federica bianco - Associate Professor

(she/her)

University of Delaware | Biden School of Public Policy and Administration

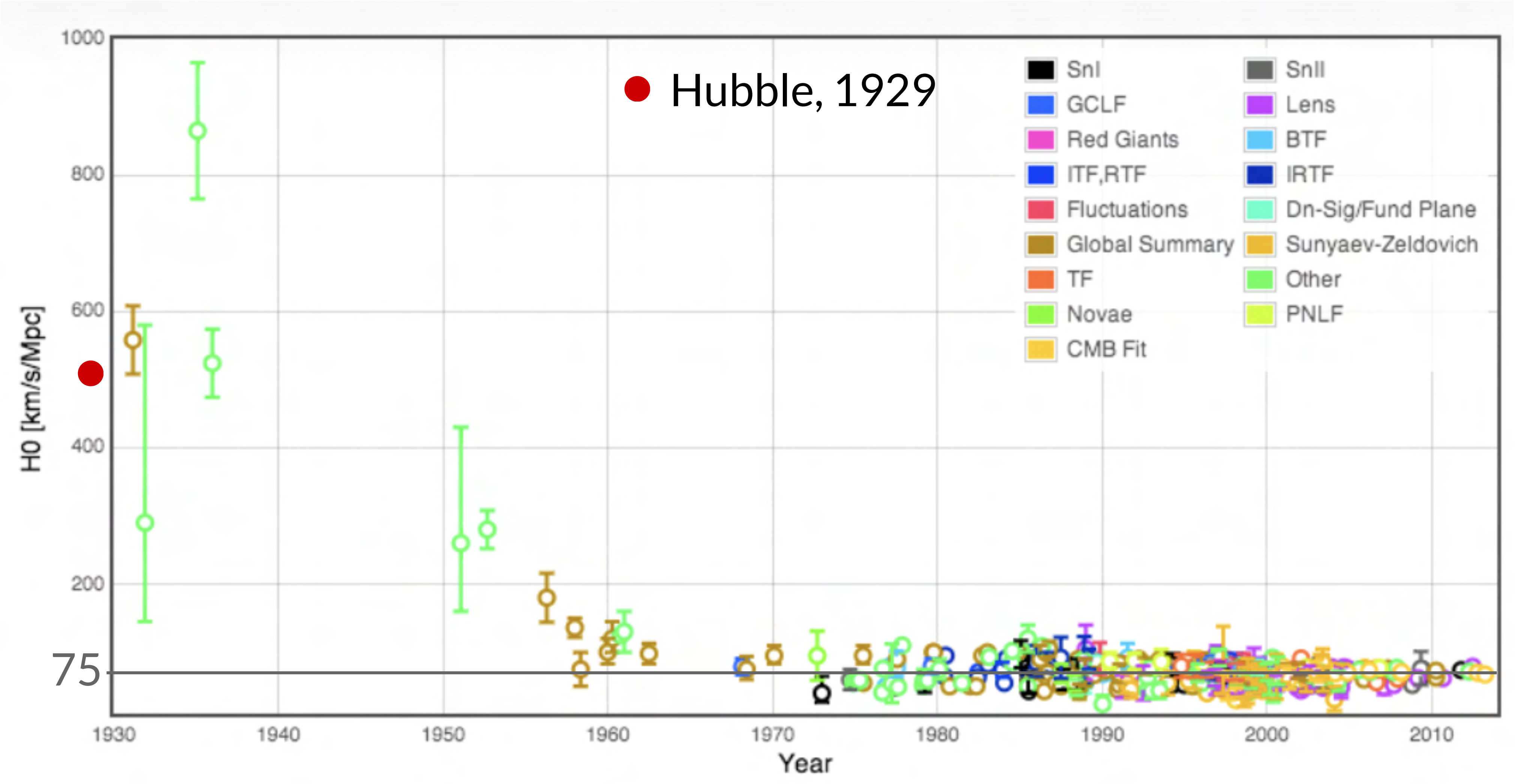
Department of Physics and Astronomy | Data Science Institute

Rubin Observatory Construction Project - *Deputy Project Scientist*

Rubin Transients and Variable Stars Science Collaboration

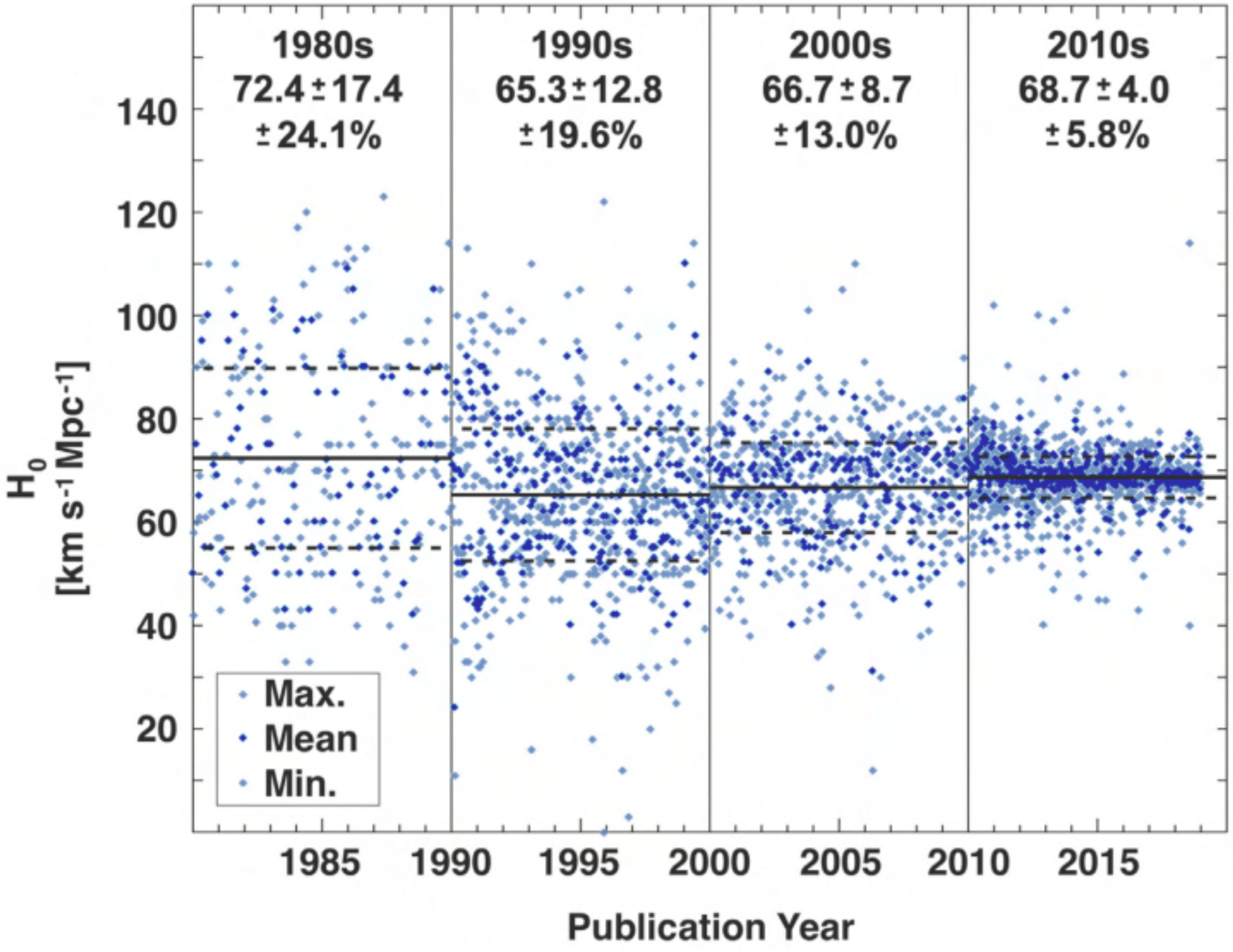
H0 measurements over time

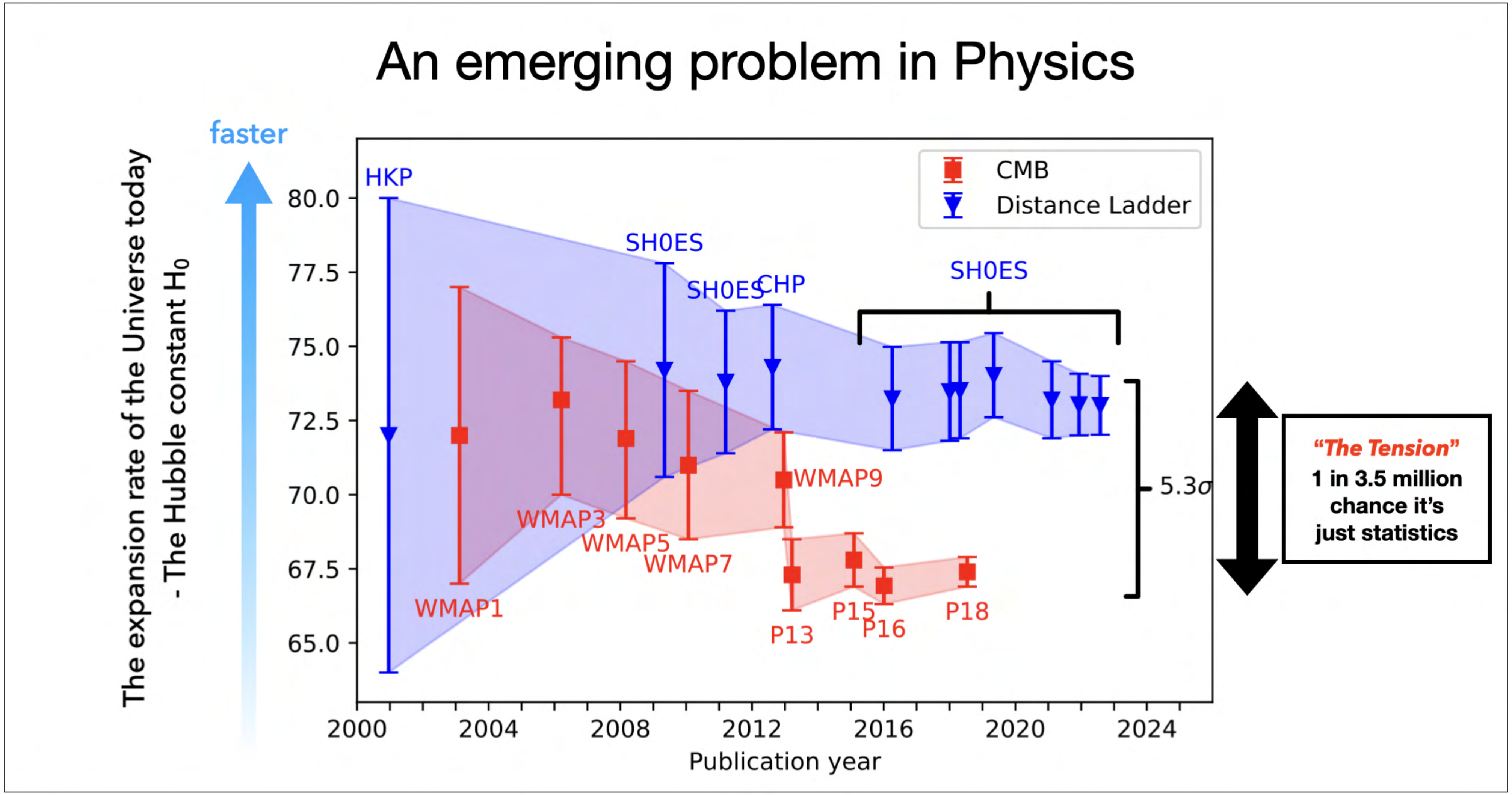
vicky scowcroft (cosmology lectures)



H0 measurements over time

Ian Steer, 2020





https://www.aura-astronomy.org/blog/2023/03/06/our-mysterious-universe-still-evades-cosmological-understanding/

adapted from Freedman et al. 2017 & Perivolaropoulos and Skara 2022

stochastic or random errors

unpredictable uncertainty in a measurement
due to lack of sensitivity in the measurement or
to stochasticity in a process

2.0 +/- ε cm, ε > 0.1 cm

stochastic or random errors

1) As the size of a sample tends to infinity the mean of the sample tends to the mean of the population

2) Count statistics follow a Poisson distribution with mean λ = N number of counts

if λ is large (>30) Poisson ~ Gaussian

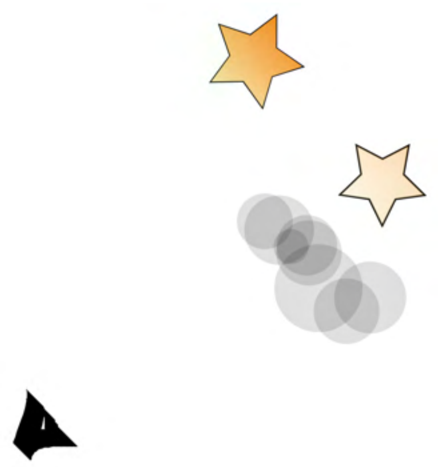
$$\hat{X} \sim N(\lambda, \sqrt{\lambda})$$

For inherently random phenomena that involve counting individual events or occurrences, we measure only a single number N. This kind of measurement is relevant to counting the number of radioactive decays in a specific time interval from a sample of material. It is also relevant to counting the number of Lutherans in a random sample of the population. The (absolute) uncertainty of such a single measurement, N, is estimated as the square root of N.

As example, if we measure 50 radioactive decays in 1 second we should present the result as 50±7 decays per second.

https://www.edouniversity.edu.ng/oerrepository/articles/phy_119_general_physics_practical_20182019.pdf

systematic errors



reproducible inaccuracy introduced by faulty equipment, calibration, or technique.

~~2.5~~ 2.7 => 2.5 + 0.2 +/- 0.1

systematic errors

reproducible inaccuracy introduced by faulty equipment, calibration, or technique.

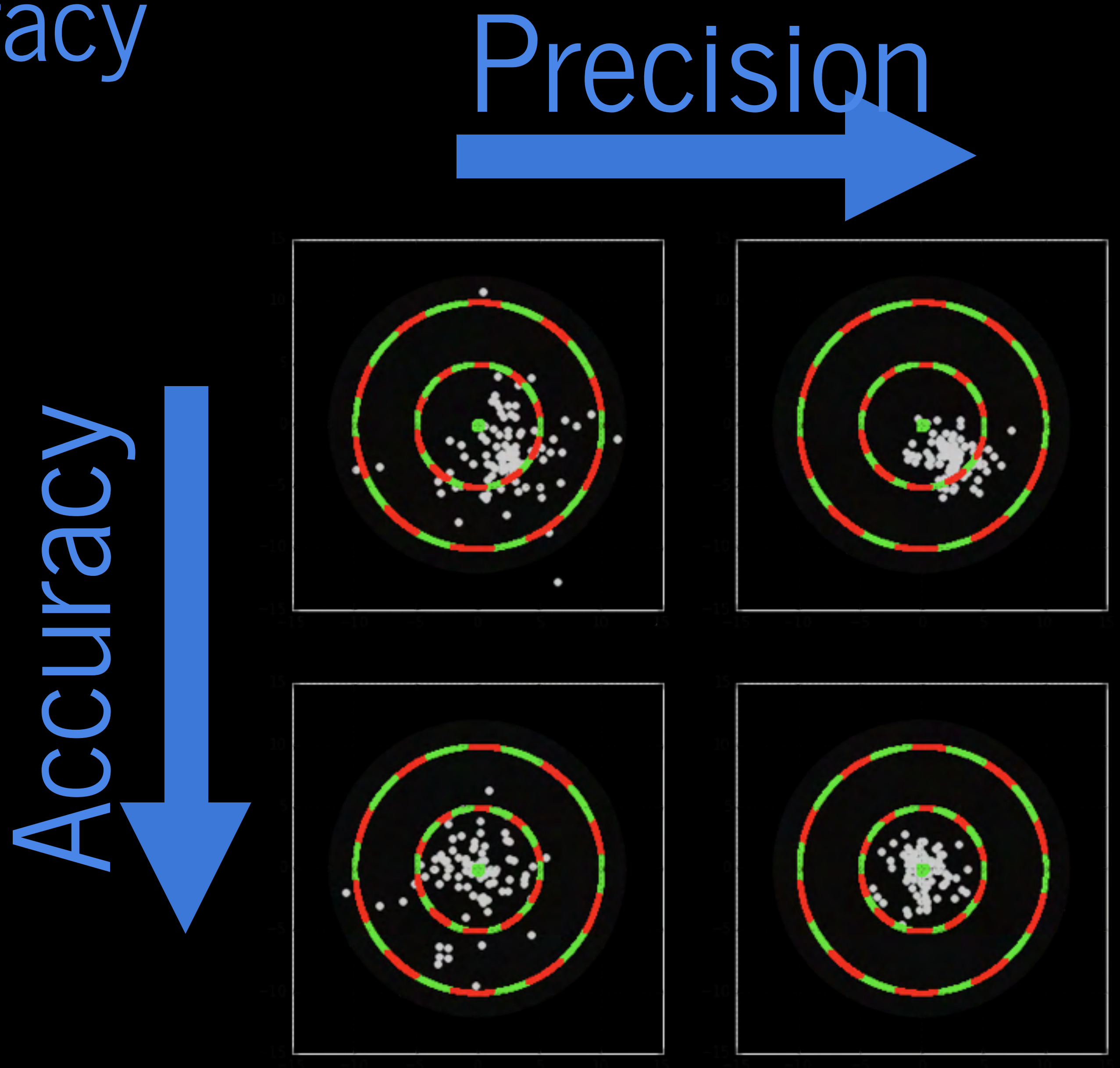
- Measurements are taken at 22 C with a steel rule calibrated at 15 C. This is a systematic *bias* and not a systematic *uncertainty*
- *Brightness* is known, distance is estimated accordingly. In space interstellar dust can make sources dimmer, but not brighter. systematic *uncertainty*

~~2.5~~ 2.7 => 2.5 + ? +/- 0.1

Stochastic vs Systematics

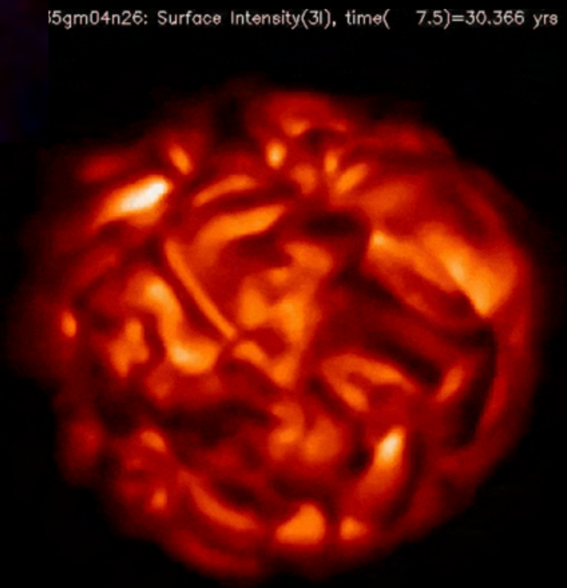
Statistical	**Systematic**
No preferred direction	Biases the measurement *in one direction*
Shrinks with the sample size (typically as $\sqrt{N}$)	Affects the sample regardless of the size
Typically Gaussian or Poisson	Any distribution, including constant

Precision vs Accuracy

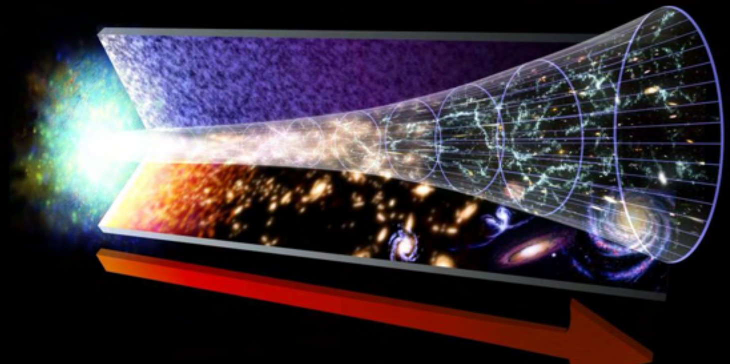


Reason to study Supernovae

SN are enable life in the Universe



SN are natural extreme physics laboratories

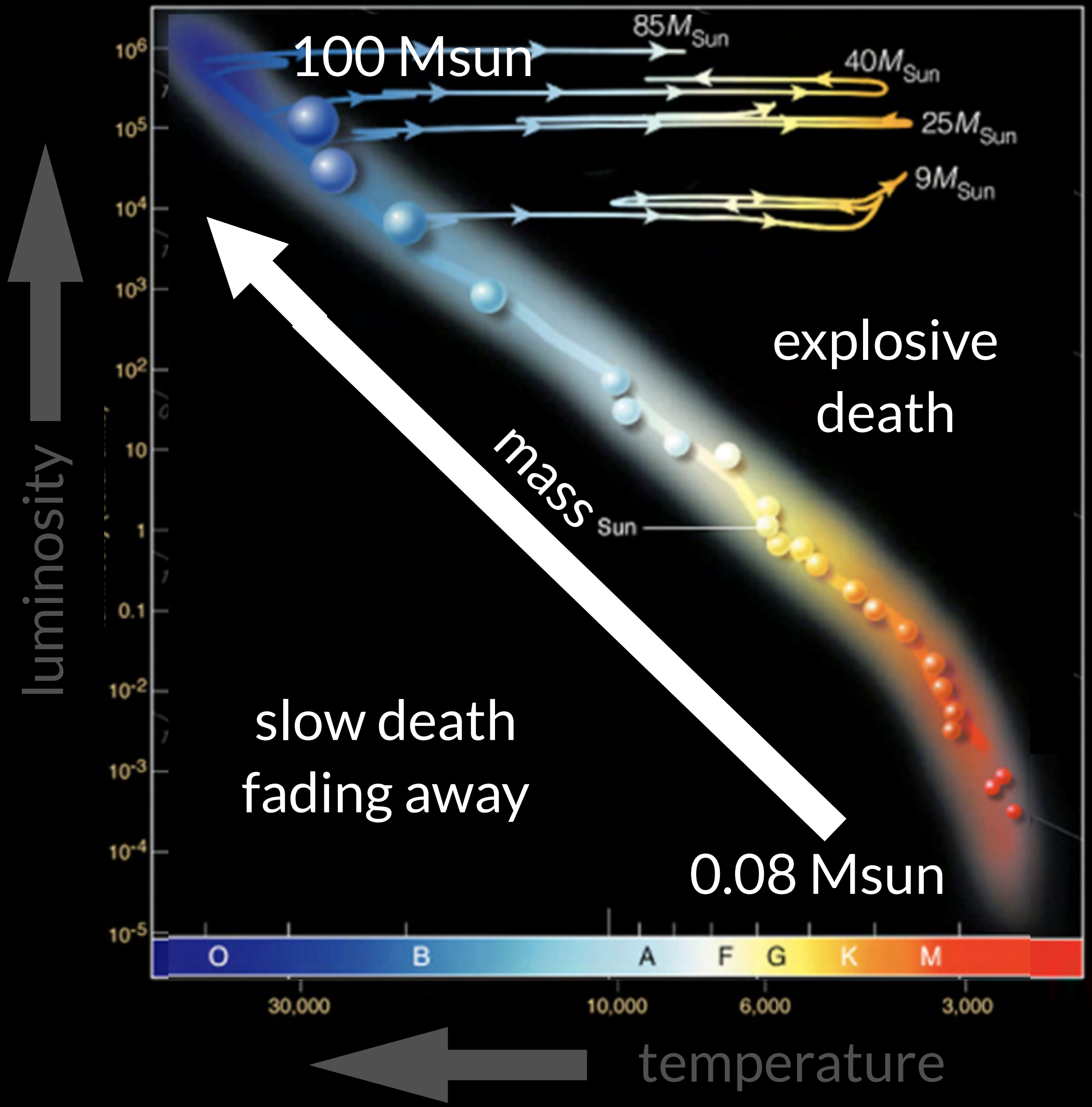


SN trace the evolution of the Universe

lives of stars

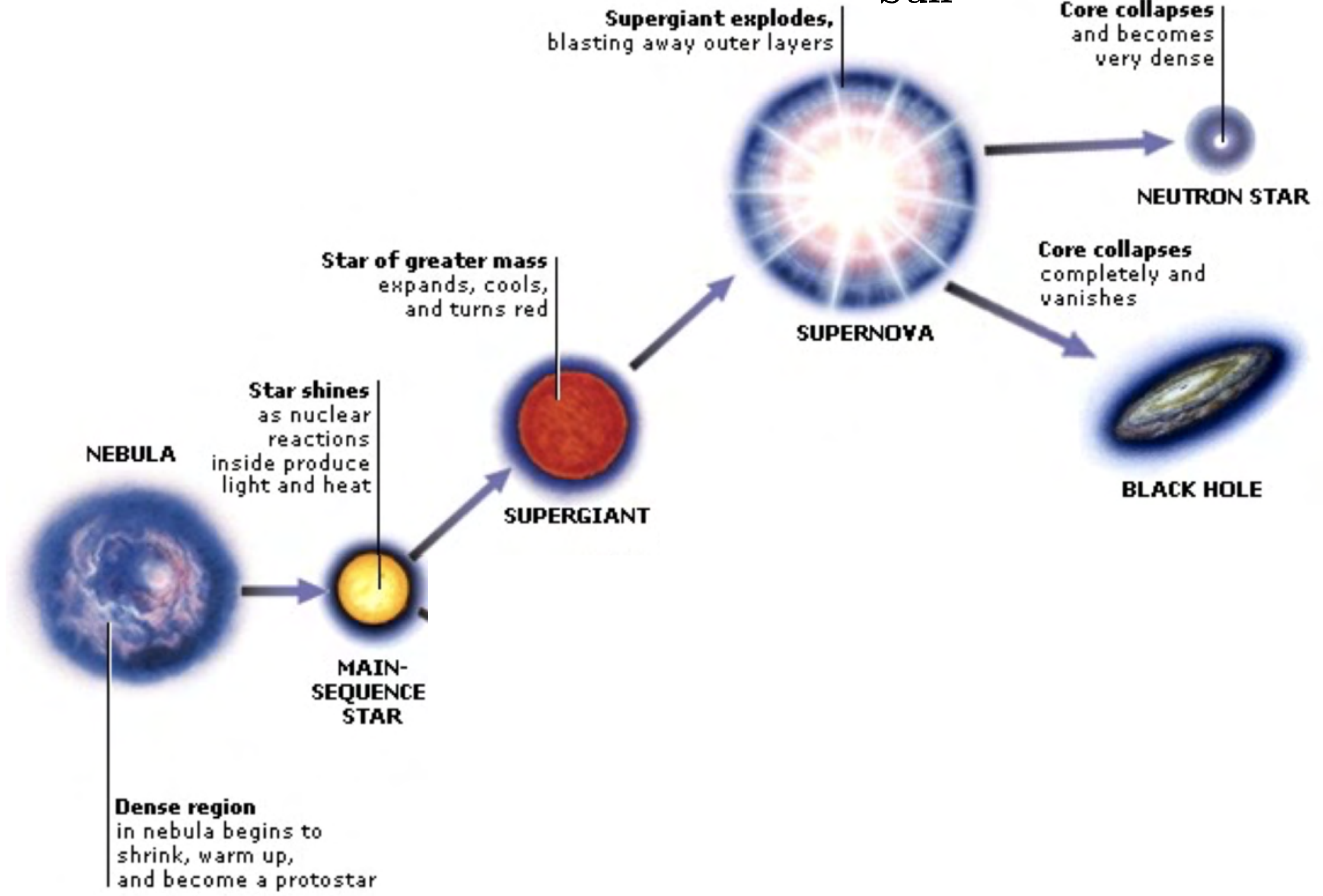
Twinkle twinkle little star
I'm aware of what you are
you are a glowing ball of gas
how you live depends on mass

Adapted from Prof. Viviana Aquaviva



lives of stars

$$t_{\mathrm{MS;Sun}} = 10 \text{ Billion years} \qquad \frac{t_{\mathrm{MS}}}{t_{\mathrm{Sun}}} = \left(\frac{M_{\mathrm{Sun}}}{M}\right)^{2.5}$$



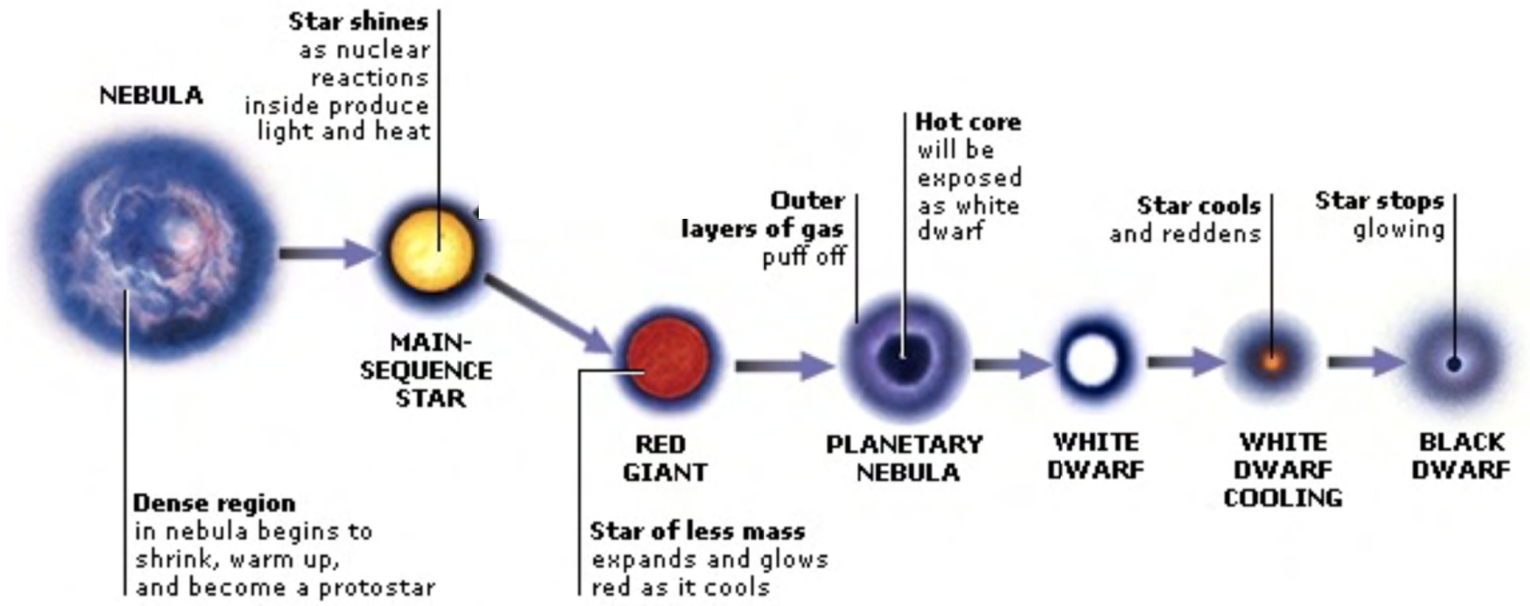
high initial mass

8-100 M_{Sun}

live fast and die in spectacular explosions

lives of stars

$$t_{\text{MS;Sun}} = 10 \text{ Billion years} \qquad \frac{t_{\text{MS}}}{t_{\text{Sun}}} = \left(\frac{M_{\text{Sun}}}{M}\right)^{2.5}$$

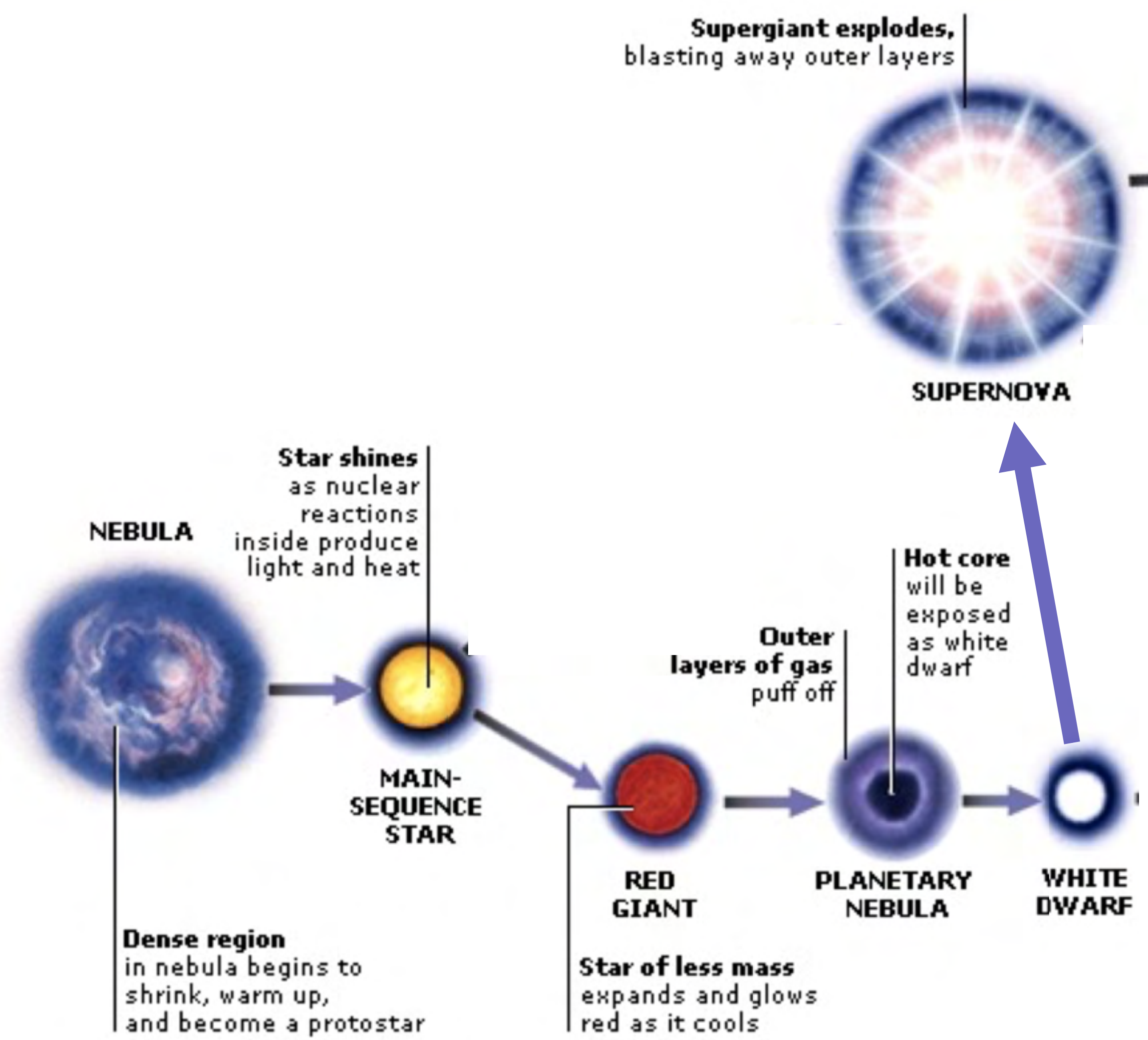


low initial mass

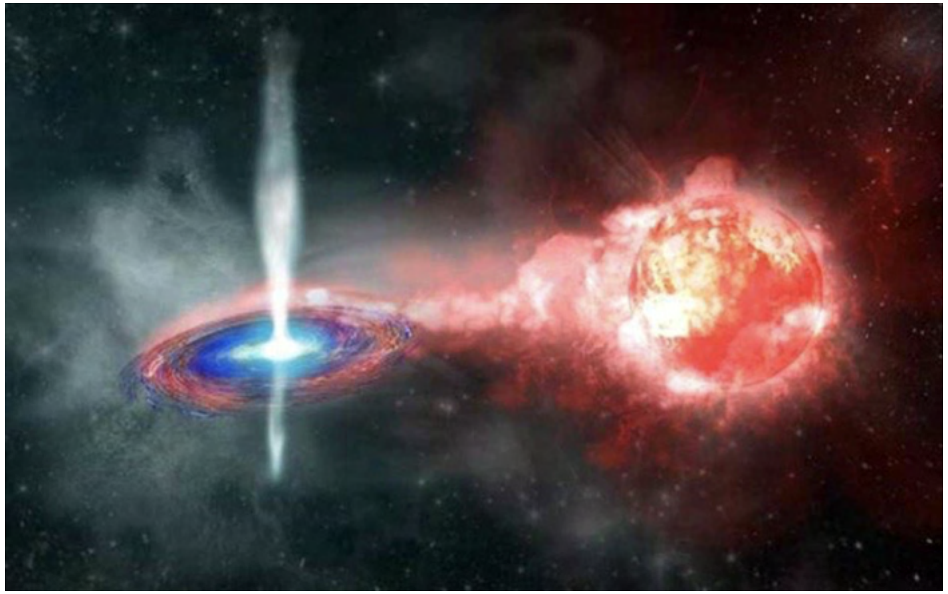
0.1-8 M_{Sun}

….. live to be old and die peacefully by slowly cooling down

lives of stars

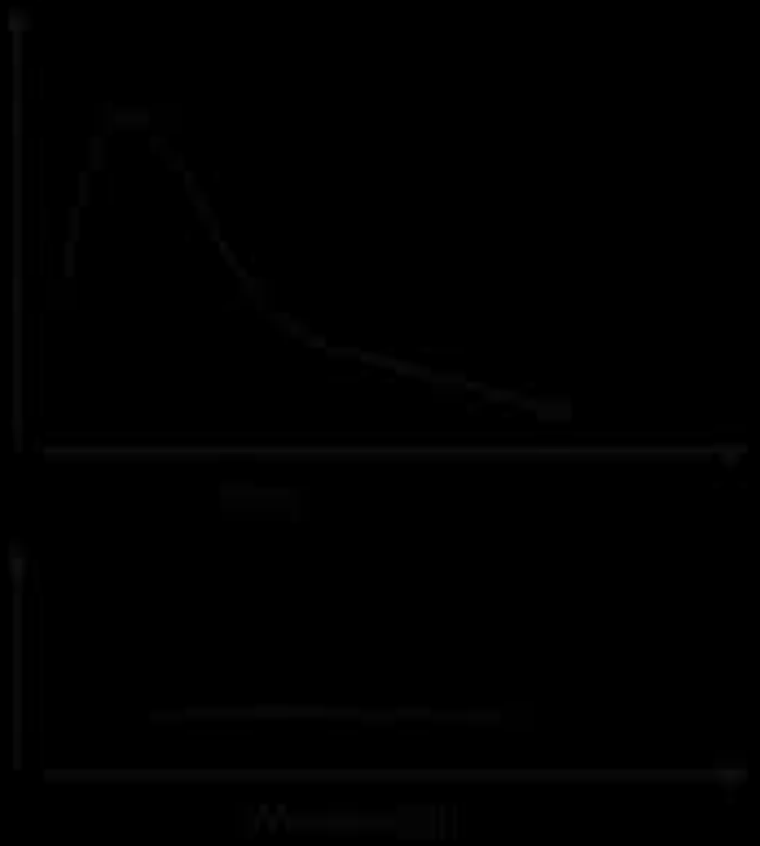


even a low mass start will explode if its in a binary system and captures mass from the companion



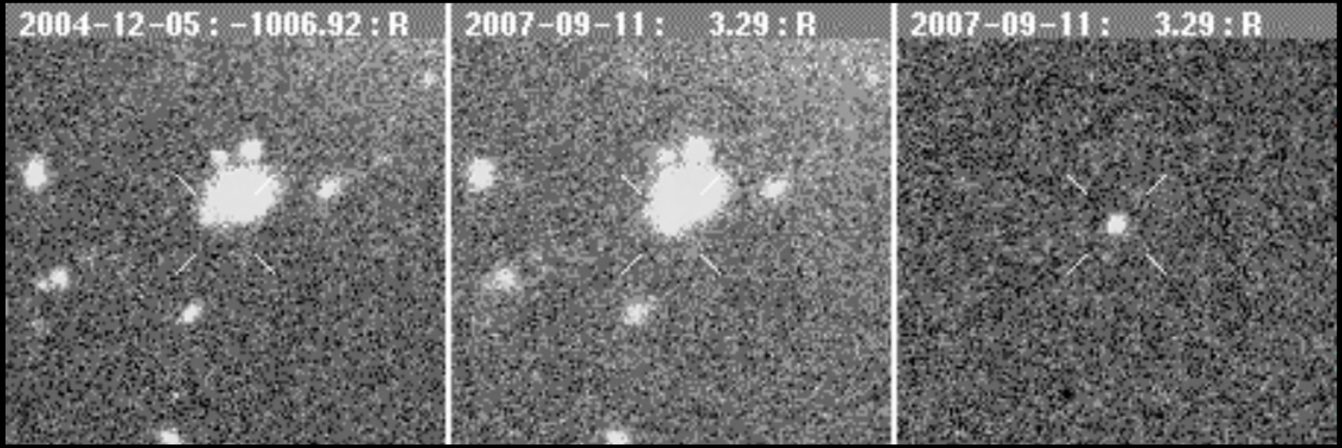
low initial mass but with a sibling

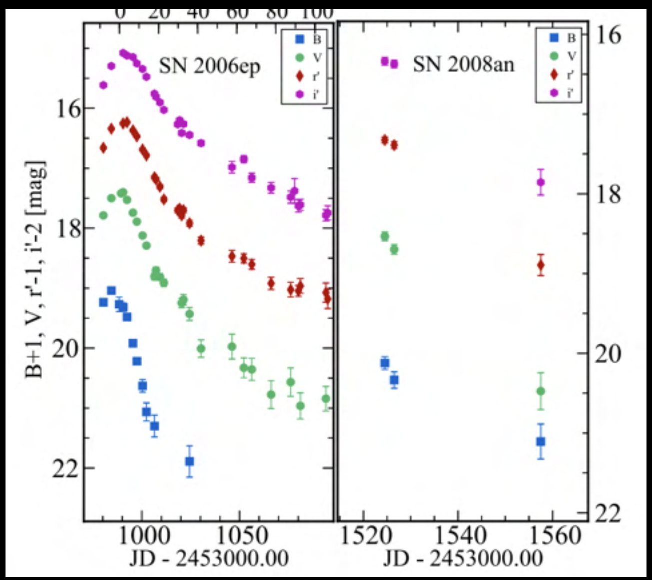
how we study SNe

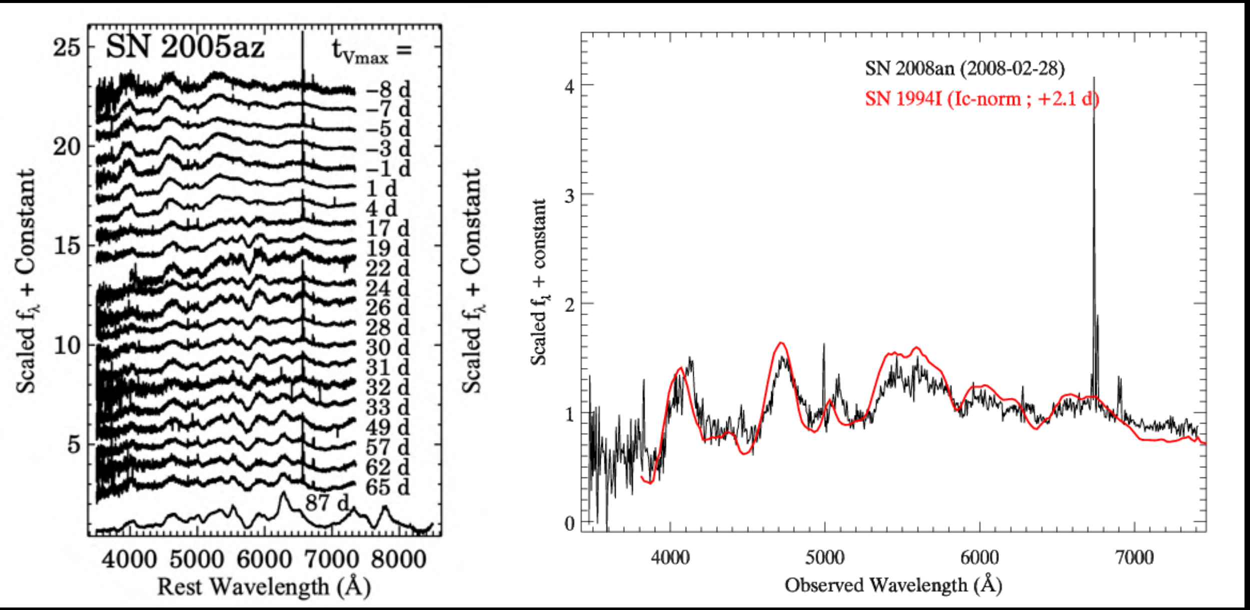


https://www.youtube.com/watch?v=aiAQqzIB-O8

how we study SNe







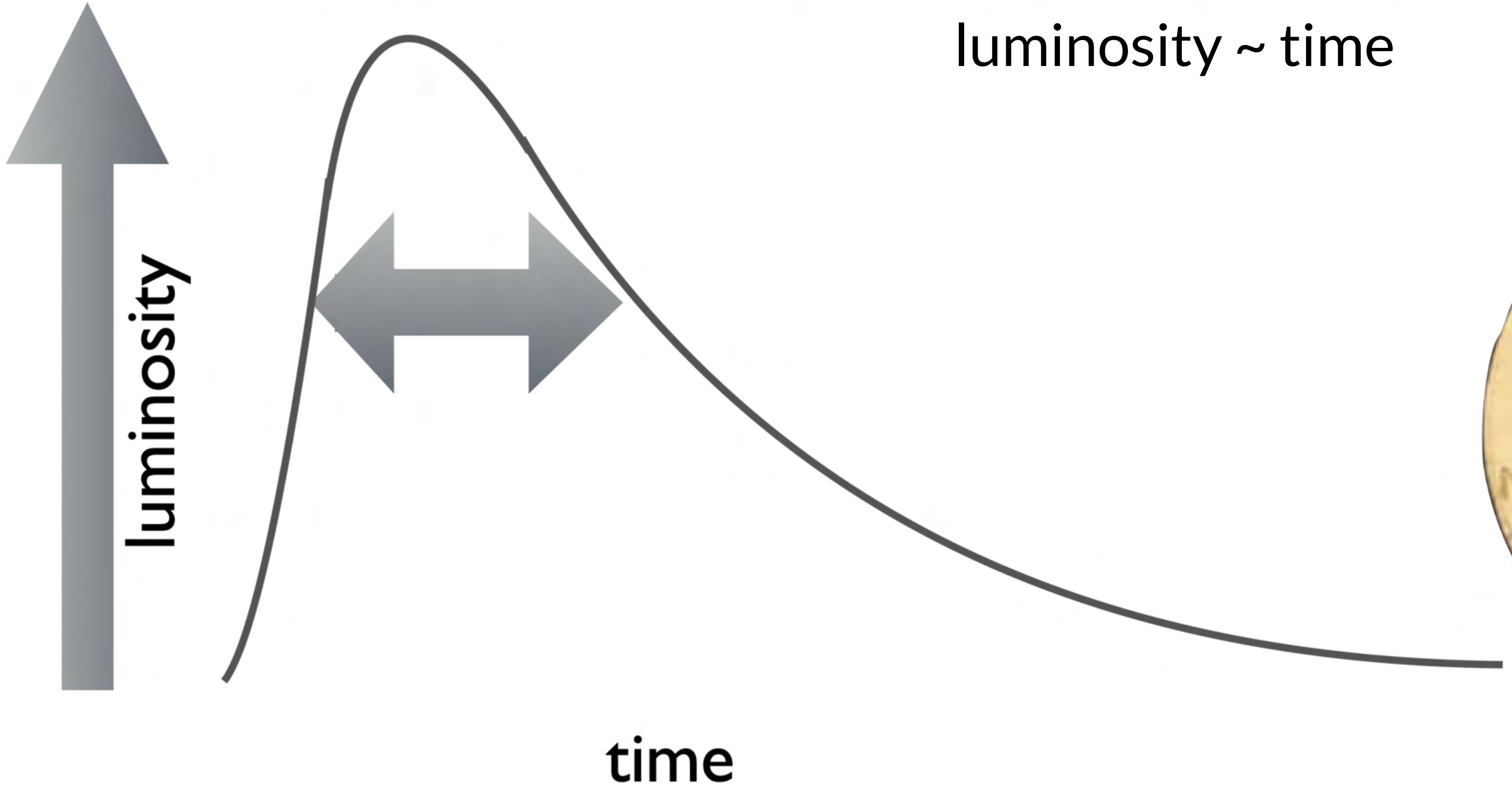
SN Ia cosmology

Nobel Prize winning - SN Ia

$$\mu_0 = m_0 - M_0 = 5\log D + 25[Mpc]$$

A special type of Supernova: SN Ia

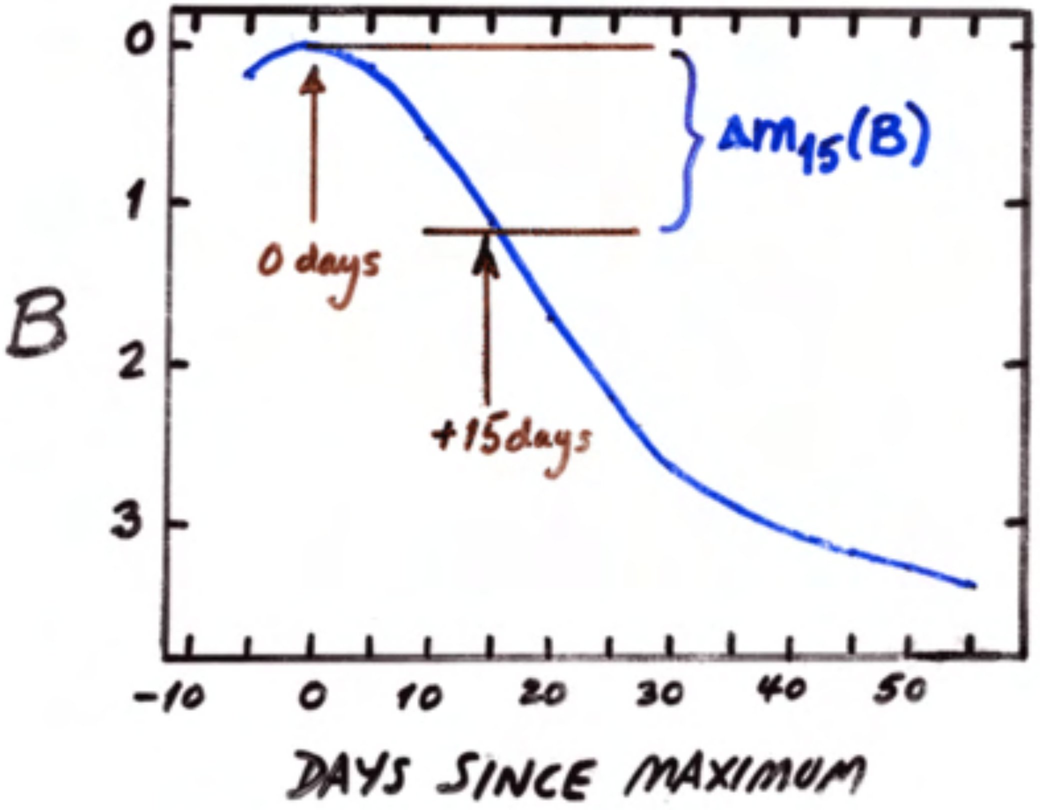
luminosity ~ time



S. Perlmutter

A.Riess, B. Schmidt

SN Ia are *standardizable* candles

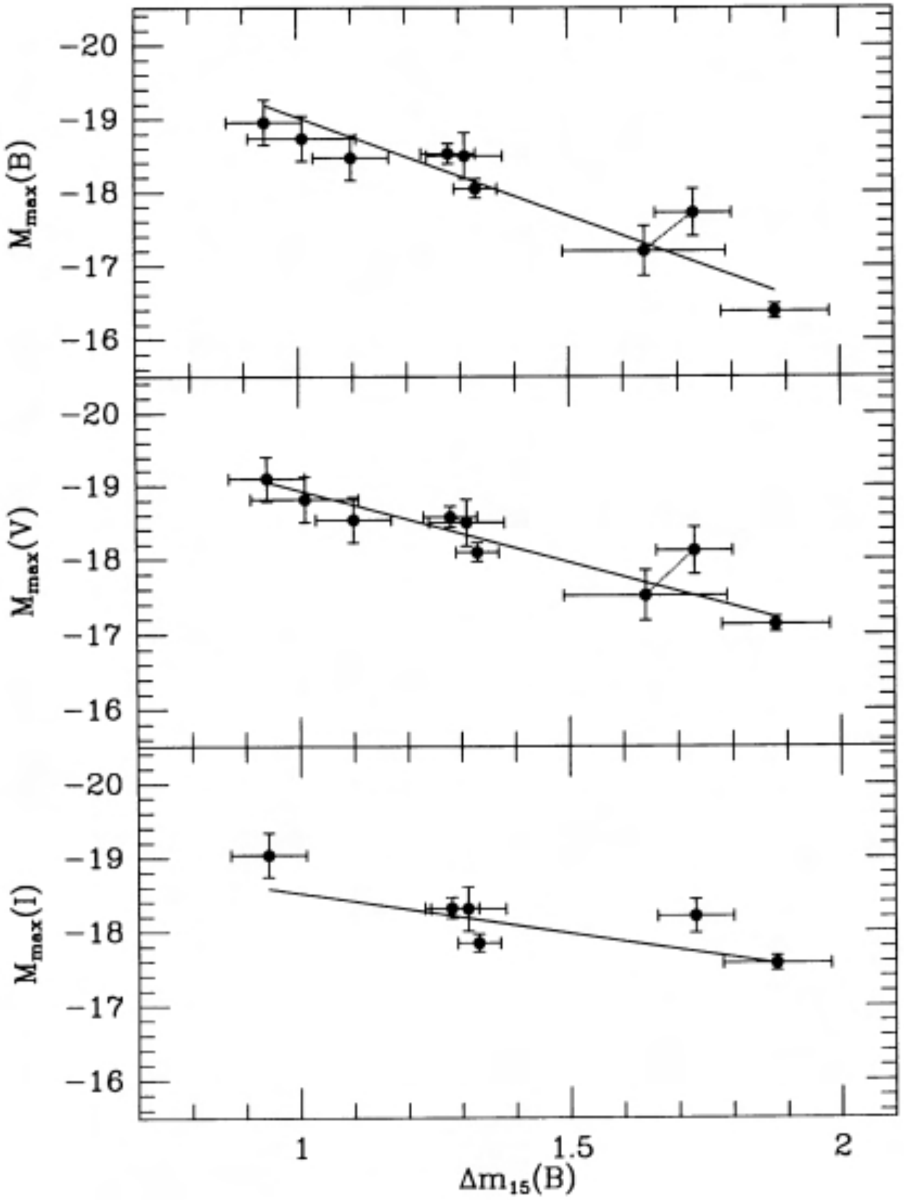


THE ABSOLUTE MAGNITUDES OF TYPE Ia SUPERNOVAE

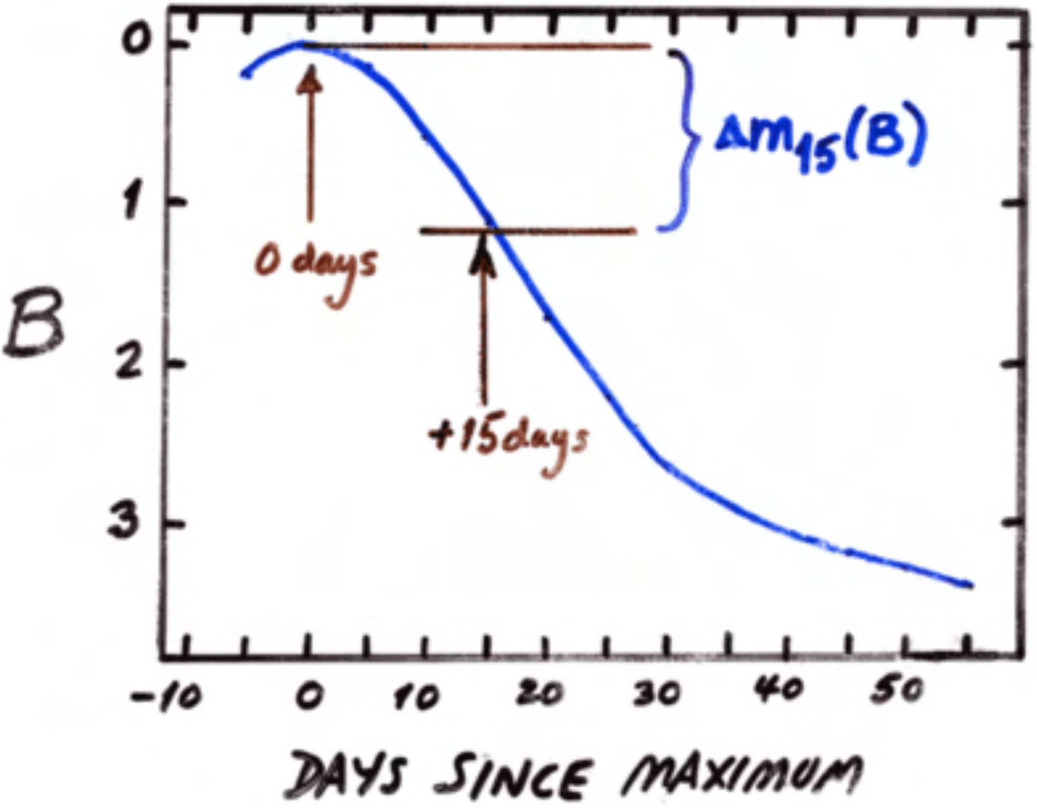
M. M. PHILLIPS

Cerro Tololo Inter-American Observatory, National Optical Astronomy Observatories,[1] Casilla 603, La Serena, Chile

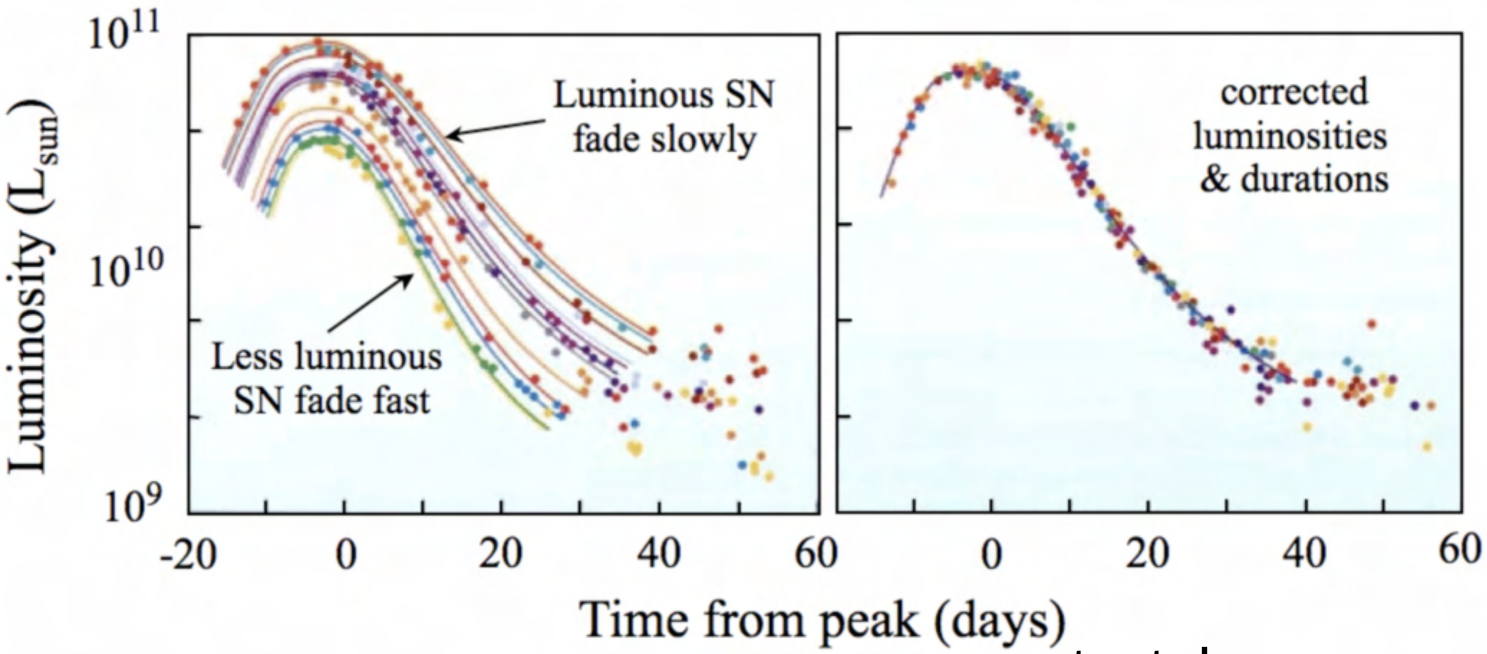
Received 1993 March 22; accepted 1993 June 2



SN Ia are *standardizable* candles



$$M_{\max}(B) = -21.726 + 2.698\Delta m_{15}(B)$$



stretch

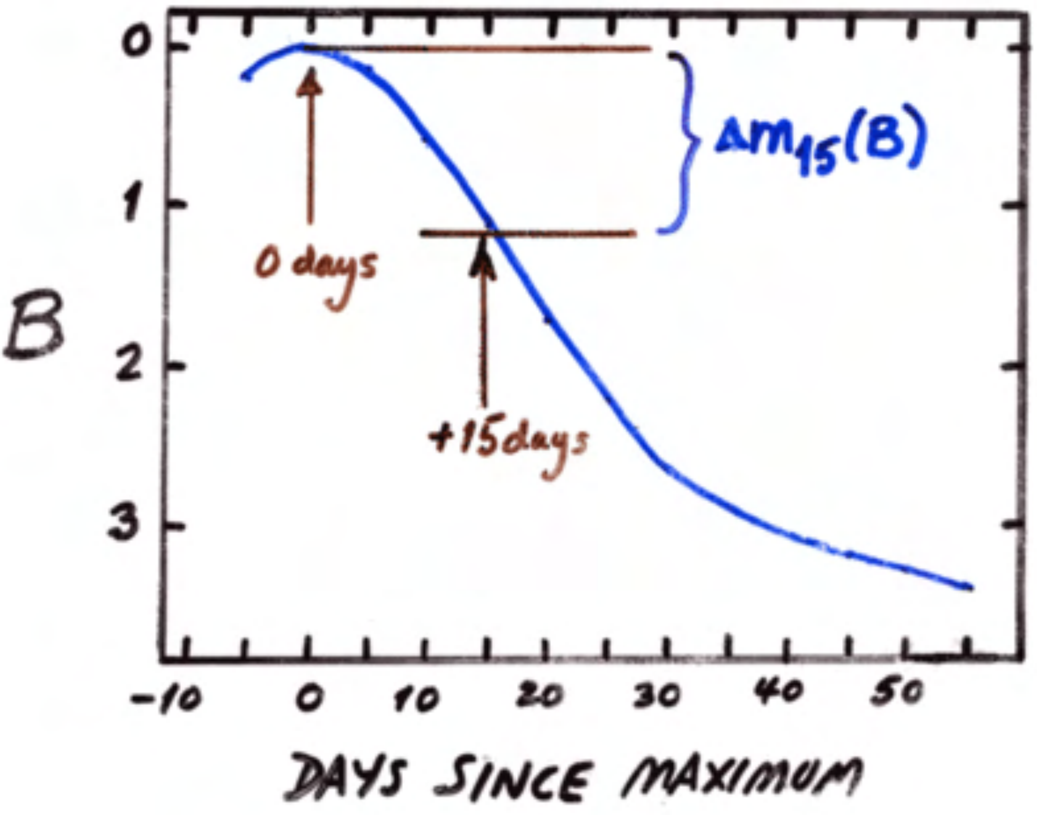
$$\mu = m_B + \alpha x_1 - \beta c - M$$

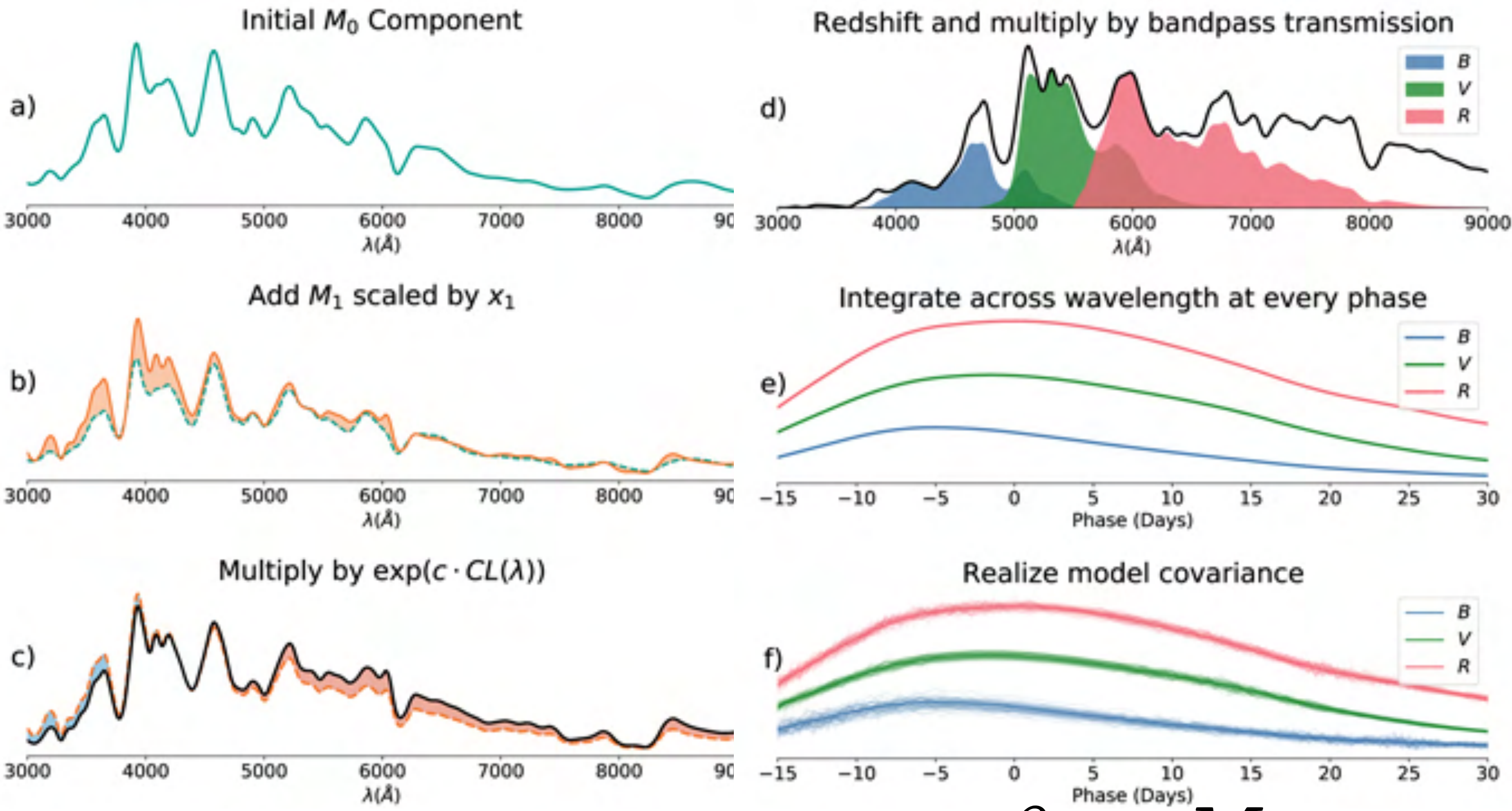
color

$$\sigma_\mu = \sigma^2_{\rm int} + \sigma^2_{\mu,z} + \sigma^2_{\rm lens} + \sigma^2_{m_B} + (\alpha\sigma_{x_1})^2 + (\beta\sigma_c)^2 + 2\alpha\beta\sigma_{c,x_1} + 2\alpha\sigma_{m_B,x_1} + 2\beta\sigma_{m_B,c}, \quad (17)$$

SN Ia are *standardizable* candles

https://iopscience.iop.org/article/10.3847/1538-4357/ac30d8





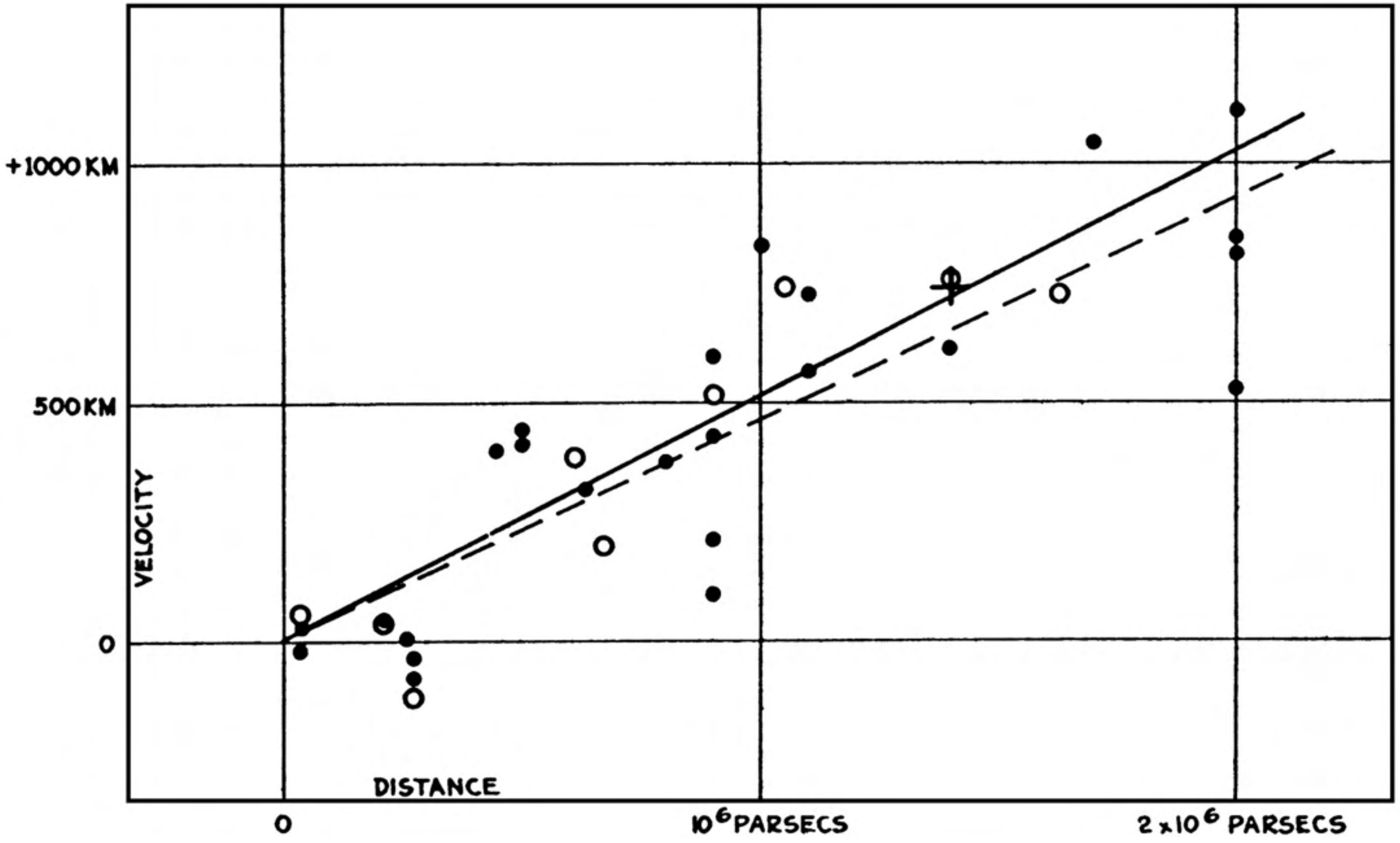
$$\mu = m_B + \alpha x_1 - \beta c - M$$

$$\sigma_\mu = \sigma^2_{\mathrm{int}} + \sigma^2_{\mu,z} + \sigma^2_{\mathrm{lens}} + \sigma^2_{m_B} + (\alpha\sigma_{x_1})^2 + (\beta\sigma_c)^2 + 2\alpha\beta\sigma_{c,x_1} + 2\alpha\sigma_{m_B,x_1} + 2\beta\sigma_{m_B,c}, \qquad (17)$$

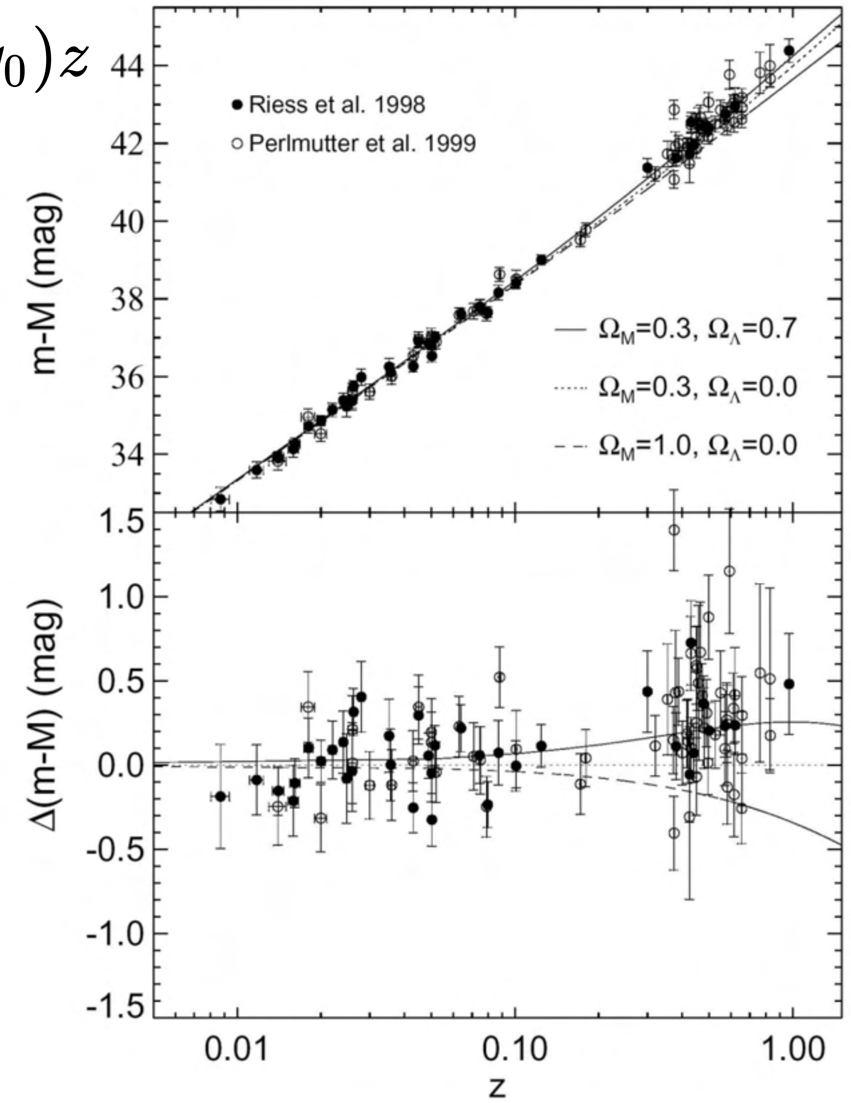
Nobel Prize winning - SN Ia

$$\mu_0 = m_0 - M_0 = 5\log D + 25[Mpc]$$

$$\mu_0 = 43.17 - 5\log_{10}\left(\frac{H_0}{70\,\frac{m}{s\,Mpc}}\right) + 5\log_{10}(z) + 1.086(1-q_0)z$$



Hubble 1929



Nobel Prize winning - SN Ia

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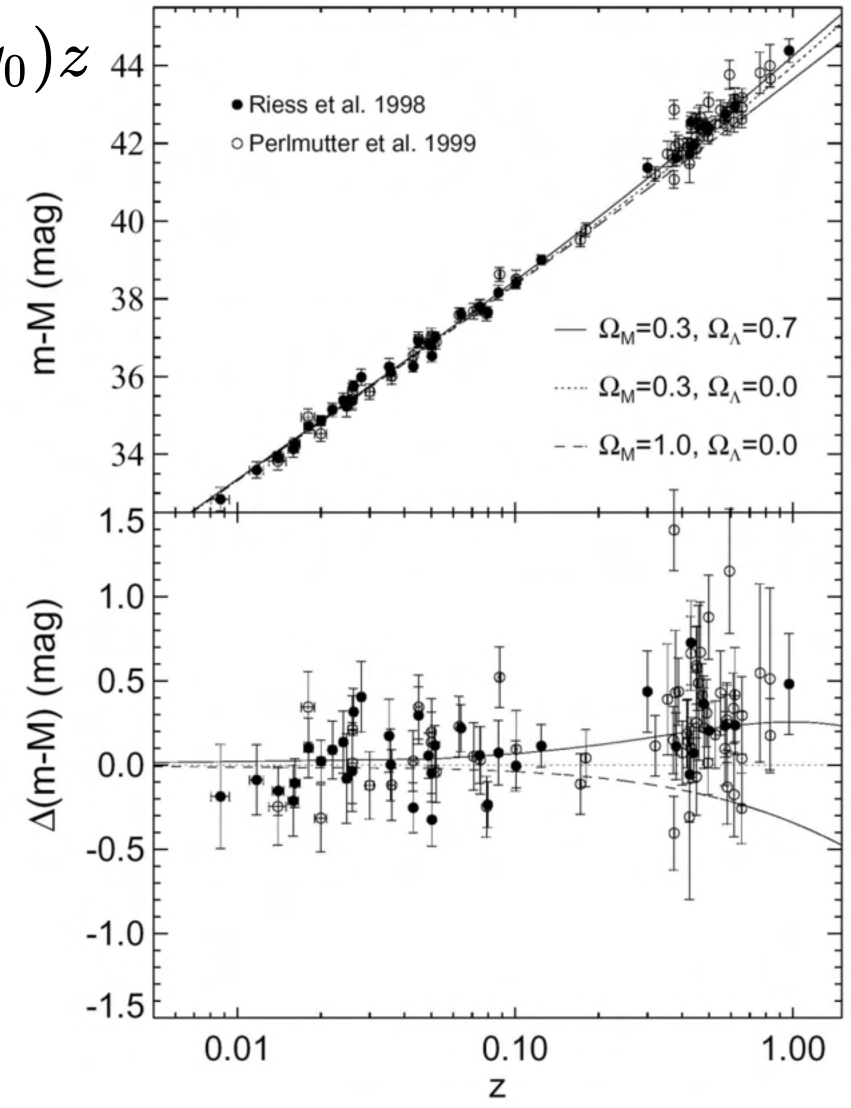
$$\mu_i^{model}(z_i;\Omega_m, w_0) \propto 5log_{10}\left(\frac{c(1+z)}{h_0}\right)\int_0^z \frac{dz'}{E(z')}$$

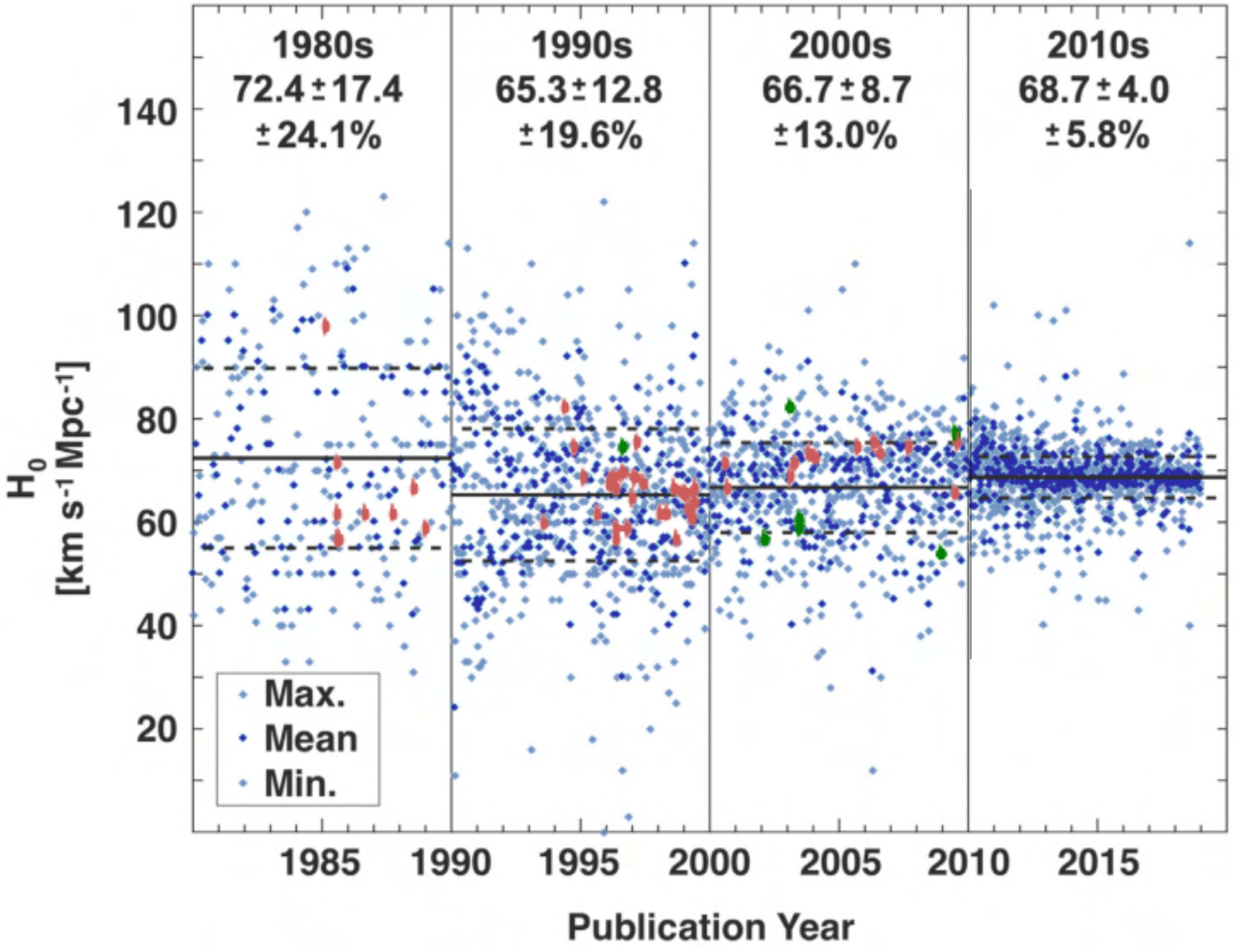
$$E(z) = \sqrt{\Omega_m(1+z)^3 + (1-\Omega_m)e^{3\int_0^z dln(1+z')[1+w(z')]}}$$

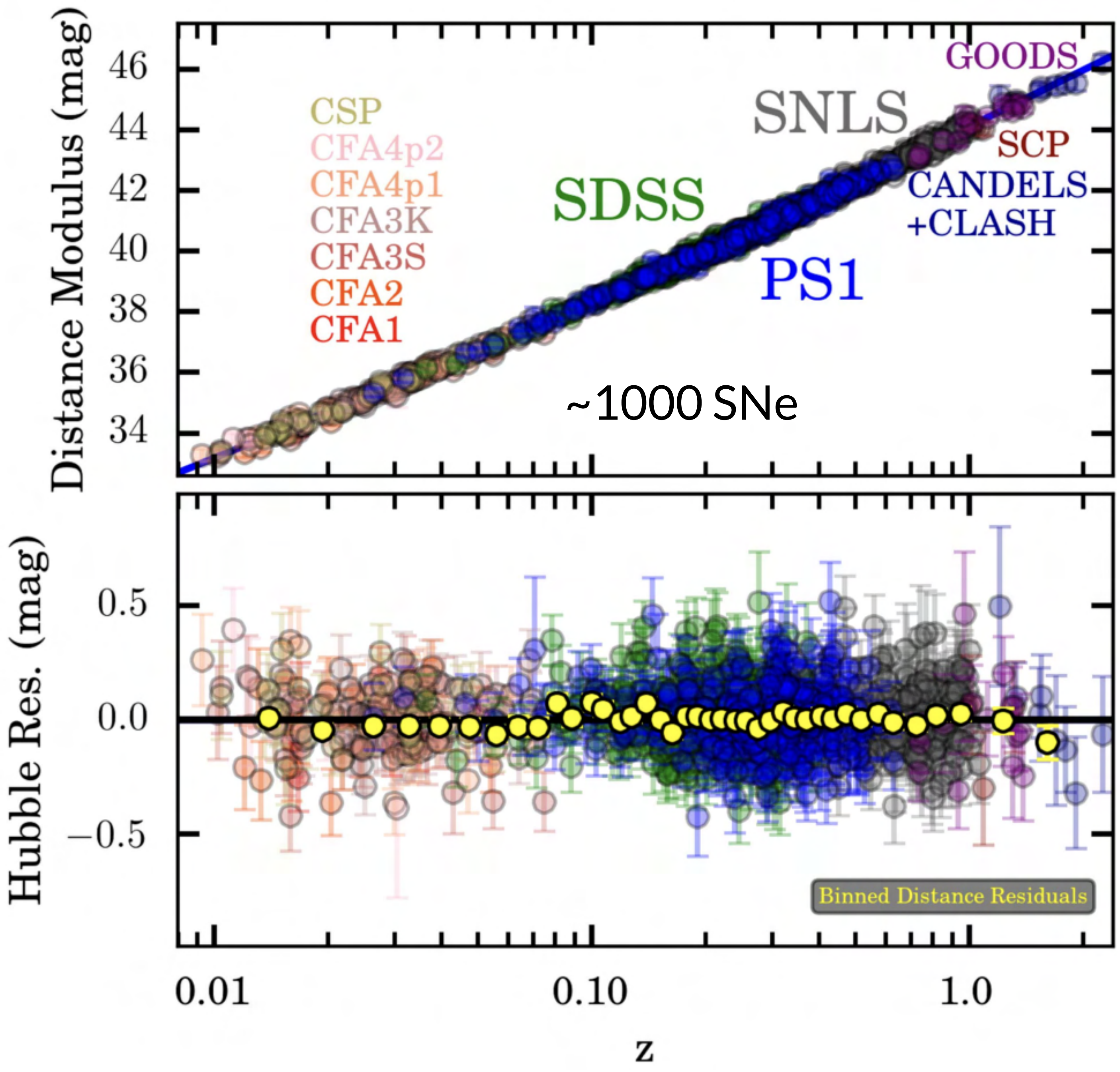


H0 measurements
over time

Ian Steer, 2020

derived from SN Ia
derived from SN II



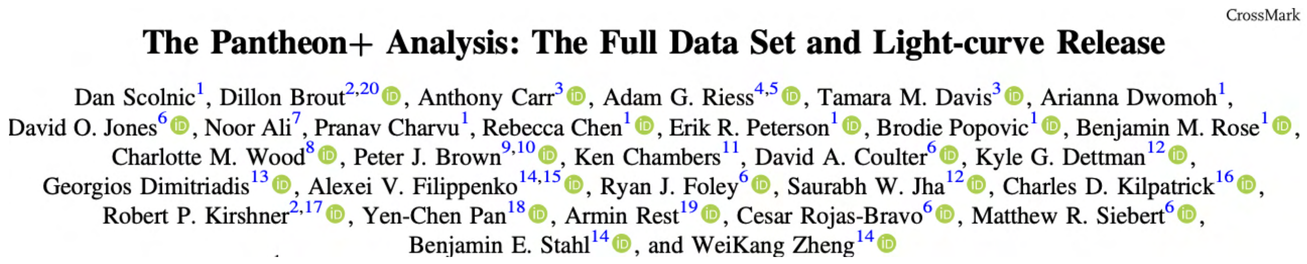


Scolnic+ 2022

Systematics affecting SN cosmology

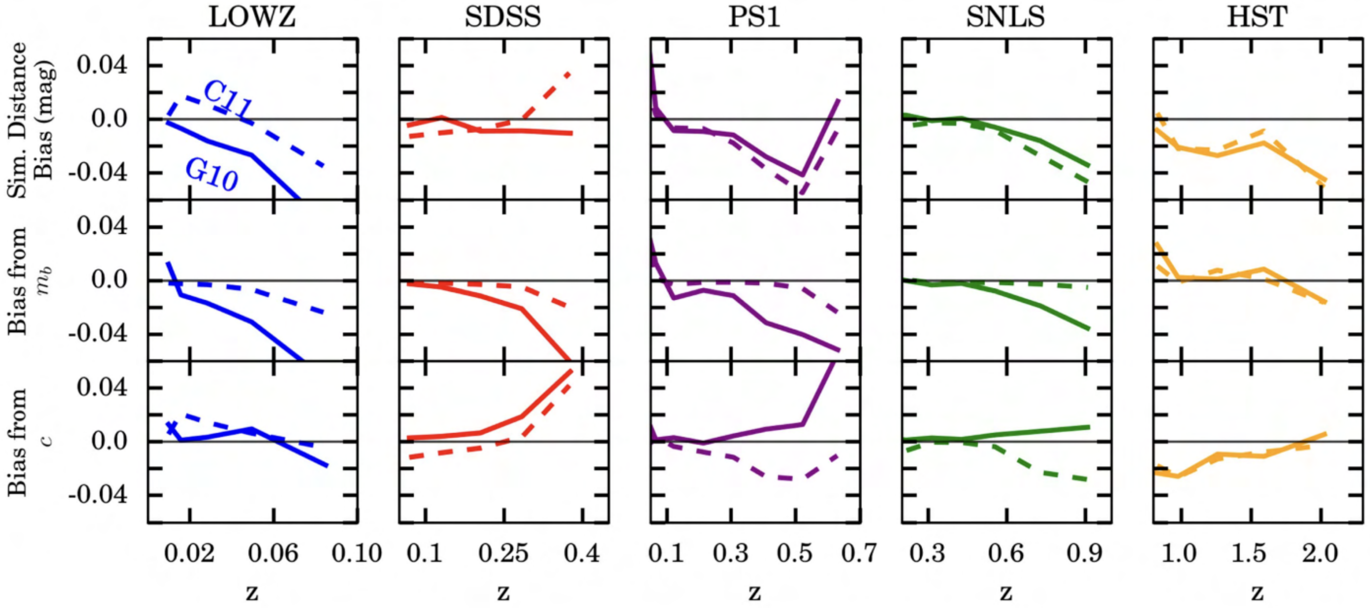
"The statistical and systematic uncertainties in recent SN Ia cosmology analyses have been roughly equal."

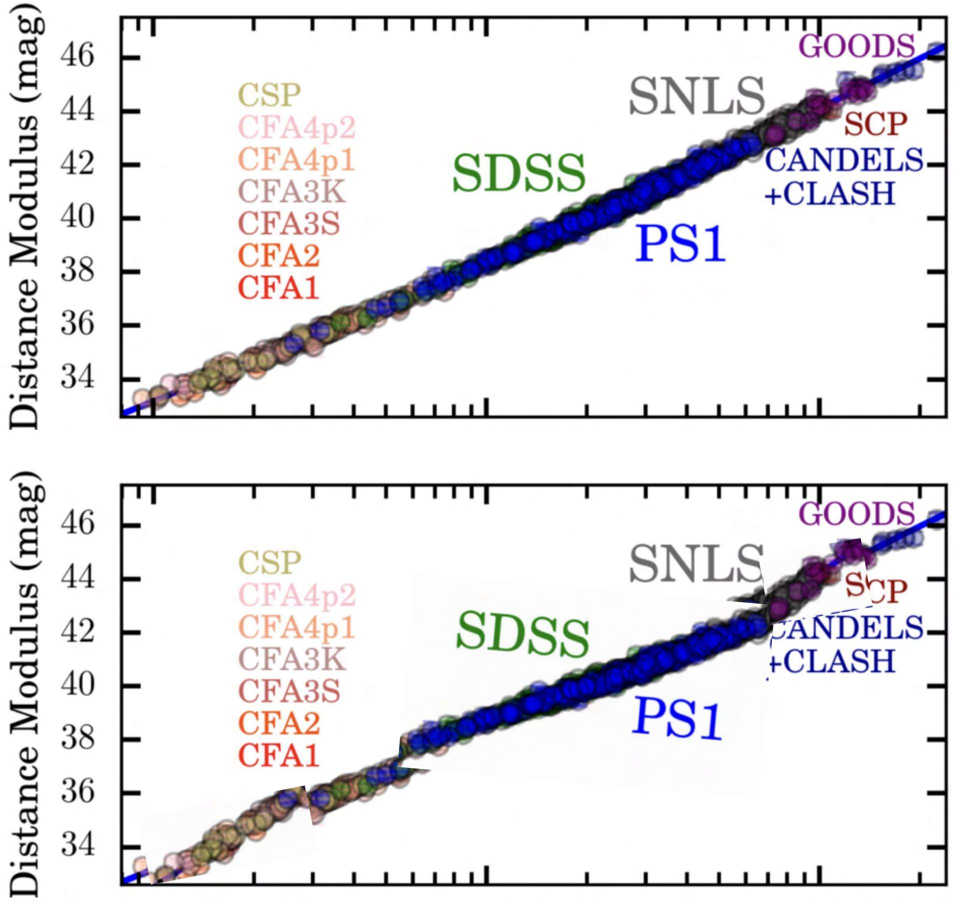
279 spectroscopically confirmed SNe

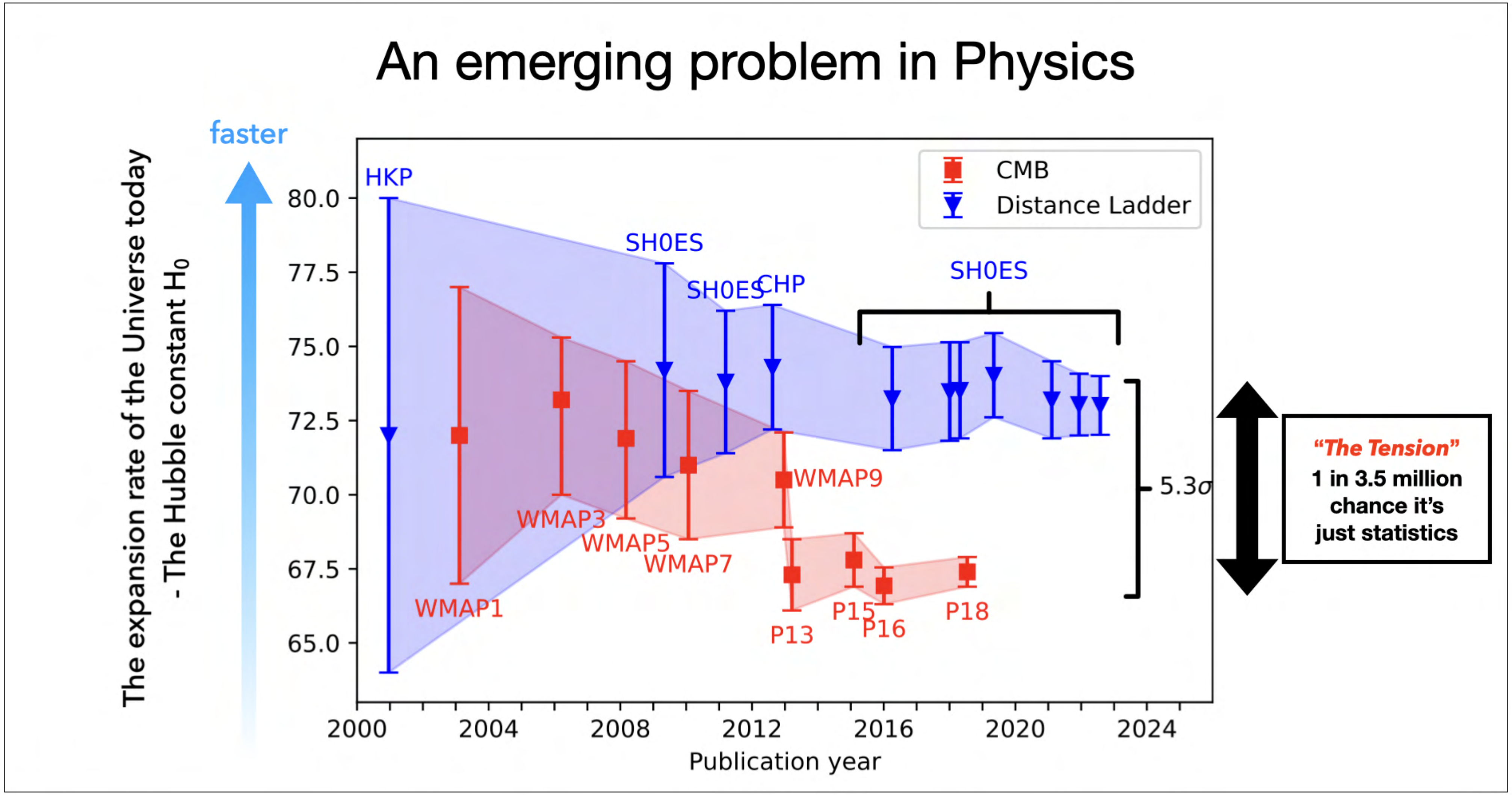

CrossMark

The Pantheon+ Analysis: The Full Data Set and Light-curve Release

Dan Scolnic[1], Dillon Brout[2,20], Anthony Carr[3], Adam G. Riess[4,5], Tamara M. Davis[3], Arianna Dwomoh[1], David O. Jones[6], Noor Ali[7], Pranav Charvu[1], Rebecca Chen[1], Erik R. Peterson[1], Brodie Popovic[1], Benjamin M. Rose[1], Charlotte M. Wood[8], Peter J. Brown[9,10], Ken Chambers[11], David A. Coulter[6], Kyle G. Dettman[12], Georgios Dimitriadis[13], Alexei V. Filippenko[14,15], Ryan J. Foley[6], Saurabh W. Jha[12], Charles D. Kilpatrick[16], Robert P. Kirshner[2,17], Yen-Chen Pan[18], Armin Rest[19], Cesar Rojas-Bravo[6], Matthew R. Siebert[6], Benjamin E. Stahl[14], and WeiKang Zheng[14]







https://www.aura-astronomy.org/blog/2023/03/06/our-mysterious-universe-still-evades-cosmological-understanding/

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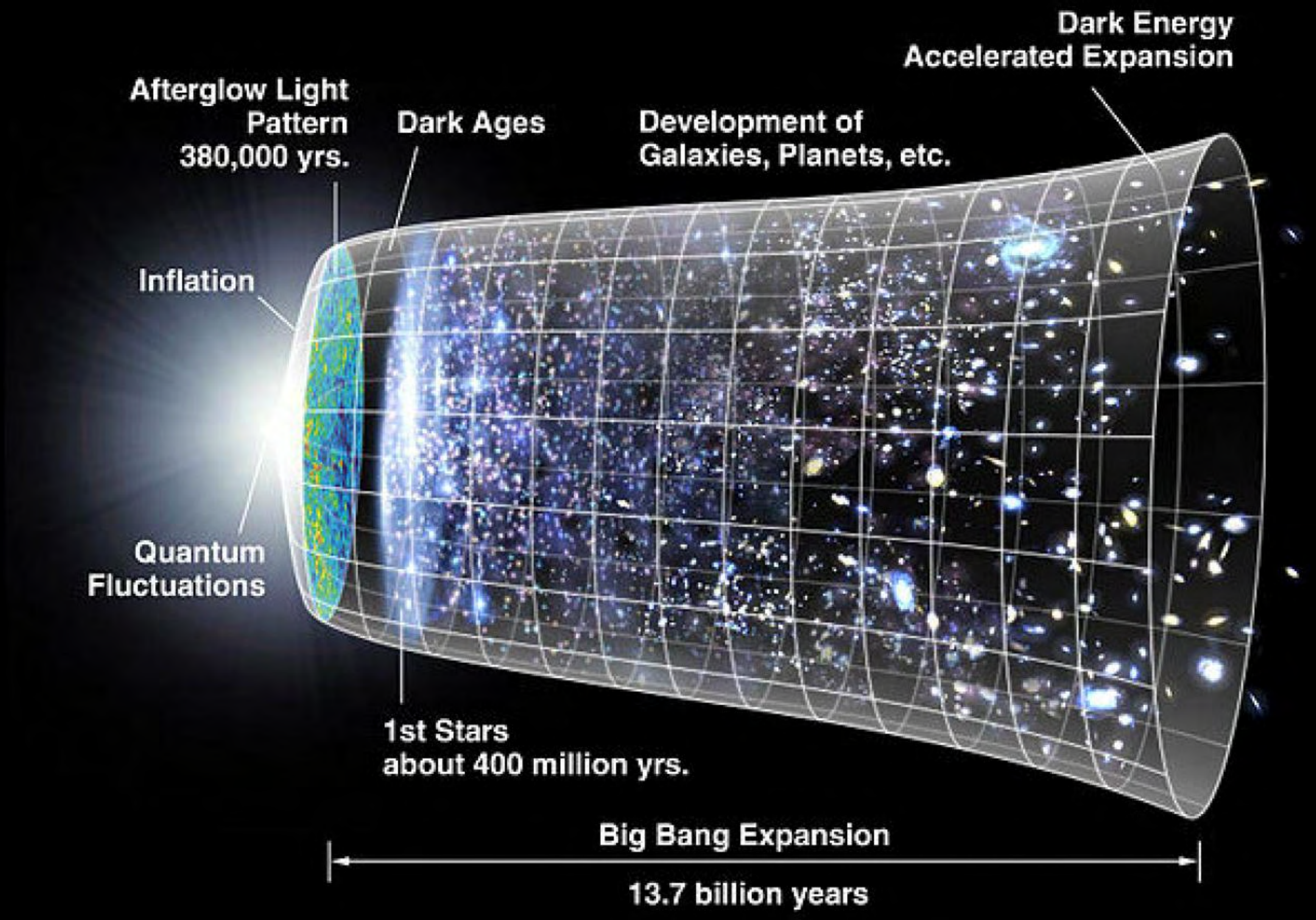
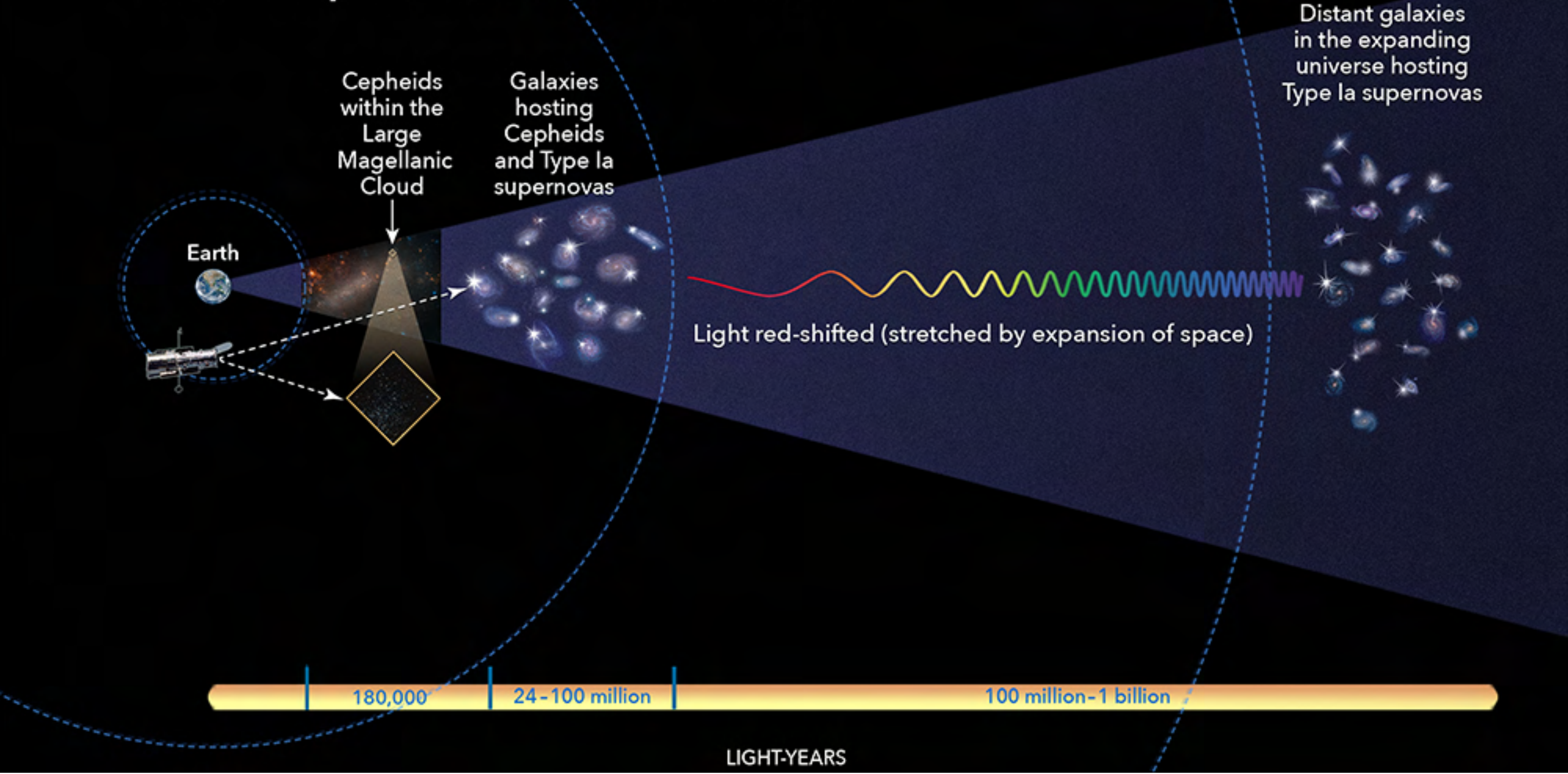
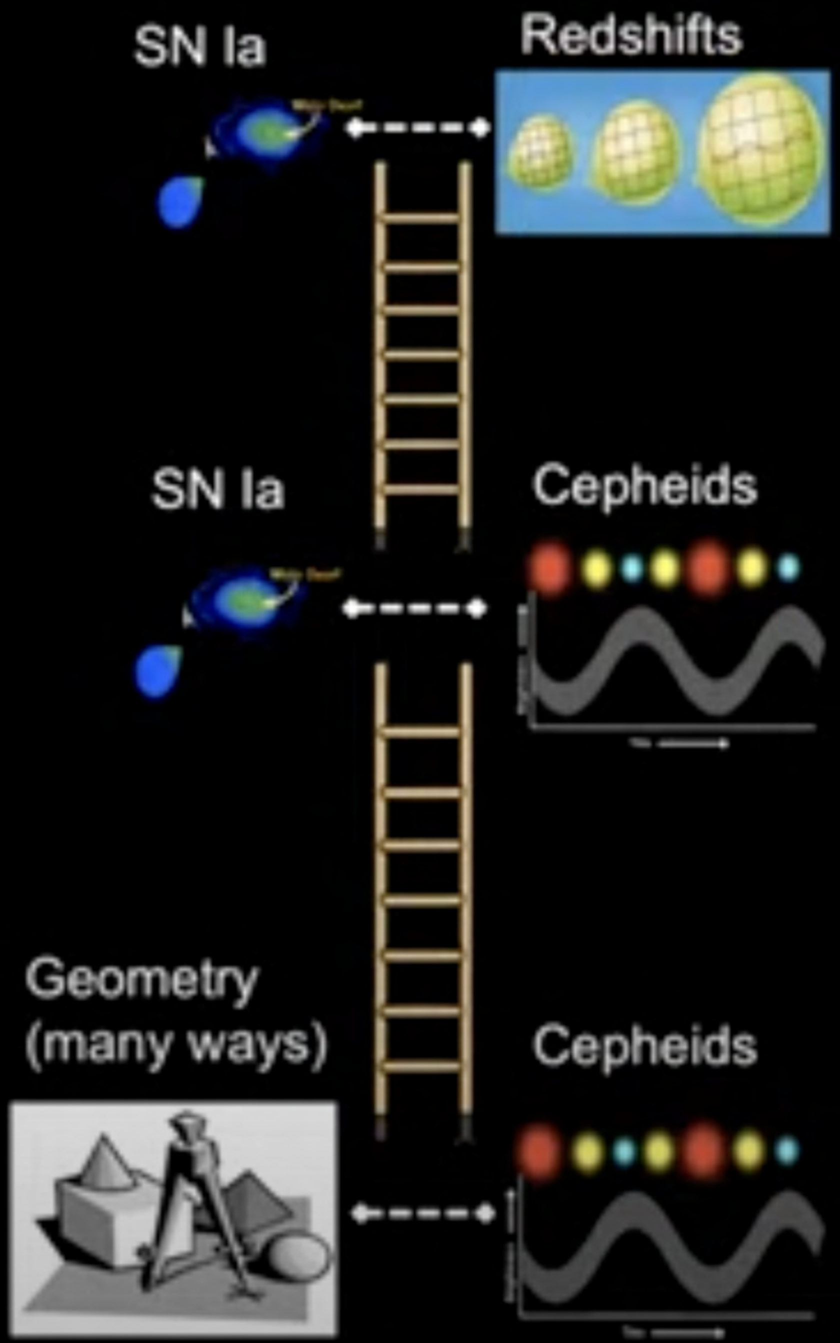


z=2 =>8.2 billion years

What could explain the tension? (hint: at least 3 things)

Three Steps to the Hubble Constant





Hubble Flow:
D~Gpc, z~0.1

Cross-calibrate:
D~10-40 Mpc

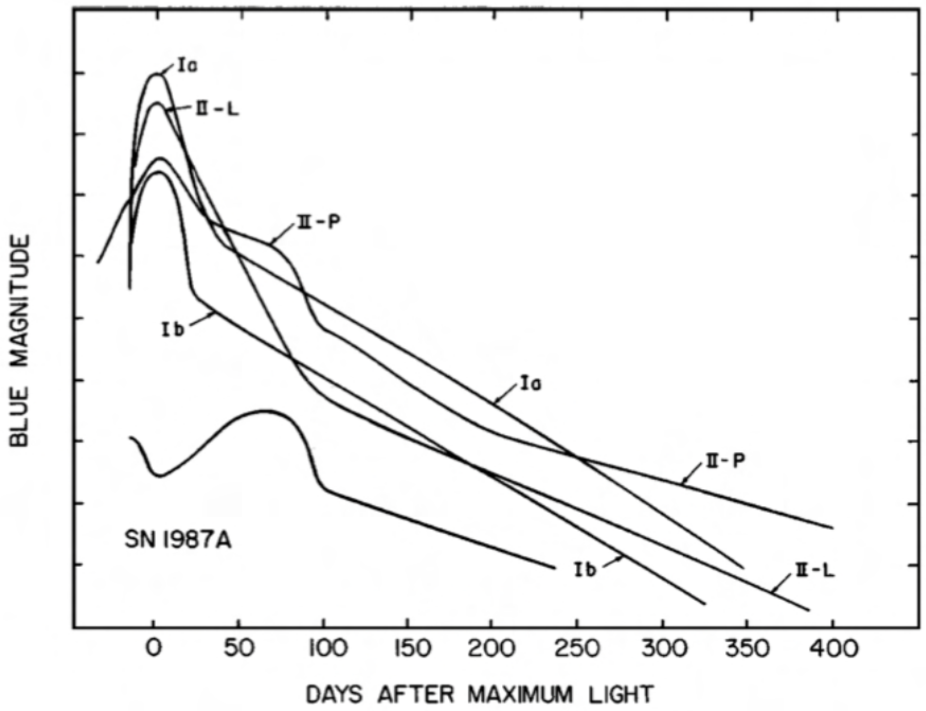
Anchors:
D~Kpc or Mpc

https://www.youtube.com/watch?v=JmDszPExepc

I : SN Ia cosmology

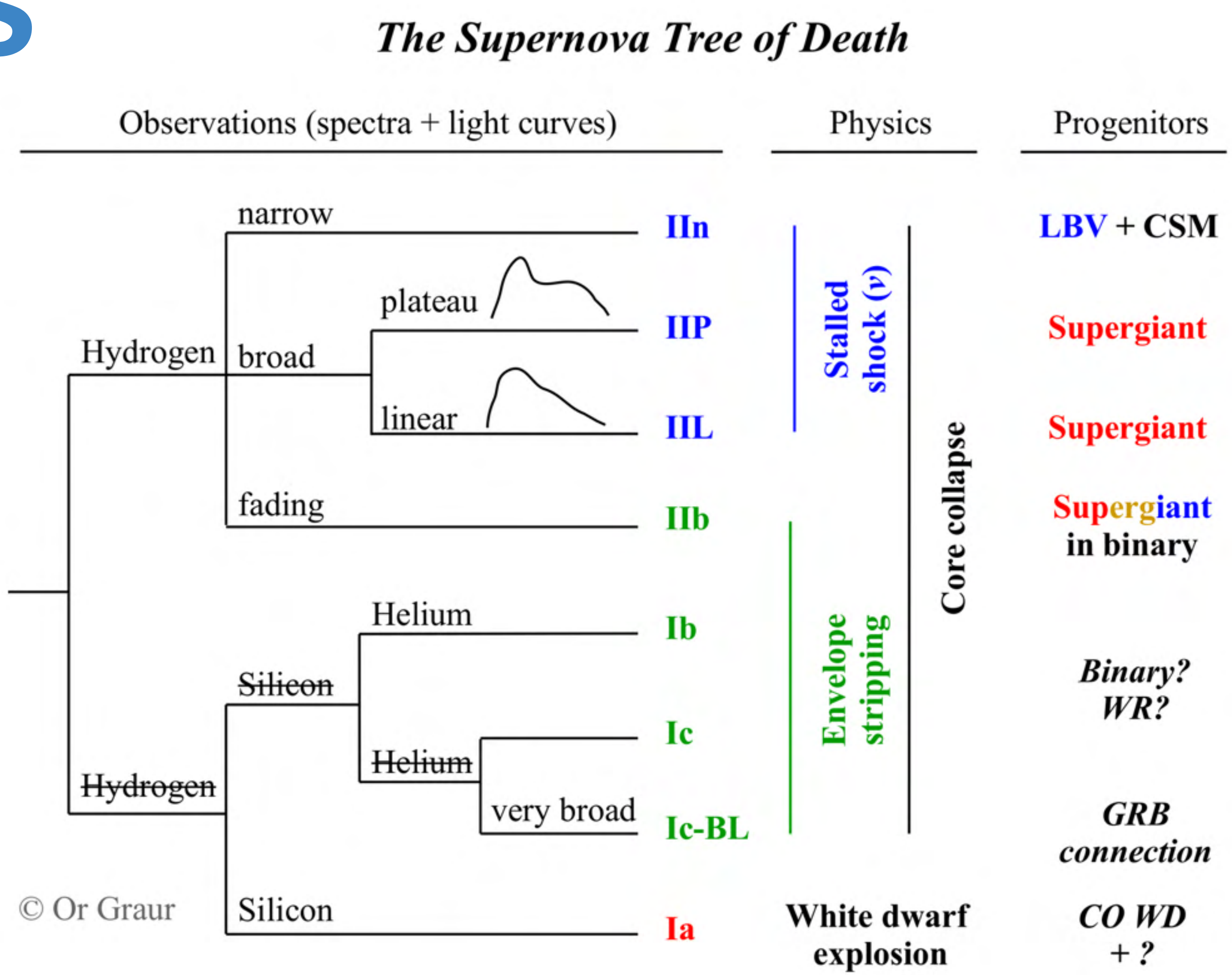
Sample Purity

I. Selecting the right SN types



https://www.physics.rutgers.edu/analyze/wiki/Ia_supernovae.html

Credit: Or Graur



$$\mu_0 = m_0 - M_0 = 5 \log D + 25$$

... but... not all SN Ia are equal after all

The fact that supernovae were not all the same was discovered early.. but its still one of our main issues with SN cosmology 45 years later!

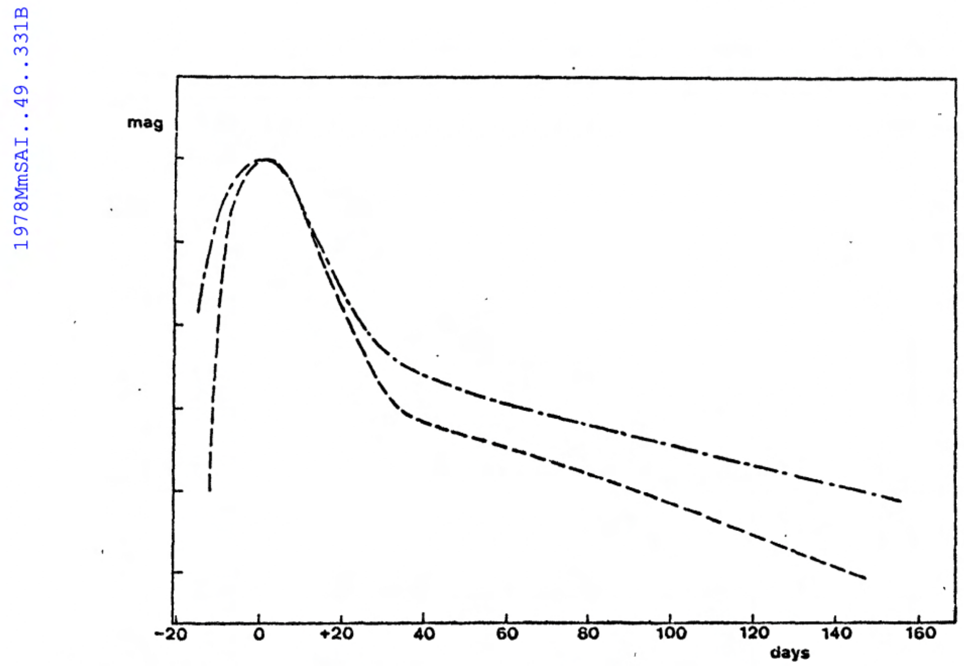
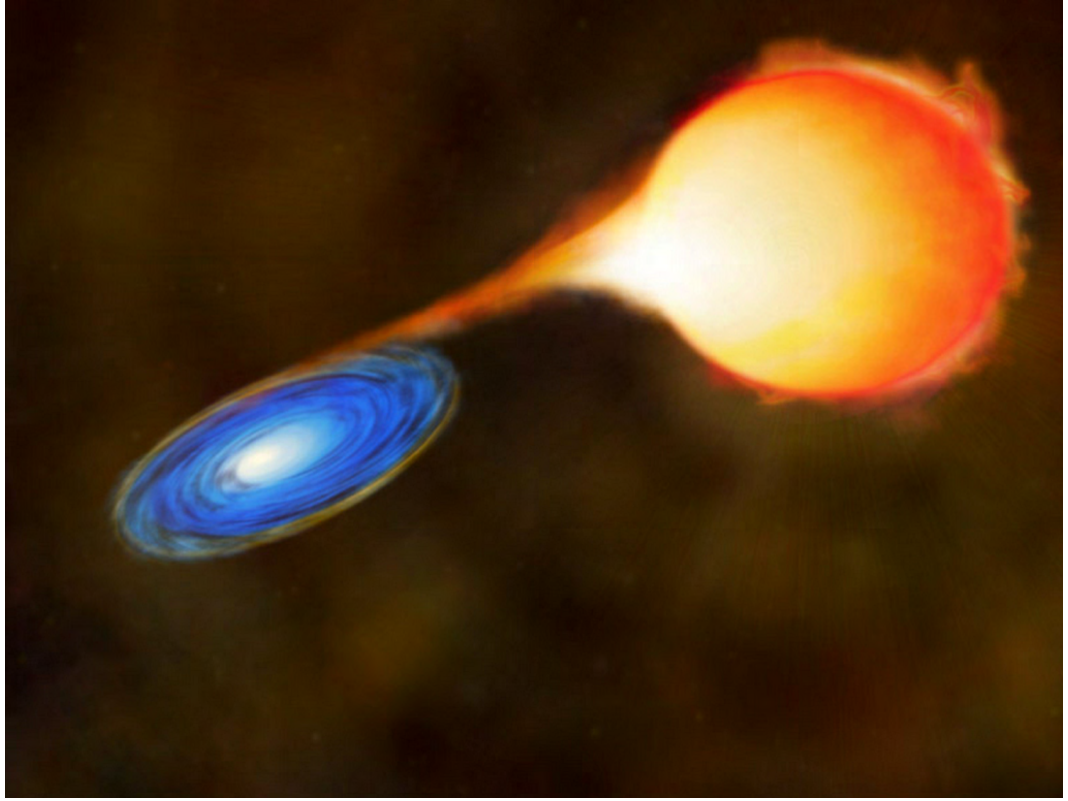


Fig.1: Schematic light curve for fast and slow type I supernovae

Barbon, 1978

SN Ia come from the detonation of CO White Dwarfs.

Ignition of carbon occurs at or near the Chandrasekhar limit



NATURE VOL. 314 28 MARCH 1985 LETTERS

Hubble's constant and exploding carbon–oxygen white dwarf models for Type I supernovae

W. David Arnett*, David Branch† & J. Craig Wheeler‡

The discussion above has rested on the tacit assumption that all SN I have identical properties. Observationally, this is a tenable proposition, except for a few supernovae (SN 1885a, 1954a, 1962l, 1964l, 1980i, 1983n) which have shown definite spectroscopic and/or photometric peculiarities, and theoretically it is attractive because the ignition of carbon necessarily occurs near the Chandrasekhar mass. There is some evidence, however, for a correlation between peak absolute magnitude and the rate of decline of the initial post-peak light curve[16-18].

The type Ia supernova SNLS-03D3bb from a super-Chandrasekhar-mass white dwarf star

D. Andrew Howell, Mark Sullivan, Peter E. Nugent, Richard S. Ellis, Alexander J. Conley, Damien Le Borgne, Raymond G. Carlberg, Julien Guy, David Balam, Stephane Basa, Dominique Fouchez, Isobel M. Hook, Eric Y. Hsiao, James D. Neill, Reynald Pain, Kathryn M. Perrett & Christopher J. Pritchet

Nature **443**, 308–311 (2006) | Cite this article

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SN Ia come fr

Ignition of

C

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Draft version July 24, 2019
Typeset using LaTeX **twocolumn** style in AASTeX62

Evidence for Sub-Chandrasekhar Type Ia Supernovae from Stellar Abundances in Dwarf Galaxies*

Evan N. Kirby,[1] Justin L. Xie,[2] Rachel Guo,[2] Mithi A. C. de los Reyes,[1] Maria Bergemann,[3] Mikhail Kovalev,[3] Ken J. Shen,[4] Anthony L. Piro,[5] and Andrew McWilliam[5]

NATURE VOL. 314 28 MARCH 1985 LETTERS

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$$\mu_0 = m_0 - M_0 = 5\log D + 25$$

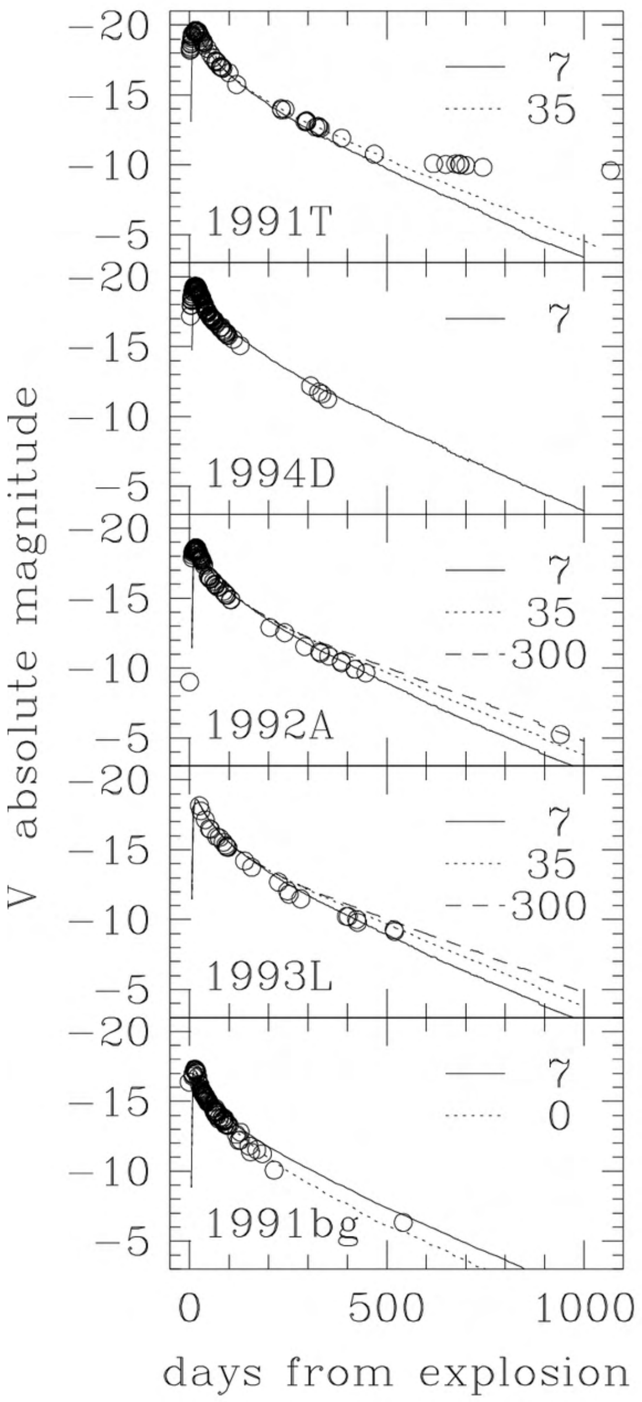
$$M_{\max}(B) = -21.726 + 2.698\Delta m_{15}(B)$$

... but... not all SN Ia are equal after all

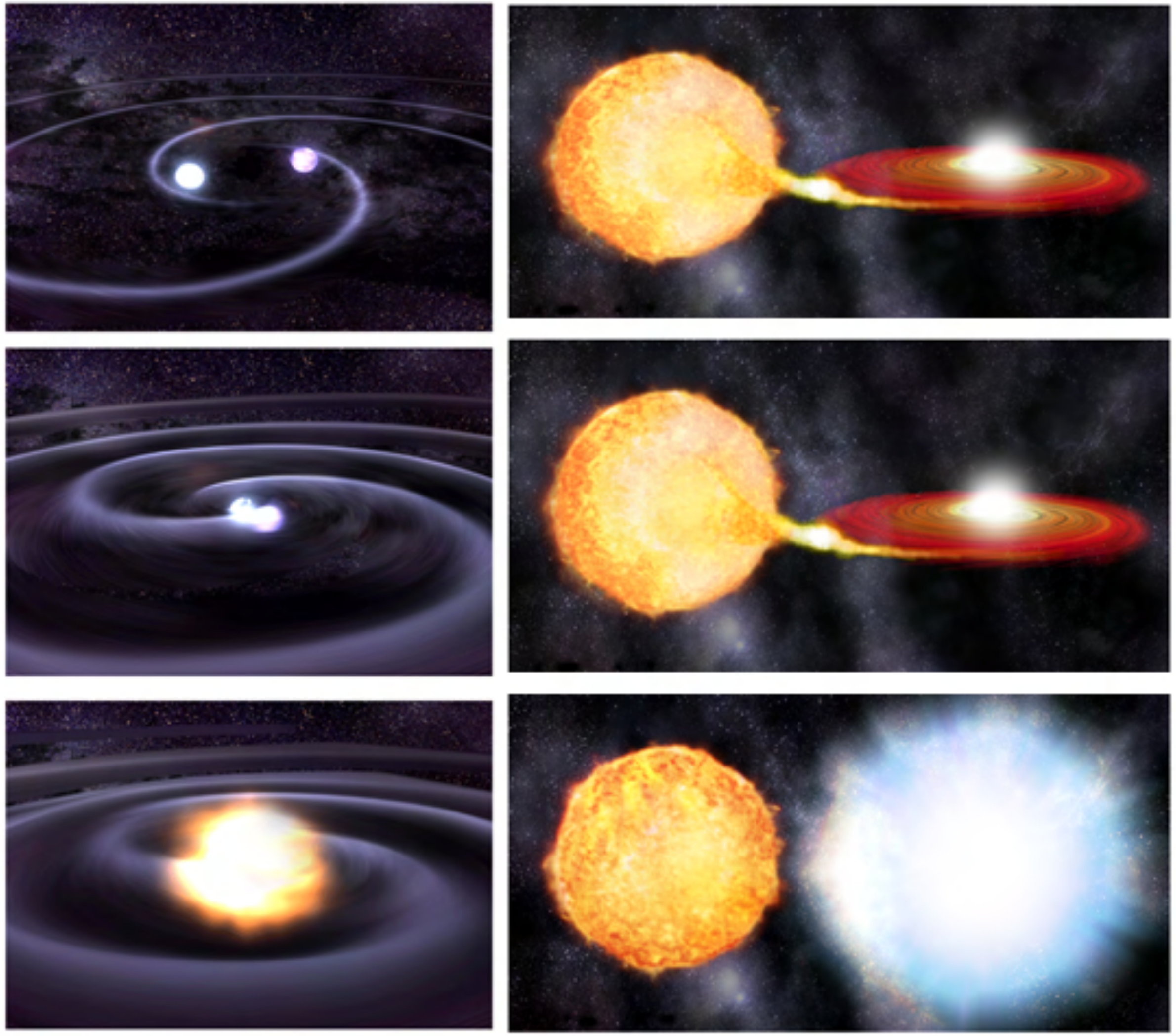
Faint: SN 1991bg-like

Slow declining: SN 1991T-like

Rapid declining: SN2000cx-like (SN Iax)



Double or single degenerate?



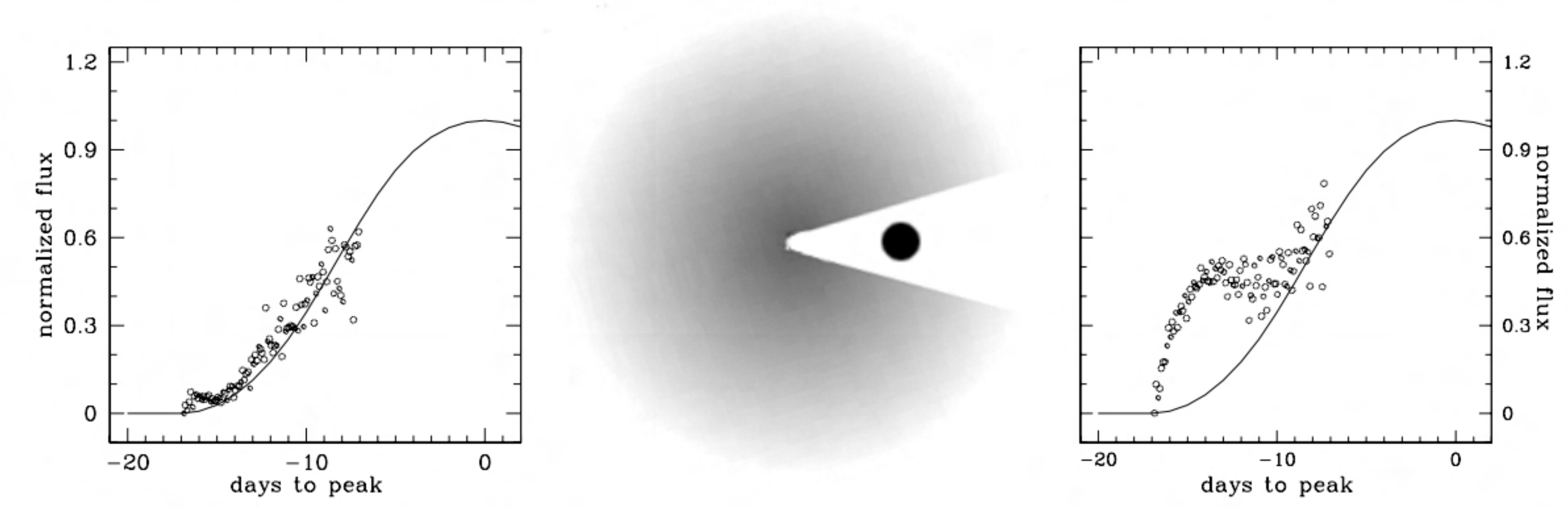
Wikipedia Commons and Discover Magazine

What is the donor star in a SN Ia?

does it have an impact on the lightcurve evolution?

Double or single degenerate?

Bianco+ 2011



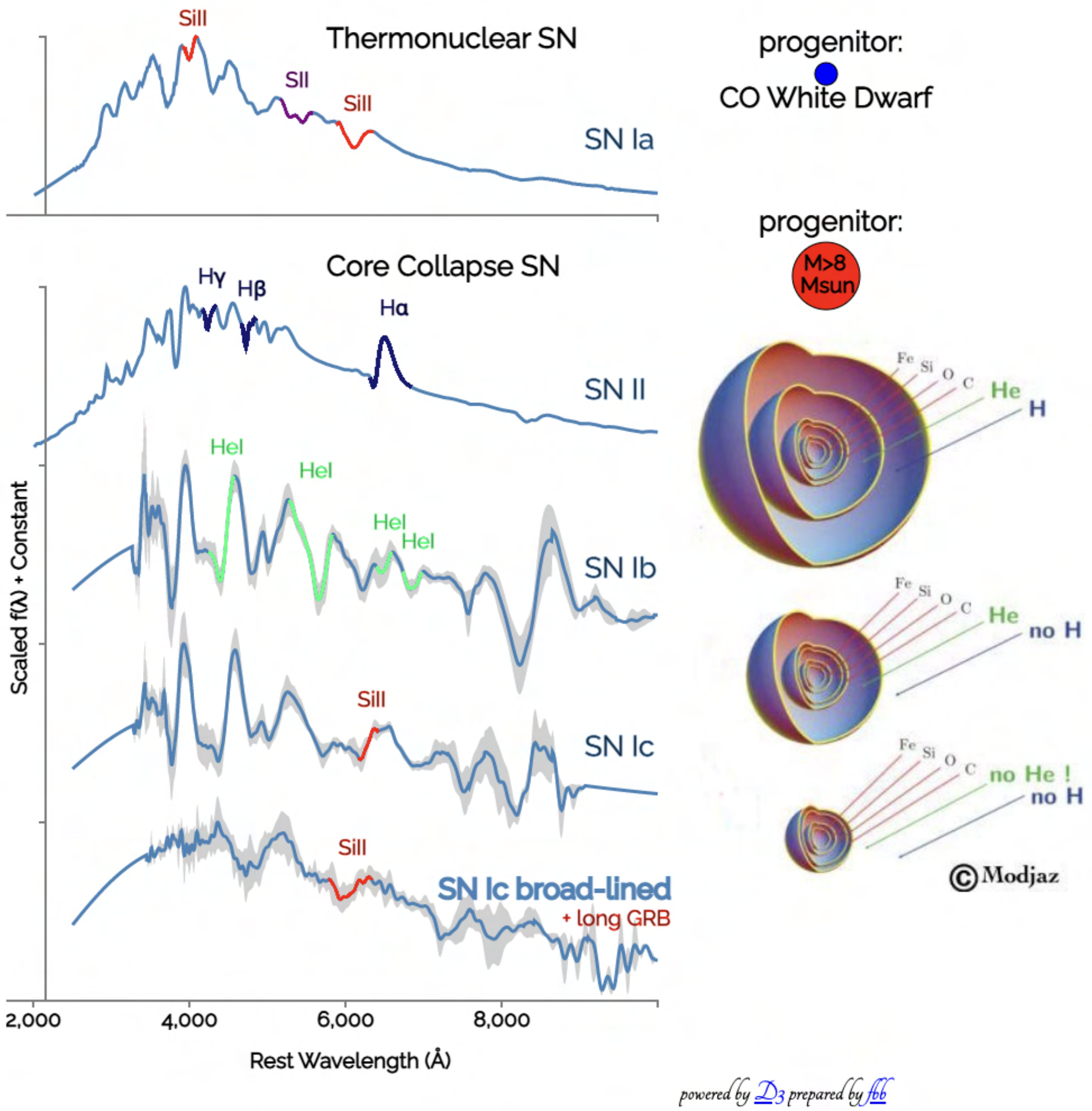
Kasen 2010: the progenitor does life a fingerprint in the lightcurve

2011fe: definitely double degenerate (Nugent+12)

PTF11kx: definitely single degenerate (Dildey+12)

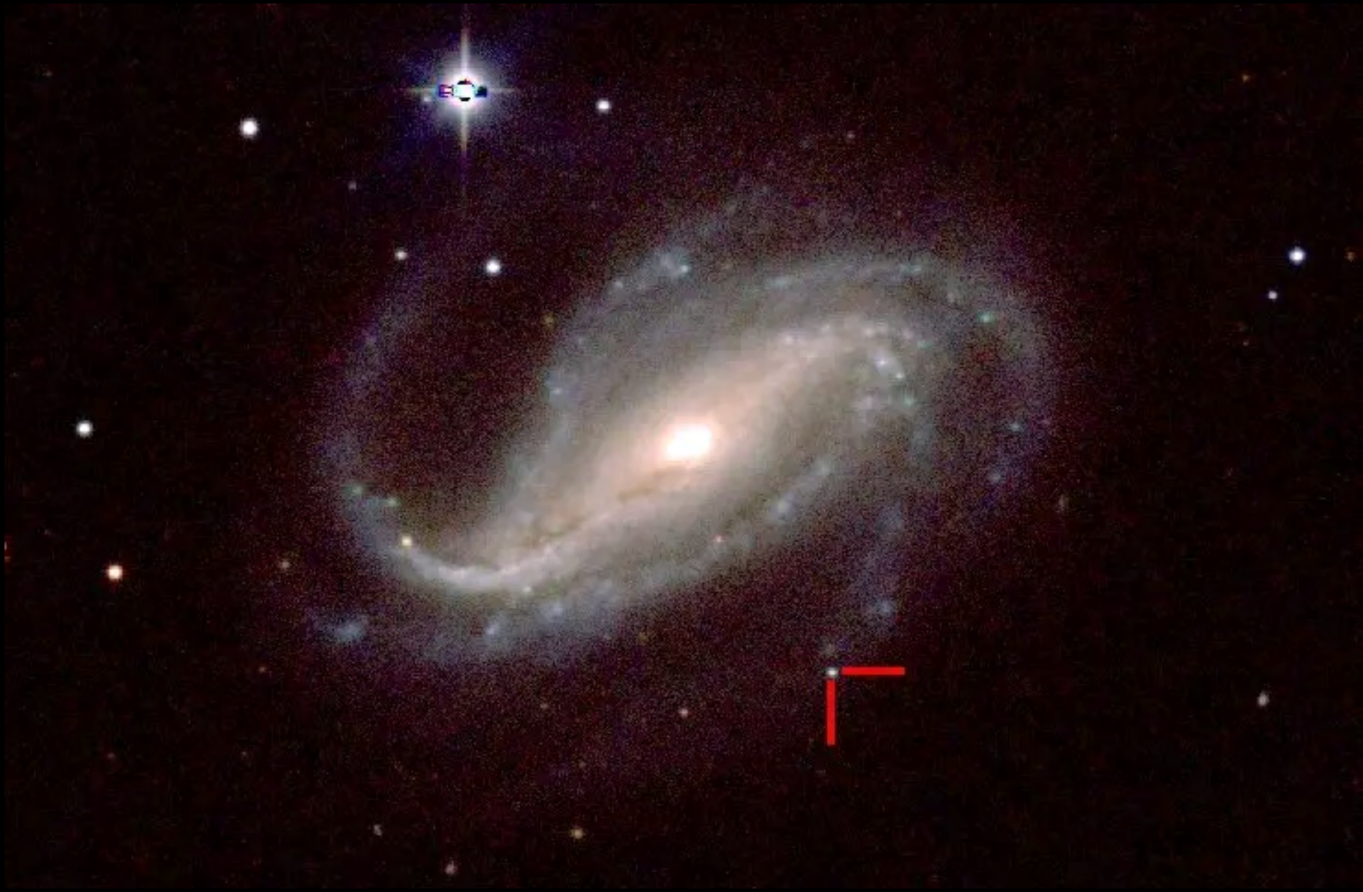
<20% SD progenitors (Bianco+2011)

disfavors SD progenitors (Hayden+2010)



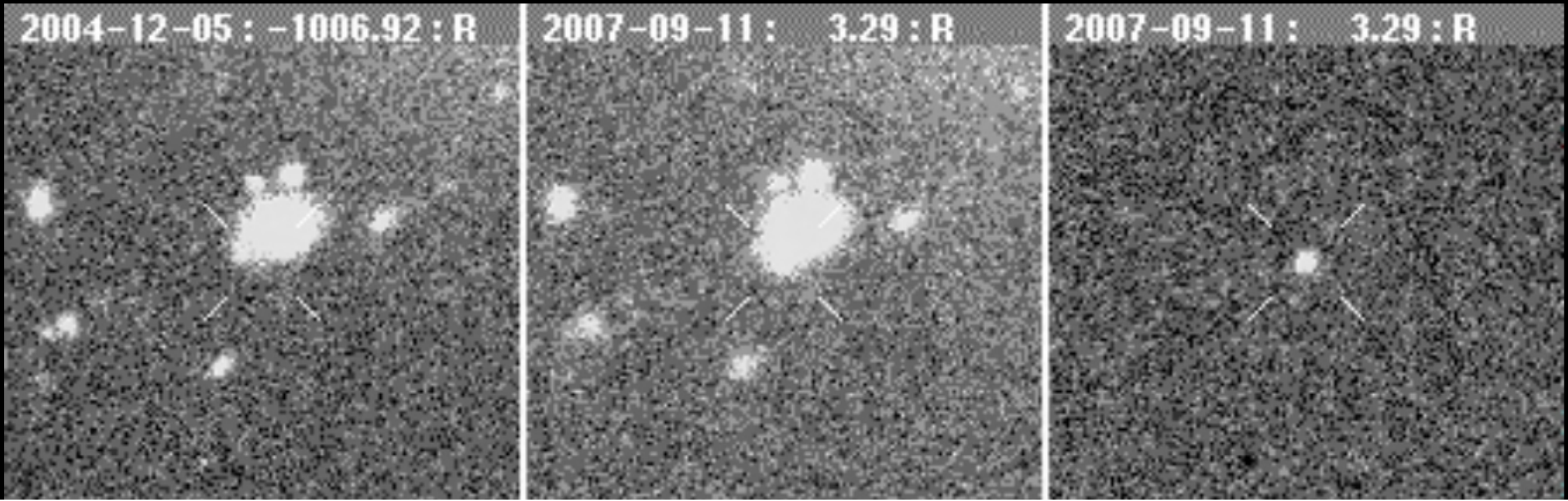
SN spectral classification

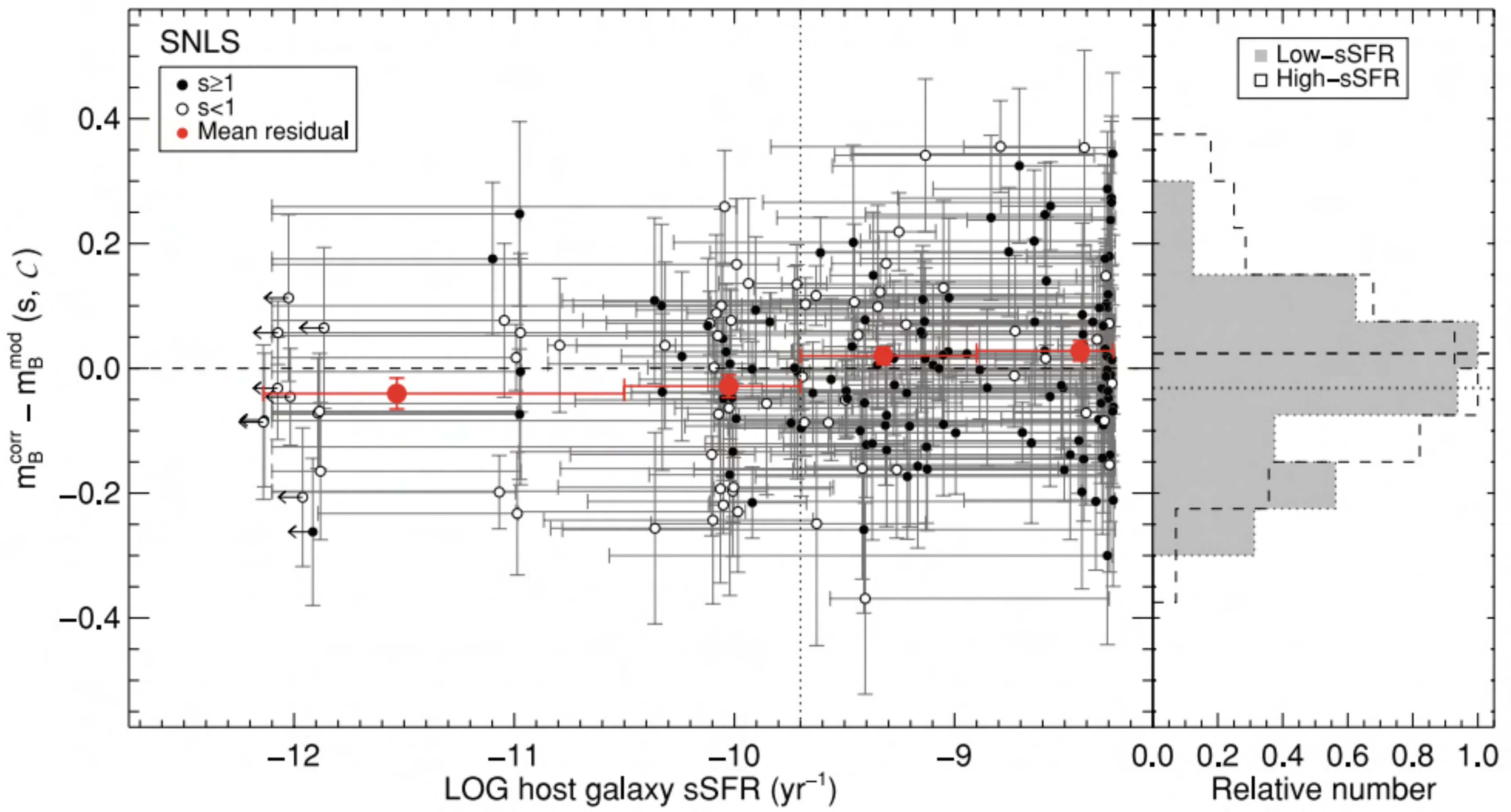
II. Correcting for Host Systematics



II. Correcting for Host Systematics

- photometry
- host property dependency
- distance determination (photo-z)

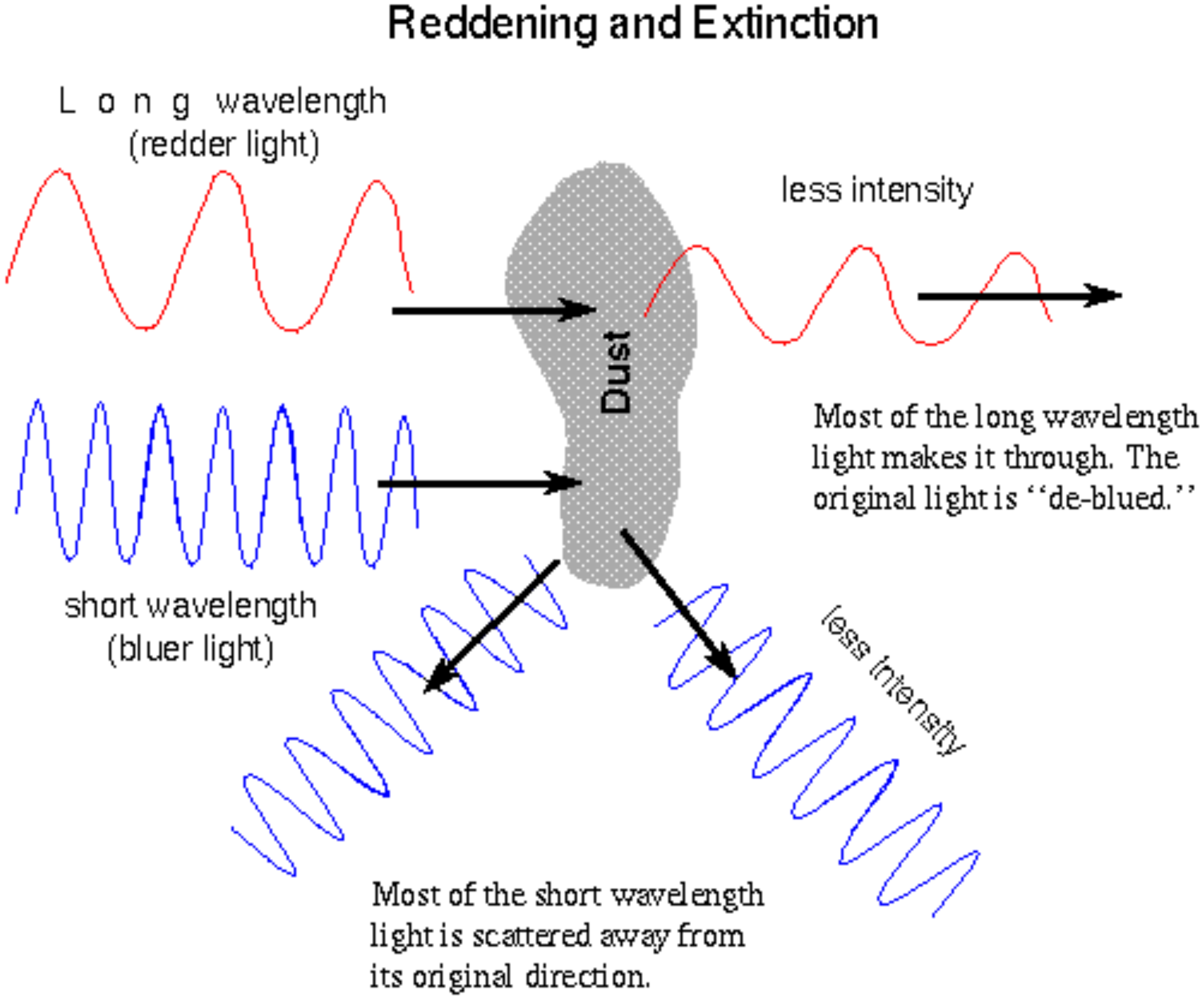




The dependence of Type Ia Supernovae luminosities on their host galaxies

M. Sullivan,[1★] A. Conley,[2] D. A. Howell,[3,4] J. D. Neill,[5] P. Astier,[6] C. Balland,[7,8] S. Basa,[8] R. G. Carlberg,[9] D. Fouchez,[10] J. Guy,[6] D. Hardin,[6] I. M. Hook,[1,11] R. Pain,[6] N. Palanque-Delabrouille,[12] K. M. Perrett,[9,13] C. J. Pritchet,[14] N. Regnault,[6] J. Rich,[12] V. Ruhlmann-Kleider,[12] S. Baumont,[6,15] E. Hsiao,[16] T. Kronborg,[6] C. Lidman,[17] S. Perlmutter[16,18] and E. S. Walker[1,19]

These is evidence of an explicit dependence of the SN luminosity on host galaxy



http://www.chm.bris.ac.uk/webprojects2002/murphy/colour_and_interstellar_clouds.htm

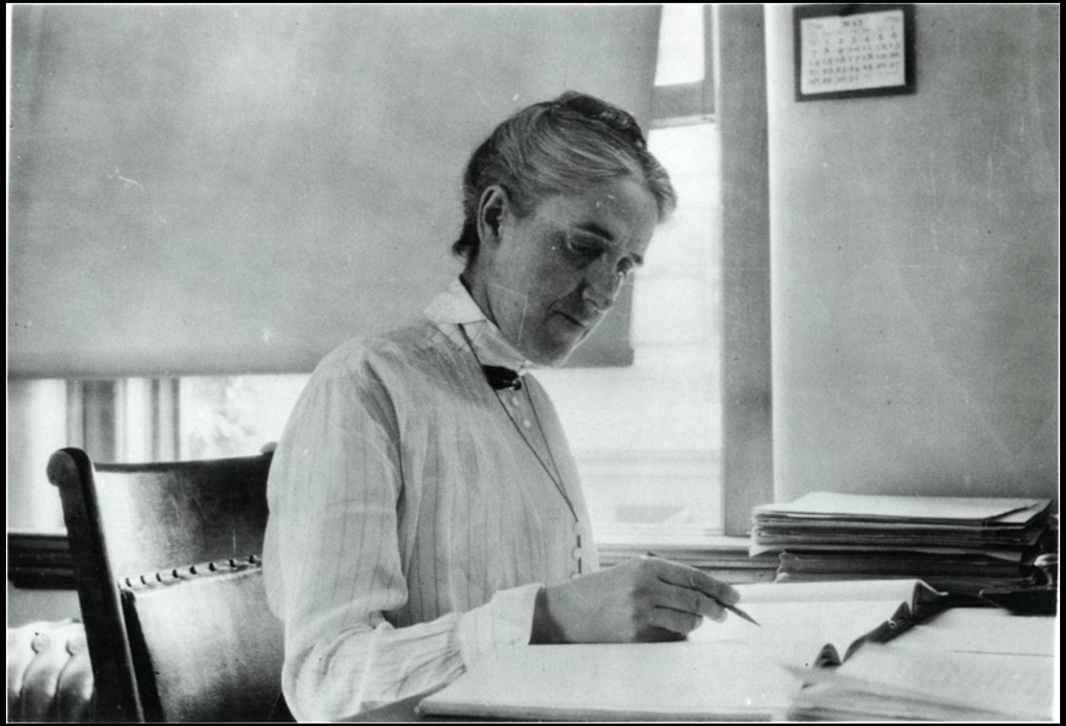
Specific reddening law can contaminate LC fitting

a mitigation is analysis in the NIR or joint analysis in NIR + optical

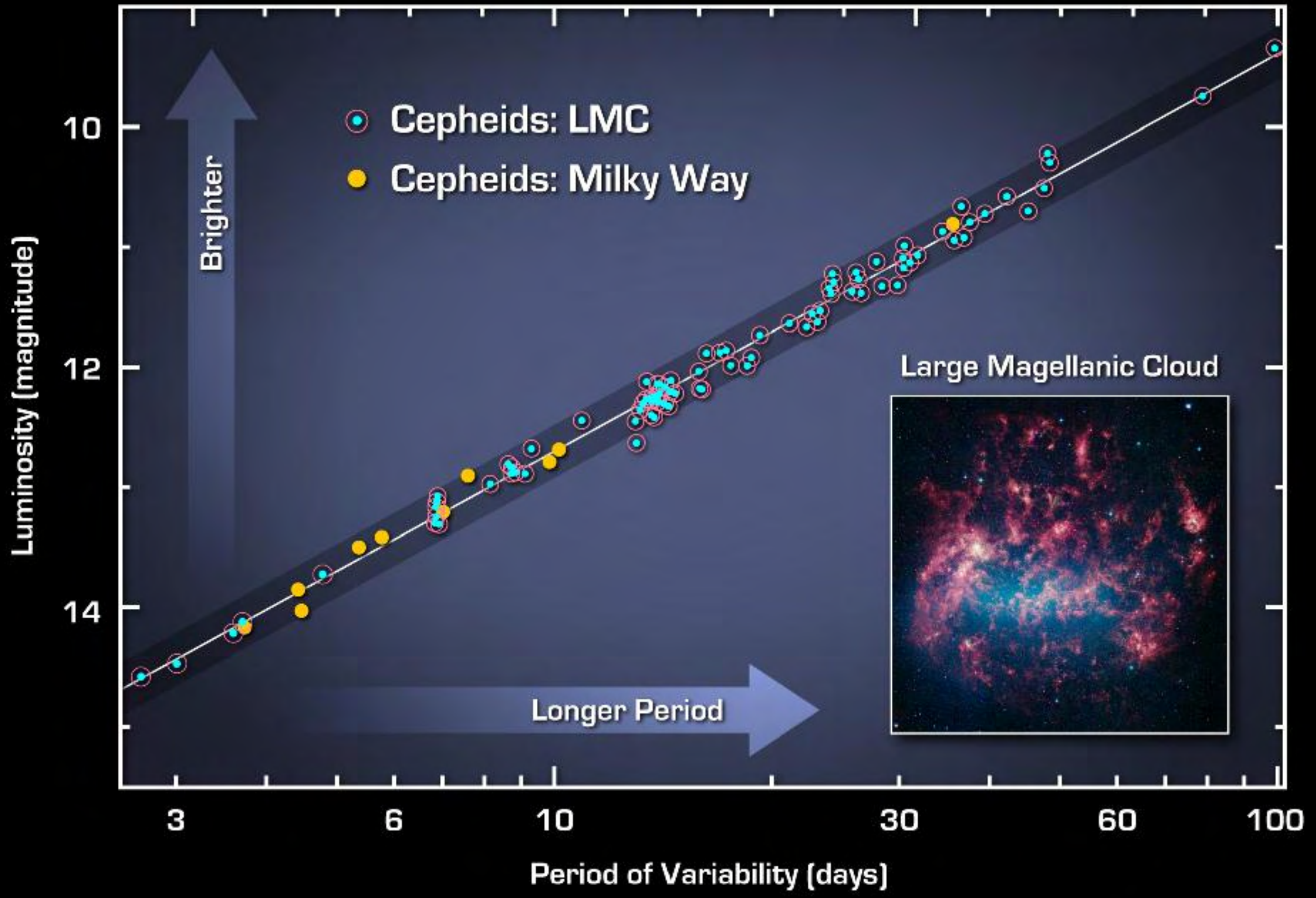
A BayeSN Distance Ladder: H_0 from a consistent modelling of Type Ia supernovae from the optical to the near infrared

Suhail Dhawan,[1★] Stephen Thorp,[1] Kaisey S. Mandel,[1,2,3] Sam M. Ward,[1] Gautham Narayan,[4,5] Saurabh W. Jha,[6] and Thaisen Chant[1,7]

low-z: cepheid stars ladder



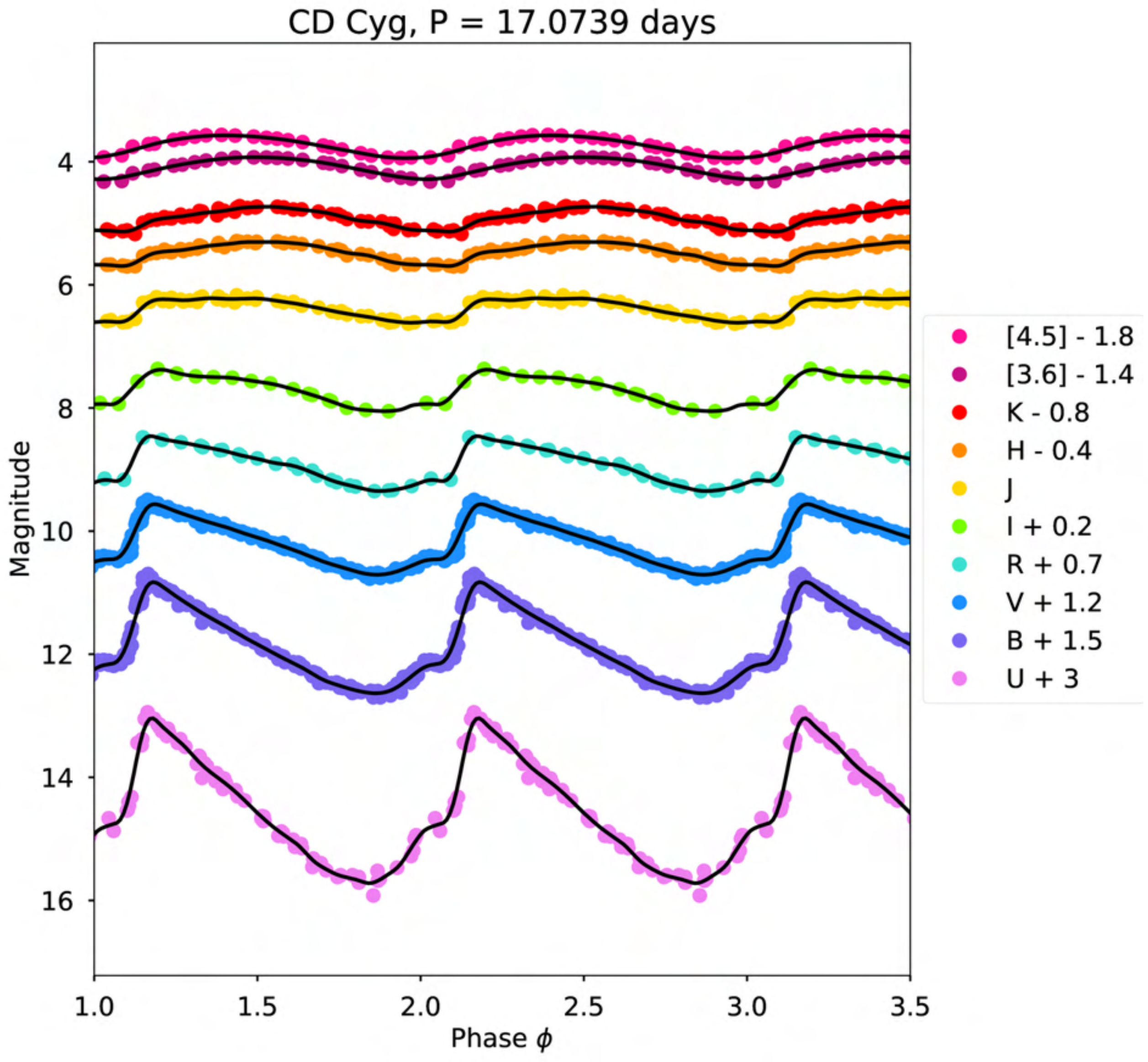
First noted by Harietta Leavitt in 1912

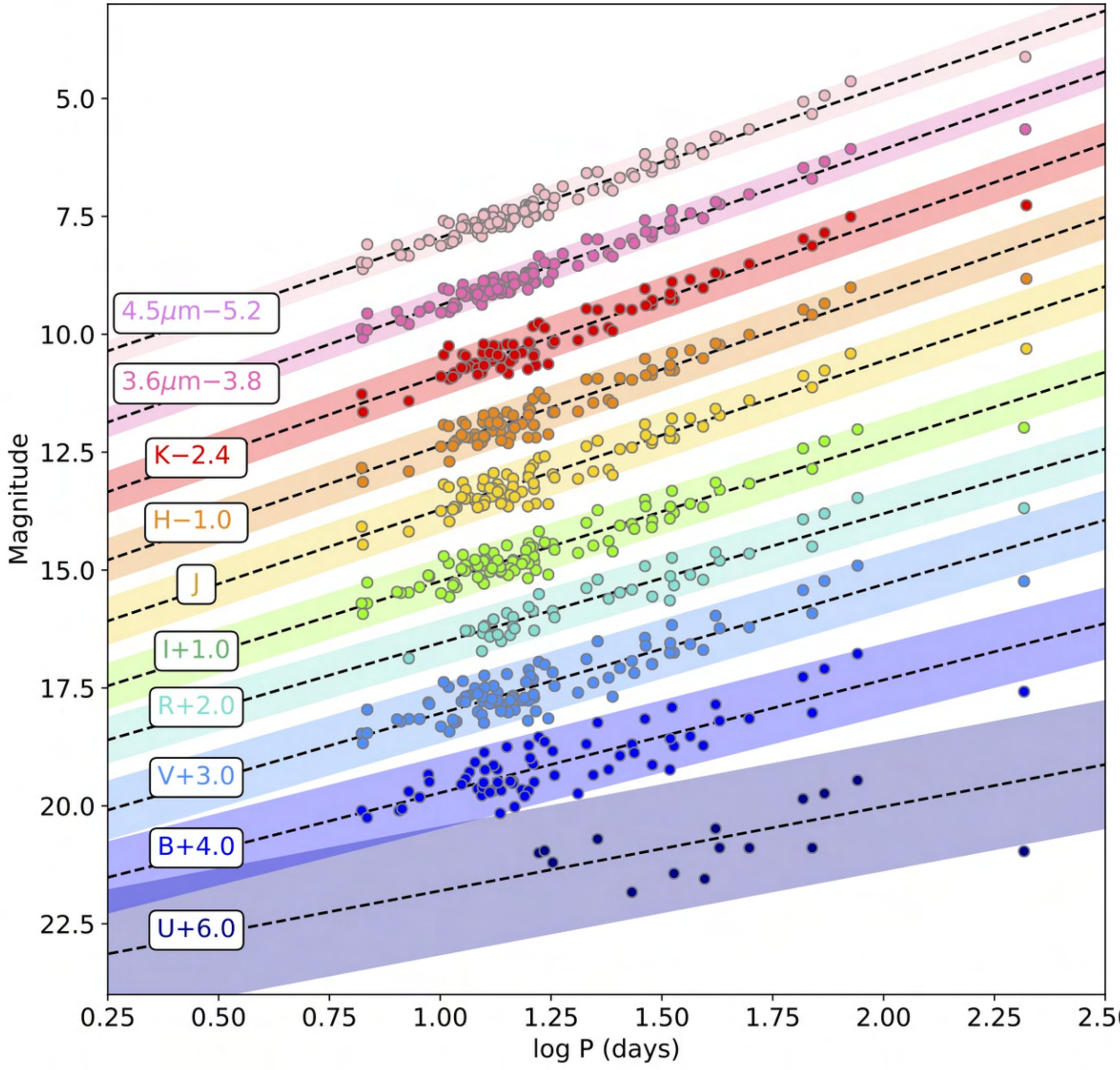


$$M_{\mathrm{v}} = (-2.43 \pm 0.12)\,(\log_{10} P - 1) - (4.05 \pm 0.02)$$

The period of variation is proportional to the luminosity with a different proportionality at different wavelengths

$$M_{?} = a\,(\log_{10} P - 1) + b$$





Scowcroft et al. (2016).

Cluster Cepheids with High Precision Gaia Parallaxes, Low Zero-point Uncertainties, and Hubble Space Telescope Photometry

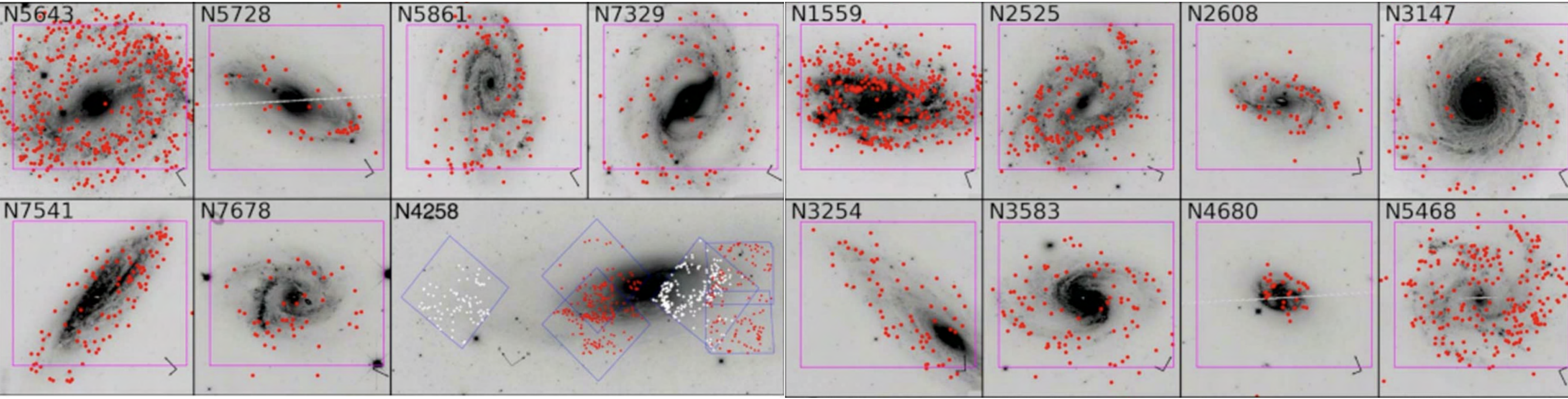
Adam G. Riess[1,2], Louise Breuval[2], Wenlong Yuan[2], Stefano Casertano[1], Lucas M. Macri[3], J. Bradley Bowers[2], Dan Scolnic[4], Tristan Cantat-Gaudin[5], Richard I. Anderson[6], and Mauricio Cruz Reyes[6]

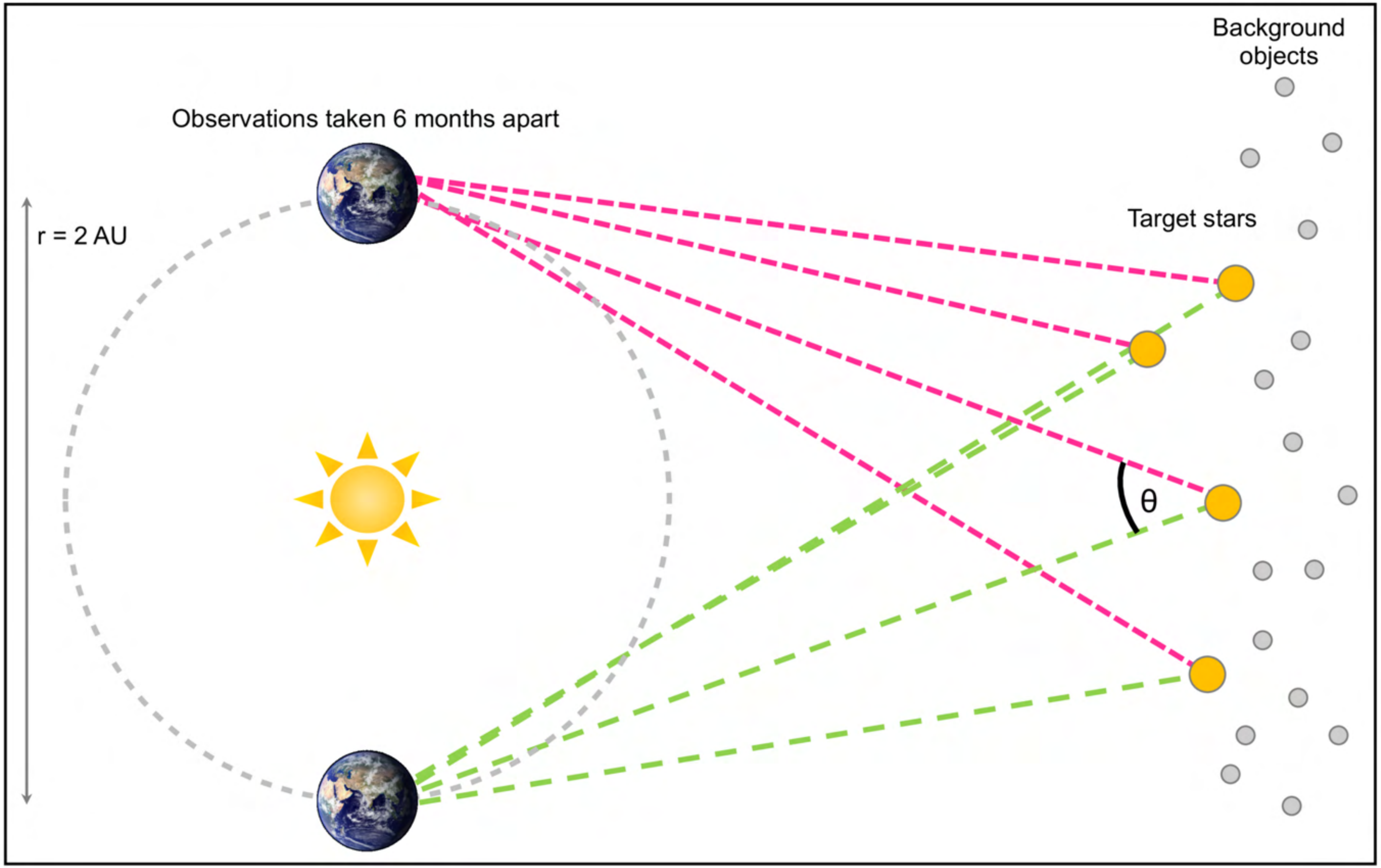
CrossMark

A 2.4% DETERMINATION OF THE LOCAL VALUE OF THE HUBBLE CONSTANT*

Adam G. Riess[1,2], Lucas M. Macri[3], Samantha L. Hoffmann[3], Dan Scolnic[1,4], Stefano Casertano[2], Alexei V. Filippenko[5], Brad E. Tucker[5,6], Mark J. Reid[7], David O. Jones[1], Jeffrey M. Silverman[8], Ryan Chornock[9], Peter Challis[7], Wenlong Yuan[3], Peter J. Brown[3], and Ryan J. Foley[10,11]

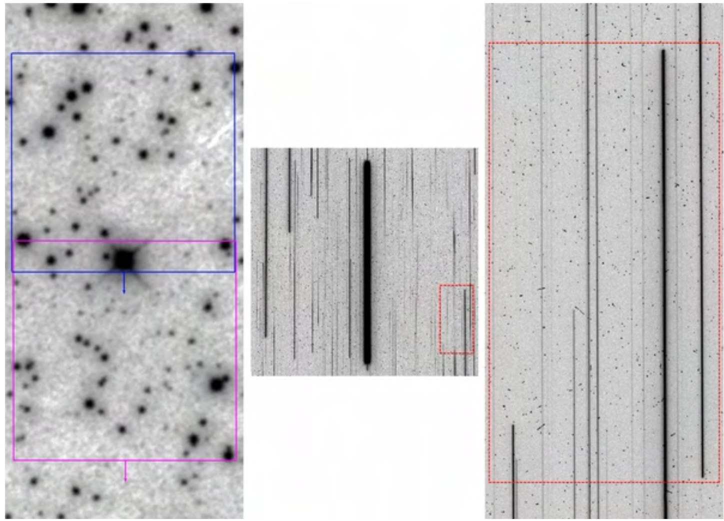
1566 Cepheids in the 19 SN Ia





drift scanning HST to measure parallaxes

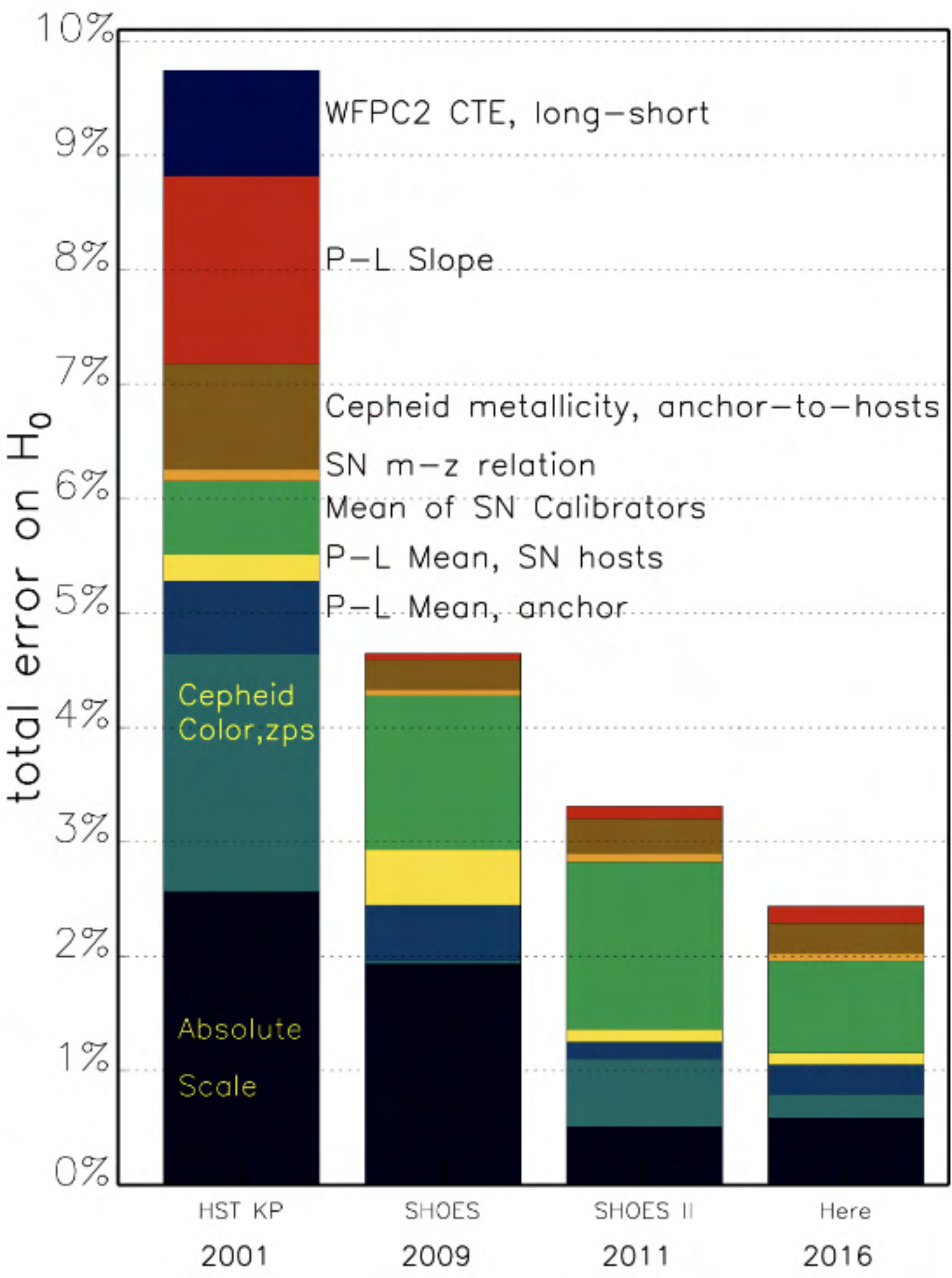
precision of 20–40 μas

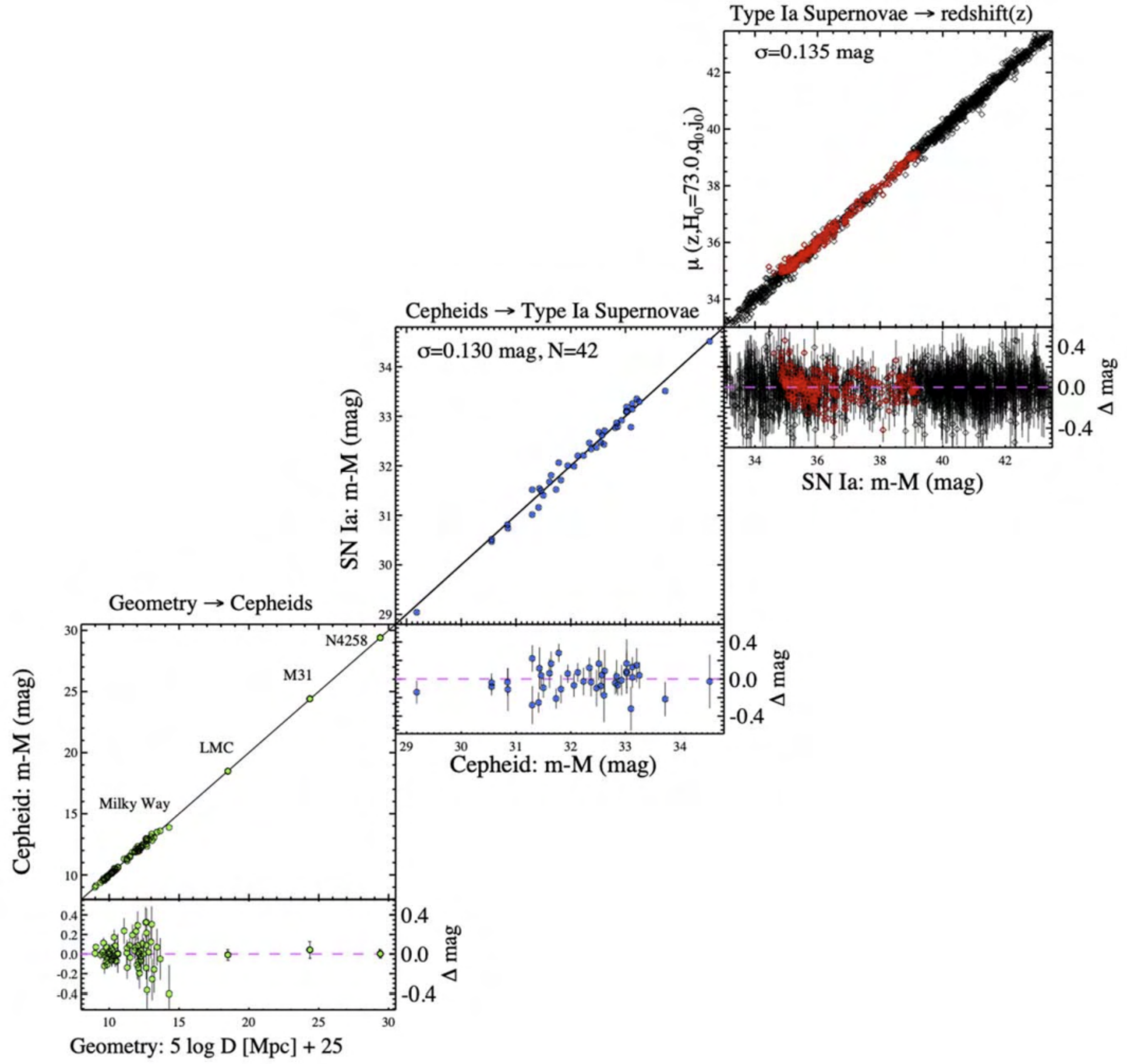


A 2.4% DETERMINATION OF THE LOCAL VALUE OF THE HU

ADAM G. RIESS[1,2], LUCAS M. MACRI[3], SAMANTHA L. HOFFMANN[3], DAN SCOLNIC
ALEXEI V. FILIPPENKO[5], BRAD E. TUCKER[5,6], MARK J. REID[7], DAVID O. JONES[1], JEFFREY
PETER CHALLIS[7], WENLONG YUAN[3], PETER J. BROWN[3], AND RYAN

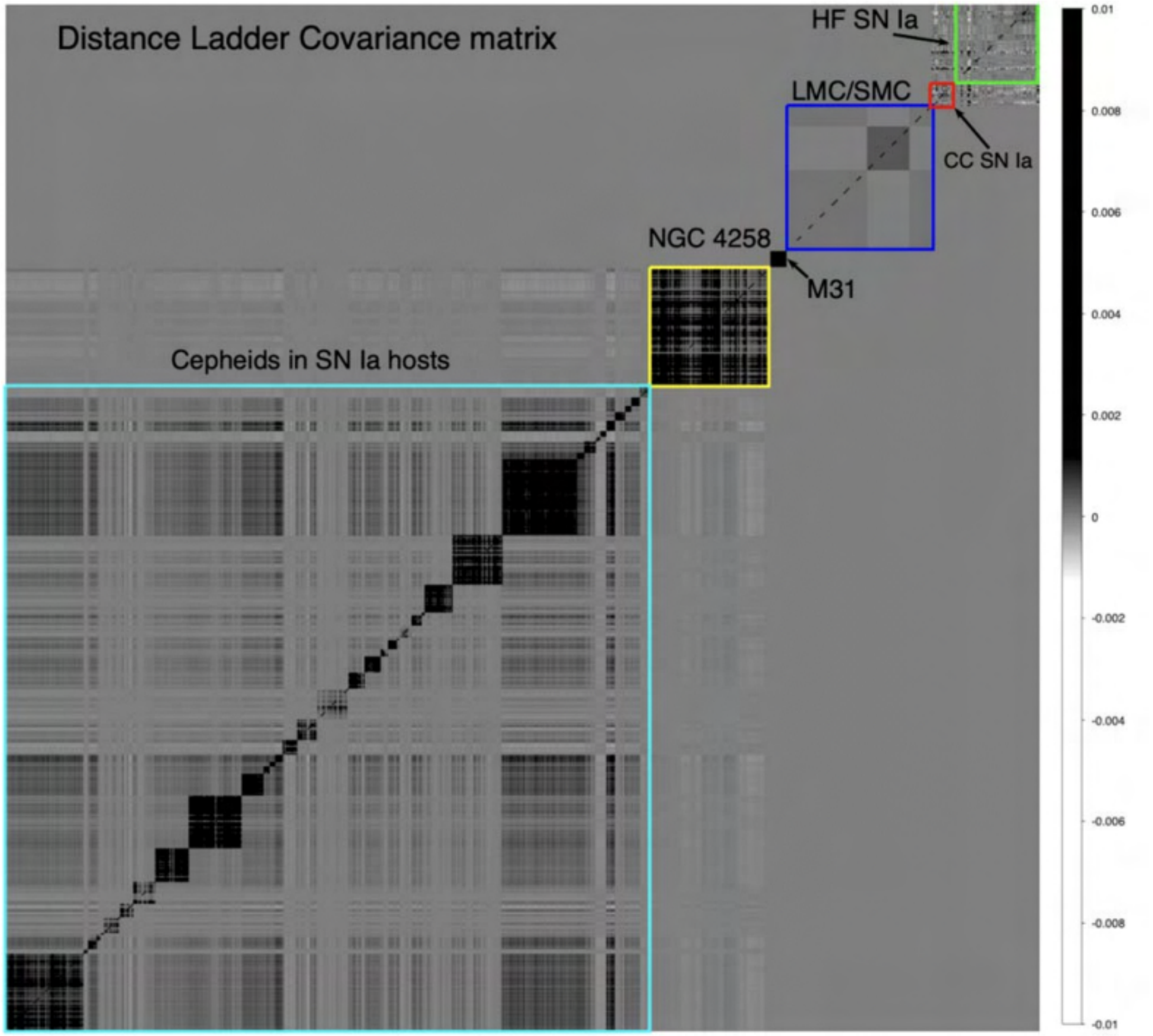
In the HST Key Project, the ladder was tied to our nearest galaxy, the Large Magellanic Cloud (LMC). *SH₀ES* reduced this uncertainty by tying their calibration to Cepheids with parallaxes in the Milky Way (MW), Cepheids in the LMC, and Cepheids in host galaxy NGC4258 (Type 2 Seyfert, and a Type II supernova).



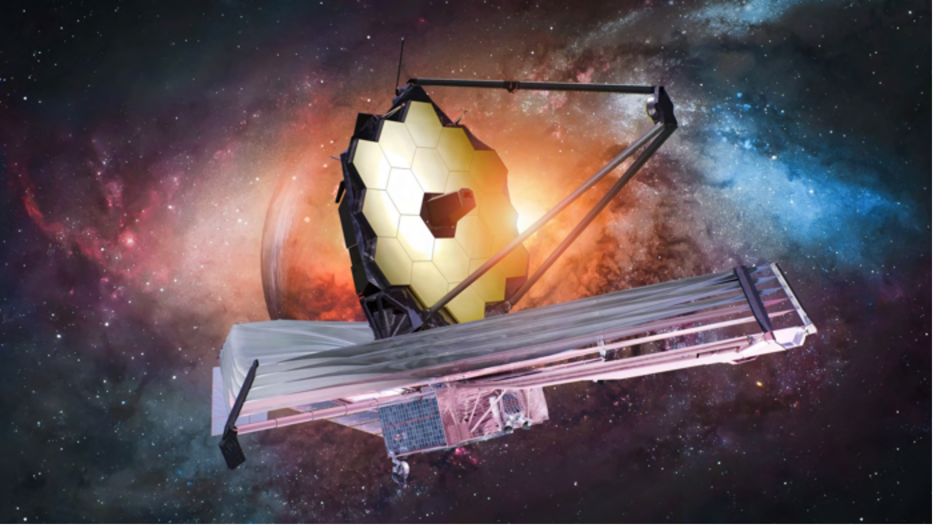


Type Ia Supernovae → redshift(z)
σ=0.135 mag
μ (z,H0=73.0,q0,j0)
SN Ia: m-M (mag)
Cepheids → Type Ia Supernovae
σ=0.130 mag, N=42
SN Ia: m-M (mag)
Cepheid: m-M (mag)
Geometry → Cepheids
N4258
M31
LMC
Milky Way
Cepheid: m-M (mag)
Geometry: 5 log D [Mpc] + 25
Δ mag

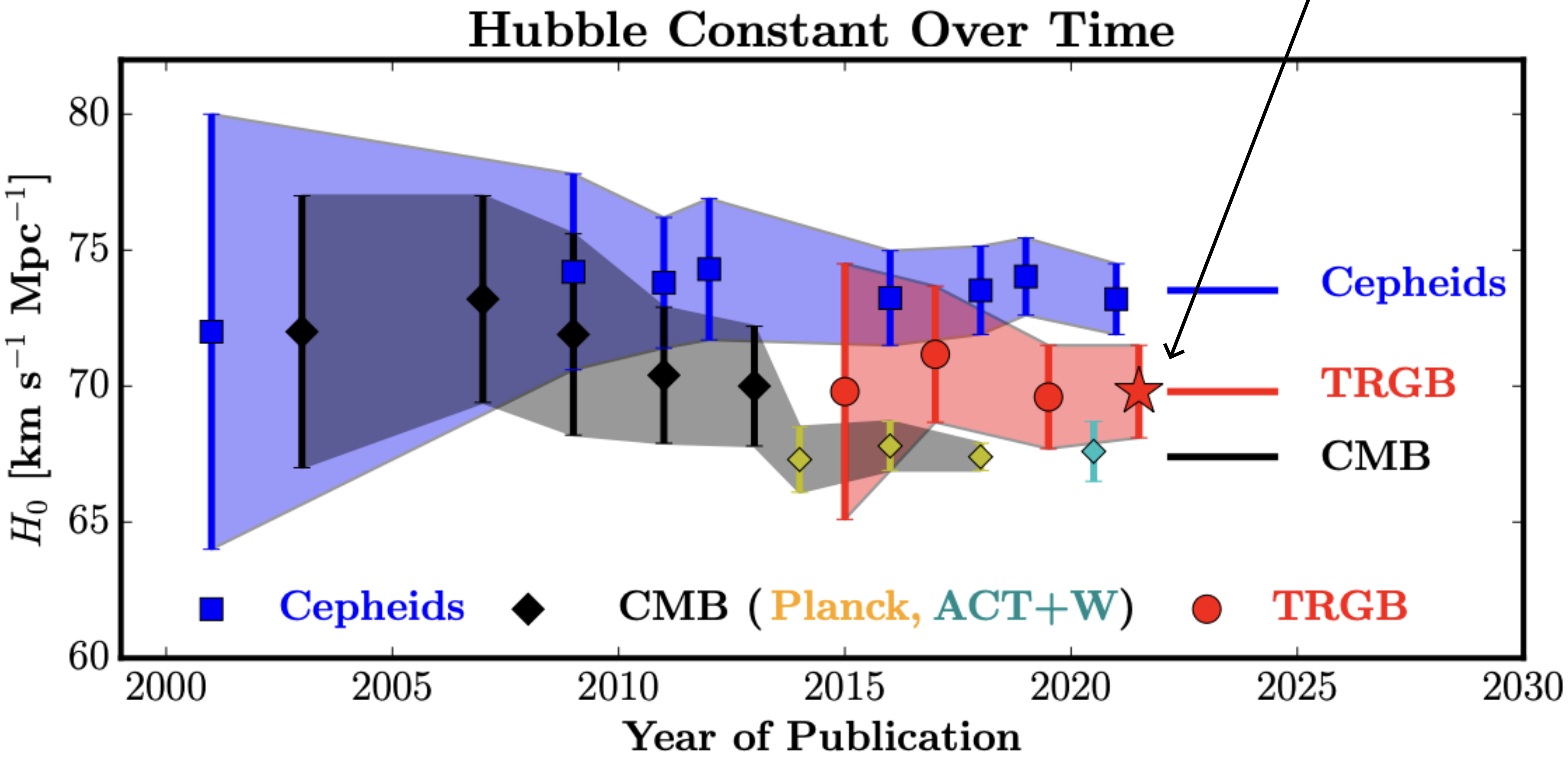
Riess+2022



Distance Ladder Covariance matrix
HF SN Ia
LMC/SMC
CC SN Ia
NGC 4258
M31
Cepheids in SN Ia hosts



If its a calibration problem maybe a better method and a better telescope will help... here comes the Just Wonderful Space Telescope (JWST)



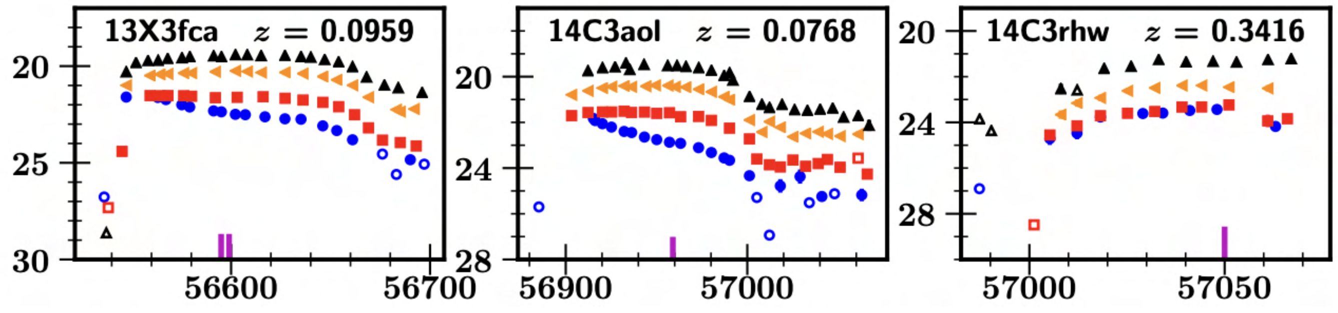
Freedman et al. 2021

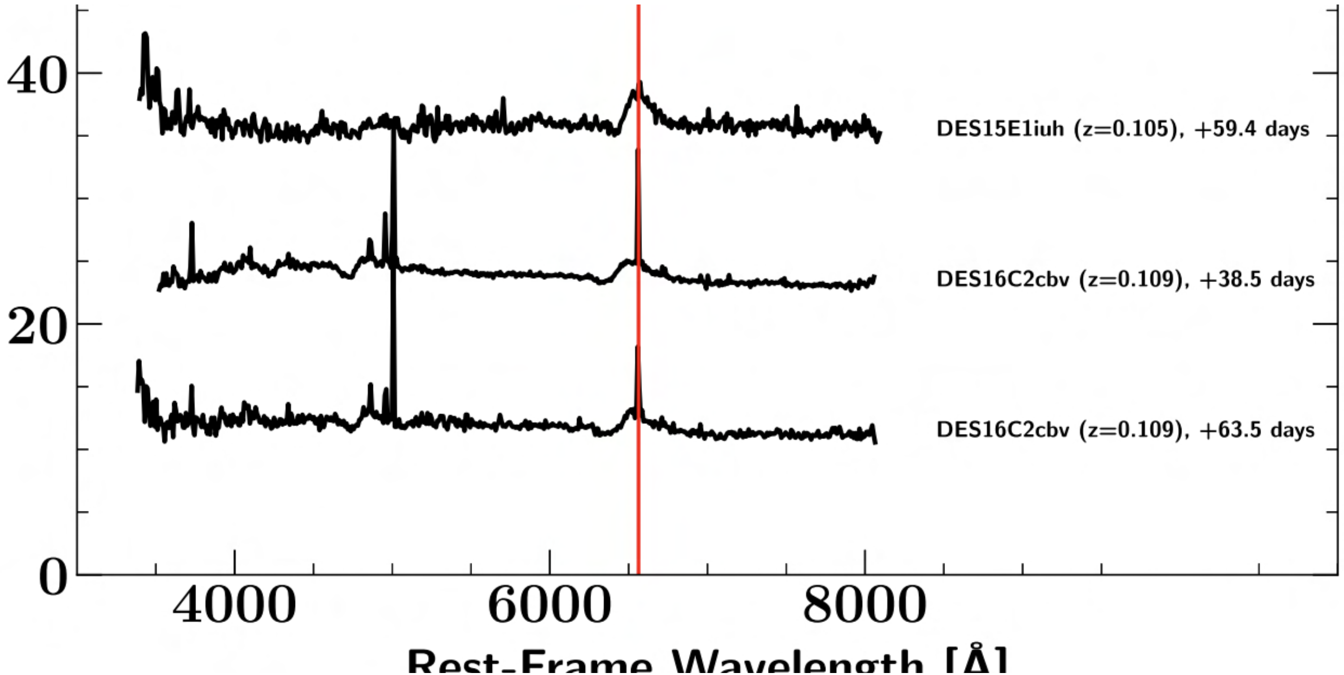
higher-z: Cosmology with other SN types

Studying Type II supernovae as cosmological standard candles using the Dark Energy Survey

T. de Jaeger,[1,2★], L. Galbany,[3] S. González-Gaitán,[4] R. Kessler,[5,6] A. V. Filippenko,[1,7] F. Förster,[8,9]

2020 MNRAS



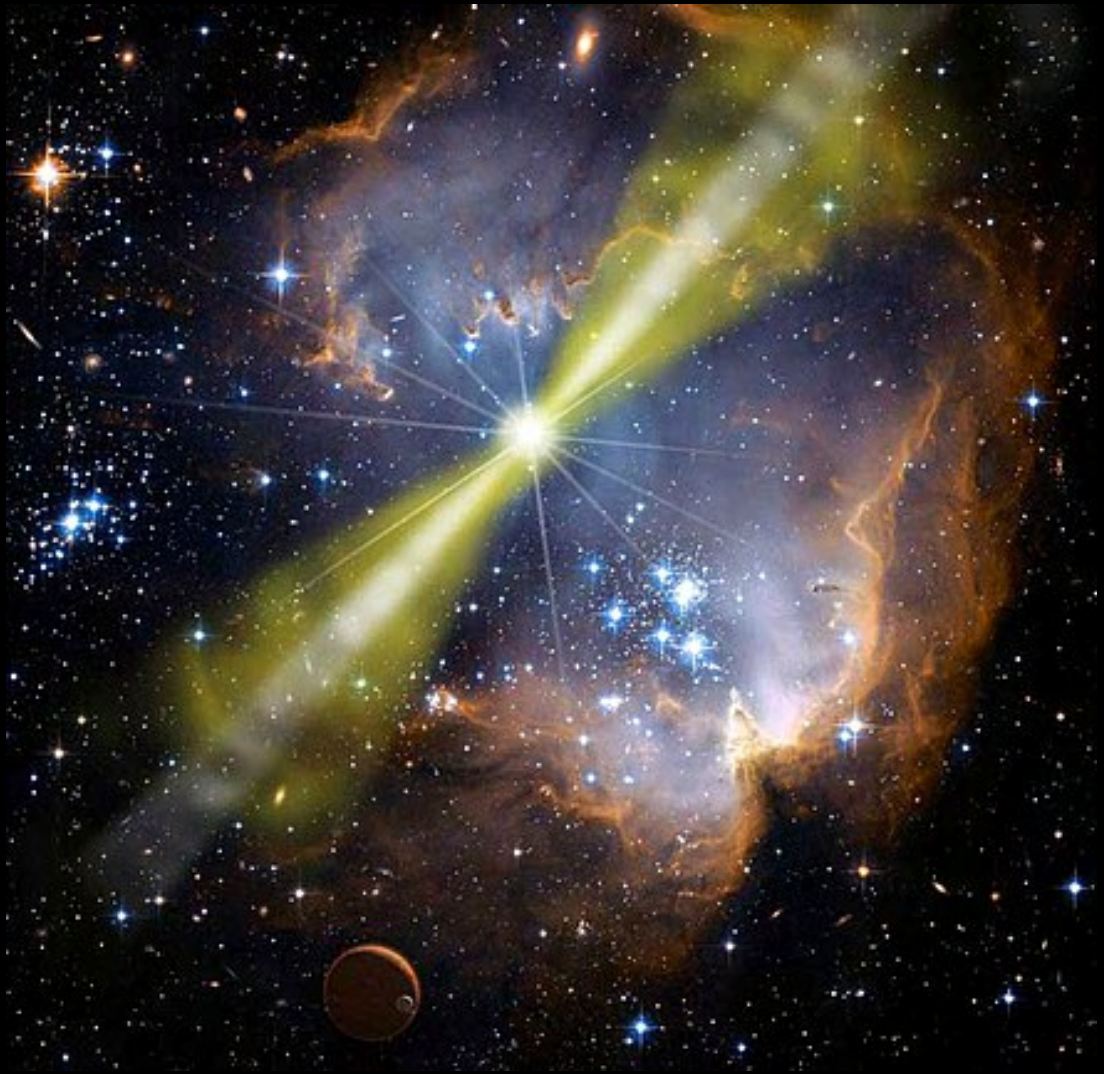


The standard candle method for SNII is an empirical method based on the observed correlation between SN II **luminosity** and **photospheric expansion** velocity during the plateau phase - with color corrections

$$m_i^{\text{model}} = \mathcal{M}_i - \alpha \log_{10}\left(\frac{v_{\text{H}\beta}}{< v_{\text{H}\beta} >}\right) + \beta[(r-i) - <(r-i)>] + 5\log_{10}(\mathcal{D}_L(z_{\text{CMB}}|\Omega_{\text{m}}, \Omega_\Lambda)),$$

higher-Z :

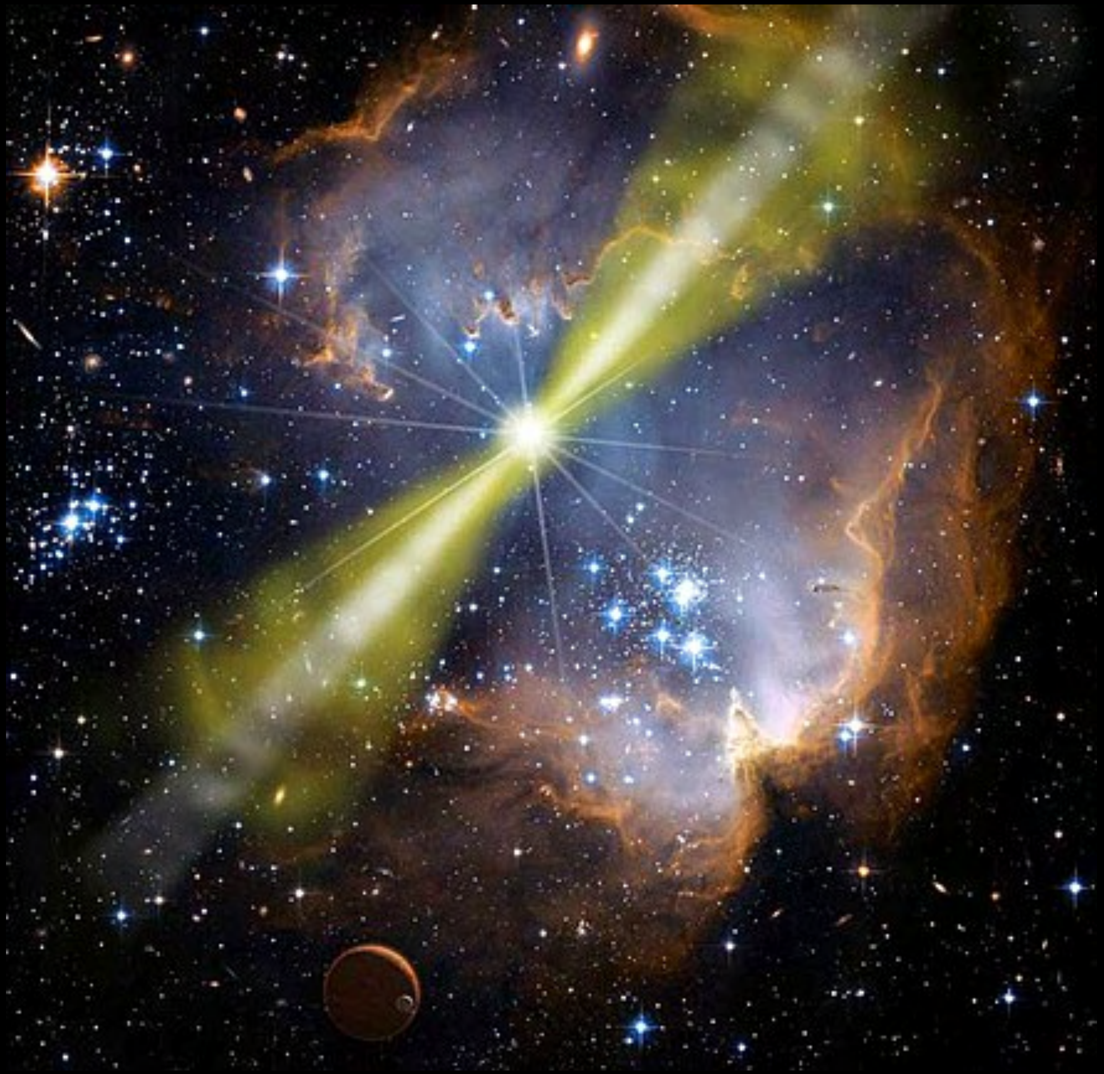
GRB



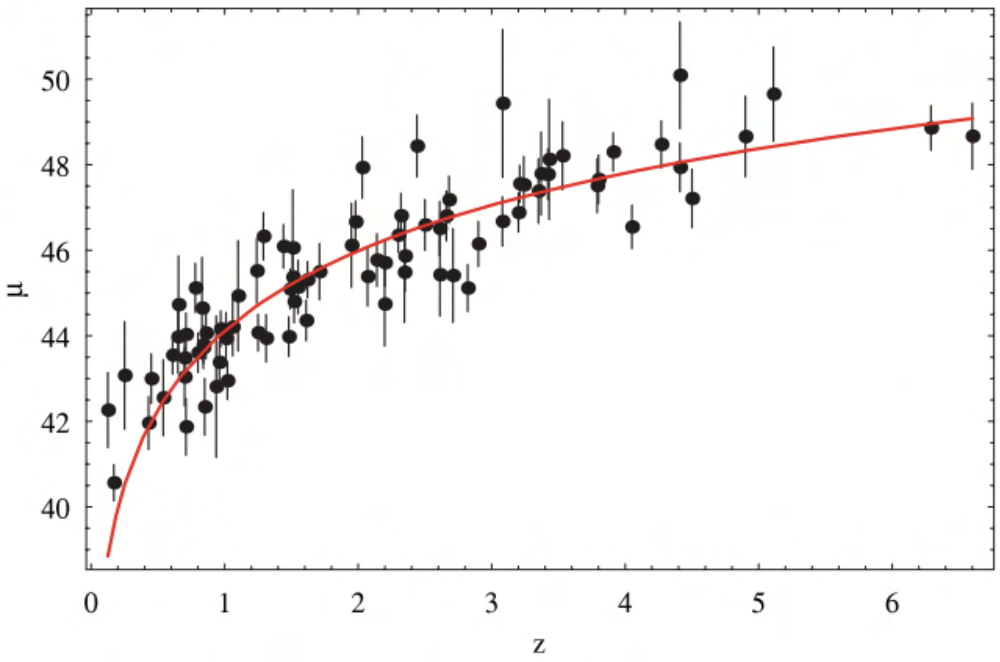
GRB have been detected to z~9!

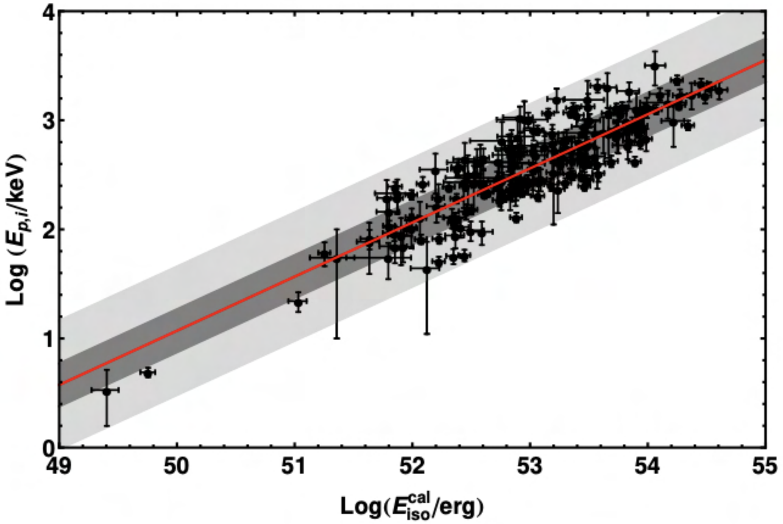
Highly energetic explosions out to redshift~9

- short gamma ray emission
- long(er) afterglow
- long GRBs: related to SNe (SN Ic-BL)
- short GRBs: related to NS mergers



modeling the Sp requires cosmological model assumption: known as the "circularity problem"





$$L = 4\pi d_L^2(z) P_{\mathrm{bolo}},$$

$$E_\gamma = 4\pi d_L^2(z) S_{\mathrm{bolo}} F_{\mathrm{beam}} (1+z)^{-1}.$$

Cardone+ 2009

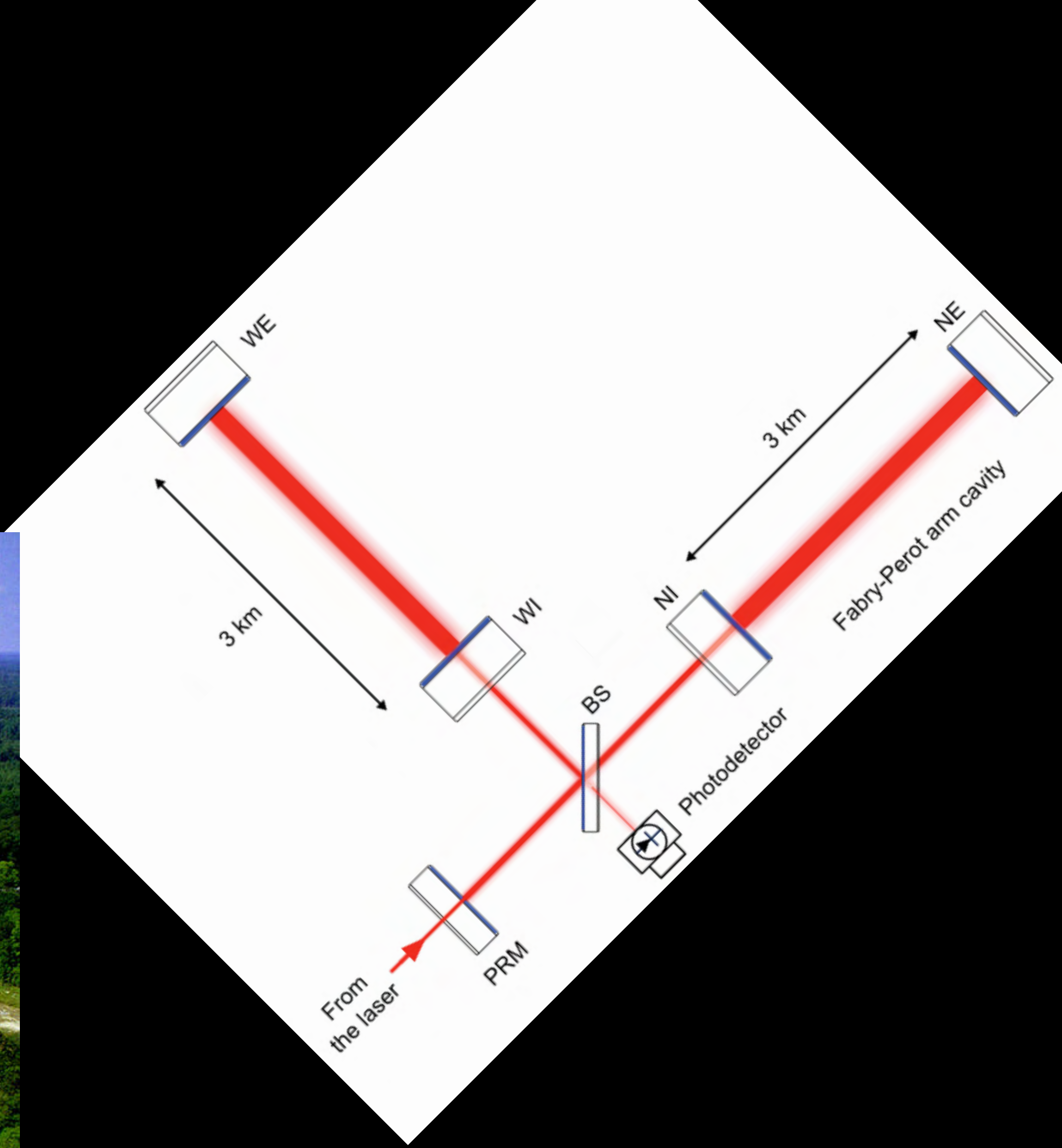
$$E_{\mathrm{iso}} = 4\pi d^2{}_L(z, cp) S_{bolo} (1+z)^{-1},$$

$$\log\left(\frac{E_{\mathrm{iso}}}{1\ \mathrm{erg}}\right) = b + a \log\left[\frac{E_{\mathrm{p,i}}}{300\ \mathrm{keV}}\right],$$

Amati+ 2019

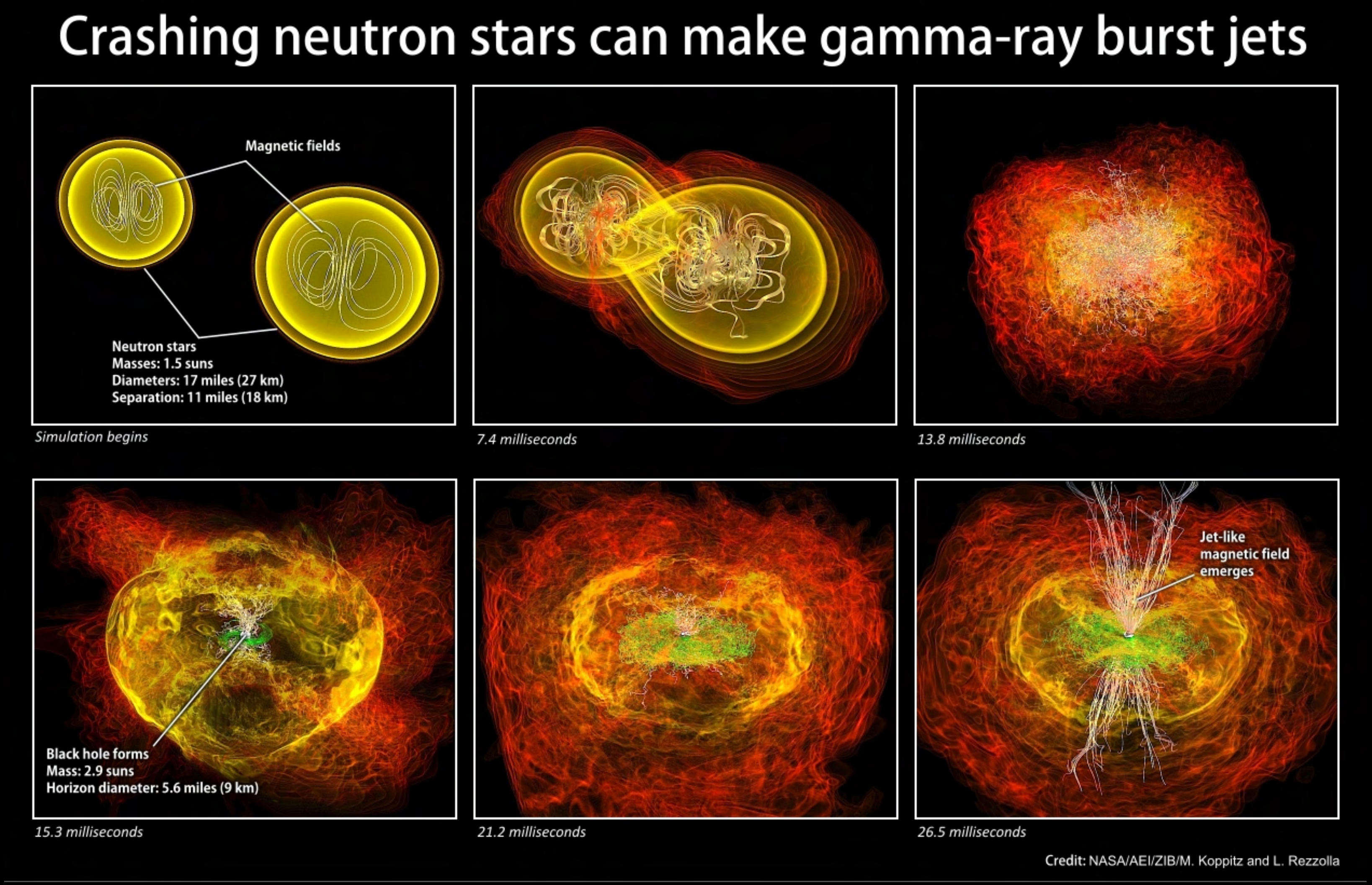
Kilonovae

LIGO Virgo Arrays



https://www.youtube.com/embed/TWqhUANNFXw?enablejsapi=1

10^{-18} **meters** - this is 1000 times smaller than the diameter of a proton



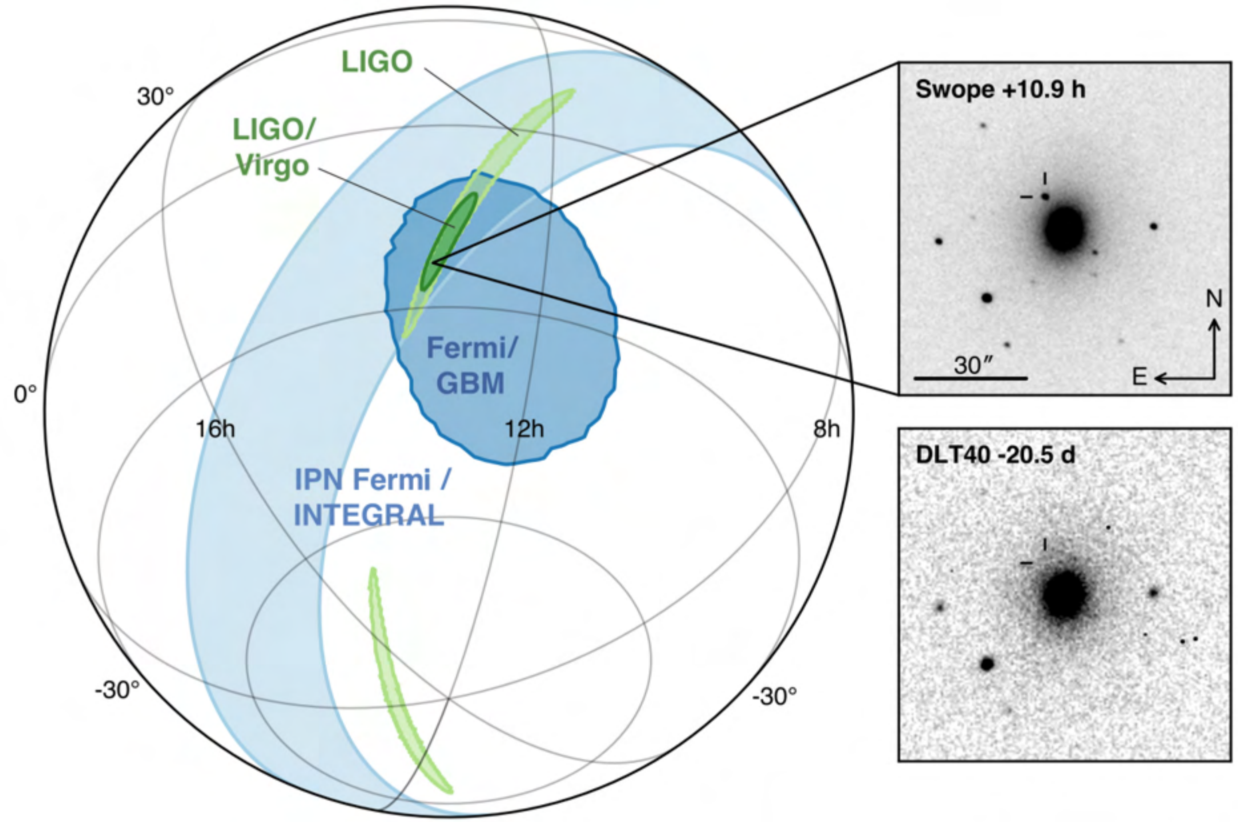
Electromagnetic emission: *Kilonova*

MMA in the next decade

LIGO/VIRGO area of localization ~100deg square

Ursa Minor contains 255.86 square degrees

S190425z 18% of the sky localization

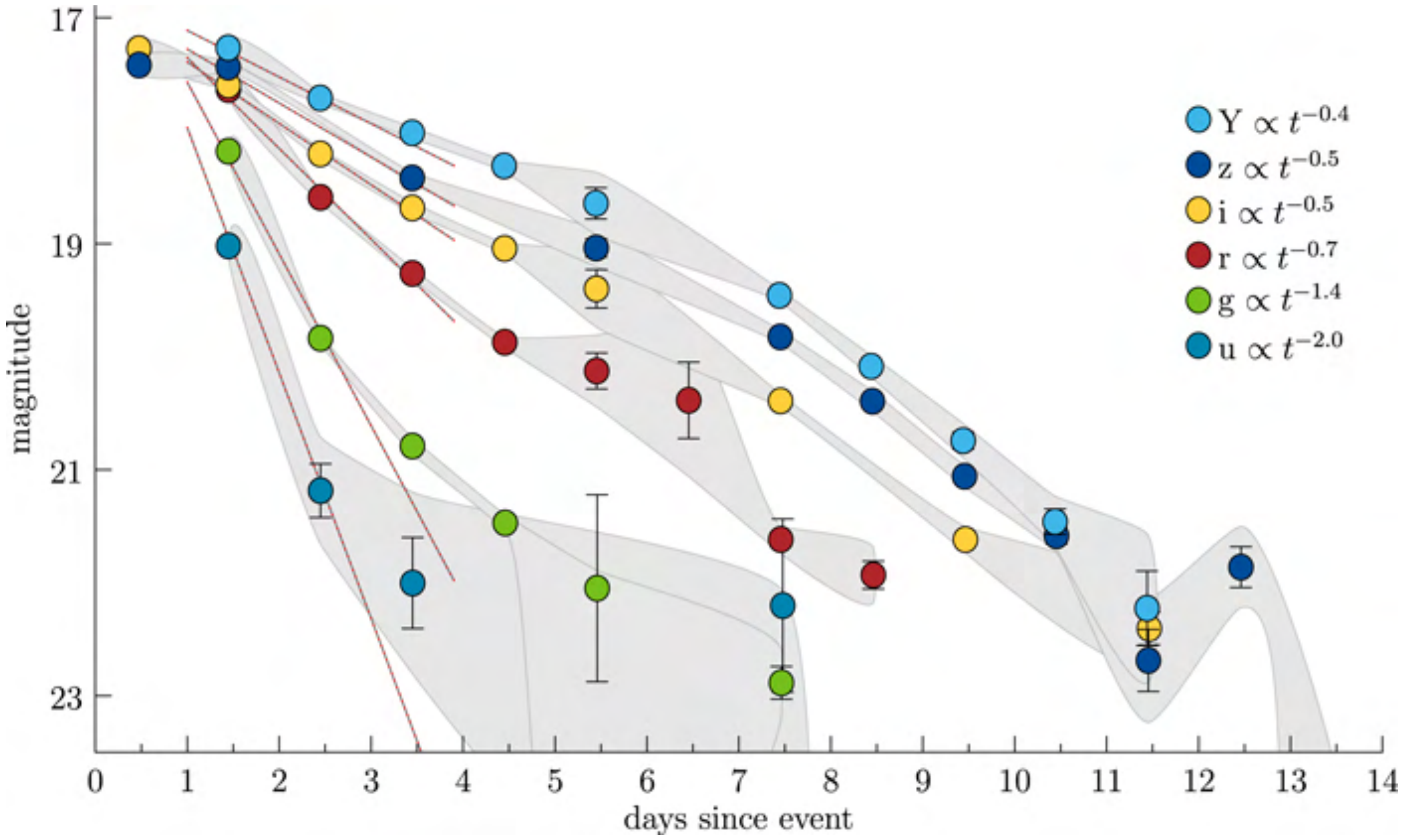


AT 2017gfo (SSS17a)

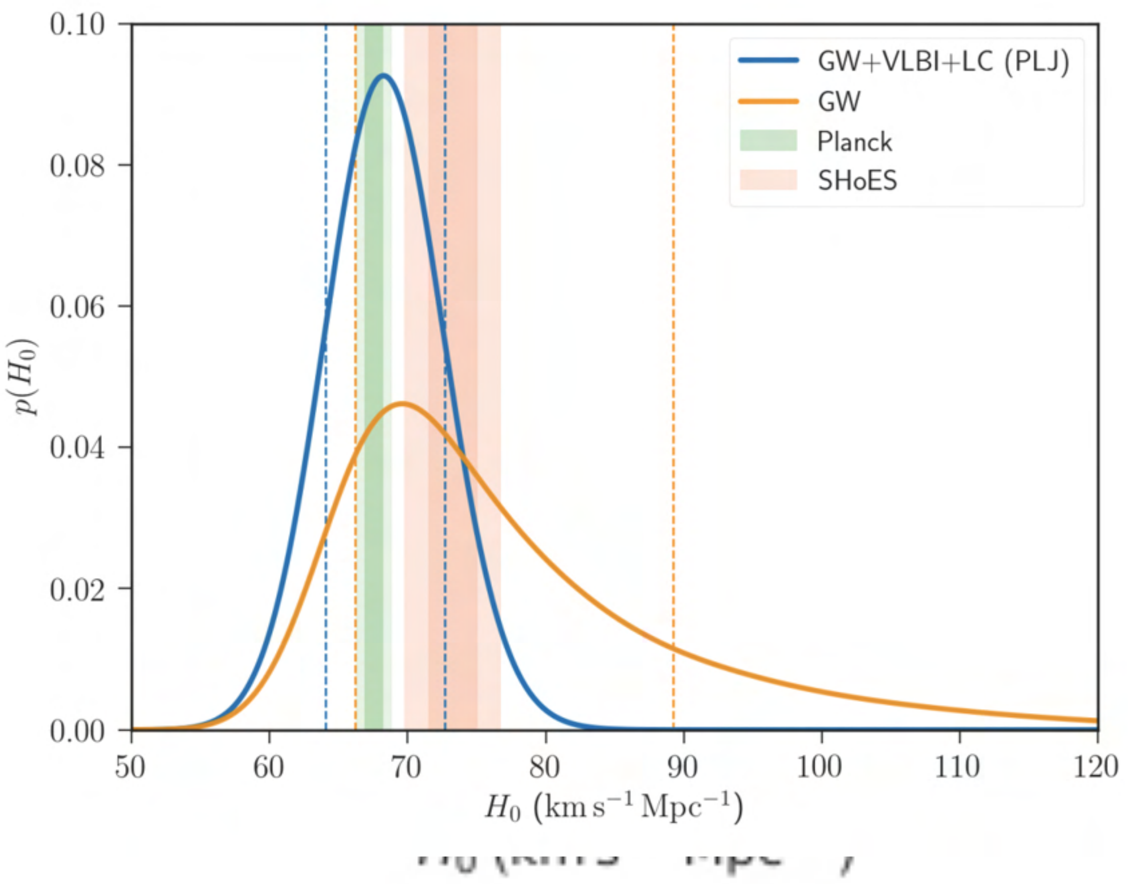
optical counterpart we have identified near NGC 4993 is associated with GW170817

Soares-Santos+ 2017

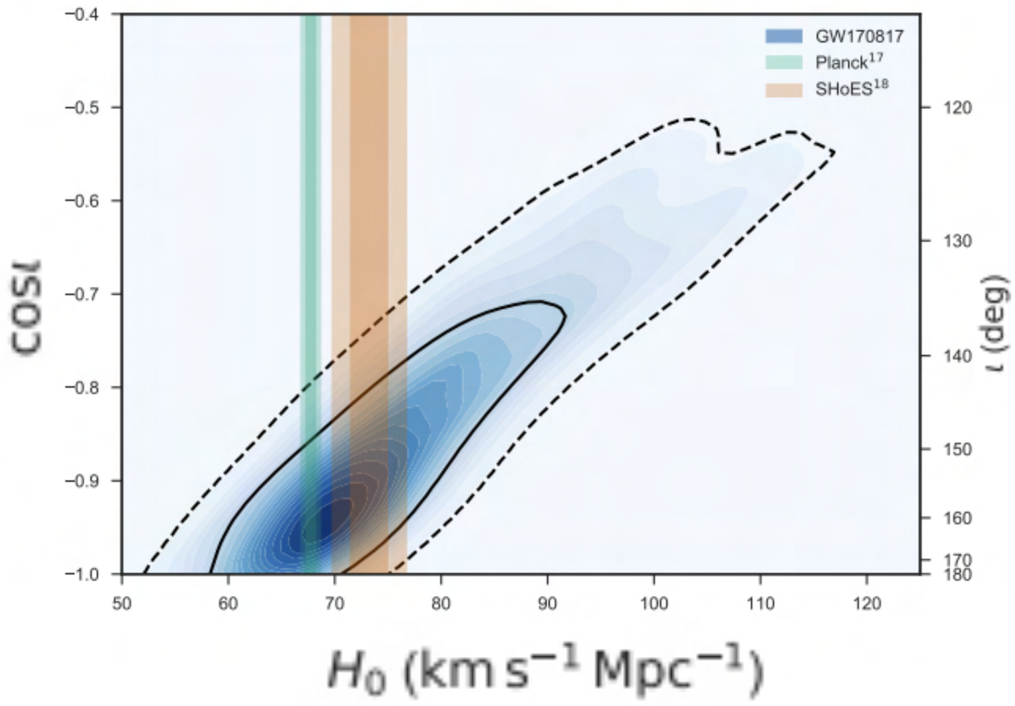
(but also Abbott+2017, Drout+2017......)



Evidence that mergers of NS are significant sources of *r-process* elements heavier than iron, including gold and platinum, which was previously attributed exclusively to supernova explosions



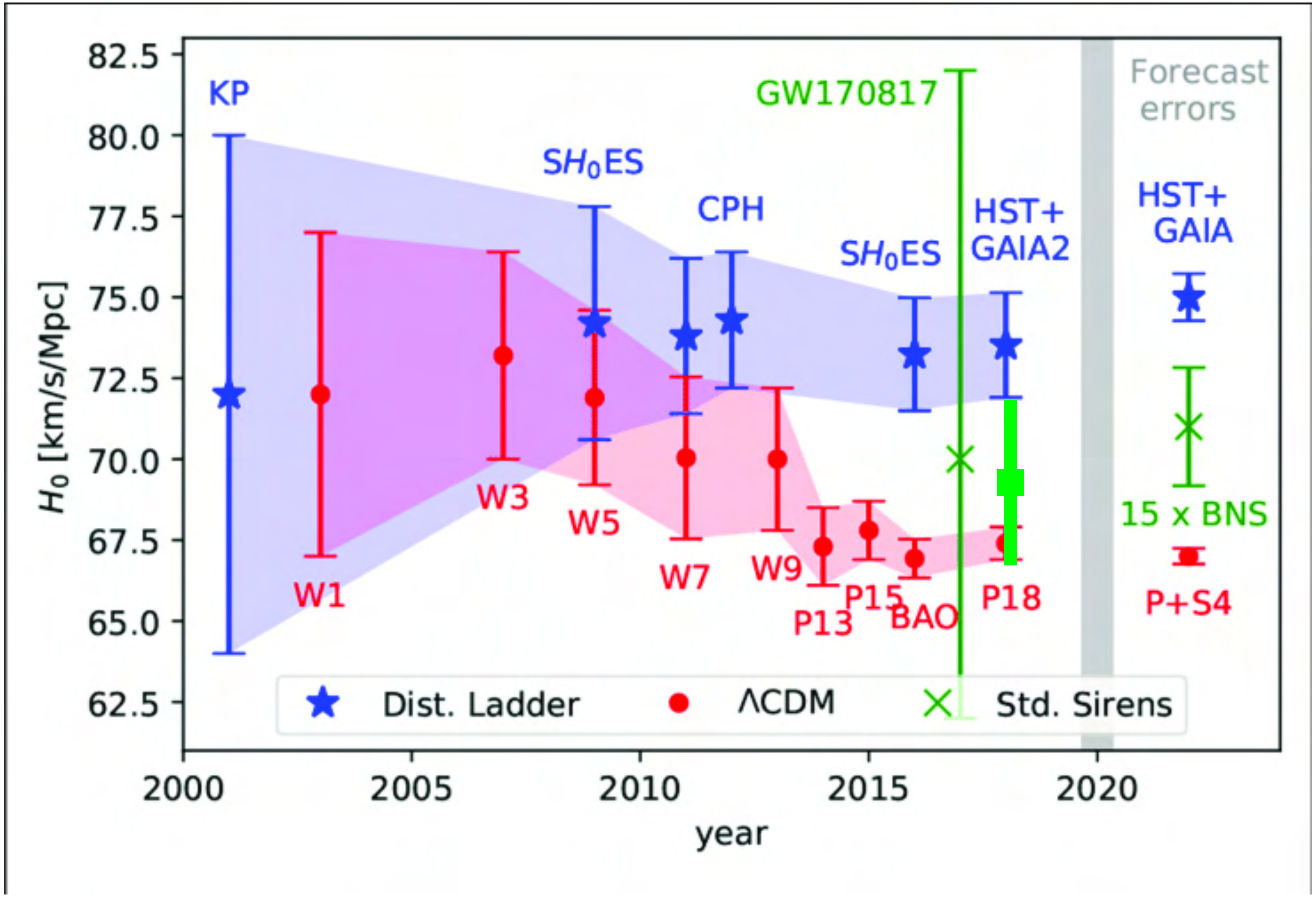
Hotokezaka+ 2018



The source distance DL is inferred directly from the GW signal while its redshift *z* is obtained from an electromagnetic (EM) counterpart.

Merger inclination is the main source of uncertainty

Text



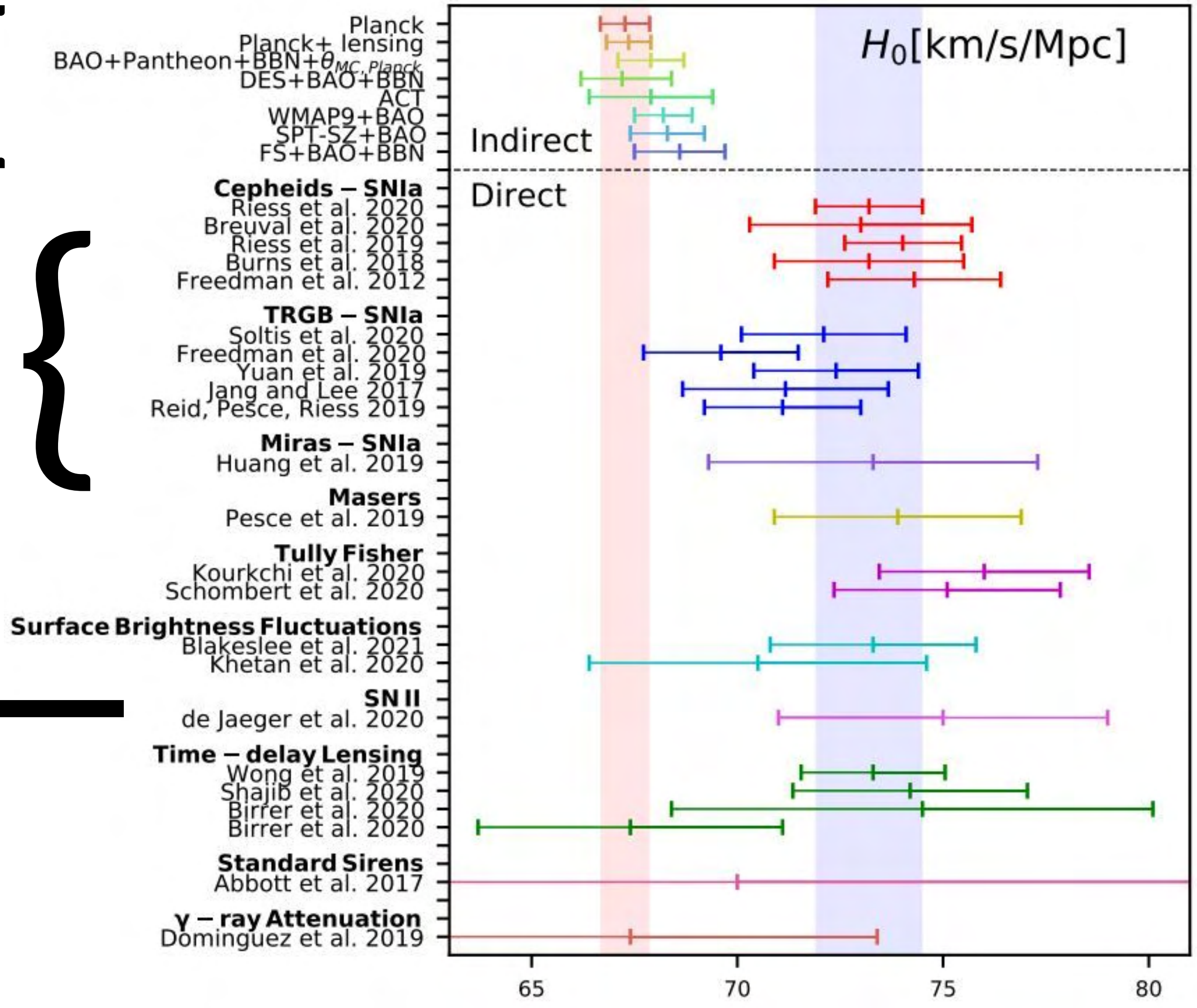
Std Sirens+EM

Beaton et al. 2016

CMB

SN

SN



discrepancy ~5sigma

need a 20% mag correction on SNe to reconcile

Di Valentino [2011.00246]

thank you!

federica bianco

University of Delaware
Department of Physics and Astronomy
Biden School of Public Policy and Administration
Data Science Institute

Rubin Observatory Construction Project
LSST Transient and Variable Stars Science Collaboration

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fbianco@udel.edu