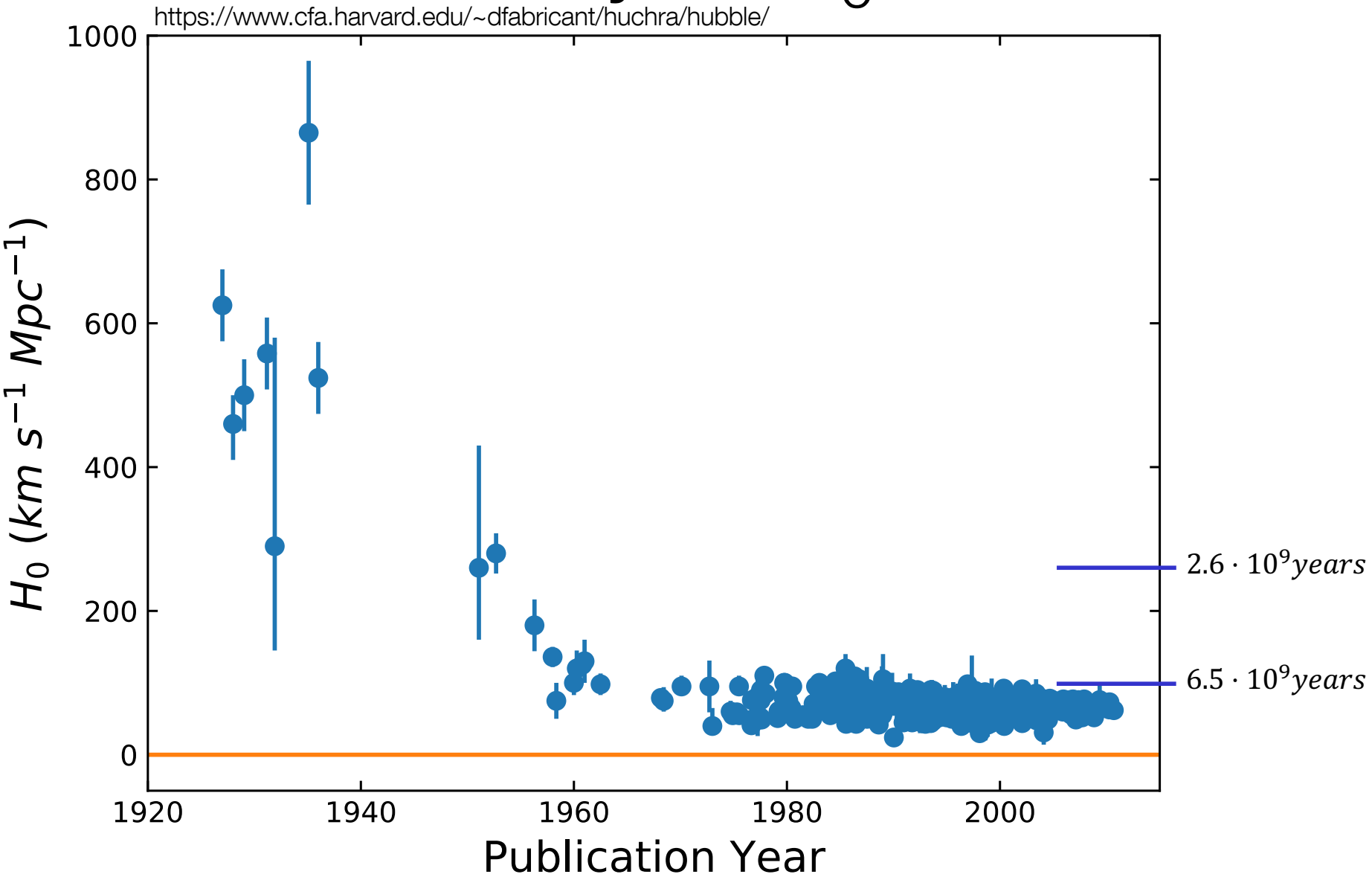
# adH0cc
# Local $H_0$ in one step

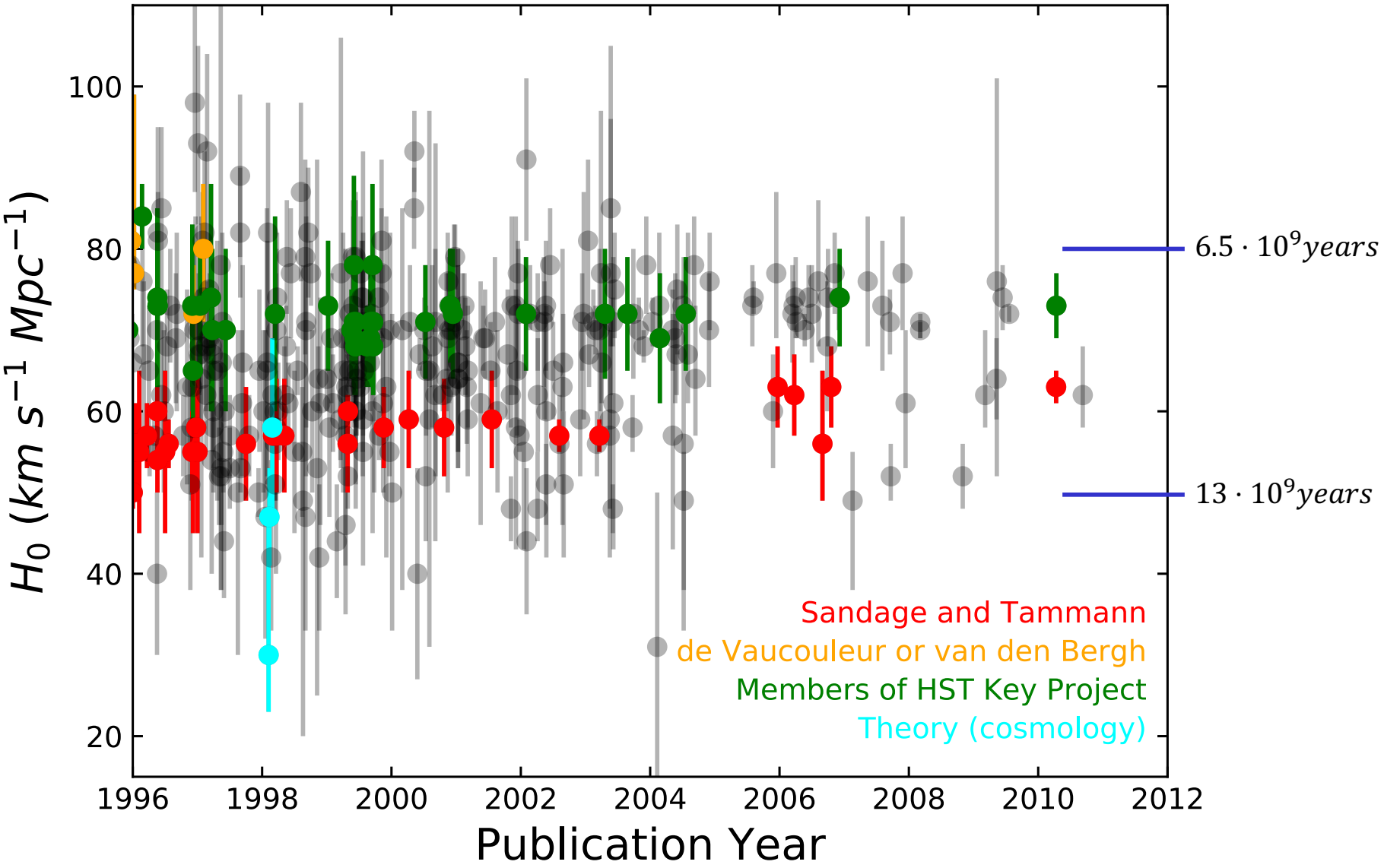
Status report

Bruno Leibundgut
on behalf of the adH0cc Team

# History of $H_0$



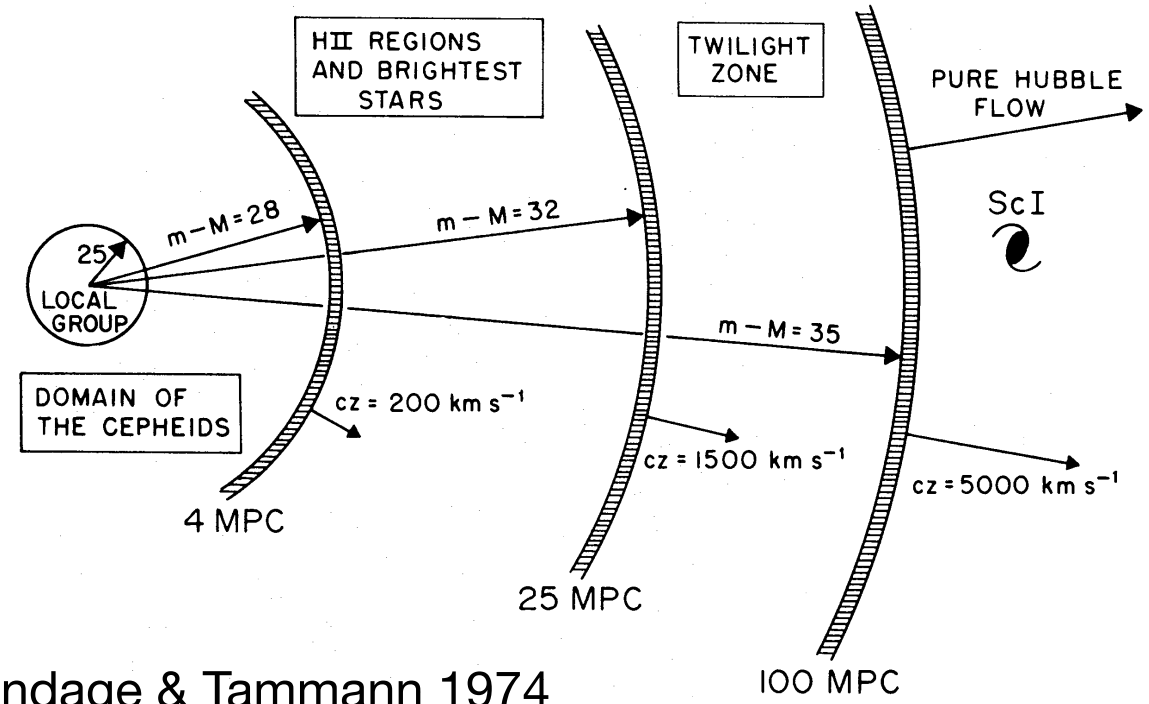
# History of $H_0$



# Measuring $H_0$

## Classical approach

→ distance ladder to reach (smooth) Hubble flow

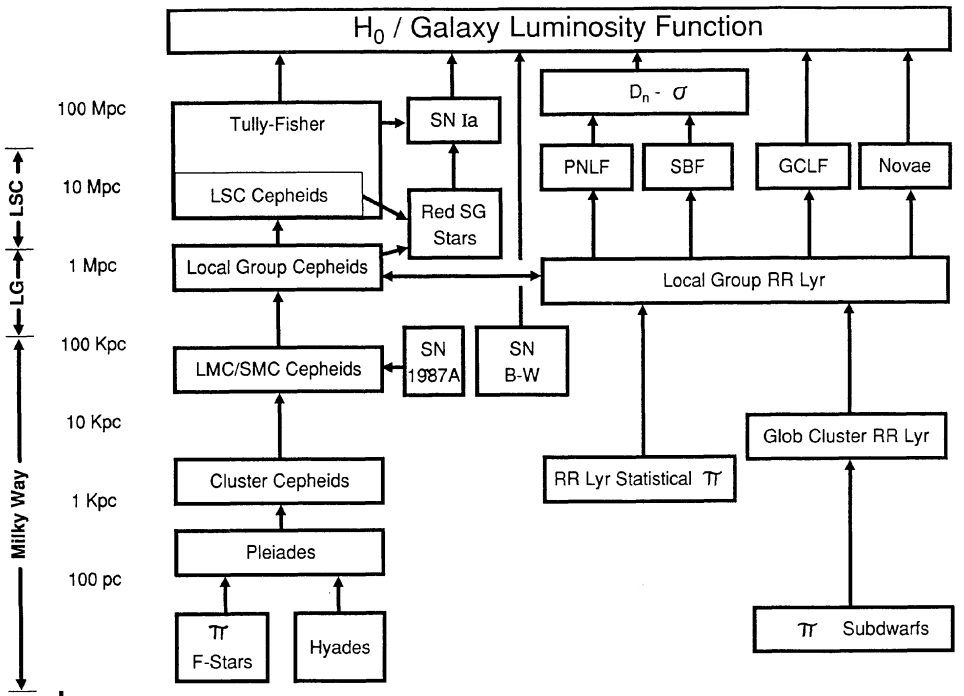



Sandage & Tammann 1974

# Classical Distance Ladder

## Distance indicators

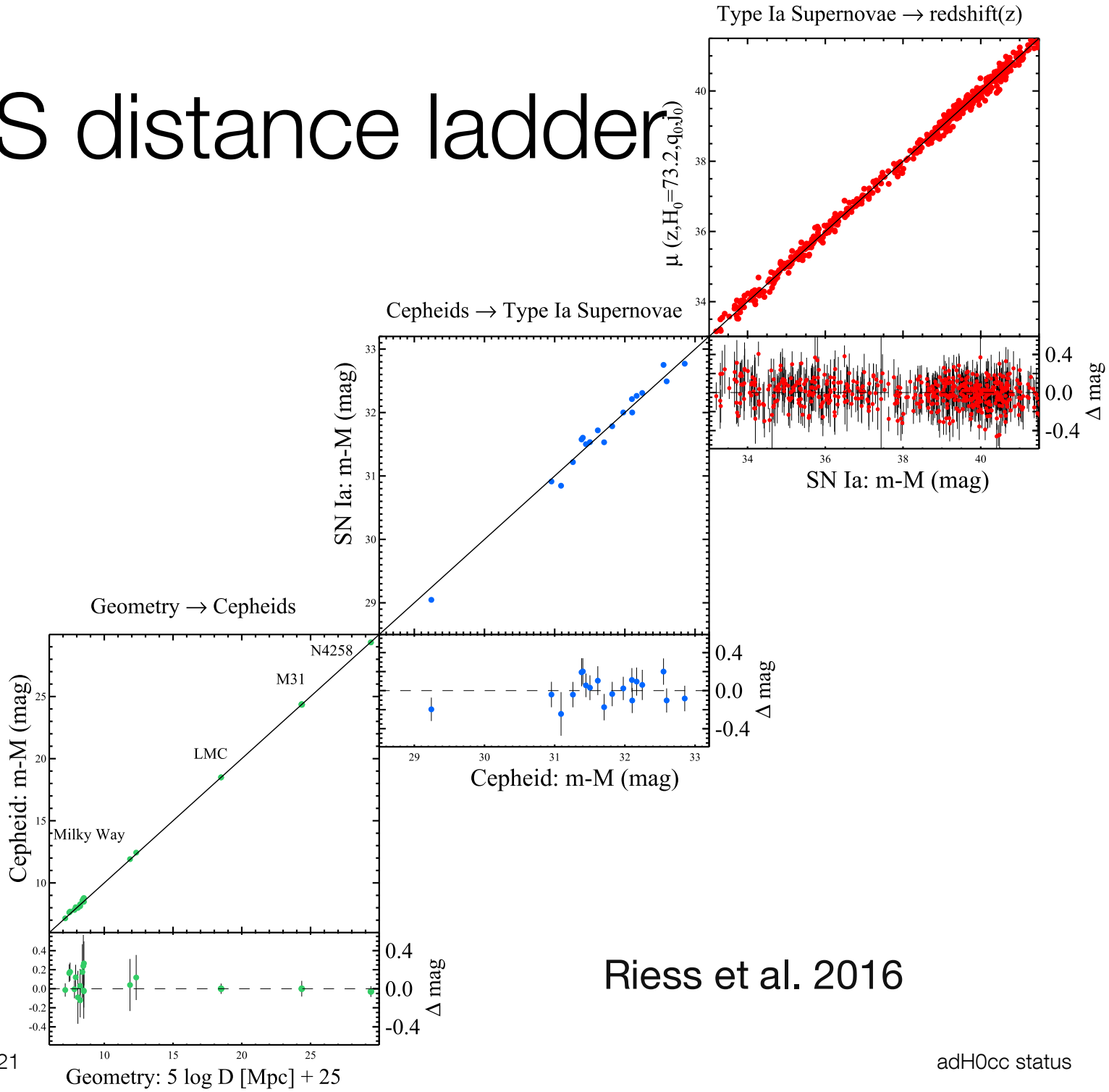
- trigonometric parallax
- apparent luminosity
  - main sequence
  - red clump stars
  - RR Lyrae stars
  - eclipsing binaries
  - Cepheid stars
- Galaxy relations
  - Tully-Fisher, Faber-Jackson
- SNe Ia



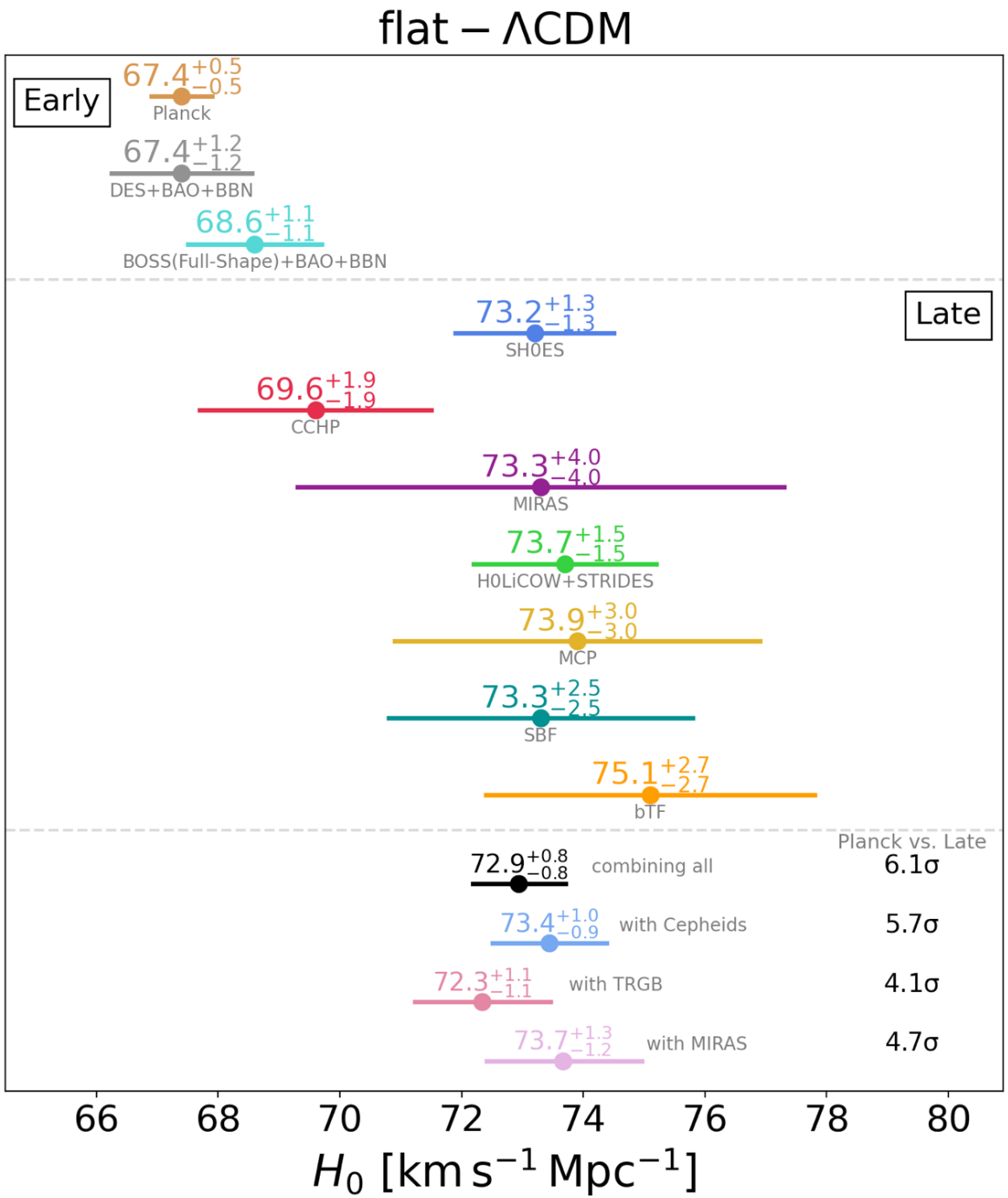

*Pathways to Extragalactic Distances*

Jacoby et al. 1992

# $SH_0ES$ distance ladder




Riess et al. 2016




# $H_0$ Status

Bonvin and Millon
https://doi.org/10.5281/zenodo.3635517

# adH0cc – Basics

- accurate determination of $H_0$ with core-collapse (supernovae)
- Individual distances (to about 10%) to Type II supernovae in the Hubble flow ($0.03 < z < 0.15$)
- Distance determination based on calibrated physics
  - No distance ladder, i.e. no empirical calibration
  - Ideal for $H_0$

# adH0cc – Basics

- Collaboration: MPA, ESO, TUM, LAM, GSI, QUB, Turku, Weizmann, EPFL
- Web page: https://adh0cc.github.io

## adH0cc

**accurate determination of $H_0$ with core-collapse supernovae**

We aim to determine the current expansion rate of the Universe, the so-called Hubble constant $H_0$. To this end, we measure distances to Type IIP supernovae in the Hubble flow using the Tailored Expanding Photosphere Method.


This project is based on the ESO-VLT Large Programme 1104.A-0380.

# adH$_0$cc – Team

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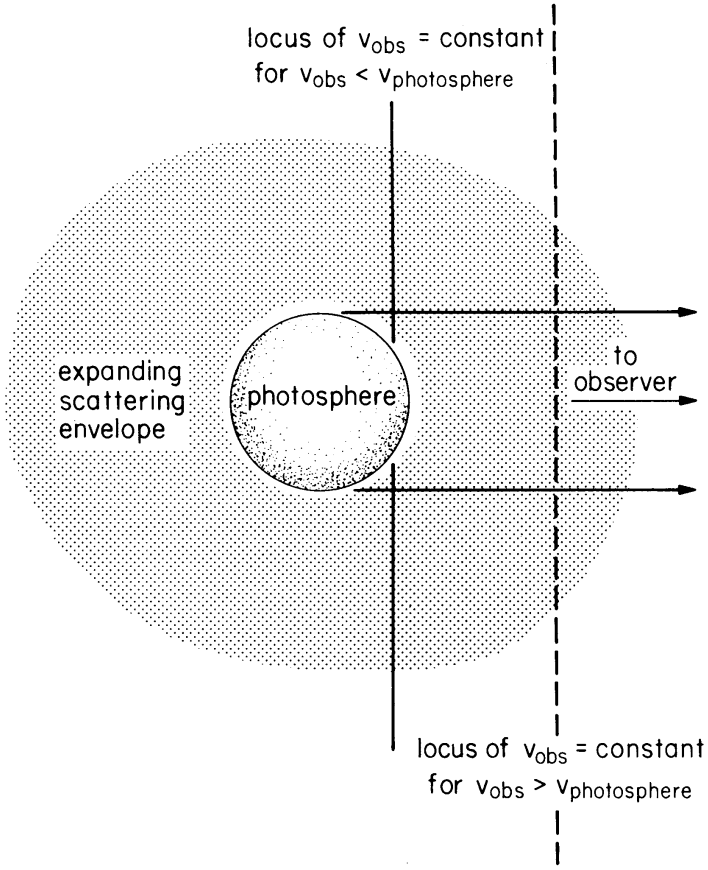
# Expanding Photosphere Method

Modification of Baade-Wesselink method for variable stars

Assumes

- Sharp photosphere
  → thermal equilibrium
- Spherical symmetry
  → radial velocity
- Free expansion



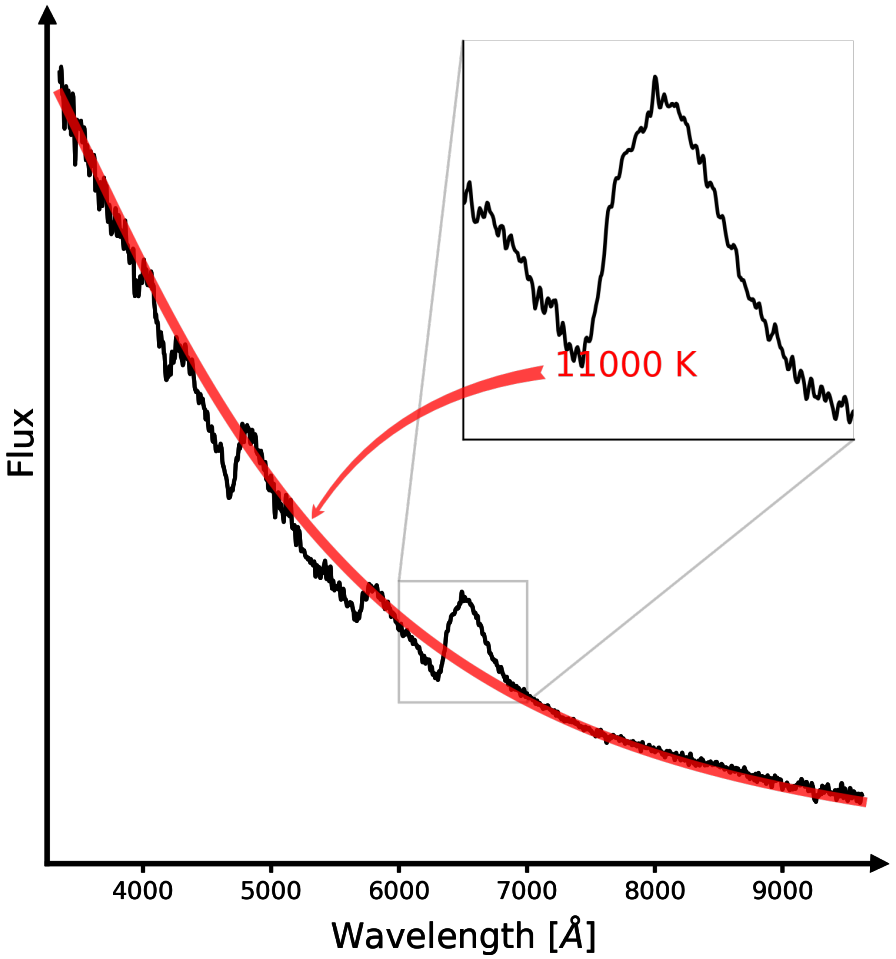

Kirshner & Kwan 1974

# Expanding Photosphere Method

$$\theta = \frac{R}{D} = \sqrt{\frac{f_\lambda}{\zeta_\lambda^2 \pi B_\Lambda(T)}};\ R = v(t - t_0) + R_0;\ D_A = \frac{v}{\theta}(t - t_0)$$

- *R* from radial velocity
  - Requires lines formed close to the photosphere
- *D* from the surface brightness of the black body
  - Deviation from black body due to line opacities
  - Encompassed in the dilution factor $\zeta^2$

# EPM: it's all in the spectra




C. Vogl

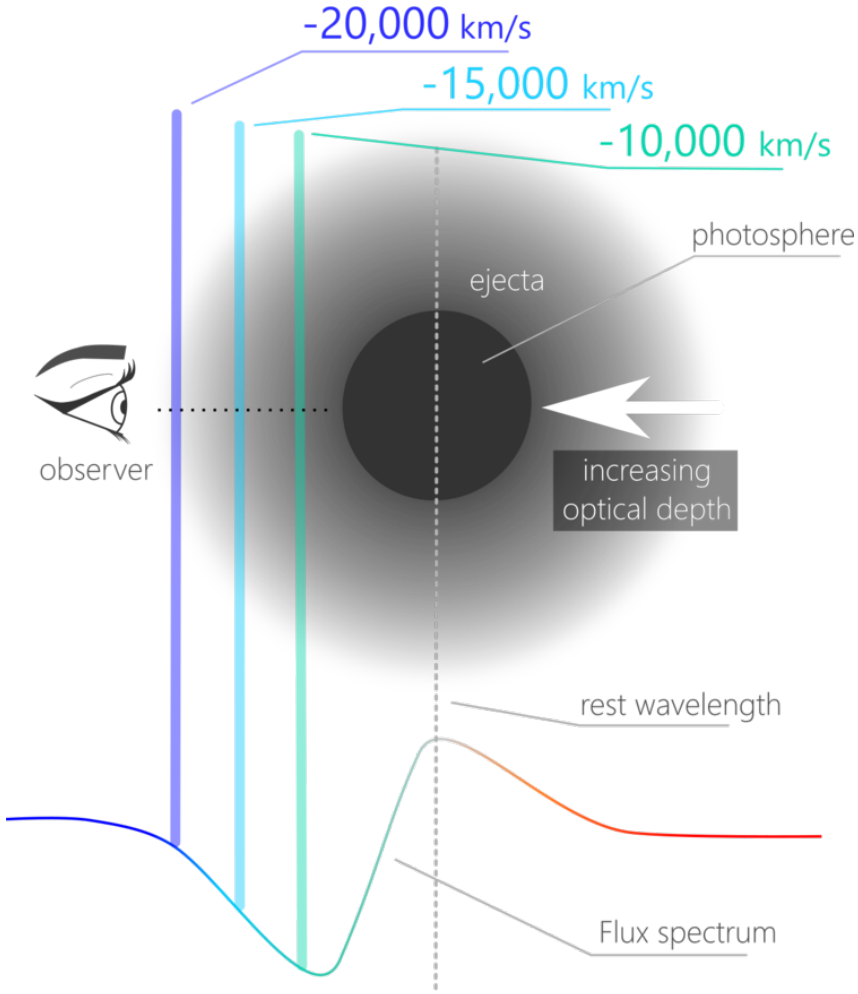
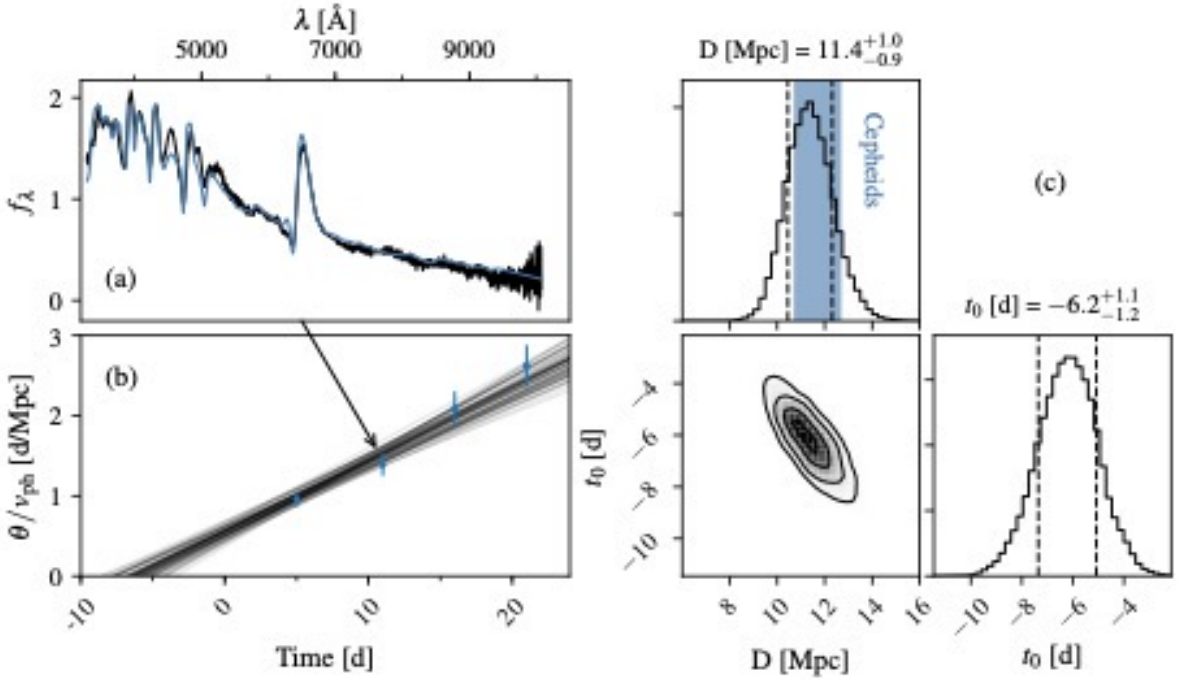



Image: Héloïse Stevance

# EPM improvements (C. Vogl)

Developed in Christian Vogl's thesis

- Individual fitting of each SN epoch
- Consistent parameters for the SN atmosphere
- Accurate explosion date from observations

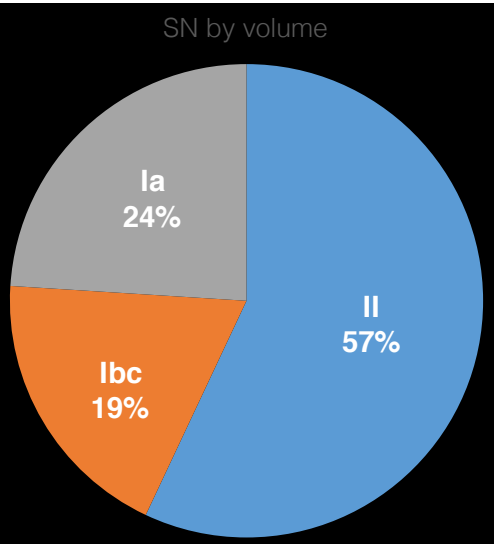



Vogl et al. 2020

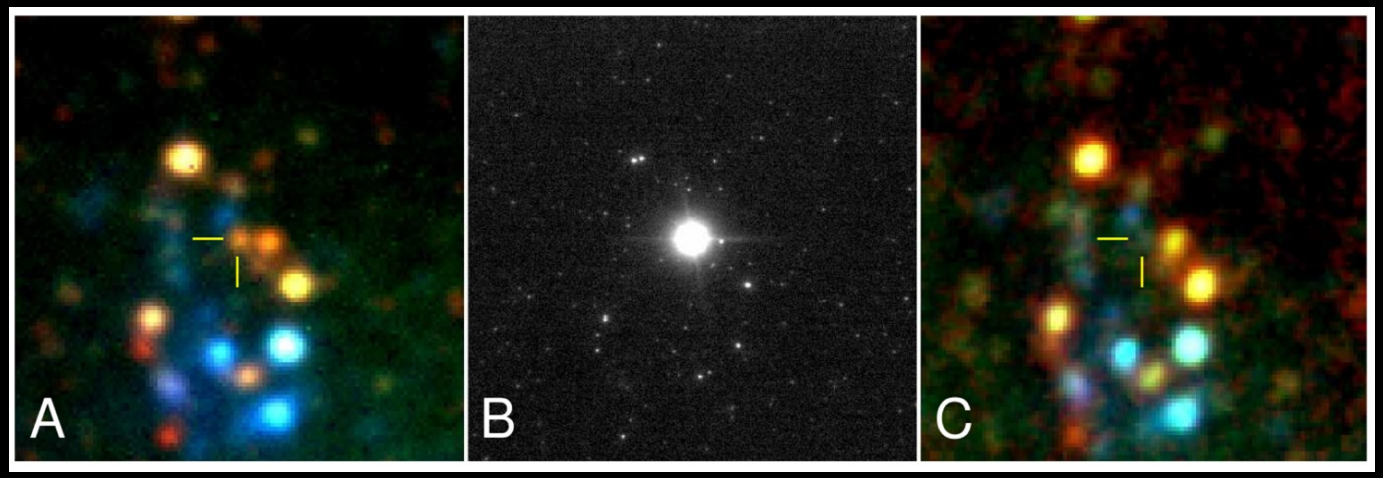
# adH0cc – Goal

- $H_0$ with 3% uncertainty
- Observe 12 SNe II with $\mathbf{0.04 < z < 0.1}$
  - 6 epochs spectroscopy and photometry
  - Explosion date known to $\pm 3\ days$
  - 150 hours observing time with VLT/FORS2 over 1.5 years (→ 2 years with pandemic)
  - Elaborate observing scheme
    - Classification (ToO) → first epoch (ToO)
      → second epoch (ToO)
      → three regular epochs (spread over 3 weeks)
- Complement existing data set
  - 20 SNe from SNFactory ($\mathbf{0.01 < z < 0.04}$)

# Type II Supernovae




## Core-collapse explosions of massive, red-supergiant stars




Mattila et al. 2010

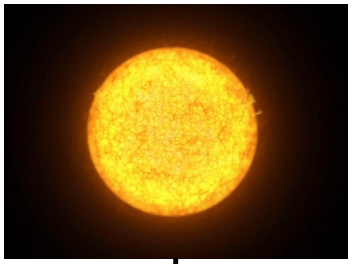
- Peak absolute mags between -16 and -18

  → observable up to z ≈ 0.4

- Most common supernova type by volume

# Why type II supernovae?

Luminosity ~ Period



Type II supernovae




Riess et al. 2016

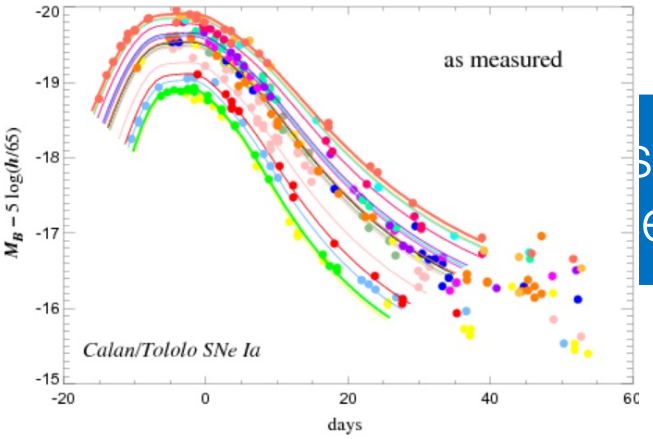
Type II supernovae:

simple physics

Luminosity

one-s… measure…

Luminosity ~ light curve width

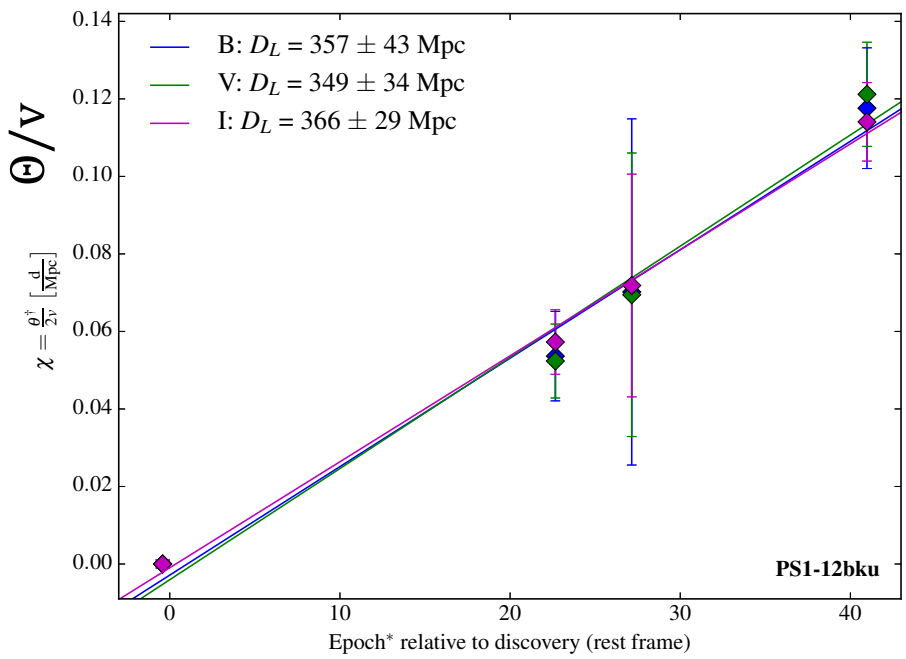



…sics …ed

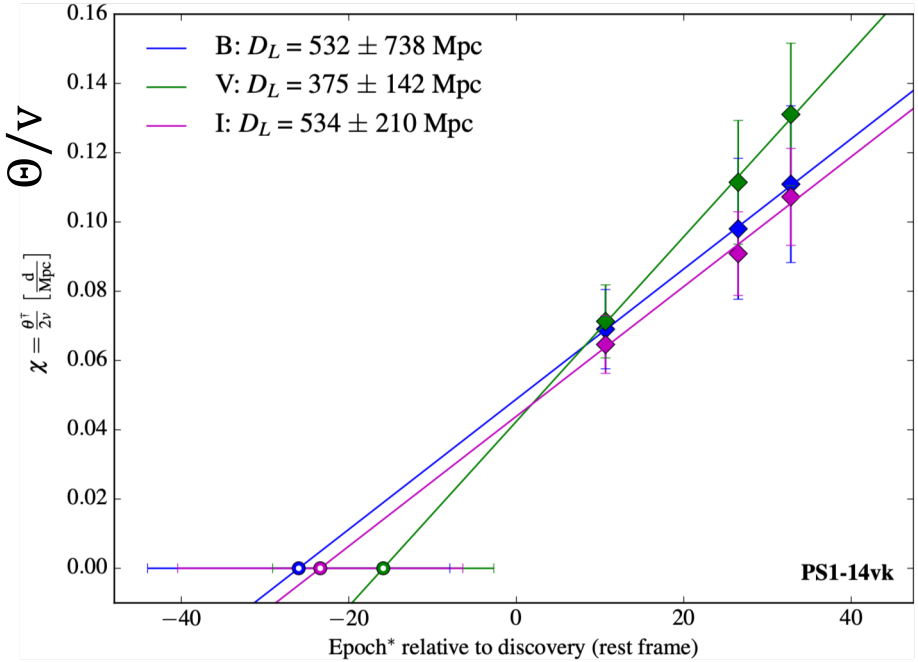
# Expanding Photosphere Method

$$\frac{\Theta}{v} = \frac{1}{D_A}(t - t_0)$$

Gall et al. 2018




$t - t_0$



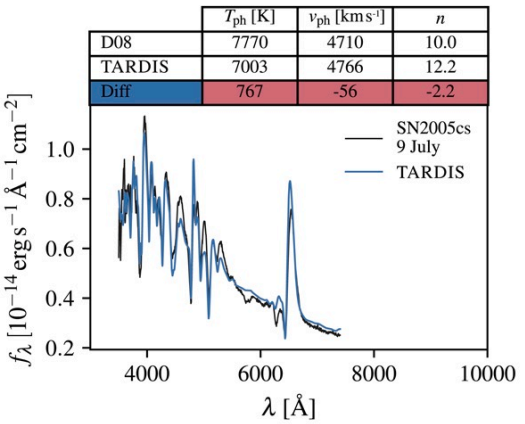

$t - t_0$

# Expanded Photosphere Method Reloaded

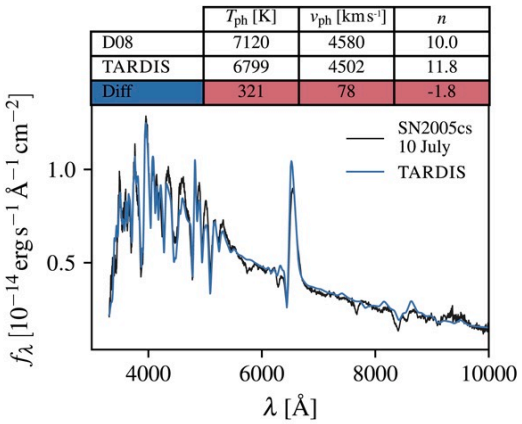
- Use individual atmospheric models for the spectral fits
  - use of the TARDIS radiation transport model
  - absolute flux emitted
- Accurate explosion date
  - accurate zero point
- At least 5 epochs per supernova

# Atmosphere Models

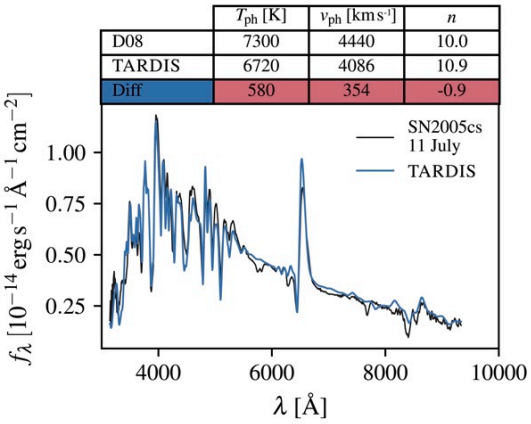
TARDIS fits for different epochs



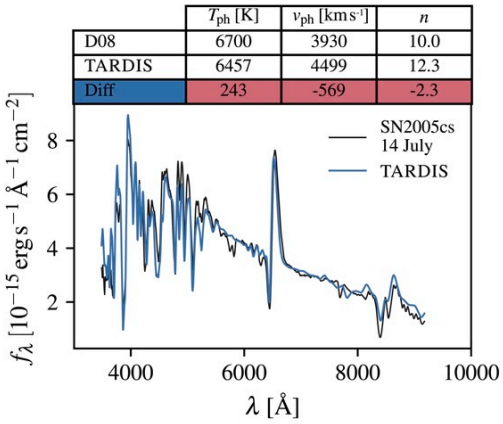

(a) 9 July 2005



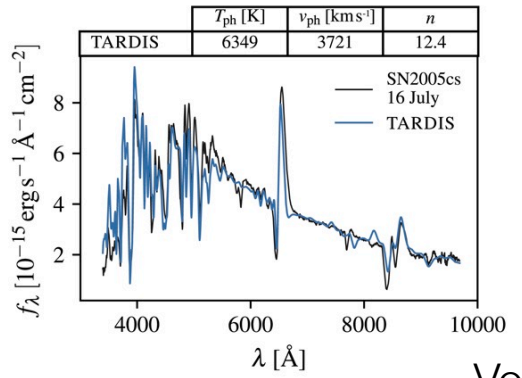

(b) 10 July 2005




(c) 11 July 2005




(d) 14 July 2005



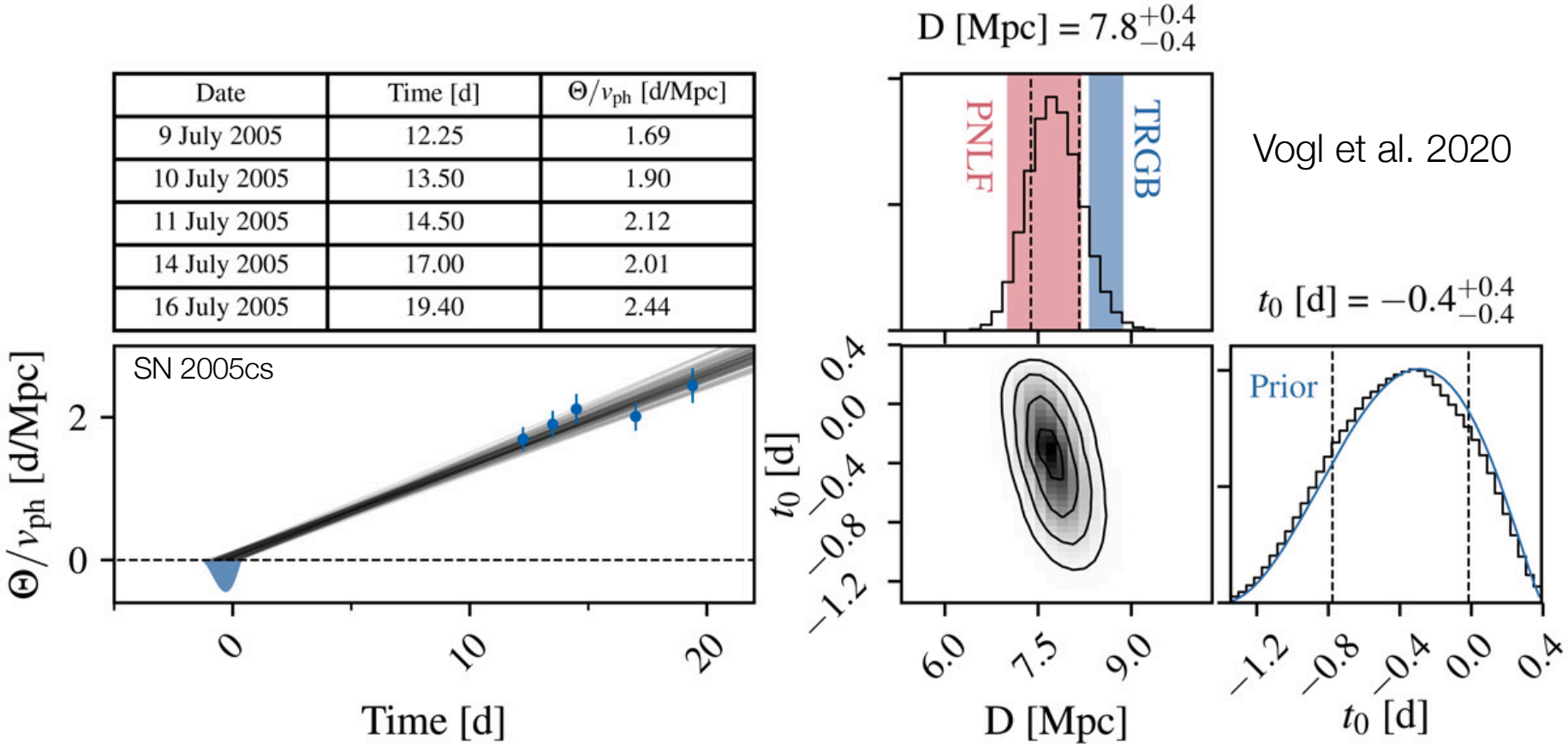

(e) 16 July 2005

Vogl et al. 2020

# Distance Determination

Slope is inverse distance: $\frac{\Theta}{v} = \frac{1}{D_A}(t - t_0)$

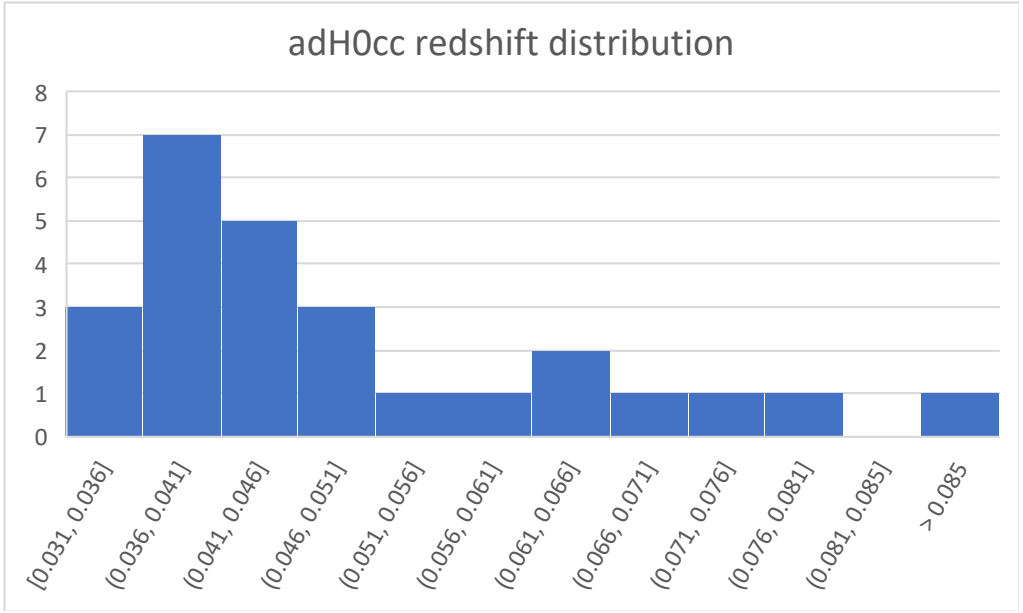
| Date | Time [d] | $\Theta/v_{\rm ph}$ [d/Mpc] |
|---|---|---|
| 9 July 2005 | 12.25 | 1.69 |
| 10 July 2005 | 13.50 | 1.90 |
| 11 July 2005 | 14.50 | 2.12 |
| 14 July 2005 | 17.00 | 2.01 |
| 16 July 2005 | 19.40 | 2.44 |



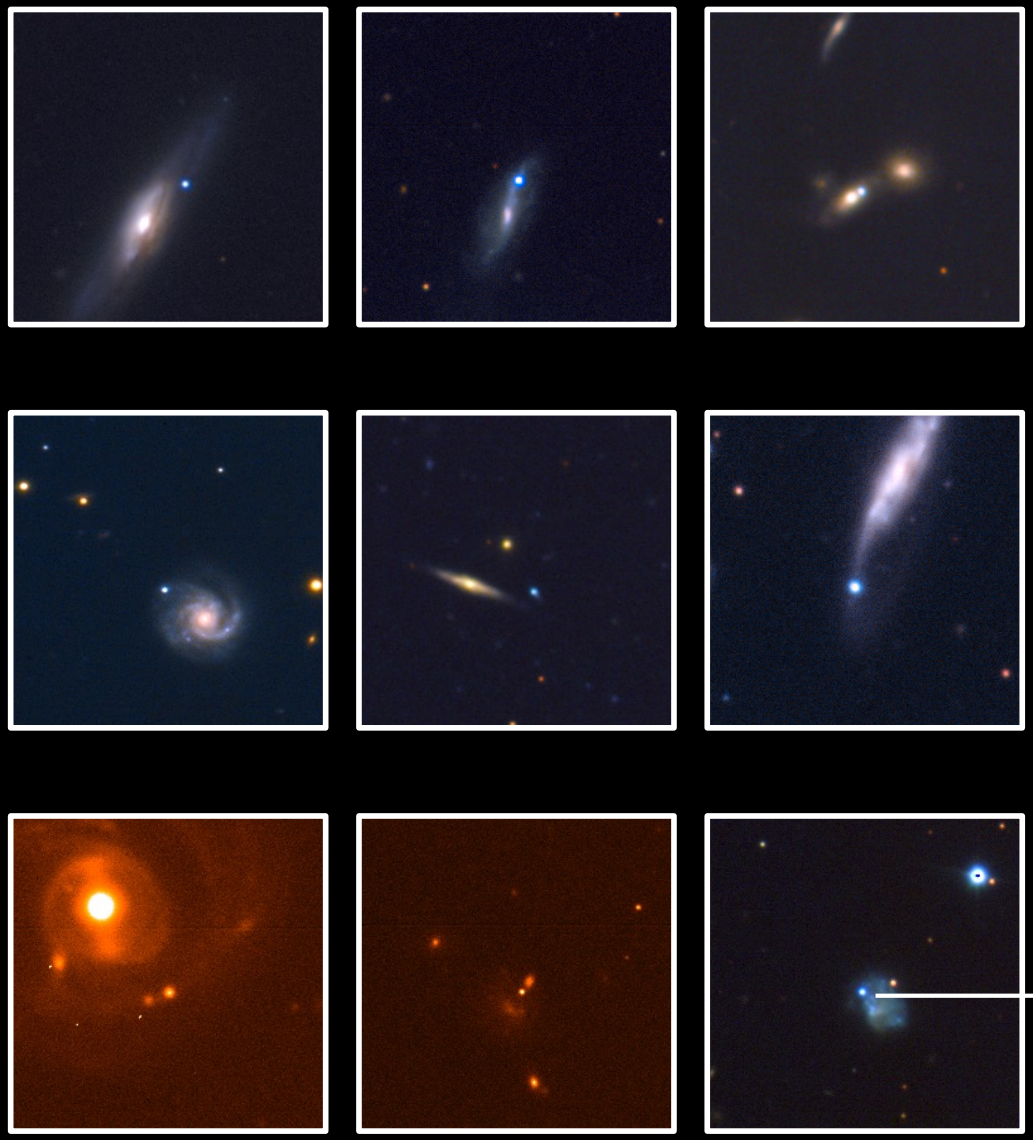

Vogl et al. 2020

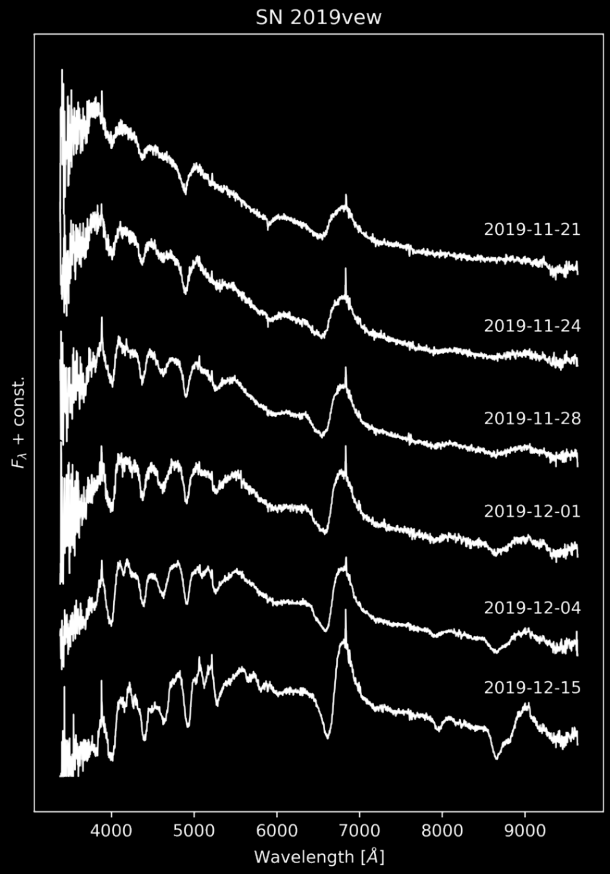
# adH0cc – Status

- Observations finished – 1 October 2021
- 44 classifications
  - 26 SNe II, 12 SNe Ia, 6 other types (Ibc)
    - One new type SN Icn (SN 2021ckj)
  - 20 SNe II with follow-up observations
    - Added another six objects not classified by us



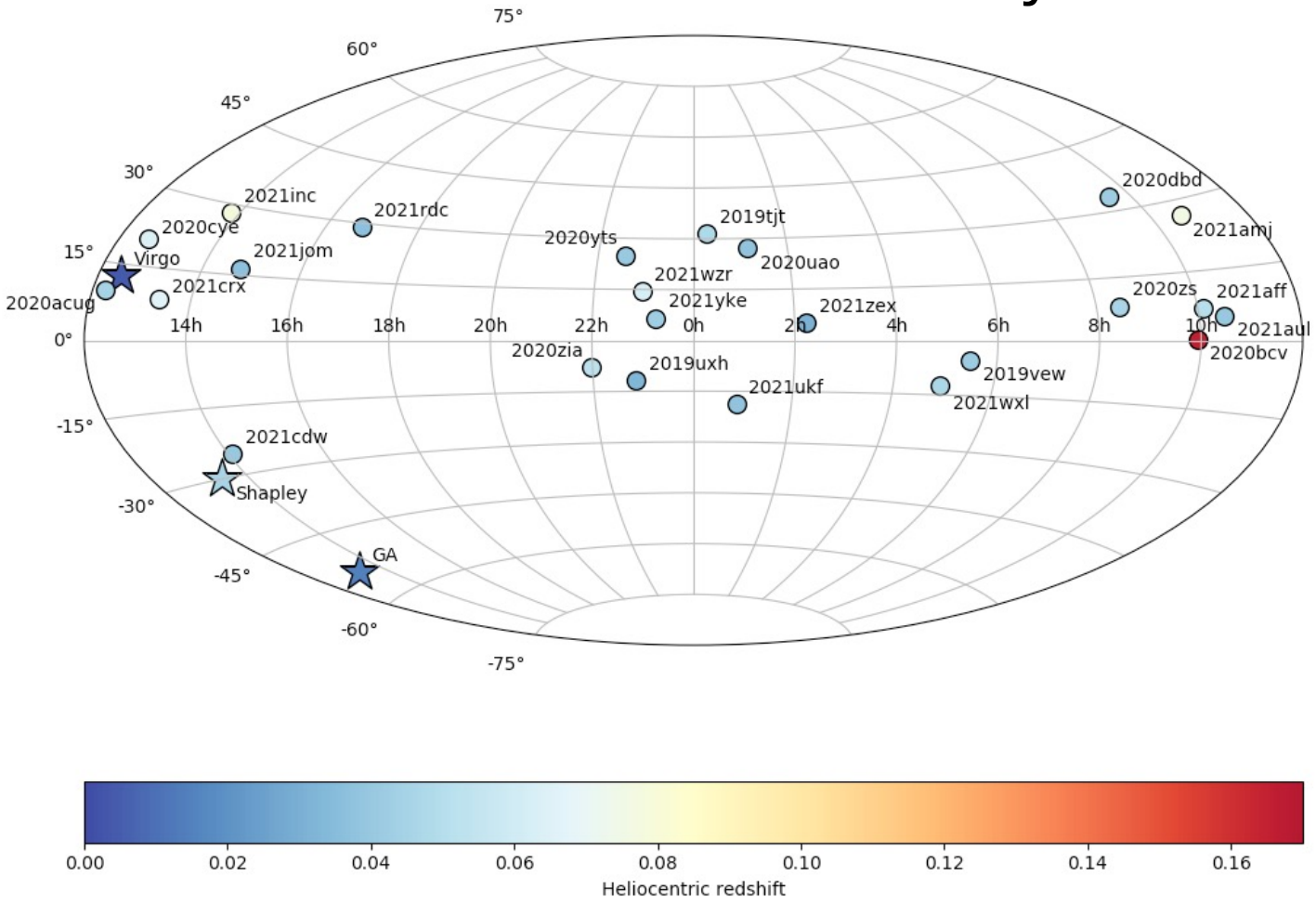
# adH0cc – Observations





# adH0cc – Observations

## Distribution on the sky



# adH0cc – Status

- Data analysis workshop
  - 27 Sep – 1 Oct at MIAPP
- Photometry
  - Requires template observations one year after SN
- Spectroscopy
  - Data reductions ongoing
    - Two independent data reductions

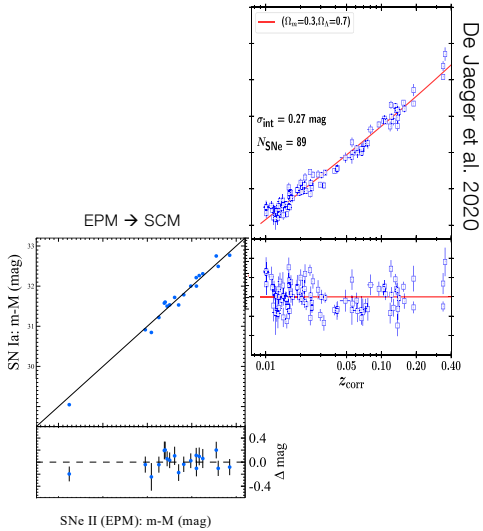
# adH0cc – Status

Discussions of analysis

- Investigations of systematics
  - Peculiar velocities
  - Code comparisons
  - Contamination by galaxy light
  - Reddening
  - Circumstellar interactions
  - Asymmetric explosions
- Blinding procedures

# adH0cc – Associated projects

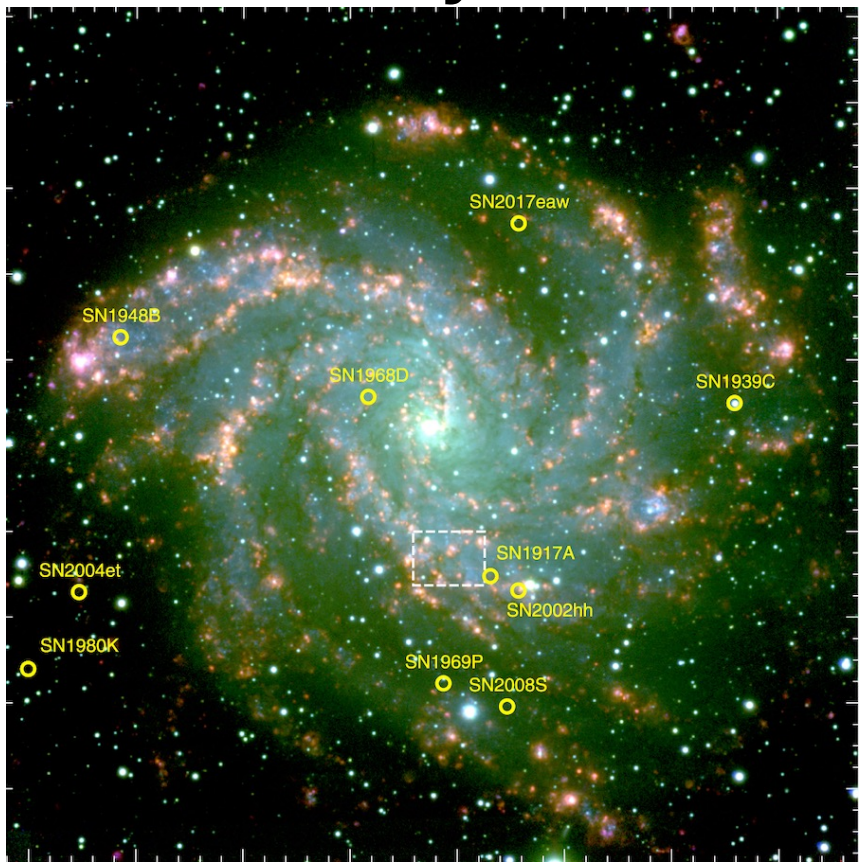
- Calibrate Standardizable Candle Method (SCM)
  - Same data required
  - Replace external calibration through Cepheids and/or TRGB




- First SCM publication by Alexander Holas for the SNFactory data in preparation
  - Still based on Cepheid and TRGB calibrations

# adH0cc – Associated Projects

- Sibling supernovae
  - Determine EPM distance to SNe II in the same galaxy
    - Internal consistency
    - Systematics
      - e.g. reddening
    - Internal scatter of the method



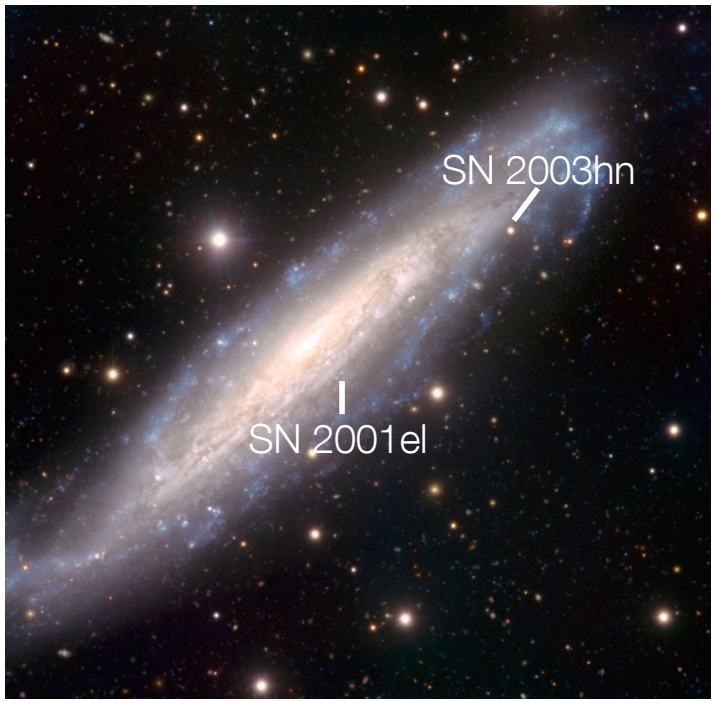

https://aasnova.org/2019/04/22/featured-image-hunting-for-past-fireworks/

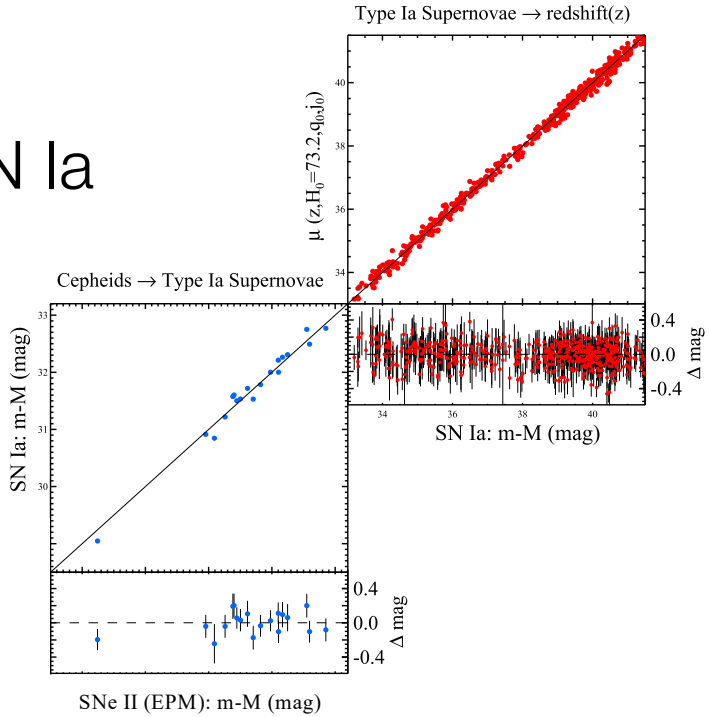
NGC 6946; AAS Nova

- Done for five of six suitable galaxies by Géza Csörnyei
  - To be presented at SuperVirtual workshop

# adH0cc – Associated Projects

- Calibrate SNe Ia with EPM distances
  - ‘Siblings of a different kind’
    - Galaxies with a SN II and a SN Ia




Riess et al. 2016

# adH0cc – Summary

- All data obtained
  - 26 SNe II with multiple epochs and good explosion dates
    - Analysis ongoing
- Individual distances to 10%
  - EPM of sibling SNe II independently check method
  - Statistical error well below 3%
- Systematics most critical