Exploring the Transient Sky with Subaru and Keck

Masaomi Tanaka (NAOJ)
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- **Frontier of the transient survey**
- Transient survey with Subaru/HSC and on-going collaboration with Keck
- Synergetic projects with Keck
The sources of interest to these facilities are connected to spectacular explosions. However, the horizon (radius of detectability), either for reasons of optical depth (GZK cut-off) or sensitivity, is limited to the Local Universe (say, distance $\approx 100$ Mpc). Unfortunately, these facilities provide relatively poor localization. The study of explosions in the Local Universe is thus critical for two reasons: (1) sifting through the torrent of false positives (because the expected rates of sources of interest is a tiny fraction of the known transients) and (2) improving the localization via low energy observations (which usually means optical). In Figure 2 we display the phase space informed by theoretical considerations and speculations. Based on the history of our subject we should not be surprised to find, say a decade from now, that we were not sufficiently imaginative.

Figure 2. Theoretical and physically plausible candidates are marked in the explosive transient phase space. The original figure is from Rau et al. (2009). The updated figure (to show the unexplored sub-day phase space) is from the LSST Science Book (v2.0). Shock breakout is the one assured phenomenon on the sub-day timescales. Exotica include dirty fireballs, newly minted mini-blazars and orphan afterglows. With ZTF we aim to probe the sub-day phase space (see §5).

The clarity afforded by our singular focus – namely the exploration of the transient optical sky – allowed us to optimize PTF for transient studies. Specifically, we undertake the search for transients in a single band ($R$-band during most of the month and $g$ band during the darkest period). As a result our target throughput is five times more relative to multi-color surveys (e.g. PS-1, SkyMapper).

Given the ease with which transients (of all sorts) can be detected, in most instances the transient without any additional information for classification does not represent a useful, let alone a meaningful, advance. It is useful here to make the clear detection between detection and discovery. Thus the burden for discovery is considerable since for most

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The first signals from supernova explosion - probe of the very last stage of massive stars -

SN shock breakout ($\tau \sim R/c \sim 1\,\text{hr}$)

Subsequent cooling ($\tau \sim \text{a few days}$)
What else??

- **BH-forming SN**
  - Disk outflow $M_{\text{ej}} \sim 0.01 \, M_{\odot}$
  - $t \sim \text{a few days}$ (Kashiyama+15)

- **Accretion induced collapse of WDs**
  - Disk outflow $M_{\text{ej}} \sim 0.01 \, M_{\odot}$
  - $t \sim 1 \, \text{day}$ (Darbha+10)

- **Neutron star merger**
  - Disk outflow, $t \sim \text{a few days}$ (Kasen+15)
  - Free neutron, $t \sim 1 \, \text{day}$ (Metzger+15)

- **Unknown unknown...**

Need real-time spectroscopy

=> Synergy with Keck
Multi-messenger astronomy

Abbott et al. 2016, PRL, 061102

=> 10-100 deg² after Virgo and KAGRA
Optical emission from GW sources: “kilonova”

Subaru/HSC is the unique instrument for GW follow-up
(J-GEM= Japanese collaboration for GW-EM follow-up: Yoshida et al.)
Need spectroscopy for the smoking gun => Synergy with Keck
More opportunities for multi-messenger

IceCube: high-E (TeV-PeV) neutrino
Real-time alert (2016-)

Consistent with homogeneous distribution
No correlation with TeV gamma-ray sources/GRBs

Localization ~ 1 deg => Subaru/HSC
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Transient surveys with Subaru/HSC

1. Pilot high-cadence transient survey
   - 2014-2016 (PI: Nozomu Tominaga)
   - 1 hr cadence for 12 deg$^2$ (7 field of views), gr~25.5 mag
   - Follow-up with Subaru/FOCAS, Gemini/GMOS, Keck/LRIS

2. SSP UltraDeep layer transient survey
   - 2016 Nov - 2017 May (HSC transient WG)
   - ~3 day cadence for 1.8 deg$^2$ (COSMOS), grizY ~ 25-26 mag
   - Follow-up with Subaru/FOCAS, Gemini/GMOS, Keck/LRIS

3. GW follow-up observations
   - 2015- (J-GEM collaboration, PI: Michitoshi Yoshida)
   - ToO for ~60 deg$^2$, iz ~ 25-26 mag
Transients showing up in < 1 day

Rest-frame near-UV survey

MT, Tominaga, Morokuma, Yasuda+2016
In this section, we compare our samples with earlier phases of SNe. Our samples might correspond to the rising phase of SLSNe, which have never been caught. However, our samples could be interpreted as the very early phase after SN shock breakout (Gezari et al. 2010). The right panel of Figure 5 shows comparison of our samples with SLSN SN 2010gx, PS1-10awh, and PS1-10ky with a good temporal coverage (Pastorello et al. 2010; Chomiuk et al. 2011).

Figure 3.—Light curves of the five rapidly rising transients on Days 1 and 6. The blue triangles show the photometry from the pilot survey (2011 February to April), while photometry in the 1-night stacked data is shown in blue and red. For nearby SNe after a few days from the explosion, the absolute magnitudes of our samples are not consistent with those of Type Ia SNe at any phase, while photometry in the 1-night stacked data is shown in blue. Triangles show our samples, The blue colors of our samples (∼0.5 m) have a much brighter SNe, such as superluminous SNe (SLSNe, too faint). The early 2-day exposure is shown in pale blue color.

Comparison with Type IIP SN 2006bp, Type IIb SN 2011dh, Type IIn SN 11ht, and Type Ib SN 2007Y (Pritchard et al. 2014). However, the rising rates for our samples are faster than the very early phase of SN 2011fe, one of the best observed Type Ia SNe. We also compare with Type IIb SN 2008ax, Type IIn SN 2011ht, and Type IIP SN 2006bp (Pritchard et al. 2012) and Type IIP SN 2006bp (Pritchard et al. 2014). Their rising rates are more than the very early phase of core-collapse SNe in Section 3.3.

The absolute magnitudes of our samples are brighter than the peak magnitude of Type Ia SN 2011fe explosion. The absolute magnitudes of our samples are as bright as the peak magnitude of Type Ia SN 2011fe explosion. The absolute magnitudes of our samples are brighter than the peak magnitude of Type Ia SN 2011fe explosion. The absolute magnitudes of our samples are as bright as the peak magnitude of Type Ia SN 2011fe explosion. The absolute magnitudes of our samples are brighter than the peak magnitude of Type Ia SN 2011fe explosion.

1. pilot survey
MT, Tominaga, Morokuma, Yasuda+2016

see also Ofek et al.; Gezari et al.
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High-cadence survey: synergy with Keck

Collaboration with Shri Kulkarni (Caltech)

led by Nozomu Tominaga
SSP Transient survey (2016 Nov-)
led by the HSC transient working group:

The deepest/widest transient survey as ever

Collaboration with Keck
with Jeff Cooke (Swinburne)
led by Takashi Moriya

with Peter Nugent (LBL), Thomas de Jaeger (Berkley)
led by Keiichi Maeda
J–GEM observations for GW151226


HSC: 1256 candidates and ~60 likely extragalactic transients
=> Need spectroscopy for firm identification

3. GW follow-up

987 deg²
Subaru/HSC: 64 deg² (7%)
Kiso/KWFC: 778 deg² (9%)
MOA: 145 deg² (13%)
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Exploring short-timescale transient sky with Subaru/Keck

- **New survey with HSC (10 nights x 2)**
  - Depth: 25 mag (1 min exposure)
  - Cadence: ~1hr
    "1 hr + 1 day + 1 month cadence"

- Area: ~75 deg² (~50 pointing)

- Spectroscopy with Keck/LRIS (~10 nights)
Summary

- Frontier of transient science
  - Short-timescale of < 1 day
  - Multi-messenger astronomy (GW and neutrino)

- What we did/are doing
  - Pilot high-cadence survey
  - SSP transient survey => Follow-up with Keck (and Gemini)
  - Follow-up of GW sources

- Possible synergetic projects
  - NEW HSC survey dedicated to explore short-timescale transient sky
    - Size: ~20 nights Subaru/HSC + ~10 nights Keck/LRIS
    - Timeline: can start NOW (unique before LSST)
  - Collaboration on GW (and neutrino) follow-up?