Cosmology in the Multi-messenger Era

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2nd year Examination, 10th Oct 2019

Outline

- Introduction and background
- Motivation, basic idea of my main project
- Methodology and results
- A parallel project
- Future perspective

Introduction

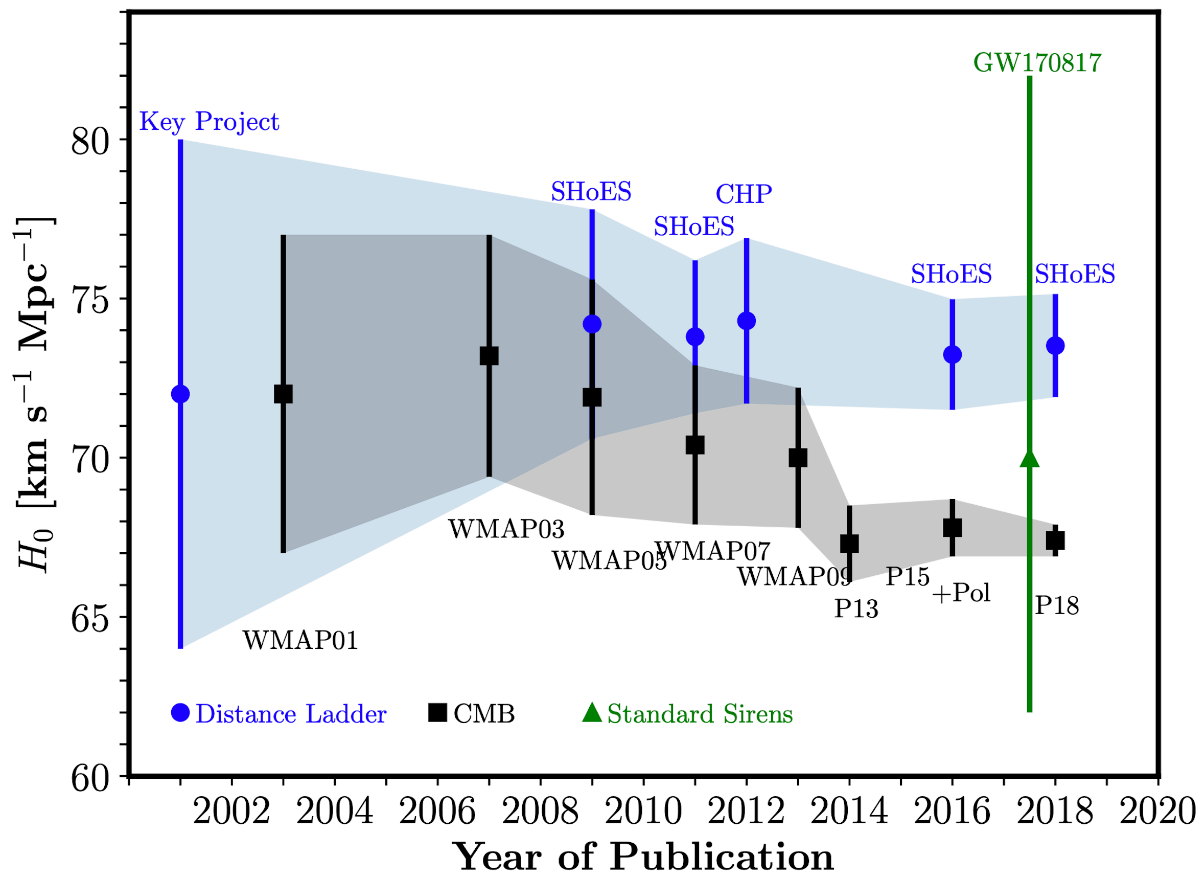
- Local distance ladder
  $H0 = 74.03 \pm 1.42 kms^{-1}Mpc^{-1}$
  (Riess et al, 2019)

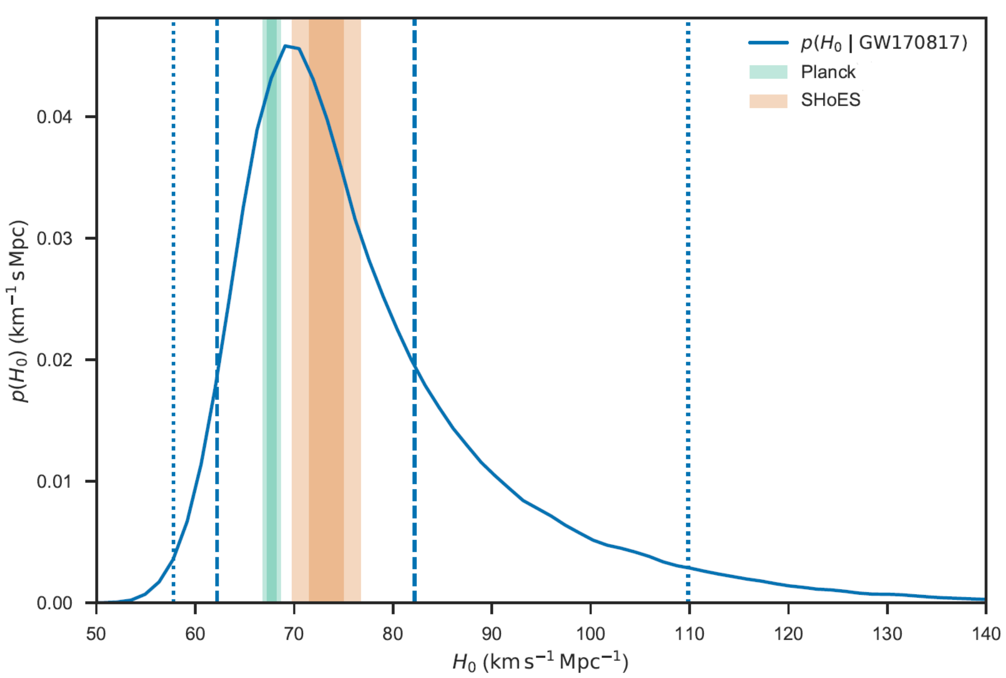
- CMB contraints
  $H0 = 67.36 \pm 0.54 kms^{-1}Mpc^{-1}$
  (Planck collaboration, 2018)

- Tension now 3.8 σ

- Gravitational Waves
  $H0 = 70.0^{+12.0}_{-8.0} kms^{-1}Mpc^{-1}$
  (LVC collaboration, 2017)

- Exciting opportunity:
  new physics or stronger concordance!!





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How fast is the Universe expanding? Cosmologists just got more confused

Hotly anticipated technique fails to resolve disagreement over speed of cosmic expansion — for now.

Davide Castelvecchi

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The Carnegie-Chicago Hubble Program. VIII. An Independent Determination of the Hubble Constant Based on the Tip of the Red Giant Branch

Wendy L. Freedman, Barry F. Madore, Dylan Hatt, Taylor J. Hoyt, In-Sung Jang, Rachael L. Beaton, Christopher R. Burns, Myung Gyoon Lee, Andrew J. Monson, Jillian R. Neeley, Mark M. Phillips, Jeffrey A. Rich, Mark Seibert

(Submitted on 12 Jul 2019)

We present a new and independent determination of the local value of the Hubble constant based on a calibration of the Tip of the Red Giant Branch (TRGB) applied to Type Ia supernovae (SNeIa). We find a value of Ho = 69.8 +/- 0.8 (+/-1.1\% stat) +/- 1.7 (+/-2.4\% sys) km/sec/Mpc. The TRGB method is both precise and accurate, and is parallel to, but independent of the Cepheid distance scale. Our value sits midway in the range defined by the current Hubble tension. It agrees at the 1.2-sigma level with that of the Planck 2018 estimate, and at the 1.7-sigma level with the SHoES measurement of Ho based on the Cepheid distance scale. The TRGB distances have been measured using deep Hubble Space Telescope (HST) Advanced Camera for Surveys (ACS) imaging of galaxy halos. The zero point of the TRGB calibration is set with a distance modulus to the Large Magellanic Cloud of 18.477 +/- 0.004 (stat) +/-0.020 (sys) mag, based on measurement of 20 late-type detached eclipsing binary (DEB) stars, combined with an HST parallax calibration of a 3.6 micron Cepheid Leavitt law based on Spitzer observations. We anchor the TRGB distances to galaxies that extend our measurement into the Hubble flow using the recently completed Carnegie Supernova Project I sample containing about 100 well-observed SNeIa. There are several advantages of halo TRGB distance measurements relative to Cepheid variables: these include low halo reddening, minimal effects of crowding or blending of the photometry, only a shallow (calibrated) sensitivity to metallicity in the I-band, and no need for multiple epochs of observations or concerns of different slopes with period. In addition, the host masses of our TRGB host-galaxy sample are higher on average than the Cepheid sample, better matching the range of host-galaxy masses in the CSP distant sample, and reducing potential systematic effects in the SNeIa measurements.

"This week is too much. Go home H0, you're drunk," tweeted Dan Scolnic,

a natureresearch journal

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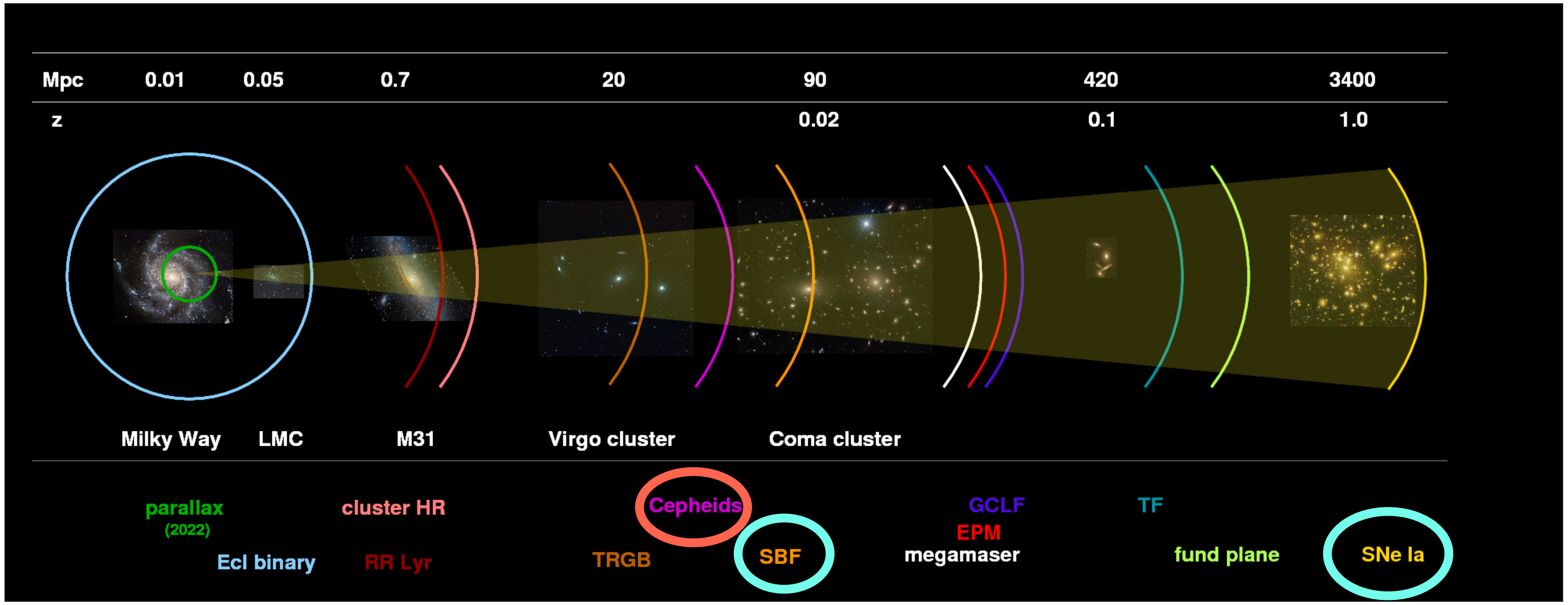
SNe Ia as Standard Candles

- Most influential measurements for H0 in local universe, showed evidence for accelerating universe, Nobel Prize in 2011
- Many surveys to detect SNe for their use as distance probes
- Need a local 'anchor' to calibrate the luminosity, Cepheids have been used primarily, especially by Adam Riess
- Precise calibrating distances are crucial to determine the SNe Ia empirical relations for measuring distances
- We need alternative and independent methods to cross check and complement Cepheids (numbers, distance, host type)

My Intention

- To explore an alternate local distance probe : Surface Brightness Fluctuations (SBF) , for its use as calibrator for SNe Ia
- Compare Cepheids and SBF
- Estimate Hubble-Lemaitre constant (H0) and then measure other cosmological parameters



SBF

A precise distance measuring method in the near by universe

Closer ⟷ More grainy

Farther ⟷ Less grainy

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- A measurement of the fluctuations in the mean intensity of stars encompassed by a CCD pixel.
- Needs a knowledge of galactic modelling, works well on E/SO types
- Future instruments like JWST will increase the SBF catalog

Methodology and Results

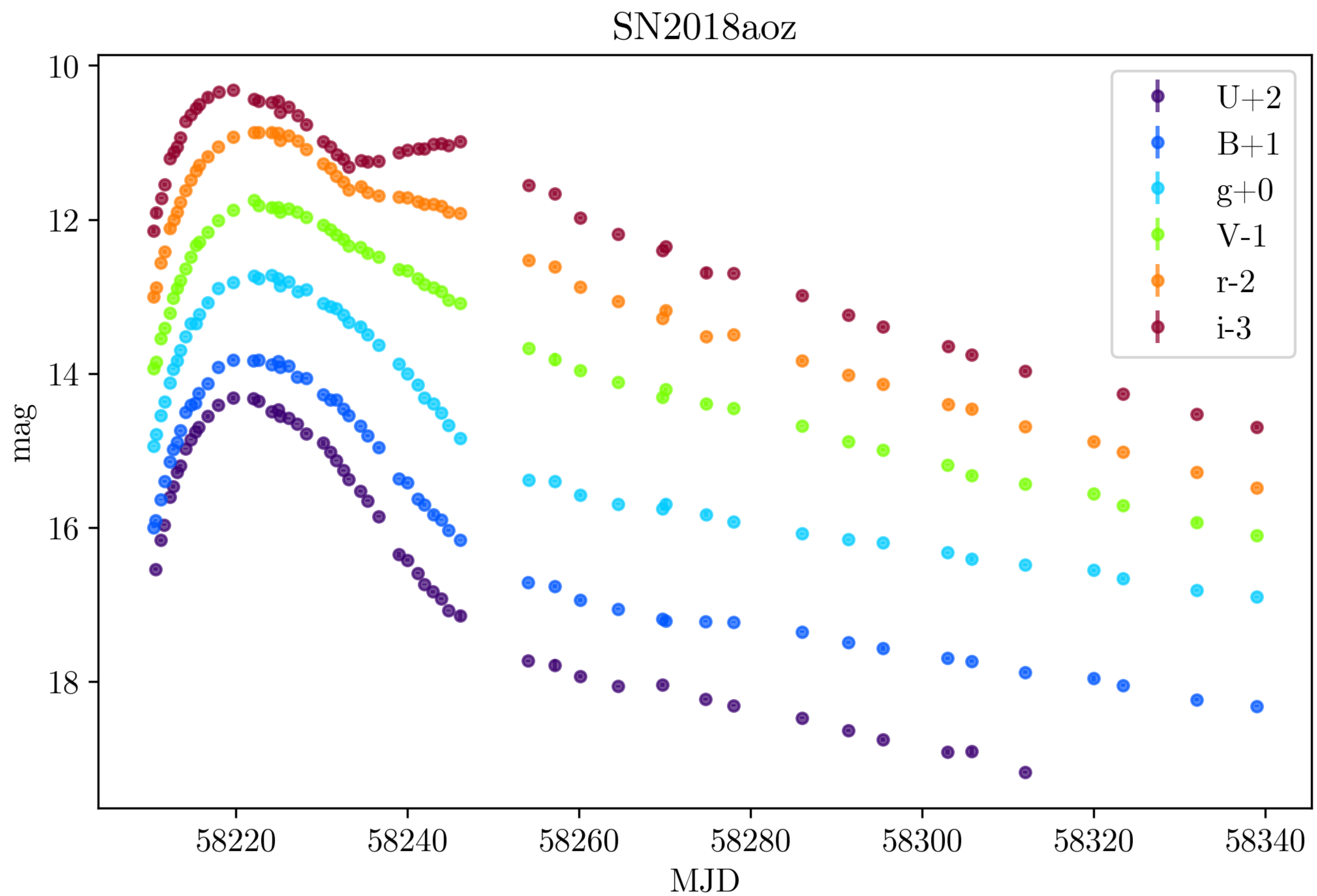
Calibrator Sample

- We select SNe Ia that exploded in galaxies having SBF distance estimates
- We took multi wavelength Photometric Light curves (LC) of these SNe and the SBF distances to their host
- Data sources : Online Catalogs, Literature, SNe group for recent objects
- Filtering - B and V band data, Data quality and cadence, colour and shape

→ A sample of well observed 29 calibrator objects with SBF distances

- SHOES sample as a control sample -19 spiral galaxies hosting SNe Ia with distances estimated using cepheids

Calibrator Sample



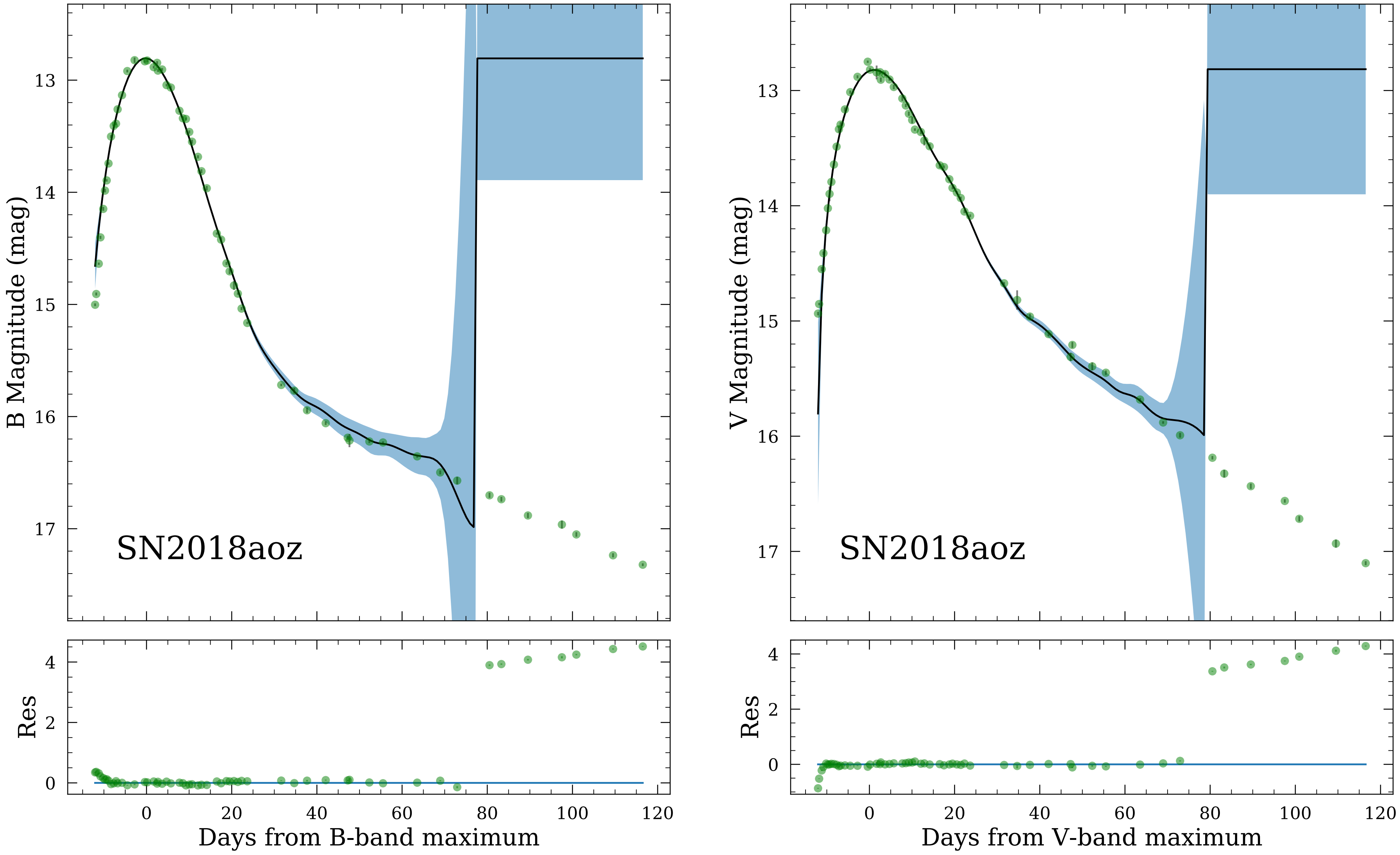
Light Curve fitting

- SNooPy - facilitates a python environment for fitting SNe light curves and calculating the fit parameters

- Get the maximum magnitude in each band (m_B, m_V) and the decline rate of the Light curve (Δm_{15} or s_{BV}) along with their uncertainties.

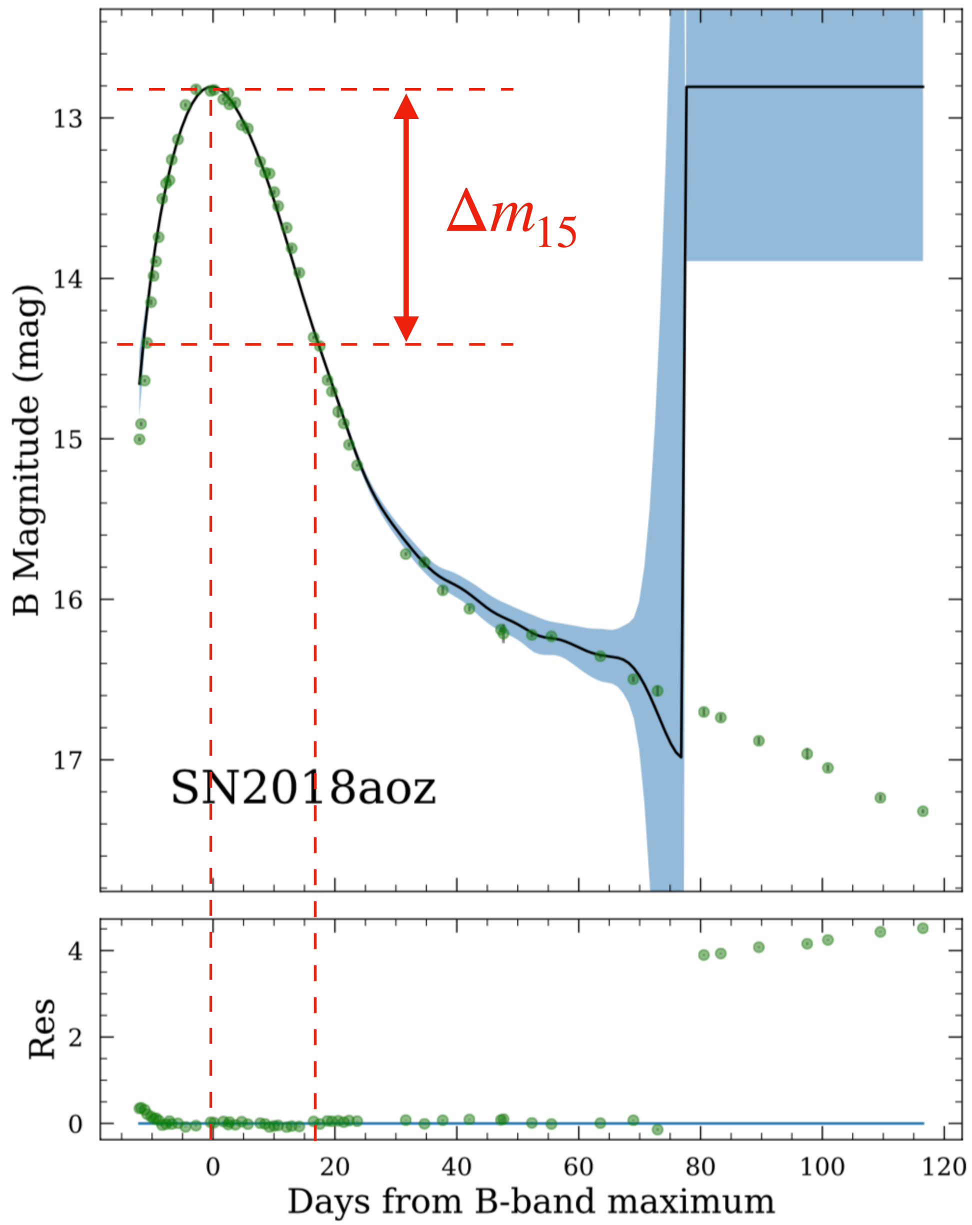
- Performed LC fitting for both SBF sample and SHOES sample

LC fitting

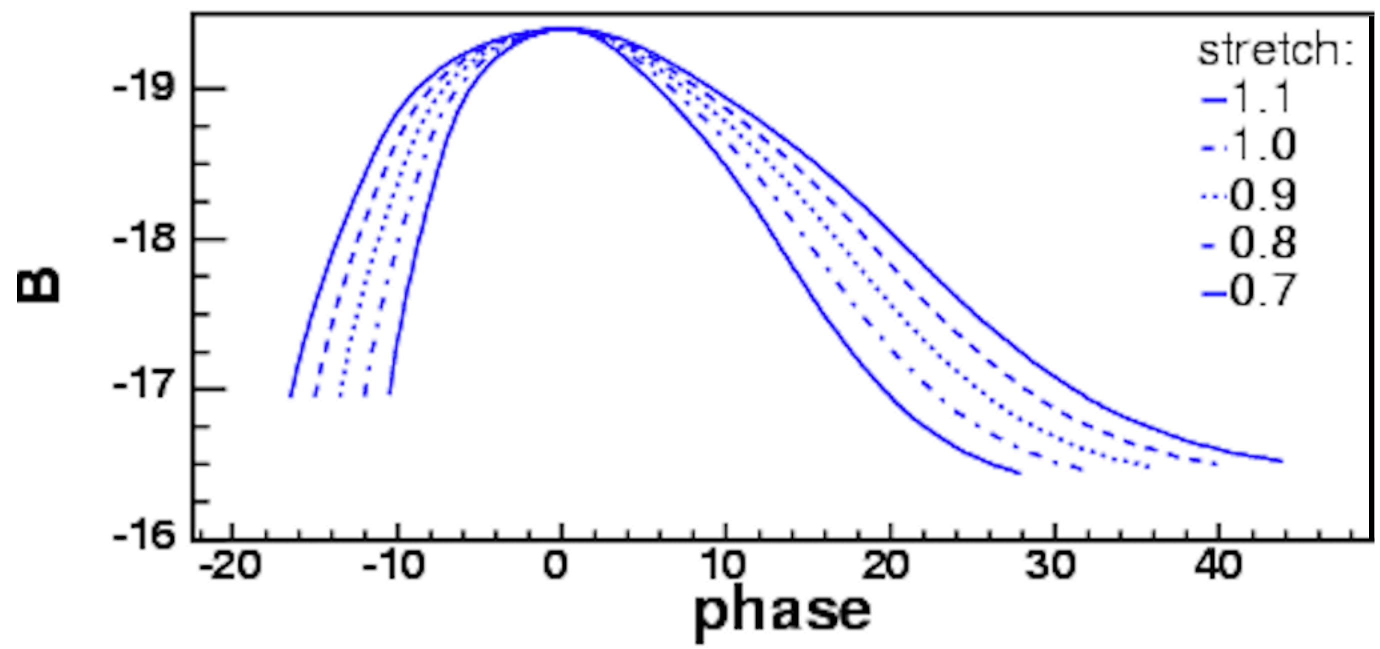


SN2018aoz
B Magnitude (mag)
Res
Days from B-band maximum
SN2018aoz
V Magnitude (mag)
Res
Days from V-band maximum

Δm_{15} and stretch



Stretch (s_{BV})



Tripp Calibration

1993, M.Phillips
How fast a SNe Ia fades is correlated to its Intrinsic brightness!

SNe Ia are standardisable!

$$M_{max} = a + b\Delta m_{15}(B)$$

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$$M_{max} = a + b\Delta m_{15}(B)$$

1998, Robert Tripp
2 parameter correction, added a colour term

SBF

$$m_B = M_0 + \beta(\Delta m_{15} - 1.1) + R(m_B - m_V) + \mu(z)$$

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$$m_B = P_0 + P_1(s_{BV} - 1) + R(m_B - m_V) + \mu(z)$$

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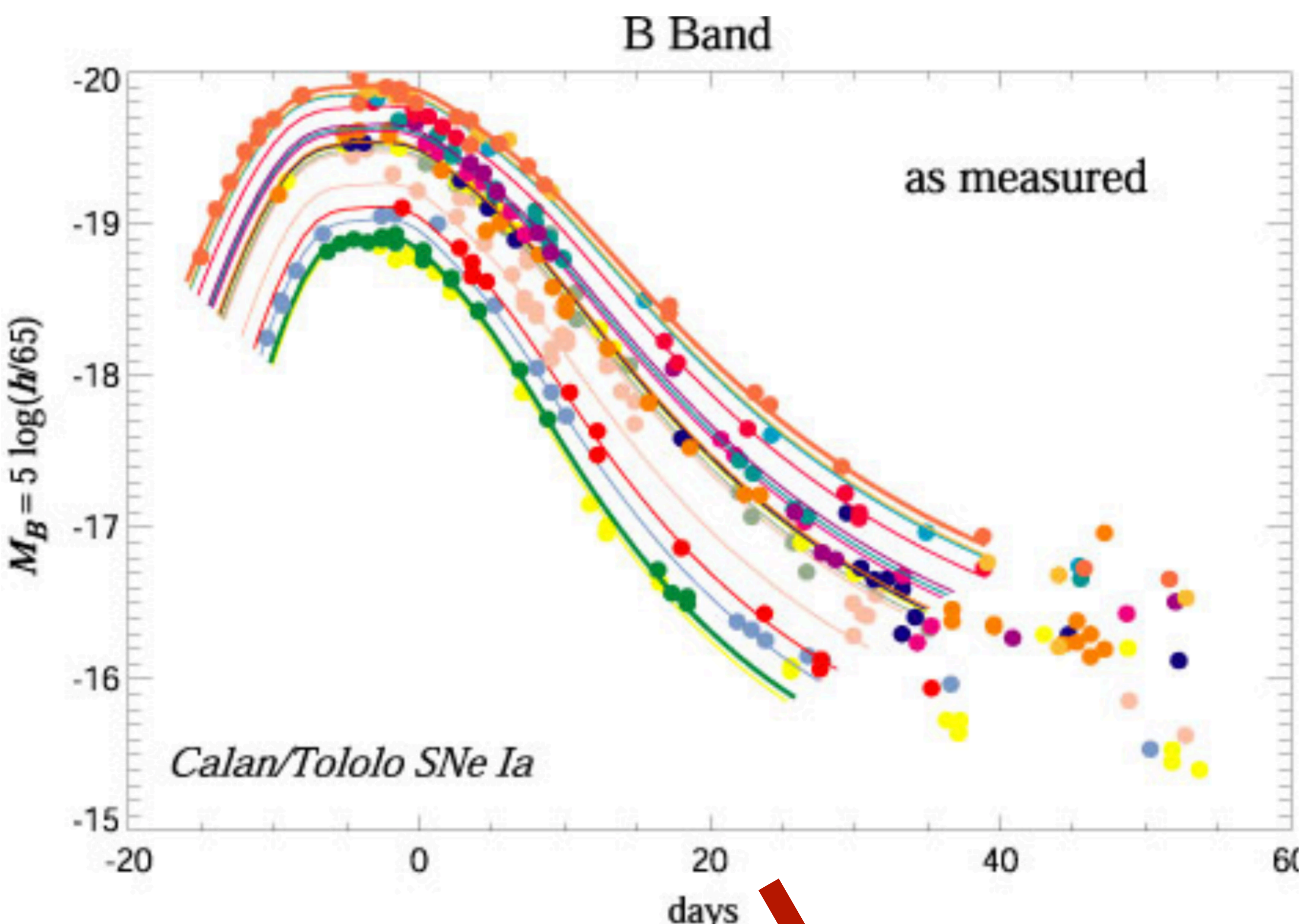
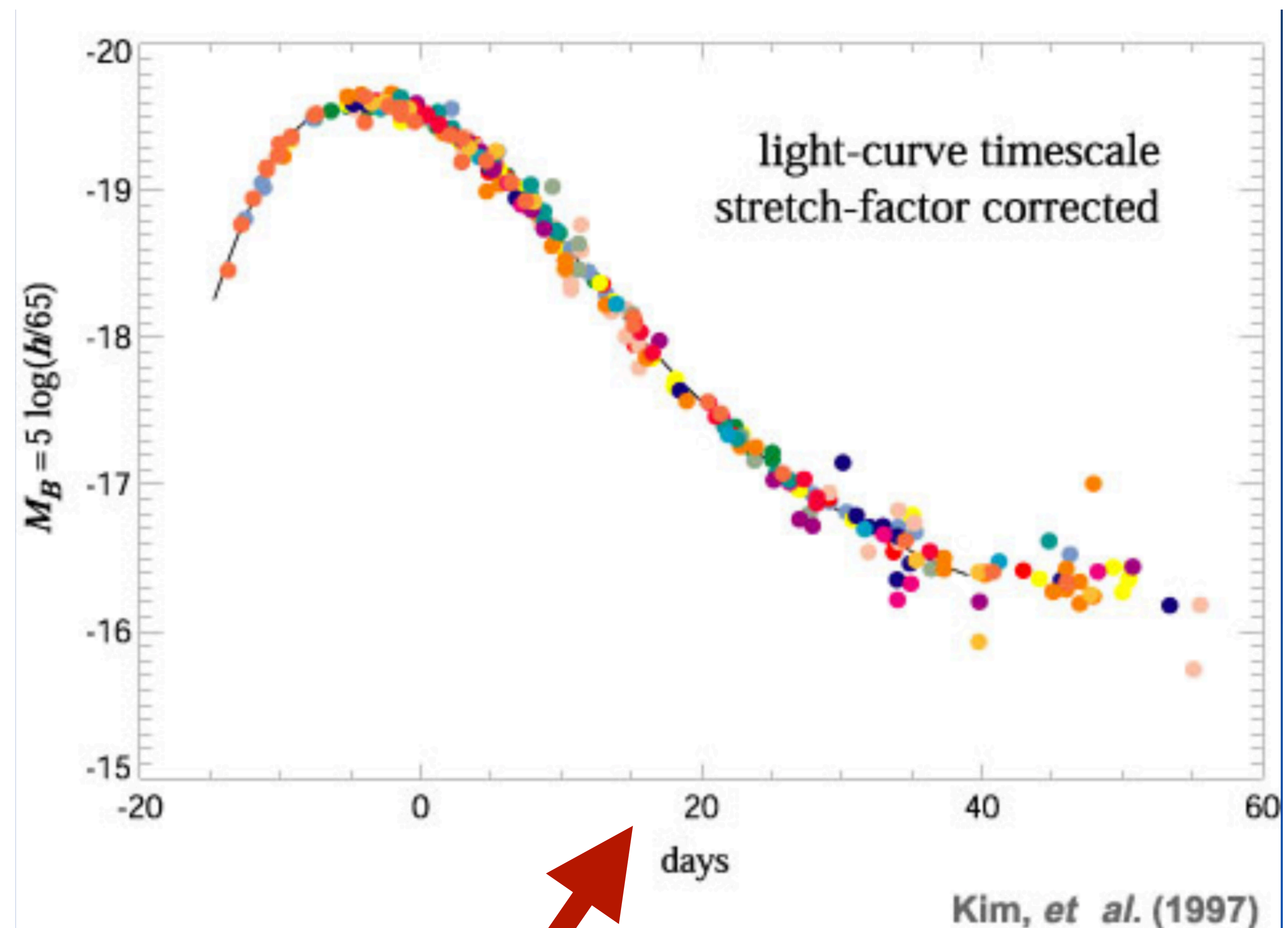
We fit this via linear regression with MCMC using Light Curve parameters (m_B, m_V, Δm_{15} or s_{BV}) as inputs.

Simultaneously solving for the correlation coefficients.

Tripp Calibration





$$m_B = P_0 + P_1(s_{BV} - 1) + R(m_B - m_V) + \mu(z)$$

Hubble Flow sample

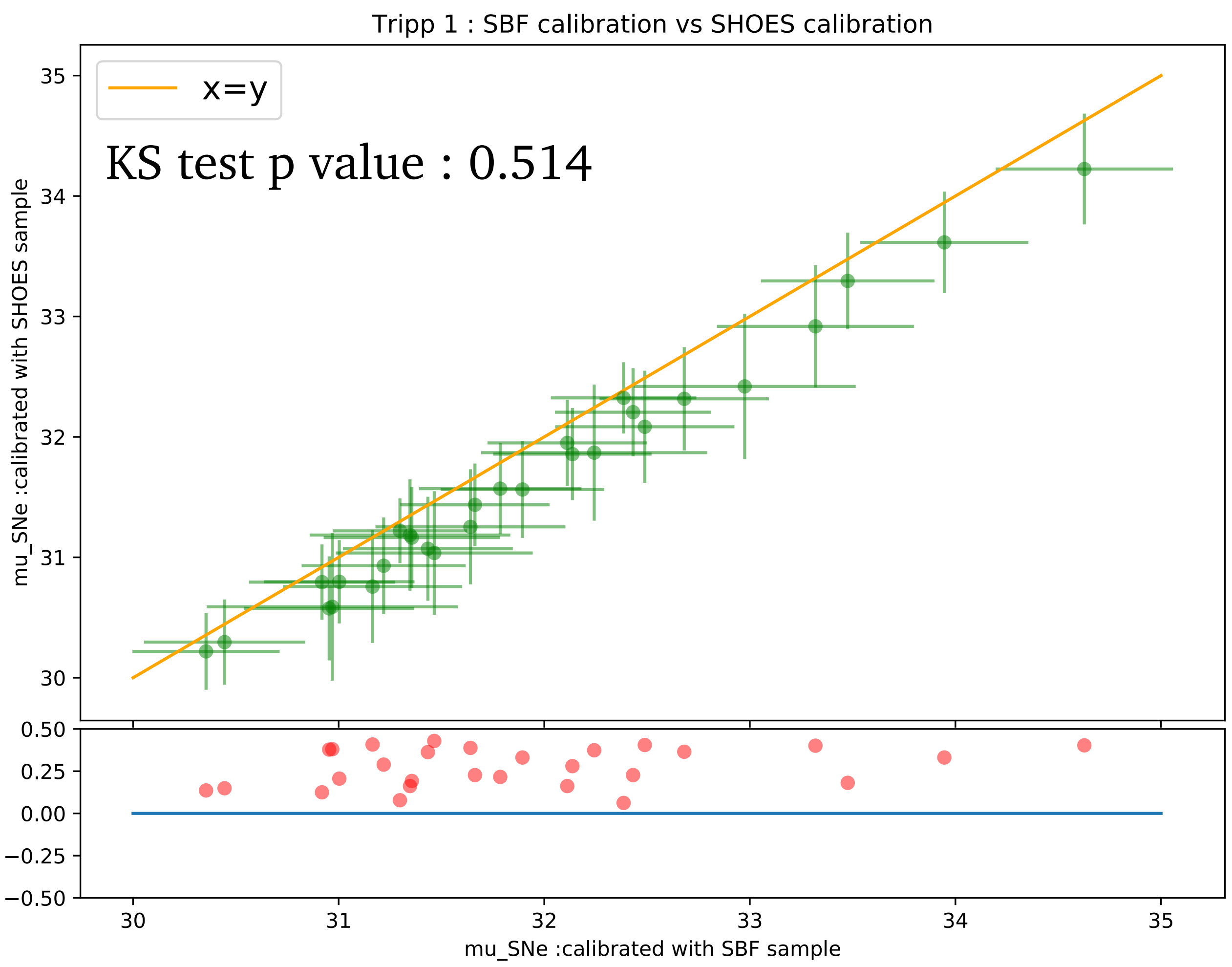
- Build our smooth Hubble flow sample ($z > 0.01$), no peculiar velocity contamination
- Data from PANTHEON set, It has spectroscopically confirmed 1048 SNe Ia , $0.01 < z < 2.3$
- Surveys : SNLS, SDSS, HST, CSP, CfA…..
- Perform LC fitting with SNooPy getting observable parameters
- Calculate distance modulus as:

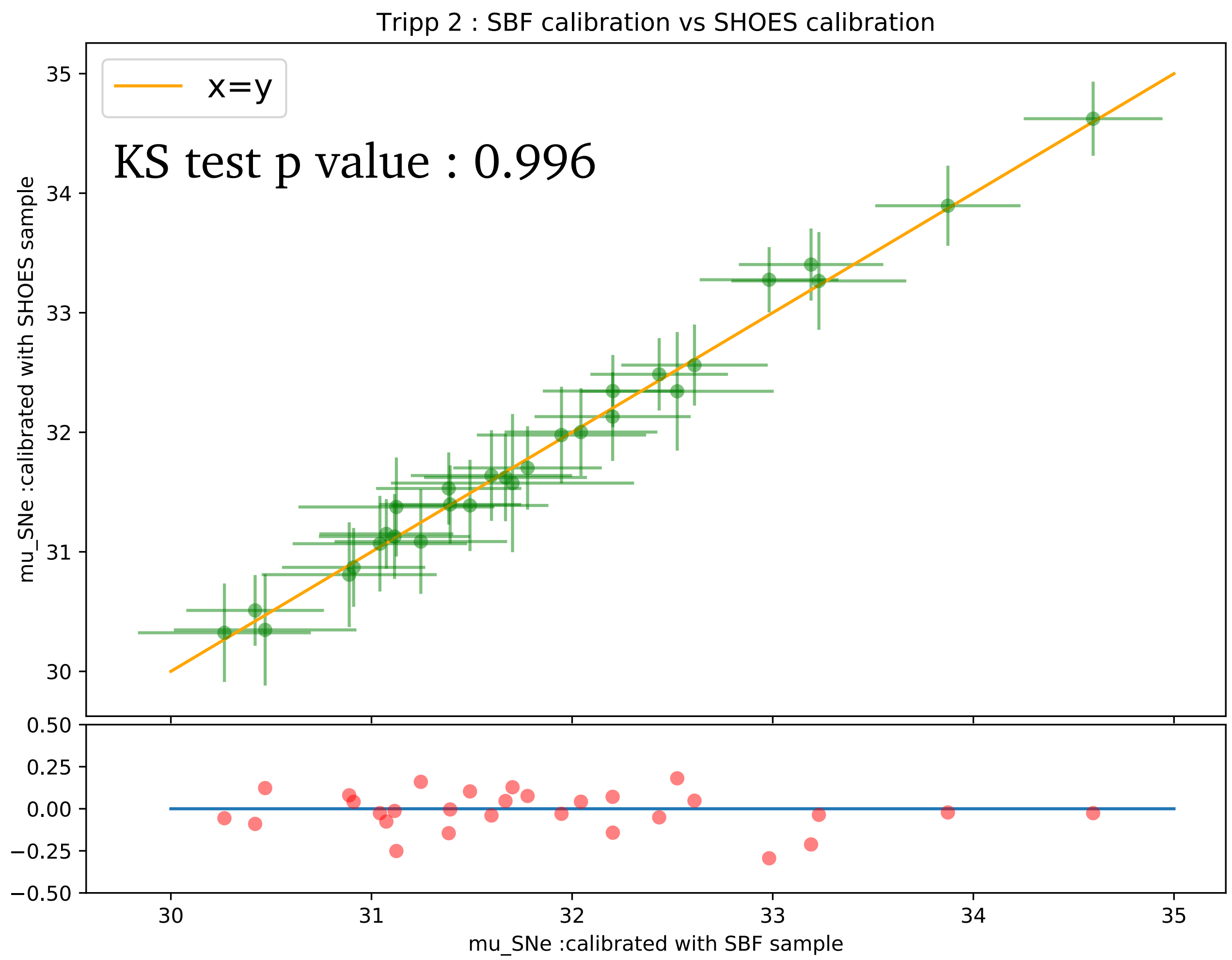
$$\mu = m_B - M_B$$

$$\mu = m_B - P_0 - P_1(s_{BV} - 1) - R(m_B - m_V)$$

Compare SBF and SHOES

Calibrator sample : 29 objects



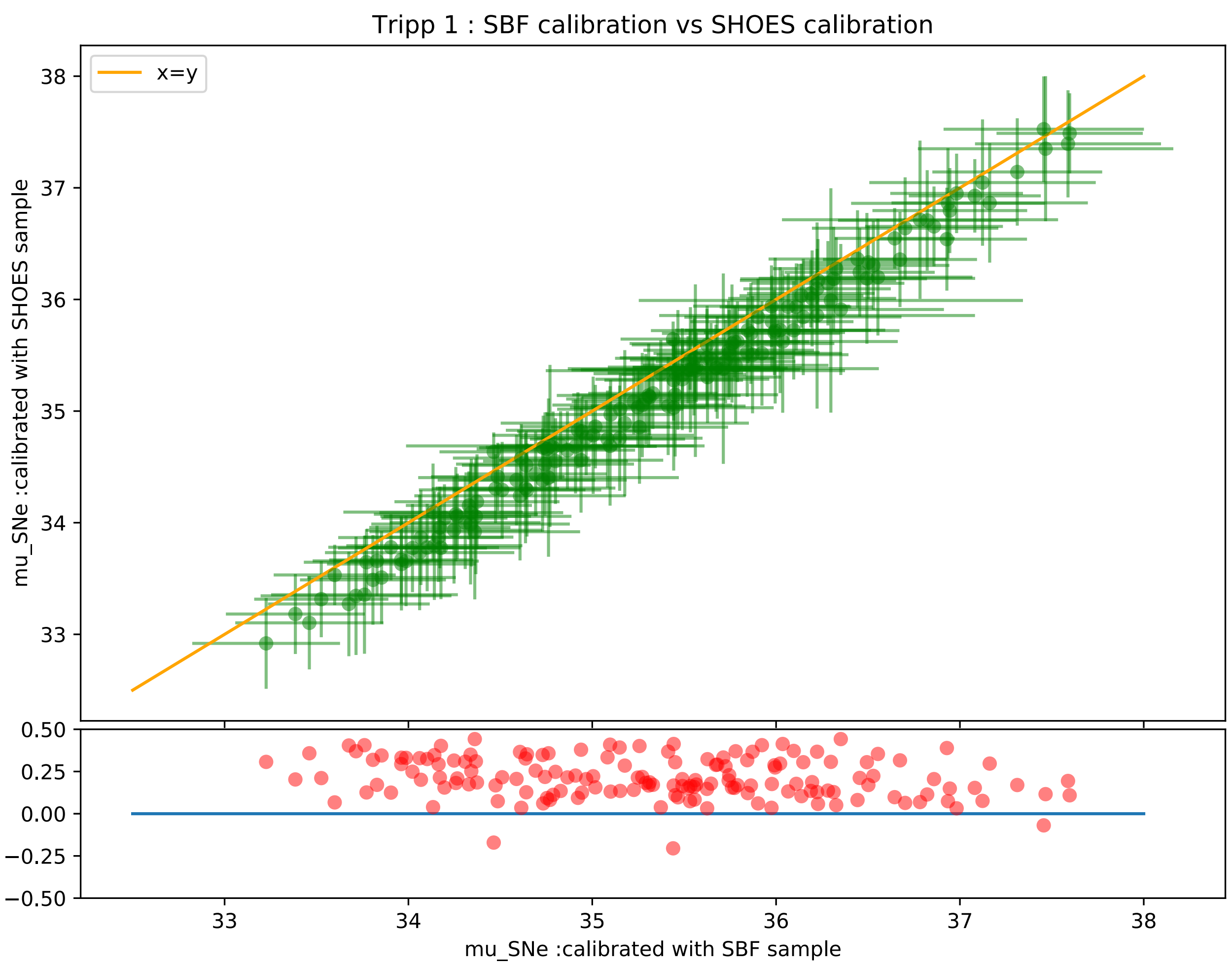


Tripp Calibration with Δm_{15} **Tripp Calibration with** s_{BV}

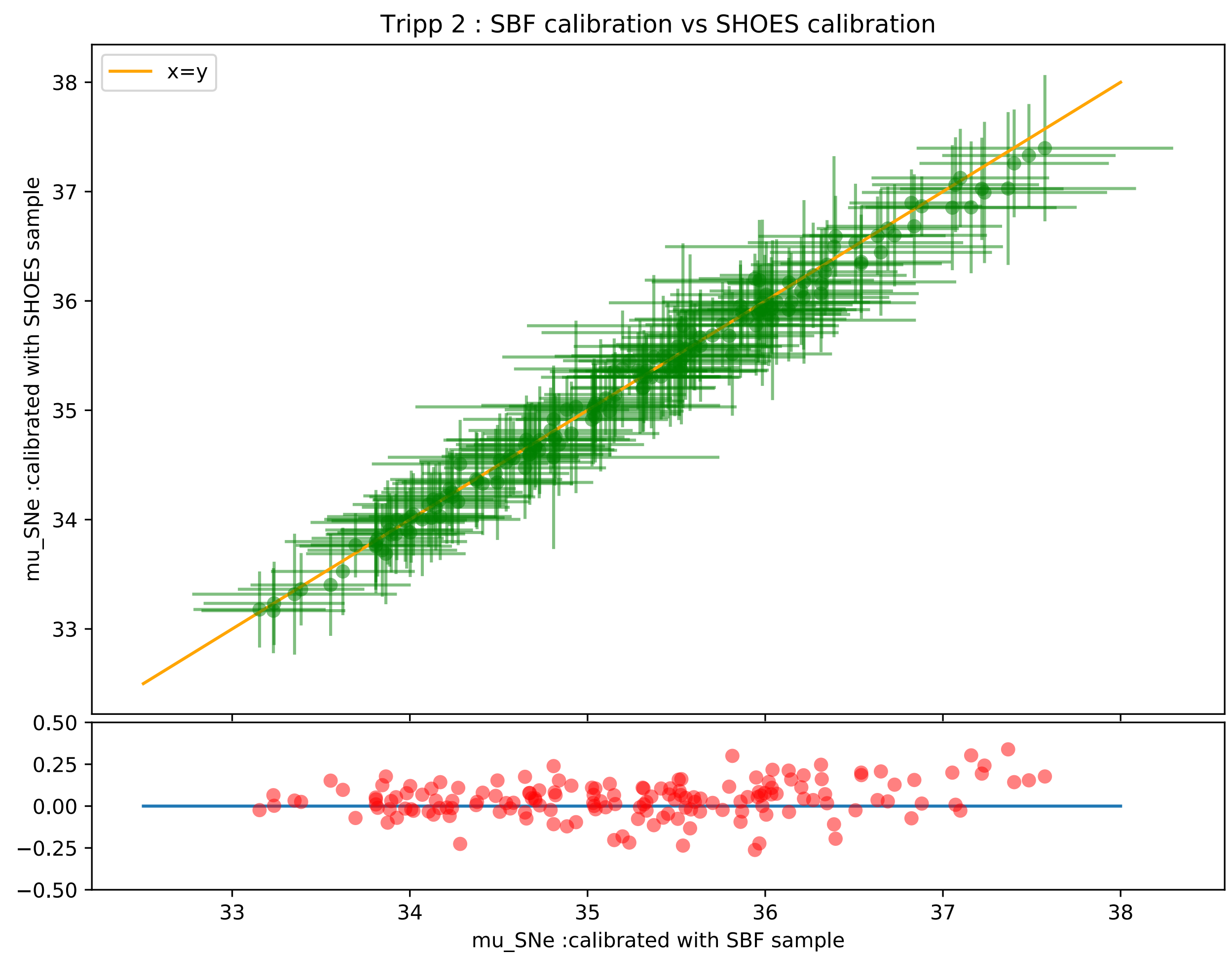
- Observe a systematic offset between the two samples when using Δm_{15}

Compare SBF and SHOES

Hubble Flow sample : 160 objects



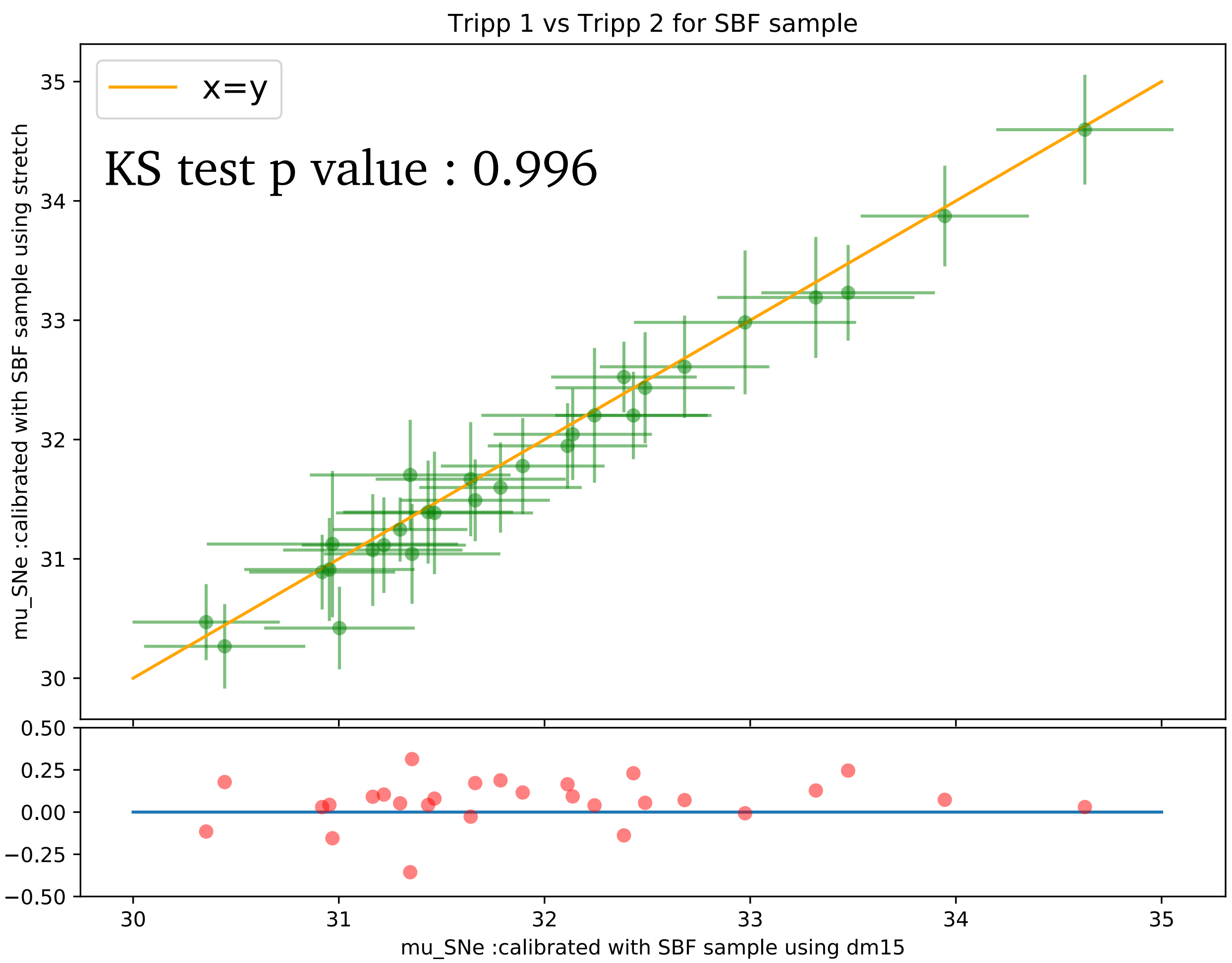
Tripp Calibration with Δm_{15}



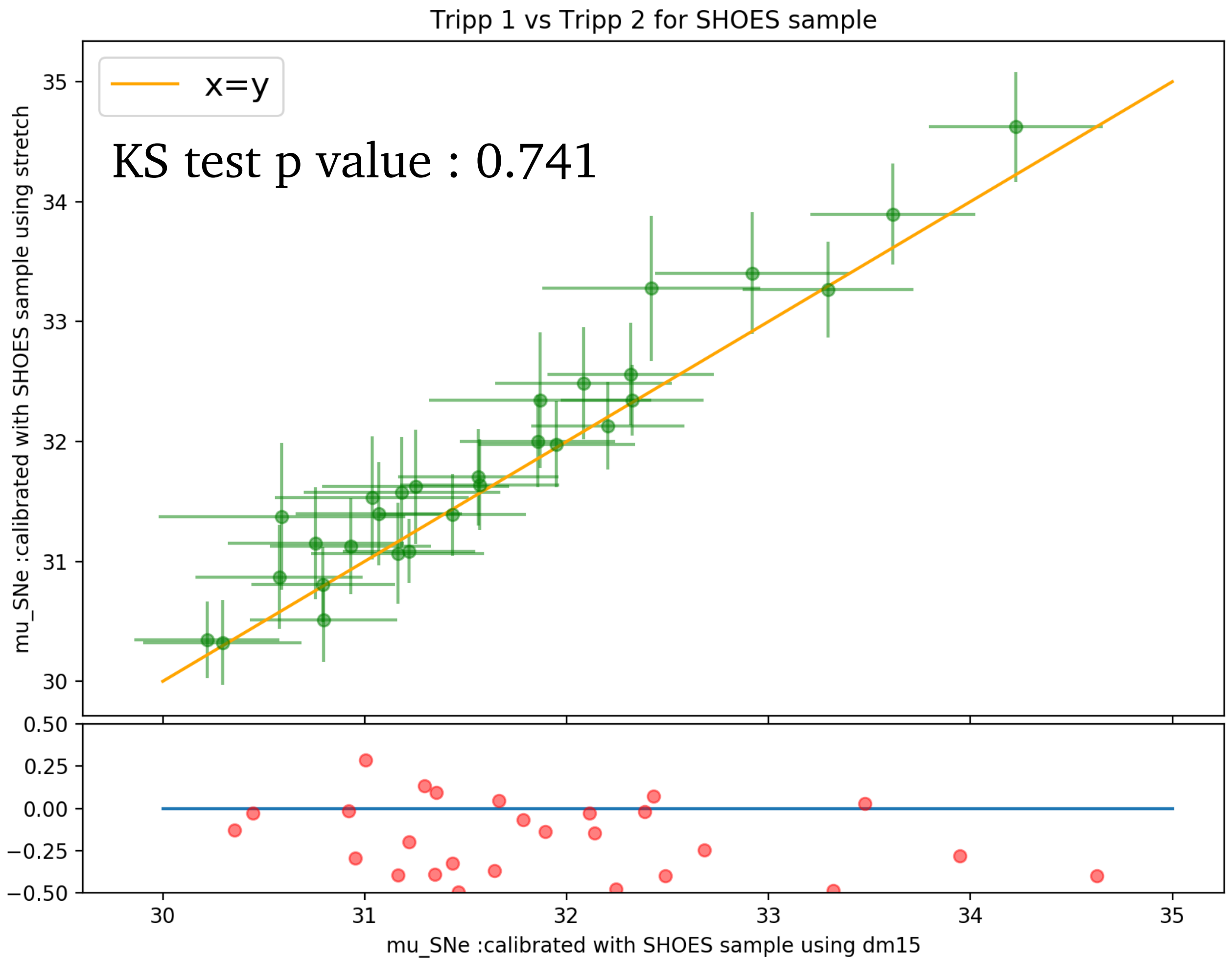
Tripp Calibration with s_{BV}

- Observe a systematic offset between the two samples when using Δm_{15}

Compare Δm_{15} and s_{BV}



Δm_{15} vs stretch for SBF sample



Δm_{15} vs stretch for SHOES sample

- SHOES sample shows inconsistency : distance estimates using stretch are higher for the SHOES sample.
- SBF sample is consistent for both the shape parameters

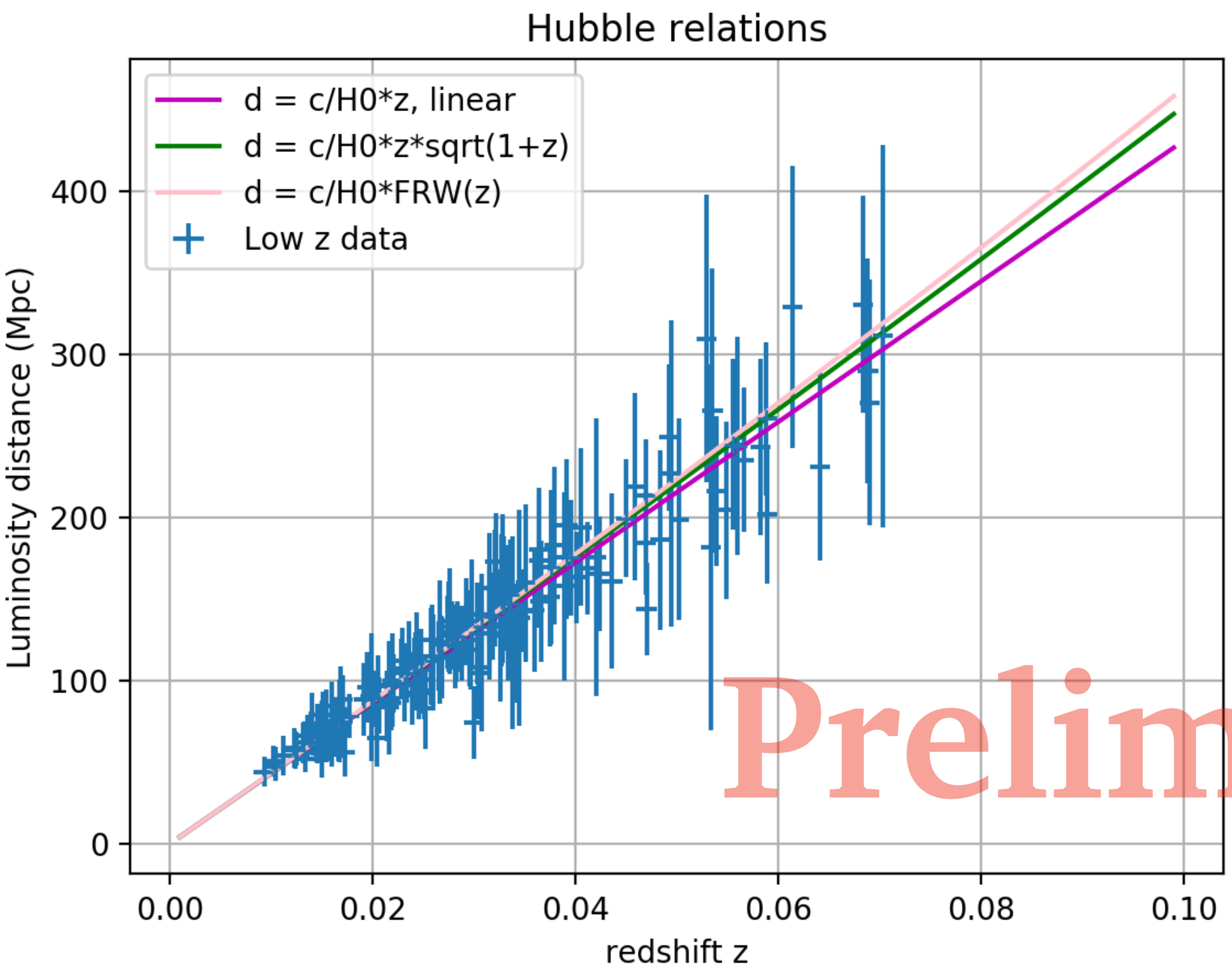
Offset Problem

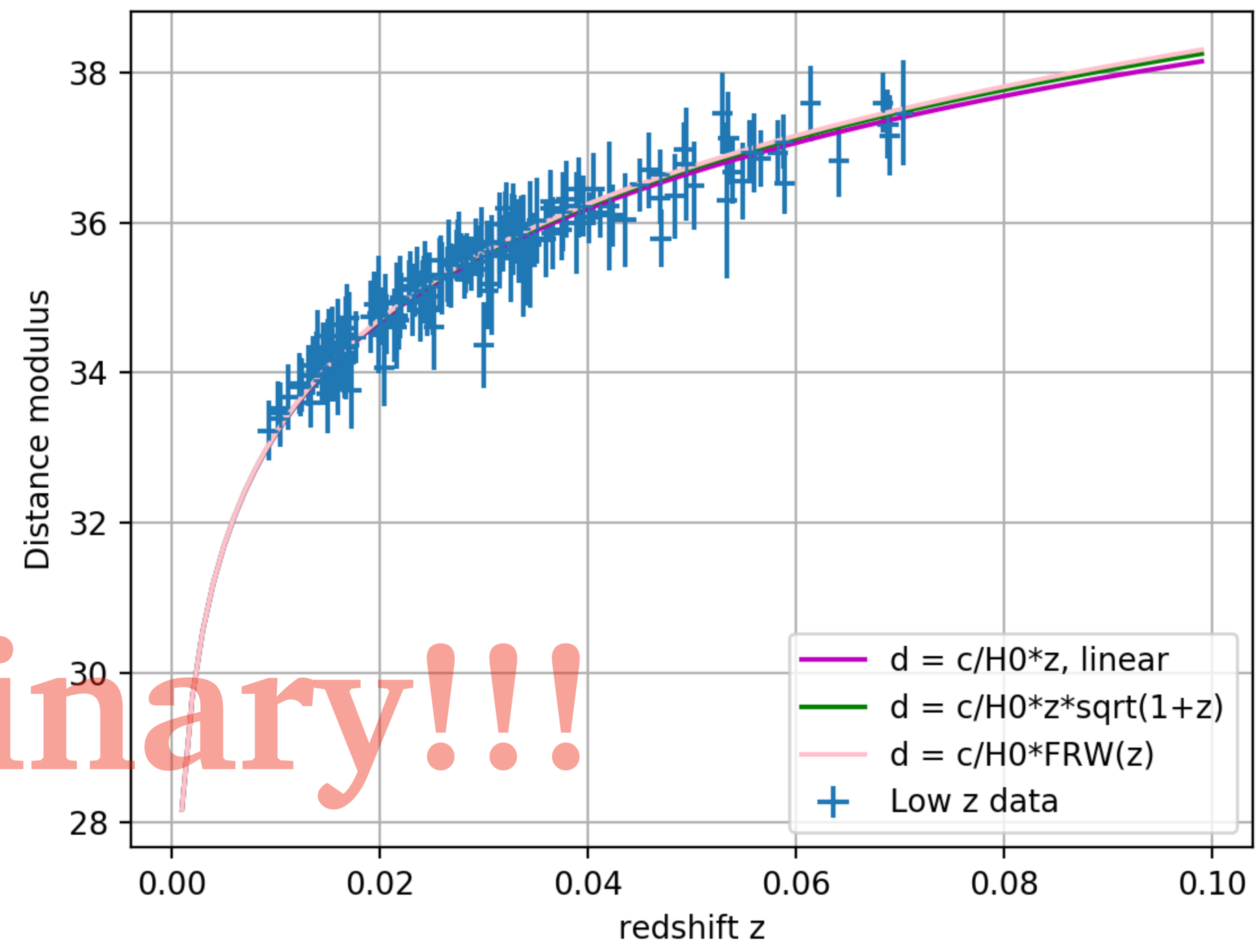
- Investigating possible reasons for this inconsistency between the two parameters
- Evidences : Luminosity depending on host type: differences in host stellar mass, SFR, Metallicities, environment (gas and dust), progenitor channel
- SBF sample - E/So types - Early type galaxies
- SHOES sample - Spirals - Late type galaxies
- Stretch parameter is more sensitive to these differences - may be?
- One possible solution: mass correlation ???

$$m_B = P^N(s_{BV} - 1) + R_B(m_B - m_V) + \alpha(\log_{10} M_*/M_\odot - \log_{10} M_0) + \mu(z)$$

Hubble - Lemaitre Constant

A very Preliminary estimation





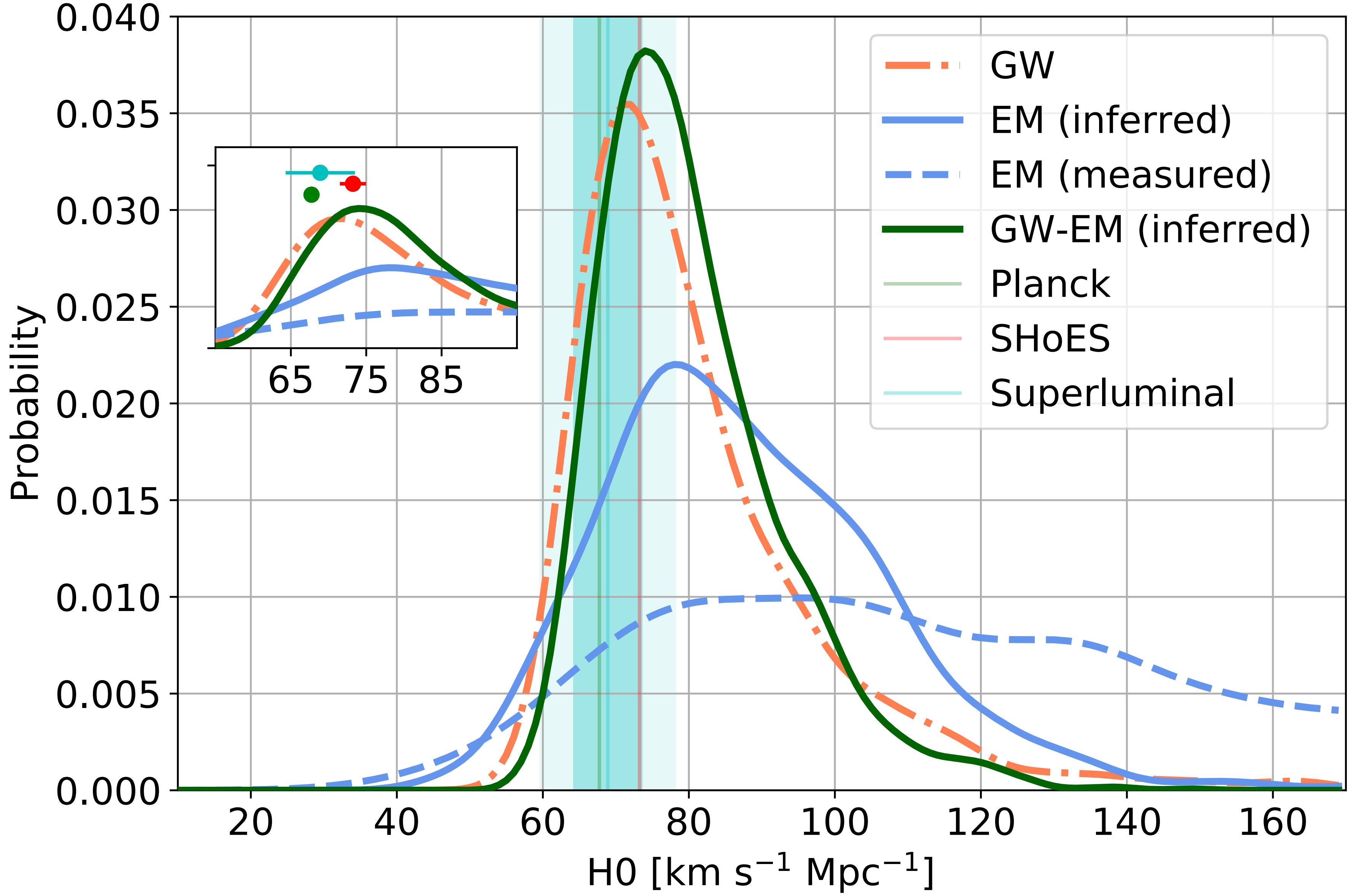
For Low z regime using only linear relation : H0 = cz/d and getting mean value
$H_0 = 72.41 \mathrm{kms}^{-1}\mathrm{Mpc}^{-1}$

Work Under progress….

Kilonovae as Standard Candles

- Kilonovae - EM emission from BNS - first observation GW170817
- Has characteristics that can provide an independent distance measurement (without any information from GW)
- Detect them independently with LSST
- Explored the color-mag diagrams and decay rate-mag diagrams of simulations ⟶ Trends motivate potential for standardisation
- As with SNe Ia, Modeled some observed and inferred quantities to get distances and then H0
- Tested our both models with GW170817

Kilonovae as Standard Candles



For measured and Inferred analyses , we give Kilonovae-only Hubble constant measurement of $H_0 = 109^{+49}_{-35} \mathrm{km s^{-1} Mpc^{-1}}$ and $H_0 = 85^{+21}_{-16} \mathrm{km s^{-1} Mpc^{-1}}$

Paper submitted to PRL (https://arxiv.org/pdf/1908.00889.pdf)

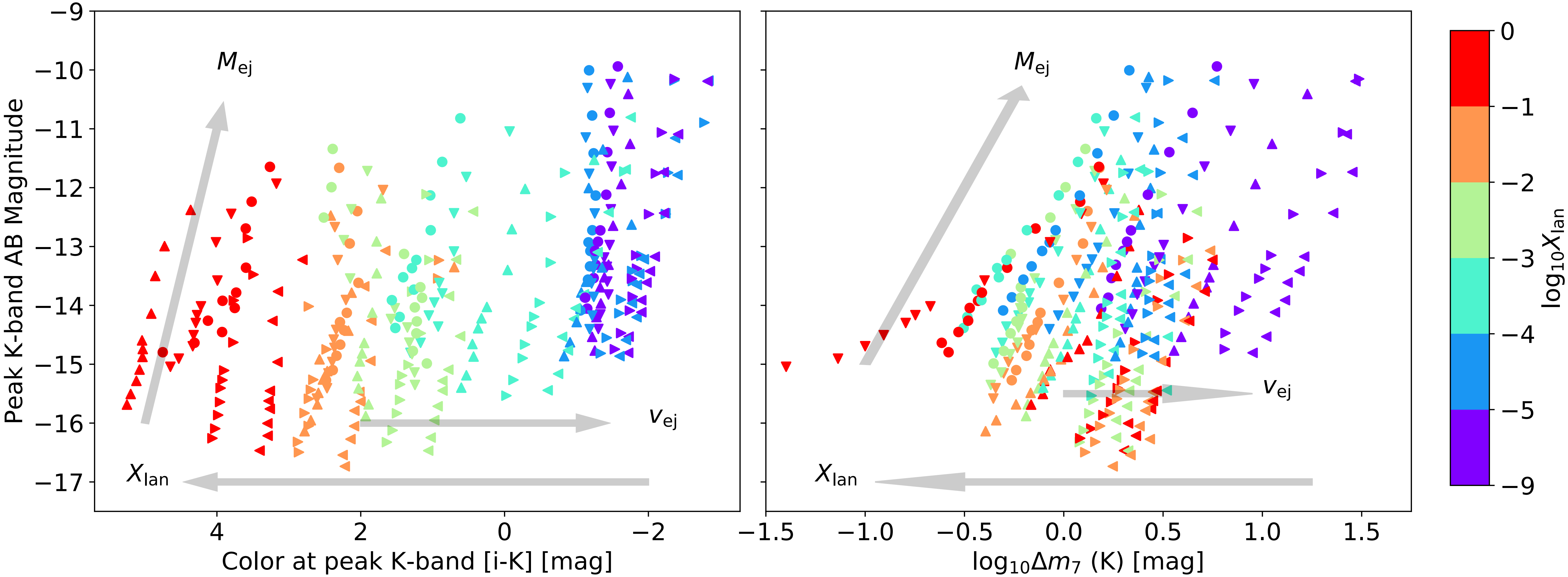
Future

- Visit Swinburne Uni of Technology, Australia, to work with Prof. Jeffery Cooke to study use of Super Luminous Supernovae (SLSN) as distance indicators.
- High peak luminosities - Reach higher redshifts
- Group has photometric UV data that I will analyse
- Build a catalog of SNe Ia exploded in galaxy clusters for LIGO-VIRGO collaborations
- A possibility to work on theoretical simulations to study SNe Ia environment, collaboration with La Sapienza group
- Paper writing and thesis submission

Back up

SBF 101

- N —mean number of stars per pixel
- F - mean flux per star
- Mean pixel intensity is N*F and variance is NF^2
- Ratio of observed mean to observed variance is F
- This decreases inversely with the square of the distance.



Peak K-band AB Magnitude
Color at peak K-band [i-K] [mag]
$\log_{10}\Delta m_7$ (K) [mag]
$\log_{10}X_{\rm lan}$
$M_{\rm ej}$
$v_{\rm ej}$
$X_{\rm lan}$