ZTF Cosmo

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ZTF Cosmology Science Working Group

— Status —

Core group of ~40 peoples

Research: SN Ia for Cosmology

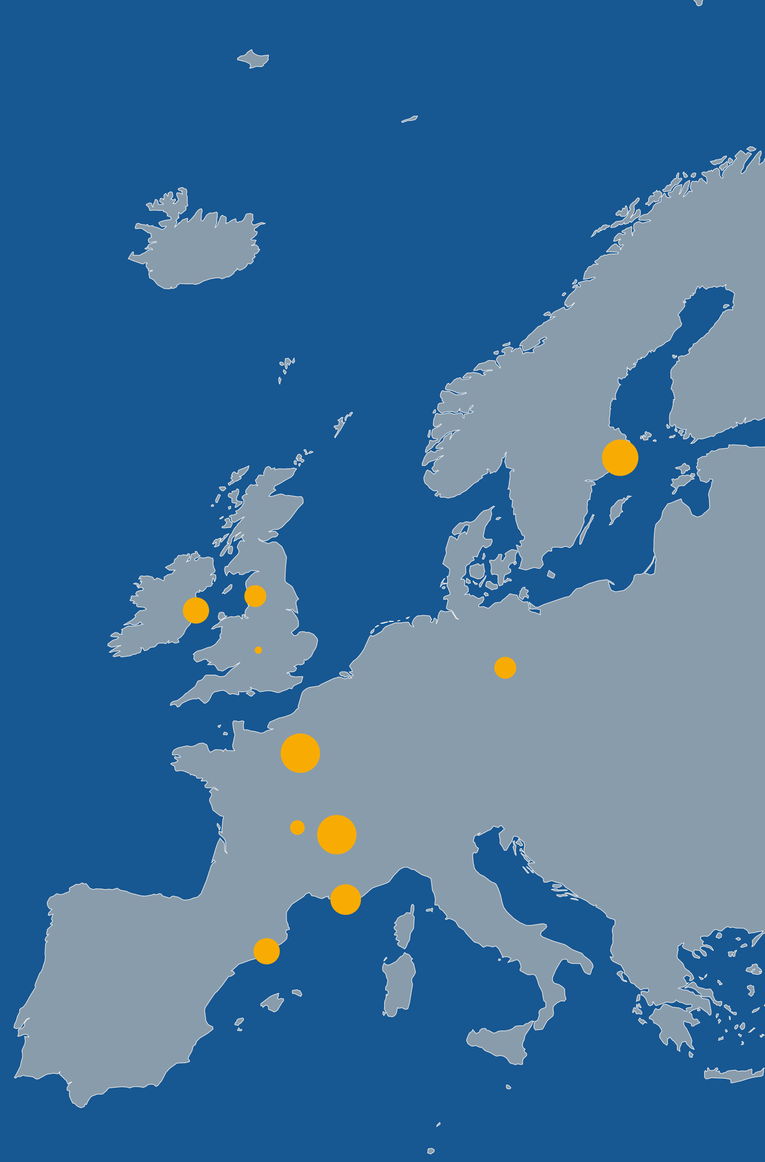
Progenitor-issue | Astro-bias

Calibration | Cosmo-Inference

Close connection with

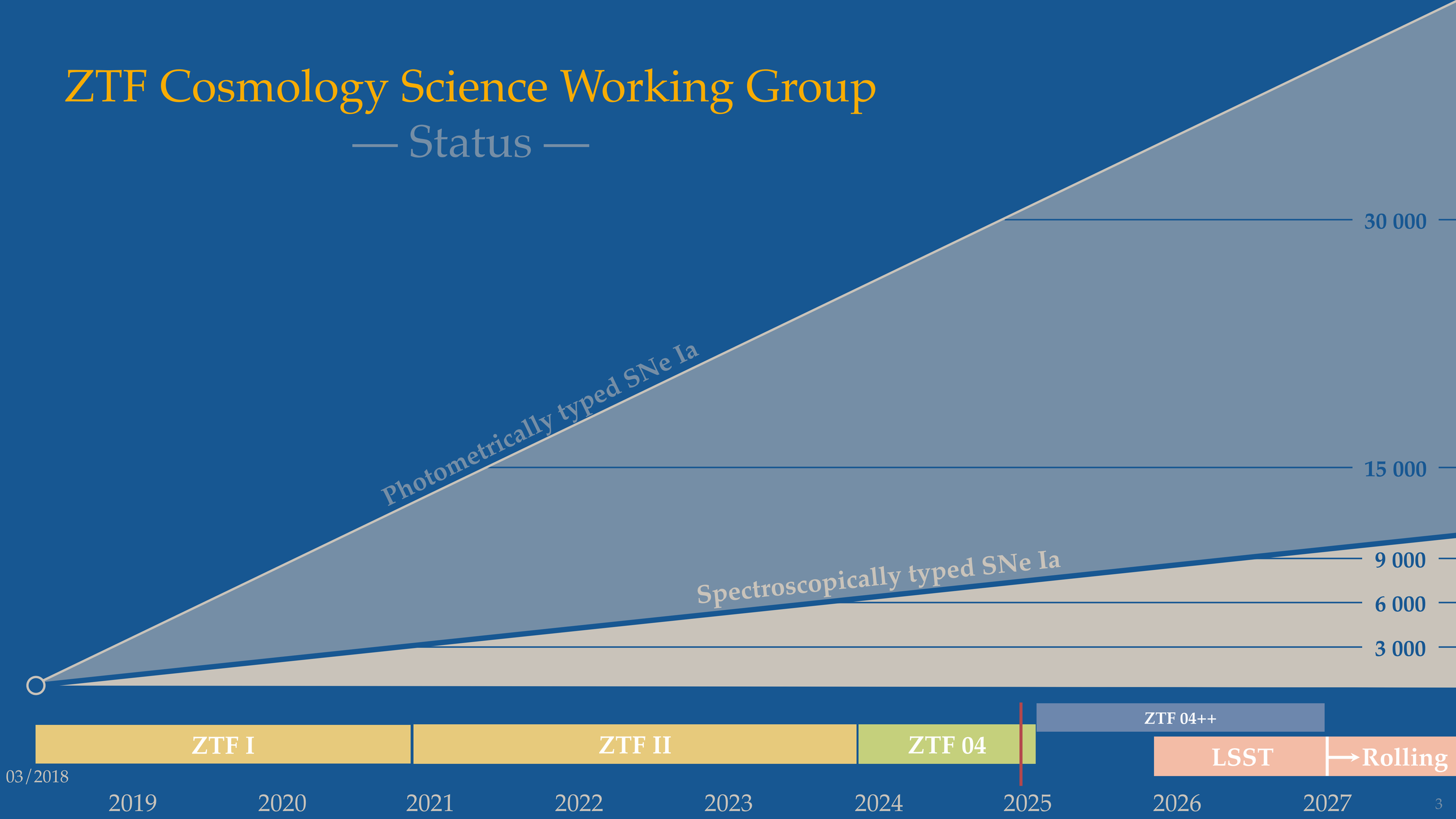
“Bright Transient Survey” & “SN physics”

Share most spectroscopy ressources



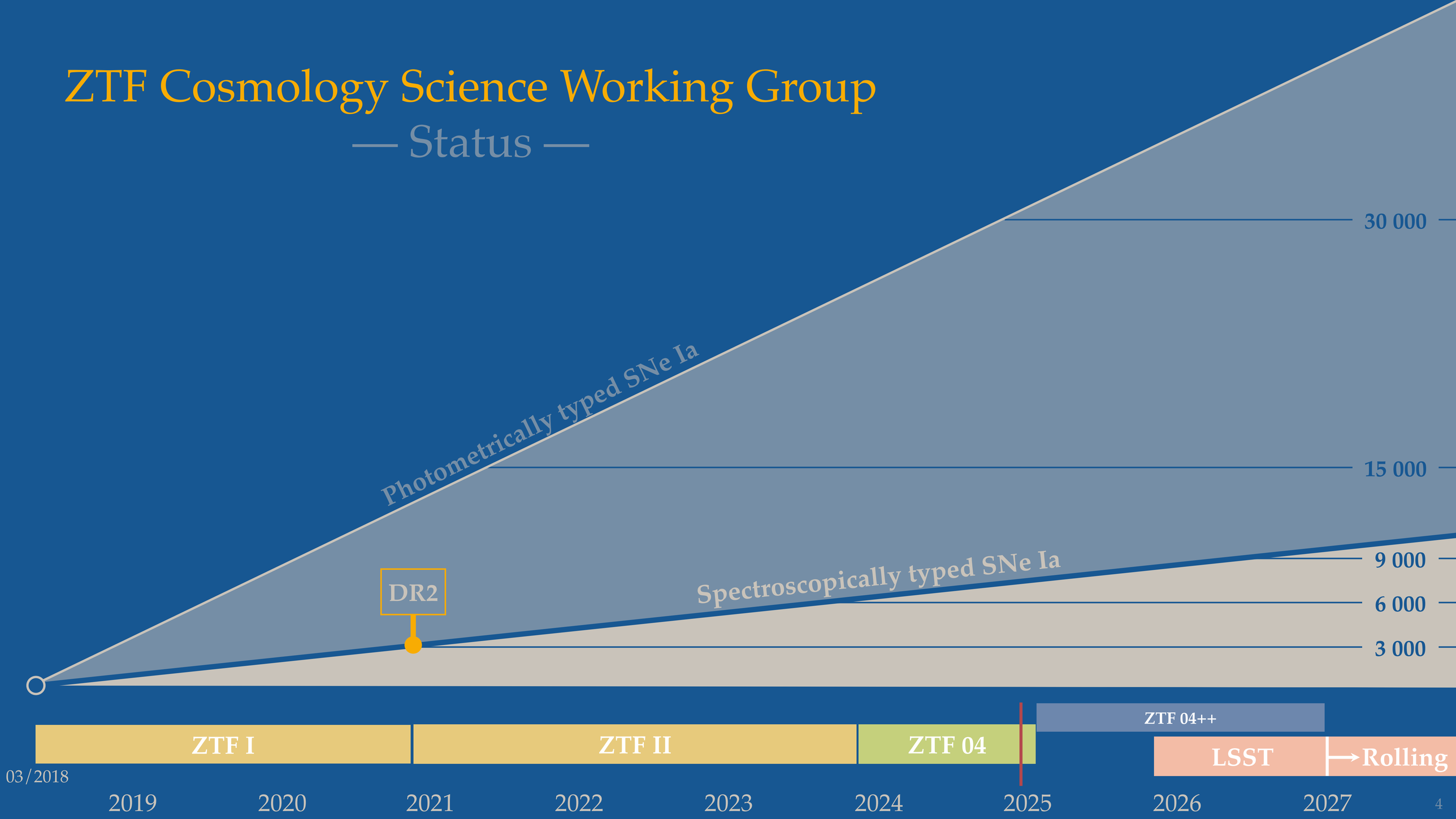
ZTF Cosmology Science Working Group

— Status —



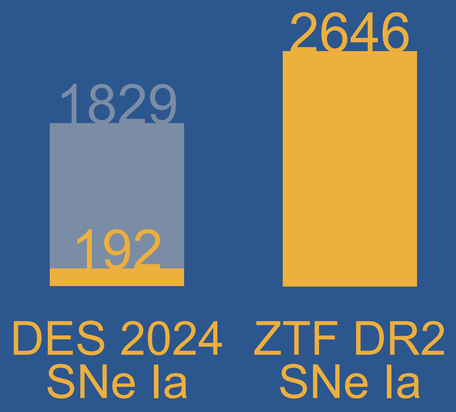
ZTF Cosmology Science Working Group

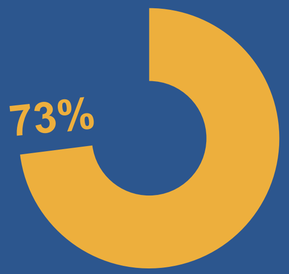
— Status —



ZTF SN Ia DR2

2.5 years of ZTF | 33%





Cosmology quality SNe Ia

21 Papers Astronomy &Astrophysics **Special issue**

First Author		Short title
● Rigault (a, this work)	arXiv	DR2 overview
○ Smith		DR2 data review
○ Lacroix		DR2 photometry
○ Johansson		DR2 spectra review
● Rigault (b)	arXiv	Light-curve residuals
● Kenworthy		Light-curve modeling
● Amenouche	arXiv	DR2 sample simulations
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● Aubert	arXiv	SNe Ia in voids
● Carreres	arXiv	Velocity systematics
● Burgaz (a)		SN Ia spectral diversity
● Dimitriadis	arXiv	Thermonuclear SN diversity
● Terwel	arXiv	Late-time CSM interaction
● Harvey		High-velocity features
● Deckers	arXiv	Secondary maxima
● Burgaz (b)		SNe Ia in low-mass hosts
● Senzel	arXiv	Bulge vs. Disk SNe Ia

● *accepted* ● *responded* ● *submitted / replying* ○ *to be sub.*

ZTF SN Ia DR2

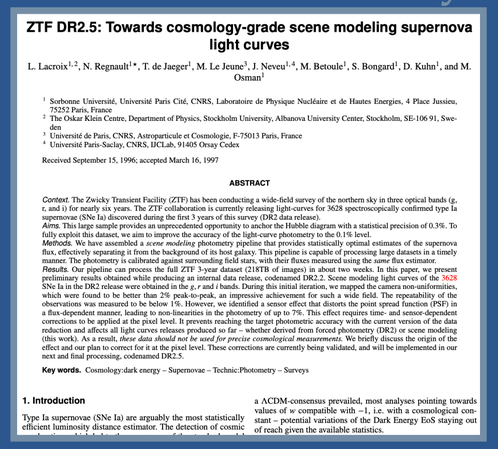
10 Accepted

8 Refereed

3 Internal

A&A Special issue initial realise: Feb. 2025

Lacroix | Photometry



ZTF DR2.5: Towards cosmology-grade scene modeling supernova light curves

L. Lacroix[1,2], N. Regnault[1]★, T. de Jaeger[1], M. Le Jeune[3], J. Neveu[1,4], M. Betoule[1], S. Bongard[1], D. Kuhn[1], and M. Osman[1]

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Received September 15, 1996; accepted March 16, 1997

ABSTRACT

Context. The Zwicky Transient Facility (ZTF) has been conducting a wide-field survey of the northern sky in three optical bands (*g*, *r*, and *i*) for nearly six years. The ZTF collaboration is currently releasing light-curves for 3628 spectroscopically confirmed type Ia supernovae (SNe Ia) discovered during the first 3 years of this survey (DR2 data release).
Aims. This large sample provides an unprecedented opportunity to anchor the Hubble diagram with a statistical precision of 0.3%. To fully exploit this dataset, we aim to improve the accuracy of the light-curve photometry to the 0.1% level.
Methods. We have assembled a *scene modeling* photometry pipeline that provides statistically optimal estimates of the supernova flux, effectively separating it from the background of its host galaxy. This pipeline is capable of processing large datasets in a timely manner. The photometry is calibrated against surrounding field stars, with their fluxes measured using the *same* flux estimator.
Results. Our pipeline can process the full ZTF 3-year dataset (218TB of images) in about two weeks. In this paper, we present preliminary results obtained while producing an internal data release, codenamed DR2.2. Scene modeling light curves of the 3628 SNe Ia in the DR2 release were obtained in the *g*, *r* and *i* bands. During this initial iteration, we mapped the camera non-uniformities, which were found to be better than 2% peak-to-peak, an impressive achievement for such a wide field. The repeatability of the observations was measured to be below 1%. However, we identified a sensor effect that distorts the point spread function (PSF) in a flux-dependent manner, leading to non-linearities in the photometry of up to 7%. This effect requires time- and sensor-dependent corrections to be applied at the pixel level. It prevents reaching the target photometric accuracy with the current version of the data reduction and affects all light curves releases produced so far – whether derived from forced photometry (DR2) or scene modeling (this work). As a result, *these data should not be used for precise cosmological measurements.* We briefly discuss the origin of the effect and our plan to correct for it at the pixel level. These corrections are currently being validated, and will be implemented in our next and final processing, codenamed DR2.5.

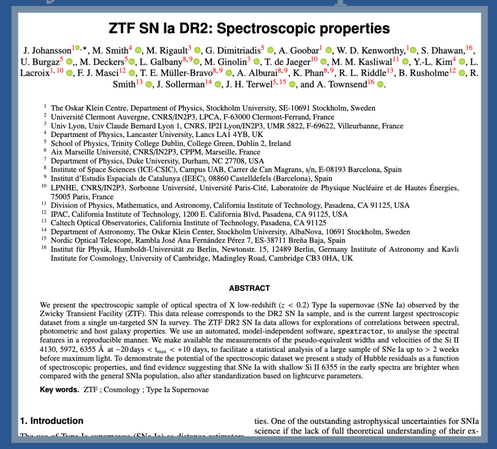
Key words. Cosmology:dark energy – Supernovae – Technic:Photometry – Surveys

1. Introduction

Type Ia supernovae (SNe Ia) are arguably the most statistically efficient luminosity distance estimator. The detection of cosmic

a ACDM-consensus prevailed, most analyses pointing towards values of w compatible with -1, i.e. with a cosmological constant – potential variations of the Dark Energy EoS staying out of reach given the available statistics.

Johansson | Spectra



ZTF SN Ia DR2: Spectroscopic properties

J. Johansson[15]★, M. Smith[4], M. Rigault[3], G. Dimitriadis[5], A. Goobar[1], W. D. Kenworthy,[1], S. Dhawan,[16], U. Burgaz[5], M. Deckers[3], L. Galbany[6,7], M. Ginolin[3], T. de Jaeger[10], M. M. Kasliwal[11], Y.-L. Kim[4], L. Lacroix[2,10], F. J. Masci[12], T. E. Müller-Bravo[6,7], A. Alburai[6,7], K. Phan[6,7], R. L. Riddle[13], B. Rusholme[12], R. Smith[13], J. Sollerman[14], J. H. Terwel[3,15], and A. Townsend[16].

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ABSTRACT

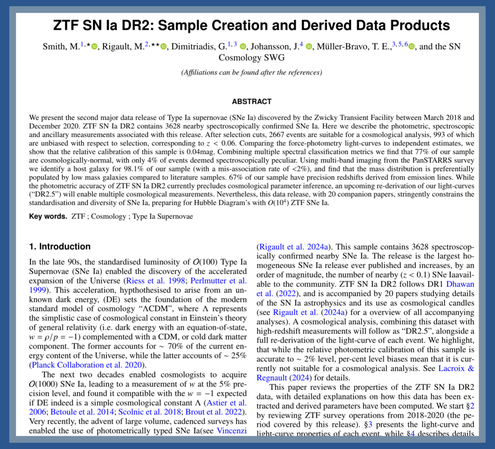
We present the spectroscopic sample of optical spectra of X low-redshift ($z < 0.2$) Type Ia supernovae (SNe Ia) observed by the Zwicky Transient Facility (ZTF). This data release corresponds to the DR2 SN Ia sample, and is the current largest spectroscopic dataset from a single un-targeted SN Ia survey. The ZTF DR2 SN Ia data allows for explorations of correlations between spectral, photometric and host galaxy properties. We use an automated, model-independent software, `spectractor`, to analyse the spectral features in a reproducible manner. We make available the measurements of the pseudo-equivalent widths and velocities of the Si II 4130, 5972, 6355 Å at -20days $< t_{\rm max} < +10$ days, to facilitate a statistical analysis of a large sample of SNe Ia up to > 2 weeks before maximum light. To demonstrate the potential of the spectroscopic dataset we present a study of Hubble residuals as a function of spectroscopic properties, and find evidence suggesting that SNe Ia with shallow Si II 6355 in the early spectra are brighter when compared with the general SNIa population, also after standardization based on lightcurve parameters.

Key words. ZTF ; Cosmology ; Type Ia Supernovae

1. Introduction

ties. One of the outstanding astrophysical uncertainties for SNIa science if the lack of full theoretical understanding of their ex-

Smith | Data



ZTF SN Ia DR2: Sample Creation and Derived Data Products

Smith, M.[1,•], Rigault, M.[2,••], Dimitriadis, G.[1,3], Johansson, J.[4], Müller-Bravo, T. E.[3,5,6], and the SN Cosmology SWG

(Affiliations can be found after the references)

ABSTRACT

We present the second major data release of Type Ia supernovae (SNe Ia) discovered by the Zwicky Transient Facility between March 2018 and December 2020. ZTF SN Ia DR2 contains 3628 nearby spectroscopically confirmed SNe Ia. Here we describe the photometric, spectroscopic and ancillary measurements associated with this release. After selection cuts, 2667 events are suitable for a cosmological analysis, 993 of which are unbiased with respect to selection, corresponding to $z < 0.06$. Comparing the force-photometry light-curves to independent estimates, we show that the relative calibration of this sample is 0.04mag. Combining multiple spectral classification metrics we find that 77% of our sample are cosmologically-normal, with only 4% of events deemed spectroscopically peculiar. Using multi-band imaging from the PanSTARRS survey we identify a host galaxy for 98.1% of our sample (with a mis-association rate of <2%), and find that the mass distribution is preferentially populated by low mass galaxies compared to literature samples. 67% of our sample have precision redshifts derived from emission lines. While the photometric accuracy of ZTF SN Ia DR2 currently precludes cosmological parameter inference, an upcoming re-derivation of our light-curves ("DR2.5") will enable multiple cosmological measurements. Nevertheless, this data release, with 20 companion papers, stringently constrains the standardisation and diversity of SNe Ia, preparing for Hubble Diagram's with $O(10^4)$ ZTF SNe Ia.

Key words. ZTF ; Cosmology ; Type Ia Supernovae

1. Introduction

In the late 90s, the standardised luminosity of $O(100)$ Type Ia Supernovae (SNe Ia) enabled the discovery of the accelerated expansion of the Universe (Riess et al. 1998; Perlmutter et al. 1999). This acceleration, hypothesised to arise from an unknown dark energy, (DE) sets the foundation of the modern standard model of cosmology "ΛCDM", where Λ represents the simplistic case of cosmological constant in Einstein's theory of general relativity (i.e. dark energy with an equation-of-state, $w = p/\rho = -1$) complemented with a CDM, or cold dark matter component. The former accounts for $\sim 70\%$ of the current energy content of the Universe, while the latter accounts of $\sim 25\%$ (Planck Collaboration et al. 2020).

The next two decades enabled cosmologists to acquire $O(1000)$ SNe Ia, leading to a measurement of w at the 5% precision level, and found it compatible with the $w = -1$ expected if DE indeed is a simple cosmological constant Λ (Astier et al. 2006; Betoule et al. 2014; Scolnic et al. 2018; Brout et al. 2022). Very recently, the advent of large volume, cadenced surveys has enabled the use of photometrically typed SNe Ia(see Vincenzi (Rigault et al. 2024a). This sample contains 3628 spectroscopically confirmed nearby SNe Ia. The release is the largest homogeneous SNe Ia release ever published and increases, by an order of magnitude, the number of nearby ($z < 0.1$) SNe Iaavailable to the community. ZTF SN Ia DR2 follows DR1 Dhawan et al. (2022), and is accompanied by 20 papers studying details of the SN Ia astrophysics and its use as cosmological candles (see Rigault et al. (2024a) for a overview of all accompanying analyses). A cosmological analysis, combining this dataset with high-redshift measurements will follow as "DR2.5", alongside a full re-derivation of the light-curve of each event. We highlight, that while the relative photometric calibration of this sample is accurate to $\sim 2\%$ level, per-cent level biases mean that it is currently not suitable for a cosmological analysis. See Lacroix & Regnault (2024) for details.

This paper reviews the properties of the ZTF SN Ia DR2 data, with detailed explanations on how this data has been extracted and derived parameters have been computed. We start §2 by reviewing ZTF survey operations from 2018-2020 (the period covered by this release). §3 presents the light-curve and light-curve properties of each event, while §4 describes details

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● Rigault (a, this work)	arXiv	DR2 overview
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● Harvey		High-velocity features
● Deckers	arXiv	Secondary maxima
● Burgaz (b)		SNe Ia in low-mass hosts
● Senzel	arXiv	Bulge vs. Disk SNe Ia

● *accepted* ● *responded* ● *submitted / replying* ○ *to be sub.*

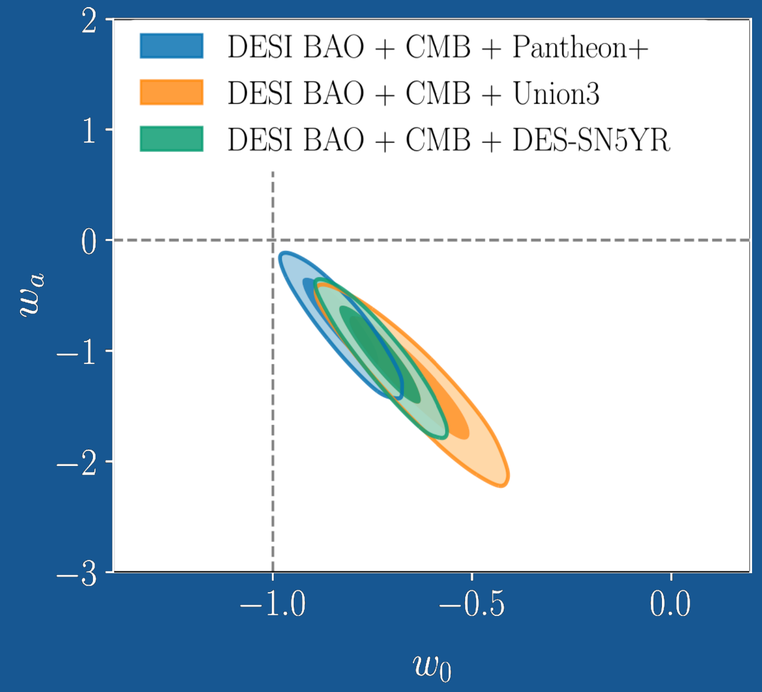
“Lemaitre”

DR2.5

Summer 2025

DR2 SN Ia (Spectro) SNLS 5yr (Spectro) Subaru (Photo)

~3500 SN Ia → Cosmology



w_0, w_a : Dark energy

New photometry: ztfimg / ztfin2p3

New simulations: skysurvey

New inference: NaCl → EDRIS

$f\sigma_8$: Peculiar velocities

H_0 : Inverse distance ladder

Extensions | to be planned already

Lemaitre (ZTF only?) + DES + Pantheon.

Cross calibrations | methodology (BBC?, Salt ?) | sample definition

DR3

Fall 2026

This will be the legacy ZTF SN Ia sample

O(10k) SN Ia (Spectro)

O(30k) SN Ia (Photo)

Initial sample (same?) to be defined

Spectra

SEDm: Hypergal mostly done

Non SEDm spectra: To be gathered

Redshifts

SNID redshift: Automated

DESI redshifts: is that all set up ?

LightCurves

Force photometry: Do we need that ?

Scene modelling: for when ?

Host

Identification: Code ready ? Human ?

Properties: Include UV & NIR ? Prospector ?

DR3

Fall 2026

This will be the legacy ZTF SN Ia sample

O(10k) SN Ia (Spectro)

O(30k) SN Ia (Photo)

Initial sample (same?) to be defined

SPECTRA

SEDm & Non SEDm: To be gathered

REDSHIFTS

SNID & DESI: that all set up ?

LIGHTCURVES

photometry: forced & scene

HOST

Identification & Properties: who?

Classification:	Sciences (DR3 spectra)	Sciences
A.I. for Photo-typing	Rates	Cosmo
SNID Automated	Bumps and co.	
Spectra feature based	Low-metallicity hosts	
	Standardisation (twins & correlations)	

DR3

Fall 2026

This will be the legacy ZTF SN Ia sample

O(10k) SN Ia (Spectro)

O(30k) SN Ia (Photo)

Initial sample (same?) to be defined

SPECTRA

SEDm & Non SEDm: To be gathered

REDSHIFTS

SNID & DESI: that all set up ?

LIGHTCURVES

photometry: forced & scene

HOST

Identification & Properties: who?

Classification:	Sciences (DR3 spectra)	Sciences
A.I. for Photo-typing	Rates	Cosmo
SNID Automated	Bumps and co.	
Spectra feature based	Low-metallicity hosts	
	Standardisation	

Sample defined
Spectra gathered
SNID Ran

01/2025

Host matching and
Their propertiesDone

Post Cleaning
DR3 spectrum
data study starts

06/2025

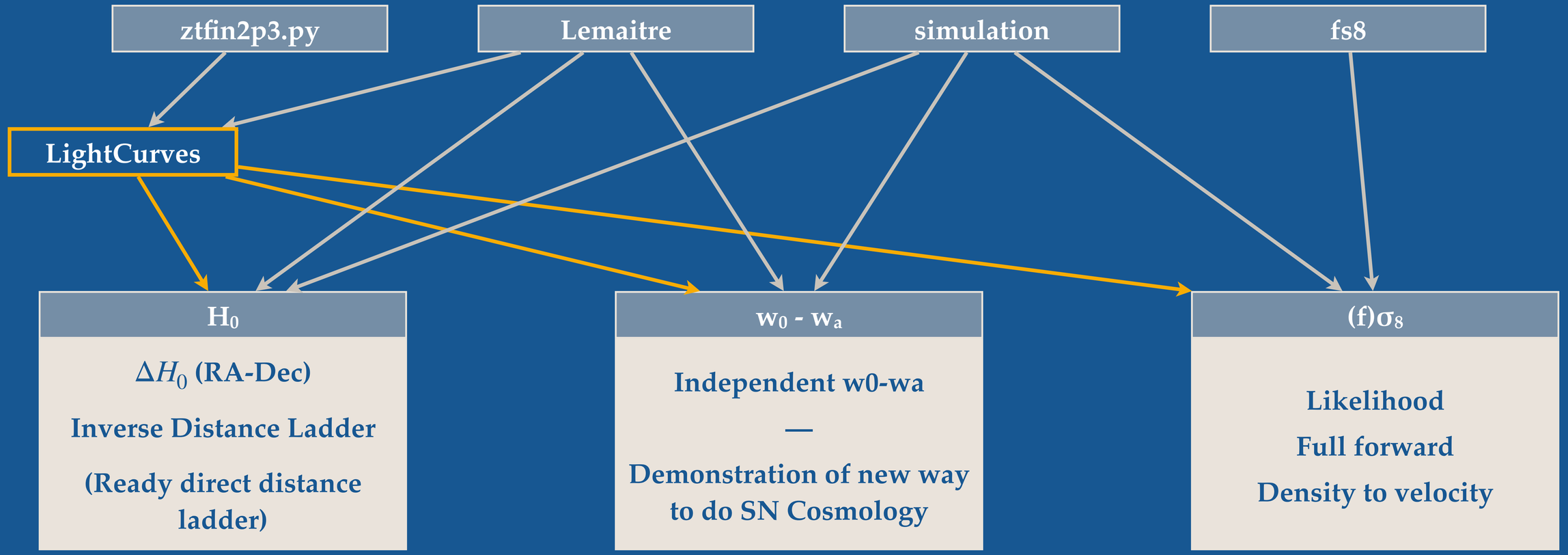
DR2.5

DR2 SNe Ia
+Subaru SNe Ia & SNLS5yr

ztfin2p3 pipeline

Scene modeling

New Inference
New "LC modeling"



D2.5 Steps
Photometry

Marie's Talk

Mathieu's Talk

Nicolas' Talk

Brodie' Talk

Sensors ✓

Pocket Effect
(Bright Fatter)

—

Field #600 validation

Time Scale: Feb 2025

Camera ✓

StarFlats
Filters (incl. Gaia)

—

Aperture photometry

Time Scale: Feb 2025

Ztfimg ✓

What is happening
Prod speed
No Science concept

—

No much details

Time Scale: Feb 2025

Ubercal ↻

Self vs. Gaia vs. PS1

—

What is missing ?

Time Scale: march 2025

LC release ↻

PSF modeling
Link with all other products.

Time Scale: march 2025

ZTF DR2.5
Lightcurves
internal release
Christmas 2024

D2.5 Papers

Simulation

Mickael's tutorial

Madeleine's Talk

Skysurvey ✓	DataChallenges ↻	SN Modeling ↻
ModelDag Technical aspect Examples	Concept of work DC1, DC2, DC3 summaries (Incl. fs8 modeling)	What we think the Underlying surveys modelling is (DC2/5)
Time Scale: Janv 2025	Time Scale: April 2025	Time Scale: June 2025

Missing 3D in SkySurvey. This is now the top priority for the Sim development.
(Help from Paris and Marseille needed)

D2.5 Papers

Methods

Mahmoud's tutorial

Dylan's Talk

D'Arcy's Talk

NaCl ✓
DC1: Methodology
Why NaCl
NaCl (simu vs. Fit)
NaCl vs. SALTx

Time Scale: Feb 2025

Selection Functions ↻
PeTS (SN selection)
Redshifts
Host Information
Photo-Typing

Time Scale: May 2025

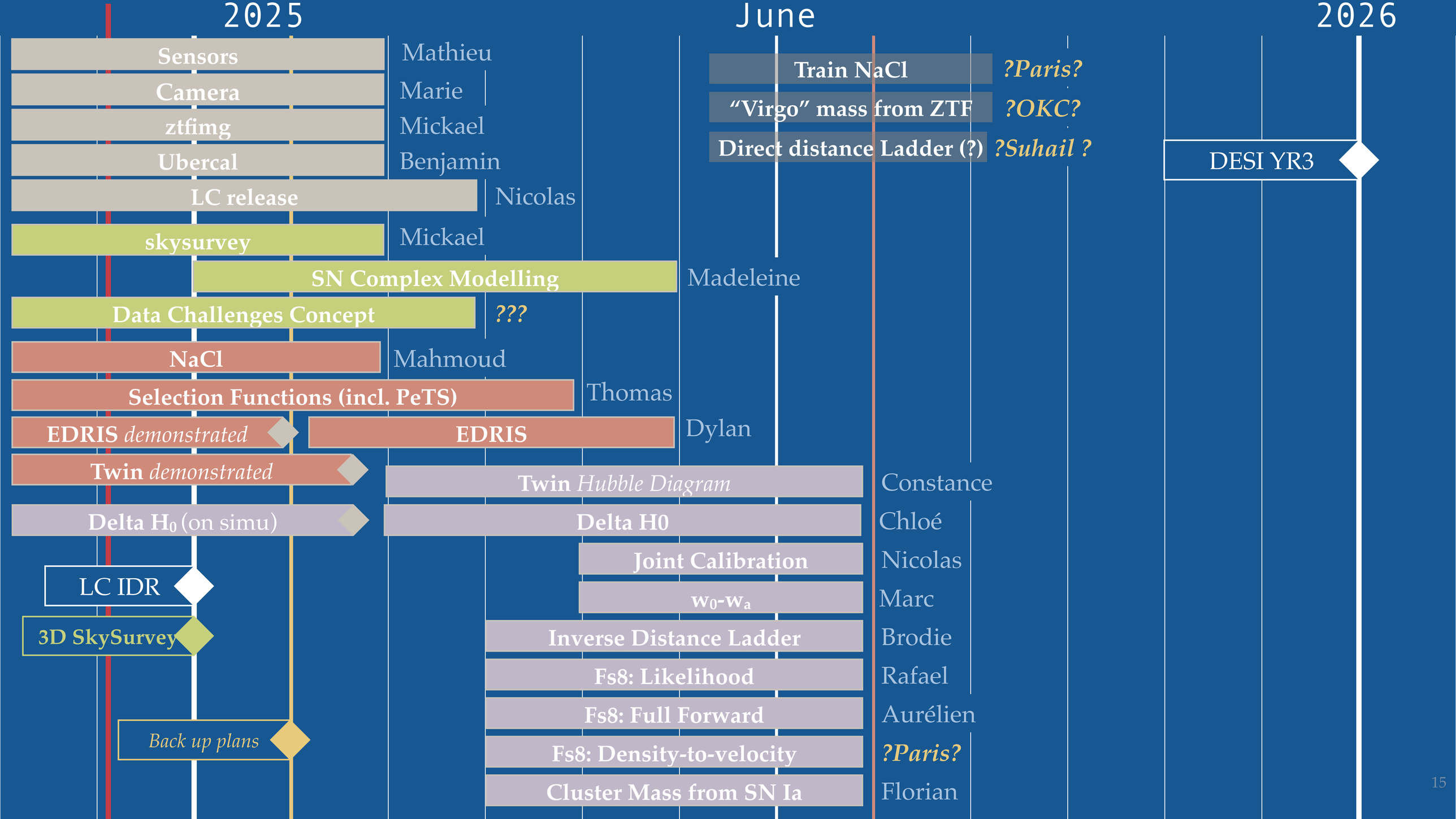
Photo-Typing. To be checked

Host Info uniformity. Support needed

Edris ↻
How does this work
Why Edris
—
Demonstrated on DC2

Time Scale: June 2025

Core worry to me


2025
June
2026
Sensors
Mathieu
Camera
Marie
ztfimg
Mickael
Ubercal
Benjamin
LC release
Nicolas
skysurvey
Mickael
SN Complex Modelling
Madeleine
Data Challenges Concept
???
NaCl
Mahmoud
Selection Functions (incl. PeTS)
Thomas
EDRIS demonstrated
EDRIS
Dylan
Twin demonstrated
Twin Hubble Diagram
Constance
Delta H0 (on simu)
Delta H0
Chloé
Joint Calibration
Nicolas
w0-wa
Marc
LC IDR
3D SkySurvey
Inverse Distance Ladder
Brodie
Fs8: Likelihood
Rafael
Fs8: Full Forward
Aurélien
Back up plans
Fs8: Density-to-velocity
?Paris?
Cluster Mass from SN Ia
Florian
Train NaCl
?Paris?
"Virgo" mass from ZTF
?OKC?
Direct distance Ladder (?)
?Suhail ?
DESI YR3

ZTF Cosmology Science Working Group

Photometrically typed SNe Ia

30 000

15 000

Spectroscopically typed SNe Ia

9 000

6 000

3 000

ZTF I

ZTF II

ZTF 04

ZTF 04++

LSST

→Rolling

03/2018

2019 2020 2021 2022 2023 2024 2025 2026 2027

“Lemaitre”

DR2.5

Summer 2025

Extensions to be planned

DR2 SN Ia (Spectro) SNLS 5yr (Spectro) Subaru (Photo)

~3500 SN Ia → H_0 | w_0, w_a | $f\sigma_8$

New photometry, simulations & inference

DR3

Fall 2026

O(10k) SN Ia (Spectro)

Hypergal | sub-classifications

A.I. for SN spectro study (e.g. twins)

O(30k) SN Ia (Photo)

Sampled definition

A.I. for Photo-typing

$f\sigma_8$: Likely the baseline for more than a decade

w_0, w_a : The LSST / Roman era anchoring sample

This will be the legacy ZTF SN Ia sample