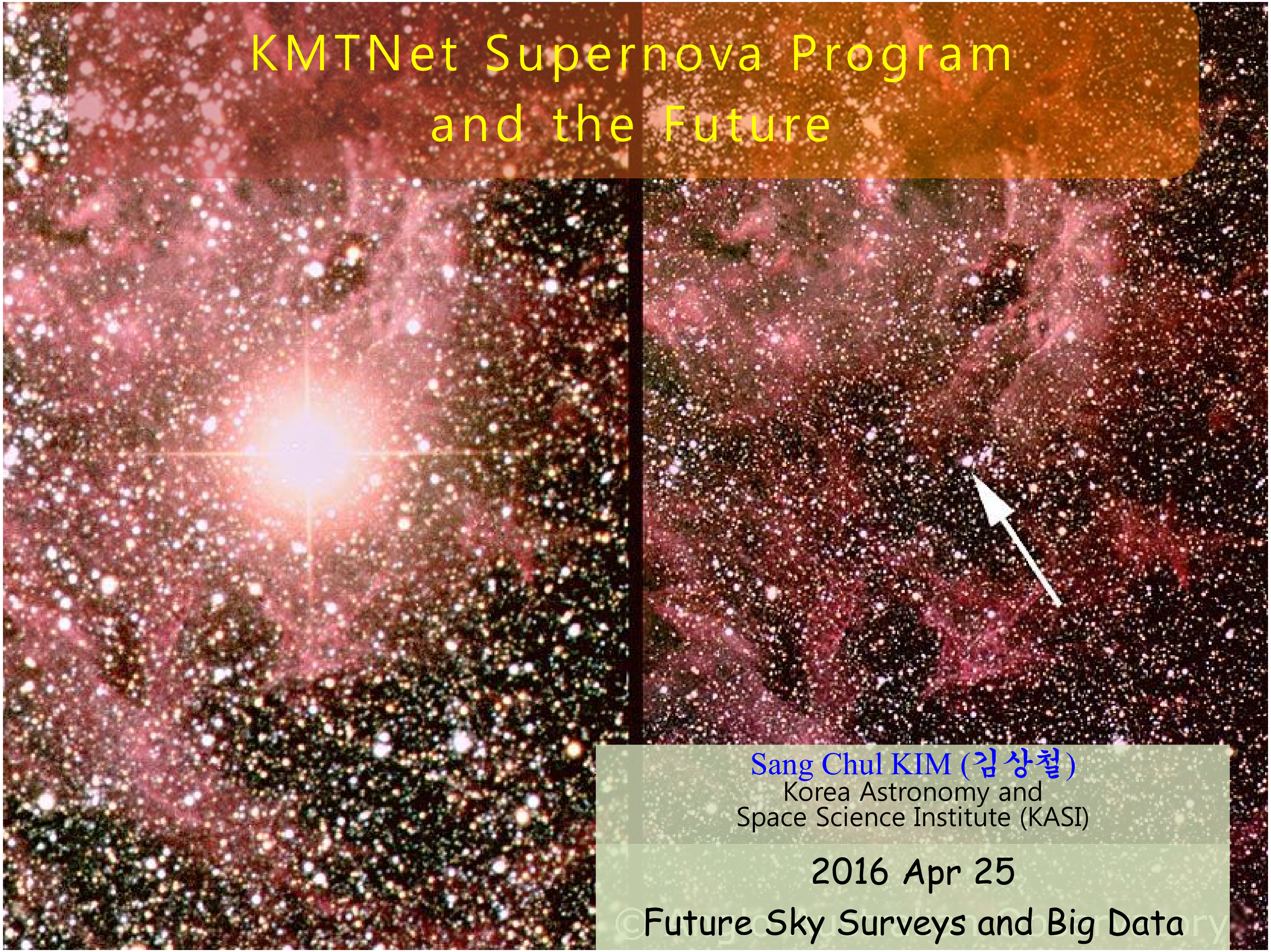
KMTNet Supernova Program and the Future



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

3

Supernova Remnant

Kepler's SN

1604 October 9, northern Italy

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

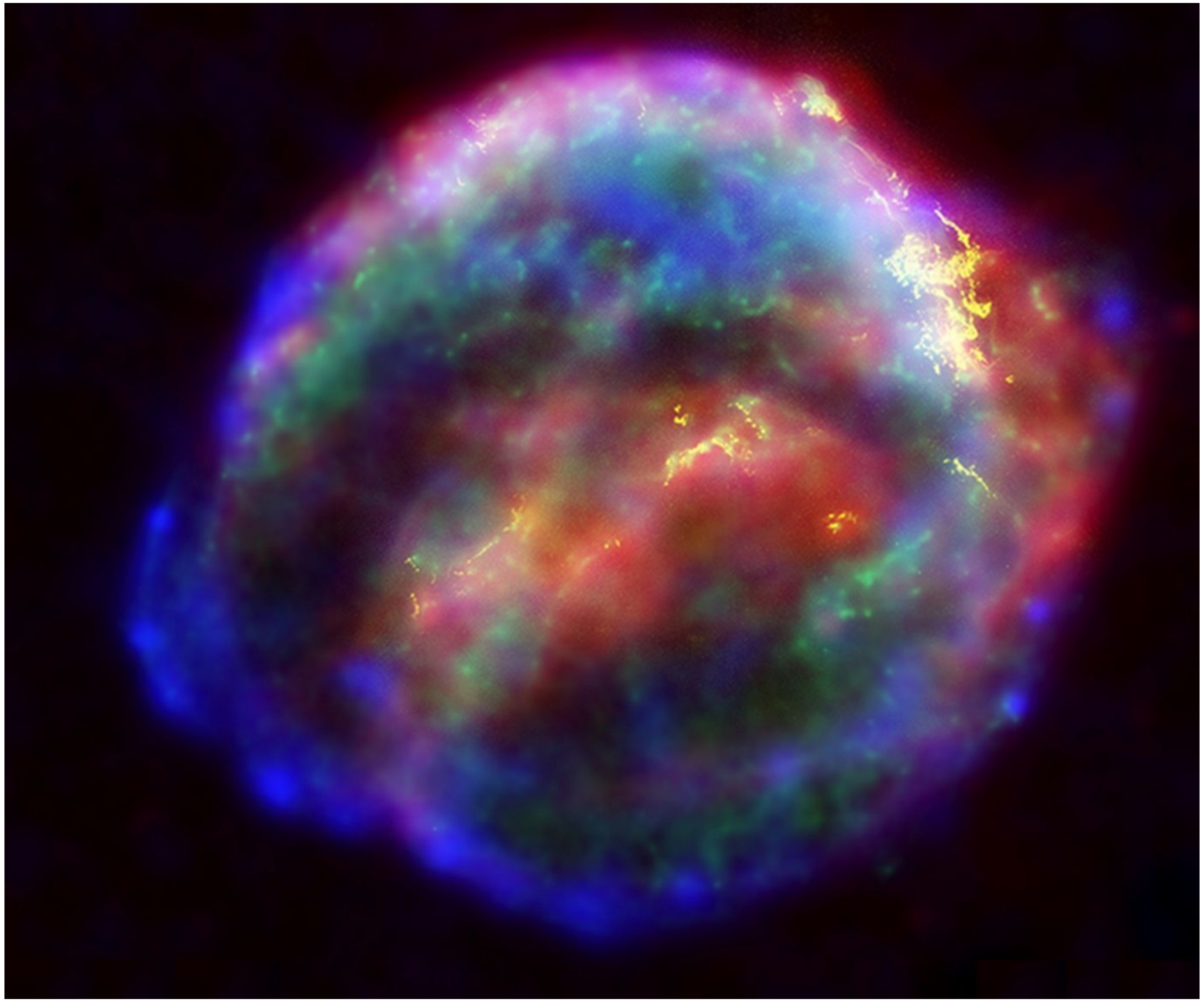
Johannes Kepler → started observation from Oct 17

: became invisible in Nov

: reappeared in 1605 Jan

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

α(J2000)= 17^h 30^m 42^s, 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

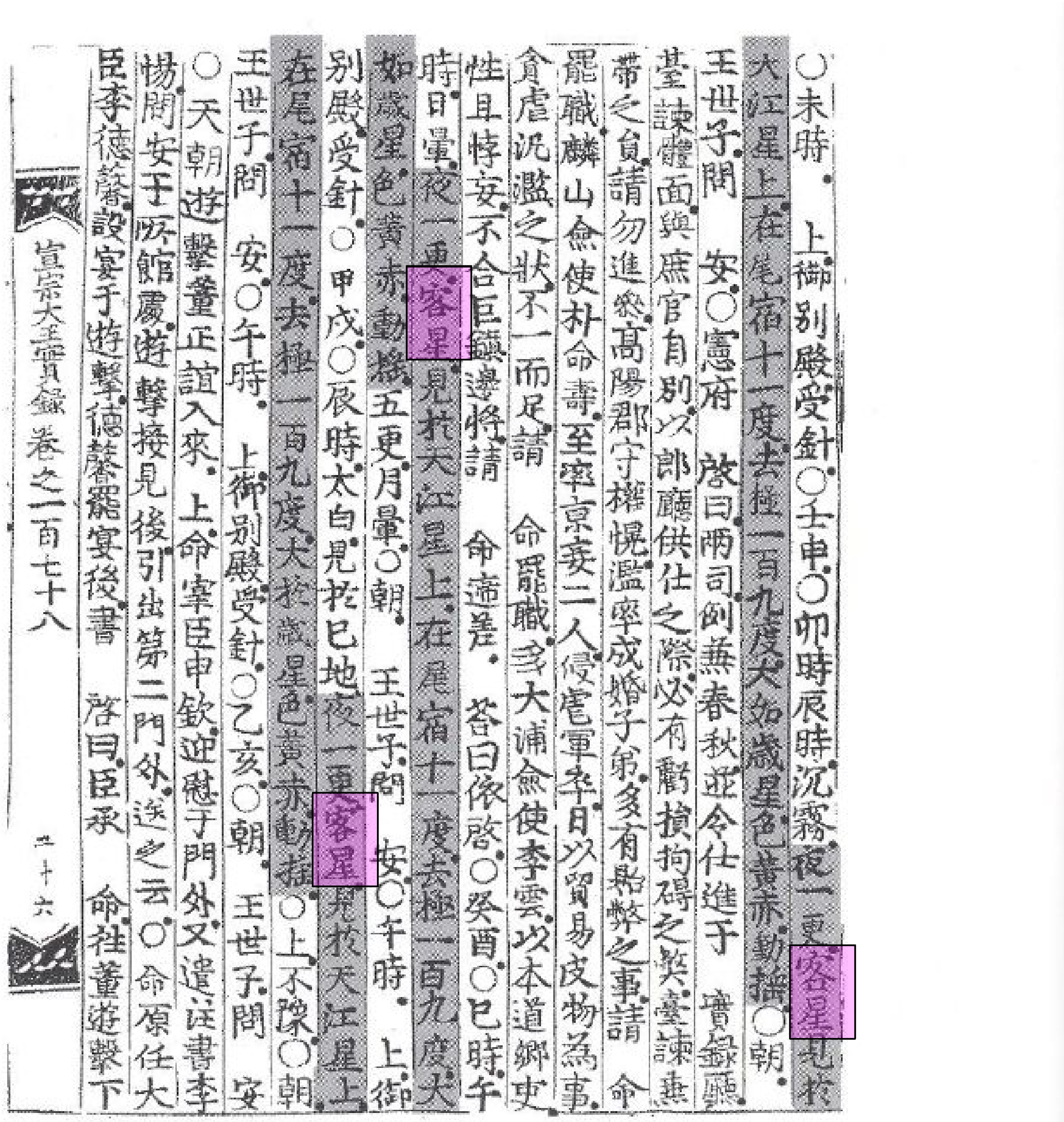
SN name	Observer	Remnant
SN 185	[China]	RCW 86 (G315.4−2.3)
SN 1006	[China, Japan, Iraq, Egypt, and Europe, North American petroglyphs]	G327.6+14.6
SN 1054	[China]	Crab Nebula (G184.6–5.8)
SN 1572	Tycho Brahe	G120.1+1.4
SN 1604	Johannes Kepler	G4.5+6.8
1680 (unobserved)		Cassiopeia A
1868 (unobserved)		G1.9+0.3

Annals of the Joseon Dynasty
(조선왕조실록, 朝鮮王朝實錄) – Kepler SN

Joseon dynasty
King Sunjo yr 37
(선조 宣祖 37년)

(1604 October)

관상감(觀象監,
Joseon Royal
Observatory)

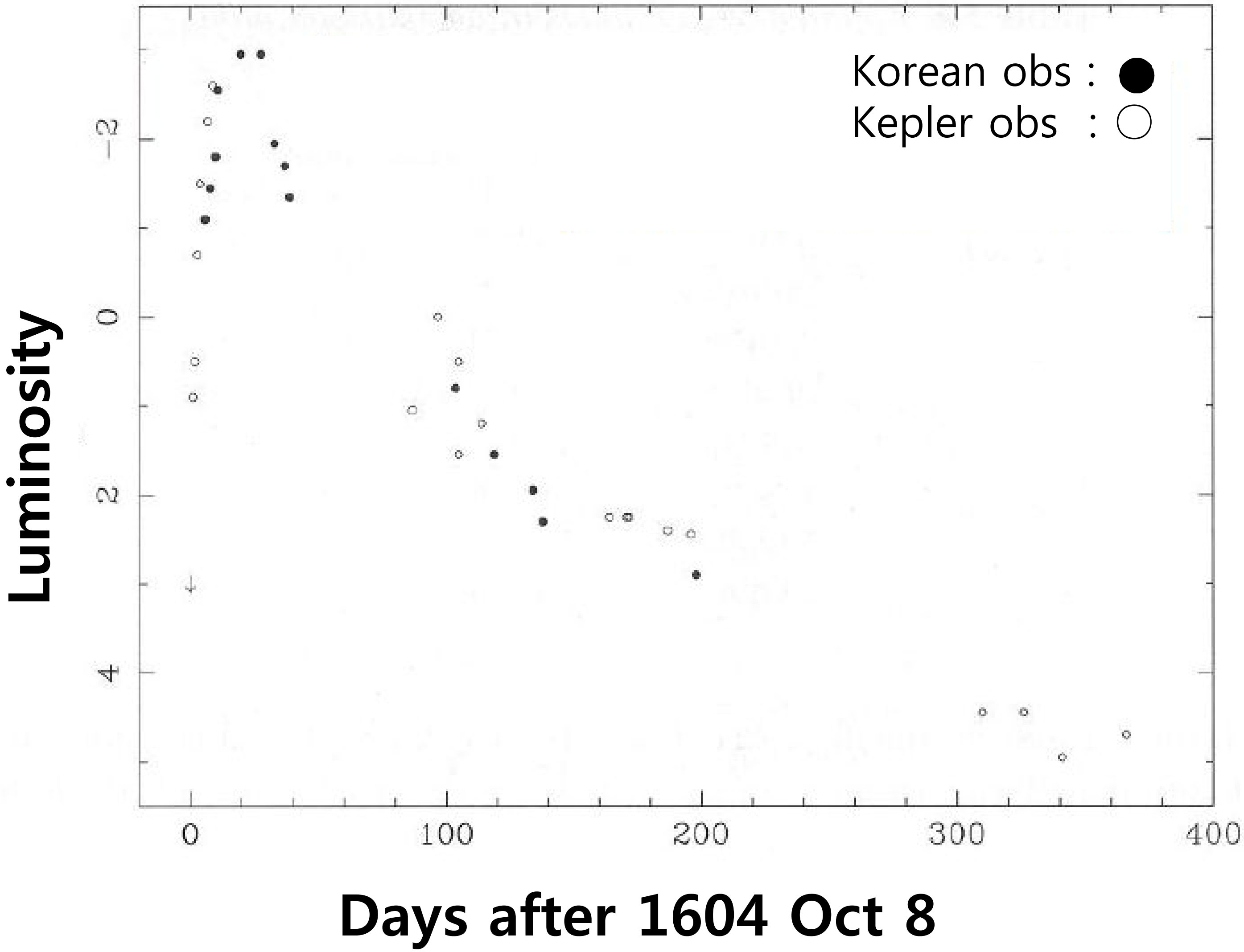

○未時 上御別殿受針○壬申○卯時辰時沉霧夜一更客星見於
大江星上在尾宿十一度去極一百九度大如歲星色黃赤動搖○朝
王世子問 安○憲府 啓曰兩司例兼春秋並令仕進于 實錄廳
臺諫體面與庶官自別以郎廳供仕之際必有斷損拘碍之樊臺諫並
帶之員請勿進參高陽郡守權愰濫率成婚子弟多有駱弊之事請 命
罷職麟山僉使朴命壽至率京妾二人侵虐軍卒日以貿易皮物爲事
貪虐汎濫之狀不一而足請 命罷職參大浦僉使李雲以本道鄕吏
性且恃安不合巨鎮邊將請 命遞差 答曰依啓○癸酉○巳時午
時日暈夜一更客星見於天江星上在尾宿十一度去極一百九度大
如歲星色黃赤動搖五更月暈○朝 王世子問 安○午時 上御
別殿受針○甲戌○辰時太白見於巳地夜一更客星見於天江星上
在尾宿十一度去極一百九度大於歲星色黃赤動搖○上不豫○朝
王世子問 安○午時 上御別殿受針○乙亥○朝 王世子問 安
○天朝遊擊藁正誼入來 上命宰臣申欽迎慰于門外又遣注書李
惕問安于所館處遊擊接見後引出第二門外送之云○命原任大
臣李德馨設宴于遊擊德馨罷宴後書 啓曰臣承 命往華遊擊下

宣宗大王實錄卷之一百七十八

二十六

Guest star(客星)

SN 1604 (type Ia)



The Historical Supernovae (D. H. Clark & F. R. Stephenson, 1977, p. 78)

Korean studies on old records

PUBLICATIONS OF THE KOREAN ASTRONOMICAL SOCIETY
5:85~94, 1990

朝鮮王朝實錄에 기재된 Kepler超新星의 관측기록

(Observation Records on Kepler Supernova in the Annals of the Joseon Dynasty)

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.

JKAS – SN 1994I

JOURNAL OF THE KOREAN ASTRONOMICAL SOCIETY
28: 31 ~ 43, 1995

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 $(V - R) \approx 0.2$ mag $((V - I) \approx 0.3$ mag, $(B - V) \approx 0.7$ mag) on April 4 to $(V - R) \approx 0.6$ mag $((V - I) \approx 0.9$ mag, $(B - V) \approx 1.3$ mag) on April 18. Afterwards $(V - R)$ colors get bluer slightly (by ~0.005 mag/day), while $(V - I)$ colors stay almost constant around $(V - I) \approx 1.0$ mag. The color at the maximum brightness is $(B - V) = 0.9$ mag,

JKAS – SN 1994I

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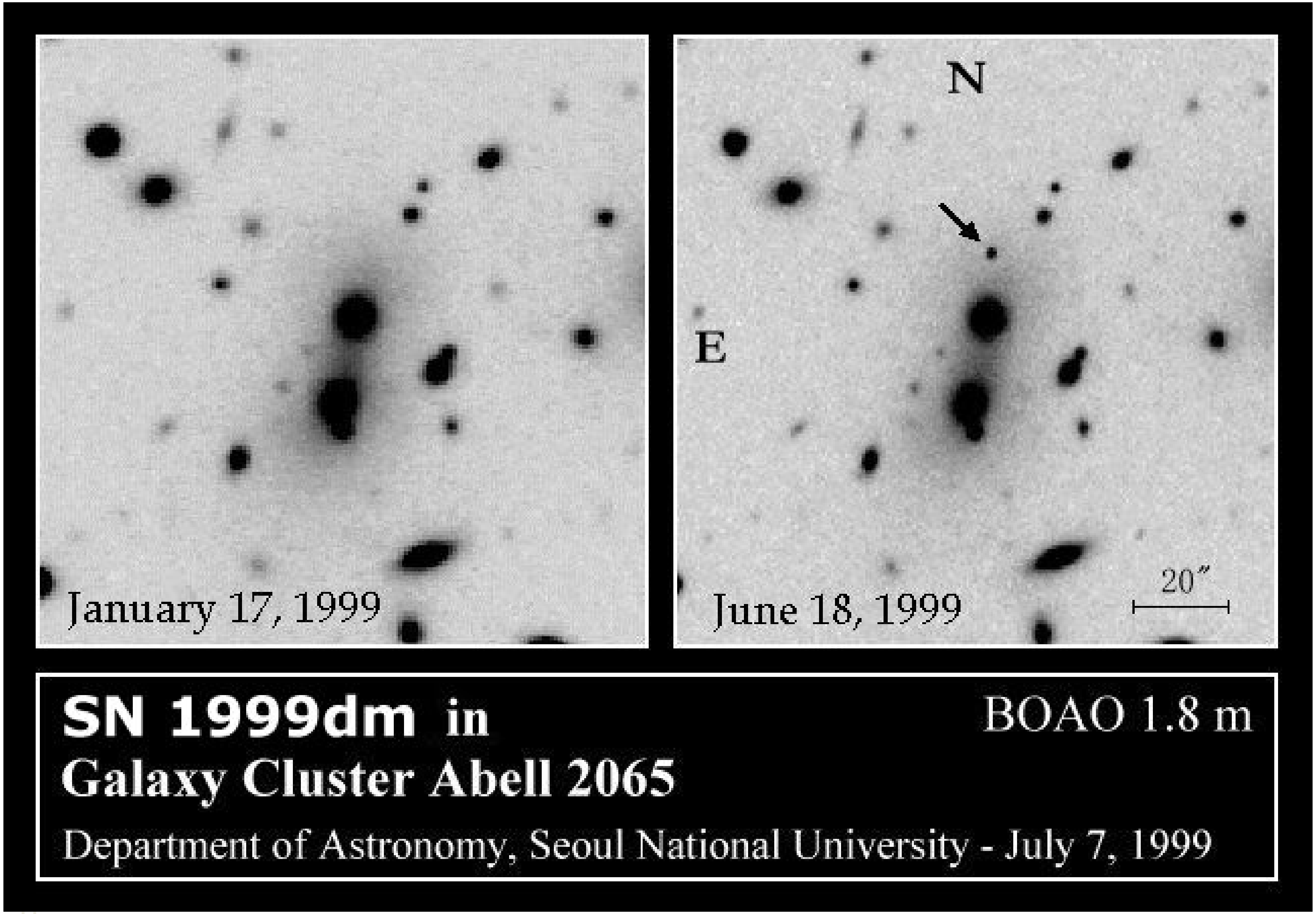
We present *UBVRI* CCD photometry of the Type Ic supernova SN 1994I in M51 which was discovered on April 2, 1994 (UT). *UBVRI* CCD photometry of SN 1994 I were obtained for the period of the first two months from April 4, 1994, using the Seoul National University Observatory 60 cm telescope. The light 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 $(V - R) \approx 0.2$ mag ($(V - I) \approx 0.3$ mag, $(B - V) \approx 0.7$ mag) on April 4 to $(V - R) \approx 0.6$ mag ($(V - I) \approx 0.9$ mag, $(B - V) \approx 1.3$ mag) on April 18. Afterwards $(V - R)$ colors get bluer slightly (by ~0.005 mag/day), while $(V - I)$ colors stay almost constant around $(V - I) \approx 1.0$ 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

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 *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 $8'.1 \times 8'.1$ at the f/7 Cassegrain focus of our telescope. The gain

SN 1999dm in Abell 2065



SN 1999dm in Abell 2065

IAUC 7241

Circular No. 7241

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INTERNATIONAL ASTRONOMICAL UNION
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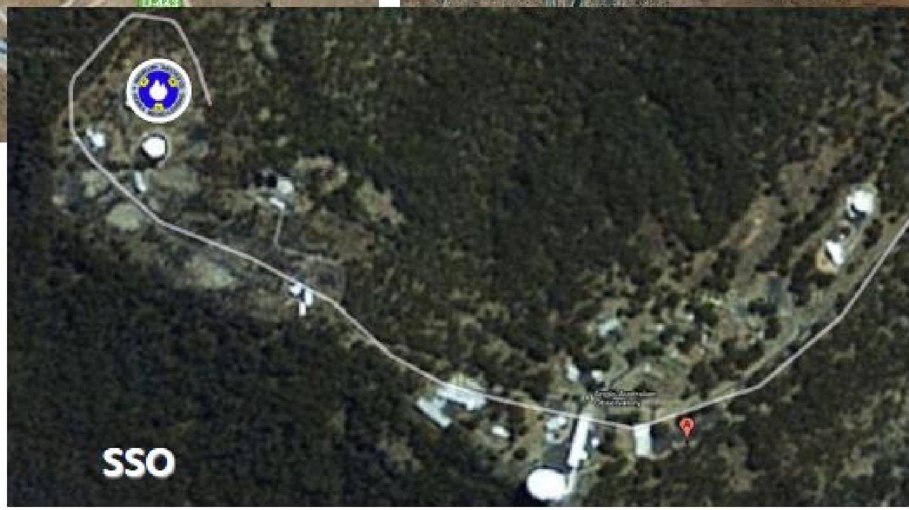
BMARSDEN@CFA.HARVARD.EDU or DGREEN@CFA.HARVARD.EDU (science)
URL http://cfa-www.harvard.edu/iau/cbat.html ISSN 0081-0304
Phone 617-495-7244/7440/7444 (for emergency use only)

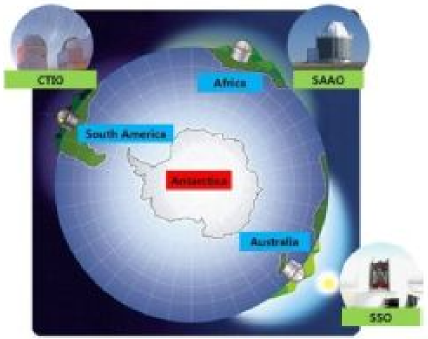
SUPERNOVA 1999dm IN MCG +05-36-022

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 1988, not 1998. On line 11, for BAO reflector read BOA reflector

M. M. M. Santangelo and S. Donati, Monte Agliale, 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.





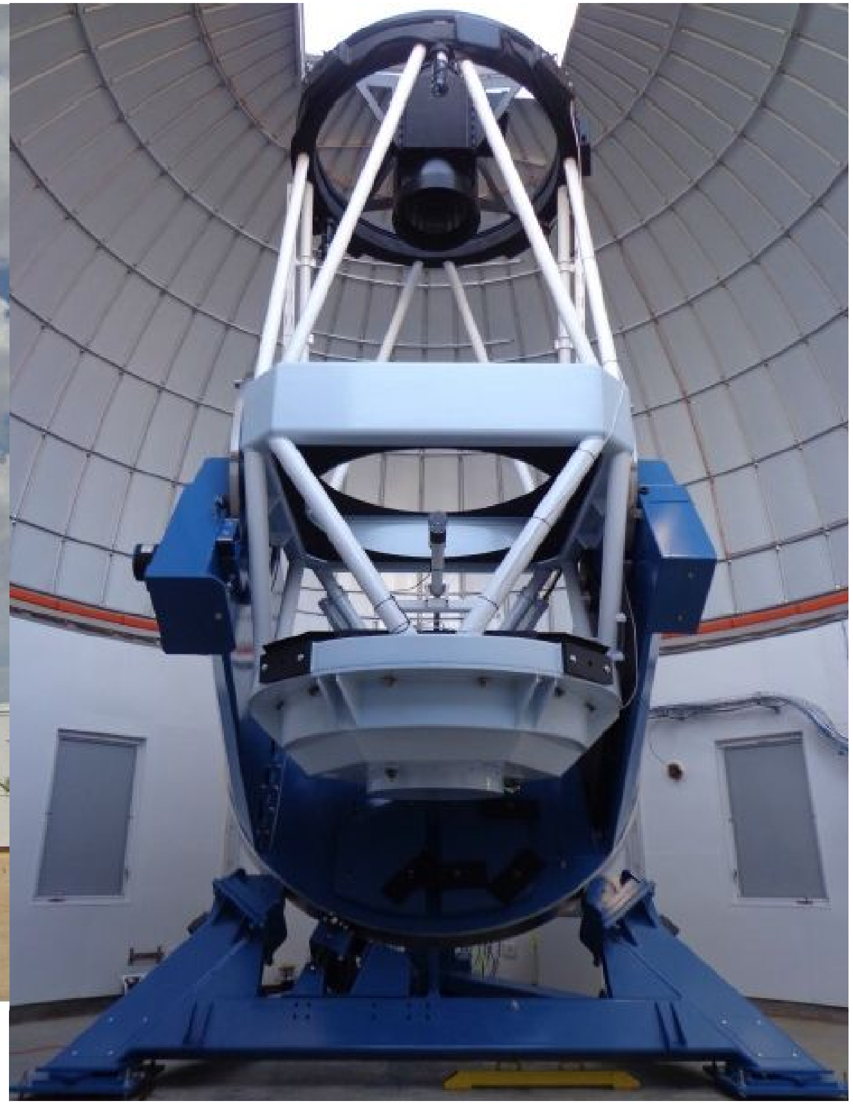
Korea Microlensing Telescope Network (KMTNet): Three new 1.6-m wide-field telescopes in the southern hemisphere, providing 24-h sky coverage.

	SAAO	CTIO	SSO
Longitude	339:11:21.5	70:48:52.7	210:56:19.7
Latitude	-32:22:46	-30:09:56	-31:16:24
Altitude	1798m	2200m	1149m
Time Zone	-2	4	-10
Temperature	5<T(C)<35	3<T(C)<19	5<T(C)<35
Humidity (Med.)	44%	35%	63%
Humidity (Max.)	85%	70%	95%
Wind speed (Med.)	6.0m/s	4.0m/s	2.7m/s
Wind speed (Max.)	13m/s	11m/s	6.0m/s
Atmospheric Seeing	0.8~1.4"	0.6~1.0"	1.0~2.0"
Electric Voltage	230V	120V	240V
Electric Frequency	50Hz	60Hz	50Hz

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

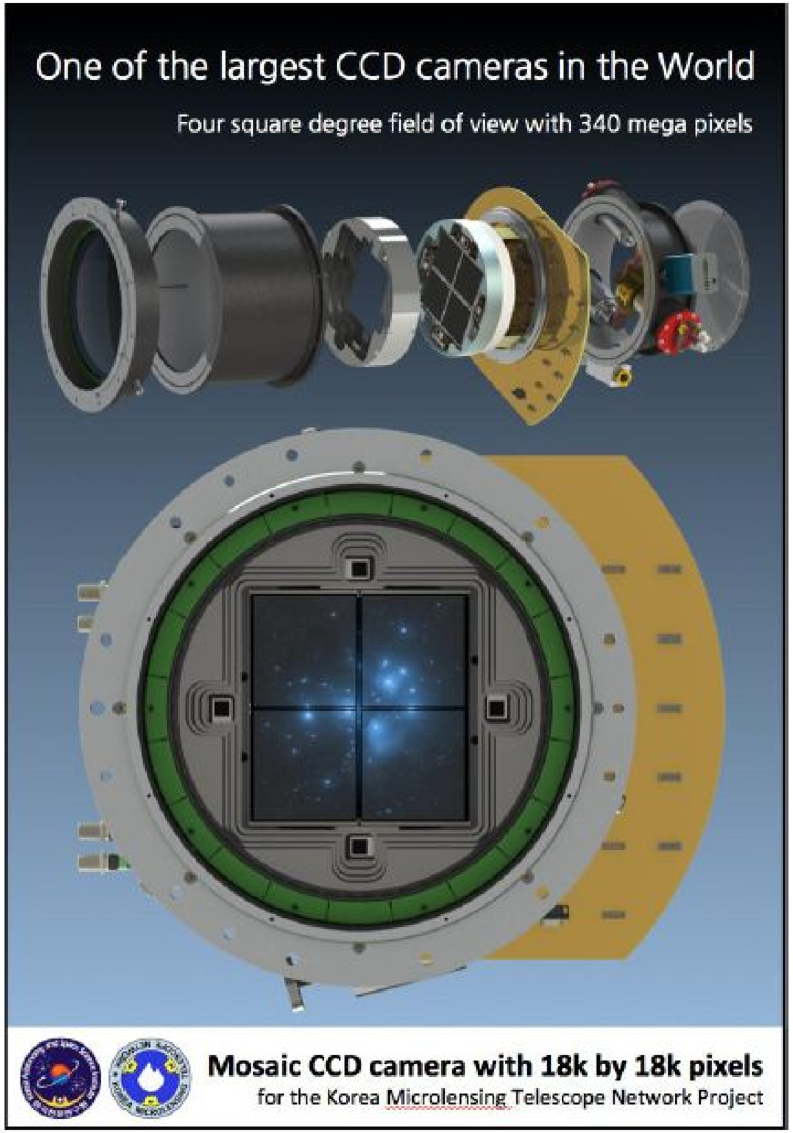


Chilean Site

Korea Microlensing Telescope Network

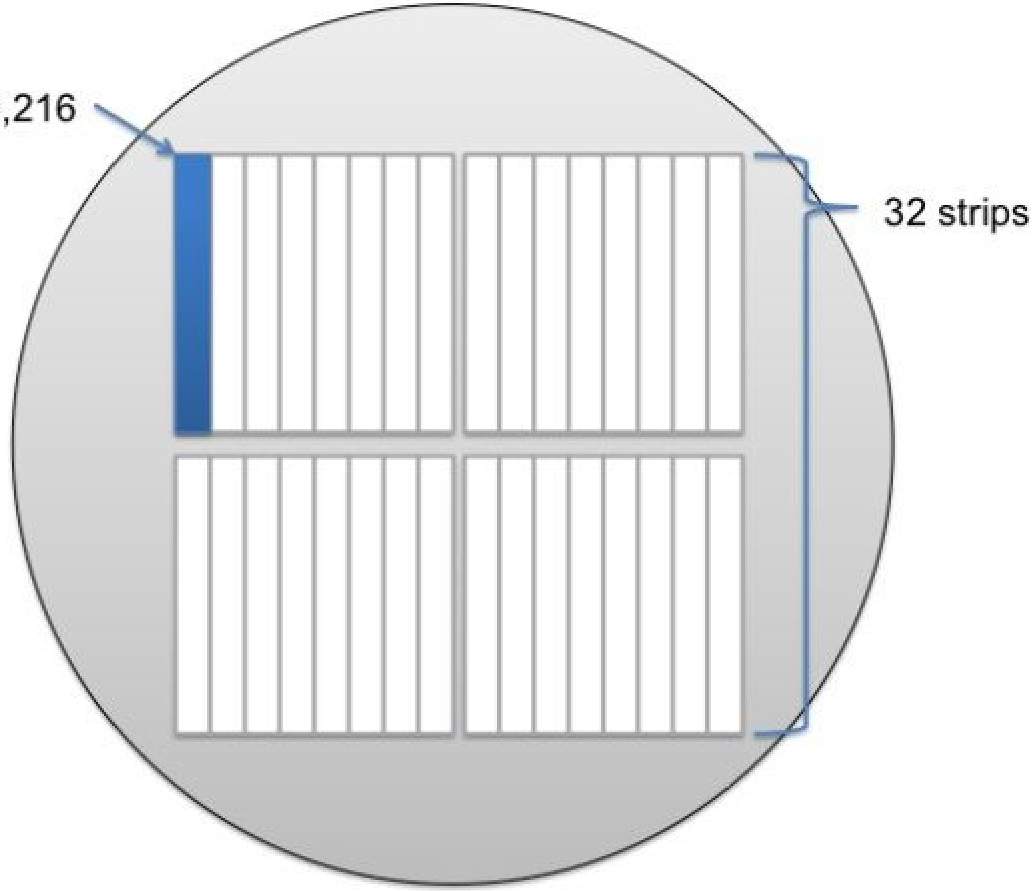
Wide Field CCD Imager: 2° × 2° Field of View

- Four e2v Mosaic CCD Chips
- 340M pixels (18K×18K), each 10 μm
- 0.40 arcsec/pixel, 2 degree × 2 degree FOV
- Mechanical cooling (-110 ℃)
- 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

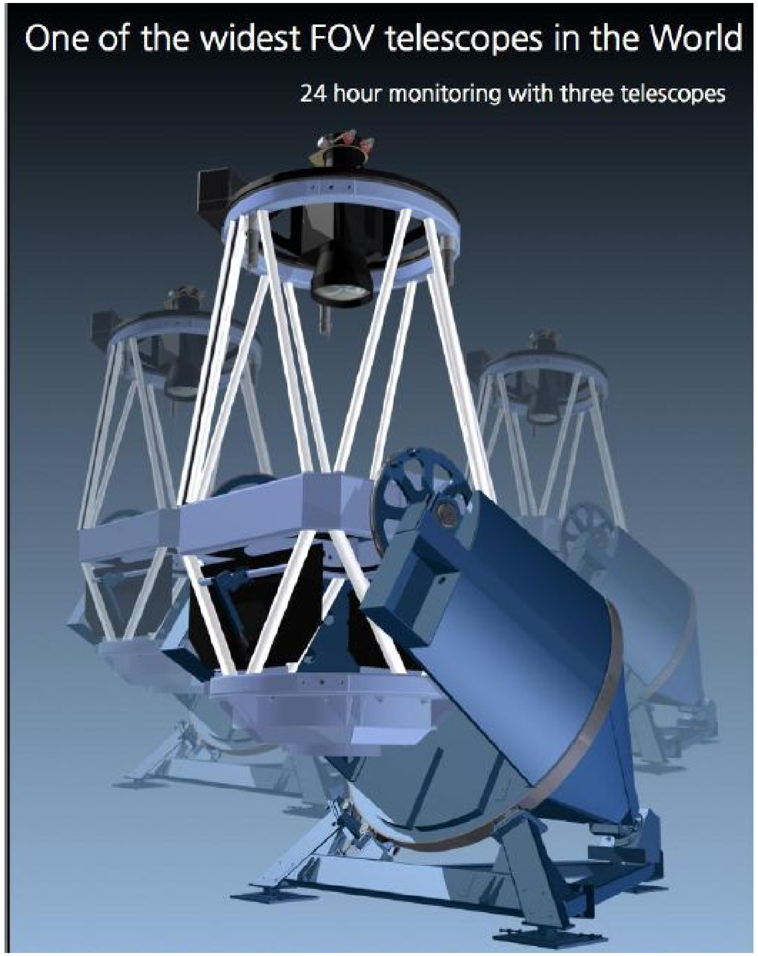
Wide Field CCD Imager: 2° × 2° Field of View



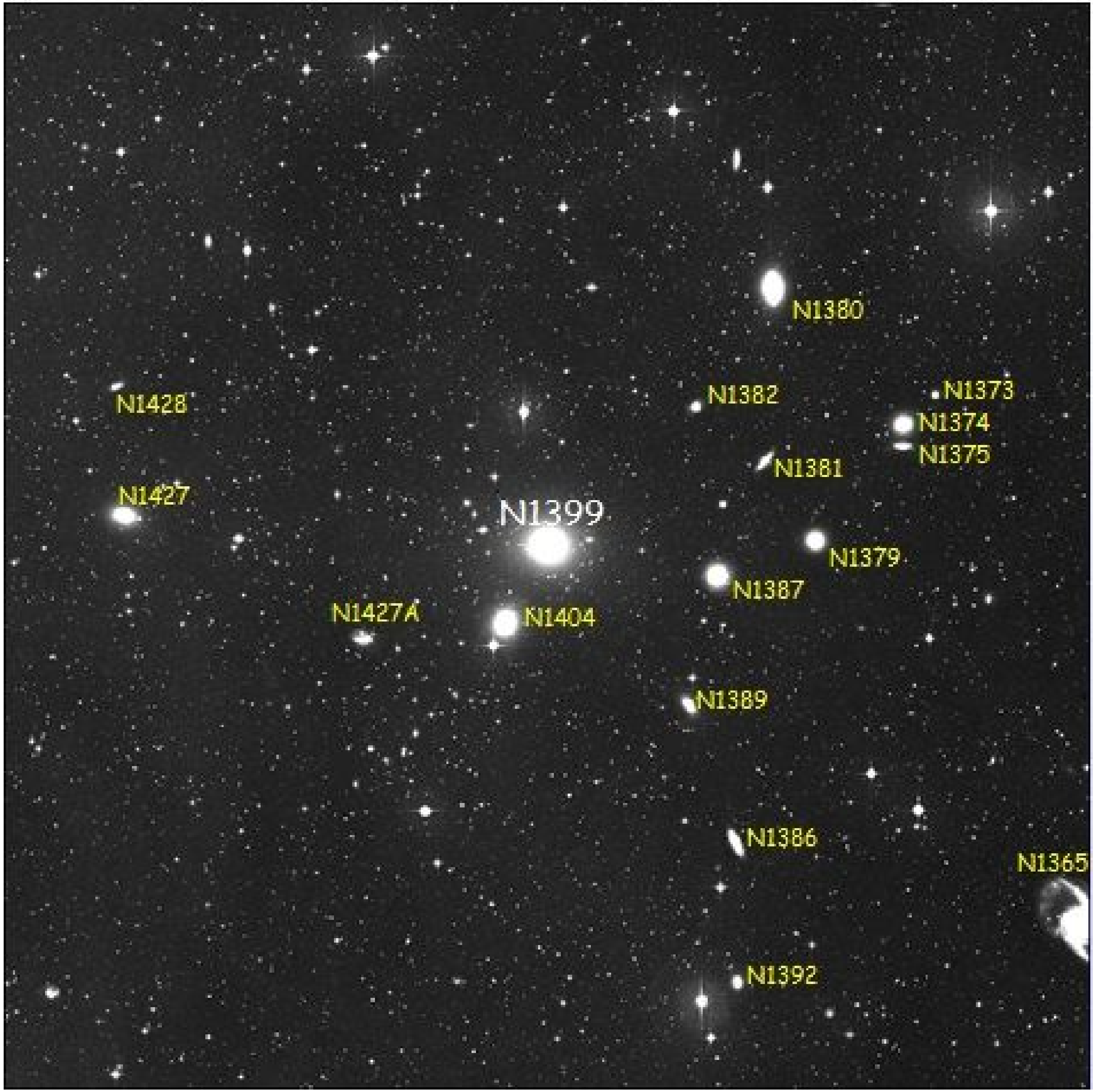
Korea Microlensing Telescope Network

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

  KMTNet : $(1.6\ m)^2 \times (2\ deg)^2 \approx$ 10.2 (m^2 sqd)
  CFHT MegaCam : $3.6^2 \times 1^2 \approx$ 13.0 (m^2 sqd)
  PTF : $1.2^2 \times 7 \approx$ 10.1 (m^2 sqd)
  (Palomar Transient Factory)
  Pan-STARRS : $1.8^2 \times 7 \approx$ 22.7 (m^2 sqd)
  MOA : $1.8^2 \times 2.4 \approx$ 7.8 (m^2 sqd)
  SkyMapper : $1.35^2 \times 5.7 \approx$ 10.4 (m^2 sqd)



Fornax cluster center (d～19Mpc) 2 deg x 2 deg / DSS1



Korea Microlensing Telescope Network

Data contents

- Real time data transfer to the KASI data center

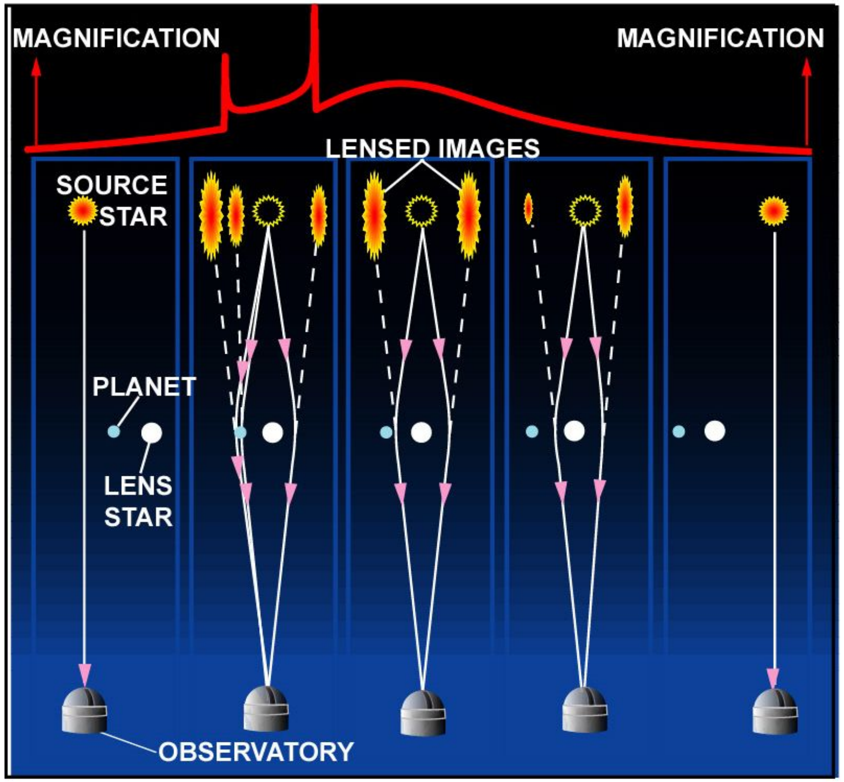
- Big data reduction pipeline : 150 GB/night/site
- Photometry database : 10^7 stellar variability monitoring data
- Image analysis within 1 day → DB update
- 5-year raw data 560 TB

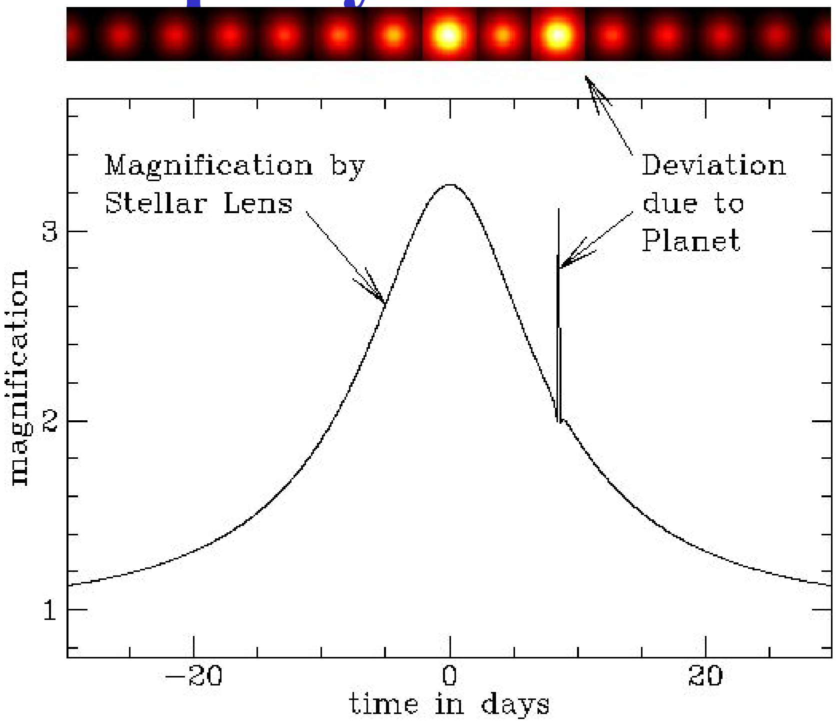
  analyzed images 2.24 PB

  photometry DB 200 TB

Korea Microlensing Telescope Network

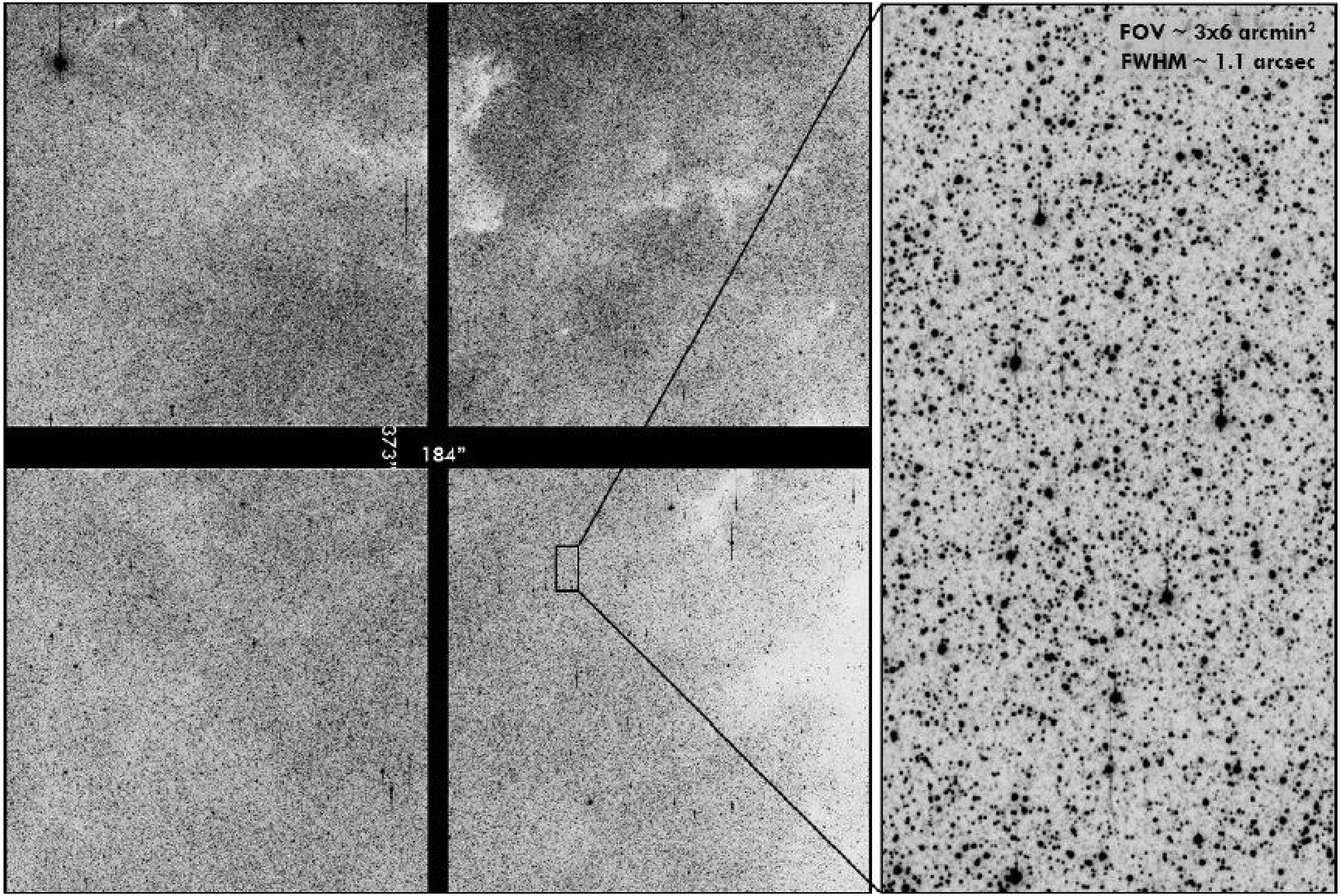
The main objective is to detect "Microlensing events of earth-like planets" from the Galactic Bulge for approximately 6 months per year.





David Bennett

Galactic Bulge field



SSO, I-band, 60 sec
FWHM ~ 1.1″

3′×6′

Journal of the Korean Astronomical Society
49: 37 ~ 44, 2016 February
http://jkas.kas.org

KMTNet: A Network of 1.6 m Wide-Field Optical Telescopes Installed at Three Southern Observatories

Seung-Lee Kim[1,2], Chung-Uk Lee[1,2], Byeong-Gon Park[1,2], Dong-Jin Kim[1], Sang-Mok Cha[1,3], Yongseok Lee[1,3], Cheongho Han[4], Moo-Young Chun[1], and Insoo Yuk[1]

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

KMTNet for Supernova Search/Monitoring

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!"

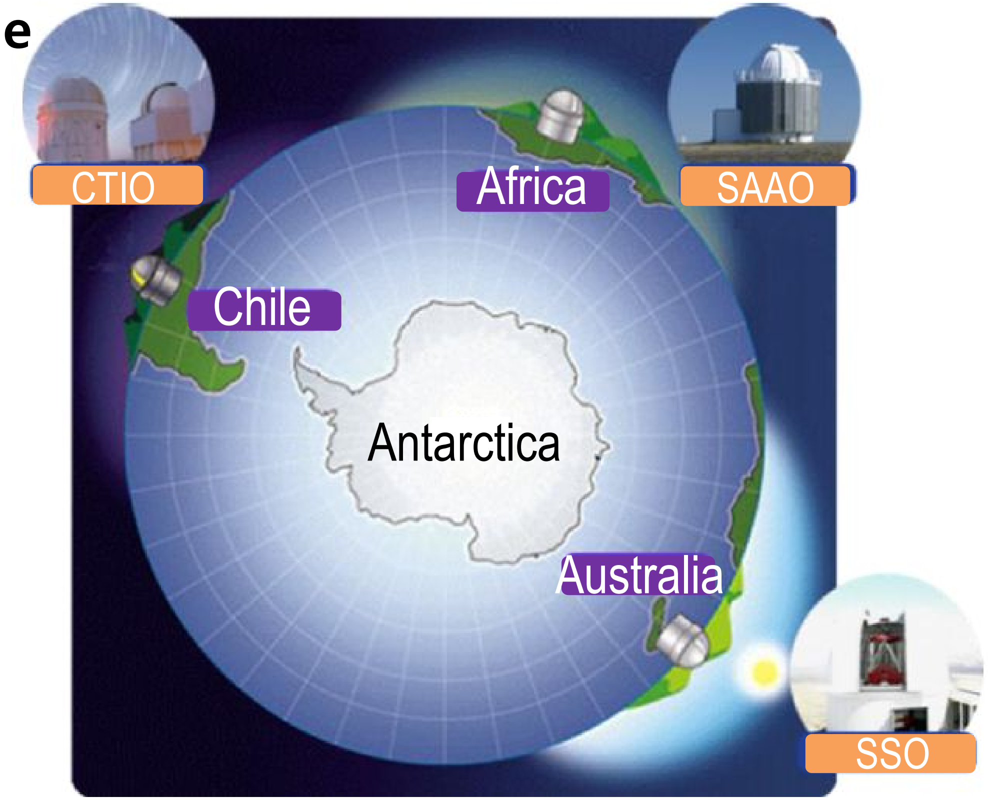
KMTNet (외계행성 탐색시스템)
(Korea Microlensing Telescope Network)

- **High competitive etendue (A×Ω)**
  Large enough diameter(1.6m) and wide field-of-view : 2°×2°

- **Excellent pixel scale(0.4”) and filter sets**
  (BVRI g′r′i′z′ Hα)

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

→ **Discovery of New, Young SNe**



KMTNet Sciences

2012 May 15~July 15
Proposal call,
submission

50%

Bulge
- Exoplanets
  - Microlensing
  - Transit
- Variables/ Transients

12%

Asteroids and comets

7%

Director's Engineering Etc.

4%

External galaxies

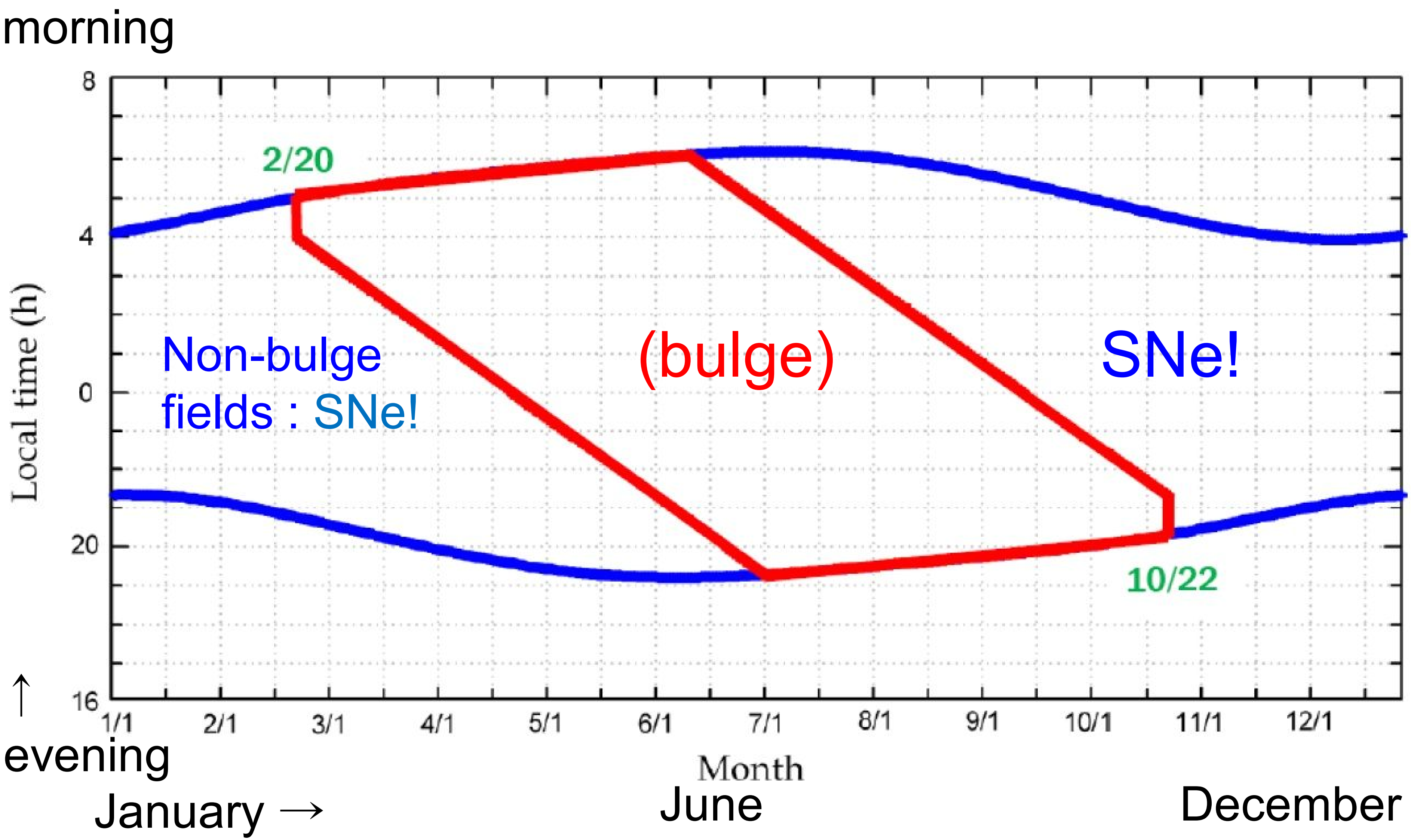
17%

Supernovae

※10%
- Chile
- South Africa
- Australia

Phase 1 : five years
(2015-2020)

KMTNet Observing Months



Supernovae – (classical) Taxonomy

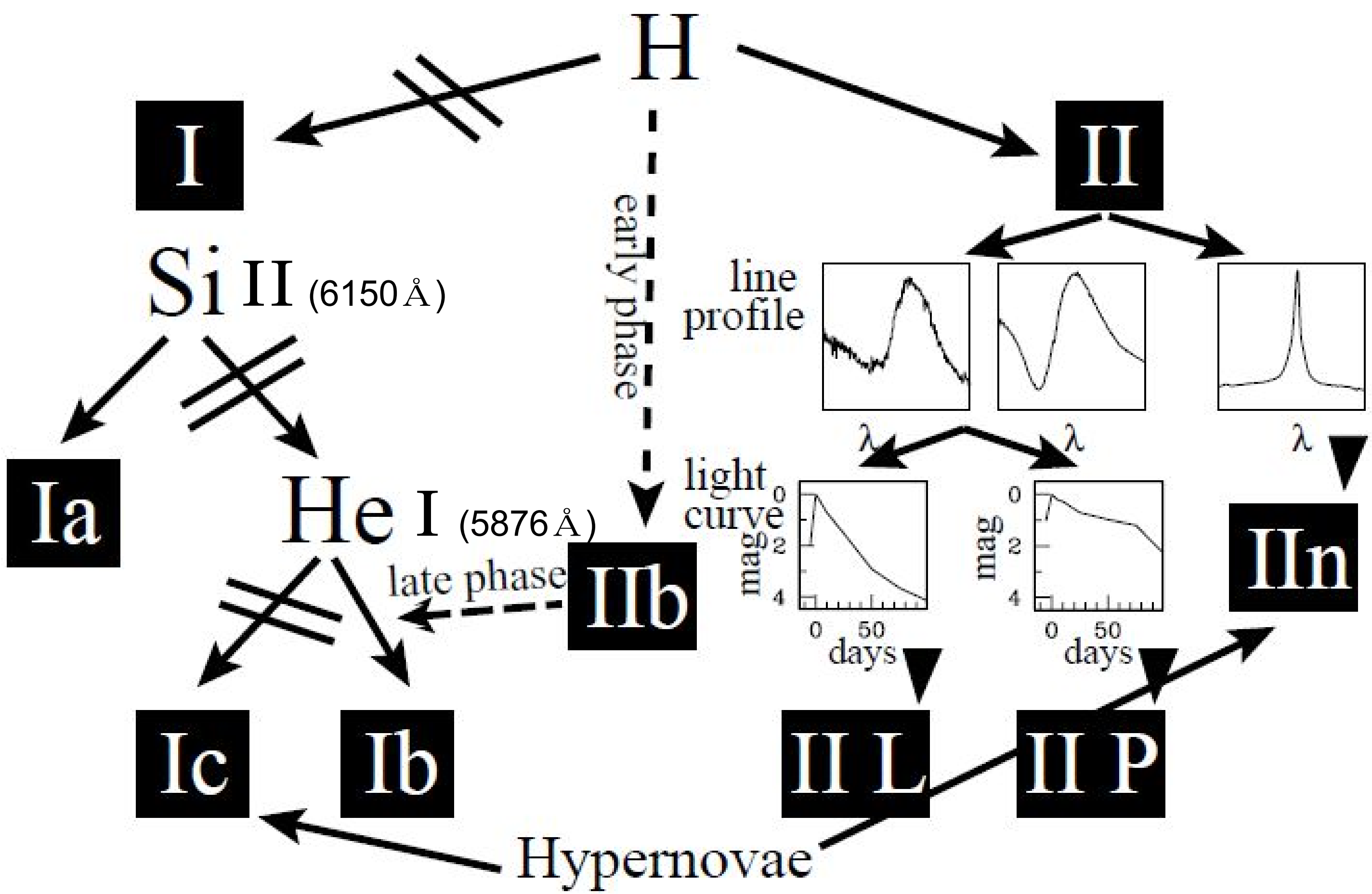


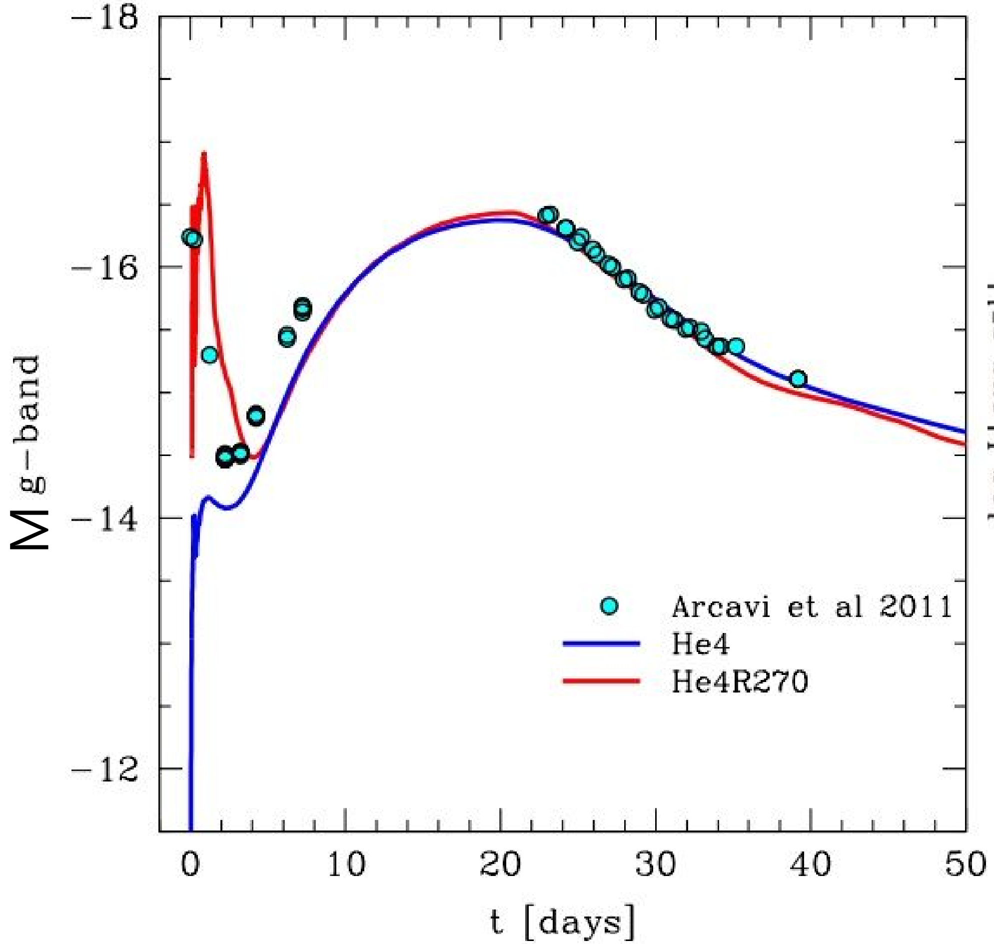
Figure 2. The detailed classification of SNe requires not only the identification of specific features in the early spectra, but also the analysis of the line profiles, luminosity and spectral evolutions

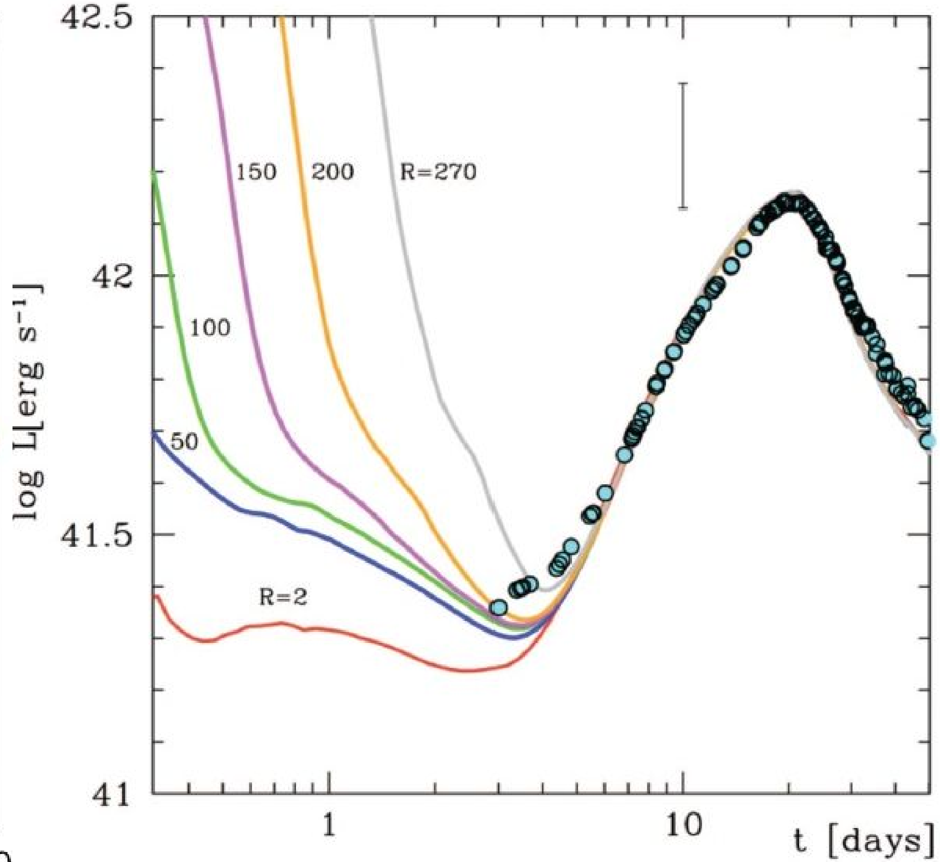
Cappellaro & Turatto (astro-ph/0012455)

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 $R_\odot$

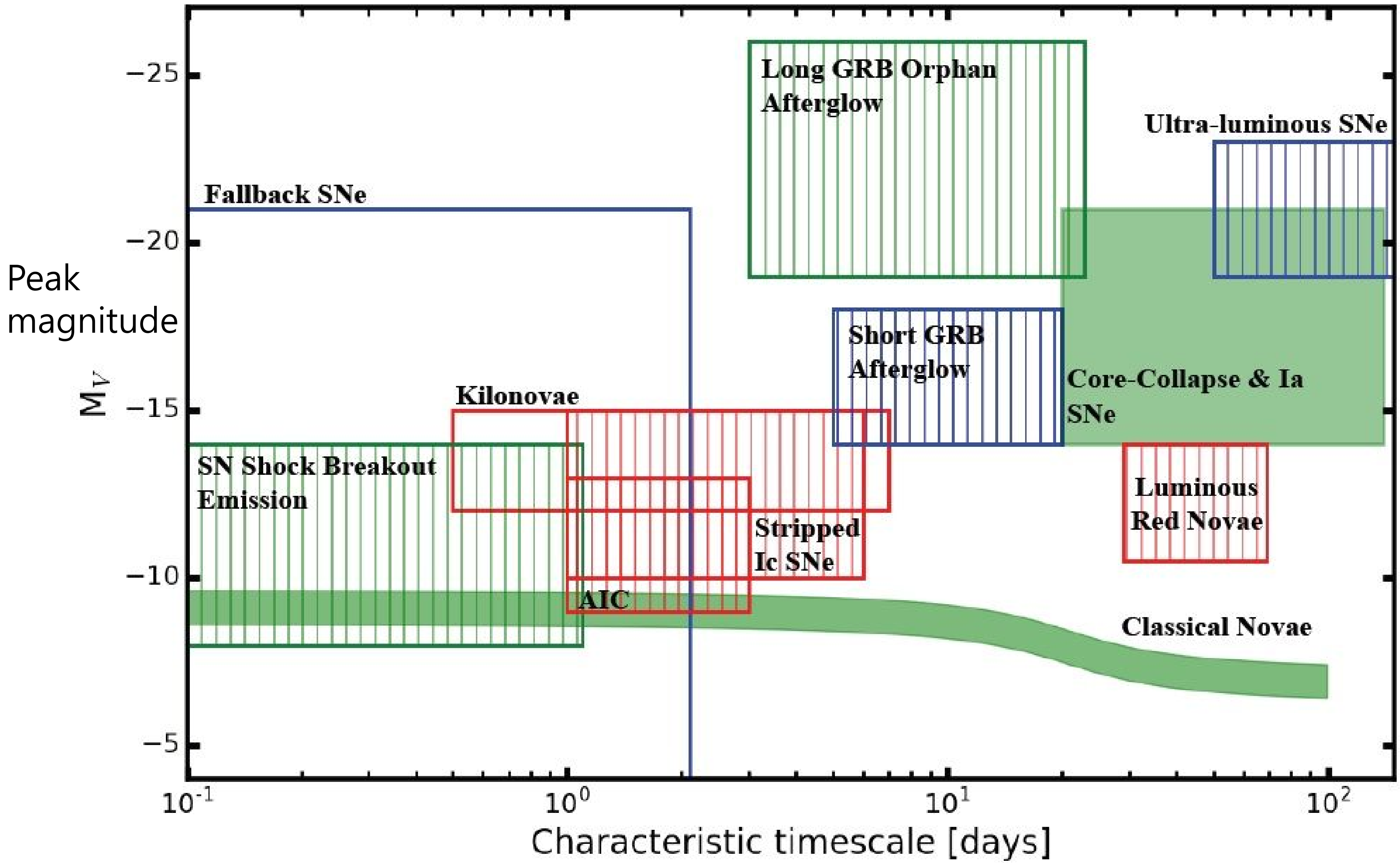
Compact vs extended progenitor

SN 2011dh (type IIb) in M51

Bersten et al. 2012 (ApJ, 757, 31)

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-IIn, 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)

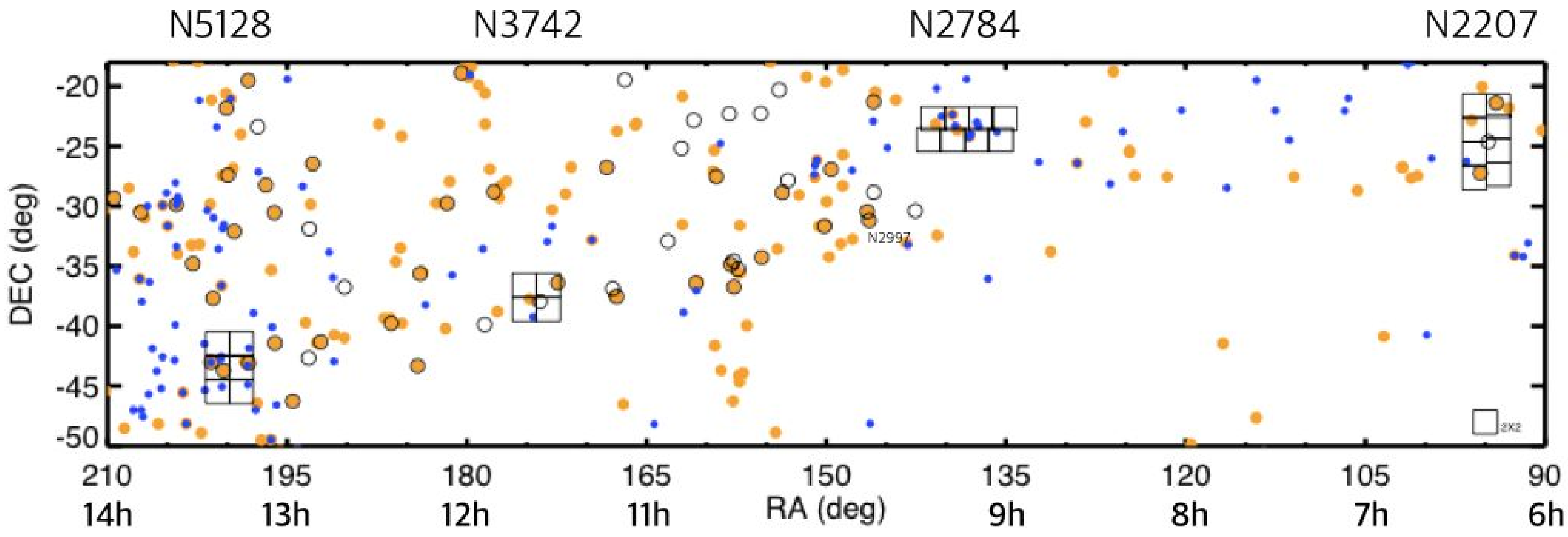
  : Image subtraction, source detection, image reprojection, astrometry, photometry, etc

  : 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

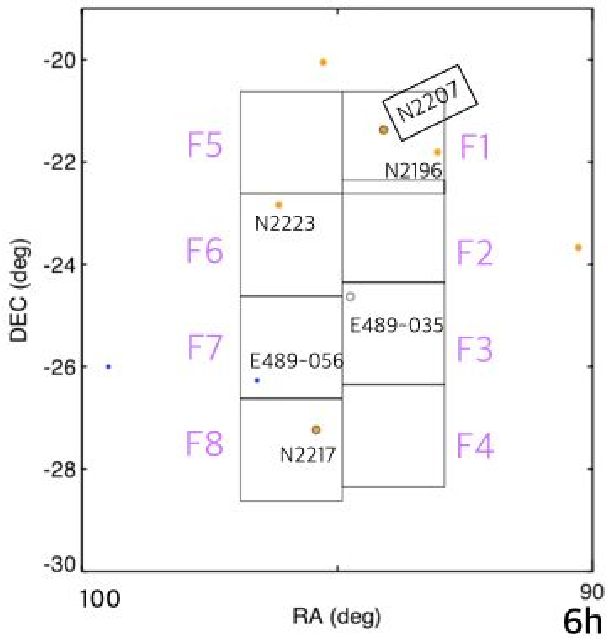
KMTNet Supernova Program (KSP) – initial targets



Blue dots: Nearby galaxy catalogue from Karachentsev et al. (2013, A&A, 404, 93)
Orange filled circles: Bright galaxy catalogue from Ho et al. (2011, ApJS, 197, 21)
Black open circles: Group catalogue from Makarov & Karachentsev (2011, MNRAS, 412, 2498)

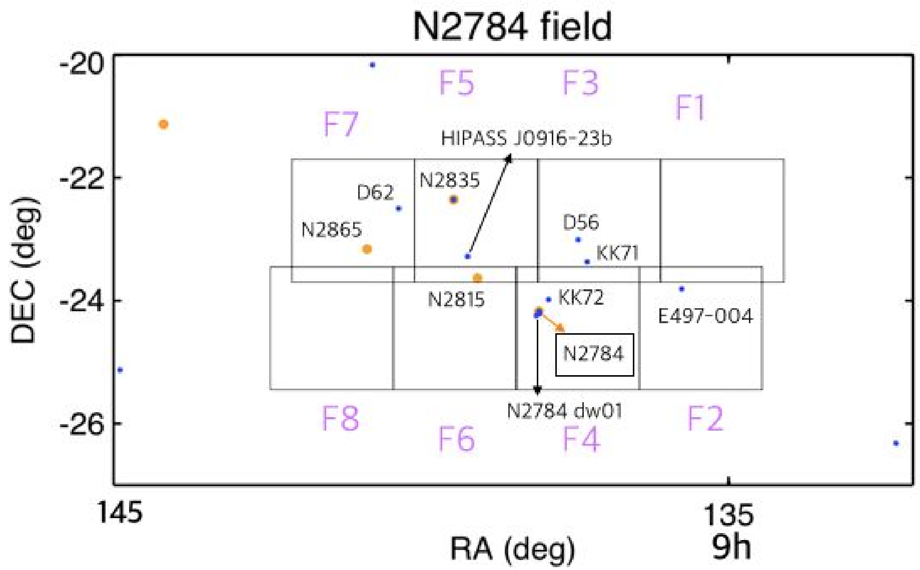
Group name	Number of member	V_{LG} (km/s)
N2207	5	2570
ESO489-035	4	2557
N2217	5	1559

KMTNet Supernova Program (KSP) – initial targets



N2207 field

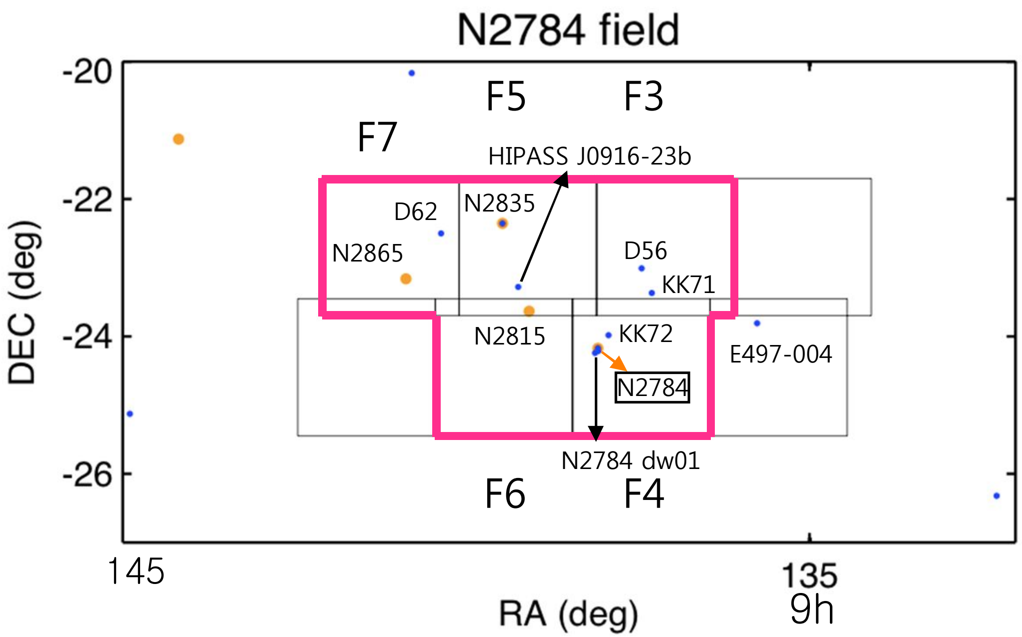
1 N2207-F1 (06:15:36, -21:37:12)
2 N2207-F2 (06:15:36, -23:21:05)
3 N2207-F3 (06:15:36, -25:21:05)
4 N2207-F4 (06:15:36, -27:21:05)
5 N2207-F5 (06:23:36, -21:37:12)
6 N2207-F6 (06:23:36, -23:37:12)
7 N2207-F7 (06:23:36, -25:37:12)
8 N2207-F8 (06:23:36, -27:37:12)



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)
12 N2784-F4 (09:09:48, -24:27:00)
13 N2784-F5 (09:16:24, -22:42:00)
14 N2784-F6 (09:17:48, -24:27:00)
15 N2784-F7 (09:24:24, -22:42:00)
16 N2784-F8 (09:25:48, -24:27:00)

KMTNet Supernova Program (KSP) – initial targets

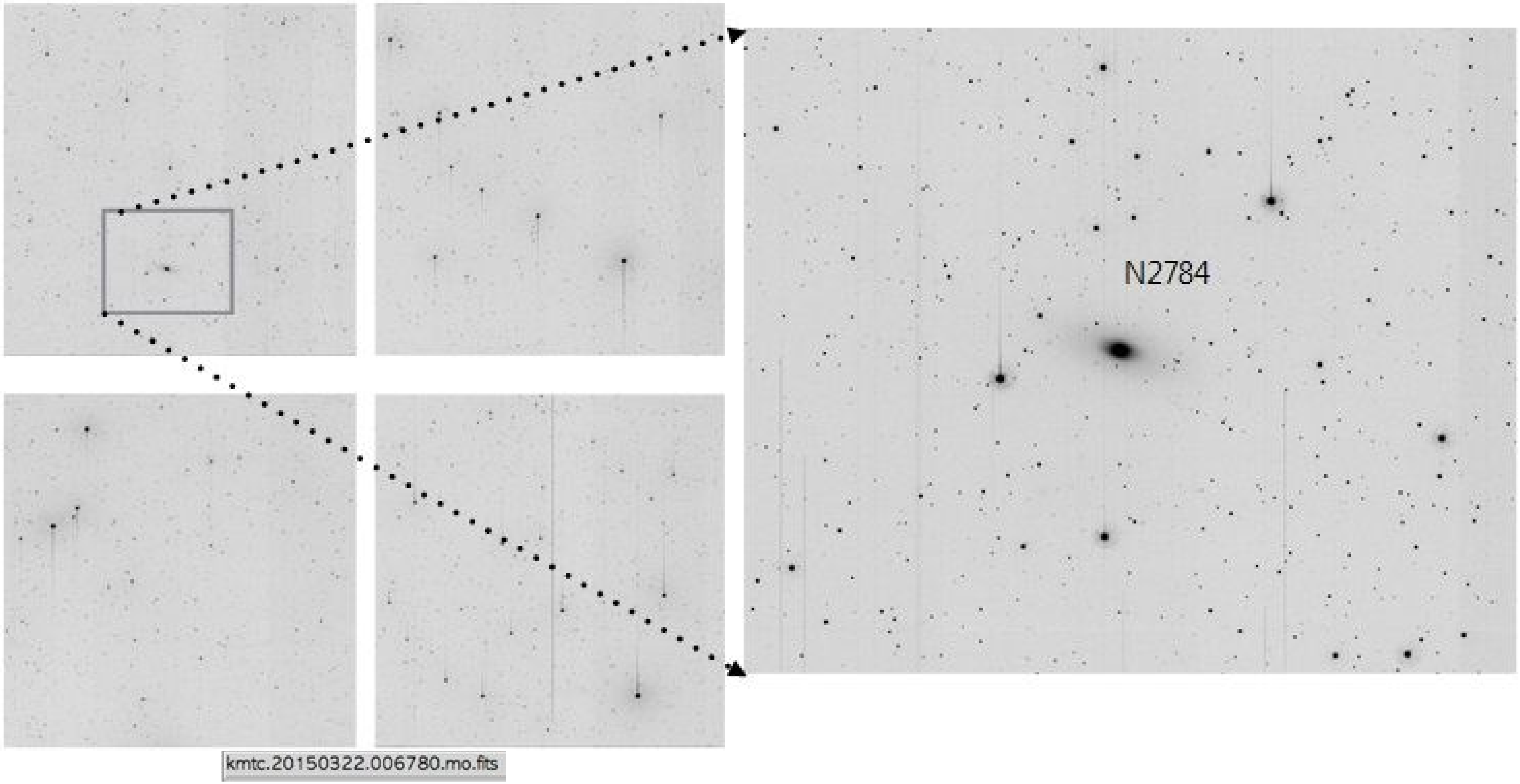


N2784 field

11	N2784-F3 (09:08:24, -22:42:00)
12	N2784-F4 (09:09:48, -24:27:00)
13	N2784-F5 (09:16:24, -22:42:00)
14	N2784-F6 (09:17:48, -24:27:00)
15	N2784-F7 (09:24:24, -22:42:00)

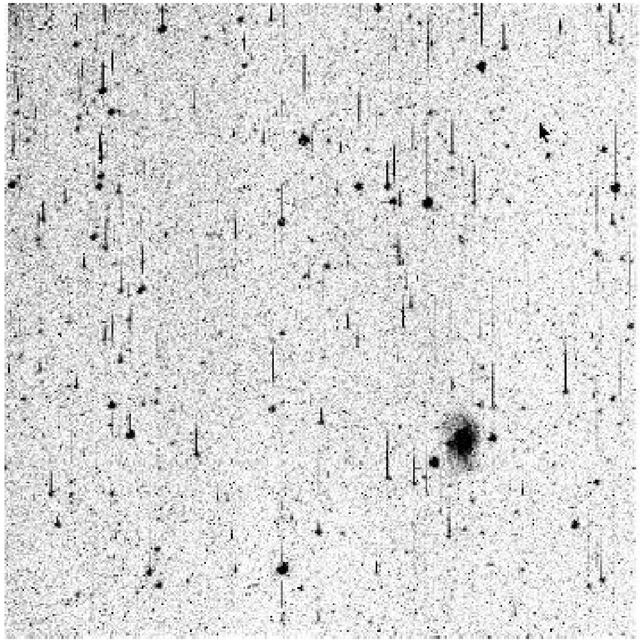
KMTNet Supernova Program (KSP) – sample field

N2784-4 : 2015. 03. 22.
2°×2°

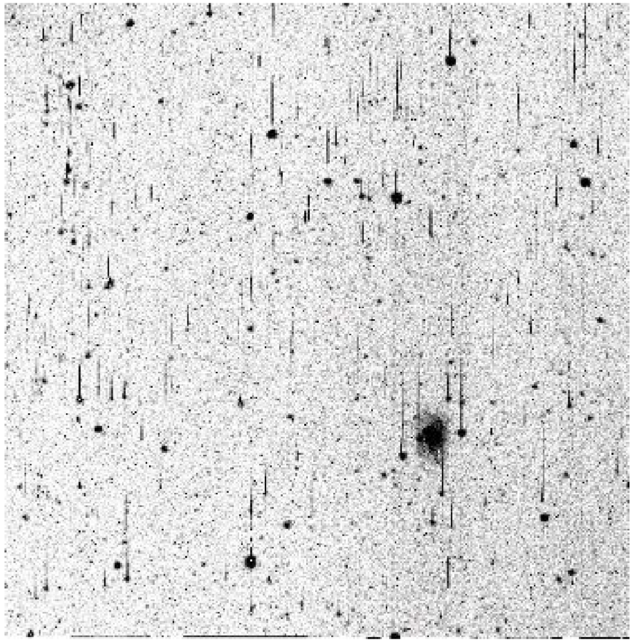


KMTNet Supernova Program (KSP) – image subtraction example

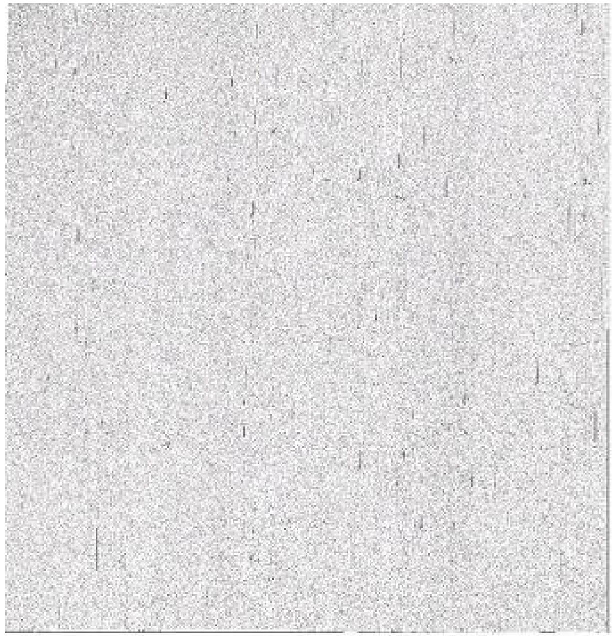
- **NGC 2784**



1st epoch



2nd 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 $\alpha = 0^\circ$ → Sculptor group

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

- Filter : B, V, I
- Exposure time : 60 sec each
- Number of images : ~950 / filter

  Till August : 350 min

  Total 950 min

  Background size : 512, 1024 px

KMTNet Supernova Program (KSP) – Newly found – a rapid evolving optical transient

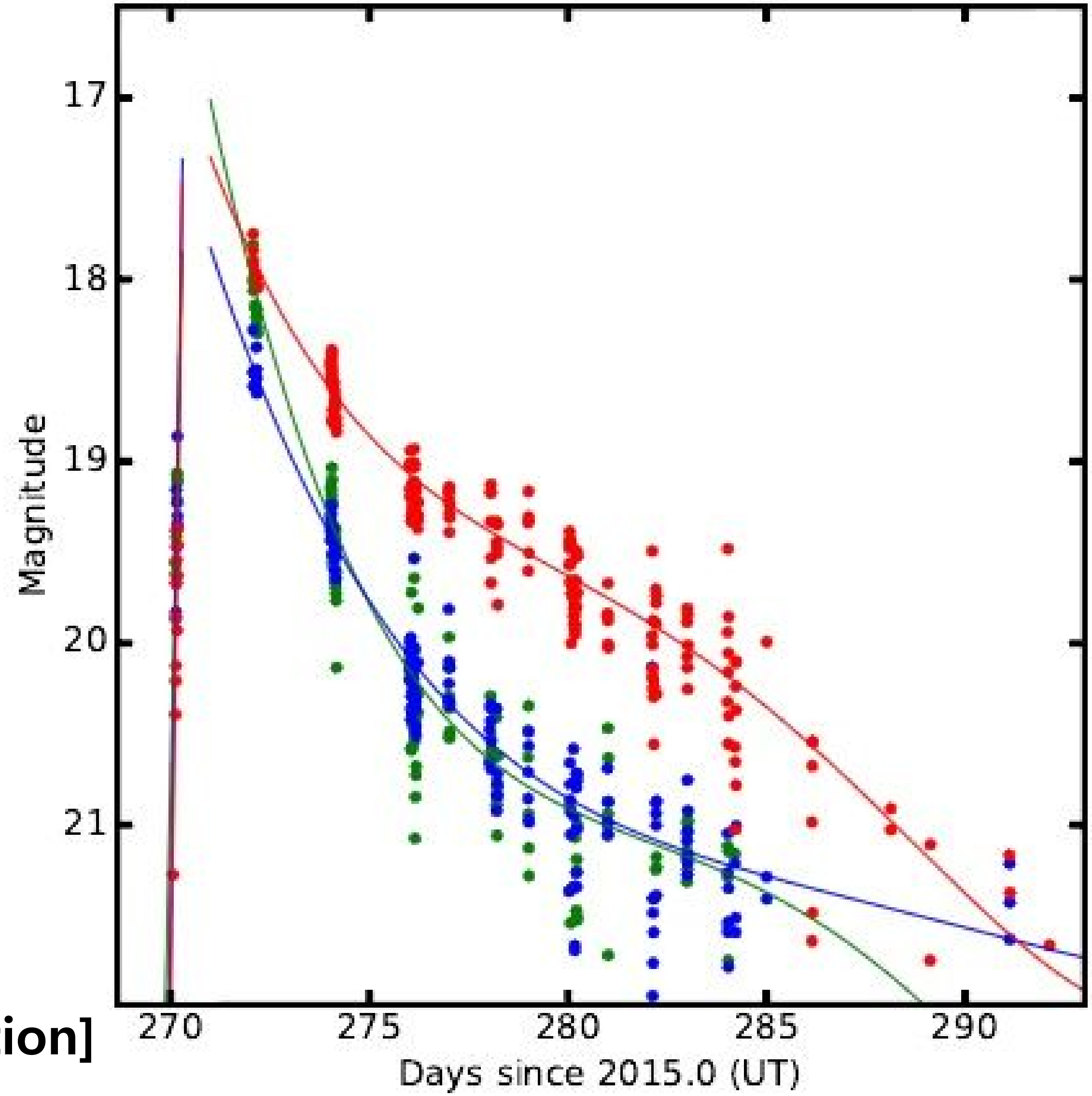
- High-cadence, three-bands

  B

  V

  I

- If our automatic transient identification system worked → identification would start at ~19.5 mag, i.e. a few hours after its onset



Antoniadis et al. [in preparation]

Moon et al. [in preparation]

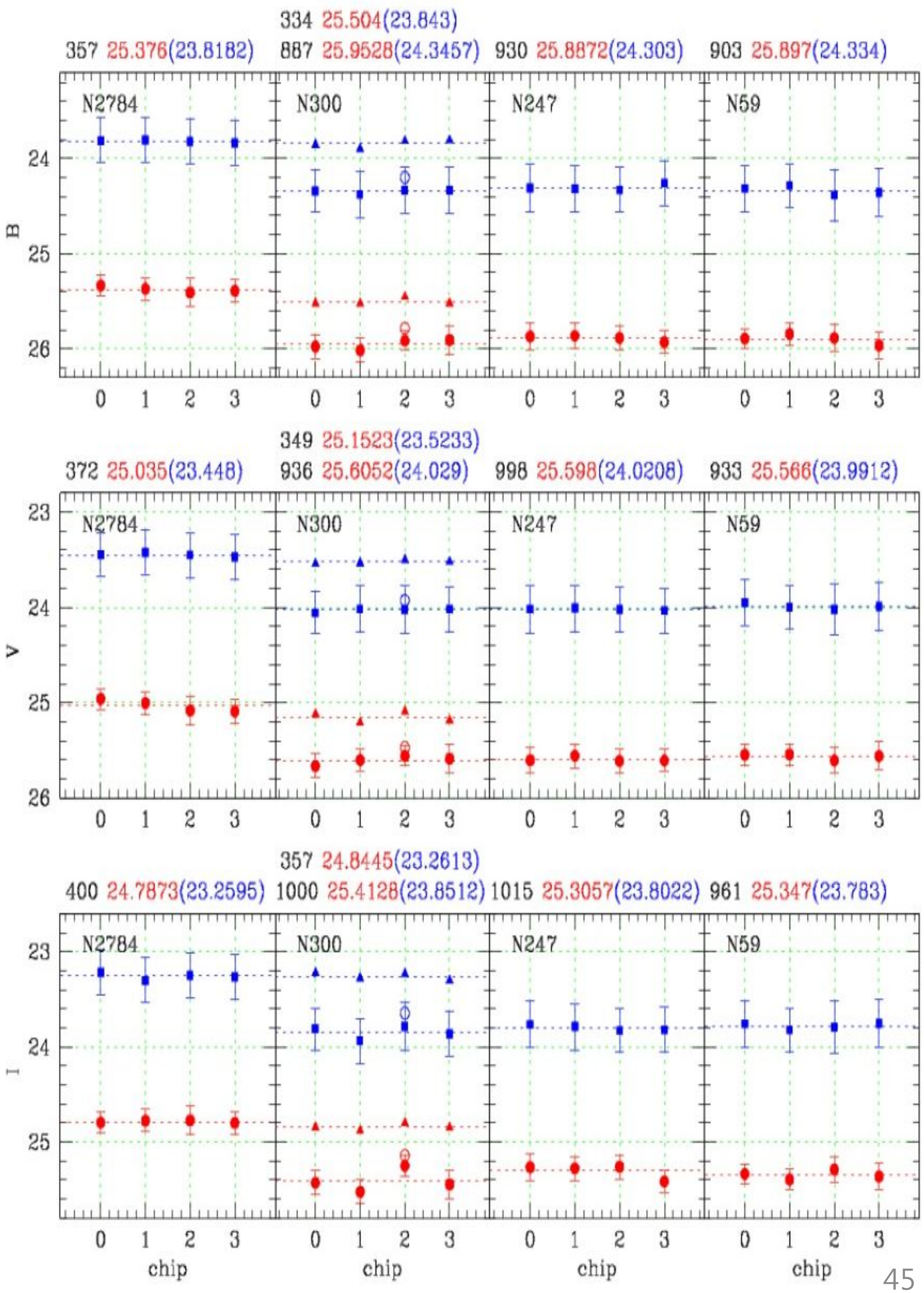
limiting magnitudes
N2784, N300, N247, N59

blue : mag error = 0.1 mag (10 σ)

	T_{exp}=900 min	T_{exp}=350 min
B	24.3 mag	23.8 mag
V	24.0 mag	23.5 mag
I	23.8 mag	23.3 mag

Red : mag error = 0.3 mag (3 σ)

	T_{exp}=900 min	T_{exp}=350 min
B	25.9 mag	25.4 mag
V	25.6 mag	25.1 mag
I	25.3 mag	24.8 mag

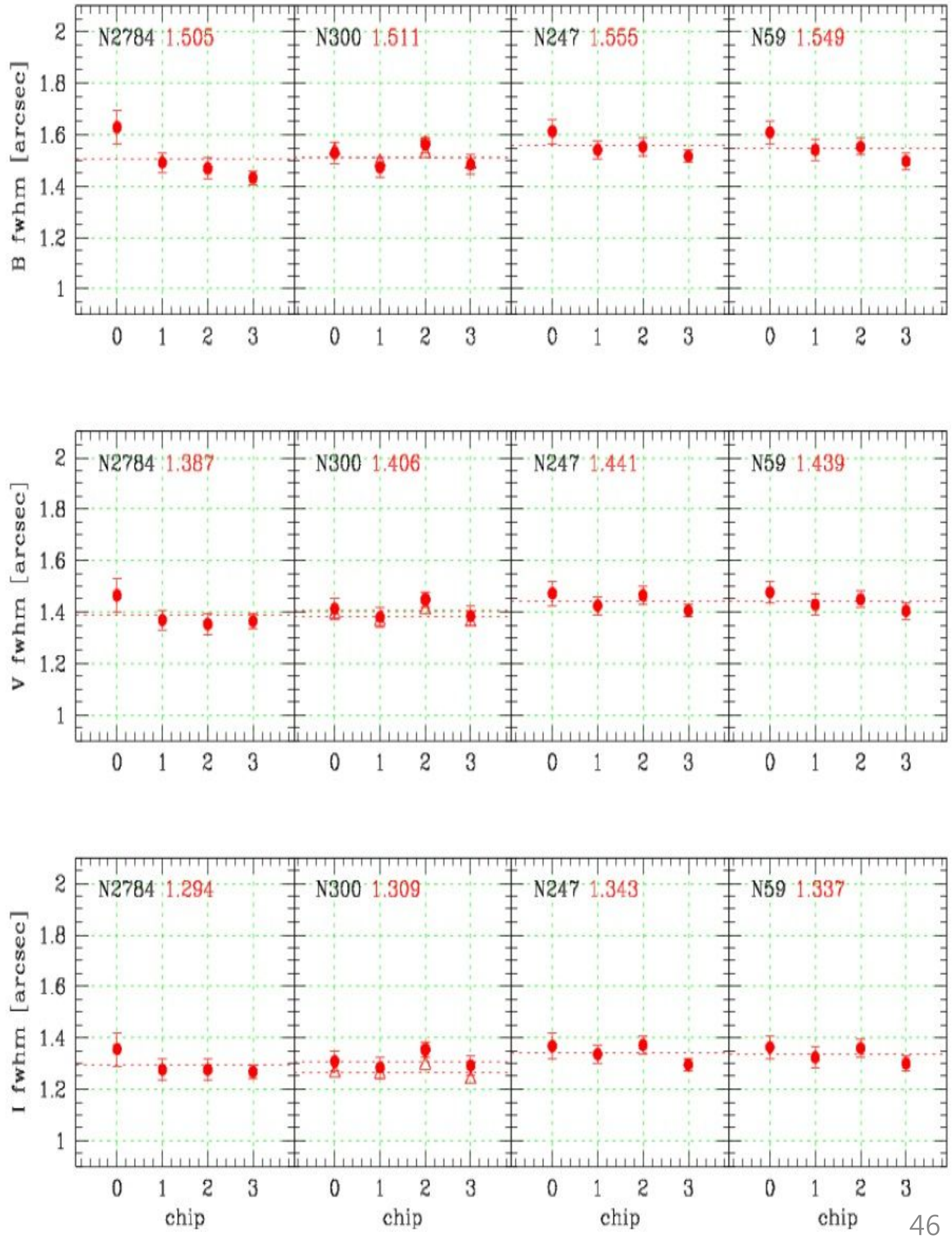


Seeing (FWHM)
N2784, N300, N247, N59

B : ~1.5"

V : ~1.4"

I : ~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

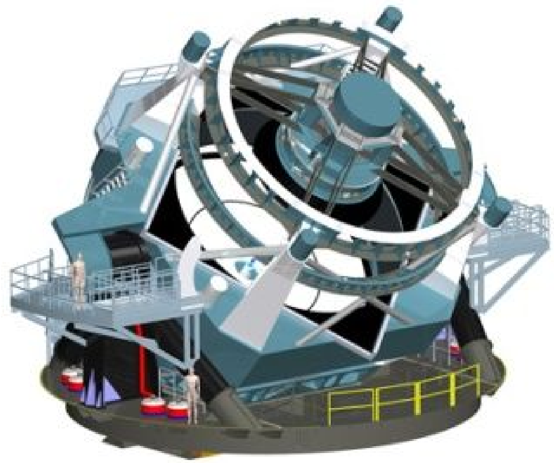
- Need more manpower…

- 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