



European
University Cyprus

LAUREATE INTERNATIONAL UNIVERSITIES

Dr. Andreas Papadopoulos

Dr. Chris D'Andrea

Dr. Mark Sullivan

Prof. Bob Nichol

DES Supernovae Working Group

Supernovae & Cosmology

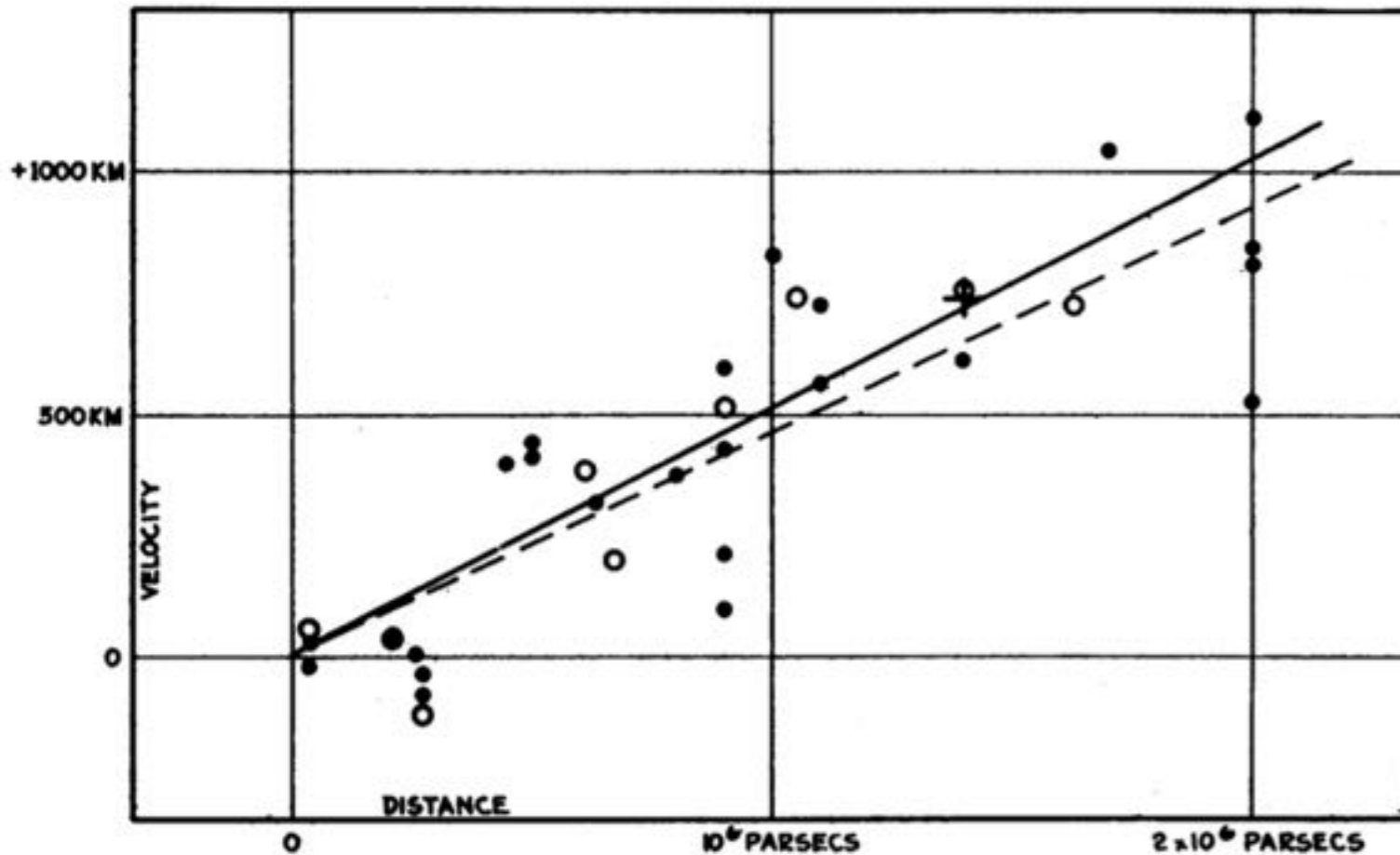
Dark Energy Survey



27-October-2015
European University Cyprus



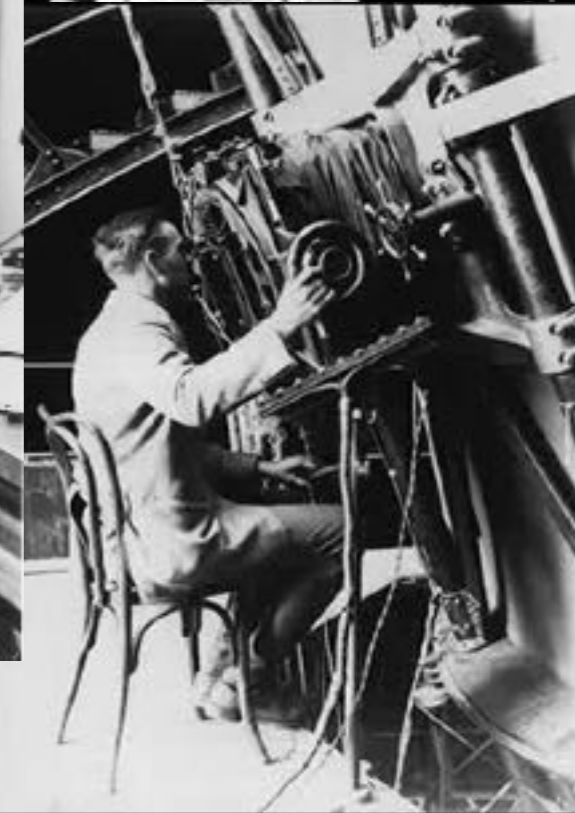
History of the Universe



Galaxies further away are moving faster.

$$U = H_0 \times d$$

The Universe is Expanding!

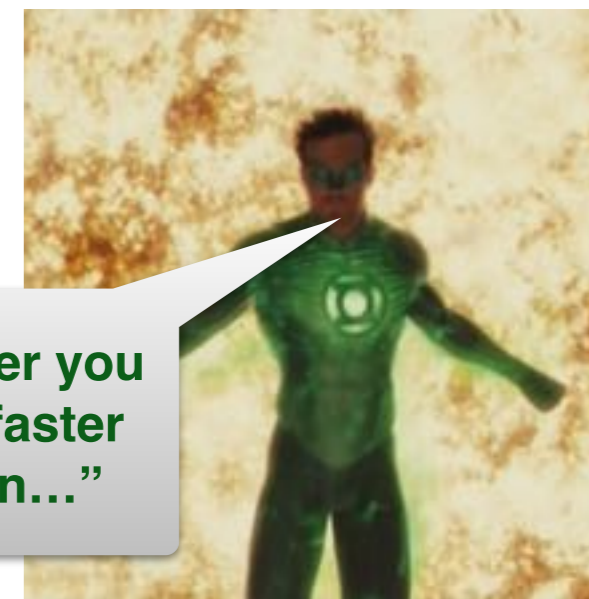
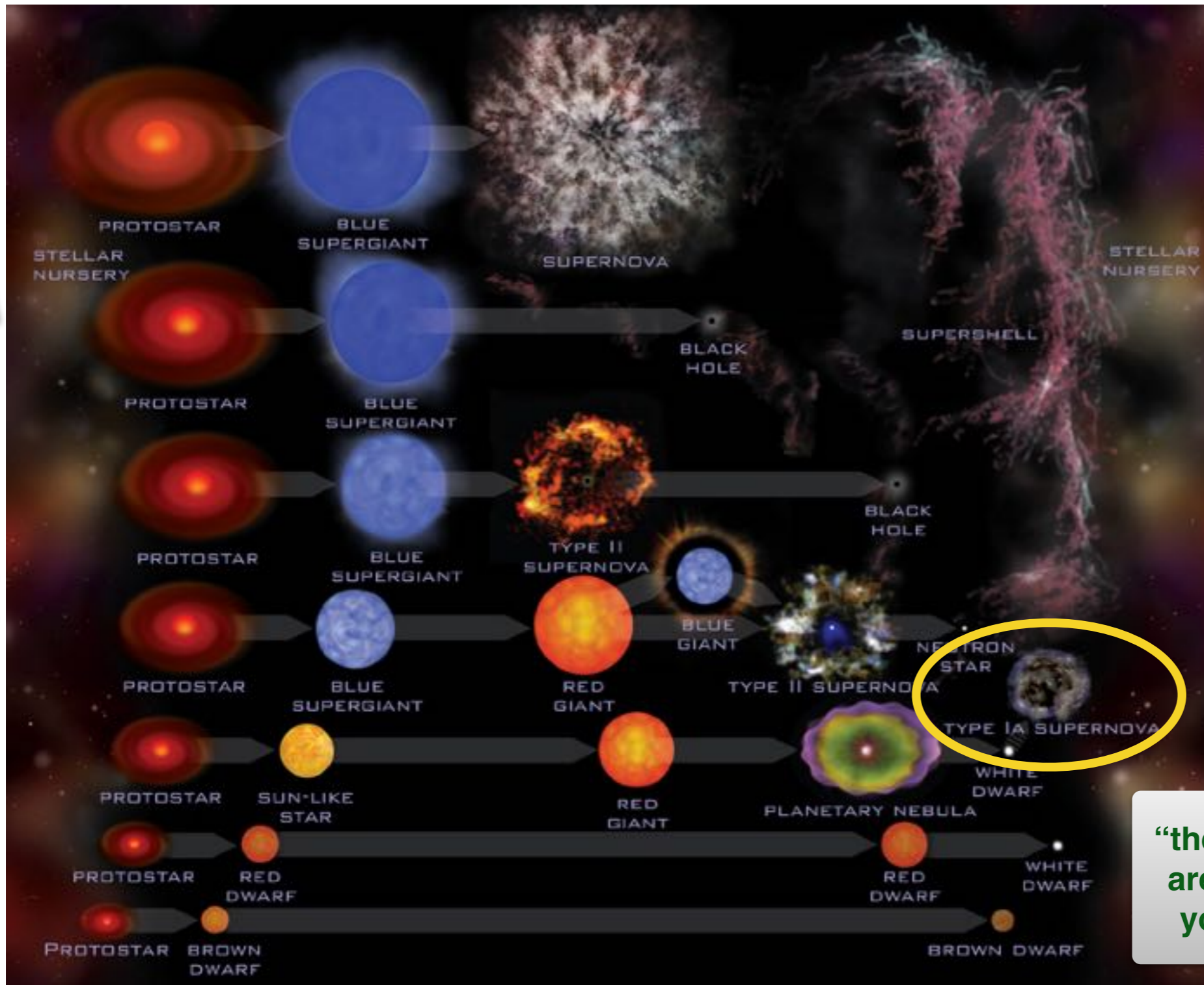


Edwin Hubble is shown looking through the 100-inch telescope at the Mt. Wilson Observatory (photo date: ~1922).



Supernovae - SNe

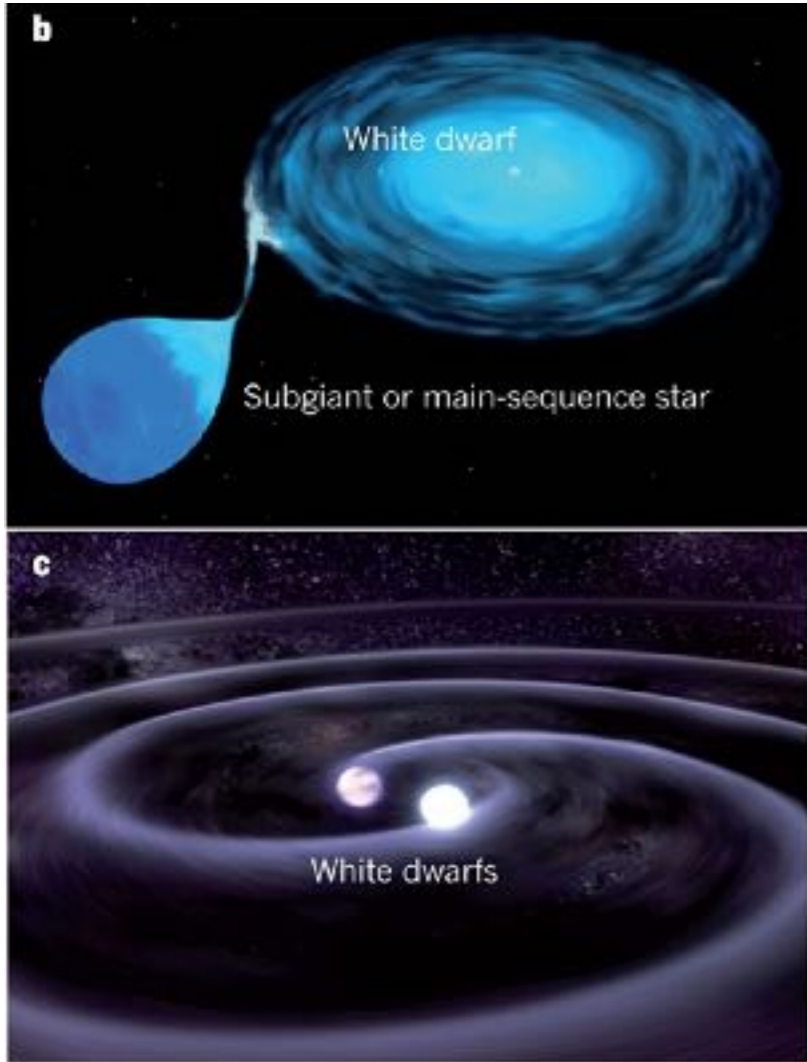
↑
MASS



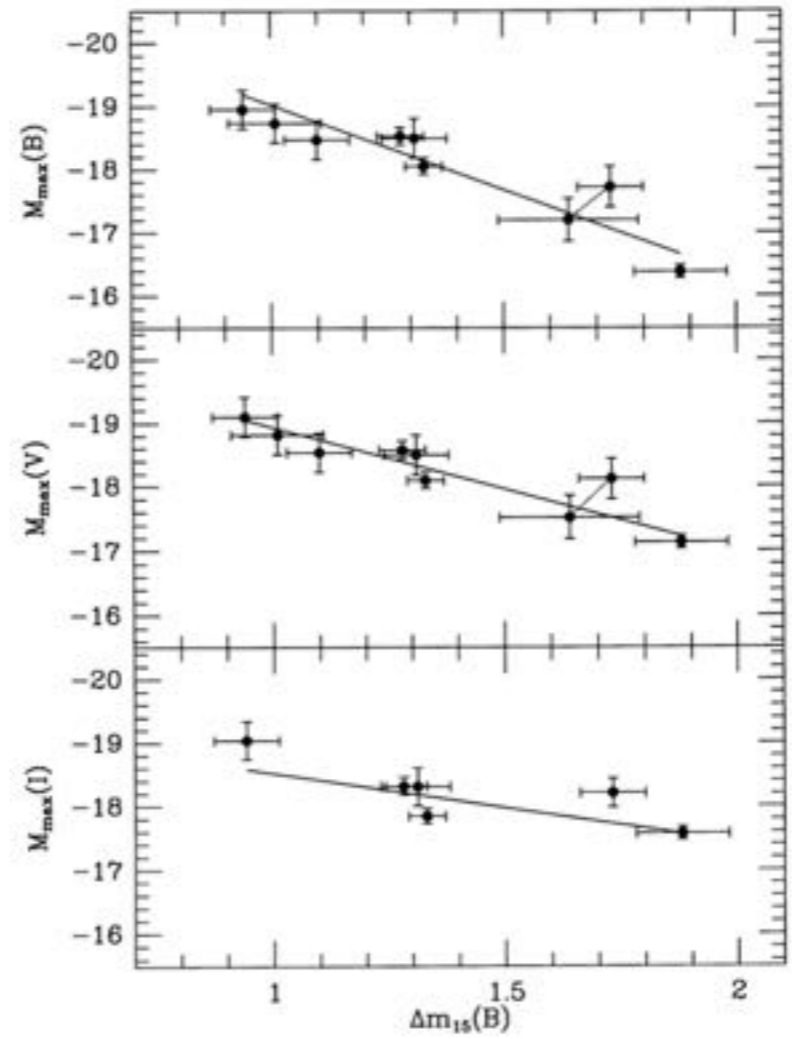
“the bigger you are, the faster you burn...”



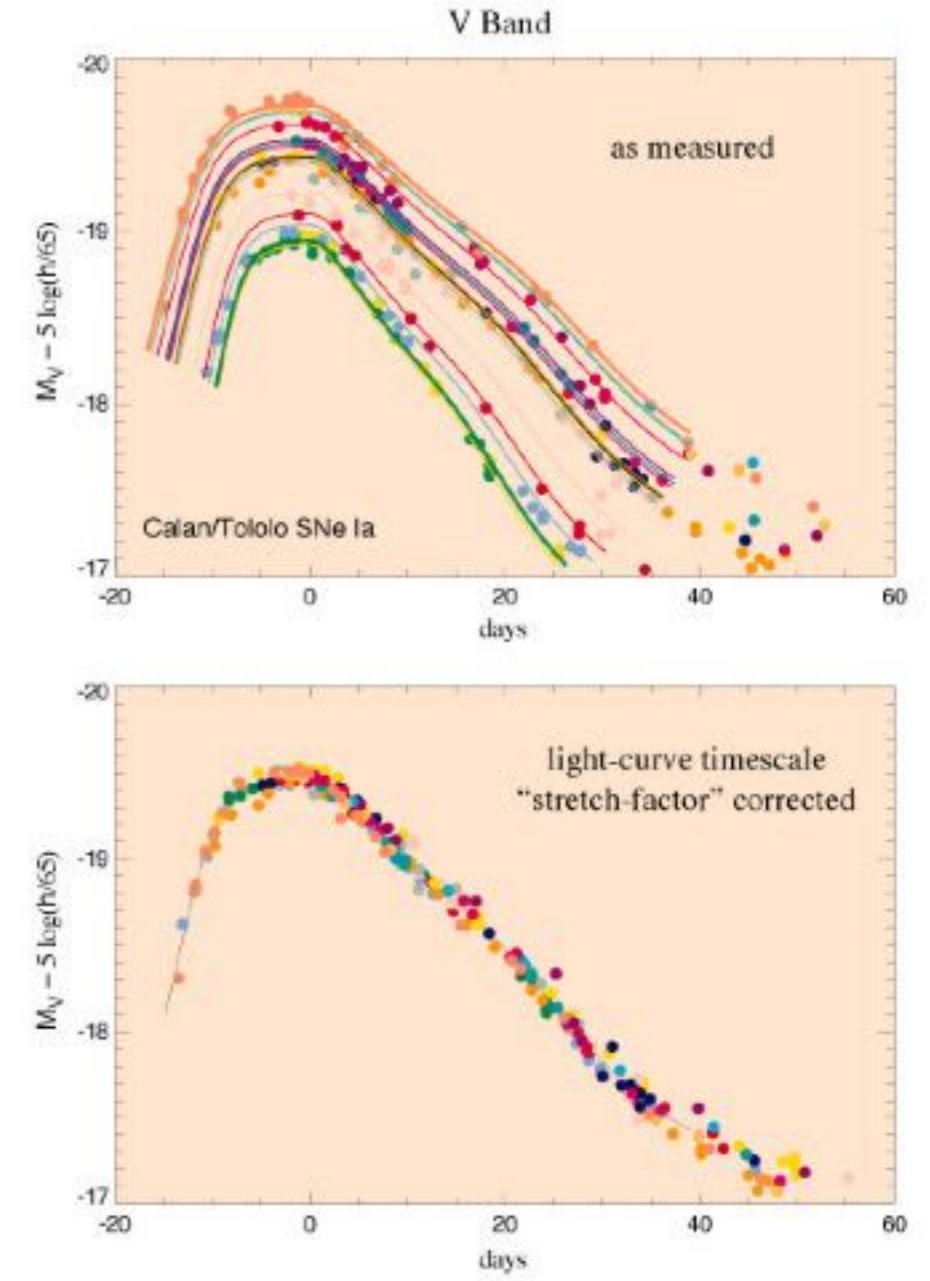
SNe type Ia



White Dwarfs accreting mass
 $M \sim 1.4 M_{\odot}$
 Thermonuclear explosion



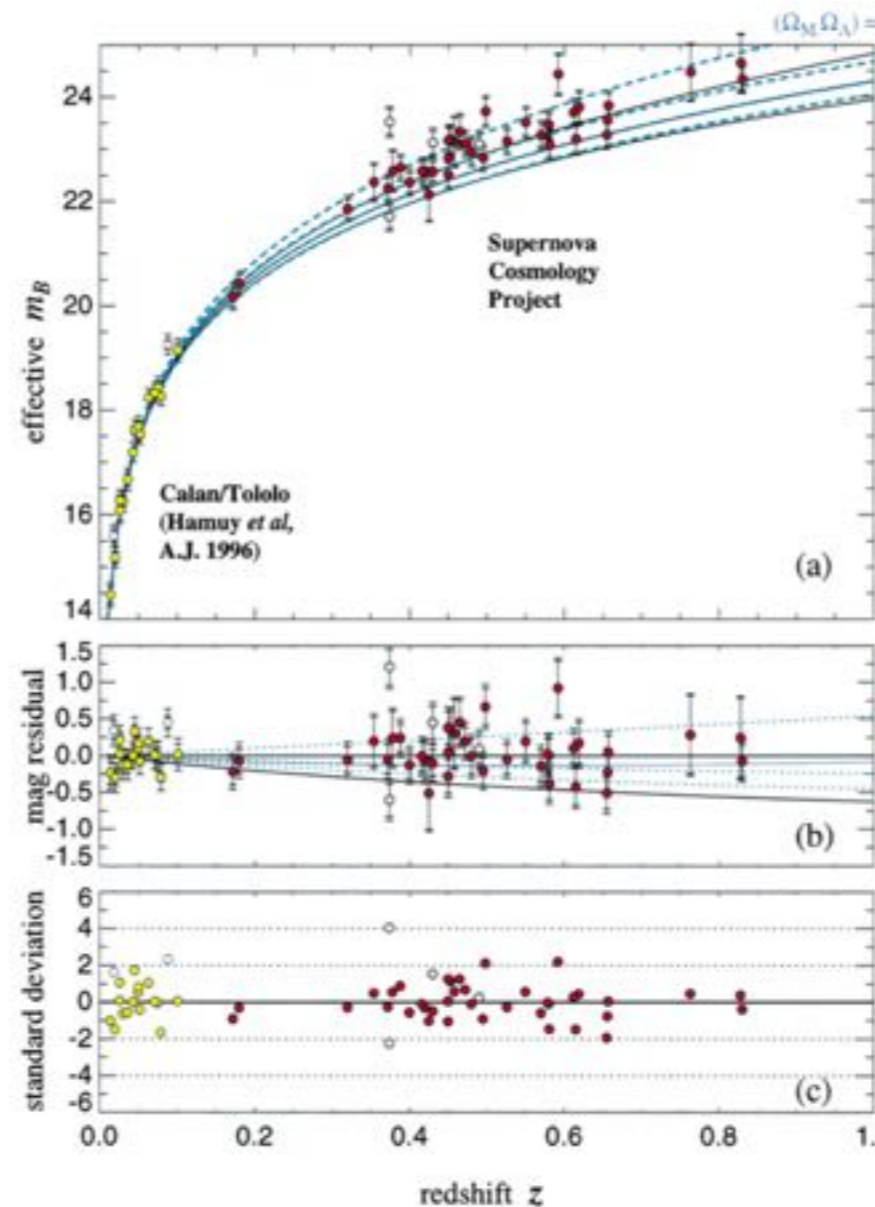
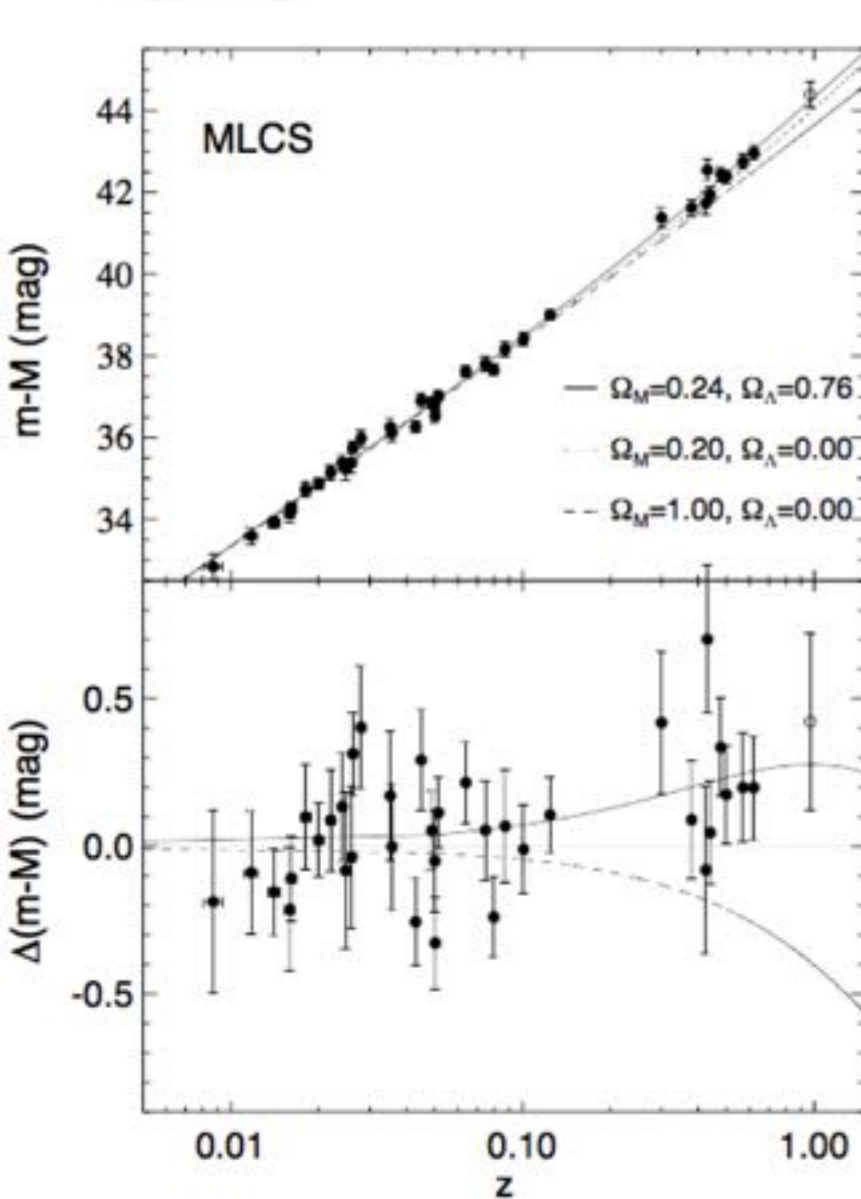
Phillips et al. 1993



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



Photo: U. Montan
Saul Perlmutter



Photo: U. Montan
Brian P. Schmidt



Photo: U. Montan
Adam G. Riess

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".



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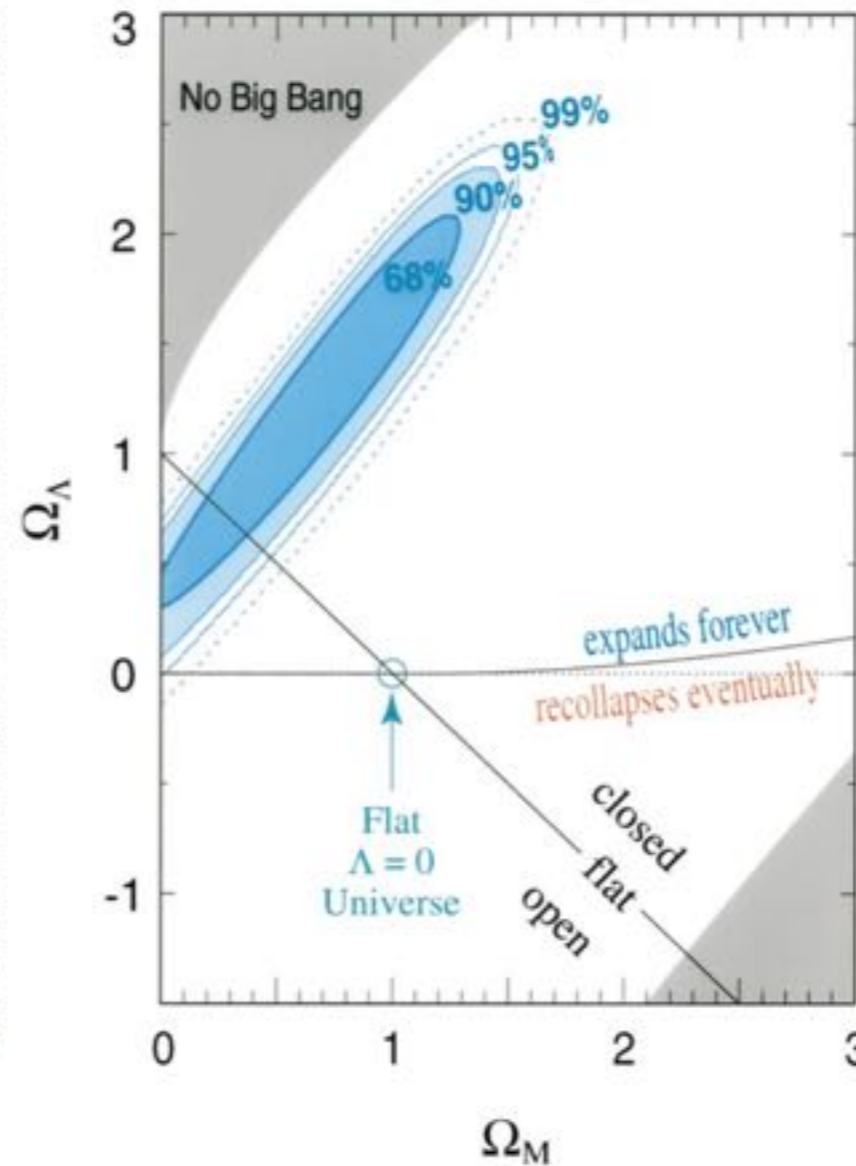
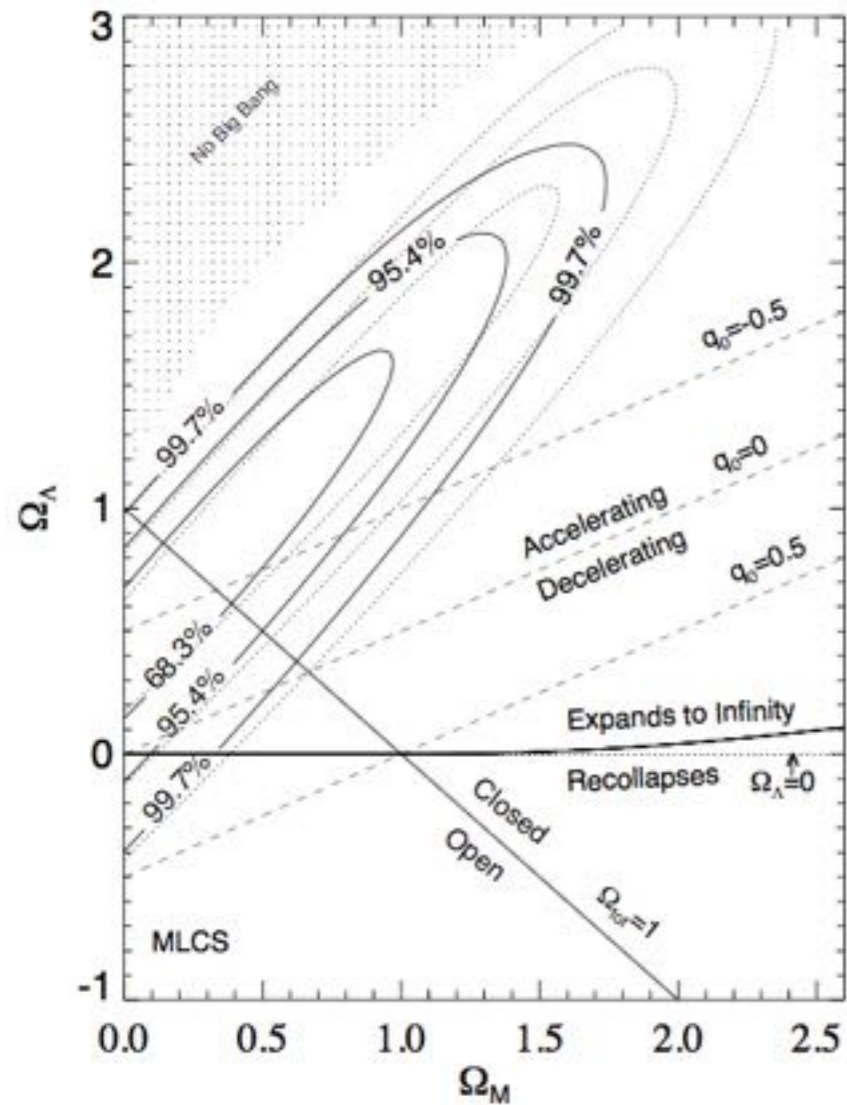
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A.Papadopoulos@external.euc.ac.cy





Universe & the Accelerating Expansion



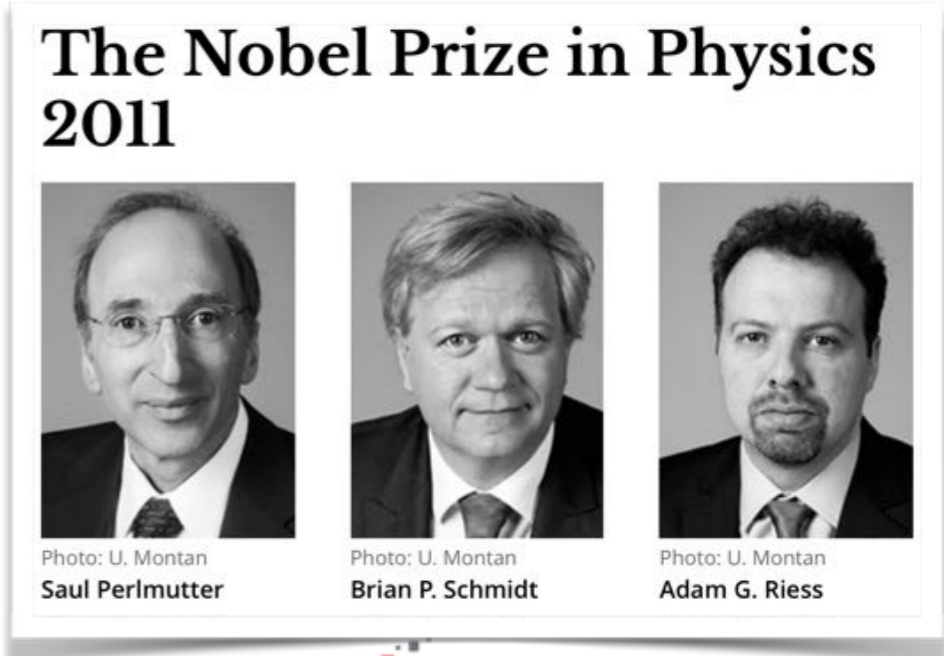
$$\mu = f [z, \Omega_m, \Omega_\Lambda, w(z)]$$

\downarrow Amount of Matter $\sim 30\%$

\downarrow Amount of Dark Energy $\sim 70\%$

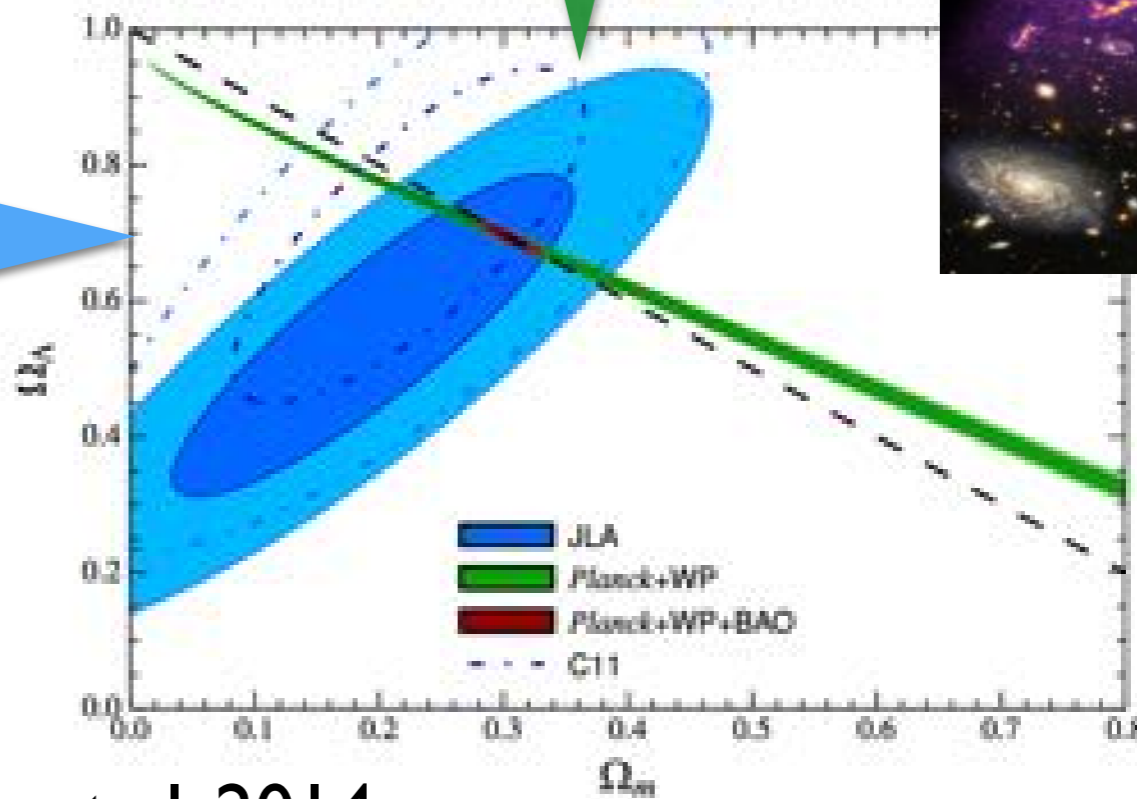
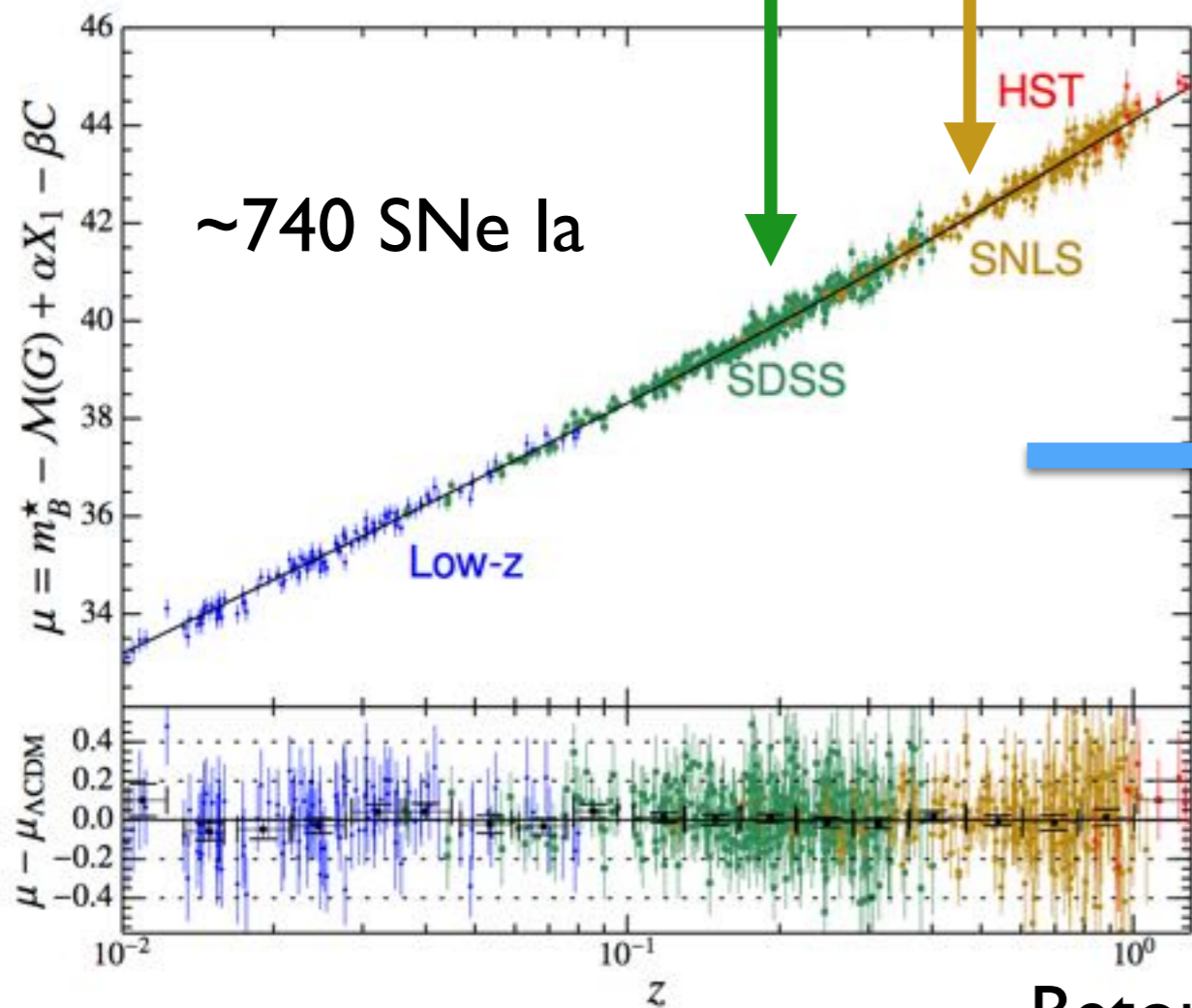
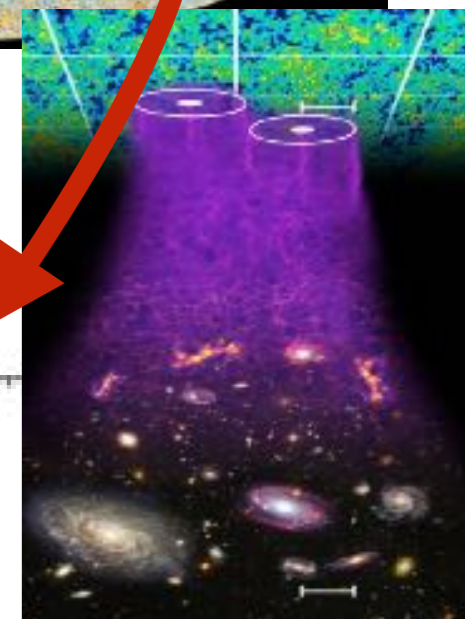
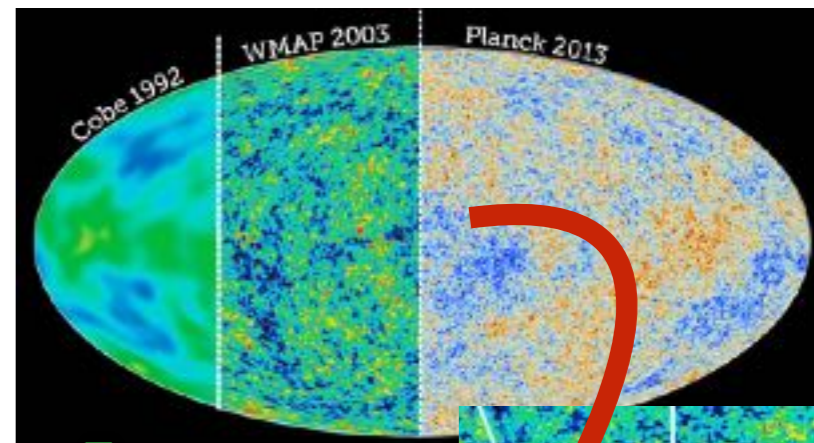
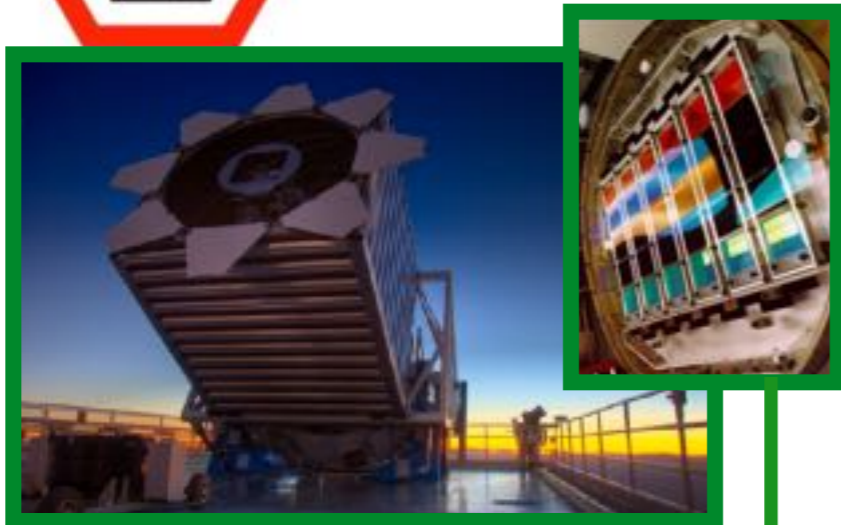
\downarrow Equation of state for Dark Energy

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".





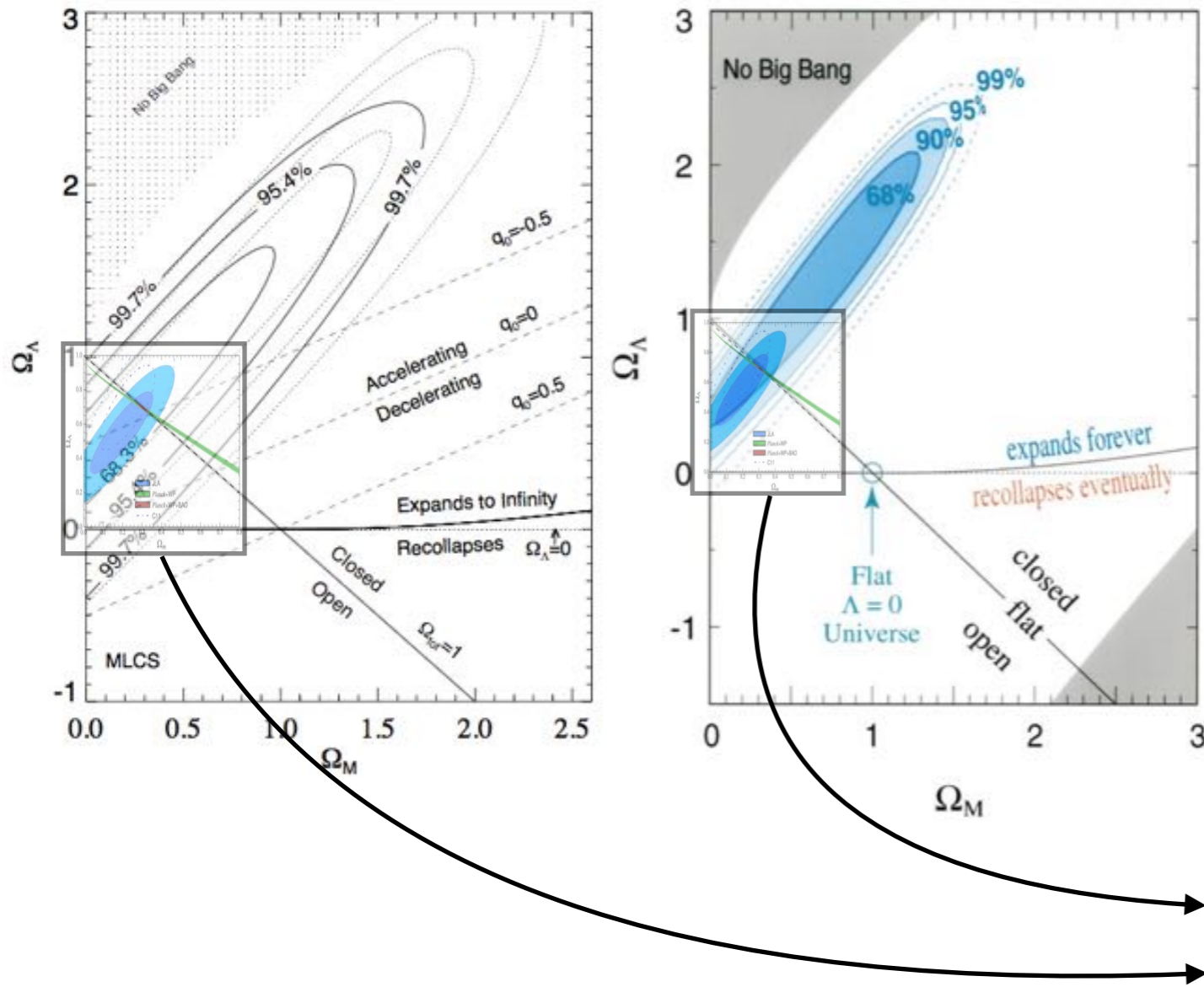
Universe & the Accelerating Expansion



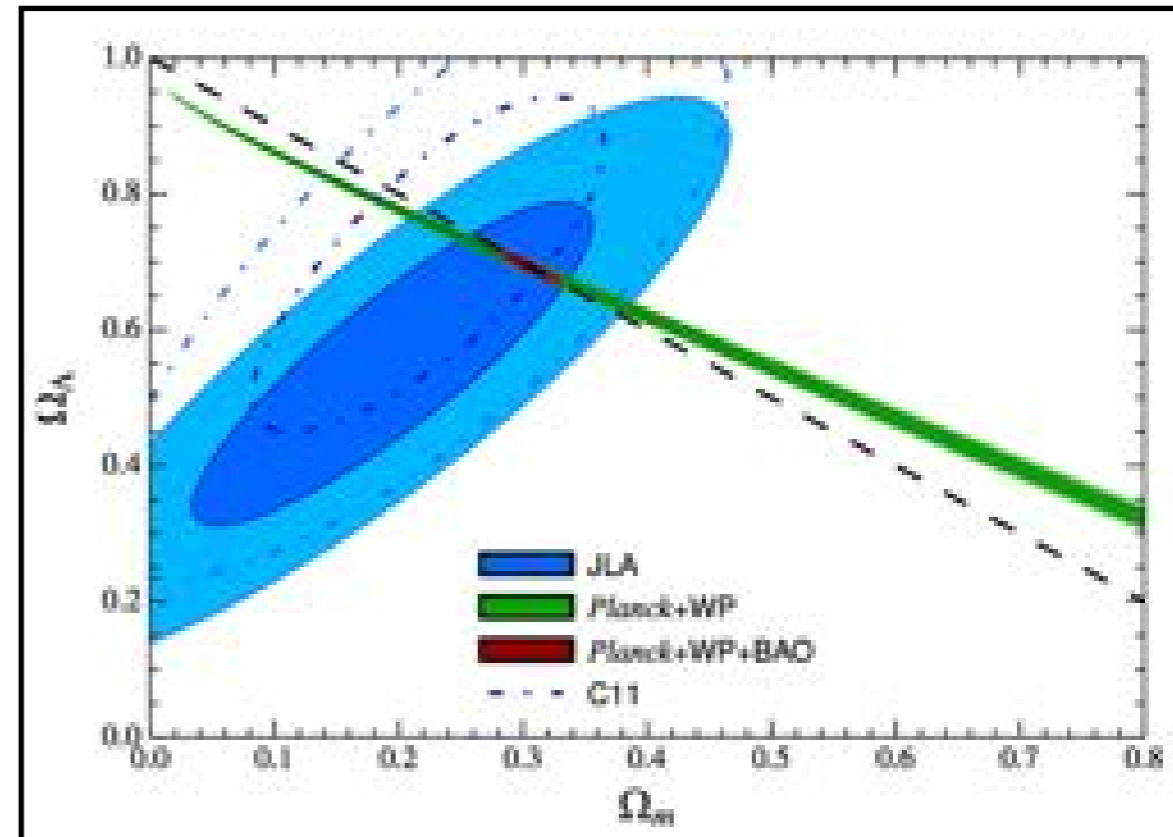
Betoule et al. 2014



Universe & the Accelerating Expansion

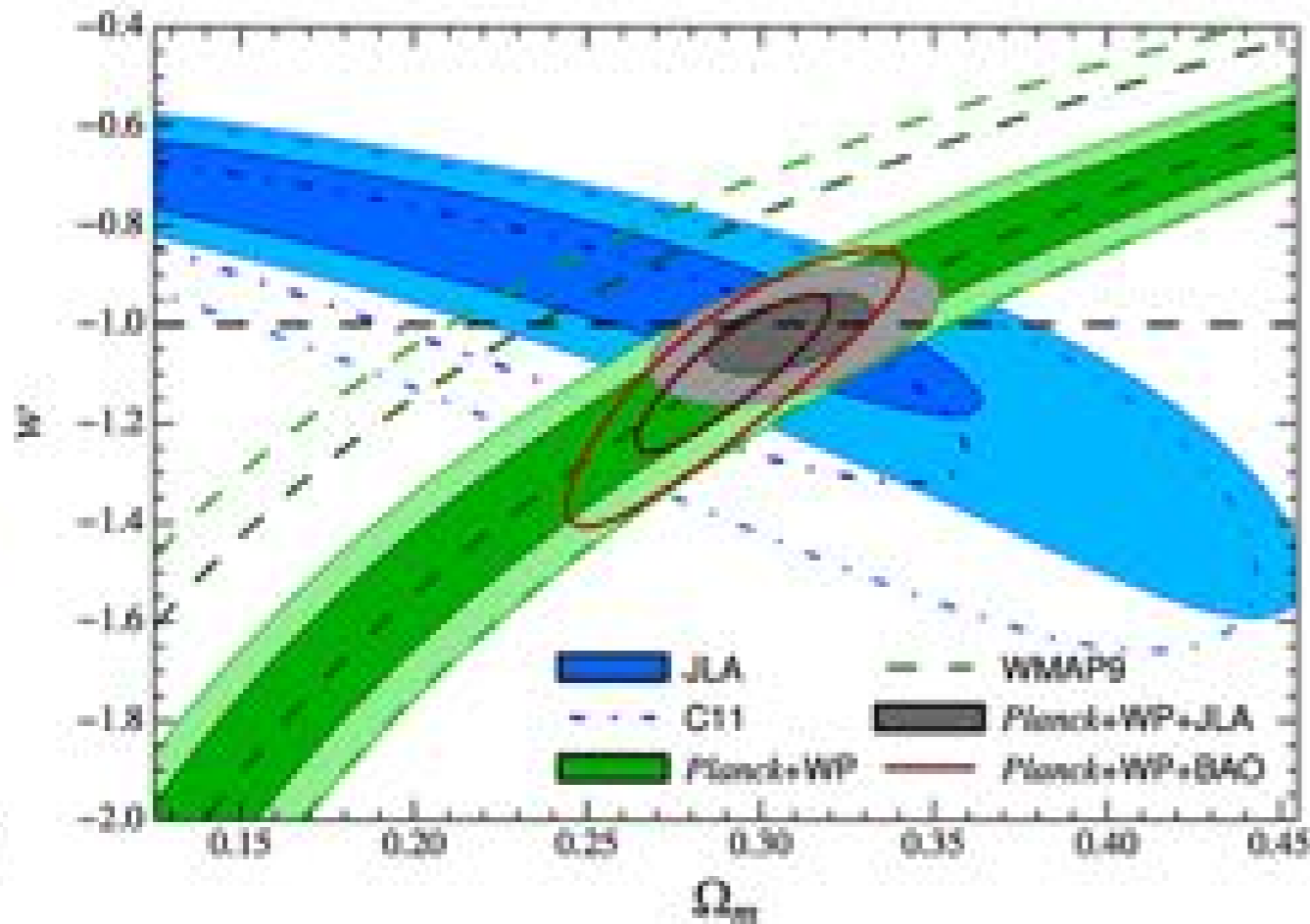


Betoule et al. 2014





Universe & the Accelerating Expansion



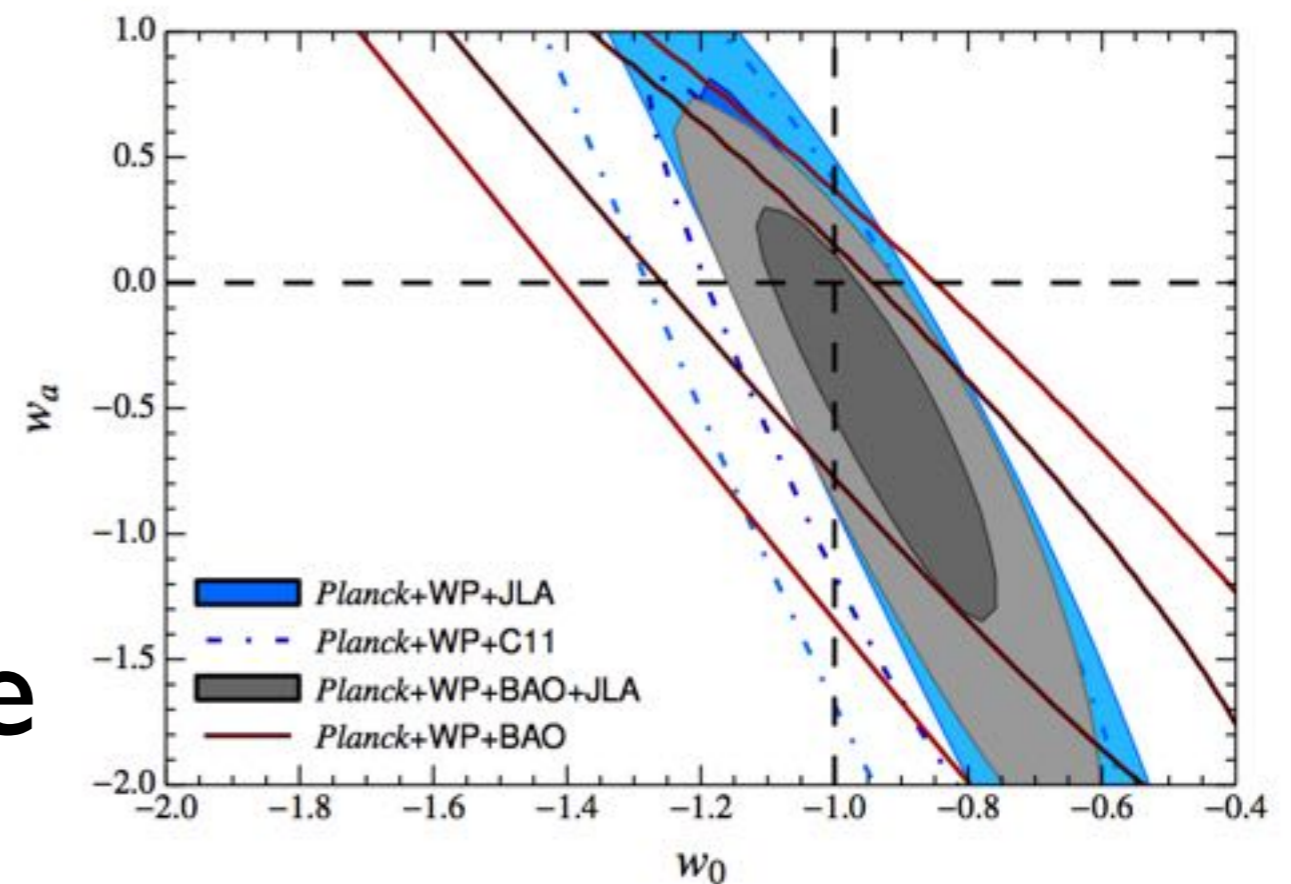
$$\Omega_m = 29.5\%$$

$$\Omega_\Lambda = 70.5\%$$

$$w = 1.018 \pm 0.057$$

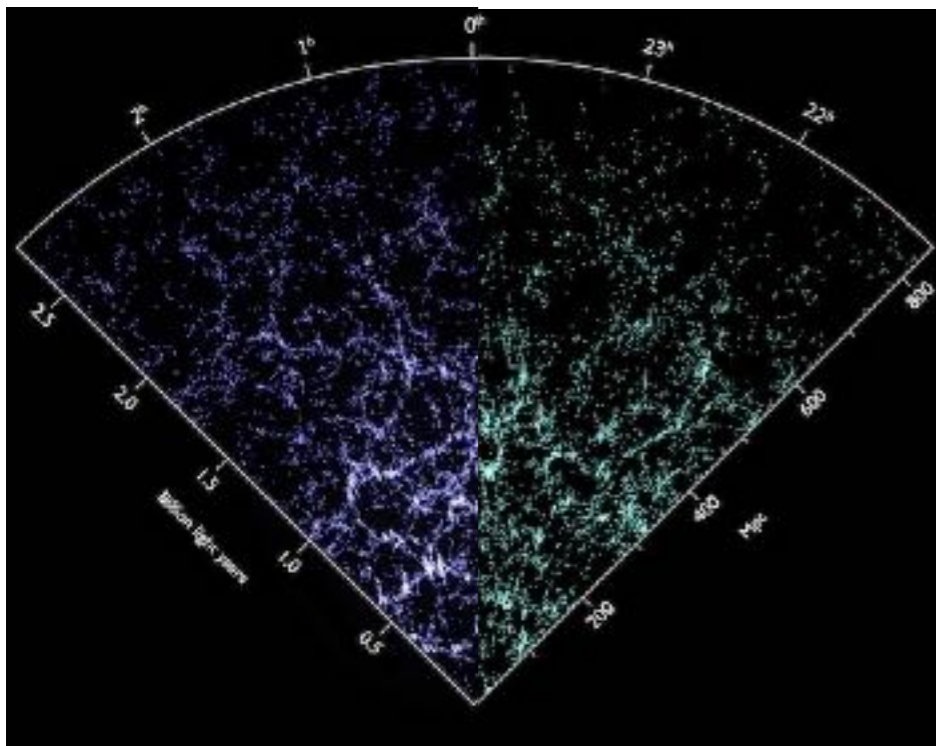
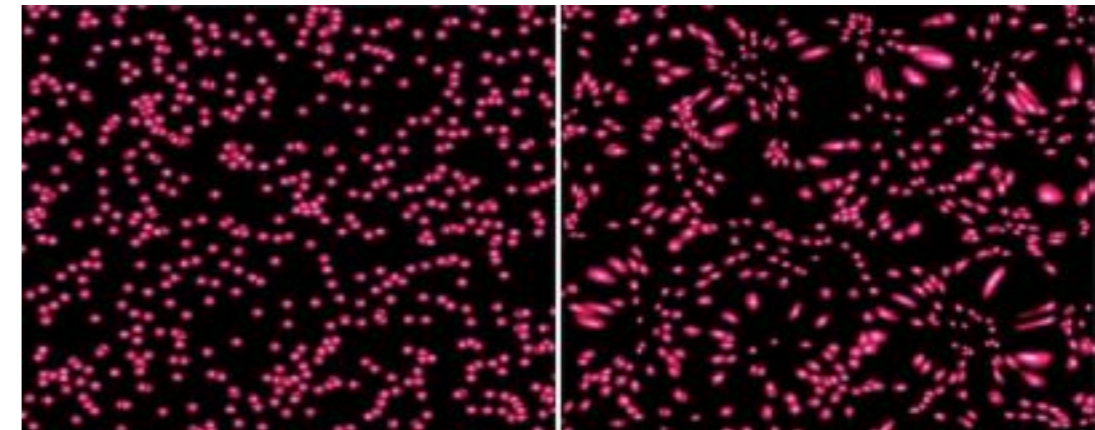
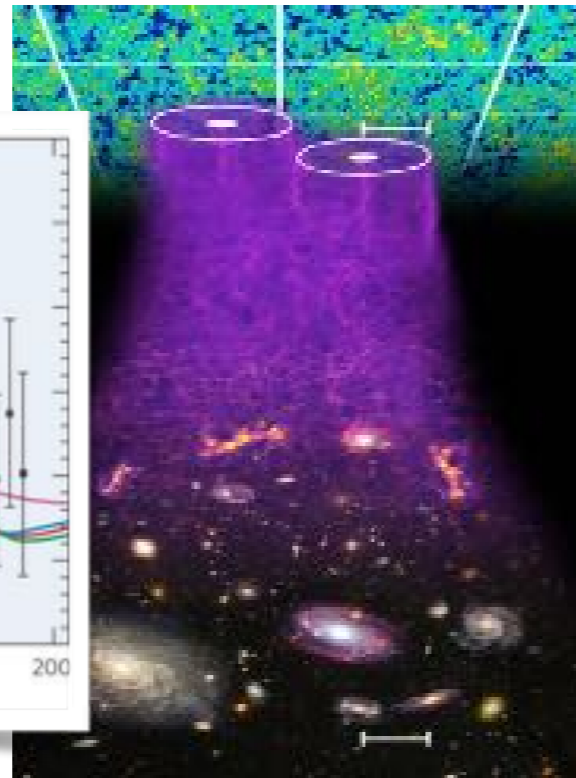
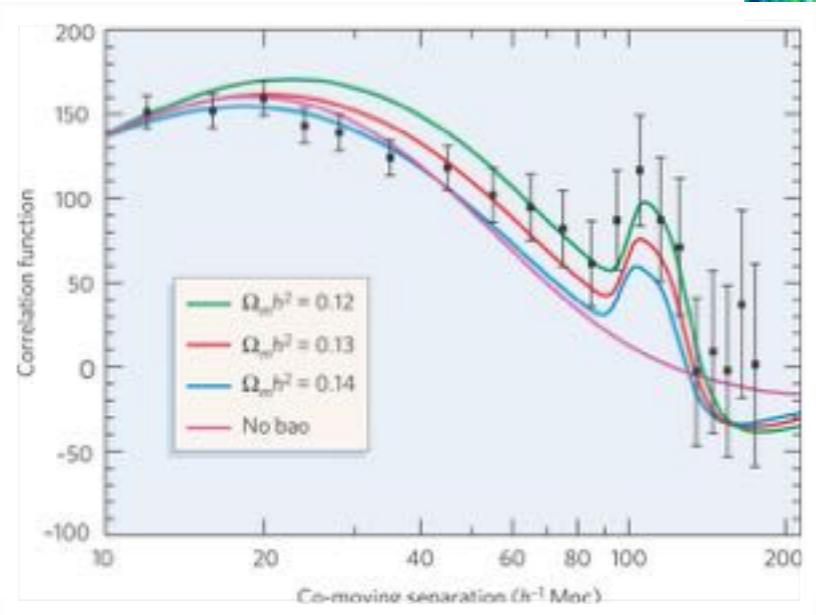
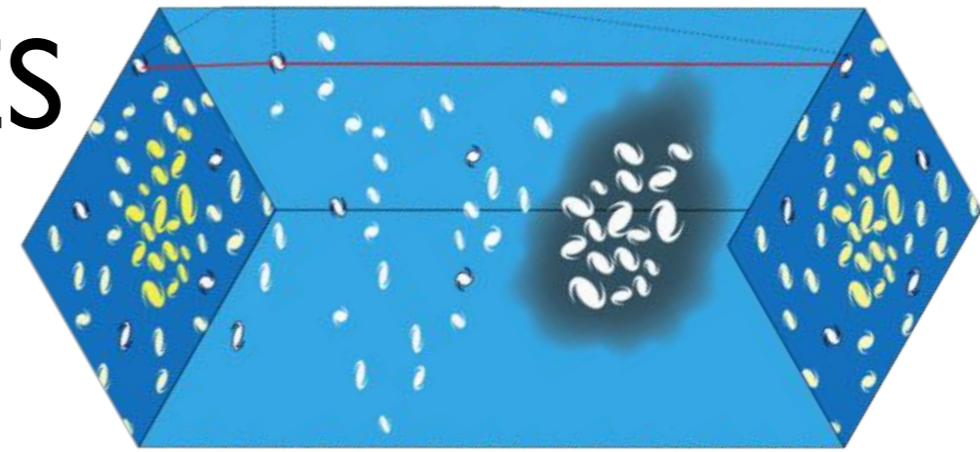
Betoule et al. 2014

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





Dark Energy Survey - DES



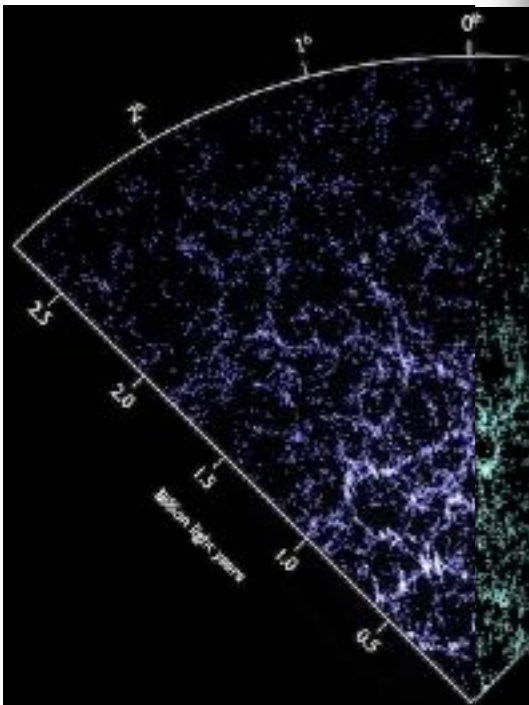
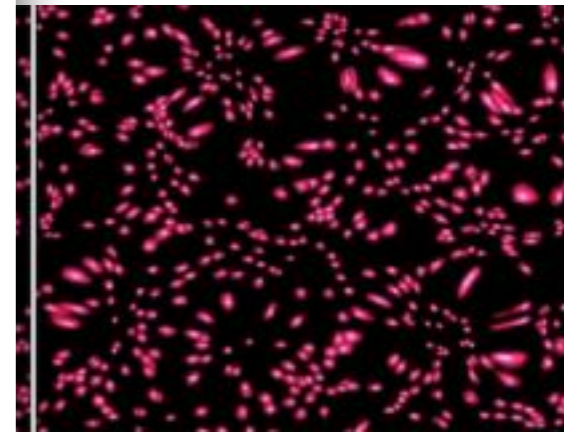
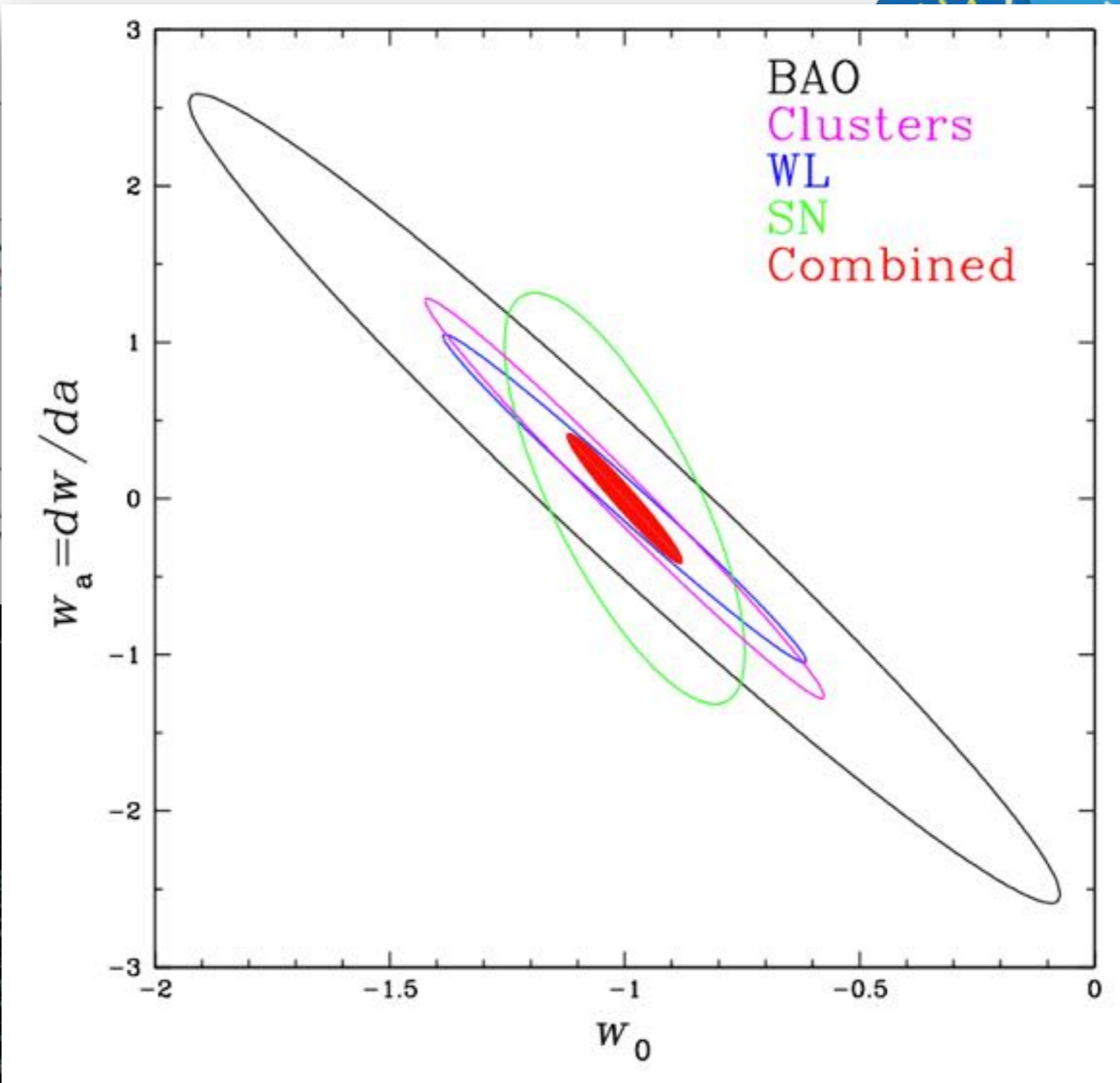
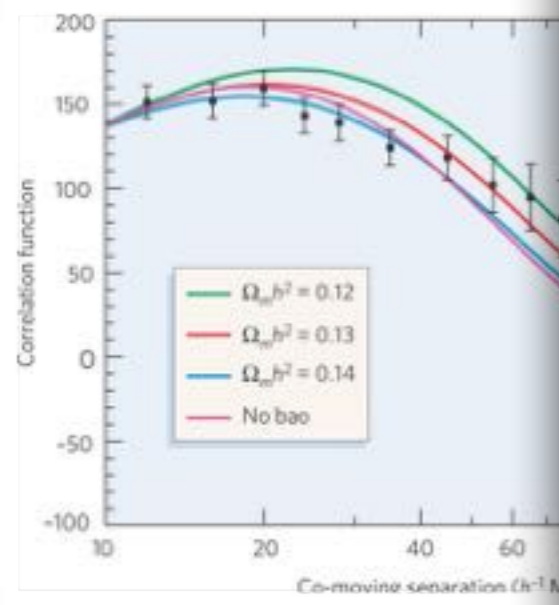
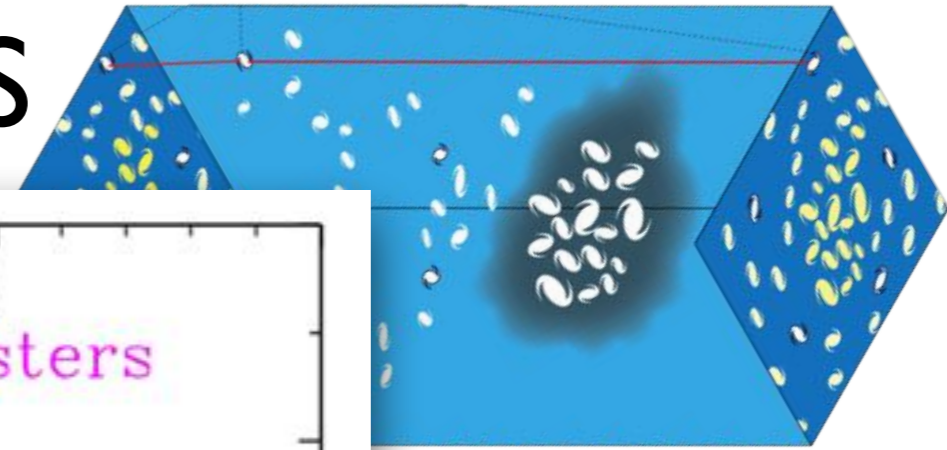
Dark Energy probes:

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



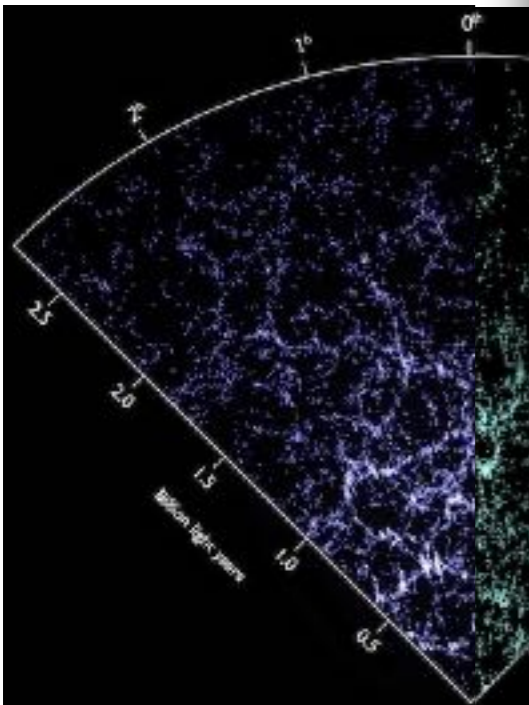
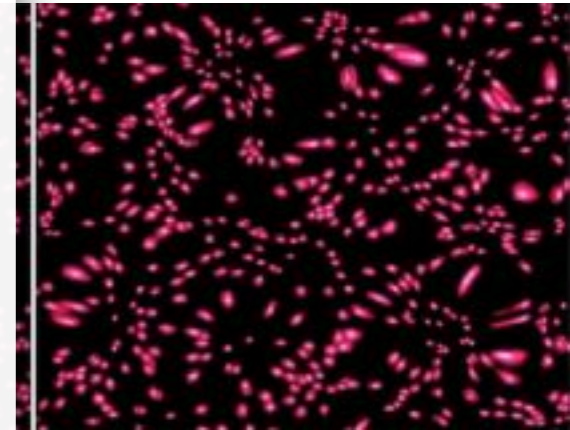
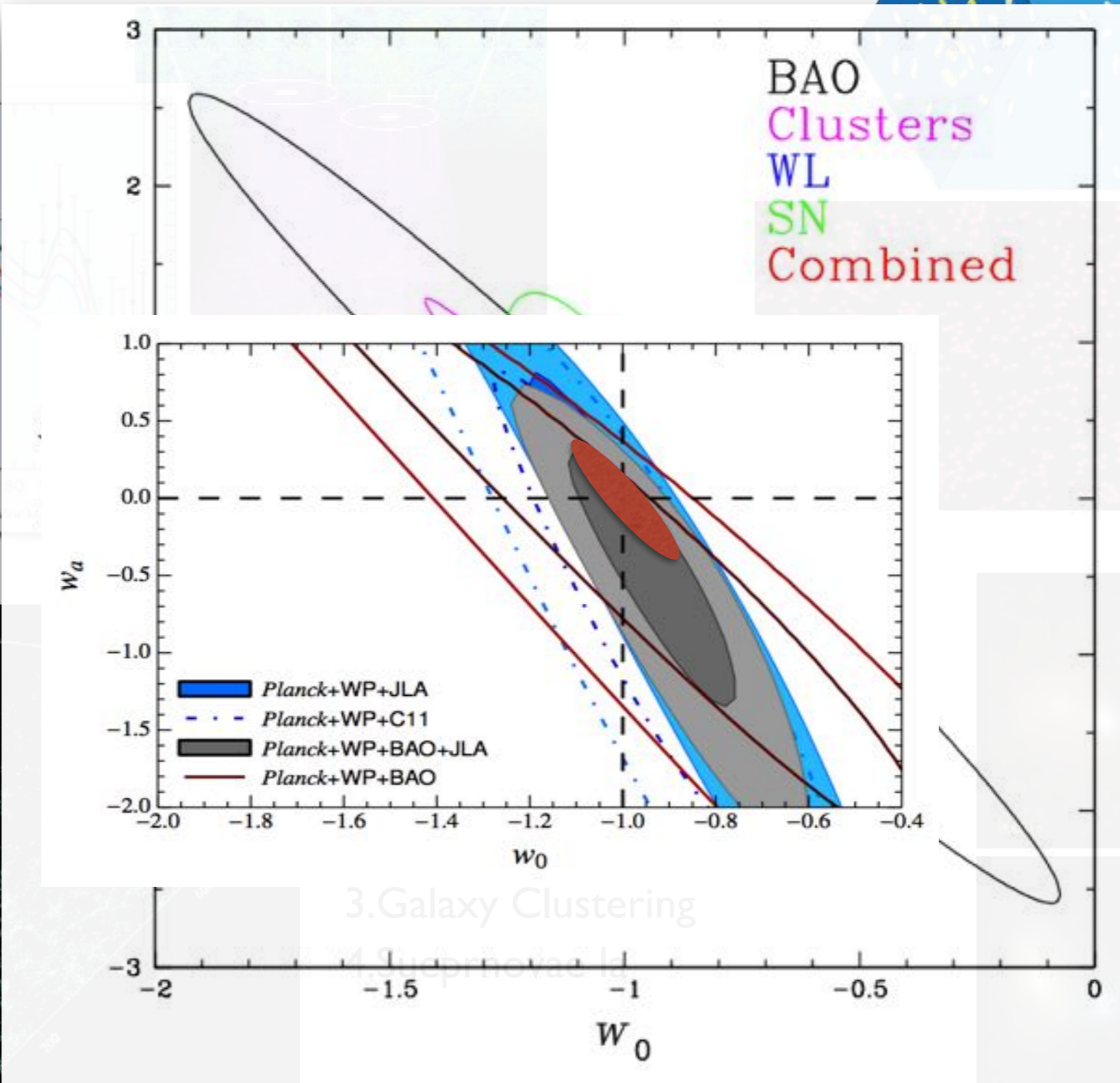
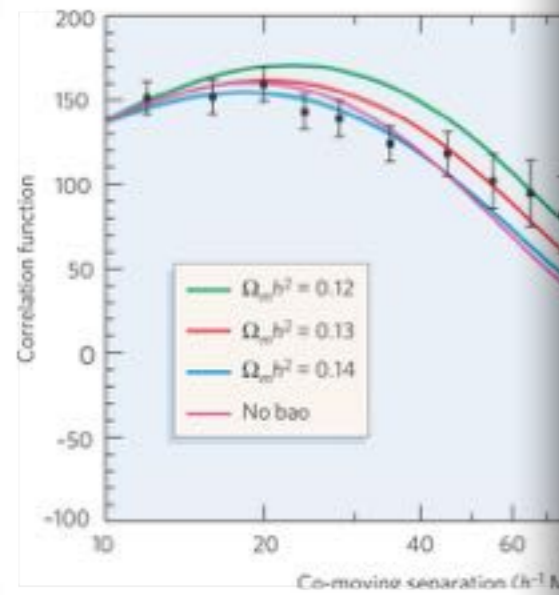
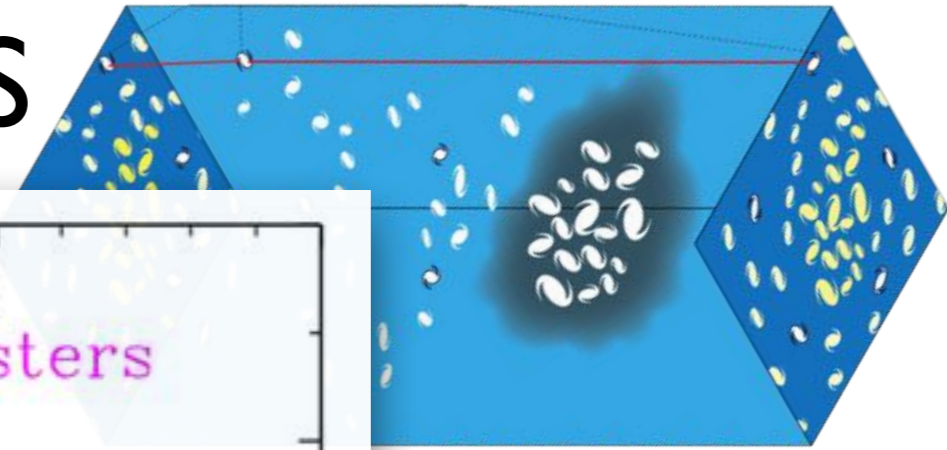


Dark Energy Survey - DES





Dark Energy Survey - DES





Dark Energy Survey - DES

Location:

- Cerro Tololo, Chile
- 2207 m

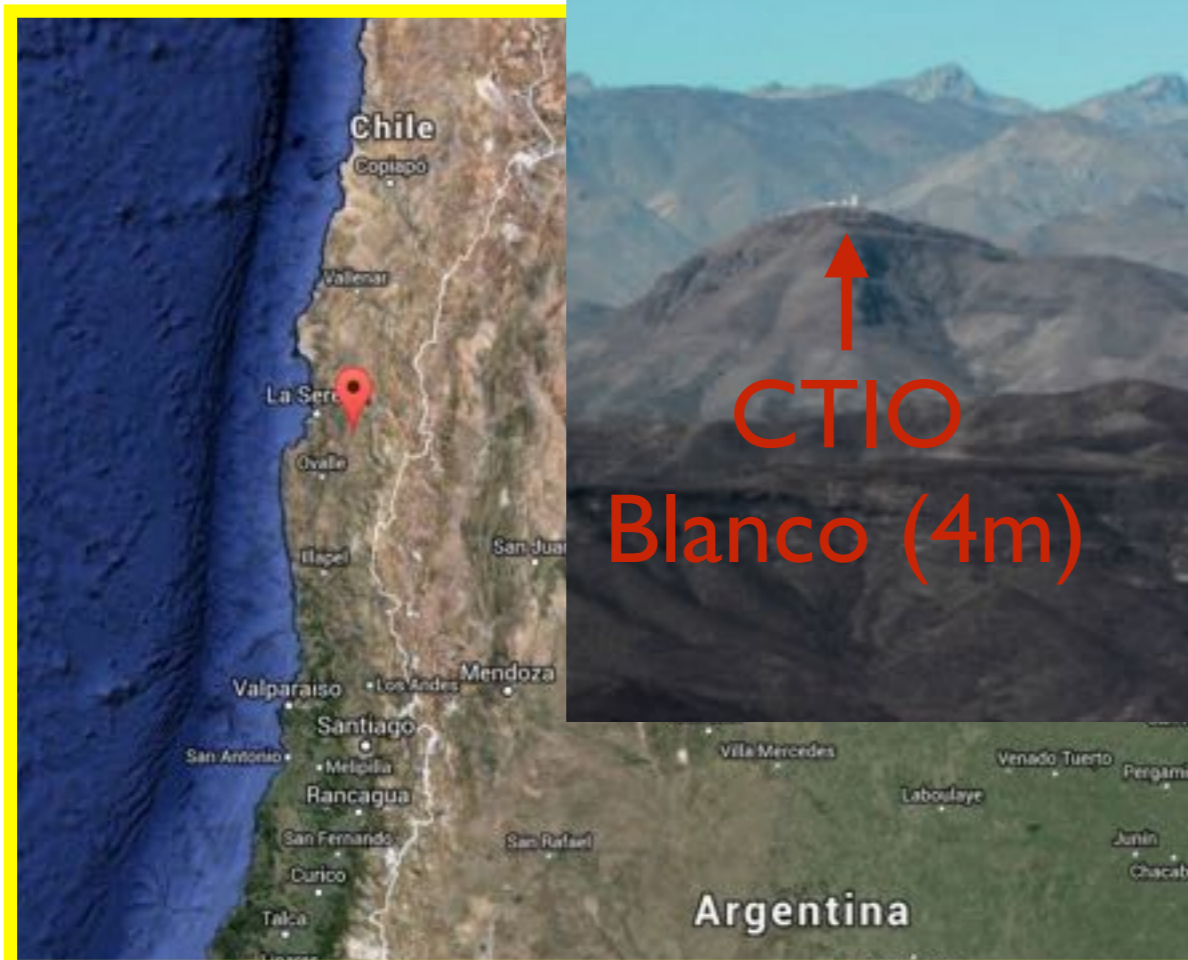
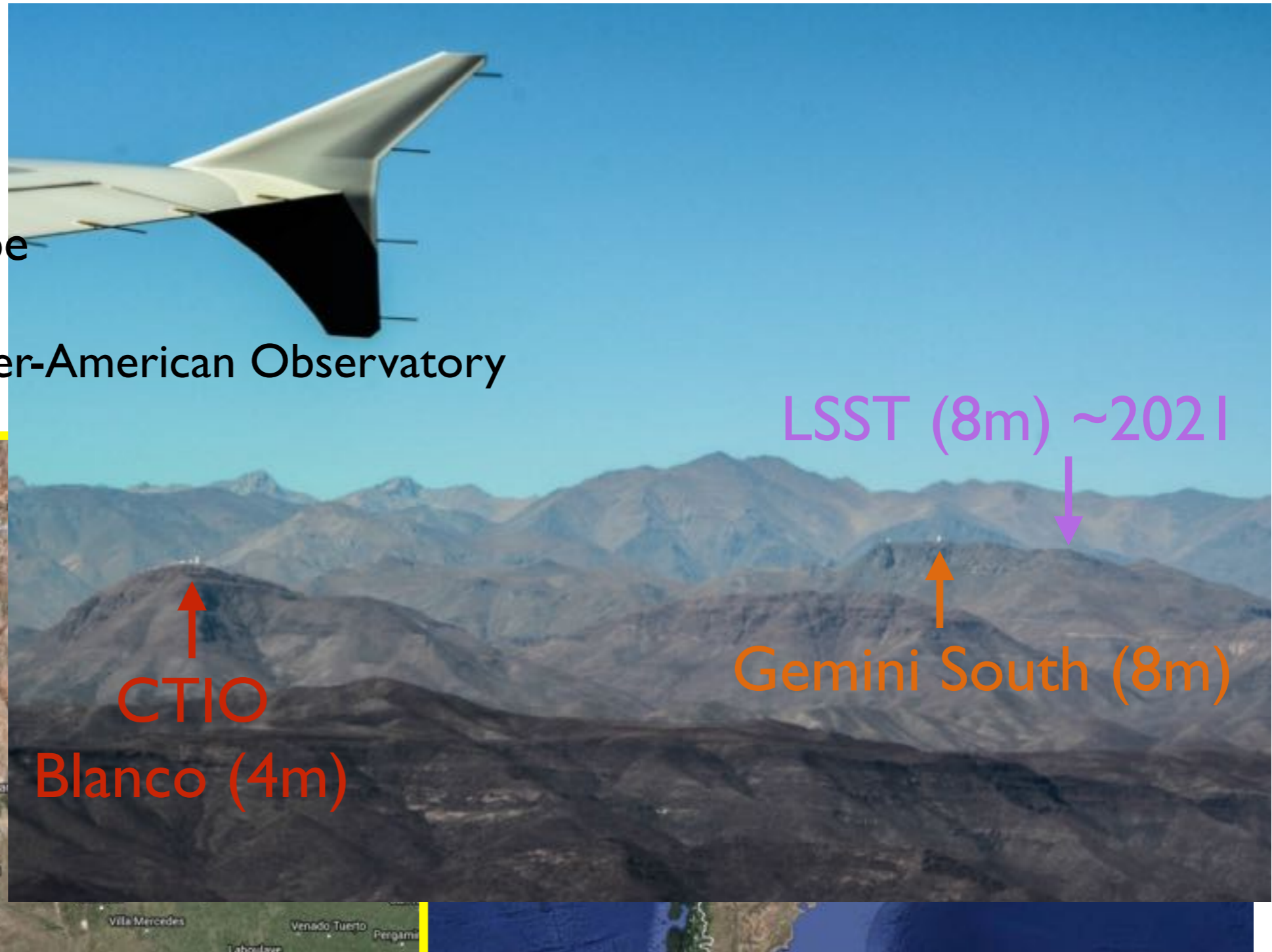




Dark Energy Survey - DES

Location:

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

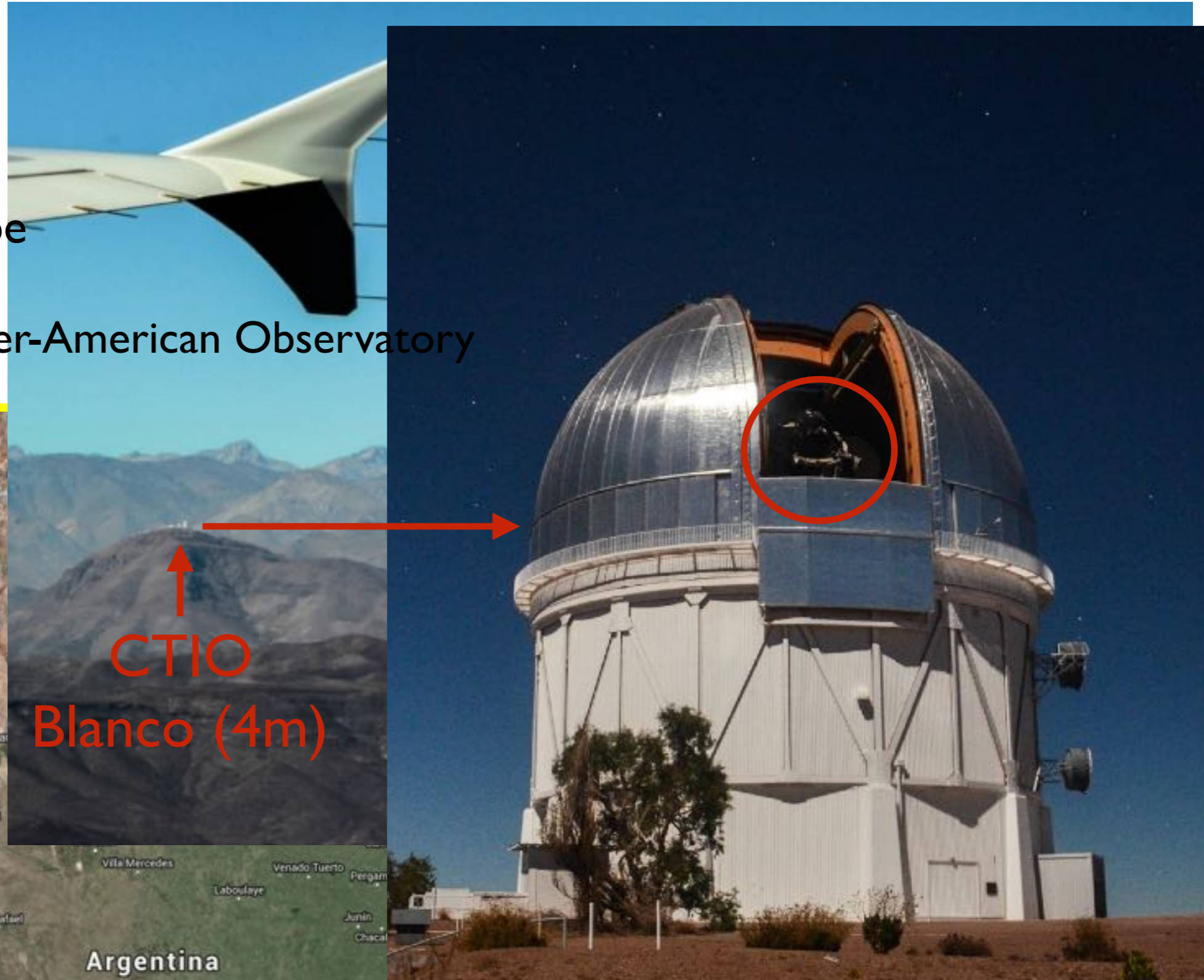
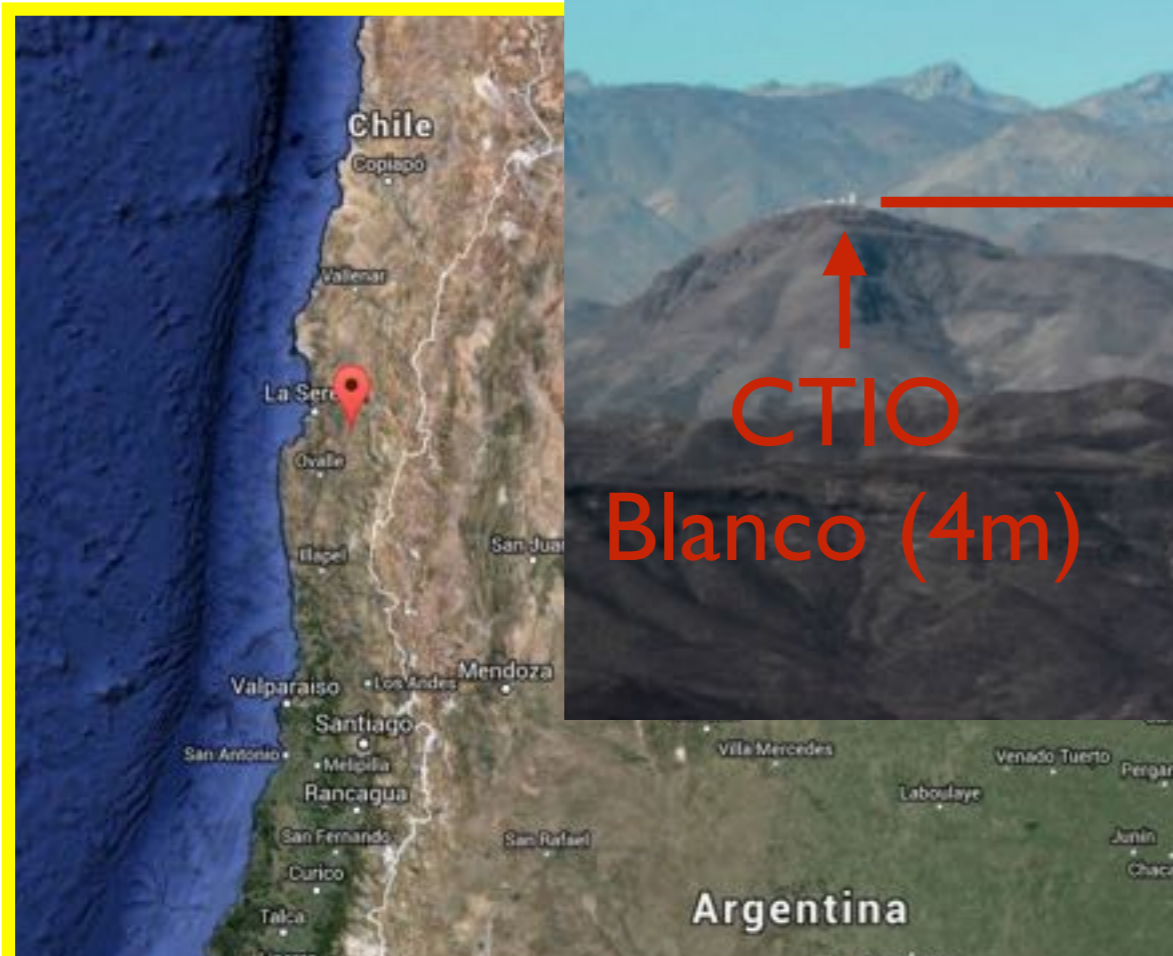




Dark Energy Survey - DES

Location:

- Cerro Tololo, Chile
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 - Cerro Tololo Inter-American Observatory



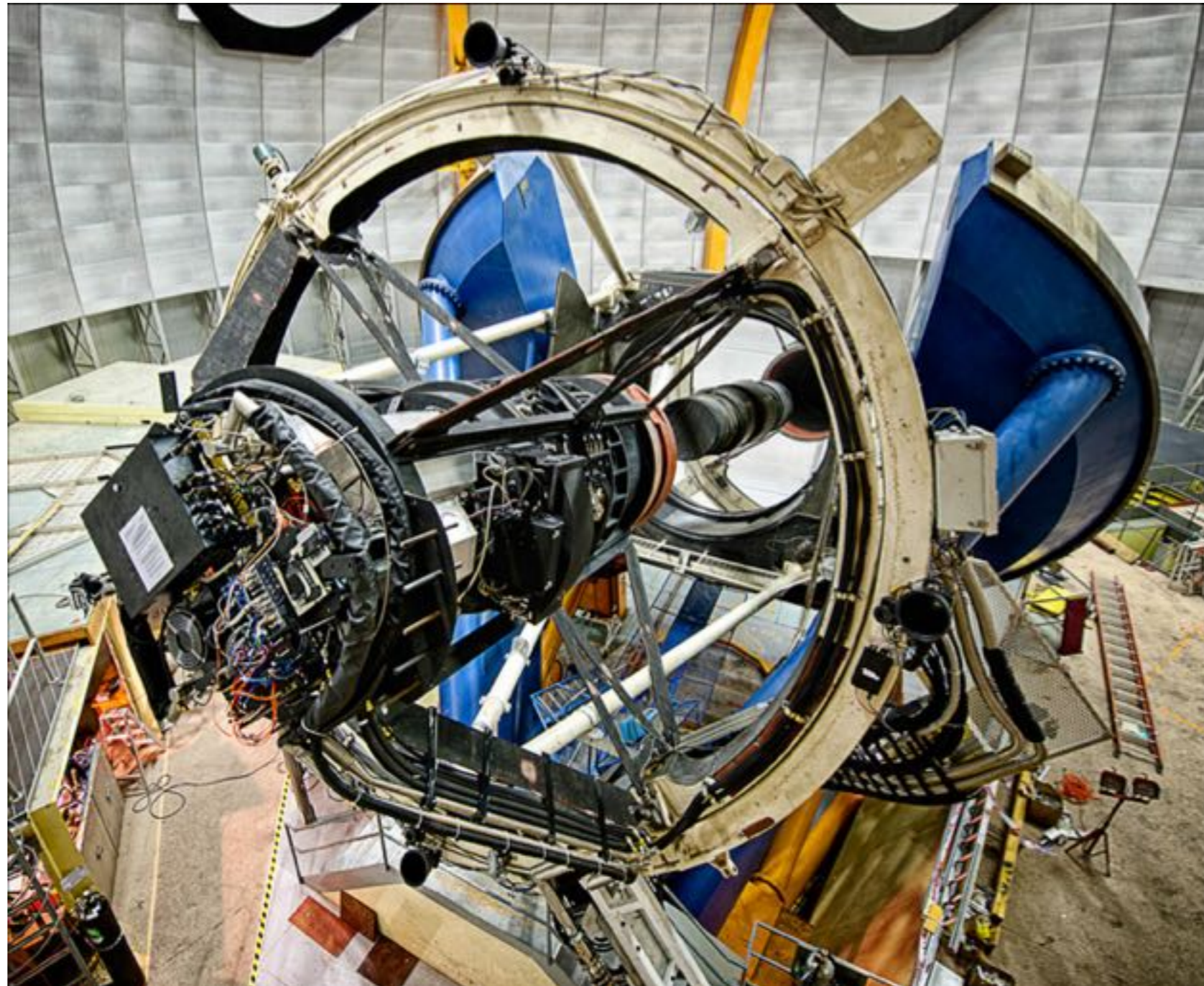
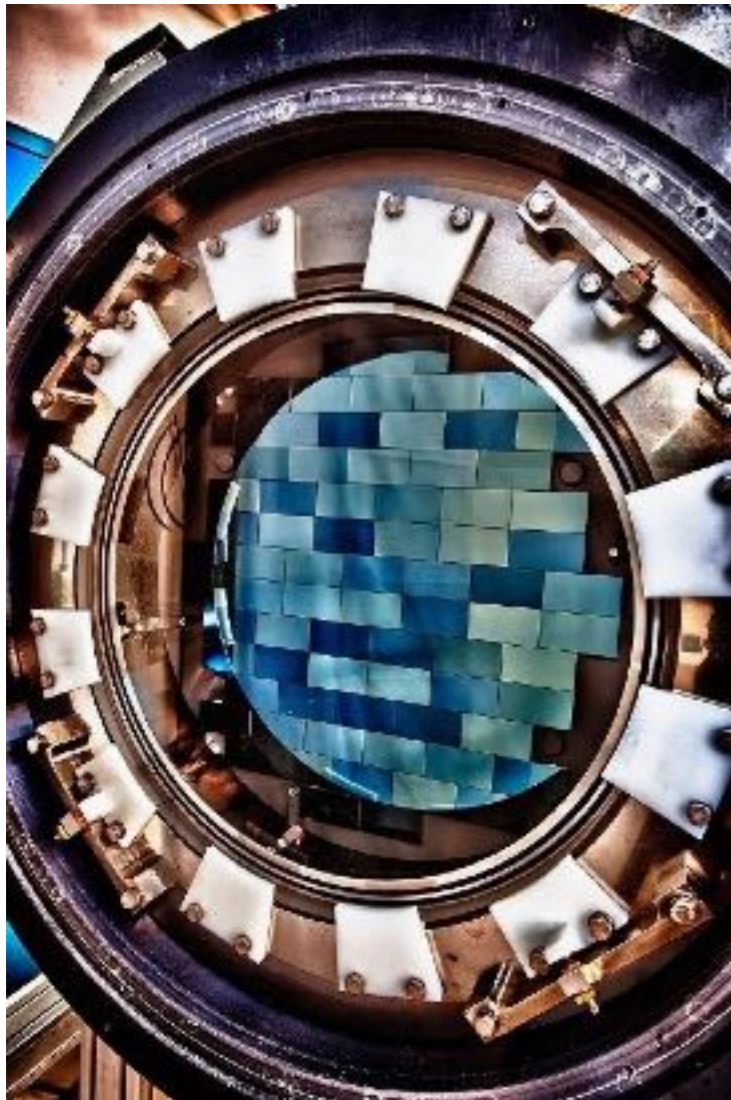
CTIO
Blanco (4m)





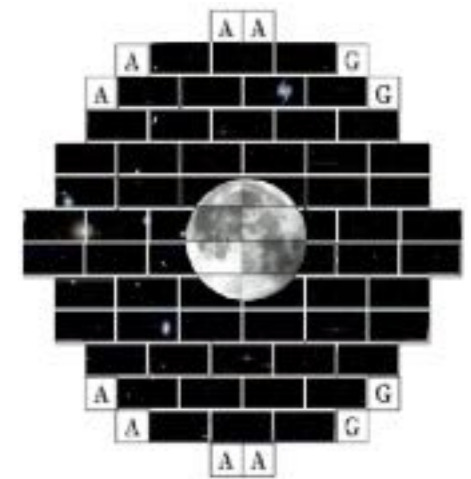
Dark Energy Survey - DES

Dark Energy Camera - DECam:

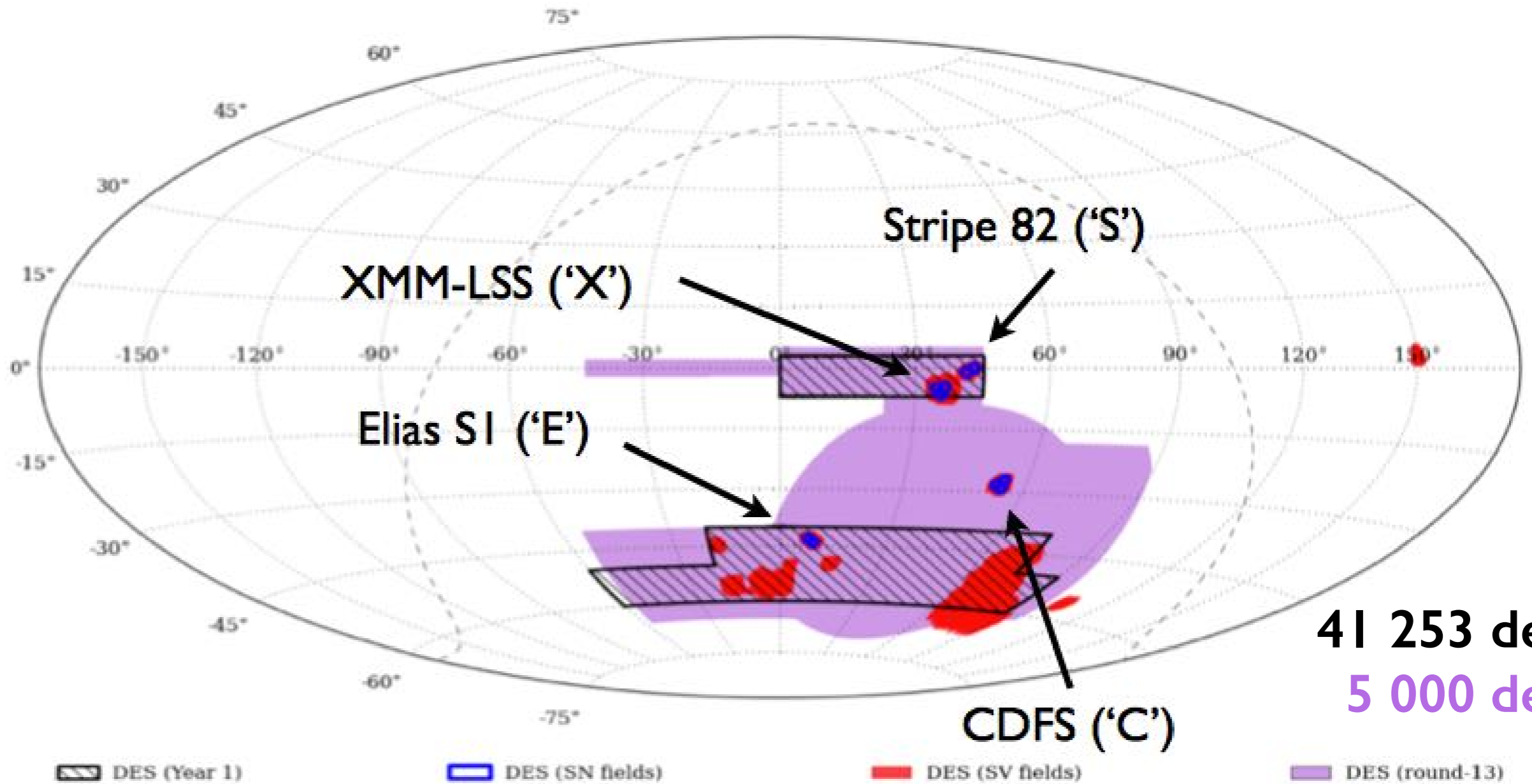




Dark Energy Survey - DES



Survey Footprint:

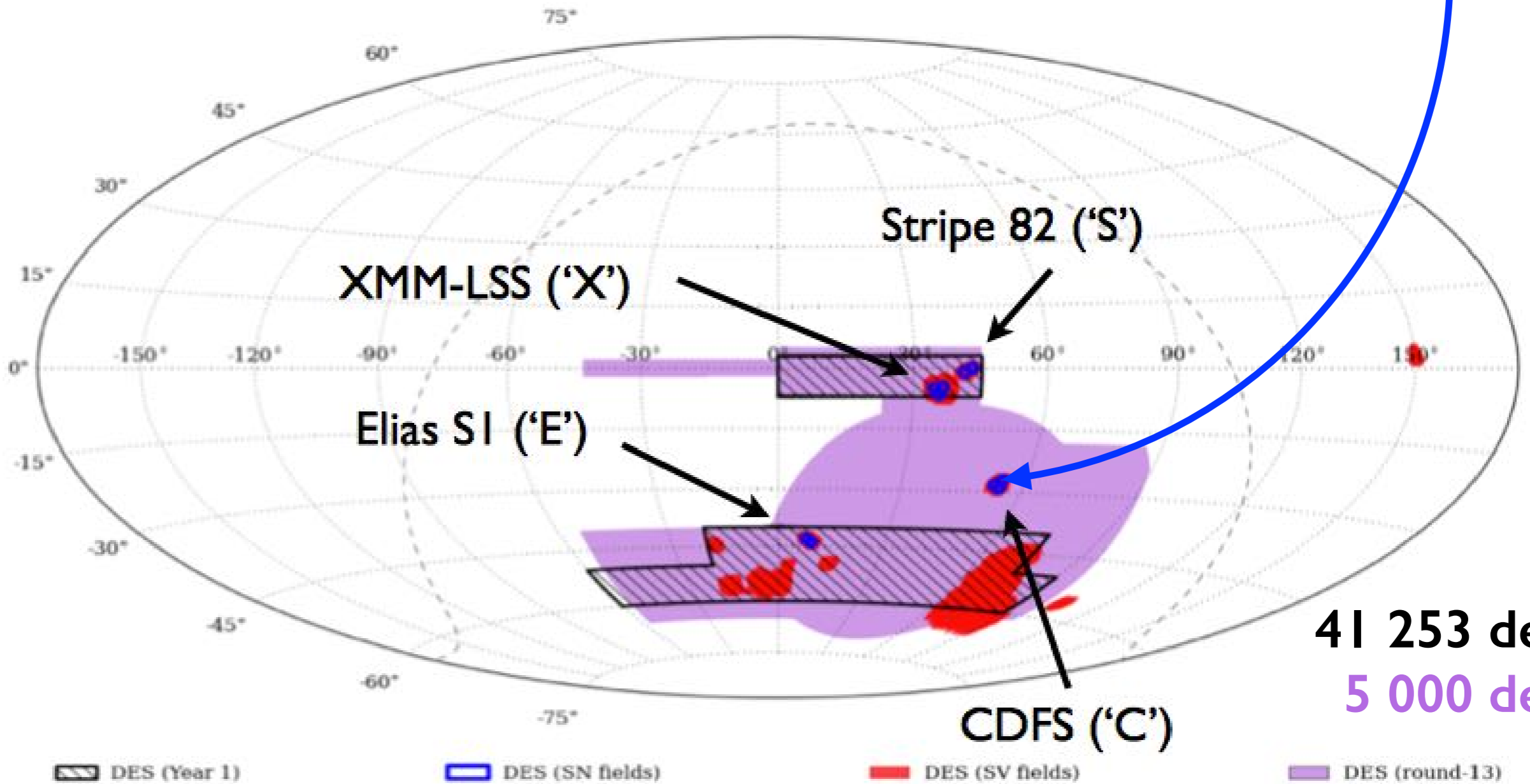


41 253 deg²
5 000 deg²



Dark Energy Survey - DES

Survey Footprint:



41 253 deg²
5 000 deg²



Dark Energy Survey - DES

Dark Energy Camera - DECam:

3500 kg

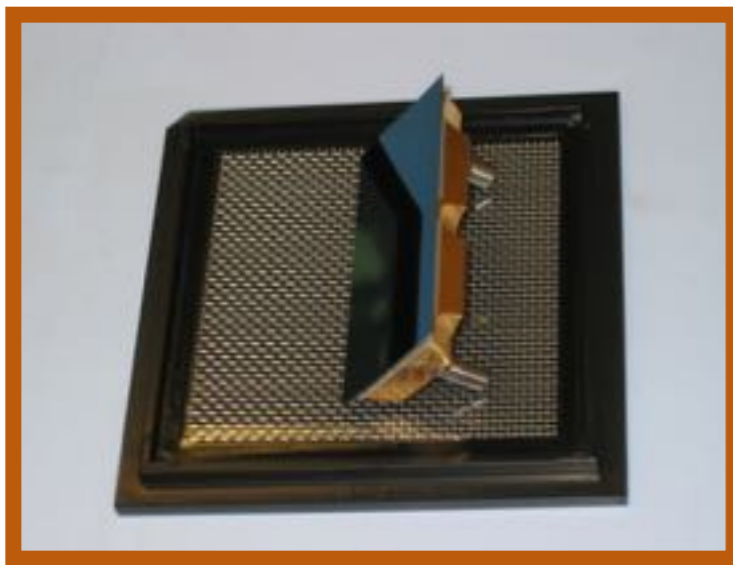
570 Mpx

62 Science CCDs

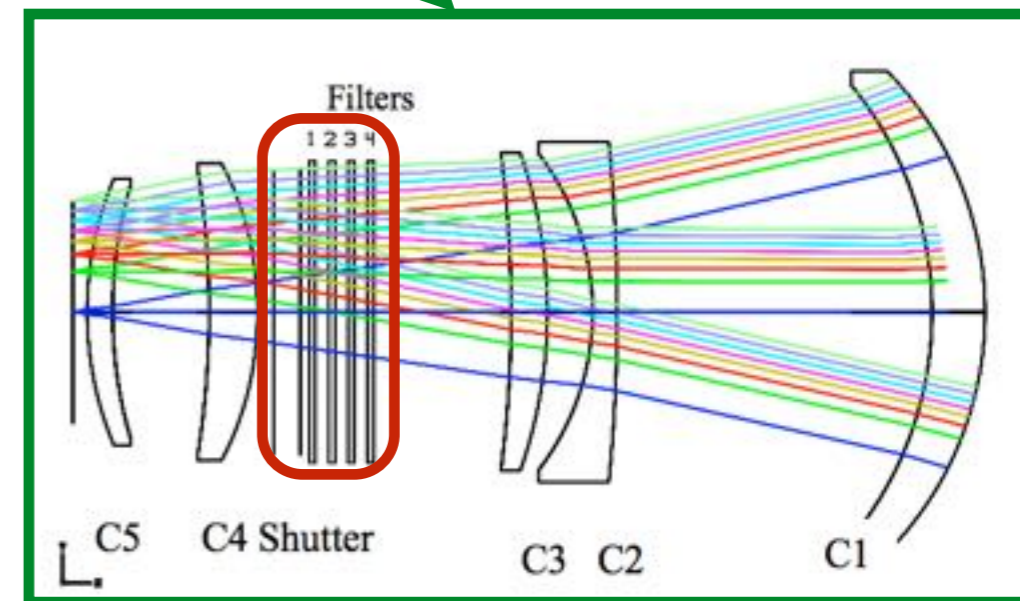
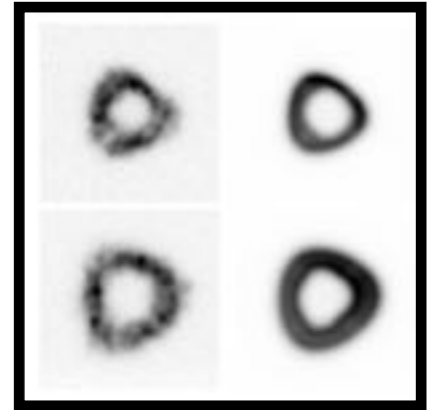
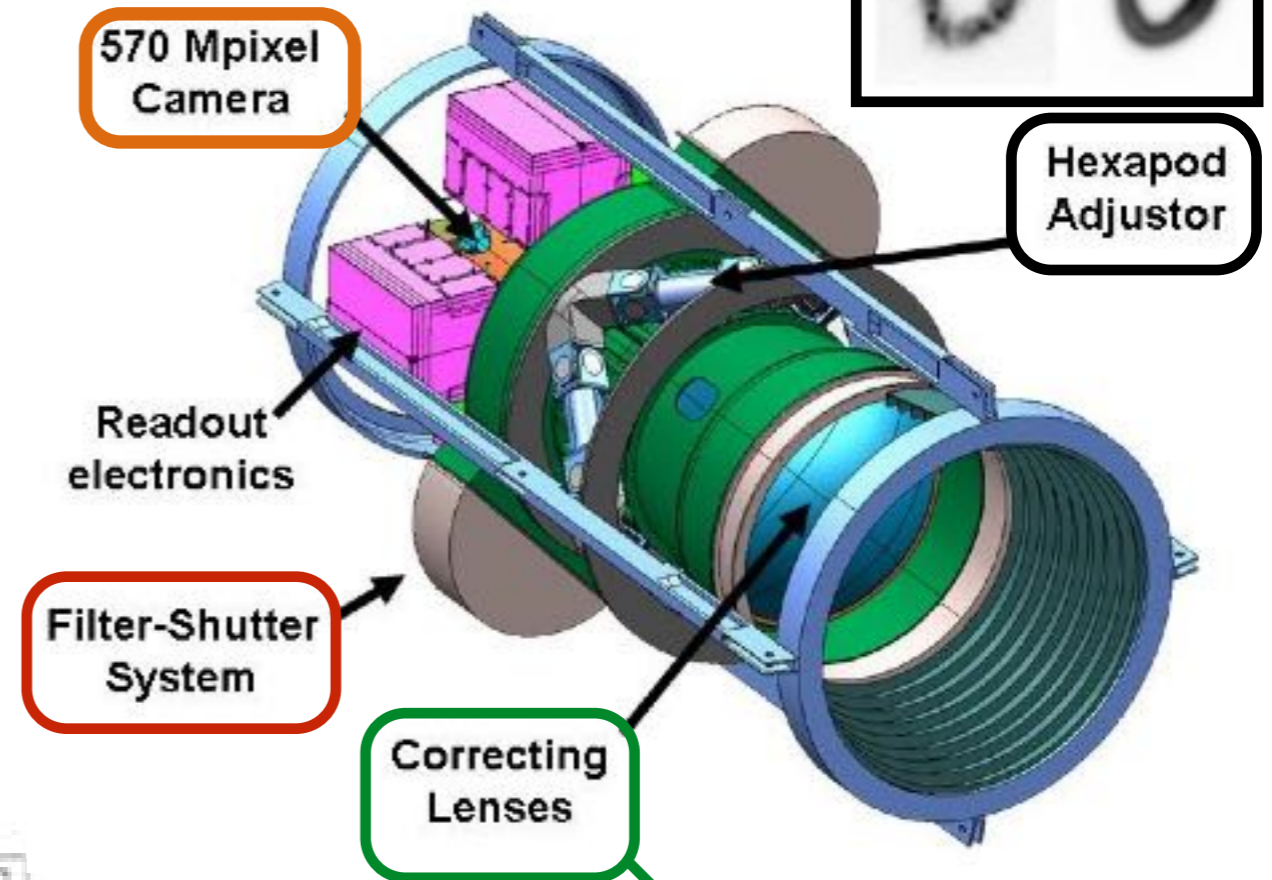
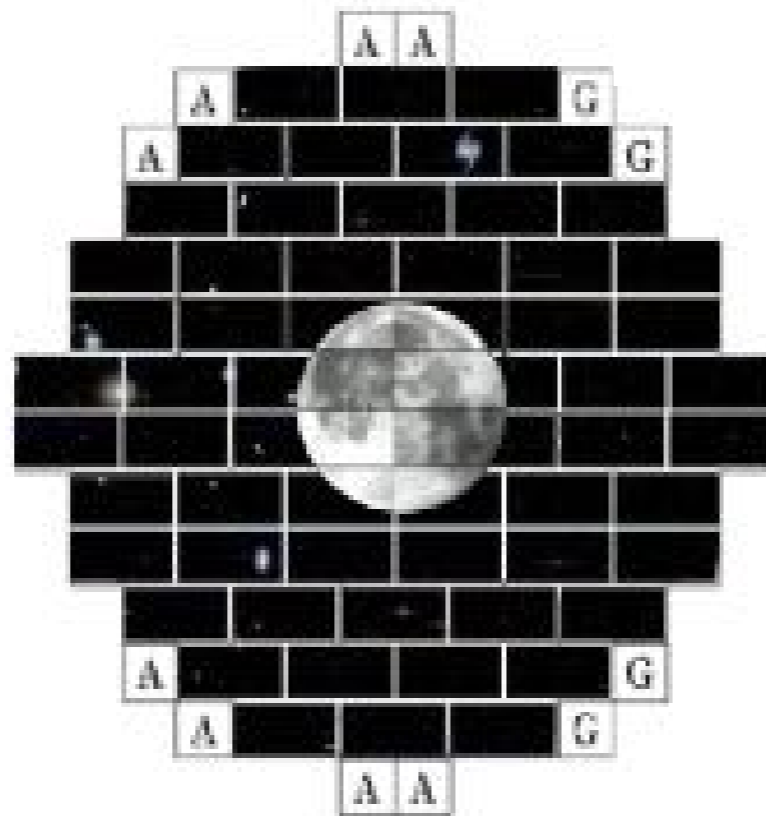
5 m above the telescope 4m mirror

3 deg² FoV (~10 times full Moon)

1 GB per exposure



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











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

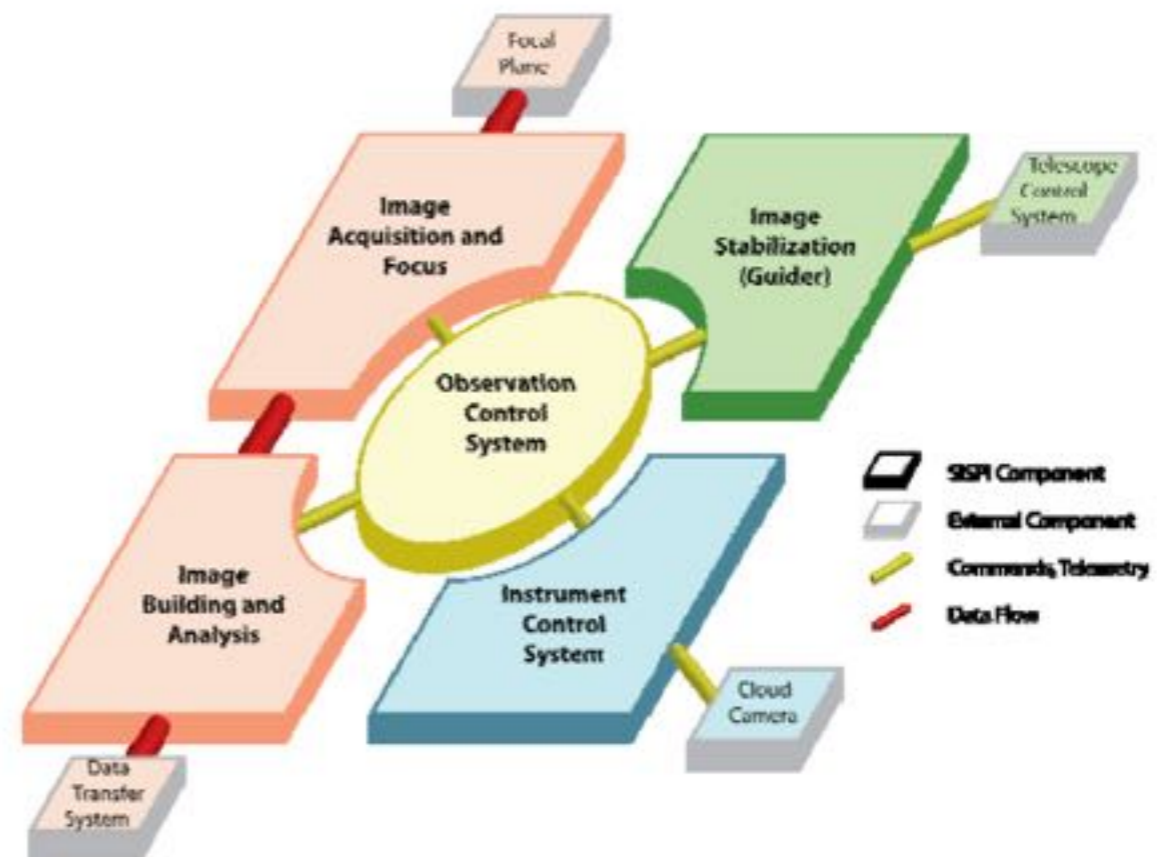


Figure 2: Block diagram of the DECam read-out and control system (SISPI).

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



Dark Energy Survey - DES

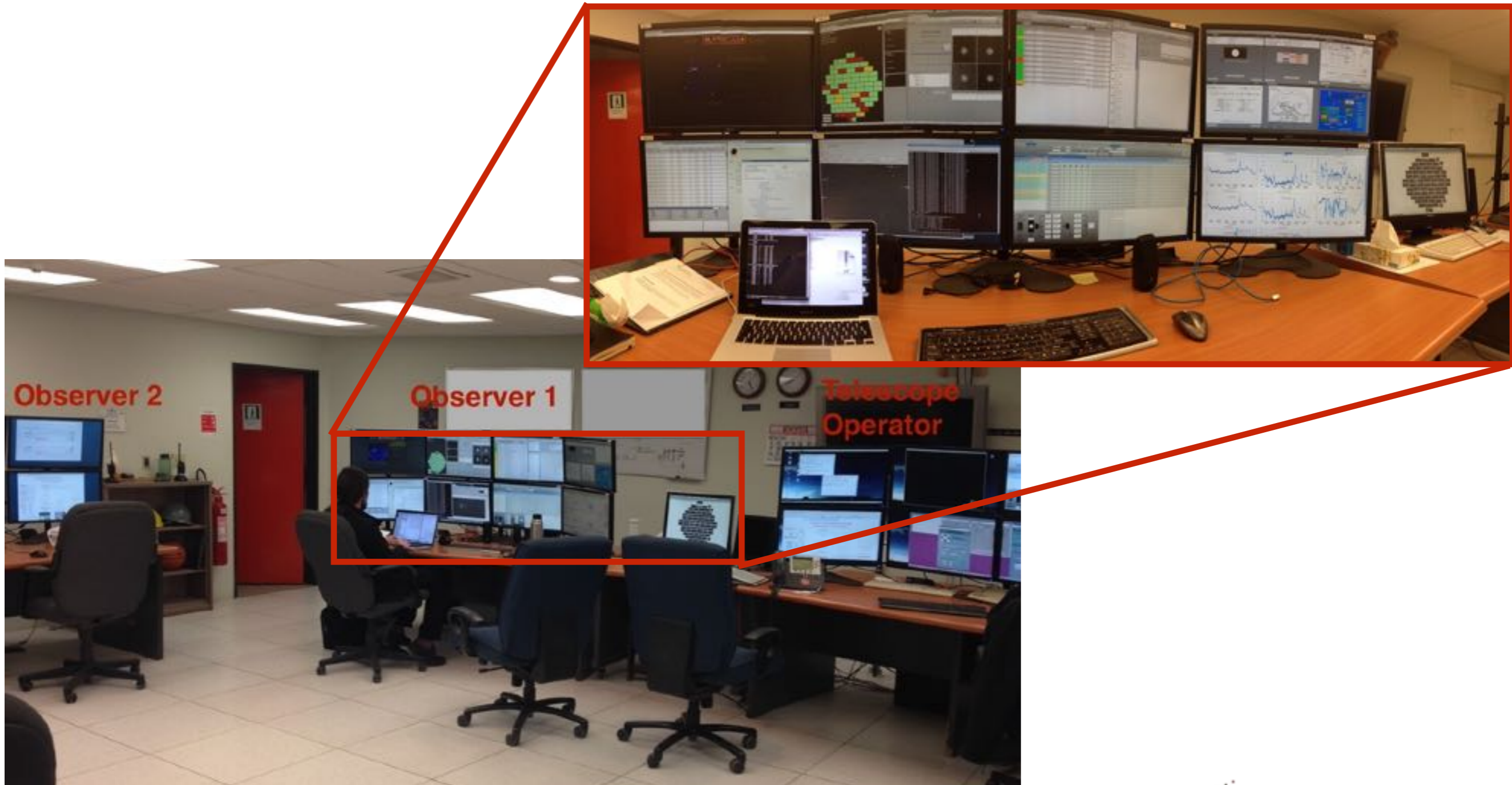
DECam & SISPI - Survey Image System Process Integration:





Dark Energy Survey - DES

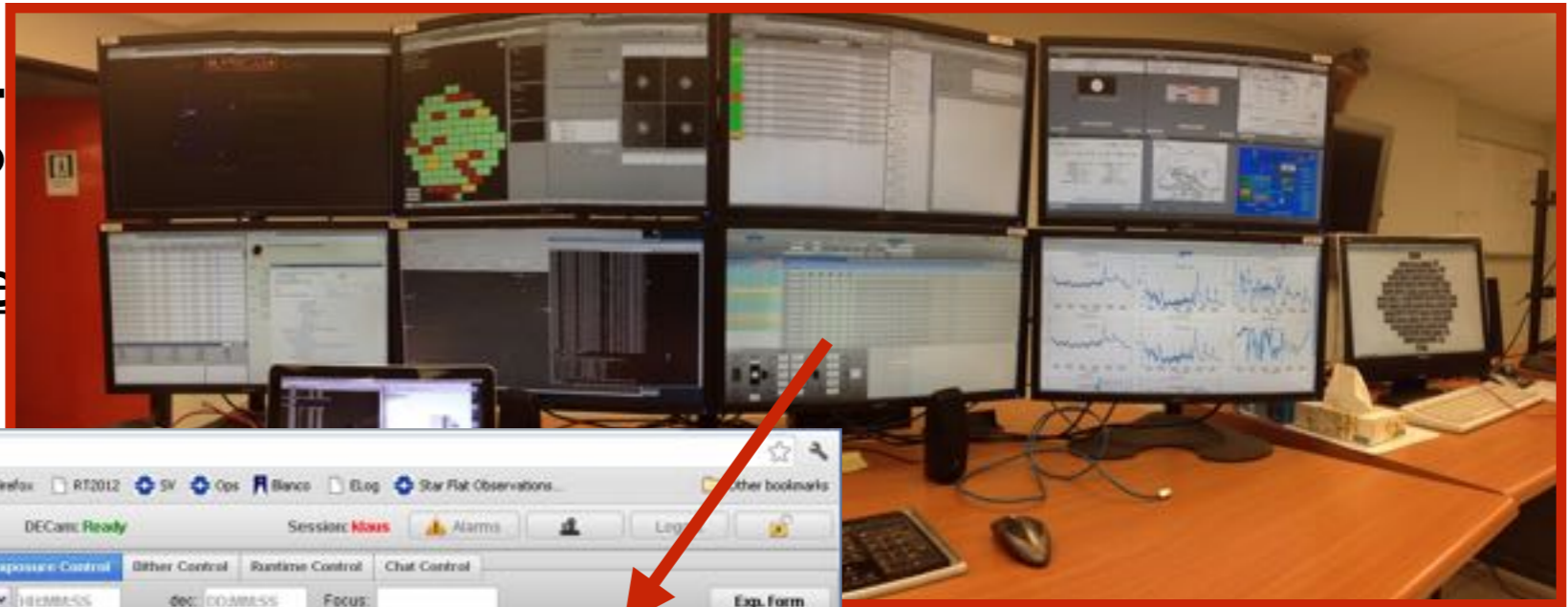
DECam & SISPI - Survey Image System Process Integration:





Dark Energy

DECam & SISPI - Survey Image



Observer Console

DECam: Ready Session: Klaus Alarms Log

Systems Control Exposure Control Filter Control Runtime Control Chat Control

Monitor: LEDs: Off Setup: Interlock: Visib: OCS: (READY)

Current Constants: DECam CURRENT

Exposure Queue 320 Exposure Loop: Go Clear Step 1

AutoObs: zero, 0s, None, [0,0], S: 10 exposures (1 of 10)

Current Exposure 0 0.0

Exposure History

Exposure ID	Type	Time	Filter	RA	Dec	Focus	File
156918	zero	30 Nov 12, 20:05:37.000	block	300.3448	-30.2440		File: pipeline5.ctbo.noao.edu/data_local/images/DTS/2012B-9990/DECam_00156918.fits.gz
156917	zero	30 Nov 12, 20:01:14.000	block	299.2454	-30.2429		File: pipeline4.ctbo.noao.edu/data_local/images/DTS/2012B-9990/DECam_00156917.fits.gz
156916	zero	30 Nov 12, 19:55:49.000	block	297.8871	-30.2414		File: pipeline3.ctbo.noao.edu/data_local/images/DTS/2012B-9990/DECam_00156916.fits.gz
156915	zero	30 Nov 12, 19:52:30.000	block	297.0555	-30.2405		File: pipeline2.ctbo.noao.edu/data_local/images/DTS/2012B-9990/DECam_00156915.fits.gz
156914	zero	30 Nov 12, 19:43:12.000	block	294.7205	-30.2379		File: pipeline1.ctbo.noao.edu/data_local/images/DTS/2012B-9990/DECam_00156914.fits.gz
156913	zero	30 Nov 12, 19:42:40.000	block	294.4865	-30.2377	Seq: 5 exposures (5 of 5)	File: pipeline5.ctbo.noao.edu/data_local/images/DTS/2012B-9990/DECam_00156913.fits.gz
156912	zero	30 Nov 12, 19:42:13.000	block	294.3779	-30.2375	Seq: 5 exposures (4 of 5)	File: pipeline4.ctbo.noao.edu/data_local/images/DTS/2012B-9990/DECam_00156912.fits.gz
156911	zero	30 Nov 12, 19:41:47.000	block	294.0954	-30.2164	Seq: 5 exposures (3 of 5)	File: pipeline3.ctbo.noao.edu/data_local/images/DTS/2012B-9990/DECam_00156911.fits.gz
156910	zero	30 Nov 12, 19:41:20.000	block	283.2854	-30.2067	Seq: 5 exposures (2 of 5)	File: pipeline2.ctbo.noao.edu/data_local/images/DTS/2012B-9990/DECam_00156910.fits.gz
156909	zero	30 Nov 12, 19:40:54.000	block	281.4671	-30.2047	Seq: 5 exposures (1 of 5)	File: pipeline1.ctbo.noao.edu/data_local/images/DTS/2012B-9990/DECam_00156909.fits.gz

Blanco TCS READY Filters READY BCAM READY GCS READY Hexapod READY

PANA IDLE DWSA READY IB1 WAITING

PANB IDLE DWSB READY IB2 WAITING

PANc IDLE DWSC READY IB3 WAITING

PAND IDLE DWSd READY IB4 WAITING

PANE IDLE DWSF READY IB5 WAITING

DTS

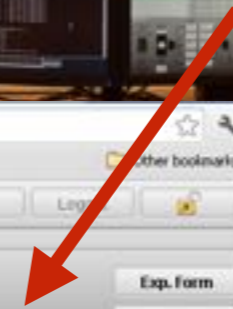
PML at 15:03: SUCCESS

OCS at 15:03: Disarming qManager (exposure queue)

OCS at 15:03: Stop exposure loop requested. Current loop count: -1. Current queue length: 0

PML at 15:03: SUCCESS

OCS at 15:03: Starting exposure 156918. (thread: 1)



Observer console

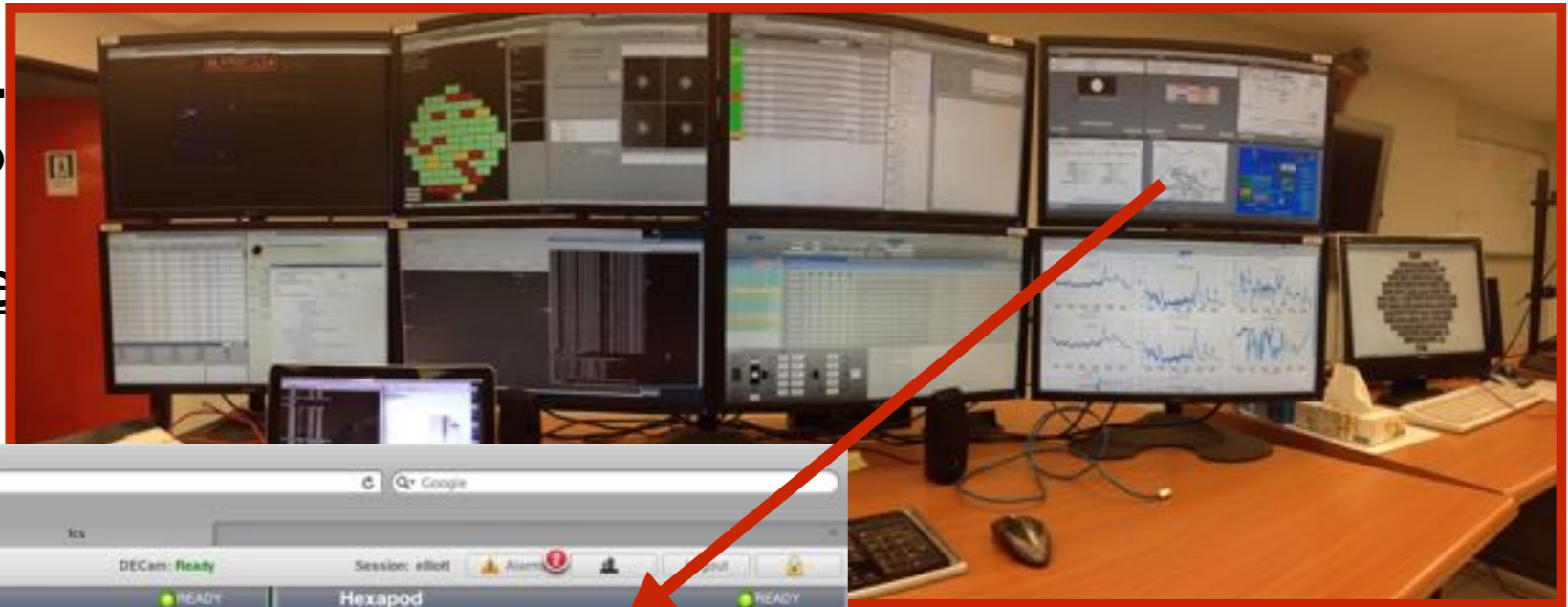
Obstac - scripts

visual data flow



Dark Energy

DECam & SISPI - Survey Image



ICS

DECam: Ready

Session: ellott

Shutter READY

Exposure: 130401
Requested Time: 0
Actual Time: 0

Connected: ● READY
Open Time: 0
Close Time: 0

Filter READY

Limit Switch: 00000000 Humidity: 50 % (2.5 V), ok
Air Command: 00000000 Supply Pressure: 90 PSI (2.25 V), ok
Connected: ● READY Temperature: 10 C (2.5 V)

Hexapod READY

Connect: ● Tweakable ● Ref. Temp.: 25 Status: READY

Configuration: Mirror TCS Tweakable
Lookup: Telescope Filter Temperature

X	Y	Z	Tip	Tilt
0 μm	0 μm	0 μm	0 °	0 °
0	0	0	0	0
0	0	0	0	0

Error message: 0

BCam App: ● READY BCam Hardware: ALIVE BCams Active: ●

BCam Corrections to Hexapod: undefined, undefined, undefined, undefined, undefined

BCam Calibrated: 2012-07-31

TCS READY

RA: 07:27:27.000 DEC: 20:40:00.120

Tracking: ● In Control ● In Position ● Connected: ●

Air Mass: 1.58
Dome Az: 359.99
Hour: 00:00:01.08
MJD: 55000
Sidereal: 07:27:28.08
Tel Az: 359.99
Tel El: 39.1
Tel Zd: 50.9

Environment

2012-07-31

25.36%

17.5570°C 7.7596°C
10.5868°C 16.7791°C
1.0362°C 8.8931°C

Outside Conditions: 30%, 7.2m/s, 17°C, 255.145kg, 737hPa, 0.7arcsec

ICS

DECam Instrument Control System Status

O₂ Drogen System, Vacuum 3.7549E-7, Turbo Pump, LN2 Pressure, LN2 Level, LN2 Pump, Rough Pump, Ion Pump, photodiode, Liberator, He compressor, Enabled / AutoSub, ICS or ICS to S, Hevent, Show Vacuum G, Field, LN2, ICC, Lamp, Window

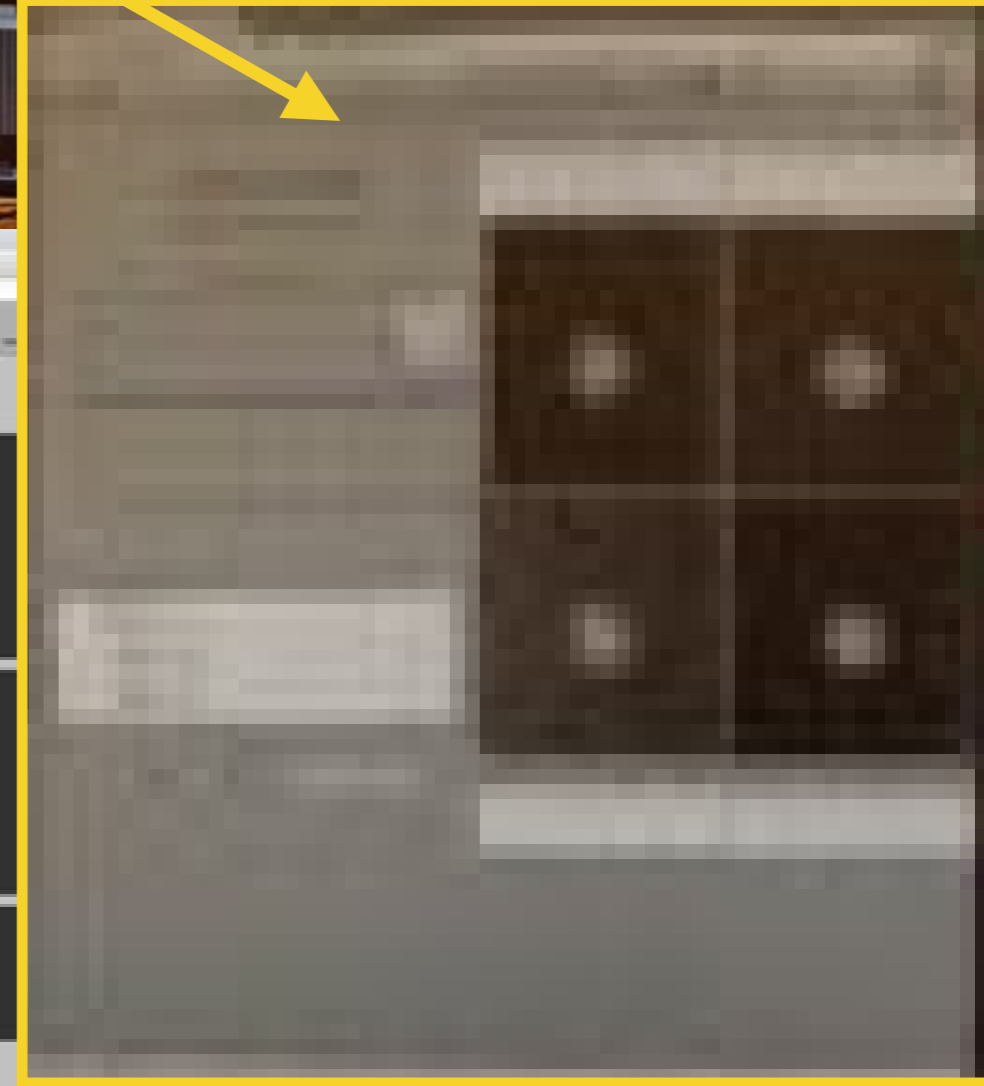
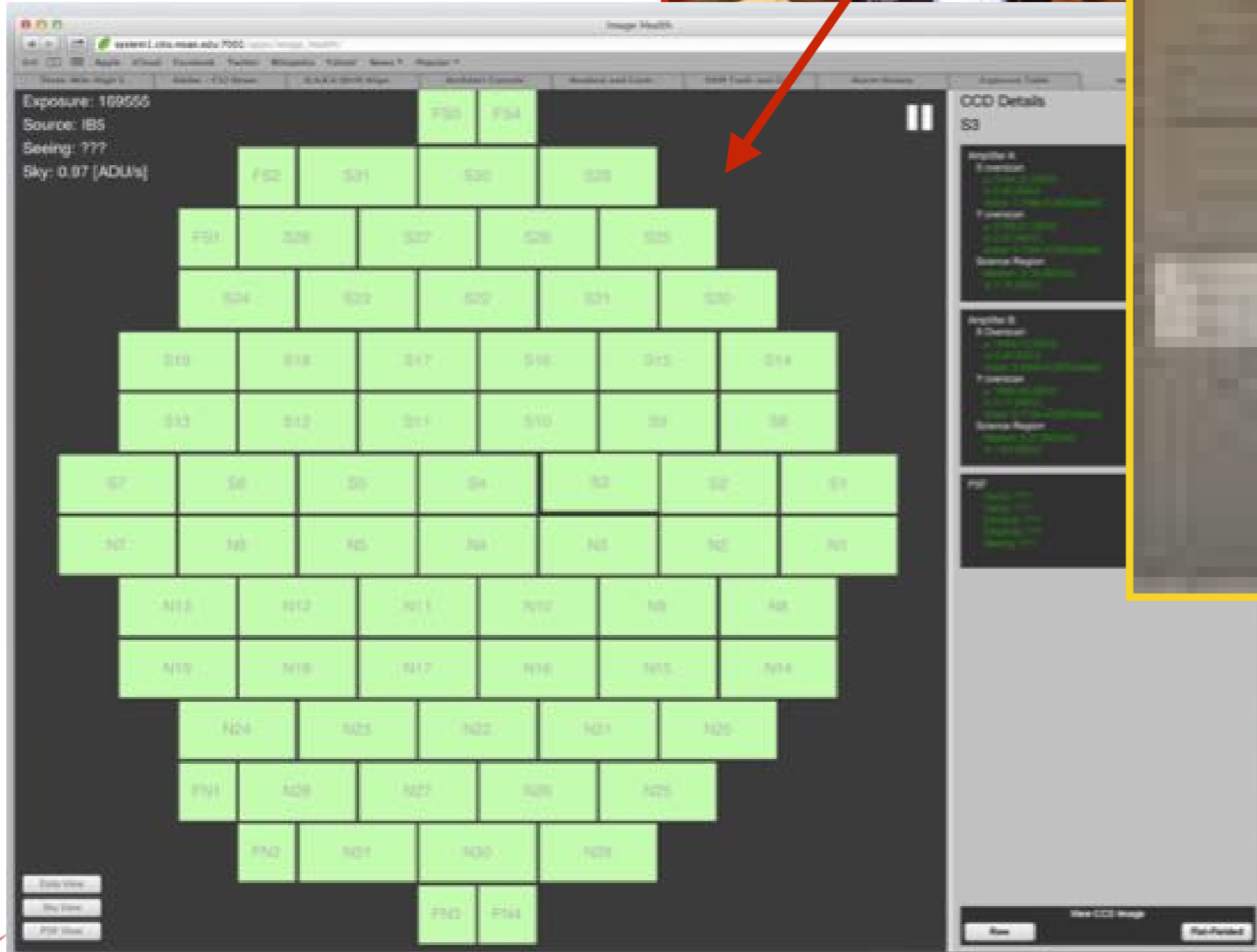
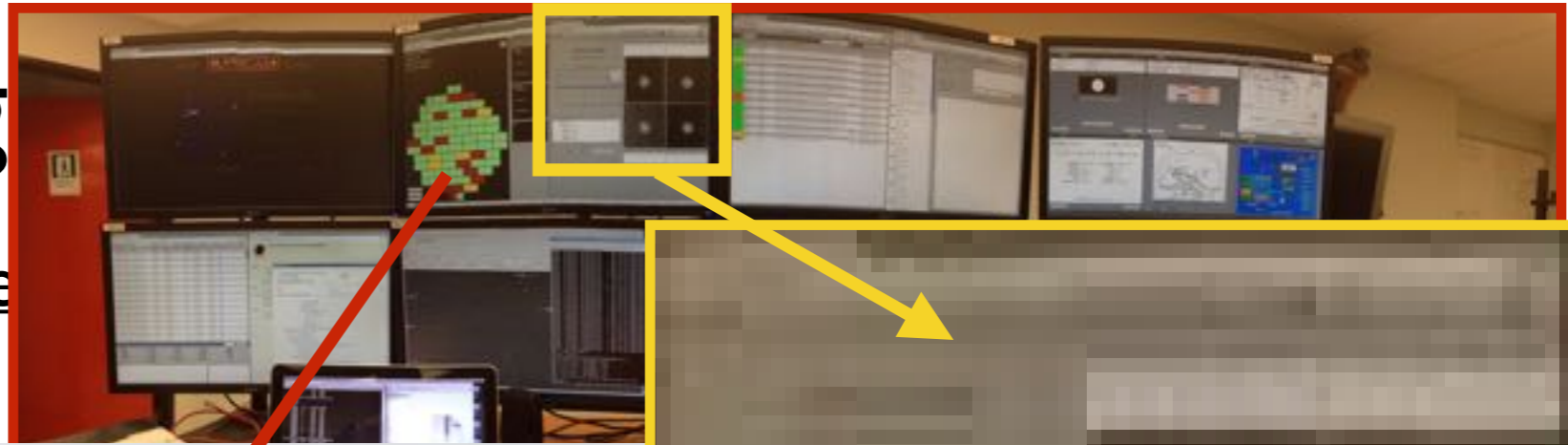
Instrument Control System-ICS:

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



Dark Energy

DECam & SISPI - Survey Image



Guider - live image

Image health

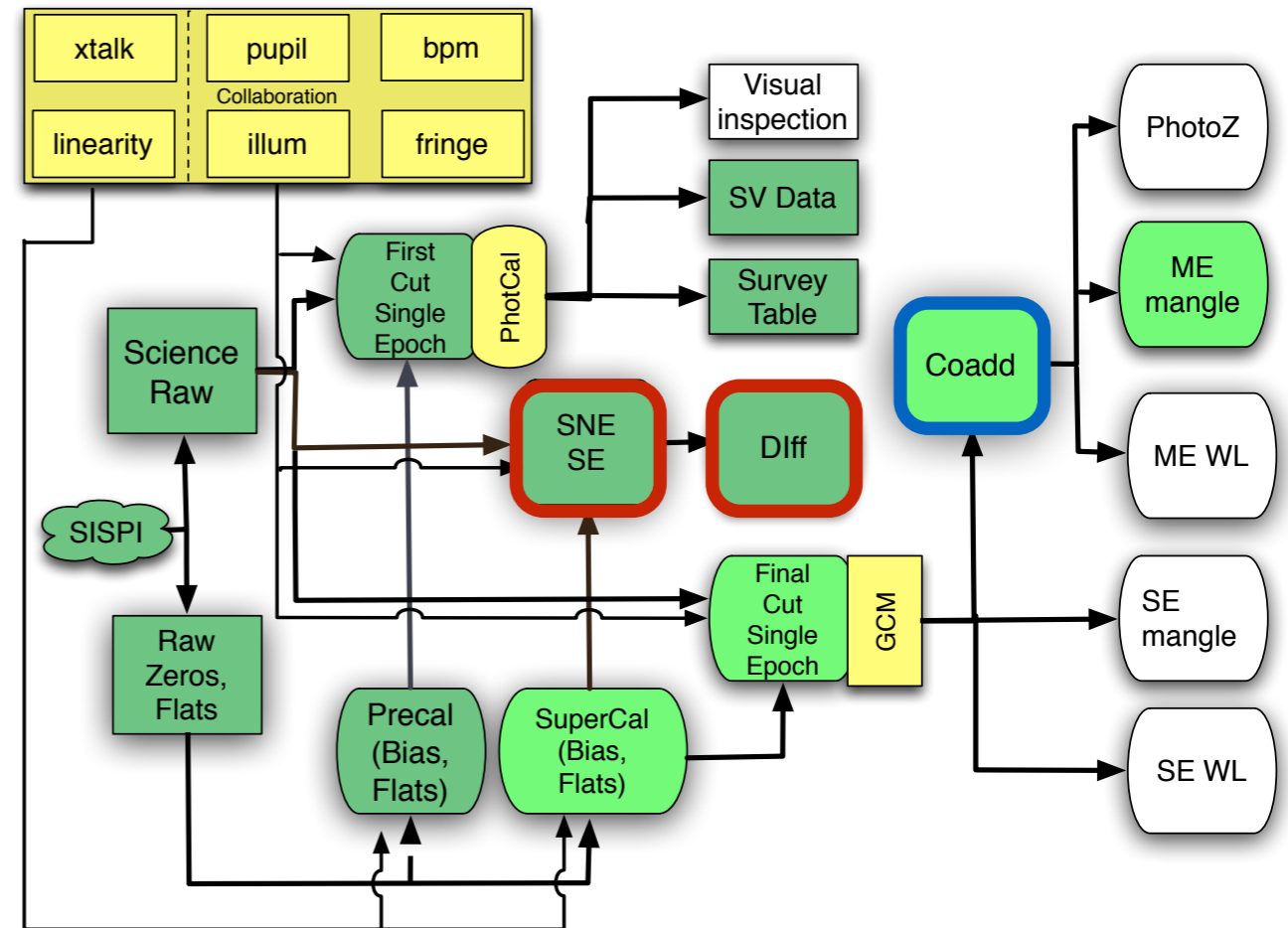


Dark Energy Survey - DES

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

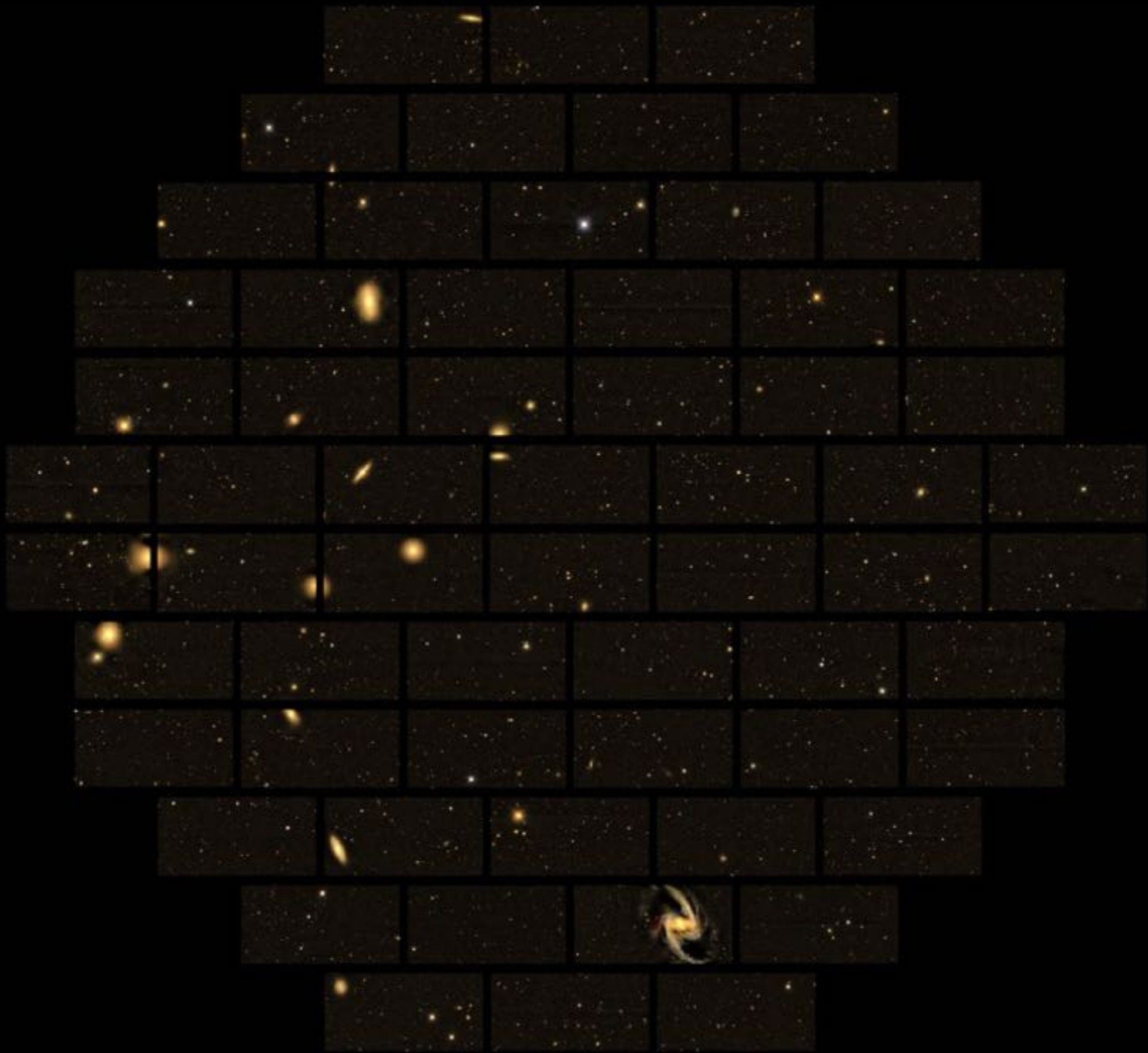
~12hrs turnaround for SNe data

~6 months for the yearly data releases

Data products accessible via SQL database

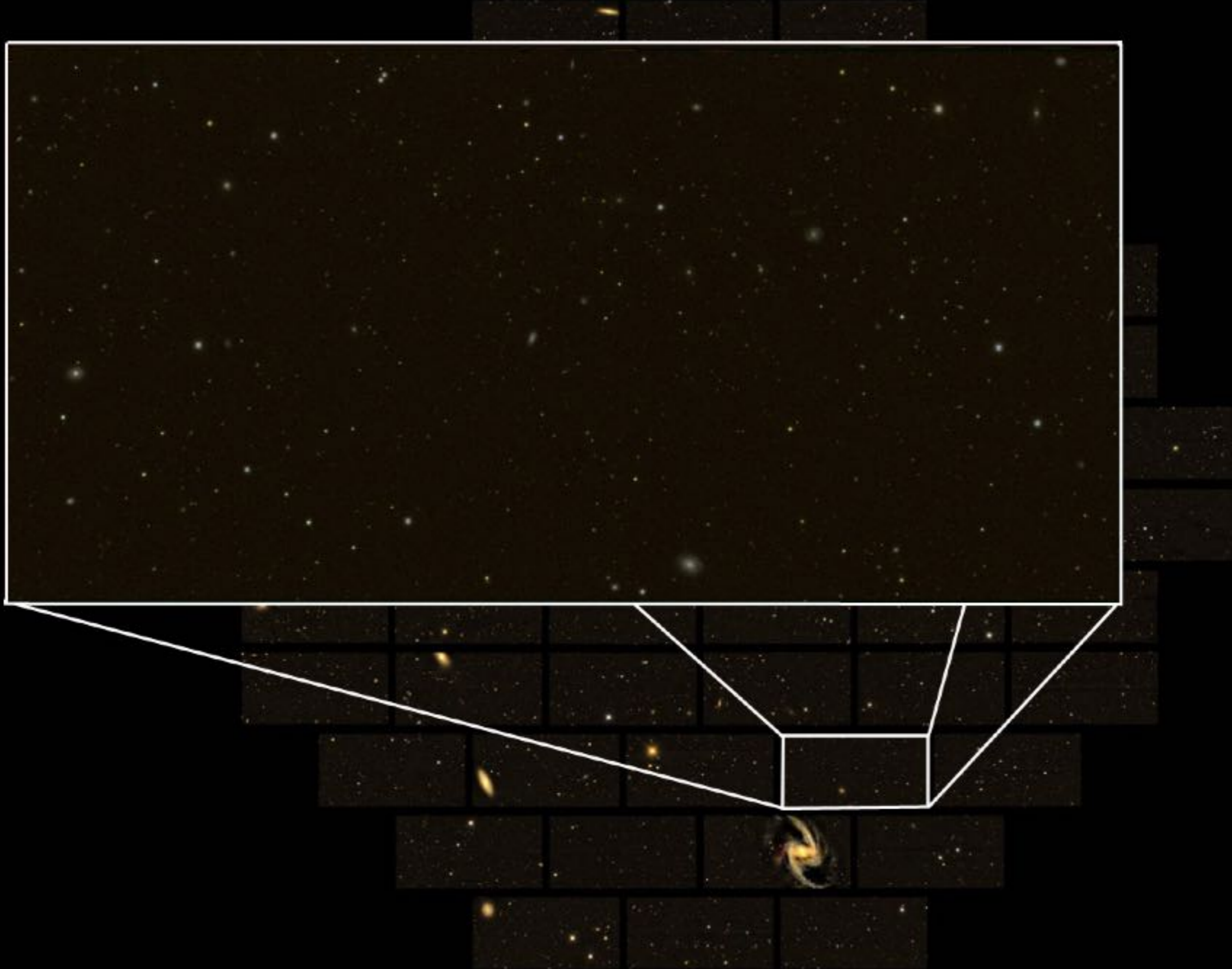


THE DARK ENERGY SURVEY



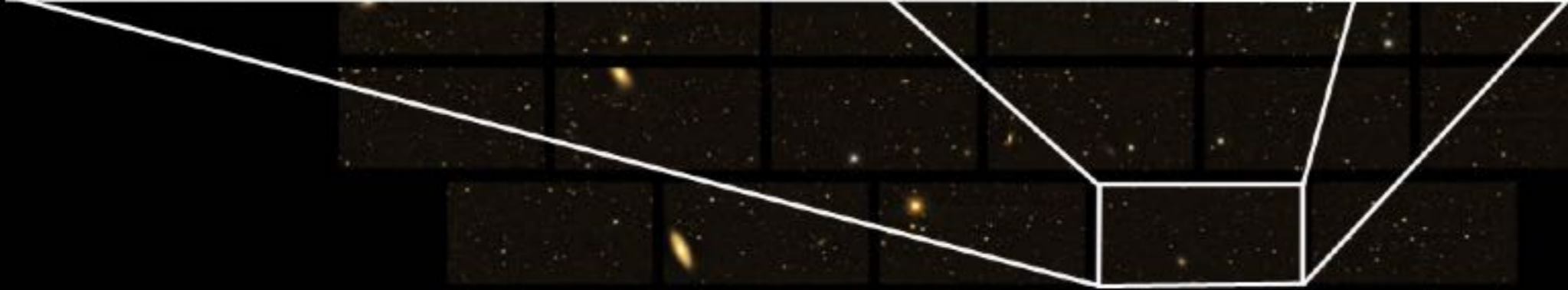
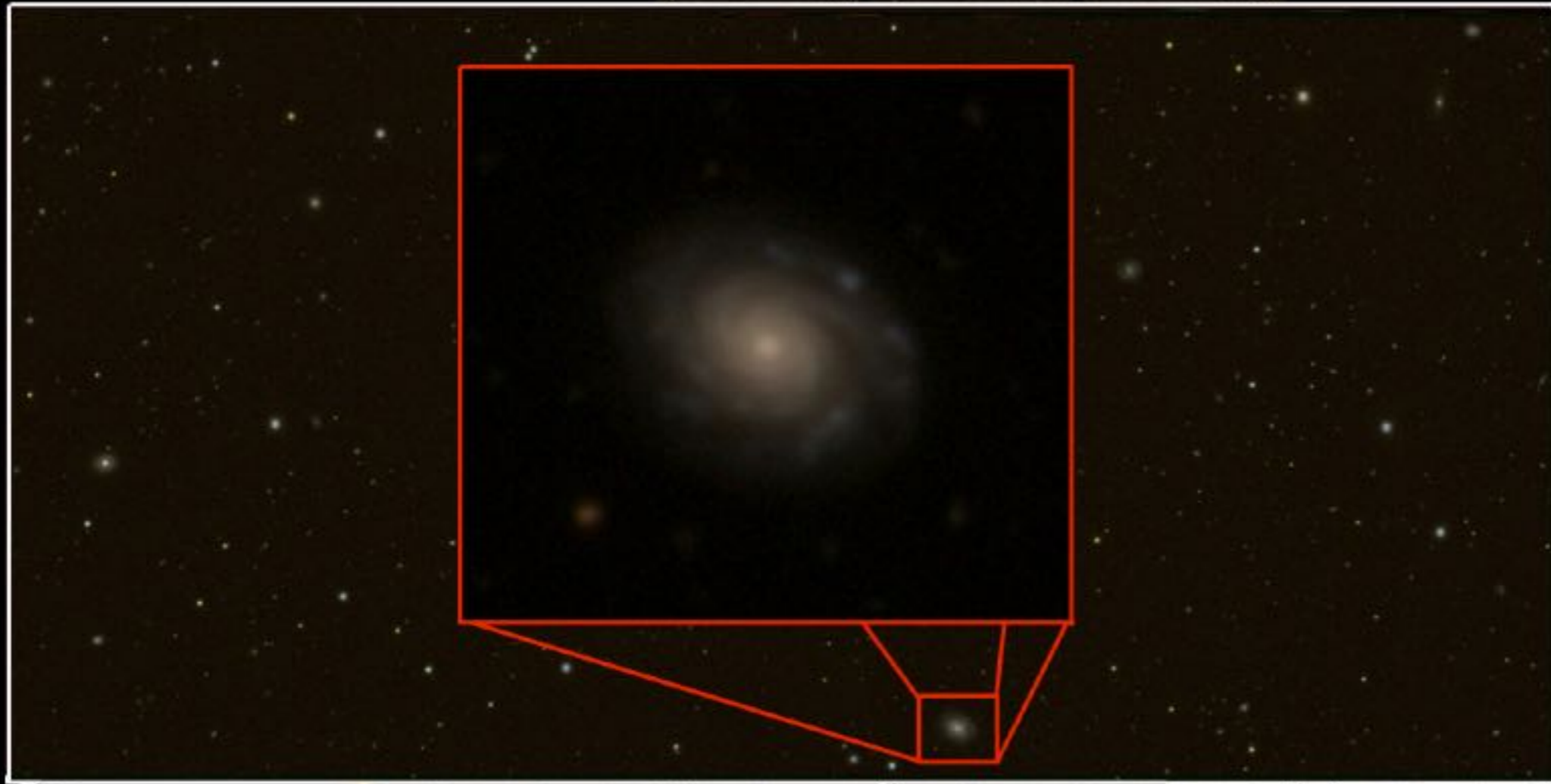


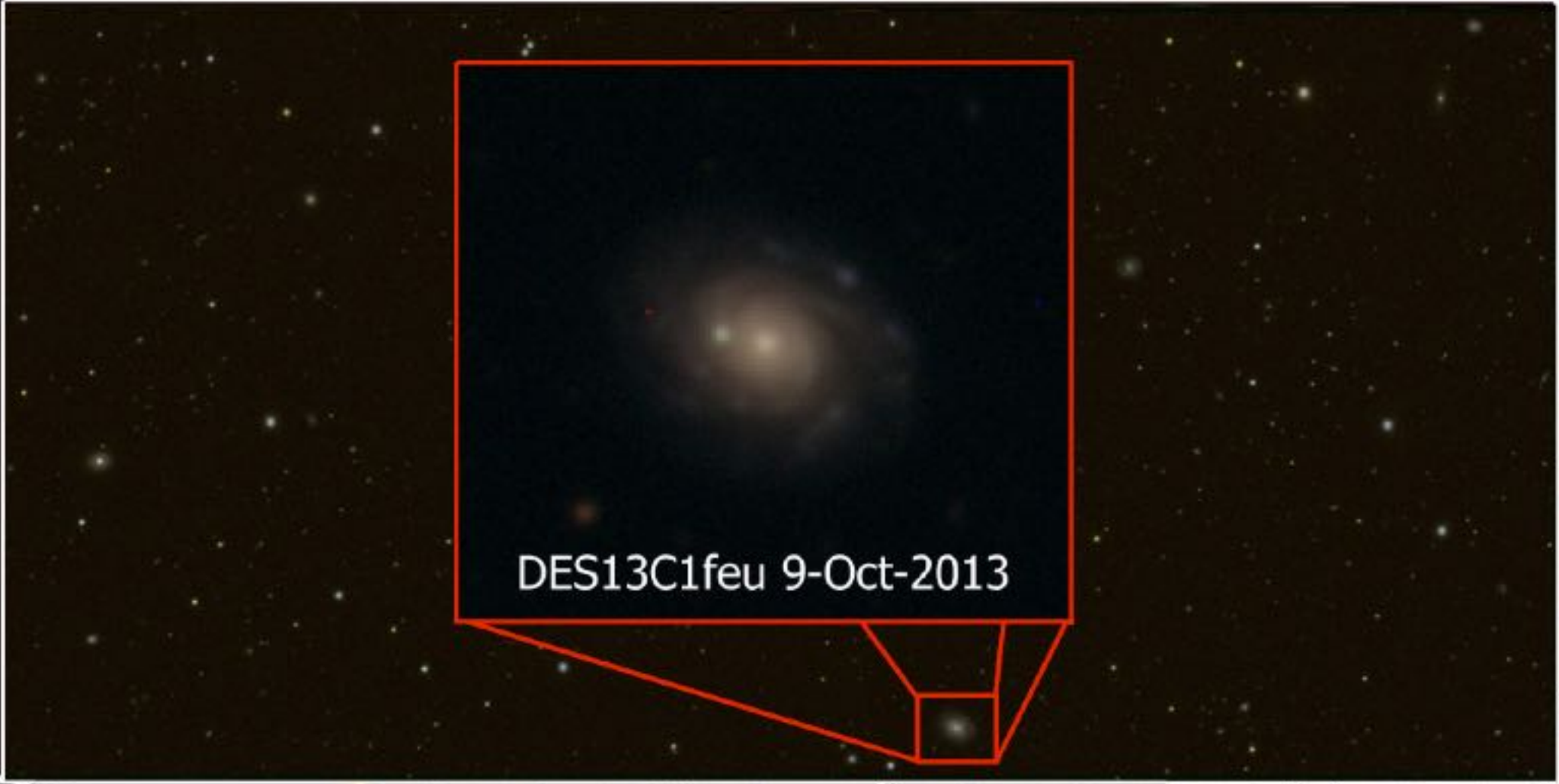
THE DARK ENERGY SURVEY





THE DARK ENERGY SURVEY





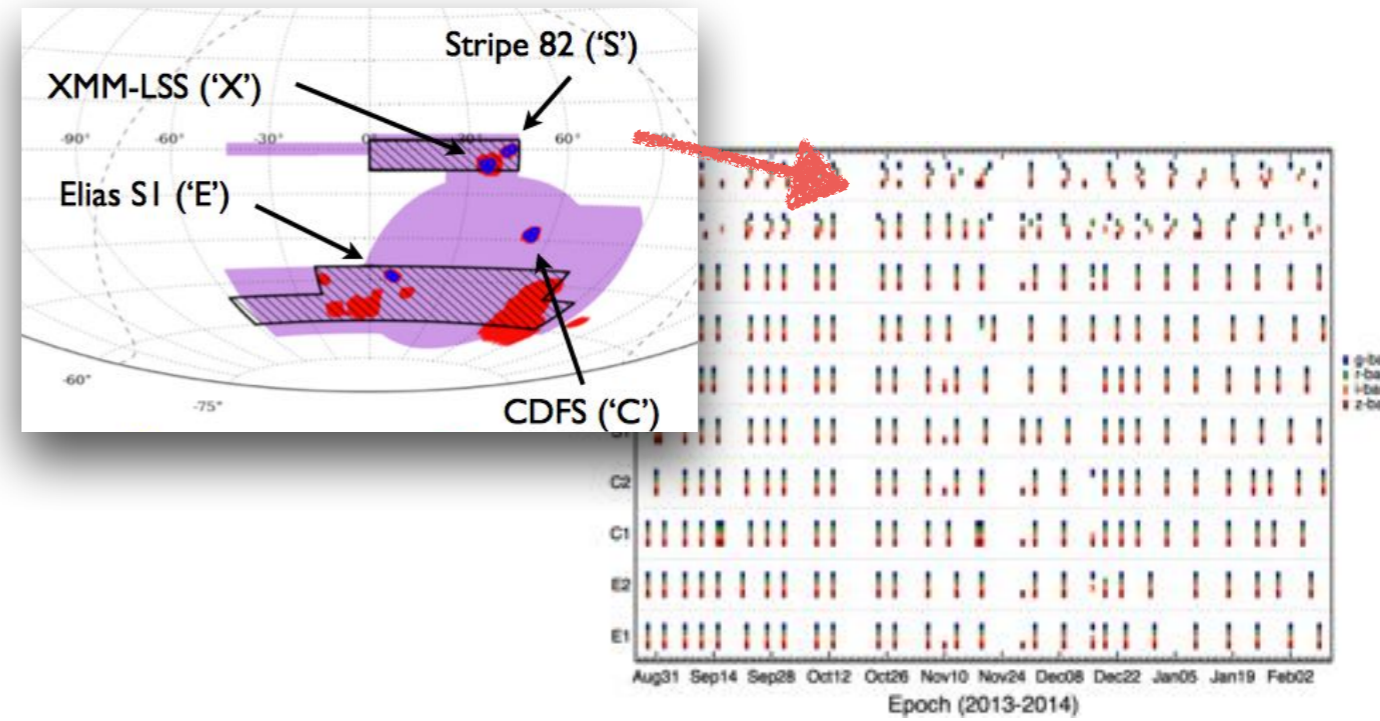
DES13C1feu 9-Oct-2013



DES Supernovae

- **DES SNe search:**

- 10 fields (E1, E2, S1, S2, C1, C2, C3*, X1, X2, X3*)
- Transients naming convention: DES-I3-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





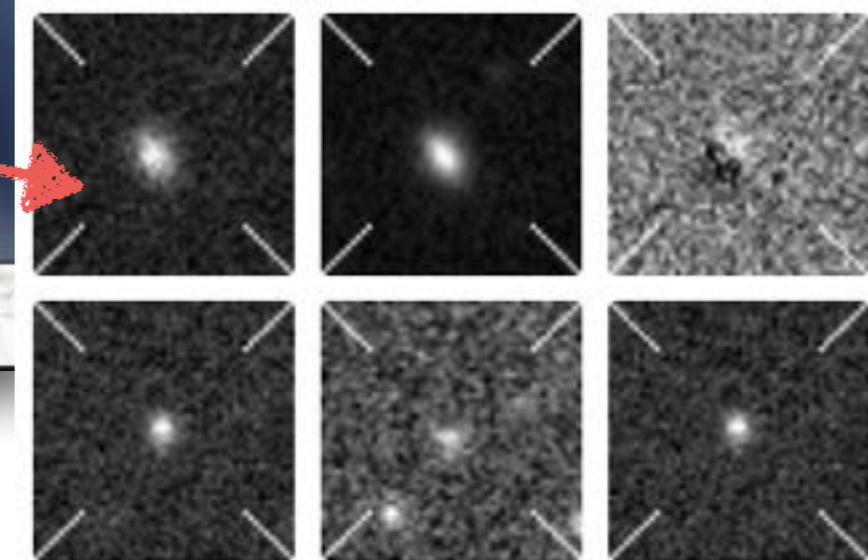
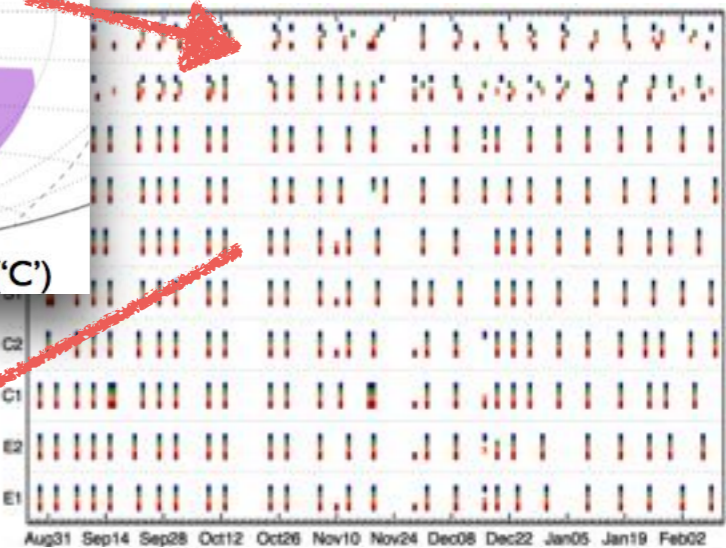
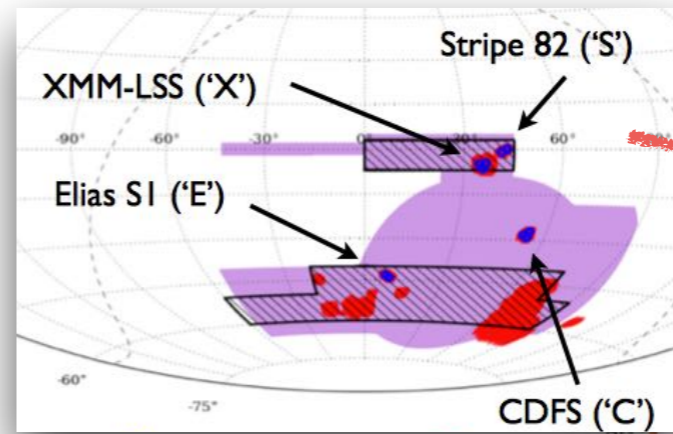
DES Supernovae

• DES SNe search:

- 10 fields (E1,E2,S1,S2,C1,C2,C3*,X1,X2,X3*)
- Transients naming convention: DES-I3-S2-abcd
- ~5-7 days cadence in *griz*
- DES Y1:
 - Sep-2013 ⇔ Feb-2014 : ~1
- DES Y2:
 - Aug-2014 ⇔ Feb-2015 : ~1
- DES Y3:
 - Aug-2015 ⇔ Feb-2016 : ~1

• 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



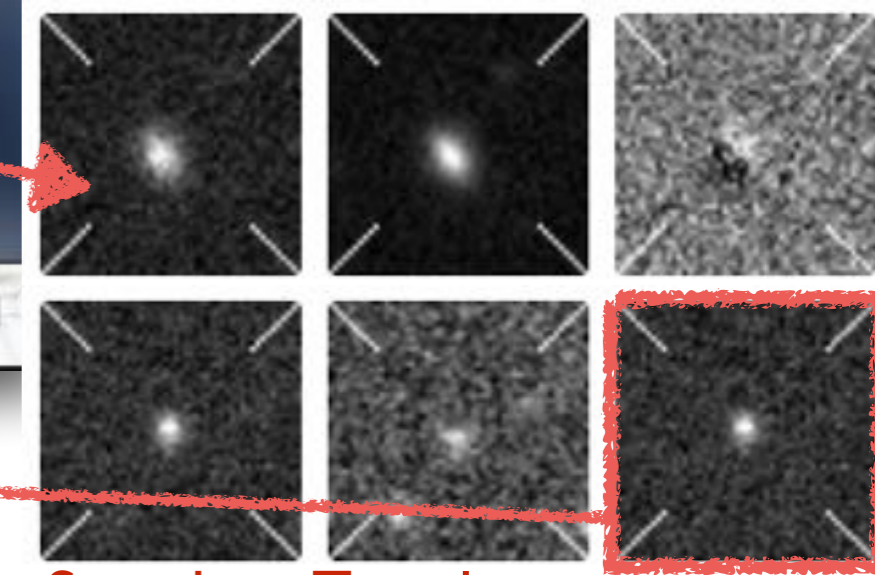
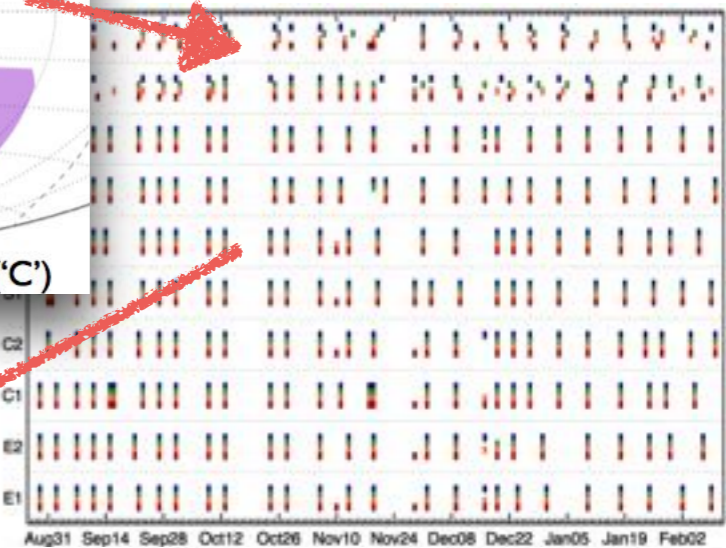
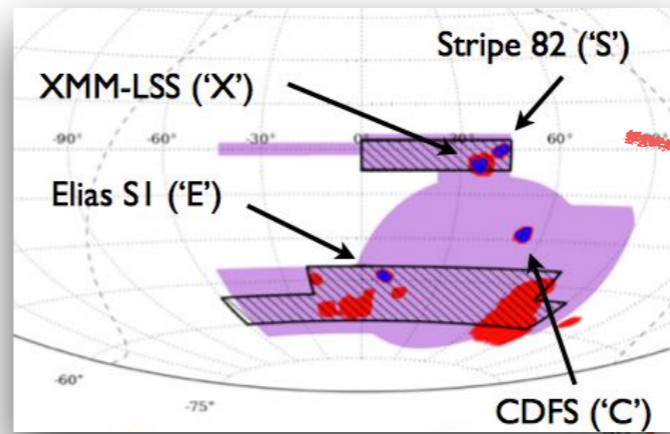
DES Supernovae

DES SNe search:

- 10 fields (E1, E2, S1, S2, C1, C2, C3*, X1, X2, X3*)
- Transients naming convention: DES-I3-S2-abcd
- ~5-7 days cadence in *griz*
- DES Y1:
 - Sep-2013 ⇔ Feb-2014 : ~1
- DES Y2:
 - Aug-2014 ⇔ Feb-2015 : ~1
- DES Y3:
 - Aug-2015 ⇔ Feb-2016 : ~1

Data processing:

- turn around time is *essential* for spectroscopy
 - *FirstCut Pipeline* - *Difference pipeline*
 - *Human scanning* - *Transient identification*
- Photometric classification



Search - Template = Difference





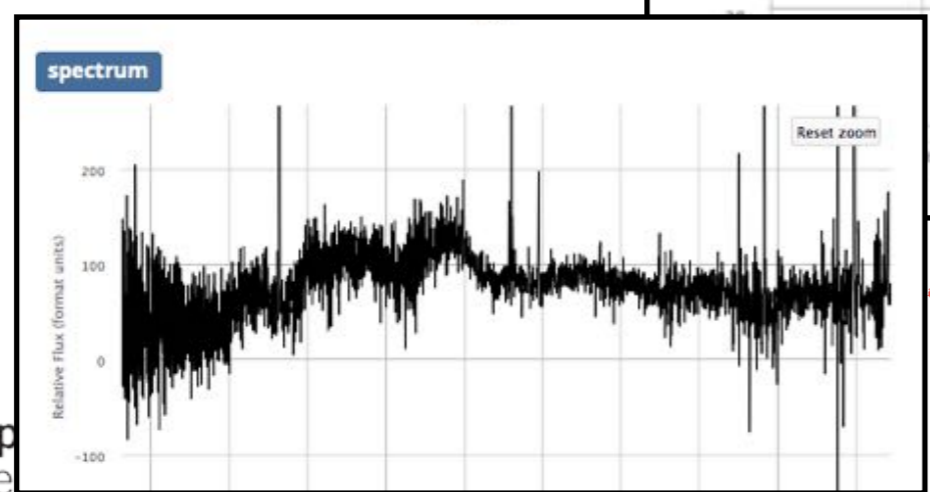
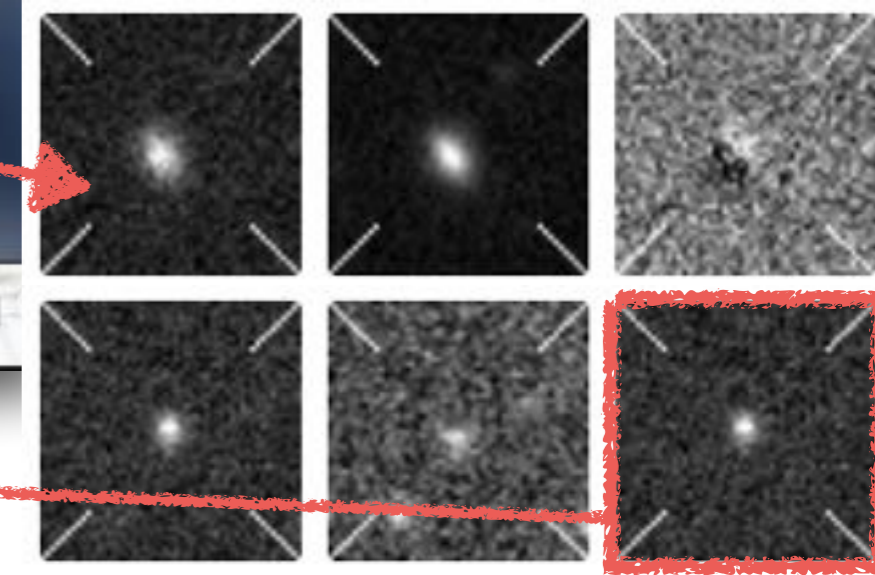
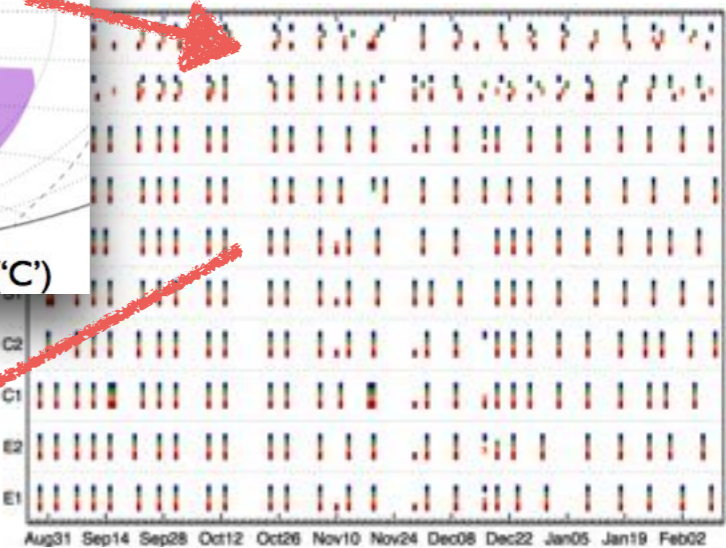
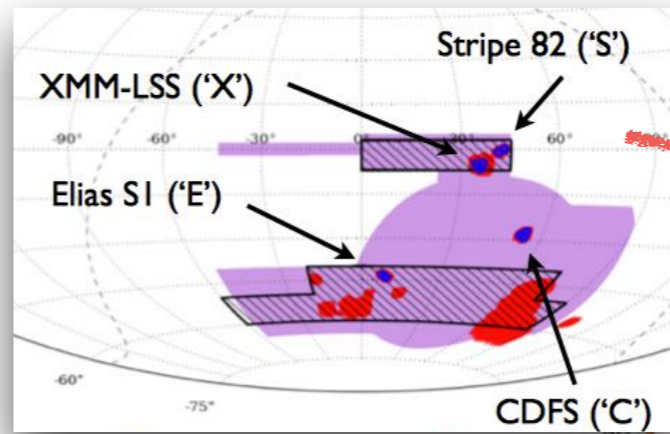
DES Supernovae

DES SNe search:

- 10 fields (E1, E2, S1, S2, C1, C2, C3*, X1, X2, X3*)
- Transients naming convention: DES-I3-S2-abcd
- ~5-7 days cadence in *griz*
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- DES Y3:
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Data processing:

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





DES Supernovae

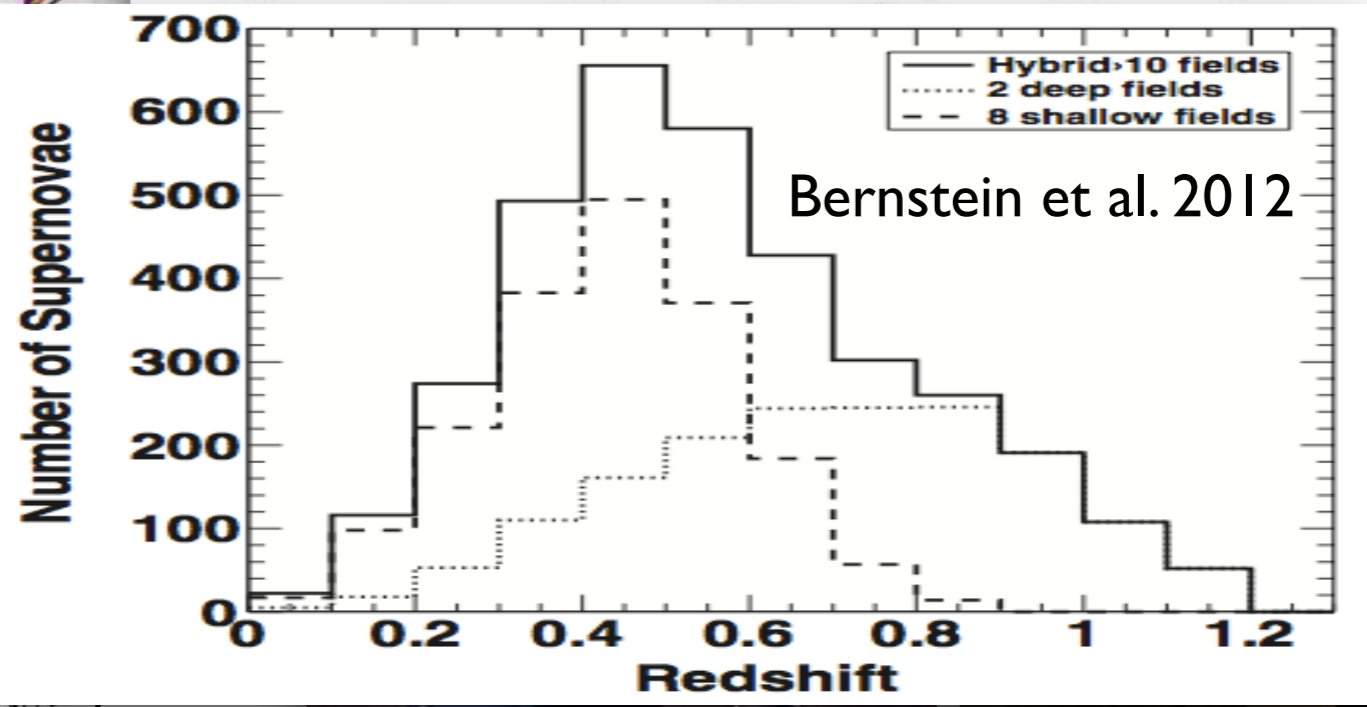
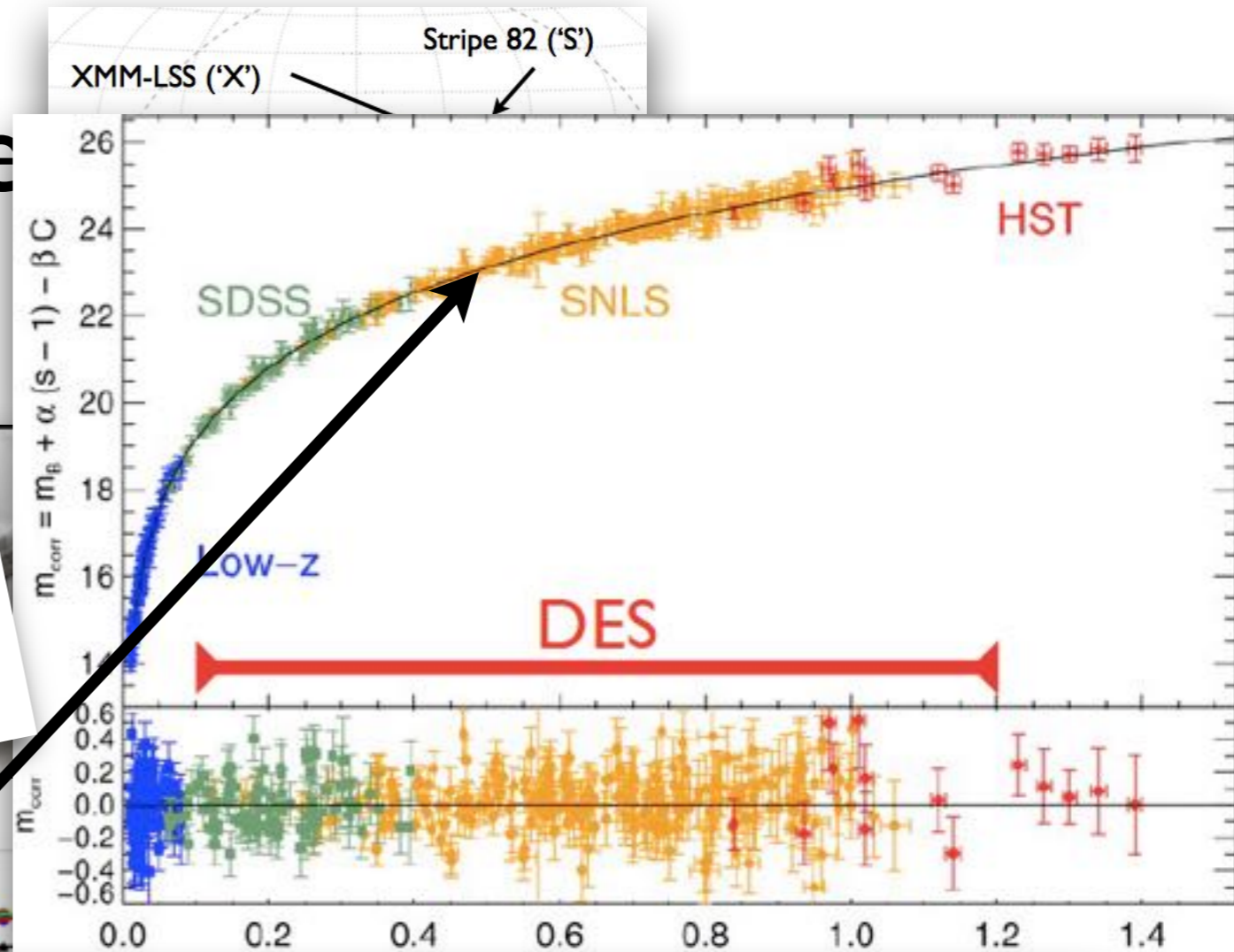
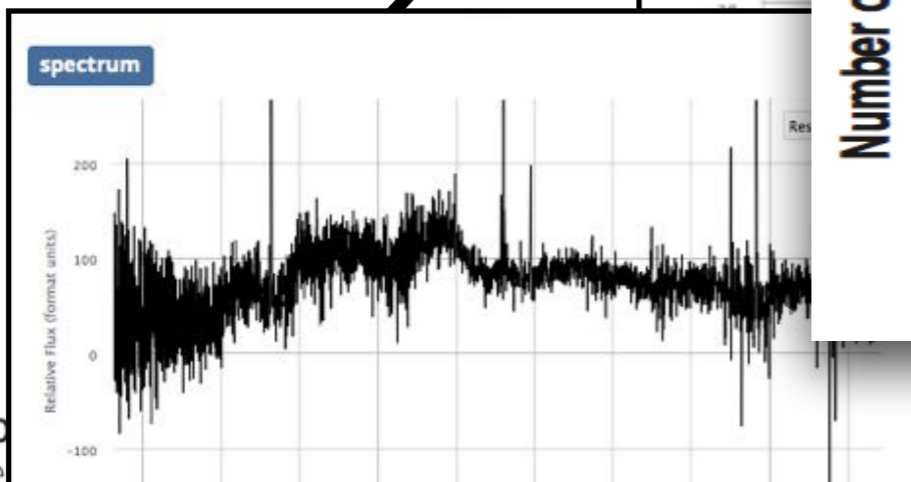
DES SNe search:

- 10 fields (E1,E2,S1,S2,C1,C2,C3*,X1,X2,X3*)
- Transients naming convention: DES-IJ-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 spectroscopy
 - *FirstCut Pipeline* - Difference pipeline
 - *Human scanning* - Transient identification
- Photometric classification
- Spectroscopic follow-up



European University Cyprus

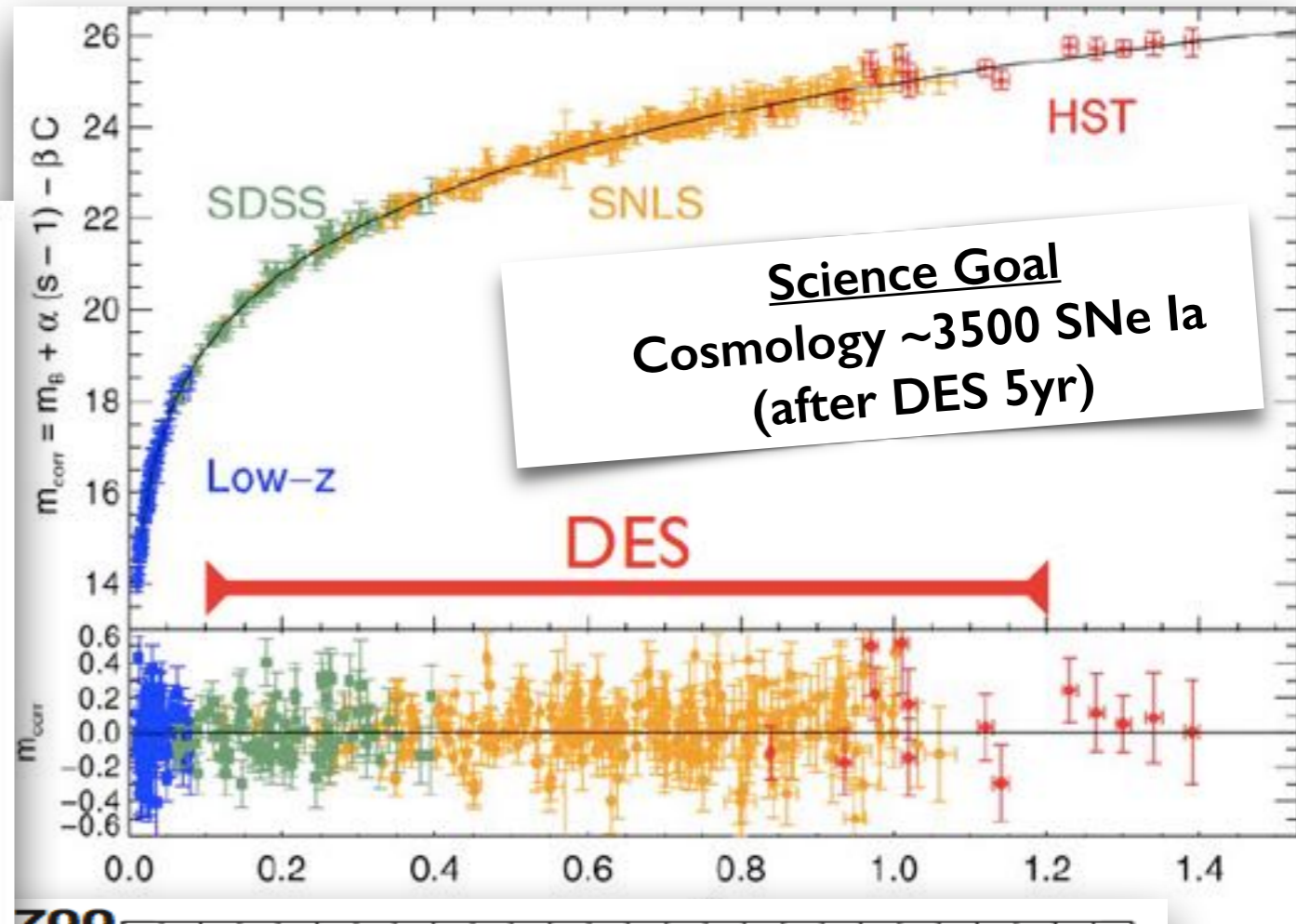
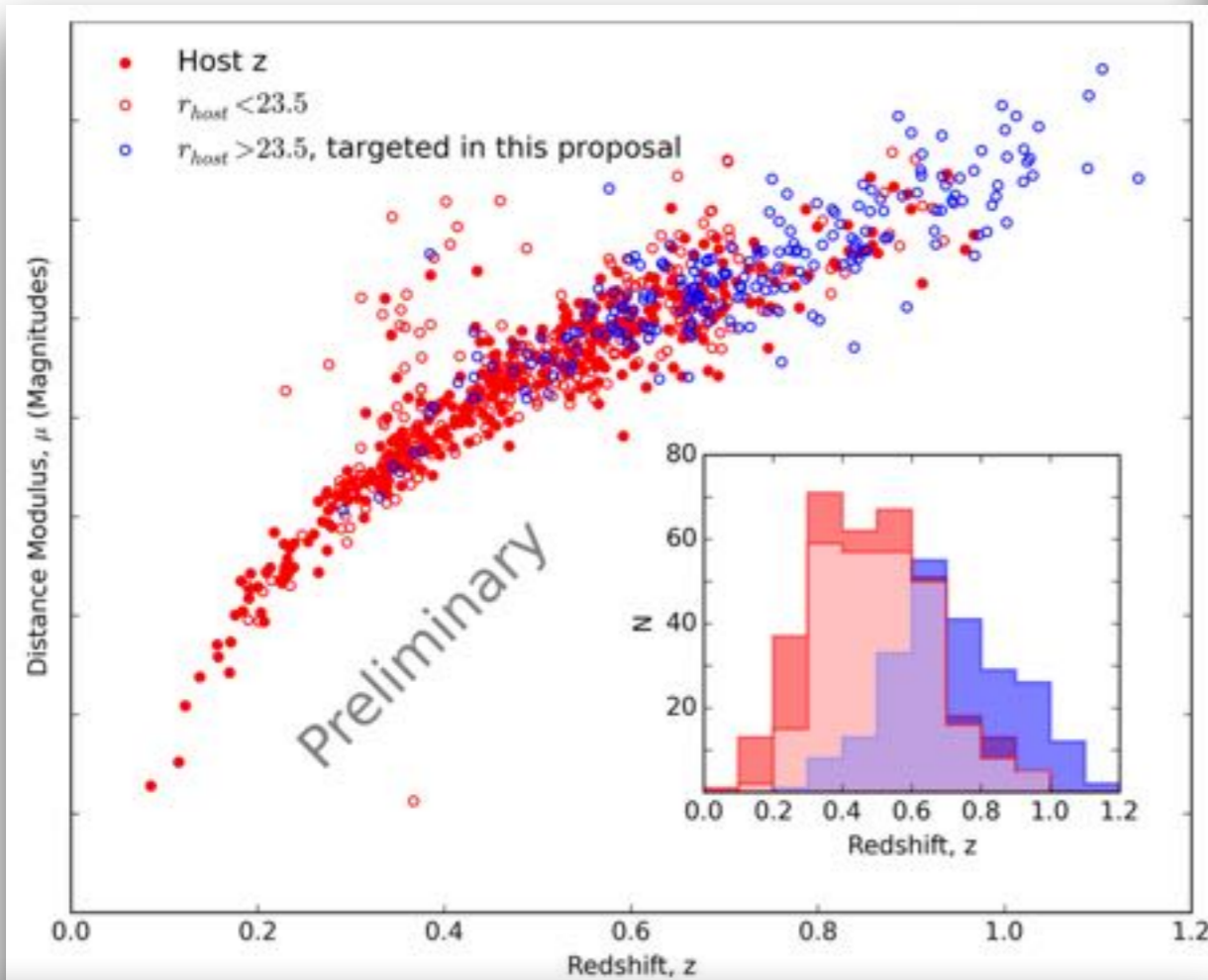
LAUREATE INTERNATIONAL UNIVERSITIES

A.Papadopoulos@external.euc.ac.cy

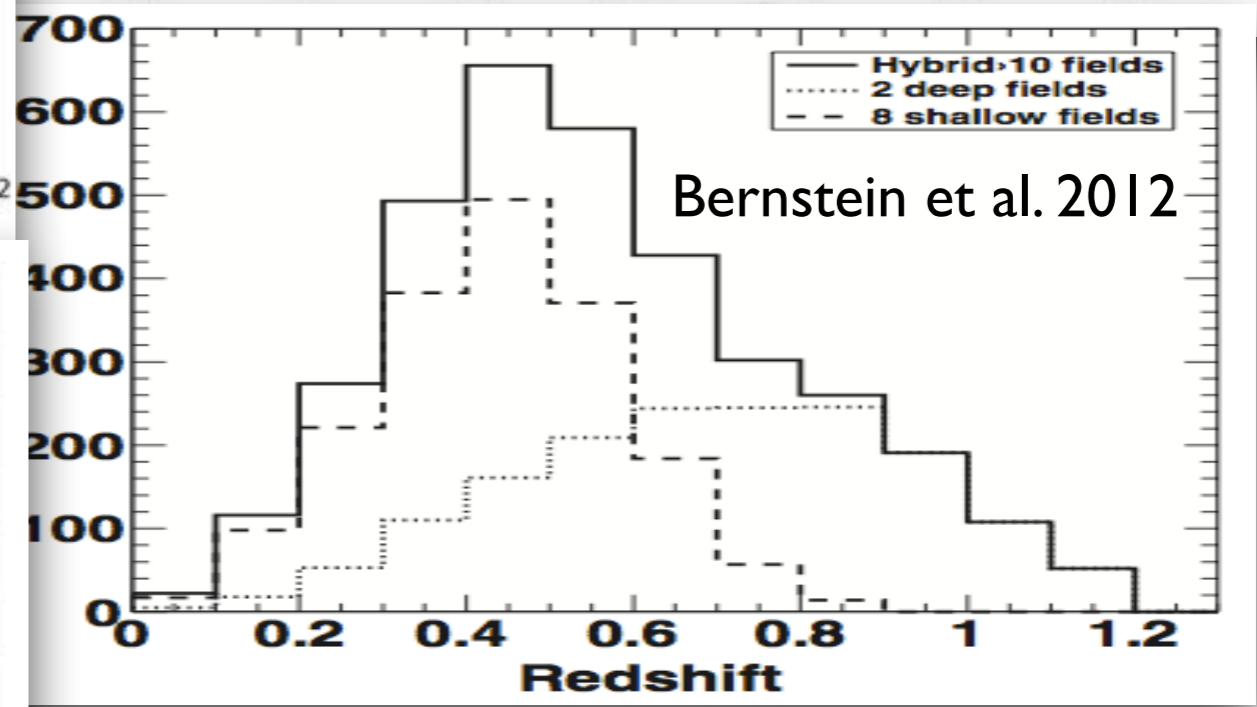
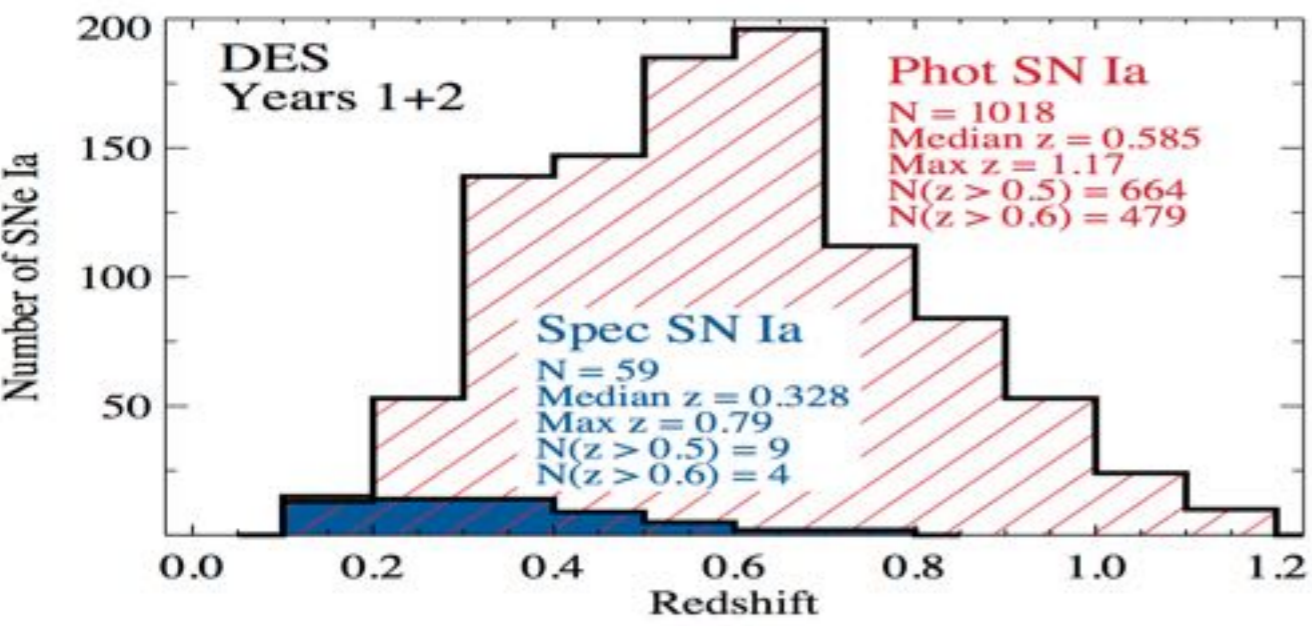




Update



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





Superluminous SNe (SLSNe)

Superluminous:

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

Light-curves:

- 100s of days
- long rise/fall timescales

Rare events:

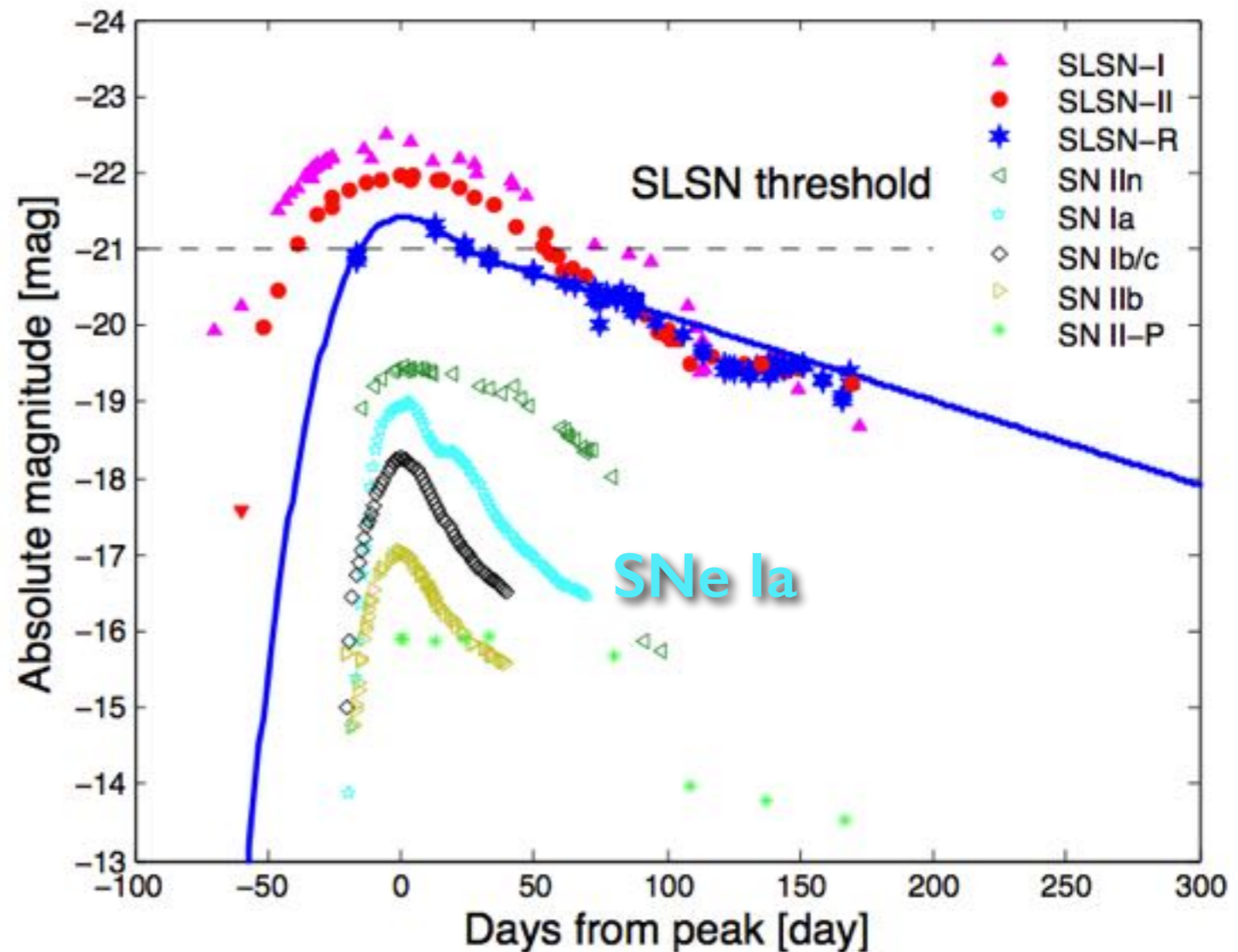
- ~40 discovered up to date
- 0.01% of **SNe Ia** rates
 - local Universe
- *15 increase @ $z > 1$
 - SNLS, Cooke et al. 2012

High-z:

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

UV emitters:

- redshifted to the observed optical



Gal-Yam, SLSNe review, 2012

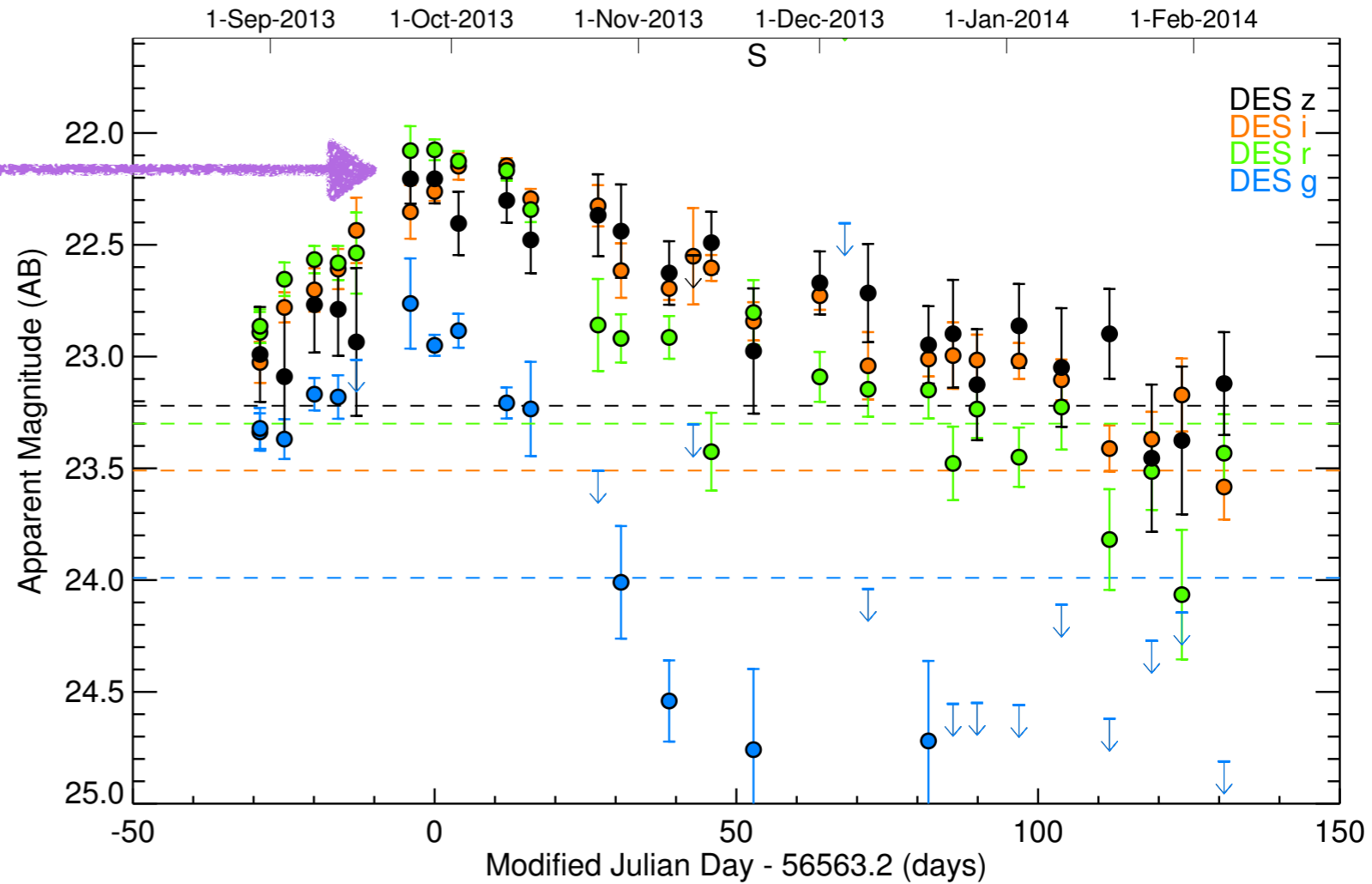


DES I 3S2cmm

- ~30 days rise time
- $z = 0.663 \pm 0.001$
- $M_U = -21.09$

Peak Brightness:

- 28-September-2013



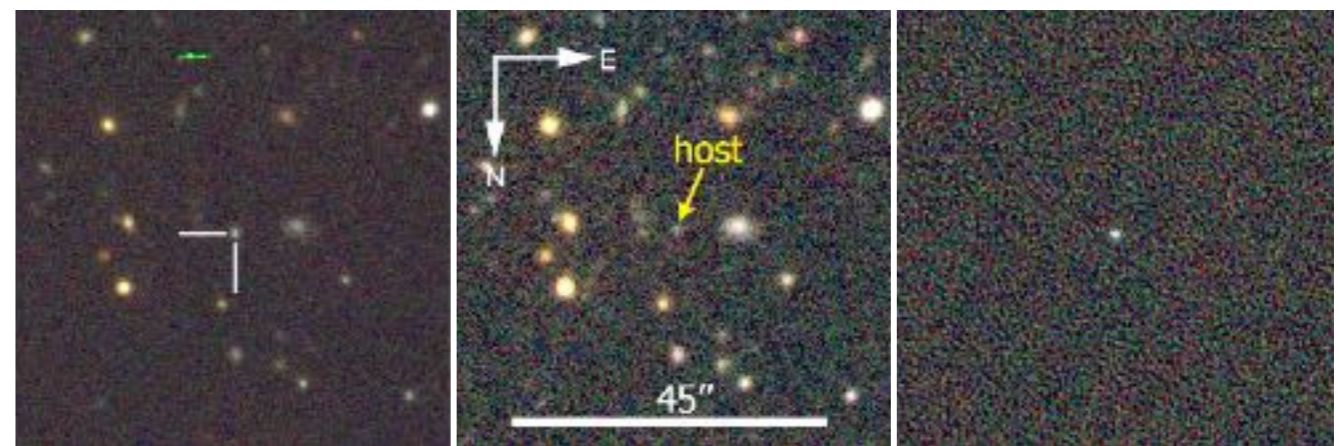
DES13S2cmm: the first superluminous supernova from the Dark Energy Survey
 A. Papadopoulos,^{1*} C. B. D'Andrea,¹ M. Sullivan,² R. C. Nichol,¹ K. Barbary,³
 R. Biswas,⁴ P. J. Brown,⁵ R. A. Covarrubias,^{6,7} D. A. Finley,⁸ J. A. Fischer,⁹
 R. J. Foley,^{1,10} D. Goldstein,^{11,12} R. R. Gupta,⁴ R. Kessler,^{13,14} E. Kovacs,⁴
 S. E. Kuhlmann,⁵ 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,³ 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,^{27,37} V. Scarpine,⁸ M. Schubnell,²⁵
 I. Sevilla,³⁸ M. Soares-Santos,⁸ E. Suchyta,²⁹ M. Swanson,⁶ G. Tarle,²⁵
 J. Thaler,³⁰ L. D. Tucker,⁸ R. H. Wechsler,³⁸ and J. Zuntz.³⁹

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ABSTRACT
 We present DES13S2cmm, the first spectroscopically confirmed superluminous supernova (SLSN) from the Dark Energy Survey (DES). We briefly discuss the data and search algorithms 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 $M_U^{\text{peak}} = -21.09 \pm 0.10$ 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 the bolometric light curves of all SLSNe-I studied herein and find that the peak magnitudes of all 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 important for ‘standard candle’ use in cosmology. We also find that the peak magnitudes of all 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 important for ‘standard candle’ use in cosmology. We also find that the peak magnitudes of all 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 important for ‘standard candle’ use in cosmology.

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

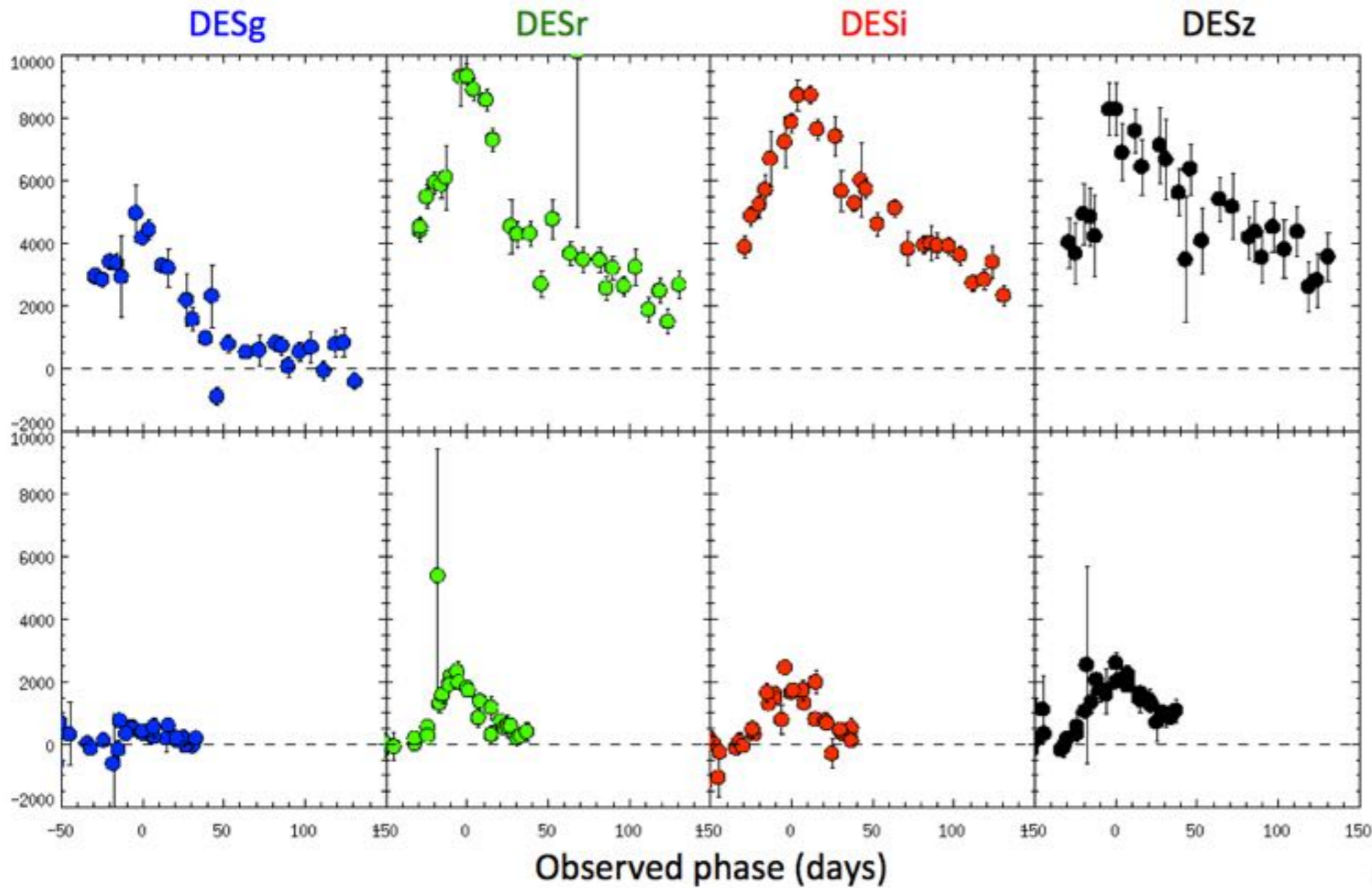
Papadopoulos et al. 2015
arxiv.org/abs/1501.07232



Search Template Difference

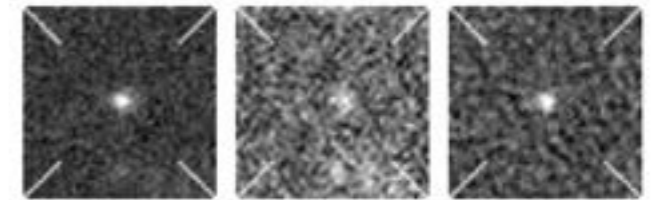


DES I 3S2cmm Vs SNe type Ia



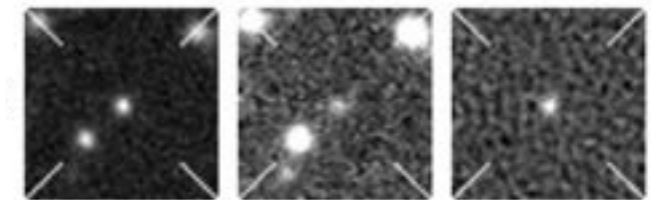
DES I 3S2cmm:

- VLT
 - $z = 0.663$
- SLSN-I



DES I 3C3abht:

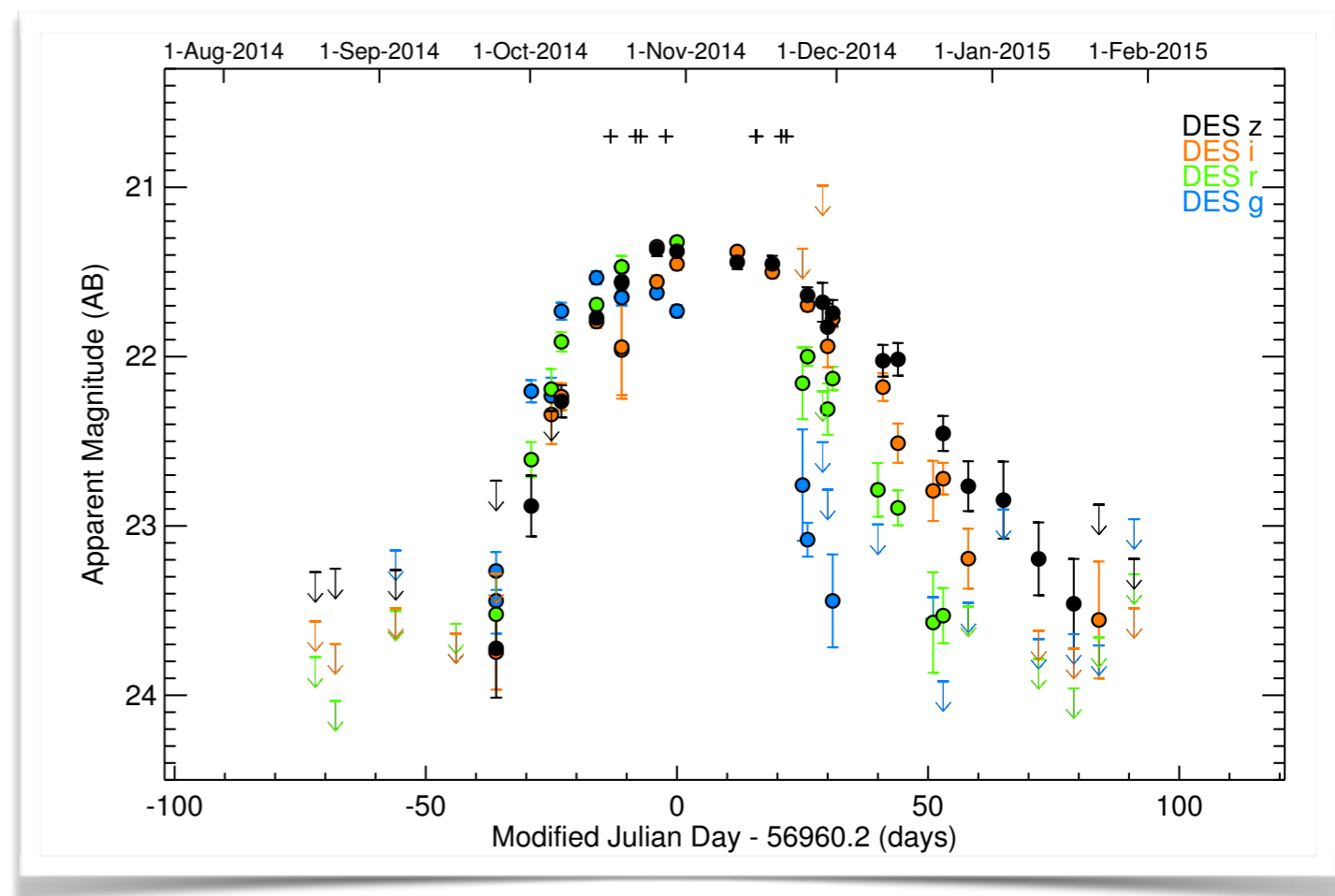
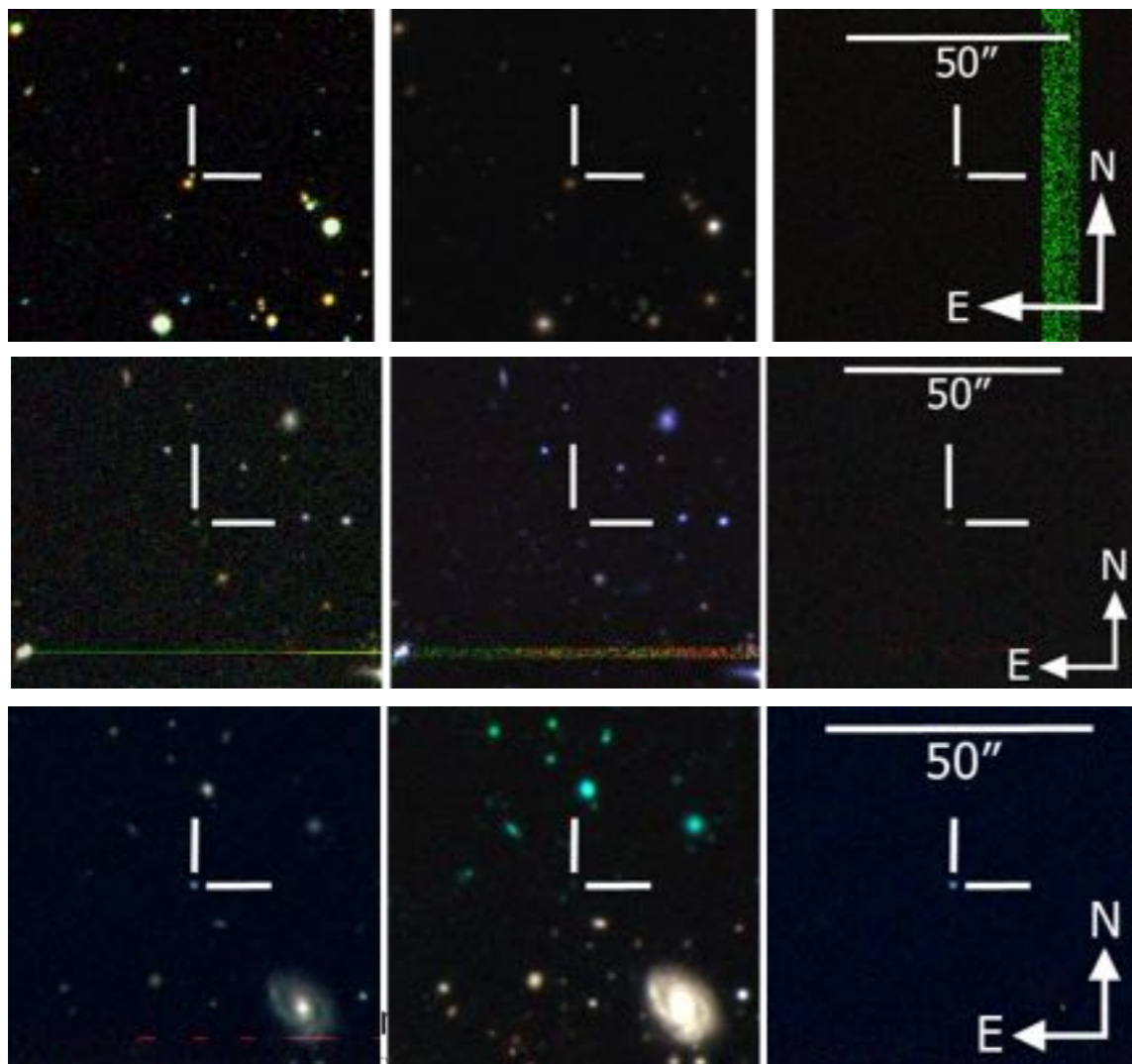
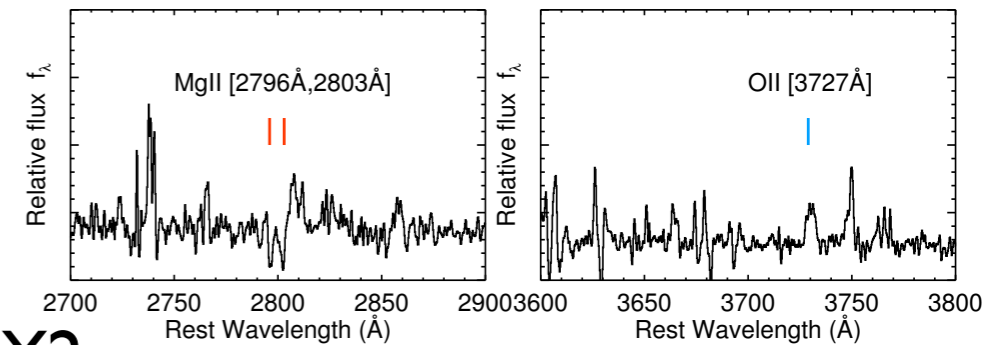
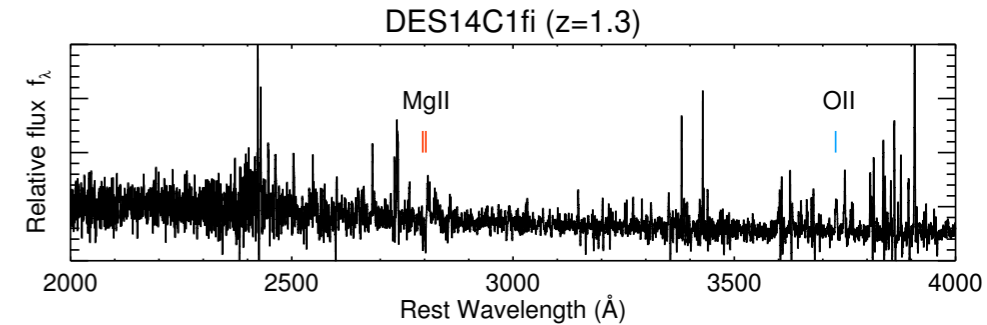
- Gemini-South
 - $z = 0.690$
- type Ia





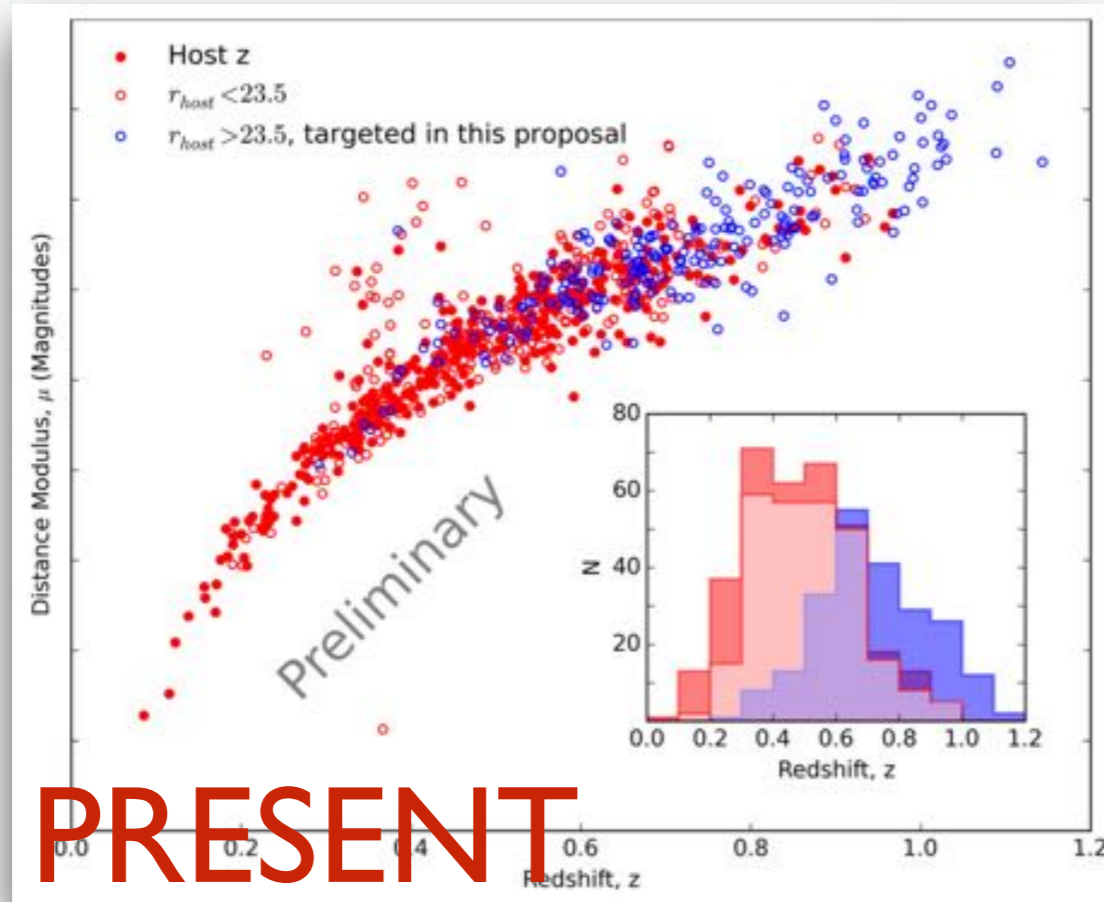
SLSNe in DES - update

- 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...

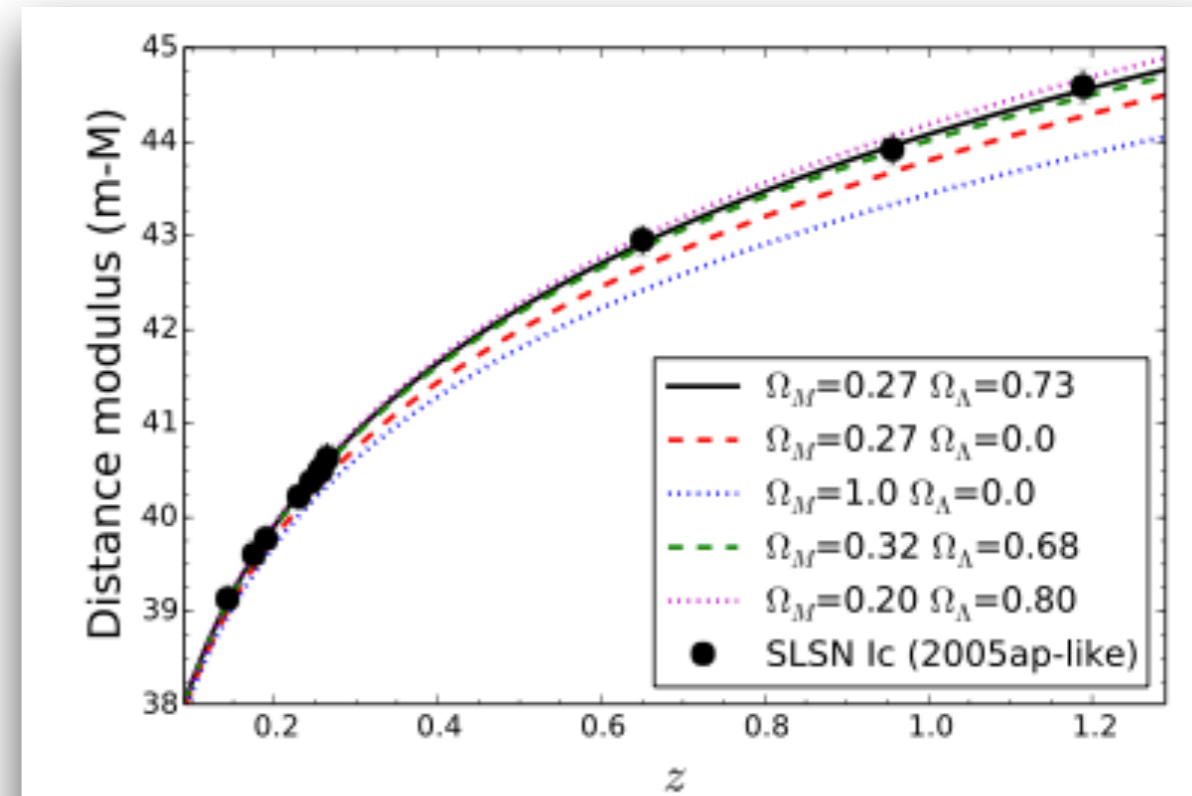




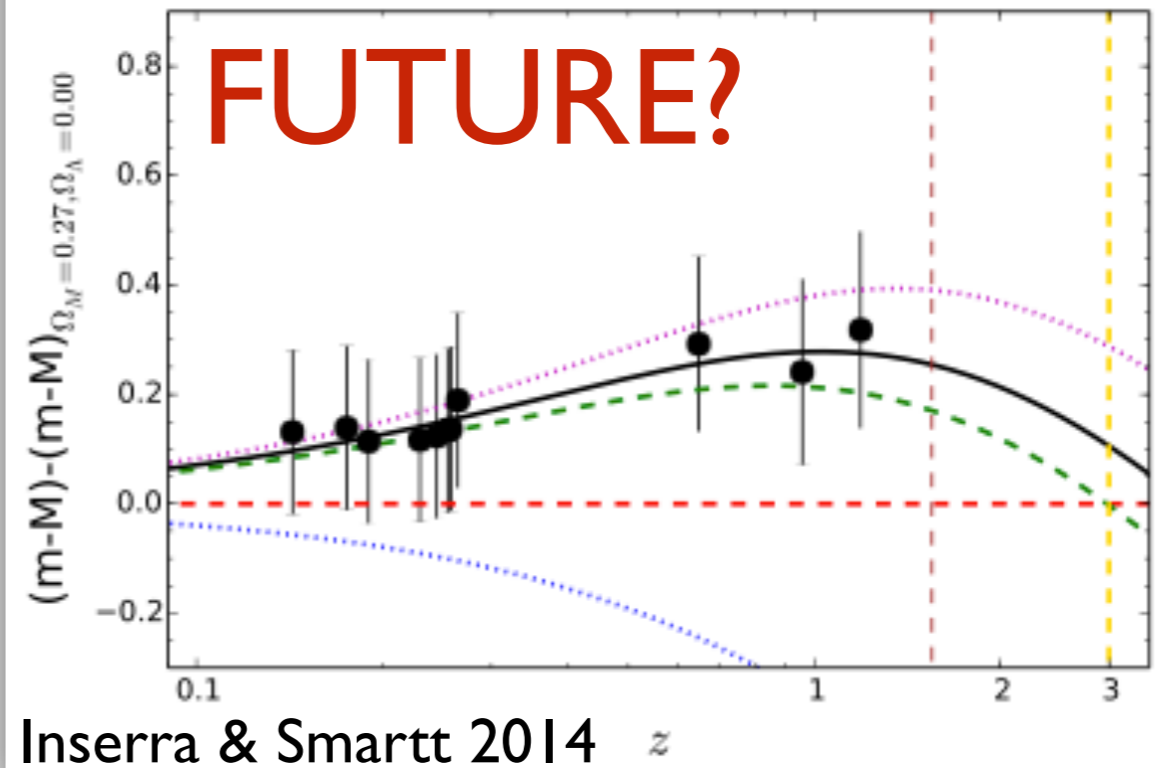
SLSNe - Standardisation?



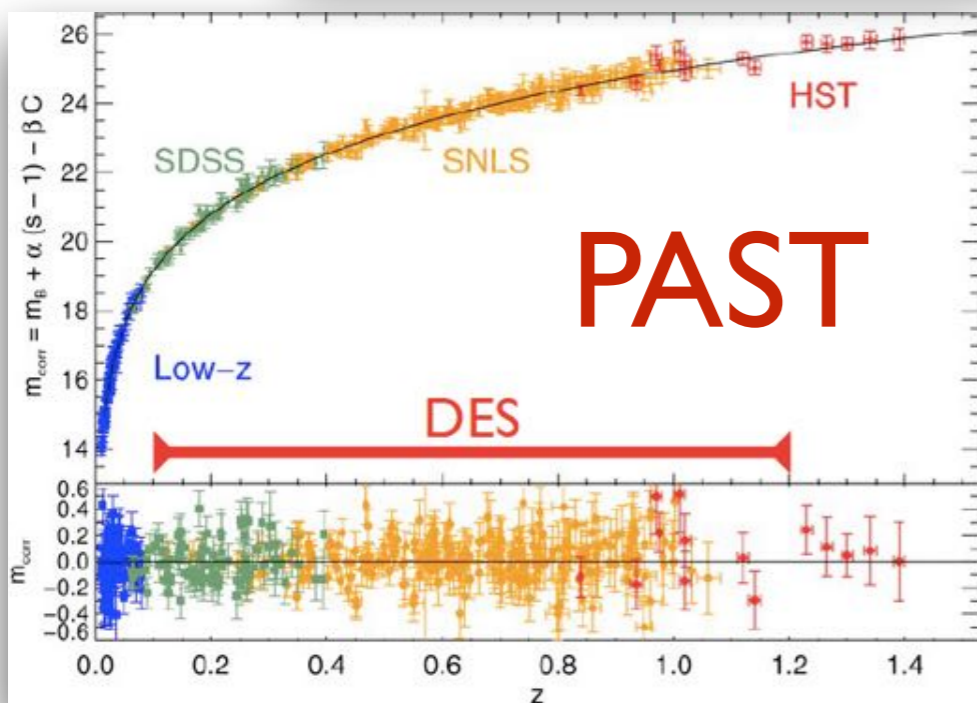
PRESENT



FUTURE?



Inserra & Smartt 2014



MACS J1149.6+2223

SN HFF14Ref (Refsdal)

HST HFF

ACS/WFC F606W+F814W

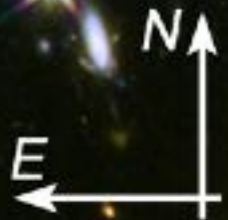
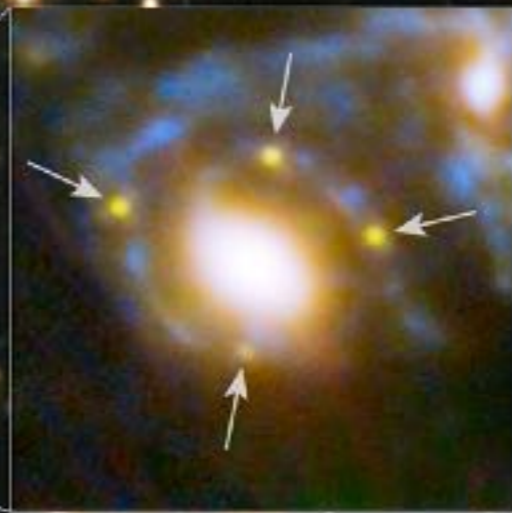
WFC3/IR F105W+F125W

WFC3/IR F140W+F160W

SN may have appeared
here in 1995

SN may appear here
in 2015-2020

Observed
in 2014



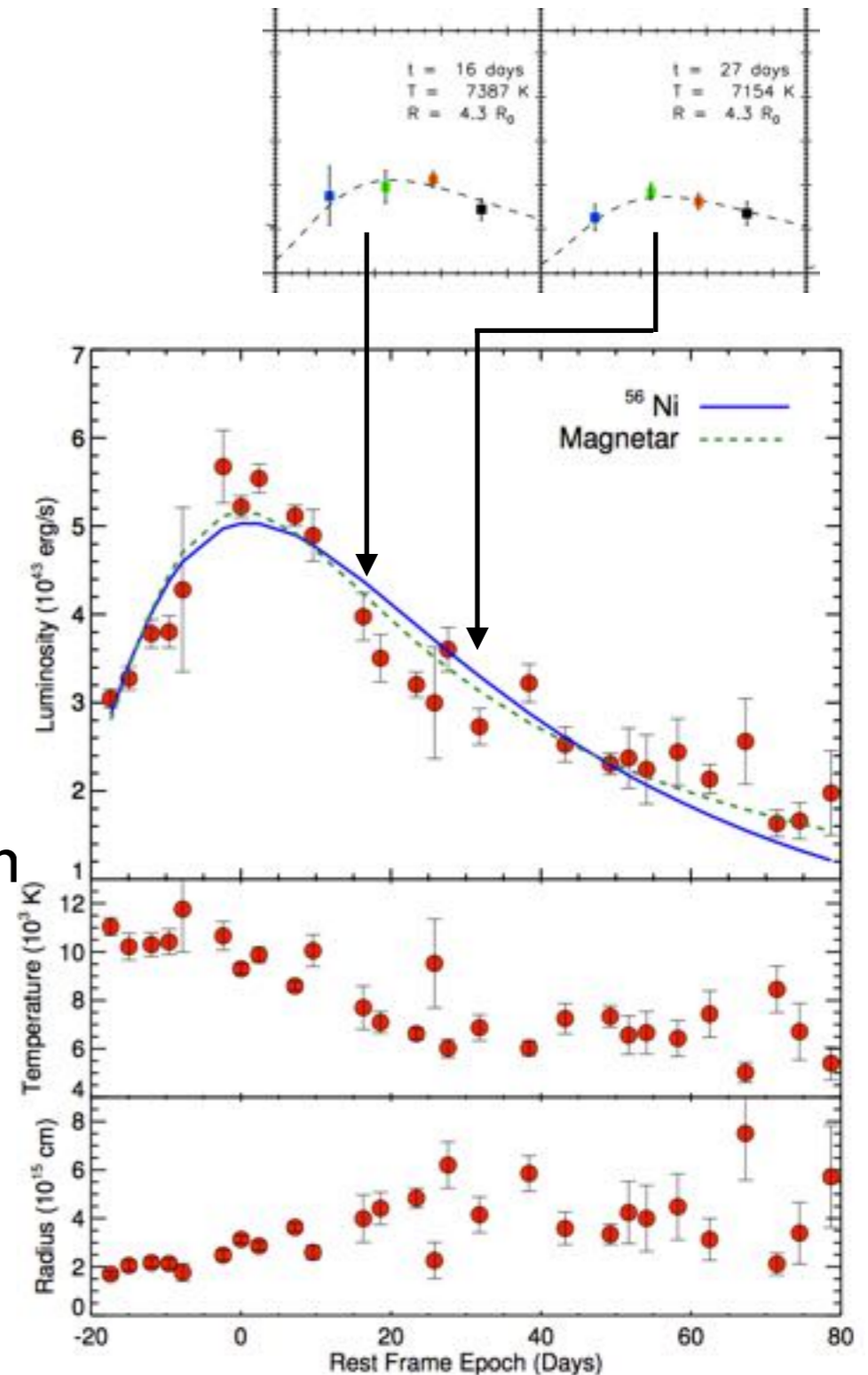
30''
46



DES I 3S2cmm: 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
 - $t_0, P_{ms}, B_{14}, \tau_m$





DES I 3S2cmm: Modelling

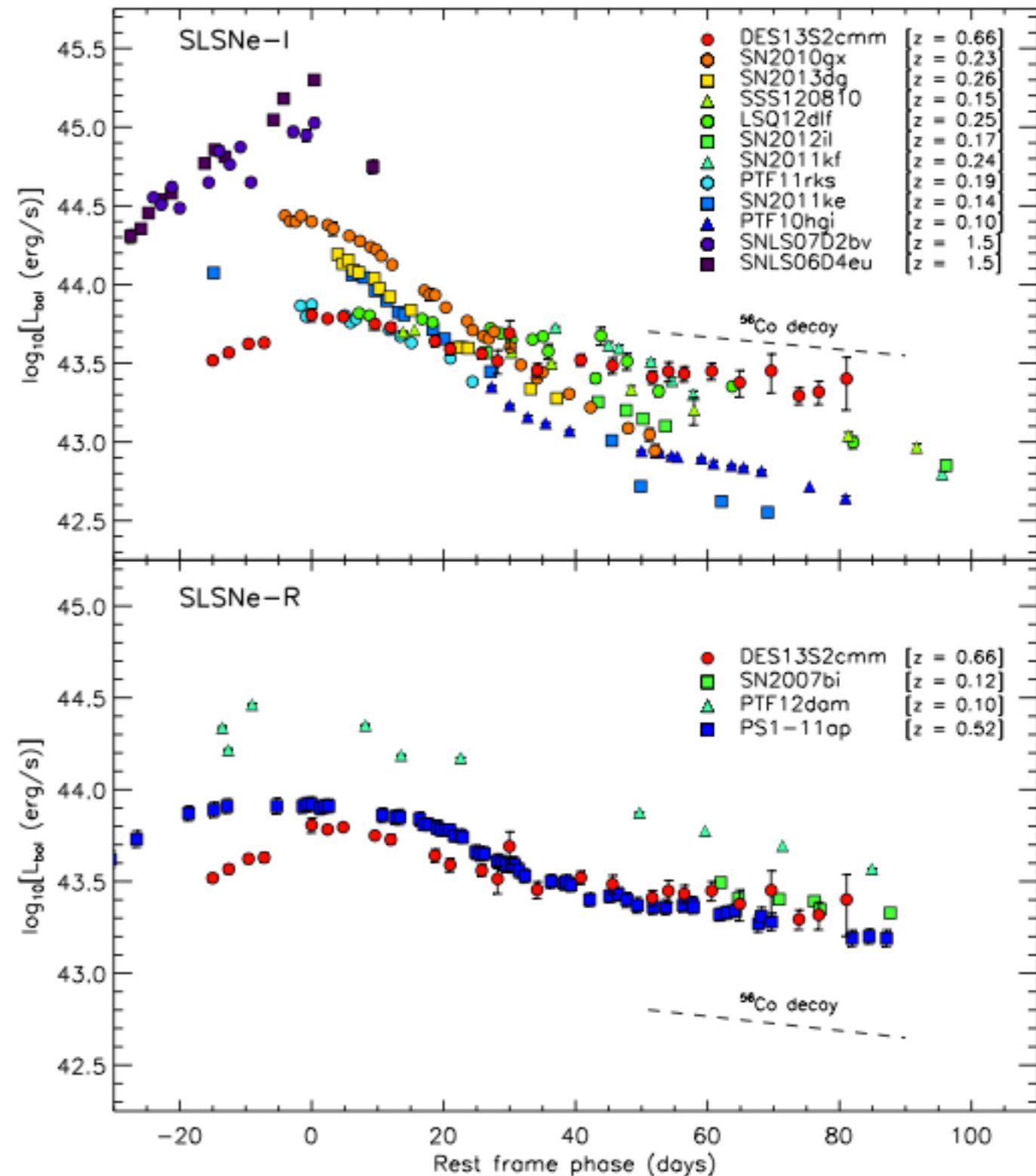
SLSNe-I:

- Pastorello et 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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