HITS: High cadence Transient Survey at CMM / MAS

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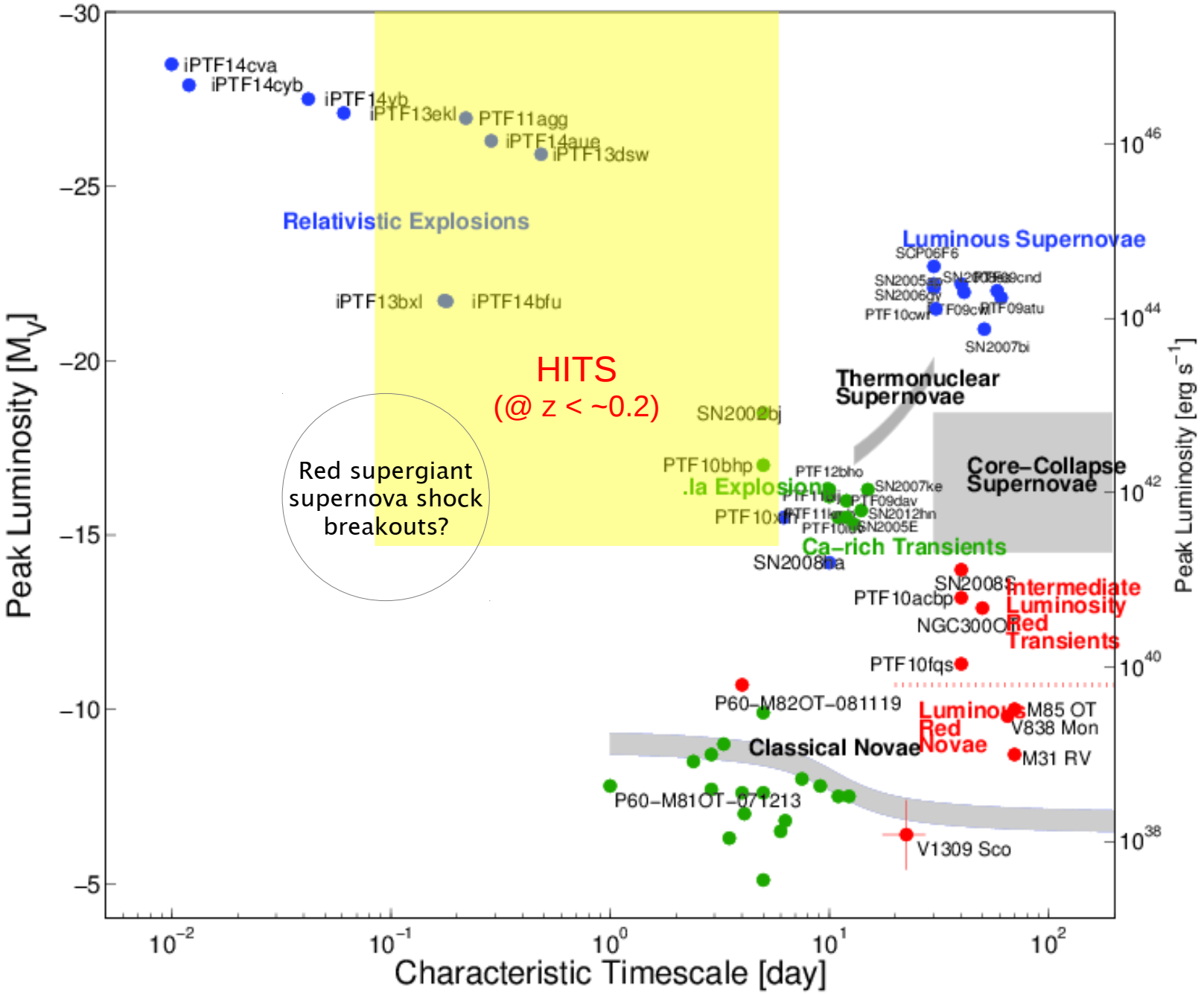
NLHPC National Laboratory for High Performance Computing Chile

MILLENNIUM INSTITUTE OF ASTROPHYSICS

CONICYT Ministerio de Educación

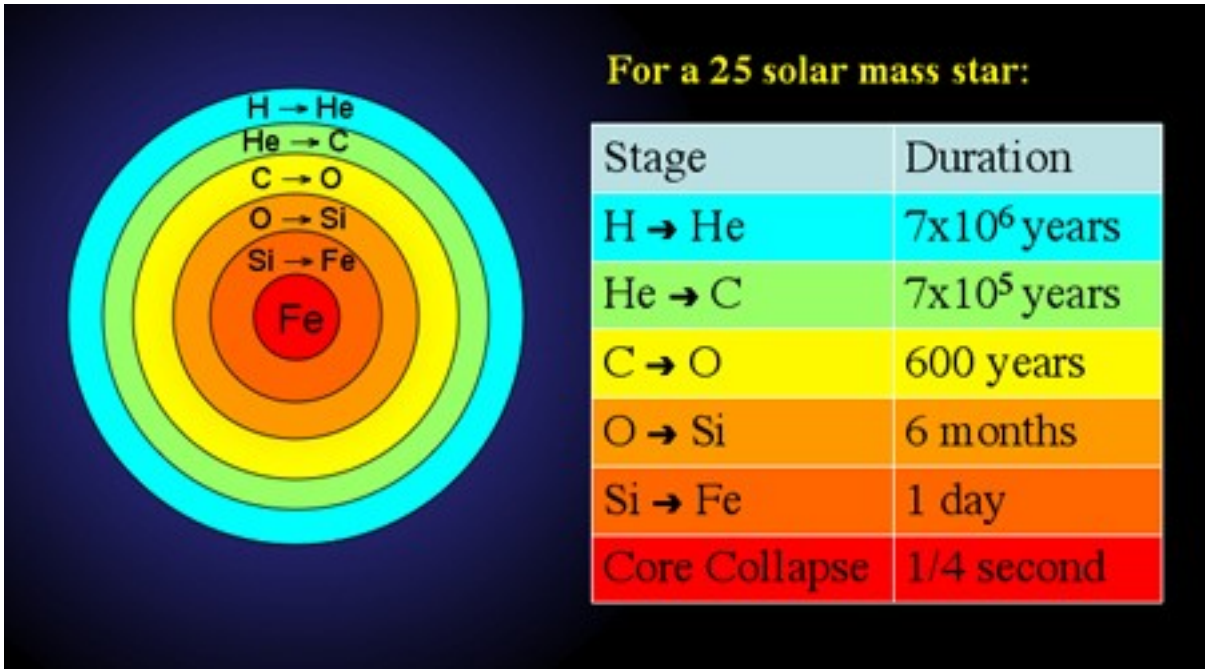
Gobierno de Chile

Optical transient sky



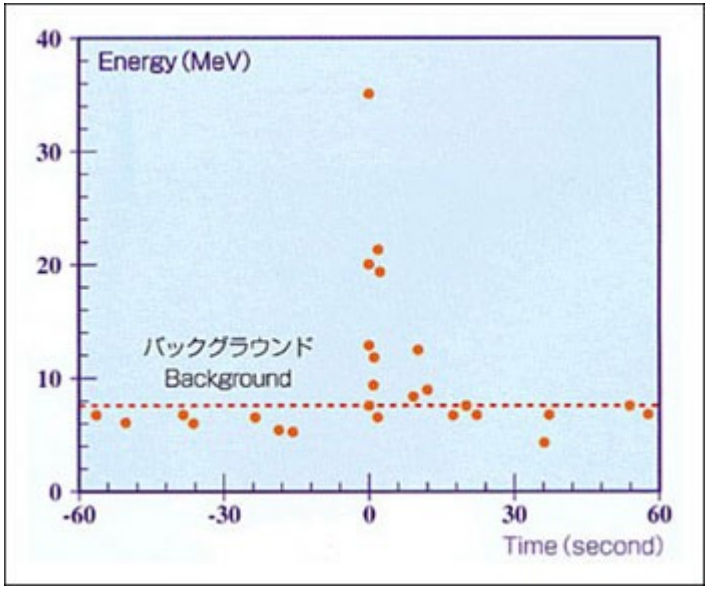
Credit: Mansi Kasliwal

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



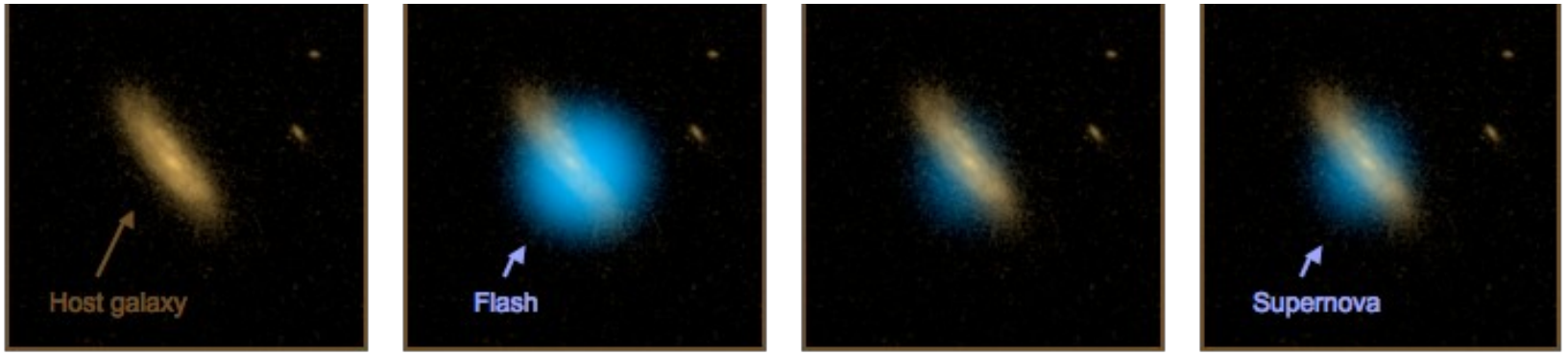
Formation of a neutron star and shock formation (~sec)

Shock emergence (~hrs) → Supernova shock breakout

Star's free expansion (~day)

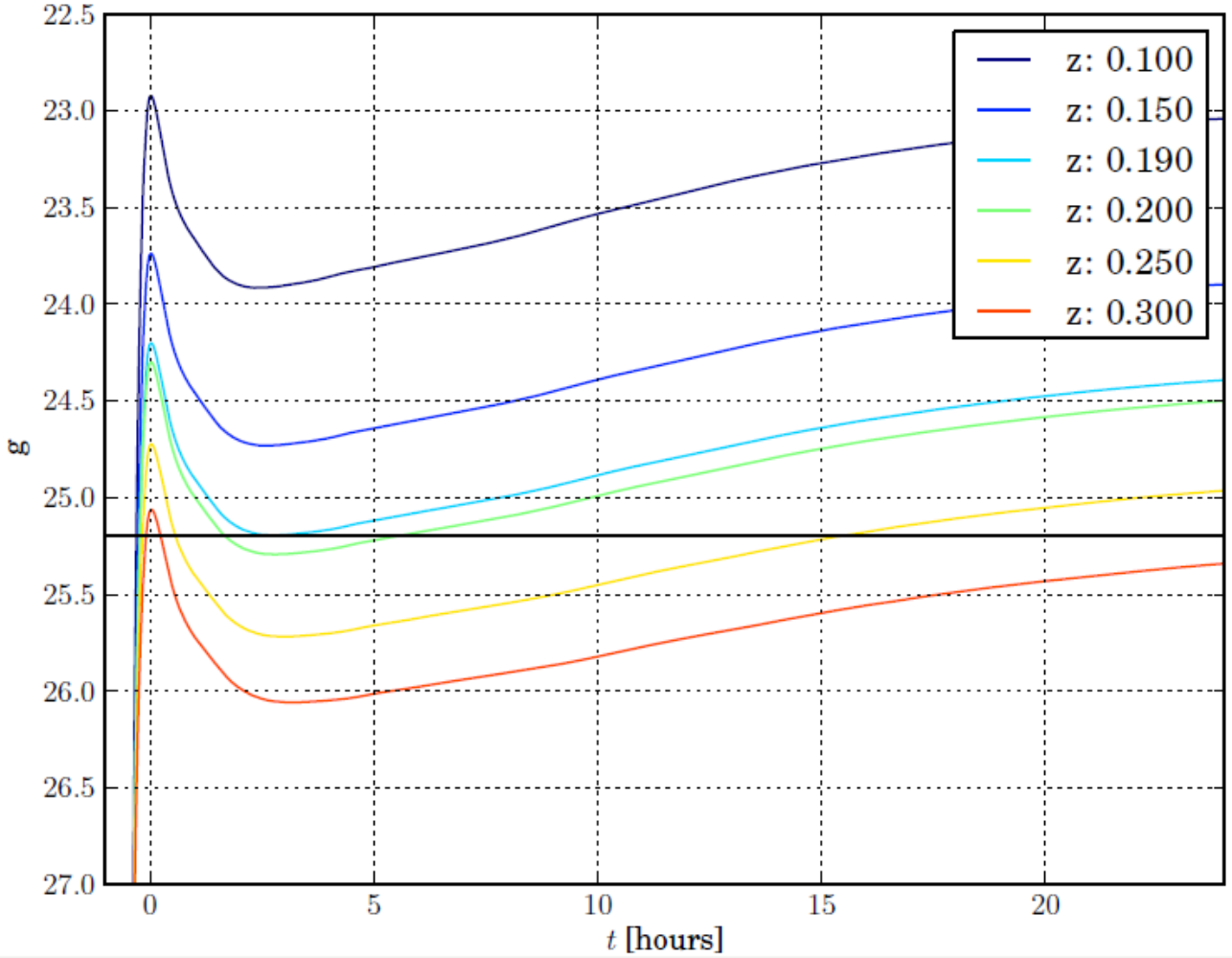
Fast expanding (~0.1 c), glowing ejecta (~weeks, months) → Main supernova light curve

Remnant diffusion into the interstellar medium (kyr)



Supernova shock breakouts with DECam

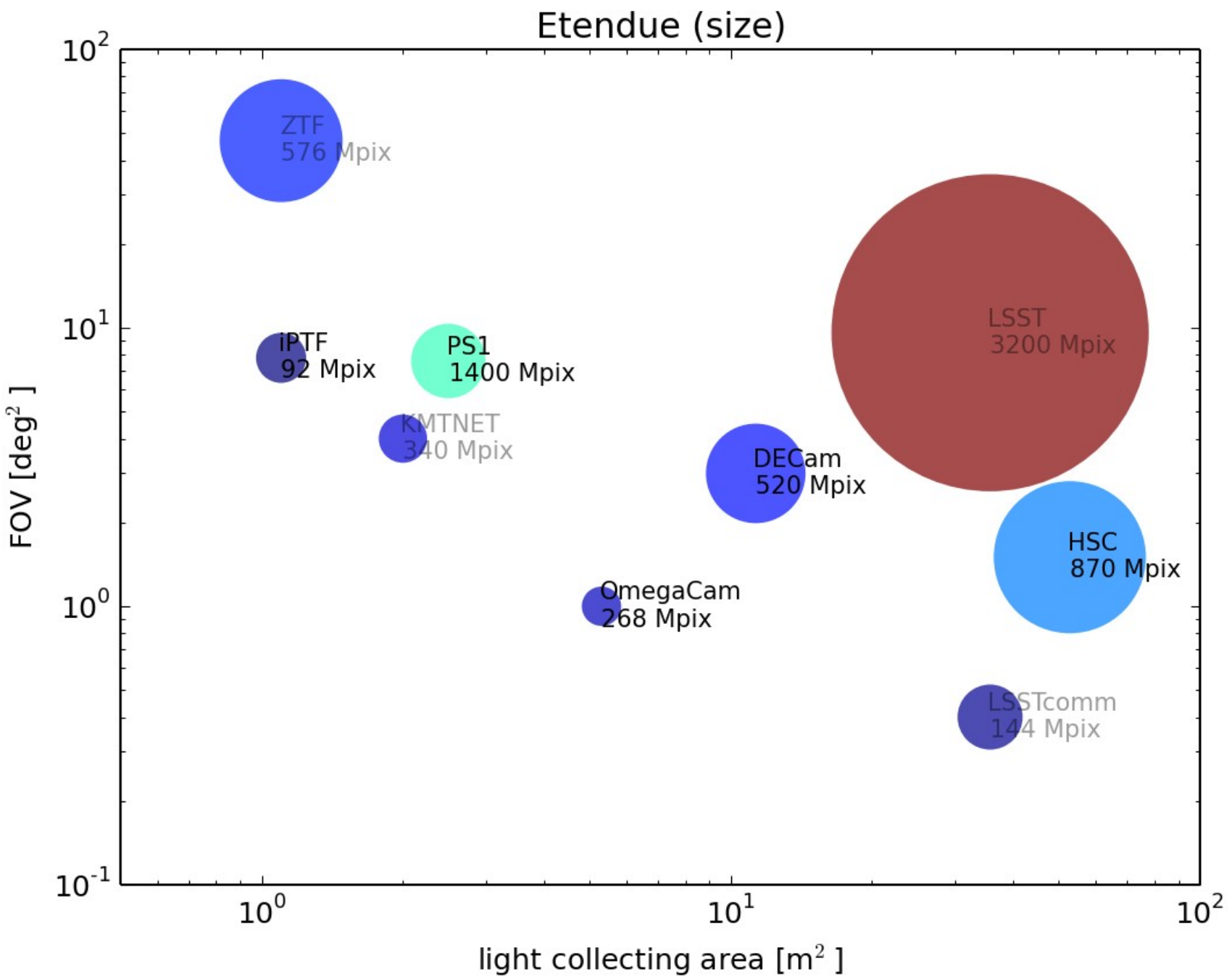
M = 13 M_{Sun}, M_{preSN} = 12.7 M_{Sun}, R_{preSN} = 564 R_{Sun}



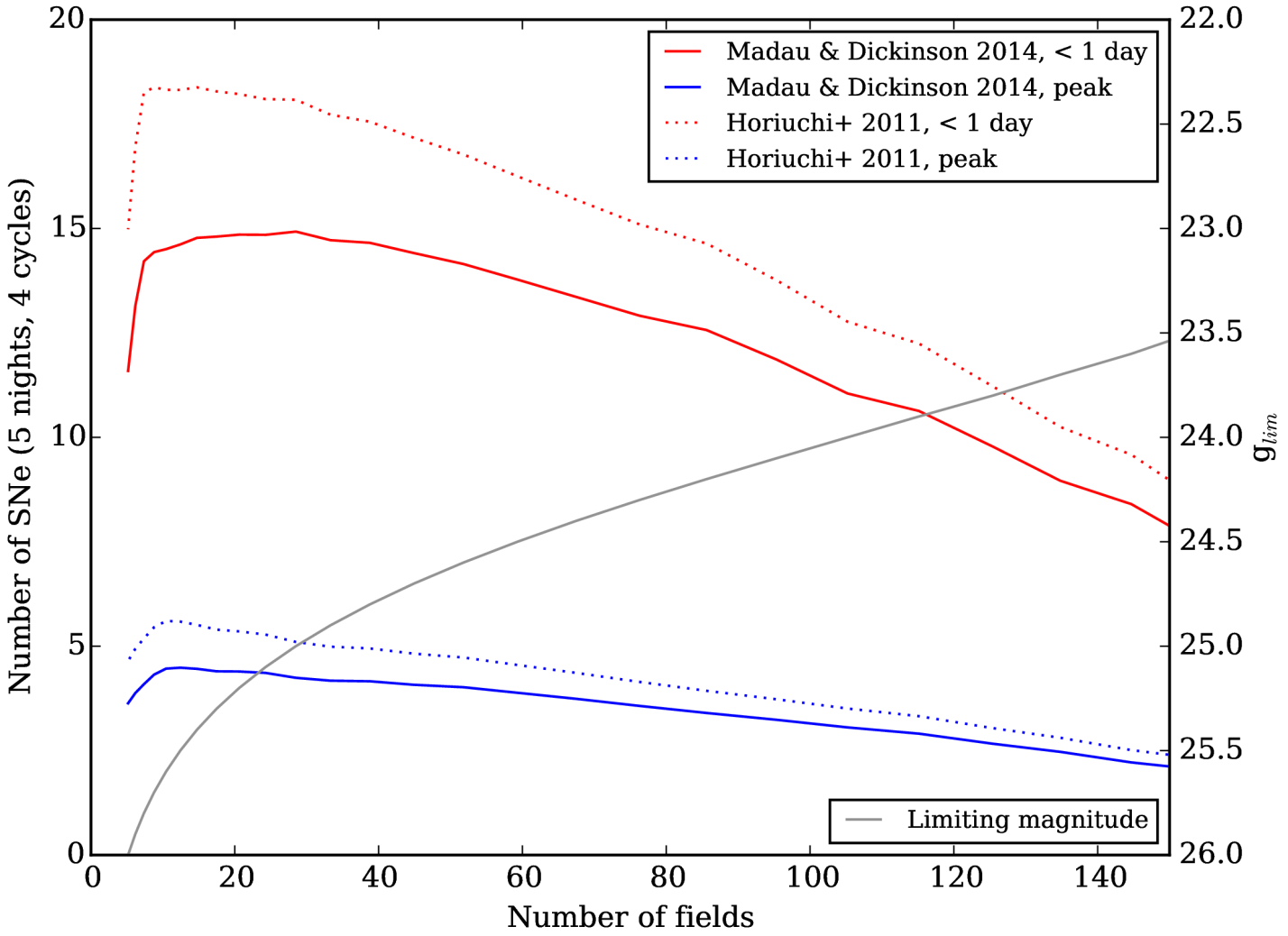
N. Tominaga

M. Hamuy

Etendue and number of pixels



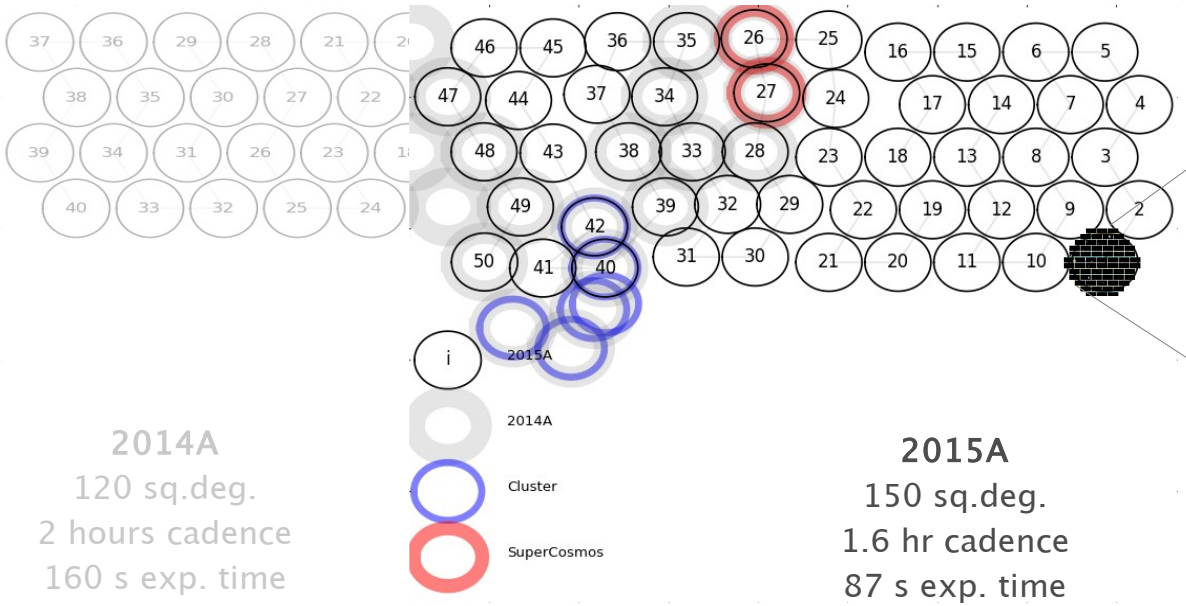
Expected number of young supernovae (SNR ~ 8)



More difficult to follow up

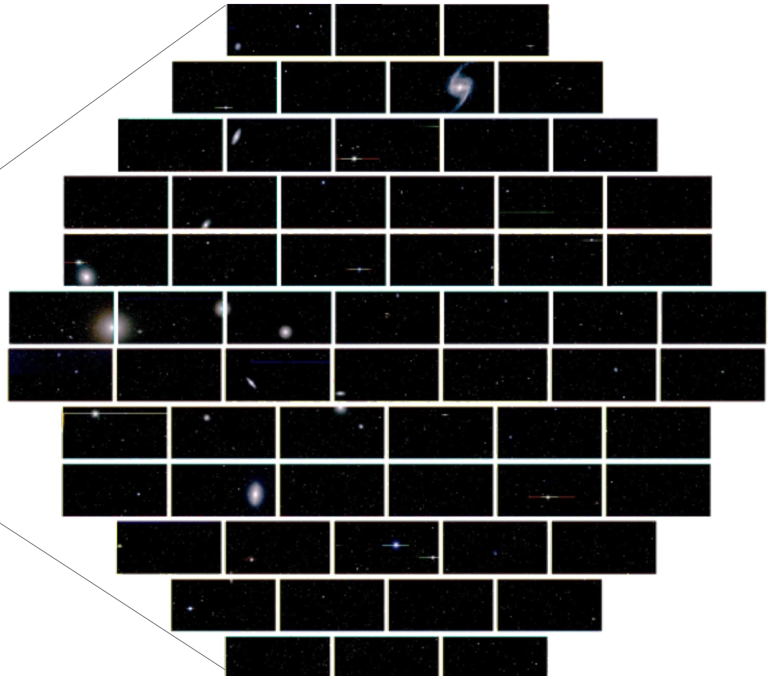
Faster file transfer/pipeline required

HITS challenges (2014A/2015A)



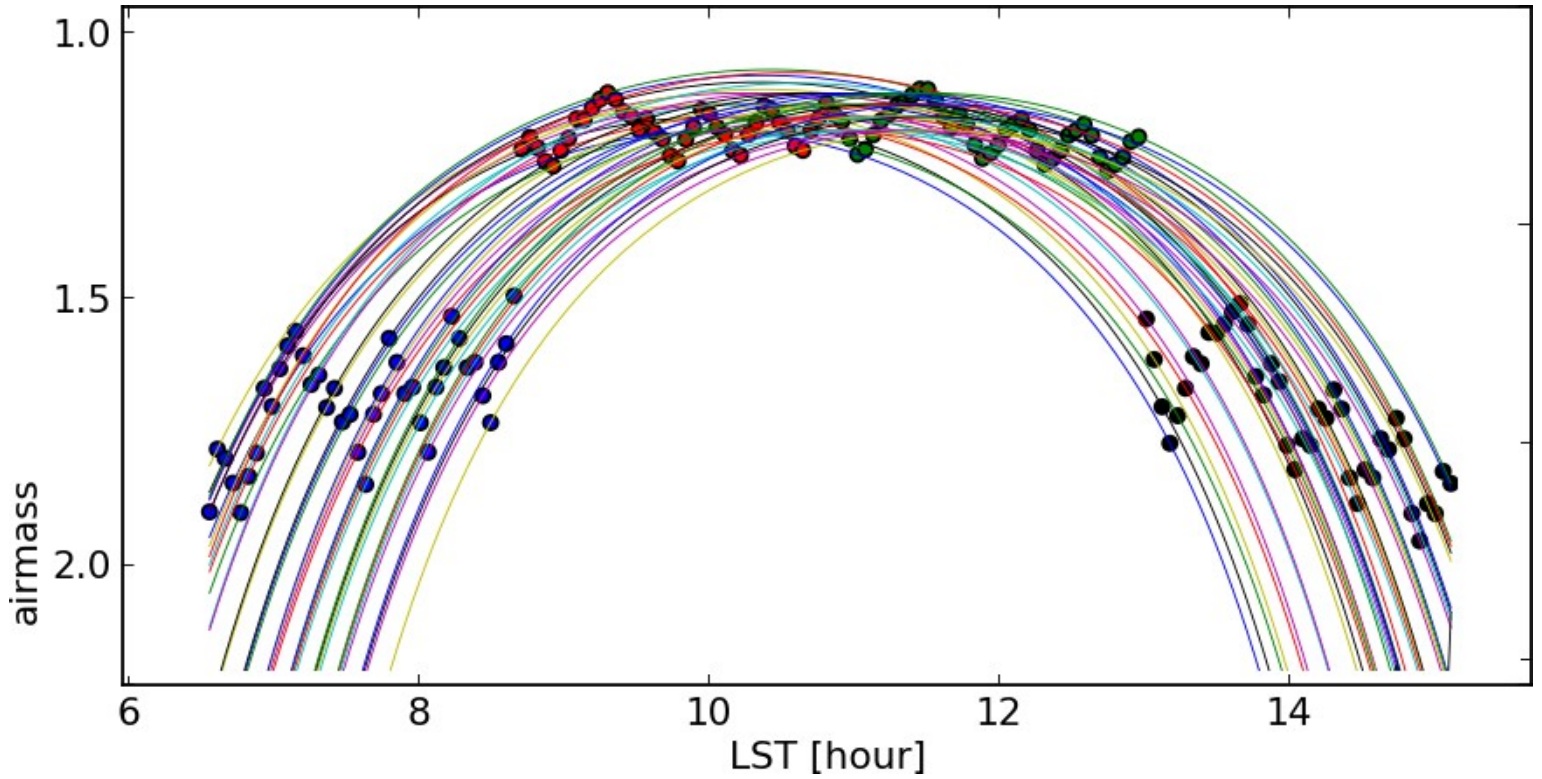
2014A
120 sq.deg.
2 hours cadence
160 s exp. time

2015A
150 sq.deg.
1.6 hr cadence
87 s exp. time



- 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)

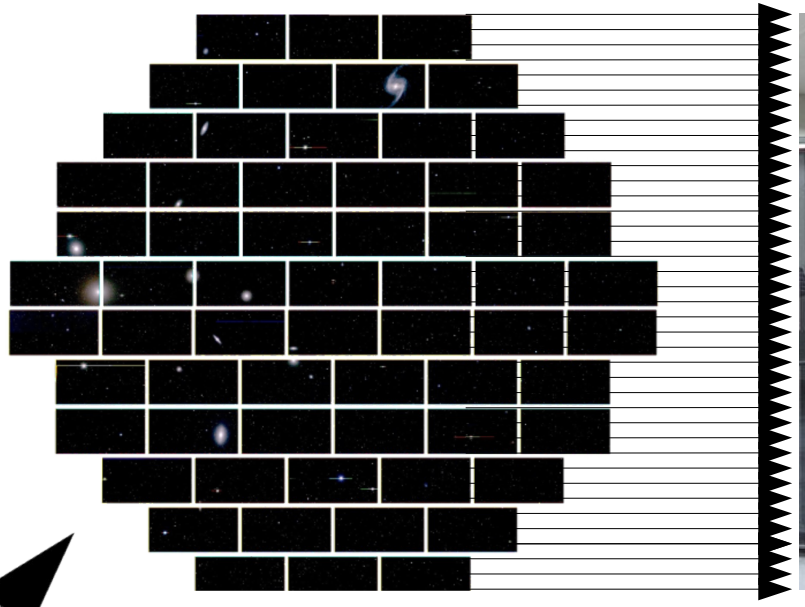
Observing strategy



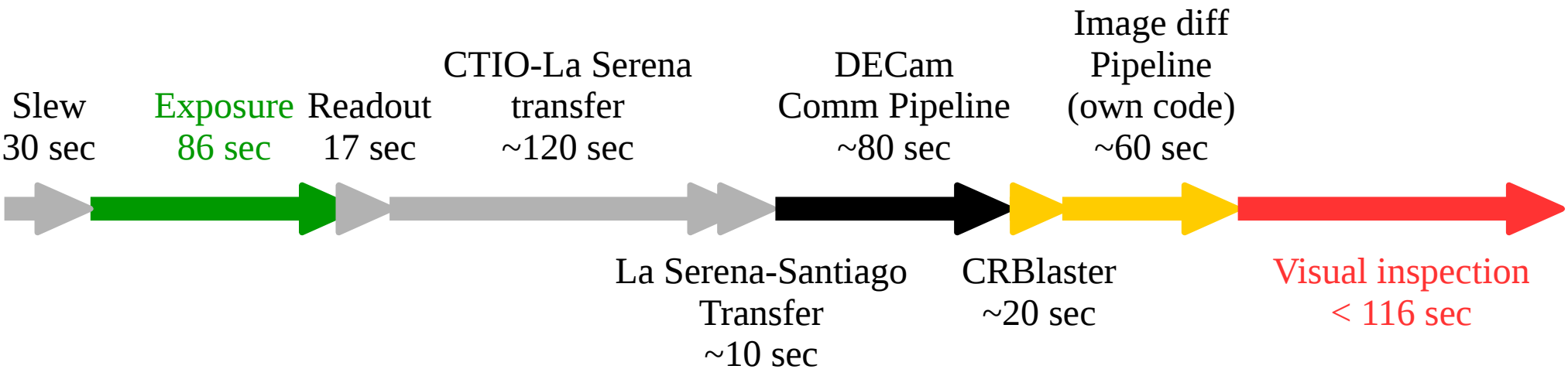
- RA chosen to guarantee full night visibility
- DEC chosen to minimize combined atmospheric + galactic extinction

- 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

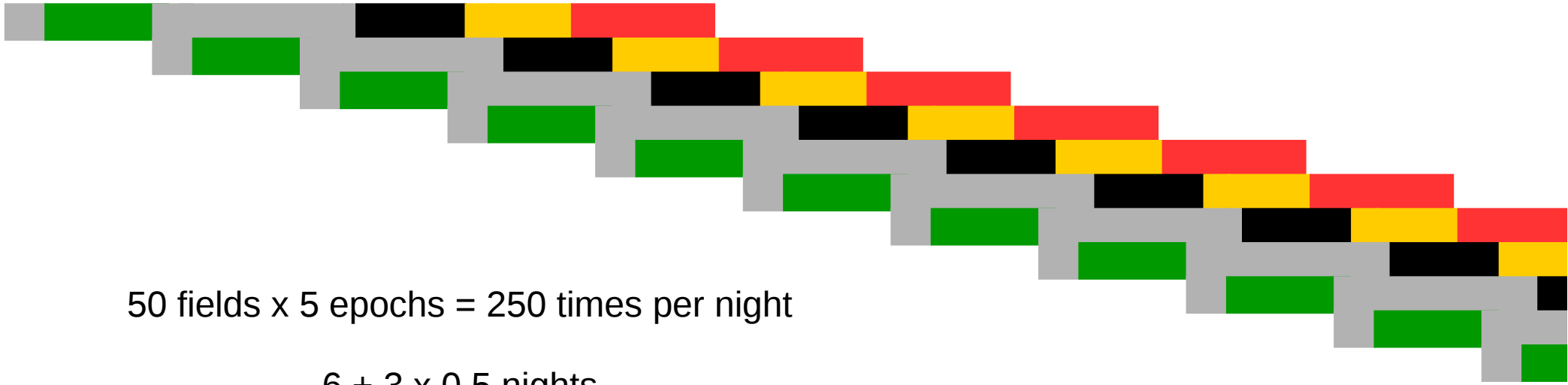
Real time processing



Pipeline flow outline



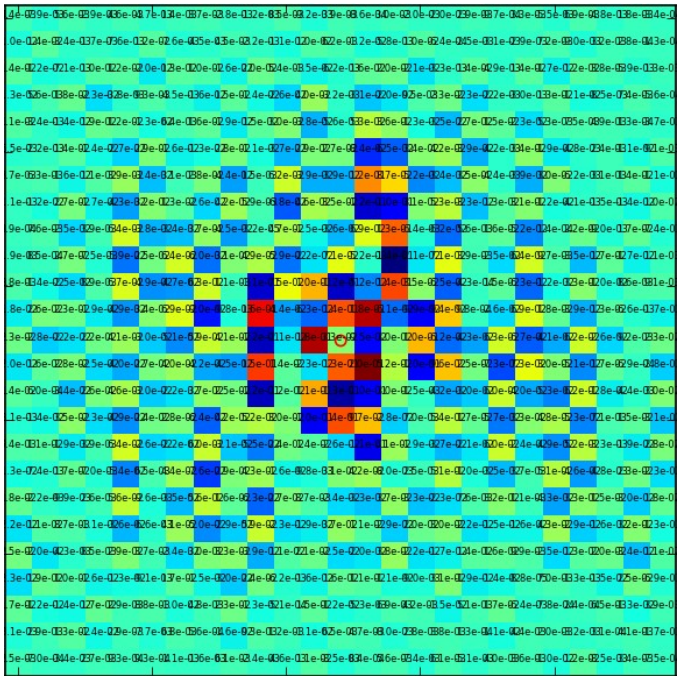
~5-6 min lag



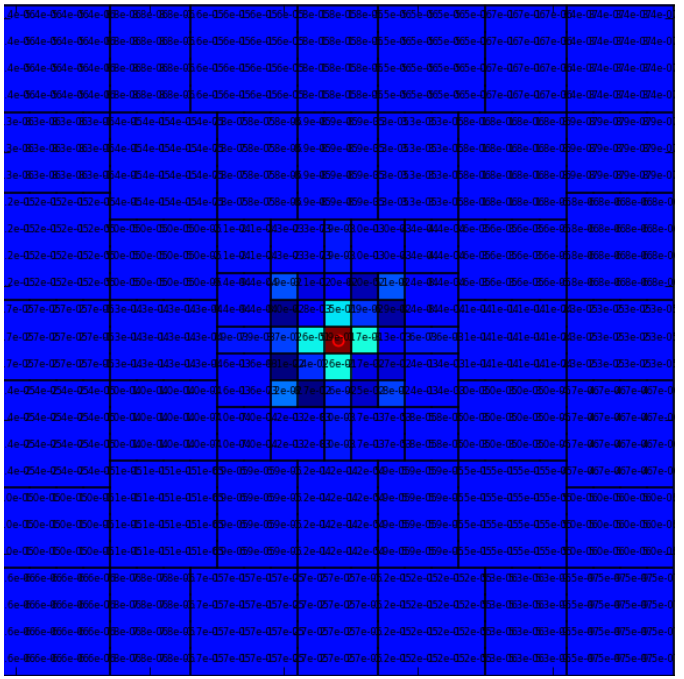
50 fields x 5 epochs = 250 times per night

6 + 3 x 0.5 nights

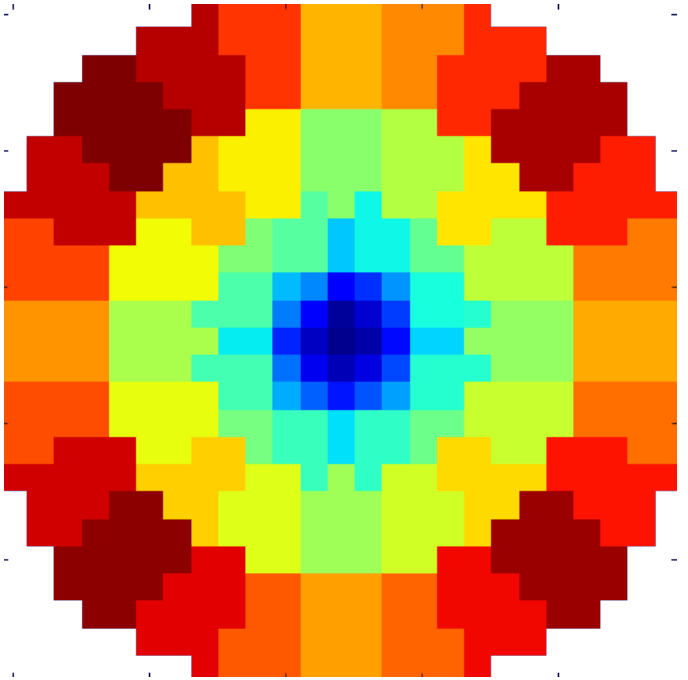
PSF matching: convolution kernel



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



Variable size kernel pixels:
no oscillations → fewer artifacts

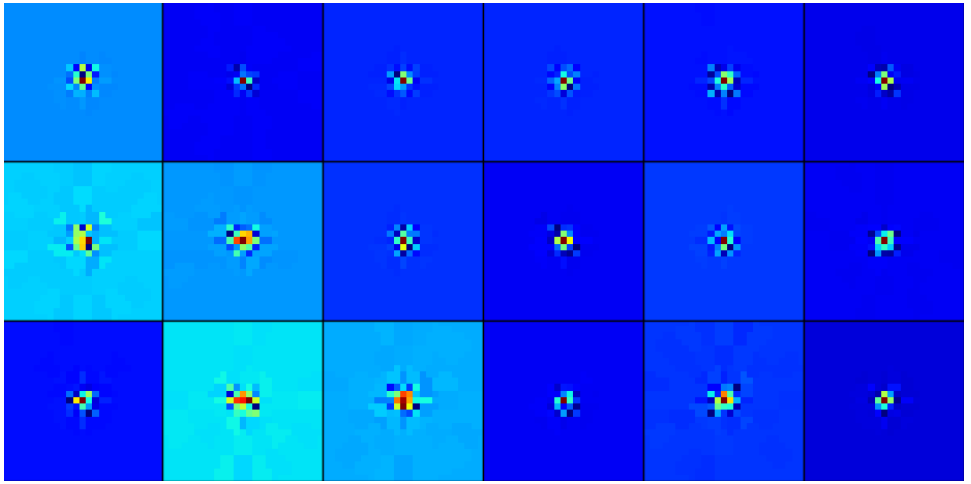


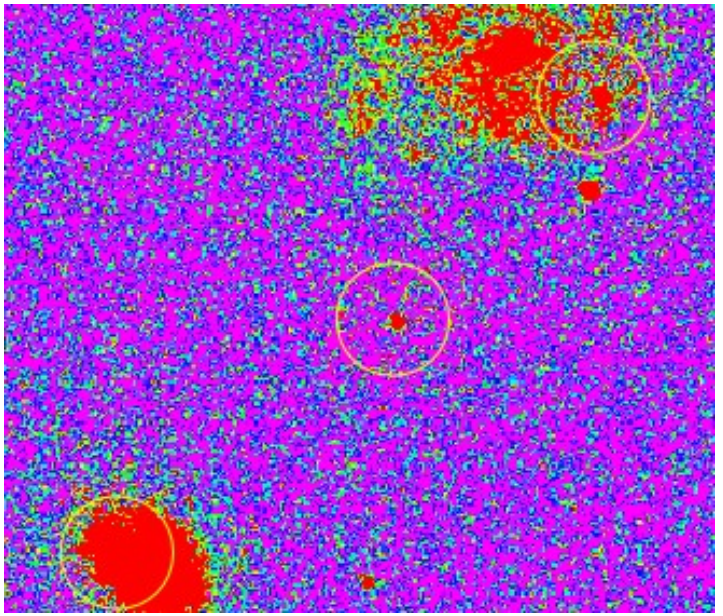
Final kernel model
25 x 25 pixels,
81 free parameters,
circular shape

(Fortran 95 + OpenMP + F2PY)

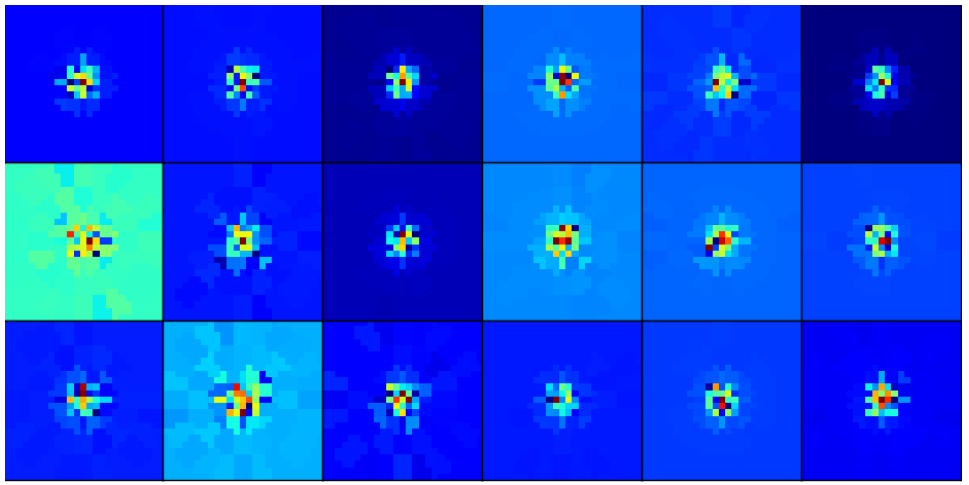
PSF matching: convolution kernel

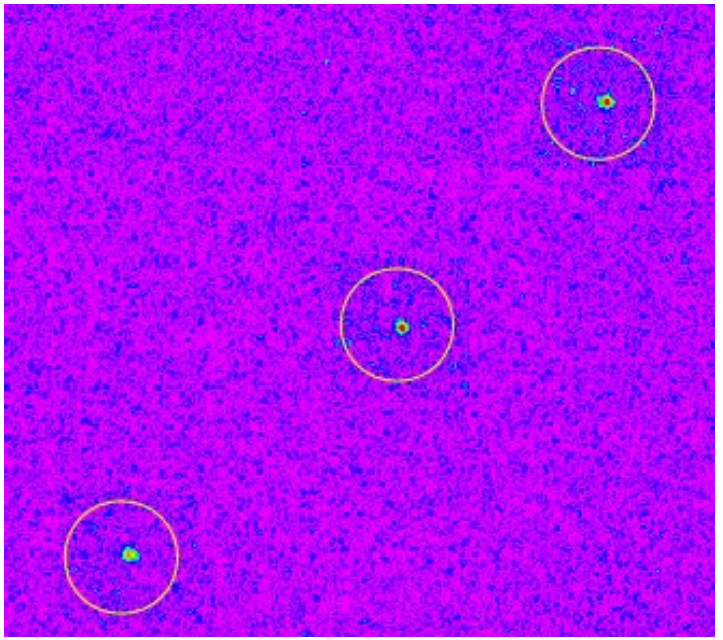
FWHM ~ $FWHM_{ref}$





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

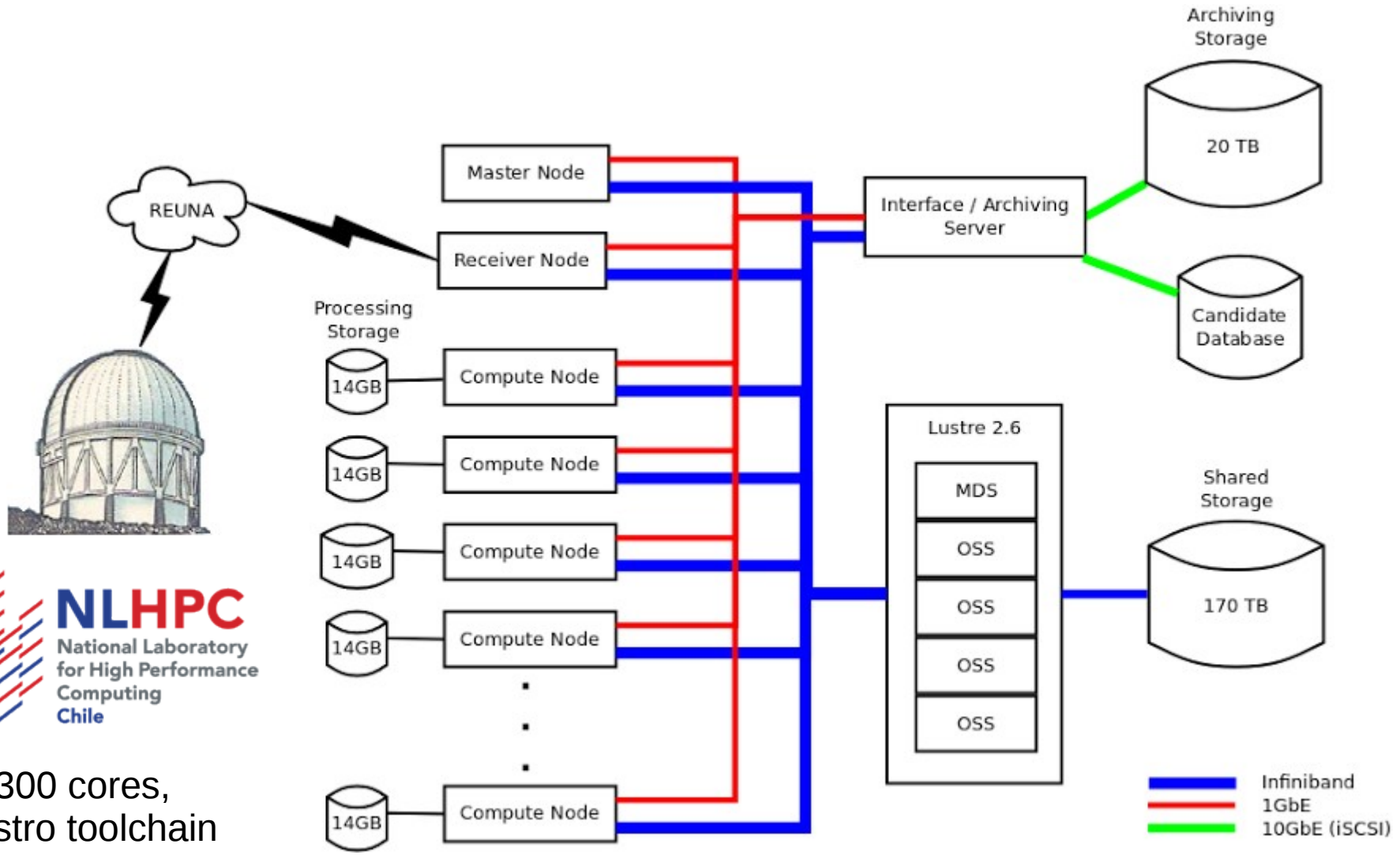
$$W_{k,l} = \frac{P^{E}_{k,l} / V_{k,l}}{\sum_{i,j} \left(P^{E}_{i,j} \right)^2 / V_{i,j}}$$

Variance at given pixel

Flux variance

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

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

Candidate selection

1. SNR of integrated flux > 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**

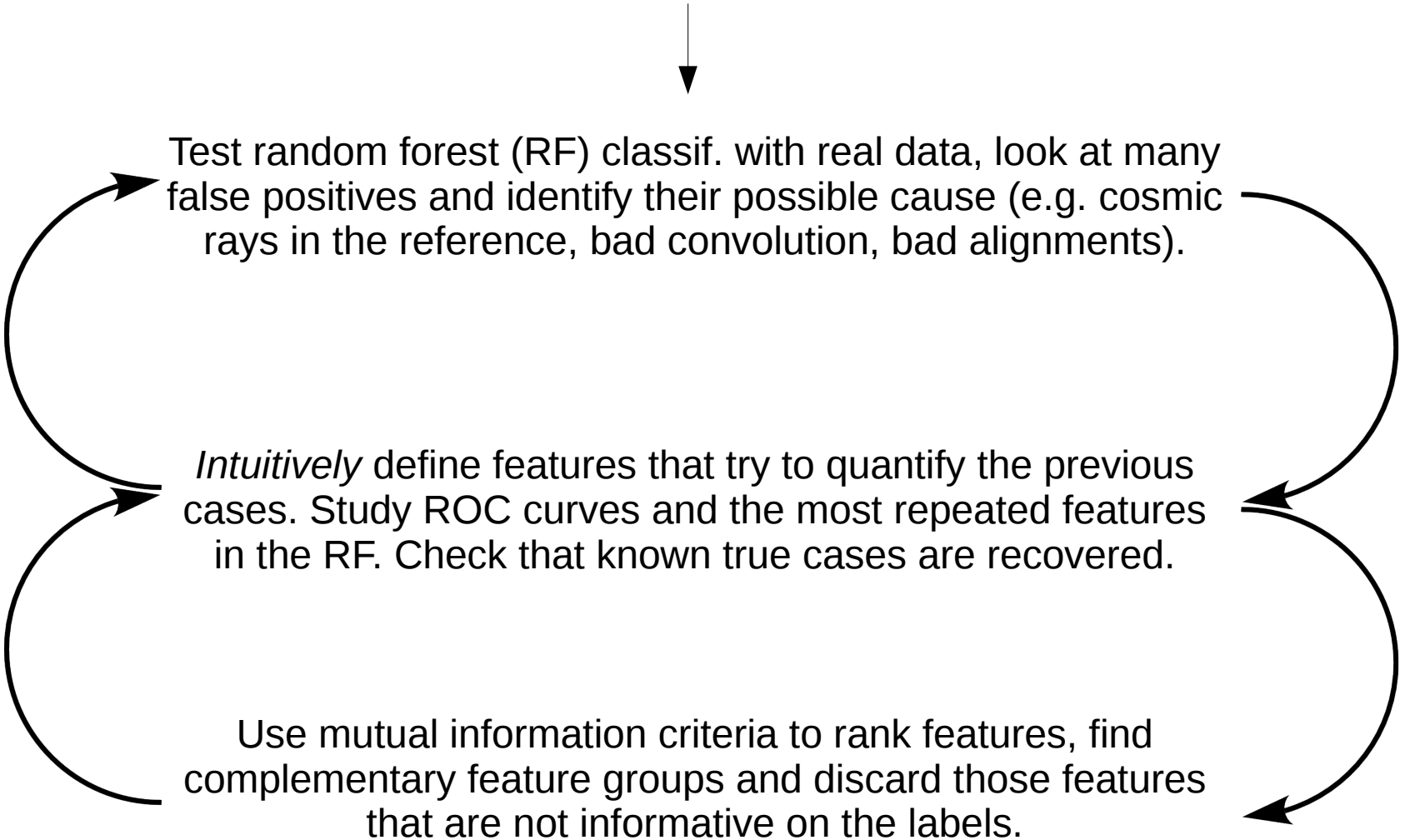
    + **repeated at least once** in the same location

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

Feature engineering

Feature engineering

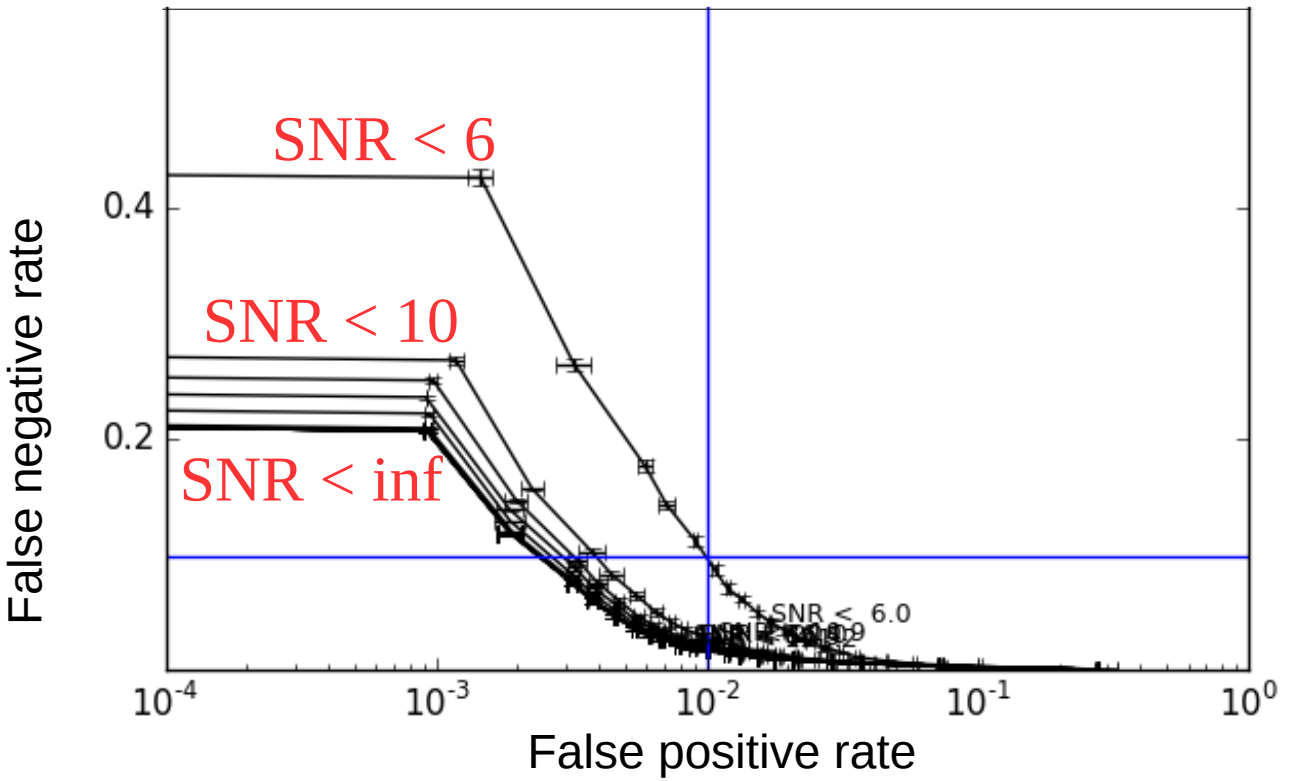
Intuitively define features based on visual inspection of many candidates. Visualize features in many dimensions and fine tune them to give a better visual separation.



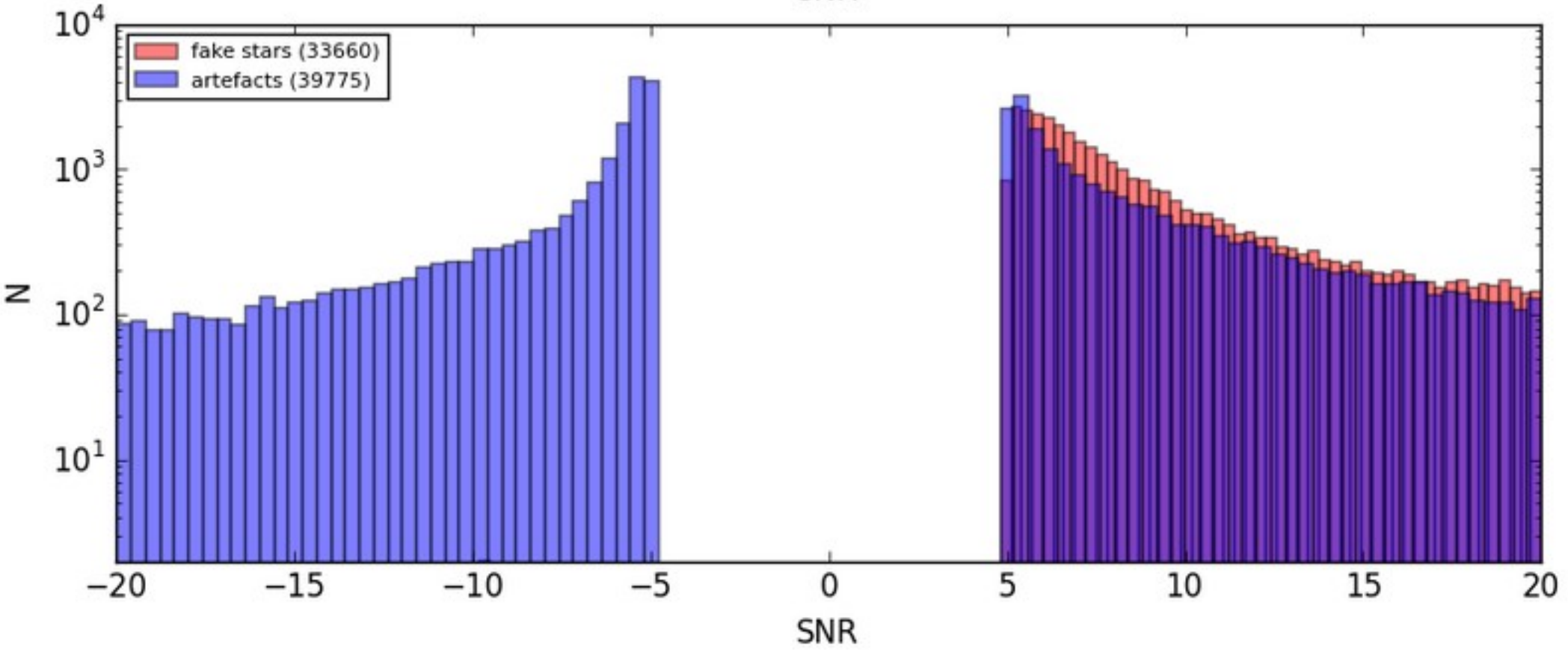
Random forest efficiency and purity

ROC curves depend strongly on the test candidate SNR.

Different SNR distributions in the training and test samples can change the ROC curve significantly



Training sample



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

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**'

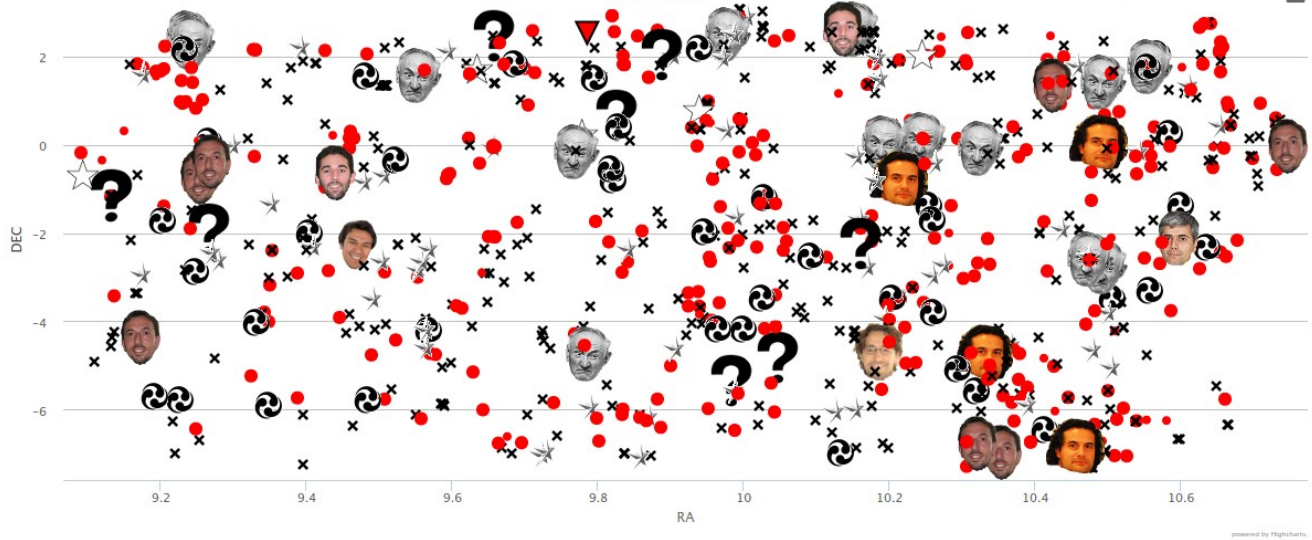
… '**ratiomax2**' '**dhu3_4**' '**dhu1_4gt**' '**nmax1**' '**nmax2**' '**ksupport**' '**PCA3**' '**dhu7_4**' '**maximmin**' '**kratio**' '**dhu7_4gt**' '**PCA2**' '**PCA5**' '**PCA1**' '**PCA4**' '**PCA6**' '**dhu7_2**' '**dhu4_4**' '**dhu2_4**' '**dhu3_4gt**' '**dhu6_4**' '**dhu5_4**' '**dhu2_4gt**'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

Interactive web

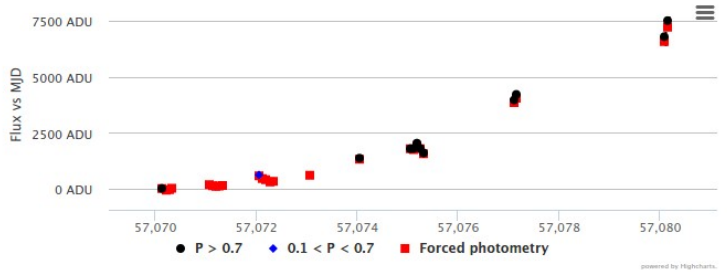
Semester: Blind15A ▾ Field: all ▾ CCD: all ▾ Reference epoch: 02 ▾ Threshold: 0.85 getData!!!

Observer : FF - Logou

USNO stars ▲ Single epoch candidates ■ Repeated candidates · Repeated positive cand. (small if matches a known star)



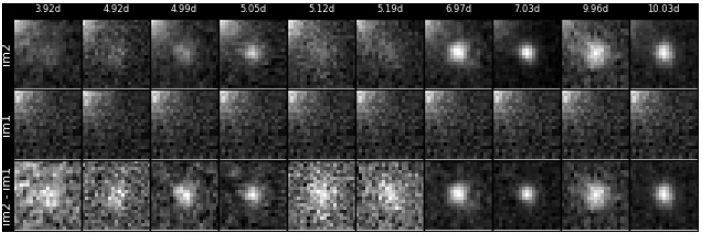
Field: Blind15A_25, CCD: S14, RA: 9:47:5.68, DEC: 2:31:49.86 (avg. pixels: 1111, 1660), probpair: 0.98, diffs: 17-02t>19-02t>20-02t>21-02t>22-02t>23-02t>25-02t>26t-02>28-02t>29-02t



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

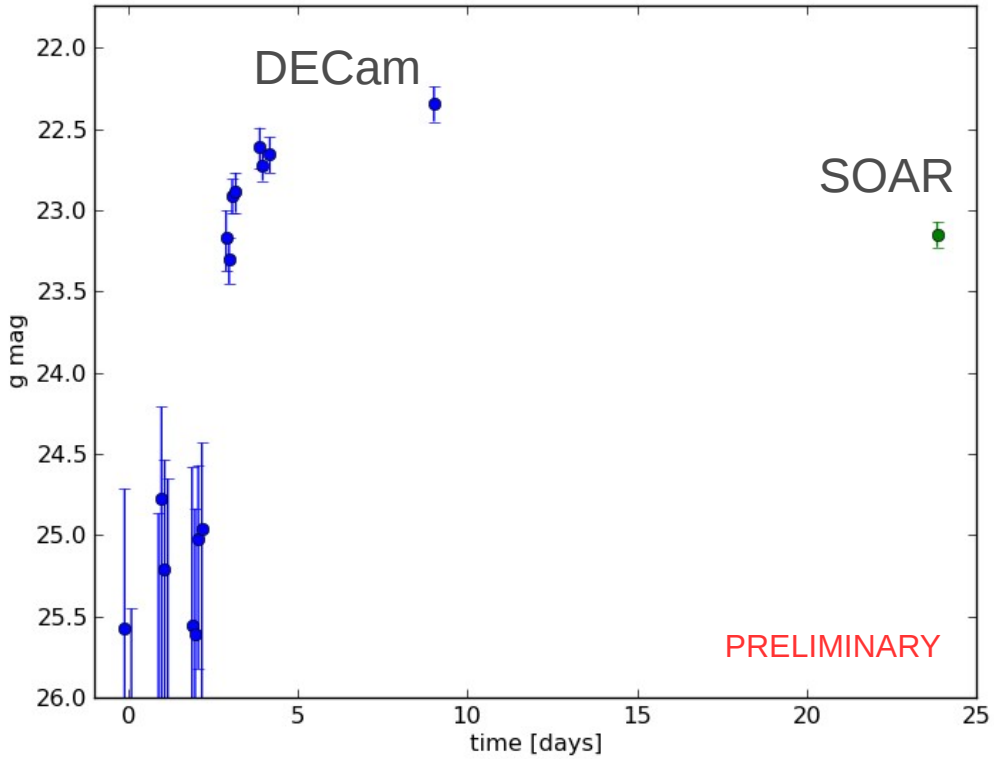
Send

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

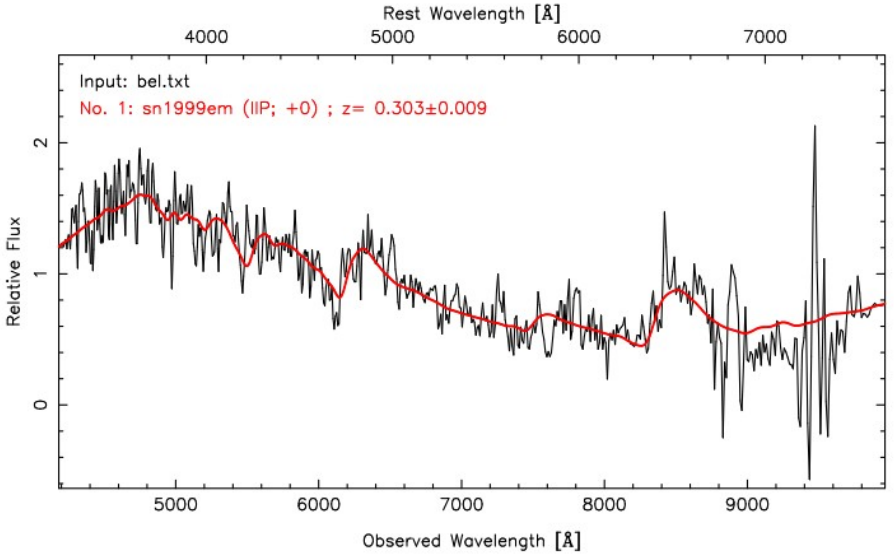


[Juan Carlos Maureira] Posible Shock Break out!
[FF] SN candidate Teahine

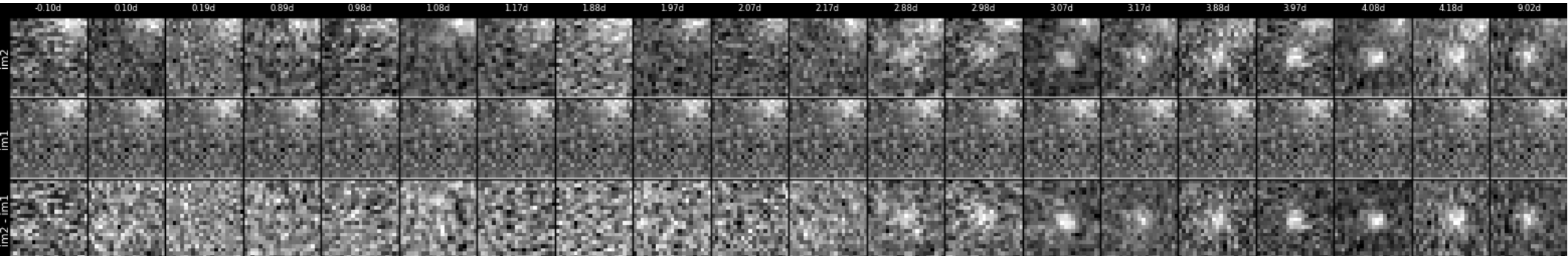
Revisit/follow up strategy



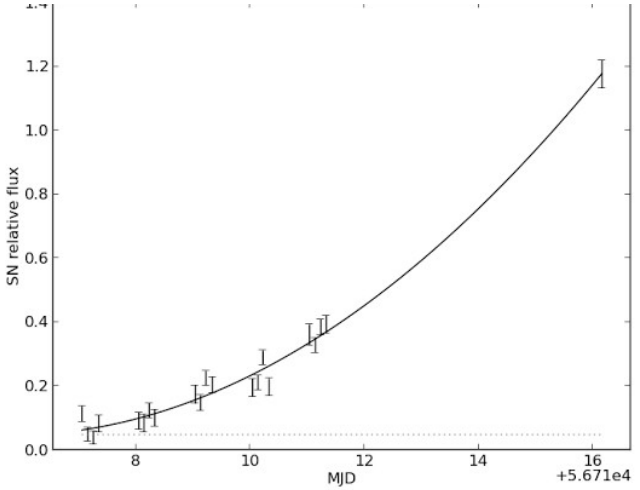
VLT



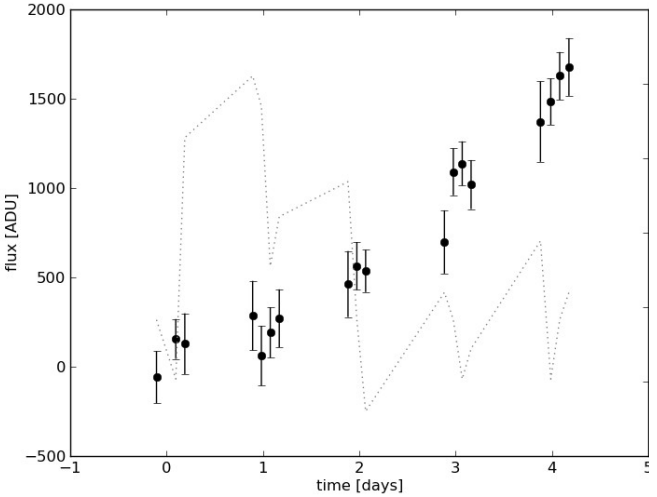
Cannot reconcile high luminosity + fast evolution + low expansion velocities (CSM interaction?)

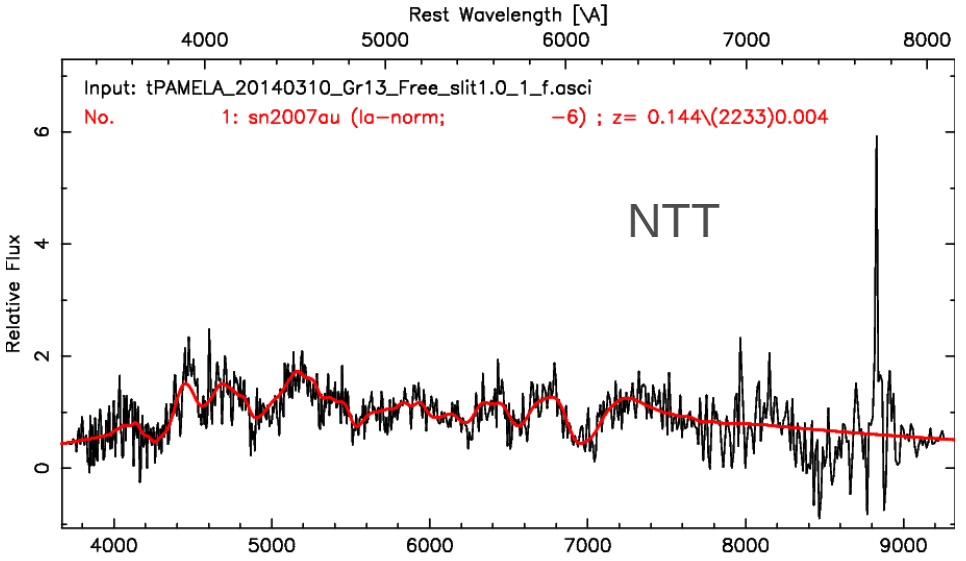


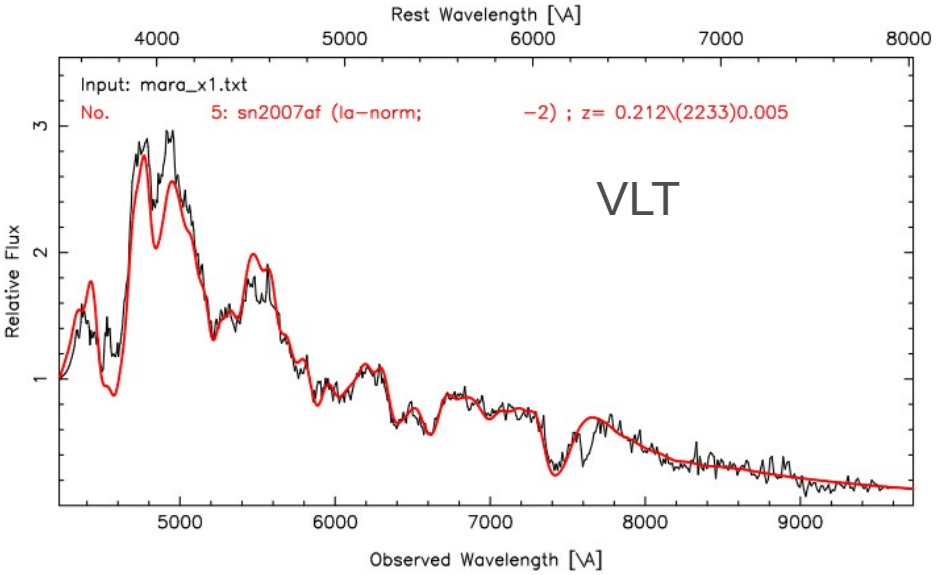
Follow up strategy

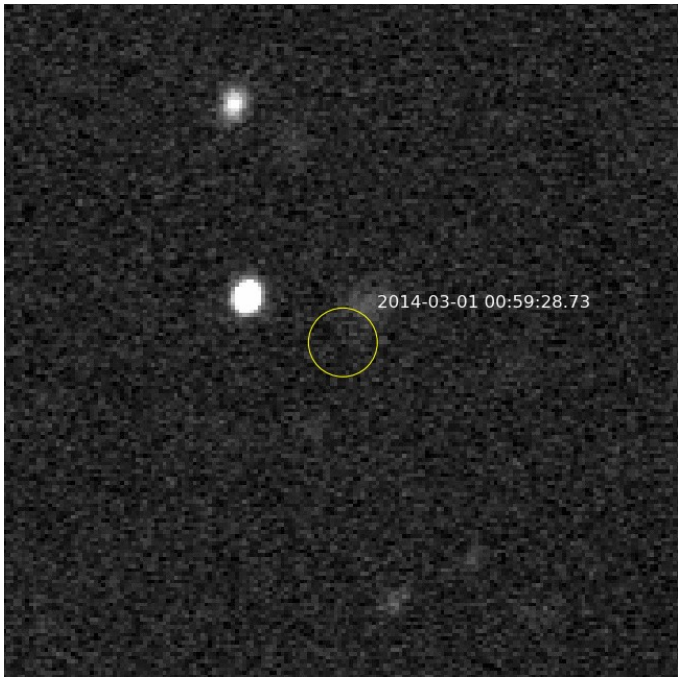


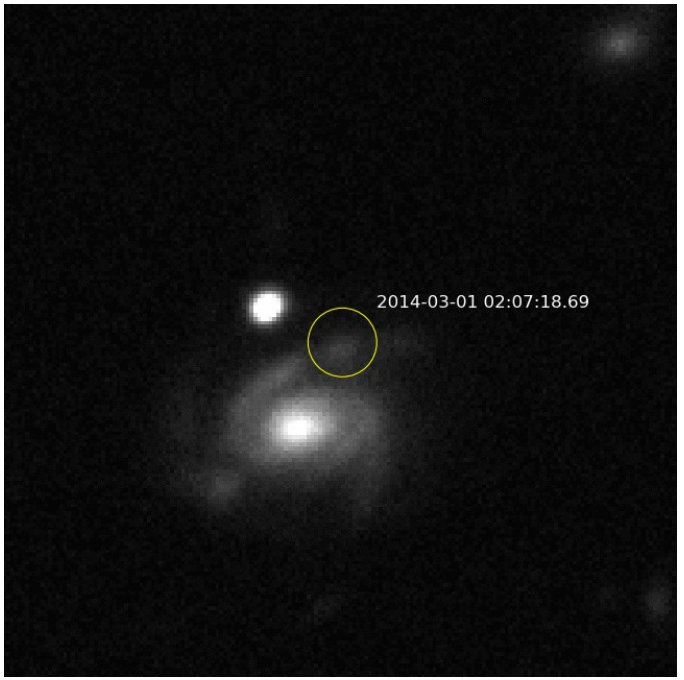
PRELIMINARY

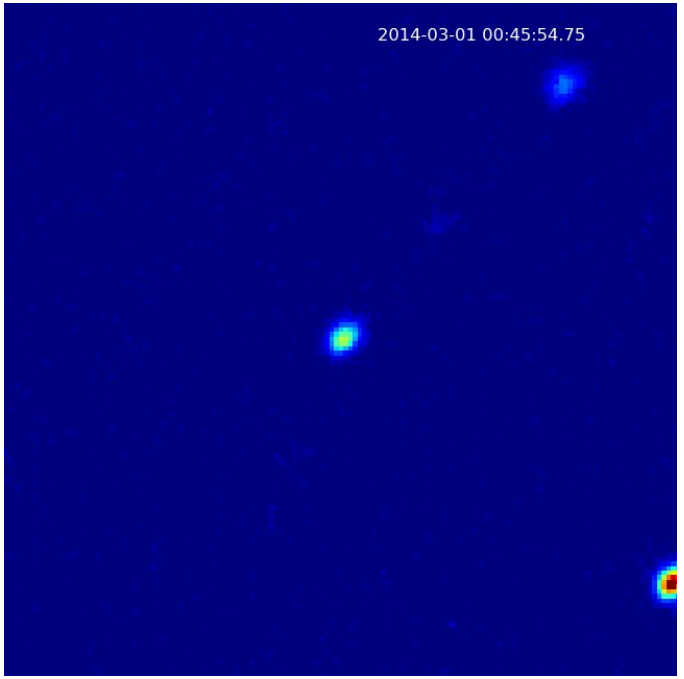


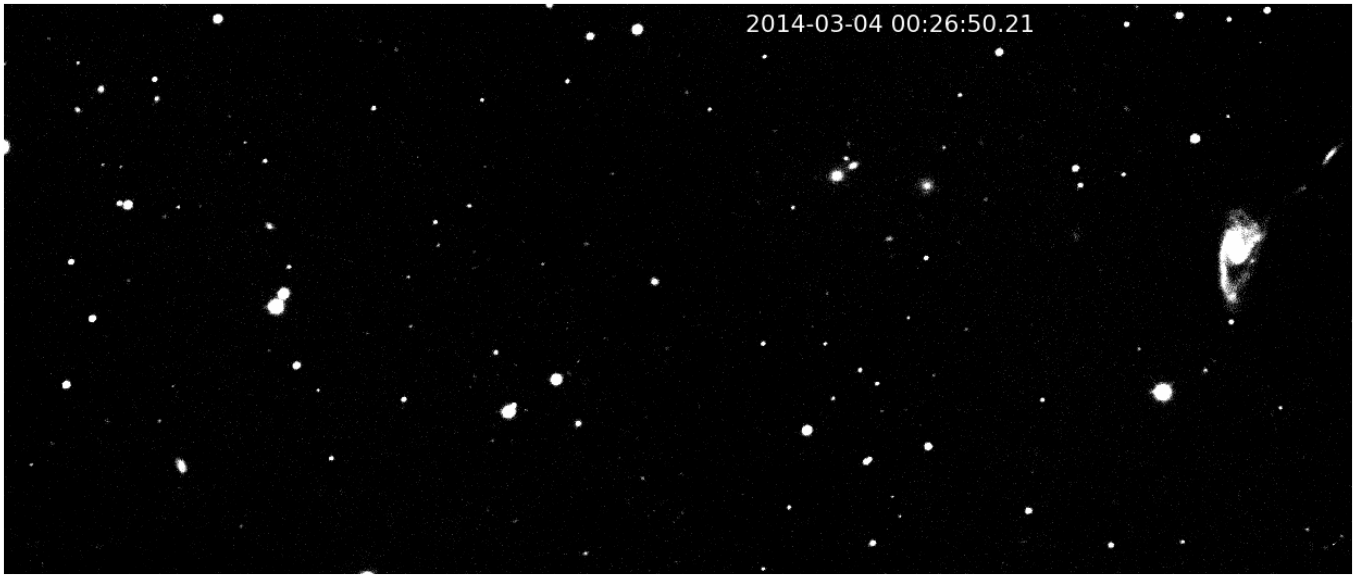


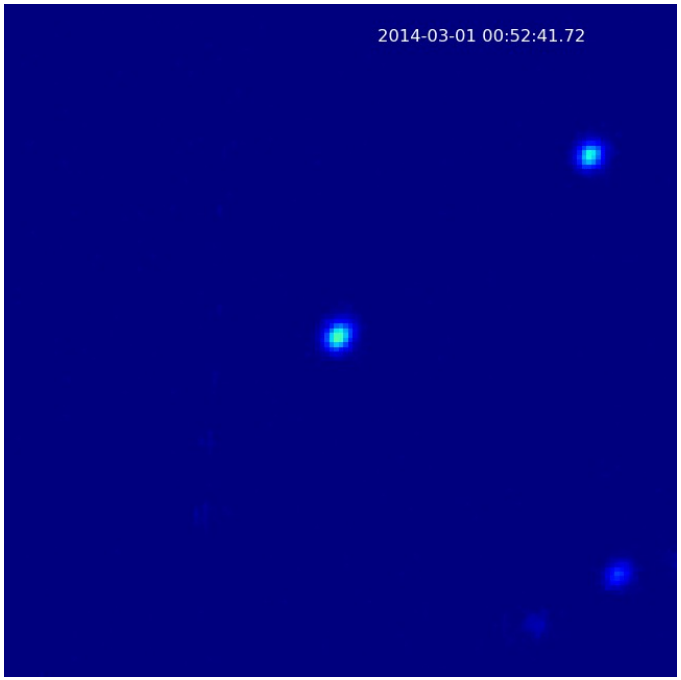




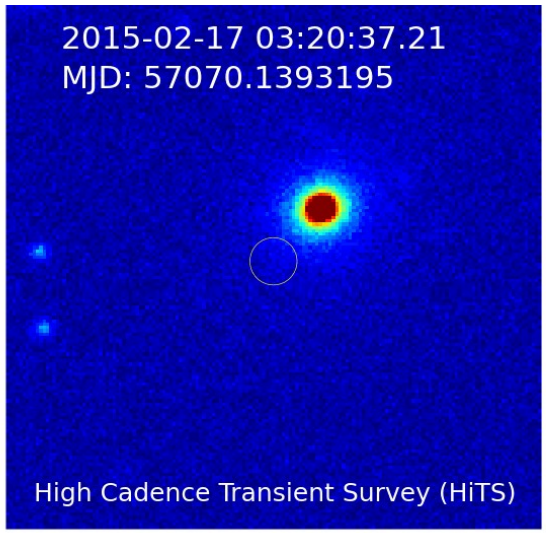


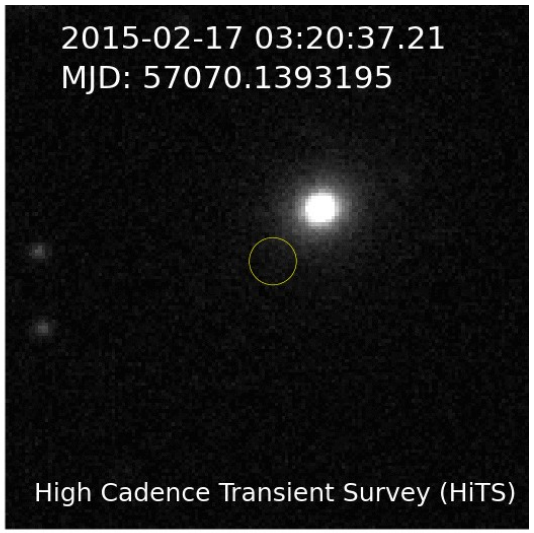


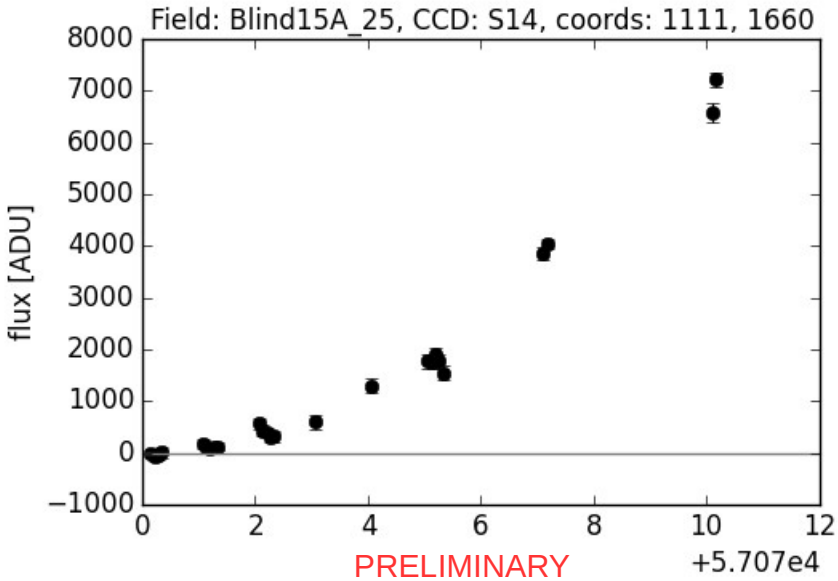


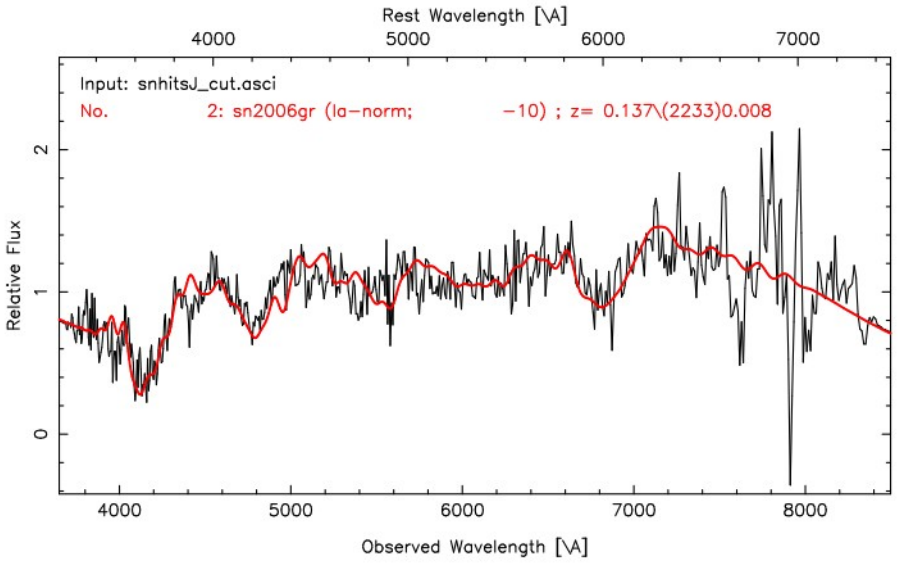


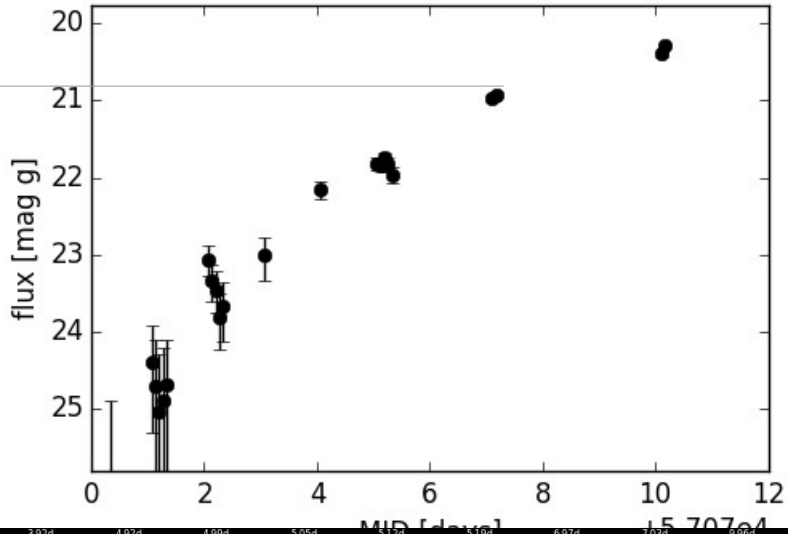
ATELs 5949, 5956

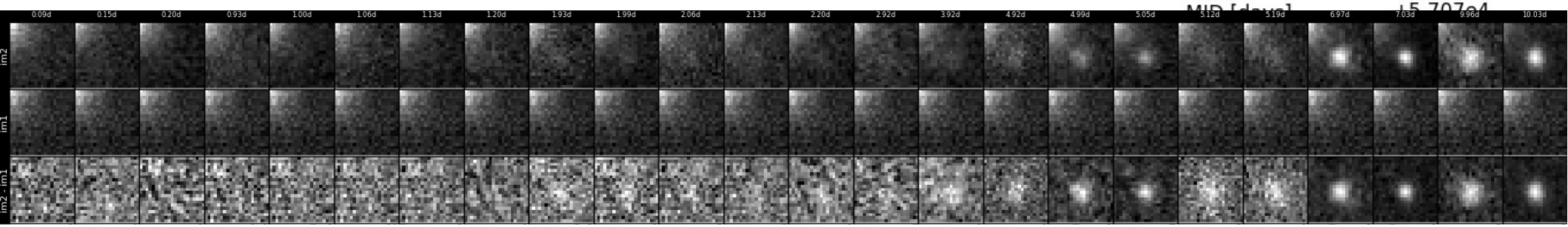












ATELs 7099, 7108, 7115, 7122, 7131, 7146, 7148, 7149

Summary

DECam offers a unique opportunity to study the transient sky today!

First real time DECam data reduction achieved (~0.4 Tpix processed in real−time in 2014, ~1 Tpix processed in 2015, ~1.5 TB raw data, ~40 TB processed data).

SN candidates made public the same night of discovery.

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

12 young SN candidates discovered in 2014A (**32** young SN candidates after reanalysis with new classifier), **61** young SN candidates in 2015A.

>100 new RR Lyrae stars, >1000 new asteroids, dozens of unknown objects (flares? other?)

No shock breakout events, but sample of very young SNe (< 1 day).
We need more non−detection → detection → confirmation **triplets.**

Interdisciplinary collaboration crucial for Astronomy in Big Data era

THANKS!

CMM Center for Mathematical Modeling

NLHPC National Laboratory for High Performance Computing Chile

MILLENNIUM INSTITUTE OF ASTROPHYSICS

CONICYT Ministerio de Educación Gobierno de Chile

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http://www.ctio.noao.edu/noao/content/Acknowledgment-DECam#sthash.Z7MCPHs3.dpuf

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Training the next generation of scientists (in fields of astronomy, mathematics, computer science, and others) in the tools and techniques of massive data in Astronomy

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