Time-Domain Science in the Era of the Simons Observatory

mm-Universe
June 26th 2025

Allen Foster

PC: Nicholas Galitzki

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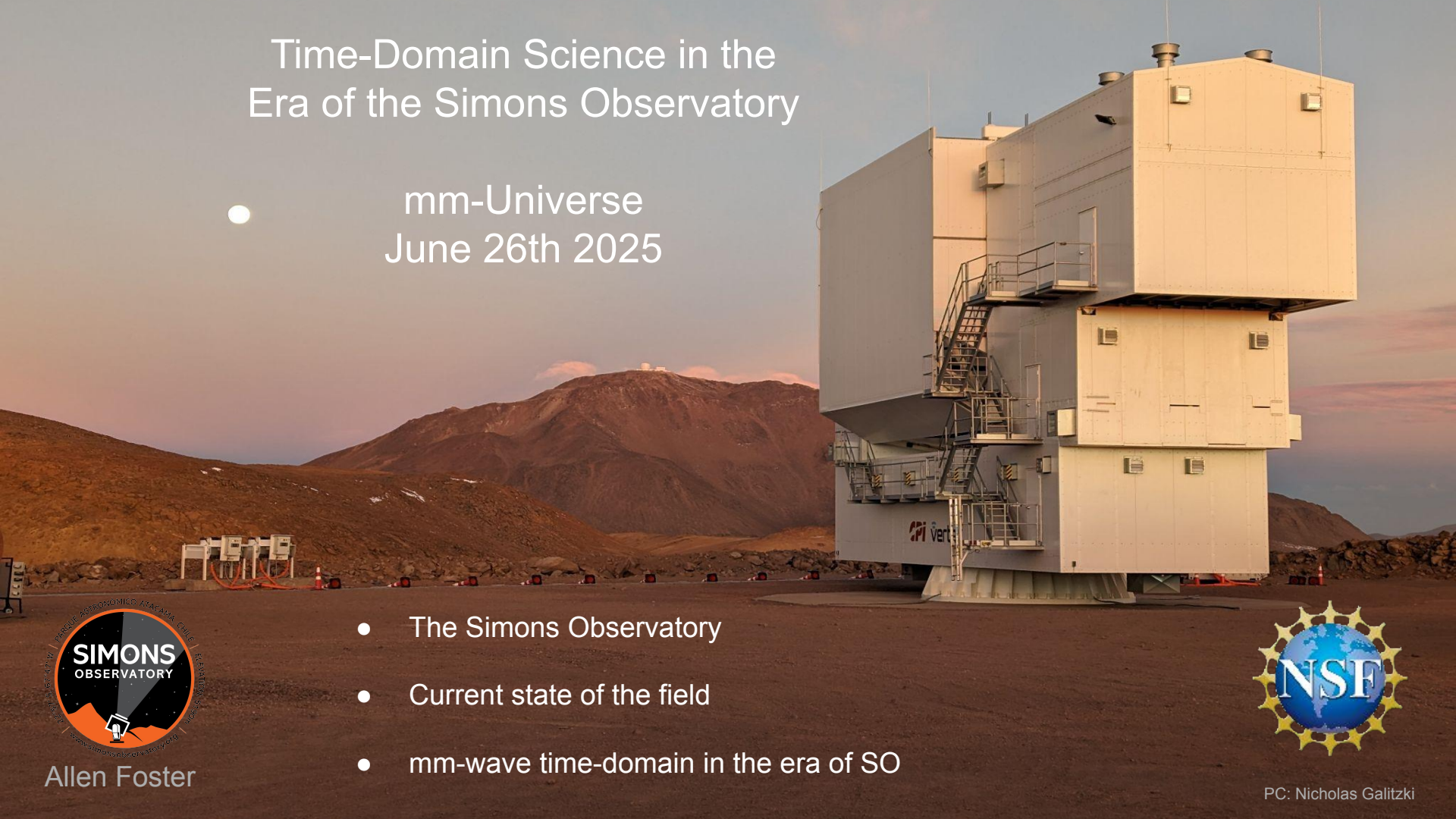


- The Simons Observatory
- Current state of the field
- mm-wave time-domain in the era of SO

Allen Foster

PC: Nicholas Galitzki

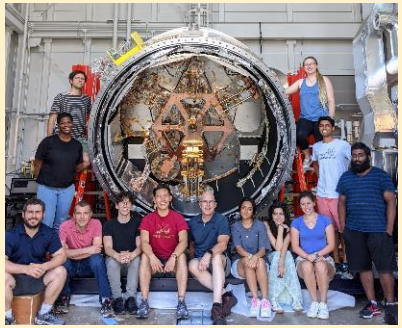
Time Domain Astrophysics

Tidal Disruption Events

Stellar Flares

Variable AGN

Training the Next Generation



Extragalactic Astronomy

Missing Baryons

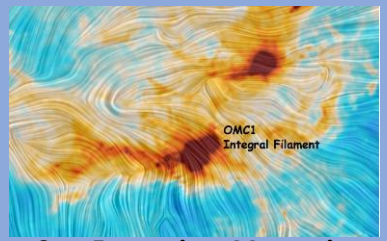
Sources

Galaxy Clusters

SIMONS OBSERVATORY

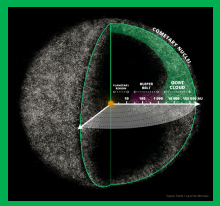
Galactic Astronomy

Interstellar Dust



Star Formation, Magnetic Fields and Turbulence

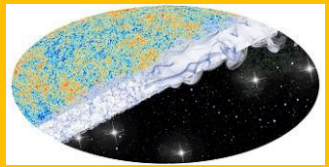
Planetary Science



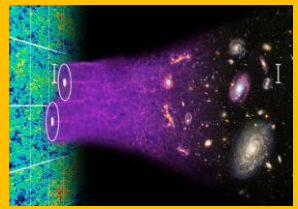
Exo-Oort Clouds

Planet 9

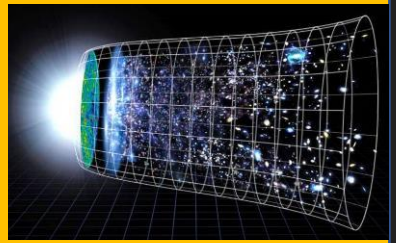
Cosmology and Particle Physics



H_0 Tension and New Physics



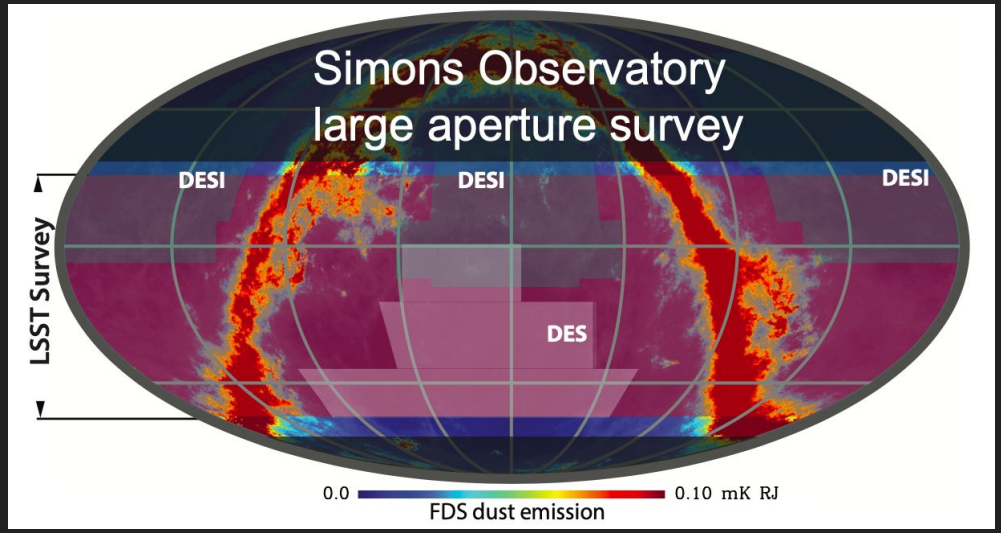
Light Relics and Neutrinos

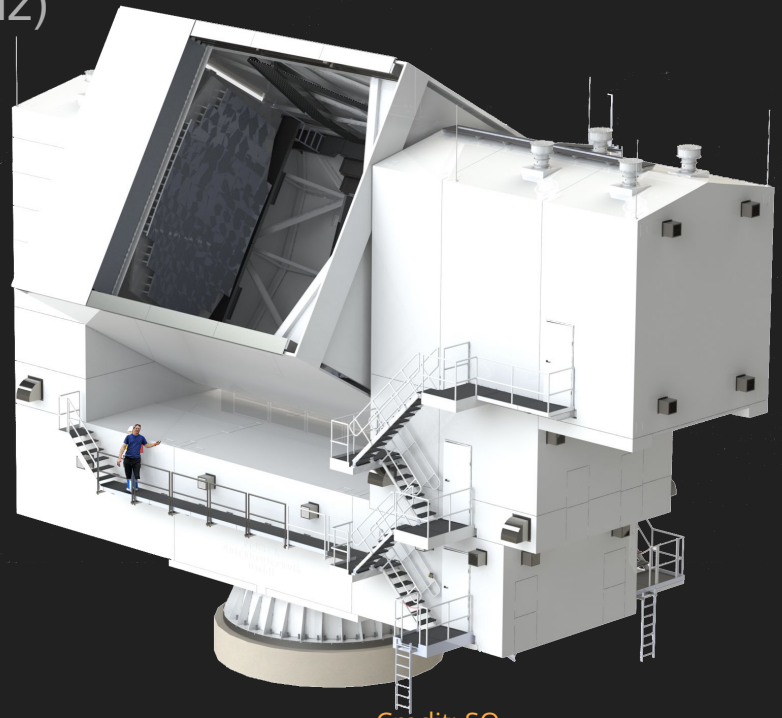


The Evolution of the Universe Over Cosmic Time

Observatory Telescopes (LAT)

Survey ~50% of the sky on a ~daily cadence.
6 frequency bands ([27/34,] 93/145, 225/280 GHz)





Credit: SO

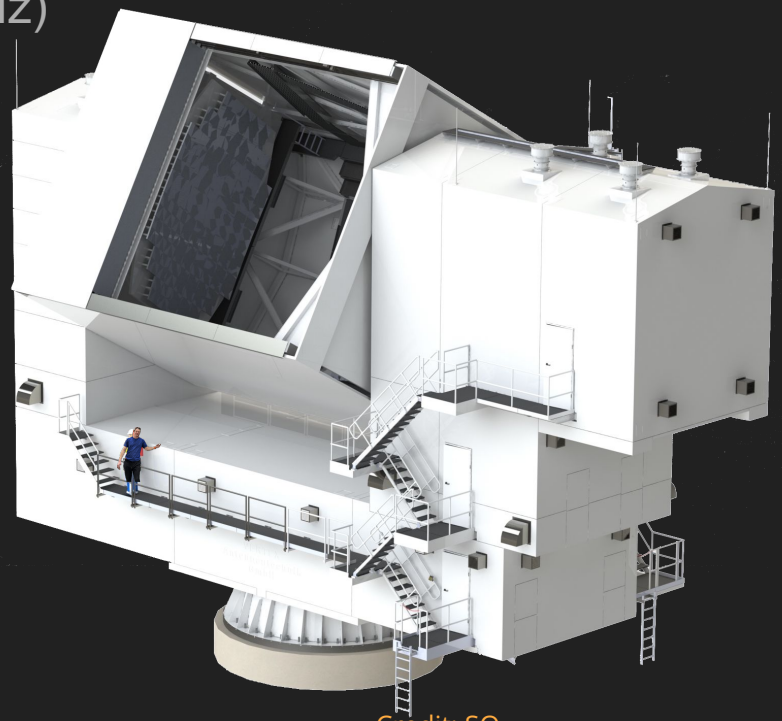
Observatory Telescopes (LAT)

Survey ~50% of the sky on a ~daily cadence.
6 frequency bands ([27/34,] 93/145, 225/280 GHz)

Target daily sensitivity:

27 mJy at 27 GHz
19 mJy at 39 GHz
7 mJy at 93 GHz
9 mJy at 145 GHz
17 mJy at 225 GHz
34 mJy at 280 GHz

Similar to SPT3G single obs



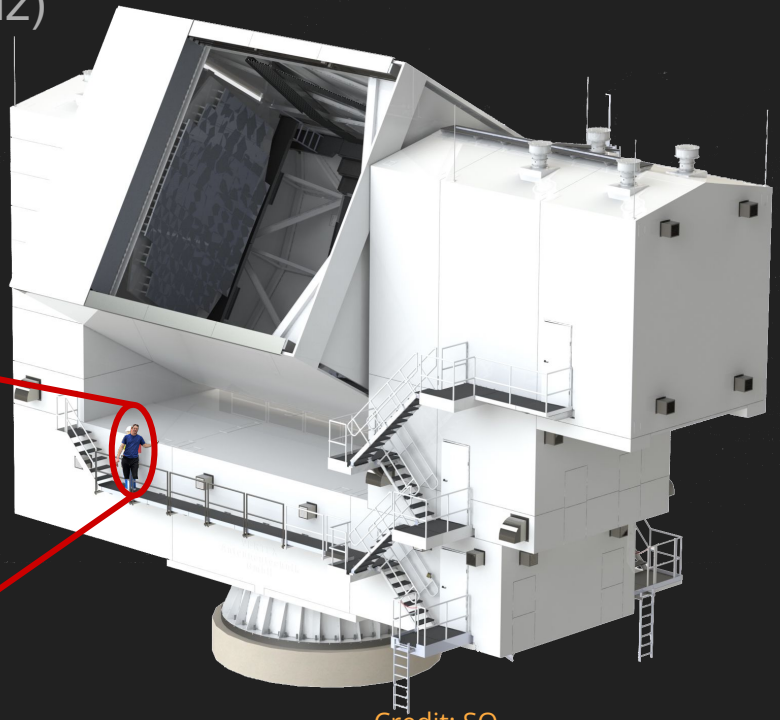
Credit: SO

Obs opes (LAT)

Surve ce.
6 frequ 30 GHz)

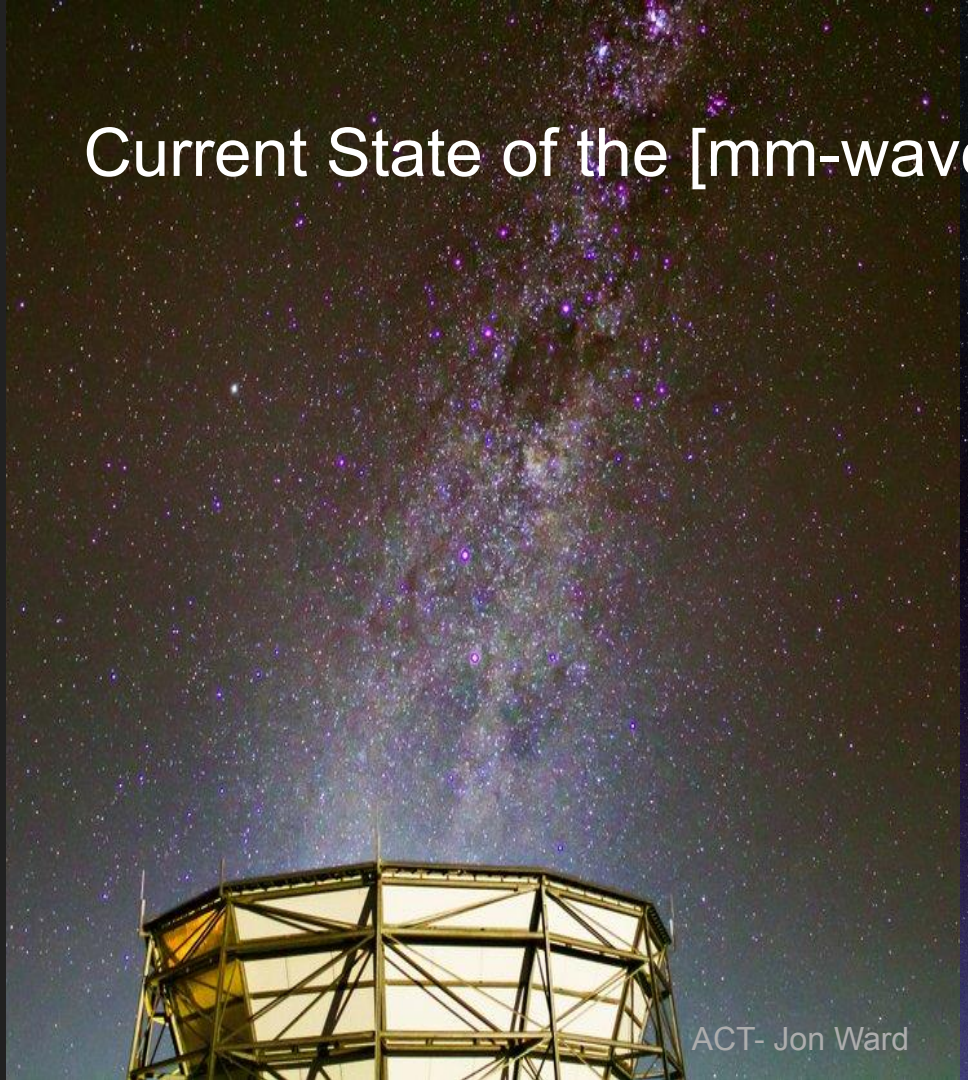
Target

27
19
7 T3G
9
17
34



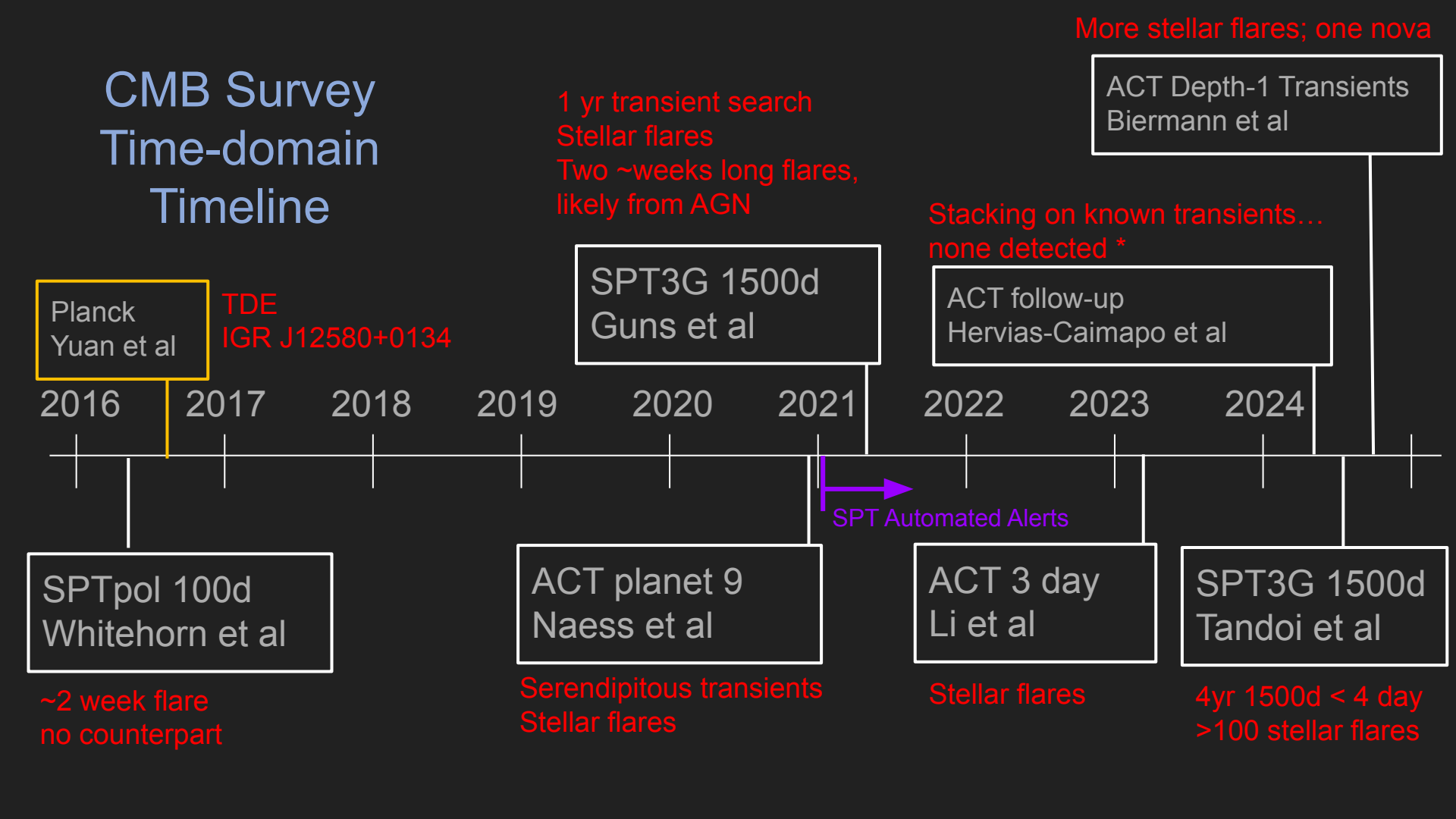
Credit: SO

Current State of the [mm-wave survey] Field



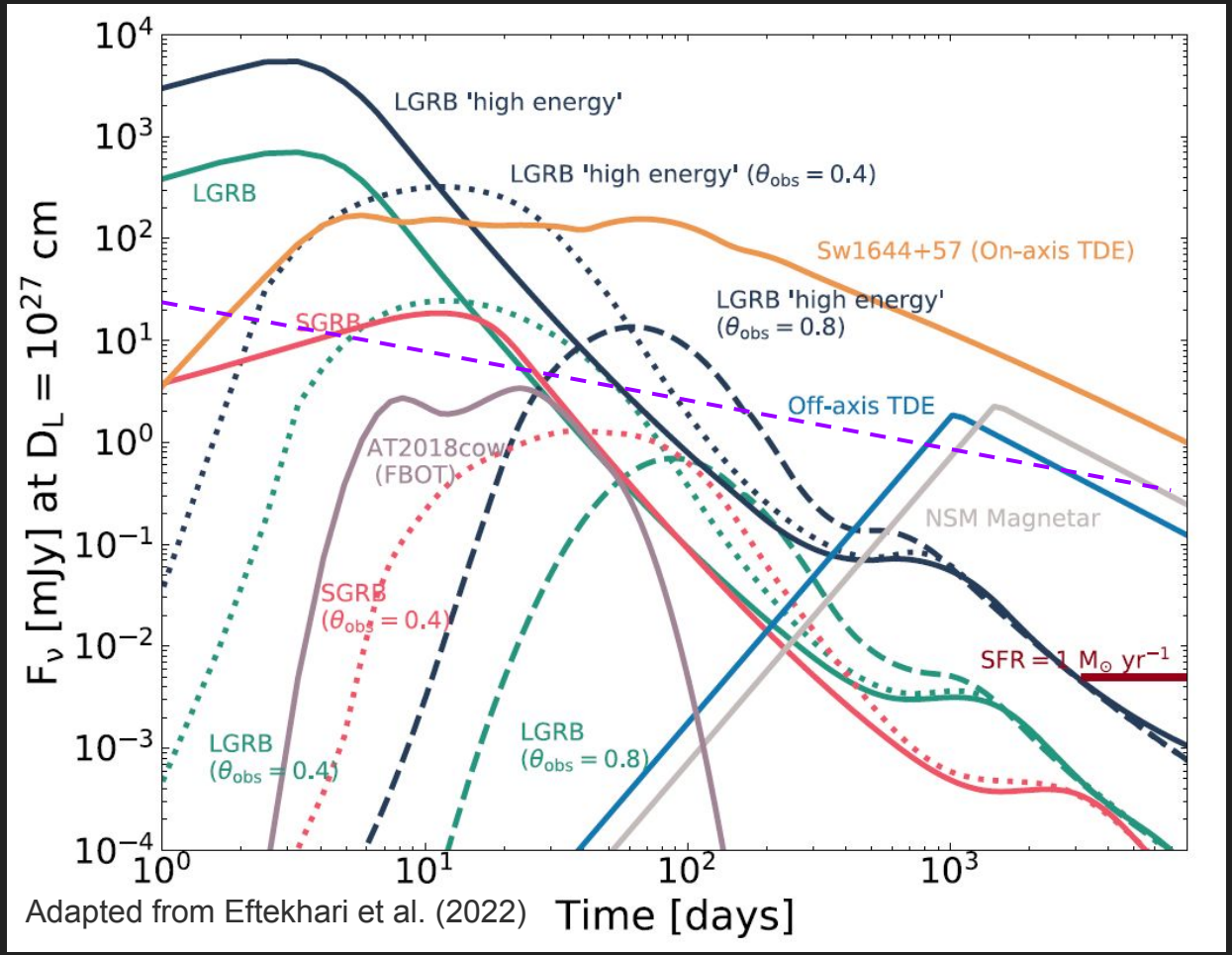
ACT- Jon Ward

SPT - Yuya Makino


CMB Survey
Time-domain
Timeline
More stellar flares; one nova
ACT Depth-1 Transients
Biermann et al
1 yr transient search
Stellar flares
Two ~weeks long flares,
likely from AGN
Stacking on known transients…
none detected *
SPT3G 1500d
Guns et al
ACT follow-up
Hervias-Caimapo et al
Planck
Yuan et al
TDE
IGR J12580+0134
2016
2017
2018
2019
2020
2021
2022
2023
2024
SPT Automated Alerts
SPTpol 100d
Whitehorn et al
~2 week flare
no counterpart
ACT planet 9
Naess et al
Serendipitous transients
Stellar flares
ACT 3 day
Li et al
Stellar flares
SPT3G 1500d
Tandoi et al
4yr 1500d < 4 day
>100 stellar flares

Of course, there have also been many targeted mm observations of transients discovered at other wavelengths as well.

In 2022, a nice review + prediction of millimeter transients in current and future CMB surveys was presented by Eftekhari et al.



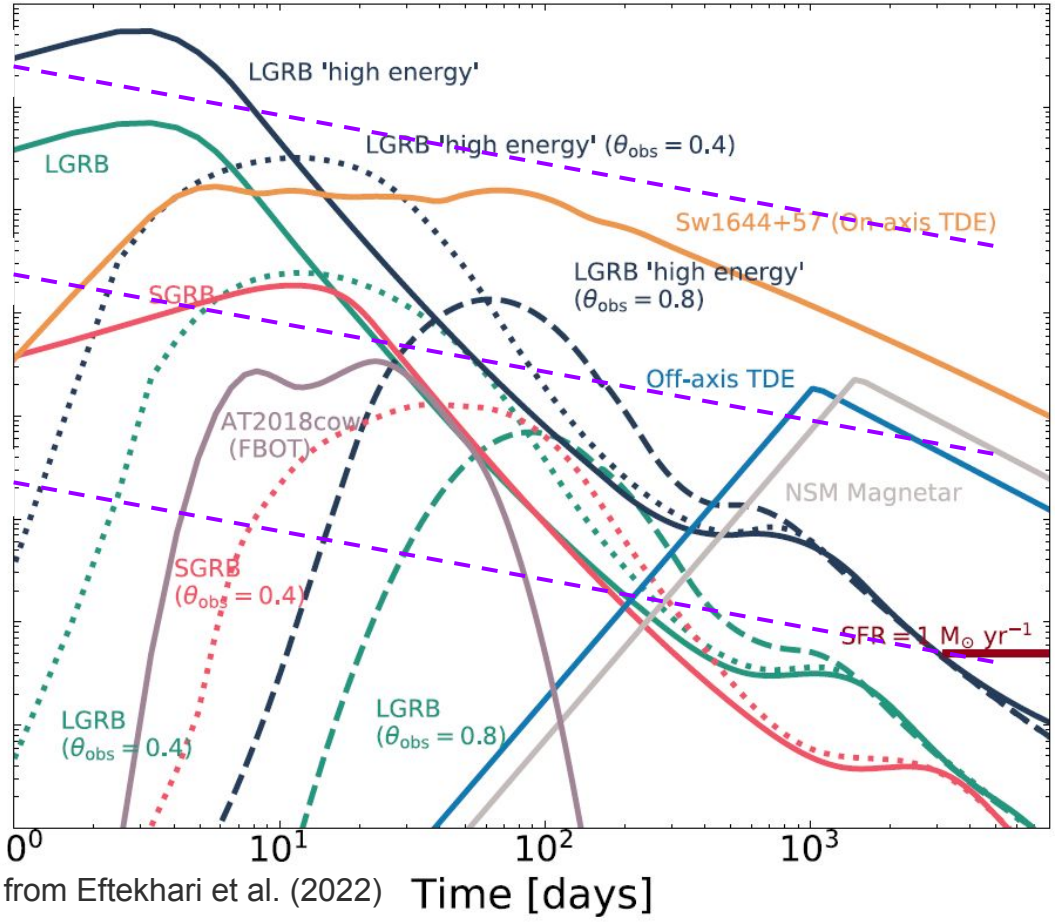
Adapted from Eftekhari et al. (2022)

~3σ

Sensitivity @ z=1.0

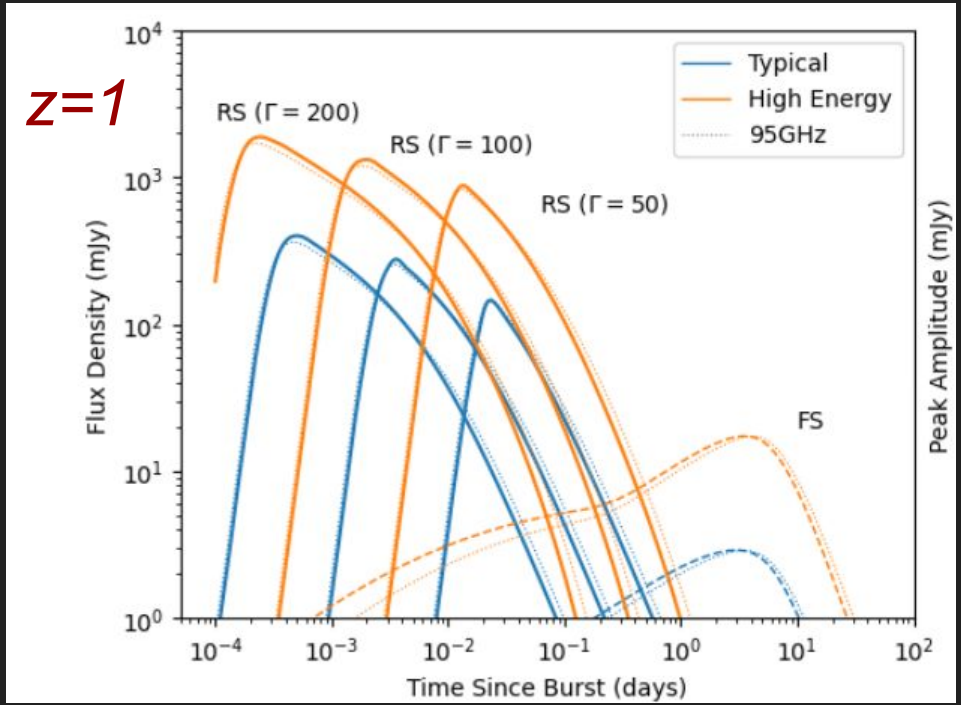
Sensitivity @ z=0.1

Sensitivity @ z=0.01



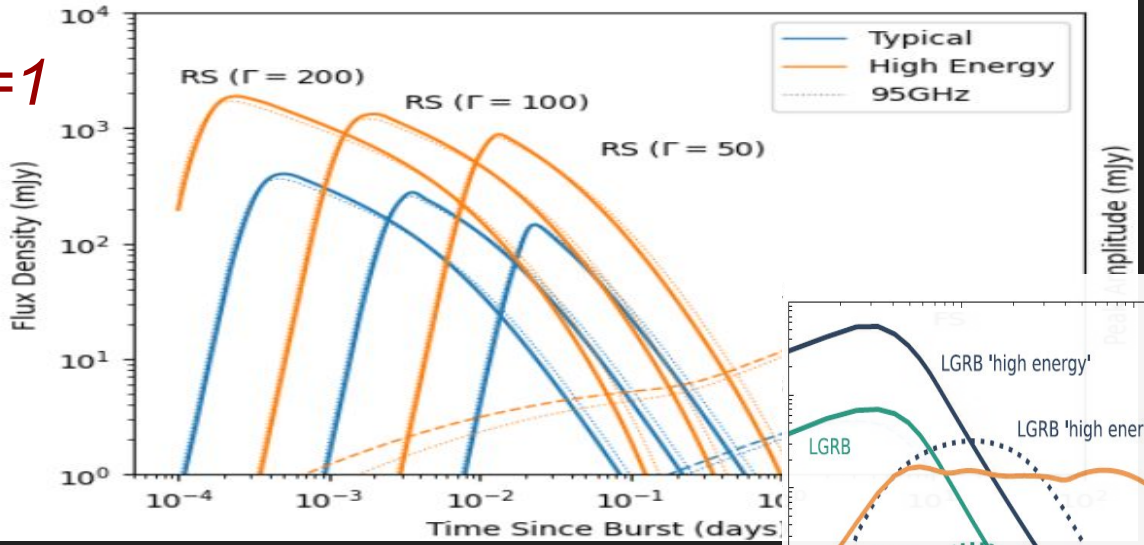
Adapted from Eftekhari et al. (2022)

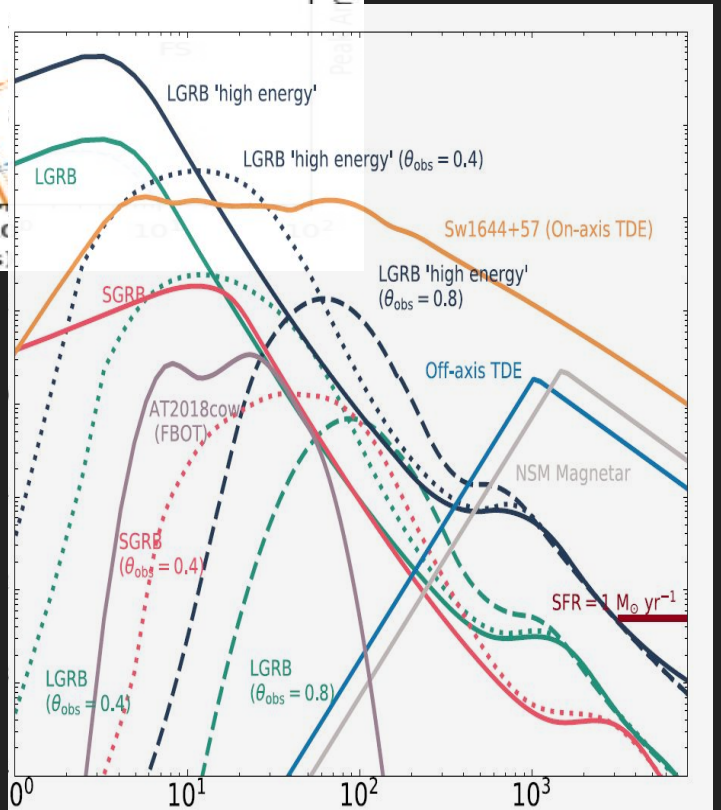
GRB Reverse Shocks!



Plot adapted from Eftekhari et al. (2022), Guns et al. in prep.

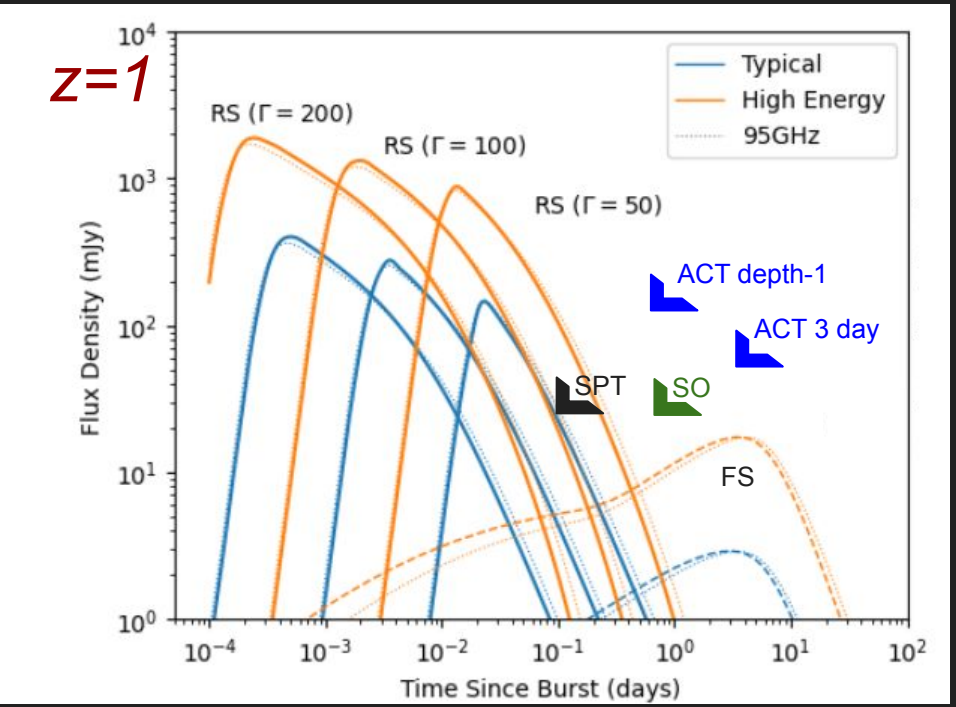
z=1





Redshift distribution of GRBs peaks around z~2

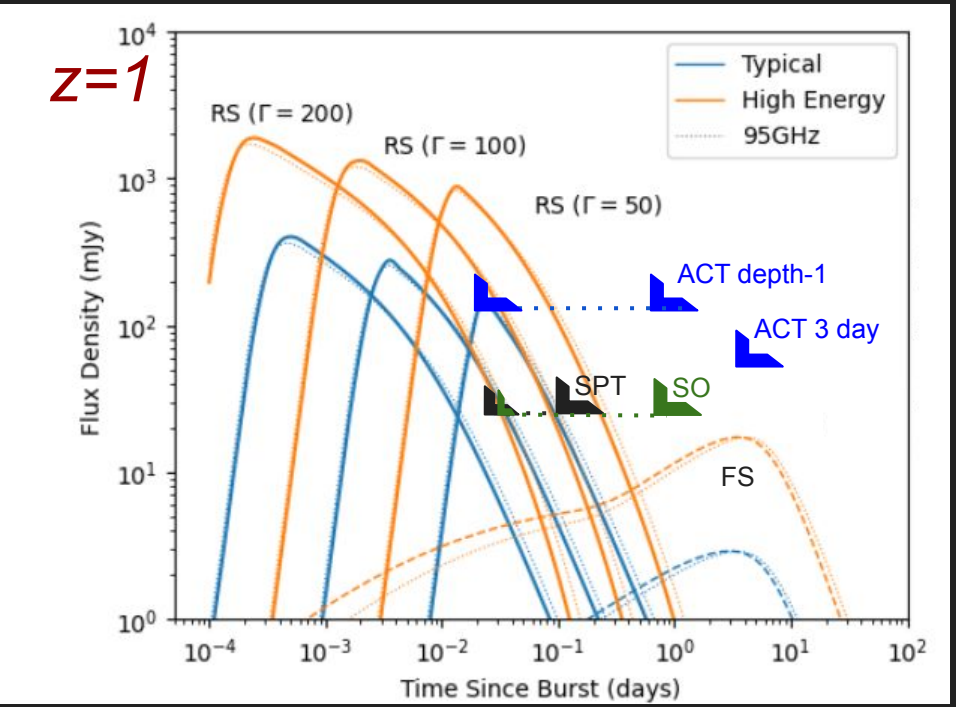
GRB Reverse Shocks!



* ACT depths variable (as well as re-observation cadence)

Plot adapted from Eftekhari et al. (2022), Guns et al. in prep.

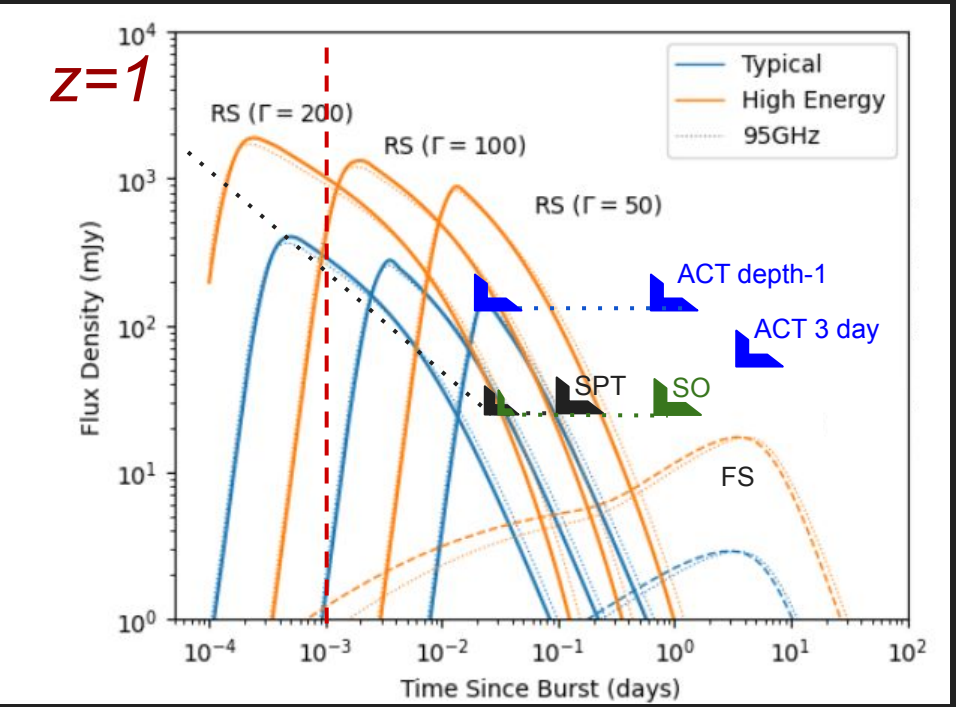
GRB Reverse Shocks!



Single observations of a point on the sky really only observed for ~15-20 minutes

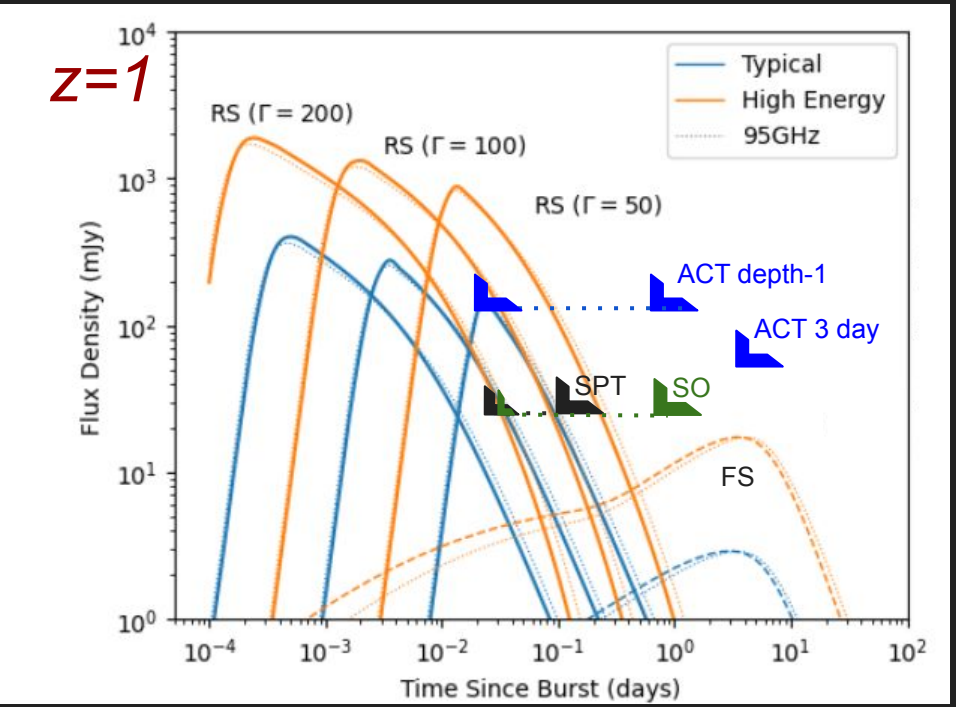
Plot adapted from Eftekhari et al. (2022), Guns et al. in prep.

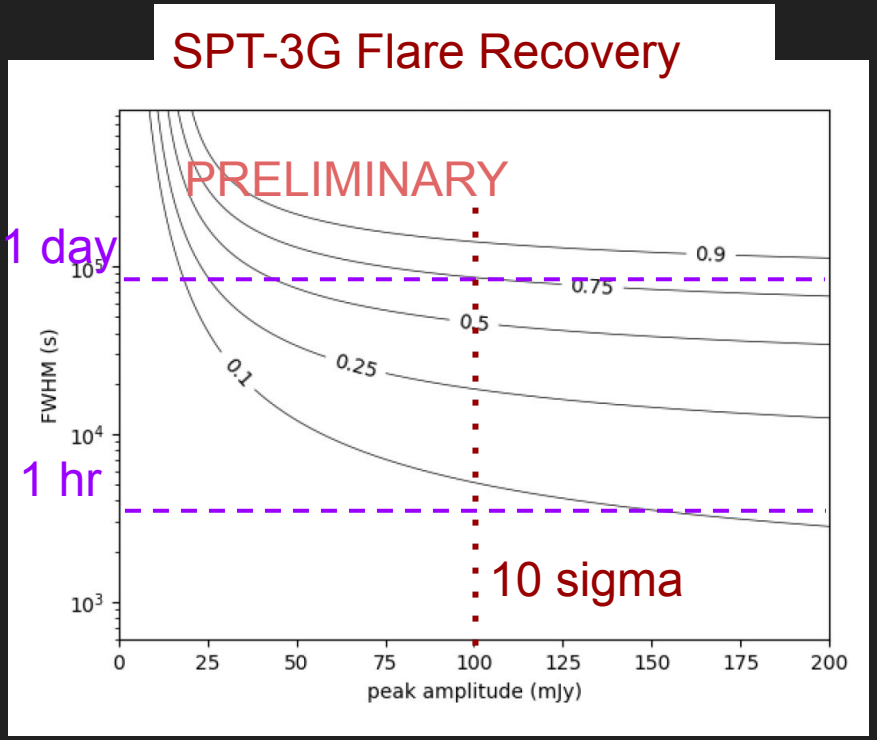
1min



As you go to shorter times, you are reducing the number of detector-seconds on target

Plot adapted from Eftekhari et al. (2022), Guns et al. in prep.





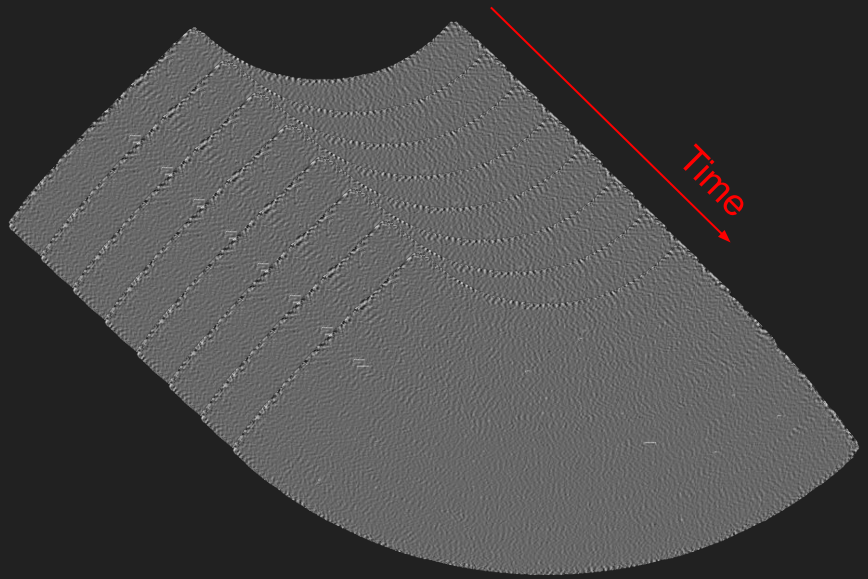
Plot adapted from Eftekhari et al. (2022), Guns et al. in prep.

Current State Summary

- Models suggest we should observe several GRB RS per year, however no extragalactic bona-fide transients discovered in ACT or SPT-3G surveys.
- Need to understand detection efficiency as a function of flare parameters, especially on short timescales.
- Need to search for longer duration events, and to understand how to separate AGN from transients.

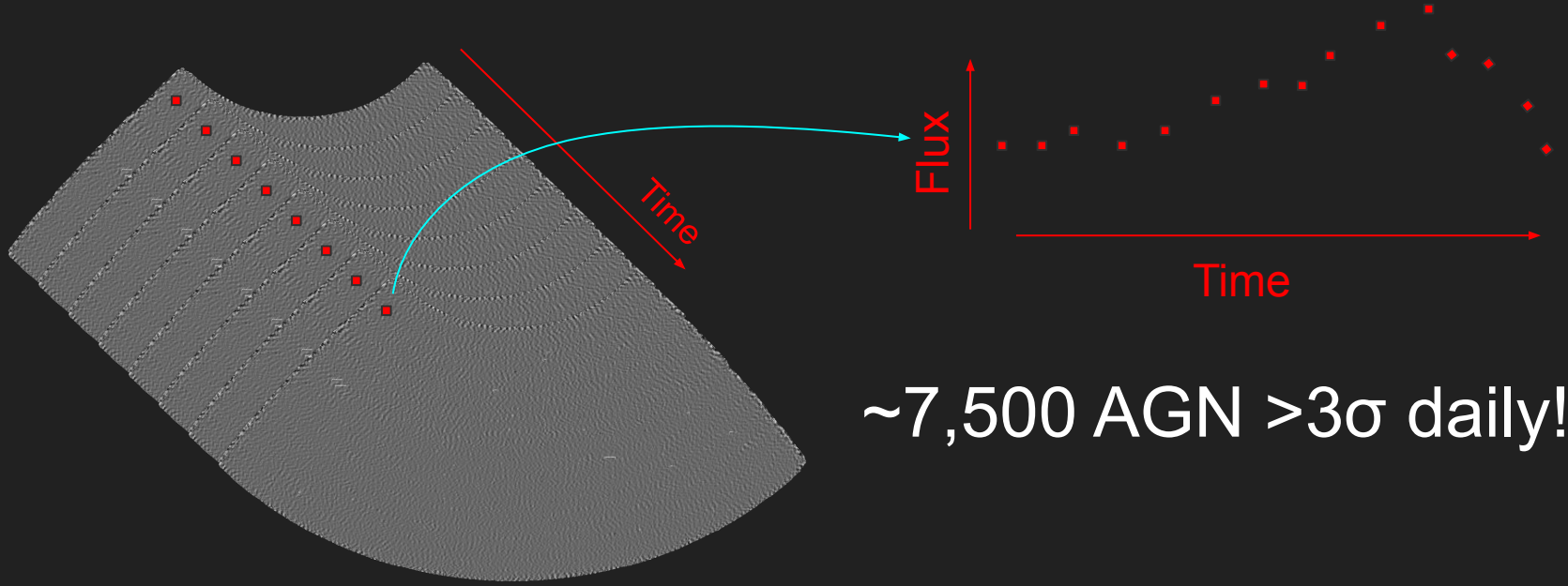
Simons Observatory Time Domain Pipeline

Make daily maps



Make daily maps

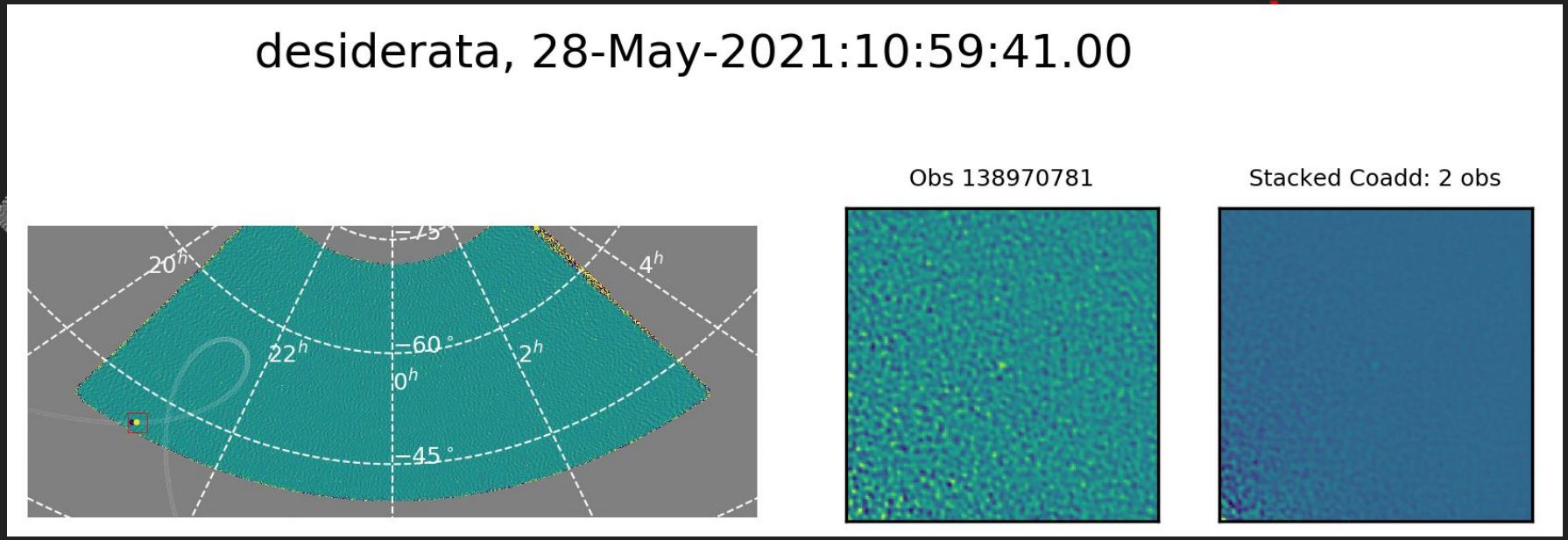
Record fluxes of known sources



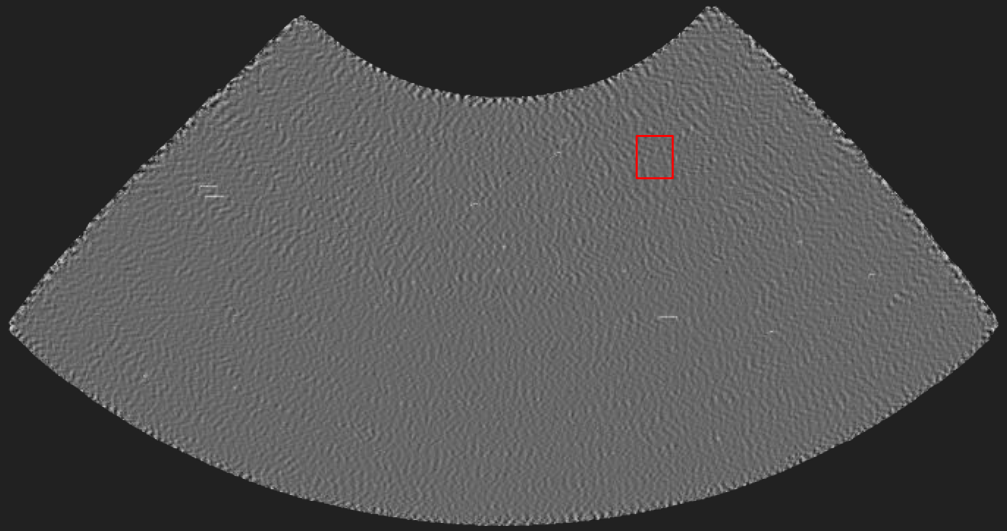
~7,500 AGN >3σ daily!

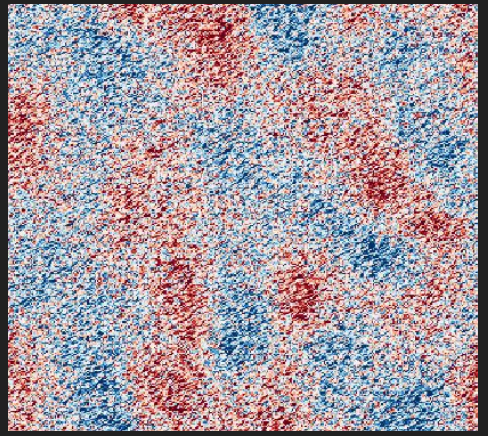
Make daily maps

Record fluxes of known sources (including asteroids)

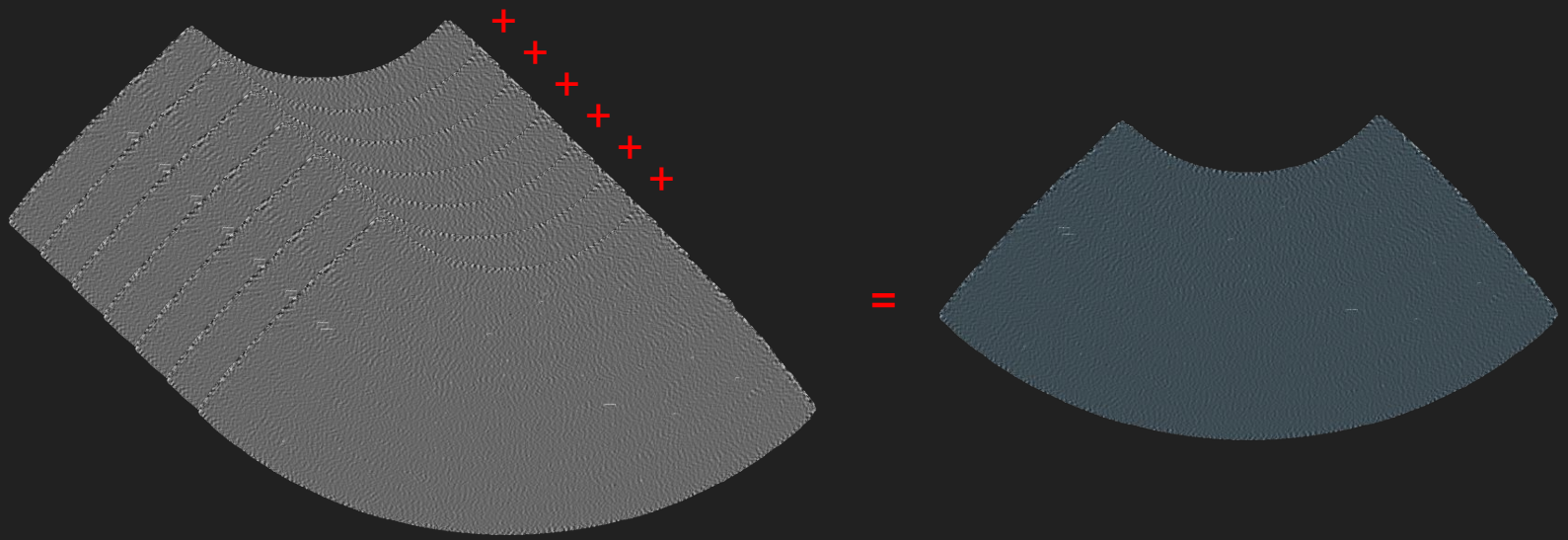


Search each map for new sources





Also stack weekly / monthly / yearly maps

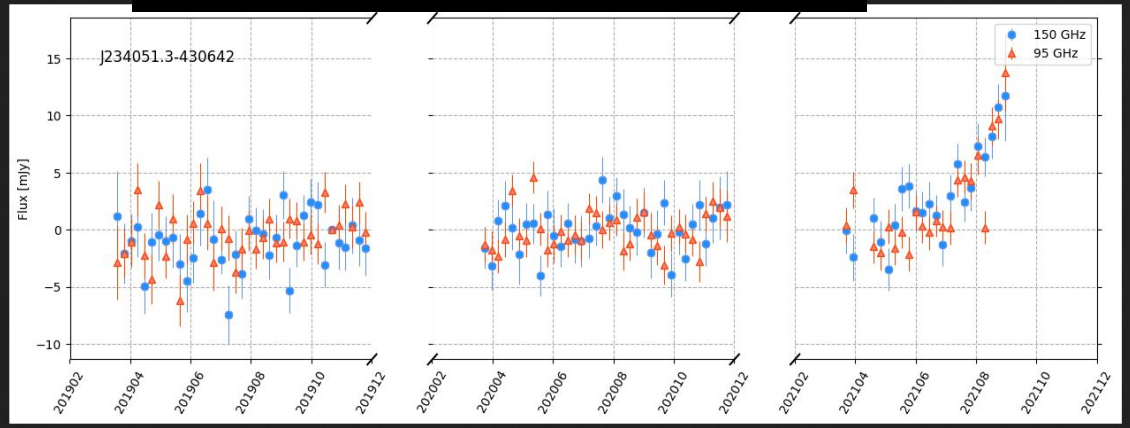


rinse + repeat

Send alerts on interesting objects

SPT-210903 - South Pole Telescope Reports Detection of a Millimeter-Band Flaring Source

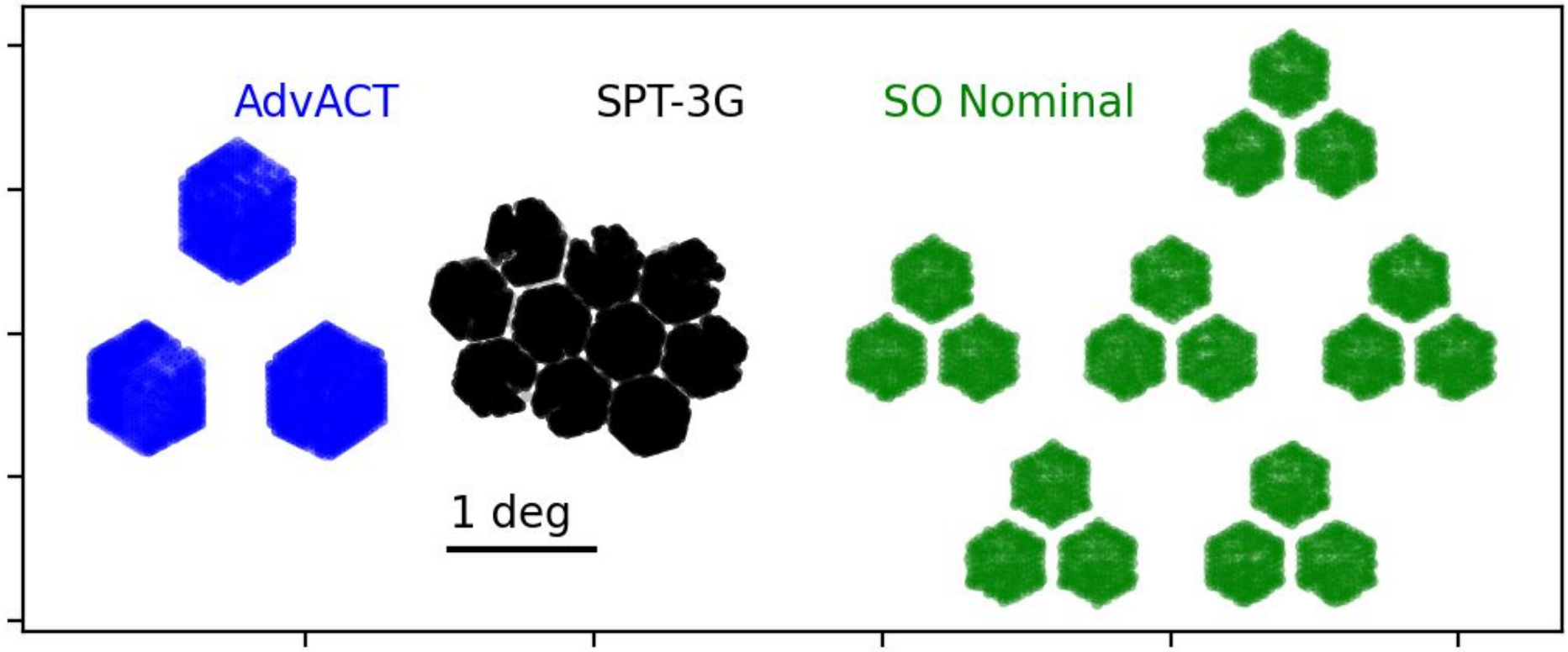
ATel #14891; *Sam Guns, Allen Foster, SPT-3G Collaboration*
*on **3 Sep 2021; 23:00 UT***
Credential Certification: Sam Guns (sguns@berkeley.edu)

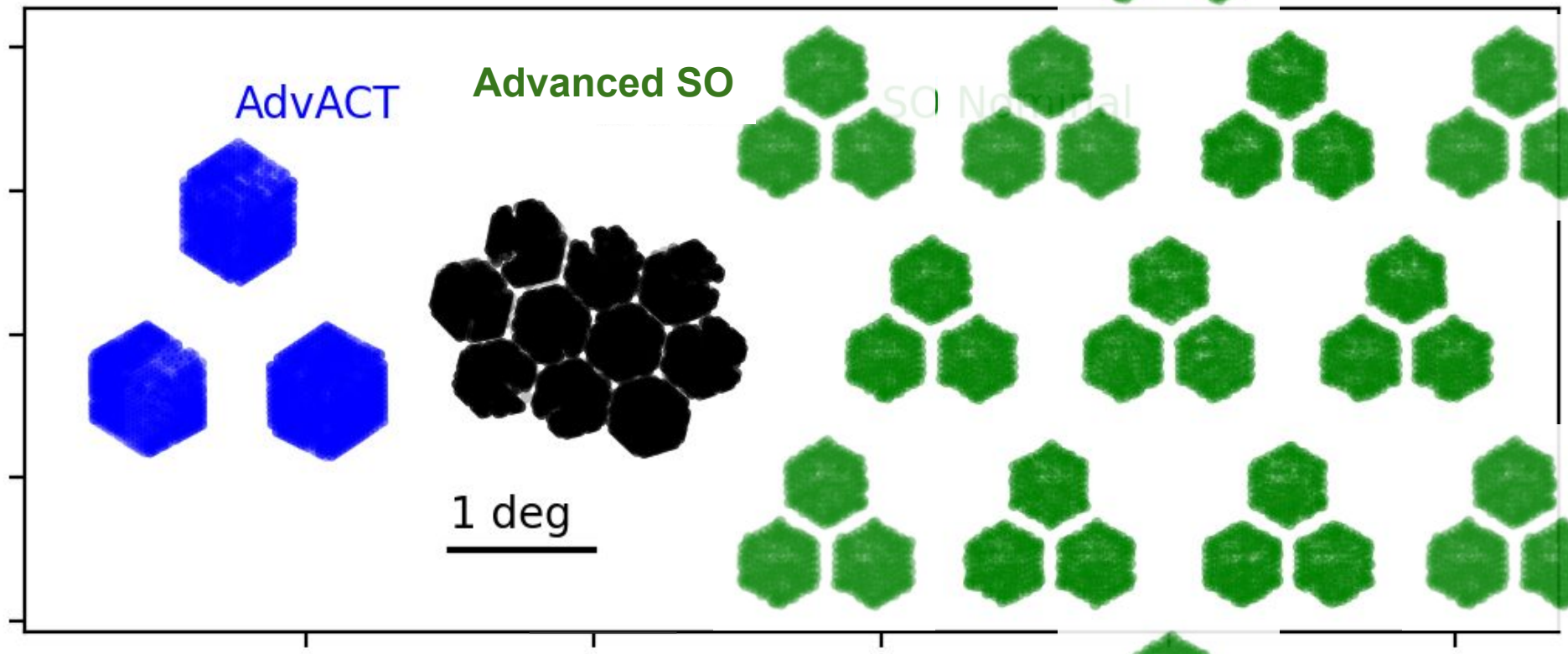


ACT-T J061647-402140: a Strongly Variable, Flaring Source at 90, 150 and 220 GHz Positionally Coincident with the Transient Gamma-Ray Blazar, Fermi 0617-4026

ATel #12738; *Sigurd Naess (Center for Computational Astrophysics, Flatiron Institute) on behalf of the ACT Collaboration*
*on **8 May 2019; 23:32 UT***
Credential Certification: John P. Hughes (jph@physics.rutgers.edu)

So… what’s new?

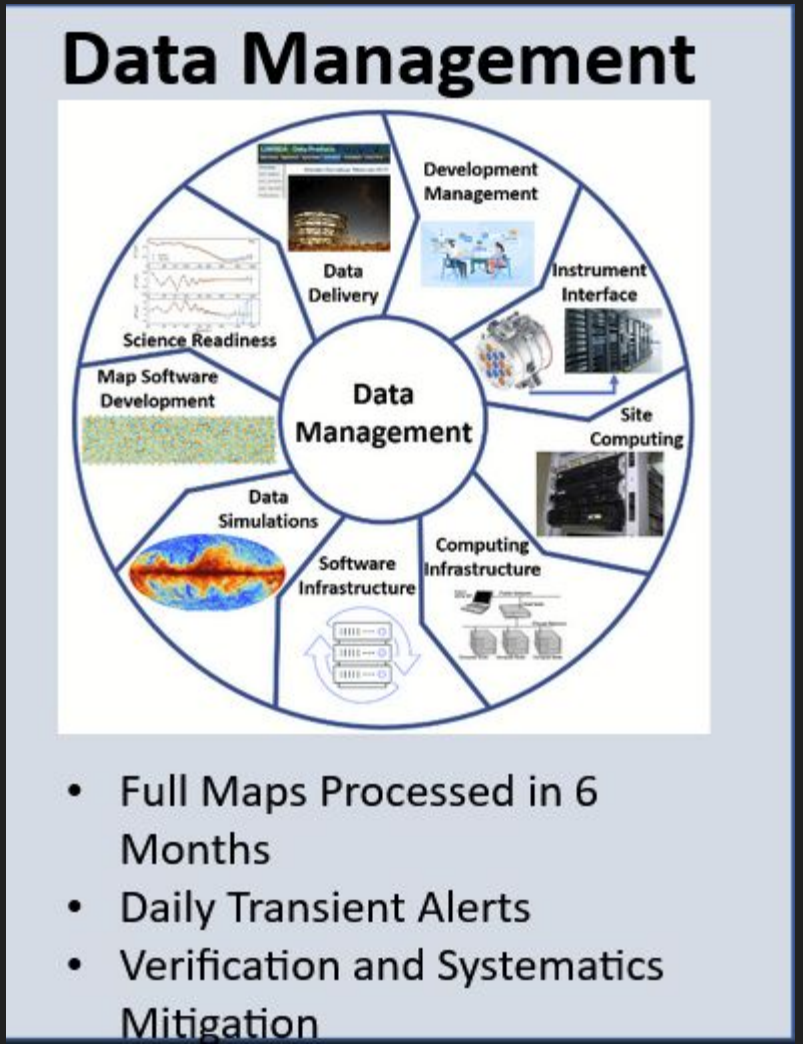

AdvACT
SPT-3G
SO Nominal
1 deg


AdvACT
Advanced SO
1 deg

So… what's new?

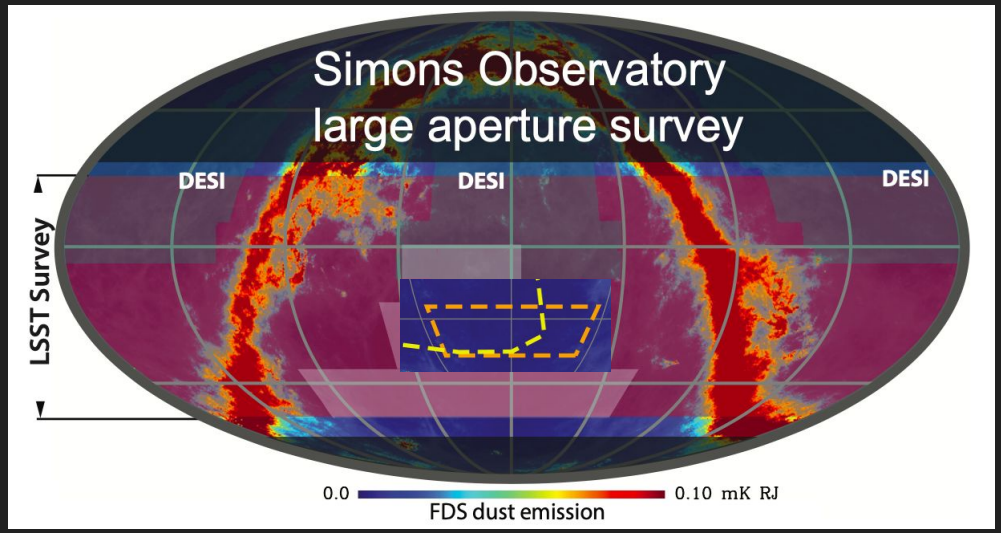
Developing an extremely flexible and modular pipeline.

Open source!

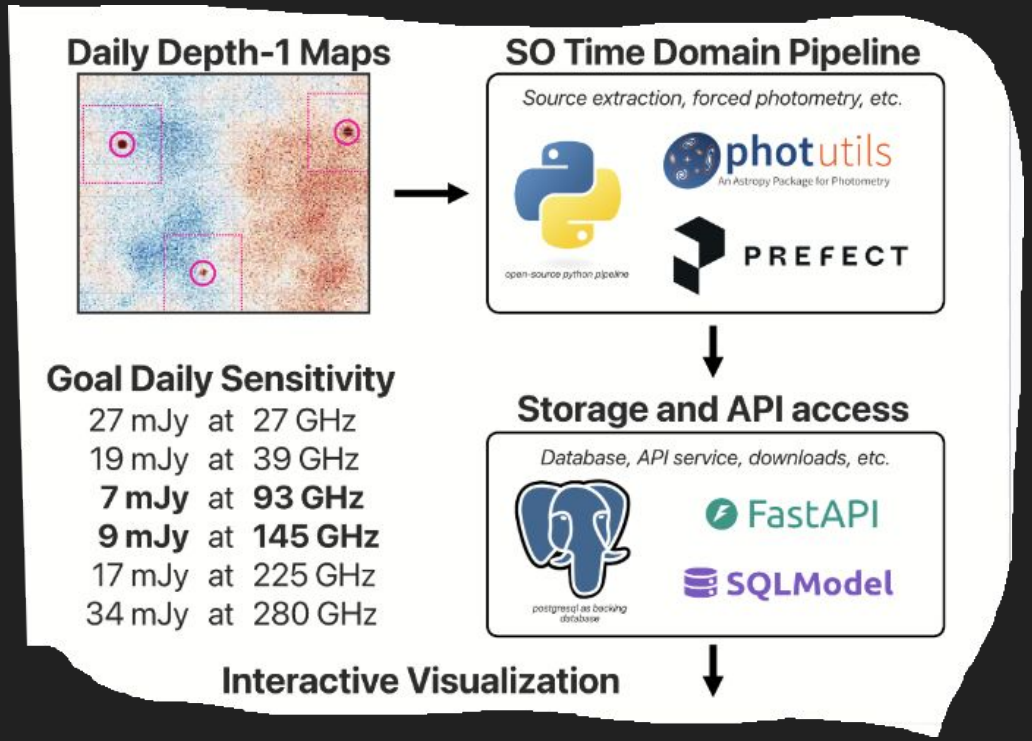


Deliver **TO THE PUBLIC:**

- ~7,500 bright AGN light curves with ~daily cadence.
- Alerts of transients within 30 hours of detection.
- Open source software for map-based source detection and monitoring.



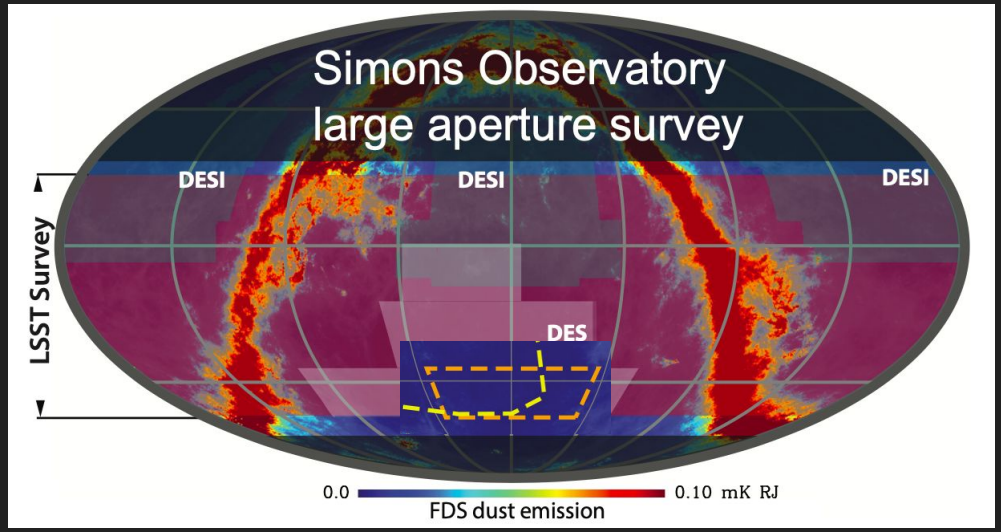
Public data availability
with nice user-interfaceable frontends

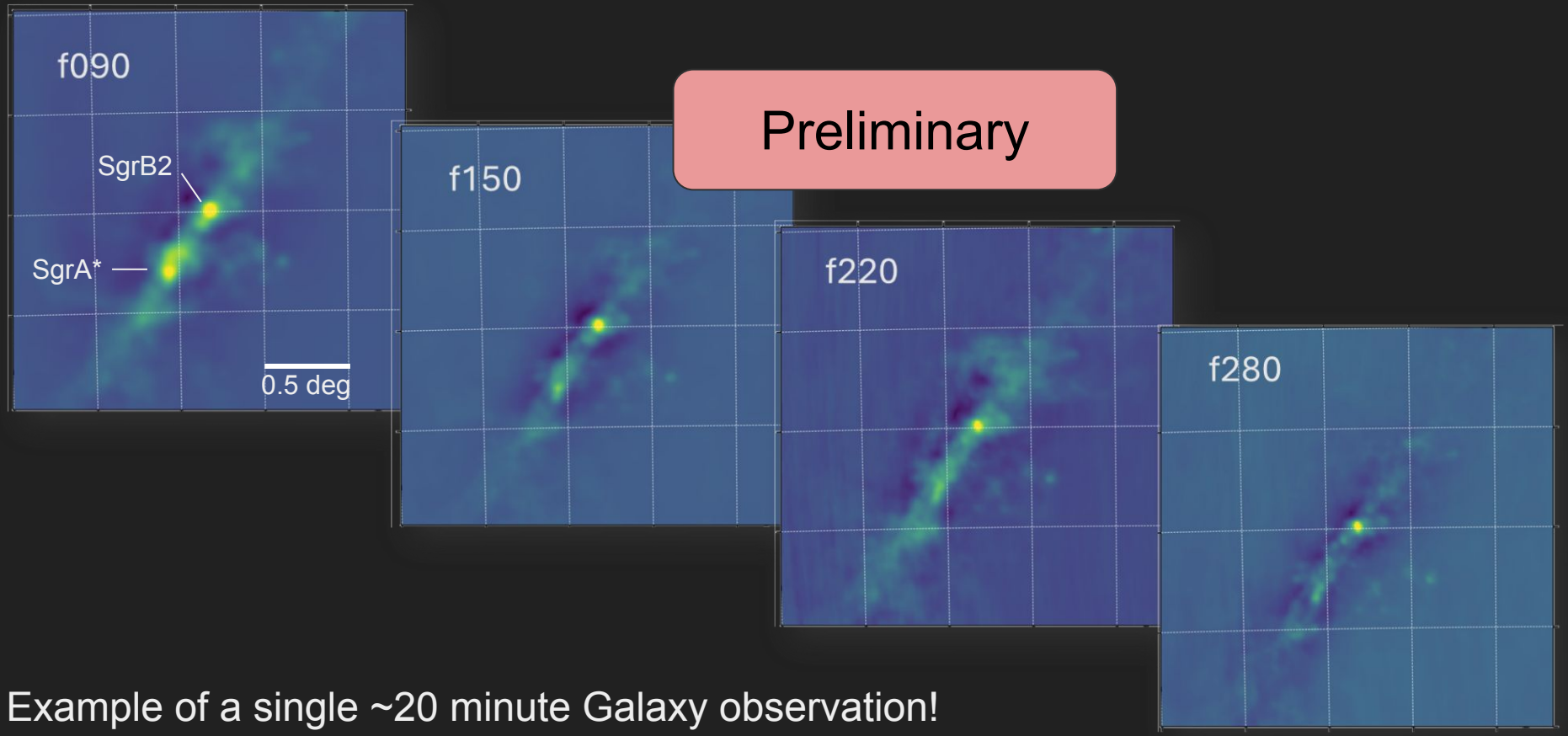


Open source data delivery service

Daily maps with ~SPT-3G single-obs depth (~8mJy) over 10x the area

AND coverage of the galactic plane!

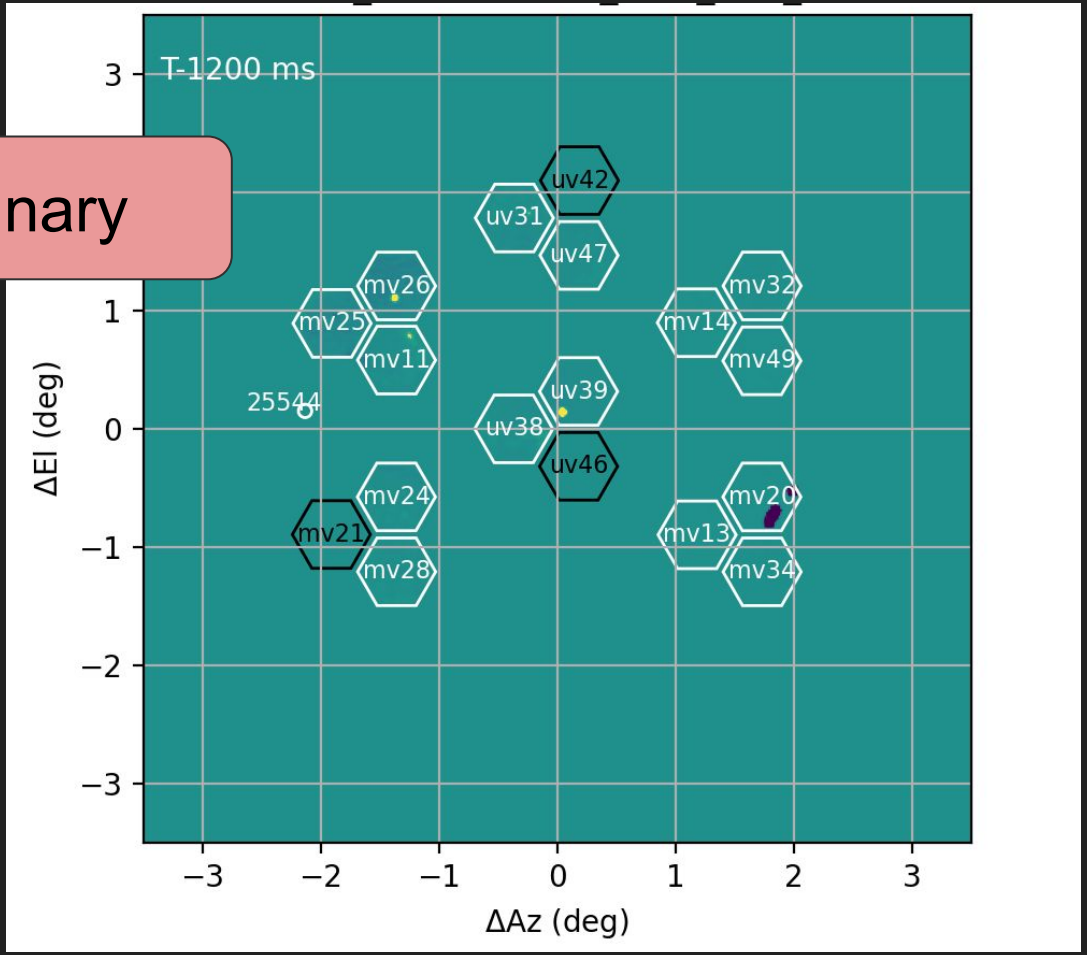




Preliminary

Example of a single ~20 minute Galaxy observation!

Preliminary



SO detects thermal emission from the International Space Station!

Estimated to be on the order of 100 Jy at 100 GHz!

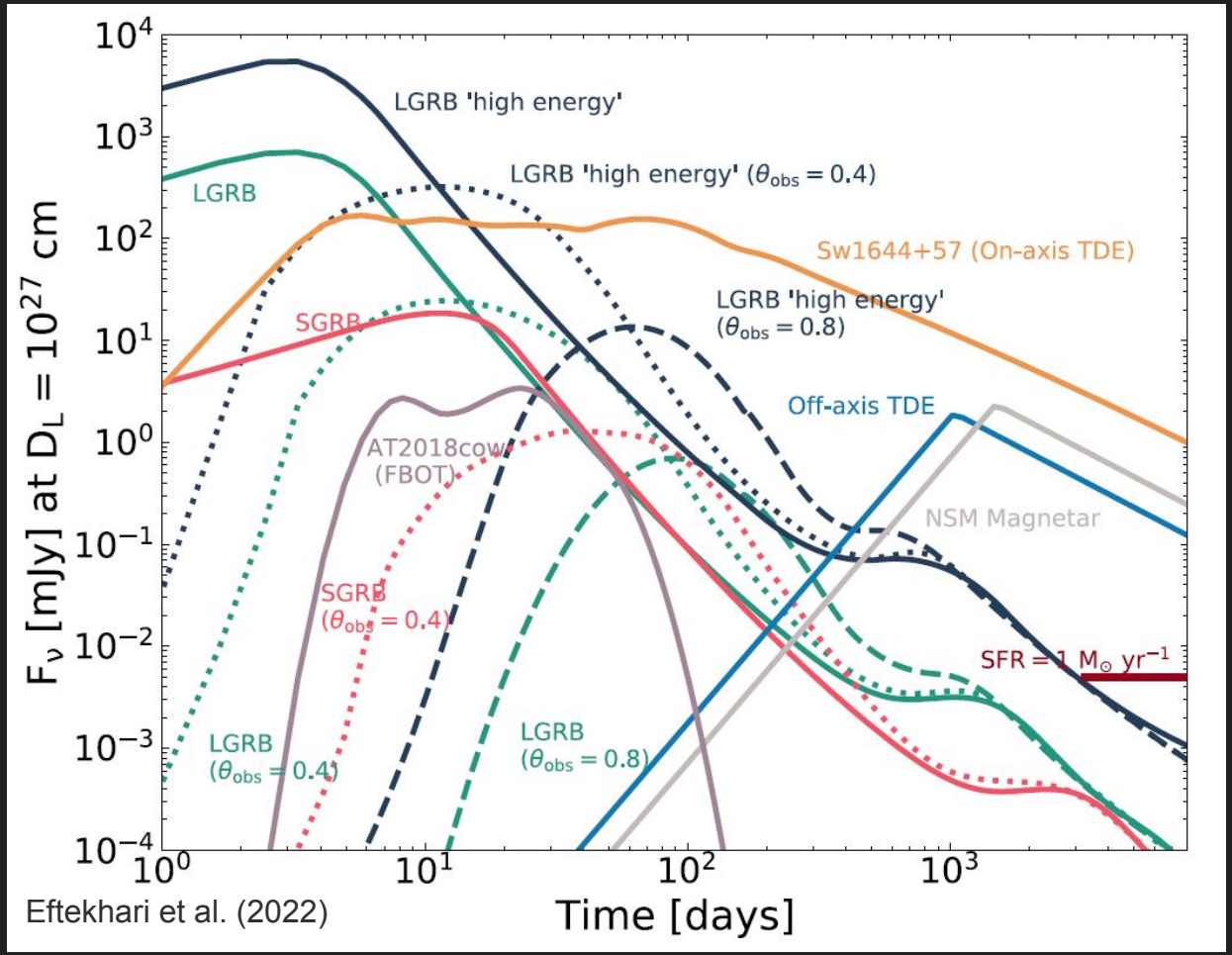
In summary,

SO will lead the field in public time-domain deliverables:

- Open source software to analyze maps for time-domain science and deliver light curves.
- ~7,500 AGN on a nearly daily cadence (~12,000 averaged weekly)
- Measurement of O(1000) asteroid regoliths with “real-time” monitoring of several large asteroids.
- Alert on detected transients within 30 hours and provide publicly accessible light curves.

And the most exciting of all is the unknowns!

Backup Slides



Eftekhari et al. (2022)

The (time-varying) mm-wave sky

- Gamma ray bursts (GRBs)
- Supernovae (SNe)
- Tidal disruption events (TDEs)

Science drivers for future CMB transient considerations

“True transient events”

- Active galactic nuclei (AGNs)

Relatively well studied (at least the luminous ones...)

- Stellar flares
- Solar system objects (Asteroids, deep solar system objects?)

Interest / science unknown

- Gravitational wave systems (i.e. NS-NS merger)
- Neutrino events

… a man can dream!

The (time-varying) mm-wave sky

- Gamma ray bursts (GRBs)
- Supernovae (SNe)
- Tidal disruption events (TDEs)

Science drivers for future CMB transient considerations

“True transient events”

Th

- tidal disruption events (TDEs)

A REVERSE SHOCK IN GRB 181201A

Tanmoy Laskar[1], Hendrik van Eerten[1], Patricia Schady[1], C. G. Mundell[1], Kate D. Alexander[2*], Rodolfo Barniol Duran[3], Edo Berger[4], J. Bolmer[5], Ryan Chornock[6], Deanne L. Coppejans[2], Wen-fai Fong[2], Andreja Gomboc[7], Núria Jordana-Mitjans[1], Shiho Kobayashi[8], Raffaella Margutti[2], Karl M. Menten[9], Re'em Sari[10], Ryo Yamazaki[11], V. M. Lipunov[12,13], E. Gorbovskoy[13], V. G. Kornilov[12,13], N. Tyurina[13], D. Zimnukhov[13], R. Podesta[14], H. Levato[15], D. A. H. Buckley[16], A. Tlatov[17], R. Rebolo[18], and M. Serra-Ricart[18]

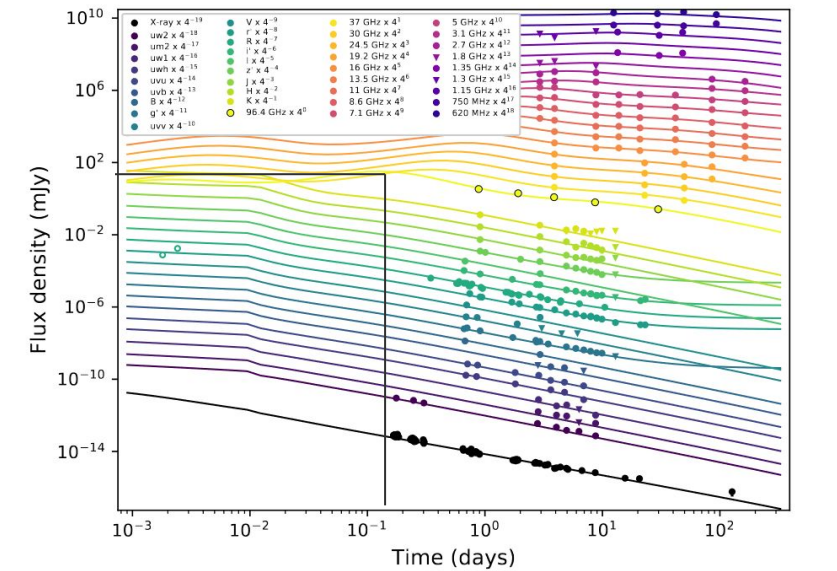


Figure 8. X-ray to radio light curves of GRB 181201A, together with the FS+RS model presented in Section 4, presented together for reference. The combined model explains the overall behavior of the light curves at all 36 observing frequencies.

"True transient events"

Reverse shocks may be bright at mm-waves early in burst (< ~days). [Laskar et al, 2019]

May be able to see "orphan" flares where the GRB jet is not aligned wrt viewing angle; i.e. obscured at other wavelengths. [Metzger et al, 2015]

Th

Tanmoy L
Rodolfo Barnio
Andreja Gom
Re'em Sari[10]
D. Zimnukhov[13], R

Alexander[2*],
ans[2], Wen-fai Fong[2],
Karl M. Menten[9],
3], N. Tyurina[13],
nd M. Serra-Ricart[18]

tidal disruptio

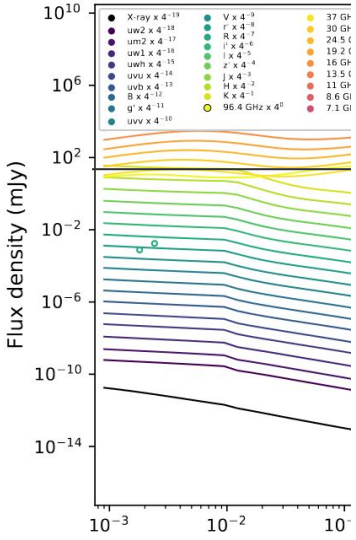


Figure 8. X-ray to radio light curves of GRB 181201A, together with the FS+RS model presented in Section 4, presented together for reference. The combined model explains the overall behavior of the light curves at all 36 observing frequencies.

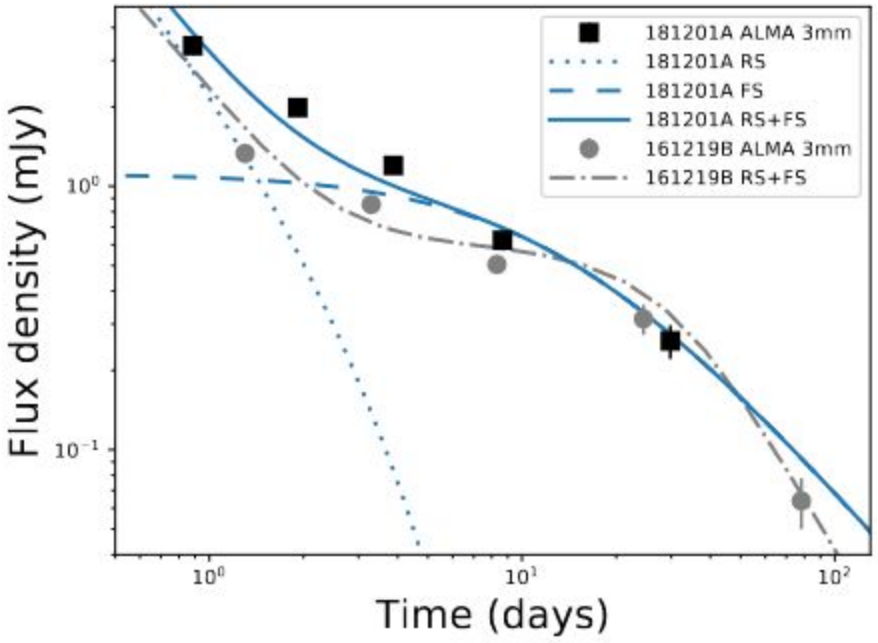


Figure 12. ALMA 3 mm light curve of GRB 181201A (black squares) compared with that of GRB 161219B (grey circles; Laskar et al. 2018c), together with RS+FS models (lines). Both GRBs exhibit excess mm-band emission near the RS-FS transition, indicating additional physics not captured by the model.

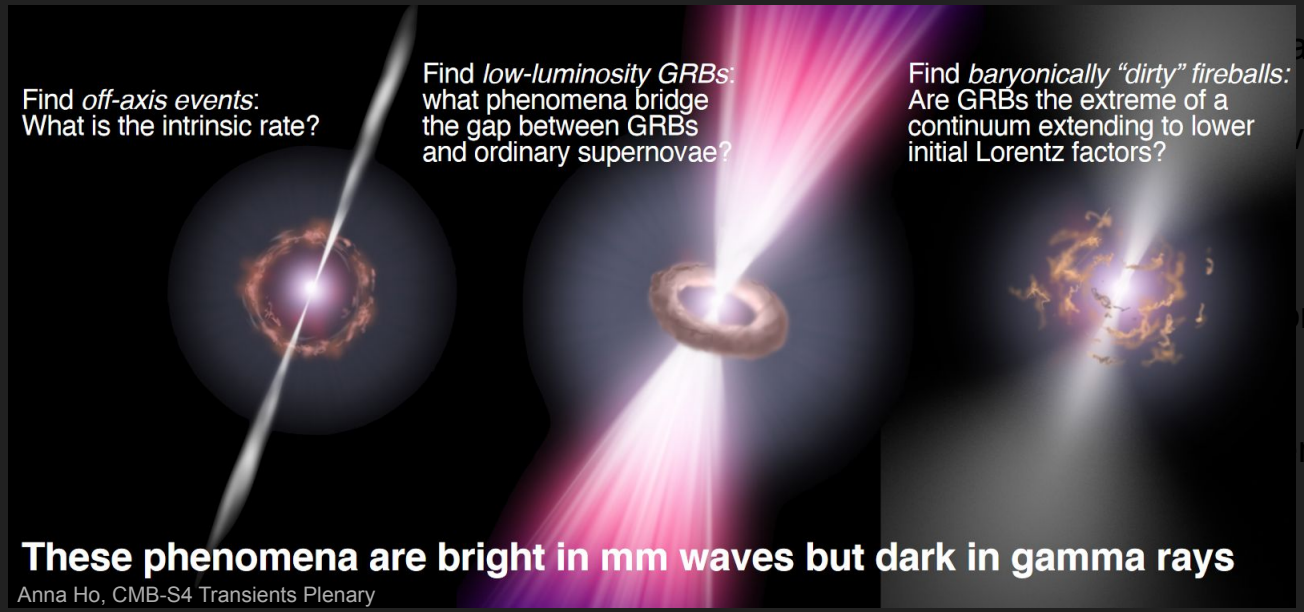
t at mm-waves
ar et al, 2019]

lares where the
wing angle; i.e.
s. [Metzger et al,

The (time-varying) mm-wave sky

- Gamma ray bursts (GRBs)
- Supernovae (SNe)
- Tidal disruption events (TDEs)

Type 1A are well defined and understood, but is there a spectrum between core collapse SNe, GRBs and FBOTs?



ast ~3 day rise time)

vavelengths for days.

n detected in Swift

nt (?)

The (time-varying) mm-wave sky

- Gamma ray bursts (GRBs)
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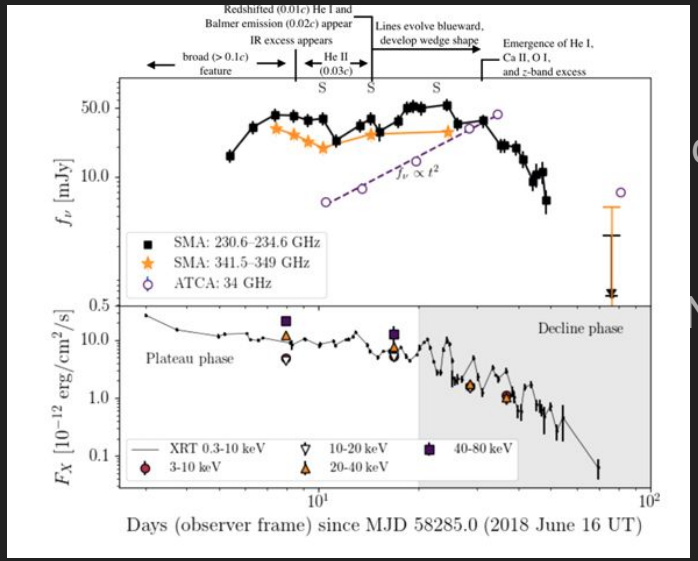

AT2018cow: A Luminous Millimeter Transient

Anna Y. Q. Ho[1], E. Sterl Phinney[2], Vikram Ravi[1,3], S. R. Kulkarni[1], Glen Petitpas[3], Bjorn Emonts[4], V. Bhalerao[5], Ray Blundell[3], S. Bradley Cenko[6,7], Dougal Dobie[8,9] + Show full author list

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Citation Anna Y. Q. Ho *et al* 2019 *ApJ* **871** 73

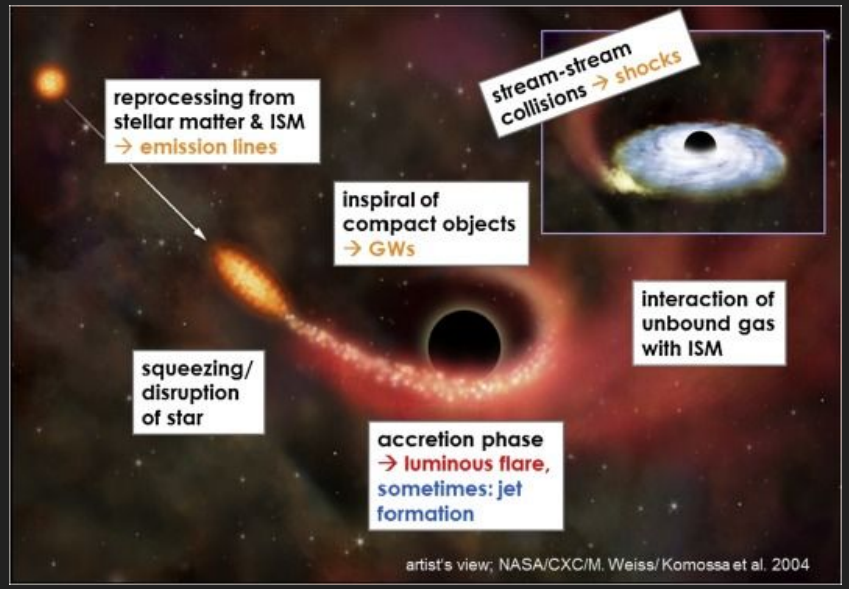
- Discovered in optical (fast ~3 day rise time)
- Bright at mm/sub-mm wavelengths for days.
- Nearby (~60Mpc)
- No high energy emission detected in Swift BAT/ Fermi GBM/LAT
- SN in dense environment (?)

The (time-varying) mm-wave sky

- Gamma ray bursts (GRBs)
- Supernovae (SNe)
- Tidal disruption events (TDEs)

Science drivers for future CMB transient considerations

“True transient events”



TDEs…

Pretty big buzz word in literature right now.

Seems difficult to distinguish flares in AGN from a TDE

TDEs thought to occur in galaxies with lower central BH masses ($< 10^8 M_\odot$; so called “intermediate mass black holes”, or IMBHs)

The (time-varying) mm-wave sky

- Gamma ray bursts (GRBs)
- Supernovae (SNe)
- Tidal disruption events (TDEs)

Need multi-wavelength observations with high cadences!

Rubin Observatory (LSST) to be online soon
-- will provide optical coverage of our field

- Active galactic nuclei (AGNs)

eROSITA is currently observing , providing all-sky X-ray coverage.

- Stellar flares
- Solar system objects (Asteroids, deep solar system objects?)

- Gravitational wave systems (i.e. NS-NS merger)
- Neutrino events