The SED Machine - Fast classification of transient objects

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Outline

1. Introduction
   - The Palomar Transient Factory (PTF)
   - Traditional follow-up
   - A new approach

2. The SED Machine
   - The Instrument
   - Data Reduction
   - Progress
According to Astro-2010 decadal report, field of time-domain astronomy expected to enjoy golden age during this decade.

Number of on-going and soon-to-be-commissioned optical surveys (PTF, PanSTARRS, CSS, SkyMapper, LSST) will keep field vibrant well into next decade.

Number of newly discovered transient objects expected to rise quickly.
PTF (Law 2009, Rau 2009) is a wide-field synoptic survey designed to discover transients in the Universe, including SN, GRBs, and other rare and exotic transients, as well as the study of stellar variability.

Utilises the Palomar 48-inch Samuel Oschin Schmidth Telescope (P48), equipped with a mosaic camera providing a field-of-view of \( \sim 7.26 \text{ deg}^2 \).

Discovery rate of PTF is \( \sim 4,000 \) candidate transients per year.

Only \( \approx 10\% \) of transient candidates can be followed-up and classified.
Traditional follow-up and classification of transients

- Transients traditionally classified spectroscopically using
- Medium to large aperture telescopes
- Classification requires wide wavelength range and $SNR \gtrsim 15$ per resolution element
- Long exposure times needed with medium to high-resolution spectrographs
A new classification approach

Low resolution spectrograph!

- Low resolution spectra require a lot less light to achieve the same SNR
  => less observing time on smaller telescopes
- $R \sim 100$ is enough to contain as much information for classification as $R \sim 1,000$ spectra, but with an increase in signal-to-noise per second of a factor of 3
Follow-up of transient candidates

PTF discovered transients (~7000/year)
Spectroscopic Follow-up (~900/year)

Goal for SED Machine on P60
$R \sim 100$ spectra
The SED Machine - Key scientific objectives

- **Spectroscopy of infant SN** – Early time data can provide powerful clues to origins and physics of SN of all types
- **Shock breakouts** – Carry valuable information about SN progenitors and explosion physics
- **Rare SN** – SEDM can sort through mundane optical transients and discover the rare phenomena
- **GRBs** – SEDM can function as low-resolution photometric redshift instrument, providing prompt redshifts for GRBs for redshift range $z \approx 2 – 6$
- **Asteroids** – SEDM well suited to classify asteroids as taxonomy of Bus & Binzel (2002) is itselft based on $R \sim 100$ optical spectroscopy
Employs two main instruments:

- **Rainbow Camera (RC)** – Sloan $u, g, r, i$ for target acquisition and flux calibration
- **Integral-Field Unit (IFU)** – Lenslet-based IFU (370 – 920 nm) for spectroscopic analysis of transient candidates
The SEDM Rainbow Camera

- Photometric subsystem taking images in 4 bands simultaneously (Sloan $u, g, r, i$)
- Used for target acquisition and flux calibration
- e2v CCD with $2k \times 2k$ 13$\mu$m pixels (0.376$''$/pixel)
The SED Machine Integral Field Unit

- Lenslet-based IFU, covering 26” × 26” on the sky
- Lenslet array has 60 × 60 hexagonal lenslets, each covering 0.74” on the sky
- Spectrograph with triple prism provides nearly constant resolution (R ∼ 100) over the
- Wavelength range 370 – 920 nm (∼ 220 pixels long), sufficient for spectroscopic classification of transient candidates
SED Machine Optical Interfaces

Palomar 60" Focal Plane

Unvignetted Field: 18.1"

P60 Scale: 64.7 μas

IFU: 30"

12.8 x 12.8 FOV

Image slicing

Spectrograph input (pupil images)

Focal plane: lenslet array

Spectrograph

Detector
IFU Design
Rainbow Camera

- Written in PyRAF (C. C. Ngeow, NCU, Taiwan)
- Includes basic reduction steps plus automatic identification of standard stars and flux measurement

Integral Field Unit

- Based on the STELLA pipeline (Ritter & Washüttl 2004, AN 325, 663)
- Includes basic reduction steps with latest optimal-extraction algorithms (Ritter et al., PASP, subm.)
- Two modes:
  - Quick look for quality checks and fast TOC classification
  - Sophisticated optimal extraction with multi-object decomposition (cross-talk between spectra) for more detailed analysis
Commissioning

SEDM I currently being commissioned at the Palomar 60in Telescope (P60).

Robert Quimby [PS]
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SED Machine I finished

- Total costs 675 K$
- First light June 2013
- Currently 11 nights on the telescope
- Throughput measurements
- Testing instrument stability, focus, flexure
Some pretty pictures - Rainbow Camera

Unvignetted \( \varnothing 17' \) circle

- \( g \sim 40\% \)
- \( u \sim 8\% \)
- \( i \sim 30\% \)
- \( r \sim 45\% \)

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Some pretty pictures - Saturn (u band)
Some pretty pictures - Asteroid spectrum
Some pretty pictures - Planetary Nebula
The SED Machine

Some pretty pictures - Super Nova

10 M - ASAS-SN 13AR - 15.2 V
Summary

- SED Machine optimal for fast classification of transient objects
- SEDM I finished and currently being tested at Palomar Observatory
- Total costs: 675 K$
- SEDM II will go to 2m Telescope at Lulin Observatory (Taiwan)
- more to follow