7-Dimensional Telescope & 7-Dimensional Sky Survey

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(Seoul National University)
2021-12-22

Scope of the workshop

▸ 7DT & 7DS Introduction

▸ 7DT/7DS Science Case Exploration

▸ Invitation for collaboration

▸ Discuss survey strategy, etc

- Presentation/Discussion in Korean or English
- We will ask speakers to provide their presentation files

History

- 2014-2015 incubation of ideas

- 2016. 2 : SRC proposal → succeeded, but failed, long story

- 2020: resurrection of the project

- 2021: 7DT project approved as a part of GWUniverse initiative

Project

- 과학난제도전 융합연구사업
  - 중력파우주연구단(PI: Hyung Mok Lee, SNU)
    Center for the GW Universe (GWUniverse)

- 4.5 year (2021 – 2025), 90억 원

- Cosmology with Multi-Messenger Astronomy and Artificial Intelligence

- 2 Subgroups
  - GW Cosmology (Hyung Mok Lee, Chunglee Kim, A. Shafieloo)
  - EM Counterpart with AI (M. Im, Jaehun Jung, Z. Lucas Uhm)

Collaborators

GWUniverse	7DS
Hyung Mok Lee (SNU) Myungshin Im (SNU) Arman Shafieloo (KASI) Chunglee Kim (Ewha W. U) Jae-Hun Jung (Postech) Z. Lucas Uhm (KASI)	Changbom Park (KIAS) Sung-Chul Yoon (SNU) Yong-Ik Byun (Yonsei U) Jeong-Eun Lee (Kyunghee U) Hyunjin Shim (Kyung-pook N.U) Minjin Kim (Kyung-pook N. U) Soojong Pak (Kyunghee U) Yujin Yang (KASI)

7-Dimensional Telescope, 7DT

- Multiple telescope system with ~20 small telescopes
- The multiple telescope system in the biggest scale
- Medium-band filter for spectroscopy over the whole FoV

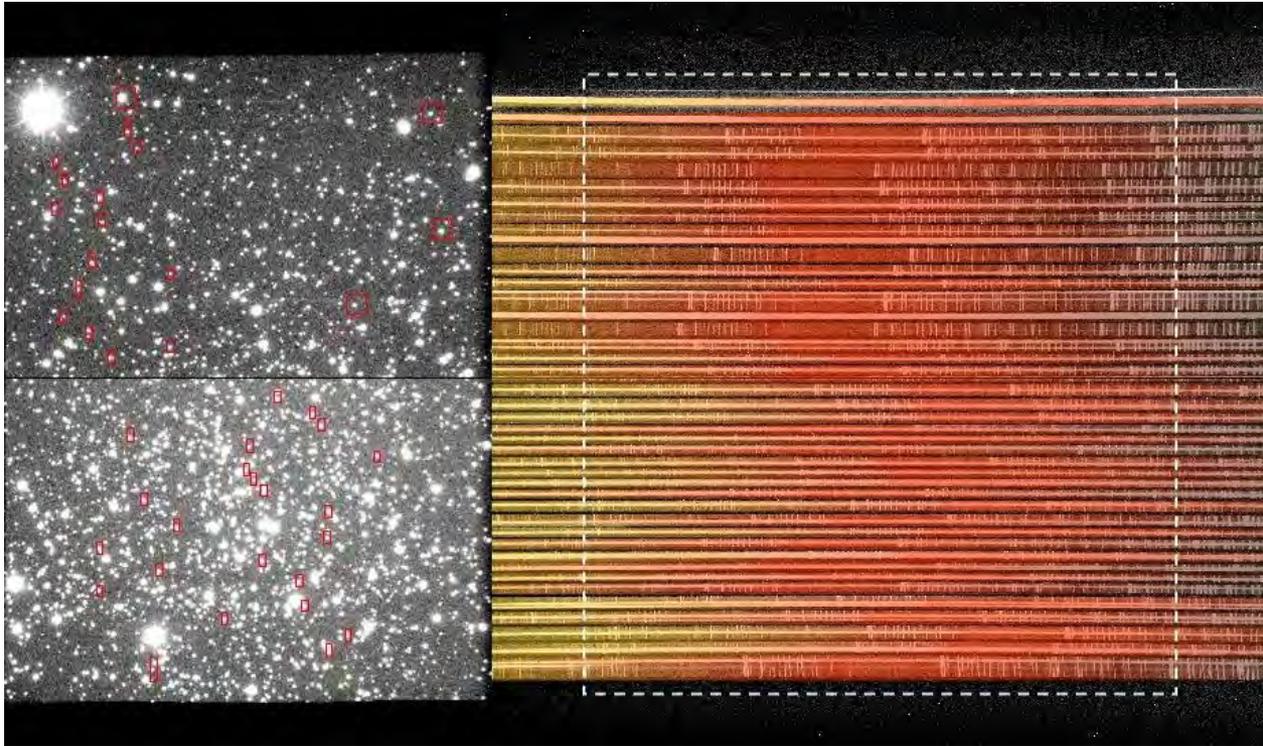# Why 7D?

- X, Y, Z (3D)
- Time (1D)
- Flux (1D) at a wavelength (1D)
- Radial velocity (1D)

- The telescope explore the universe in 7-dimensional parameter space

- Wide-field, time-domain, IFU telescope

We get spectra for everything in a wide field of view and study their time evolution

The first survey of this kind – 60M spectra in one shot

▸ 60M spectral movie of the Universe

~3000 Astronomers worked on GW170817, the first case of GW
EM counterpart: Cosmology, Stellar Evolution, Galaxy Evolution,..

2017-08-17 12:41:04 UTC
라이고 및 비르고 중력파 신호 포착

+2초 후
페르미 및 인티그랄 감마선 신호 포착

KMTNet(서울대/한국천문연구원)

+약 11시간 후
칠레 천문대 망원경들이
가시광선 신호 포착

+약 21시간 후
국내연구진 호주 이상각망원경으로
추적관측시작. 이후 약 4주간 추적관측
(KMTNet, BOOTES-5망원경 등)

+약 9일 후
찬드라 우주망원경
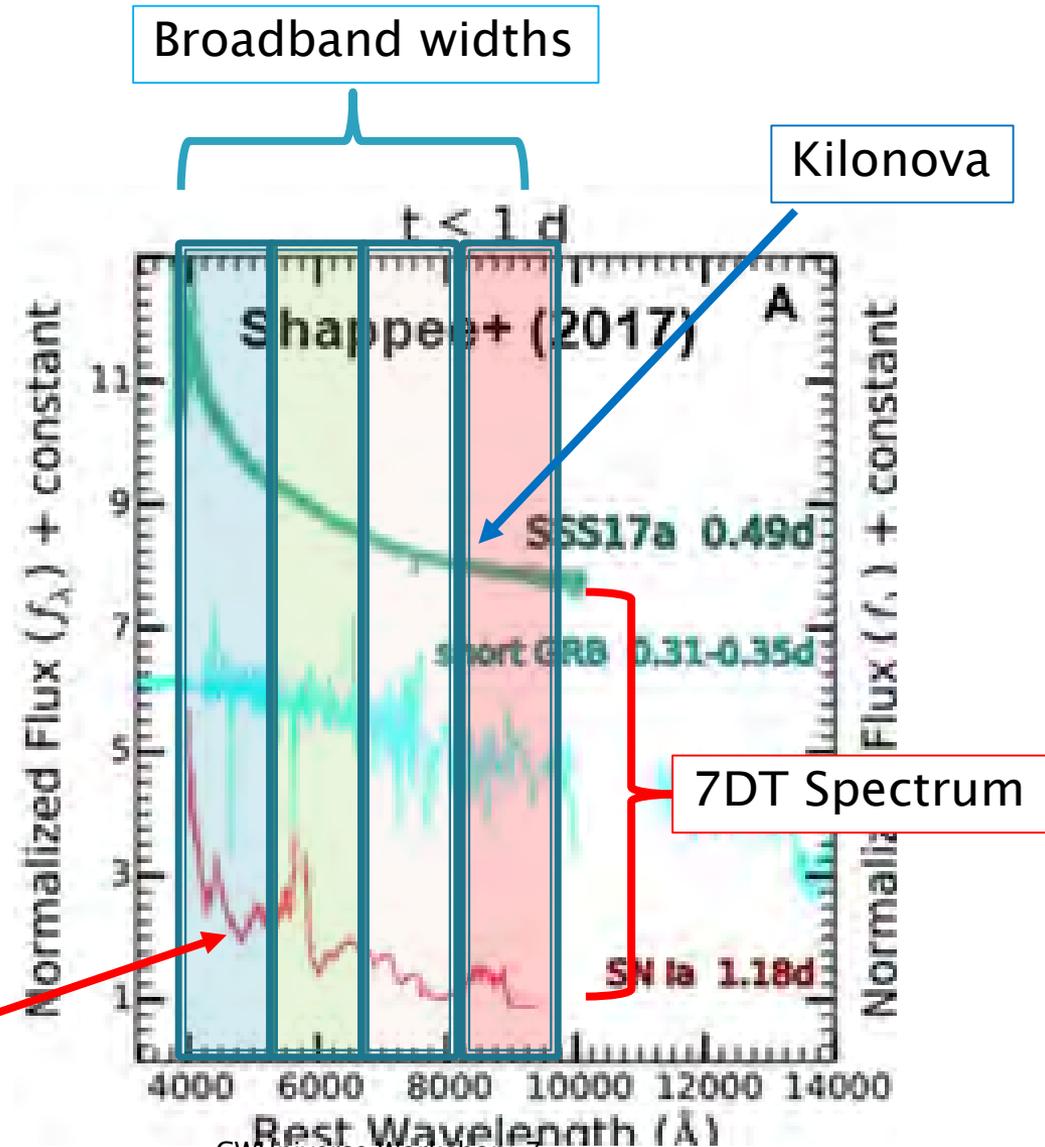X-선 신호 포착

+약 16일 후
지상 전파망원경
전파 신호 포착

그림출처: LIGO, NASA, 1M2H/UC Santa Cruz and Carnegie Observatories/Ryan Foley,
서울대/한국천문연구원/임명신, NSF/Sonoma 주립대/A. Simonnet, NRAO

서울대학교 초기우주천체연구단
(임명신)

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

- Poor GW source localization (>10'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

Broadband widths

Kilonova

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

7DT Spectrum

Supernova

t < 1d

Shappee+ (2017)

SSS17a 0.49d

short GRB 0.31-0.35d

SN Ia 1.18d

Normalized Flux (f_λ) + constant

Rest Wavelength (Å)

4000 6000 8000 10000 12000 14000

7DT

▸ 20, 0.5-m wide-field telescopes

▸ High precision telescope mount

▸ 60M to 150M pixel BI CMOS camera (3.76 micron)

▸ 40 medium-band + 2-3 broad band

7DT Specification

- 20, 0.5m, f/3.0 telescopes
- Effective diameter: ~2.3m
- FoV: 1.4 – 2.8 deg^2
- Maximum FoV: 28 – 56 deg^2
- Pixel size: 0.51 – 0.65 arcsec
- Limiting mag: 20.2, 19.8, 18.9 AB mag @ 425, 675, 825 nm (5-sigma, point source, 3min)
- Seeing: 1–1.5 arcsec
- 40 medium-band + 2 broad-band(g, r)

Each telescope observe the sky at two wavelengths

40 Medium-band filter

- 2 filters x 20 telescopes = 40 passbands
- Passband width: 20nm (vs broad-bands 150nm)
- Wavelength interval: 10nm
- R ~ 40 low resolution spectroscopy
- Obtain spectra for all the pixels

MB vs BB
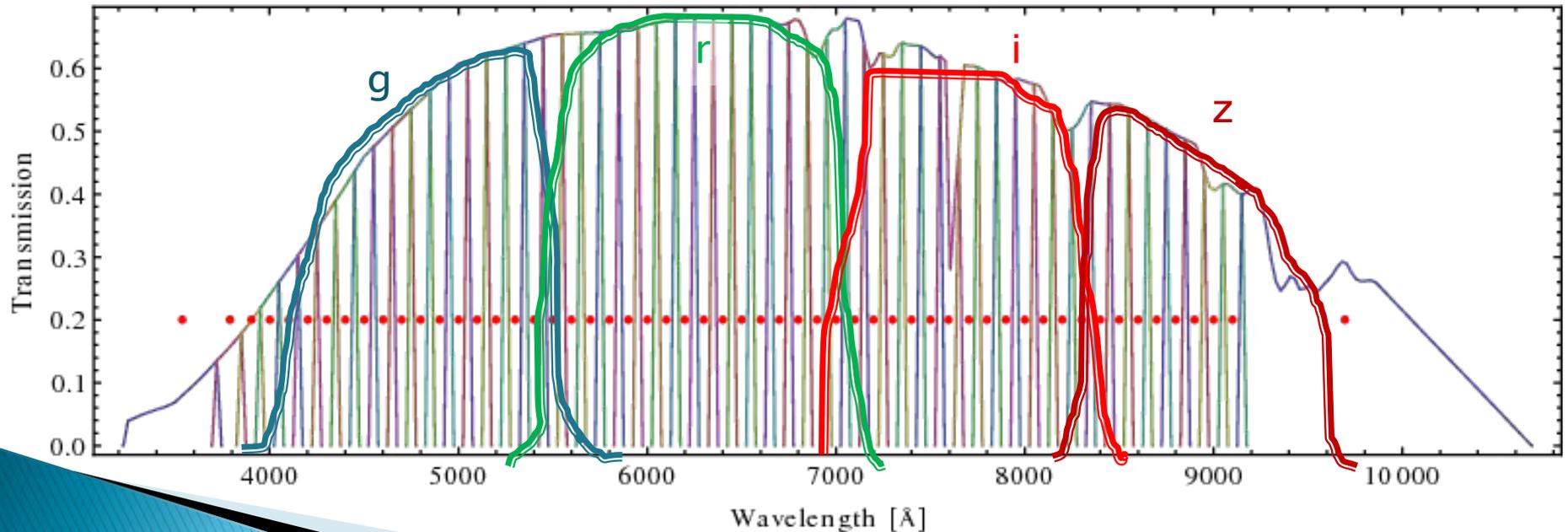
MB spectrum
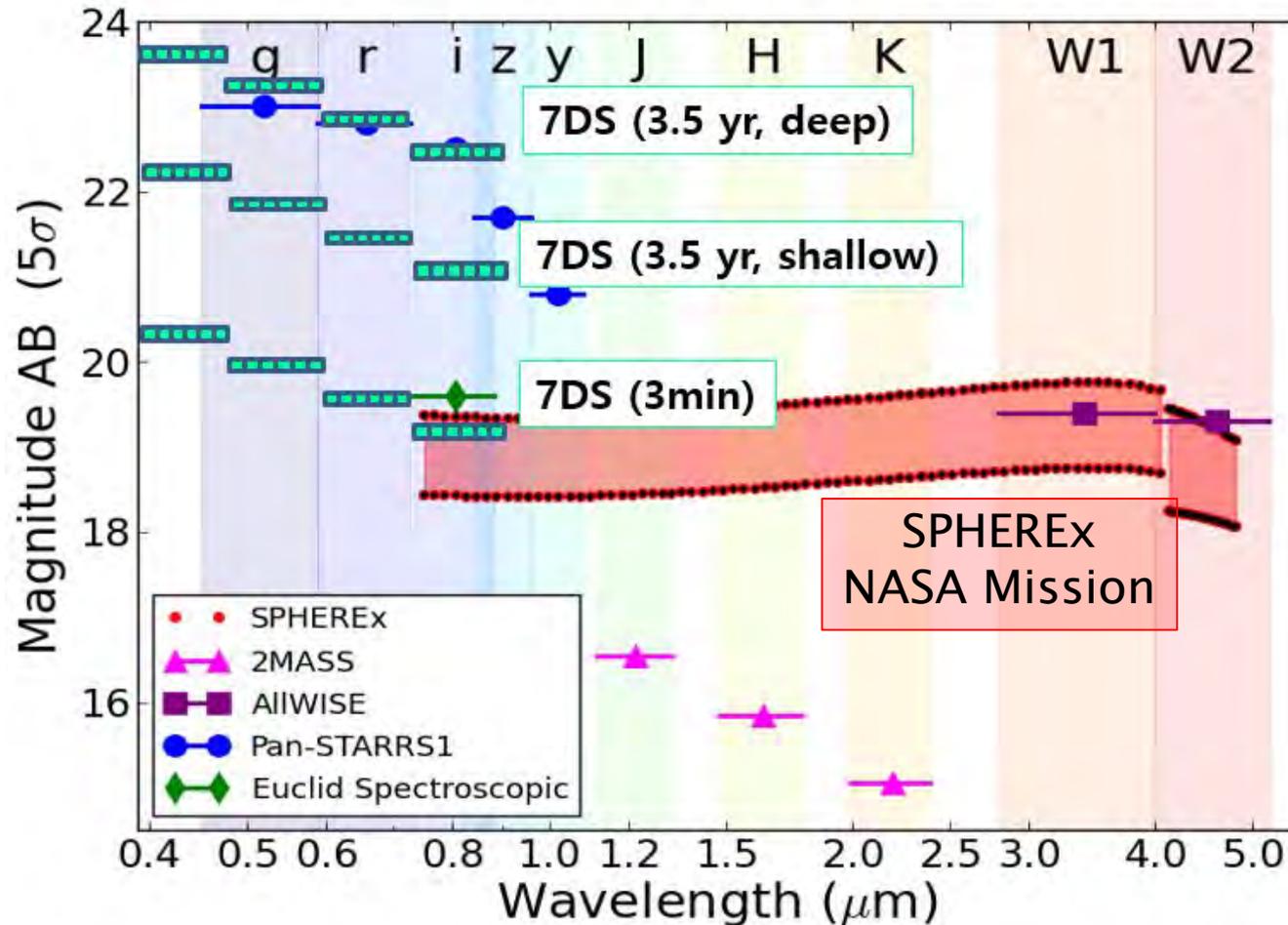
- Best suited for broad continuum features and broad emission lines continuum
- Photometric redshift: < 0.3% – 1% accuracy
- Emission line/continuum can be separated well (vs broad-band)
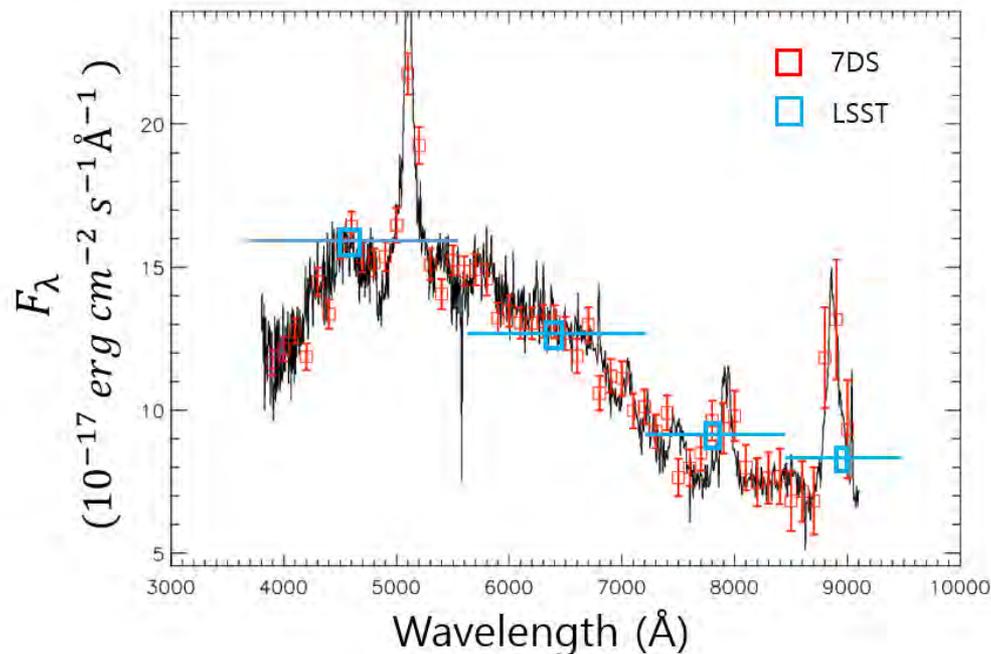
Z = 0.822,
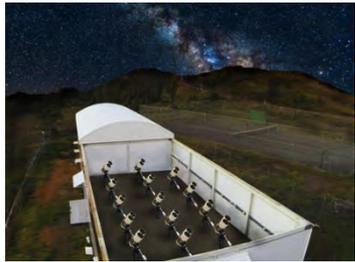i = 18.3 quasar spectrum
(black: SDSS
 red: 7DS
 blue: LSST)

7DT Depths: Comparable or deeper than SPHEREx

7DS Detection Limits

Figure labels: g, r, i, z, y, J, H, K, W1, W2

- 7DS (3.5 yr, deep)
- 7DS (3.5 yr, shallow)
- 7DS (3min)

SPHEREx NASA Mission

Legend:
- SPHEREx
- 2MASS
- AllWISE
- Pan-STARRS1
- Euclid Spectroscopic

Y-axis: Magnitude AB (5σ)
X-axis: Wavelength (μm)
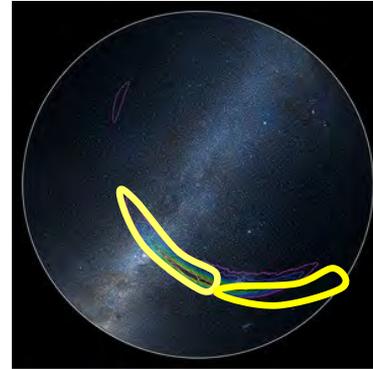
7DT, Three Advantages

2. Wide-field Mode
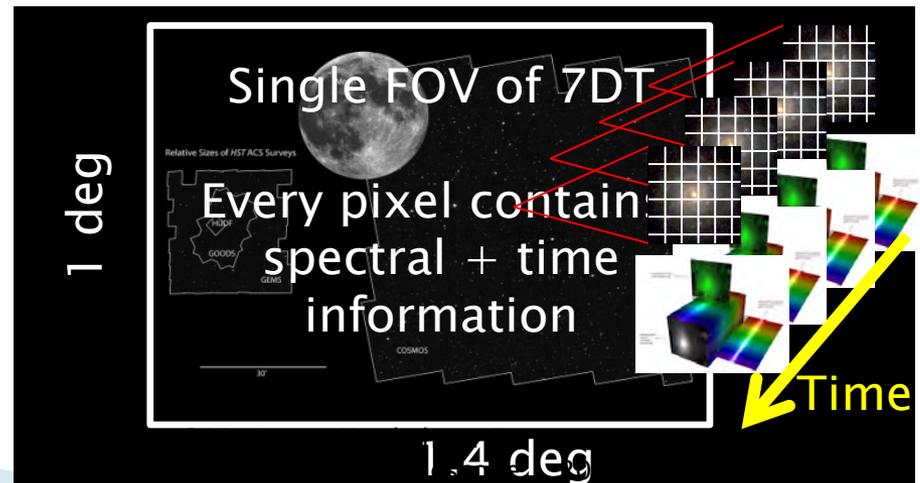All telescope looking at different locations
28 deg^2 with a single filter

GW150914 can
be covered by
two pointings

1. Deep Observing Mode
All telescope pointing at the same location
= 2.3m wide-field telescope

7DT   SDSS

3. Spectroscopic Mode
Wide field IFU-type observation

1 deg

Single FOV of 7DT
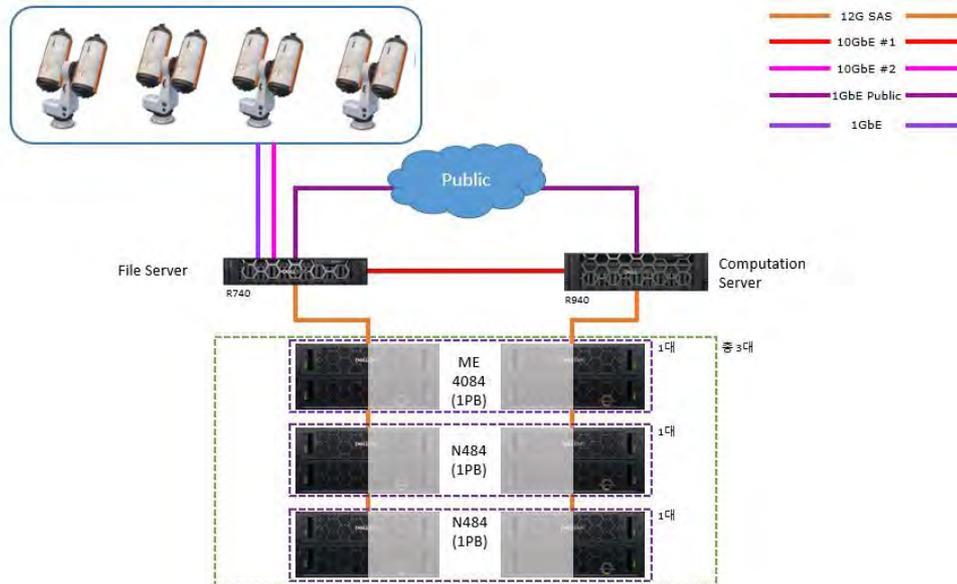
Every pixel contain
spectral + time
information

Time

1.4 deg

Telescope site

▸ Chile, San Hurtado Valley (near CTIO/Cerro Pachon)

▸ Altitude: 1700 m

▸ 320 clear nights

▸ <1" Seeing

▸ ObsTech or DeepSkyChile

Data

- Raw data: ~1.5 TB per night
- 1.5 PB per year (including processed data)
- 3PB → 6PB, gradual increase of the data capacity
- Data transfer: 10Gbps line or on-site processing

Observations

- ## 7-dimensional sky survey (7DS)
  - ~1,600 – 20,000 deg^2 to 20 AB mag (5-σ) per epoch
  - ~ 14 day cadence
  - Multi-purpose survey: Transient search reference image and other science cases
  - ~3+ yrs

- ## Kilonova search during GW O4/O5run
  - Target-of-opportunity observations during the GW runs
  - Identify KNe and obtain their redshifts fast (7DT and 8-m class telescopes) ➔ cosmology, etc

Schedule

▸ **1st Step (Year 1,2,3)**
- 7DT completion (5 units every 0.5yr)
- Pilot 7DT observations
- Data analysis system complete

▸ **2nd Step (Year 4,5)**
- Regular 7DT operation (7DS + GW TOO)

▸ **3rd Step (Year 6+)**
- 7 Dimensional sky survey

Expected results

- ~ Rapid identification of 10-20 KNe

- ~1% accuracy for H_0

- GW EM counterpart search for BBH, BH+NS mergers ➔ unexpected outcome

- Characterization of KNe and their environment ➔ where the gold mines of the universe?

- Other sciences with 7DS

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

Summary

- 7DT:

 - The biggest multiple telescope system with 20 wide-field telescopes

- Wide-field, IFU-type observation:
 - One shot, 60M spectra of the Universe

- Will be used to search GW EM counterparts and other science cases (7DS)
 - New window to the Universe

Timeline

Tasks	2021B	2022A	2022B	2023A	2023B	2024A	2024B	2025A	2025B
7DT Construction	Design /Order	5 units, Enclosure	10 units	15 units	20 units Finish				
7DS Reference Imaging		Pilot survey			Full survey				
GW EM counterpart Search			O4 run					O5 run	O5 run
7DT Database System	Order	1 PB unit		2PB		4PB		6PB	
AI Analysis system	Order		Finish						
7DT ops software		Finish	Optimization						
7DT analysis software/ database		Finish	Optimization			Improvement			