HITS: High cadence Transient Survey at CMM / MAS

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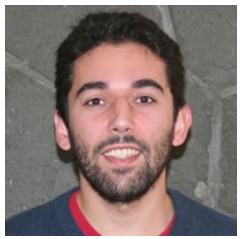
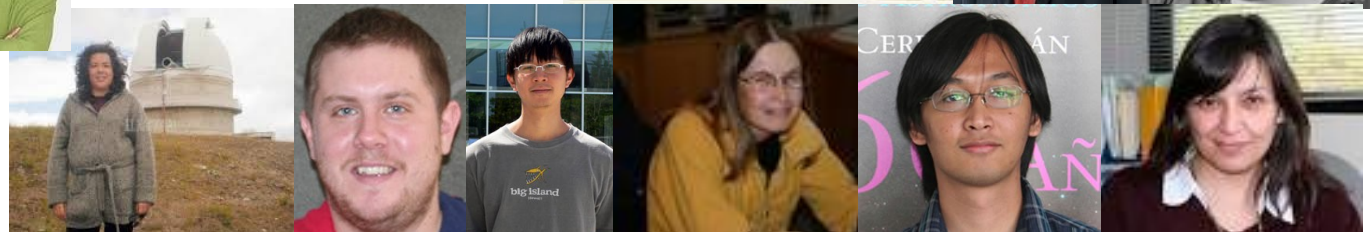
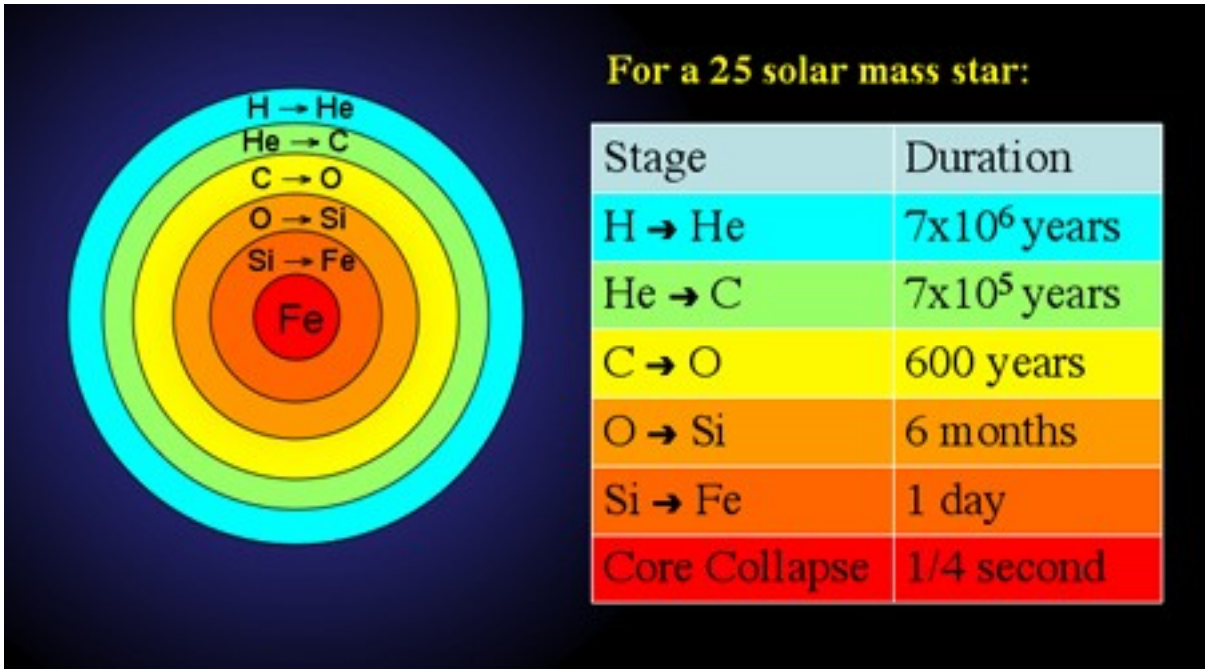
The HITS team (PI: Förster)



- Search strategy
- Observations
- Data transfer
- Image subtraction
- Feature design
- Classification
- HPC
- Follow up

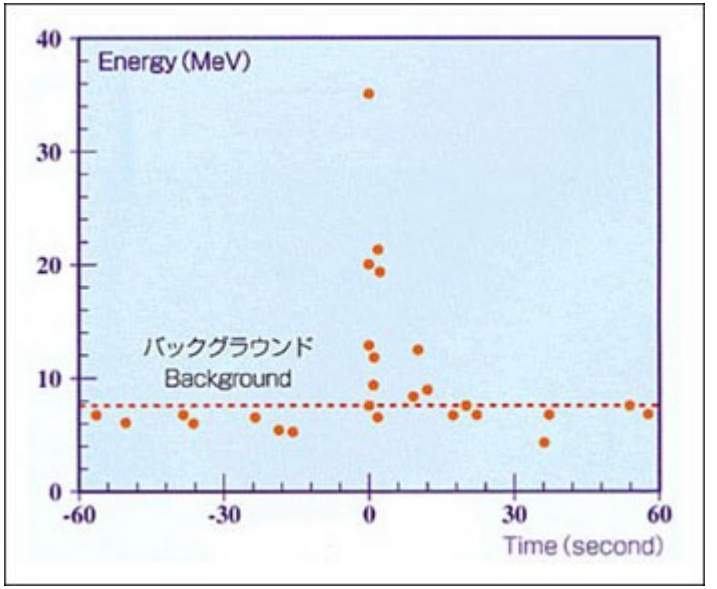


Life and death of a massive star

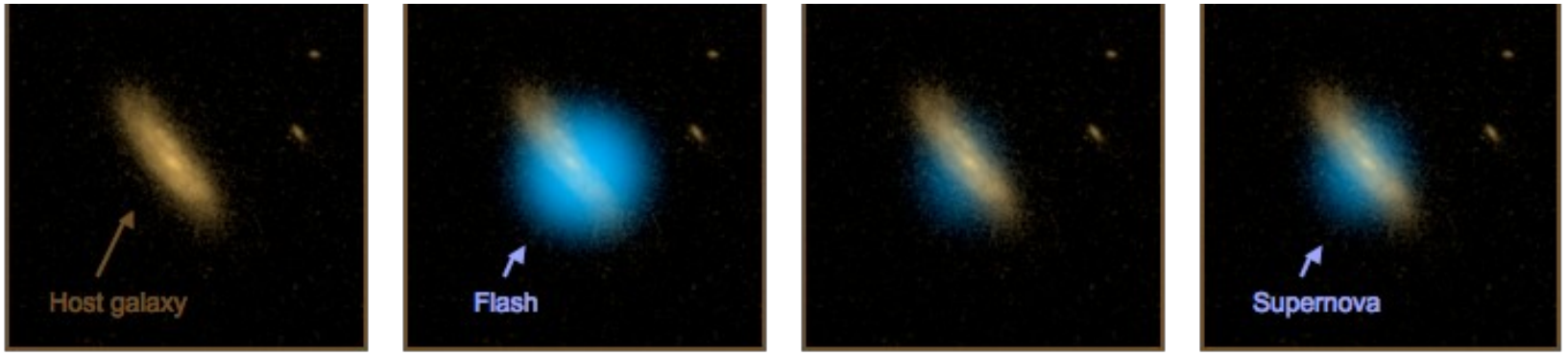


For a 25 solar mass star:

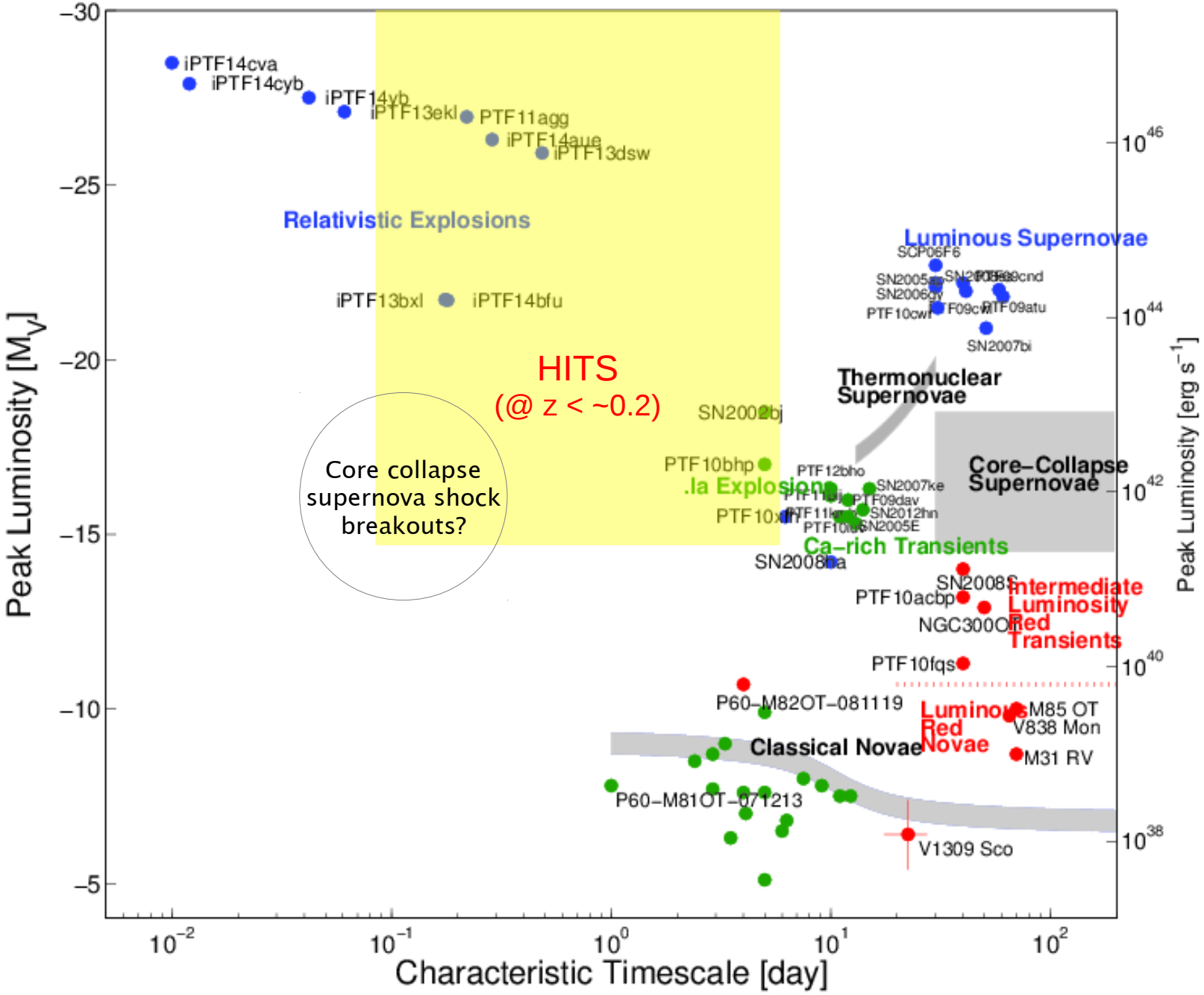
Stage	Duration
H → He	7×10^6 years
He → C	7×10^5 years
C → O	600 years
O → Si	6 months
Si → Fe	1 day
Core Collapse	1/4 second



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

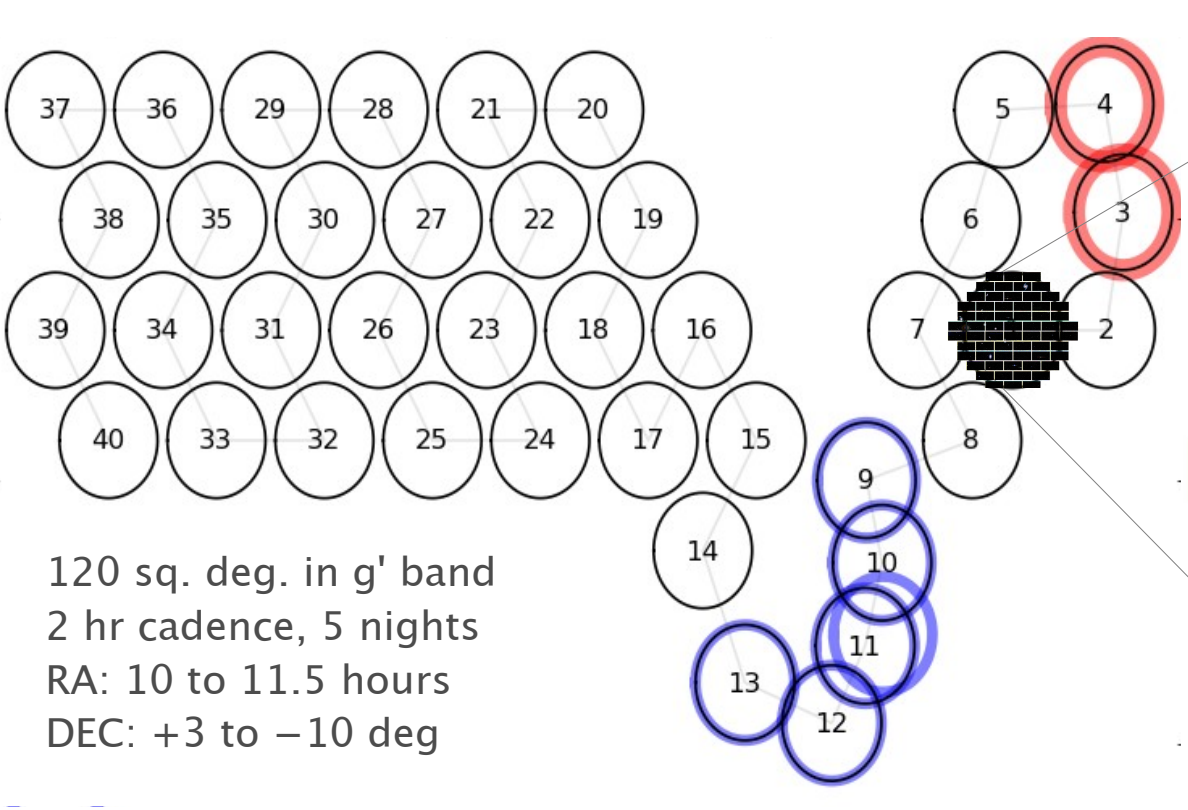


Transient sky

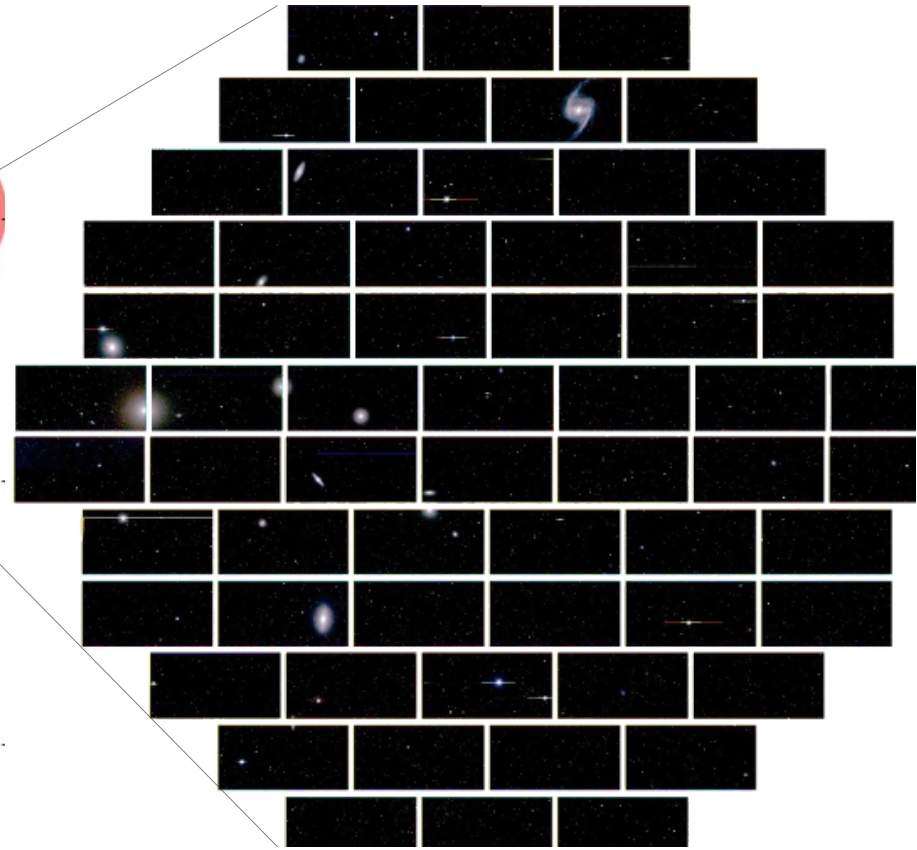


Credit: Mansi Kasliwal

HITS challenges

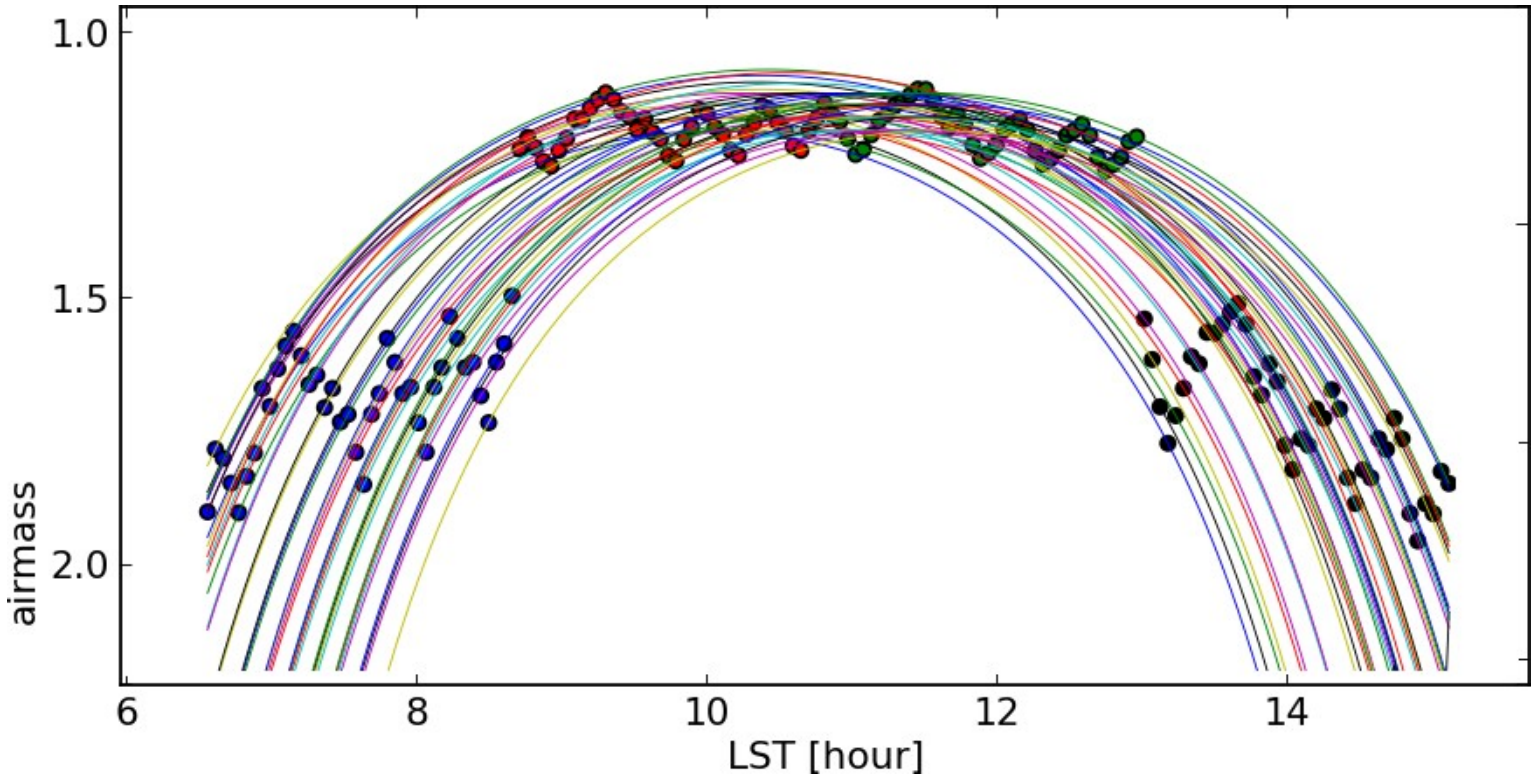


120 sq. deg. in g' band
2 hr cadence, 5 nights
RA: 10 to 11.5 hours
DEC: +3 to −10 deg



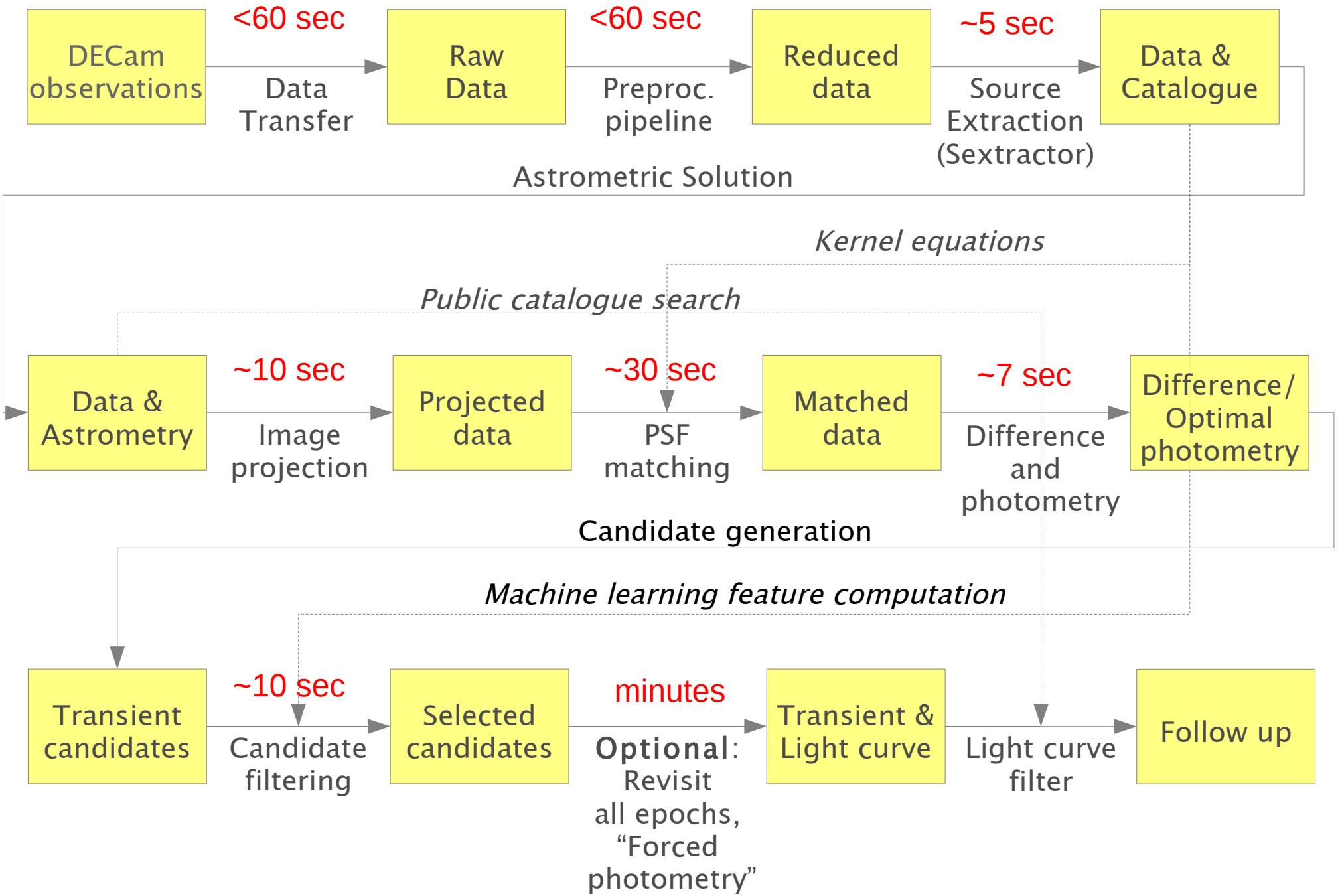
- Observe 40 fields every two hours for 5 consecutive nights with DECam (Done)
- Transfer every image from CTIO to CMM faster than one exposure time (Done)
- Run image subtraction in 62 CCDs in less than one exposure time (Done)
- Filter false positives while keeping a low number of false negatives (Done)
- Trigger follow up observations in real time (Pending... 1 day reaction in last run)

Observing strategy
Blanco/DECam Feb 28th - Mar 4th, 2014



- 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 (2 sq. deg, ~25 mag g)

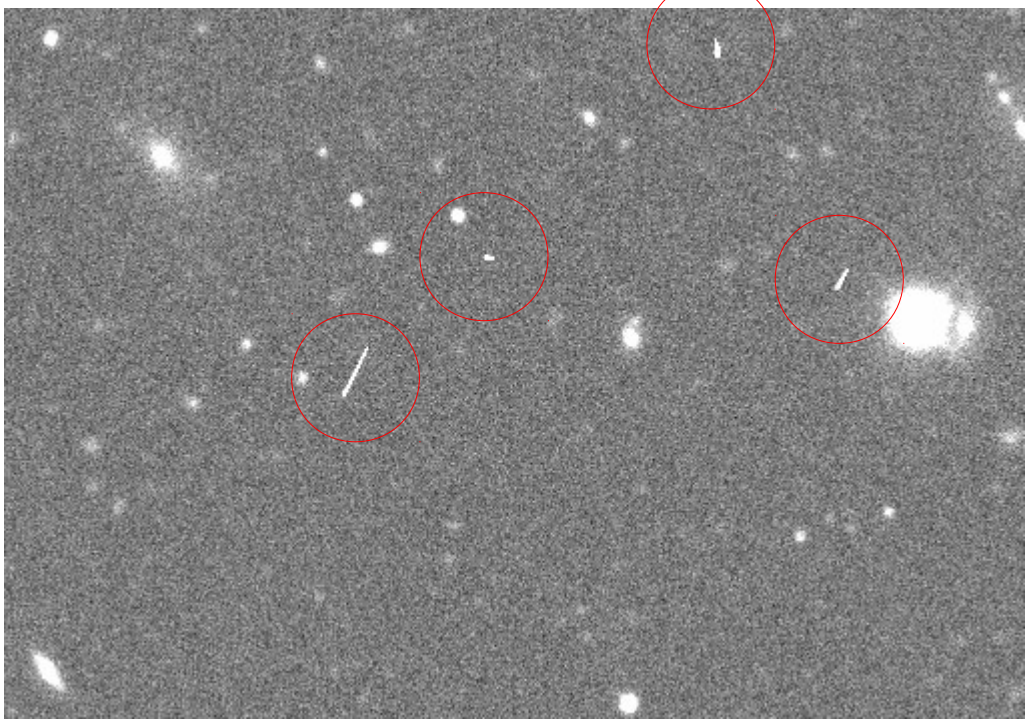
Pipeline flow outline



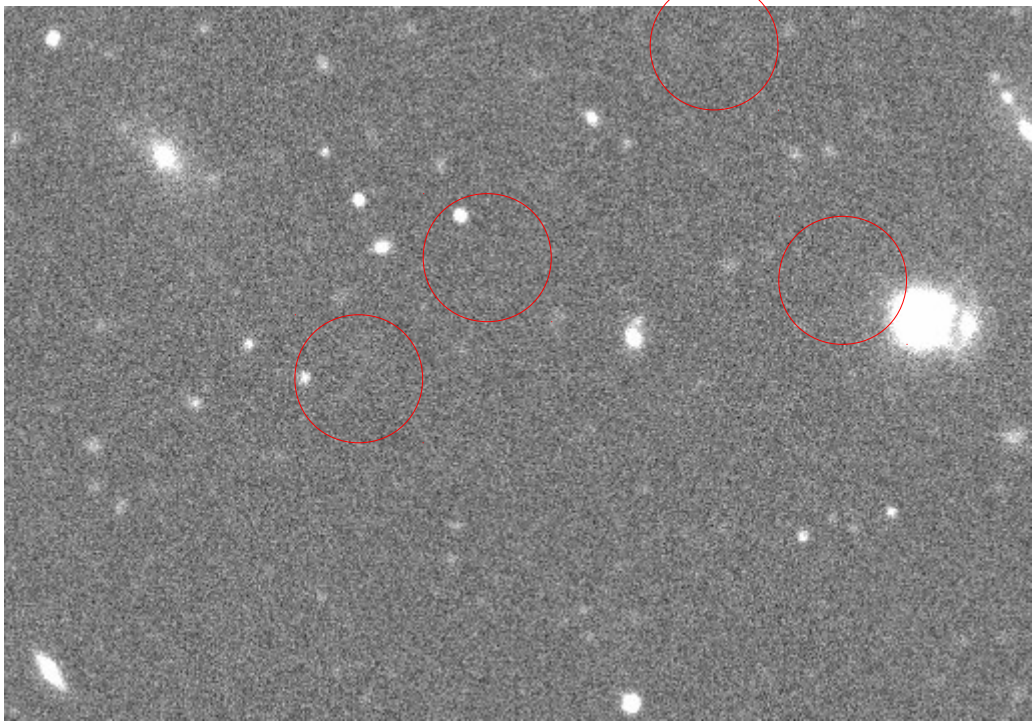
Preprocessing

- Bias correction + flat fielding + bad pixel mask using own code. Adapting DECam community pipeline (cross talk corrections very important!), LSST pipeline in the future?
- 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.

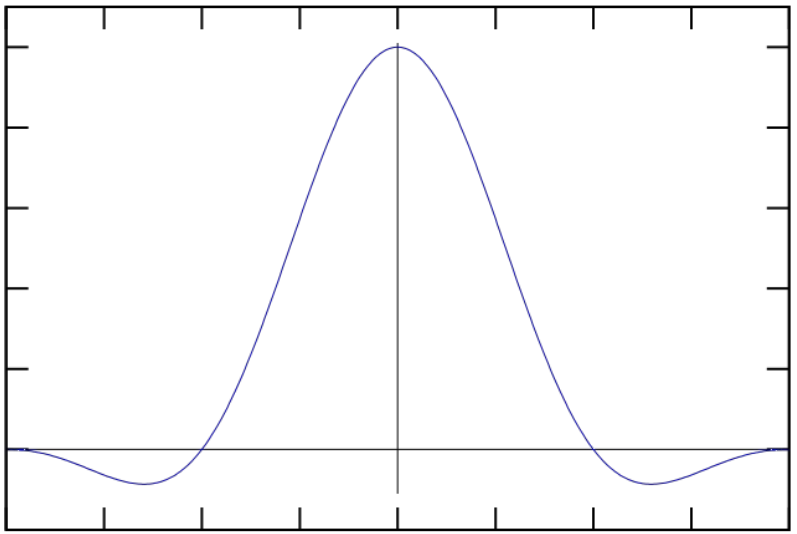
Astrometric solution and image projection

- Astrometric solution: two arbitrary order transformations based on Sextractor catalogues
  - New image to reference image in pixel coordinates (image projection)
  - Catalogue to reference image in celestial coordinates (catalogue comparison)

- Image projection: Lanczos−windowed sinc (a = 2) interpolation kernel (Fortran 95 + OpenMP + F2PY, c.f. numpy)

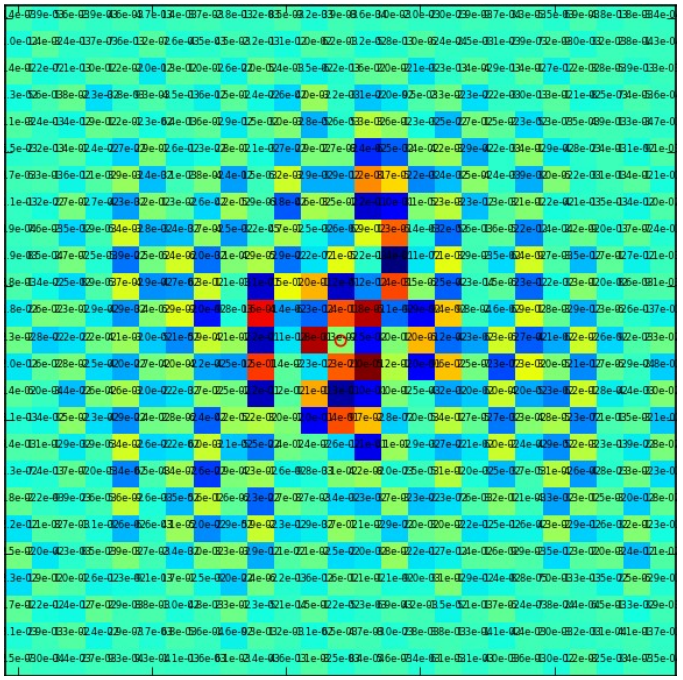
$$L(x) = \begin{cases} \operatorname{sinc}(x)\,\operatorname{sinc}(x/a) & \text{if} \quad -a < x < a \\ 0 & \text{otherwise} \end{cases}$$

$$S(x,y) = \sum_{i=\lfloor x \rfloor - a + 1}^{\lfloor x \rfloor + a} \sum_{j=\lfloor y \rfloor - a + 1}^{\lfloor y \rfloor + a} s_{ij} L(x-i) L(y-j).$$

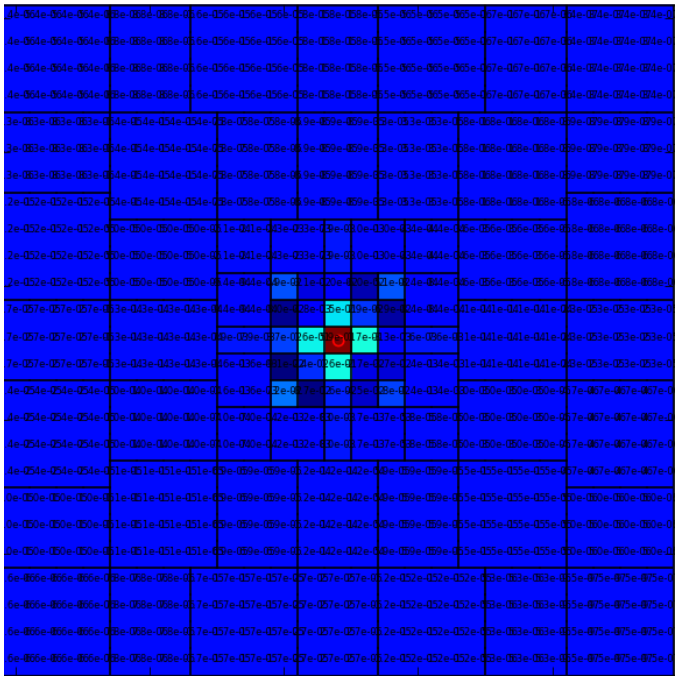


"The Lanczos−windowed sinc functions offer the best compromise in terms of reduction of aliasing, sharpness, and minimal ringing" (Turkowski & Gabriel 1979)

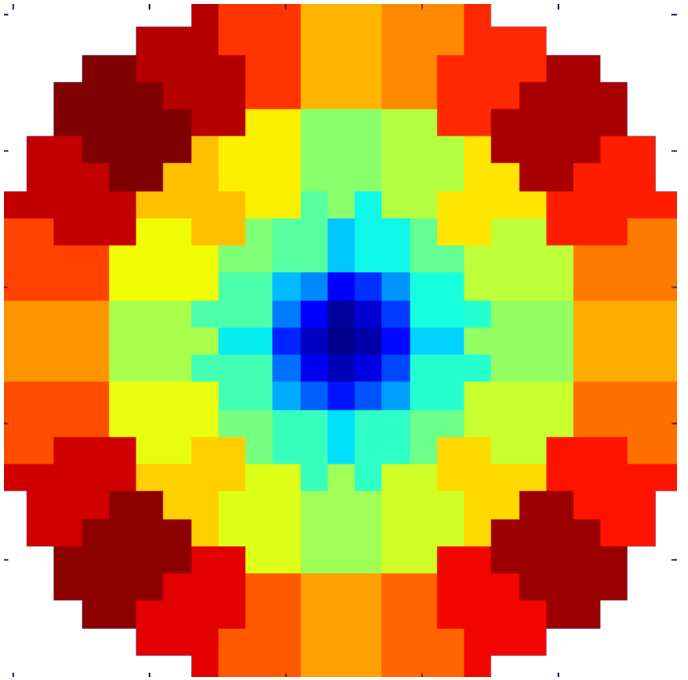
PSF matching: convolution kernel



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)

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

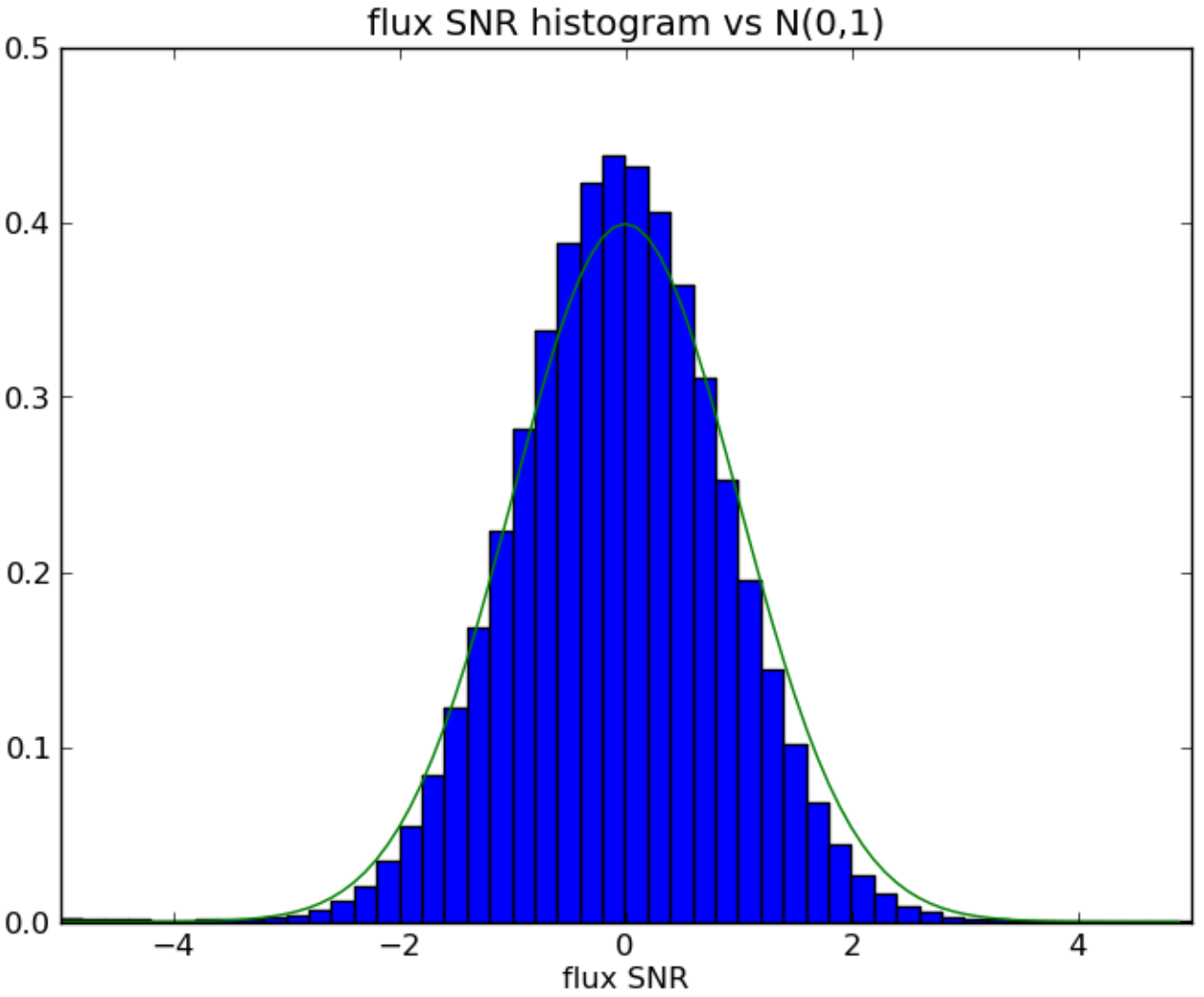
$$W_{k,l} = \frac{P^{E}_{k,l} / V_{k,l}}{\sum_{i,j} \left(P^{E}_{i,j} \right)^2 / V_{i,j}}$$

Variance at given pixel

Flux variance

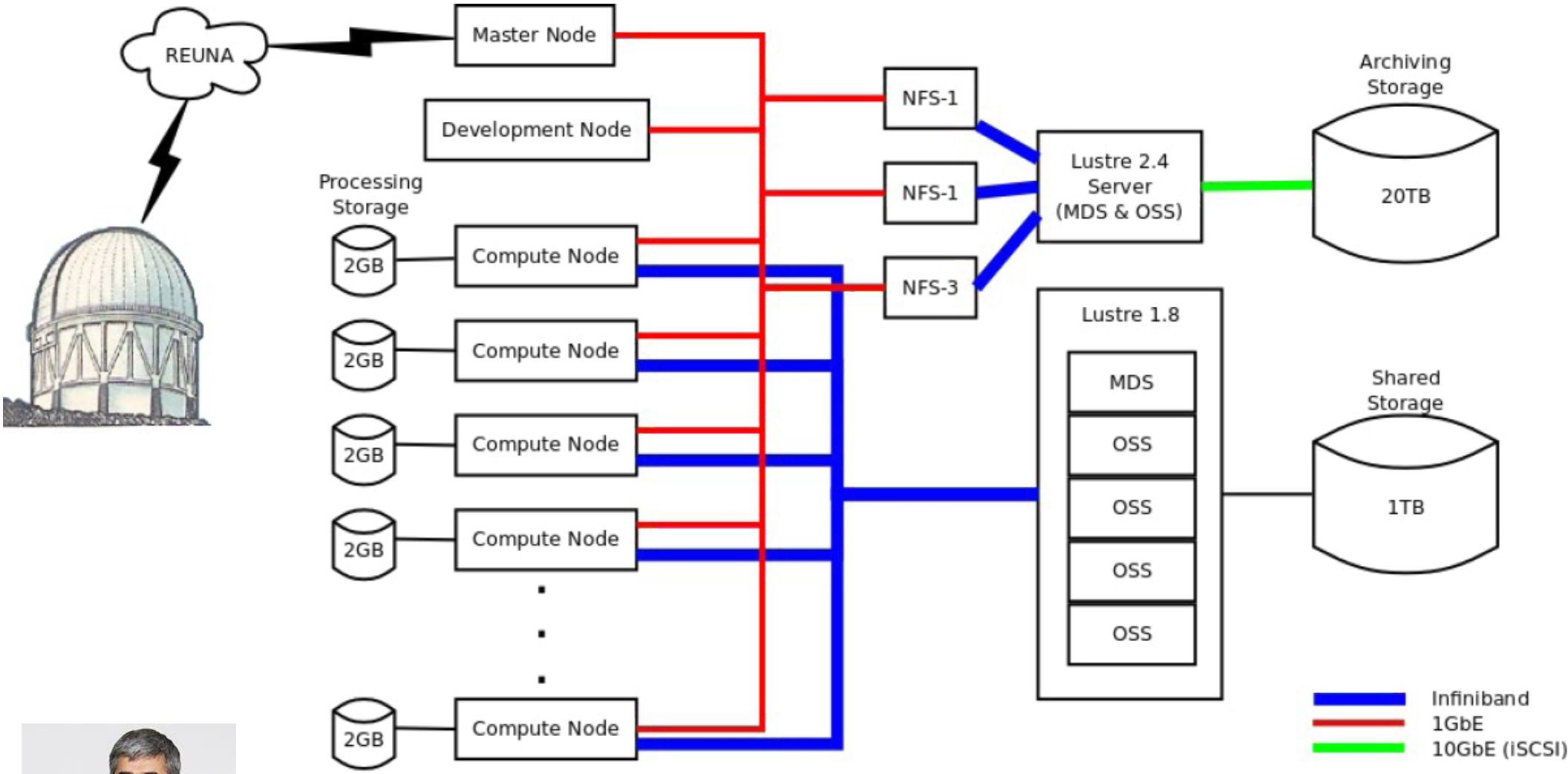
$$Var\left(F\right) = \sum_{i,j} W^2_{i,j} V_{i,j}$$

Optimal photometry



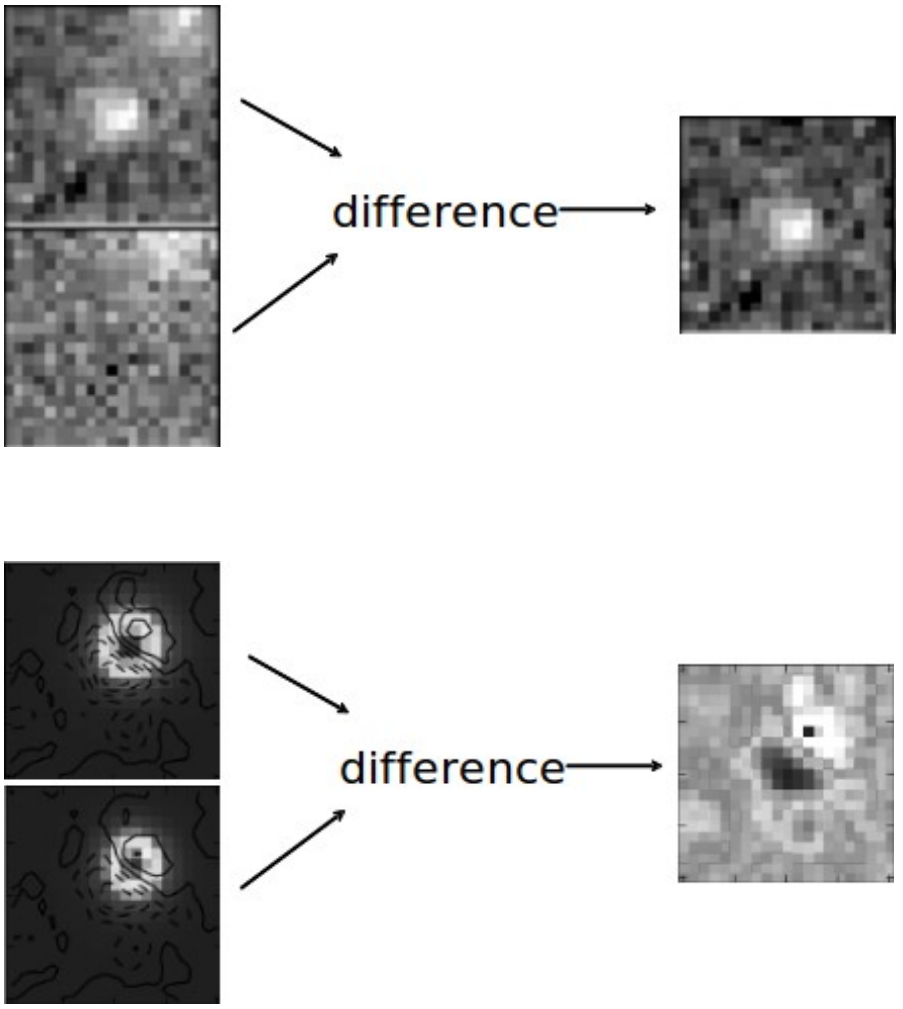
Optimal photometry signal to noise ratio histogram consistent with modeled errors!

Hierarchical storage



J.C. Maureira

Data flows produce the most difficult bottle necks!


difference
difference

Classification: supervised learning

Given a **training set** {<xi, yi>}

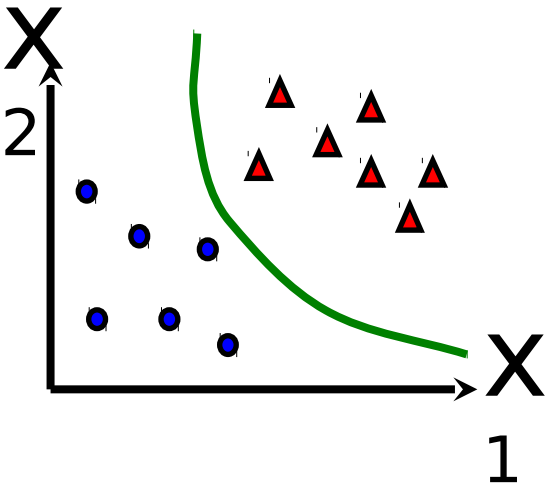
xi: **attributes**, yi: **classes**

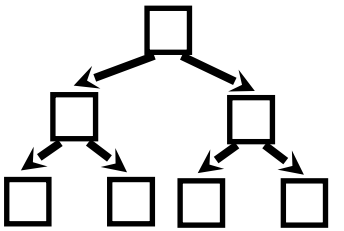
determine a **learning function**

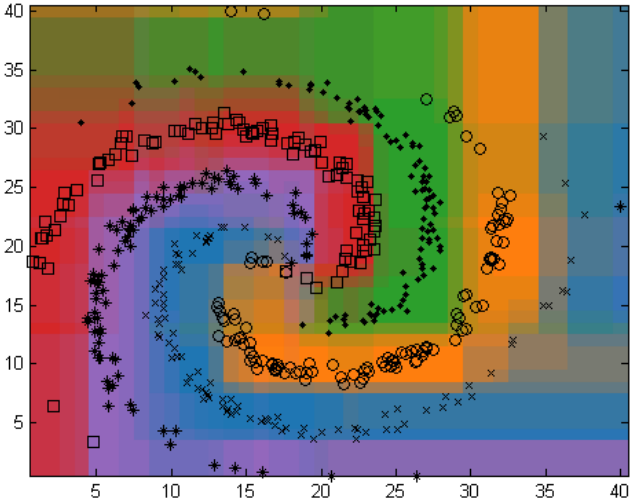
$f : X \rightarrow Y$

to **predict** the class of a given set of attributes

$y = f(x)$







The goal is to train a classification model that achieves a **low false positive ratio** (purity) and a **low false negative ratio** (efficiency).

Features (attributes)

Candidates are stamps in the difference images (21 x 21 = 441 pixels)

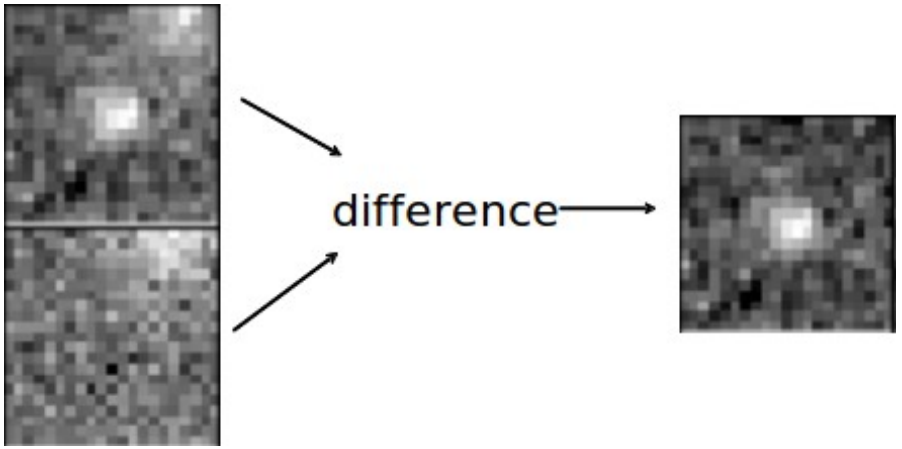
High−dimensional problem!

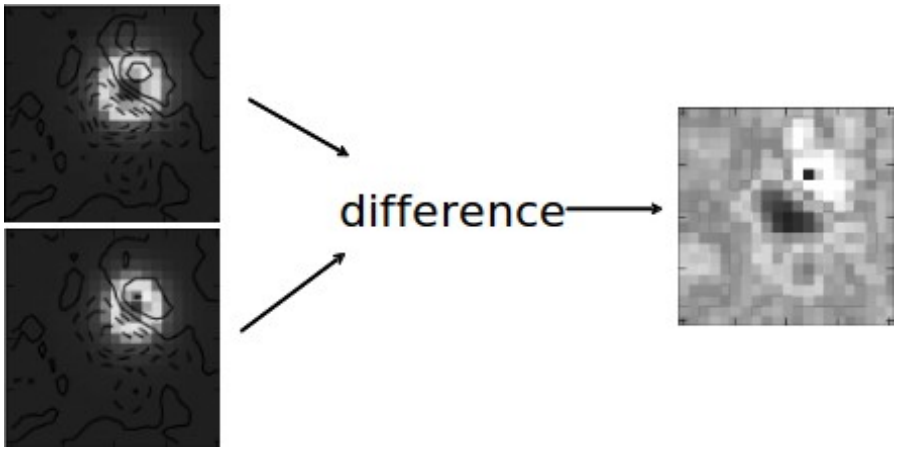
Feature engineering:

- Design features that describe what we "see" and mathematical knowledge.
- Use multidimensional visualization to confirm discrimination potential

Features from:

- Original unsubtracted images
- Difference images
- **SNR of the difference image**
- Density of candidates





Training

Training sample

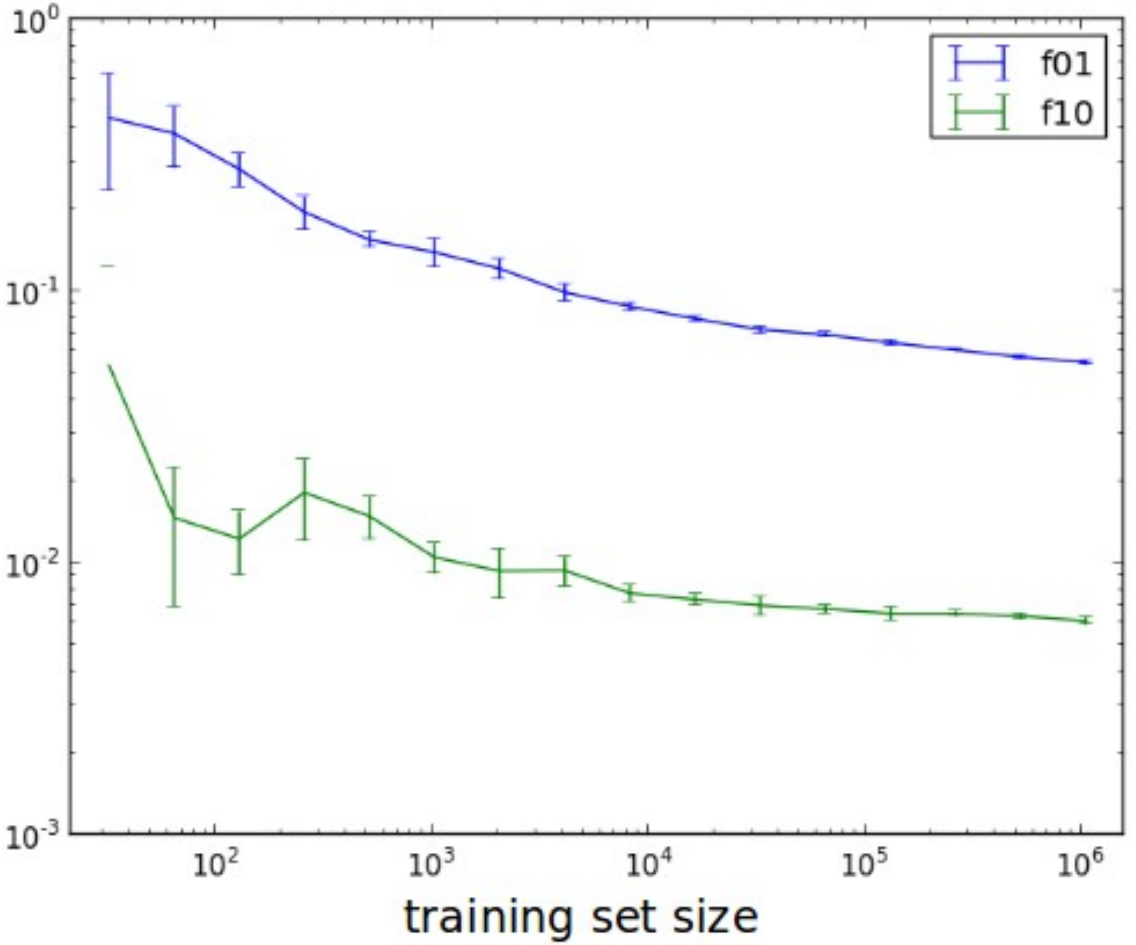
- 8,957,497 candidates
- 23 % positives (fake SNe)
- 77 % negatives (artifacts)

Fake SNe:

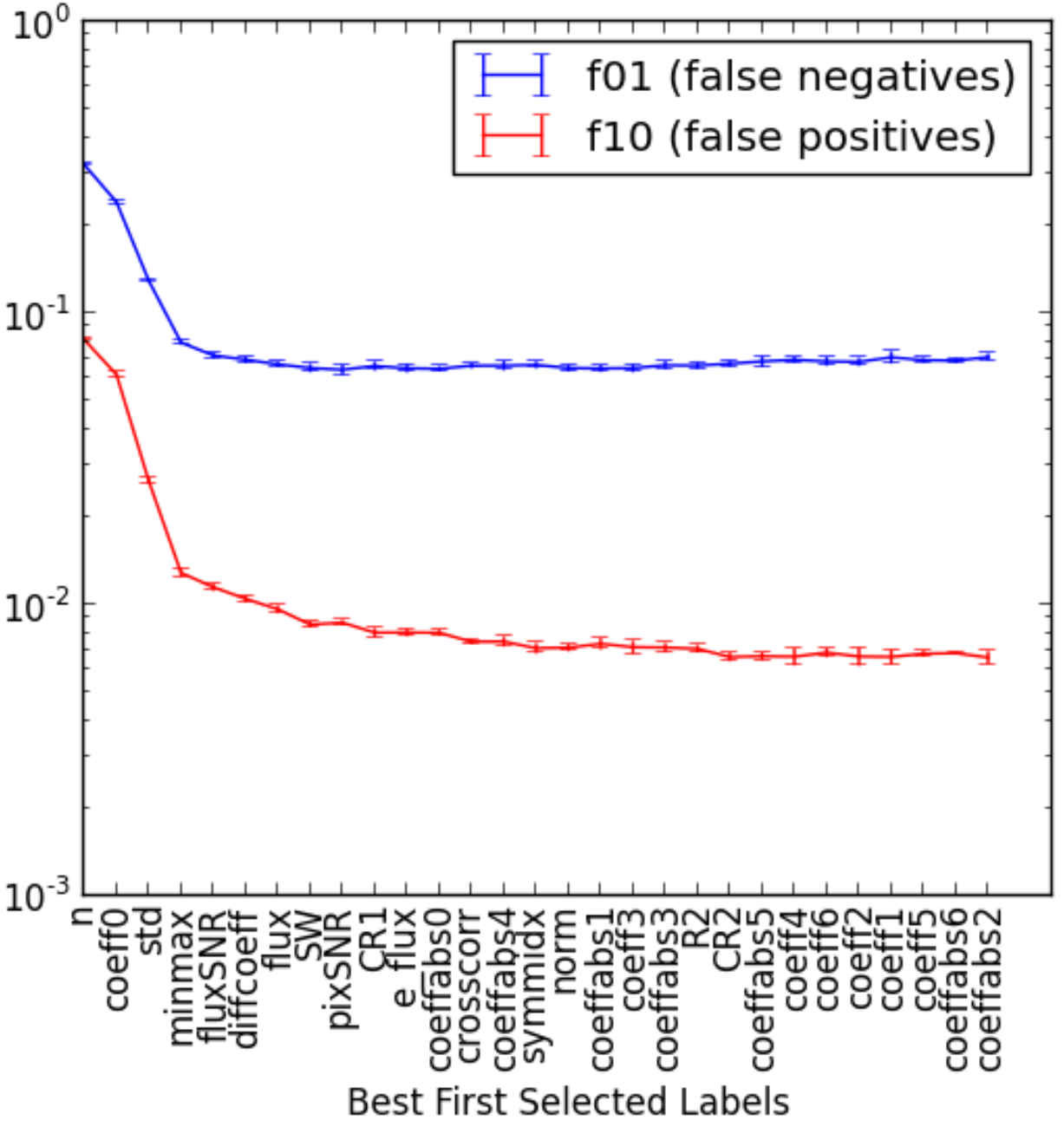
- Randomly selected stars added to predefined locations

Artifacts:

- Assume non fake SNe are artifacts during training



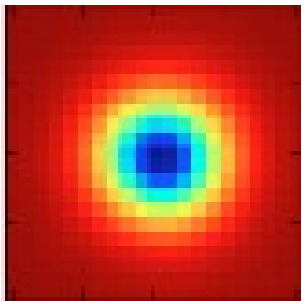
Feature selection (random forest)



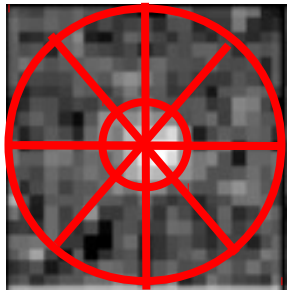
Most important features

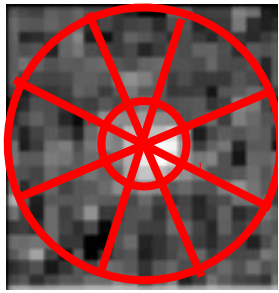
1. Number of candidates within a specific radius
2. Normalized first principal component in the **signal to noise ratio (SNR) difference image**
3. Standard deviation of the SNR difference image
4. Minimum maximum of the two original unsubtracted images
5. Flux SNR

6. Shapiro−Wilk normality test over residuals of SNR image with representation in 6 PCs
7. SNR of the central pixel
8. Cosmic ray parameters (Laplacian filter)
9. Flux error
10. Dot product between normalized difference image stamp and empirical PSF
11. Outer symmetry index: maximum normalized deviation between slices in the SNR difference image
12. Absolute normalized difference between absolute values of first PCs of |SNR| image and SNR image

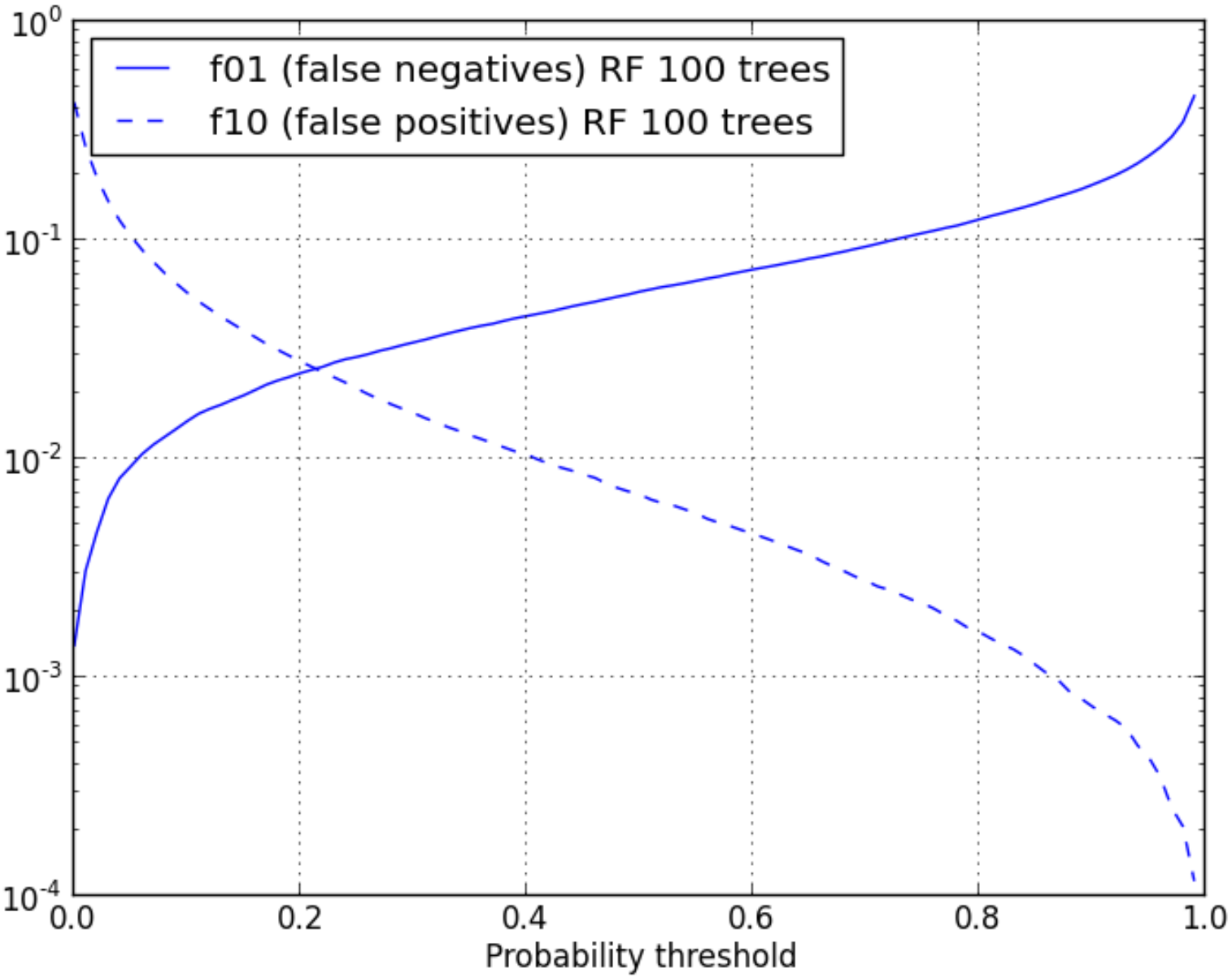


Use SNR statistics to eliminate Poisson noise problem

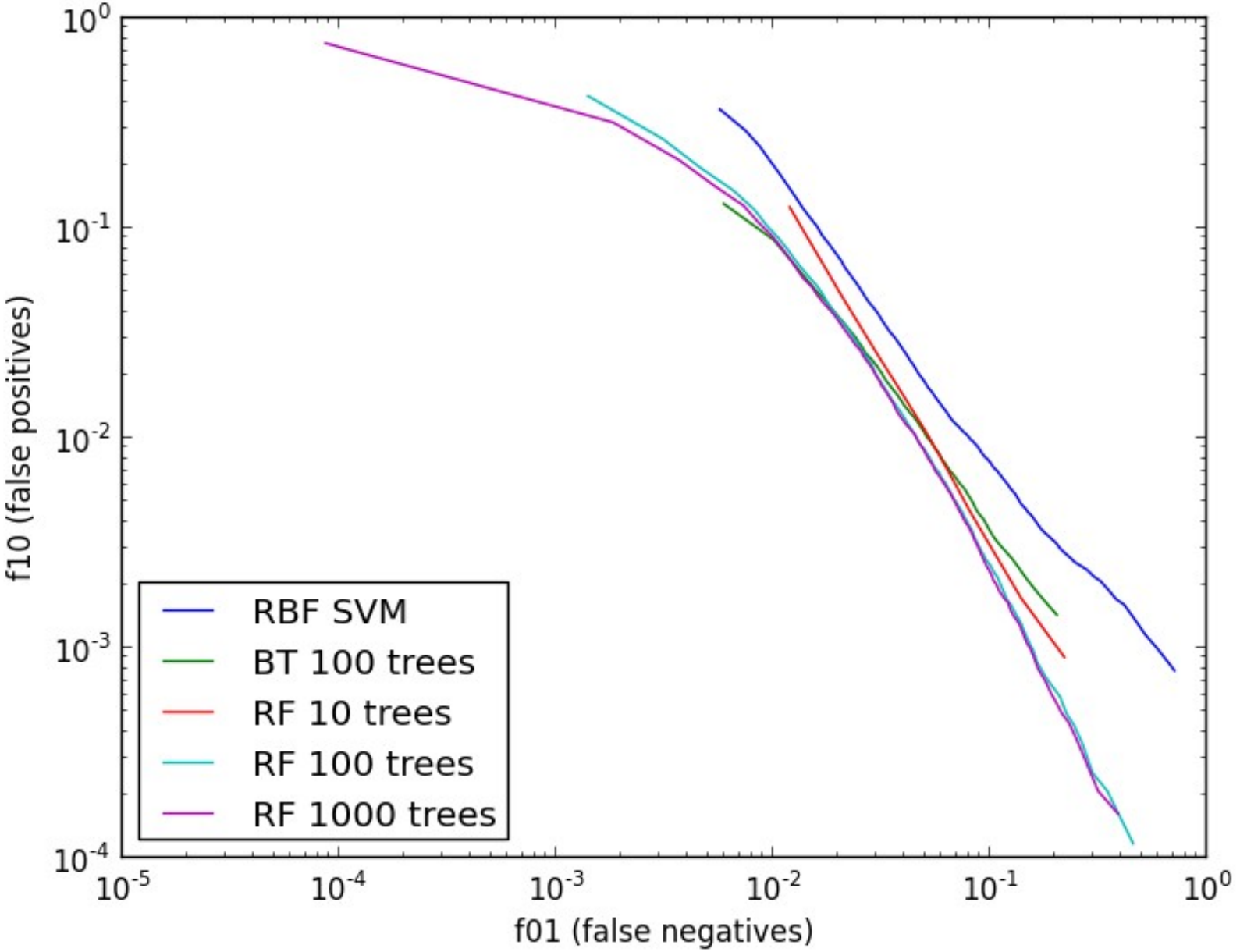




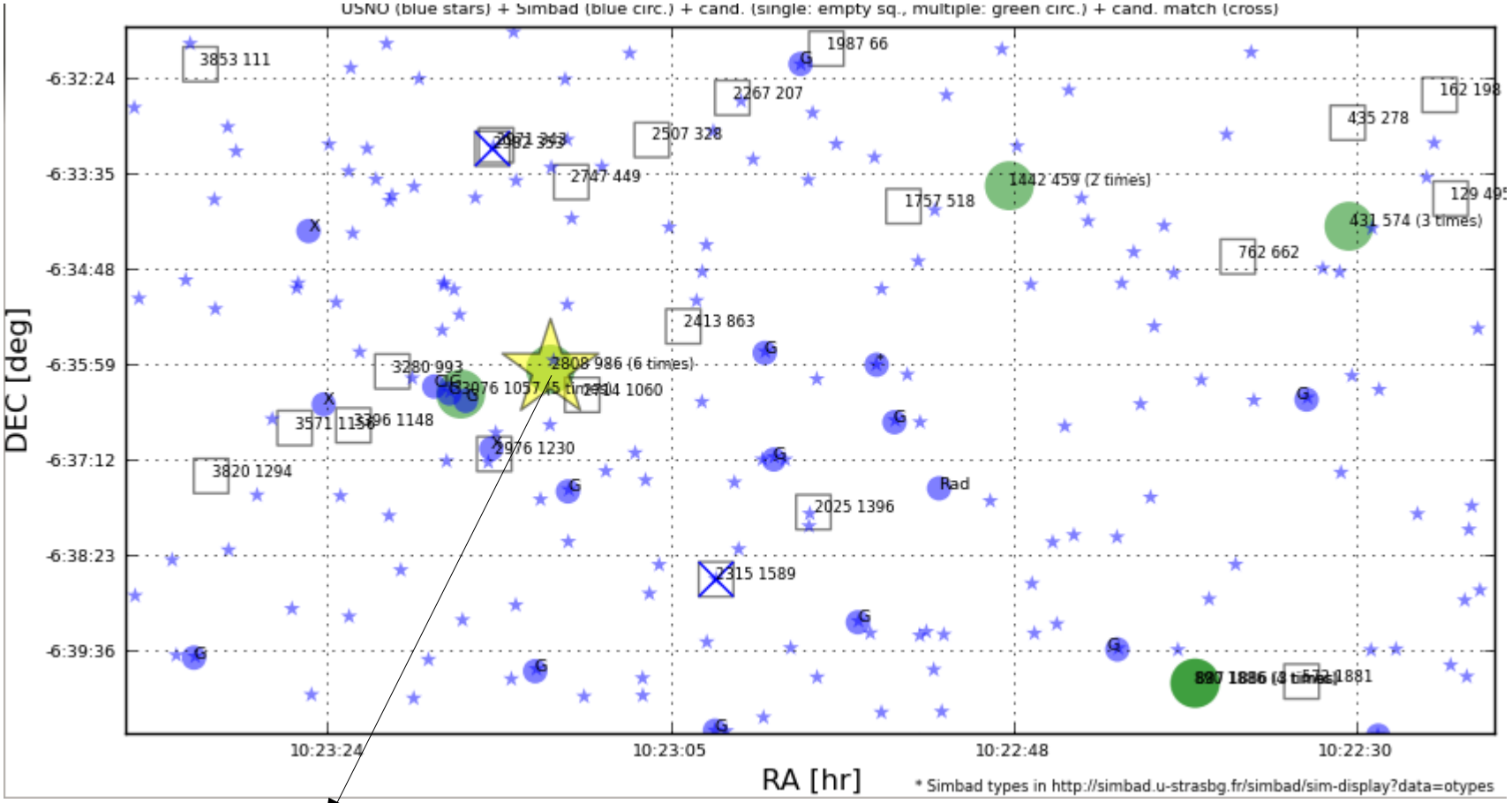
Probability threshold

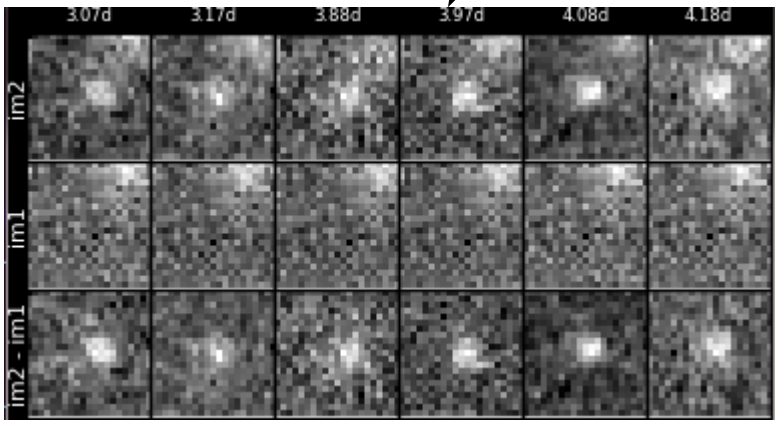


Comparison with other classification methods



Webpage generation

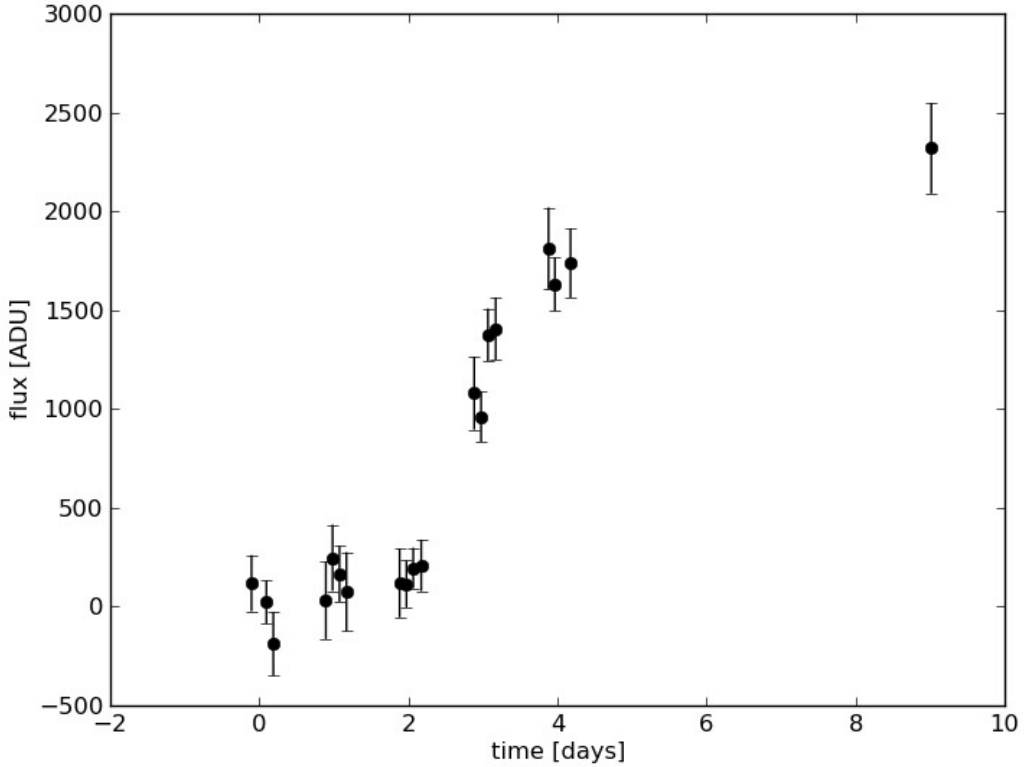


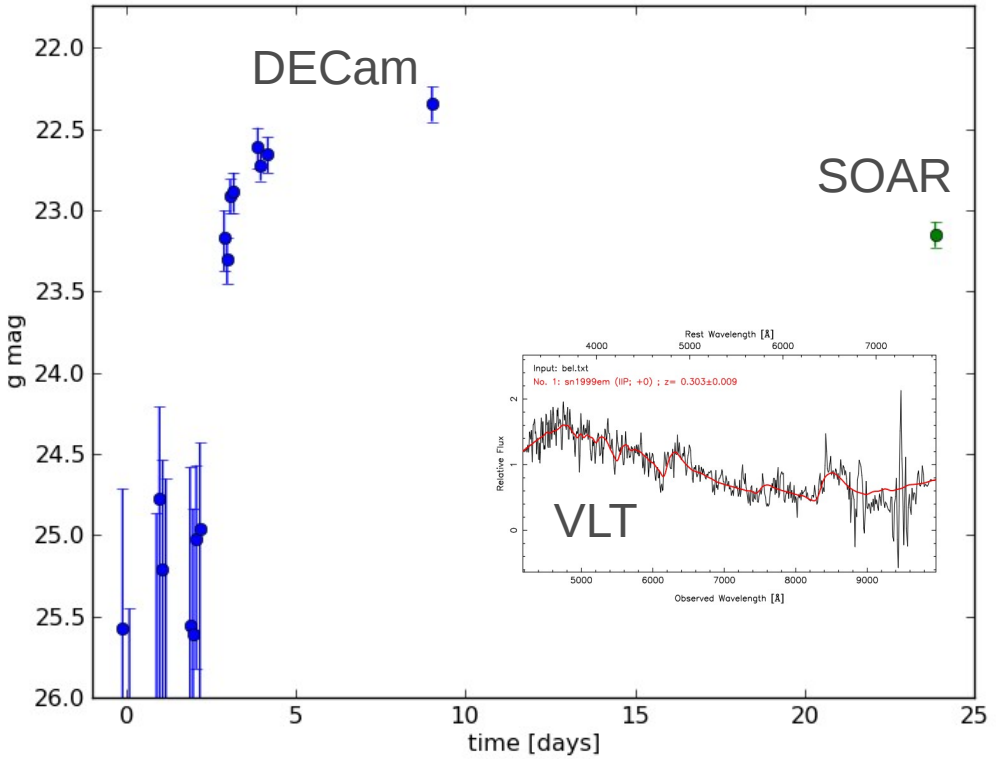


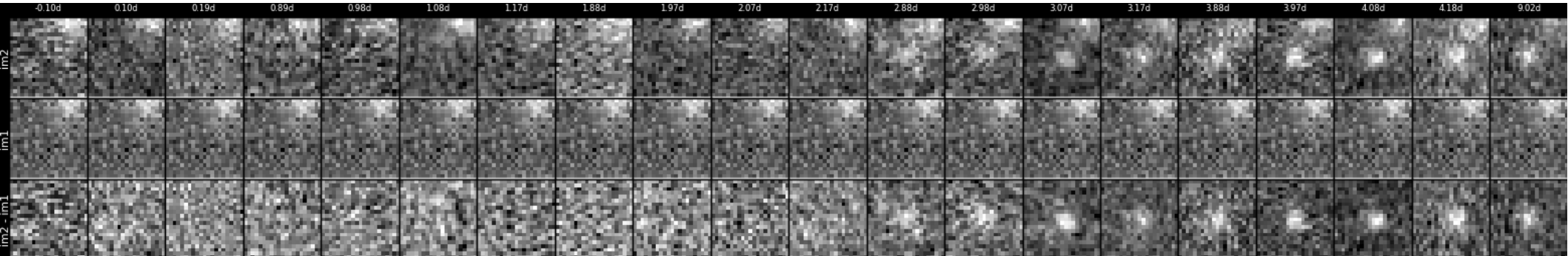
Additional filters:

- At least two detections to avoid moving objects
- At least one possitive difference to avoid moving objects in the reference image
- Periodogram without very significant periods

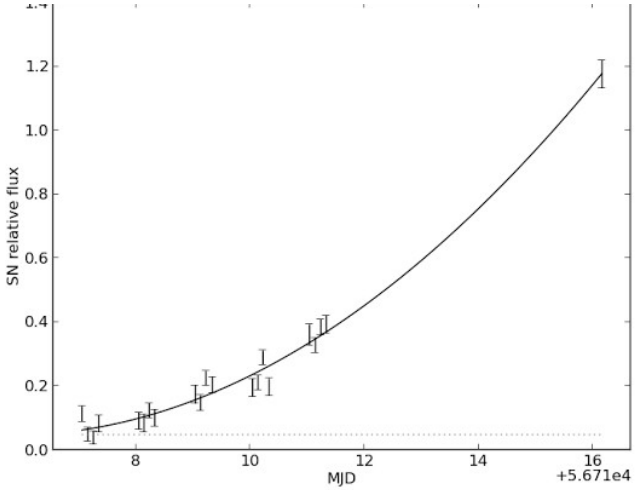
Revisit/follow up strategy

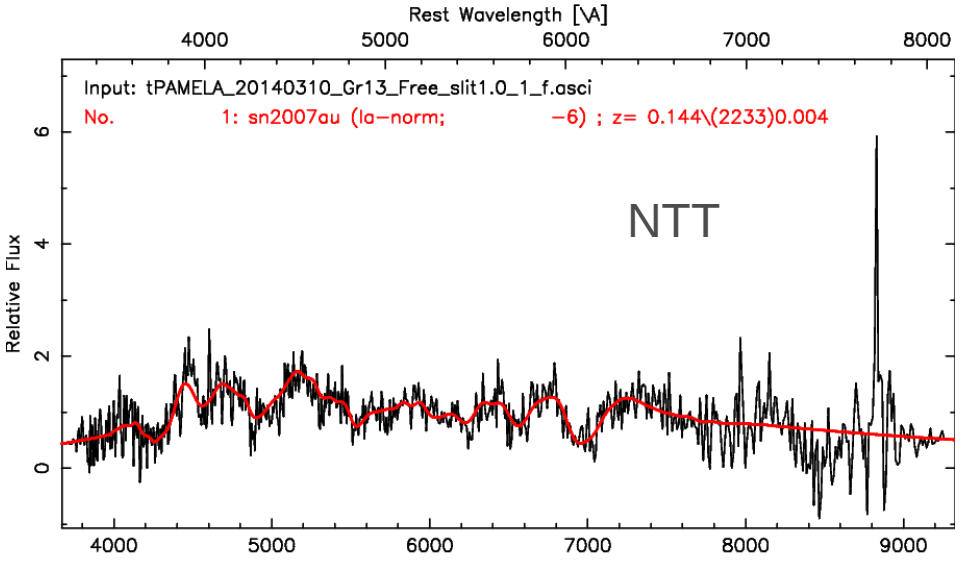


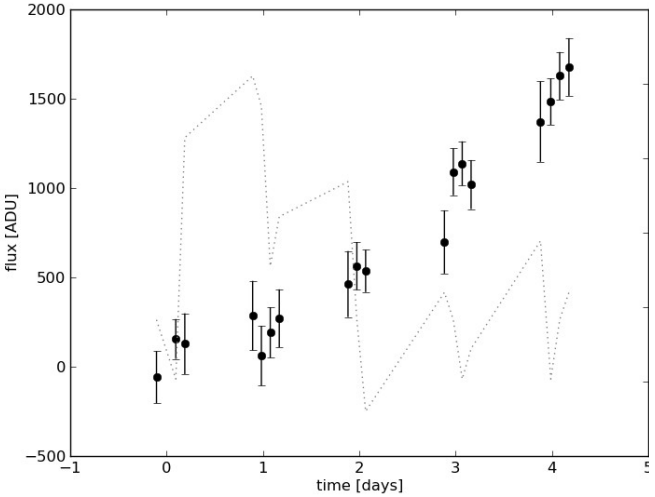


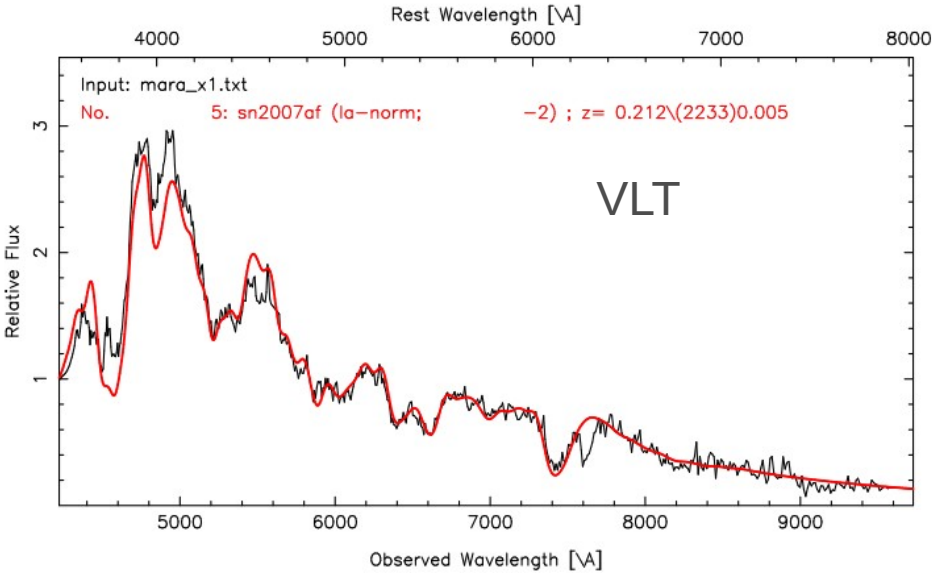


Follow up strategy

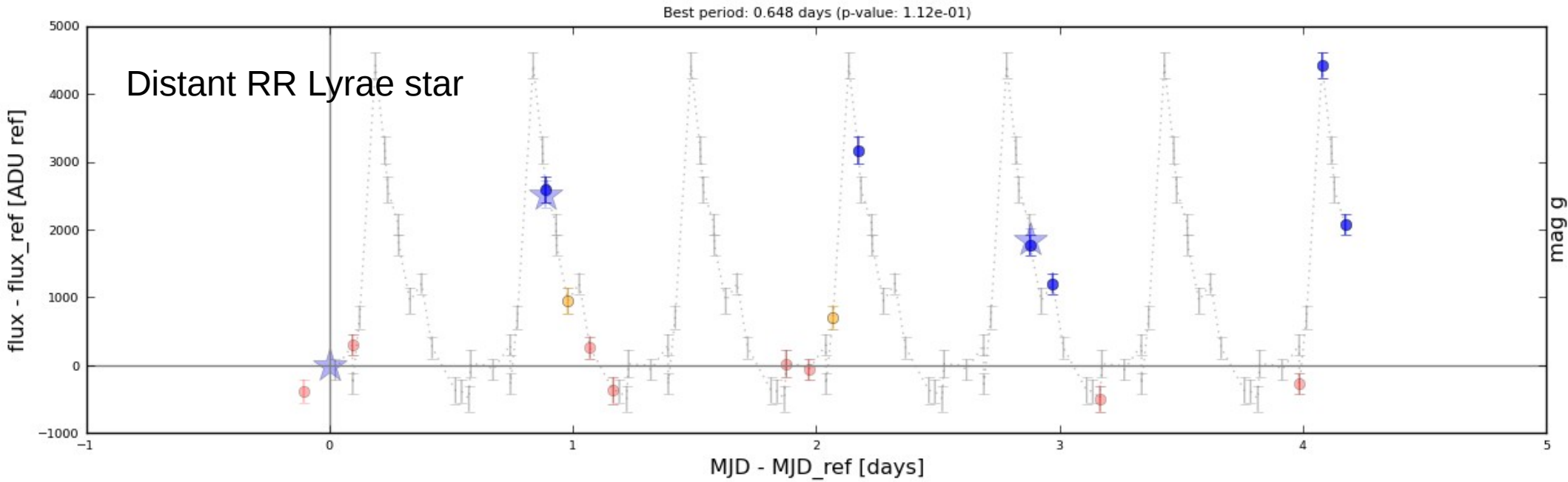


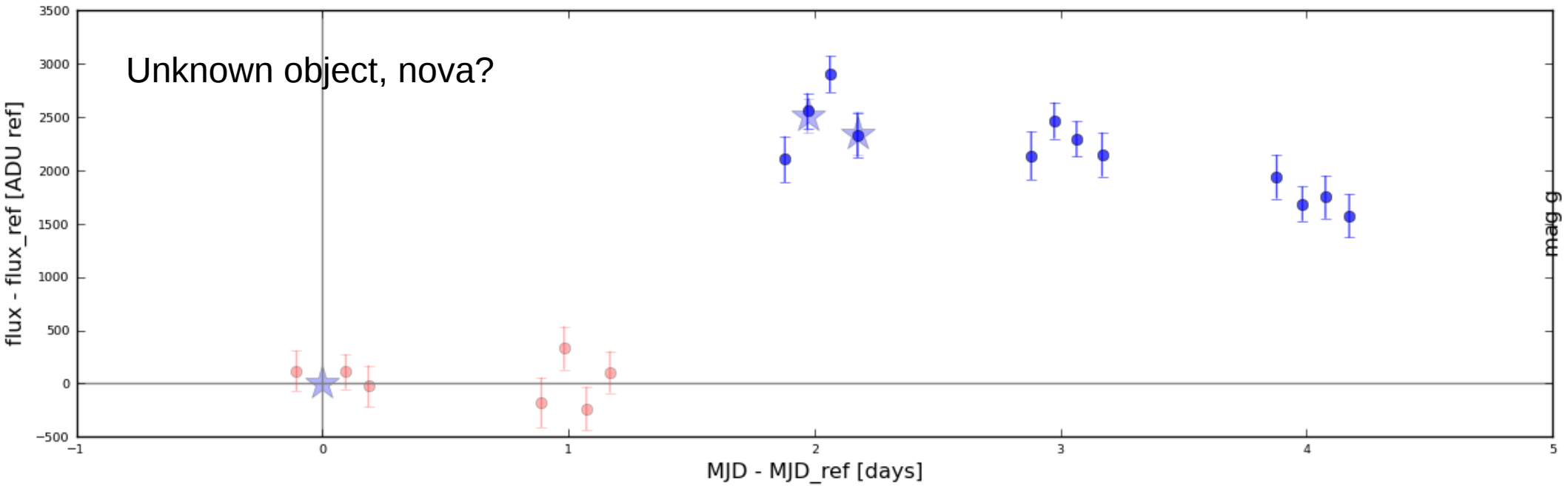


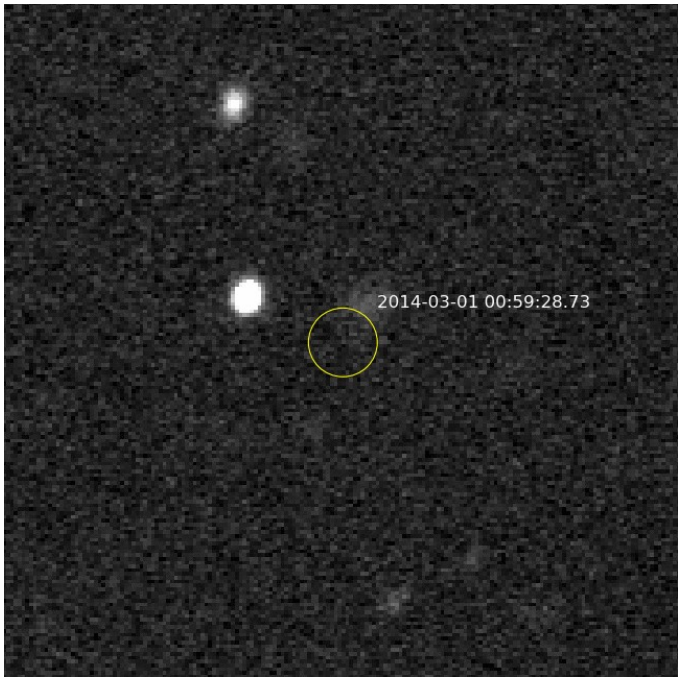


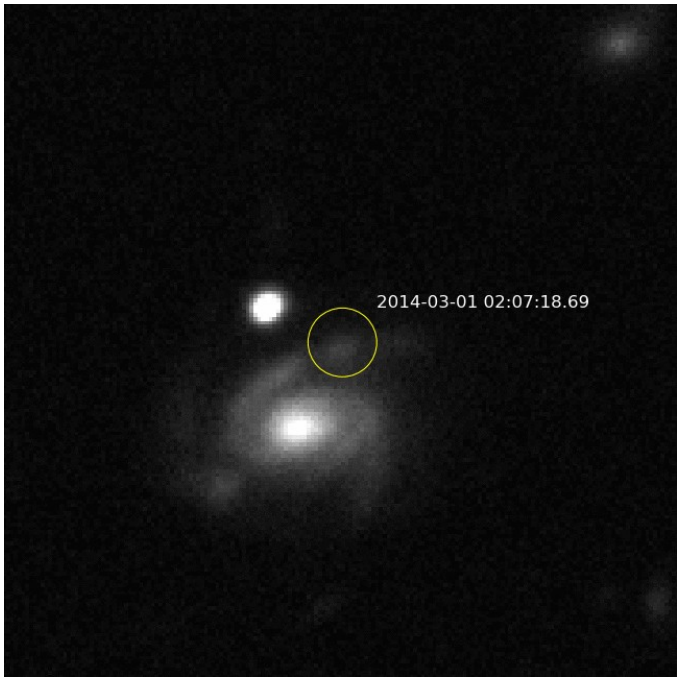


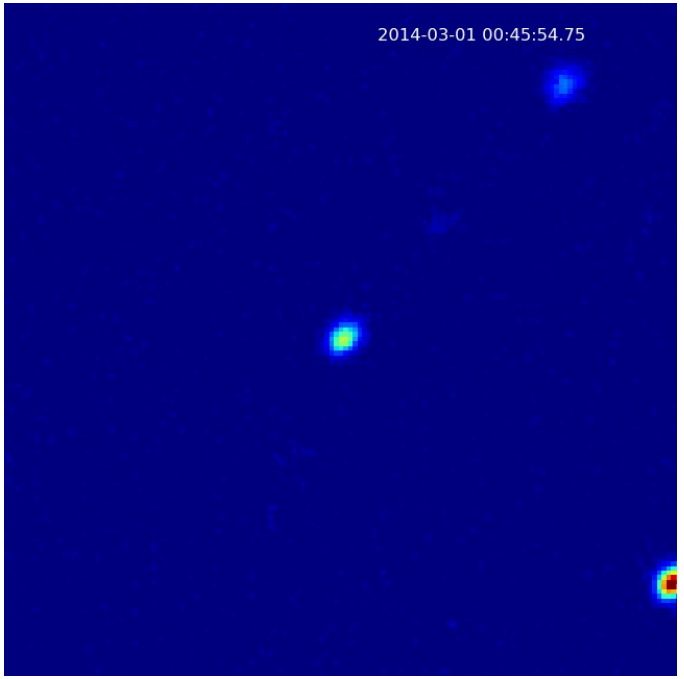
Other objects

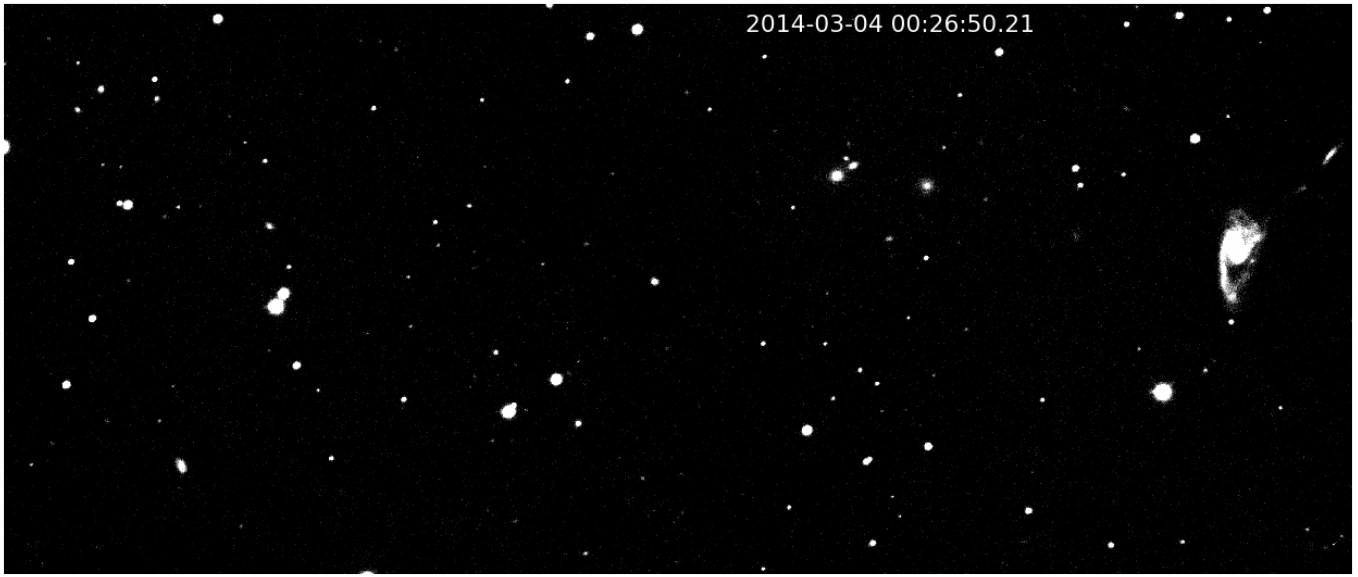


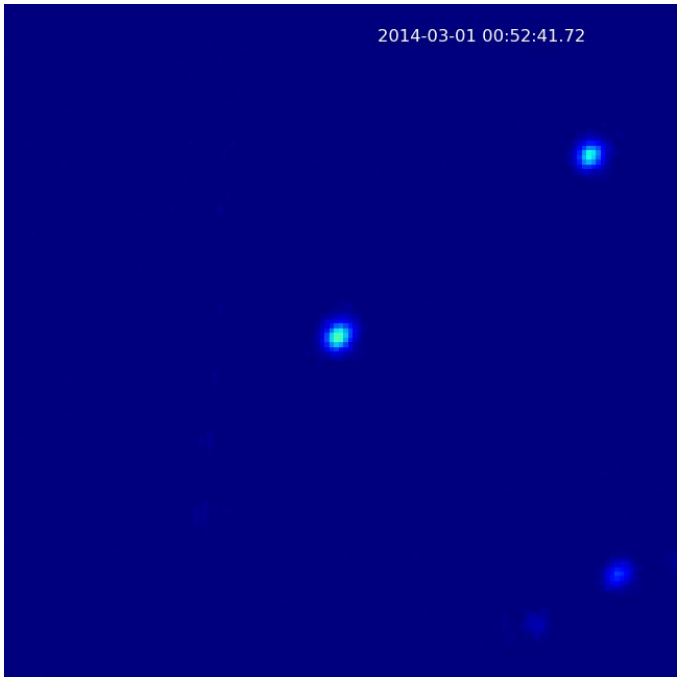












ATEL 5949, 5956

http://www.das.uchile.cl/~fforster/ATEL/summary_das.html

Summary

Real time DECam data reduction achieved (>400 billion pixels processed!)
First real time (optical) astronomy application with this data rate (~6x iPTF, ~ZTF)?

Rapid reaction possible with 2 hour cadence survey
(<1 day reaction after explosion in last run, <4 hours doable, <2 hours difficult)

12 very young SNe discovered, possibly hours after explosion
(Förster et al. 2014, *in preparation*)

Hundreds of variable stars (RR Lyrae), thousands of new asteroids?, dozens of unknown objects (flares? other?).

Supernova shock breakout not yet detected! Search continues with deeper version of our image subtraction pipeline.

LSST cadence critical to discover shock breakout events.
We need non−detection → detection → confirmation **triplets**!

THANKS!

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