

# 重力波源の光赤外追観測

富永望  
(甲南大学)



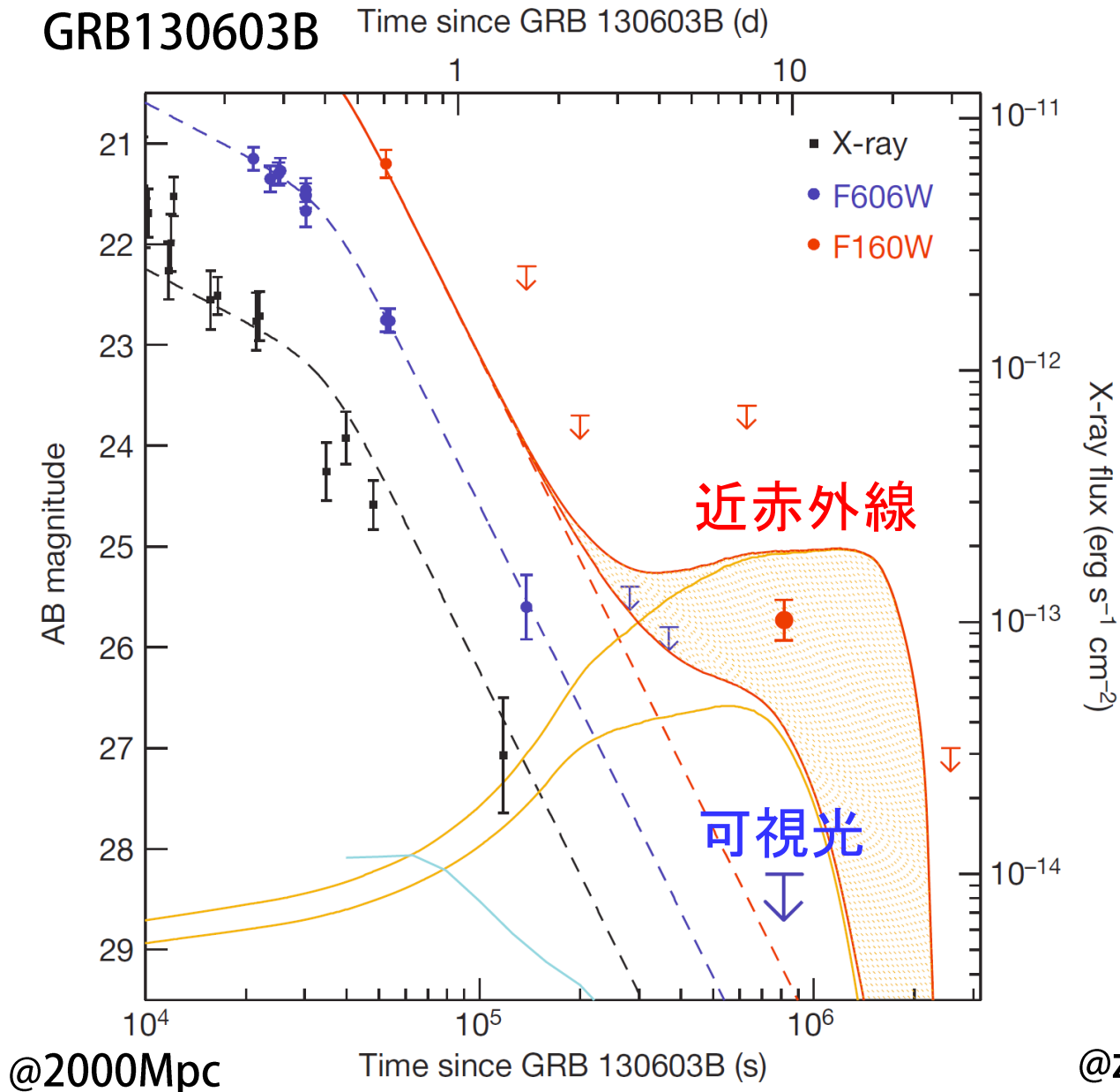
1<sup>st</sup> Oct 2018  
第17 回DECIGO ワークショップ

# 目次

- Kilonova/Macronova
- Subaru/Hyper Suprime-Cam
- GW170817
- DECIGO/B-DECIGOへの期待

Kilonova/Macronova

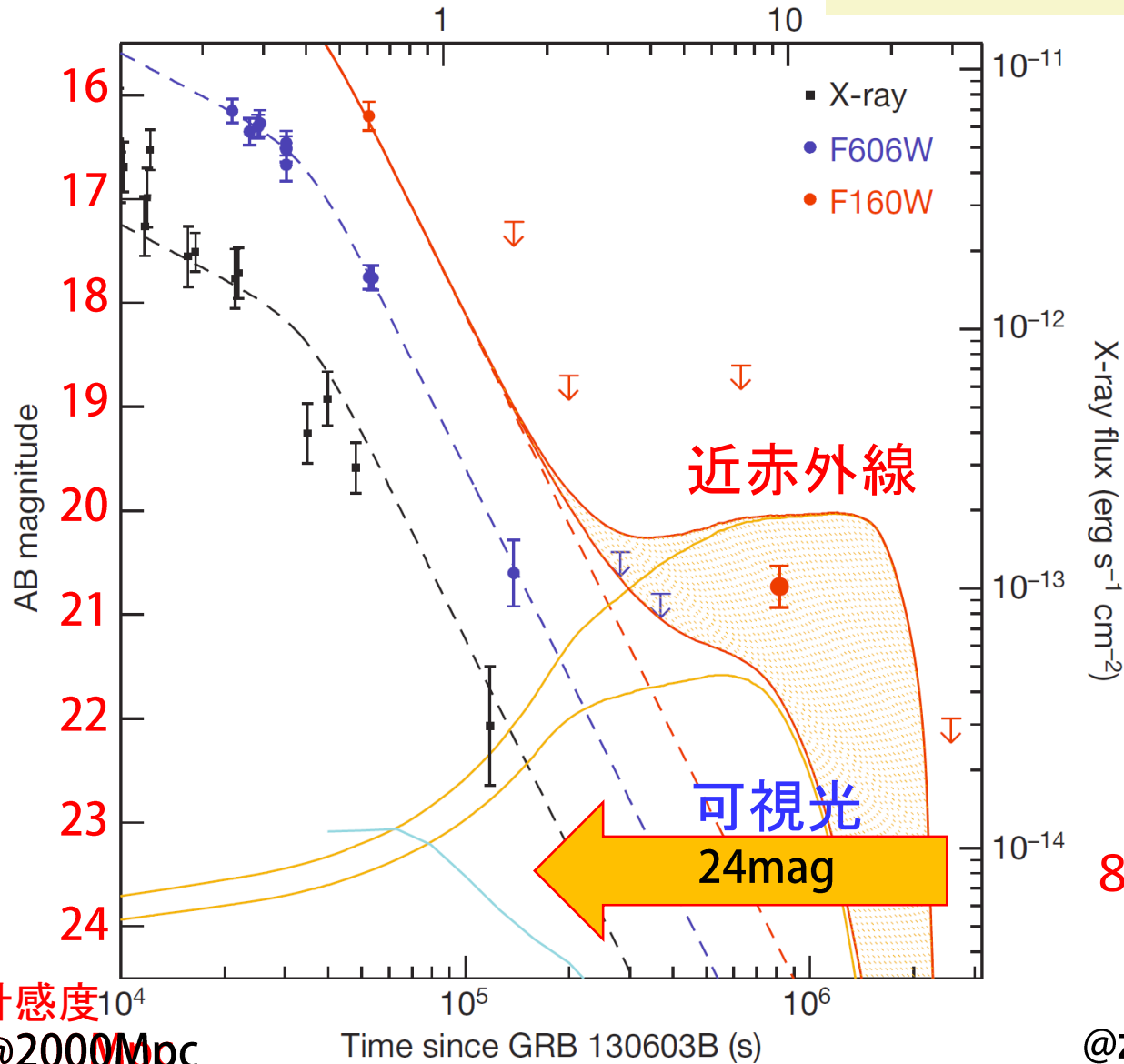
# sGRB残光中の赤外超過



# sGRB残光中の赤外超過

Kilonova/Macronova

GRB130603B Time since GRB 130603B (d)



8m望遠鏡が必要

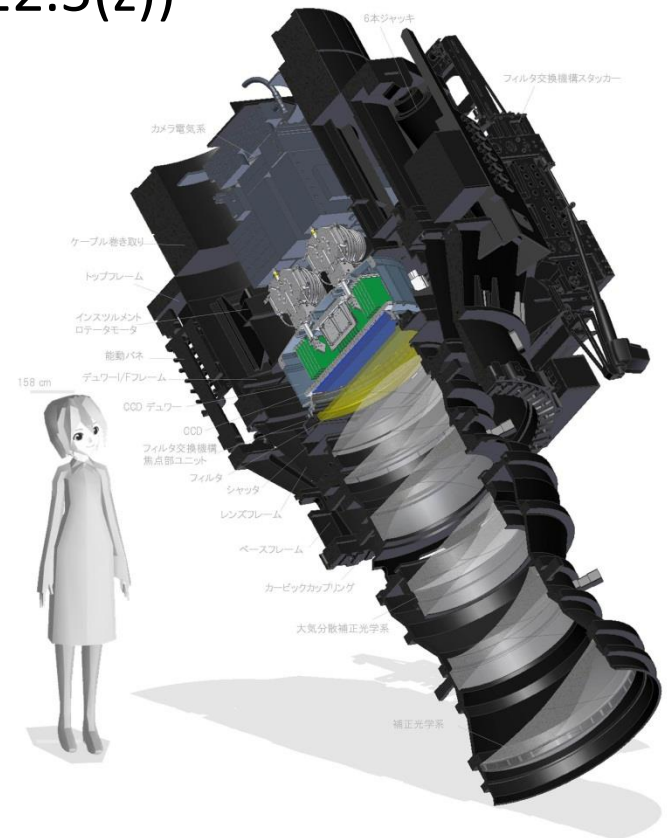
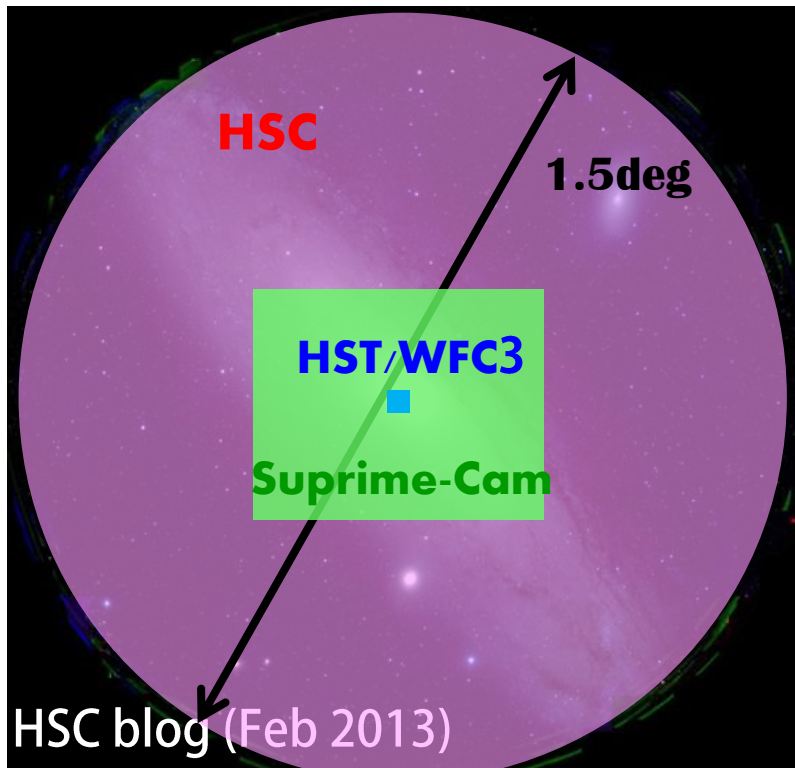
LIGO設計感度  
@2000Mpc

@z=0.356

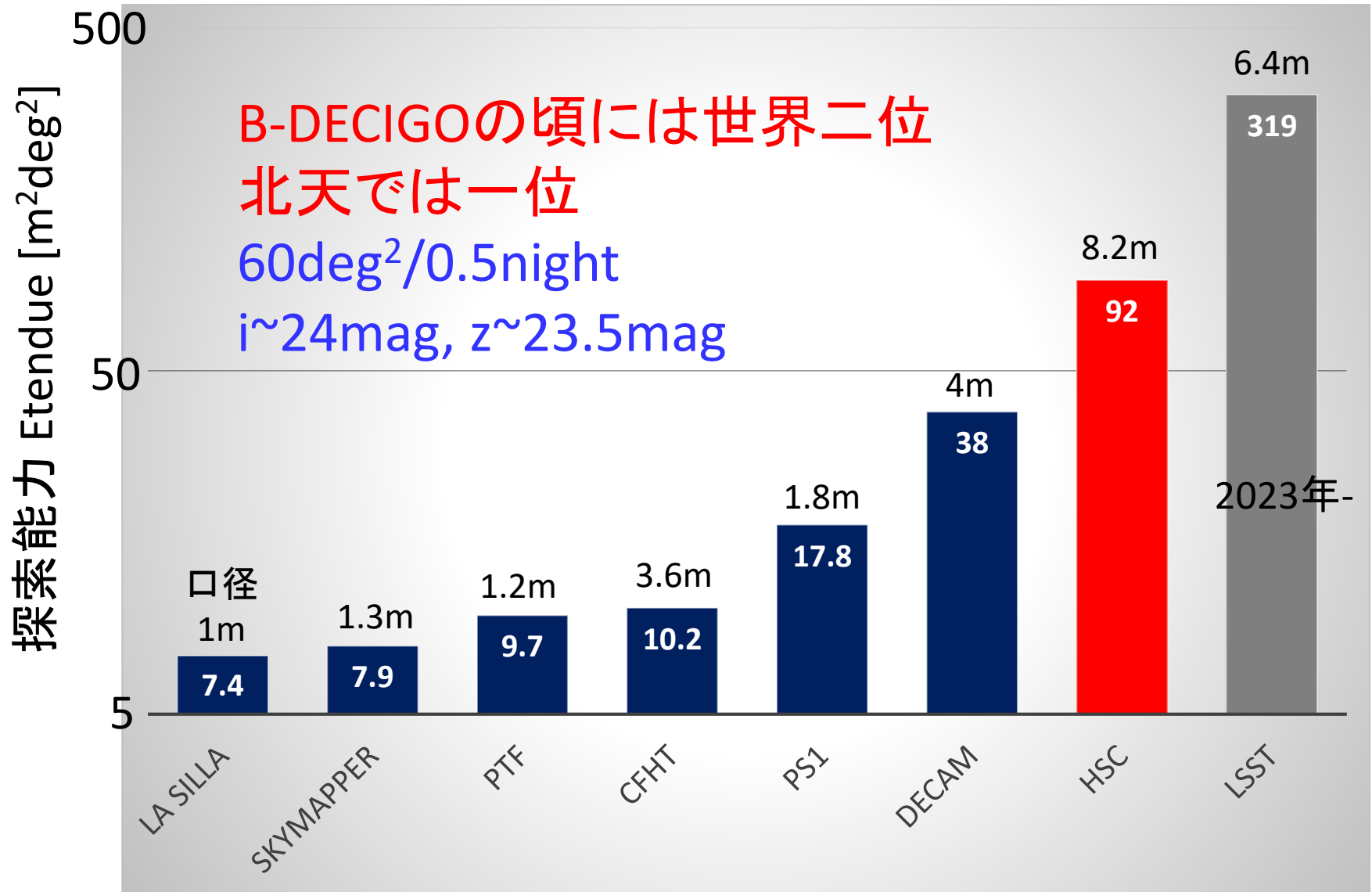
Berger+13  
Tanvir+13

# すばる望遠鏡HSC

- Hyper Suprime-Cam (HSC)
  - 口径: 8.2m, 視野:  $1.77\text{deg}^2$ ,  $\sim 900\text{M}$  pixels
  - 限界等級(1分,  $5\sigma$ ): **24.5(i)**, **23.8(z)**  
(DECam 1分: 23.3(i), 22.5(z))



# 可視光望遠鏡の探索能力



# すばる望遠鏡の観測

## Accepted proposals for Semester S17B

The Call for Proposals for Semester S17B received 133 and 2 submitted proposals for the Normal and Intensive Programs, respectively, requesting a total of 294 nights. After screening by TAC, 44 (+ 11 ToO) nights were allocated to the following 37 proposals. In addition, 17.5 nights are assigned to the HSC SSP Project, 3.5 nights are assigned to the Service Program observations. and total 14.5 nights are assigned to the on-going 3 Intensive Programs (5 nights for S16A-119, 4.5 nights for S16B-001, and 5 nights for S16B-071).

| ID       | PI                 | Proposal Title                                                                    | Inst                      | Nts   |
|----------|--------------------|-----------------------------------------------------------------------------------|---------------------------|-------|
| S17B-001 | Toru Misawa        | Transverse Proximity Effects around BAL Quasars                                   | FOCAS                     | 2     |
| S17B-002 | Tadayuki Kodama    | Mahalo Deep Field: Low mass end of the star-forming main sequence at high-z       | MOIRCS                    | 3.5   |
| S17B-003 | Michitoshi Yoshida | Optical--infrared follow-up observation of gravitational wave sources             | HSC,FOCAS,MOIRCS,IRCS,HDS | 4 ToO |
| S17B-004 | Shogo Nishiyama    | General Relativistic Measurement of Mass of the Galactic SMBH 2                   | IRCS+LGS-AO               | 2     |
| S17B-005 | Ken Mawatari       | Panoramic HI mapping in the $z=3.1$ supercluster with HSC                         | HSC(Queue)                | 0.4   |
| S17B-010 | Tomonori Totani    | Subaru Follow-up of Fast Radio Bursts                                             | HSC&FOCAS/HDS/MOIRCS/IRCS | 2 ToO |
| S17B-017 | Masao Hayashi      | 3D large-scale structures at $z=0.4$ revealed by two adjacent narrow-band filters | HSC(Queue)                | 1     |

- Target-of-opportunity (ToO) 観測
  - 事前に「**重力波アラート**がかかったら行われている観測に割り込んで観測を行う」と申請
  - その時に**装着されている観測装置**のみ使用可能
  - ハワイ観測所所長(現在はJ-GEM PI)の許可が必要



# すばる望遠鏡の 観測schedule

- いつでも使いたい  
装置が使えるわけ  
ではない。

| Sun                               | Mon                                 | Tue                           | Wed                           | Thu                               | Fri                                  | Sat                                 |
|-----------------------------------|-------------------------------------|-------------------------------|-------------------------------|-----------------------------------|--------------------------------------|-------------------------------------|
|                                   |                                     |                               |                               |                                   |                                      | <b>Dec 01</b>                       |
|                                   |                                     |                               |                               |                                   |                                      | Queue<br>HSC                        |
| <b>Dec 02</b>                     | <b>Dec 03</b>                       | <b>Dec 04</b>                 | <b>Dec 05</b>                 | <b>Dec 06</b>                     | <b>Dec 07</b> ☛                      | <b>Dec 08</b>                       |
| Queue<br>HSC                      | SSP<br>HSC                          | SSP<br>HSC                    | SSP<br>HSC                    | SSP<br>HSC                        | SSP<br>HSC                           | Keck-C276<br>Brown<br>HSC           |
| Queue<br>HSC                      | Keck-C276<br>Brown<br>HSC           | Keck-C276<br>Brown<br>HSC     | Keck-C276<br>Brown<br>HSC     | Keck-C276<br>Brown<br>HSC         | Keck-C276<br>Brown<br>HSC            |                                     |
| <b>Dec 09</b>                     | <b>Dec 10</b>                       | <b>Dec 11</b>                 | <b>Dec 12</b>                 | <b>Dec 13</b>                     | <b>Dec 14</b> ☐                      | <b>Dec 15</b>                       |
| SSP<br>HSC                        | S18B-<br>162[Aus]<br>Spitler<br>HSC | SSP<br>HSC                    | SSP<br>HSC                    | SSP<br>HSC                        | S18B-029<br>Uyama<br>CHARIS+SCEXAO   | S18B-020<br>Currie<br>CHARIS+SCEXAO |
| Keck-C276<br>Brown<br>HSC         |                                     | S18B-071<br>Yoshida<br>HSC    | S18B-071<br>Yoshida<br>HSC    |                                   | S18B122<br>Fukagawa<br>CHARIS+SCEXAO |                                     |
| <b>Dec 16</b>                     | <b>Dec 17</b>                       | <b>Dec 18</b>                 | <b>Dec 19</b>                 | <b>Dec 20</b>                     | <b>Dec 21</b> ○                      | <b>Dec 22</b>                       |
| Eng<br>MIMIZUKU                   |                                     |                               | Eng<br>Telescope              | UH-05B<br>Hodapp<br>CHARIS+SCEXAO | UH-05B<br>Hodapp<br>CHARIS+SCEXAO    | UH-05B<br>Hodapp<br>CHARIS+SCEXAO   |
|                                   |                                     |                               |                               | Obs<br>MOIRCS                     | UH-15A1<br>McPartland<br>MOIRCS      | UH-15A1<br>McPartland<br>MOIRCS     |
| <b>Dec 23</b>                     | <b>Dec 24</b>                       | <b>Dec 25</b>                 | <b>Dec 26</b>                 | <b>Dec 27</b>                     | <b>Dec 28</b>                        | <b>Dec 29</b> ☛                     |
| UH-05B<br>Hodapp<br>CHARIS+SCEXAO | UH-31A<br>Gaidos<br>IRD+AO188       | UH-31A<br>Gaidos<br>IRD+AO188 | UH-31A<br>Gaidos<br>IRD+AO188 | Queue 0.2+SSP<br>0.5<br>HSC       | Queue 0.2+SSP<br>0.5<br>HSC          | Queue<br>HSC                        |
| UH-11A2<br>Huber<br>IRD+AO188     | UH-11A2<br>Huber<br>IRD+AO188       | UH-11A2<br>Huber<br>IRD+AO188 | UH-11A2<br>Huber<br>IRD+AO188 | Queue (0.3)<br>HSC                | Queue (0.3)<br>HSC                   | Queue<br>HSC                        |
| <b>Dec 30</b>                     | <b>Dec 31</b>                       |                               |                               |                                   |                                      |                                     |
| Queue(0.2)<br>HSC                 | SSP<br>HSC                          |                               |                               |                                   |                                      |                                     |
| SSP(0.8)<br>HSC                   |                                     |                               |                               |                                   |                                      |                                     |

# GW170817

Utsumi, Tanaka, NT + PASJ 17 (arXiv:1710.05848)

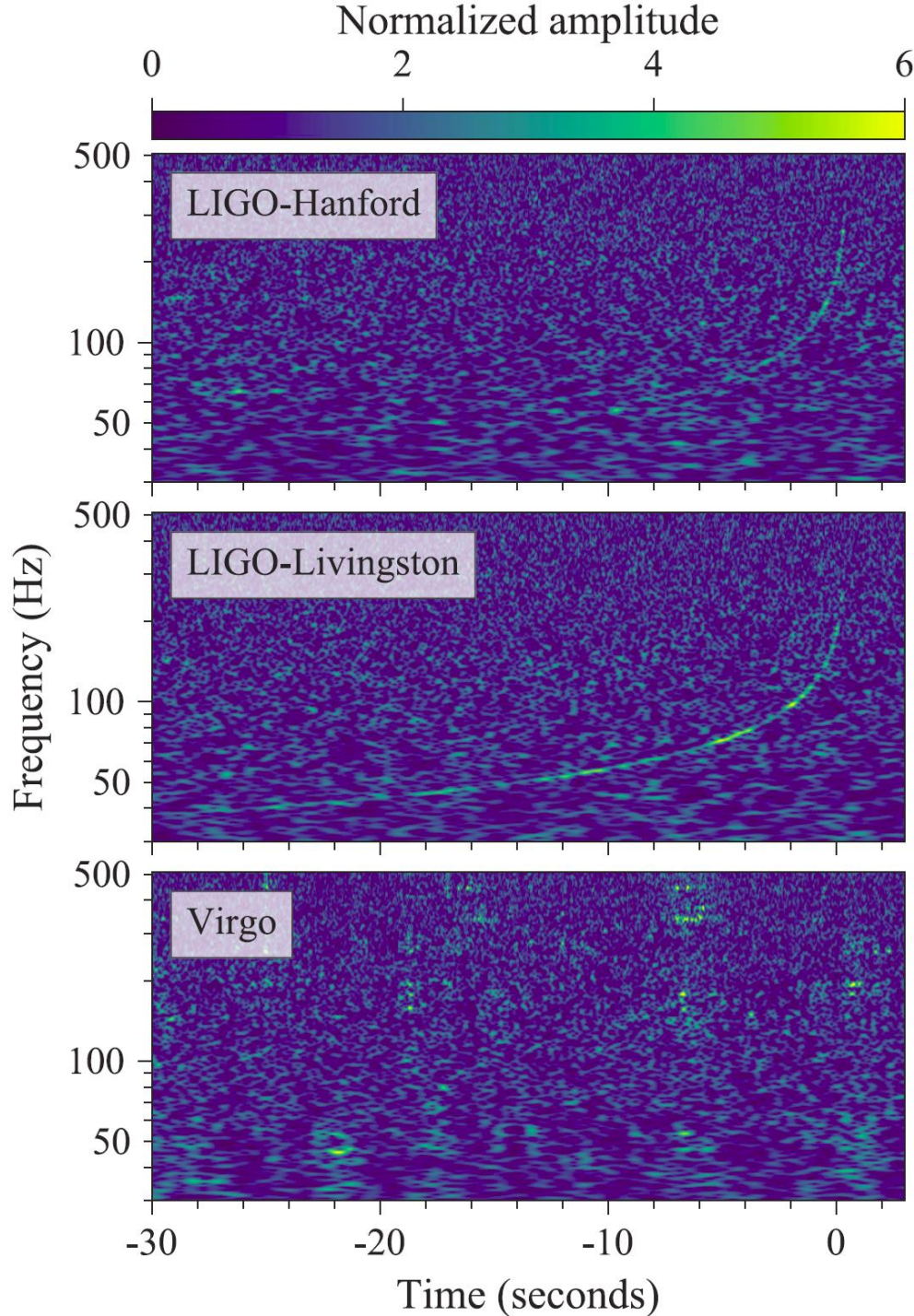
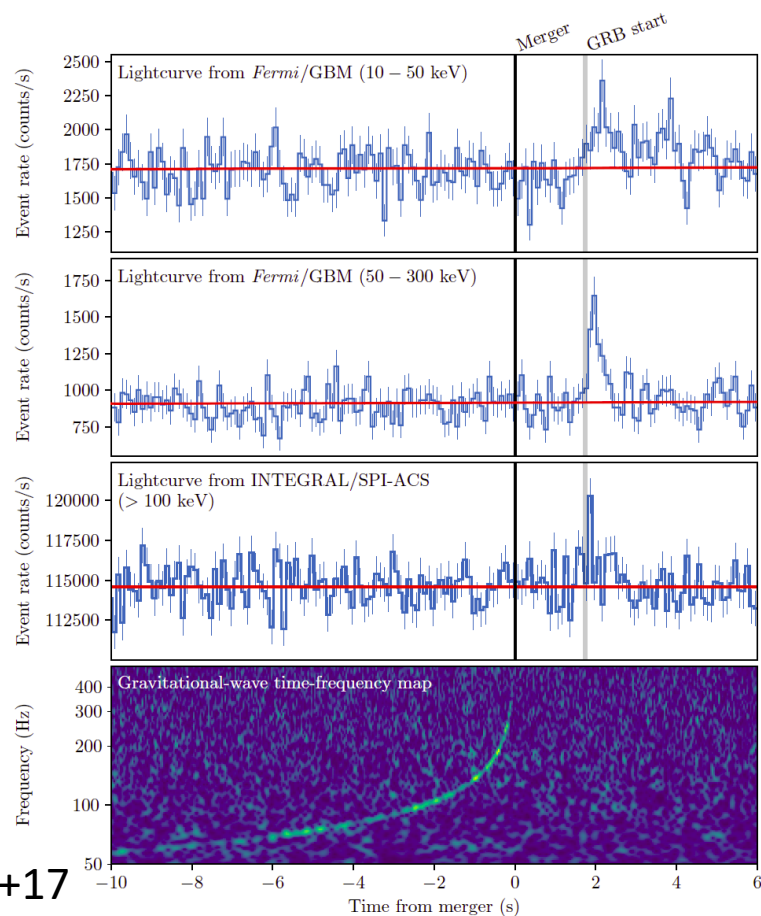
Tanaka, Utsumi, Mazzali, NT + PASJ 17 (arXiv:1710.05850)

Tominaga, Tanaka, Morokuma + PASJ 18 (arXiv:1710.05865)

# GW170817

それぞれの質量:  $1.17\text{--}1.60\text{ M}_{\odot}$

全質量:  $2.74^{+0.04}_{-0.01}\text{ M}_{\odot}$ .



# First circular

TITLE: GCN CIRCULAR

NUMBER: 21505

SUBJECT: LIGO/Virgo **G298048**: Fermi GBM trigger 524666471/170817529:

LIGO/Virgo Identification of a possible gravitational-wave counterpart

DATE: 17/08/17 13:21:42 GMT

FROM: Reed Clasey Essick at MIT <ressick@mit.edu>

The LIGO Scientific Collaboration and the Virgo Collaboration report:

The online CBC pipeline (gstlal) has made a preliminary identification of a GW candidate associated with the time of Fermi GBM trigger 524666471/170817529 at gps time 1187008884.47 (Thu Aug 17 12:41:06 GMT 2017) with RA=186.62deg Dec=-48.84deg and an error radius of 17.45deg.

**The candidate is consistent with a neutron star binary coalescence with False Alarm Rate of  $\sim 1/10,000$  years.**

An offline analysis is ongoing. Any significant updates will be provided by a new Circular.

# すばる望遠鏡HSCの対応

- 17/08/17 13:21:42 GMT
  - LIGO/Virgo Identification of a possible gravitational-wave counterpart (Fermi GBM/LVC CBC pipeline)
- 17/08/17 14:09:25 GMT
  - Identification of a binary neutron star candidate coincident with Fermi GBM

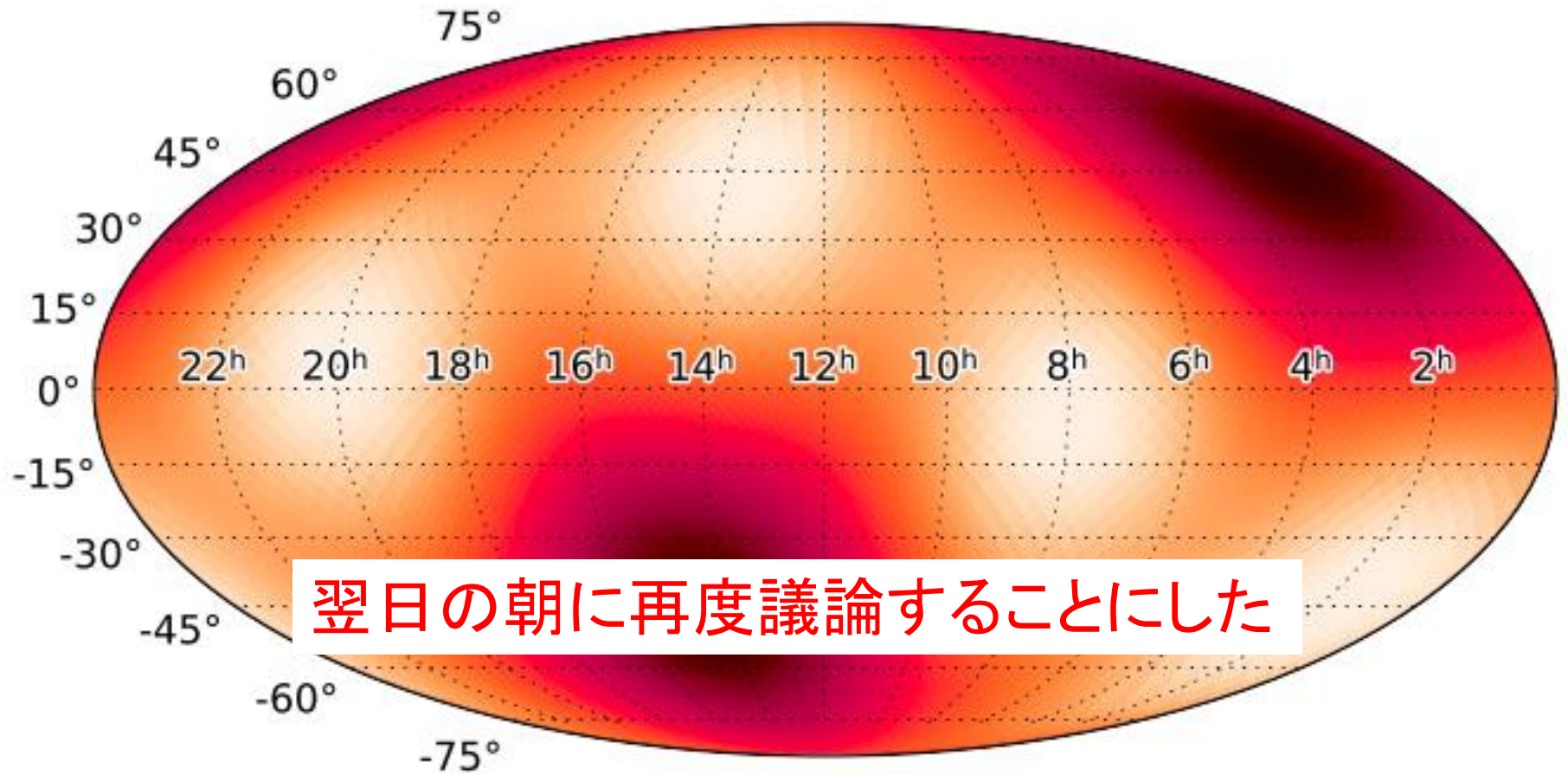
| Aug 13                              | Aug 14                              | Aug 15                          | Aug 16                          | Aug 17                          | Aug 18                          | Aug 19                |
|-------------------------------------|-------------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|-----------------------|
| S17B-093<br>Currie<br>CHARIS+SCEXAO | S17B-130<br>Kotani<br>CHARIS+SCEXAO | SSP<br>HSC                      | S17B-108(EAO)<br>Jose<br>HSC    | S17B-003[ToO]<br>Yoshida<br>HSC | S17B-003[ToO]<br>Yoshida<br>HSC | SSP<br>HSC            |
| Eng<br>SCEXAO                       | Eng<br>SCEXAO                       | S17B-003[ToO]<br>Yoshida<br>HSC | S17B-003[ToO]<br>Yoshida<br>HSC | Keck<br>Bradac<br>HSC           | Keck<br>Bradac<br>HSC           | Keck<br>Bradac<br>HSC |

GW170814の★観測

GW170817 ©すばる望遠鏡観測スケジュール  
(ハワイ時間)



# この時点での到来方向分布



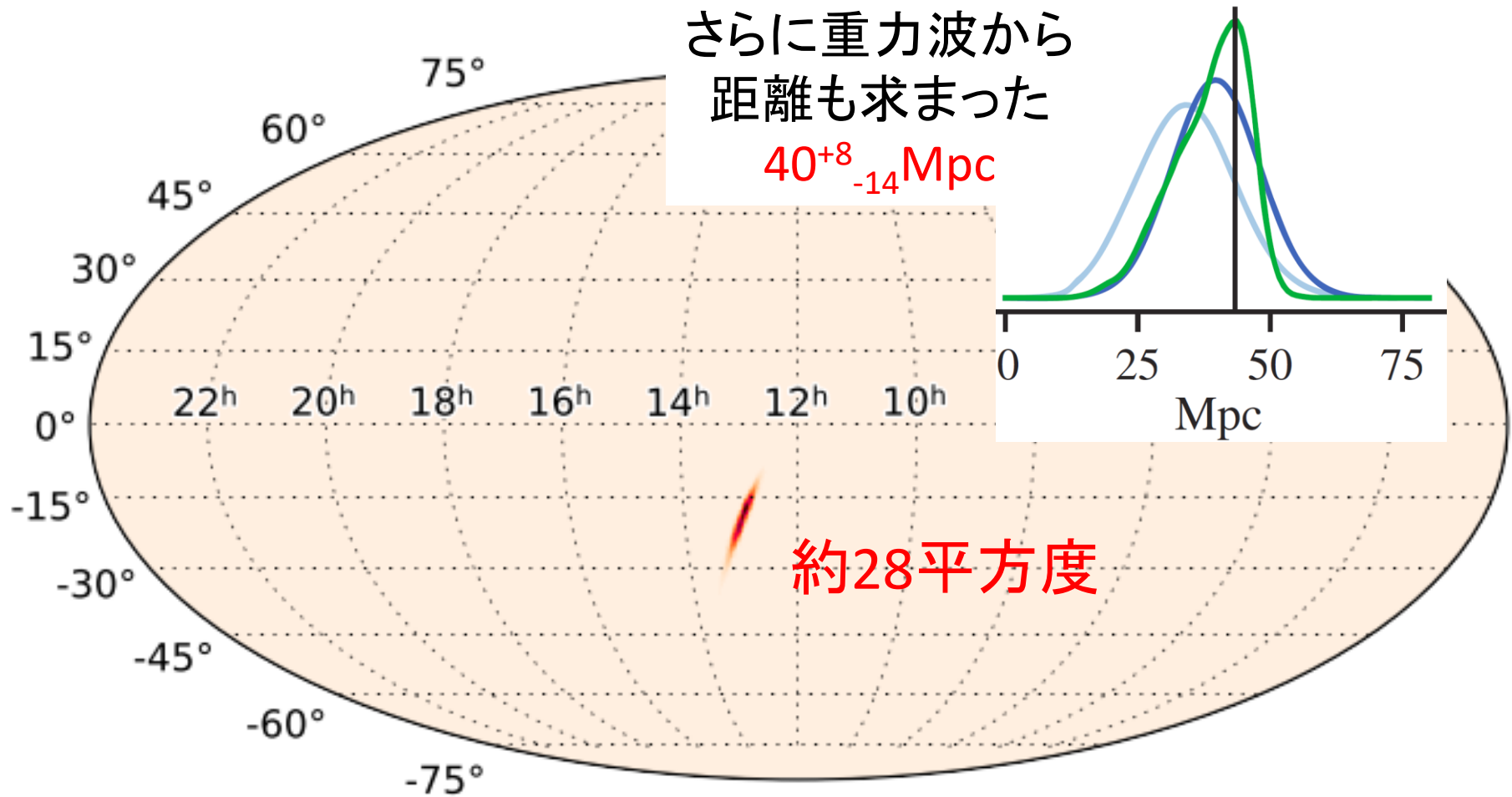
翌日の朝に再度議論することにした

LIGO-Hanfordのみ

# タイムライン

- 17/08/17 13:21:42 GMT
  - LIGO/Virgo Identification of a possible gravitational-wave counterpart (Fermi GBM/LVC CBC pipeline)
- 17/08/17 14:09:25 GMT
  - Identification of a binary neutron star candidate coincident with Fermi GBM
- 17/08/17 17:54:51 GMT
  - Initial skymap is announced
- 17/08/17 23:54:40 GMT
  - Preliminary skymap is announced

# この時点での到来方向分布



LIGO-Hanford, LIGO-Livingston, Virgo

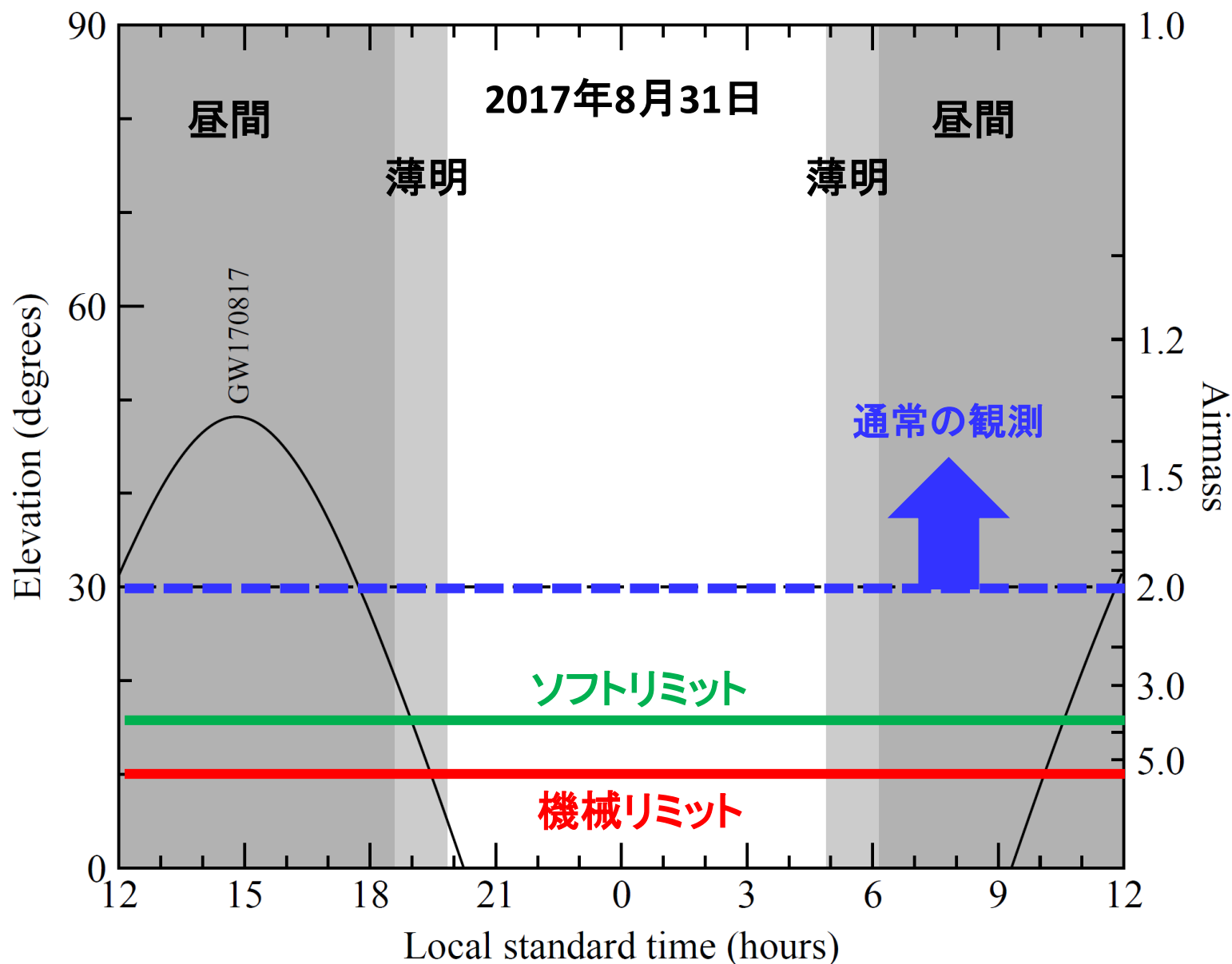


# GW170817の到来方向

- 北半球からの観測は厳しかった

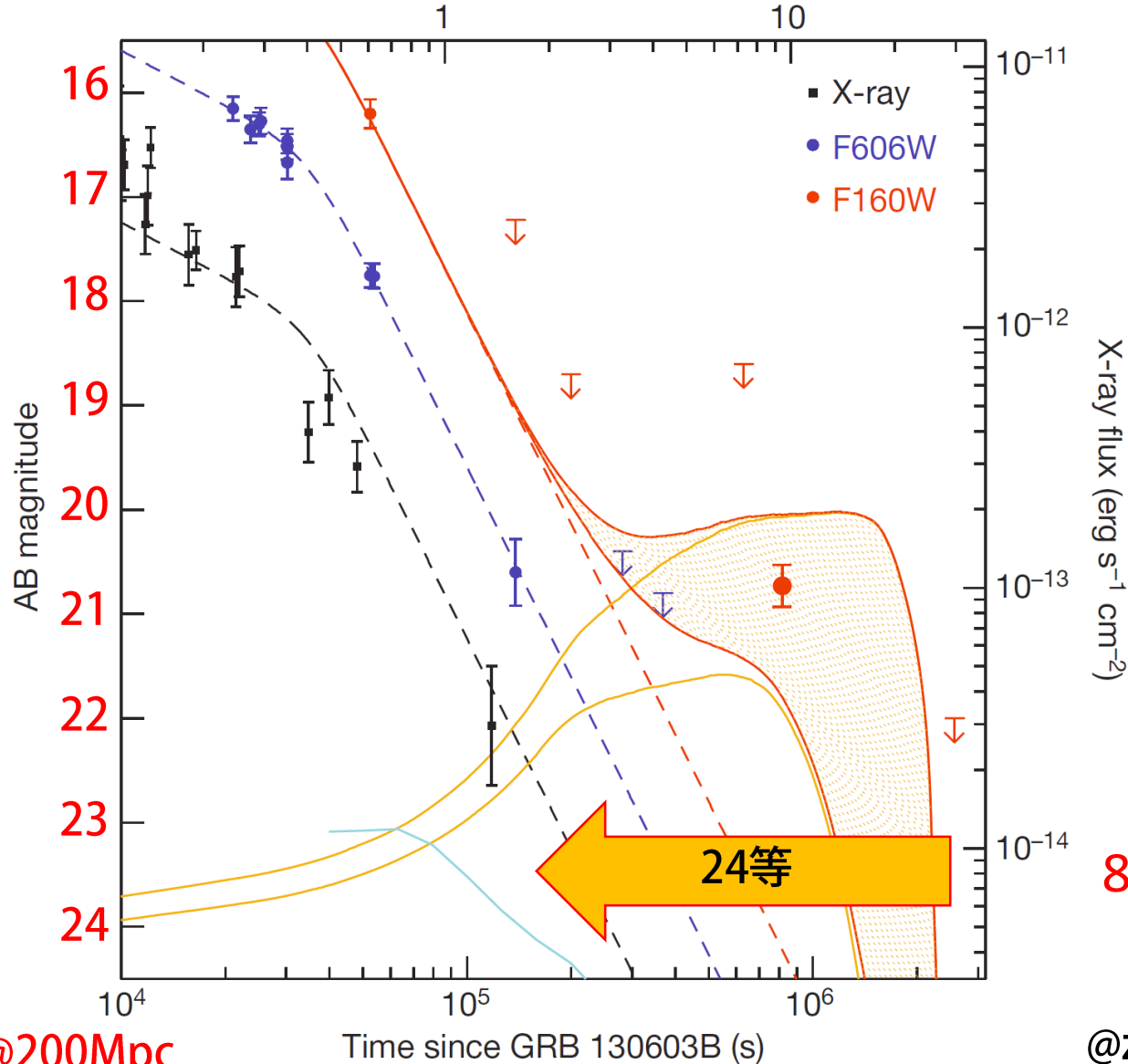


# ハワイからでも非常に困難



# GW170817は非常に近かった

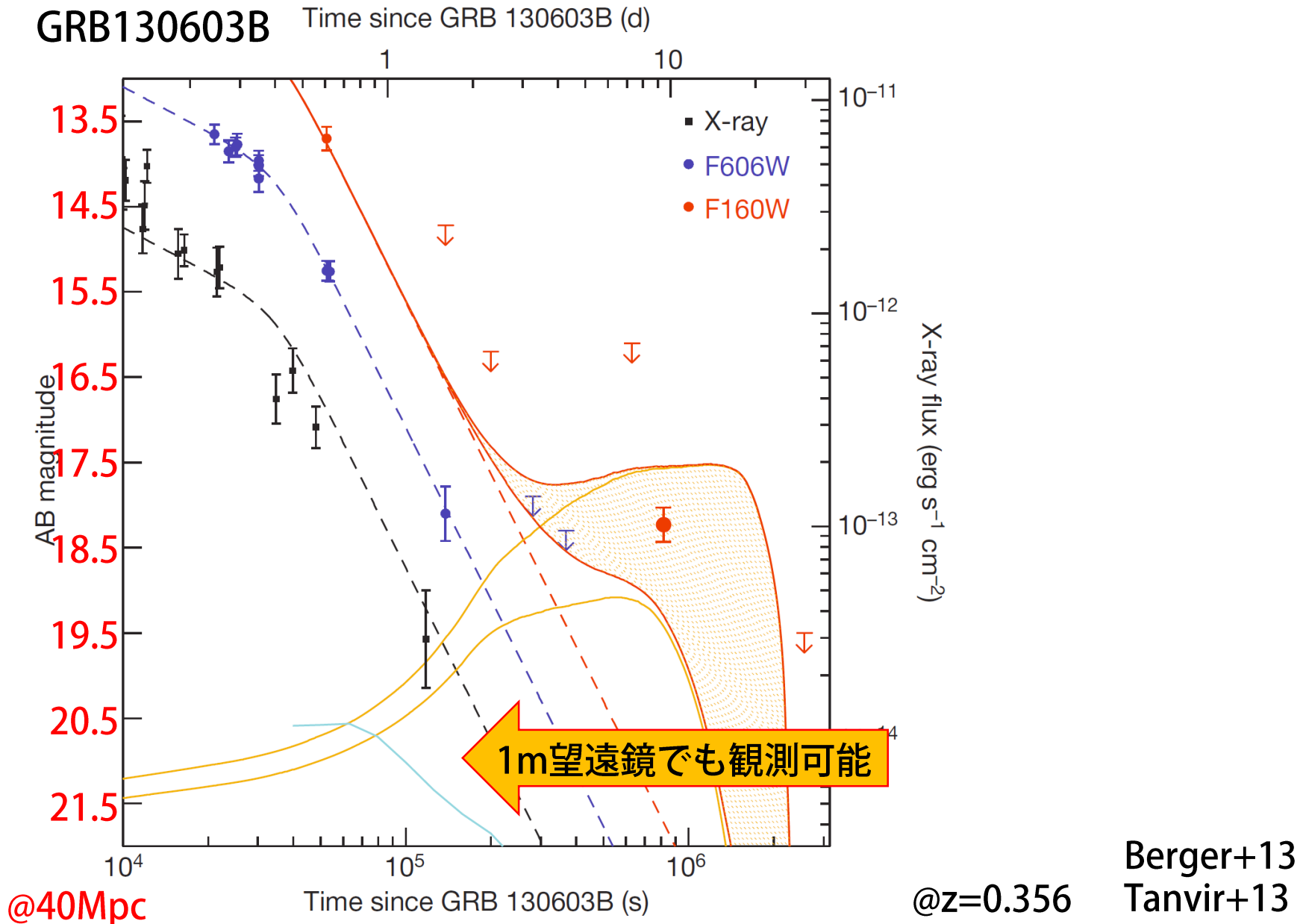
GRB130603B Time since GRB 130603B (d)



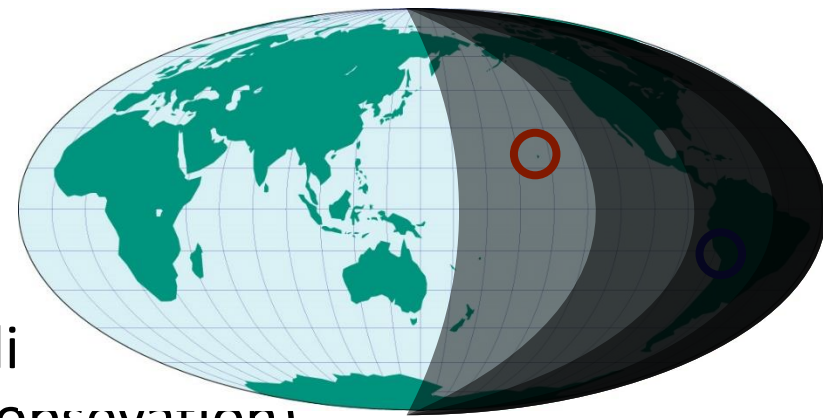
8m望遠鏡が必要

Berger+13  
Tanvir+13

# GW170817は非常に近かった



# タイムライン



- 17/08/18 01:05:23 GMT
  - Potential optical counterpart discovered by **Swope** telescope (targeted observation)
- 17/08/18 01:15:01 GMT
  - **DECam** optical candidate
- 17/08/18 01:41:13 GMT
  - **DLT40** optical candidate

チリにある望遠鏡で  
候補天体発見

GW170817の観測可能時間

| Aug 13                              | Aug 14                              | Aug 15               | Aug 16                       | Aug 17                | Aug 18                | Aug 19                |
|-------------------------------------|-------------------------------------|----------------------|------------------------------|-----------------------|-----------------------|-----------------------|
| S17B-093<br>Currie<br>CHARIS+SCEXAO | S17B-130<br>Kotani<br>CHARIS+SCEXAO | SSP<br>HSC           | S17B-108(EAO)<br>Jose<br>HSC | S17B-003[ToO]<br>HSC  | S17B-003[ToO]<br>HSC  | SSP<br>HSC            |
| Eng<br>SCEXAO                       | Eng<br>SCEXAO                       | S17B-003[ToO]<br>HSC | S17B-003[ToO]<br>HSC         | Keck<br>Bradac<br>HSC | Keck<br>Bradac<br>HSC | Keck<br>Bradac<br>HSC |

GW170817の観測

GW170814の観測

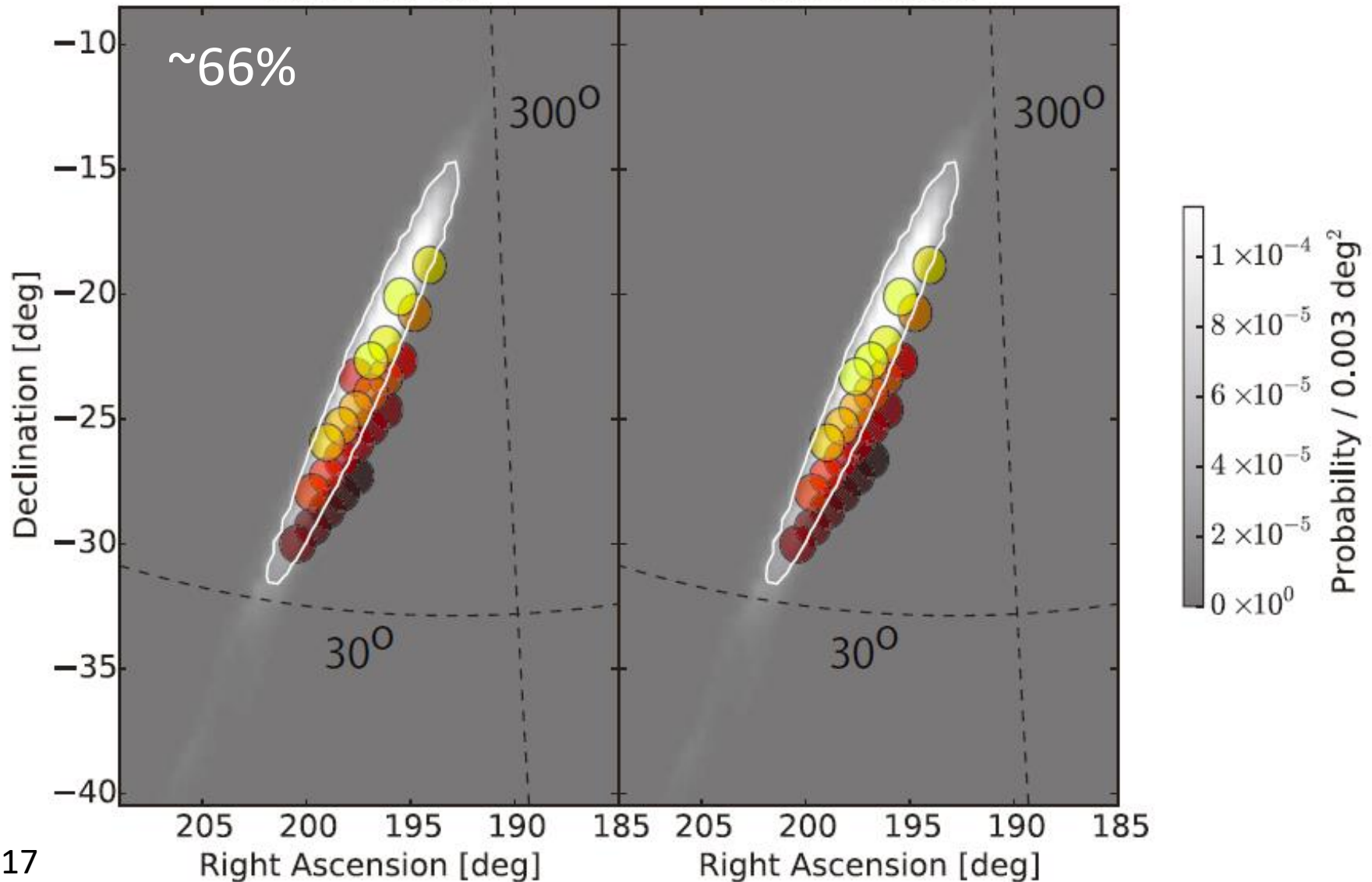
GW170817 ©すばる望遠鏡観測スケジュール  
(ハワイ時間)

# すばる望遠鏡HSCの観測

HSC Pointing map for GW170817

2017-08-18

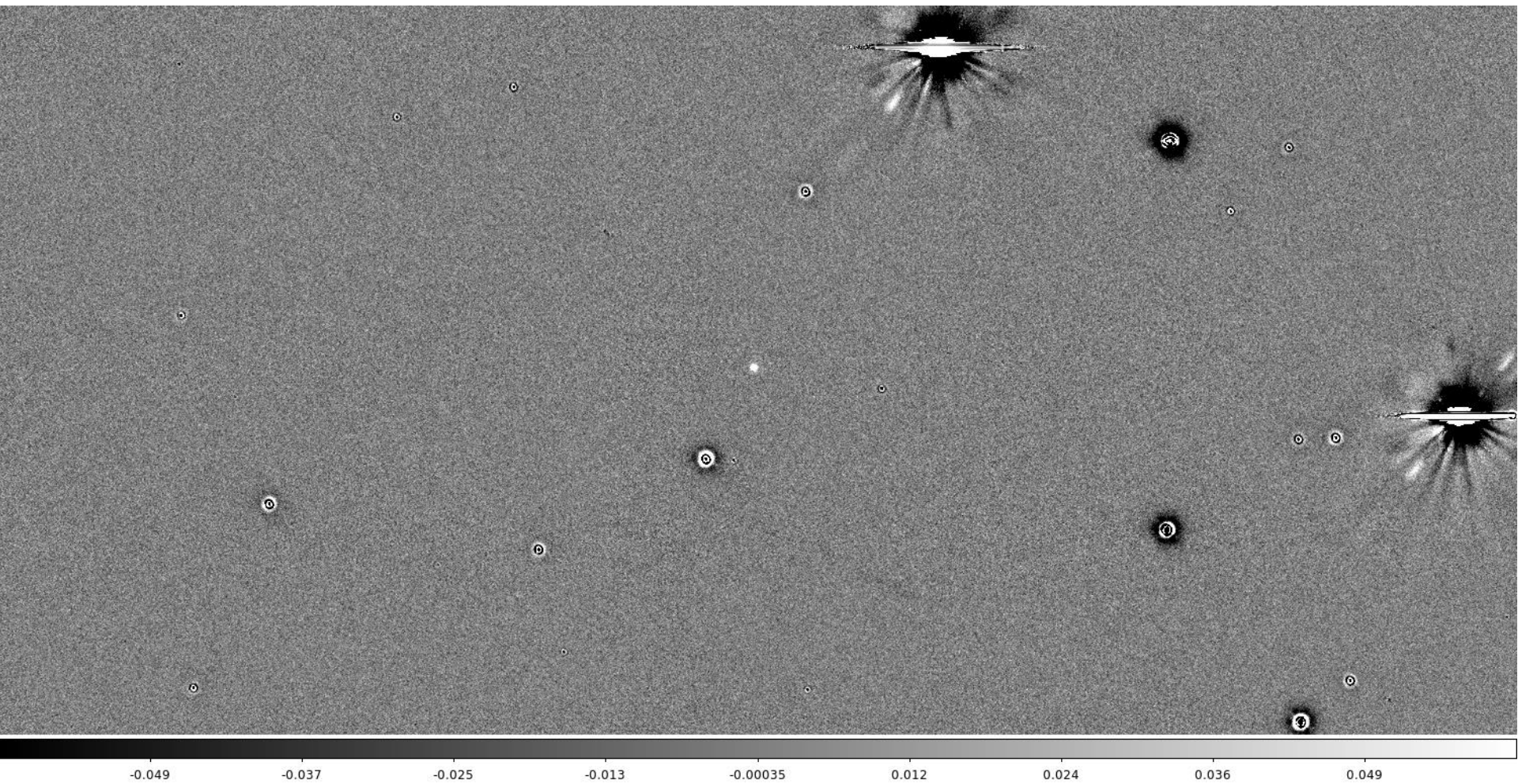
2017-08-19





# 変動天体検出

## -画像引き算-



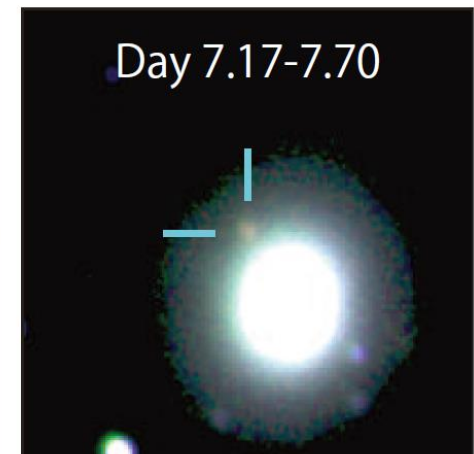
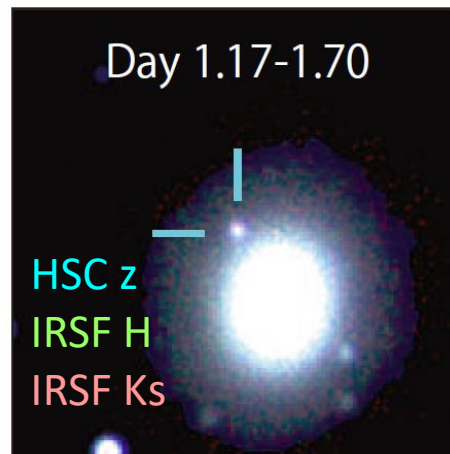
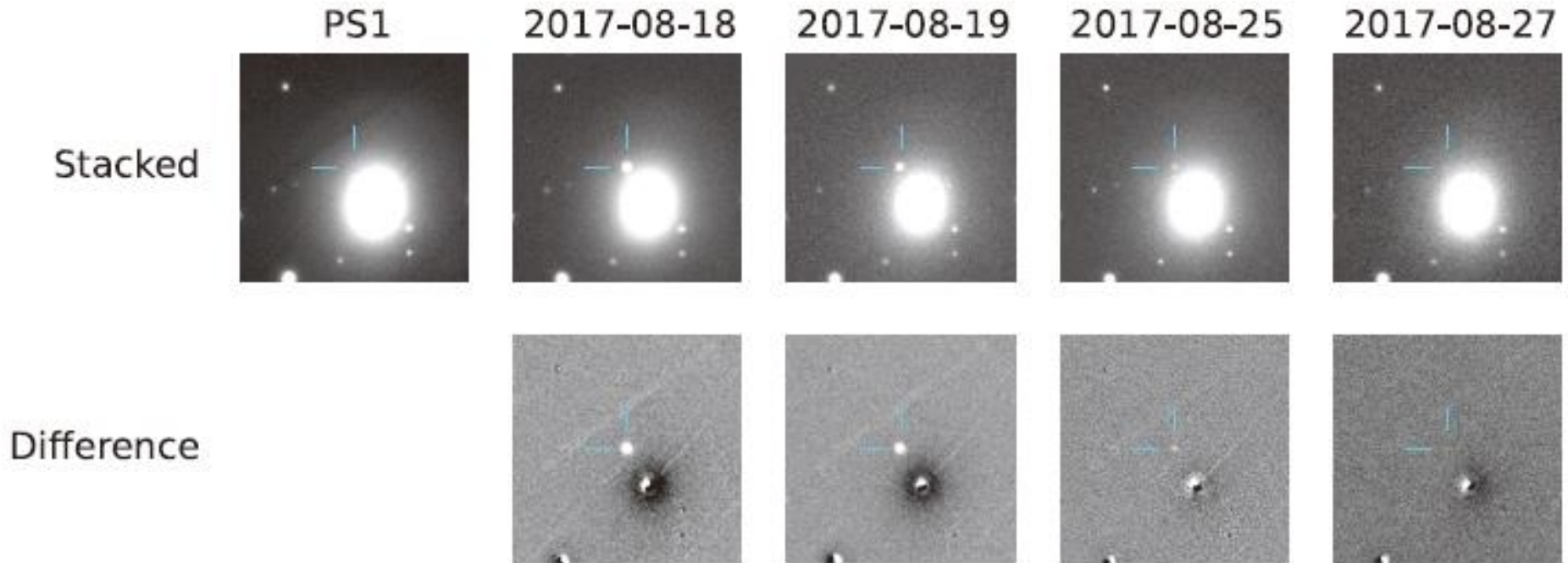
# 候補天体の選択

Sources  
1551

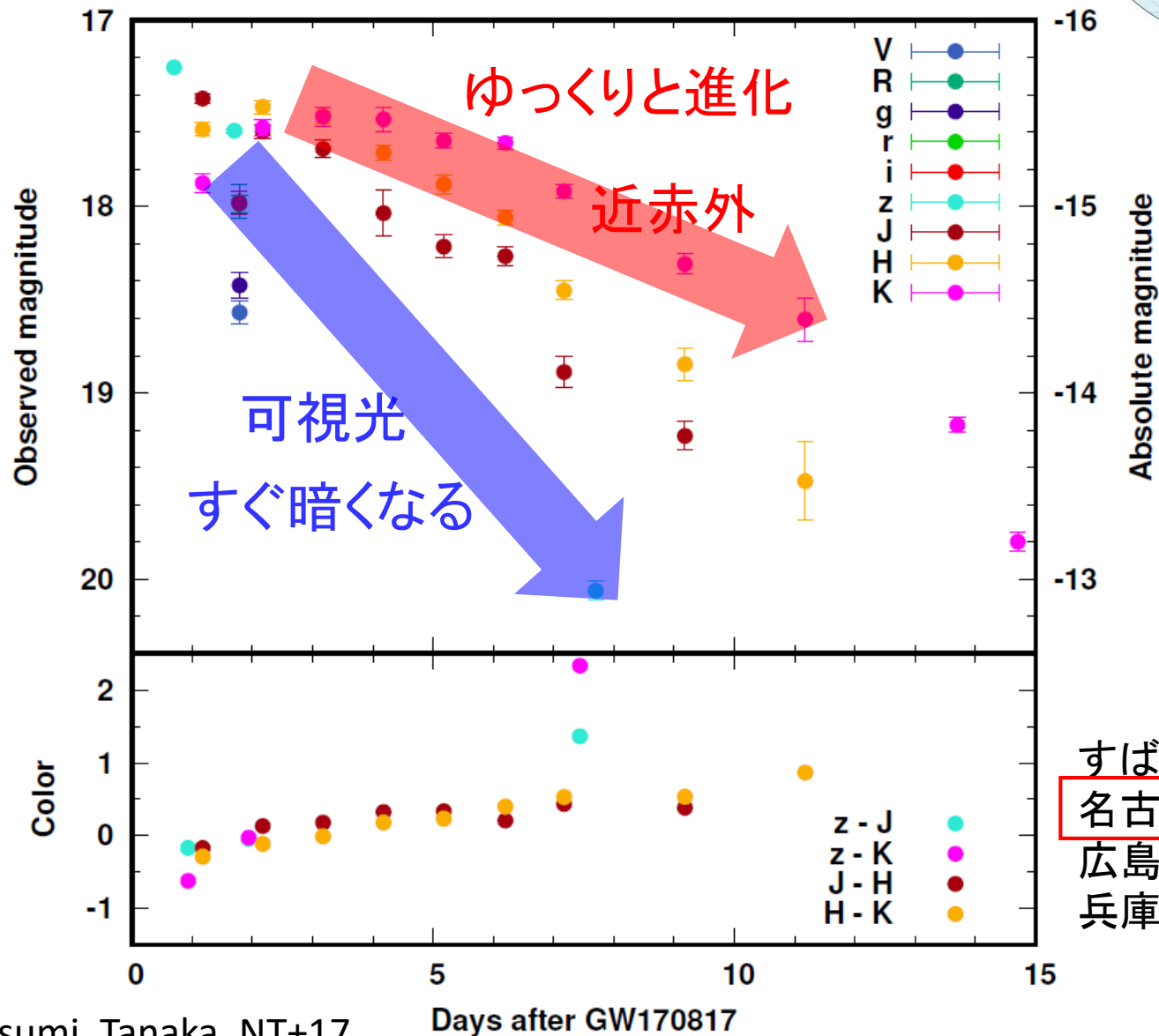
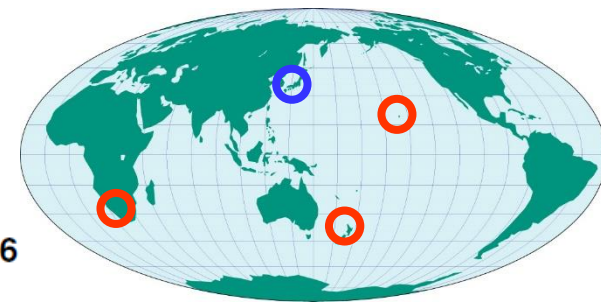


# J-GEM17btc (SSS17a)

他に有力な可視光対応天体候補は存在しないことを示した



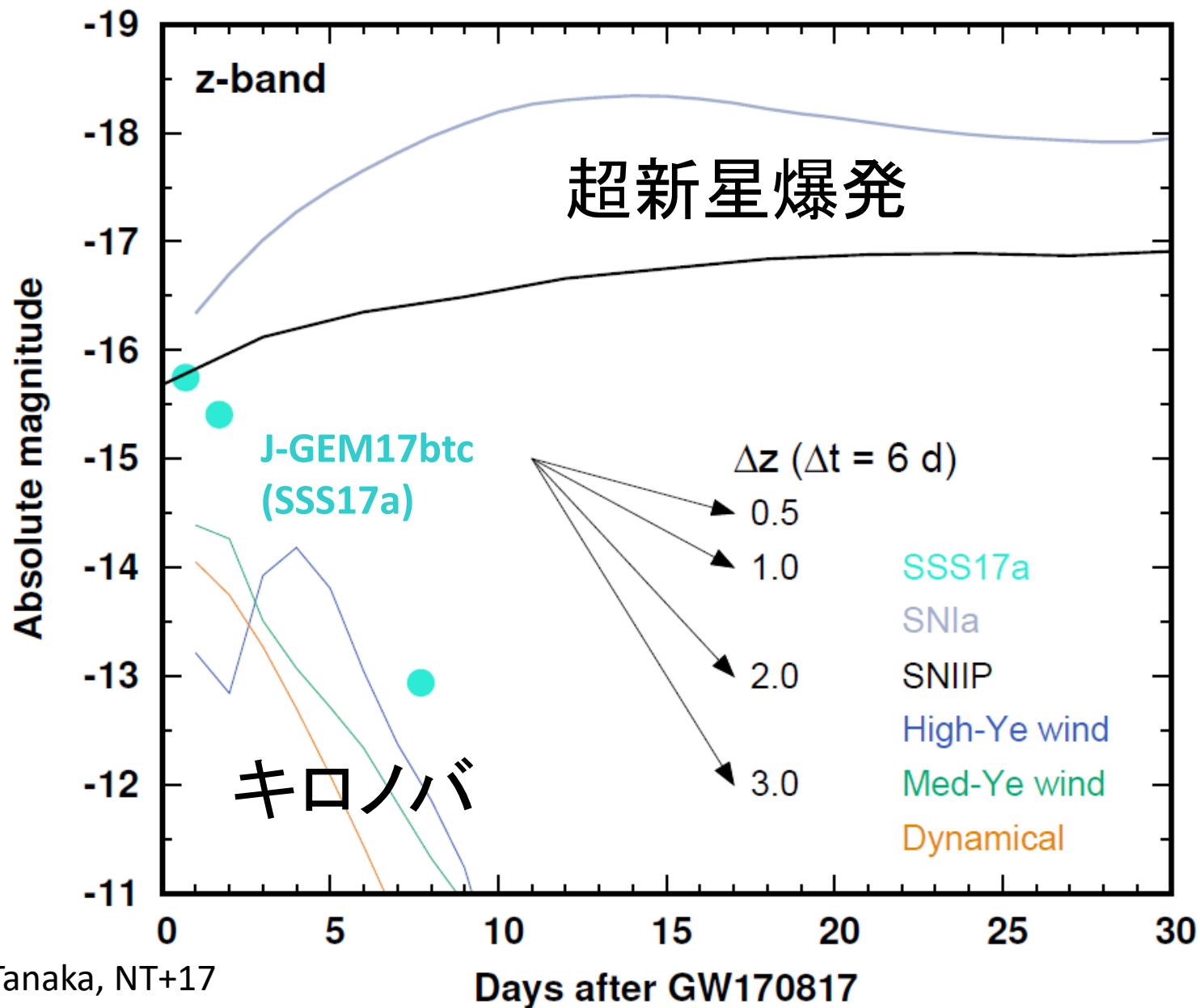
# 多色光度曲線



すばる望遠鏡/HSC, MOIRCS  
 名古屋大/IRSF, MOA-II, B&C  
 広島大/Kanata  
 兵庫県立大/Nayuta

南半球

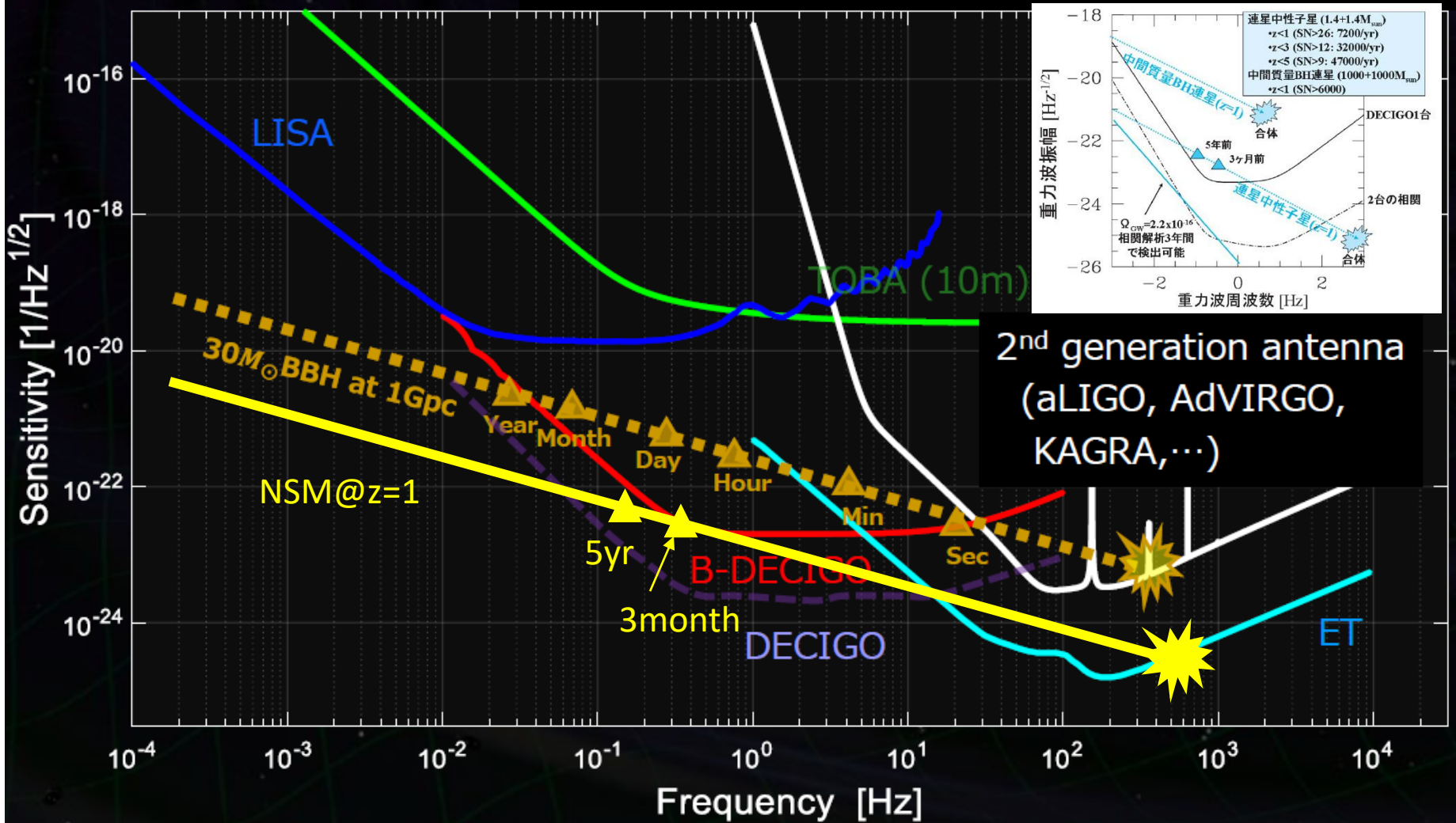
# 可視光での急減光



DECIGO/B-DECIGO  
への期待

# DECIGO/B-DECIGOへの期待

T. Nakamura et al., Prog. Theor. Exp. Phys. 093E01 (2016)



# 候補天体の選択

過去画像が必要

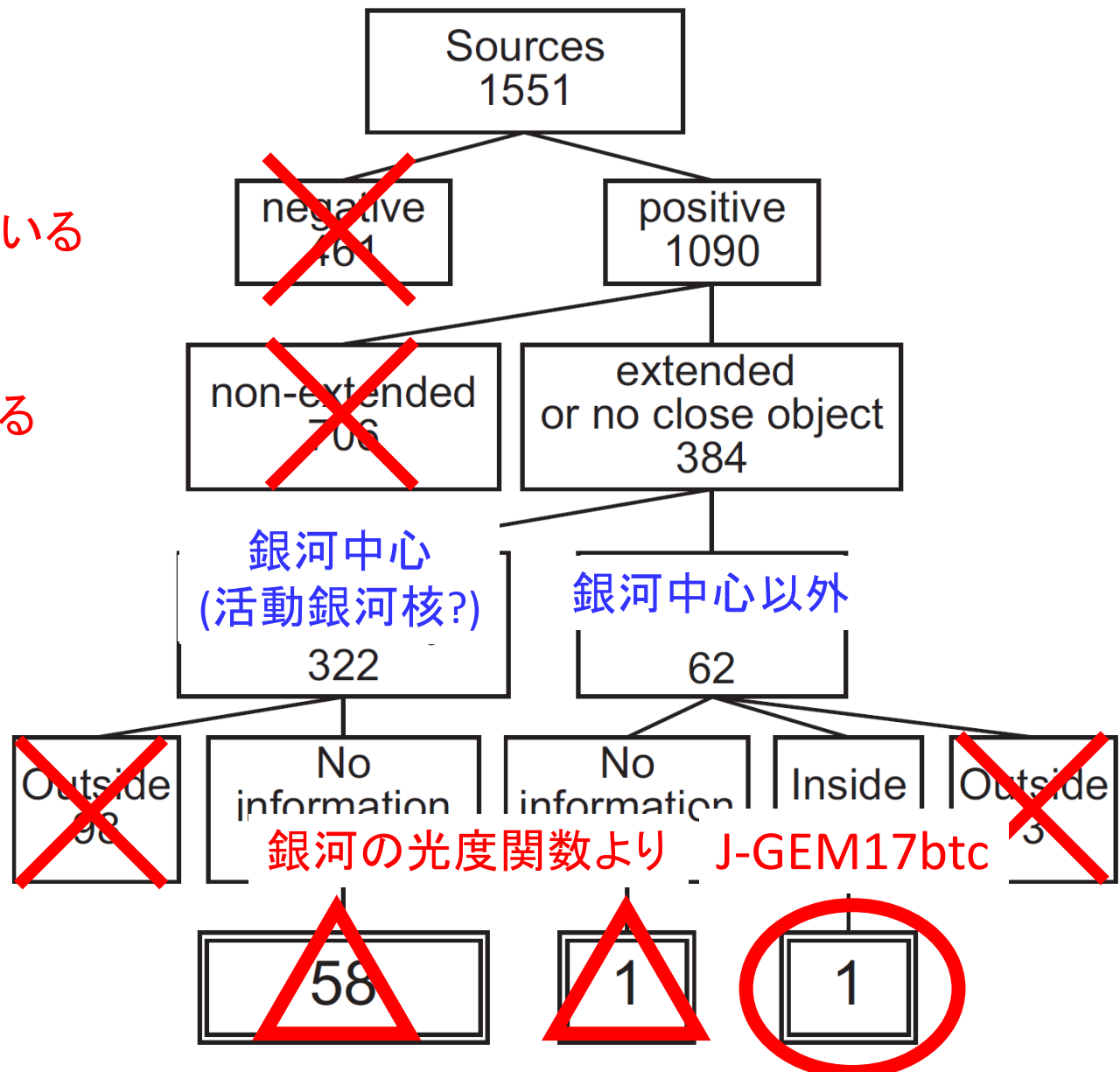
8/18, 8/19 に暗くなっている

点源(星)に付随している

天体の位置

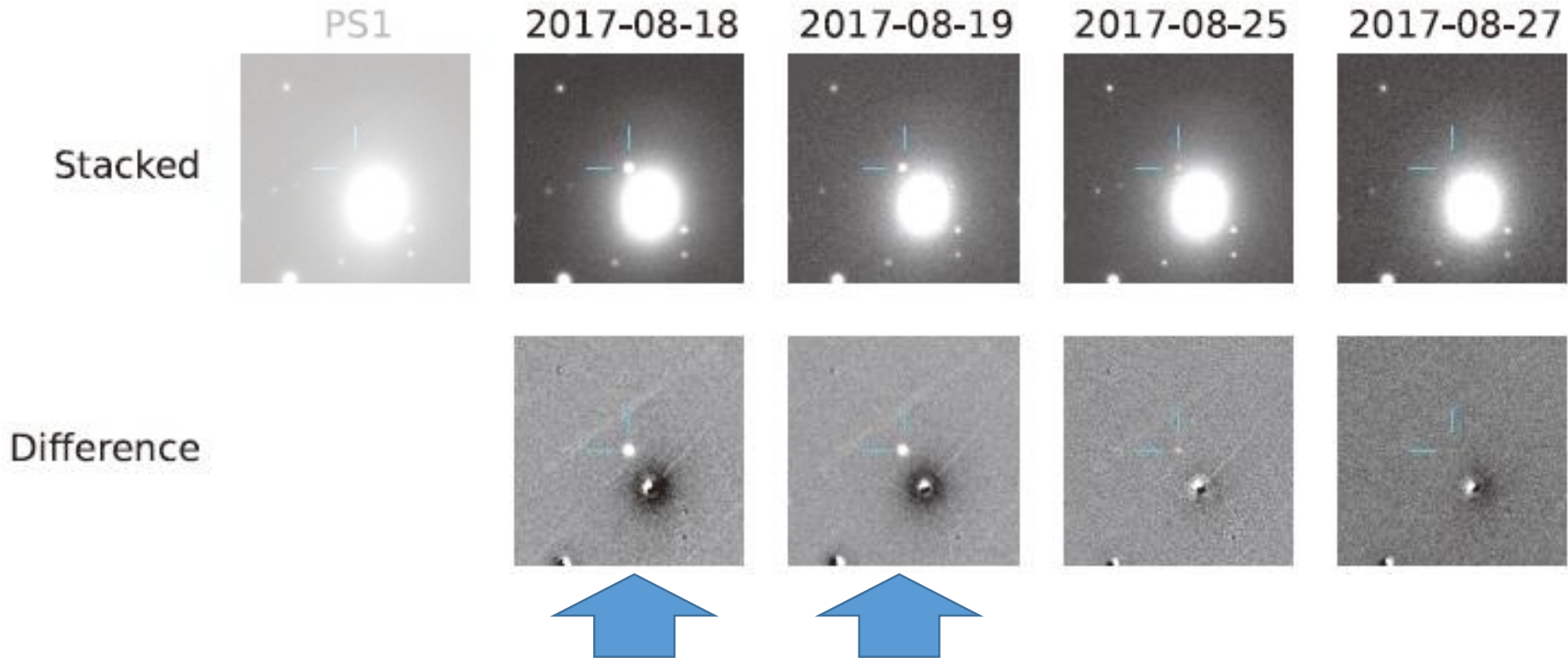
明らかに3D skymapの外に存在する

人間の目で確認



# J-GEM17btc (SSS17a)

もしPan-STARRSの画像では足りない距離で起こったら



事前に場所がわかれば reference 画像を  
事前に取得することもできる



# Subaru telescope schedule

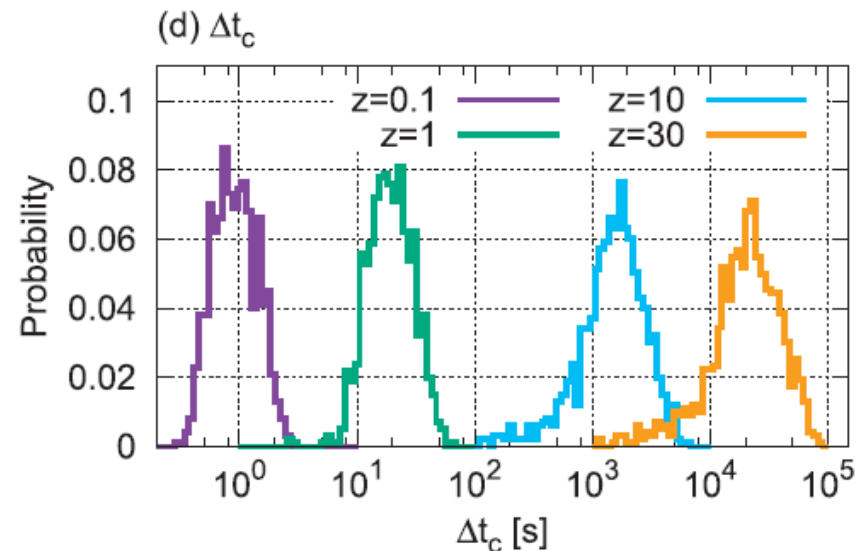
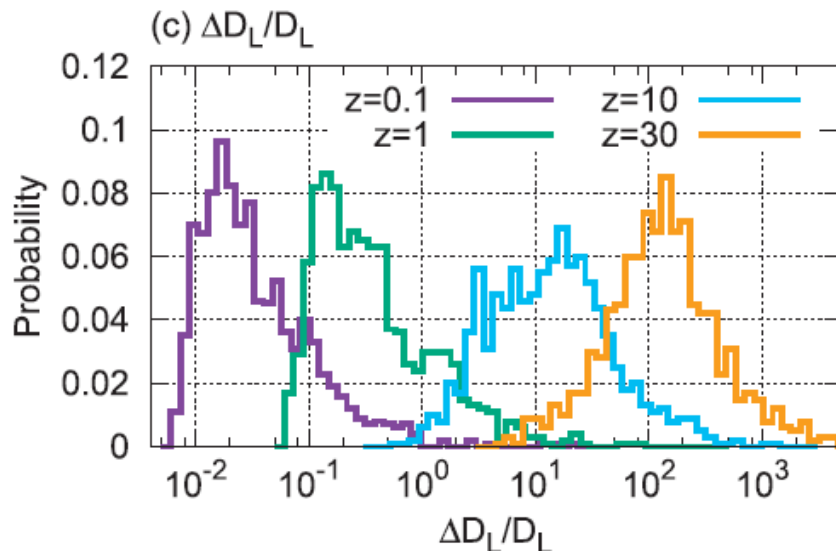
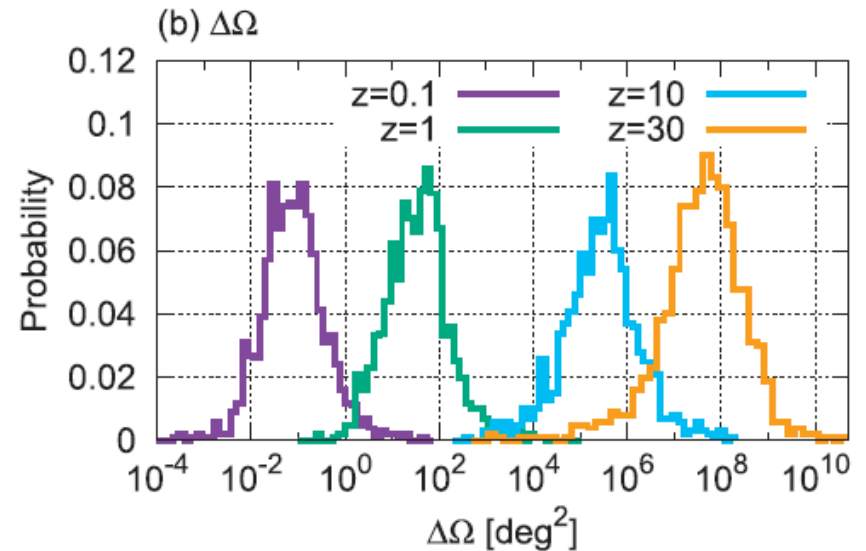
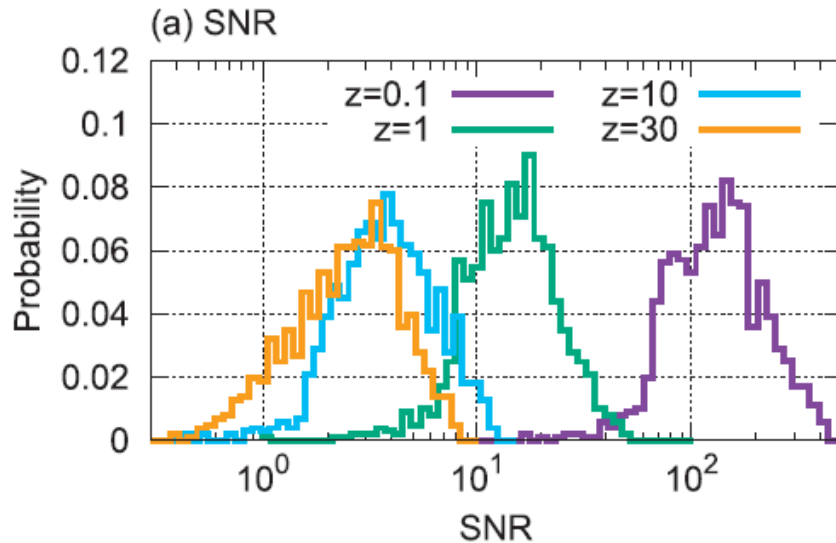
- ~ Sep 10: deadline for proposal submission
- ~ Dec 10: announcement of results
- Feb-Jul: Semester A
- ~ Mar 10: deadline for proposal submission
- ~ Jun 10: announcement of results
- Aug-Jan: Semester B

もし6ヶ月以上前に、**いつ、どこで、**  
合体が起こるか分かれば、  
ToO観測は不要

**どの程度の精度で時刻、位置、距離が分かるのでしょうか？**

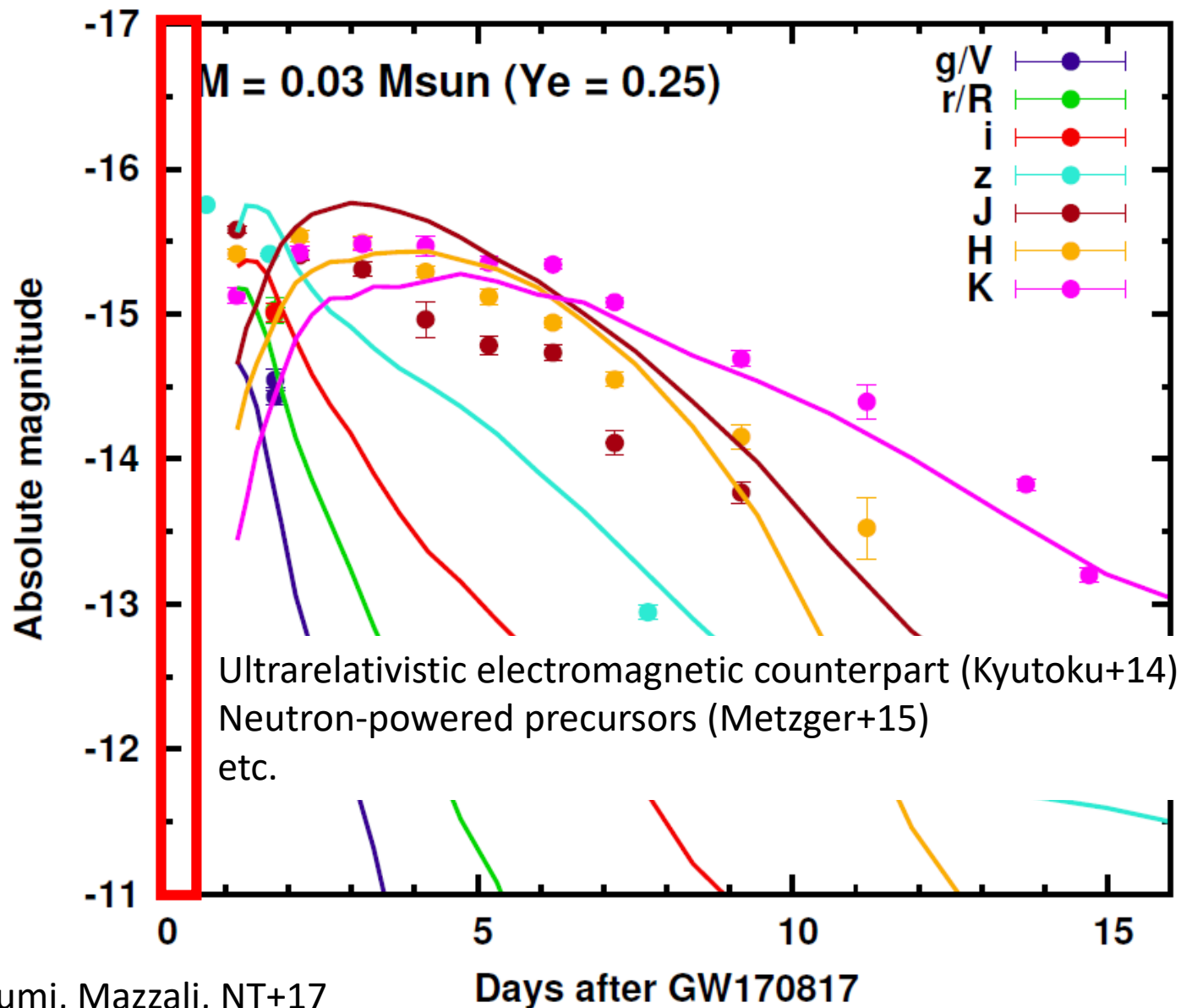
(B-DECIGO) ~1s、~0.1deg<sup>2</sup>、~3% @ 1週間前 (Nakamura+16)

# 30Msun BH binary merger



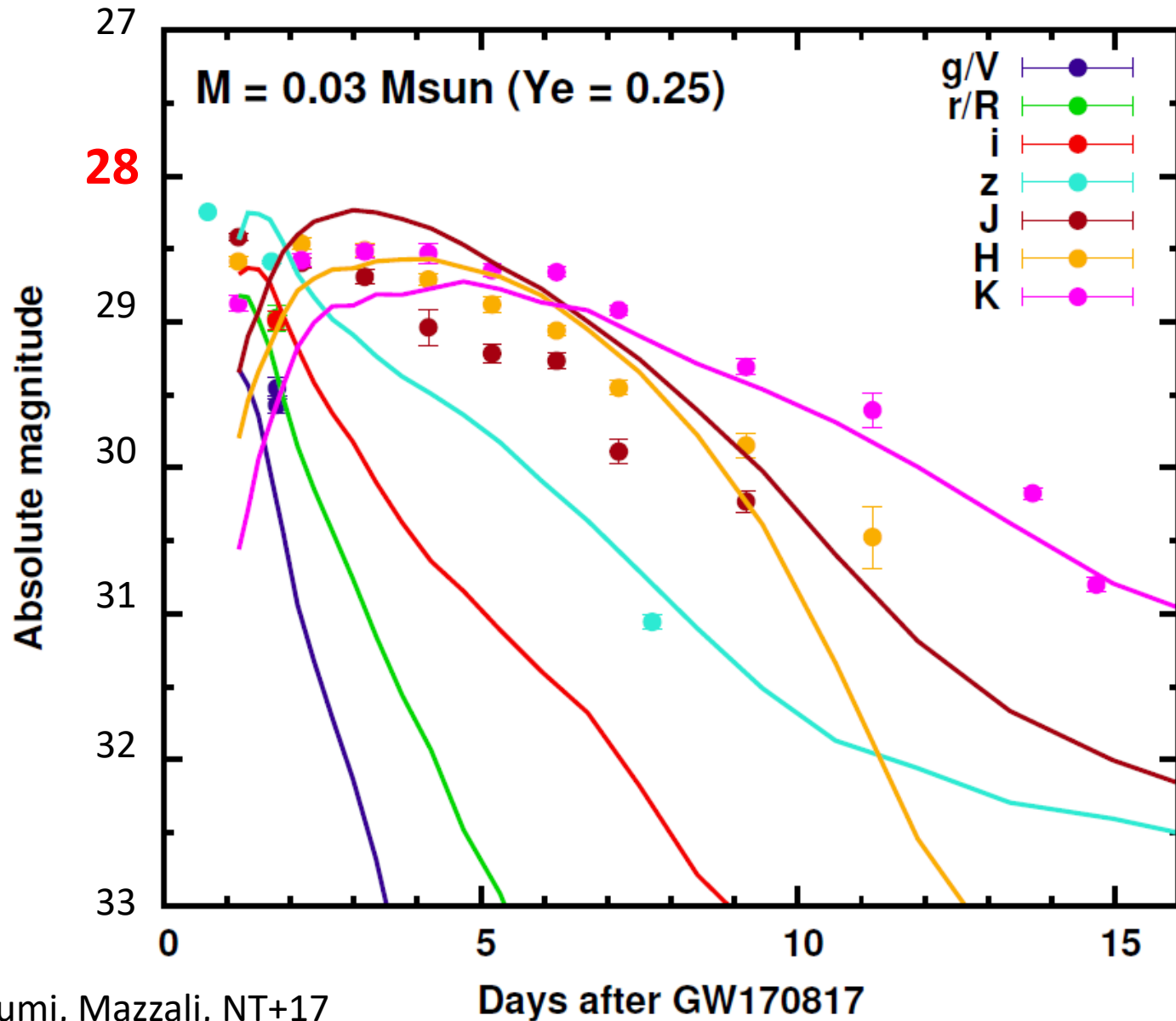
ぜひ NSM で合体までの時間の関数として見積もって下さい。

# 合体直前/直後の観測が可能



# 予想等級

@ $z=0.2$



# まとめ

- **すばる望遠鏡HSC**はB-DECIGO時代にも最前線
- GW170817: ToO観測によって追観測を行った
- DECIGO/B-DECIGOへの期待
  - **事前アラート(時刻、位置、距離)**
  - 即日電磁波対応天体同定
  - 合体直前から観測可能
    - > Ultrarelativistic electromagnetic counterpart,  
Neutron-powered precursors, etc.
  - $z=1$  の GW170817は28mag (可視光観測は厳しい)
    - >  $z=0.2$  ( $\sim 24\text{mag}$ )で OK
  - Rate<sub>NSM</sub>  $\sim 1540 \text{Gpc}^{-3} \text{yr}^{-1}$  (LVC+17) ->  $\sim 800 \text{NSM/yr}$  (北天夜)
    - >  $\sim 240 \text{NSM/yr}$  (HSC夜)
- 現在のSN観測:  $> \sim 1000 \text{SN/yr}$  と同程度 (面白い天体のみ注目される)