Measuring cosmic distances

Grzegorz Pietrzynski CAMK

Araucaria PROJECT

Plan of my presentation

=> Short introduction (context)

=> Selected examples of our research

=> The team

=> Our dedicated observatory in Chile

=> Our phd and postdoc positions

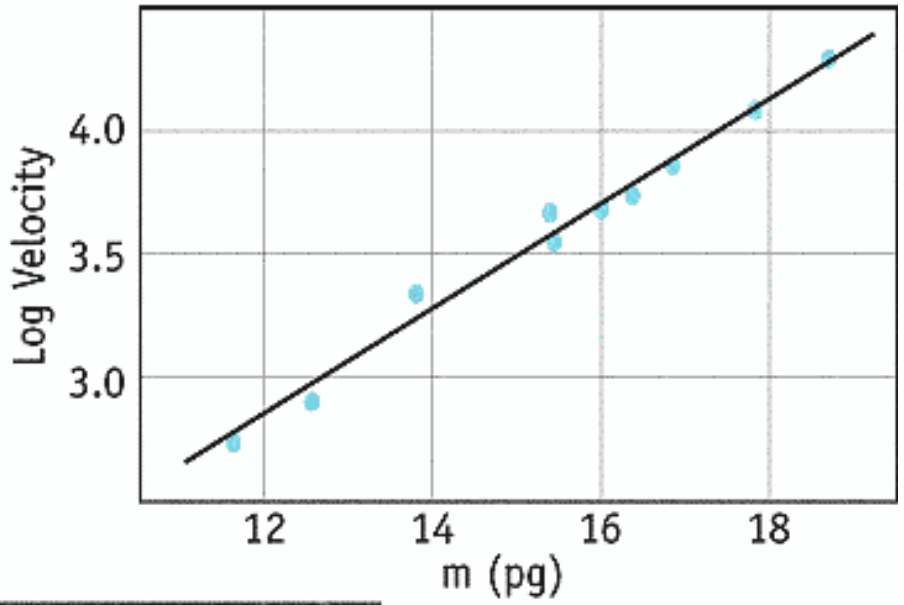
=> Why should you apply ? (very obvious)

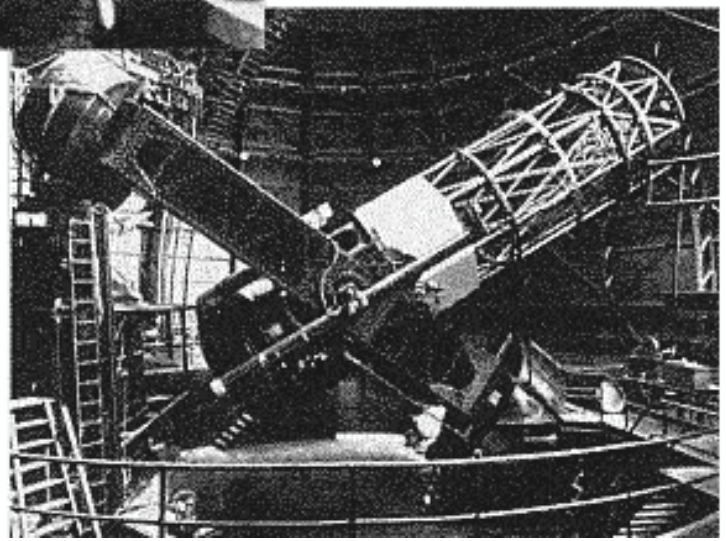
Knowing distances is much more than just knowing the scale; it also means knowing the physical nature of objects in the universe, and **each significant improvement** in the **accuracy** of the distance scale opens whole new fields of astrophysical research.

Hubble Law

$$Vr = H_0 \times d$$

Edwin Hubble





Mt. Wilson
100 Inch
Telescope

Hubble constant

Distances to very distant objects (defines physical and energetical scale)

Equation of state $$H^2 \equiv \left(\frac{\dot{a}}{a}\right)^2 = \frac{8\pi G}{3}\rho - \frac{kc^2}{a^2} + \frac{\Lambda c^2}{3},$$

Age $$t_H \equiv \frac{1}{H_0} = \frac{1}{67.8(\mathrm{km/s})/\mathrm{Mpc}} = 4.55 \cdot 10^{17}\mathrm{s} = 14.4 \text{ billion years.}$$

Test for modern physics and unique way to verify the physical nature of mysterious dark energy

Accelerated expansion !

Enigmatic dark energy !

But we still have more questions than answers !!

H_0 controversy

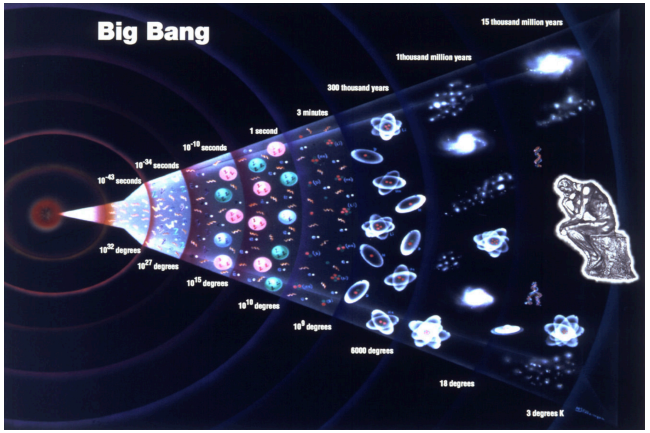
Cepheid / SN Ia: $H_0 = 74 \pm \mathbf{1.42}$ km/s/Mpc

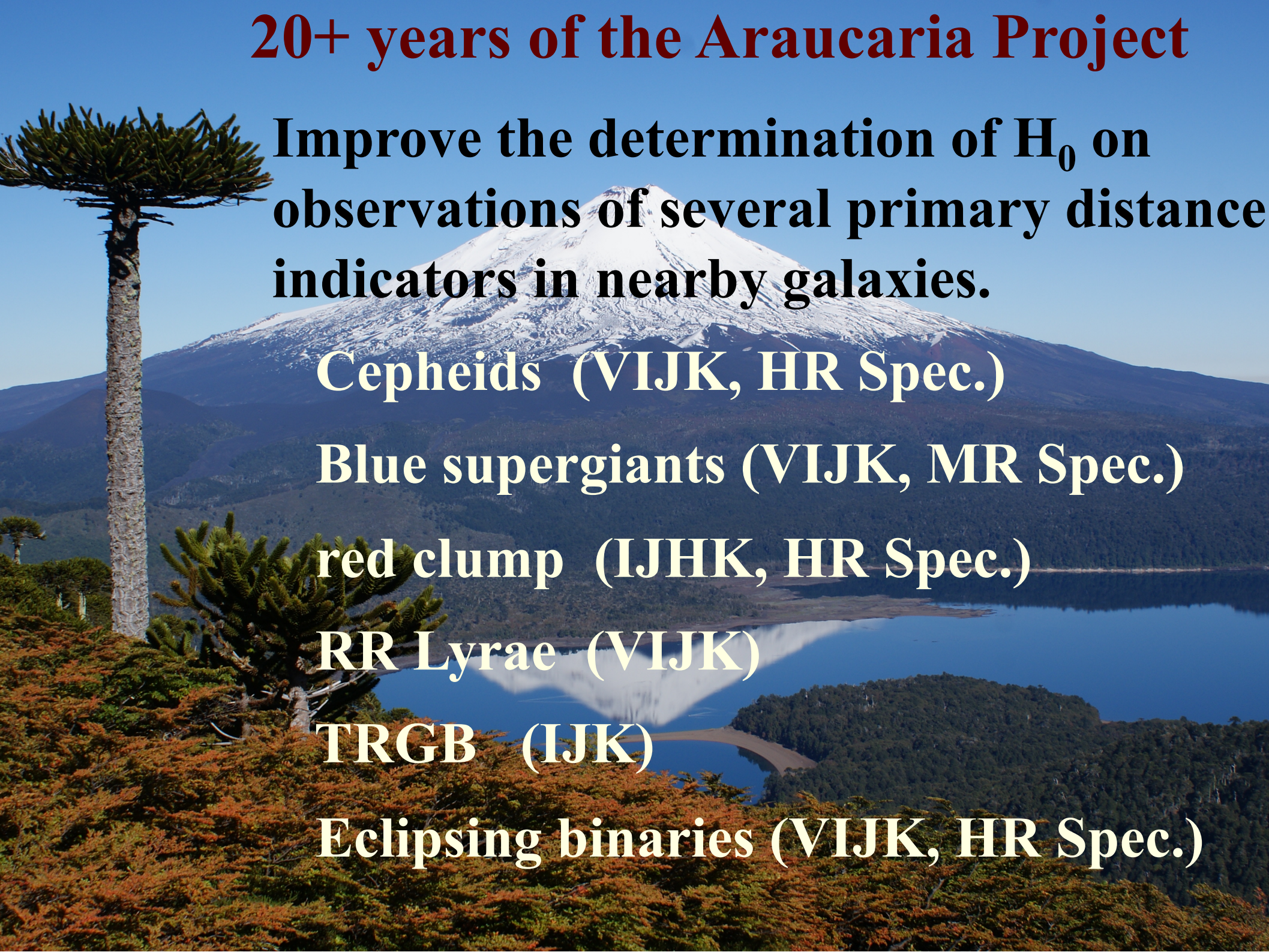
Based on a ΛCDM model and the Planck CMB data $H_0 = 66.93 \pm 0.62$ km/s/Mpc.

So we have a controversy (crisis!) and modern physics might require revision ...

One of the biggest and most urgent challenge for contemporary science still unsolved !!!

Systematics or physics ?





20+ years of the Araucaria Project

Improve the determination of H_0 on observations of several primary distance indicators in nearby galaxies.

Cepheids (VIJK, HR Spec.)

Blue supergiants (VIJK, MR Spec.)

red clump (IJHK, HR Spec.)

RR Lyrae (VIJK)

TRGB (IJK)

Eclipsing binaries (VIJK, HR Spec.)

200+ papers (6 in Nature)

140+ invited talks

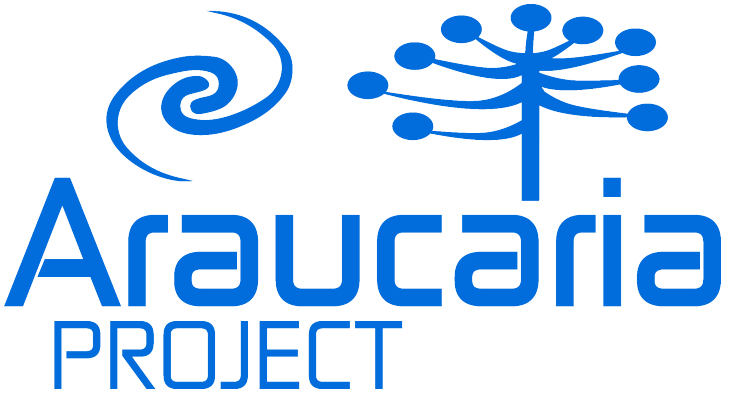
280+ proposals (accepted)

2400+ nights at observatories,

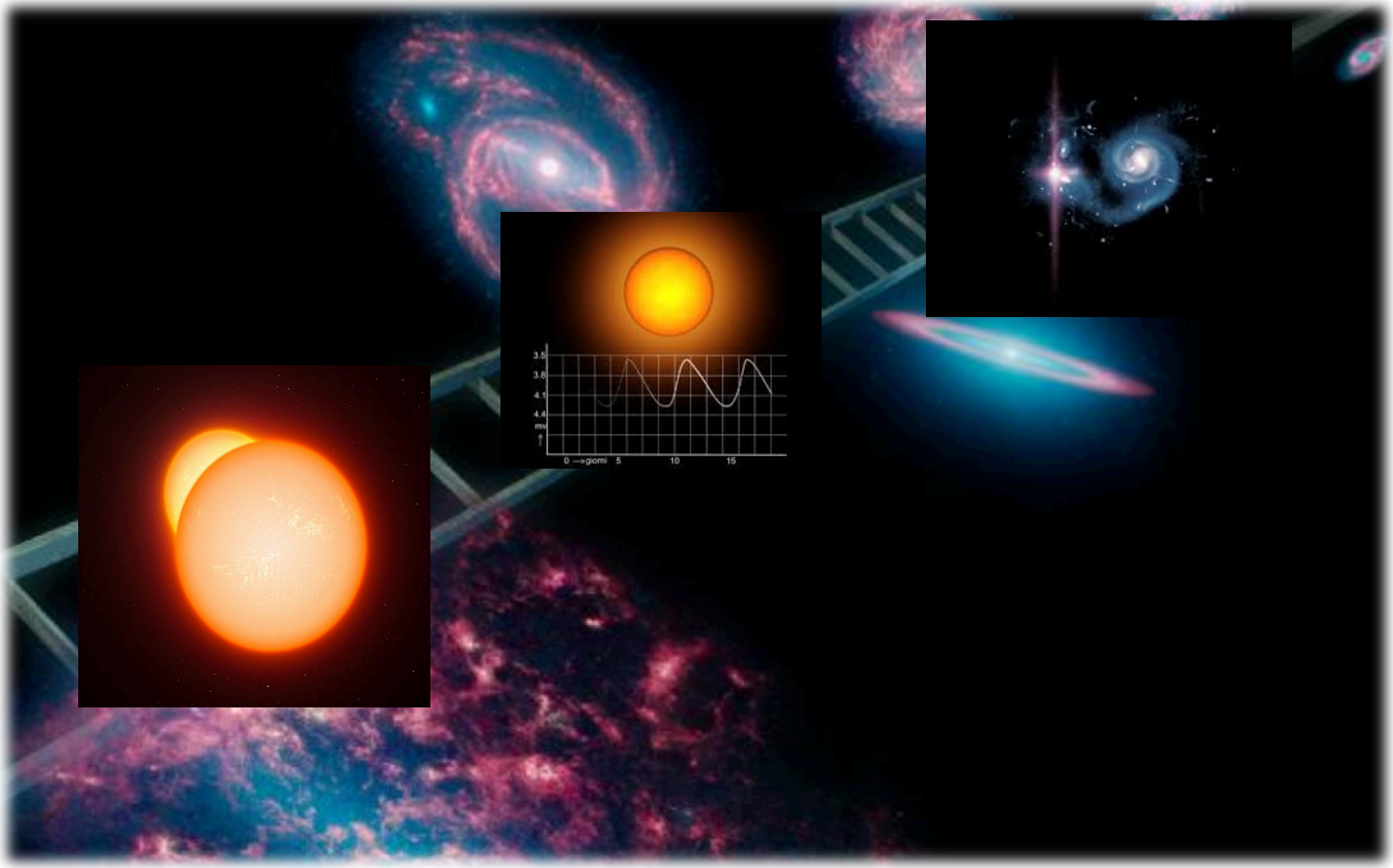
Phd, habilitations, professor titles …

6 ESO PR, 5 articles in Messanger

300+ articles in the press 150+ auditions in radio, TV

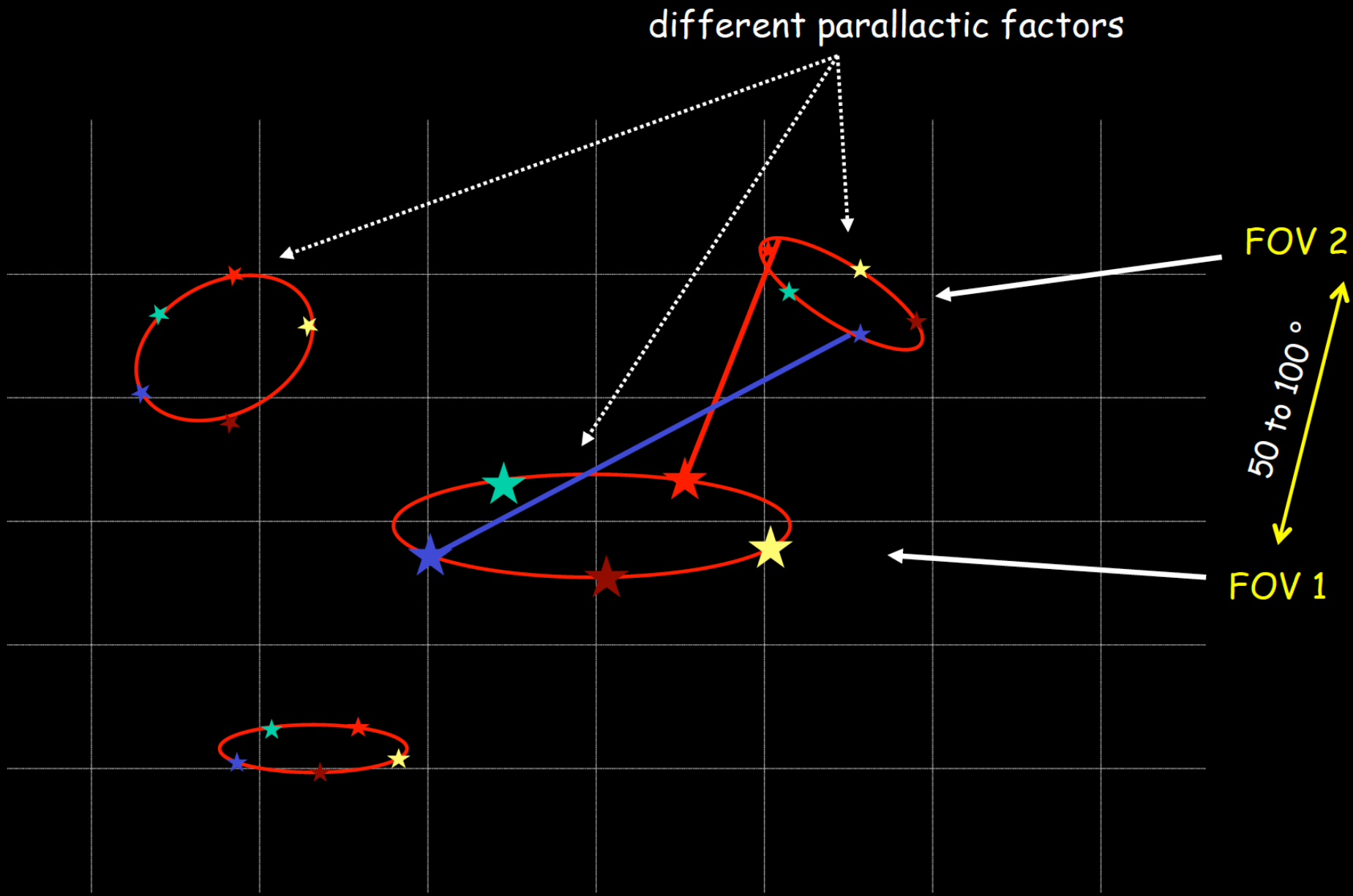


https://araucaria.camk.edu.pl/



„Classical” method based on geometrical distances and standard candles.

How parallaxes get absolute with Gaia



Measurable quantity : $f_2(t)*\pi_2 - f_1(t)*\pi_1$ → π_2 and π_1

Gaia mission - summary

1) Additional measurements required (photometry, extinction, ect).

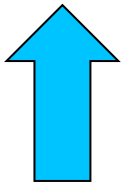
2) Problem with absolute „zero point” (additional corrections)

3) Range – 1% at 1 kpc (nominal). Precise distances only in a small region of the Milky Way. Small range of metallicity etc.

NOT sufficient to calibrate the cosmic distance scale

Eclipsing binaries

$$d(pc) = 1.337 \times 10^{-5} \times r(km)/\varphi(mas)$$

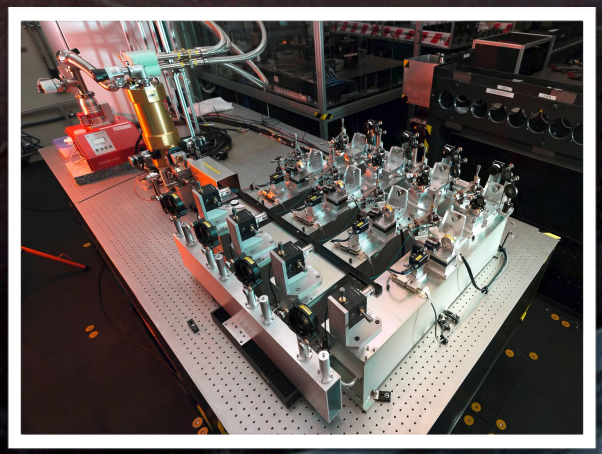


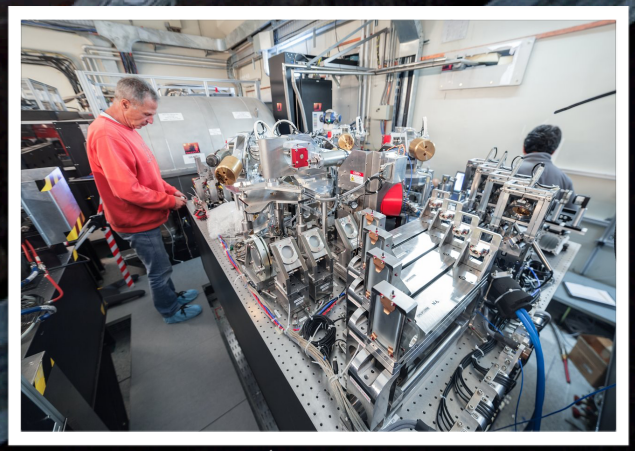
Light + RV curves analysis

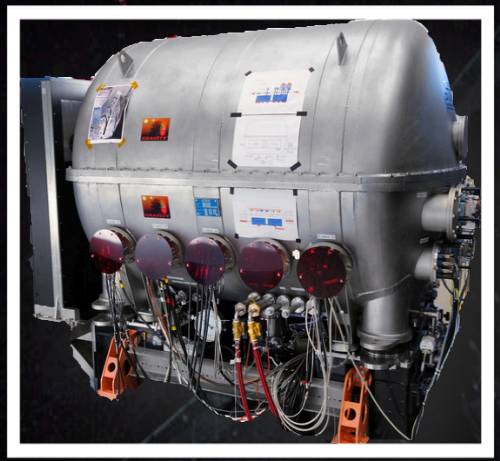
$\Rightarrow$ ~ 1% radii already in 90s (e.g. Andersen 1991)

$\Rightarrow$ now (Kepler, TESS) we can obtain ~ 0.2% precision

Credit: ESO/G. Hudepohl







Late-type eclipsing binaries

$$d(pc) = 1.337 \times 10^{-5} \times r(km)/\varphi(mas)$$

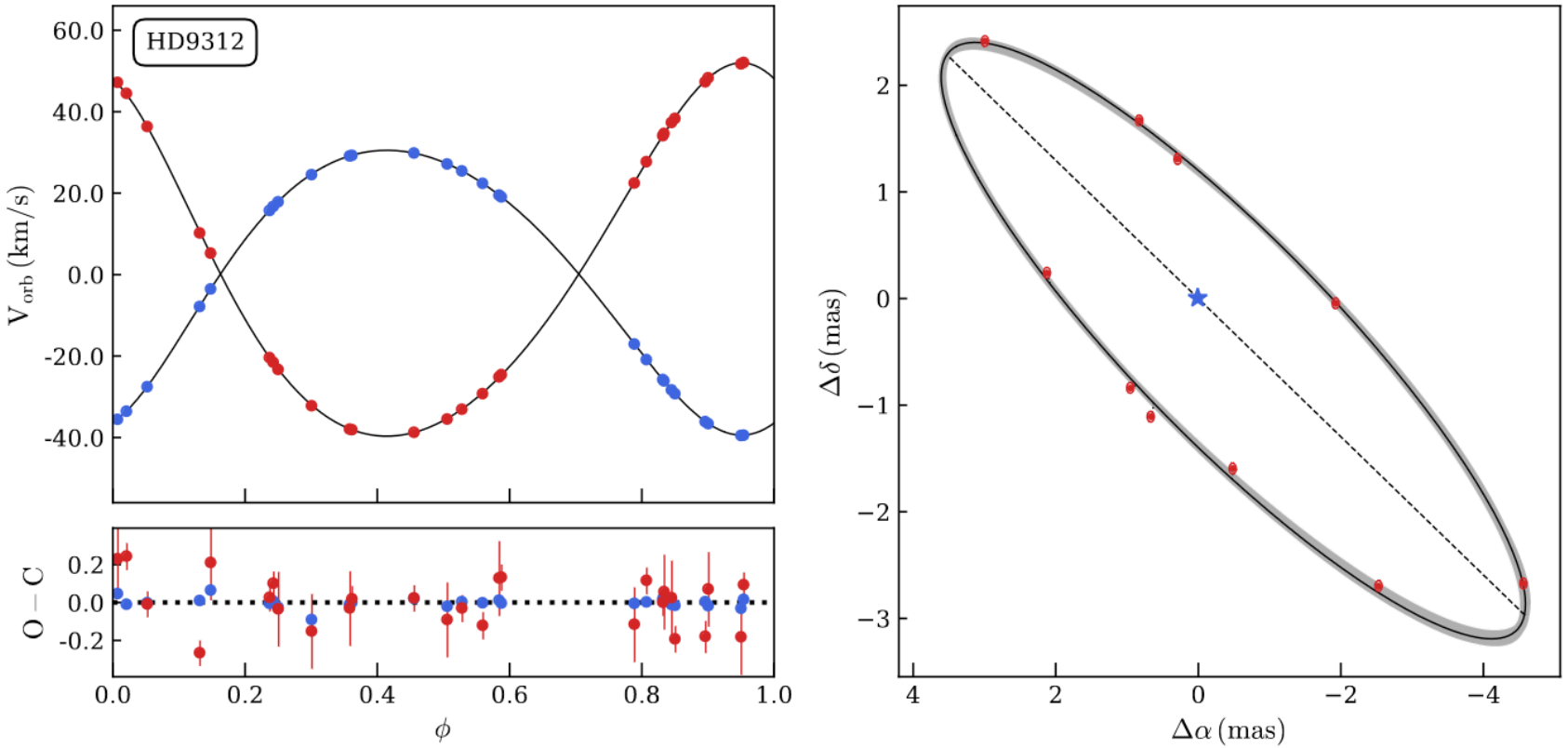
φ is derived from the surface brightness - color relation, very well established for late-type stars based on interferometric data (di Benedetto 2005; Kervella et al. 2004)

$$S_V = 2.656 + 1.483 \times (V-K)_0 - 0.044 \times (V-K)_0^2$$

$$\phi\ [\mathrm{mas}] = 10^{0.2 \cdot (S - m_0)}$$

Until 2019 the r.m.s. on such relation was 0.01 mag (0.8 % !)

Astrometric binaries



$$M_1 = \frac{1.036149 \times 10^{-7}(K_1 + K_2)^2 K_2 \, P \, (1 - e^2)^{3/2}}{\sin^3 i},$$

$$M_2 = \frac{1.036149 \times 10^{-7}(K_1 + K_2)^2 K_1 \, P \, (1 - e^2)^{3/2}}{\sin^3 i},$$

$$a_{\mathrm{AU}} = \frac{9.191940 \times 10^{-5}(K_1 + K_2) \, P \sqrt{1 - e^2}}{\sin i},$$

$$d = \frac{a_{\mathrm{AU}}}{a},$$

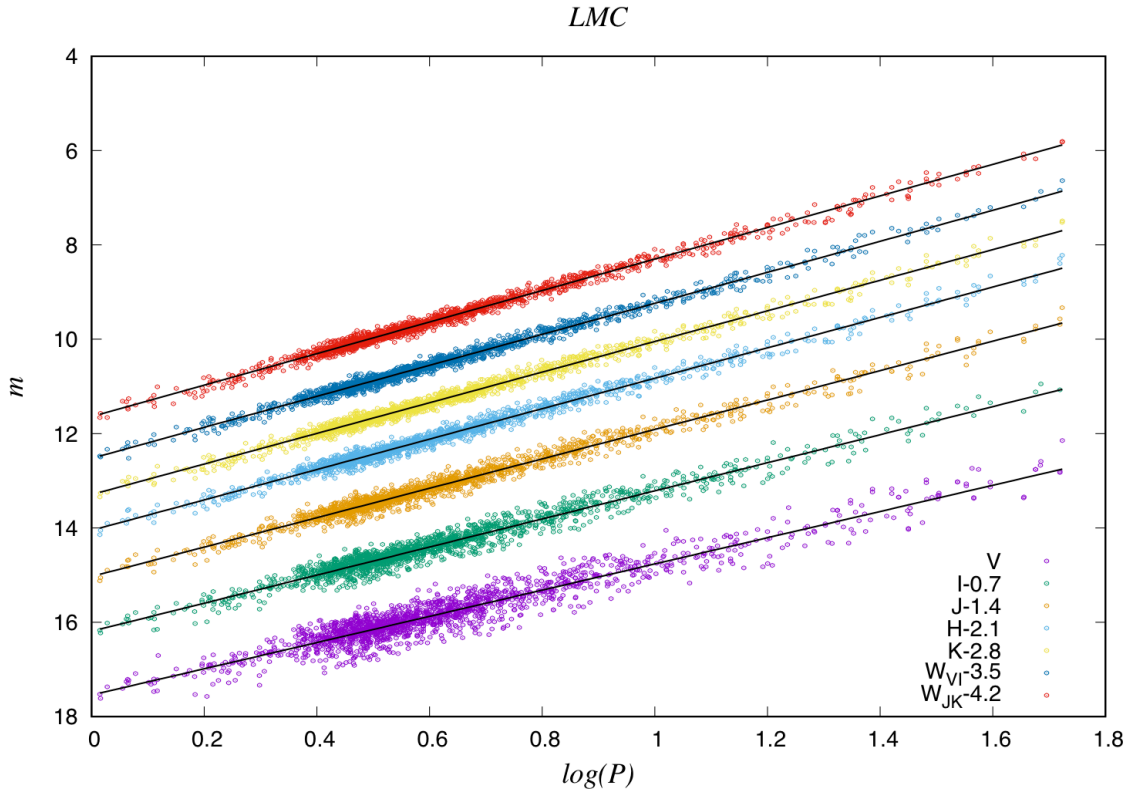
10 systems:

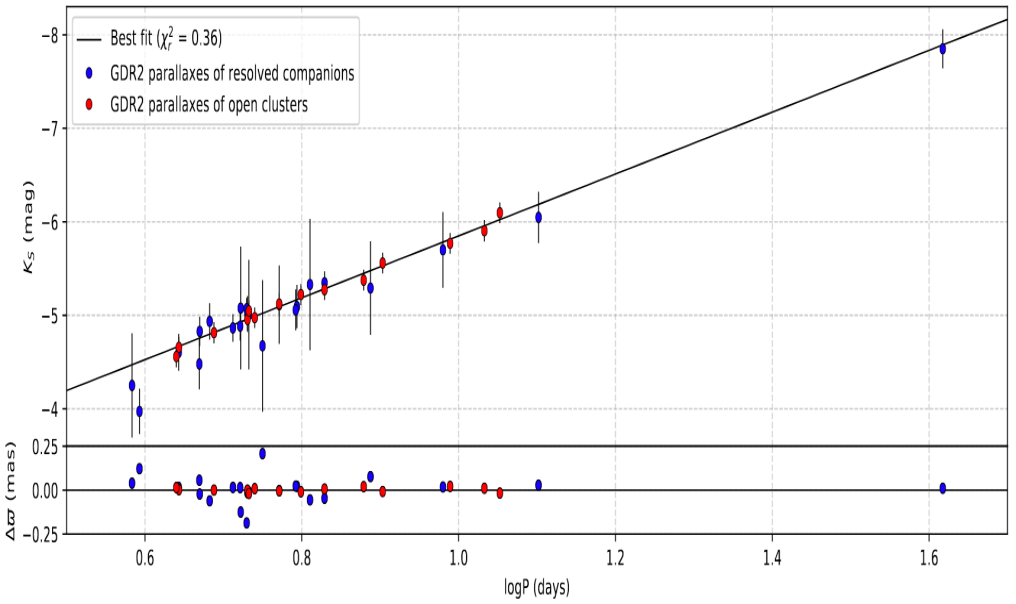
masses **0.03%** (0.2% average)
distances **0.08%** (0.3% average)

Good agreement with Gaia ~ 2 sigma

Range ~ 200 pc

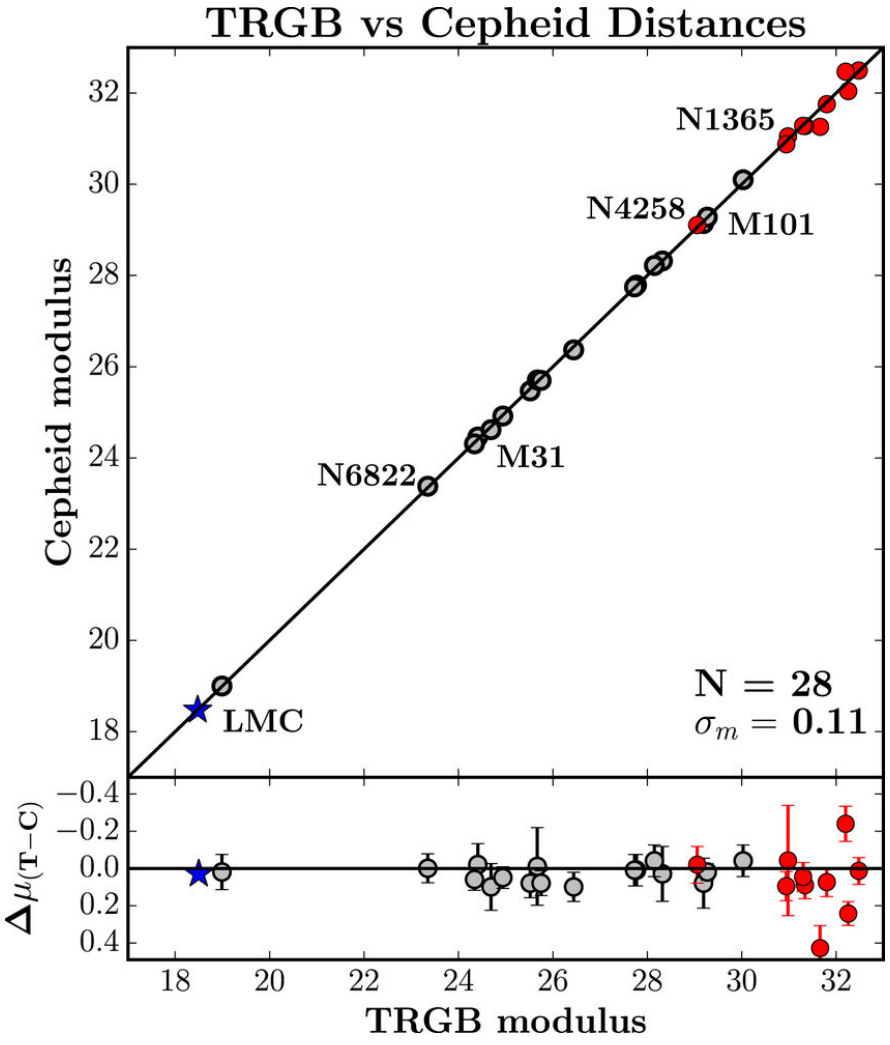
Araucaria PROJECT

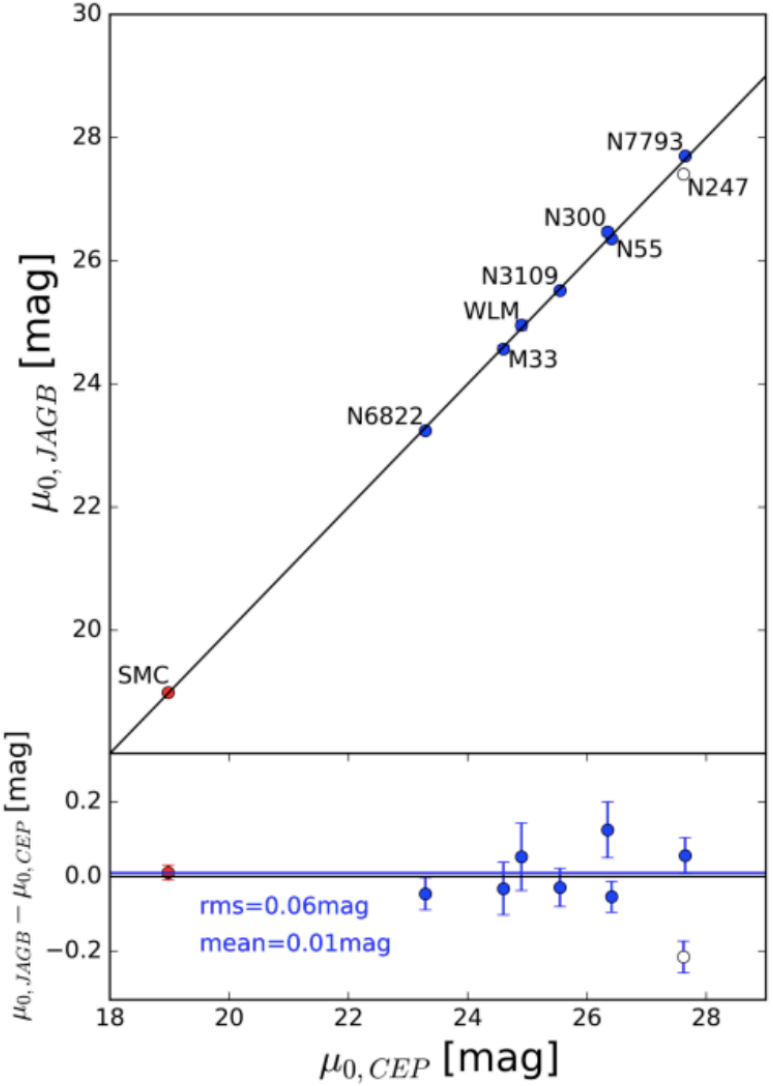

LMC
m
log(P)
V
I-0.7
J-1.4
H-2.1
K-2.8
W_VI-3.5
W_JK-4.2

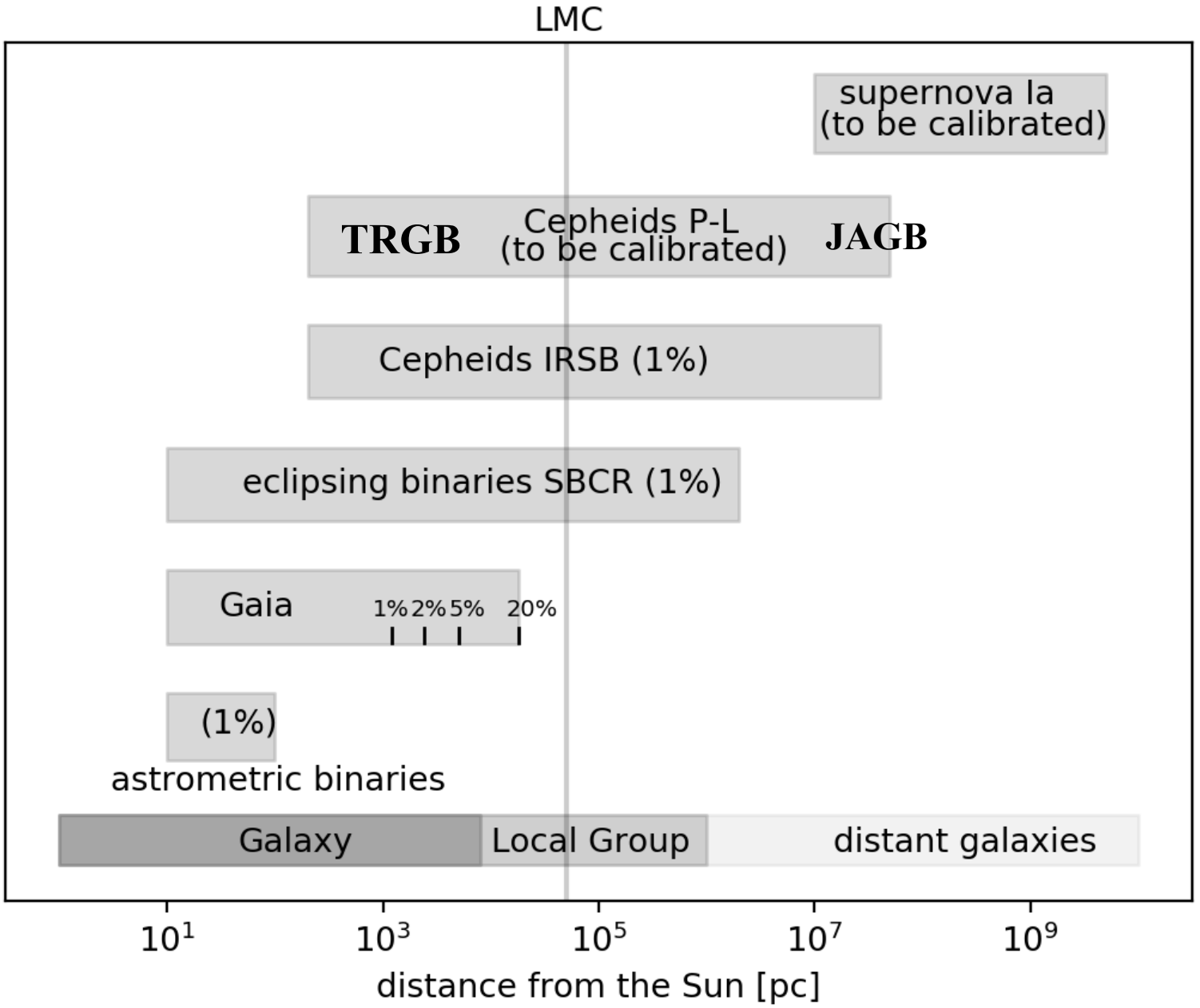

Best fit (χ^2_r = 0.36)
GDR2 parallaxes of resolved companions
GDR2 parallaxes of open clusters
K_S (mag)
$\Delta\varpi$ (mas)
logP (days)

2nd step – standard candles

Cepheids, TRGB, JAGB (Miras)





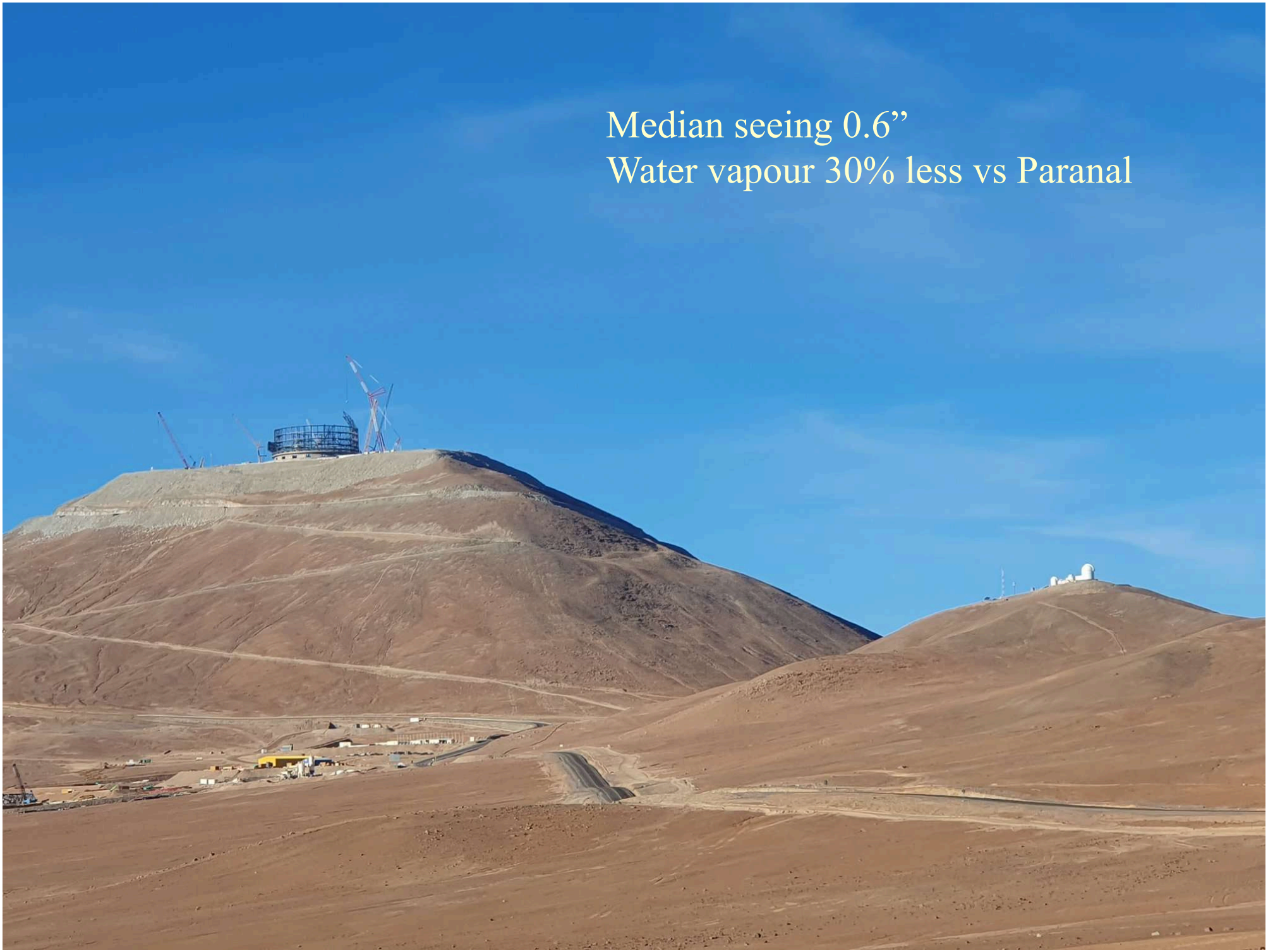

LMC
supernova Ia
(to be calibrated)
TRGB
Cepheids P-L
(to be calibrated)
JAGB
Cepheids IRSB (1%)
eclipsing binaries SBCR (1%)
Gaia
1%
2%
5%
20%
(1%)
astrometric binaries
Galaxy
Local Group
distant galaxies
10^1
10^3
10^5
10^7
10^9
distance from the Sun [pc]

Expected results

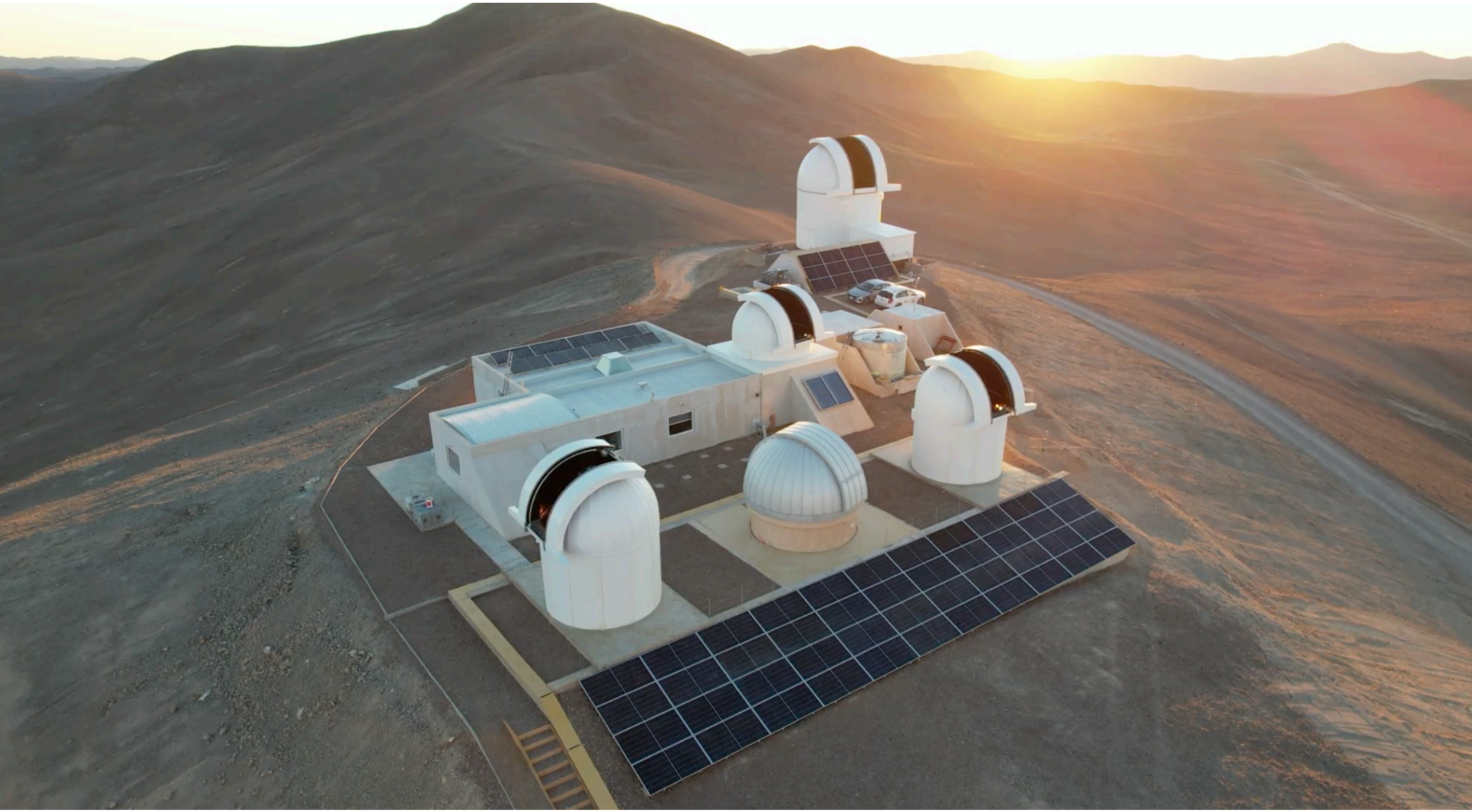
Three unique tools for geometrical distance measurements. Three independent methods to calibrate SN Ia.

1) 1% H_0 determination
2) Massive direct distances to nearby galaxies
3) Precision (0.1-0.5%) parameters (mass, radii, etc) for some 600 stars

A very good moment to start working on cosmic distances !!


Median seeing 0.6”
Water vapour 30% less vs Paranal

Polish Astronomical Observatory CAMK PAN in Chile



Sopot 2021

Some 35 pretigious grants including:

ERC advanced 2015-2022

ERC Synergy (14 milion Euro)
2021-2027
Polish Ministry of Science 7 M Eur
2024 - 2028

ERC Synergy grant position (deadline 30 April):

1 phd (TRGB and JAGB, space data HST, JWST)
Oustanding renumeration and working conditions offered

Several offers for summer projects (observations in our observatory?)

Two positions for data managers (observatory)

Positions will be annouced in a few days

https://araucaria.camk.edu.pl/

https://www.camk.edu.pl/en/

Astrojob

Who is expected

Young enthusiastic and independent persons

Ready to work in the team

Who like to work on data driven projects

Who love to observe (apply, execute, reduce, and publish)

With programing skills and astronomical beckground !

Who like to participate in our huge international exchange (synergy) hopefully providing new nodes ☺

Why join us ?!

⇒ Work on extremely hot science topic

⇒ Time to harvest from huge surveys like Gaia / TESS/ LSST etc. New observations.

⇒ Young international group (fantastic communication and collaboration)

⇒ Very close collaboration with 11 institutions in Poland, France, Germany, Chile, Austria, … Extended visits, ect.

⇒ Access to all telescopes in Chile (through our collaboration with Chilean Universities)

⇒ Our own dedicated observatory in the best observing site on this planet !