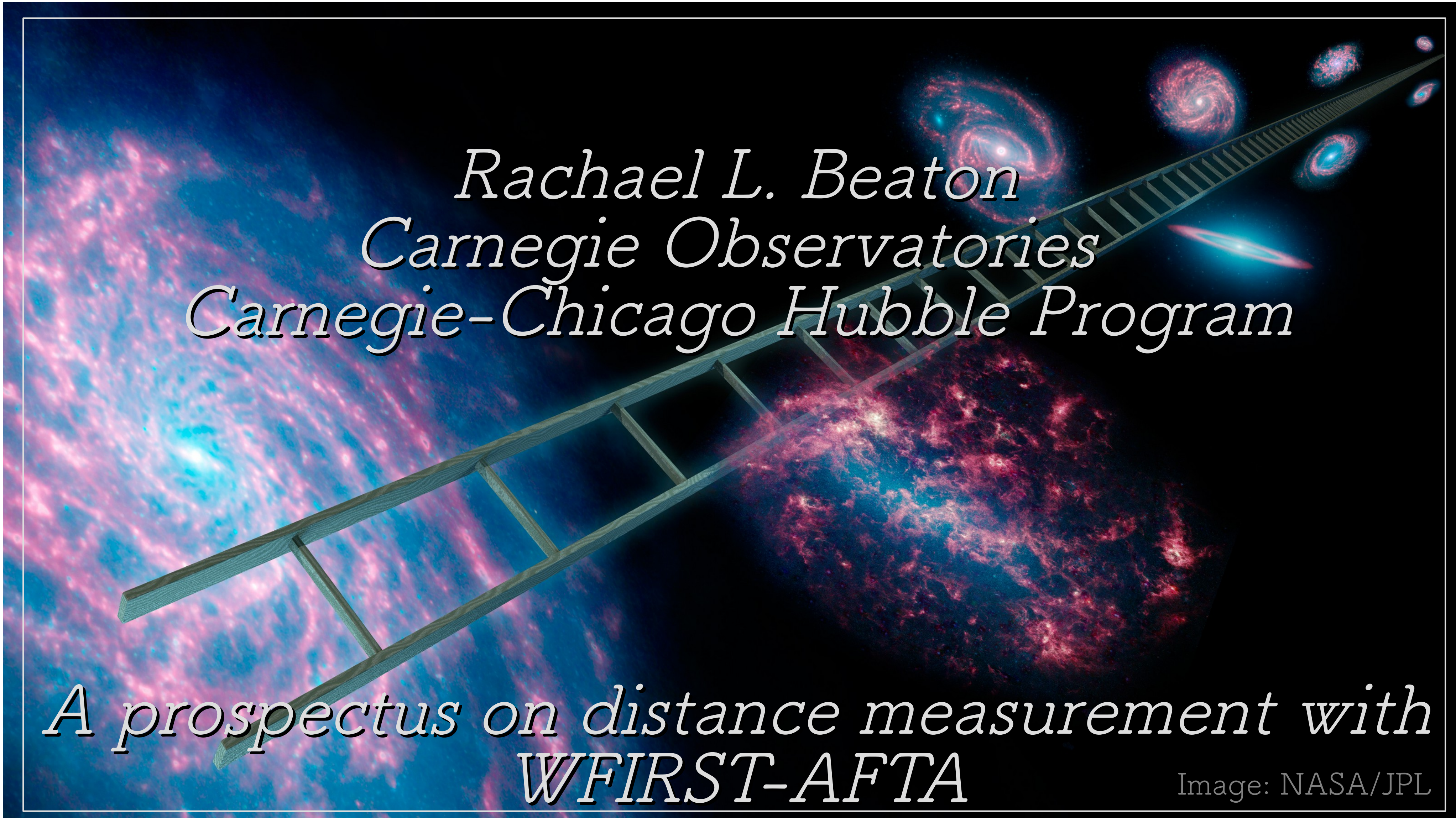
That other way to measure H_0:

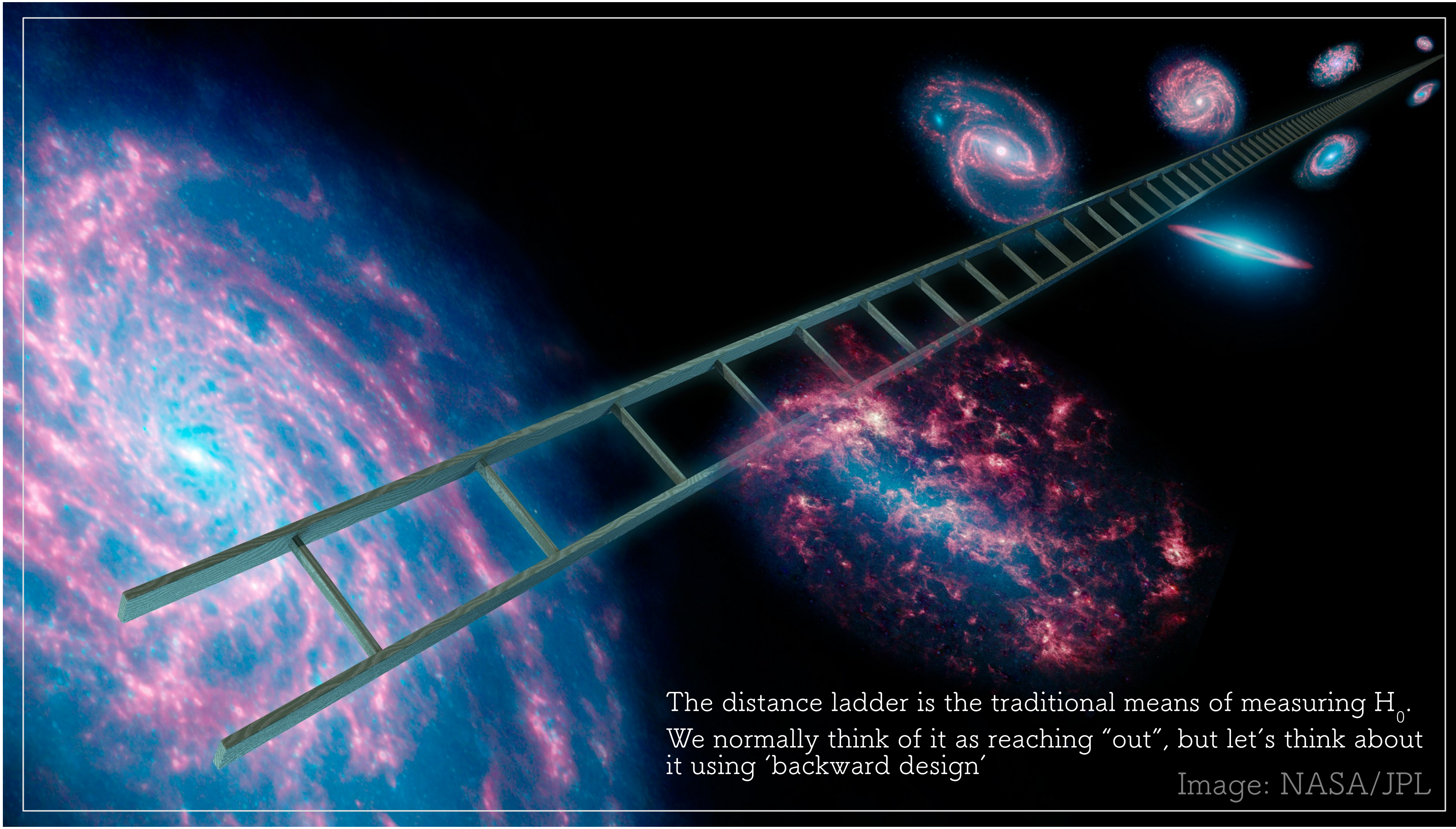


Rachael L. Beaton
Carnegie Observatories
Carnegie-Chicago Hubble Program

A prospectus on distance measurement with WFIRST-AFTA

Image: NASA/JPL

Distance Ladder



The Hubble Diagram

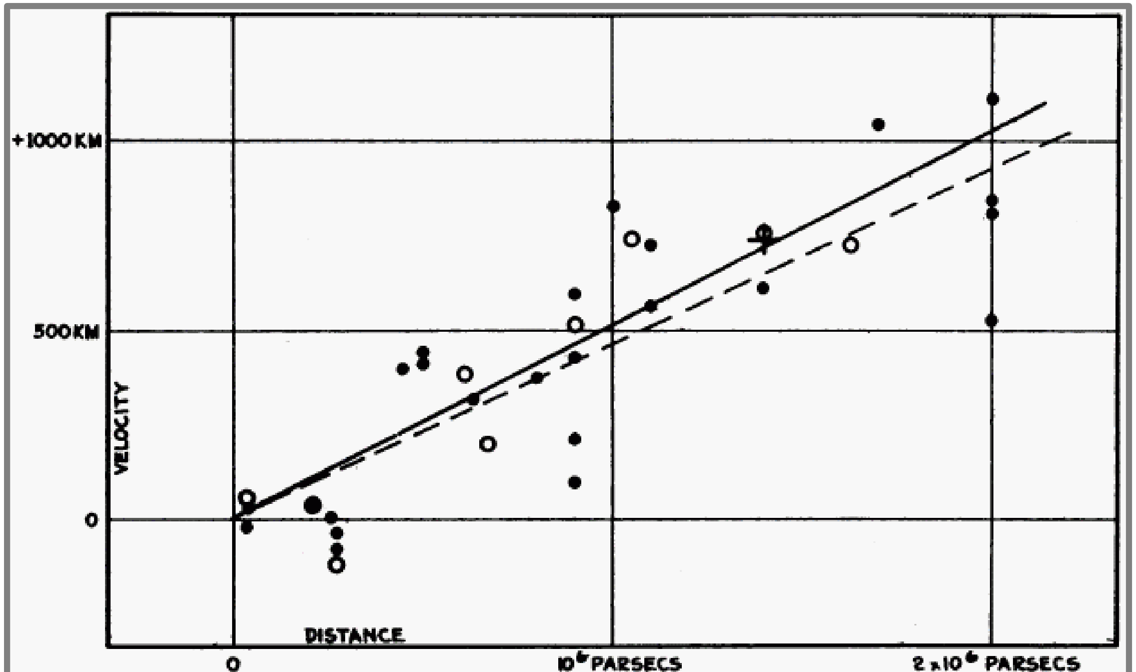
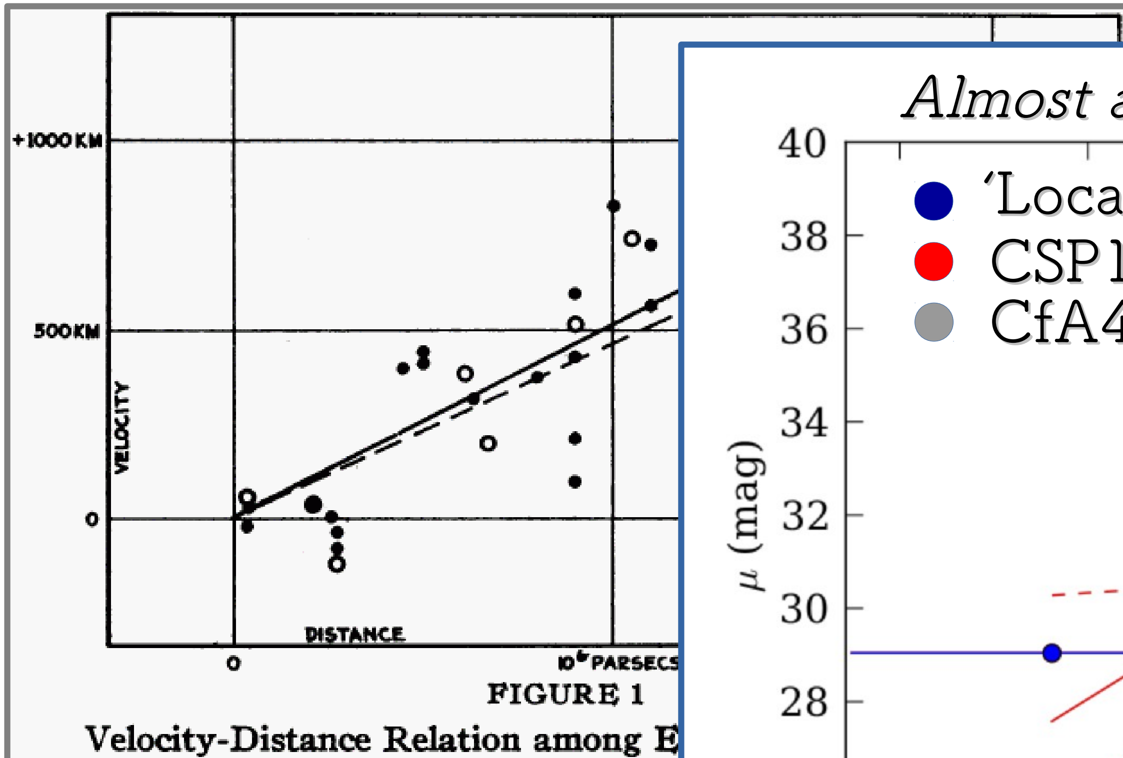


FIGURE 1
Velocity-Distance Relation among Extra-Galactic Nebulae.

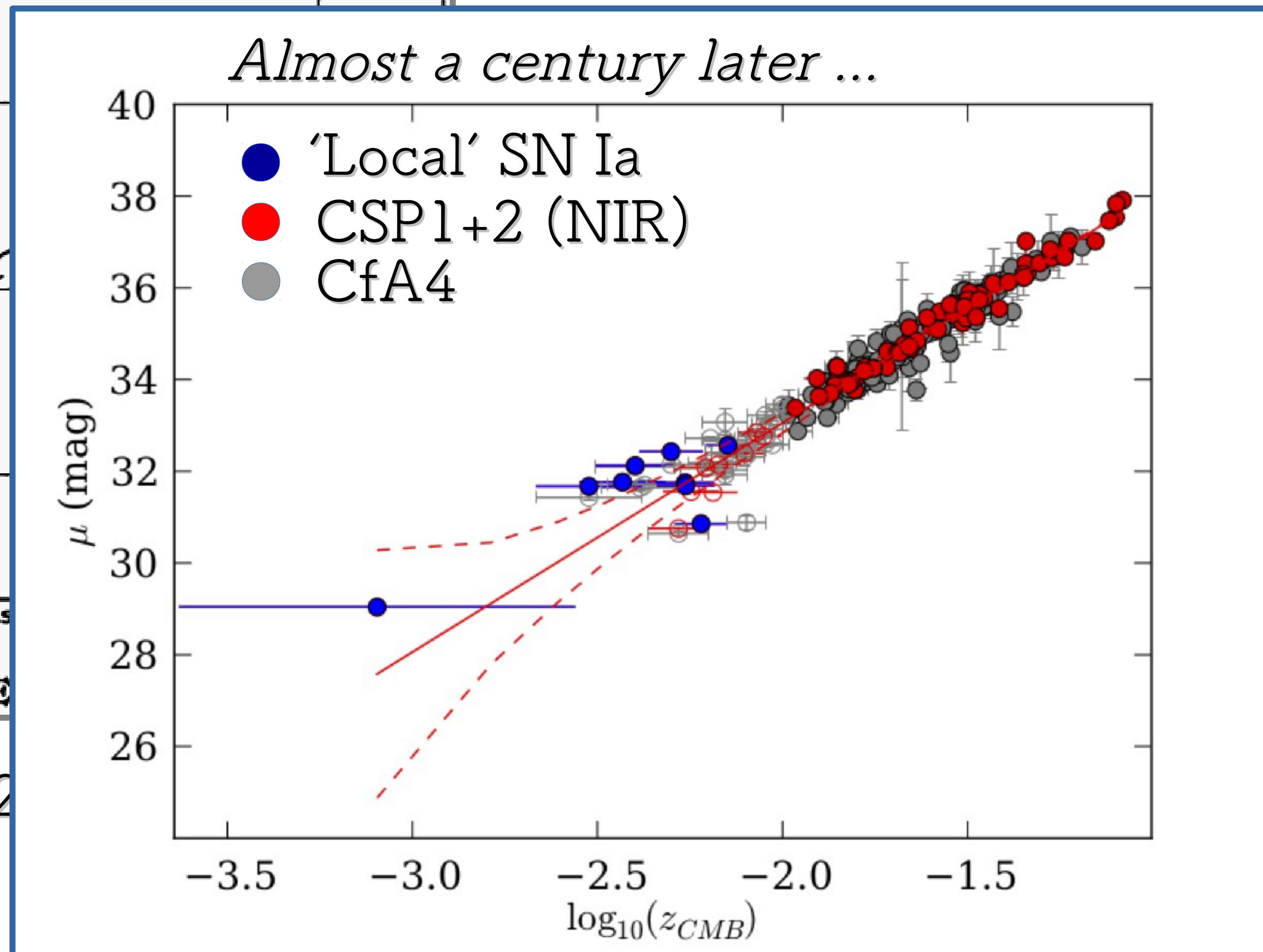
Hubble (the man) 1929

H_0 is the proportionality constant
between redshift (y-axis) and distance (x-axis).

The Hubble Diagram

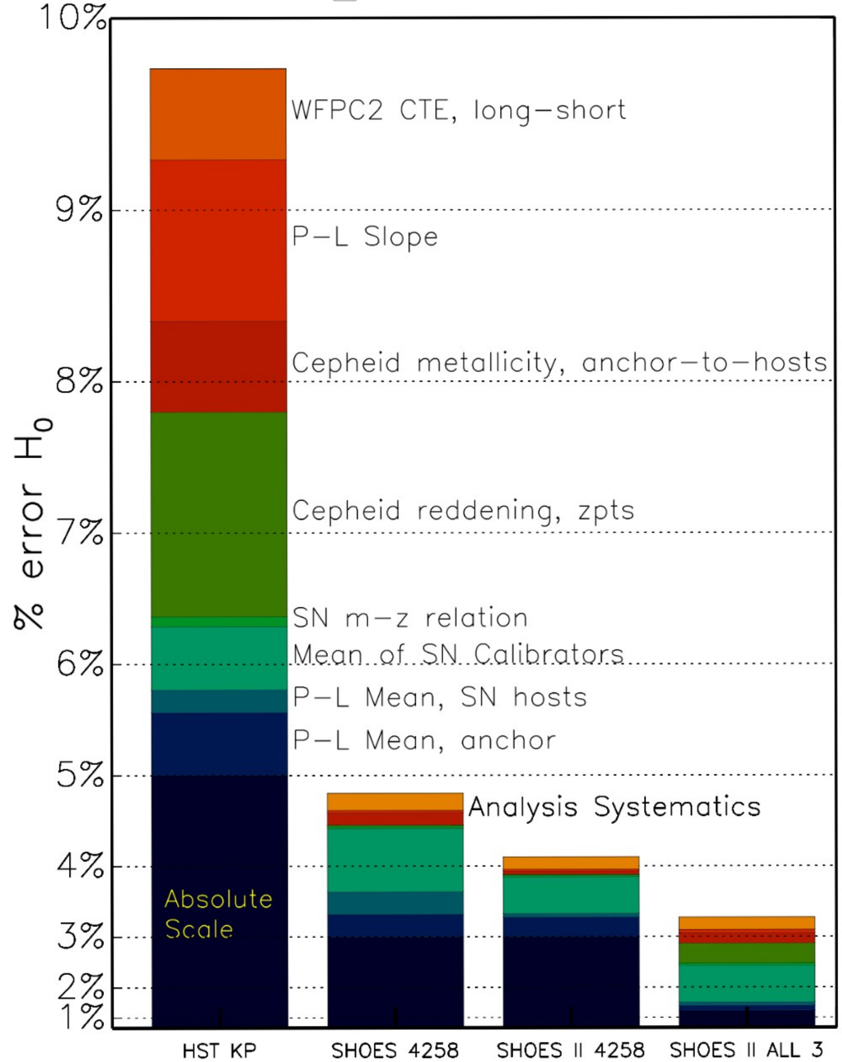


Hubble 192



The calibration of the absolute luminosity for the SN Ia rests on a sample of order 10 objects.
This sets a floor to H_0 of about 2.5%

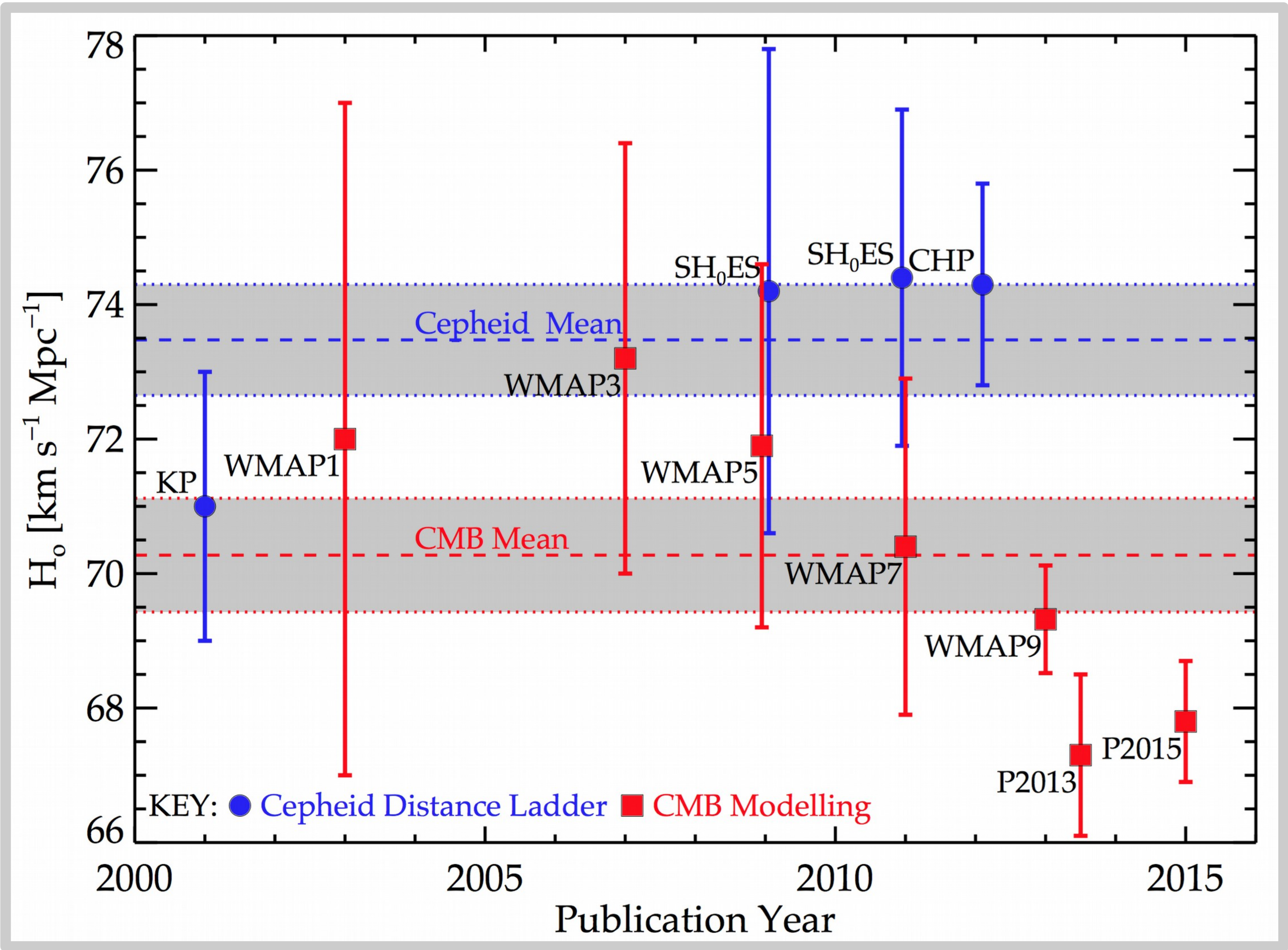
In the (recent) past, this was okay:



The other sources of variance swamped the contribution from the SN Ia anchors.

from Riess et al. 2011
The SH_0ES Collaboration

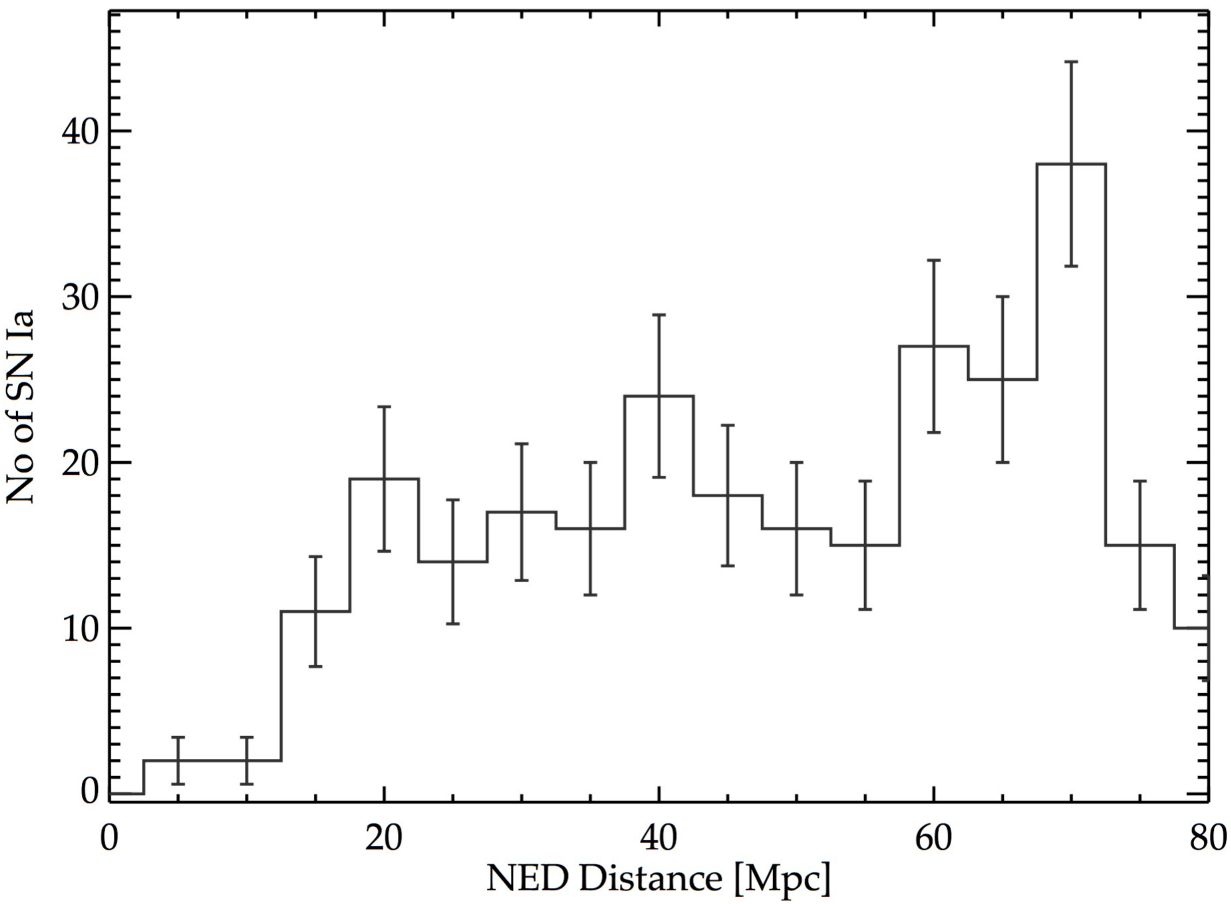
But, today it is not:



Even 0.05 mag (2.5%) variance from SN Ia is now a detail to 'sweat'.

Beaton et al. submitted

Why so few SN Ia Calibrators?



Its just not for a 'lack' of SN Ia in the 'Local Volume'

SN Data from: http://www.rochesterastronomy.org/snimages/
Distances from NASA Extragalactic Database: ned.ipac.caltech.edu

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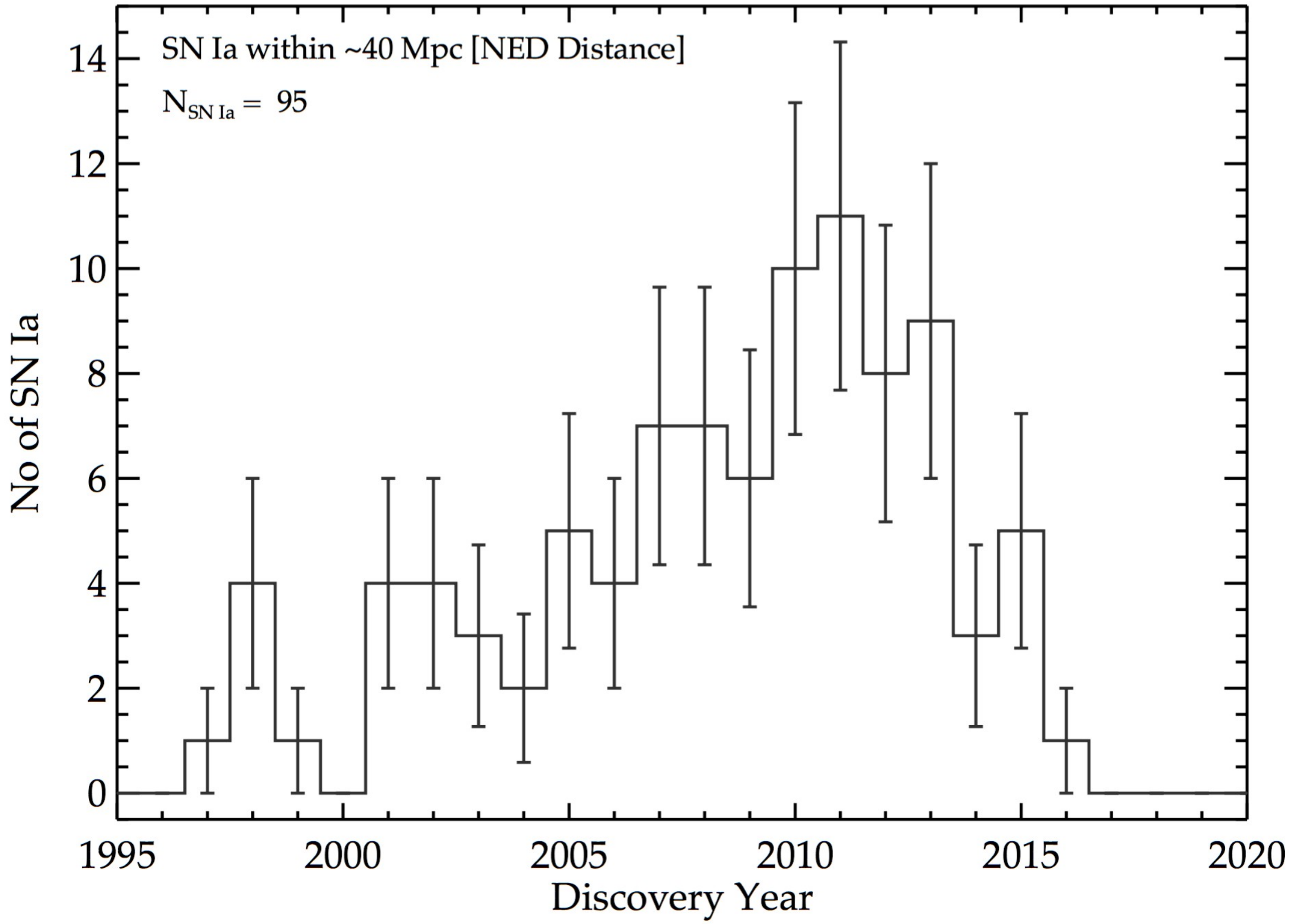

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SN Data from: http://www.rochesterastronomy.org/snimages/
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(1) Can I characterize the SN?	(2) Can I measure the distance?

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(1) Can I characterize the SN?	(2) Can I measure the distance?
• Did I find it before peak light? • Can I remove the galaxy light and/or nearby bright sources? • Do I have quality light curves? • Can I measure local extinction? • ⋯ and related issues.	

SN Ia Suitability is:

(1) Can I characterize the SN?	(2) Can I measure the distance?
YES (most of the time)	

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Thanks to phenomenal efforts from the SN community – ~40 of the ~95 SN within 40 Mpc have this data*.

**Data from Chris Burns (CSP) and Ben Shappee (ASAS SN)*

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(2) Can I measure the distance? **With Cepheids?**

Is the host galaxy:

- Star forming?
- Luminous?
- Approx. face on?

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Is the host galaxy:

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If yes to *all* of the above, then:

- Do I have 10-20 epochs in 2 optical filters to ID Cepheids?
- Do I have enough Cepheids to sample log(P)?
- Do I have spatially resolved metallicity information? (*is that information suitable for stellar measurements?)*
- Can I measure local extinction?
- … and related issues.

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And herein lies the limitation …

Data from Chris Burns (CSP) and Ben Shappee (ASAS SN)

SN Ia Suitability is:

(1) Can I characterize the SN?

YES (~50%)

- Did I find it before peak light?
- Can I remove the galaxy light and/or nearby bright sources?
- Do I have quality light curves?
- Can I measure local extinction?
- … and related issues.

Thanks to phenomenal efforts from the SN community – ~40 of the ~95 SN within 40 Mpc have this data*.

(2) Can I measure the distance?

YES, for ~ten of them.

Is the host galaxy:

- Star forming?
- Luminous?
- Approx. face-on?

If yes to all of the above, then:

- Do I have 10-20 epochs in 2 optical filters to ID Cepheids?
- Do I have en… Cepheids … sample …?
- Do I have spatially resolved metallicity information? (*is that information suitable for stellar measurements?*)
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- … and related issues.

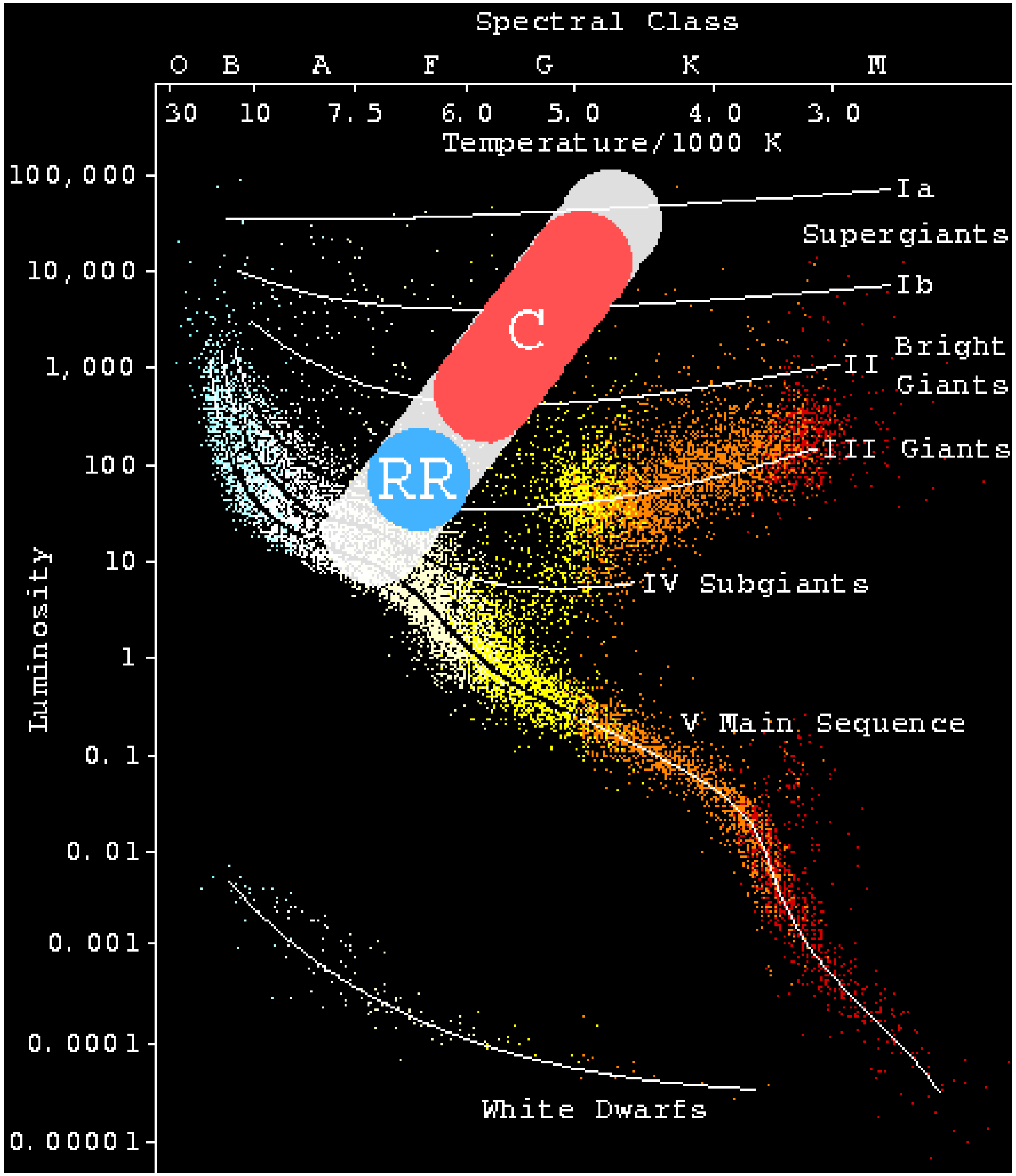
And herein lies the limitation …

1) Cepheids are fantastic, but their application to the SN Ia population is limited.

2) The data to characterize them is expensive, requires multiple facilities, relies on many different observational techniques.

**Data from Chris Burns (CSP) and Ben Shappee (ASAS SN)*

Let's go back to CMD101:



Lecture Notes of M. Hanson, Univ. of Cincinnati

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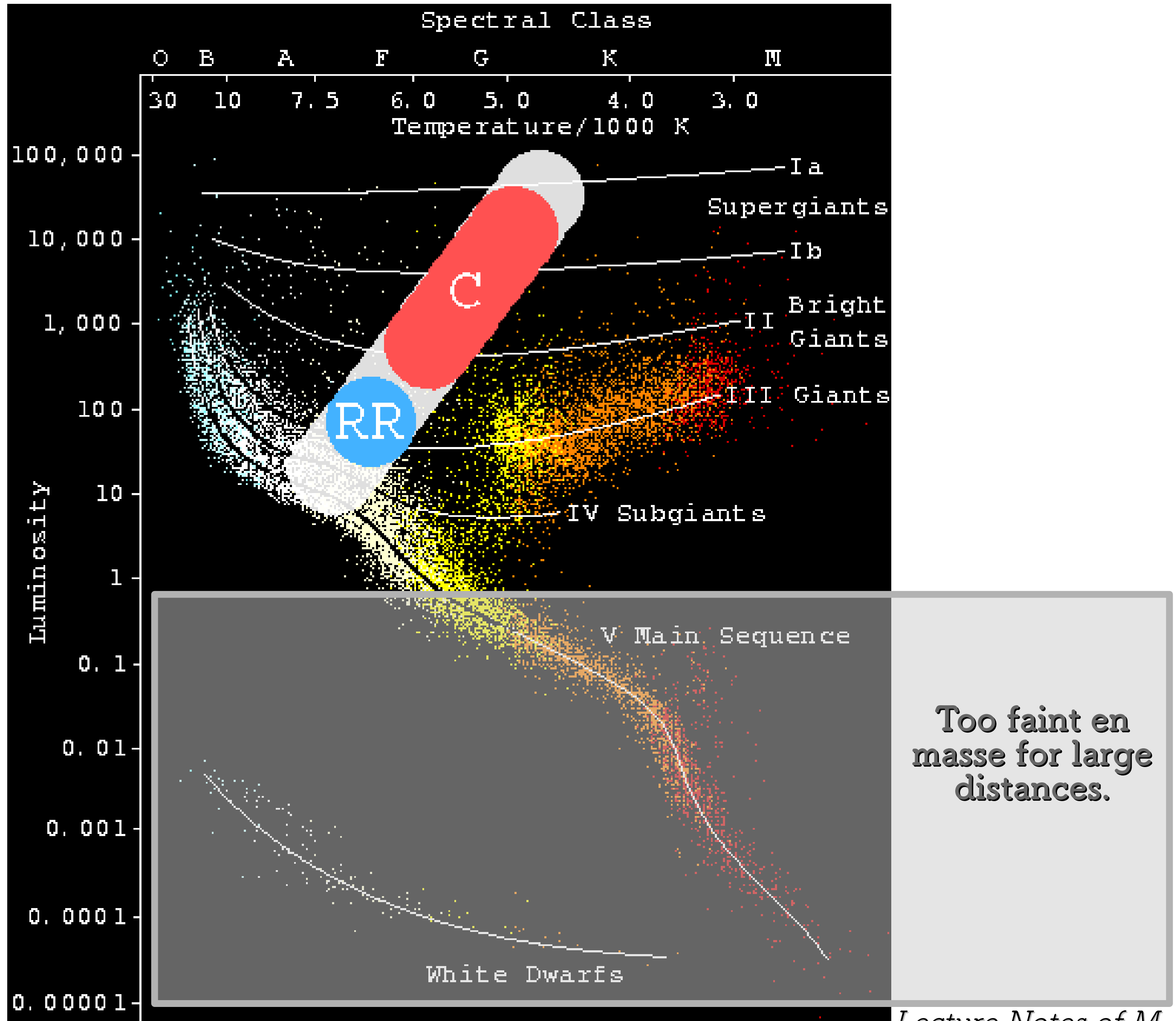
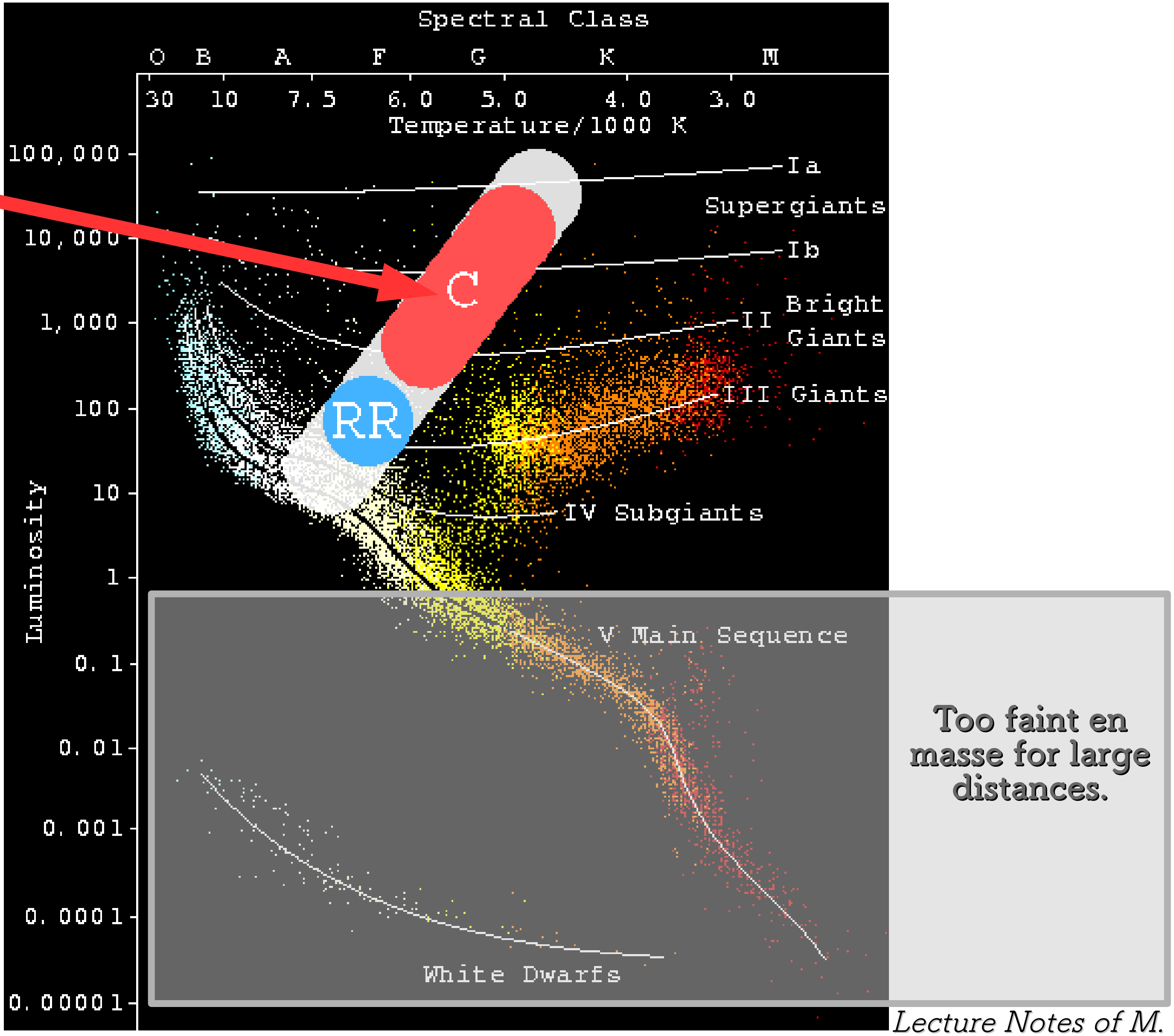


Lecture Notes of M. Hanson, Univ. of Cincinnati

Let's go back to CMD101:

Cepheids

<400 Myr
~massive
Range of metals
Galaxy disks



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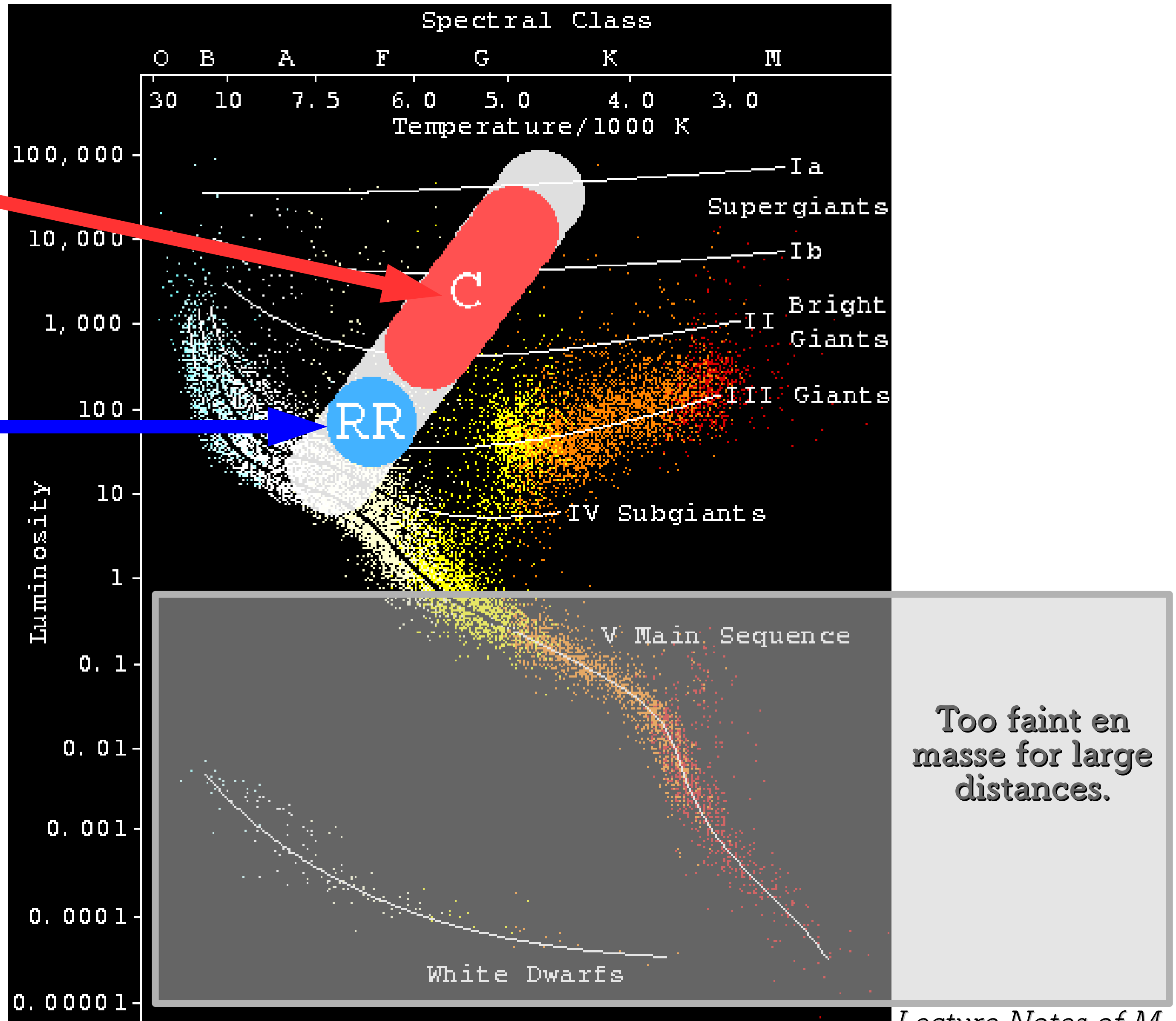
Old >few Gyr
~1 solar mass
Mostly metal poor
Disk, bulge, halo, etc.



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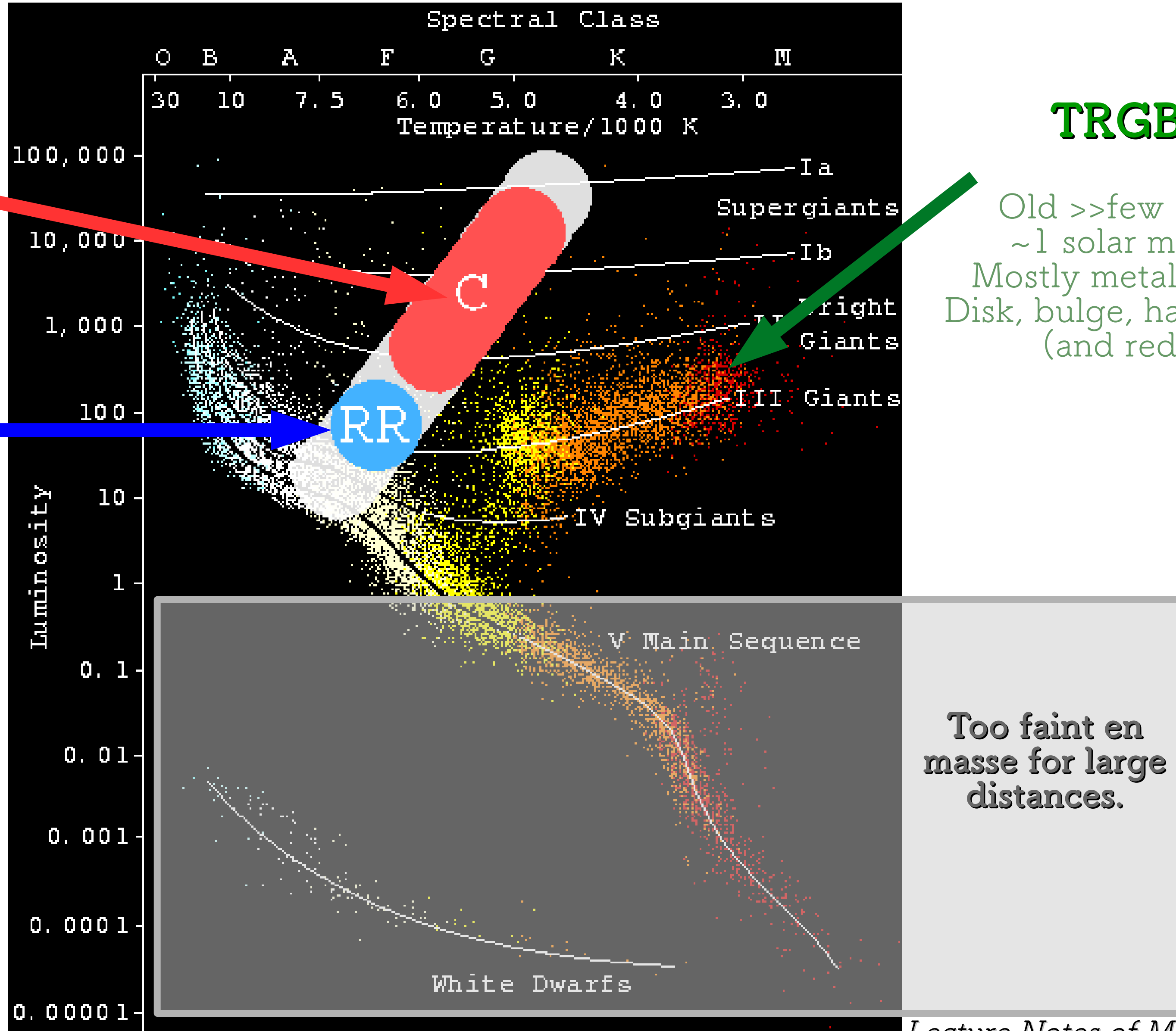


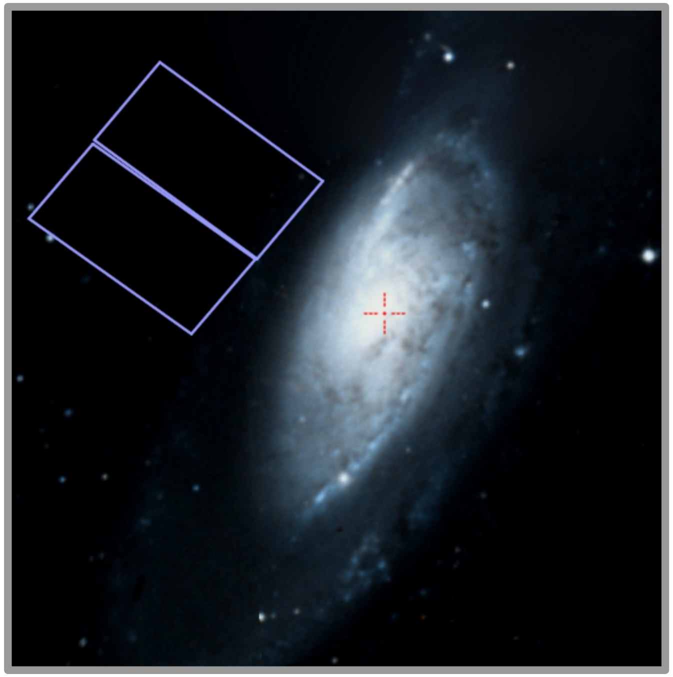
TRGB

Old >>few Gyr
~1 solar mass
Mostly metal poor
Disk, bulge, halo, etc.
(and red)

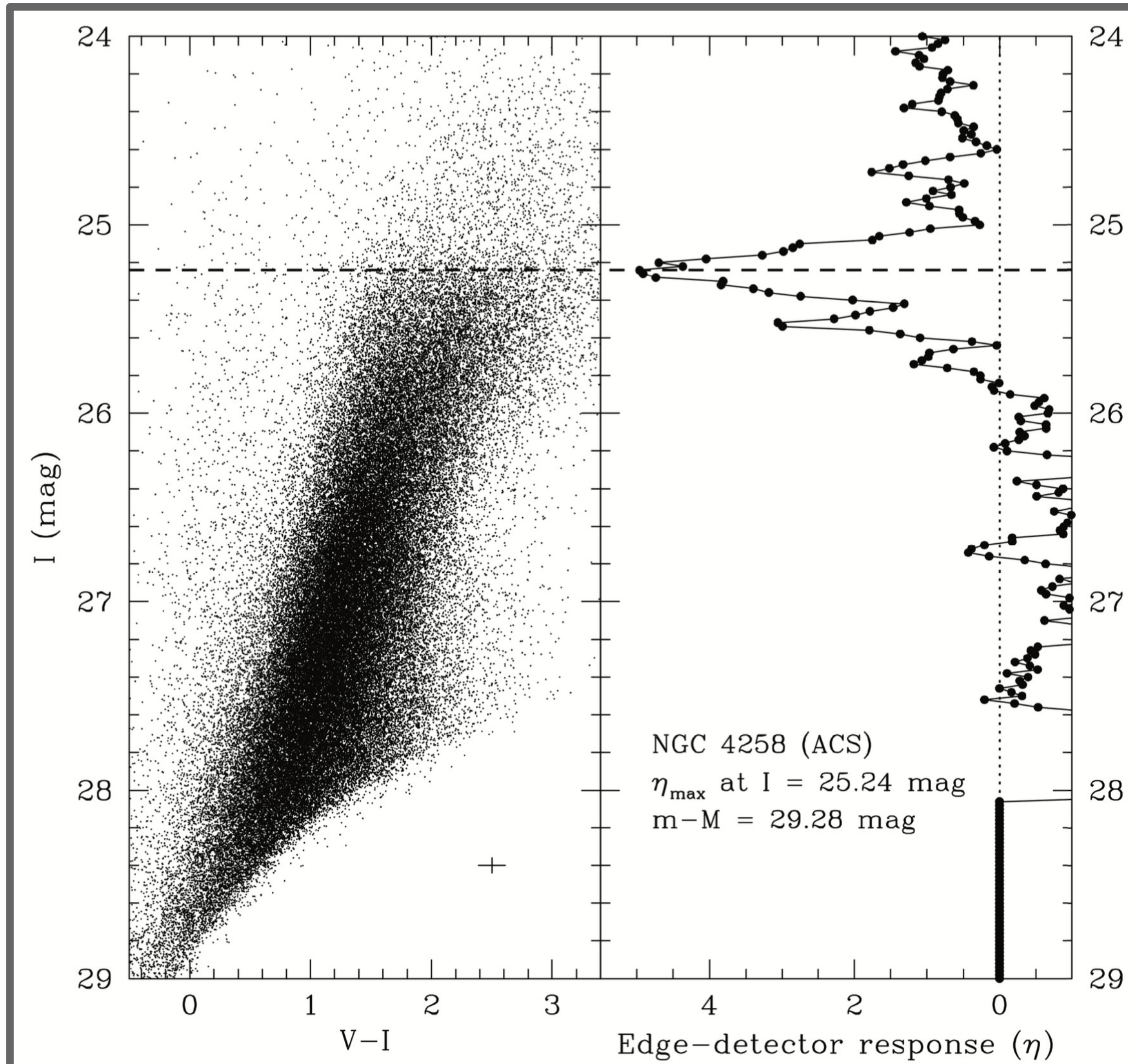
Too faint en masse for large distances.

Lecture Notes of M. Hanson, Univ. of Cincinnati

The TRGB as an alternative:



NGC4258: ~7 Mpc

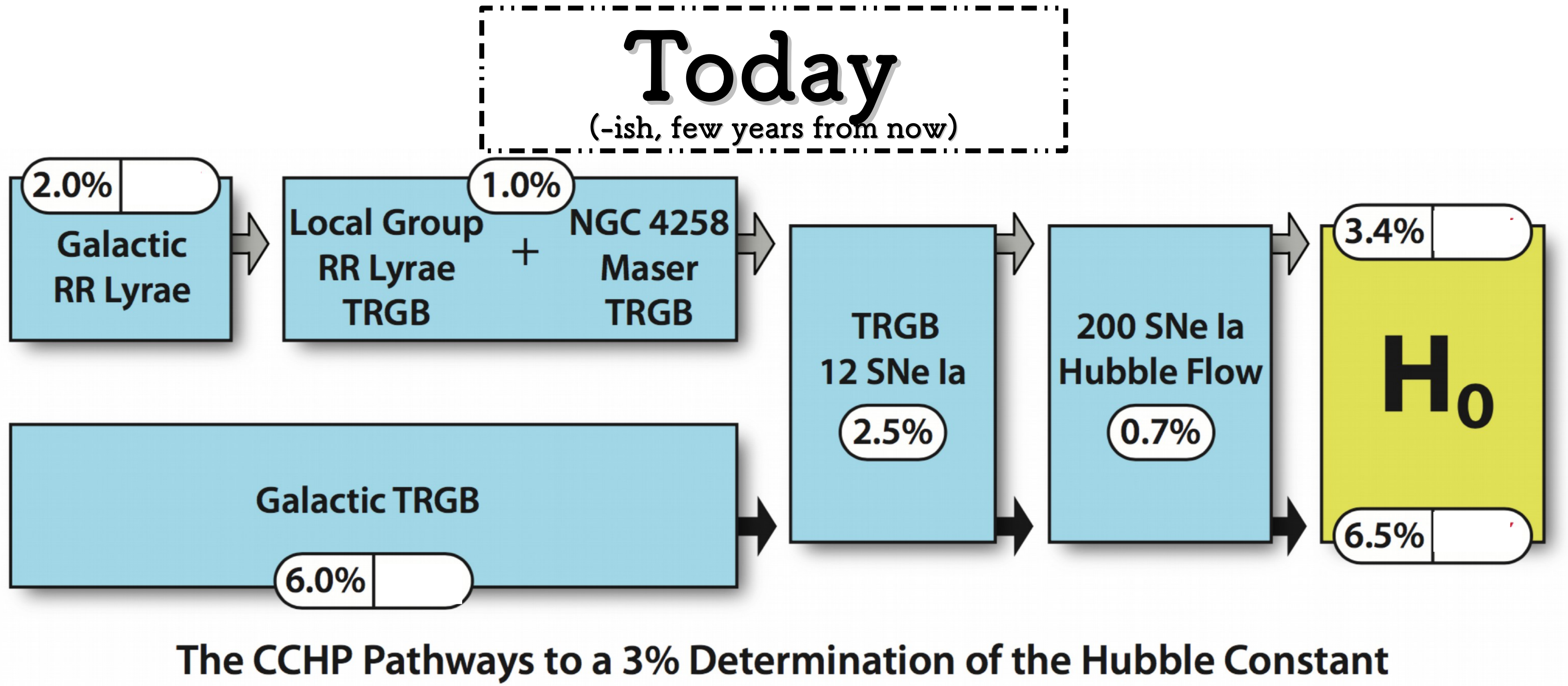


TRGB in NGC4258
(mega maser host)

- Available in galaxies of all sizes, shapes, morphology, interactions, etc.
- Point in the halo to avoid extinction, crowding, etc.
- Metallicity effect projected to color

Mager, Madore, Freedman 2008

The Bottom Line: H_0 Error Budget



Beaton et al. submitted

From HIP+HST+FGS to Gaia

NOW

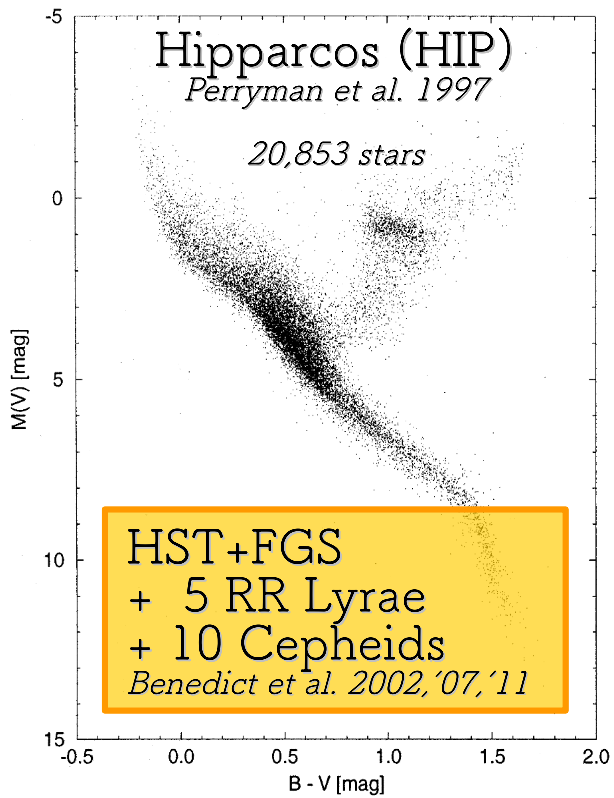


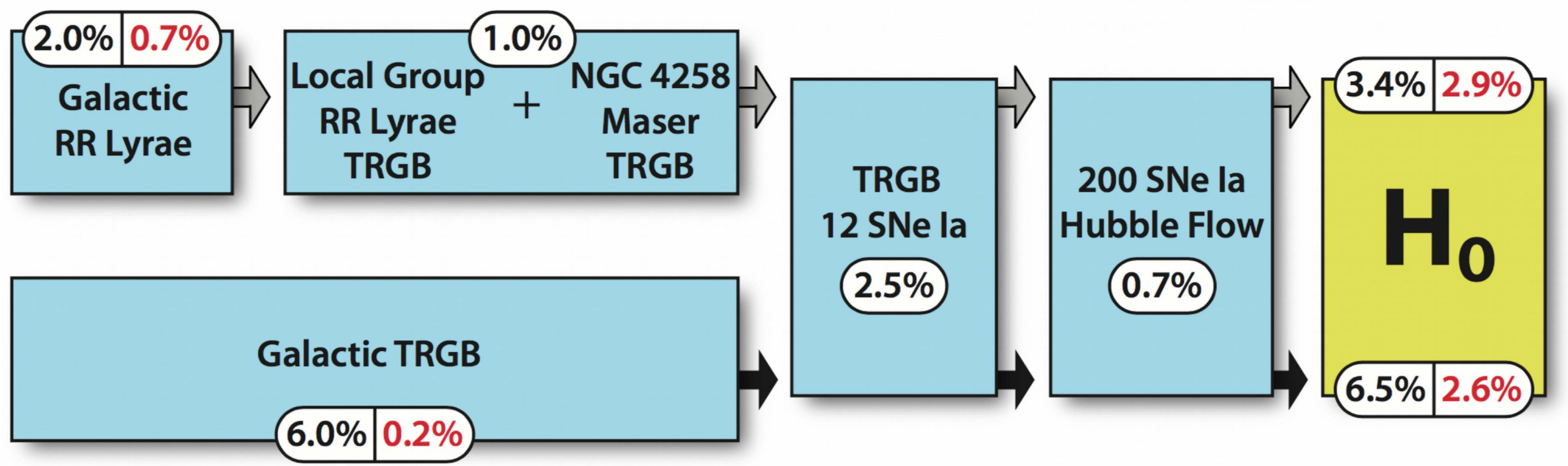
Fig. 3. The observational Hertzsprung-Russell diagram, M_V versus $B - V$, for the 20 853 stars with $\sigma_\pi/\pi < 0.1$, and with the additional constraint $\sigma_{B-V} < 0.025$ mag.

Gaia is a game changer.

For details see:
Clementini et al. 2016
Eyer et al. 2012

The Bottom Line: H_0 Error Budget

After Gaia
(and before WFIRST)

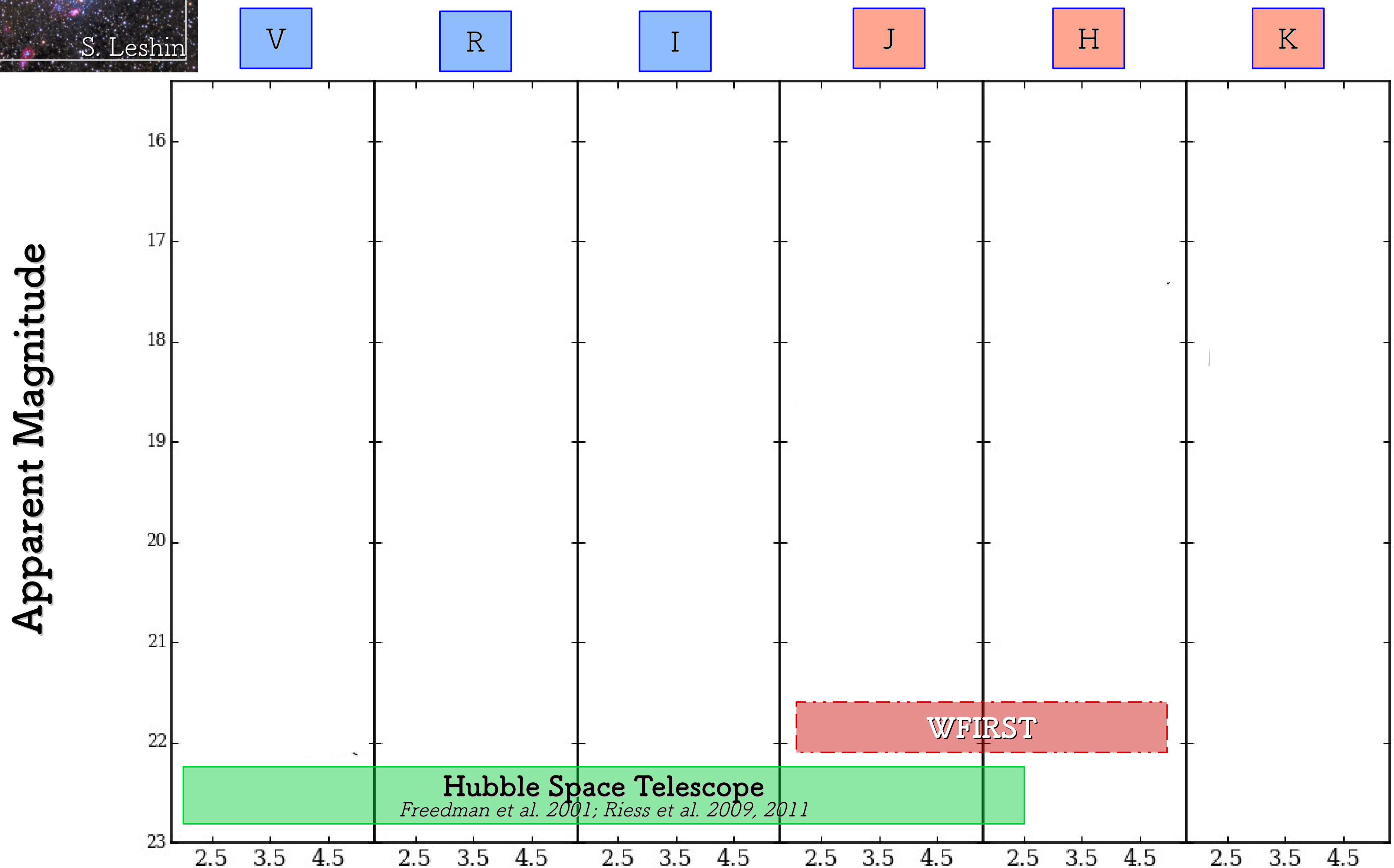


The CCHP Pathways to a 3% Determination of the Hubble Constant

For Gaia details see:
Clementini et al. 2016
Eyer et al. 2012

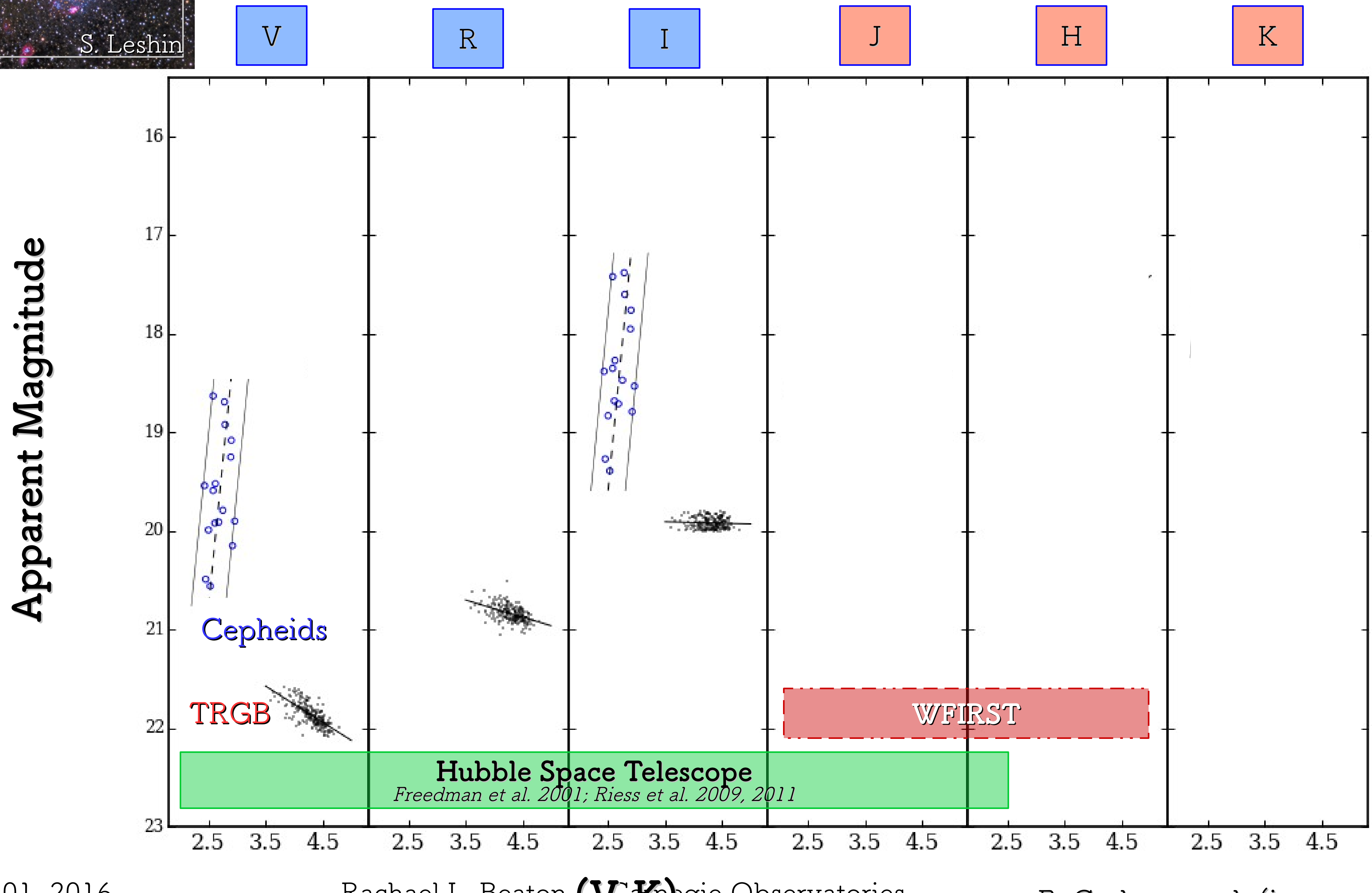
Beaton et al. submitted

Blue vs. Red Candles



E. Carlson et al. (in prep.)

Blue vs. Red Candles



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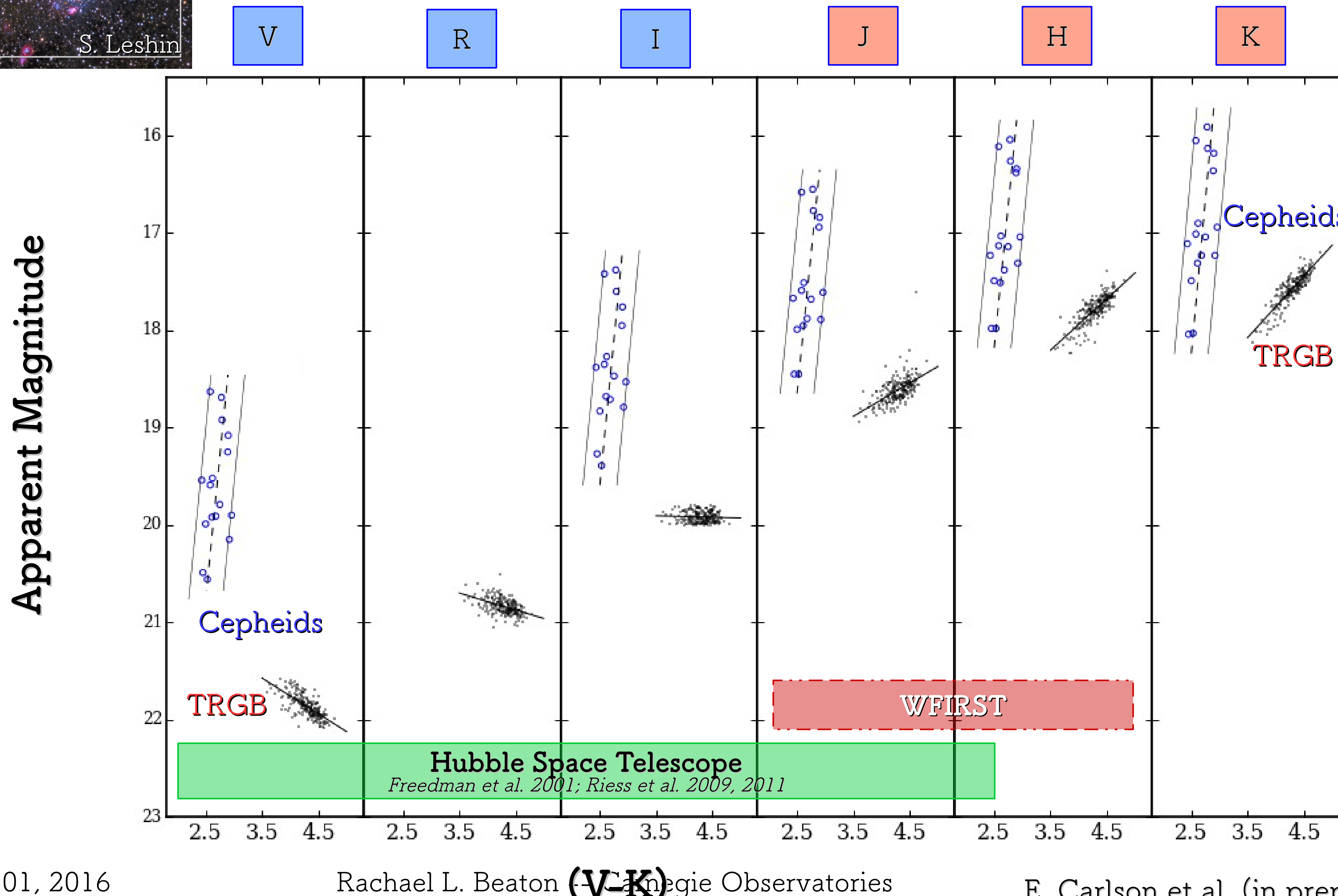
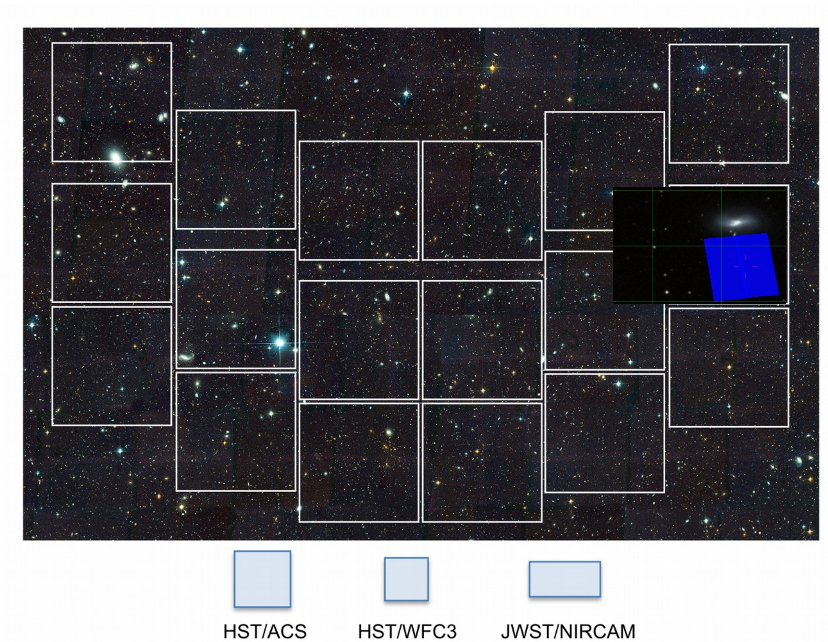
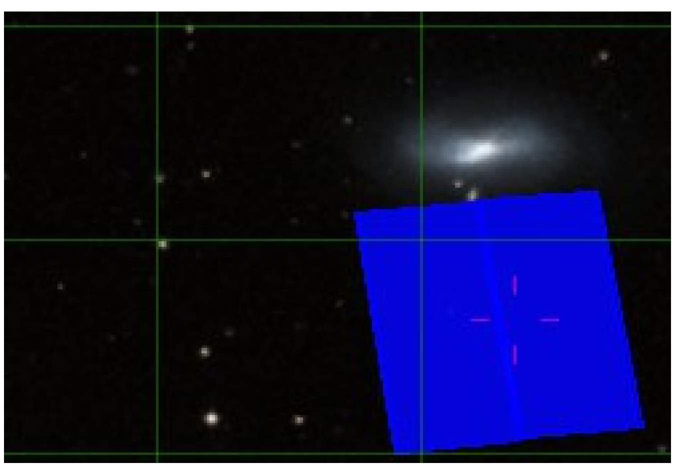
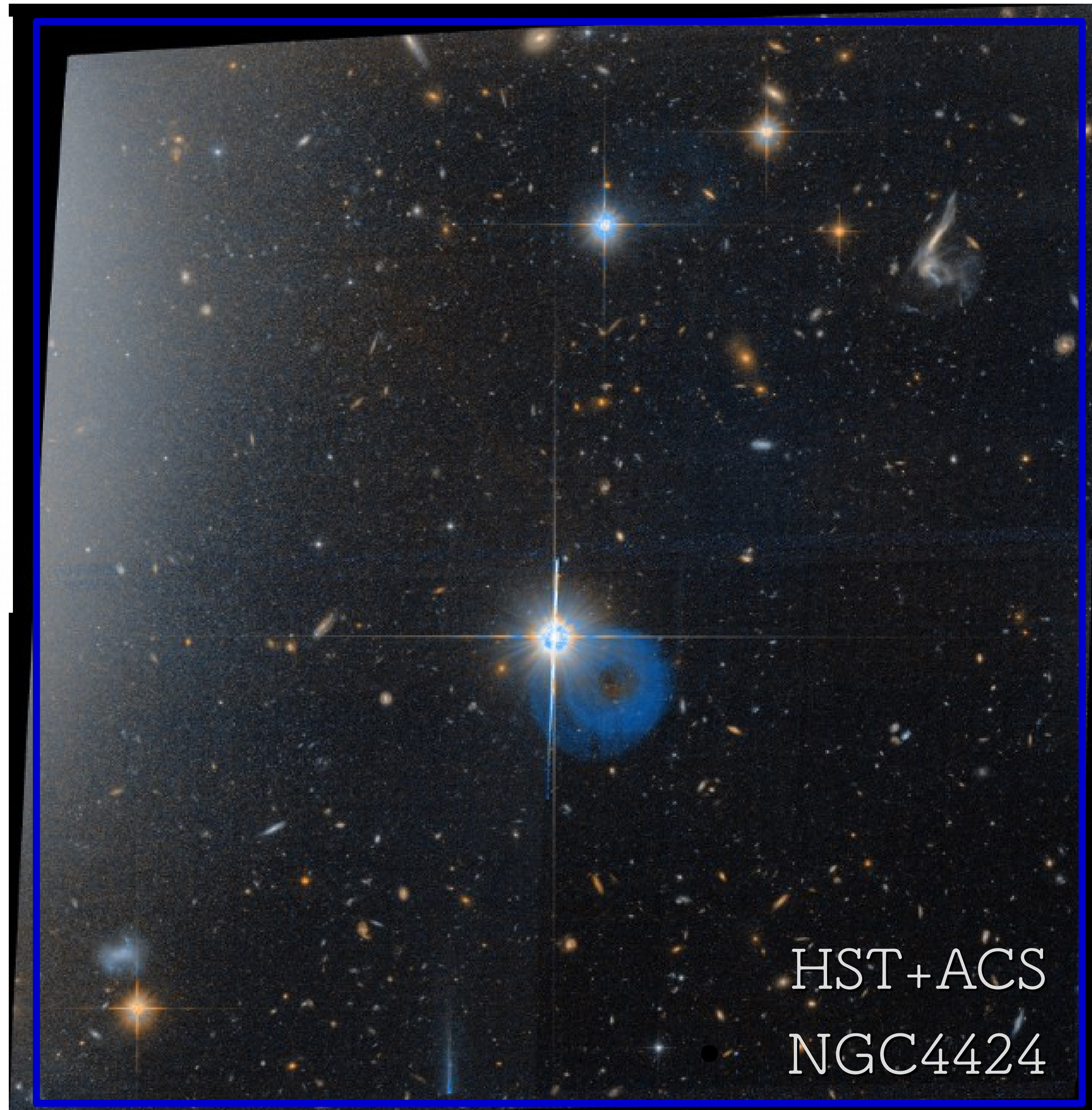


E. Carlson et al. (in prep.)

A Worked Example







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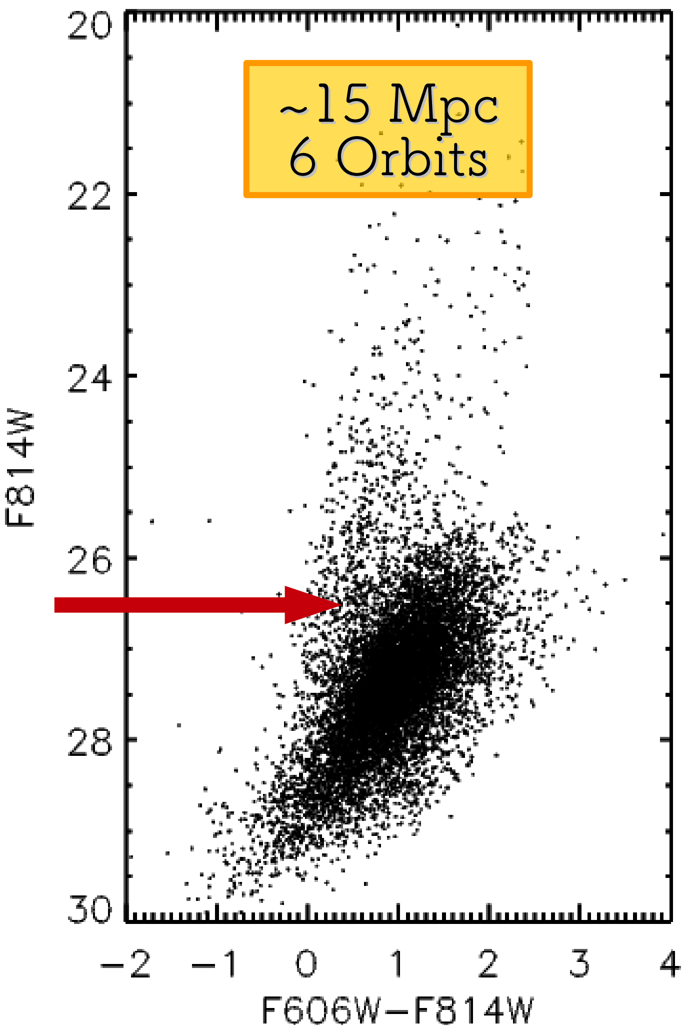
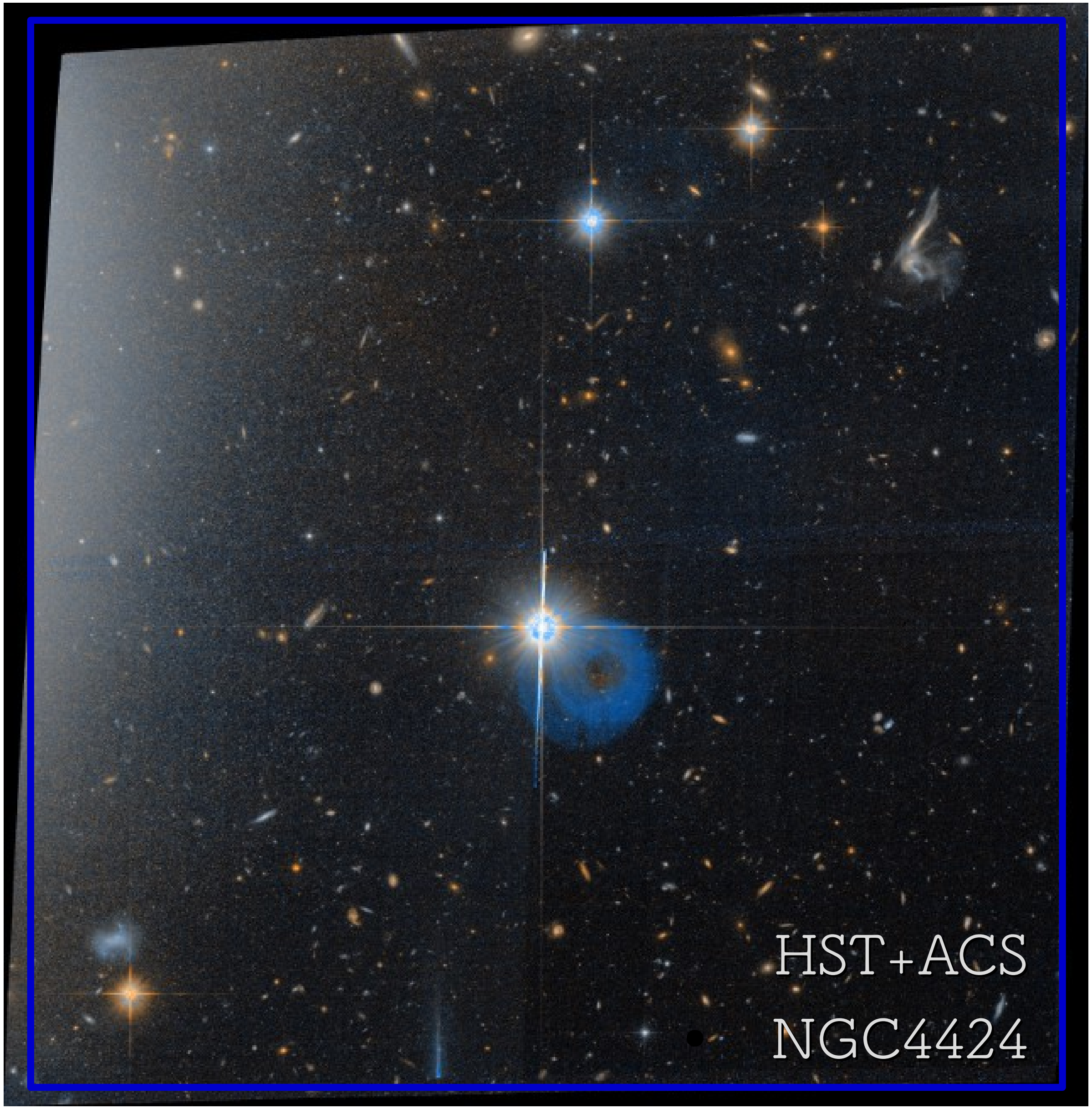
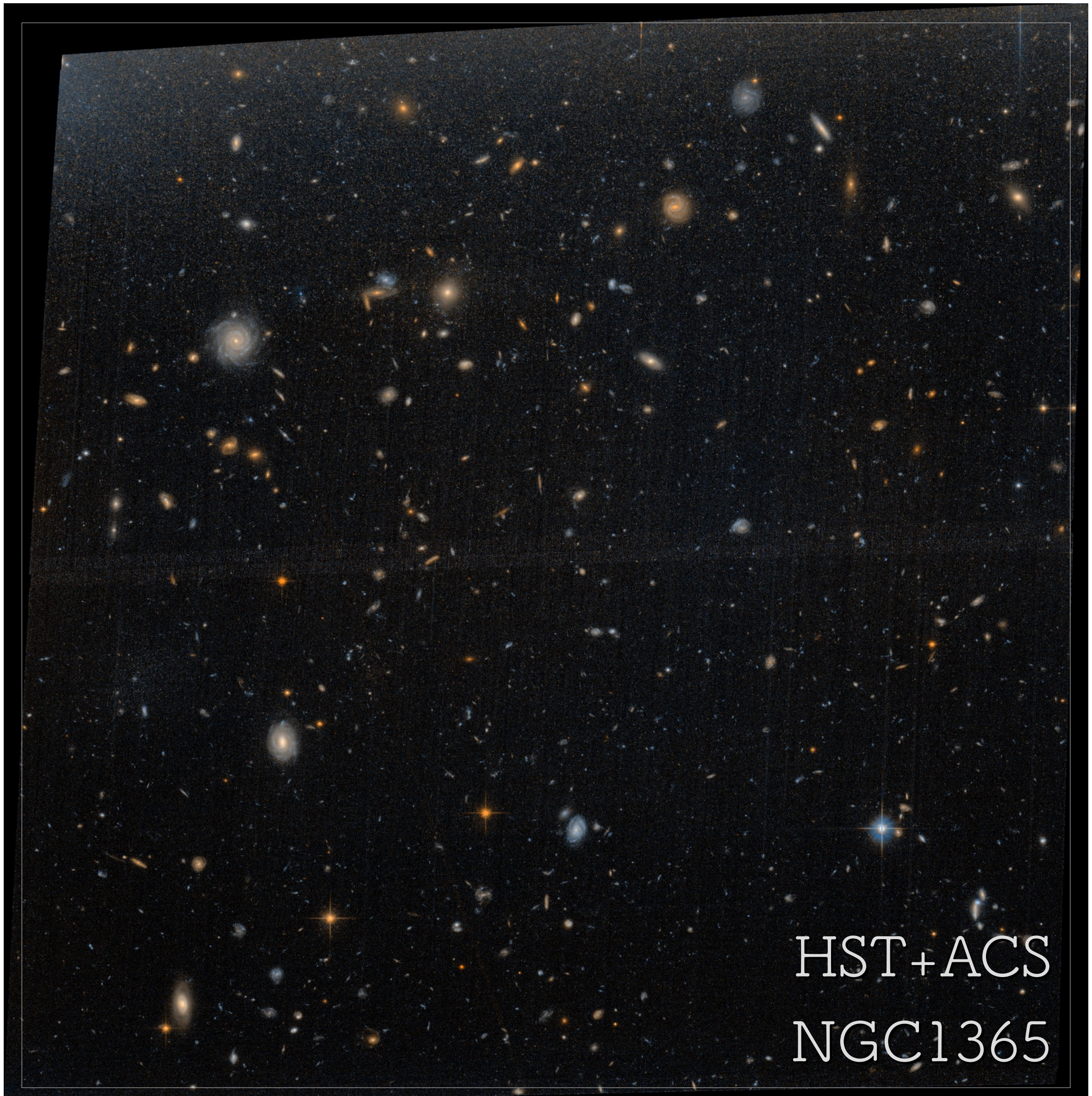


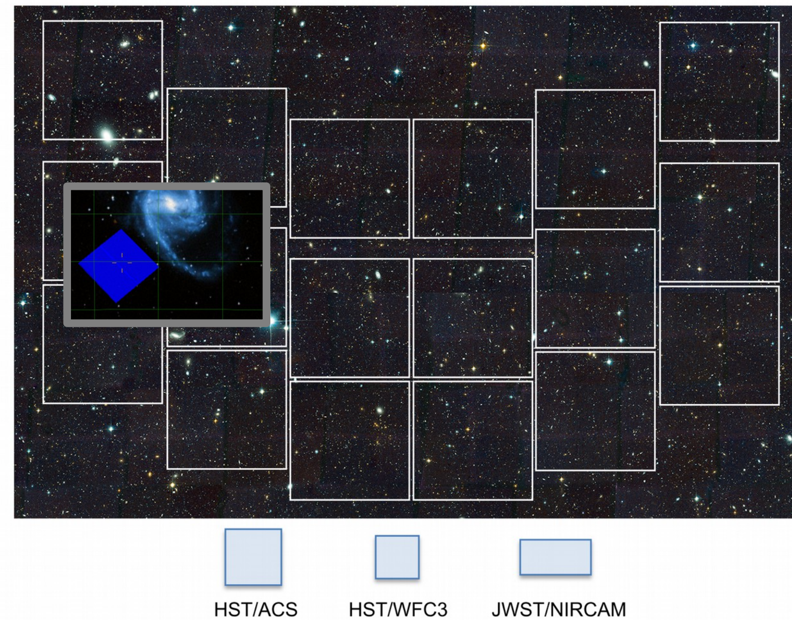


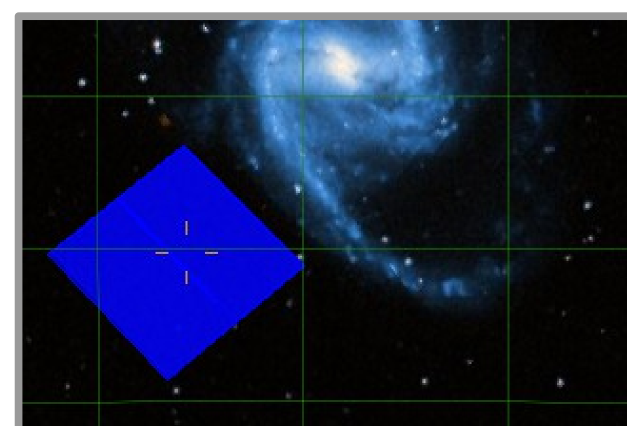
And more distant:

~18 Mpc

16 HST Orbits

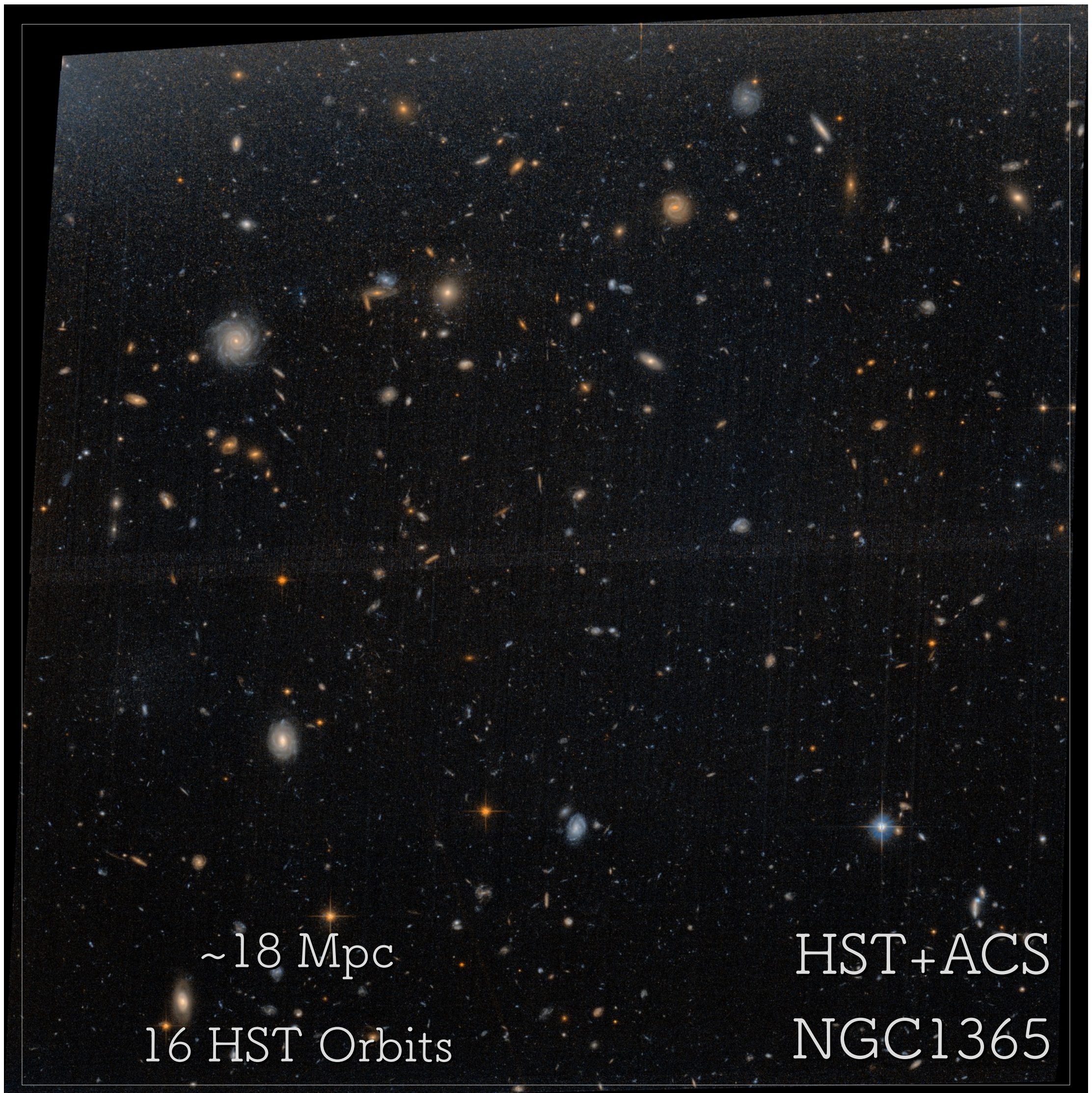






A Prospectus for WFIRST:

(modulo calibration of TRGB in WFIRST filters ...)



Guest Investigator (Archive):

Within HLS:
(m-M) ~ 31.7 [mag]
22 Mpc

Everything in the footprint is "free" @~1%

Guest Observer:

Using H for the TRGB luminosity function and Y for the CMD color:

@HLS Depth => 30 mins
< 22 Mpc

@ 1 mag fainter => 1.25 hours
< 35 Mpc

@ 2 mag fainter => 3.15 hours
< 55 Mpc

@ 3 mag fainter => 7.8 hours
< 87 Mpc