A search for millimeter-wave transient sources in the Galactic Plane with SPT-3G

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mm Universe, 06/26/2025

Mm-wave transient search with SPT

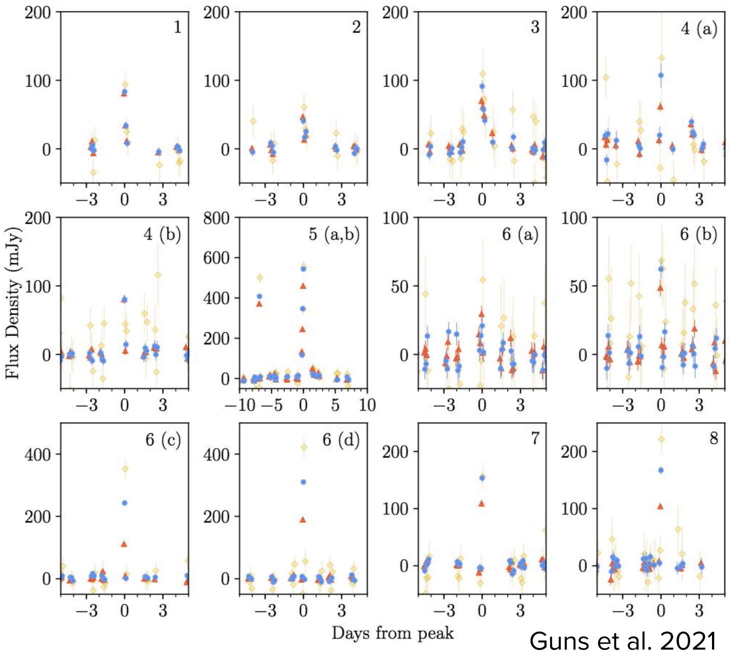
- South Pole Telescope (SPT) is a 10 meter diameter, wide field telescope located at Amundsen-Scott South Pole Station in Antarctica.
- Observing Strategy: repeated observations of the same patch of sky for multiple years with cadence between 2-20 hours.
- Observing bands: 90GHz, 150GHz, and 220GHz.
- Angular resolution: ~ 1'.
- FoV: 1.88 deg.

Talks earlier this week: overview (Gil Holder); galaxy clusters (Lindsey Bleem; Sebastian Bocquet; Kayla Kornoelje; Matthew Young); source catalogs (Joaquin Vieira; Melanie Archipley); Lensing (Yuuki Omori; Fei Ge); AGN (Aidan Simpson, John Hood); Cosmology (Wei Quan; Etienne Camphuis); LIM (Adam Anderson); etc.

Photo credit: Daniel Michalik

First systematic transient search with SPT-3G

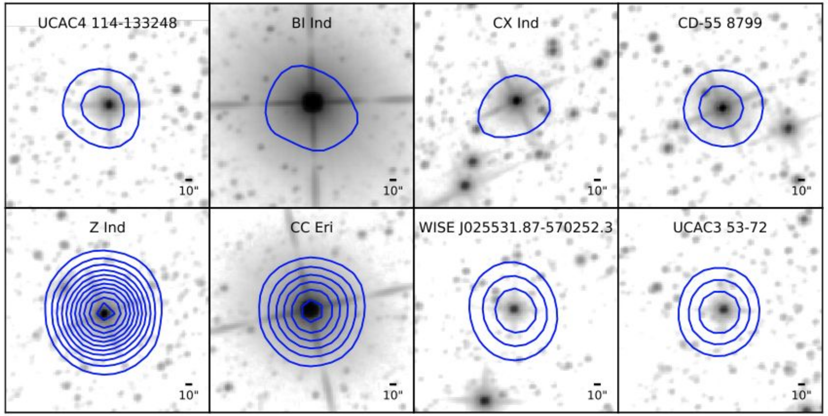
- Transient survey using one year of data covering 1500 square degrees with SPT-3G
- Detect 15 transient events: 13 stellar flares from 8 stars and 2 extragalactic events.



Guns et al. 2021

SPT lightcurves for all the detected stellar flares

90GHz 150GHz 220GHz



Guns et al. 2021

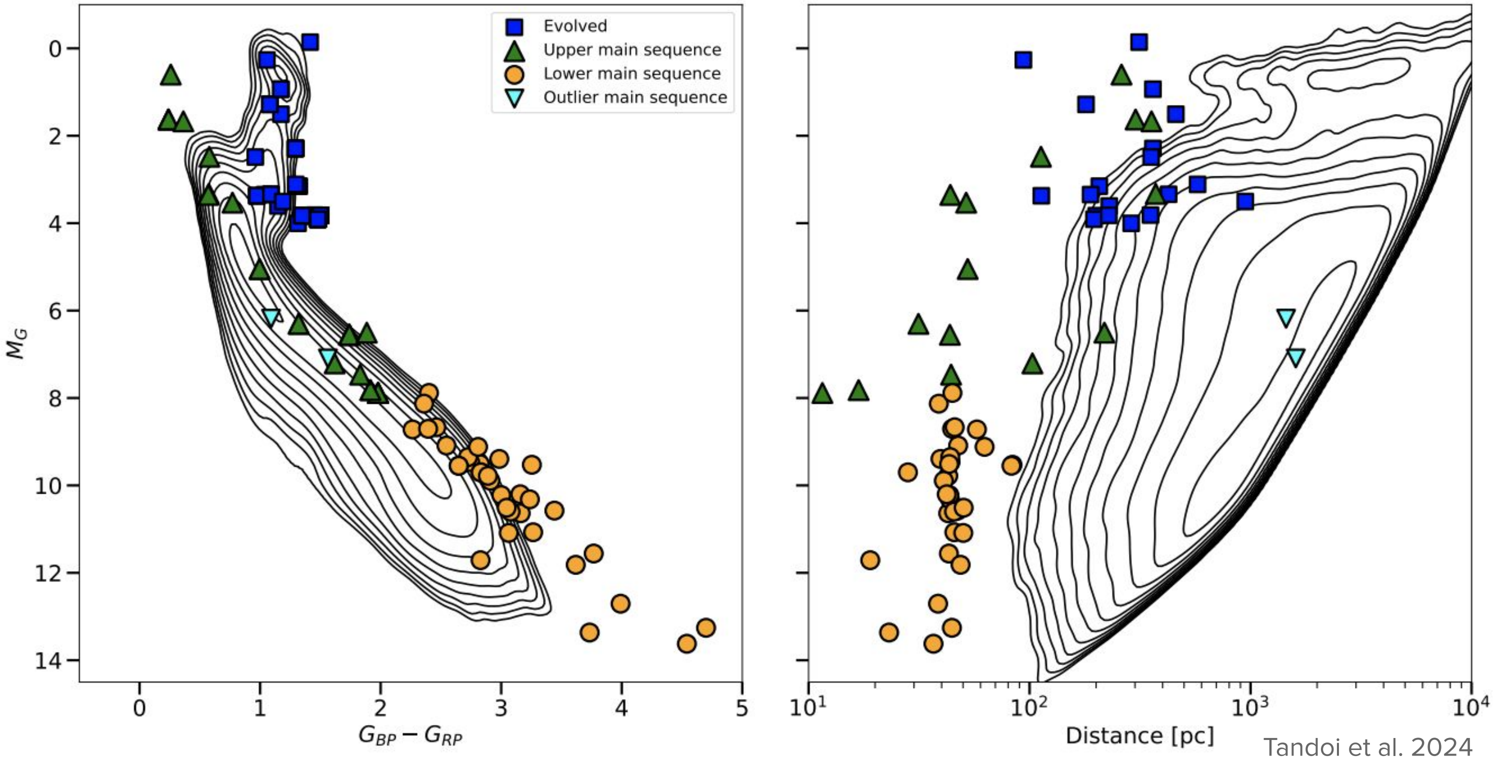
Associated stars with WISE

Blue contours: SPT 150GHz

Grayscale image: WISE W1(3.6μm)

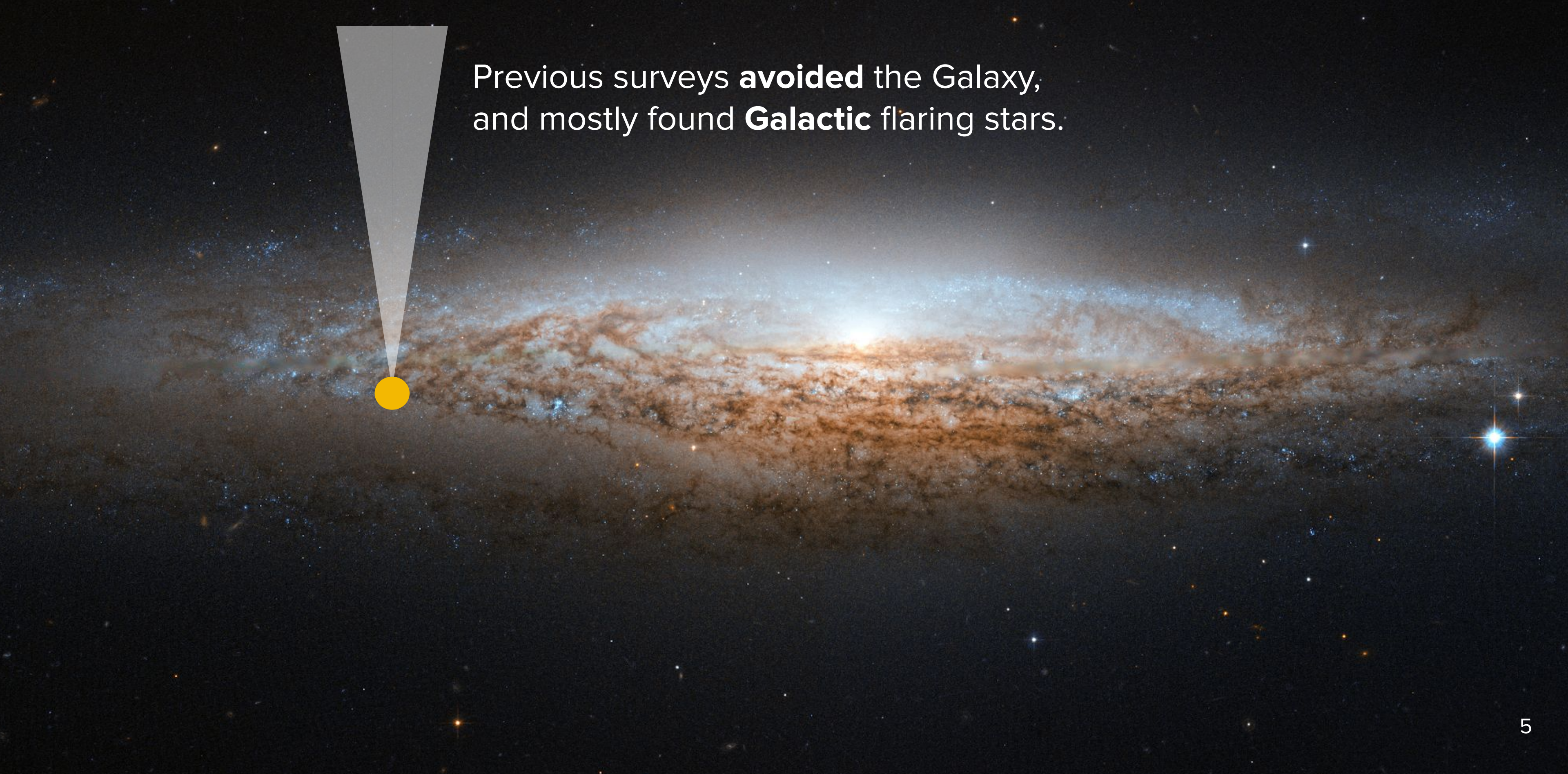
Stellar flare catalog

Stellar flare catalog from 4 year of survey data with SPT-3G, containing 111 stellar flares from 66 stars.



Tandoi et al. 2024

Motivation for the Galactic Plane transient survey



Previous surveys **avoided** the Galaxy,
and mostly found **Galactic** flaring stars.

Motivation for the Galactic Plane transient survey

If we look **towards** the plane of the Galaxy, we can see tons of stars and other interesting objects

Long wavelength Galaxy surveys

Hi-GAL, the Herschel infrared Galactic Plane Survey: 70, 160, 250, 350 and 500 um in T over ~12 deg^2; photometric maps and compact source catalogues. (Malinari et al. 2016)

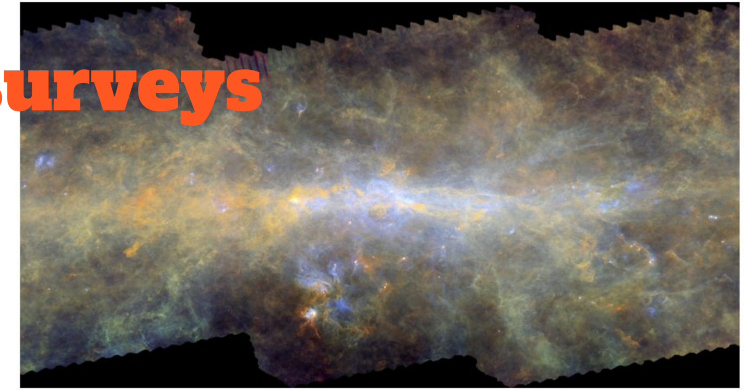
MeerKAT observed 6.5 deg^2 at 1.3GHz (Heywood et al. 2022)

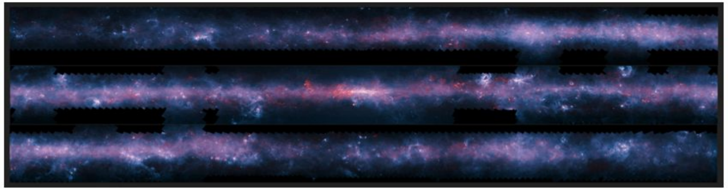
ACTpol observed 32 deg^2 in T and P in 2019 (Guan et al. 2021)

APEX/LABOCA ATLASGAL observed 400 deg^2 at 870um from 2017-2010 (Schuller et al. 2009, Contreras et al. 2013, Csengeri et al. 2014)

These were all static continuum surveys

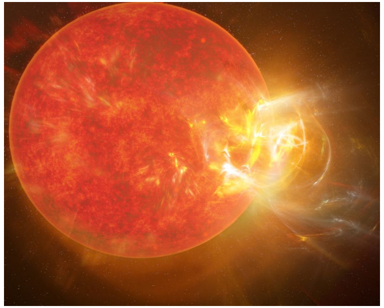
Not time-domain





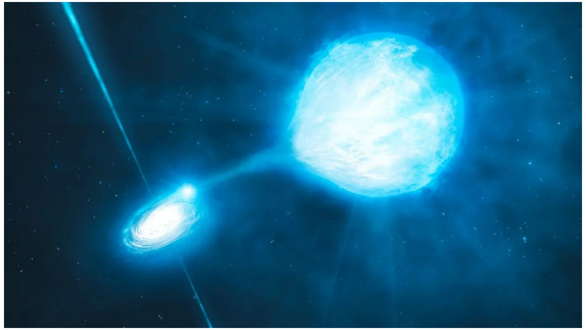
Science Cases

Stellar flare



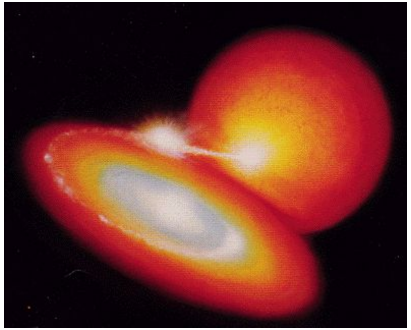
Credit: S. Dagnello, NRAO/AUI/NSF

X-ray binary



Credit: ESO/L. Calçada/M.Kornmesser

Accreting white dwarf

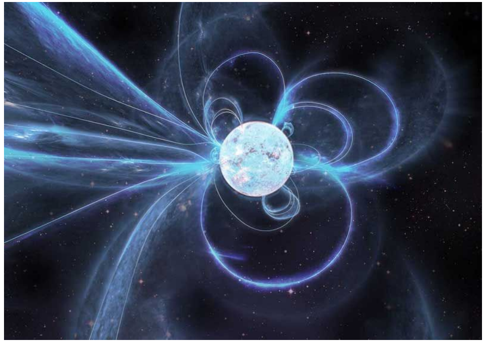


Credit: Dana Berry, STScI

Planetary Nebula

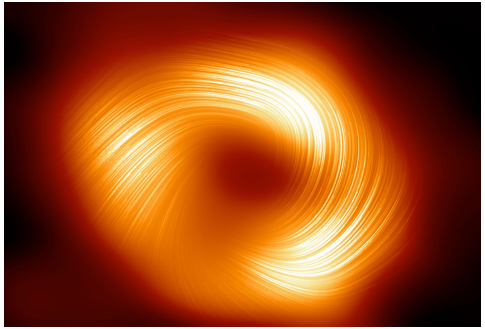
Credit: NASA, ESA and the Hubble Heritage (STScI/AURA)-ESA/Hubble Collaboration

Magnetar



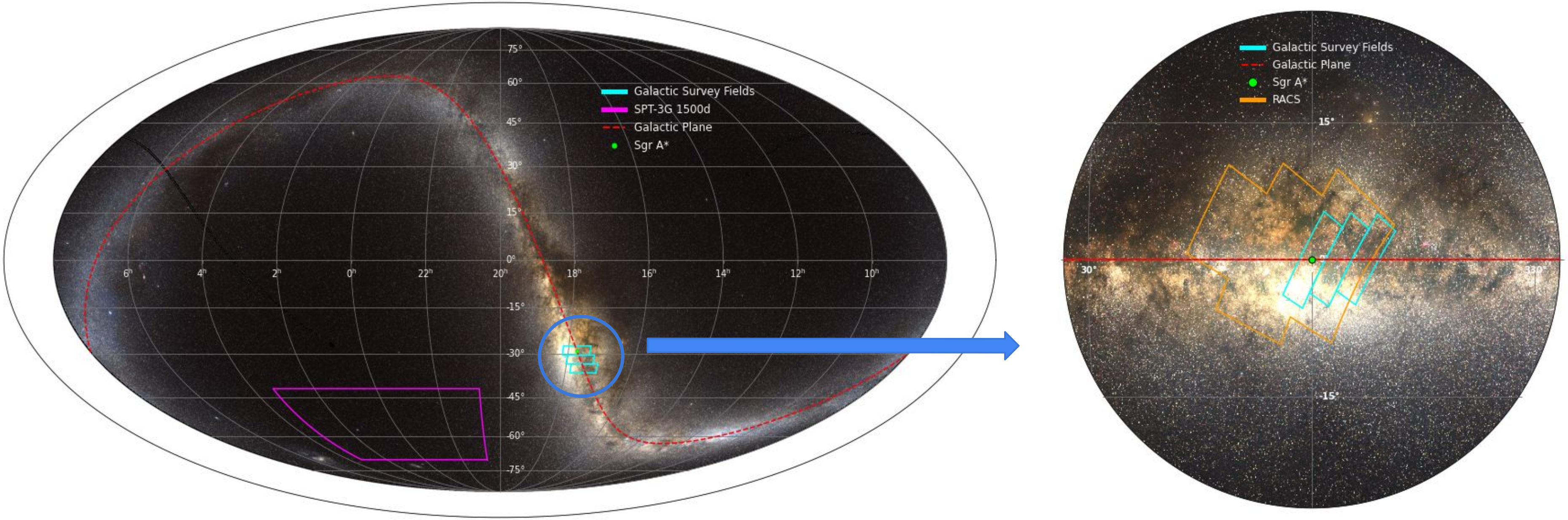
Credit: Carl Knox, OzGrav

Sgr A*



Credit: EHT Collaboration

The Galactic Plane transient survey

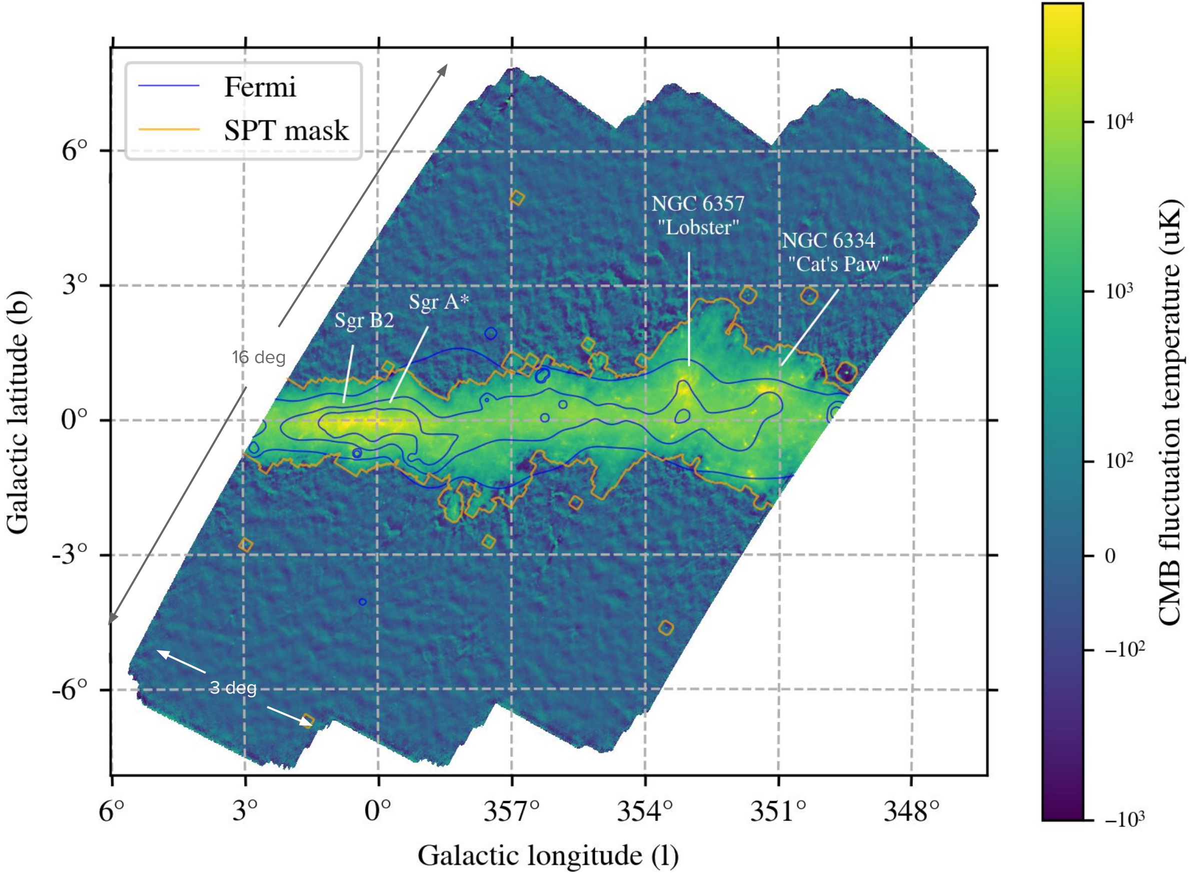


Images Credit: Paul Chichura

Location: The Galactic Plane

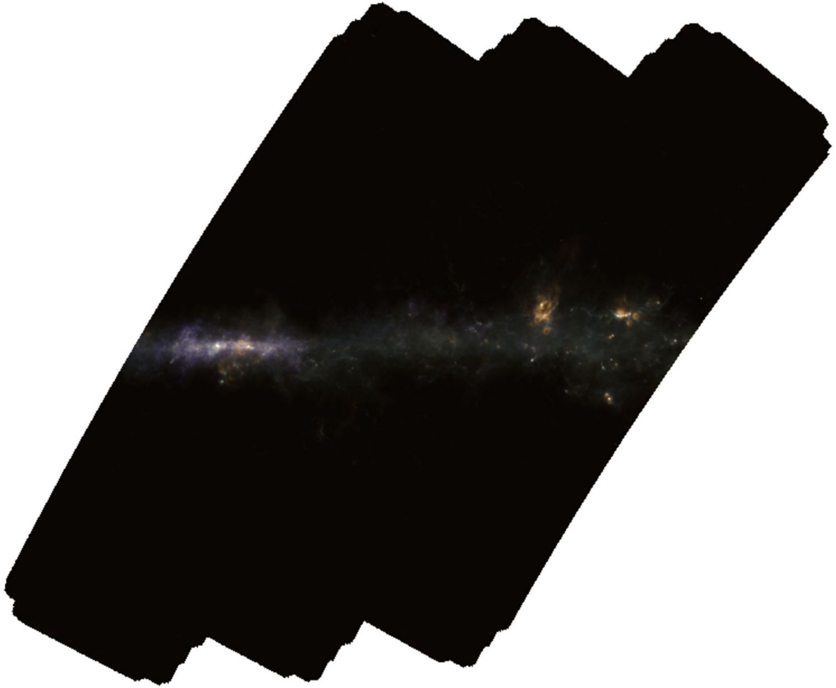
Time: Roughly one month every year starting from 2023

The Galactic Plane transient survey



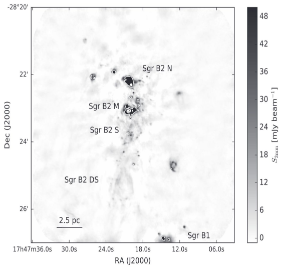
- Total area: ~98 deg^2
- Number of obs: ~500
- Observing bands: 90, 150, and 220 GHz
- Coadded depth: 5.6, 6.8 and 23uK-arcmin at 90, 150 and 220GHz

The Galactic Plane transient survey

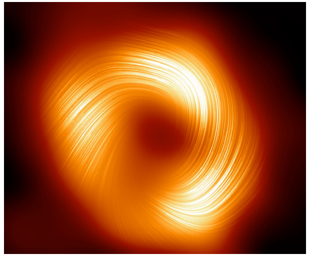


90GHz/3mm 150GHz/2mm 220GHz/1.4mm

The Galactic Plane transient survey



Ginsburg et al. 2018



Credit: EHT Collaboration

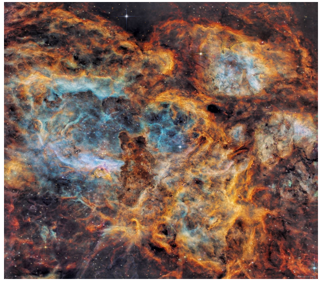
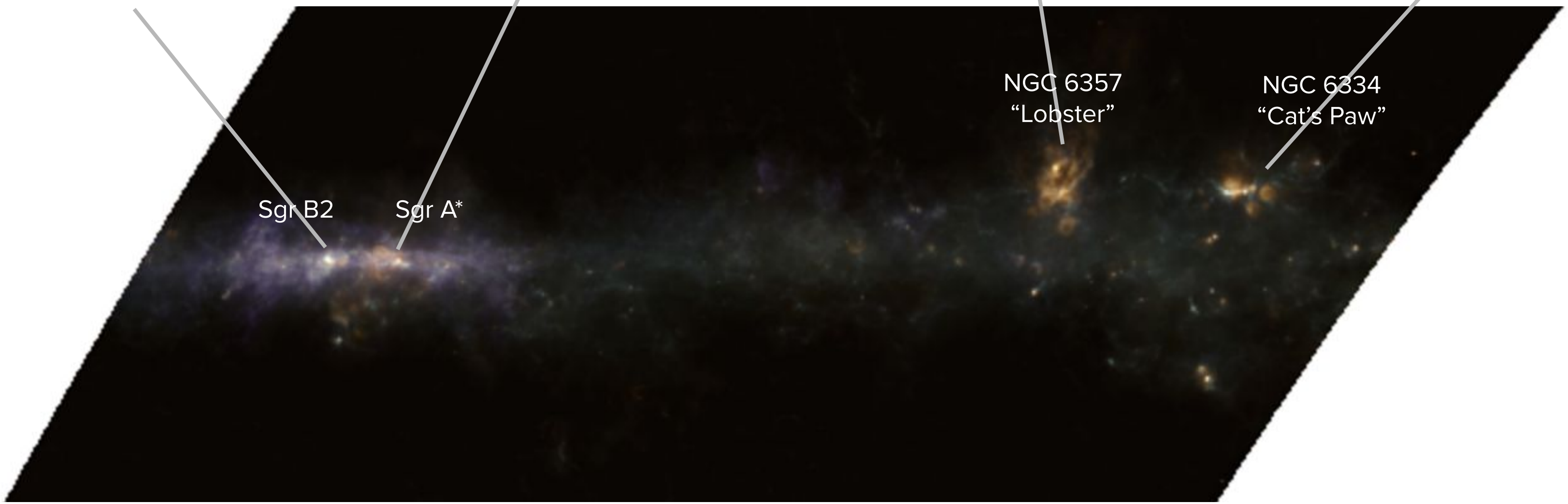


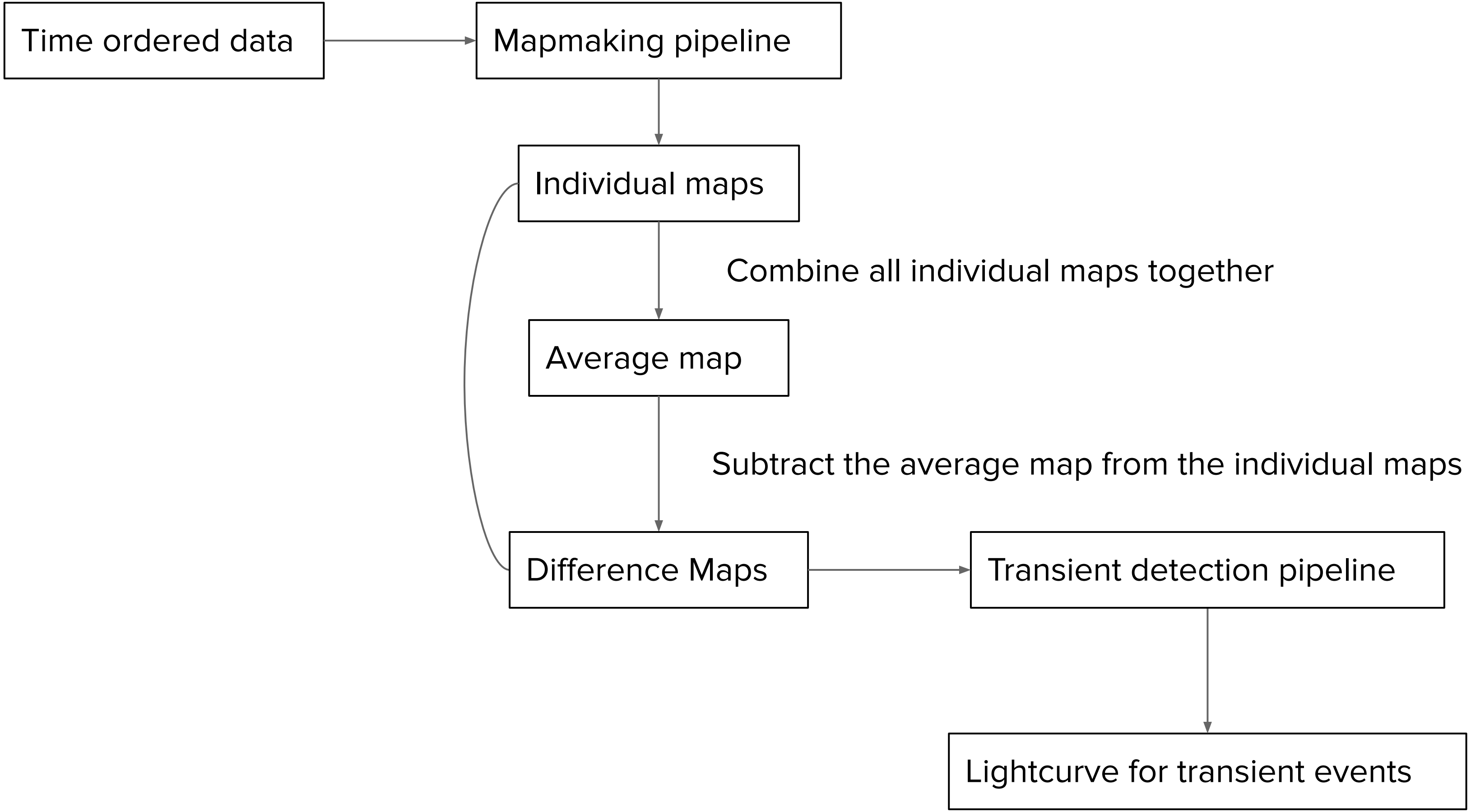
Image credit: Mark Hanson

Image credit: Daniel Stern



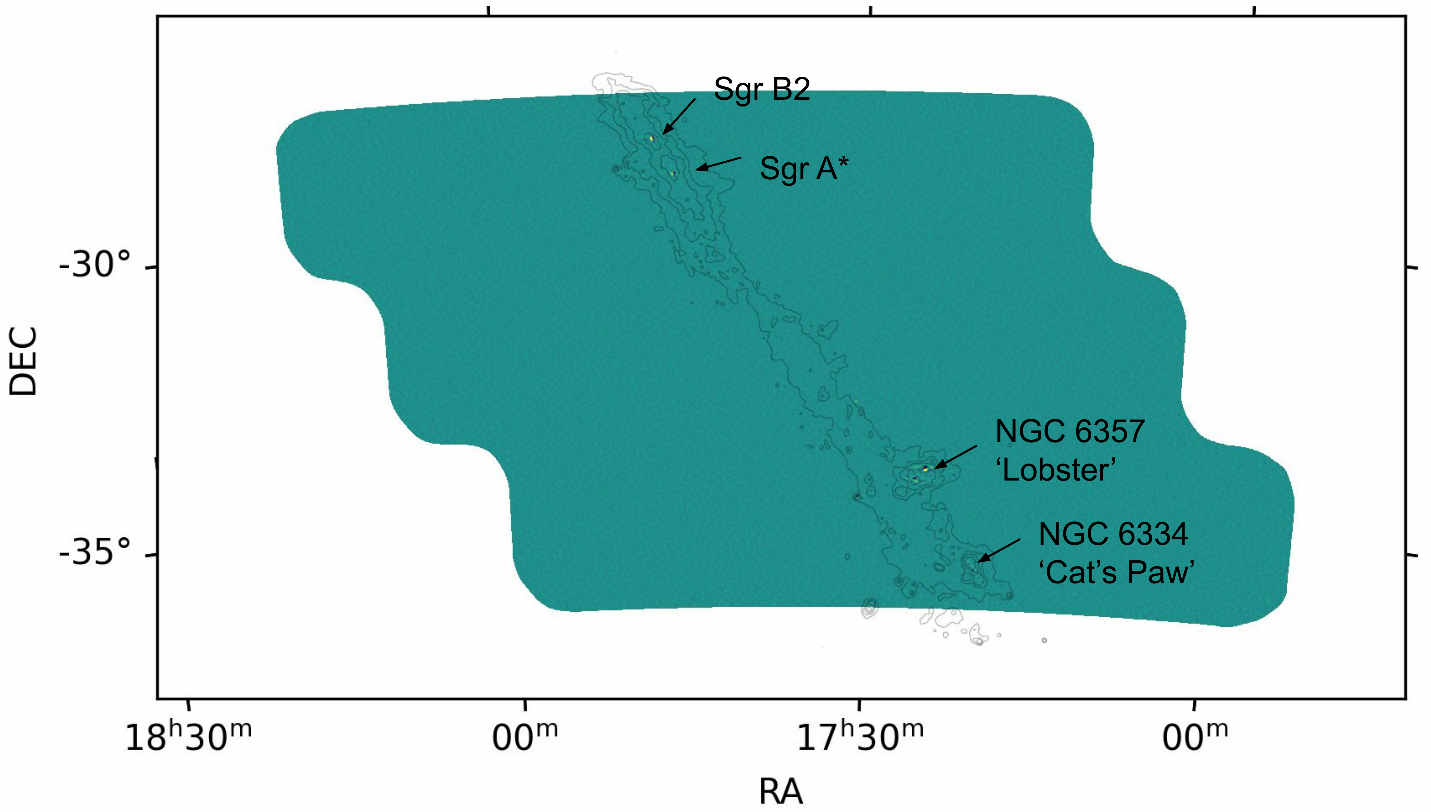
90GHz/3mm 150GHz/2mm 220GHz/1.4mm

Workflow for transient detection

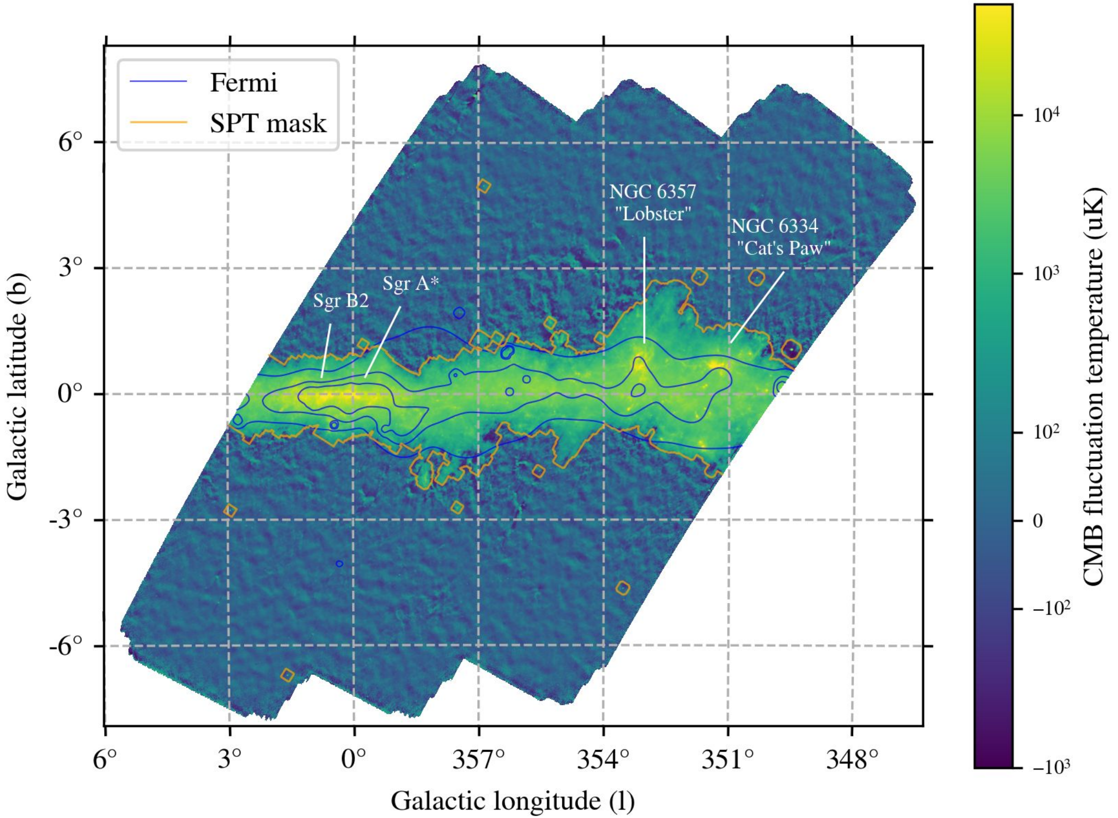


Transient detection

- Run through all difference maps in the same subfield in each year
- Mask bright sources
- Find outlier pixels (5 sigmas in both 90 and 150GHz simultaneous in one observation)
- Extract lightcurve for outlier pixels

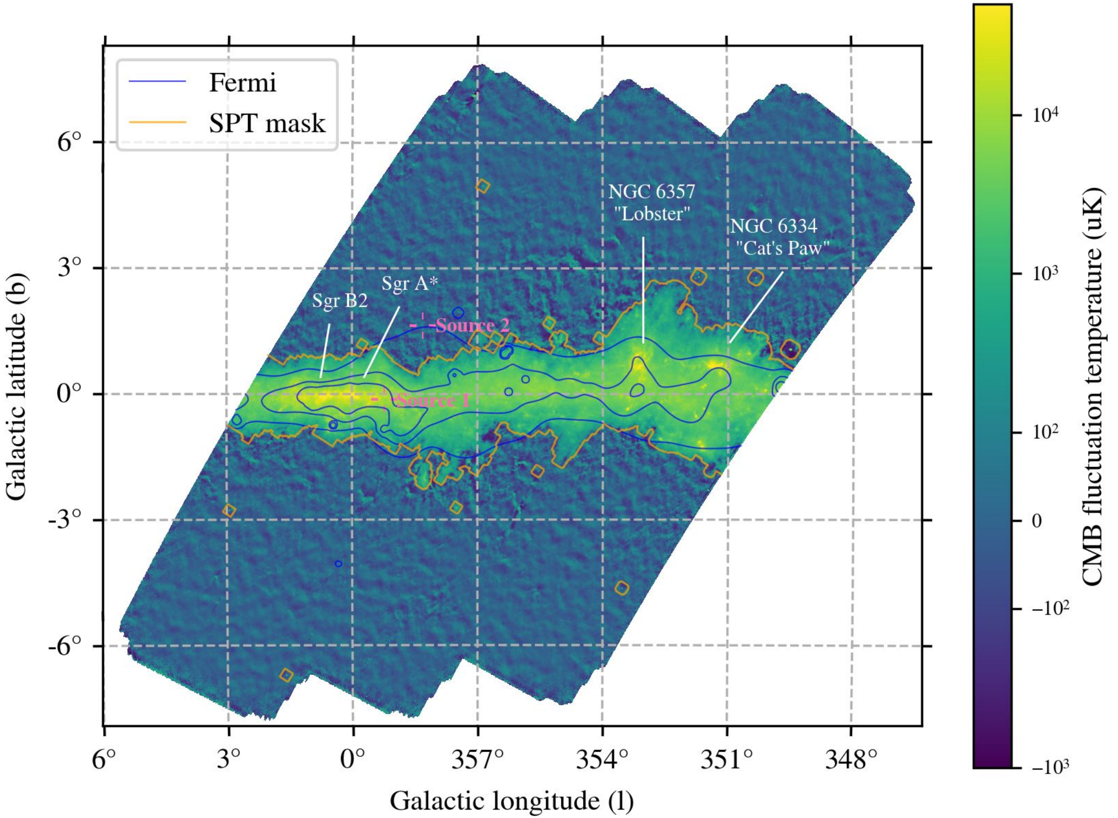


Results



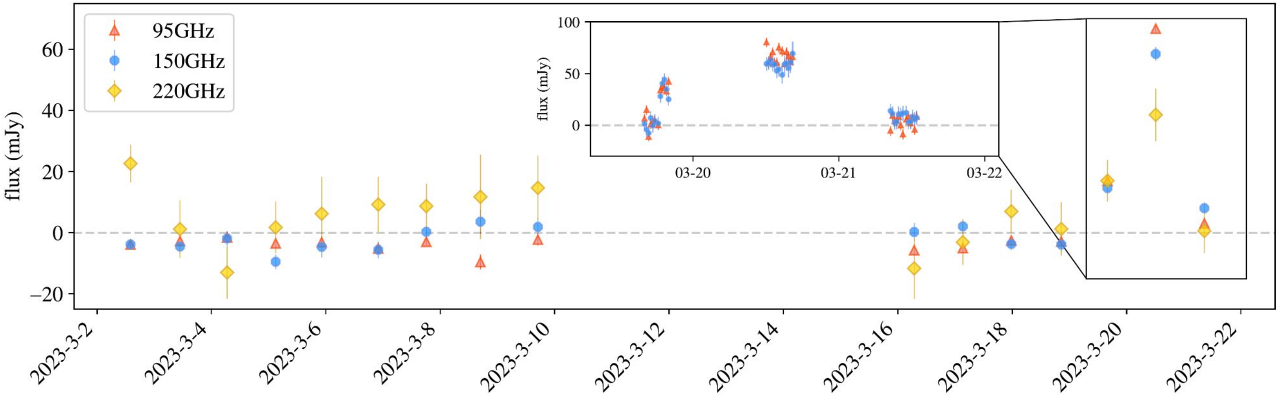
Fermi
SPT mask
NGC 6357
"Lobster"
NGC 6334
"Cat's Paw"
Sgr B2
Sgr A*
6°
3°
0°
-3°
-6°
Galactic latitude (b)
6°
3°
0°
357°
354°
351°
348°
Galactic longitude (l)
10^4
10^3
10^2
0
-10^2
-10^3
CMB fluctuation temperature (uK)

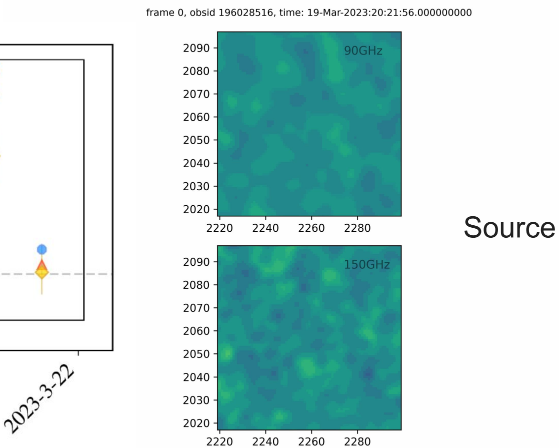
Results



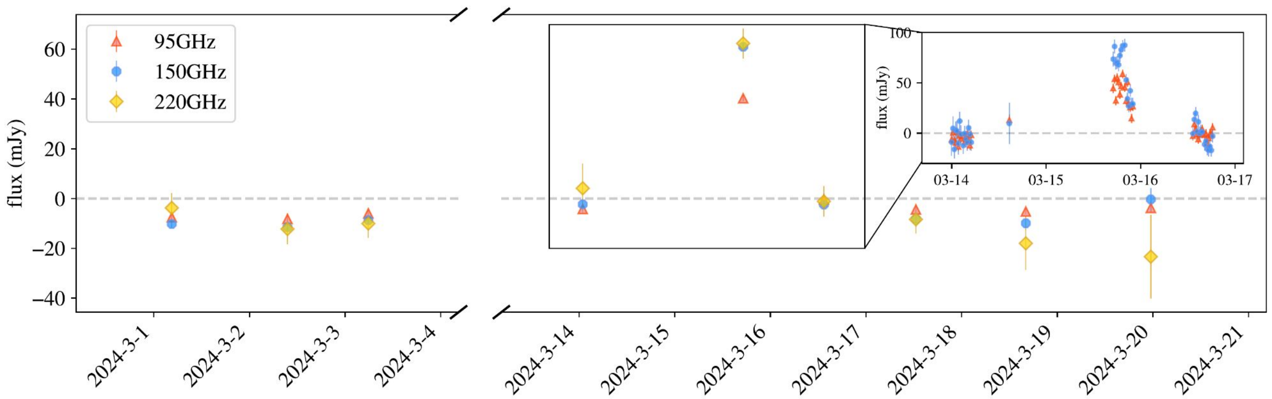
We have found at least **two transients** during 500 hours of observations in 2023 and 2024 in the Galactic Plane with SPT-3G!

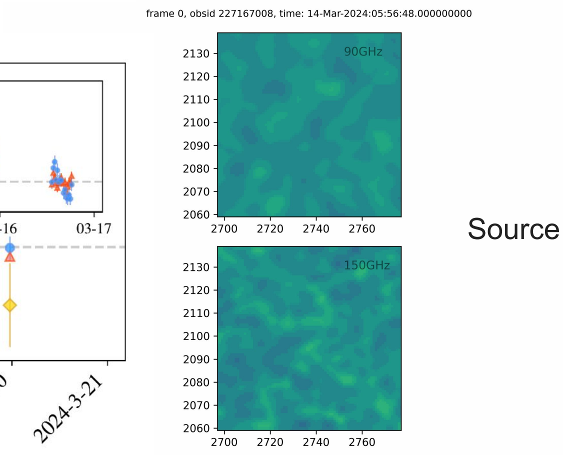
SPT lightcurves and thumbnails





Source 1

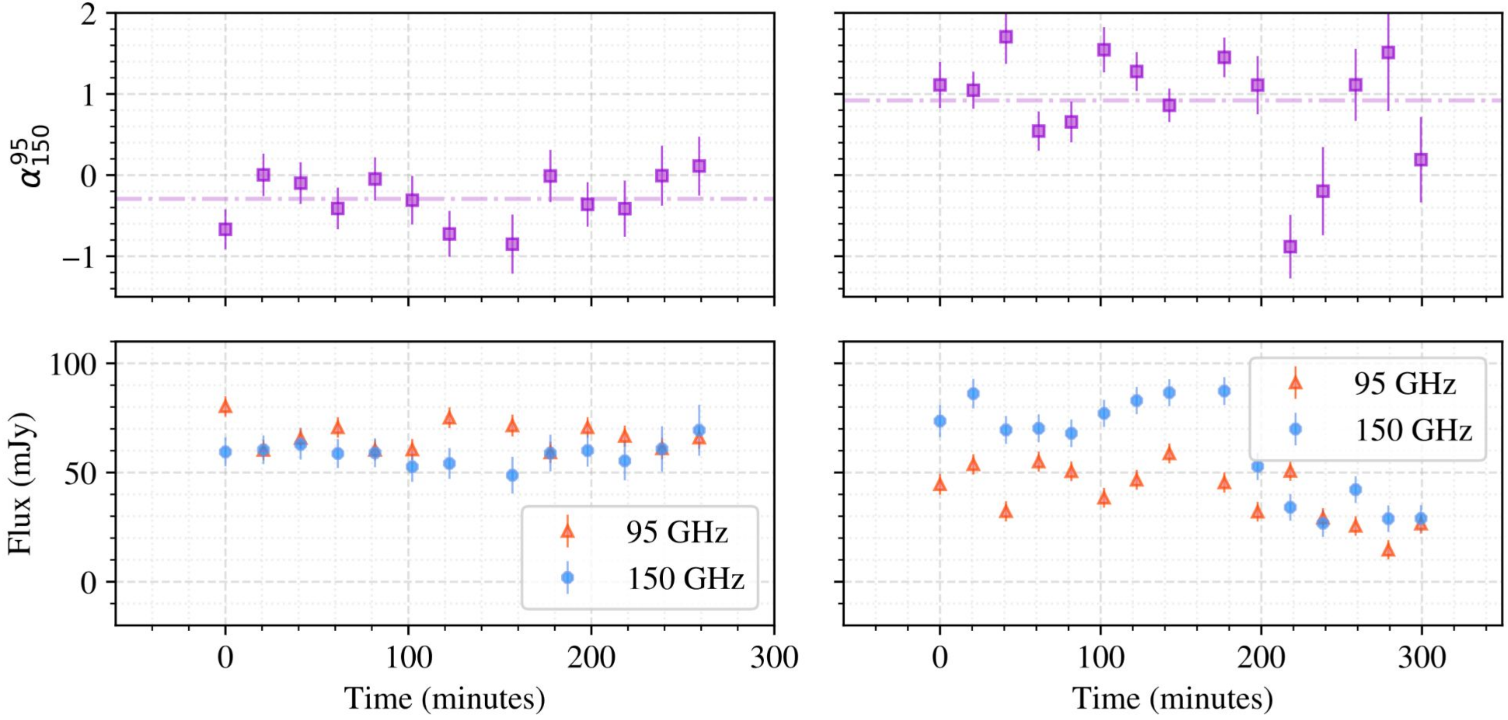




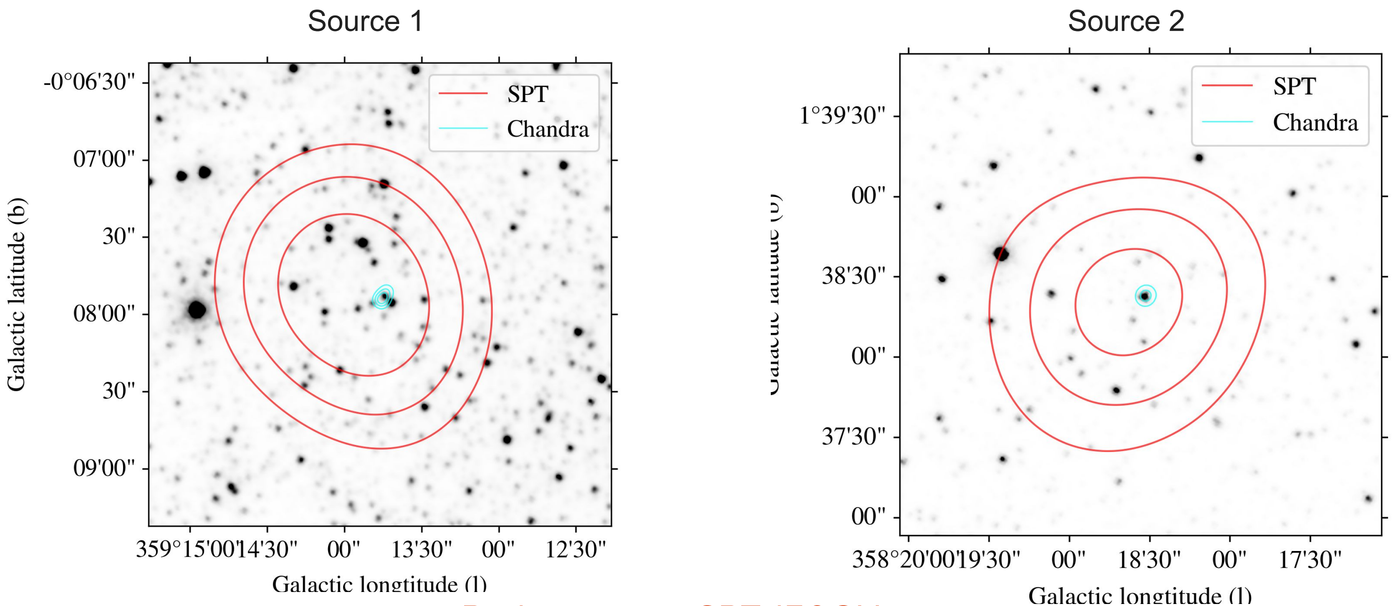
Source 2

Spectral index by observations

Source 1	Source 2
$\alpha_{150}^{90} = -0.293 \pm 0.037$	$\alpha_{150}^{90} = 0.921 \pm 0.034$
$\alpha_{220}^{150} = -1.042 \pm 0.257$	$\alpha_{220}^{150} = 0.054 \pm 0.116$
Falling spectrum	Rising to flat spectrum



Crossmatch with other surveys



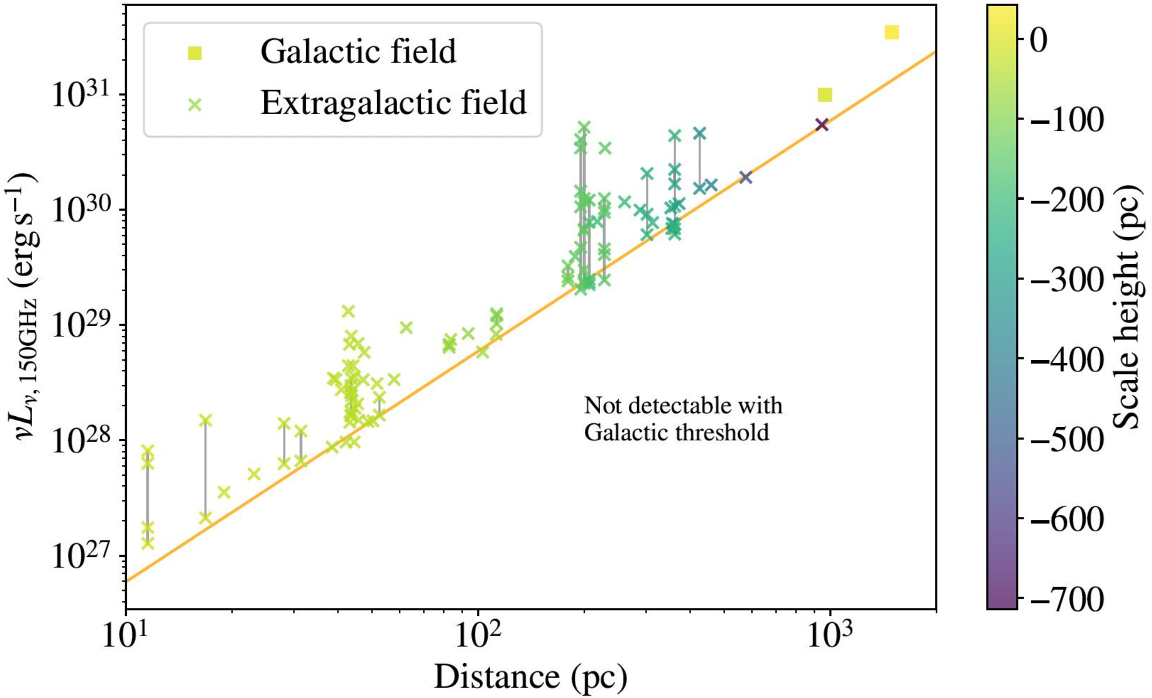
Red contours: SPT 150GHz

Blue contours: *Chandra*/ACIS(0.2-7.0keV)

Grayscale image: Spitzer/IRAC(3.6um)

- We found counterparts in other surveys, such as *Chandra*, *Gaia*, 2MASS, and etc
- Both sources are accreting white dwarfs – source 1 has a subgiant companion and source 2 has a giant companion.

Comparison with previous results



We find sources that are further away and have higher luminosities with the SPT-3G Galactic Plane Survey compared to main field survey.

Interpretation

- The emission mechanism for the mm flares is likely partially self-absorbed synchrotron emission.
- The flare likely originates from the accretion disks. (Hayashi et al. 1996) (i.e. if the flare comes from the stars, we would expect more detections with RS CVn systems.)

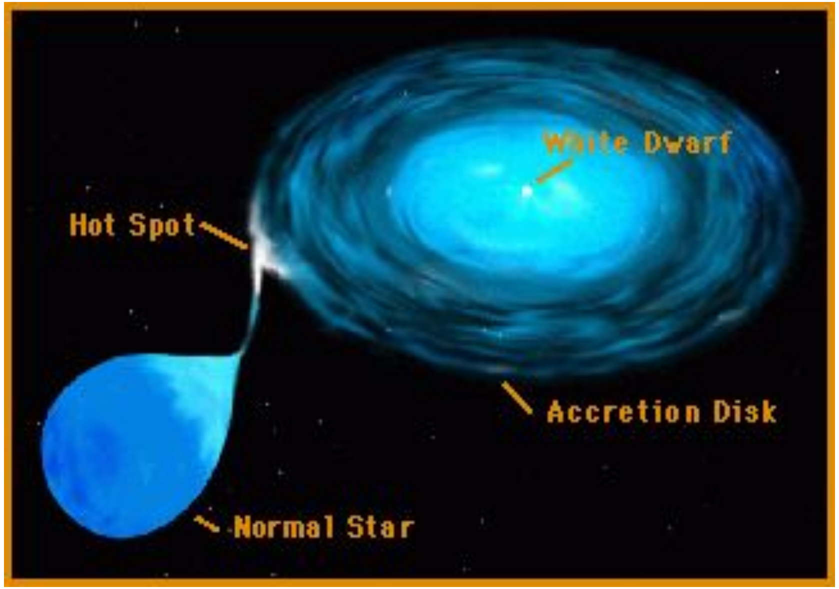


Image credit: NASA

Future

- This is the first results from the SPT-3G Galactic Plane Survey with high snr threshold (5 sigma at 90 and 150GHz bands simultaneously). We plan to:
    - Lower the snr threshold to 3 sigma
    - Enable single band detection
    - Increase the time resolution by investigating single-scan lightcurves.
    - Incorporating new data after 2024.
- Future surveys such as CMB-S4 and SO will cover the Galactic Plane so this study can serve as a pathfinder.

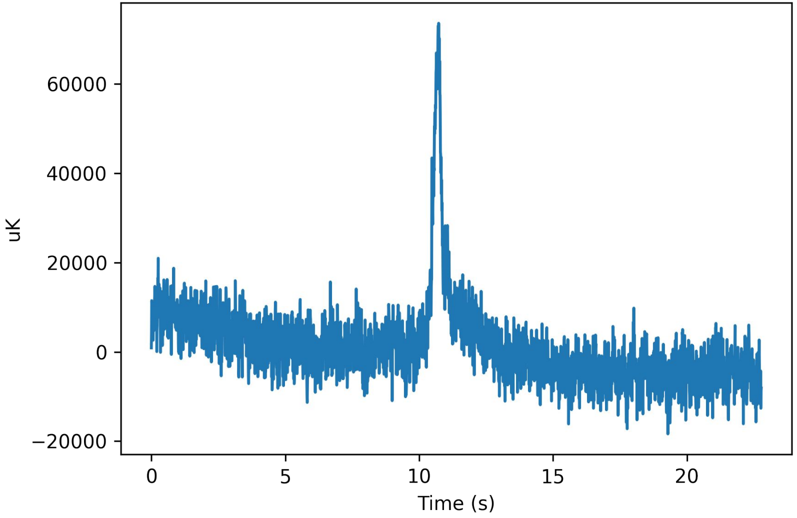
Conclusion

- We conduct the SPT-3G Galactic Plane survey:
  - The survey field is ~100 deg^2 towards the Galactic Plane
  - We observe the field for roughly one month per year since 2023
  - We have ~500 observations in 2023 and 2024
- We have found two transient events so far:
  - Both events have timescales of approximately one day
  - They are not detected in the coadded map.
  - Both are associated with accreting white dwarfs
  - The mm flares likely originate from self-absorbed synchrotron emission
- **Paper in collaboration review and coming soon!!**

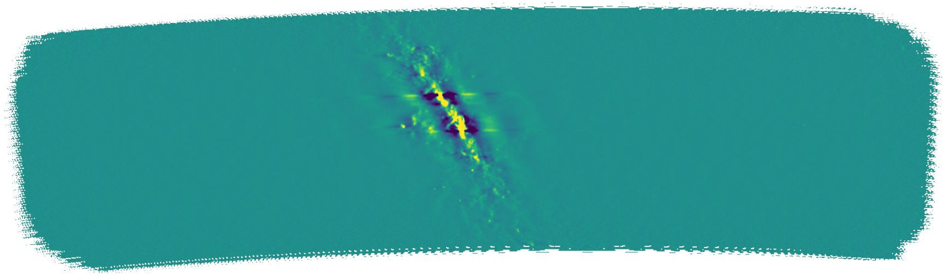
Back up slides

Mapmaking pipeline

- Mapmaking pipeline converts time-ordered data to maps



Time-ordered data for a single detector in a single scan for a single observation

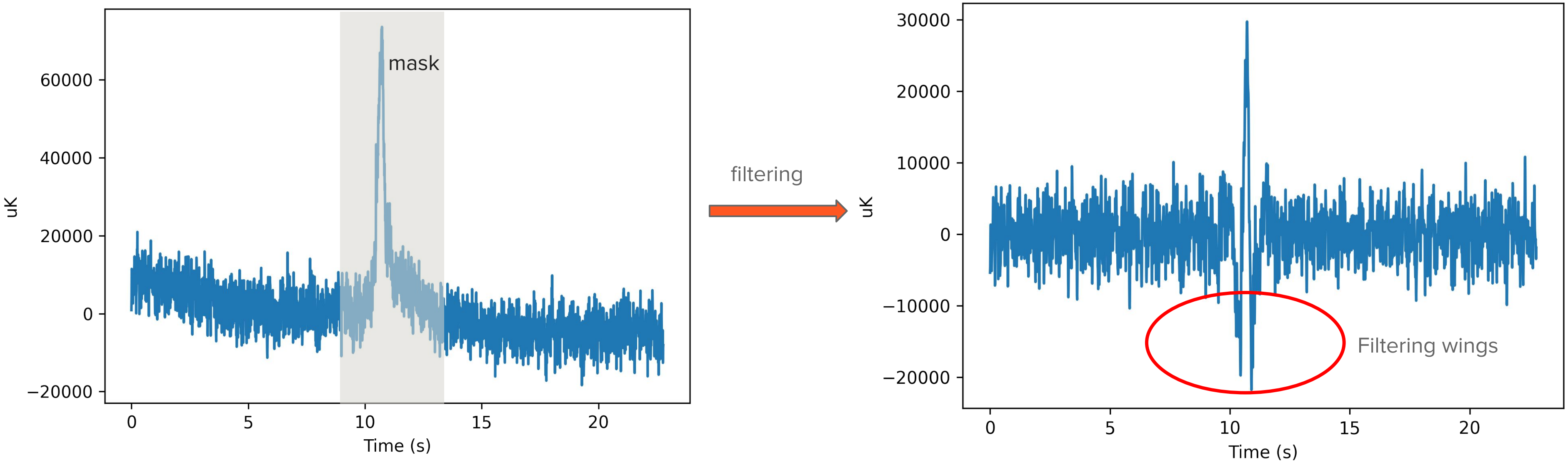


Individual observation map

Mapmaking pipeline

Many filtering steps are applied on TODs to reduce noise:

- Common mode filter: atmosphere (with mask)
- Polynomial filter: atmosphere, 1/f noise (with mask)
- High pass filter: atmosphere (without mask)
- Low pass filter: noise on scale smaller than the pixel size (without mask)

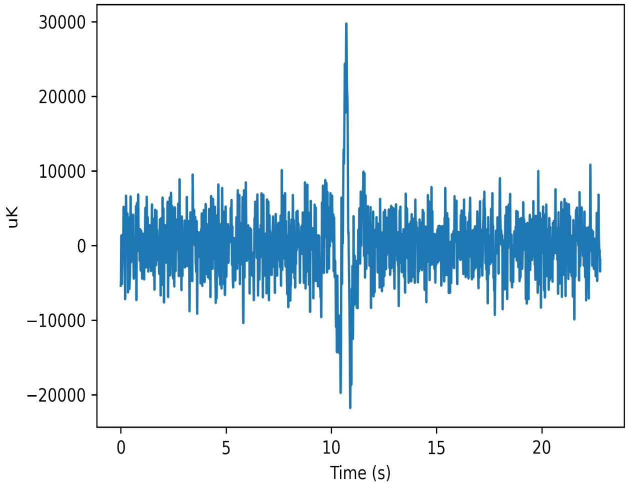


TOD

Filtered TOD

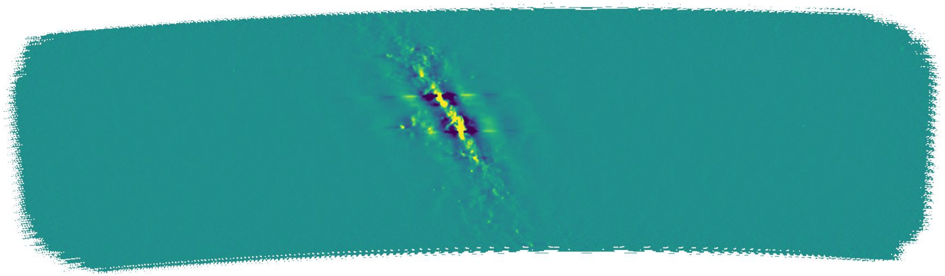
Mapmaking pipeline

- We then weight and bin the TODs from all the detectors in all the scans in one observation to form the individual observation map.



Filtered TOD

binning

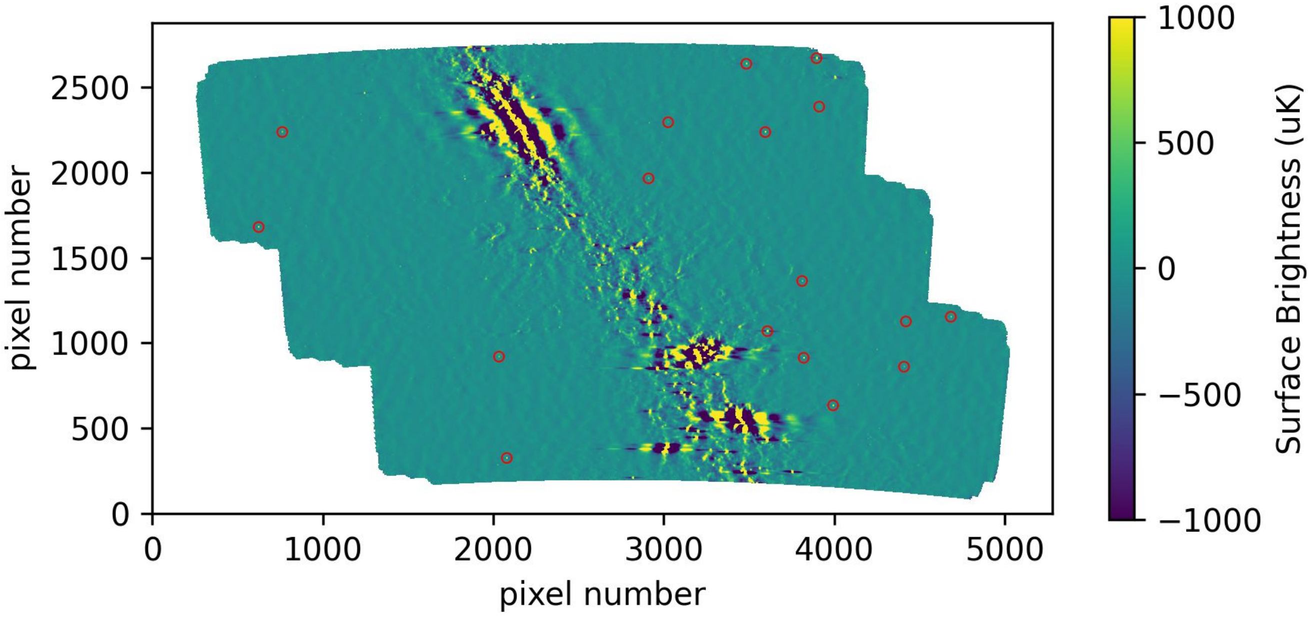


Individual observation map

Pointing Correction

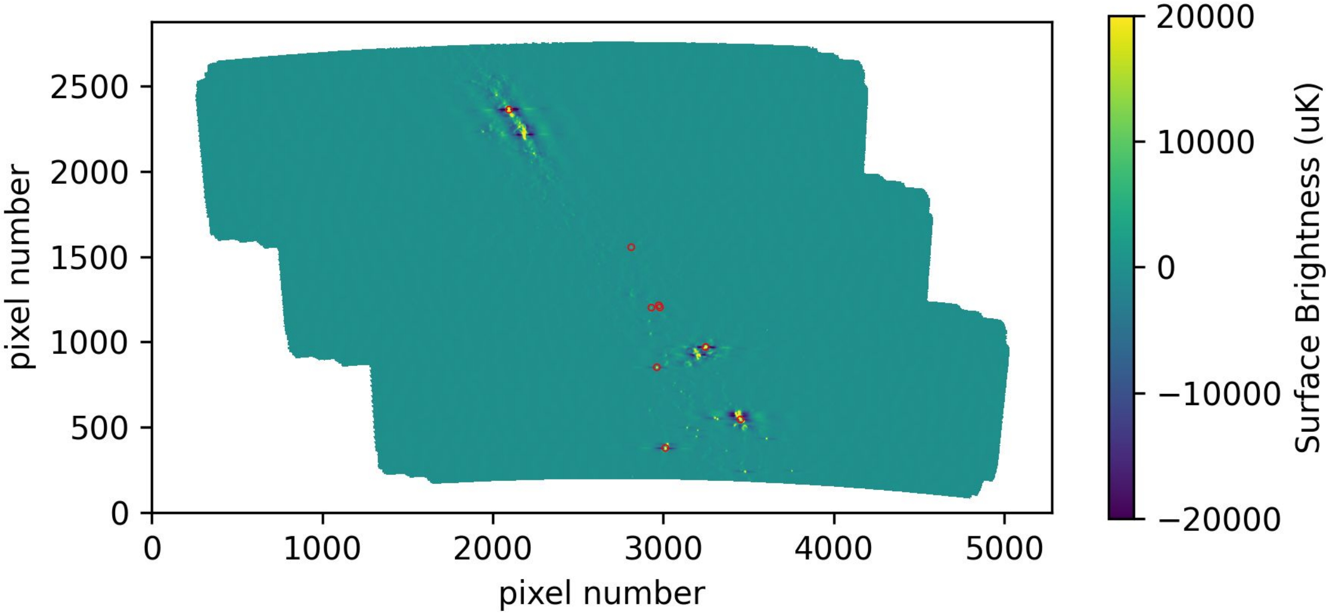
- We apply online pointing correction during mapmaking pipeline, which corrects pointing to ~10 arcseconds.

- We apply offline pointing correction using Australia Telescope 20GHz Survey (AT20G) catalog, which brings us to pointing precision of a few arcseconds.

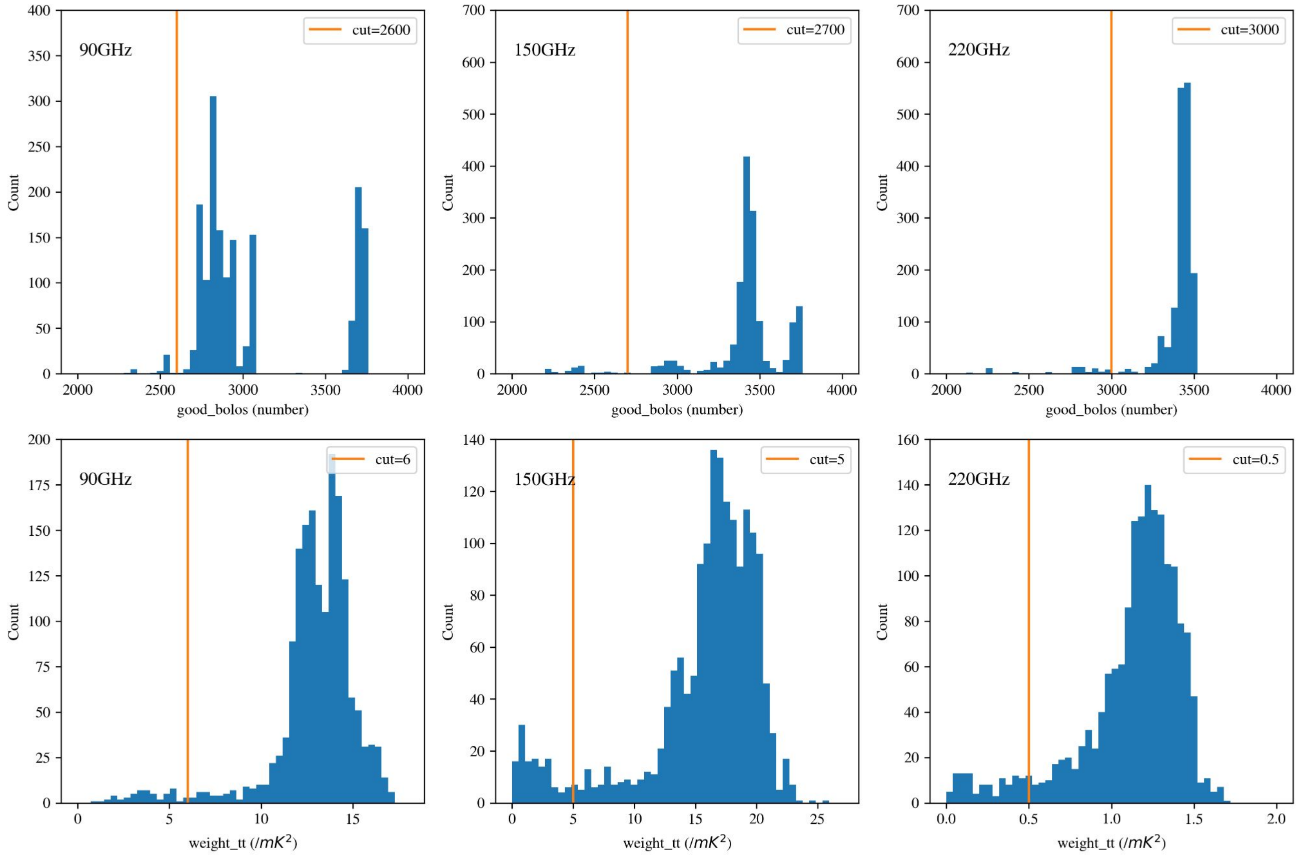


Gain calibration

- In each subfield, we pick several static point sources as reference.
- For the top subfield, we only use Sgr B2 as reference because we know it is very stable in mm wavelength.

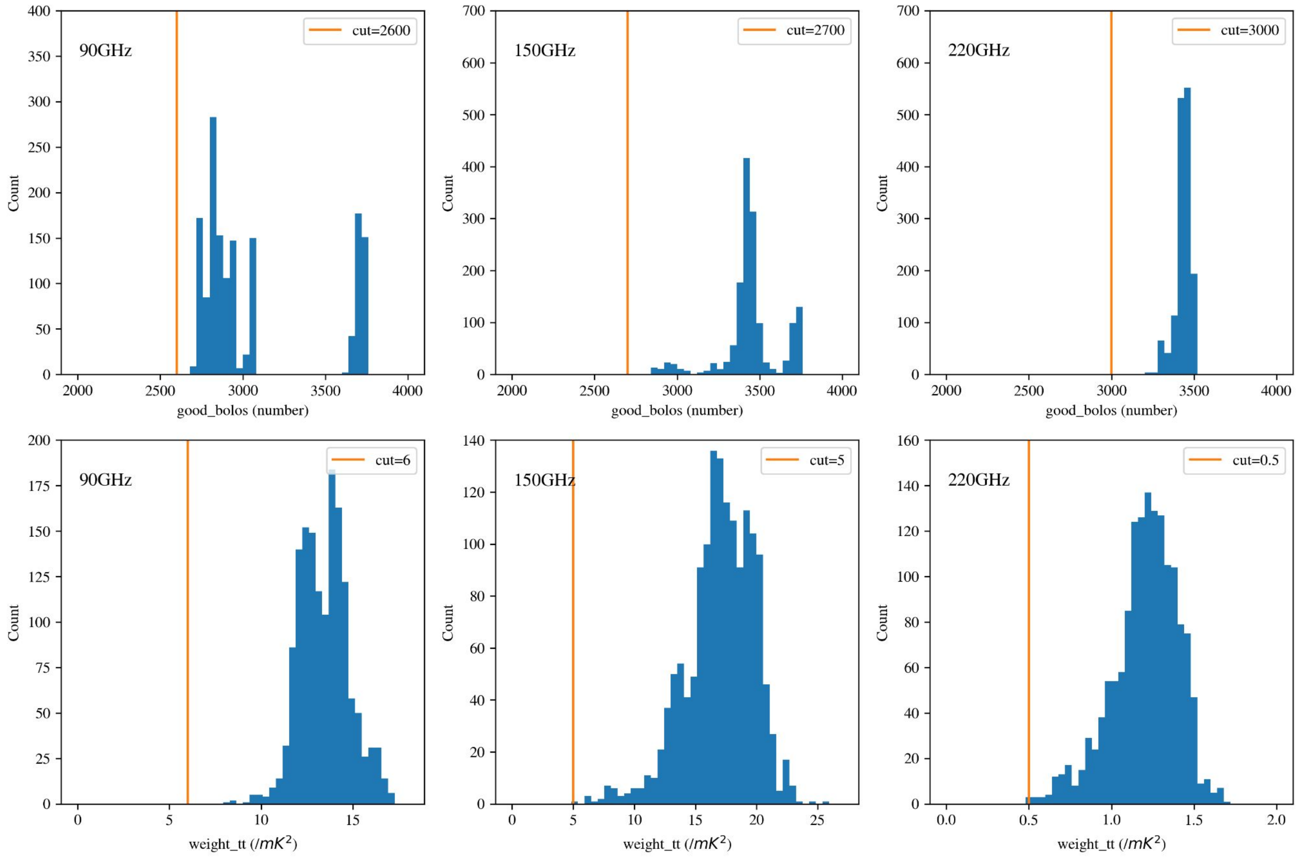


Map cuts



- We want to exclude low-quality maps for transient analysis.
- **Good_bolos**: The number of functioning bolometers (detectors) during the observation.
- **Weight_tt**: The weight of the temperature map.

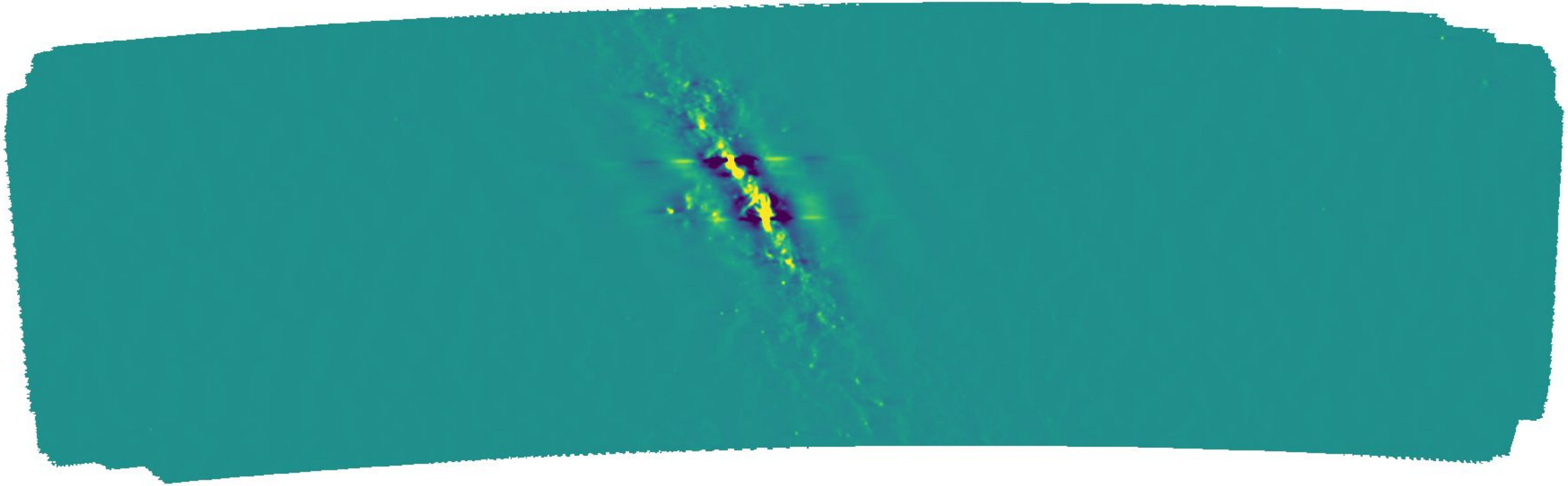
Map cuts



- We want to exclude low-quality maps for transient analysis.
- **Good_bolos**: The number of functioning bolometers (detectors) during the observation.
- **Weight_tt**: The weight of the temperature map.
- Cut 186 maps from a total of 1692 maps, leaving 1506 maps in the analysis.

Average map

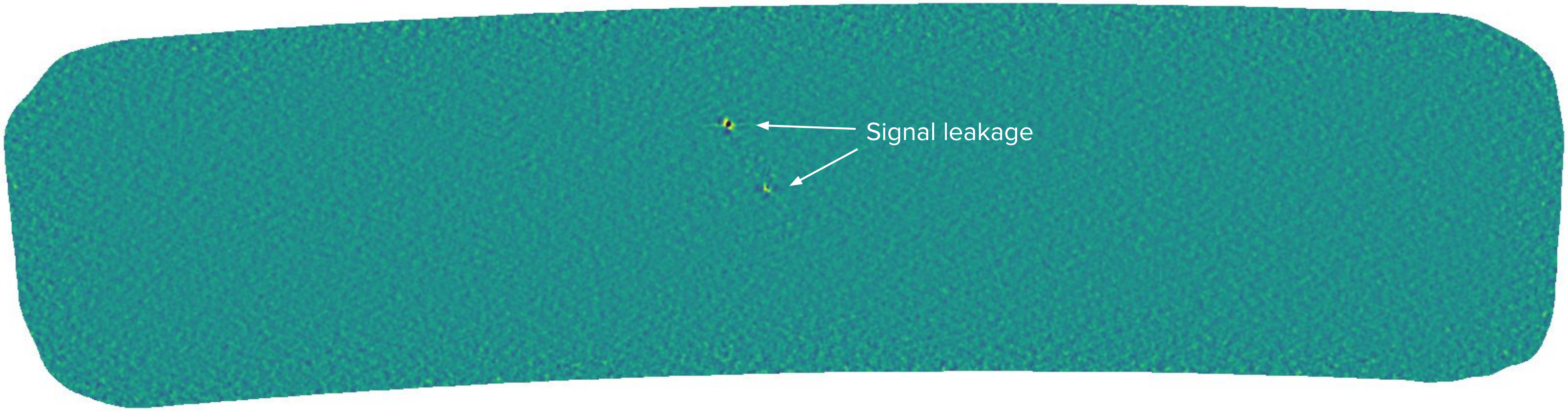
- We then calculate a weighted average for all the remaining individual maps.



Average map for the top subfield

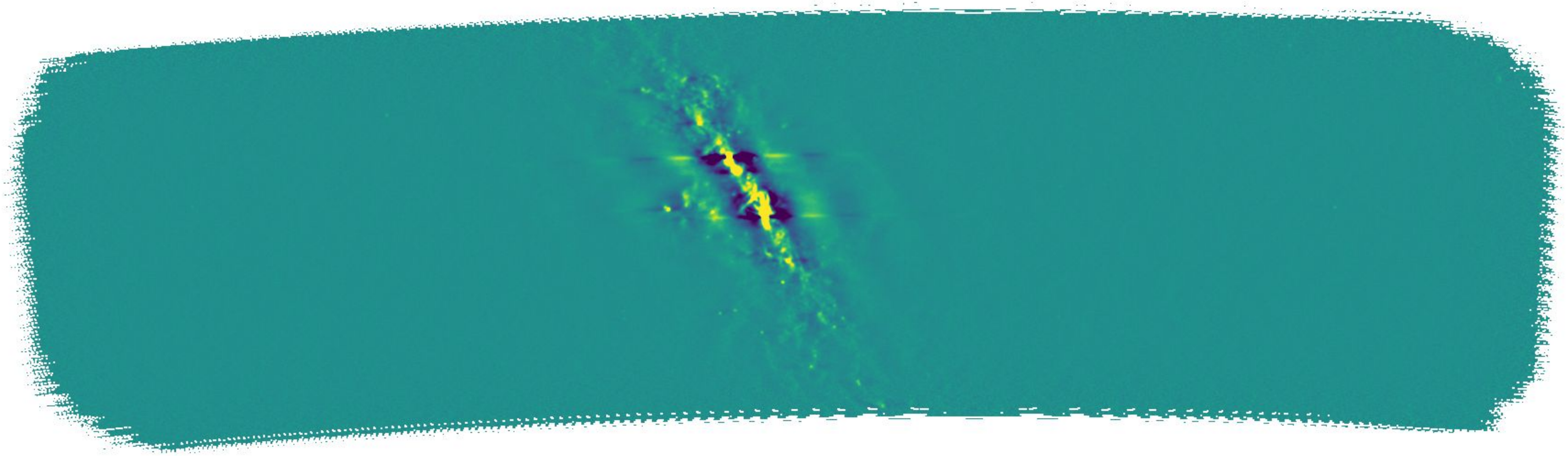
Difference maps

- Difference map is made by subtracting the average map from the individual map.
- Differencing removes CMB background and bright point sources.
- We then apply a convolutional filter to maximize sensitivity to point sources.



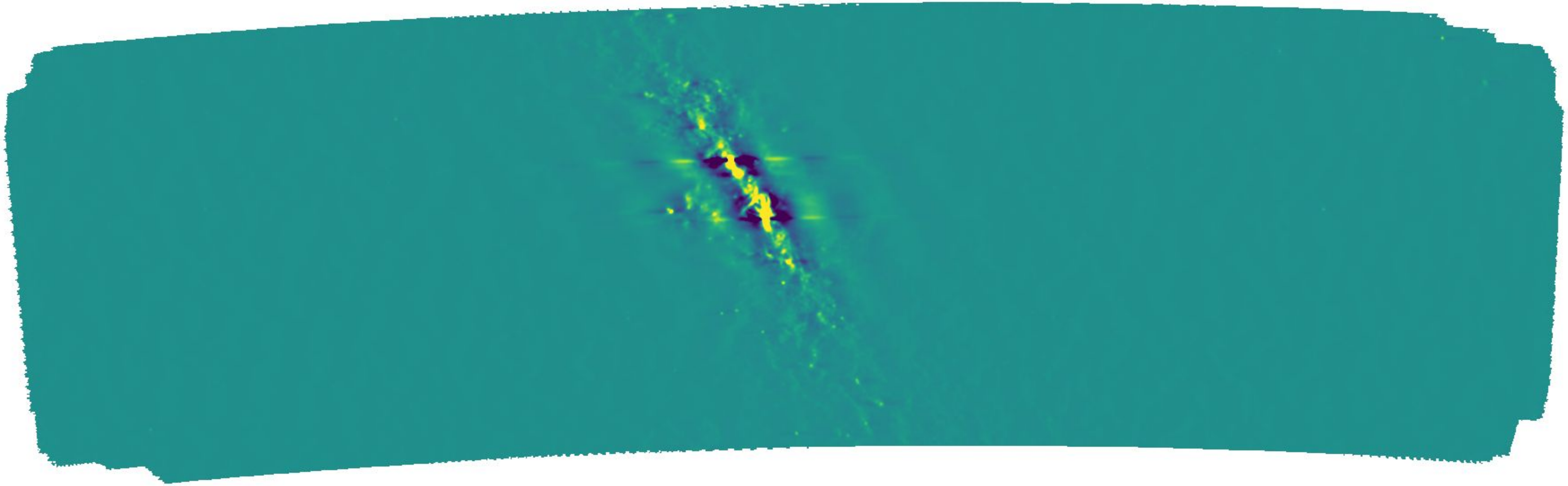
Example of a difference map for one observation

Summary



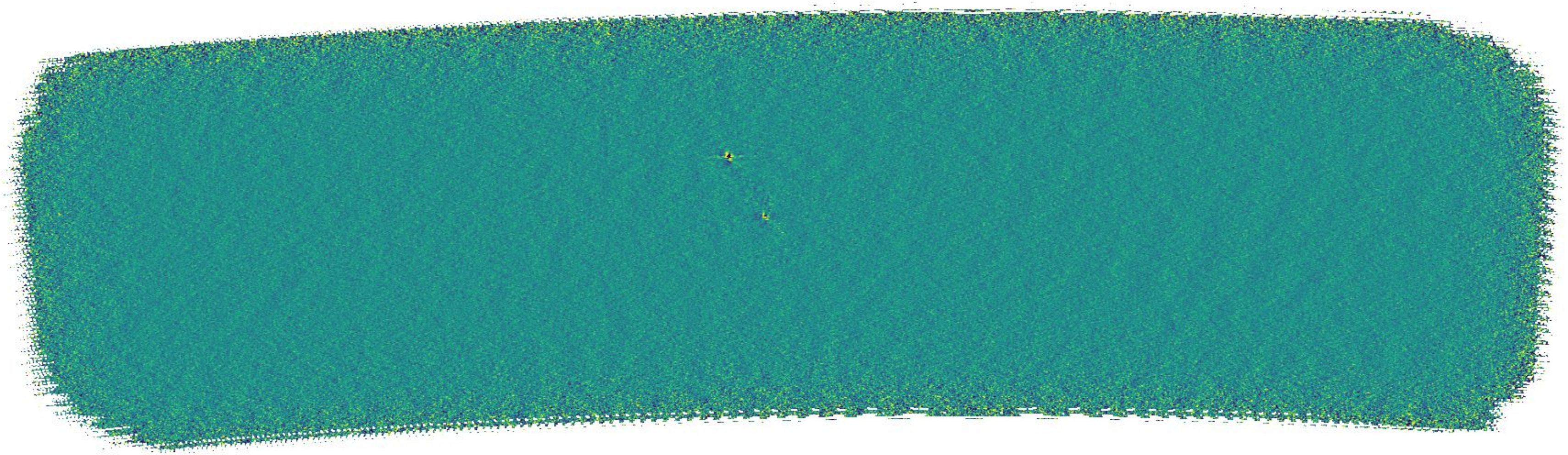
- Generate individual observation map using the mapmaking pipeline

Summary



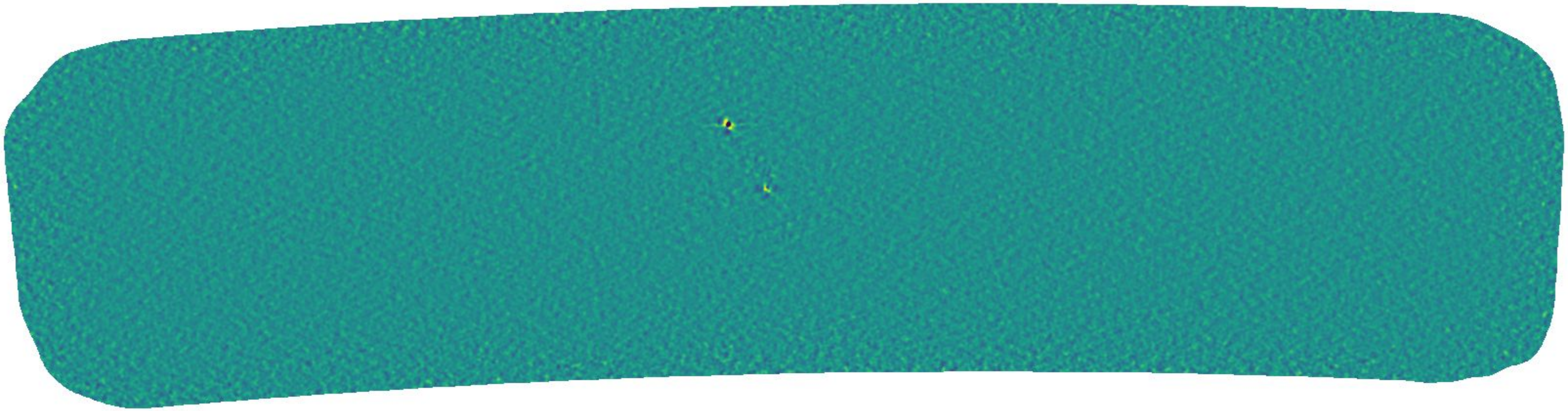
- Generate individual observation map using the mapmaking pipeline
- Make coadded map from all the observations

Summary



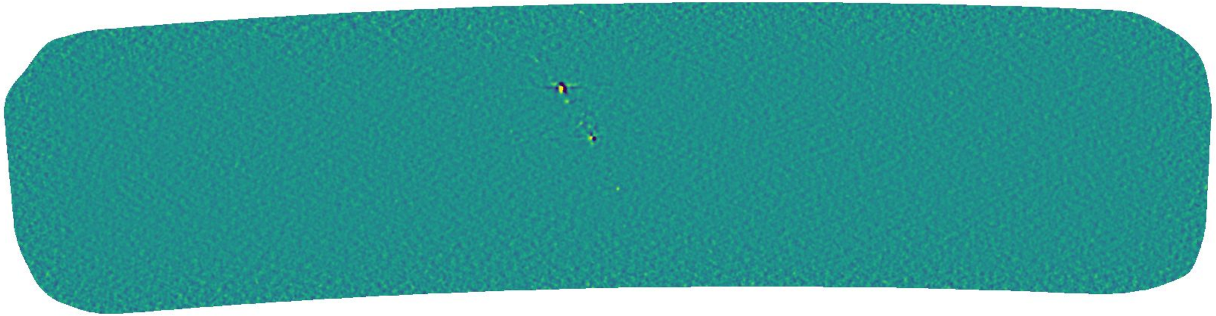
- Generate individual observation map using the mapmaking pipeline
- Make coadded map from all the observations
- Generate difference map by subtracting coadded map from each observation map

Summary



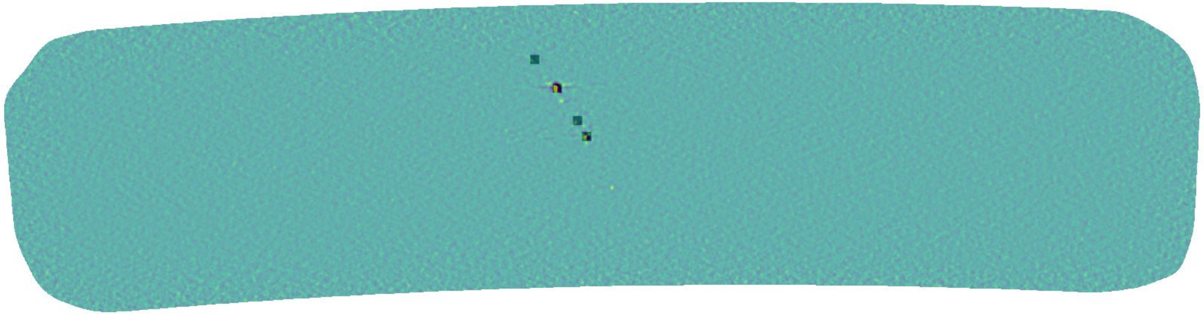
- Generate individual observation map using the mapmaking pipeline
- Make coadded map from all the observations
- Generate difference map by subtracting coadded map from each observation map
- Transient filter the difference map

Transient detection Pipeline



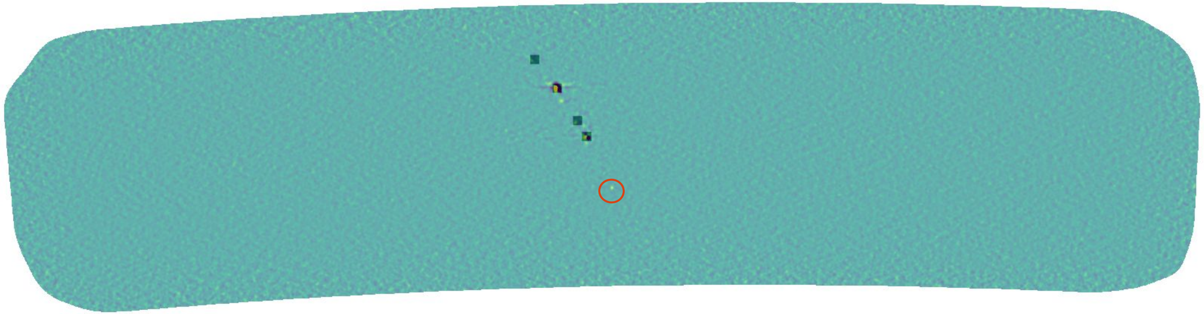
- Run through all difference maps in the same subfield in each year

Transient detection Pipeline



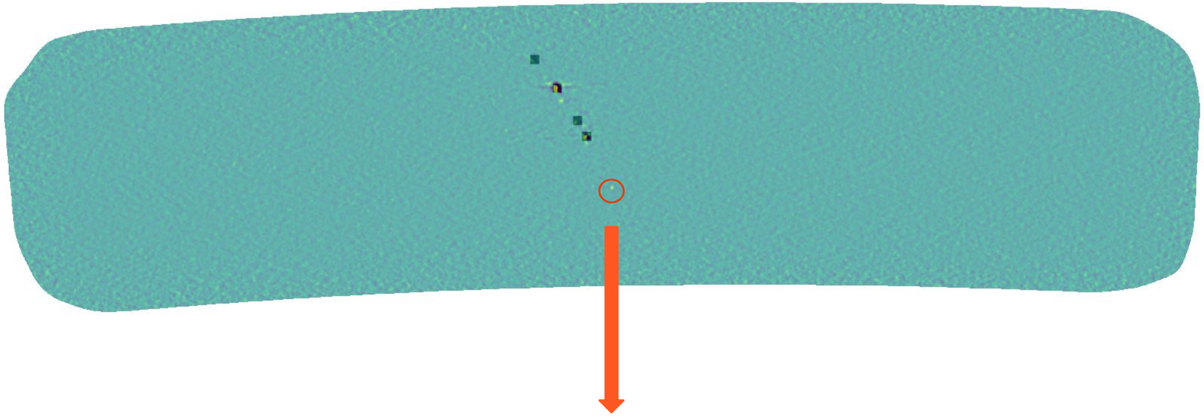
- Run through all difference maps in the same subfield in each year
- Mask bright sources

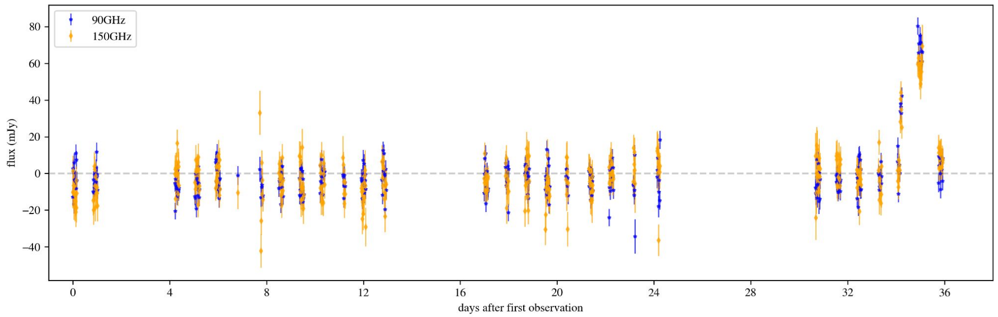
Transient detection Pipeline



- Run through all difference maps in the same subfield in each year
- Mask bright sources
- Find outlier pixels (5 sigmas in both 90 and 150GHz simultaneous in one observation)

Transient detection Pipeline





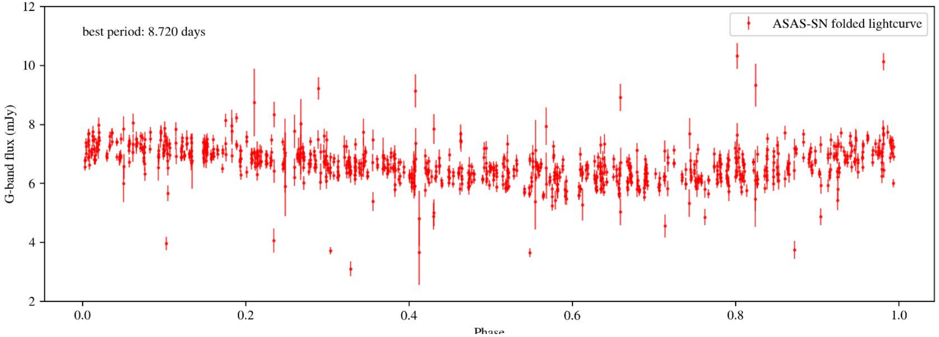
- Run through all difference maps in the same subfield in each year
- Mask bright sources
- Find outlier pixels (5 sigmas in both 90 and 150GHz simultaneous in one observation)
- Extract lightcurve for outlier pixels

Source 1

The *Swift* Bulge Survey: optical and near-IR follow-up featuring a likely symbiotic X-ray binary and a focused wind CV

A. W. Shaw,[1,2★] C. O. Heinke,[1] T. J. Maccarone,[3] G. R. Sivakoff,[1] J. Strader,[4] A. Bahramian,[5] N. Degenaar,[6] J. A. Kennea,[7] E. Kuulkers,[8] A. Rau,[9] L. E. Rivera Sandoval,[3] L. Shishkovsky,[4] S. J. Swihart,[4] A. J. Tetarenko,[10] R. Wijnands[6] and J. J. M. in 't Zand[11]

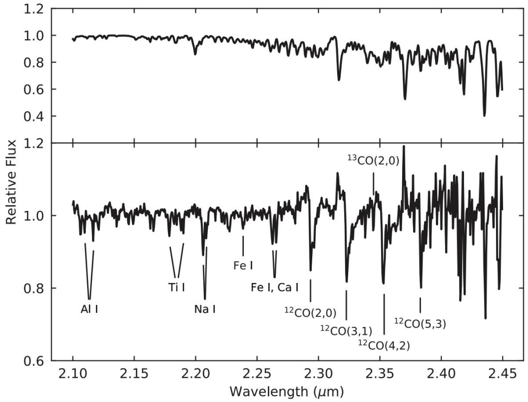
ASAS-SN folded lightcurve



5.4 3XMM J174417.2–293944: A white dwarf binary with a subgiant companion

- The spectrum suggests that the donor star might be a subgiant (class IV).
- The spectrum also suggests that the primary star is probably a white dwarf accretor.

VLT/SINFONI spectra

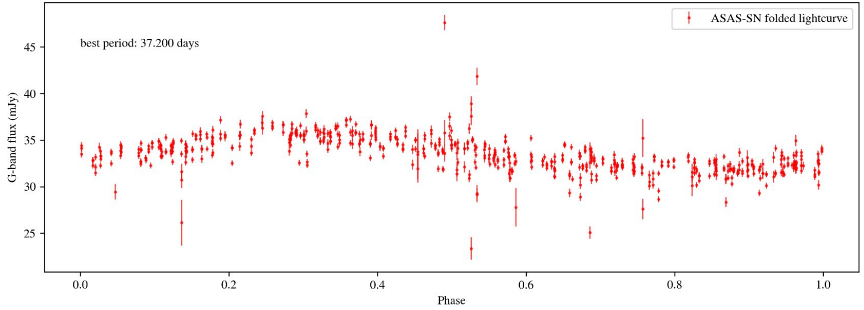


Source 2

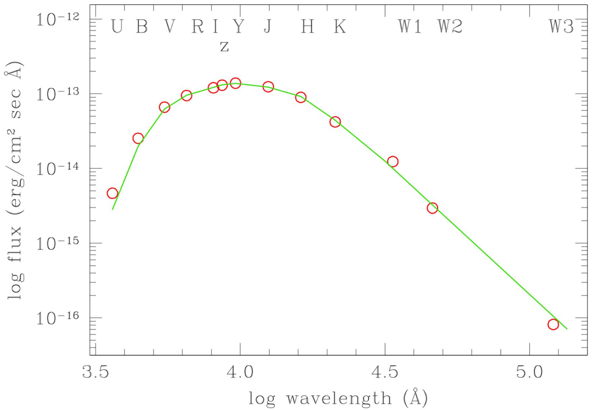
Photometry and spectroscopy of the new symbiotic star 2SXPS J173508.4-292958

U. Munari[1], P. Valisa[2], A. Vagnozzi[2], S. Dallaporta[2], F -J. Hambsch[2] and A. Frigo[2]

ASAS-SN folded lightcurve



SED fitting



- The energy distribution matches well with a K4III star.
- Emission in Halpha and excess in U band probably suggest direct emission from the accretion disk.
- The conclusion is that this source is a symbiotic star (white dwarf with a giant).