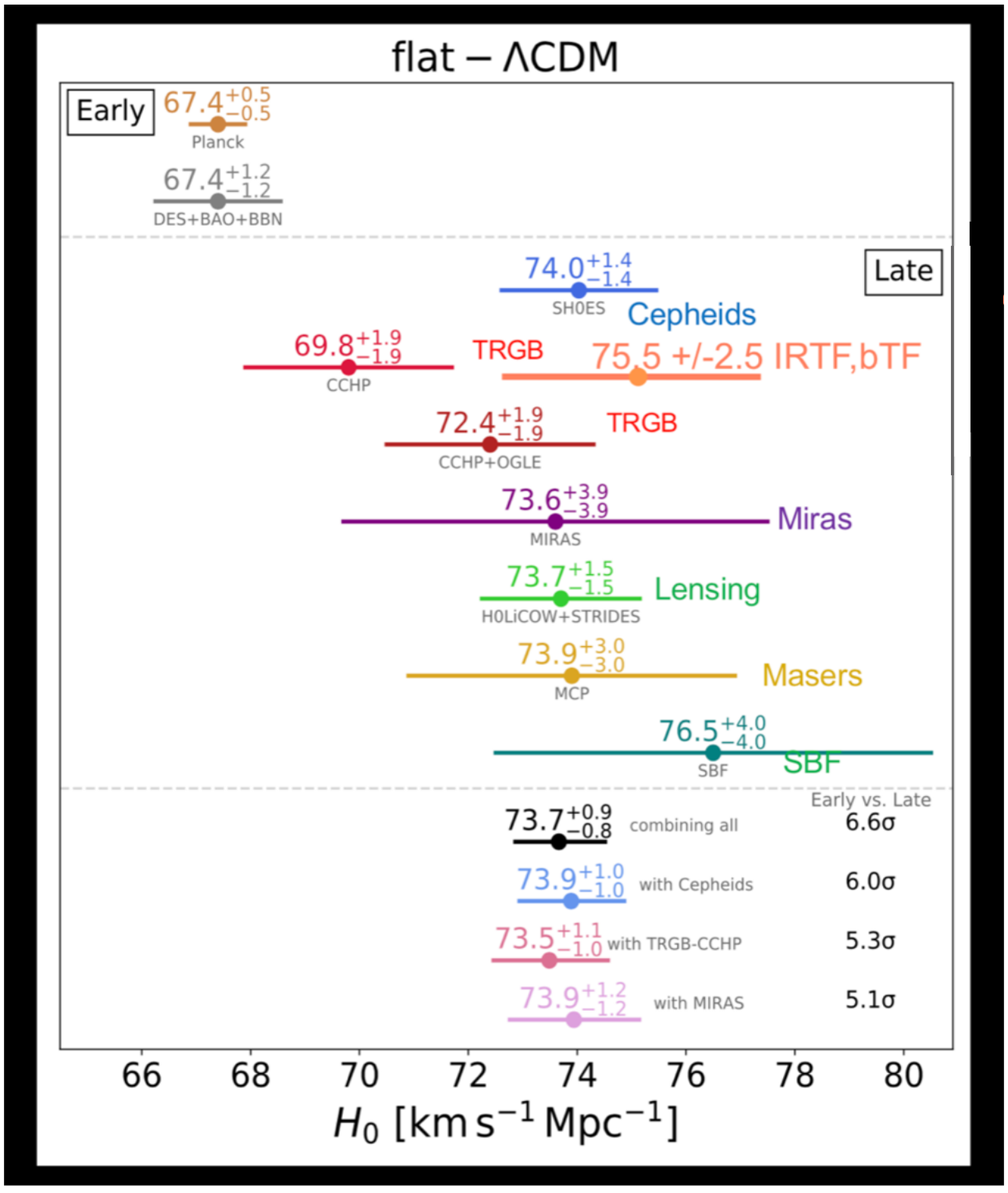
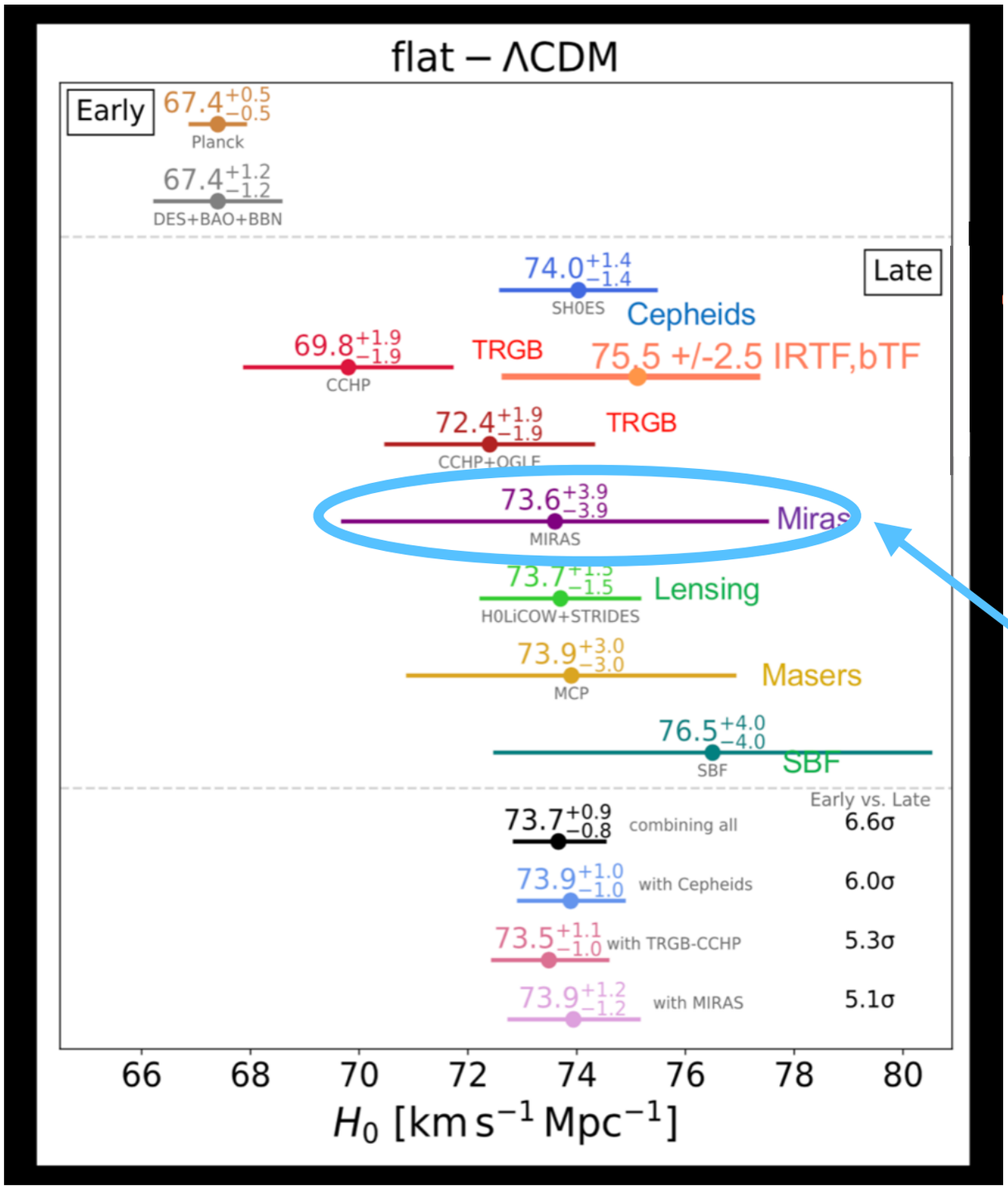
Stefano Casertano, Lucas Macri

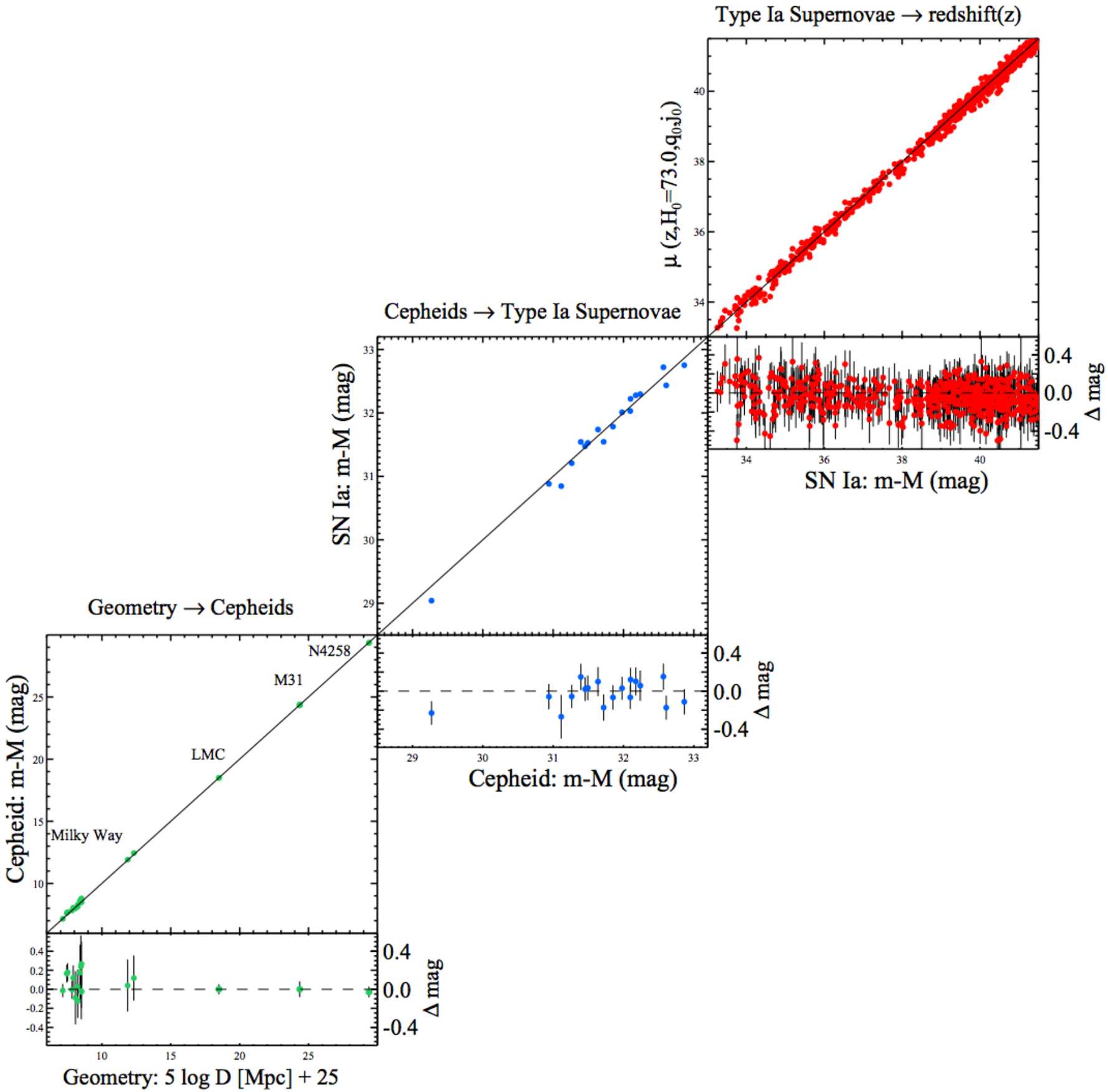
H0 Tension


flat – ΛCDM
Early
$67.4^{+0.5}_{-0.5}$
Planck
$67.4^{+1.2}_{-1.2}$
DES+BAO+BBN
Late
$74.0^{+1.4}_{-1.4}$
SH0ES
Cepheids
$69.8^{+1.9}_{-1.9}$
CCHP
TRGB
75.5 +/-2.5 IRTF,bTF
$72.4^{+1.9}_{-1.9}$
CCHP+OGLE
TRGB
$73.6^{+3.9}_{-3.9}$
MIRAS
Miras
$73.7^{+1.5}_{-1.5}$
H0LiCOW+STRIDES
Lensing
$73.9^{+3.0}_{-3.0}$
MCP
Masers
$76.5^{+4.0}_{-4.0}$
SBF
SBF
Early vs. Late
$73.7^{+0.9}_{-0.8}$
combining all
6.6σ
$73.9^{+1.0}_{-1.0}$
with Cepheids
6.0σ
$73.5^{+1.1}_{-1.0}$
with TRGB-CCHP
5.3σ
$73.9^{+1.2}_{-1.2}$
with MIRAS
5.1σ
66
68
70
72
74
76
78
80
H_0 [km s^{-1} Mpc^{-1}]

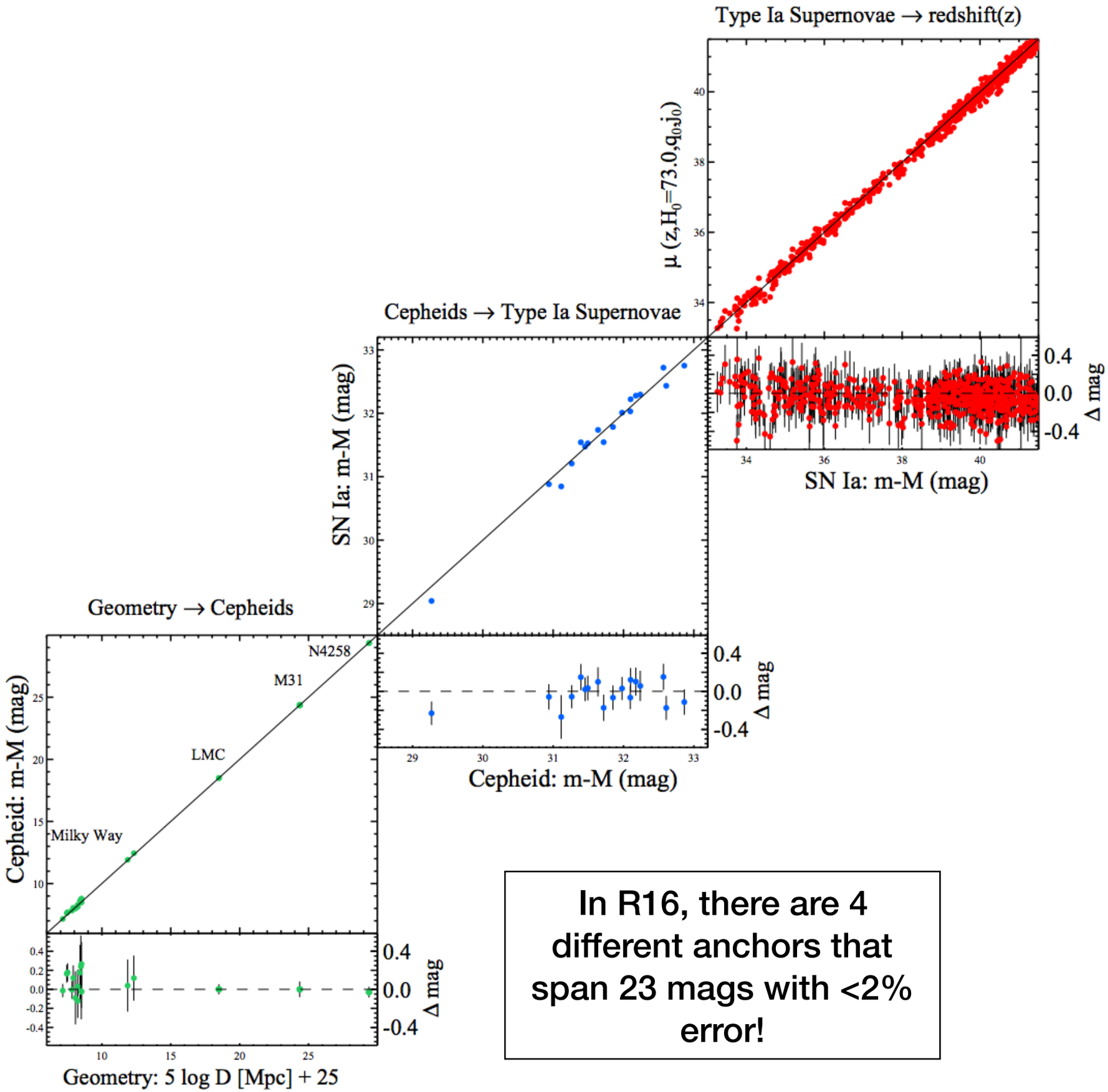
H0 Tension



This work

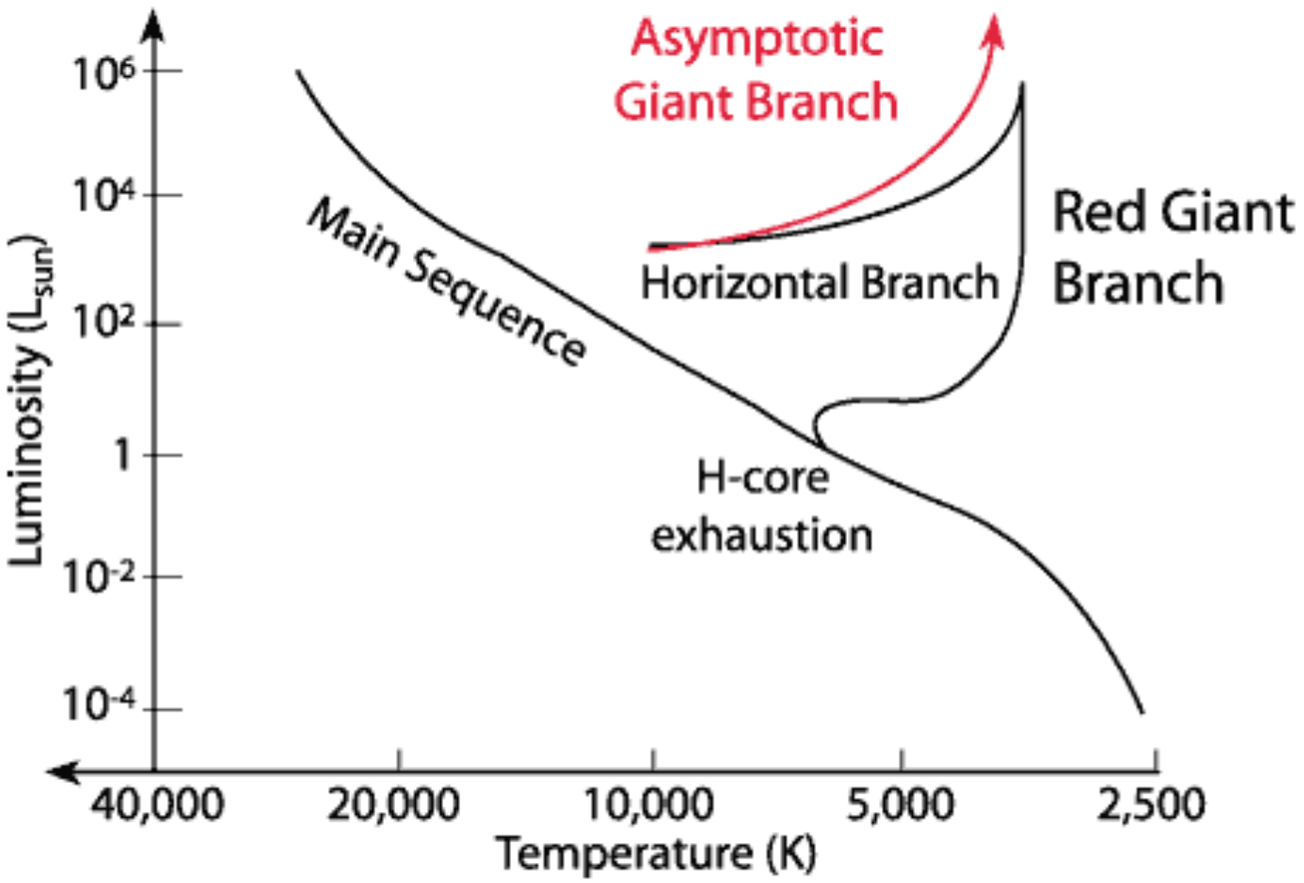


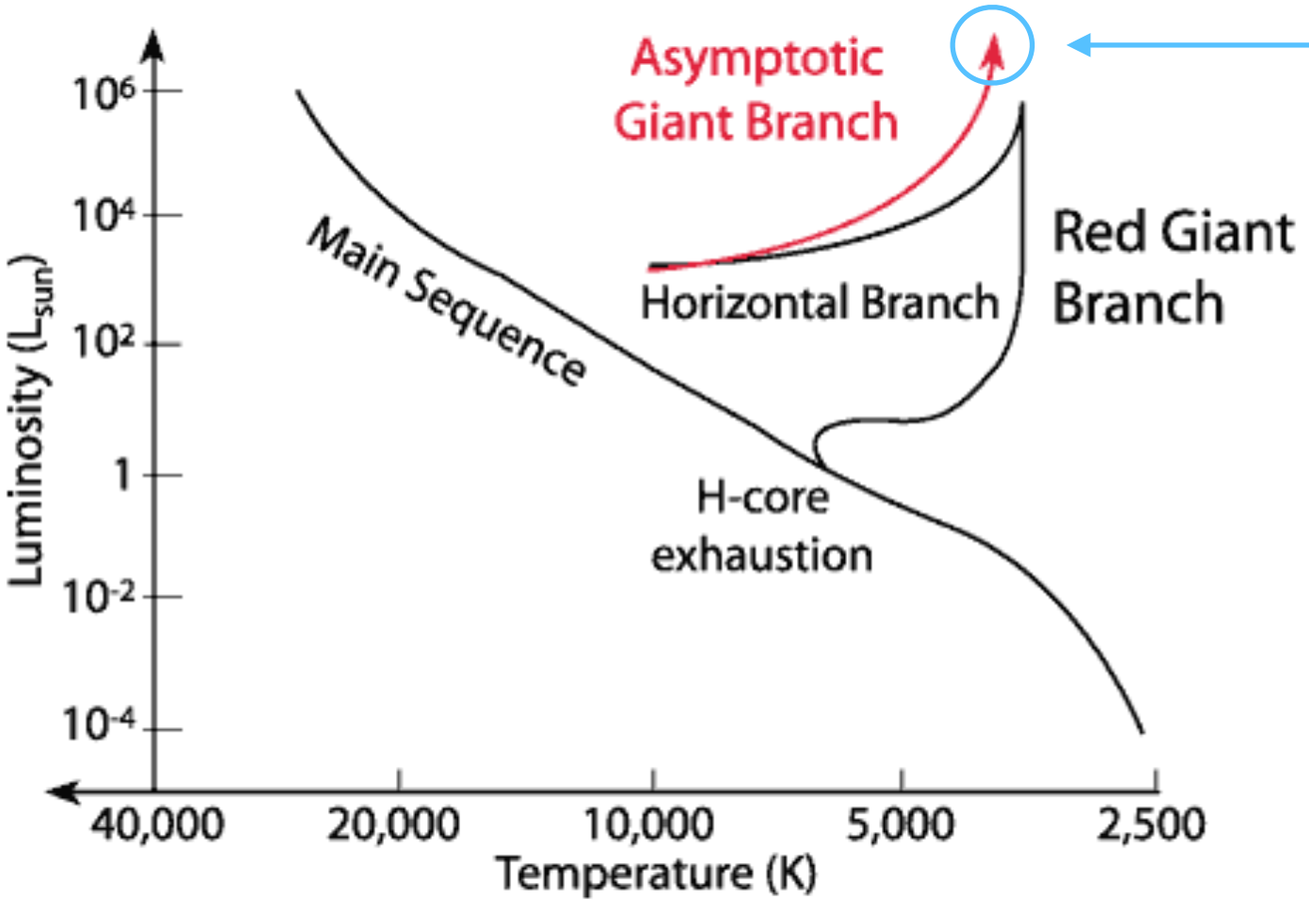
Riess et al. 2016



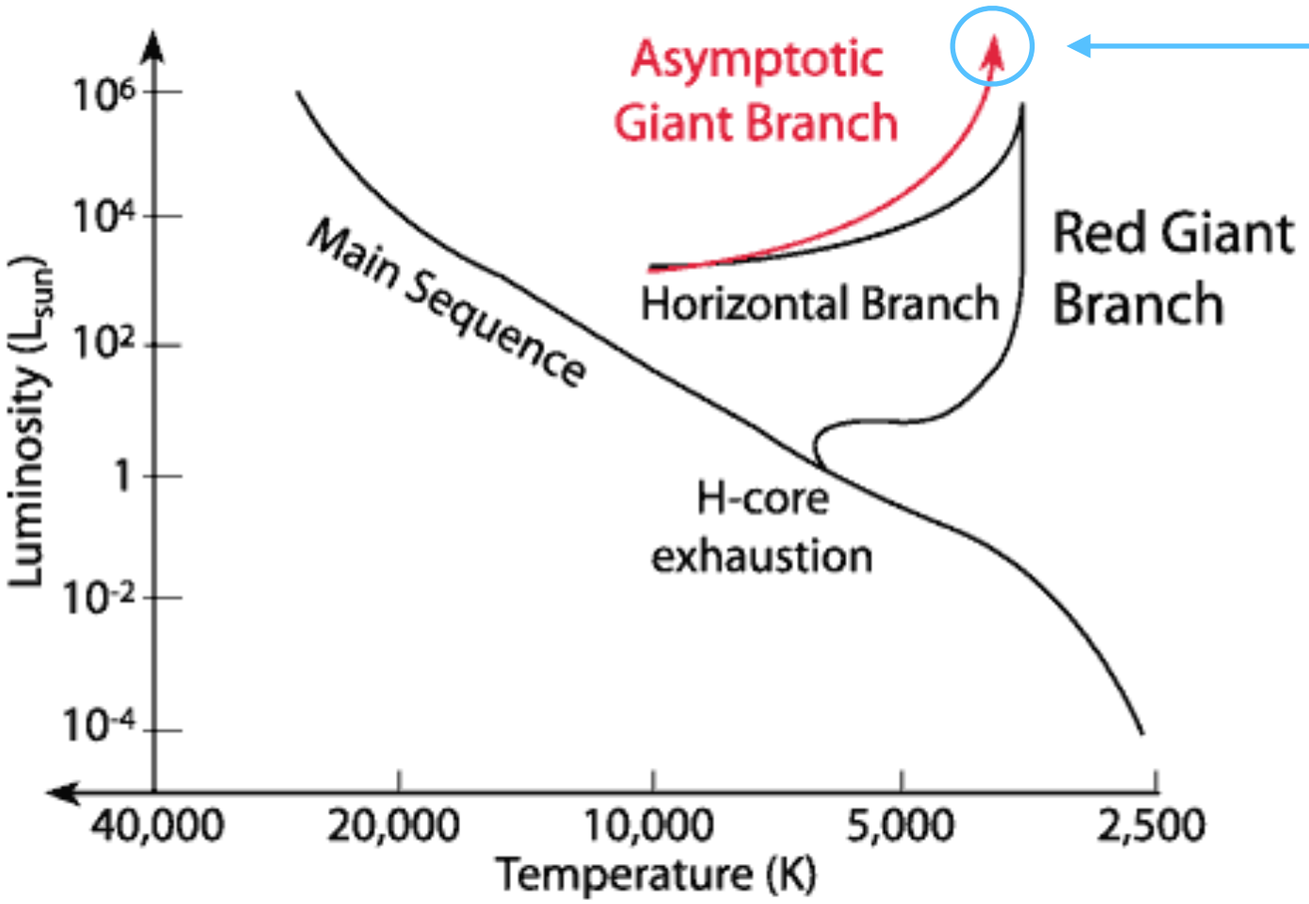
In R16, there are 4 different anchors that span 23 mags with <2% error!

Riess et al. 2016

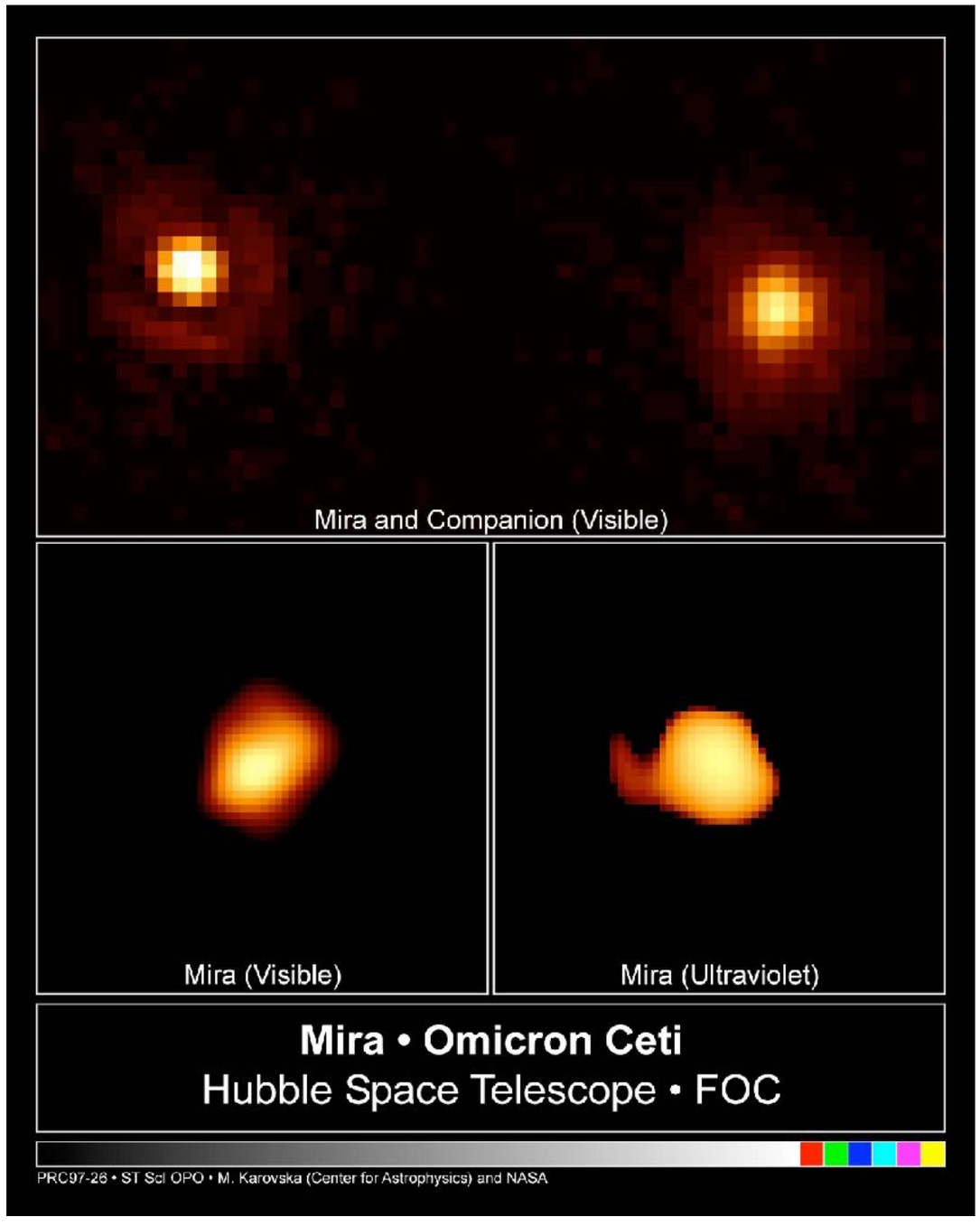

Asymptotic
Giant Branch
Red Giant
Branch
Horizontal Branch
Main Sequence
H-core
exhaustion
Luminosity (L_{sun})
10^6
10^4
10^2
1
10^{-2}
10^{-4}
40,000
20,000
10,000
5,000
2,500
Temperature (K)

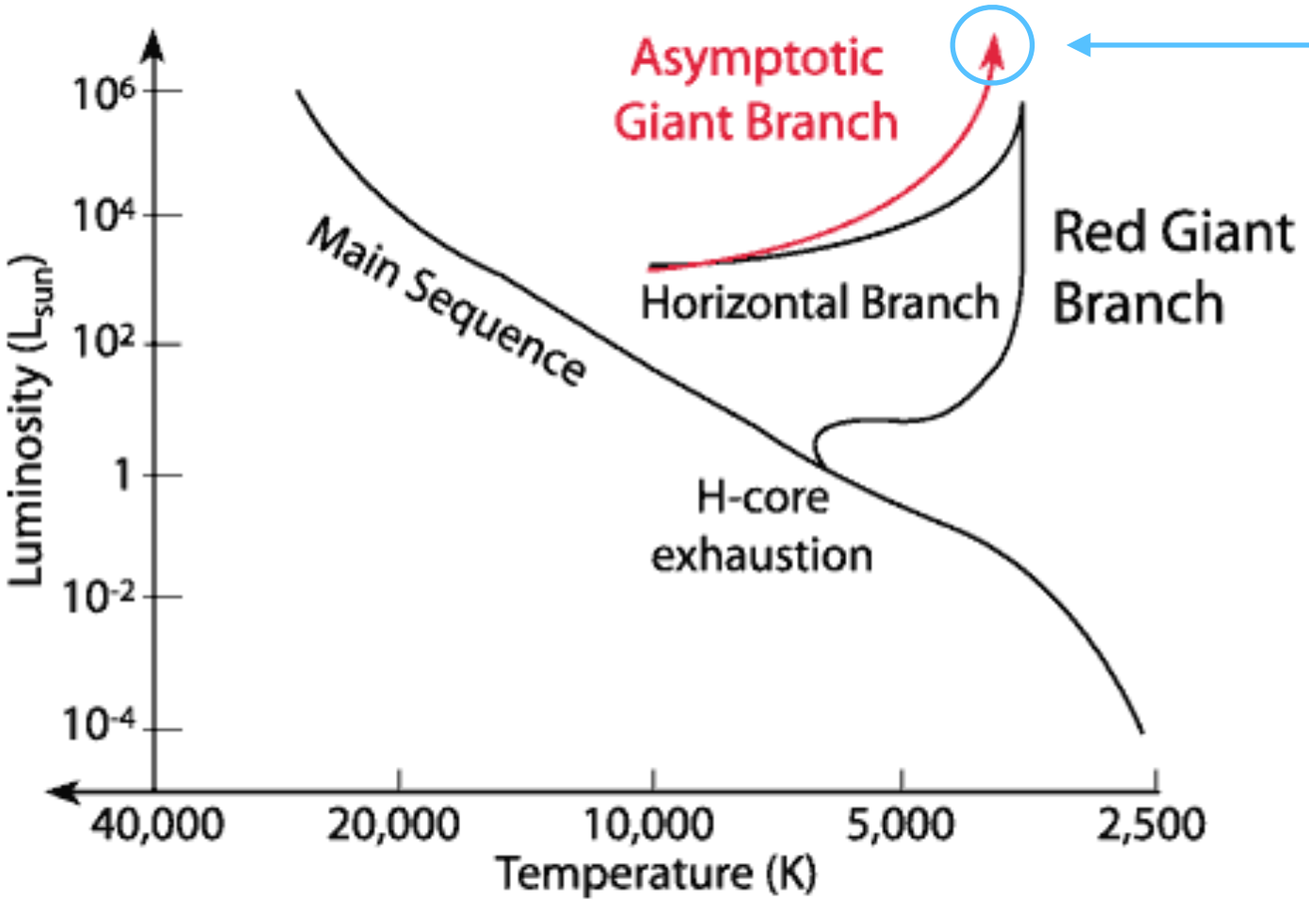


Miras are tip of the Asymptotic Giant Branch stars with periodic variability

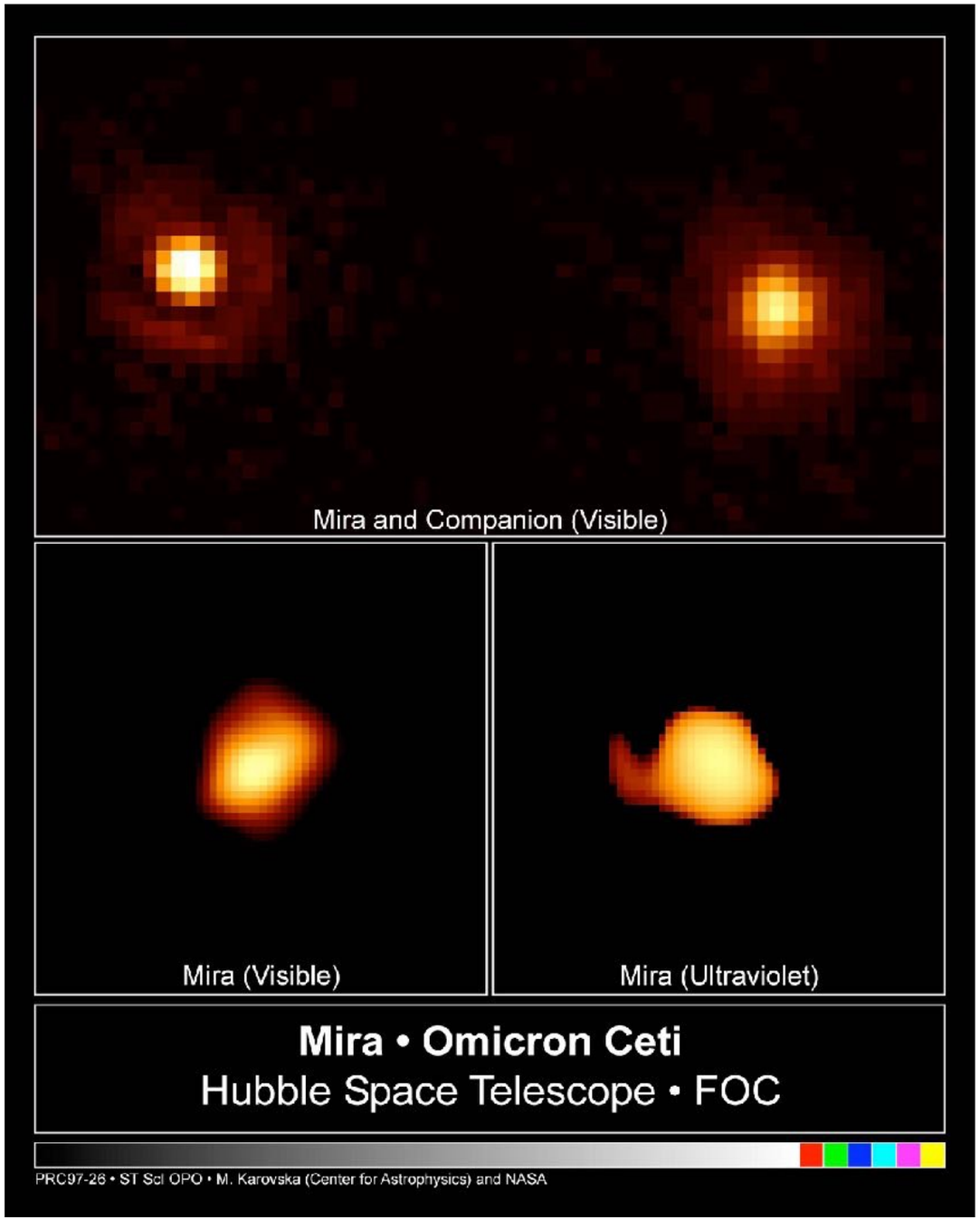


Miras are tip of the Asymptotic Giant Branch stars with periodic variability

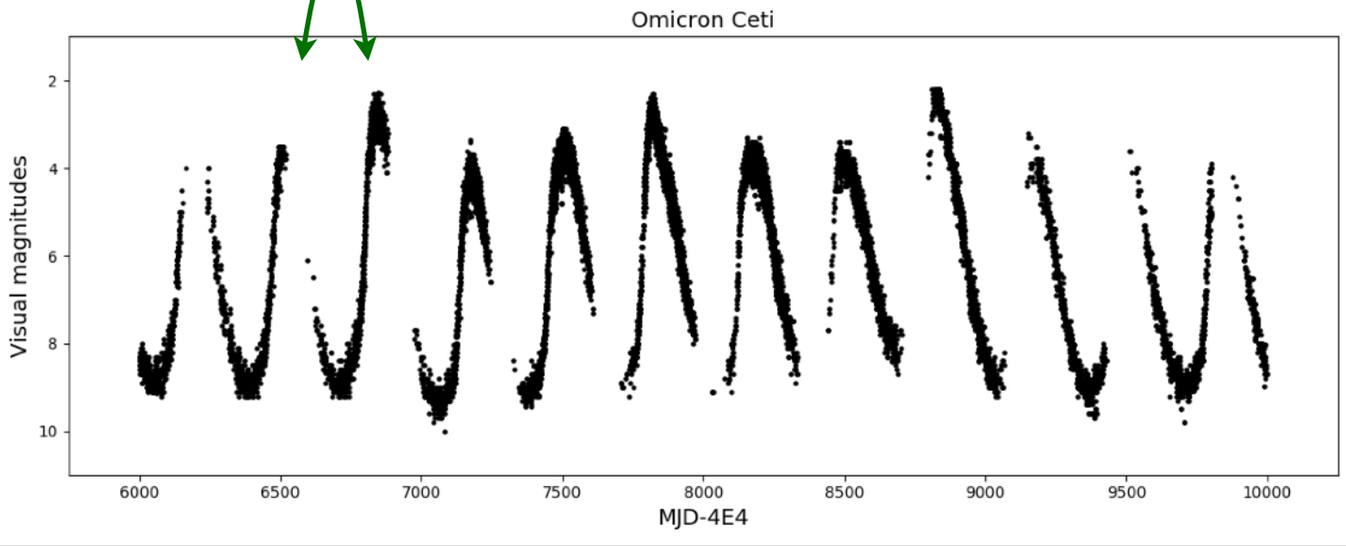




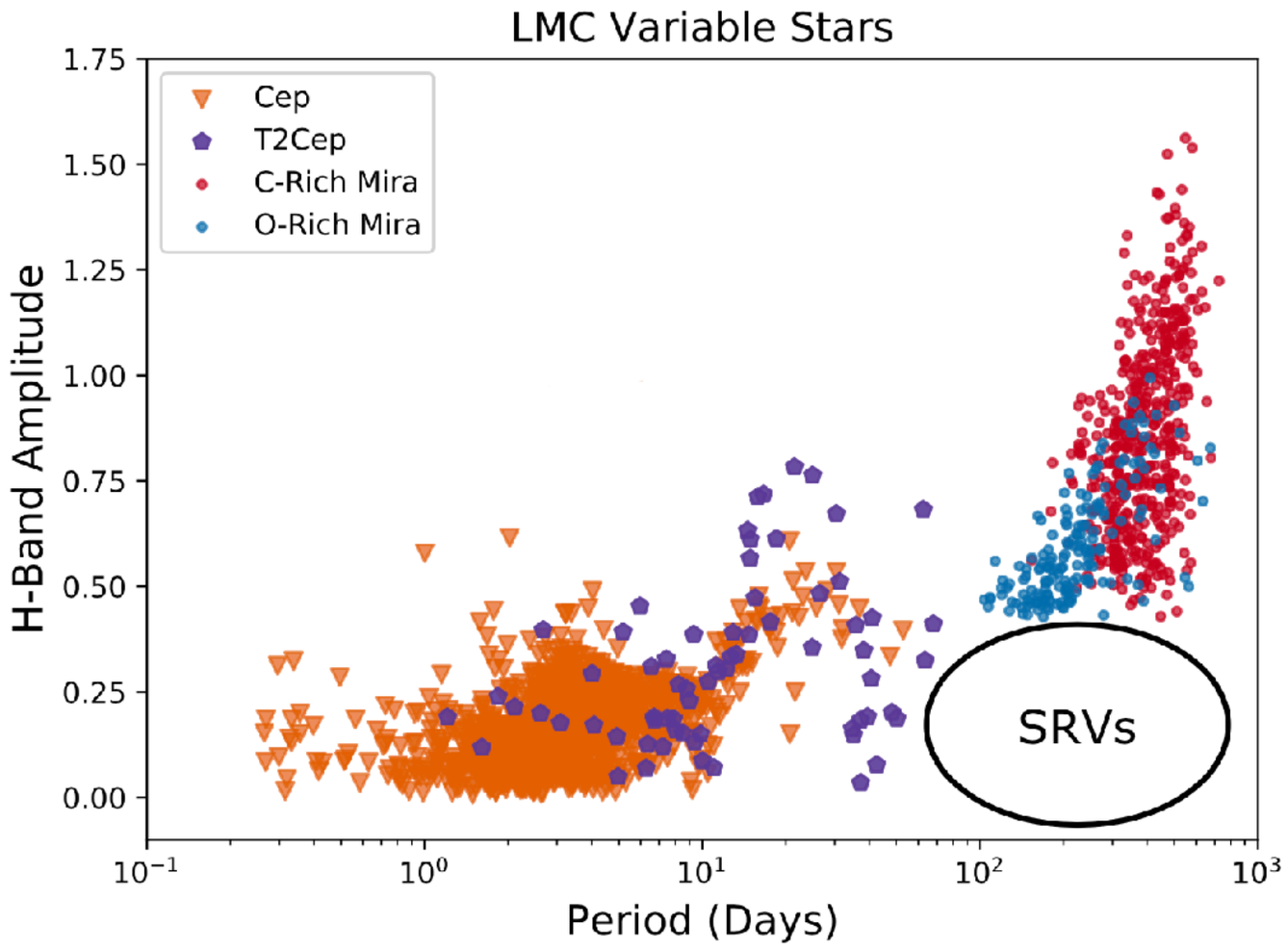
Miras are tip of the Asymptotic Giant Branch stars with periodic variability



P ~330 days

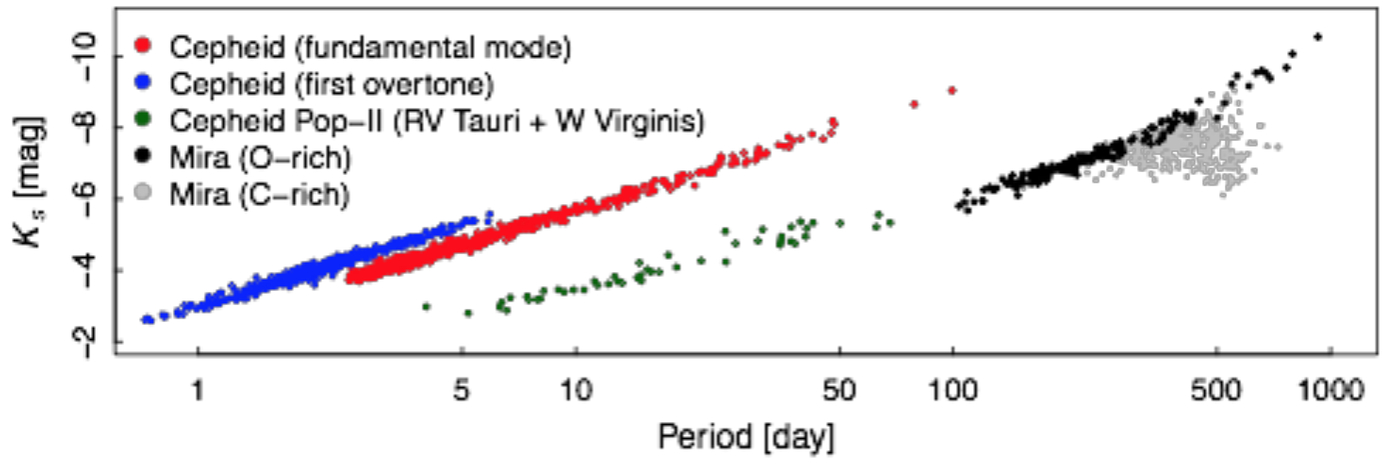


Margarita Karovska



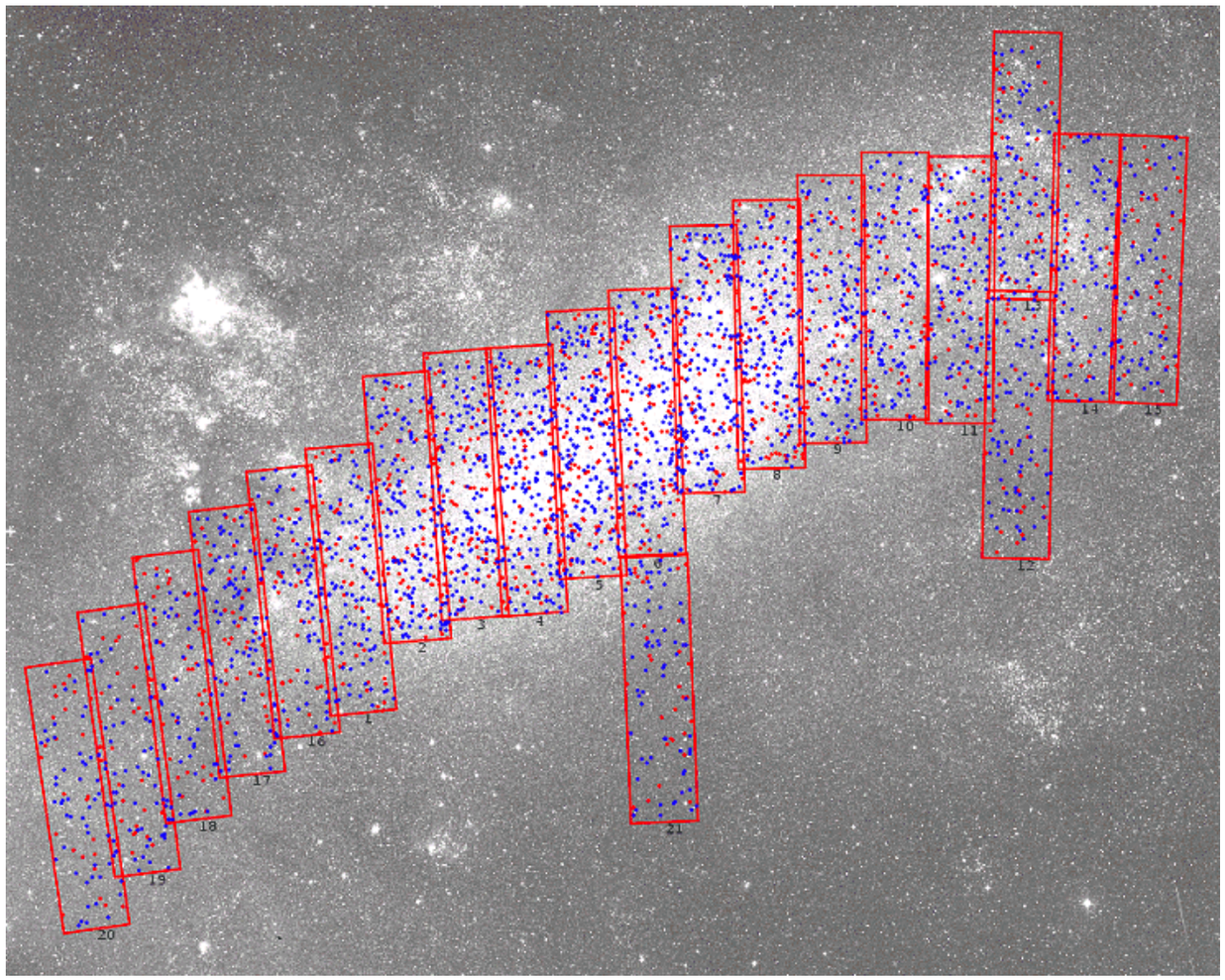
- Miras have the largest amplitudes of periodic variable stars
- They follow Period-Luminosity Relations (PLRs) in the Near-Infrared (NIR)
- For the distance ladder we primarily focus on P < 400 day Miras

They are comparable in luminosity to Cepheids, but unlike Cepheids, are ubiquitous, and can be detected in the NIR

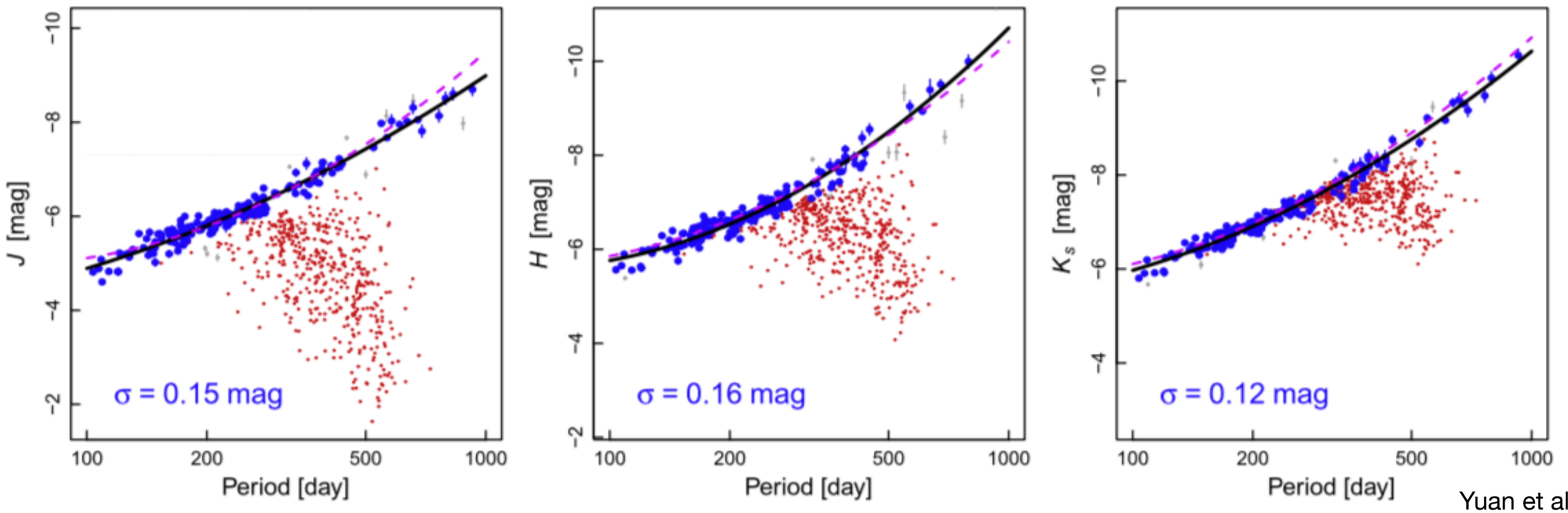


LMC

The geometric distance to the LMC has been measured using detached eclipsing binary stars. As of Pietrzyński et al. 2019, this is precise to 1 percent: 49.59 ± 0.09 (stat) ± 0.54 (sys) kpc



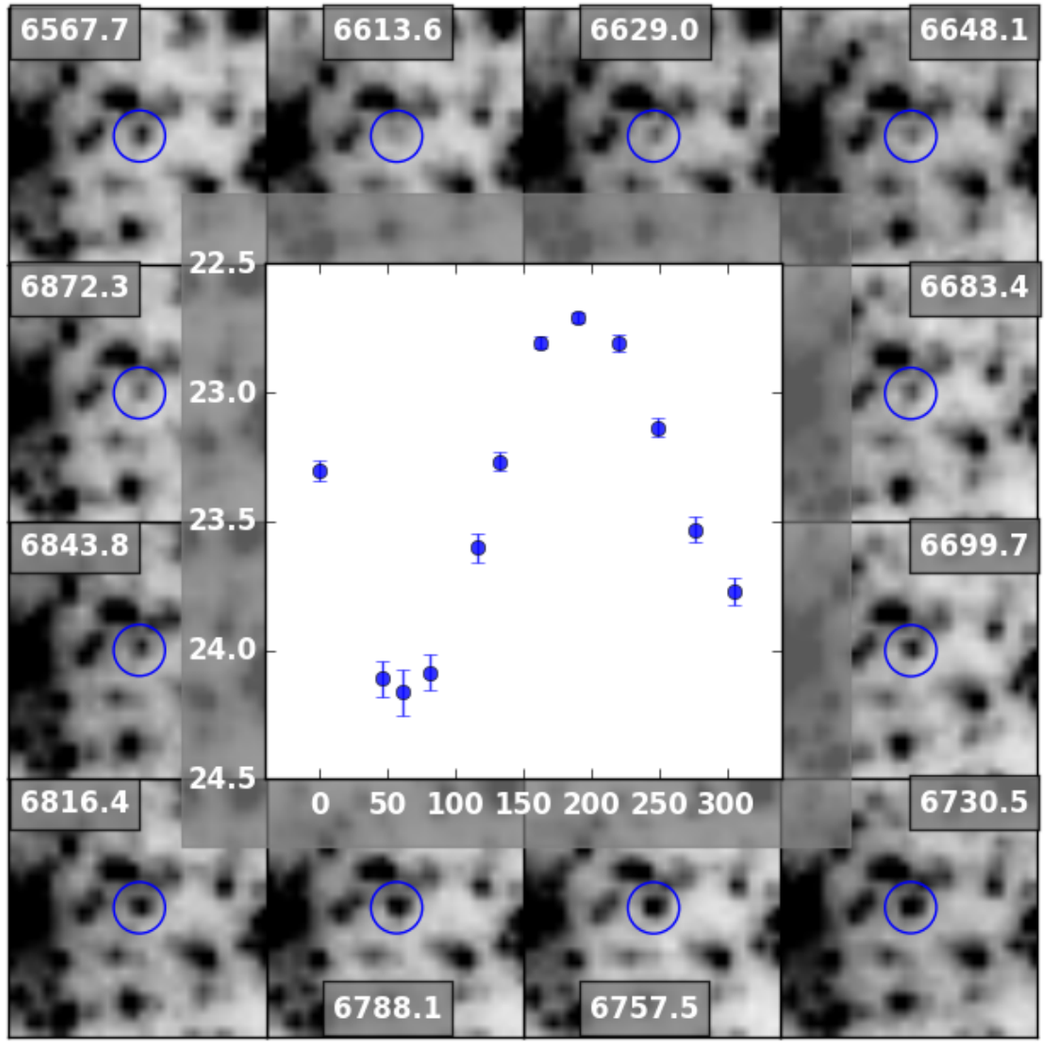
http://ogle.astrouw.edu.pl



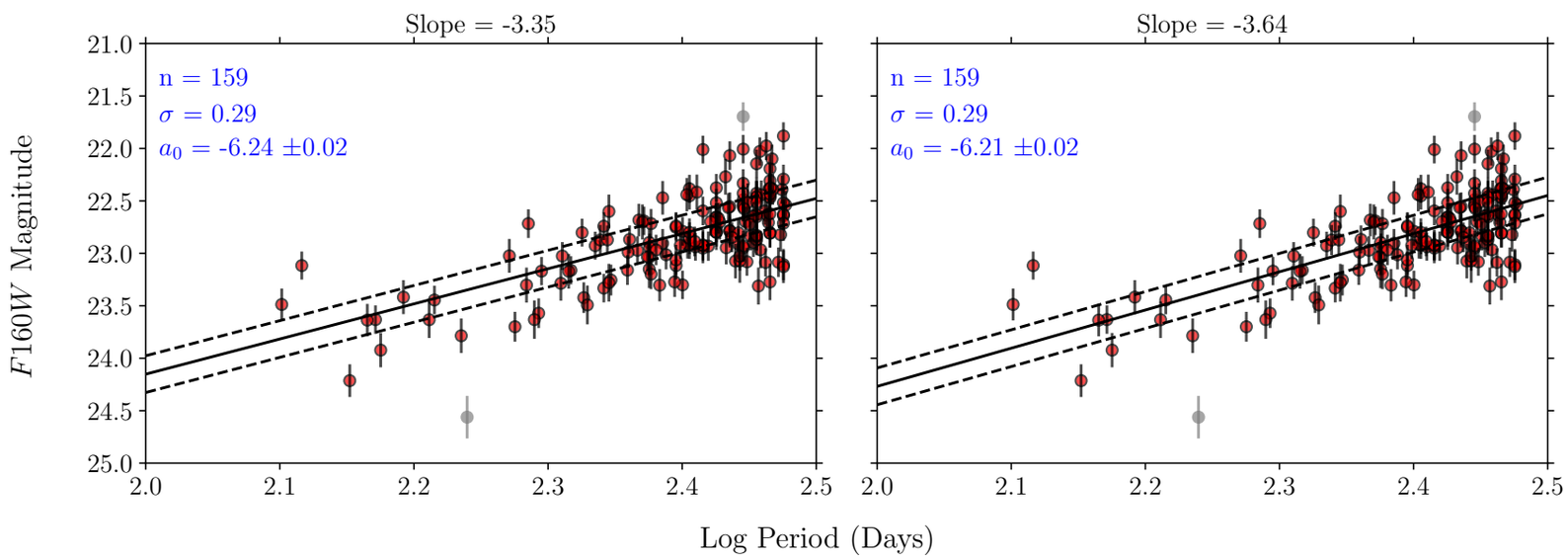
Yuan et al. 2017

NGC 4258

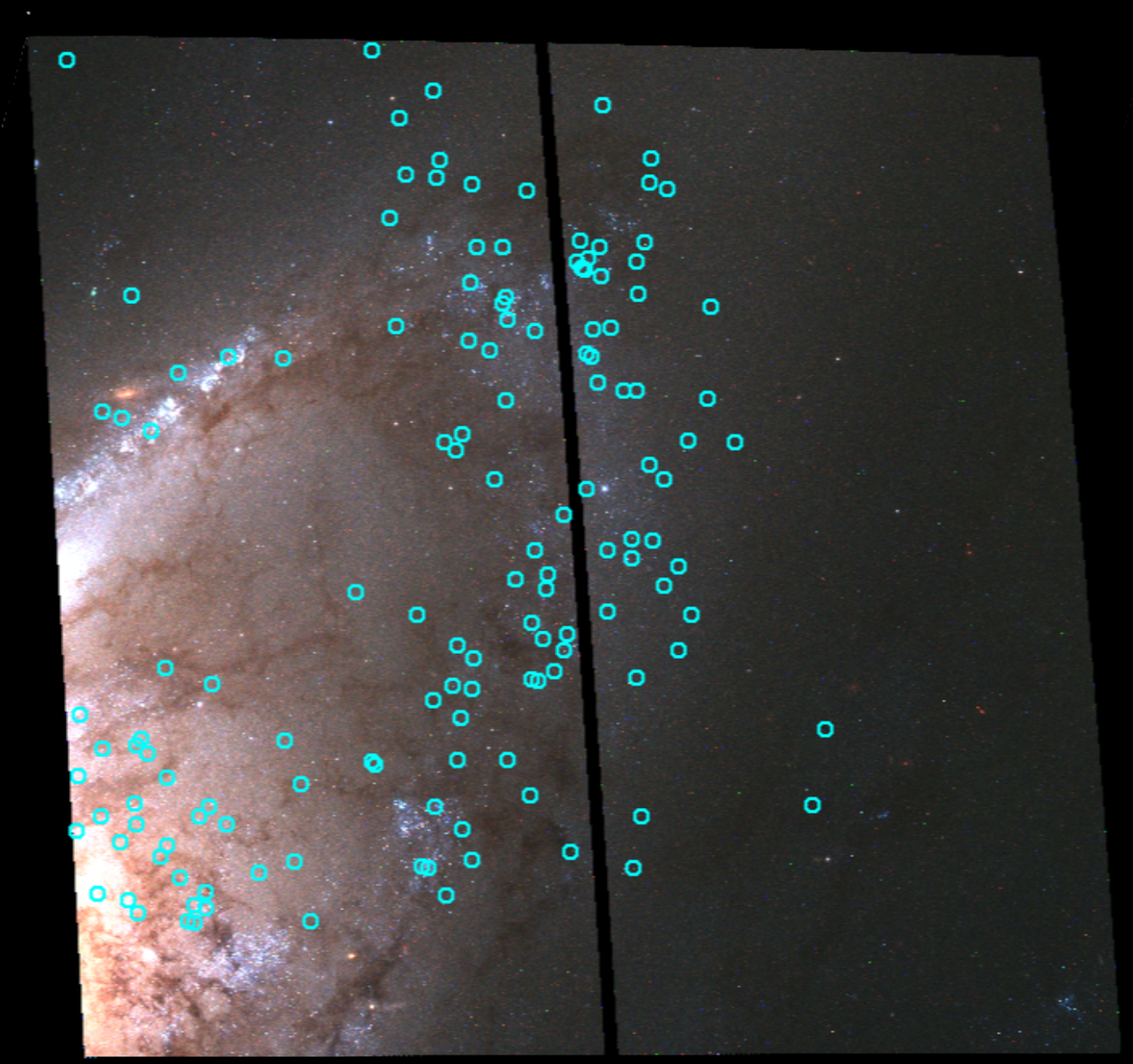
NASA, ESA, Hubble Heritage Team, and R.Gendler



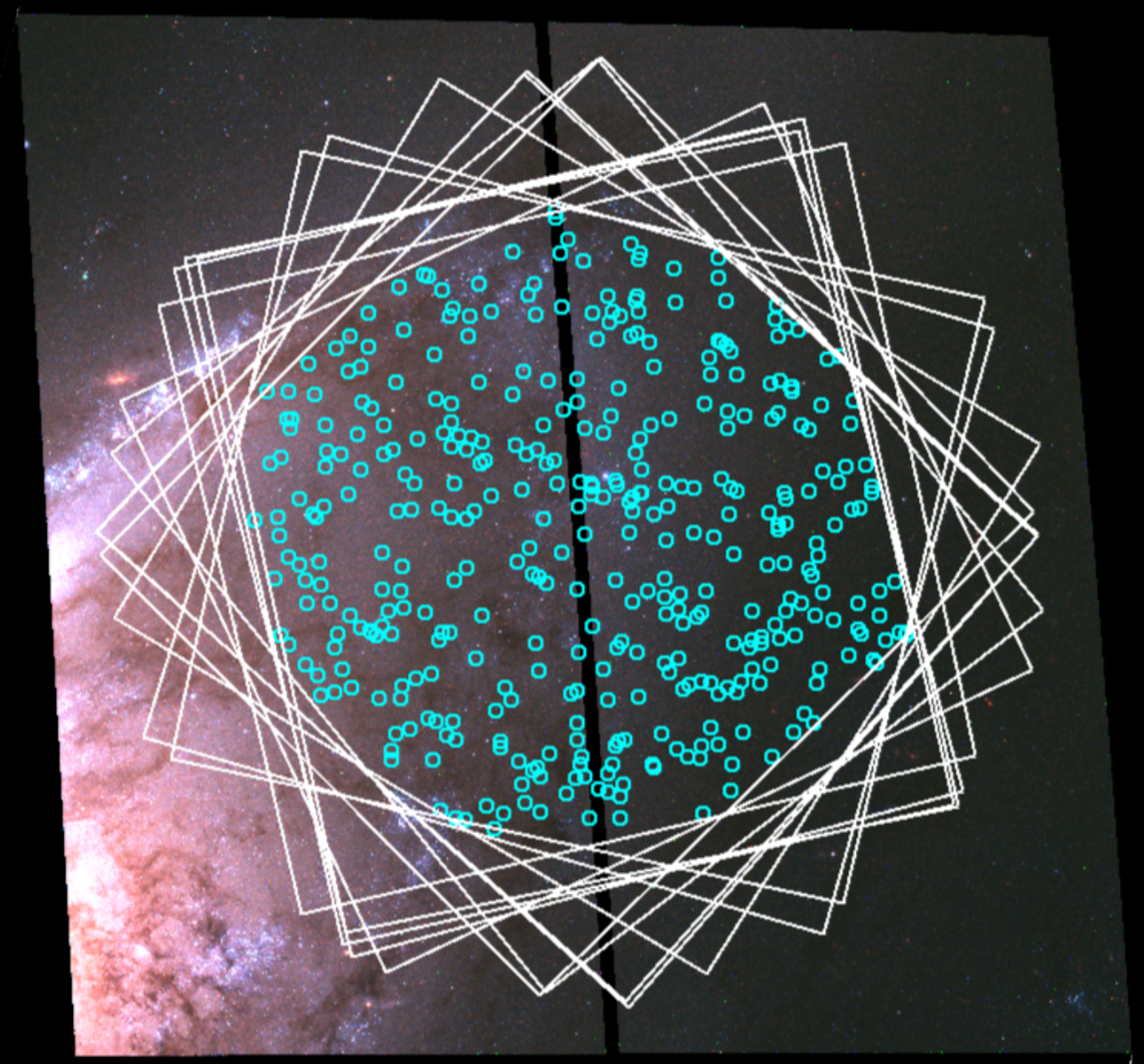
NGC 4258 is host to a water megamaser with a geometric distance of 1.5% precision as of Reid et al. 2019: 7.58 ± 0.08 ± 0.08 Mpc



Cepheid

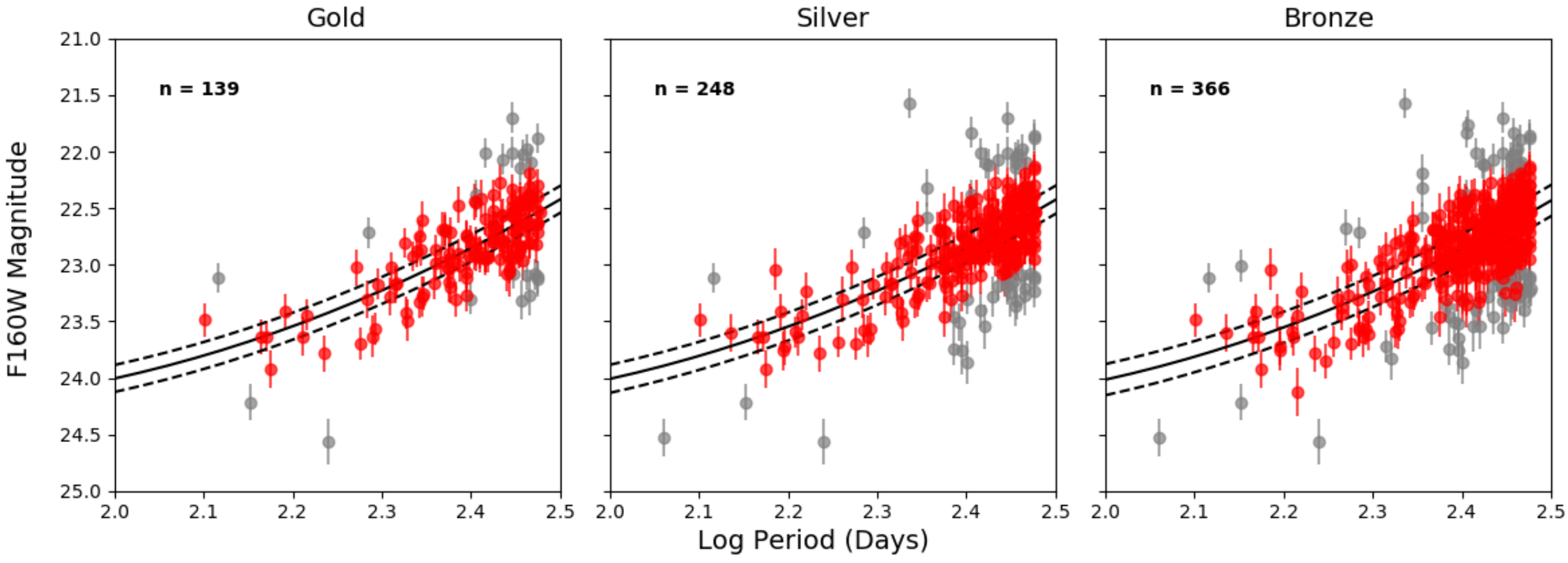


Mira



Sample Selection Criteria

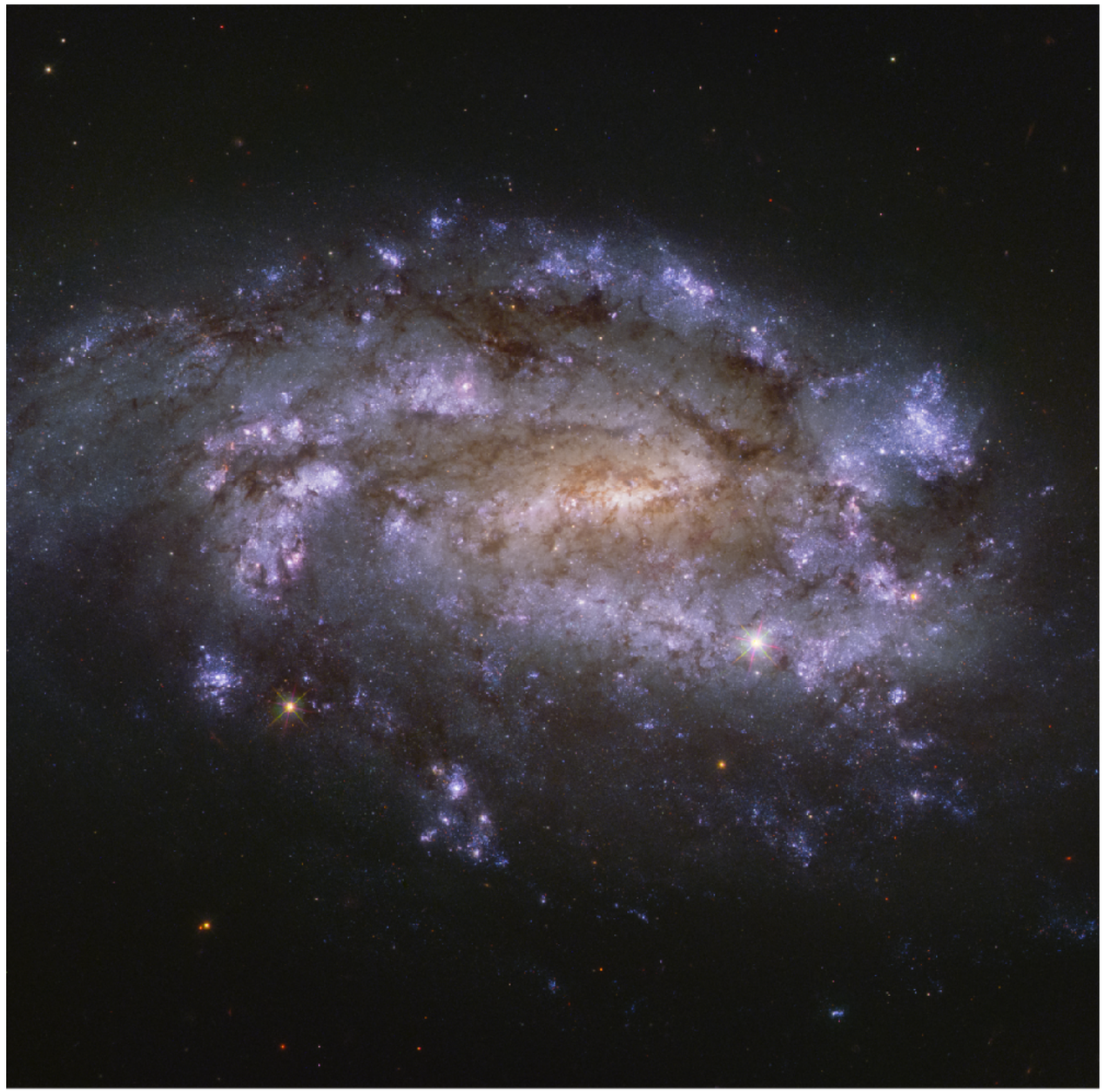
	Bronze	Silver	Gold
Period Cut:	$P < 300$ days	$P < 300$ days	$P < 300$ days
Amplitude Cut:	$0.4 < \Delta F160W < 0.8$ mag	$0.4 < \Delta F160W < 0.8$ mag	$0.4 < \Delta F160W < 0.8$ mag
Color Cut:	$m_{F125W} - m_{F160W} < 1.3$	$m_{F125W} - m_{F160W} < 1.3$	$m_{F125W} - m_{F160W} < 1.3$
$F814W$ Detection:	–	$F814W$ detection	Slope-fit to $F814W$ data$> 3\sigma$
$F814W$ Amplitude:	–	–	$\Delta F814W > 0.3$ mag



Zeropoints of the gold, silver, and bronze PLRs were: 23.24 ± 0.02 mag, 23.25 ± 0.02 mag, 23.26 ± 0.02 mag

NGC 1559

- Host of SN Ia 2005 df
- Will also have a Cepheid distance
- Data collection completed in September 2018
- 10 epochs of *F160W*, each 1005 seconds, baseline 370 days
- First of 4 Type Ia SNe host galaxies targeted by SH0ES

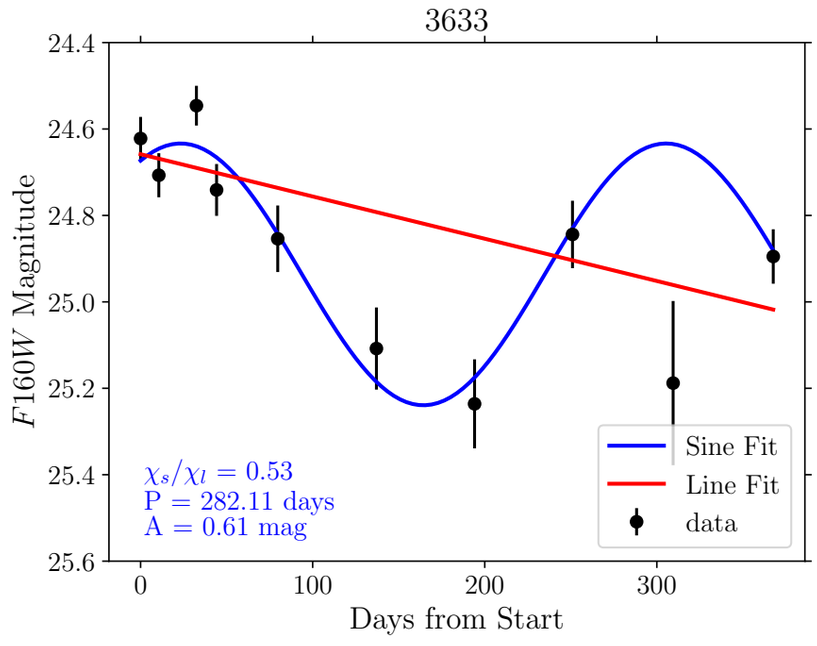


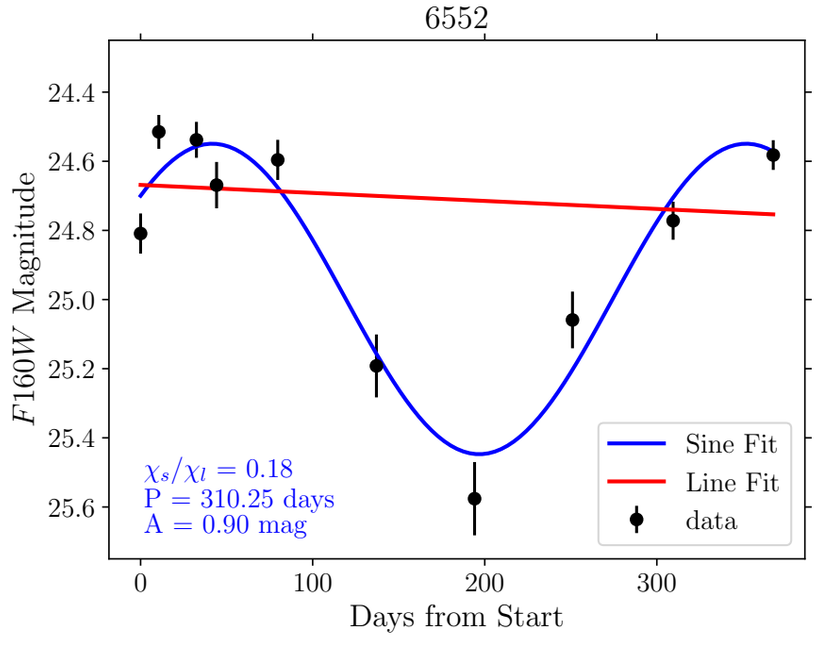
Judy Schmidt

Mira Sample Criteria

	NGC 1559	NGC 4258 (gold)
Period Cut (days):	$240 < P < 400$	$P < 300$
Amplitude Cut (mag):	$0.4 < \Delta F160W < 0.8$	$0. < \Delta F160W < 0.8$
Surface Brightness Cut:	421 counts/second	—
F-statistic:	$\chi^2_s/\chi^2_l < 0.5$	—
Color Cut (mag):	—	$m_{F125W} - m_{F160W} < 1.3$
$F814W$ Detection:	—	Slope-fit to $F814W$ data$> 3\sigma$
$F814W$ Amplitude (mag):	—	$\Delta F814W > 0.3$

Similar to NGC 4258 criteria but with surface brightness cut and additional cut on the F-statistic



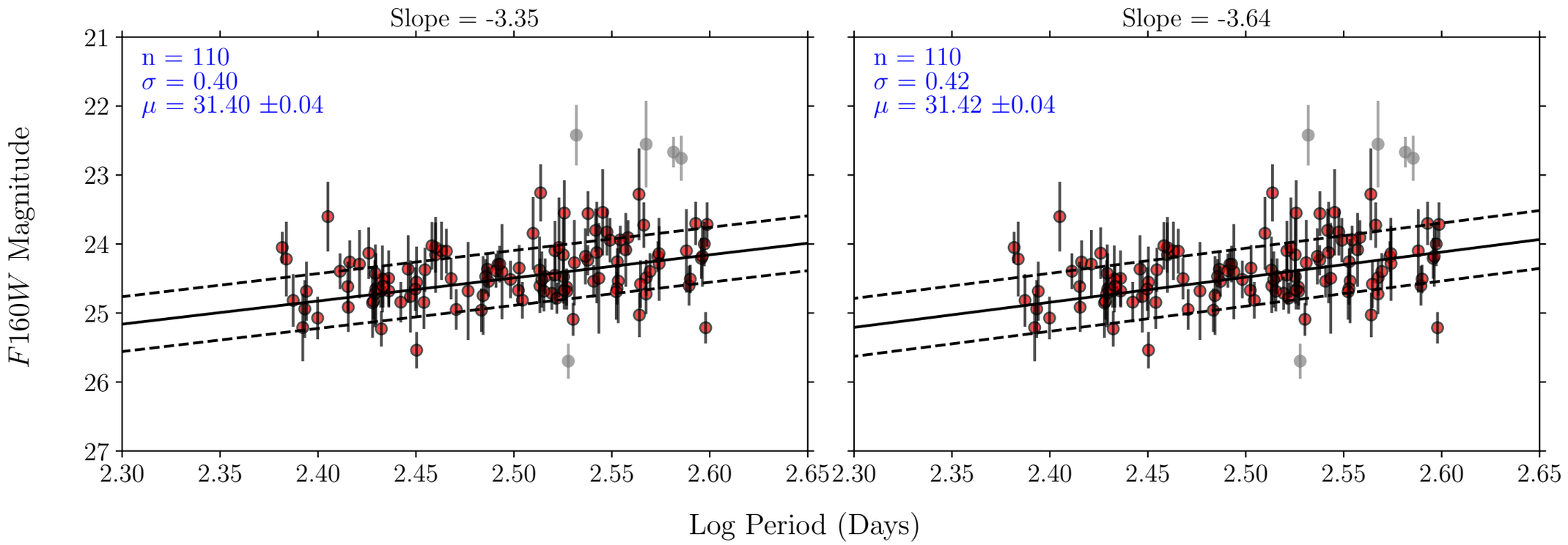


Systematic and Statistical Uncertainties

Source	Systematic Uncertainty (mag)	Statistical Uncertainty (mag)
a_B	0.00176	—
Aperture Correction	—	0.01
C-rich Correction	—	0.024
Color Term	0.02	—
Differential Extinction	0.04	—
LMC Distance Modulus	0.0263	—
LMC Zeropoint	—	0.01
Metallicity	0.03	—
NGC 1559 Zeropoint	—	0.038
NGC 4258 PLR	—	0.017
NGC 4258 Distance Modulus	0.032	—
Uncertainty in Slope (both slopes)	0.01	—
Supernova Peak Magnitude	—	0.11
Subtotals (NGC 4258)	0.060	0.050
Subtotals (LMC)	0.046	0.047

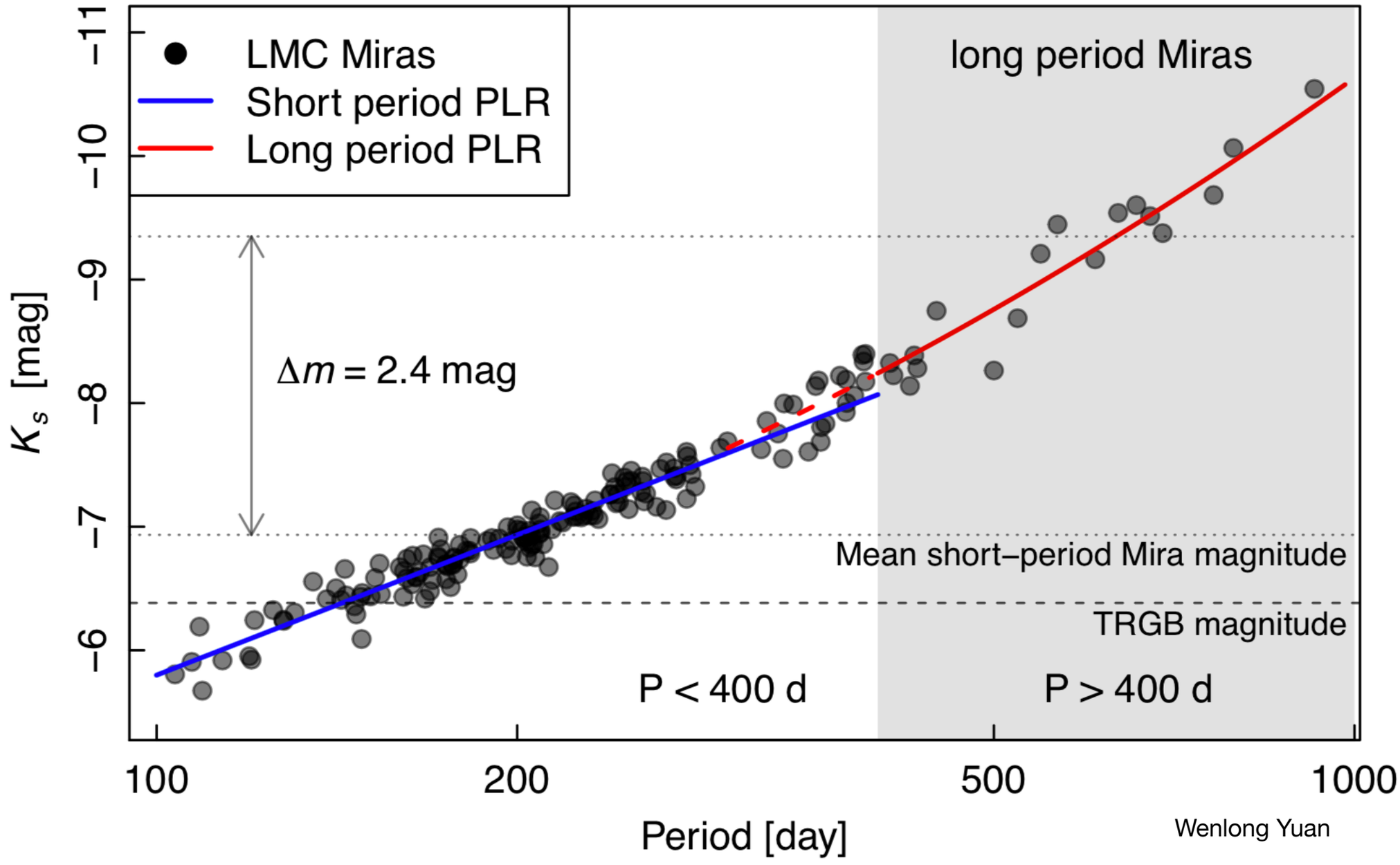
The systematic uncertainty is dominated by uncertainty in differential extinction between NGC 4258 and SN Ia host galaxies. Statistical uncertainty is dominated by SN Ia peak magnitude

Anchor	Period Range (days)	H_0 (km s^{-1} Mpc^{-1}) Slope = −3.35	Slope = −3.64
NGC 4258	$240 < P < 300$	74.6 ± 5.1	74.7 ± 5.1
NGC 4258	$240 < P < 400$	72.7 ± 4.6	72.5 ± 4.6
LMC	$240 < P < 400$	73.9 ± 4.3	73.6 ± 4.3
LMC + NGC 4258	$240 < P < 400$	**73.3 ±4.0**	73.2 ± 4.0



Our best value of **73.3 ± 4.0 km s^{-1} Mpc^{-1}** is in agreement with Cepheid results and is a 5.5% measurement of H_0. It is dominated by the random error from the Type Ia SN magnitude

Long-Period Miras

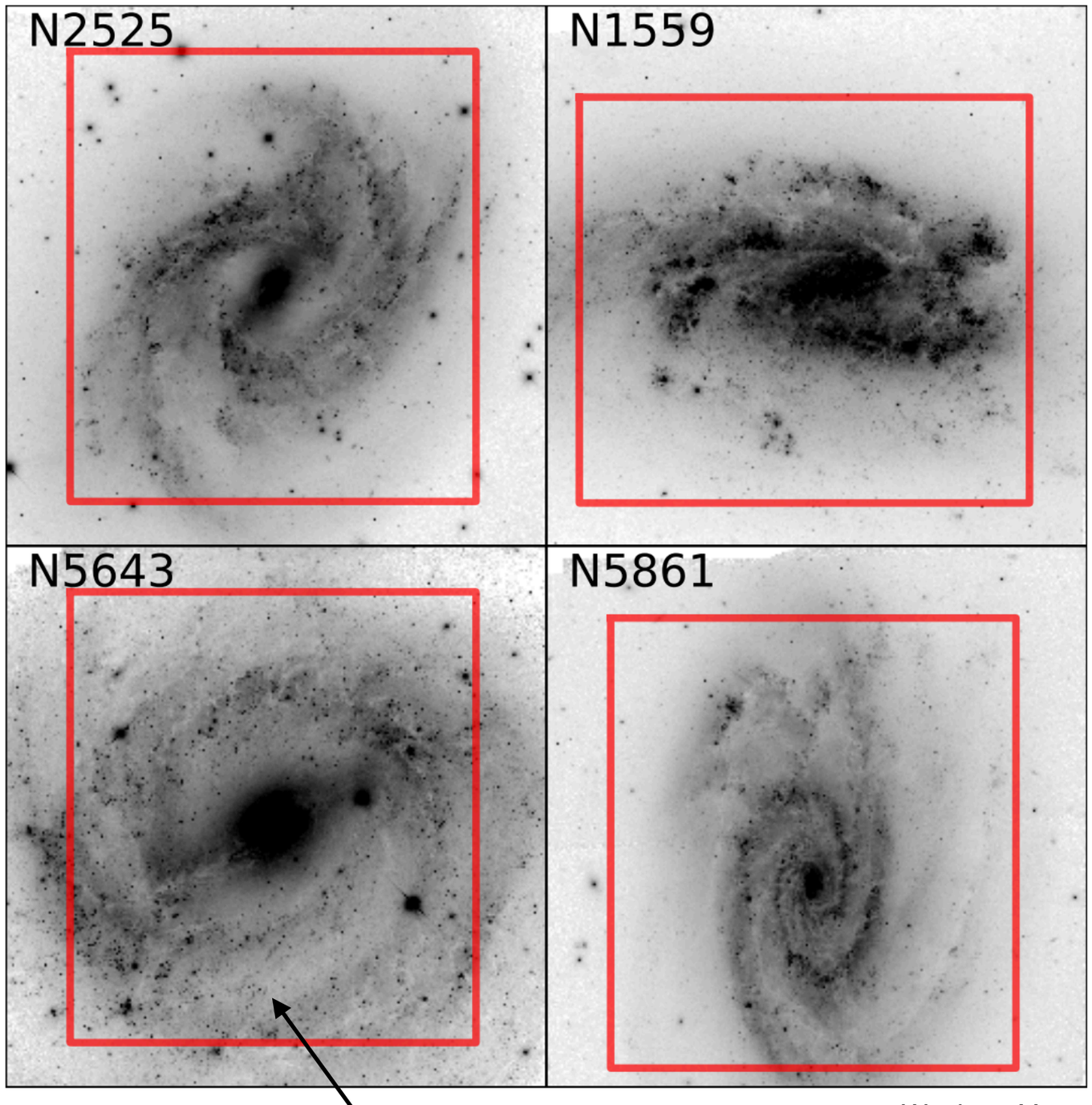


Wenlong Yuan

Future Work

SH0ES obtained NIR time-series observations of three additional SN Ia hosts in which we will also search for Mira variables.

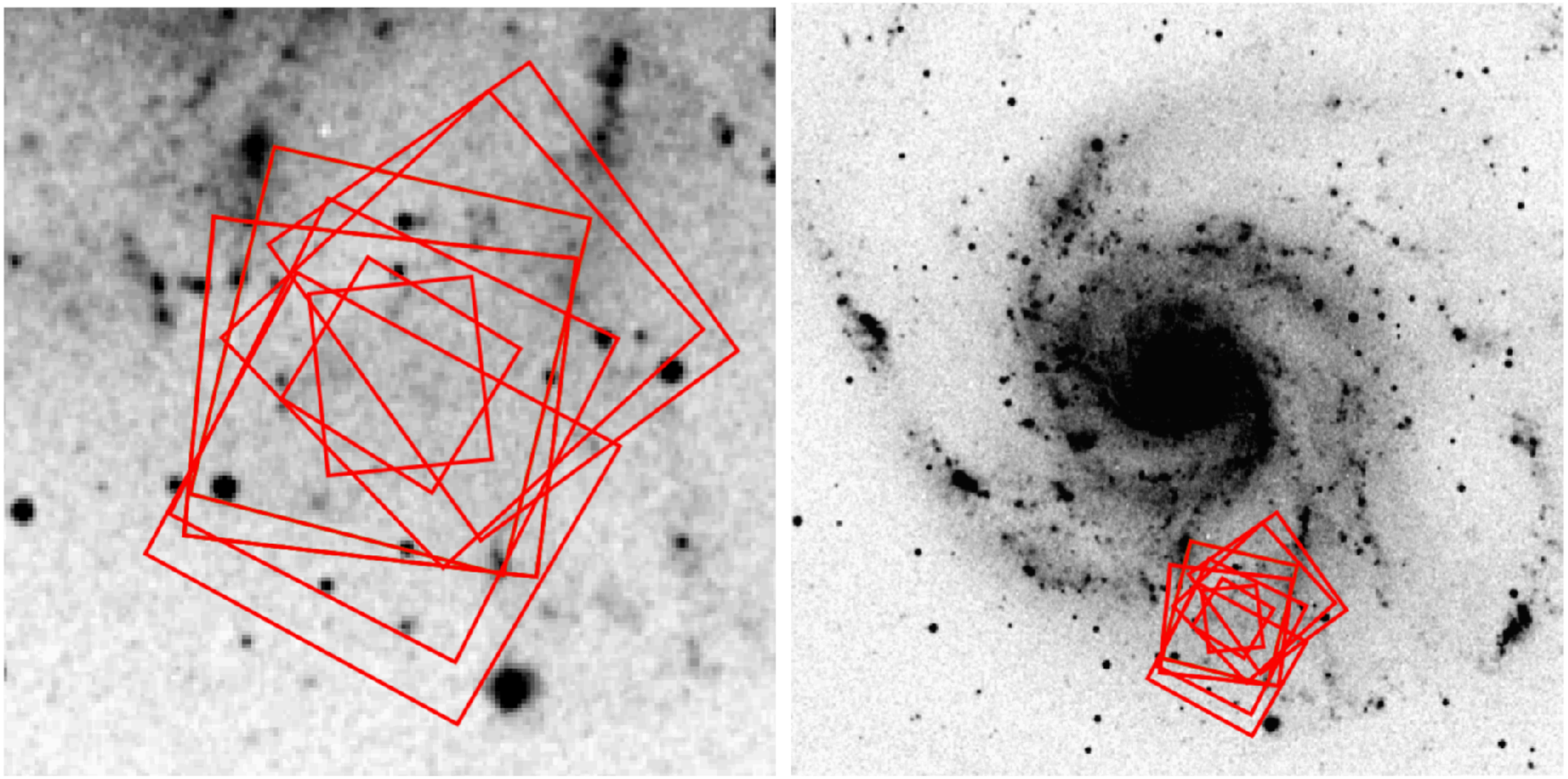
Wenlong Yuan led a Cycle 28 proposal which will obtain an additional 13 orbits to get NIR colors and have a longer observational baseline in these galaxies.



Wenlong Yuan

Two SNe Ia!

Future Work



SN 2011fe was the nearest SN Ia in decades. I am leading a Cycle 28 archival proposal to search for Miras in SN Ia field of M101, bringing the total number of calibrating SNe Ia up to 6.

Summary

- Increasing precision in independent measurements of the Hubble constant are needed to understand the tension

- Miras are a possible independent calibrator of SN Ia that will benefit from future IR and NIR missions

- Long-period Miras, which will need to be calibrated separately from short-period Miras, can be important for reaching even greater distances

- With the additional Cycle 28 observations, we have a total of 6 local SNe Ia in the next couple of years, bringing the uncertainty in H0 from 5.5% to ~3%

- Resources on inclusivity in astrophysics from astrobites: https://astrobites.org/2020/06/12/blackinastro-black-representation-in-astrophysics-and-the-impact-of-discrimination/