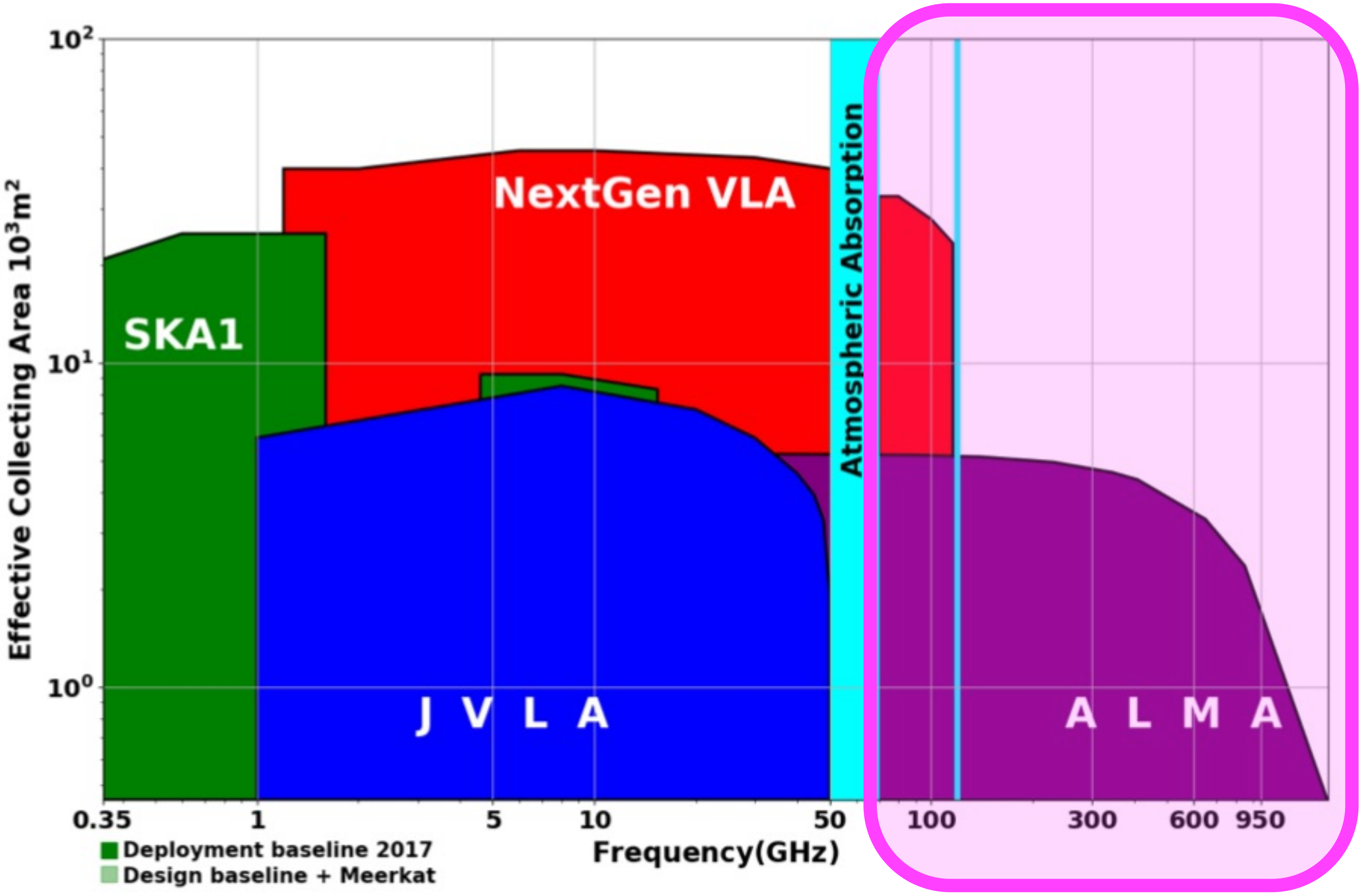
Radio follow-up of GRBs and neutrino events

Yuji Urata

Millimeter & Sub-millimeter Observations

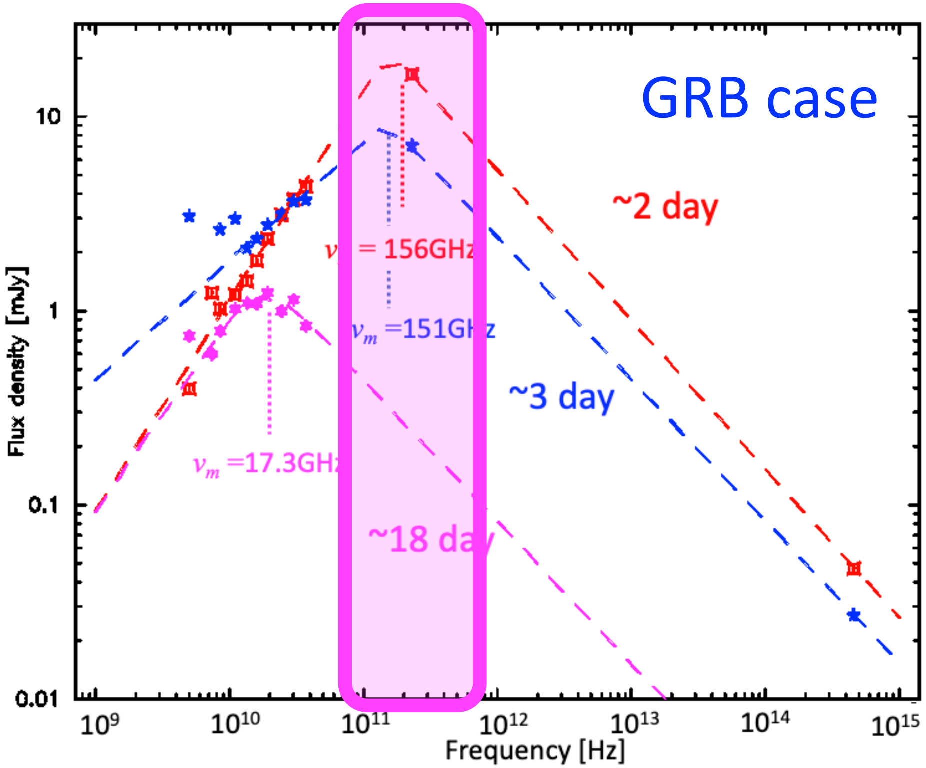
Frequency & major projects



Two advantages of millimeter obs on multi-messenger astronomy

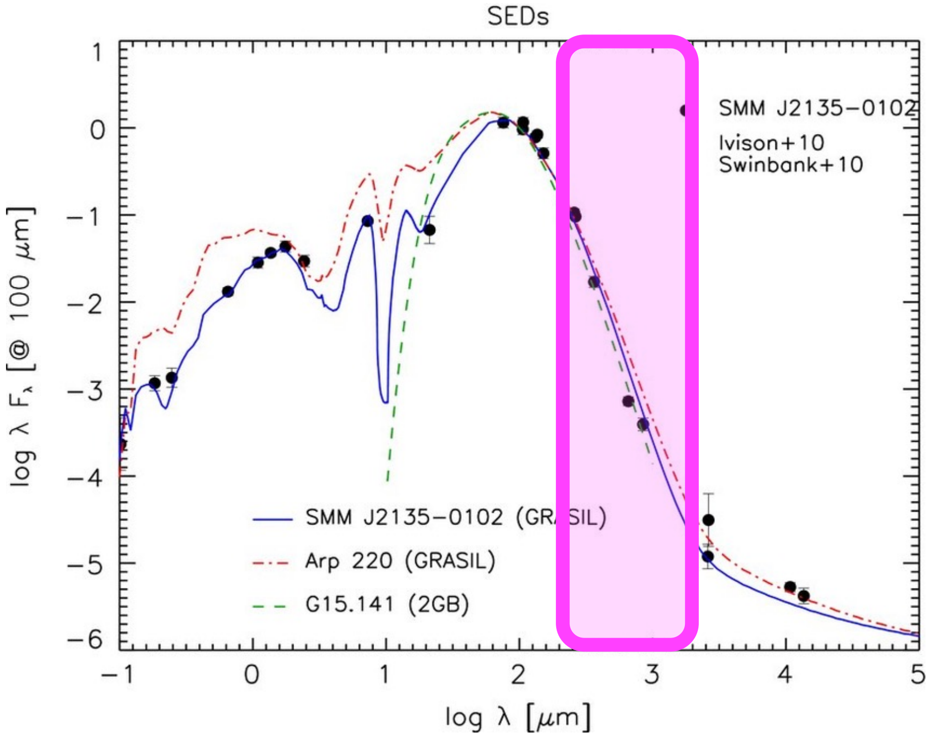
Characterization of synchrotron radiation

Spectral peak and its temporal evolution
Providing various physical parameters



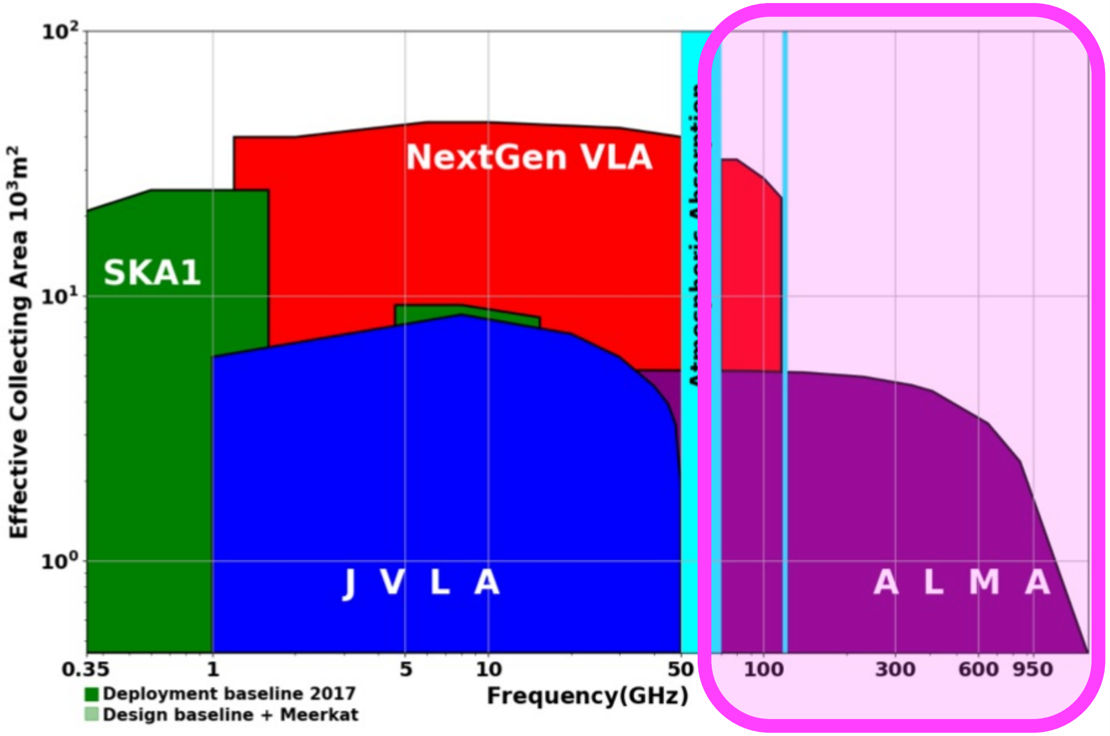
SED of dusty galaxies and AGN

As counterpart of neutrino events

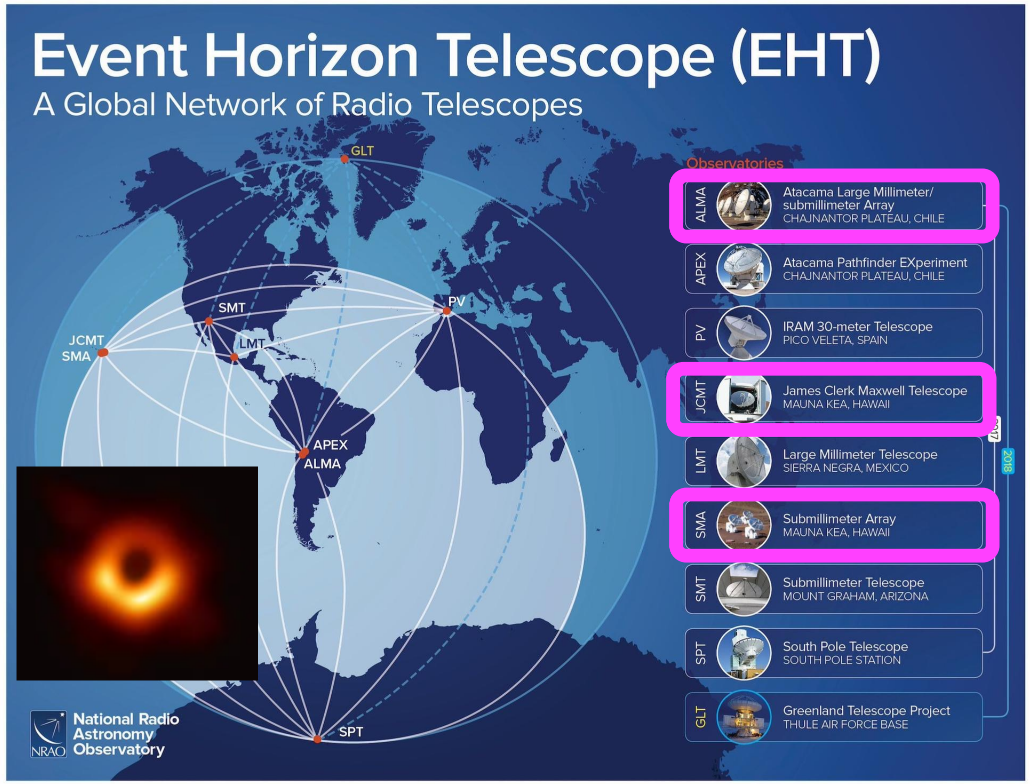


Millimeter & Sub-millimeter Observations

Frequency & major projects



Mm/submm telescopes



Millimeter & Sub-millimeter Observations

ALMA

Interferometer
High resolution
Narrow FOV
Photometry
Spectroscopy
Polarization

ToO(OT) & DDT

SMA

Interferometer
High resolution
Narrow FOV
Photometry
Spectroscopy
Polarization

ToO(Classical) &DDT

JCMT

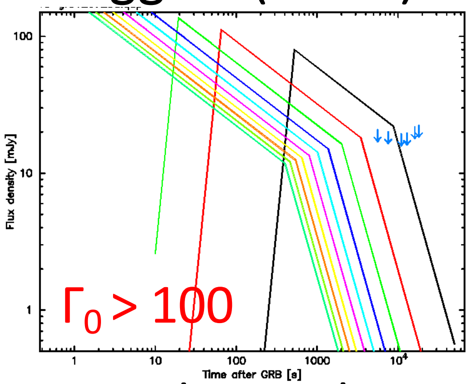
Single dish
Wide FOV
Poor resolution
Photometry
Spectroscopy

ToO (rapid& OT) &DDT

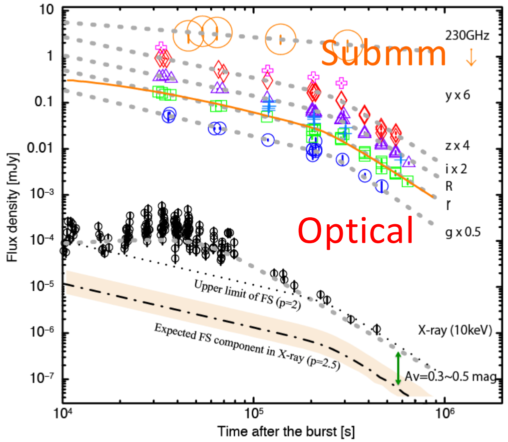
High level ToO managements

Rapid response

RS search with ~1hr from GRB triggers (JCMT)

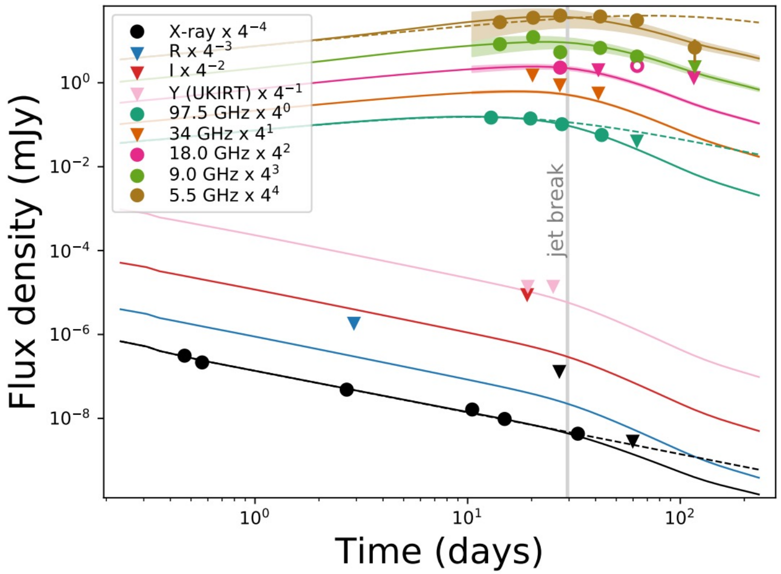


Intra-day evolution



Joint monitoring

(multi-mm telescopes) JCMT+SMA+ACA +ALMA+VLA

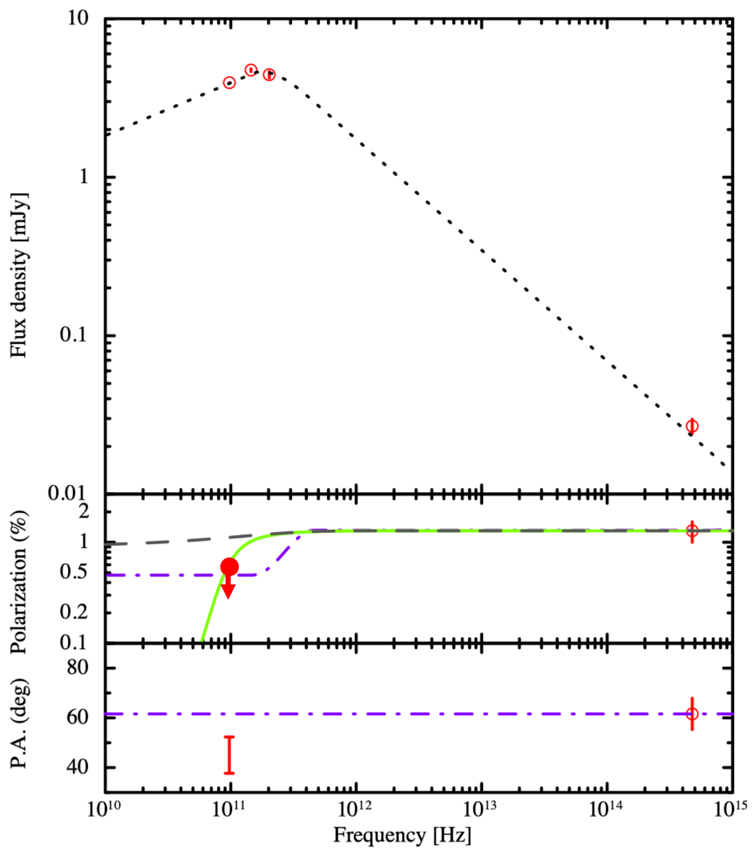


Essential for short/long GRB afterglow characterizations

1 short GRB detection

Multi-wavelength simultaneous polarimetry

(ALMA + VLT / IXPE)



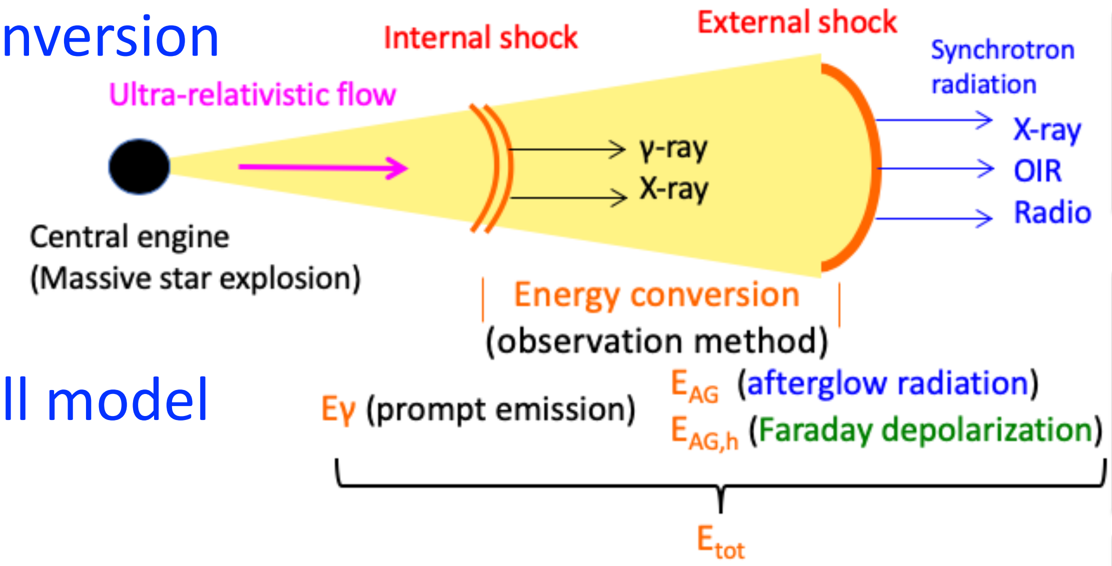
Examples of ToO managements : GRB polarimetry

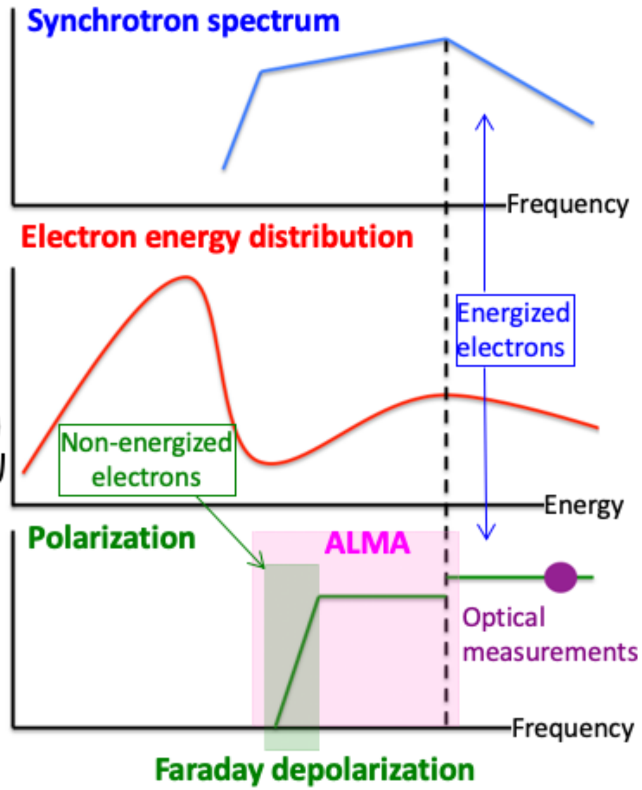
■True energy including shock acceleration efficiency can reveal the nature of their progenitor

(c.f. SNR , solar winds; not 100% acceleration)

Energy conversion

Fireball model





Total energies have been estimated without acceleration efficiency at the shock

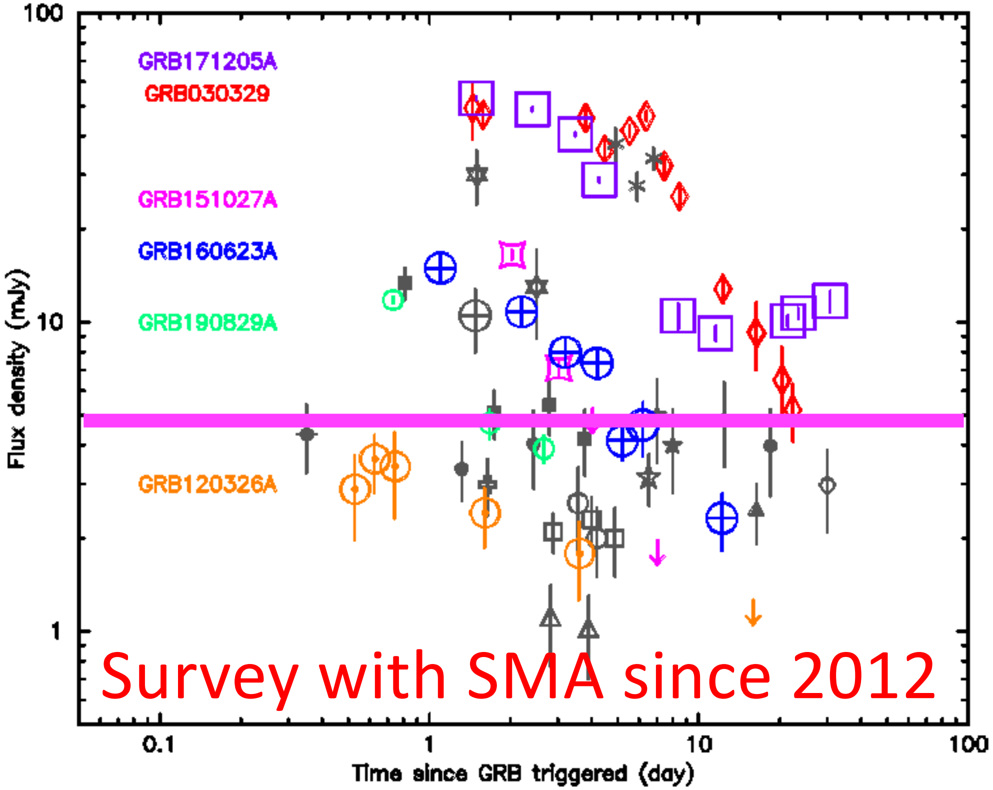
➡ ALMA polarimetry

Difficulty of Radio and Simultaneous Polarimetry

Brightness of millimeter AF

- Polarimetry requires bright events

Pre-SMA only 1 or 2 events was discovered.

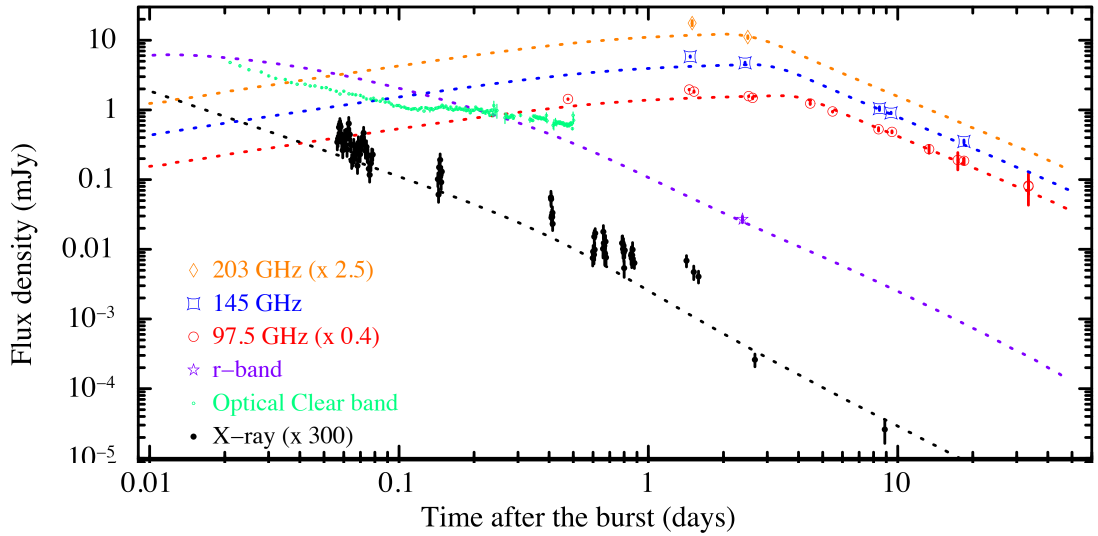


Timing (bright phase)

Light curves

X-ray, Optical : Fading from ~0.1 days

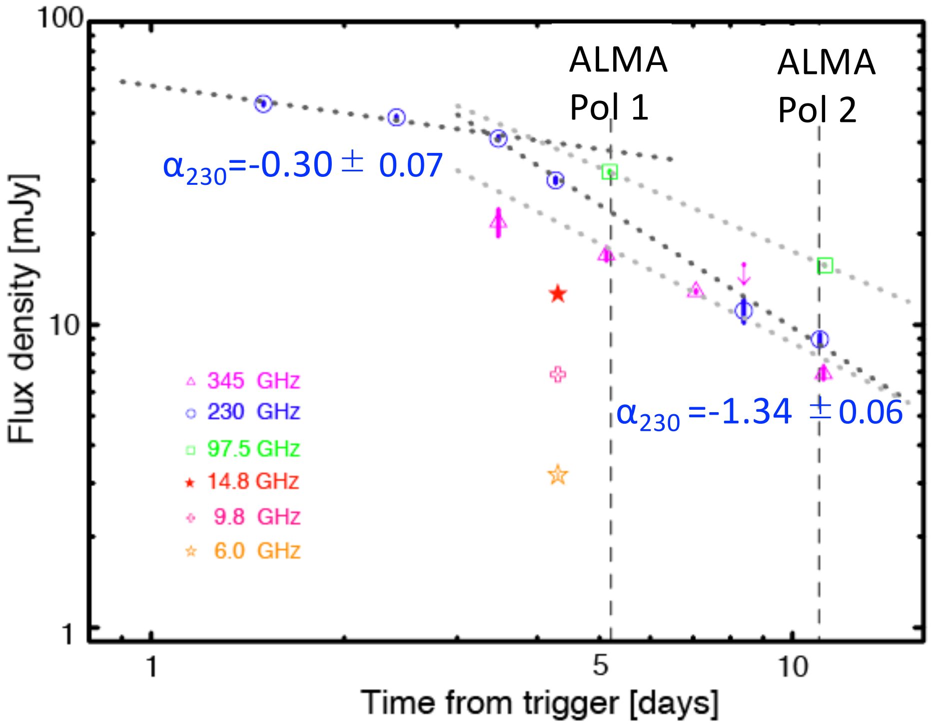
Radio : Peaking 3~5 days

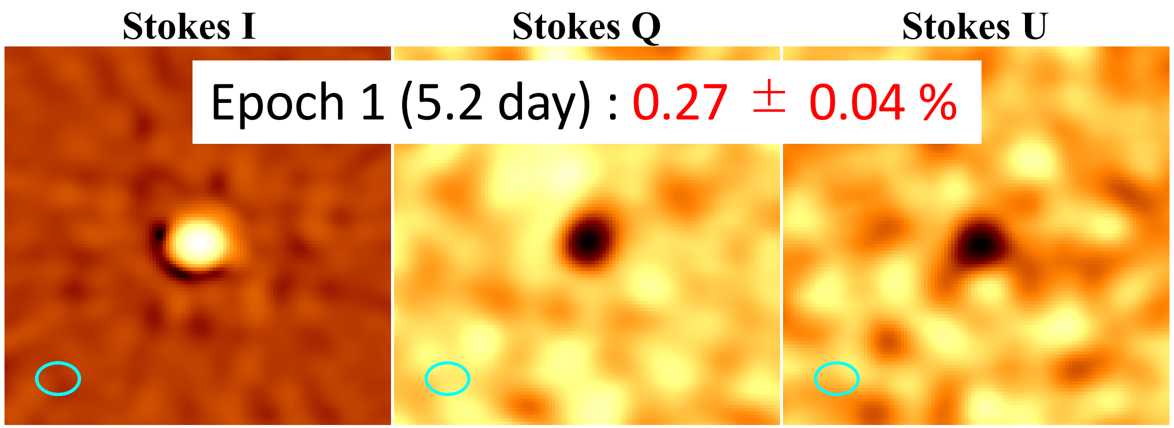


First Detection of Radio Linear in a GRB afterglow

Urata+19 ApJL

- First Detection of Radio Linear Polarization on GRB171205A
- The brightest (~50 mJy) mm afterglow (brighter than GRB0303029)
- GRB 171205A (z= 0.0368 : Low-Luminosity GRB)





Significantly smaller than typical value of optical afterglows (i.e. Forward shock)

Weighted average 1.2 %

Simple average 1.7 %

Range 0.5-10%

Faraday depolarization

First Detection of Radio Linear in a GRB afterglow

Urata+19 ApJL

Only radio polarimetry

Assuming original polarization (P_0) based on optical afterglow statistics (average ~1%, range 0.5-10%)

Polarization spectrum

(1) averagel value of optical afterglows, 1%

(2) minimum value of optical afterglows, 0.5 %

the acceleration efficiency, *f* (<1):

P_0=1.0%: *f*=1/12

P_0=0.5 %: *f*=1/10

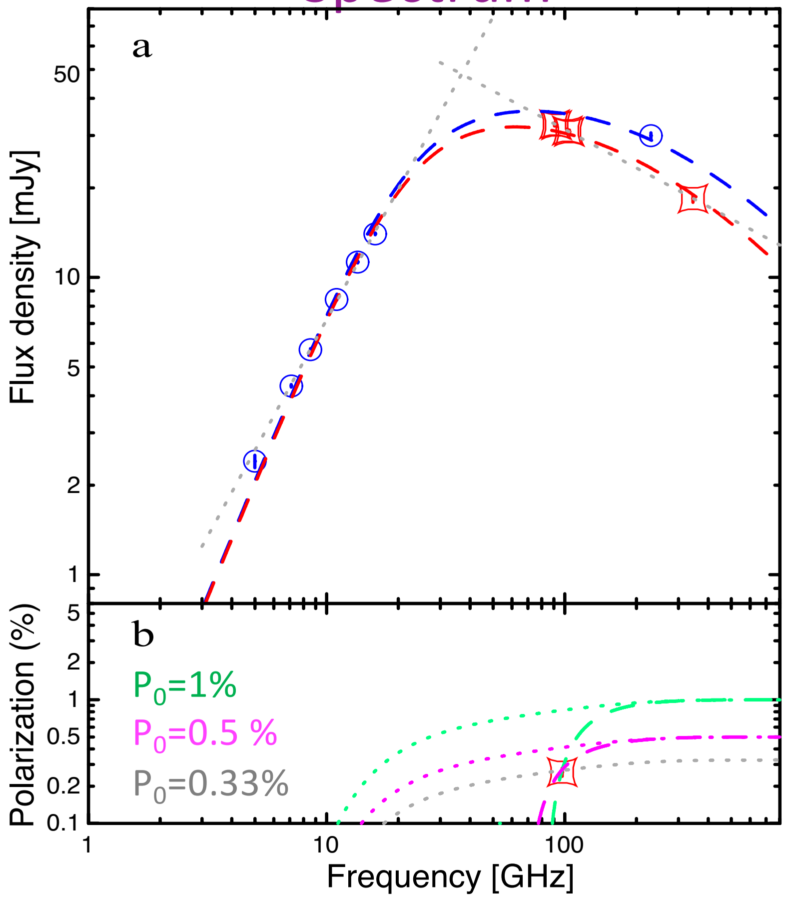
i.e. only ~ 10% of electrons are accelerated

(P_0=0.33%: *f*=1 i.e. no Faraday depolarization)

Revising total energy ~10 times larger

Further confirmation, simultaneous polarimetry in radio and optical is required.

Spectrum

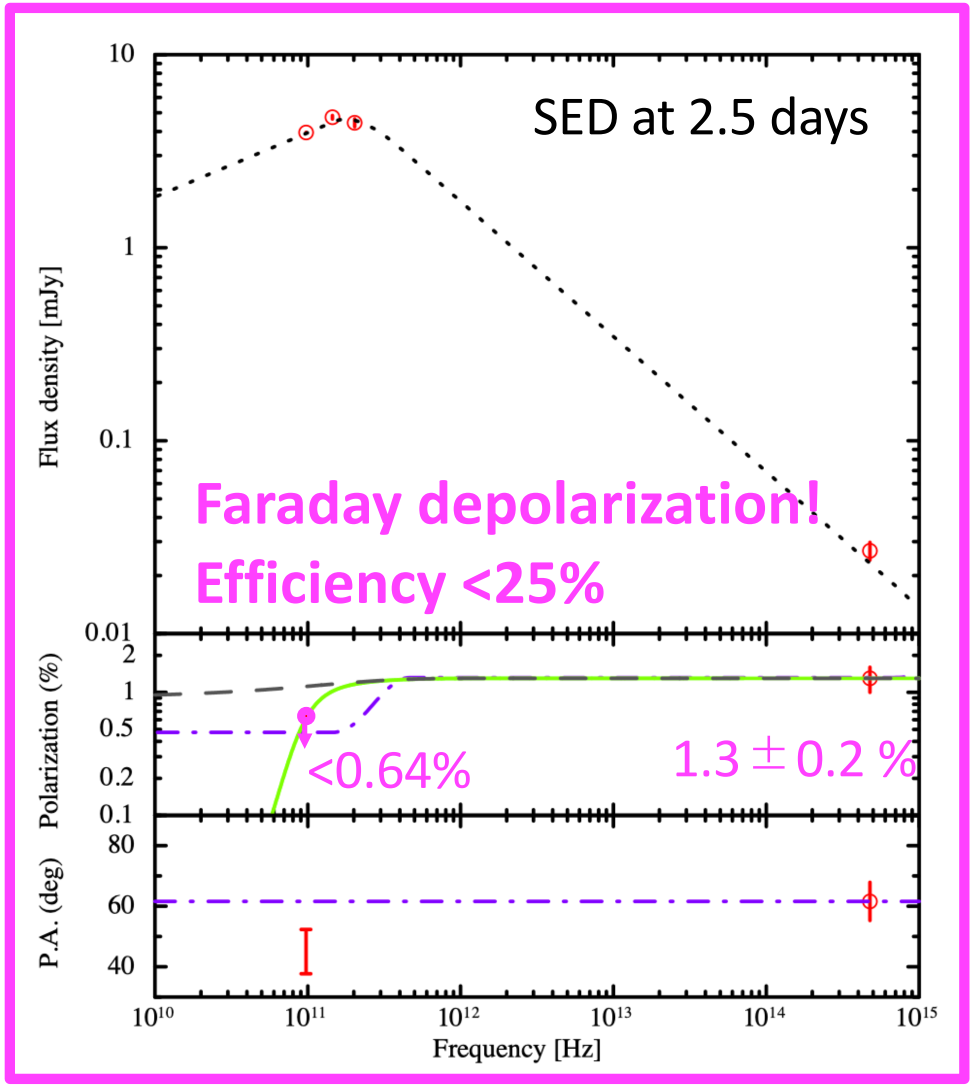


Multi-band polarimetry for GRB afterglows

Urata+19 ApJL
Urata+23 Nature Astr.

- Four polarimetry with ALALMA
- GRB171205A (low luminosity GRB)
  First detection radio polarization 0.27%
  Efficiency ~ 10%
- GRB191221B (Classical GRB)
  First simultaneous polarimetry with optical
  Efficiency <25%
- GRB190829A (with TeV emission)
  TeV emission
- GRB221009A (Brightest Of All Time)
  TeV emission
  First simultaneous polarimetry with X-ray
  First multi-frequency radio polarimetry
  No Faraday depolarization

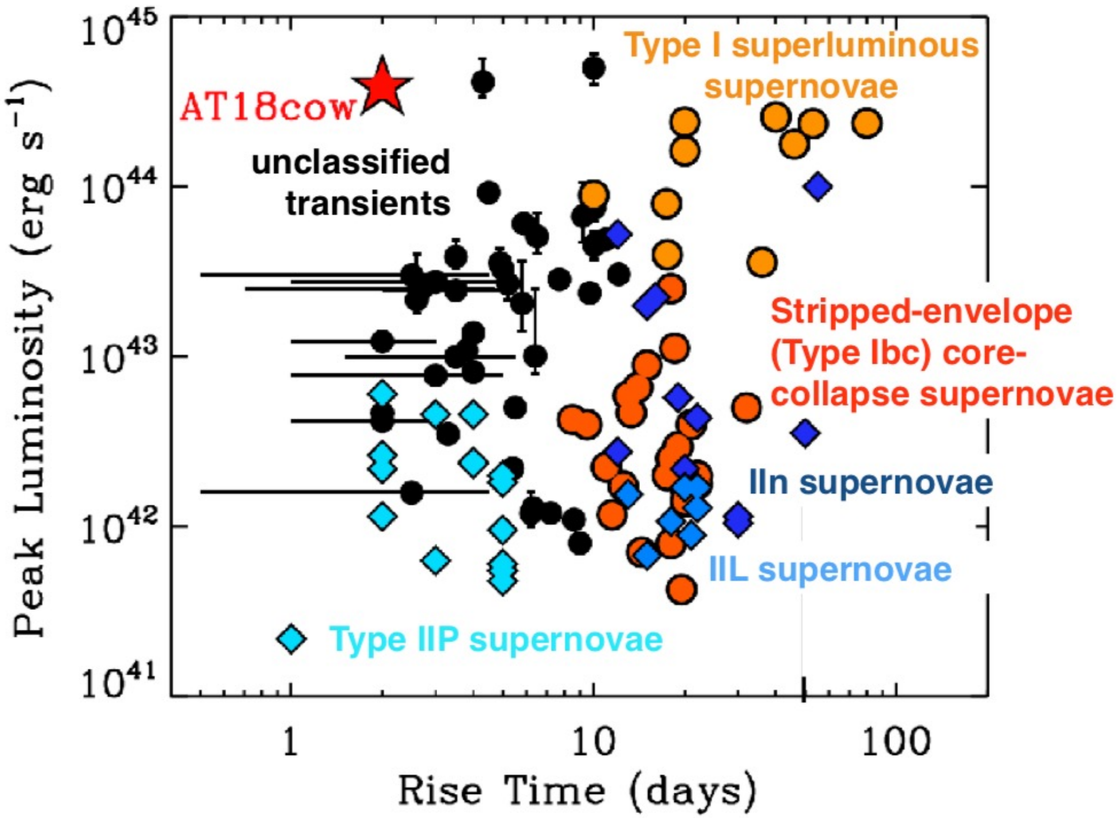
Efficiency seems different along with GRB types.

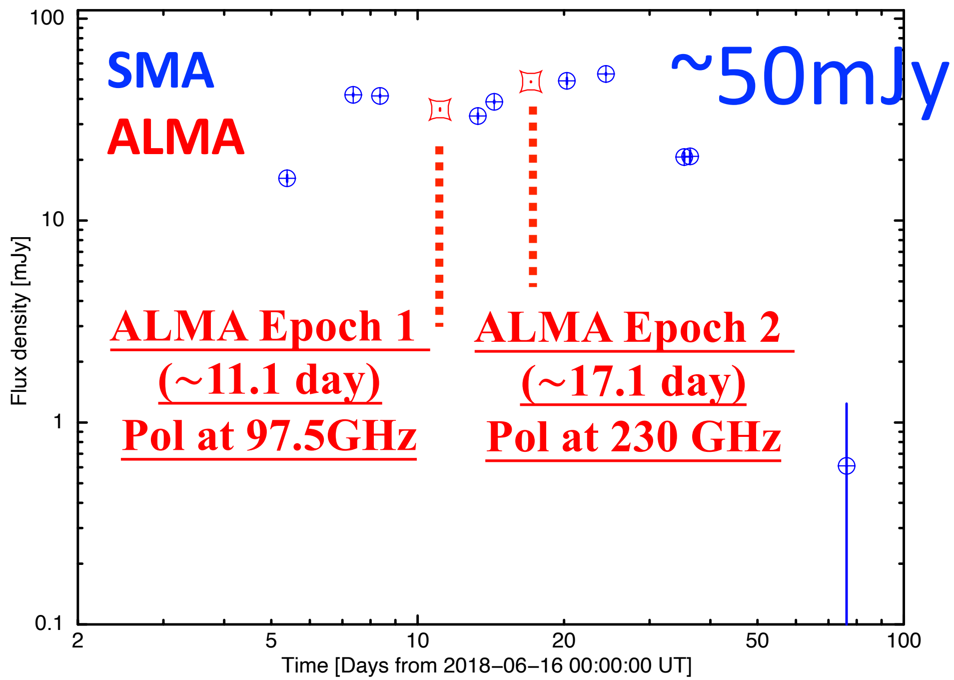


Application to Fast-rising Blue Optical Transient: AT2018cow

➤SMA identified the millimeter counterpart
➤ALMA DDT
➤2 epoch of photometric and polarimetric

New type of transient





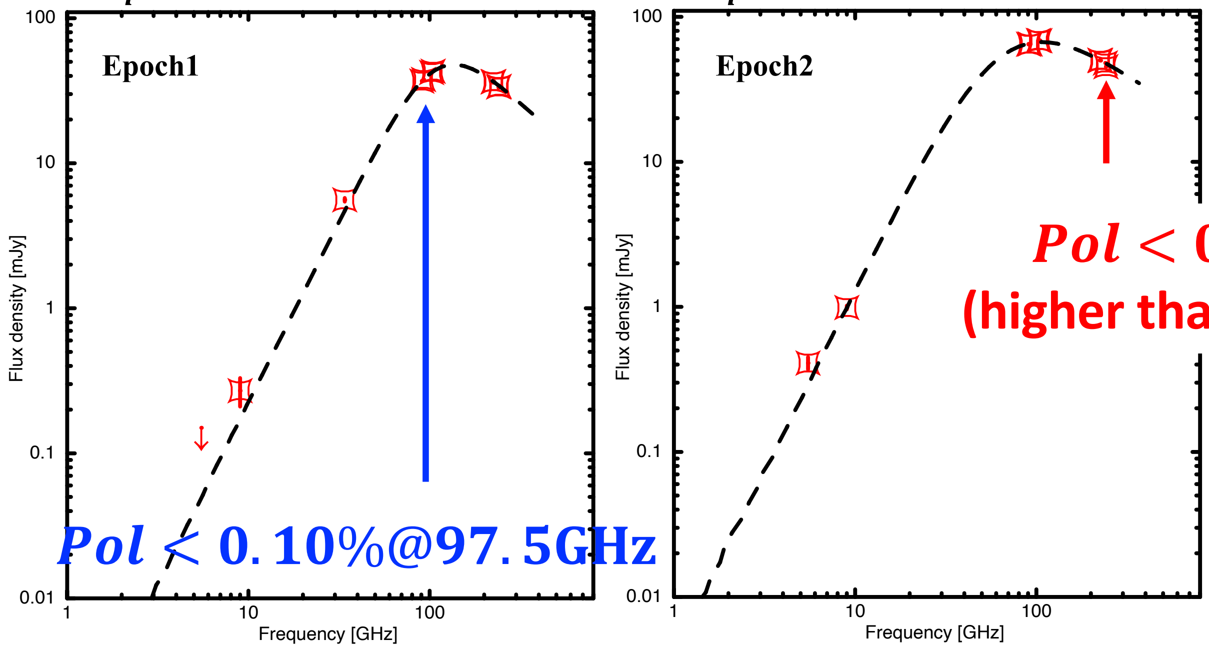
AT2018cow : Results (SED & Polarization)

Huang, YU+2019 ApJL

- **Confirmation of the synchrotron radiation and self-absorption (SSA)**
- **Time dependence of υ_p** $\propto t^{-1.1}$ is consistent with theoretical model
- **Polarization limit (<0.15%) at 230 GHz (higher than the SSA frequency)**
  - **Internal Faraday depolarization : high electron density and strong magnetic field**

→ AT2018cow could be a stellar explosion as PeV cosmic-ray counterpart!

$\upsilon_p = \upsilon_a \sim 109.8 \pm 0.5\ GHz$ $\quad$ $\upsilon_p = \upsilon_a \sim 67.4 \pm 1.6\ GHz$



$Pol < 0.10\%@97.5GHz$

$Pol < 0.15\%@230GHz$

(higher than the SSA frequency)

IceCube reported 1.8σ detection

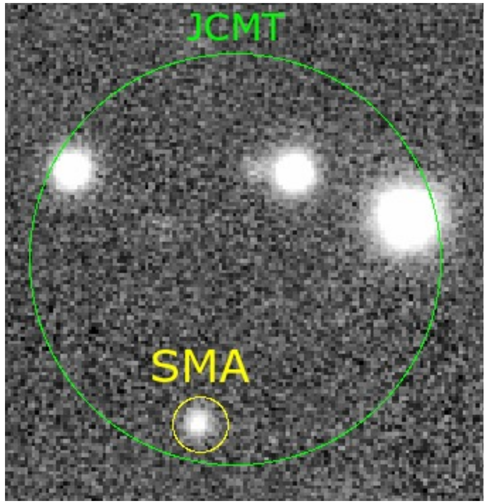
Millimeter follow-ups for neutrino events (JCMT + SMA)

All candidates have millimeter counterparts!

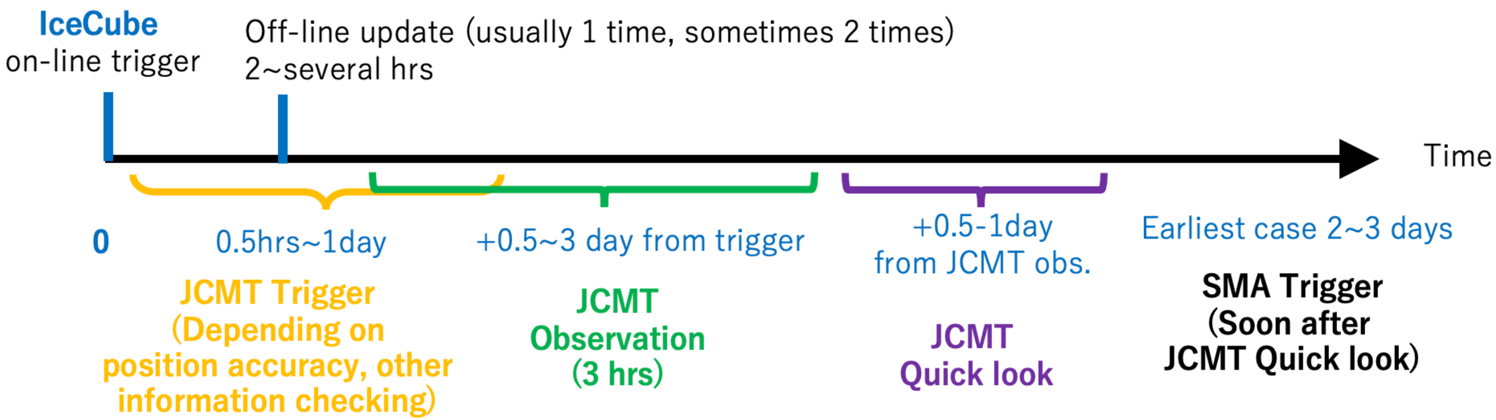
Potential source	Other real time alerts	Persistent source	Finding as transients or variables	Potential major contributor of neutrino?
GRBs	Yes	No	Yes (various wavelength)	Lower possibility
TDE	Usually no	No	Yes (X-ray, optical, radio)	Higher <30%
Supernova	No	No	Yes (optical)	Lower possibility
AT2018cow type	No	No	Yes (X-ray, optical, radio)	Probably lower possibility
Blazar	No	Yes	Yes (various wavelength)	Lower possibility <6%
AGN(w/o γ-rays)	No	Yes	Yes/No	Higher (<~40 %, 27-100%)
Starforming galaxies	No	Yes	No	Higher (<~40%)
Totally new type	Maybe no	?	?	?

Less contamination from other sources

JCMT (Survey ~1deg FOV)
+
SMA (accurate localization)
→ multi-wavelength

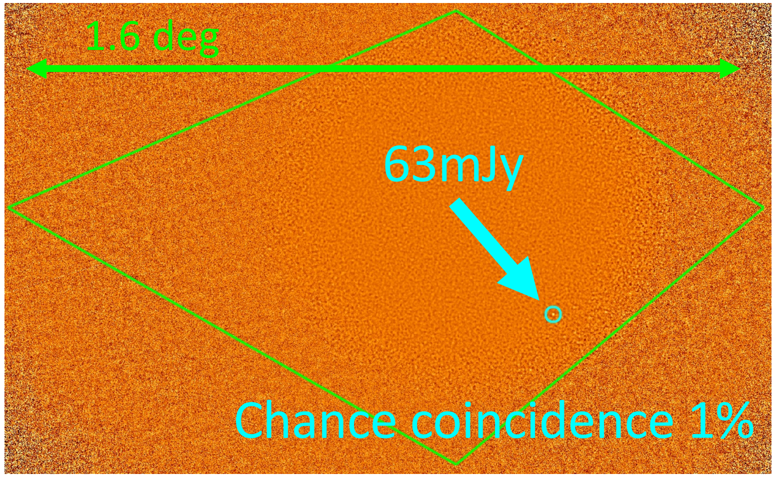


Timeline for JCMT and SMA coordination

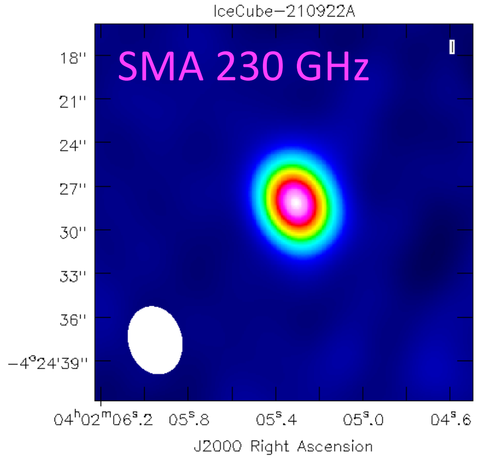


IceCube-210922A as star forming galaxies with AGN?

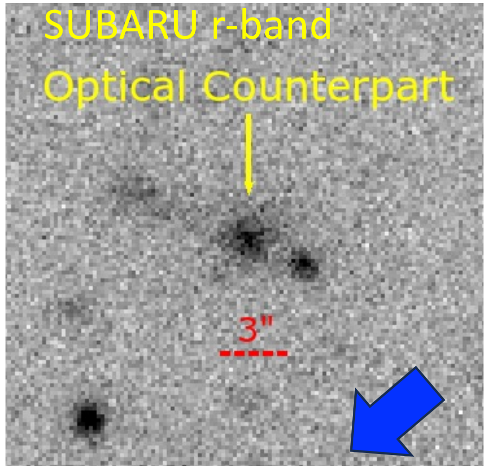
JCMT search

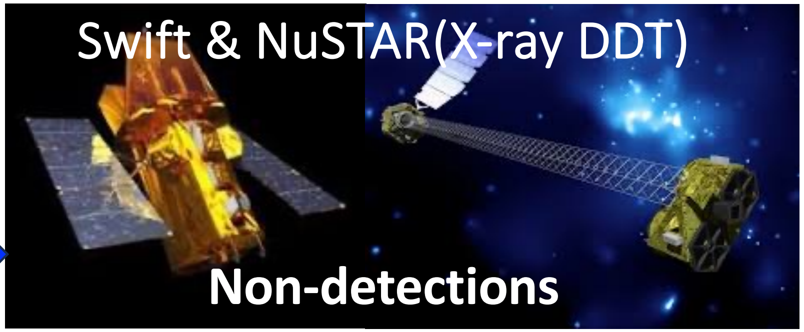


SMA(Fine localization)



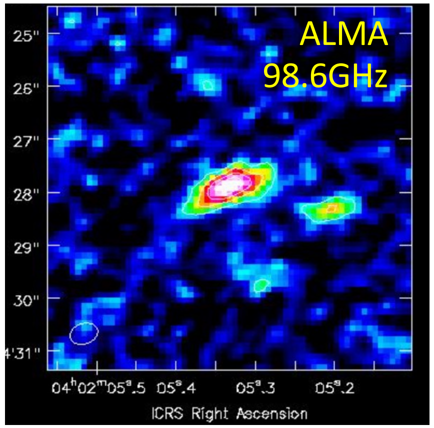
OIR identification

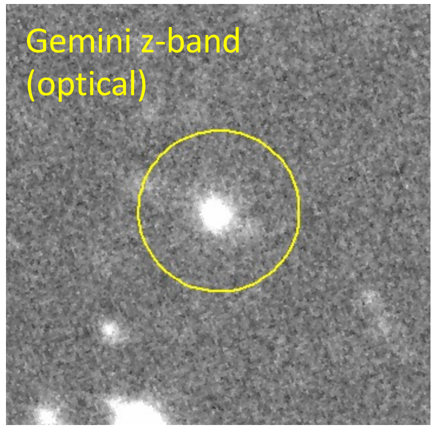




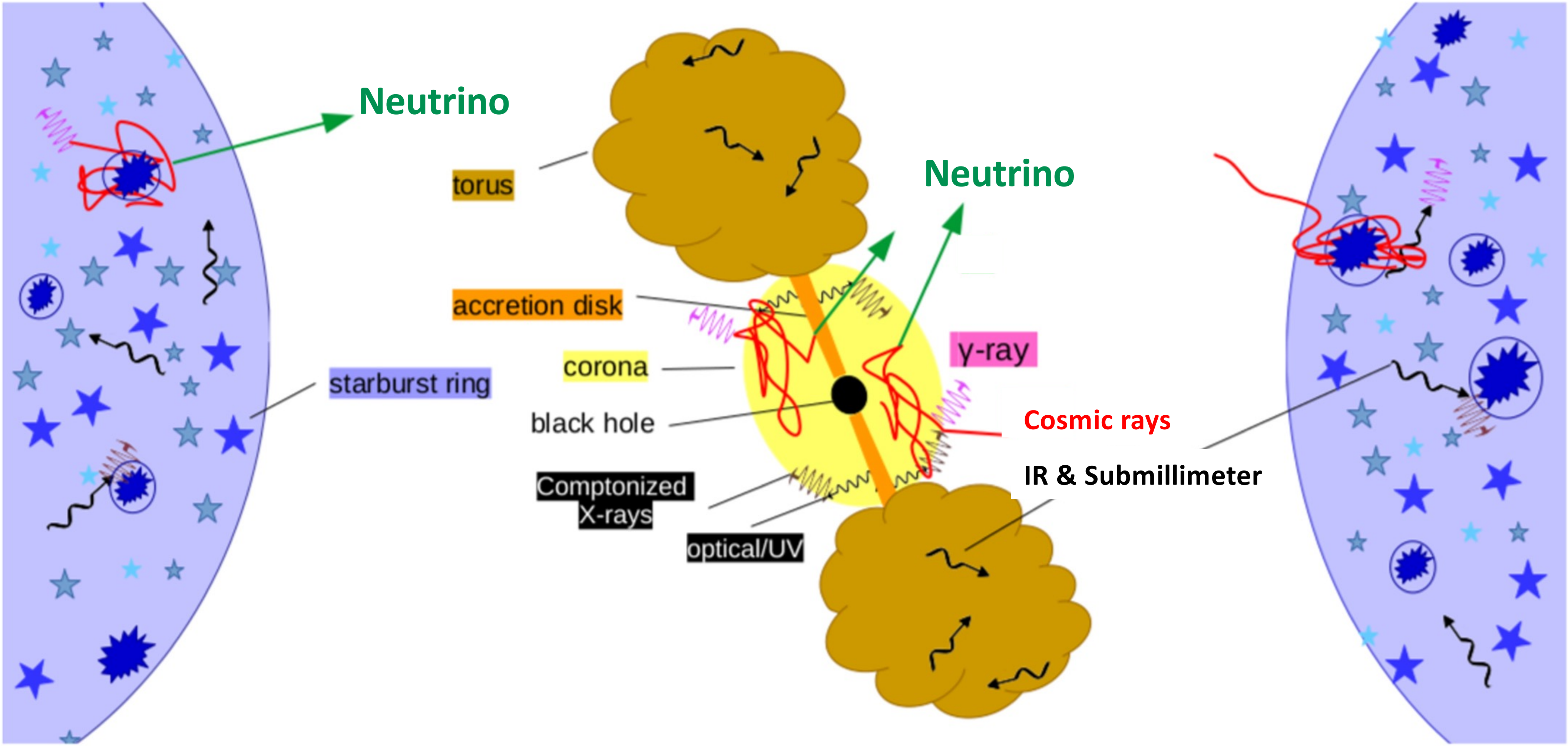
No transient source
(Fermi, Swift, DES, ZTF)

Detail characterization





Two-zone model for NGC1068



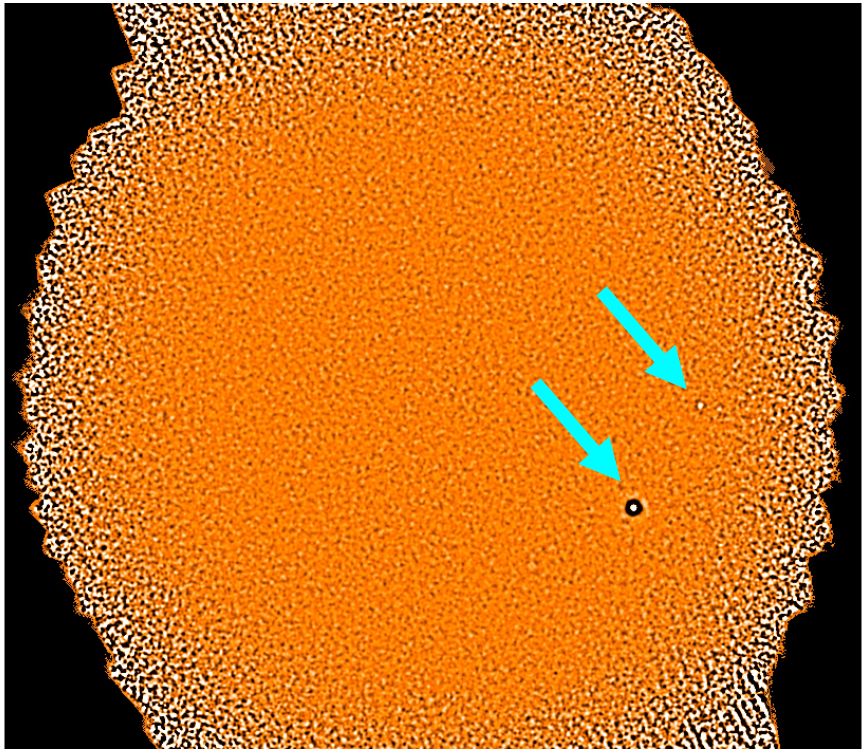
Millimeter follow-ups for neutrino events (essential?)

10 events

Events	N of sources	Remark
IC200926	0	
IC200929	0	
IC201007	0	
IC210922A	1	Star-forming gal
IC220115A	1	Variable? (bad weather)
IC220624A	0	
IC221223A	0	
IC230707A	0	
IC230724A	0	
IC240105A	2	Blazar

IC240105A

Identify 2 blazar candidates



Summary

- Millimeters & submillimeter can provide critical information for multi-messenger astronomy

- Complicated ToO can be managed with multiple telescopes

- ALMA can characterize details of HE objects (e.g., GRBs, AT2018cow etc)

- Submillimeter wide FOV follow-ups can also be managed

References

- Urata et al. 2023 Nature Astronomy, 7, 80
- Chen, YU et al. 2021 ApJ 915, 46
- Chen, YU et al. 2020 ApJL 891, 15
- Urata et al. 2019 ApJL 884, L58
- Huang, YU et al. 2019 ApJL 878, L25