Realtime follow-up of astrophysical transients with the IceCube Neutrino Observatory

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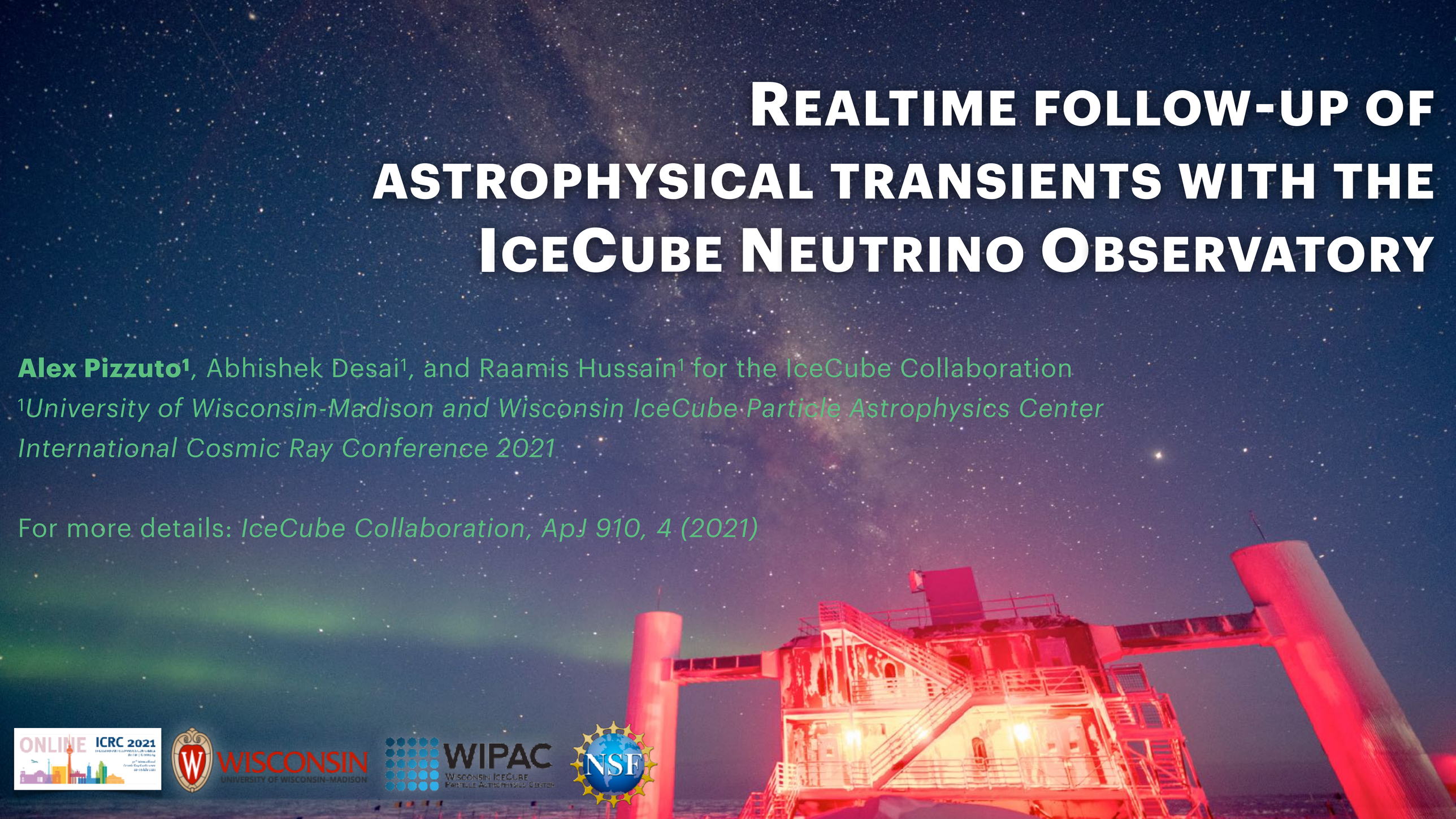
International Cosmic Ray Conference 2021

For more details: *IceCube Collaboration, ApJ 910, 4 (2021)*



Introduction

- **Recent advances in neutrino astronomy enabled by realtime observations**
  - TXS 0506+056 was first identified because of the IceCube alert event, IC170922A
  - Recent interest in radio bright AGN because of possible correlation with neutrino alerts
- **Neutrino astronomy can be done with more than just "alert" quality events**
  - Indications of neutrino sources become apparent when including lower energy events (*IceCube Collaboration, Phys. Rev. Lett. 124, 051103 (2020)*)
- **IceCube has a low-latency, large effective area data sample**
  - Data are available within ~30 seconds
  - All-sky sample, >99% uptime

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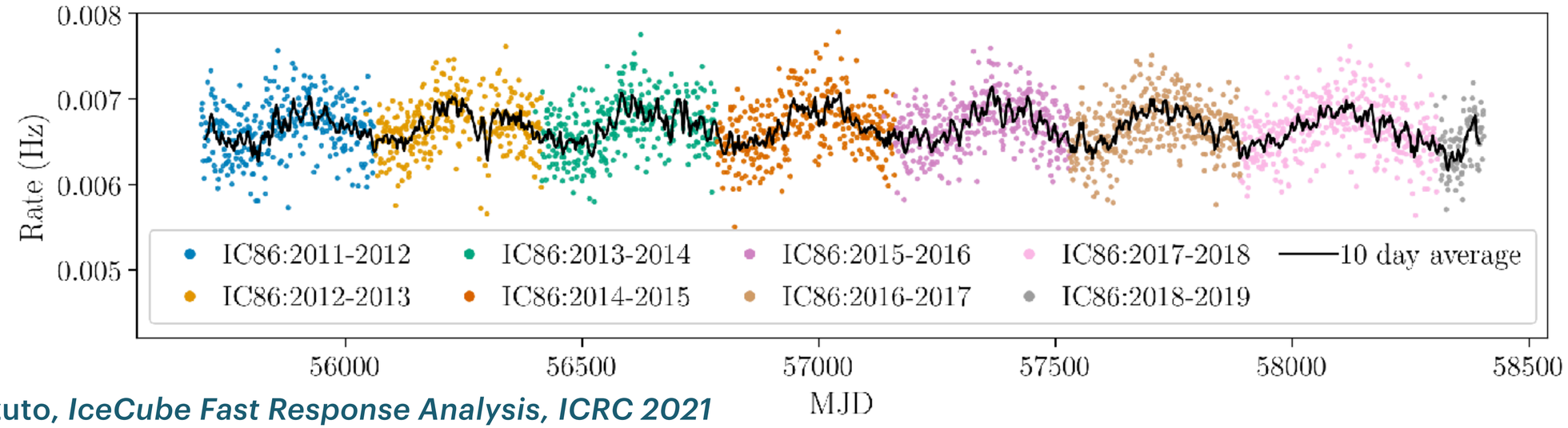
In addition to using neutrino alerts to trigger multi-wavelength followup, we follow up interesting transients with neutrinos

Search Strategy

- **Unbinned maximum likelihood analysis with an "extended likelihood"**

$$\mathscr{L}\left(n_s \mid n_b, \{x_i\}\right) = \frac{\left(n_s + n_b\right)^N e^{-\left(n_s + n_b\right)}}{N!} \times \prod_{i=1}^{N} \left[\frac{n_s}{n_s + n_b} \mathcal{S}\left(x_i\right) + \frac{n_b}{n_s + n_b} \mathcal{B}\left(x_i\right) \right]$$

- **All-sky background rate of ~6 mHz**
- **Effective area comparable with other IceCube track samples**



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Is the number of events on the sky consistent with background?

Signal expectations from Monte Carlo

Background PDFs of energy and zenith angle determined from data

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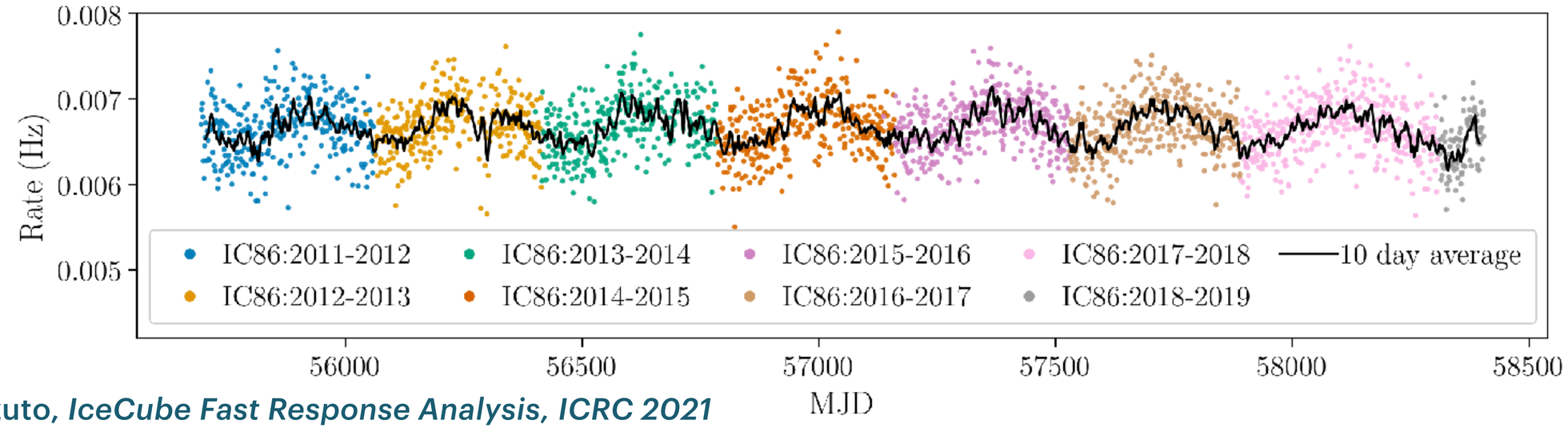
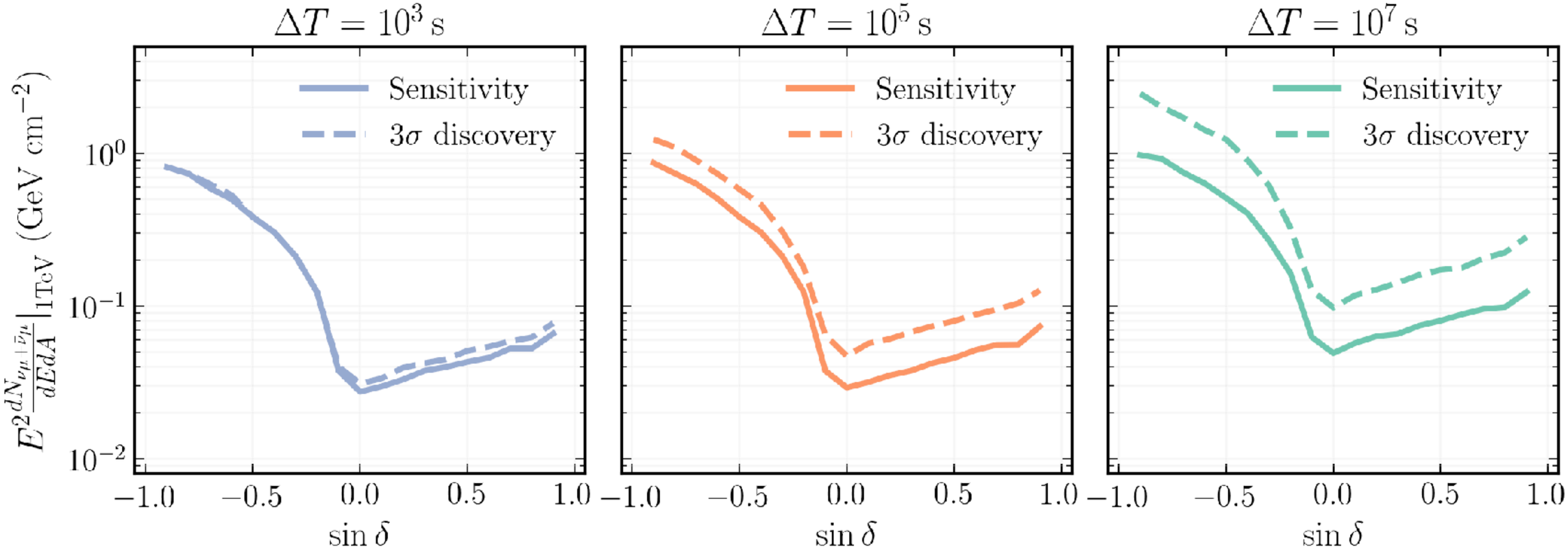


Analysis Sensitivity

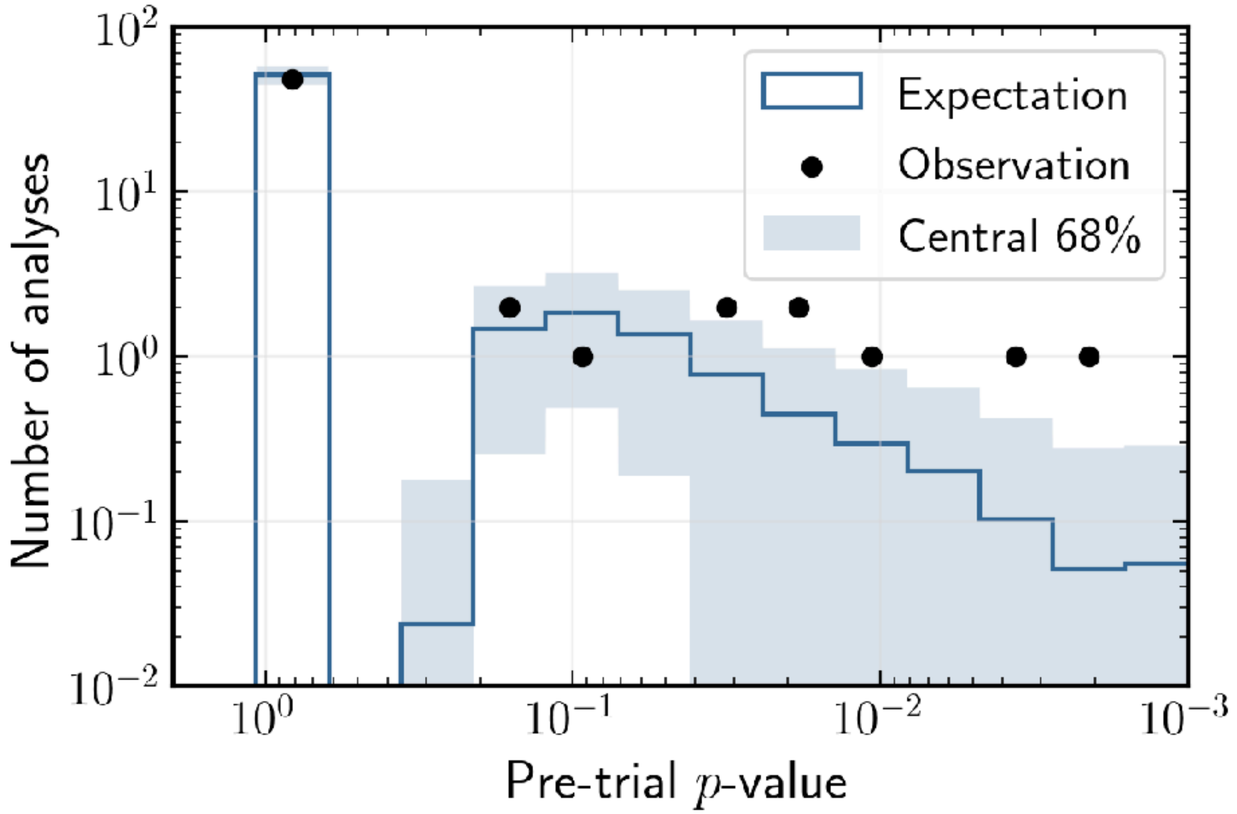
- **Analysis is sensitive to individual events**
- **Performs best at the Equator and in the Northern Celestial hemisphere**
- **Most sensitive for short time windows**
  - Remains sensitive to single events for time windows as long as a few days



Alex Pizzuto, *IceCube Fast Response Analysis, ICRC 2021*

Ensemble of Results

- **Analysis has been used over 50 times to follow up interesting transients, such as:**
  - Bright GRBs
  - FRBs
  - Blazar flares
  - AMON multi-observatory alerts (https://www.amon.psu.edu/)
  - Rare transients, e.g. AT2018cow
- **No significant detections to date**
- **Constraints have been incorporated into models of extreme transients**
- **Limits on nearby, bright transients can be used to constrain populations of sources**



Targets: Fast Radio Bursts

- **FRBs could provide promising environment for cosmic-ray acceleration**
  - ✦ See Metzger et al. (2020) [2008.12318]
- **Recent detection of FRB 200428A coincident with the Galactic magnetar SGR 1935+2154**
  - ✦ Nearby FRB allows us to set stringent constraints on neutrino luminosity of FRBs
- **Searched for neutrinos from FRB 200428A, no significant signal**
- **Limits allow us to constrain contribution of FRBs to the diffuse neutrino flux**

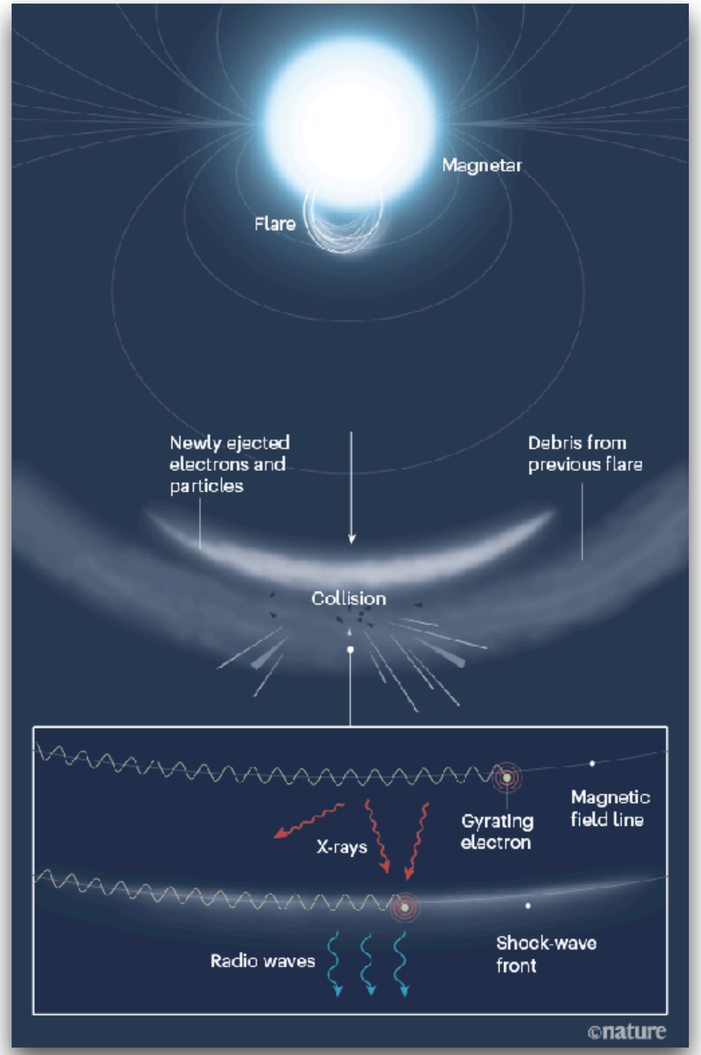


Figure from Nature **587, 43-44 (2020)*

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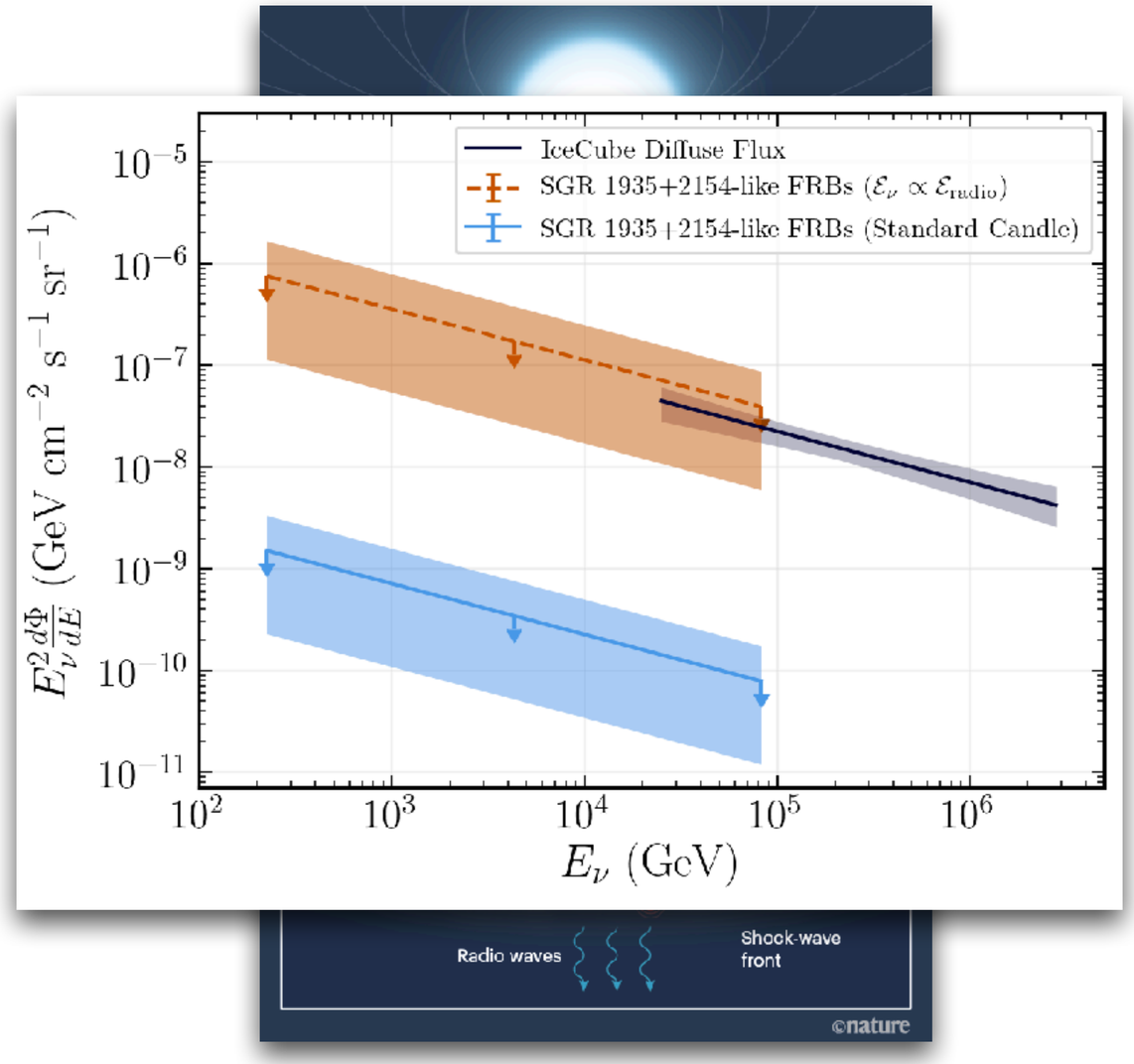


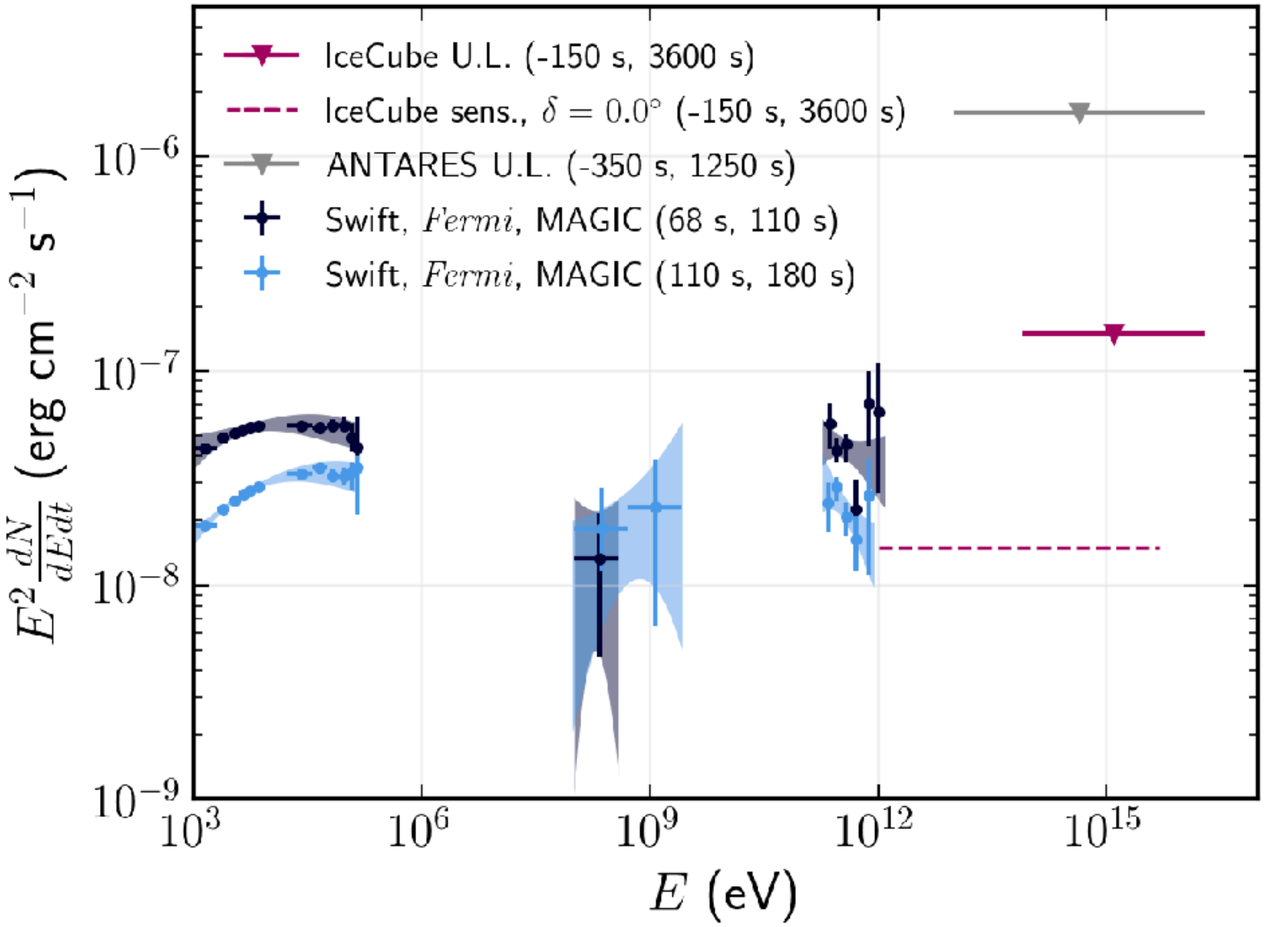
Figure from Nature **587, 43-44 (2020)*

Targets: Gamma-Ray Bursts

- **Gamma-ray bursts (GRBs) have long been considered potential neutrino sources**
- **First few GRBs detected by IACTs in real time**

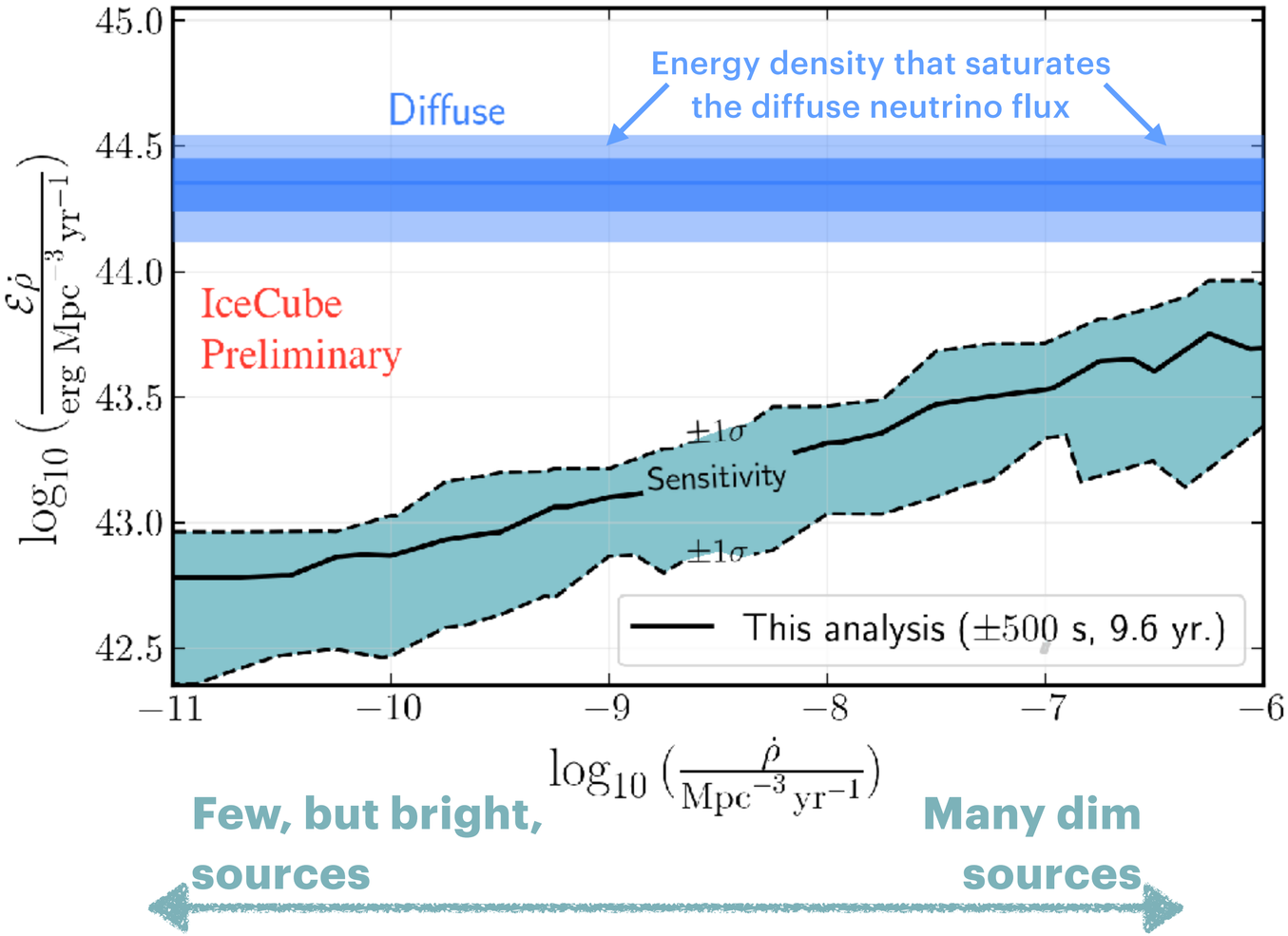
Source	Analysis p-value	Upper limit (x10^{-2} GeV cm^{-2})
GRB 200729A	1.0	5.3
GRB 201015A	1.0	5.9
GRB 201216C	1.0	4.0

Limits on neutrino emission from GRB 190114C



Self-Triggered Analyses

- **Pipeline can also be used to follow up high-energy neutrino alerts**
  - ✦ Provides a way to look for transients that does not depend on multi-wavelength information
- **High-energy alert events could be accompanied by lower-energy neutrinos in the low-latency sample**
- **Future results can be used to constrain generic populations of neutrino sources**
- **For more on self-triggered neutrino searches, see Martina Karl's Poster (this session, PoS:940)**



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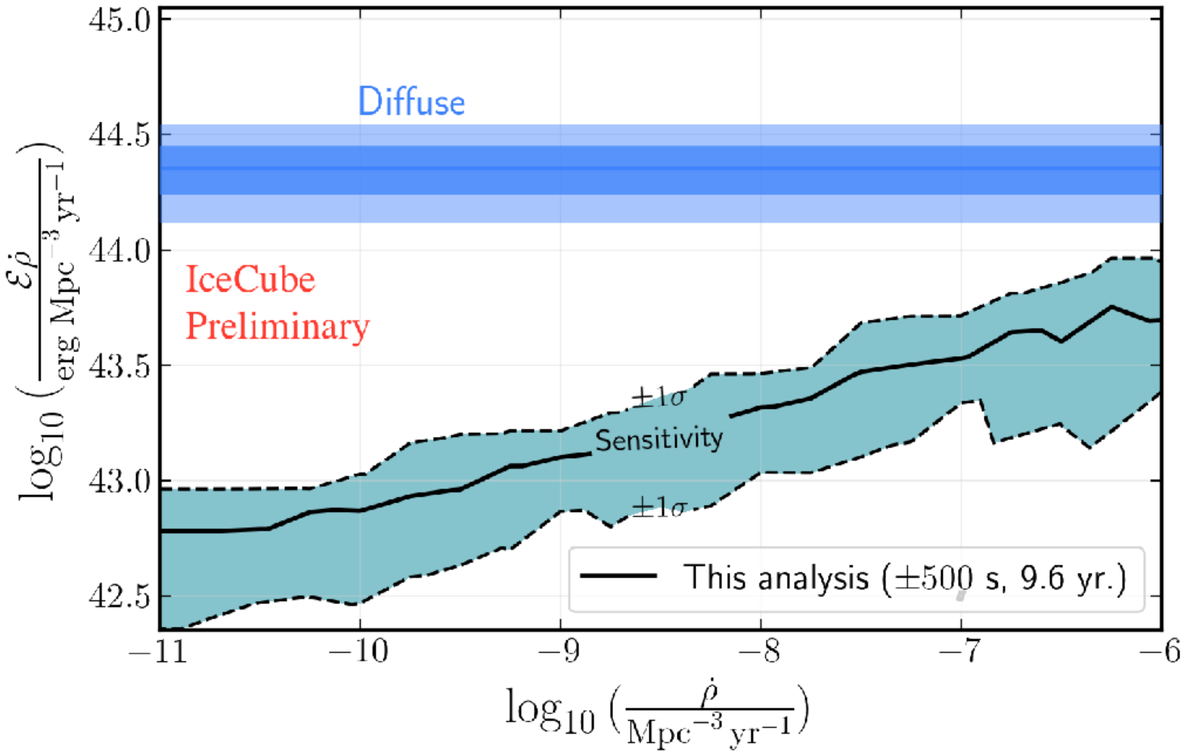
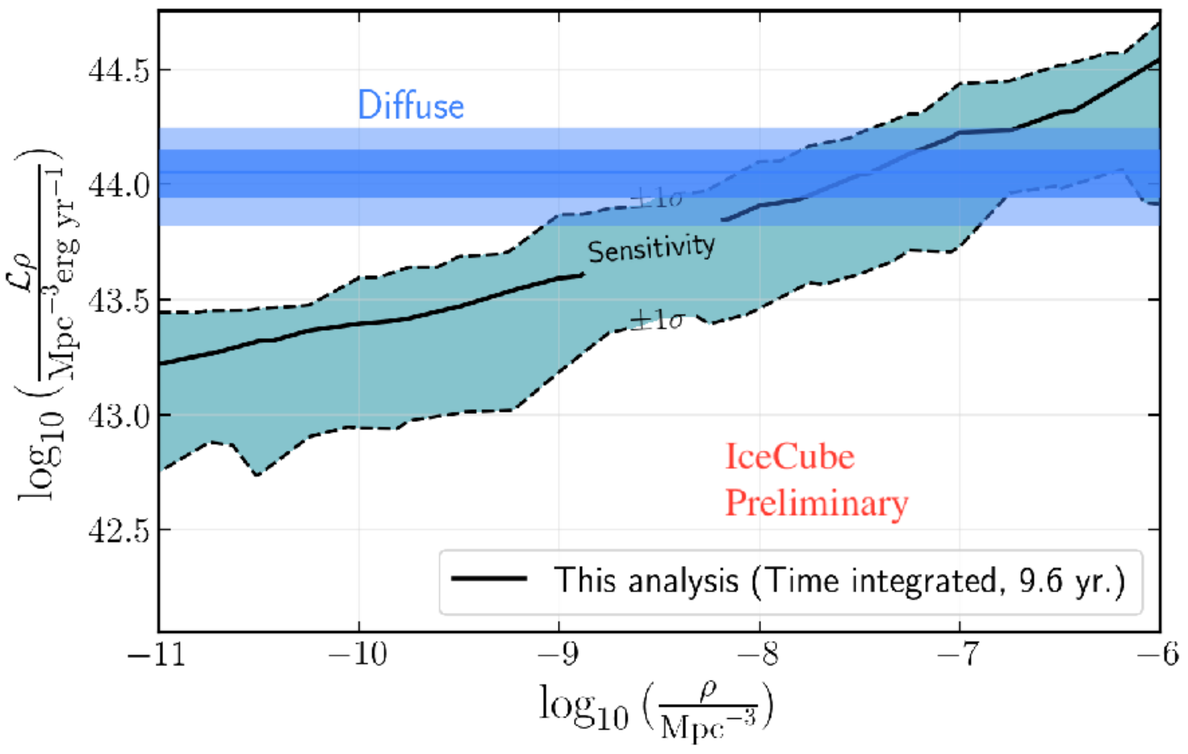
Self-Triggered Analyses

- Currently developing analysis on a sample of archival alert-quality events
- Testing a variety of hypotheses, including (1) short-timescale transients and (2) steady neutrino sources
- Most sensitive to rare populations

Transient sources



Steady sources



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Conclusion & Outlook

- **Pipeline is able to quickly respond to interesting transients, including bright GRBs and FRBs**
  - Object you would like us to investigate? Email roc@icecube.wisc.edu
  - Similar pipelines exist for specific astrophysical source classes (see Doga Veske's talk on using neutrinos to respond to gravitational wave triggers, PoS:950)
- **Analysis has been used over 50 times, no significant detections to date**
  - Most results are sent to the community via channels such as the Astronomer's Telegram or GCN circulars
- **Future update will also constrain neutrino source populations by following up neutrino alerts**
- **Full analysis details available: See *IceCube Collaboration, ApJ 910, 4 (2021)***

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Thank you for listening!

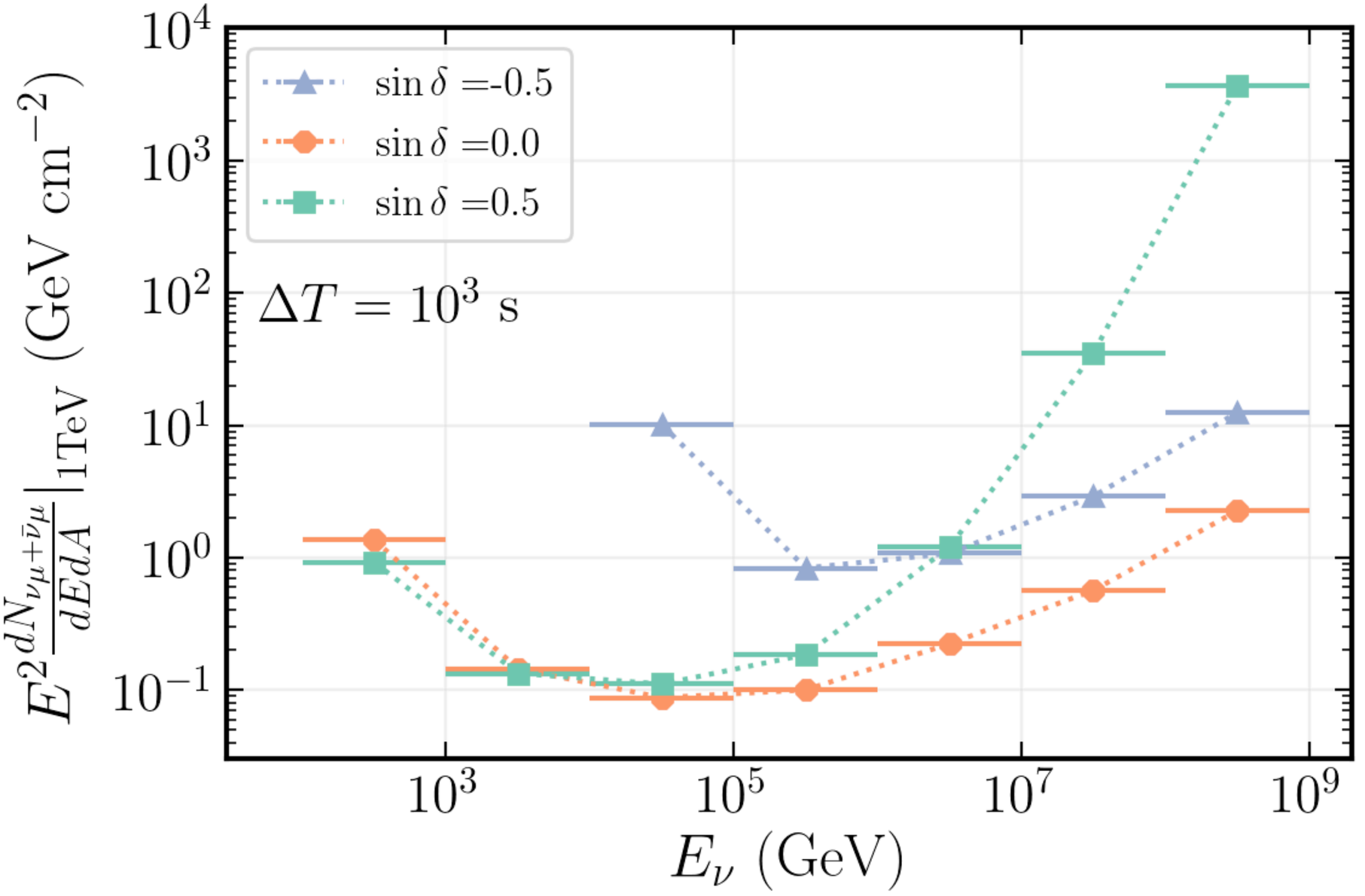
WIPAC Wisconsin IceCube Particle Astrophysics Center

NSF

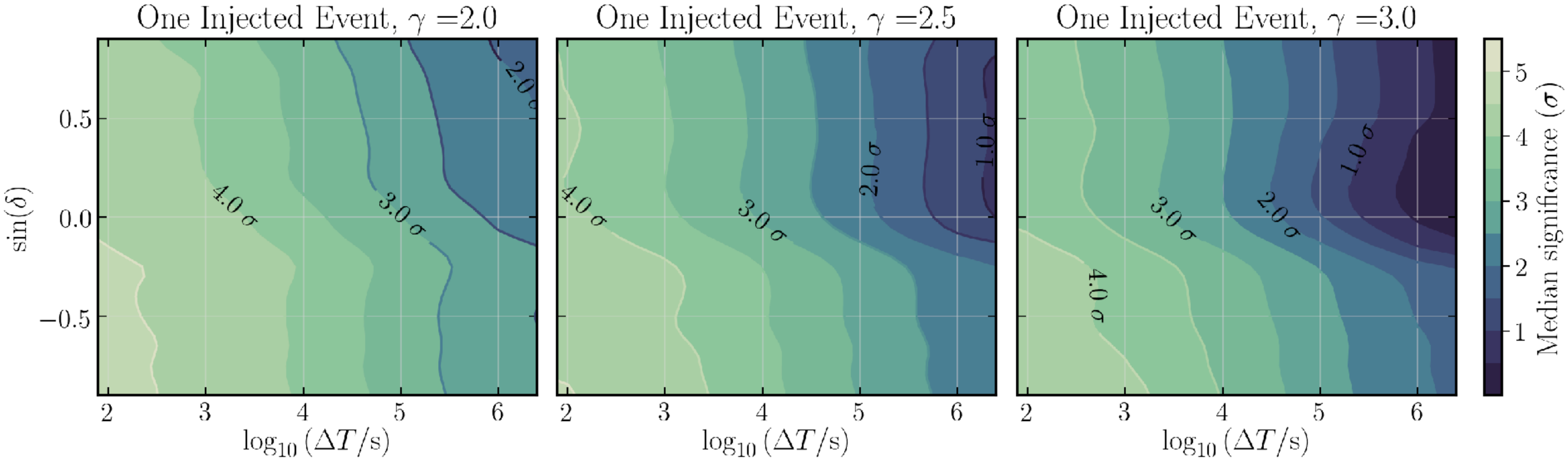
Backup Slides

Analysis Sensitivity

- Differential sensitivity with bins spanning one decade in energy
- Northern sky: most sensitive around 100 TeV
- Southern sky: most sensitive around 1 PeV



Median Analysis Response



Targets: Blazar Flares

- Followed up a few bright blazar flares
- Constraints are comparable to $E^2 dN/dE$ in the gamma-ray band for bright flares