Observation:

Optical and Infrared Transients

Mickael **Rigault** | **Cargèse** | **28th of May 2019**

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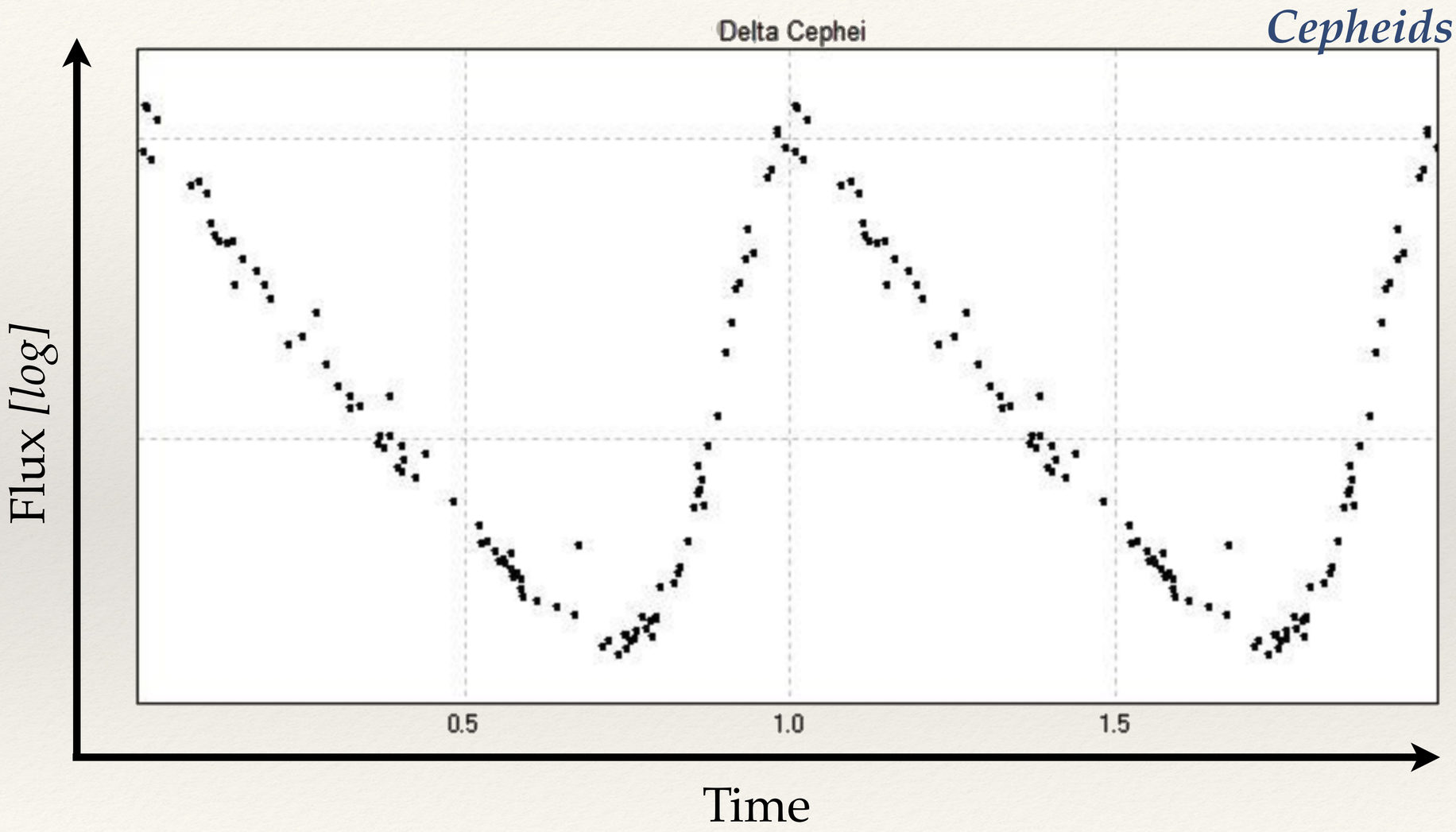
Light Curves

Light Curves



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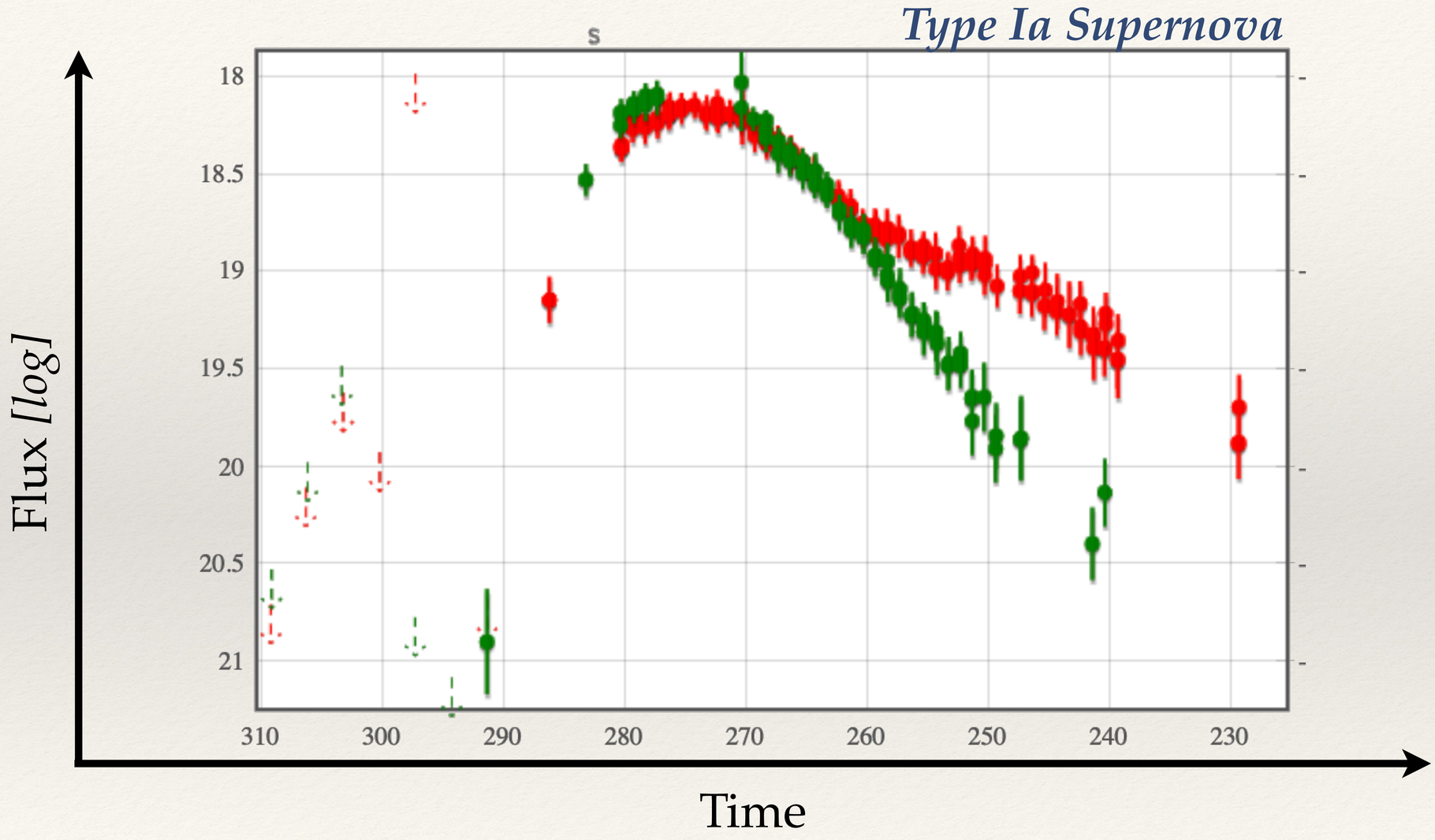
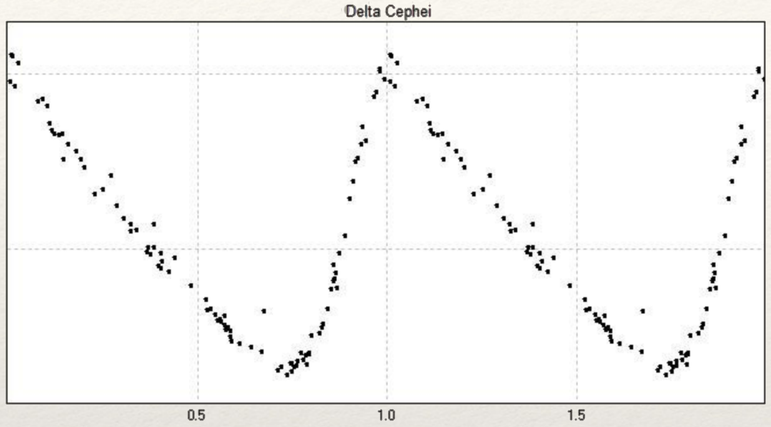


Transients | *Explosion or not*

Non-Exploding



Variable stars
Cepheids, RRLyra, etc

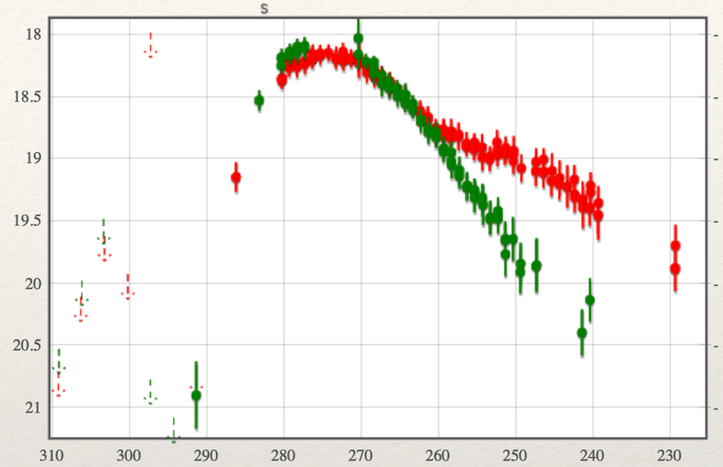
Moving objects

Cataclysmic Variables *or Nova**

Active Galaxy Nucleus *(AGN)**

…

Exploding



Supernovae
Thermonuclear or core collapse

Super Luminous Supernova

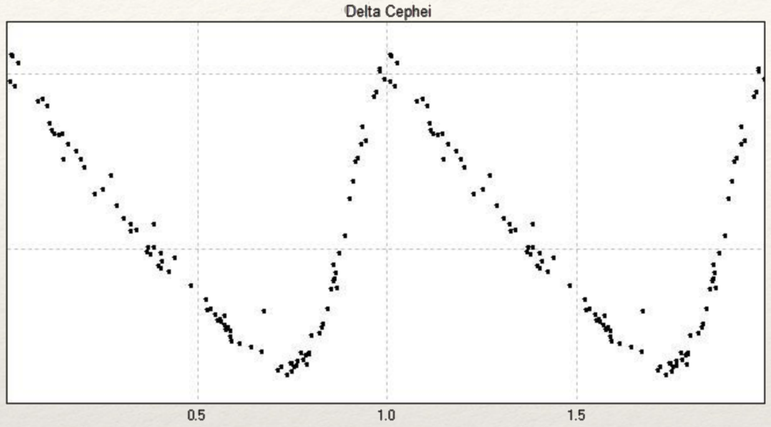
Tidal Tail disruption events (TDE)

Kilonova

…

Transients | *Explosion or not*

Non-Exploding



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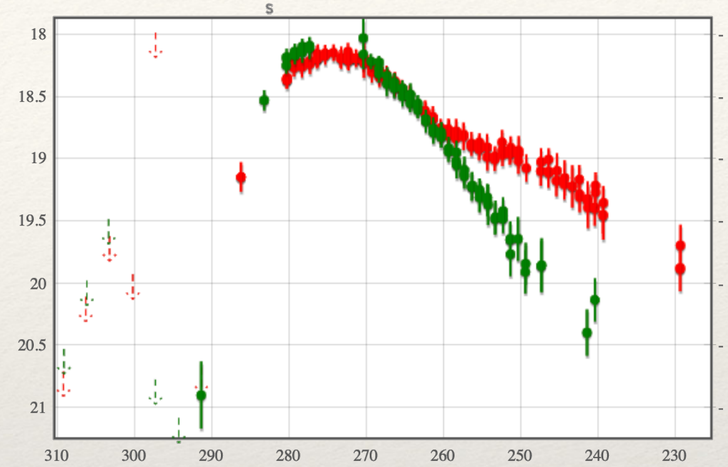

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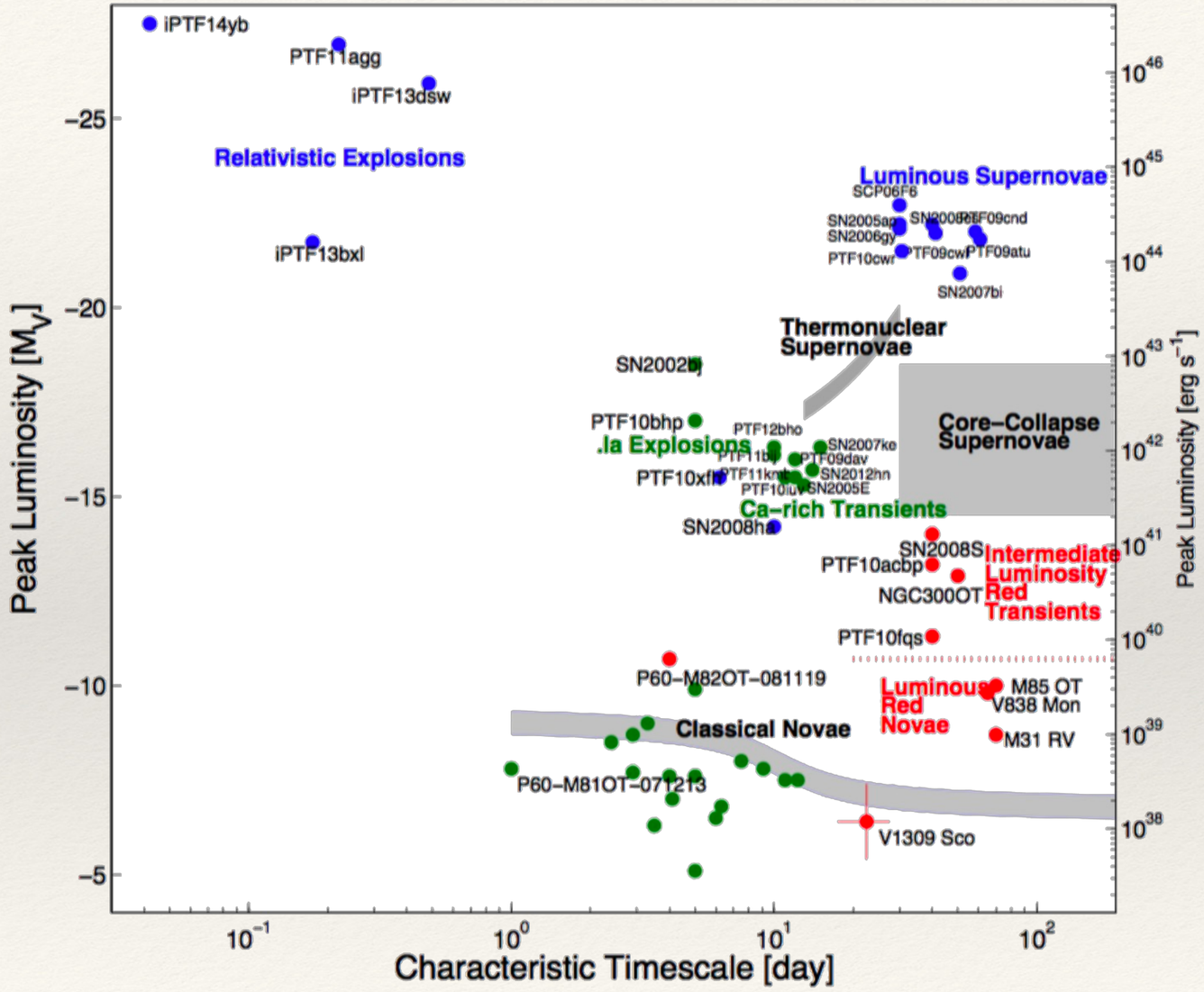
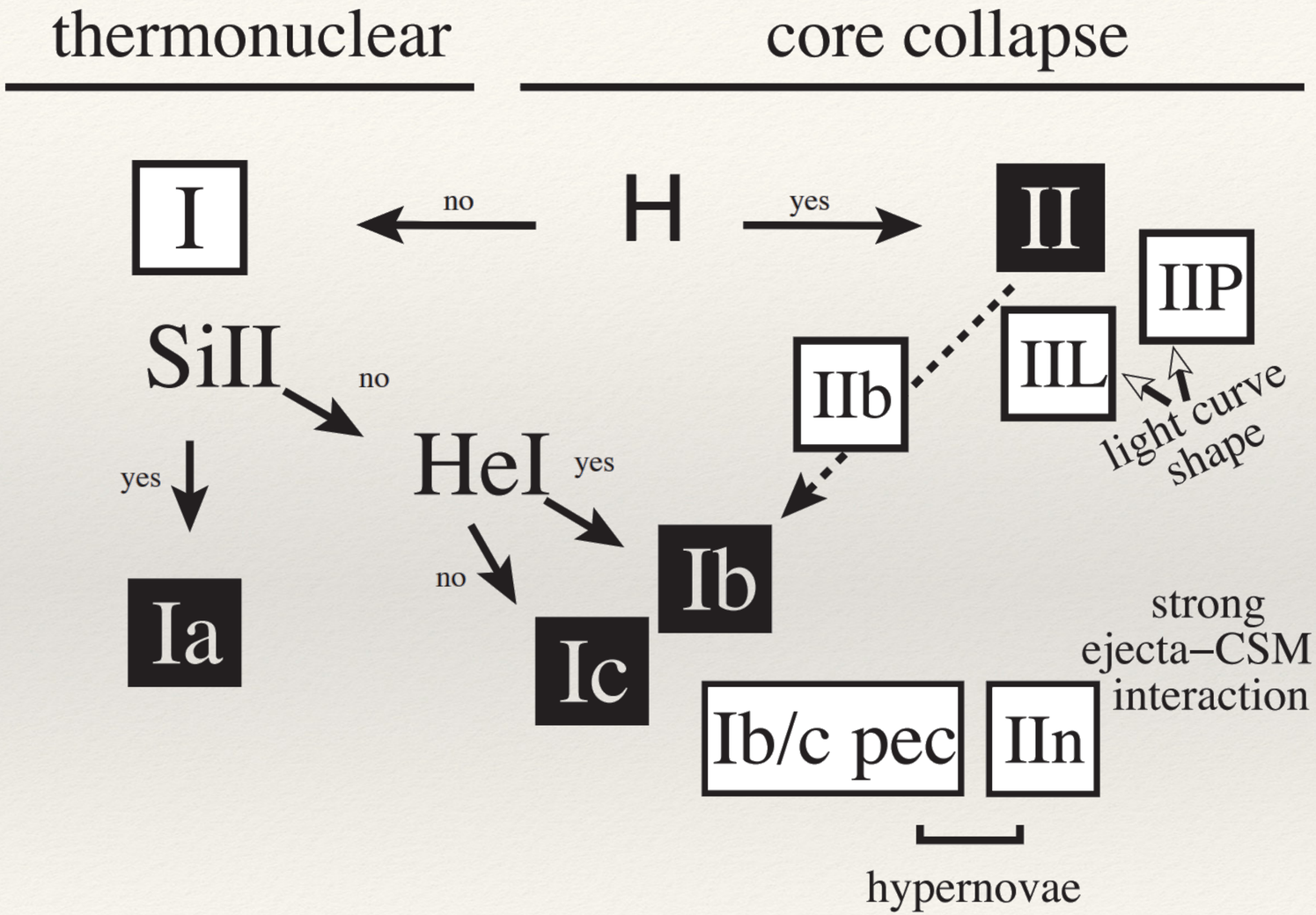
Time and Brightness



Supernovae

Time Scale: 1 week/month
Brightness: -15 / -20 mag



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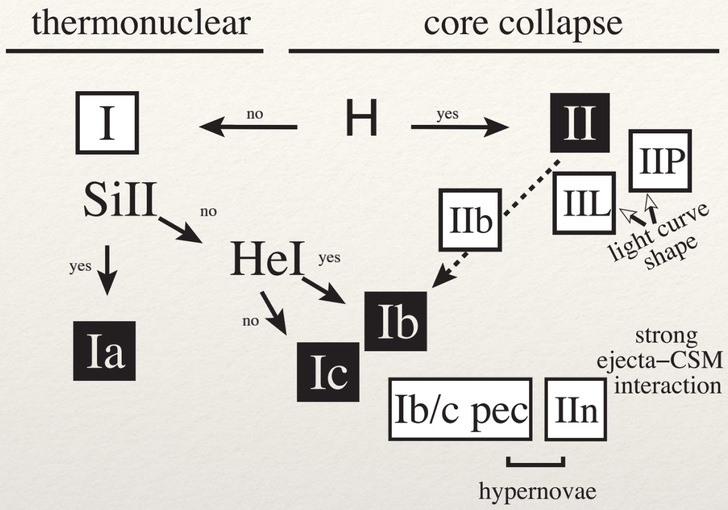

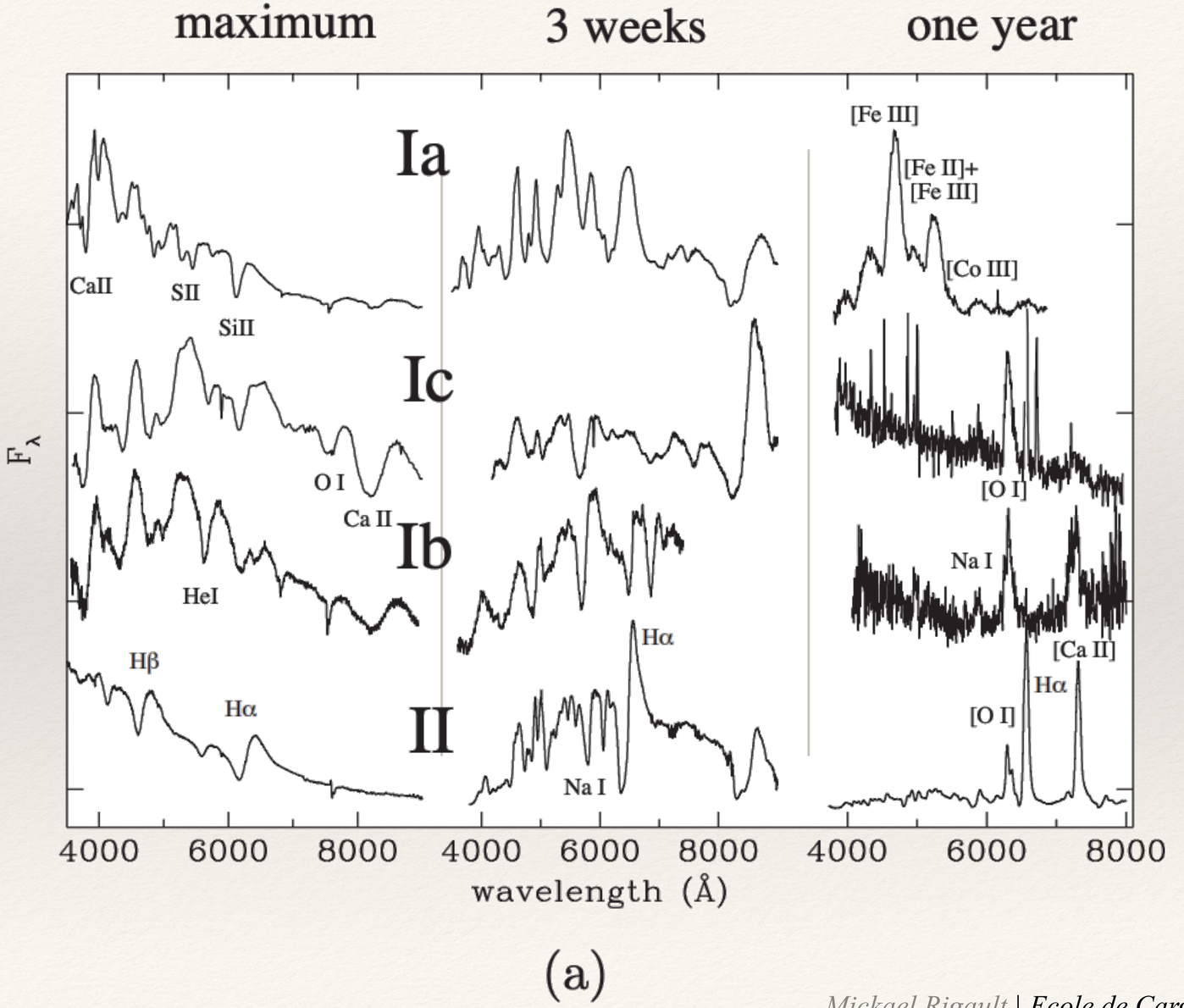

(a)

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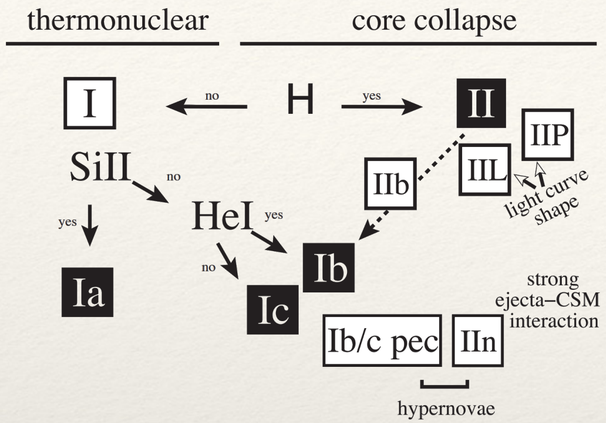
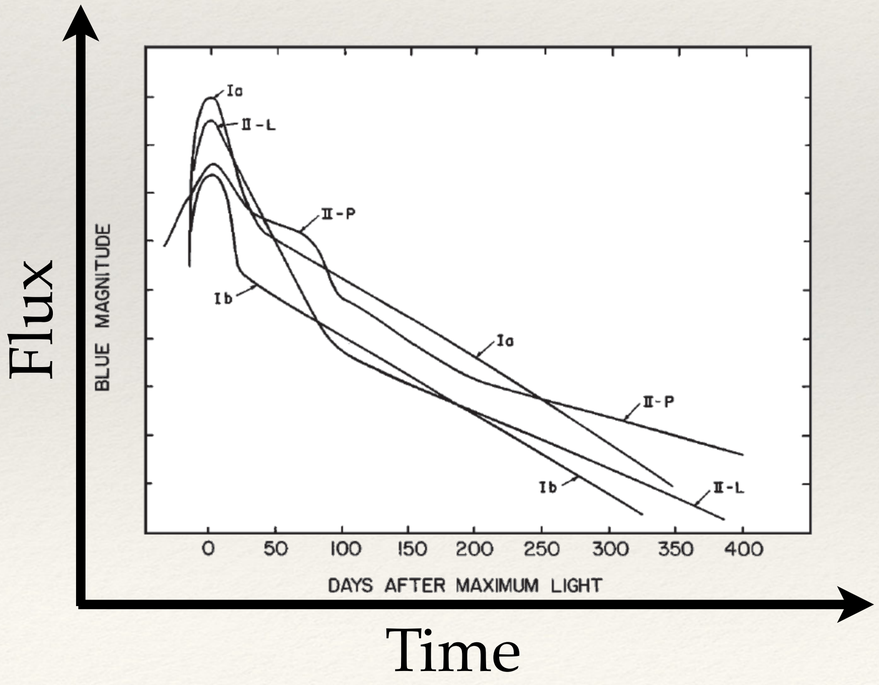
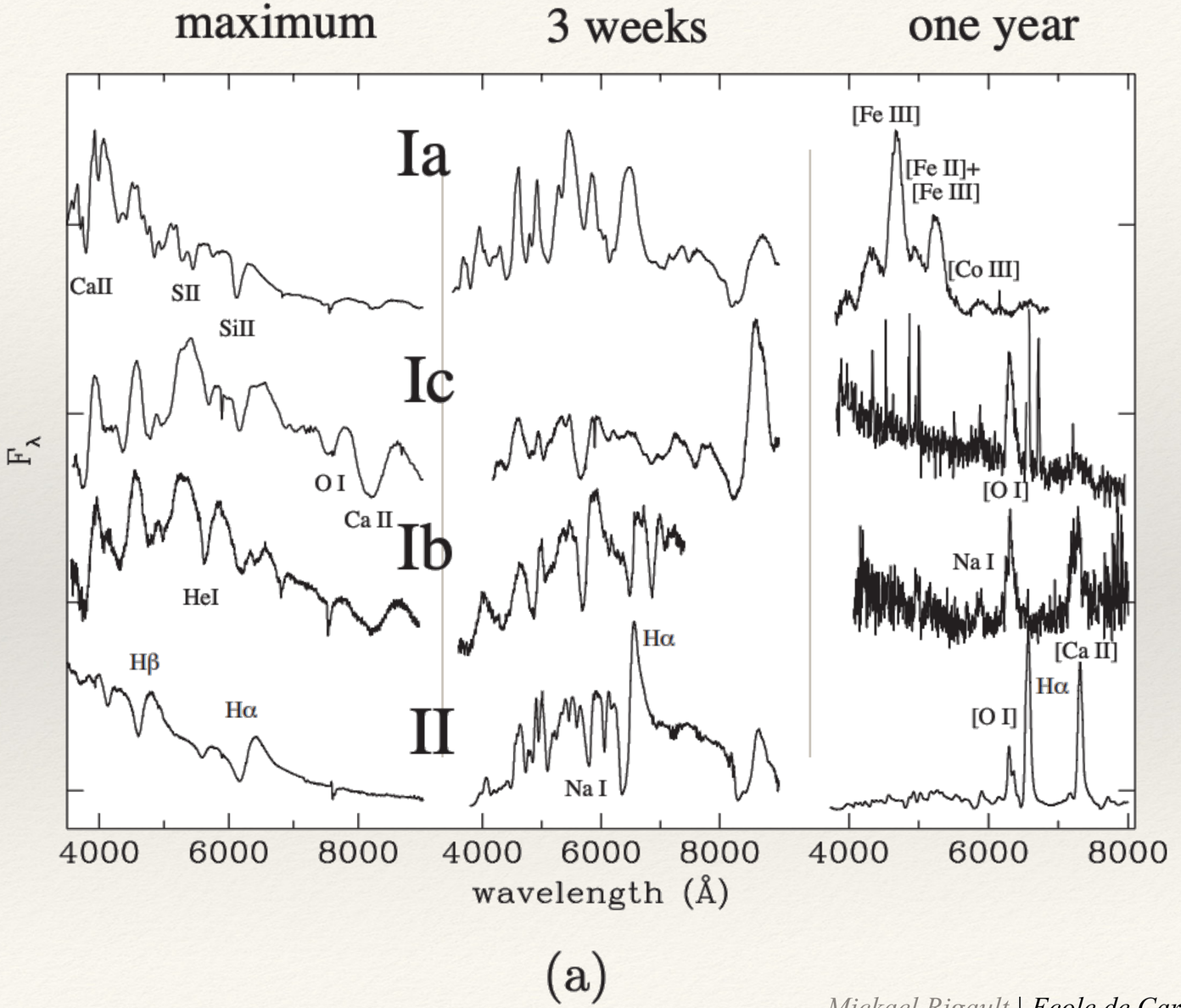
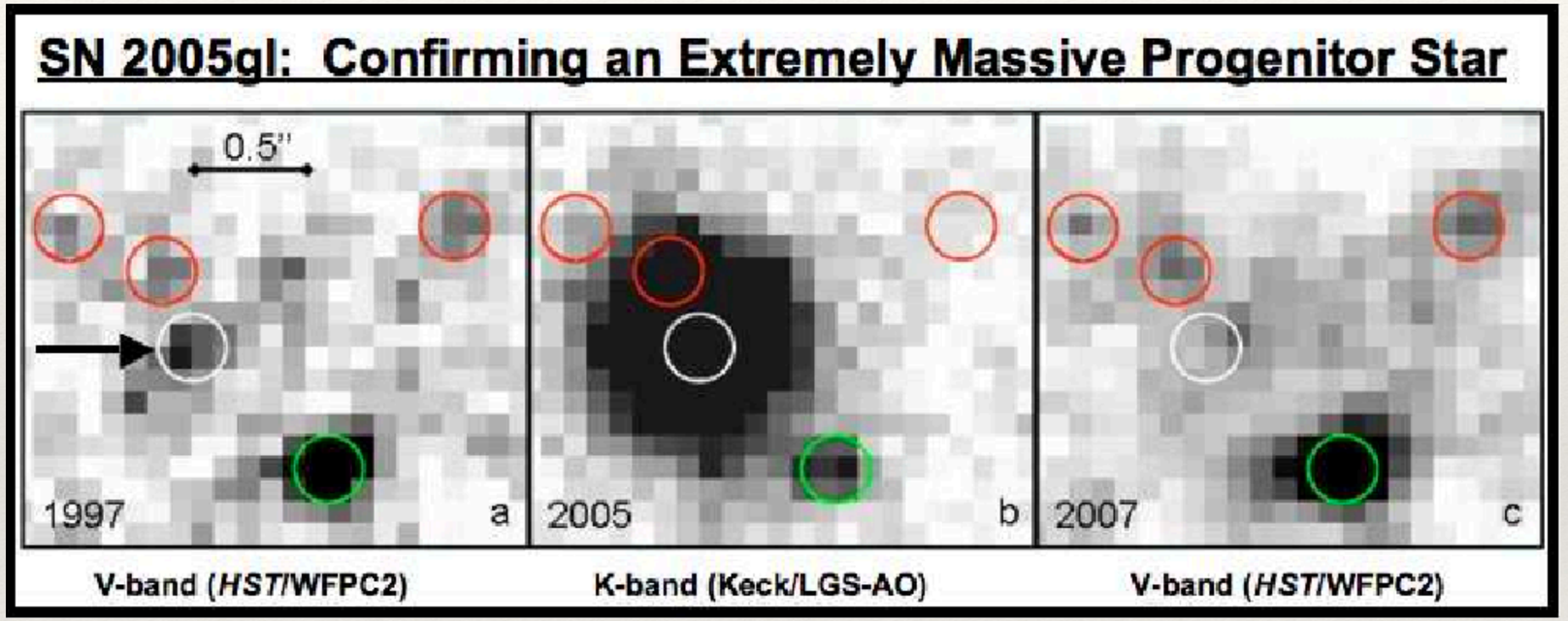






Core Collapse SNe

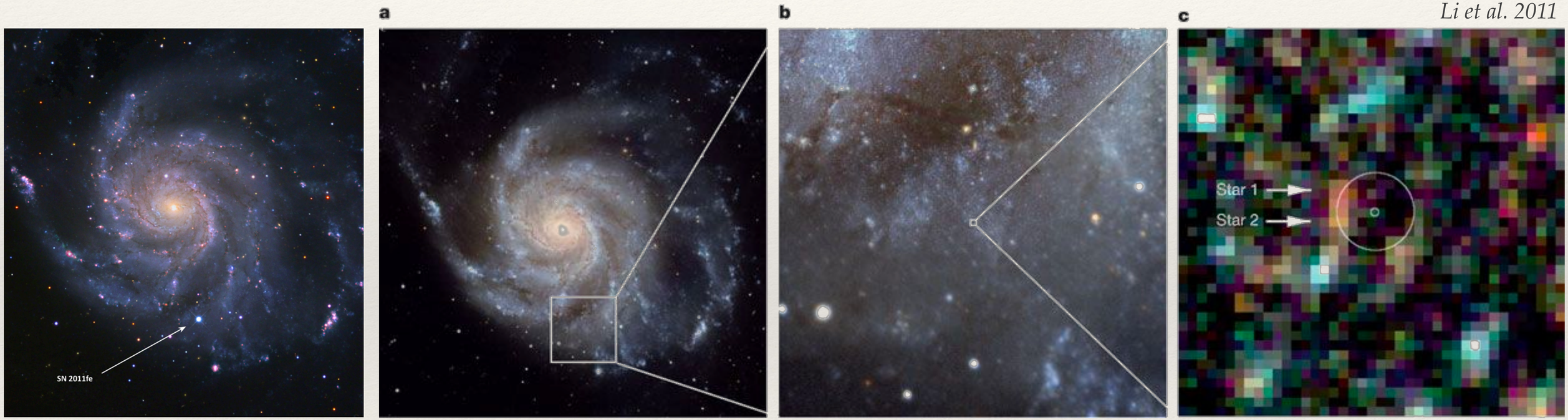
$M>8\ M_{\odot}$



Type Ia Supernovae

$M<8\ M_{\odot}$

Li et al. 2011



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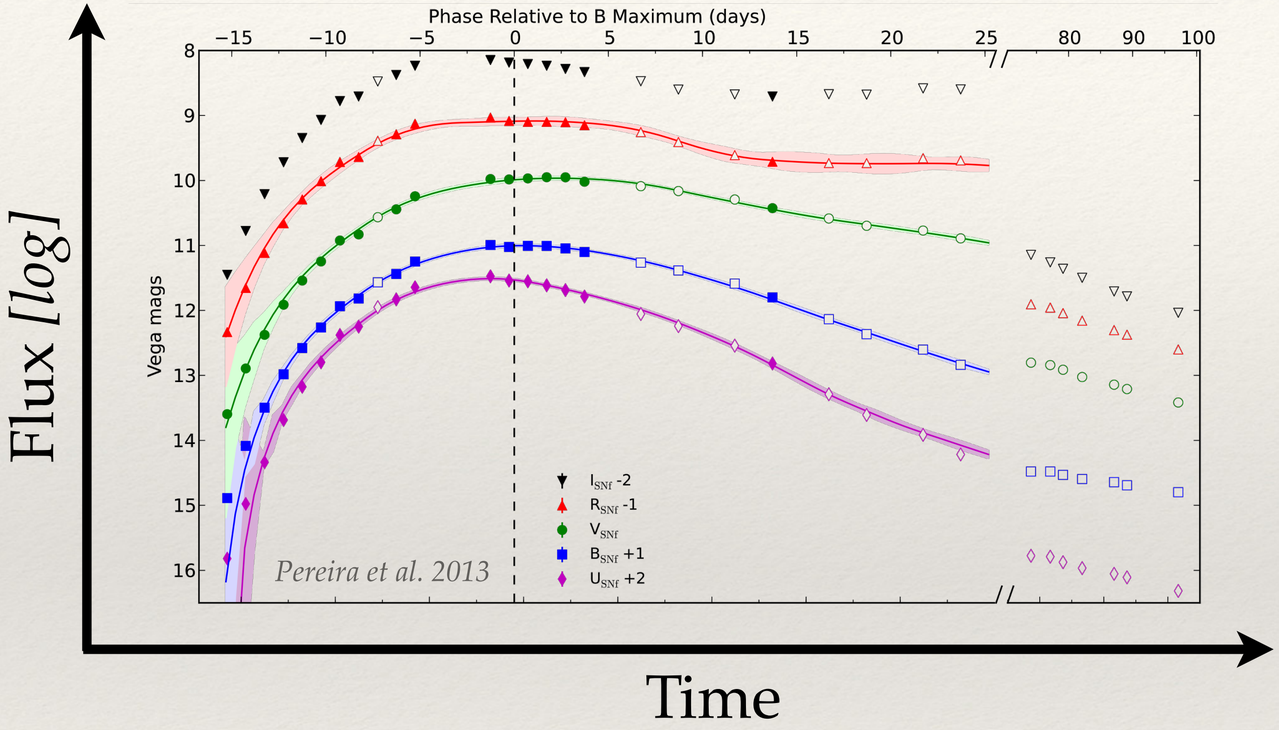
— A Standard Candle for Cosmology —



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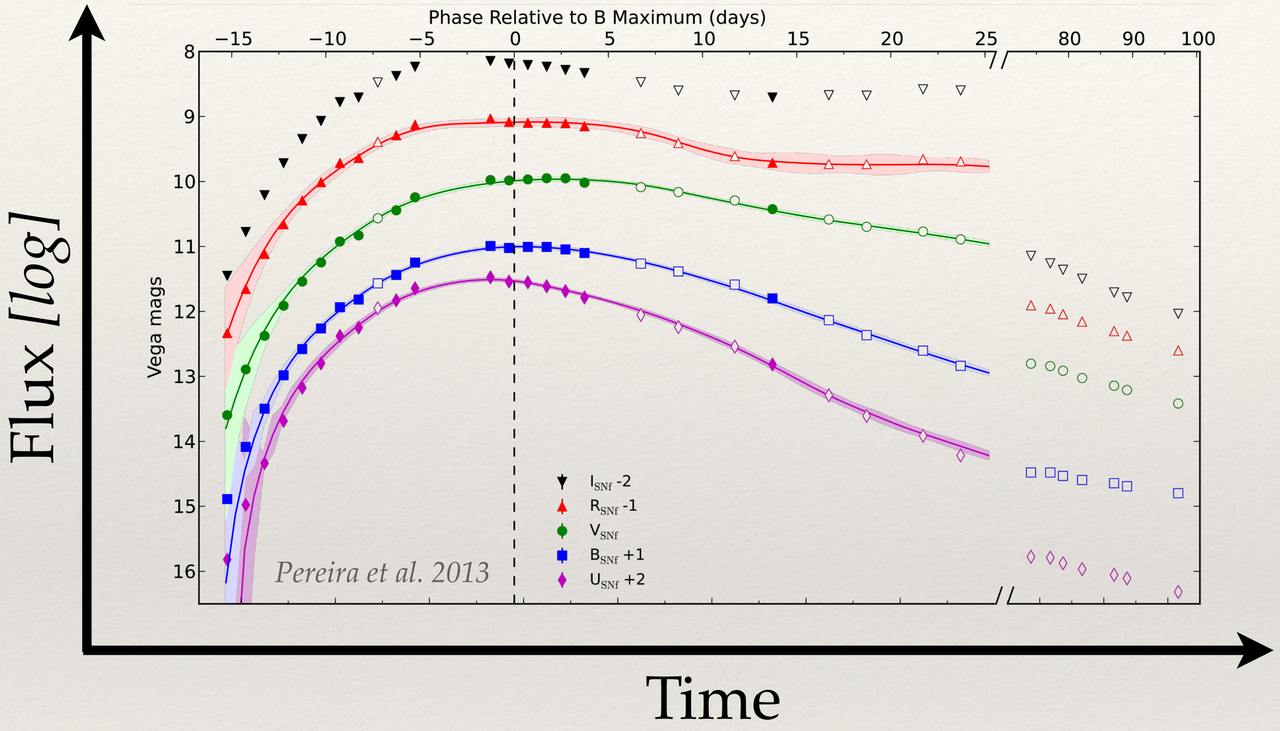

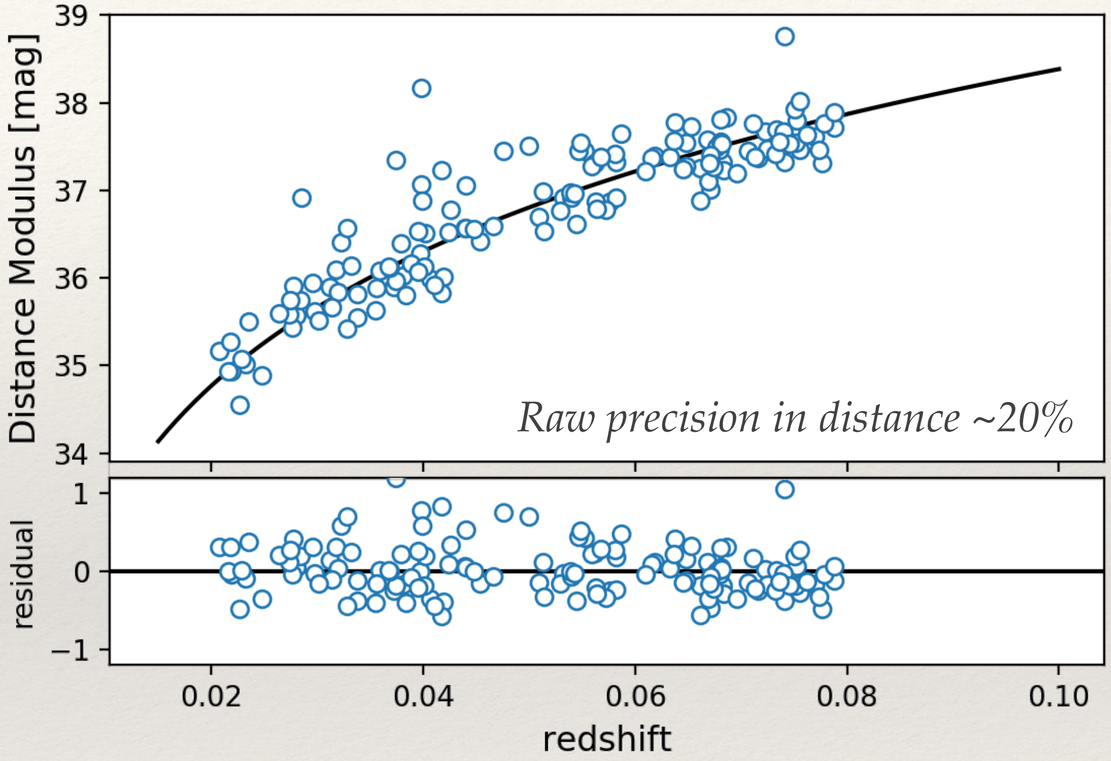

& Really bright (~galaxy, i.e. ~10^{10} Suns)

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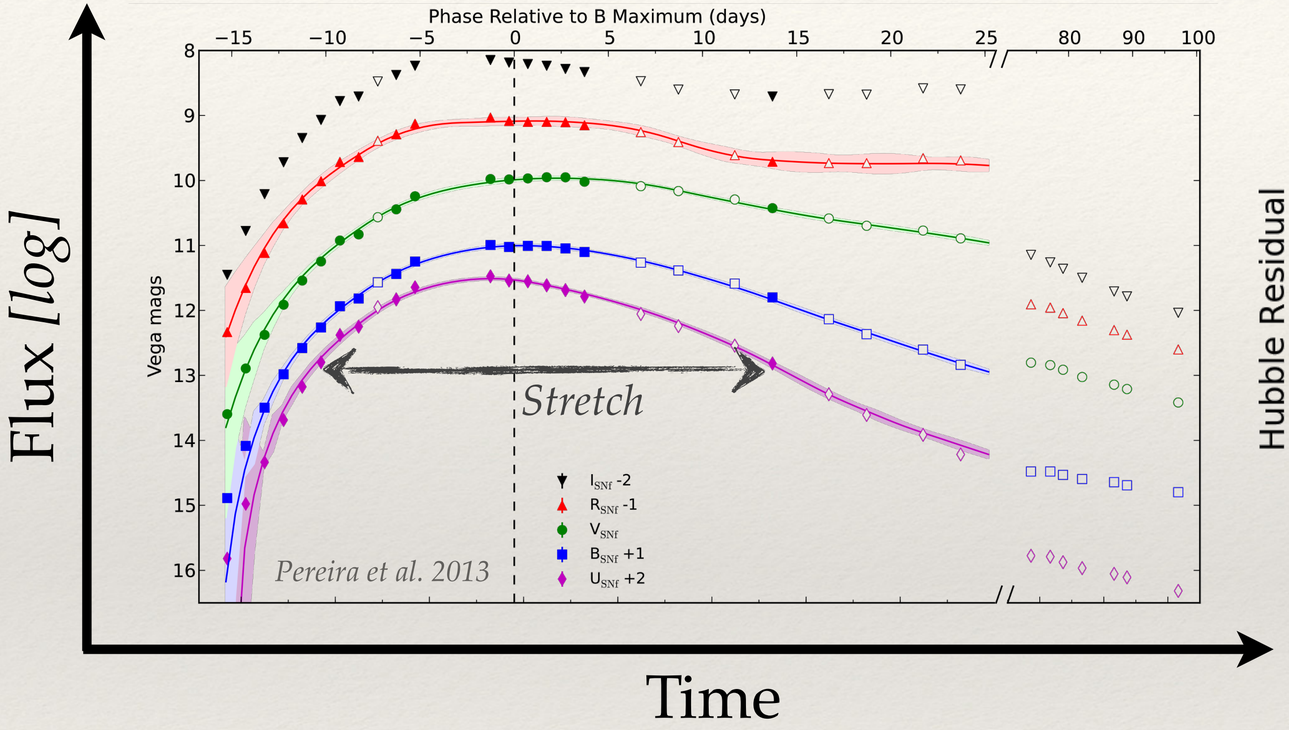

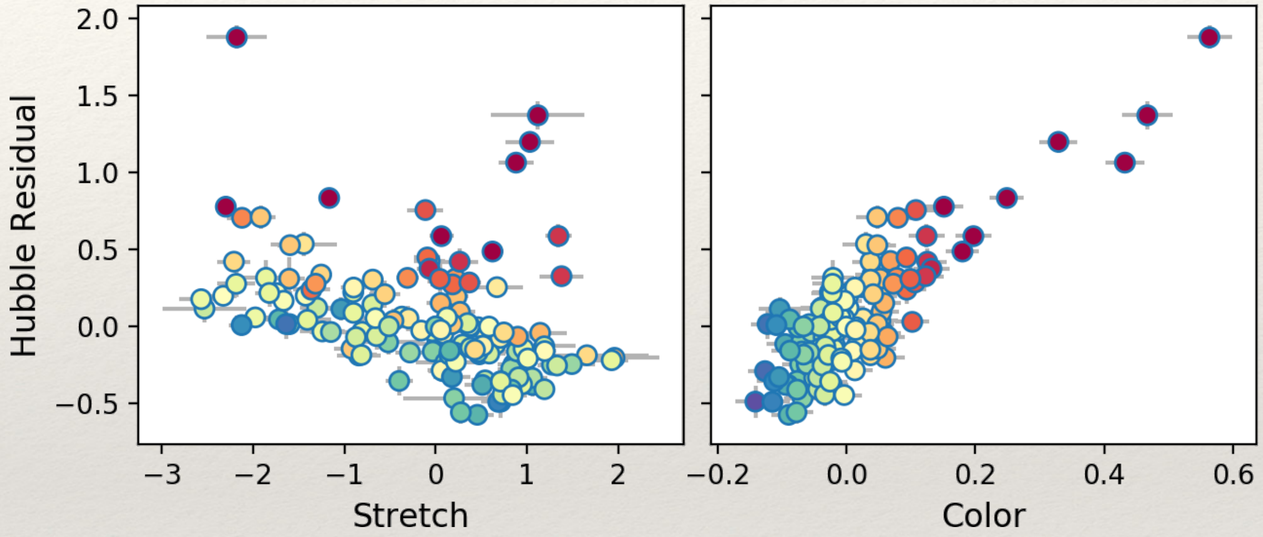

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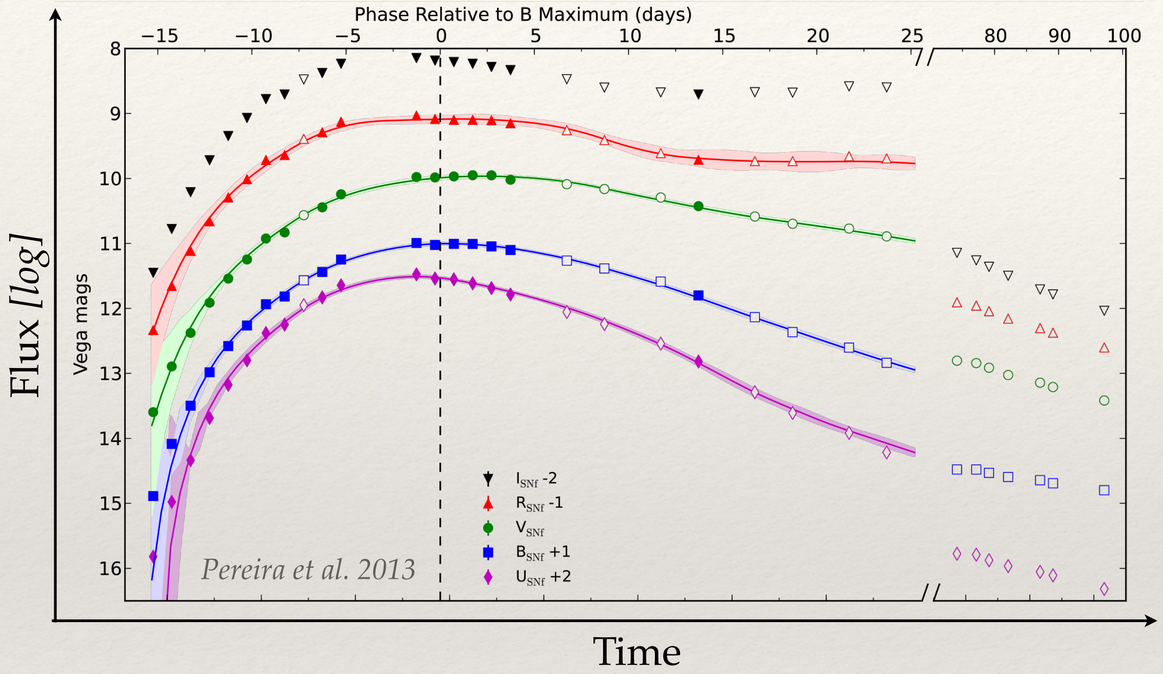

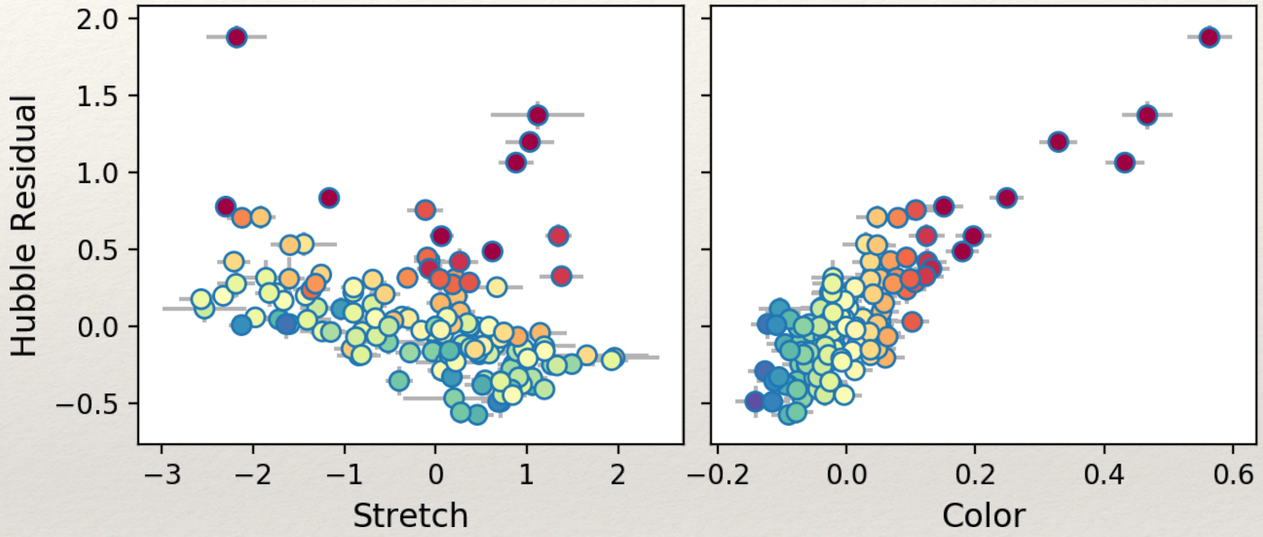

SN parameters | *Lightcurve magnitude in B at max* | *Lightcurve Stretch* | *Lightcurve Color*

Standardised Magnitude

$$\mu = m_B - M + (\alpha x_1 - \beta c)$$

Type Ia Supernovae

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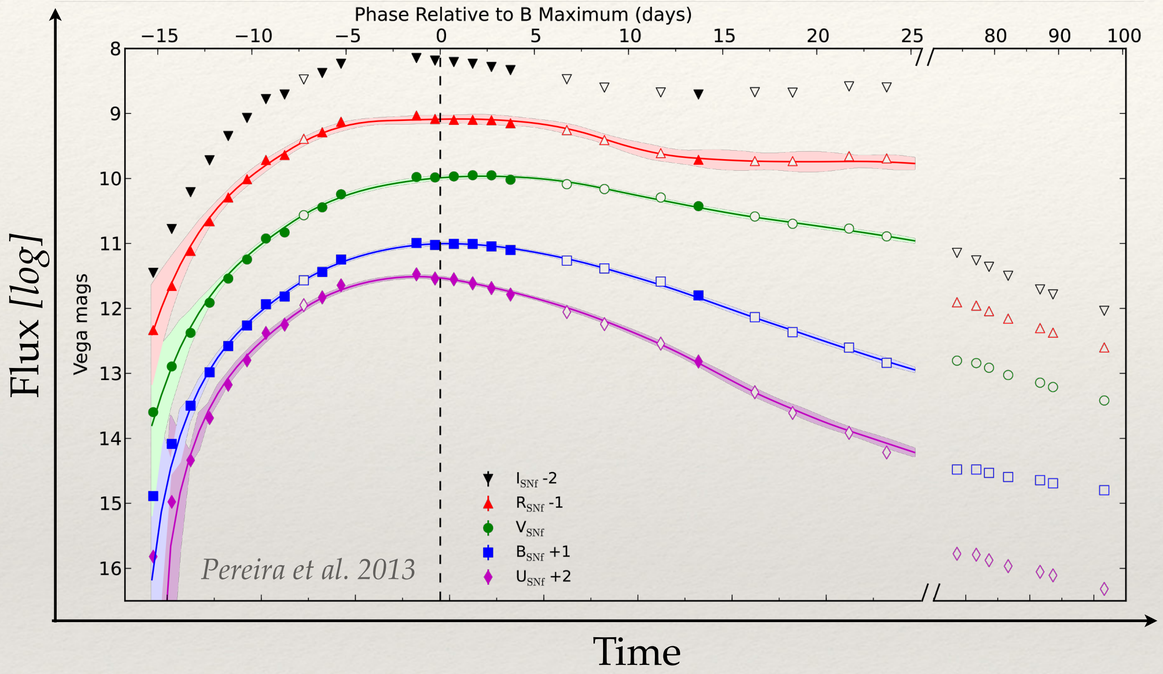

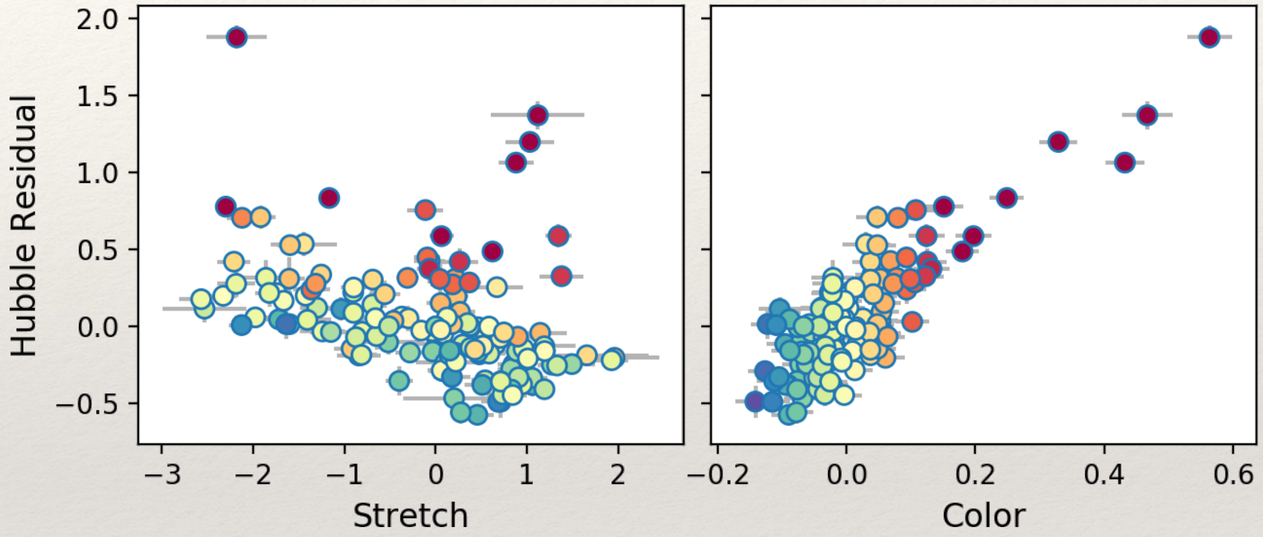

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Absolute Relation | SN magnitude — "Stretch-low" — "Color-low"

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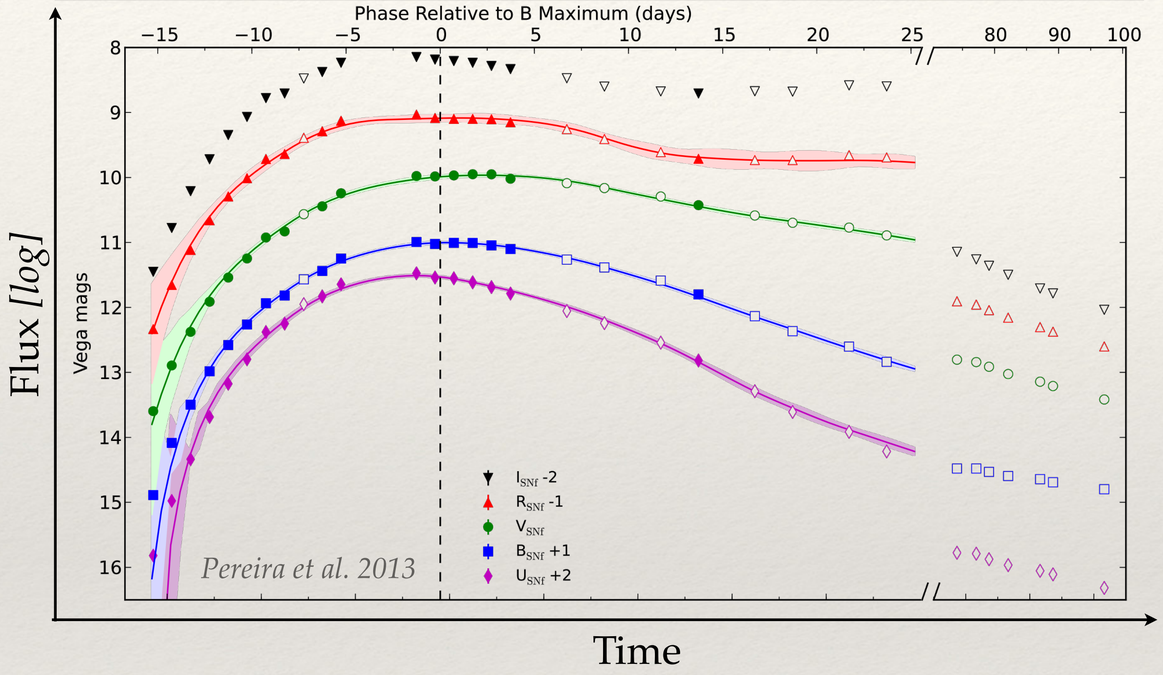

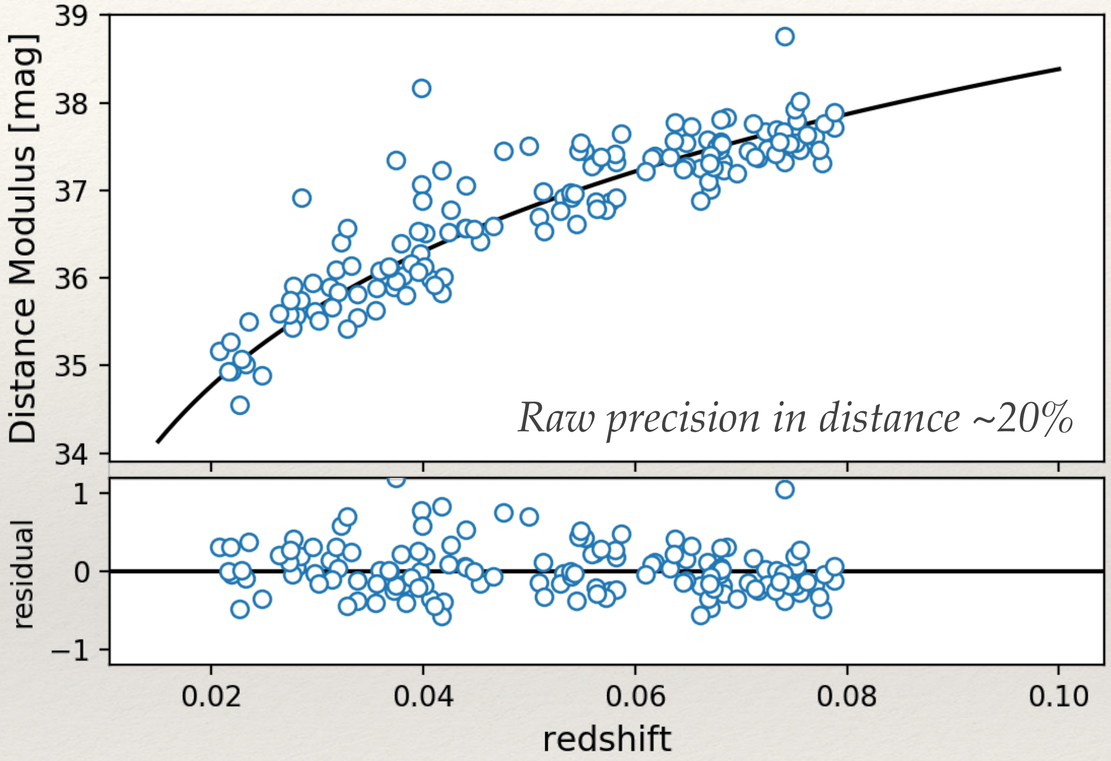

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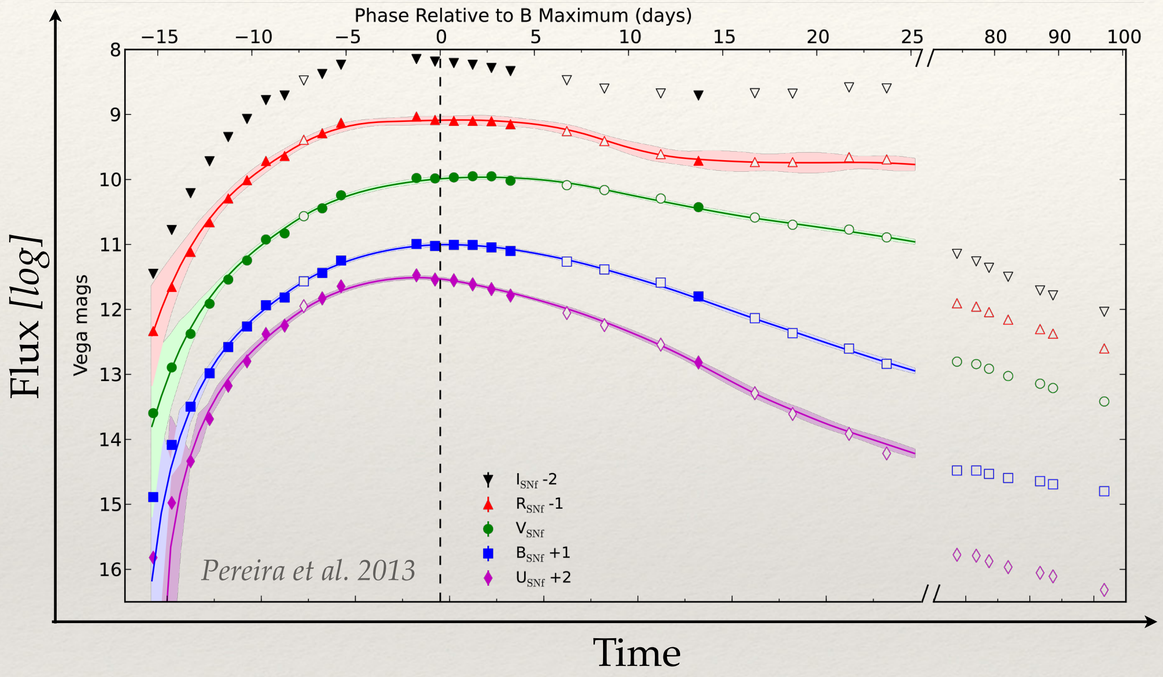

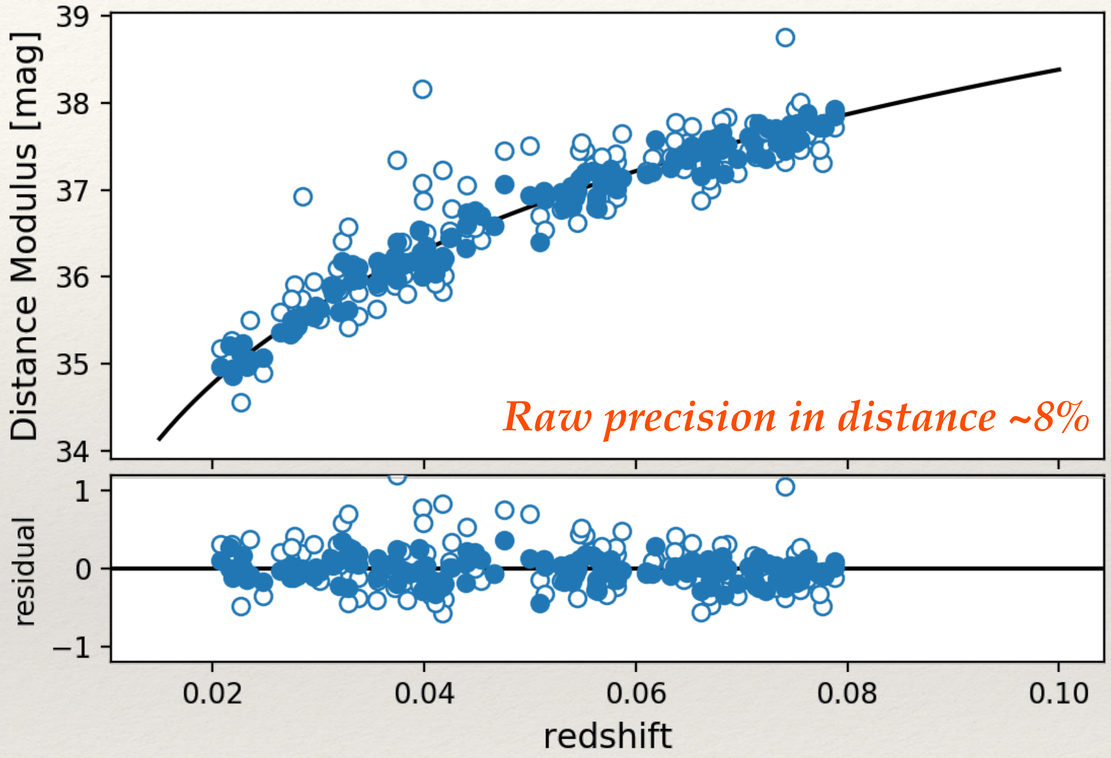

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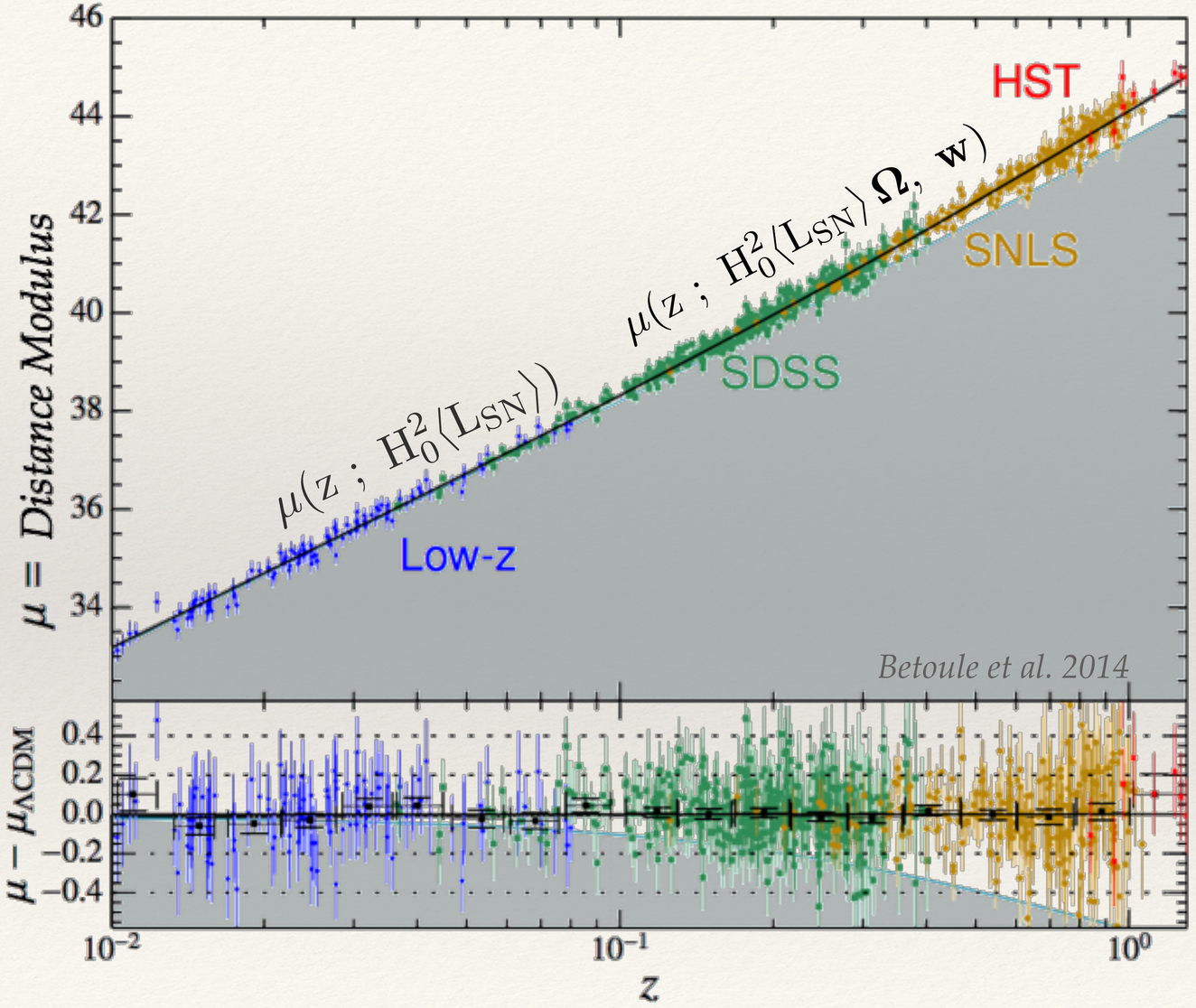


$\Omega_m = 0.295$
$\Omega_\Lambda = 0.705$

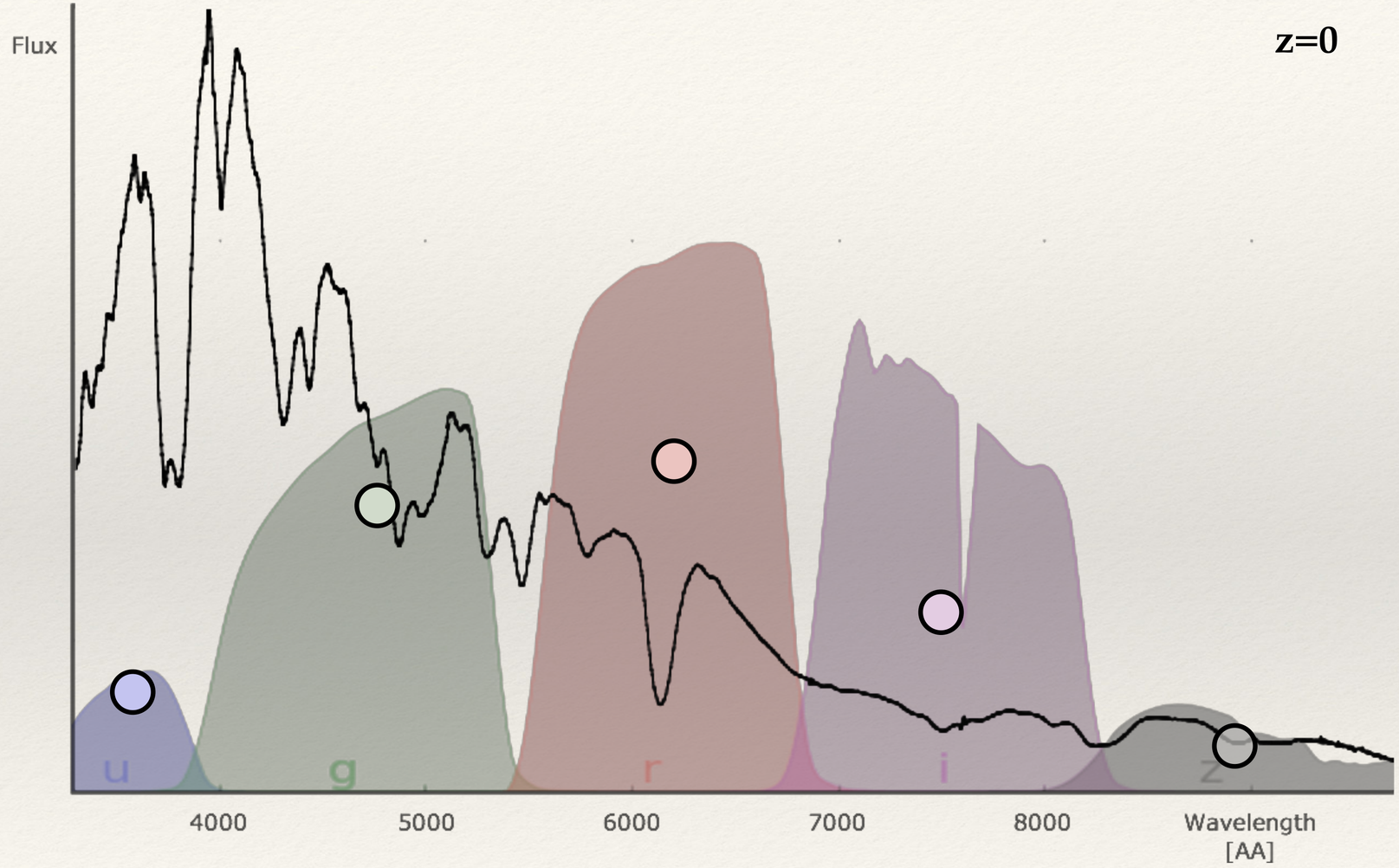
$\Omega_m = 1$
$\Omega_\Lambda = 0$

~70% Dark Energy

~30% matter

Observations | *it's all about details*

— K-correction —



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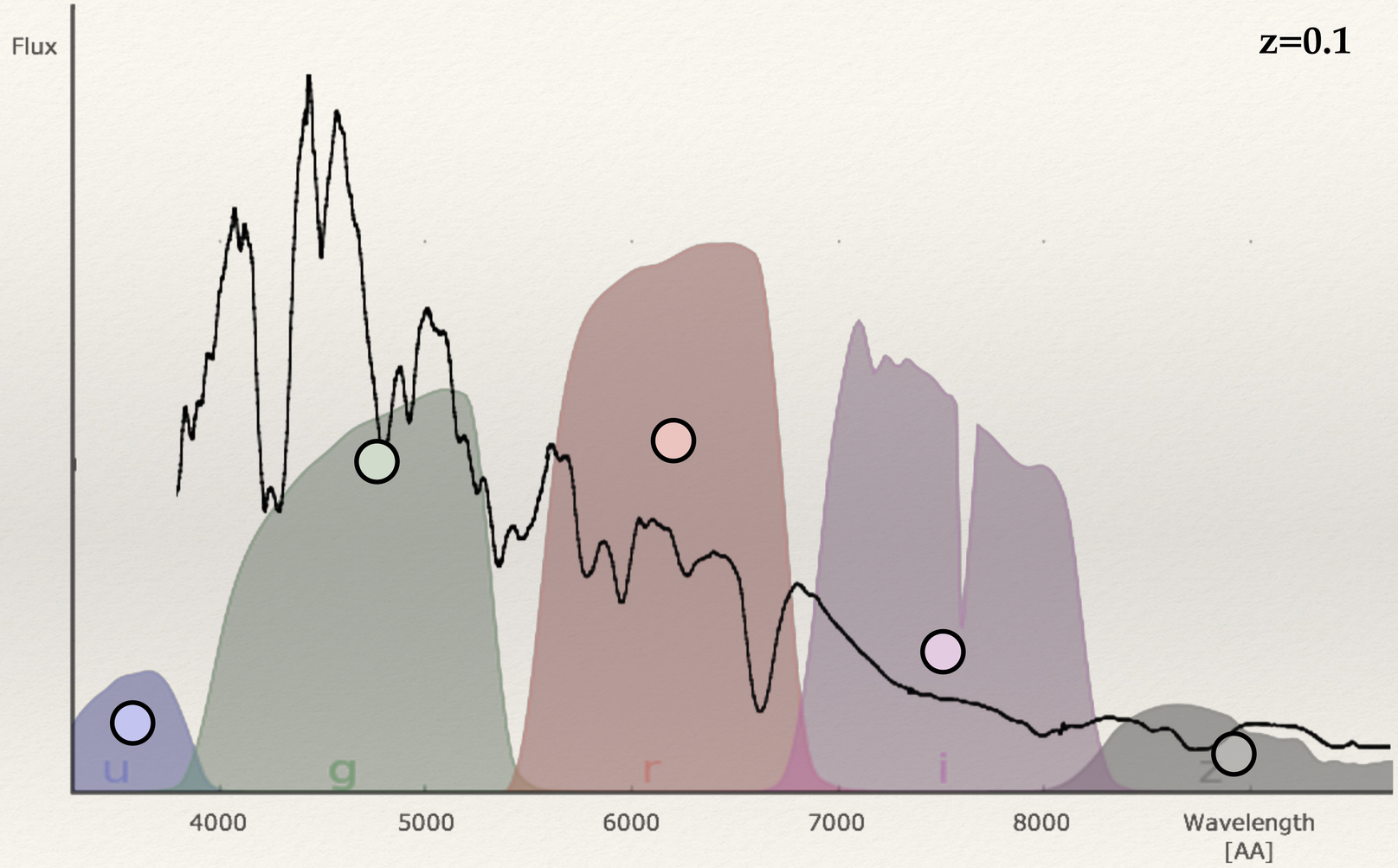

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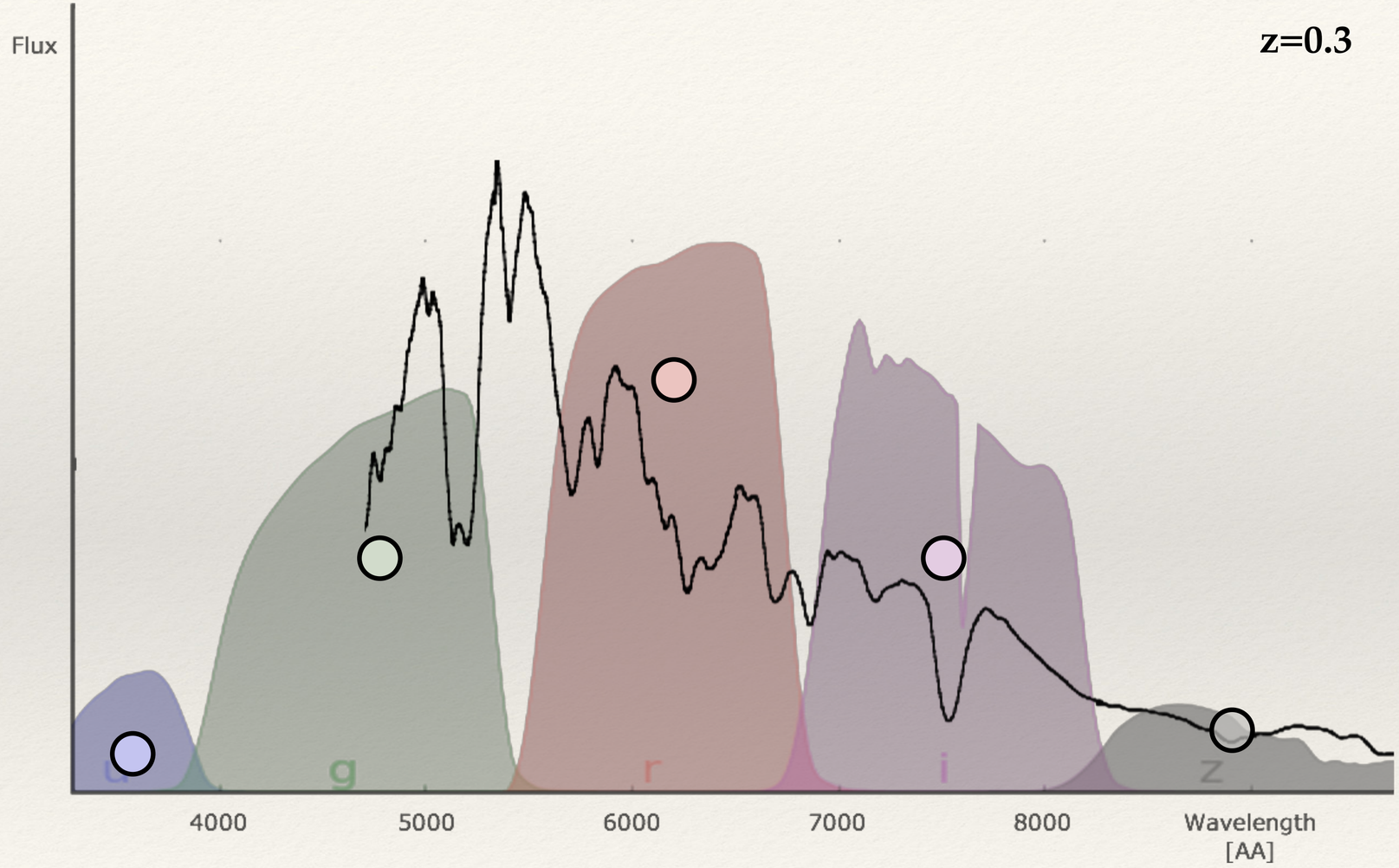

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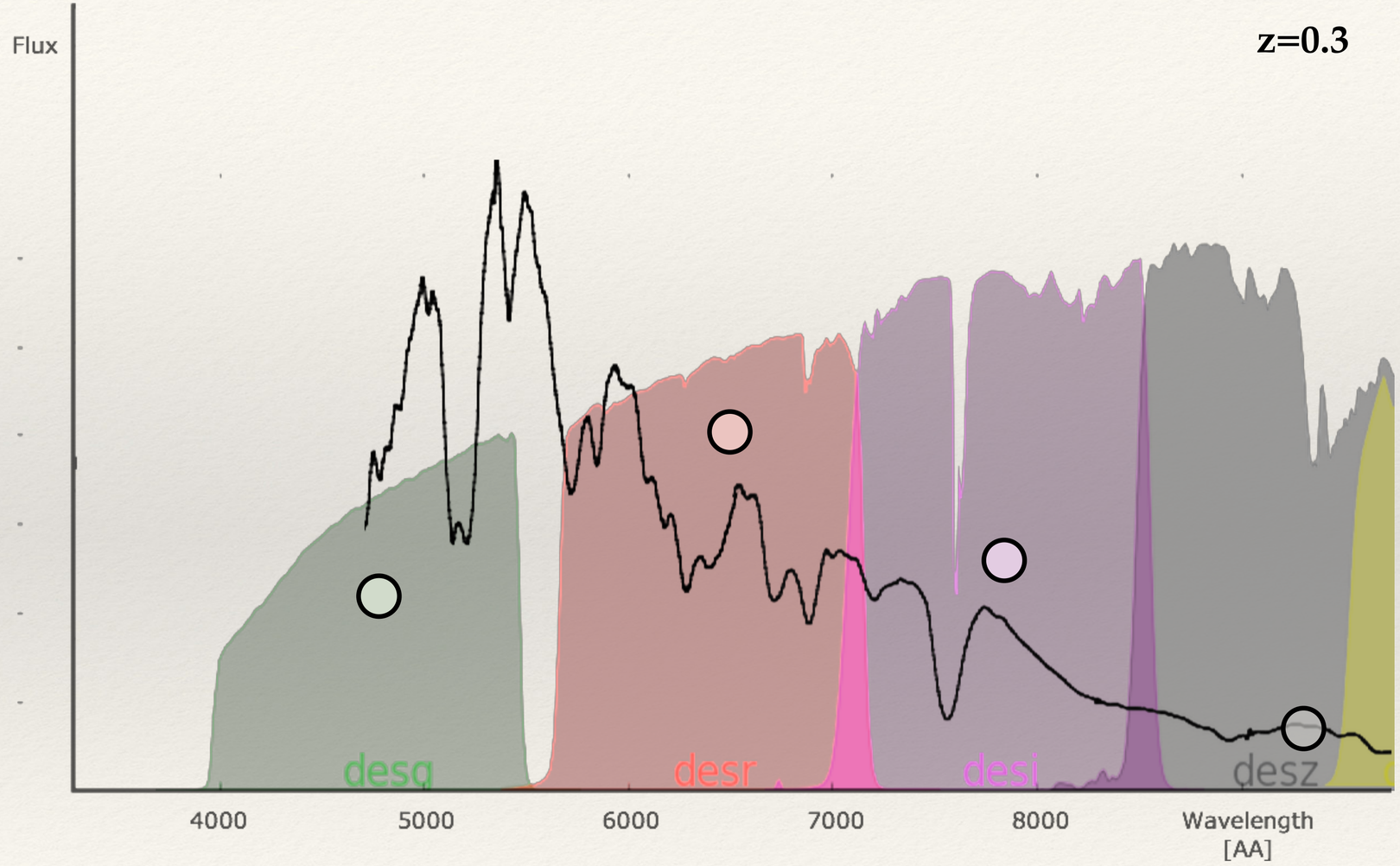
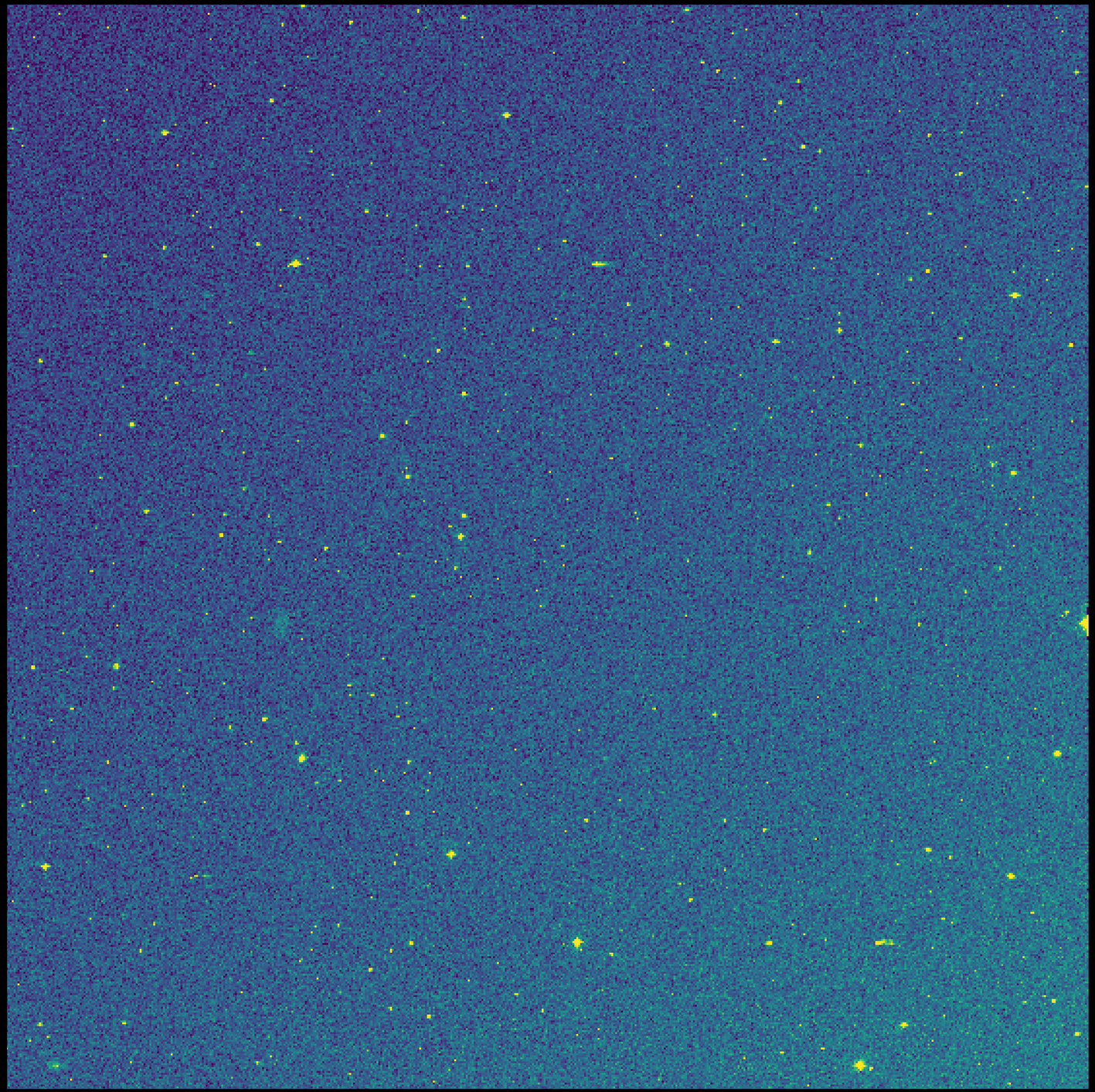
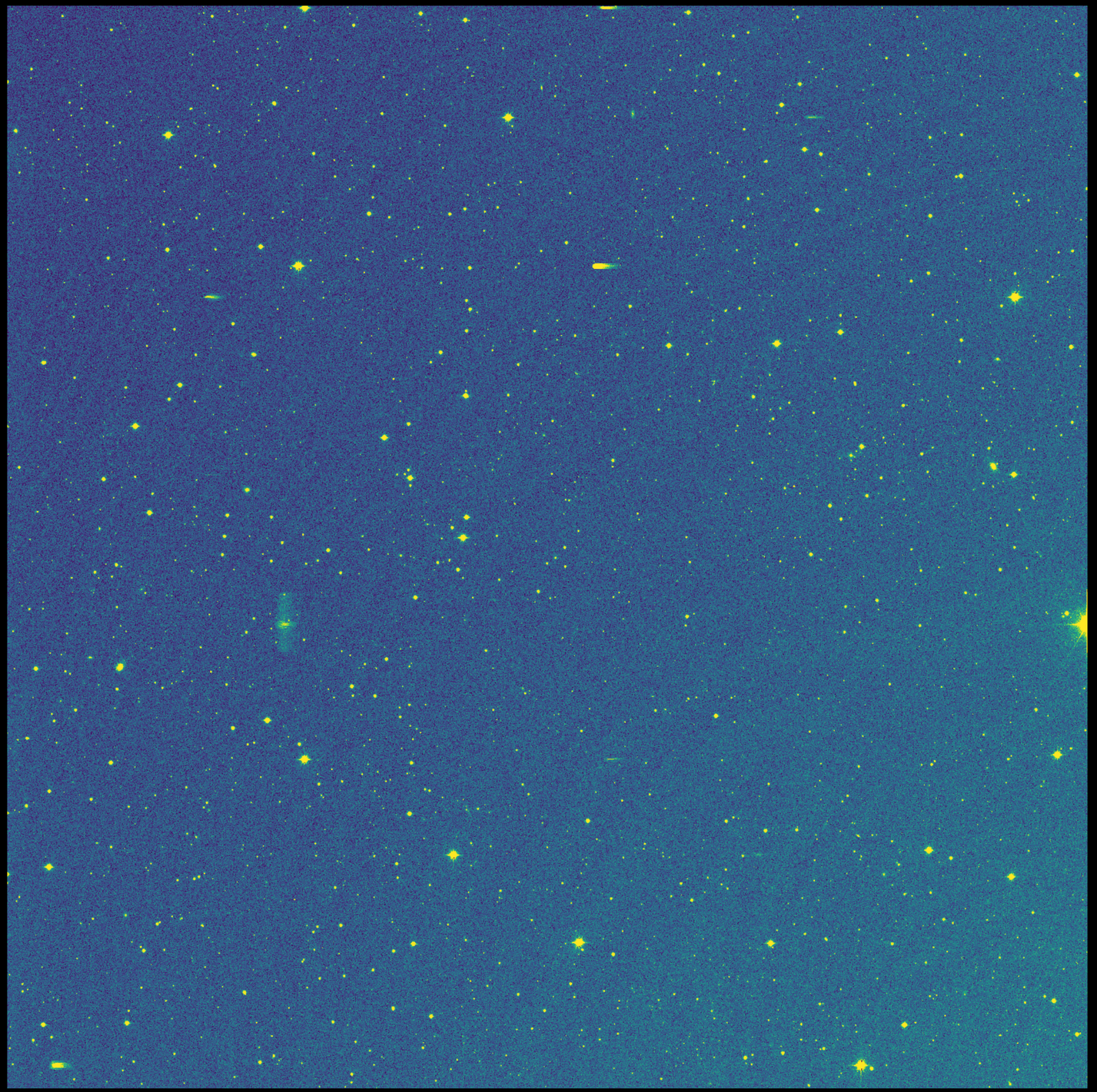
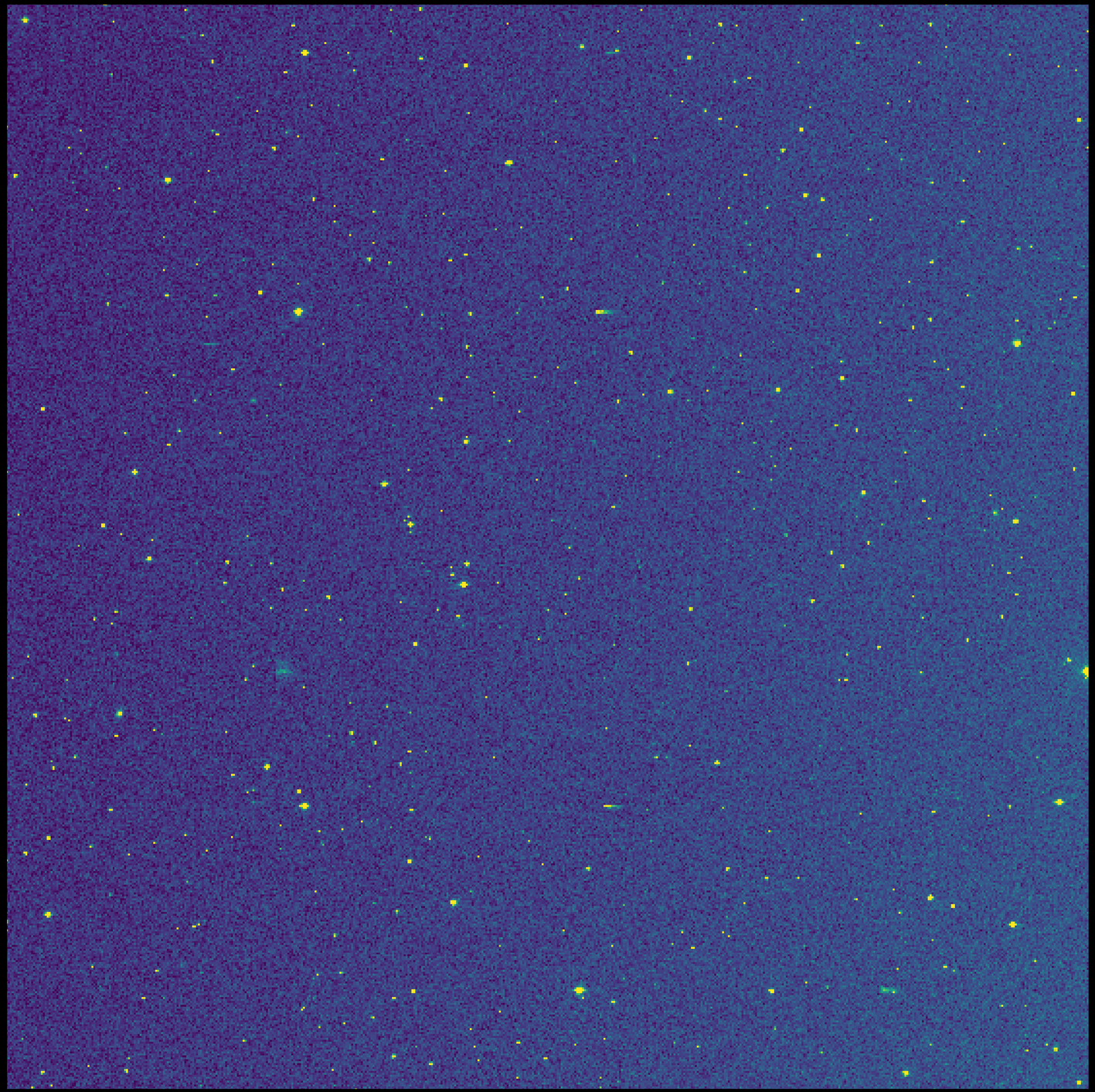
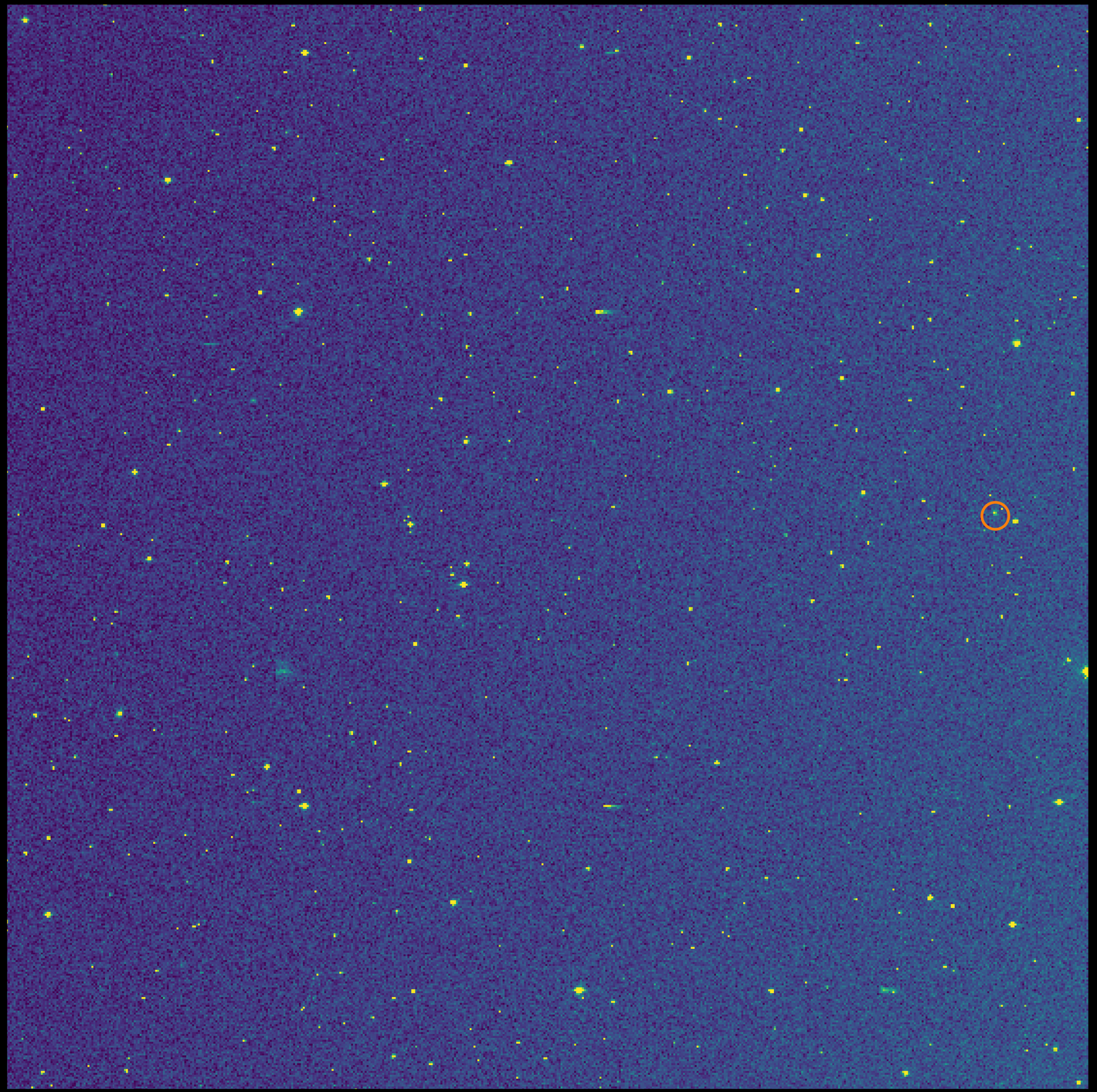


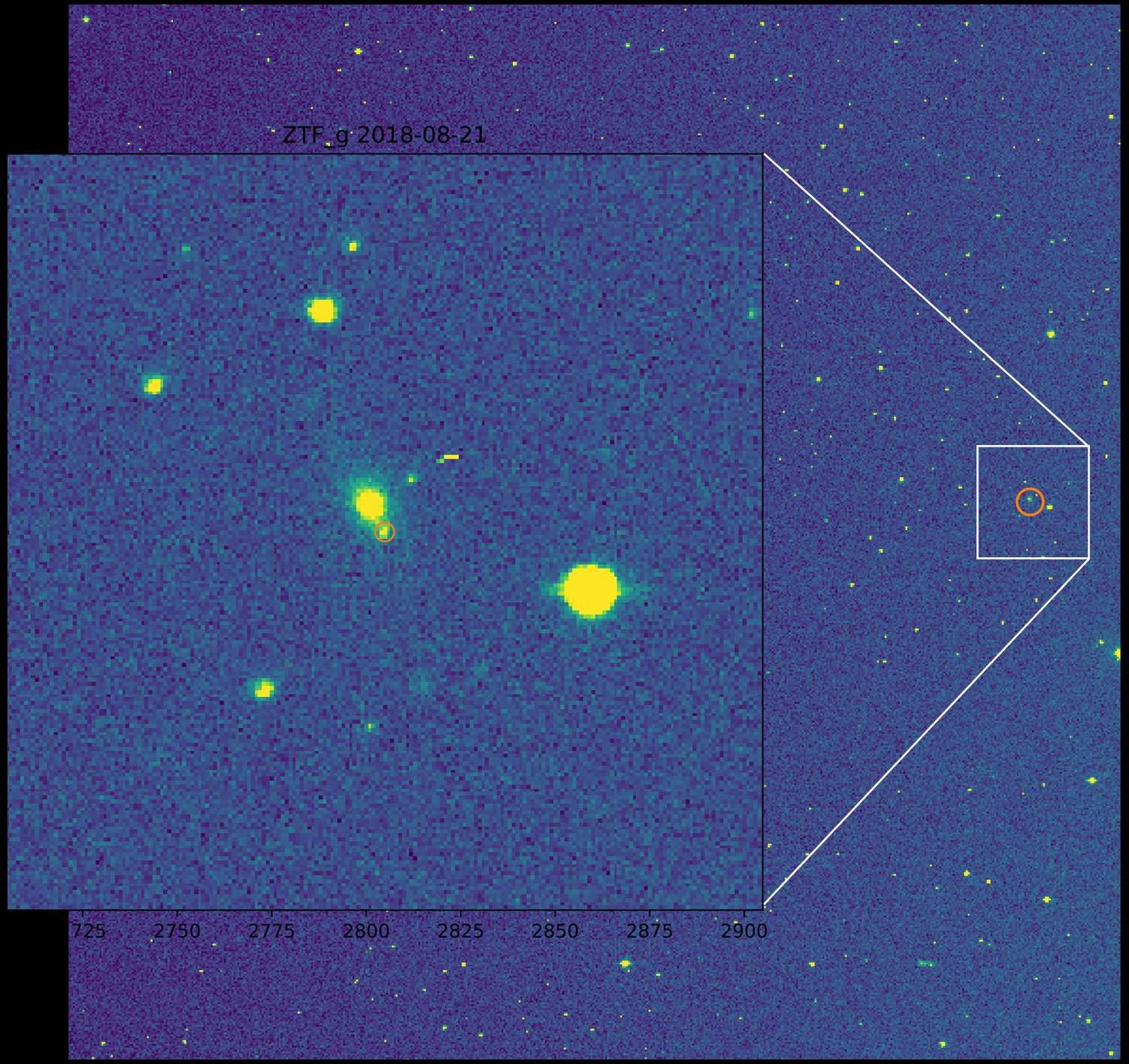
What kind of data do we really have ?







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2775
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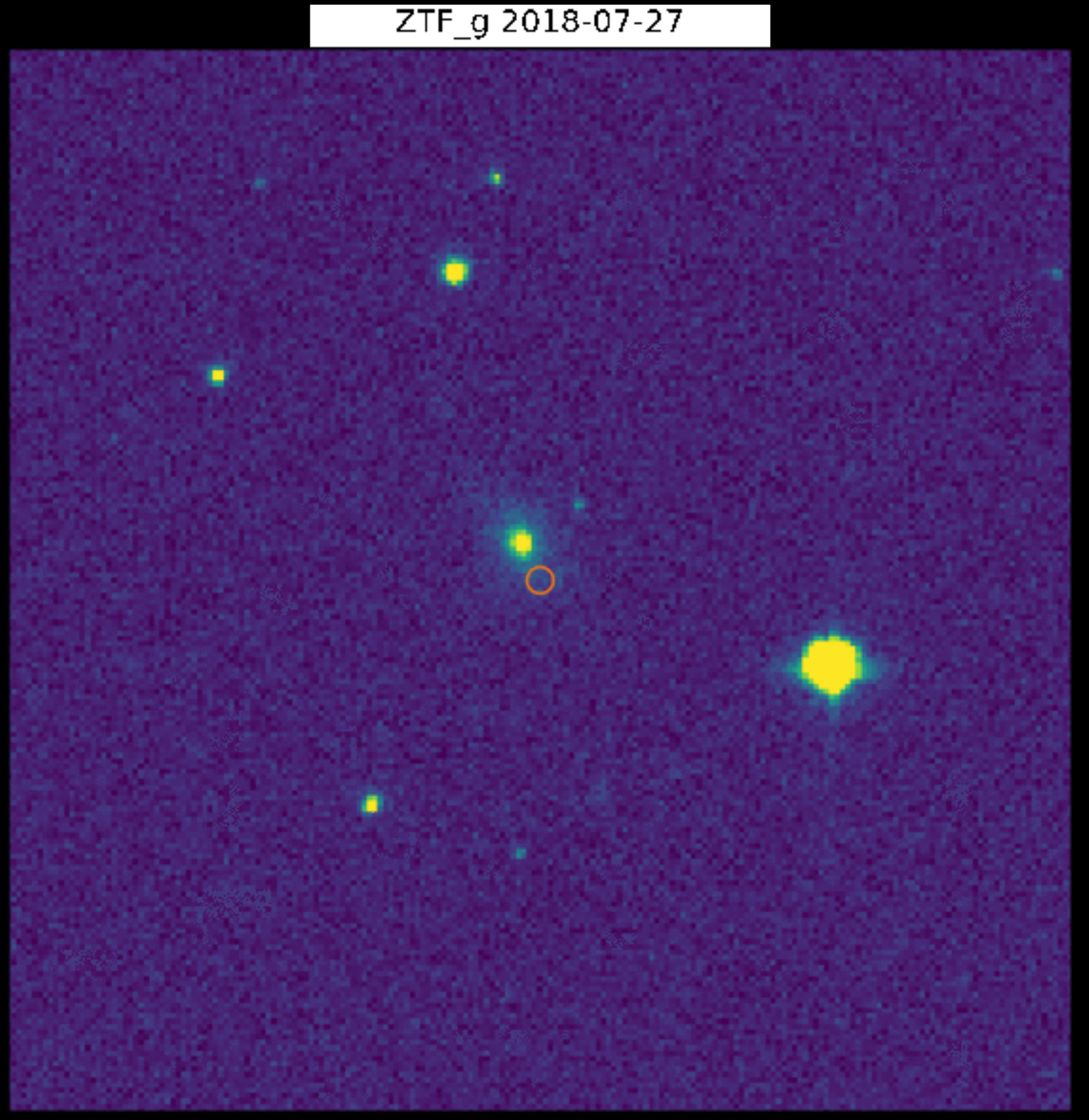
2900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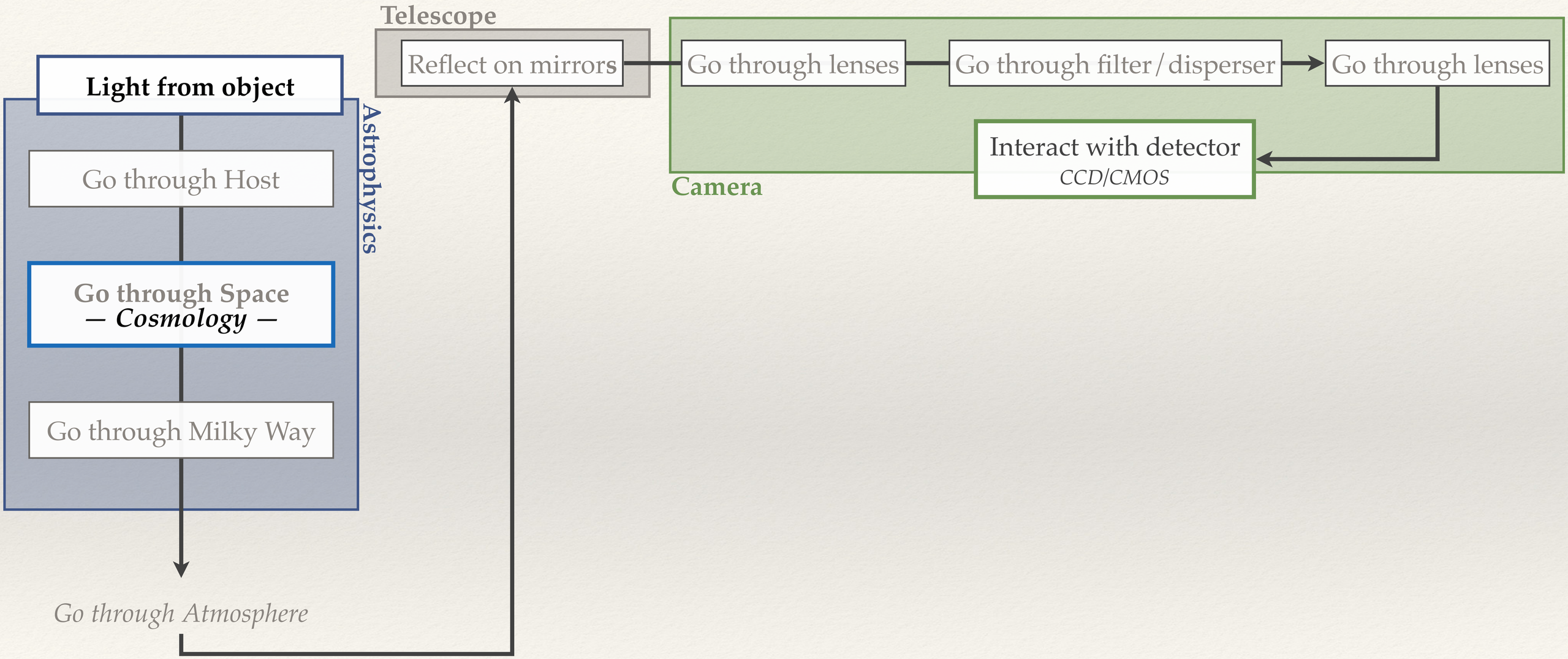
What is happening ?



What is happening ?

Telescope

Reflect on mirrors

Light from object

Go through lenses

Go through filter / disperser

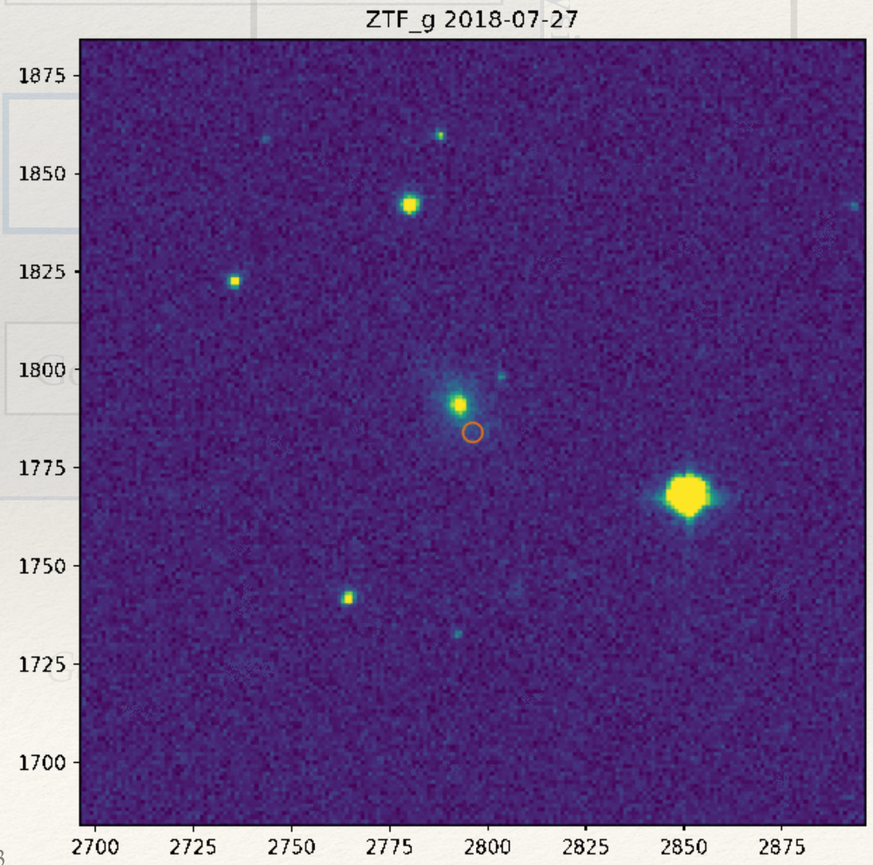
Go through lenses

Interact with detector
CCD/CMOS

Camera

Go through Host

Astrophysical



Calibration

Flat Fielding
(Was is the QE per pixels per wavelength ?)

Filter Response
(as function of position angle and time [k-corr])

PSF Shape
(Do not loose fluxes on the tails)

Astrometry
(mis-placed centroid = less flux)

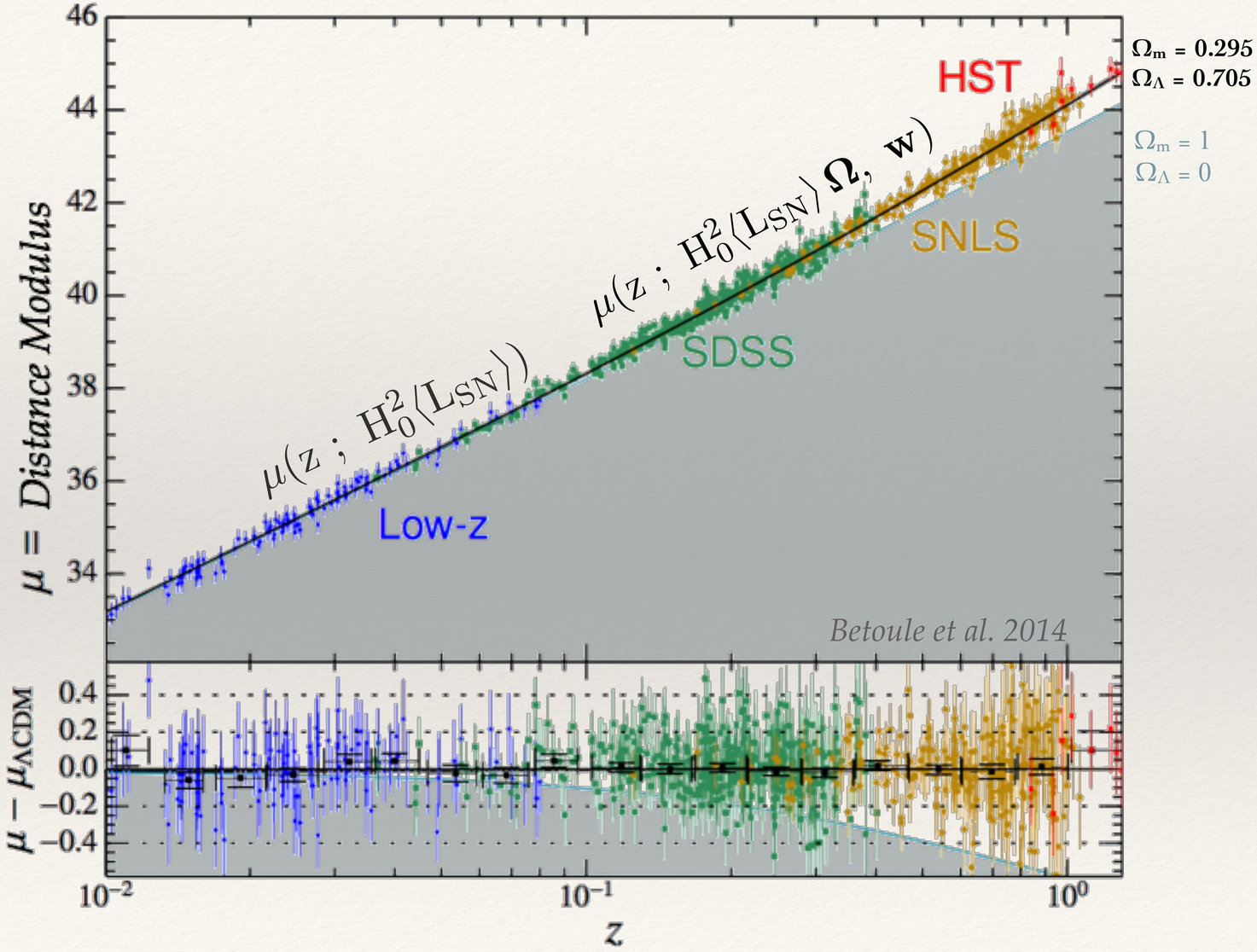
Linearity
(PSF estimated on star ~5mag bright)

Host removal
(You only want SN light)

...

Current state of the art: few mmag repeatability (SNLS | DES | PanSTARRS)

Type Ia Supernova Cosmology



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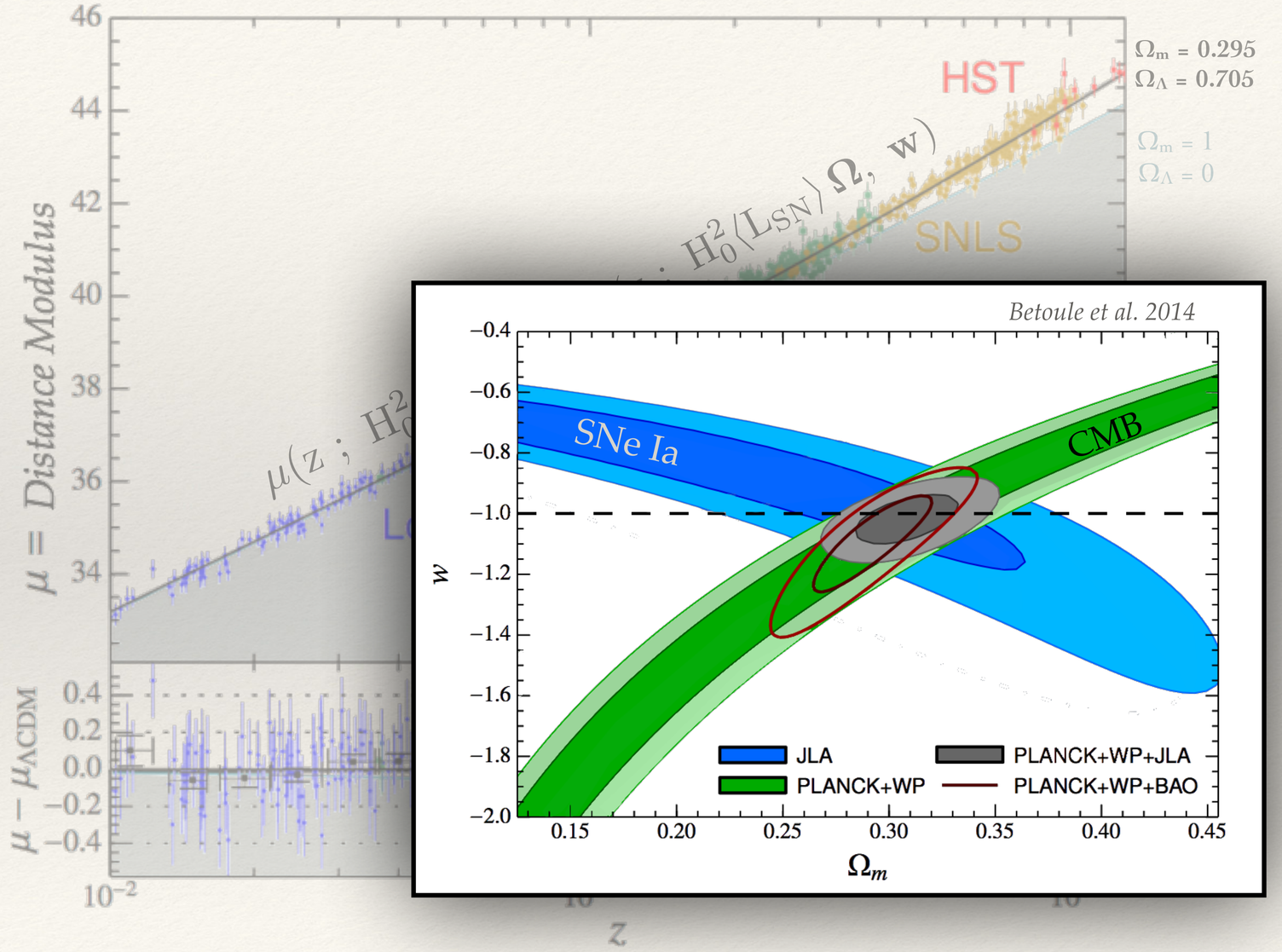
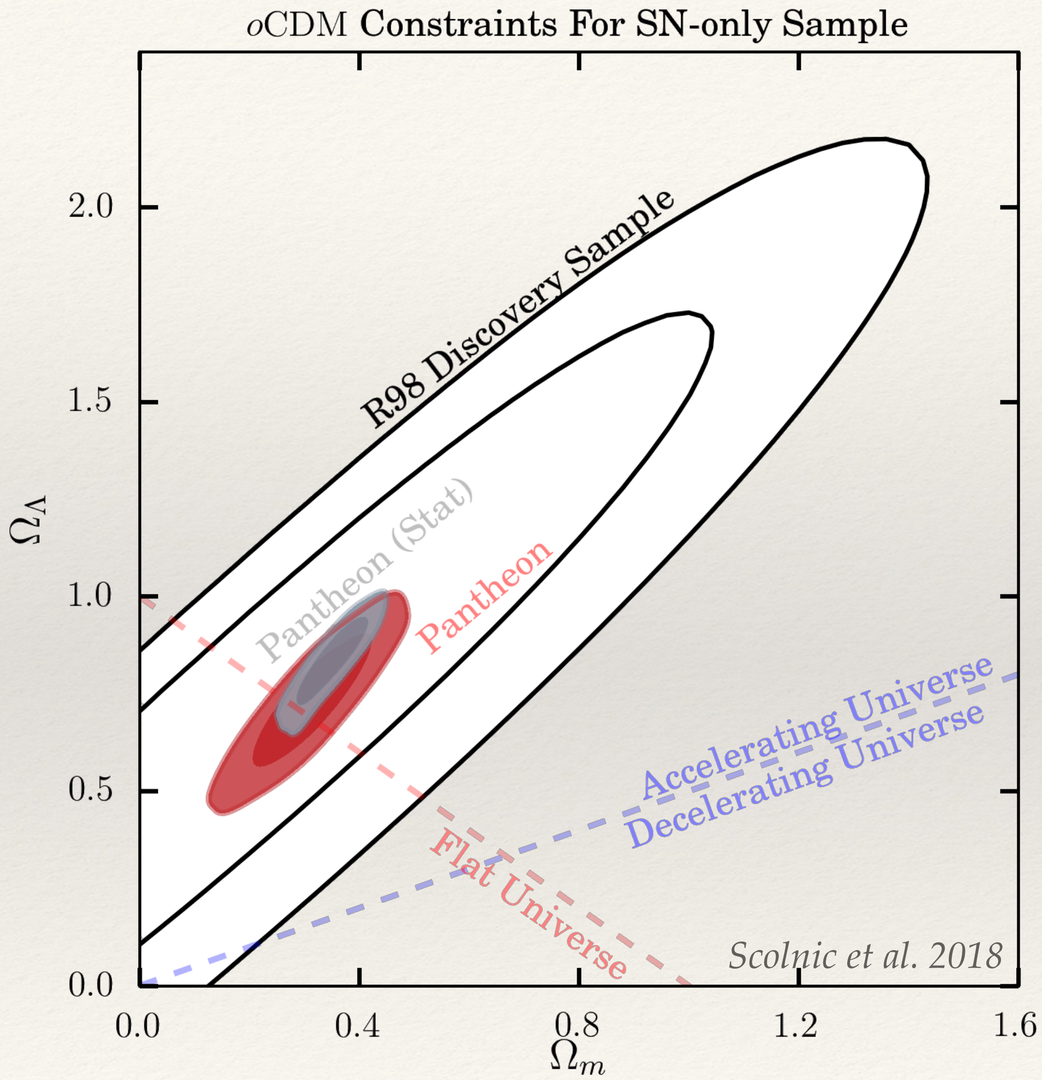


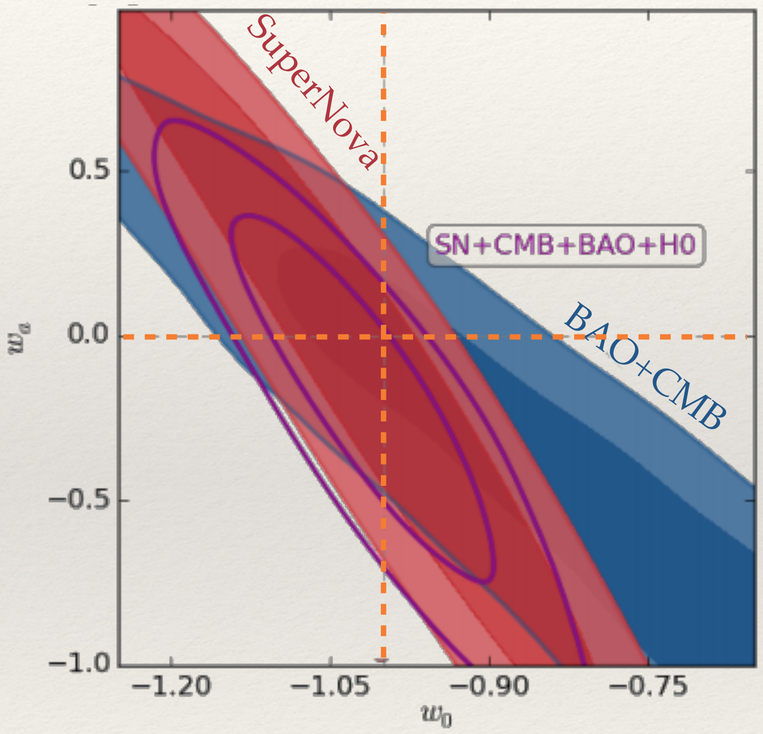
Only 20 years !



Is Dark Energy a Cosmological Constant?

« Figure of Merit = $(\sigma_{w0}^2+\sigma_{wa}^2)^{-1/2}$»

Does « Dark Energy » change as a function of time? No=0



Could Dark Energy be a cosmological Constant? yes=-1

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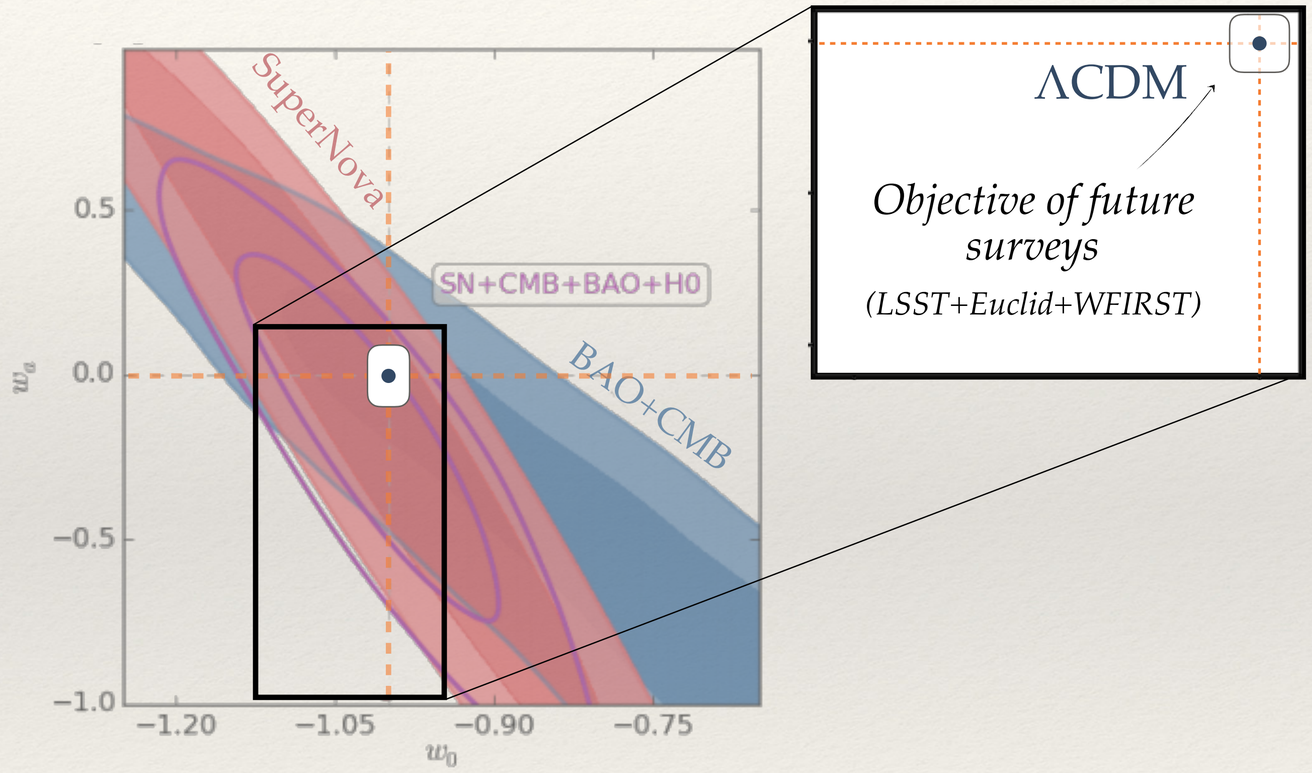

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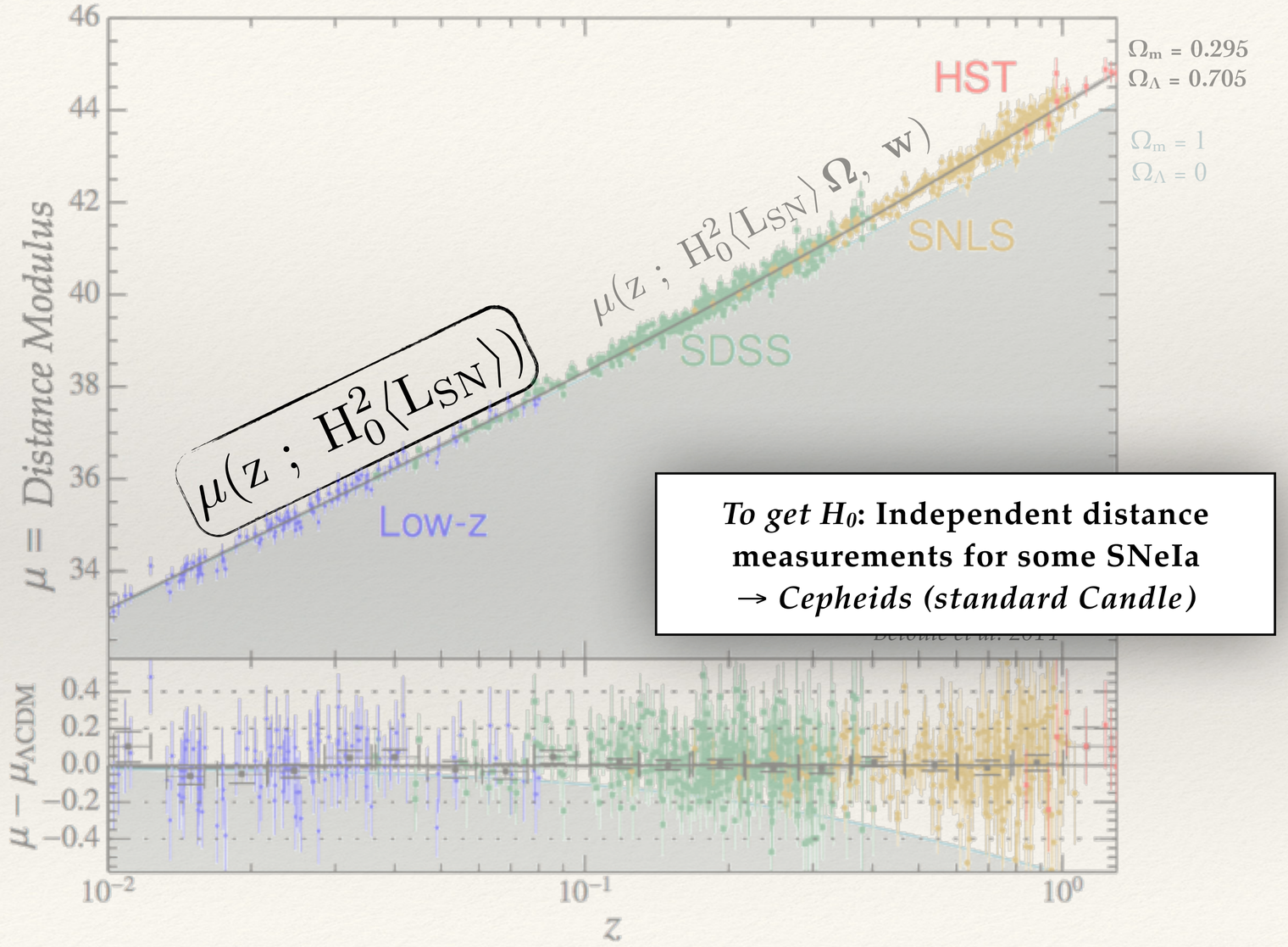
Type Ia Supernova Cosmology | H_0

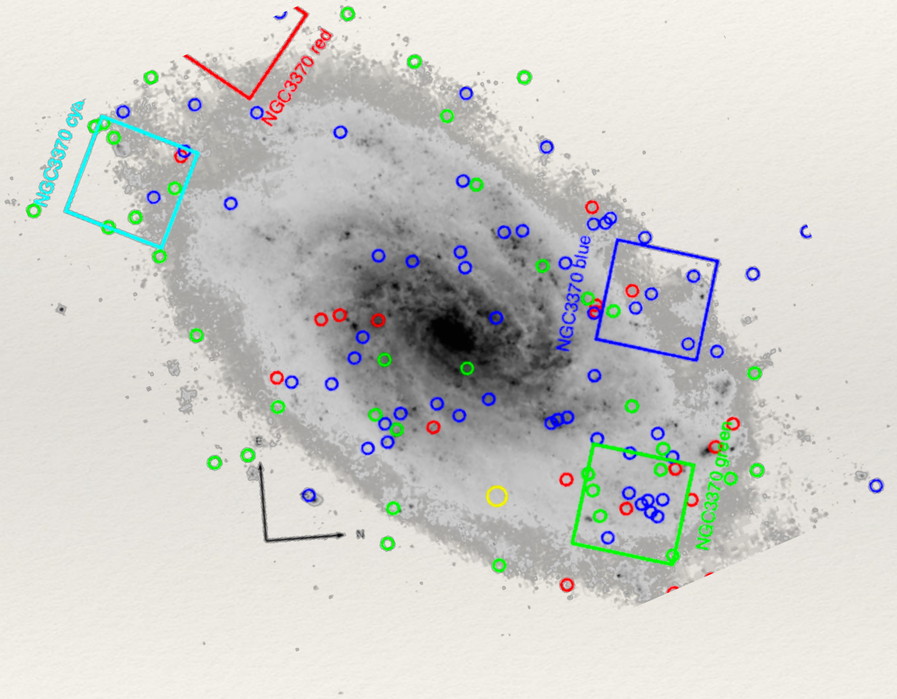


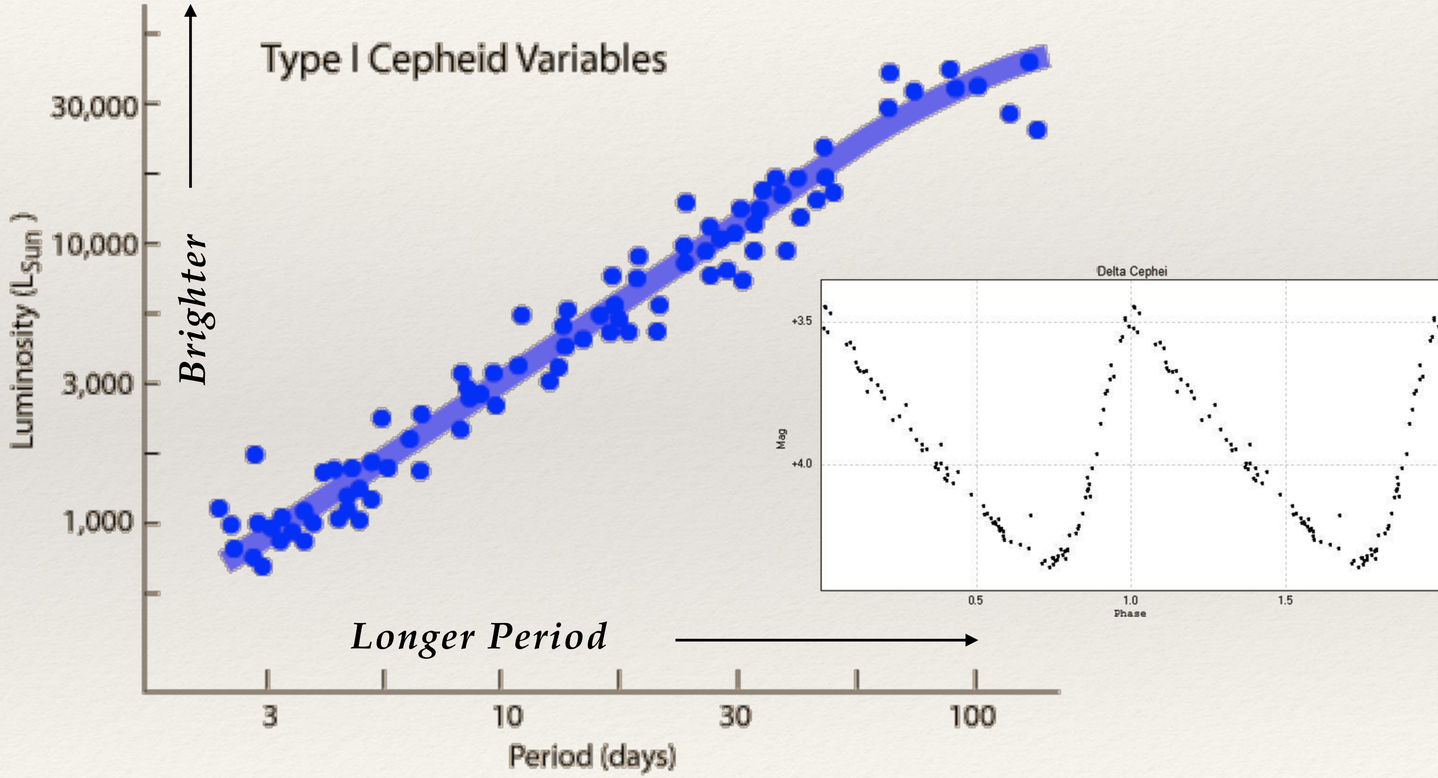
***To get H_0*: Independent distance measurements for some SNeIa**
→ *Cepheids (standard Candle)*

The Cepheid Leavitt relation

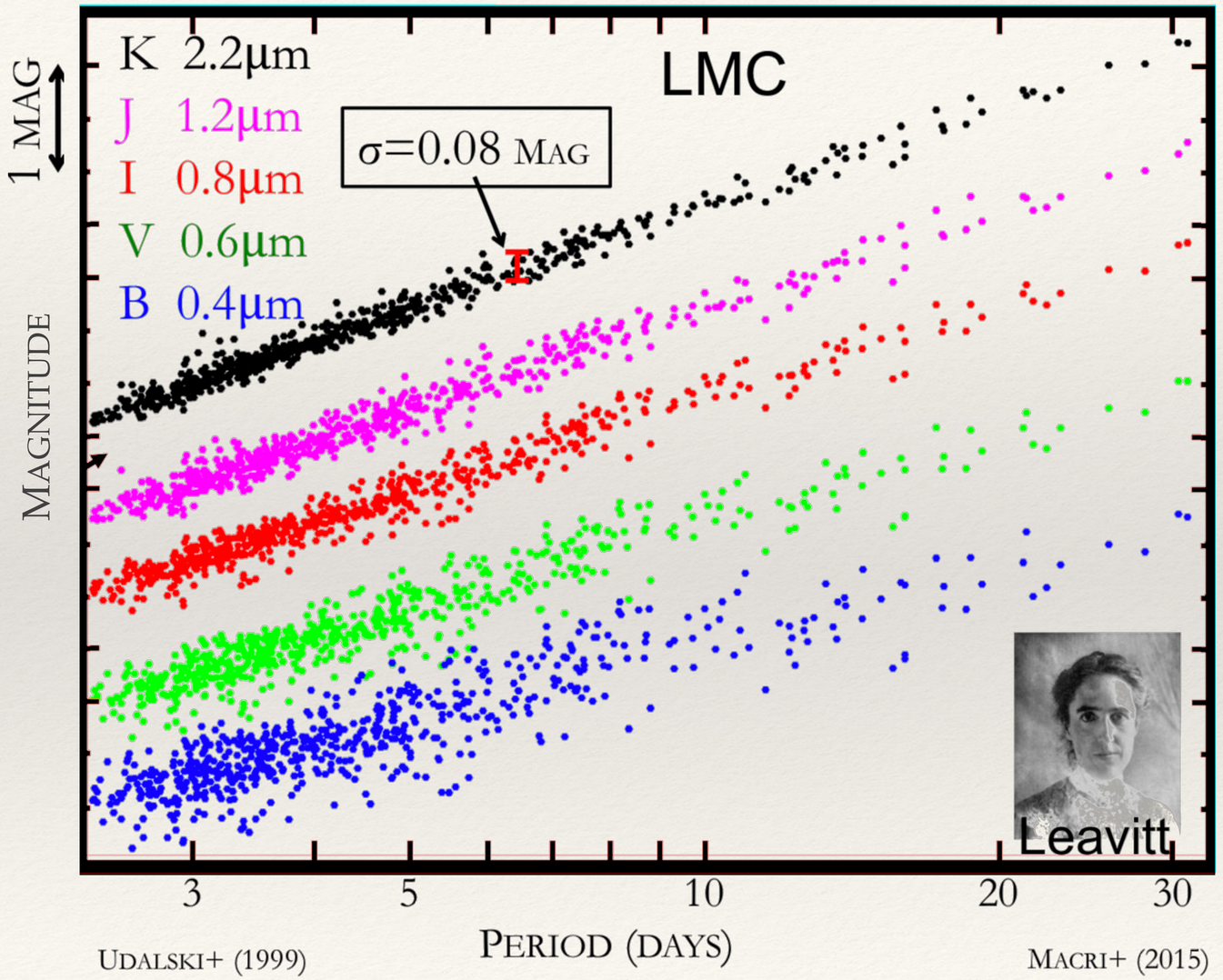
Cepheids: *bright young stars with a* ***pulsation-luminosity*** *relation*

Riess et al. 2009



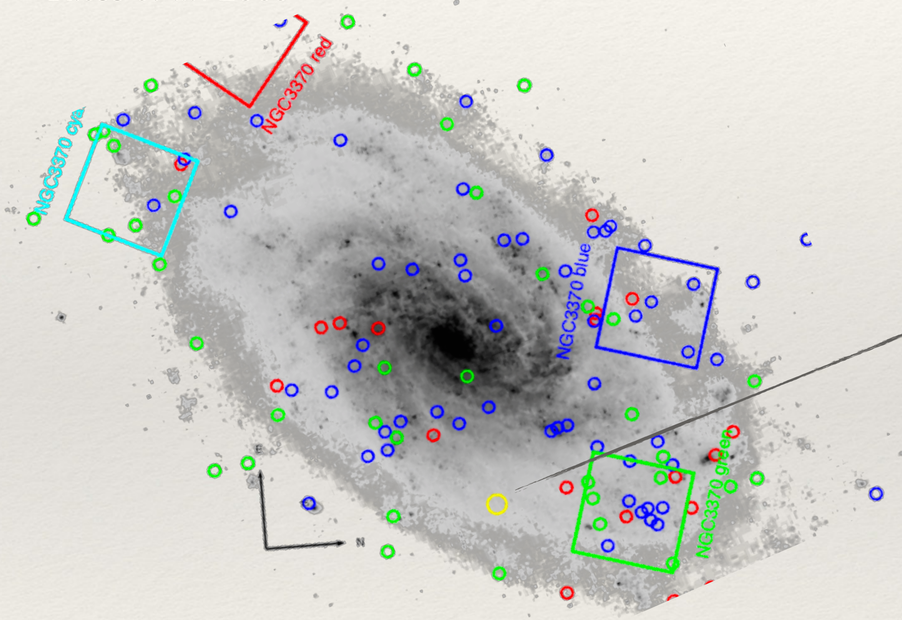


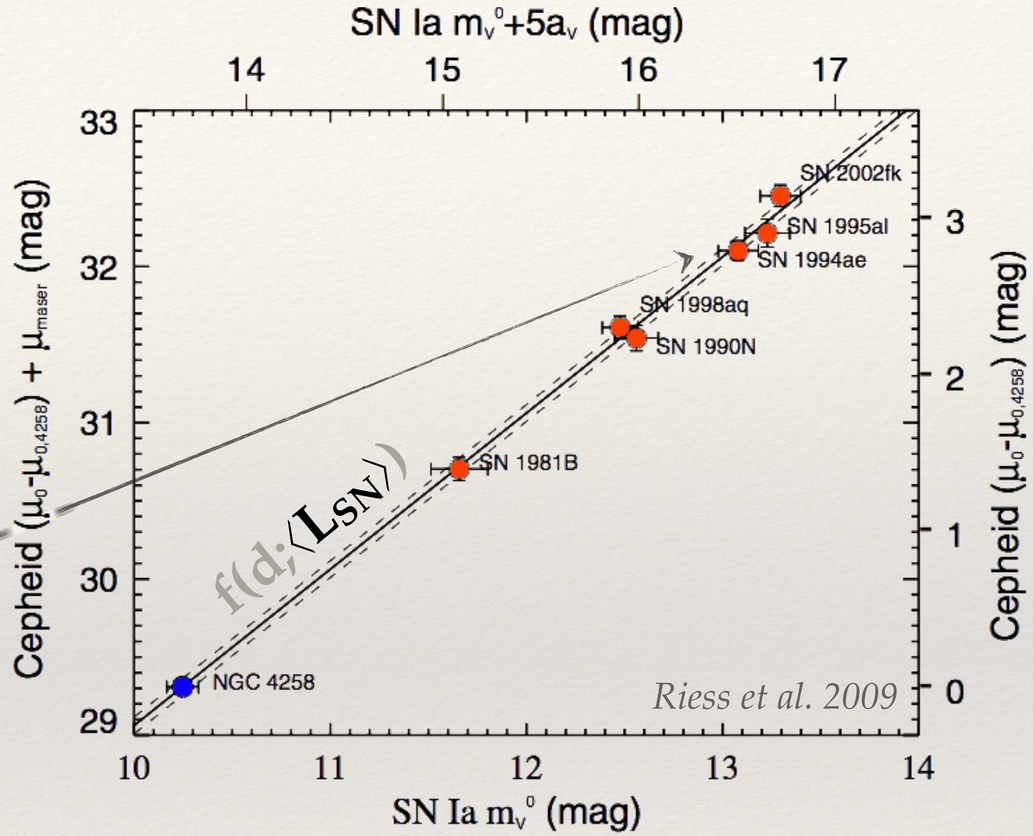
What is the benefit of Infrared *(no dust!)*



Disentangle H_0 from L_{SN}

Riess et al. 2009



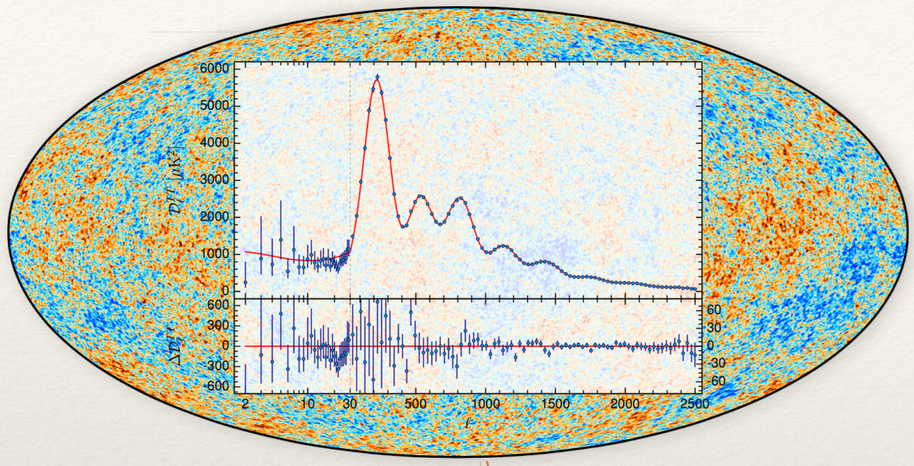


$$H_0 = 73.5 \pm 1.7 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

(2.3% ; Riess et al 2016, 2018)

The Hubble Constant | *CMB*

Planck 2018 results



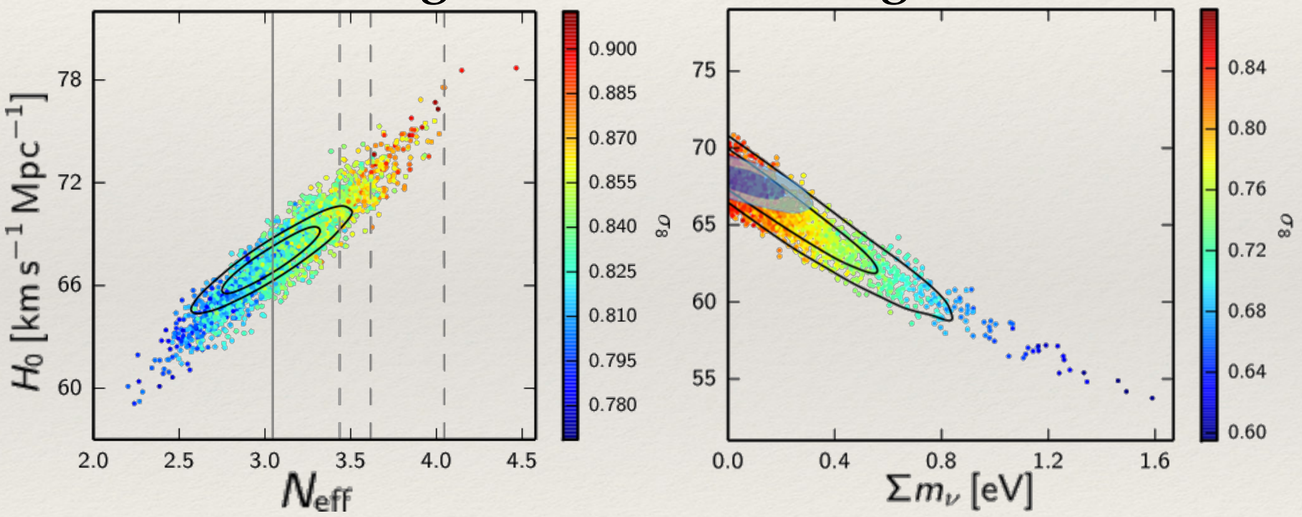
z~1000

THE MODEL CONTRAINS H_0

z~0

Test the concordance model
— ΛCDM —

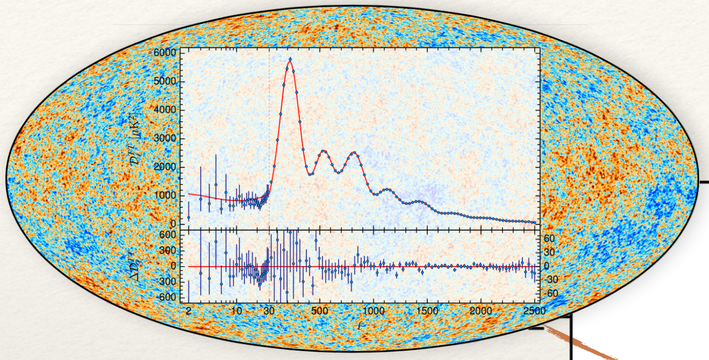
Change the model, change H_0



Illustrative plots from Planck 2015

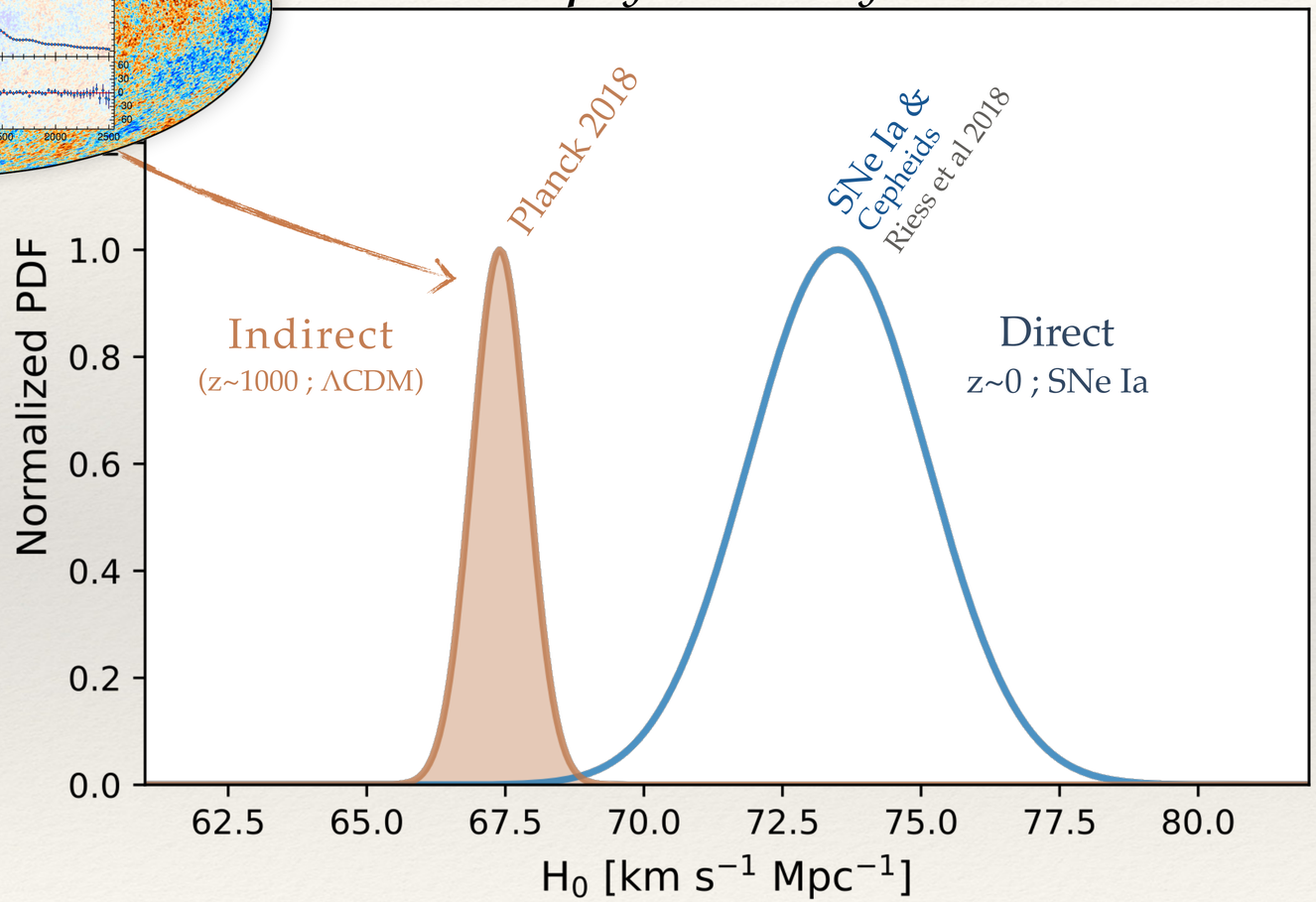
$H_0 = 67.4 \pm 0.5$ *km s^{-1} Mpc^{-1}*
— based on ΛCDM —

Tension in the concordance model?

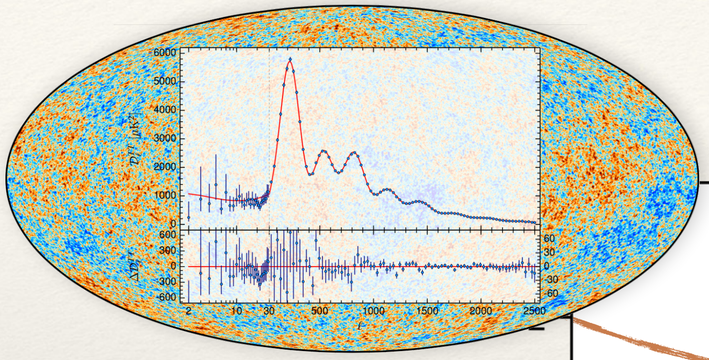


~4σ

New physics or a systematic error ?

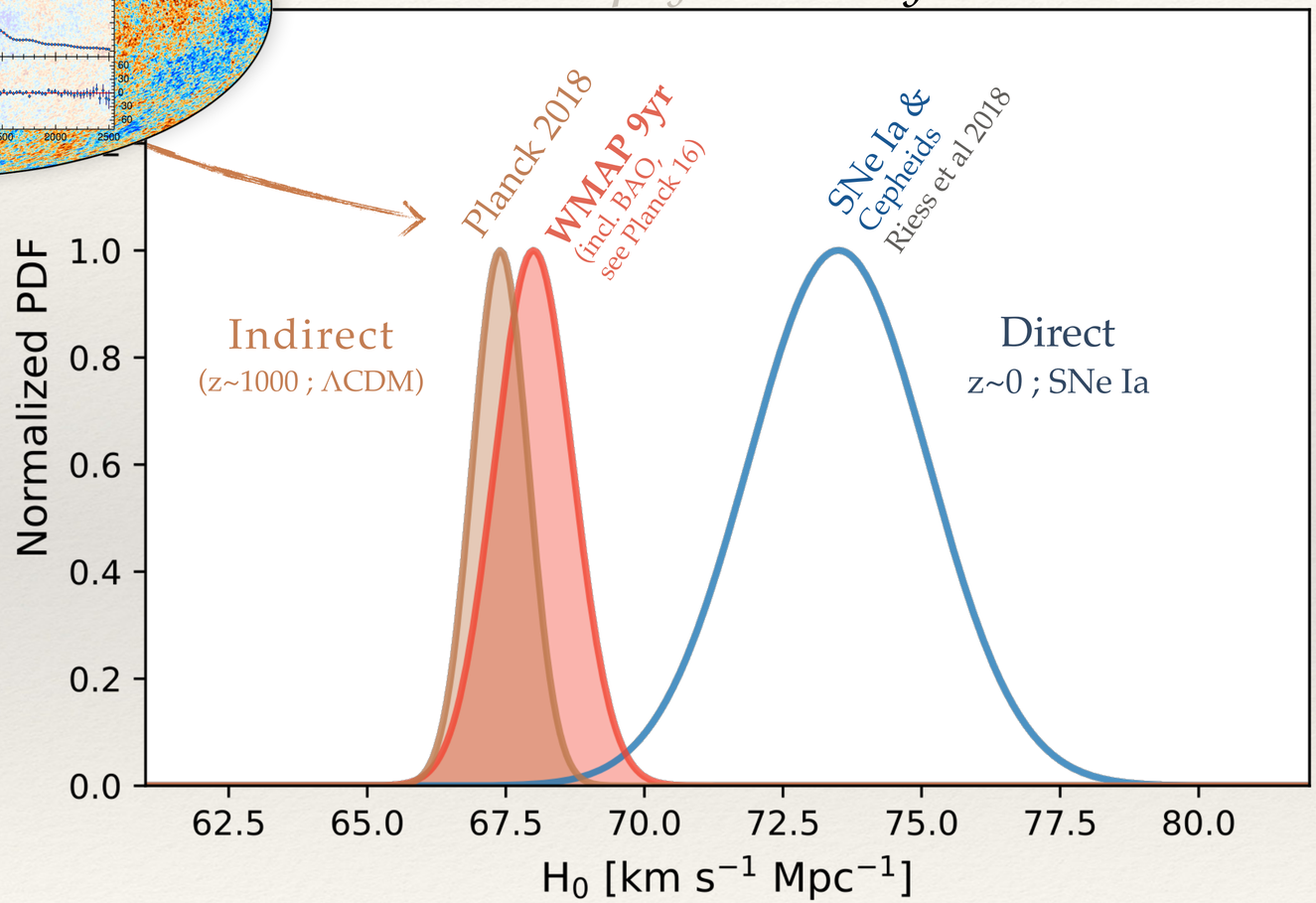


Tension in the concordance model?



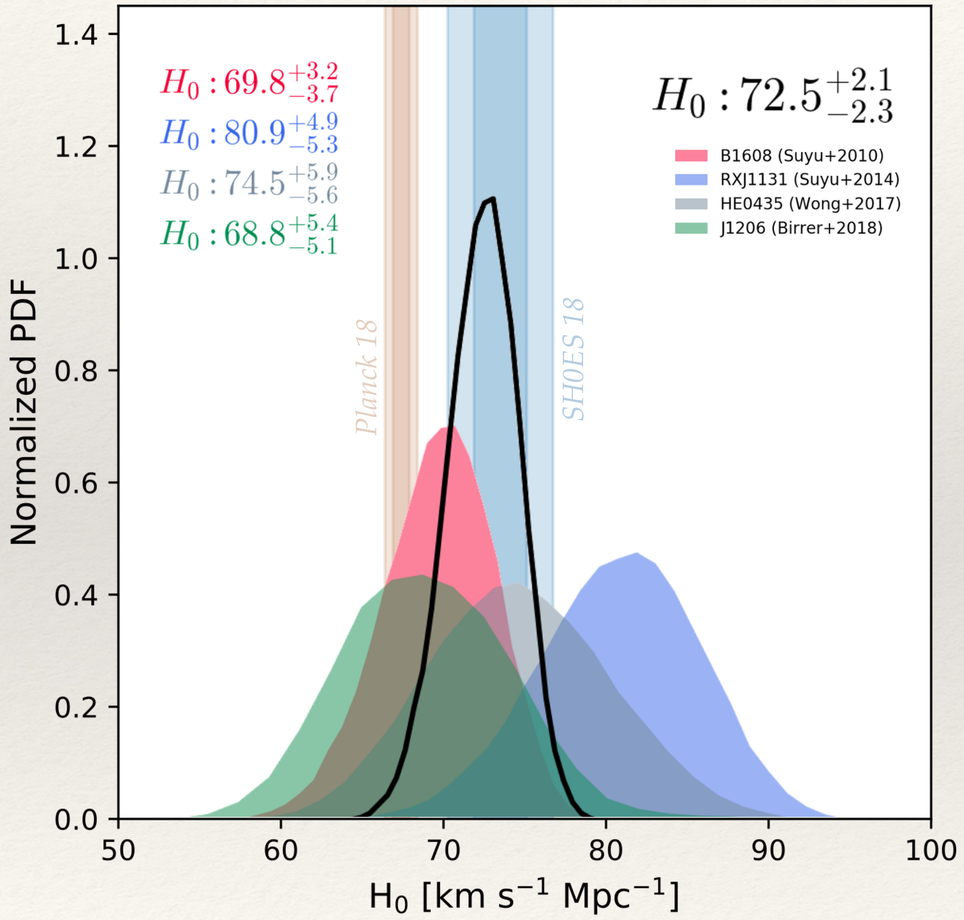
New physics ***or a systematic error ?***

in Planck Analysis ?

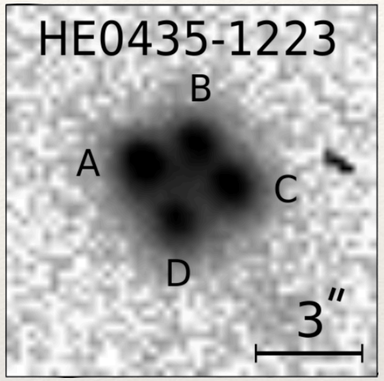


Strongly lensed transients

New physics ***or a systematic error ?***



Independent measurements ?

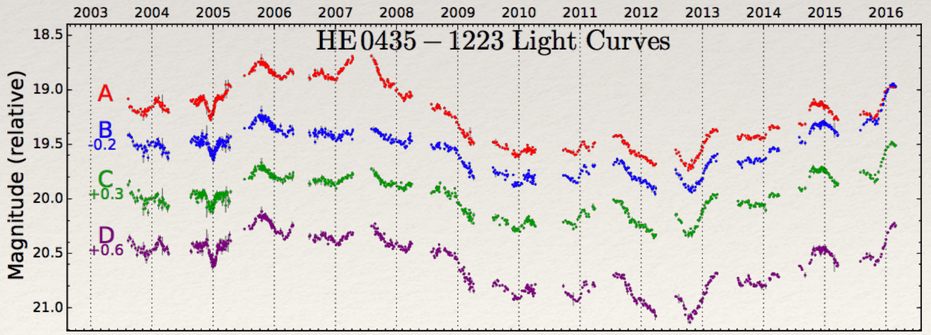


Strong Lensing

$\Delta t \rightarrow H_0$

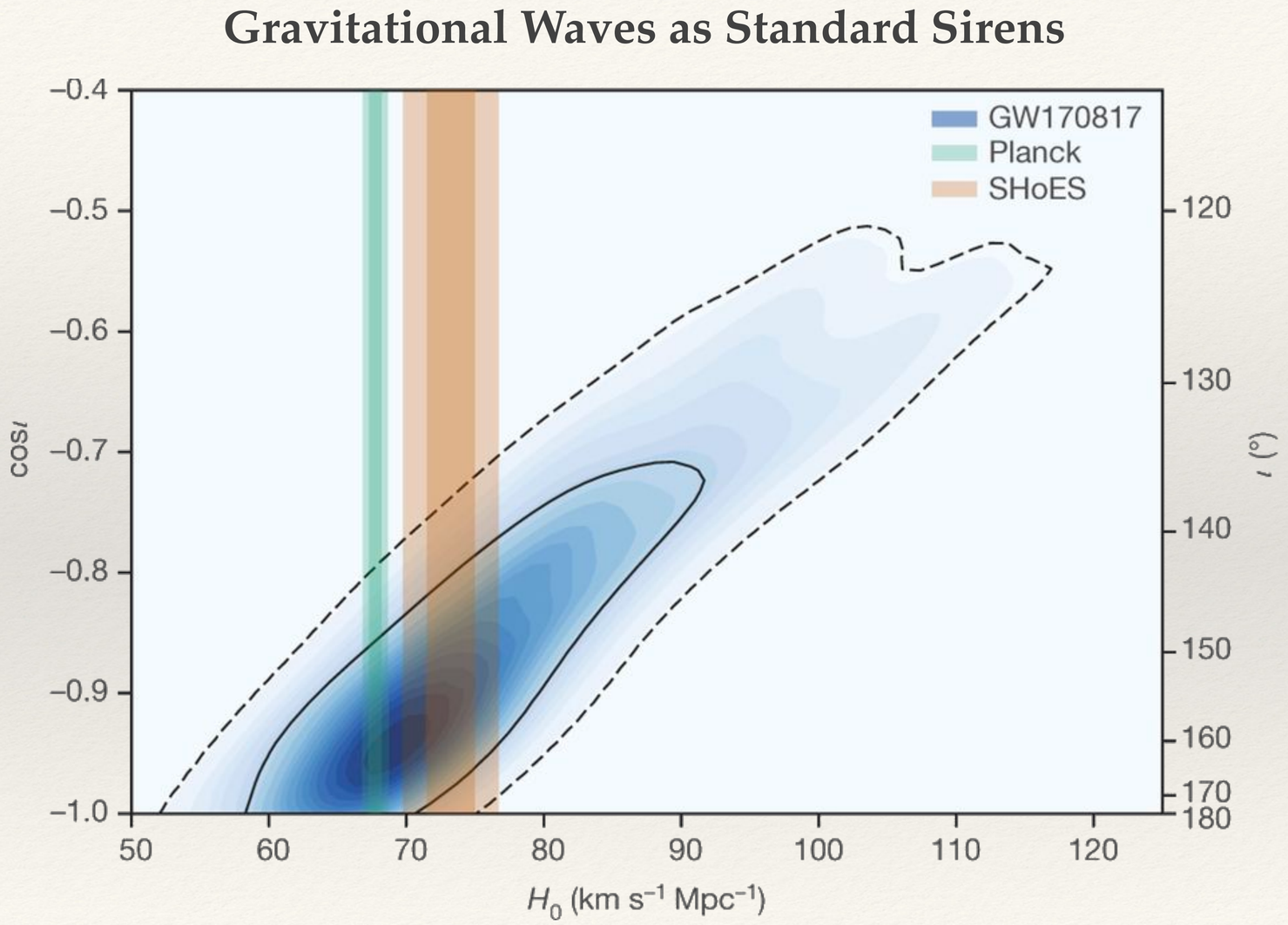
(assuming cosmo)

Bonvin et al. 2017



Gravitational waves as Standard Sirens

See N. Leroy



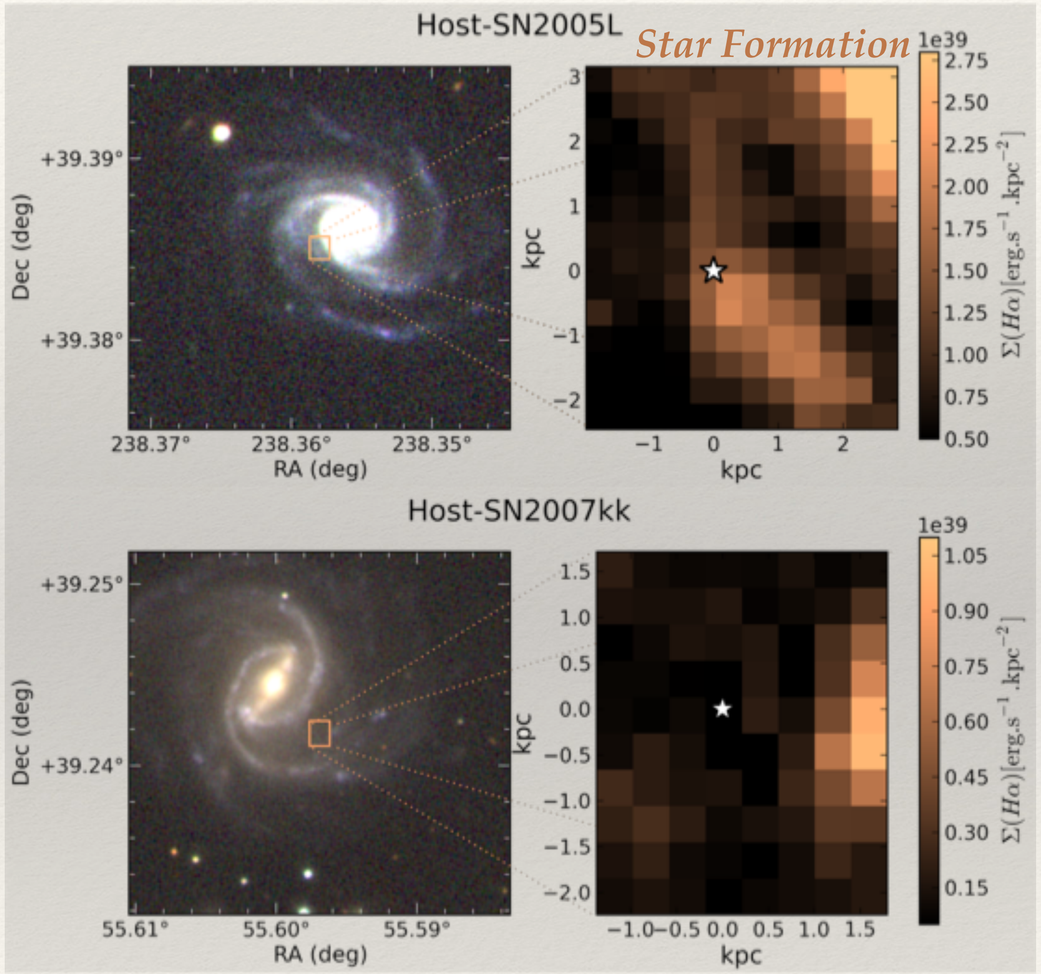
SN2011fe

The Local Perspective

Rigault et al. 2013

GLOBAL

Spiral, Star Forming, host galaxies



LOCAL

Star Formation

—

Young Stars

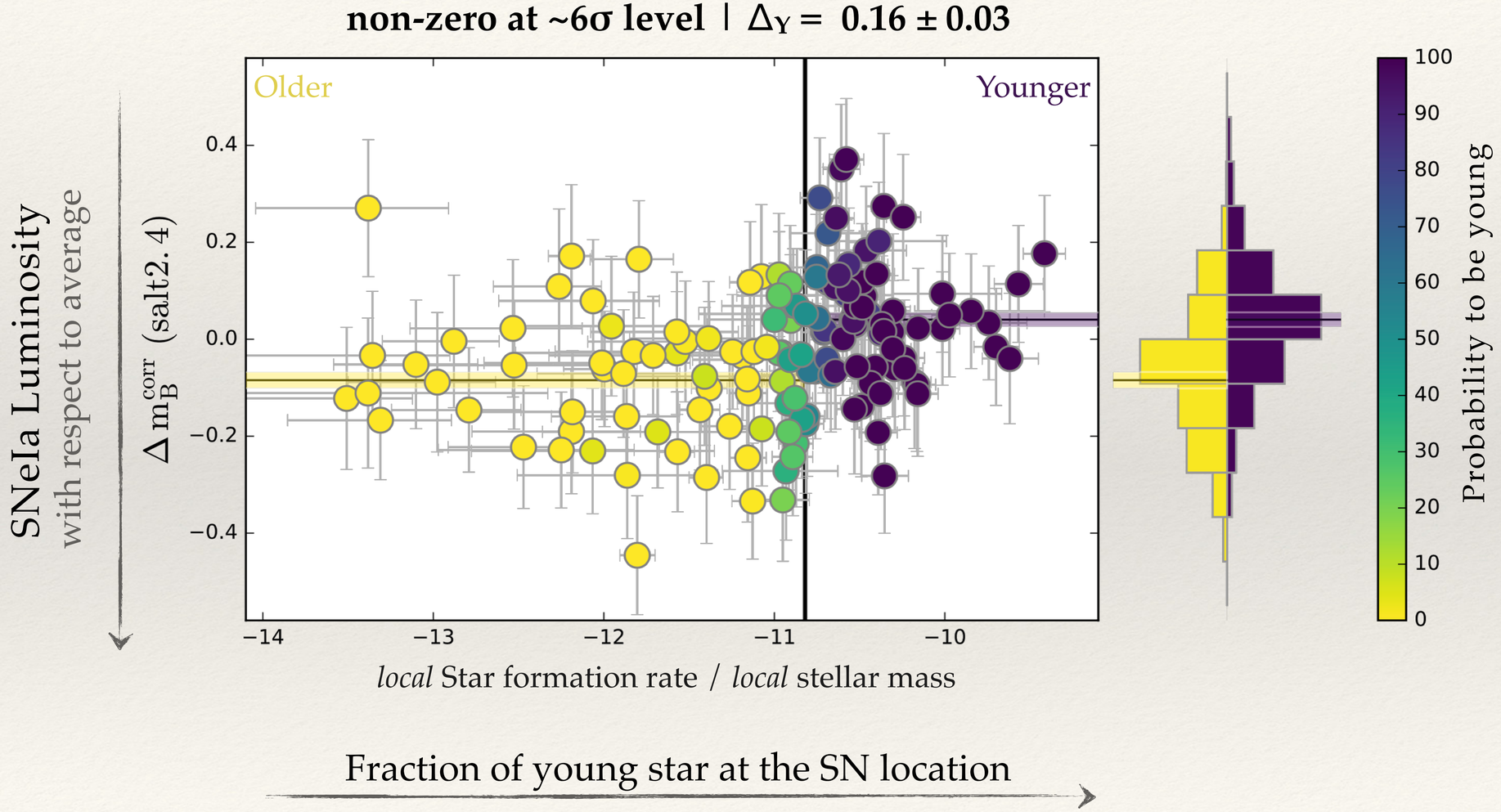
No Star Formation

—

Older Stars

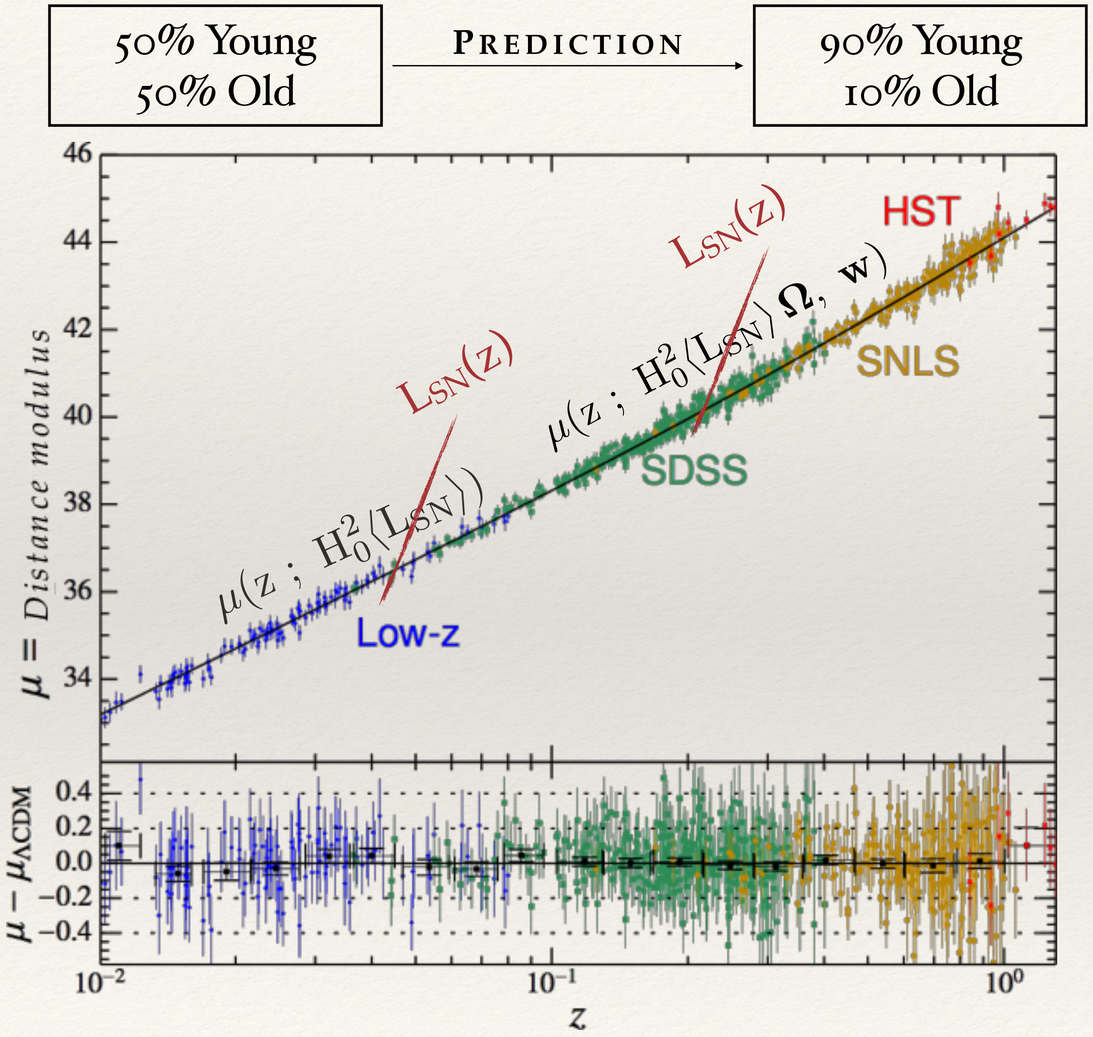
The Age Step

Rigault et al. 2018



Impact on derivation of Dark Energy properties

Rigault et al. 2013, 2018

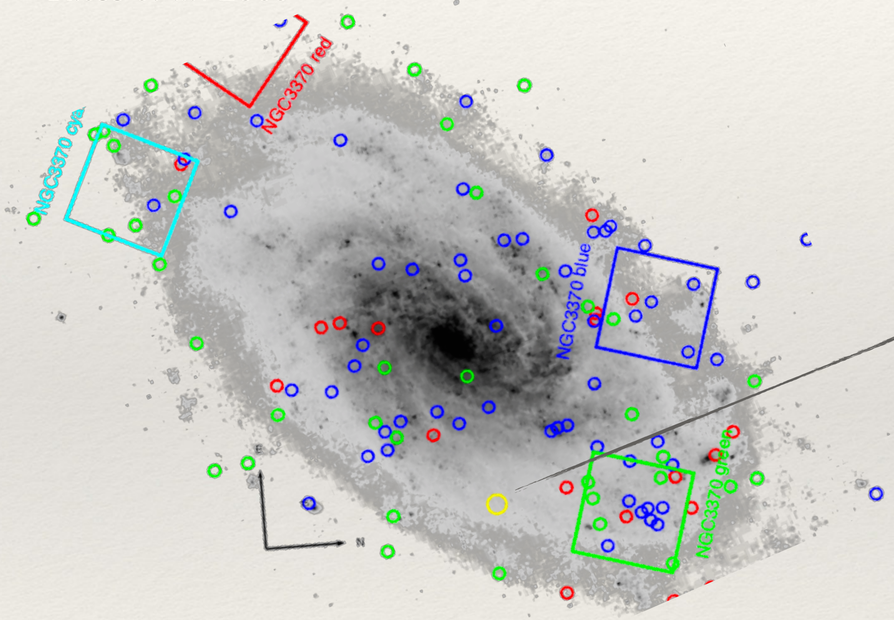


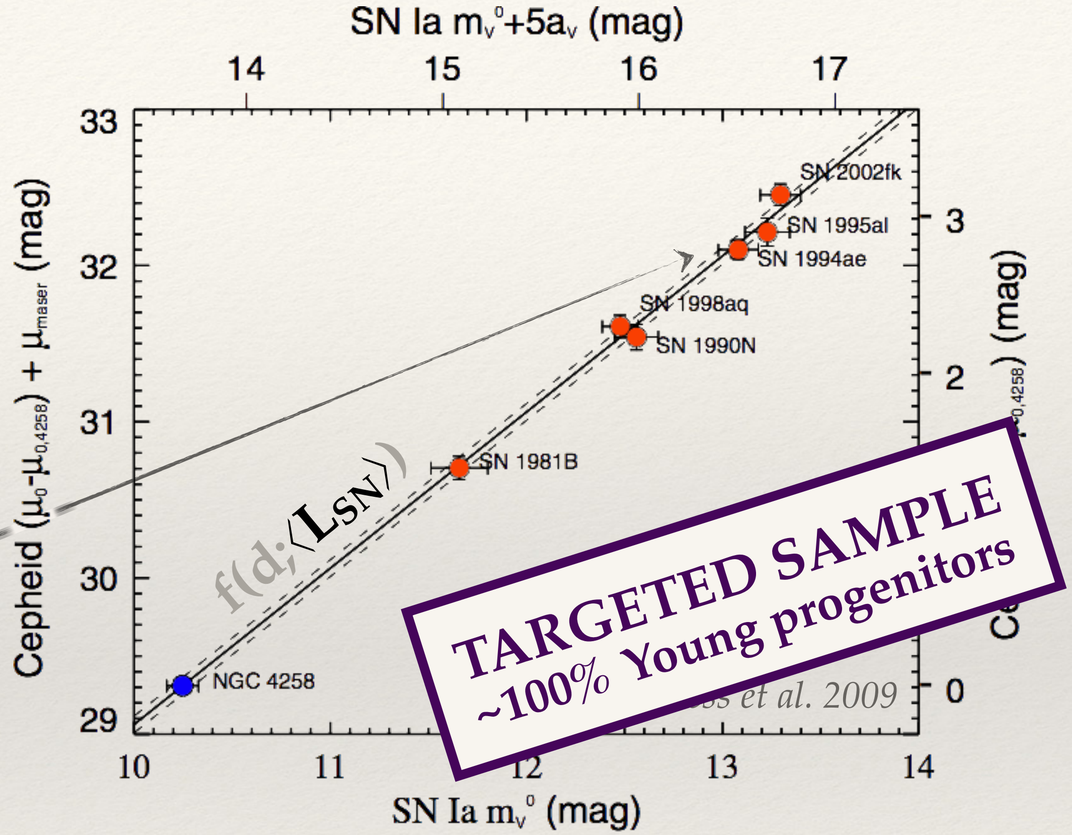
Galaxies are more star forming at higher redshift

Could significantly bias *(by a lot!)* the determination of dark energy equation of state parameters (w_0,w_a)

Disentangle H_0 from L_{SN}

Riess et al. 2009





TARGETED SAMPLE
~100% Young progenitors

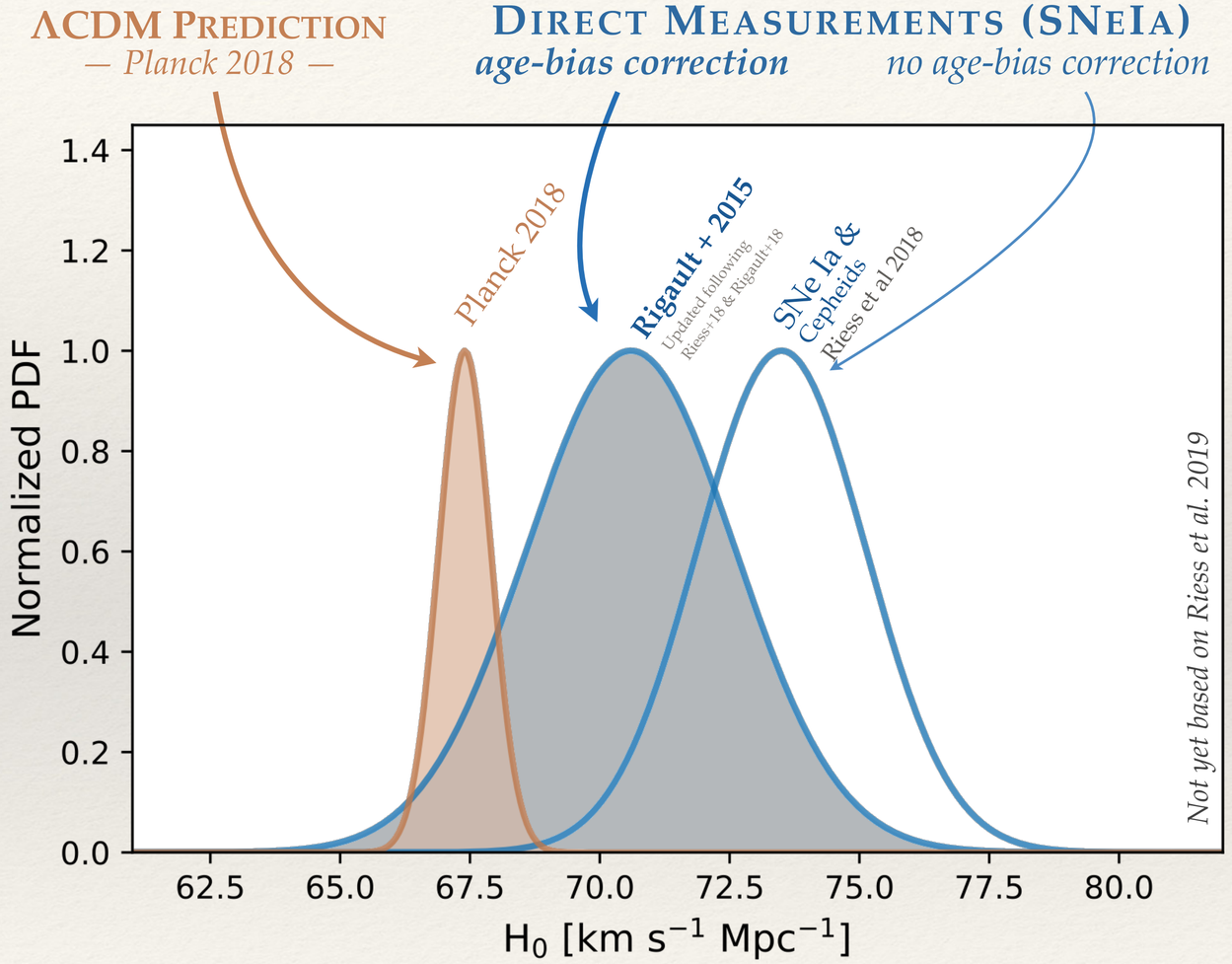
Riess et al. 2009

$$H_0 = 73.5 \pm 1.7 \text{ km s}^{-1} \text{ Mpc}^{-1}$$

(2.3% ; Riess et al 2016, 2018)

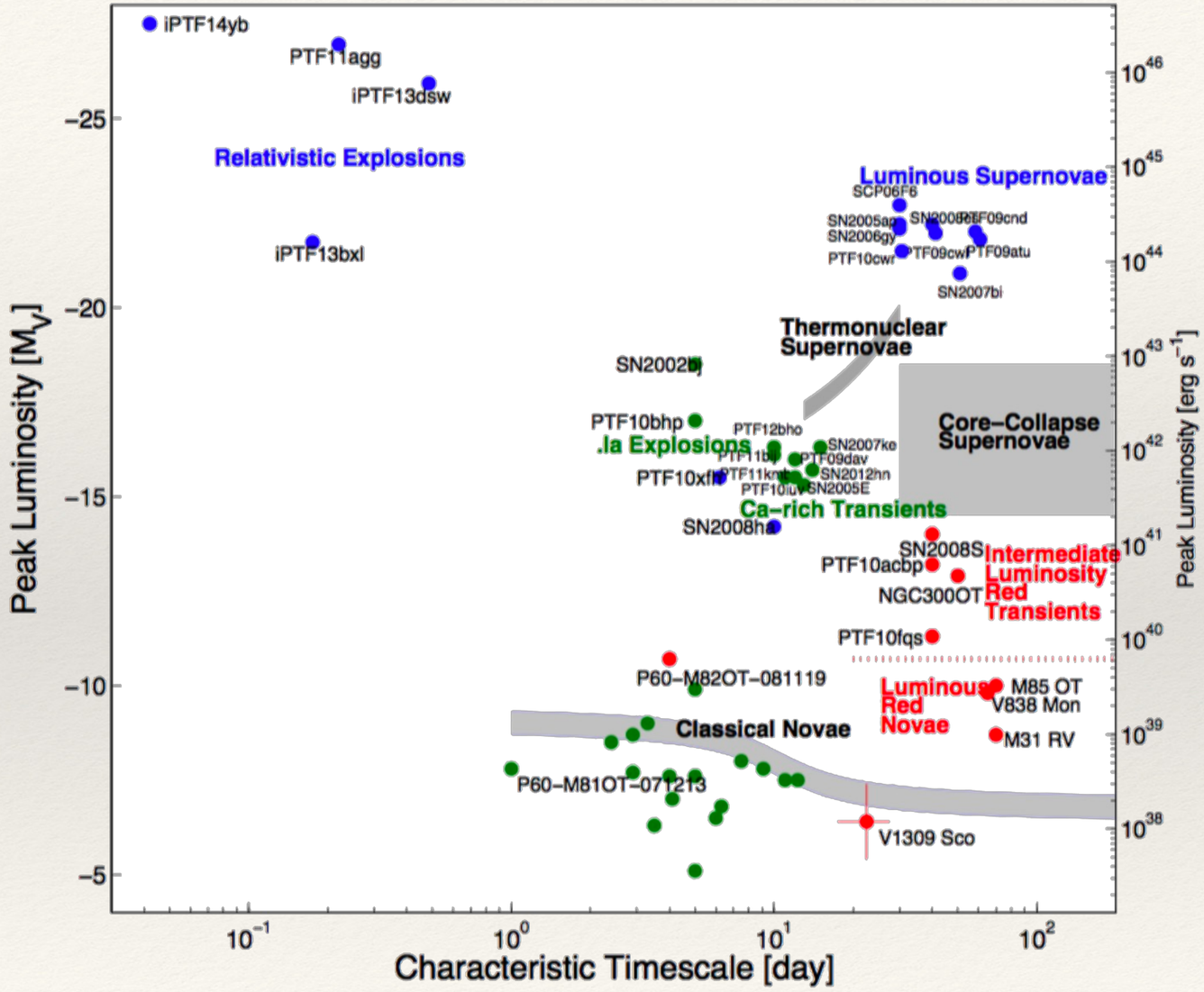
Astrophysical bias in direct measurement of H_0 ?

Rigault et al. 2015, 2018

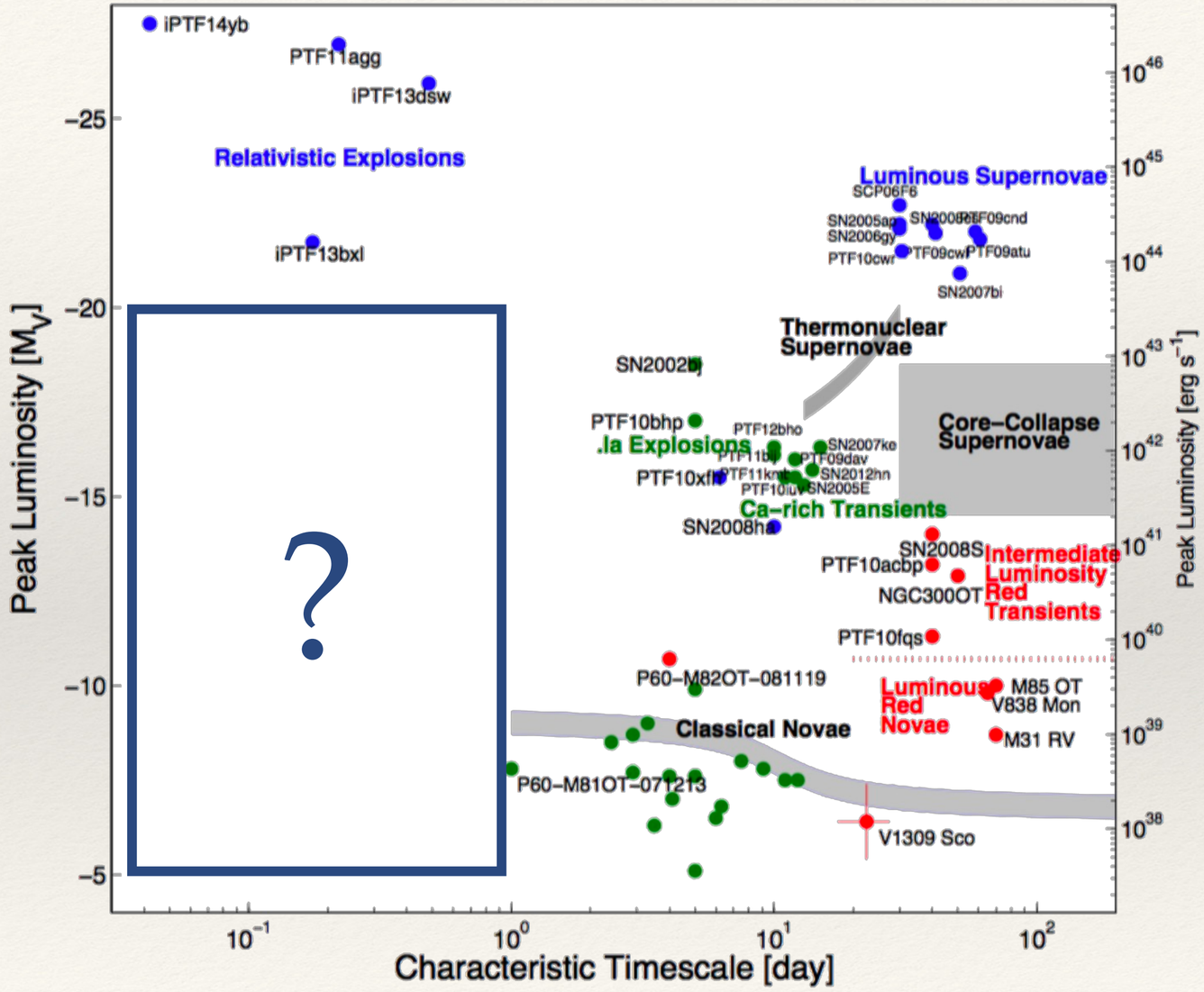


$H_0 \sim 70.6 \pm 2.5$ km s^{-1} Mpc^{-1}

Time and Brightness

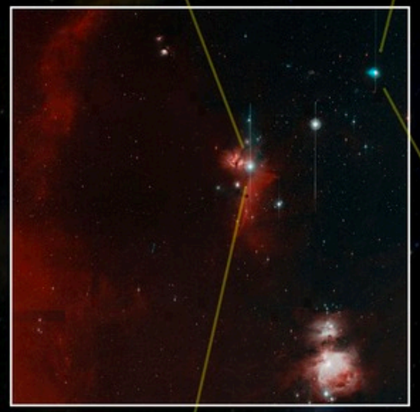


Time and Brightness



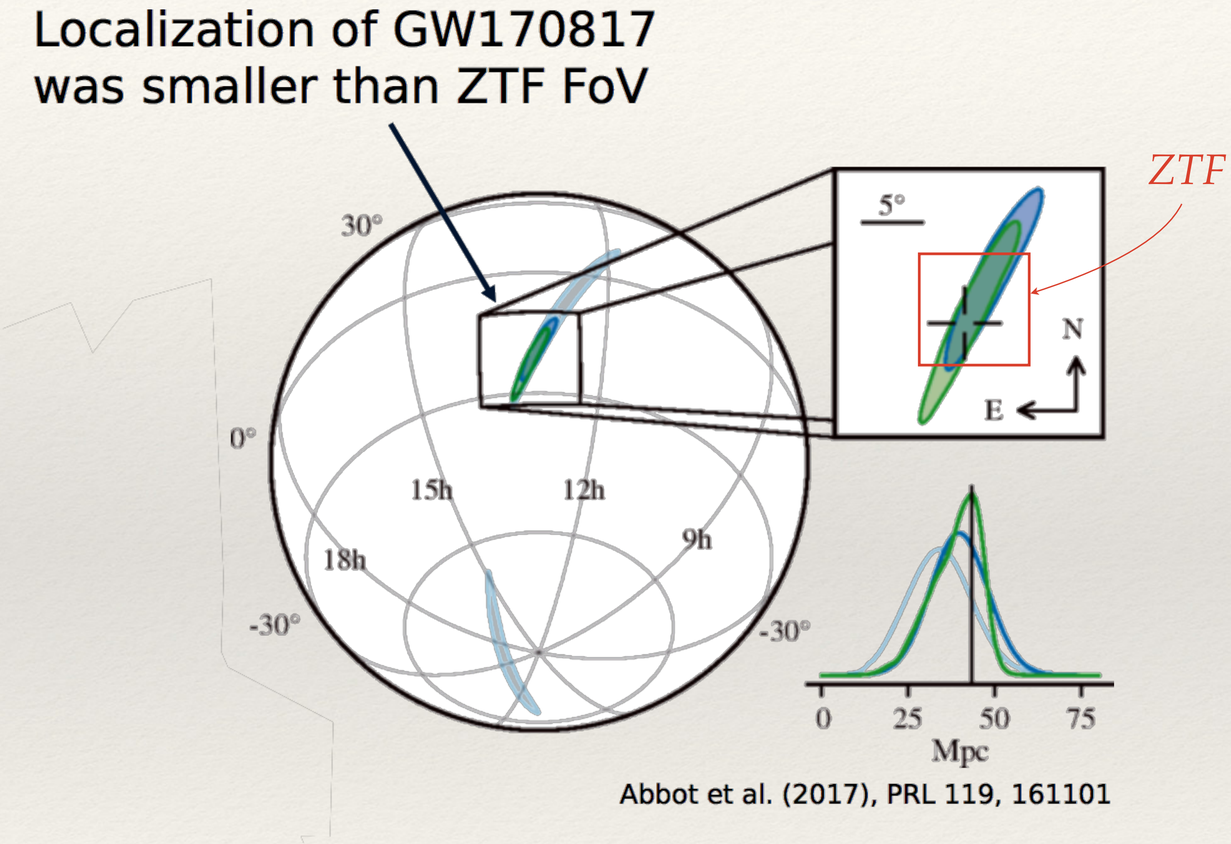
ZTF | Goes Fast (30s exp.), Scans Large (full visible sky)

We have about 10^5 events/night ; 10% of LSST



Video link

Multi Messenger Follow Up



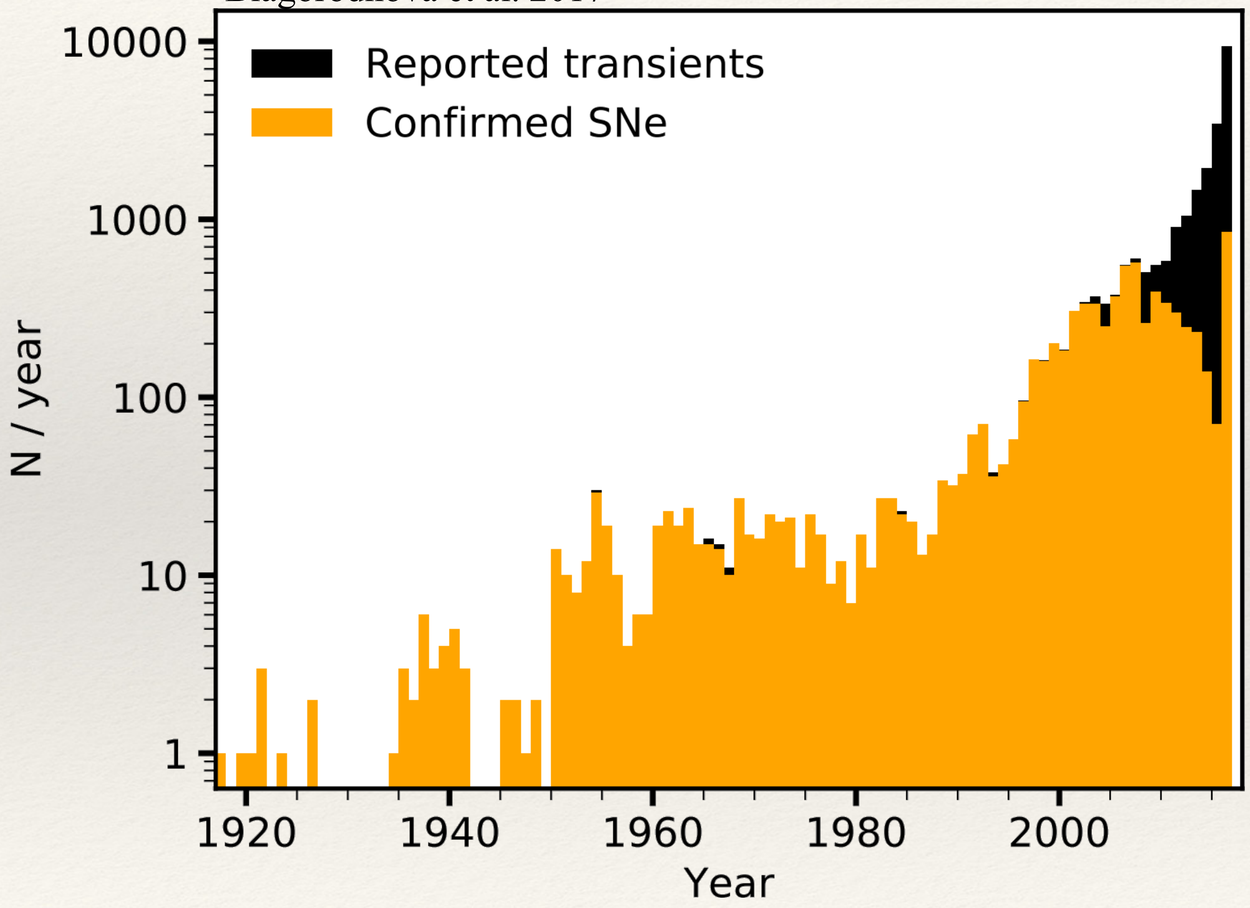
Abbot et al. (2017), PRL 119, 161101

Day 000

Day 000

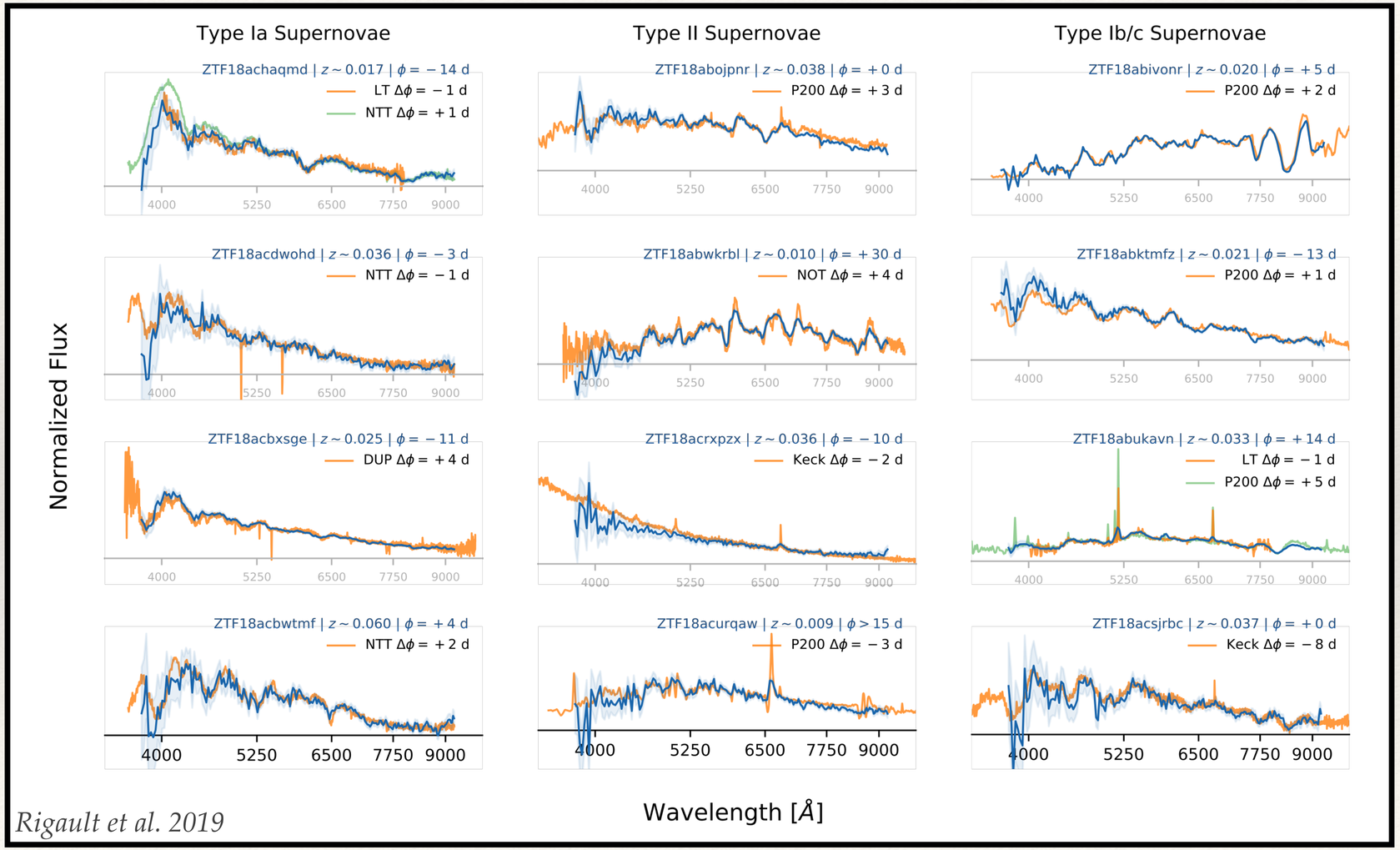
Big Issue : **Typing !**

Blagorodnova et al. 2017



Big Issue : **Typing !**

Getting Spectra | "easy" for bright (<20mag) objects: 10 to 20min on 2m telescopes | ***Low resolution is enough***



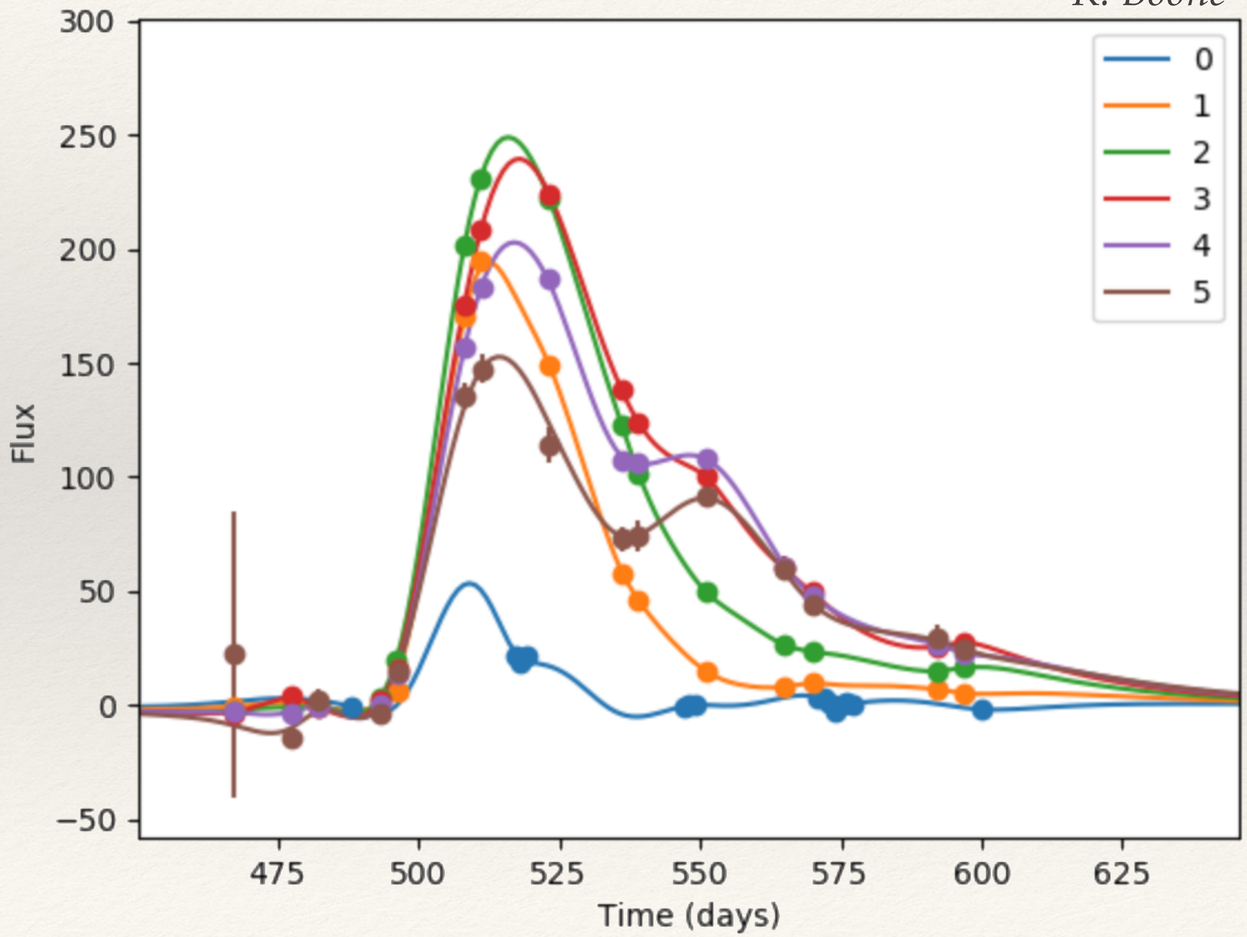
Rigault et al. 2019

Big Issue : **Typing !**

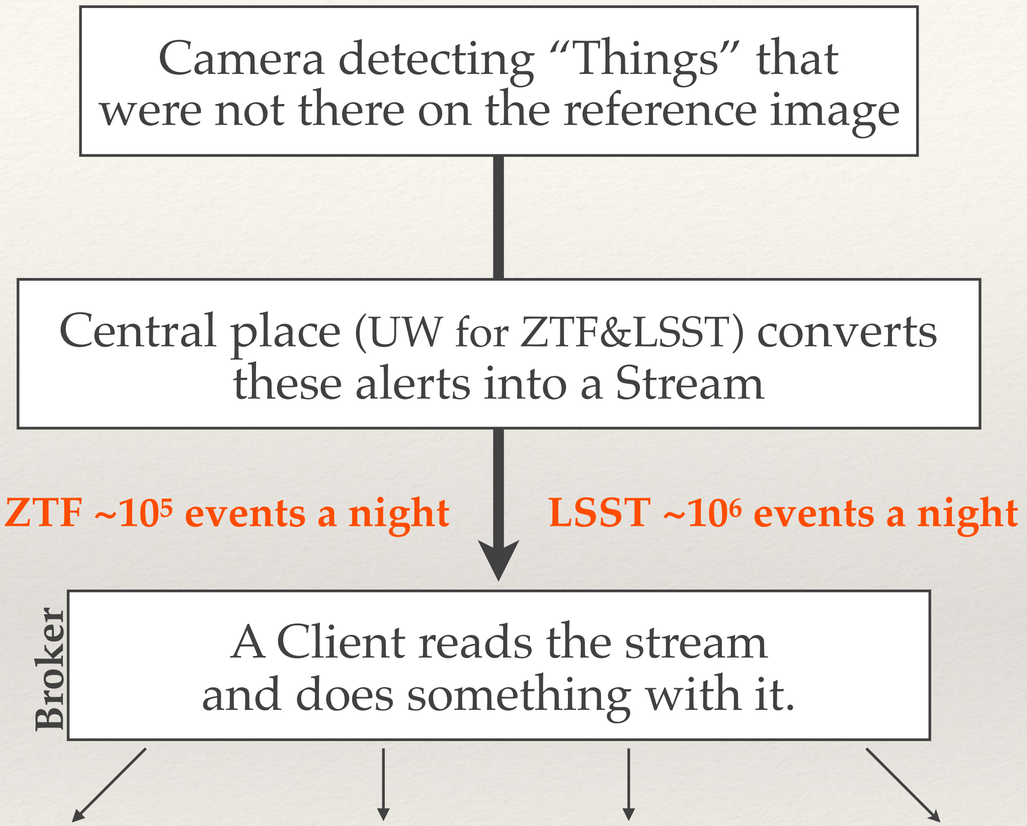
Getting Spectra | "easy" for bright (<20mag) objects: 10 to 20min on 2m telescopes | ***Low resolution is enough***

But for the rest: Phototyping ? Using Machine Learning ?

K. Boone



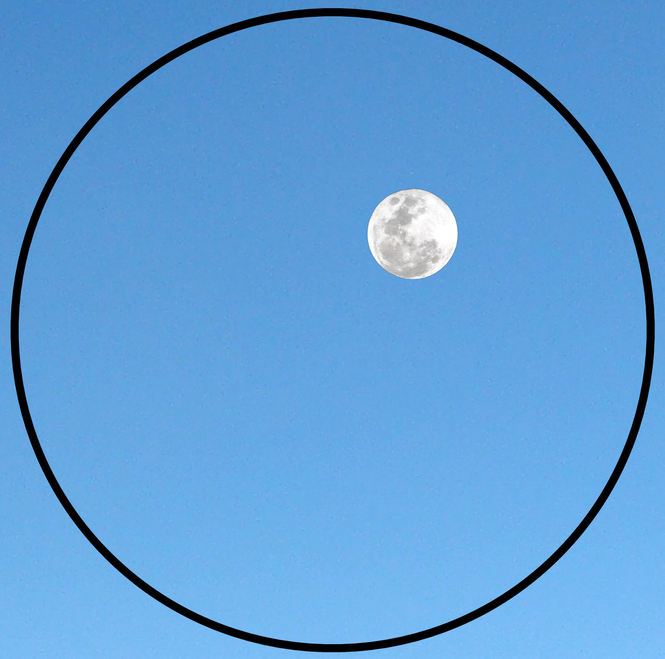
Why does one need a Broker ?

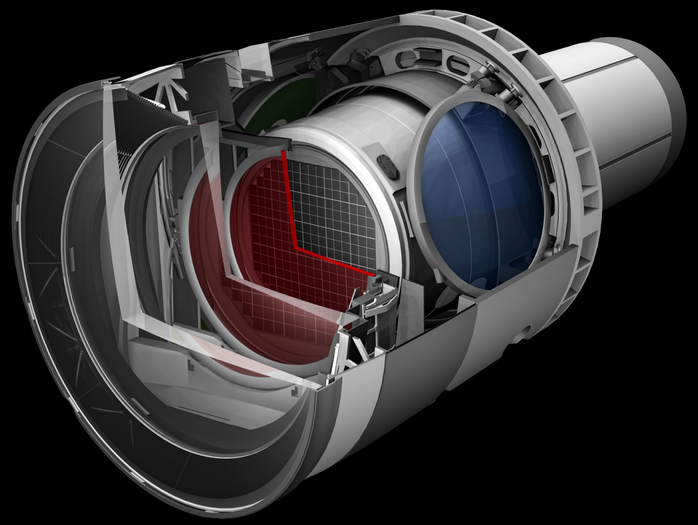


Check out AMPEL

Nordin et al. 2019

Large Synaptic Survey Telescope





3.2 Giga-pixels

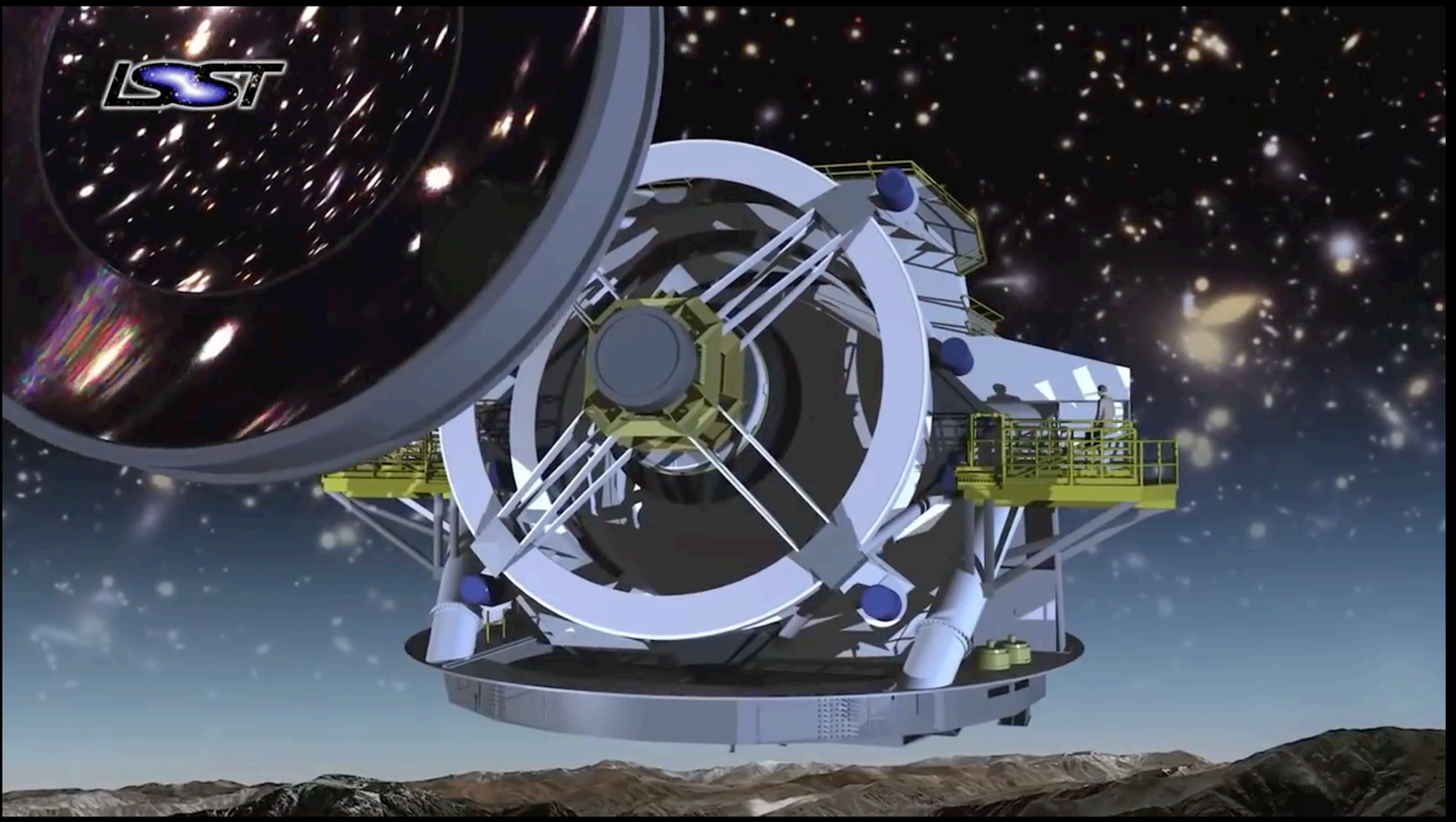
1500 HD screens to see all pixels

2 seconds

Read-out time

20 TeraBit (TB)

Data Volume created per night



8.4m diameter

38s

Between 2 images

10 années

Nominal survey duration

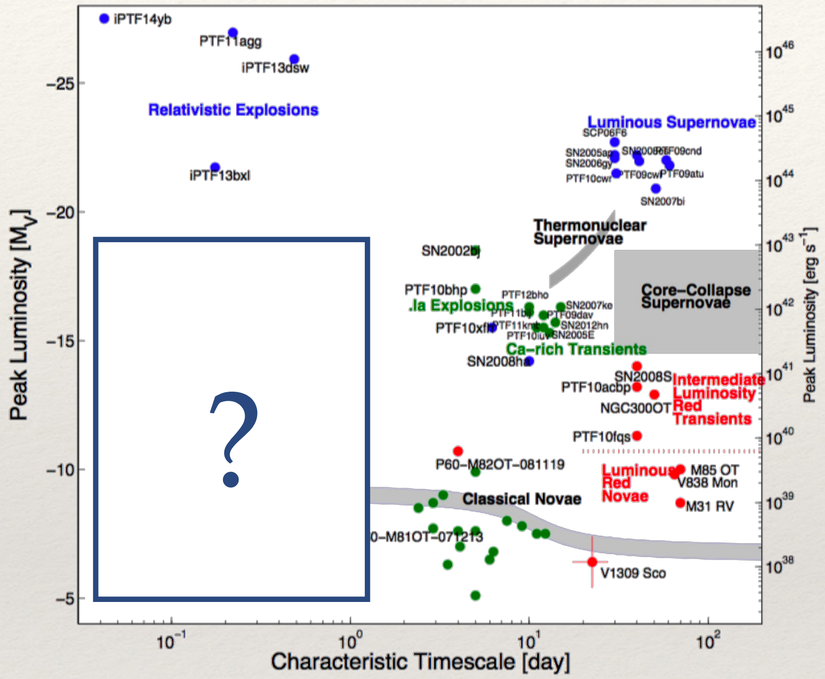
500 000 000 Gigabit

Raw images created

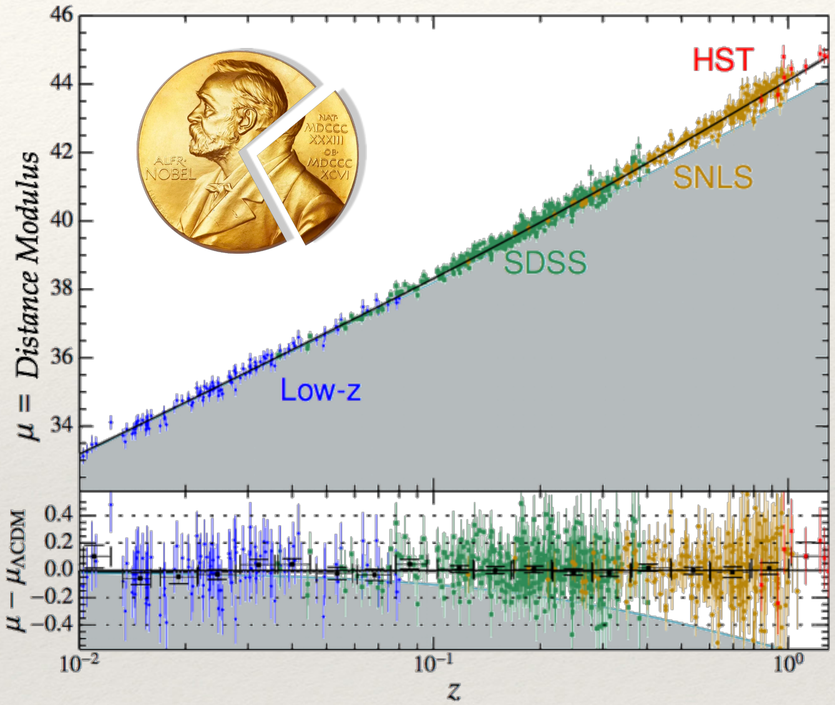
Conclusion

Large Variety of Astrophysical objects

Lots of unknown ones



Cosmology | *Leading probes are transients*

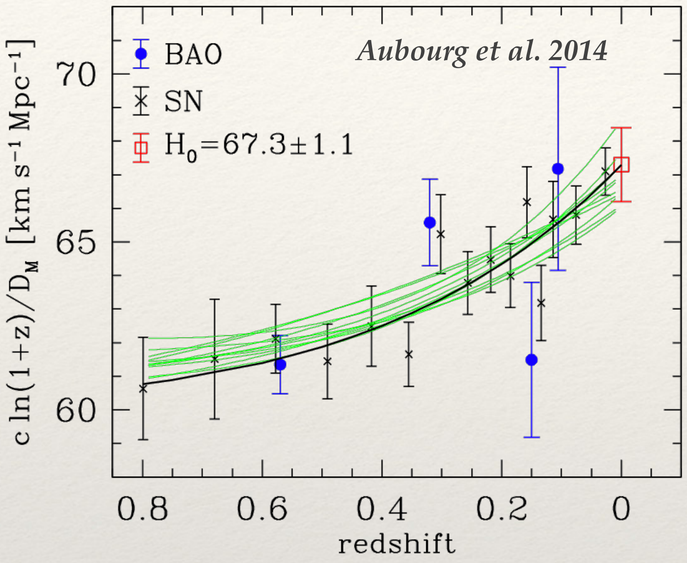


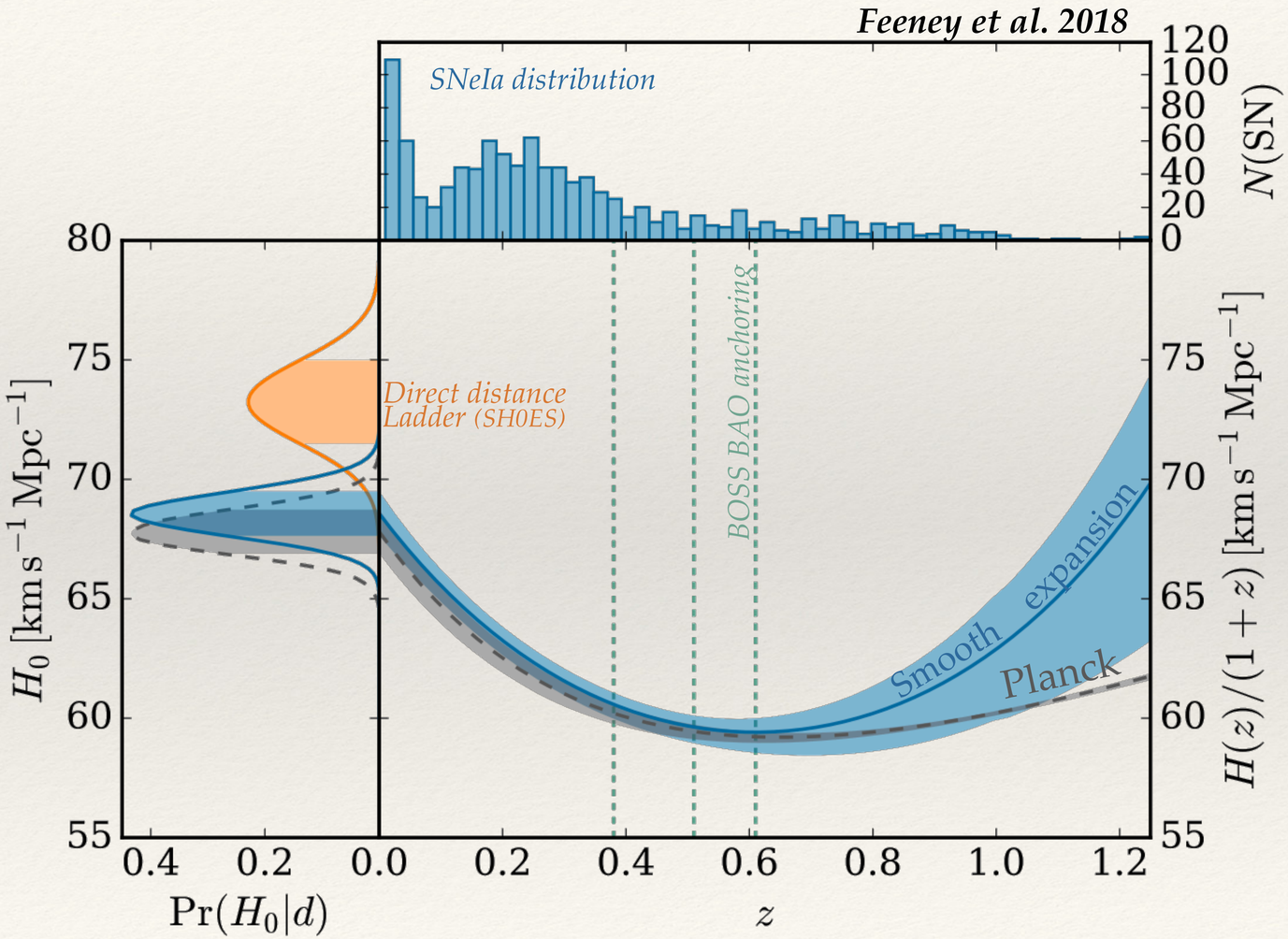
Challenges today | Follow up, Calibrations, Typing, Data processing | *What do we do with 10^6 alerts a day ?*

Next big player | LSST

Inverse Distance Ladder

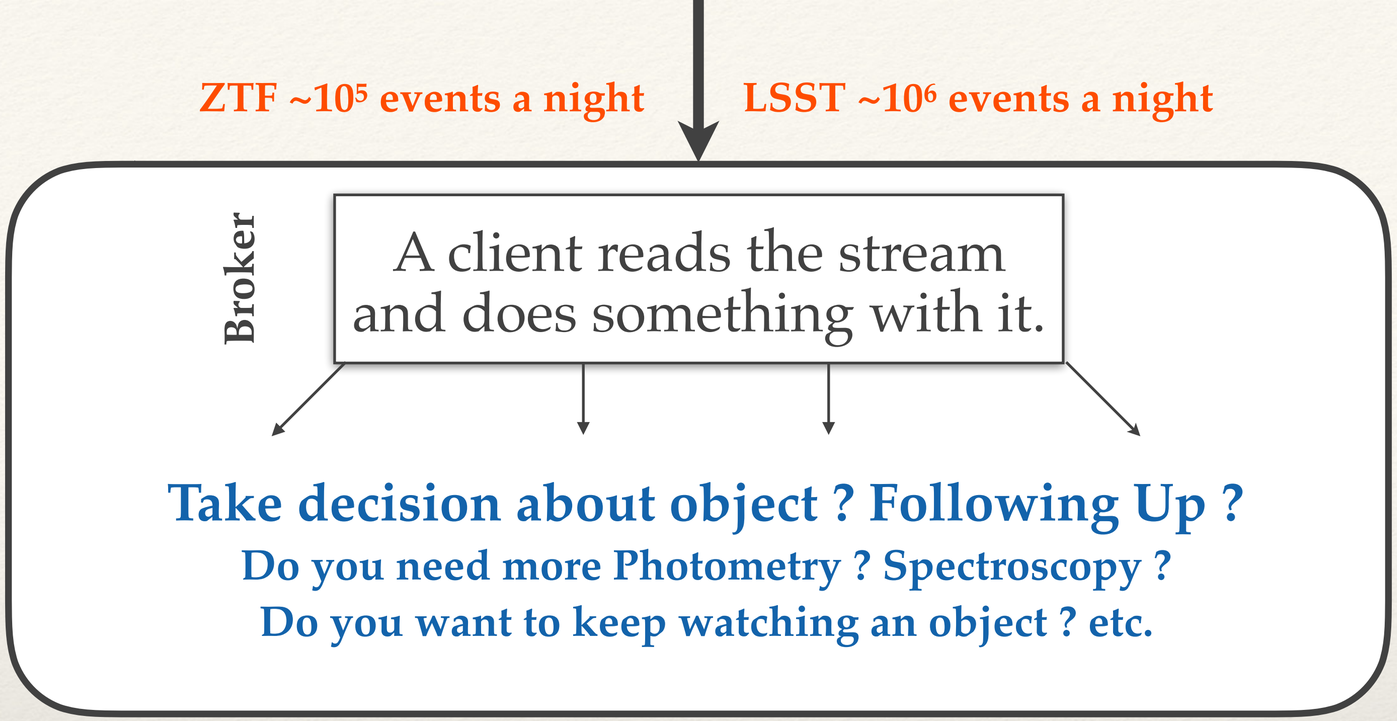
Only using r_d from CMB





ZTF ~10^5 events a night

LSST ~10^6 events a night



— AMPEL —

Alert Management, Photometry and Evaluation of Lightcurves

Nordin et al. 2019

AMPEL | Concept

Nordin et al. 2019

The Filter Stage

The Transient DataBase

The Scientific Analyses

The Decisions

AMPEL | SN Example

Nordin et al. 2019

The Filter Stage

The Transient DataBase

The Scientific Analyses

The Decisions

EXAMPLE | TYPE IA SUPERNOVA COSMOLOGY

"Give me anything that is rising for at least 5 days in at least 2 different bands"

"Keep track of the incoming data and do force photometry if no new data (upper limits)
Re-do photometry if improved software"

- Fit SNeIa lightcurve template and derive:
  (1) Expected Maximum & (2) likelihood to be a "Ia"
- Look for a host redshift in catalogs
  Derive Photo-z on PanStarrs Data if necessary

Is at max ? *Look for an available spectrograph and get a spectrum*

No signal for 20 days ? *Purge it to the Archive DataBase*

AMPEL | SN Example

Nordin et al. 2019

10^5 events/day

The Filter Stage

10^3 events/day

The Transient DataBase

10^2 events/day

The Scientific Analyses

10^1 events/day

The Decisions

EXAMPLE | TYPE IA SUPERNOVA COSMOLOGY

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AMPEL | Neutrino ToO

Nordin et al. 2019

10^5 events/day

The Filter Stage

10^3 events/day

The Transient DataBase

10^2 events/day

The Scientific Analyses

10^1 events/day

The Decisions

EXAMPLE | COSMIC NEUTRINO ALERT

"Give me anything within 1 degree from this location"

"Recover anything of the last 3 month within this region for anything passing the filter "

- Look for a host redshift in catalogs
  Derive Photo-z on PanStarrs Data if necessary

Does this seem real ?
Look for an available spectrograph and get a spectrum

No signal for 20 days ? *Purge it to the Archive DataBase*

AMPEL |GW ToO

Nordin et al. 2019

10^5 events/day

The Filter Stage

10^3 events/day

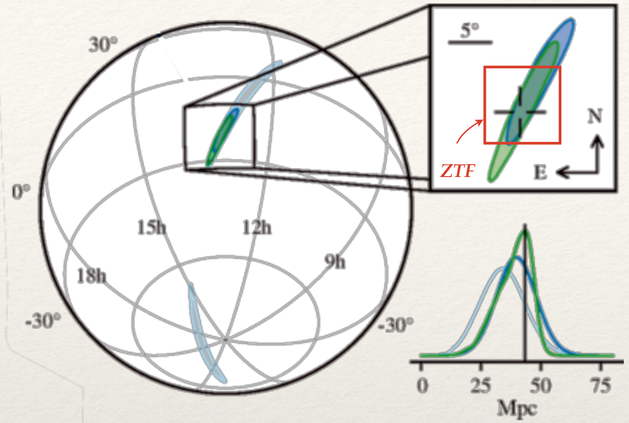
The Transient DataBase

10^2 events/day

The Scientific Analyses

10^1 events/day

The Decisions



Abbot et al. (2017), PRL 119, 161101

EXAMPLE | GW ALERT

"Give me anything within the location contours"

"Recover every former alerts within the last 2 days that could have passed the new cut "

- Look for a host redshift in catalogs
  Derive Photo-z on PanStarrs Data if necessary
- Check galaxy catalogs and give *p(host)*

Does this seem real ?
Look for an available spectrograph and get a spectrum

No signal for 10 days ? *Purge it to the Archive DataBase*