SUPERNOVAE THROUGH THE AGES

UNDERSTANDING THE PAST TO PREPARE FOR THE FUTURE

EASTER ISLAND 9–13 AUG 2016

www.sn2016.cl sn2016.loc@gmail.com

To celebrate the careers of Mark Phillips and Nicholas Suntzeff

TOPICS

- Past/current/future discovery and follow-up surveys
- Supernova science in the era of big data
- Supernova discovery and follow-up within hours of explosion
- Supernova cosmology
- Supernova hosts/environments and rates
- Supernova explosion models, progenitors, and their link to stellar evolution models
- Extreme/peculiar events
- The first supernovae

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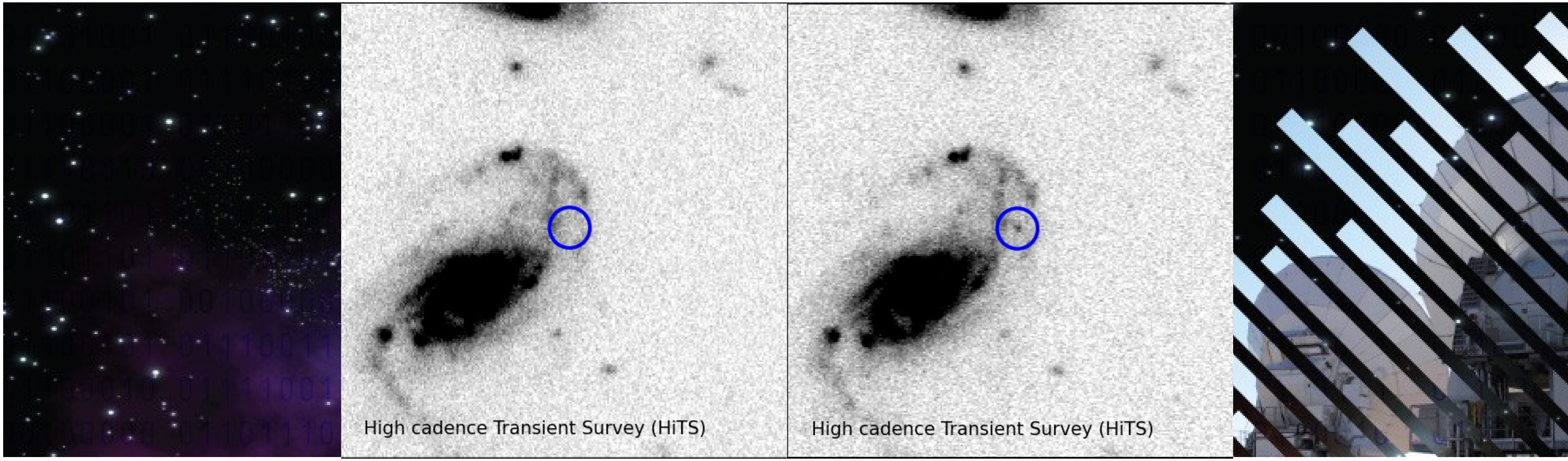
PHOTO CREDIT "Orion and Aldébaran rise above the Tongariki ahu Moais." © Stéphane Guisard, http://sguisard.astrosurf.com



HITS: The High cadence Transient Survey

F. Förster, J.C. Maureira, J. San Martín, M. Hamuy, P. Estévez, R.C. Smith, K. Vivas, P. Huijse, G. Cabrera, S. Flores, J. Littín, J. Anderson, F. Bufano, Ll. Galbany, Th. de Jaeger, S. González-Gaitán, G. Pignata, J. Martínez, G. Medina, R. Muñoz, E. Vera, C. Pérez

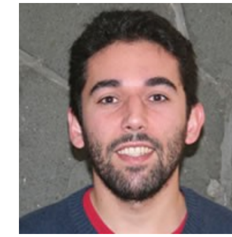
CMM Center for Mathematical Modeling

NLHPC National Laboratory for High Performance Computing Chile

MILLENNIUM INSTITUTE OF ASTROPHYSICS

CONICYT Ministerio de Educación Gobierno de Chile

The HITS team (PI: Förster)



- Search strategy

- Observations
- Data transfer

REUNA
CIENCIA Y EDUCACIÓN EN RED

- Image subtraction

- Feature design

- Classification

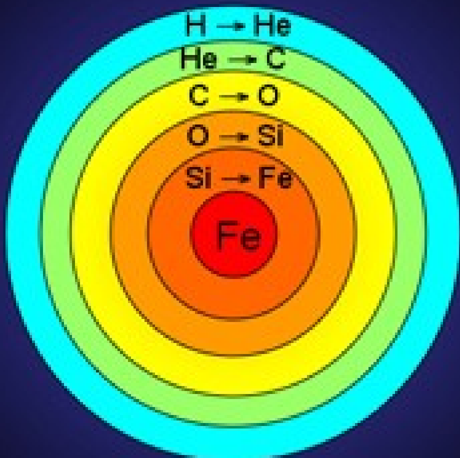
- HPC

Pessto

- Follow up

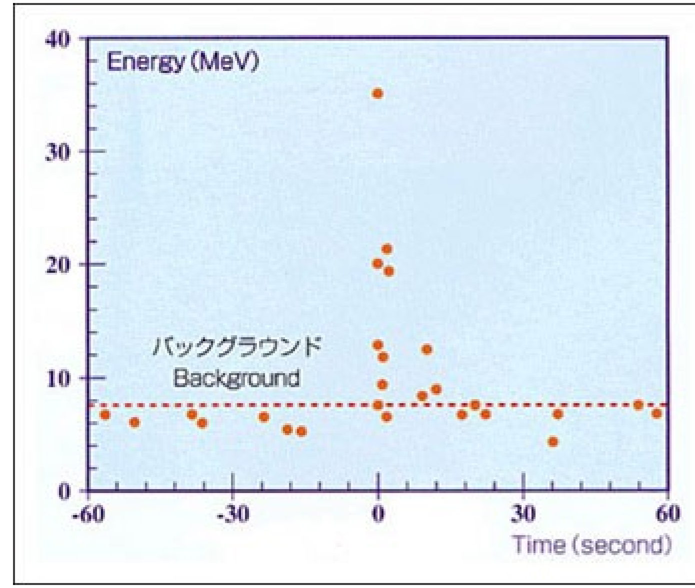
- Analysis

Life and death of a massive star

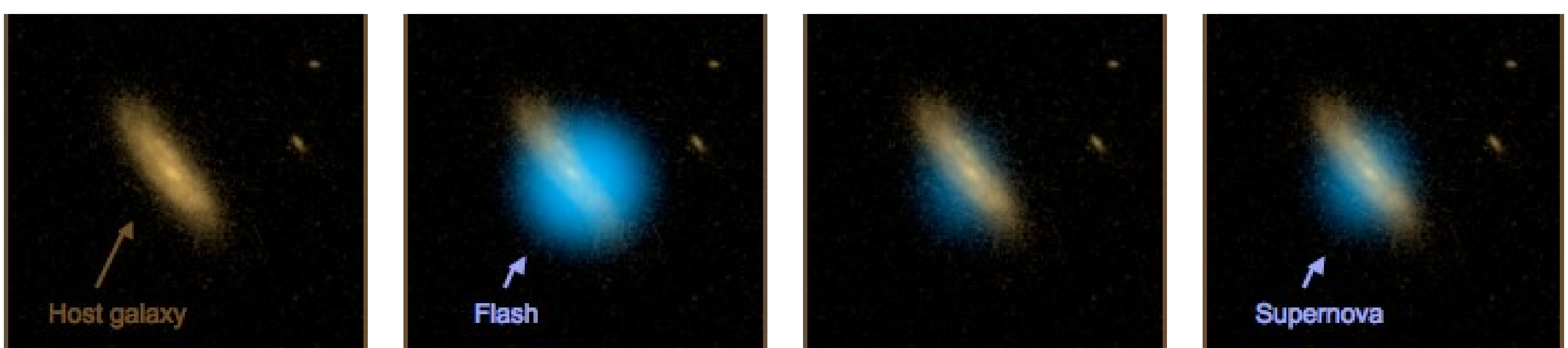


For a 25 solar mass star:

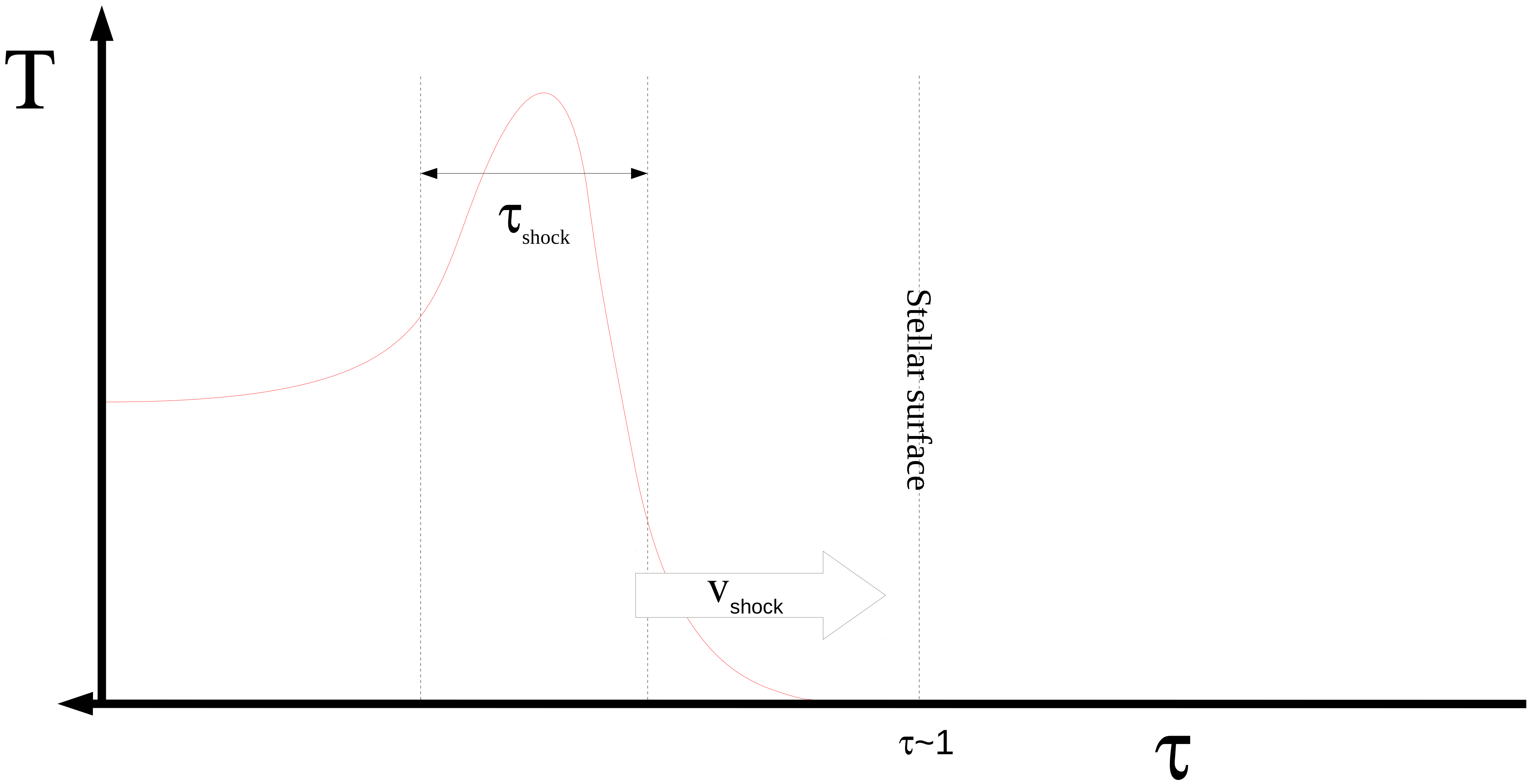
Stage	Duration
H → He	7×10^6 years
He → C	7×10^5 years
C → O	600 years
O → Si	6 months
Si → Fe	1 day
Core Collapse	1/4 second



Formation of a neutron star and shock formation (~sec)
Shock acceleration down density slope and emergence (~hrs) → Supernova shock breakout
Star disruption and free expansion (~day)
Fast expanding (~0.1 c), glowing ejecta (~weeks, months) → Main supernova light curve
Remnant diffusion into the interstellar medium (kyr)



Shock breakout



Shock breakout

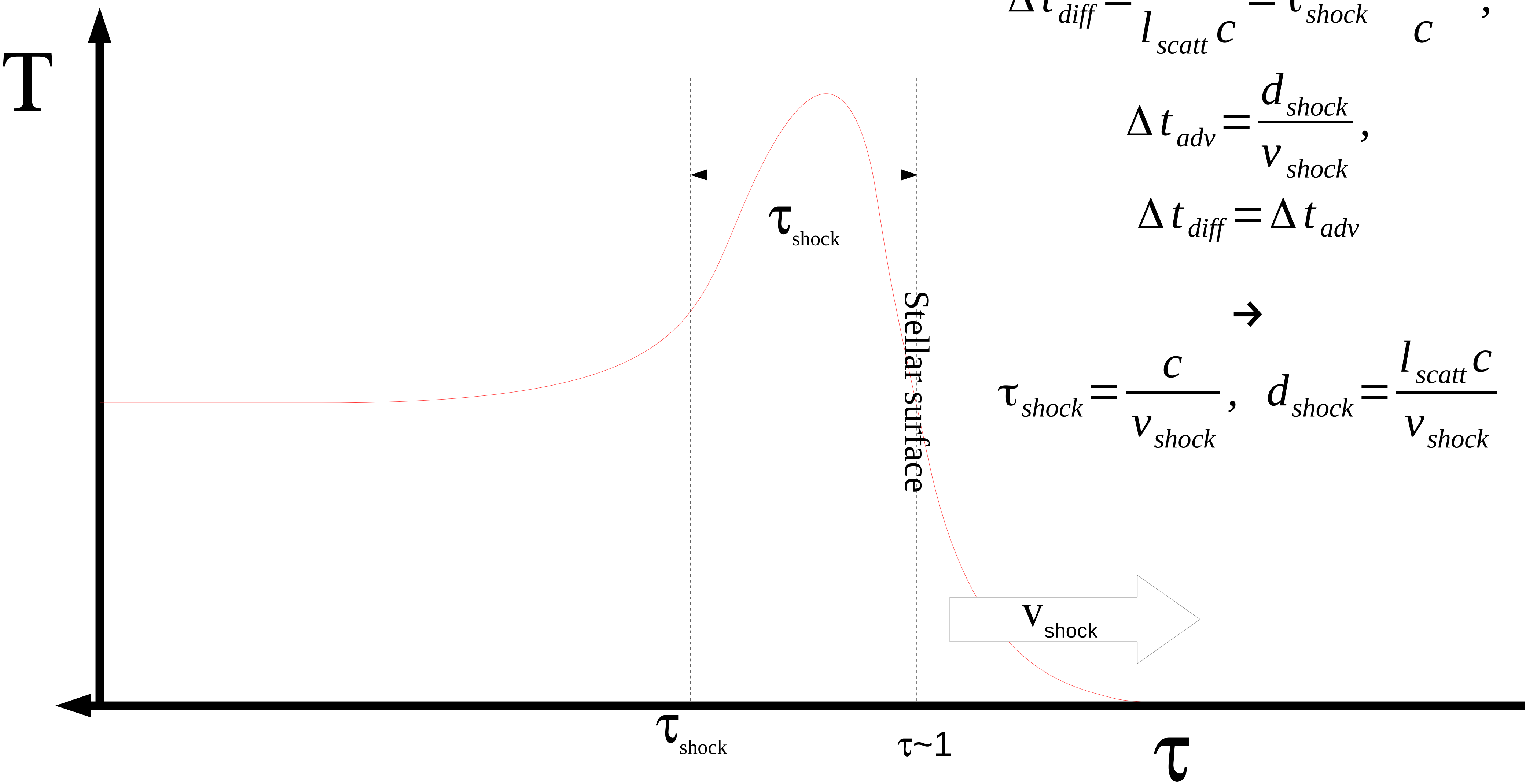
$$\Delta t_{diff} = \frac{d_{shock}^2}{l_{scatt}\, c} = \tau_{shock} \frac{d_{shock}}{c},$$

$$\Delta t_{adv} = \frac{d_{shock}}{v_{shock}},$$

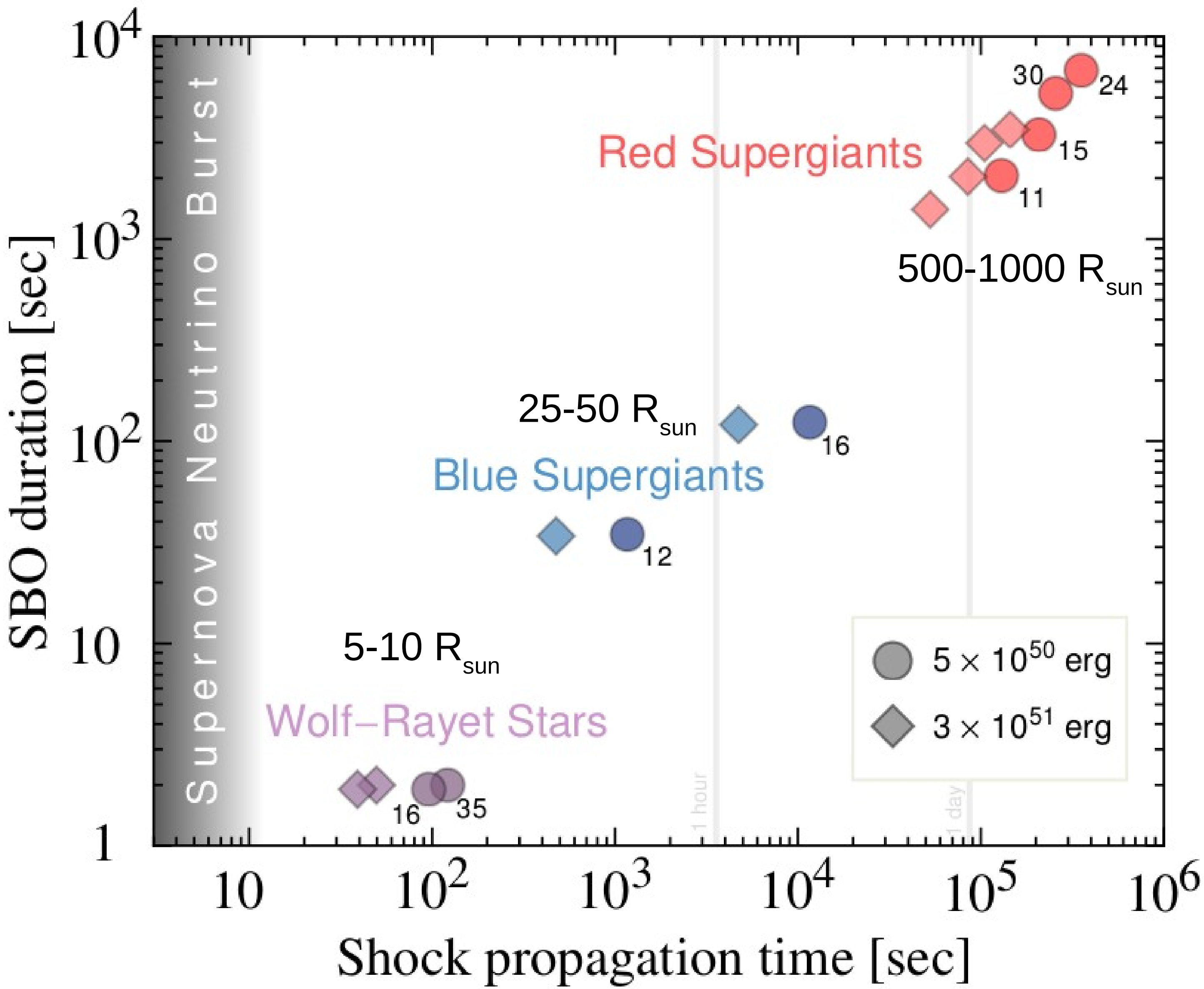
$$\Delta t_{diff} = \Delta t_{adv}$$

$$\rightarrow$$

$$\tau_{shock} = \frac{c}{v_{shock}}, \quad d_{shock} = \frac{l_{scatt}\, c}{v_{shock}}$$

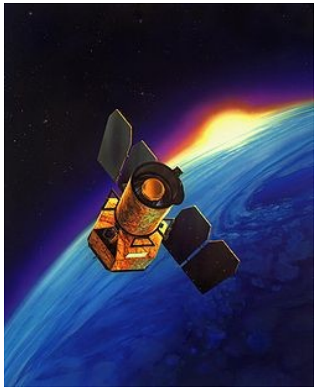


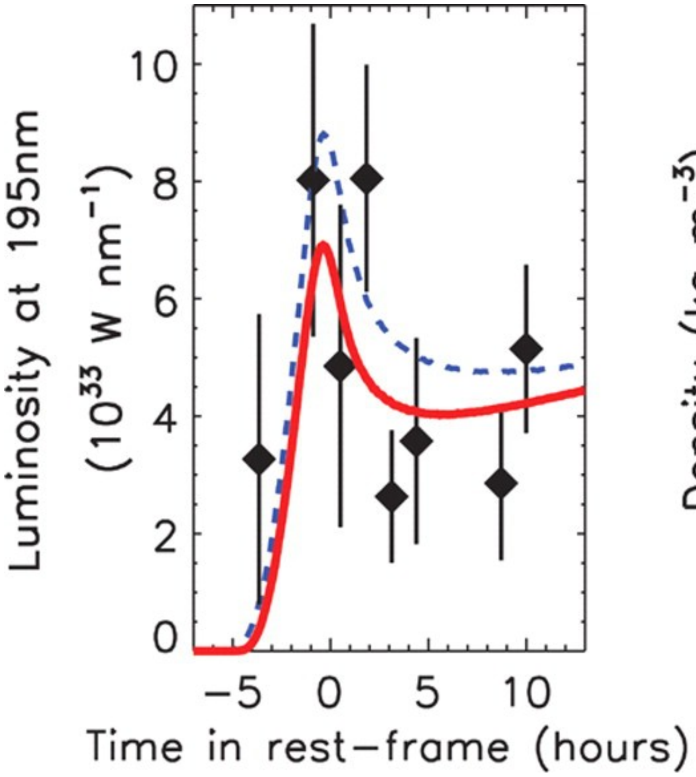
Supernova shock breakout (SBO) timescales

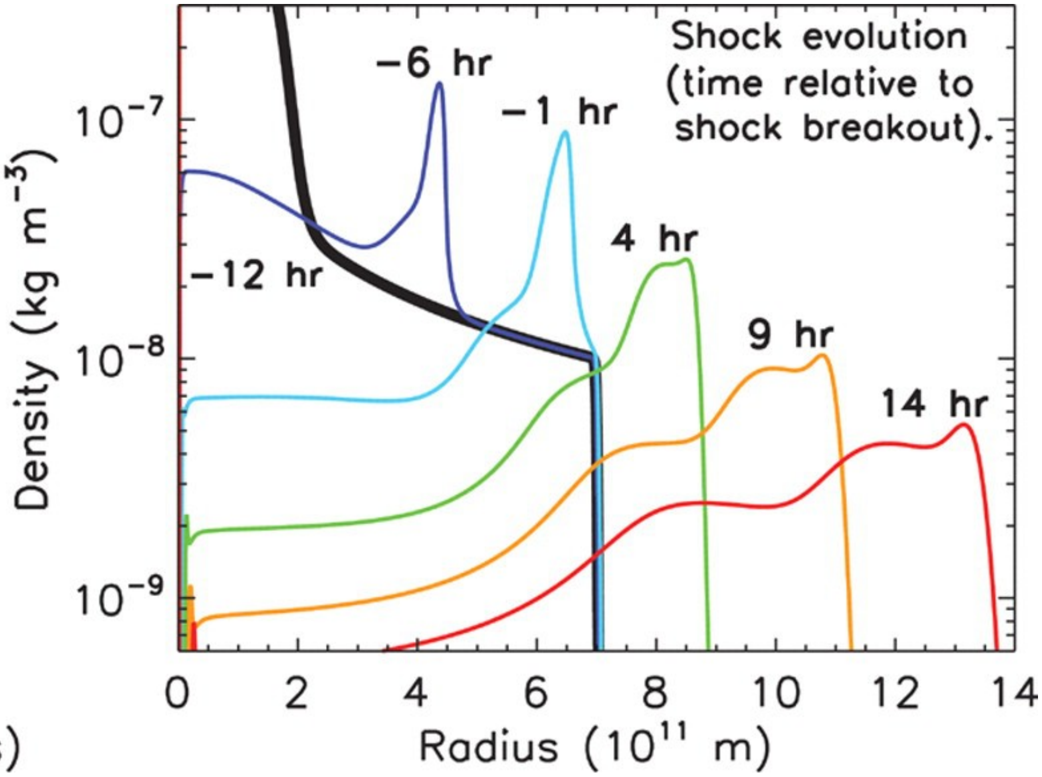


Kistler, Haxton & Yüksel 2014

Red supergiant SBO







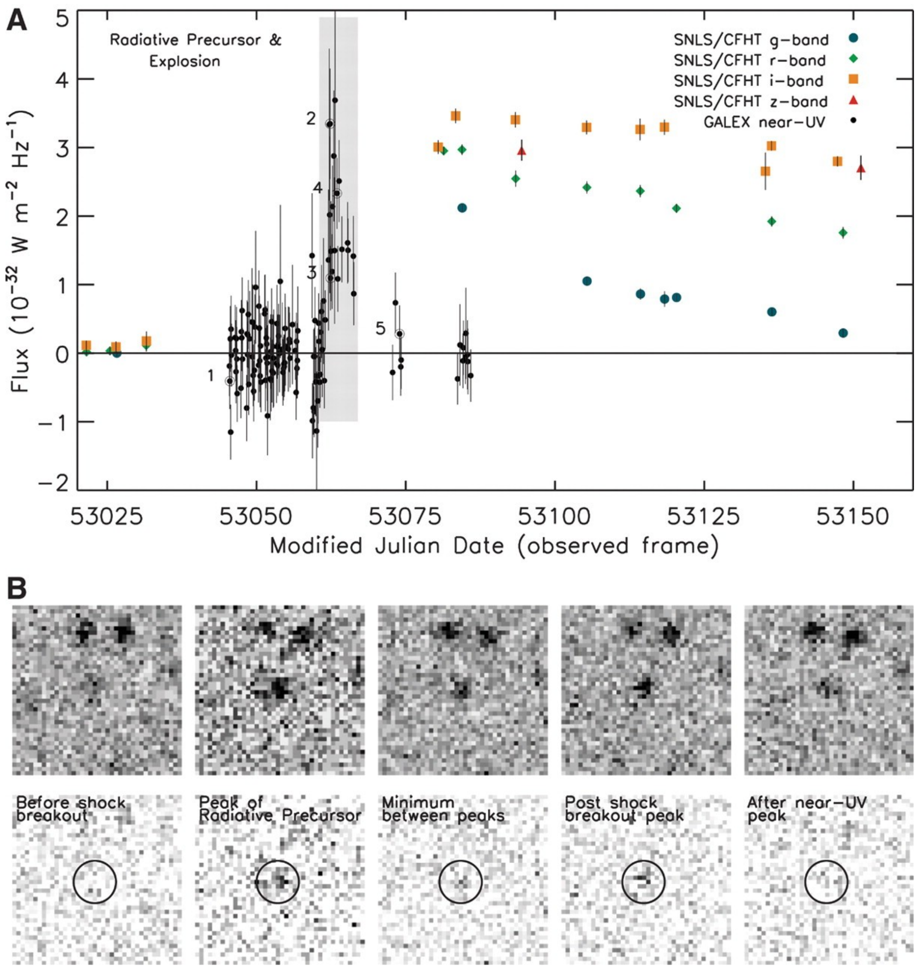
Schawinski et al. 2008 (Science)

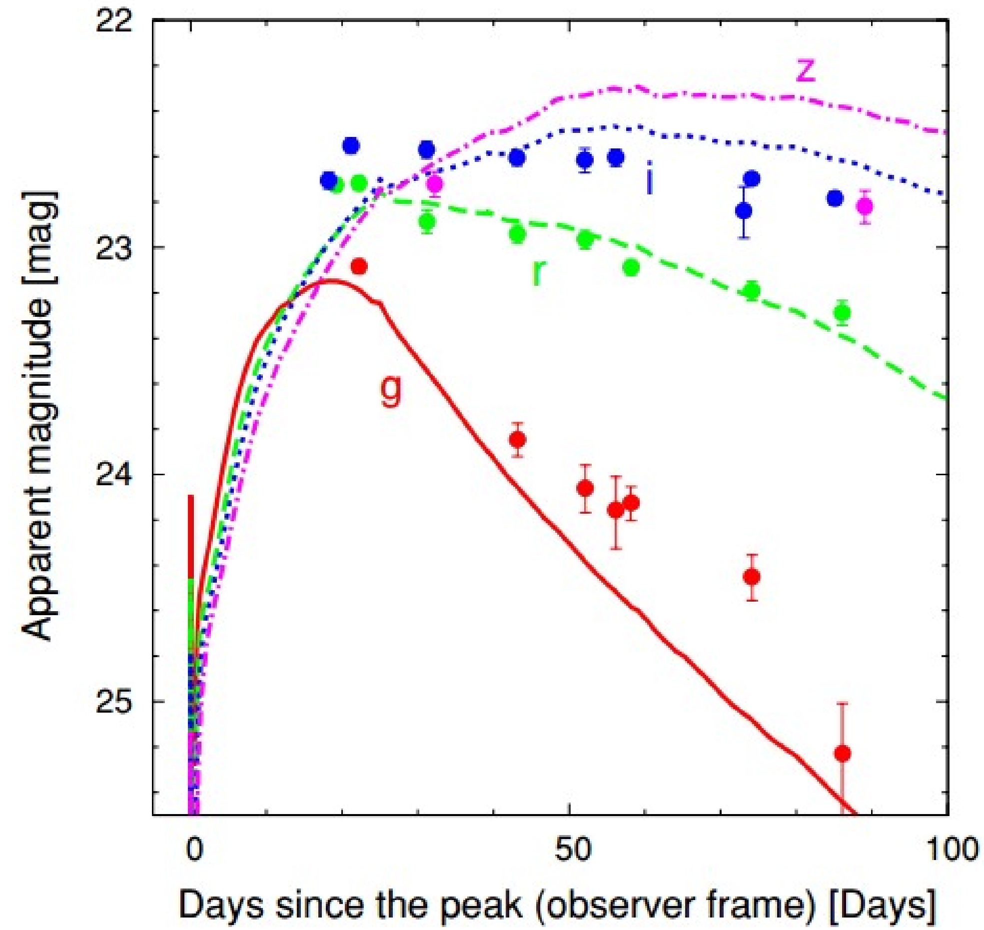
High energy (10^{48} erg) – Low temperature (~ 10 eV) burst → extended progenitor

Light curve and spectra consistent with SN IIP

Long duration (~ hr) consistent with red supergiant star

Red supergiant SBO



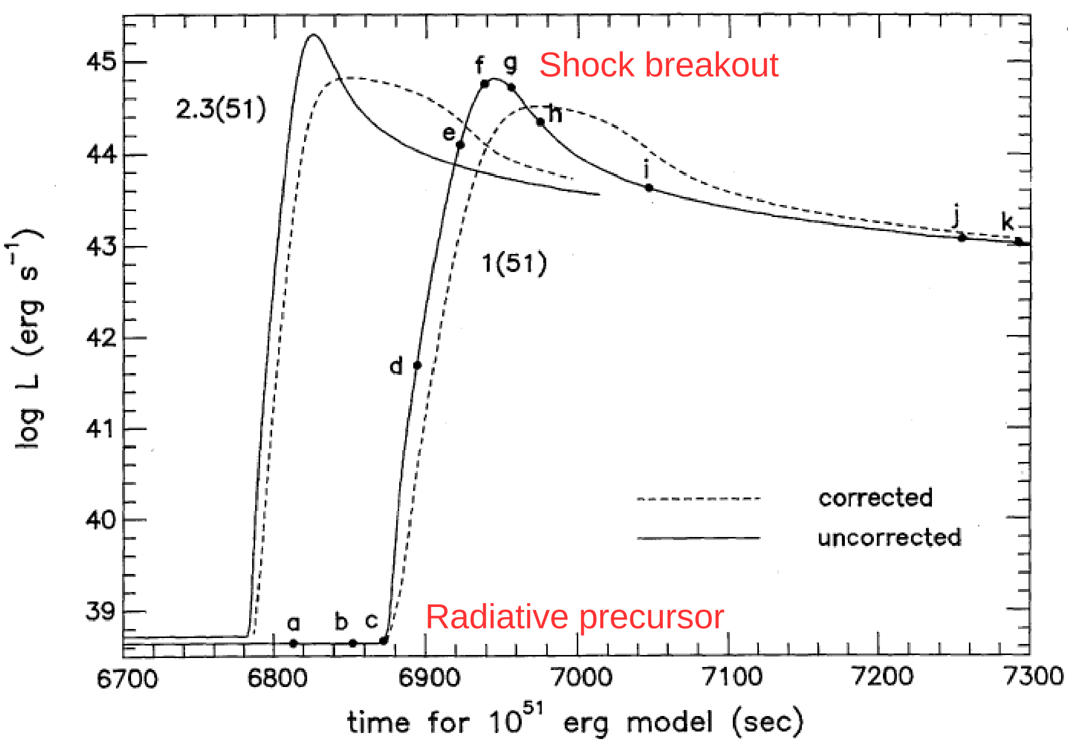


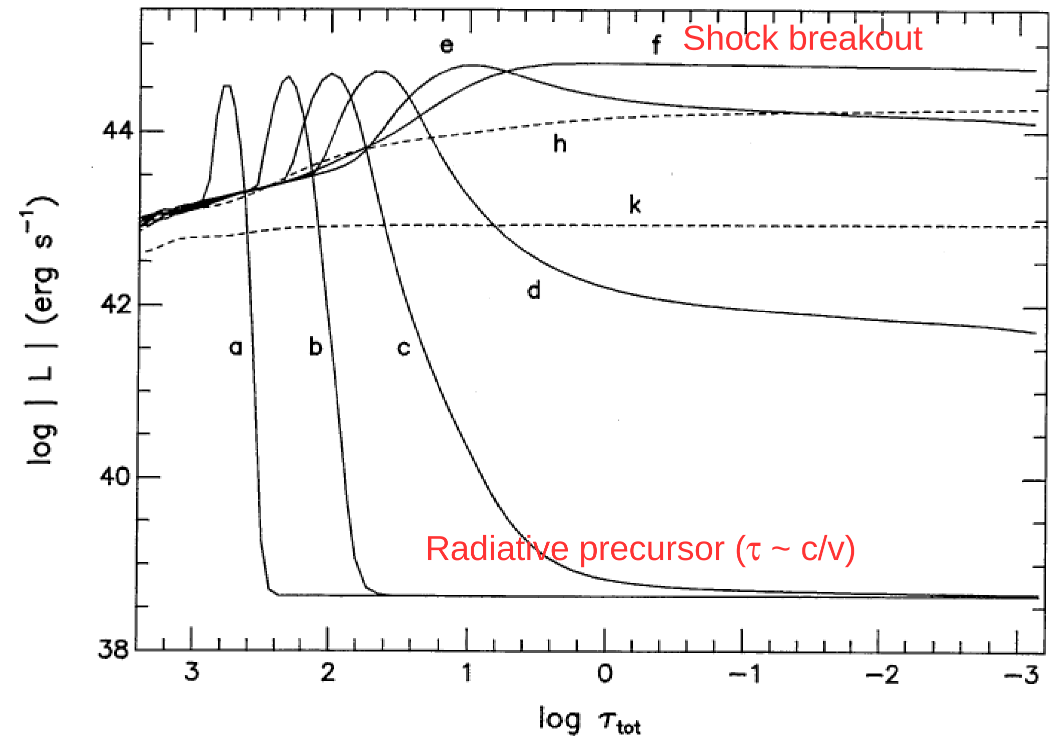
Schawinski et al. 2008, Science
Gezari et al. 2008, ApJ

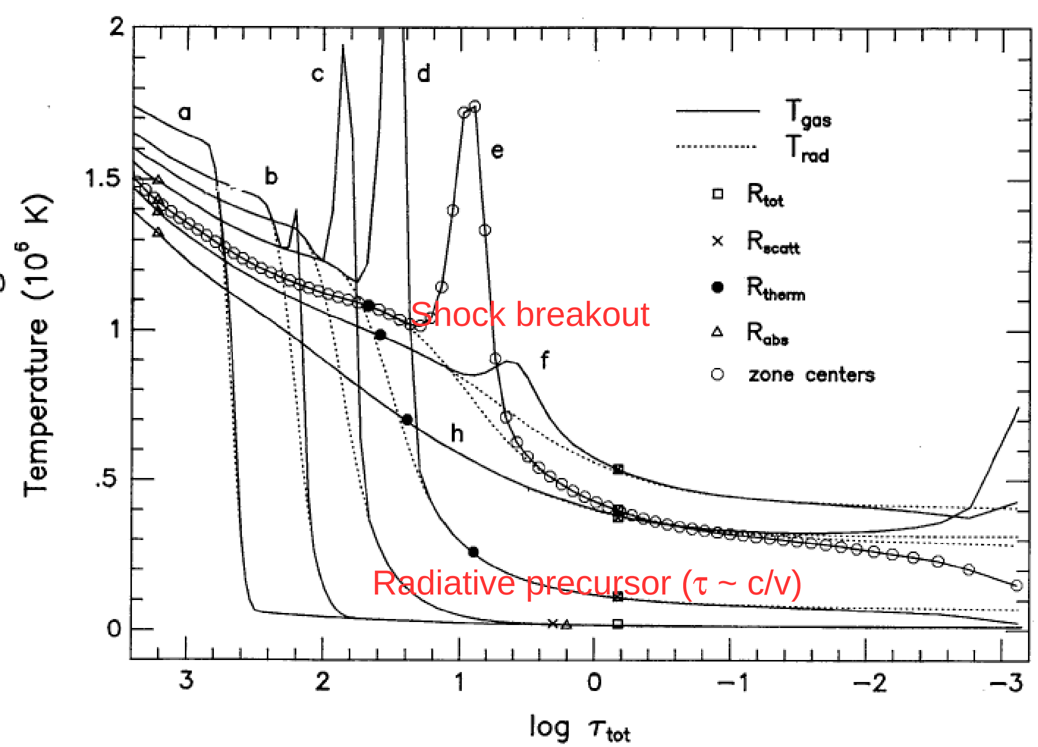
Tominaga et al. 2009, ApJ

M_{ZAMS} = 20 M_{Sun}, M_{preSN} = 18.4 M_{Sun}, and R_{preSN} = 800 R_{Sun}, E = 1.2×10^{51} erg.

Blue supergiant SBO (model for SN 1987A)



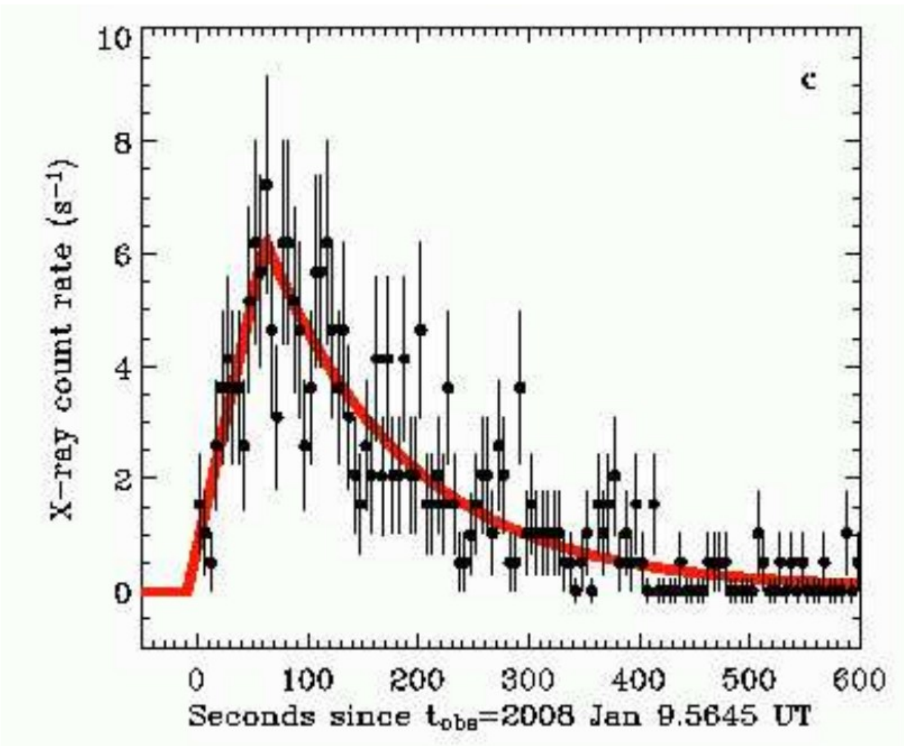


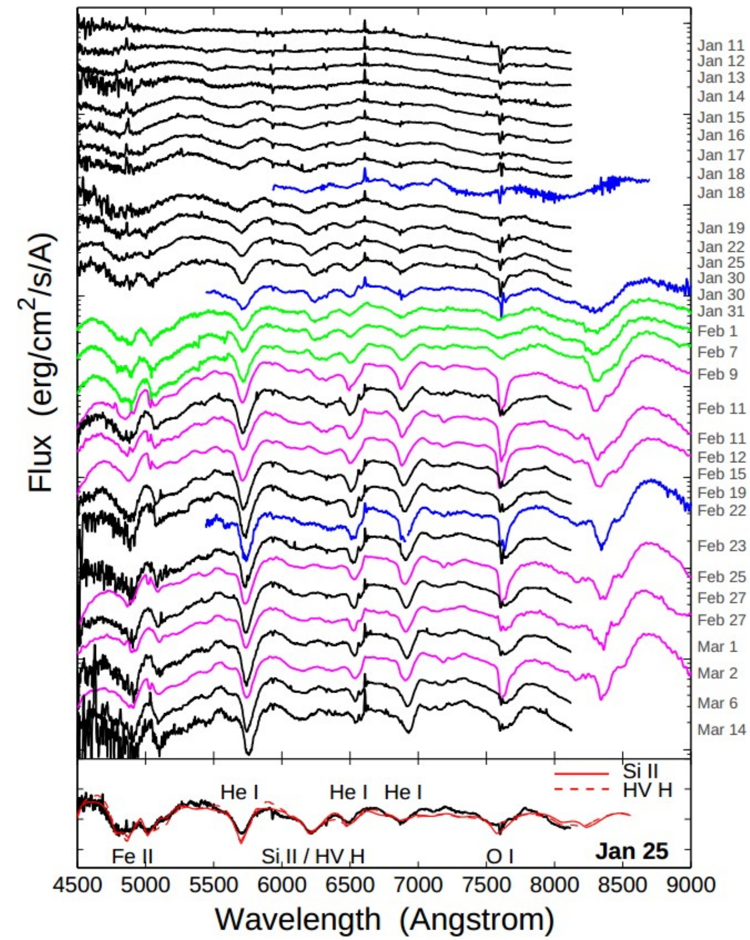


Ensman & Burrows 1992 ApJ

16.3 M_{sun} (ejecta), 46 R_{sun}, 10^{51} erg

Wolf Rayet SBO (SN 2008D)





Soderberg et al. 2008 (Nature)

Low energy (10^{46} erg) – High temperature (~ 5 keV) burst → compact progenitor

Spectra consistent with SN Ic spectra

Duration may be too long (~100 sec) for expected progenitor size → wind breakout?

Type Ia Supernova

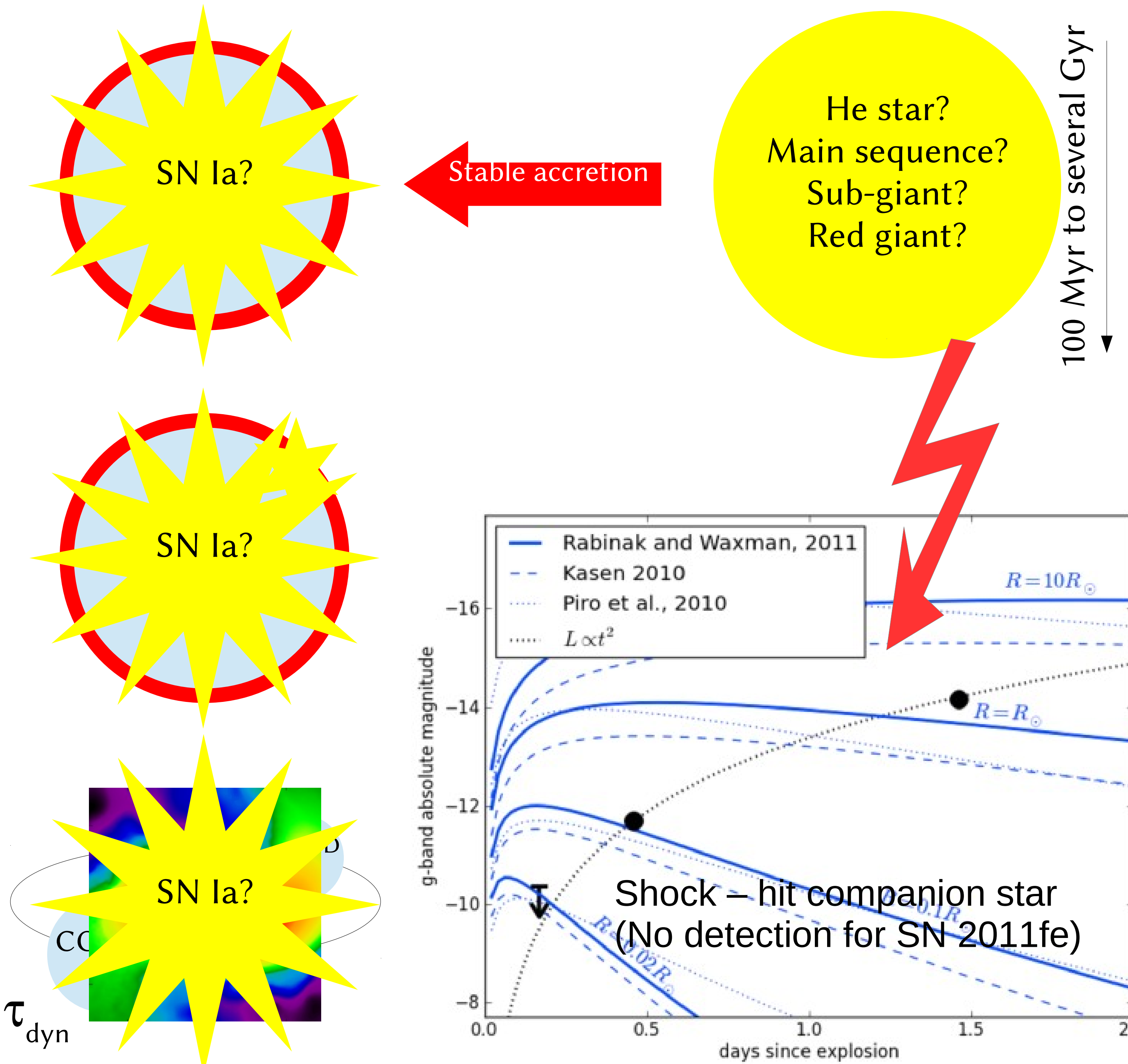
1. Single degenerate, Chandrasekhar mass (SD – M_{Ch})

M ⩽ MCh

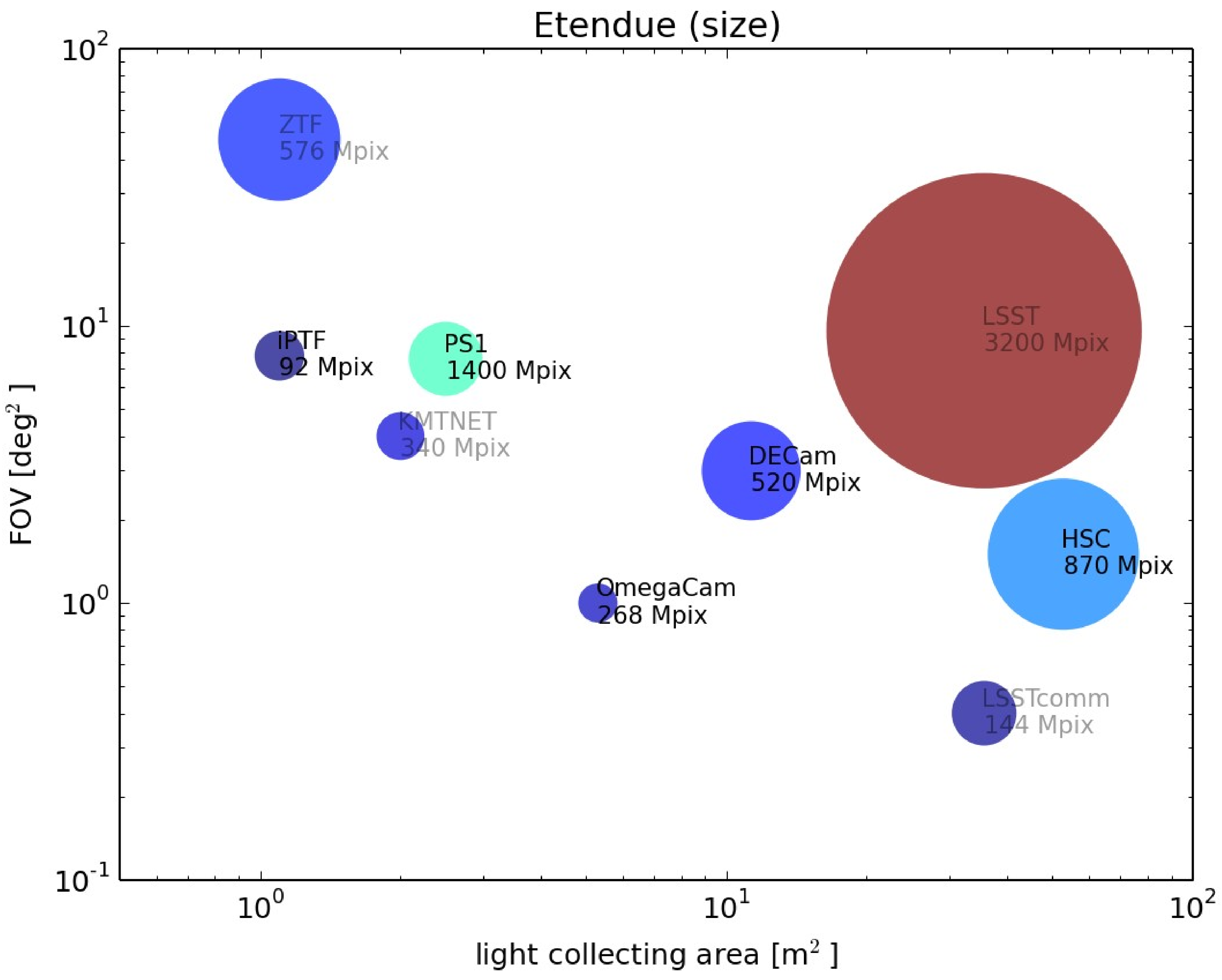
2. Single degenerate, sub-Chandrasekhar mass (SD – sub M_{Ch})

M < MCh

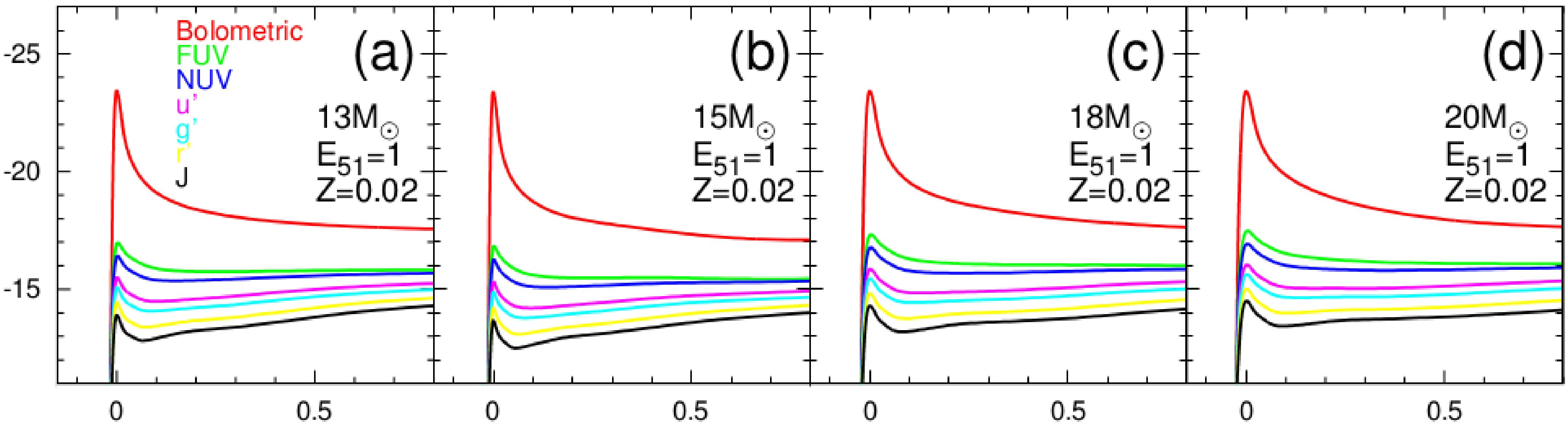
3. Double degenerate merger (violent or slow DD mergers)



Etendue and number of pixels

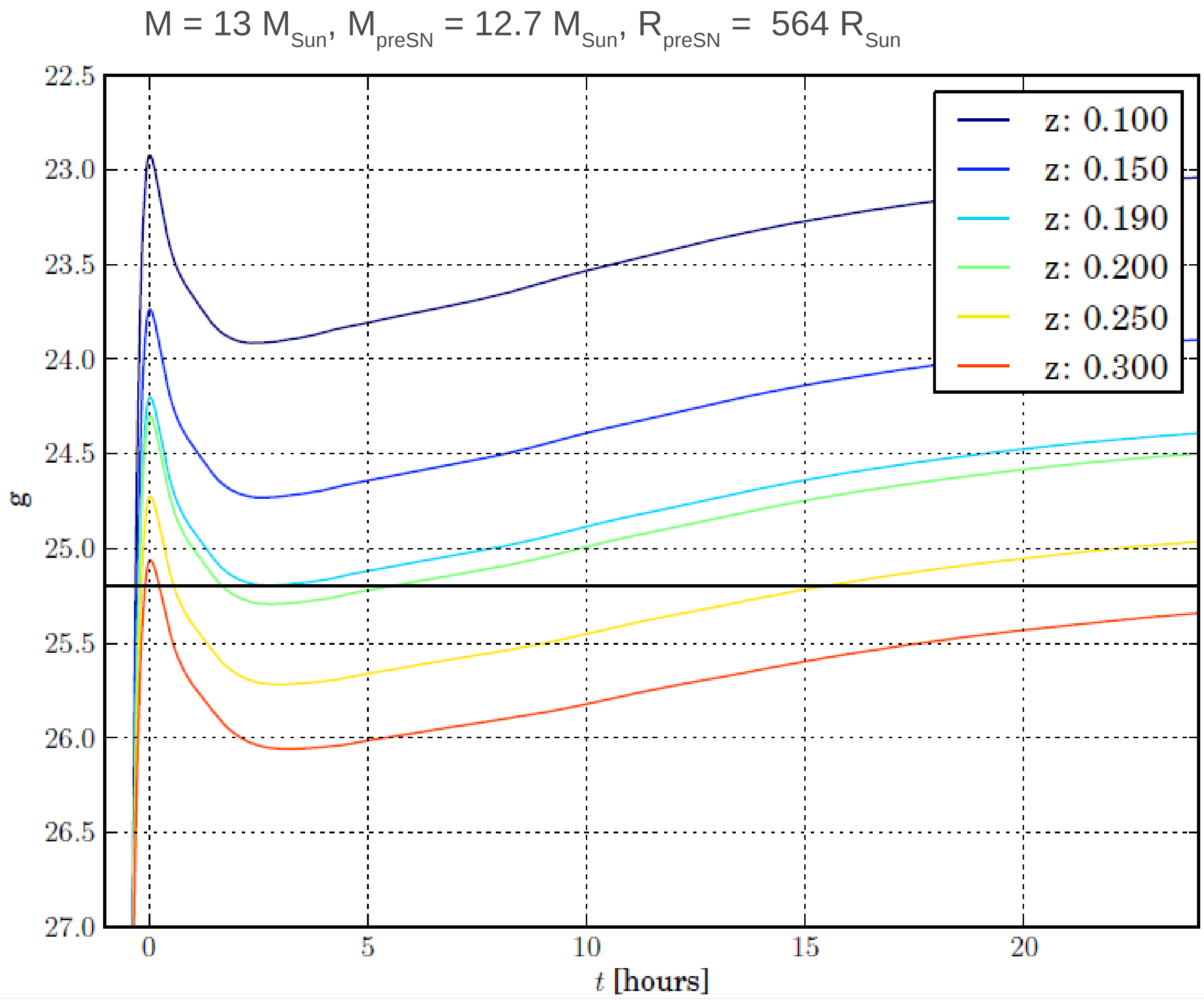


SBO multicolor light curves



Tominaga et al. 2011, ApJ

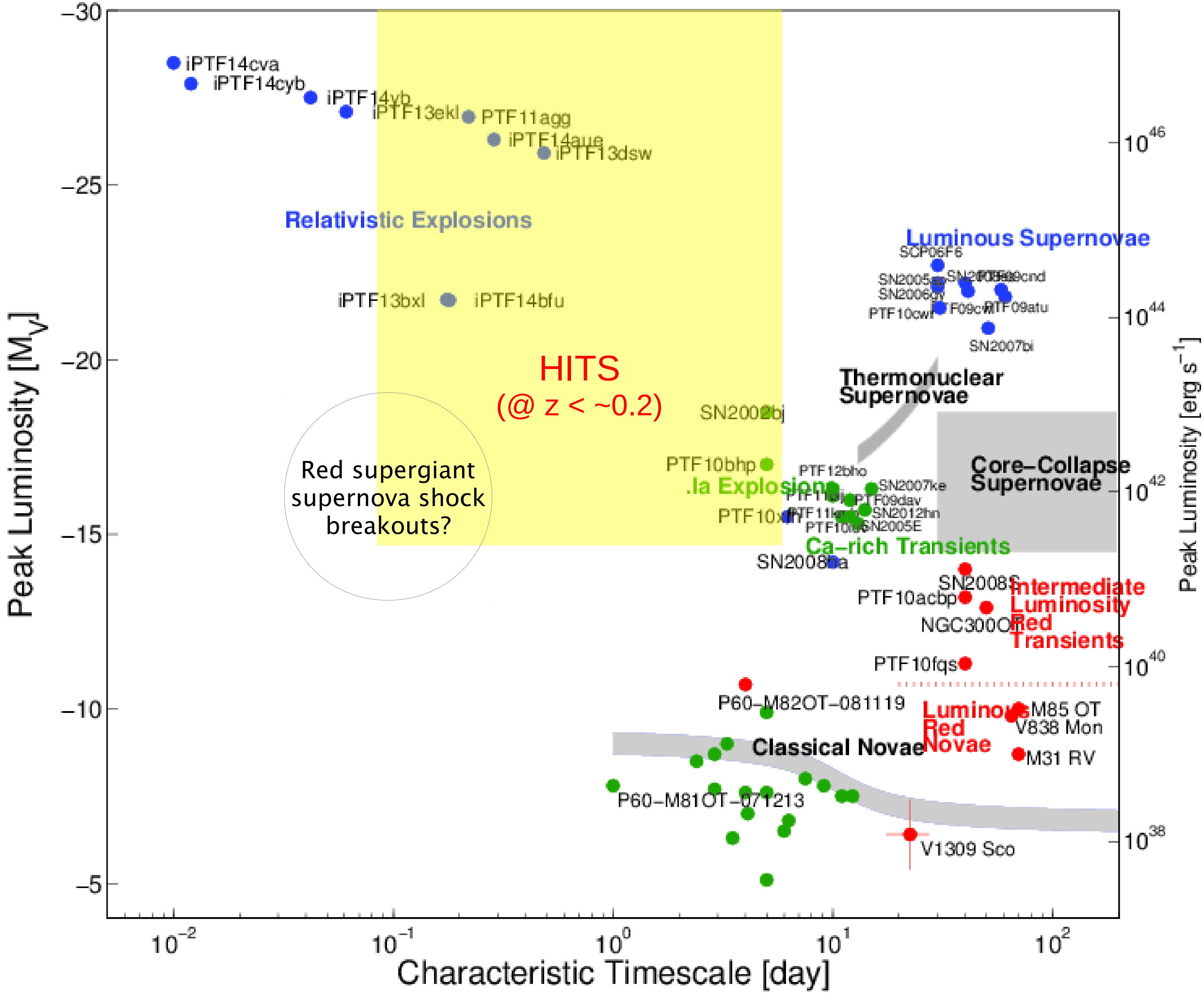
Supernova shock breakouts with DECam



N. Tominaga

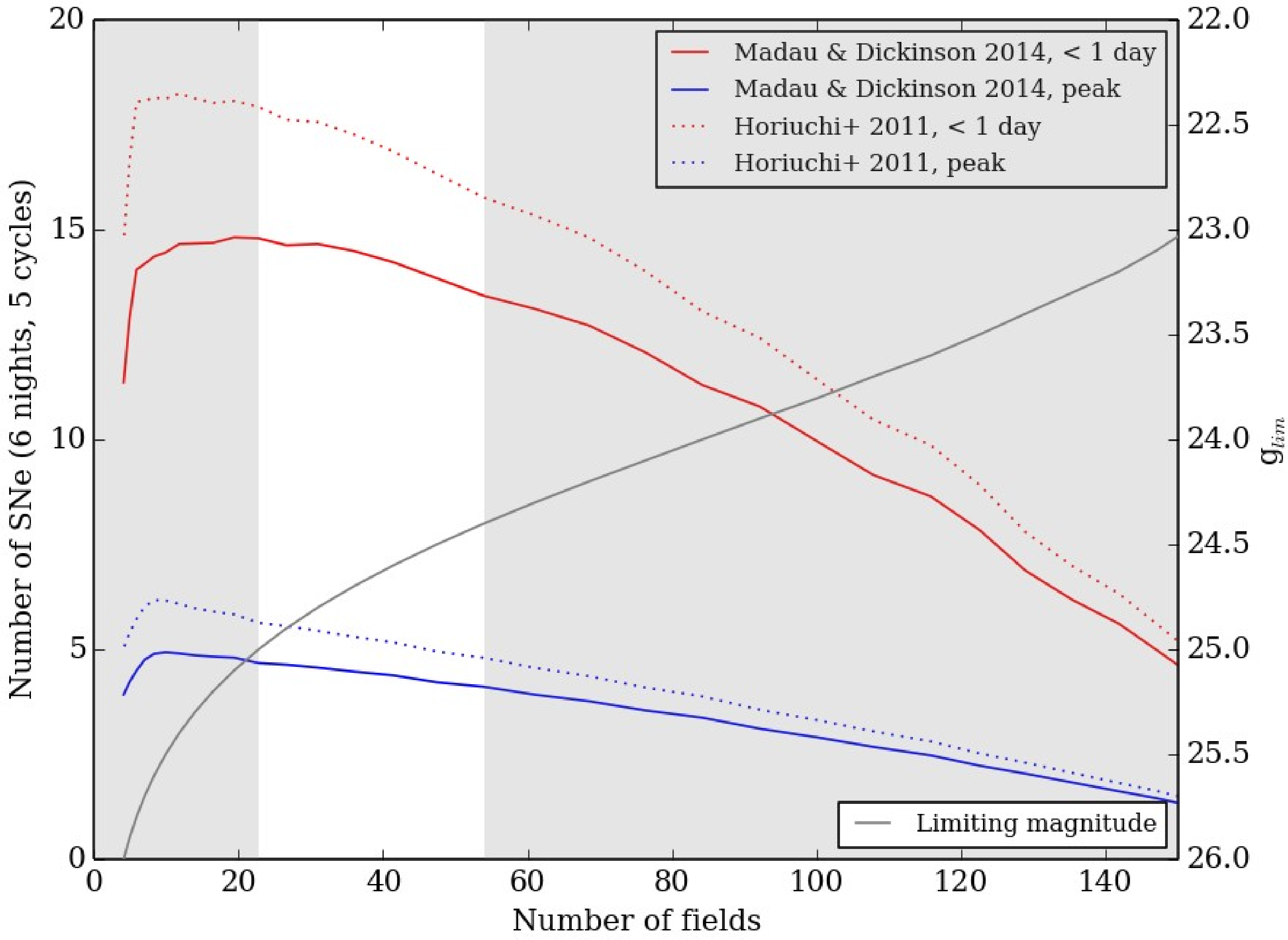
M. Hamuy

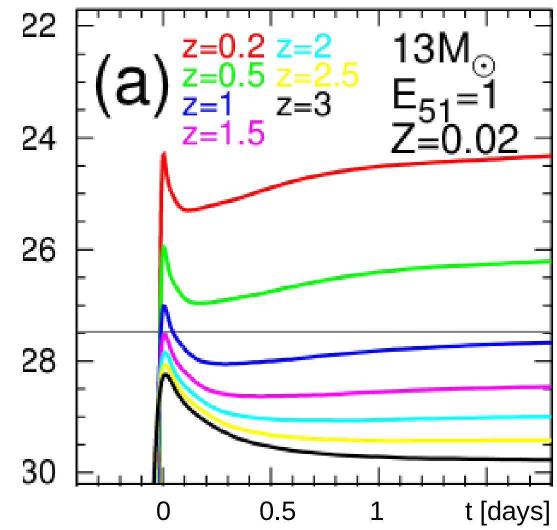
Optical transient sky



Credit: Mansi Kasliwal

Expected number of young supernovae (SNR ~ 8)





Tominaga et al. 2011

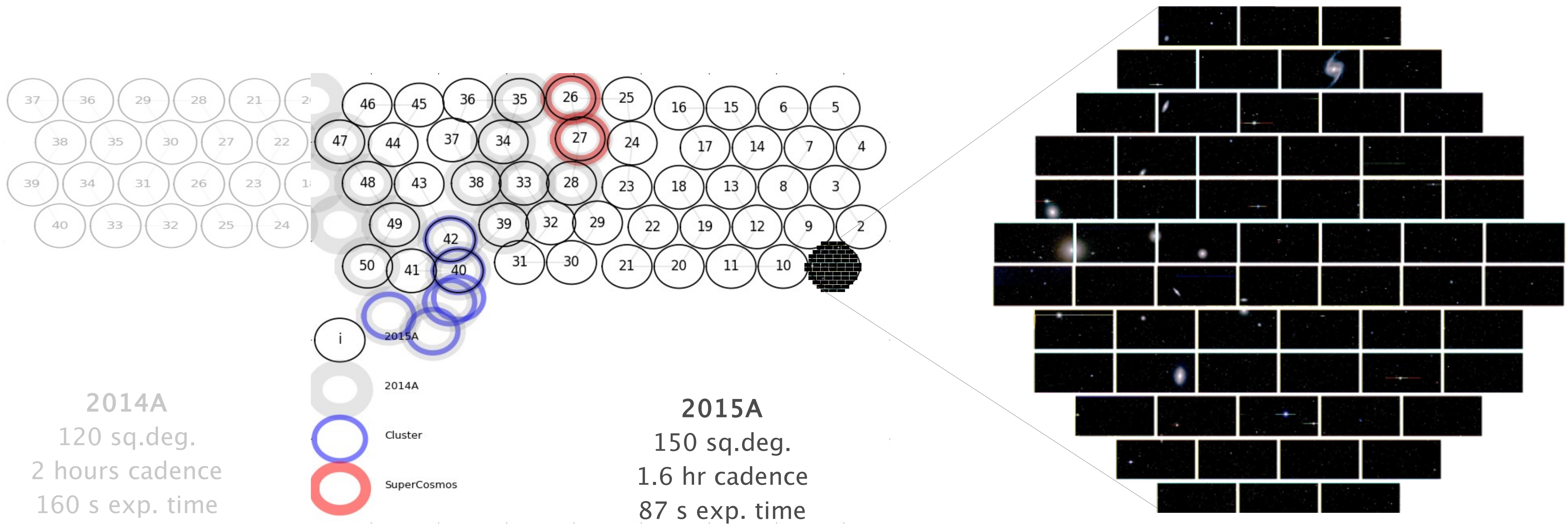
Using ETC v5!

More difficult to follow up ←

Faster file transfer/pipeline required

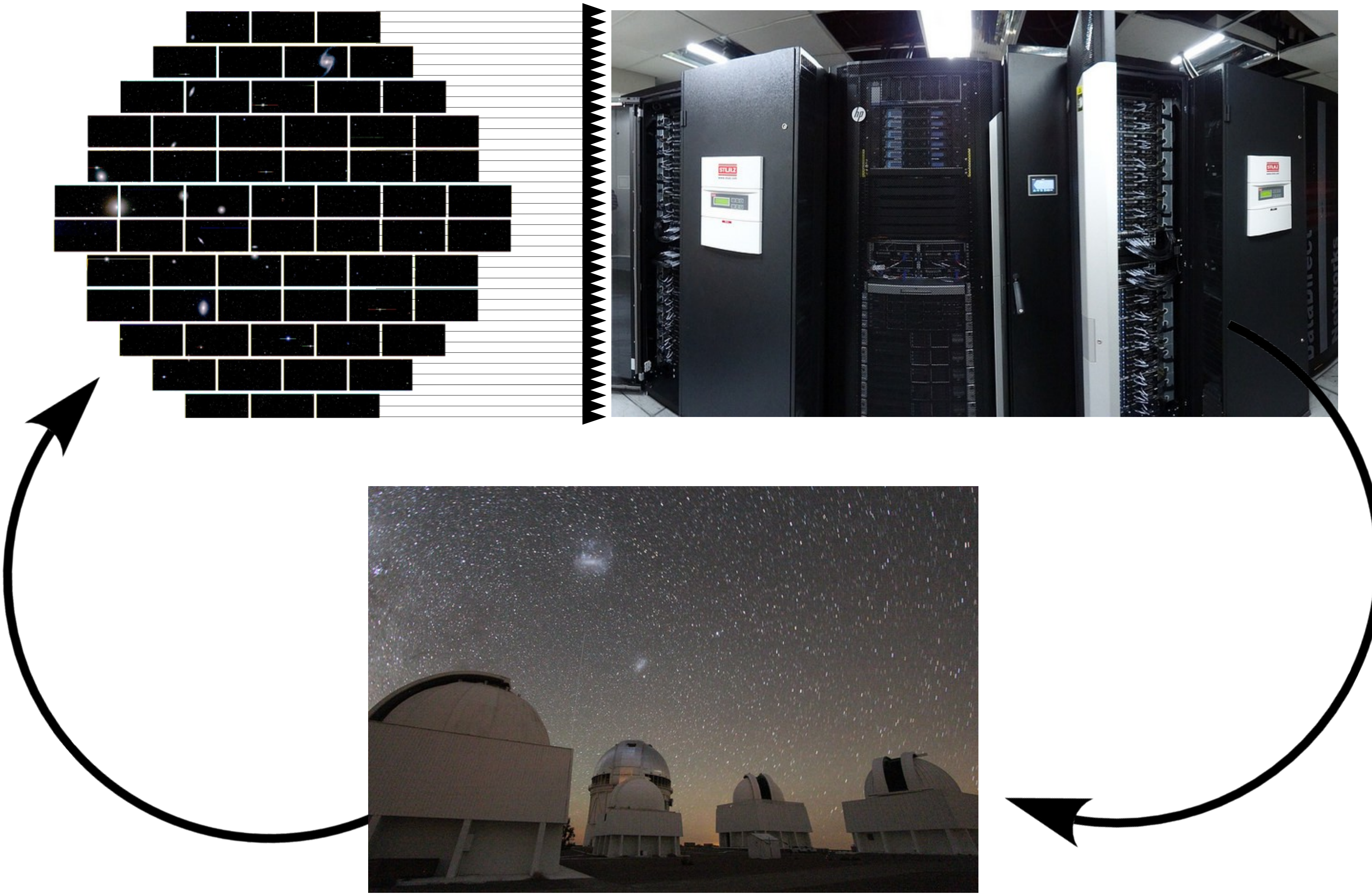
→ larger overhead fraction

HITS challenges (2014A/2015A)

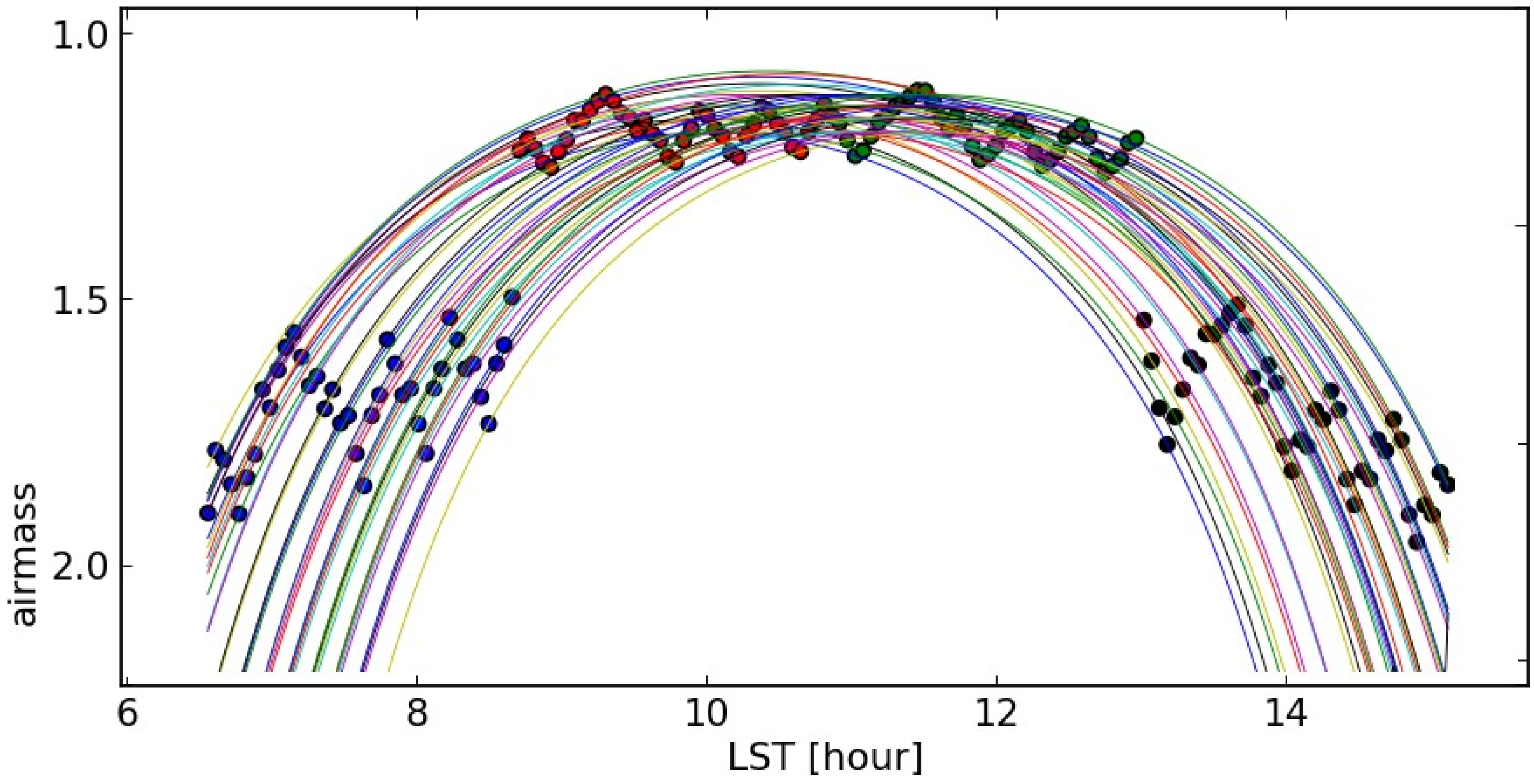


- Observe 40/50 DECam fields every 2/1.6 hr for 5/6 consecutive nights (Done)
- CTIO → La Serena → CMM file transfer faster than one exposure time (Done)
- Run preprocessing pipeline in 60 CCDs in less than one exposure time (Done)
- Run image subtraction pipeline in 60 CCDs in less than one exposure time (Done)
- Filter false positives keeping efficiency high in real–time (Done)
- Trigger follow up observations in real time (1 day/3.2 hr reaction possible)

Real time processing



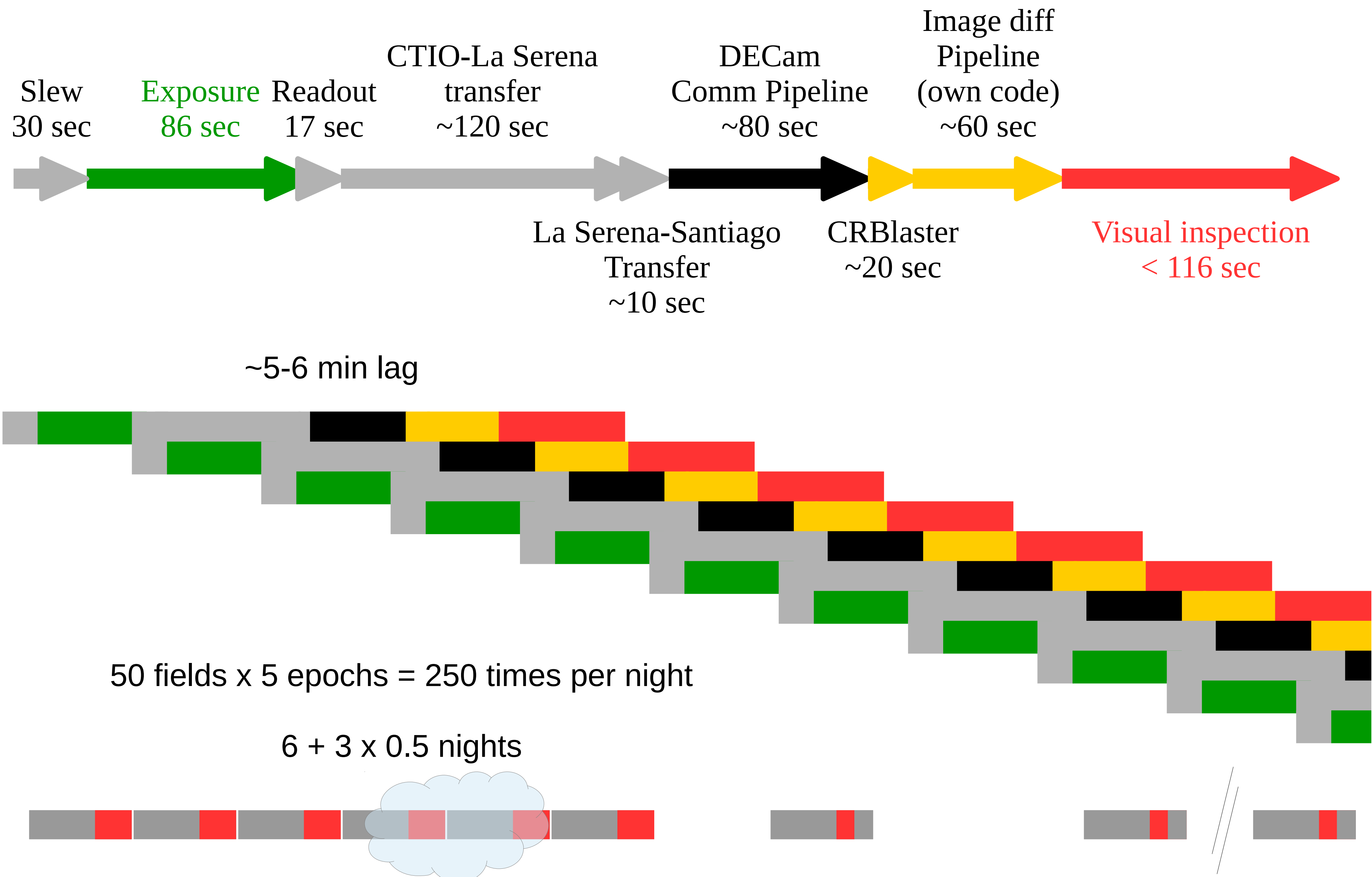
Observing strategy



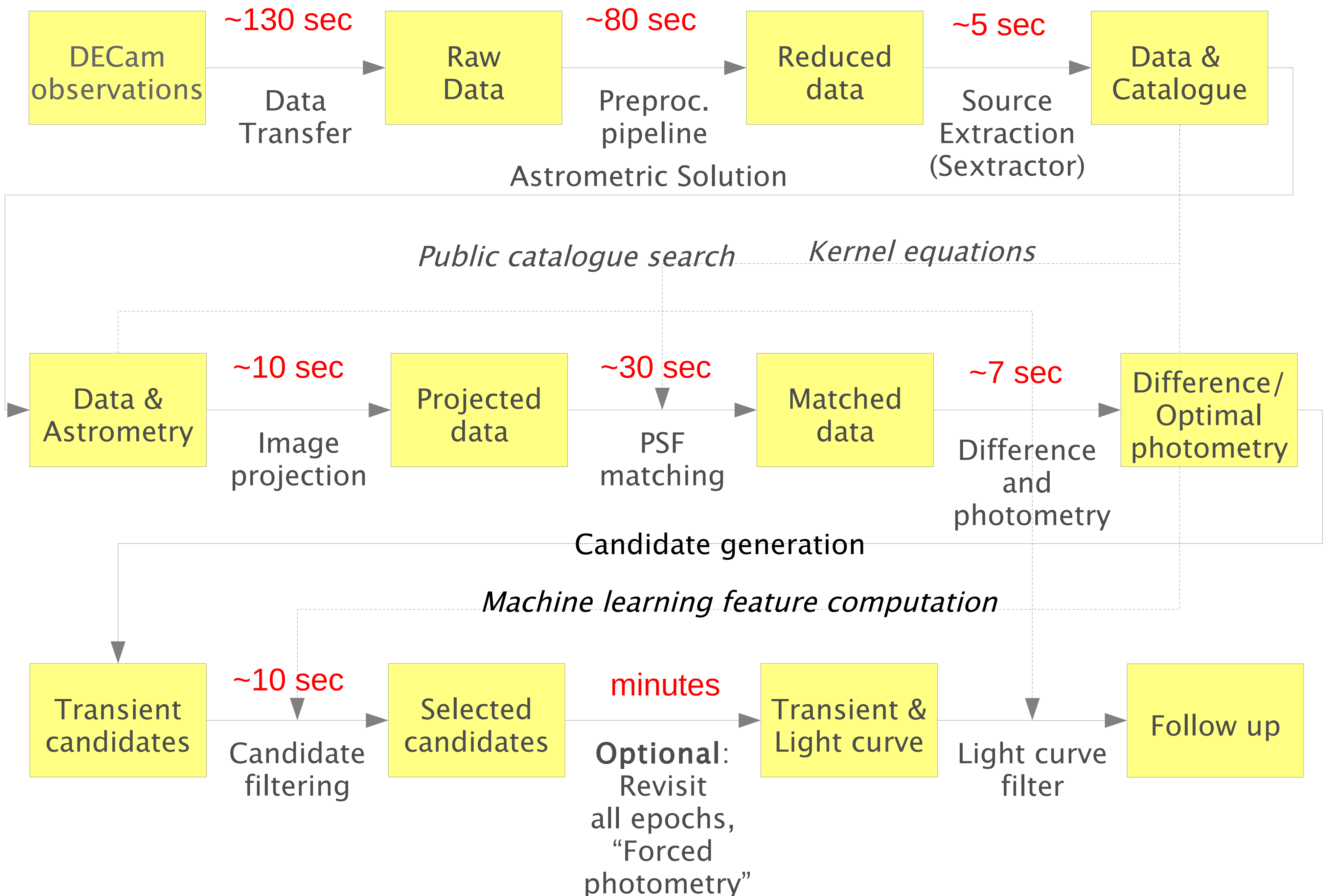
- RA chosen to guarantee full night visibility
- DEC chosen to minimize combined atmospheric + galactic extinction

- 2 x 40 x 5 = 400 **triplets** with a cadence of 2 hours
- 3 x 50 x 6(4) = 900(600) **triplets** with a cadence of 1.6 hours

Pipeline flow outline



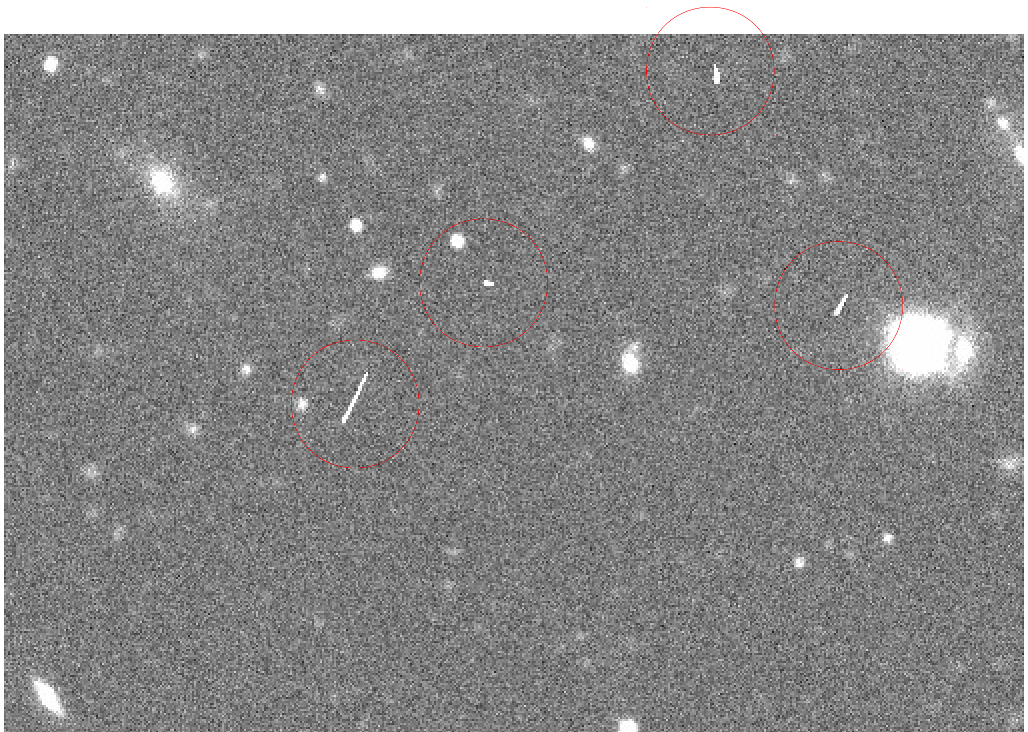
Pipeline flow outline



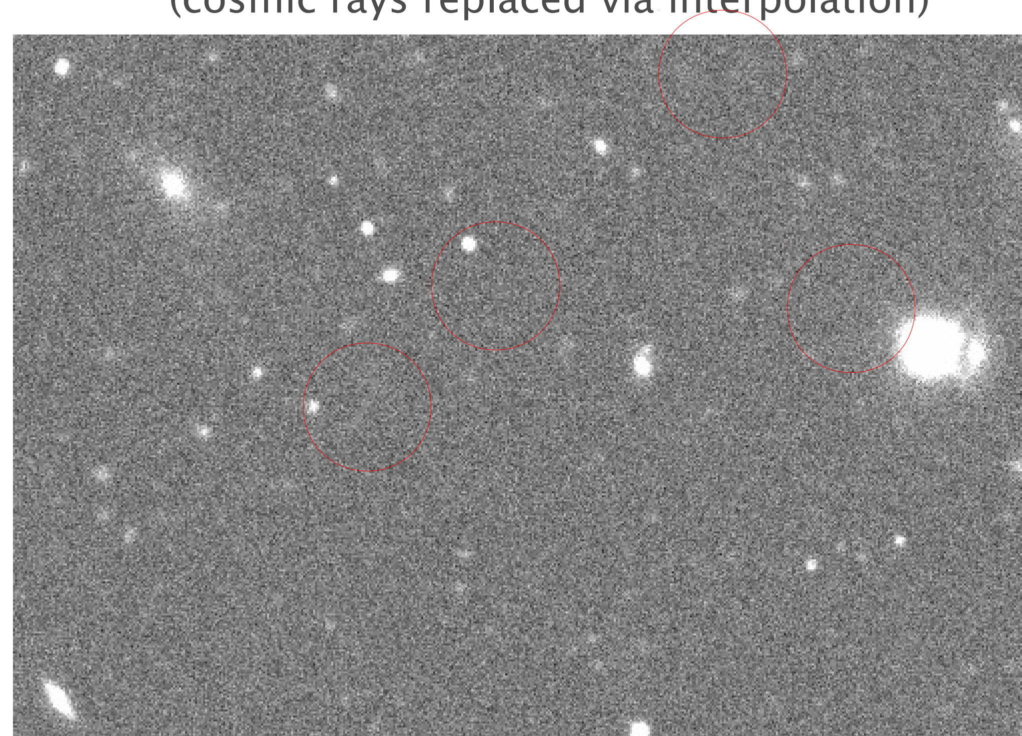
Preprocessing

- Bias correction + flat fielding + bad pixel mask using own code (2014) and DECam community pipeline (2015)
- Cosmic ray removal using CRBLASTER (Mighell 2010), based on the Laplacian cosmic ray identification routine LA−cosmic (van Dokkum 2001)

Before CRBLASTER

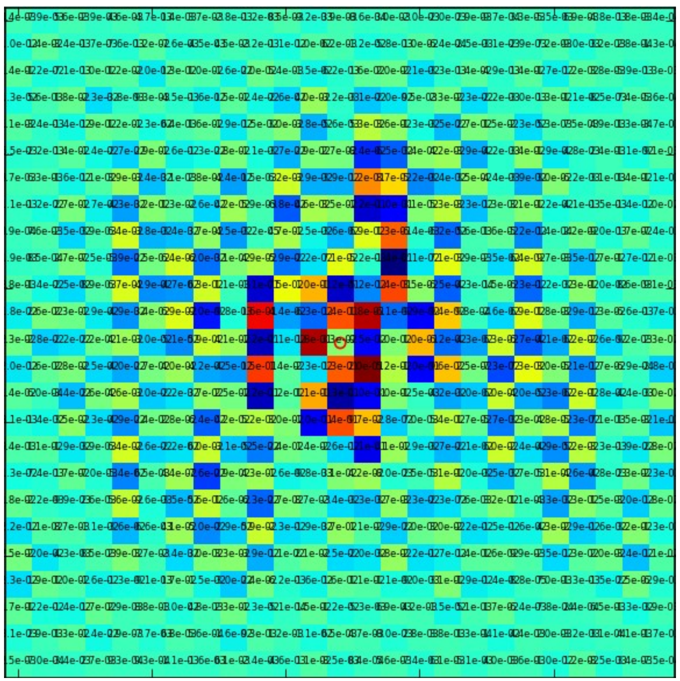


After CRBLASTER
(cosmic rays replaced via interpolation)

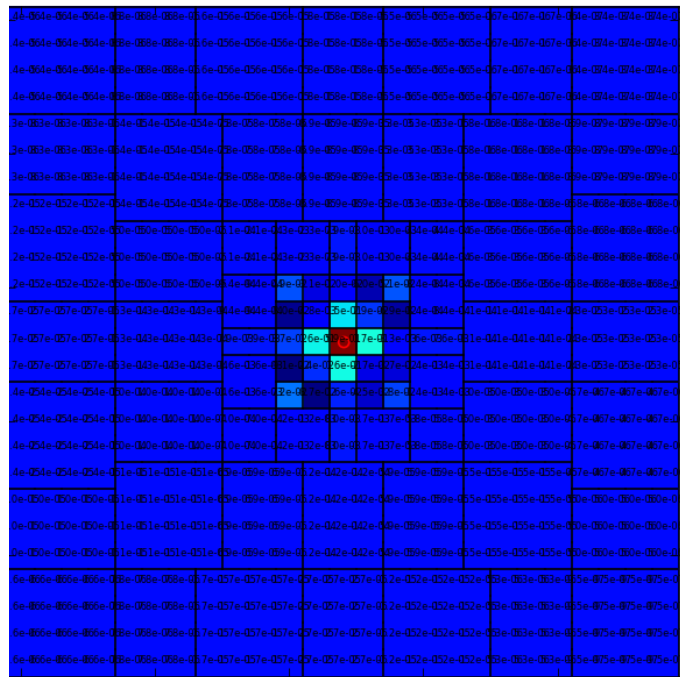


CRBLASTER uses OpenMP and runs in ~20 sec with 4 cores per image.

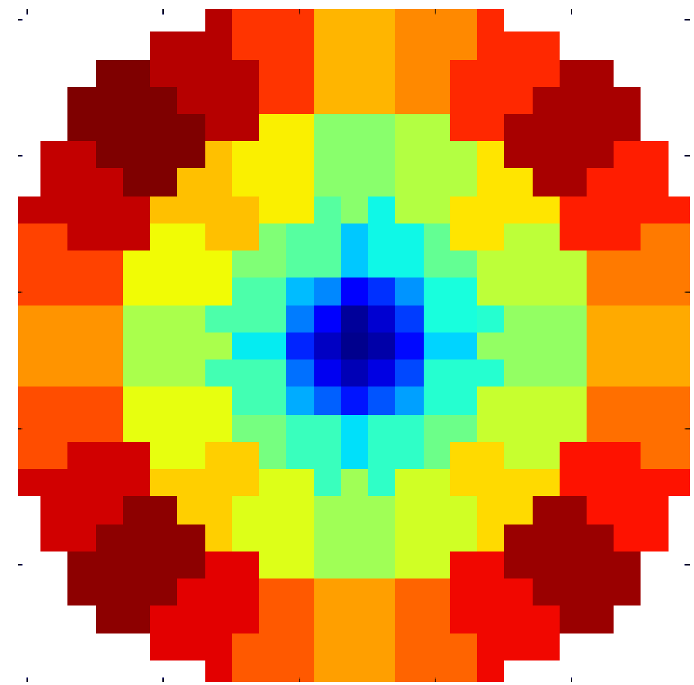
PSF matching: convolution kernel



Fixed size kernel pixels:
over−fitting produces
oscillations between pixels



Variable size kernel pixels:
no oscillations → fewer artifacts

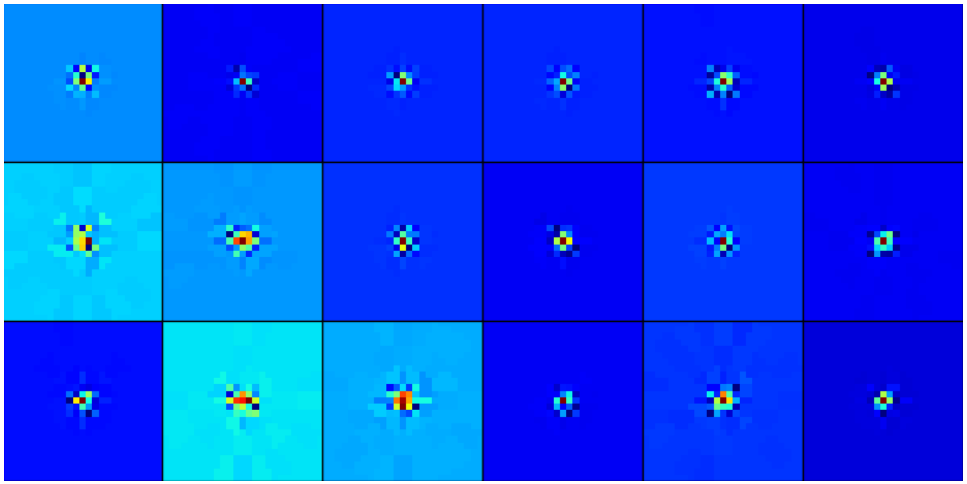


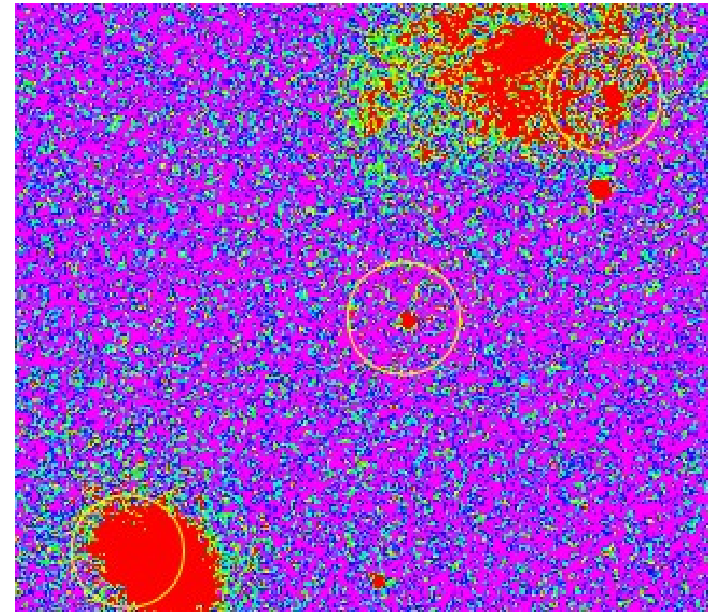
Final kernel model
25 x 25 pixels,
81 free parameters,
circular shape

(Fortran 95 + OpenMP + F2PY)

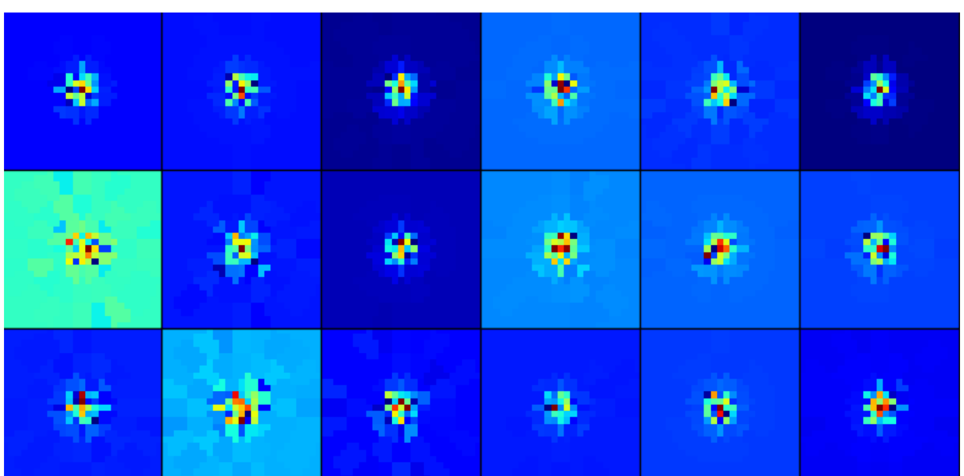
PSF matching: convolution kernel

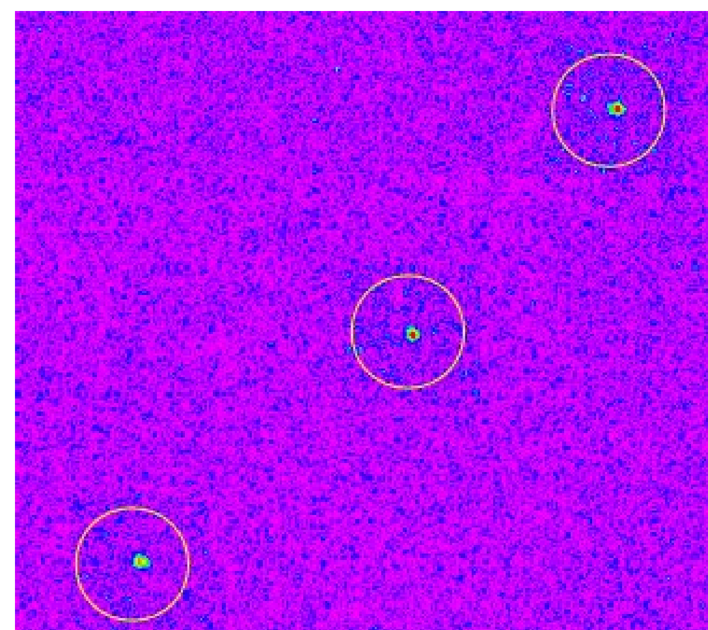
FWHM ~ $FWHM_{ref}$





FWHM ~ 2 x $FWHM_{ref}$





Optimal photometry

We perform optimal photometry (Naylor 1998) centered in **every pixel** of the difference images (Fortran 95 + OpenMP + F2PY)

Pixel counts

Sky counts at given pixel

Flux

$$F = \sum_{i,j} W_{i,j} \left(D_{i,j} - S_{i,j} \right)$$

Empirical PSF at given pixel

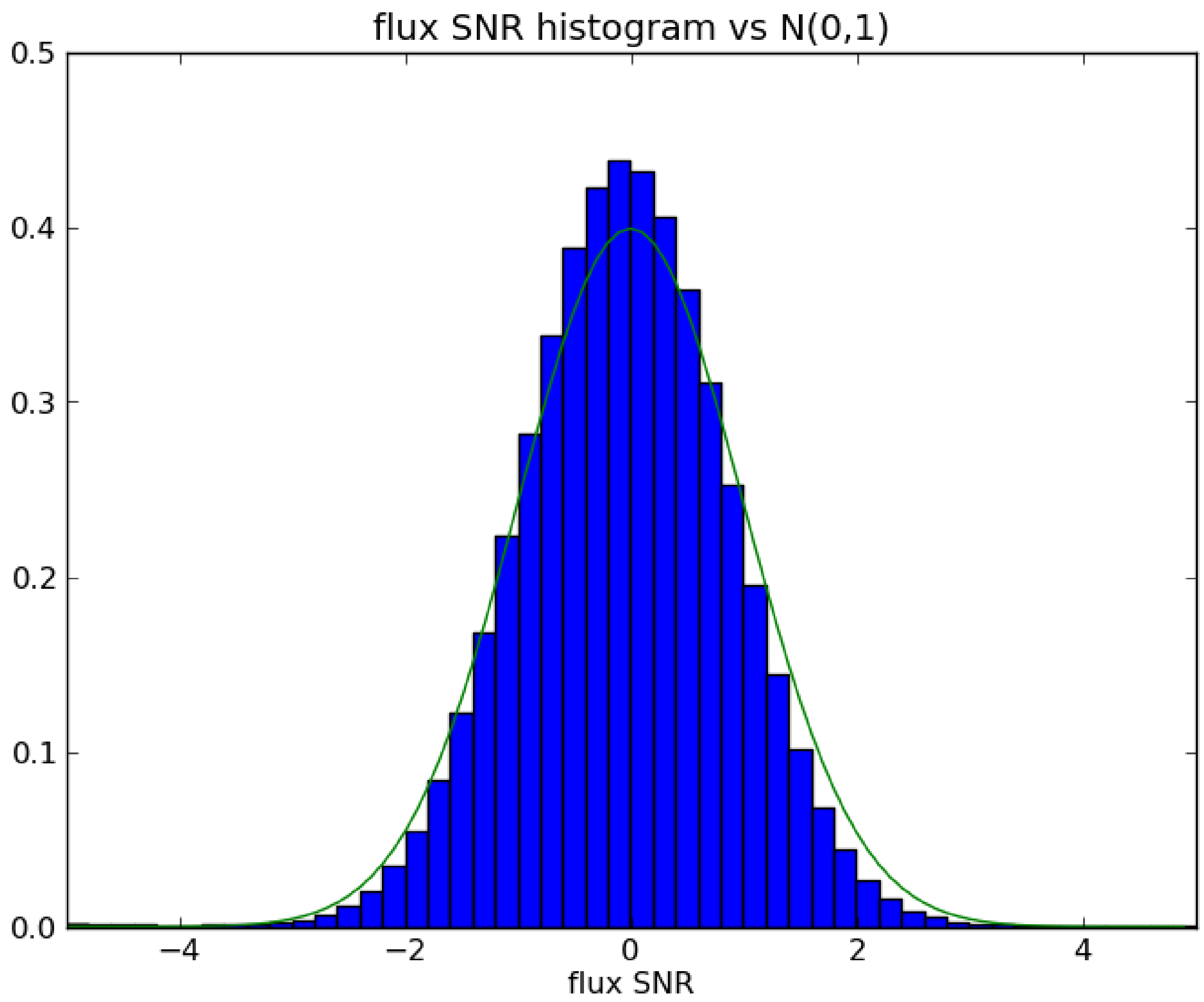
$$W_{k,l} = \frac{P^E_{k,l} / V_{k,l}}{\sum_{i,j} \left(P^E_{i,j} \right)^2 / V_{i,j}}$$

Variance at given pixel

Flux variance

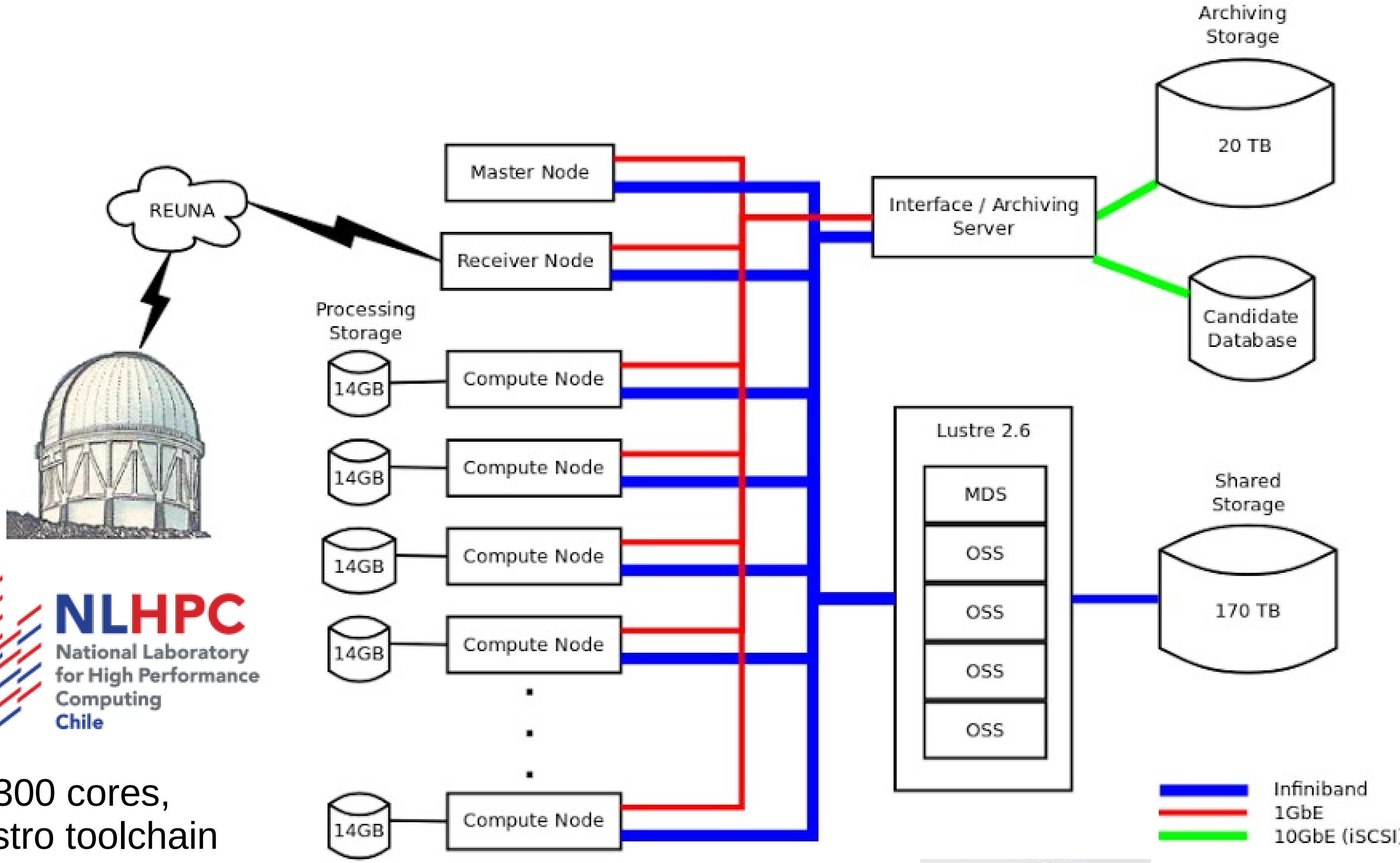
$$Var\left(F\right) = \sum_{i,j} W^2_{i,j} V_{i,j}$$

Optimal photometry SNR distribution



Optimal photometry signal to noise ratio histogram
consistent with modeled errors

High performance computing - storage



NLHPC
National Laboratory for High Performance Computing Chile

~300 cores,
astro toolchain

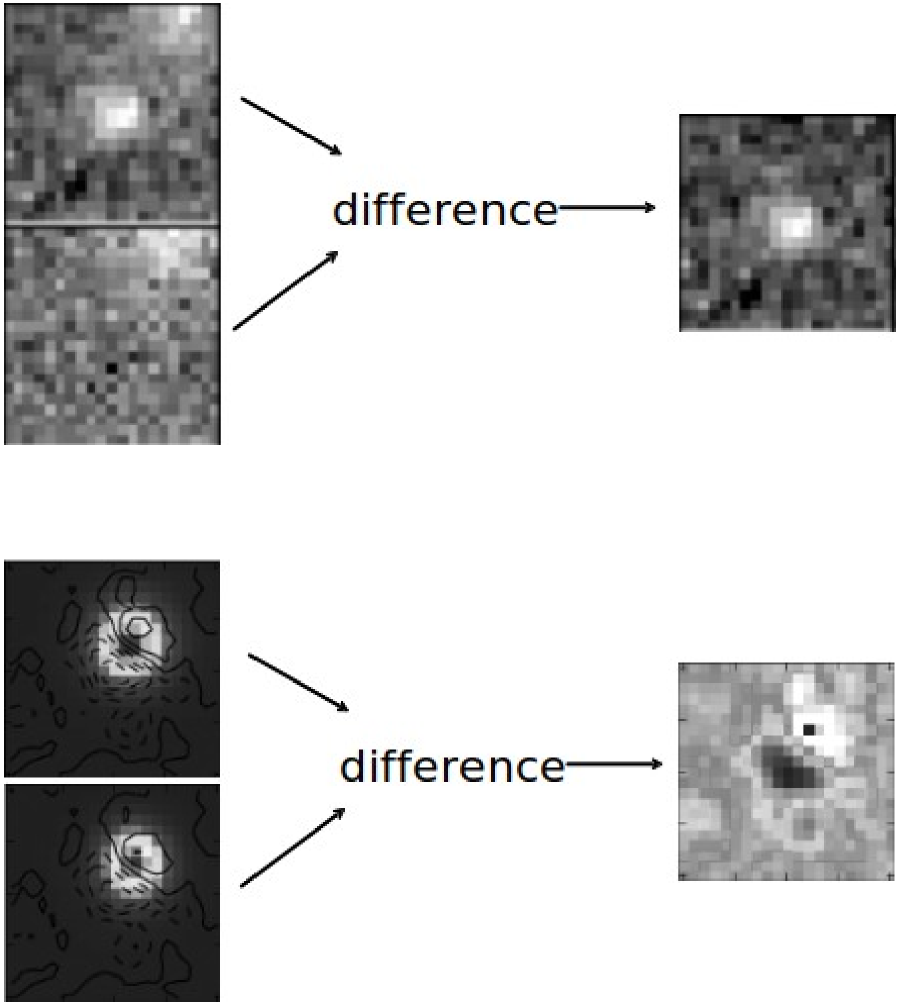
Most important bottle necks:

2014: slow to fast storage file transfer

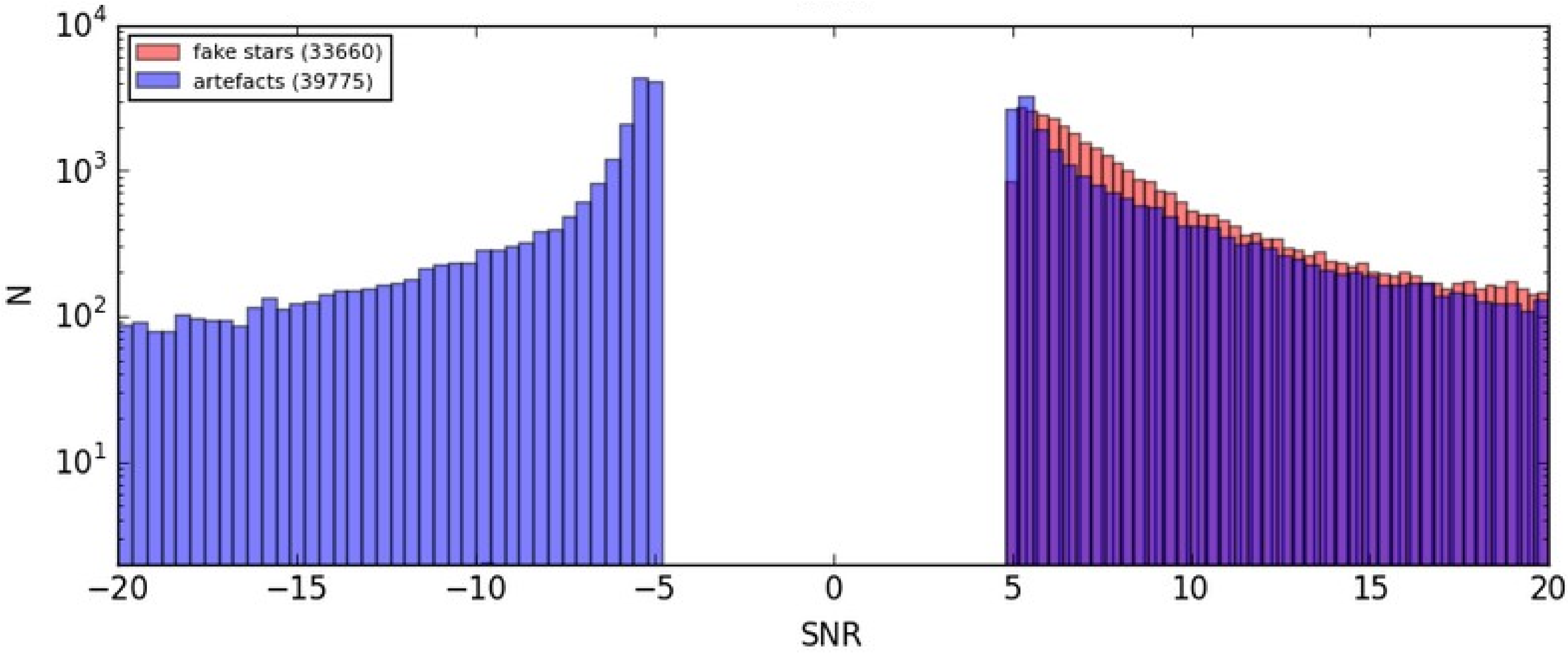
2015: CTIO → La Serena transfer

J.C. Maureira

Machine learning



Training sample



We insert observed stars into predefined positions, scaled down to force a given SNR distribution resembling the artefact SNR distribution.

Machine learning - families of features

Use dimensionless features, based on:

- **difference image**
- **SNR image of the difference**
- **unsubtracted image stamps**
- **density of candidates**
- **convolution kernel properties**

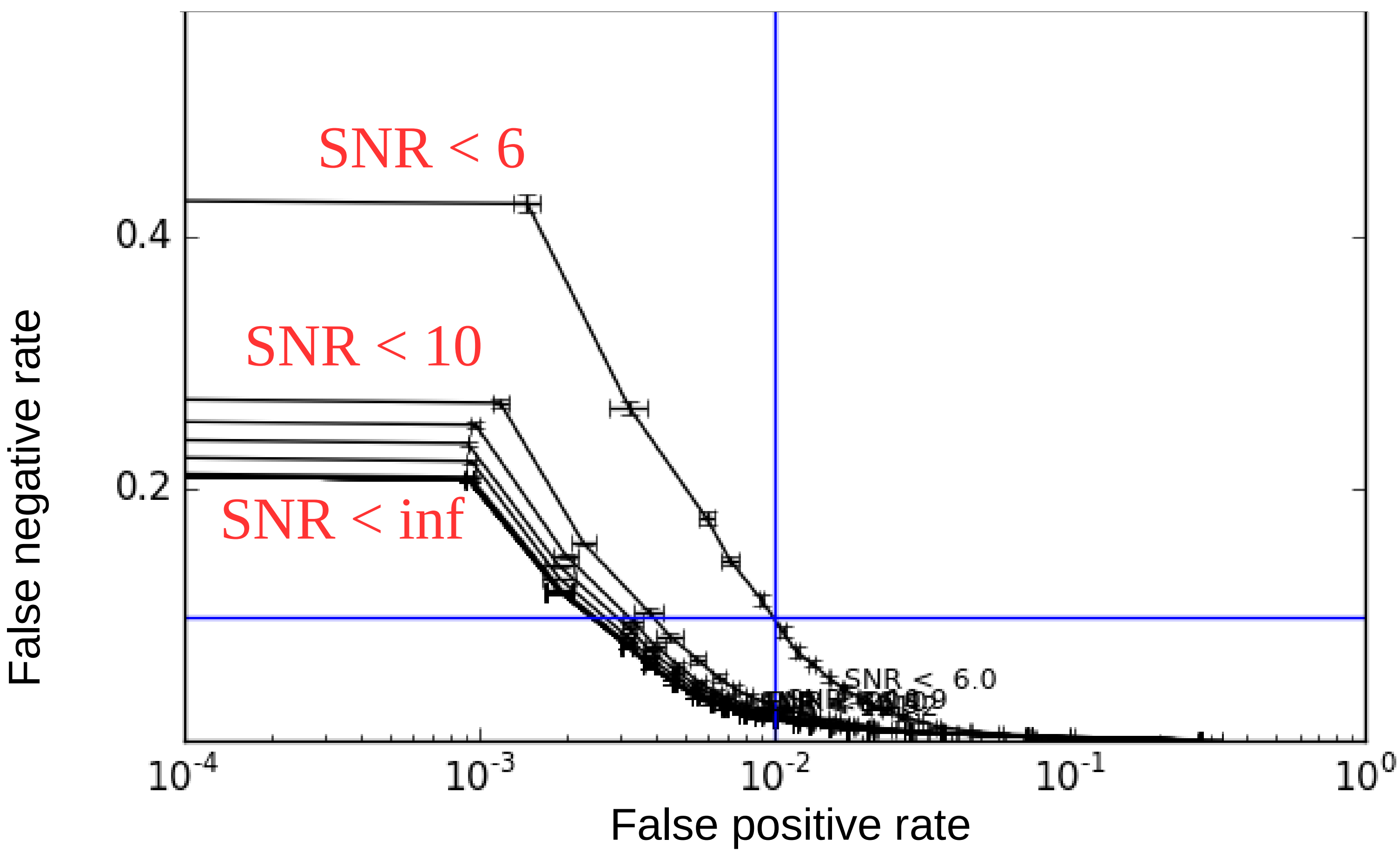
Most important features in RF (colors as above)

'**crosscorr**' '**crosscorr8**' '**dCCPCA0**' '**dhu2_2**' '**ncand**' '**offset**' '**dhu3_2**' '**fluxSNR**' '**dhu4_2**' '**dhu1_2**' '**minimmax**' '**dhu0_2**' '**SW**' '**dhu1_4**' '**crosscorr5**' '**pixSNR**' '**dhu0_4gt**' '**entropy**' '**bump**' '**ratiomax1**' '**dhu0_4**' '**PCA0**' '**crosscorr3**' '**symmidx**' '**dhu5_2**' '**dhu6_2**' '**std**' '**diffcoeff**' '**R2**' '**CRmax**'

… '**ratiomax2**' '**dhu3_4**' '**dhu1_4gt**' '**nmax1**' '**nmax2**' '**ksupport**' '**PCA3**' '**dhu7_4**' '**maximmin**' '**kratio**' '**dhu7_4gt**' '**PCA2**' '**PCA5**' '**PCA1**' '**PCA4**' '**PCA6**' '**dhu7_2**' '**dhu4_4**' '**dhu2_4**' '**dhu3_4gt**' '**dhu6_4**' '**dhu5_4**' '**dhu2_4gt**' '**dhu4_4gt**' '**dhu5_4gt**' '**dhu6_4gt**'

Random forest efficiency and purity

ROC curves depend strongly on the test (and training) candidate SNR distribution!



Candidate selection

1. SNR of integrated flux difference > 5

 + **not too close to flagged pixels**

 + **difference between pre and post CRBlaster in reference** smaller than a threshold

 + **candidate density** around the candidate smaller than a threshold

2. Classified as real based on selected features with **probability > 0.5**

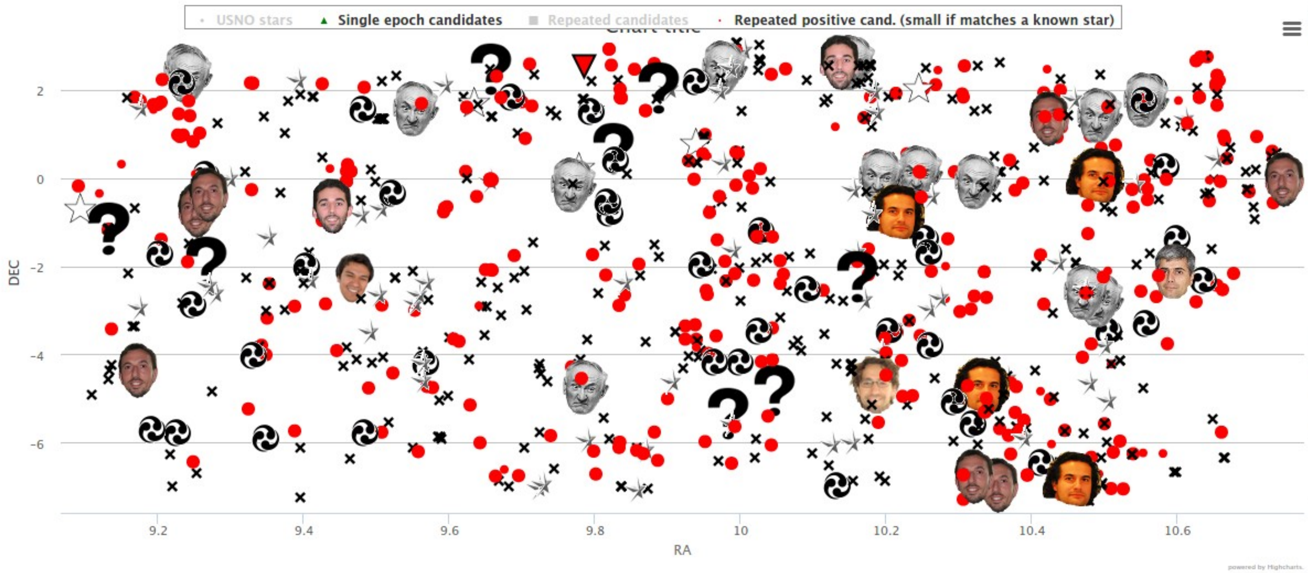
 + **repeated at least once** in the same location

 + **positive difference** with respect to the reference.

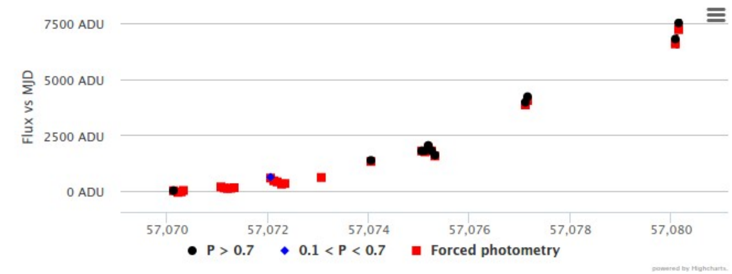
Interactive web: how to visualize 1 Tpix

Semester: Blind15A ▾ Field: all ▾ CCD: all ▾ Reference epoch: 02 ▾ Threshold: 0.85 getData!!!

Observer : FF - Logout



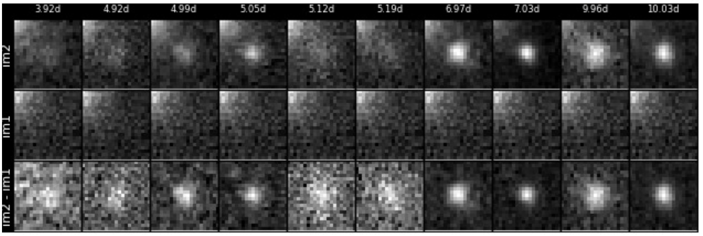
Field: Blind15A_25, CCD: S14, RA: 9:47:5.68, DEC: 2:31:49.86 (avg. pixels: 1111, 1660), probpair: 0.98, diffs: 17-02t>19-02t>20-02t>21-02t>22-02t>23-02t>25-02t>26t-02>28-02t>29-02t



Bad Calibr.	Cosmic Ray
Conv.Problem	Bad Pixels
Asteroid	WTF
SN Good Cand.	SN Possible Cand.
VS Good Cand.	VS Possible Cand.

Send

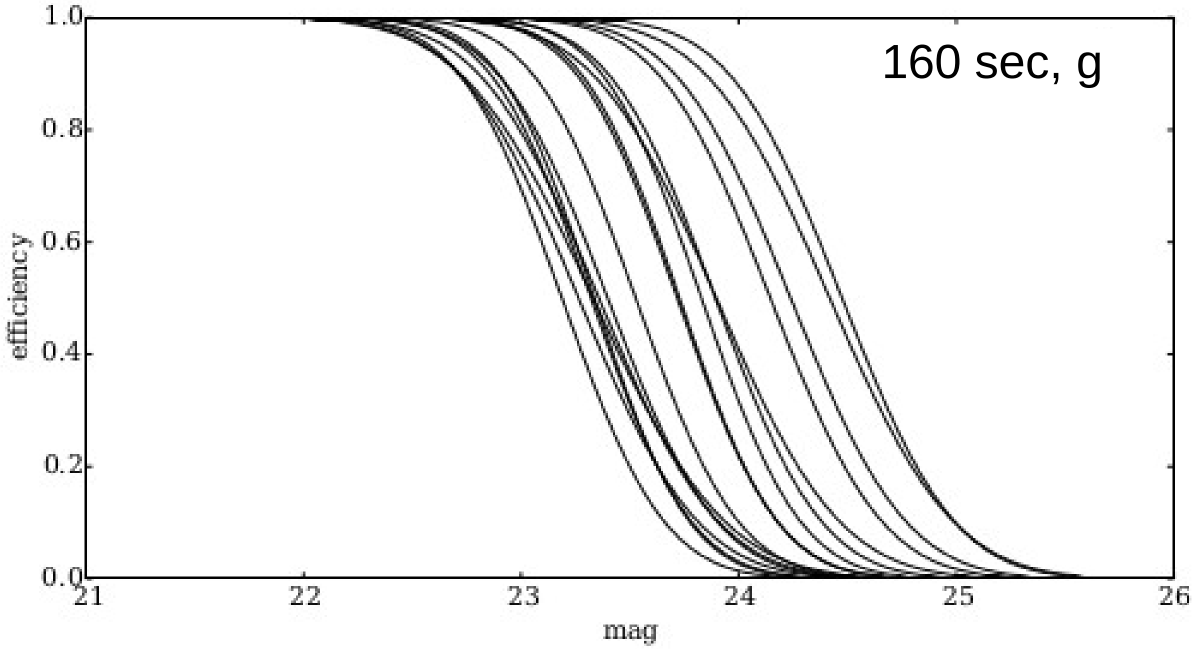
Field: Blind15A_25, CCD: S14, RA: 9:47:5.68, DEC: 2:31:49.86 (pixels: 1111, 1660).. Diffs: 17-02t>19-02t>20-02t>21-02t>22-02t>23-02t>25-02t>26t-02>28-02t>29-02t. Key :146.774:2.531, Light curve, animation and finding chart

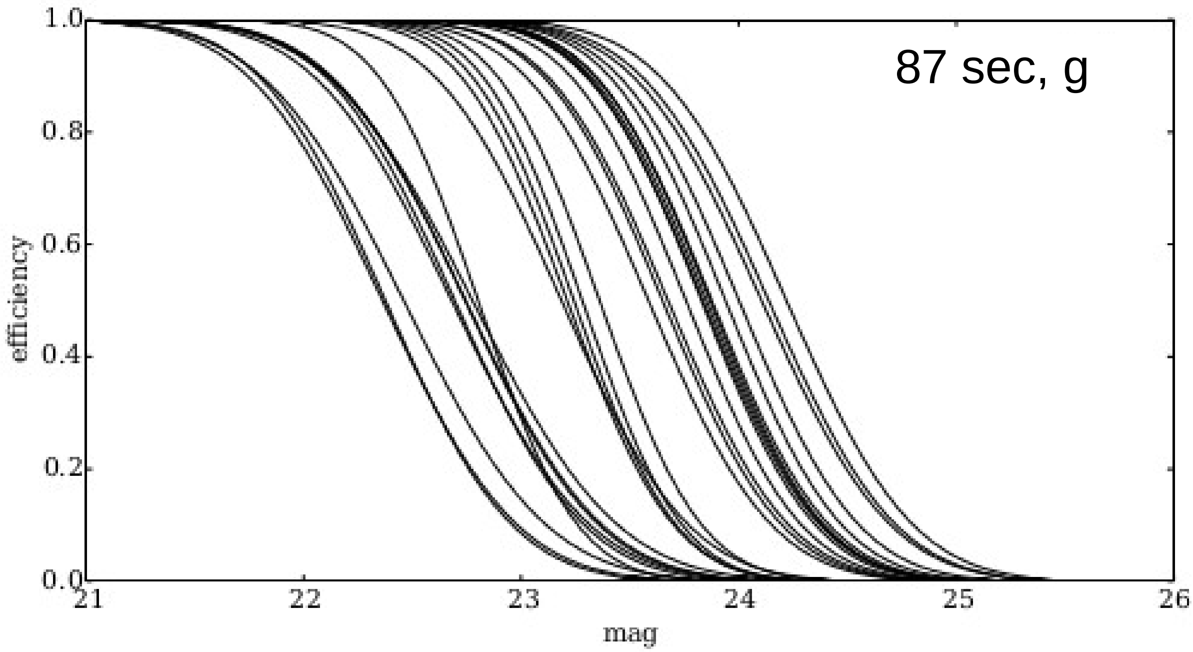


[Juan Carlos Maureira] Posible Shock Break out!
[FF] SN candidate Teahine

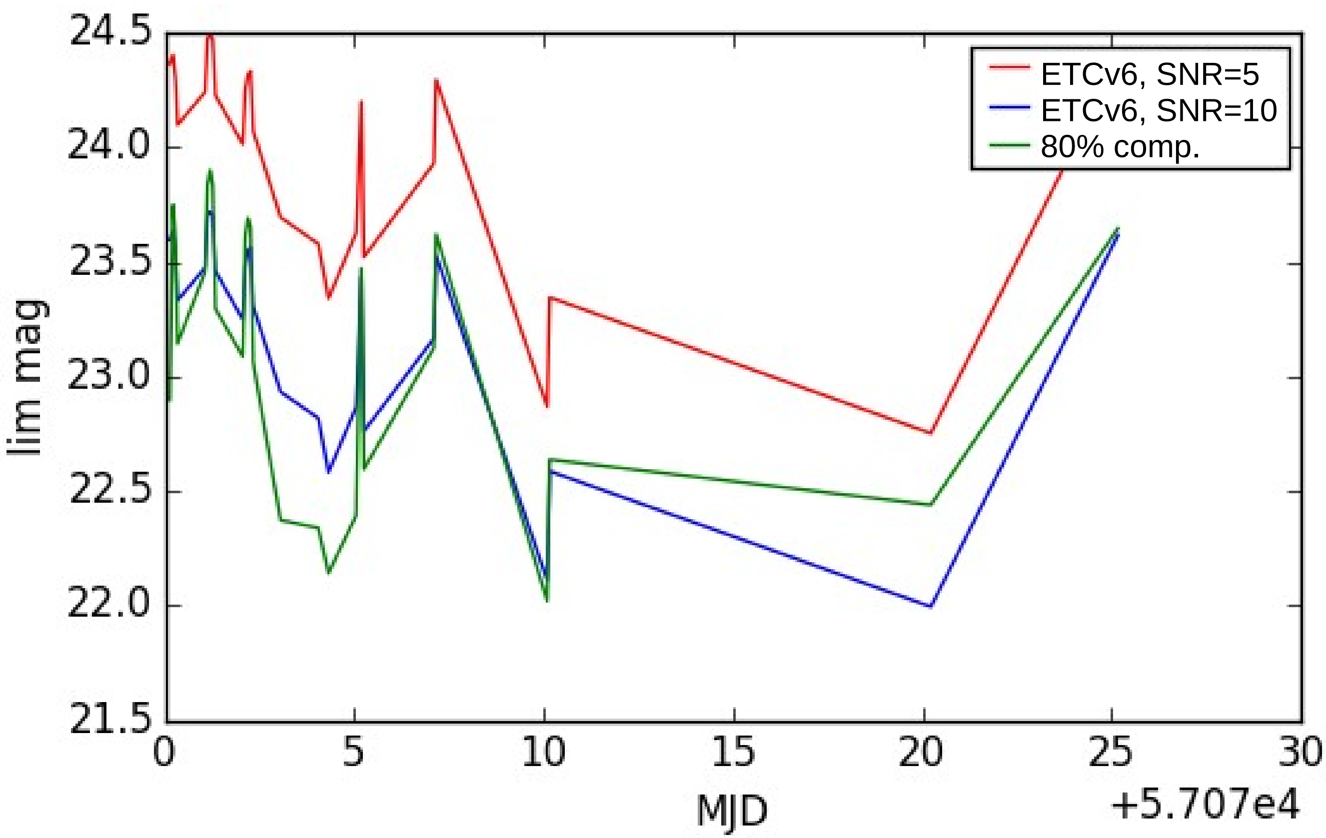
RESULTS

Survey depth





Completeness magnitude vs ETC (g band)

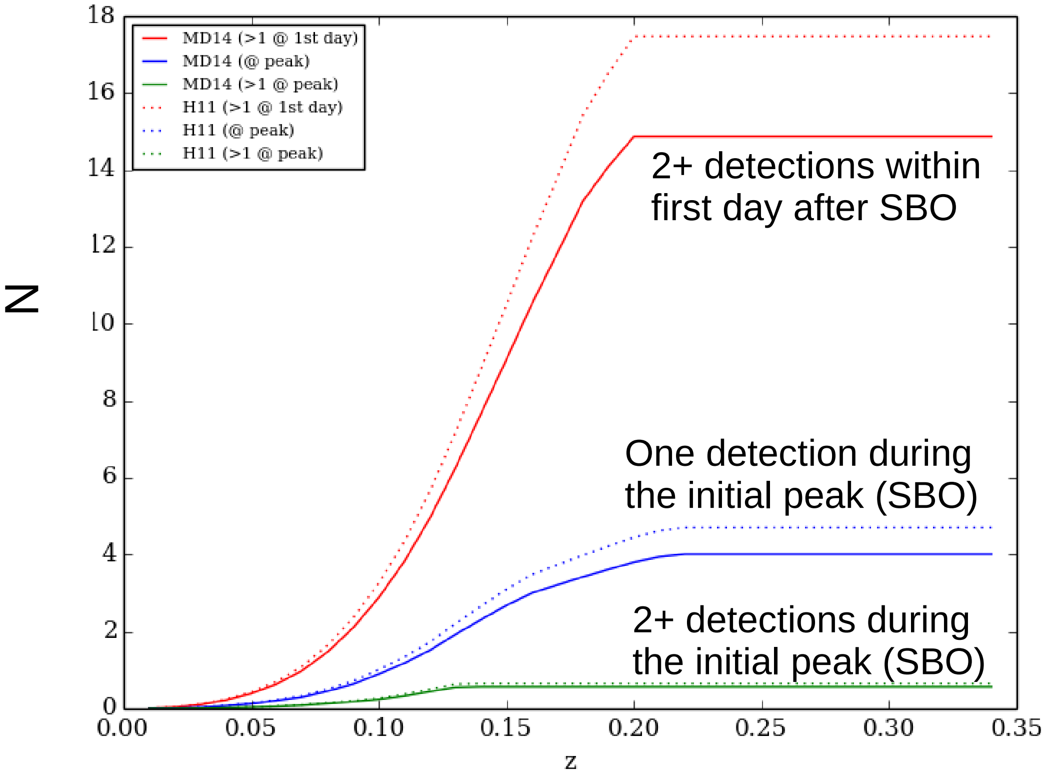


2015A, 87 sec exposure

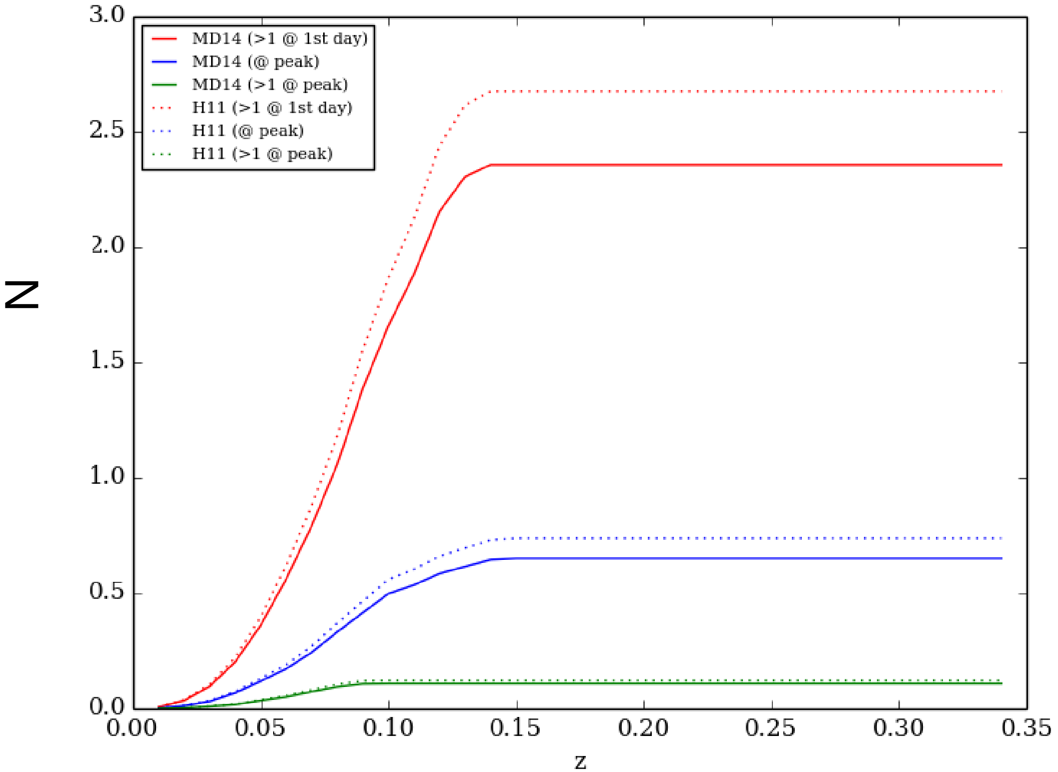
50% comp. ~ ETC v6, SNR=5
80% comp. ~ ETC v6, SNR=10

80% comp. ~ ETC v6, SNR=5 − 0.7
80% comp. ~ ETC v5, SNR=10 − 0.7
50% comp. ~ ETC v5, SNR=5 − 0.7
80% comp. ~ ETC v5, SNR =5 − 1.5

Simulated number of events in expected vs actual obs.

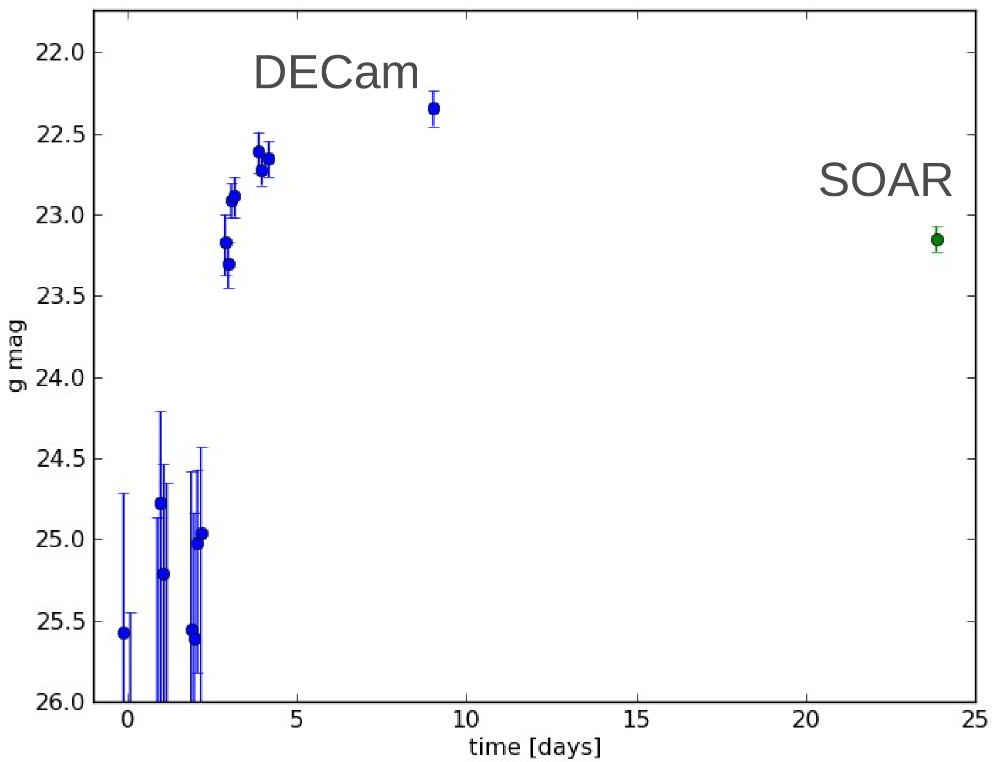


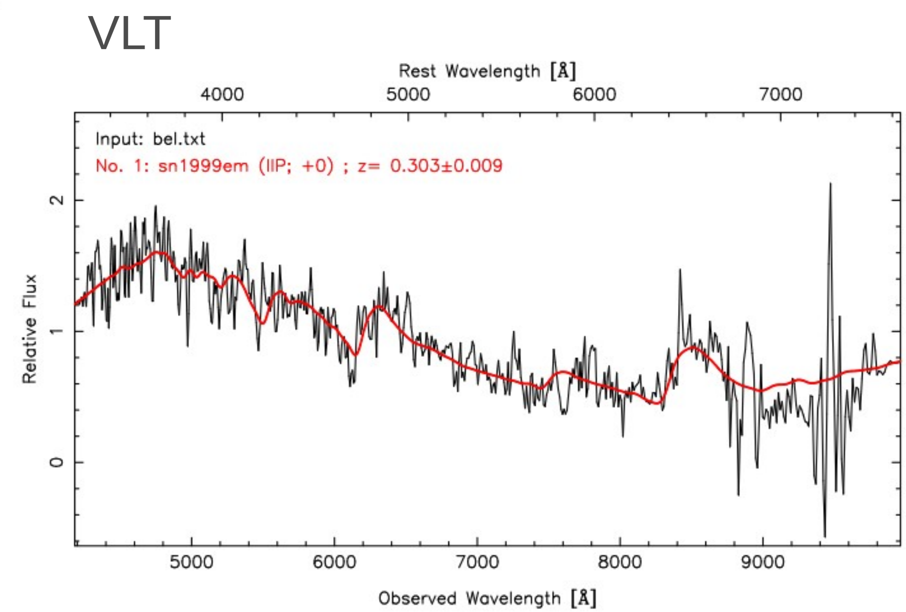
Simulated using ETC v5, SNR=8



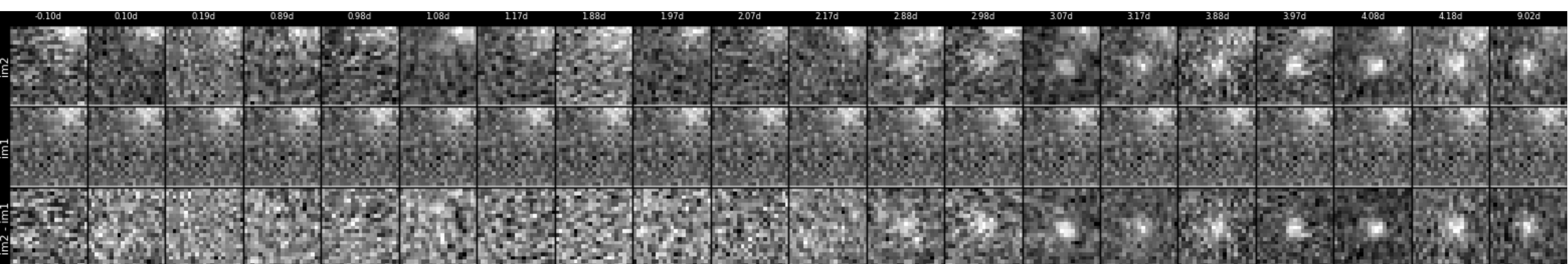
Simulated using actual limiting magnitude

Very fast rise in SNe IIP, no SBO observed

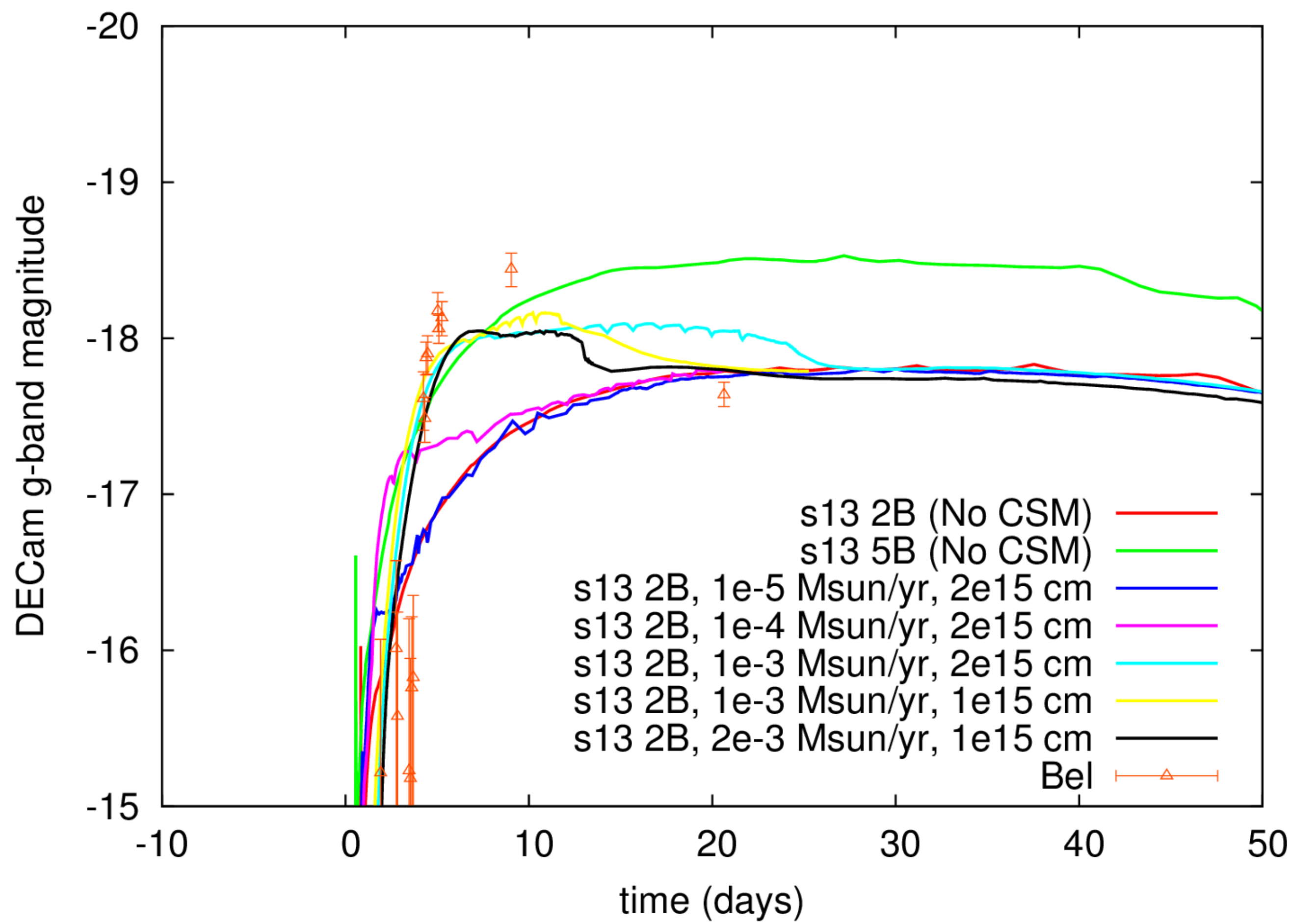




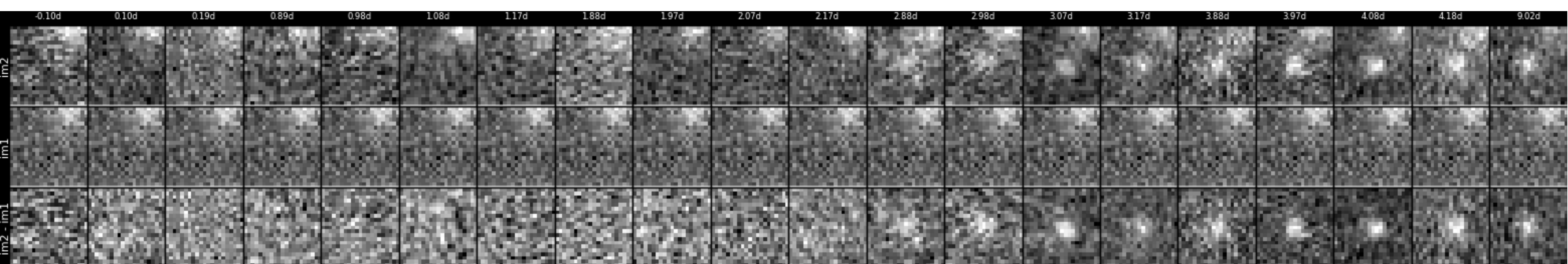
Cannot reconcile high luminosity + fast evolution + low expansion velocities (CSM interaction?)



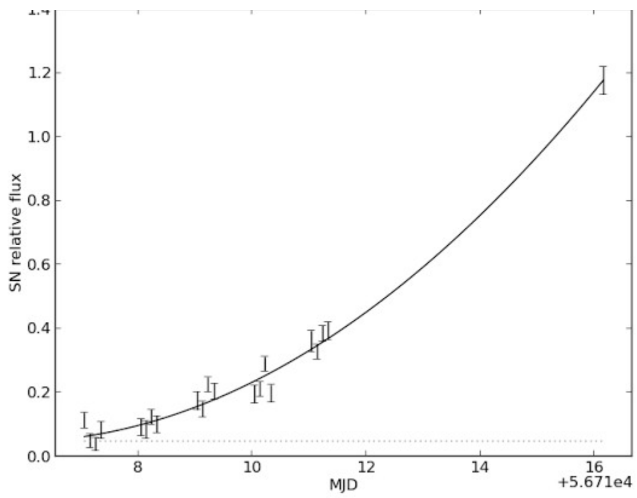
Light curve modelling

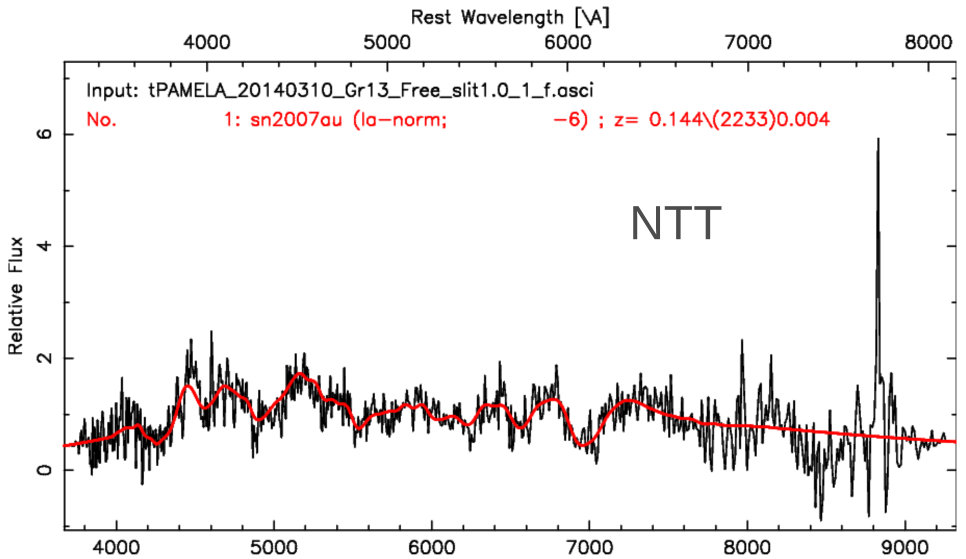


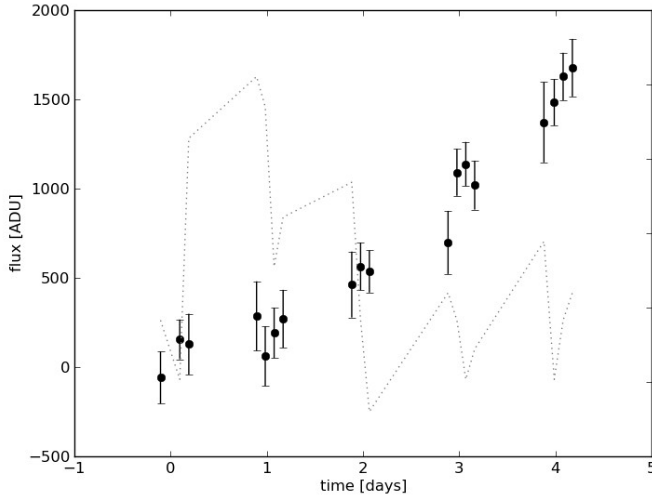
Takashi Moriya

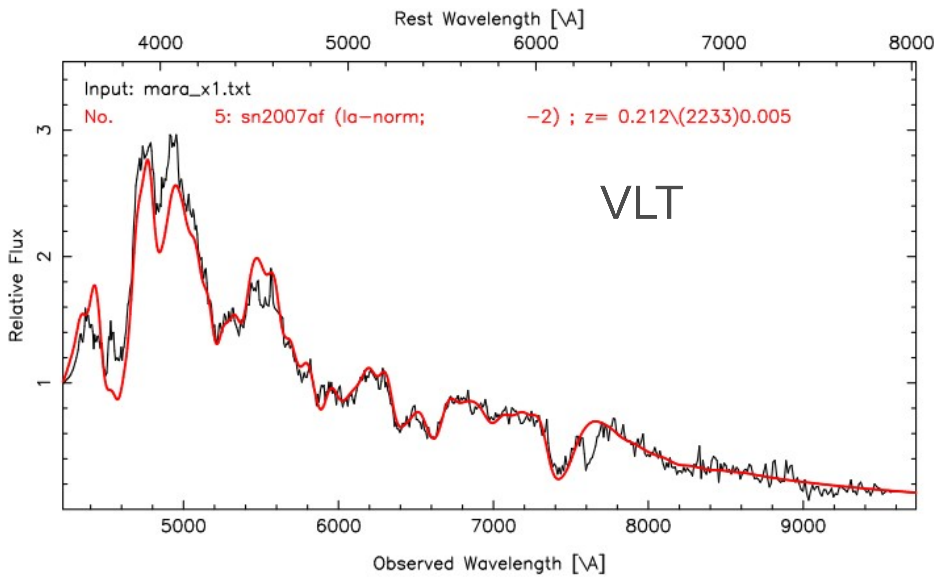


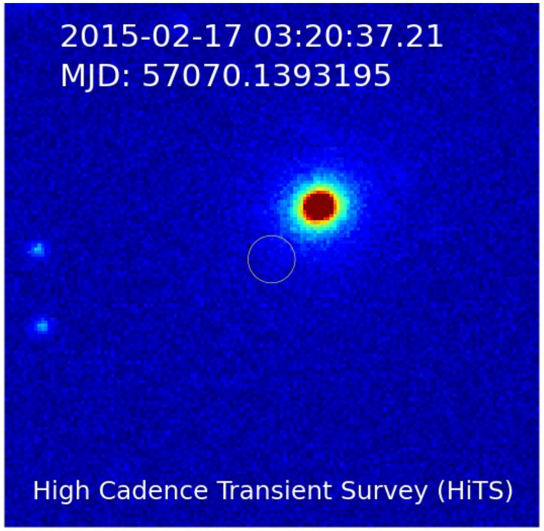
~t^2 rise in SNe Ia, no obvious interaction (?)

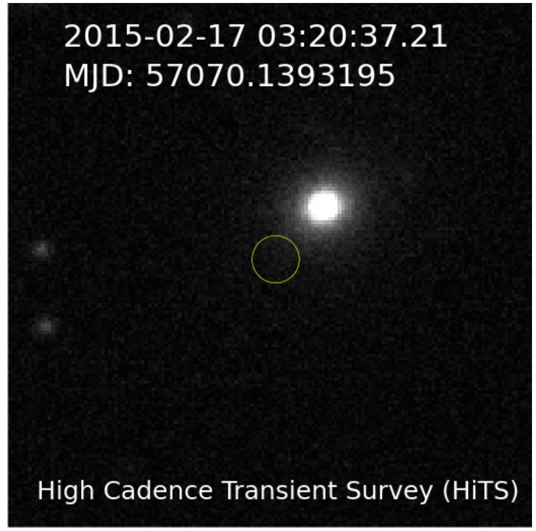


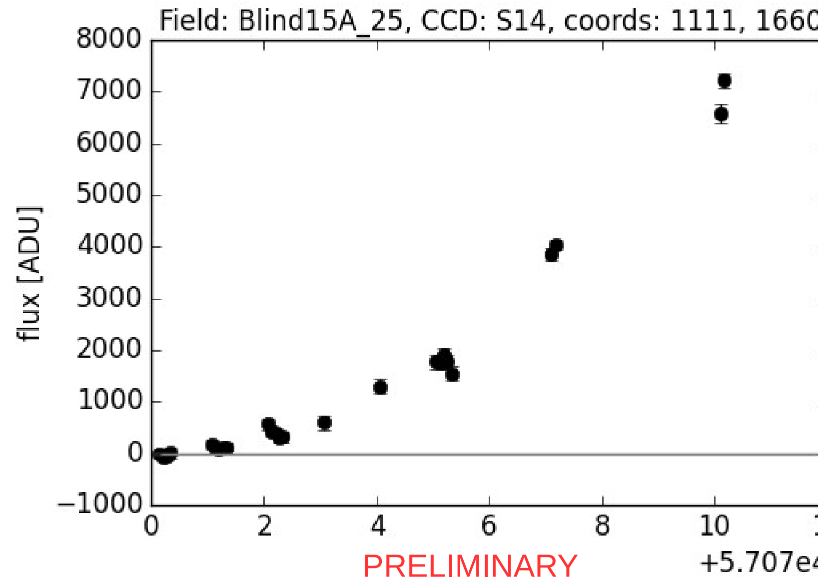


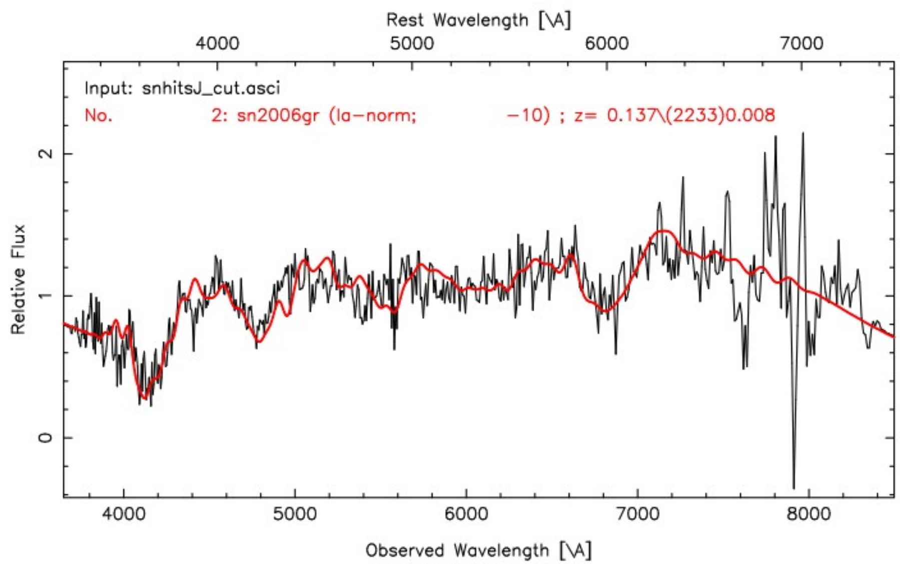


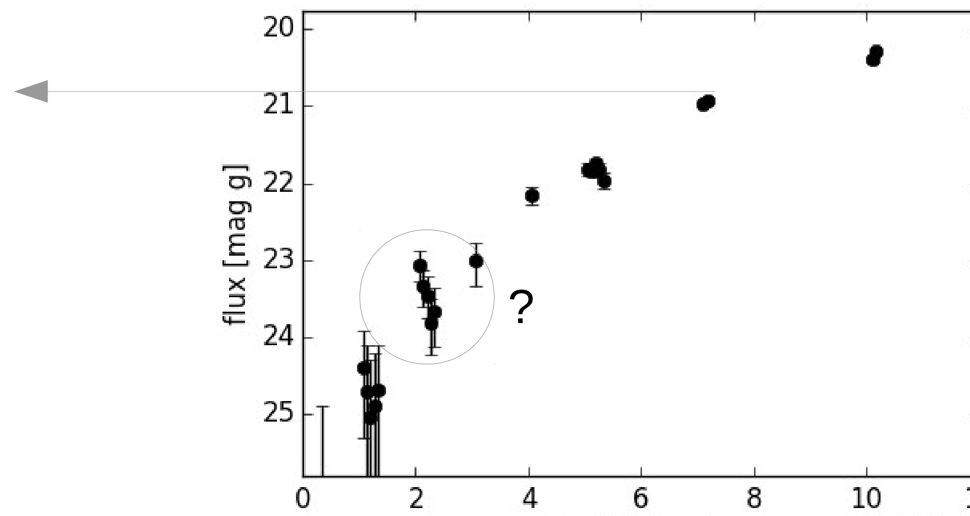


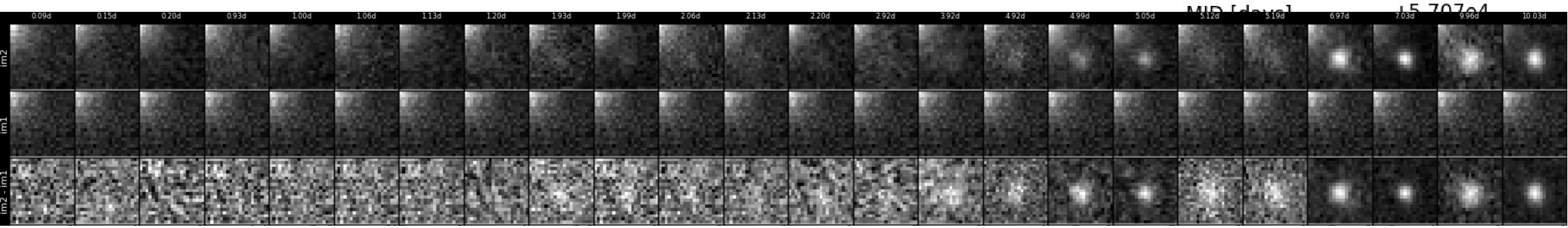






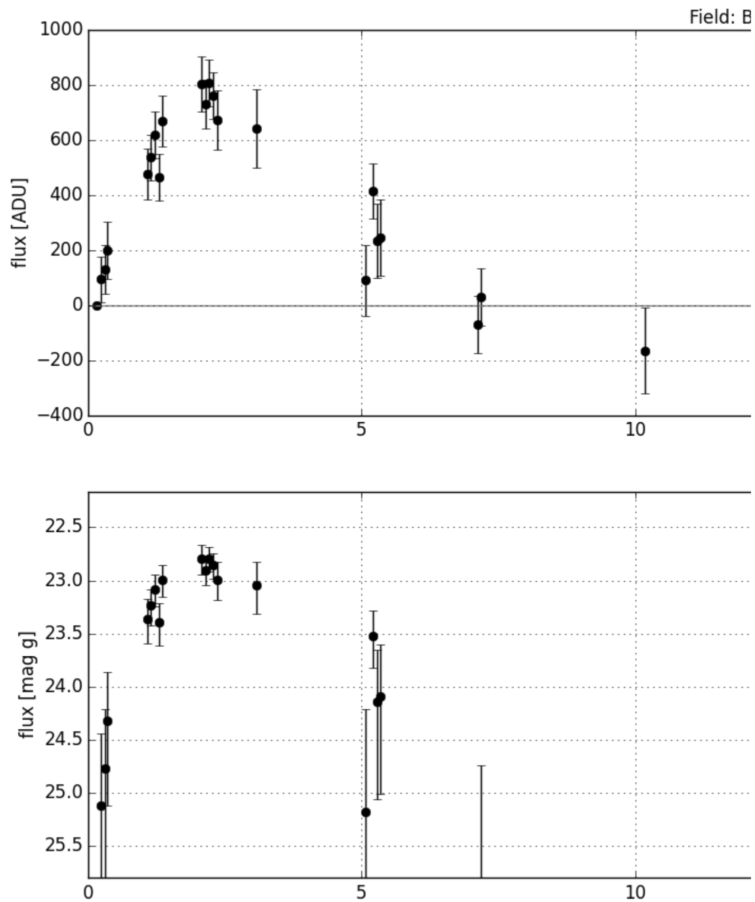


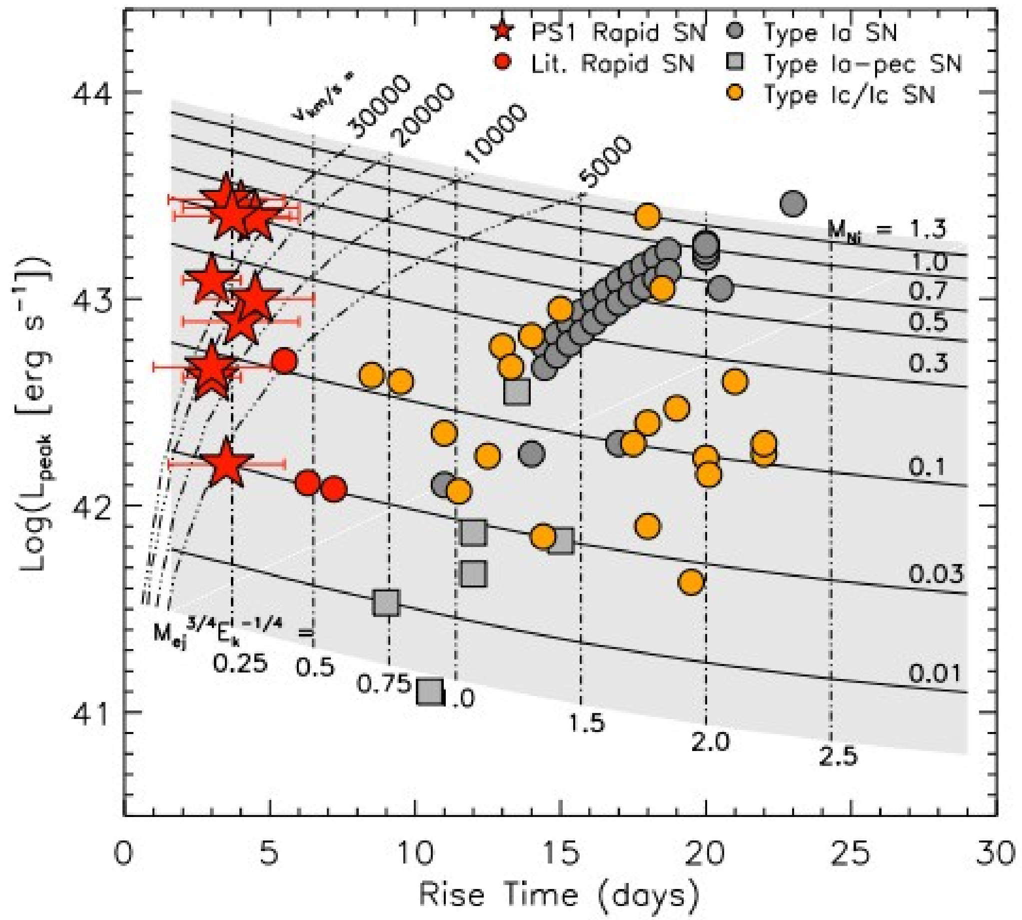




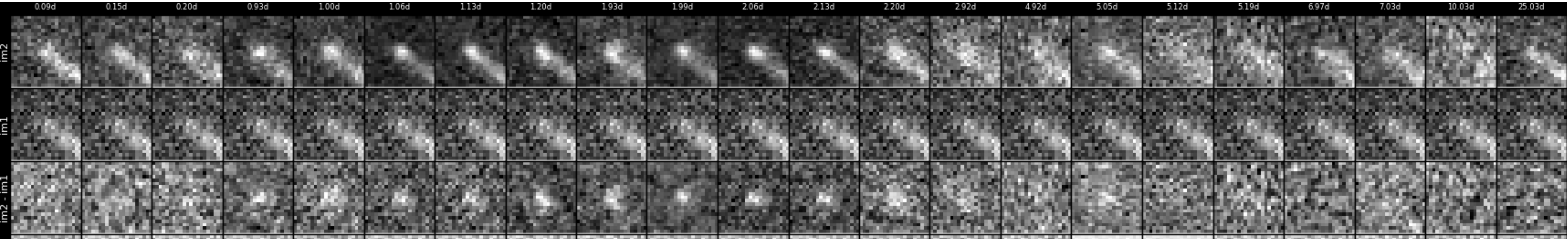
ATELs 7099, 7108, 7115, 7122, 7131, 7146, 7148, 7149

SNHiTS15B: fast transient (2 day rise + 8 day decline)

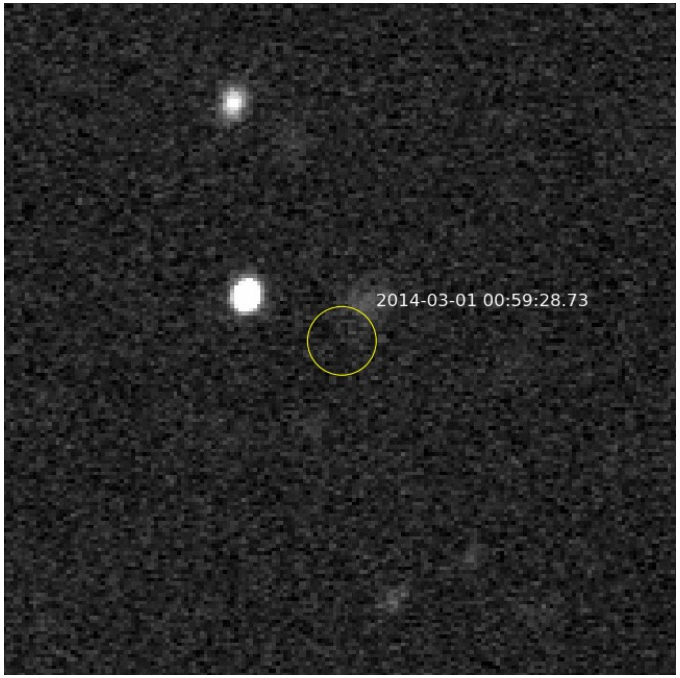


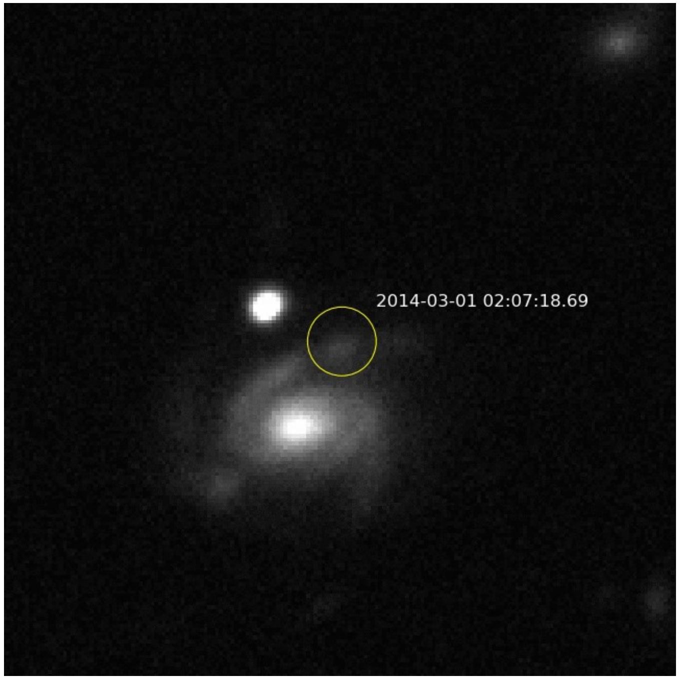


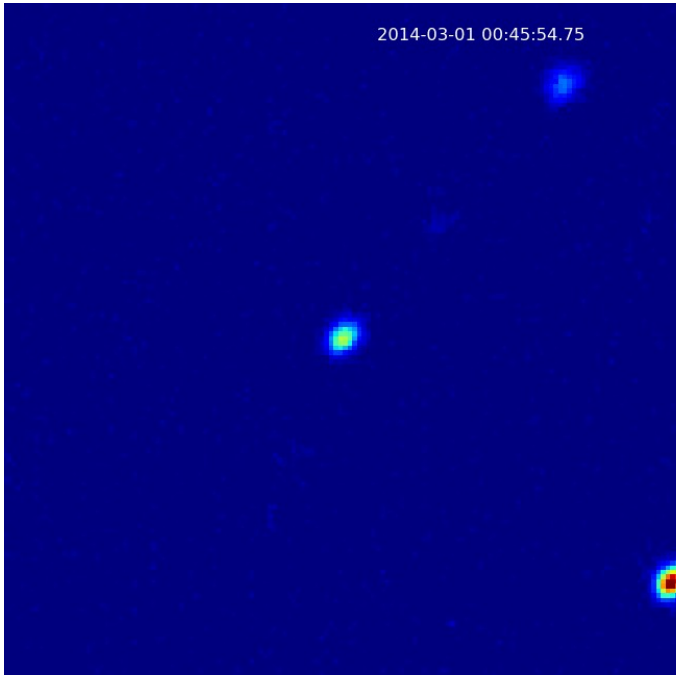
Drout+14 (4-7% of the CC rate)

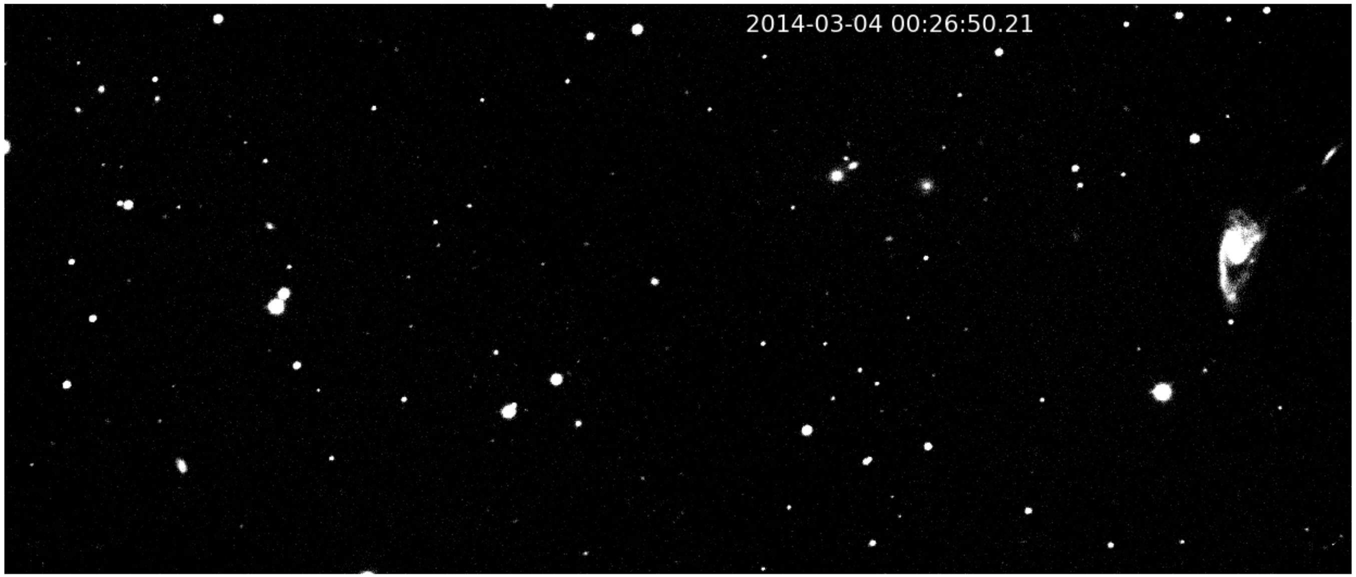


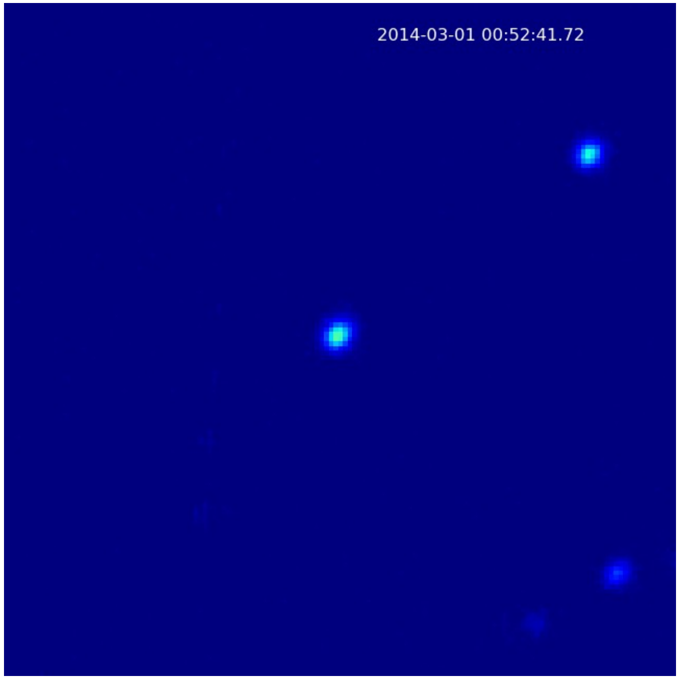
~10^2 SNe, ~10^3 asteroids, ~10^2 of RR Lyrae, ? eclipsing stars











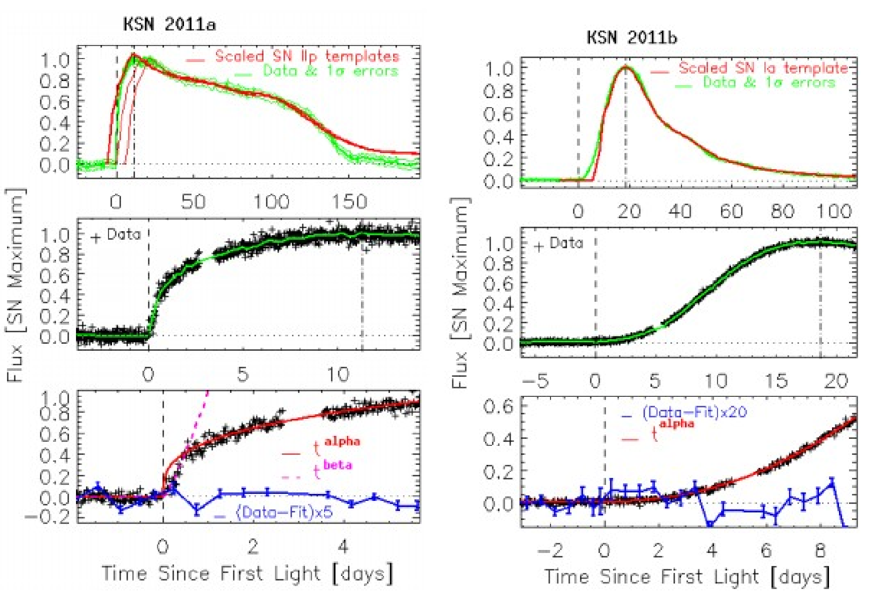
ATELs 5949, 5956

Collaboration with Kepler Extragalactic Survey

Extragalactic Science with Kepler in two Gyro Mode, a White Paper

Rob Olling[1], Brad Tucker[2,4], Ed Shaya[1], Alex Fillipenko[4], Peter Garnavich[3], Dan Kasen[4,8], Armin Rest[5], James Rhodes[6], John Tonry[7], Richard Mushostsky[1], Steve Margheim[7]

[1]University of Maryland, [2]The Australian National University, Mt. Stromlo Observatory, [3]University of Notre Dame, [4]Departments of Physics and Astronomy, UC Berkeley, [5]Space Telescope Science Institute, [6]Arizona State University, [7] Gemini Observatory, [8]Nuclear Science Division, Lawrence Berkeley National Laboratory



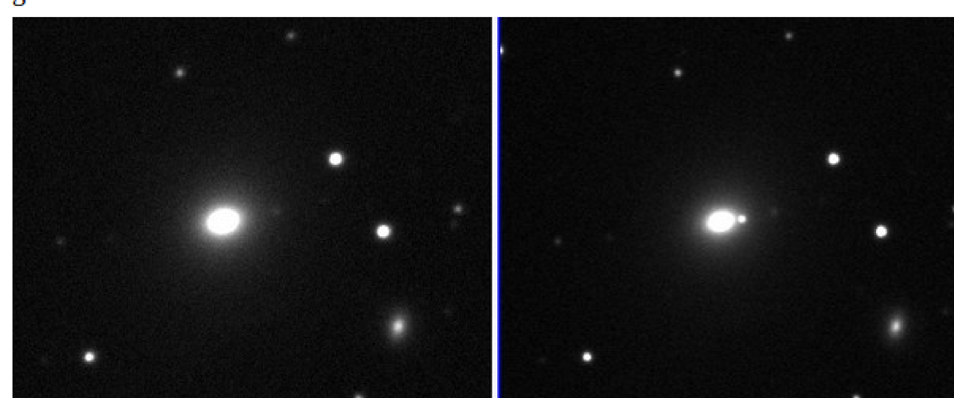
Olling et al.

KEGS/HiTS Discovery of a Young Type Ia Supernova in the K2 Campaign 5 Field.

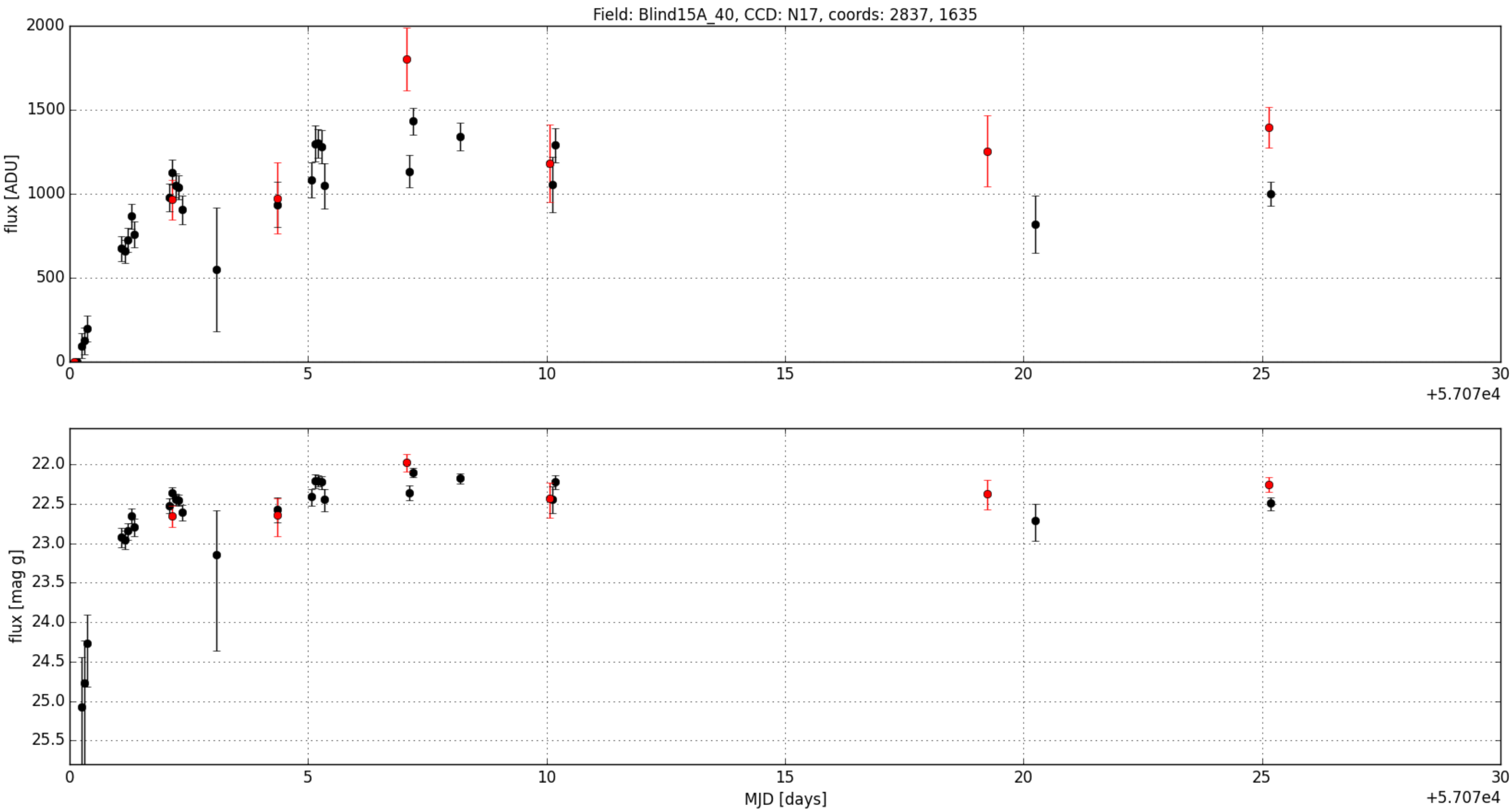
ATel #7664; *A. Zenteno (CTIO), F. Forster (CMM, MAS), A. Rest (STScI), S. Margheim (Gemini), B. Tucker (ANU/UCB), P. Garnavich (Notre Dame), D. Kasen (UCB/LBL), R. Olling, E. Shaya, R. Mushotzky (Maryland), T. GonÃ§alves (UFRJ), A. Bonaca (Yale), J. C. Maureira (CMM), L. Magill, A. Cardwell, and P. Candia (Gemini)*
on ***19 Jun 2015; 01:50 UT***
Credential Certification: Brad Tucker (brad@mso.anu.edu.au)

Subjects: Optical, Supernovae

KEGS, the Kepler Extra-Galactic Survey, reports the discovery of a supernova candidate (KSN-2015a, RA: 8:23:50.14, DEC: 11:32:56.17) using the Dark Energy Camera (DECam, NOAO 2015A-0397 and 2015A-0371) on the 4m Blanco Telescope at Cerro Tololo (CTIO). The data analysis was performed using the High Cadence Transient Survey (ATELs #5949, #5956) pipeline, developed at the Center for Mathematical Modelling (CMM) in collaboration with the Millennium Institute for Astrophysics (MAS), using computation resources from the National Laboratory for High Performance Computing (NLHPC). The supernova was visible in an i-band image taken on 2015-06-03 with a magnitude of 18.49 +- 0.02, but was not visible on 2015-04-06. The reported magnitude is based on the difference with respect to the reference image taken on 2015-04-06. Spectroscopy was obtained on June 17.96 UT with the Gemini-South Telescope on Cerro Pachon with GMOS-S (GS-2015A-Q-33). Cross-correlation with a library of supernova spectra, the "Supernova Identification" code (SNID; Blondin and Tonry 2007, Ap.J. 666, 1024), confirmed KSN-2015a as a type Ia supernova just before maximum light (best fit is 03cg at -2 days) with z=0.034. The Kepler extended mission (K2) is currently monitoring the field that includes KSN-2015a using a 30-minute cadence but a single broad filter. Multi-color observations of this event are encouraged.



Sample of very early IIP light curves



Summary

First real time DECam data reduction achieved (~0.4 Tpix processed in real−time in 2014, ~1 Tpix processed in 2015, ~5 TB raw data, ~40 TB processed data!).

Rapid reaction after explosion possible (<1 day in 2014, <3.2 hours in 2015)

32 young SN candidates discovered in 2014A, **90** young SN candidates in 2015A (with spectra: 7 Ia + 3 II). Candidates made public the same night of discovery.

SBO detection in the optical difficult with observed DECam limiting magnitudes.

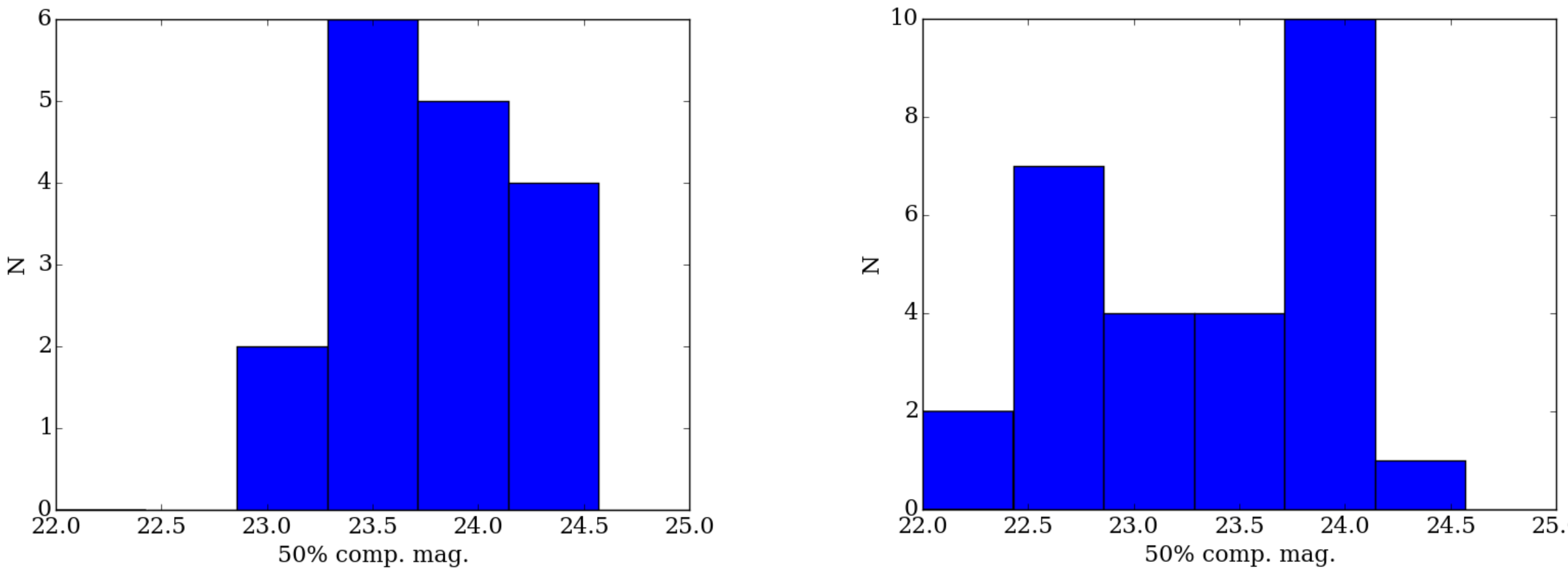
New sample of very young SNe (< 1 day) shows very fast early evolution of core collapse SNe in the optical (consistent with Olling et al.)

Other science: $>10^2$ new distant RR Lyrae stars, $>10^3$ new asteroids, dozens of unknown objects (flares? Other?). Public catalogue of light curves under construction (PhD student J. Martínez).

Interdisciplinary collaboration crucial for Big Data astronomy (LSST)

¡Muito obrigado!

This project used data obtained with the Dark Energy Camera (DECam), which was constructed by the Dark Energy Survey (DES) collaborating institutions – See more at: http://www.ctio.noao.edu/noao/content/Acknowledgment-DECam#sthash.Z7MCPHs3.dpuf


N
50% comp. mag.
N
50% comp. mag.

5 cycles per night