Searching for EM Counterpart of GW Source with KMTNet

MMA workshop 2020

2020.02.05

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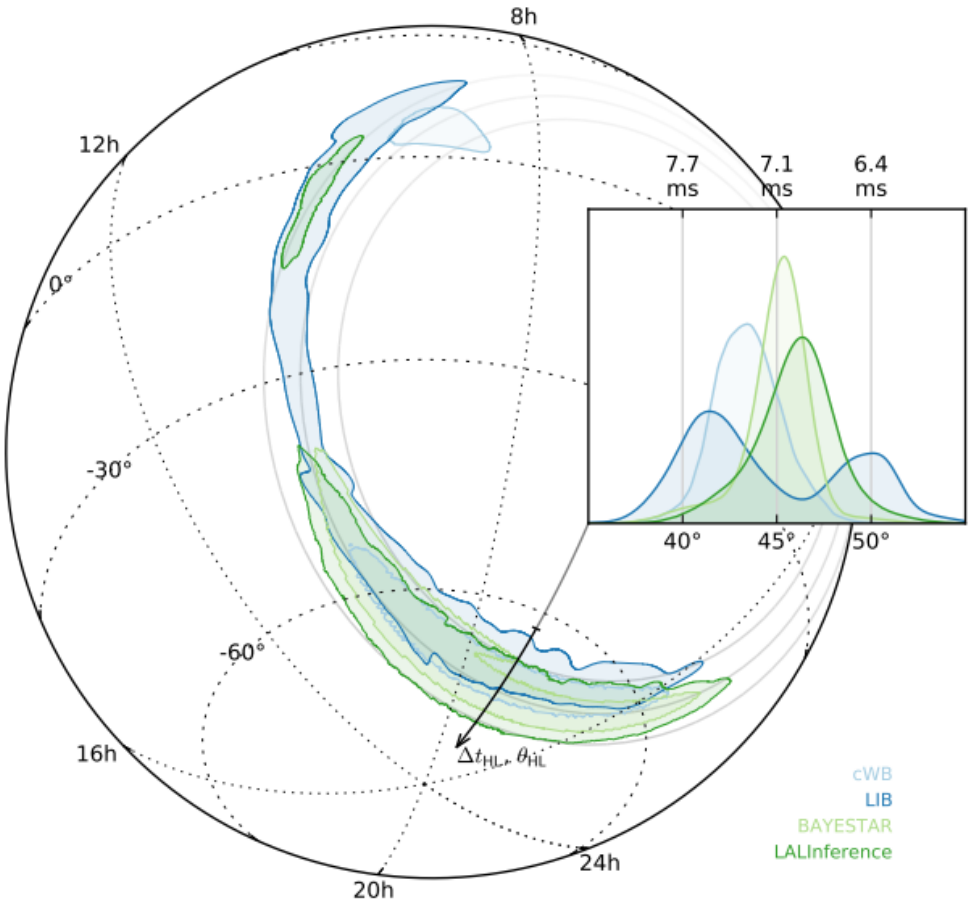
1st GW detection: GW150914

- GW150914
  - Binary black holes
  - Localization ~ $600\ deg^2$
- EM detection of GW
  - Position
  - Distance & redshift
  - Collision mechanism
  - Progenitor
  - Environment

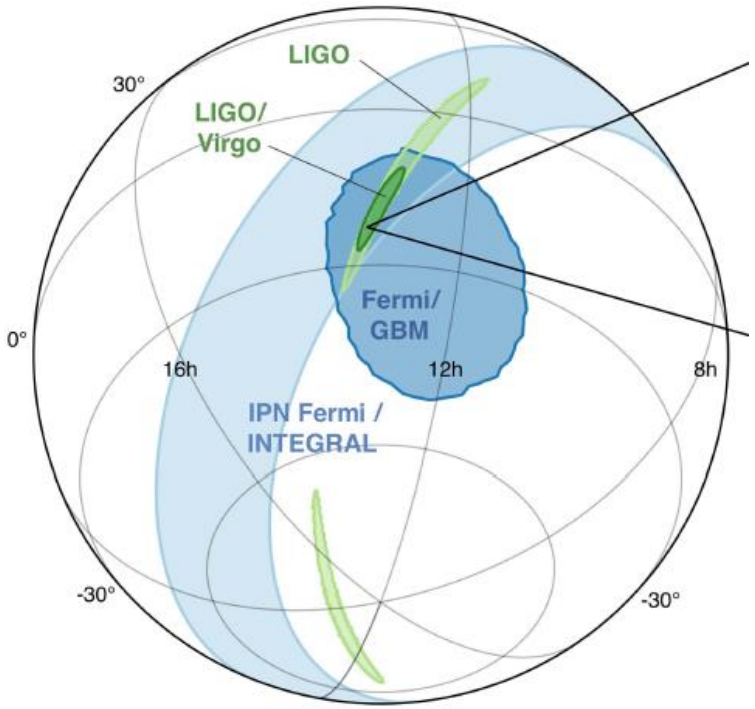
Abbott et al. 2016



1st EM counterpart: GW170817

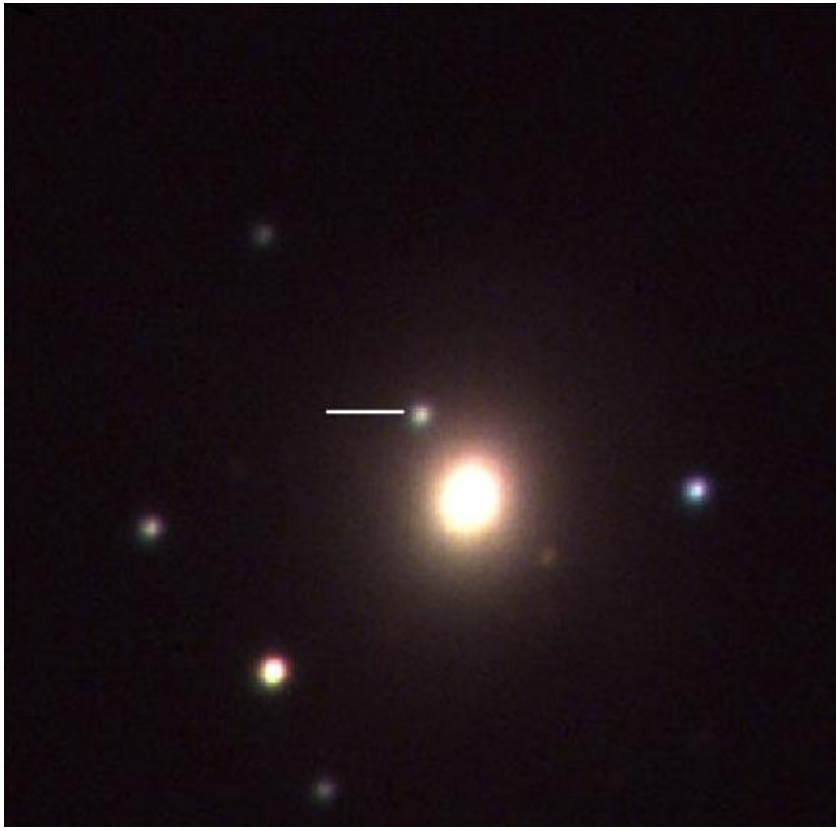
- GW170817
  - 2017.08.17 12:41:04 UTC
  - Binary neutron stars merger
  - Distance ~ $40^{+8}_{-8}\,Mpc$
  - Localization ~ $30\,deg^2$
- GRB
  - +2 seconds
  - Off-axis GRB
- Optical counterpart
  - +11 hours
  - Kilonova in NGC4993
  - First optical counterpart of GW
  - Multi-messenger astronomy

Abbott et al. 2017



1st EM counterpart: GW170817

- KMTNet SAAO
  - +28 hours
  - BVRI
- KMTNet data
  - SAAO, CTIO, SSO
  - 2018.08.18 - 24
  - I-band 17 – 21 mag



Im et al. 2017

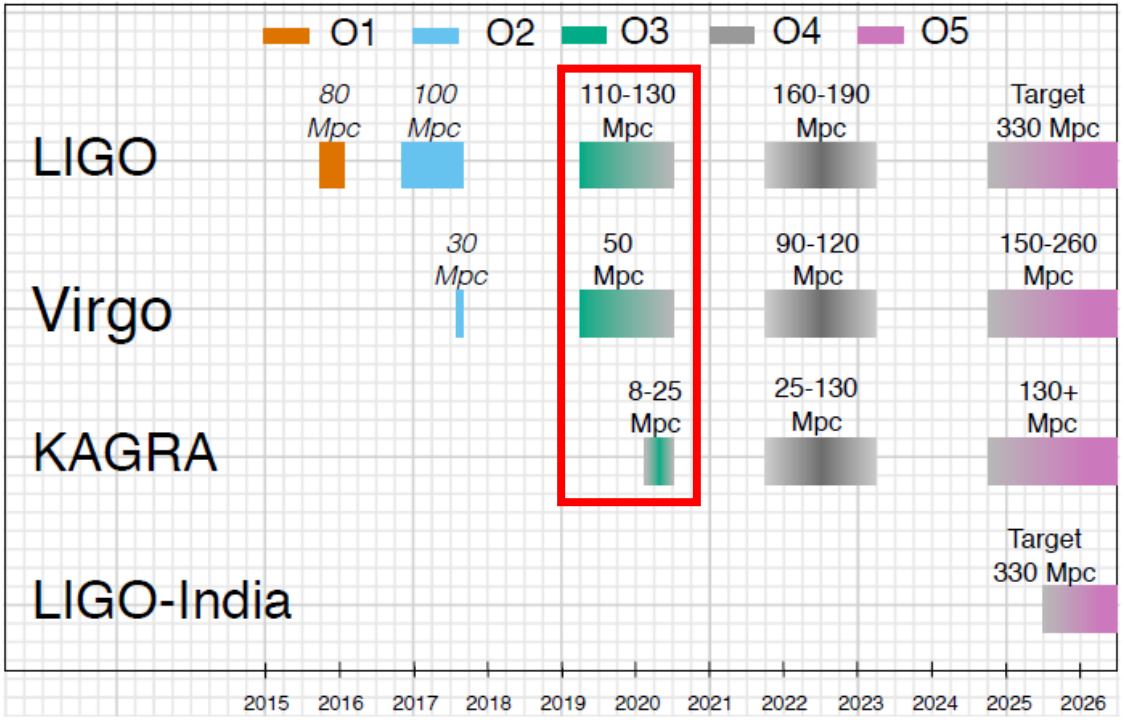
1st EM counterpart: GW170817

- 3 Papers
  - Multi-messenger astronomy
    - Abott, … , 임명신, 최창수, 김준호, 윤용민, 임구, 이성국, 이충욱, 김승리, 고승원, 조정우, 권민경, 김부진, 임상규, 최정식, … , et al. 2017, ApJL
  - X-ray & optical counterpart
    - Troja, … , 임명신, 이성국, 최창수, 김준호, 김승리, 이충욱, 이형목, 임구, 윤용민, … , et al. 2017, Nature
  - Characteristics of host galaxy NGC4993
    - 임명신, 윤용민, 이성국, 이형목, 김준호, 이충욱, 김승리, Troja, 최창수, 임구, 고종완, 심현진, 2017, ApJL

- 2 Awards
  - 2017 올해의 과학자상 수상
    - 임명신 서울대 교수, 한국중력파연구협력단 (단장 이형목 서울대 교수 등 25명)
  - 2018 국가연구개발 우수성과 100선 선정
    - 한국천문연구원 이충욱, 김승리, 이동주, 김동진, 차상목, 이용석, 김현우, 임진선, 김부진, 임상규, 권민경, 최정식, 고승원, 유성현

O3 run

- O3 run: 2019 Apr~
  - Higher sensitivity



Abott et al. 2020

O3 run

- O3 run: 2019 Apr~
  - Higher sensitivity

Observation Run	Network	Expected BNS Detections	Expected NSBH Detections	Expected BBH Detections
O3	HLV	1^{+12}_{-1}	0^{+19}_{-0}	17^{+22}_{-11}
O4	HLVK	10^{+52}_{-10}	1^{+91}_{-1}	79^{+89}_{-44}
		Area (deg^2) 90% c.r.	Area (deg^2) 90% c.r.	Area (deg^2) 90% c.r.
O3	HLV	270^{+34}_{-20}	330^{+24}_{-31}	280^{+30}_{-23}
O4	HLVK	33^{+5}_{-5}	50^{+8}_{-8}	41^{+7}_{-6}

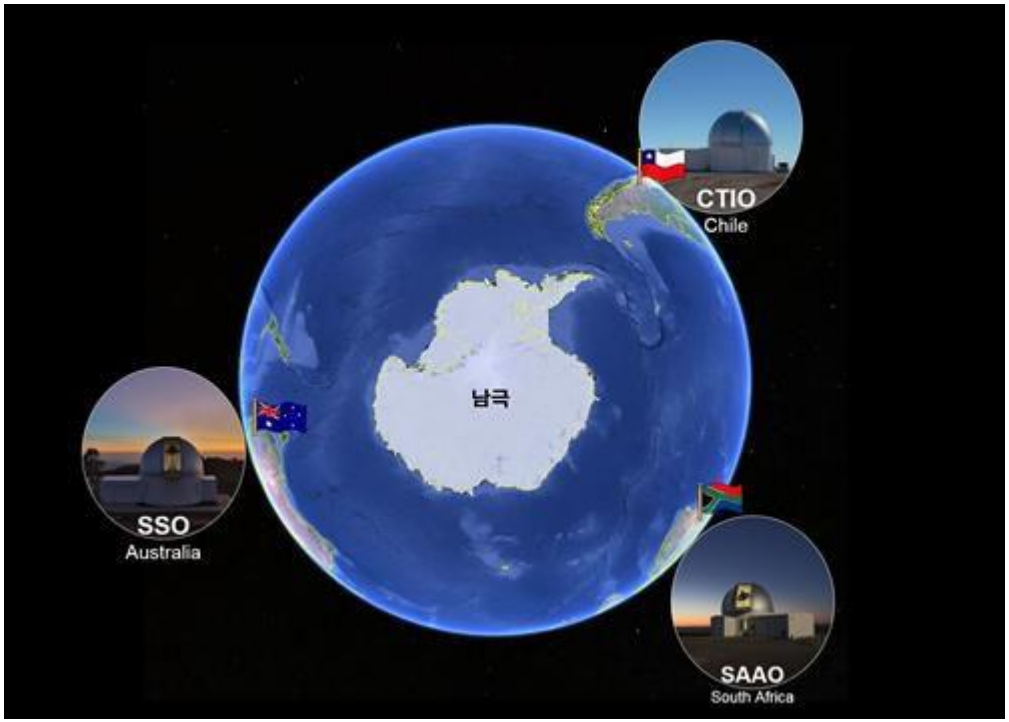
Abott et al. 2020

KMTNet

- Three 1.6m telescopes on three sites
  - Australia, Chile, South Africa
  - The observatory on which stars never set

- Enough depth
  - KMTNet depth ~ 22 mag (240s in R band)
  - Kilonova at 330Mpc

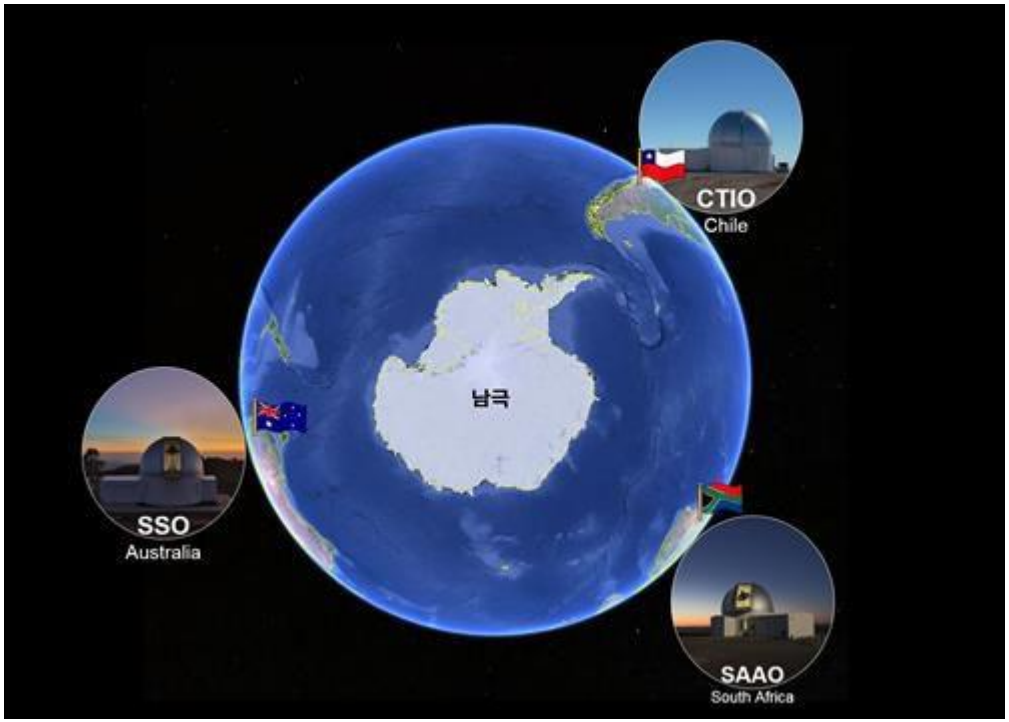
  → 21.5 mag in R band



KMTNet

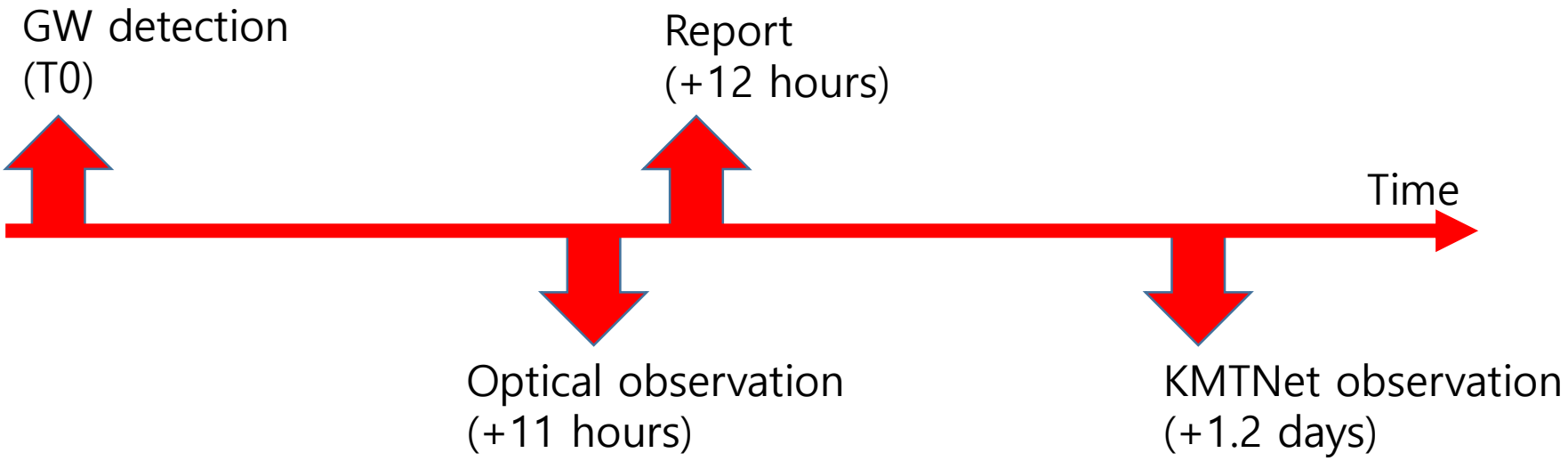
- Large field of view
  - 2 deg x 2 deg
  - 270 deg^2
  - → 68 observation

- Example
  - 15 arcmin x 15 arcmin
  - 270 deg^2
  - → 4320 observation



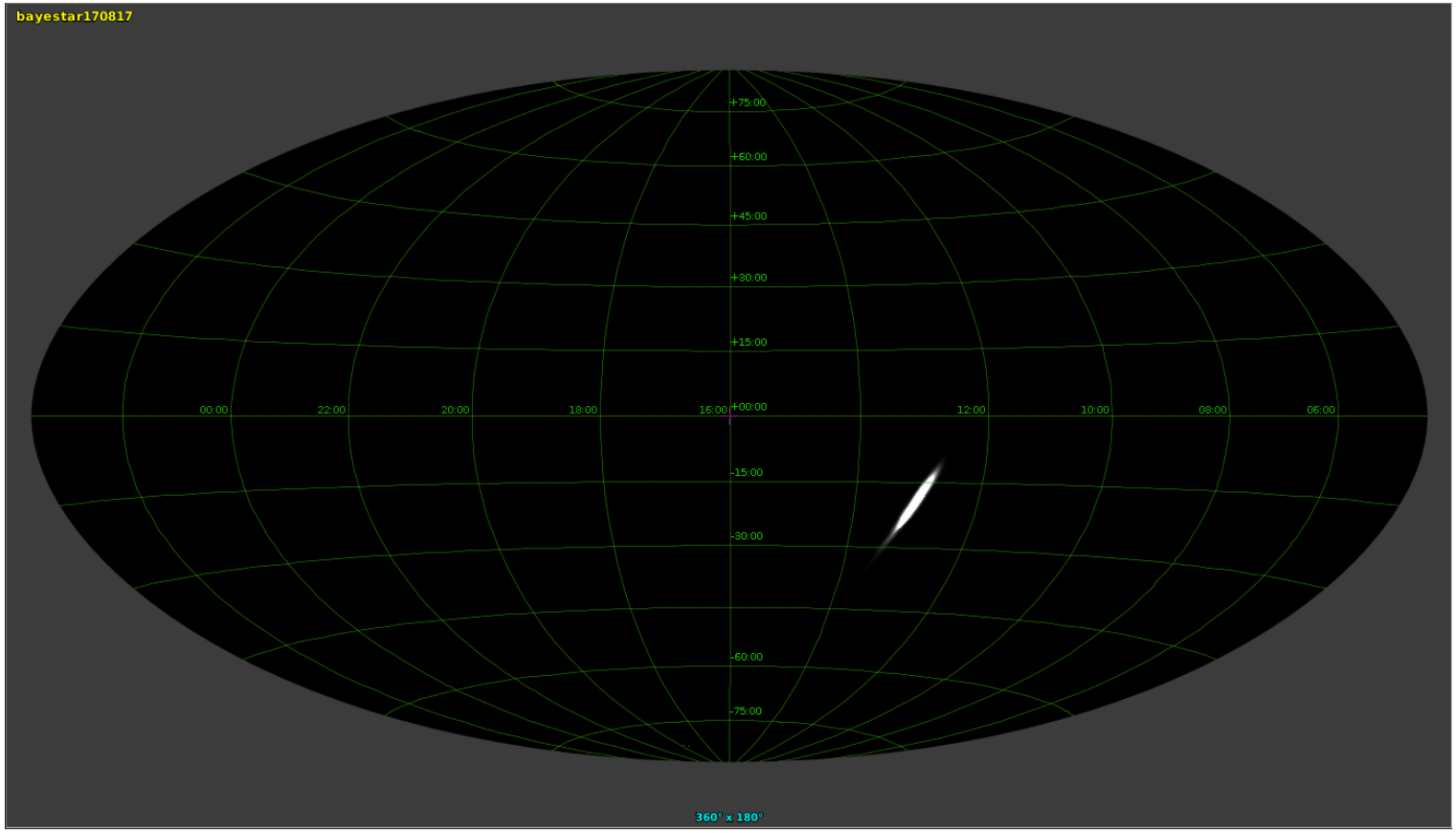
Our goal

- O3 run: 2019 Apr~
- Goal: observation before 1st report of GW optical counterpart

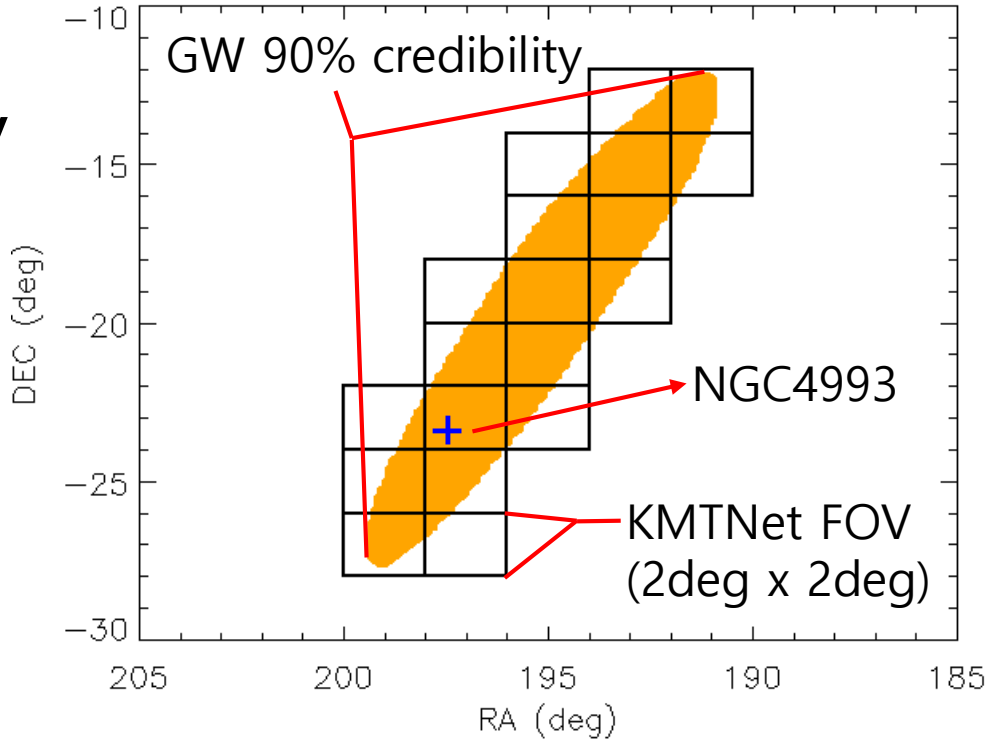


Searching strategy

- Localization map [probability / pixel]
  - GW170817



Searching strategy



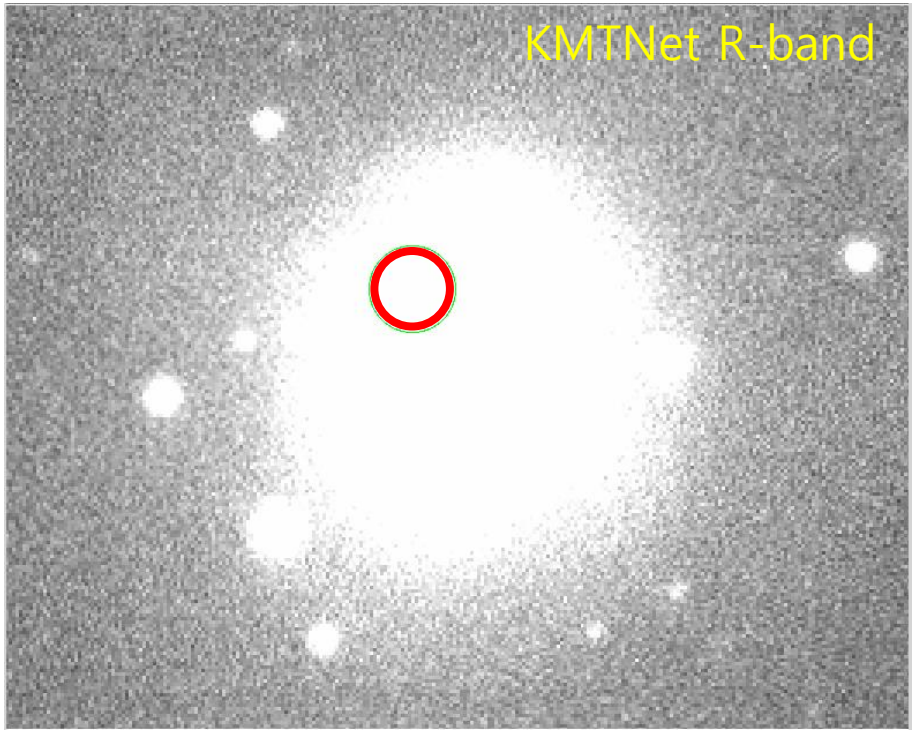
- Tiling observation
- Test with GW170817
  - GW 90% credibility
    Localization ~ 30 deg^2
    → 19 KMTNet Fields
- Band and exposure
  - B, R bands
  - 120s x2 with dithering
    (Image depth, 240s R band, 5σ → ~22 mag)
  - → Total 152 min exposure
    (228 min with overhead time)
- Make KMTNet observation script automatically
- Check visibility, KMTNet operation, observation time, …

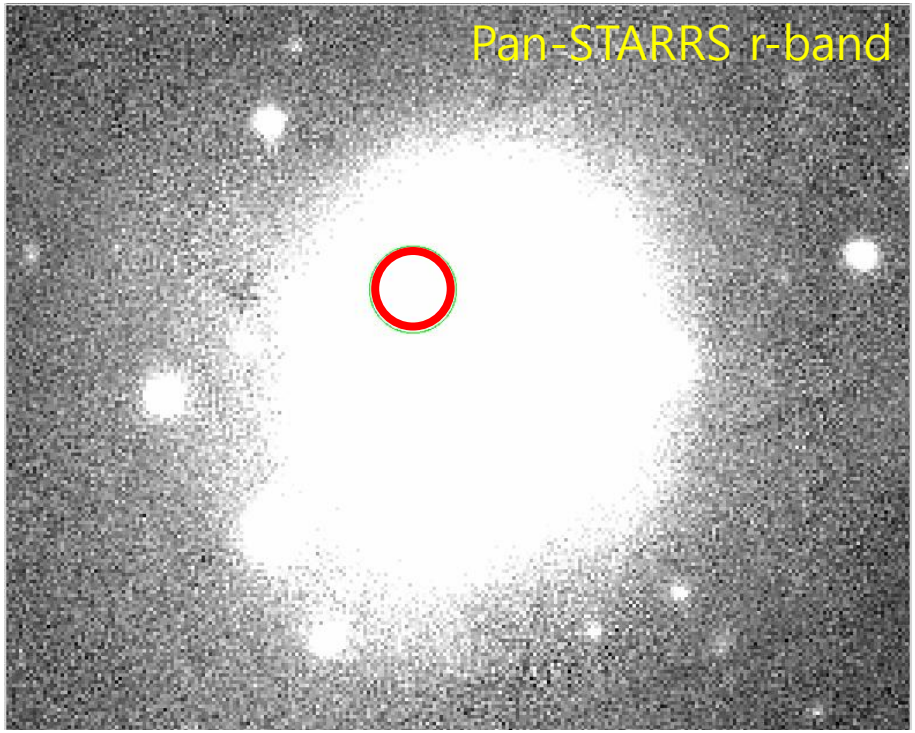
Searching strategy

GW type	Localization area	Filter set	Time/event	Event rate per year
BNS or NSBH	~5 deg^2	B, V, R, I	~80 min	3
	~20 deg^2	B, R	~100 min	15
	~150 deg^2	R or B	~300 min	42
BBH	~5 deg^2	R	~20 min	15
Unexpected	Any	R	~150 min	0.1

Searching strategy

- Around host galaxy candidates
- Image subtraction
  - KMTNet image - Pan-STARRS image





Searching strategy

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- Image subtraction
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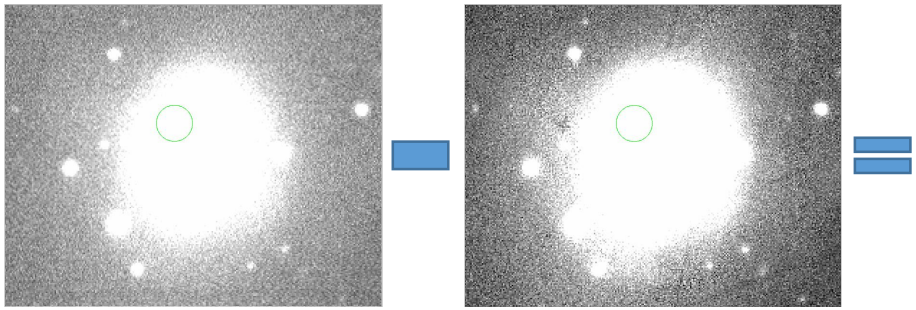
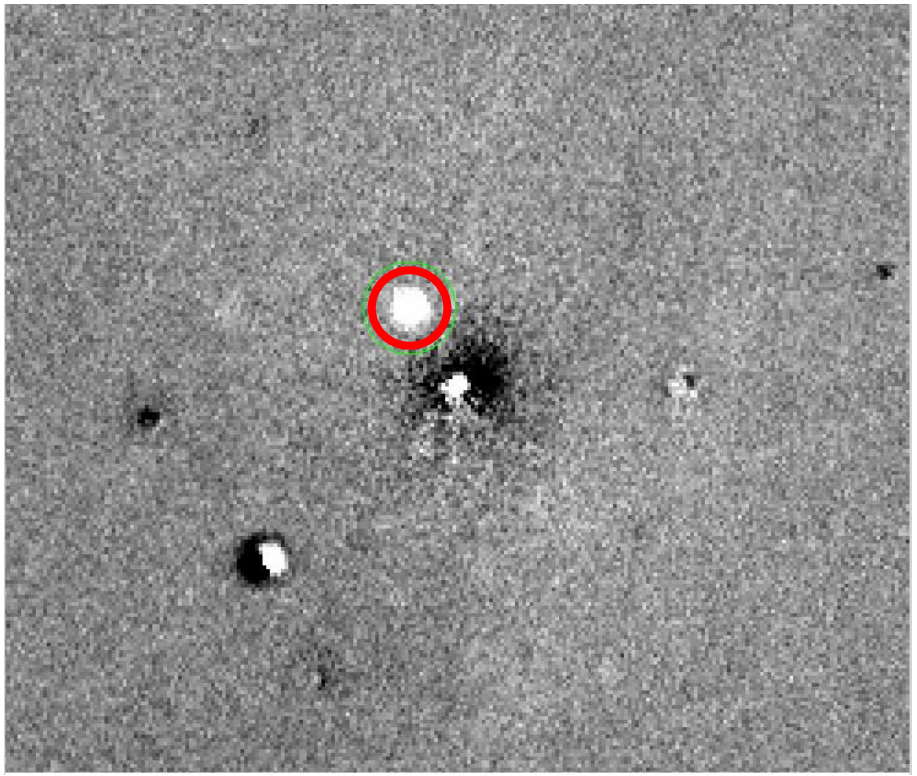




- Find optical counterpart
- Photometry
- GCN circular report

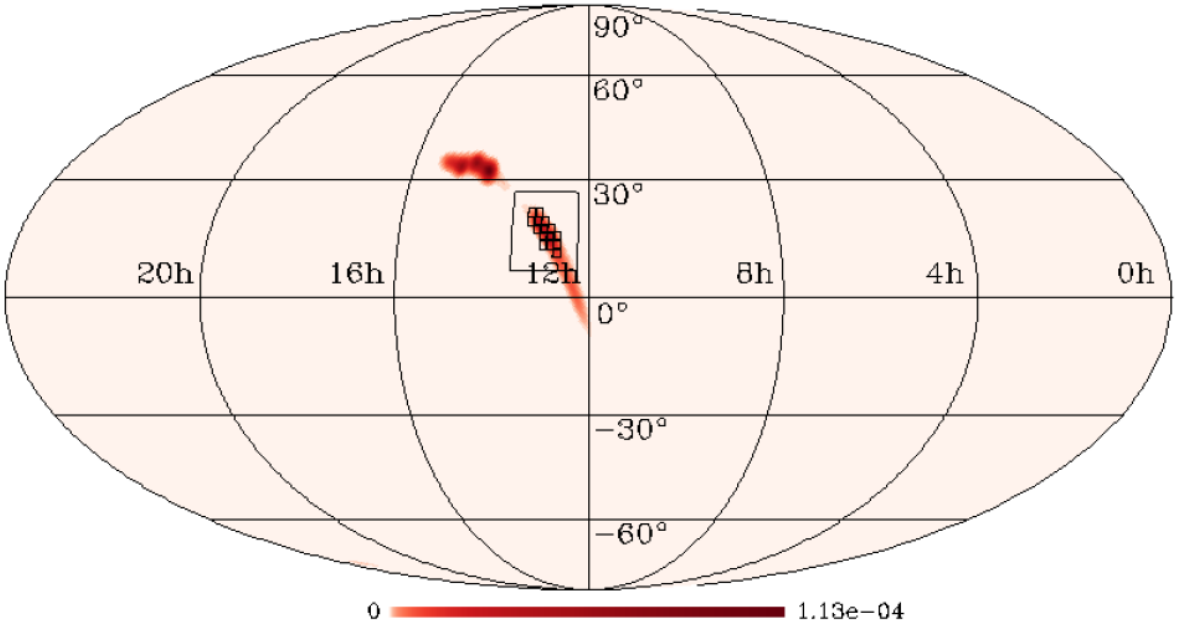
- Follow-up observation
  - Gemini
  - UKIRT

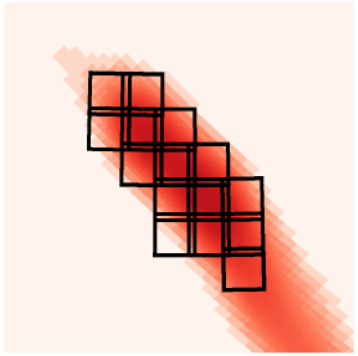
Observation result

Event	Class	Localization [deg^2]	Distance [Mpc]	Start time from alert	Number of field
S190408an	BBH	387	1478	100 minutes	8
S190412m	BBH	156	812	6 hours	15
S190425z	BNS	7461	156	4 hours	200
S190503bf	BBH	448	421	4 hours	13
S190510g	BBH	1166	227	150 minutes	28
S190701ah	BBH	49	1849	12.5 hours	12
S190814bv	NSBH	23	267	8.5 hours	18
S200114f	IMBH	403	?	9.5 hours	24

Observation result

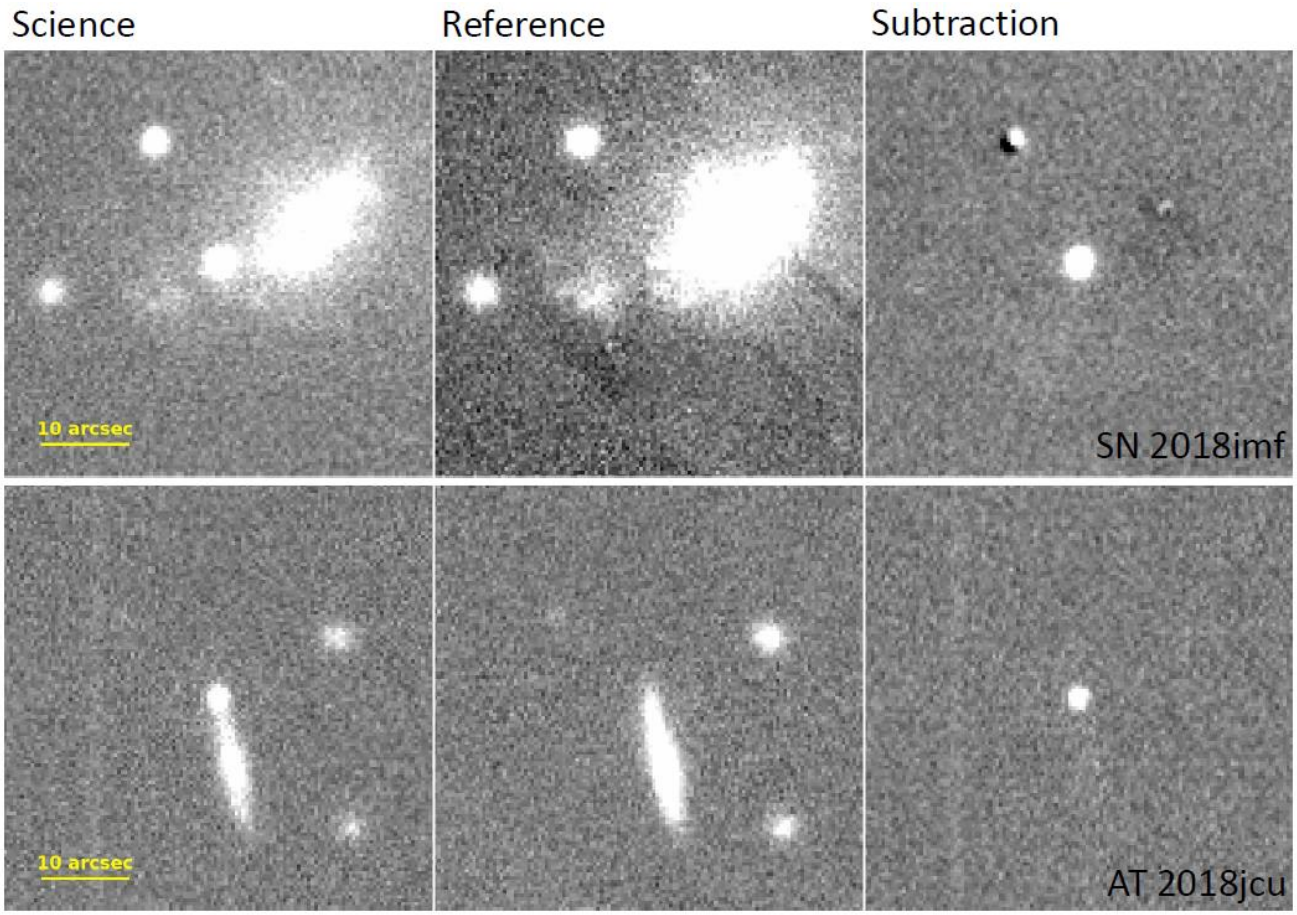
S190412m





Kim et al. in preparation

Observation result



Kim et al. in preparation

Summary

- KMTNet observation of 1st GW EM counterpart GW170817
- Use KMTNet to discover GW EM counterpart
- Tiling observation of KMTNet
- Image subtraction and find transient
- 8 observation during O3 run

Searching strategy

- Time for this process
  - One KMTNet field: $4\ deg^2$
  - 10 galaxies in the field

  - Astrometry
  - Image combine
  - Pan-STARRS image download
  - Image subtraction

  → ~8min

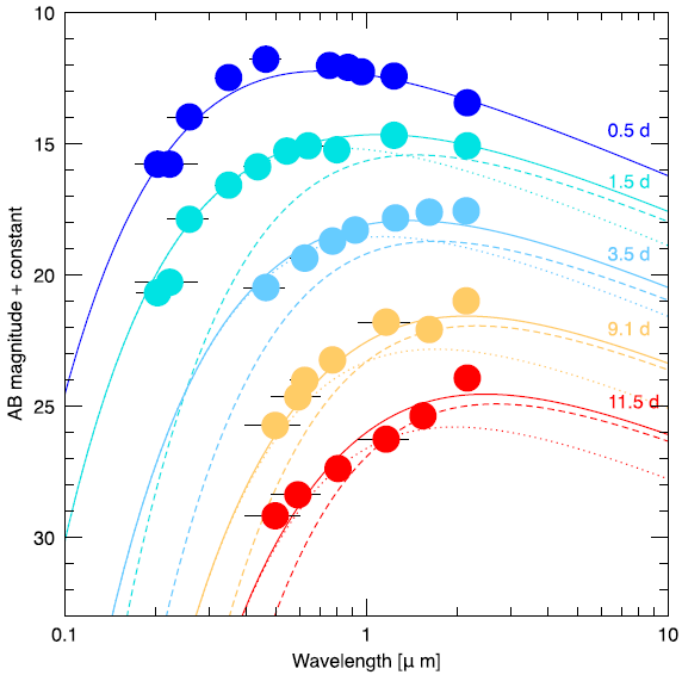
Searching strategy

- 240s depth (R band, 5σ) → ~22mag

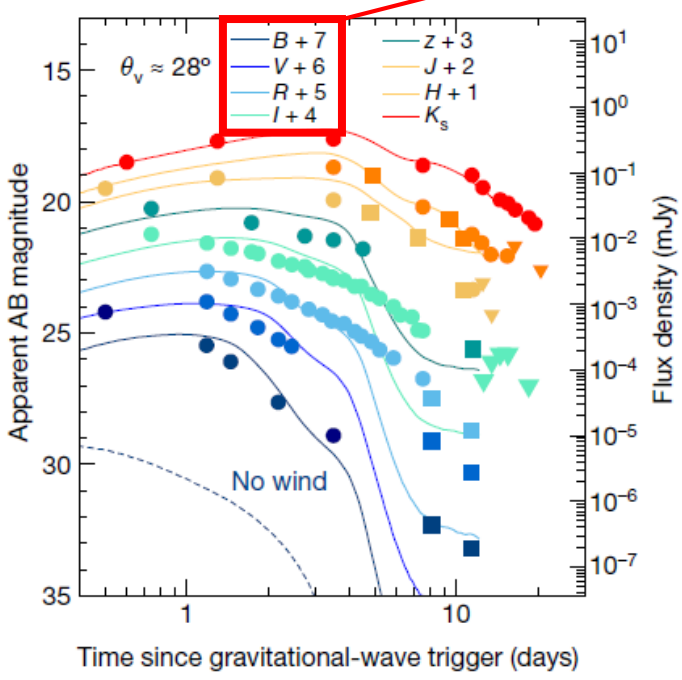
- Expected apparent magnitude
  - Suppose same absolute magnitude with GW170817
  - 100 Mpc → 19 mag
  - 200 Mpc → 20.5 mag
  - 1500 Mpc → 25 mag

GW study

- Constrain kilonova model
  - Two blackbody component
  - Off-axis kilonova with viewing angle ~28 deg



KMTNet data



Troja et al. 2017

GW study

- Characteristics of host galaxy NGC4993
  - SED modeling
  - Distance, age, star formation, stellar mass, …

Im et al. 2017