

Simultaneous optical limits on repeating FRB 20190520B by 24.4 fps observations with Tomo-e Gozen (Niino *et al.* 2022, *ApJ*, 931, 109)

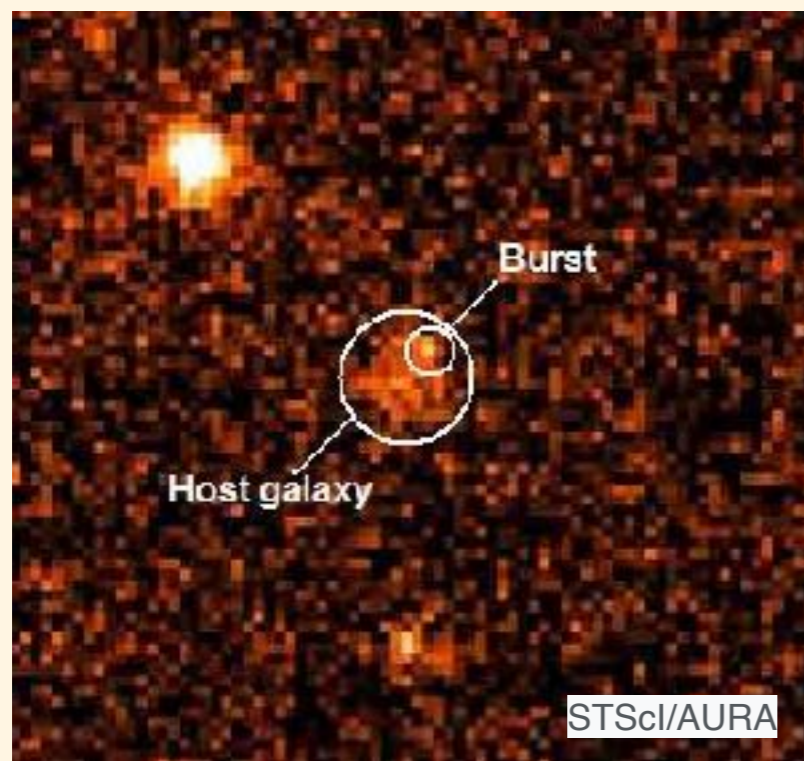
Yuu Niino (U. Tokyo)

in collaboration with:

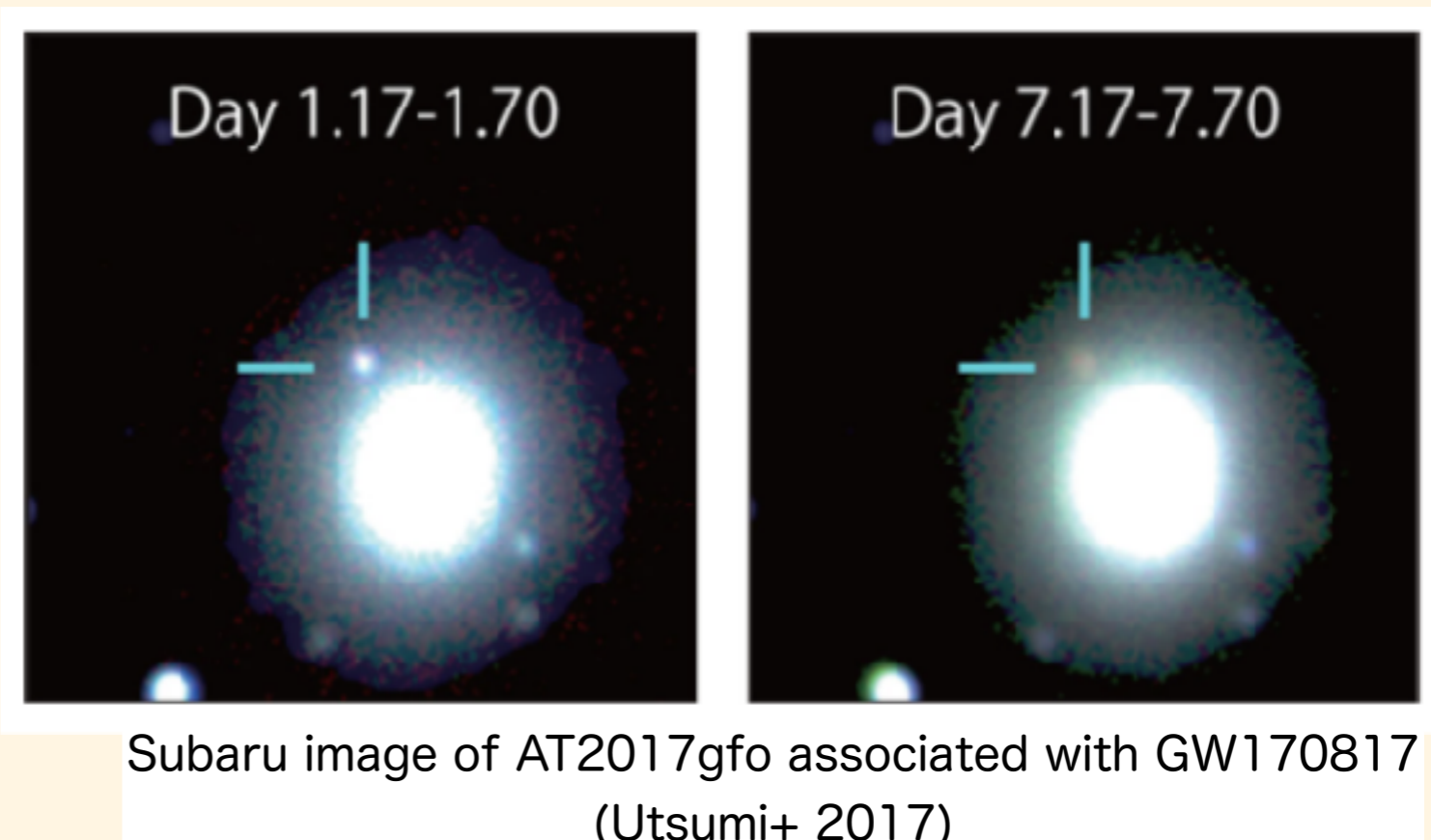
M. Doi, S. Sako, R. Ohsawa, N. Arima, J. Jiang, N. Tominaga,
M. Tanaka, D. Li, C.-H. Niu, C.-W. Tsai, N. Kobayashi, H.
Takahashi, S. Kondo, Y. Mori, T. Aoki, K. Arimatsu, T. Kasuga,
and S. Okumura

Other wavelength (messenger) counterparts of transients

- Discovery of an other wavelength counterpart is important to understand the nature of a mysterious astronomical transient.
- GRB: afterglows & associated SN
- GW: kilonova & GRB



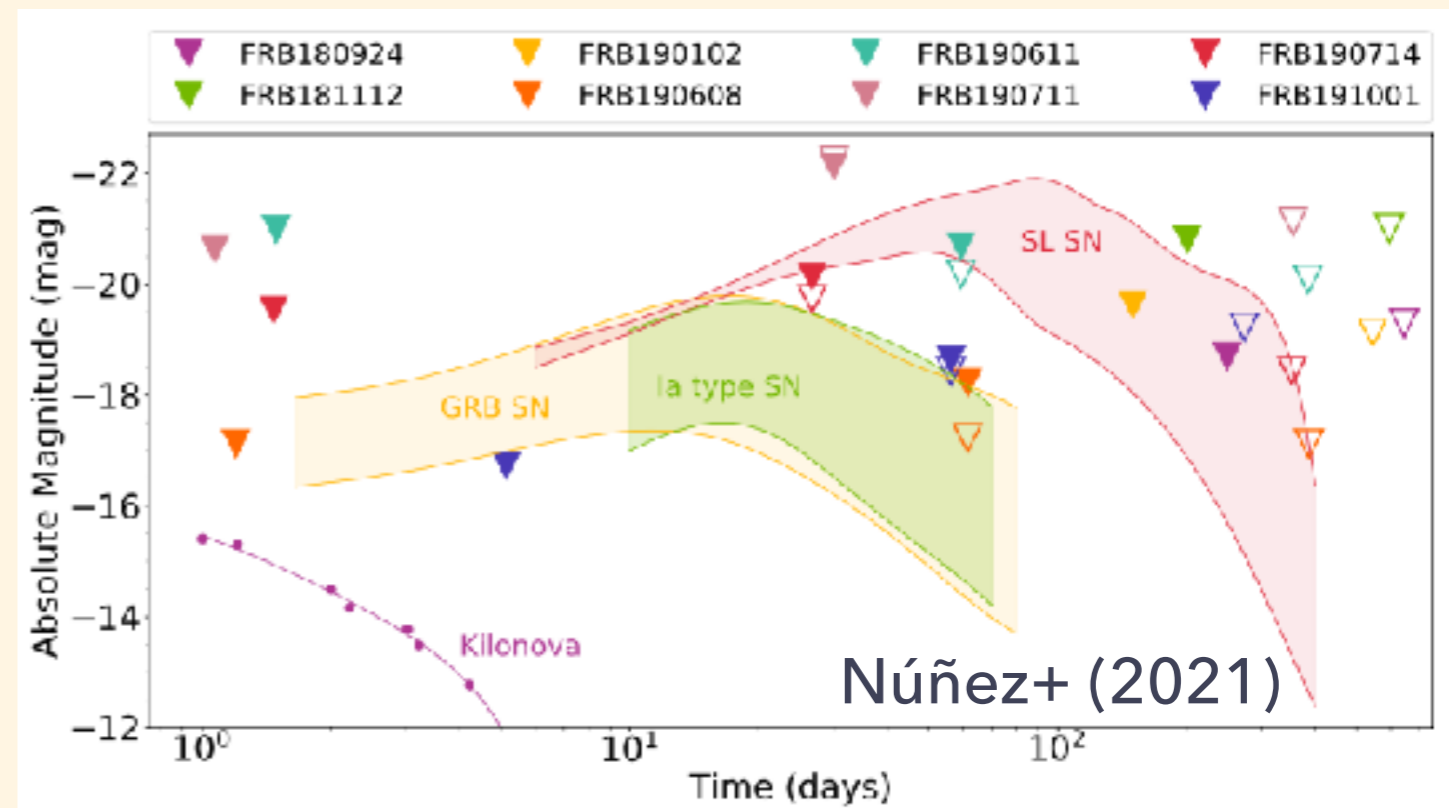
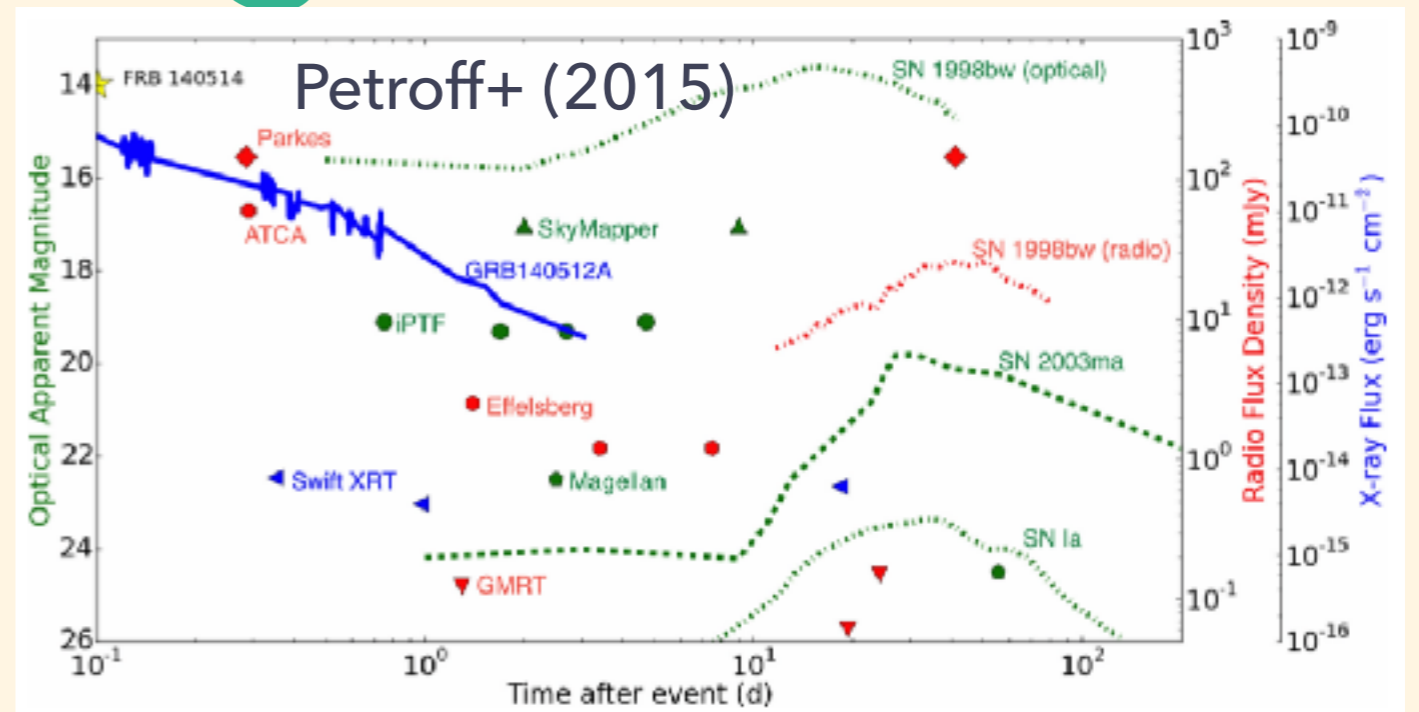
GRB 970228 afterglow by HST



Subaru image of AT2017gfo associated with GW170817
(Utsumi+ 2017)

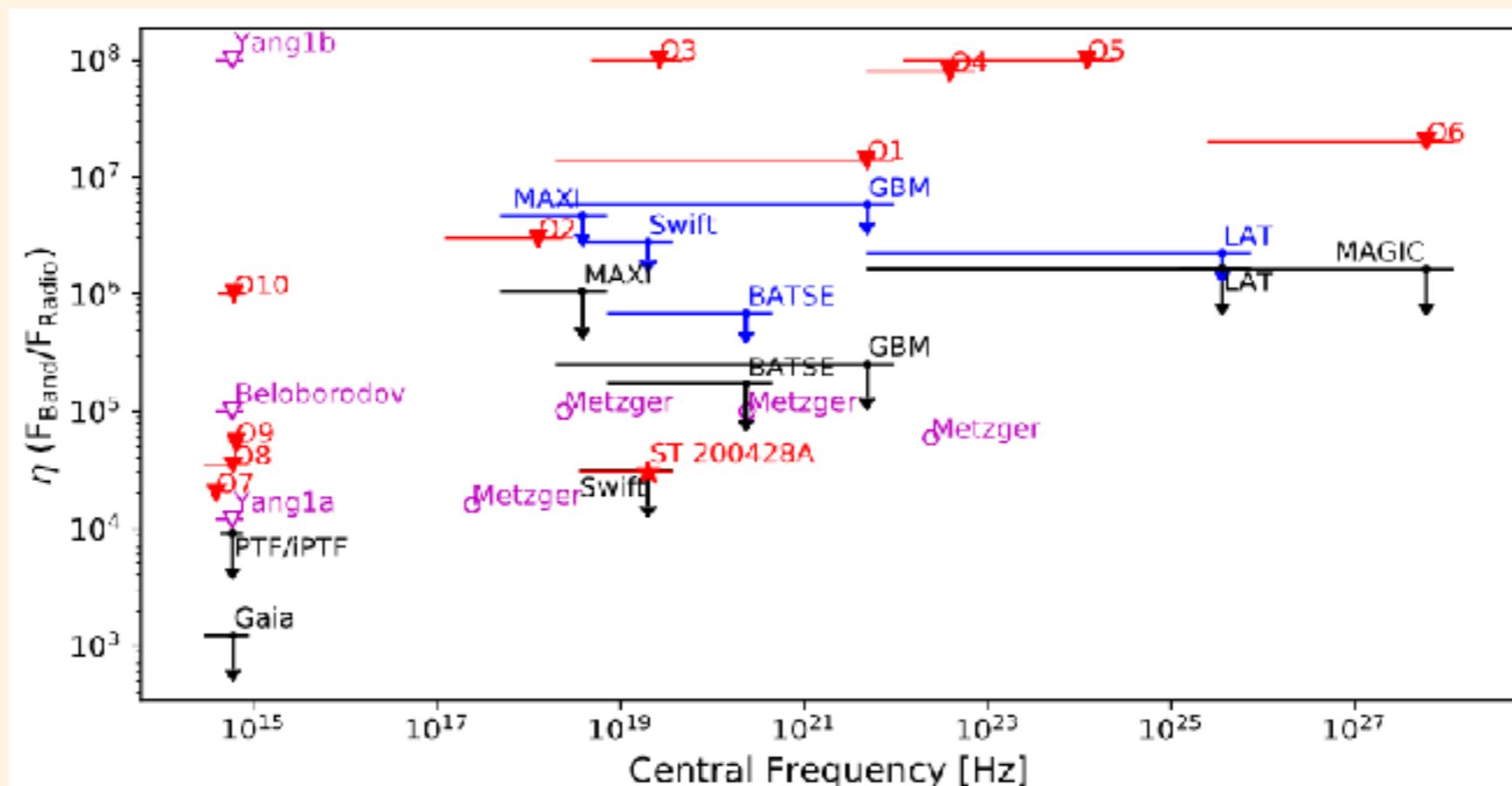
FRB counterpart search in various wavelength

- ToO observations are conducted in various wavelength and delay time.
- No robust association so far.
- In optical:
 - Association of some population of bright transients are ruled out.
 - Association of optical transients as faint as type II SN remains possible.



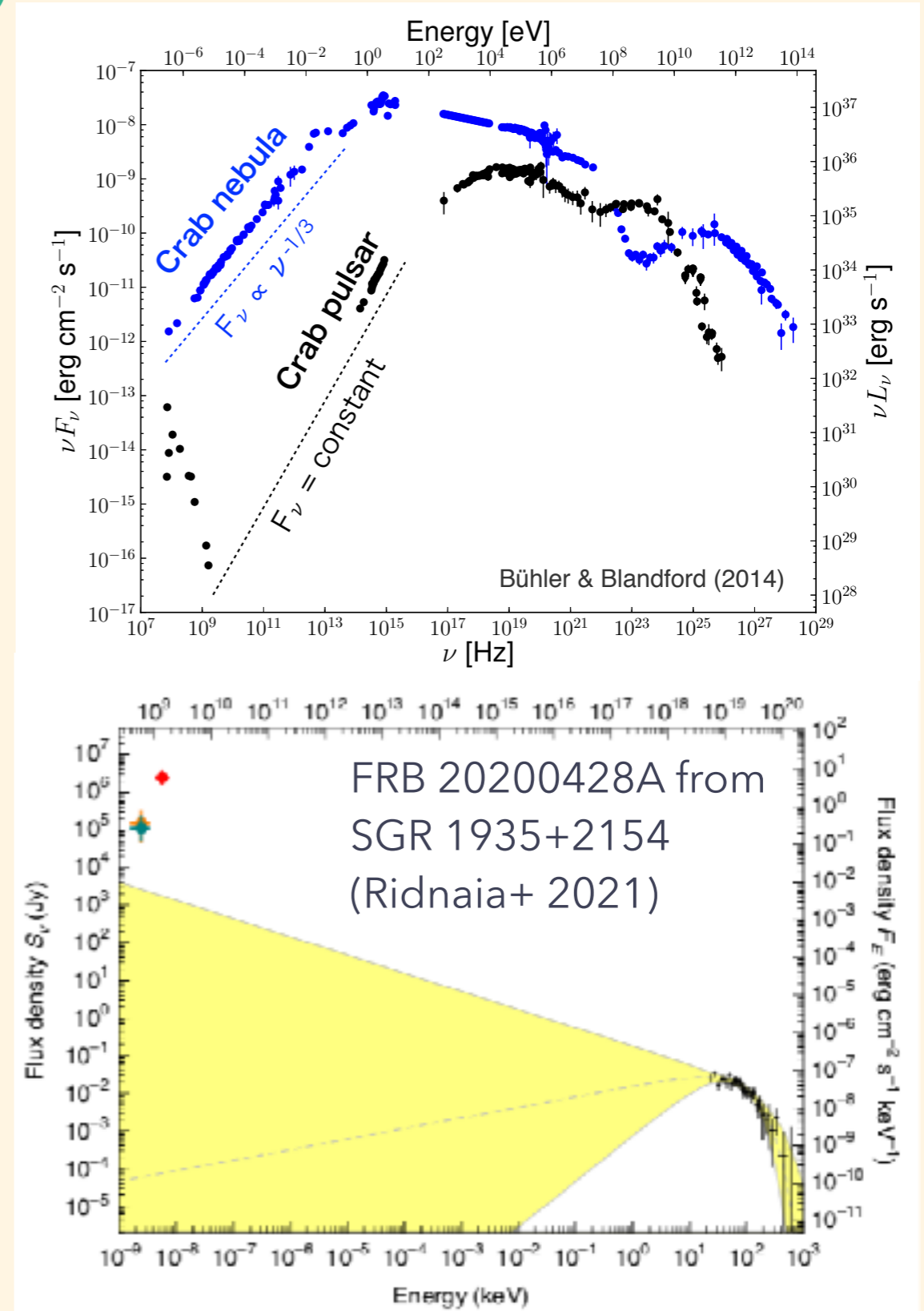
Statistical upper limit

- Statistical limits on FRB counterparts based on wide field surveys in various wavelength (Chen+ 2020).
- major assumption:
 - Functional form of luminosity functions are the same in different wavelength.
 - No FRB counterpart is detected in the surveys.
 - Unidentified objects? Possible artificials?



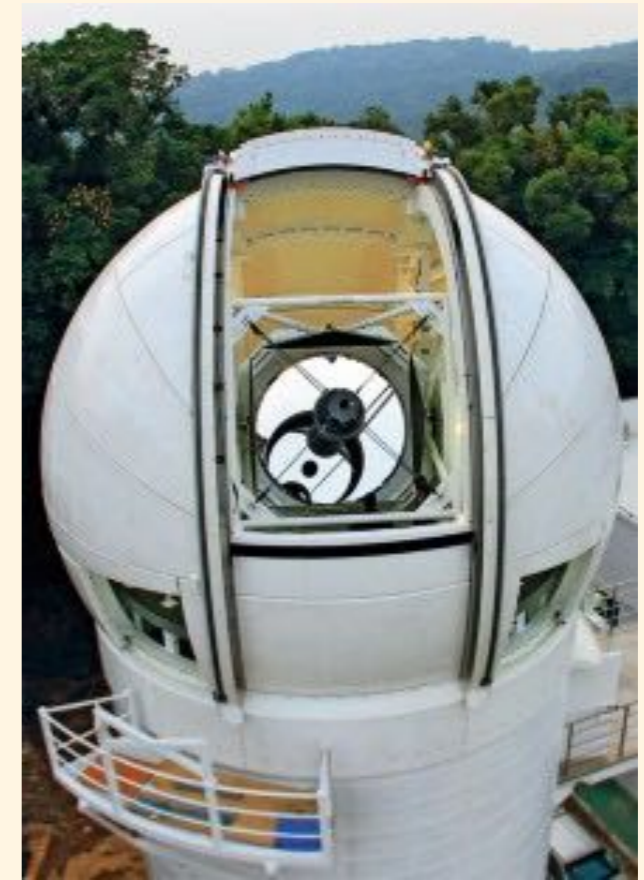
Simultaneous emission in other wavelength?

- Some pulsars are detected in wide variety of passbands.
- FRB 20200428A
 - An FRB like burst from a galactic SGR was detected accompanied with an extraordinary X-ray flare.
- No simultaneous emission is found for extragalactic FRBs.
- Theoretical predictions
 - inverse Compton in a pulsar magnetosphere (Yang+ 2019)
 - blastwave collision into a hot wind bubble (Beloborodov+ 2020)

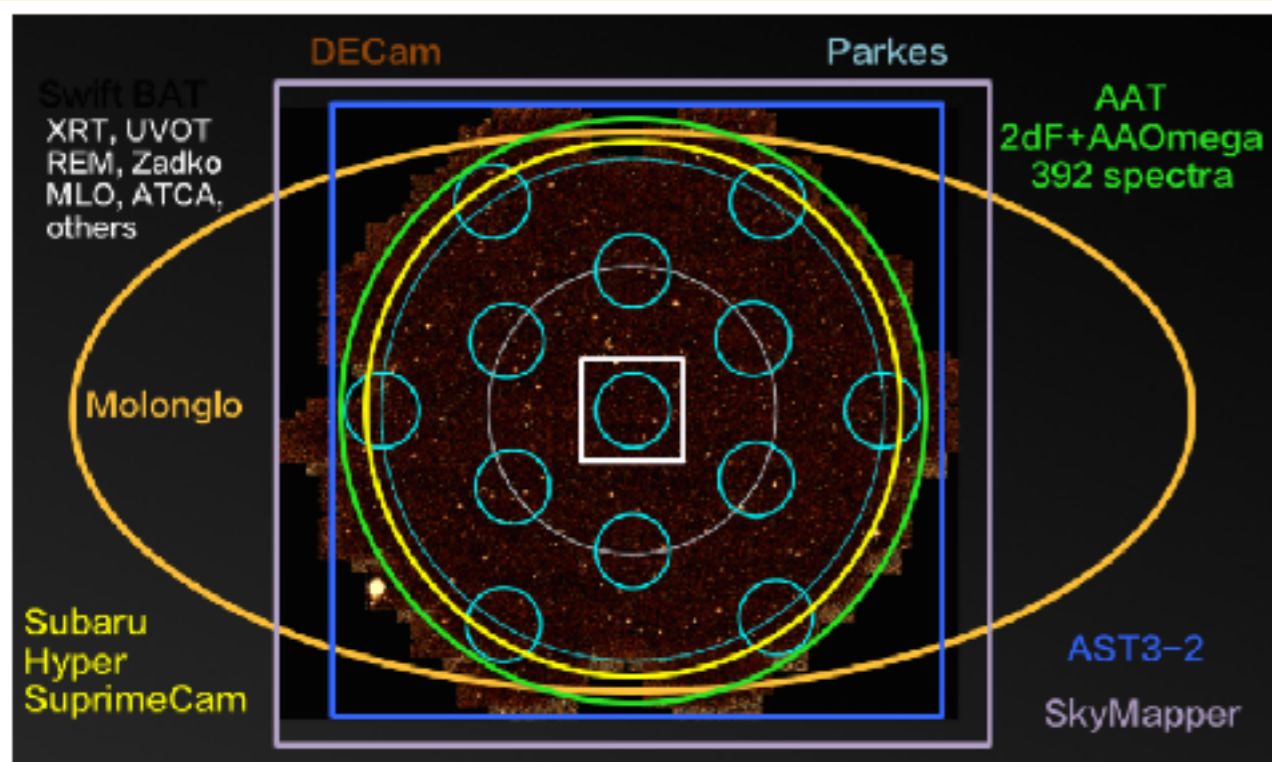


FRB simultaneous observations in optical

- Most of the existing optical facilities observes with time scales $>$ seconds.
- wide field survey
 - Deeper Wider Faster (Andreoni & Cooke 2019)
 - optical component is not so fast
- FRB 121102 monitoring
 - Hardy+ (2017) using ULTRASPEC
 - < 0.33 mJy with 70 ms using EMCCD
 - MAGIC collaboration (2018)
 - < 8.6 mJy with ~ 1 ms using photomultiplier



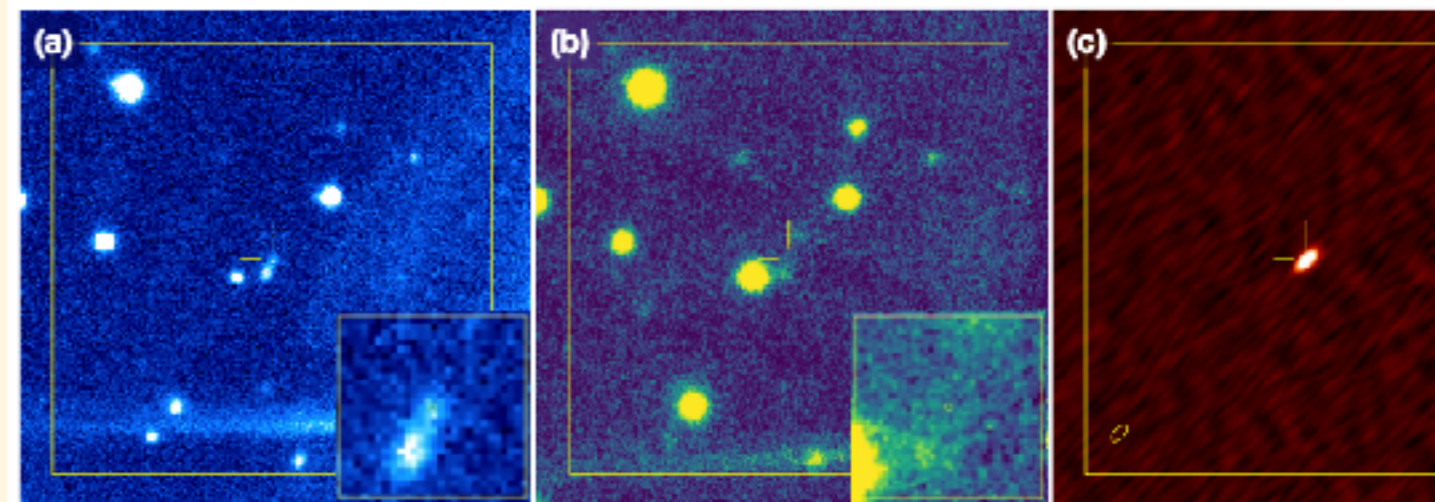
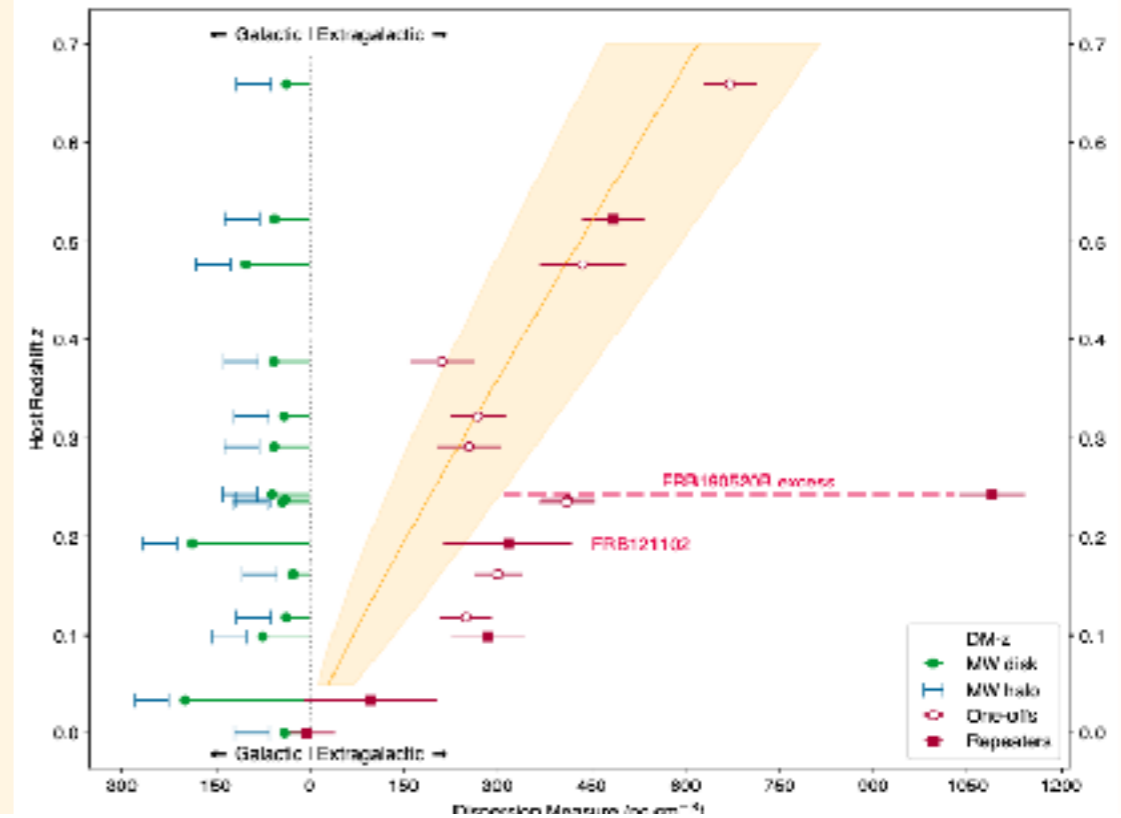
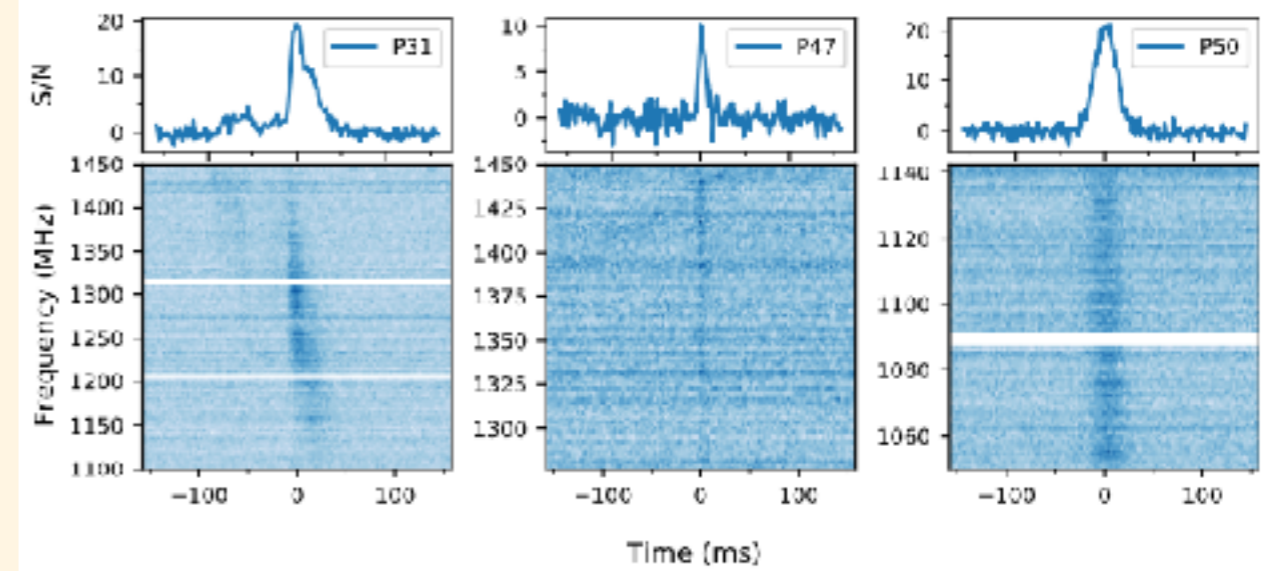
Soonthornthum (2018)



Credit: R. Wagner

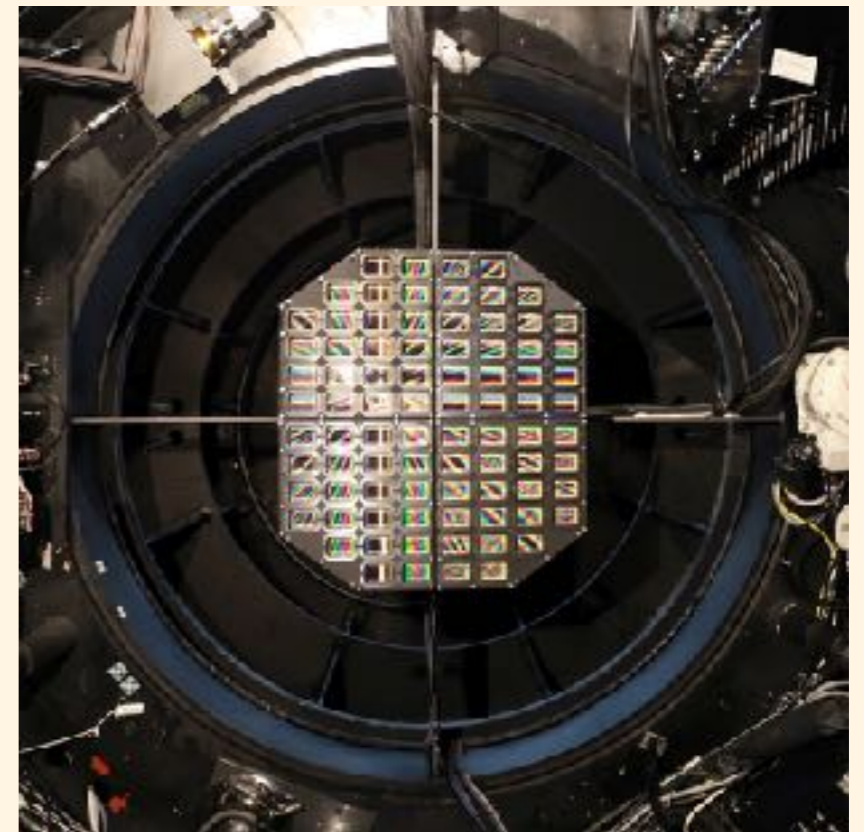
FRB 20190520B

- Niu+ (2022)
 - discovery by FAST
 - localization by VLA
 - $DM_{\text{ex}} = 1200 \text{ cm}^{-3}\text{pc}$
 - $z > 1$ if IGM
 - host galaxy redshift = 0.24
 - associated with a compact radio source
 - > 80 bursts detected so far



The Kiso Schmidt telescope & Tomo-e Gozen

- 1.05 m telescope
- FoV: 9 deg diameter
- Tomo-e Gozen
 - 20 deg² wide field CMOS camera
 - 84 chips sparsely distributed on the focal plane (2,000 x 1,128 pix each)
 - high frame rate: 2 fps with full-frame
- operated by an automated queue system
 - daily all sky survey
 - targeted observations
 - automatic followup triggered by VOEvents
 - GW
 - GRB (under development)
 - MAXI (under development)
 - etc...



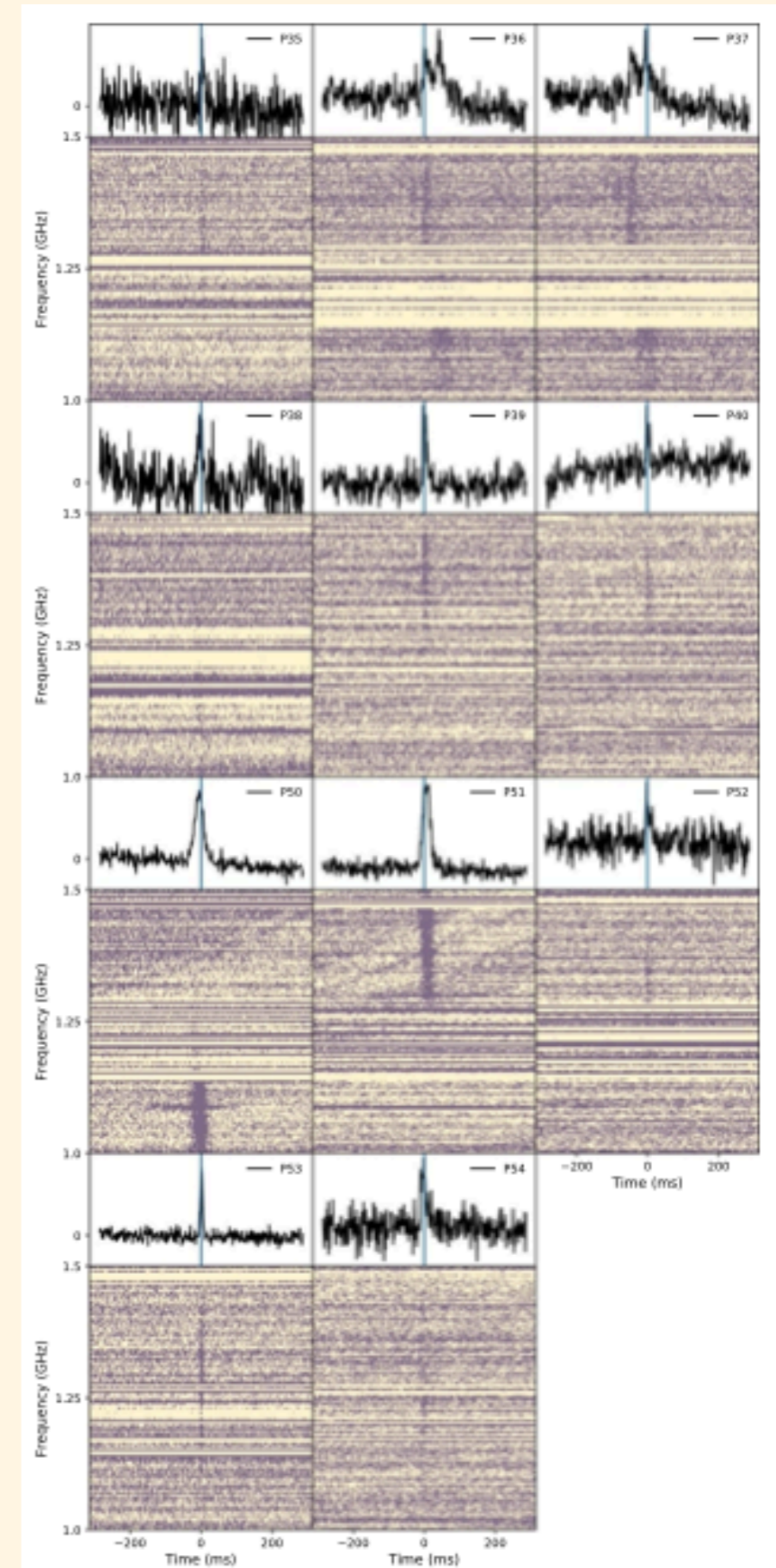
Simultaneous observation with FAST

- Simultaneous observation with FAST on Aug. 4, 6, 14, 16, 2020.
- 24.4 fps with partial readout
 - FoV $\sim 8 \times 5$ arcmin²
 - 40.9 ms/frame
 - gap between frames ~ 0.1 ms
- unfiltered passband
 - ~ 3700 - 7300 Å



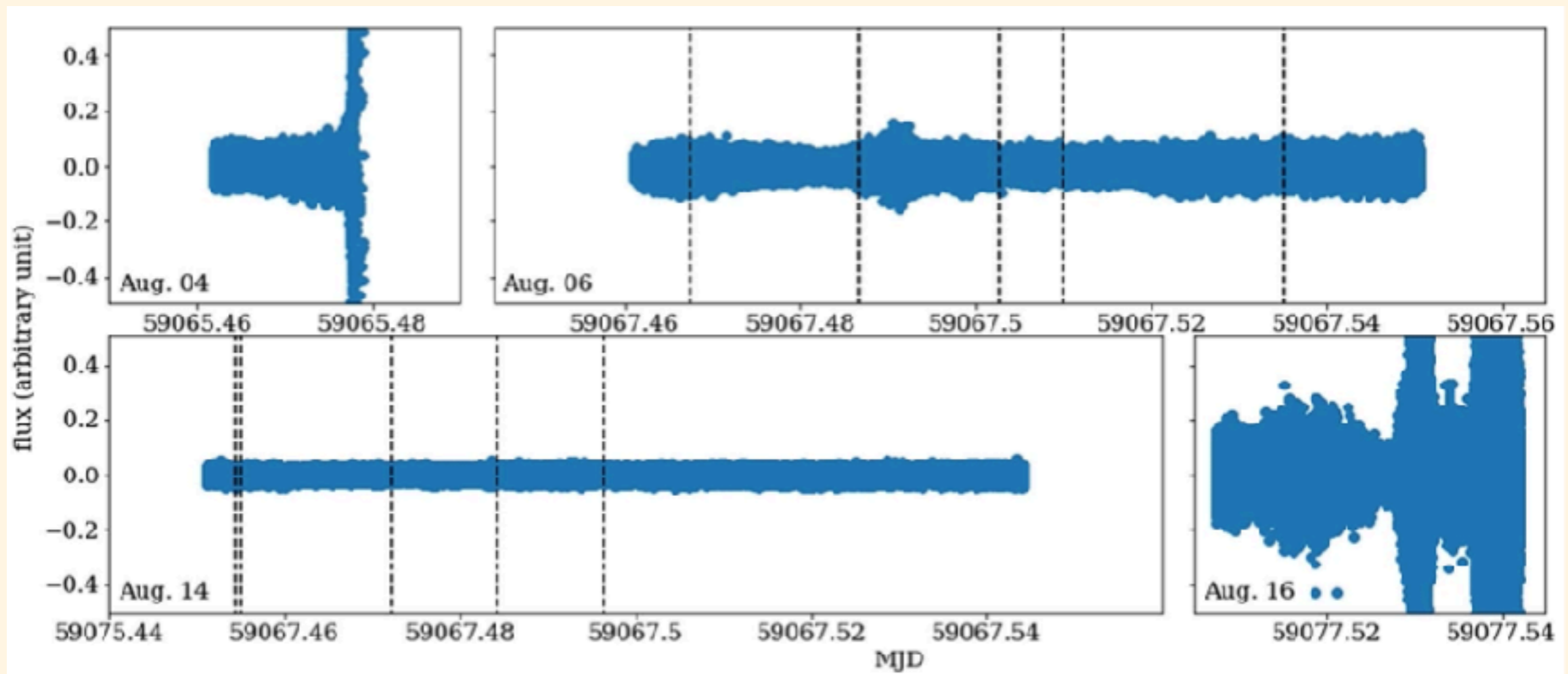
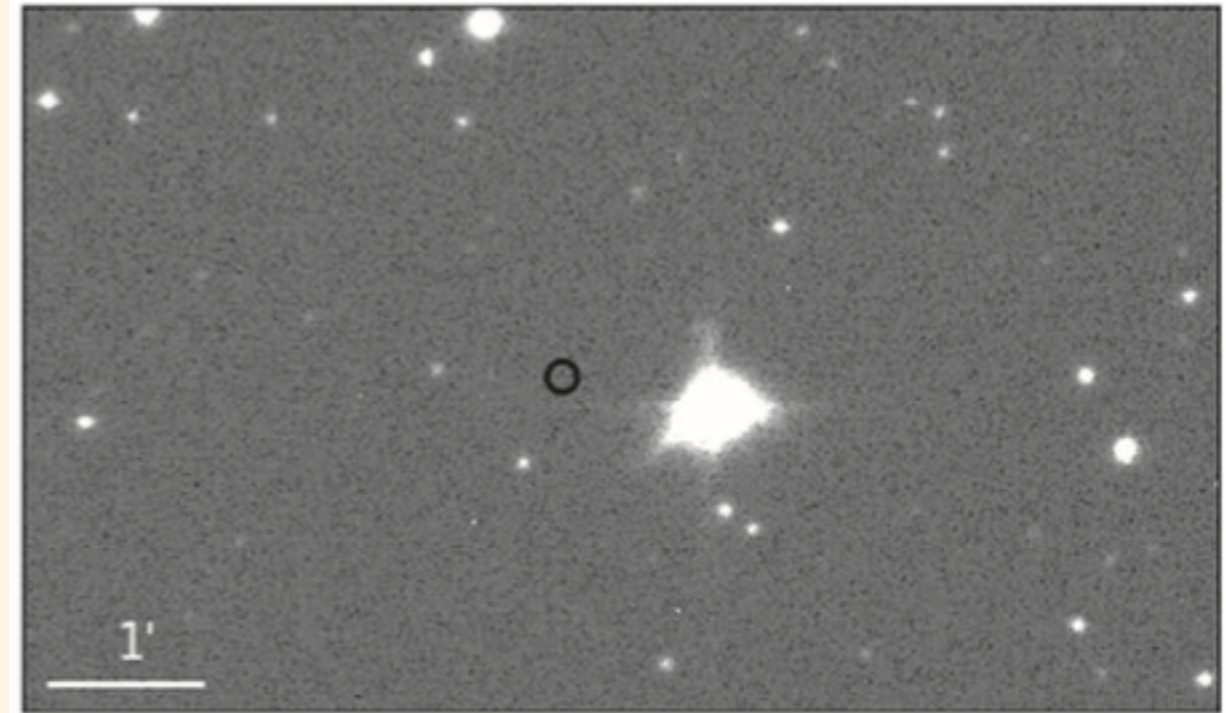
Radio burst detections

- 11 bursts are detected
 - 6 bursts on Aug. 6
 - 5 bursts on Aug. 14
 - 0 bursts on Aug. 4 & 16
- fluence range $\sim 60\text{-}300$ mJy



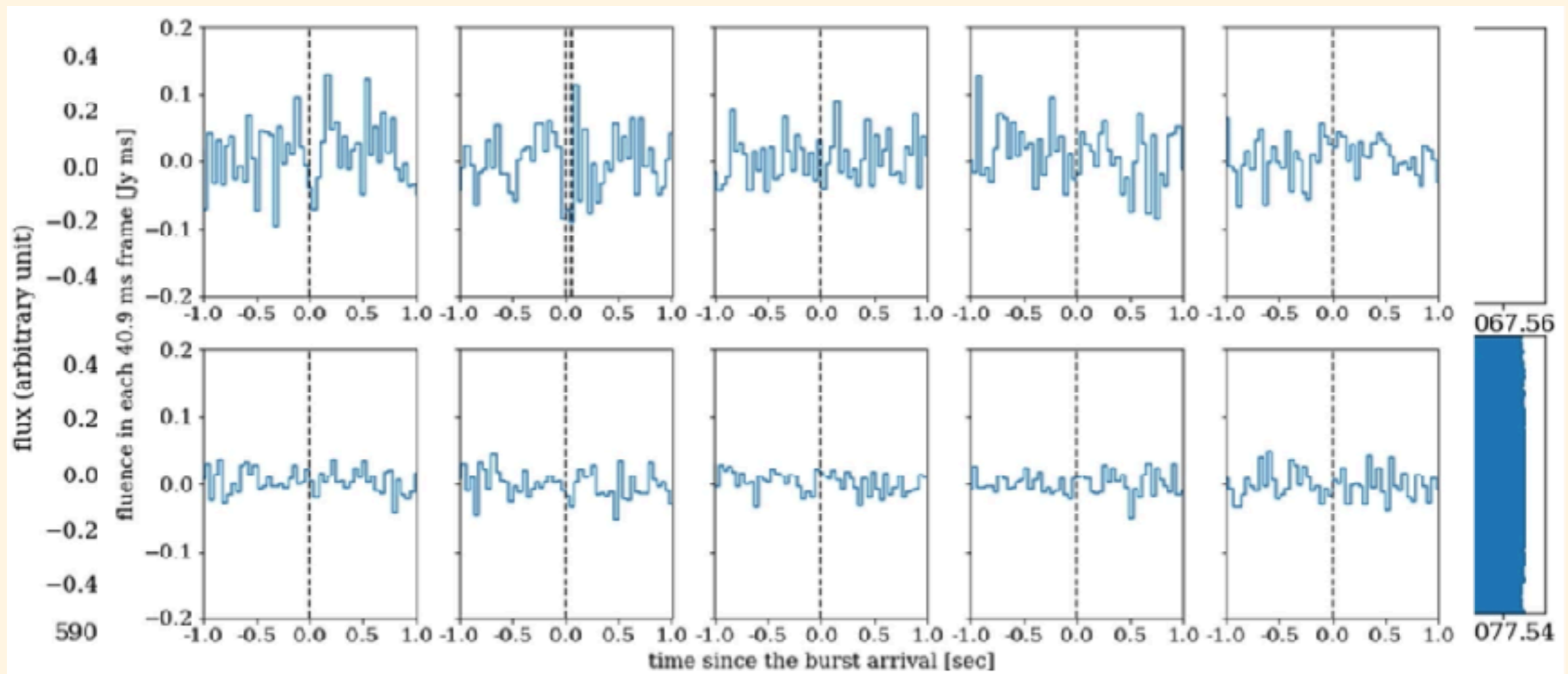
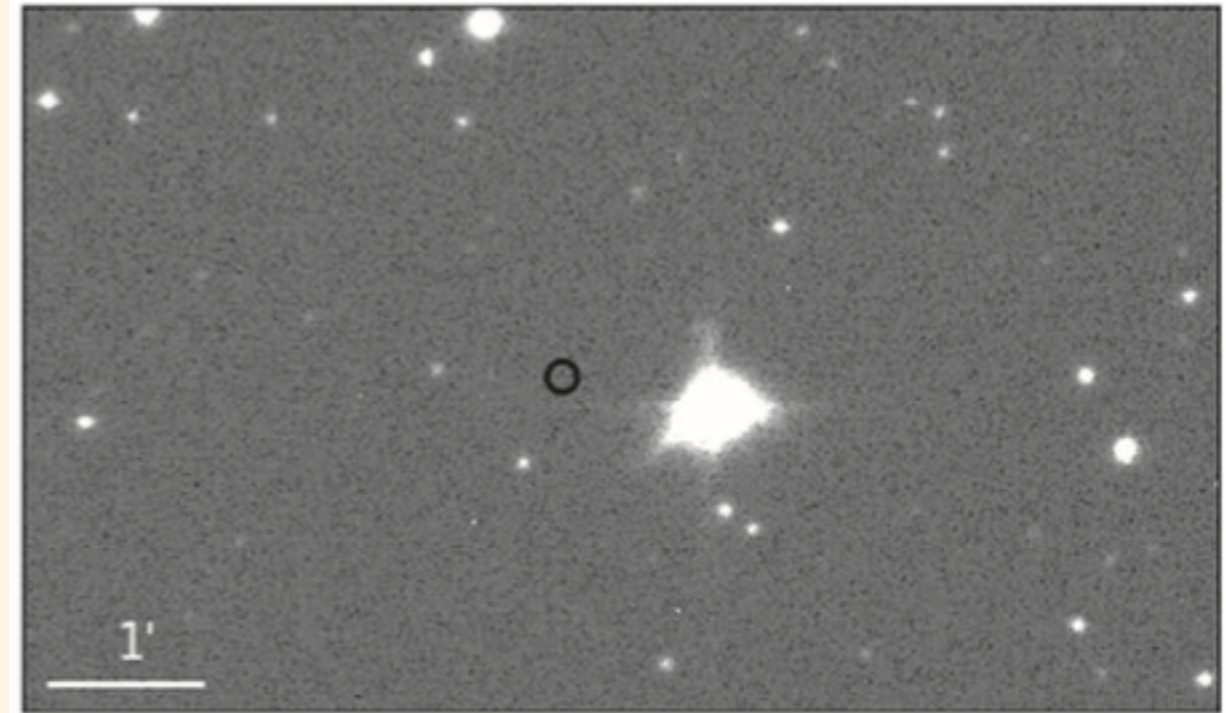
Optical lightcurve

- No persistent source (e.g. host galaxy) at the burst coordinate.
- Extract optical light curve by the forced photometry.
- no burst found



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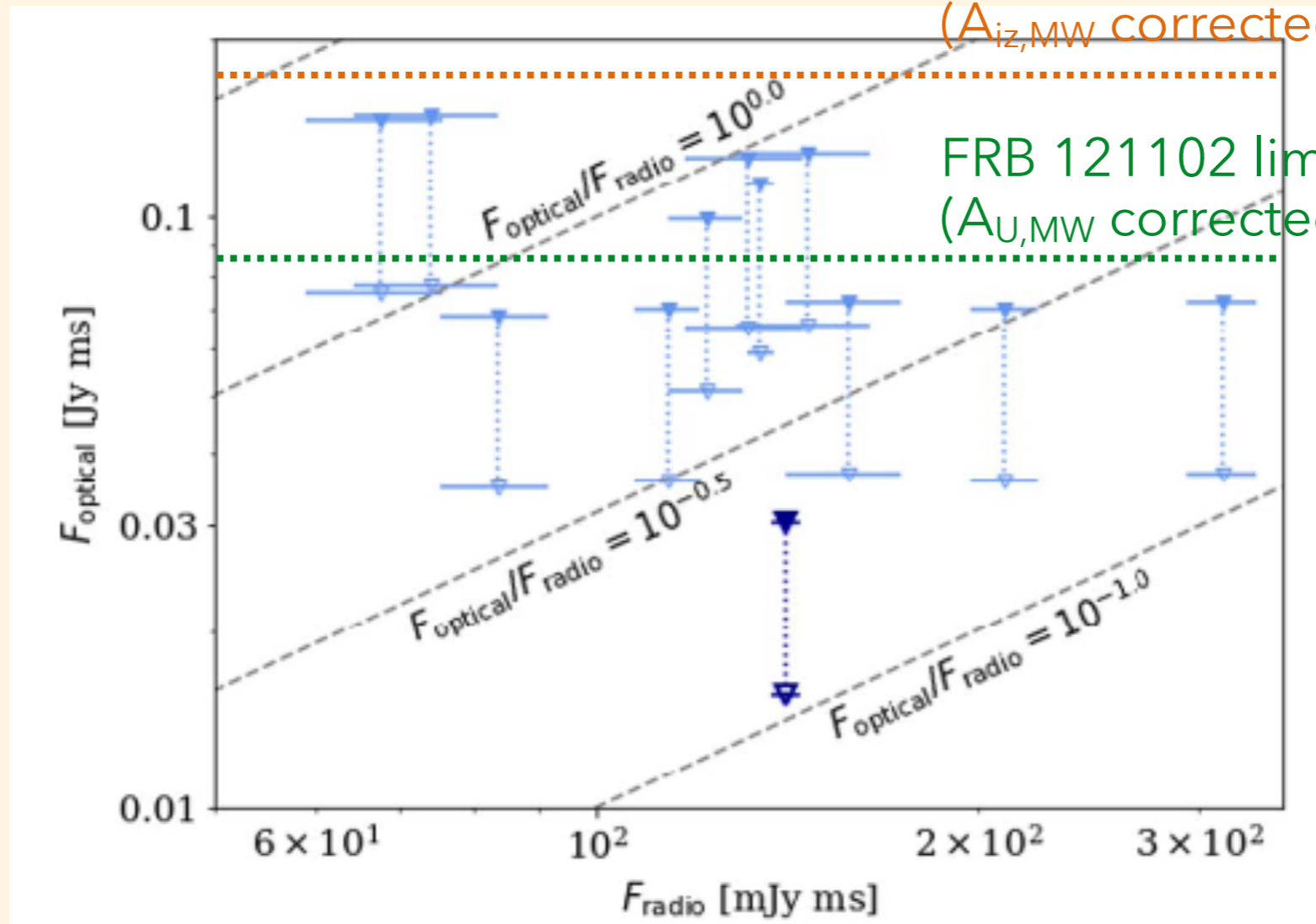


Optical fluence limits

- extinction corrected fluence limit ($E_{B-V,MW} = 0.25$)
 - 0.068-0.149 Jy ms (individual)
 - 0.029 Jy ms (stacked)
- $F_{\text{opt}}/F_{\text{radio}} \approx 0.2-2.1$

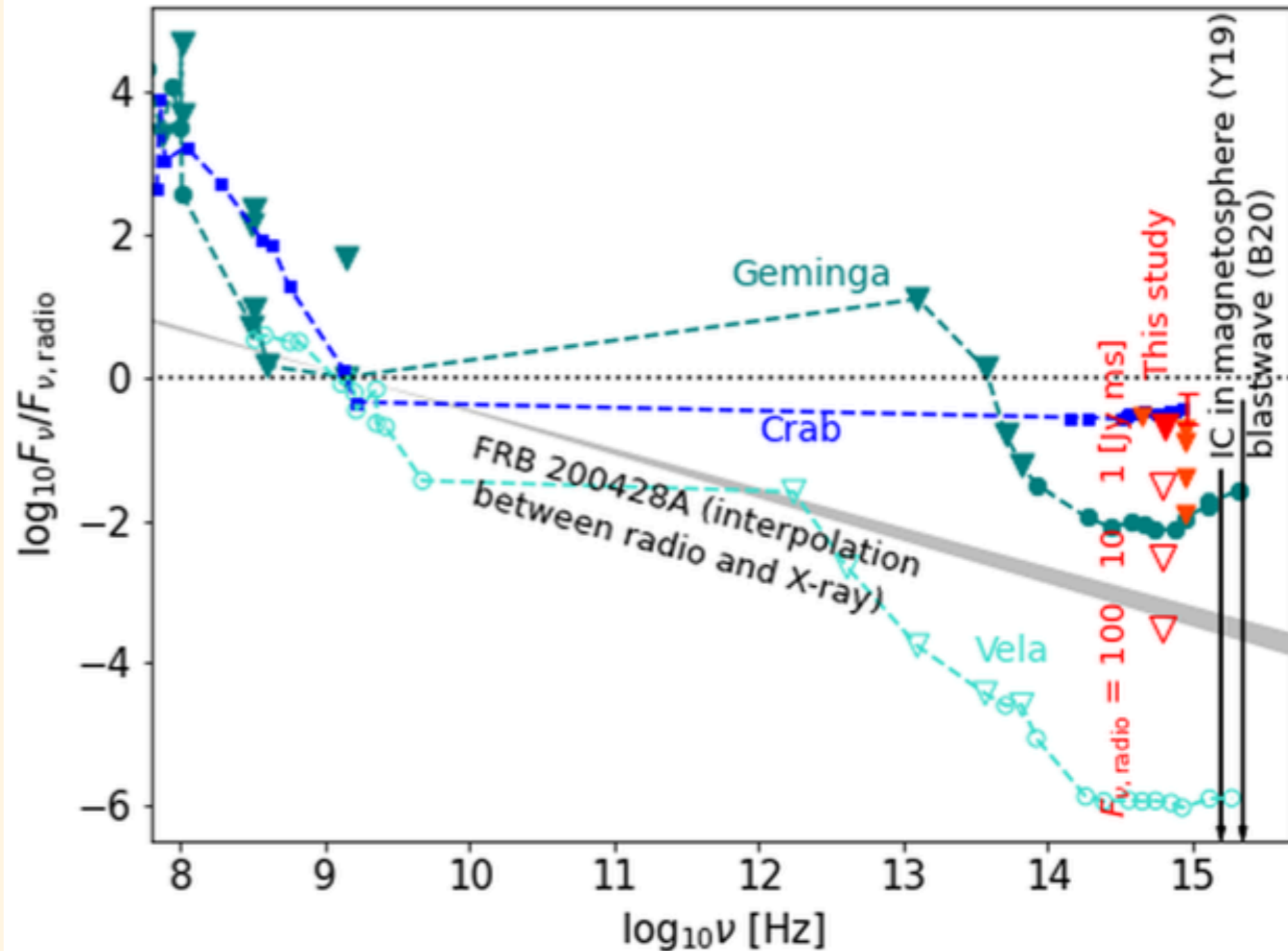
FRB 121102 limit by ULTRASPEC
($A_{iz,MW}$ corrected, 70 ms)

FRB 121102 limit by MAGIC
($A_{U,MW}$ corrected, 1 ms)



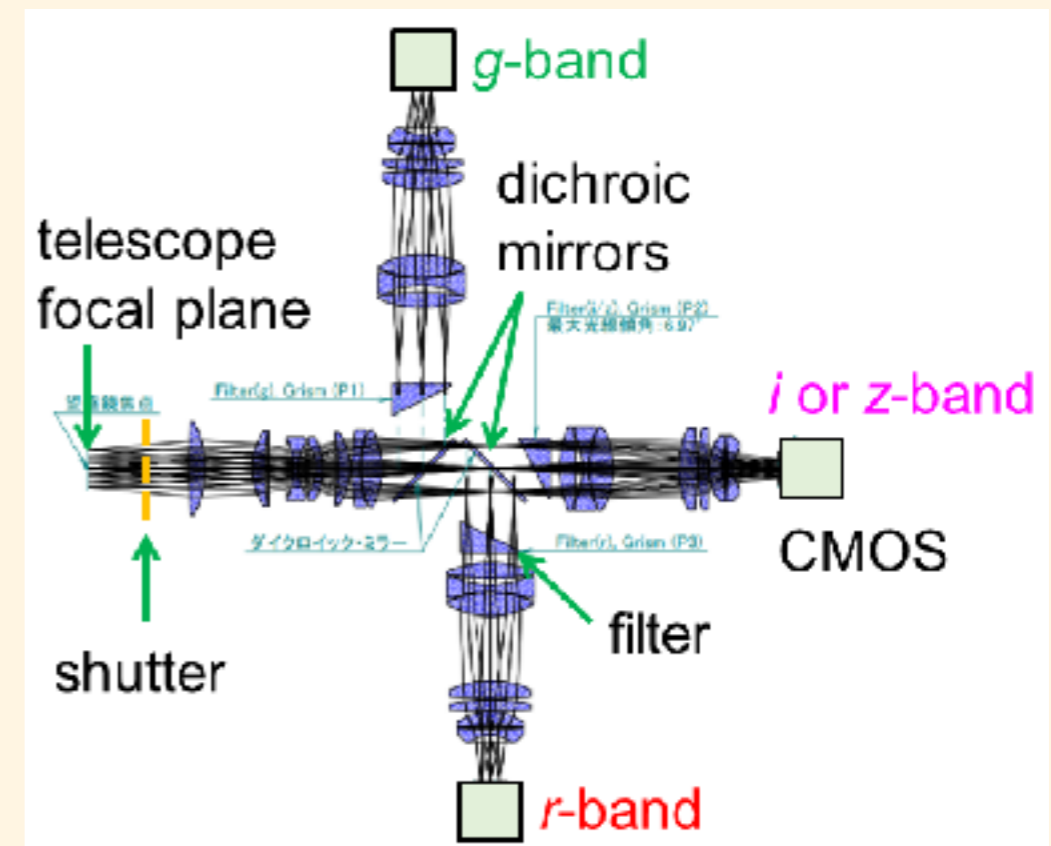
Limits on SED

- The current limits are comparable to the Crab SED.
- If our limit is obtained simultaneously with a $\sim 100 \text{ Jy ms}$ burst, we will detect:
 - Geminga SED
 - radio-X interpolation of FRB 200428A



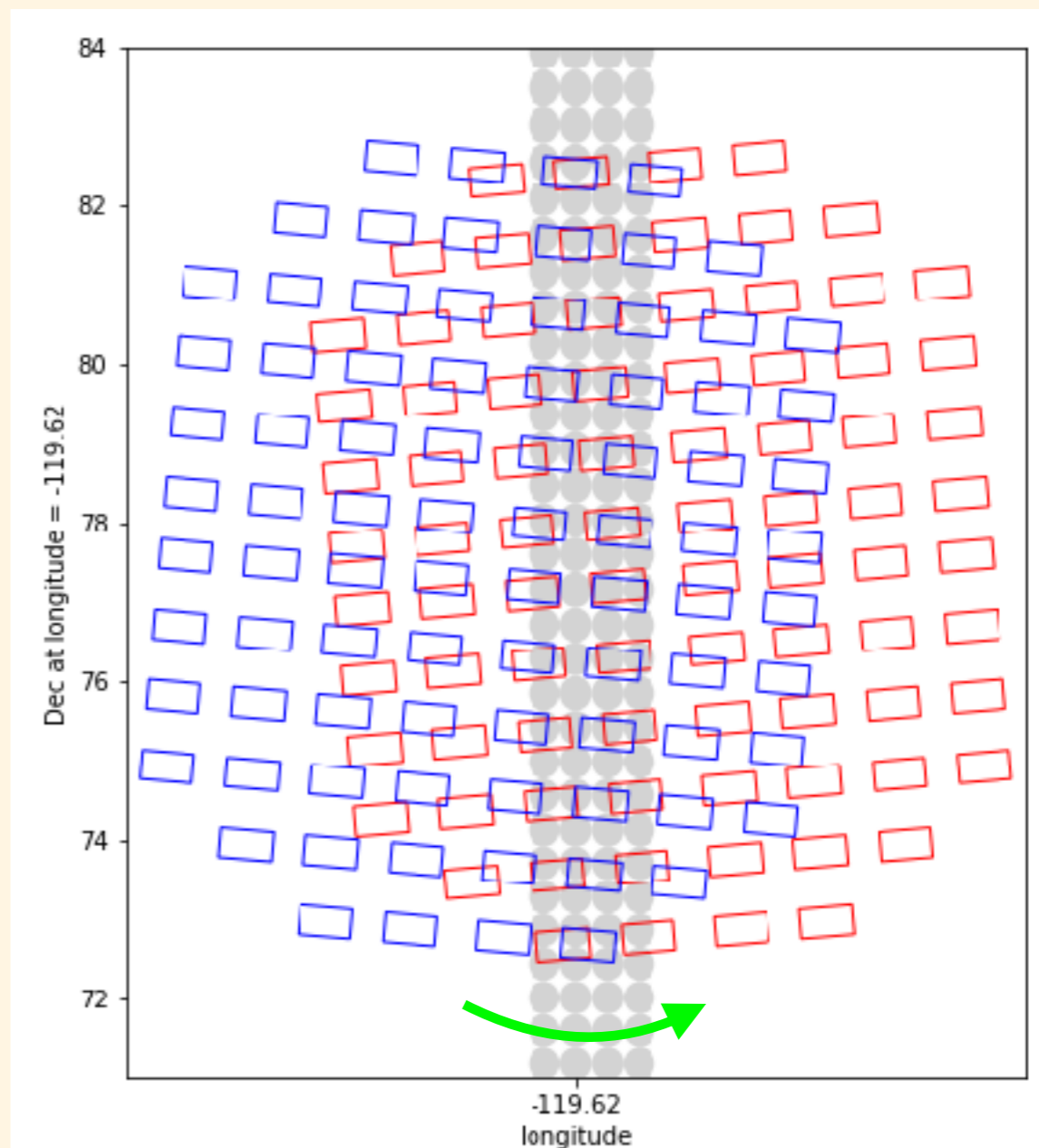
High-Speed Observations With TriCCS

- Seimei telescope
 - 3.8 m telescope operated by Kyoto U
- TriCCS
 - imager with frame rate of 98 fps
 - spectroscopic mode is coming soon
 - FoV $\sim 12.6 \times 7.5$ arcmin²
 - 3 bands at once (g, r, + i or z)
 - fluence detection limit
 - ~ 0.02 Jy ms with 10 ms under a good condition



Wide field non-repeater search by Tomo-e Gozen with CHIME/FRB

- FoV of CHIME $\sim 250 \text{ deg}^2$
 - E-W $\sim 2^\circ$, N-S $\sim 120^\circ$
- Tomo-e Gozen observes the meridian of the CHIME location at Dec $\sim 80^\circ$.
 - overlapped FoV $\sim 5 \text{ deg}^2$
 - HA $\pm 2.5 \text{ deg}$ (20 min period)
- rate of FRBs detectable by CHIME/FRB
 - $\sim 820 \text{ sky}^{-1}\text{day}^{-1}$ (CHIME/FRB collaboration 2021)
 - expected event rate in the overlapped FoV $\sim 1 \text{ per } 240 \text{ hrs}$



Summary

- We conducted the high-speed optical observation of repeating FRB 20190520B simultaneously with the radio observation by FAST.
 - 24.4 fps (40.9 ms) data covering the arrival times of the 11 radio bursts
- no optical burst detected
- $F_{\text{opt}} < 0.029 \text{ Jy ms}$ (stacked, extinction corrected)
 - Strong constrained on an FRB SED can be obtained if the radio fluence is large.