

# The Hubble Constant and Planck: New Physics or Old Systematics?

Chris Burns

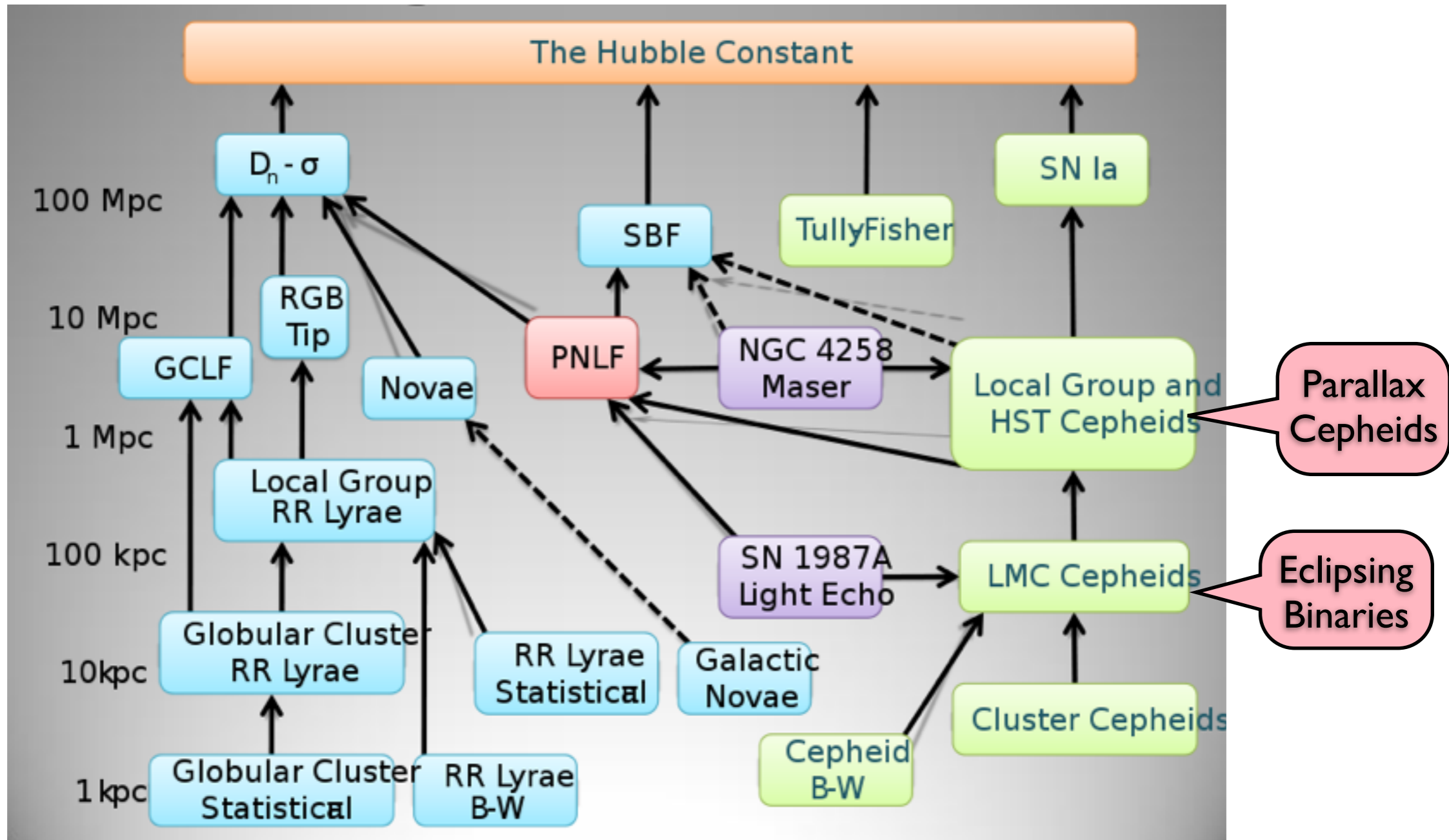
*Observatories of the Carnegie Institution for Science*

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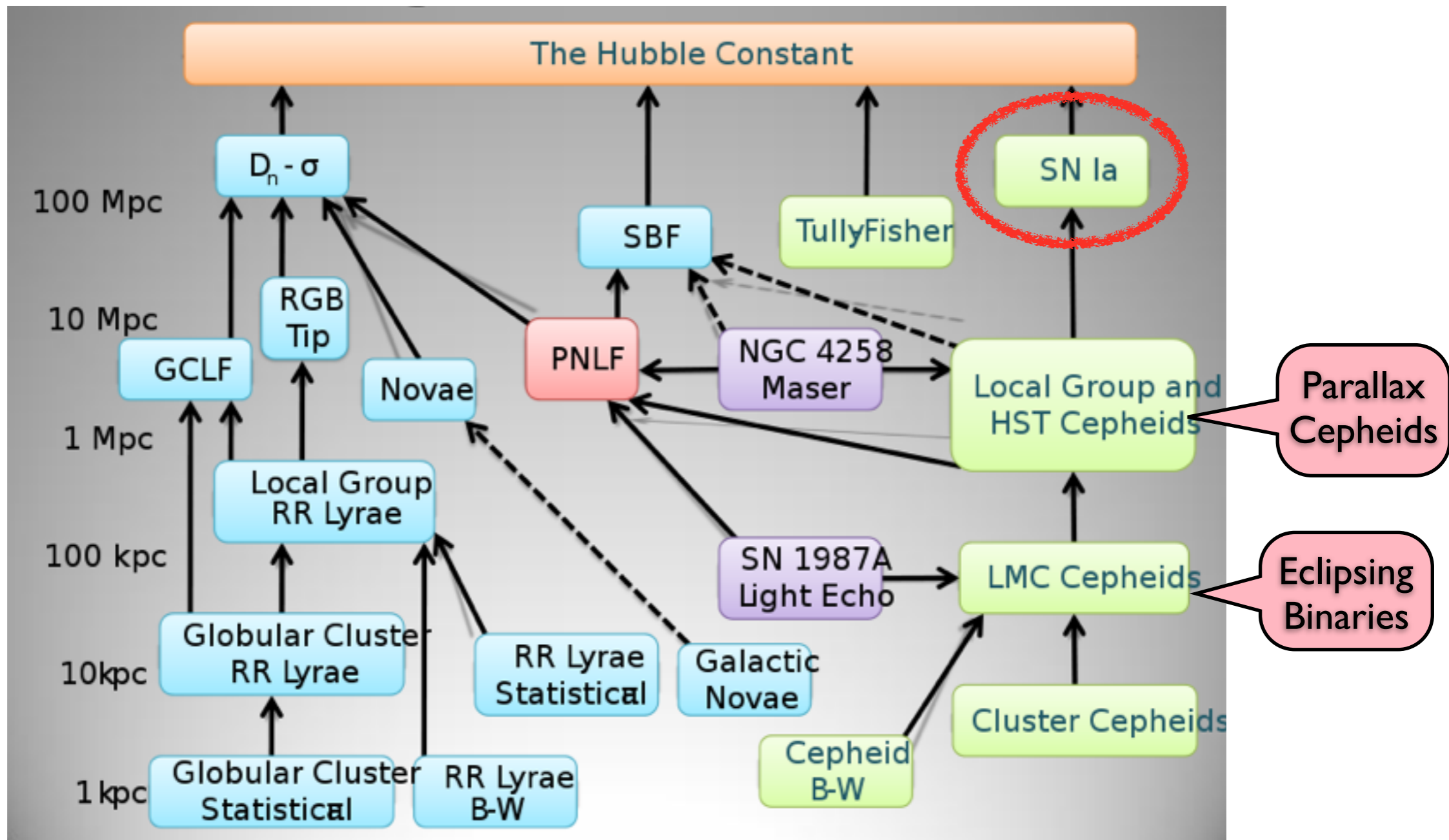
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# Distance Ladder



Credit: Robin Ciardullo

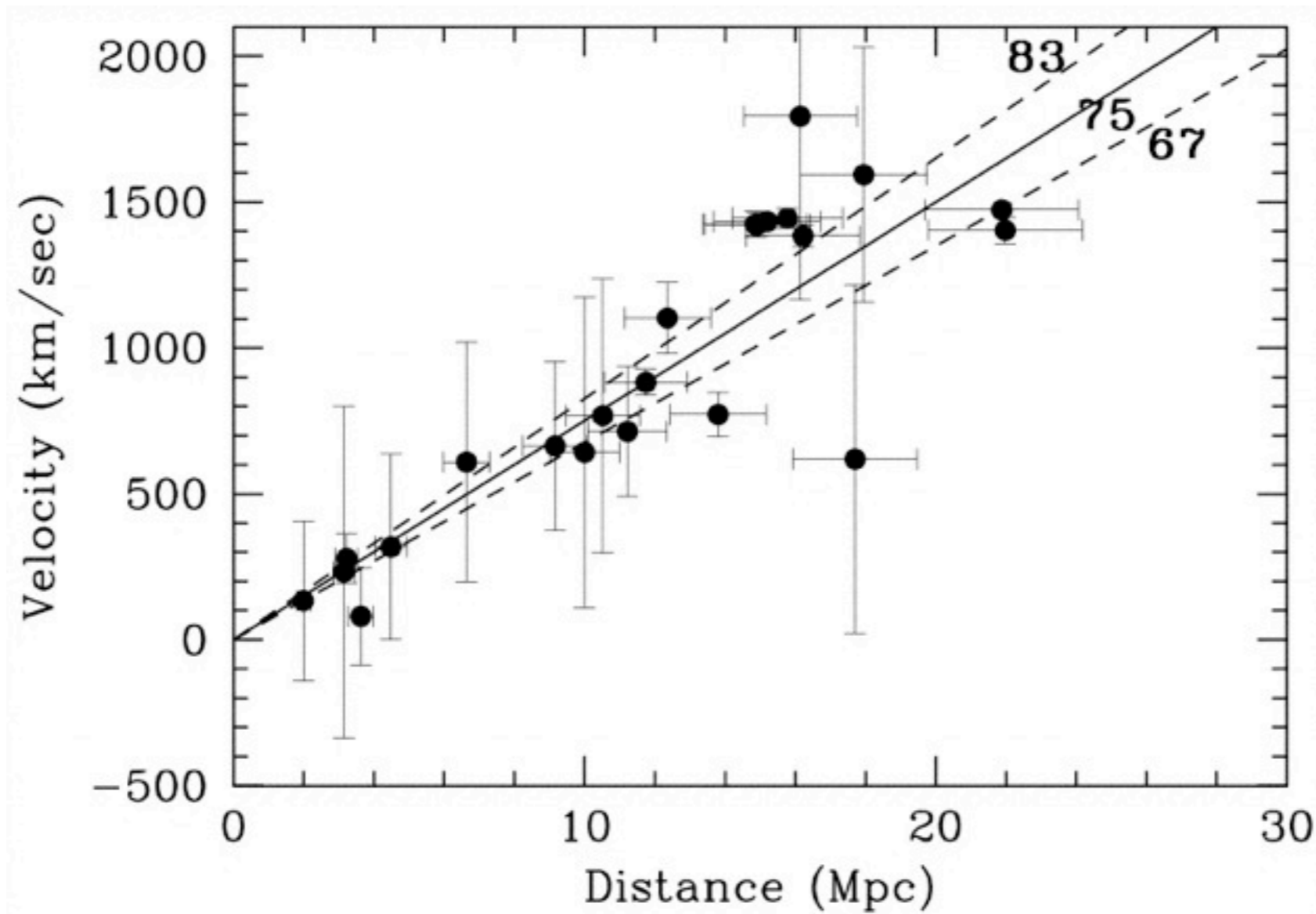
# Distance Ladder



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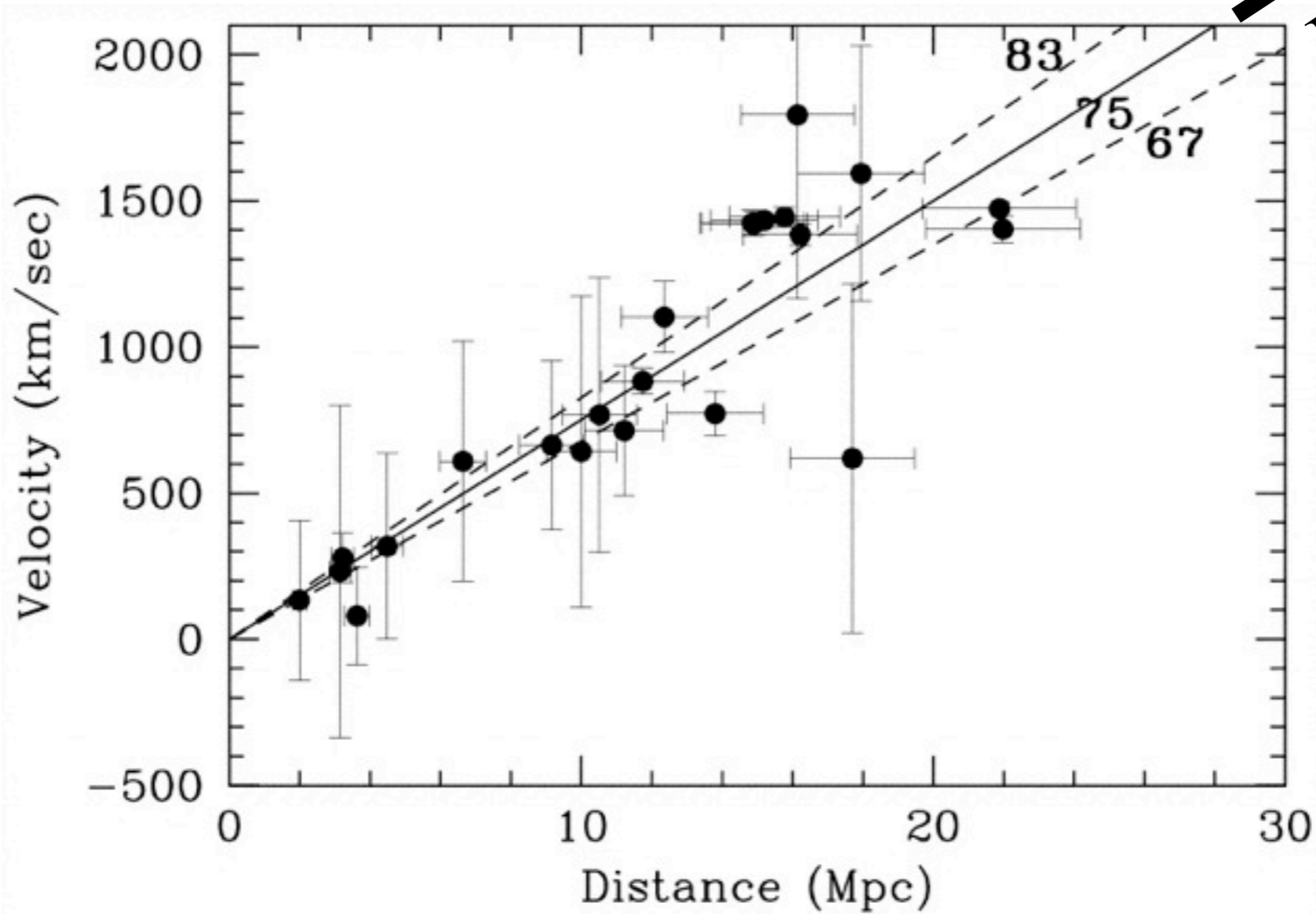


# Key Project

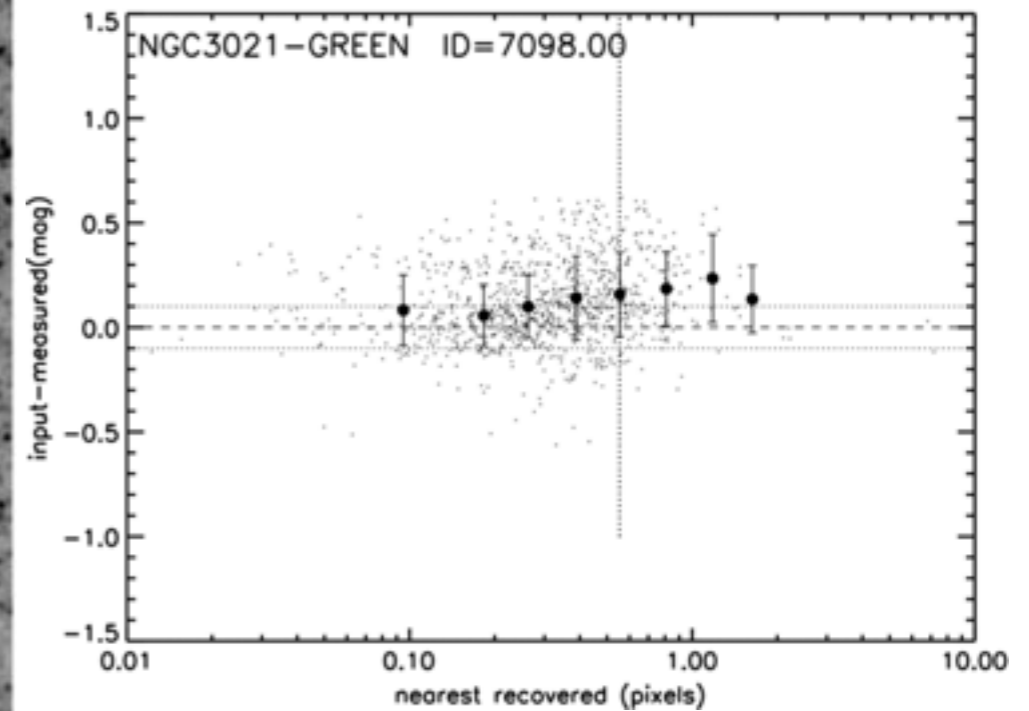
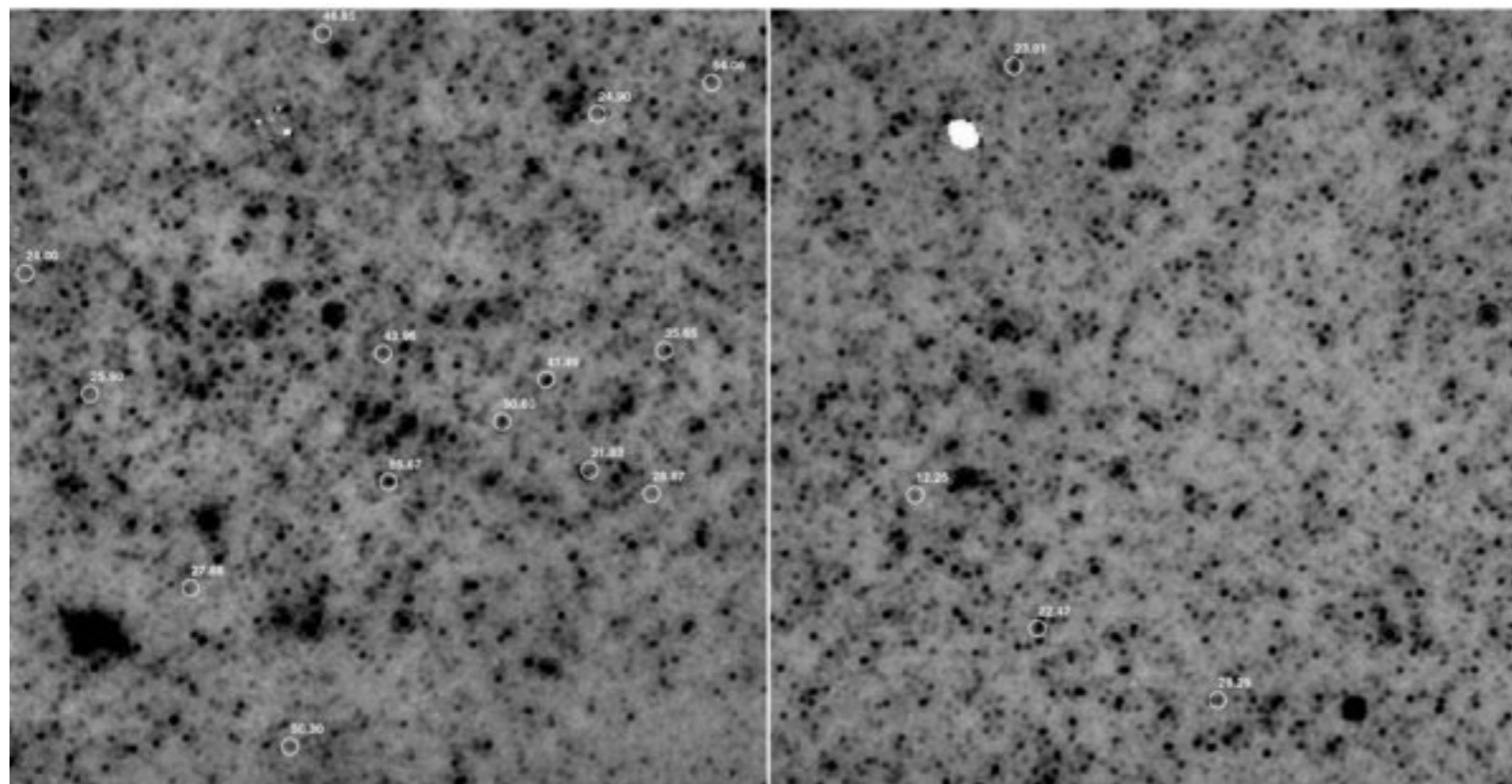


# Key Project

Hubble Flow



# Cepheid photometry is hard



Riess et al. (2009)



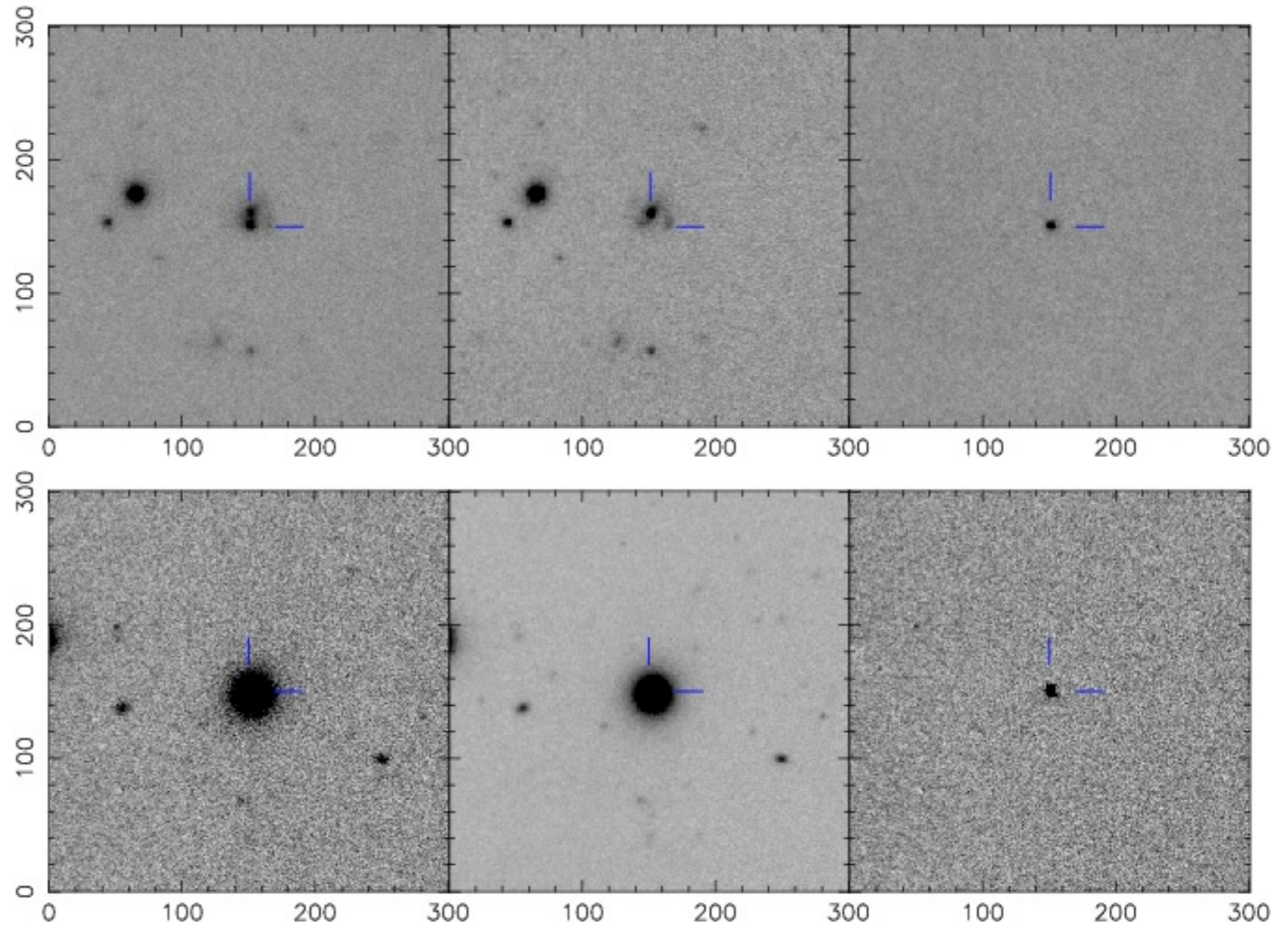
# SN Photometry is Easy(er)

SNe can get you farther:

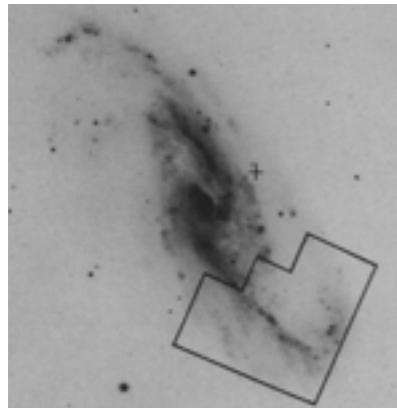
- Higher Luminosity
- Transient
- Photometry is much cleaner.

**But:**

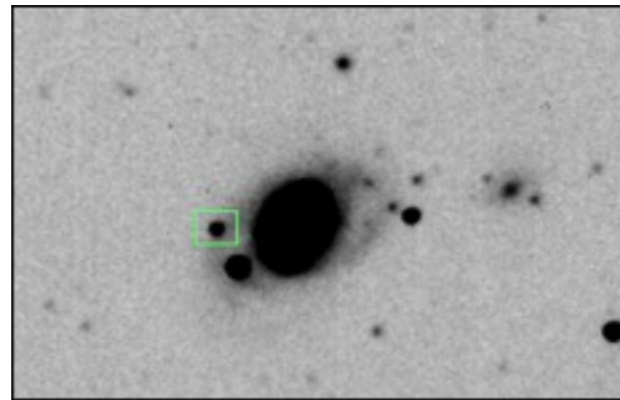
- Rarer
- No direct distances to SNIa
- Must calibrate with Cepheids



# Galaxies with Ia's and Cepheids



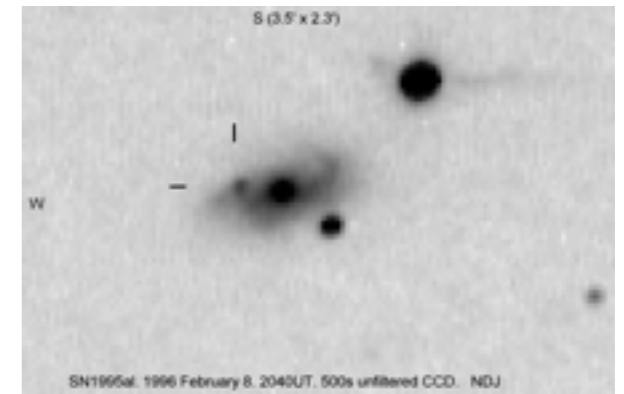
SN1981B (NGC 4536)



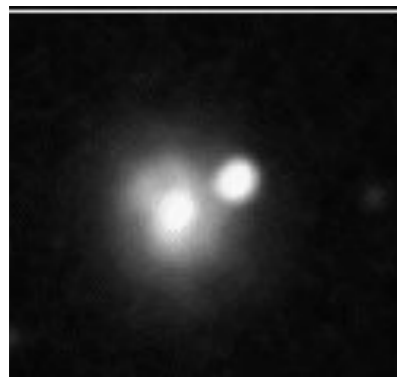
SN1990N (NGC 4639)



SN1994ae (NGC 3370)



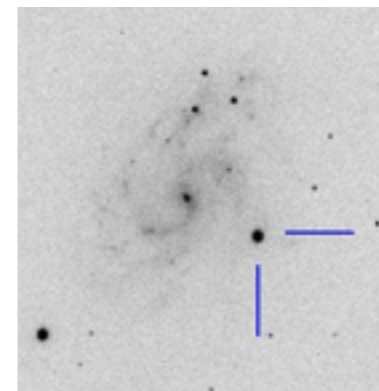
SN1995al (NGC 3021)



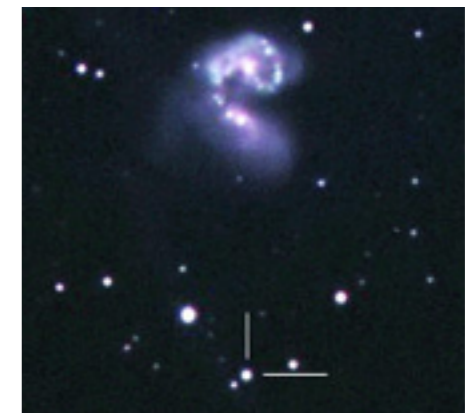
SN1998aq (NGC 3982)



SN2002fk (NGC 1309)



SN2007af (NGC 5584)

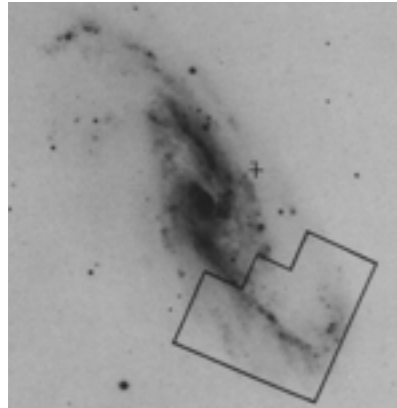


SN2007sr (NGC 4038)

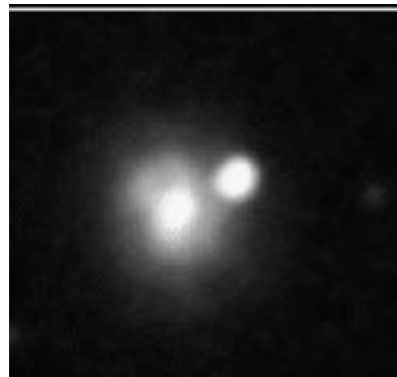


Galaxies

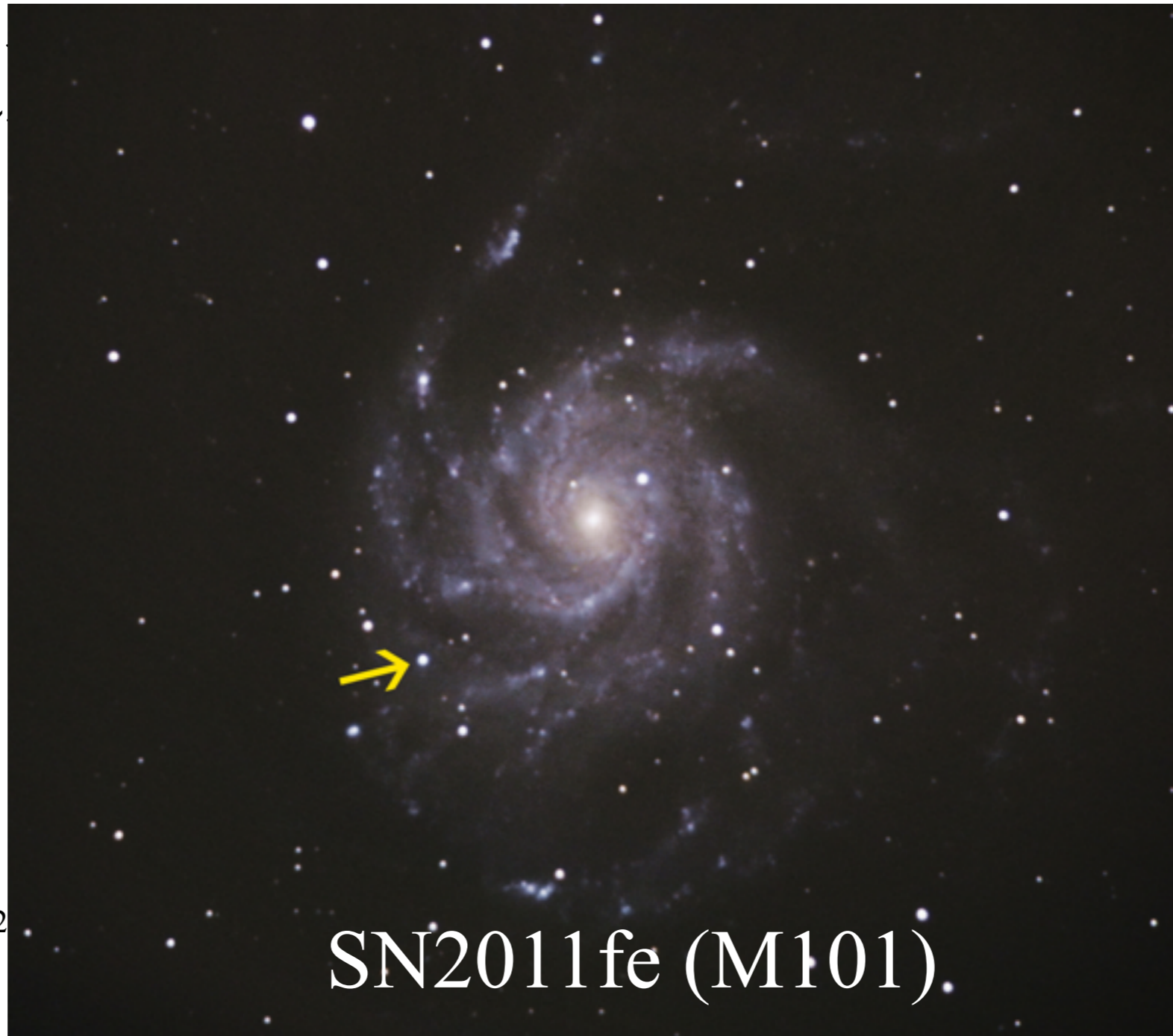
Supernovae



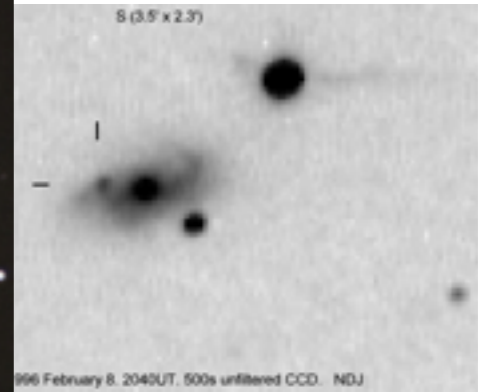
SN1981B (NGC 4536)



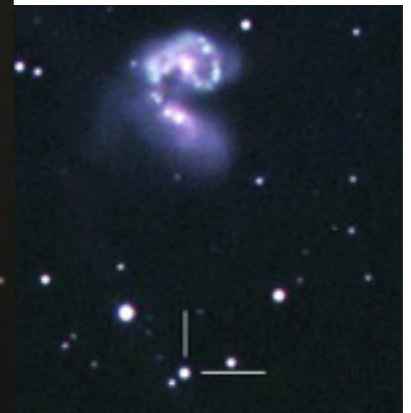
SN1998aq (NGC 3982)



SN2011fe (M101)



SN1995al (NGC 3021)

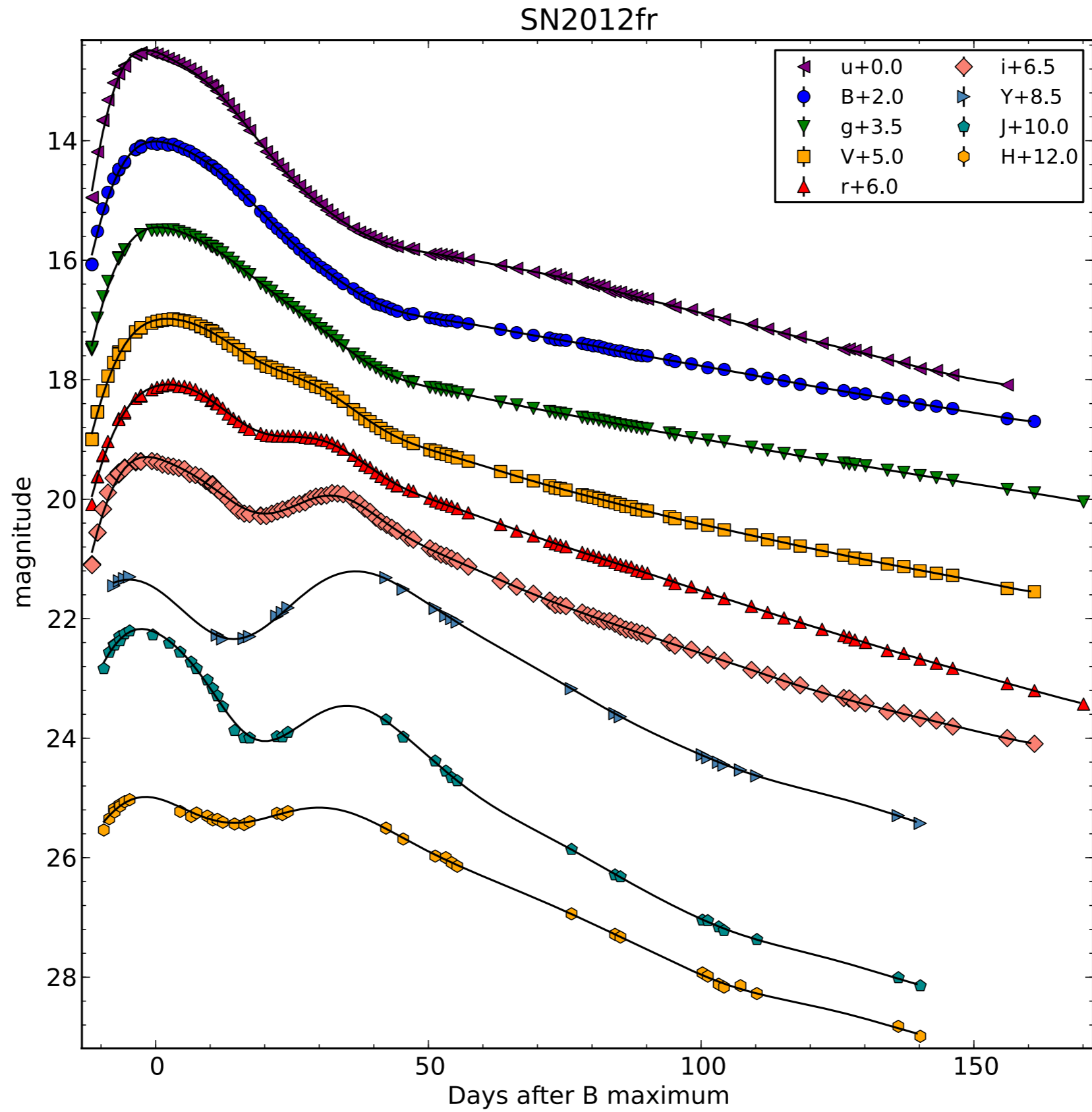


SN2007sr (NGC 4038)

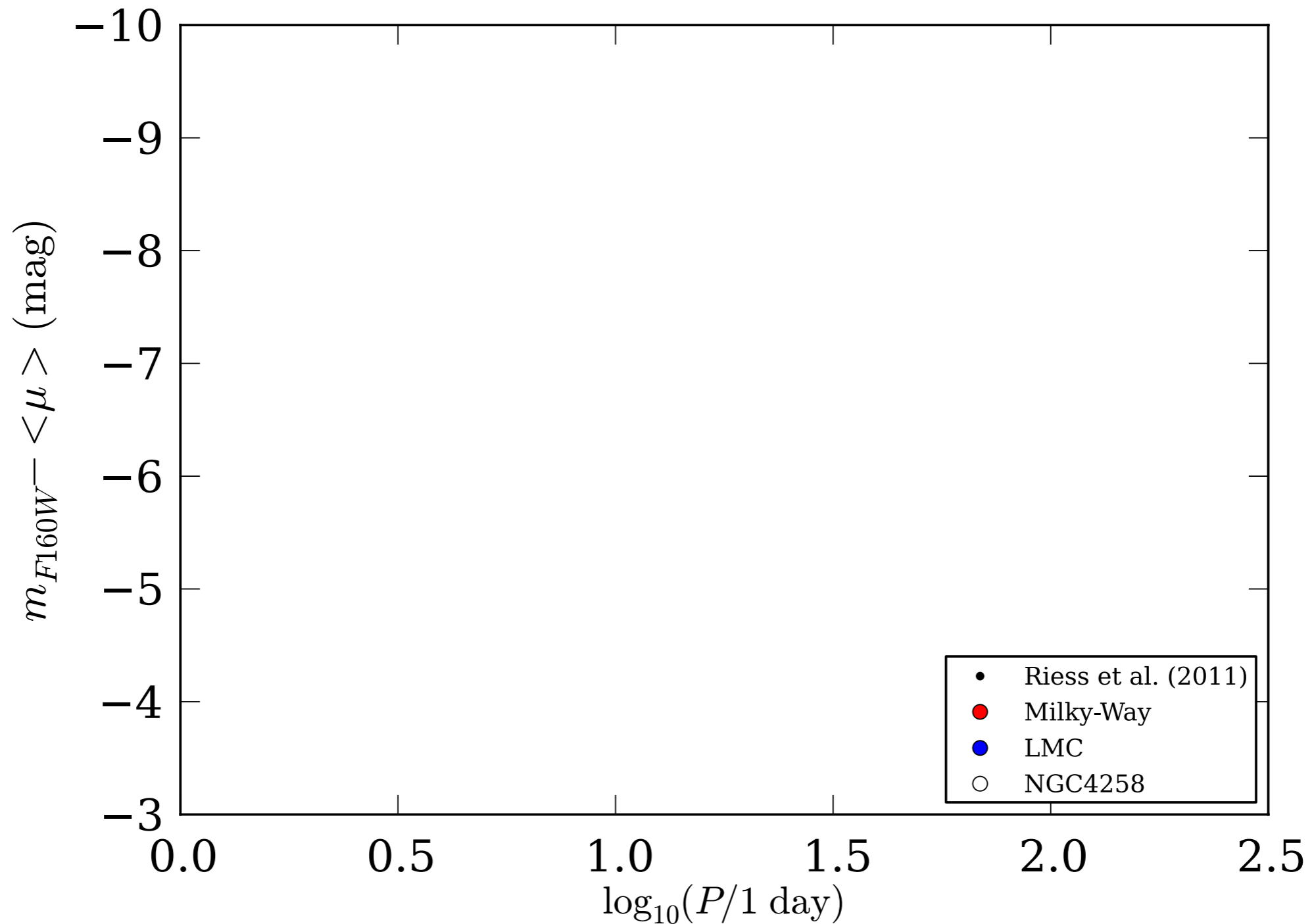


# Soon: SN2012fr!

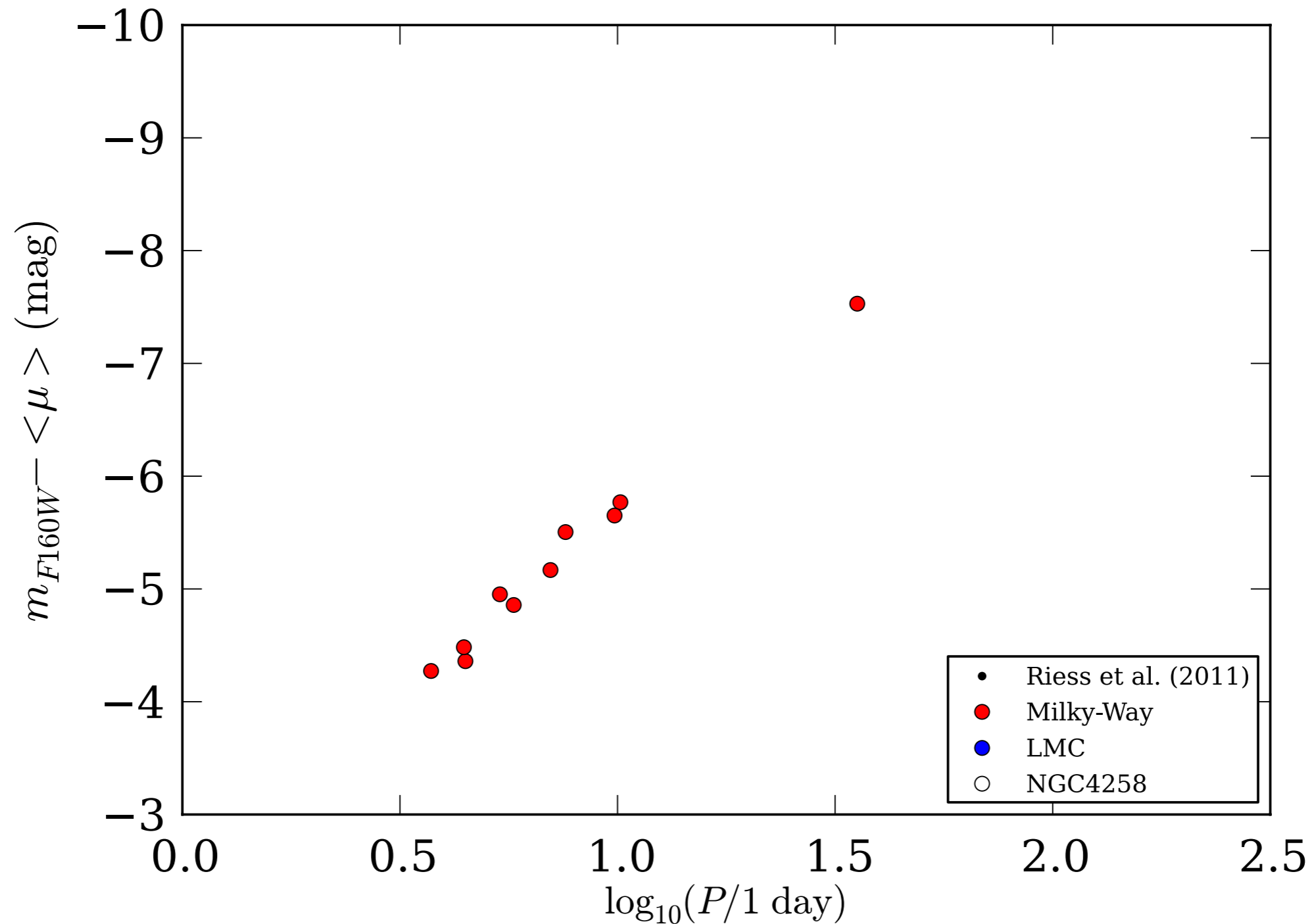




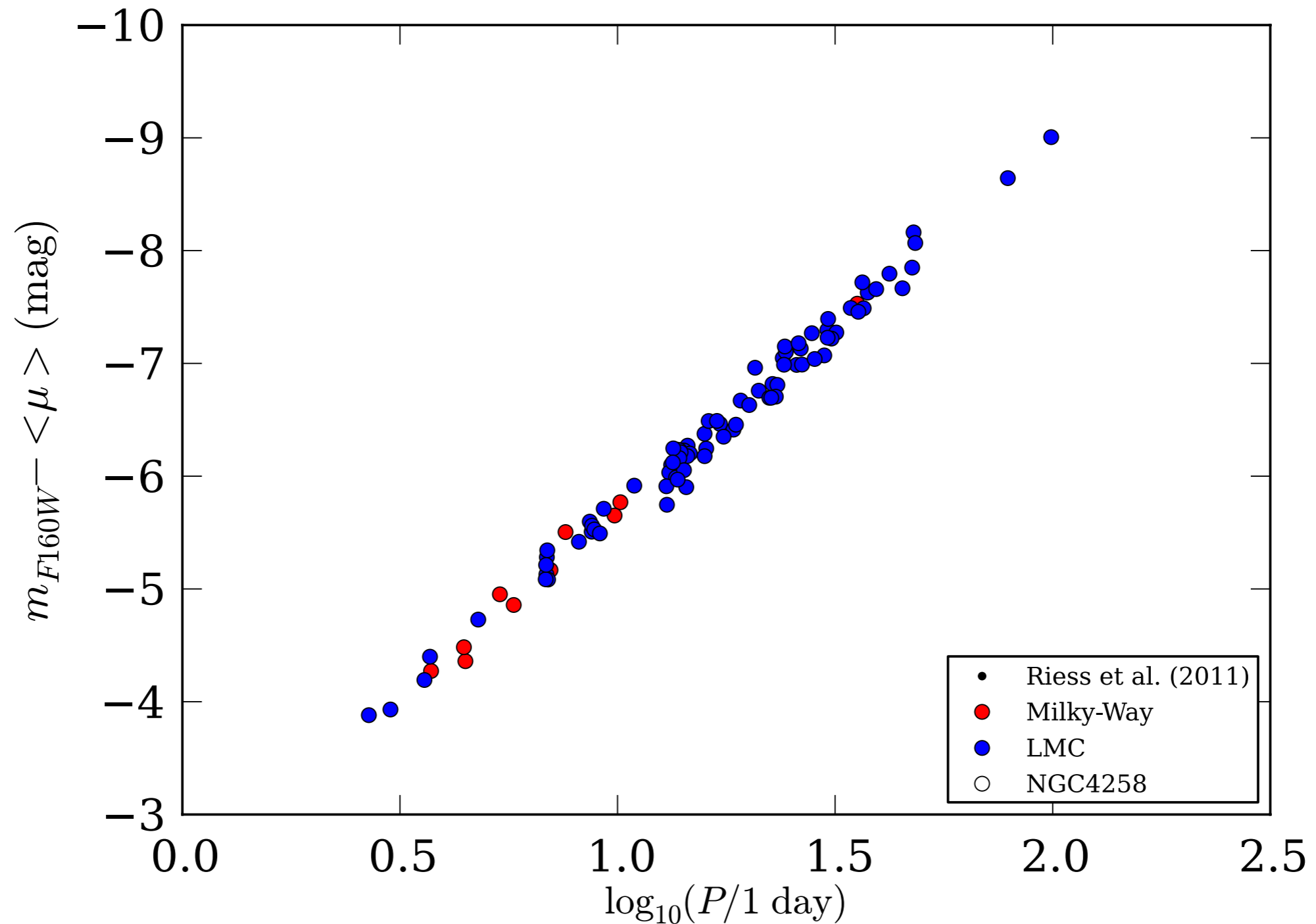
# Calibrating the Ia's with Cepheid distances



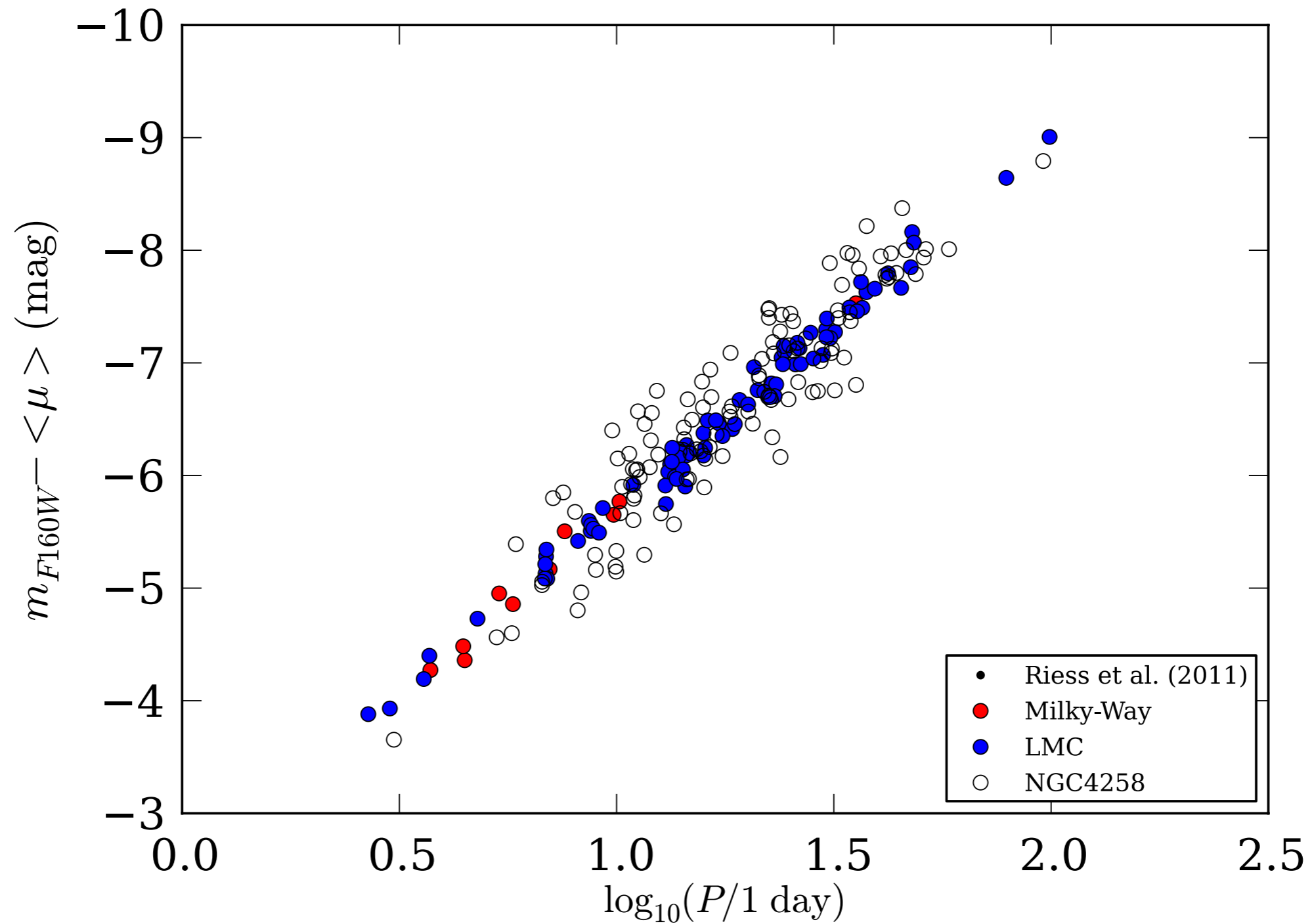
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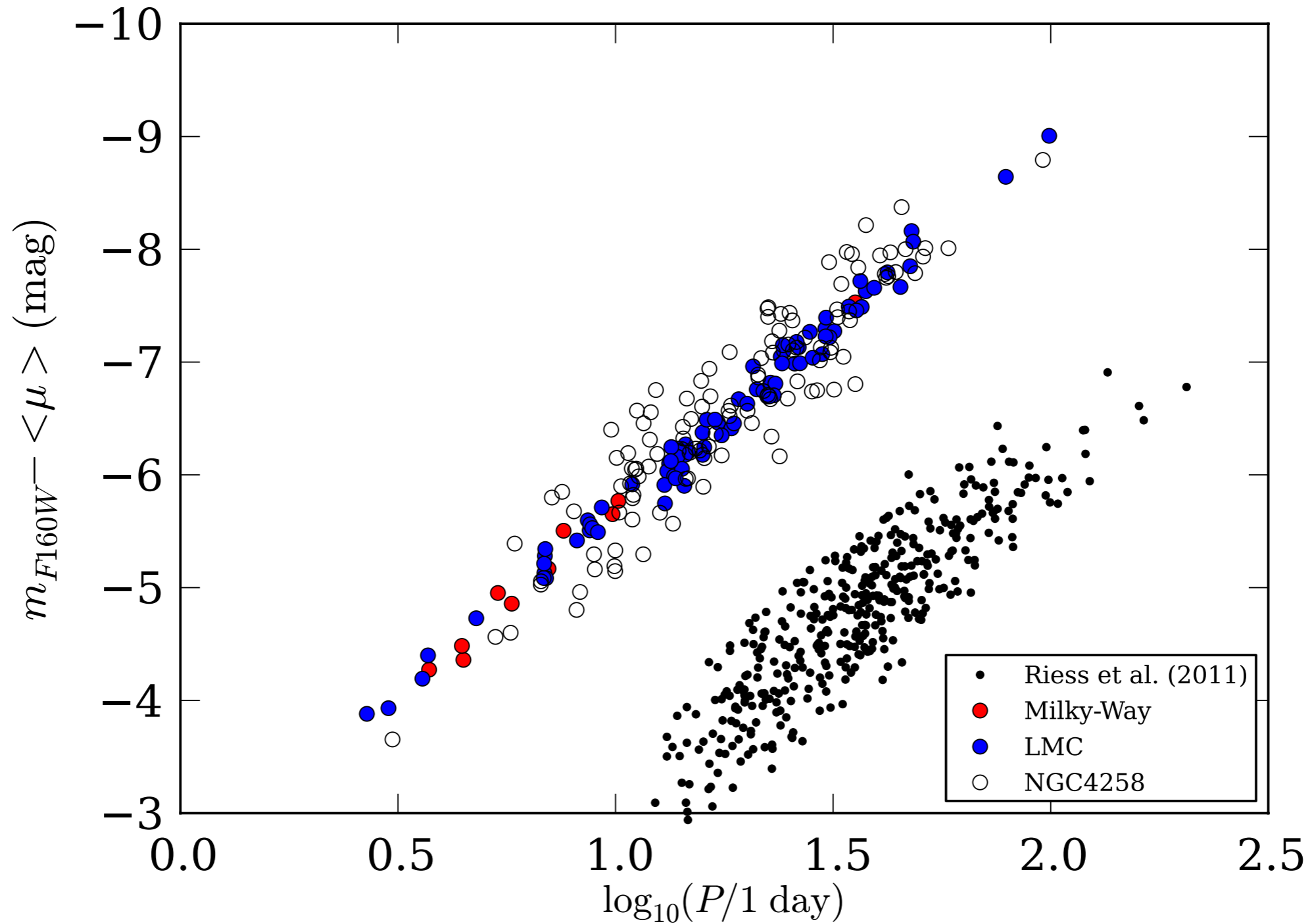


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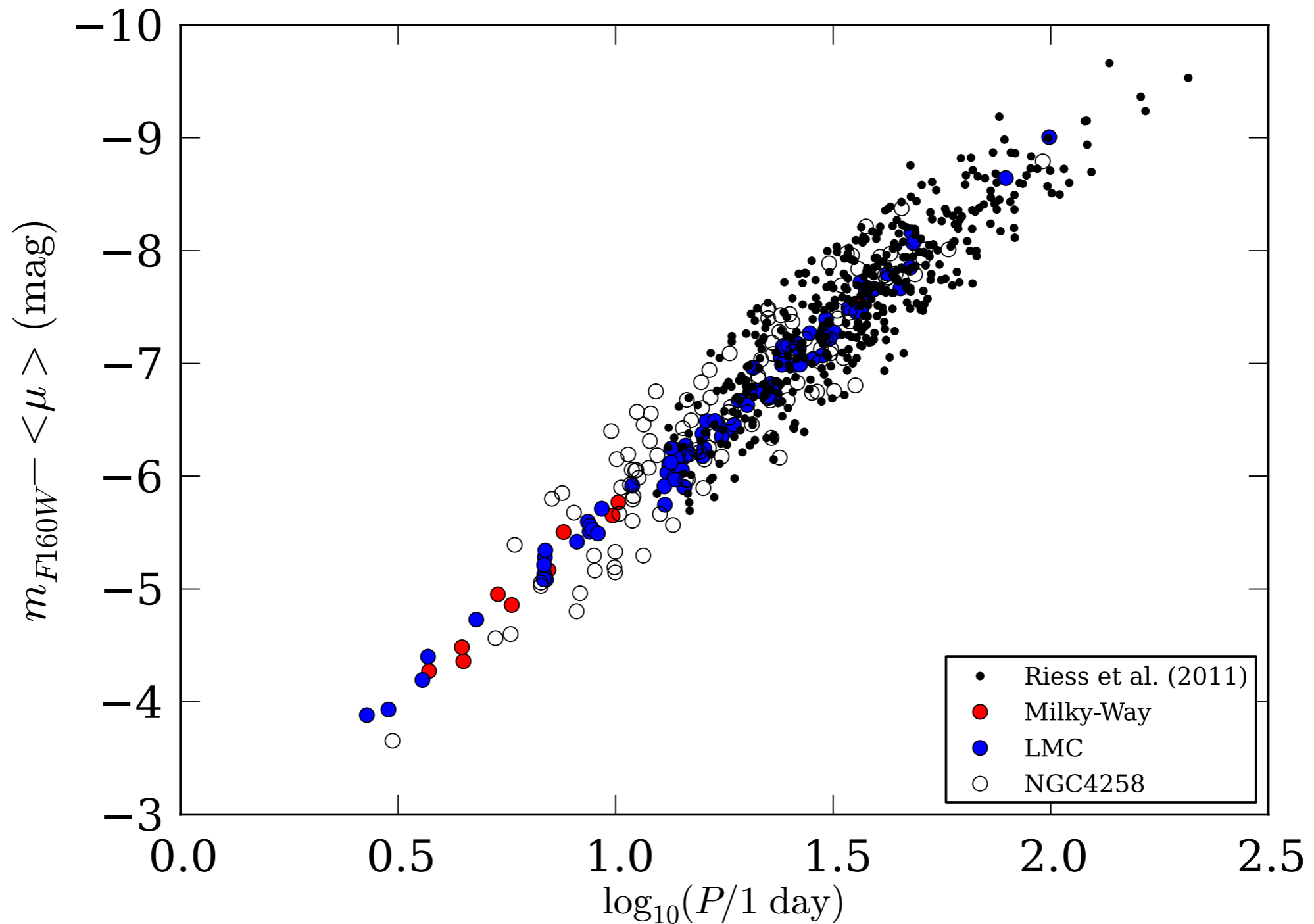


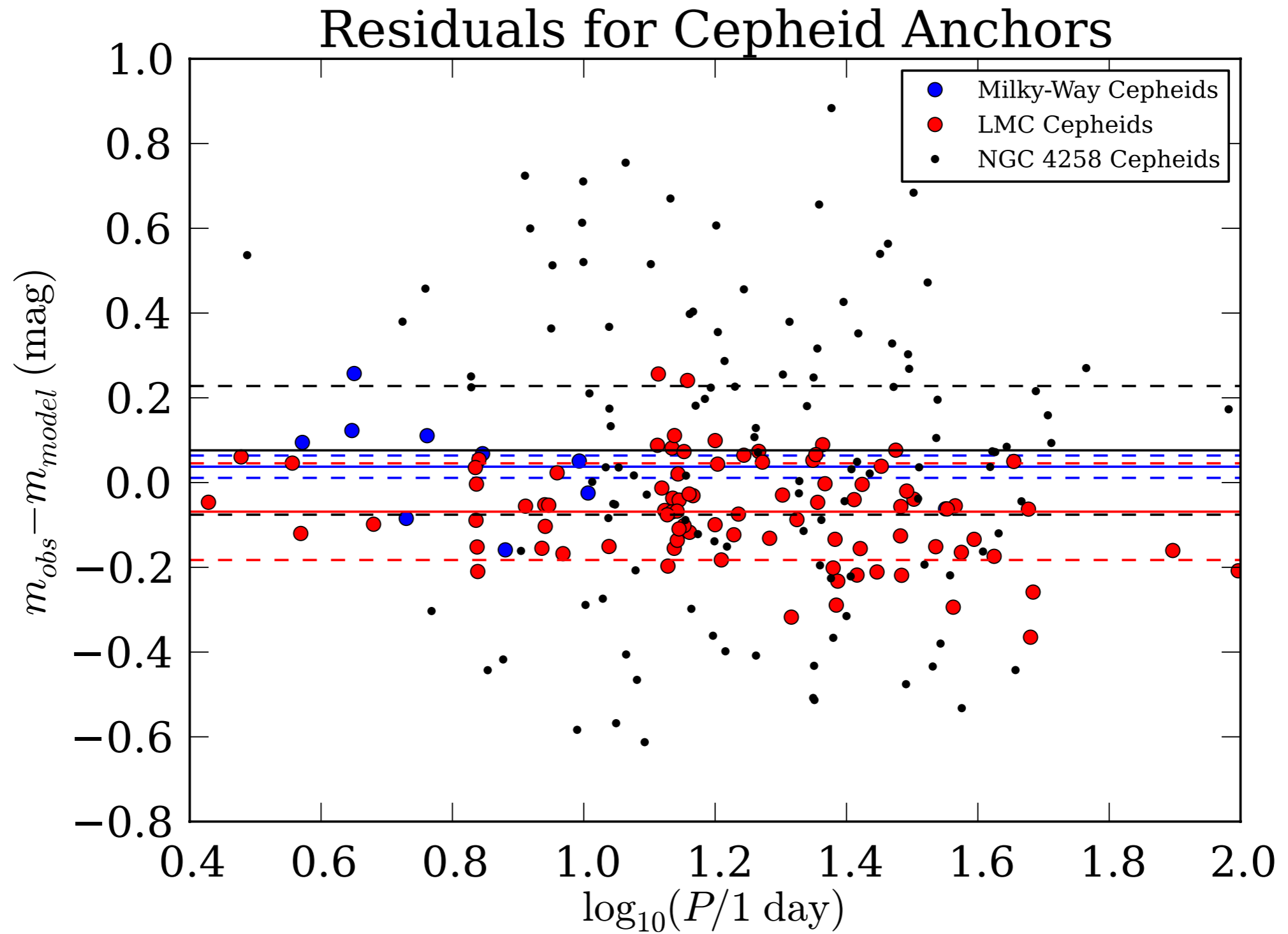


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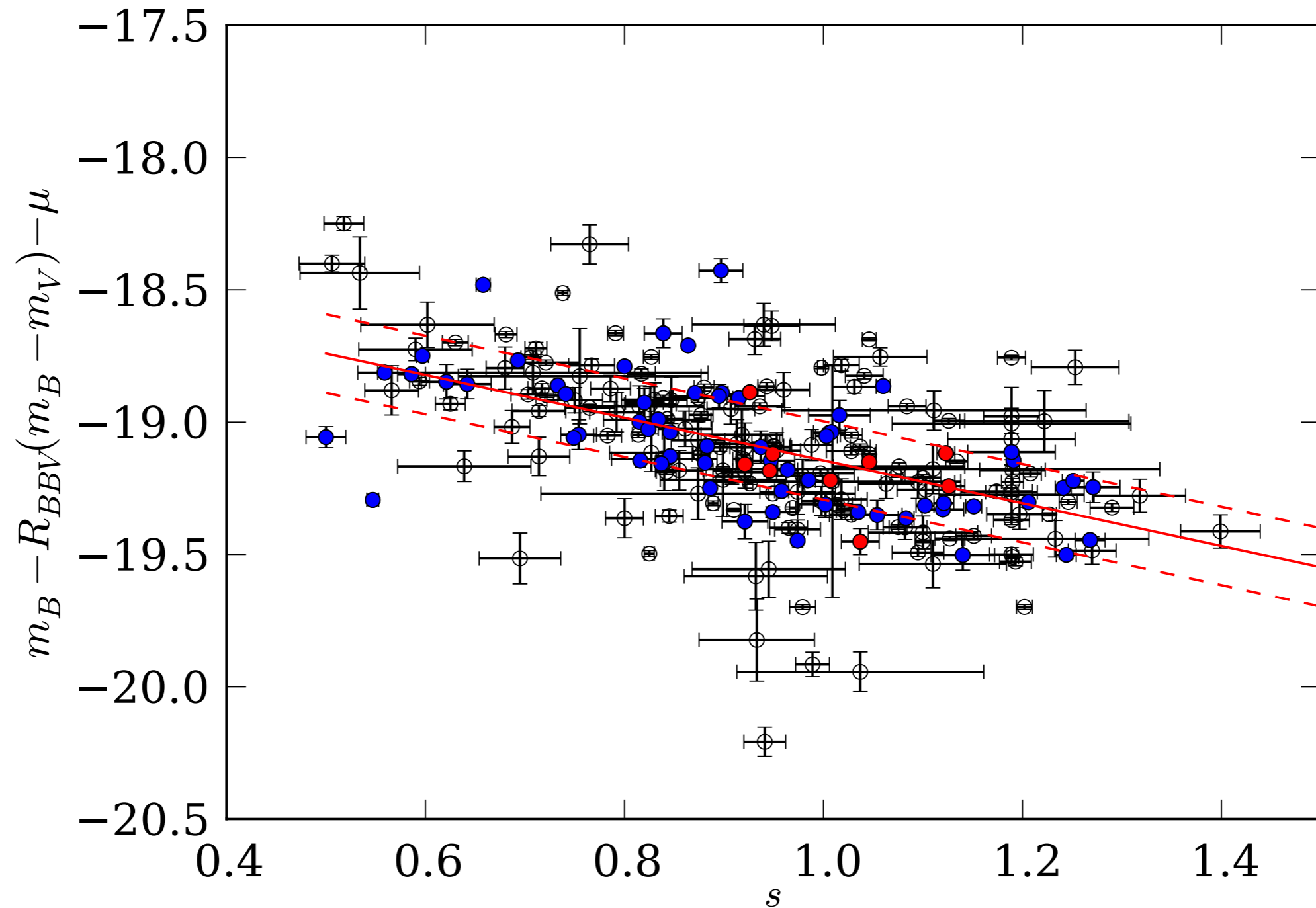


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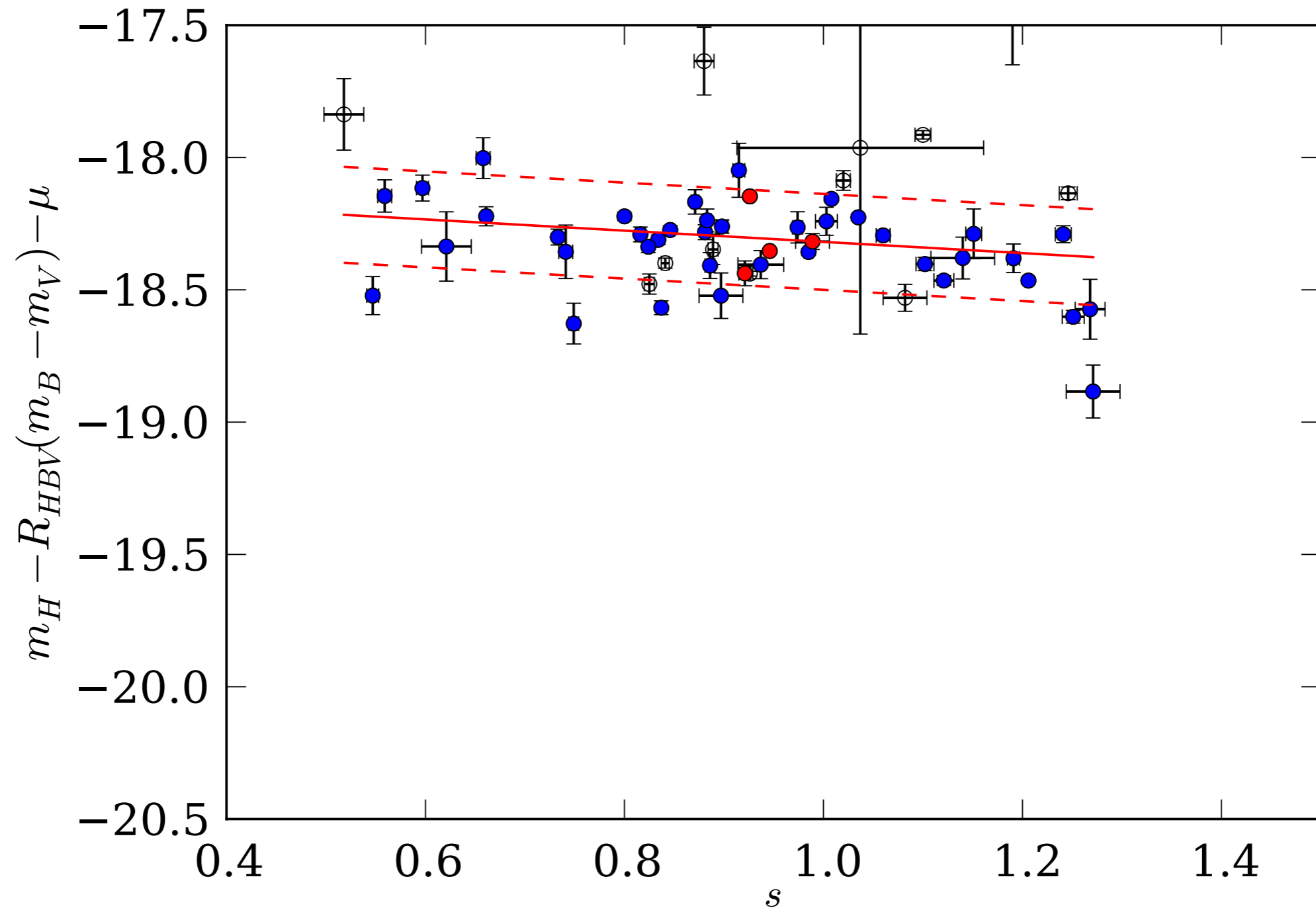




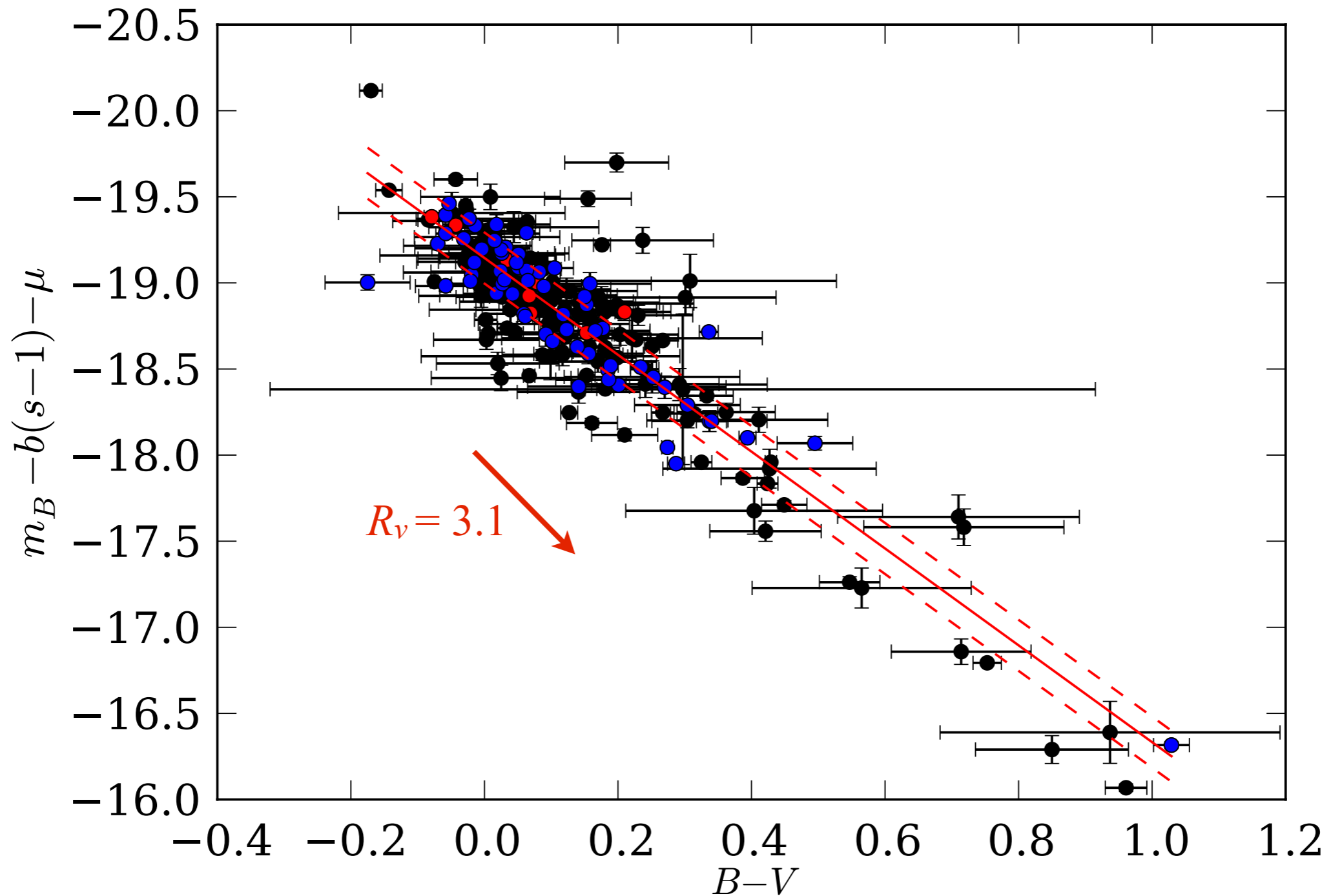
# Phillips Relation



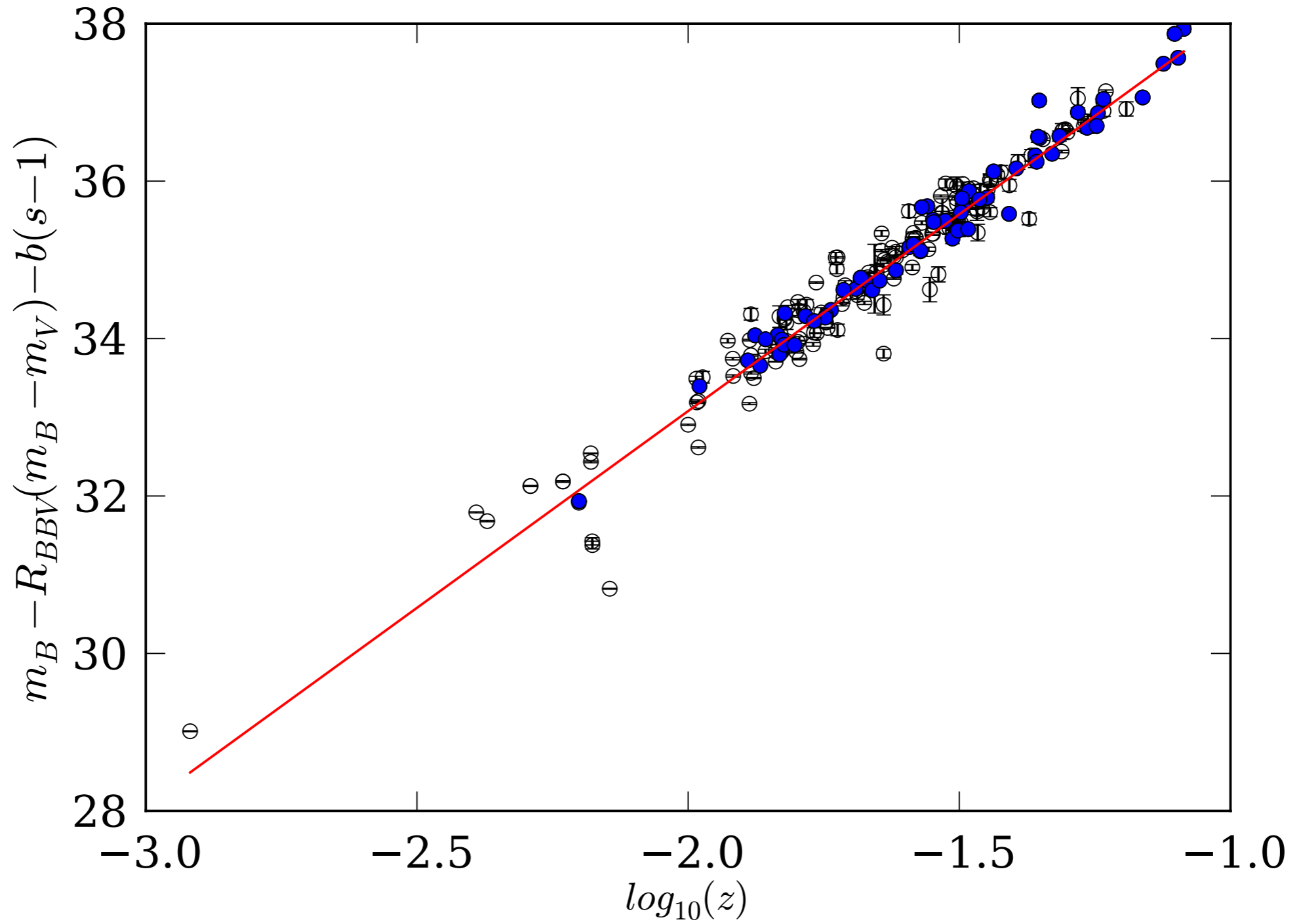
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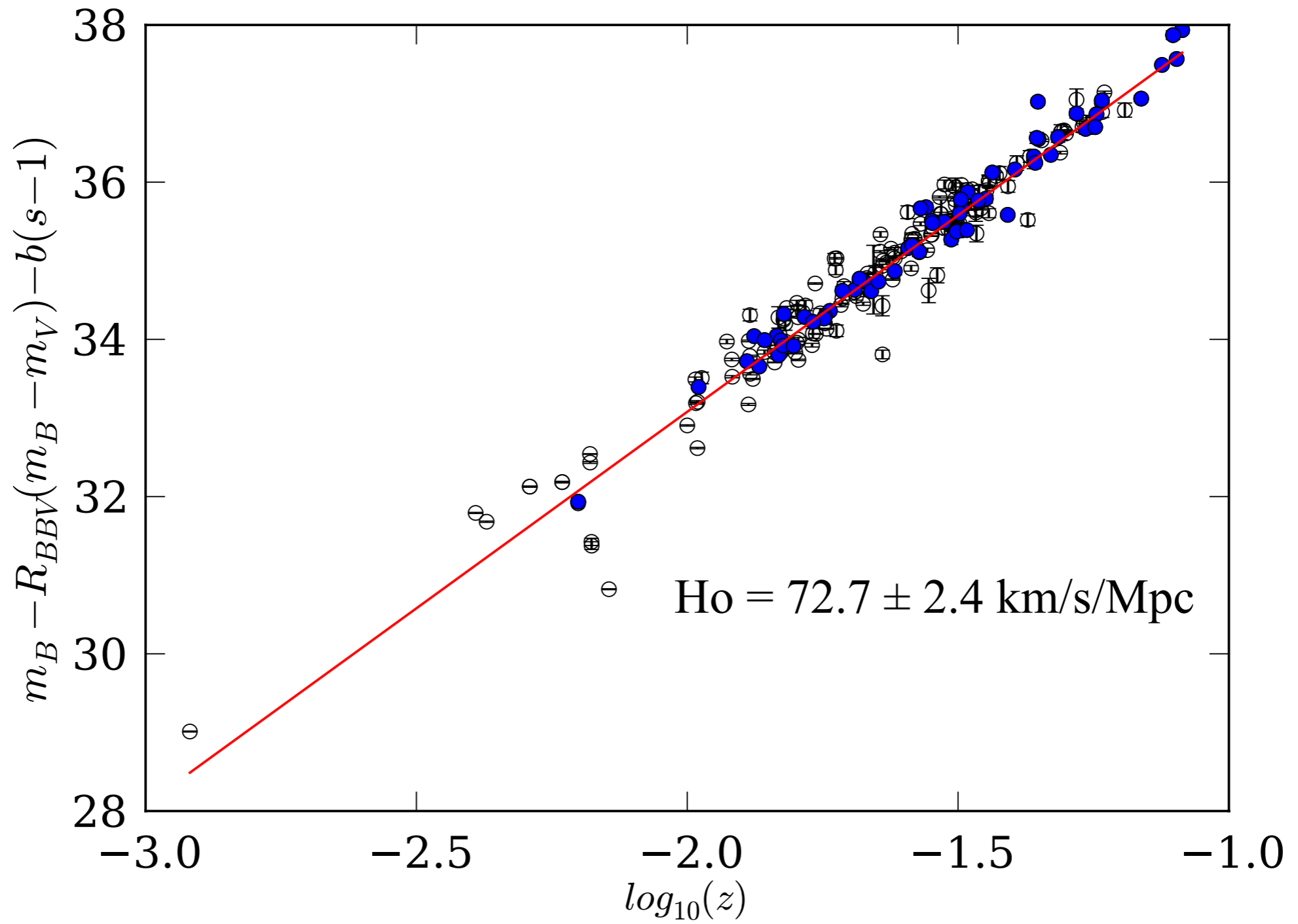


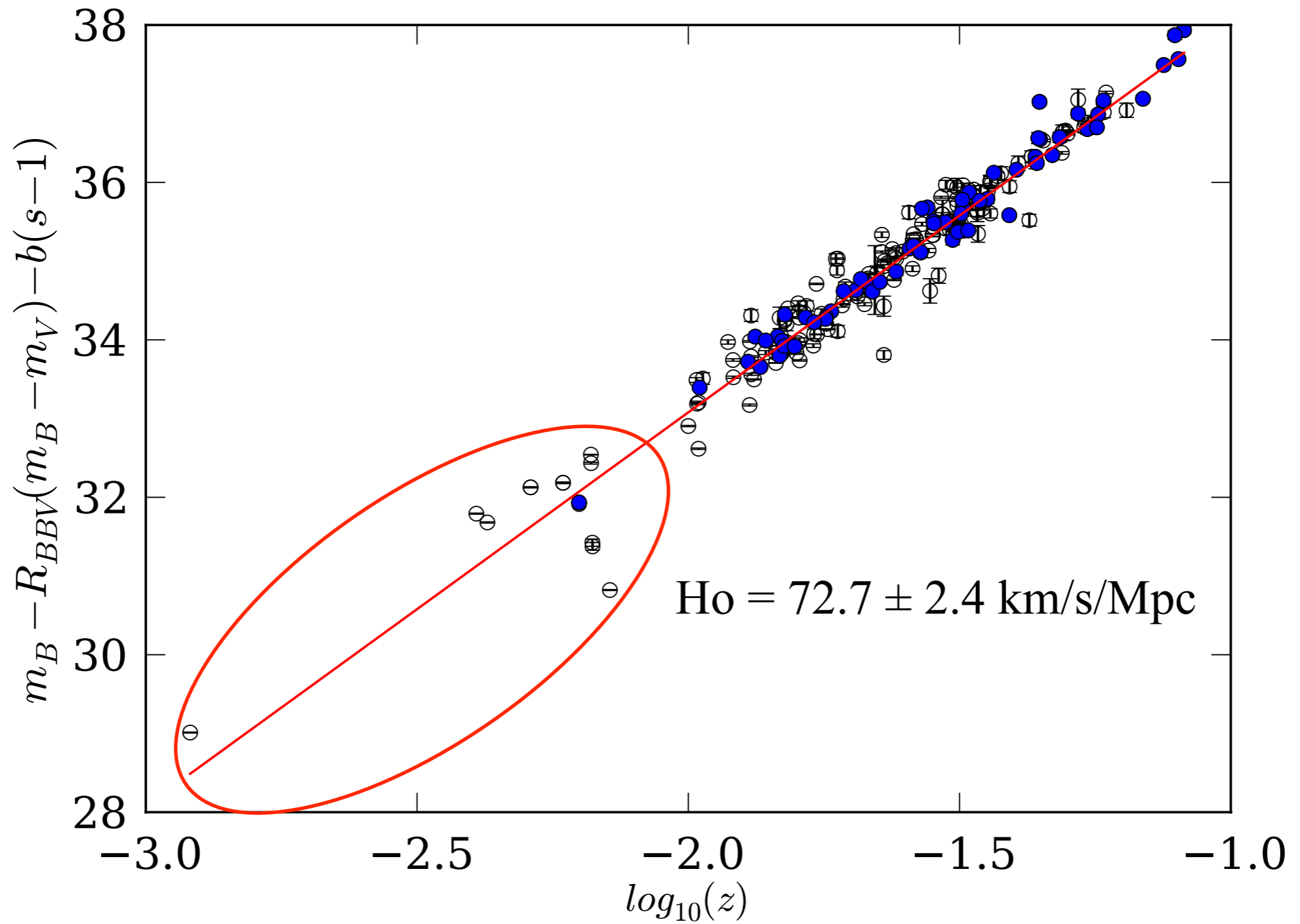
# Color correction

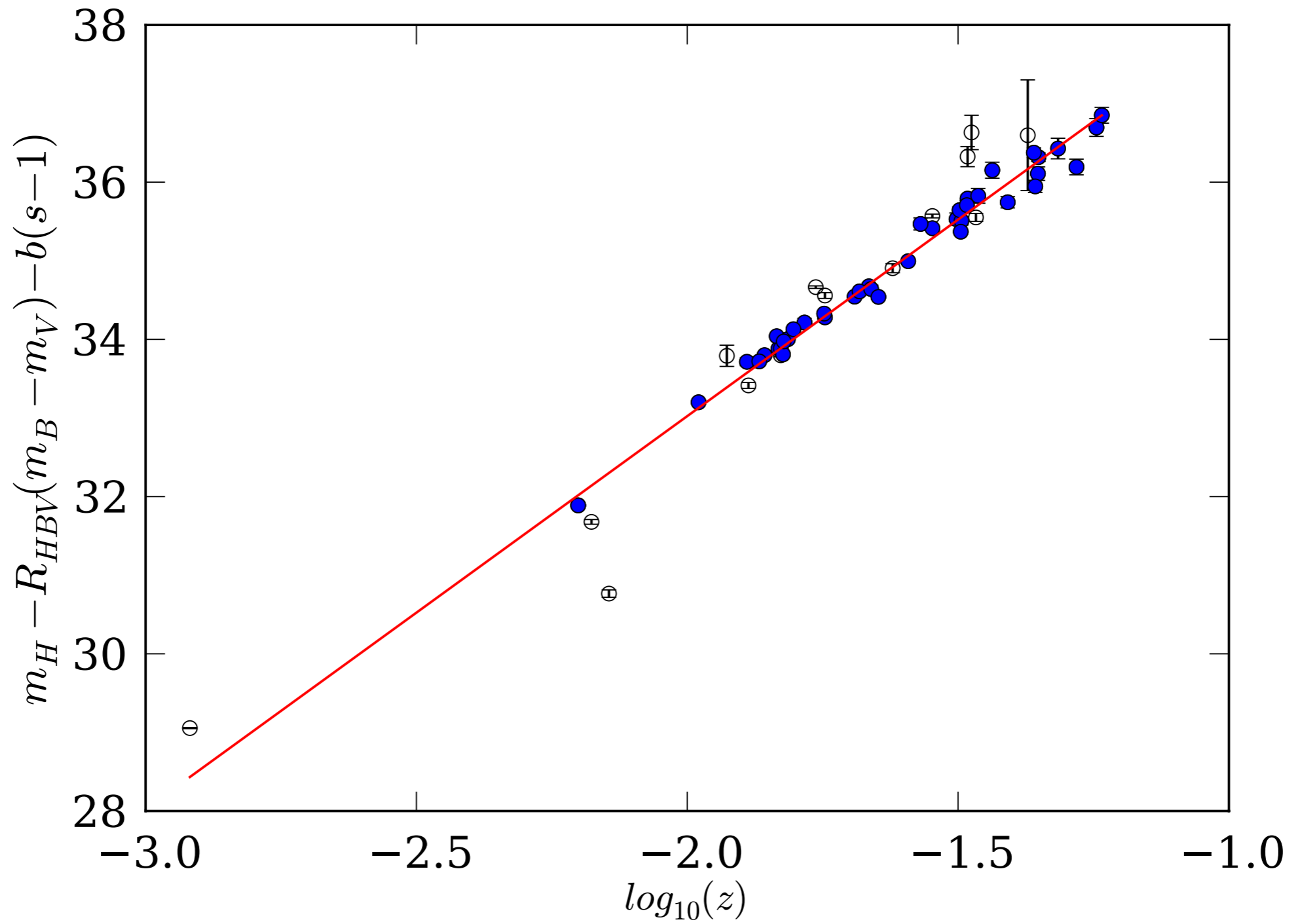


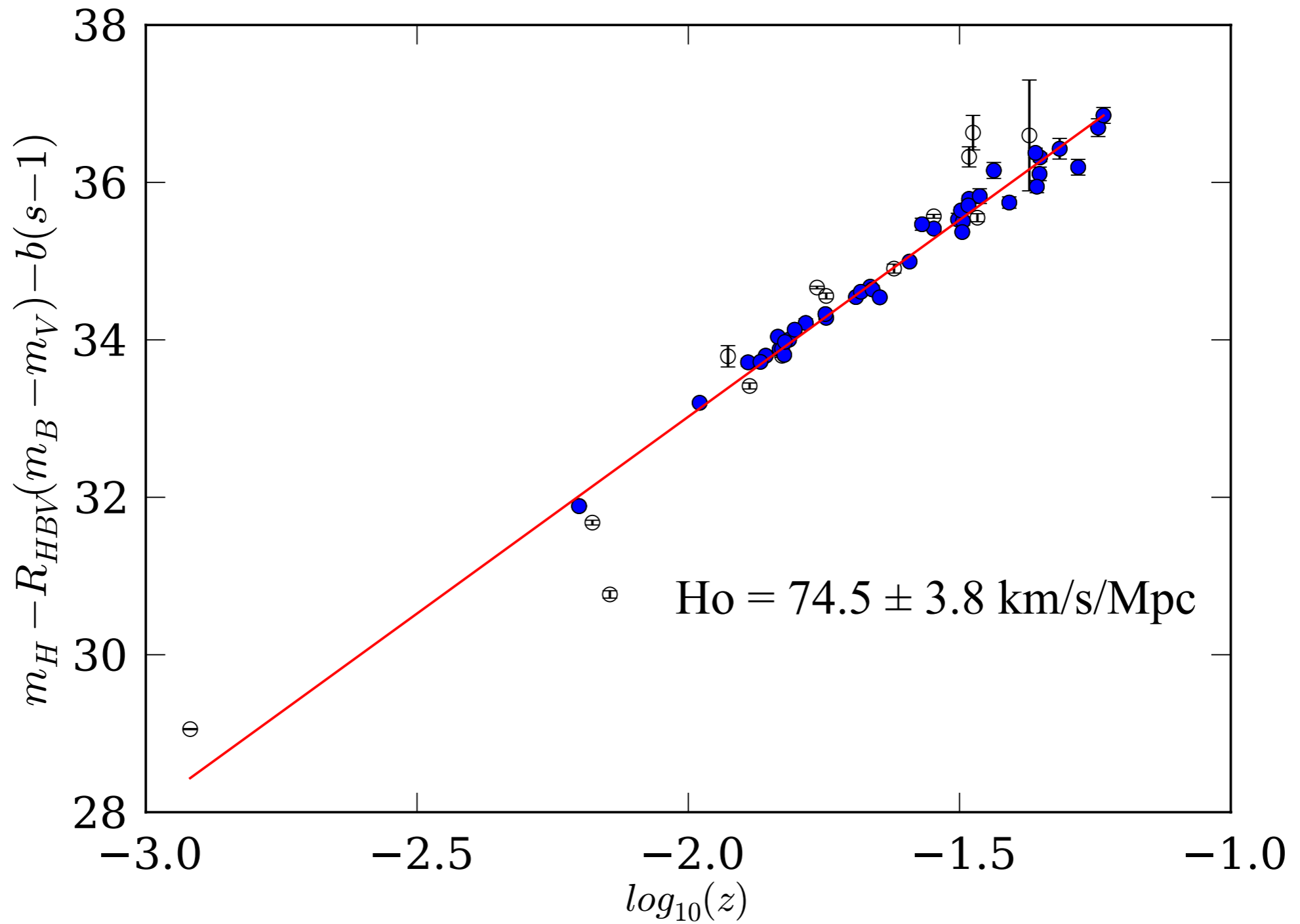


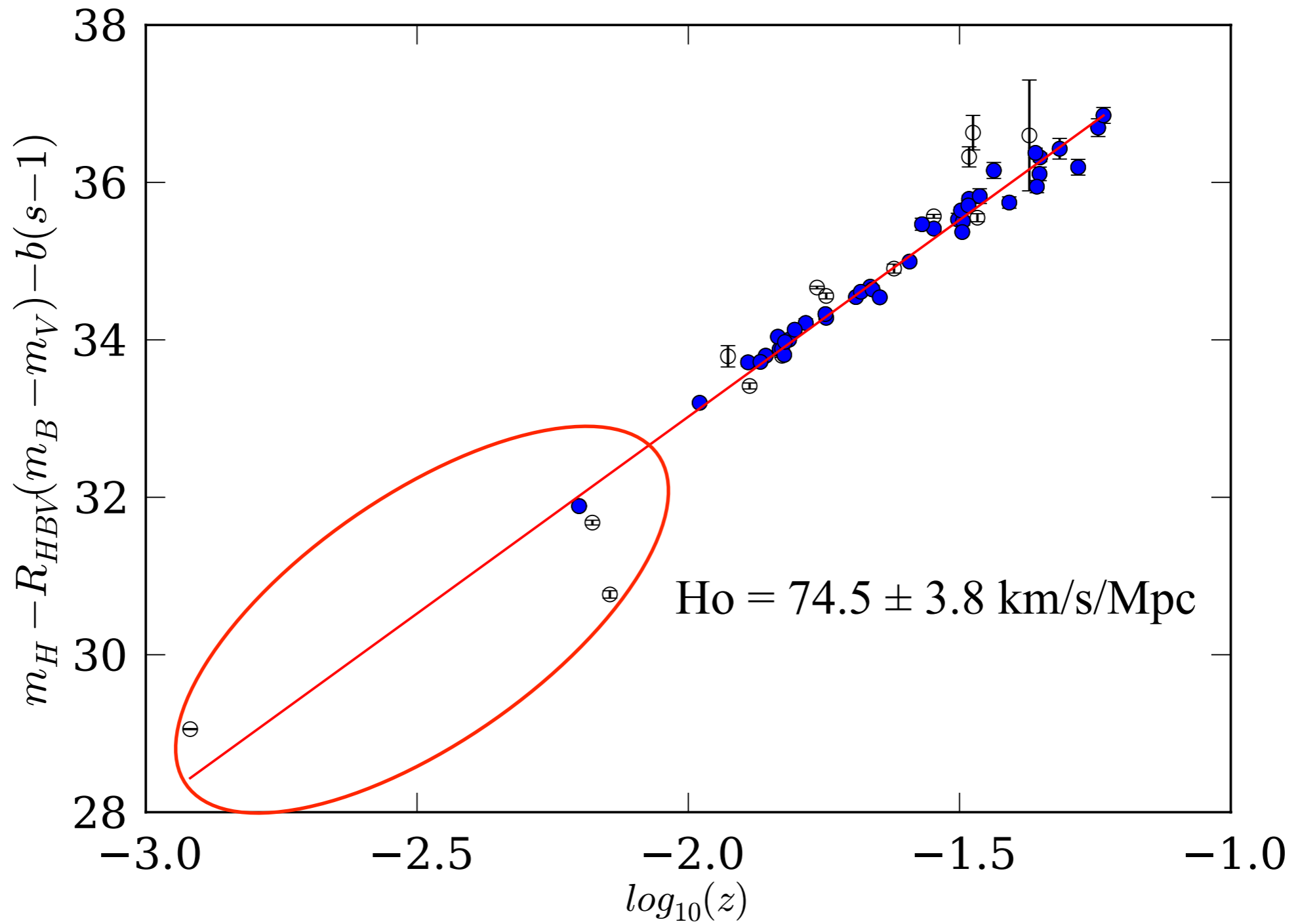




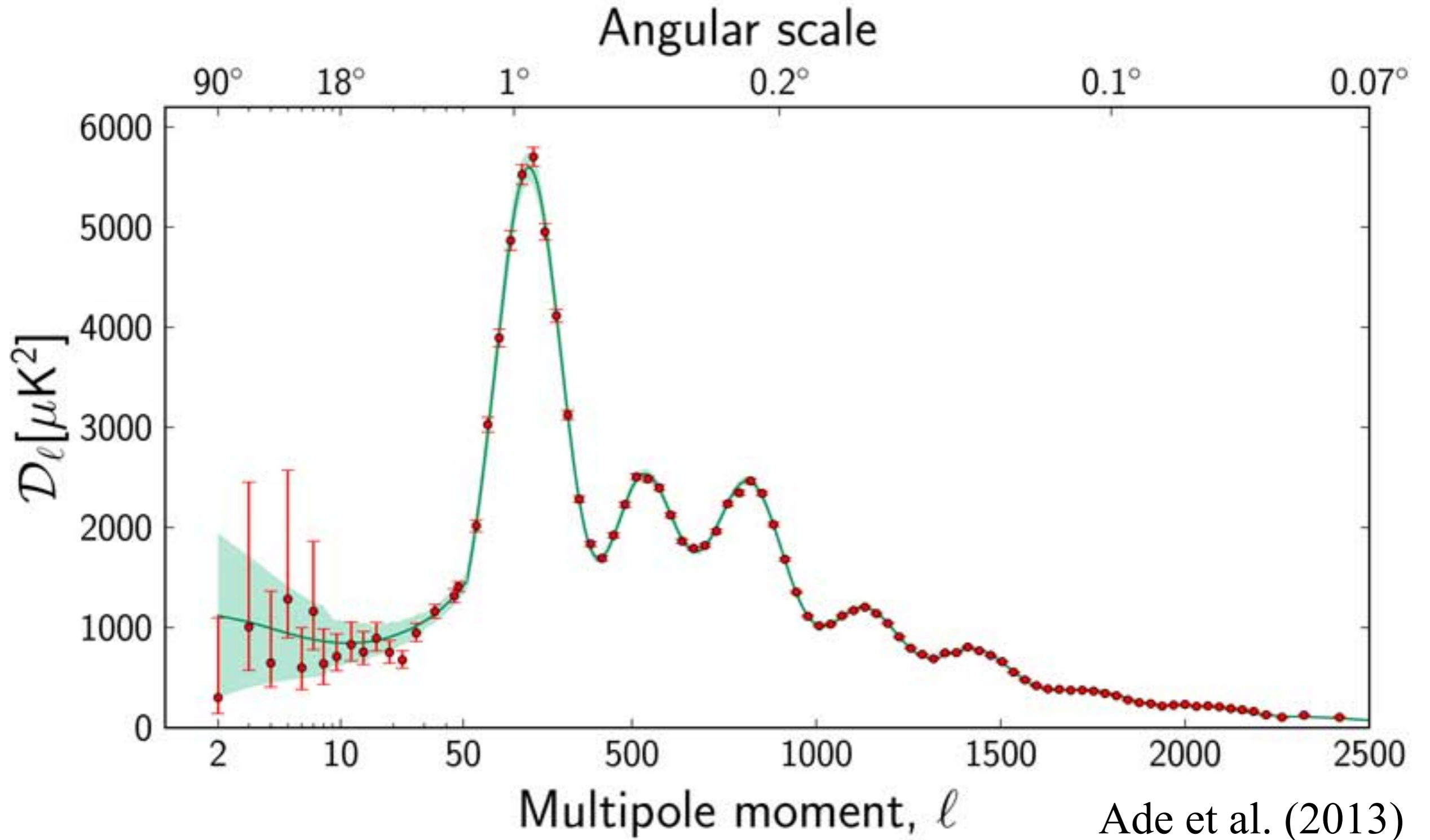




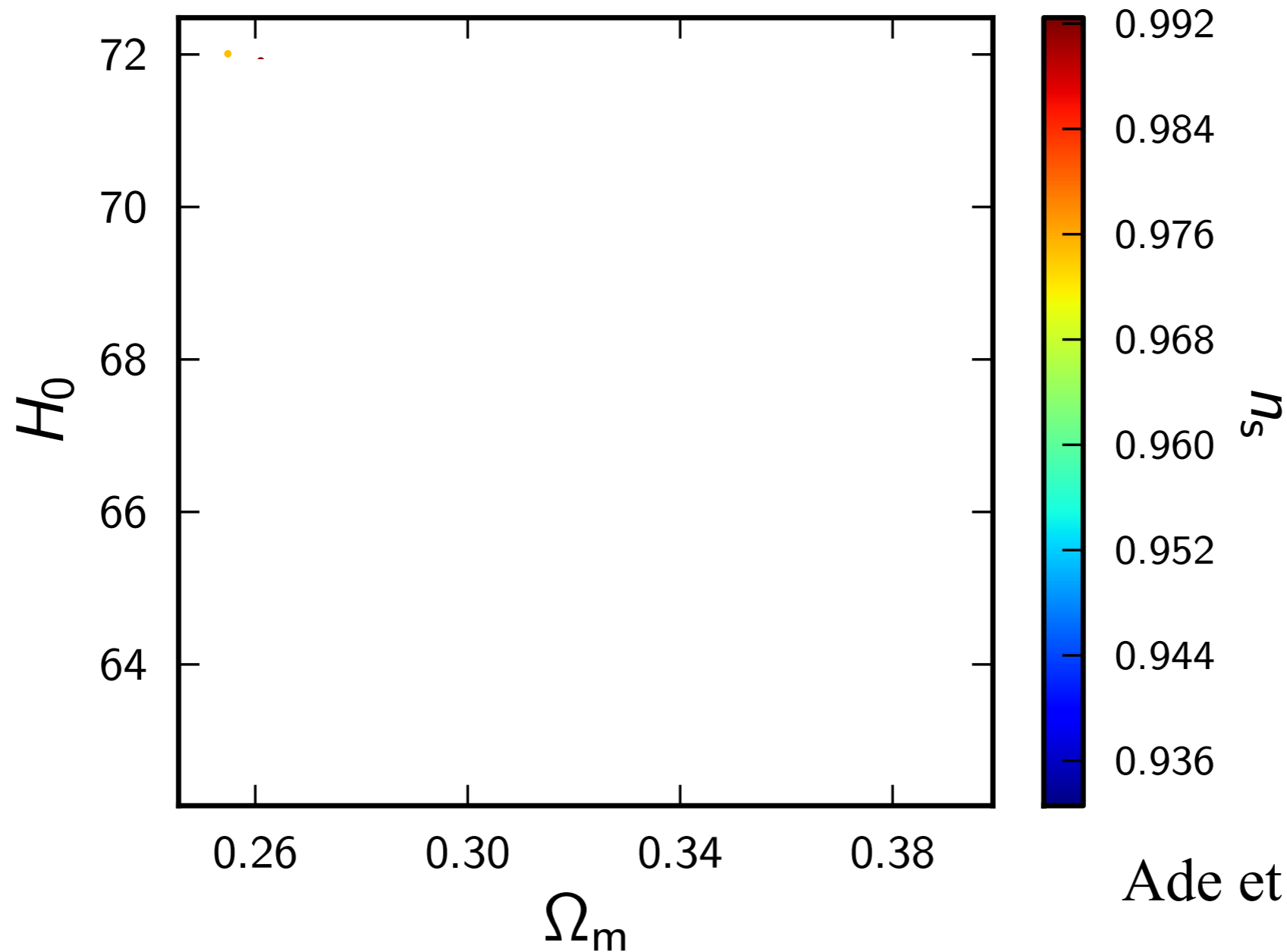






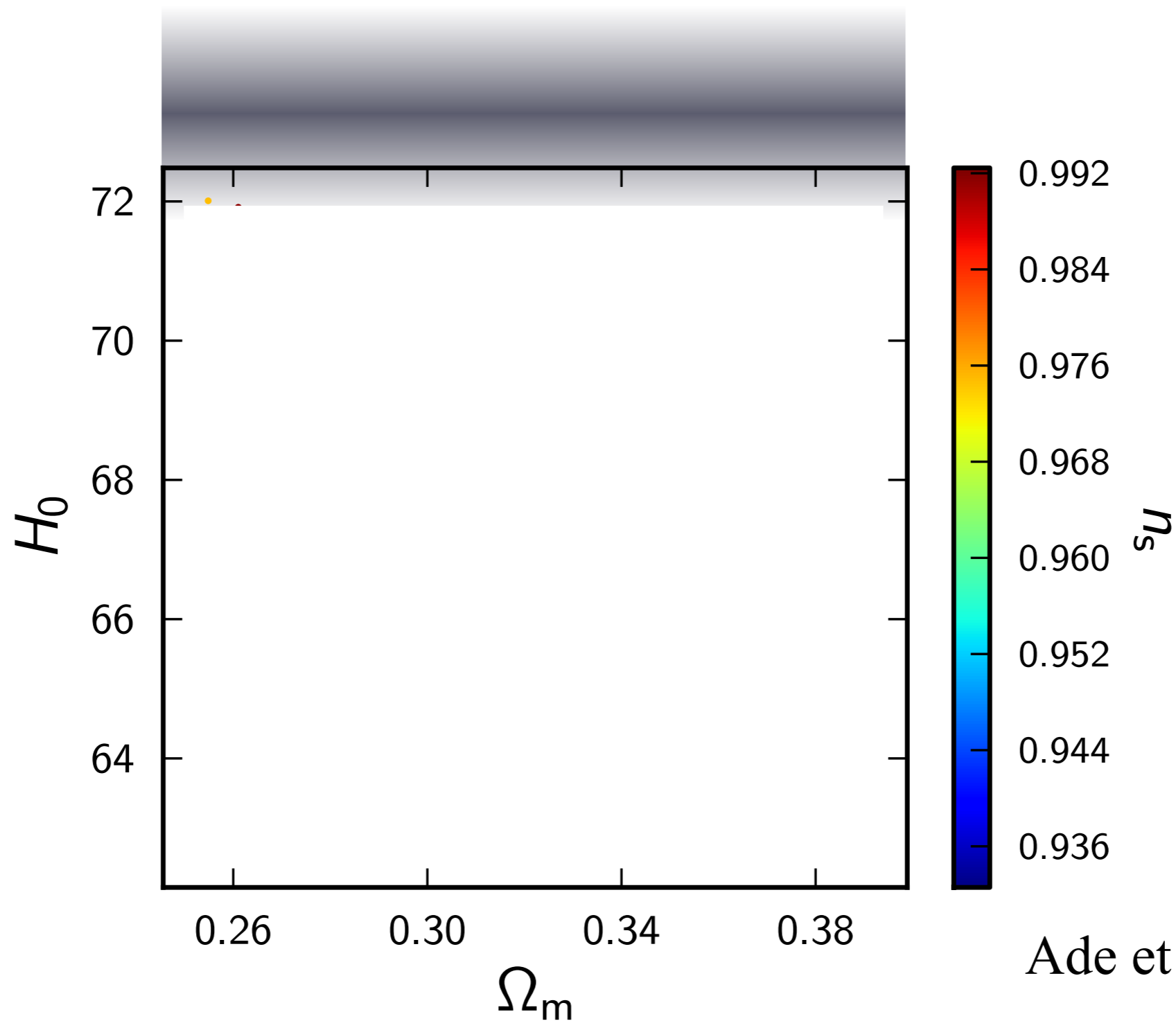


# There's Trouble a-brewin'



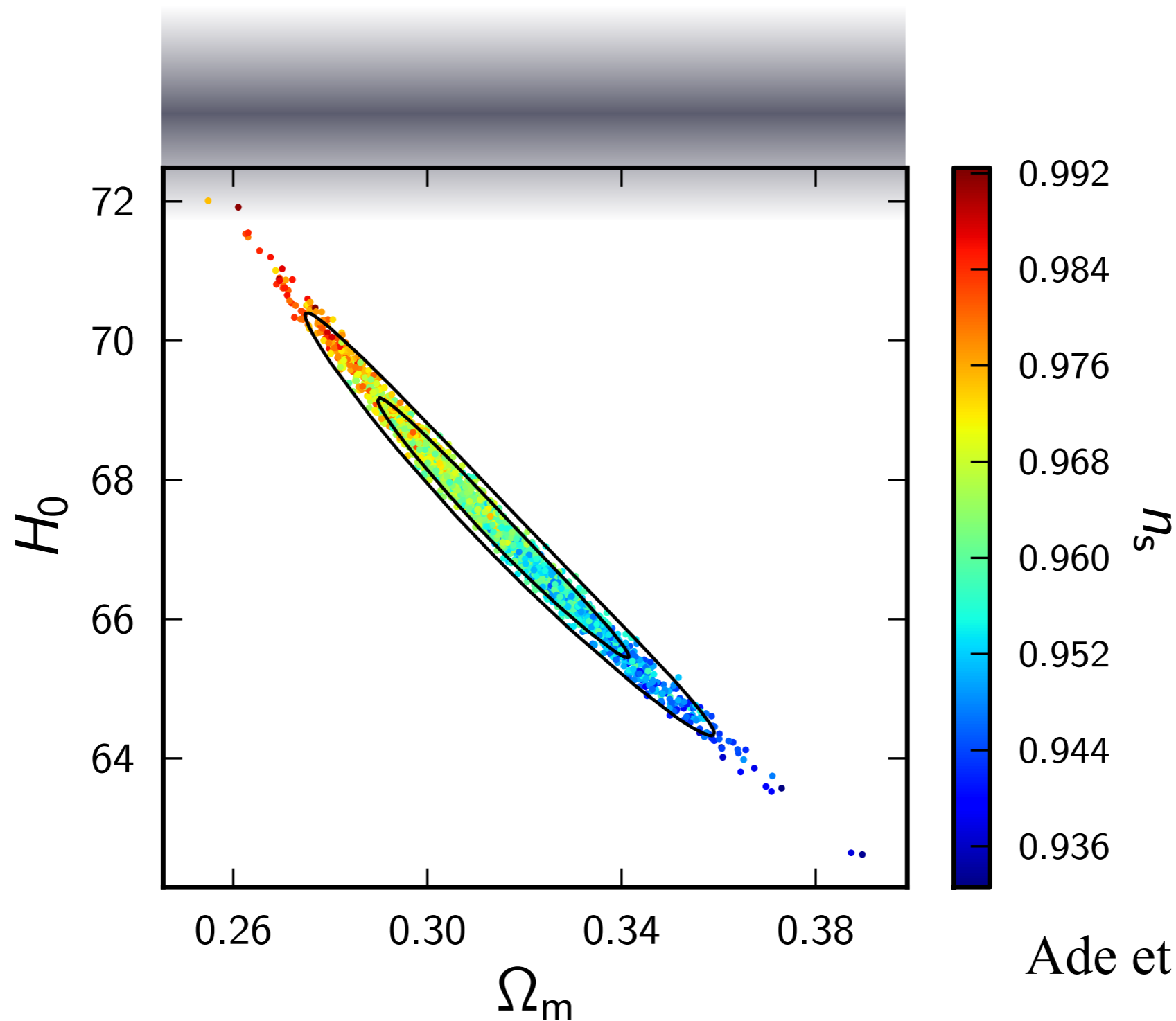
Ade et al. (2013)

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Ade et al. (2013)

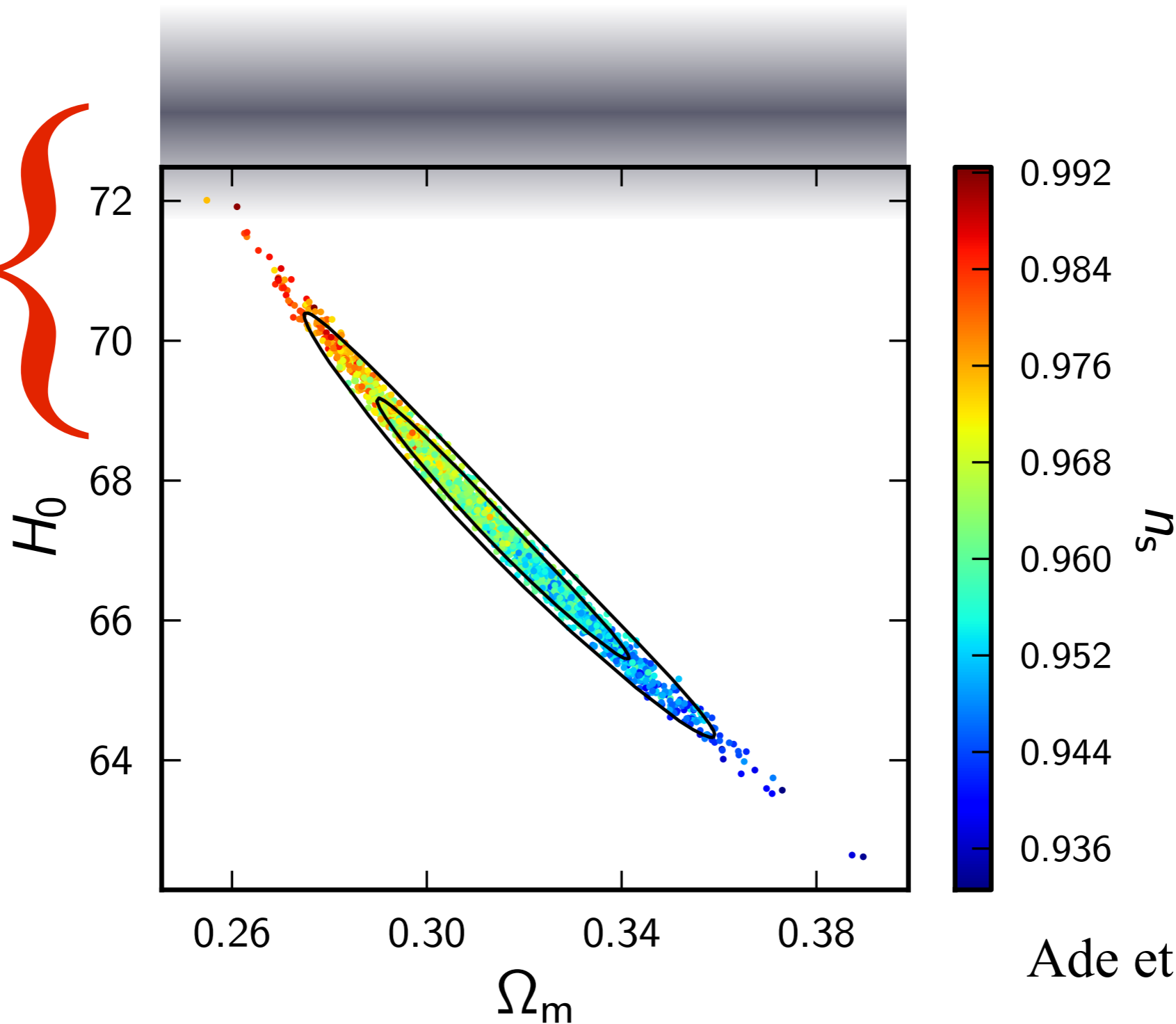
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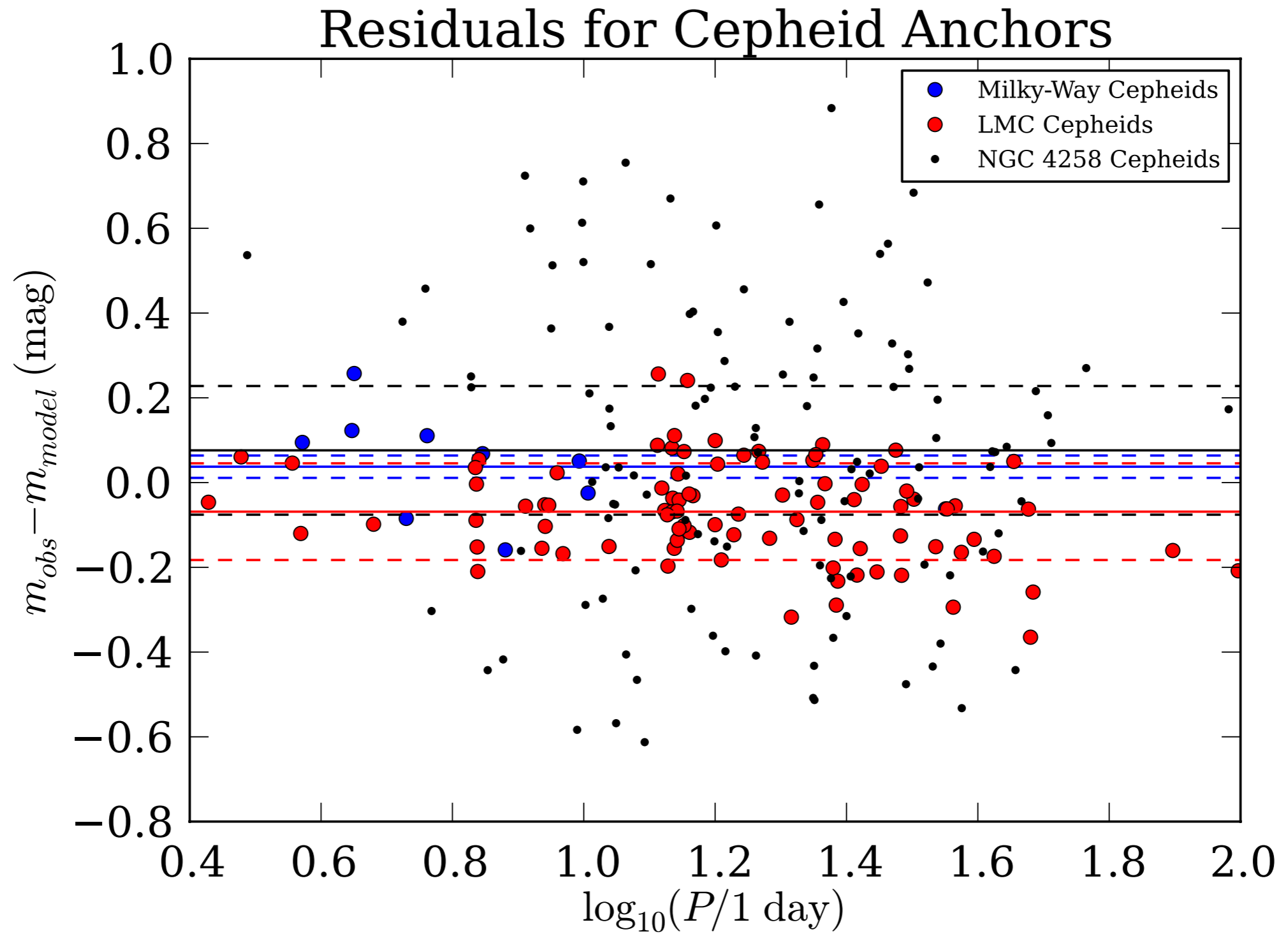


Ade et al. (2013)

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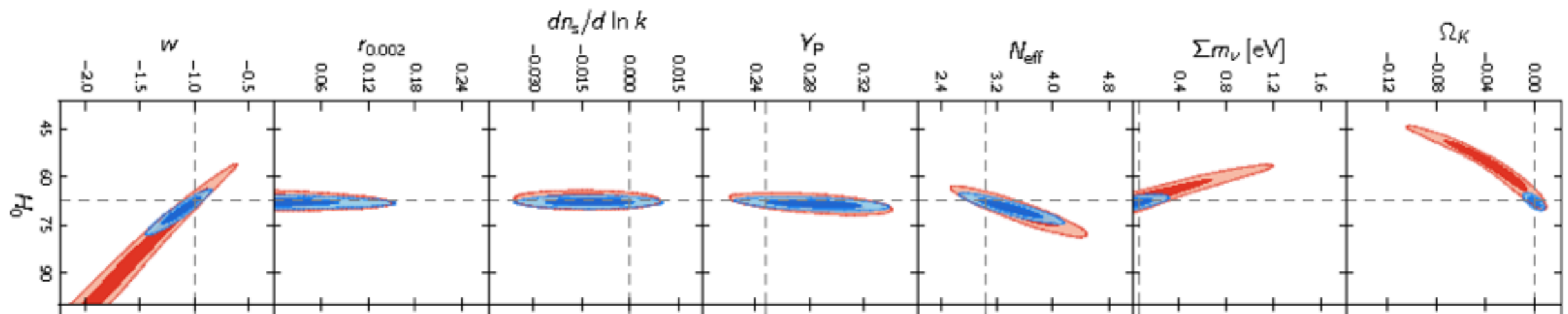
0.2 mag







# Adding More Parameters Can Help

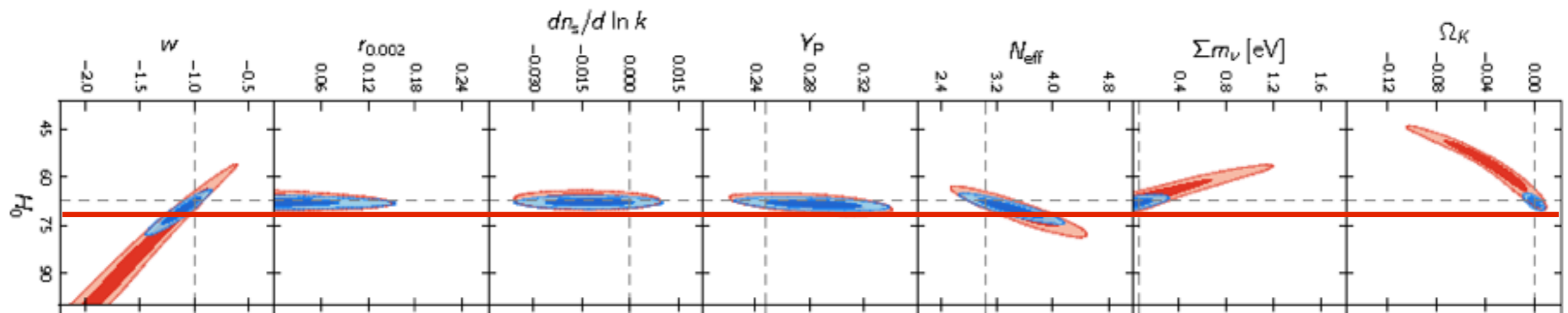


More exotic  
Dark Energy  
models

Number of  
relativistic  
particles

Ade et al. (2013)

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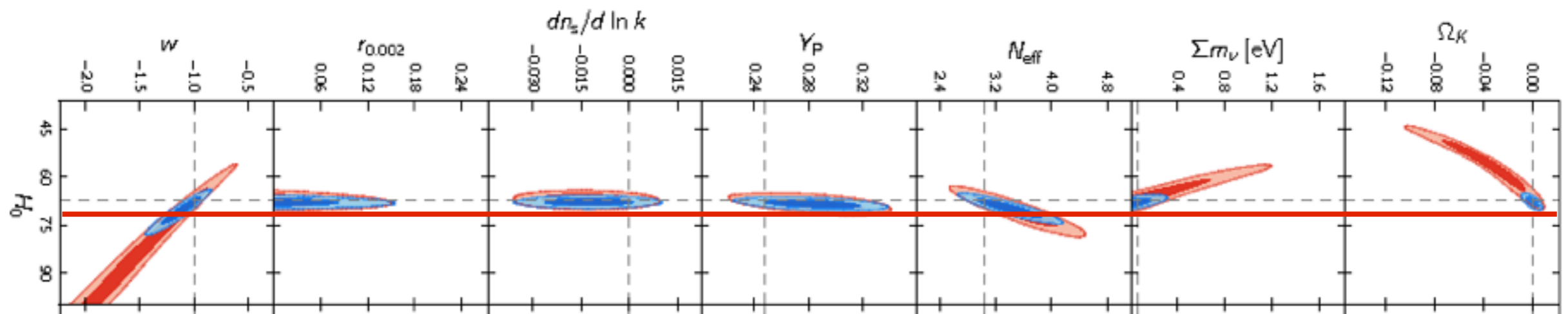


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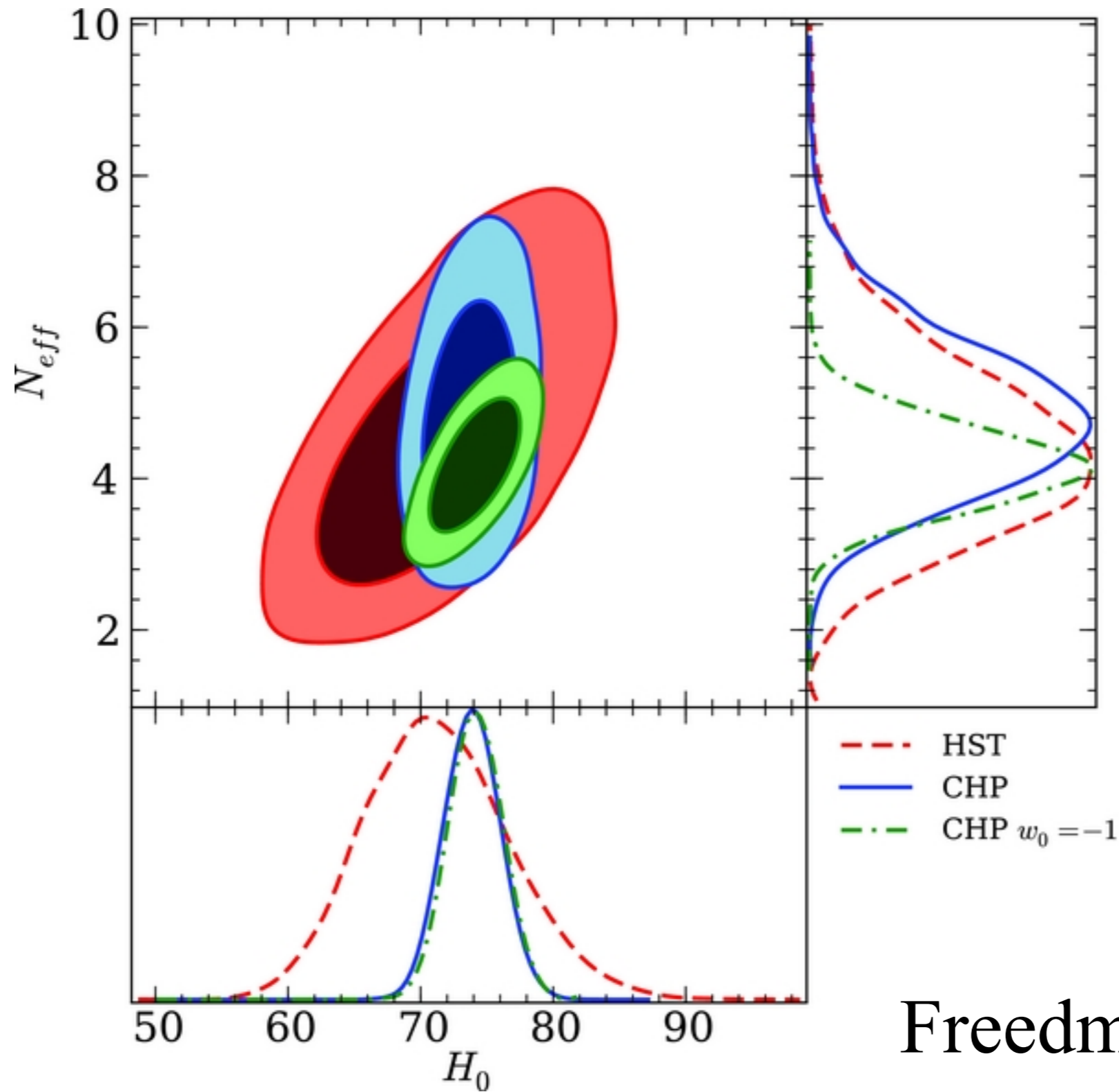


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Ade et al. (2013)

New Physics?



Freedman et al. (2012)

# Plain Old Systematics?

Local  $H_0$  depends on standard candle distances

- ◆ First rung could be wrong(er)
- ◆ Each rung could be wrong(er)
- ◆ Inter-stellar extinction could be different.
- ◆ Photometric crowding bias

Planck  $H_0$  depends on Early Universe physics and Cosmology

- ◆ GR may be wrong
- ◆ Assumed model (dark energy + dark matter) could be wrong.
- ◆ Signs of inconsistencies with WMAP?