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Dr. Andreas Papadopoulos
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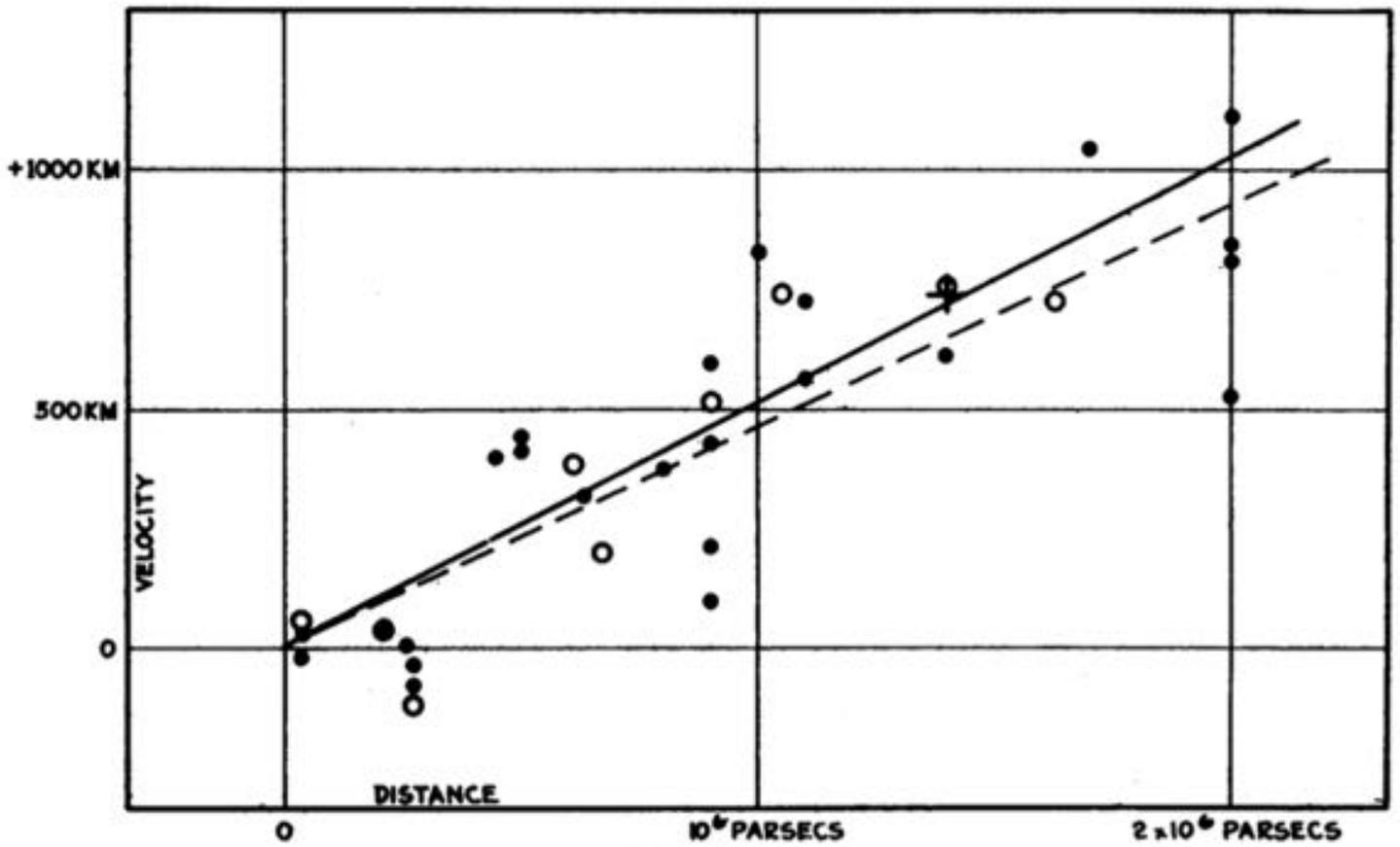
Dr. Mark Sullivan
Prof. Bob Nichol
DES Supernovae Working Group

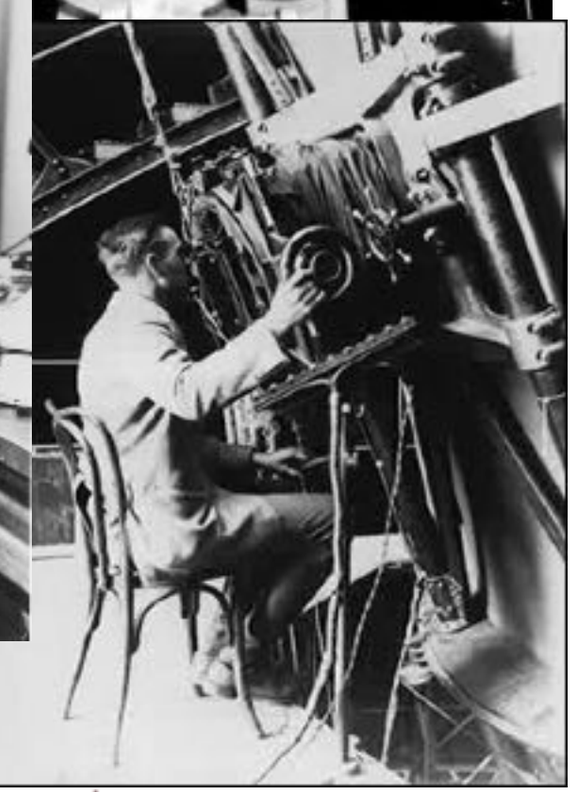
Supernovae & Cosmology
Dark Energy Survey

AHPC

27-October-2015
European University Cyprus

History of the Universe





Edwin Hubble is shown looking through the 100-inch telescope at the Mt. Wilson Observatory (photo date:~1922).

Galaxies further away are moving faster.

$$\upsilon = H_0 \times d$$

The Universe is Expanding!

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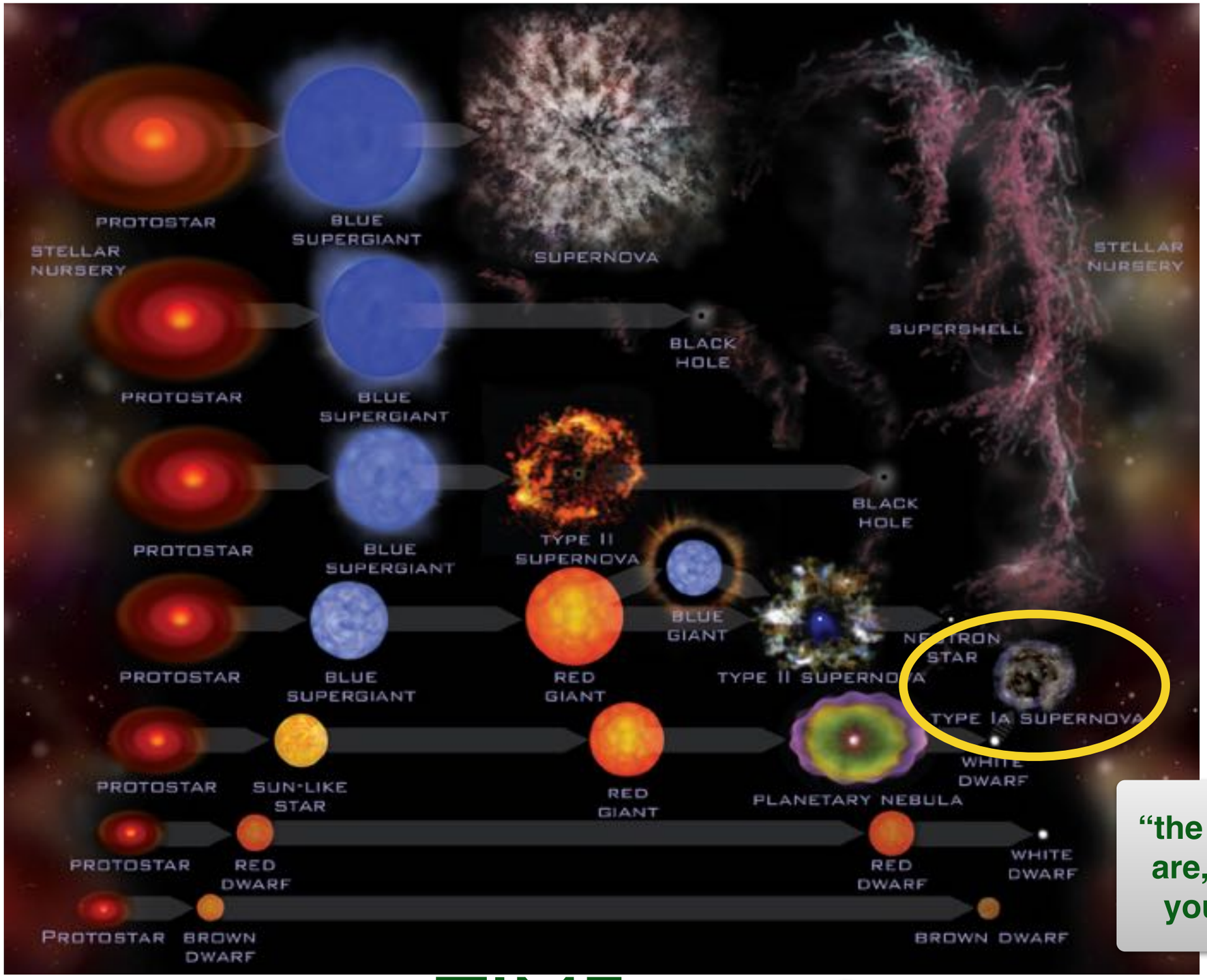
Supernovae - SNe

MASS



TIME

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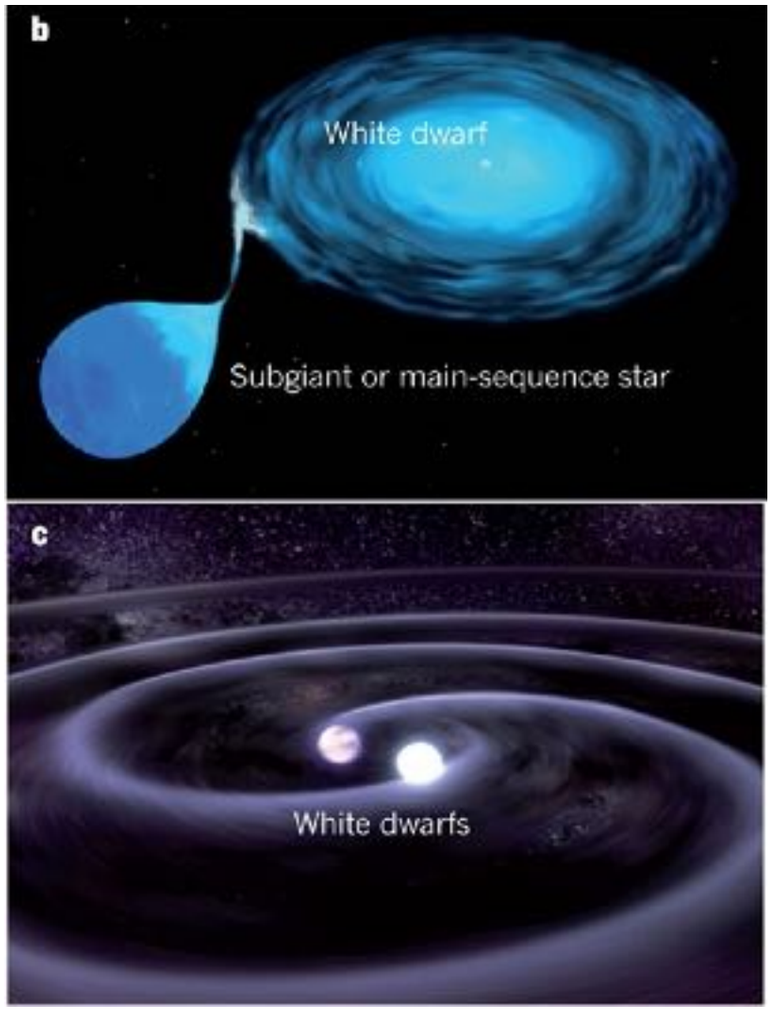
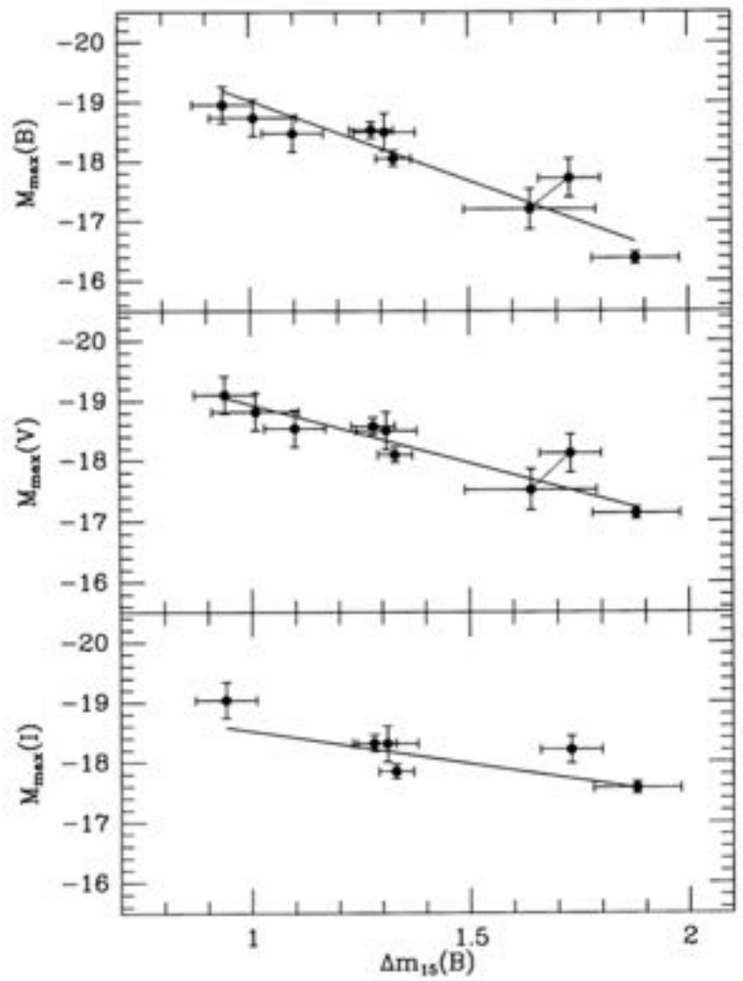
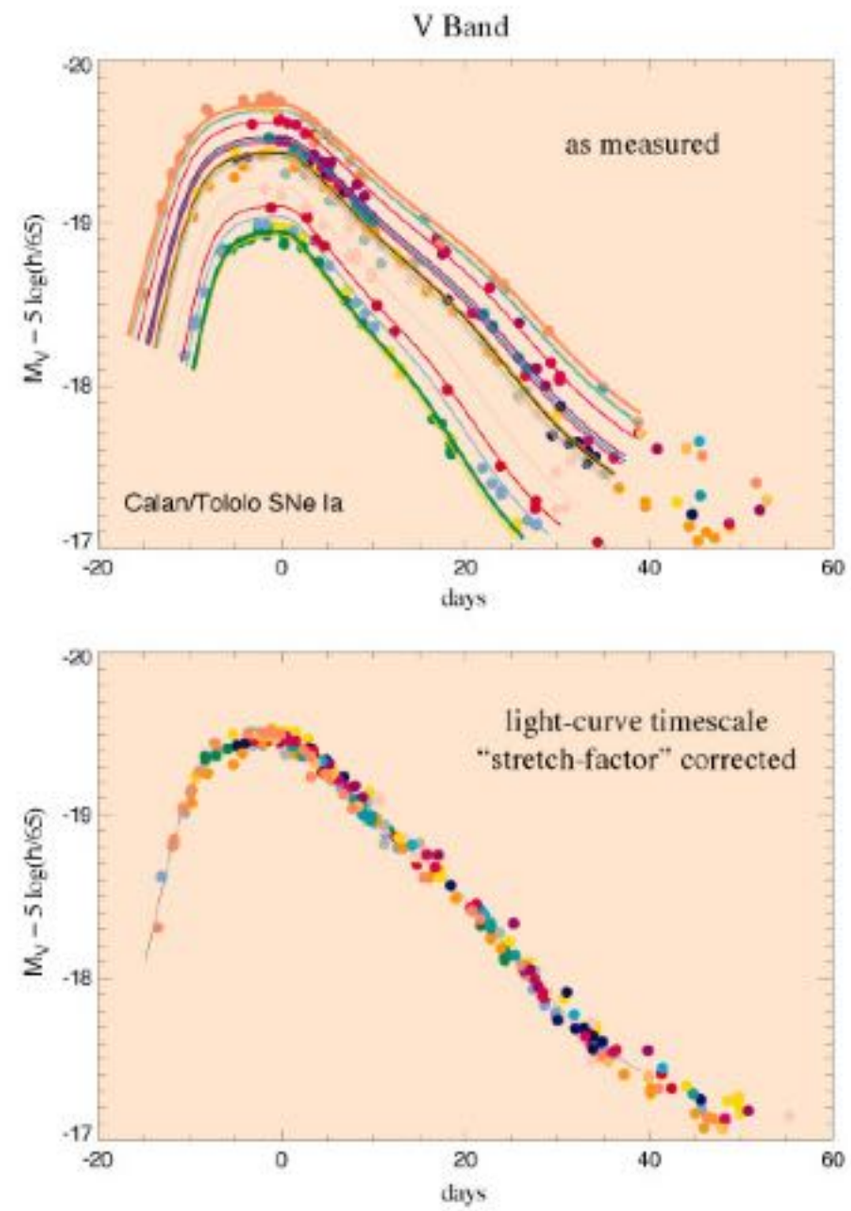
SNe type Ia



White Dwarfs accreting mass
M~1.4M$_\odot$
Thermonuclear explosion

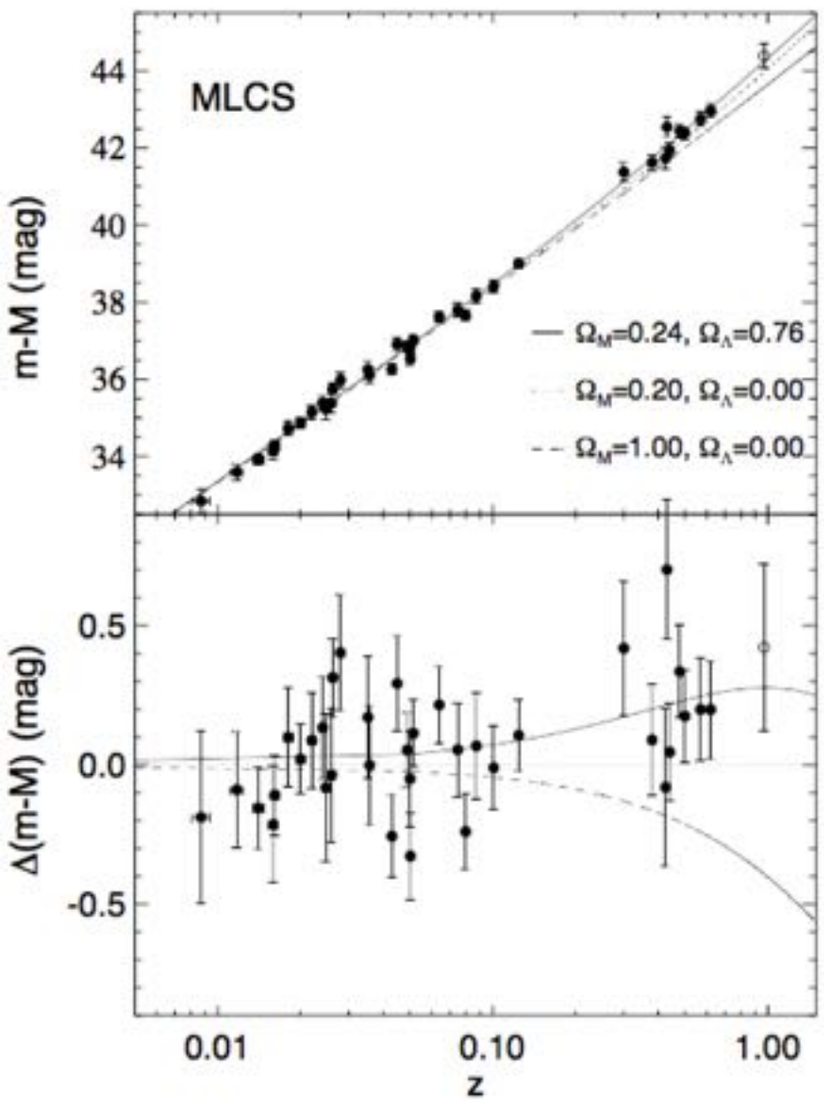


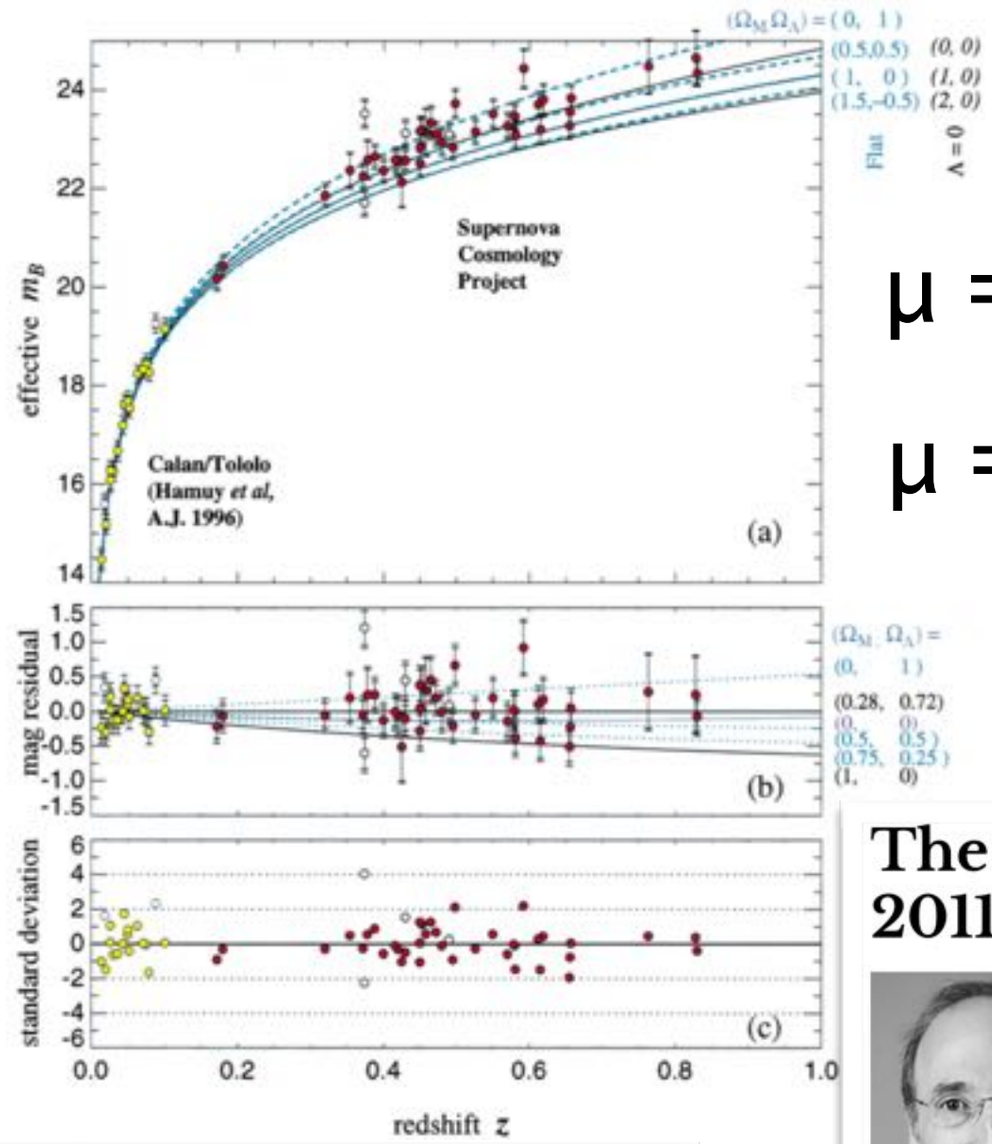
Phillips et al. 1993



Supernova Cosmology Project

Universe & the Accelerating Expansion





$$\mu = m_B - M + \alpha x - \beta c$$

$$\mu = f\,[z, \Omega_m, \Omega_\Lambda, w(z)]$$

The Nobel Prize in Physics 2011 was divided, one half awarded to Saul Perlmutter, the other half jointly to Brian P. Schmidt and Adam G. Riess *"for the discovery of the accelerating expansion of the Universe through observations of distant supernovae"*.

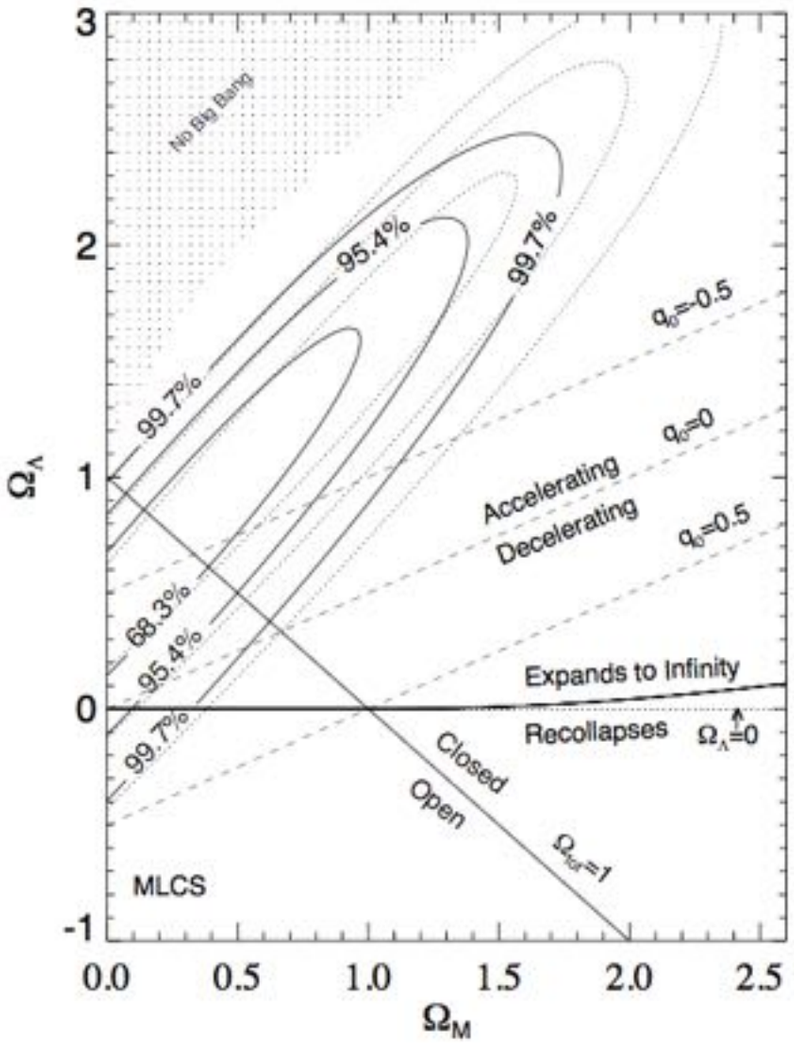
The Nobel Prize in Physics 2011

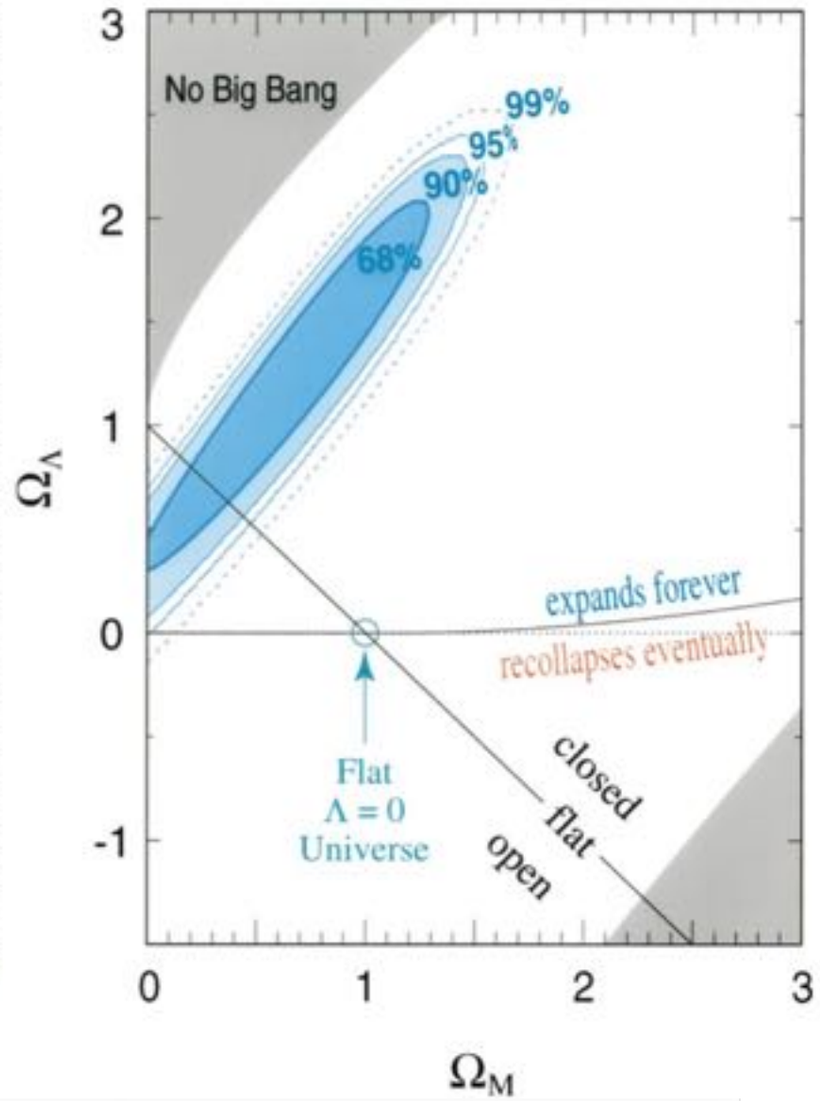
Photo: U. Montan
Saul Perlmutter

Photo: U. Montan
Brian P. Schmidt

Photo: U. Montan
Adam G. Riess

Universe & the Accelerating Expansion





$$\mu = f\,[z, \Omega_m, \Omega_\Lambda, w(z)]$$

Amount of Matter ~ 30%

Amount of Dark Energy ~70%

Equation of state for Dark Energy

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The Nobel Prize in Physics 2011

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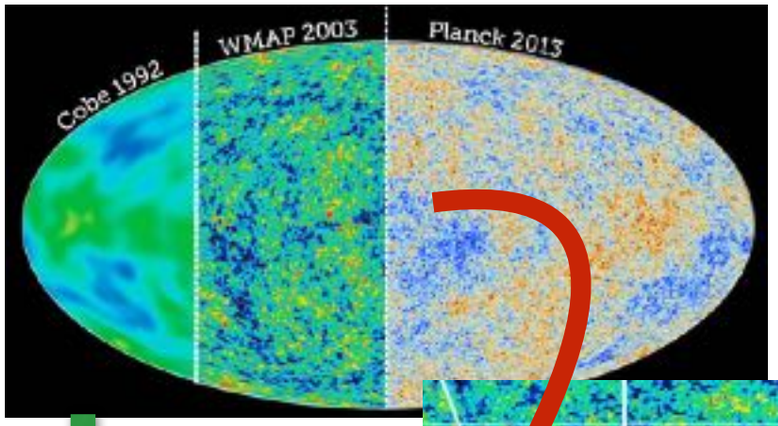
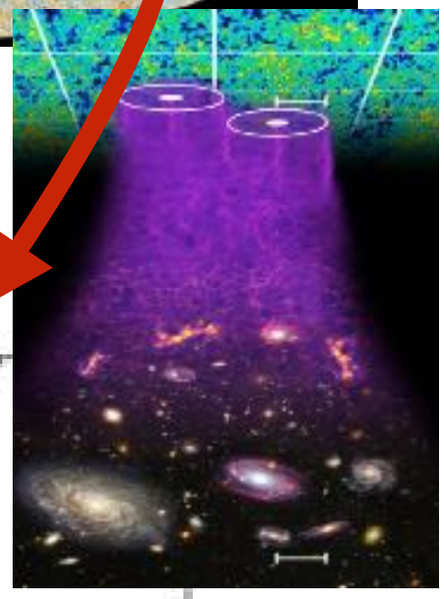
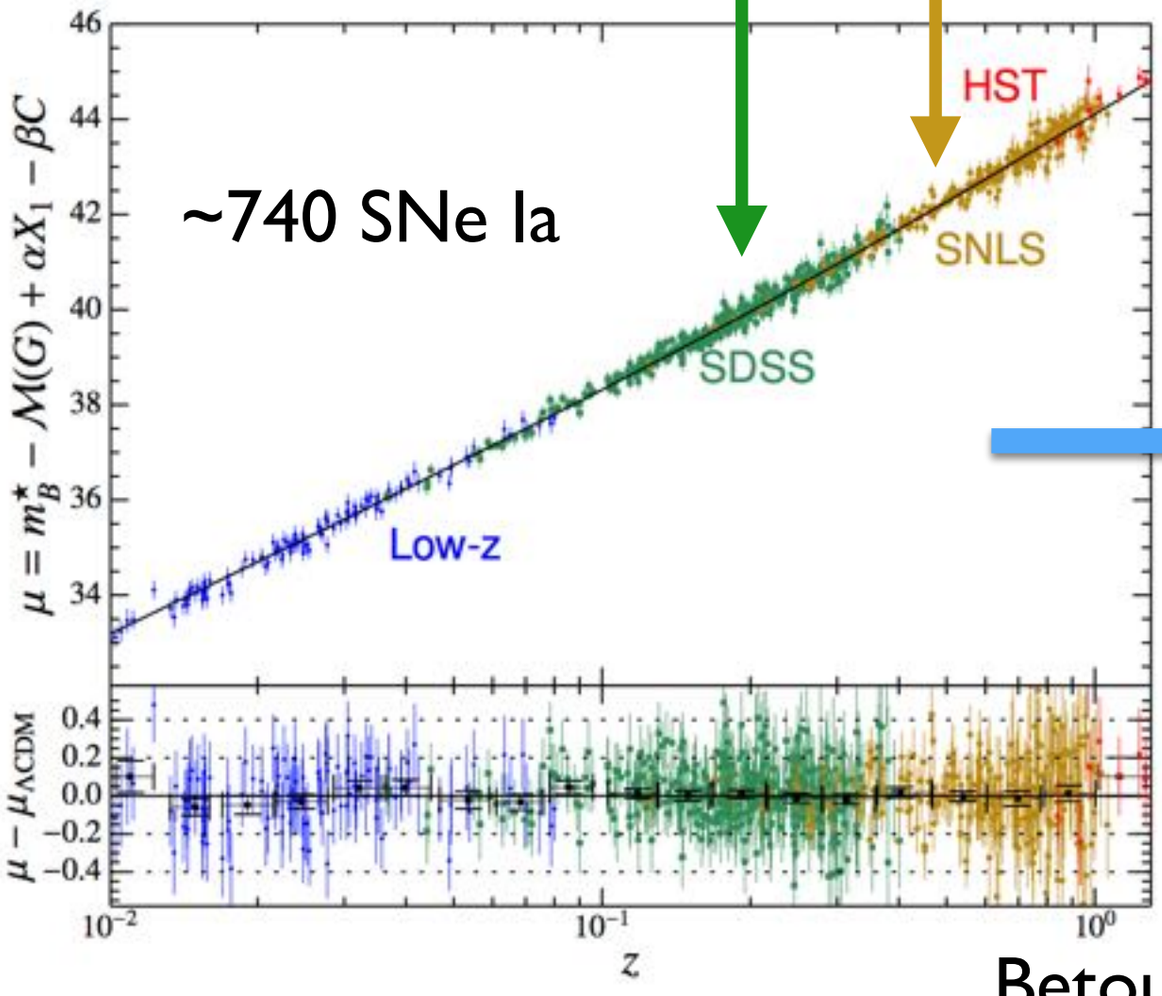
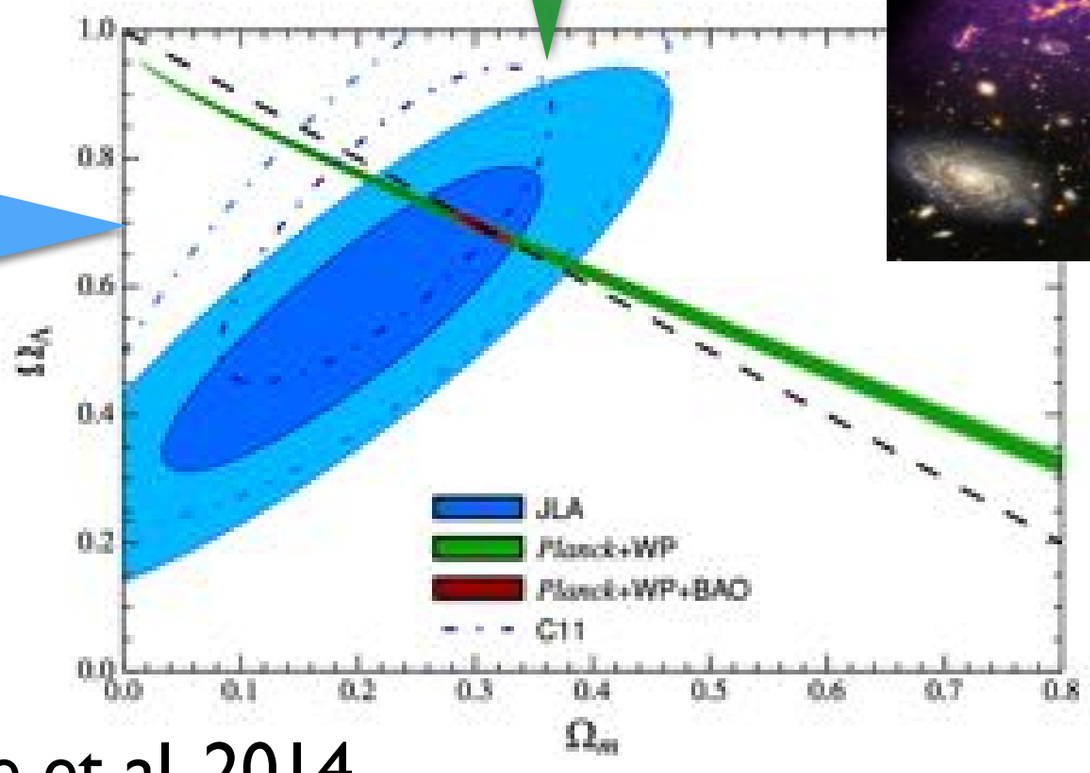
Universe & the Accelerating Expansion









Betoule et al. 2014

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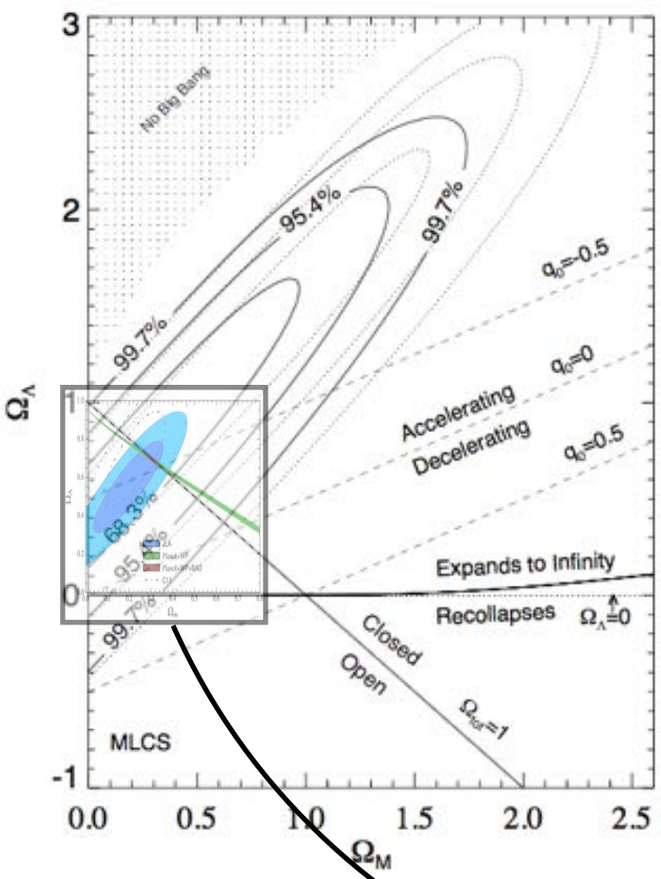
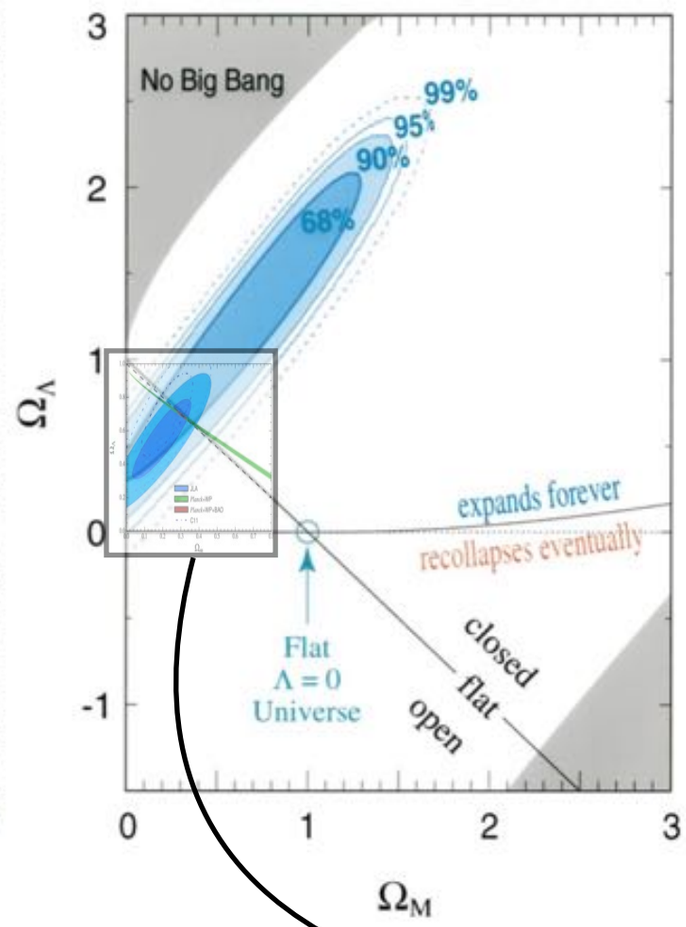
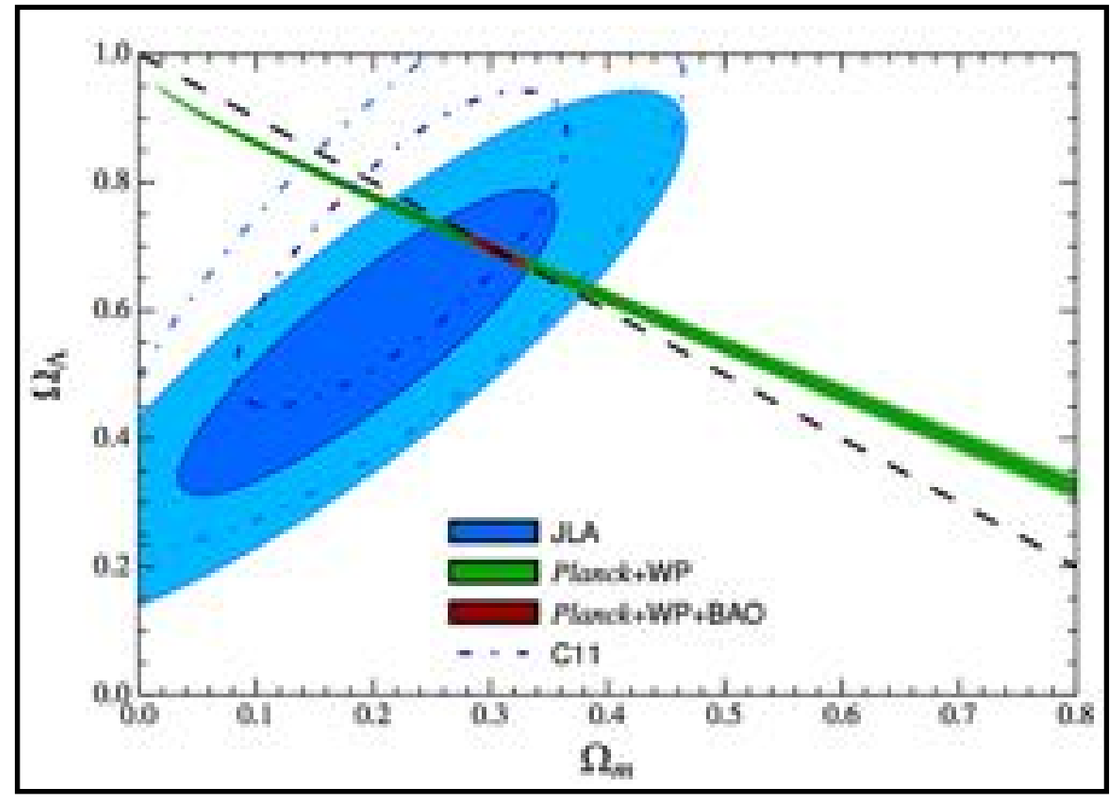
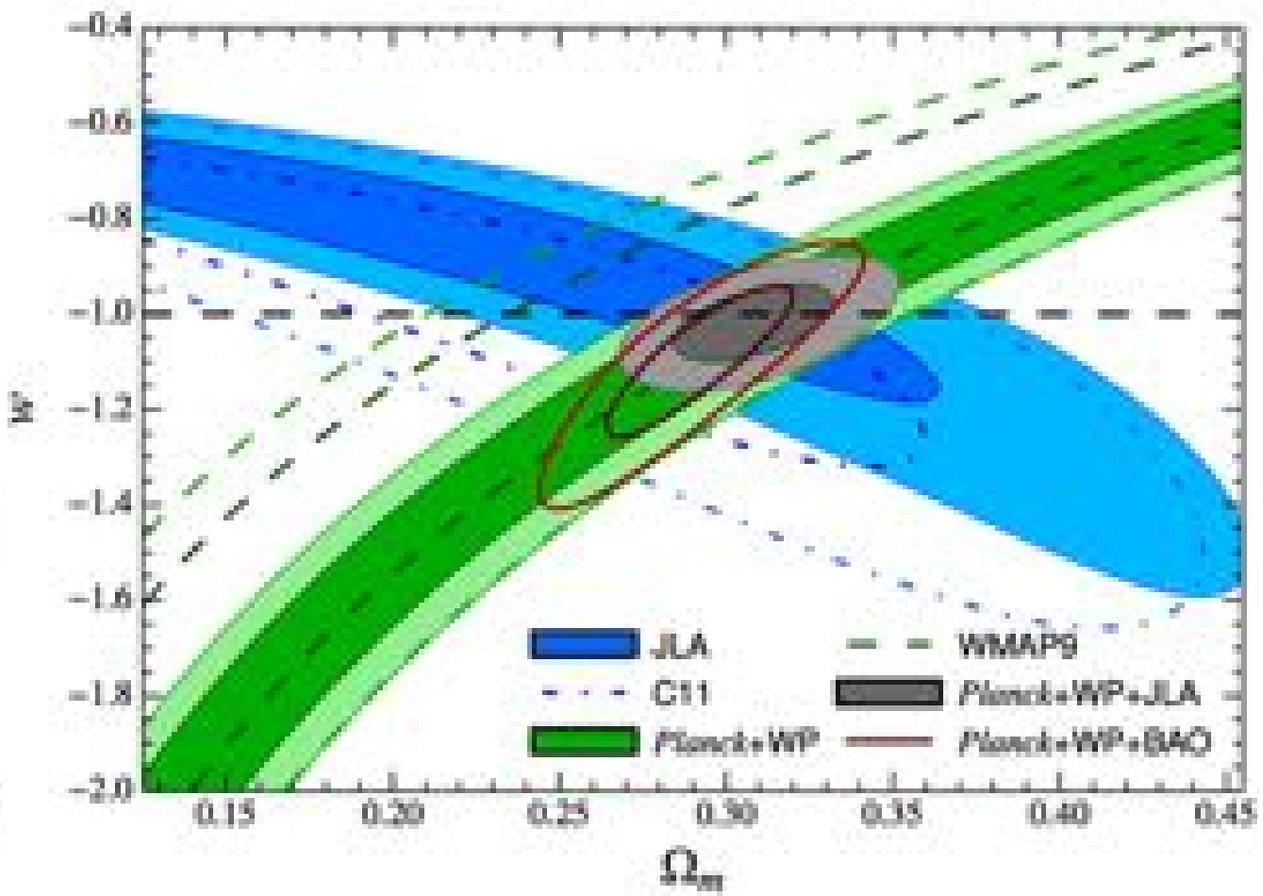




Betoule et al. 2014

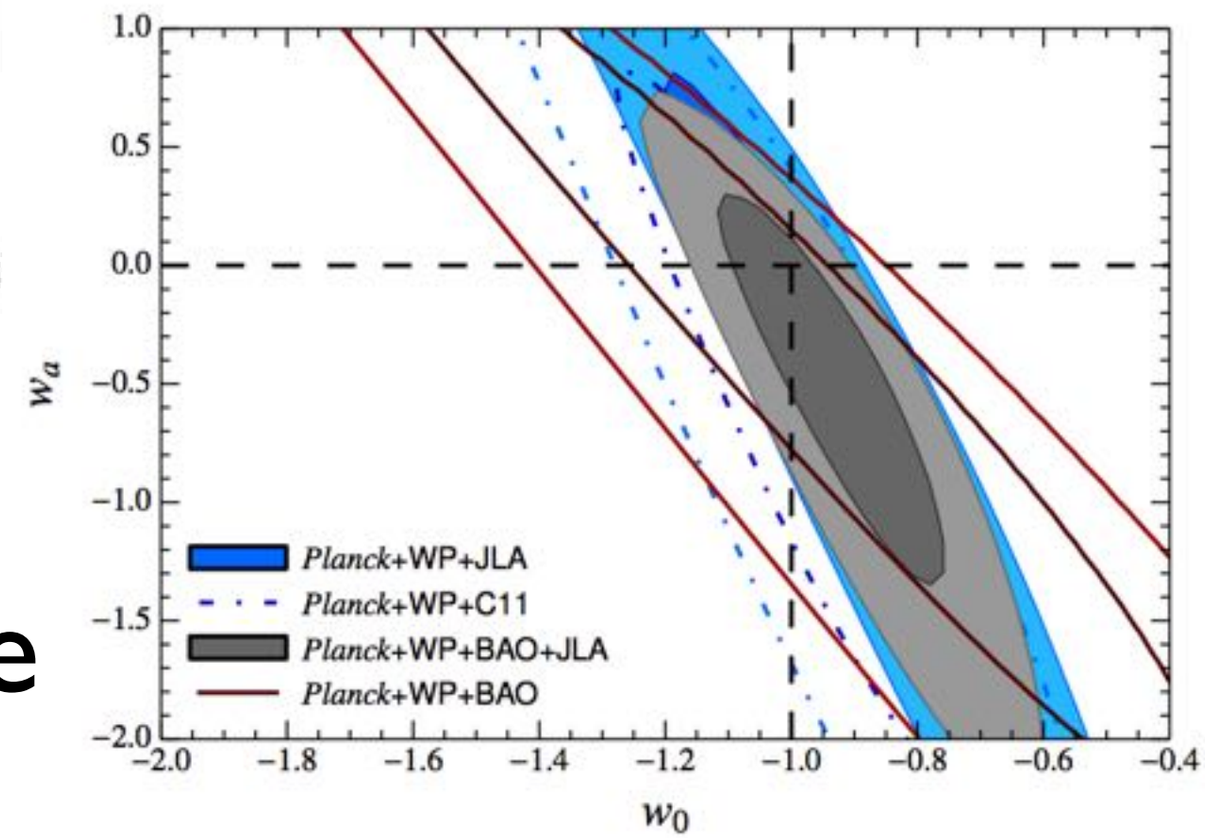


Universe & the Accelerating Expansion



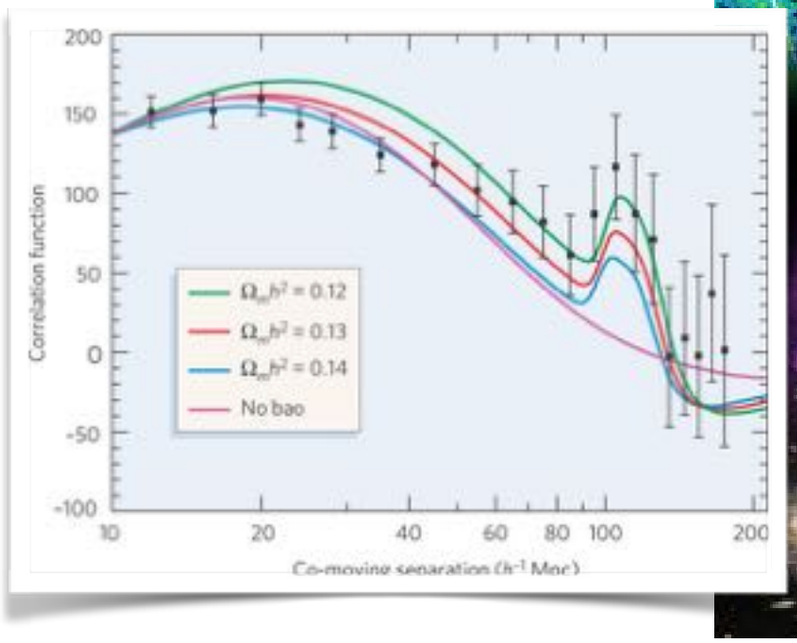
Ω_m = 29.5%
Ω_Λ = 70.5%
w = 1.018 +/- 0.057

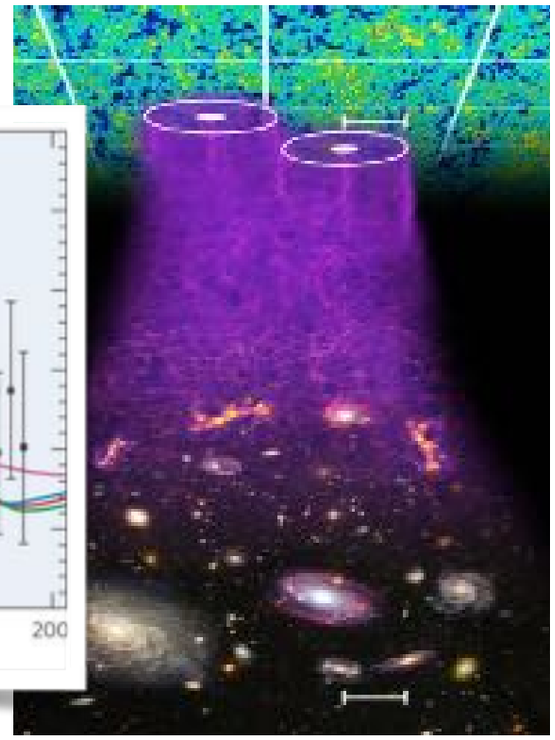
Betoule et al. 2014

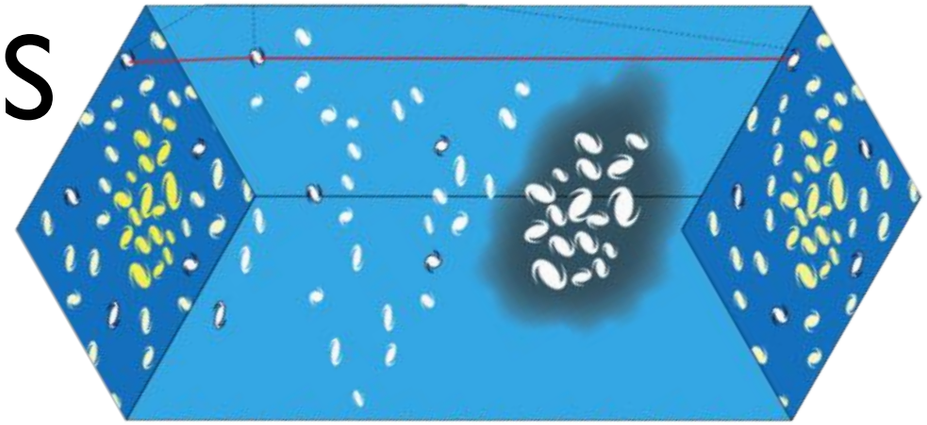


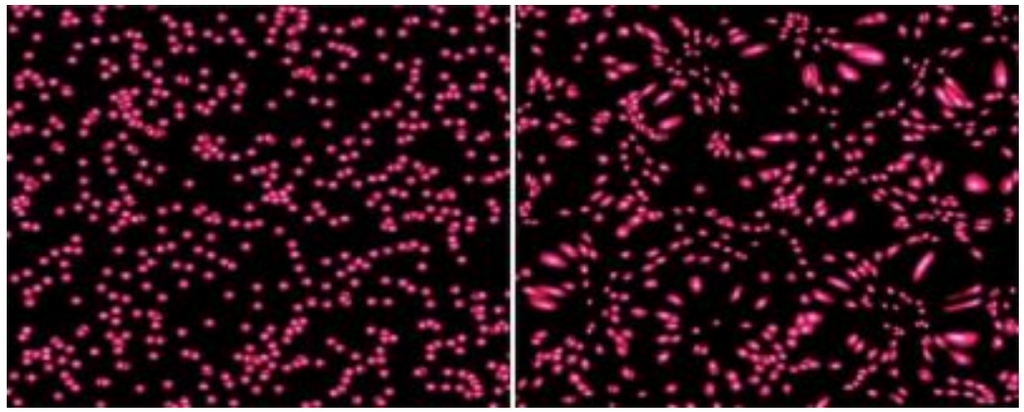
$w_\alpha = dw/d\alpha$
change of w with time

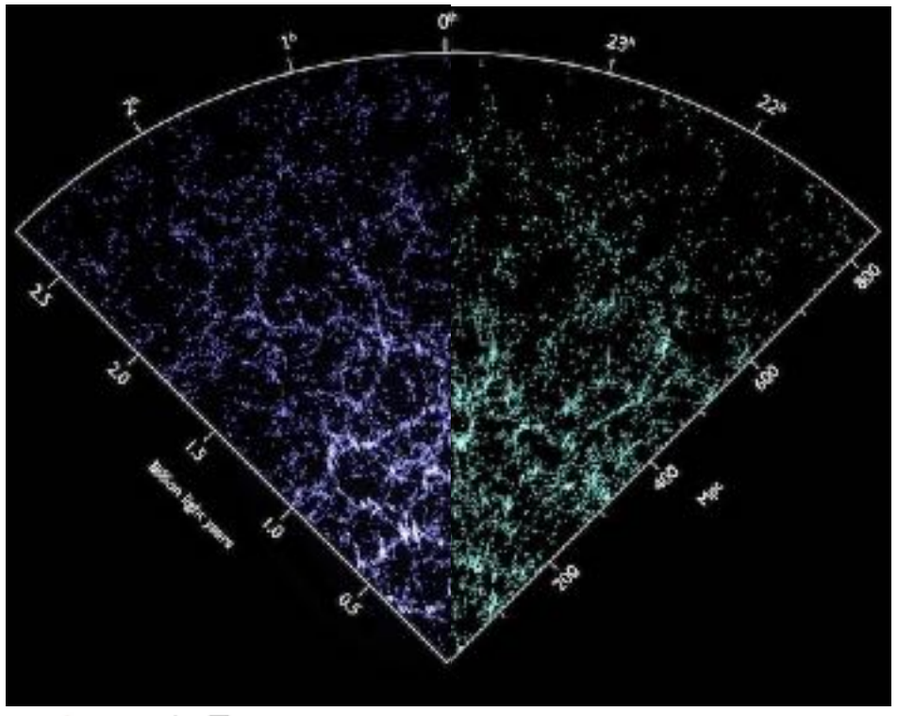
Dark Energy Survey - DES











Dark Energy probes:

1. Barionic Acoustic Oscillations
2. Weak (gravitational) Lensing
3. Galaxy Clustering
4. Sueprnovae Ia

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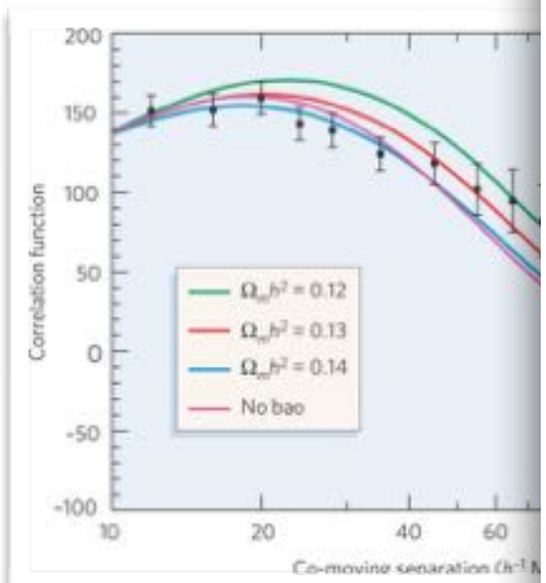

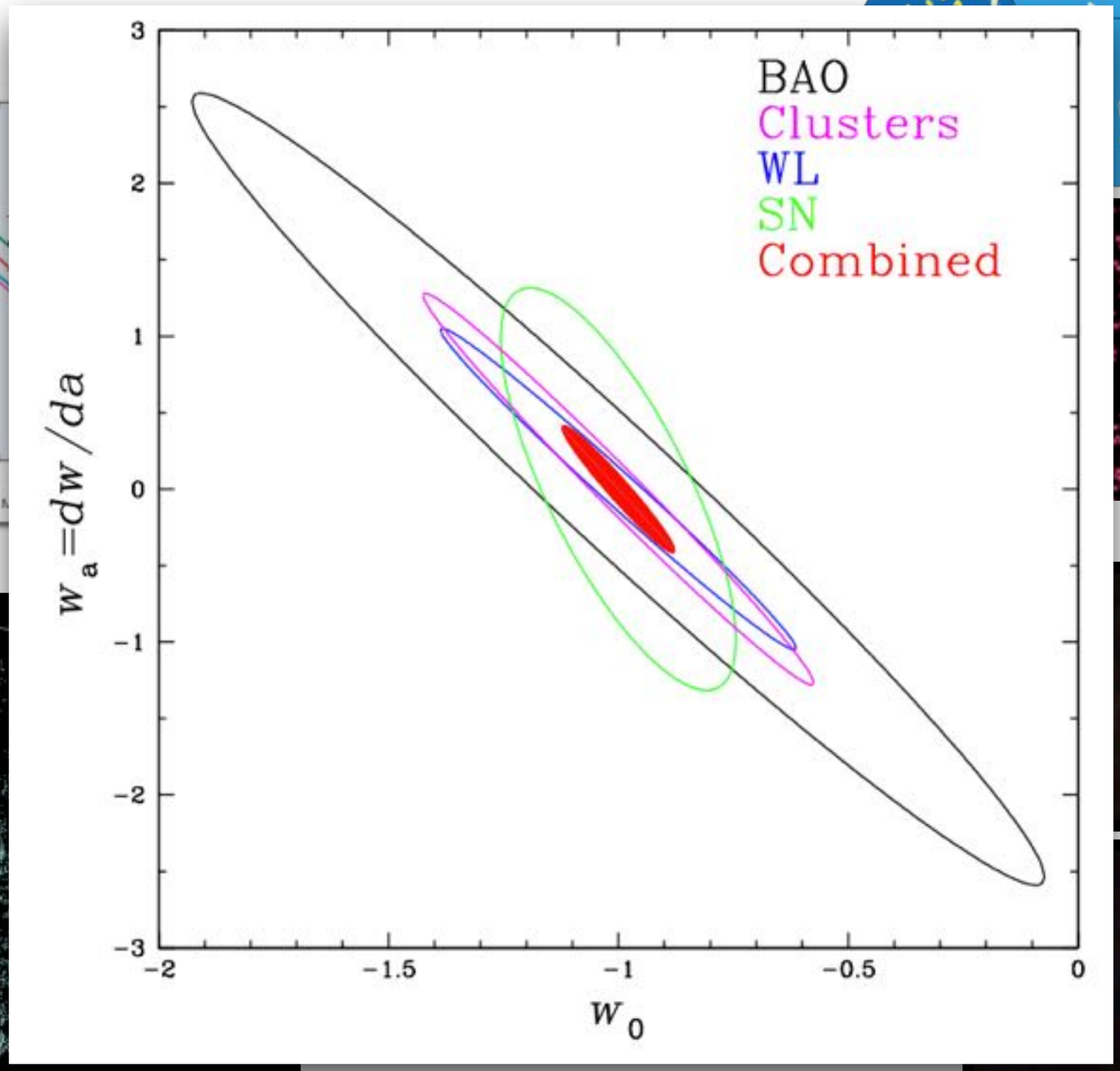

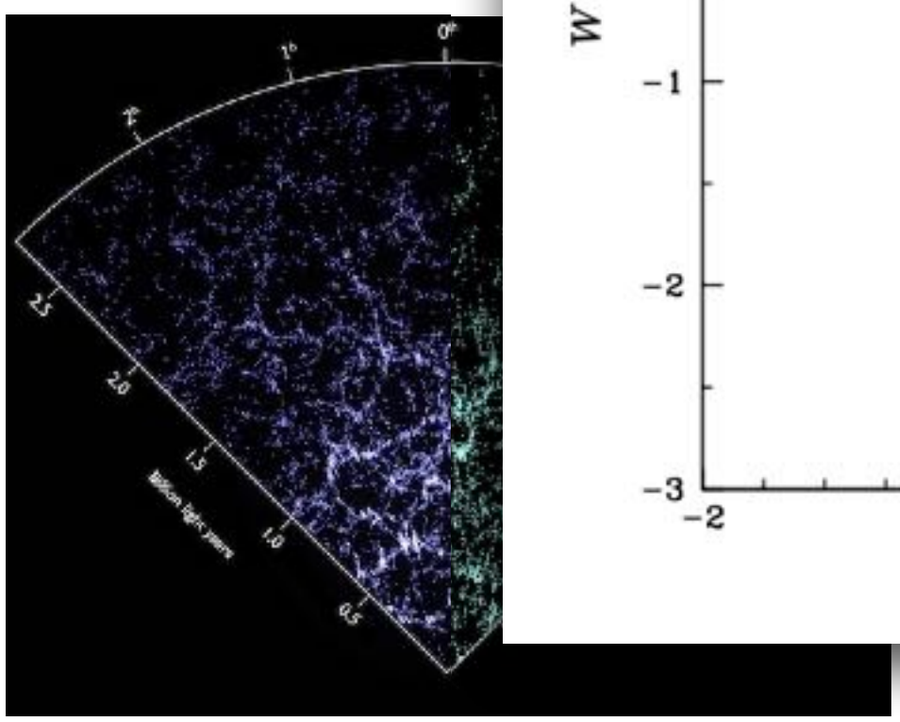

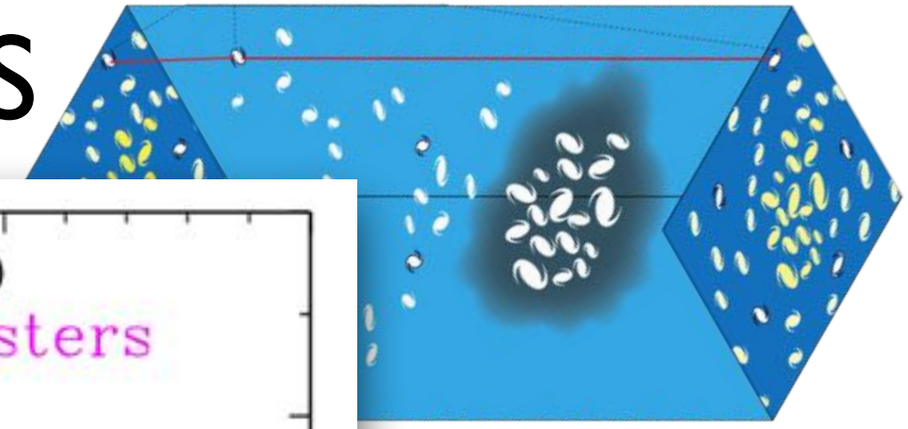

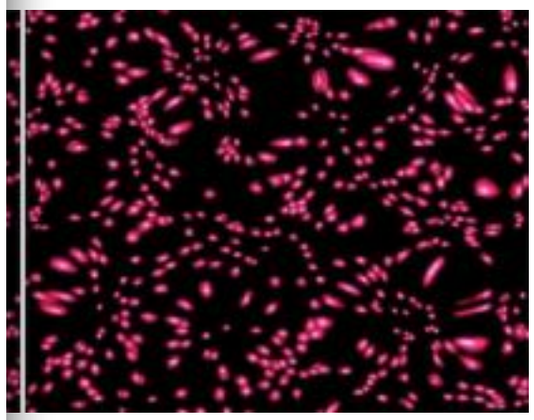

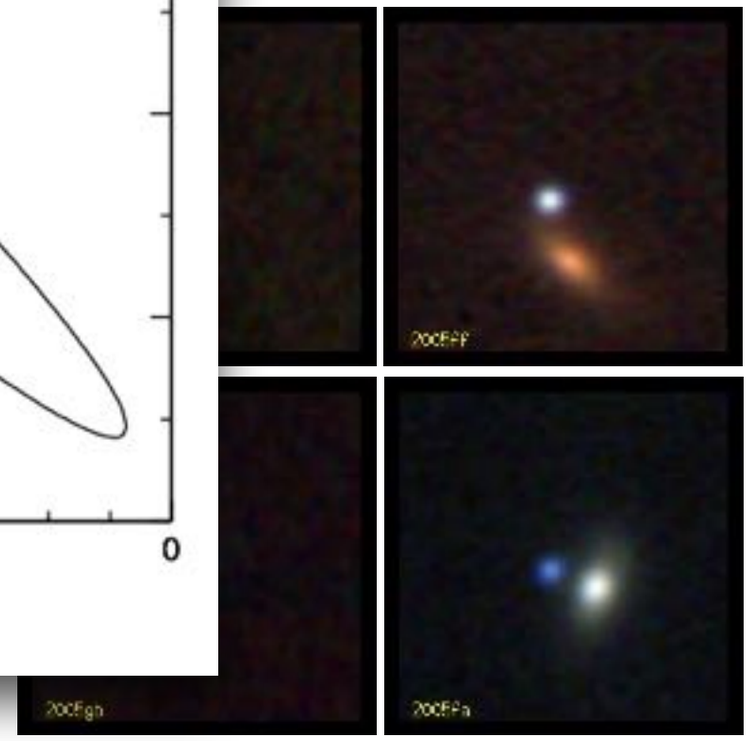

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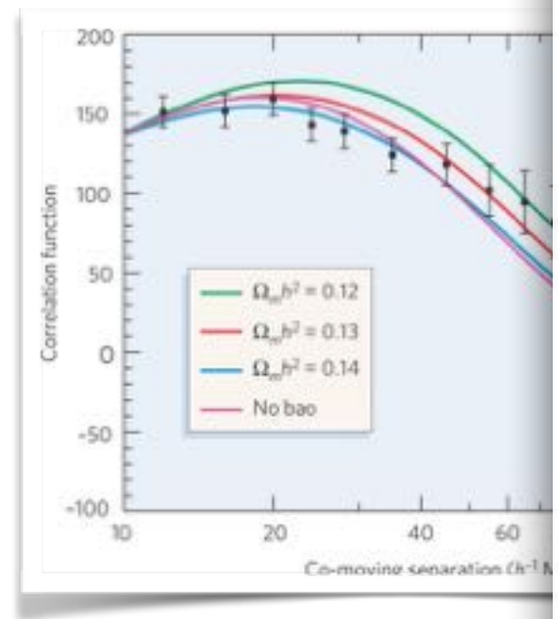

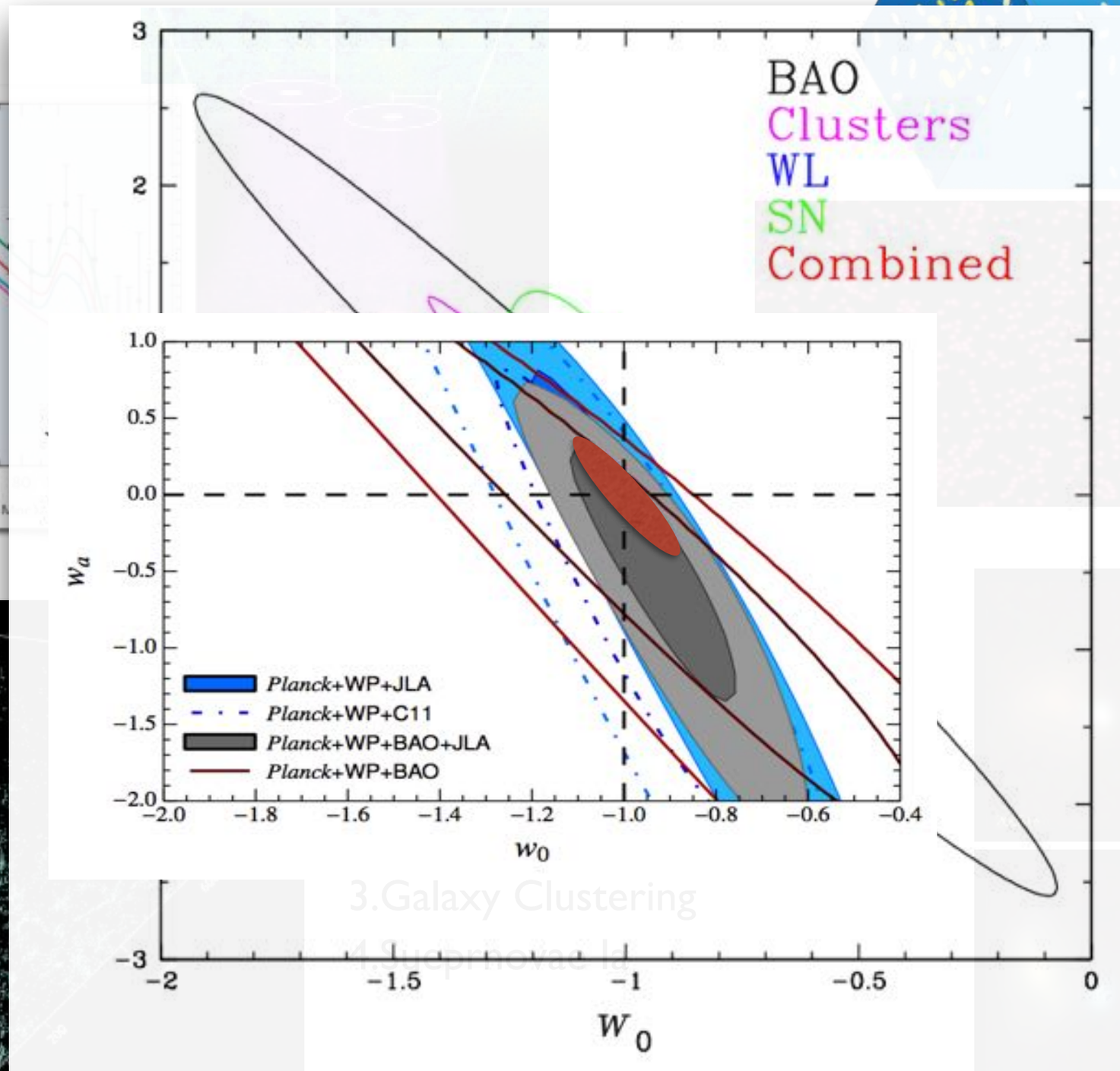

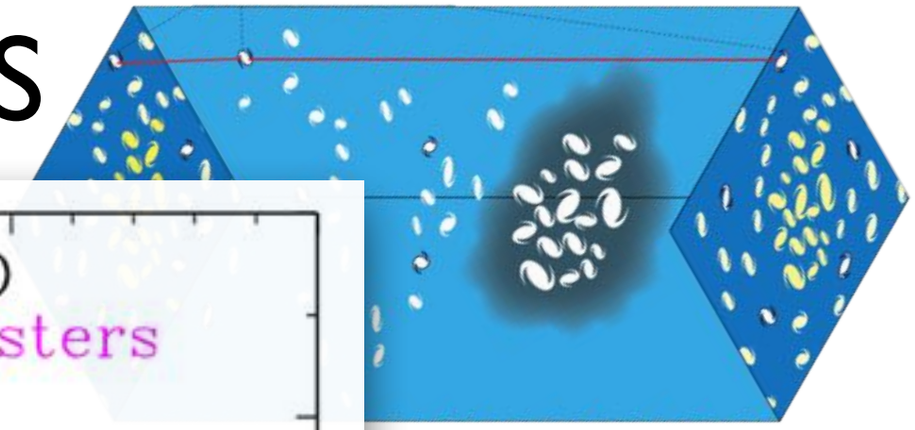

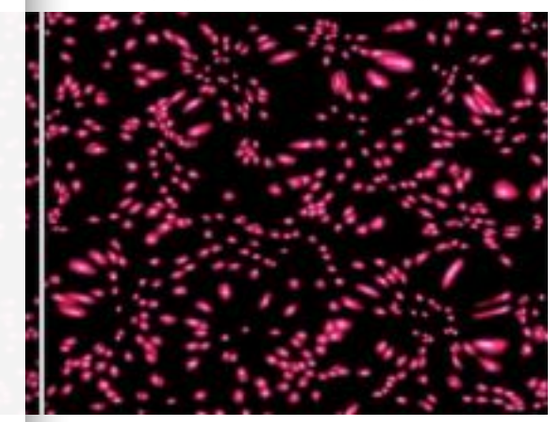

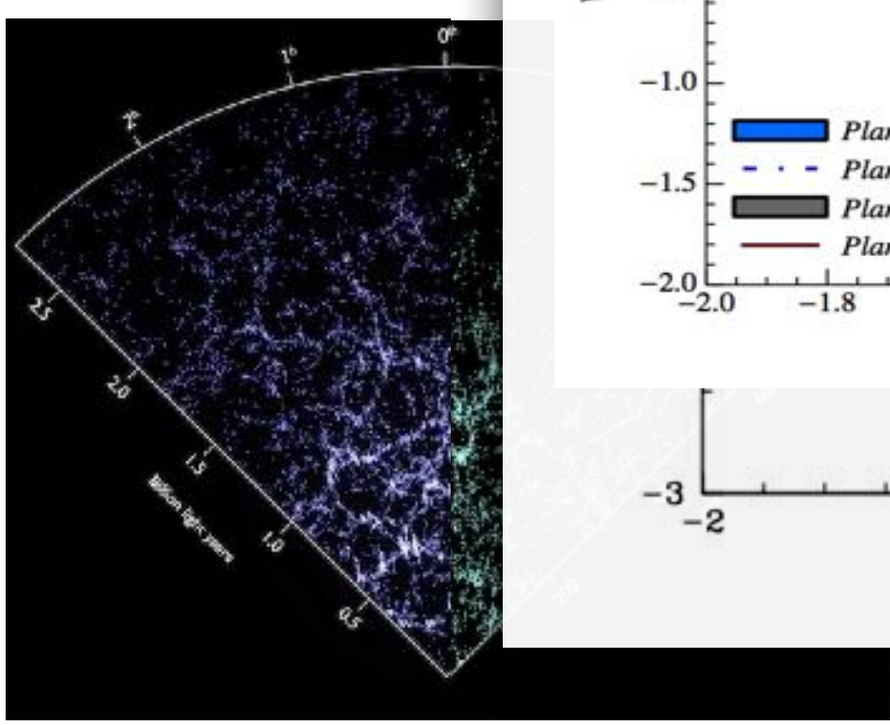

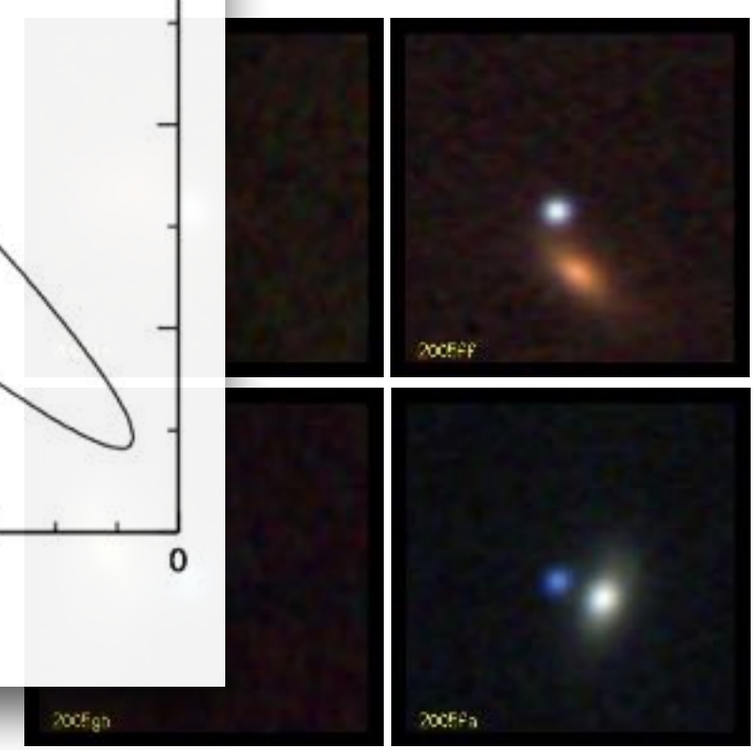

3.Galaxy Clustering

4.Supernovae Ia

Dark Energy Survey - DES

<u>Location:</u>

- Cerro Tololo, Chile
- 2207 m

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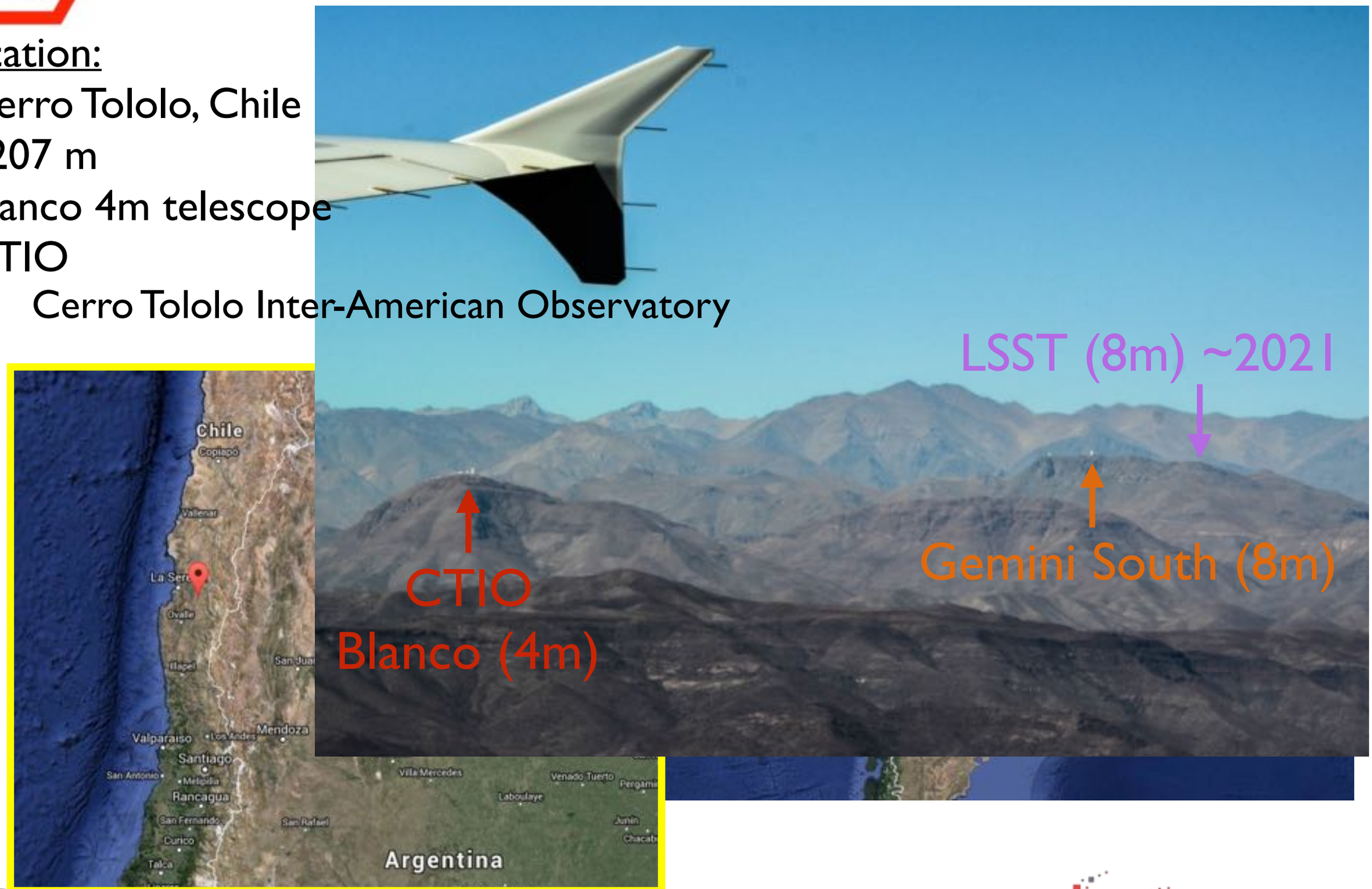
Dark Energy Survey - DES

<u>Location:</u>

- Cerro Tololo, Chile
- 2207 m
- Blanco 4m telescope
- CTIO
  - Cerro Tololo Inter-American Observatory



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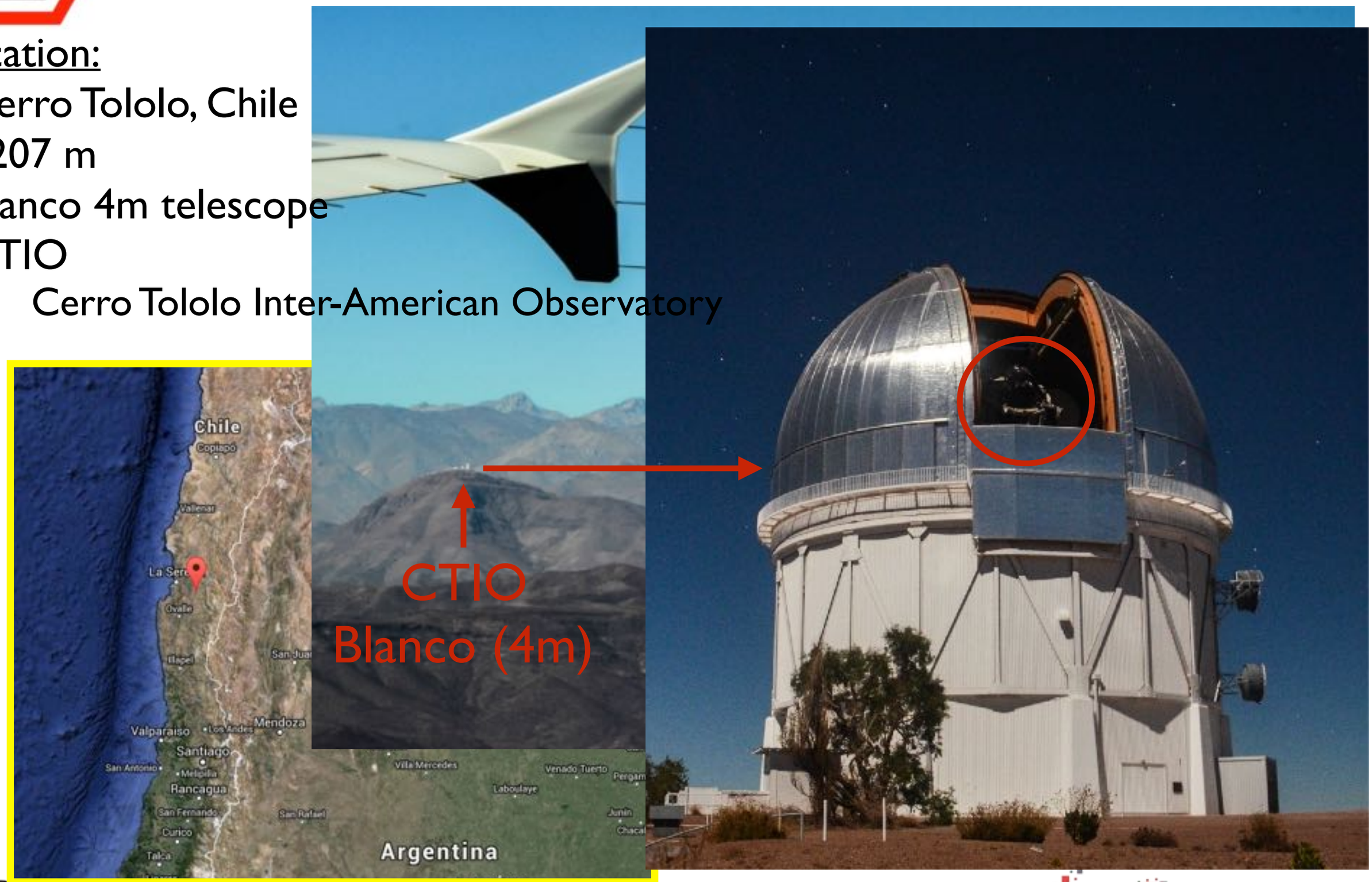

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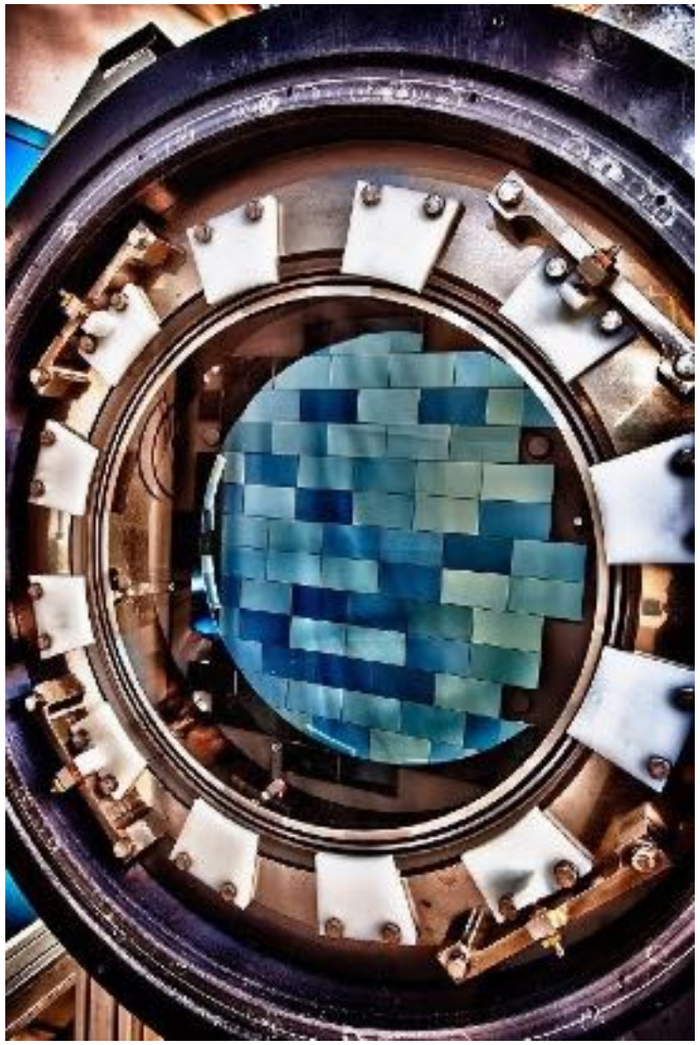
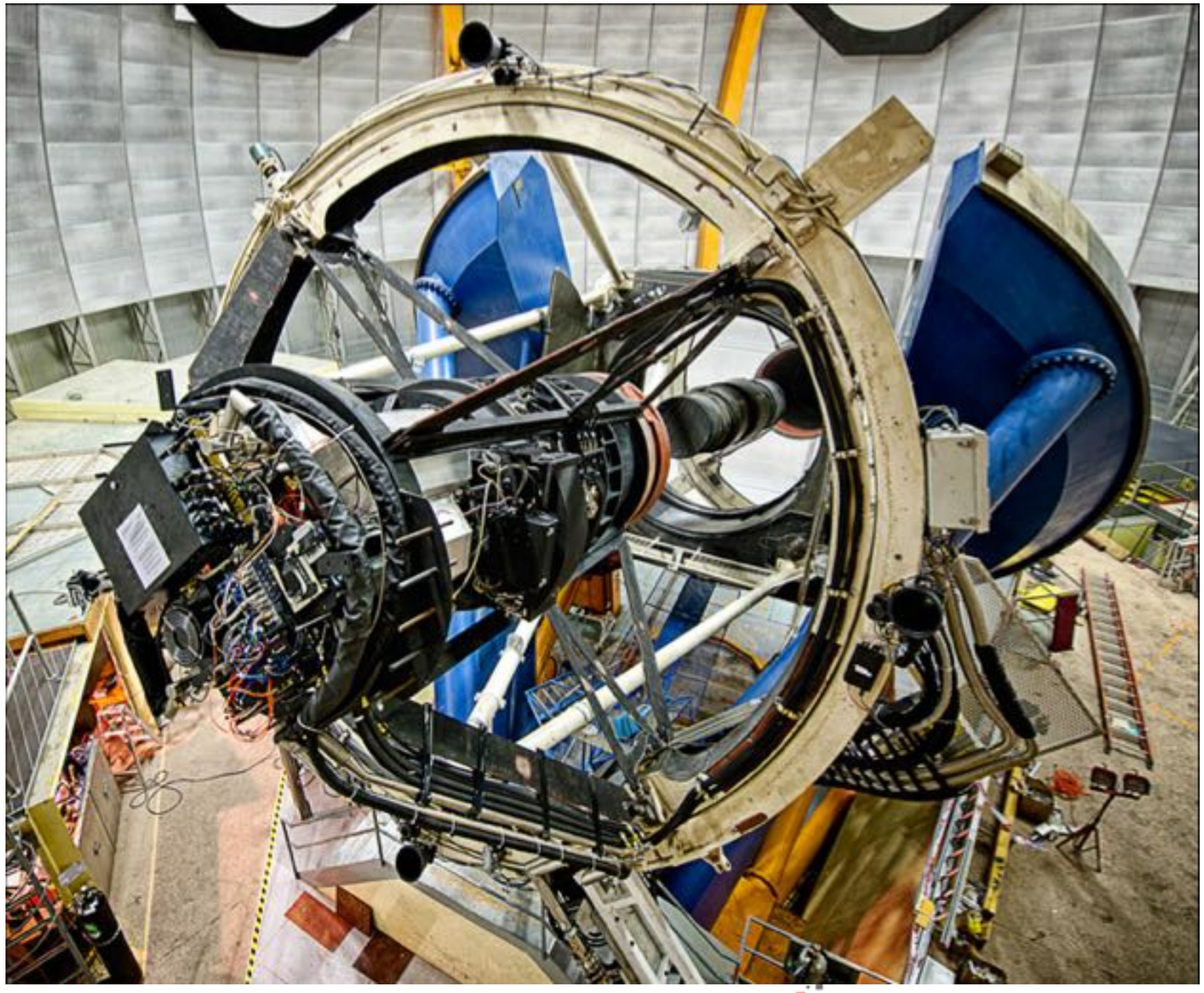
Dark Energy Survey - DES

Dark Energy Camera - DECam:





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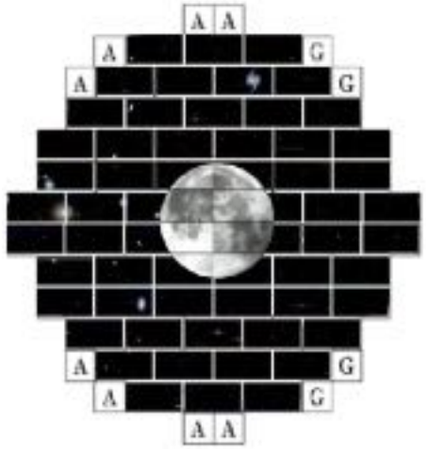
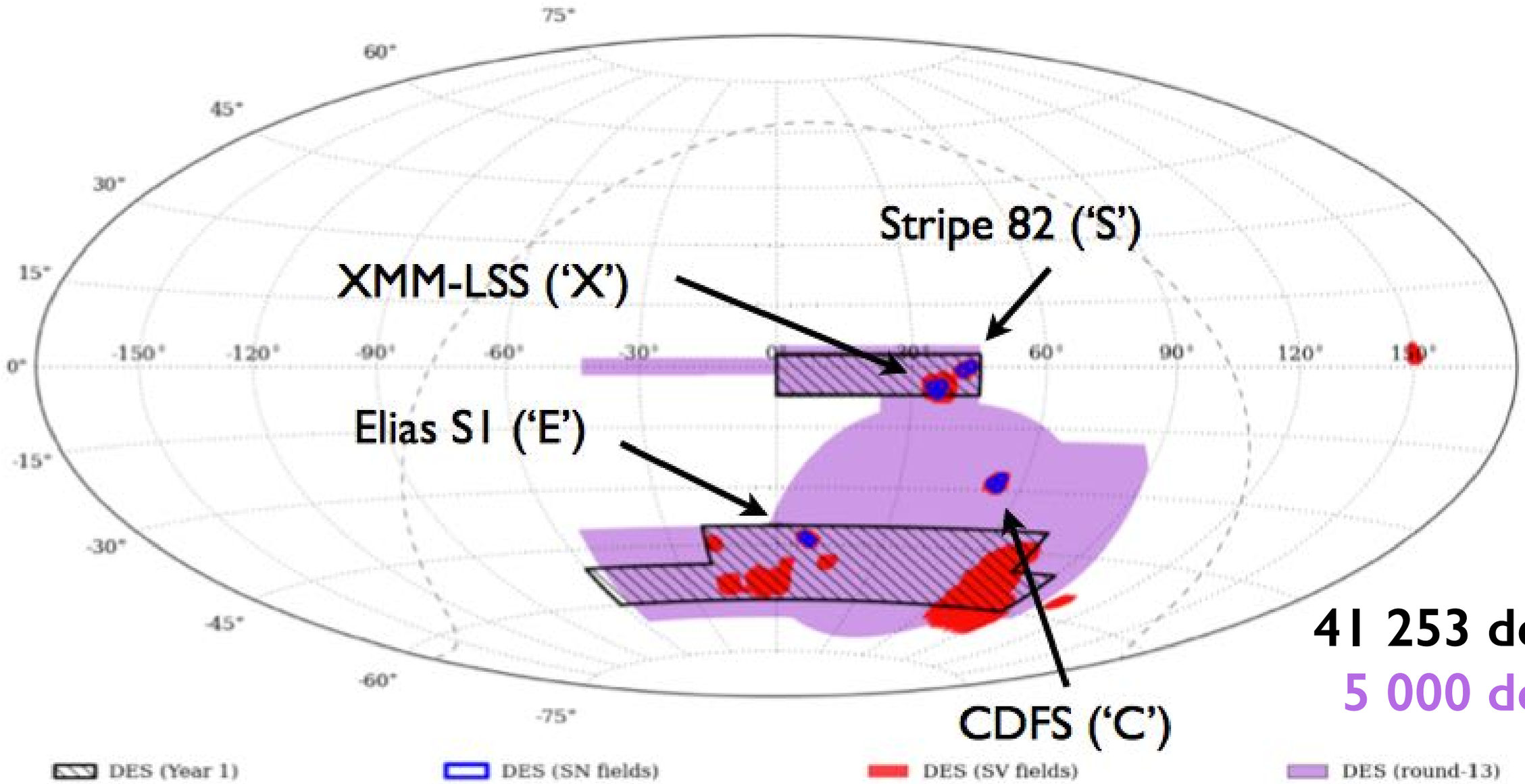
Dark Energy Survey - DES



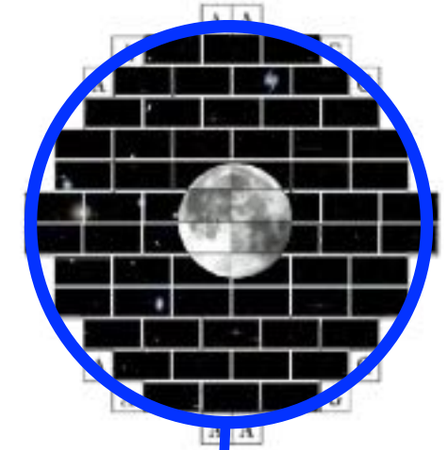
Survey Footprint:



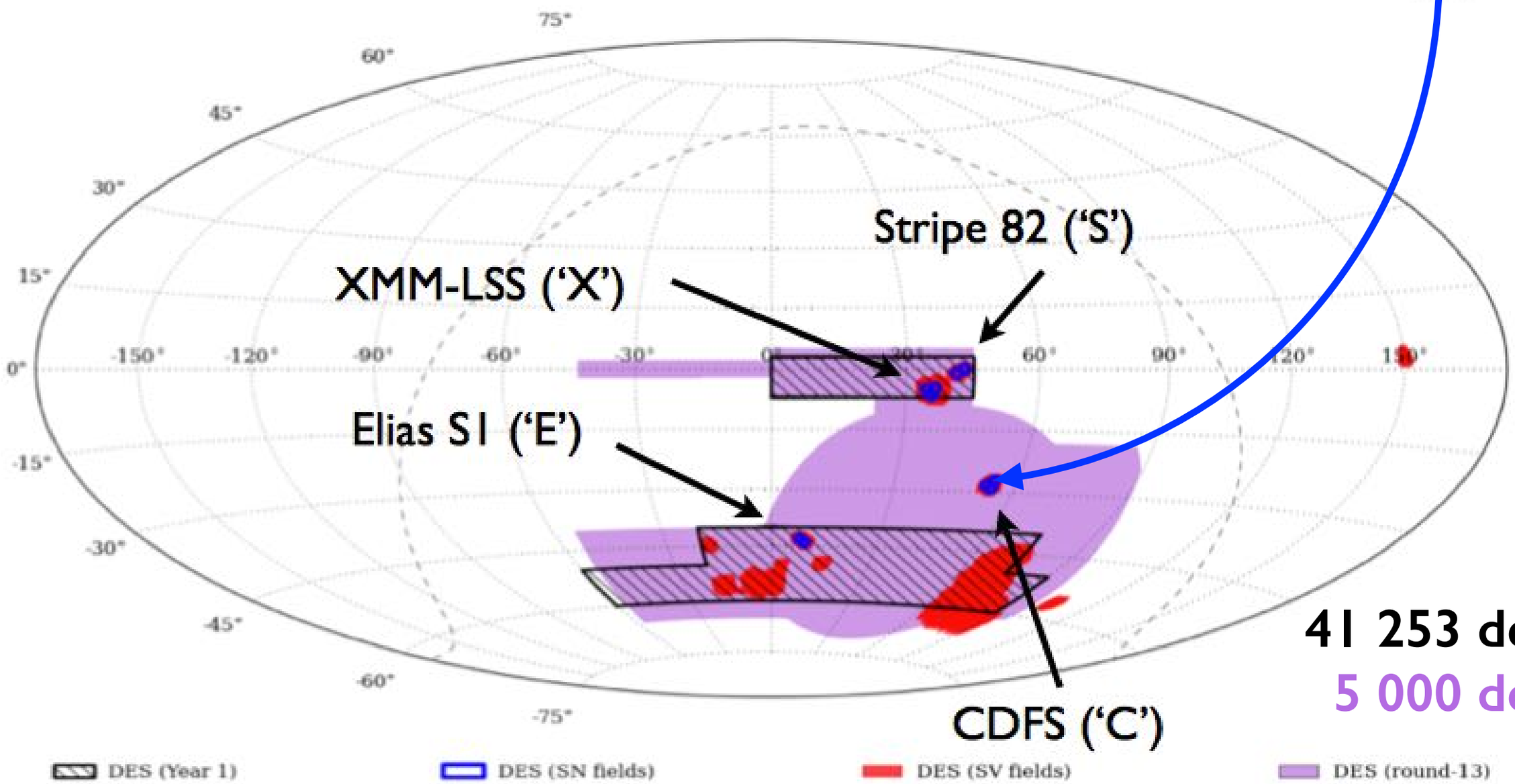
41 253 deg^2

5 000 deg^2

Dark Energy Survey - DES



Survey Footprint:



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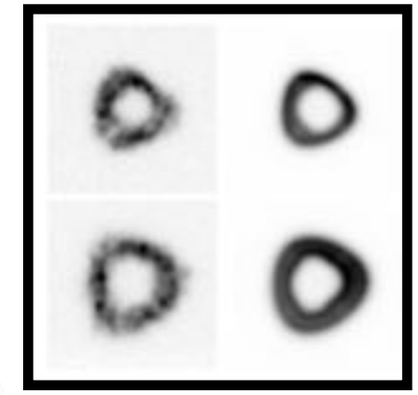
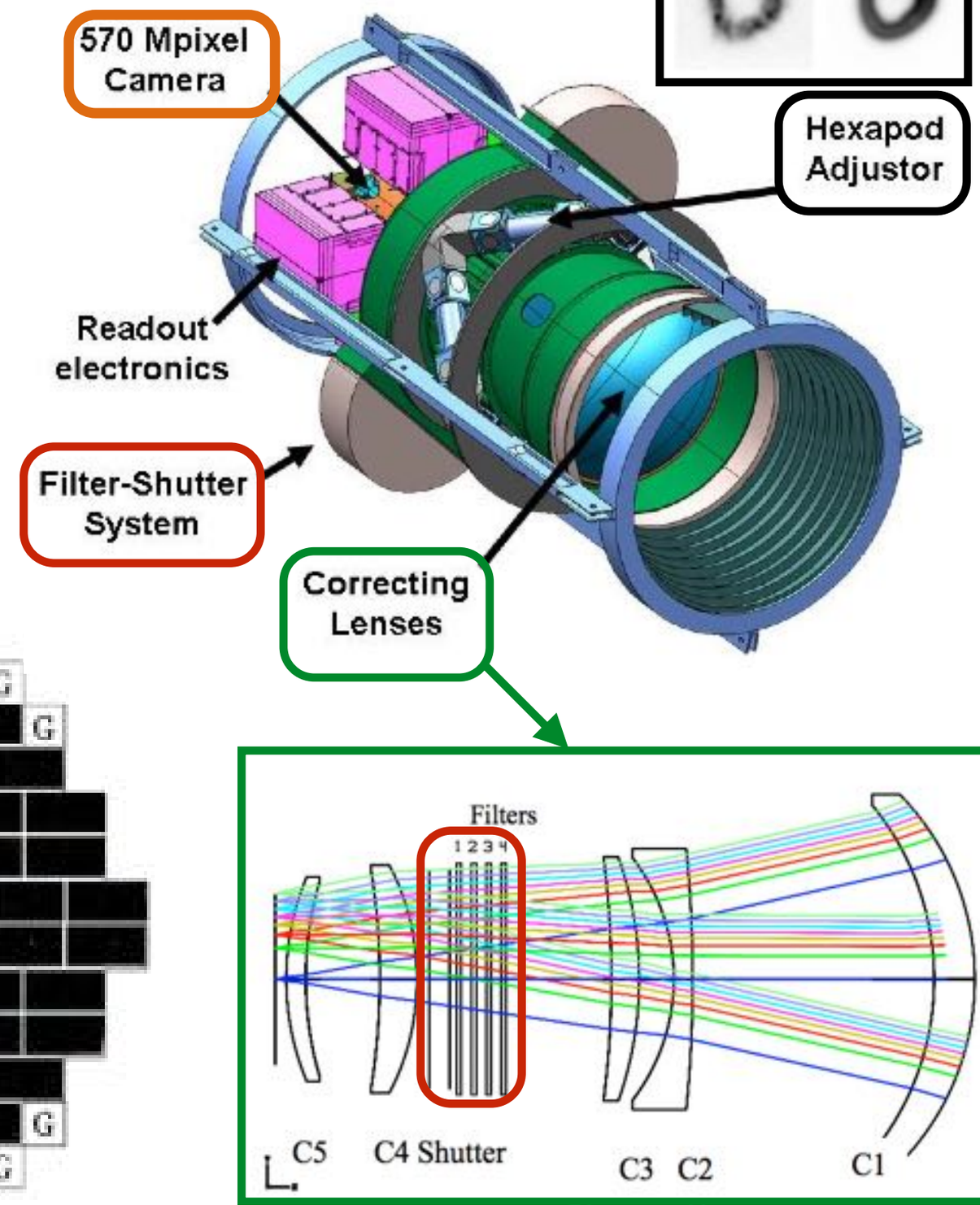
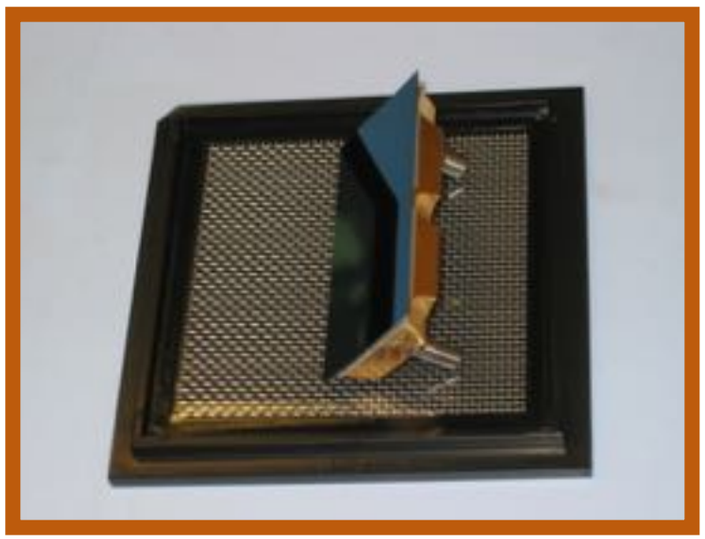


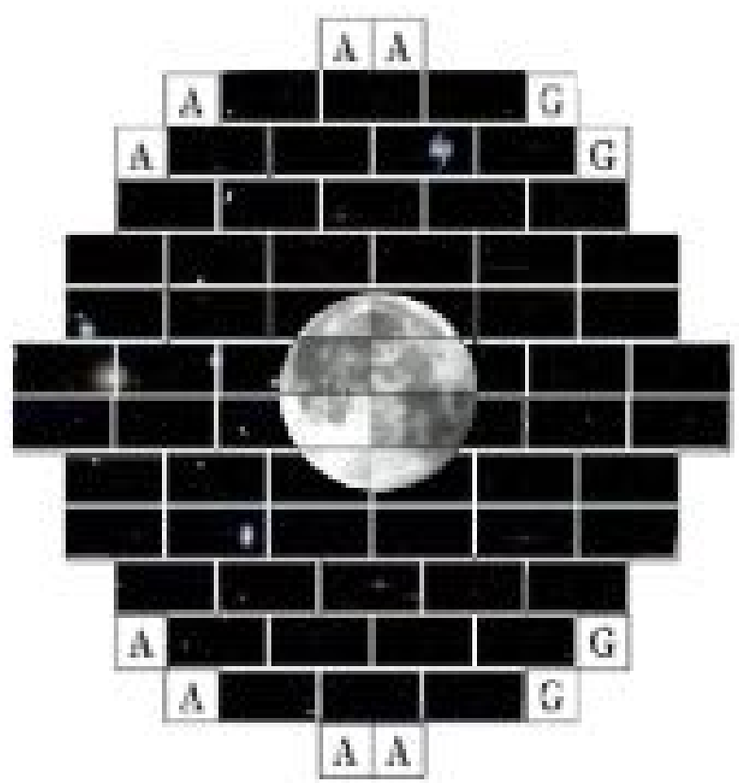
<u>Dark Energy Camera - DECam:</u>

3500 kg
- 570 Mpx
  - 62 Science CCDs
    - 5 m above the telescope 4m mirror
    - 3 deg^2 FoV (~10 times full Moon)
    - 1 GB per exposure





2048 px * 4096 px
250μm thick
15 μm (0.264") pixel size



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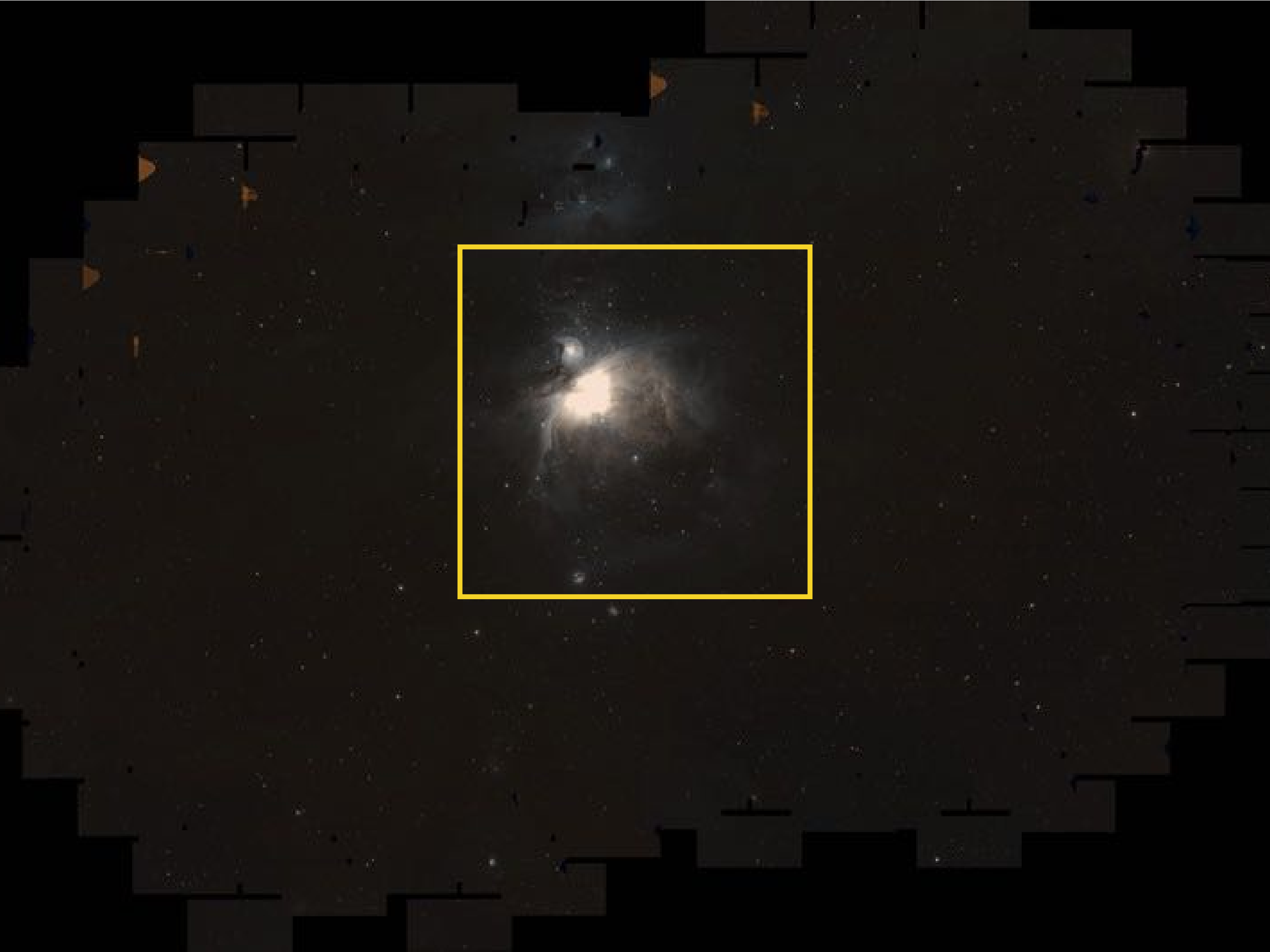


Dark Energy Survey - DES

DECam & SISPI - Survey Image System Process Integration:

Honscheid, K. et al., "The Readout and Control System of the Dark Energy Camera", Proc. SPIE 8451, 845112 (2012)
Honscheid, K., "Lessons learned: reviewing the DECam data acquisition system after one year in service", Proc. SPIE 9152, 9152-14 (2014)

What SISPI does:

- control system of DECam
- data acquisition
- image pipeline
- observer console
- image quality monitoring
- observing strategy tool

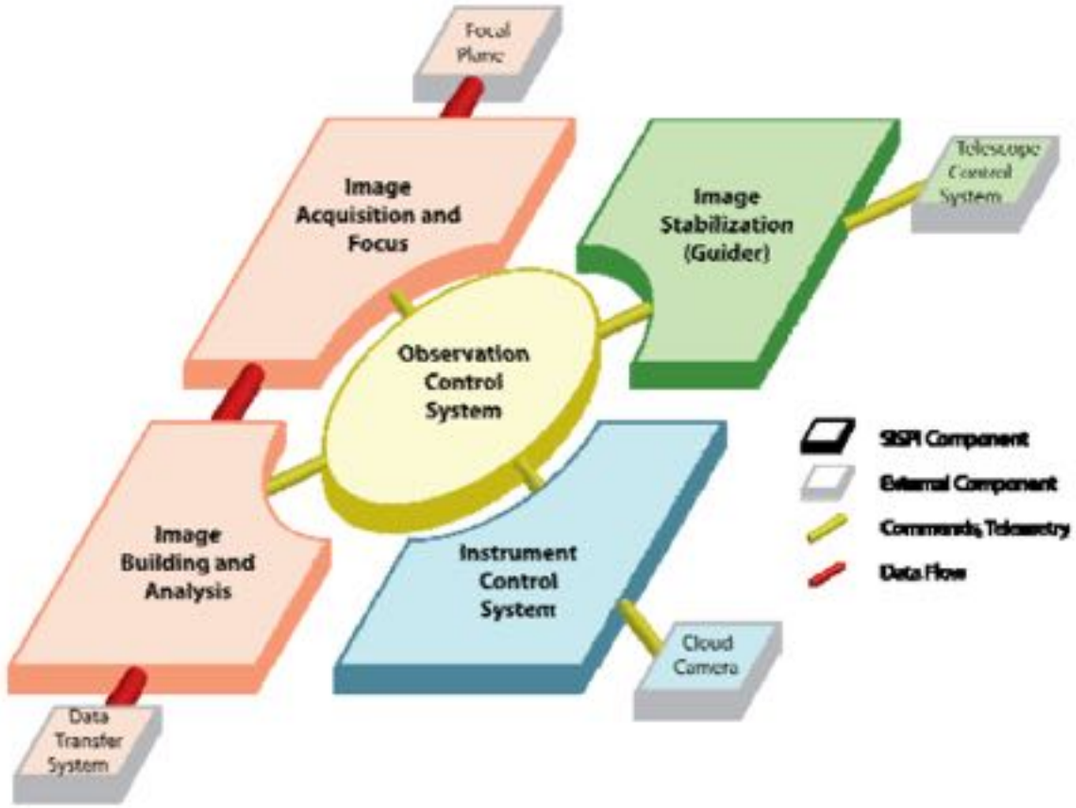
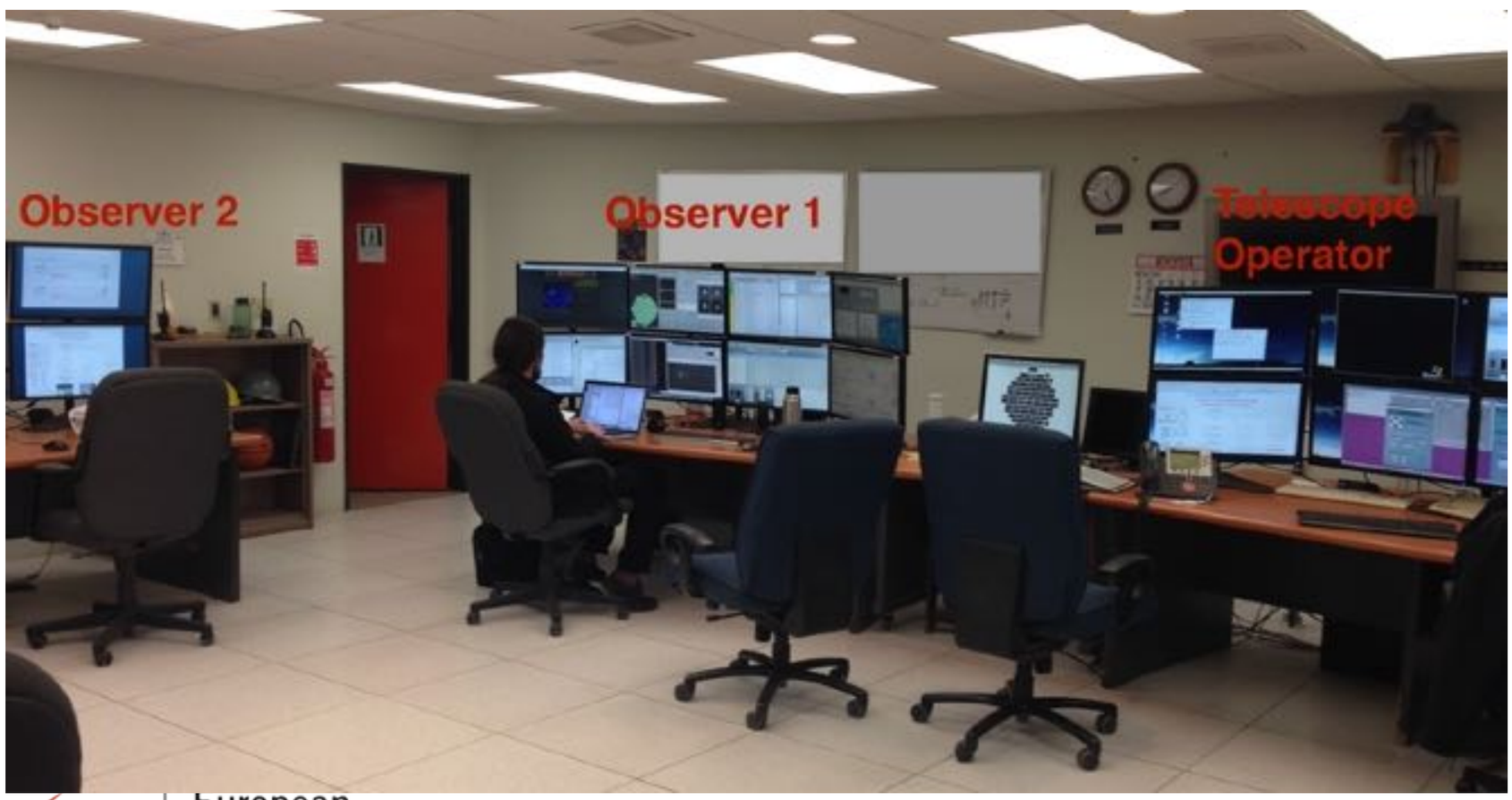


Figure 2: Block diagram of the DECam read-out and control system (SISPI).

"The underlying message passing protocol is based on PYRO, a powerful distributed object technology system written entirely in **Python**."

Dark Energy Survey - DES

DECam & SISPI - Survey Image System Process Integration:



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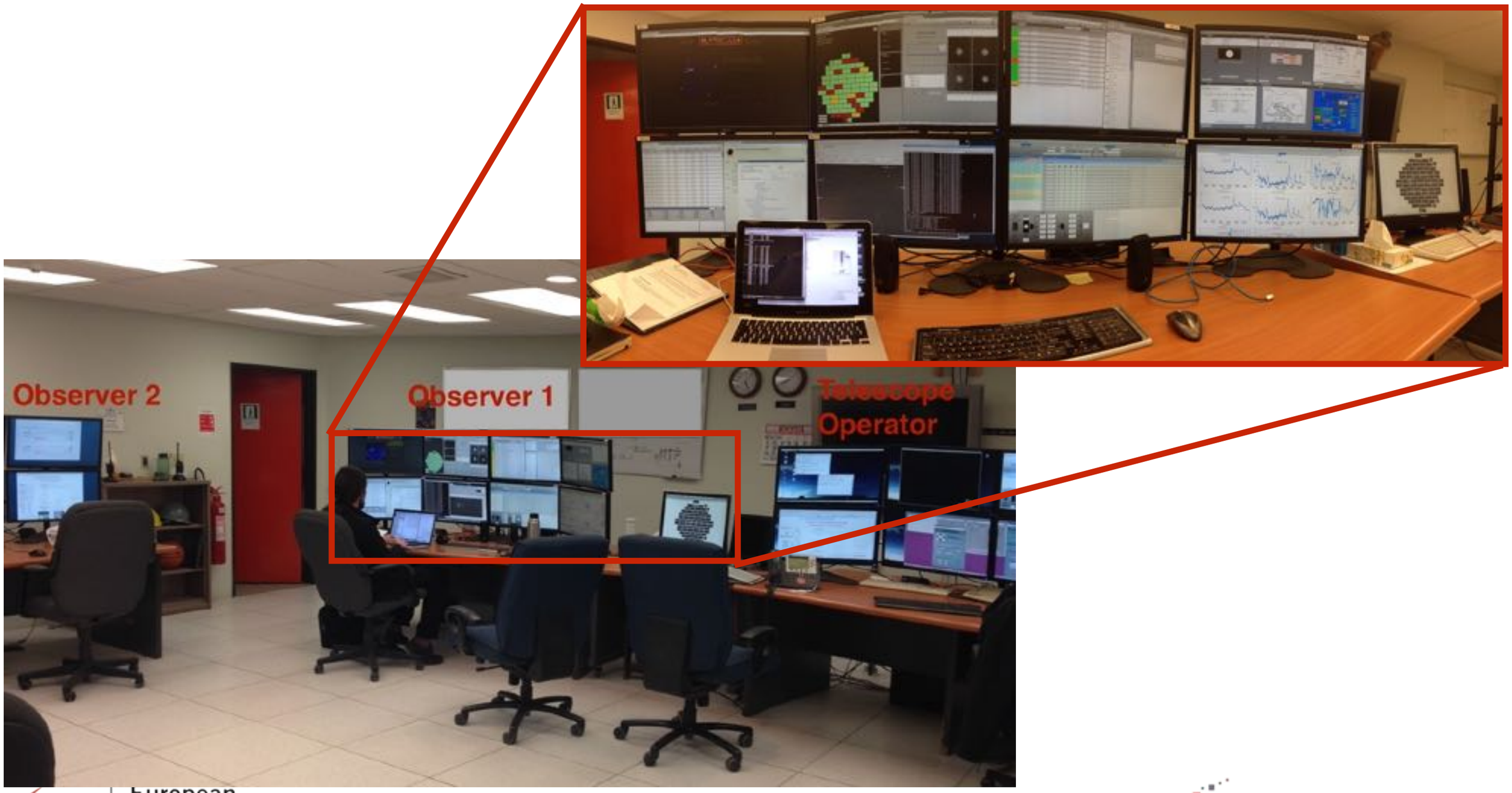
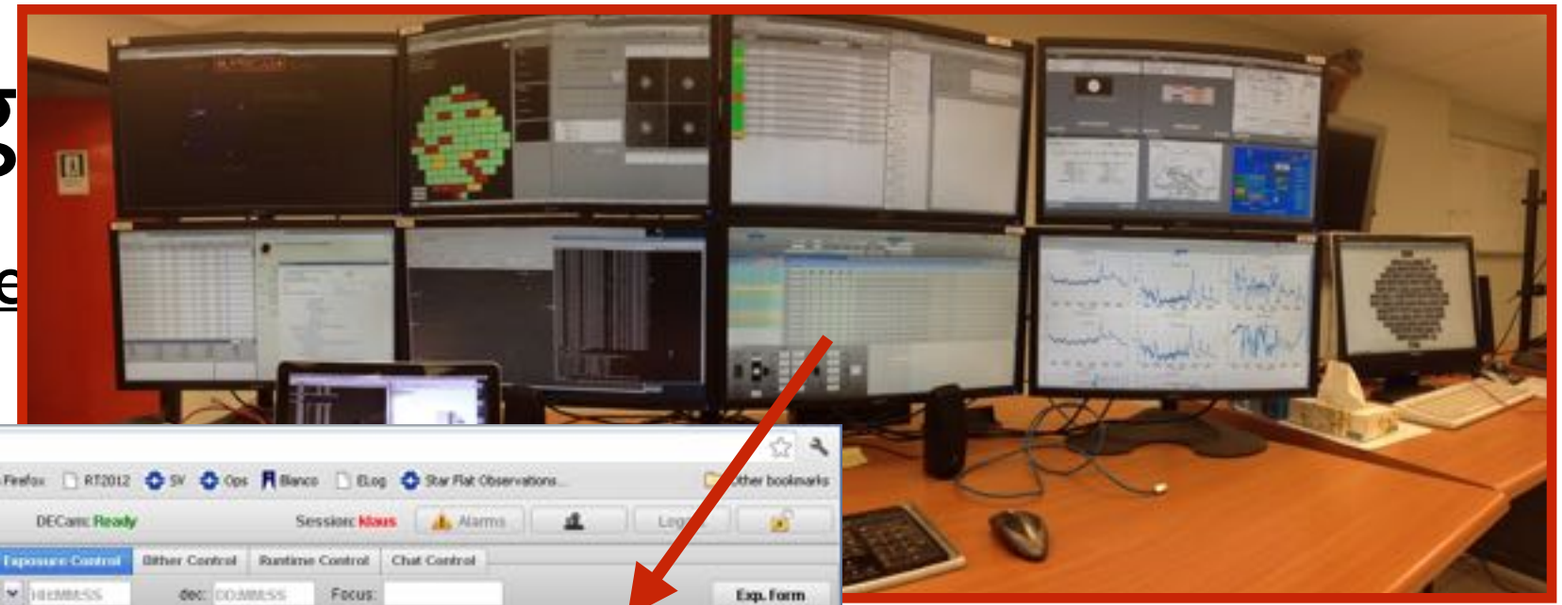
Dark Energy Survey - DES

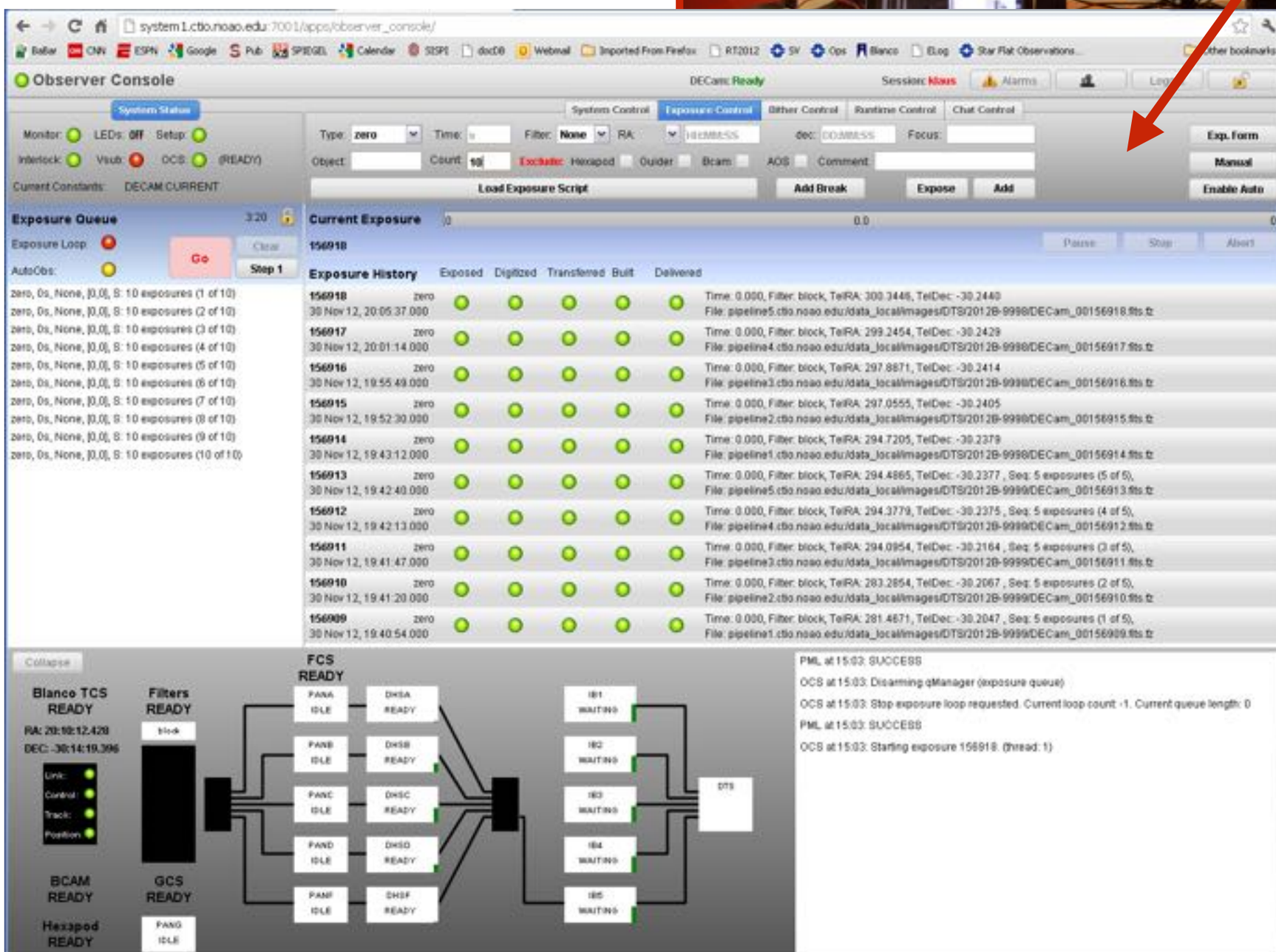
DECam & SISPI - Survey Image System Process Integration:



Dark Energ

DECam & SISPI - Survey Image





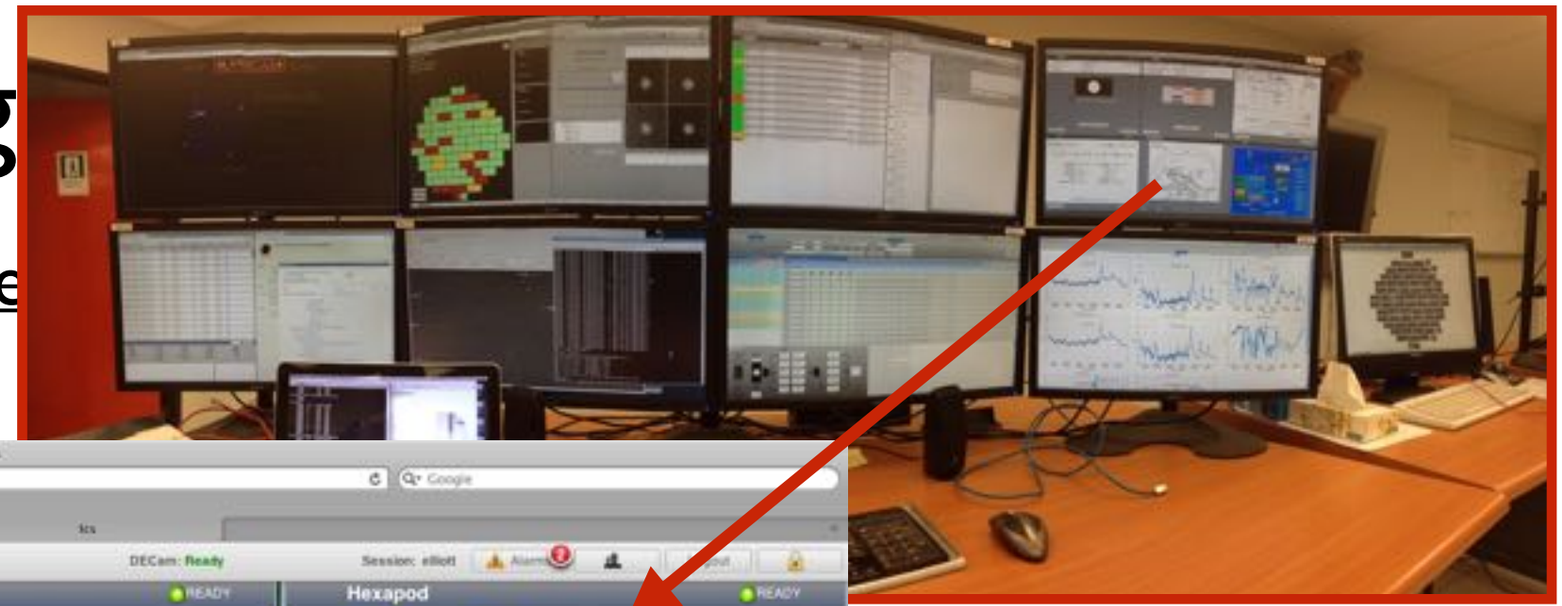
Observer console

Obstac - scripts

visual data flow

Dark Energ

DECam & SISPI - Survey Image



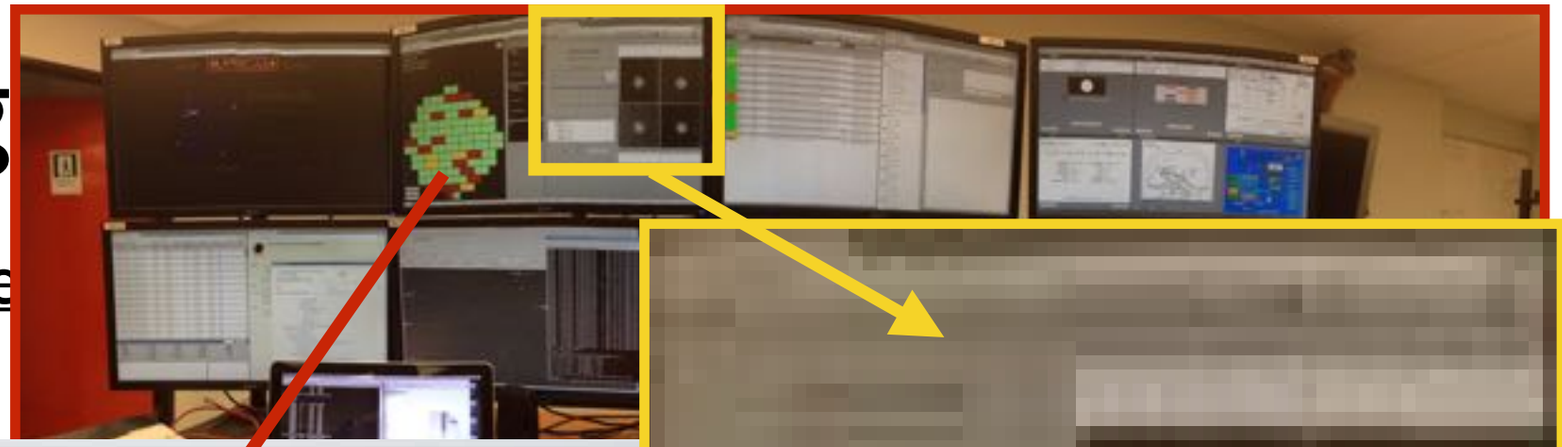
Instrument Control System-ICS:

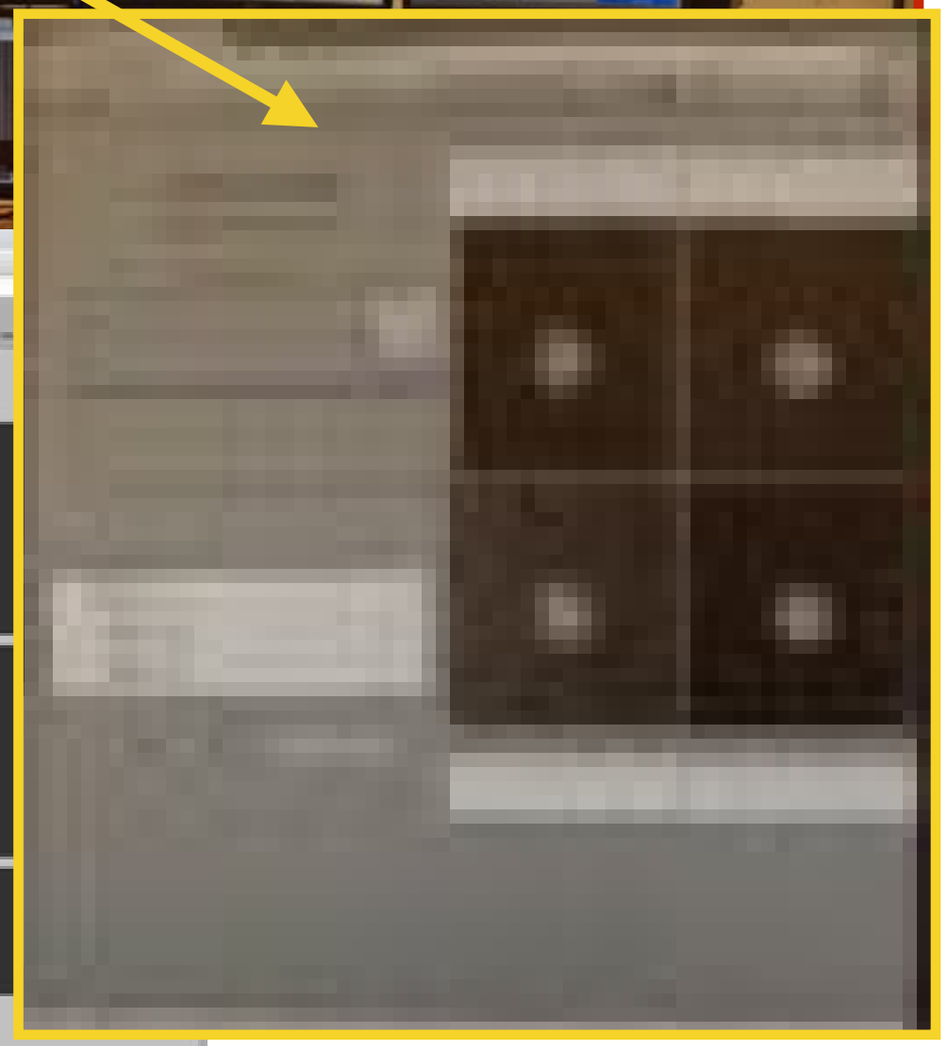
1. Shutter+exposure timing
2. Filter selection
3. Hexapod configuration
4. Telescope Pointing
5. Dome environment
6. ICS status

A.Papadopoulos@external.euc.ac.cy

Dark Energ

DECam & SISPI - Survey Image





Guider - live image

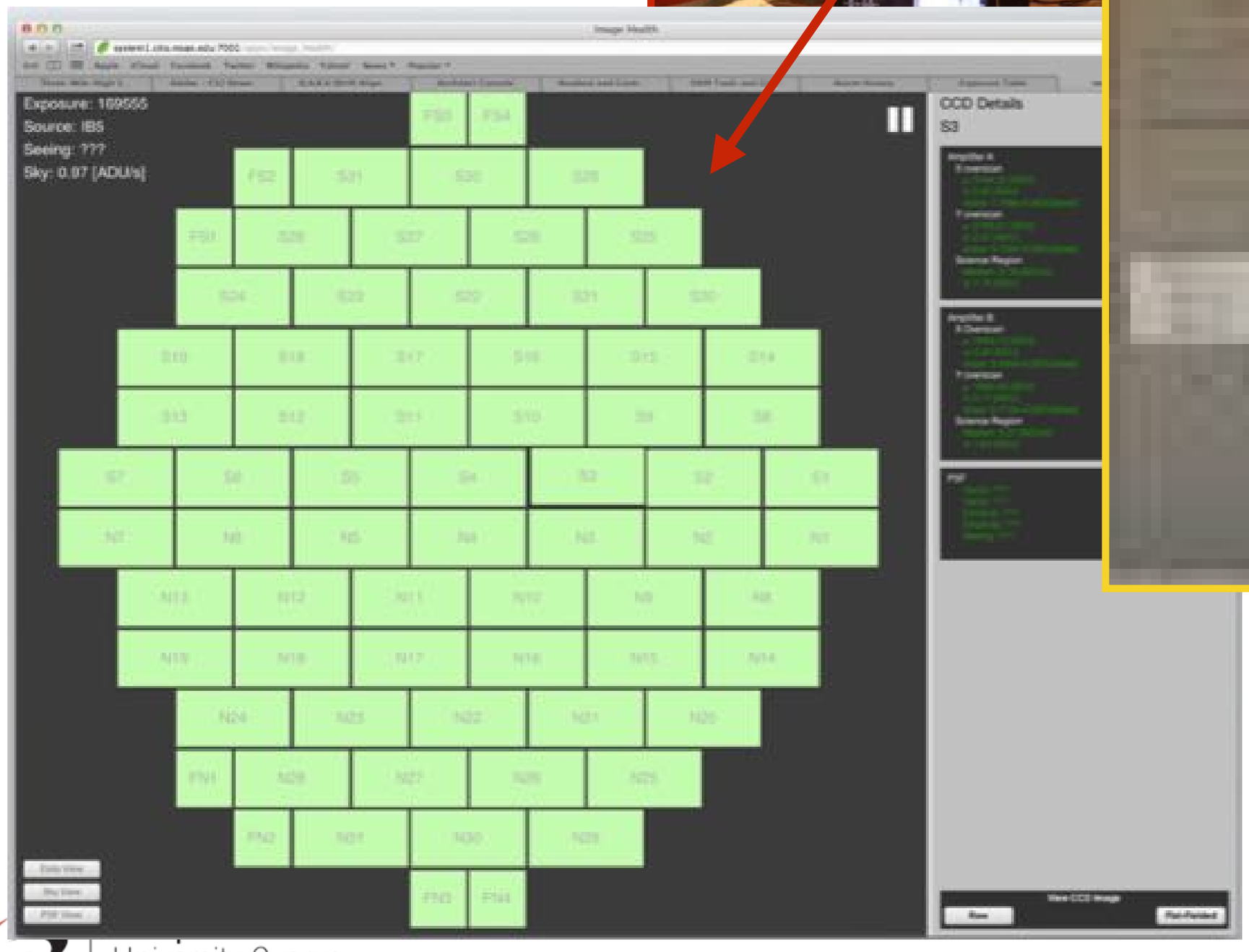
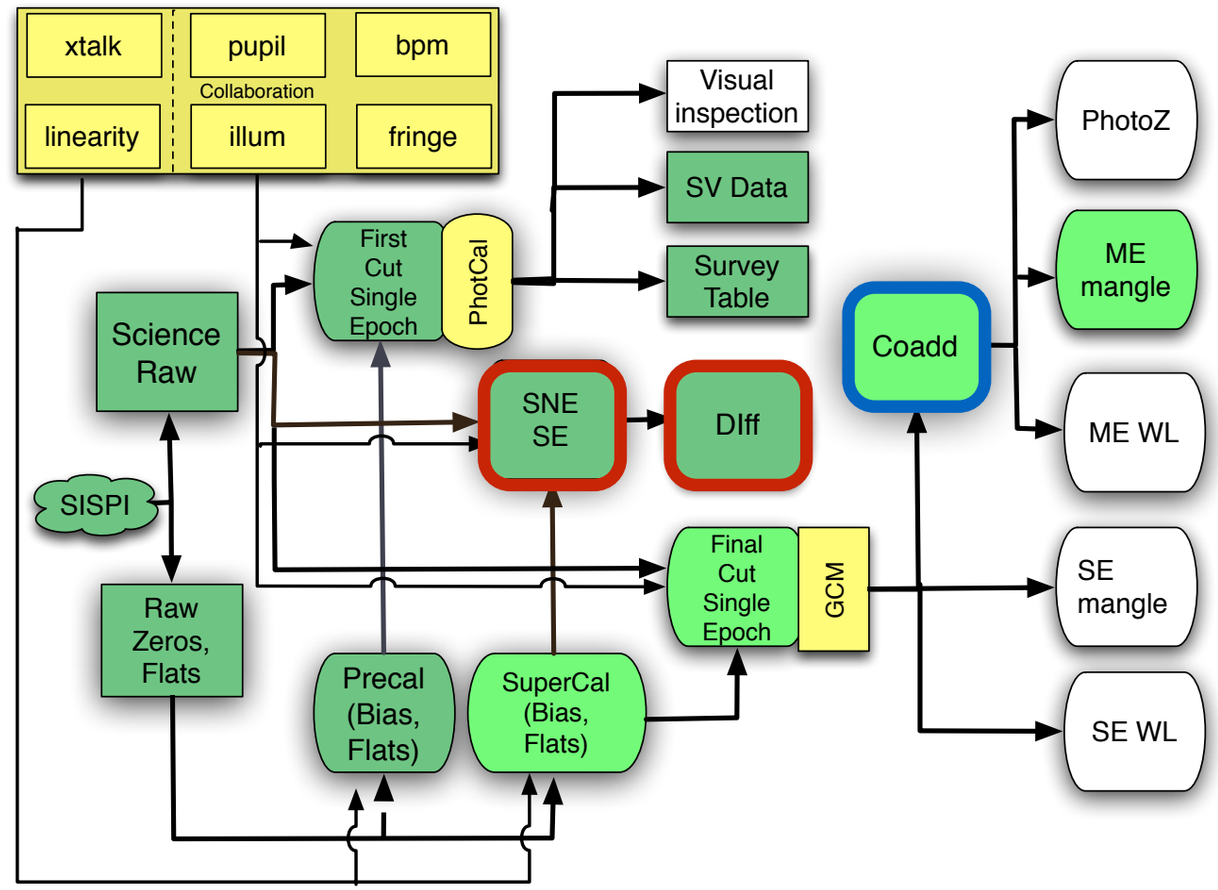


Image health

Dark Energy Survey - DES

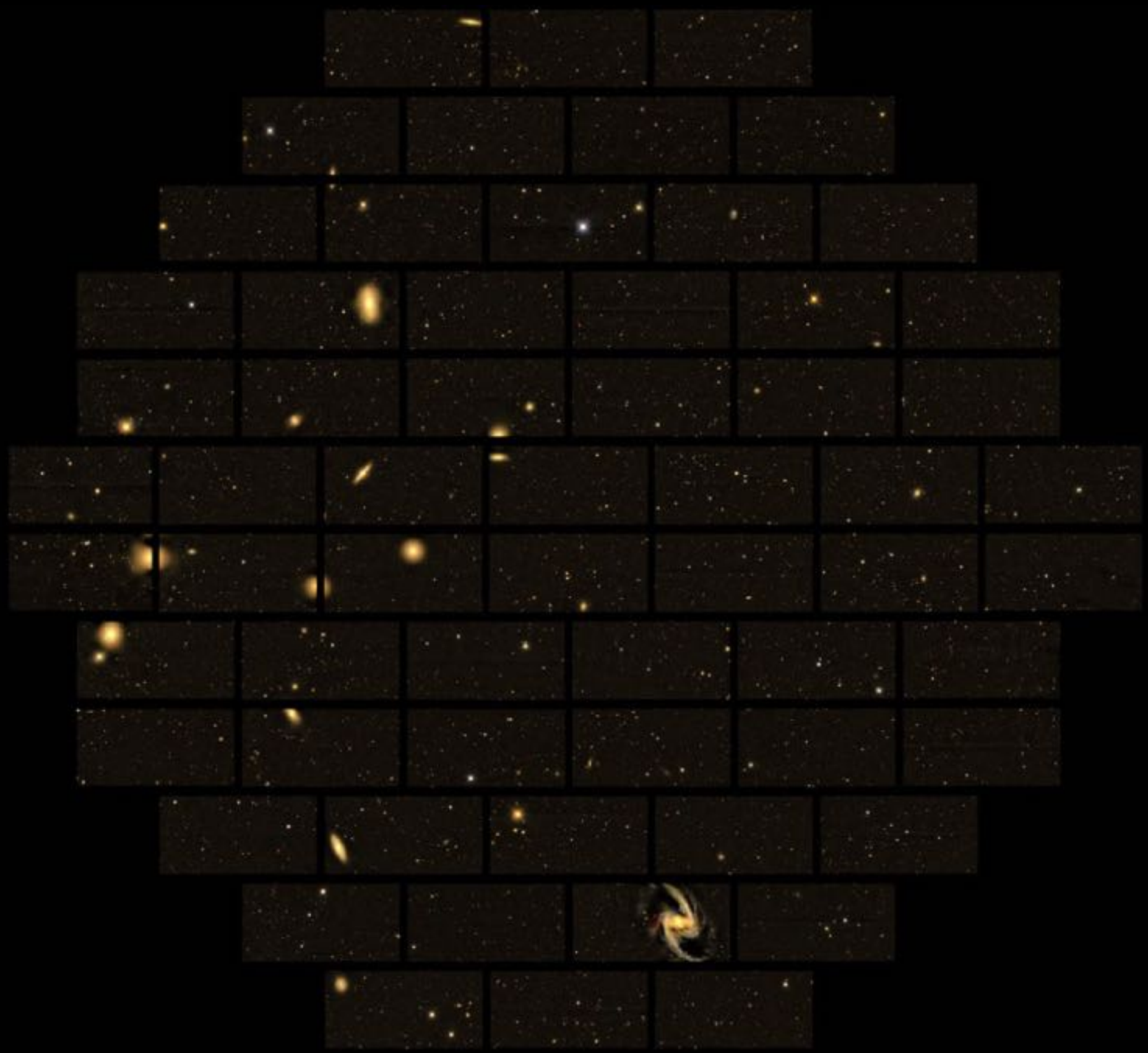
DES Data Management - DESDM:

National Center for Supercomputing Applications - NCSA
(University of Illinois, Urbana-Champaign, USA) home of BLUE WATERS

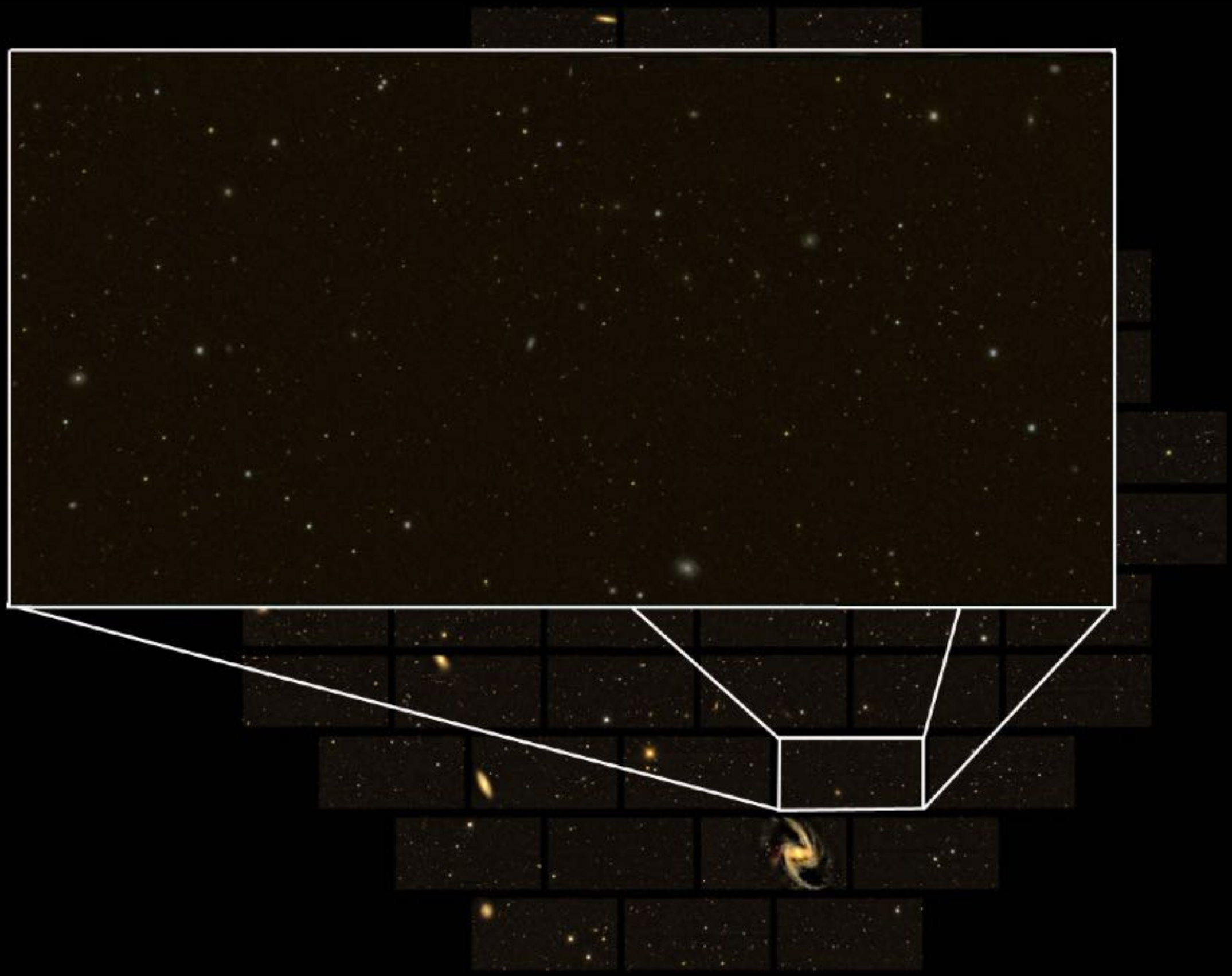


300GB per night produced by DECam
~12hrs turnaround for SNe data
~6 months for the yearly data releases
Data products accessible via SQL database

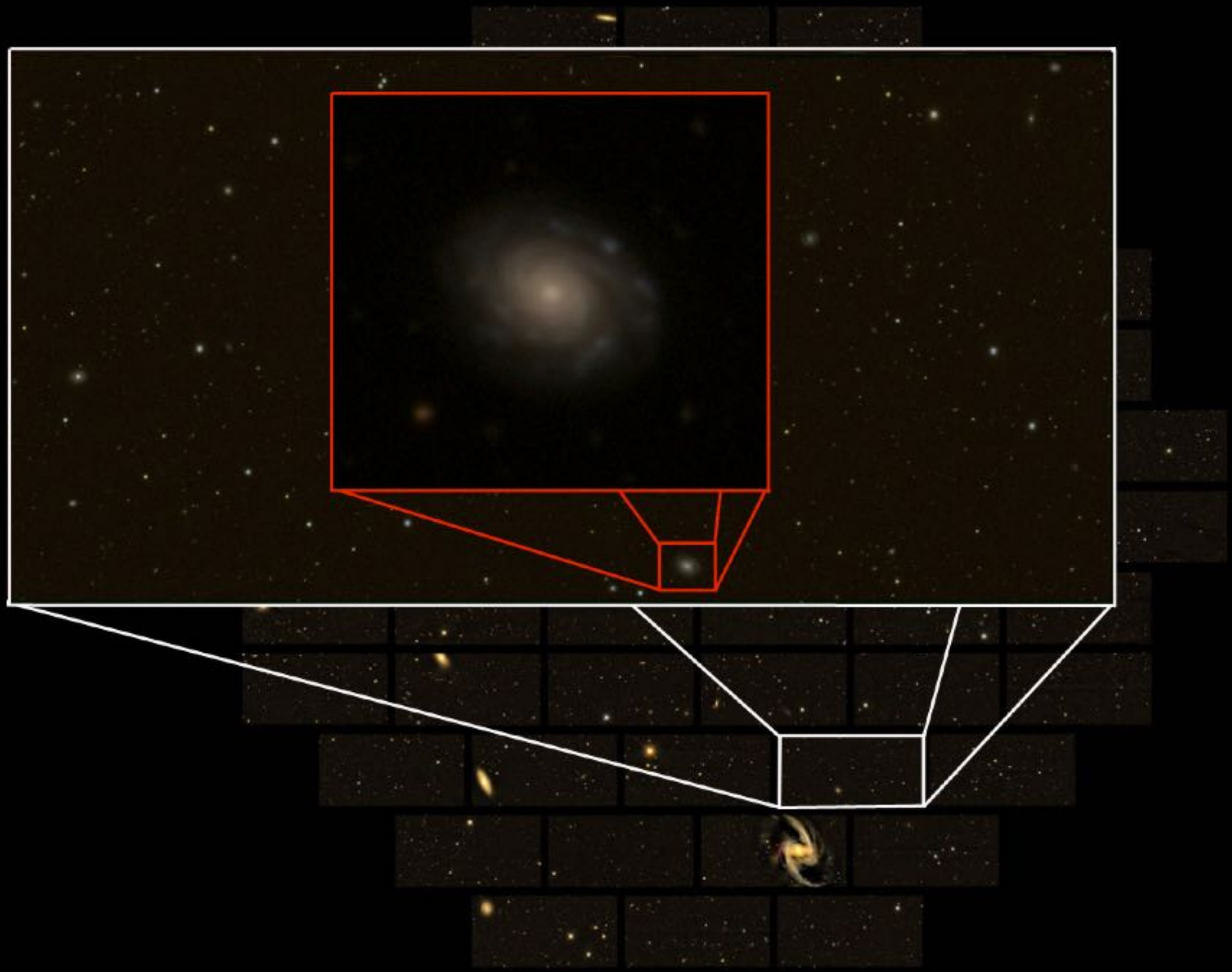
THE DARK ENERGY SURVEY



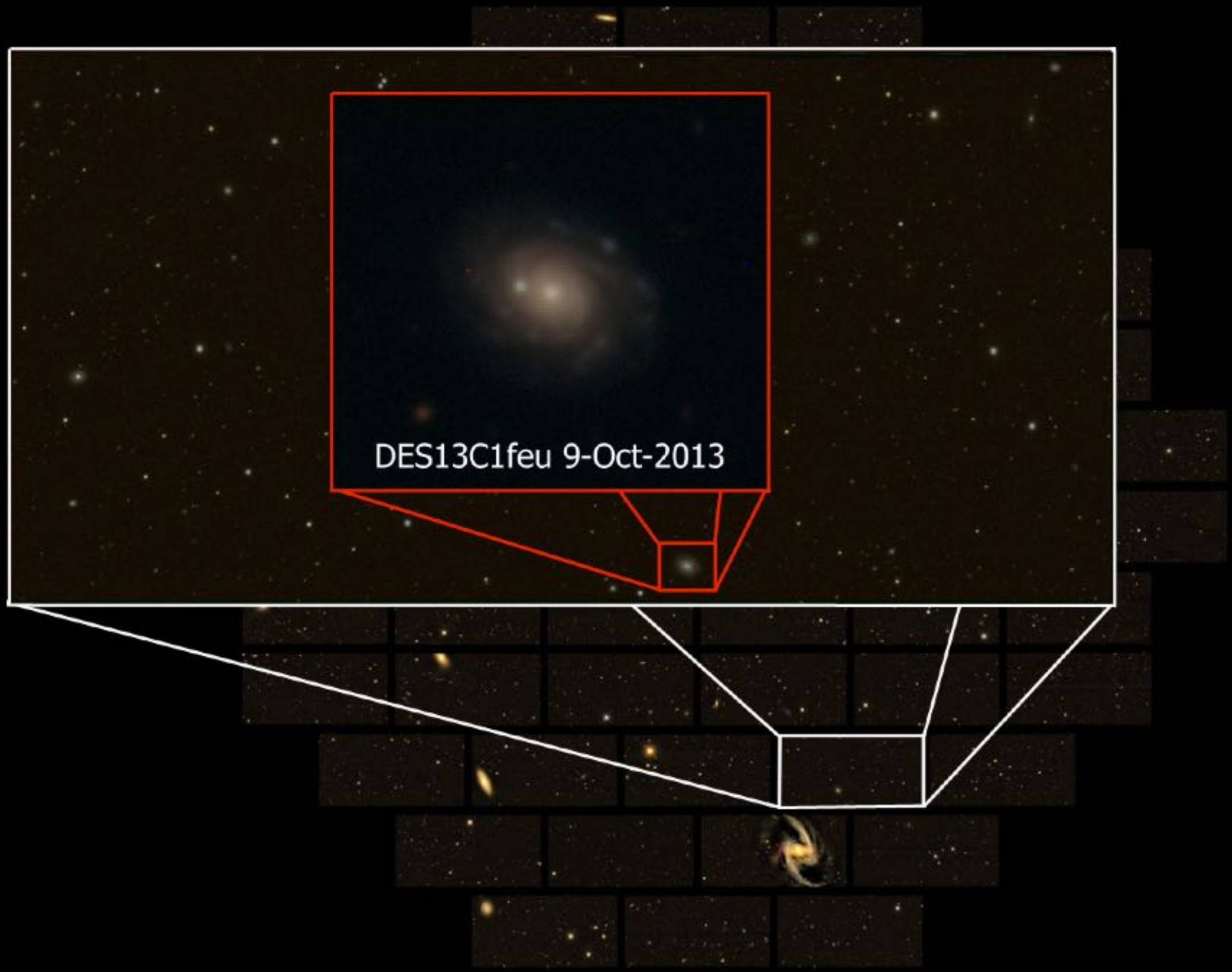
THE DARK ENERGY SURVEY



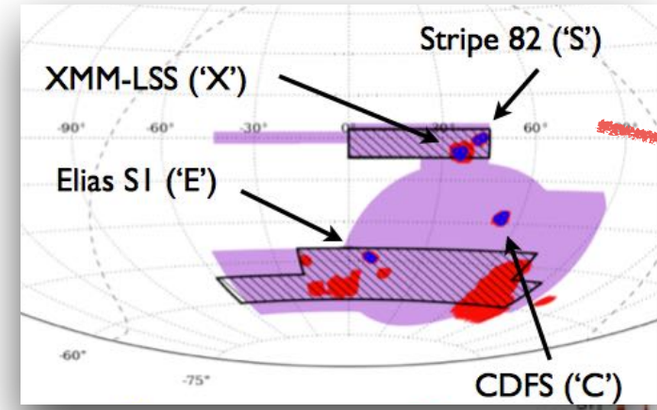
THE DARK ENERGY SURVEY

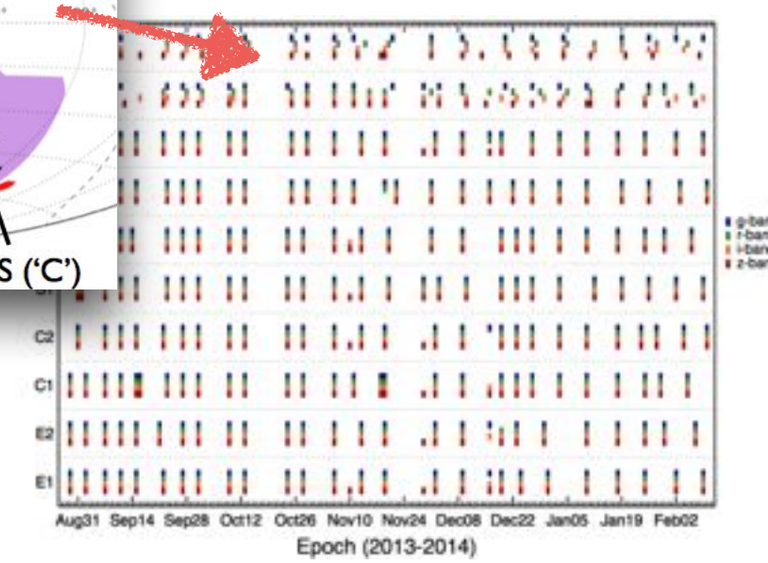


THE DARK ENERGY SURVEY



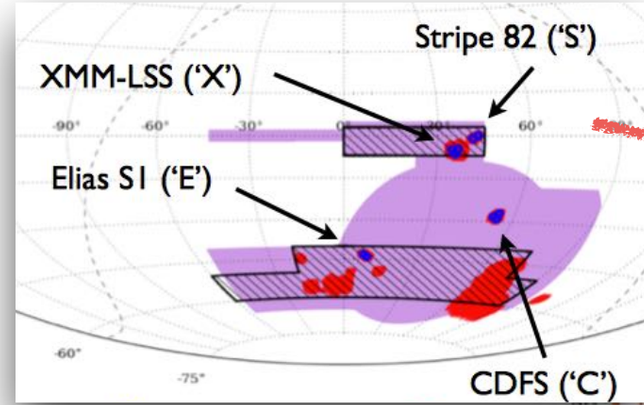
DES Supernovae

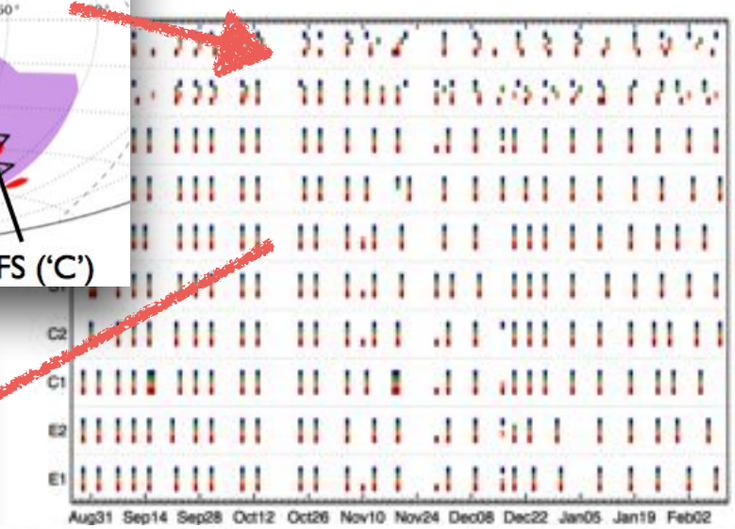




- **DES SNe search:**
  - 10 fields (E1,E2,S1,S2,C1,C2,C3*,X1,X2,X3*)
  - Transients naming convention: DES-13-S2-abcd
  - ~5-7 days cadence in *griz*
  - DES Y1:
    - Sep-2013 ⇔ Feb-2014 : ~165 nights
  - DES Y2:
    - Aug-2014 ⇔ Feb-2015 : ~155 nights
  - DES Y3:
    - Aug-2015 ⇔ Feb-2016 : ~155 nights

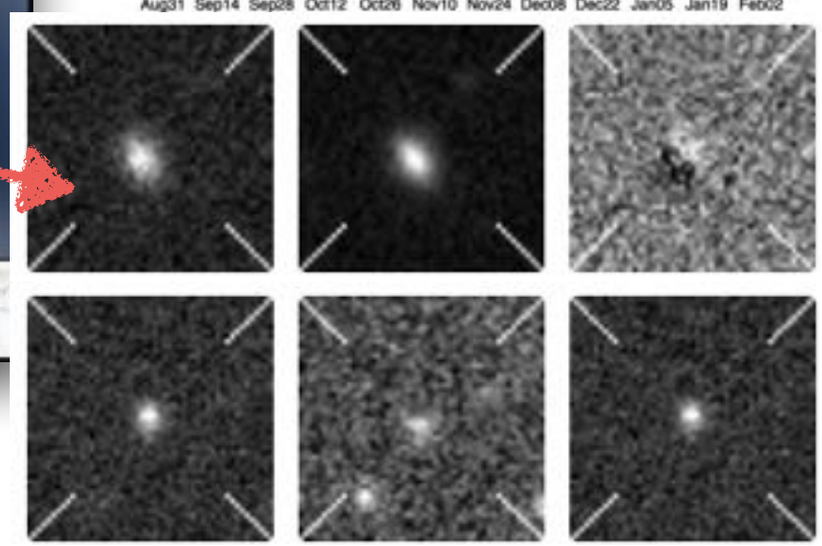
DES Supernovae





- **DES SNe search:**
  - 10 fields (E1,E2,S1,S2,C1,C2,C3*,X1,X2,X3*)
  - Transients naming convention: DES-13-S2-abcd
  - ~5-7 days cadence in *griz*
  - DES Y1:
    - Sep-2013 ⇔ Feb-2014 : ~1
  - DES Y2:
    - Aug-2014 ⇔ Feb-2015 : ~
  - DES Y3:
    - Aug-2015 ⇔ Feb-2016 : ~

- **Data processing:**
  - turn around time is ***essential*** for spectroscopic follow-up
    - *FirstCut Pipeline - **Difference pipeline** - Machine Learning Algorithm - Human scanning - Transient identification*



Search - Template = Difference

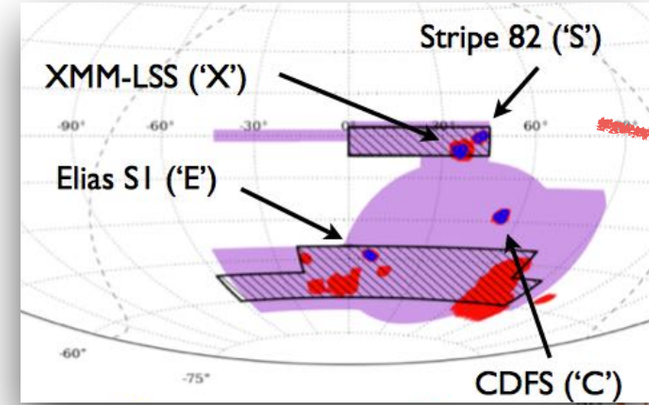
Difference pipeline - Kessler et al. 2015 - arxiv.org/abs/1507.05137

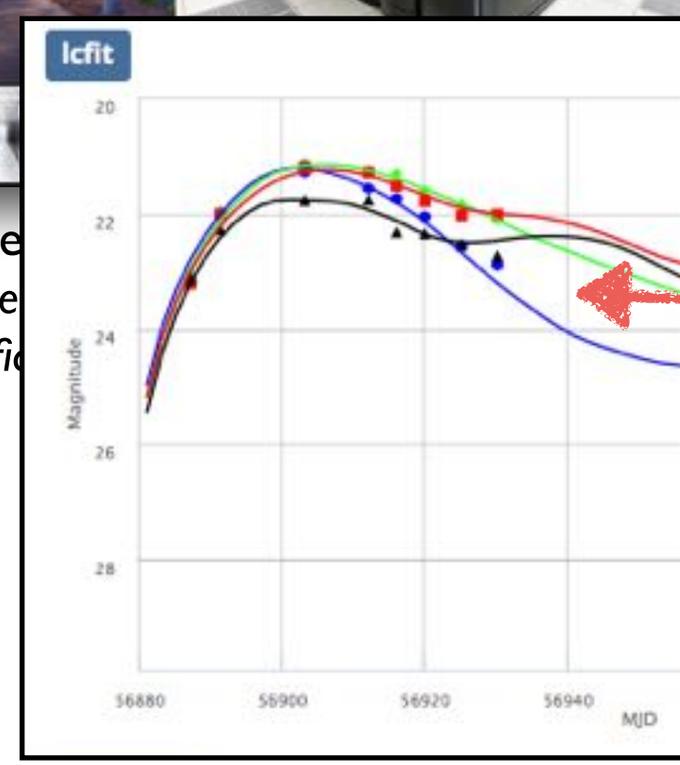
AUTOSCAN - Goldstein et al. 2015 - arxiv.org/abs/1504.02936

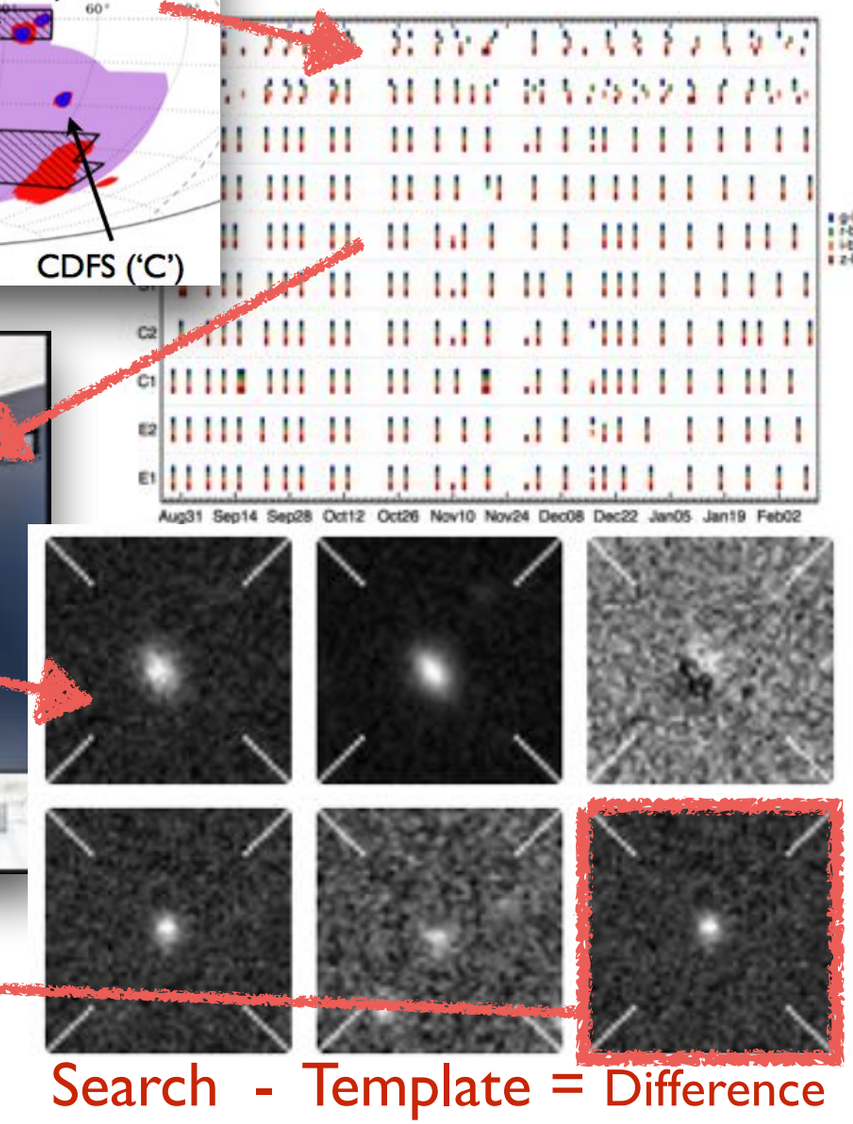
DES Supernovae

- **DES SNe search:**
  - 10 fields (E1,E2,S1,S2,C1,C2,C3*,X1,X2,X3*)
  - Transients naming convention: DES-13-S2-abcd
  - ~5-7 days cadence in *griz*
  - DES Y1:
    - Sep-2013 ⇔ Feb-2014 : ~1
  - DES Y2:
    - Aug-2014 ⇔ Feb-2015 : ~
  - DES Y3:
    - Aug-2015 ⇔ Feb-2016 : ~

- **Data processing:**
  - turn around time is ***essential*** for spe
    - *FirstCut Pipeline - Difference pipeline*
      Human scanning - Transient identific
  - **Photometric classification**







DES Supernovae

- **DES SNe search:**
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  - Transients naming convention: DES-13-S2-abcd
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  - DES Y1:
    - Sep-2013 ⇔ Feb-2014 : ~1
  - DES Y2:
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  - DES Y3:
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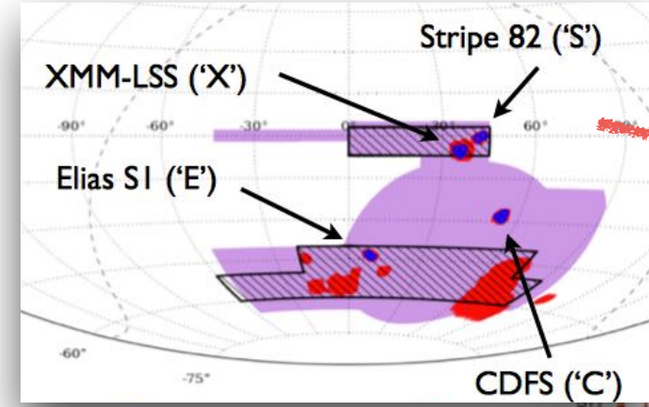
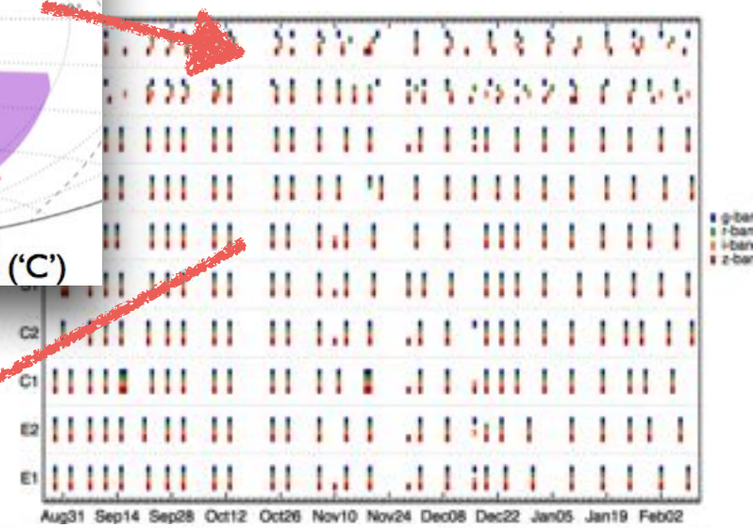
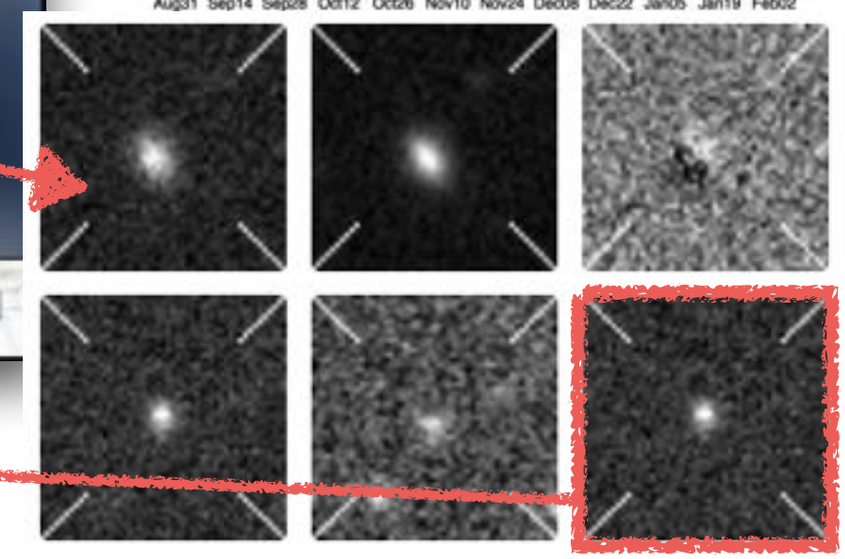
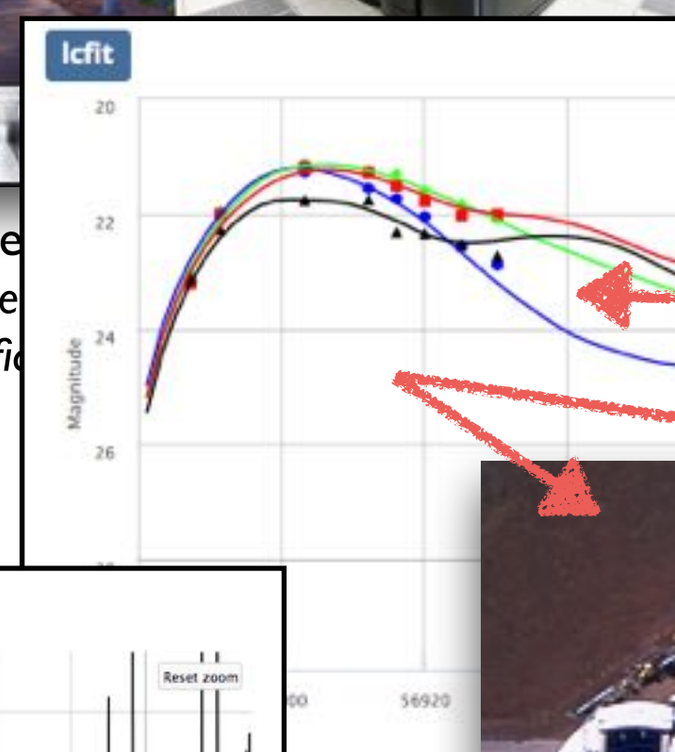
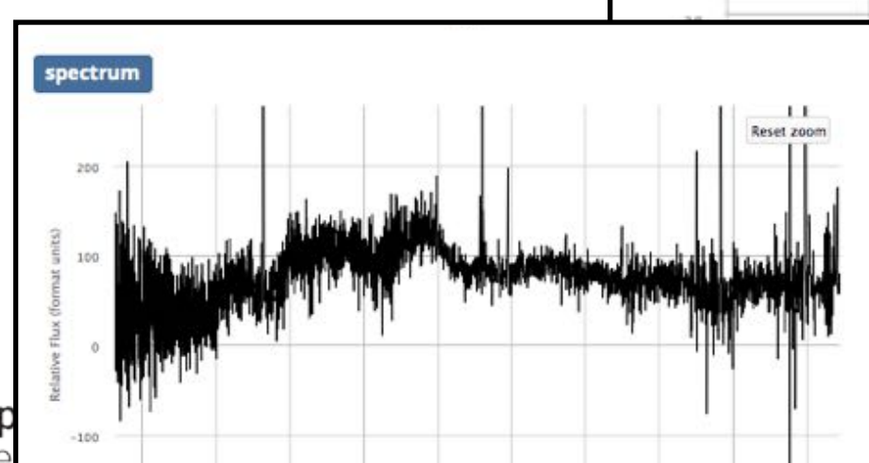
- **Data processing:**
  - turn around time is ***essential*** for spe
    - *FirstCut Pipeline - Difference pipeline*
      Human scanning - Transient identific
  - Photometric classification
  - **Spectroscopic follow-up**

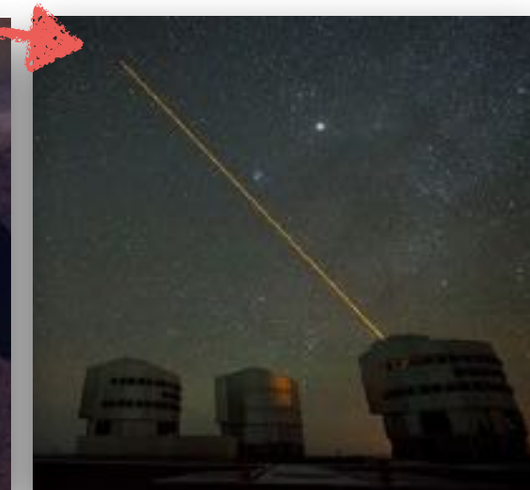












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DES Supernovae

- **DES SNe search:**
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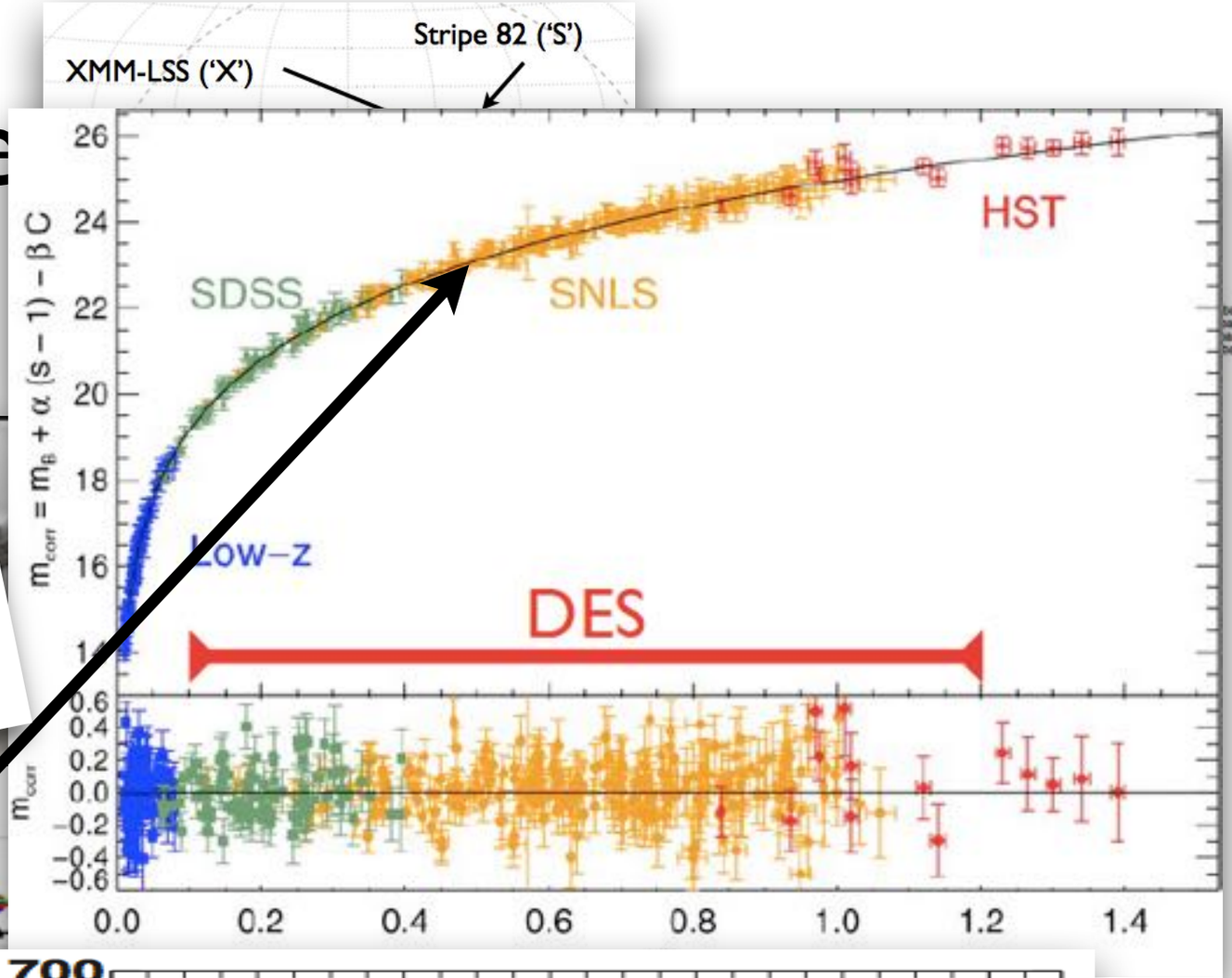
  - Transients naming convention: DES-13-S2
  - ~5-7 days cadence in *griz*
  - DES Y1:

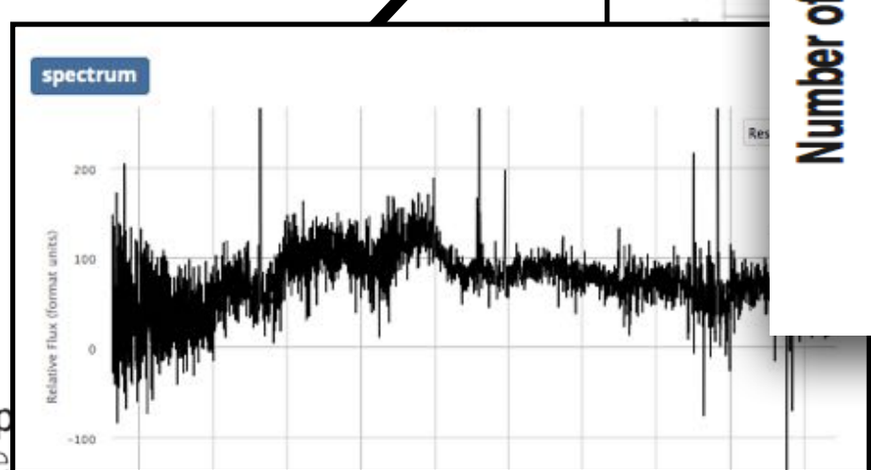
Science Goal

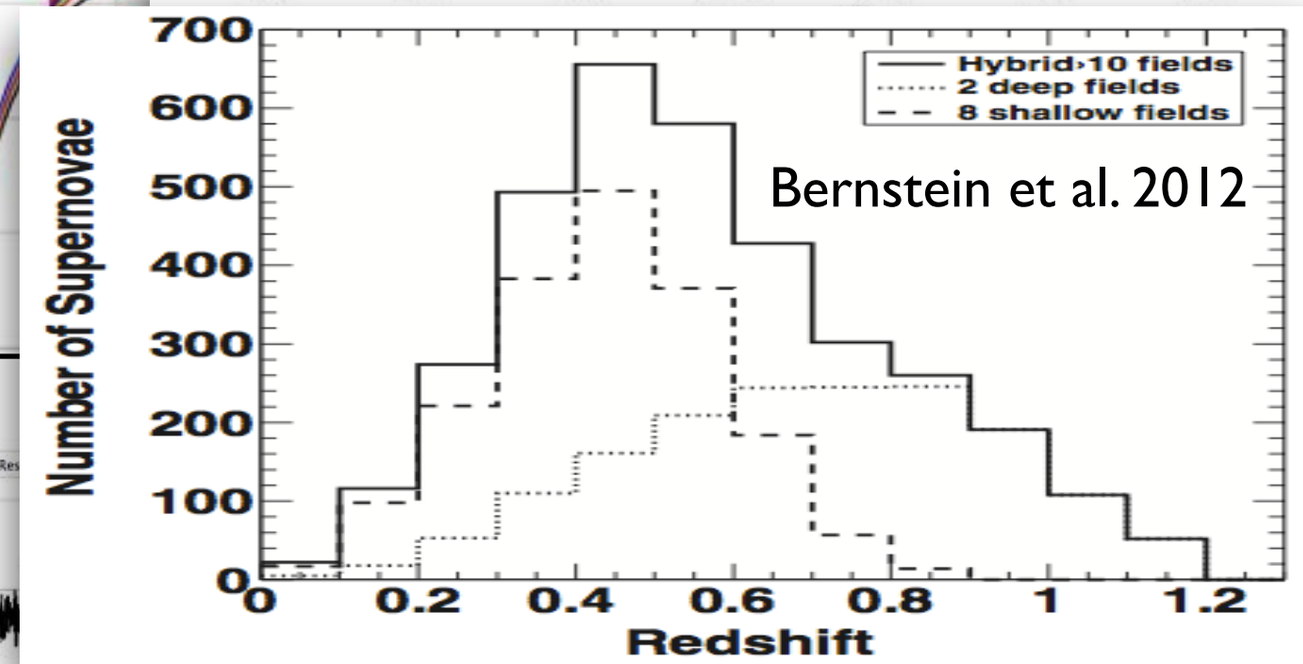
Cosmology ~3500 SNe Ia (after DES 5yr)

Processing:

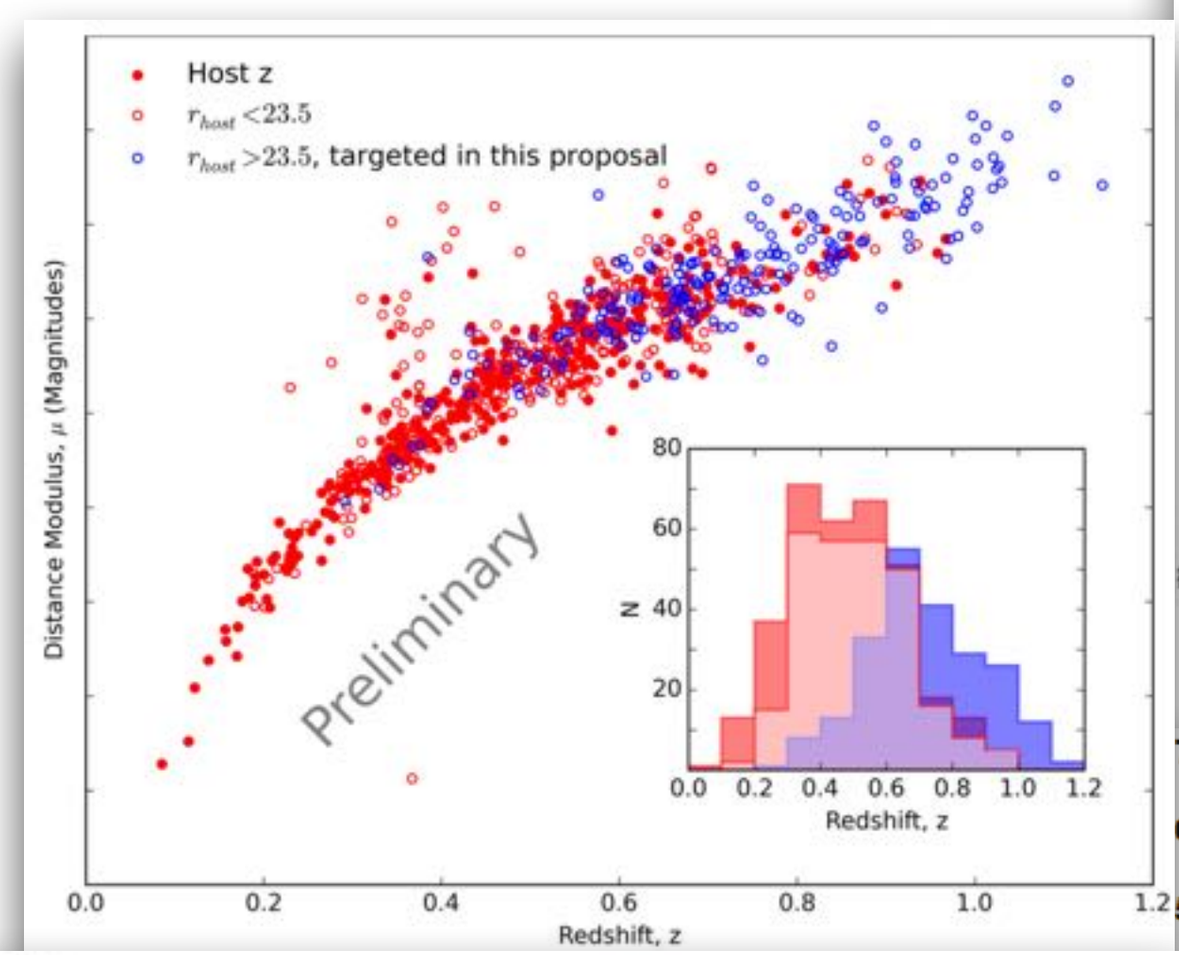
- turn around time is ***essential*** for spe
  - *FirstCut Pipeline - Difference pipeline*
    Human scanning - Transient identific
- Photometric classification
- **Spectroscopic follow-up**

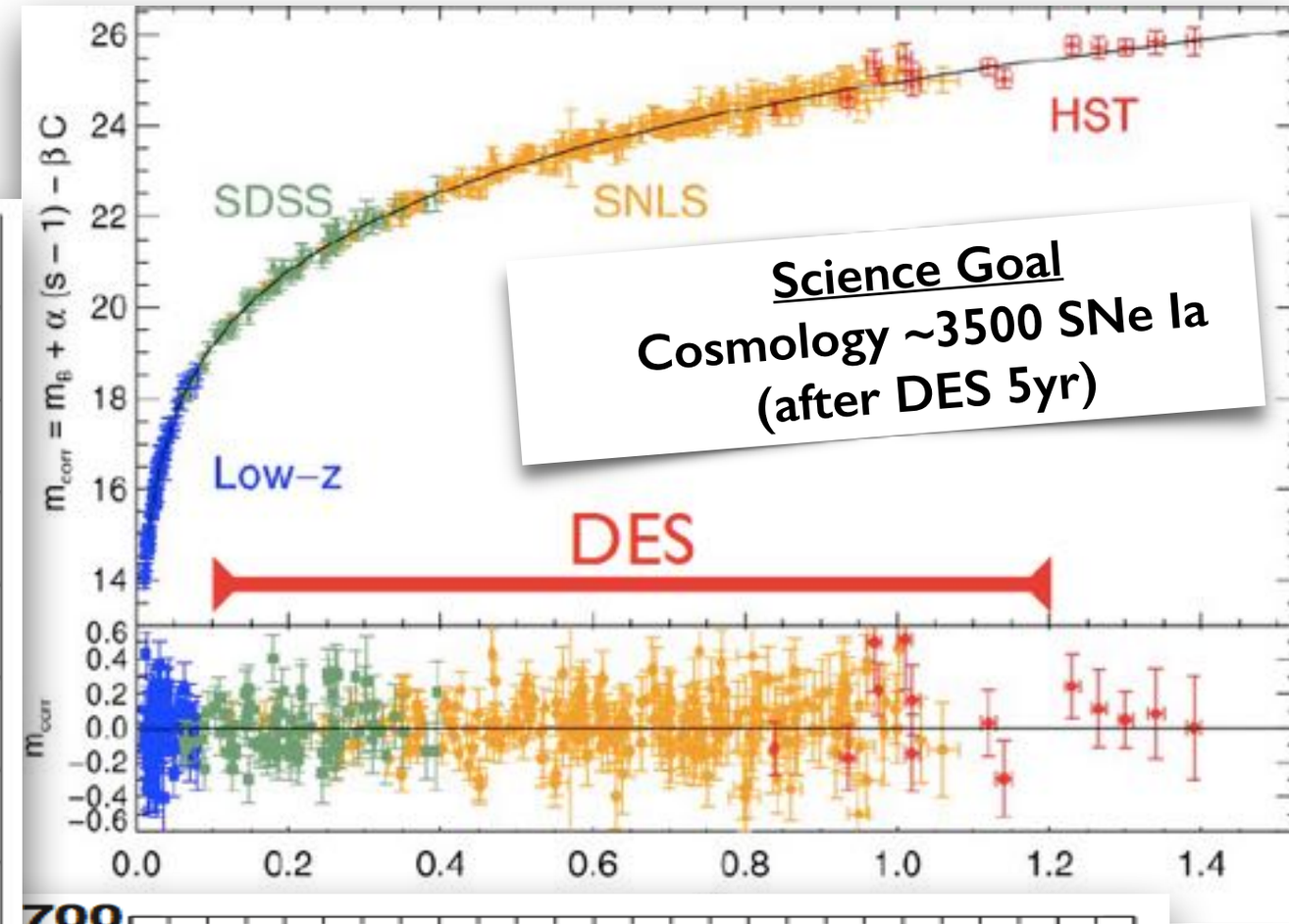




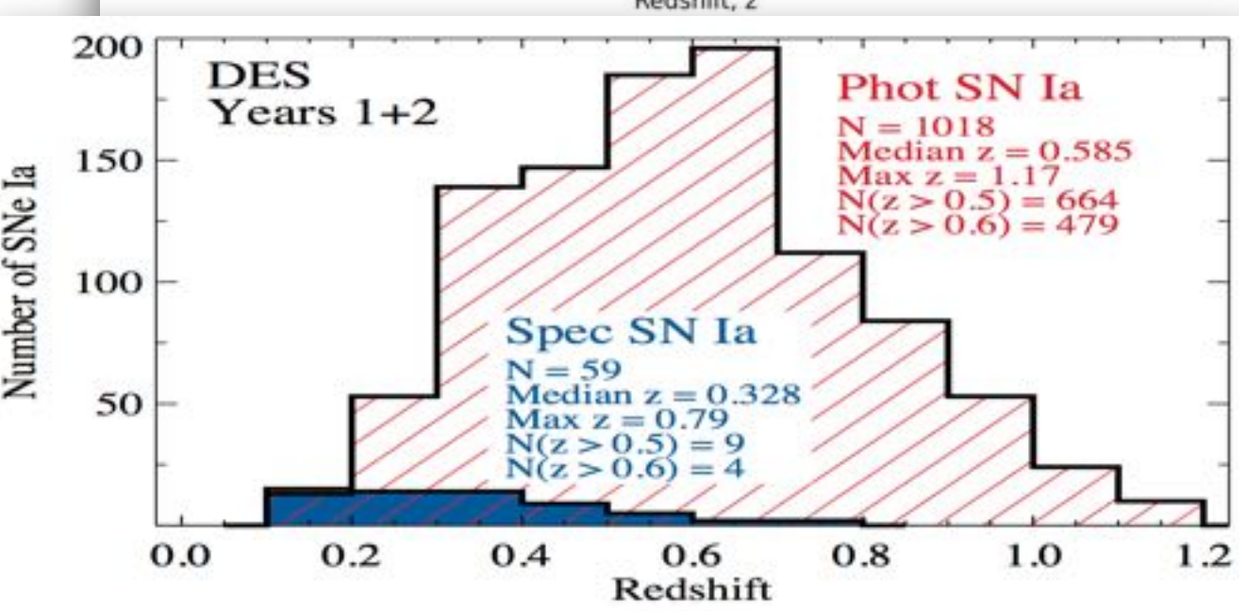


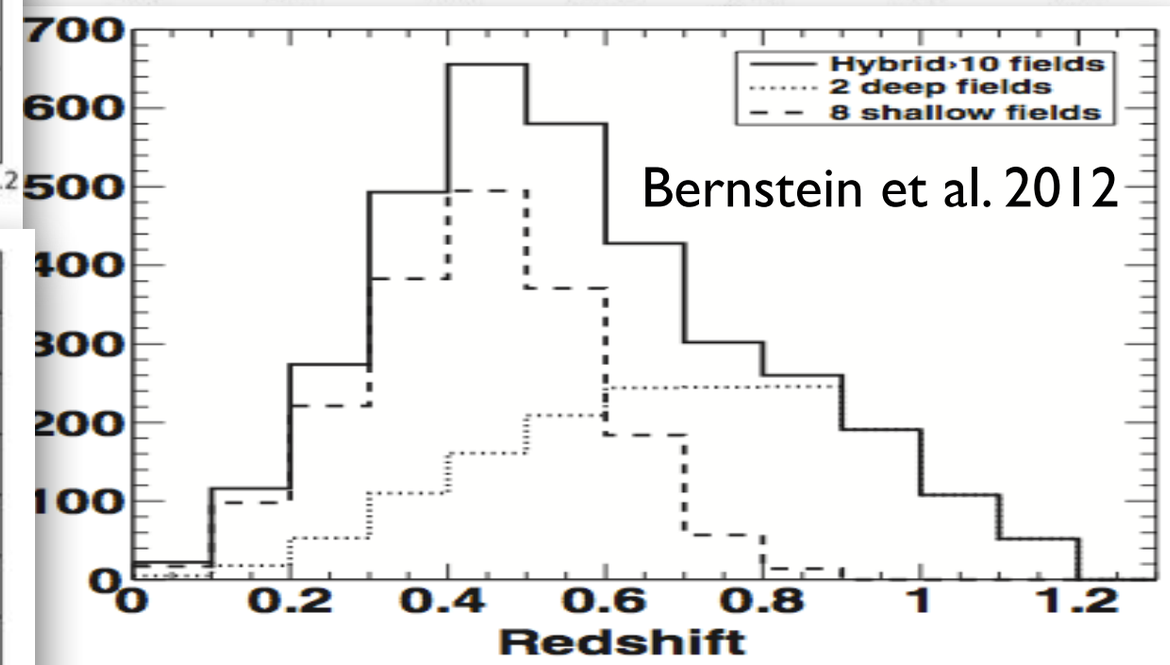
Update





Science Goal
Cosmology ~3500 SNe Ia (after DES 5yr)





Bernstein et al. 2012

Superluminous SNe (SLSNe)

Superluminous:

- $M_{absolute} < -21$
- ~50 times brighter

Light-curves:

- 100s of days
- long rise/fall timescales

Rare events:

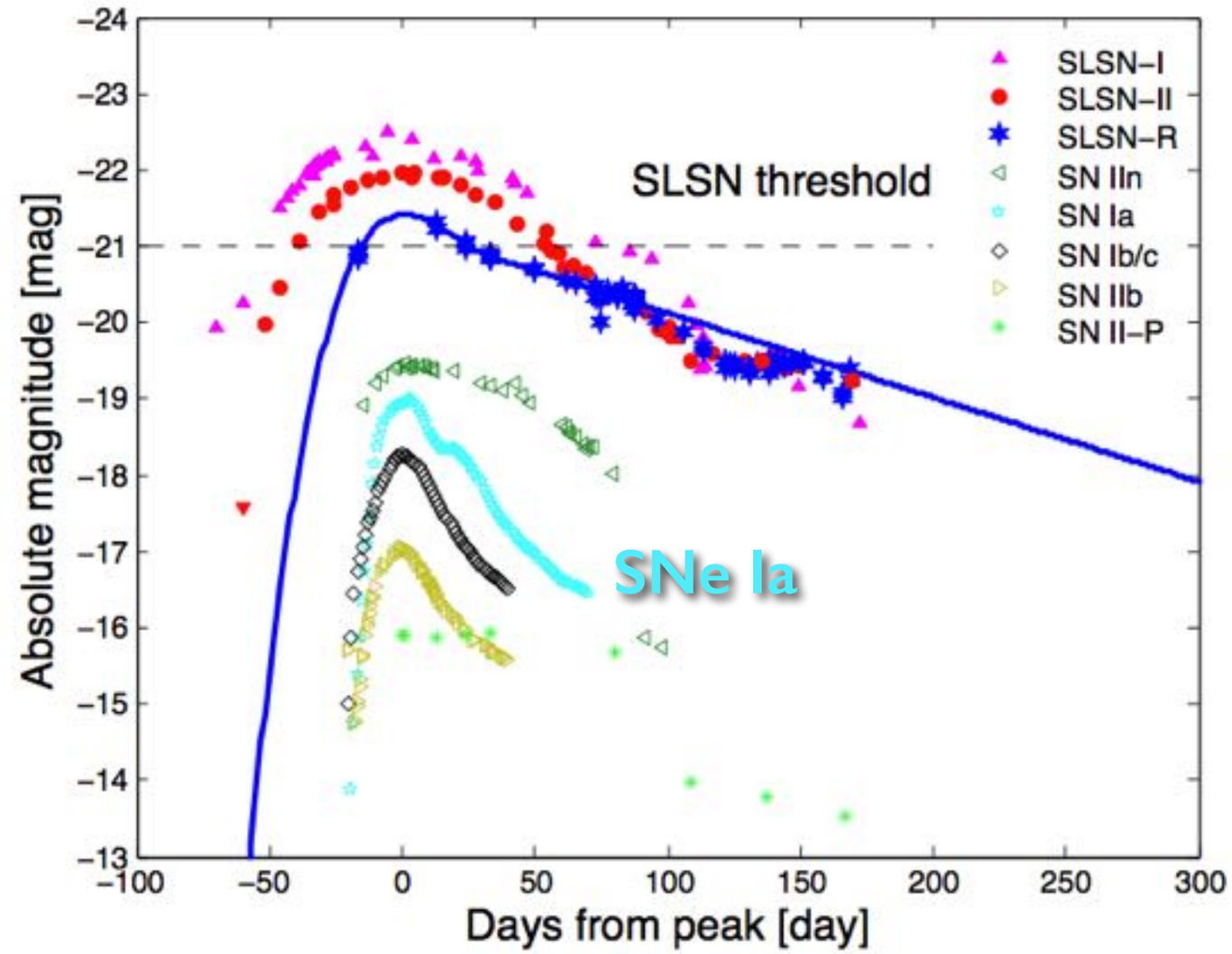
- ~40 discovered up to date
- 0.01% of SNe Ia rates
  - local Universe
- *15 increase @ z>1
  - SNLS, Cooke et al. 2012

High-z:

- SN 1000+0216 @ z=3.9
  - Cooke et al. 2012

UV emitters:

- redshifted to the observed optical



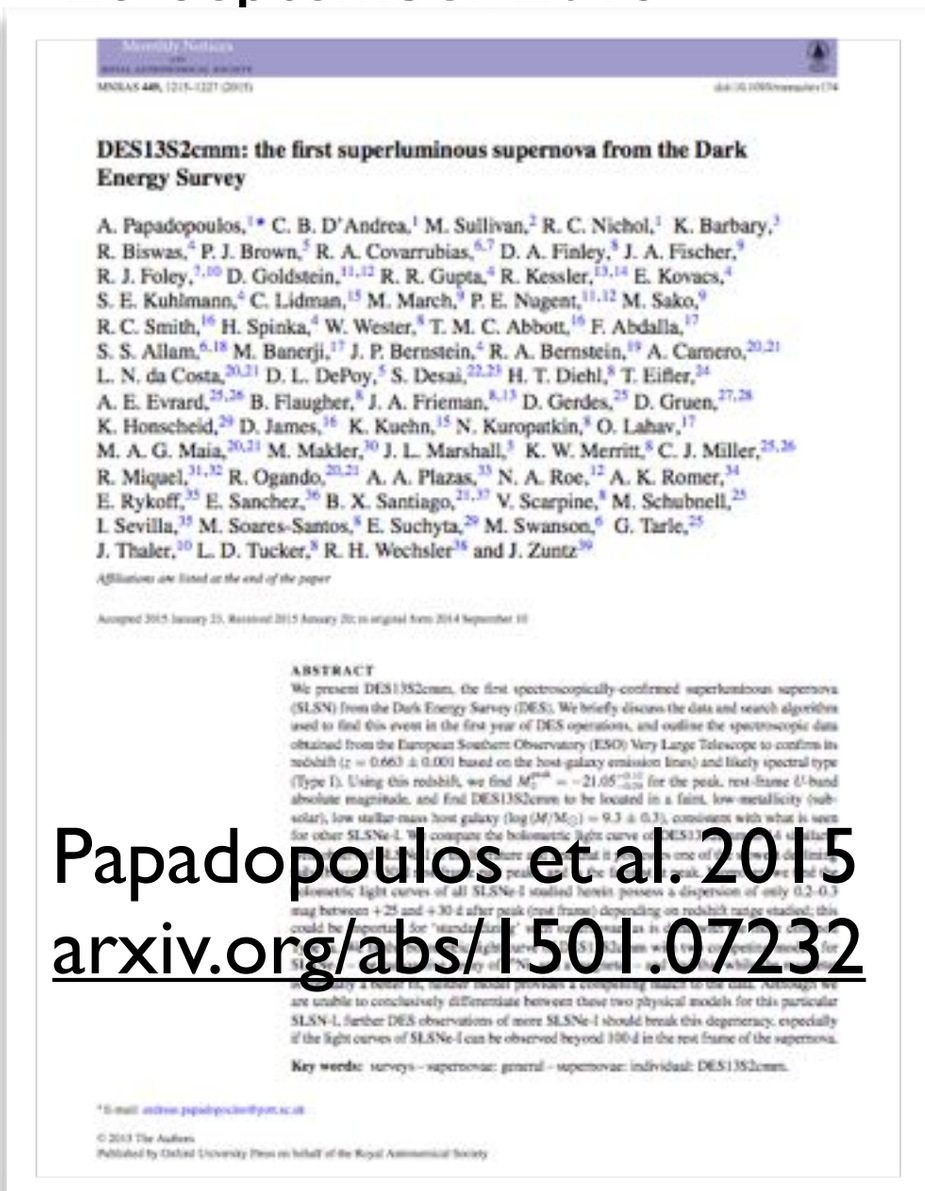
Gal-Yam, SLSNe review, 2012

DES13S2cmm

- ~30 days rise time
- z = 0.663 ± 0.001
- M_U = -21.09

Peak Brightness:

- 28-September-2013



DES13S2cmm: the first superluminous supernova from the Dark Energy Survey

A. Papadopoulos,[1*] C. B. D'Andrea,[1] M. Sullivan,[2] R. C. Nichol,[1] K. Barbary,[3] R. Biswas,[4] P. J. Brown,[5] R. A. Covarrubias,[6,7] D. A. Finley,[8] J. A. Fischer,[9] R. J. Foley,[7,10] D. Goldstein,[11,12] R. R. Gupta,[4] R. Kessler,[13,14] E. Kovacs,[4] S. E. Kuhlmann,[4] C. Lidman,[15] M. March,[9] P. E. Nugent,[11,12] M. Sako,[9] R. C. Smith,[16] H. Spinka,[4] W. Wester,[8] T. M. C. Abbott,[16] F. Abdalla,[17] S. S. Allam,[6,18] M. Banerji,[17] J. P. Bernstein,[4] R. A. Bernstein,[19] A. Carnero,[20,21] L. N. da Costa,[20,21] D. L. DePoy,[5] S. Desai,[22,23] H. T. Diehl,[8] T. Eifler,[24] A. E. Evrard,[25,26] B. Flaugher,[8] J. A. Frieman,[8,13] D. Gerdes,[25] D. Gruen,[27,28] K. Honscheid,[29] D. James,[16] K. Kuehn,[15] N. Kuropatkin,[8] O. Lahav,[17] M. A. G. Maia,[20,21] M. Makler,[30] J. L. Marshall,[5] K. W. Merritt,[8] C. J. Miller,[25,26] R. Miquel,[31,32] R. Ogando,[20,21] A. A. Plazas,[33] N. A. Roe,[12] A. K. Romer,[34] E. Rykoff,[35] E. Sanchez,[36] B. X. Santiago,[21,37] V. Scarpine,[8] M. Schubnell,[25] I. Sevilla,[35] M. Soares-Santos,[8] E. Suchyta,[29] M. Swanson,[6] G. Tarle,[25] J. Thaler,[10] L. D. Tucker,[8] R. H. Wechsler[38] and J. Zuntz[39]

Affiliations are listed at the end of the paper

Accepted 2015 January 23. Received 2015 January 20; in original form 2014 September 10

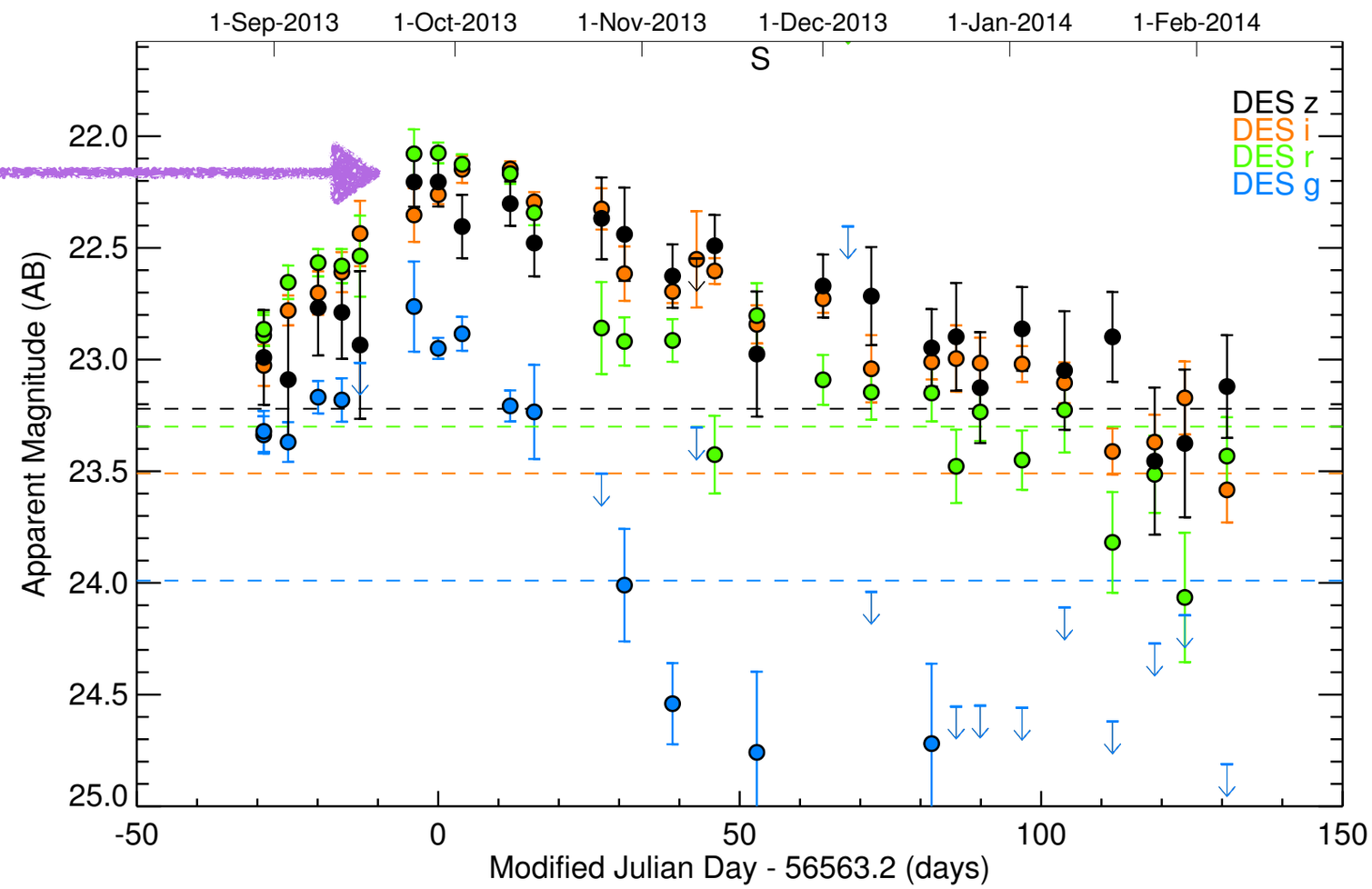
ABSTRACT

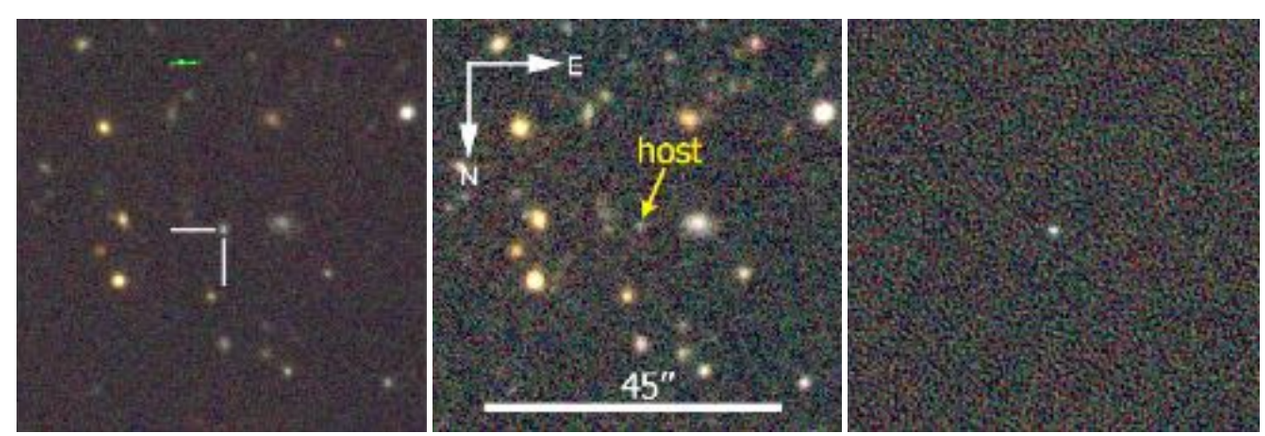
We present DES13S2cmm, the first spectroscopically-confirmed superluminous supernova (SLSN) from the Dark Energy Survey (DES). We briefly discuss the data and search algorithm used to find this event in the first year of DES operations, and outline the spectroscopic data obtained from the European Southern Observatory (ESO) Very Large Telescope to confirm its redshift ($z = 0.663 \pm 0.001$ based on the host-galaxy emission lines) and likely spectral type (Type I). Using this redshift, we find $M_U^{peak} = -21.05^{+0.10}_{-0.09}$ for the peak, rest-frame U-band absolute magnitude, and find DES13S2cmm to be located in a faint, low-metallicity (sub-solar), low stellar-mass host galaxy ($\log(M/M_\odot) = 9.3 \pm 0.3$), consistent with what is seen for other SLSNe-I. We compare the bolometric light curve of DES13S2cmm to other SLSNe-I, and find it to be one of the slowest-evolving events. Although the bolometric light curves of all SLSNe-I studied herein possess a dispersion of only 0.2–0.3 mag between +25 and +30 d after peak (rest frame) depending on redshift range studied, this could be reported for "standardizing" SLSNe-I as it is only a factor of 2 better than the dispersion of the peak absolute magnitudes. Although a better fit, further model provides a comparing match to the data. Although we are unable to conclusively differentiate between these two physical models for this particular SLSN-I, further DES observations of more SLSNe-I should break this degeneracy, especially if the light curves of SLSNe-I can be observed beyond 100 d in the rest frame of the supernova.

Key words: surveys – supernovae: general – supernovae: individual: DES13S2cmm.

*E-mail: andrew.papadopoulos@port.ac.uk

Papadopoulos et al. 2015
arxiv.org/abs/1501.07232





Search Template Difference

European University Cyprus
LAUREATE INTERNATIONAL UNIVERSITIES

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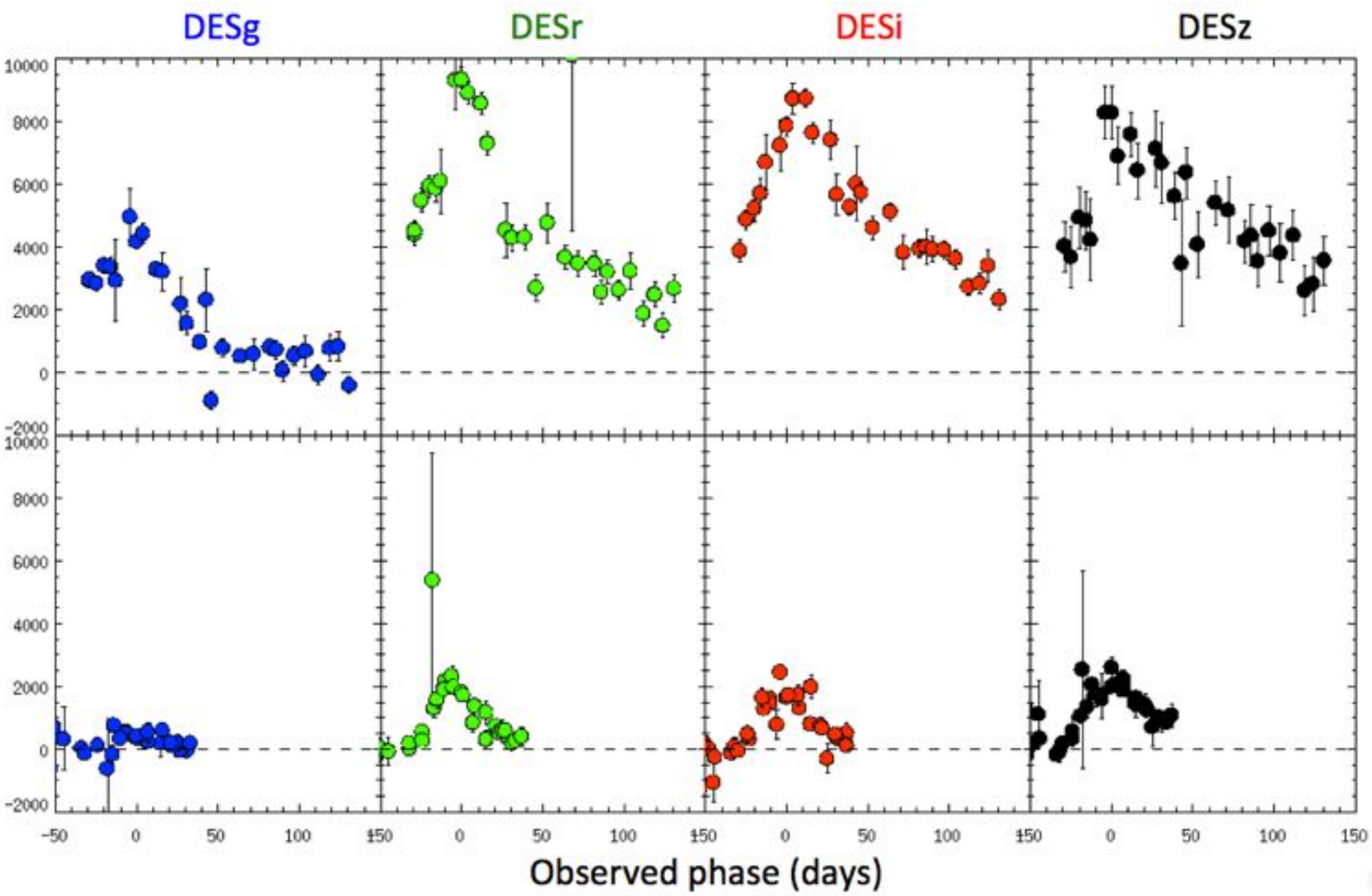
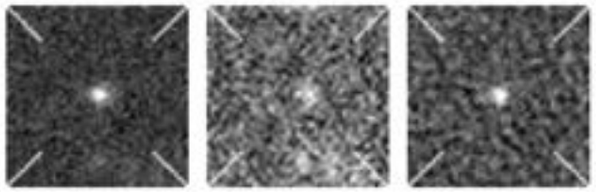
AHPC

DES13S2cmm Vs SNe type Ia



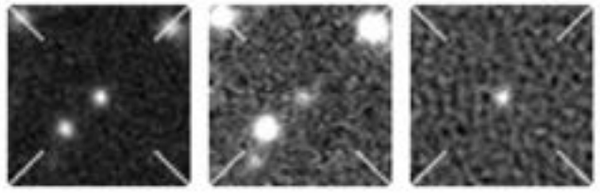
DES13S2cmm:

- VLT
  - z = 0.663
- SLSN-I

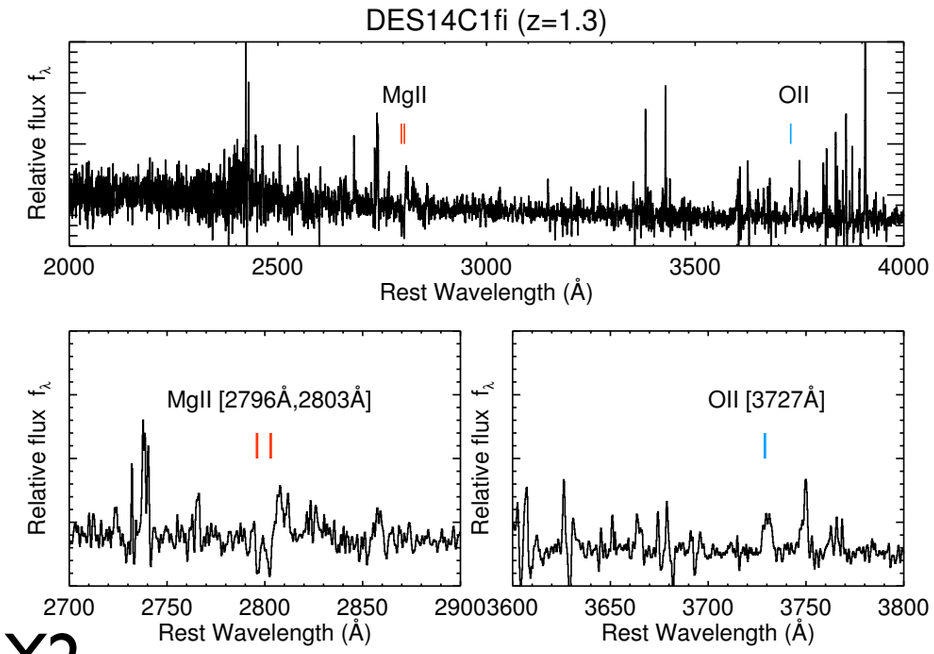


DES13C3abht:

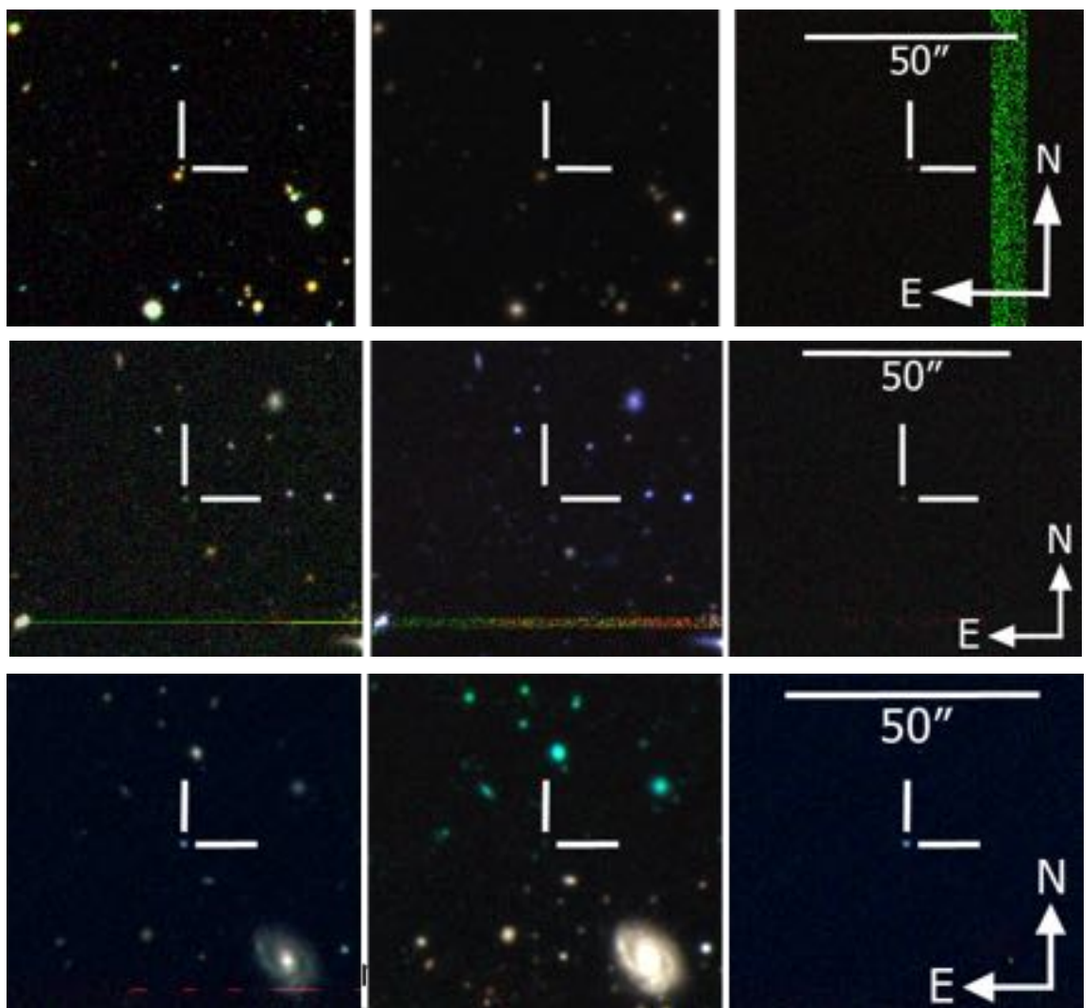
- Gemini-South
  - z = 0.690
- type Ia

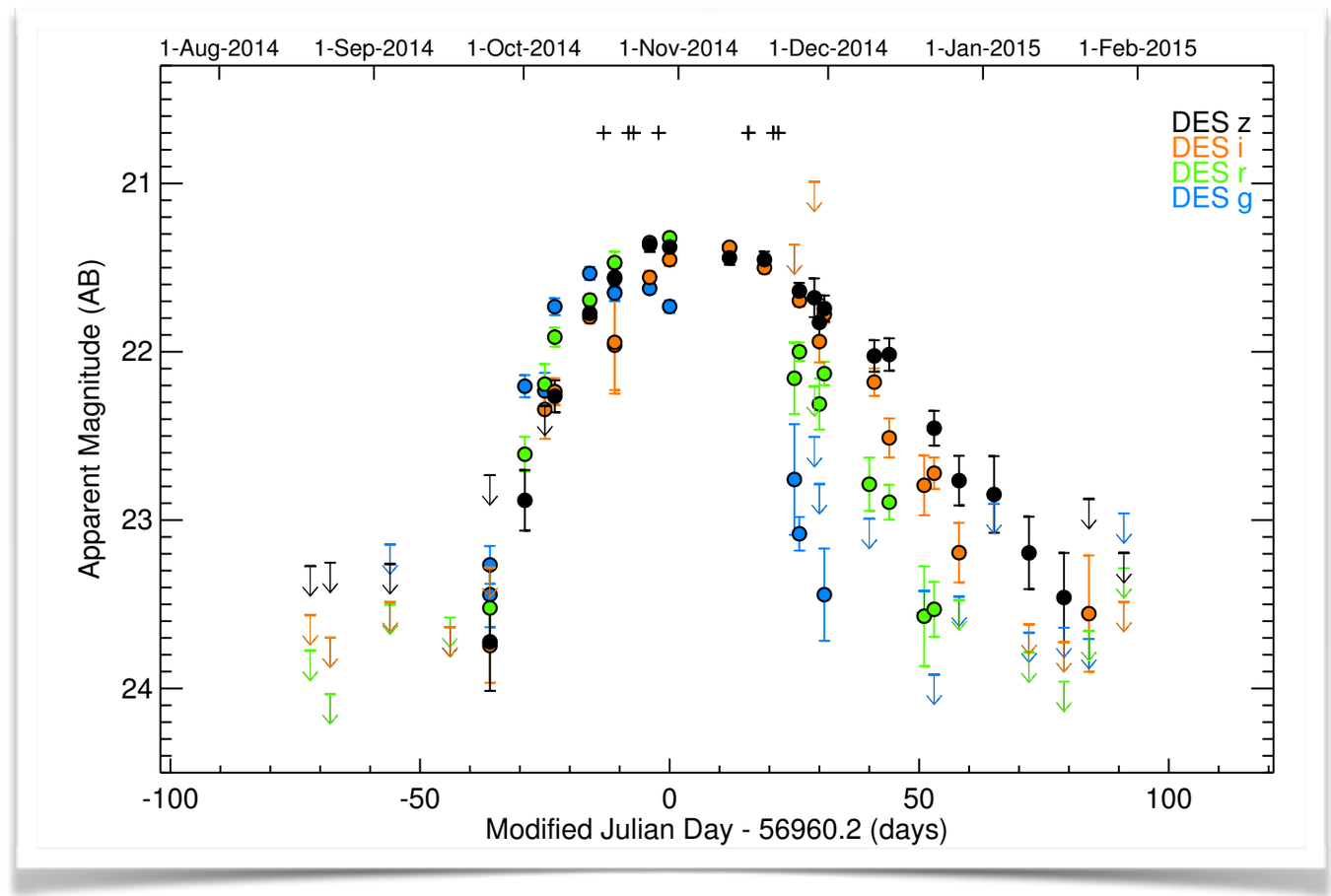


SLSNe in DES - update

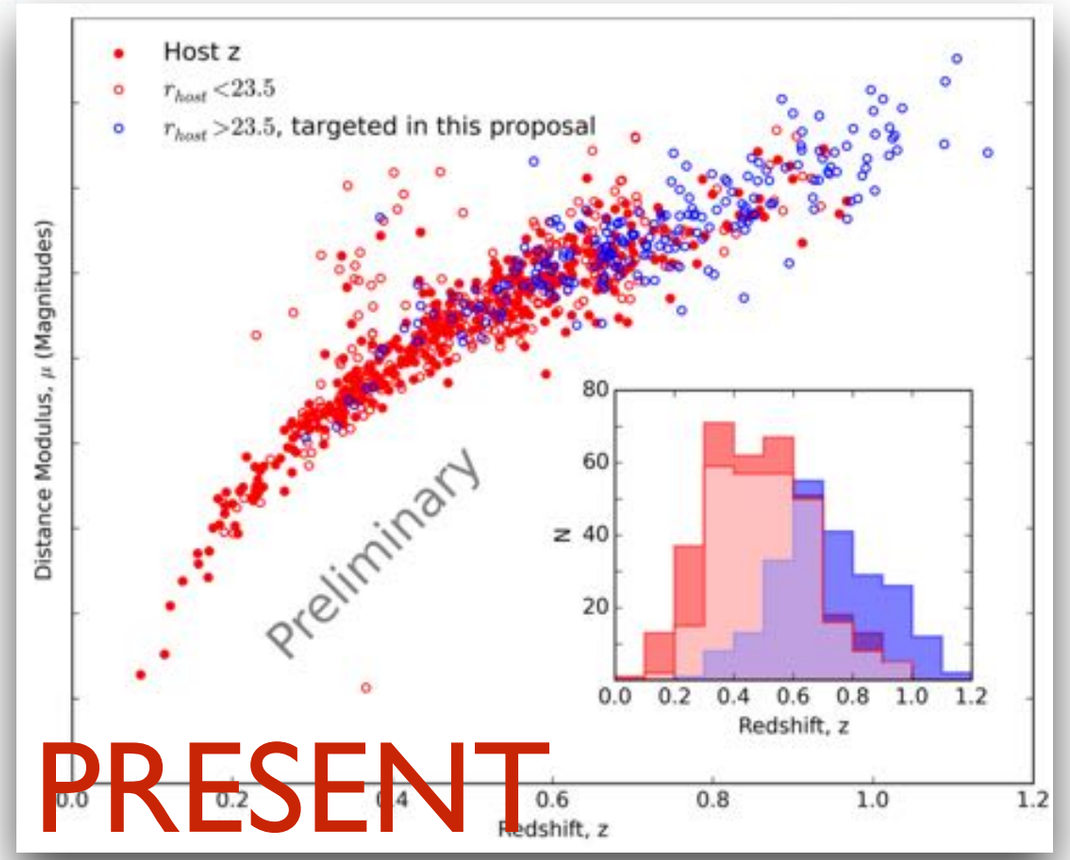


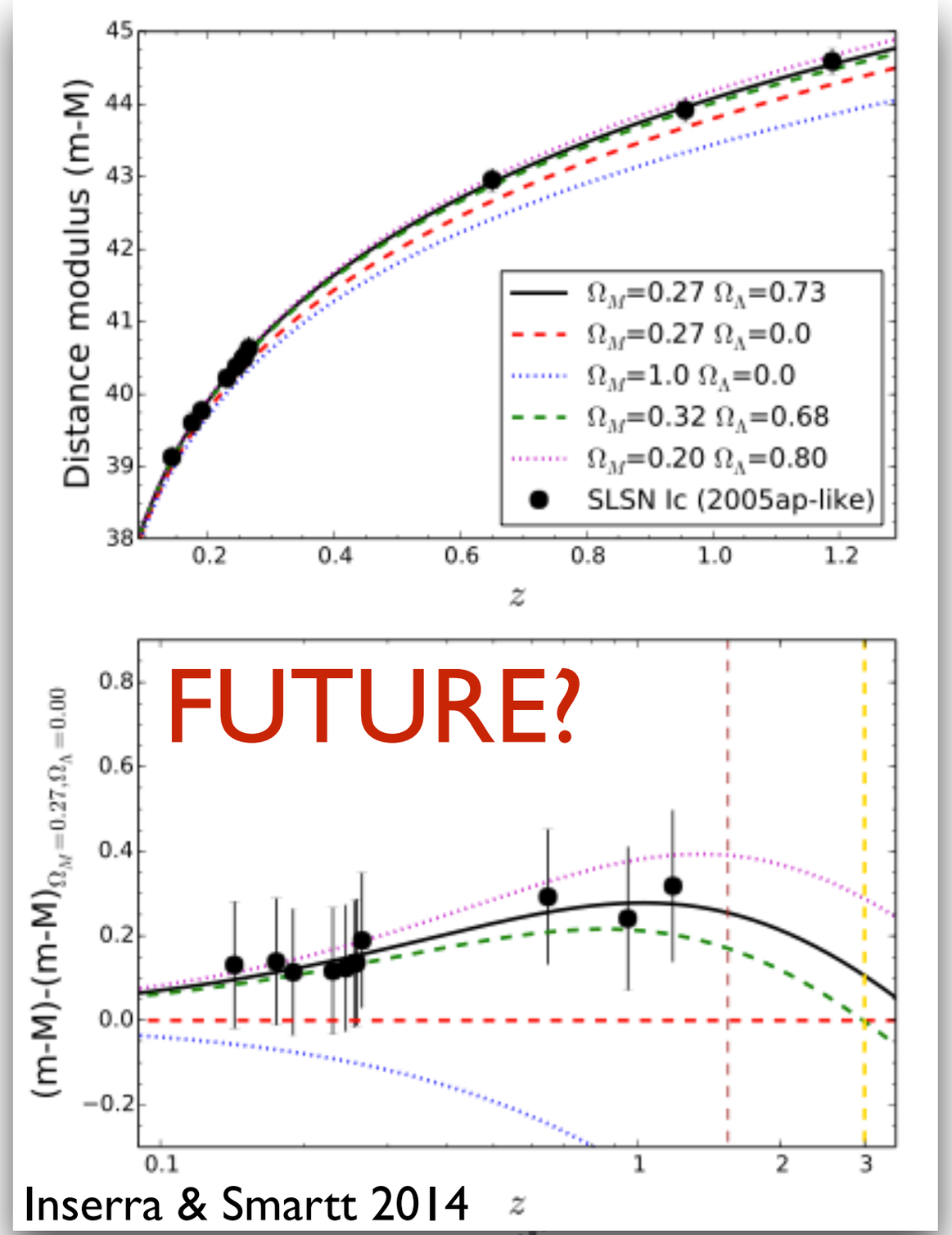
- 1 SLSN confirmed from Y1
- 7 SLSNe confirmed from Y2
  - most luminous SN ever discovered (2-3 months)
  - highest redshift (z=1.3) SLSN-II ever discovered
- ~15 candidates awaiting for host-z confirmation from Y2
- 2 SLSNe confirmed from Y3…



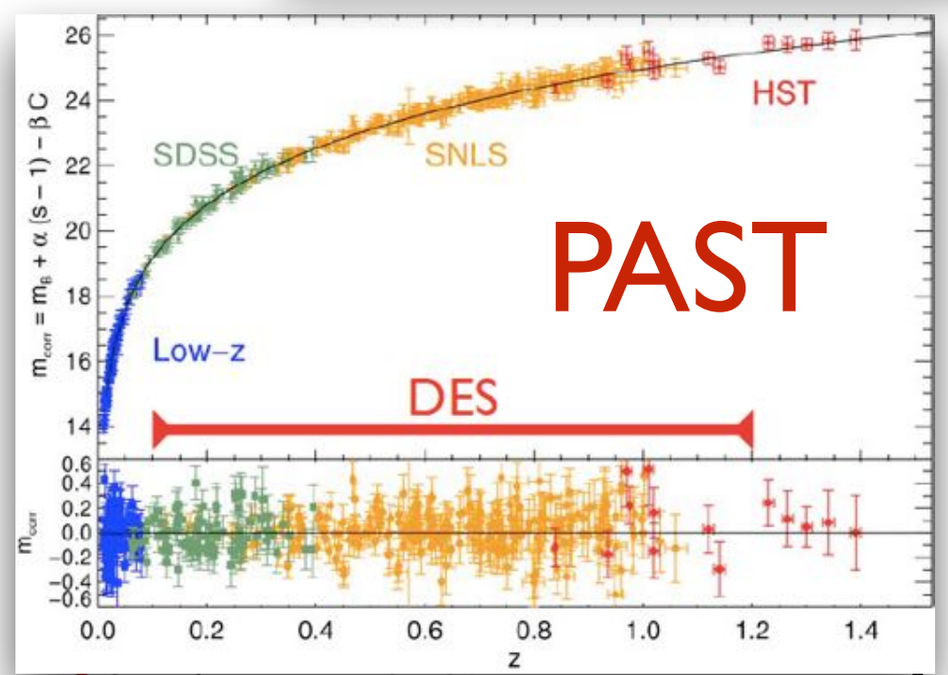


SLSNe - Standardisation?

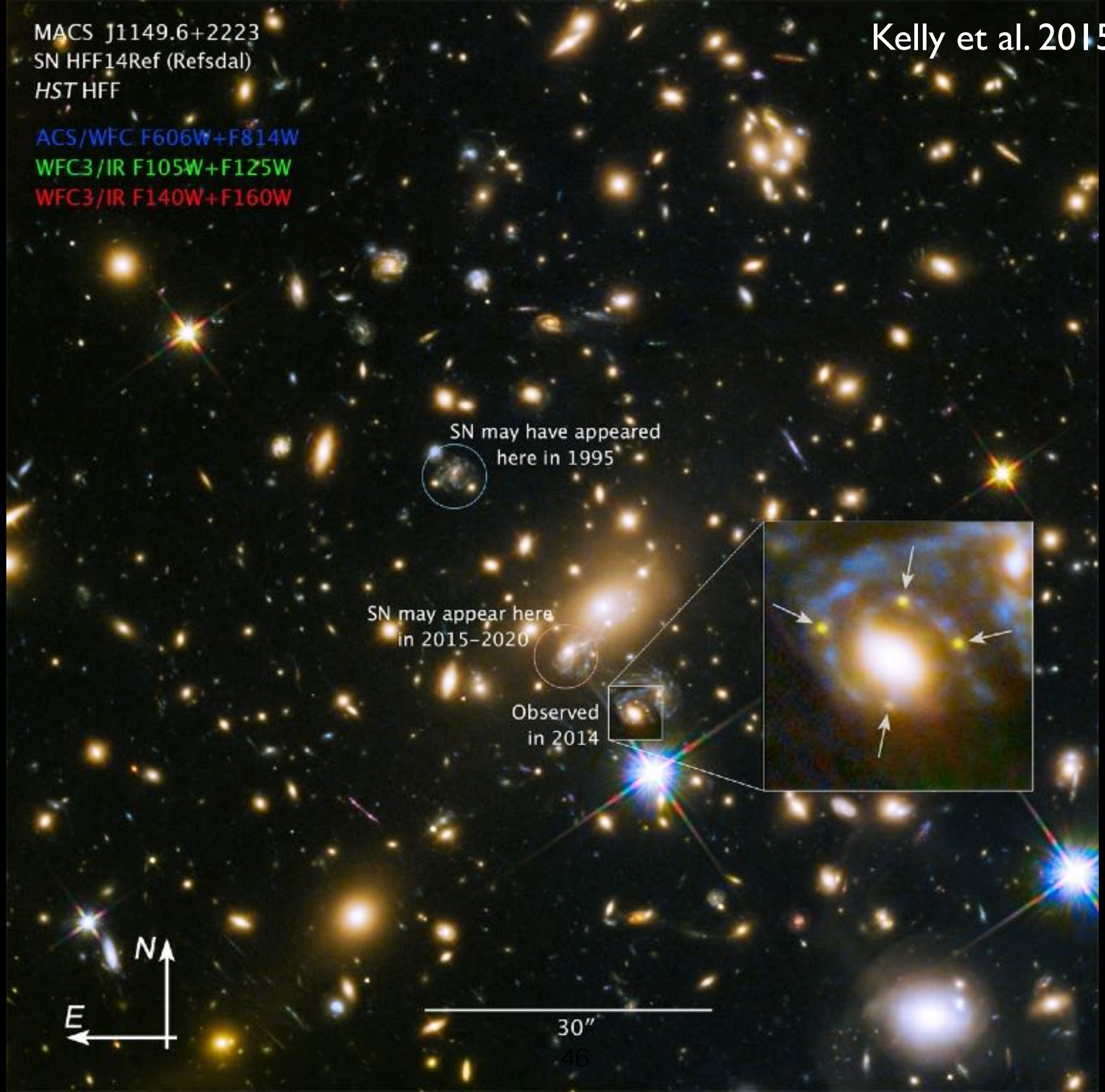




Inserra & Smartt 2014



Kelly et al. 2015 (Nature)



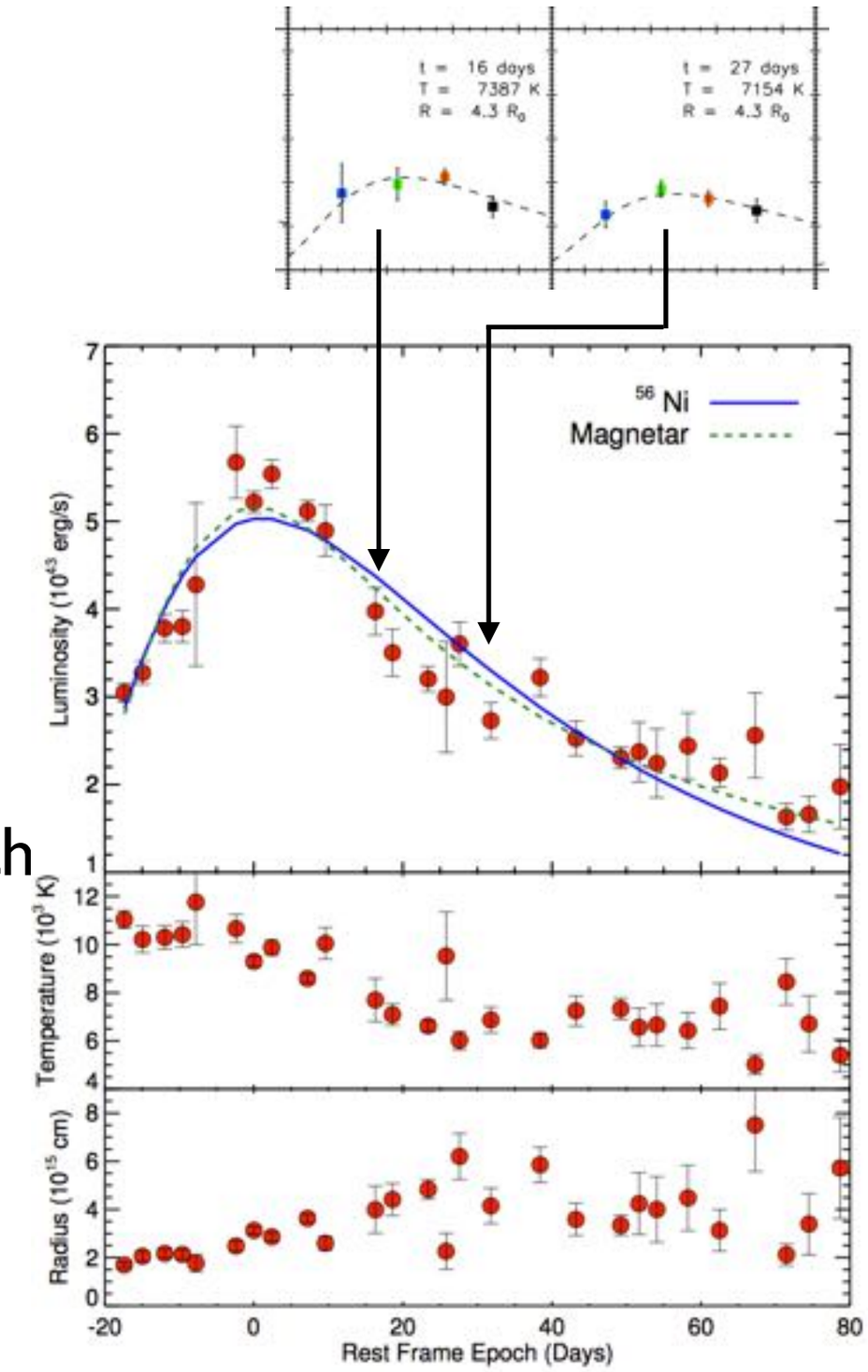
DES13S2cmm: Modelling

Bolometric LC (rest frame):

- Black body SED fits - Temperature & Radius
  - each epoch with >3 filter/observations
  - integrate the best fit SEDs = L_{bol}

- Nature of the power source:
  - *Radioactive decay of nickel - ^{56}Ni*
    - t_0, E_{exp}, M_{ej}, M_{Ni}

  - *Magnetar**
    - rapid spin-down of a Neutron star with
    - t_0, P_{ms}, B_{14}, τ_m



DES13S2cmm: Modelling

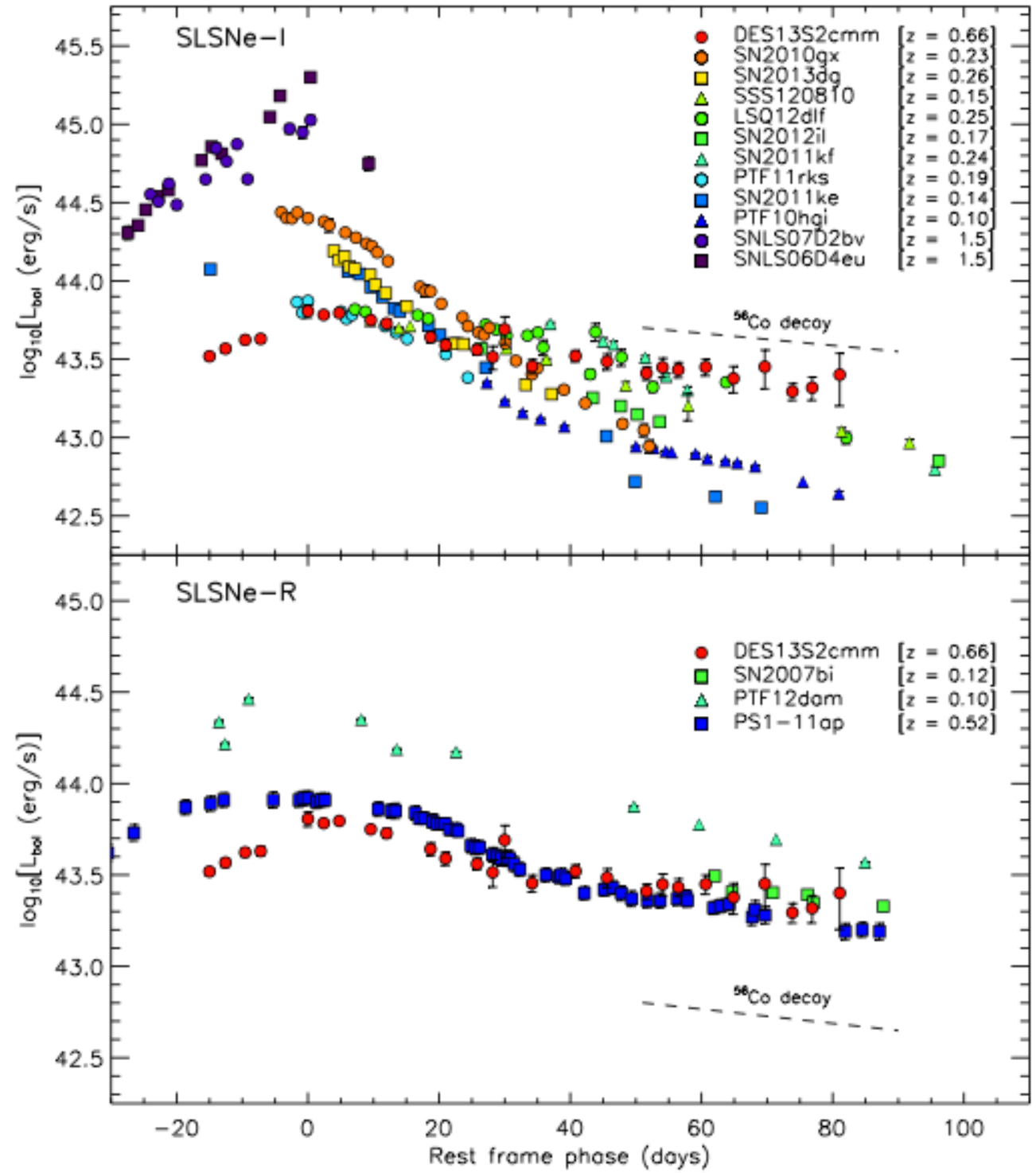
SLSNe-I:

- Pastorello el al. 2010, Inserra et al. 2013, Howell et al. 2013 ,Nicholl et al. 2014
- ***Same luminosity at +25 days***
- ***hints for Standardisation?***

SLSNe-R:

- Gal-Yam et al. 2009, McCrum et al. 2013 ,Nicholl et al. 2013
- Can't be ruled out

A.Papadopoulos et al. (submitted)



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