KMTNet Supernova Program and the Future

Sang Chul KIM (김상철)
Korea Astronomy and Space Science Institute (KASI)

2016 Apr 25
Future Sky Surveys and Big Data
KMTNet Supernova Program (KSP) : The Team

- **PI : Dae-Sik Moon (Univ of Toronto, Canada)**
- Korea : Sang Chul KIM, Jae-Joon Lee, Mina Pak, Hong Soo PARK, Moo-Young Chun, Bon-Chul Koo
- Canada : John Antoniadis, Matthias He, Maria R. Drout, Christopher Matzner, Raymond Carlberg (U. Toronto)
- Israel : Avishay Gal-Yam (Weizmann Inst.)
- USA : S. Bradley Cenko(GSFC/NASA), D. Andrew Howell (LCOGT), Dennis Zaritsky (U. Arizona)
- Chile : Mario Hamuy, Santiago González-Gaitán(U. Chile), Giuliano Pignata(U. Andres Bello)
- Australia : Stuart Ryder(ANU)
- South Africa : David Gilbank (SAAO)
- UK : Mark Sullivan (Southampton)
- Japan : Motohide Tamura (NAOJ)
- And others...
Supernova (SN) Explosion

SN 1987A
LMC, Tarantula Nebula
d~51.4 kpc (Panagia 2005)
1987 Feb 24
II-P, B3 supergiant
Peak : +2.9 mag
(B-V) = +0.085
Supernova Remnant

Kepler’s SN

1604 October 9, northern Italy

J. Brunowski in Prague (Oct 10, meteorologist) : notified

Johannes Kepler → started observation from Oct 17

: became invisible in Nov

: reappeared in 1605 Jan

: remained visible until 1606 Mar → naked eye visibility of 18 months

α(J2000)= 17h 30m 42s, δ(J2000)= -21° 29′ (Ophiuchus)

Type Ia
Peak V = -2.25 to -2.5 mag (brighter than any other star)
→ Visible for >3 weeks
D=6.1 kpc

G4.5+6.8
X-ray, Optical & Infrared Composite
(Chandra, HST, Spitzer)
## Historical SNe from the Milky Way Galaxy

<table>
<thead>
<tr>
<th>SN name</th>
<th>Observer</th>
<th>Remnant</th>
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</thead>
<tbody>
<tr>
<td>SN 185</td>
<td>[China]</td>
<td>RCW 86 (G315.4−2.3)</td>
</tr>
<tr>
<td>SN 1006</td>
<td>[China, Japan, Iraq, Egypt, and Europe, North American petroglyphs]</td>
<td>G327.6+14.6</td>
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<tr>
<td>SN 1054</td>
<td>[China]</td>
<td>Crab Nebula (G184.6−5.8)</td>
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<tr>
<td>SN 1572</td>
<td>Tycho Brahe</td>
<td>G120.1+1.4</td>
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<tr>
<td>SN 1604</td>
<td>Johannes Kepler</td>
<td>G4.5+6.8</td>
</tr>
<tr>
<td>1680 (unobserved)</td>
<td></td>
<td>Cassiopeia A</td>
</tr>
<tr>
<td>1868 (unobserved)</td>
<td></td>
<td>G1.9+0.3</td>
</tr>
</tbody>
</table>
Joseon dynasty
King Sunjo yr 37
(선조 宣祖 37년)
(1604 October)

관상감(觀象監, Joseon Royal Observatory)

Guest star(客星)
SN 1604 (type Ia)

Days after 1604 Oct 8

Korean studies on old records

Kyung Loh YU (俞 景 老)

ABSTRACT

Wangjo Silok, the official chronicle of Lee Dynasty, carries 131 records on the Kepler Supernova 1604; all of them are given in the present report. Among them 112 records are detailed descriptions about the observed brightness variation over the period from October 13, 1604 (the 37th year of King Sunjo) to April 23, 1605. On July 14, 1605, an addendum is given as a final assessment of the guest star incidence. Since the apparent brightness, size and position are carefully described as compared to bright planets and stars, these records are ideal for retrieving light curve of the Kepler Supernova over the seven month period. Simple procedures are suggested for the derivation of light curve.
UBVRI CCD PHOTOMETRY OF 
THE TYPE Ic SUPERNOVA SN 1994I IN M51: 
THE FIRST TWO MONTHS

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(Received Feb. 6, 1995; Accepted Feb. 23, 1995)

ABSTRACT

We present UBVRI CCD photometry of the Type Ic supernova SN 1994I in M51 which was discovered on April 2, 1994 (UT). UBVRI CCD photometry of SN 1994 I were obtained for the period of the first two months from April 4, 1994, using the Seoul National University Observatory 60 cm telescope. The light curves of SN 1994I show several interesting features: (a) SN 1994I reaches the maximum brightness at B-band on April 8.23 ($B = 13.68$ mag), at V-band on April 9.10 ($V = 12.89$ mag), and at I-band on April 10.32 ($I = 12.48$ mag); (b) The light curves around the maximum brightness are much narrower than those of other types of supernovae; (c) The light curves after the peak decline more steeply than those of other types of supernovae; and (d) The colors get redder from ($V - R$) ≈ 0.2 mag ($V - I$) ≈ 0.3 mag, ($B - V$) ≈ 0.7 mag) on April 4 to ($V - R$) ≈ 0.6 mag ($V - I$) ≈ 0.9 mag, ($B - V$) ≈ 1.3 mag) on April 18. Afterwards ($V - R$) colors get bluer slightly (by $\approx 0.005$ mag/day), while ($V - I$) colors stay almost constant around ($V - I$) ≈ 1.0 mag. The color at the maximum brightness is ($B - V$) = 0.9 mag,
JKAS – SN 1994I

ABSTRACT

We present \textit{UBVRI} CCD photometry of the Type Ic supernova SN 1994I in M51 which was discovered on April 2, 1994 (UT). \textit{UBVRI} CCD photometry of SN 1994 I were obtained for the period of the first two months from April 4, 1994, using the Seoul National University Observatory 60 cm telescope. The light curves of SN 1994I show several interesting features: (a) SN 1994I reaches the maximum brightness at B-band on April 8.23 (B = 13.68 mag), at V-band on April 9.10 (V = 12.89 mag), and at I-band on April 10.32 (I = 12.48 mag); (b) The light curves around the maximum brightness are much narrower than those of other types of supernovae; (c) The light curves after the peak decline more steeply than those of other types of supernovae; and (d) The colors get redder from (V − R) ≈ 0.2 mag ((V − I) ≈ 0.3 mag, (B − V) ≈ 0.7 mag) on April 4 to (V − R) ≈ 0.6 mag ((V − I) ≈ 0.9 mag, (B − V) ≈ 1.3 mag) on April 18. Afterwards (V − R) colors get bluer slightly (by ~0.005 mag/day), while (V − I) colors stay almost constant around (V − I) ≈ 1.0 mag. The color at the maximum brightness is (B − V) = 0.9 mag, which is ~1 mag redder than the mean color of typical Type Ia supernovae at the maximum brightness.

(a) Observations

\textit{UBVRI} CCD images of M51 including SN 1994I were obtained using the Seoul National University Observatory (SNUO) 60cm telescope and the Photometrics PM 512 CCD camera. SNUO is located on the campus of the Seoul National University at the southern area of Seoul in Korea. We started our observations of SN 1994I on April 4, 1994 (UT) and stopped on June 3, when SN 1994I was too faint to be observed with our telescope. The filters used are Johnson-Kron-Cousins \textit{UBVRI} filter set No. 1 of SNUO. The CCD chip has an area of 512 × 512 pixels and the size of the field of view in the CCD image is 8’.1 × 8’.1 at the f/7 Cassegrain focus of our telescope. The gain
SN 1999dm in Abell 2065

Galaxy Cluster Abell 2065

January 17, 1999

June 18, 1999

SN 1999dm in Abell 2065

BOAO 1.8 m

Department of Astronomy, Seoul National University - July 7, 1999
SN 1999dm in Abell 2065

IAUC 7241

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INTERNATIONAL ASTRONOMICAL UNION
Mailstop 18, Smithsonian Astrophysical Observatory, Cambridge, MA 02138, U.S.A.
IAUSUBS@CFA.HARVARD.EDU or FAX 617-495-7231 (subscriptions)
BMARSDEN@CFA.HARVARD.EDU or DGREEN@CFA.HARVARD.EDU (science)
URL http://cfa-www.harvard.edu/iau/cbat.html ISSN 0081-0304
Phone 617-495-7244/7440/7444 (for emergency use only)

SUPERNOVA 1999dm IN MCG +05-36-022

Corrigenda. On IAUC 7237, the position for the nucleus of the host galaxy (MCG +05-36-022 = Abell 2065-164) of SN 1999dm was provided, rather than the supernova's position. Lee et al. provide the supernova's position as R.A. = 15h22m28s.90, Decl. = +27 42' 58".0 (equinox 2000.0). The reference on line 8 was published in 1998, not 1999. On line 11, for BAO reflector read BOA reflector.

M. M. M. Santangelo and S. Donati, Monte Agliate, Italy, report that their CCD patrol frames of the galaxy cluster Abell 2065 obtained on Mar. 24.09 and May 17.96 UT with the 0.51-m reflector (limiting mag R about 20.0) show nothing new near the host galaxy.
Korea Microlensing Telescope Network (KMTNet): Three new 1.6-m wide-field telescopes in the southern hemisphere, providing 24-h sky coverage.
Korea Microlensing Telescope Network (KMTNet): Three new 1.6-m wide-field telescopes in the southern hemisphere, providing 24-h sky coverage.

<table>
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<th>SAAO</th>
<th>CTIO</th>
<th>SSO</th>
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<td>2200m</td>
<td>1149m</td>
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<tr>
<td>Time Zone</td>
<td>-2</td>
<td>4</td>
<td>-10</td>
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<tr>
<td>Temperature</td>
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<td>3&lt;T(C)&lt;19</td>
<td>5&lt;T(C)&lt;35</td>
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<tr>
<td>Humidity (Med.)</td>
<td>44%</td>
<td>35%</td>
<td>63%</td>
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<tr>
<td>Humidity (Max.)</td>
<td>85%</td>
<td>70%</td>
<td>95%</td>
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<td>Wind speed (Med.)</td>
<td>6.0m/s</td>
<td>4.0m/s</td>
<td>2.7m/s</td>
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<tr>
<td>Wind speed (Max.)</td>
<td>13m/s</td>
<td>11m/s</td>
<td>6.0m/s</td>
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<tr>
<td>Atmospheric Seeing</td>
<td>0.8~1.4”</td>
<td>0.6~1.0”</td>
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<tr>
<td>Electric Frequency</td>
<td>50Hz</td>
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<td>50Hz</td>
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</table>
Korea Microlensing Telescope Network (KMTNet): Three new 1.6-m wide-field telescopes in the southern hemisphere, providing 24-h sky coverage.

“Star never sets on the KMTNet”
Korea Microlensing Telescope Network

Chilean Site
Korea Microlensing Telescope Network
Wide Field CCD Imager: 2° × 2° Field of View

- Four e2v Mosaic CCD Chips
- 340M pixels (18K×18K), each 10 μm
- 0.40 arcsec/pixel, 2 degree × 2 degree FOV
- Mechanical cooling (-110 °C)
- 32 readout channels
- Filters: BVRI (3 sites), g’r’i’z’ Hα (Chile)
- Quantum effie: ∼85% in V, ∼80% in I
Korea Microlensing Telescope Network
Wide Field CCD Imager: $2^\circ \times 2^\circ$ Field of View
Korea Microlensing Telescope Network

- **High competitive etendue \((A \times \Omega)\)**
  Large enough diameter (1.6m) and wide field-of-view: \(2^\circ \times 2^\circ\)

KMTNet: \((1.6 \text{ m})^2 \times (2 \text{ deg})^2 \approx 10.2 \ (\text{m}^2 \text{ sqd})\)
CFHT MegaCam: \(3.6^2 \times 1^2 \approx 13.0 \ (\text{m}^2 \text{ sqd})\)
PTF: \(1.2^2 \times 7 \approx 10.1 \ (\text{m}^2 \text{ sqd})\)
  (Palomar Transient Factory)
Pan-STARRS: \(1.8^2 \times 7 \approx 22.7 \ (\text{m}^2 \text{ sqd})\)
MOA: \(1.8^2 \times 2.4 \approx 7.8 \ (\text{m}^2 \text{ sqd})\)
SkyMapper: \(1.35^2 \times 5.7 \approx 10.4 \ (\text{m}^2 \text{ sqd})\)
Fornax cluster center \((d \sim 19\text{Mpc})\)  \(2 \text{deg} \times 2 \text{deg} / \text{DSS1}\)
Korea Microlensing Telescope Network

Data contents

- Real time data transfer to the KASI data center
- Big data reduction pipeline: 150 GB/night/site
- Photometry database: $10^7$ stellar variability monitoring data
- Image analysis within 1 day → DB update
- 5-year raw data 560 TB
  analyzed images 2.24 PB
  photometry DB 200 TB
The main objective is to detect “Microlensing events of earth-like planets” from the Galactic Bulge for approximately 6 months per year.
Galactic Bulge field

SSO, I-band, 60 sec
FWHM $\sim 1.1''$

$3' \times 6'$

FOV $\sim 3 \times 6$ arcmin$^2$
FWHM $\sim 1.1$ arcsec
KMTNet: A Network of 1.6 m Wide-Field Optical Telescopes Installed at Three Southern Observatories

Seung-Lee Kim¹,², Chung-Uk Lee¹,², Byeong-Gon Park¹,², Dong-Jin Kim¹, Sang-Mok Cha¹,³, Yongseok Lee¹,³, Cheongho Han⁴, Moo-Young Chun¹, and Insoo Yuk¹

Abstract: The Korea Microlensing Telescope Network (KMTNet) is a wide-field photometric system installed by the Korea Astronomy and Space Science Institute (KASI). Here, we present the overall technical specifications of the KMTNet observation system, test observation results, data transfer and image processing procedure, and finally, the KMTNet science programs. The system consists of three 1.6 m wide-field optical telescopes equipped with mosaic CCD cameras of 18k by 18k pixels. Each telescope provides a 2.0 by 2.0 square degree field of view. We have finished installing all three telescopes and cameras sequentially at the Cerro-Tololo Inter-American Observatory (CTIO) in Chile, the South African Astronomical Observatory (SAAO) in South Africa, and the Siding Spring Observatory (SSO) in Australia. This network of telescopes, which is spread over three different continents at a similar latitude of about −30 degrees, enables 24-hour continuous monitoring of targets observable in the Southern Hemisphere. The test observations showed good image quality that meets the seeing requirement of less than 1.0 arcsec in I-band. All of the observation data are transferred to the KMTNet data center at KASI via the international network communication and are processed with the KMTNet data pipeline. The primary scientific goal of the KMTNet is to discover numerous extrasolar planets toward the Galactic bulge by using the gravitational microlensing technique, especially earth-mass planets in the habitable zone. During the non-bulge season, the system is used for wide-field photometric survey science on supernovae, asteroids, and external galaxies.

Key words: telescopes: KMTNet — techniques: photometric — surveys: wide-field — stars: planetary systems
The main objective is to detect “Microlensing events of earth-like planets” from the Galactic Bulge for approximately 6 months per year.

So what do we do for the remaining 6 months?

(Of course) “Supernova Search!”
KMTNet (외계행성 탐색시스템)
(Korea Microlensing Telescope Network)

- High competitive etendue ($A \times \Omega$)
  Large enough diameter (1.6m) and wide field-of-view $2^\circ \times 2^\circ$

- Excellent pixel scale (0.4") and filter sets
  (BVRI $g'r'i'z' H_\alpha$)

- 24-hour Continuous sky coverage
  CTIO, SAAO, SSO
  High-cadence Light Curve for early, rare objects

→ Discovery of New, Young SNe
2012 May 15~July 15
Proposal call, submission

Phase 1: five years
(2015-2020)

KMTNet Sciences

50%
Bulge
- Exoplanets
- Variables/ Transients

17%
Supernovae

12%
Asteroids
and comets

4%
External galaxies

7%
Director’s Engineering Etc.

27%

※ 10%
- Chile
- South Africa
- Australia

- Microlensing
- Transit
KMTNet Observing Months

morning

Local time (h)

Non-bulge fields: SNe!

↑

evening

January → June December

(bulge)

SNe!

2/20

10/22
Figure 2. The detailed classification of SNe requires not only the identification of specific features in the early spectra, but also the analysis of the line profiles, luminosity and spectral evolutions.
Rare and Interesting Supernovae

- Single degenerate SN Ia (WD + MS/RG)
- Double degenerate SN Ia (WD + WD)
- SN impostors
- Pair Instability (super-luminous core-collapse SNe)
- Sub-luminous type Ia
- Type Ia SNe with super-Chandrasekhar-mass WD
- He-rich companion SNe
- high-z SNe (z $\geq 0.5$)
- Fallback SNe
- Core-collapse SNe metal poor galaxies (Ia from SF gal)
- Core-collapse SNe with peculiar GRBs
- new...?
Supernovae - progenitors

- **He4**: He core of $4 \, M_\odot$ and $R = 2 \, R_\odot$
- **He4R270**: with extended envelope of $R = 270 \, R_\odot$

Compact vs extended progenitor

SN 2011dh (type IIb) in M51
KMTNet Supernova Program – scientific objectives

- Early young SNe (< 1 day) and explosion mechanisms (e.g., shock-breakout, non-spherical behavior, G-wave, neutrinos, etc)
- Rare/peculiar types, especially fast decays and super/sub-luminous SNe (e.g., other SN type – Ia, Ib, Ic, IIP, IIL, IIn, IIb, Ic-BL/hypernova, Ia, Iax, super-Chandrasekhar Ia, Ia-IIIn, kilonova,...)
- High-cadence multi-color light curves → systematic demographic studies using well-sampled multi-color data (e.g., photometric typing)
- Precise estimation of the SN parameters - (e.g., $^{56}$Ni mass)
- Progenitors (digital archive data of host galaxies) (e.g., populations, structure/size/composition, companion interaction)
- SN host galaxies
- Auxiliary sciences (e.g., GRBs, AGN variability, tidal disruption event; galaxies, optical transients, variables, etc)
- Serendipitous/unexpected discoveries
Characteristic decay timescale (time required to fade by 2 mag from the peak luminosity)
KMTNet Supernova Program – Real Practical Advantage

“[On season] New supernovae every night. Life is miserable”

“[Off Season] No new supernovae for at least 6 months, go drink!”
KMTNet Supernova Program (KSP) – status

• Quasi-automated processes of data reduction
• Flexible image stacking
• Variable source catalog, light curves, etc.
• Automated photometric calibration (incl. differential photometry)
• Papers are prepared and being written from the first results of data

KSP - Future

• Almost ready to start real-time SN/transient discovery routine
• To be done – machine learning algorithm, random forest, big data analysis (full scientific exploitation of the data, etc.)
KMTNet Supernova Program (KSP) – softwares

- Standardized software adapted for KSP (python modules)
  : Image subtraction, source detection, image reprojection, astrometry, photometry, etc
  : using HOTPANTS, SExtractor, SCAMP, SWARP, astrometry.net, etc.
- False alarm: cosmic rays, cosmetics (e.g. cross talks), imperfect PSF fits, optical ghosts, AGNs, asteroids, etc.
- Automated operational software from image analyses to image stack, subtraction, variable/transient source light curve, catalog (IDL routines)
- Science modeling softwares (e.g., SNID, superfit, SiFTO, etc.)

KSP - hardwares

- 2 dedicated XEON servers and data storage at KASI
- 1 server at U. Toronto
KMTNet Supernova Program (KSP) – initial targets

Orange filled circles: Bright galaxy catalogue from Ho et al. (2011, ApJS, 197, 21)

<table>
<thead>
<tr>
<th>Group name</th>
<th>Number of member</th>
<th>$V_{LG}$ (km/s)</th>
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<tbody>
<tr>
<td>N2207</td>
<td>5</td>
<td>2570</td>
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<tr>
<td>ESO489-035</td>
<td>4</td>
<td>2557</td>
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<tr>
<td>N2217</td>
<td>5</td>
<td>1559</td>
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</table>
KMTNet Supernova Program (KSP) – **initial targets**

### N2207 field
1. N2207-F1 (06:15:36, -21:37:12)

### N2784 field
9. N2784-F1 (09:00:24, -22:42:00)
10. N2784-F2 (09:01:48, -24:27:00)
11. N2784-F3 (09:08:24, -22:42:00)
14. N2784-F6 (09:17:48, -24:27:00)
15. N2784-F7 (09:24:24, -22:42:00)
KMTNet Supernova Program (KSP) – initial targets

N2784 field

11. N2784-F3 (09:08:24, -22:42:00)
14. N2784-F6 (09:17:48, -24:27:00)
15. N2784-F7 (09:24:24, -22:42:00)
KMTNet Supernova Program (KSP) – sample field

N2784-4 : 2015. 03. 22.
2° × 2°
KMTNet Supernova Program (KSP) – image subtraction example

- NGC 2784

1\textsuperscript{st} epoch 2\textsuperscript{nd} epoch subtracted
KMTNet Supernova Program (KSP) – targets

• First year – simplify!
  Narrow down the number of search fields
  Increase the cadence
  Nearby galaxies – early (faint) detection (groups/clusters...)
  Use 3 filters (B, V, I) (Hα if possible)
• 3-5 fields (galaxies) per each RA position

• Year one (can be re-organized) :
  RA = 0h – 1h : 3 fields in Sculptor group (NGC 300 etc.)
  RA = 6h – 7h : 4 fields in NGC 2207 group
  RA = 10h – 11h : 4 fields in NGC 3275 area
  RA = 13h – 14h : 3 fields in NGC 5128 group
KMTNet Supernova Program (KSP) – targets with $\alpha = 0^\circ \rightarrow$ Sculptor group

- Targets
  - NGC 300 : $d=2.0$ Mpc, $\alpha(J2000)=00:54:54$, $\delta=-37:41:04$, $v=144$ km/s
  - NGC 247 : $d=3.6$ Mpc, $\alpha(J2000)=00:47:09$, $\delta=-20:45:37$, $v=156$ km/s
  - NGC 59 : $d=4.9$ Mpc, $\alpha(J2000)=00:15:25$, $\delta=-21:26:40$, $v=362$ km/s

- Filter : B, V, I
- Exposure time : 60 sec each
- Number of images : $\sim 950 / \text{filter}$
  - Till August : 350 min
  - Total 950 min
  - Background size : 512, 1024 px
KMTNet Supernova Program (KSP) – Newly found – a rapid evolving optical transient

• High-cadence, three-bands
  \( \text{B} \)  
  \( \text{V} \)  
  \( \text{I} \)

• If our automatic transient identification system worked \( \rightarrow \) identification would start at \( \sim 19.5 \) mag, i.e. a few hours after its onset

Antoniadis et al. [in preparation]  
Moon et al. [in preparation]
limiting magnitudes
N2784, N300, N247, N59

**blue : mag error = 0.1 mag (10σ)**

<table>
<thead>
<tr>
<th></th>
<th>$T_{exp} = 900$ min</th>
<th>$T_{exp} = 350$ min</th>
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<tbody>
<tr>
<td><strong>B</strong></td>
<td>24.3 mag</td>
<td>23.8 mag</td>
</tr>
<tr>
<td><strong>V</strong></td>
<td>24.0 mag</td>
<td>23.5 mag</td>
</tr>
<tr>
<td><strong>I</strong></td>
<td>23.8 mag</td>
<td>23.3 mag</td>
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**Red : mag error = 0.3 mag (3σ)**

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<th>$T_{exp} = 350$ min</th>
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<tr>
<td><strong>B</strong></td>
<td>25.9 mag</td>
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</tr>
<tr>
<td><strong>V</strong></td>
<td>25.6 mag</td>
<td>25.1 mag</td>
</tr>
<tr>
<td><strong>I</strong></td>
<td>25.3 mag</td>
<td>24.8 mag</td>
</tr>
</tbody>
</table>
Seeing (FWHM)
N2784, N300, N247, N59

B : $\sim 1.5''$

V : $\sim 1.4''$

I : $\sim 1.3''$
Mass production of well-calibrated data

- **Papers** being prepared:
  - Perspectives
  - NGC 2784 group
  - GRB afterglow
  - NGC 300 dwarf nova
  - NGC 2784 variable objects catalog
  - Sculptor group galaxies, galaxy clusters

- **Unique/excellent quality data** – supernovae, transients, variables + galaxies, GRBs, etc

- Need more **manpower**...
  - KSP operation – **data** management/reduction, software, data analyses, etc.
  - **Science** – SNe, transients, variables, GRBs + galaxies (populations, tidal streams, star clusters...)
KMTNet SN Program – and the Future

- Extension to phase 2 operation of the KMTNet - after 2020
- Bigger Telescope ~ LSST (8.4m) + spectroscopy using 25m GMT
- (Near-) Infrared Telescopes
- Space telescopes (JWST, WFIRST...?)
Thank you.

KASI road
Taken by Mina PAK