Stellar transients in ACT data

The Atacama Cosmology Telescope: Detection of mm-wave transient sources

https://arxiv.org/abs/2012.14347

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ACT efforts on transient sources

Topic	People
Blind transient search	Sigurd Naess (Flatiron), Emily Biermann (Pittsburgh), Yaqiong Li (Princeton)
Archival/Targeted transient searches	Carlos Hervias-Caimapo (Florida State), Yilun Guan (Pittsburgh), Pato Gallardo (Cornell), Brian Koopman (Yale)
Planet-9 search	Sigurd Naess (Flatiron)
Variable AGN	Xiaoyi Ma / Adam Hincks (Toronto) following Heather Prince (Princeton)
Fast transients (e.g. Fast Radio Bursts)	Fernando Zago (McGill)
… plus other projects	

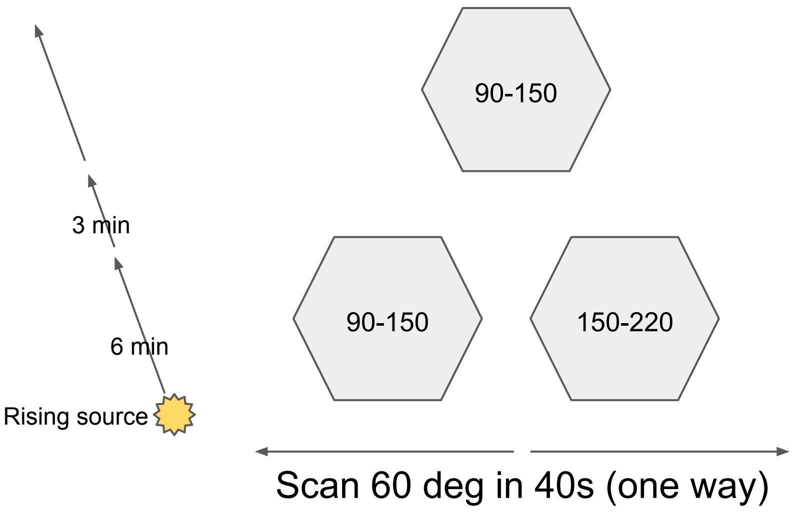
Summary of ACT transient paper

- We identified 3 bright transient events in ACT data.
- Each is spatially close to a bright, nearby star.
    - These stars show evidence of being young
    - The stars have x-ray activity
    - 2 of the stars are known binaries
- The luminosity is similar to other mm-wave flares seen in young stars (but much more luminous than a flare on on the Sun).
- Stellar flares can be caused by magnetic reconnection, enhanced by binarity and protoplanetary disks

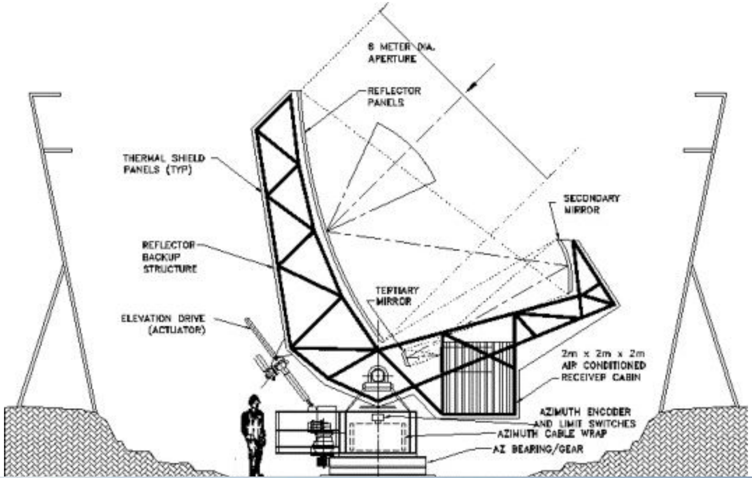
Atacama Cosmology Telescope

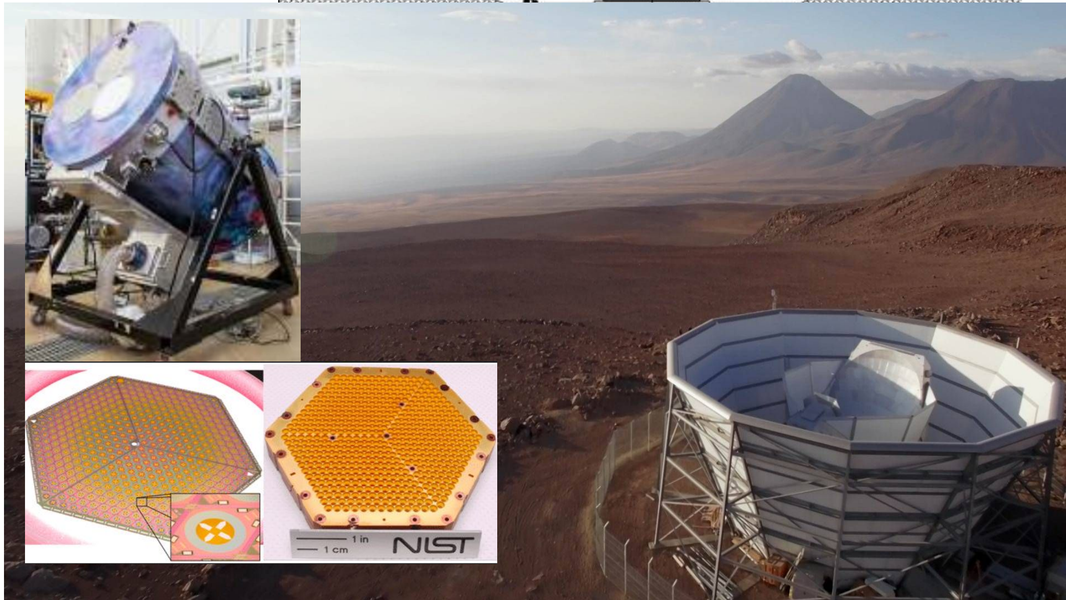
18000 sq deg survey, wide scans in azimuth

3 dichroic arrays (90-220 GHz):

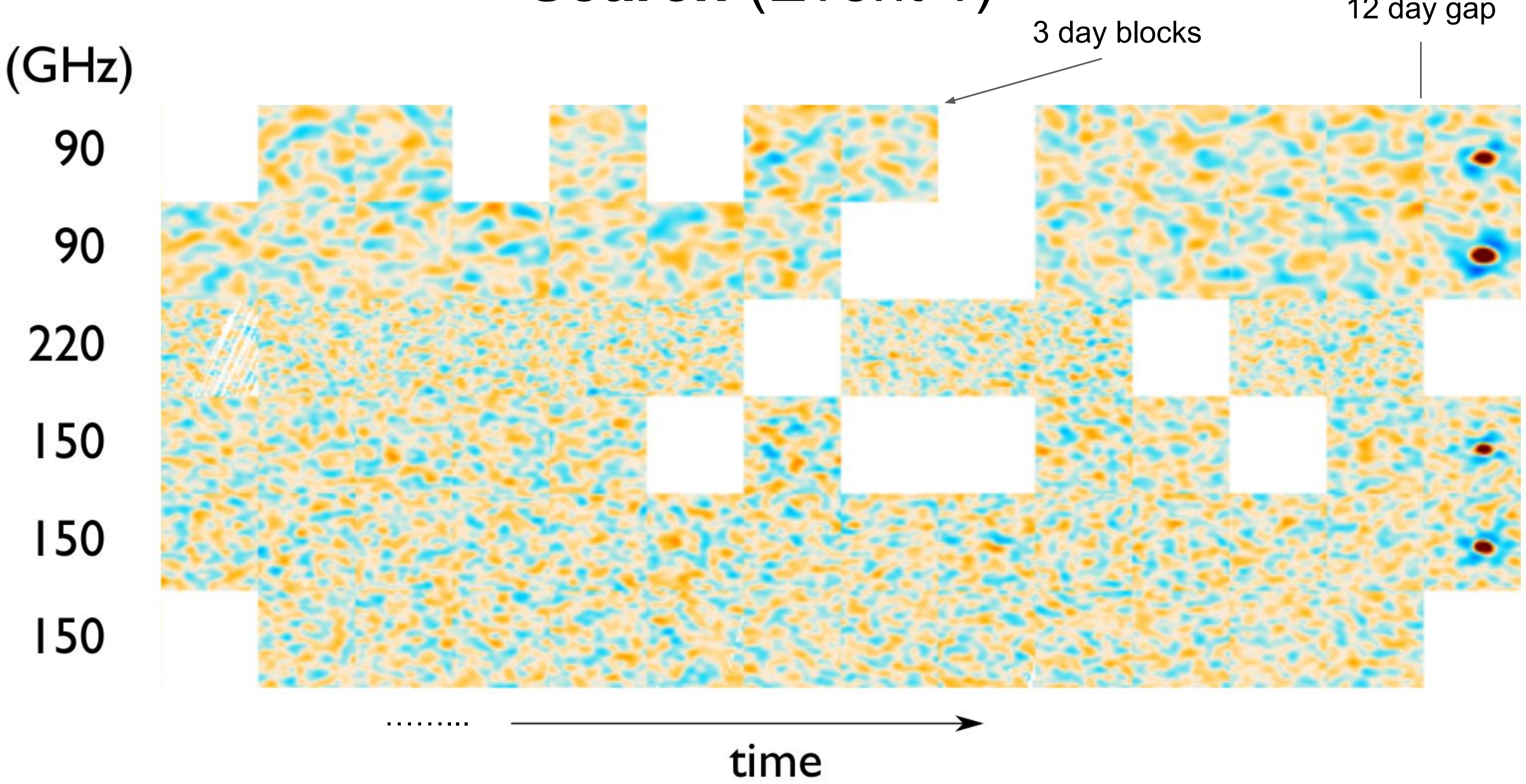


pointing acc. approx 3” in Dec, RA/cos(Dec)

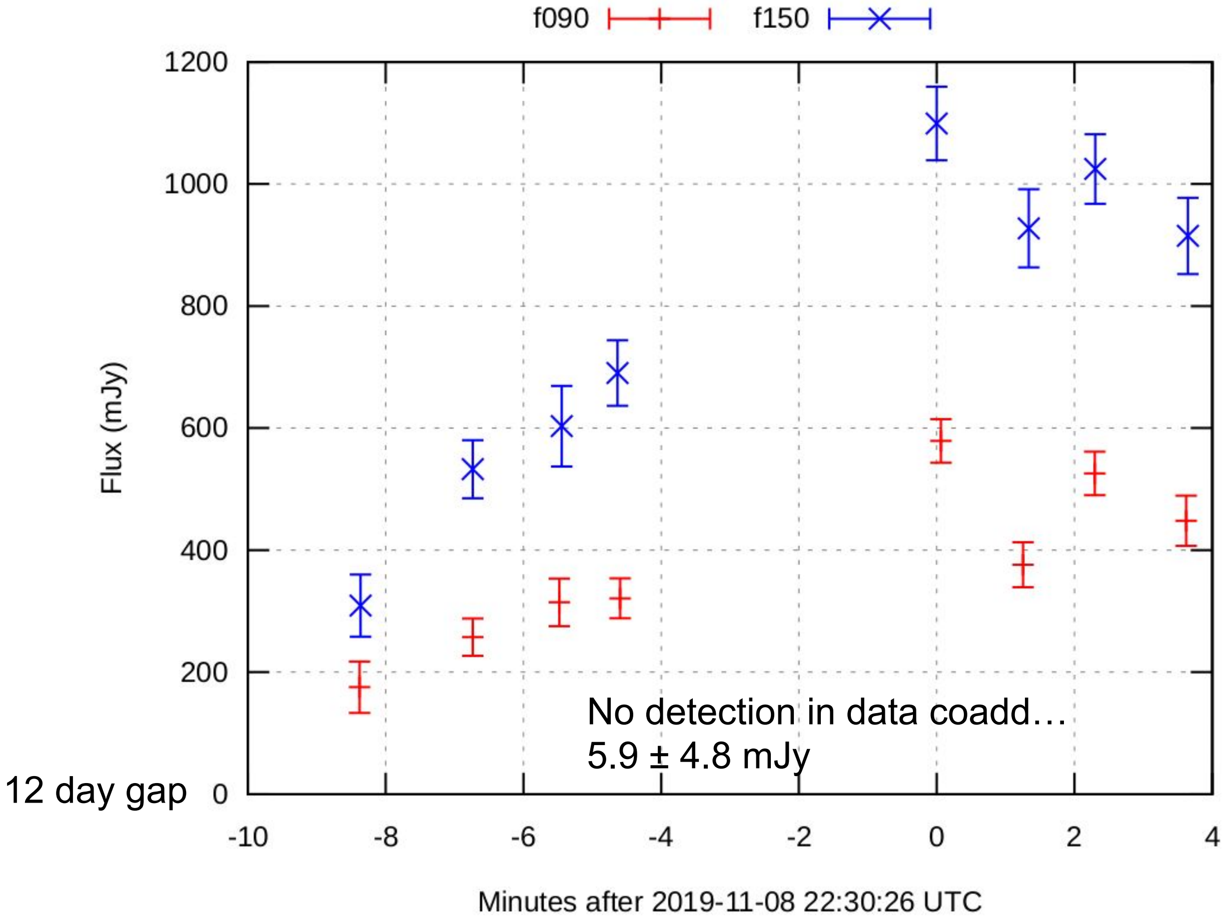




Search (Event 1)



Event 1: detailed light curve



Peak is bright!

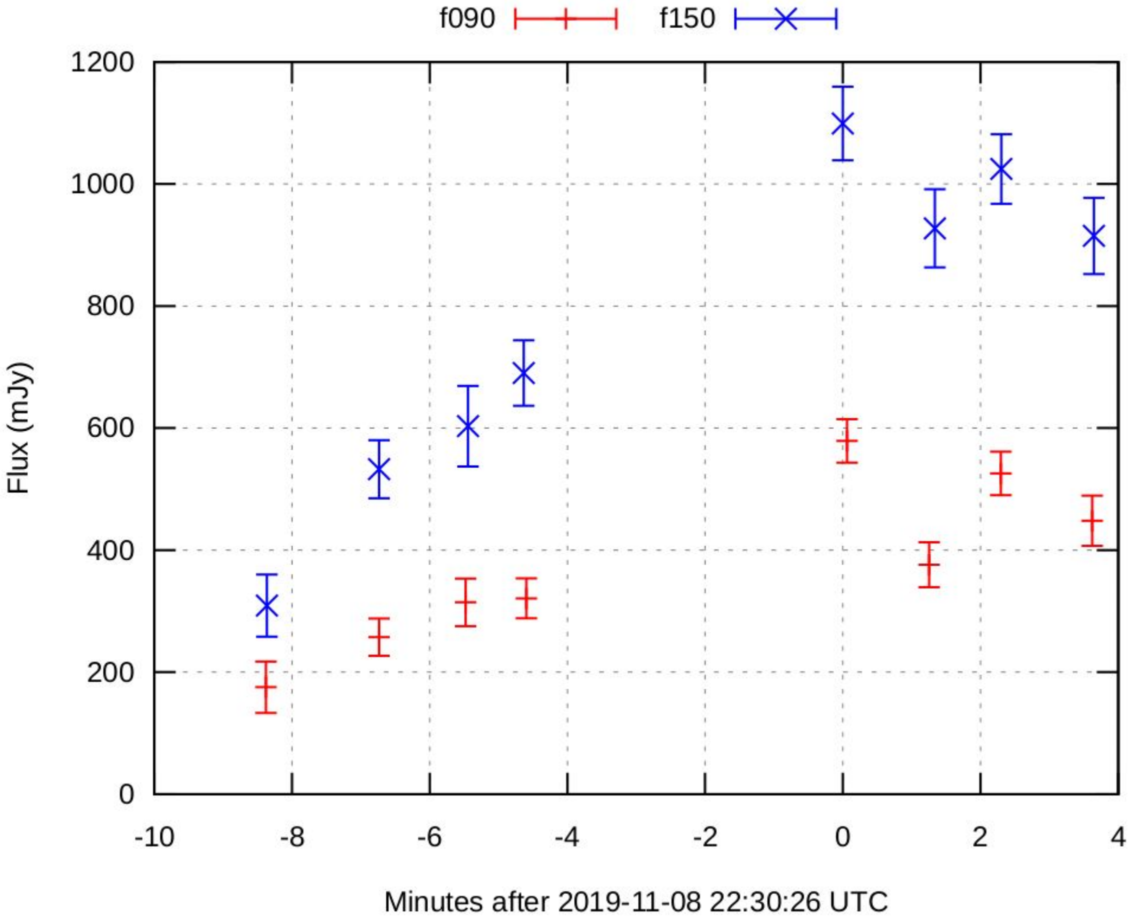
579 ± 36 mJy (f090)

1099 ±60 mJy (f150)

Only 50 brighter objects in whole survey

Fast rise! 8 minutes.

Event 1: detailed light curve



Polarization limits:

<76.8 (15%) (f090)

<57.1 (10%) (f150)

Spectral index:

1.5 ± 0.2

Event 1 associated to 2MASS J18151564-4927472

Association argument by proximity:

$P = 1 - \exp(-n\pi r^2)$ is probability of random association

n is local density of stars brighter than g = 11.72 (from Gaia)

r is the angular separation to the star (3.5”)

$P = 3.7 \times 10^{-4}$ is probability of a star this bright or brighter, this close or closer.

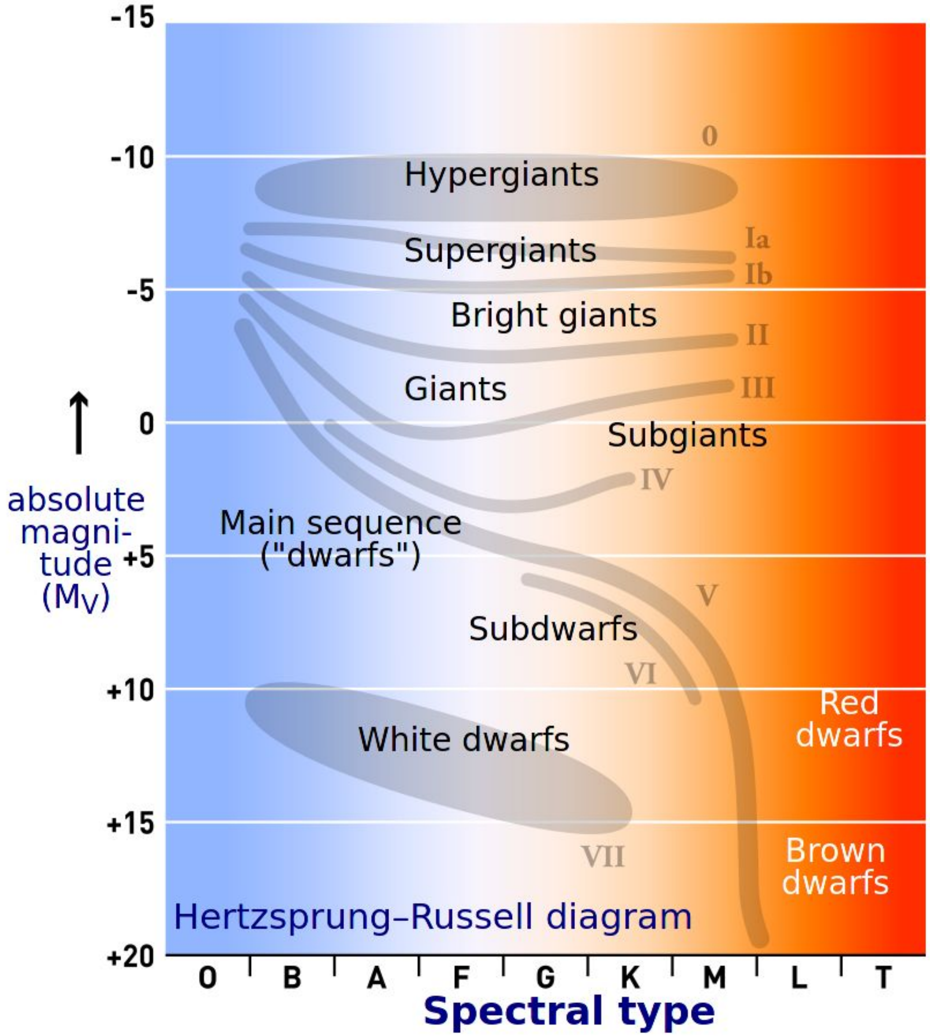
About 2MASS J18151564-4927472

- M3 V star
- High proper motion, only 62 pc distant
- Coincident with ROSAT x-ray source
- Indications of young age:
  - Candidate member of β Pictoris moving group or possibly the Argus assoc: stellar associations with few tens of Myr lifetimes
  - TESS observations with a 0.4 day periodicity, which suggests that it is a rapid rotator.
- Single line spectroscopic binary star

At that distance:

$\nu L_\nu = 2.61 \pm 0.16 \times 10^{22}$ W (f090) $\nu L_\nu = 7.59 \pm 0.42 \times 10^{22}$ W (f150).

(a million times brighter than a bright solar flare, assuming isotropic)



-15
-10
-5
0
+5
+10
+15
+20
absolute magni- tude (M_V)
Hypergiants
Supergiants
Bright giants
Giants
Subgiants
Main sequence ("dwarfs")
Subdwarfs
White dwarfs
Red dwarfs
Brown dwarfs
0
Ia
Ib
II
III
IV
V
VI
VII
Hertzsprung–Russell diagram
O B A F G K M L T
Spectral type

Event 2

Steady flux discovered after 8 day gap:

143 ± 13 mJy (f090)	pol < 74.2 mJy(41%)
304 ± 18 mJy (f150)	pol < 63.0 mJy (31%)

Not observed subsequently in season.

Spectral index $\alpha = 1.8 \pm 0.2$

Event 2 associated to star HD 52385

Chance P = 8.9×10^{-5} (10.7 arcsec separation, g = 8.11)

About the star:

- Type K0 III
- 403 pc distant in star forming region Canis Major R1
- Associated X-ray source
- mass > 5 M and young (< 1? Myr, Gregorio-Hetem et al. 2009)

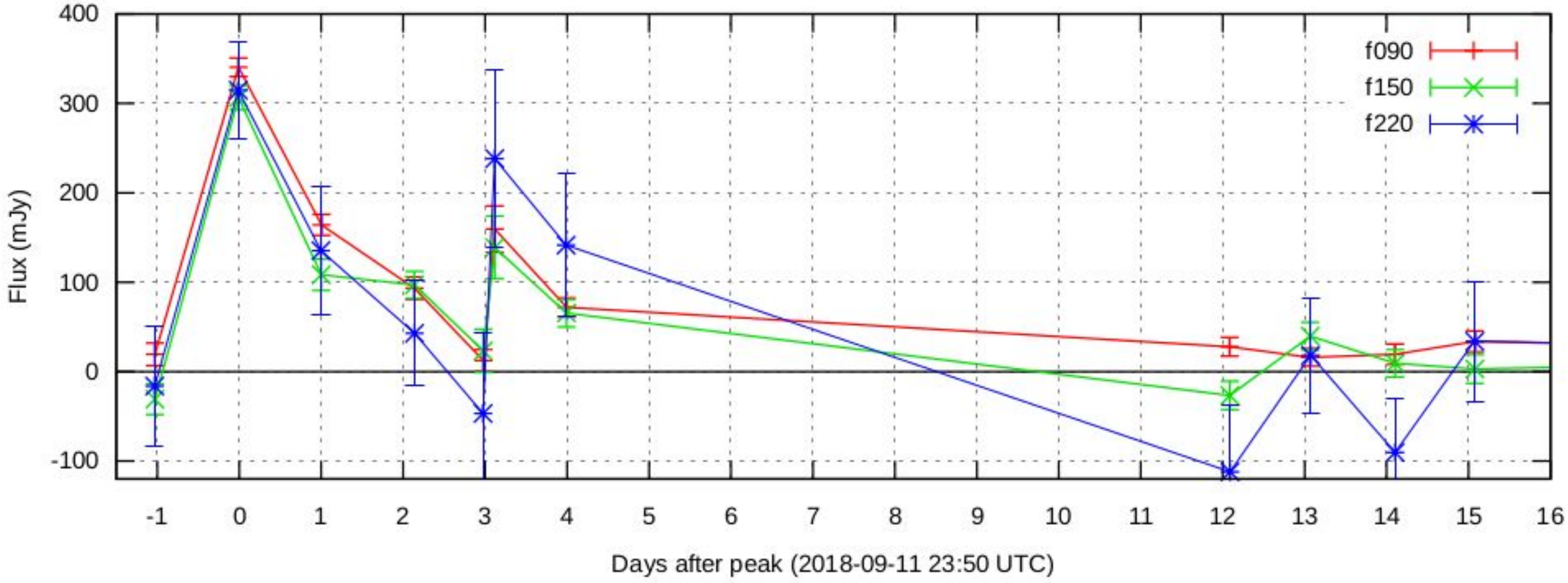
$\nu L_\nu = 27 \pm 2 \times 10^{22}$ W (f090)

$\nu L_\nu = 89 \pm 5 \times 10^{22}$ W (f150)

(10× luminosity of Event 1)

Event 3

Somewhat better time coverage
Spectral index consistent with flat



Event 3 associated to star HD 191179

Chance P = 2.8×10^{-5} (6.4 arcsec separation, g = 7.96)

About the star:

- Spec. binary, types K0 IV + G2 V or K0 IV + G2 IV
- 219 pc distance
- Associate with X-ray source
- Categorized in literature as young, fast rotating, chromospherically active

Common features in our stellar associations

- Likely young stars
- Producing X-rays: energetic processes
- 2/3 known binaries
- 2/3 known fast rotators

Comparison to other mm stellar flares

- These were targeted observations
- Luminous events tend to be young and/or binary stars
- Starforming regions, T Tauri stars

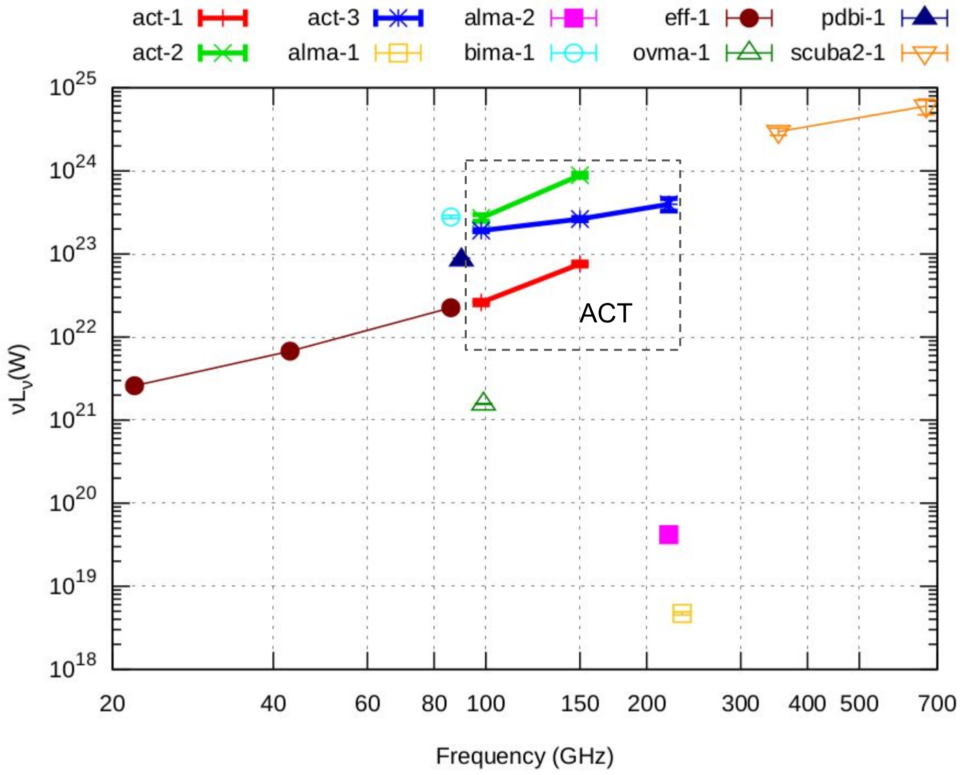


FIG. 4.— Comparison of the characteristic luminosity with other bright mm-wave star flares from the literature. **act-1/2/3**: Event 1/2/3 from this paper. **alma-1/2**: Proxima Centauri (MacGregor et al. 2018) and AU Mic (MacGregor et al. 2020) flares measured with ALMA. **bima-1**: Flaring of GMR-A in the Orion Nebula (Bower et al. 2003). **eff-1, pdbi-1**: V773 Tau by Umemoto et al. (2009) and Massi et al. (2006) respectively. **ovma-1**: σ Gem (Brown & Brown 2006). **scuba2-1**: JW 566 (Mairs et al. 2019).

Finally some physics

- Mechanism for stellar flares is magnetic reconnection
- enhanced in young stellar objects by interactions with protoplanetary disc
- enhanced in binary star systems (corona interactions)
- Reconnection physics not well-understood

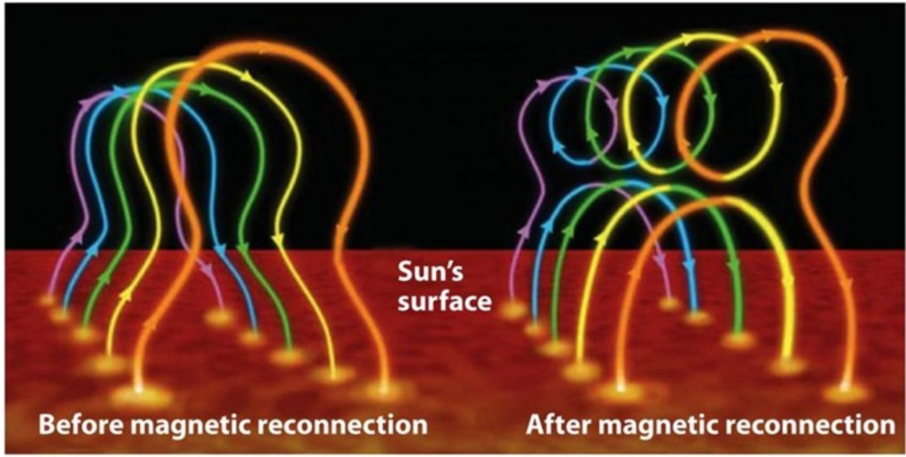
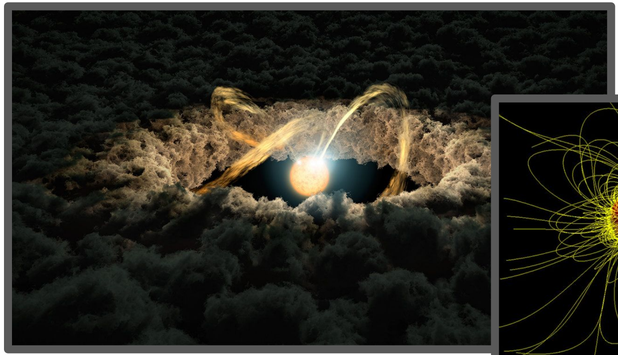
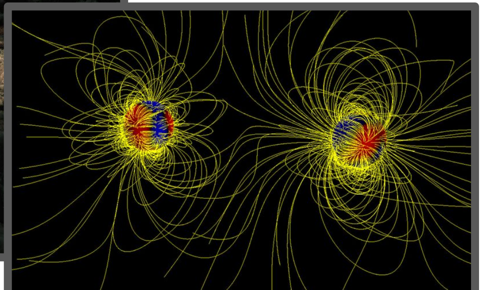
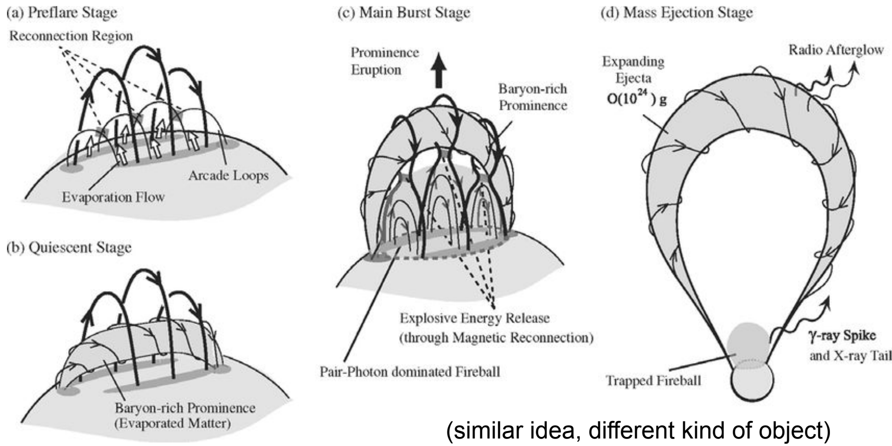


Figure 16-26b
Universe, Tenth Edition







(similar idea, different kind of object)

Discussion / Conclusions

- Our search was too un-systematic to establish a rate, but these stellar flares must be common
- ACT, Simons Observatory, and CMB-S4 doing wide area searches
- SPT, South Pole Observatory, and CMB-S4 doing rapid cadence searches
- Our lack of time coverage shows the importance of regular and frequent cadence
- Complementary the Vera Rubin Observatory’s detection of transients
- Blind search will constrain rates inside and outside of star-forming regions