Real-time Classification for The Palomar Transient Factory

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Mini-Workshop on Computational AstroStatistics

Transient Classification Project (TCP)

Berkeley Astronomy:
Dan Starr, Dovi Poznanski, Maxime Rischard, Nat Butler, Chris Klein, Rachel Kennedy, Justin Huggins, Adam Morgan, Adam Miller, Josh Bloom

San Francisco State University:
John M. Brewer

Berkeley Statistics:
Sahand Negahban, James Long, Noureddine El Karoui, John Rice, Tamara Broderick, ...

Berkeley EECS:
Martin Wainwright, Massoud Nikravesh

Lawrence Berkeley Lab:
Peter Nugent, Horst Simon

Los Alamos Nat. Lab. / UC Santa Cruz:
Damian Eads

NSF grant 0941742

Cyber-enabled Discovery and Innovation (CDI)

Outline

1. Palomar Transient Factory (PTF)
2. Transient Classification Project (TCP)
   - DotAstro.org
   - Features for Classification
3. Light Curve Classification using Diffusion Map
   - Supernova Classification Challenge
   - Diffusion Map Classifier for PTF?

Palomar Transient Factory (PTF)

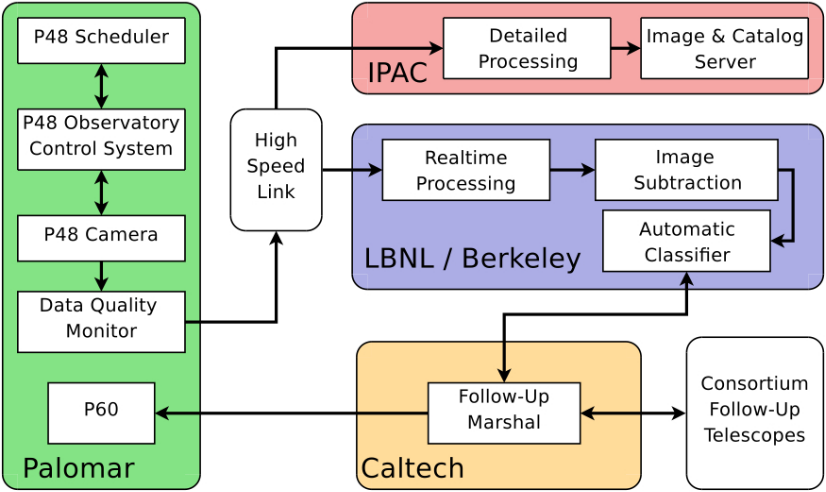
- Fully-automated survey to explore the optical transient sky
- Palomar 48" telescope (P48): 8.1 square-degree FoV, 101 megapixel CCD array, 2 filters

Experiment	**Science Goals**	**Setup**
5-day Cadence	SNe Ia, CC SNe, AGNs, QSOs, Novae, etc.	60 sec. exposures 8000 deg^2 / year
Dynamic Cadence	Unexplored (fast) regimes RR Lyr, CVs, flare stars, SNe, etc.	60 sec. exposures 1 min.- 5 day cadences
Orion Field	transiting planets	single field
Hα	Hα sky survey	narrow-band on/off Hα

- Follow-up of detected transients by Palomar 60" (P60) and telescopes at other facilities
- Follow-up decisions based on source classifications

Palomar Transient Factory (PTF)

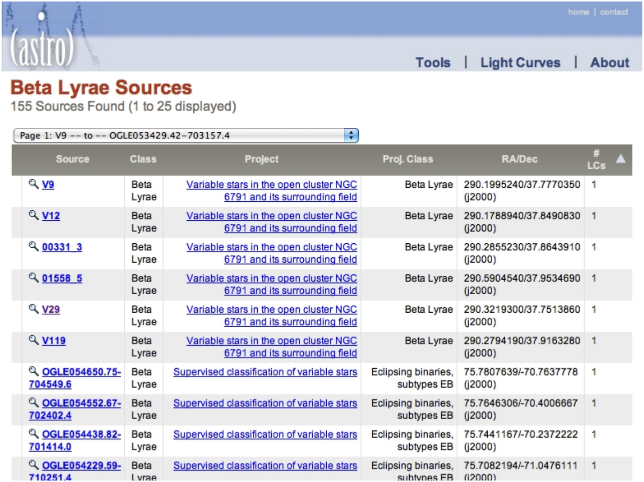
Law et al. (2009, PASP, 121, 1395)



Transient Classification Project (TCP)

- For optimal allocation of follow-up resources, need accurate, real-time classifications of transient events
- Some challenges:
  1. Need labeled data to train & validate our classifier

TCP: DotAstro.org



(astro)

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Beta Lyrae Sources

155 Sources Found (1 to 25 displayed)

Page 1: V9 -- to -- OGLE053429.42-703157.4

Source	Class	Project	Proj. Class	RA/Dec	# LCs
V9	Beta Lyrae	Variable stars in the open cluster NGC 6791 and its surrounding field	Beta Lyrae	290.1995240/37.7770350 (j2000)	1
V12	Beta Lyrae	Variable stars in the open cluster NGC 6791 and its surrounding field	Beta Lyrae	290.1788940/37.8490830 (j2000)	1
00331_3	Beta Lyrae	Variable stars in the open cluster NGC 6791 and its surrounding field	Beta Lyrae	290.2855230/37.8643910 (j2000)	1
01558_5	Beta Lyrae	Variable stars in the open cluster NGC 6791 and its surrounding field	Beta Lyrae	290.5904540/37.9534690 (j2000)	1
V29	Beta Lyrae	Variable stars in the open cluster NGC 6791 and its surrounding field	Beta Lyrae	290.3219300/37.7513860 (j2000)	1
V119	Beta Lyrae	Variable stars in the open cluster NGC 6791 and its surrounding field	Beta Lyrae	290.2794190/37.9163280 (j2000)	1
OGLE054650.75-704549.6	Beta Lyrae	Supervised classification of variable stars	Eclipsing binaries, subtypes EB	75.7807639/-70.7637778 (j2000)	1
OGLE054552.67-702402.4	Beta Lyrae	Supervised classification of variable stars	Eclipsing binaries, subtypes EB	75.7646306/-70.4006667 (j2000)	1
OGLE054438.82-701414.0	Beta Lyrae	Supervised classification of variable stars	Eclipsing binaries, subtypes EB	75.7441167/-70.2372222 (j2000)	1
OGLE054229.59-710251.4	Beta Lyrae	Supervised classification of variable stars	Eclipsing binaries, subtypes EB	75.7082194/-71.0476111 (j2000)	1

www.DotAstro.org: 100,000 sources, 150 classes

Astronomer-classified objects (from over 100 papers)

Transient Classification Project (TCP)

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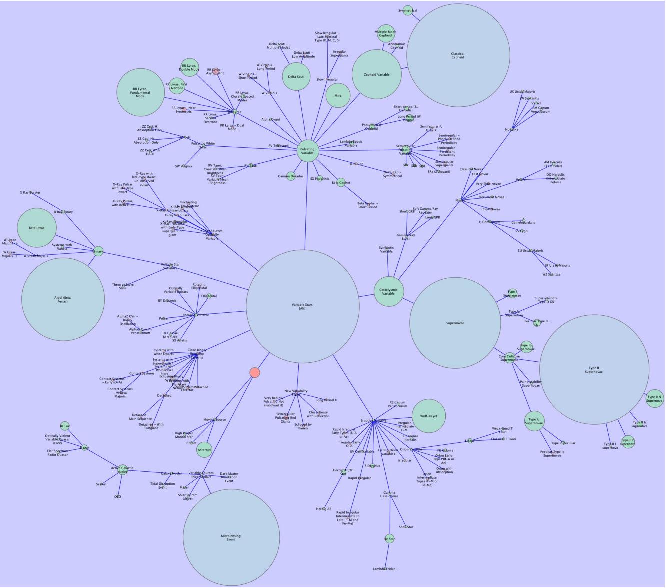
  2. Highly multi-class problem with nested classifications

TCP: DotAstro.org Classification Taxonomy



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Question: What information should we extract from the light curves to train our classifier?

TCP: Features for Classification

TCP currently uses:

1. Features derived from time-series light curves
   - flux quantiles, skewness, slope
   - period, amplitude of largest peaks of Lomb-Scargle periodogram
   - light-curve fitting parameters
   - color information
2. "Context" information
   - galactic latitude & longitude
   - distance from ecliptic plane
   - distance to nearest galaxy, properties of that galaxy

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Many possible features, lots of missing data, high levels of noise on some features!

Light Curve Classification using Diffusion Map

Light Curve Classification using Diffusion Map

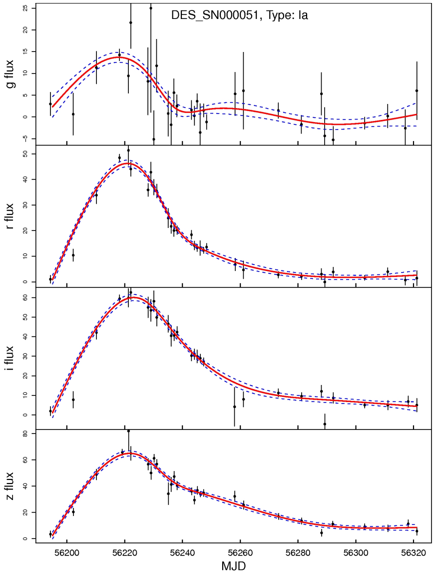
- Idea: First map each light curve, $\mathbf{x}$, into m-dimensional diffusion space $\mathbf{x} \mapsto \{\psi_1(\mathbf{x}), ..., \psi_m(\mathbf{x})\}$
- Use the diffusion map coordinates as features for a classifier
- Advantages:
  - All we need is distance between each pair of light curves, $s(\mathbf{x}_i, \mathbf{x}_j)$
  - Exploits the underlying sparse structure of the data set
  - Can avoid estimating physical parameters of each light curve

Supernova Classification Challenge

- DES SN Photometric Classification Challenge to test supernova light curve classification methods (Kessler et al. 2010, arXiv:1008.1024)
- *griz* SN light curves simulated from templates
- 1300 labeled SNe (Ia / II / Ibc) to classify 18,000

- Our entry: Find sparse structure in the SN database, exploit low-dimensional representation to build classifier
- InCA Group team: JWR, D. Homrighausen, C. Schafer, and P. Freeman

SN Photometric Classification: Methods



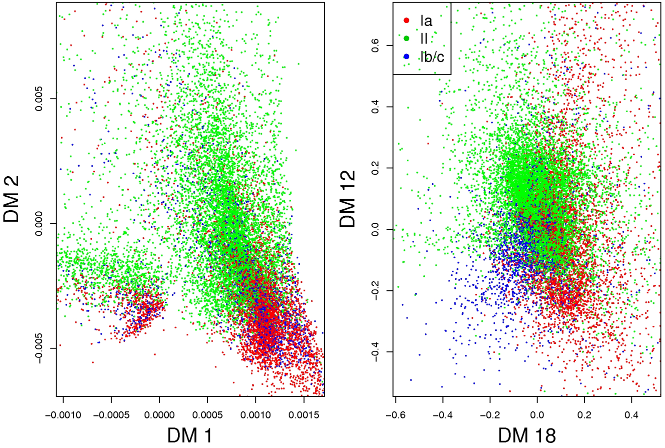
Data: Noisy realizations from SN LC templates in each of 4 filters

Our Approach:

1. Fit regression spline in each filter of each SN
2. Distances between SNe: weighted-ℓ_2 distance between normalized spline fits
3. Apply standard classification method using diffusion coords.

SN Photometric Classification: Results

Two-dimensional diffusion map representations of 18,000 SNe



Richards et al. (2010), in preparation

SN Photometric Classification: Results

SN Photometric Classification Challenge judged on both efficiency and purity of type Ia classifications.

$$\mathrm{FoM} = \frac{\mathrm{N}_{\mathrm{Ia}}^{\mathrm{true}}}{\mathrm{N}_{\mathrm{Ia}}^{\mathrm{Total}}} \times \frac{\mathrm{N}_{\mathrm{Ia}}^{\mathrm{true}}}{\mathrm{N}_{\mathrm{Ia}}^{\mathrm{true}} + 3\mathrm{N}_{\mathrm{Ia}}^{\mathrm{false}}}$$

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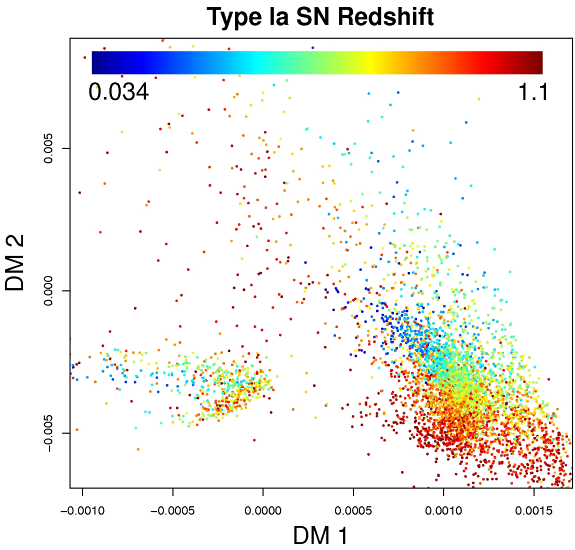
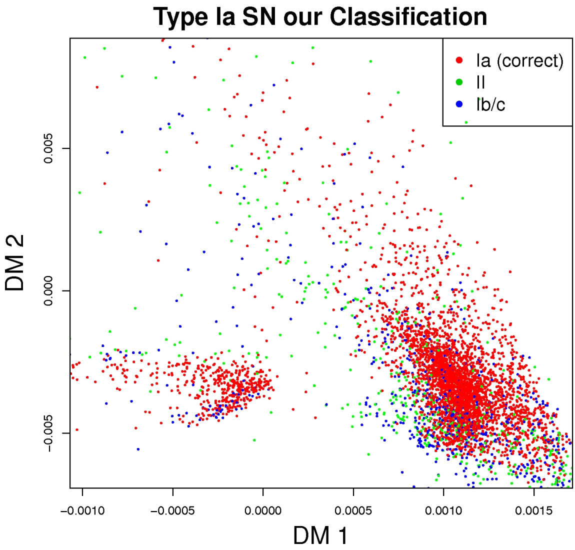
Submission	Description	Training FoM	Test FoM
this work	**Diffusion Map with Random Forest Classifier**	**0.810**	**0.236**
Rodney	Template Fitting	0.488	0.319
Gonzalez	Template Fitting	0.528	0.169
SNANA cuts	Template Fitting	0.582	0.221
Sako	Template Fitting	0.802	0.506
MGU+DU-1	Difference Boosting Neural Network on Light Curve Slopes	0.385	0.079
MGU+DU-2	Random Forest on Light Curve Slopes	0.635	0.148
JEDI KDE	Kernel Density Estimation with 21 Parameters*	0.946	0.371
JEDI Boost	Boosted Decision Trees with 21 Parameters*	0.961	0.204
All Ia	Classify all SNe as Type Ia	0.385	0.107

*light curve for each filter is fit to a modified Γ-distribution function with five parameters

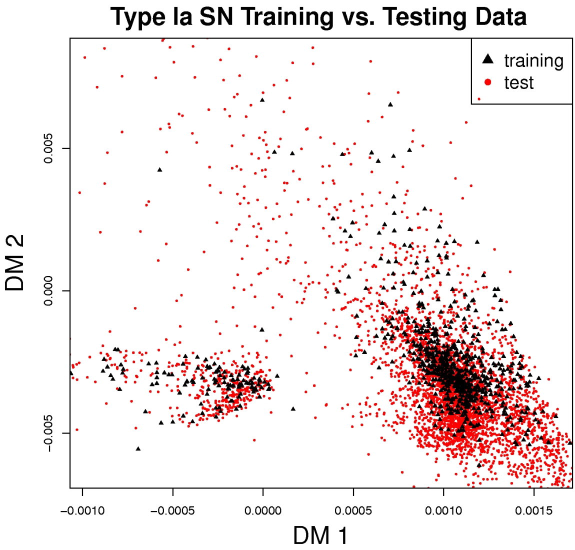
SN Photometric Classification: Redshift



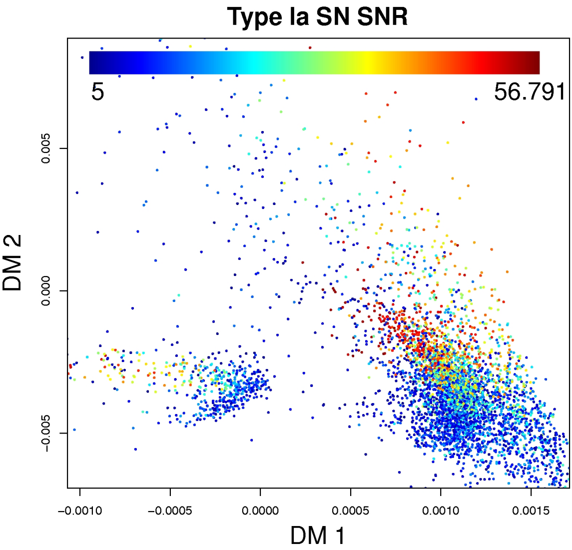
SN Photometric Classification: Predicted Class



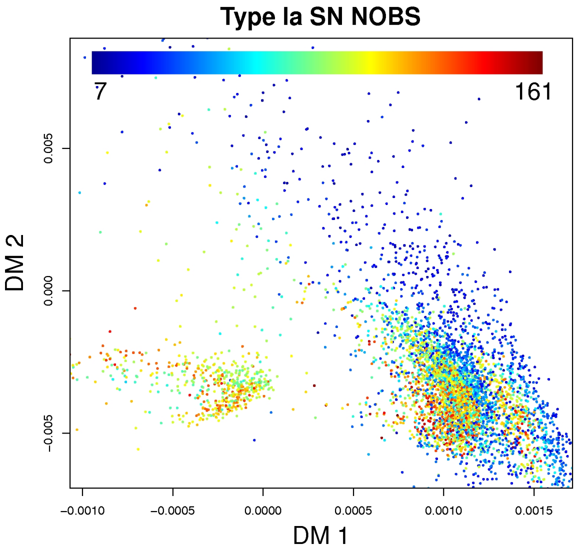
SN Photometric Classification: Training vs. Test



SN Photometric Classification: SNR



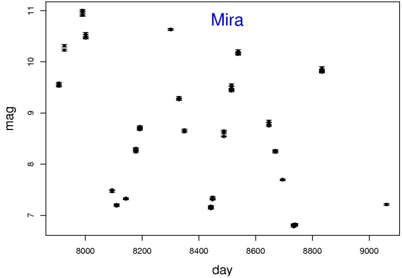
SN Photometric Classification: No. of Obs.

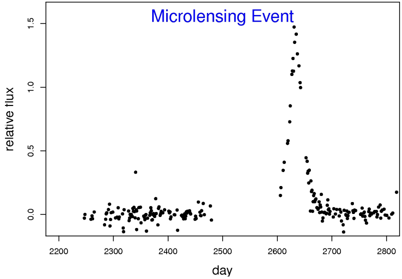


SN Photometric Classification: Lessons Learned

- Diffusion map is a competitive method for SN classification
- Latent variables (e.g. redshift) are captured by the diffusion coordinates.
  - No time dilation or K-corrections!
  - Can be used as photo-z estimator
- Need more SN training data at high-z!
  - If spectral coverage is not possible, can we model the physics?
- Much care is needed in choosing $s(\cdot, \cdot)$

Diffusion Map for PTF Classifier: Challenges





- Must deal with periodic (e.g. variable stars) and non-periodic (e.g. explosive events) light curves
- How do we construct a **general distance measure**, $s(\cdot,\cdot)$?
- Flux normalization? Time zero-point? Period folding? Fourier space?

Summary

- Accurate, real-time transient classification is imperative for the PTF (and LSST)
- `DotAstro.org` contains expert-classified light curves for 100,000 sources
- Classification problem is highly multi-class and data are noisy and heterogeneous
- What are the optimal features for classification? Can we incorporate measurement errors?
- Diffusion map can be used to uncover simple structure in sets of light curves
    - Application to SN Classification Challenge yielded impressive results
- Can we adapt this methodology to build a general transient classifier?

TCP Publications

Bloom, J. S., Starr, D. L., Butler, N. R., Nugent, P., Rischard, M., Eads, D., Poznanski, D. **Towards a real-time transient classification engine** (2008, AN, 329, 284)

Starr, Dan L., Bloom, J. S., Butler, N. R. **Real-time Transient Classification Pipeline** (2008, AIPC, 1000, 635)

Bloom, Joshua S., Starr, D. L., Butler, N. R., Poznanski, D., Rischard, M., Kennedy, R., Brewer, J. **Rapid and Automated Classification of Events from the Palomar Transient Factory** (2009, AAS, 41, 419)

Poznanski, Dovi et al. **The Standard Candle Method For Type II-P Supernovae - New Sample And PTF Perspective** (2009, AAS, 41, 419)

Brewer, J. M., Bloom, J. S., Kennedy, R., Starr, D. L. **A Web-Based Framework For a Time-Domain Warehouse** (2009, ASPC, 411, 357)

Starr, D. L., Bloom, J. S., Brewer, J. M., Butler, N. R., Poznanski, D., Rischard, M., Klein, C. **The Berkeley Transient Classification Pipeline: Deriving Real-time Knowledge from Time-domain Surveys** (2009, ASPC, 411, 493)

Butler, Nathaniel R., Bloom, Joshua S. **Optimal Time-Series Selection of Quasars** (2010, arXiv:1008.3143)