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Transients and variables with S4

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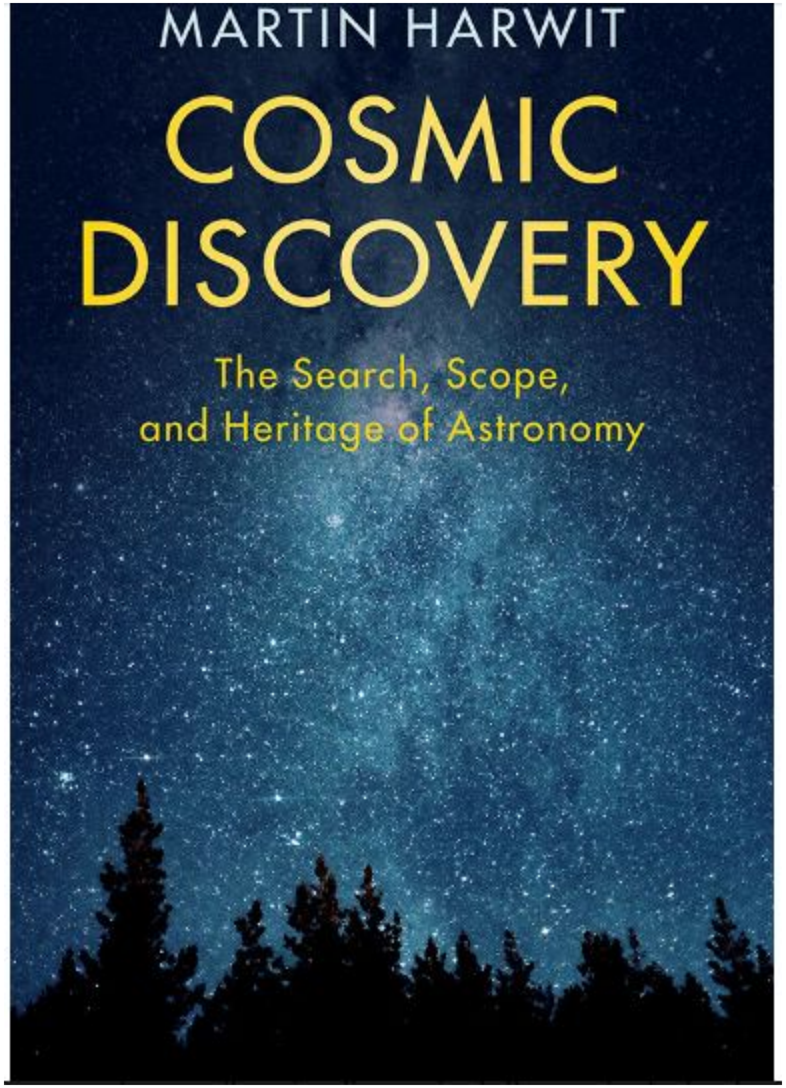
Overview

Some thoughts about different approaches to science

Why S4 is revolutionary for transients

Types of objects for which S4 can make important measurements

A philosophical thought



- Two key processes in science: discovery and analysis
- Both are vital
- Most of S4 core science is about analysis, but transients and variables include a lot of discovery

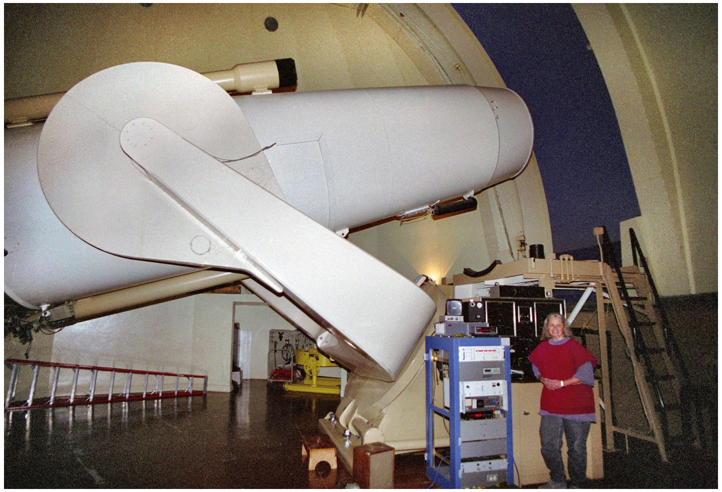
Early optical transients: 7 classes in first 28 objects

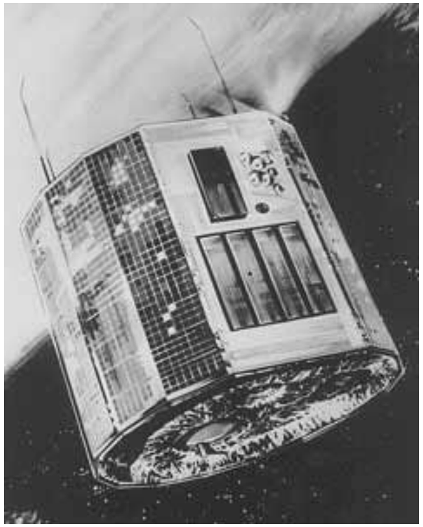
Object name	Disc yr.	m_V	Class	Comment
B Cas	1572	−5	Supernova	Tycho's
S And	1885	7	Supernova	in M31
V Per	1887	9.2	classical nova	
N Per 1901	1901	0.0	Classical nova	GK Per
T Aur	1891	4.5	classical nova	
N Gem 1903	1903	5.1	classical nova	
N Vel 1905	1905	9.7	classical nova	
RS Carinae	1895	8	classical nova	
Z Cen	1895	8	supernova	in NGC 5252
Nova Cir	1906	9.5	classical nova	typo on year in Fleming & Pickering (1912)
R Norma	1893	7	Mira Ceti variable	
T Cor B	1866	2	recurrent nova	red giant donor
T Sco	1860	7	classical nova	in globular cluster M80
Nova Ara	1910	6	classical nova	
N Oph 2	1848	5.5	classical nova	
N Oph 1	1604	−4	supernova	Kepler's
RS Oph	1898	7.7	recurrent nova	red giant donor
N Sco 2	1906	8.8	classical nova	
N Sgr 2	1910	7.5	classical nova	
N Sgr 4	1901	10.4	classical nova	
N Sgr 3	1899	8.5	classical nova	
N Sgr 1	1898	4.7	classical nova	
N Aql 2	1905	9.1	classical nova	
N Aql 1	1899	7	classical nova	
11 Vul	1670	3	classical nova	CK Vul
P Cyg	1600	3.5	luminous blue variable	
Q Cyg	1876	3	classical nova	
N Lac	1910	5	classical nova	

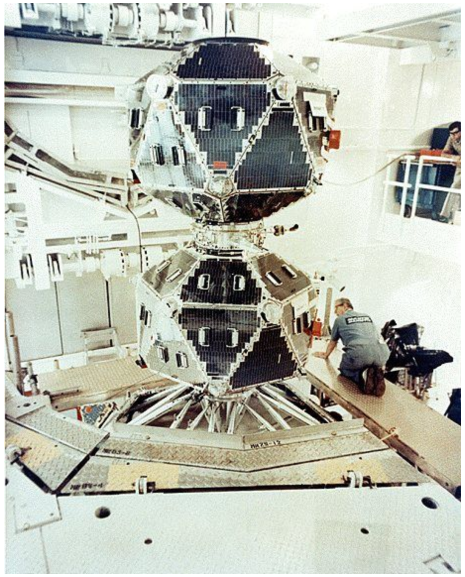
Table 1. The 28 "novae" from Fleming & Pickering (1912). The columns are the object name, the year of the discovery of the source, the peak apparent magnitude of the object, the class of object, and any comments that might be relevant to the objects.

Maccarone 2021

Wide field transient searches at other wavelengths







These techniques have been in use for centuries (ultra-shallow optical surveys), 150 years (going back to photographic plates), 50 years (X-rays and gamma-rays)

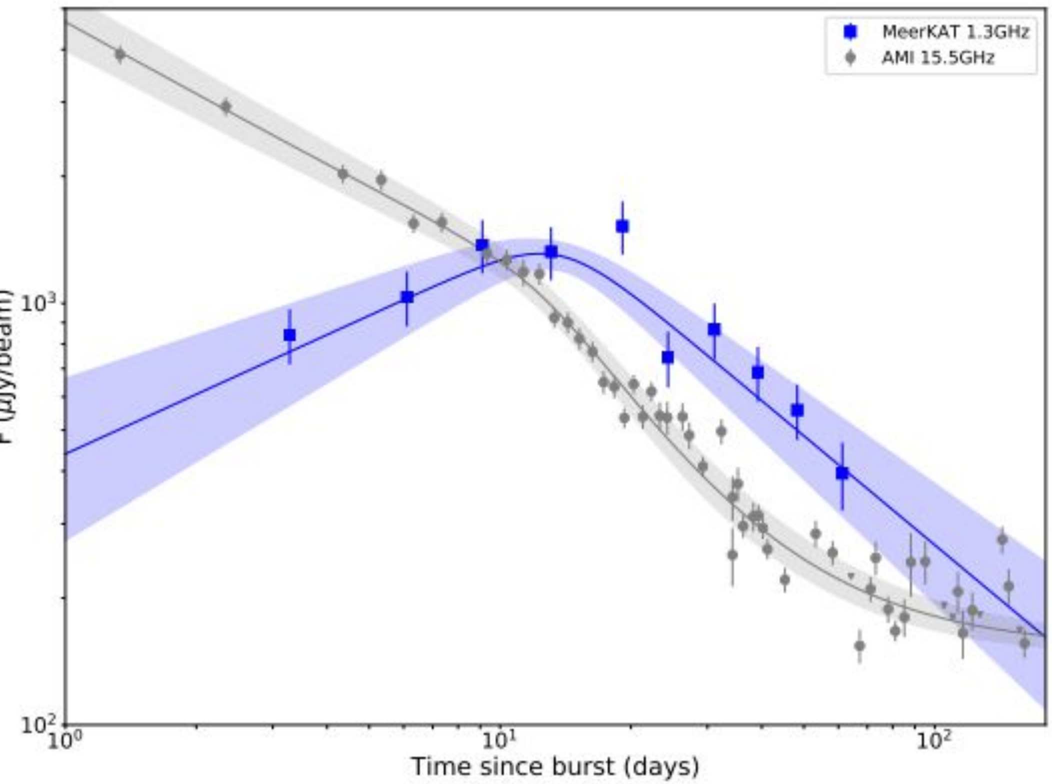
Attempts to do this at long wavelengths (i.e. low frequency radio) have been unsuccessful except for meteor searches because of source physics

SPT/ACT have shown proof of concept for mm bands, that we *will* detect transients

General considerations

- The first radio/mm sky monitor of real value!
  - Most interesting discoveries will probably be new phenomena, but I'll talk about what we know already
  - mm band interferometers have very small fields of view
- Broad range of questions without the same kind of unifying theme as much of the rest of S4
- Extragalactic transients generally evolve from high to low frequency, so mm band gets them first; also higher cadence that radio surveys
- Most stars do not emit radio/sub-mm, so the ones that do are unusual and interesting.
  - Probes stars in earliest and latest stages!

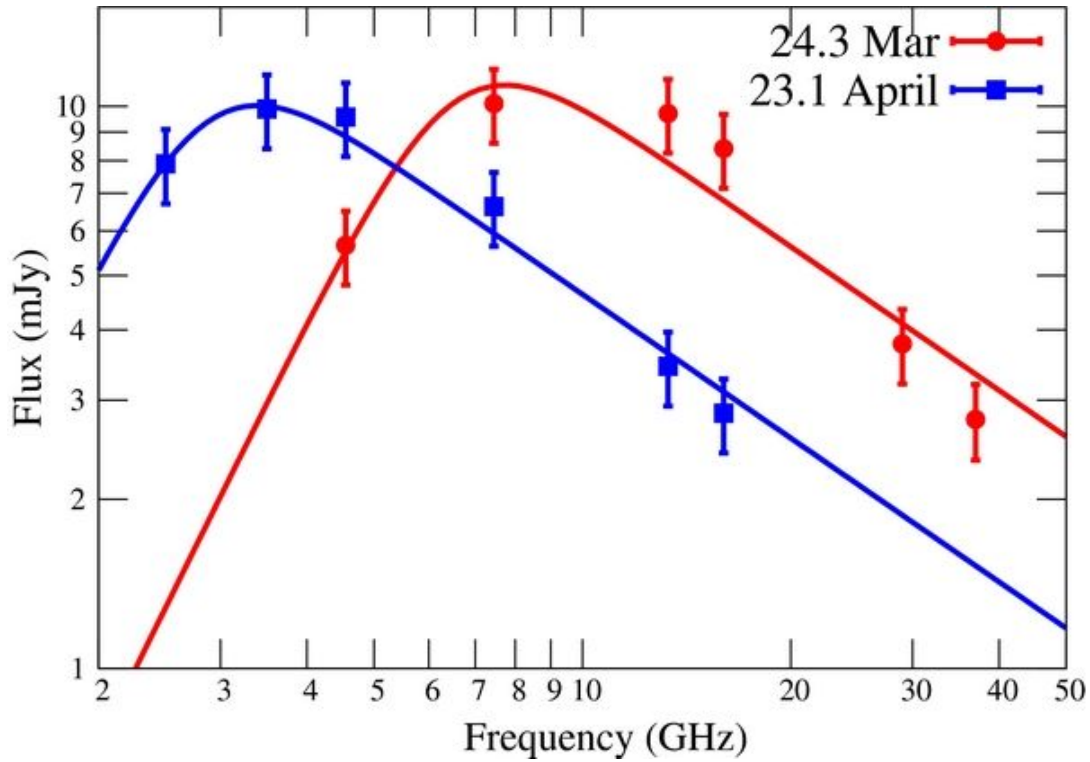
Gamma-ray bursts (the phenomenon that sets requirements)



From Rhodes et al. 2020

- Prompt emission from GRBs: only observable on-axis
- Afterglow: observable off-axis, as jet slows down
- Radio/mm searches open up orphan afterglows, highest frequencies get fastest detections

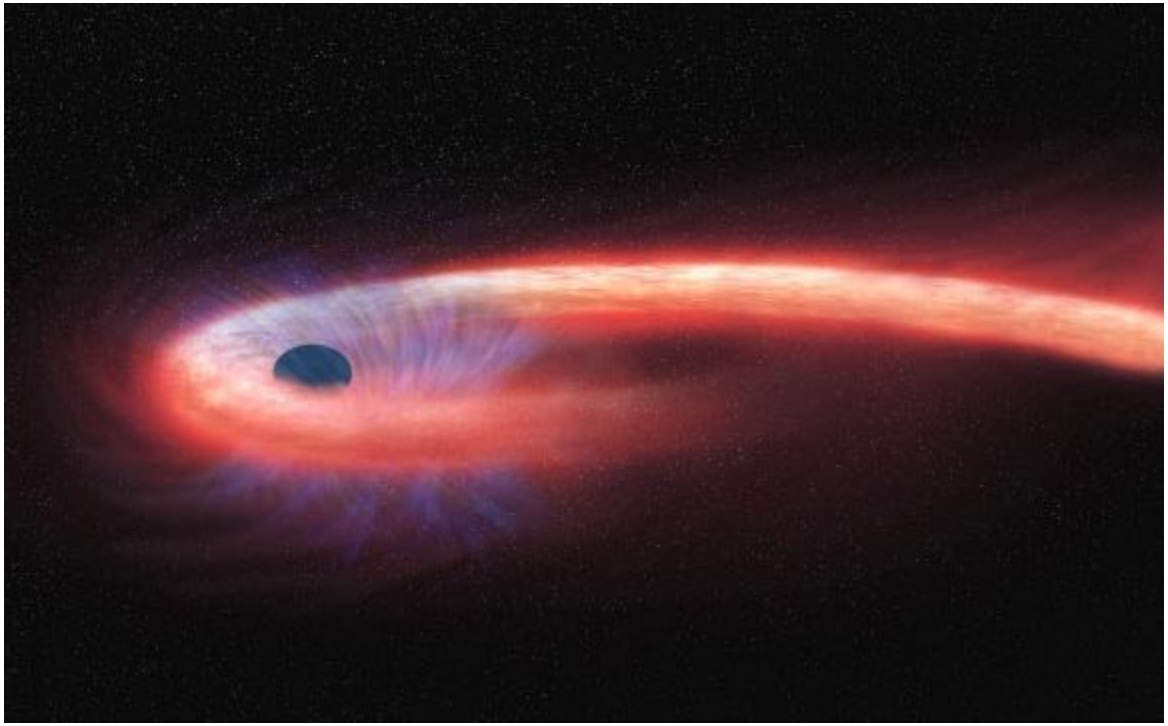
Supernovae



Kamble et al. 2014; supernova was discovered March 14

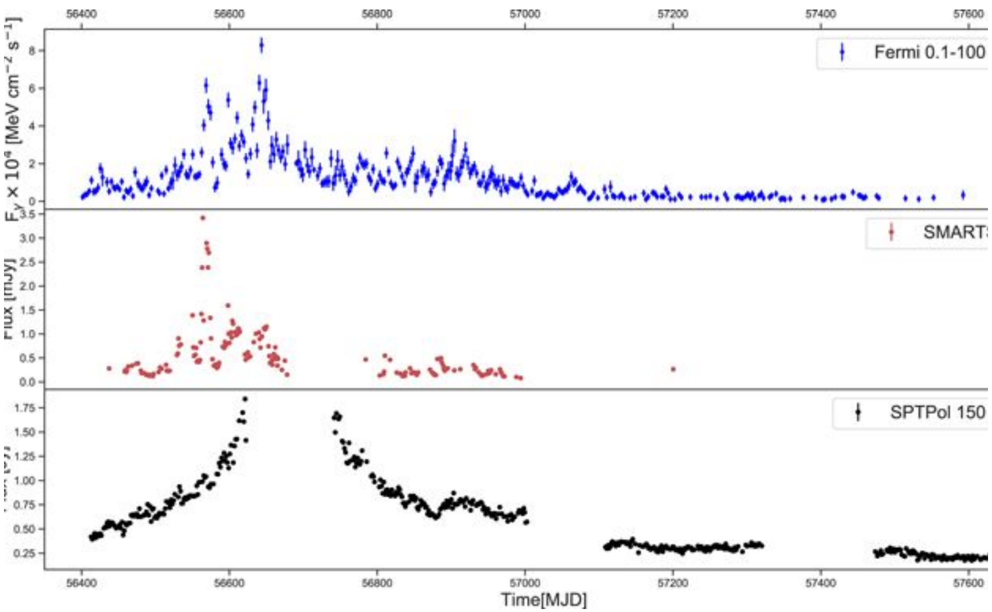
- Shock interactions with stellar winds
- See through absorption in S4 band
- Higher frequencies come earlier

Tidal disruption events

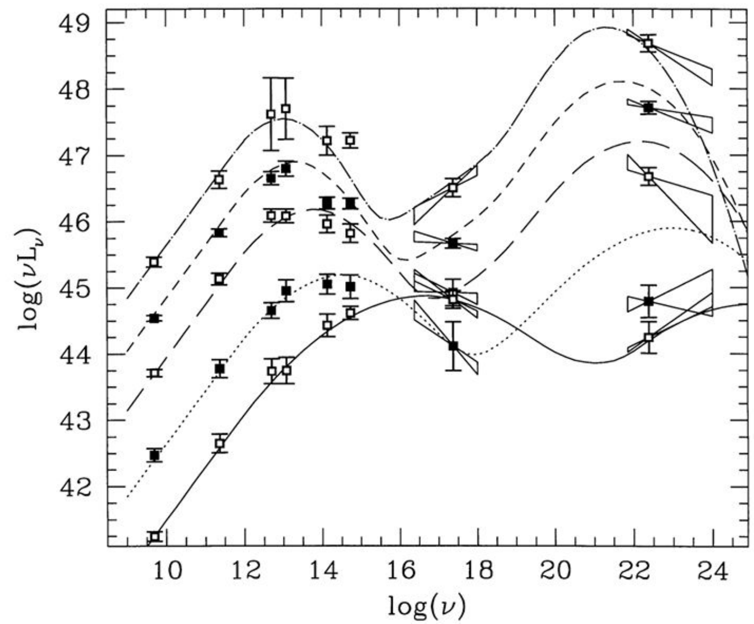


- Find low mass black holes, spinning high mass black holes
- Understand supermassive BH accretion in real time
- Mechanisms for emission still not well understood

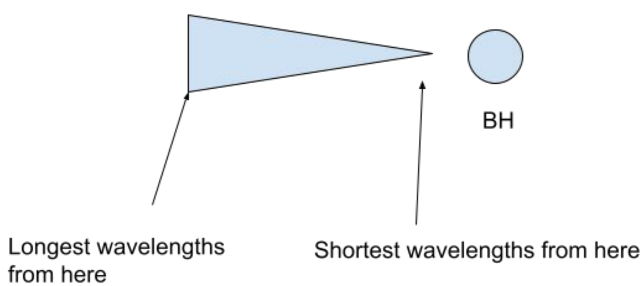
Active Galactic Nuclei



Hood et al. 2023

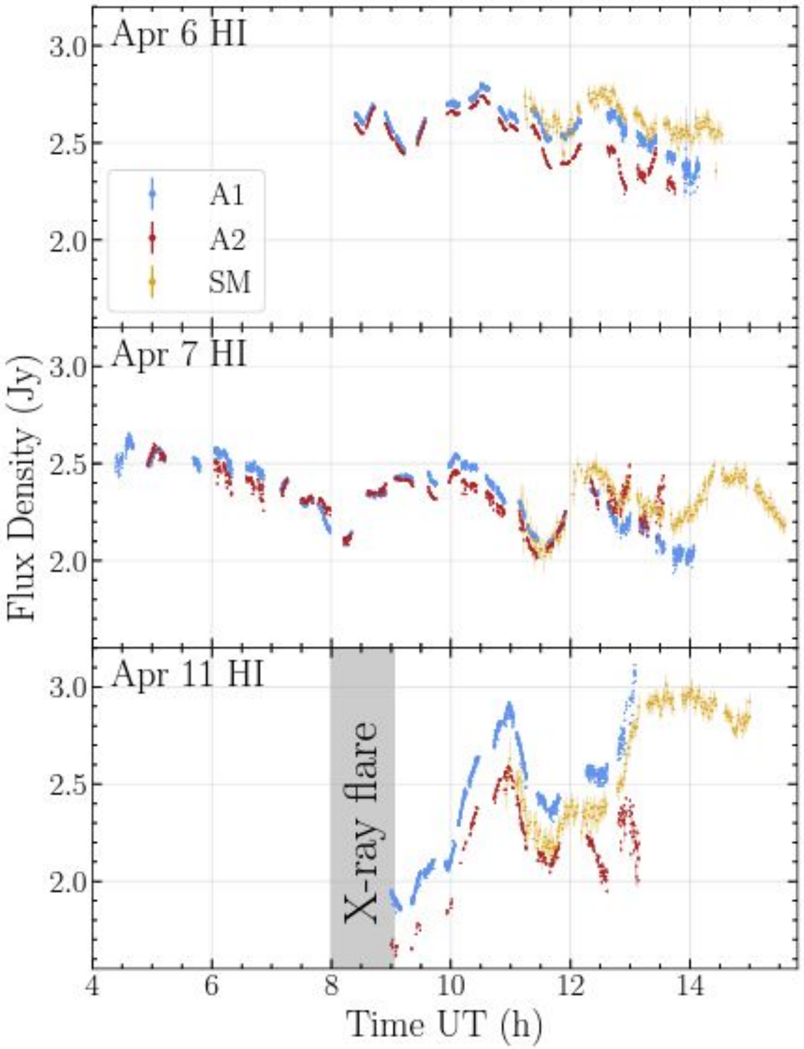


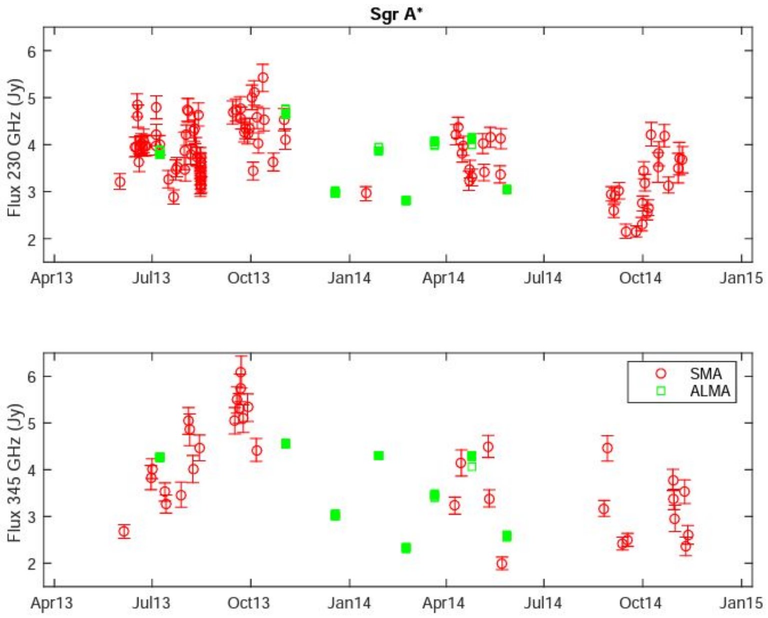
Fossati et al. 1998



Synchrotron self absorption means that the highest photon frequencies come from the parts of the jet closest to the BH (e.g. Blandford & Konigl 1979)

Sgr A* monitoring





Bower et al. 2015

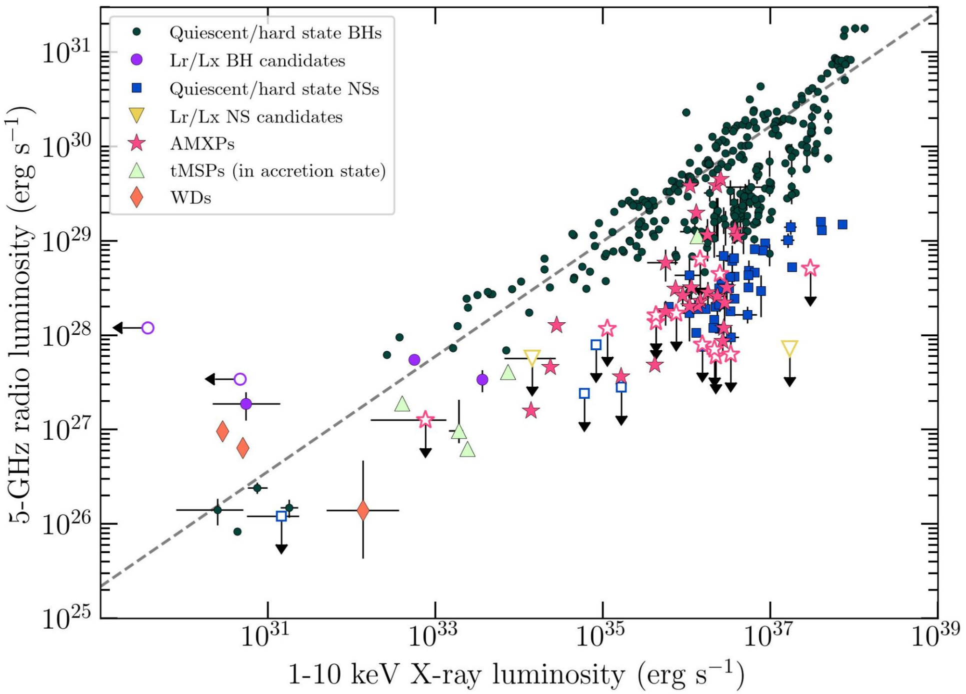
Jet or inner hot flow?

Frequency dependent lags can help sort this out!

Wielgus et al. 2022

Stellar Mass Black Hole Jets

- Physics of jet production best probed via stellar mass objects
- Steady jets and ballistic ejections both seen (triggering ngEHT)



Plot from Arash Bahramian's compilation; see e.g. Hannikainen et al. 1997

Crooked branch: beaming (e.g. Motta et al. 2018)? Disk structure (e.g. Carotenuto et al. 2021)

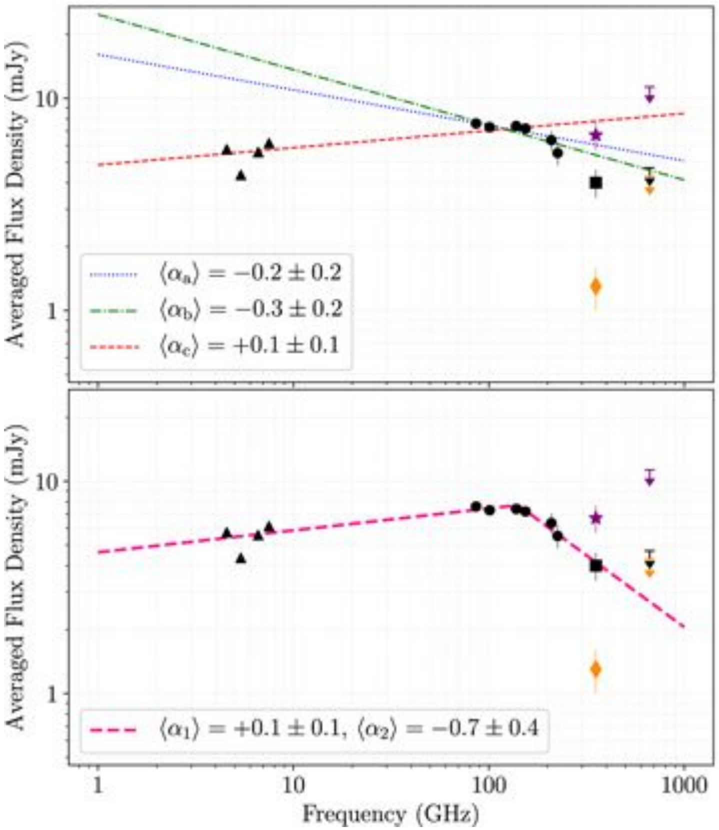
Need more monitoring to solve. Spectral indices help understanding greatly

Magnetars

Neutron stars powered by magnetic field decay

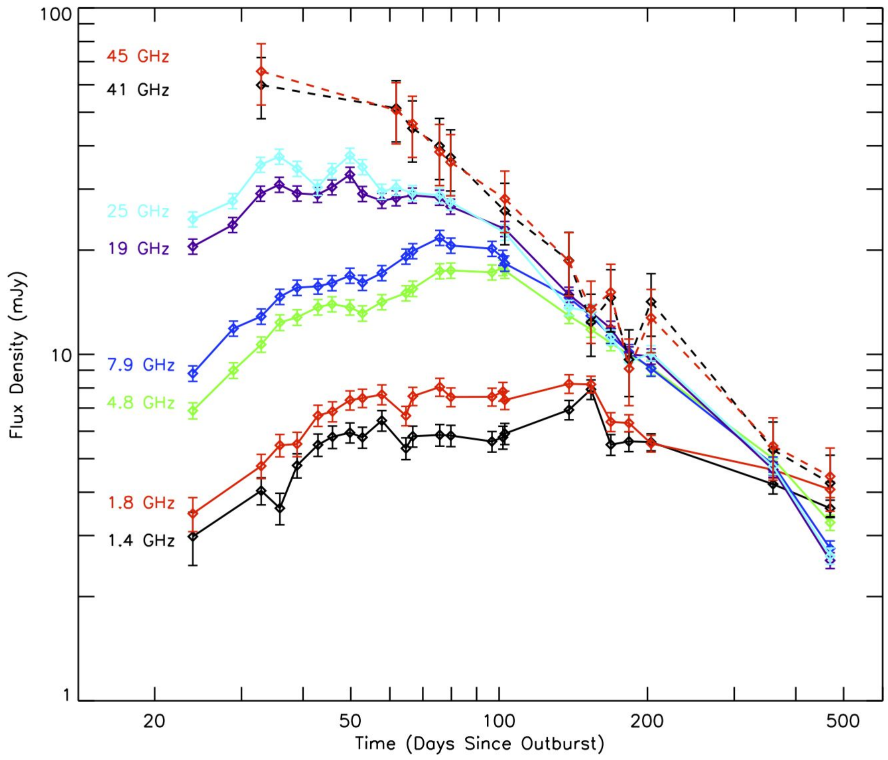
Show flat spectrum radio emission during outbursts, probably associated with X-ray flares

Magnetar pulsations a driver for eventually getting second-timescale time resolution



Classical Novae

- Thermonuclear explosions of accreted material on white dwarf surfaces
- Understanding them may be relevant to understanding Type Ia supernova progenitors, some aspects of cosmic nucleosynthesis
- Many are missed in the Galactic Plane due to foreground extinction
- Shocks, thermal, or both?



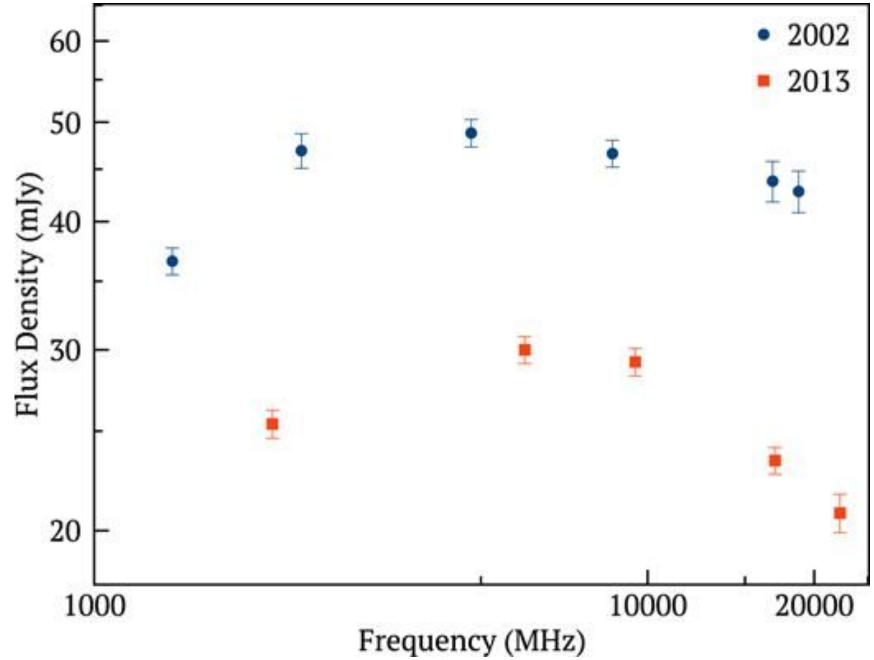
JVLA nova team

S4 should detect lots of young PNe as bright persistent sources

Small fraction vary

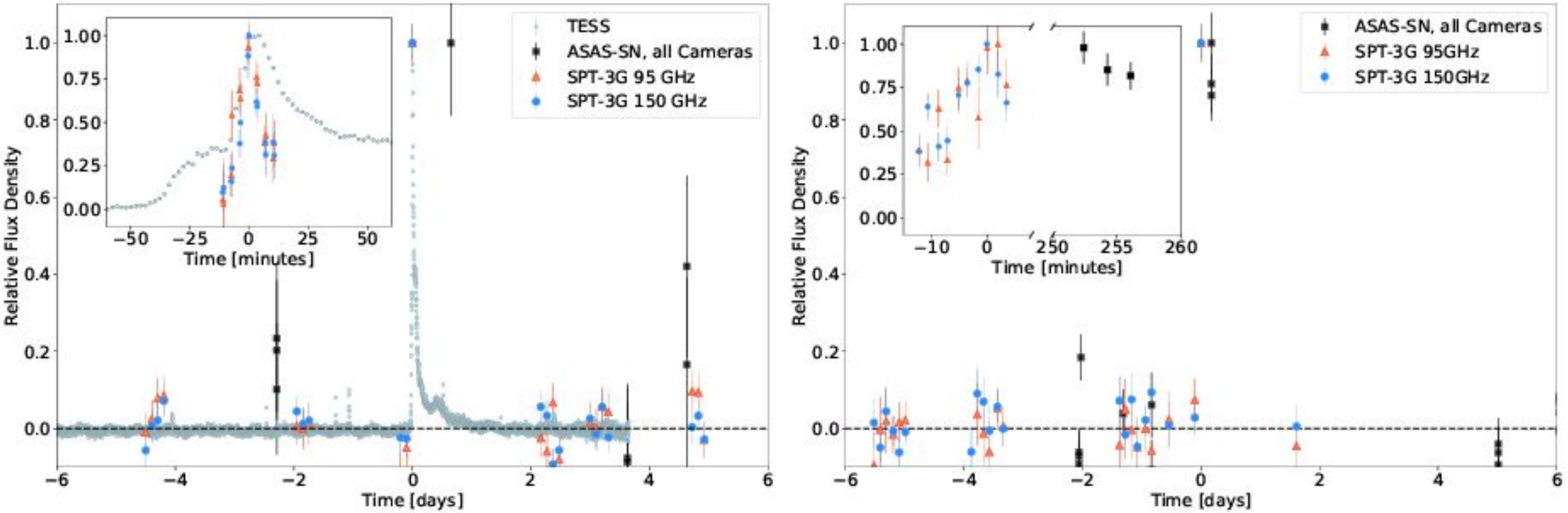
Late thermal pulses?

Jets escaping from nebula?



Stingray Nebula with ATCA, from Harvey-Smith et al. 2018

Stellar Flares

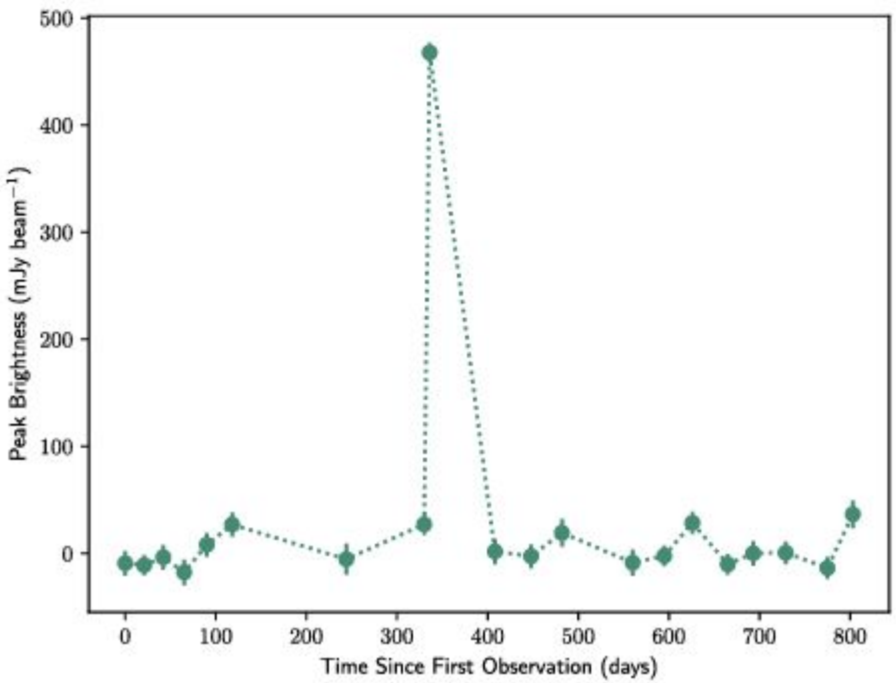


Guns et al. 2021

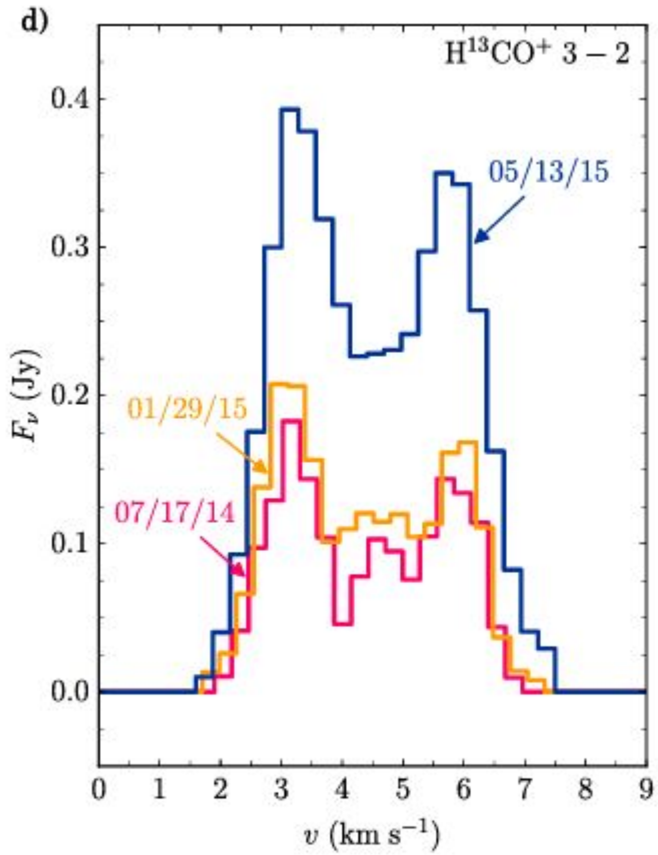
Understand stellar magnetism

Understand flares' impact on planetary habitability

Young stellar object flares



Mairs et al. 2019



Cleeves et al. 2017

Synergies with other facilities

Radio: MWA/LWA (quasi-all-sky), SKA (~100 sq deg)

Optical/IR: Evryscope/Argus (quasi-all-sky) Gattini-IR (25 sq. deg), LSST (fast scanning)

X-ray: Swift/Fermi, Lobsters (~1000 sq deg), STROBE-X, eXTP (~⅓ of sky)

Gamma-ray: CTA (80 sq. deg)

- Follow-up with other millimeter facilities
- ALMA:maybe "overly" sensitive
- SMA: well matched, but in wrong hemisphere

Conclusions

Broad range of astrophysics possible with S4

Some of it can be enabled by coordinating observations done by other facilities with S4 schedule

Current reporting times are largely sufficient, but there could be some benefit to faster reporting of lower quality alerts