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

Time-domain astronomy

- 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

The Palomar Transient Factory (PTF)

- 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 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

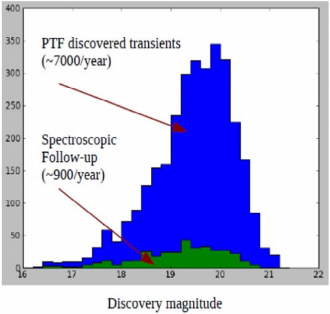
- Transients traditionally classified spectroscopically using
- Medium to large aperture telescopes
- Classification requires wide wavelength range and $SNR \gtrsim 15$ per resolution element
- Long exposure times needed with medium to high-resolution spectrographs

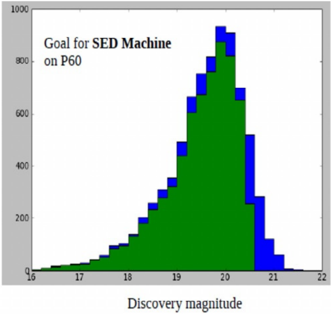
A new classification approach

Low resolution spectrograph!

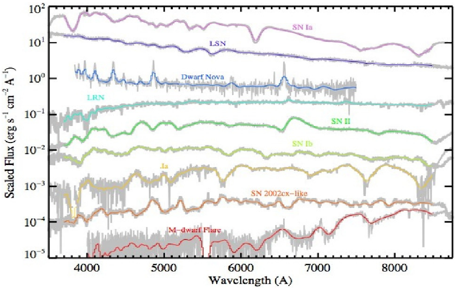
- Low resolution spectra require a lot less light to achieve the same SNR
  => less observing time on smaller telescopes
- $R \sim 100$ is enough to contain as much information for classification as R$\sim$1,000 spectra, but with an increase in signal-to-noise per second of a factor of 3

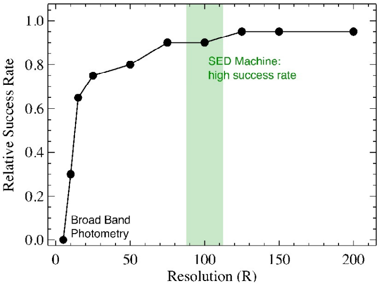
Follow-up of transient candidates





$R \sim 100$ 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 valueable 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

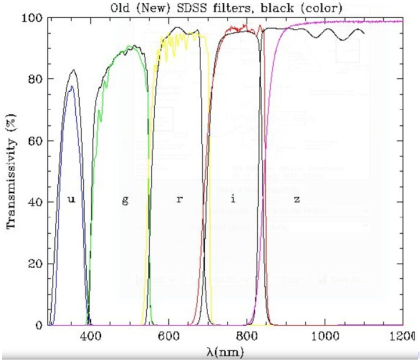
The SED Machine

Employs **two** main instruments:

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

The SEDM Rainbow Camera

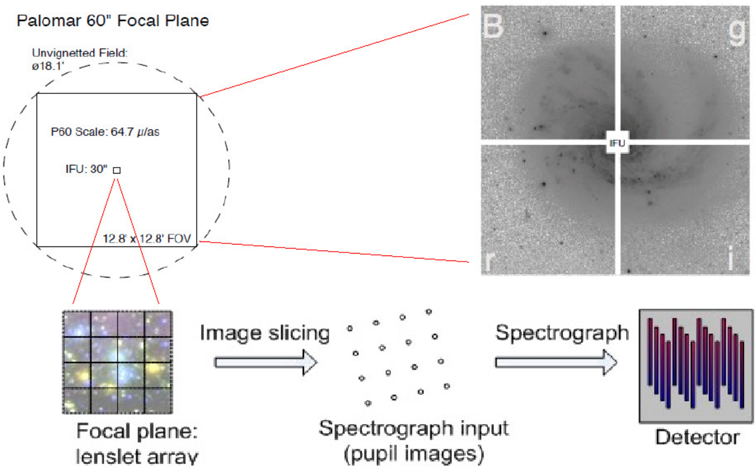
- Photometric subsystem taking images in 4 bands simultaneously (Sloan *u*, *g*, *r*, *i*)
- Used for target aquisition and flux calibration
- e2v CCD with $2\mathrm{k} \times 2\mathrm{k}$ $13\mu\mathrm{m}$ pixels ($0.376''/\mathrm{pixel}$)



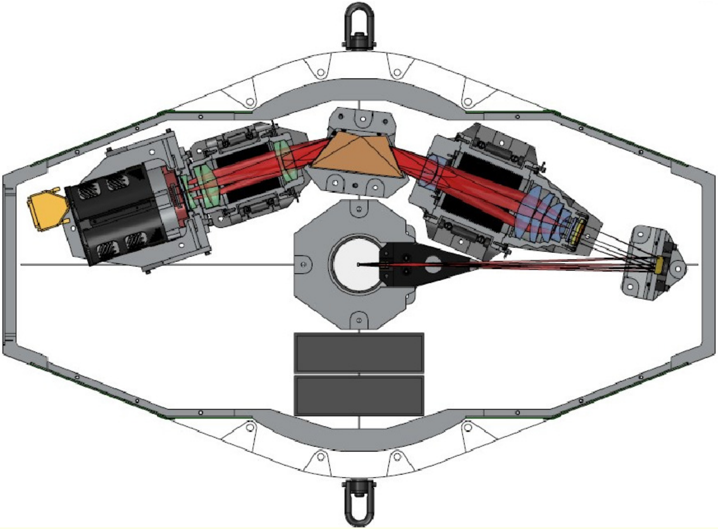
The SED Machine Integral Field Unit

- Lenslet-based IFU, covering $26'' \times 26''$ 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 ($R \sim 100$) over the
- Wavelength range $370 - 920$ nm (~ 220 pixels long), sufficient for spectroscopic classification of transient candidates

SED Machine Optical Interfaces



IFU Design



Data Reduction

Rainbow Camera

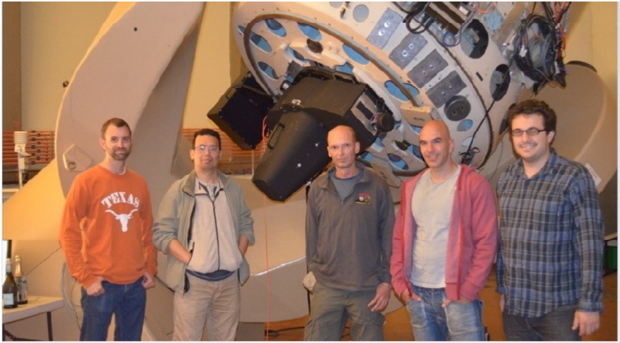
- Written in PyRAF (C. C. Ngeow, NCU, Taiwan)
- Includes basic reduction steps plus automatic identification of standard stars and flux measurement

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)



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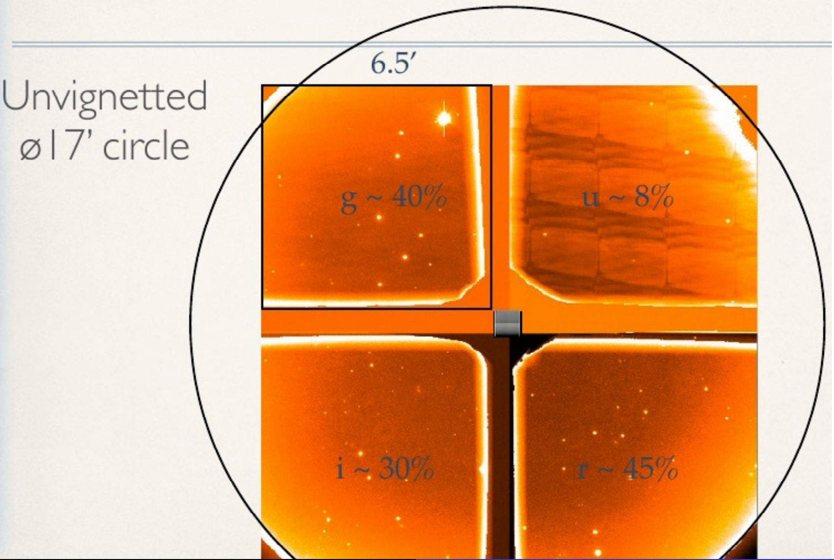
Choong Ngeow [DRP] Sagi Ben-Ami [RC]

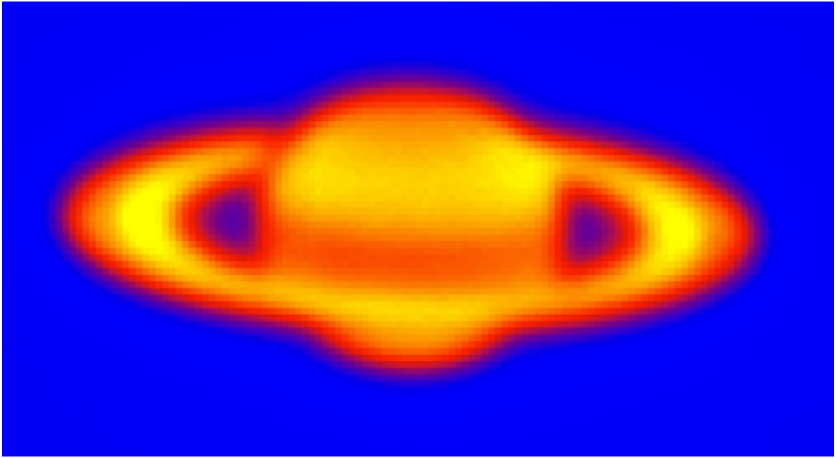
SED Machine I finished

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

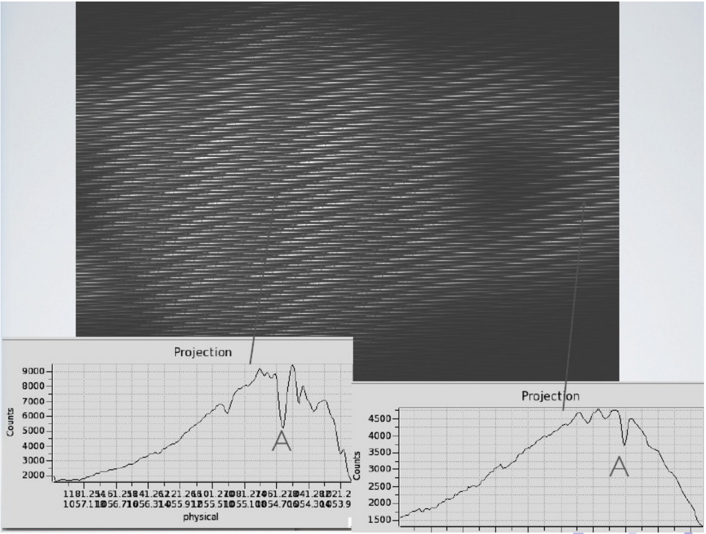
Some pretty pictures - Rainbow Camera



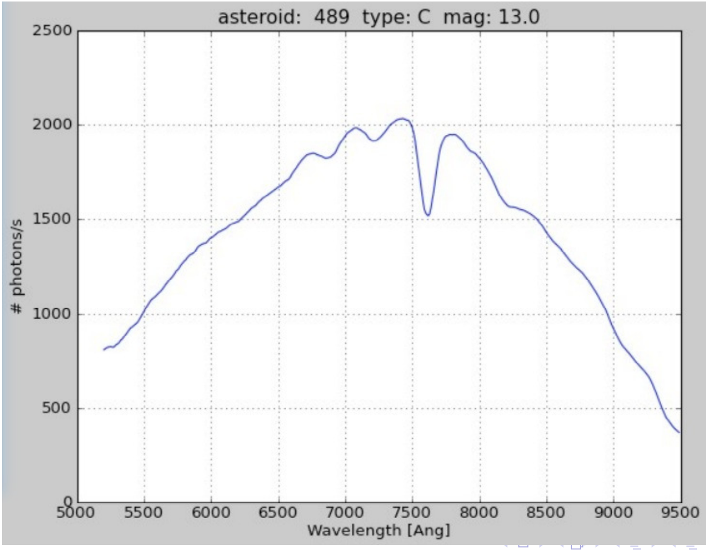
Some pretty pictures - Saturn (*u* band)



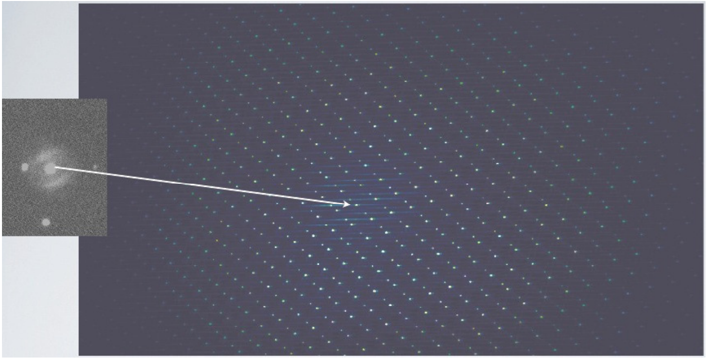
Some pretty pictures - Saturn in the IFU



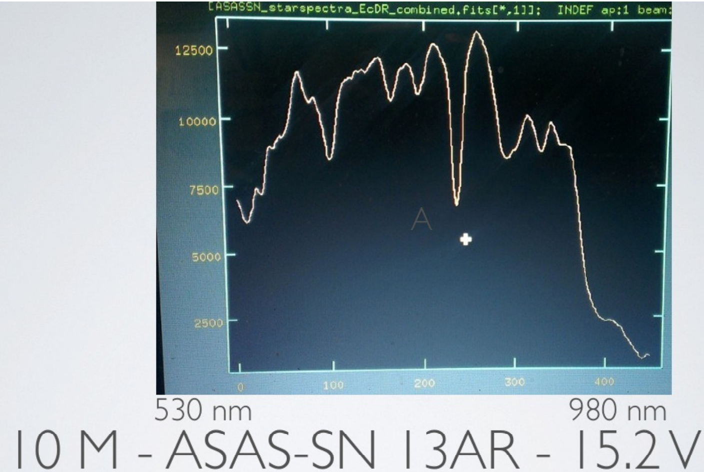
Some pretty pictures - Asteroid spectrum



Some pretty pictures - Planetary Nebula



Some pretty pictures - Super Nova



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

THANK YOU