Astrostatistics

Monday, 03 February 2020

- Statistics Foundations
  - Ivezic Ch 4 “Classical Statistical Inference” & Ch 5 “Bayesian Statistical Inference”
  - F&B Ch 3 “Statistical Inference”
- Review (on your own) properties of multivariate Gaussian random variables and densities
  (see multivariate_gaussian_notes.pdf on website)
- and also other standard distributions (F&B Ch 4 and Ivezic Ch 3)

Determining Astronomical Distances using Standard Candles

1. Estimate or model Luminosity L of a Class of Astronomical Objects

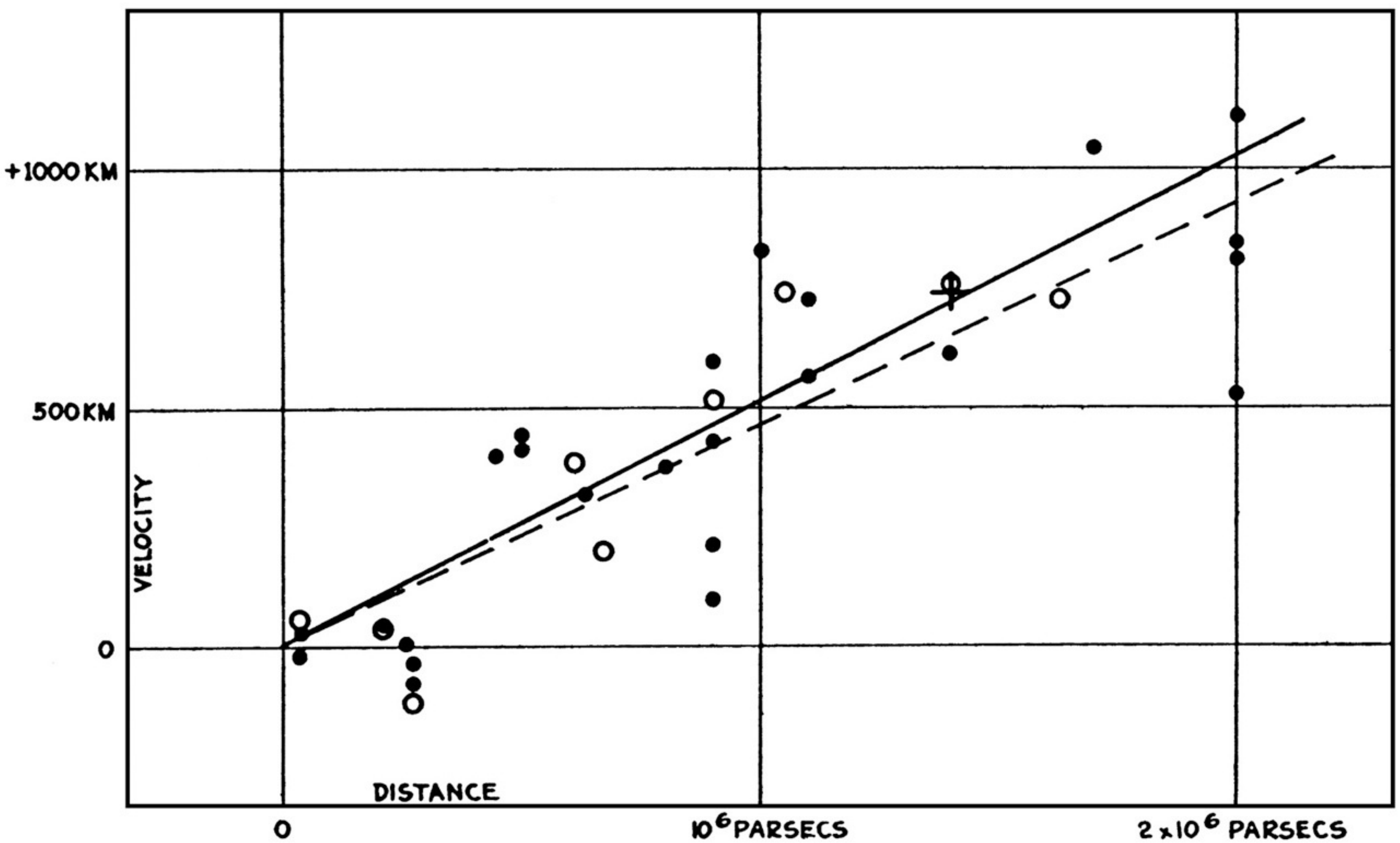
2. Measure the apparent brightness or flux F

3. Derive the distance D to Object using Inverse Square Law: $F = L / (4\pi D^2)$

4. Optical Astronomer's units: $\mu = m - M$

m = apparent magnitude [log apparent brightness flux],
M = absolute magnitude [log Luminosity],
μ = distance modulus [log distance].

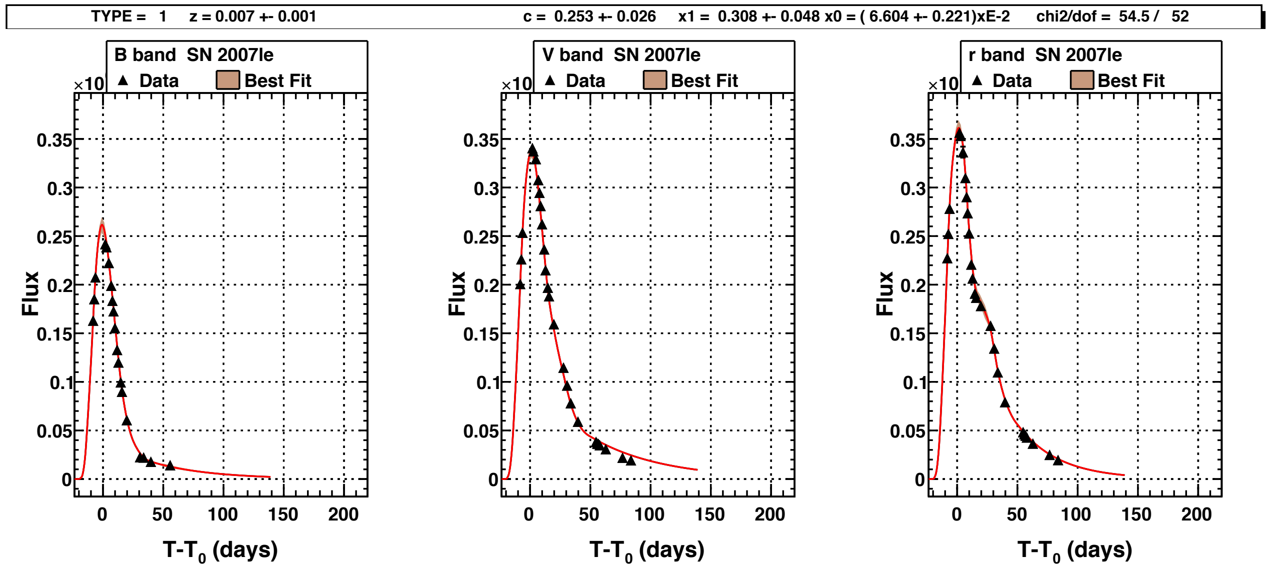
The Expanding Universe: Galaxies are moving apart! Hubble's Law (1929)



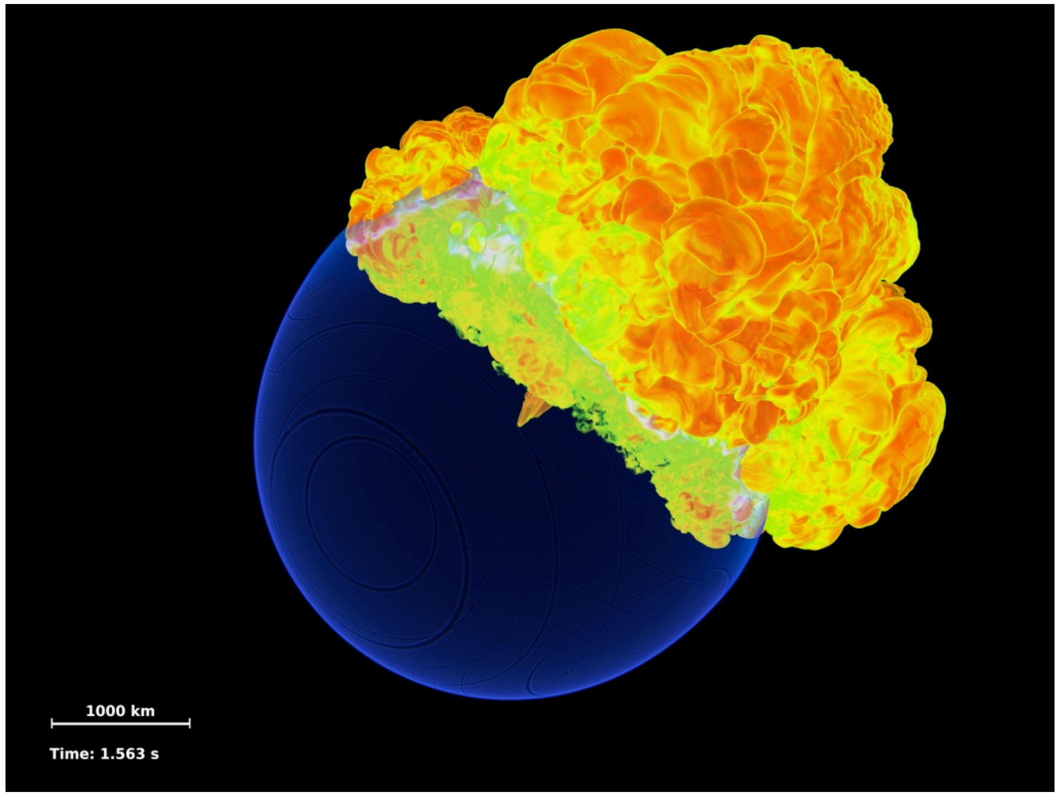
Einstein & Hubble

Distance $\propto$ Velocity (Redshift)

Type Ia Supernovae (SN Ia) are Almost Standard Candles

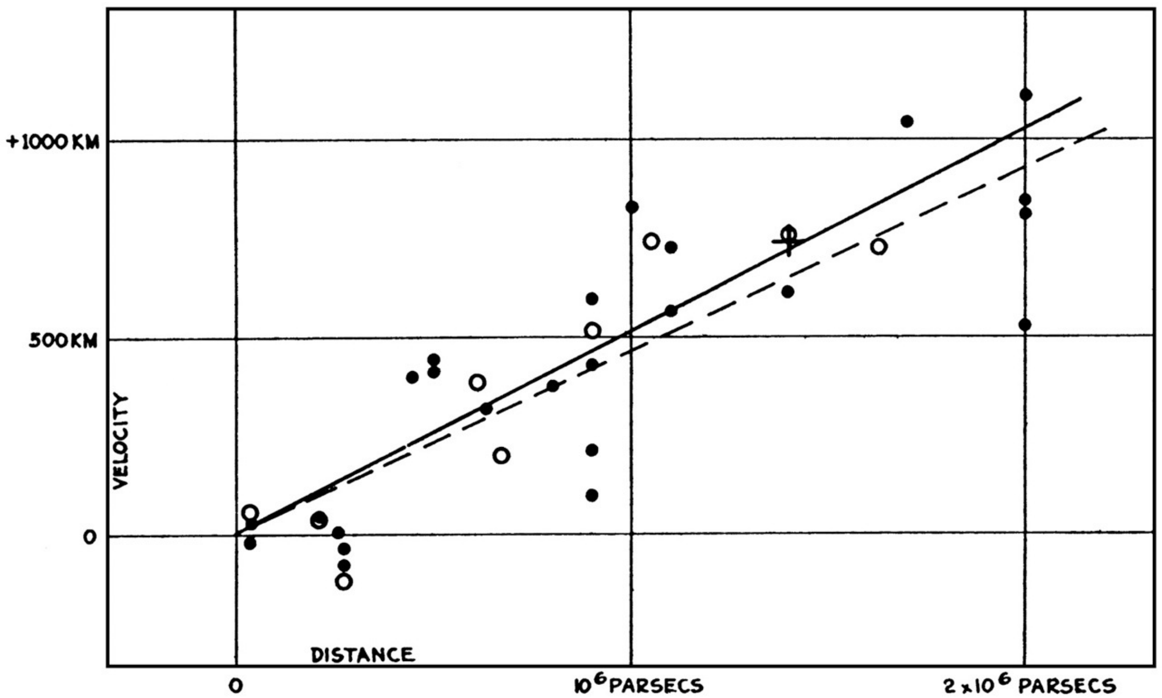


- Progenitor: C/O White Dwarf Star accreting mass leads to instability
- Thermonuclear Explosion: Deflagration/ Detonation
- Nickel to Cobalt to Iron Decay + radiative transfer powers the light curve

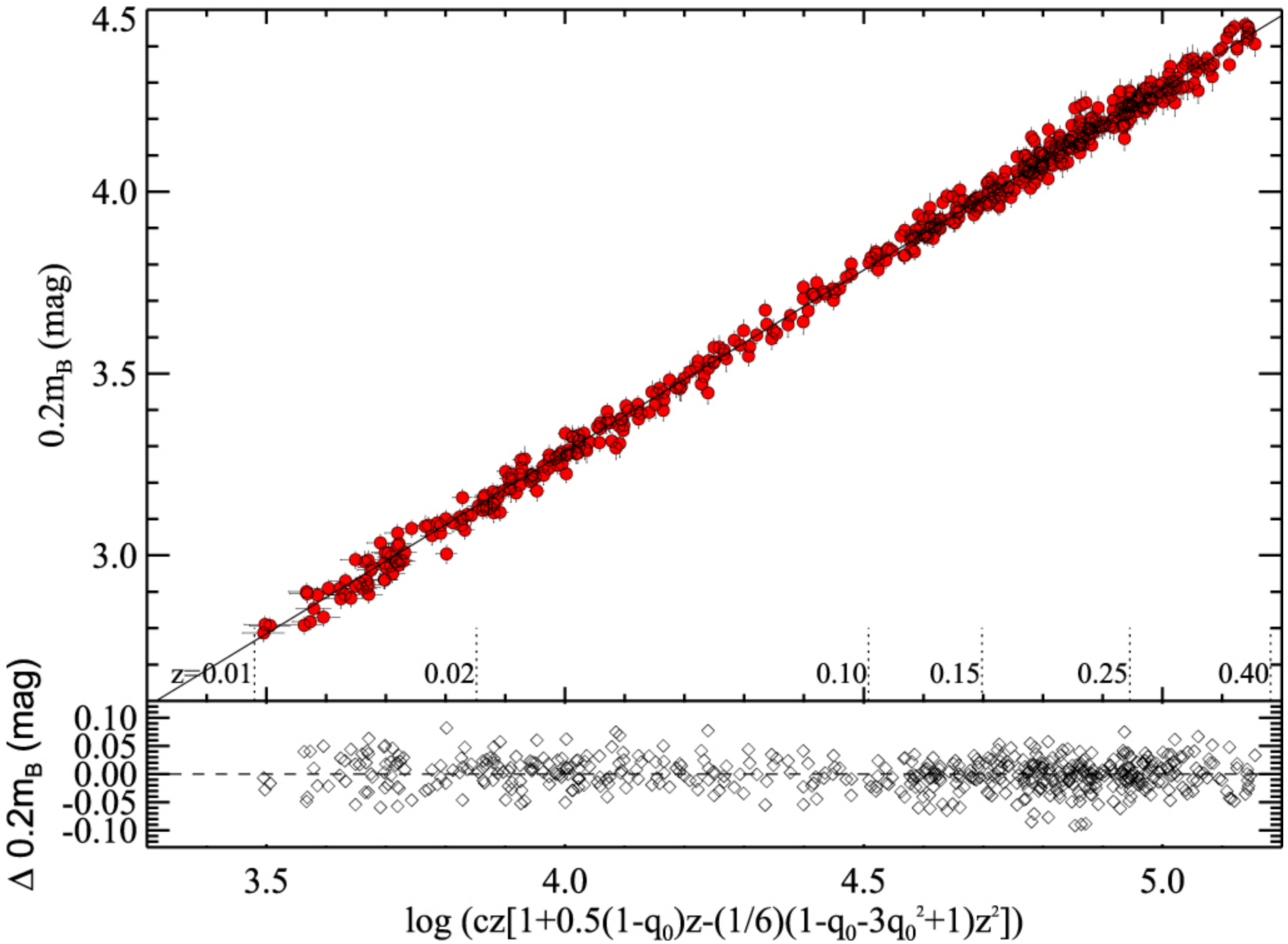


Hubble Constant

velocity = $H_0 \times$ distance



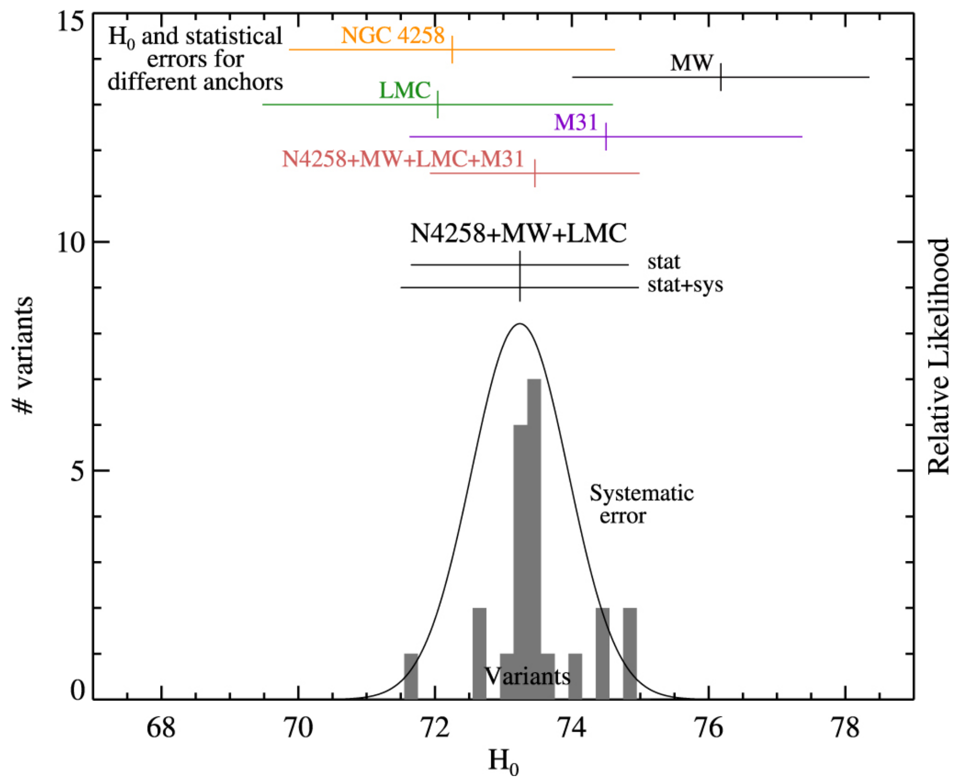
Hubble (1929)

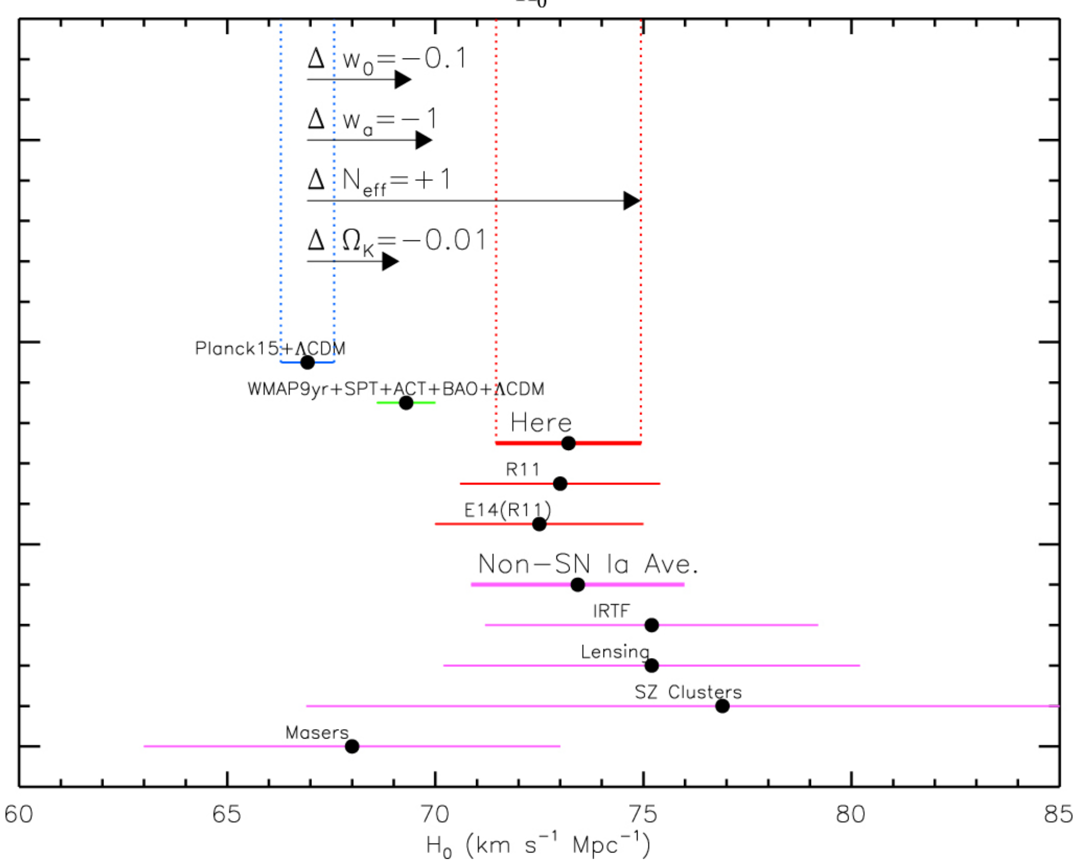


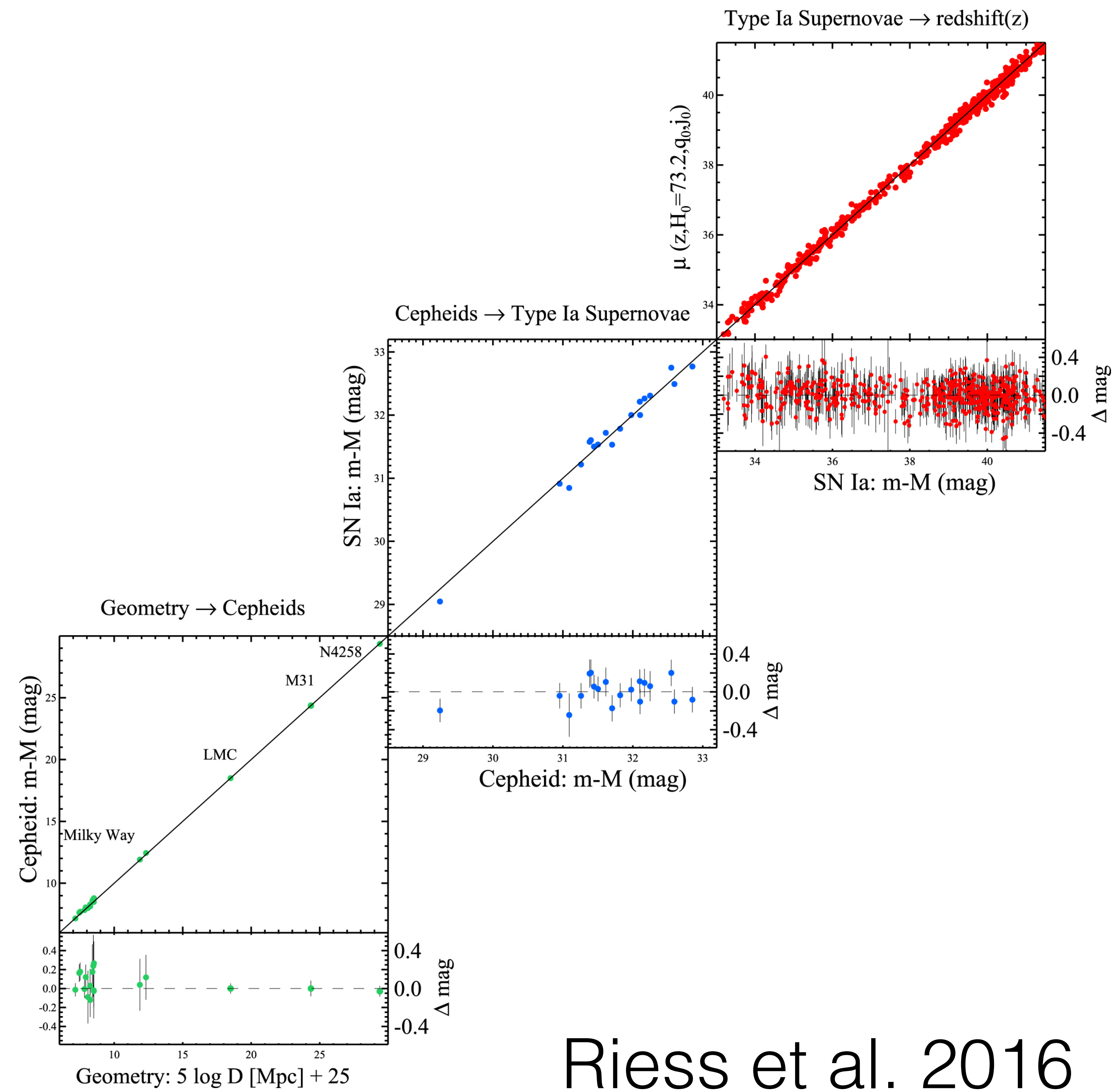
Riess et al. 2016

Hubble Constant

velocity = $H_0 \times$ distance

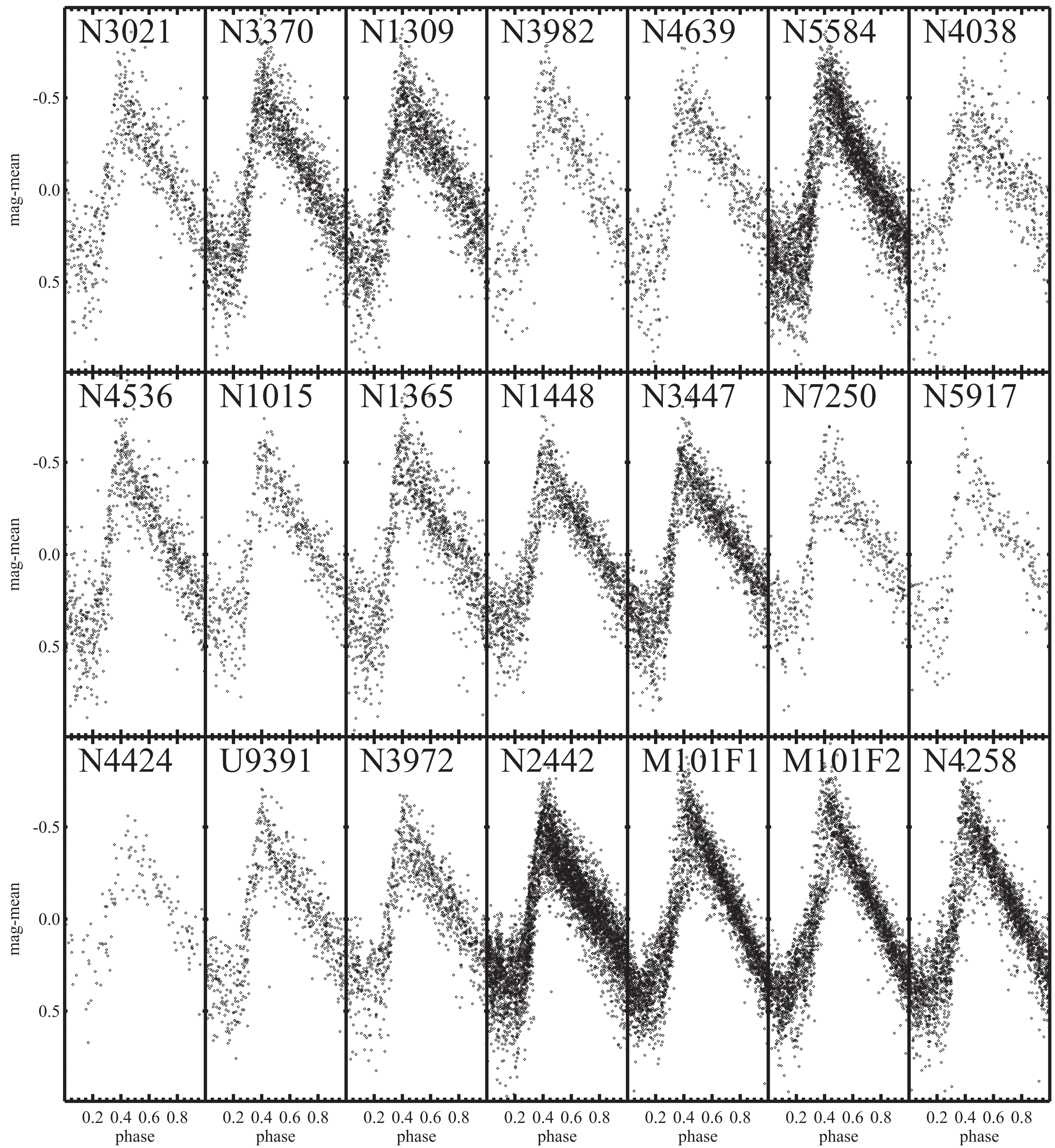






Riess et al. 2016

Example: Cepheid Light Curves (Time Series)



Riess et al. 2016

Example: Leavitt's Law: Period-Luminosity Relation

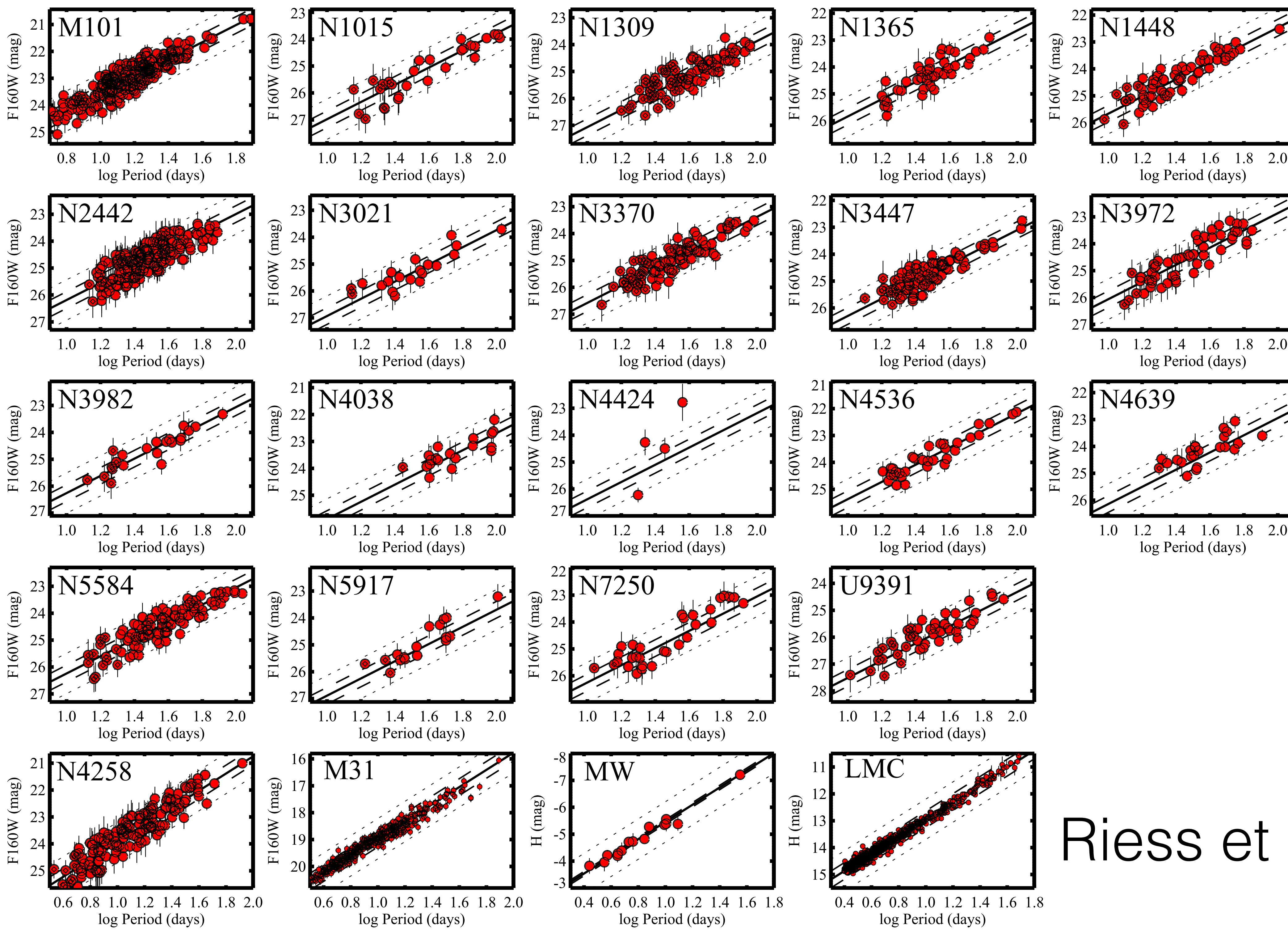


Figure 6. Near-infrared Cepheid *P–L* relations. The Cepheid magnitudes are shown for the 19 SN hosts and the four distance-scale anchors. Magnitudes labeled as *F160W* are all from the same instrument and camera, WFC3 *F160W*. The uniformity of the photometry and metallicity reduces systematic errors along the distance ladder. A single slope is shown to illustrate the relations, but we also allow for a break (two slopes) as well as limited period ranges.

Riess et al. 2016

Calibrating SN Ia Standard Candles
(Avelino, Friedman, Mandel et al. 2019)

Determining the Distribution of Absolute Magnitudes

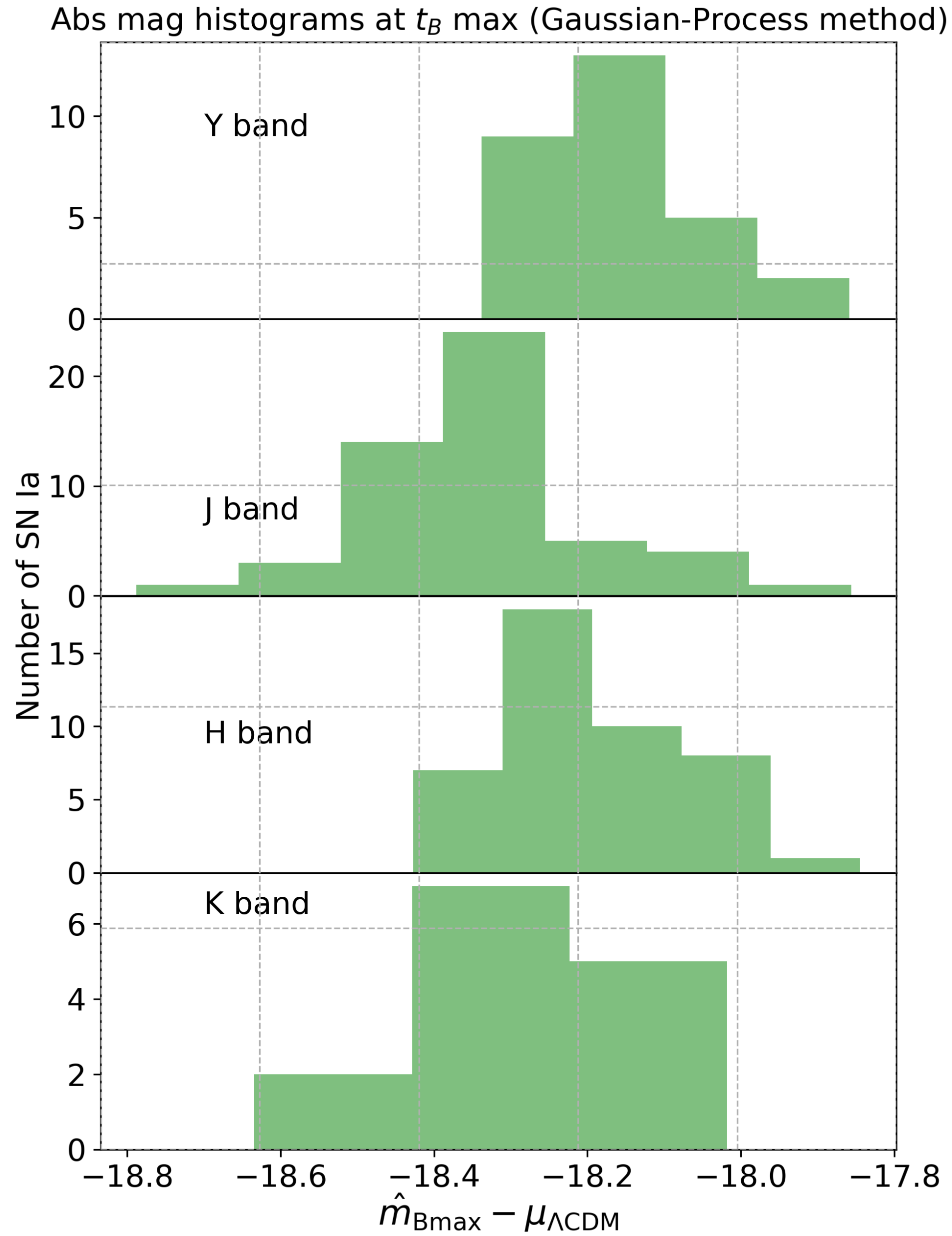
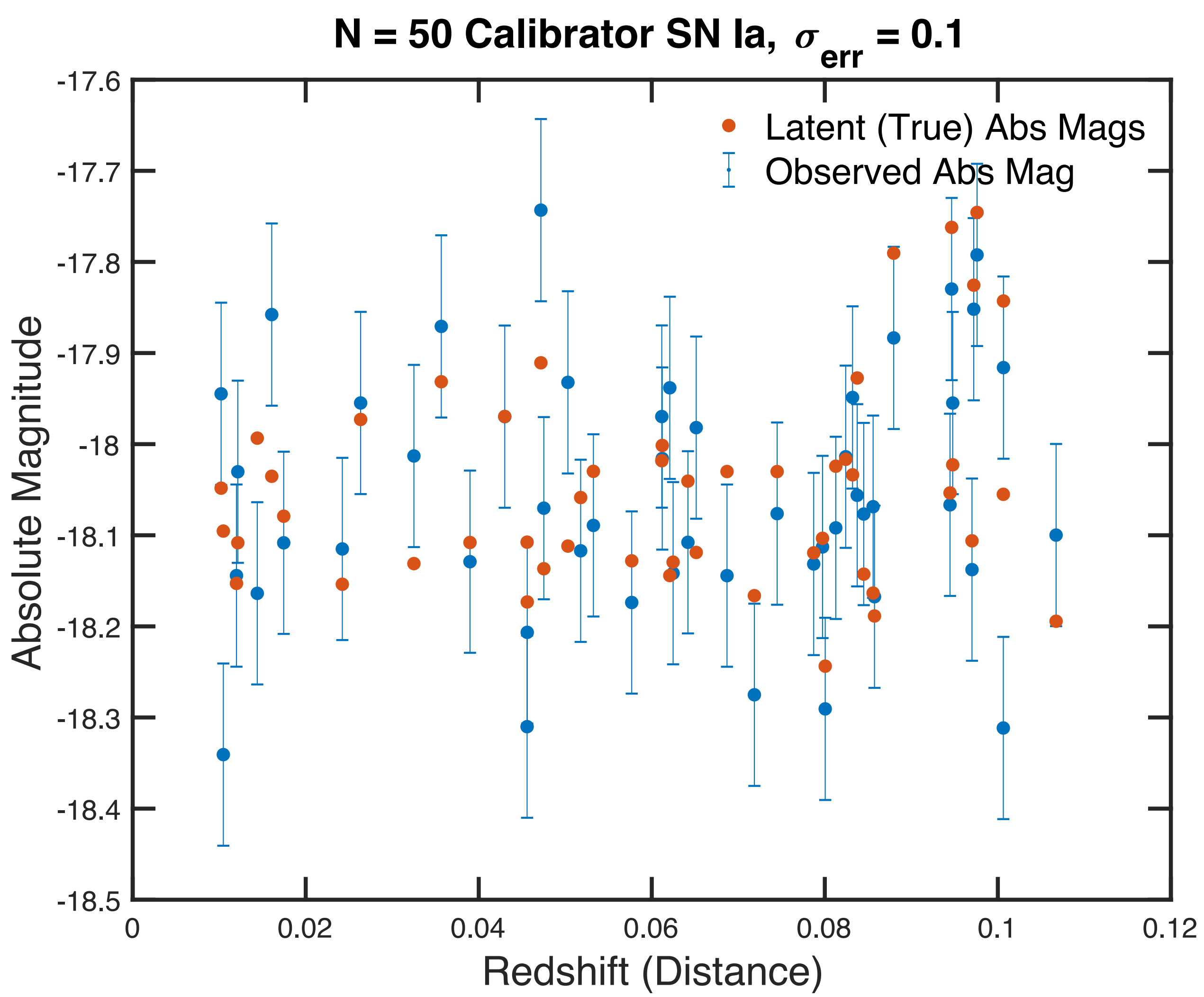
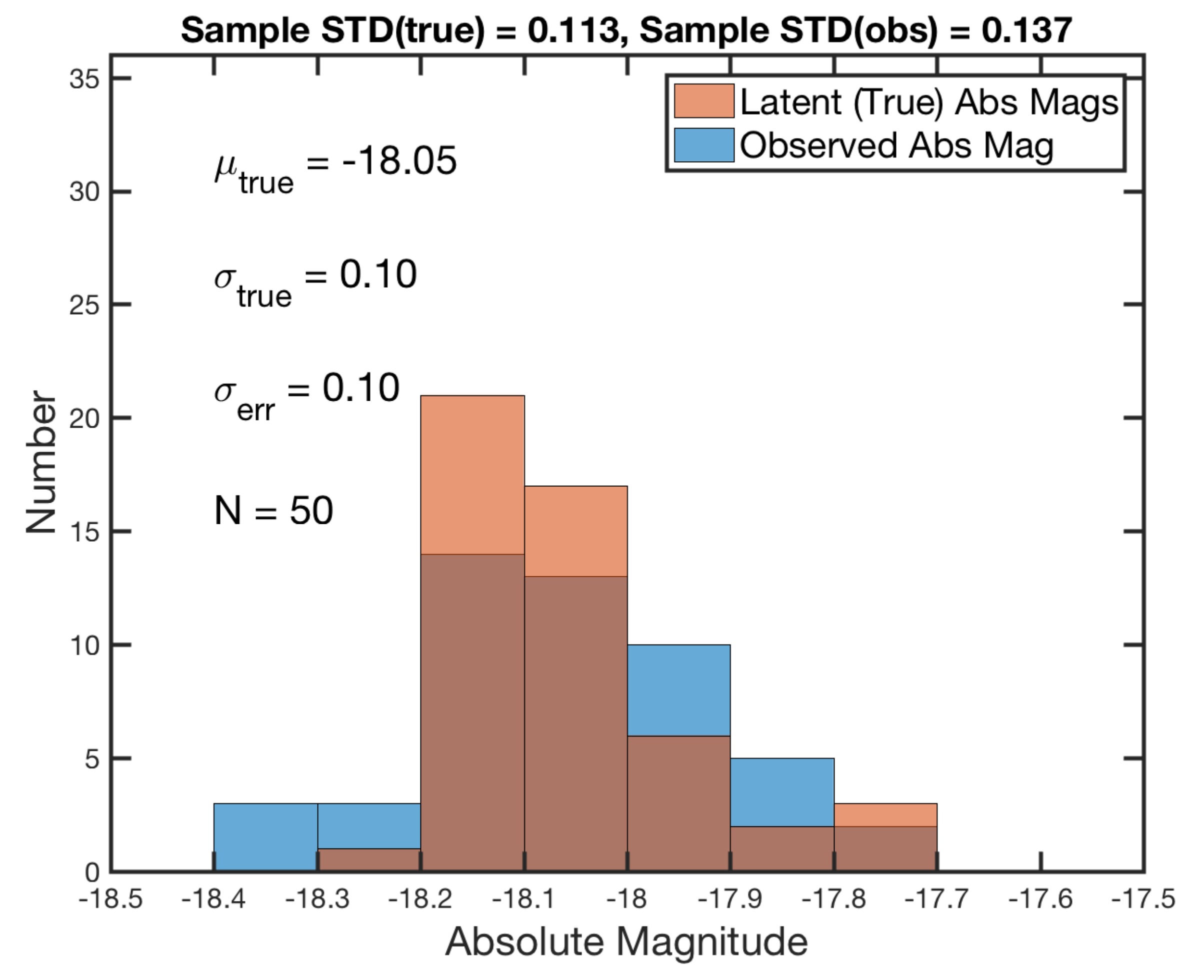


Figure 4: Normalized histograms of the absolute magnitudes at phase = B_{max}, defined as $M_{B_{\mathrm{max}},s} \equiv \hat{m}_{B\mathrm{max},s} - \mu_{\Lambda\mathrm{CDM}}(z_s)$ for the SN Ia sample in the GP method at B max. The mean, the standard deviation, and the number of supernovae in each histogram are

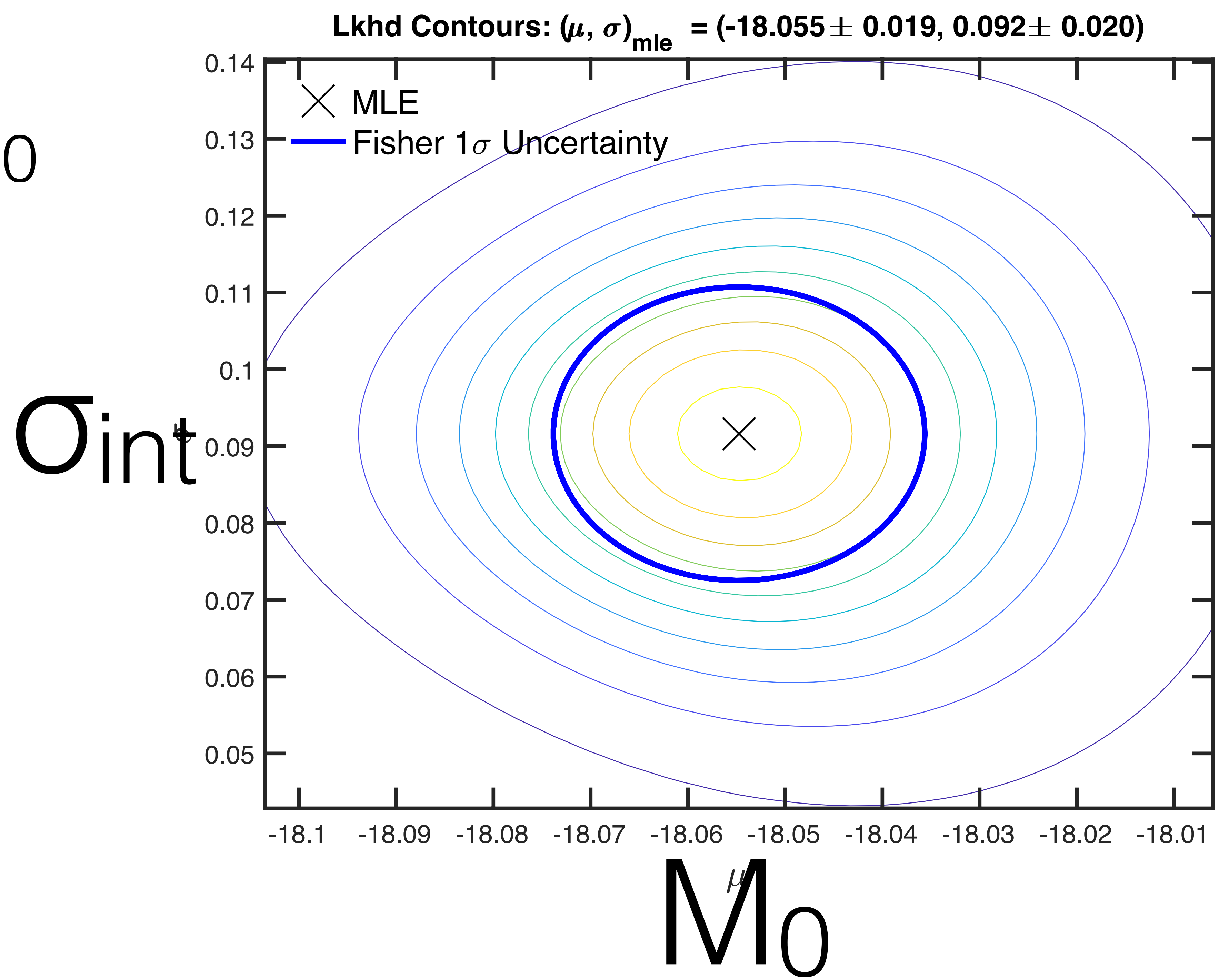
Want to Calibrate SN Ia (N=50)
determine M_0, σ_{int}
from data with measurement error std dev σ_{err} = 0.1



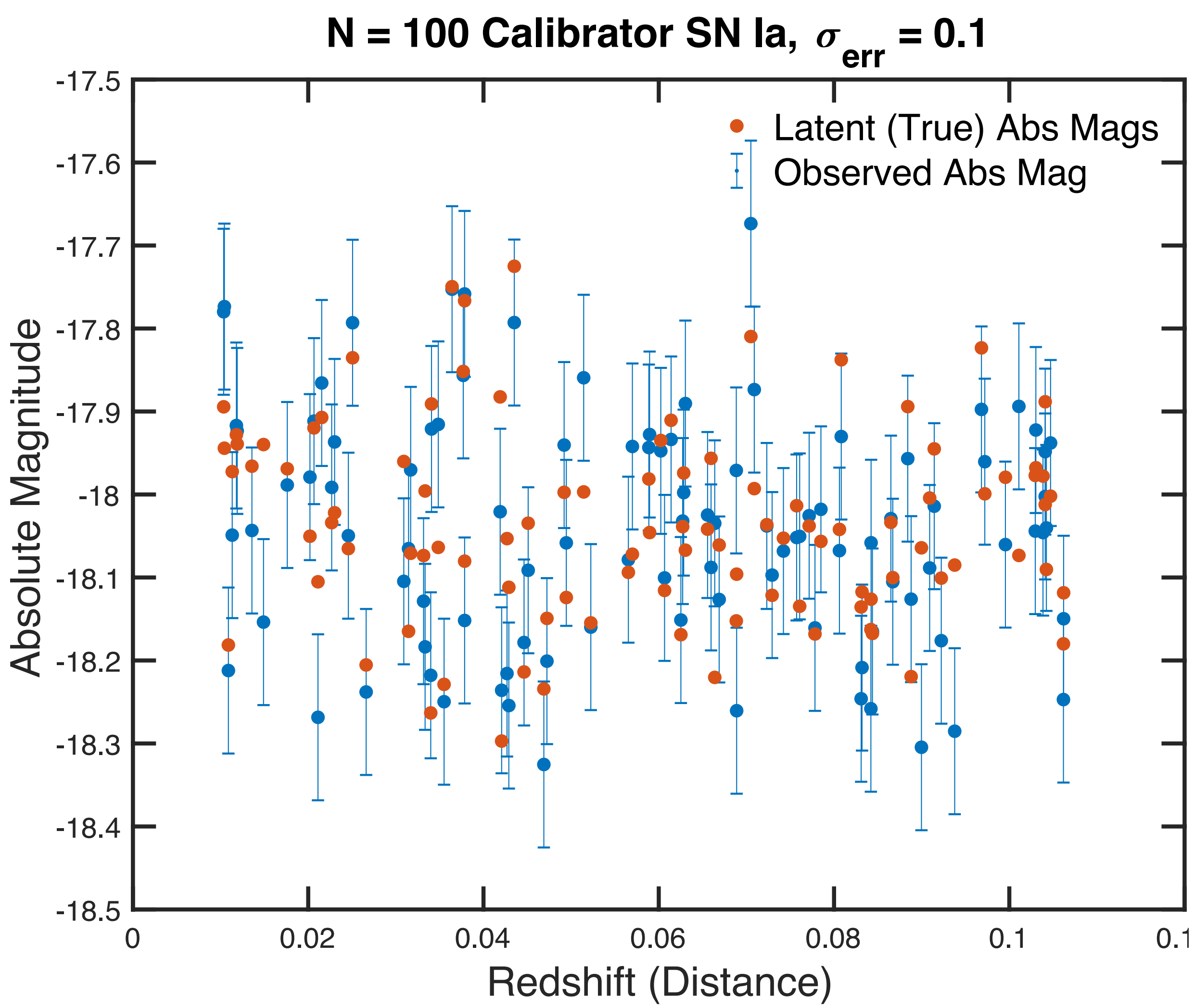


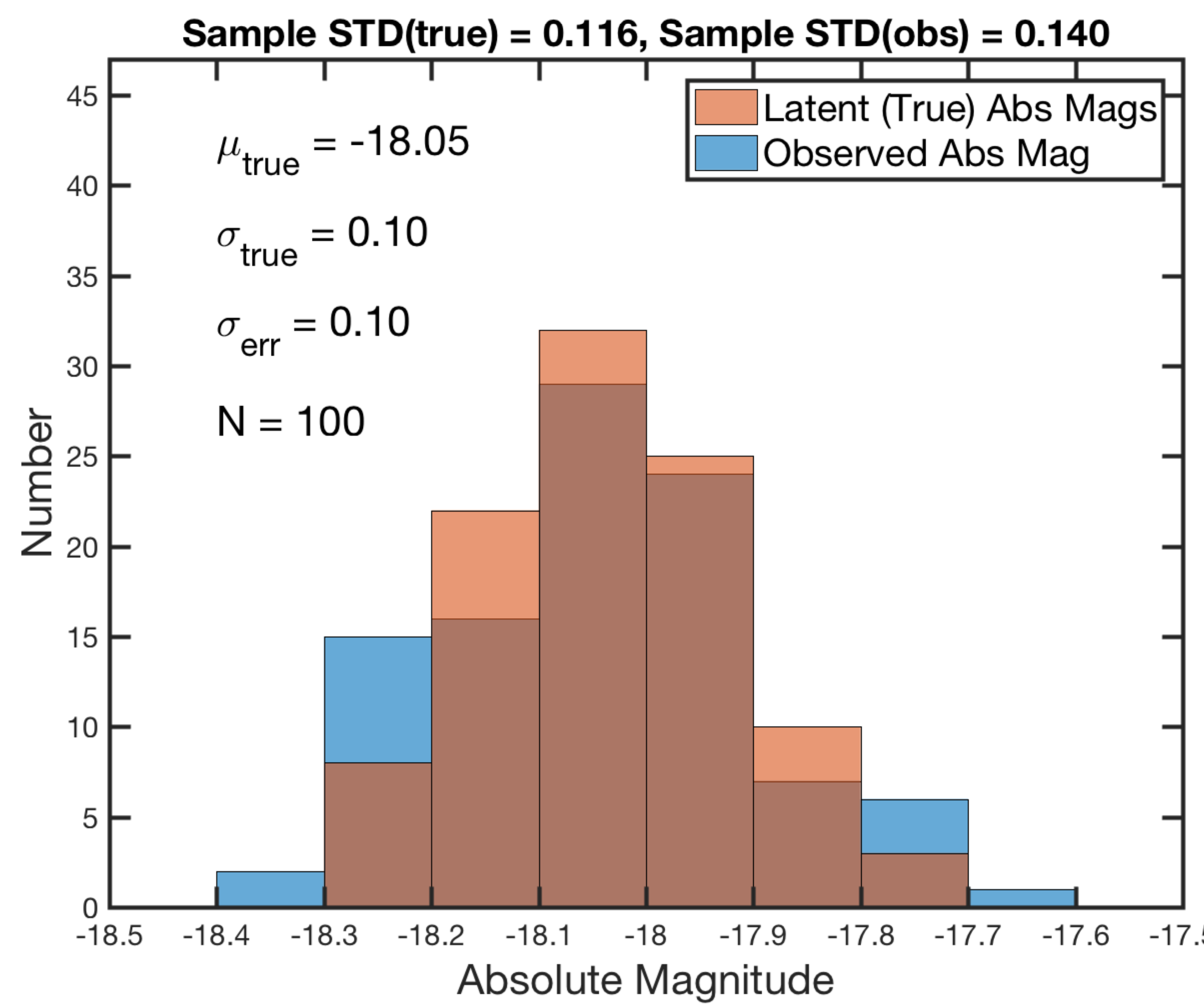
Maximum Likelihood with measurement error

N = 50



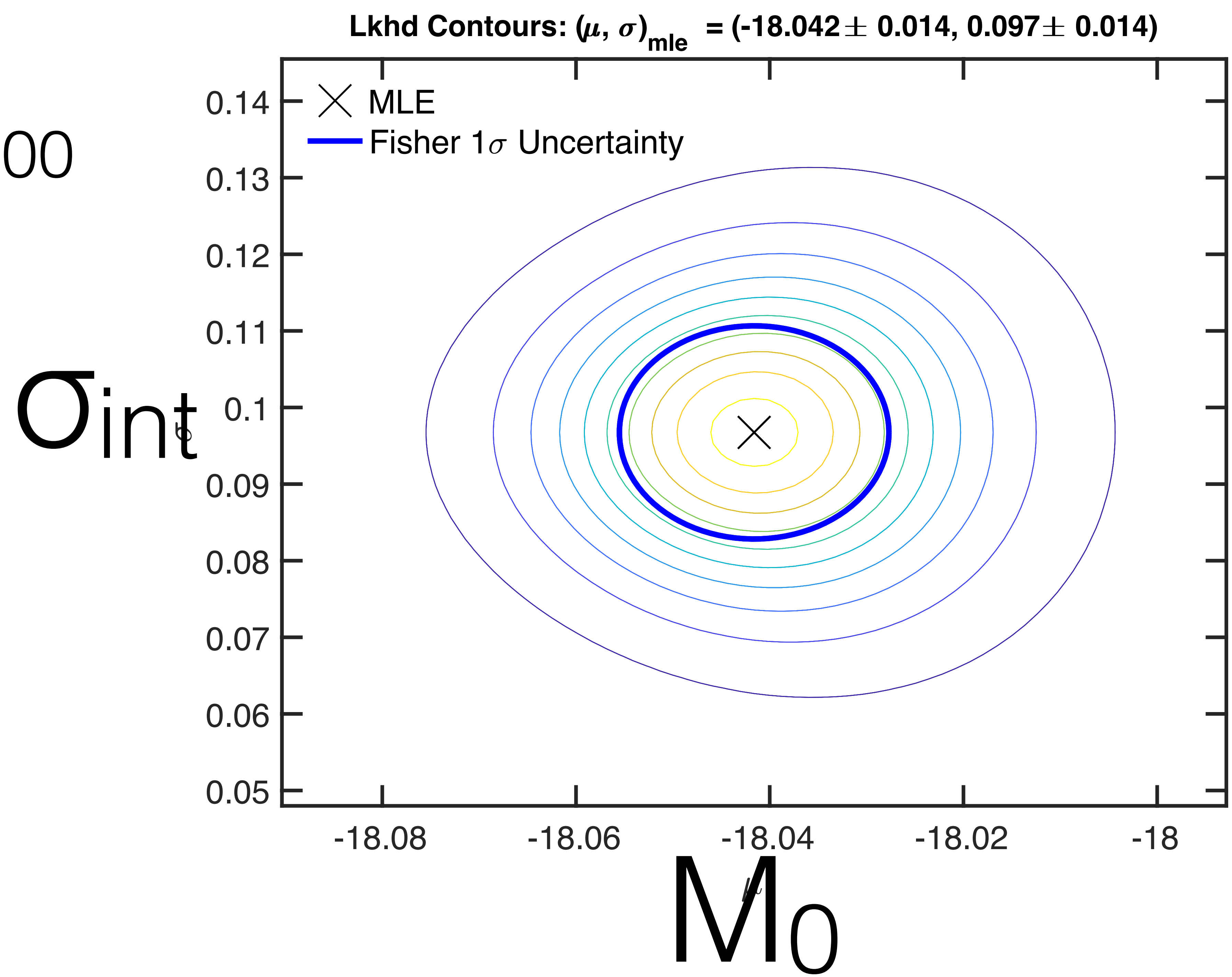
Want to Calibrate SN Ia (N=100) determine M_0, σ_{int}



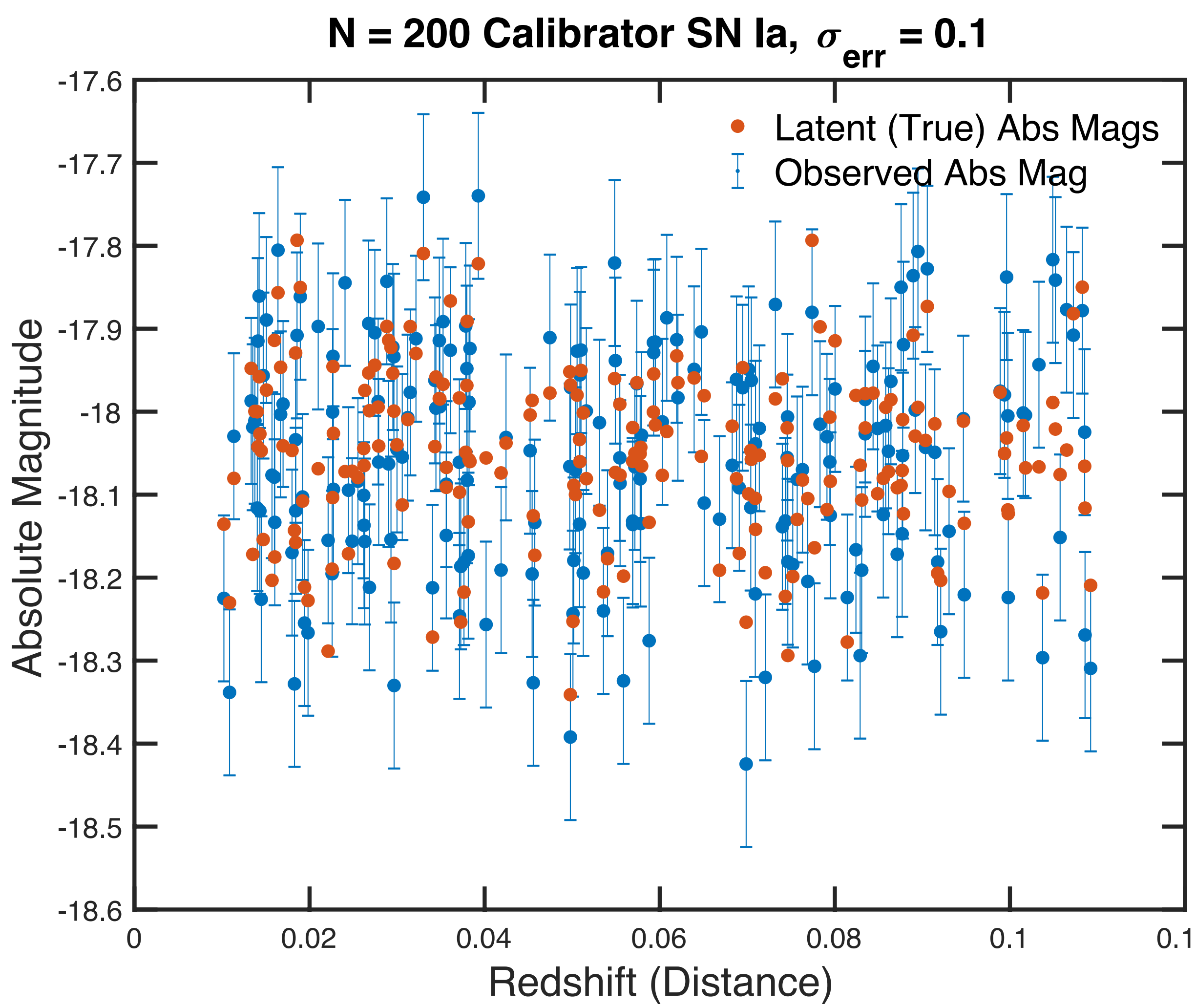


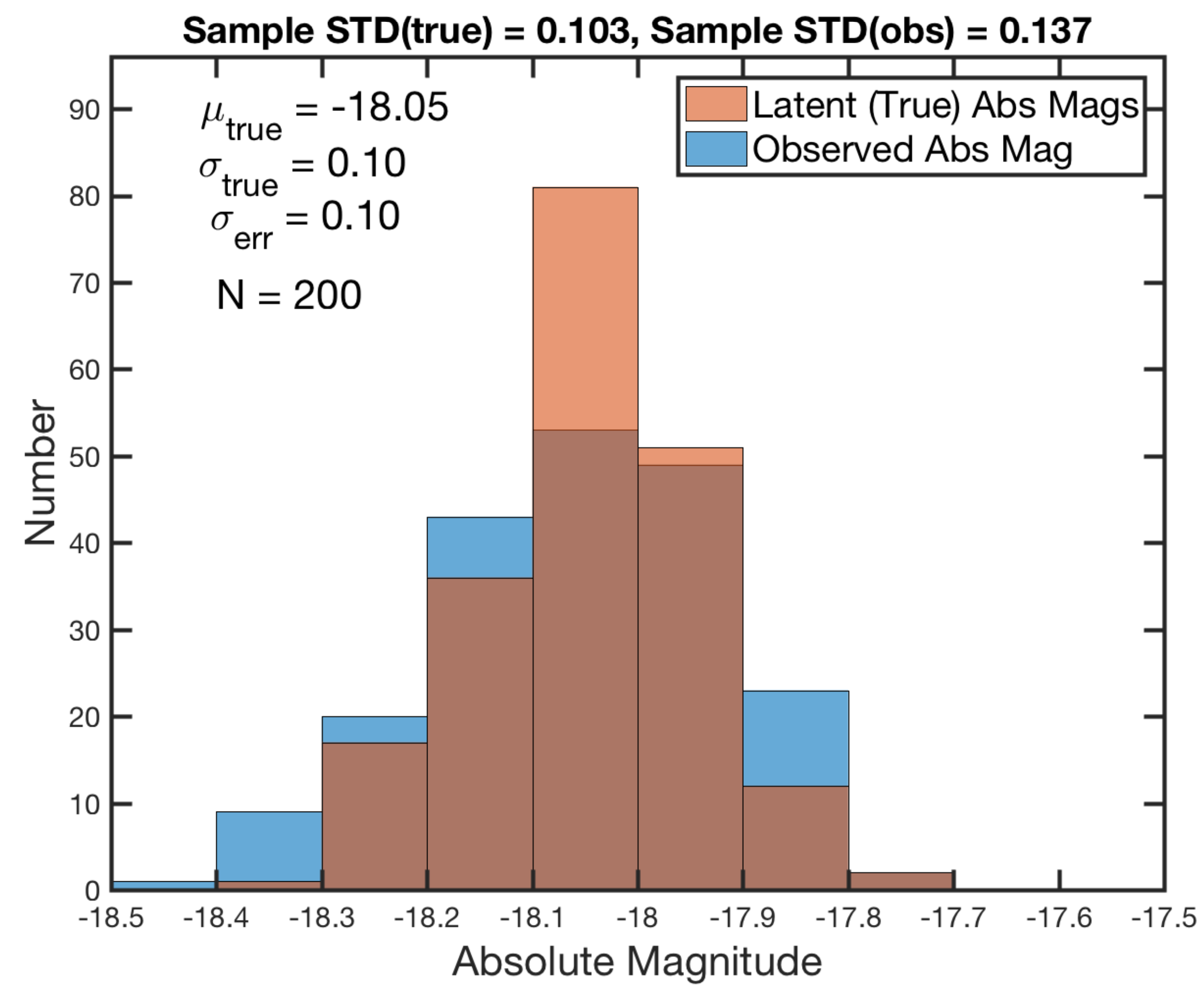
Maximum Likelihood with measurement error

N = 100



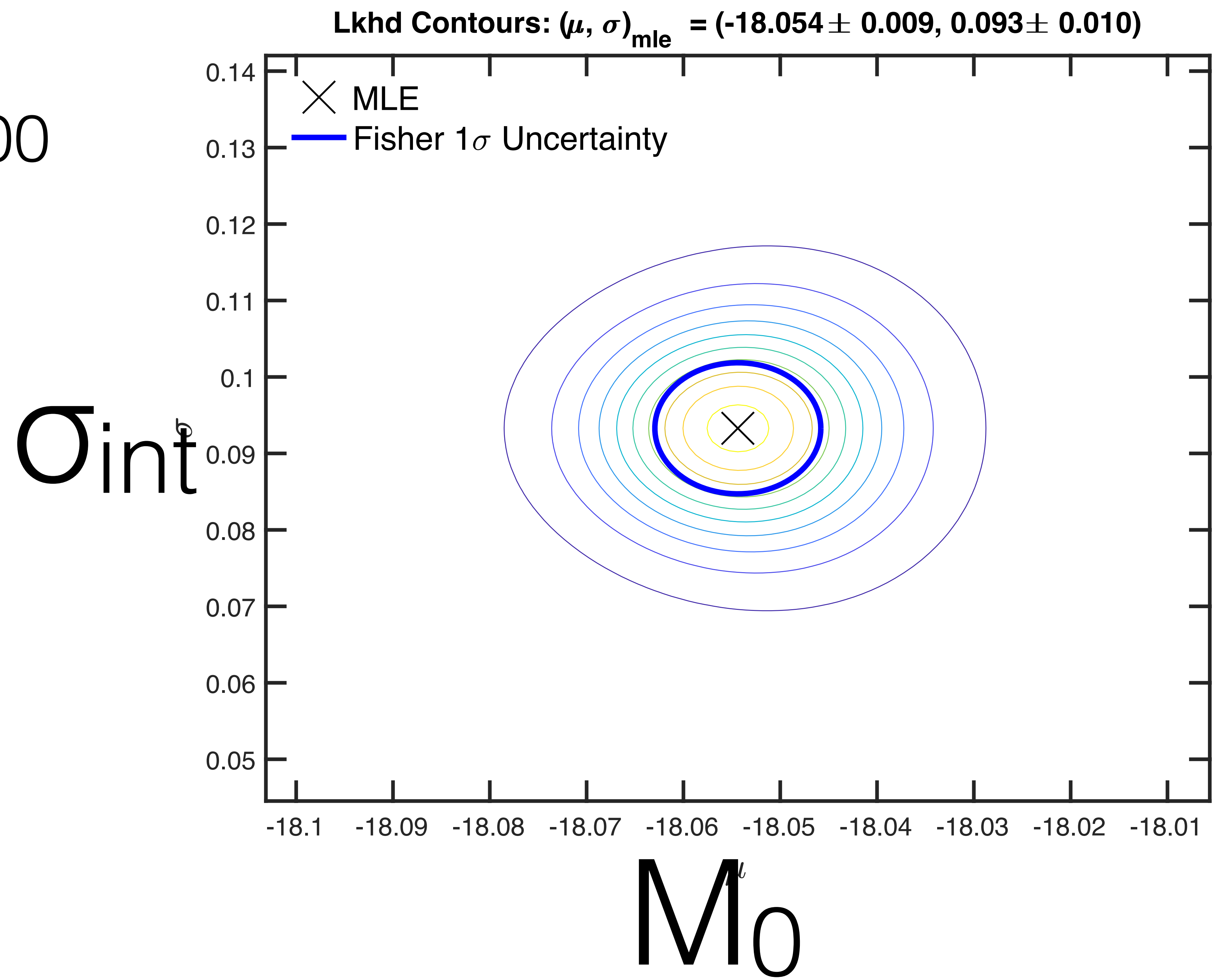
Want to Calibrate SN Ia (N=200) determine M_0, σ_{int}



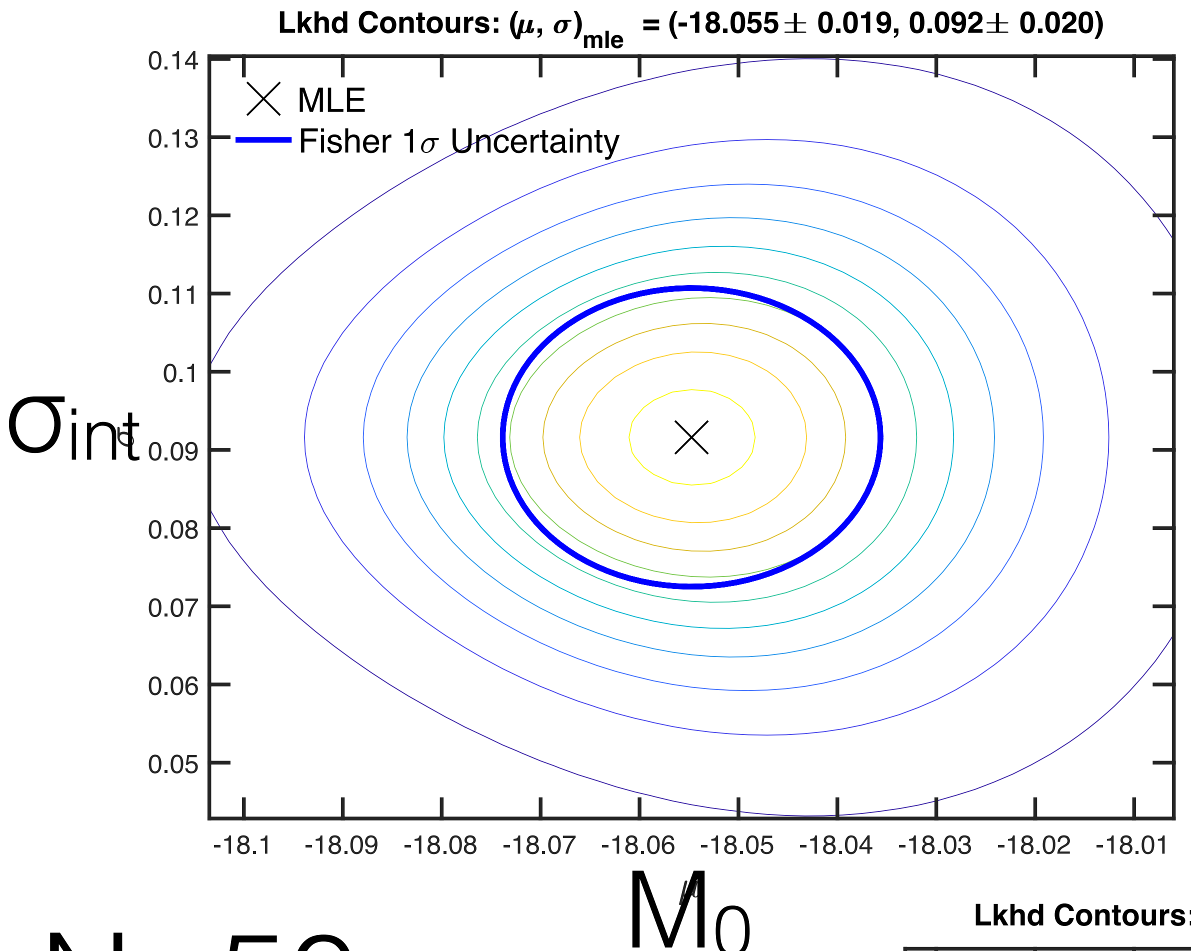


Maximum Likelihood with measurement error

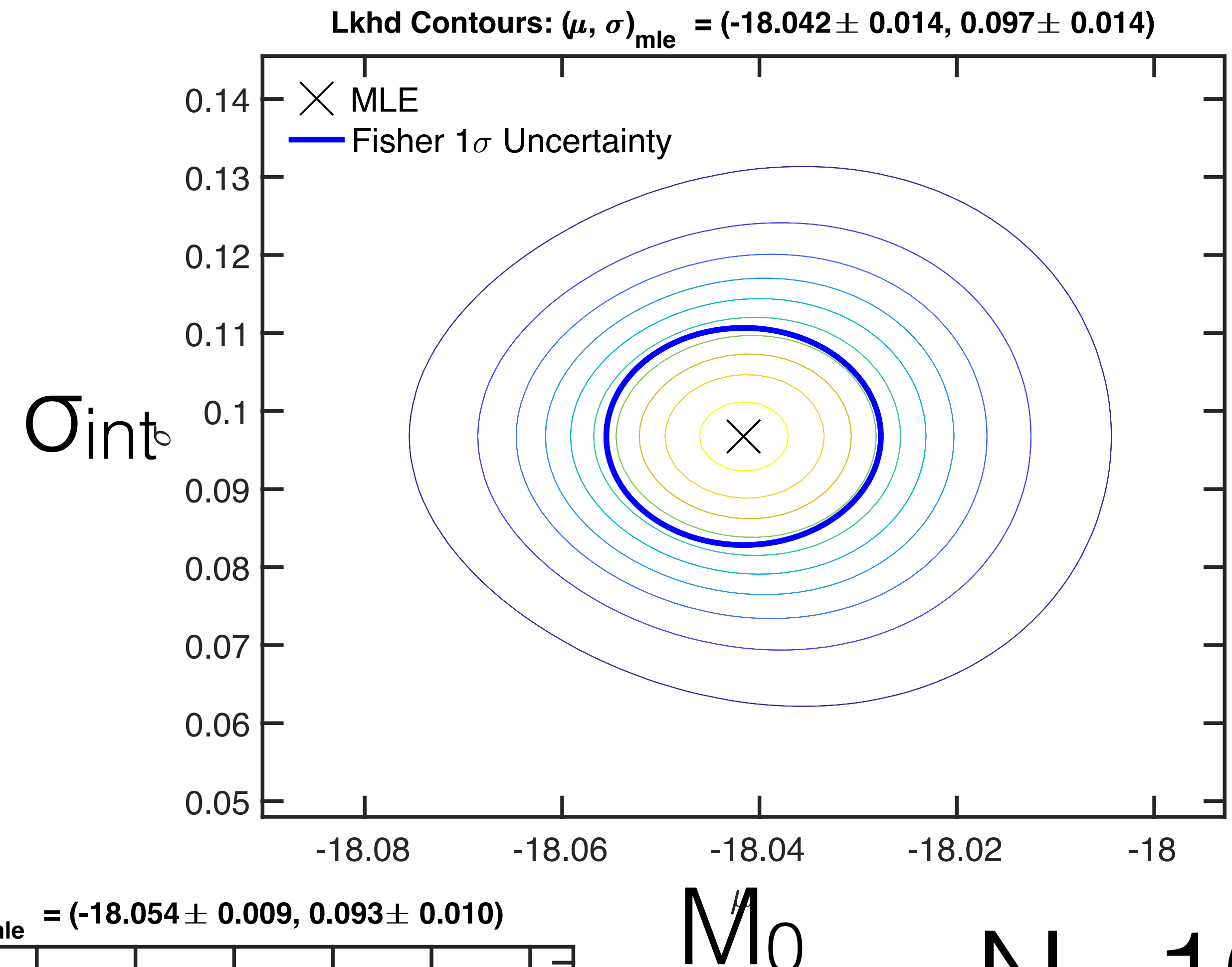
N = 200



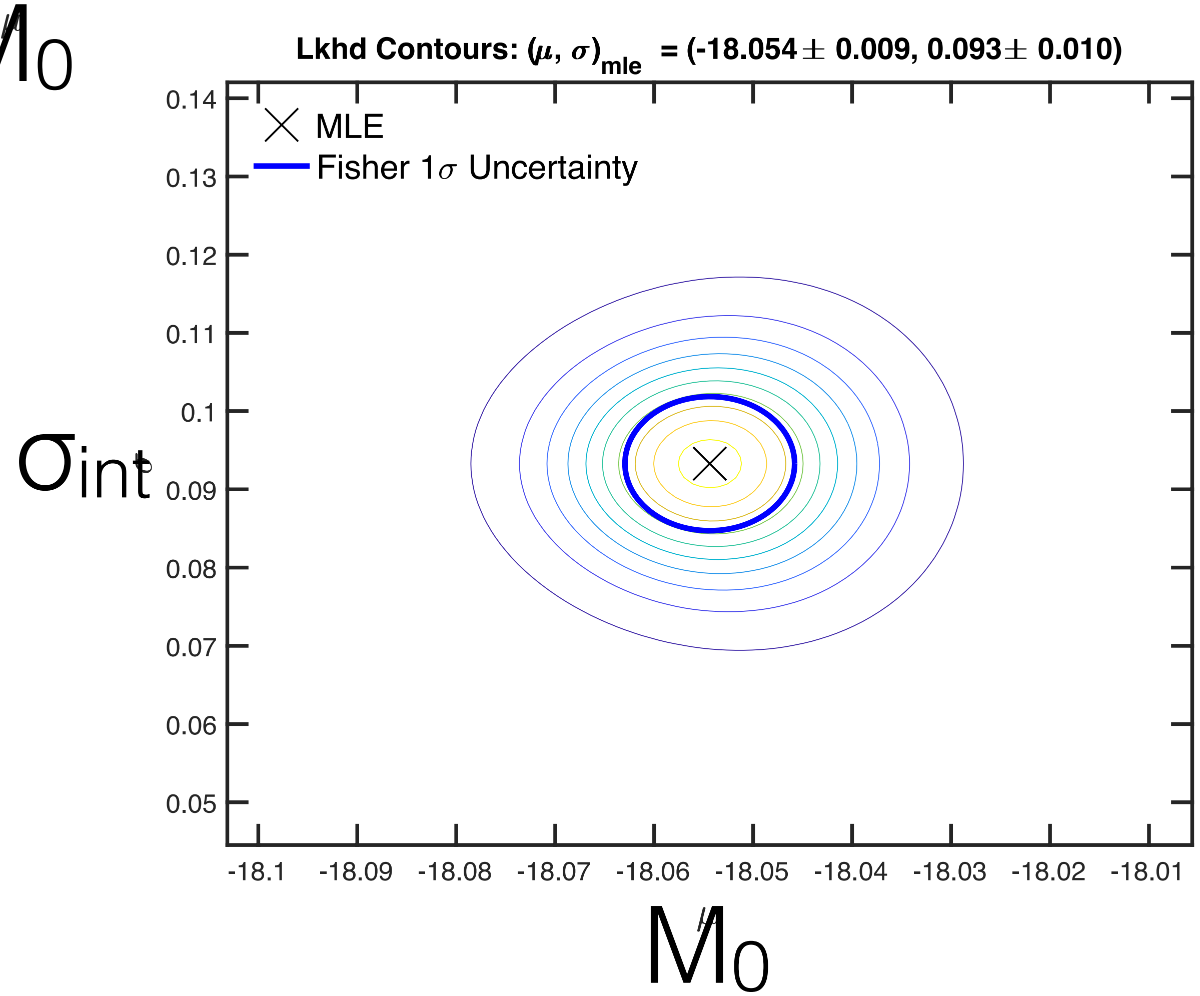
Constraints vs. sample size



N=50

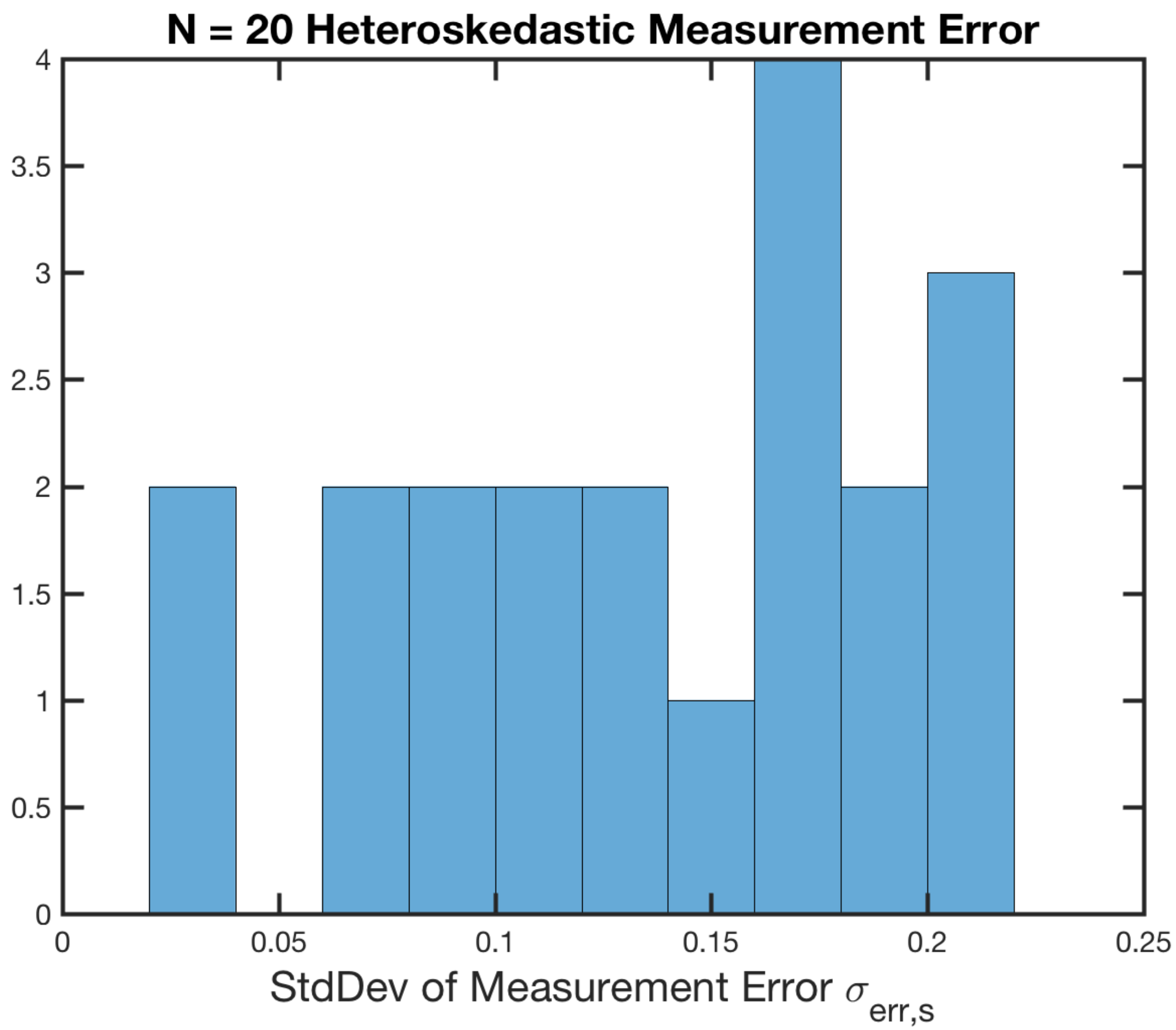


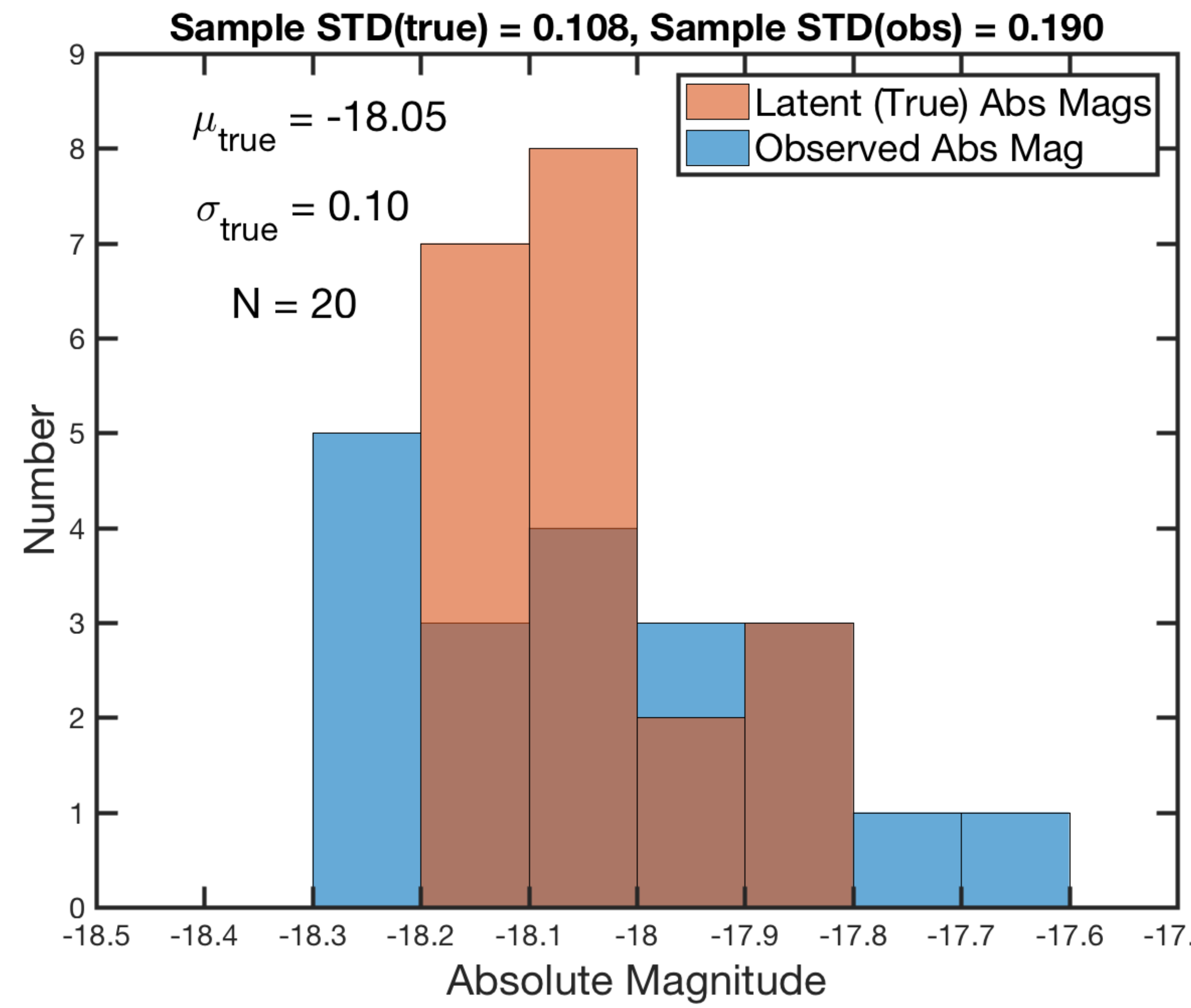
N=100



N=200

Maximum Likelihood with heteroskedastic measurement error with std devs σ_{err} = 0.01 to 0.21

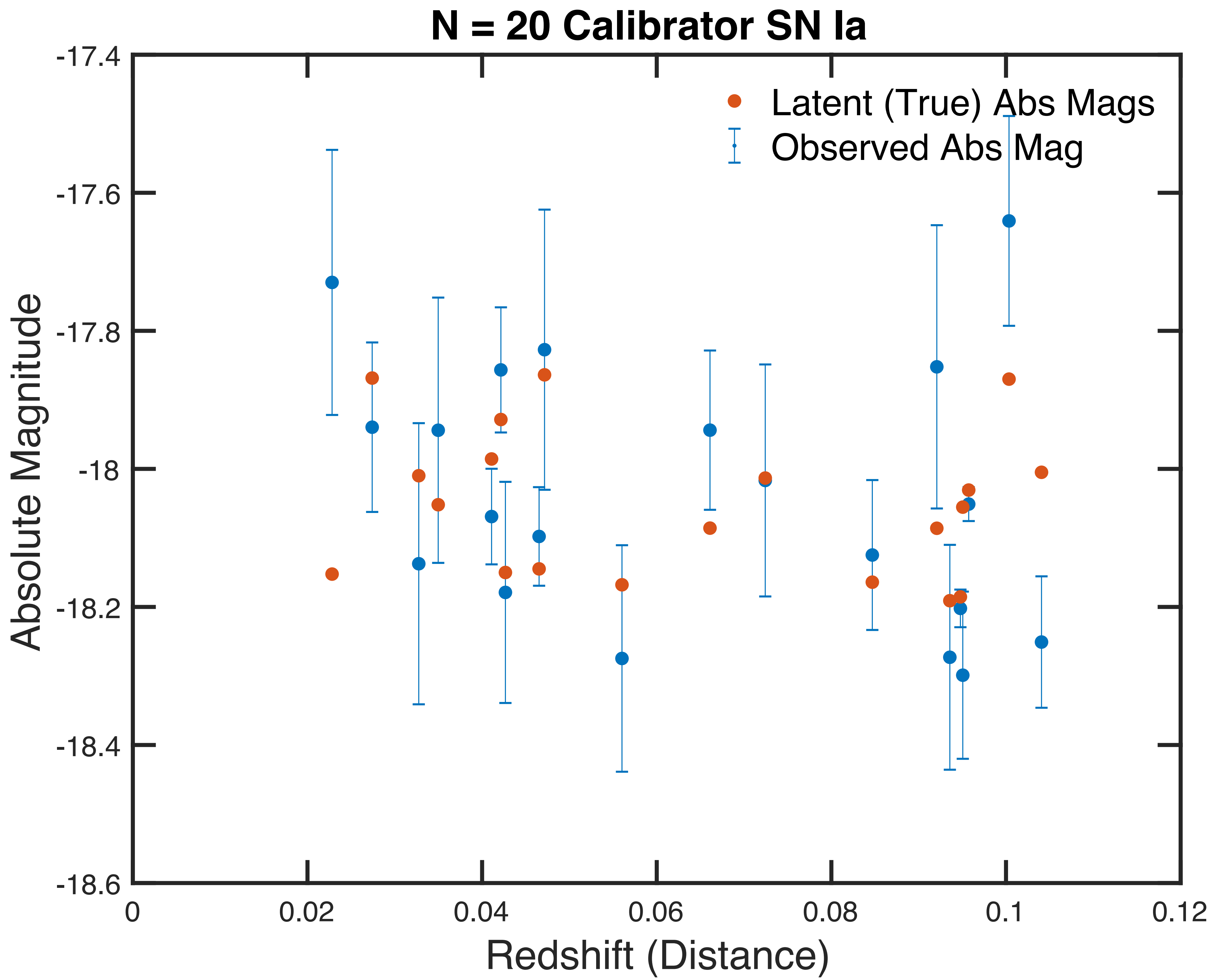




N = 20

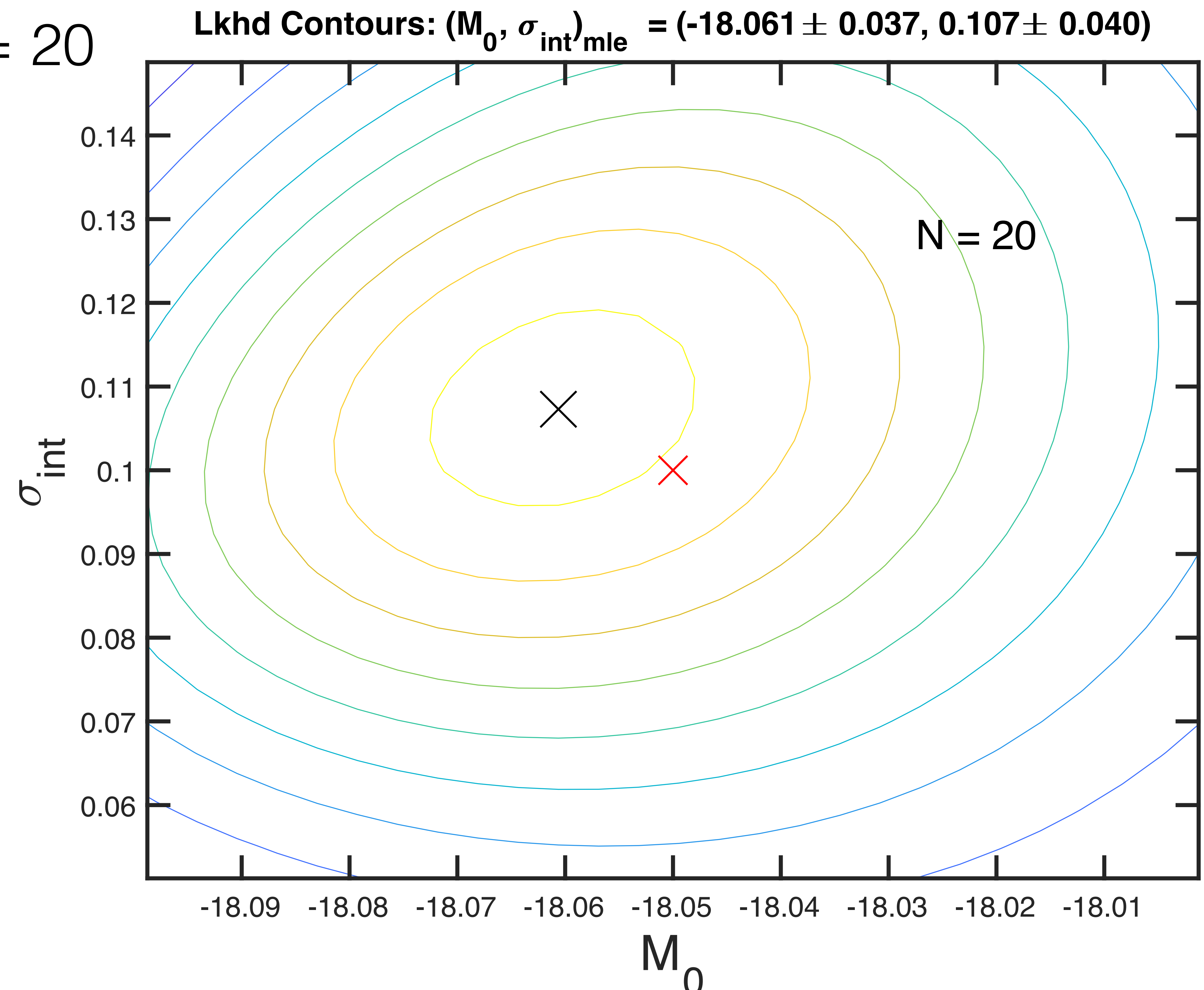
Maximum Likelihood with heteroskedastic measurement error with std devs σ_{err} = 0.01 to 0.21

N = 20

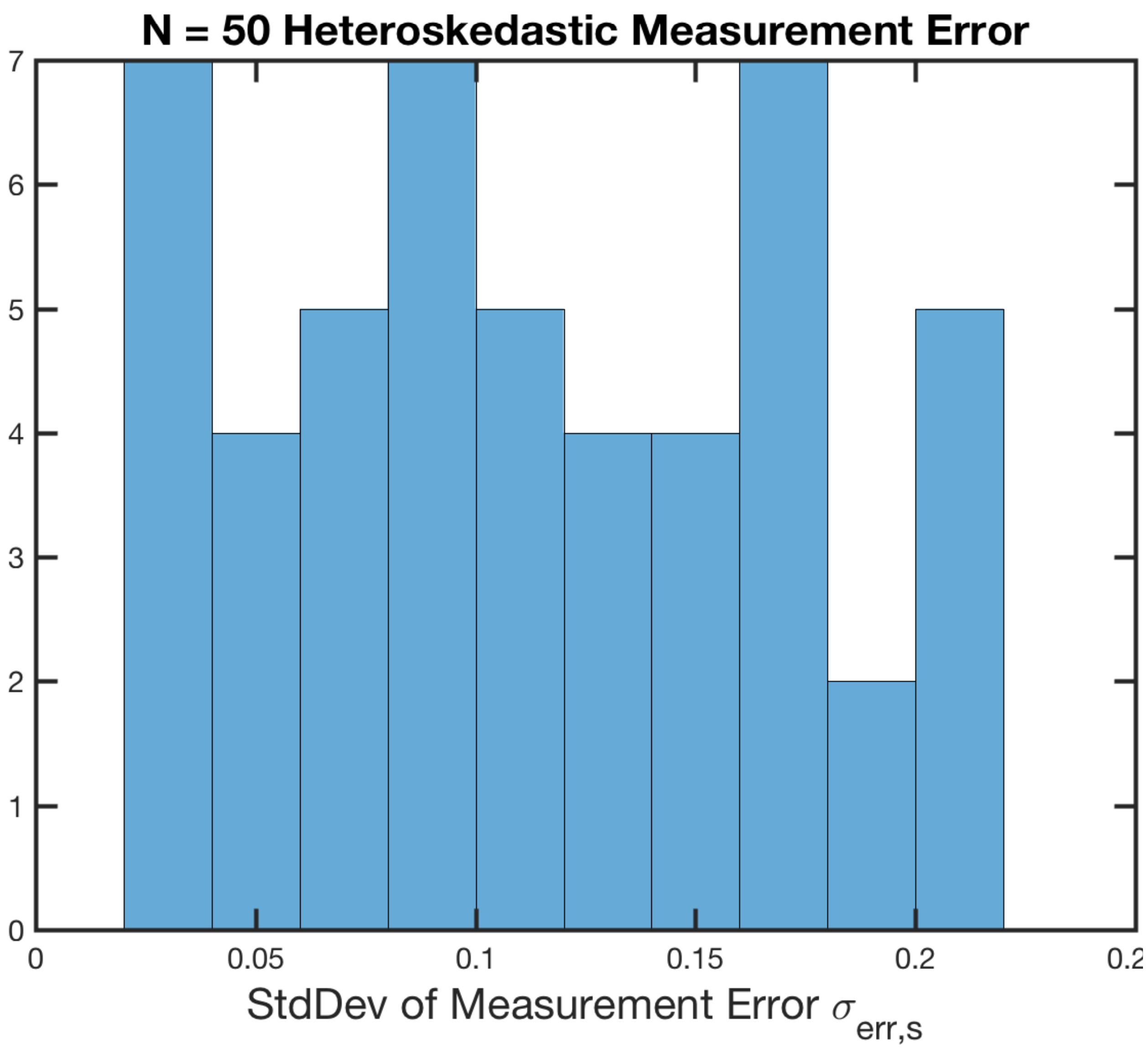


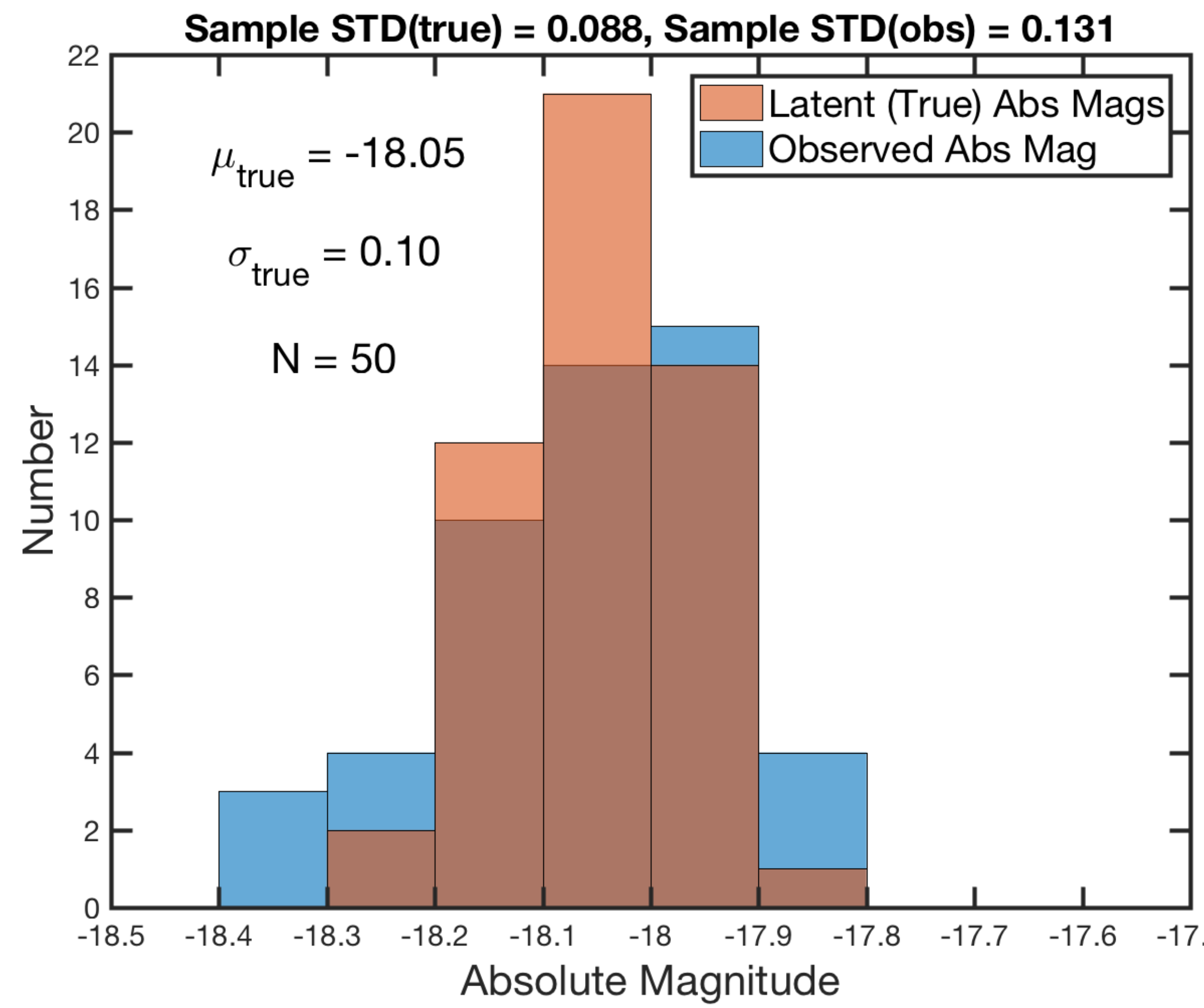
Maximum Likelihood with heteroskedastic measurement error with std devs σ_{err} = 0.01 to 0.21

N = 20



Maximum Likelihood with heteroskedastic measurement error with std devs σ_{err} = 0.01 to 0.21

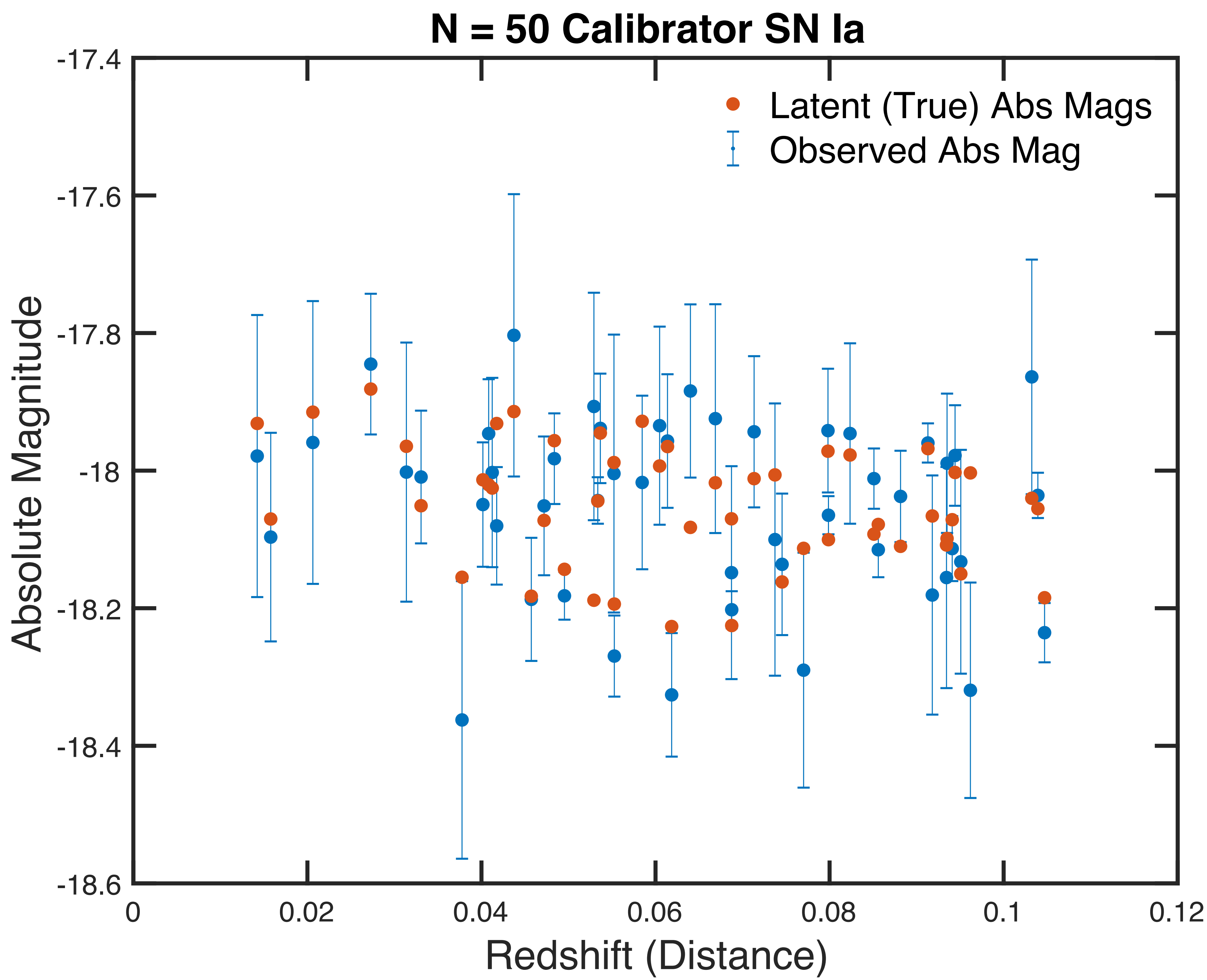




N = 50

Maximum Likelihood with heteroskedastic measurement error with std devs σ_{err} = 0.01 to 0.21

N = 50



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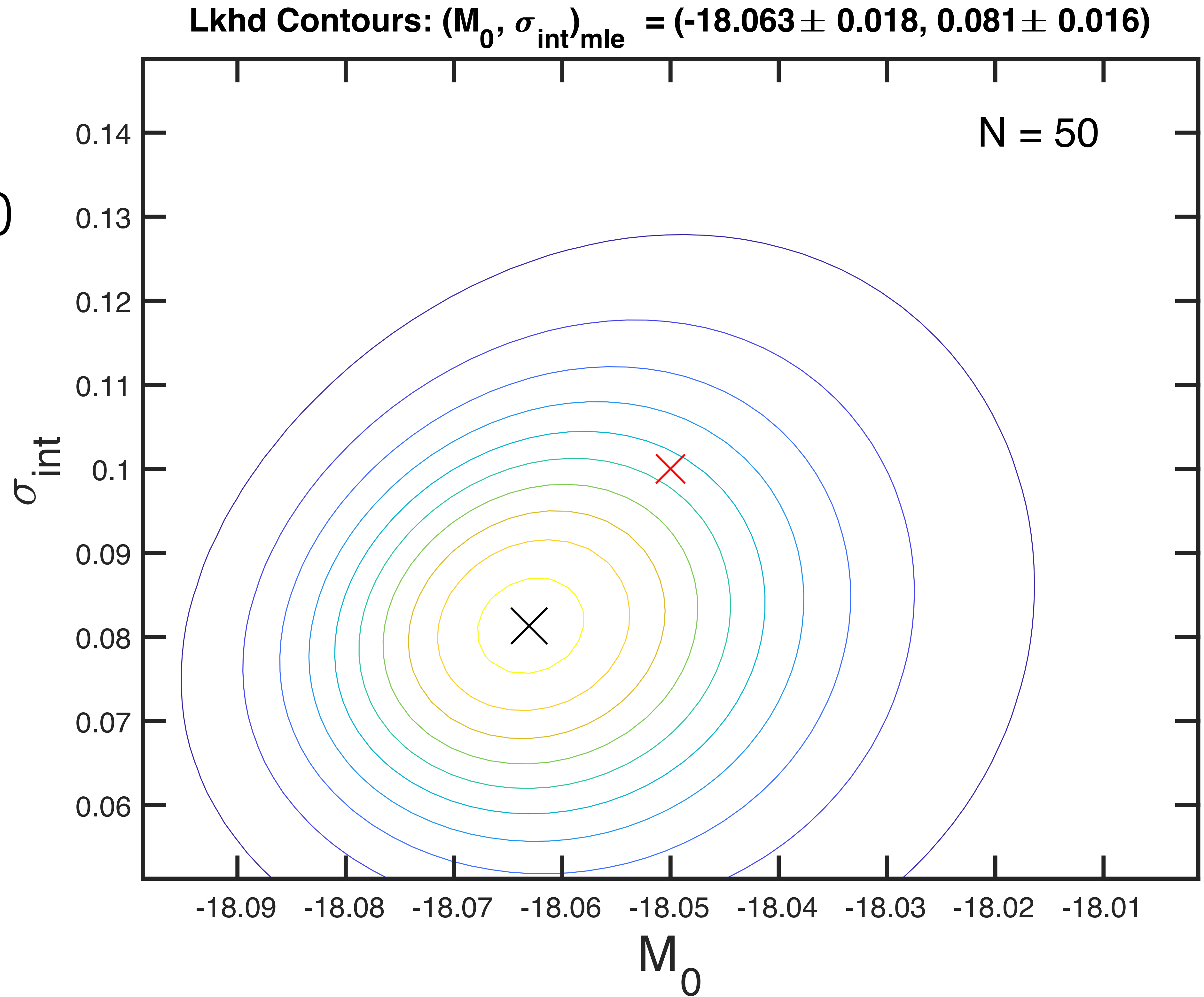

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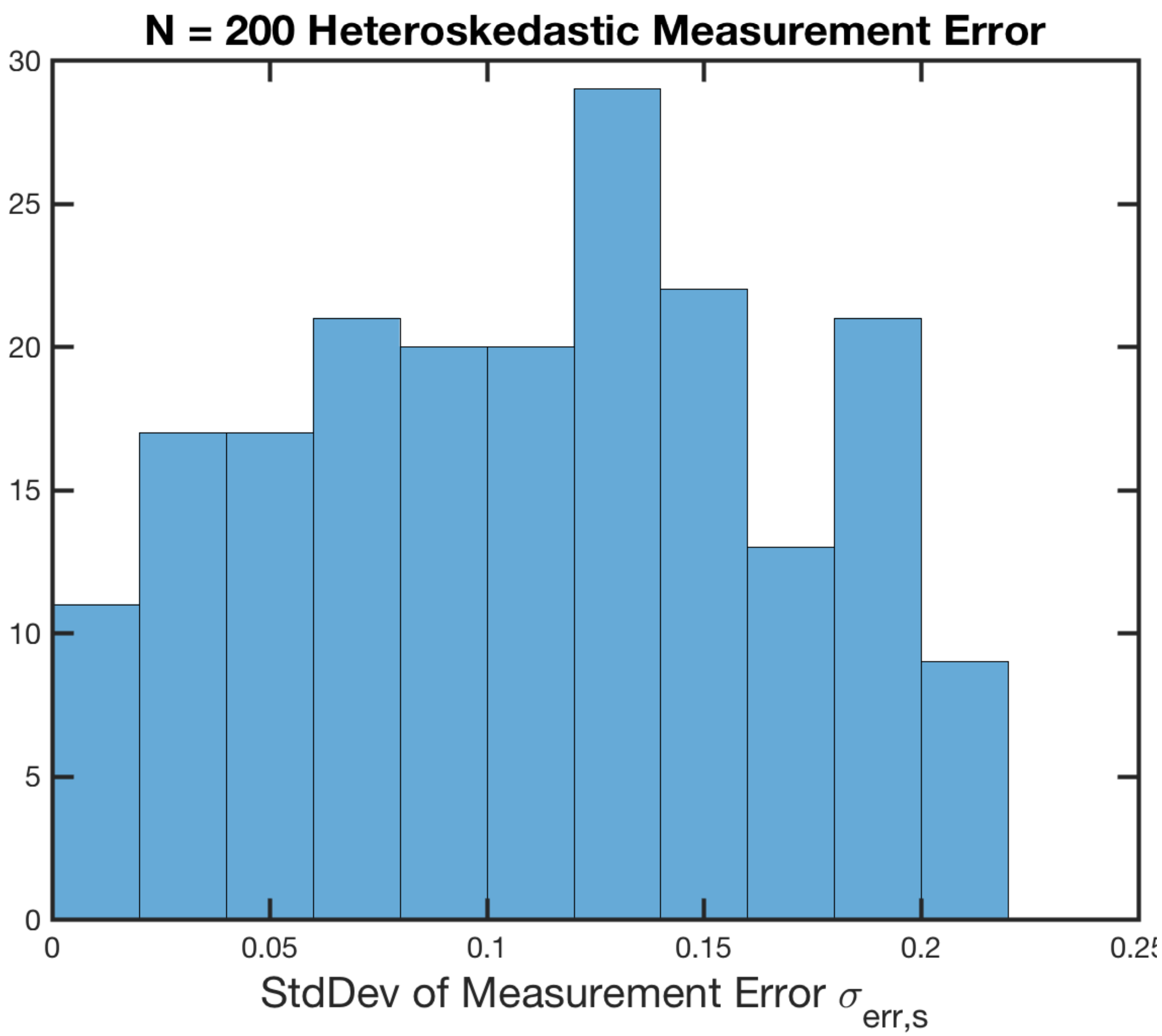

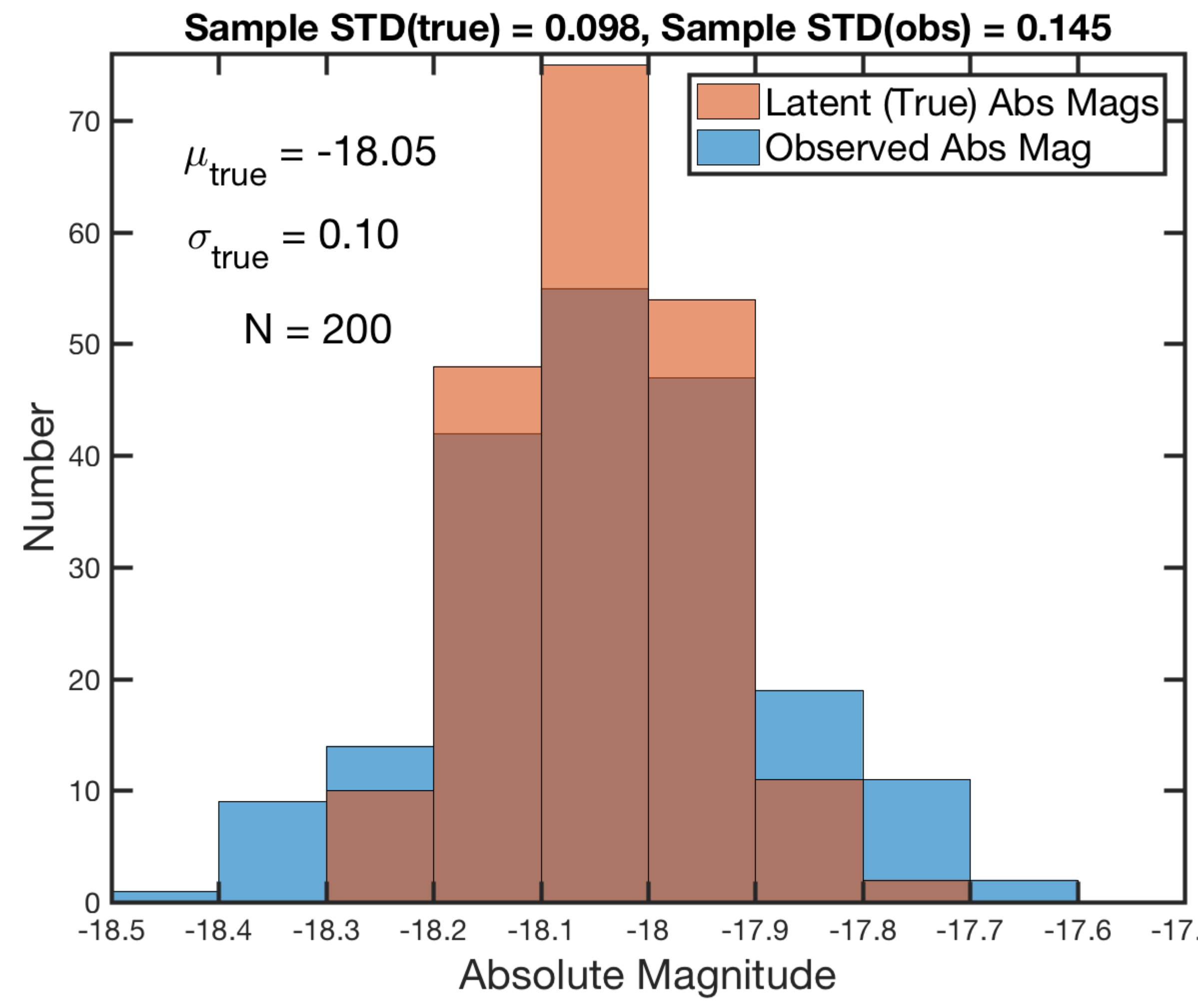

N = 200

Maximum Likelihood with heteroskedastic measurement error with std devs σ_{err} = 0.01 to 0.21

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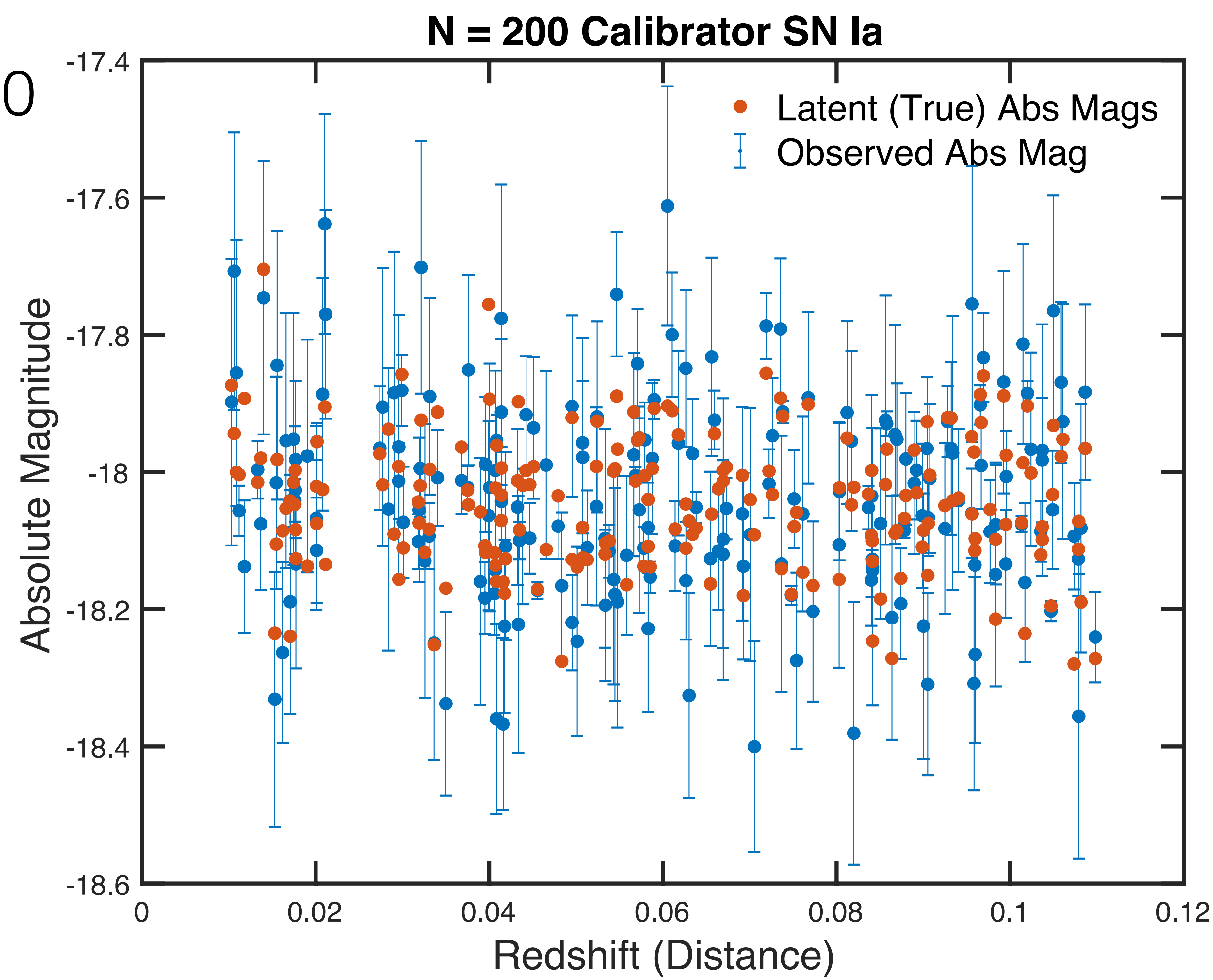

Maximum Likelihood with heteroskedastic measurement error with std devs σ_{err} = 0.01 to 0.21

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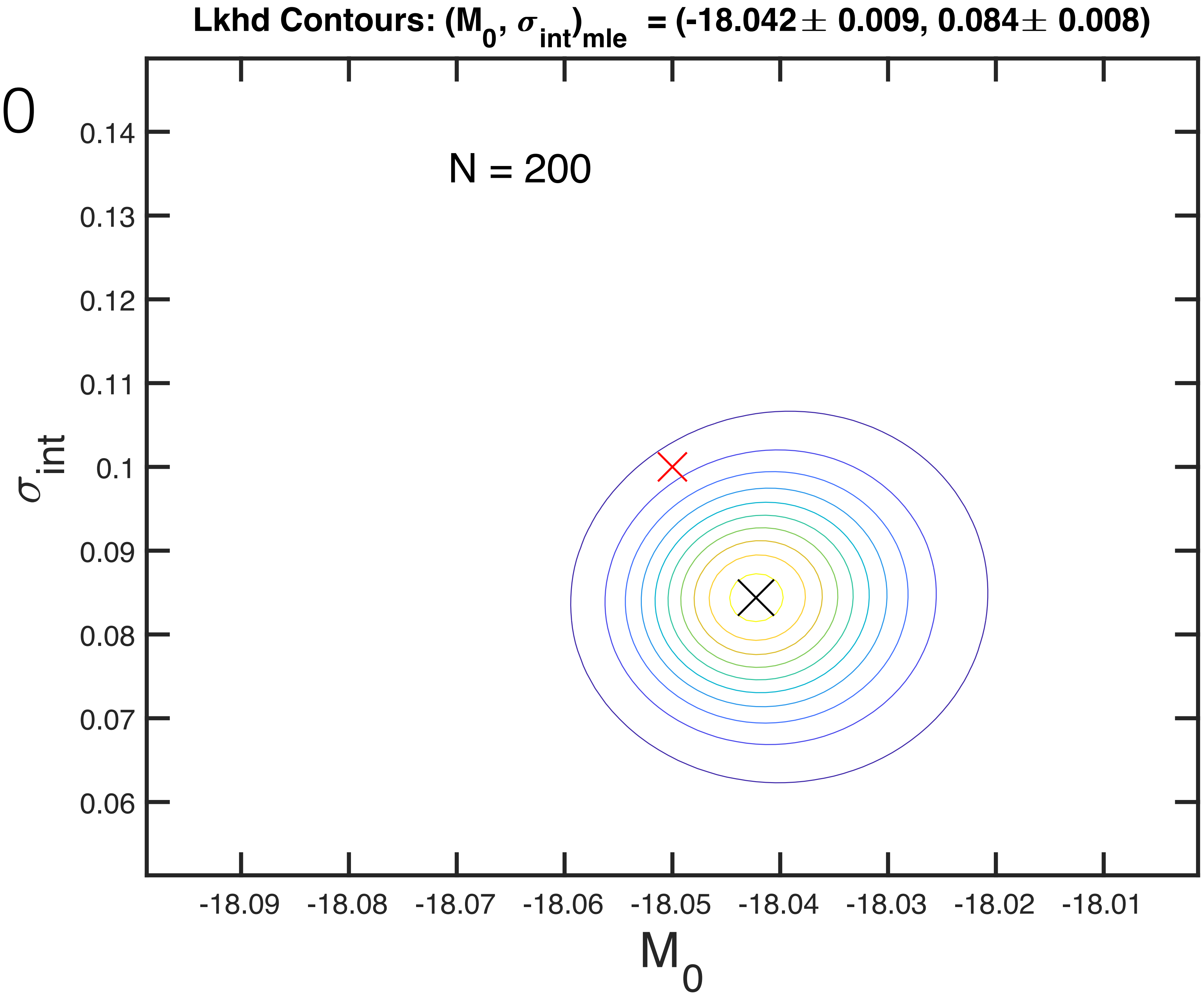
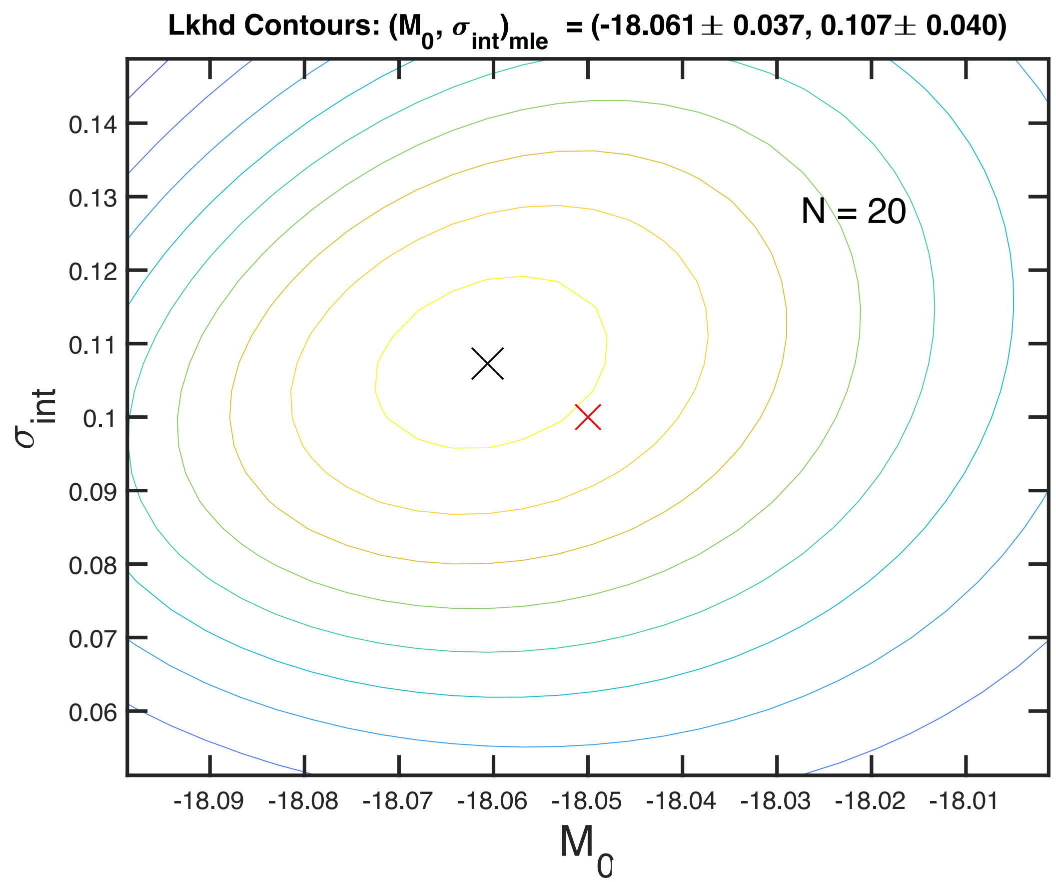
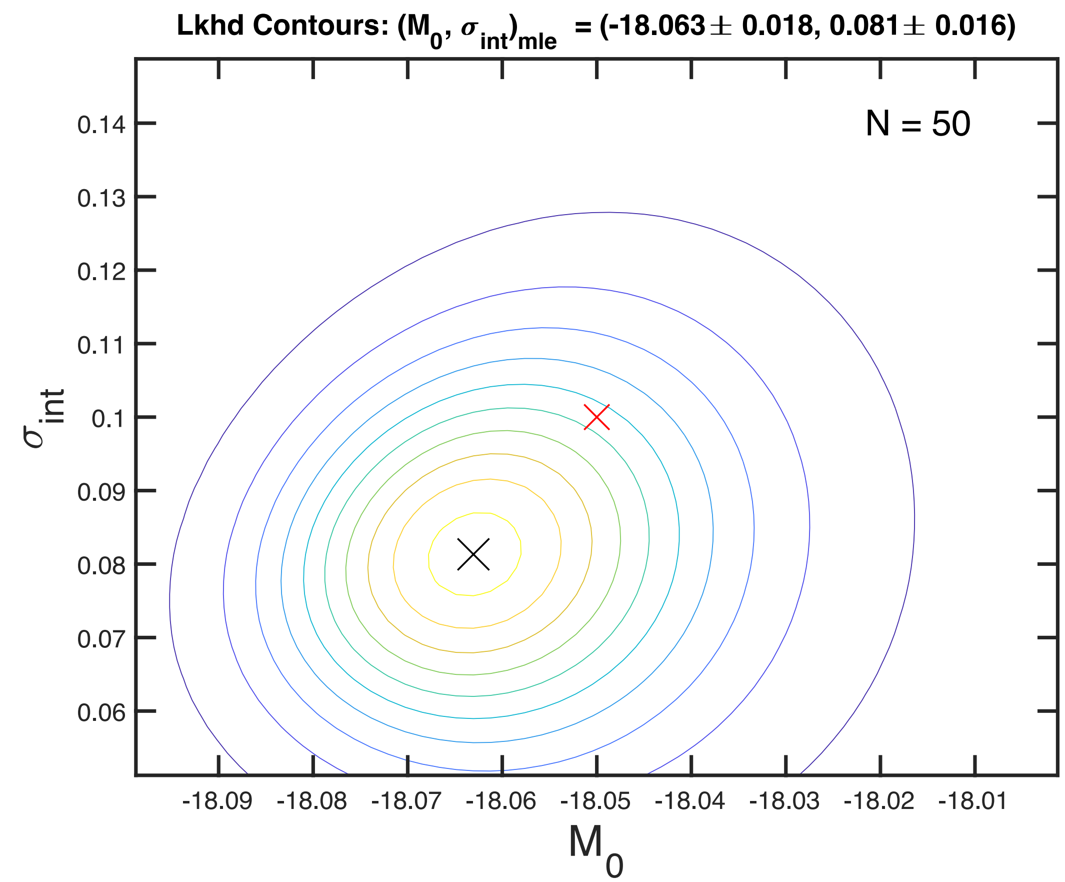


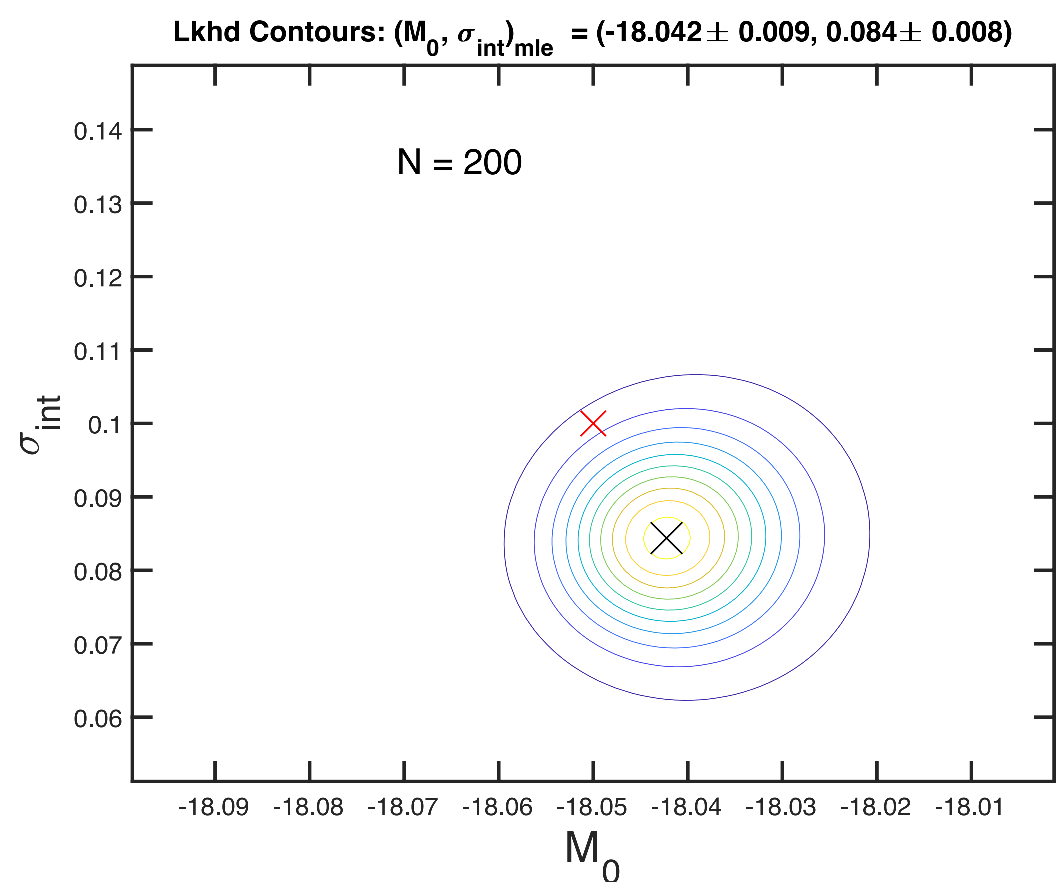
Constraints vs. sample size





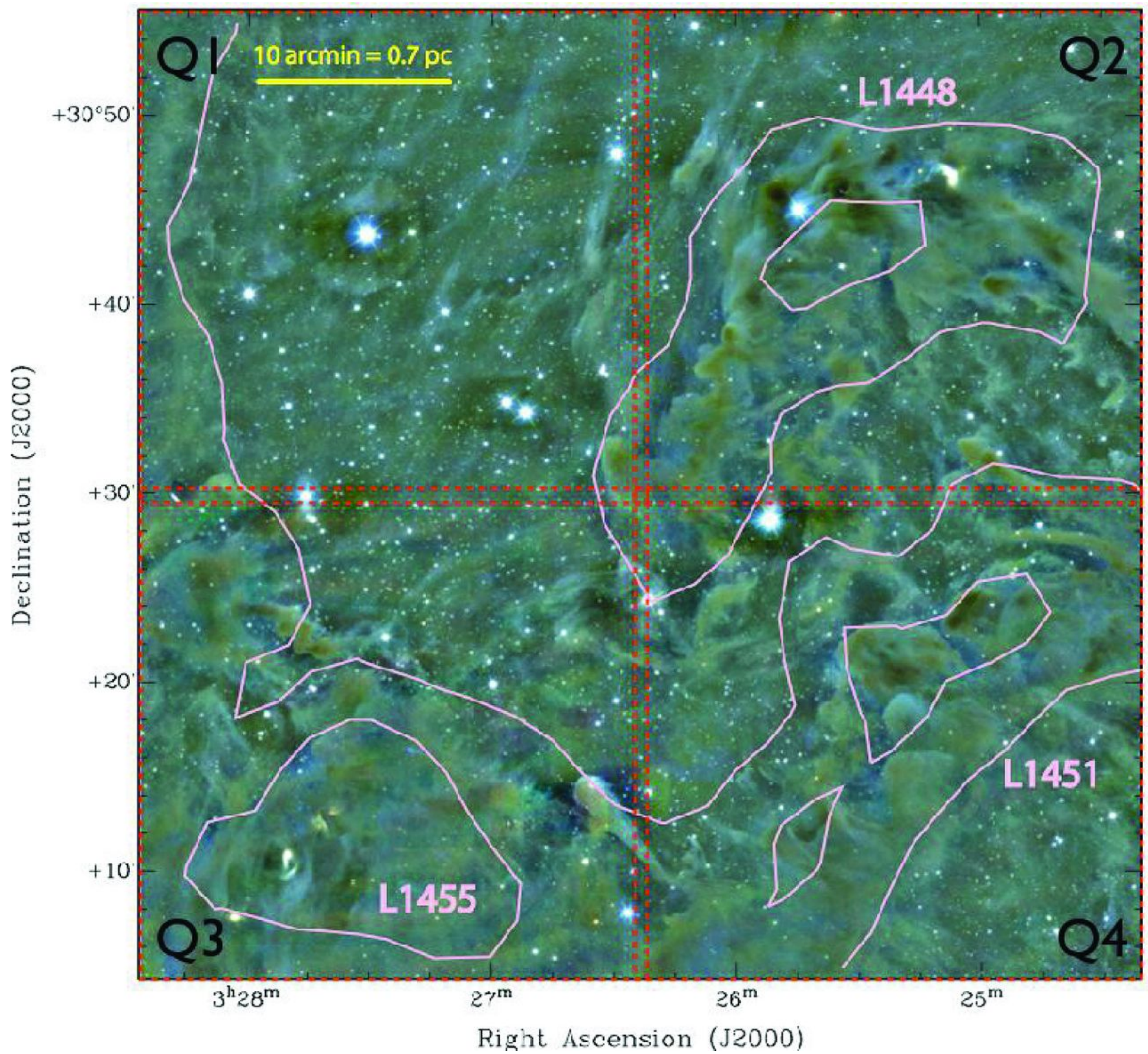
N=20

N=50

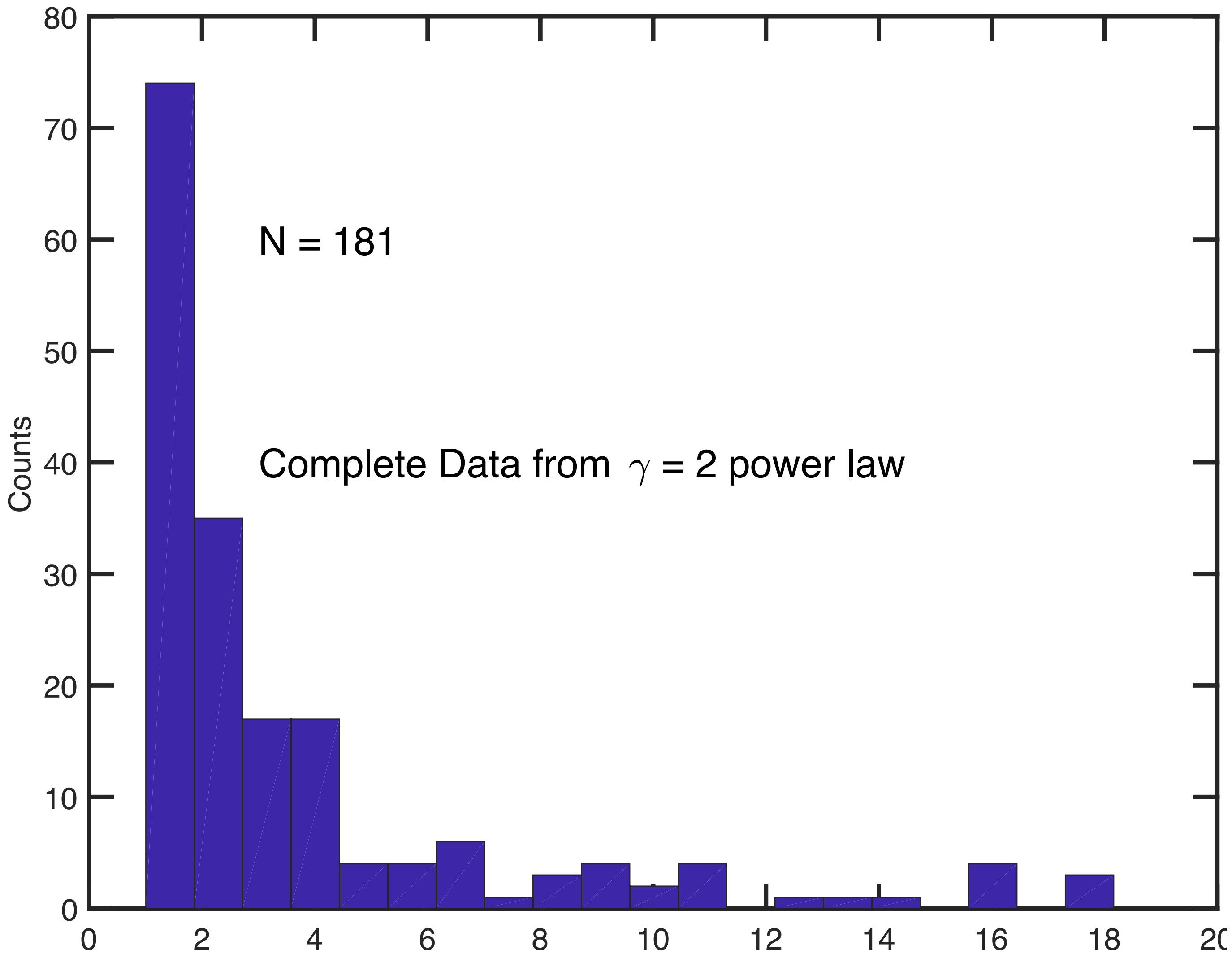


N=200

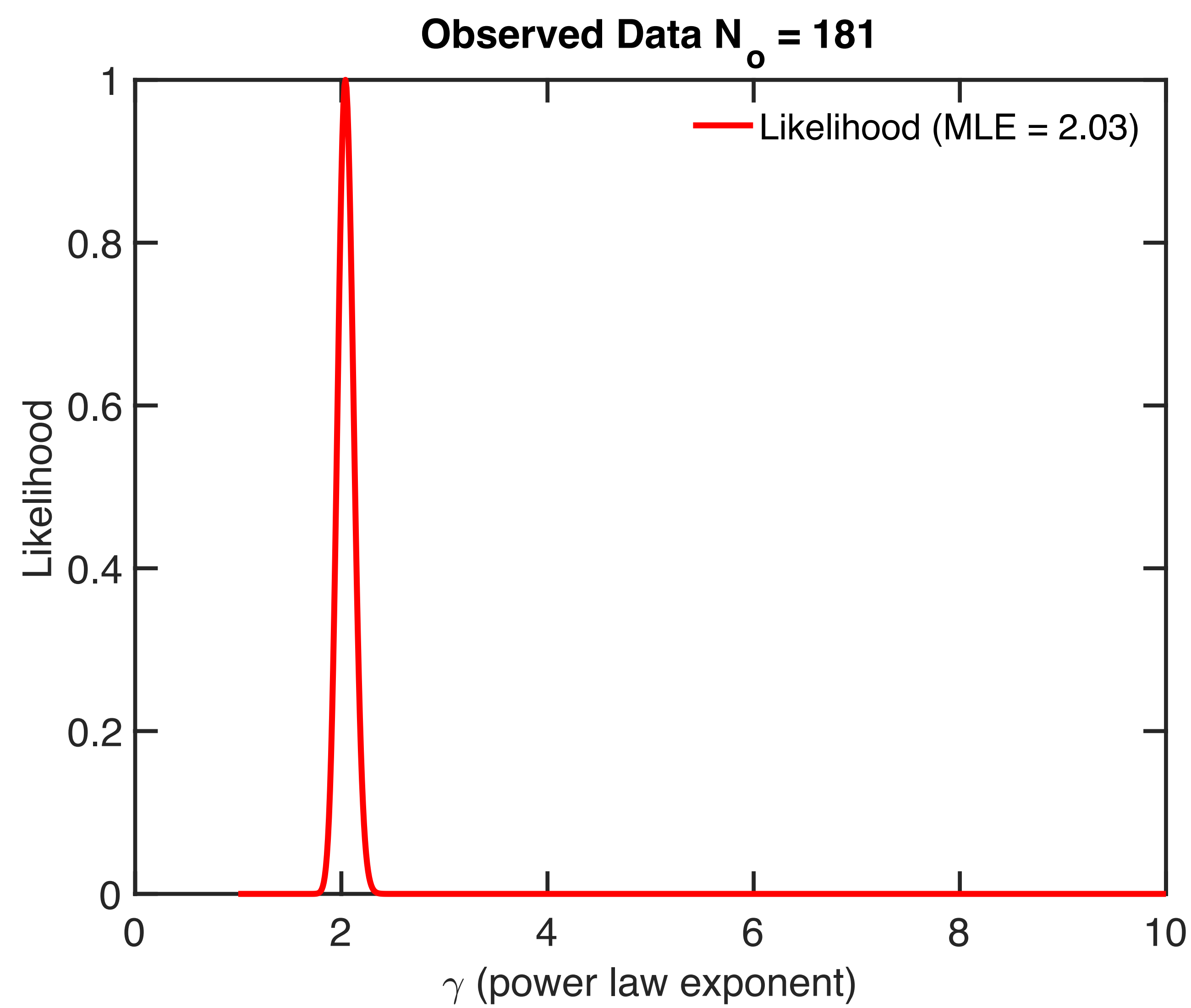
Star Formation in Perseus



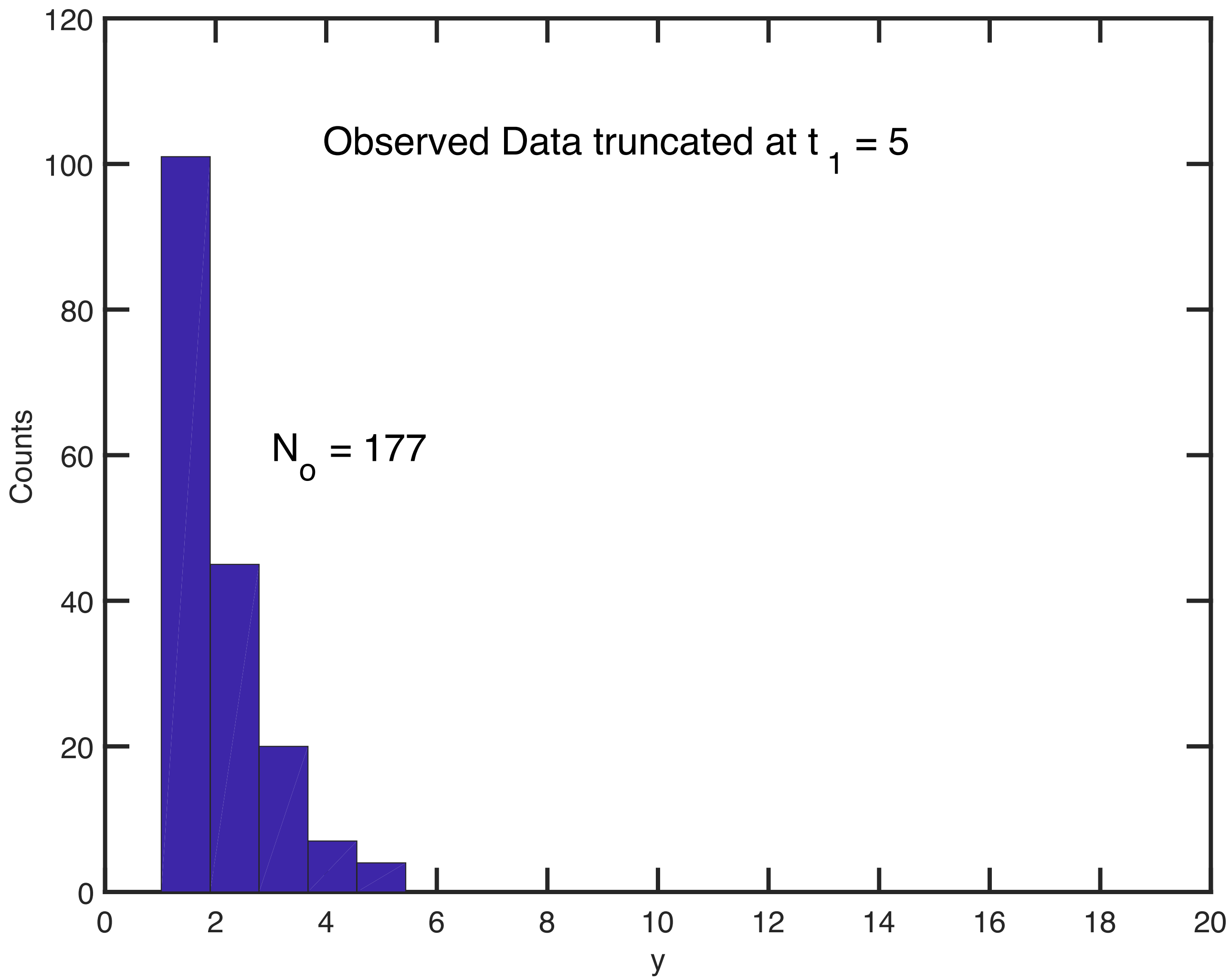
Inference of Stellar Mass Function
$P(M) \propto M^{(-\boldsymbol{\gamma})}$

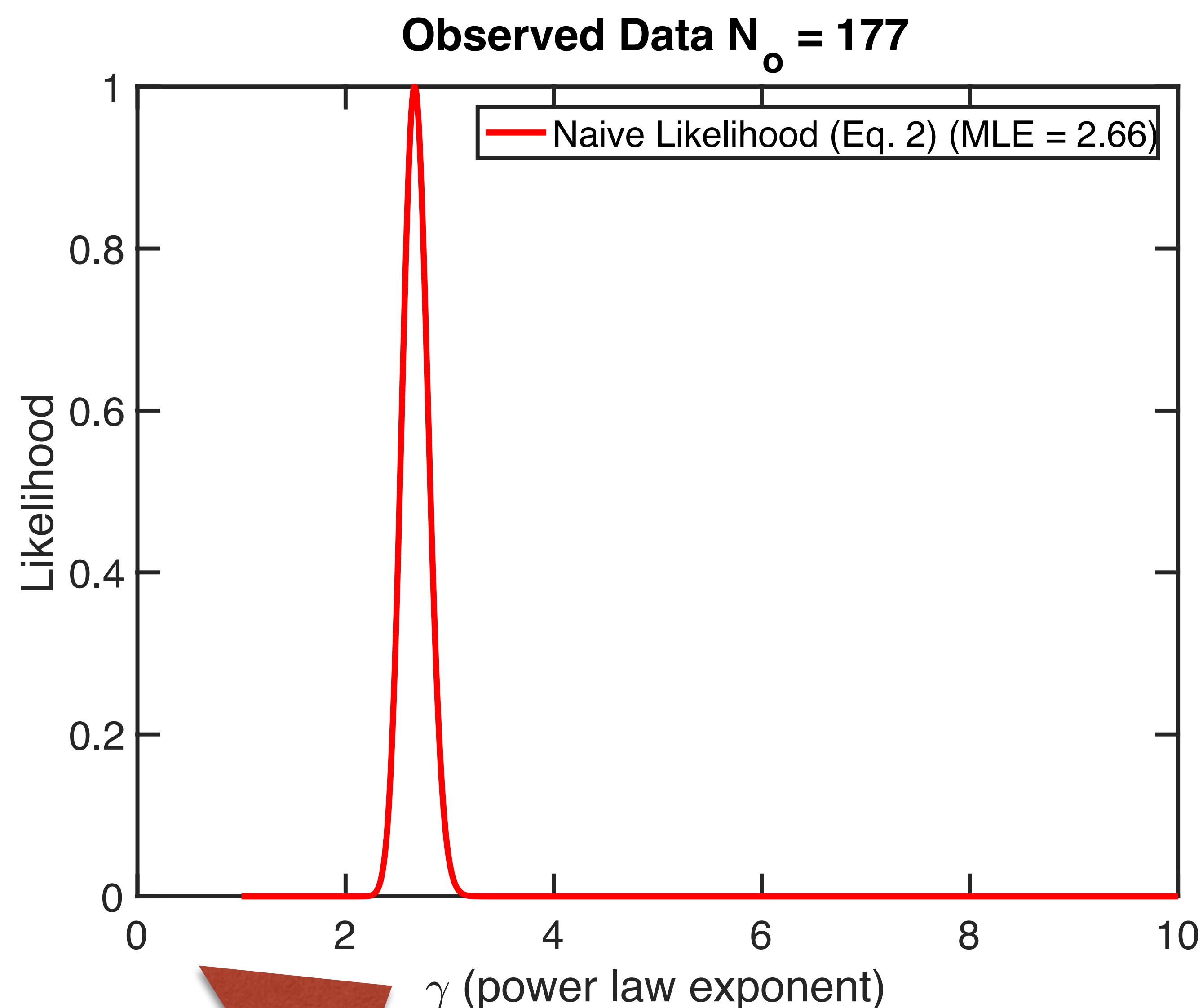


Mass



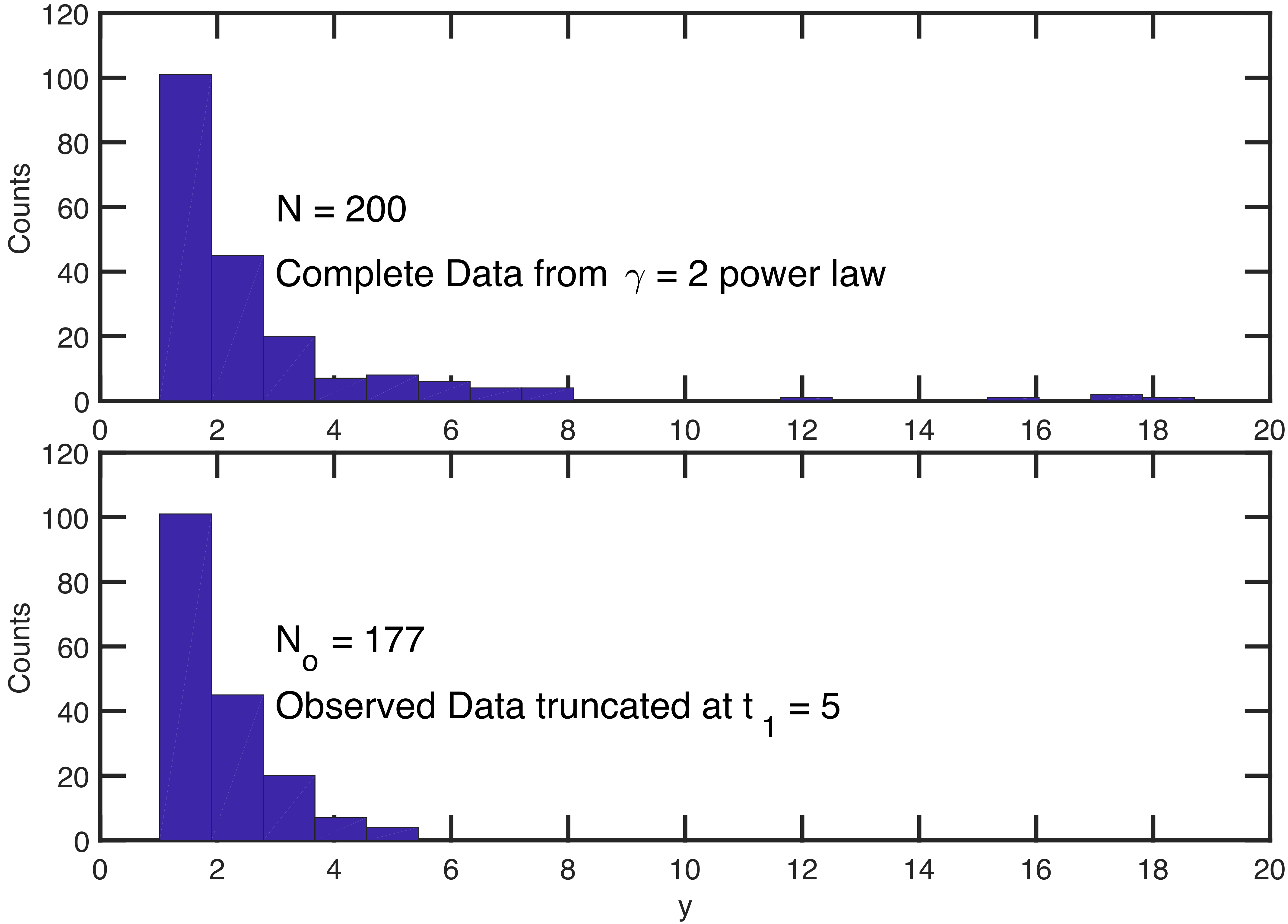
Selection Effect (Truncation)





MLE Biased!

Stellar Mass Function Inference with Selection Effect: Complete Data vs. Truncated Data



Stellar Mass Function Inference with Selection Effect: Modified Likelihood Function