

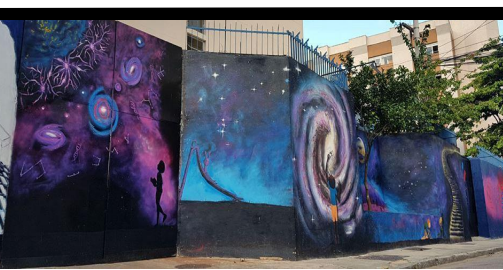
The S-PLUS Transient Extension Program (STEP)



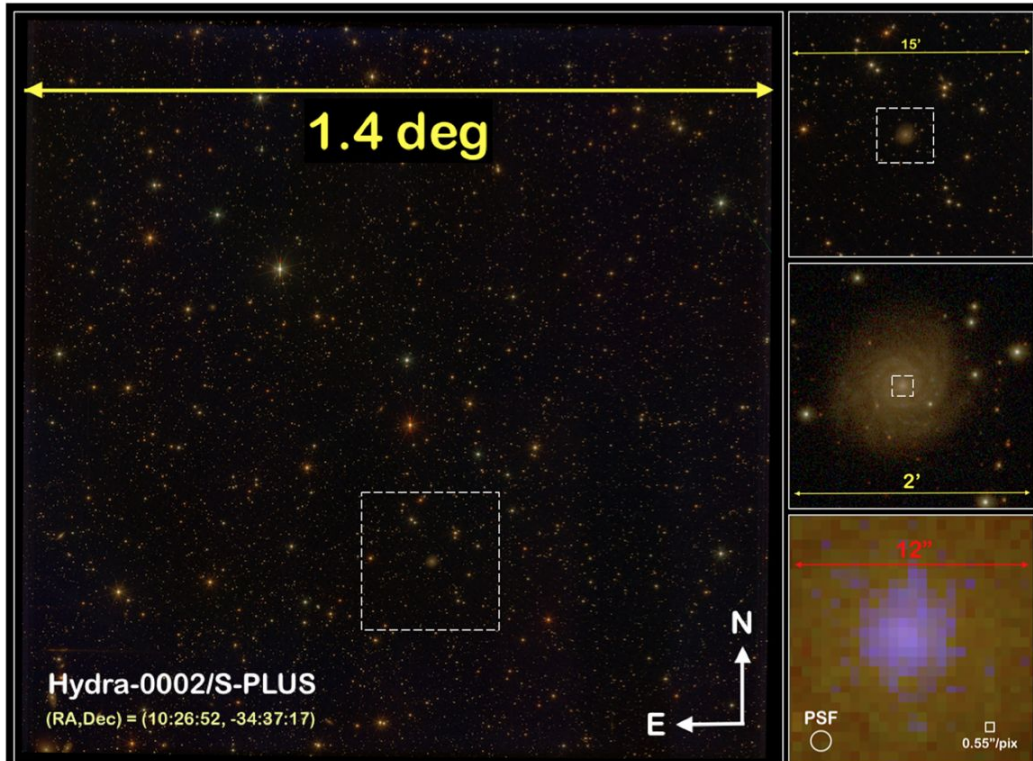
Discovering Supernovae and targeting GW Follow-ups

Andre Santos – andsantos@cbpf.br

in behalf of S-PLUS collaboration

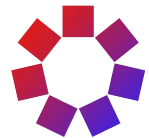


Southern Photometric Local Survey (S-PLUS) Overview

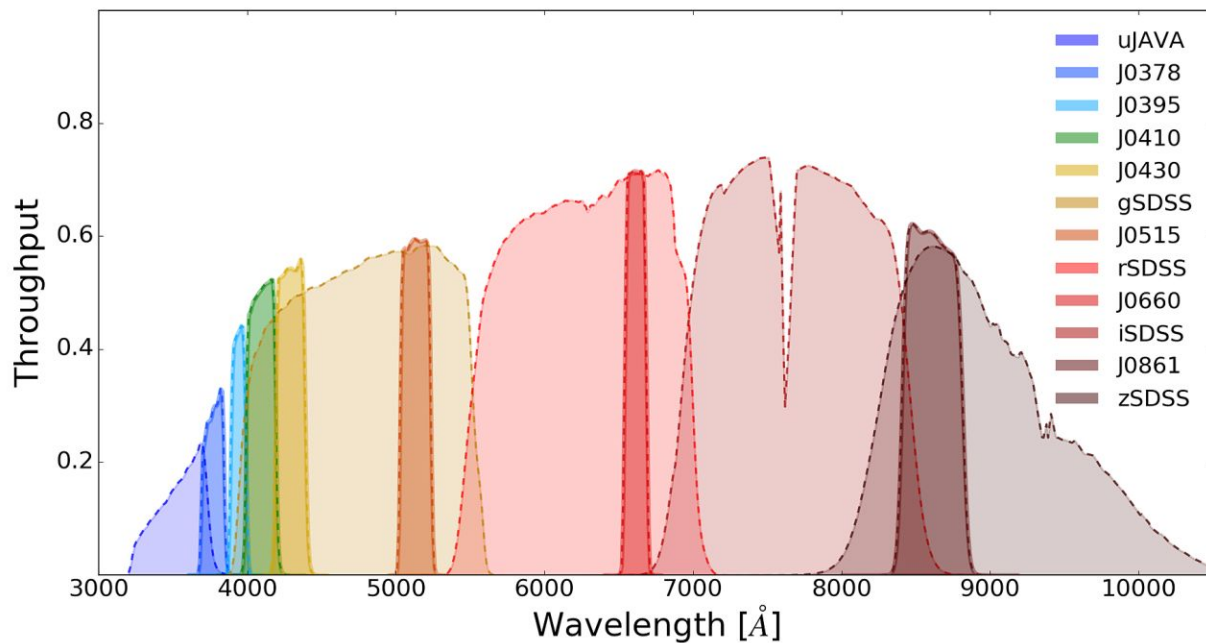


C. Mendes de Oliveira et al., 2019

Southern Photometric Local Survey (S-PLUS) Overview



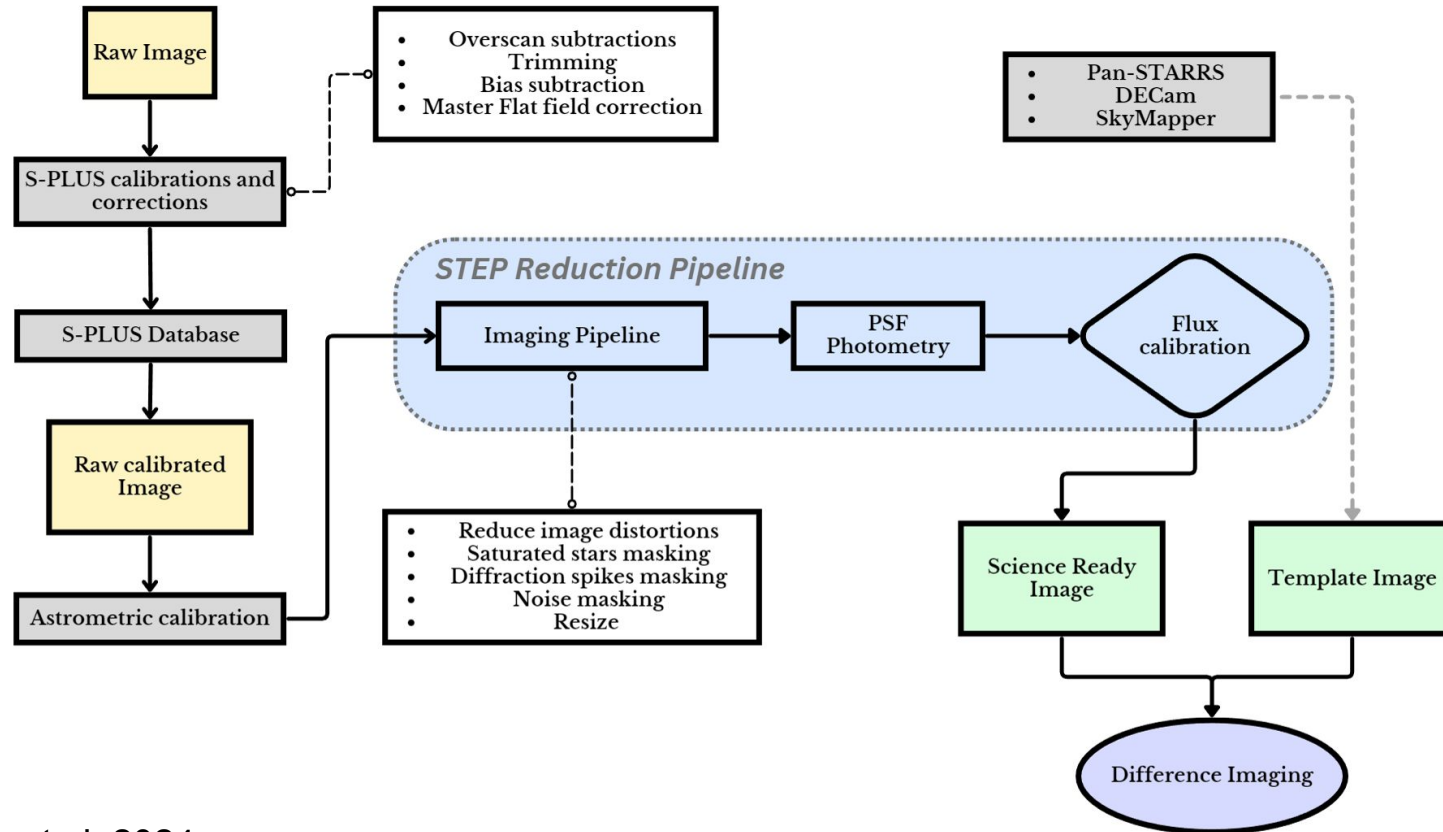
S-PLUS Southern Photometric
Local Universe Survey



STEP Goals

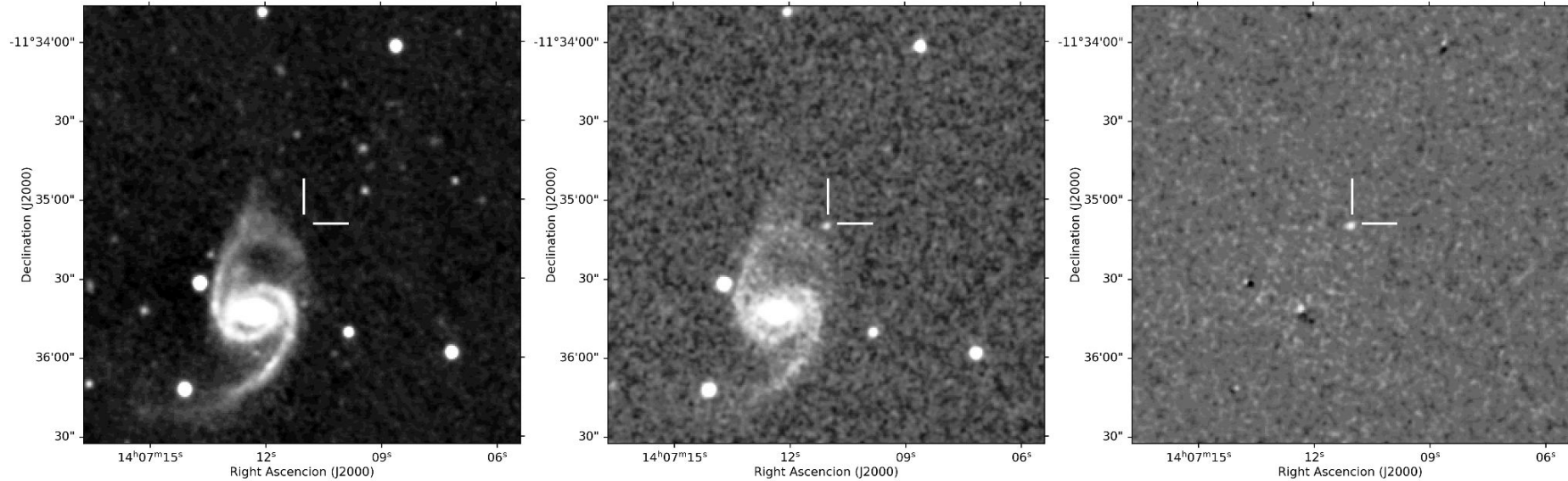
- ★ Difference Imaging Analysis to discover transients in S-PLUS data.
- ★ Follow-up of particular SNe (Type II with pre-explosion images)
- ★ Search for EM counterpart of Gravitational Wave Events.

How it is Done



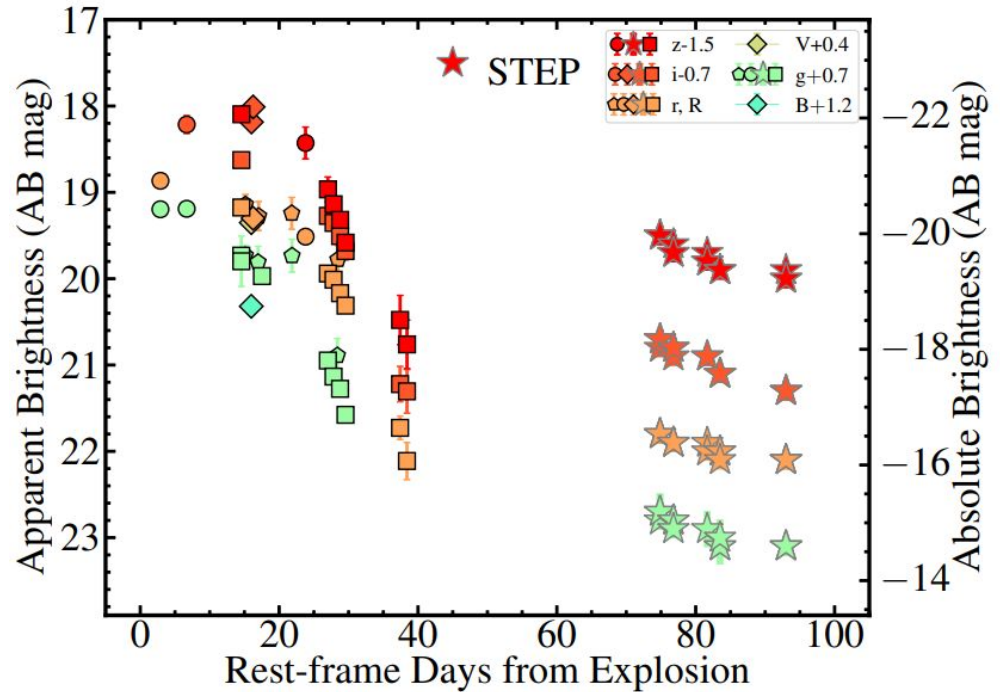
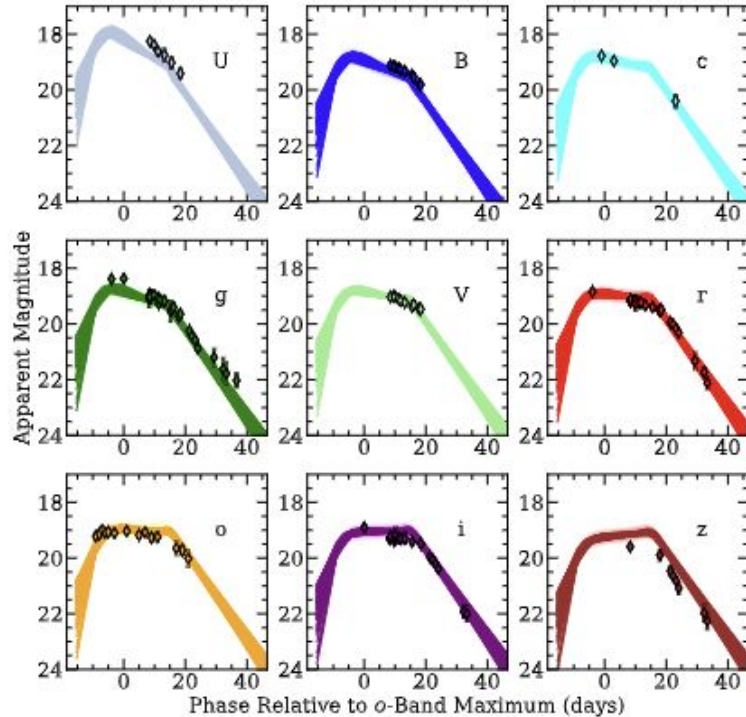
Untargeted discovery of transients

PSN discovered in S-PLUS data (field splus_n09s45)

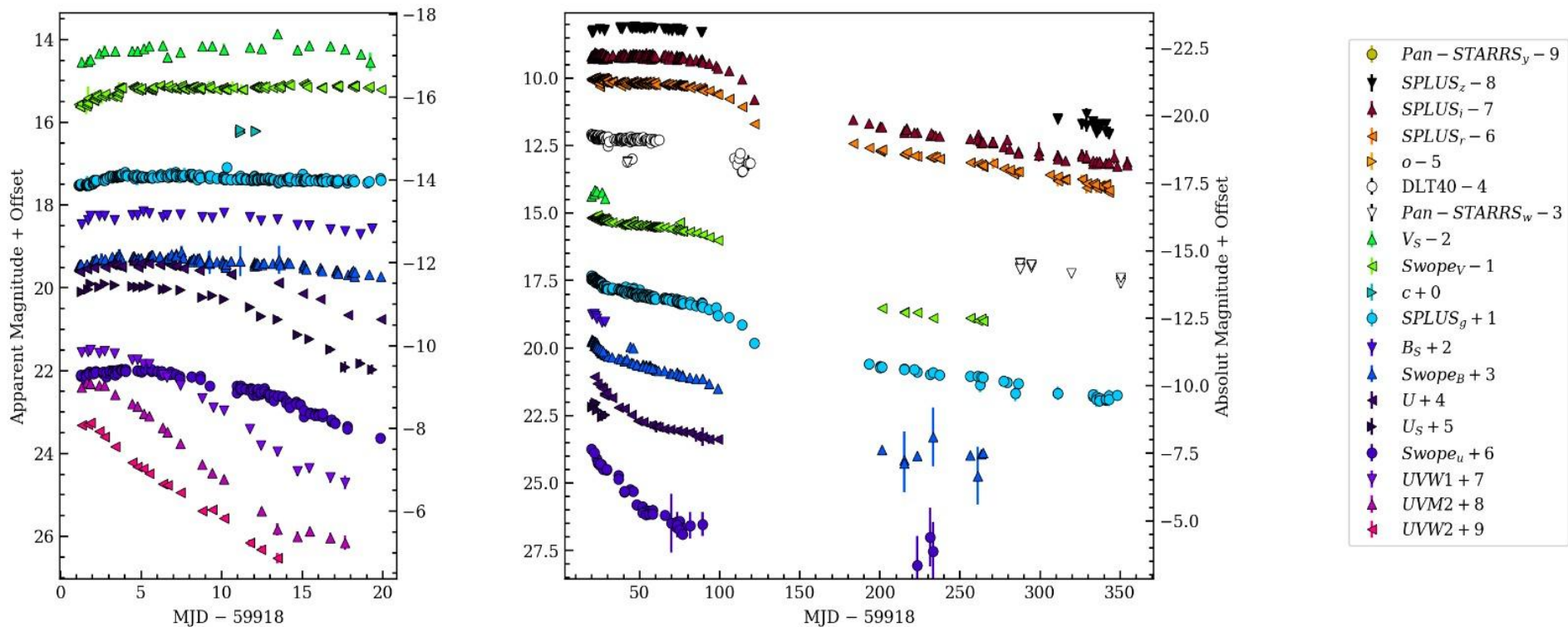


Follow-up with of known Supernovae: 2022ann

SN 2022ann: A type Icn supernova from a dwarf galaxy that reveals helium in its circumstellar environment

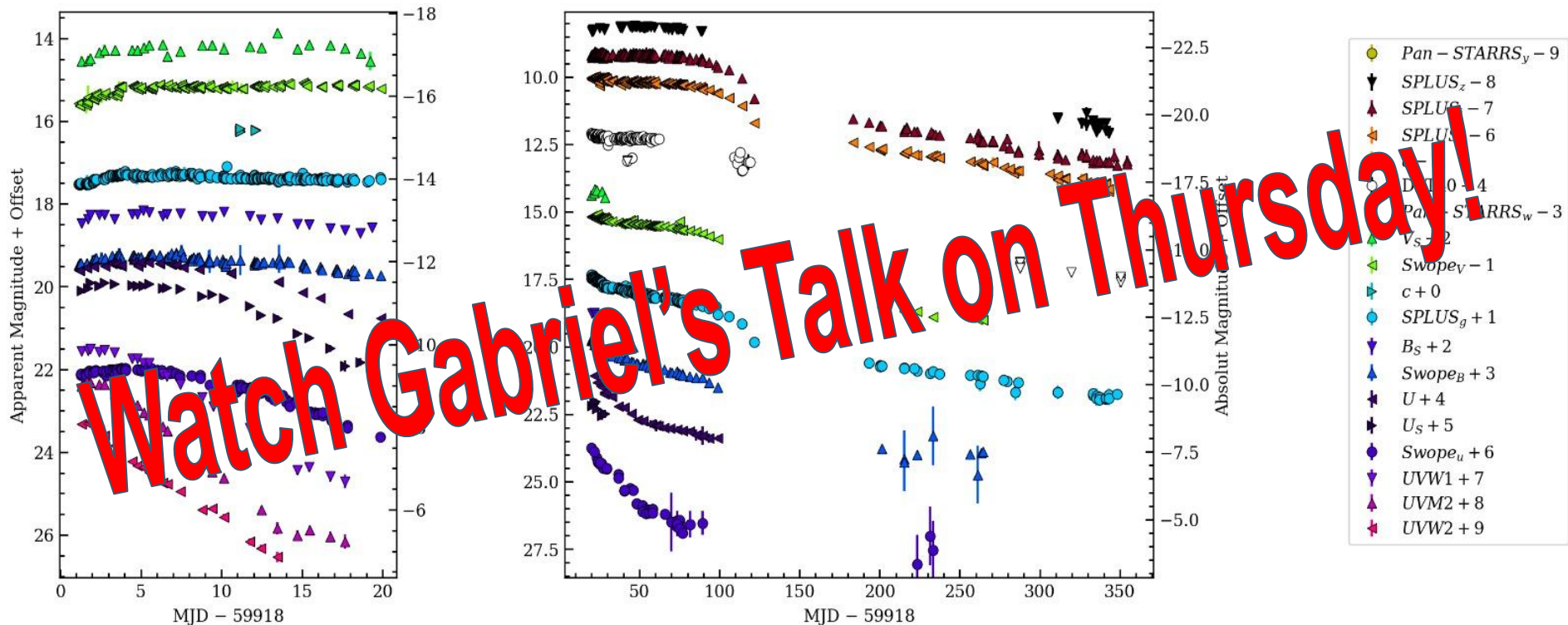


Follow-up with of known Supernovae: 2022acko



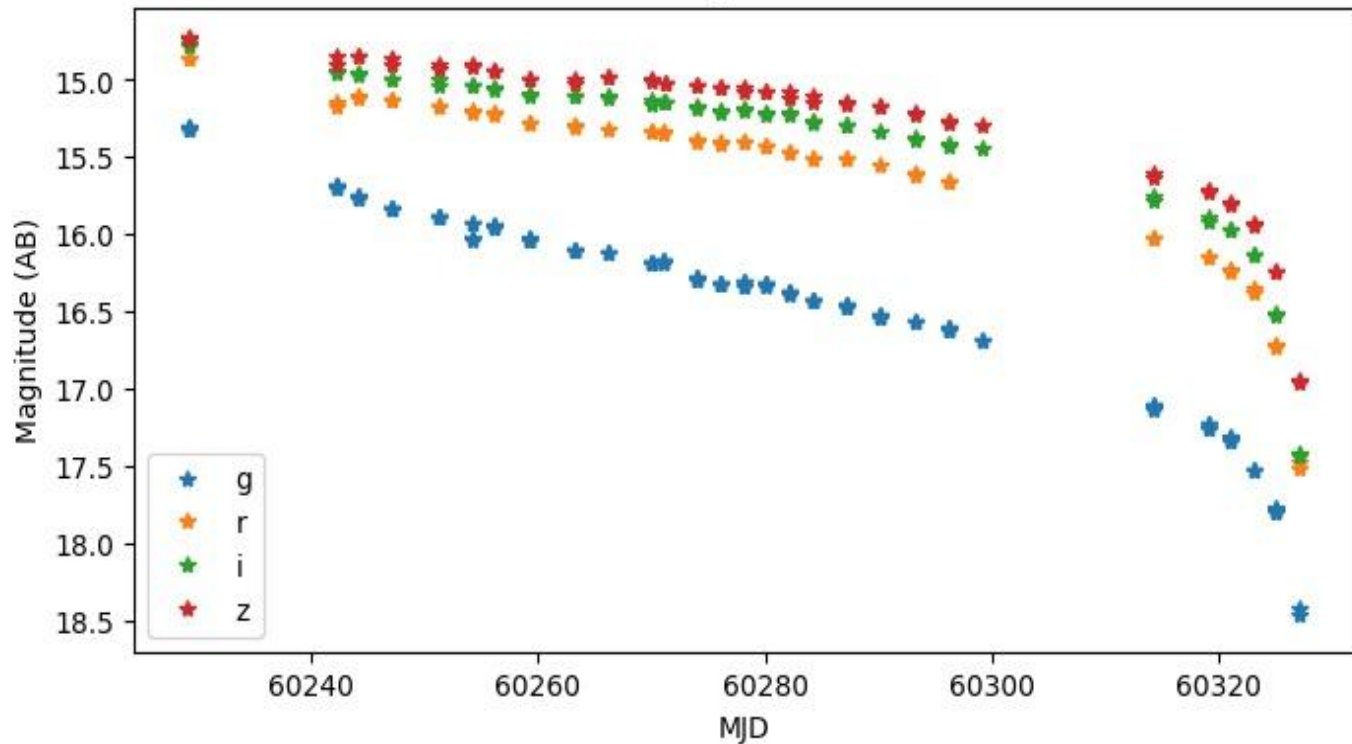
G. Teixeira et al. (in prep)

Follow-up with of known Supernovae: 2022acko



G. Teixeira et al. (in prep)

Follow-up with of known Supernovae: 2023rve



Santos et al. (in prep)

Search for Kilonovae within LIGO-VIRGO(+KAGRA) GW alerts

Neutron Star merger

Kilonova

Observed only once (GW170817)



Credit: Carl Knox OzGrav–Swinburne University

Neutron Star + Black Hole merger

Kilonova

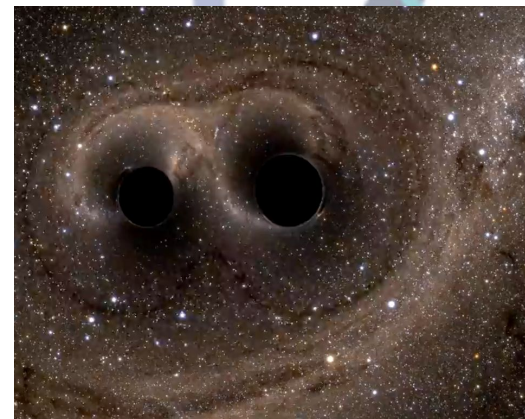
Never Observed in optical



Credit: Carl Knox OzGrav–Swinburne University

Binary Black Hole Merger

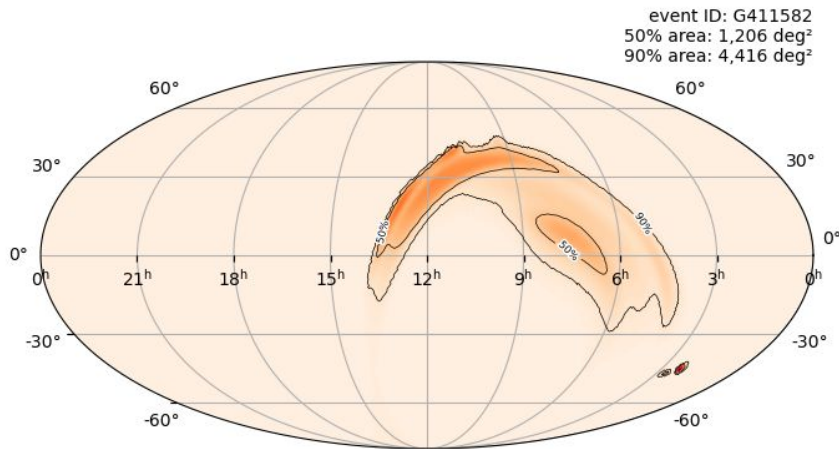
Never Observed in optical



Credit: SXS Project

Fourth Observing Run (O4) so Far

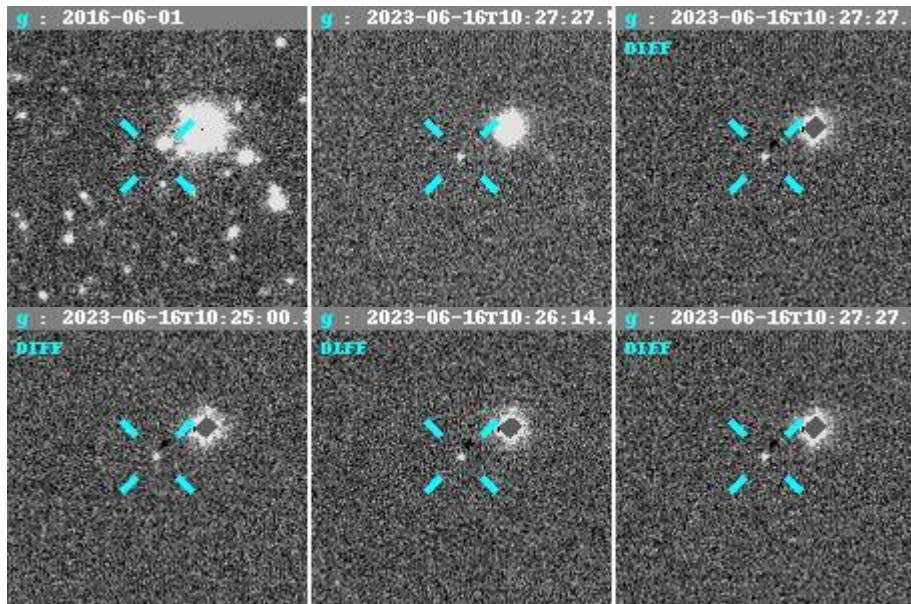
Test run on Superevent **S230615az**



- **BNS Merger with 85% probability**
- **FAR is 4 per year**
- **Most part is located in the north**
- **Small blob in the south**
- **~274Mpc distance**

Fourth Observing Run (O4) so Far

Results of the search using T80-South:



- ★ We searched for the counterpart using G band, with 33 seconds as exposure time.
- ★ We took 3* exposures per tile, observing 24 tiles of the 26 total in that region
- ★ Found 1 candidate at magnitude 19.8 (AB) (g band)

ID	476
RA	02:43:11.940
Dec	-46:39:09.04
field	t80_002727
CCD#	1

Fourth Observing Run (O4) so Far

Results of the search using T80-South:

GCN Circular 33986

Subject LIGO/Virgo/KAGRA S230615az: T80S Search and Candidate Counterpart Identification
Date 2023-06-17T22:15:01Z (10 days ago)
From André Santos <andsouzasanttos@gmail.com>

A. Santos (CBPF/Fermilab), C. D. Kilpatrick (Northwestern), C. R. Bom (CBPF), Eduardo Lacerda (IAG-USP) report on behalf of the STEP-GW collaboration:

We conducted an optical search for candidate counterparts in the localization region of LVK gravitational wave event S230615az with the T80S 0.8-m robotic telescope using the 1.4 x 1.4 field-of-view camera. The tiling was optimally determined using the latest localization map from the LVK and galaxy catalogs in Teglon (Coulter et al., in prep.). In total, T80S observed 24 fields (68 individual exposures at total) within the 90th percentile localization region of S230615az. All of our completed pointings have been uploaded to the GW Treasure Map (Wyatt et al., 2020) at <https://treasuremap.space/alerts?graceids=S230615az>.

Subtracting DECam and SkyMapper template images from the T80S images using photpipe (Rest et al., 2005), we identified the following candidate counterpart in our imaging:

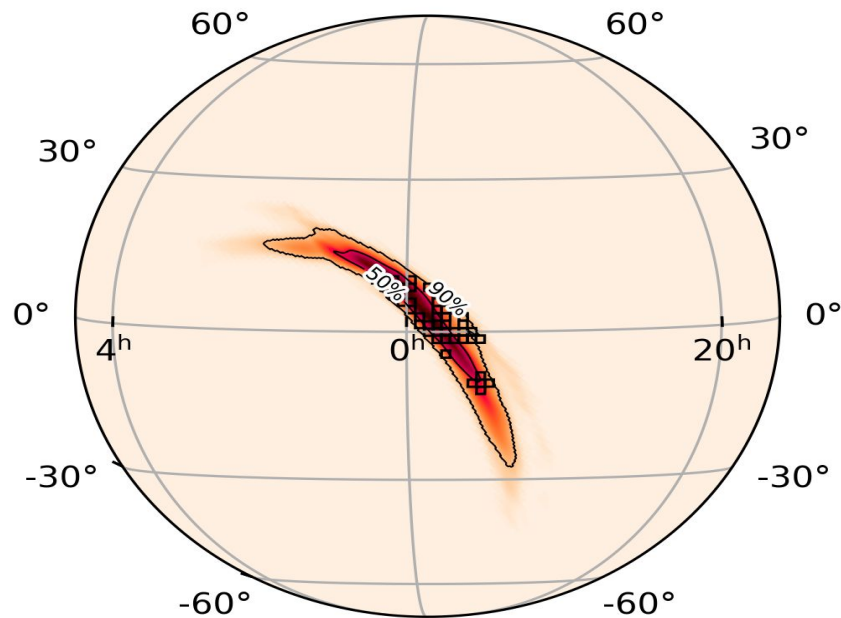
Name MJD RA(deg) Dec(deg) Filter Mag Magerr
STEP23a 60111.4340 40.79975 -46.65150667 g 19.806 0.09

We have checked the Minor Planet Center and Transient Name Server, finding no previously reported solar system object or transient. We encourage follow-up observations of this source.

Fourth Observing Run (O4) so Far

Search and Follow-up of event **S231206cc**

event ID: S231206cc
50% area: 90 deg²
90% area: 342 deg²
T80S coverage: 90 deg²



- **BBH (>99% probability)**
- **FAR is 1 per 1.6402e+27 years**
- **1467 +/- 264 Mpc**
- **342 sq-deg (90% c. region)**

Fourth Observing Run (O4) so Far


Search and Follow-up of event S231206cc

☰ 🔍 Search 🔄 Data Transfer ∞ Gravitational Waves

Gravitational Waves

Superevent
Enter an event name from the O3 or O4 runs (e.g. S230709bi).

Credible level
From 0 (most likely) to 1 (least likely)

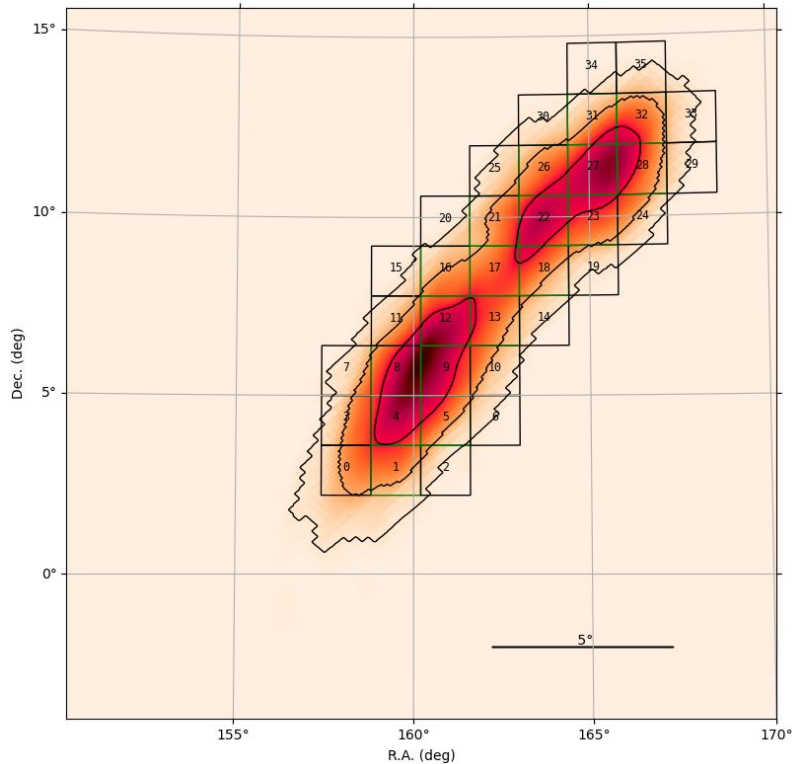


ALADIN

objectId	Classification	Number of measurements	Delay (day)
ZTF23abrydal	Solar System MPC	1	-0.8772626440040767
ZTF23abryden	Solar System MPC	1	-0.8772626440040767
ZTF23abryder	Solar System MPC	1	-0.8772626440040767
ZTF23abrydcs	Solar System MPC	1	-0.8772626440040767
ZTF23abrydet	Solar System MPC	1	-0.8772626440040767
ZTF23abrydar	Solar System MPC	1	-0.8772626440040767
ZTF23abrydas	Solar System MPC	1	-0.8772626440040767
ZTF23abrydat	Solar System MPC	1	-0.8772626440040767

Fourth Observing Run (O4) so Far

Search and Follow-up of event **S240413p**:



- **BBH (>99% probability)**
- **FAR is 1 per 100 years**
- **526 +/- 101 Mpc**
- **34 sq-deg (90% c. region)**

Fourth Observing Run (O4) so Far

Search and Follow-up of event **S240413p**:

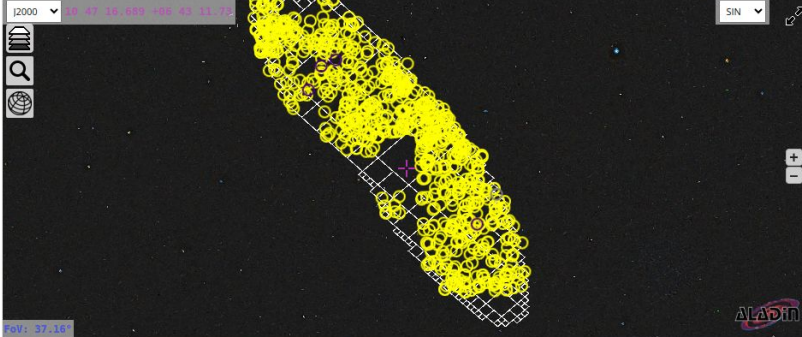
☰ 🔍 Search 🔄 Data Transfer 🌐 Gravitational Waves

Gravitational Waves

Superevent
Enter an event name from the O3 or O4 runs (e.g. S230709b).

Credible level
From 0 (most likely) to 1 (least likely)

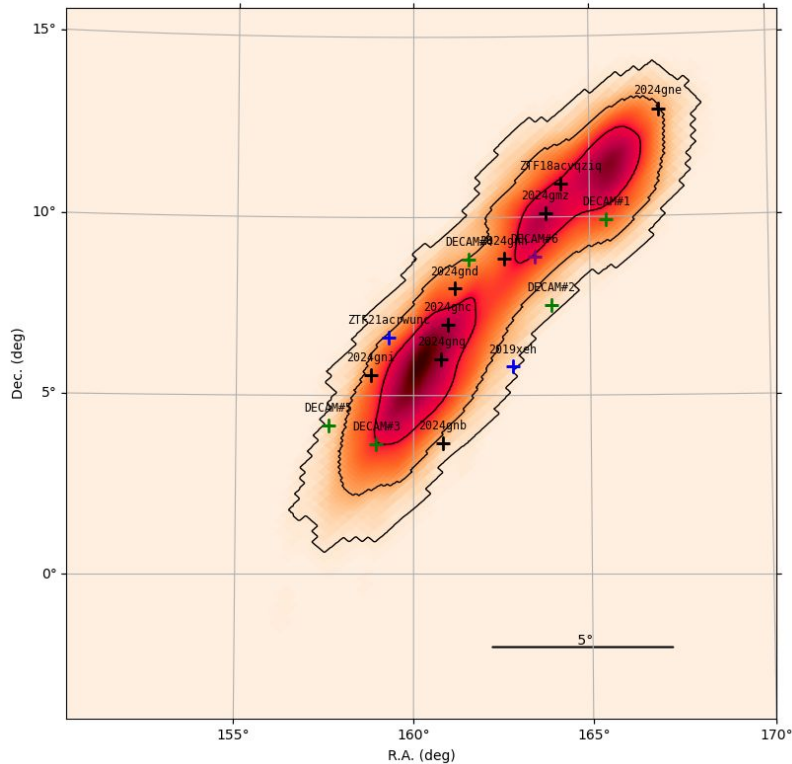
[Search for alerts matching](#)



objectId	Classification	Number of measurements	Delay (day)
ZTF24aaifjae	Solar System MPC	1	-0.8773245313204825
ZTF24aaifjiv	Solar System MPC	1	-0.8773245313204825
ZTF24aaifkcf	Solar System MPC	1	-0.8773245313204825
ZTF24aaifjwx	Solar System MPC	1	-0.8773245313204825
ZTF24aaifjww	Solar System MPC	1	-0.8773245313204825
ZTF24aaifjvw	Solar System MPC	1	-0.8773245313204825
ZTF24aaifjvz	Solar System MPC	1	-0.8773245313204825
ZTF24aaifjvu	Solar System MPC	1	-0.8773245313204825

Fourth Observing Run (O4) so Far

Search and Follow-up of event **S240413p**:



- **BBH (>99% probability)**
- **FAR is 1 per 100 years**
- **526 +/- 101 Mpc**
- **34 sq-deg (90% c. region)**

Fourth Observing Run (O4) so Far

Results of the search using T80-South:

GCN Circular 36146

Subject LIGO/Virgo/KAGRA S240413p: STEP - T80S Search and Candidate Counterpart Identification
Date 2024-04-17T14:16:10Z (16 days ago)
From Clecio Bom at CBPF <debom@cbpf.br>
Via Web form

C.R.Bom (CBPF), A. Santos (CBPF), C. D. Kilpatrick (Northwestern), Luidhy Santana-Silva (CBPF), Phelipe Darc (CBPF), Claudia Mendes de Oliveira (IAG-USP) report on behalf of the STEP-GW collaboration:

We conducted an optical search for candidate counterparts in the localization region of LVK gravitational wave event S240413p with the T80S 0.8-m robotic telescope using the 1.4 x 1.4 field-of-view T80S-Cam imager. The tiling was optimally determined using the latest localization map from the LVK and galaxy catalogs in Teglon (Coulter et al., in prep.). In total, T80S observed 28 fields within the 90th percentile localization region of S240413p.

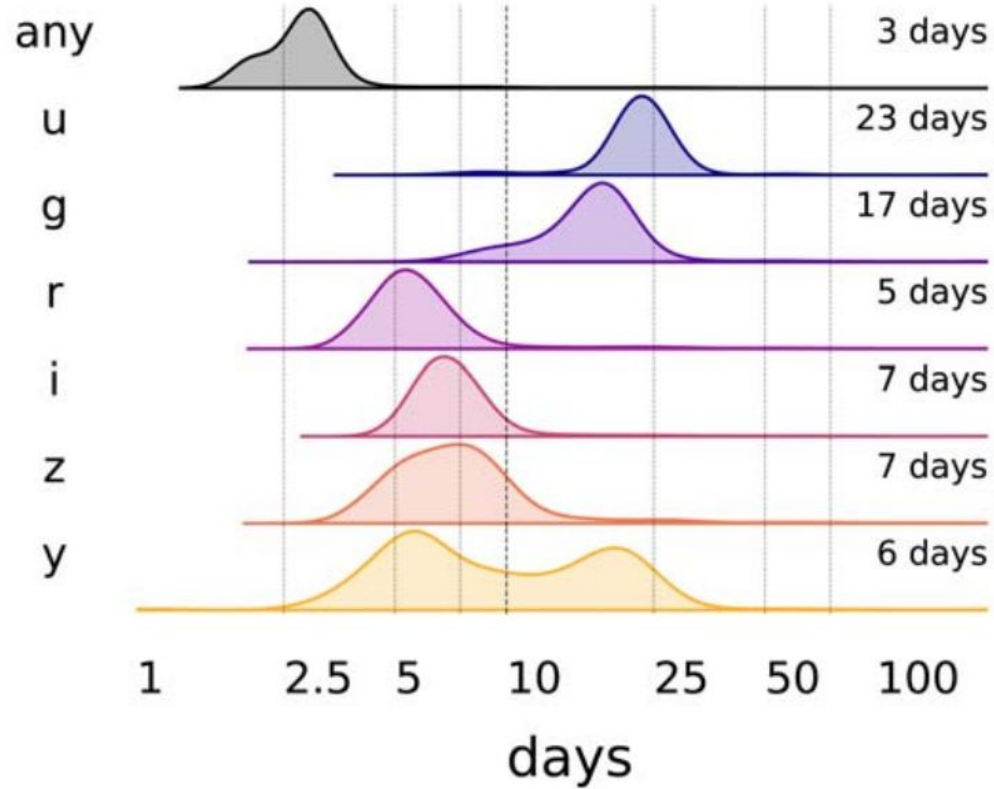
We subtracted Pan-STARRS template images from the T80S images using photpipe (Rest et al., 2005). As this GW event is classified as a binary black hole merger (GCN #36075), we also cross-matched with known AGNs. we identified the following candidate counterpart in our imaging:

```
Name MJD RA(deg) Dec(deg) Filter Mag Magerr
STEP24a 60416.109690 162.814 5.806 10:51:15.43 +05:48:24.69 g 18.626 0.046
```

This candidate shows a possible flare and has a spectroscopic redshift of 0.069, which falls close to the lower end of the 2-sigma distance distribution of S240413p.

We have checked the Minor Planet Center and Transient Name Server, finding no previously reported solar system object or transient. We encourage follow-up observations of this source.

S-PLUS Transient Extension Program in Rubin Era



Summary

- ★ S-PLUS is a very interesting tool to Supernova Discovery before LSST.
- ★ After LSST, S-PLUS could play important role as a follow-up resource.
- ★ T-80 South could be used to future ToO for Bright objects and auxiliary in searches for faint objects.