# Mixing Bayesian Techniques for Effective Real-time Classification of Astronomical Transients

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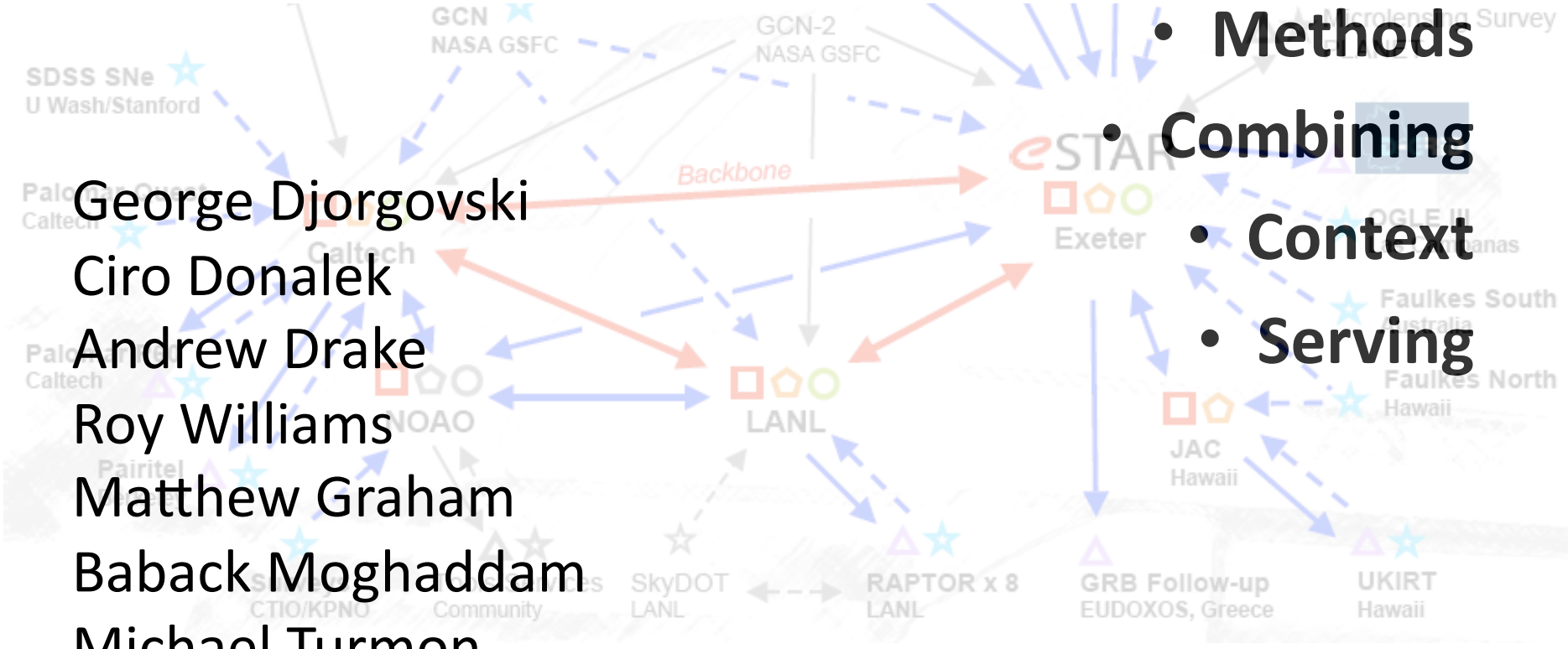
Sapporo, ADASS, 6 Oct 2009

# Overview




George Djorgovski
Ciro Donalek
Andrew Drake
Roy Williams
Matthew Graham
Baback Moghaddam
Michael Turmon

- **Methods**
- **Combining**
- **Context**
- **Serving**

# Terry Pratchett in *Equal Rites* (1987)

Animals never spend time dividing experience into little bits and speculating about all the bits they've missed. The whole panoply of the universe has been neatly expressed to them as things to

(a) mate with,

(b) eat,

(c) run away from, and

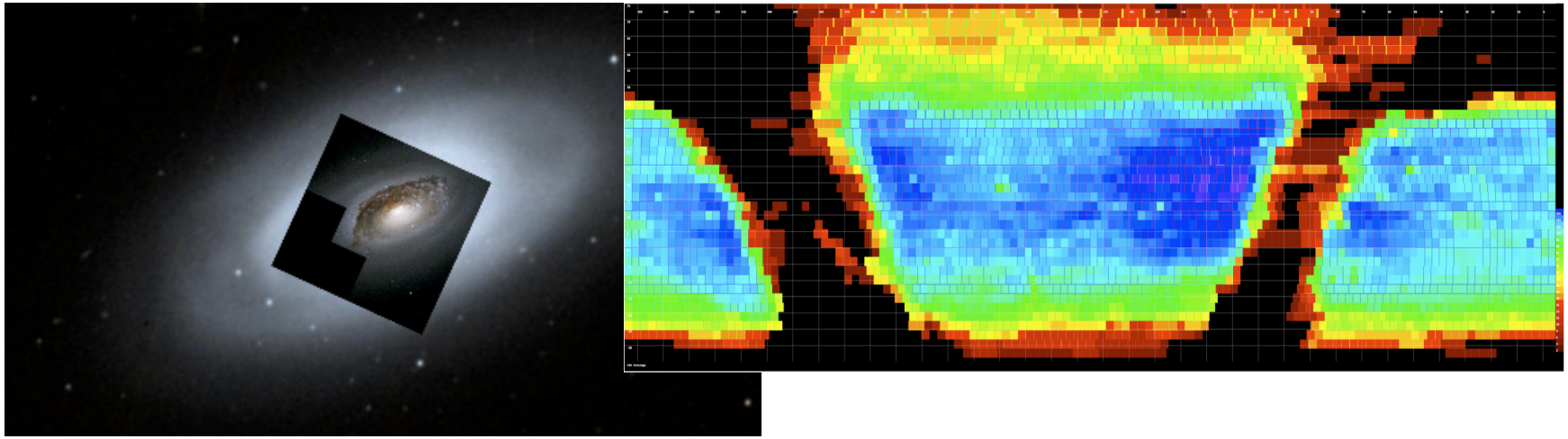
(d) rocks.

# Ancient Astronomical context

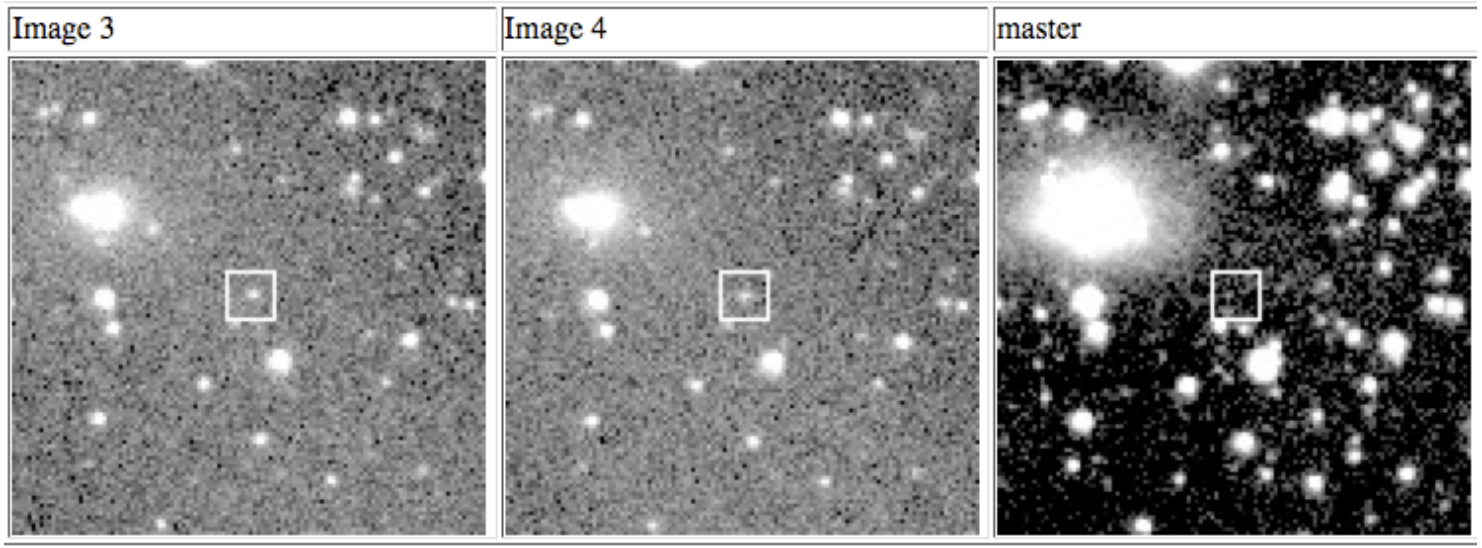
(a) mate with,
(= speculative/sexy science)
(b) eat,
(= bread and butter objects)
(c) run away from,
(= crazy cosmologies)
and
(d) rocks
(= transients)

- Besides the known unknowns, we want to look for unknown unknowns
- We are forced to classify
- And in Real-Time!

# Transformations in astronomy



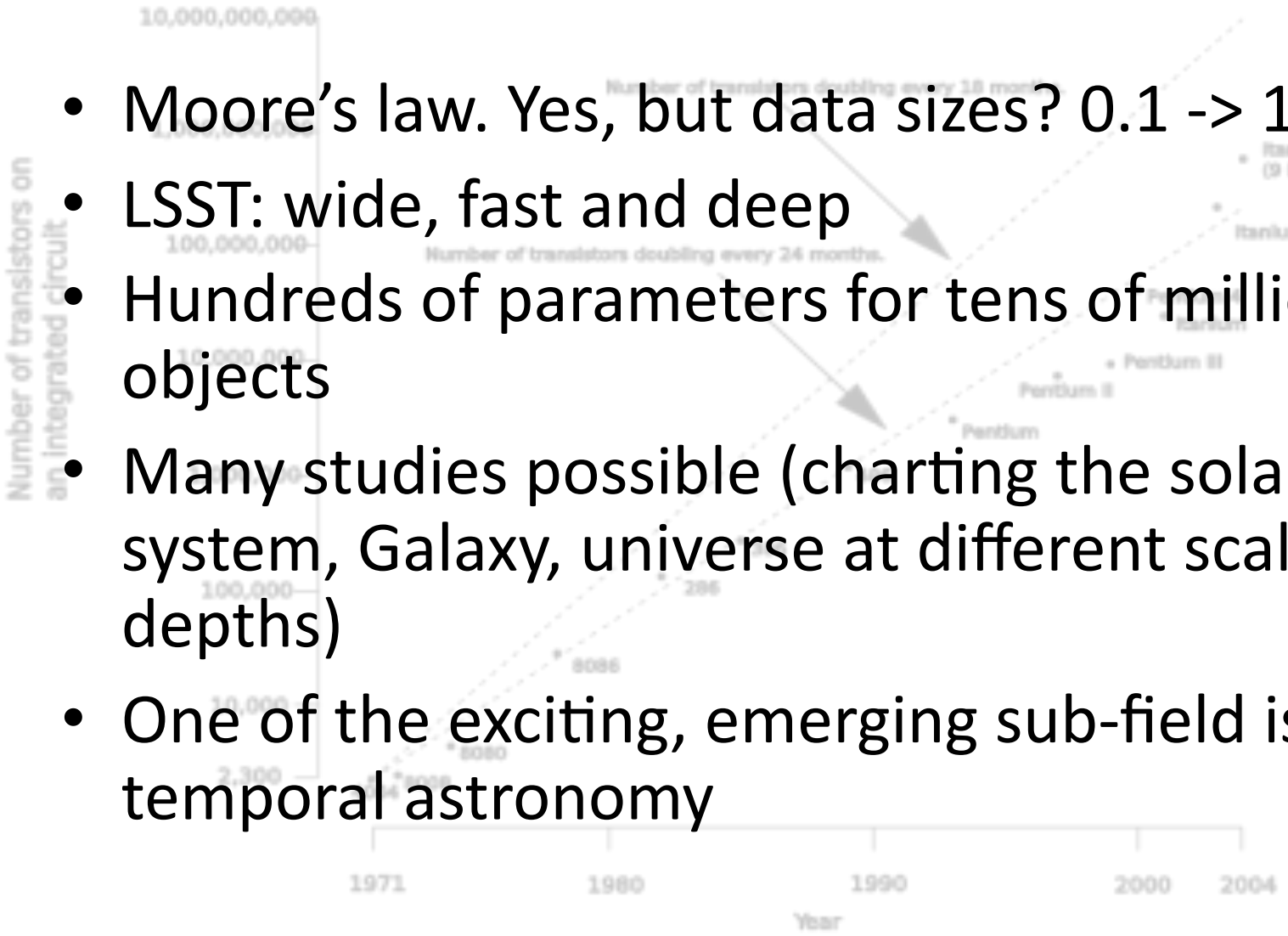
**Shallow to deep; Small to large; Sporadic to repeated; more wavelengths**




SN z=0.05
CSS 20090711

# Data sizes and number of parameters

- Moore's law. Yes, but data sizes? 0.1 -> 10x TB
- LSST: wide, fast and deep
- Hundreds of parameters for tens of millions of objects
- Many studies possible (charting the solar system, Galaxy, universe at different scales and depths)
- One of the exciting, emerging sub-field is of temporal astronomy



# The Palomar-Quest Event Factory

Detect ~ 1 - 2 *$10^6$ sources per half-night scan

Compare with the baseline sky

Find ~ $10^3$ apparent transients (in the data)

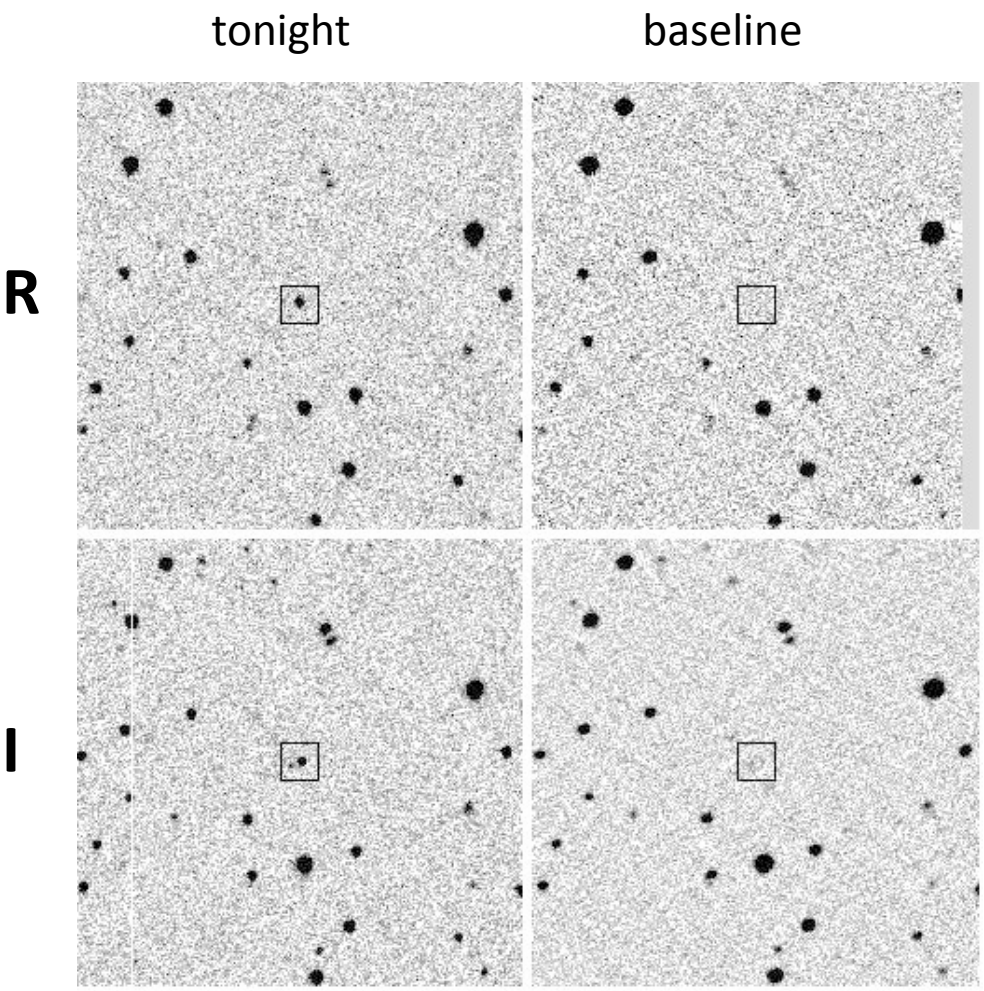
Remove instrum. artifacts

Identify ~ 2 - 4 *$10^2$ real transients (on the sky)

Remove asteroids

Identify ~ 1 - 10 possible Astrophysical transients

Classification and follow-up



# Synoptic skysurveys: Opening up new dimensions

Being tackled in various ways:

- BNs
- GPRs

(using colors, lightcurves, and contextual information like Galactic latitude, proximity to a galaxy etc.)

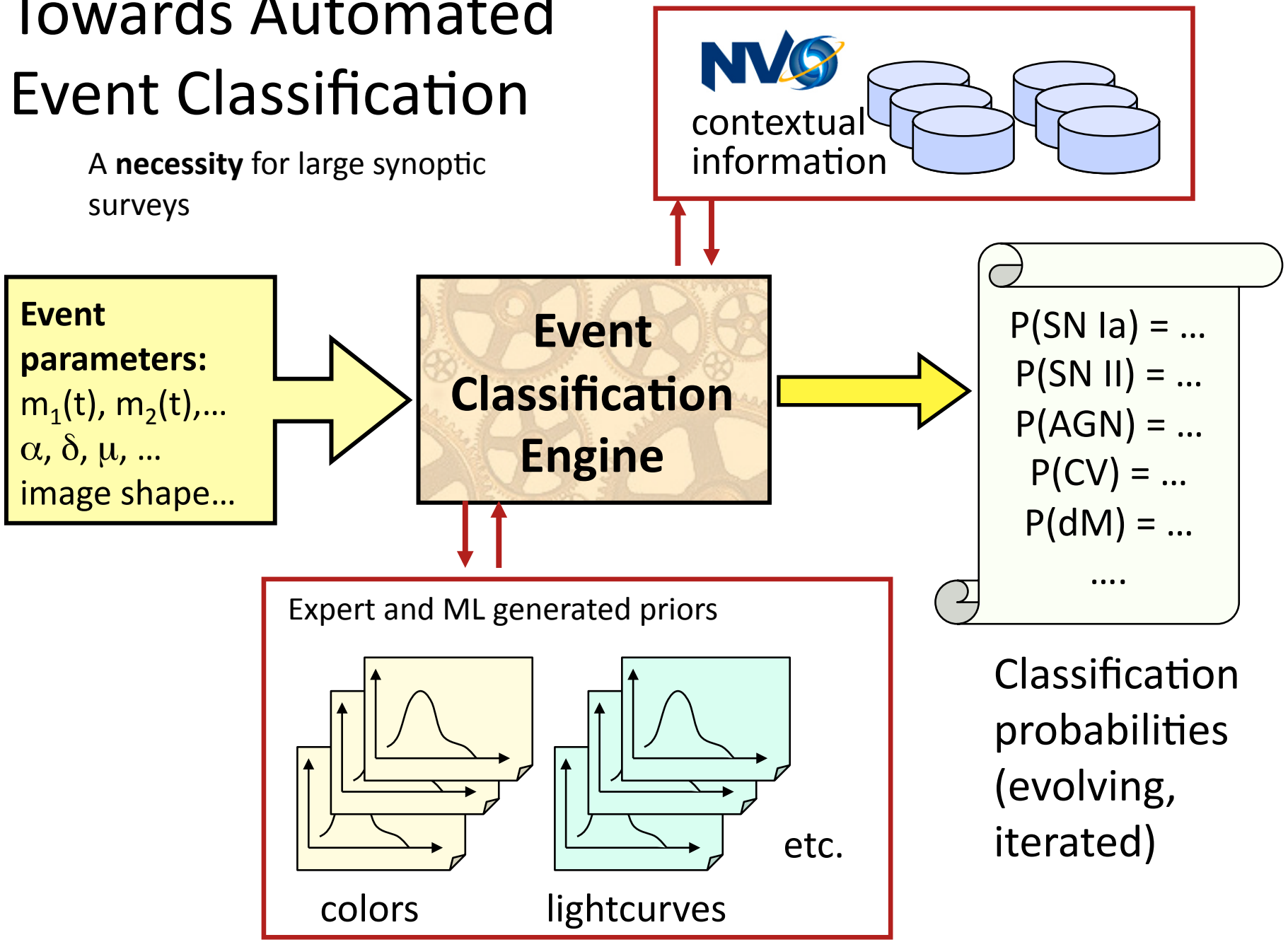

Challenges (besides data mining):

- Lots of follow-up observing
- Selecting candidates to follow

  (from tens of thousands per night)
- In real-time!

# Towards Automated Event Classification

A **necessity** for large synoptic surveys

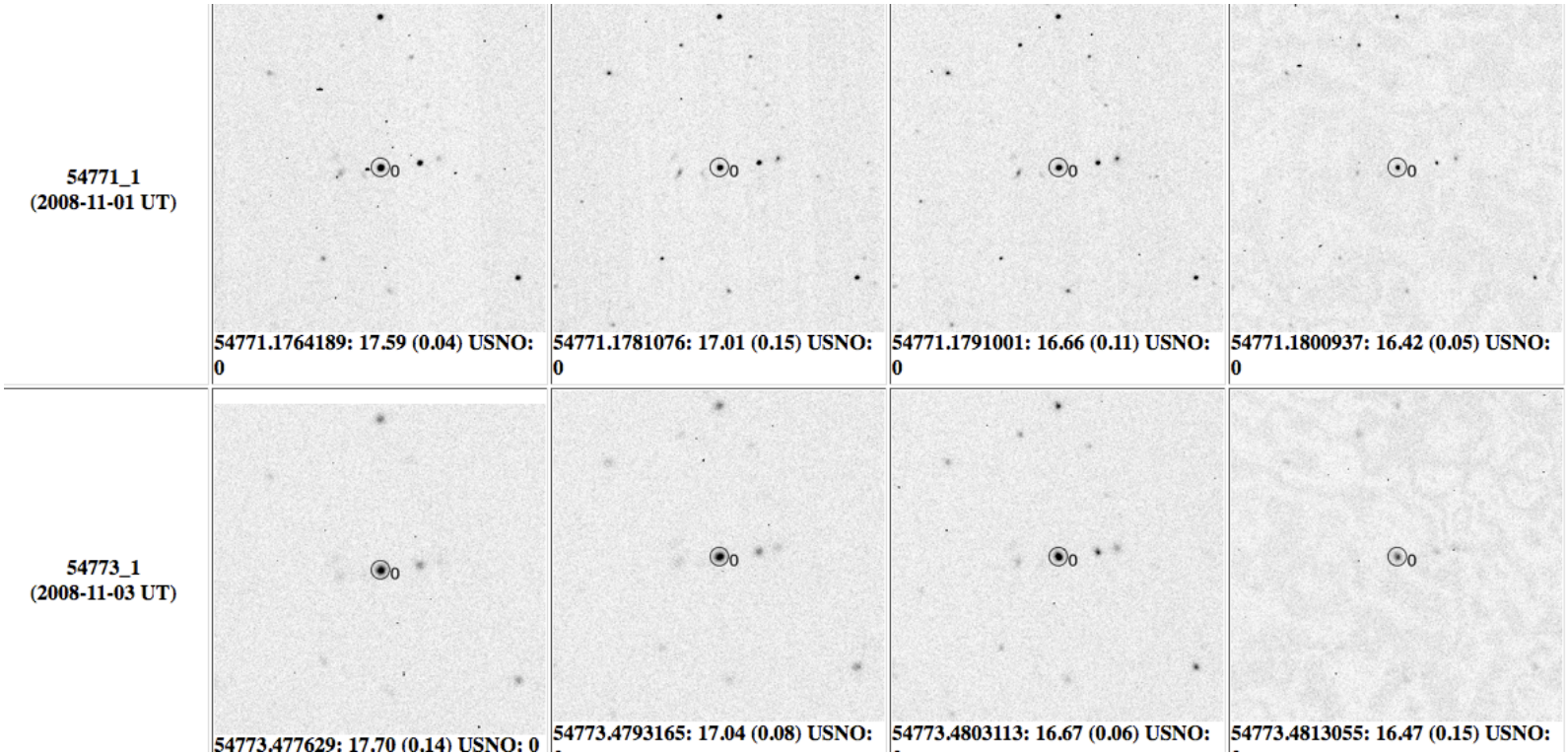


# Transient classification mantra

- Obtain a couple of epochs in one or more filters
- Assign probabilities for different classes
- Choose [to do more] observations (filters, wavelengths) for best discrimination
- Feed the new observations back in
- Revise probabilities, choose observations, …
- Based on confirmed class revise priors

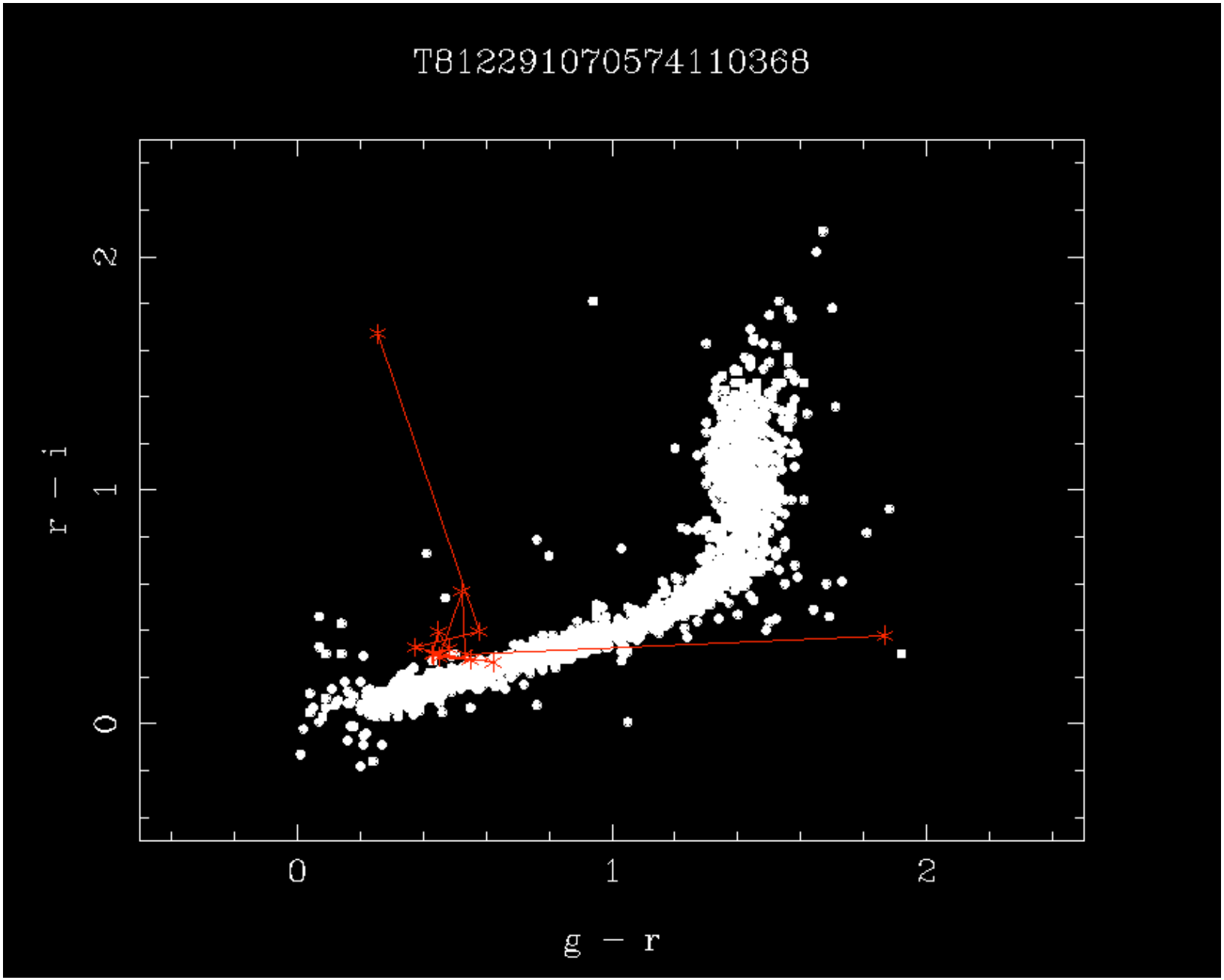
# Status

- Started with CRTS (P60 colors/lightcurves)
- Applying to PTF (P60 colors/spectra)



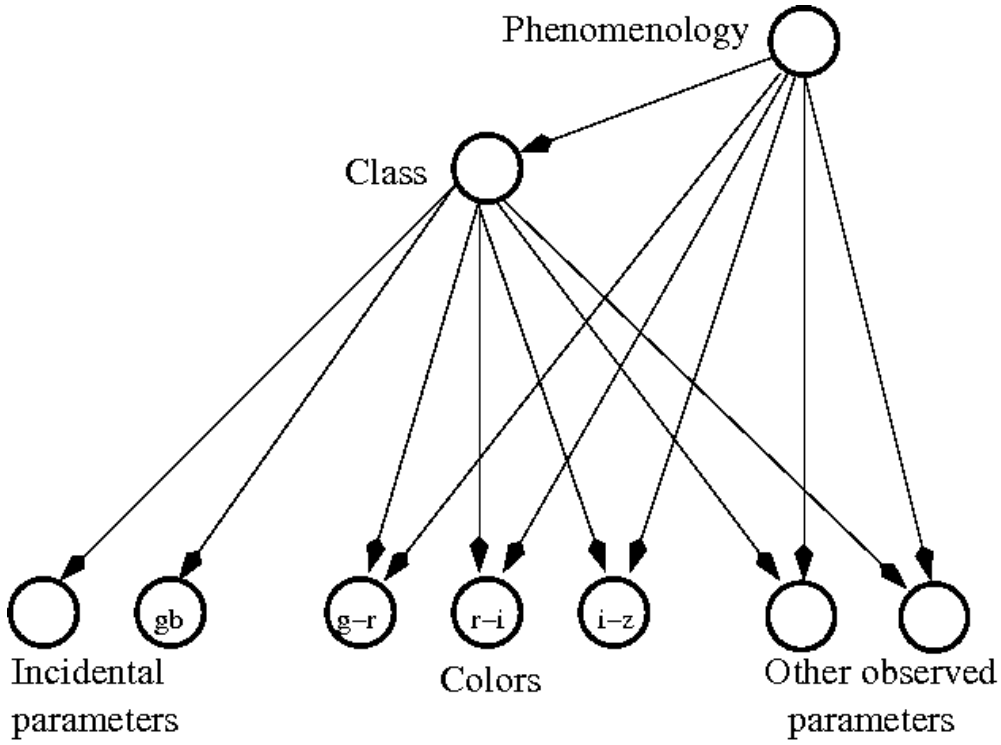

http://www.astro.caltech.edu/P60FollowUp/

Radio + X-ray



# Building Bayesian Networks

- Local dependencies, irrelevancies are evaluated using modeling
- Priors, likelihoods are obtained
- Directed Acyclic Graph is constructed
- Data define network
- No “training” necessary




Radio, for instance

8% CV classified as SN, 65% of objects classified as CV are actually CV

| 3 colors + gb (WTA) | CV (0.65) | SN (0.71) | BL (0.33) | REST (0.23) |
|---|---|---|---|---|
| CV | 0.72 | 0.08 | 0.08 | 0.13 |
| SN | 0.23 | 0.46 | 0.12 | 0.19 |
| BL | 0.24 | 0.03 | 0.49 | 0.24 |
| REST | 0.34 | 0.18 | 0.21 | 0.26 |

Priors based on CRTS data.
Delta-m > 2

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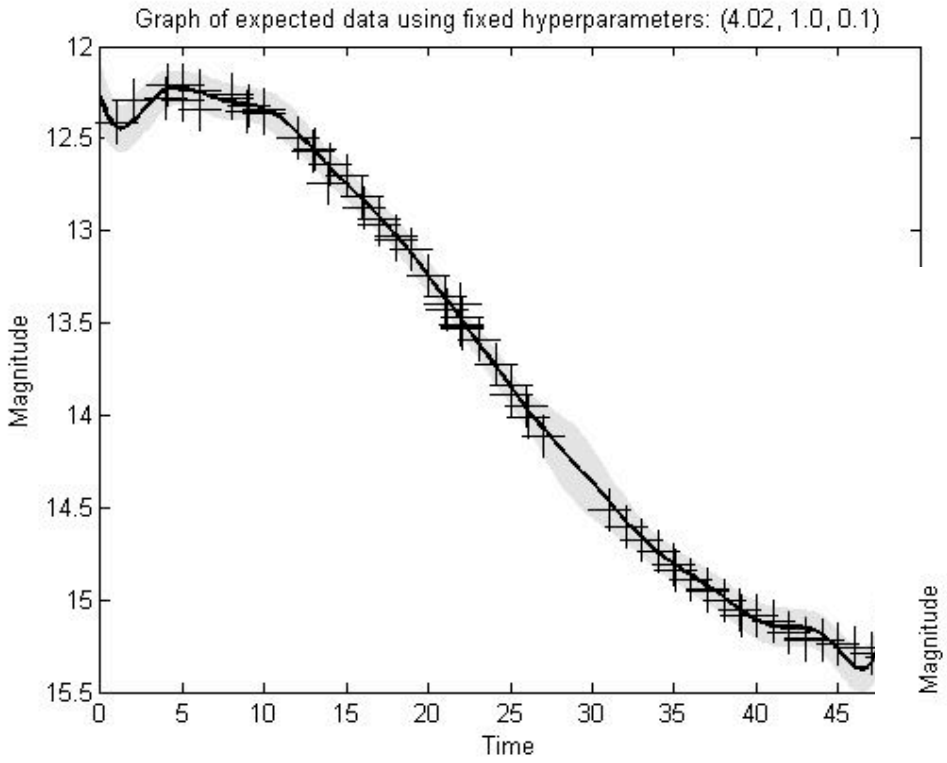
| Type | CV | SN | BL | REST |
|---|---|---|---|---|
| 3,n,w | 0.60 | 0.73 | 0.30 | 0.22 |
| 3,y,w | 0.65 | 0.71 | 0.33 | 0.23 |
| 2+,n,w | 0.58 | 0.77 | 0.31 | 0.17 |
| 2+y,w | 0.65 | 0.78 | 0.41 | 0.19 |
| 3,y,50 | 0.75 | 0.83 | 0.37 | 0.19 |
| 3,y,40-10 | 0.73 | 0.82 | 0.37 | 0.18 |
| 2+,y,50 | 0.74 | 0.88 | 0.43 | 0.19 |

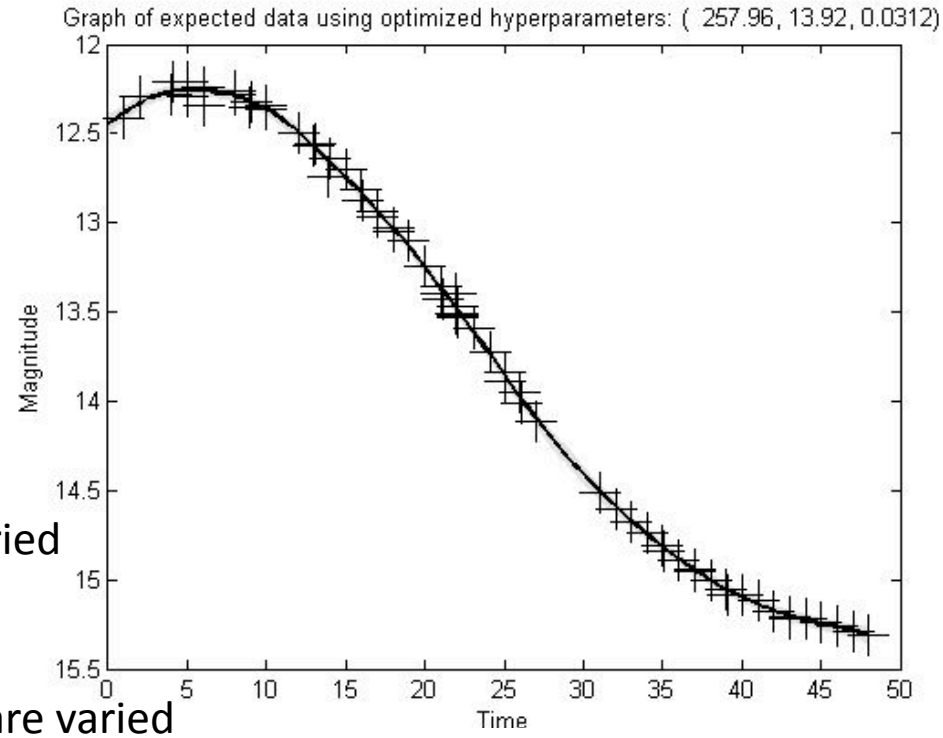
- Adding gb helps (of course)
- Having an additional colors is good (generally)
- More context info helps (distance to nearest galaxy, for instance)

| 3 colors + gb + galaxy prox. (WTA) | CV (0.74) | SN (0.84) | BL (0.31) | (1-contam.) |
|---|---|---|---|---|
| CV | 0.74 | 0.08 | 0.16 | |
| SN | 0.21 | 0.50 | 0.27 | |
| BL | 0.19 | 0.00 | 0.80 | |
| | | | | completeness |

# Using GPR with lightcurves




Given several epochs and corresponding magnitudes, estimate the likelihood of a particular magnitude for a new epoch (using some covariance function)




The 3 hyperparameters are “free” and are varied

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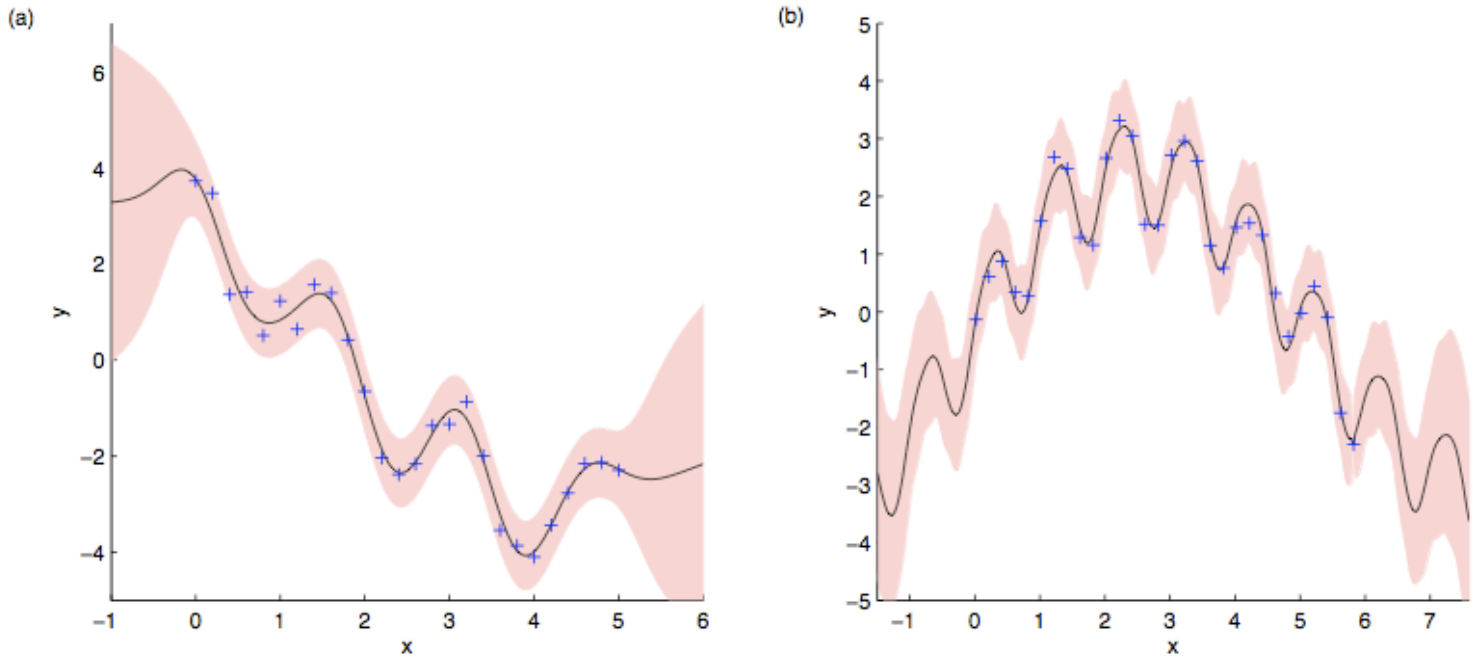
$$Cov(f(x_p), f(x_q)) = k_y(x_p, x_q) = \sigma_f^2 e^{-\frac{1}{2}l^2(x_p - x_q)^2} + \sigma_n^2 \delta_{pq}$$

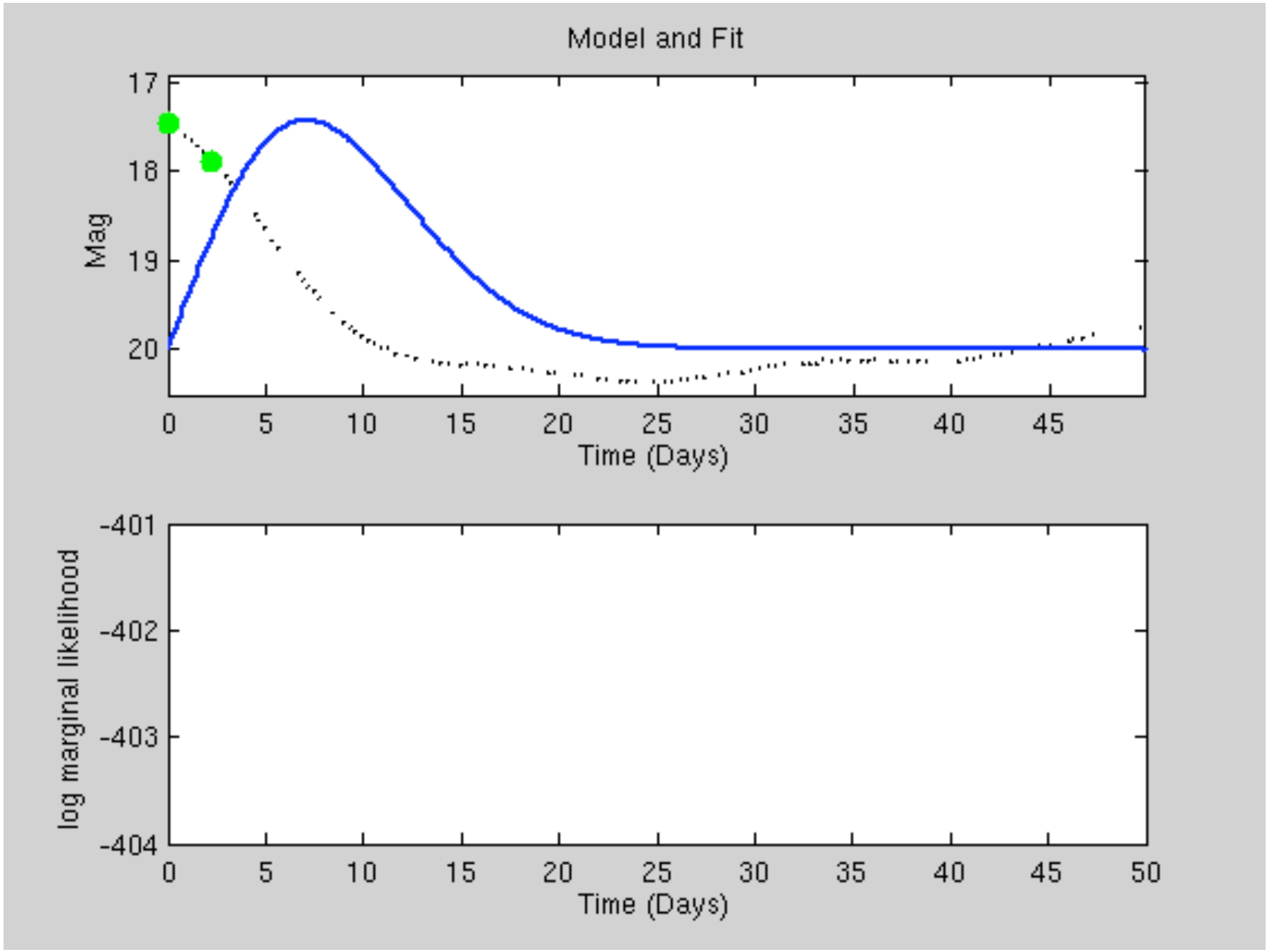


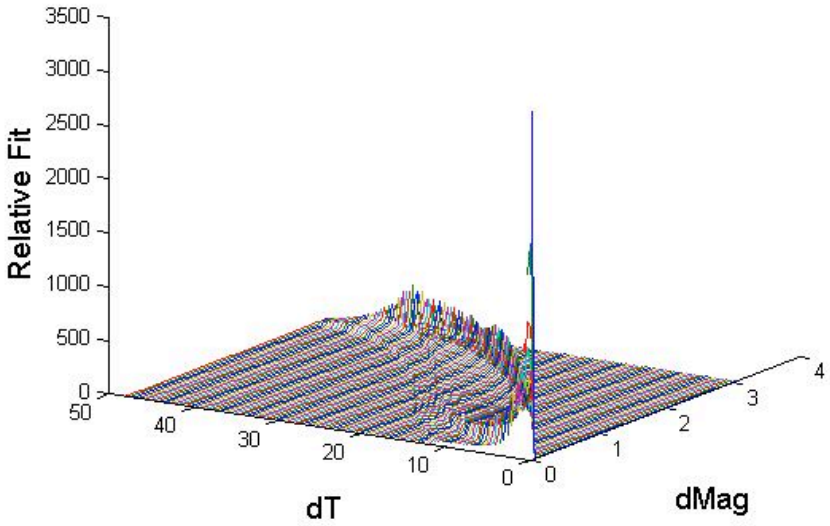

M. Ebden

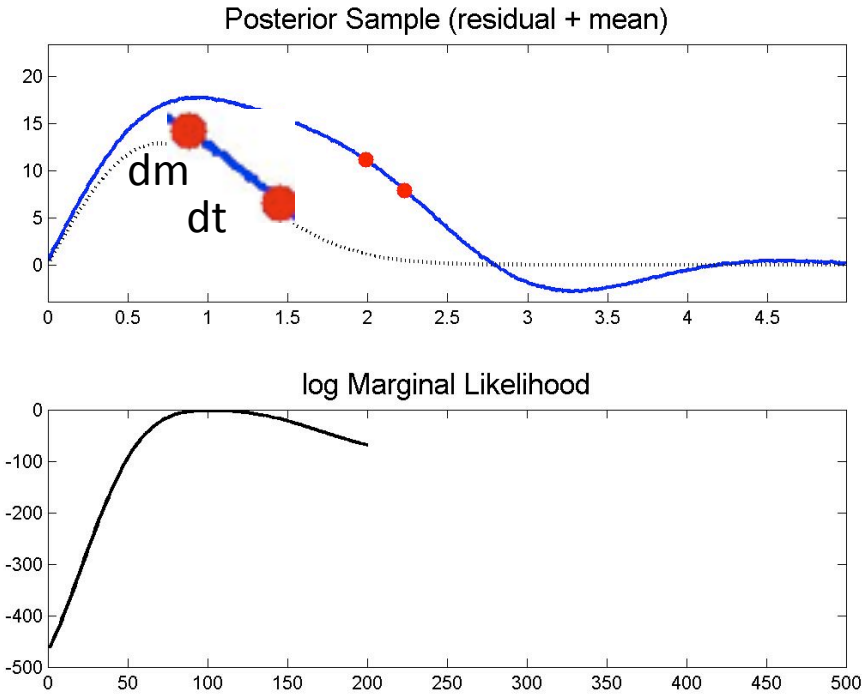
Figure 3: Estimation of $y_*$ (solid line) for a function with **(a)** short-term and long-term dynamics, and **(b)** long-term dynamics and a periodic element. Observations are shown as crosses.

$$k(x, x') = {\sigma_f}_1^2 \exp\left[\frac{-(x-x')^2}{2l_1^2}\right] + {\sigma_f}_2^2 \exp\left[\frac{-(x-x')^2}{2l_2^2}\right] + \sigma_n^2 \delta(x, x')$$

$$k(x, x') = \sigma_f^2 \exp\left[\frac{-(x-x')^2}{2l^2}\right] + \exp\{-2\sin^2[\nu\pi(x-x')]\} + \sigma_n^2 \delta(x, x')$$


Model and Fit
Mag
17
18
19
20
0
5
10
15
20
25
30
35
40
45
Time (Days)
log marginal likelihood
-401
-402
-403
-404
0
5
10
15
20
25
30
35
40
45
50
Time (Days)




Difficult tool to train for periodic variables.

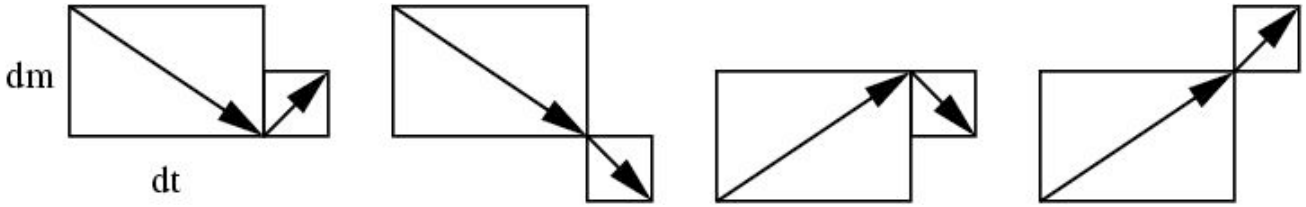
132 Mira from ASAS:

Period: 55 – 523 days

Peak mag: 4.89 – 13.29

Amplitude: 1.63 – 6.65

More points => better performance

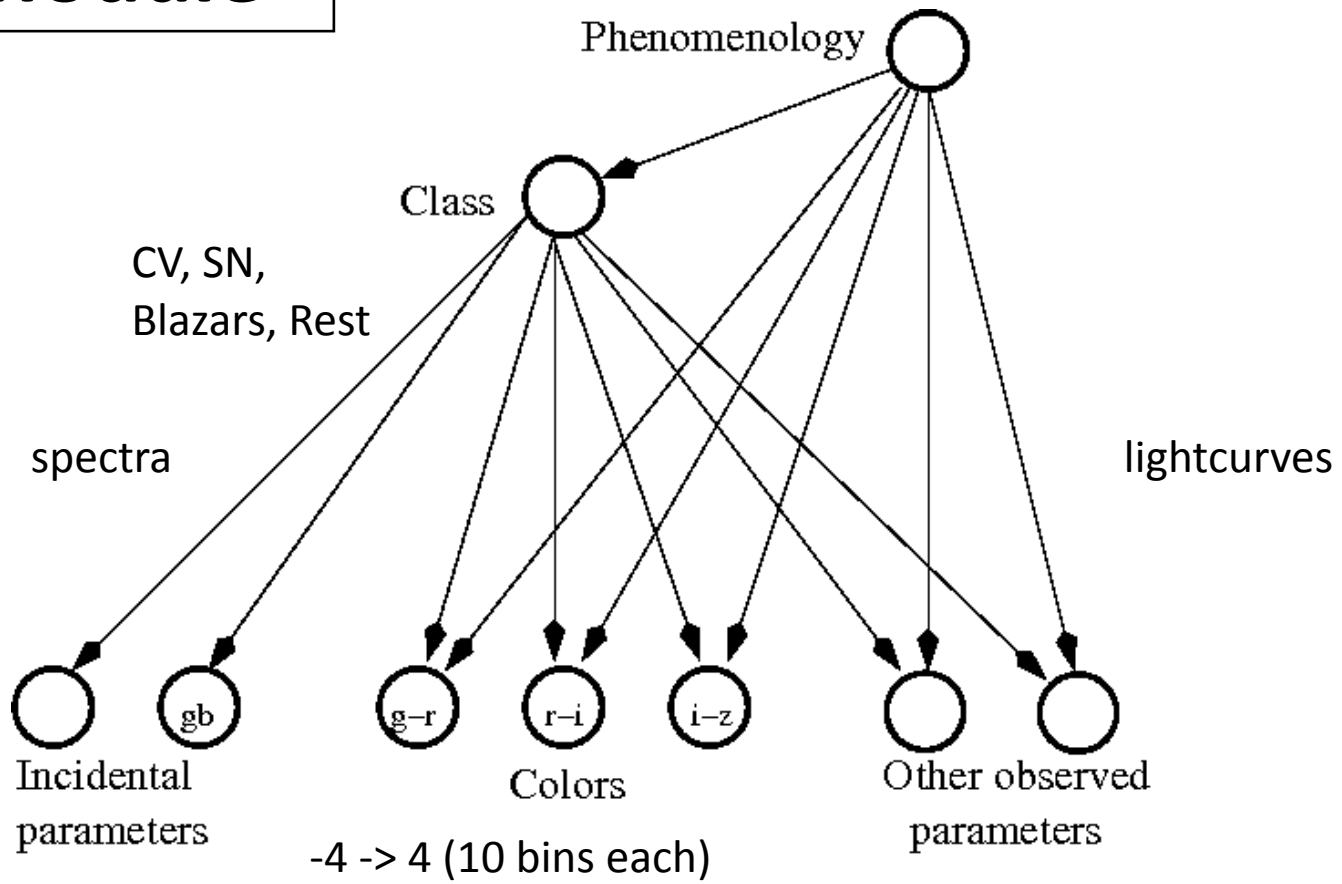


**BN** **GPR**

**Fusion Module**

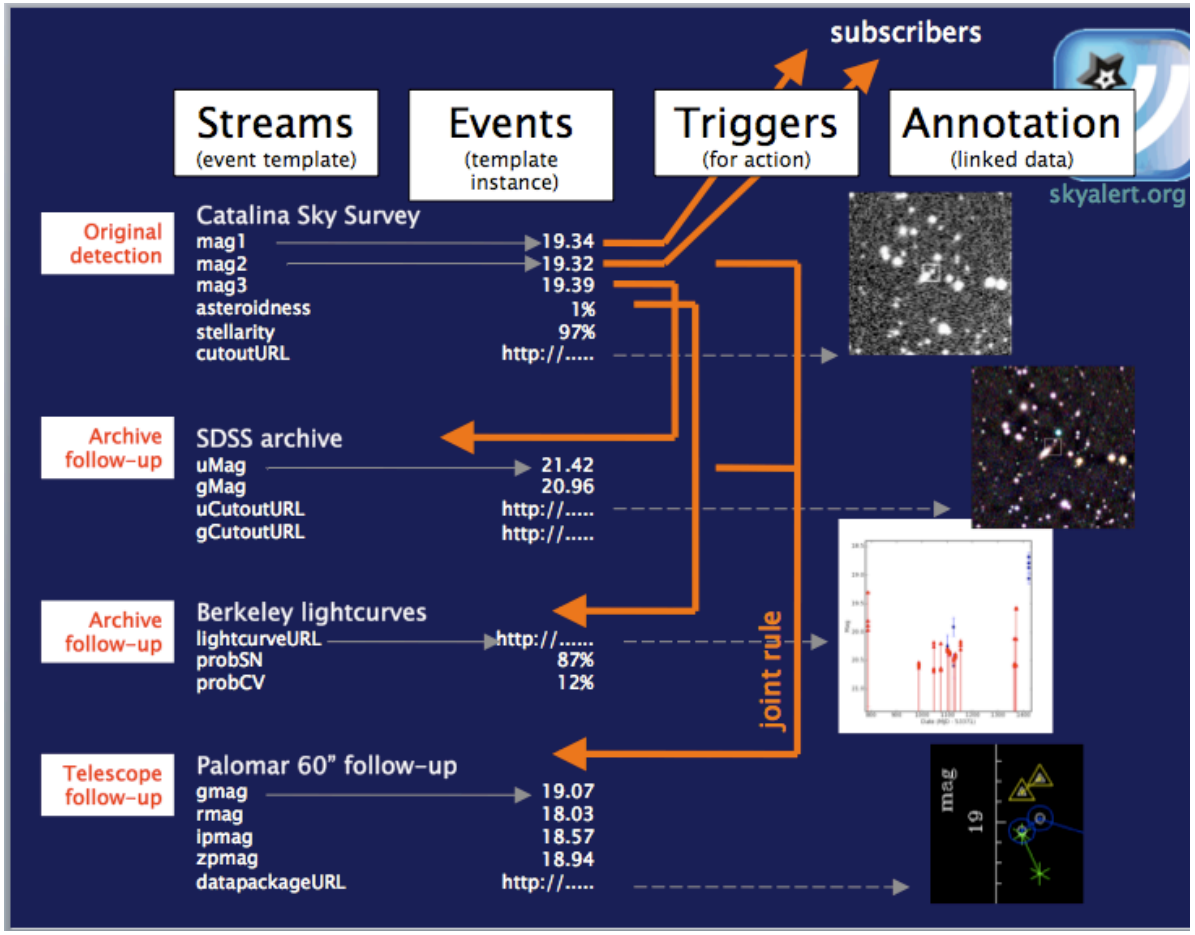
$\mathcal{P}$

Next steps include combining CRTS, P60, PTF etc. data



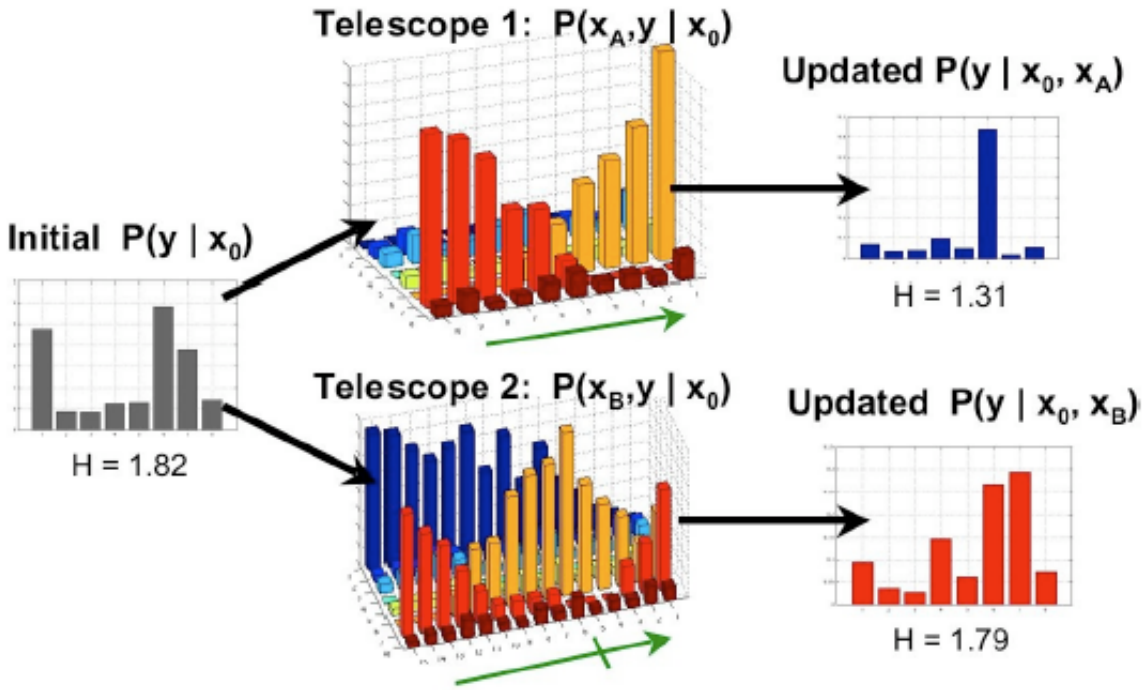
# Portfolios, semantic linking and skyalert (http://www.skyalert.org)

- Active follow-up
  - New images
  - New colors
  - Better astrometry
  - Spectra
- Passive follow-up (annotators)
  - Galaxy distance
  - Classification
    - Program
    - Expert

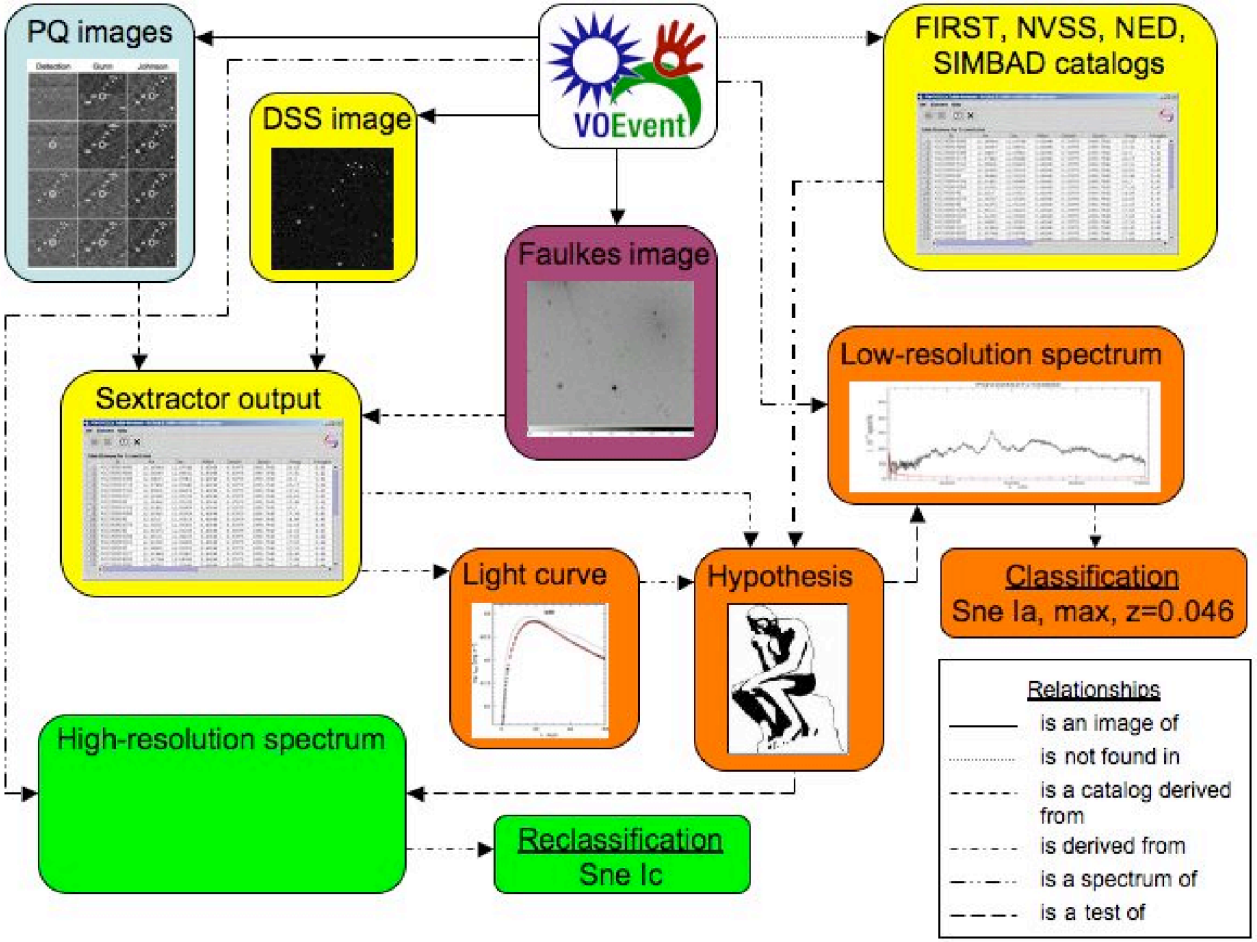


# Follow-up (for  missing values)

- Such that it will help discriminate better
- Serve probabilities so that consumers can choose their types of transients
- Widest possible models
- (resource uniformity)
- (well connectedness)



# Towards the Glass Bead Game




Natural and artificial classifiers; varied inputs; unified output

Difficult but exciting problem

To boldly classify what no one has classified before …