Measuring H_0 using Type Ia supernovae as near infrared standard candles

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Talk Outline

- Motivation to study H_0
  - Recent studies and H_0 tension
  - Explanations for the tension
- Role of NIR observation
- Methodology
- Results
- Ongoing and future work
- Conclusion

Motivation to measure H_0

- Sets absolute distance scale
- Important to constrain energy densities
- Constrain key physical parameters
  - N_{eff}
  - Σm_ν
- Cosmological model selection
  - Dynamical dark energy
  - Modified gravity

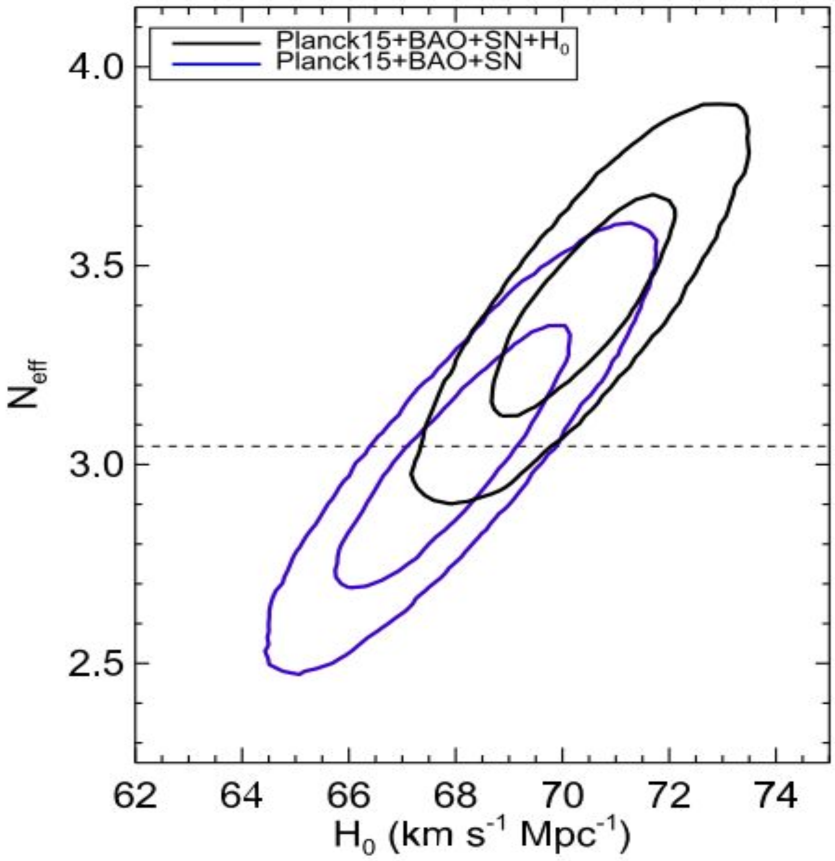
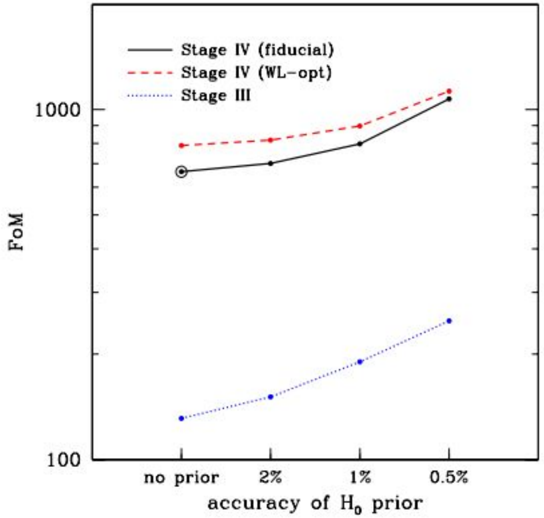


Figure: The impact of H_0 prior for N_{eff} which could point to values > 3 (Riess et al. 2016)

Impact on dark energy properties

- Several explanations for acceleration
- H_0 improves precision



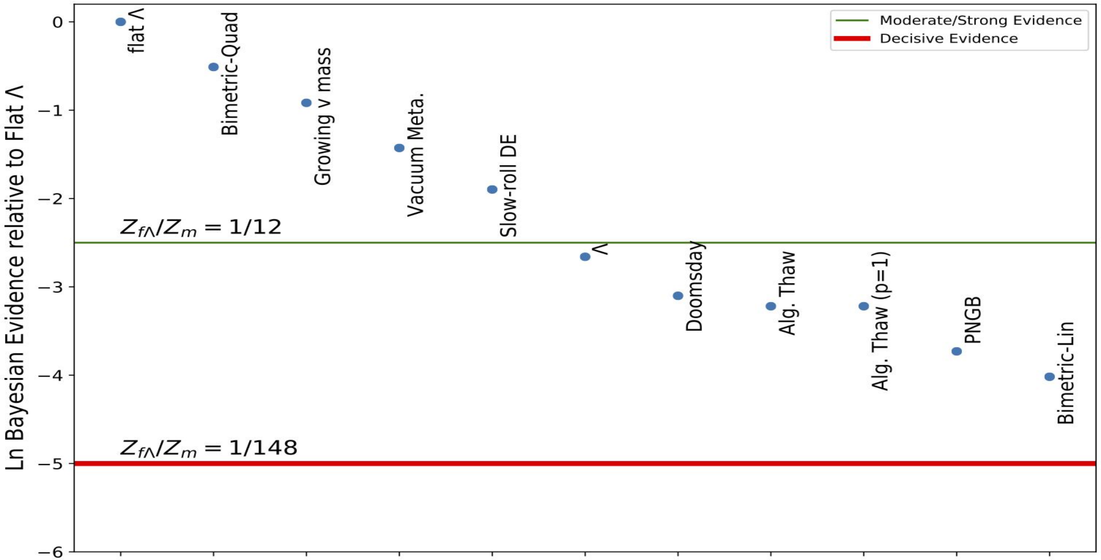


Figure:(Left): Impact of a precise H_0 prior on dark energy Figure of Merit (FoM) with Stage III and IV experiments (Suyu et al. 2012) (Right) Different non-standard models for acceleration compared to standard cosmology using the Bayesian evidence (Dhawan et al. 2017b). This analysis was H_0 independent.

Possible causes of tension

- Physical explanations for the tension
  - Late-time acceleration doesn't work (Morstell & Dhawan 2018, submitted)
    - CMB H_0 is relaxed, BAO, SNe "cut" phantom region
  - Early universe (z ~ 1100) physics (MD18)
    - Dark radiation relieves tension
    - Could be a mildly relativistic matter component
  - 1% H_0 → decisive evidence for dark radiation
- Astrophysical systematics?
  - Star formation bias claimed (Rigault et al. 2015; but see Jones et al. 2015)
  - Non-standard dust around SNe?
  - NIR calibration ⇒ an independent test

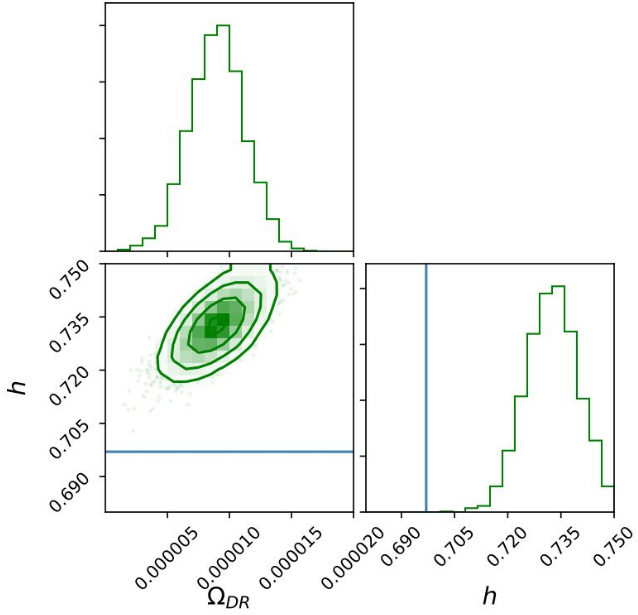
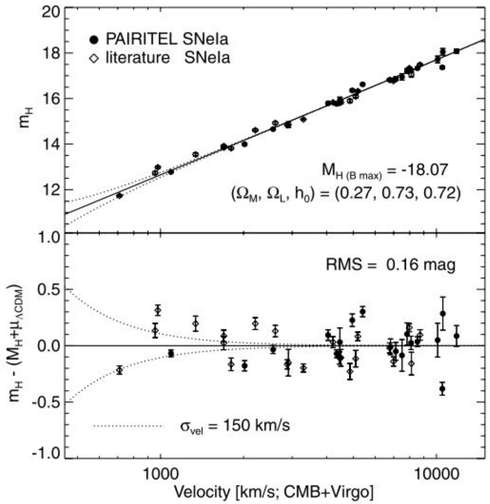
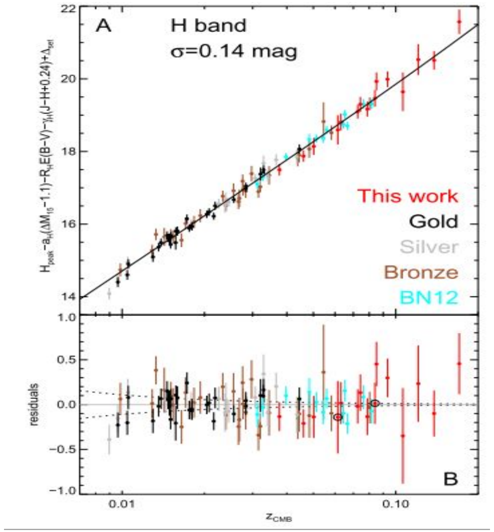


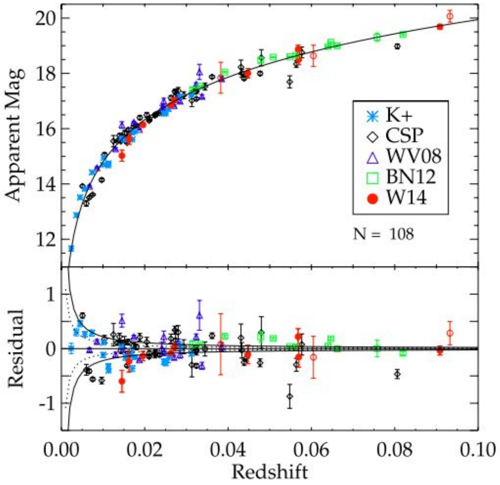
Figure: The joint posterior for the dimensionless Hubble constant and the density of dark radiation (Mortsell & Dhawan 2018, submitted arxiv:1801.07260)

Why the NIR?

- Reduced absorption from host
- Lower luminosity scatter







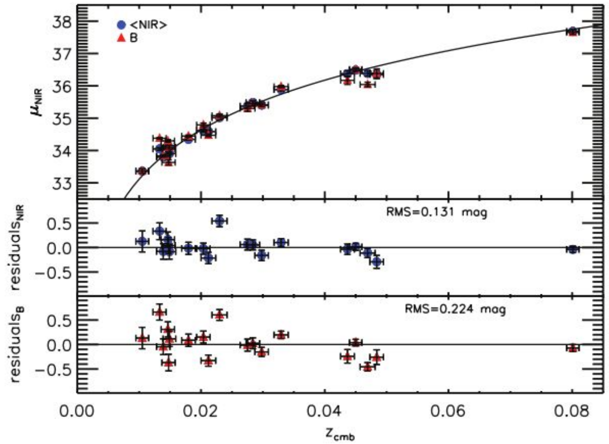
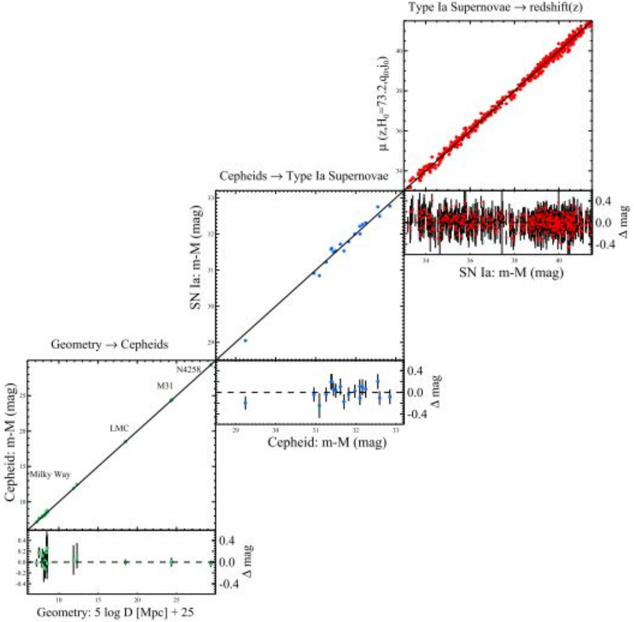


Fig: NIR Hubble diagrams from various surveys in the literature. (clockwise from top left): CfA (Wood-Vasey+ 2008), CSP (Kattner+ 2012), SweetSpot (Weyant+2014), Stanishev et al. 2018

Methodology

- Using Cepheid distances from R16
- NIR observations for SN Ia
- J-band: single filter fits
- Direct fits to data: No templates
- Applying standard candle hypothesis (no corrections)



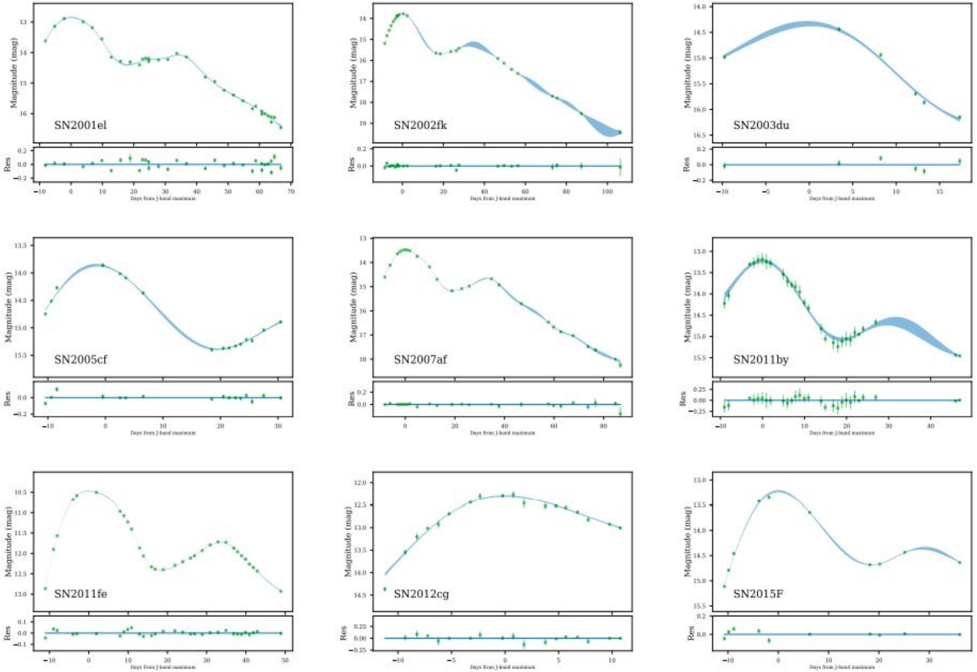
$$a_J = \log cz + \log\left[1 + \frac{(1-q_0)z}{2} - \frac{(1-q_0-3q_0^2+j_0)z^2}{6}\right] - 0.2m_J$$

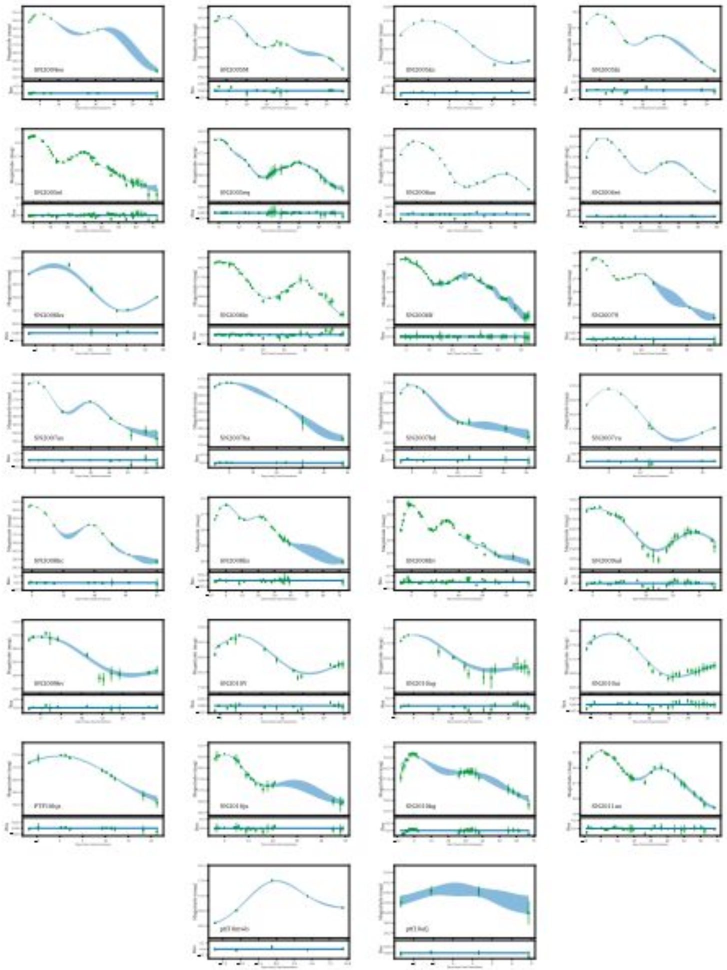
$$\log H_0 = \frac{M_J + 5a_J + 25}{5}$$

Fig: Distance ladder approach for the Hubble constant measurement (Riess et al. 2016)

Nearby and distant samples

- Smaller sample than optical
- Robust peak estimates from GP





Calibration Sample

- 19 SNe in Riess+2016
  - 12 with NIR light curves
  - 9 with sufficient sampling
- Gaussian process fits to data
- Using approximate distances
- σ_{calib} = 0.160 mag
- Heterogenous photometric systems (could contribute to scatter)

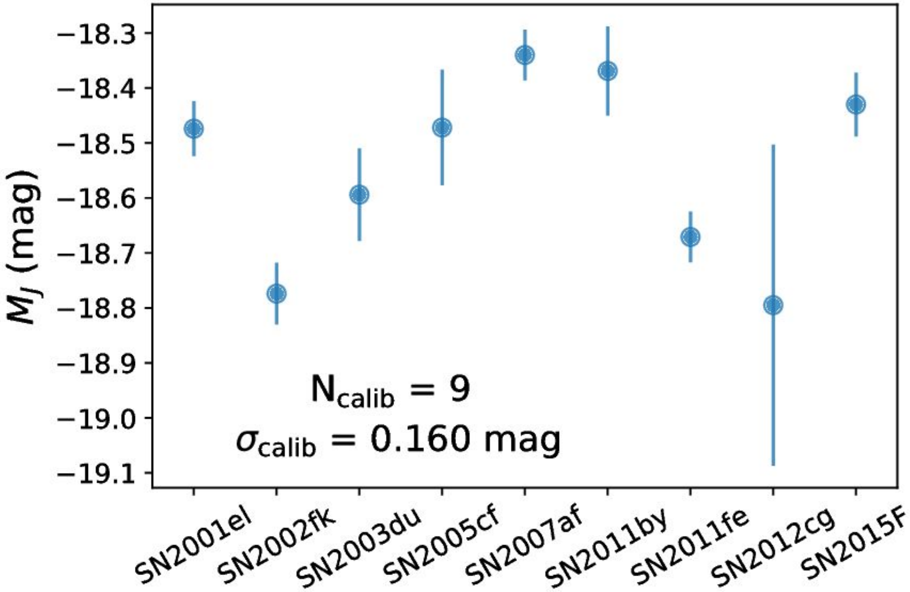


Figure: The absolute magnitudes of the 9 calibrator SNe with NIR data to measure a peak magnitude. The error is a quadrature sum of the distance error and the peak magnitude in the J band (Dhawan et al. 2018)

Hubble flow sample

- 27 SNe in hubble flow
  - Carnegie Supernova Project, CfA samples
  - Hubble flow PTF follow-up
  - $0.01 < z < 0.08$
- Sample size << R16 hubble flow
- σ_{hflow} = 0.106 mag
- Scatter lower than optical with correction
- Zero point: combination of M_J and H_0

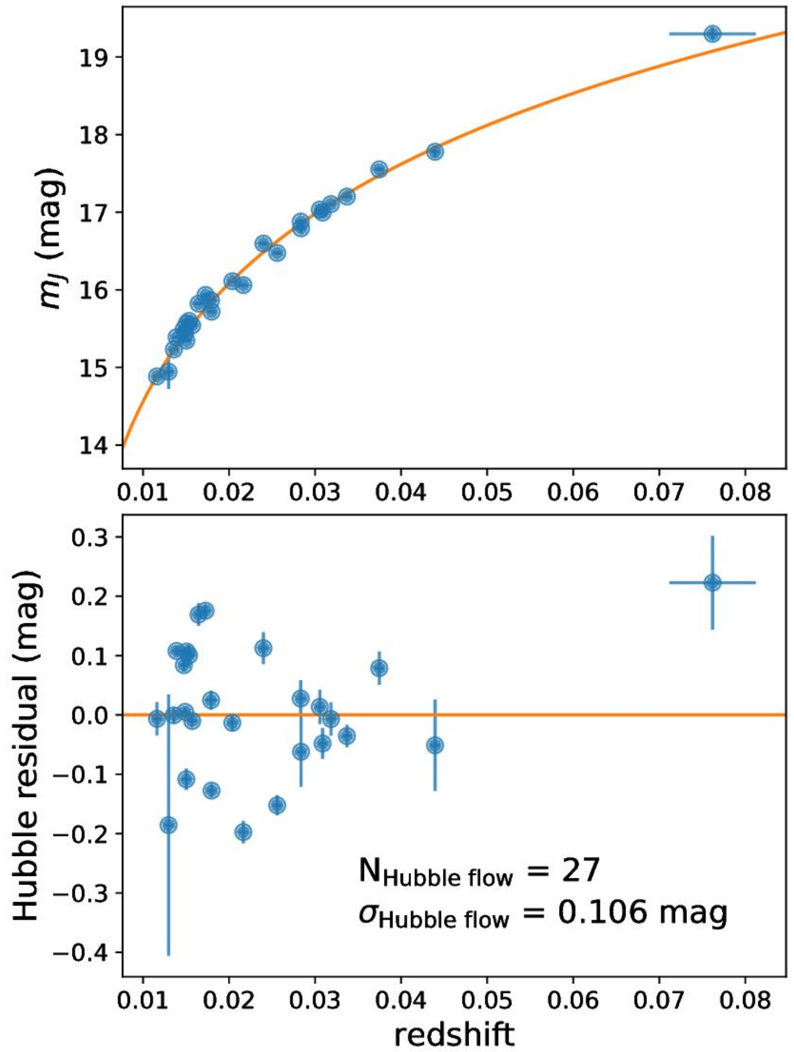


Figure: Hubble diagram in the J band for 27 SNe, treating them as standard candles without any corrections to the peak magnitude (Dhawan et al 2018).

H_0 from the NIR

- Combine the calibrators and hubble flow
  - Calibrators: Absolute M_J
  - Hubble flow: M_J and H_0
  - Combination breaks degeneracy
- H_0 = 72.8 ± 1.6 (statistical) ± 2.7 (systematic) km/s/Mpc
- Consistent with R16

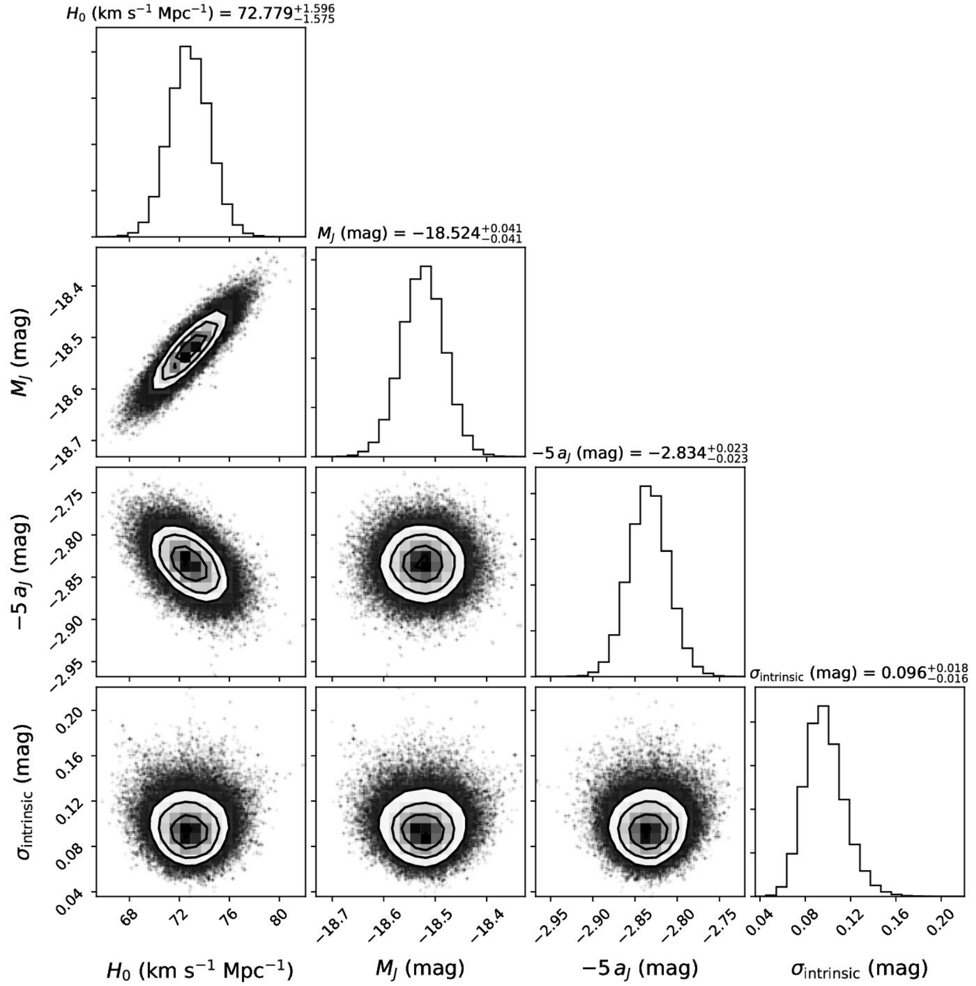


Figure: Contour plot with the joint constraints for H_0, M_J, a_J and intrinsic scatter (Dhawan et al. 2018).

Sample Selection Checks

- SN properties (e.g. Δm15)
- Redshift selection ($0.02 < z < 0.05$)
- Host galaxy and Milky Way extinction A_J
- Host morphology (only spirals in Hubble flow)
- Survey Selection
- Hierarchical Bayesian distance (Cardona+2017)
- H_0 is invariant

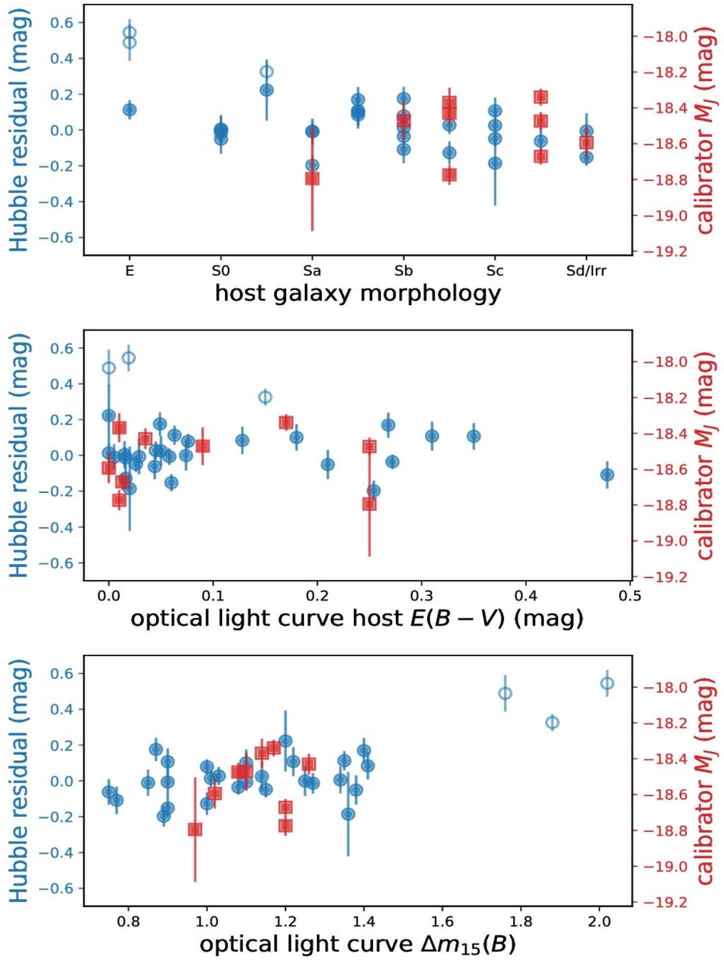


Figure: The hubble residual for the hubble flow sample and the absolute magnitude versus host morphology, host E(B-V), light curve width (Dhawan et al 2018).

Outlook and Improvements

- Use less data selective methods
- Colour information (Y,J,H combined filters)
- More calibrators with NIR data
- Photometric Calibration: Dominant Systematic
- Host mass dependence?
- “Snapshot” Method
- Higher-z Hubble flow
    - Reduce peculiar velocity errors

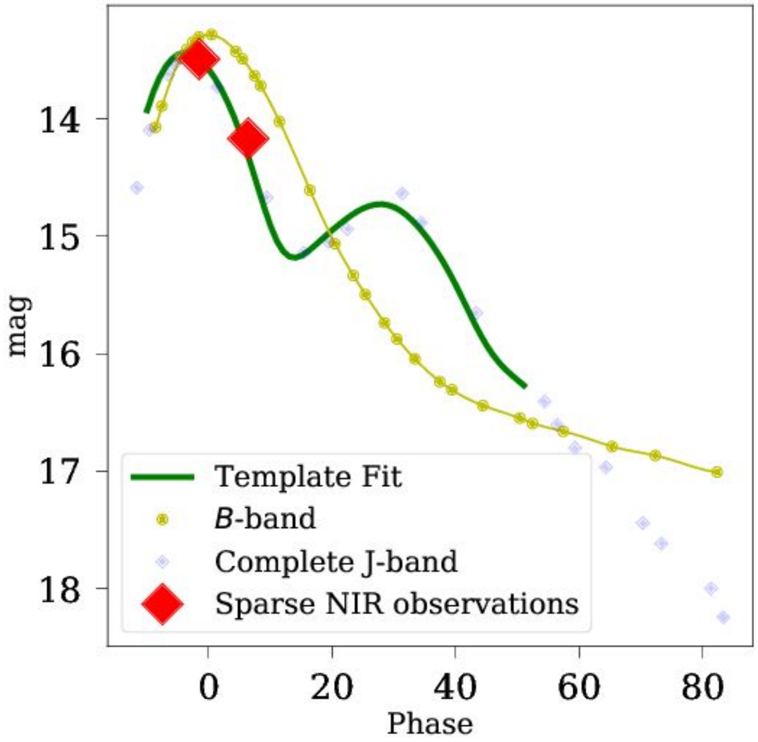


Figure: A Monte Carlo realisation from a well-sampled SN Ia in the J-band. The template fit returns the same magnitude as a smoothing of the complete light curve. The only prior is the time of B-band maximum.

Correlations with host mass?

- NIR Hubble residual
  - Template fit with optical prior
- FSPS fit to host photometry
  - SDSS: Optical photometry
  - 2MASS: NIR
  - Fitted with FAST (Kriek+2009)
- No evidence for correlation (< 1σ)
- Small sample
  - MC simulation: consistent with 0.06 mag
  - New VIRCAM follow-up will help

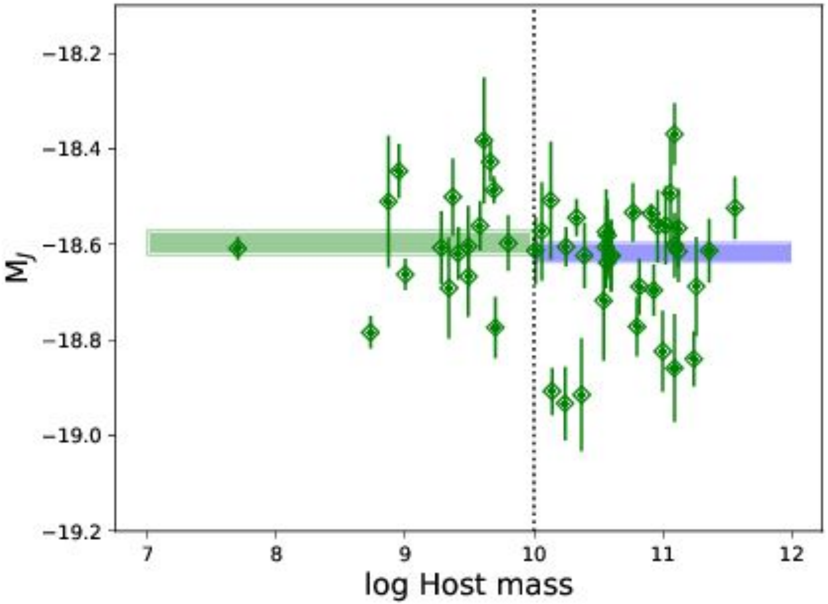


Fig: The J-band absolute magnitude versus host stellar mass, no significant evidence for “mass step” (Dhawan et al. in prep.)

“Snapshot” Method

- Stanishev + 2018 extend Hubble diagram
  - z_{max} ~ 0.2
  - Close to +10 days
  - Low scatter
- J & H band similar scatter
  - ~ 0.13 - 0.14 mag
  - Some subsamples show ~ 0.1 mag
  - Weak correlation with NIR colour
- Feasible for future high-z studies

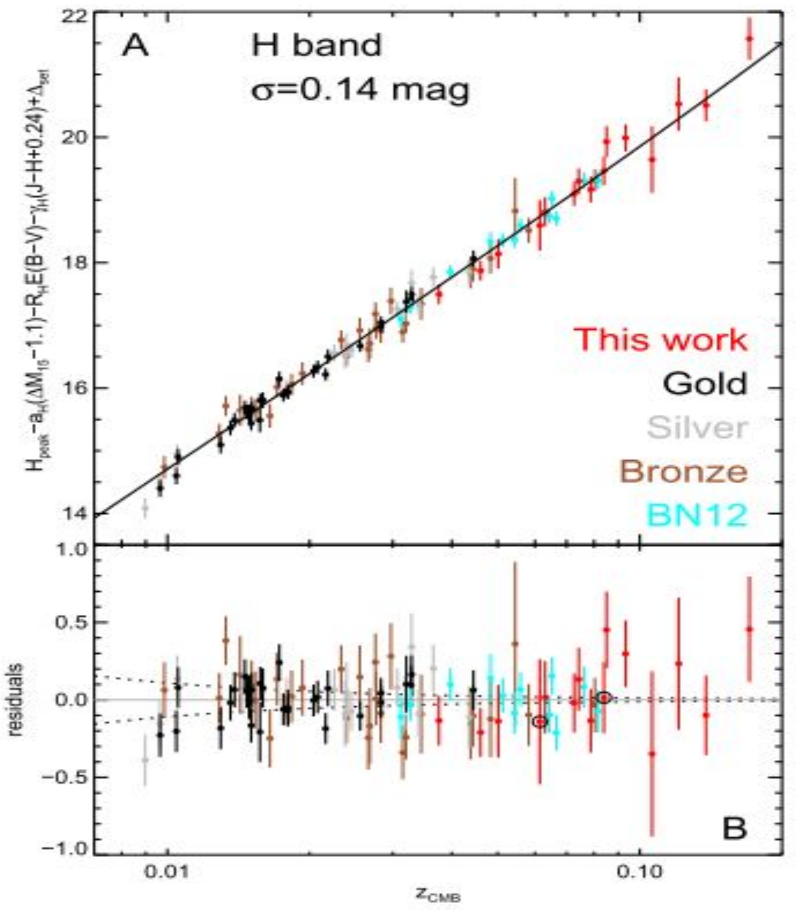


Fig: Hubble diagram from Stanishev et al. 2018 showing a low intrinsic scatter

Ongoing NIR program

- 40 SNe Ia from iPTF, 0.01 < z < 0.13, 4-10 NIR epochs
- *rizYJH* from 1.5m RATIR + *JH* with 8m VLT
- *UBVRI* / gri from NOT, P48, P60 and LCOGT

Johansson, Fox, Cenko et al. (work in progress)

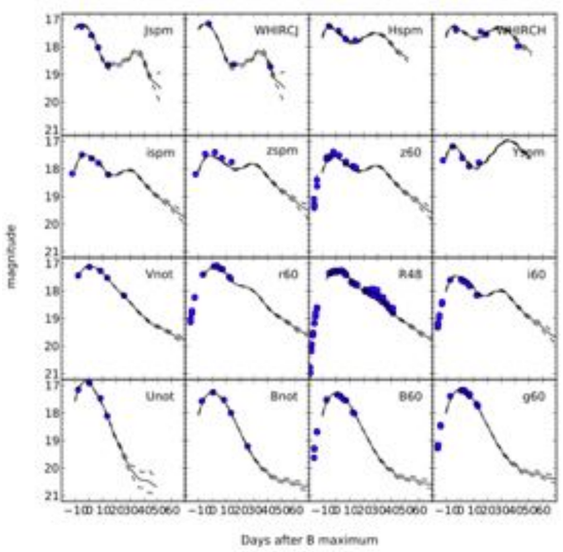
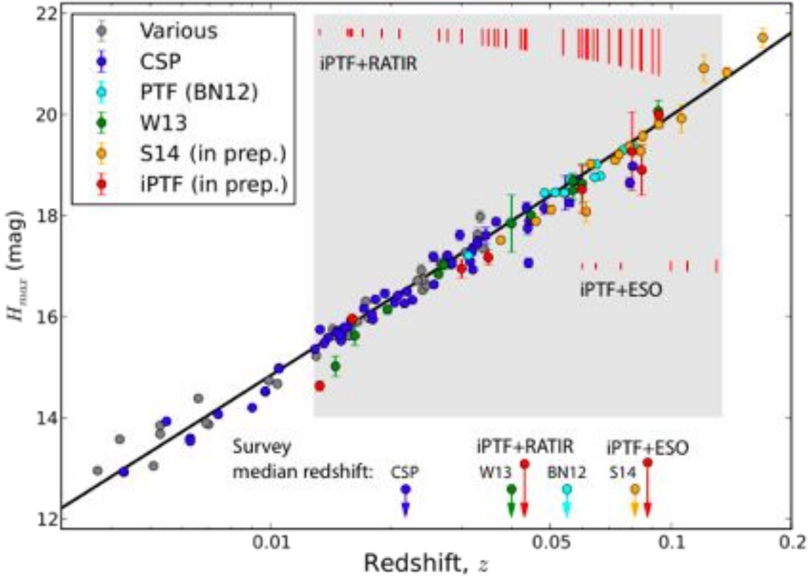
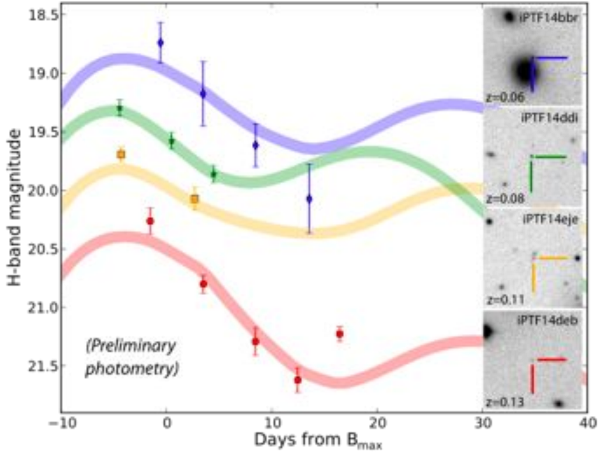


Fig: (Left): an example light curve with RATIR (iPTF13dkx). (Top right): A preliminary Hubble diagram with the iPTF SNe. (Bottom right): A higher-z SN measured with HAWK-I



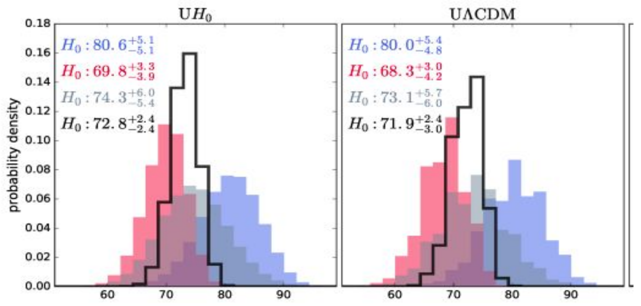


Conclusions

- NIR calibration of SN Ia magnitudes
- H_0 inferred agrees with optical
- Low statistical uncertainties
- No evidence for host correlation
- “Snapshot” Method: an interesting route to distances
- Work on higher-z SNe in progress

Precision H_0: current and future prospects

- Local distance ladder
  - Cepheids: 73.24 +/-1.74 km/s/Mpc
  - 2% with TRGB distances (Beaton et al. 2016)
- Time-delay distances (Bonvin et al. 2016)
  - H0liCOW survey: distances to 3 sources
  - H_0 = 72.8 +/- 2.4 km/s/Mpc (ΛCDM)
- Gravitational Wave: Standard sirens (Nissanke et al. 2013; Feeney et al. 2018)
  - H_0 to 5% (15 NS-NS binaries)
  - H_0 to 1% (30 beamed short GRBs)
  - “Inverse problem” to local distance ladder



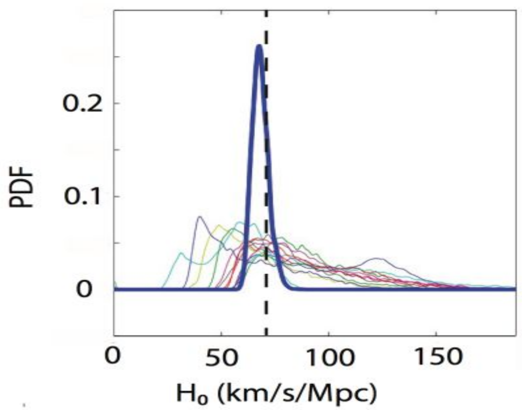


Figure: (Top) H_0 constraints from time-delay distances (Bottom) Constraints on H_0 from 15 NS-NS binaries with a three detector network (Nissanke et al. 2013).

Recent studies and H_0 tension?

- Local and CMB H_0 discrepant at ~3σ (SH$_0$ES; Riess et al. 2016)
- Exciting new physics?
- Comprehensive CMB tests (Galli et al.)
- Systematics checks: local H_0
  - Cepheid systematics (Follin & Knox 2017)
  - Hierarchical model (Feeney et al. 2017)
  - Blind analysis (Zhang et al. 2017)

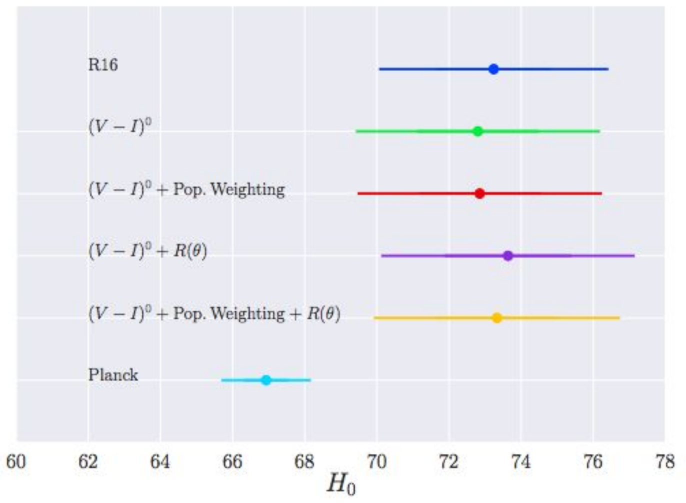


Figure: The robustness of H_0 to the different Cepheid systematic models (Follin & Knox 2017). Although the errors in the analyses could be greater than R16, they still prefer a higher H_0.