Optical monitoring of FRB20220912A and comparison with background/foreground events

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INAF ISTITUTO NAZIONALE DI ASTROFISICA
AQUEYE+ IQUEYE
Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA

Outline

- ❑ Aqueye+ and IFI+Iqueye
- ❑ FRB 20220912A
- ❑ Observations and data analysis
- ❑ Comparison with PSR J1023+0038
- ❑ ASTRI-SI^3 and Fast Optical Bursts
- ❑ Conclusions

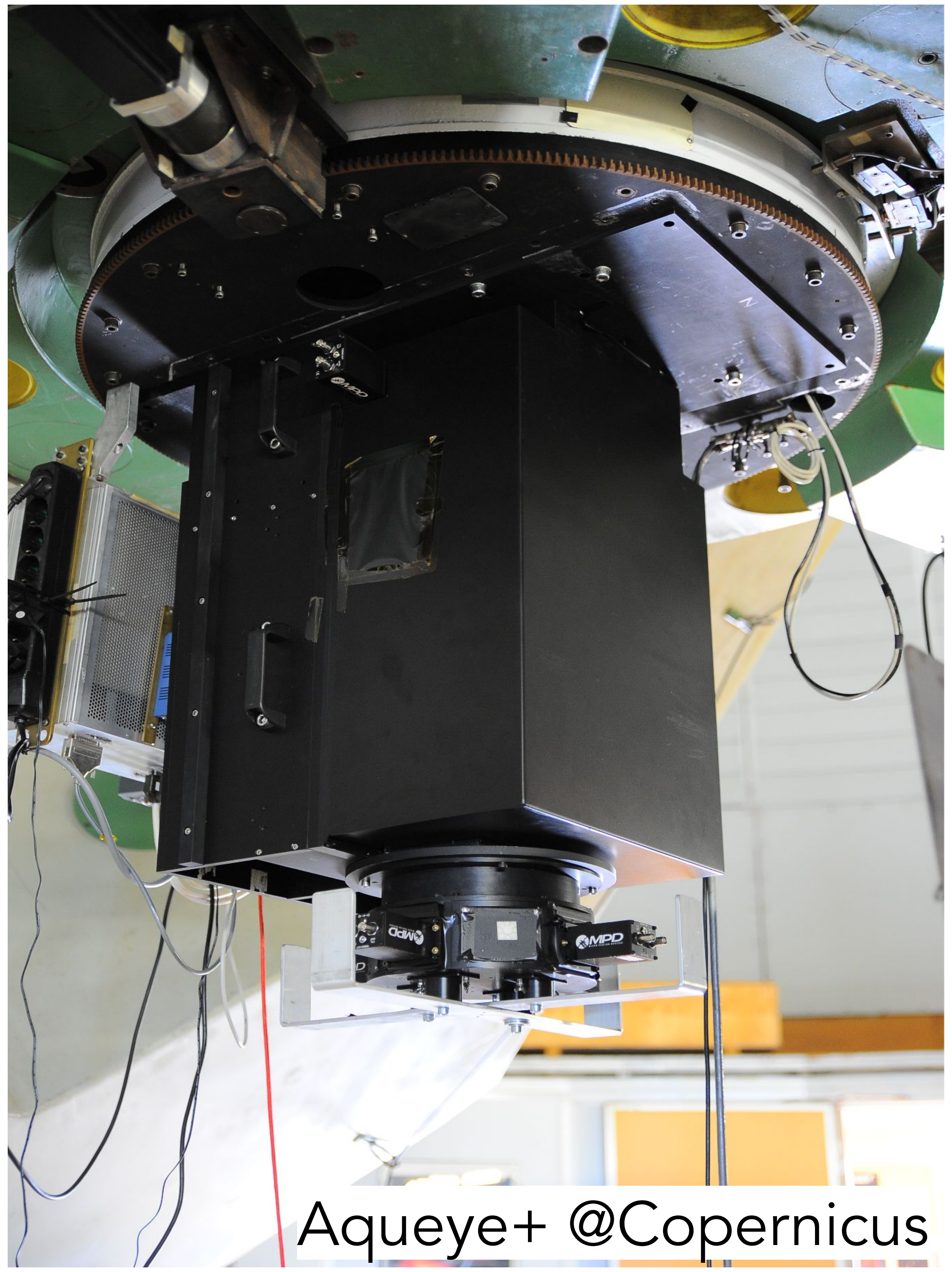
Aqueye+ & IFI+Iqueye

AQUEYE+ | IQUEYE

- ➔ Performing optical High Time Resolution
- ➔ Astrophysics with ms or sub-ms time resolution

Non-imaging instruments for very fast photon counting in the optical band.
(Barbieri+09; Naletto+09, 2013; Zampieri+15, 19)

Aqueye+ (Asiago Quantum Eye+) @Copernicus (1.8m)
Iqueye (Italian Quantum Eye) @Galileo (1.2m) [mounted at NTT, WHT, TNG]
NOW: visiting instrument @GeminiSouth (8m)


Aqueye+ @Copernicus

Field of view: few arcsec
Optical design: entrance pupil split in 4 parts with a pyramidal mirror.
Detectors: 4 SPADs on-source + 1 SPAD on sky (offset by 10 arcmin) with <50 ps time resolution
Acquisition system: sub-ns time tagging accuracy wtr UTC

Aqueye+/Iqueye: observation campaigns of FRB180916
(Pilia+20, Nicastro+21, Trudu+23)

FRB 20220912A

''Repeaters'': FRBs seen more than once.
- 1st: FRB20121102A (Spitler+16).
- crucial for investigating the emission mechanism of FRBs.

★ Active repeating FRB discovered by CHIME/FRB Collaboration in Oct. 2022 (McKinven & Chime/Frb Collaboration 2022). In 3 days, nine bursts were detected at 400-800 MHz.
★ DM=219.46 pc cm^{-3}
★ Nearby → Host galaxy PSO J347.2702+48.7066 with z=0.077 (Ravi+22).
★ Luminosity distance of 362.4 Mpc.
★ Detected from 300 MHz (Bhusare+22) to 2.3 GHz (Rajwade+22). No bursts above 3 GHz.
★ Extremely active FRB: ~400 bursts/hour at L-band [1-1.5 GHz] (Feng+22; Zhang+22, 23).
★ Pelliciari+24 detected 16 bursts at 408 MHz with the Northern Cross.
★ γ-ray luminosity UL (AGILE): $L_\gamma < 7.1 \times 10^{43}$ erg s^{-1} (Pelliciari+24)
★ X-ray luminosity UL (Swift): $L_X < 3.4 \times 10^{42}$ erg s^{-1} (Pelliciari+24)

This source → another good opportunity to place deep limits on the counterparts of a repeating FRB.

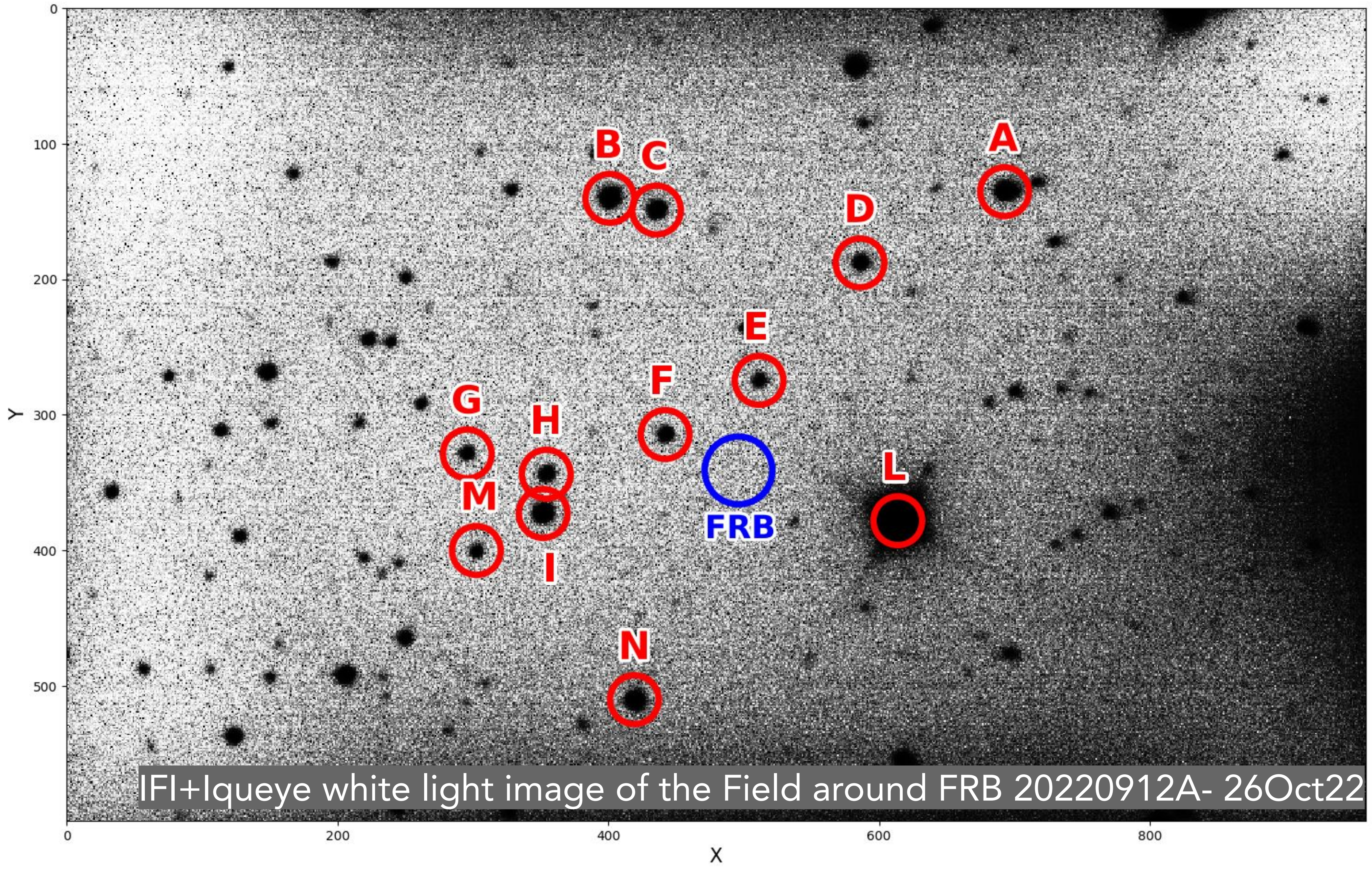
A MWL and/or optical detection would greatly enhance our understanding of the FRB phenomenon

Observations and Data Analysis - FRB 20220912A

Oct-Nov-Dec 2022 + July - Dec 2023
Total GTIs = 2.71 hr Aqueye+
19.67 hr IFI+Iqueye

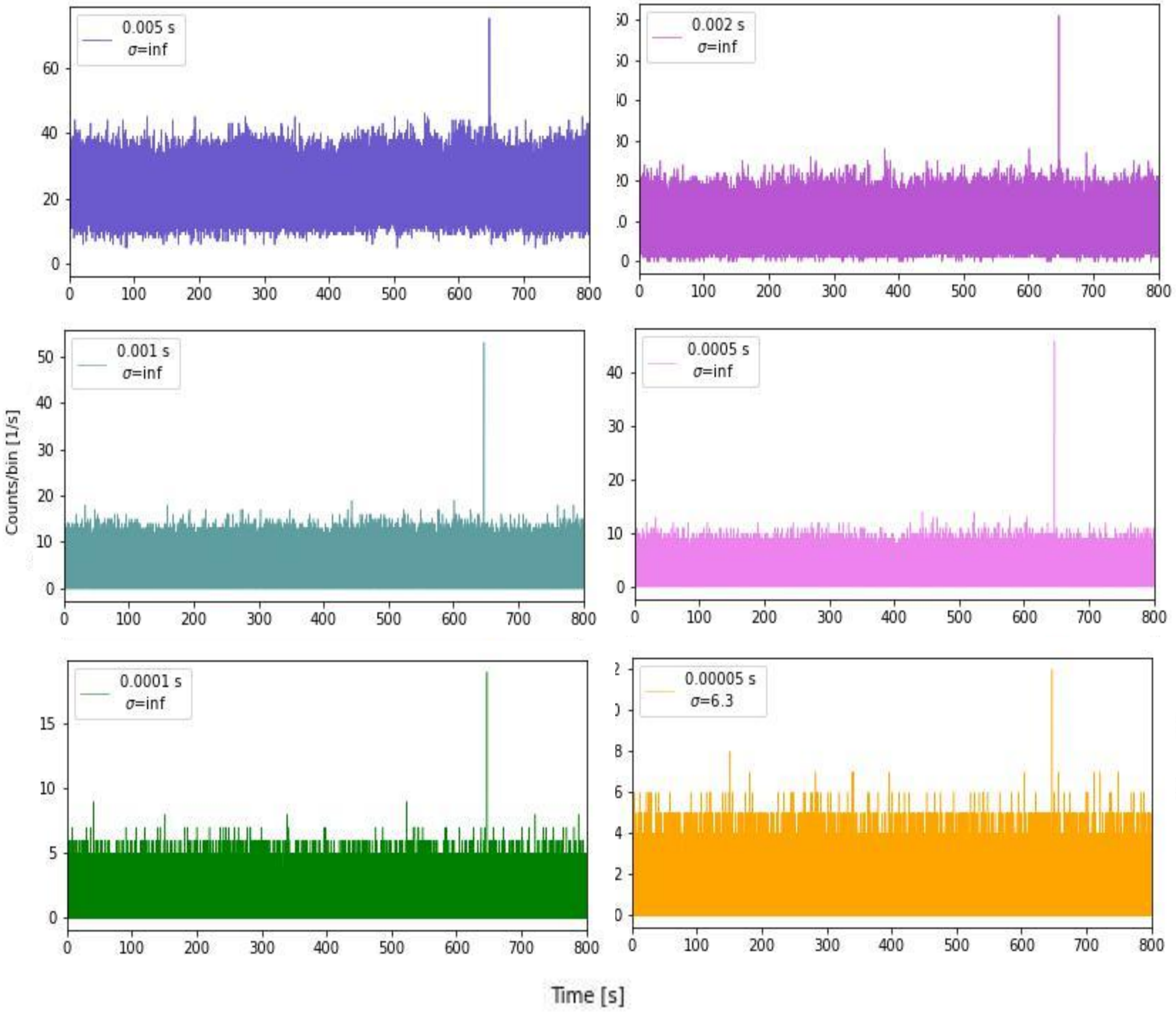
'Interesting' Peaks:
25 November 2022 [Aqueye+]
14 December 2023 [Aqueye+]

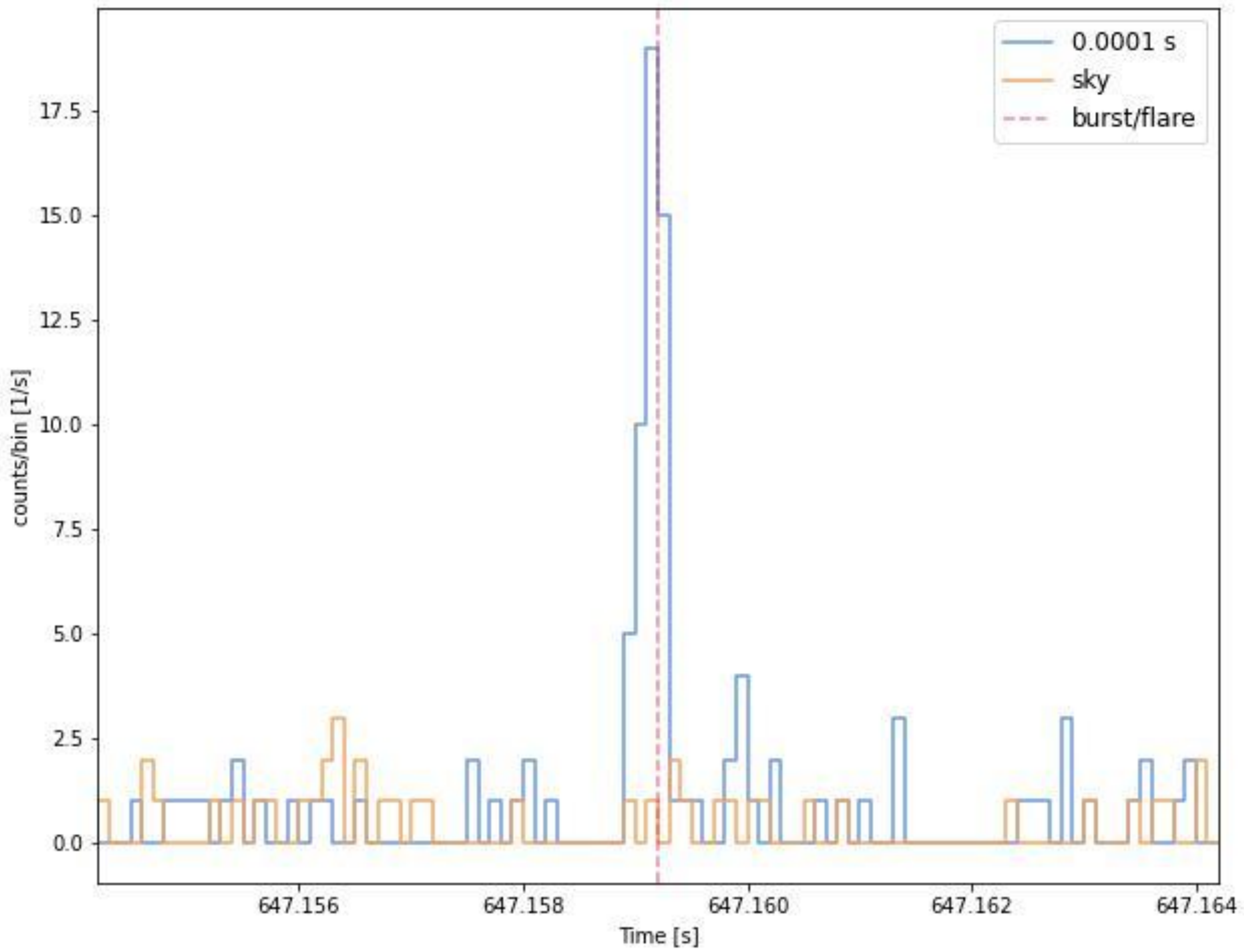
Simultaneous radio observations (14 Dec. 2023):
Northern-Cross (Bologna)



The photon event lists were reduced using a dedicated software (QUEST v.1.1.5, Zampieri+15).
Light curves with different time bins (0.01s, 0.001s, 0.002s, 0.005s, 0.0005s, 0.0001s) were computed from the reduces event lists and searched for any significant rate increase.

25 Nov. 2022 [Aqueye+] - FRB 20220912A

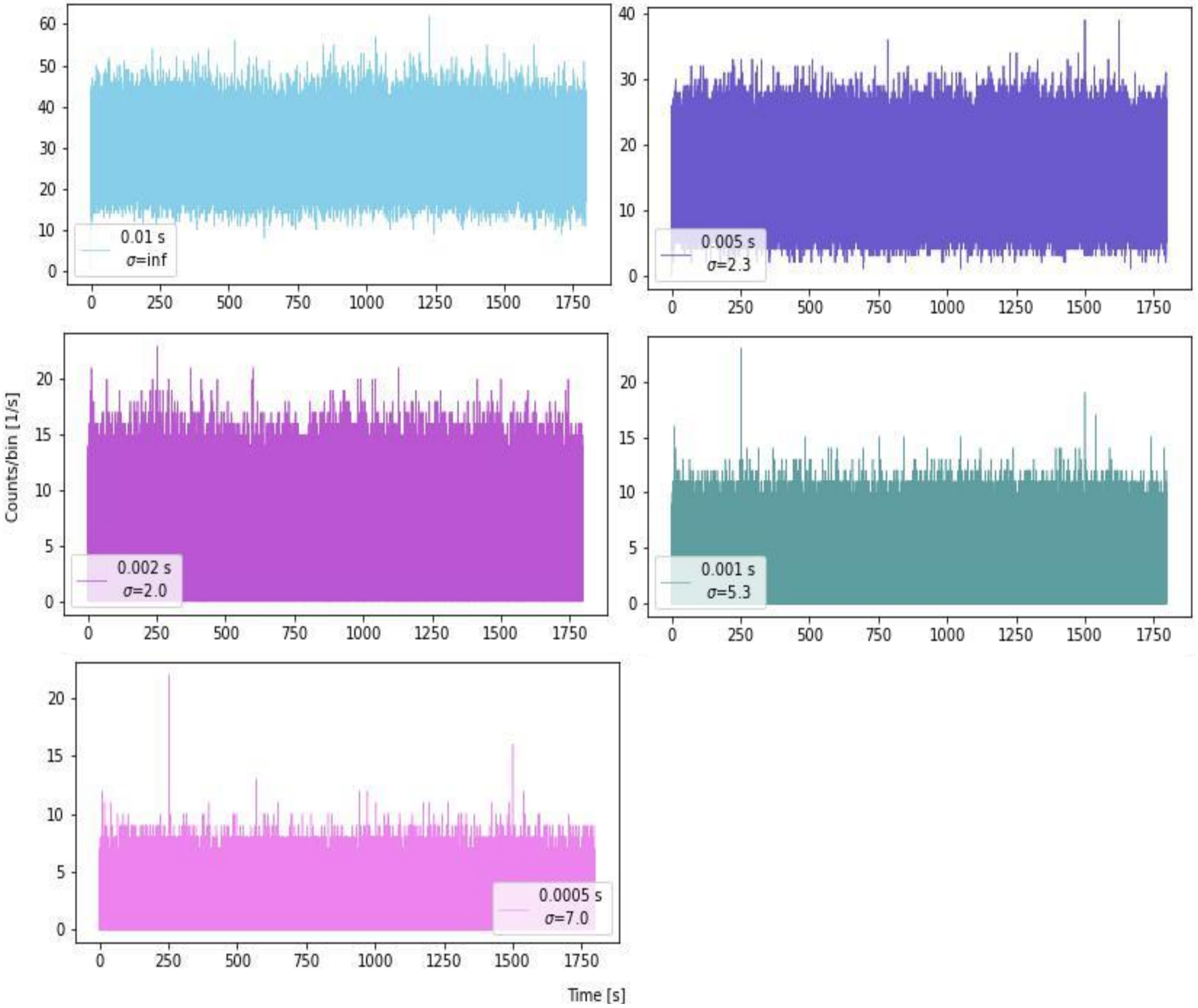


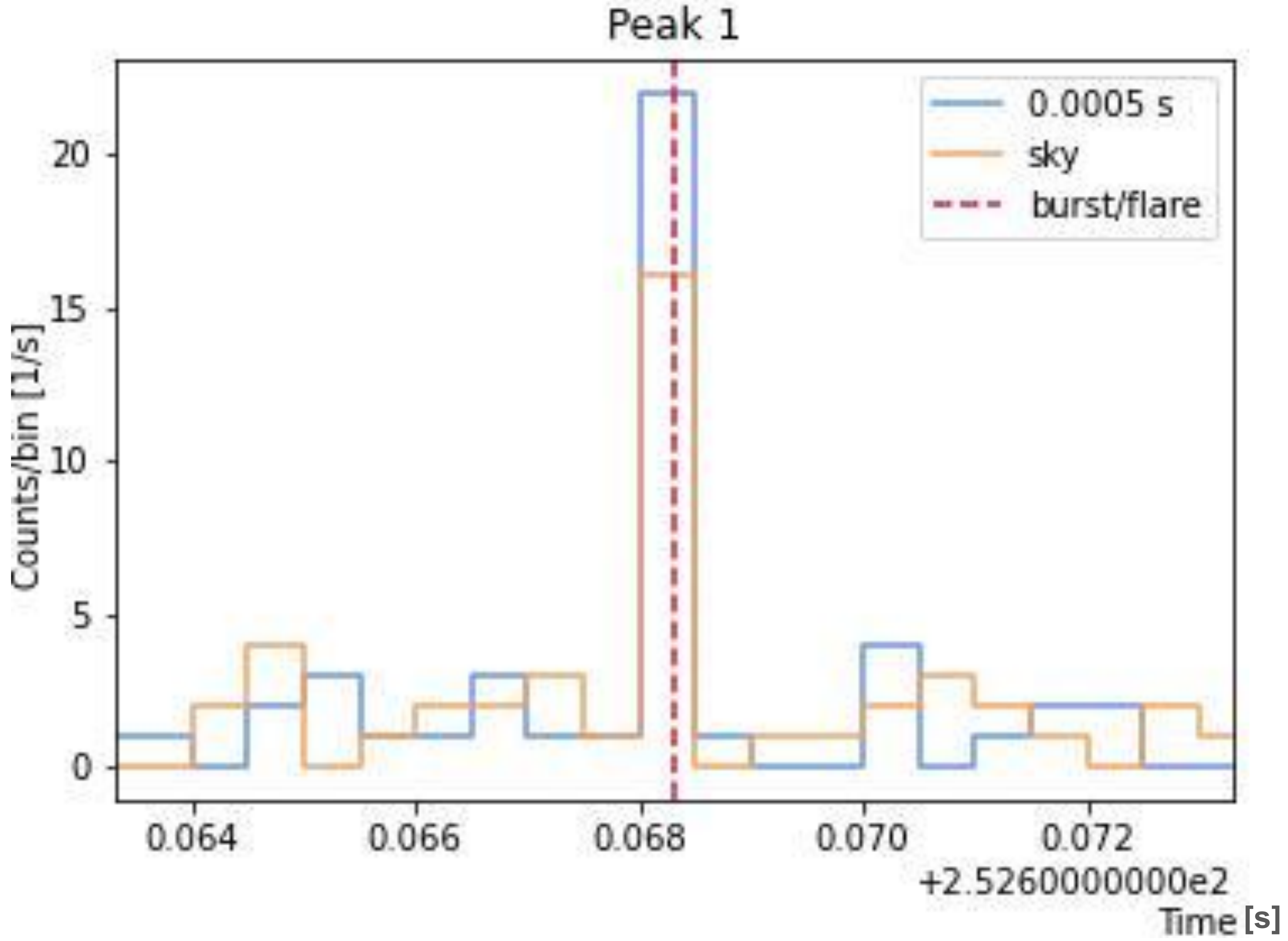


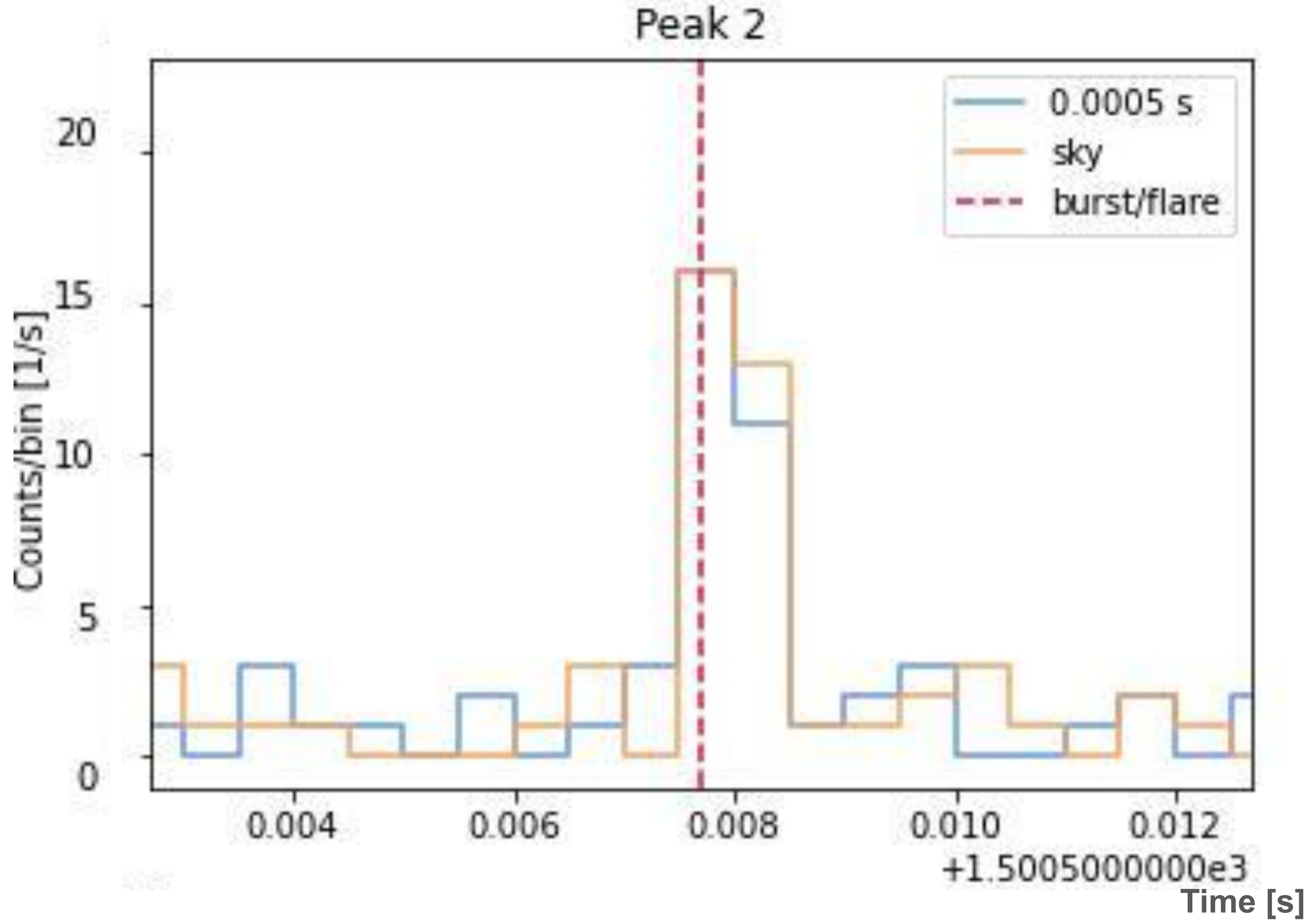
Observation ID	Time bin [s]	Time of peak [s from start]	Time of peak [UT]	on-source SPAD counts/bin	on-source SPAD σ	on-source SPAD FWHM [s]	sky-SPAD counts/bin	sky-SPAD σ	sky-SPAD FWHM [s]
20221125-233434	0.0001	647.1592	22:45:23.1591	19	>10	0.0002	-	-	-

Data not baricetrized

14 Dec. 2023 [Aqueye+] - FRB 20220912A







Observation ID	Time bin [s]	Time of peak [s from start]	Time of peak [UT]	on-source SPAD counts/bin	on-source SPAD σ	on-source SPAD FWHM [s]	sky-SPAD counts/bin	sky-SPAD σ	sky-SPAD FWHM [s]
20231214-190534	0.0005	252.6683	18:09:47.6682	22	7	0.0005	16	5.5	0.0057
	0.0005	1500.5077	18:30:35.5077	16	4.3	0.0008	16	5.5	0.0006

PSR J1023+0038

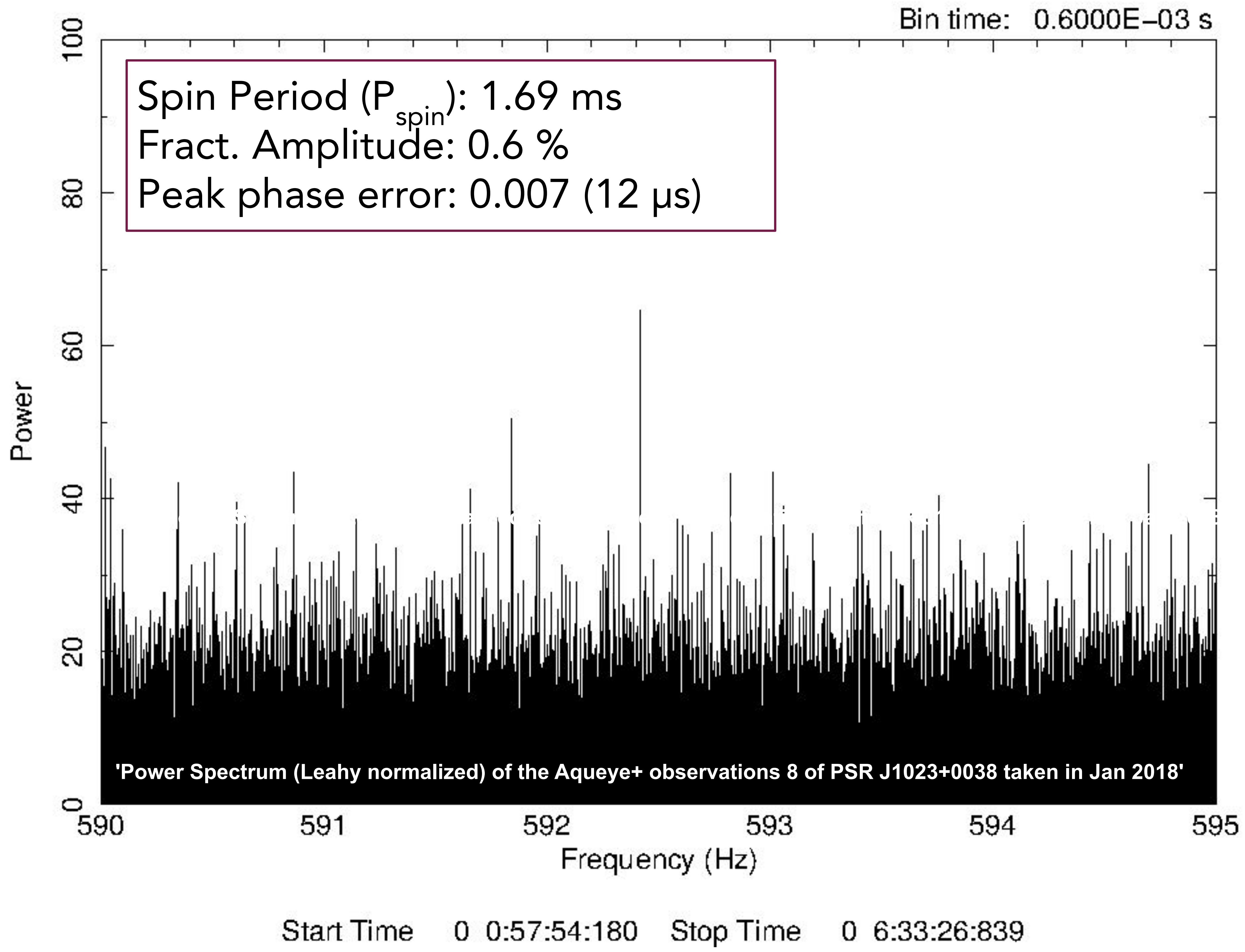
Extensively monitored with Aqueye+ (2017-2024).
$m_V \simeq 17 \rightarrow$ the source is intrinsically weak and acts as a low-level 'contaminant' of the sky background.
Determine whether a detected event is intrinsic to the source or not.

- Transitional Millisecond Pulsars (tMPs): PSR J1023+0038 (Archibald+09), XSS J1227-4853 (de Martino+2010), IGR J1824-2452 (Papitto+13).

- Swinging between a rotation-powered ms pulsar and an accretion (subluminous) phase (Papitto & de Martino 2022); last transition in 2013.

- The first ms optical and UV pulsar

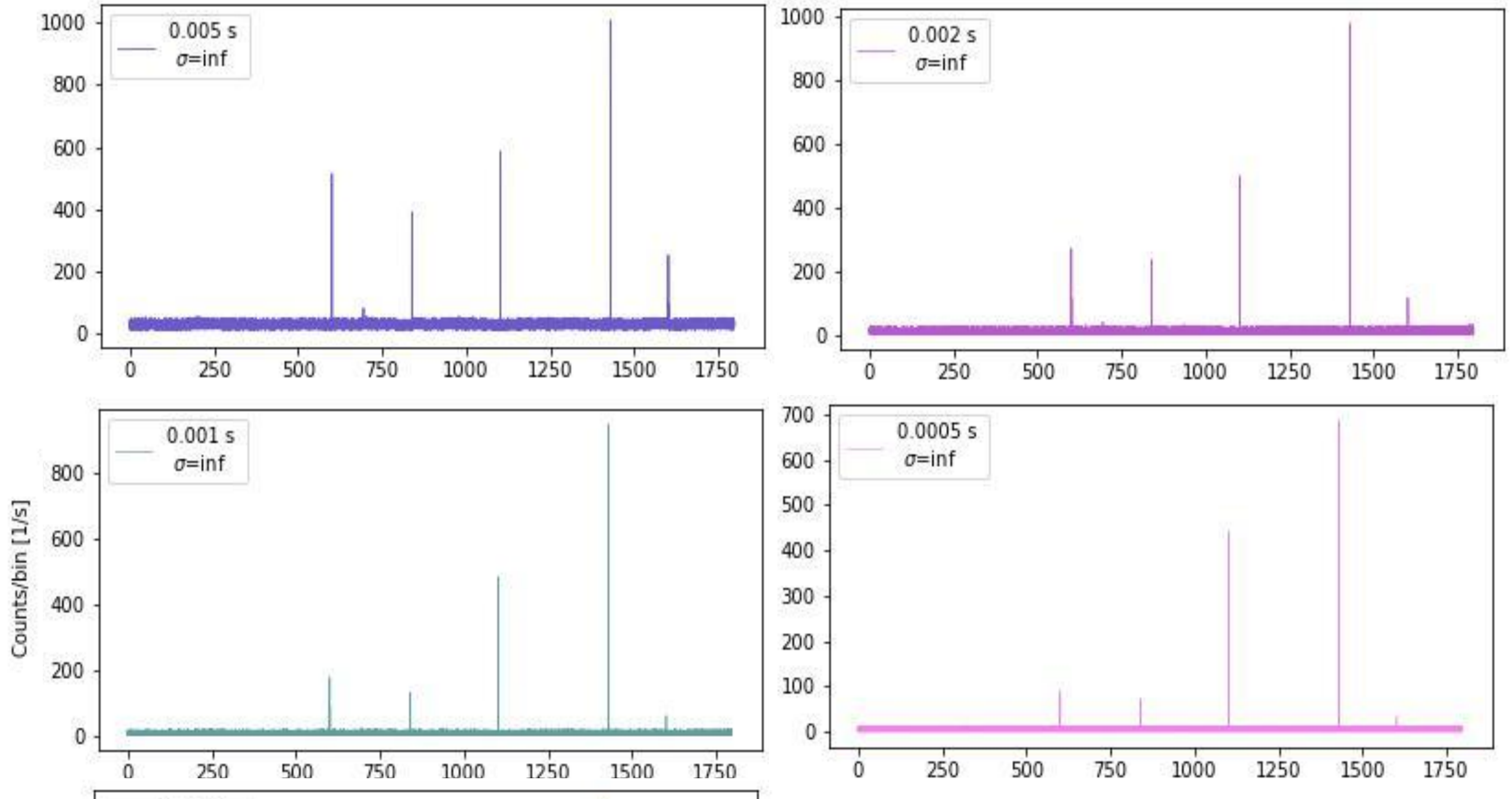
(Ambrosino+17, Zampieri+19, Karpov+19; Burtovoi+20, Jaodand+21, Miraval Zanon+22, Illiano+23)

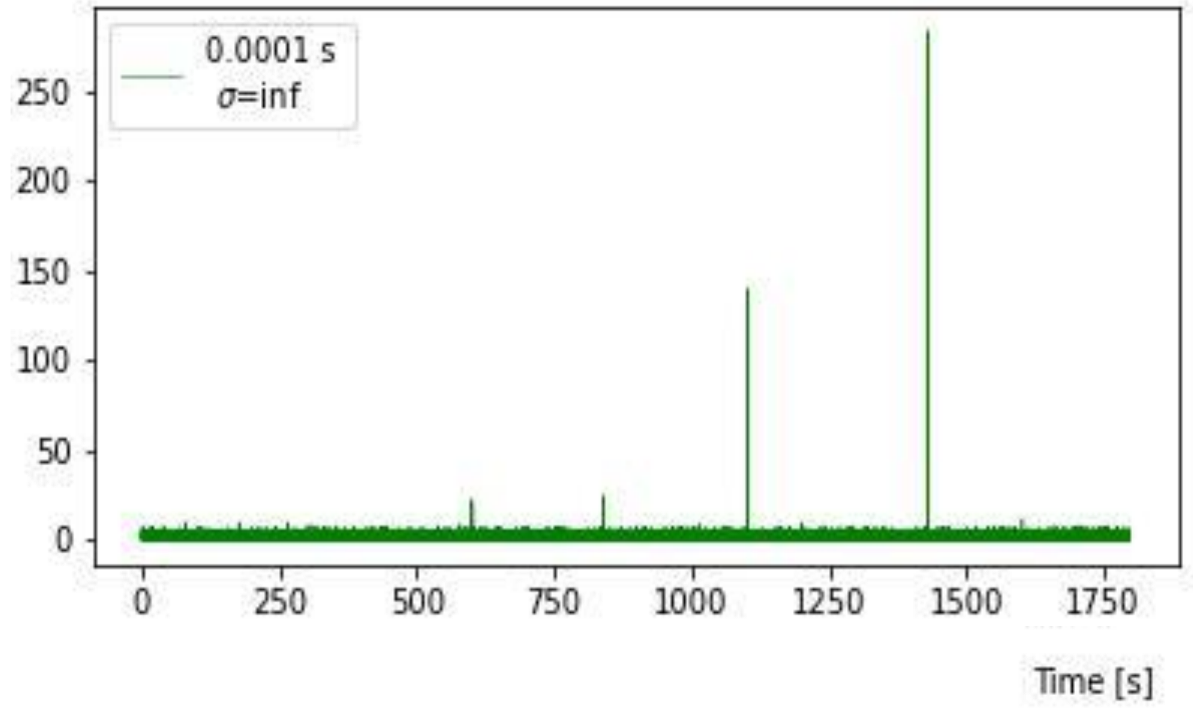


Observations and Data Analysis - PSR J1023+0038

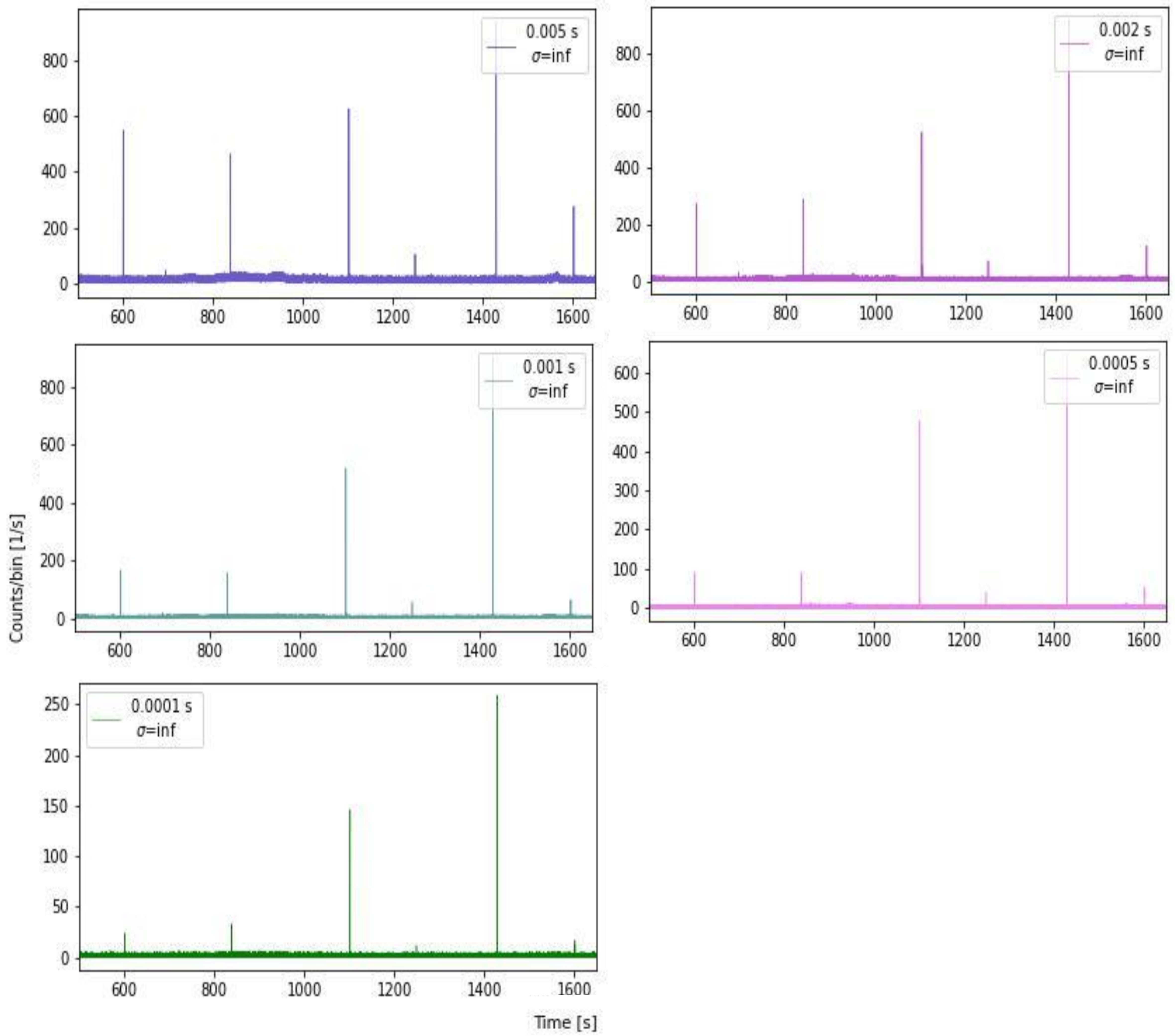
13 Dec. 2018 [Aqueye+]

ON-source





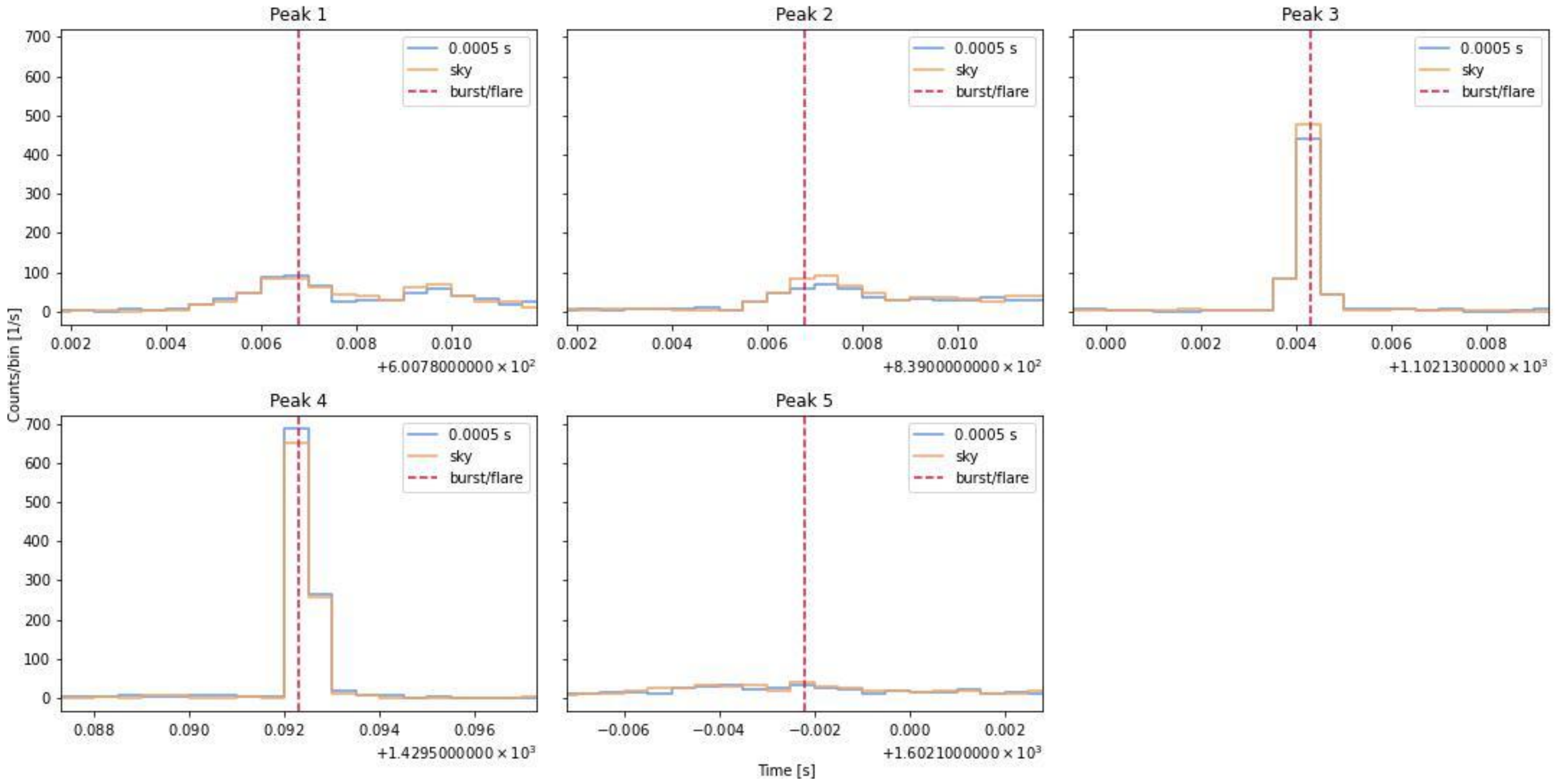
SKY



Statistics

Time bin	0.001 s
Ev. > th 23	74
Isolated	31
Coinc. sky	28 (90%)
Non coinc.	3

13 Dec. 2018 [Aqueye+] - PSR J1023+0038



Atmospheric Events?
Meteor Shower → Geminids
4 -14 Dec. 2018

- ➢ Peaks of ~951 counts/bin → m_V ~ 9 (in 1 ms)
- ➢ Extended peaks visible in both channel (on-source and sky)

- ➢ 90% of the peaks are detected both on source and on sky, and are likely to be atmospheric events (meteors' glow?)
- ➢ 10% of the peaks are detected only on source or on sky

FRB 20220912A: 1 significant on-source-only event (Nov. 25, 2022) vs 2 simultaneous on-source and on-sky events (Dec. 14, 2023)

Occurrence of 1 on-source-only event out of 3 not expected if originating from a meteor shower, but statistics too scanty.

ASTRI SII Instrument (SI^3)

The ASTRI Mini-Array: International collaboration, led by the Italian National Institute for Astrophysics (INAF).
An array of 9 Imaging Atmospheric Cherenkov Telescopes to
- study gamma-ray sources at very high energy (TeV)
- perform optical stellar intensity interferometry observations

Stellar Intensity Interferometry with ASTRI

The ASTRI Mini-array provides a suitable infrastructure for performing SII measurements at sub-milliarcesec level

Ultimate goal: using the long multiple baseline (36) of all 9 telescopes to do image reconstruction with resolution of ~ 100 μas.
Baseline = 100-700 m.
$SI^3 \Rightarrow$ narrow optical band (1-5 nm: length of the filter) [centered at 420-550 nm]. Time accuracy 1ns wrt UTC.

Expected SI^3 sensitivity for Fast Optical Bursts

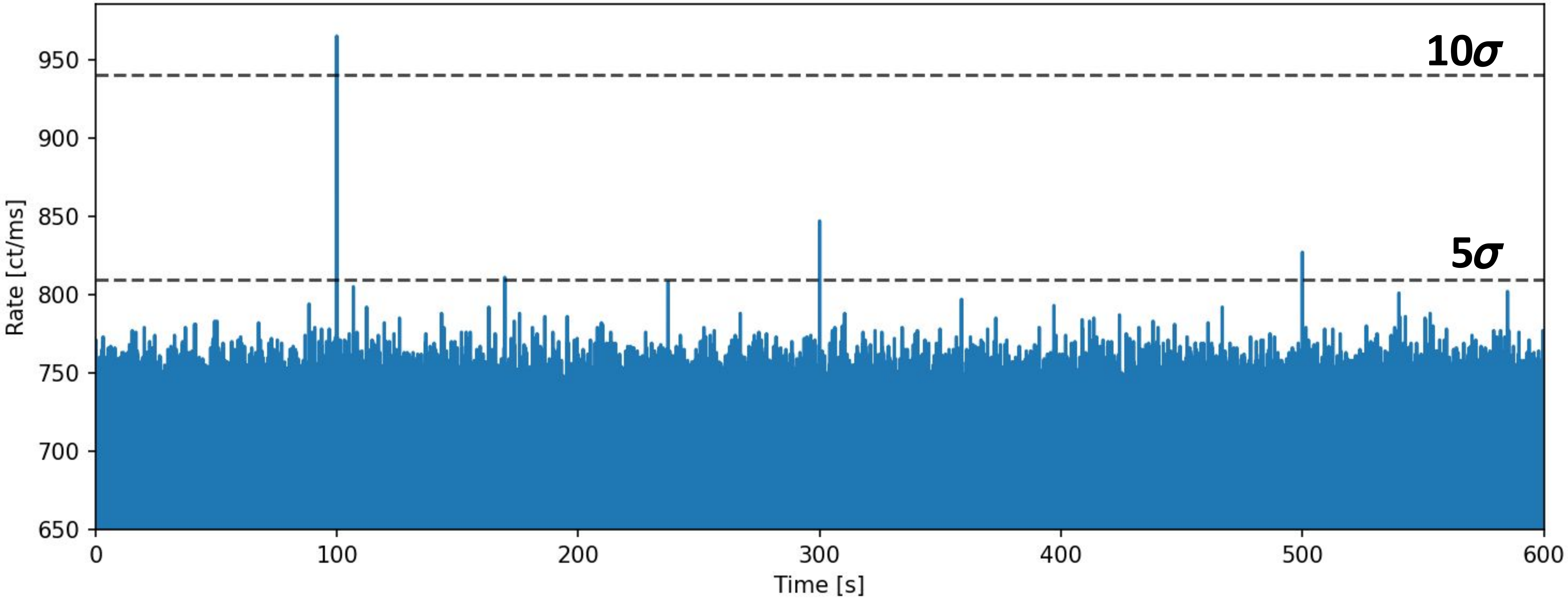
Simulated ASTRI-SI^3 light curve (550/50 nm, 10 minutes with low Moon background) + 3 fast signals.

Pros
- 9 telescopes
- High time resolution (~1 ns wtr UTC)
- Large field of view (~6 arcmin)

Cons
- High background rate

⇒ There are few instruments capable of observing such a large area with such a high temporal resolution (<= 1ms).

V_{lim} ~ 8.5 [in 1 ms]



Conclusion

FRB 20220912A observed with Aqueye+ and IFI+Iqueye in Asiago.
Occurrence of 1 on-source-only optical pulse on Nov 25, 2022.
Occurrence of 1 on-source-only event out of a total of 3 (2 on source and on sky) not expected if originating from a meteor shower, but statistics too scanty.

We analyzed the optical observations of PSR J1023+0038 in order to discriminate if the peaks that we see in the light curves are attributable to the source or to atmospheric events.

We found that the 90% of the events are detected in both the channels (source and sky), and we only have a 10% chance that the event will be detected on only one of the two channels.

MWL observational campaigns are crucial to search for potential counterparts and assess the nature of the FRB phenomenon.

Potential future instrumentation: the fast photon counter ASTRI-SI^3 (designed for Intensity Interferometry observations with ASTRI) is capable of reaching $V_{lim} \gtrsim 8.5$ with a time resolution of <= 1 ms in a large (6 arcmin) field of view.

Thank you for your attention!

SI^3

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Backup Slides

Abstract

Title: Optical monitoring of FRB20220912A and comparison with background/foreground events
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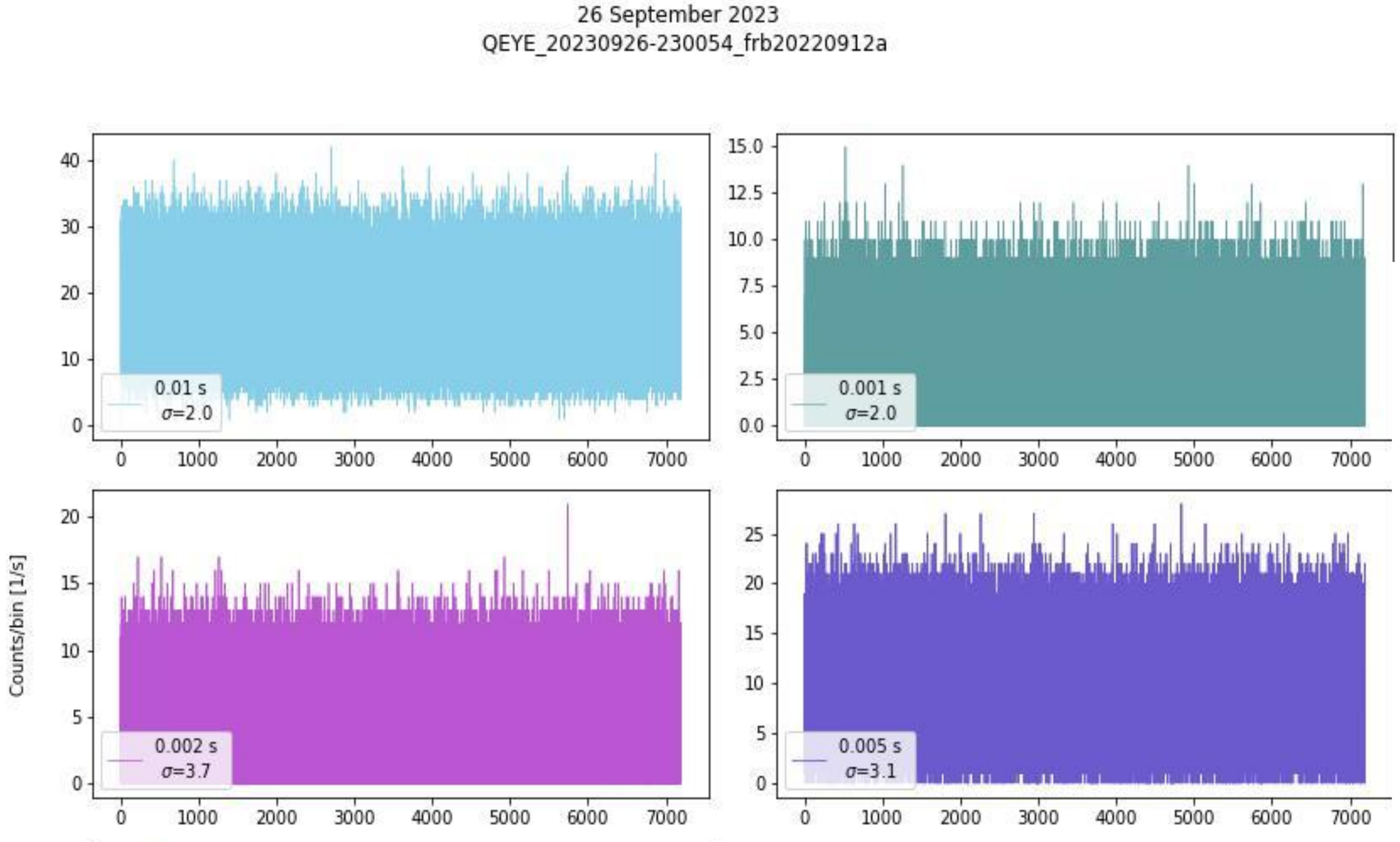
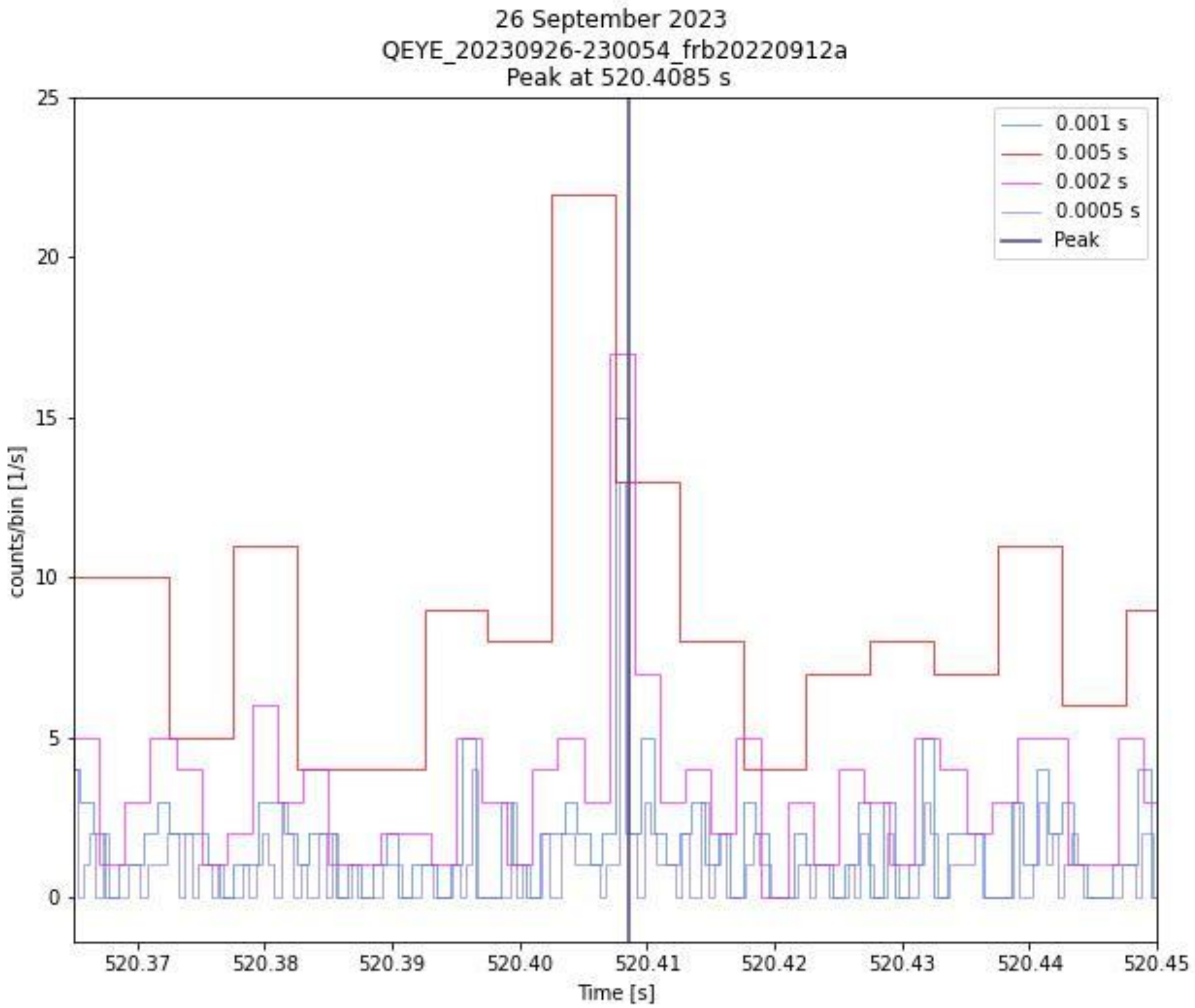
Repeating FRBs are ideal targets for multi-wavelength observational campaigns aiming at potential counterparts. We are monitoring FRB 20220912A, one of the most active repeaters, using the fast optical photon counters Aqueye+ and Iqueye at the Asiago Observatory. We are trying to characterize foreground/background events by analyzing archival Aqueye+ data taken on other fields. To this purpose we studied the field of PSR J1023+0038, considering the source as a low-level sky background contaminant. We find that 90% of the statistically significant events detected above the average rate in the 1 ms binned light curve are present both in the on-source and on sky detector fields. This fact suggests that these events are linked to diffuse atmospheric phenomena. We will compare these events with those found in the field of FRB 20220912A.

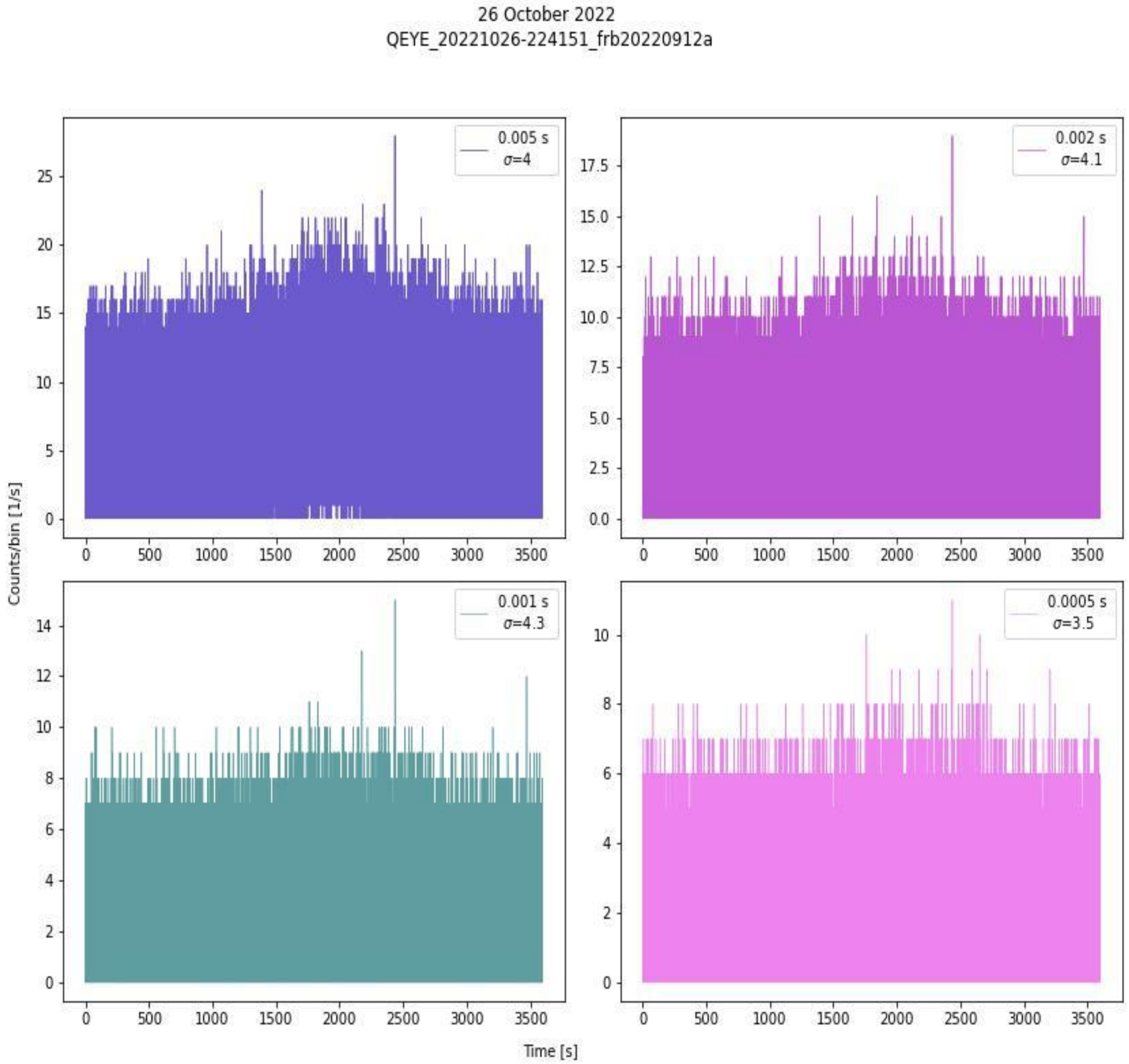
[We are also studying the feasibility of monitoring FRBs, whose position is not yet accurately known, using the fast photon-counting instrument which will be installed on the ASTRI telescopes (ASTRI SI3). Around New Moon, a sensitivity to 1 ms optical bursts of approximately 10 magnitude may be achieved, with the possibility of discriminate atmospheric foreground events on the basis of the different response of the telescopes in the array as a function of their baseline.]

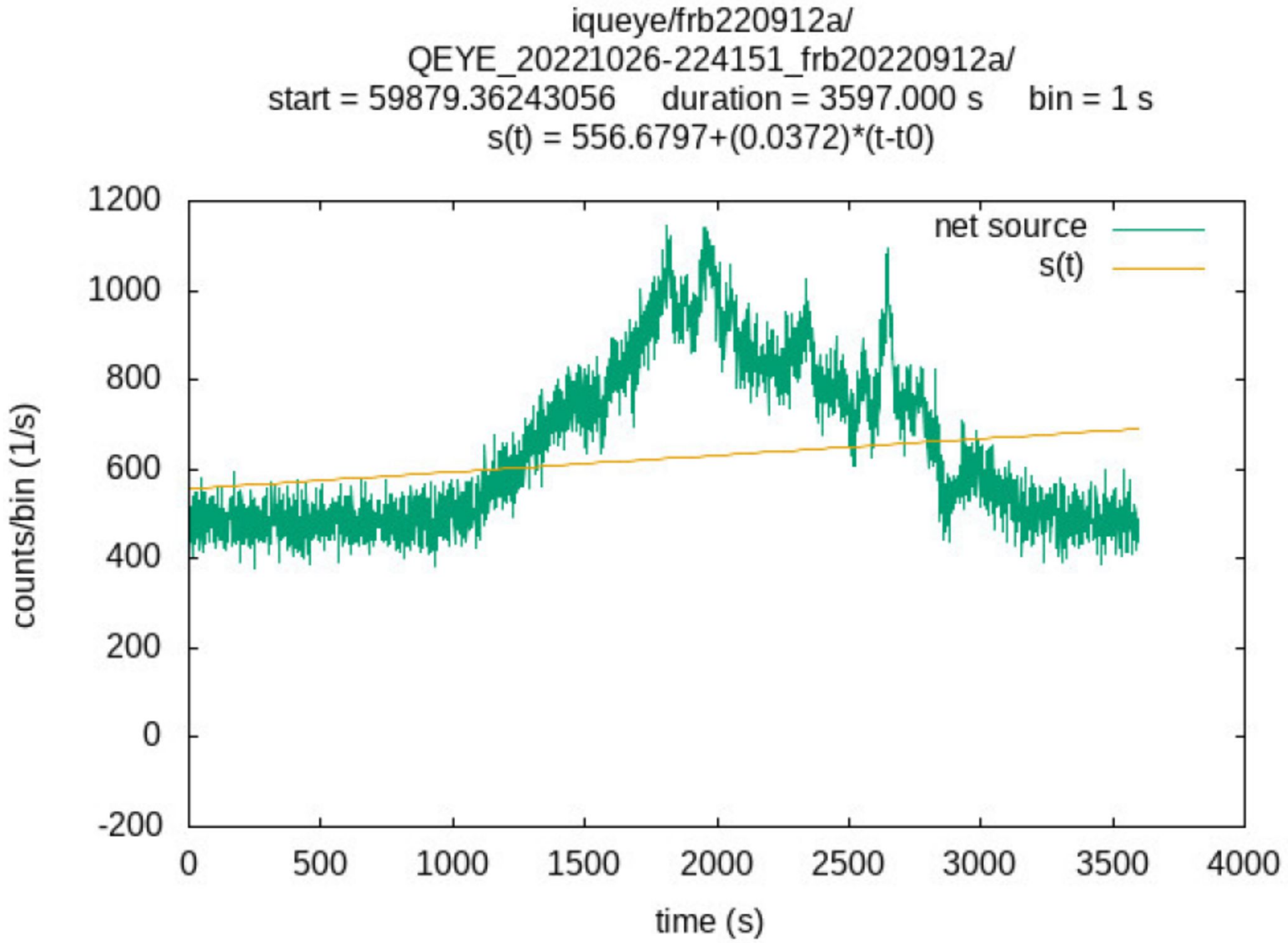
25 Sept. 2022 [Iqueye]





26 Oct. 2022 [Iqueye]





Time of peak (UT) 21:22:30.226

Fluence

With 50 counts/s → m_V ~ 12.5 (in 1 ms)
Distance host galaxy: z= 0.077 → d=330.47 Mpc

F = 4.2e-19 erg/s/cm2 in 1 ms

F*Delta lambda (=300 nm)

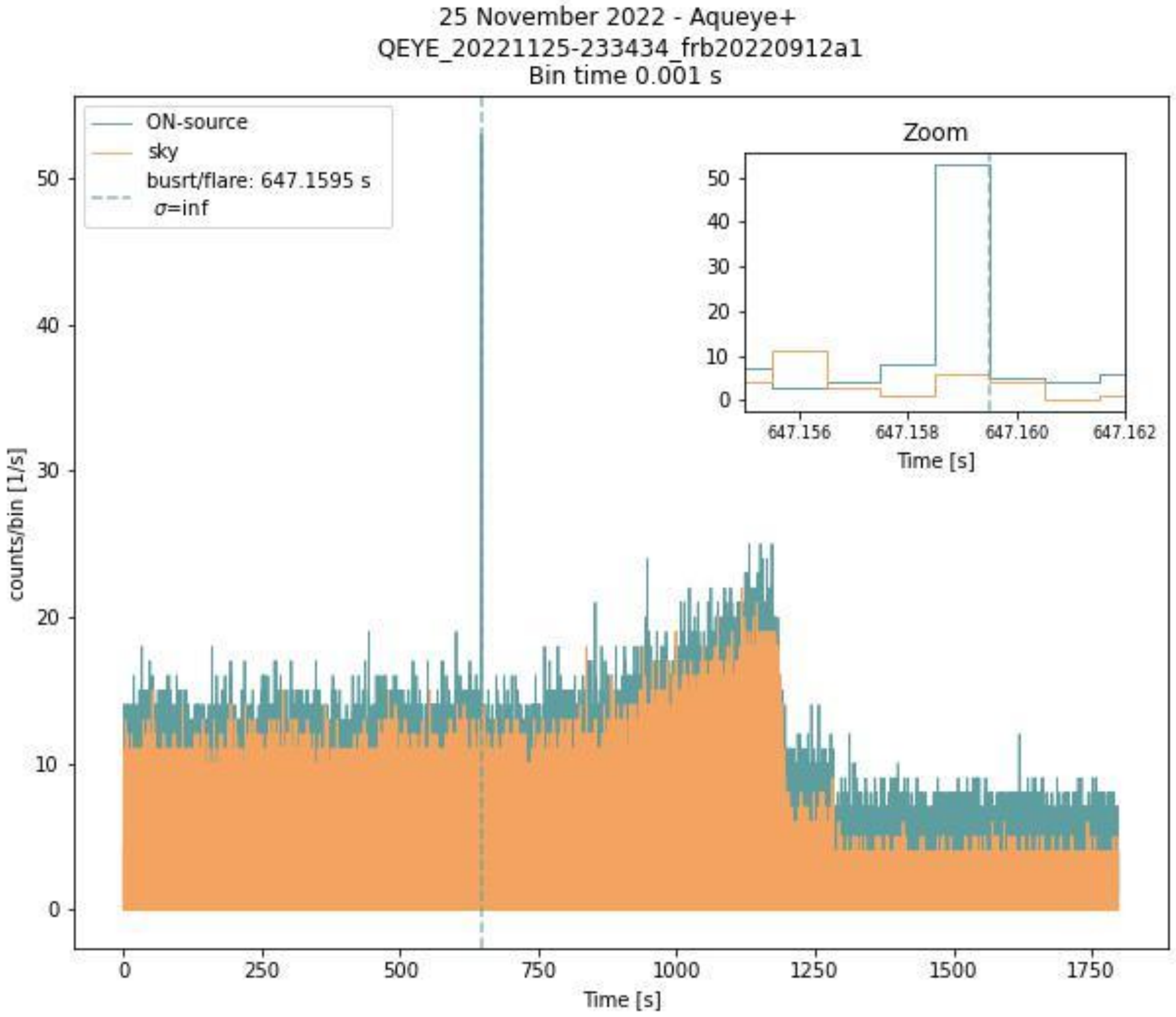
L = 4.8e41 erg/s in 1 ms

Fluence = 4.2e-22 erg/cm2

60292.75680172

MJD of FRB peaks

2022Nov25 at 22:45:23.1575 → 59908.94818469 MJD
2023Dec14 at 18:09:47.6682 → 60292.75680172 MJD



PSR J1023

Event #	Obs. ID	Time bin [s]	Time of peak [s from start]	Time of peak [UT]	on-source SPAD counts/bin	on-source SPAD σ	on-source SPAD FWHM [s]	sky-SPAD counts/bin	sky-SPAD σ	sky-SPAD FWHM [s]
1	20181211-023507	0.0005	364.7817	1:41:13.7817	24.0	5.7	0.0013	16.0	3.7	0.0015
2		0.0005	1459.0258	1:59:28.0257	60.0	>10	0.014	-	-	-
3	20181212-045713	0.0005	1687.7063	4:25:21.7062	56.0	>10	0.0006	30.0	>10	0.0005
4		0.0005	1688.0873	4:25:22.0872	40.0	>10	0.0016	74.0	>10	0.0016
5	20181213-034403	0.0005	600.7868	2:54:4.7867	90.0	>10	0.0061	83.0	>10	0.0056
6		0.0005	839.0073	2:58:3.0072	71.0	>10	0.0129	91.0	>10	0.0083
7		0.0005	1102.1343	3:2:26.1342	442.0	>10	0.0006	478.0	>10	0.0006
8		0.0005	1429.5923	3:7:53.5922	687.0	>10	0.0005	649.0	>10	0.0004
9		0.0005	1602.0978	3:10:46.0977	33.0	>10	0.0120	40.0	>10	0.0082
10	20181213-041842	0.002	15.989	3:18:58.989	52.0	>10	0.0223	47.0	>10	0.0119
11		0.002	140.337	3:21:3.337	-	-	-	49	>10	0.0039
12		0.002	140.339	3:21:3.339	39.0	3.9	0.0270	28.0	4.3	0.0039
13	20181214-055002	0.0005	194.5753	4:53:17.5753	103.0	>10	0.0005	22.0	7.1	0.0004
14	20190205-033823	0.0005	454.5772	2:45:59.5773	41.0	>10	0.0007	-	-	-
15	20190206-021915	0.001	2062.6875	1:53:39.6875	31.0	5.5	0.0010	-	-	-
16		0.001	4066.4145	2:27:3.4145	30.0	5.0	0.0148	-	-	-