

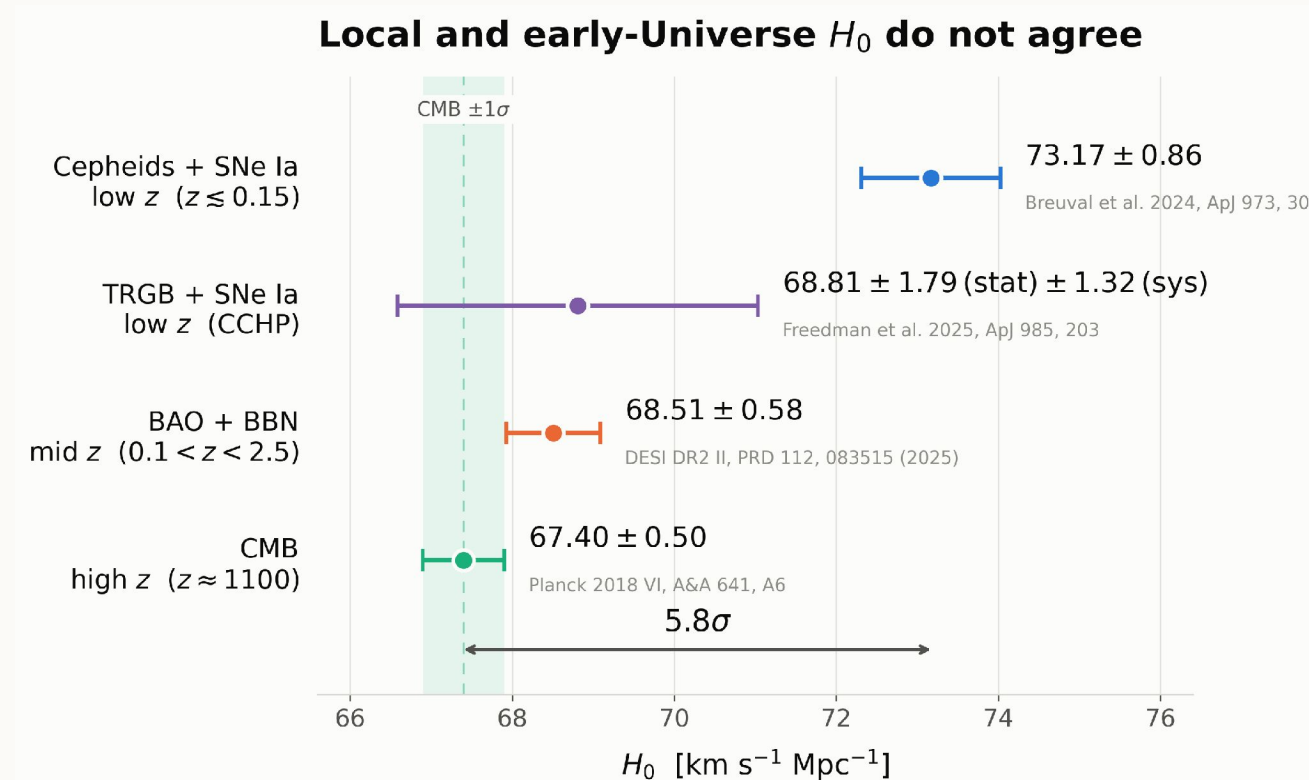
SII WORKSHOP 2026 · H10 TABURIENTE PLAYA, LA PALMA · 5–9 OCTOBER

Intensity Interferometry and the Hubble Constant

Alex Kim · Physics Division, Lawrence Berkeley National Laboratory

MOTIVATION

The H_0 tension



New Physics or Systematic errors?

The "Low- z " measurement relies on multiple steps and astrophysics, so it is the most suspect.

LOW Z · CEPHEIDS + SNE IA

Geometric anchors — Gaia parallaxes, LMC eclipsing binaries, NGC 4258 masers → Cepheid period–luminosity relation → SNe Ia out into the Hubble flow

LOW Z · TRGB + SNE IA (CCHP)

Same geometric anchors, but the tip of the red giant branch replaces Cepheids as the SN Ia calibrator

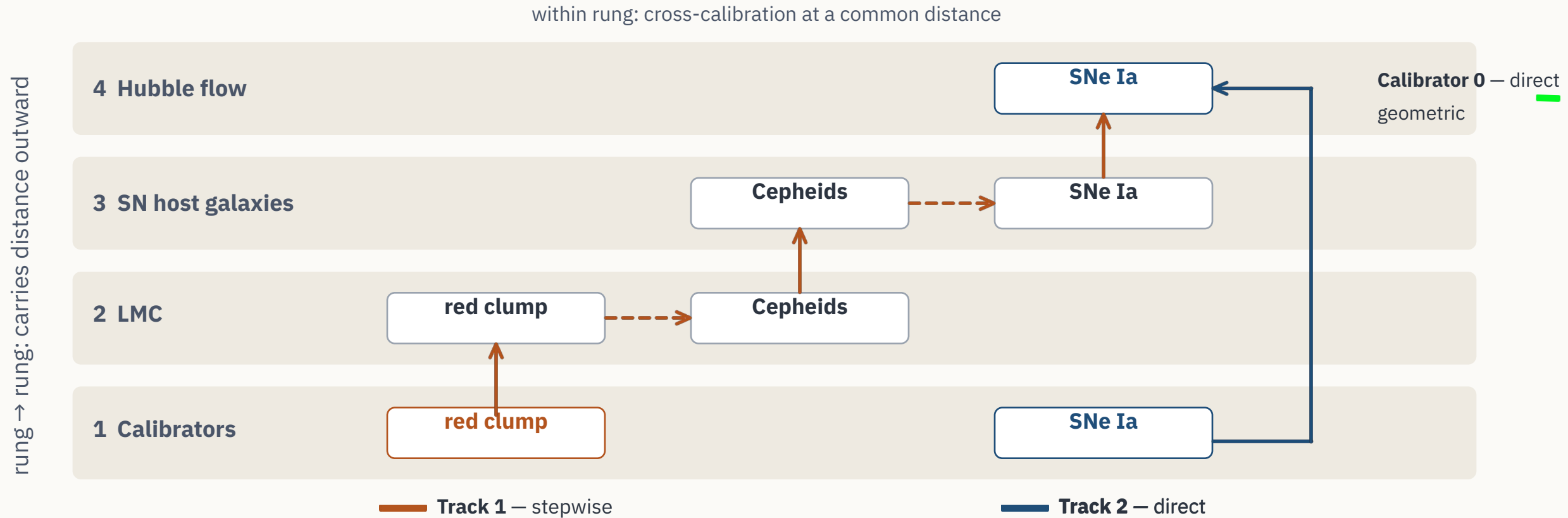
MID Z · BAO + BBN

BBN deuterium abundance fixes $\Omega_b h^2$ → sound horizon r_d as a standard ruler → DESI DR2 BAO scale from galaxies, quasars and Ly α

HIGH Z · CMB

Planck TT/TE/EE acoustic peaks → angular scale of the sound horizon θ^* → Λ CDM extrapolated forward to $z = 0$

Two (+1) calibrators considered in this presentation

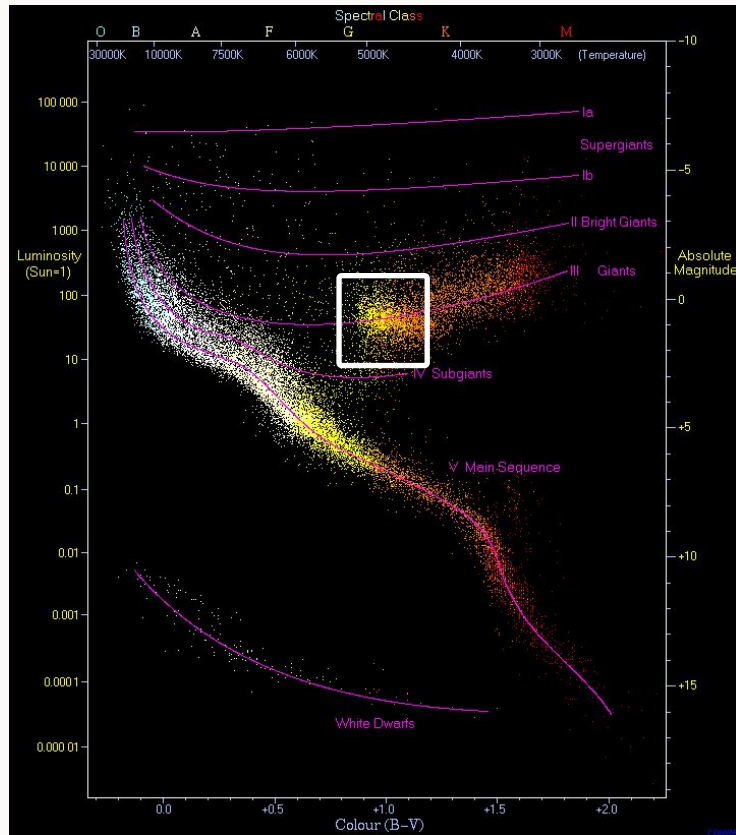


Kim & Kaiser, PASP **138**, 044202 (2026)

Kim et al., Phys. Rev. D **111**, 083047 (2025)

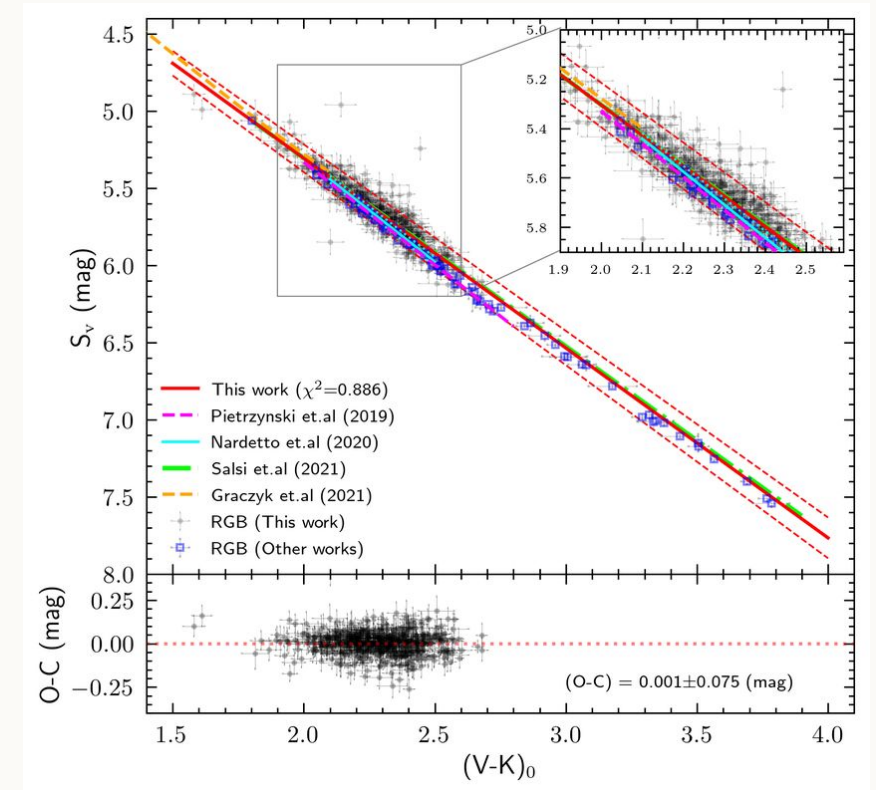
Calibrating the surface-brightness–color relation of Red Clump stars

- A small region of the HR diagram, a narrow spread in luminosity, core-helium-burning stars.
- Emission dominated by black-body radiation → a tight surface-brightness–color relation.



HR diagram: Richard Powell, *The Hertzsprung Russell Diagram*, CC BY-SA 2.5 — commons.wikimedia.org/w/index.php?curid=1736396

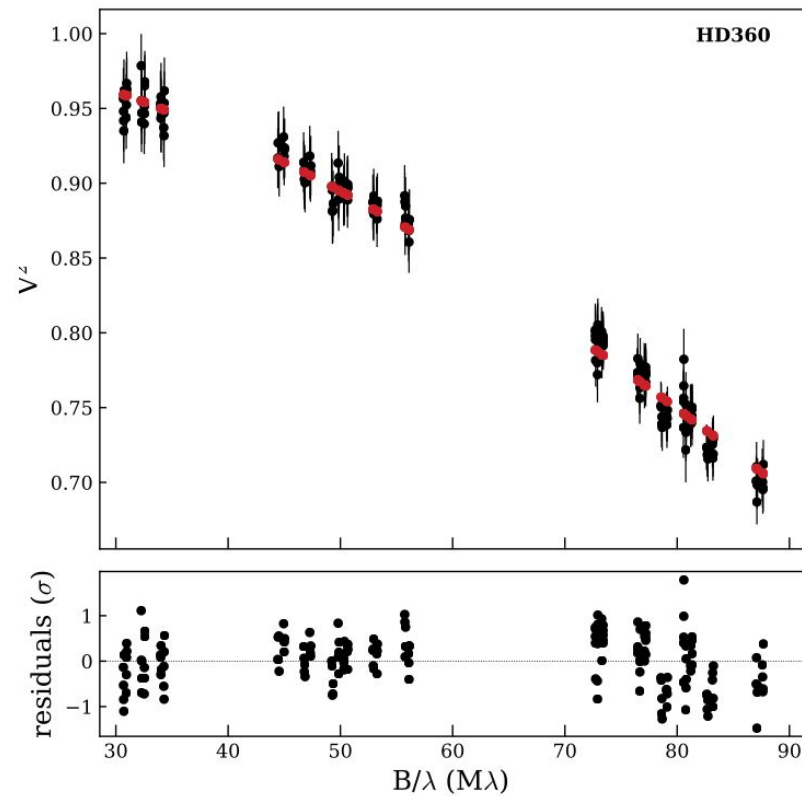
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SBC relation: Xiong et al., A&A **697**, A2925

Calibrators of the Red Clump surface-brightness relation

- 48 stars; $V = 3.9\text{--}6.3$, $K = 1.6\text{--}3.7$, $H = 1.7\text{--}3.8$ mag; angular diameter $0.89\text{--}2.3$ mas.
- Rayleigh resolution criterion, baseline = $1.22 \lambda/\theta$: in H band, 180 m at 2.30 mas to 469 m at 0.89 mas; 280–415 m typical.
- VLTI/PIONIER, H band, 6 baselines of 45–150 m: **undersampled**.



Gallenne et al., A&A **616**, A68 (2018)

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Opportunity for Intensity Interferometry

- Star-by-star check of angular size using intensity interferometry.
- Wavelength–baseline combinations that span the resolution criterion, reducing dependence on limb-darkening models.
- An independent set of systematic errors.
- Limb darkening is stronger at bluer wavelengths.

Measurement requirements: match Gallenne et al. measurement uncertainties

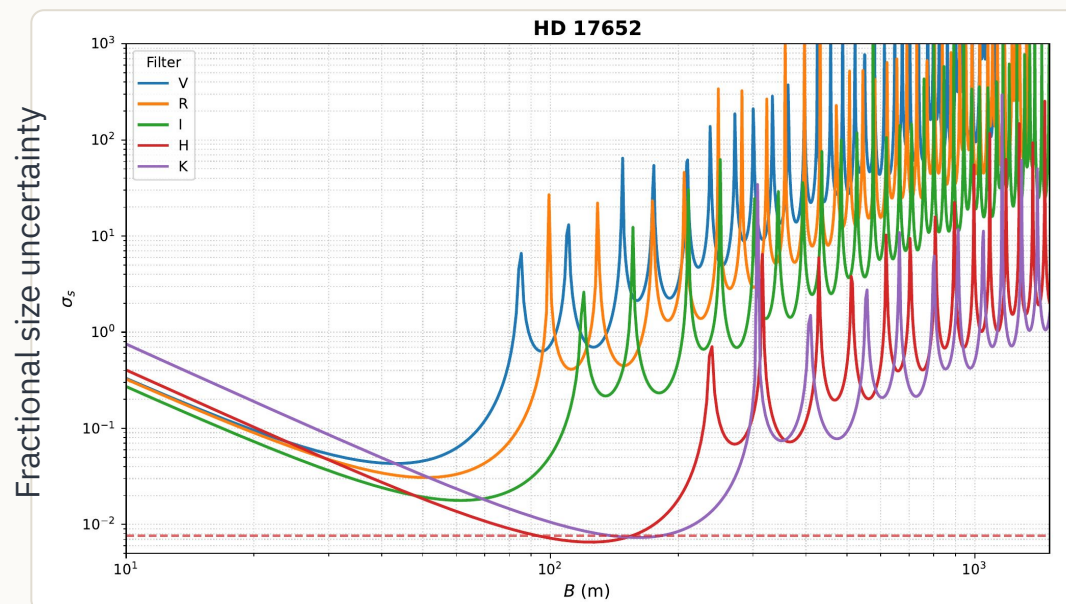
The requirement is to match $\sigma_{\square} \approx \sigma_{\square}(\text{PIONIER})$ per star — sample mean 0.012, s.d. 0.006 over a subset of stars.

Baselines:

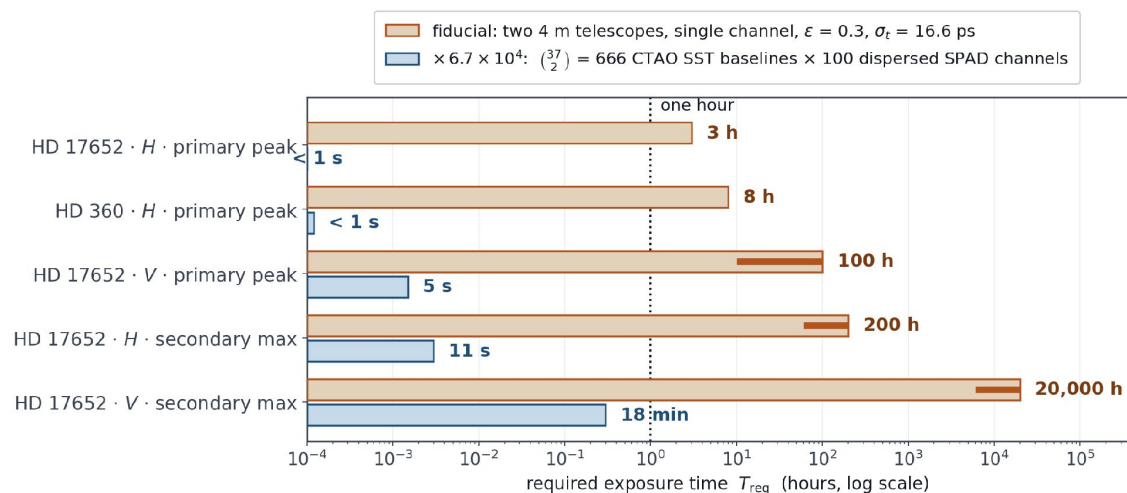
Fiducial: two 4-m telescopes, single channel, detector jitter $\sigma_{\square} = 16.6$ ps

37 telescopes, 666 CTAO SST baselines, 100 channels

1 $\Sigma_{\square}$ VS BASELINE, HD 17652, FIVE BANDS, 2 H



2 GAP CONVERTED TO TIME, AND TIME BOUGHT BACK



Three tiers:

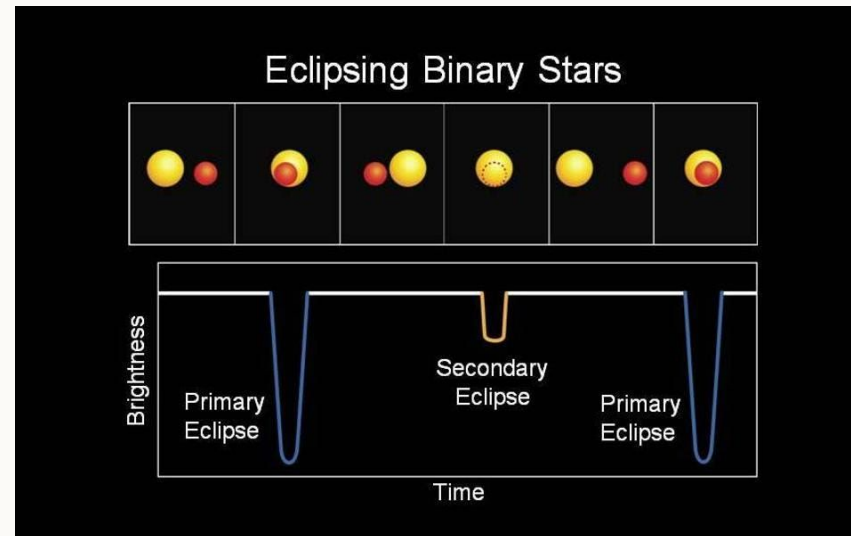
1. H-band primary peak — direct comparison with the previous result
2. V-band primary peak — comparison at an independent wavelength, with a shorter baseline
3. H-band secondary peak

Distance to the LMC given the Red Clump Surface Brightness Color Relation

Steps:

1. LMC contains Detached Eclipsing Binaries with Red Clump stars; eclipse duration and shape, two-star velocities give physical size
2. Magnitudes give angular size
3. Physical and angular sizes give distance

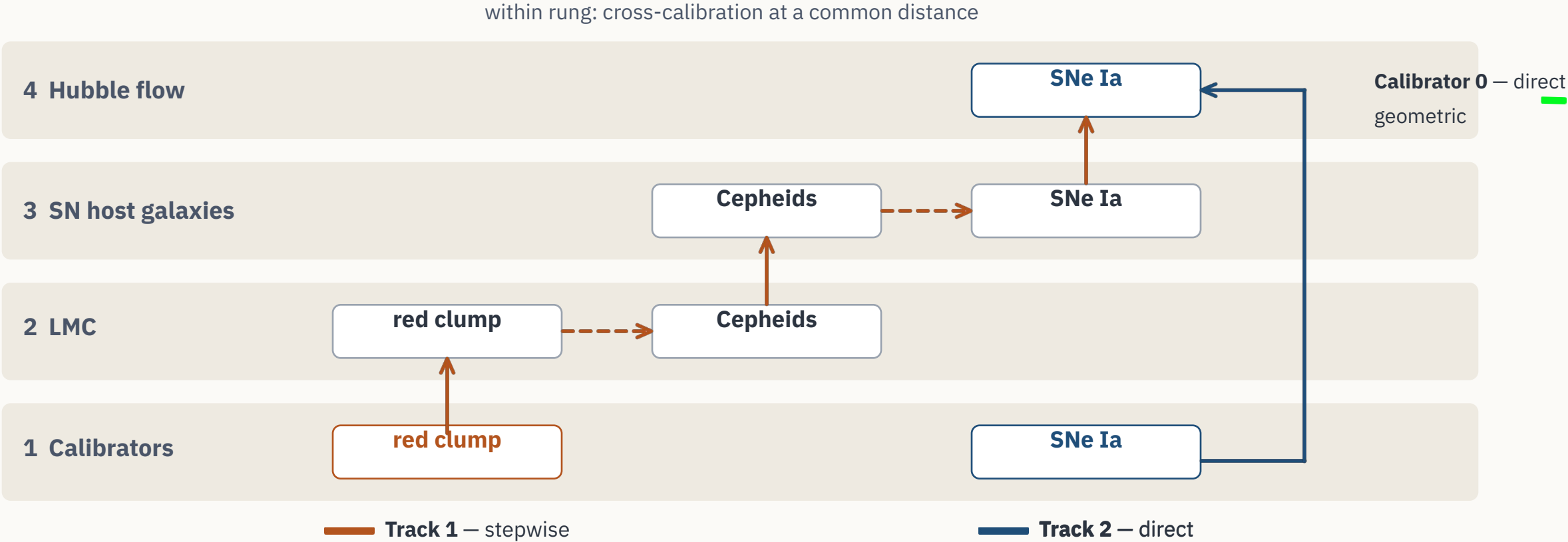
Detached Eclipsing Binaries another Intensity Interferometry Target that impacts the Hubble Constant



Spatially resolve this please

Two (+1) calibrators considered in this presentation

rung → rung: carries distance outward



Kim & Kaiser, PASP **138**, 044202 (2026)

Kim et al., Phys. Rev. D **111**, 083047 (2025)

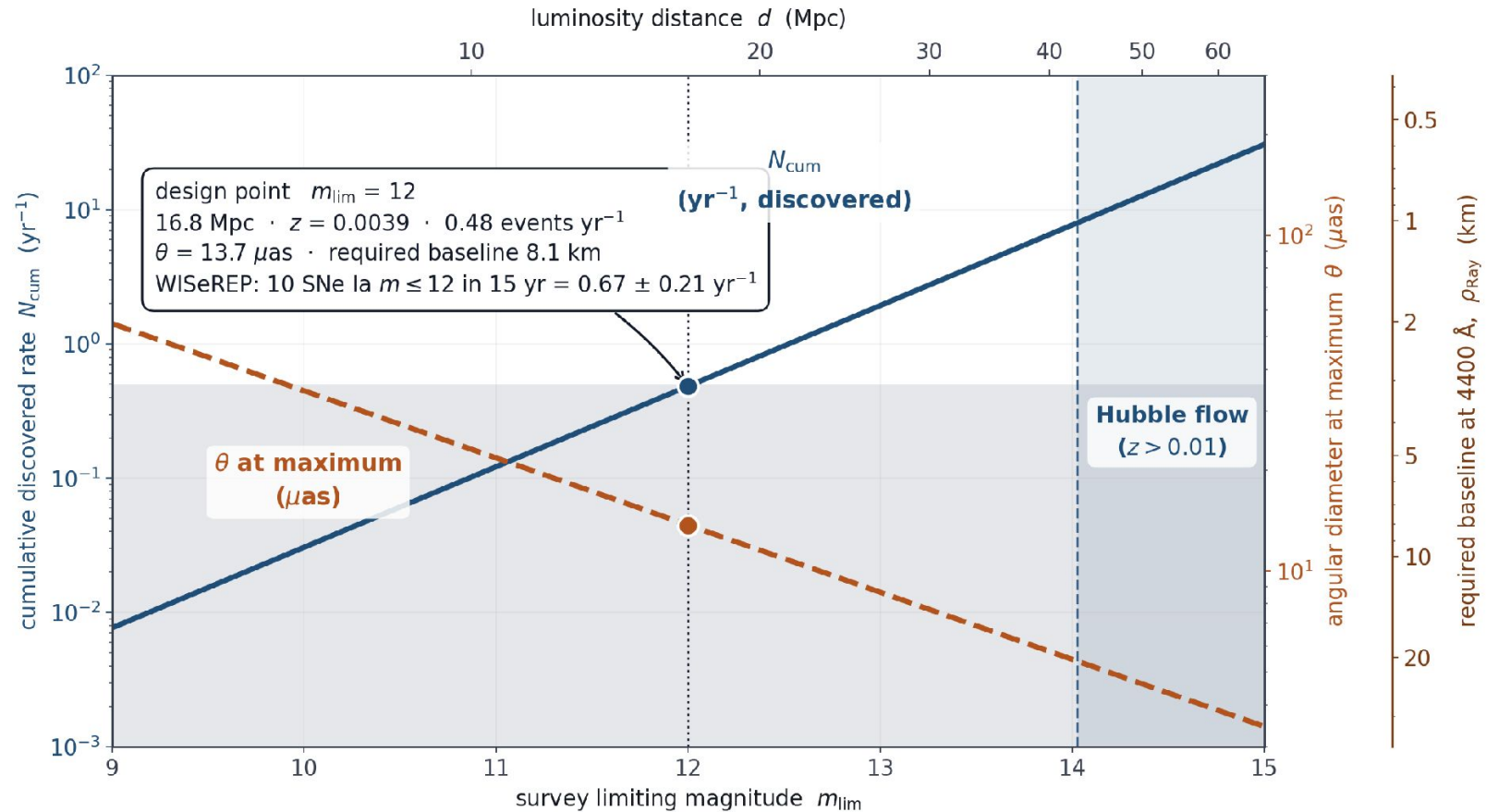


Distances with Type Ia supernovae: Standard Candles and Ruler

- Type Ia supernova progenitor: a C/O white dwarf near the Chandrasekhar limit
- Explosion triggered, e.g. by mass transfer, collision
- ~1.4 solar mass of fuel when triggered leads to a standard luminosity
- Calibrating one (or several) SNe Ia calibrates them all; Absolute magnitude dispersion $< \sim 0.14$ mag: target for measurement precision for a single calibrator
- SNe Ia in the Hubble Flow provide a geometric distance independent of their standard candle nature



Type Ia supernova discovery rates, peak magnitudes, angular diameters



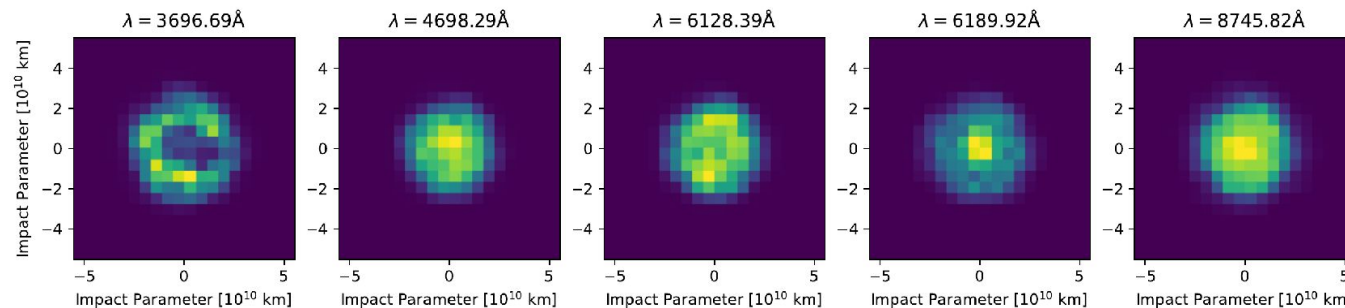
Back-of-the-envelope scalings from the design point.

Determining the physical size of a Type Ia supernova

Physical size is deduced from photometric data (date of explosion) and spectroscopic data (expansion velocity): any SN Ia bright enough for an intensity-interferometry measurement should have these supplemental data.

THIS WORK

The physical surface emission is modelled with TARDIS and SEDONA using the **full optical time-evolving light curves and spectra**. SNe Ia are highly symmetric and are well modelled when optically thick, up to and through maximum light.



SEDONA 3-D model of SN 2011fe, Chen et al. (2026), ApJ **1006**, 86

SN Intensity Profiles

Asymmetric structure due to the expansion, non-centered explosion

OTHER WORK: EXPANDING-EJECTA METHOD

P-Cygni lines used to get the velocity profile, reducing modelling systematics — particularly relevant for SN IIP. Chen et al., JCAP **08** (2026) 013

Signal-to-noise of the distance parameter s

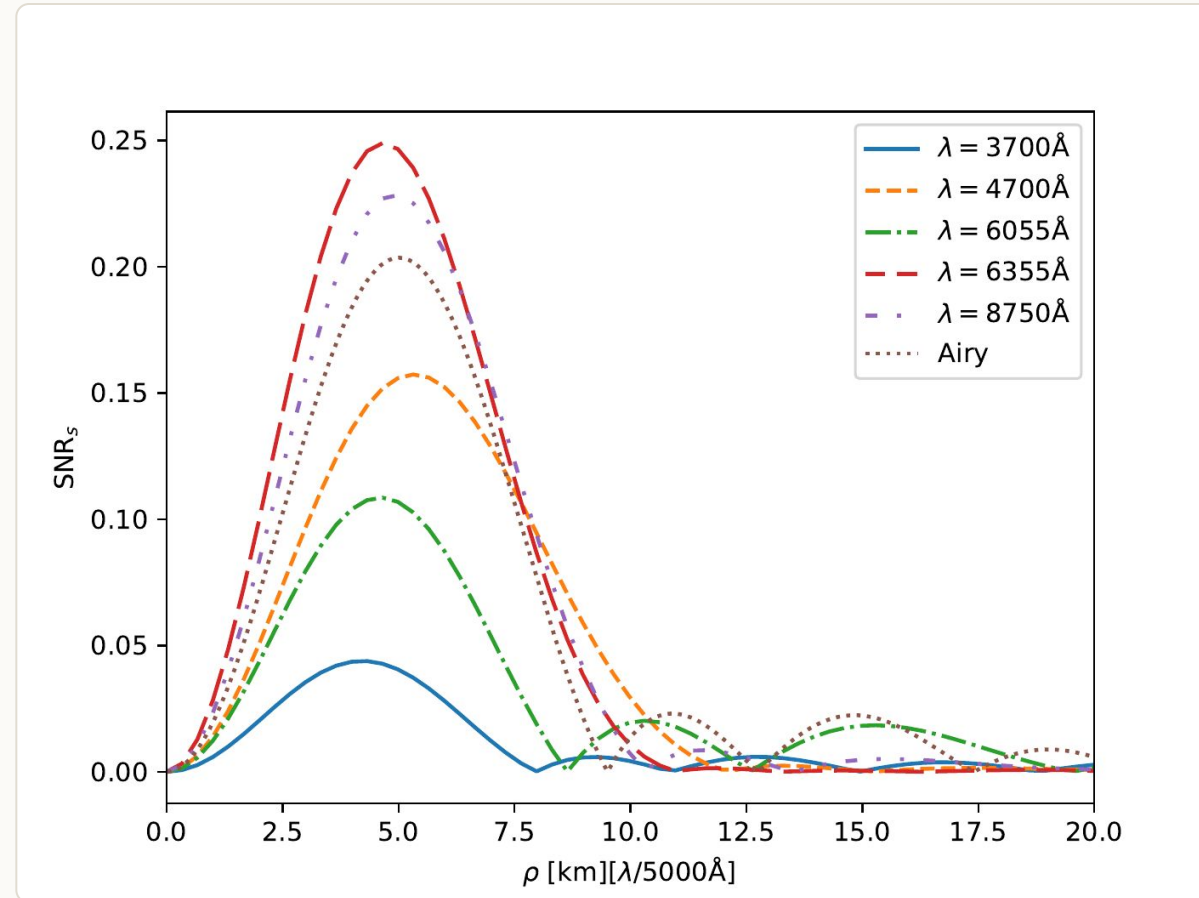


Fig. 8, Kim, Nugent, Chen, Wang & O'Brien, Phys. Rev. D **111**, 083047 (2025)

SNR of the distance parameter s against telescope separation ρ , at five selected wavelengths, for the 1-D **TARDIS** model.

Supernova at $z = 0.004$ with $B = 12$ mag, seen by **two Keck-like telescopes**, effective throughput $\varepsilon = 0.39$, **1 hour** exposure, single channel, detector jitter 30 ps FWHM ($\sigma = 13$ ps RMS).

Peak SNR ≈ 0.25 near $\rho \approx 5$ km — from **one pair in one hour**. The measurement has to be built up.

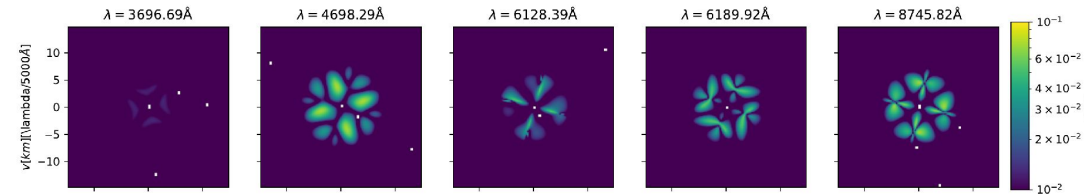
Per baseline SNR scales with collecting area; N telescopes give $N(N-1)/2$ independent pairs, and the combined SNR grows as the square root of that number.

Target SNR ~ 15 for fractional distance based on 0.14 mag dispersion

Distance precision and bias across the $u-v$ plane, SEDONA

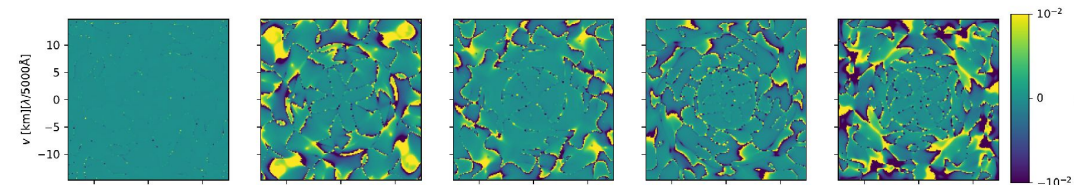
Two perpendicular pairs

S/N of distance parameter



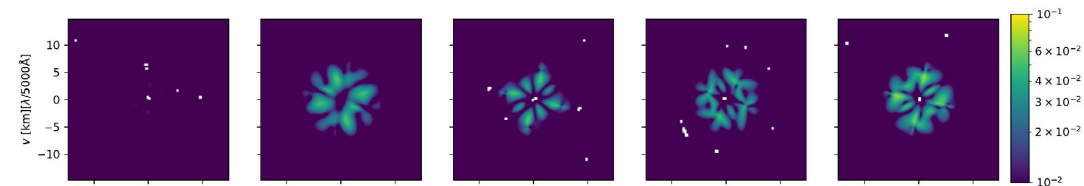
Two perpendicular pairs

bias $\delta \square$



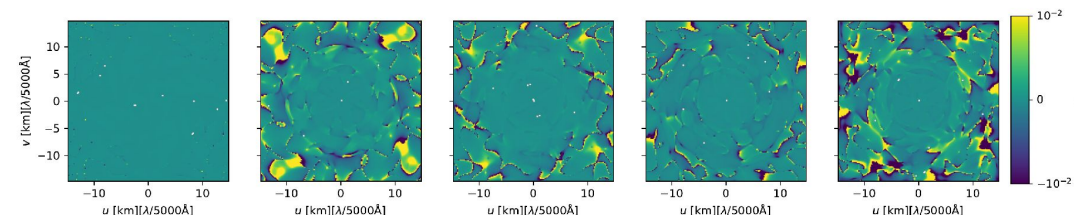
Three triangular pairs

S/N of distance parameter



Three triangular pairs

bias $\delta \square$



Bias propagated from systematic 5% intensity errors per spatial element.

Three pairs: the S/N map is **more evenly distributed**, the bias map **less speckled and lower in amplitude**. More independent orientations mitigate the systematics from profile asymmetry.

SN at $z = 0.004$, $B = 12$ mag. The $u-v$ coordinate is one of the equal-separation baselines. Fig. 12, Kim et al., Phys. Rev. D **111**, 083047 (2025)

Sources that violate the Siegert relation

- “Quantum” astronomy is not manifest only in coherent source emission.
- Spacetime foam: quantum-mechanical fluctuations of spacetime itself.
- Acts as a screen that violates the Siegert relation, with a frequency dependence **distinct from that of classical screens.**

Intended to present intensity-interferometry results here, but got interrupted by first-order coherence.

Conclusions

RED CLUMP — TARGET NOW

≈25 of the 48 SBC calibrators, H band, 50–150 m baselines, existing and near-term facilities.

Payoff: an independent check on a systematic that propagates straight into H_0 as $\delta H_0/H_0 \approx -\delta s/s$.

SNE IA — A DESIGN DRIVER

≈10 km baselines, 10-m-class collecting area, sub-100 ps timing, trigger-ready for the next event brighter than $m = 12$, at roughly one per year.

Payoff: Track 2 of the ladder — a geometric distance that bypasses the intermediate rungs entirely.

Foam — a screen that violates the Siegert relation with a frequency dependence unlike any classical screen. Second-order coherence results to come.

One technique, the $g^{(2)}$ intensity correlation — two facility scales, ≈100 m for a star and ≈10 km for a supernovae.

Lawrence Berkeley National Laboratory and U.S. Department of Energy has expertise in telescope design, building cameras, modeling, computing.

The 41 tabulated SBC calibrators

Star	RA (deg)	Dec (deg)	θ_{LD} (mas)	V	H	K	G	G_BP	G_RP
HD 9362	22.814	-49.072	2.301 ± 0.017	3.94	1.75	1.64	3.671	4.212	3.002
HD 16815	40.168	-39.855	2.248 ± 0.009	4.11	1.82	1.71	3.822	4.367	3.136
HD 219784	349.706	-32.532	2.117 ± 0.023	4.41	2.02	1.89	4.077	4.663	3.381
HD 23319	55.708	-37.314	2.033 ± 0.010	4.58	2.14	2.00	4.250	4.839	3.532
HD 39523	87.458	-56.167	1.939 ± 0.013	4.50	2.16	2.04	4.173	4.754	3.499
HD 17652	42.273	-32.405	1.835 ± 0.010	4.46	2.26	2.14	4.180	4.688	3.513
HD 11977	28.735	-67.647	1.528 ± 0.010	4.69	2.59	2.49	4.419	4.908	3.785
HD 204381	322.181	-21.807	1.524 ± 0.015	4.50	2.54	2.43	4.269	4.718	3.651
HD 62713	115.925	-40.935	1.446 ± 0.010	5.13	2.78	2.65	4.814	5.366	4.120
HD 56160	108.713	-27.038	1.411 ± 0.010	5.58	2.98	2.82	5.211	5.838	4.456
HD 17824	42.759	-21.004	1.391 ± 0.013	4.76	2.78	2.67	4.523	4.989	3.909
HD 176704	285.615	-24.848	1.317 ± 0.010	5.64	3.11	2.96	5.282	5.883	4.551
HD 30814	72.549	-16.217	1.310 ± 0.008	5.04	2.90	2.79	4.770	5.263	4.116
HD 43899	94.255	-37.737	1.264 ± 0.016	5.56	3.13	3.00	5.217	5.783	4.513
HD 39640	87.722	-52.109	1.251 ± 0.016	5.16	3.04	2.92	4.898	5.394	4.243
HD 8651	21.170	-41.493	1.228 ± 0.011	5.42	3.14	3.02	5.129	5.654	4.451
HD 60341	113.332	-19.413	1.190 ± 0.021	5.64	3.26	3.13	5.329	5.882	4.630
HD 15220	36.647	-20.042	1.185 ± 0.015	5.88	3.34	3.20	5.537	6.142	4.795
HD 15779	38.039	-1.035	1.185 ± 0.013	5.36	3.19	3.07	5.093	5.596	4.439
HD 46116	96.369	-69.689	1.145 ± 0.030	5.37	3.21	3.10	5.113	5.607	4.465
HD 36874	83.281	-35.139	1.118 ± 0.010	5.77	3.36	3.24	5.447	6.001	4.752

Star	RA (deg)	Dec (deg)	θ_{LD} (mas)	V	H	K	G	G_BP	G_RP
HD 4211	11.052	-38.421	1.100 ± 0.009	5.88	3.43	3.29	5.578	6.153	4.859
HD 23940	56.984	-30.169	1.093 ± 0.020	5.54	3.34	3.23	5.257	5.756	4.596
HD 220572	351.332	-56.849	1.092 ± 0.012	5.61	3.35	3.22	5.315	5.838	4.639
HD 12438	30.311	-30.002	1.091 ± 0.015	5.34	3.28	3.18	5.095	5.560	4.472
HD 39910	88.876	-4.617	1.090 ± 0.006	5.86	3.45	3.31	5.549	6.116	4.832
HD 53629	106.196	-22.032	1.065 ± 0.023	6.08	3.56	3.41	5.744	6.338	5.009
HD 18784	45.292	-7.663	1.036 ± 0.013	5.75	3.46	3.35	5.471	5.995	4.795
HD 191584	303.099	-42.781	1.024 ± 0.021	6.21	3.66	3.51	5.860	6.460	5.121
HD 68312	122.887	-7.773	1.020 ± 0.022	5.36	3.39	3.28	5.119	5.572	4.510
HD 74622	130.586	-55.774	1.020 ± 0.014	6.28	3.67	3.53	5.909	6.509	5.171
HD 75916	133.128	-13.233	1.013 ± 0.020	6.12	3.65	3.52	5.798	6.368	5.082
HD 40020	89.207	+11.521	1.012 ± 0.022	5.88	3.54	3.42	5.596	6.138	4.903
HD 3750	9.967	-44.796	1.003 ± 0.019	6.00	3.61	3.48	5.699	6.252	4.996
HD 5722	14.683	-11.380	0.995 ± 0.018	5.62	3.50	3.38	5.359	5.845	4.711
HD 10142	24.614	-36.529	0.964 ± 0.004	5.94	3.68	3.56	5.659	6.177	4.977
HD 15248	35.717	-73.646	0.949 ± 0.018	6.00	3.67	3.55	5.700	6.239	5.008
HD 60060	112.499	-52.651	0.948 ± 0.009	5.87	3.66	3.54	5.597	6.101	4.933
HD 23526	56.539	+6.803	0.915 ± 0.020	5.91	3.74	3.63	5.652	6.145	4.993
HD 360	2.073	-8.824	0.906 ± 0.014	5.99	3.76	3.65	5.716	6.228	5.045
HD 13468	32.899	-1.826	0.886 ± 0.009	5.93	3.78	3.67	5.680	6.165	5.026

Table 2 of the Red Clump paper. Sorted by decreasing θ . Gaia DR3 positions. $\theta = 0.886\text{--}2.301$ mas, $V = 3.94\text{--}6.28$.

SN Ia rates, depths and required baselines

$m_{i\lambda}$	d (Mpc)	z	N discovered (yr^{-1})	θ (μas)	baseline at 4400 Å (km)
10	6.70	0.0016	0.031	34.5	3.21
11	10.62	0.0025	0.122	21.8	5.09
12	16.83	0.0039	0.485	13.7	8.06
13	26.67	0.0062	1.931	8.7	12.78
14	42.27	0.0099	7.686	5.5	20.26

Cube-root scaling: $\text{baseline} = 8.1 \text{ km} \times (N / 0.48 \text{ yr}^{-1})^{(1/3)}$. A factor of ten in event rate costs a factor 2.2 in baseline.

Inputs: peak absolute magnitude $M(B) = -19.13$, volumetric rate $2.43 \times 10^{-5} \text{ yr}^{-1} \text{ Mpc}^{-3}$, $h_{70} = 1$, photospheric velocity $10,000 \text{ km s}^{-1}$, $t = 20 \text{ d}$ ($2vt = 3.46 \times 10^{10} \text{ km} = 231 \text{ AU}$), $\lambda = 4400 \text{ Å}$. The $m_{i\lambda} = 12$ row is the design point.

Exposure-time scaling and the aperture lever

SCALING EXPONENTS

- $T \propto 10^{(0.8 \Delta m)}$
- $T \propto D^{-4}$
- $T \propto \sigma^2$

THE APERTURE LEVER

4 m $\rightarrow$ 8.2 m is a factor **17.7** in exposure time — the VLT UT plus VISTA option.

Magnitude cross-check. HD 360 is 1.50 mag fainter in H than HD 17652, predicting $10^{1.2} = 15.8$ in exposure time. Table 1 of the paper gives $(188.53 / 47.31)^2 = 15.9$.

Effective-exposure multiplier on the ask slide: $6.7 \times 10^4 = 666$ simultaneous CTAO SST baselines $\times$ 100 dispersed SPAD channels.