# MULTI-MESSENGER ASTRONOMY WITH GEMINI AND IMS 2018 PROGRESS REPORT

MYUNGSHIN IM (SEOUL NATIONAL UNIVERSITY)

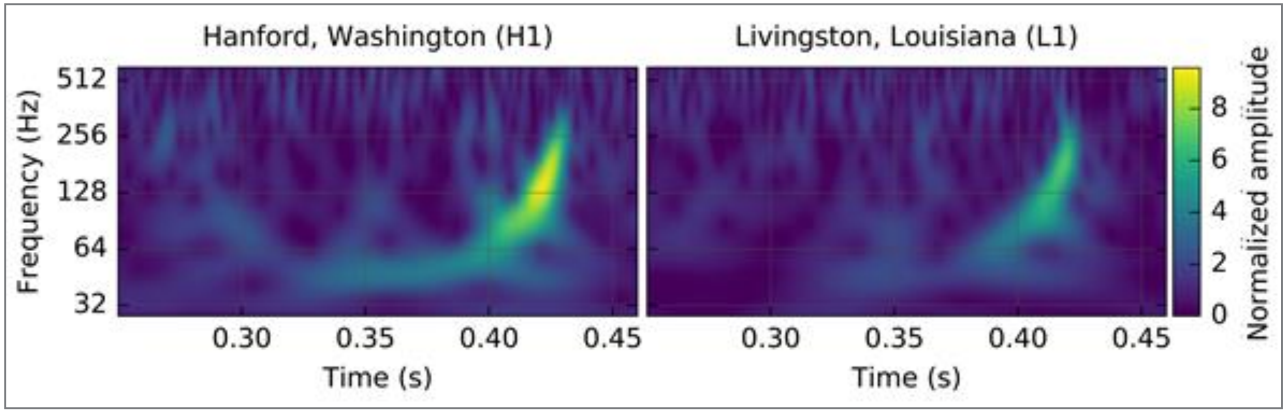
+ GW FOLLOW-UP TEAM, IMSNG TEAM, IMS TEAM

2019. 02. 13 – 15

2019 K-GMT SCIENCE PROGRAM USERS MEETING

# THE ERA OF GW ASTRONOMY HAS ARRIVED AT 2015!

## BH-BH merger, Nobel prize in 2017




| | |
|---|---|
| Primary black hole mass | $36^{+5}_{-4} M_\odot$ |
| Secondary black hole mass | $29^{+4}_{-4} M_\odot$ |
| Final black hole mass | $62^{+4}_{-4} M_\odot$ |
| Final black hole spin | $0.67^{+0.05}_{-0.07}$ |
| Luminosity distance | $410^{+160}_{-180}$ Mpc |
| Source redshift $z$ | $0.09^{+0.03}_{-0.04}$ |

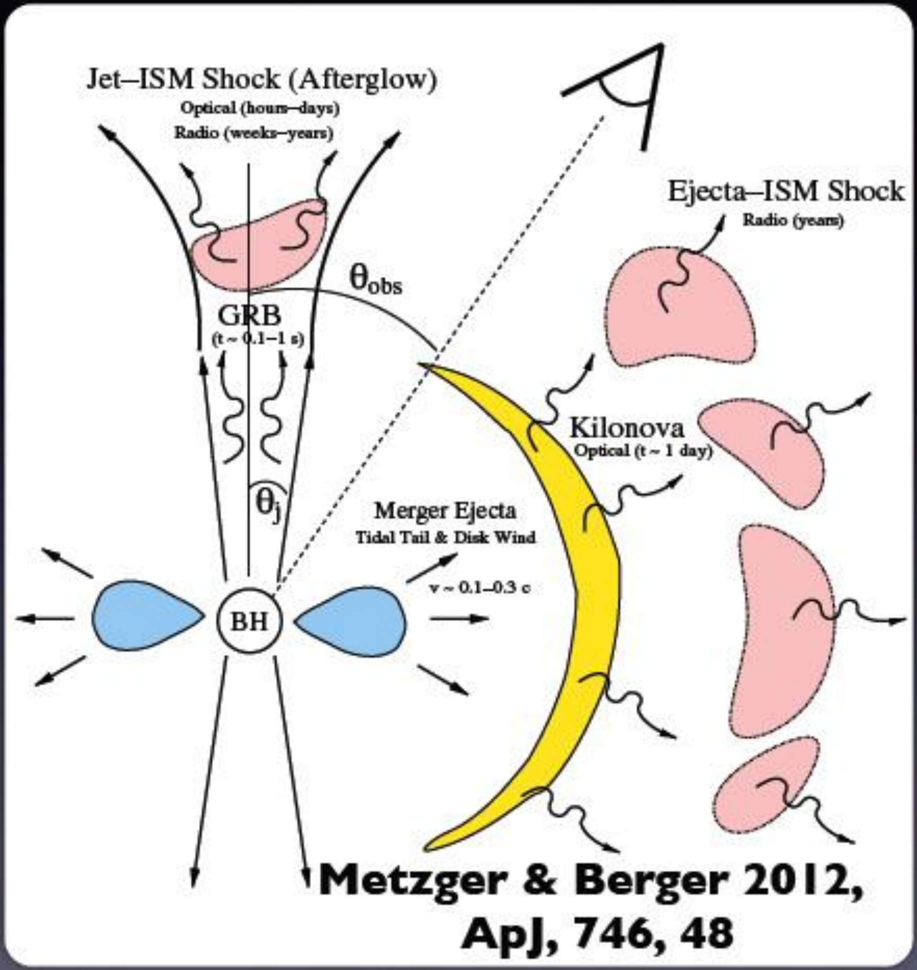
GW 150914

Abbott et al. 2016, PRL

But no EM signal (optical counterpart)

# EM signature from NS-NS merger

- On-axis short GRB
- Off-axis radio emission
- Radioactive emission
  - kilonova
  - macronova
  - mini SN
  - Merger-nova




Taken from presentation by M. Tanaka

# GW170817: NS-NS MERGER MULTI-MESSENGER ASTRONOMY

2017-08-17 GW event marked the start of MMA using GW and EM signals

3700 (39@Korea, 45 countries, 900+ institutions, 80 facilities ), 59 page ApJL paper

# FACILITIES FOR EM FOLLOW-UP: 17+ TELESCOPES

Korea:
SAO 1.0m/0.6m, SOAO 0.6m,
BOAO 1.8m, DOAO 1.0m

Maidanak:
1.5m Telescope

US: LOAO 1-m

Gemini-N

UKIRT

Gemini-S


KMTNet 1.6m
Telescopes

Australia: 0.43m LSGT
+ iTelescope.Net (SSO)

US: McDonald 2.1-m,
0.8m, 0.25m

# FIRST KOREAN OBSERVATION

At 2017-8-18, about 21 hours after the GW detection, the GW EM counterpart was detected by LSGT (0.43m telescope!)


Lee Sang Gak Telescope (LSGT@SSO)

Im et al. 2017, 2019, Abbott et al. 2017

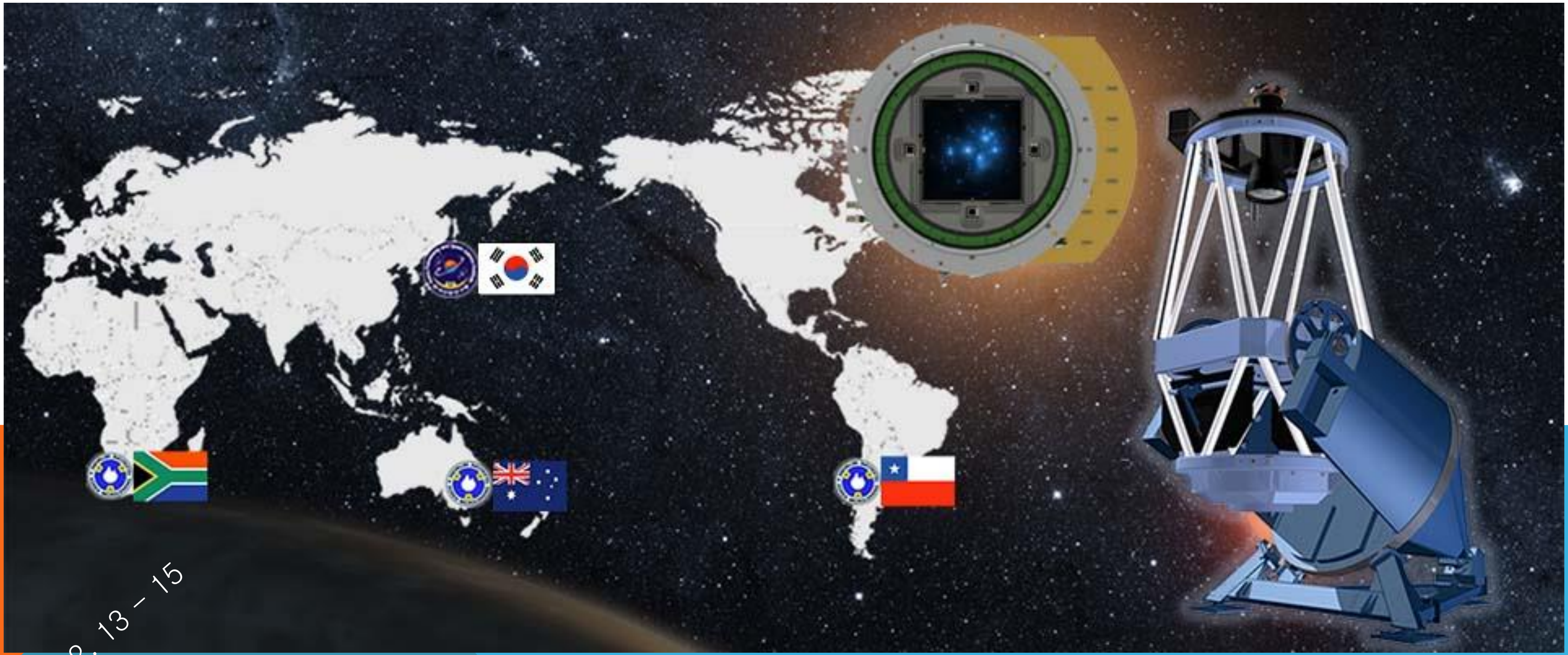

Optical counterpart of GW170817 taken with LSGT

# KMTNET FOLLOW-UP OBSERVATION

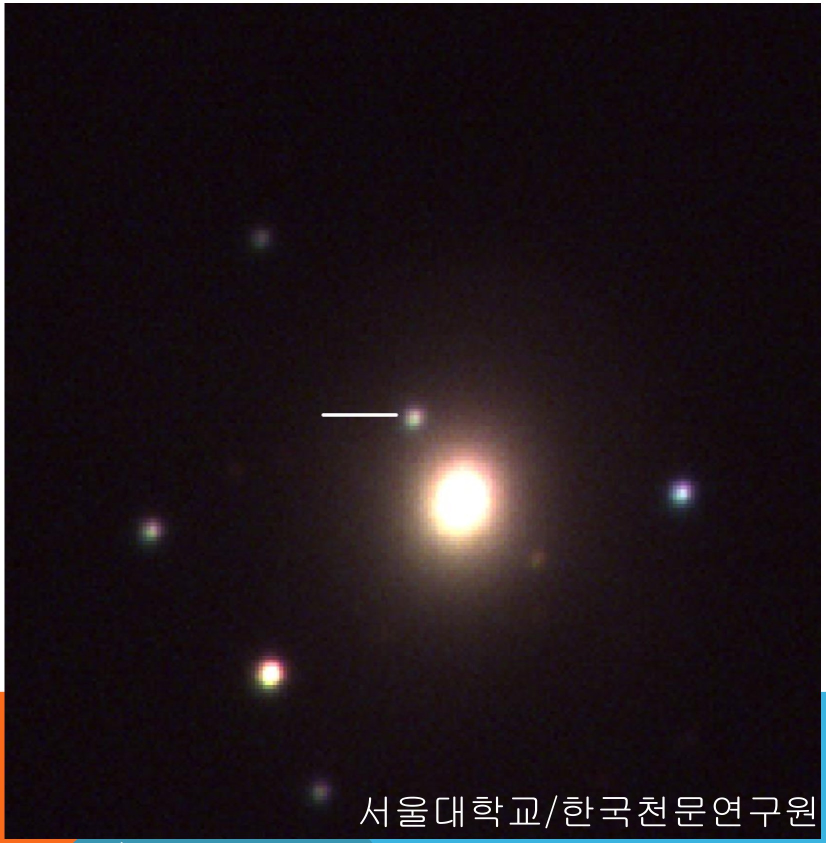
Korea Microlensing Telescope Network: Three 1.6m telescopes at Southern Hemisphere (exoplanet microlensing)

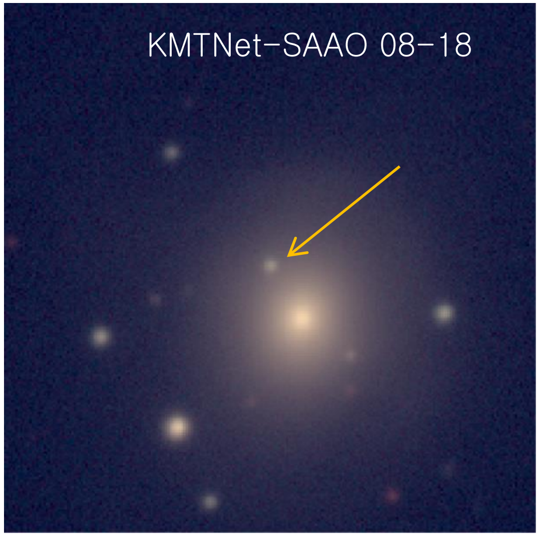
KMTNet SAO telescope started the observation at about 28 hours after the GW detection

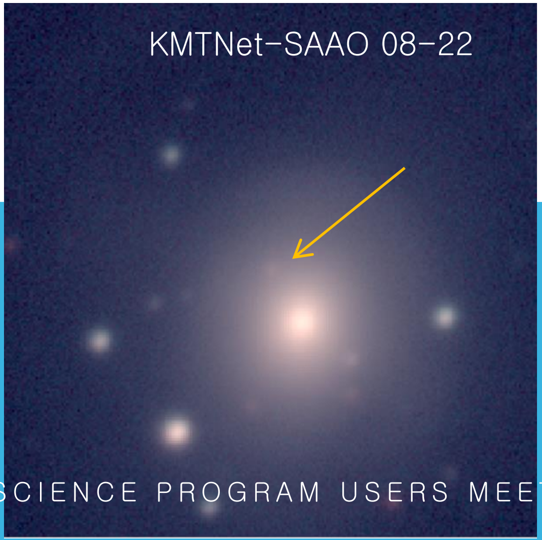
Observations continued till Sept. 9 (B,V,R,I)



# KMTNET IMAGE OF GW170817




Troja et al. 2017, Im et al. 2017, Abbott et al. 2017

# SEVERAL KEY RESULTS

Binary neutron star merger ➔ short GRB-like event? YES

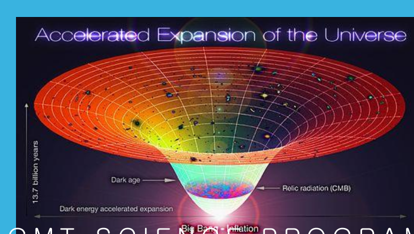
EM counterpart = Kilonova? YES

- blue or red? Both
- Brightness? 17 mag in the beginning

Environment of NS merger? Massive elliptical galaxy

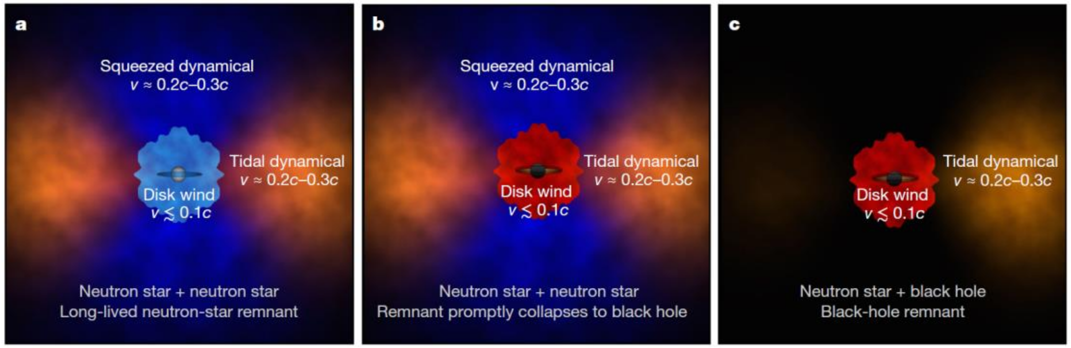
Im et al. 2017
Troja et al. 2017
Levan et al. 2017
Abbott et al. 2017
Lee MG et al. 2018
Lyman et al. 2018

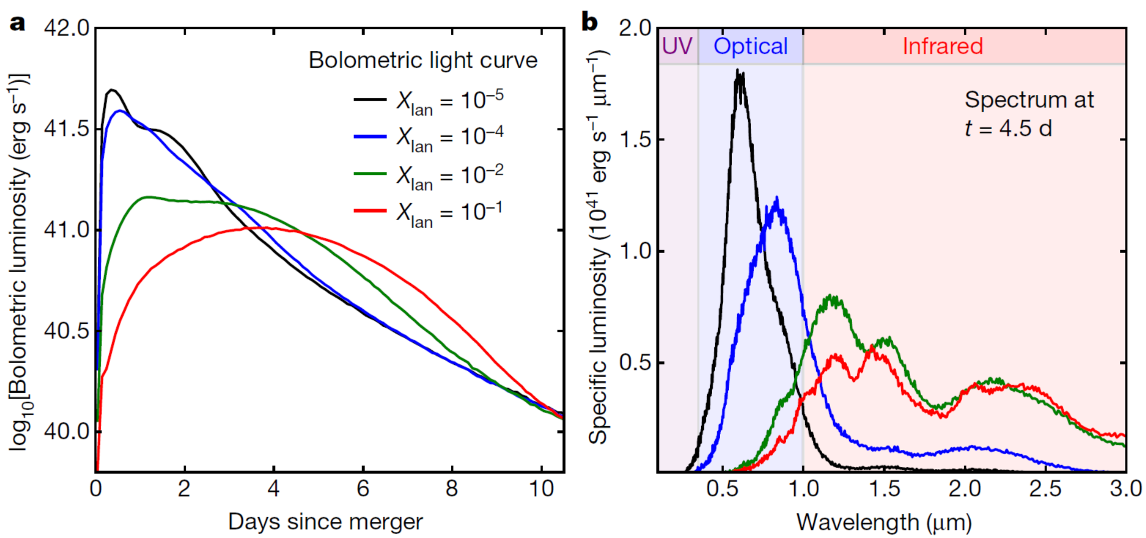
Gold!
(200 $M_E$)




$H_0$ from GW

# KILONOVA: BLUE OR RED?
# DEPENDS ON HEAVY ELEMENT PRODUCTION + MERGING TIMESCALE

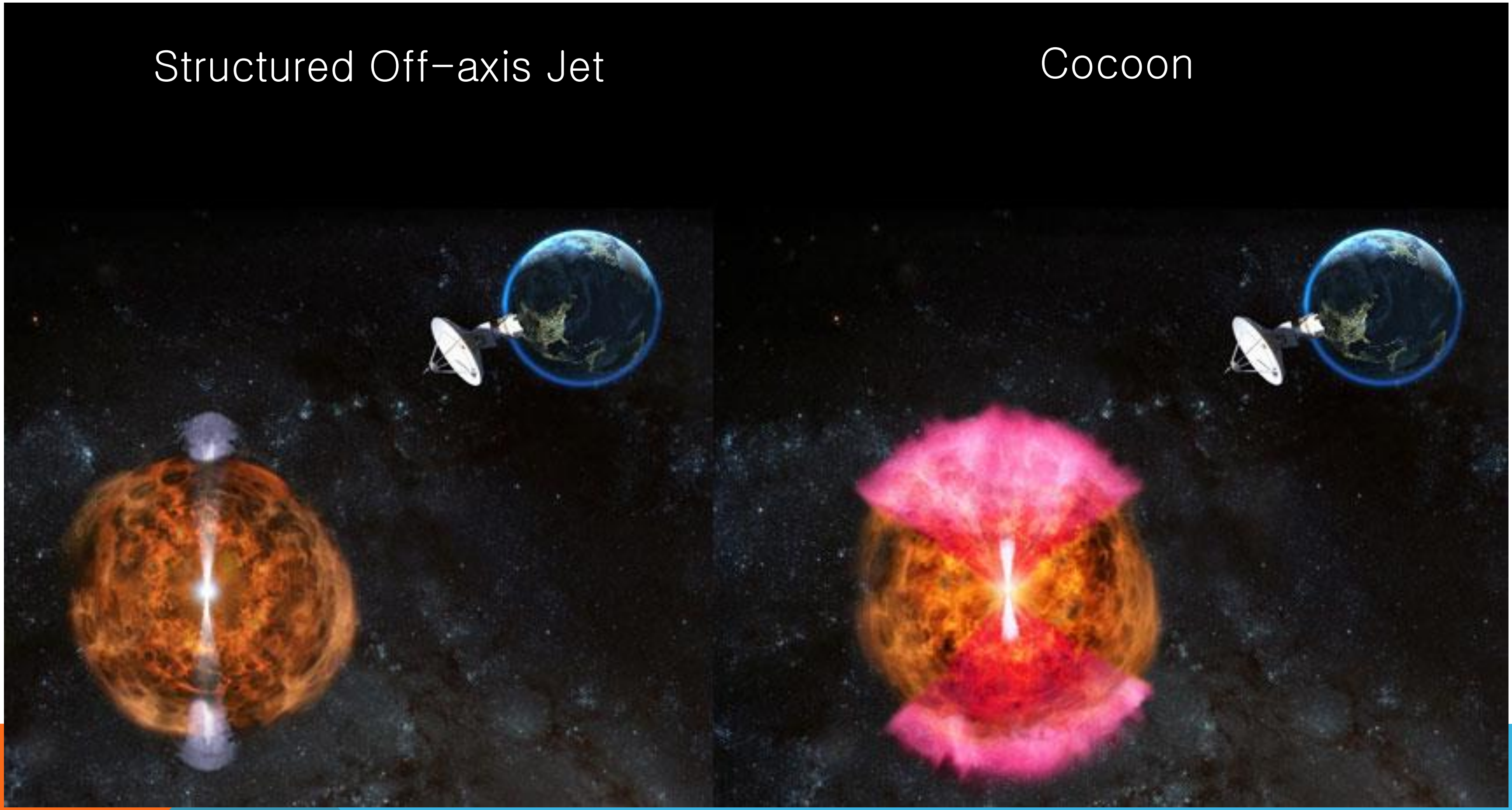



Xlan : Lanthanide fraction

Kasen et al. 2017, Nat.

# OFF-AXIS JET OR COCOON?




Credit: NRAO/AUI/NSF/D. Berry

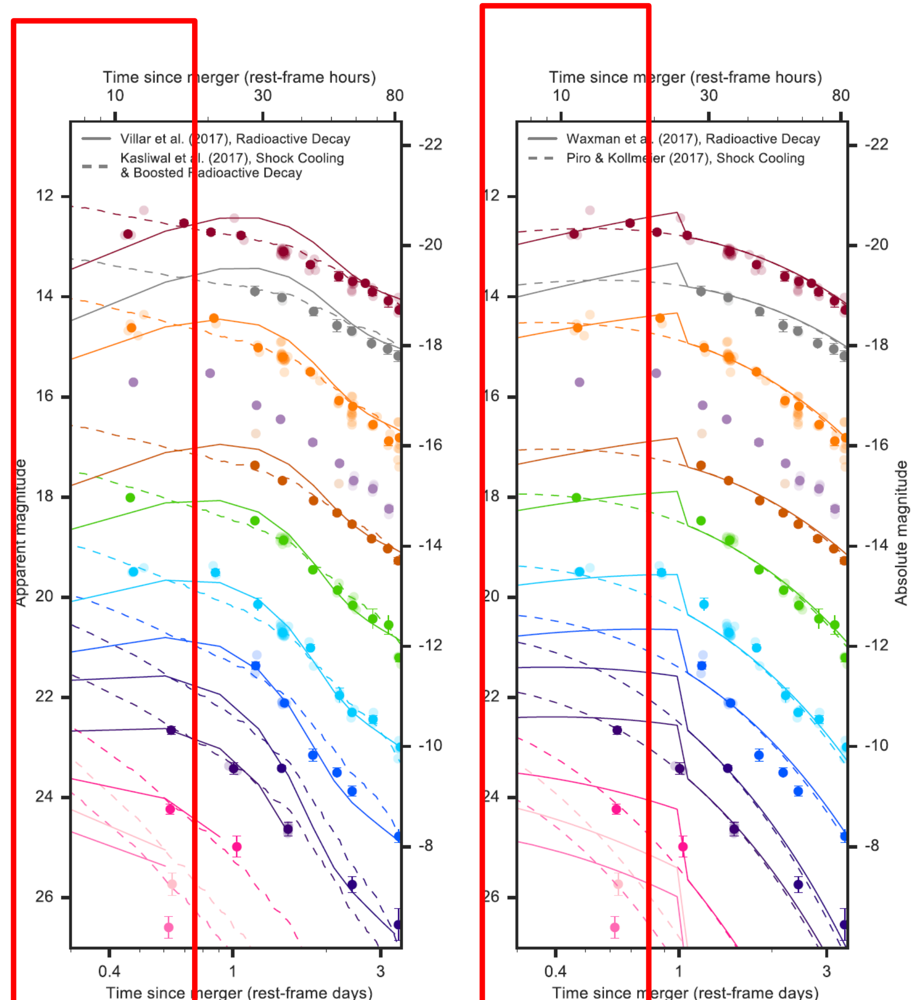
# EARLY LIGHT CURVE

Radioactive decay models
– Slowly rising curve at t < 1day

Shock–heated models
– Steadily decaying curve at t < 1day

GW170817: unclear which model is correct

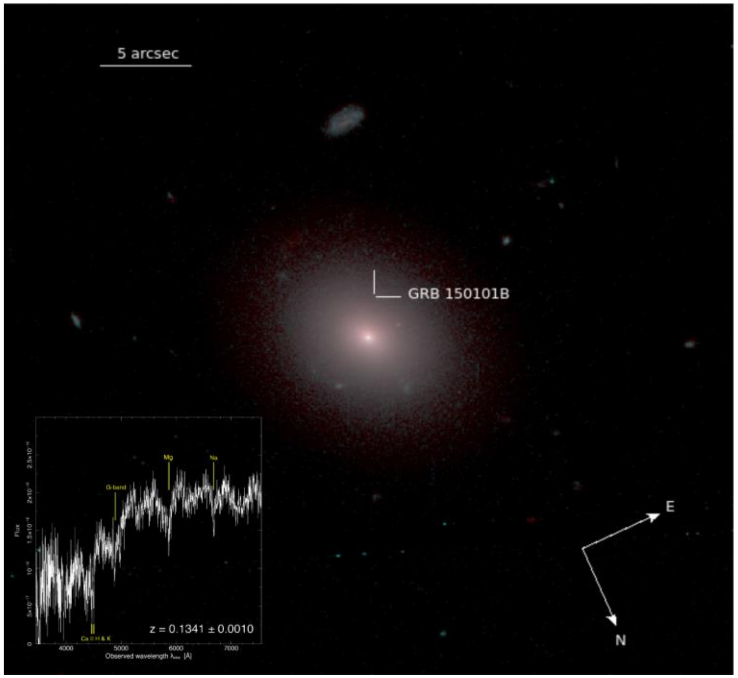
Early optical signal ➔ Important test of the kilonova emission mechanism




Arcavi (2018, ApJL)

# HOST GALAXY MYSTERY?

GW170817 host galaxy
(Im et al. 2017, ApJL)




GRB 150101B host
(Troja et al. 2018, Nat.Com.)

Massive ellipticals and near center, why?
(short GRB: 25% Es + >80% at > Reff)

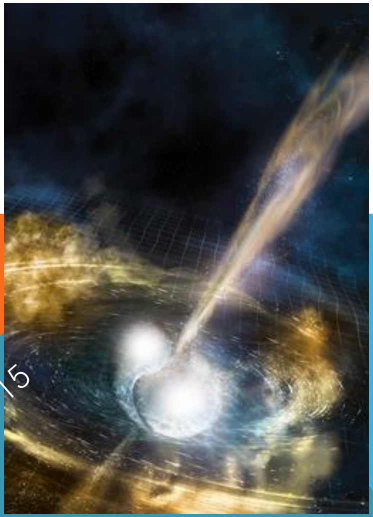
# SEVERAL KEY QUESTIONS

Binary neutron star merger ➔ off-axis short GRB or cocoon ?

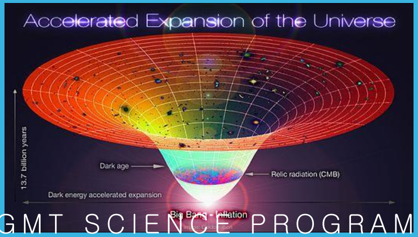
EM counterpart = Kilonova? YES?

- blue or red? Both?
- Brightness? 17 mag in the beginning?

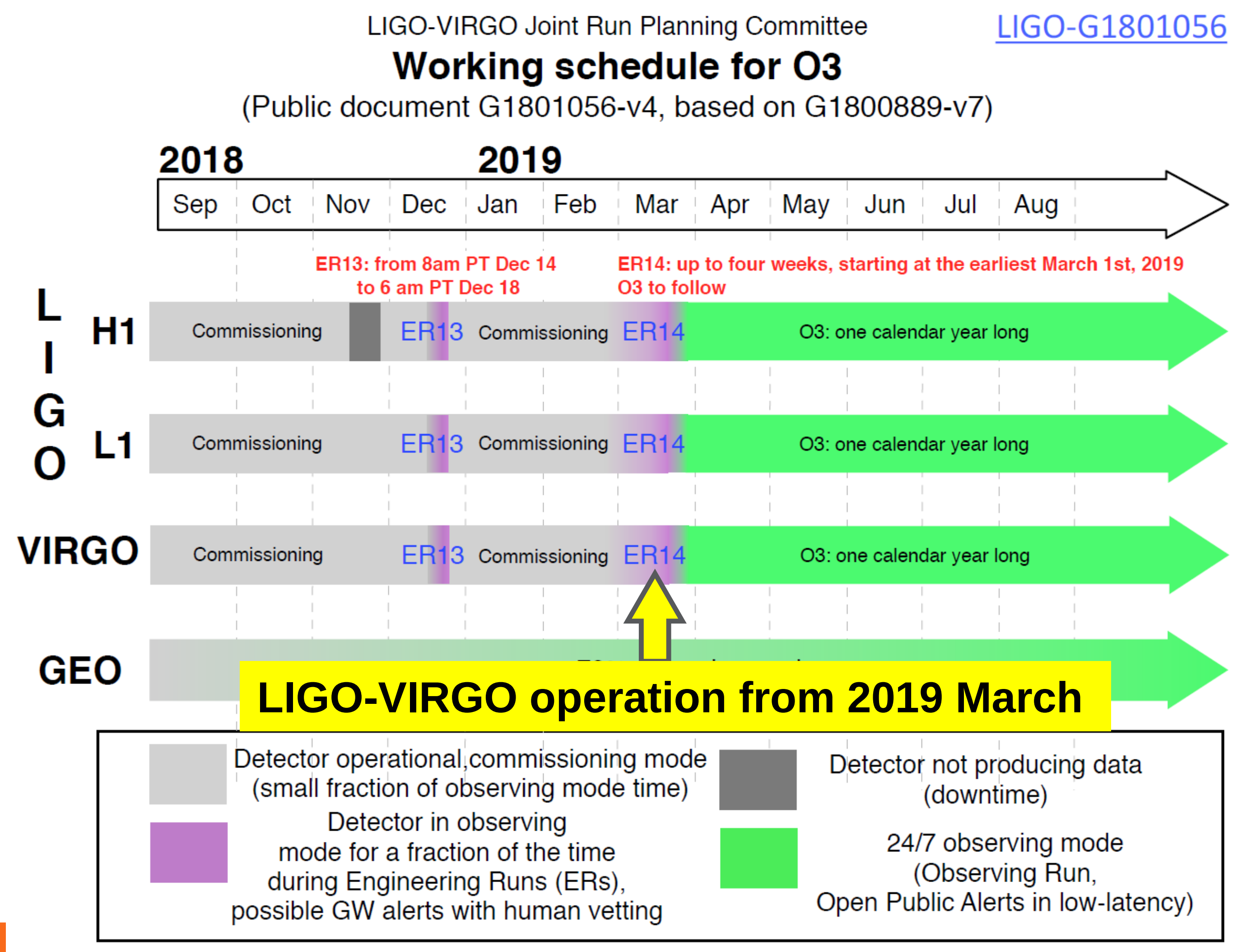
Environment of NS merger? Massive elliptical galaxy?



Gold! → how much? (200 $M_E$ ?)




Precision $H_0$ from GW




BNS sensitivity < ~100 Mpc

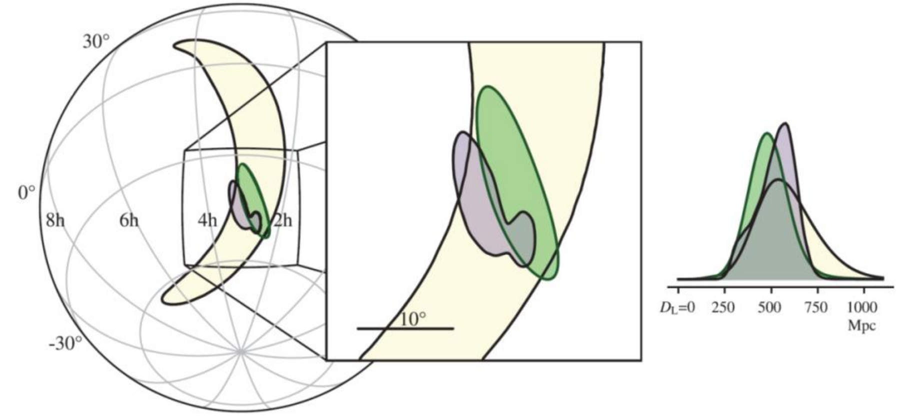
# EXPECTED EVENT RATES IN O3

BNS: 1-50 per year ➔~7 per year

BBH: 10-100 per year ➔ ~ 32 per year

NS-BH: About 1/10 of BNS

Localization area
~ 50 deg$^2$
~ 50 host gal candidates for BNS merger




GW170814 (Abbott et al. 2017, PRL, 119, 141101)

# LIGHT CURVE (IF RED)

At 100 Mpc,

r(AB) ~ 22.5 mag

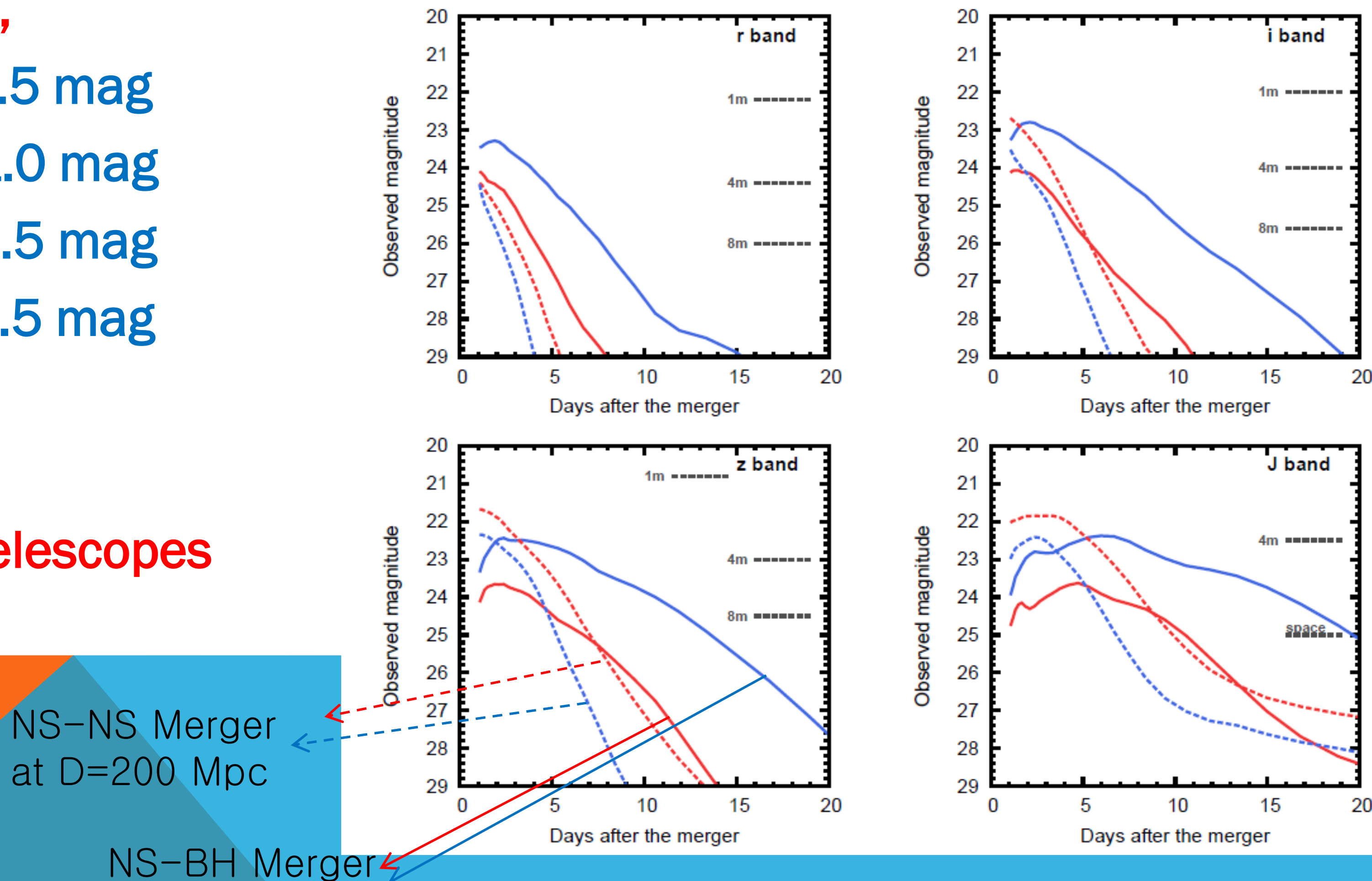
i(AB) ~  21.0 mag

z(AB) ~ 19.5 mag

J(AB) ~ 20.5 mag

Limit for

1-m class telescopes




Tanaka, M. et al. (2014, ApJ)

# Upcoming Challenges


More events: tens of events

Further distance: Faint counterparts (>20 mag)

BH-BH merger: any EM counterpart?

BH-NS/BNS merger: general characteristics

Rapid response is important

Credit: A. Simonnet

# GW FOLLOW-UP TEAM

SNU

Myungshin Im (PI)

Changsu Choi – LSGT, McDonald telescopes

Joonho Kim – KMTNet, LSGT

Gu Lim – SAO 1m/0.6m, Maidanak

Sungyong Hwang – McDonald 0.25m

Sophia Kim – McDonald 0.8m, DOAO 1m

Gregory Paek – LOAO 1.0m, DOAO 1m, BOAO/SOAO, SAO 1m

Seong-Kook Lee – Host galaxy

Yongmin Yoon – Host galaxy, transient photometry

I Paek, DH Kim, YJ Kim, M Hyun, Y Taak:

McDonald 2.1m, Gemini, UKIRT

(Myung Gyoon Lee, Sung-Chul Yoon,....)

KASI

BOAO/SOAO/LOAO
Hyun-Il Sung

KMTNet
Seung-Lee Kim
Chung-Uk Lee

Hyung Mok Lee
Sang-Hyun Ahn
(Lucas J. Uhm)

KYSC: DOAO

Wonseok Kang
Taewoo Kim

Korean GW Group (KGWG)

# STRATEGY

Localization map
Distance probability
Galaxy mass proxy

Prioritized host galaxy candidate list (~50)

OR

Tiling pattern of the whole localization area (BBH)

## Discovery (< 1 day)


UKIRT

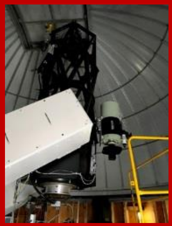

KMTNet x 3


MAO 1.5m


LOAO 1m


LSGT 0.4m


SAO 1m


McDonald 0.8m


Gemini

See Poster by Joonho Kim

## Characterization (~week)


Gemini


UKIRT

# GEMINI OBSERVATION (2019A)

**GEMINI OBSERVATORY**

*observing time request summary*

**Semester:** 2019A

**Observing Mode:** Queue + Rapid ToO

**Gemini Reference:**

**Instruments:** NIRI, GMOS South, GMOS North, GNIRS, Flamingos2

**Time Awarded:** NaN

**Thesis:** No

**Band 3 Acceptable:** No

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**Title:** **Optical/NIR Follow-up Observation of Gravitational Wave Sources**


**Principal Investigator:** **Myungshin Im**

**PI institution:** Seoul National University, Department of Physics and Astronomy 1, Gwanak-ro, Gwanak-gu Seoul, 08826, Republic of Korea

**PI status:** PhD

**PI phone/e-mail:** +82-2-880-6585 / myungshin.im@gmail.com

**Co-Investigators:** **Hyung Mok Lee**: Korea Astronomy and Space Science Institute (KASI), hmlee@kasi.re.kr


21.7 hours awarded (N+S combined)

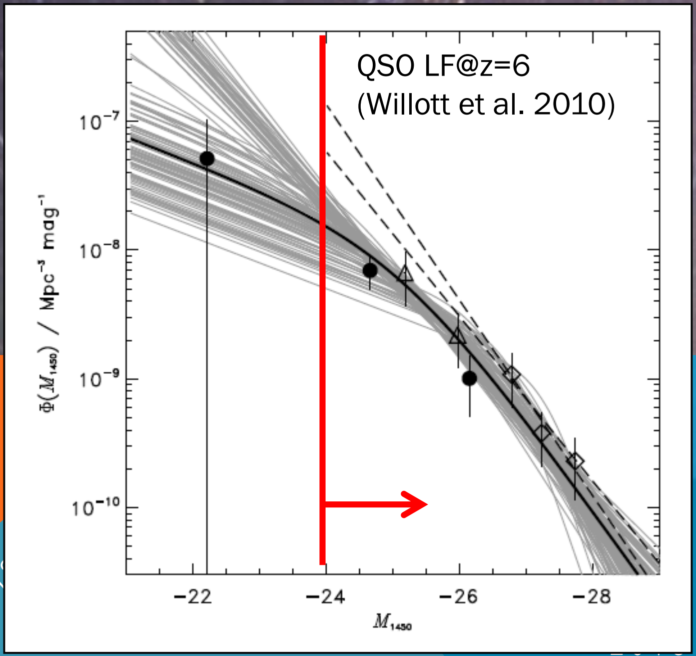
# INFRARED MEDIUM-DEEP SURVEY

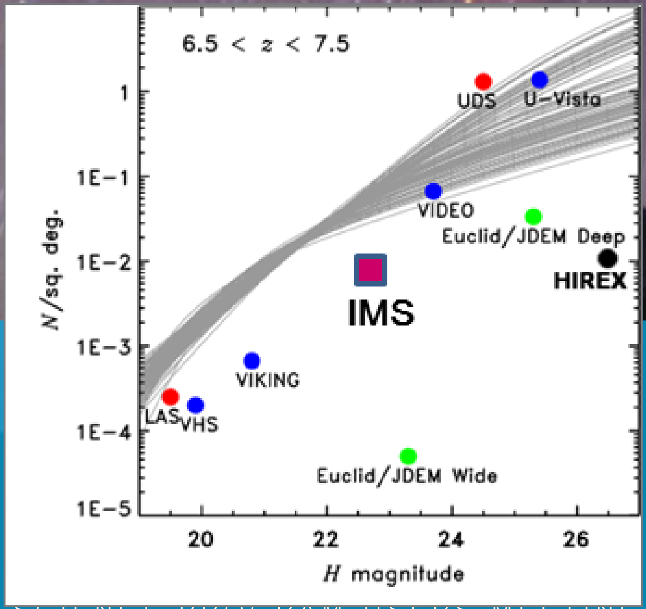
Quasars and galaxy clusters at high redshift

1 .Mag limit — Y, J ~ 23 AB mag

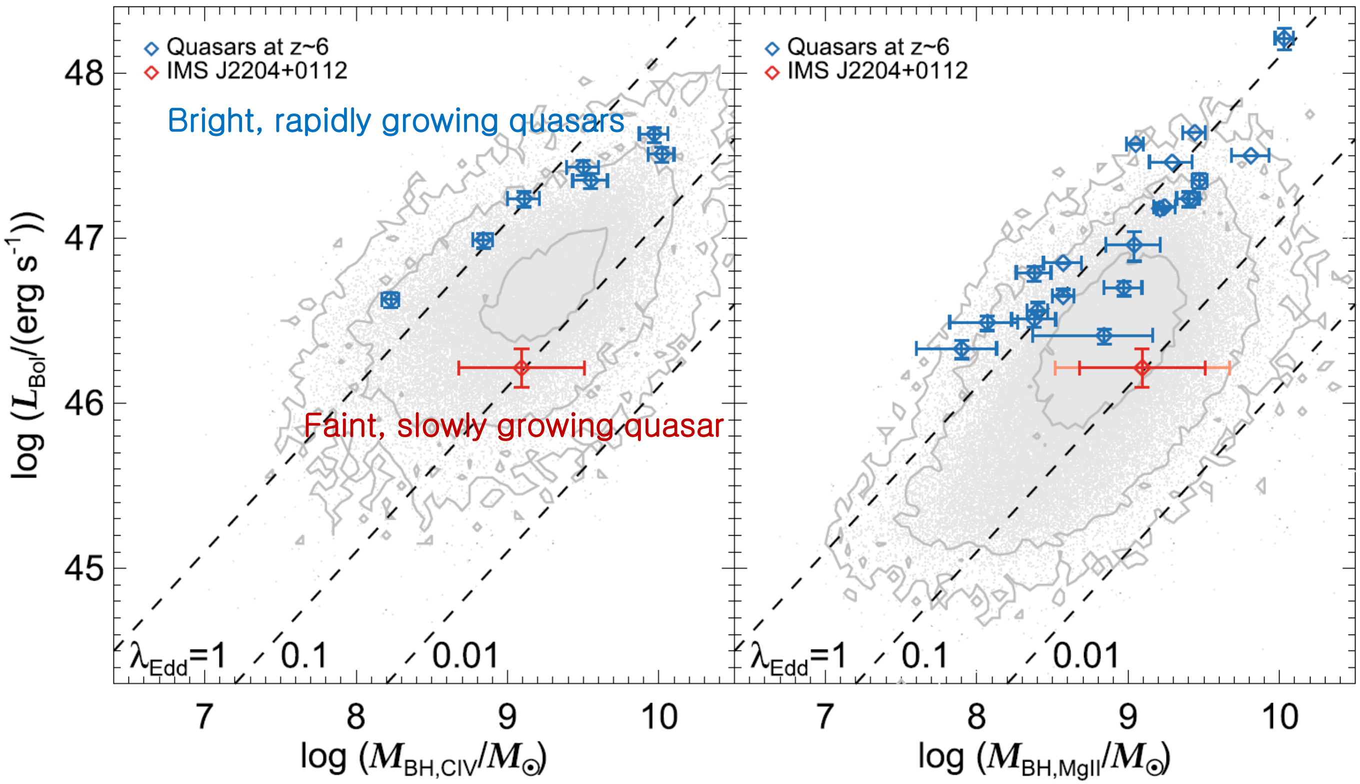
2. Area coverage — 120 deg$^2$

3. Facilities — UKIRT + McDonald 2.1m



# FAINT QUASARS AT Z ~ 6 HAVE LOW EDDINGTON RATIOS (SLOWLY GROWING)




Kim Y, MI, et al. 2018, ApJ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NEWS ASTRONOMY

# Astronomers can't figure out why some black holes got so big so fast

These behemoths defy expectations of how quickly black holes feed

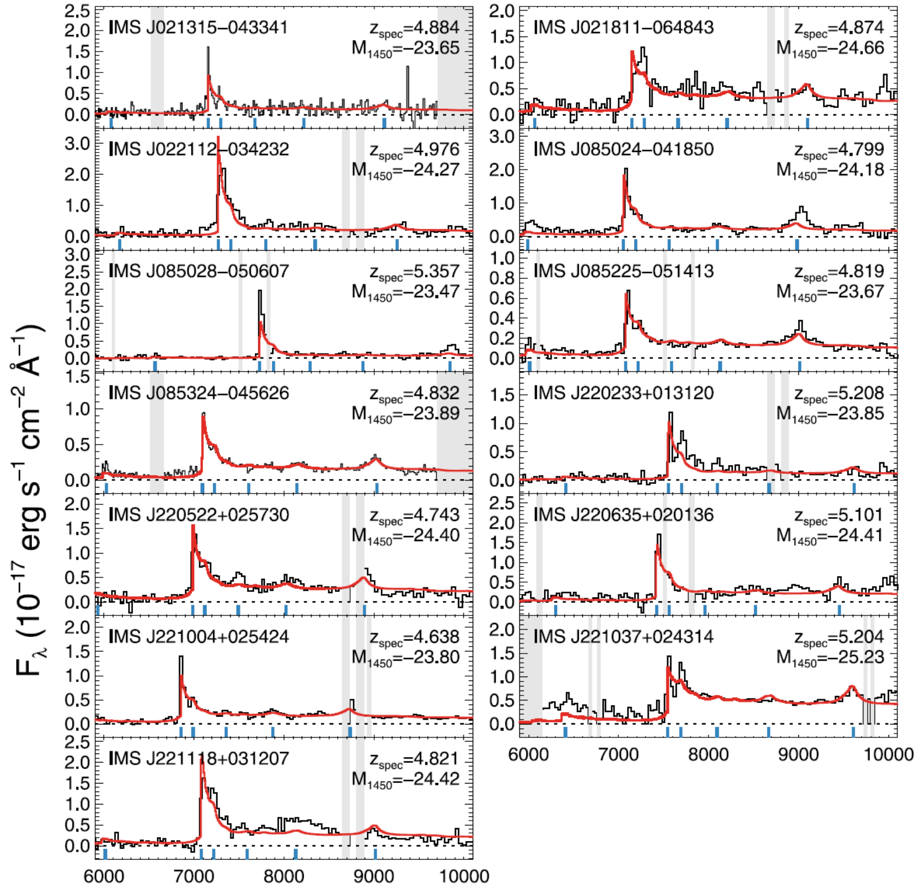
BY LISA GROSSMAN 7:00AM, MARCH 16, 2018

Science News, March 16, 2018

2019. 02. 13 – 15

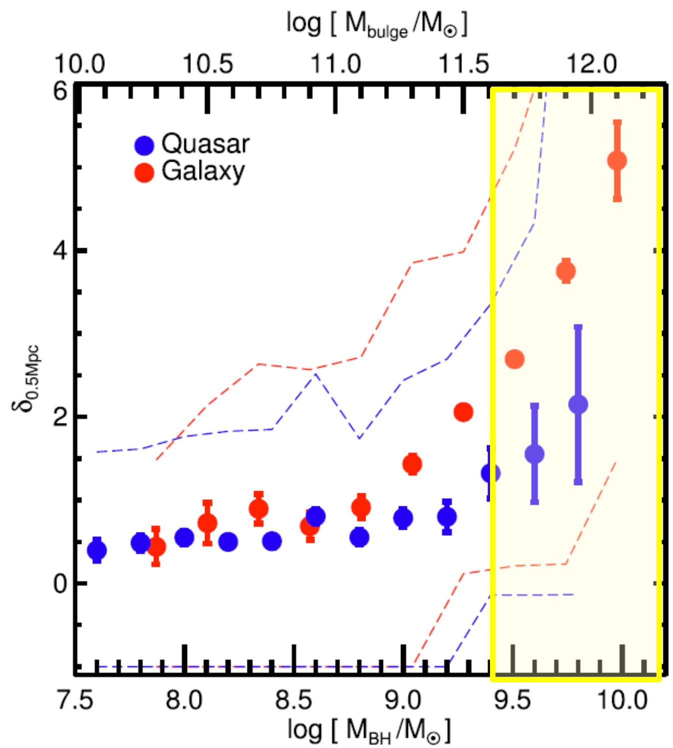
2019 K-GMT SCIENCE PROGRAM USERS MEETING

# SPECTROSCOPIC CONFIRMATION OF 11 NEW FAINT QUASARS AT Z ~ 5




Kim Y, MI, et al. 2019, ApJ
Gemini

# MASSIVE QUASARS (Z < 0.4) LIVE IN DENSE ENVIRONMENT, BUT LESS SO THAN MASSIVE GALAXIES




Yoon Y, MI et al. 2019, ApJ
MMT

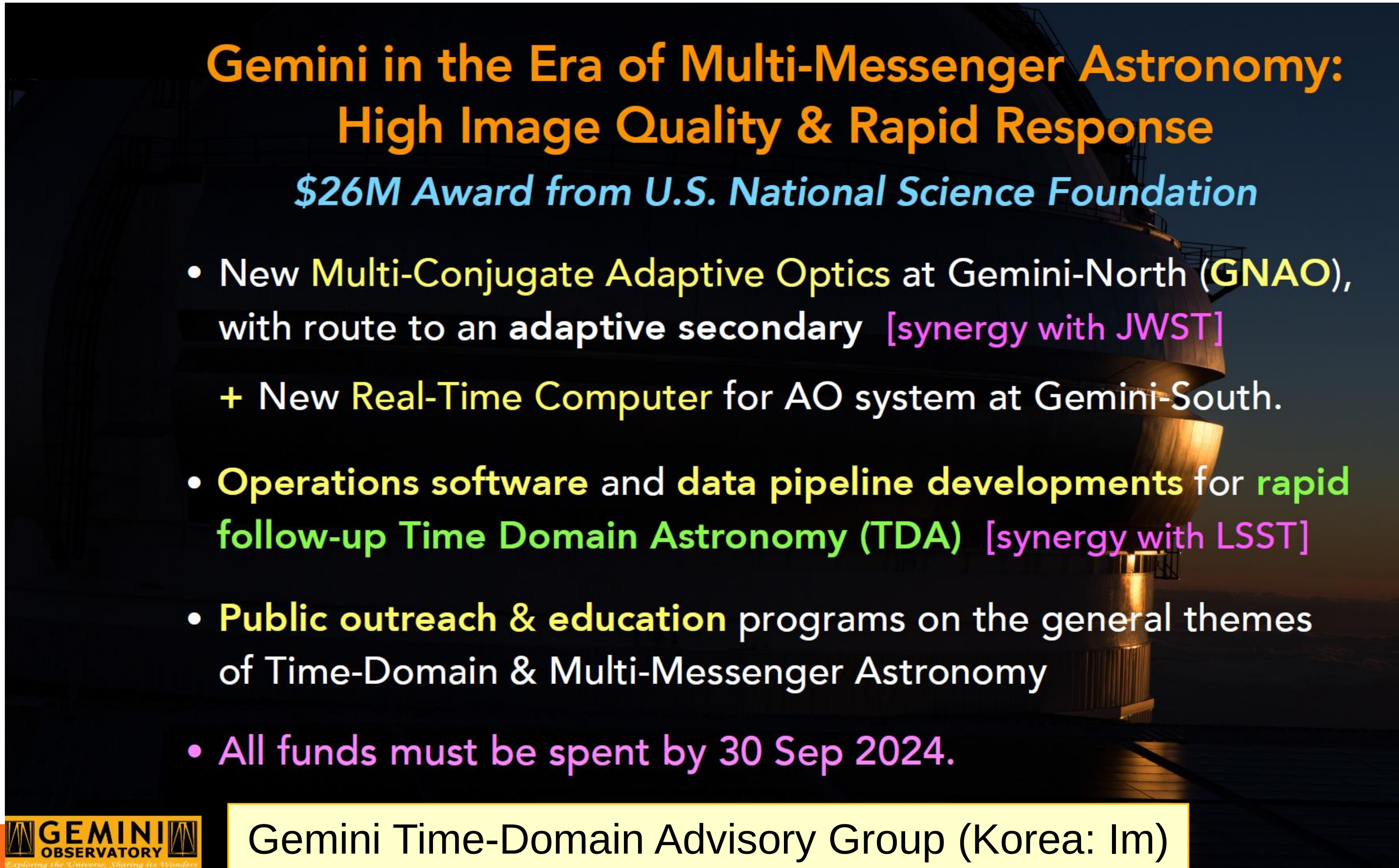
2019. 02. 13 – 15

# PAPERS PUBLISHED OR TO BE PUBLISHED SOON WITH K-GMT SCIENCE PROGRAM

| # | Author | Year | Status | Topic | Facilities |
|---|---|---|---|---|---|
| 1 | Kim, Yongjung et al. | 2015 | ApJL | QSO at z=6 | UKIRT, Gemini |
| 2 | Kim, Jae-Woo et al. | 2016 | ApJL | Supercluster at z=1 | UKIRT, Magellan |
| 3 | Jeon, Yiseul et al. | 2017 | ApJS | QSO at z=5.5 | UKIRT, Gemini, KPNO 4m, .. |
| 4 | Kim, Yongjung et al. | 2018 | ApJ | SMBH mass of z=6 QSO | UKIRT, Magellan, Gemini |
| 5 | Lee, Seong-Kook et al. [Talk] | 2019 | Submitted | Clusters/Sclusters at z=1 | UKIRT, Magellan |
| 6 | Yoon, Yongmin et al. | 2019 | ApJ | Env. of massive QSOs | SDSS, MMT |
| 7 | Kim, Jae-Woo et al. | 2019 | Draft soon | Clusters at z=1 | UKIRT, Gemini, Magellan, JCMT |
| 8 | Kim, Dohyeong et al. [Talk] | 2018 | ApJS | Red quasar spectral atlas | Gemini, IRTF |
| 9 | Kim, Yongjung et al. | 2019 | ApJ | Discovery of faint z ~ 5 quasars | Gemini, Magellan, McDonald 2.1m |

# PAPERS IN PREPARATION

| # | Authors | Year | Status | Topic | Facilities |
|---|---|---|---|---|---|
| 10 | Lee, Seong-Kook et al. | 2018 2019 | In preparation | U-dropout galaxies | UKIRT, Gemini |
| 11 | Hyun, Minhee et al. [Talk] – also I. Paek's poster | 2018 2019 | In preparation | Superclusters at z=1 | UKIRT, Magellan, Gemini? |
| 12 | Taak, Yoonchan et al. [Poster] | 2018 2019 | Draft | Gravitational lens | Gemini, Magellan, HST |
| 13 | Im, Myungshin et al. | 2018 2019 | In preparation | IMS overview | UKIRT, Gemini, Magellan, HET |
| 14 | Taak, Yoonchan et al. | 2018 2019 | In preparation | BH mass of faint z ~ 5 quasars | UKIRT, Gemini, McDonald 2.1m, Magellan |
| | … Many more to come … | | | | |




Gemini Time-Domain Advisory Group (Korea: Im)
Report to the board (2019 Nov), 2021A operation

Credit: John Blakeslee (AAS#233)