23.06.14 14:25-50 Workshop on GW & NR

GW Optical Follow-up Observation Campaign in Korea

GECKO and 7DT

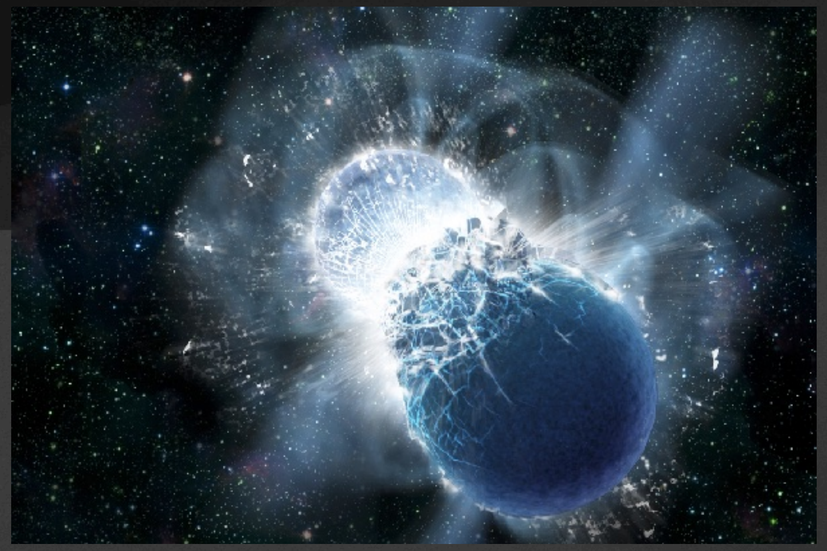
Gregory S.H. Paek (백승학),
Myungshin Im, Seo-Won Chang, Mankeun Jeong and GECKO Member

Seoul National University

Multi-Messenger Astronomy

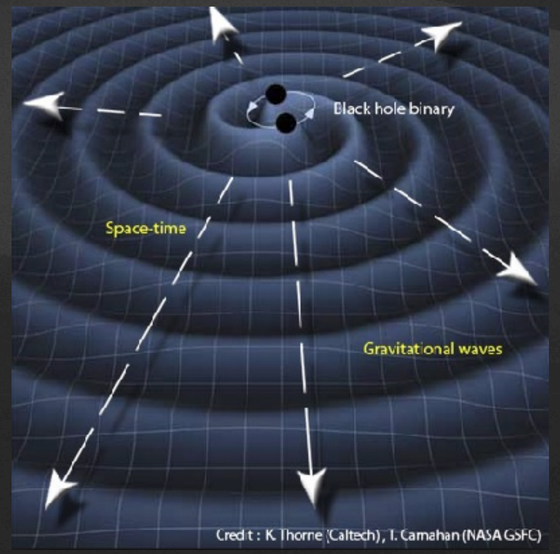
Another 'Channel' to See the Universe

Binary Neutron Star (BNS) Merger



Eletromagnetic-wave (EM)

Gravitational-wave (GW)



GW+EM Signals from a BNS Merger

GW 170817

GW

Multi-wavelength EM

γ-ray Optical/NIR Radio

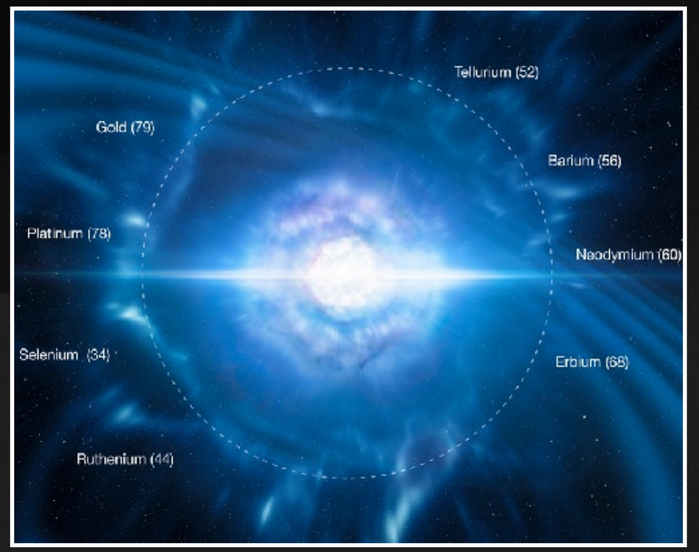
Host galaxy

Coulter+17

A New Era of GW Multi-Messenger Astronomy (MMA)

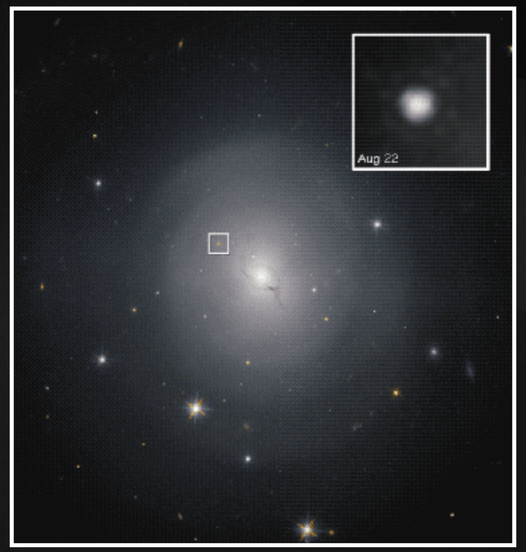
Legacy of GW 170817

Kilonova Physics



Coulter+17, Troja+17, Kasen+17

GW Host galaxy



Levan+17

GW H_0

Schutz+86

However, there is only one case (t_0 + 11 hrs) → Need More!

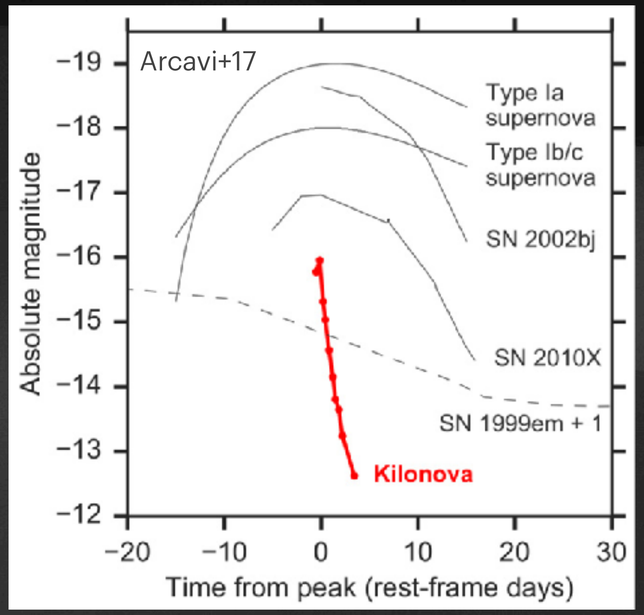
Difficulties

Poor GW Localization Area

LVK Collaboration

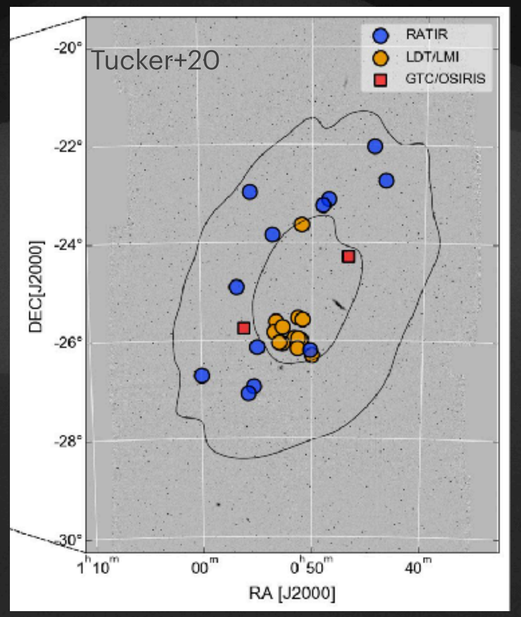
- Even upgraded GW detector has a poor localization area (Petrov+21)
- c.f. $S_{O4} \sim 1820\ \mathrm{deg}^2$

Fast Decaying Kilonova



- KN decays within a few days
  ➡⏳ Golden Time!

Too Many KN Contaminants



- Dozens of SNe or other transients
- Classification with spectroscopy or light curve is time-consuming

Gravitational wave Electromagnetic wave Counterpart Korean Observatory (GECKO)

Uzbekistan
Maidanak 1.5-m

KOREA
SAO 1.0-m
KHAO 0.76-m
DNSM 1.0-m
DOAO 1.0-m
MAAO 0.7-m

US
LOAO 1.0-m

Chile
KCT 0.36-m
RASA 0.36-m

Three KMTNet 1.6-m
- SAAO
- SSO
- CTIO

Australia
Siding Spring
LSGT 0.43-m

ToO program
Gemini-North &
Gemini-South,

7-Dimensional Telescope

The Biggest Multiple Telescope System in the World

20 0.5m Telescopes @Chile

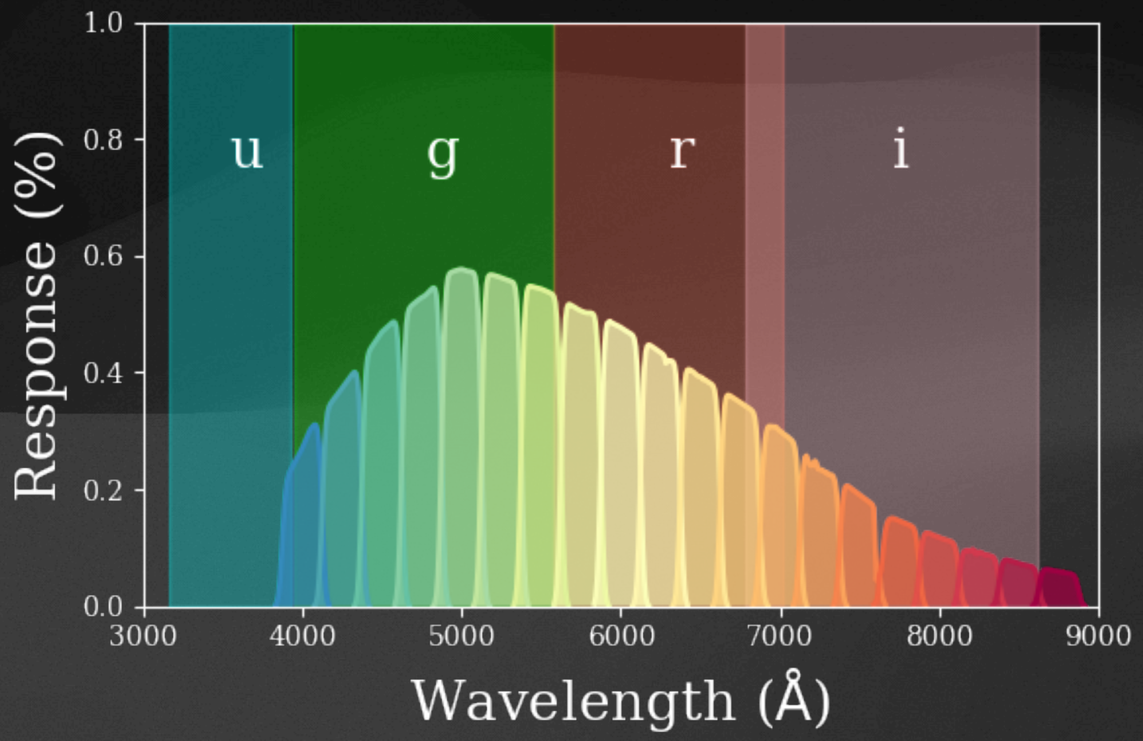
(FoV)~$1.25\ \mathrm{deg}^2$

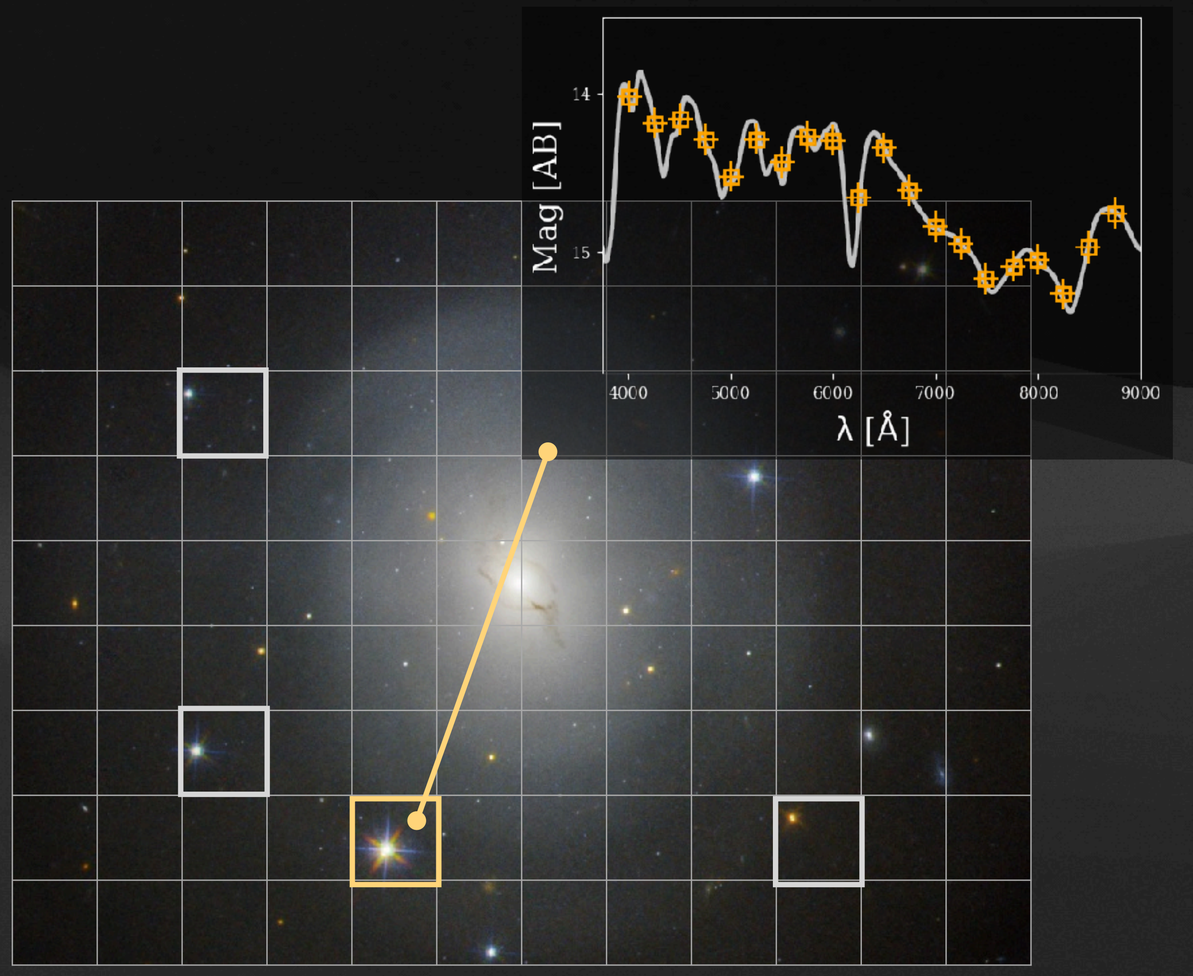
* First light of 7DT #1-4 is planned in June

Credit: M. Jeong & M. Hyun

Advantages of 7DT

Low-resolution Spectral Imaging





Classify **multiple** transients with a **single epoch** SED

G. Paek et al. in prep.

Rapid Identification of Early Kilonova with Automatic System in O4 Run

2 / month

GW Events including more than one NS

Reference

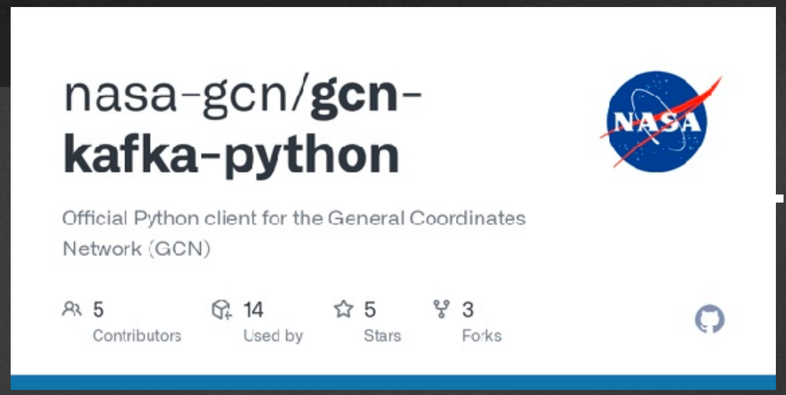
READY

READY

🚨 GW Alert

Check Significance (interesting or not?)

Alert Distributer as `json`



GECKO Digestor

slack

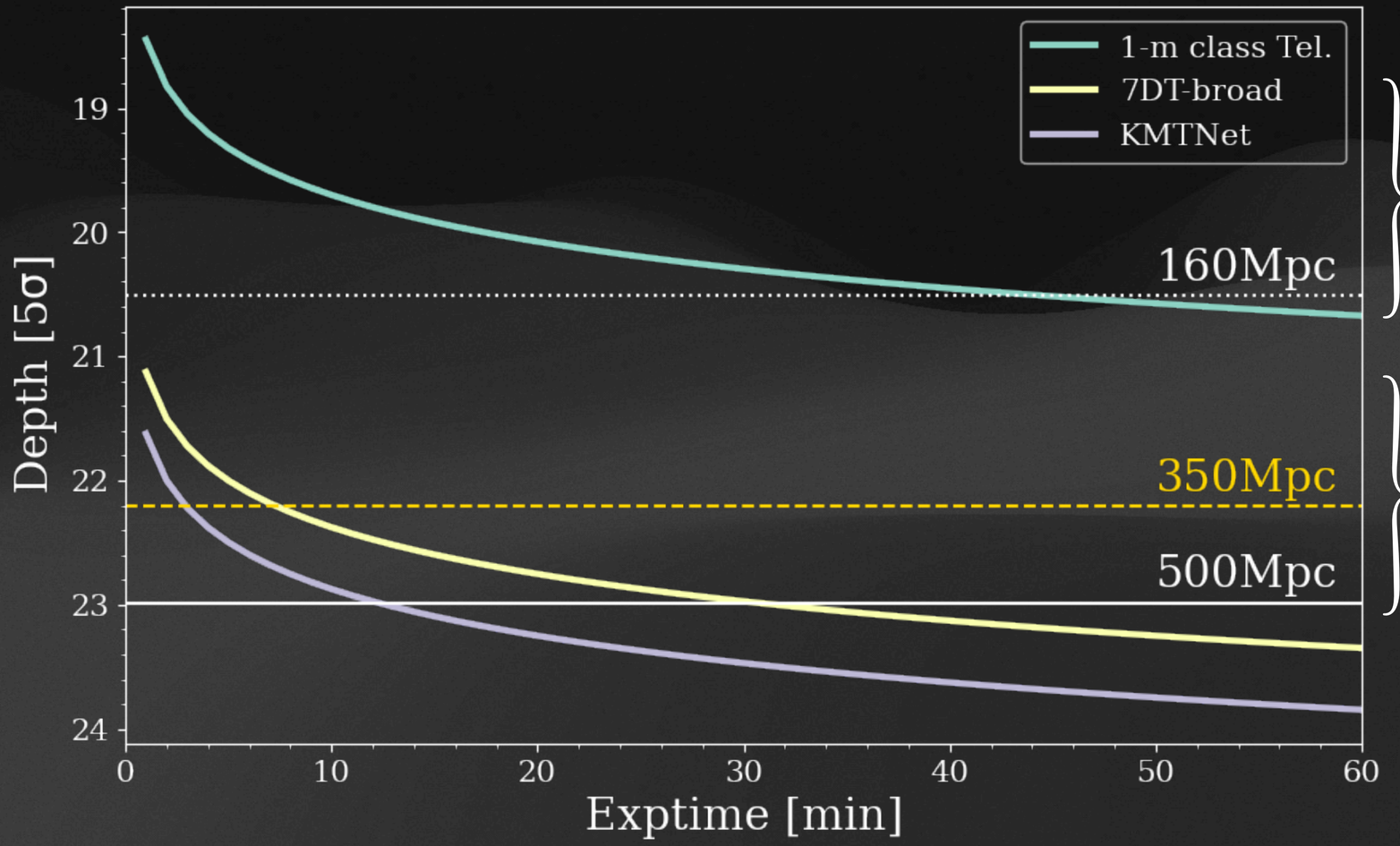
🤔 Should We Follow up? Or Not?

```
{   "alert_type": "Preliminary",

    "superevent_id": "MS181101ab",

    "event": {


        "significant": False      # FAR > 1/month CBC and 1/year BURST
                       True       # FAR < 1/month CBC and 1/year BURST
        "instruments": [ "H1", "L1", "V1"],
        "group": "CBC",


        "classification": { "BNS": 0.95, "NSBH": 0.01, "BBH": 0.03, "Terrestrial": 0.01},
        "properties": { "HasNS": 0.95, "HasRemnant": 0.91, "HasMassGap": 0.01},

         },
```

+ d_{GW}, S_{GW}, High-E Det.

Depends on our resource & capability

How Far Can We Detect a KN?



1-m Tel.
d<160 Mpc

7DT & KMTNet
d<500 Mpc

cf) 350Mpc: Data-driven 90% Median Distance in O4
(Petrov+21)

OBSERVATION

READY

🚨 GW Alert

Check Significance (interesting or not?)

- Galaxy catalog matching
- Prioritization of galaxies (tiles)

Elahe & Mankeun

OBS.

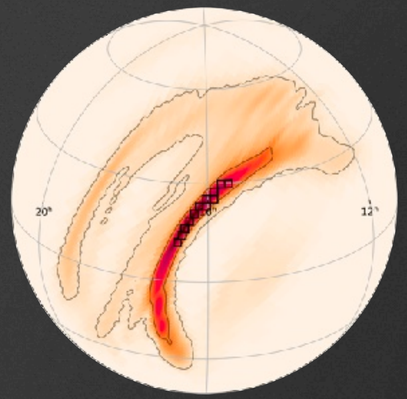
Analyze the Localization

Set Obs. configurations

Obs. Request

Observation & Data Upload

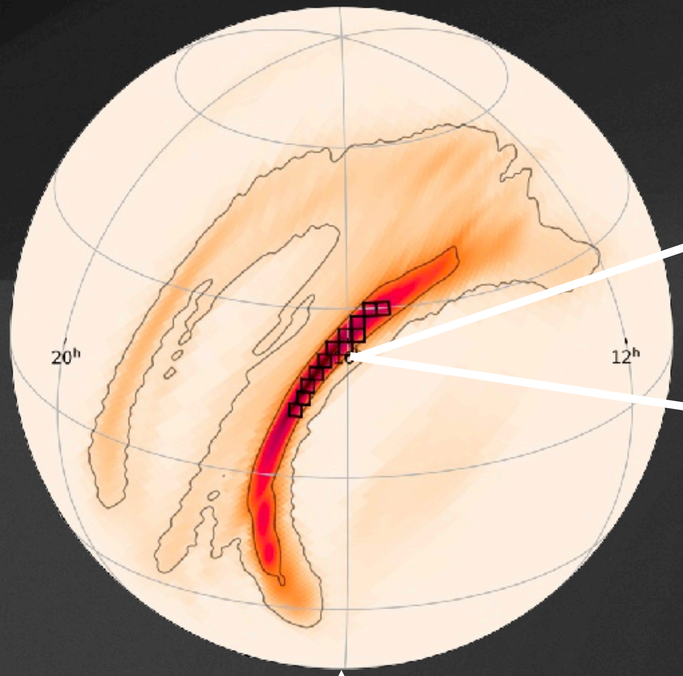
Location of GW source with Prob.



- 🤖 Robotic Telescope: Machine-Readable Script
- 🙏 Manual Telescope: Target List

Follow-up Strategies

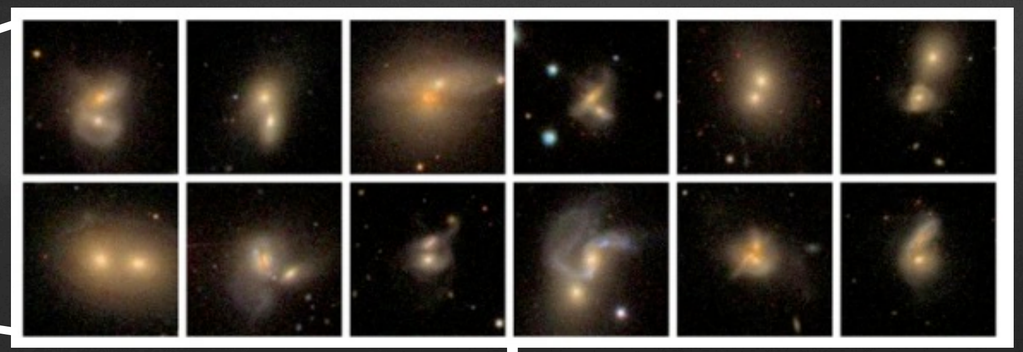
1. Tiling observation



2. Galaxy-targeted observation

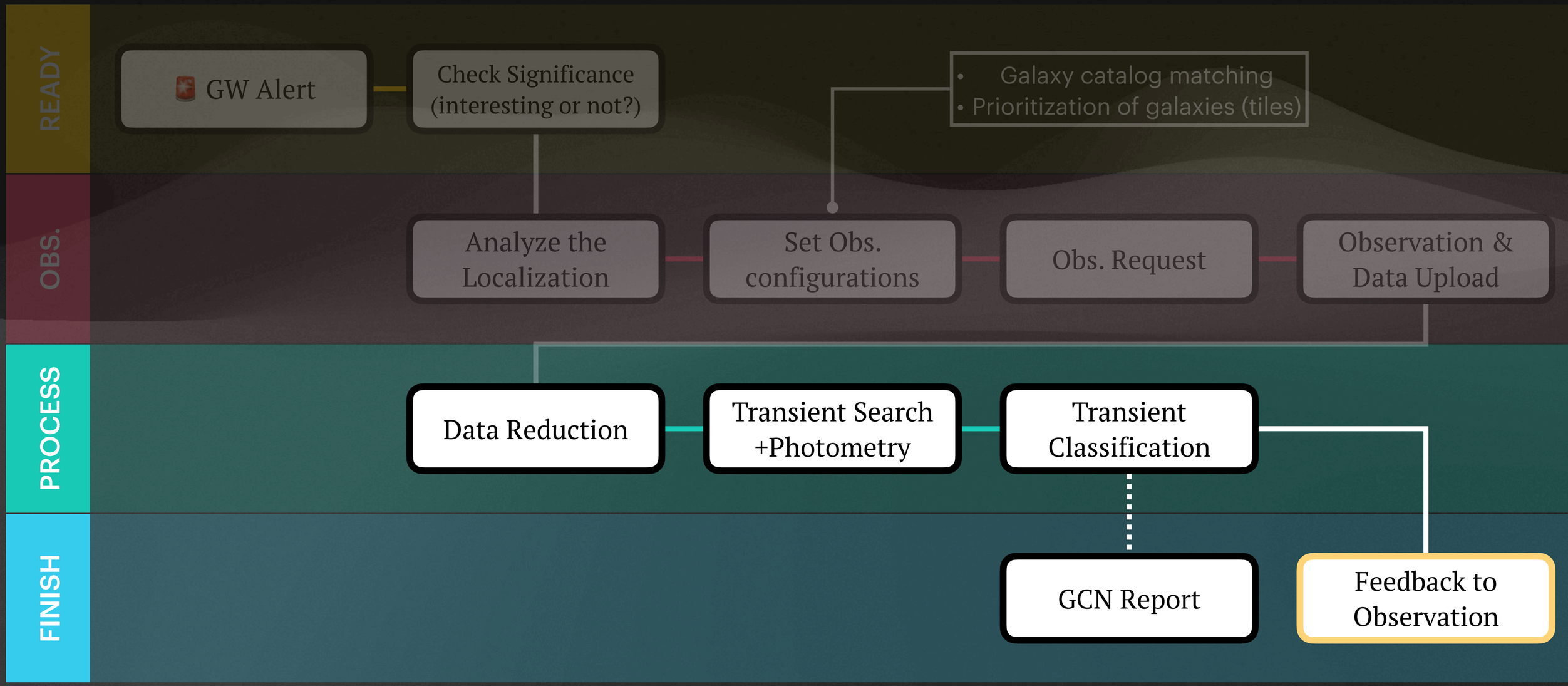
→ Matching with galaxies from GLADE+ catalog (Dalya+21)

→ Prioritizing them based on $P_{3D} \times M_*$ (Artale+19)



Prioritizing pre-determined tiles (Khalouei+in prep)

PROCESS & FINISH



Optical Follow-up of The First NSBH Event in O4

S230518h

Summary

S230518h The First NSBH Event in O4

5월 18일 목요일

GECKO-bot 앱 오후 10:38

ER15: This is a REALEVENT from the GW detectors! GraceID: S230518h (PRELIMINARY), MergerTime: 2023-05-18 12:59:08.167000+00:00, HasNS: 1.0, FAR: 3.218261352069347e-10, Event page: https://gracedb.ligo.org/superevents/S230518h/view/, GECKO page: http://qso.snu.ac.kr:8179/superevents/S230518h/

✅ 4 👀 1

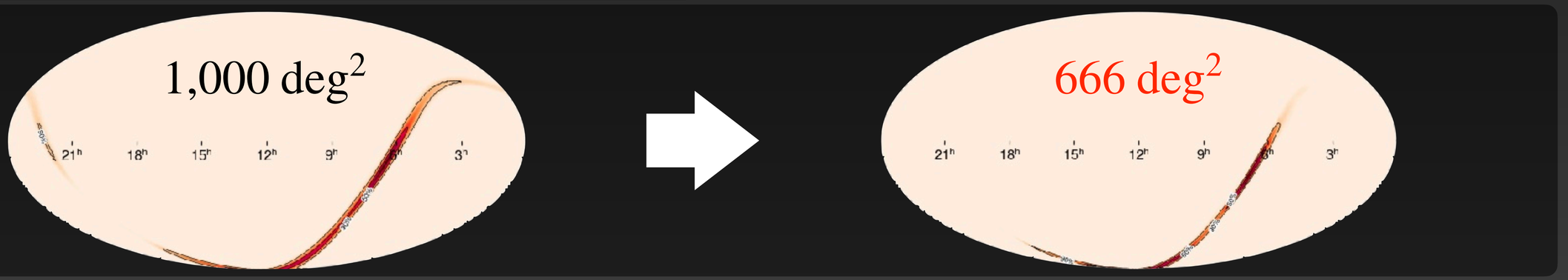
847개의 댓글 24일 전 마지막 댓글

GECKO-bot 앱 오후 11:27

[GeckoDigestor] Process is done for S230518h-PRELIMINARY (qso:../output/S230518h-PRELIMINARY)

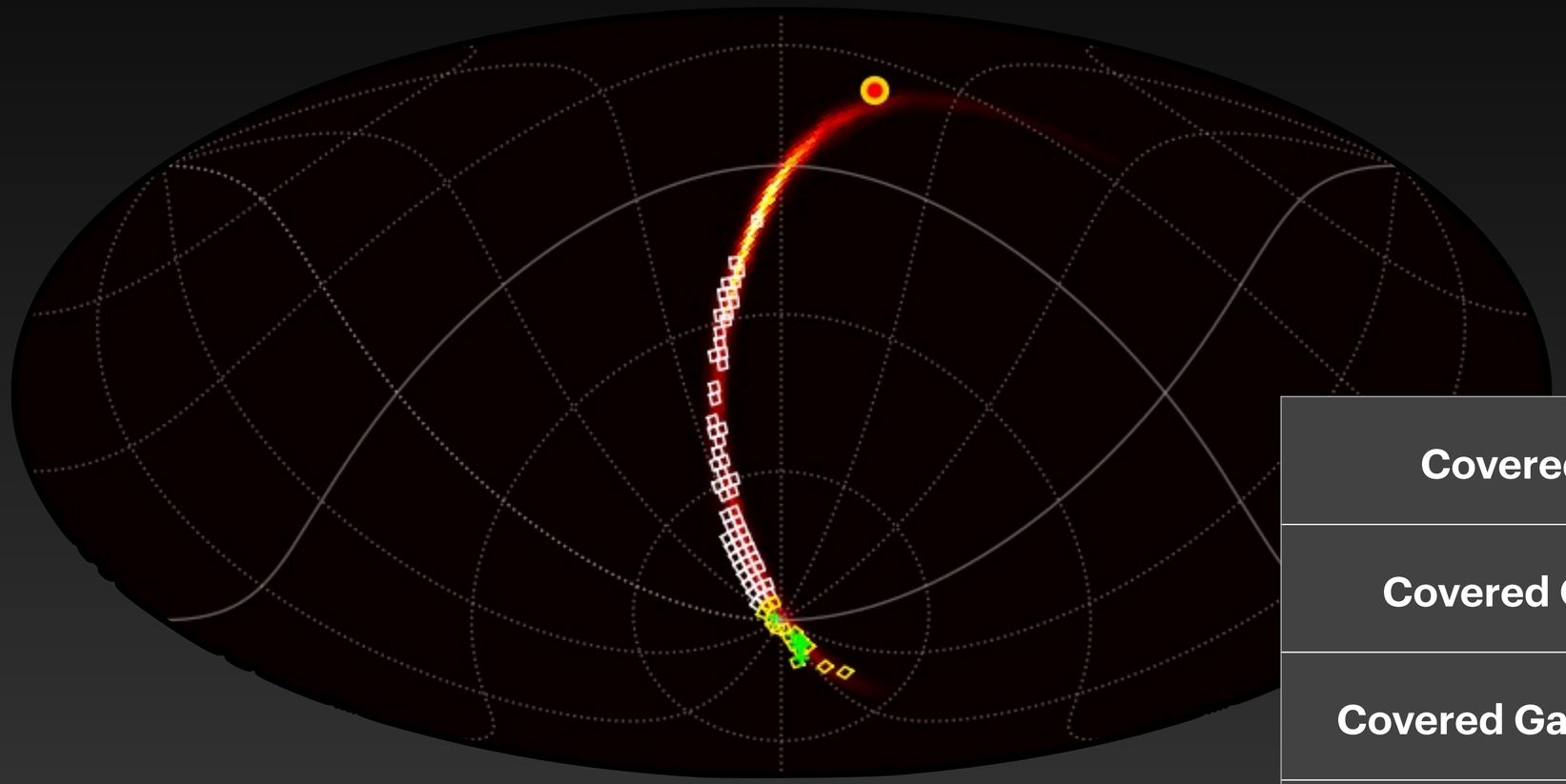
event	S230518h_PRELIMINARY
trigger_time	2023-05-18T12:59:08.167Z
process_start	2023-05-18T14:20:21.906Z
process_time(sec)	531.5
phase(day)	0.1
classification	NSBH(86.4265%)
distance(Mpc)	275.5+/-78.9
area_90%(deg2)	1001.5
radec_max(deg)	357.188,34.591
radec_max(hmsdms)	23:48:45.00,+34:35:26.07
n_host_galaxy_all	50767
n_host_galaxy_90%	18500
n_host_galaxy_50%	2856

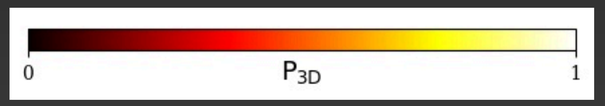
- 2023-05-18 22:38 (KST)
  - Initial: 05-19 01:00 (KST)
- (FAR) ~ 1/100yr
- $d_{GW} \sim 276 \pm 79$ Mpc
- NSBH (86%), HasNS: 1.0, HasRemnant: 0.0



Result

Challenging Observation



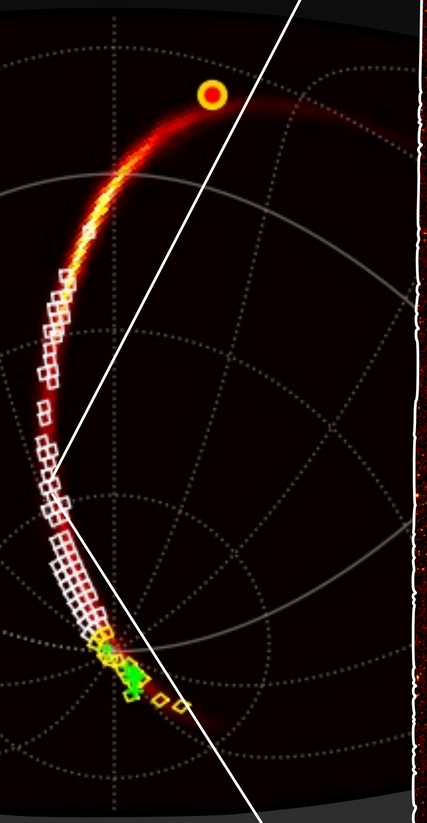


KMTNet (4 deg^2)

RASA36 (6.76 deg^2)

\+ LSGT

Covered Area	300 deg2 (45%)
Covered Galaxies	14K (52%)
Covered Galaxy Score	49%
Transient Candidates	48K+α → … (AI tech)



Moon

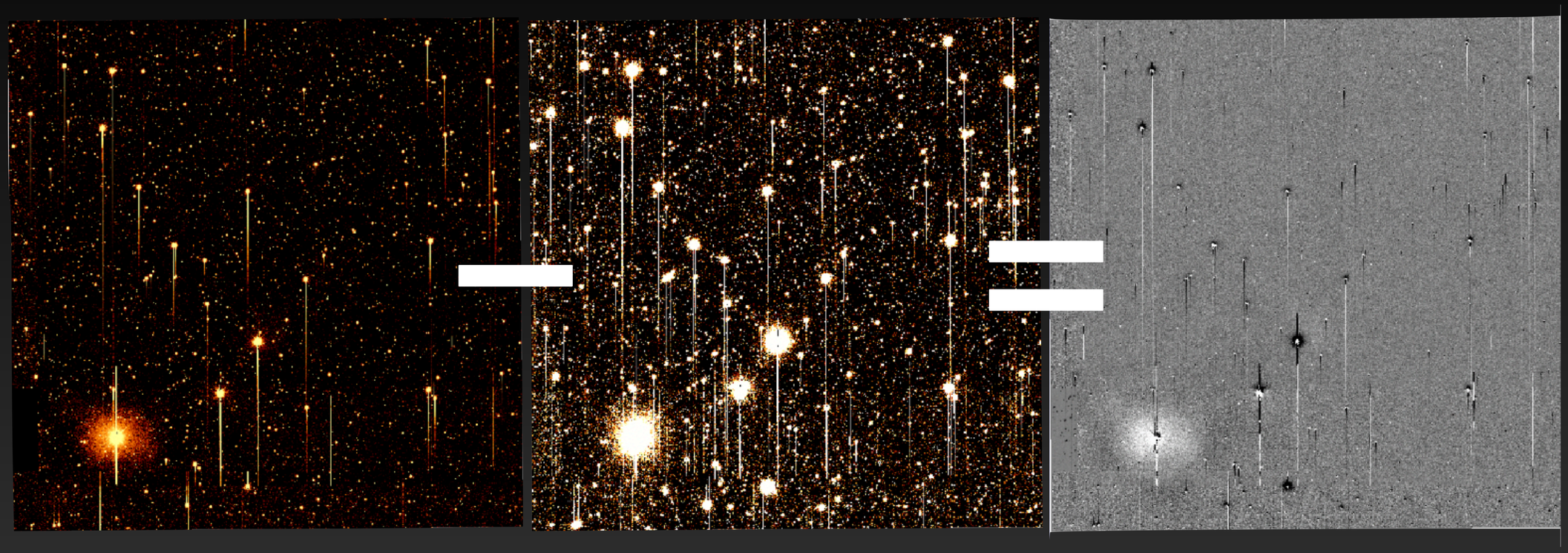
Moon (~ 0.2 deg^2)

Moon

KMTNet (4 deg^2)

x60

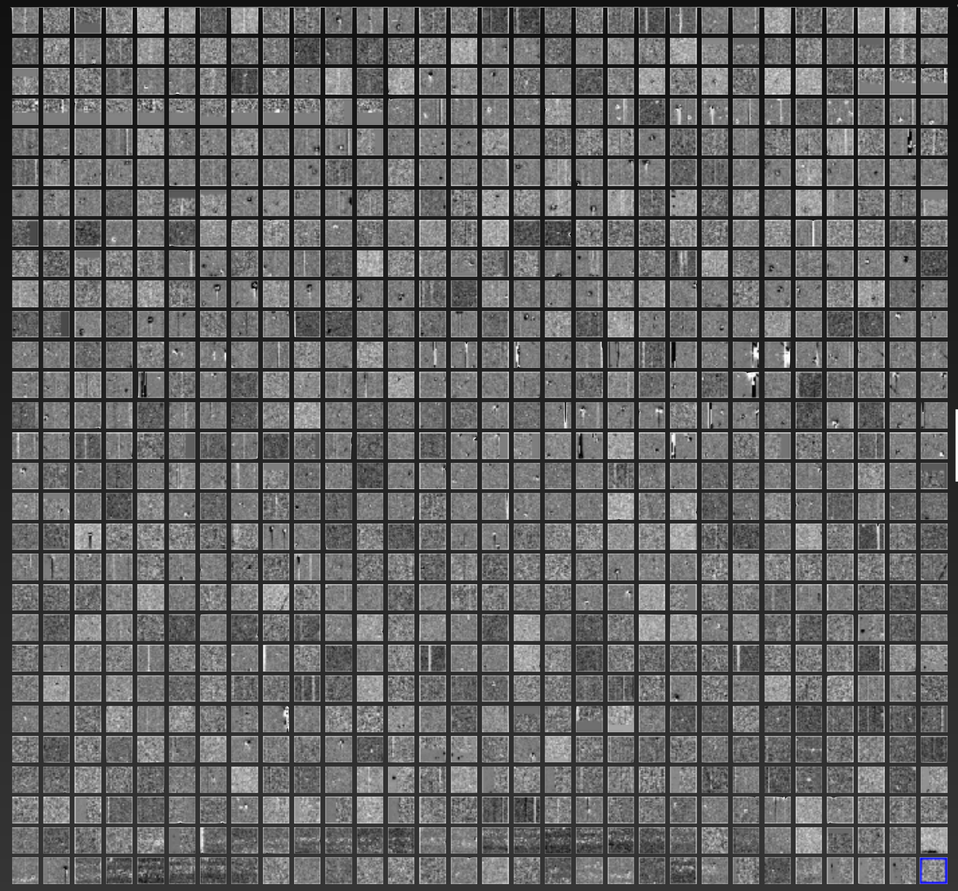
Observed Image Reference Image Subtracted Image



2023.05.18 2023.03.05

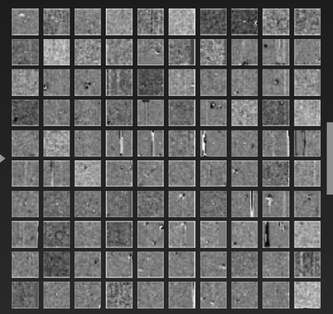
Transient Candidates

🔍 Detections 3M



🕸️ Filtering with Parameters
(*Source EXtractor*)

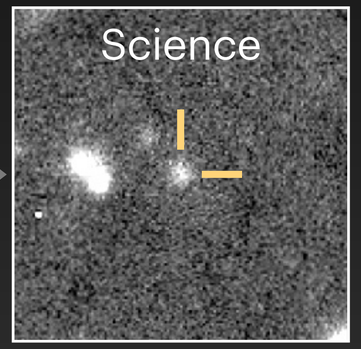
1.5K

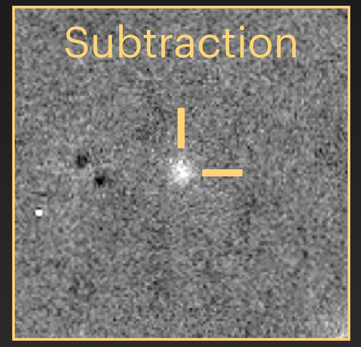


🤖 AI Classification
(*CNN*)

D.G. Lee & S.H. Lee (POSTECH)

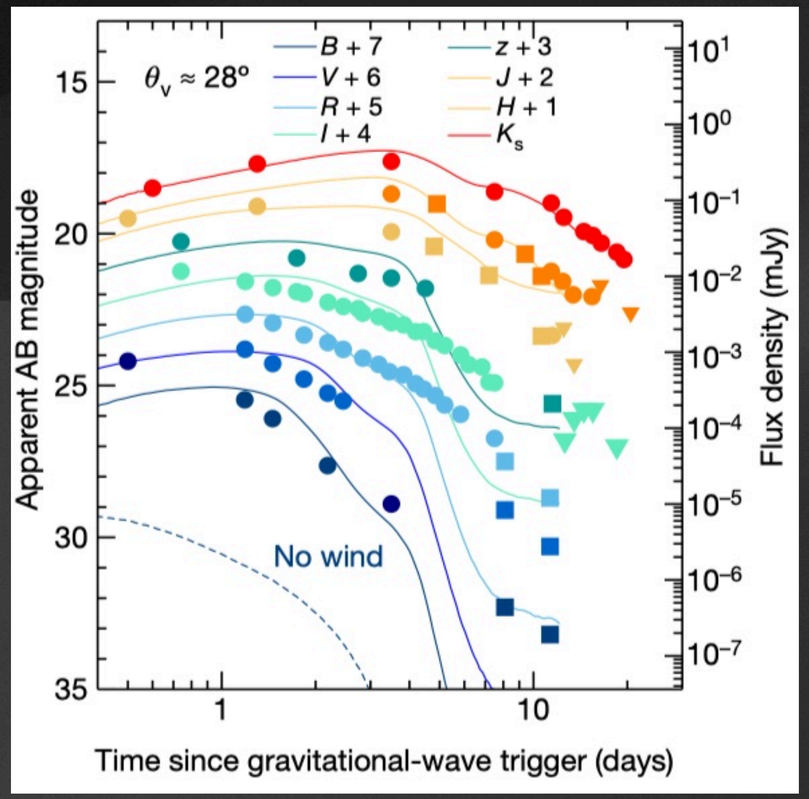
<5%





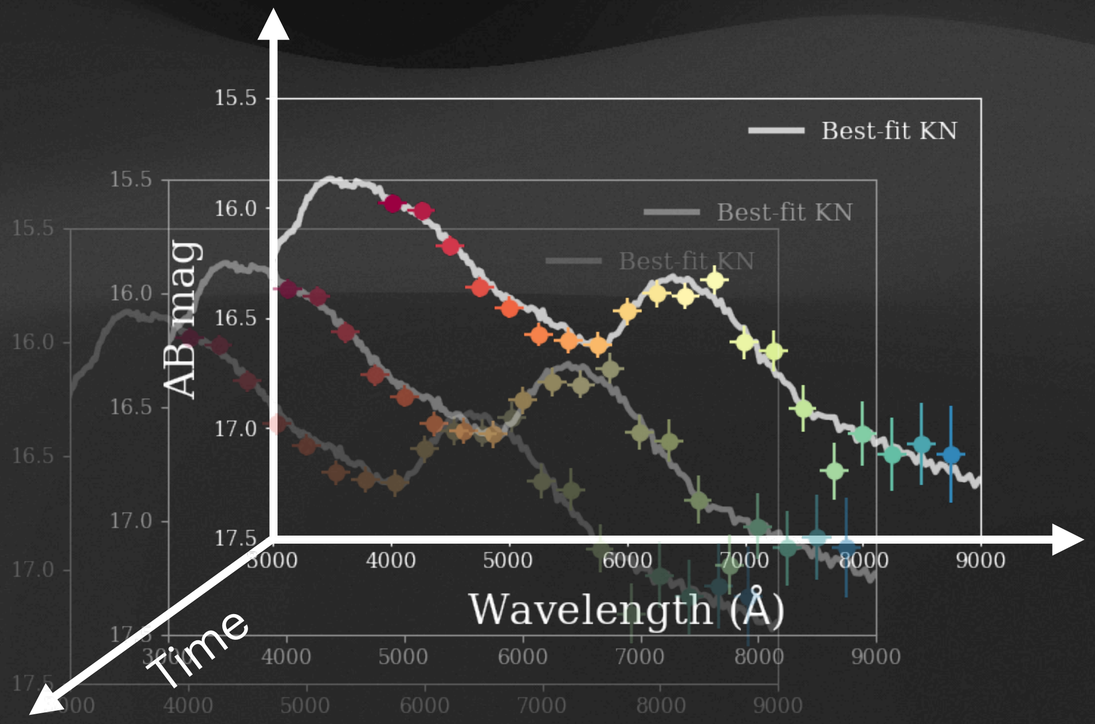
Expected Data Outcome

Broad-band Light Curve



Troja, ..., Im+17

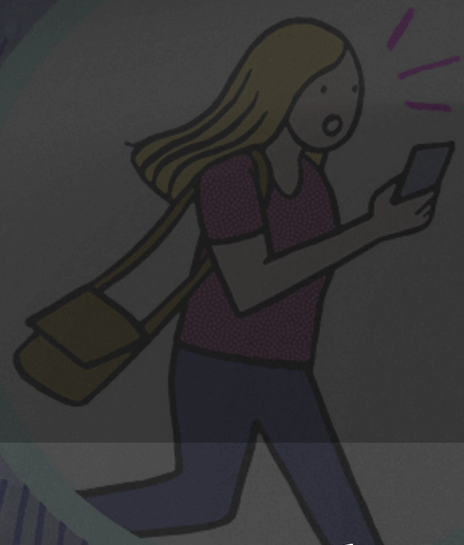
⭐ Time-series SED (*7DT)



Summary

- GECKO with 7DT is GW optical follow-up project in Korea
- We did ***massive*** follow-up observation of the 1st NSBH event in O4
- No EM counterpart found yet, but many chances will be wait for us in O4!

★ ***STAY TUNED!***



Gregory Paek @SNU

Fin