A Joint Search for the EM Counterpart to the GW Binary Black Hole Merger Candidate S250328ae with DECam and PFS

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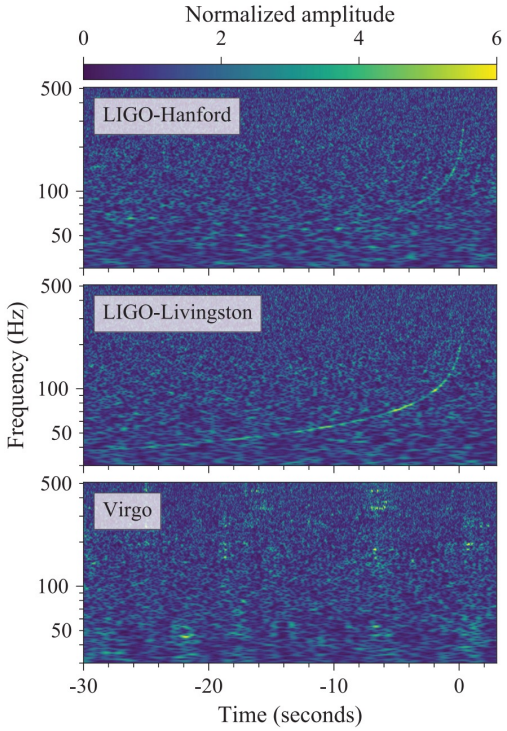
J-GEM, Subaru Telescope, and DESGW collaboration

2025/10/29

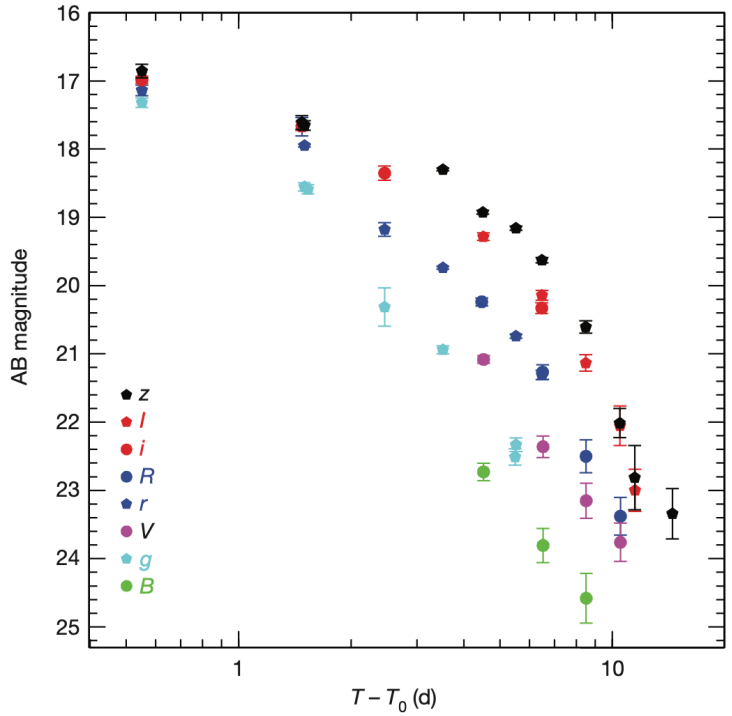
J-GEM: Japanese Collaboration for Gravitational-Wave Electro-Magnetic Follow-up
DESGW: Dark Energy Survey Gravitational Wave Collaboration

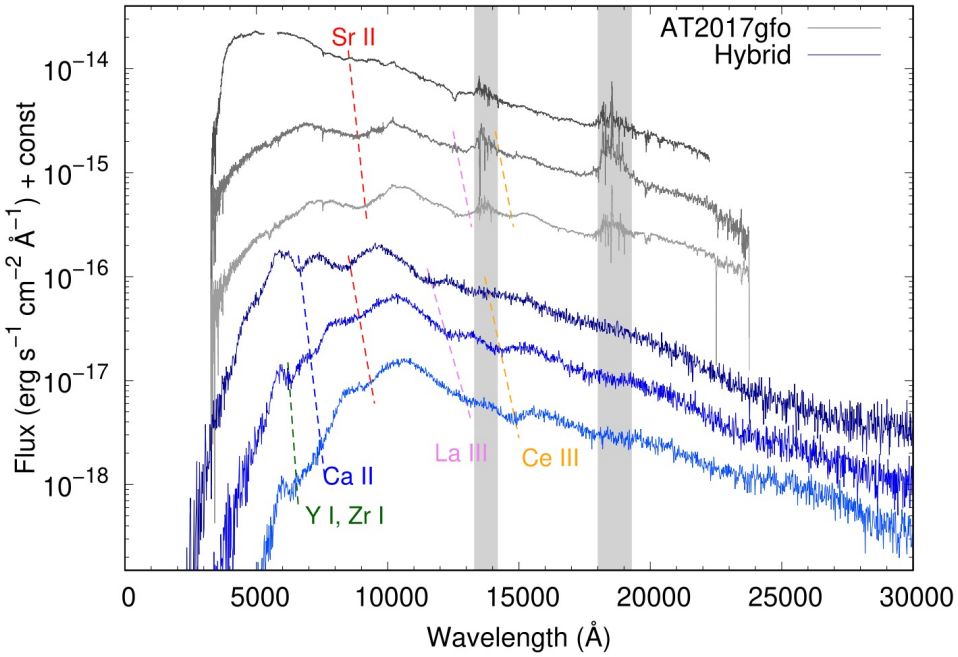
Electromagnetic counterparts to GW sources

- Ligo-Virgo-Kagra detect mergers including binary neutron star (BNS), binary black hole (BBH), and NSBH
- Successful example: GW170817 (BNS) with EM counterpart AT2017gfo (Kilonova)
- What we can learn: origin of heavy elements, cosmology (standard/dark siren), etc.



GW170817 (Ligo and Virgo 2017)

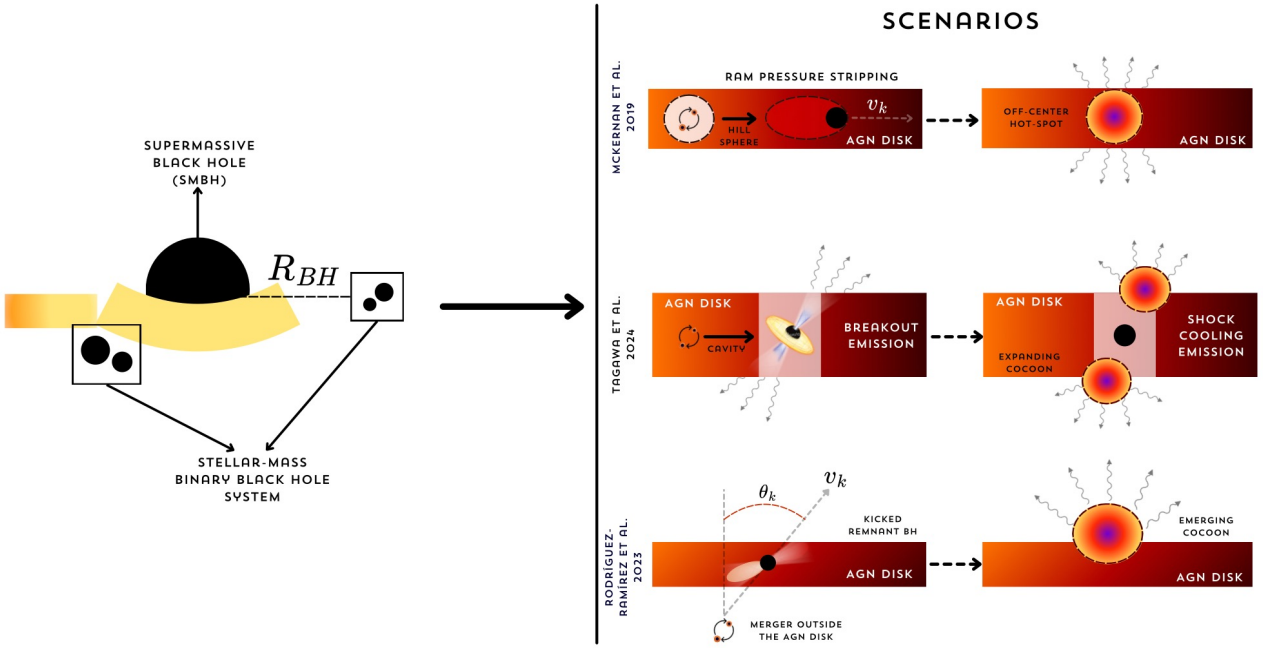




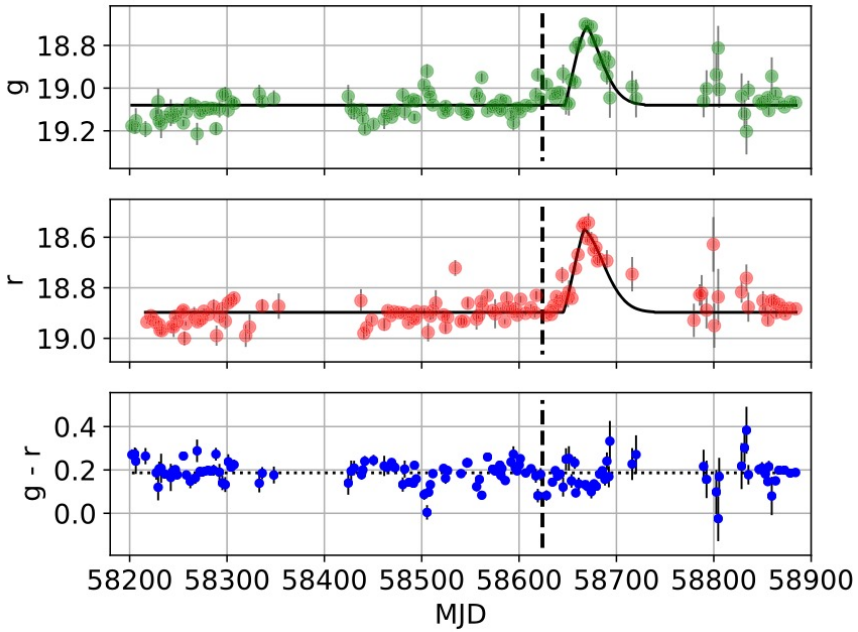
Kilonova AT 2017gfo (Pian et al. 2017; Domoto et al. 2022)

EM counterpart to BBH

- BNSs are rarely detected while BBHs are the major (≳90%) merger type detected by LVK
- But EM emission of BBHs is expected to be generally faint (under debate).
- Although predicted in some scenarios (e.g. mergers in AGN disks), there is no confirmed EM counterpart to BBH yet (a promising candidate of S190521g has been reported).



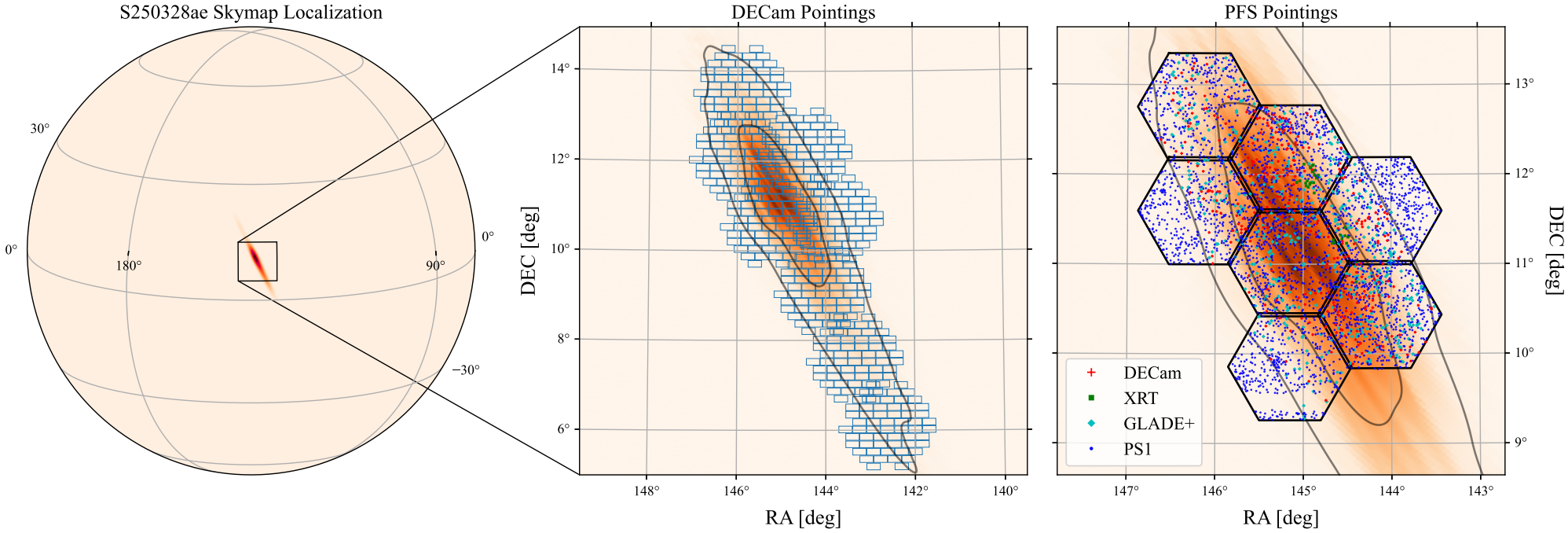
Mechanisms capable of producing EM counterparts to BBH mergers in AGN disks (Darc et al. 2025)



A promising counterpart candidate to GW S190521g (an AGN at z=0.438; Graham et al. 2020)

Our target and observations

- Our target: GW BBH candidate S250328ae (at a luminosity distance of ~511±82 Mpc)
- Localization: 3 deg^2 at 50% confidence and 15 deg^2 at 90% confidence
- DECam covers >90% of the 90% confidence, while PFS covers ~50% of the 90% confidence
- PFS targets include DECam transients, X-ray candidates, and potential host galaxies.



Skymap for S250328a with DECam and PFS pointings (arXiv:2508.00291)

Timeline of our PFS observation

- 2025-03-28: LVK reported the GW event S250328ae.
- 2025-04-02: We made an observation plan, prepared the target list (including the DECam transient candidates observed on 3/29 and 3/30) and triggered the Target of Opportunity (ToO; P.I. Michitoshi Yoshida) observation.
- 2025-04-03: We confirmed the fiber design with the observatory members and carried out the observation for a half night.
- 2025-04-09: We received the quicklook (QL) reduced data.
- 2025-04-24: We completed spectral classification and visual inspection of 3897 targets, and reported possible EM counterpart candidates to S250328ae in GCN 40221.
- 2025-06-13: We received the fully reduced data.
- 2025-07-31: We reported our results in a paper submitted to ApJ (arXiv:2508.00291).

Observation depth and epoch

- DECam: 90 seconds per exposure; separated in 4 nights; carried out by the DESGW team)
- PFS: 1800 seconds per exposure in a half night (ToO observation; carried out by the J-GEM and Subaru team)
- Our observations reach ≳21 mag (except for the PFS NIR arm)
- We expect to detect an EM counterpart if it is as bright as Graham+20.

Observation Night	Facility	Band: Limiting Magnitude m_{lim}
2025-03-29	DECam (Blanco)	$z : 21.4,\ \ i : 22.1,\ \ r : 22.7$
2025-03-30	DECam (Blanco)	$z : 21.9,\ \ i : 22.5,\ \ r : 22.8$
2025-04-03	PFS (Subaru)	$blue : 21.3,\ \ red : 21.3,\ \ NIR : 19.6$
2025-04-06	DECam (Blanco)	$z : 21.0,\ \ i : 21.2,\ \ r : 21.3$
2025-04-25	DECam (Blanco)	$z : 21.6,\ \ i : 22.1,\ \ r : 22.3$

Table 1. Observation dates and notes for DECam and PFS observations of S250328ae. DECam 10σ limiting magnitudes for the exposures are estimated using J. H. Neilsen et al. (2016). PFS limiting magnitudes are estimated for continuum using 5σ median noise of single pixels (pixel size ~ 0.8 Å) in blue, red, and NIR spectral arms, respectively.

Data reduction and visual inspection

- The DECam transient candidates are selected by DESGW team.
- In total, 3897 targets (including transients and host galaxies) are observed by PFS.
- The PFS data are reduced by the Subaru data reduction team.
- We adapt Redrock (DESI spectral fitter) and obtain the initial spectral type and spec-z.
- Visual inspection is then carried out individually by two people (Mitsuru Kokubo and Haibin Zhang), with a modified spectrum viewer based on the DESI viewer (prospect).
- We only use confident candidates (VI scores of A and B) in the following analysis.

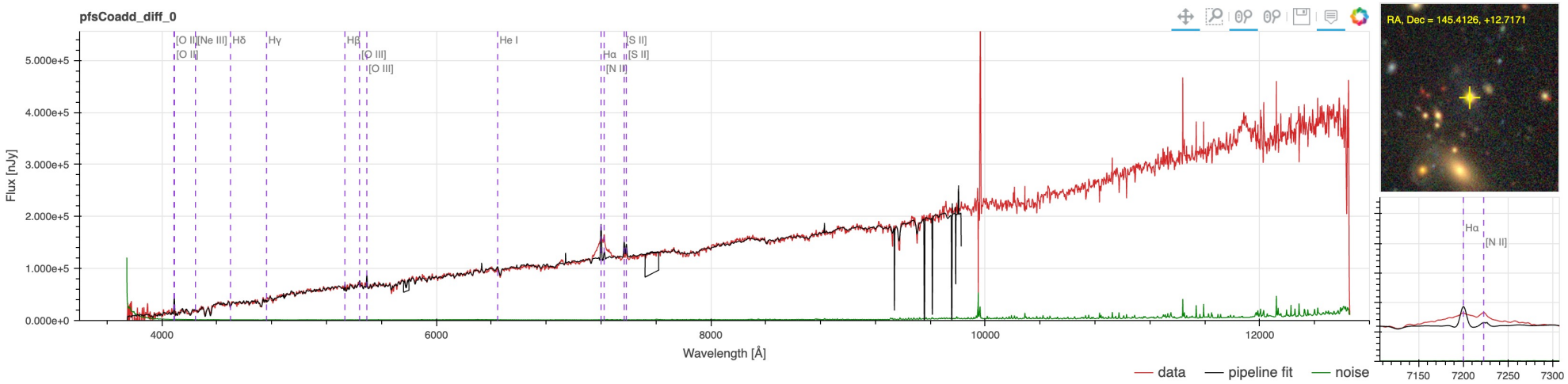
Epoch	Initial Candidates	`autoscan` > 0.7	Multiple Detections	Within 90% Region	Visual Inspection
1	4103	816	816	598	20
2	15858	1738	443	281	25
3	20474	2477	129	80	26
4	38448	3955	459	289	3

DECam transient candidates

Score	Criteria	Number of Targets
A	At least two secure spectral features	3093
B	At least one secure spectral feature with multiple weak features	147
C	One strong spectral feature but without other features to confirm what it is	37
D	Clear signal but without identified features or contaminated by nearby bright stars	167
E	No signal	453

PFS visual inspection criteria

Spectrum viewer



TARGETID: 9238

Reset X-Y range | OII-zoom | Undo OII-zoom

< 4 3 2 1 0 > Spectrum number (0 to 867): **183** 183

VI optional indications:

- Bad redshift fit
- Bad spectype fit
- Bad spectrum

VI redshift: | VI spectype: QSO

VI comment (see guidelines): 1.0e-05 | Standard comment:

Your name (3-letter acronym): hbz | VI file name: vi_pfsCoadd_diff_0_hbz.csv

Download VI

#	Flag	Opt.	VI z	VI spectype	VI comment
178	3		0.1380		7.2e-06
179	3			STAR	2.3e-06
180	0				
181	0				
182	2				
183	4			QSO	1.0e-05

Gaussian Sigma Smooth: **2**

< Redshift rough tuning: **0.09** >

Redshift value: 0.0968

Redshift fine-tuning: **0.0068** | Reset to z_pipe | Copy z to VI

Velocity tuning (km/s): **0** | Reset to v=0

Velocity value: 0

Pipeline fit:

Z	CLASS	SUBCLASS	Z_ERR	ZWARNING	RCHI2DIFF
0.0968	GALAXY	BGS_0	0.0000	0	16846.2

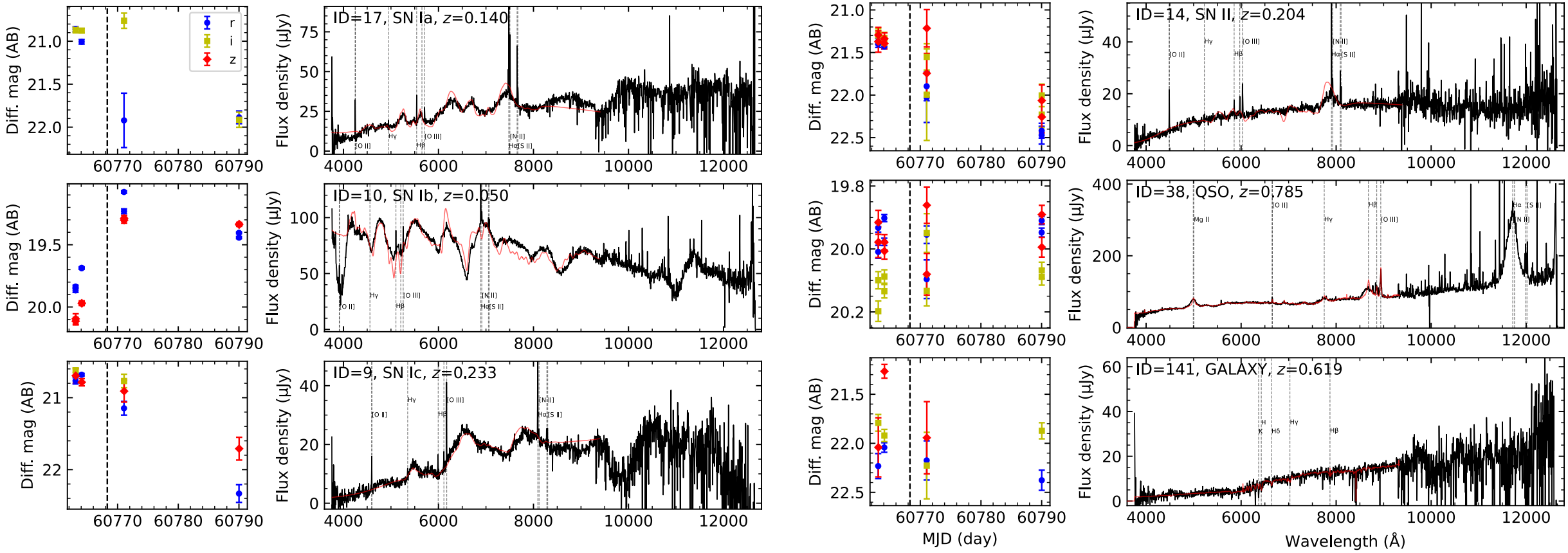
mag_g	mag_r	mag_i	mag_z	mag_y
19.86	19.04	18.62	18.36	18.03

Emission lines | Absorption lines | Supernova lines | Non-SN lines

Obs | Rest

Show only major lines

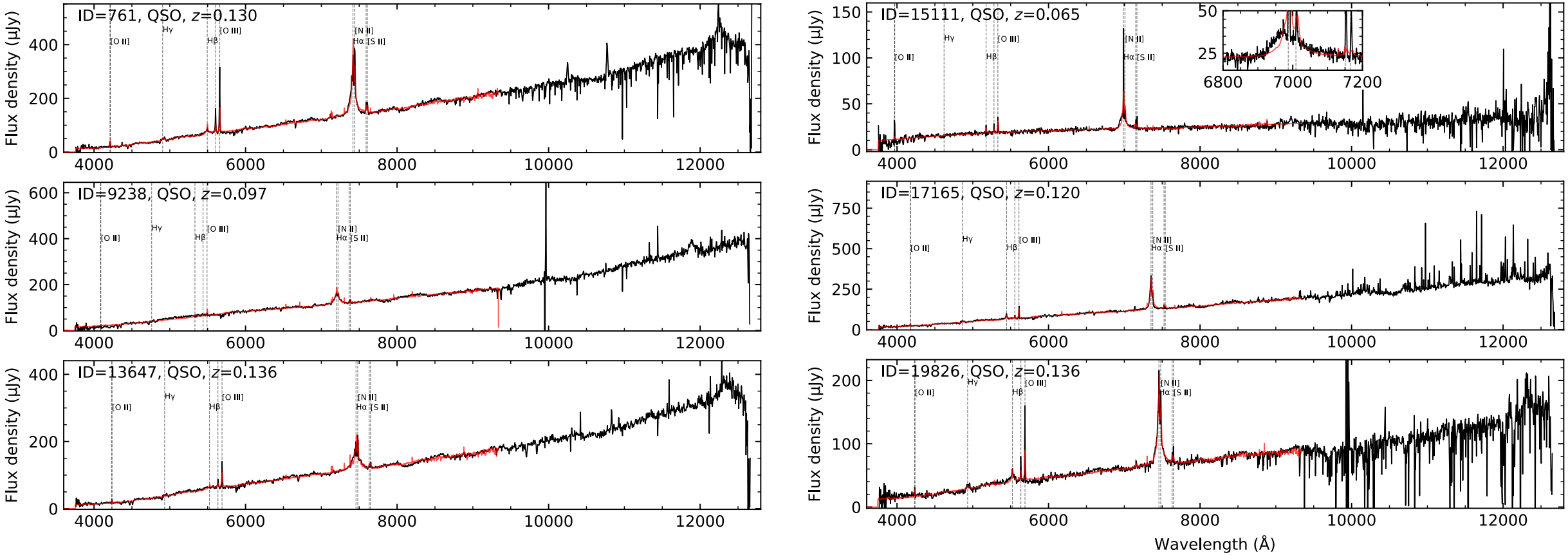
Example PFS spectra



DECam light curves and PFS spectra (black: observed; red: best-fit template)

Possible EM counterpart to GW S250328ae

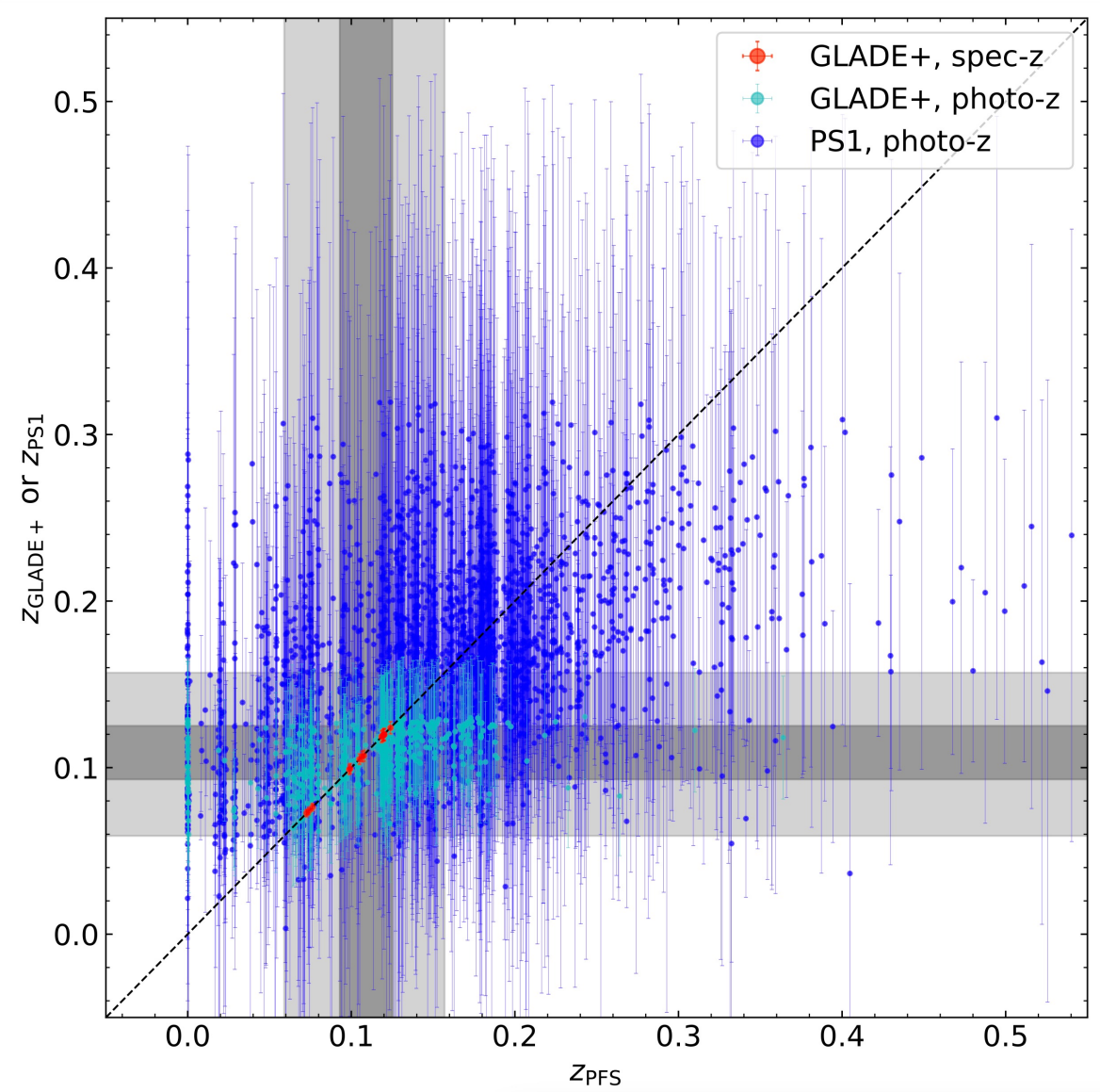
- No confident candidates. We do not find clear variability in these candidates, but cannot rule out the association as the variability of BBH EM counterparts could be faint.



PFS spectra of possible candidate to S250328ae (black: observed; red: best-fit template)

Comparison with archival redshifts

- The numbers of targets with GLADE+ spec-z, GLADE+ photo-z, and PS1-STRM photo-z are 14, 464 and 2572, respectively.
- Among these targets, 14, 442, and 2255 (100%, 95%, and 88%) targets have redshift differences of $< 0.1(1 + z)$, respectively.
- Using our confident VI results (A and B scores) as the reference, the lam1d (PFS redshift fitter) results show good consistency (96.5% with consistent type and spec-z), although the Redrock (DESI redshift fitter) is slightly more consistent (98.9%).



Future perspective

- We will carry out cosmology (dark siren) study using the spec-z we obtained. We also plan to observe more GW BBH mergers to improve the accuracy of the cosmological parameters.

- PFS is a powerful instrument and very efficient for wide field surveys (e.g. transient search).

- Future joint PFS observations of transients with DECam, LSST, etc. are promising.

- We greatly appreciate the rapid ToO observations (made possible by the great effort of Subaru observatory members and PFS hardware/software teams, etc.) and would like to continue the transient study with Subaru in the following decades hopefully.

Summary

- We carried out a joint search for the EM counterpart to the GW BBH merger candidate S250328ae with DECam and PFS.

- Confident spectral classification and spec-z of >3000 targets were obtained after template fitting and visual inspection.

- We do not find any confident EM counterpart candidates to S250328ae, although the association with 6 QSOs (and 3 transients not observed by PFS) cannot be ruled out.

- We greatly appreciate the rapid PFS ToO observations and would like to continue joint PFS observations of transients with DECam, LSST, etc. in the future.