# (High Energy) Neutrino Programs @ Grandma :

## The next Grandma Observation Campaign

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OGMA
Observations with Gravitational Waves & Multimessenger Astronomy

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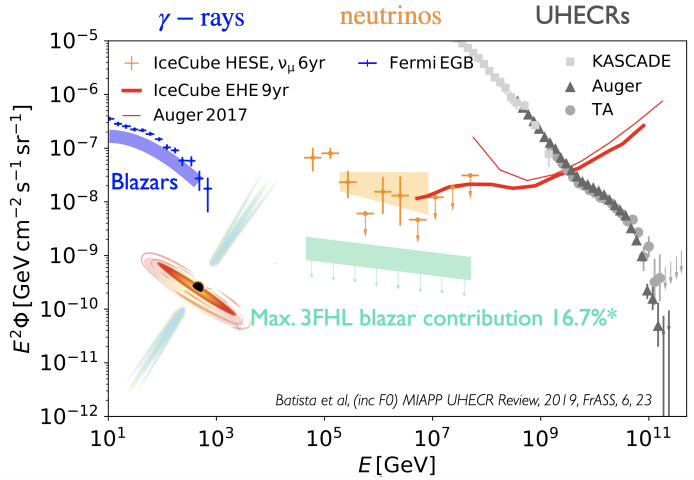
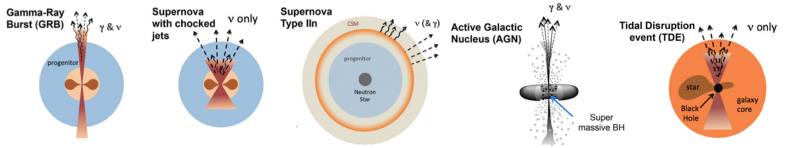
# HEN and other messengers - the Cosmic-Ray Connection




## A picture not so clear

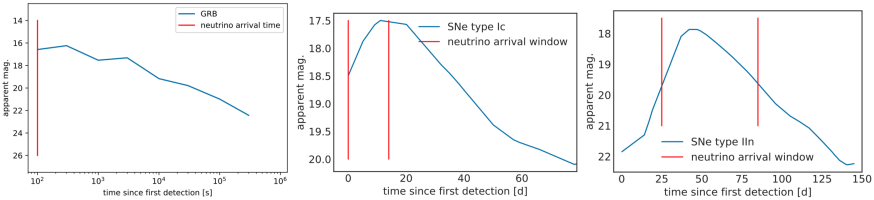
- Similar energies among messengers, but evidence for different origins ($\gamma$ Blazars $\sim$ 80%, HEN $< 15 - 30\%$)

# A large diversity of HEN sources...



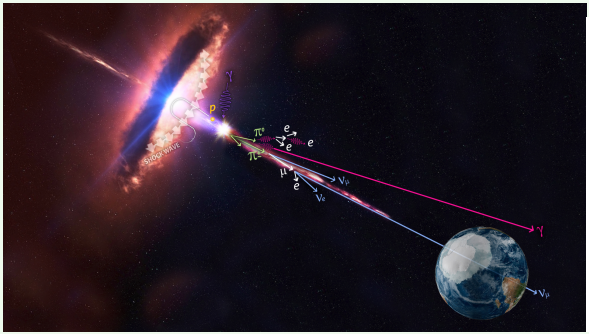

## ...and of their signals

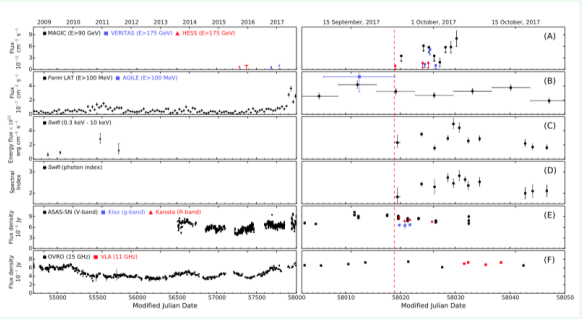
- Short duration - GRB-like - falling lightcurve, few hours
- Medium duration - SNIc, Kilonova - few weeks
- Long duration - SNIIn, TDE, AGN - few months



# AGNs ?

## AGNs - TXS0506+056

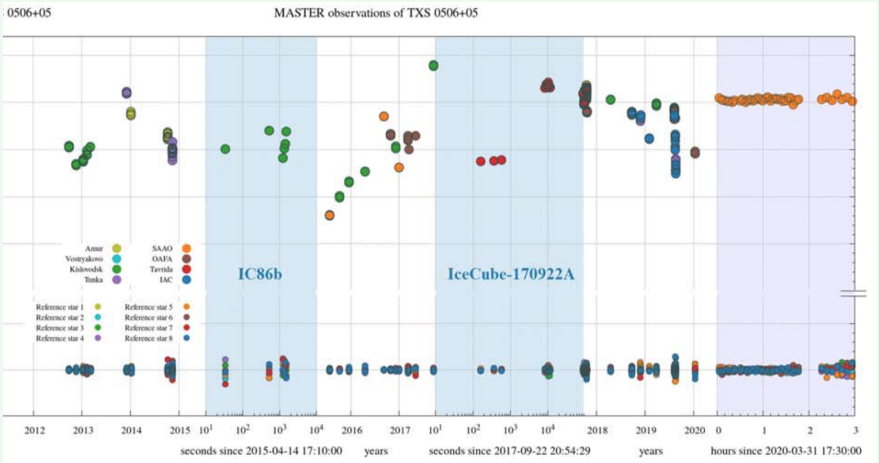



Multi-messenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A (IceCube et al, 2018)

# AGNs ?

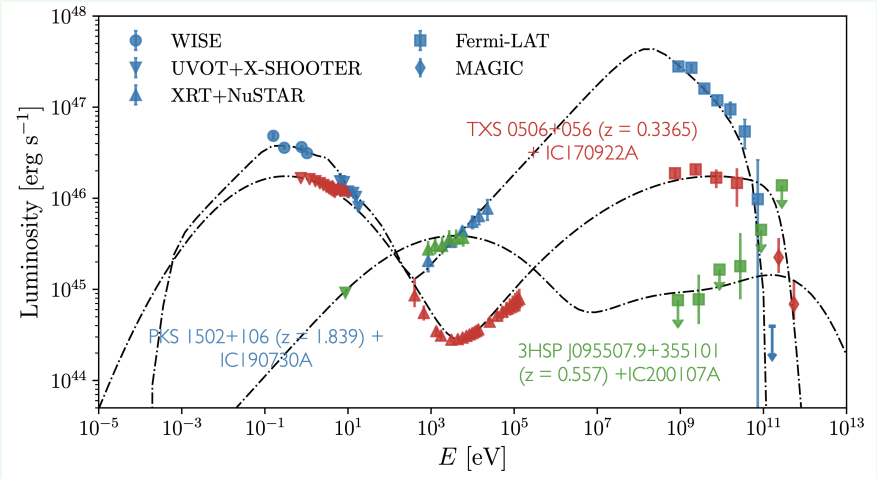
## AGNs - TXS0506+056 - HEN emission → rebrightening in optical




Optical Observations Reveal Strong Evidence for HEN Progenitor (Lipunov et al, 2020)

# AGNs ?

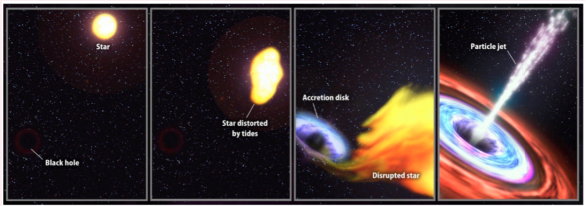
## AGNs - several hints



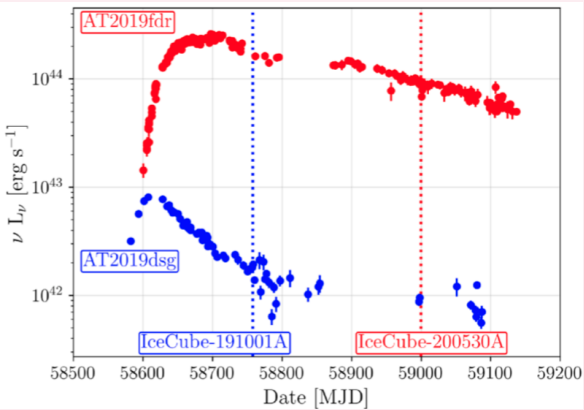

Oikonomou, ICRC 2021

# HEN Sources - Tidal Disruption Events (TDE) ?

## TDE & AT2019dsg




Credit: NASA

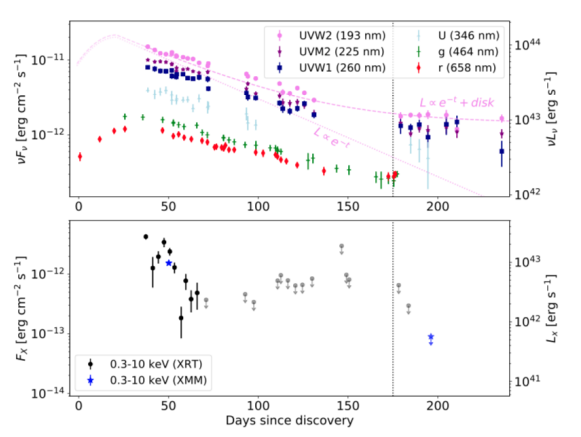



A tidal disruption event coincident with a high-energy neutrino (R. Stein et al, Nature 2021)

Neutrinos from tidal disruption events (R. Stein, 12/2020)

# HEN Sources - Tidal Disruption Events (TDE) ?

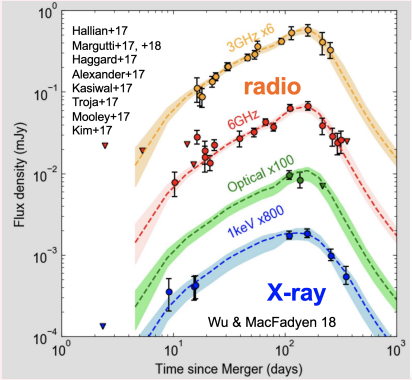
## TDE & AT2019dsg

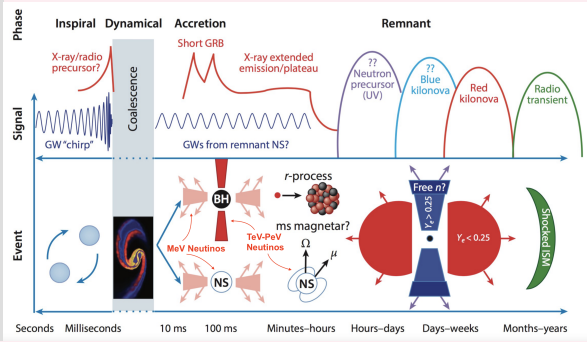



A tidal disruption event coincident with a high-energy neutrino (R. Stein et al, 2021)

# HEN Sources - GRBs of all sorts

## Electromagnetic Emissions & Multimessenger

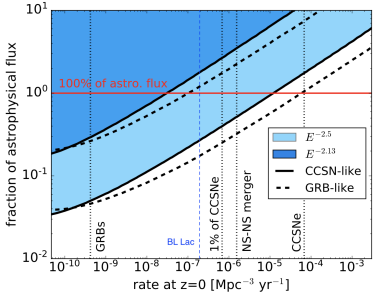



Metzger, ICRC 2021

# Upper limits & Eddington bias

| source class | local density [Mpc$^{-3}$ (yr$^{-1}$)] | min. dist. [Mpc] | limit | source energy [erg] | max. fluence [GeV$^{-1}$ cm$^{-2}$] |
|---|---|---|---|---|---|
| *long GRBs* | $4 \times 10^{-10}$ | 470 | < 1% (stacked) | $< 6 \times 10^{51}$ | $< 4 \times 10^{-3}$ |
| *short GRBs* | $3 \times 10^{-9}$ | 220 | < 32% (OFU) | $< 3 \times 10^{52}$ | $< 9 \times 10^{-2}$ |
| *llGRBs* | $1.6 \times 10^{-7}$ | 64 | < 100% (flux) | $< 1.5 \times 10^{51}$ | $< 6 \times 10^{-2}$ |
| *SNe Ic broad.* | $1.4 \times 10^{-6}$ | 30 | < 100% (flux) | $< 2 \times 10^{50}$ | $< 4 \times 10^{-2}$ |
| *SNe IIn* | $4 \times 10^{-6}$ | 20 | < 66% (stacked) | $< 4 \times 10^{49}$ | $< 1.4 \times 10^{-2}$ |
| *SNe Ib/c* | $1.7 \times 10^{-5}$ | 12 | < 32% (stacked) | $< 5 \times 10^{48}$ | $< 5 \times 10^{-3}$ |
| *CCSNe* | $7 \times 10^{-5}$ | 8 | < 100% (flux) | $< 4 \times 10^{48}$ | $< 8 \times 10^{-3}$ |
| FSRQs | $6 \times 10^{-10}$ | 1 000 | < 17% (EHE) | $< 1.6 \times 10^{53}$ | $< 3 \times 10^{-2}$ |
| BL Lac objects | $2 \times 10^{-7}$ | 120 | < 25% (EHE) | $< 3 \times 10^{51}$ | $< 2.5 \times 10^{-2}$ |
| all AGN | $10^{-3}$ | 7 | < 100% (flux) | $< 3 \times 10^{46}$ | $< 8 \times 10^{-5}$ |
| *jetted TDEs* | $3 \times 10^{-11}$ | 1 000 | < 100% (flux) | $< 10^{54}$ | $< 1.4 \times 10^{-1}$ |
| galaxy cluster | $5 \times 10^{-6}$ | 40 | < 100% (flux) | $< 3 \times 10^{50}$ | $< 3 \times 10^{-2}$ |
| starburst gal. | $3 \times 10^{-5}$ | 22 | < 100% (flux) | $< 2 \times 10^{49}$ | $< 2 \times 10^{-3}$ |



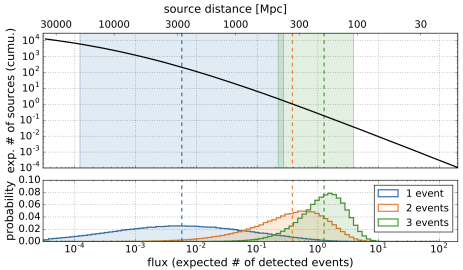

N. L. Strotjohann, PhD, https ://edoc.hu-berlin.de/handle/18452/21791

## Which alerts/objects to observe ?

- Short duration - GRB-like - **GRBs disfavored as HEN sources** (prompt phase) ⇒ **what about precursor/afterglow** ?
- Medium duration - SNIc, Kilonova - **mostly unconstrained**
- Long duration - SNIIn, TDE, AGN - **unconstrained**

⇒ **Focus on Medium / Long durations ?**

# Upper limits & Eddington bias




N. L. Strotjohann et al, https ://www.aanda.org/articles/aa/pdf/2019/02/aa34750-18.pdf

## Eddington Bias

- With only 1 neutrino $\rightarrow D \sim 0.5 - 20$ Gpc 90% (here BL Lac density, 10 events in 10 yrs for <30% detected HEN flux)
- To date, no reported multiple neutrino candidates for all Alerts (= no additional HEN found after initial IceCube alert)
  - $\Rightarrow$ Counterpart, if any, very distant/faint - depends on emission model

$\Rightarrow$ **Focus on HEN alerts with possible counterparts in 90% RoI ?**

# HEN Alerts (AMON/IceCube/KM3NeT)

## Existing Alerts - Public

- Gold Alerts : 12/yr, $> 50\%$ astrophysical - *latest : 06/03/2022* - **Observed $\approx$ 1/month**
- Bronze Alerts : 16/yr, $> 30\%$ astrophysical - *latest : 25/02/2022* - **Observed $\approx$ 1.3/month**

## Other Public Alerts

- NU_EM Alerts : 2-4/yr HAWC-IceCube + 2-4/yr Fermi-Antares (only position + 90% radius)
  - $\Rightarrow$ *latest : 20/02/2022* (IceCube - HAWC) - **Observed $\approx$ 0.7/month**
- IceCube Cascades : 8/yr, $> 85\%$ astrophysical (with FITS skymap)
  - $\Rightarrow$ *latest : 10/12/2021* - **Observed $\approx$ 0.5/month**

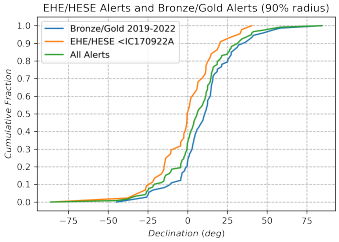
## Possible Alerts - Private - MoU needed

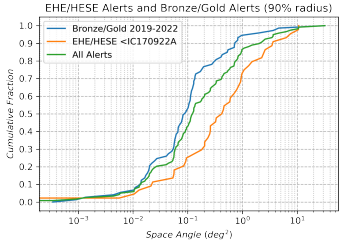
- OFU Alerts (Optical/X-ray) : GRB/SN jets, Northern, multiplets 2 evts in 100s $\Delta\Omega < 3.5^\circ$ (ROTSE, PTF, Swift)
- GFU ($\gamma$-ray) : clusters around selected sources (MAGIC, VERITAS)

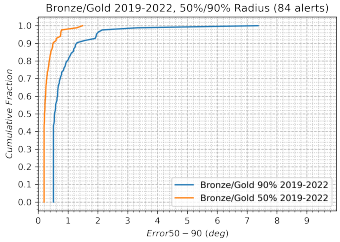
## IceCube(/KM3NeT) Alert contents

- Position + uncertainty (convertible in `fits` map) - $\lesssim 1^\circ \rightarrow 10^\circ$ (Tracks) / $20^\circ$ (Cascades)
- *Signalness* + FAR + Energy

# How often were the HEN alerts followed ?




## Since December 2021, mostly no optical followups !

1- **11 Gold** alerts **[5/11 with possible counterparts ?]**

- ⇒ **2** with no optical followup (except MASTER) and 0 4FGL in FoV, but with 4FGL activity reported nearby - **counterpart unlikely ?**
- ⇒ **3** with no followup (except MASTER/ZTF) and $\geq$1 4FGL in FoV, but with Blazar radio activity/presence - **possible counterpart ?**
- ⇒ **2** with no followup and 0 4FGL in FoV - **no counterpart searched**
- ⇒ 3 with no (public) followup reported (GCN or ATel), all with No/Many 4FGL sources in FoV - **no counterpart searched**

2- **10 Bronze** alerts **[5/10 with possible counterparts ?]**

- ⇒ **2** with multiple ATel (optical, radio etc) - **possible counterparts**
- ⇒ **2** with no report despite New FERMI-LAT sources - **counterparts ?**
- ⇒ 1+1 with no report despite 4FGL sources in FoV - **no counterpart searched**
- ⇒ 3 with no report with 0 sources in FoV - **no counterpart searched**
- ⇒ 1 with no report despite SNIIn discovered - **possible counterpart not studied**

# How often were the HEN alerts followed ?

## Since December 2021, mostly no optical followups !

1- **11 Gold** alerts **[5/11 with possible counterparts ?]**
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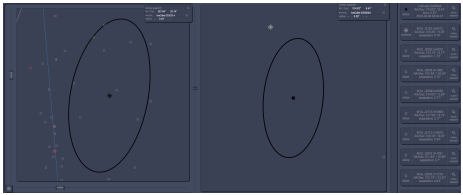
- ⇒ 3 with no report with 0 sources in FoV - **no counterpart searched**
- ⇒ 1 with no report despite SNIIn discovered - **possible counterpart not studied**

$\approx$ **1.4-2 alerts/month** with probable counterpart (only Gold/Bronze only)

+ NuEm (0.5/month)/ Cascades (0.35/month), with no (public) reports on followups
$\gtrsim$ **2 alerts/month** worth following

# **Gold Alerts -** Examples of Gold Alerts with no reports



## No 4 FGL sources in FoV

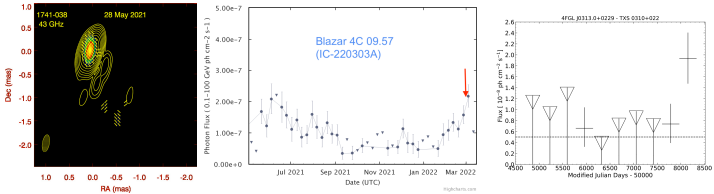
- IceCube-220202A - 0.7deg error, 151 TeV, FAR 1.9/yr
- IceCube-220306A (fig) - 0.5deg error, 413 TeV, FAR 0.4/yr (nearest at 0.8°)

## Many 4 FGL sources in FoV

- IceCube-220221A (fig) - 3.6deg error, 157 TeV, FAR 0.4/yr - 6 possible sources

**(Reported) Search for possible counterpart(s) would have been needed !**

# **Gold Alerts -** Examples of IceCube-220205B, 220303A, 220304A




## IceCube-220205B - 0.5deg error, 216 TeV, FAR 0.7/yr

- ATel# 15222 + # 15215 - **PKS 1741-03**, radio followup - low flux in 3.5-13.5mm (22-85 GHz) band - consistent ?

## IceCube-220303A - 1.2deg error, 398 TeV, FAR 0.54/yr

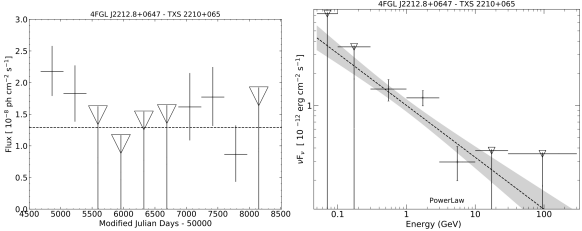
- No 4FGL sources in FoV / MASTER - **Blazar 4C 09.57** (nearest 4FGL source) / SWIFT/XRT - X-ray counterpart ?

## IceCube-220304A - 6.2deg error, 260 TeV, FAR 0.57/yr

- Many 4FGL in FoV / Fermi-LAT Flux $20\times$ **TXS0310+022** - Radio followup of this Blazar, ATel# 15266

$\Rightarrow$ **Confirmation/Characterization of these possible counterparts needed**

# **Gold Alerts -** Example of IceCube-220509A

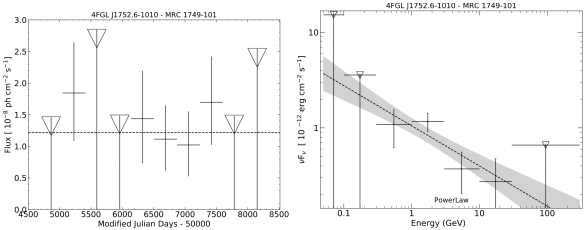



## IceCube-220509A - 1.7deg error, 177 TeV, FAR 1.5/yr

- 3 4FGL sources
- FERMI-LAT GCN - **TXS 2210+065**, $3\sigma$ in month before $T_0$
- No report except HAWC, Fermi_LAT

$\Rightarrow$ **Confirmation/Characterization of this possible counterpart needed**

# **Gold Alerts -** Example of IceCube-220425A

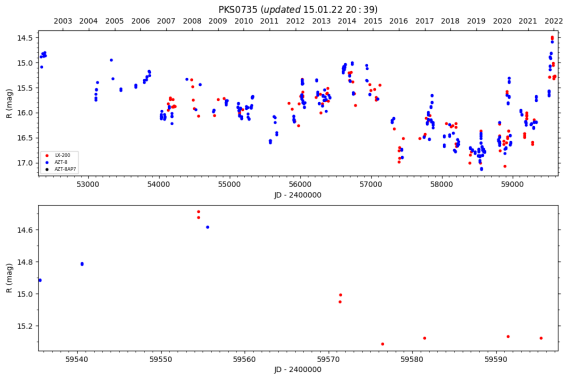


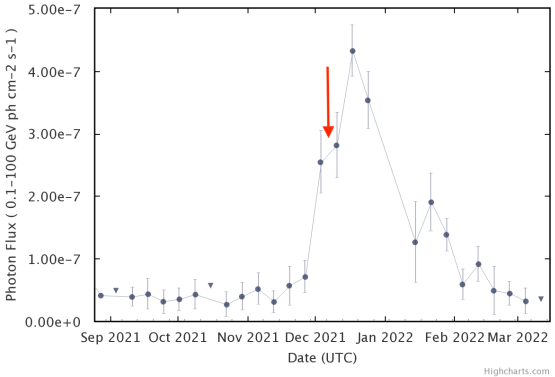

## IceCube-220425A - 1.7deg error, 604 TeV, FAR 0.6/yr

- ATel# 15363 - **TXS 1749-101**, coincident with IC181023A
- MASTER → TXS 1742-078, 3.4° away, in flaring period (brightest since 2017)

⇒ **Confirmation/Characterization of this possible counterpart needed**

# Bronze Alerts - Example of IceCube-211208A

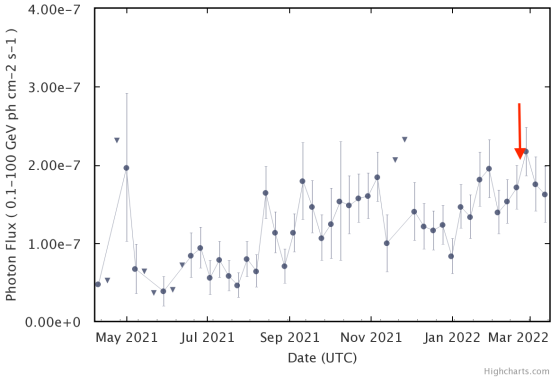


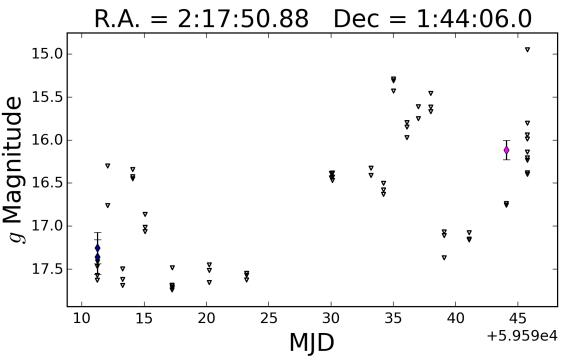




## IceCube-211208A - 2.1deg error, Bronze alert, 170 TeV, FAR 1.2/yr

- 2 possible 4FGL sources in FoV, including 4FGL J0738.1+1742 - PKS 075+178
- 13 ATels : MASTER, REM-NOT (Optical, NIR), X-rays, radio
- **Medium/longterm monitoring needed to evaluate PKS 075+178 as possible counterpart**

# **Bronze Alerts -** Example of IceCube-220225A

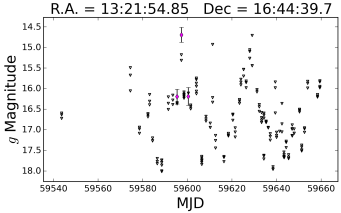



## IceCube-220225A - 2-3deg error, Bronze alert, 153 TeV, FAR 2.4/yr

- 1 possible 4FGL sources in FoV, 4FGL J0217.8+0144 - PKS 0215+015
- 3 ATels : radio to optical (# 15243, 15245 radio flare, 15248) - ASAS-SN 60 days since 20/01/2022 → 22/03
- **Medium/longterm monitoring needed to study/evaluate PKS0215+015 as possible counterpart**

# **Bronze Alerts -** IceCube-211216A, 211216B




## IceCube-211216A - 1-3deg error, Bronze alert (>30% astro), 113 TeV, FAR 2.4/yr

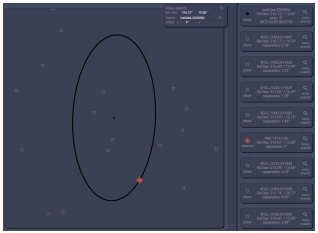
- 2 possible 4FGL sources in FoV / No follow-up reported

## IceCube-211216B - 1.55deg error, Bronze alert (>30% astro), 112 TeV, FAR 2.4/yr

- No 4FGL sources / ATel# 15123 - **SNIIn 2021gpw** (discovered March 2021, peak 25/04/2021) within 90% RoI - LC ASAS-SN (25/11/2021 to 22/03/2022)

**Rapid or medium follow-up would have been needed !**

# **Bronze Alerts -** IceCube-220115A, 220205A



## IceCube-220115A - 1.2deg error, Bronze alert (>30% astro), 110 TeV, FAR 2.1/yr

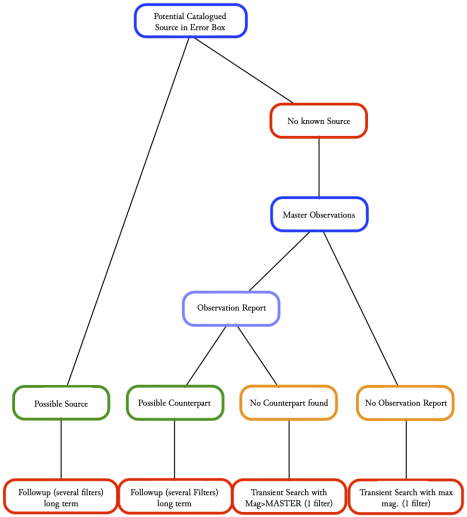
- No possible 4FGL sources in FoV
- ATel# 15166 - **New Fermi-LAT source** J2350.2+2620 within 90% RoI

## IceCube-220205A - 3deg error, Bronze alert (>30% astro), 110 TeV, FAR 2.5/yr

- Several possible 4FGL sources in FoV (PKS 1413+135 on border)
- ATel# 15211 - **New Fermi-LAT source** J1420.7+1653 within 90% RoI

**Optical characterization of the sources would have been helpful**

# Decision Tree for GRANDMA Observations




## Depending on other observations

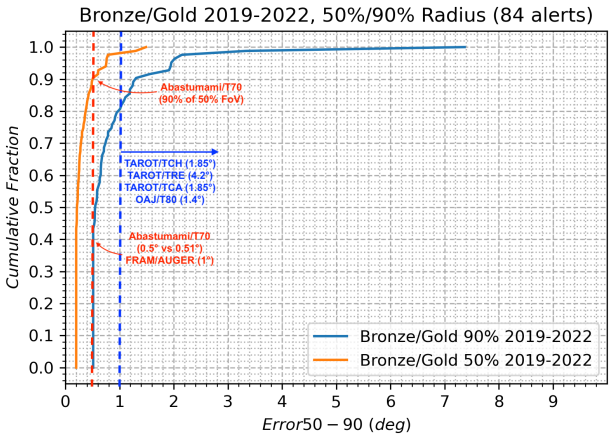
- Transient search :
  - ⇒ if no observations/counterpart
  - ⇒ well-localized GOLD/BRONZE alerts ($\lesssim 1^\circ$ - 80%)
- Characterization/Followup - medium/longterm
  - ⇒ if counterpart/catalogued source

⇒ **Send Observation Requests :**

- ⇒ min. FoV, limit mag./exposure time, Filters, Obs. schedules

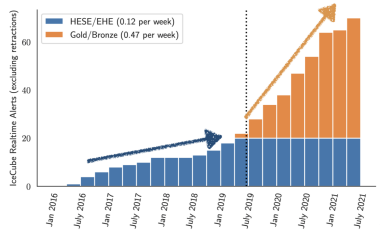
- **Tiling or not Tiling ?**

# Discussion points

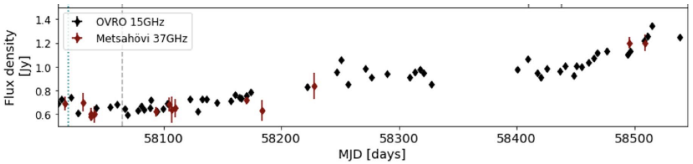



## Targets : GRB-like and AGNs

- GRB-like :
  - $\Rightarrow \lesssim 1^\circ$ GOLD/BRONZE alerts
  - $\Rightarrow$ +NuEM average $\sim 0.4^\circ$
  - $\Rightarrow$ Relevant Telescopes to observe Error Box
  - $\Rightarrow$ Counterpart search
- AGNs
  - $\Rightarrow$ Characterize potential counterparts
  - $\Rightarrow$ Followup of AGNs in Error Box
- $\lesssim 1^\circ$ GOLD + interesting BRONZE + NuEM
  - $\simeq$ 3-4/months



# (Low Frequency) Radio Observations in GRANDMA ?


## NenuFAR in Nancay (France)

- $< 100$ MHz
- Low Frequencies will arrive *after* High Frequencies (Dispersion)
  - $\Rightarrow$ An increase in HF Radio for a given AGN can trigger a NenuFAR observation
- Contact with KM3NeT/Radio physicists in Subatech (Nantes), ready to be involved