

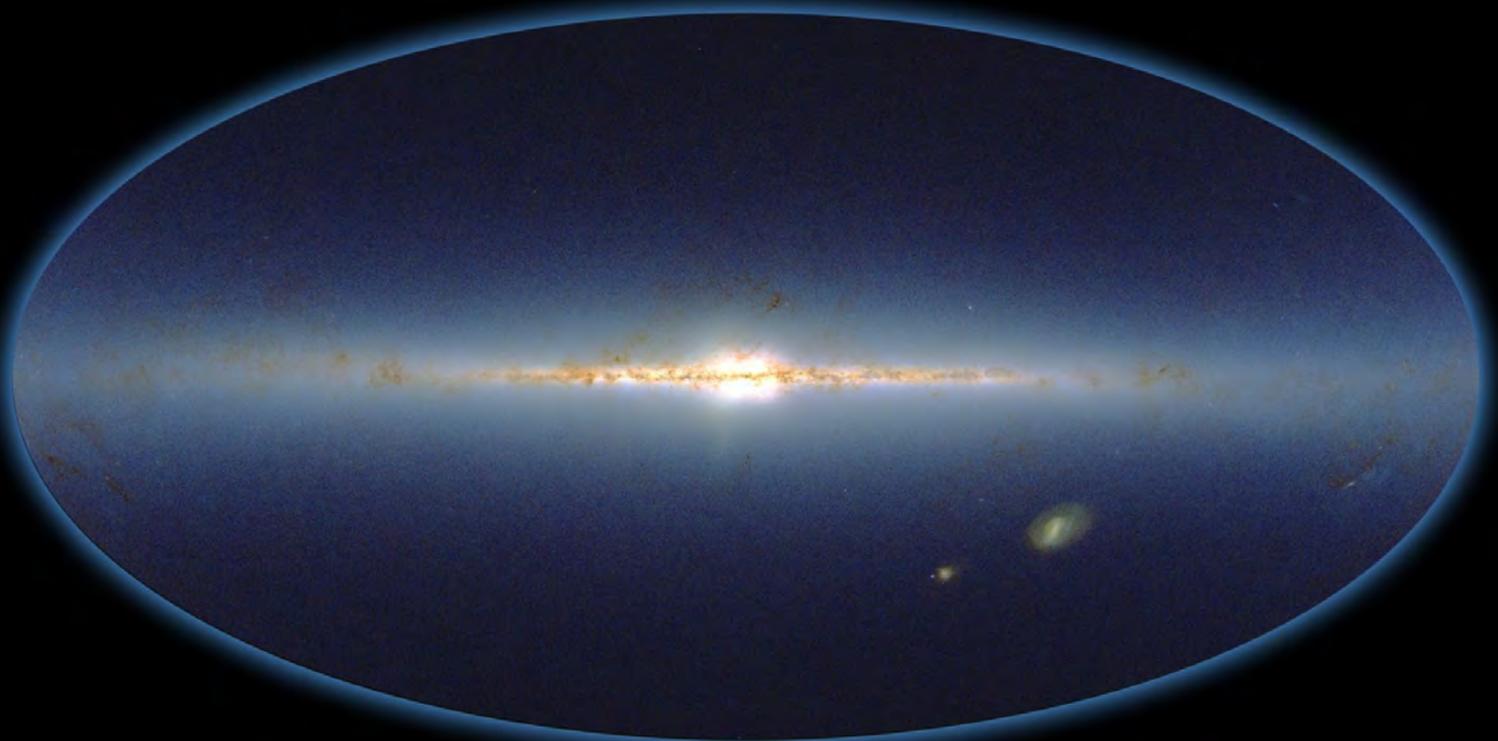
7-Dimensional Sky Survey (7DS)

A photograph of an astronomical observatory at night. The observatory has a white, dome-shaped structure with several telescopes mounted on its side. The background shows a dark, starry sky with the Milky Way galaxy visible, and a dark, forested hillside in the distance.

Myungshin Im
(Seoul National University)
2021-12-22

Astronomy in the past

2MASS Covers the Sky



The Two Micron All Sky Survey
Infrared Processing and Analysis Center/Caltech & Univ. of Massachusetts



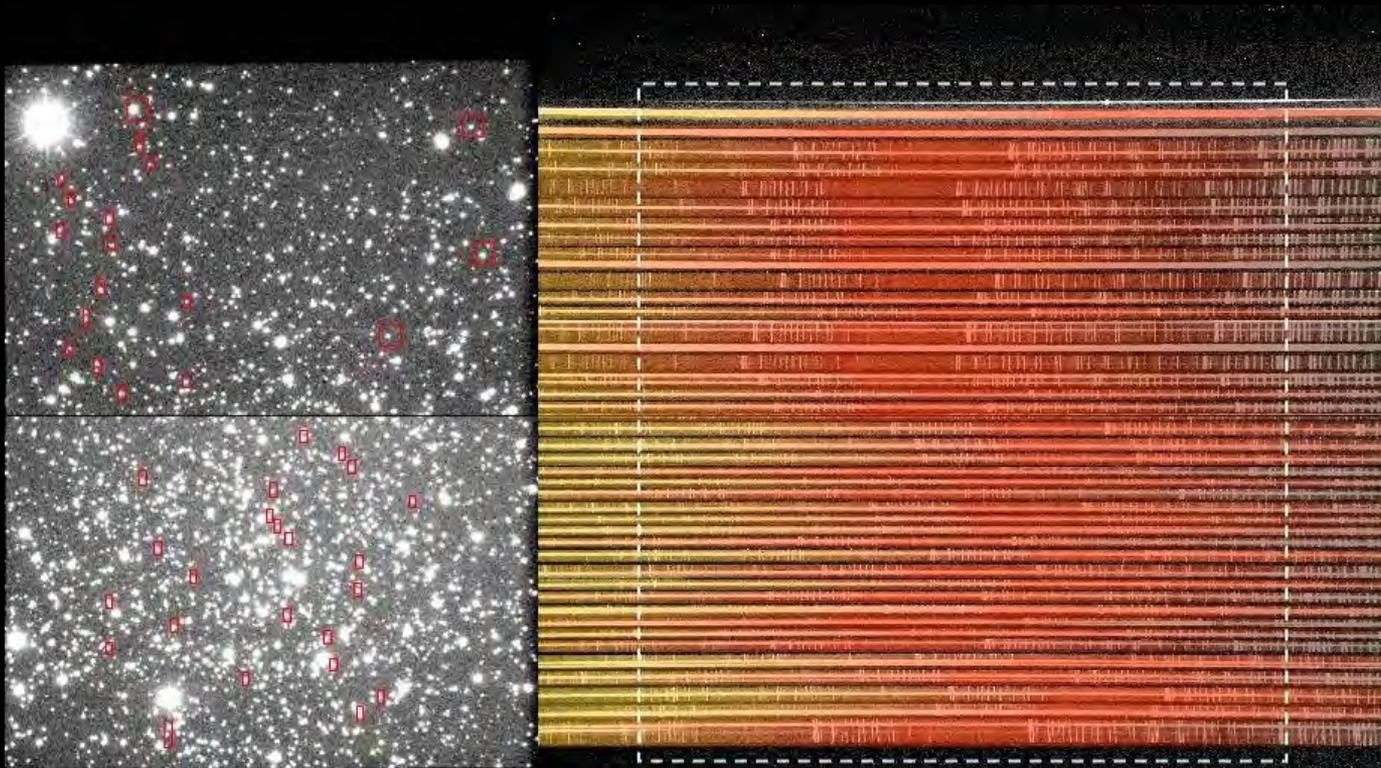
Progress in three areas in Astronomy

1. Time-domain Astronomy



Limitation: Wide-field time-series observations are done mostly with broad-band imaging, no spectroscopy

2. Multi-object spectroscopy



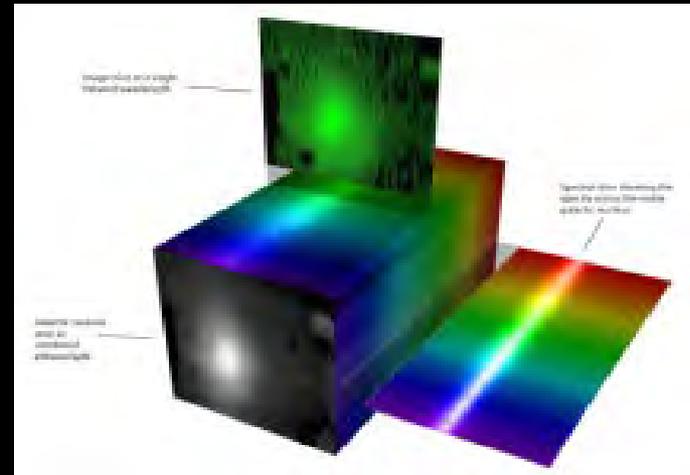
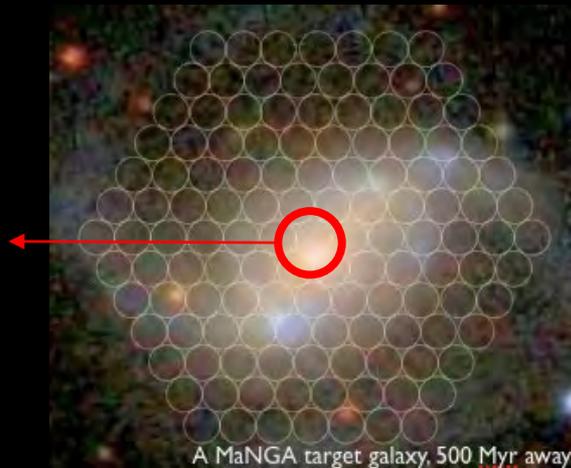
Keck Telescope

Limitation: Only a small portion of objects in FoV can be observed, observationally expensive for time-series studies

3. Spatially resolved spectroscopy (Integral Field Unit, IFU)

- ▶ Pixel-by-pixel spectroscopy
- ▶ Narrow field-of view

Spectrum
at each
point



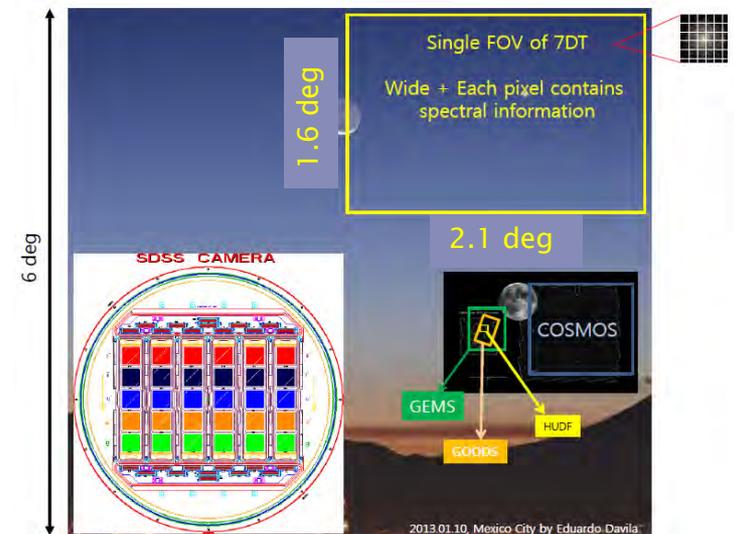
한계: Narrow-field (e.g., one galaxy)
Not practical for wide-field time-series observation

7-Dimensional Sky Survey(7DS)

Wide-field, time-series observation + Multi-object spectroscopy + IFU

7D?

- ▶ Brightness: 1D
 - ▶ RA & Dec (x, y): 2D
 - ▶ Distance: 1D
 - ▶ Wavelength: 1D
 - ▶ Radial velocity: 1D
 - ▶ Time: 1D
- Spectral movie of the universe



7-dimensional telescope, 7DT

- ▶ ~20, 0.5m telescopes
- ▶ Biggest multiple-telescope system in the world
- ▶ Medium-band filter for low resolution spectroscopy



7DS

– 3+ years, 3 surveys –

	Survey area (deg ²)	Cadence	Depth (1-epoch 5- σ , 475nm)	depth (5 years)	Exposure time per epoch/filter
Reference Imaging Survey	20,000 (SDSS, 15,000)	–	20 mag	–	3min
Wide-Field Survey (WFS)	1,620	14 days	20 mag	22..4 mag	3min
Intensive Monitoring Survey (IMS)	12.6	1 day	20 mag	23.9 mag	3min

Assumption: 1.5" seeing, 70% efficiency

Reference Image Survey (7DS RIS)

- ▶ 20,000 deg² coverage of the southern sky
- ▶ Include the galactic plane
- ▶ Survey duration: 160 nights = area coverage/efficiency/(area per night)
- ▶ Area coverage: 20,000 deg²
- ▶ Area per night: 113 deg² (assumes 9 hrs per night)
- ▶ Survey efficiency: 71%
- ▶ Cadence: one time observation (no repeating observations)
- ▶ Depth: 20 – 19 AB mag at 5-sigma (depending on the wavelength)

Wide-field Survey (7DS-WFS)

- ▶ Two week cadence survey of $1,620 \text{ deg}^2$ area of the sky (region not decided – AKARI Deep Field–South?)
- ▶ Survey duration: 5 year or more
- ▶ Area coverage: 1620 deg^2 (113 deg^2 every night)
- ▶ Cadence: 14 days (8 months coverage per region)
- ▶ Single epoch depth: 20 – 19 AB mag at 5-sigma (depending on the wavelength)
- ▶ 1 year stacked image depth: 21.5 – 20.5 AB mag
- ▶ 5 year stacked image depth: 22.4 – 21.4 AB mag

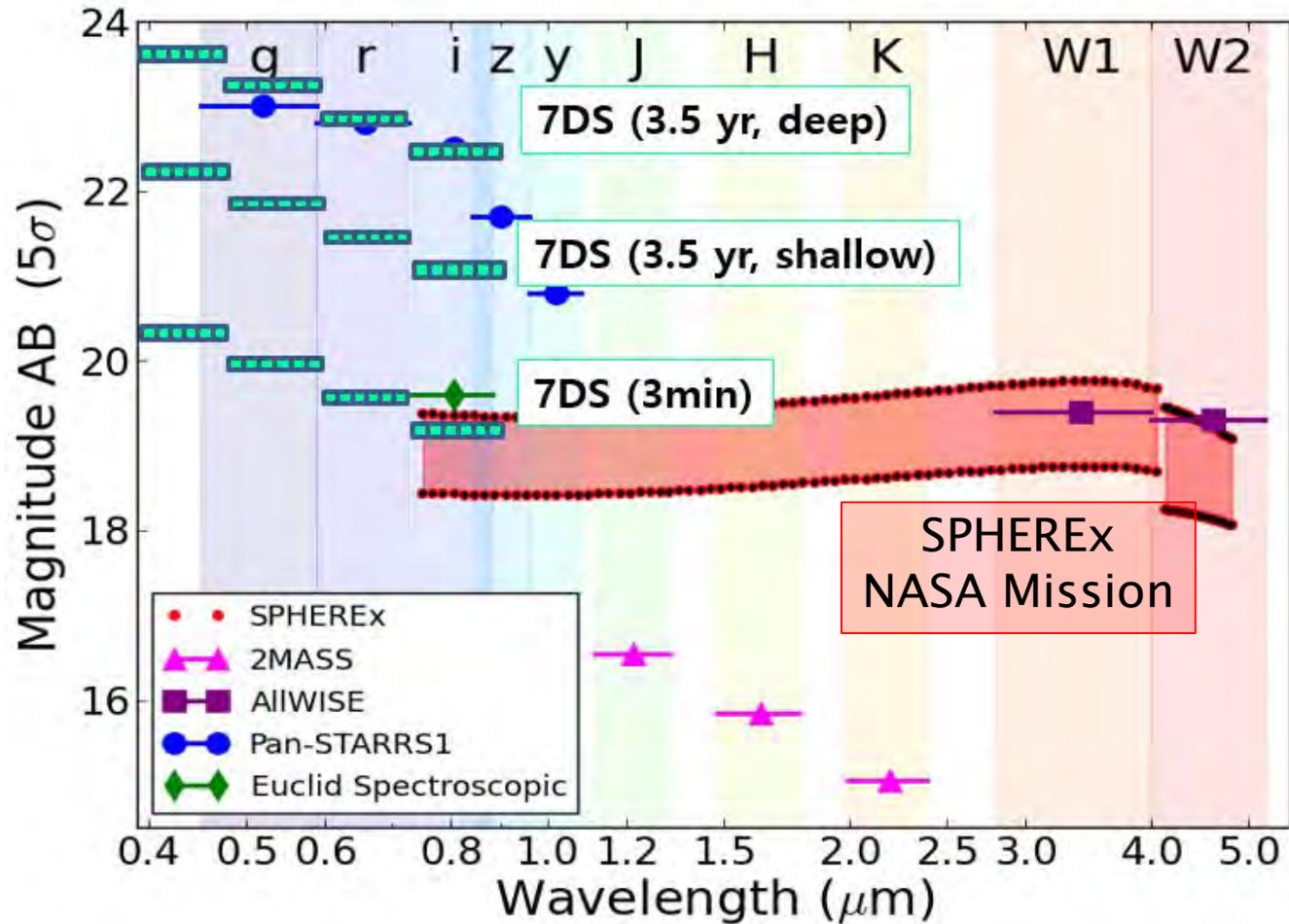
Intensive Monitoring Survey (7DS-IMS)

- ▶ Daily monitoring of a small area of the sky
- ▶ Survey field: AKARI Deep Field? (TBD)

- ▶ Survey duration: 5 year or more
- ▶ Total area coverage: 12.6 deg^2
- ▶ Area per night: 12.6 deg^2 (assumes 1 hr per night)
- ▶ Survey efficiency: 71%
- ▶ Cadence: every night
- ▶ Single epoch depth: 20 – 19 AB mag at 5-sigma (depending on the wavelength)
- ▶ 1 year depth: 23 – 22 AB mag at 5-sigma
- ▶ 5 year depth: 23.9 – 22.9 AB mag at 5-sigma

7DS Depth

7DS Detection Limits



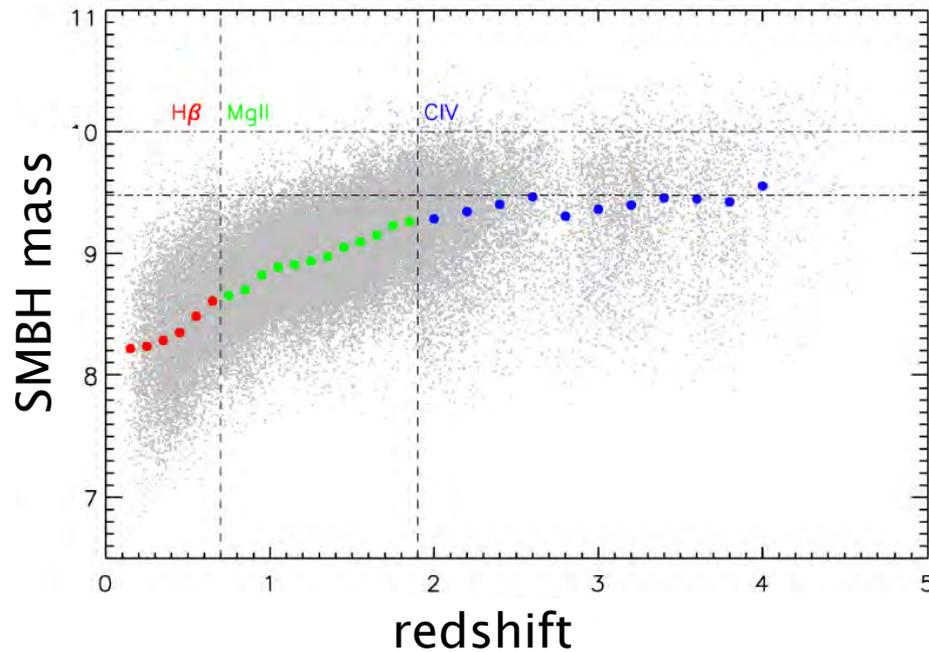
7DS Research Topics

1. Supermassive black holes & AGN
2. Cosmology
3. Galaxy evolution
4. Multi-messenger astronomy
5. Stellar population/our galaxy
6. Transients (SNe, TDE, etc)
7. Solar system objects

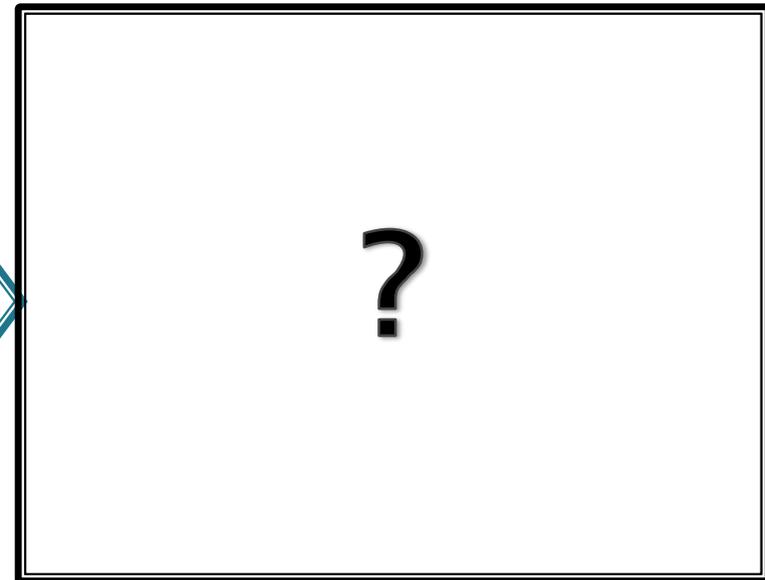
7-Dimensional Sky Survey Scientific Cases Document
<http://astro.snu.ac.kr/~mim/7ds.html>

1 M quasars discovered, but only 100s direct SMBH masses

SMBH mass from
Single-epoch method



SMBH mass from
Reverberation mapping

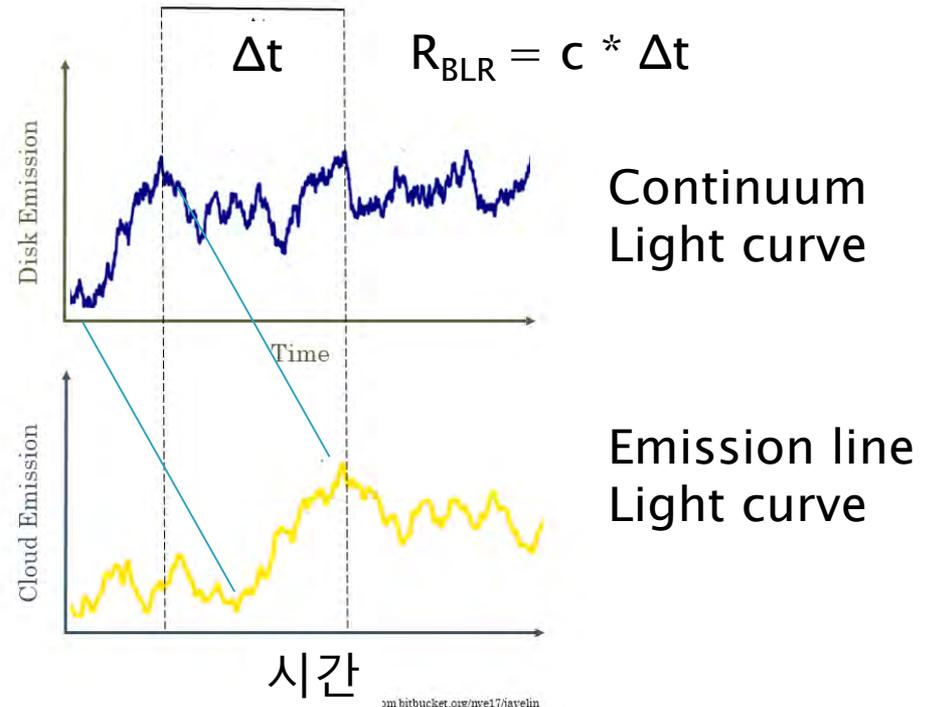
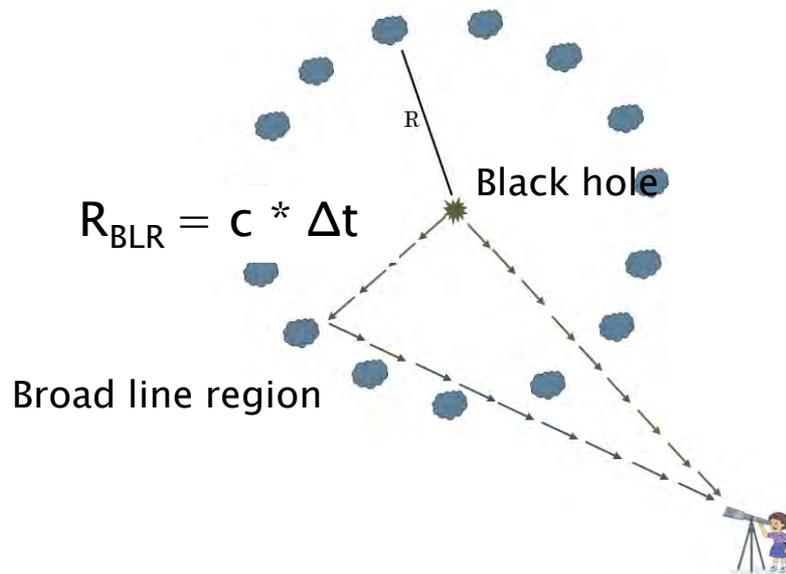


Shen et al. (2008), Jun et al. (2015) ..

Reverberation mapping

- ▶ Continuum + emission line light curve time lag $\Delta t \rightarrow R_{\text{BLR}}$
- ▶ Broad line width $\rightarrow \Delta V$

$$M_{\text{BH}} = f \frac{\Delta V^2 R_{\text{BLR}}}{G}$$

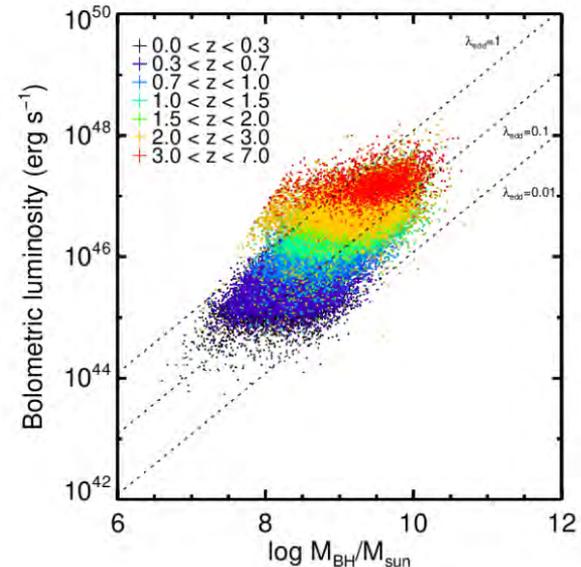
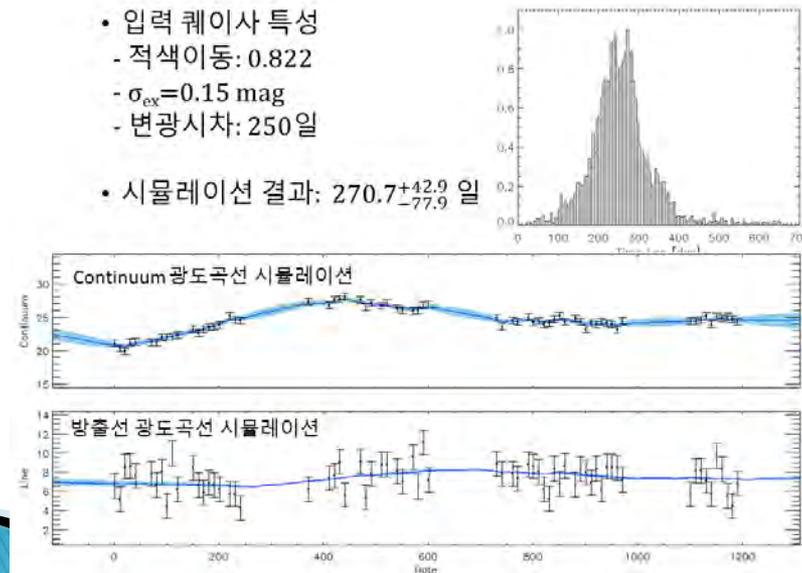


Time lag: months- years \rightarrow
 14 day cadence needed

7DS SMBH Study

- ▶ Time lag: months ~ years
- ▶ 7DS: Emission line and Continuum variability can be traced separately
- ▶ Variability 0.04 – 0.1 mag quasars time lag at <30% error (T-L relation intrinsic scatter의 40%)

Spectral variability for $>0.1 M$ quasars SMBH RM mass for $>10,000$ AGNs ($0 < z < 4$)



1. Spectral variability of $> 100,000$ and RM-based mass for $> 10,000$ AGNs

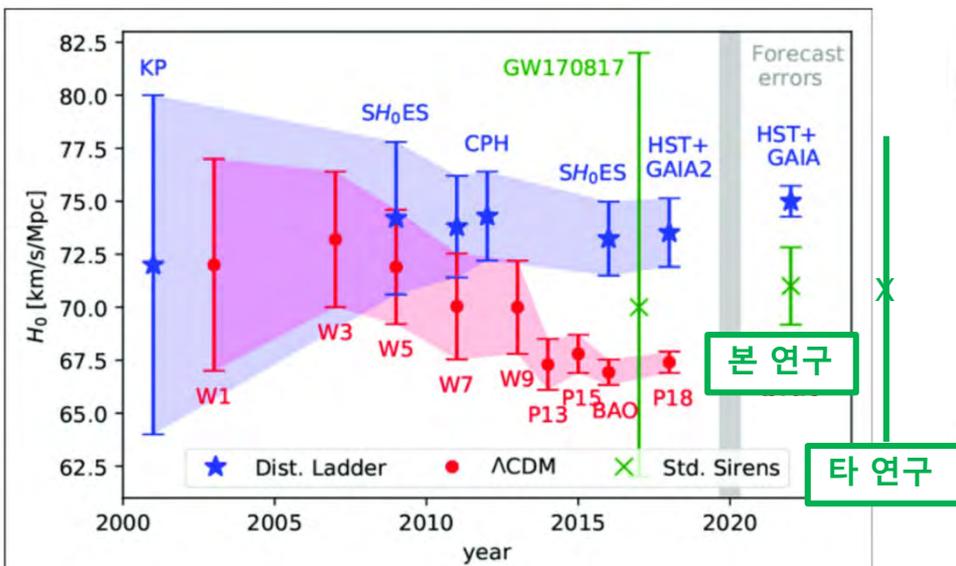
▶ $> 10x$ better than future surveys

	SDSS-V (2022?-2027)	4MOST (2022?-2027)	DESI (2020-2025)	7DS (2022-2025)
# of AGN spectra	400,000 ($i < 21.5$ mag)	1,000,000 ($r < 22.8$ mag)	2,400,000 ($r < 22.7$ mag)	600,000 ($r < 22.3$, stacked)
Spectral Variability sample	25,000	30,000 ($R < 22.8$ mag)	-	$> 100,000$ ($r < 20$ mag)
SV Cadence	Months	6 month	-	10 days
Reverberation Mapping sample	1,500 ($i < 20$ mag)	700 ($r < 22.8$ mag)	771 (OzDES)	$> 10,000$ ($i < 19$ mag)
RM cadence	~10 days	14 days	-	10 days
Survey area	All sky	10,000 deg ²	14,000 deg ²	10,000 deg ²
Spectral resolution	2,000	6,500	2,000 – 5,000	40

2. Cosmology

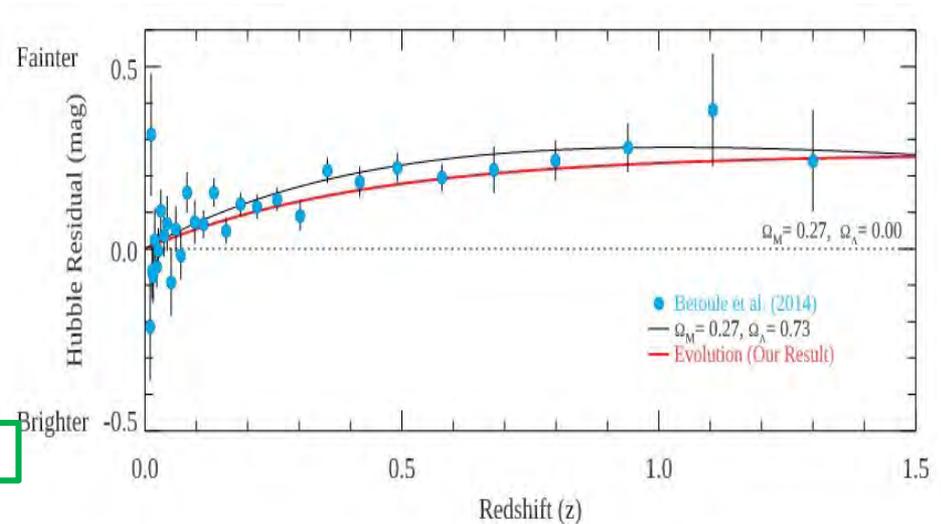
- ▶ Quasar: T-L relation, UV vs X-ray luminosity
- ▶ GW sources: Standard Siren
- ▶ Galaxy clusters, BAO
- ▶ Hubble constant at different redshift bins
- ▶ Cosmological parameters at a few % accuracy or better?

Hubble Tension



Ezquiaga & Zumalacarreui (2018)

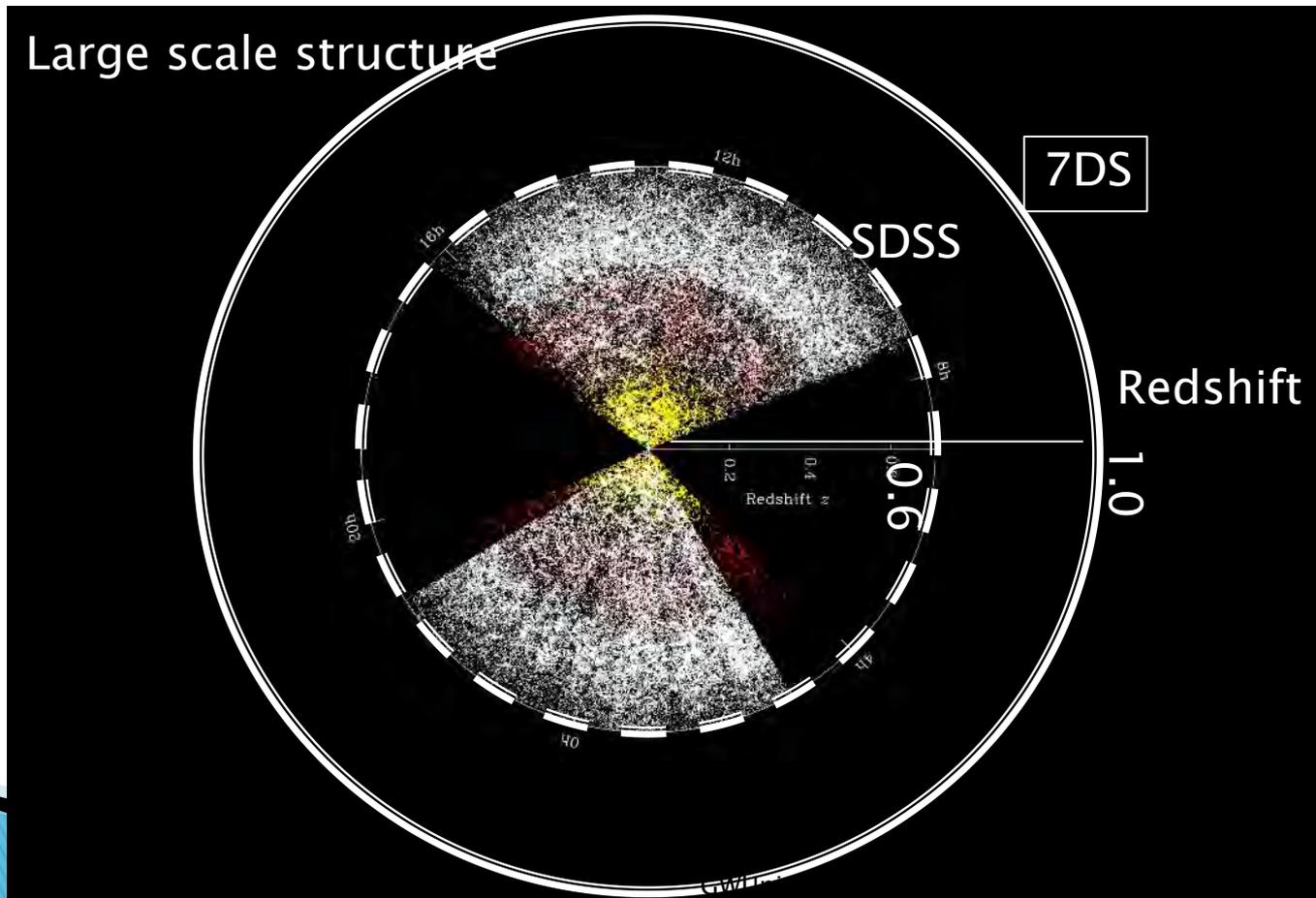
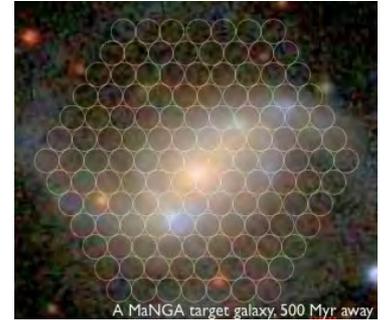
Dark energy controversy



Kang, Lee, YW, et al. (2019)

3. Galaxy evolution

- ▶ Galaxy redshifts at 0.3–1% accuracy
- ▶ Large scale structures up to $z \sim 1$
- ▶ Environmental–dependent evolution
- ▶ Spatially resolved stellar population for 10M galaxies





4. Multi-messenger Astronomy

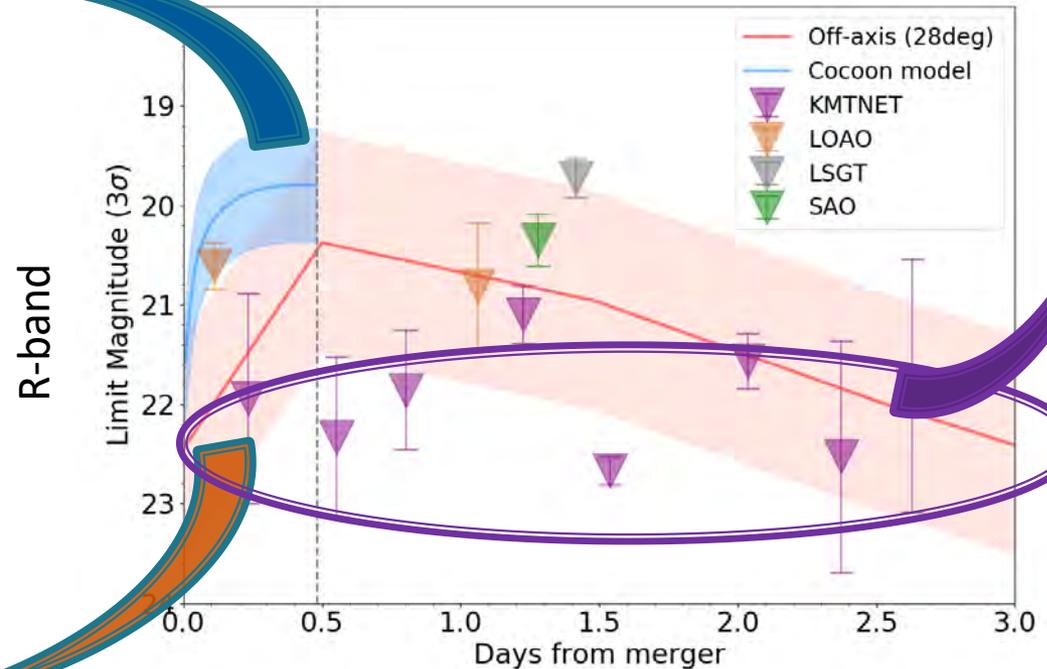
Rapid identification of tens of Kilonovae during LIGO/Virgo O4, O5 run

- 7DT: Sensitive for ~ 150 Mpc events



Structured Off-axis Jet

Cocoon

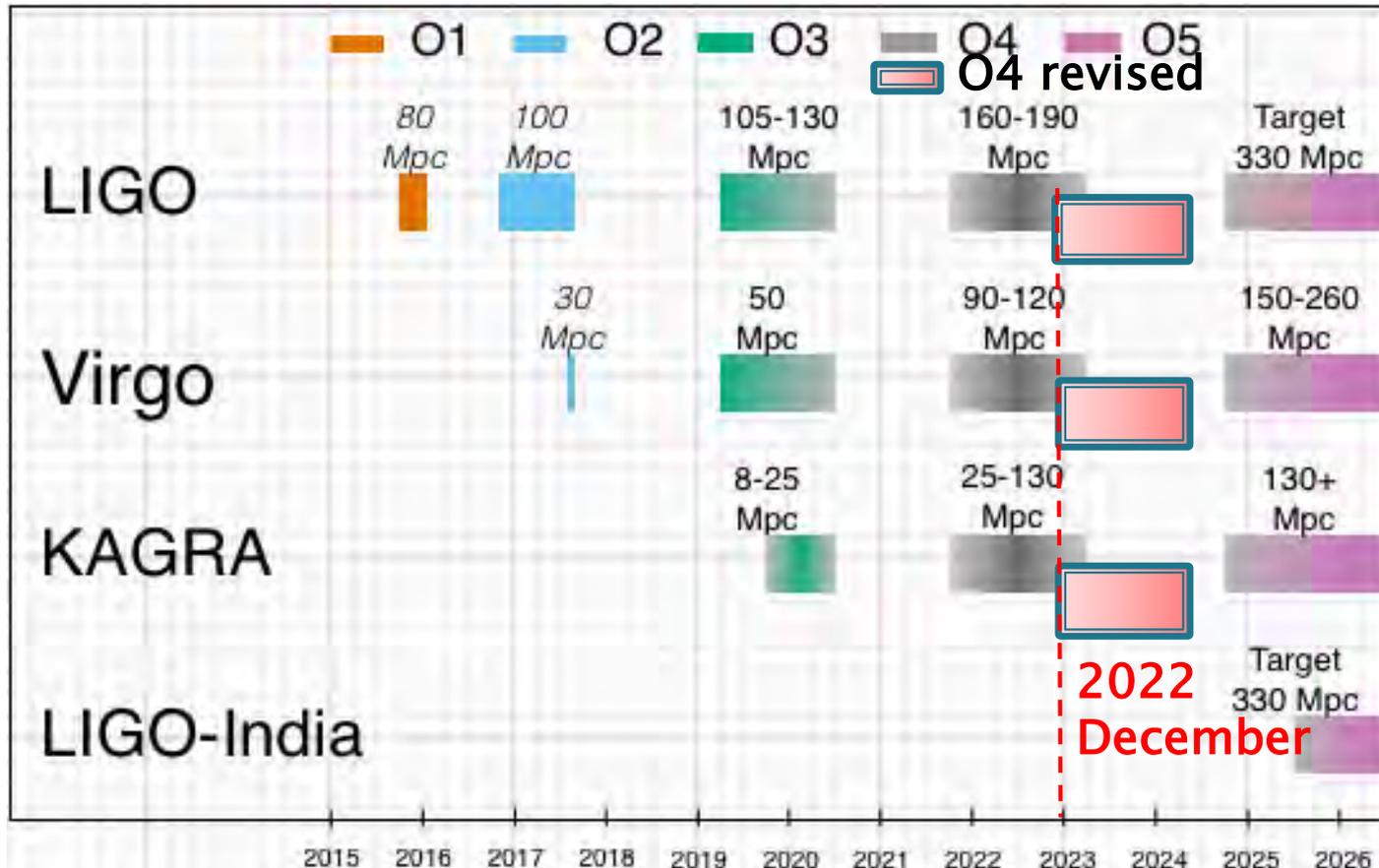


What KNe model is right?

Paek, Im+ 2020, Kim, Kim+ 2020

GW Astronomy: O4 run in late 2022

Hundreds of GW events are expected per year



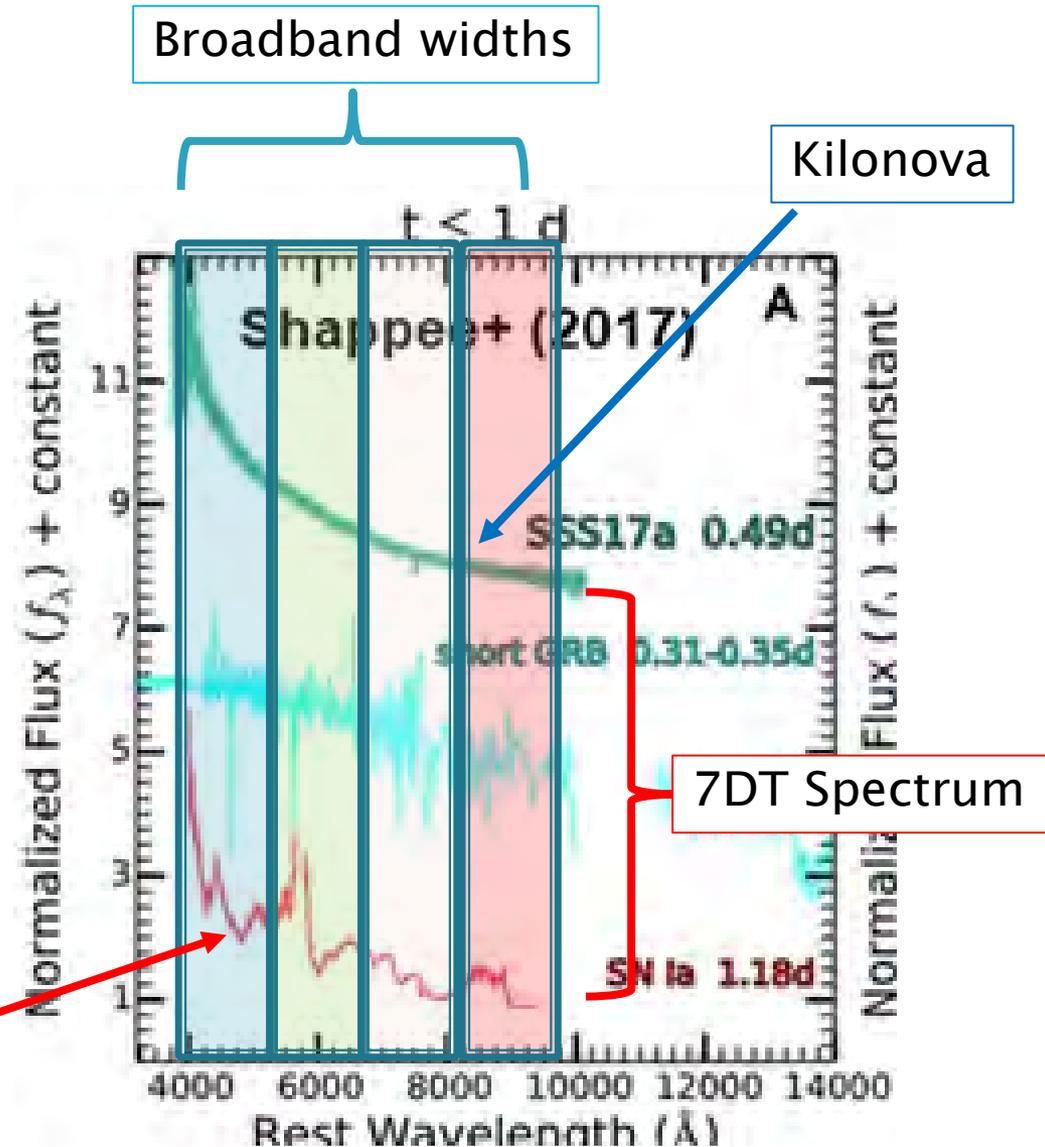
Current limitations of MMA: only one EM counterpart discovered for GW events so far

- ▶ Poor GW source localization ($> 10^{\circ}$'s deg^2)
 - ▶ EM counterparts (kilonovae, KNe) are faint and becomes fainter fast
 - ▶ Too many transients/artifacts in a wide field of view
- ➔ Need for a wide-field telescope that can catch KNe fast

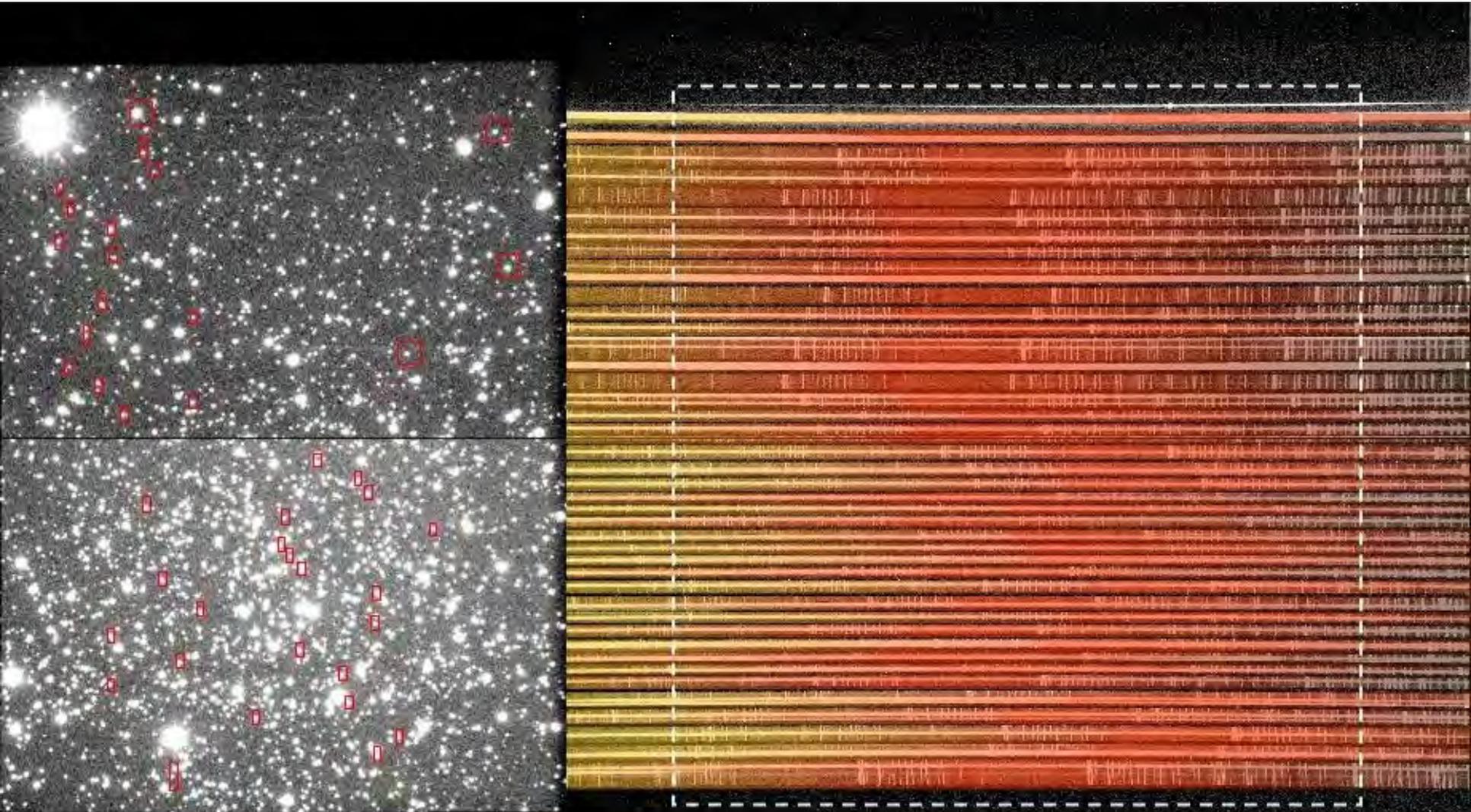
Wide-field telescope with 7DT-like capability can identify KNe fast

With Medium-band,
It is possible to distinguish SNe from
kilonovae (EM
counterpart for GW
sources)

Supernova

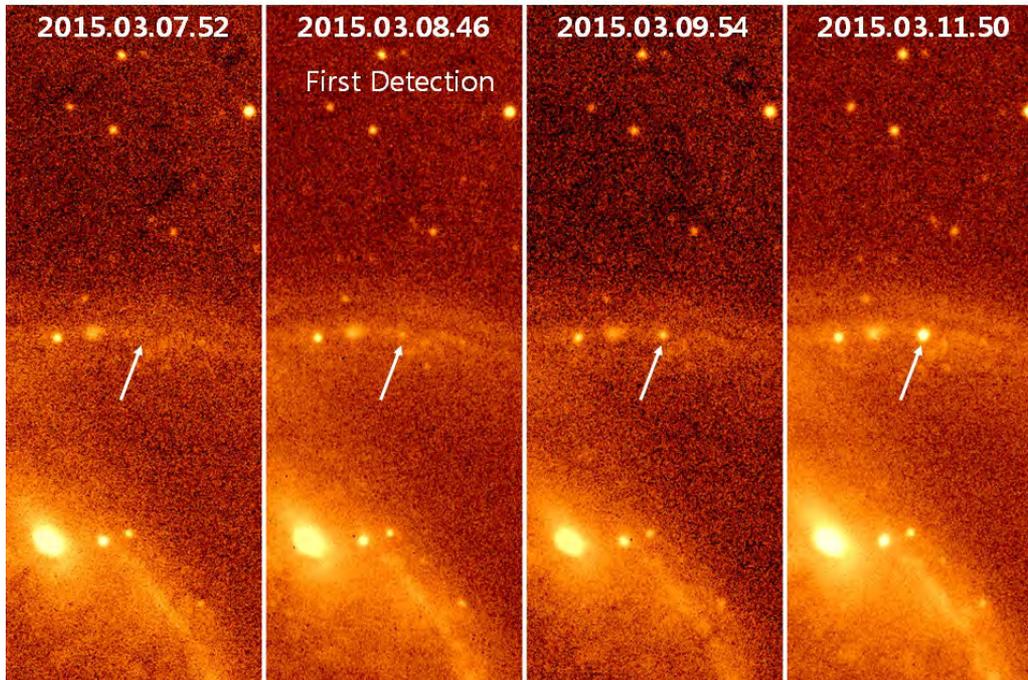


5. $\sim 10^9$ Stellar spectra for stellar population study

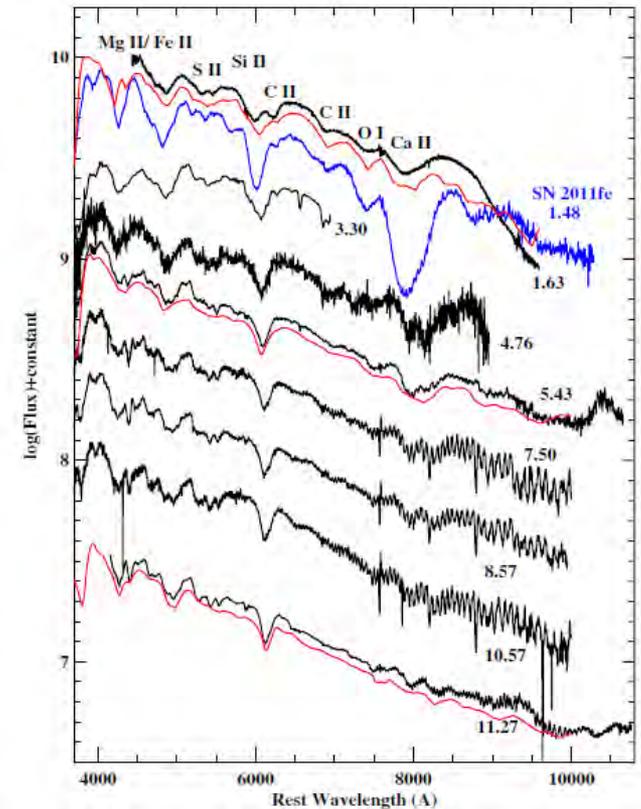


6. Transients (SNe, GRB, TDE, Changing look AGNs)

Emergence of SN 2015F in NGC 2442



Im, Choi, Yoon et al. (2015)

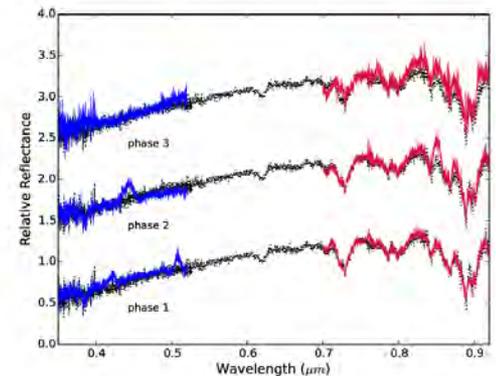
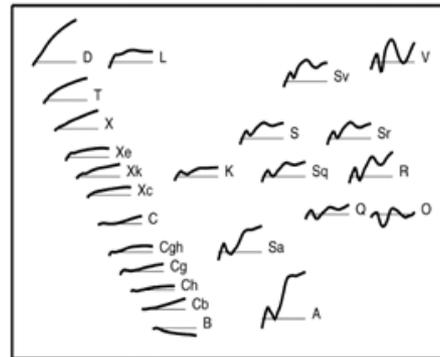
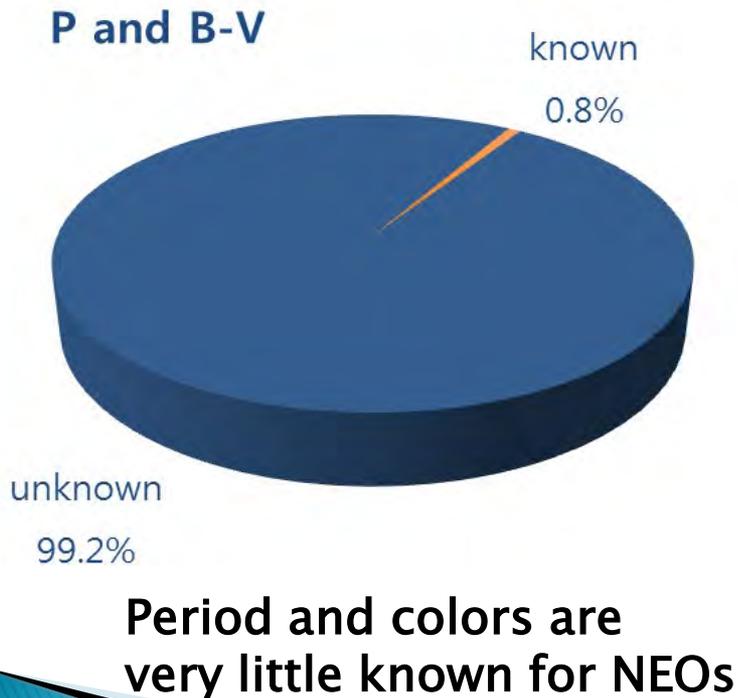


Zheng et al. (2013)

- ▶ Early spectra tell us about the progenitor star properties (chemical composition, star size, ..)

7. Solar system objects

- ▶ Comets, Asteroids, etc: key for understand the formation and evolution of the solar system
- ▶ > 10,000s time-series spectra for comets, asteroids



- Spectral classification based on only 371 objects
- Spectra can tell us the composition and surface history of asteroids

7-dimensional sky survey

- ▶ AGN, quasars, galaxies, cosmology, solar system objects, supernovae, stars, etc

Subject	Now	7DS	Scientific value
Time-series spectra of quasars	~1,000	100,000	Complete census of SMBH AGN variability
RM measurement of BH mass	~100	10,000	Growth history of SMBHs
IFU spectra of galaxies	~10,000	50,000,00	Galaxy evolution
Galaxy clusters/superclusters	100,000	100,000	Cosmology, galaxy evolution
Early spectra of supernovae	~10	>1,000	Physical mechanism of Sne
Time series stellar spectra	1,000,000	1,000,000,000	Stellar evolution
Time-series spectra of small bodies of solar system	100	>10,000	Origin of the solar system, census of asteroids/comets

Collaboration possibilities

- ▶ SPHEREx
- ▶ KMTNet
- ▶ Scientific collaboration
- ▶ Infrastructure (hardware, software, database)

7-Dimensional Sky Survey (7DS)

- ▶ First spectral time-series wide-field survey of the sky
- ▶ Participation framework is being formulated → participation is welcome



7DS Fields?

