Detection of transients with the ILMT and implications

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On behalf of ILMT team and collaborators
Outline

Transients: Supernovae
ILMT project
ILMT limiting magnitudes
Supernovae detection with ILMT
Implications and summary
Transient activities

- Flares
- Flickering
- Outbursts
- Eruptions
- Transits
- Motion
- Explosions

Stellar activities
- Stellar structure/evolution
- Binary evolution
- Accretion process
- Exoplanet

Duration: Seconds - Years

 ➤ Rapid detection and follow-up with good temporal coverage is very important!
Highly energetic transients: Supernovae (SNe)

- Catastrophic explosion of a star at the end phase of its evolution.
- Tremendous amount of energy ($\sim 10^{50}$ erg) is released.
  - Regulate new star formation.
  - Produce heavy elements.
  - Enrich surrounding ISM.
  - Distance indicators.
  - One of the sources of GW.
SN classification

- Explosion mechanism
  - **Thermonuclear SN**
    (Thermonuclear disruption of a CO WD)
  - **Core-collapse (CC) SN**
    (Gravitational collapse of stellar core)

- Observational features
  (Light curve and Spectra)
  - **Type I** (H-absent)
  - **Type II** (H-present)
    - **Thermonuclear:** Type Ia
    - **Hydrogen rich:** Type IIp, IIL, II-Pec
    - **Stripped envelope:** Type IIb, Ib, Ic, Ic-BL
    - **Interacting:** Type IIn, Ibn

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Observational diversity: Type Ia SNe

- Normal Ia SNe peak brightness = $-19.1$ mag
- SN 1991T-like: $0.2-0.5$ mag brighter
- SN 1991bg-like: $1.5-2.5$ mag fainter
- SN 2002cx-like: Low luminosity
- SN Ia-CSM: $>-19.5$ mag

Luminosity distribution

Phillips relation (1993):

$$M_{\text{max}}(B) = -21.726 + 2.698 \Delta m_{15}(B)$$
Observational diversity: Type Ia SNe

Colour evolution (Bulla+ 2020)

Sample from Zwicky Transient Facility (ZTF)
Observational diversity: CC-SNe

Recent large sample studies:

- Progenitor properties
- Explosion parameters
- Composition/environment

Major powering source
$^{56}\text{Ni} - ^{56}\text{Co} - ^{56}\text{Fe}$

Colour evolution

(Prentice+ 2016)
In search of supernovae

Targeted and large area surveys:
- LOSS
- DES
- CFHT-LS
- ESSENCE
- SDSS
- CRTS
- PTF
- ASAS-SN
- ZTF
- Pan-STARRS
- LSST

Advantages of ILMT imaging
- Inexpensive and simple design
- Easy maintenance
- Optimal imaging position (zenith)
- Continuous data acquisition (no time loss)
- Appropriate for survey programs & SN
ILMT Project

Major components

Corrector & CCD

Vertical structure

Container

Air bearing & motor

ILMT sky coverage
Detection & study of SNe with ILMT

- PhD thesis (ULg, 2014).


ILMT Limiting magnitudes

(Based on MacLean 1989, Mayya 1991 formulation)

Expected counts for a star of mag (m):

\[ N_e = 3.95 \times 10^{11} D^2 \lambda_n \Delta \lambda_n F_0^n 10^{-0.4m} A_F \eta \]

\[ N = \sqrt{(N_e e_t + S_e e_t n_p + D_e e_t n_p + R_n^2 n_p)} \]

\[ \text{SNR} = \left( \frac{N_e \times e_t}{N} \right)^{-1} \]

\[ \sigma_{mag} = 2.5 \times \log_{10} [1 + 1/\text{SNR}] \]

<table>
<thead>
<tr>
<th>Parameters</th>
<th>value</th>
</tr>
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<tbody>
<tr>
<td>Diameter</td>
<td>4.0 m</td>
</tr>
<tr>
<td>Fraction of reflecting area</td>
<td>0.95</td>
</tr>
<tr>
<td>Reflectivity</td>
<td>0.77</td>
</tr>
<tr>
<td>Mylar transmission</td>
<td>0.80</td>
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<tr>
<td>Corrector transmission</td>
<td>0.85</td>
</tr>
<tr>
<td>FWHM</td>
<td>1.5 arcsec</td>
</tr>
<tr>
<td>CCD pixel size</td>
<td>0.33 arcsec pixel(^{-1})</td>
</tr>
<tr>
<td>CCD dark noise</td>
<td>0.00083 e(^{-}) pixel(^{-1}) s(^{-1})</td>
</tr>
<tr>
<td>CCD readout noise</td>
<td>5.0 e(^{-})</td>
</tr>
<tr>
<td>CCD gain</td>
<td>4.0 e(^{-})/ADU</td>
</tr>
<tr>
<td>Wavelength (g', r', i')</td>
<td>4750, 6250, 7630 Å</td>
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<tr>
<td>Wavelength FWHM (g', r', i')</td>
<td>1450, 1500, 1500 Å</td>
</tr>
<tr>
<td>Extinction (\sim g', \sim r', \sim i')</td>
<td>0.21, 0.13, 0.08 mag</td>
</tr>
<tr>
<td>Sky mag (\sim g', \sim r', \sim i')</td>
<td>21.3, 20.5, 18.9 mag arcsec(^{-2})</td>
</tr>
<tr>
<td>CCD quantum efficiency (g', r', i')</td>
<td>0.70, 0.91, 0.91</td>
</tr>
<tr>
<td>Filter transmission (g', r', i')</td>
<td>0.92, 0.95, 0.95</td>
</tr>
<tr>
<td>System efficiency, \eta (g', r', i')</td>
<td>0.55, 0.74, 0.74</td>
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ILMT Limiting magnitudes

<table>
<thead>
<tr>
<th>Band</th>
<th>Mag</th>
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<tr>
<td>g'</td>
<td>22.8</td>
</tr>
<tr>
<td>r'</td>
<td>22.3</td>
</tr>
<tr>
<td>i'</td>
<td>21.4</td>
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</table>

~0.5 mag gain if 3 night images are stacked.
ILMT Limiting magnitudes

Magnitude errors
(<0.1 for 21 mag, each band)
Supernova detection rate with ILMT

- Star formation and SN rates (Dahlen+ 2004; Neill+ 2006; Dilday+ 2008; Graur+ 2011; Taylor+ 2014; Cappellaro+ 2015; Botticella+ 2017 etc.).

- Cosmological implications of SNe with LMTs (Borra+ 2001a,b, 2003).

- SNe (Type Ia and CC-SNe) detection rate (3 bands) in the ILMT strip (Kumar+2018).

- ILMT SN rate: methodology of Lien & Field 2009

\[ \frac{dN_{SN,obs,x}}{dt_{obs}dzd\Omega} = R_{SN}(z) f_{detect}(z; m_{lim,x}^{SN}) \frac{r(z)^2}{1+z} \frac{dr}{dz} \]

\[ R_{SN}(z) = \frac{X_{SN}}{\langle m \rangle_{SN}} \dot{\rho}_*(z) \]

Progenitor mass range
- Ia SN: 3-8 M\textsubscript{Sun}
- CC-SN: 8-50 M\textsubscript{Sun}
CC-SNe detection rate with ILMT

Detection rate of CC-SNe as a function of redshift

Green curve: without dust extinction
Brown curve: with dust extinction
Type Ia SN detection rate with ILMT

Detection rate of Type Ia SNe as a function of redshift

Green curve: without dust extinction
Brown curve: with dust extinction
SN detection for different limiting mag (1, 3 & 6 nights)

<table>
<thead>
<tr>
<th>SN type</th>
<th>Filter</th>
<th>$SNe_{1N}$</th>
<th>$SNe_{3N}$</th>
<th>$SNe_{6N}$</th>
<th>Total $SNe_{1N}$</th>
<th>Total $SNe_{3N}$</th>
<th>Total $SNe_{6N}$</th>
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<tbody>
<tr>
<td>Ia</td>
<td>$g'$</td>
<td>63</td>
<td>89</td>
<td>115</td>
<td>1299</td>
<td>1835</td>
<td>2371</td>
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<tr>
<td></td>
<td>$r'$</td>
<td>155</td>
<td>274</td>
<td>426</td>
<td>3196</td>
<td>5649</td>
<td>8783</td>
</tr>
<tr>
<td></td>
<td>$i'$</td>
<td>28</td>
<td>71</td>
<td>174</td>
<td>577</td>
<td>1464</td>
<td>3588</td>
</tr>
<tr>
<td>CC</td>
<td>$g'$</td>
<td>50</td>
<td>97</td>
<td>177</td>
<td>1031</td>
<td>2000</td>
<td>3649</td>
</tr>
<tr>
<td></td>
<td>$r'$</td>
<td>20</td>
<td>43</td>
<td>87</td>
<td>412</td>
<td>887</td>
<td>1794</td>
</tr>
<tr>
<td></td>
<td>$i'$</td>
<td>3</td>
<td>8</td>
<td>19</td>
<td>62</td>
<td>165</td>
<td>392</td>
</tr>
</tbody>
</table>
Supernovae detection with ILMT and follow-up

see talks:
A. Mahabal
F. F. Buron
H. Chand
S. Valenti
K. Sharma

Global alert
Other facilities
Data archive

Observing facilities at ARIES
1.3-m
1.04-m
3.6-m

ILMT sketch

New images (each night)
Reference frame image

Image subtraction

Inspection

Transient detection

Spectroscopic trigger

Global alert

Confirmation

Follow up

Monitoring

Other facilities
Long term monitoring of early discovered SN

Examples
Implications: early detection and follow up

- Cooling emission strongly depend on the radius and internal density structure of the progenitor star. Early detection and monitoring will be helpful to understand the progenitor properties. (cf. Stefano talk)

- Colour evolution (Ibc SNe) and light curve bump (in II SNe) are important to investigate the effect of $^{56}$Ni mixing in the outer envelope.

- Late phase follow-up can provide clue on dust formation in the ejecta.

- Cosmological importance.

Light curve evolution of Type IIb SNe 1993J and 2011fu (Kumar+ 2013)
Ni mixing effect on early colour evolution (Ibc SNe)  
(Yoon+ 2019)

- Early phase colour information of SNe (ILMT+other) will be important.
Summary

- The ILMT will reach ~22.8, ~22.3 and ~21.4 mag in g’, r’ and i’ bands (single scan) and can be further improved by co-adding images of different nights.
- It will be very useful for the SNe detection and their study.
- Every year, thousands of SNe (Ia and CC) should be discovered by the ILMT.
- SNe sample obtained from the ILMT and supported by other facilities will help us to better understand various progenitor channels and explosion mechanisms of different type of SNe.

Thanks