Study of Hubble Constant Anisotropies with the Zwicky Transient Facility

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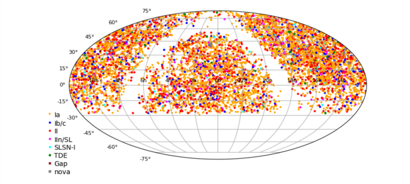
Université Clermont Auvergne - Master de Physique Fondamentales et applications - Univers et Particules

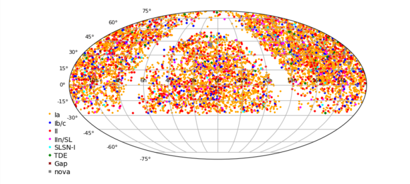
- ZTF: A **transient** detection machine



Ref: BTS Working Group

Main Goal - ZTF

- ZTF: A **transient** detection machine
- Use realistic ZTF simulation of SNe Ia to develop an analysis on **variations** of H_0 for different sky directions



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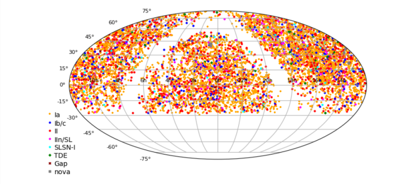
- Use realistic ZTF simulation of SNe Ia to develop an analysis on **variations** of H_0 for different sky directions
- Quantifying the sensitivity of the survey for such potential **anisotropies**



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ZWICKY TRANSIENT FACILITY

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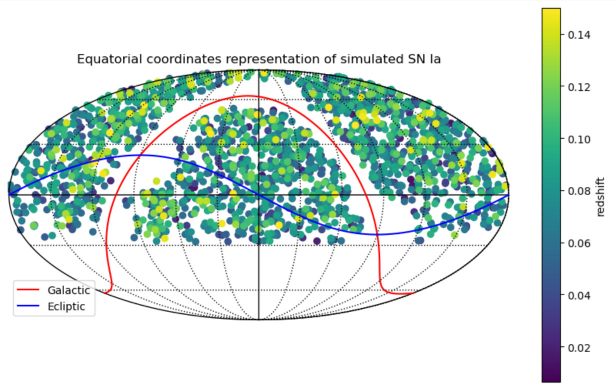
- Type Ia: presence of silicium, near intrinsic luminosity, perfectly observable **light curve**
- Supernovae Ia are **standard candles** (standardizable)

Sky Map - Clustering



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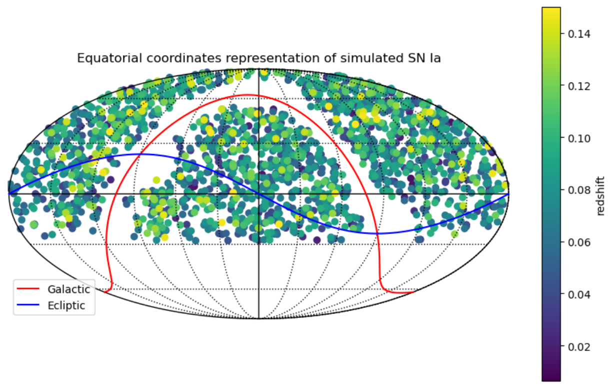

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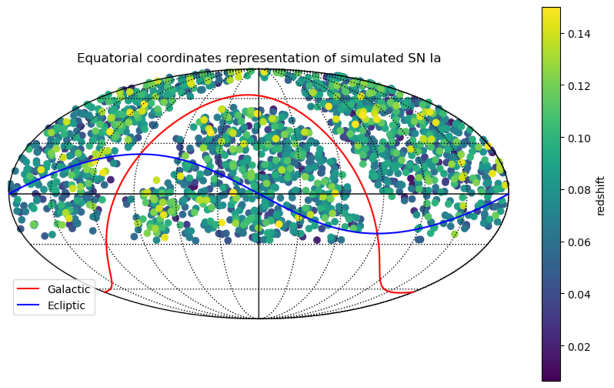

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- Partitionning the map ⇒ **Clustering**

Standardization and ΛCDM Model

Standardization
Supernovae Ia have fairly **uniform light curves**, which makes them standardizable candles. SALT2 fit the light curves in B-band with two parameters: x_1 (stretch parameter) and **c** (color parameter). This fit also obtains the maximum apparent magnitude in B-band , m_B. The **distance modulus** is then written:

$$\mu = m_B - M_B + \alpha x_1 - \beta c \tag{1}$$

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ΛCDM Model
$\Omega_k = 0 \Rightarrow \Omega_{tot} = \Omega_\Lambda + \Omega_m = 1 \Rightarrow \Omega_\Lambda = 1 - \Omega_m$
Luminosity distance:

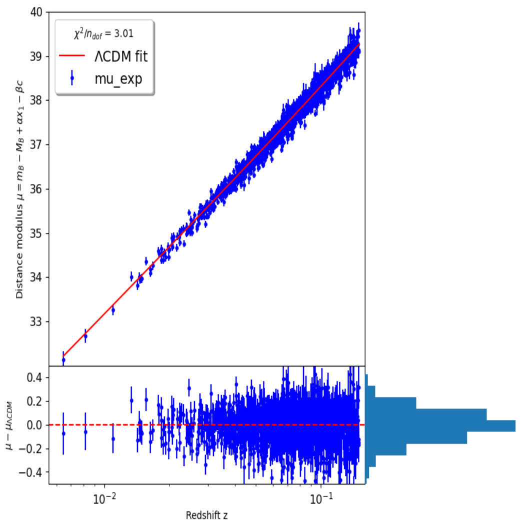
$$d_L = (1+z)\frac{c}{H_0}\int_0^z \frac{dz'}{\sqrt{((1+z)^3 - 1)\Omega_m + 1}} \tag{2}$$

Hubble Diagram

$$\mu_{\Lambda CDM} = 5\log\left(d_L(\Omega_m)\right) + 25$$

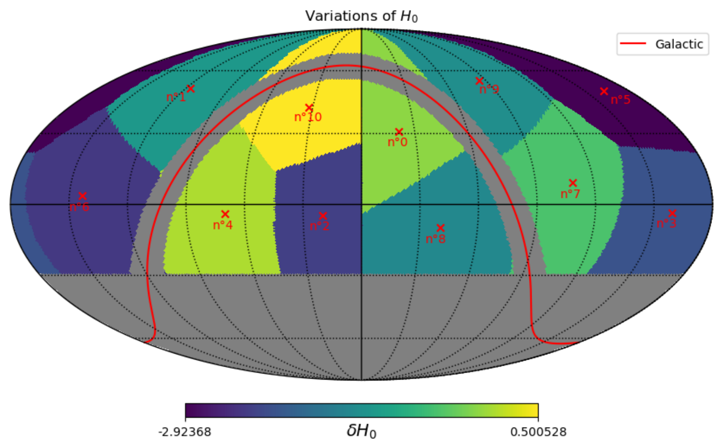
$$\chi^2 = \sum_i^{N_{SN}} \left(\frac{\mu - \mu_{\Lambda CDM}}{\sigma_i}\right)^2$$

Obtain fit parameters: M_B, α, β and Ω_m



Hubble Constant variations

$$\chi^2 = \sum_{j}^{N_{cluster}} \sum_{i_j}^{N_{SN}} \left(\frac{\mu_{i_j} - \mu_{\Lambda CDM}(\delta H_0^{i_j})}{\sigma_{i_j}}\right)^2$$



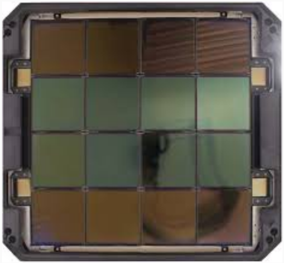
Thank you for your attention

BackUp

The Zwicky Transient Facility

- Mont Palomar Observatory (California, United States)
- Camera (CCD): **600 million-pixels** mounted on the Samuel Oschin 48-inch Schmidt telescope
- Exposure of 30 seconds
- 3 optical filters (g, r and i)
- **Redshift** range: $0.01 \leq z \leq 0.1$

ref: IPAC/Caltech



ref: Bellm et al.,"The Zwicky Transient Facility: System Overview, Performance, and First Results"

Cosmology

Cosmological Principle
The universe is a four dimensional Space-Time, spatially homogeneous and isotropic at large scale(>100 Mpc), without any specific point (no origin).

Einstein equation

$$R_{\mu\nu} - \frac{1}{2}g_{\mu\nu}R + \Lambda g_{\mu\nu} = -\frac{8\pi G}{c^4}T_{\mu\nu} \tag{3}$$

Friedmann Equations

$$H^2 = (\frac{\dot{a}}{a})^2 = \frac{8\pi G}{3}\rho + \frac{\Lambda}{3} - \frac{k}{a^2} \tag{4}$$

$$2a\ddot{a} + \dot{a}^2 + k = -8\pi GPa^2 + \Lambda a^2 \tag{5}$$

Cosmology

Hubble law

$$v = H_0 d \tag{6}$$

Redshift

$$z = \frac{\lambda_O - \lambda_S}{\lambda_S} \tag{7}$$

Pogson relation

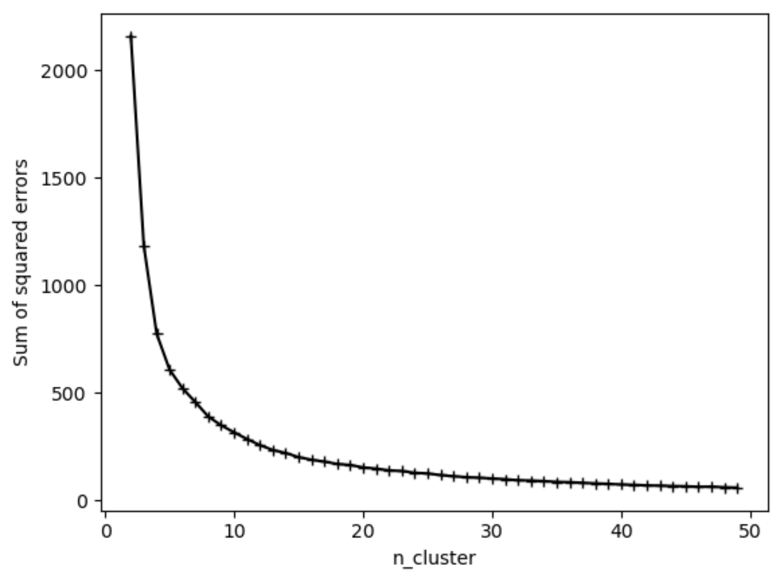
$$m_2 - m_1 = -2.5 log_{10}(\frac{F_2}{F_1}) \tag{8}$$

K-Means

- A Clustering algorithm: using a certain number of centroids in the data space
- Algorithm:
  1. Randomly select K initial center
  2. Assign each data to its closest centroids
  3. if the partition doesn't change stop
  4. Else: update centers and remake the process
- Distance function, usually prefered a Euclidian distance:

$$d(x, y) = \sqrt{\sum_{i=1}^{d} (x_i - y_i)^2} \tag{9}$$

Elbow Method



Errors

For μ_{exp}

$$\sigma_\mu^2 = \sum_{i,j} \frac{\partial \mu}{\partial x_i} \frac{\partial \mu}{\partial x_j} V_{ij} \tag{10}$$

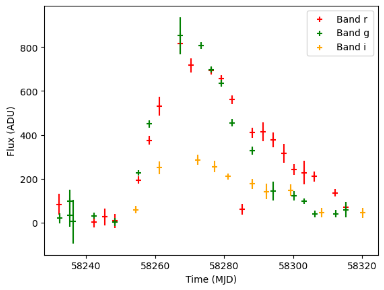
For μ_{th}

$$\sigma_{th} = |\frac{\partial \mu}{\partial z}|\sigma_z = \frac{5}{\ln(10)}(\frac{1}{1+z} + \frac{\frac{1}{\sqrt{((1+z)^3-1)\Omega_m+1}}}{\int_0^z \frac{dz'}{\sqrt{((1+z)^3-1)\Omega_m+1}}} \tag{11}$$

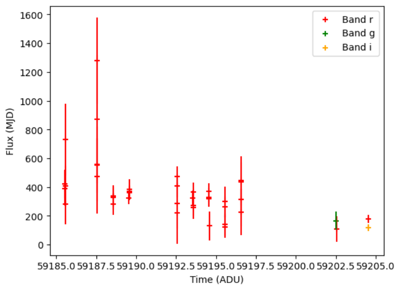
Total

$$\sigma_\mu = \sqrt{\sigma_{\mu_{exp}}^2 + \sigma_{\mu_{th}}^2} \tag{12}$$

Light Curve

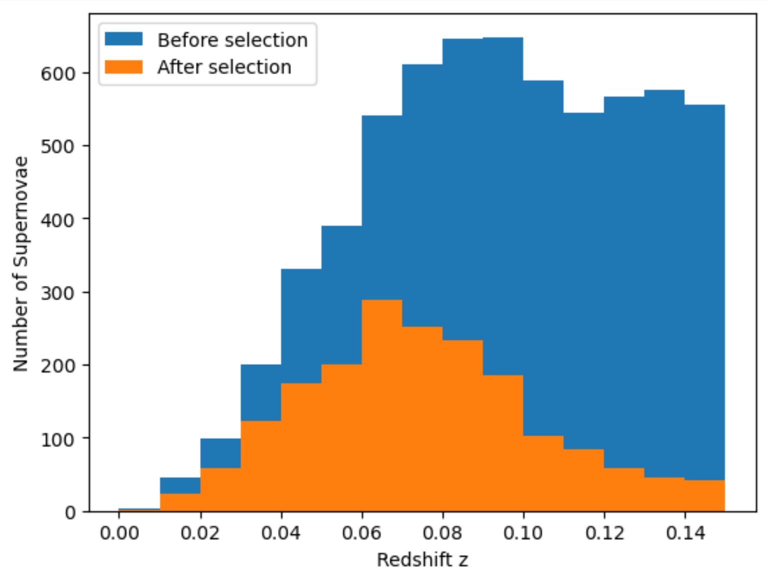


Band r
Band g
Band i
Flux (ADU)
Time (MJD)
0
200
400
600
800
58240
58260
58280
58300
58320

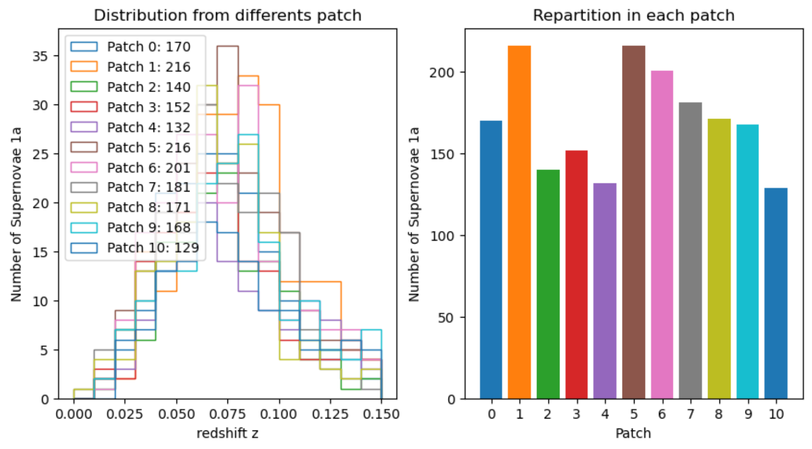


Band r
Band g
Band i
Flux (MJD)
Time (ADU)
0
200
400
600
800
1000
1200
1400
1600
59185.0
59187.5
59190.0
59192.5
59195.0
59197.5
59200.0
59202.5
59205.0

z-distribution



z-distribution by cluster



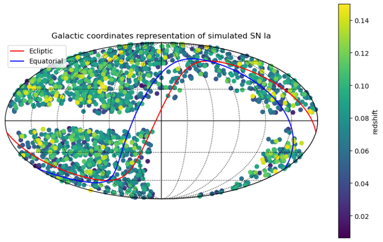
Selection Criteria

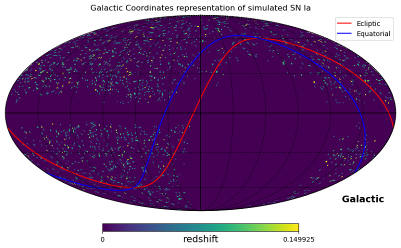
Spectroscopic
With completeness magnitude that we fit with a Sigmoid function and make a random selection

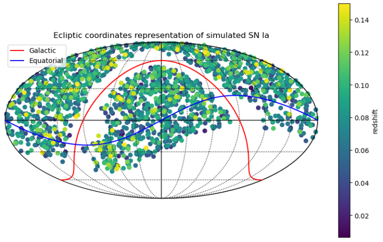
Galactic extinction
$A_v < 1$ and in galactic coordinates we suppressed all between 7 b and -7 b

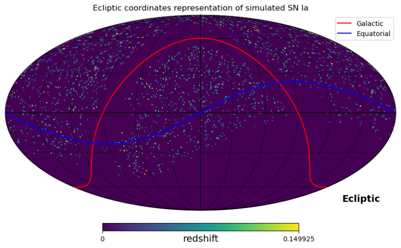
Cosmological
Good sampling: Light curves need to have $N_point \geq 7$ avec $\frac{\phi}{\sigma_\phi} \geq 5$ in the interval $[t_0 - 15 \text{ days}; t_0 + 30 \text{ days}]$, for each filter g and r 1 point before and after t_0 with $\frac{\phi}{\sigma_\phi} \geq 5$
Salt2 parameters: $\mid x_1 \mid \leq 4$ and $c \in [-0.3; 0.8]$

Representations









Coupled Charge Device - CCD

- Photographic sensor based on a charge transfer device
- steps:
  1. Detection of incident photons : generation of electron-hole pairs by photoelectric effect
  2. Charge storage: MOS (metal oxide semiconductor) capacitor
  3. Transfer of charges to the readout circuit: transfer from near to near
  4. Reading of the information: generation of a voltage at the CCD then transfer to external electronics and digitisation

Degeneracy

$$\mu = m - M = 5 \log D[Mpc] + 25$$

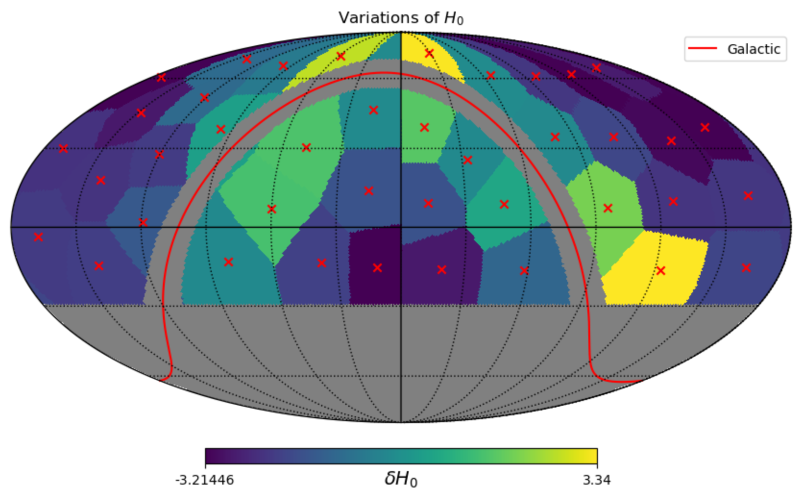
$$cz = H_0 D$$

$$m = 5 \log z + 5 \log(\frac{c}{H_0}) + 25 + M$$

$$m = f(x) = 5x + b$$

$$b = 5 \log(\frac{c}{H_0}) + 25 + M$$

More clusters



Hubble Constant