Neutrino Astronomy of Transient Signals

Multi-Messenger Observations

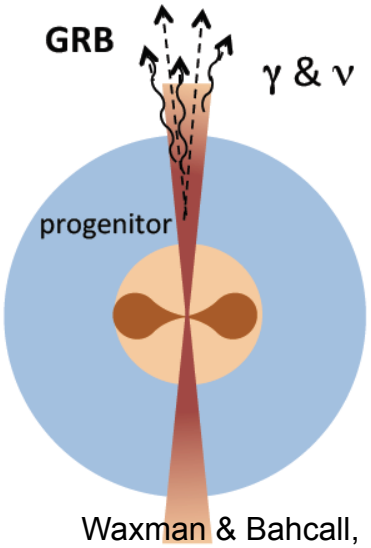
Anna Franckowiak
IPA
Madison, May 10, 2017

HELMHOLTZ ASSOCIATION

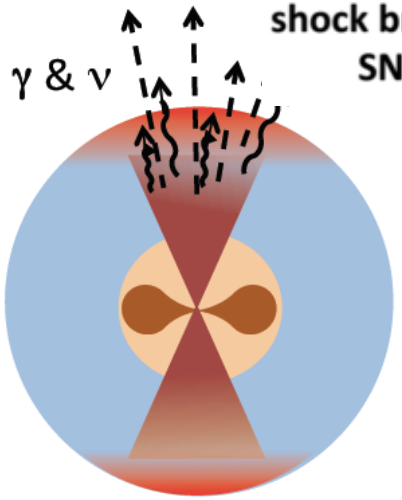
DESY

Transient / Variable Neutrino Sources

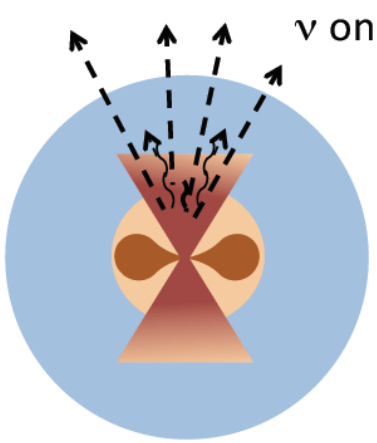
- Stellar collapses



Waxman & Bahcall, PRL, 78 (1997)

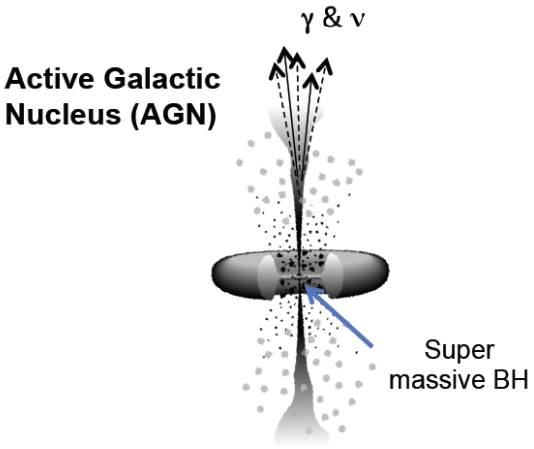


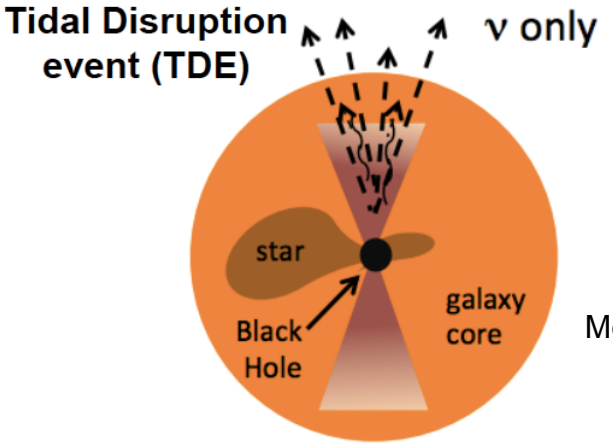
Murase et al, ApJL, 651 (2006)



Ando & Beacom, PRL 95 (2005)
Razzaque, Meszaros, Waxman PRL 93 (2004)

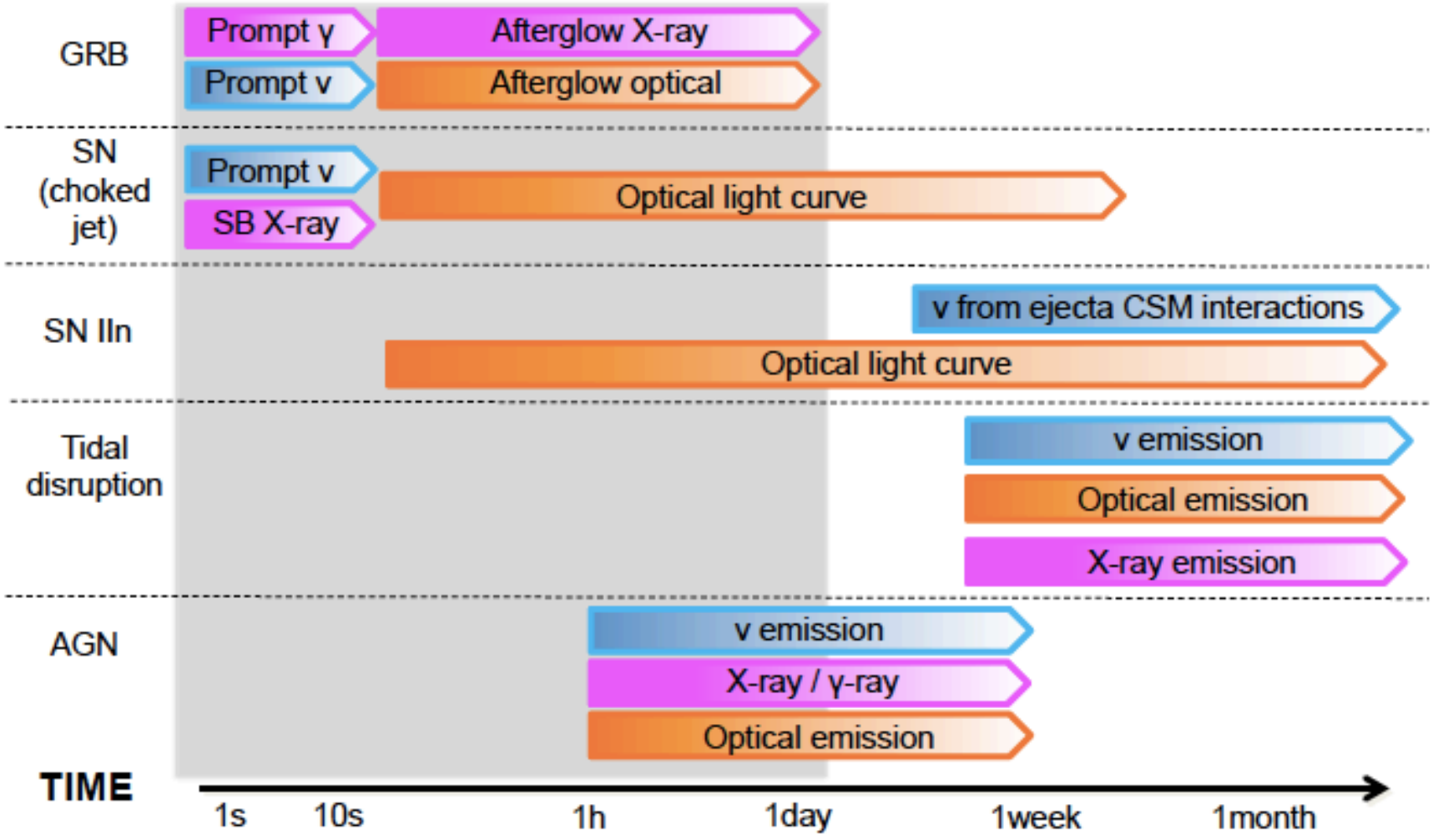
- Galaxy core activity





Lunardi & Winter, arXiv:1612.03160
Senno, Murase, Meszaros ApJ (2017) 838

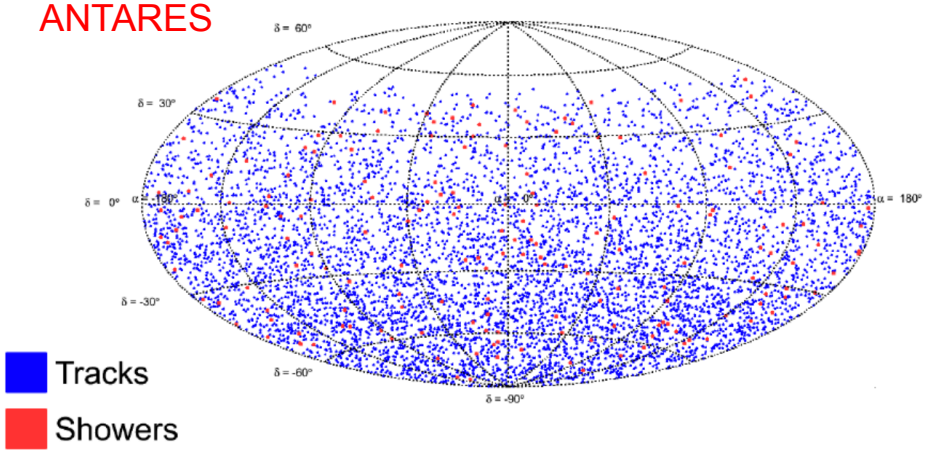
Expected Multi-Messenger Emission



Search for Neutrino Clusters in Space

See talk by A. Kouchner

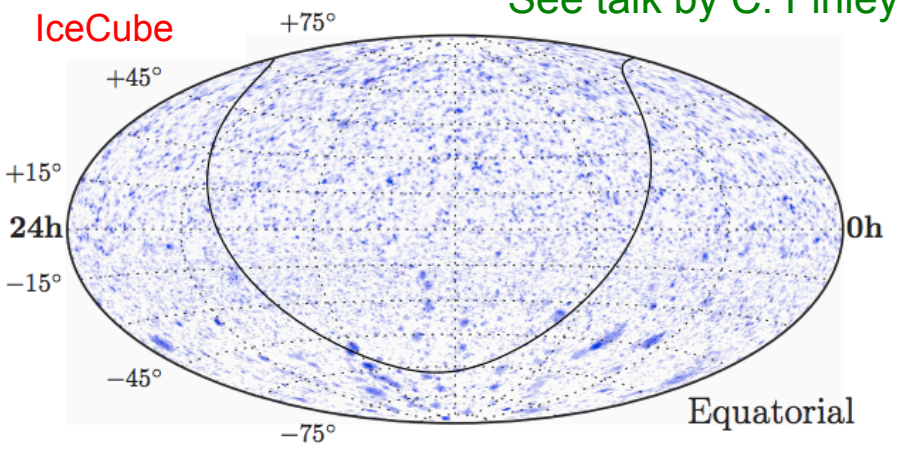
ANTARES



ANTARES ApJ 786 (2014)

See talk by C. Finley

IceCube

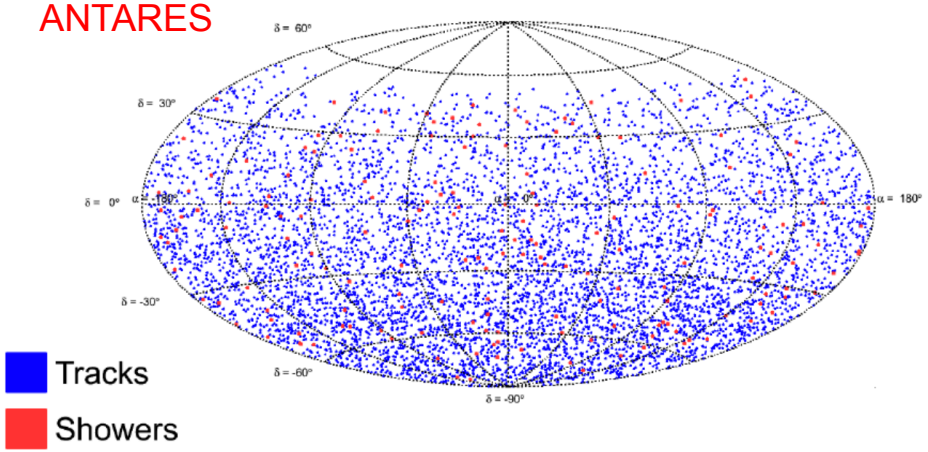


IceCube ApJ 835 (2017)

Search for Neutrino Clusters in Space and Time

See talk by A. Kouchner

ANTARES



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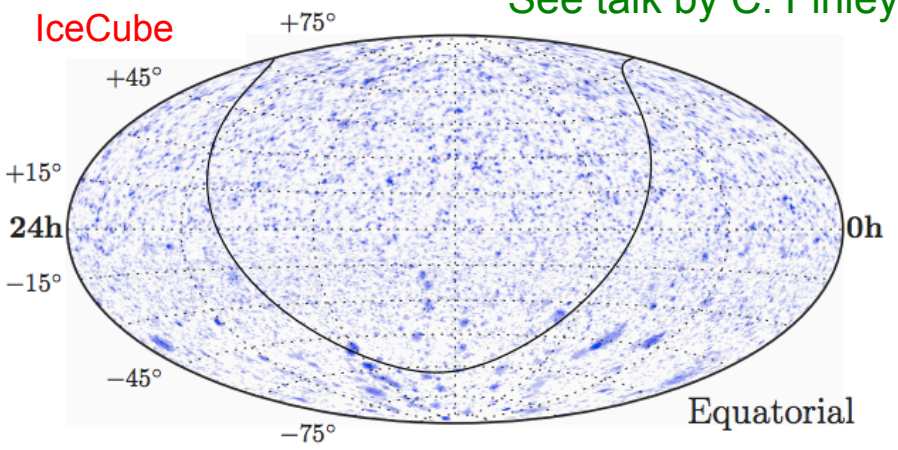
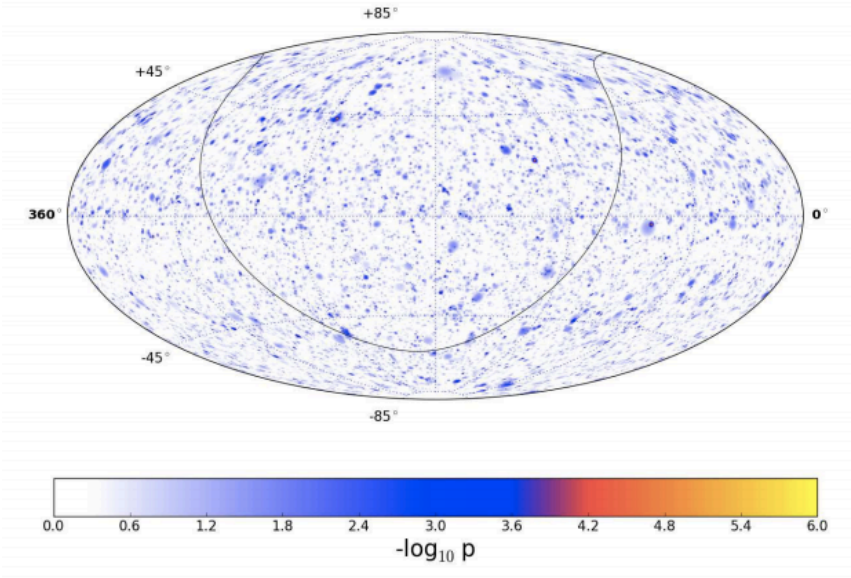


IceCube ApJ 835 (2017)



IceCube ApJ 807 (2015)

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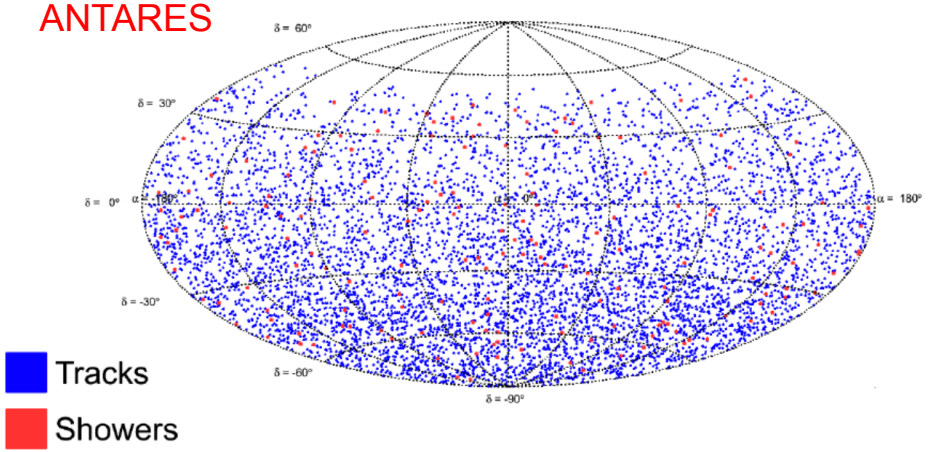

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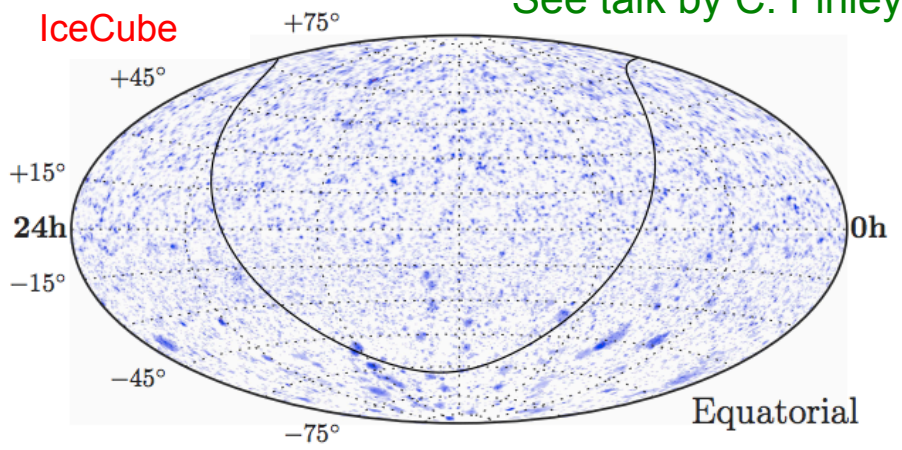
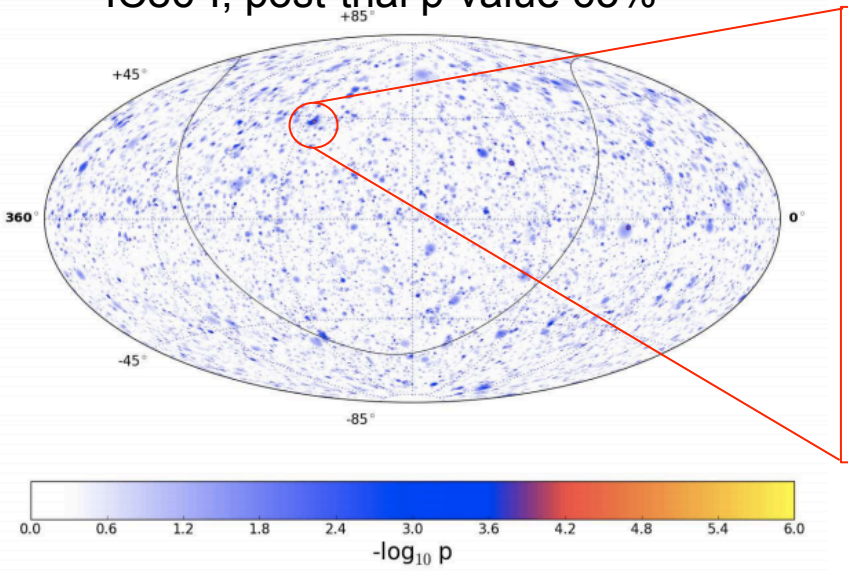
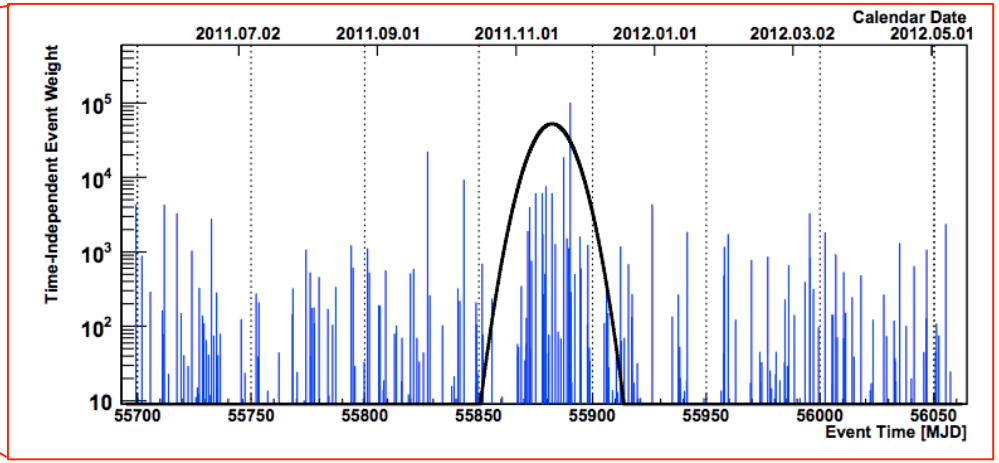


IceCube ApJ 835 (2017)

IC86-I, post-trial p-value 63%





IceCube ApJ 807 (2015)

DESY

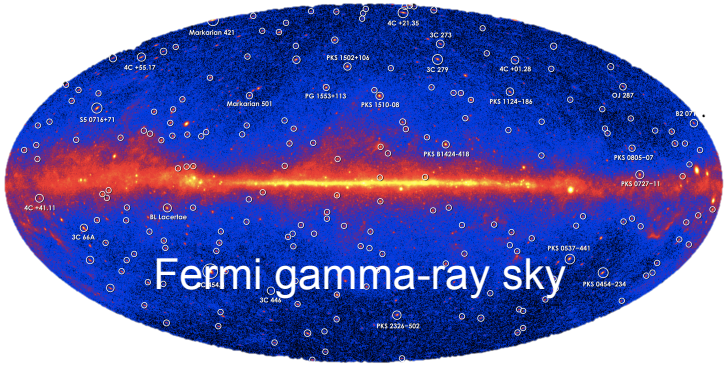
Experimental Approach: Multi-Messenger

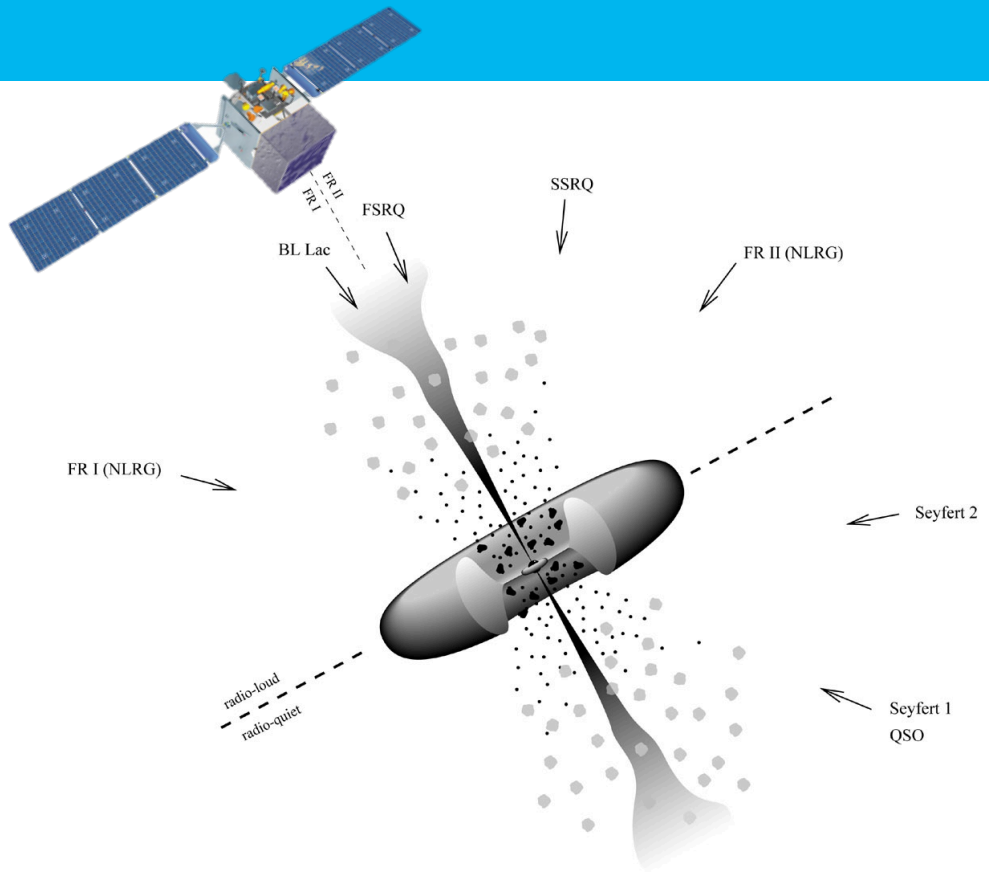
Experimental Approach: Multi-Messenger

Combine Neutrino data with other messengers to increase sensitivity and get complete picture

Blazars

- Gamma rays tell us WHERE





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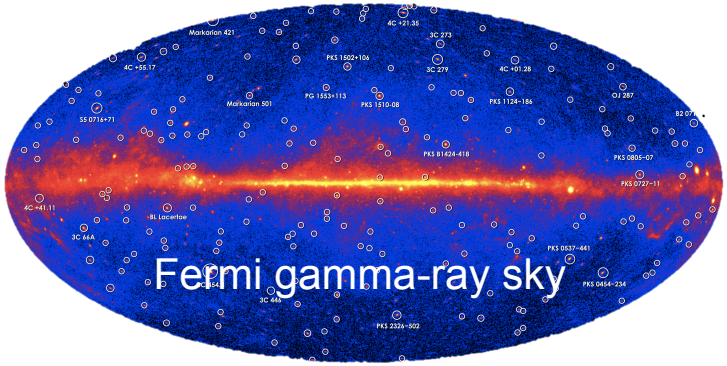
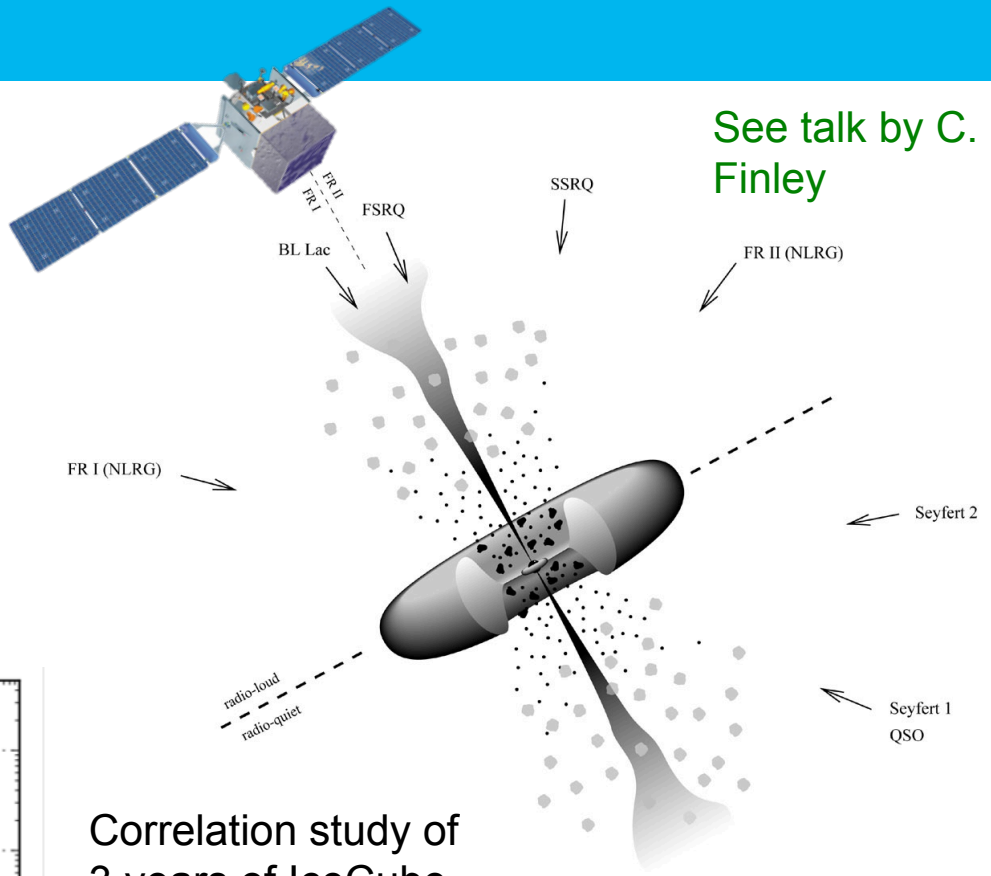
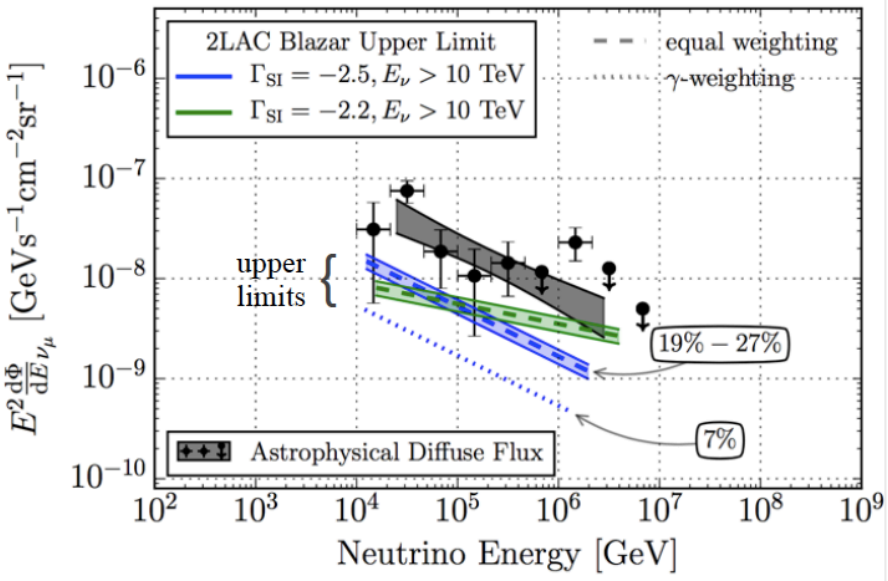




See talk by C. Finley



Correlation study of 3 years of IceCube data and 862 Fermi-LAT blazars

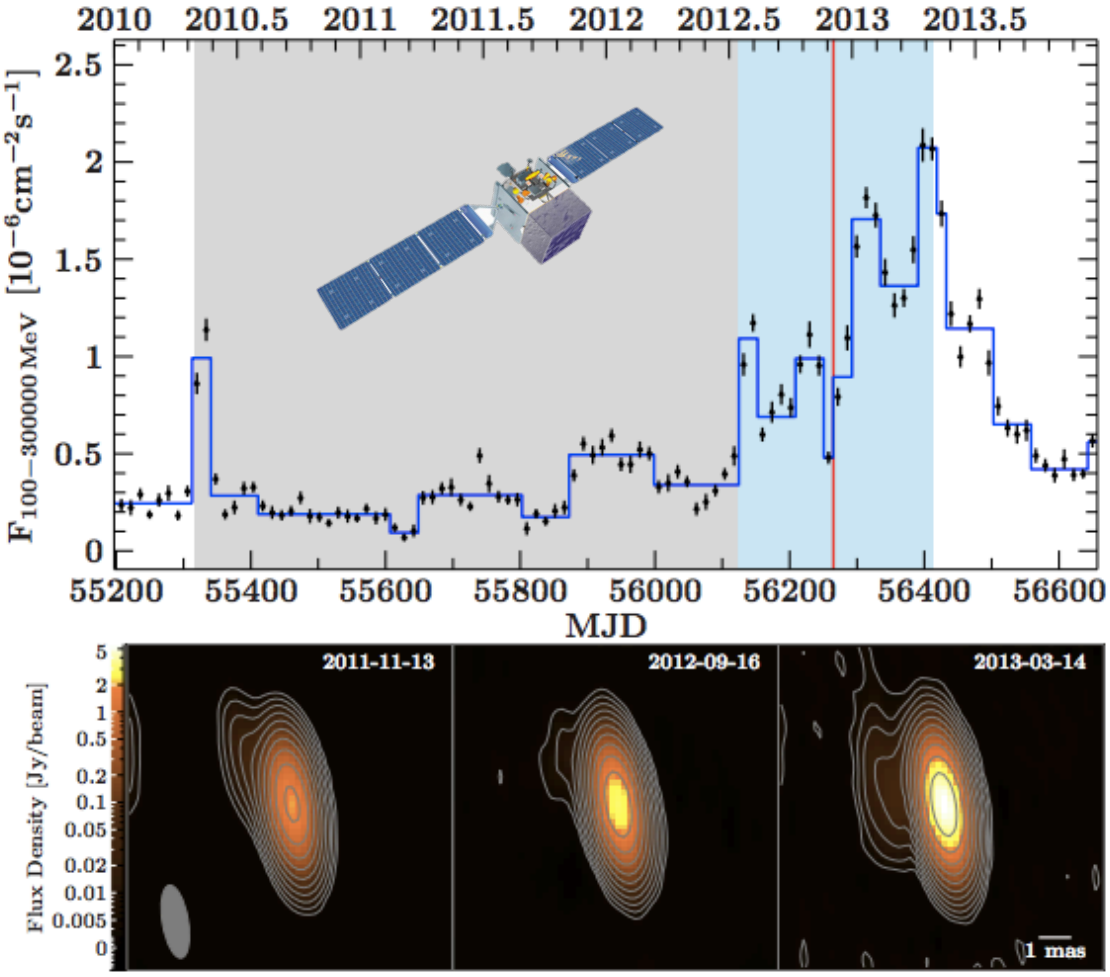
Blazars contribute less than 30% to the diffuse neutrino flux

IceCube Coll., ApJ 835, 2017

Blazar Flares

RA 208.4°
Dec -55.8°

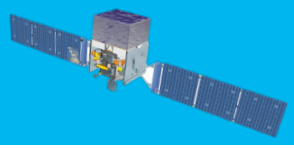
- Gamma rays tell us WHERE and WHEN
- Major outburst of blazar PKS B1424−418 occurred in temporal and positional coincidence PeV neutrino
- single source has sufficiently high fluence to explain an observed coinciding PeV neutrino event
- 5% chance coincidence



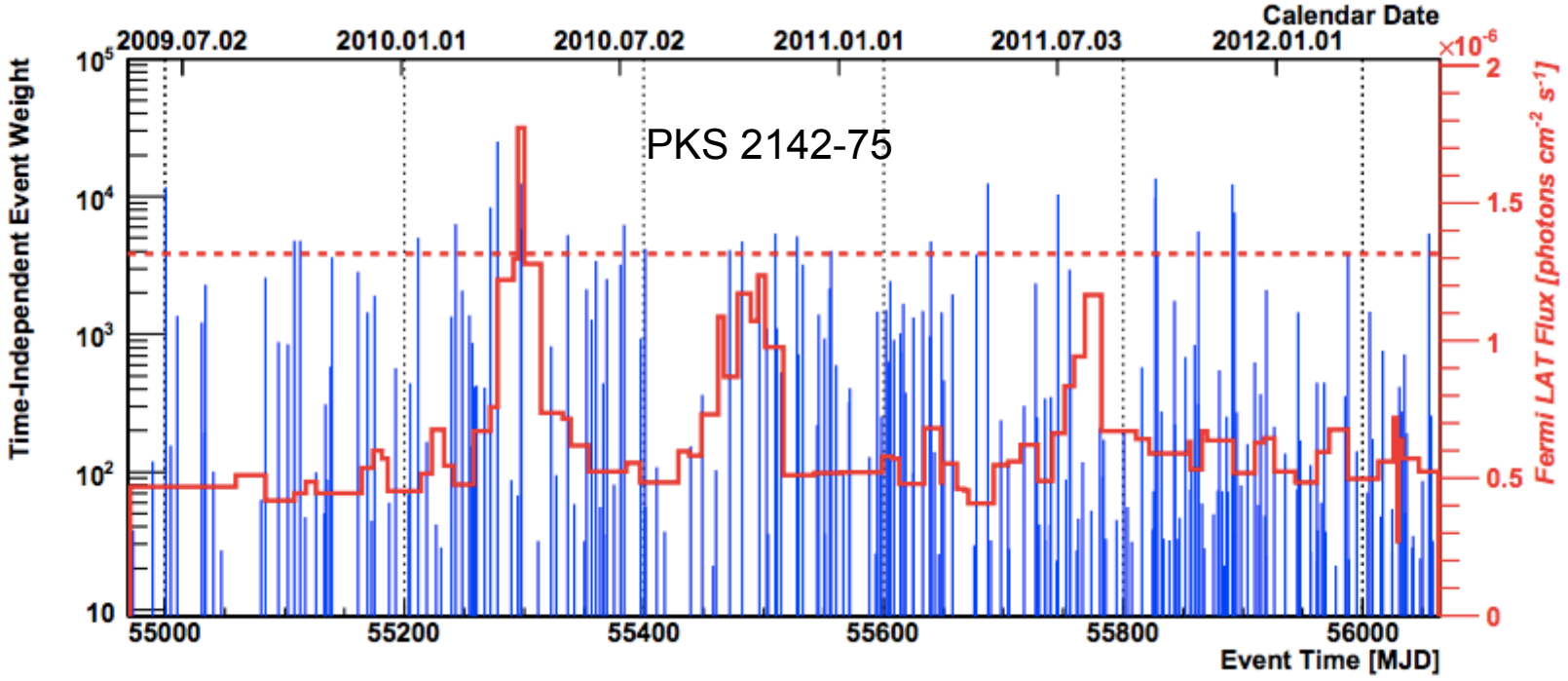
Kadler et al., Nature Physics, 2016

DESY

Using Full Blazar Light Curves



- Search for neutrinos correlated with GeV gamma-ray emission
- Denoised Fermi-LAT light curves as input time PDF



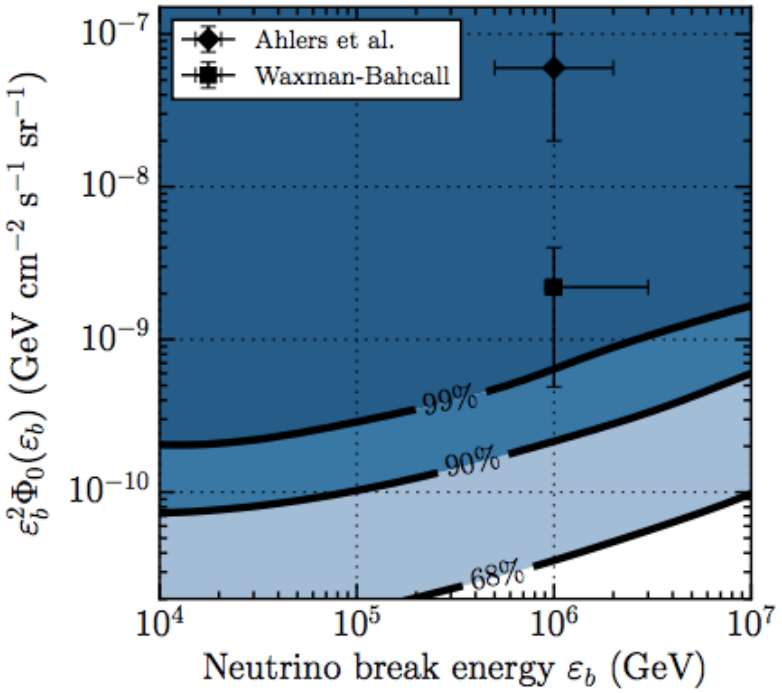
No correlation found in 3 years of IceCube data and ~50 variable gamma-ray sources

IceCube Coll. ApJ 807 (2015) 46

Gamma-Ray Bursts (GRBs)

- Extremely large energy release on the time-scale of 0.1-100 seconds
- Gamma rays and X-rays tell us WHERE and WHEN

1172 GRBs correlated with IceCube data



IceCube arXiv:1702.06868
ANTARES Eur.Phys.J. C77 (2017) no.1, 20

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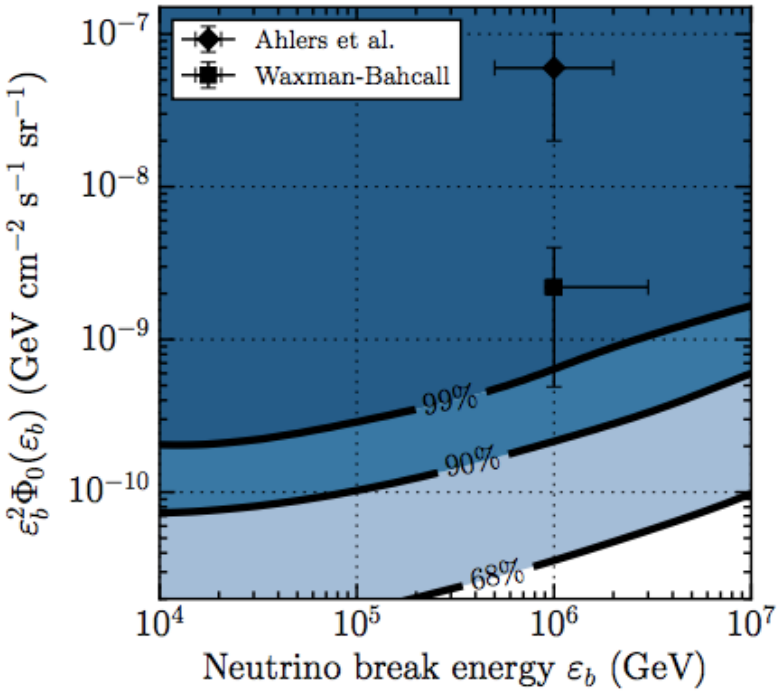
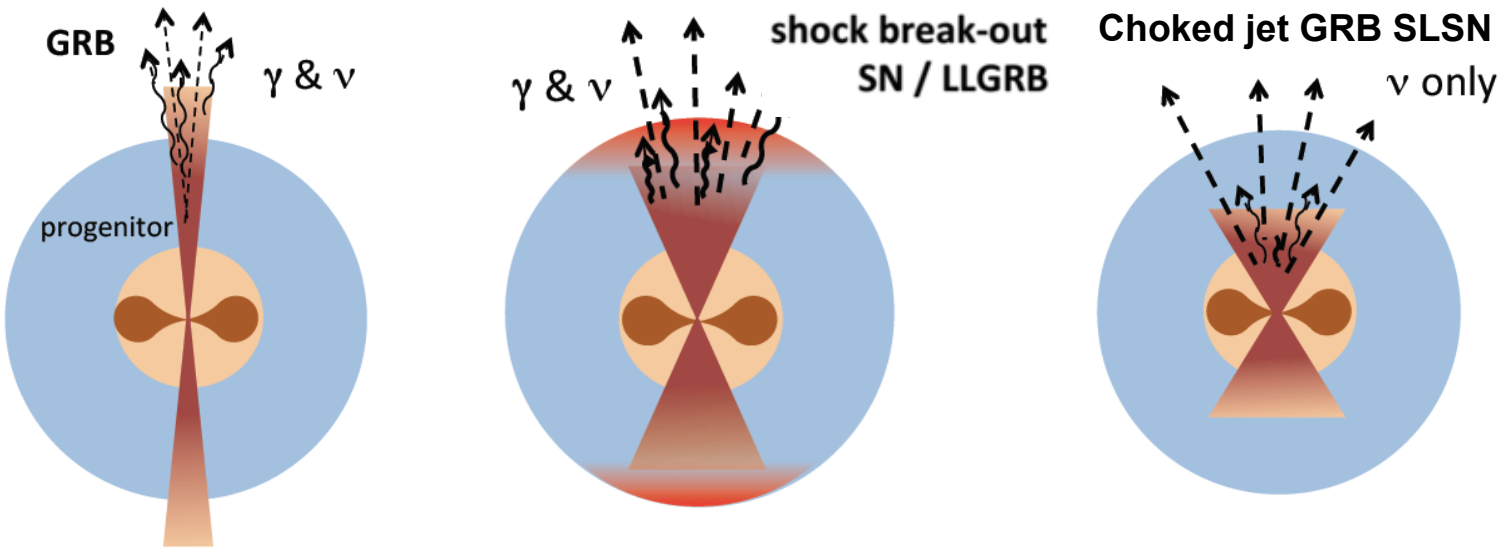


See talk by M. Bustamante

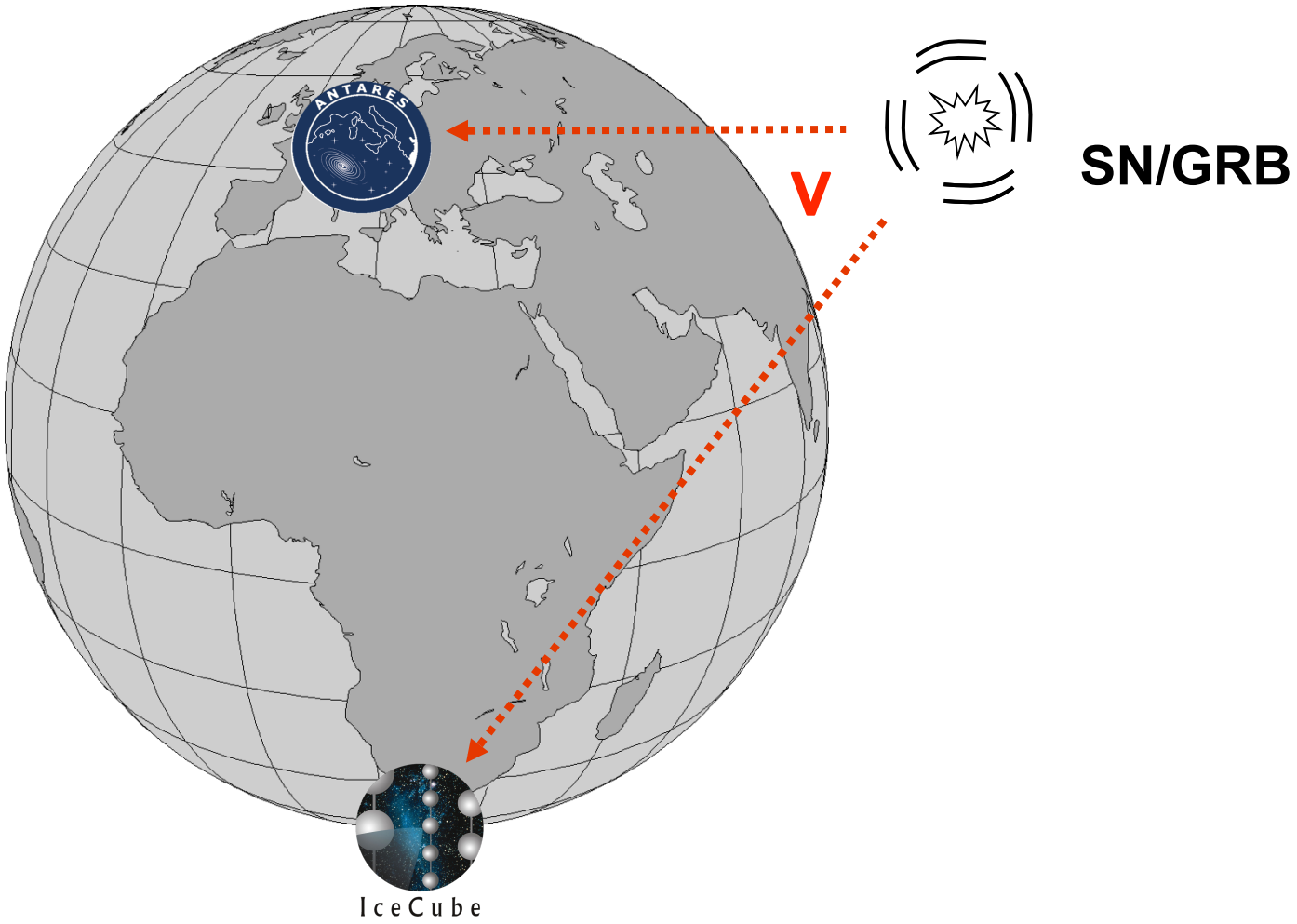
GRBs contribute less than 1% to observed diffuse neutrino flux. Potential large population of nearby low-luminosity GRBs not constrained

IceCube arXiv:1702.06868
ANTARES Eur.Phys.J. C77 (2017) no.1, 20

GRB-Supernova Connection



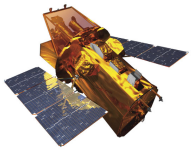
Target of Opportunity Program

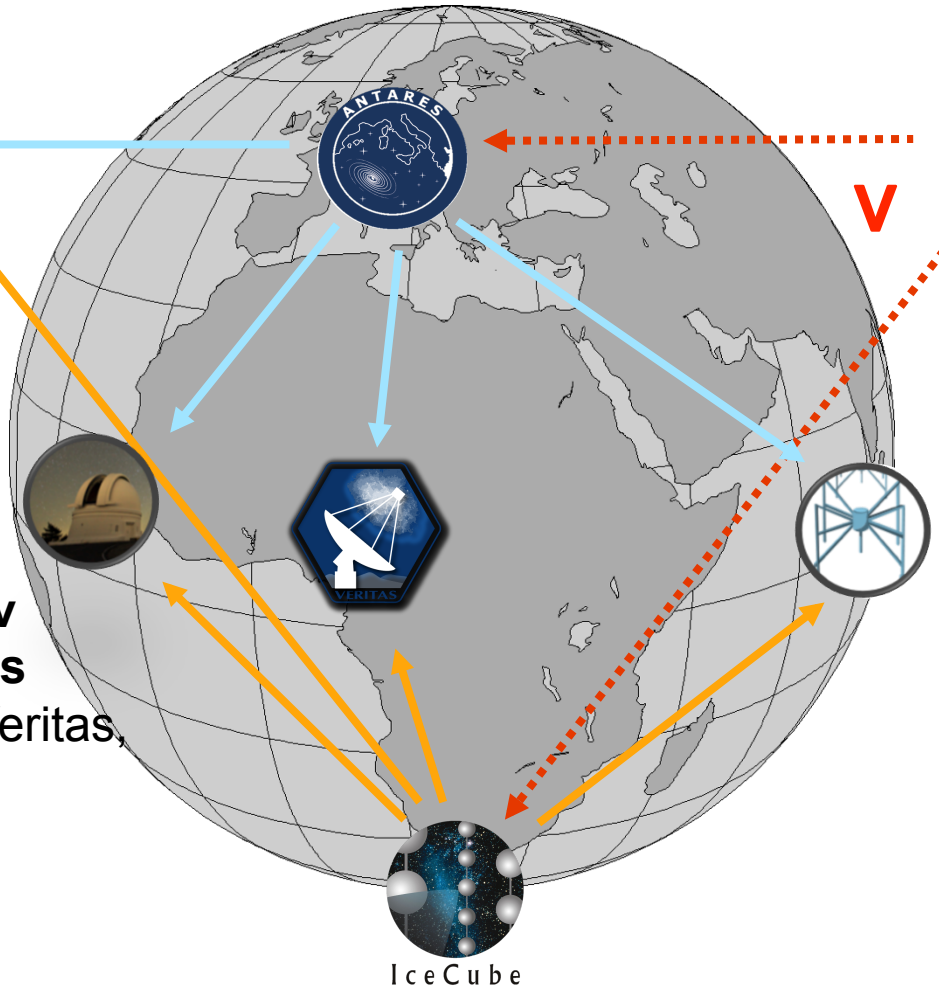


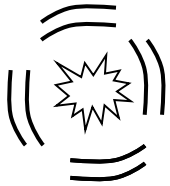
IceCube, MAGIC, VERITAS, arXiv:1610.01814
ANTARES JCAP 1602 (2016)
Ackermann et al.arXiv:0709.2640
IceCube A&A 539, A60 (2012)

Target of Opportunity Program

X-ray (Swift)







SN/GRB

Optical Telescopes
(iPTF, MASTER, Tarot, Pan-STARRS, ASAS-SN)

Cherenkov Telescopes
(MAGIC, Veritas, HESS)

Radio Telescopes
(MWA)

IceCube, MAGIC, VERITAS, arXiv:1610.01814
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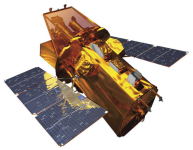

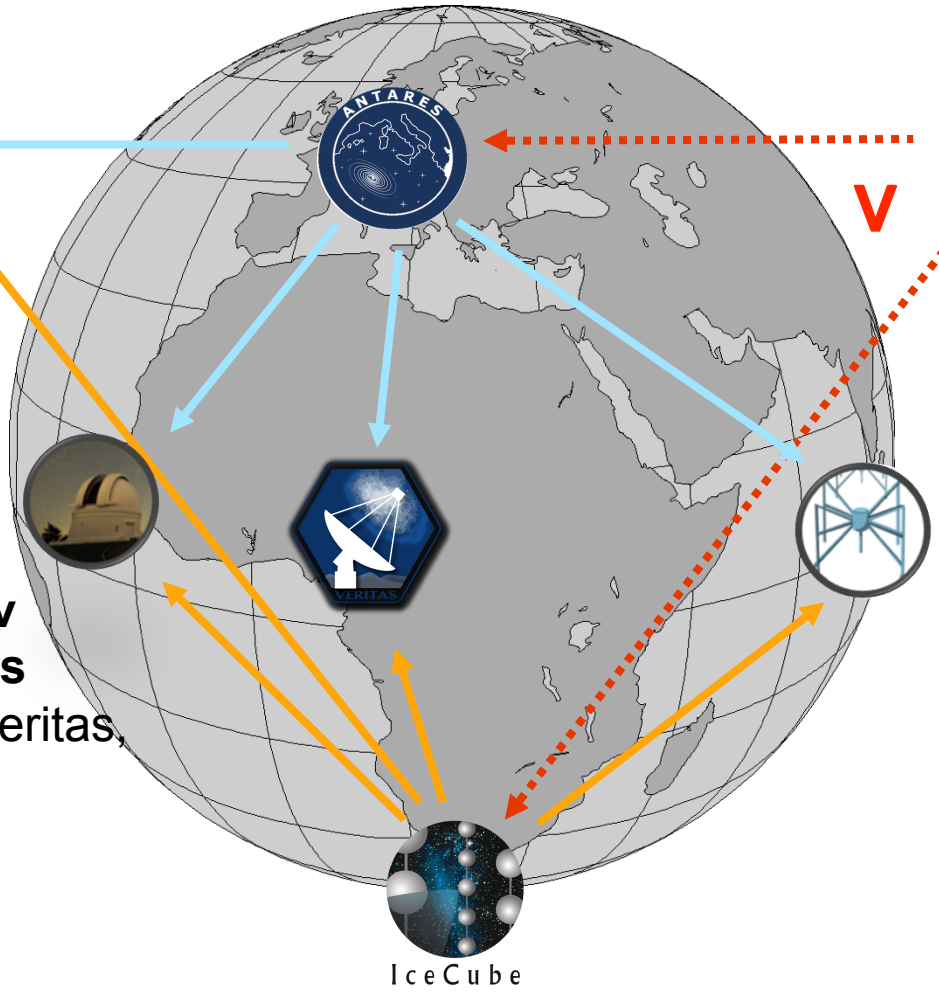

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Cherenkov Telescopes
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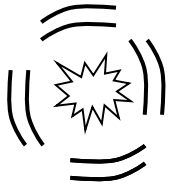
ν



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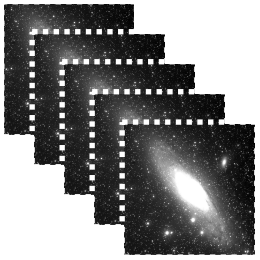

Radio Telescopes
(MWA)

IceCube, MAGIC, VERITAS, arXiv:1610.01814
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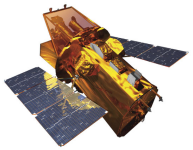

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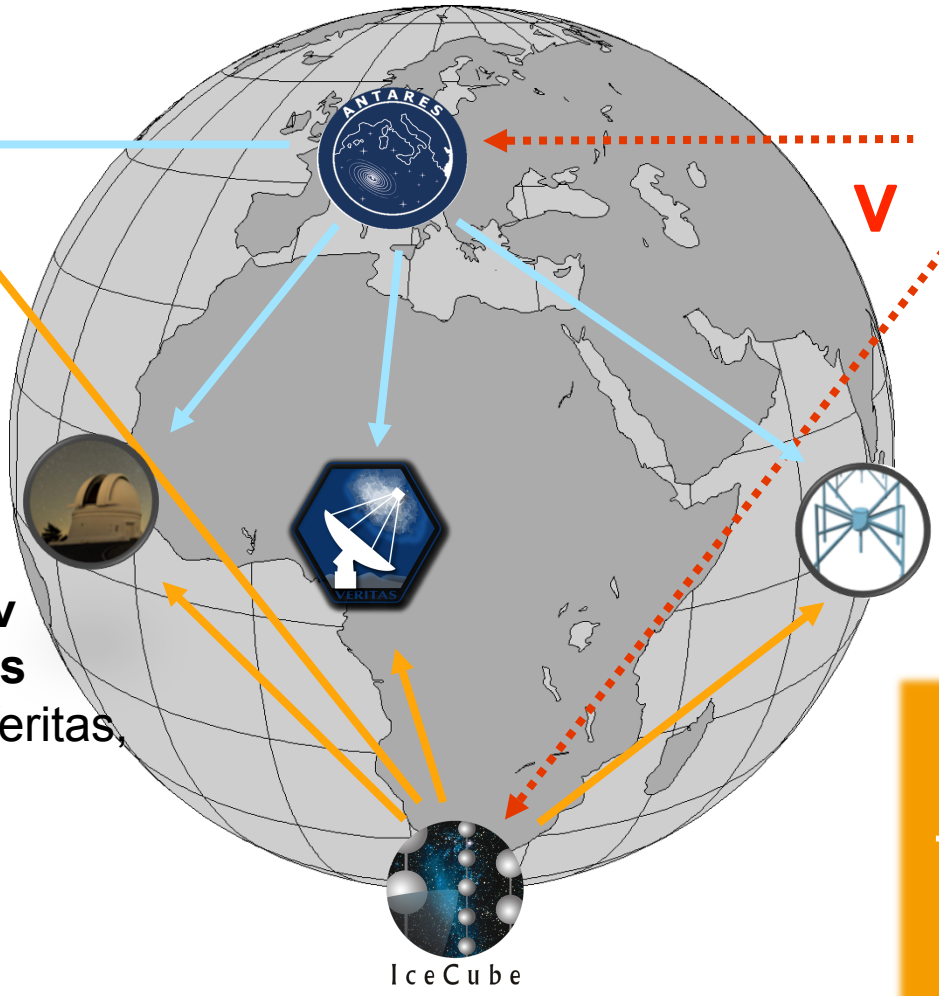

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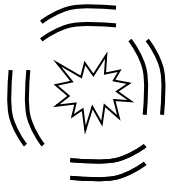

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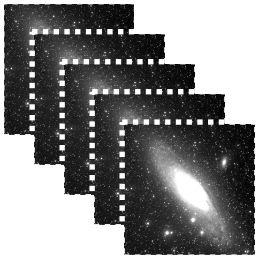

Radio Telescopes
(MWA)

Increased sensitivity for transient neutrino sources → source identification

IceCube, MAGIC, VERITAS, arXiv:1610.01814
ANTARES JCAP 1602 (2016)
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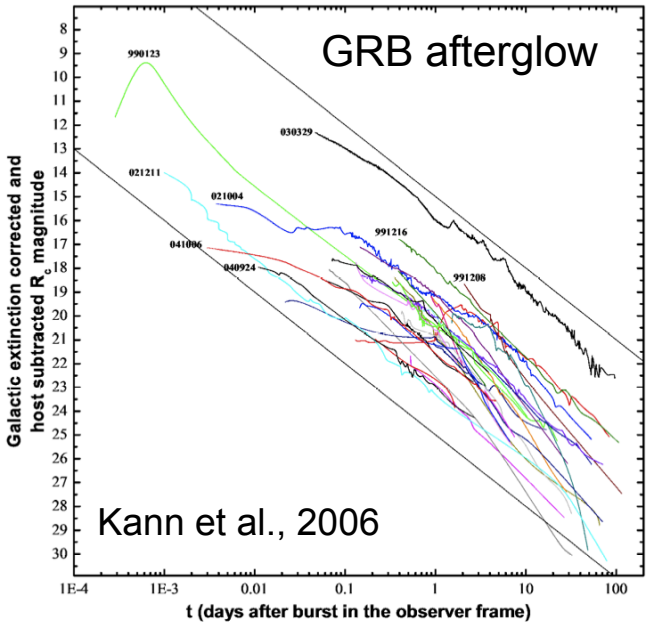
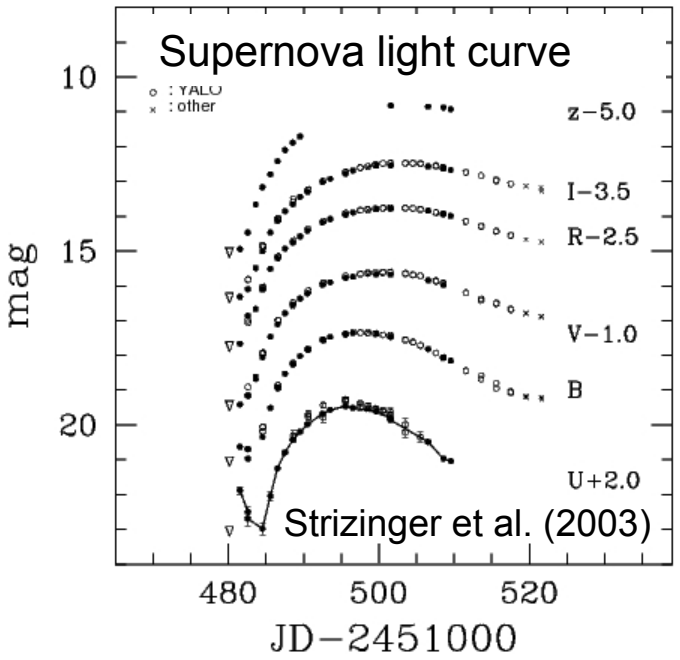
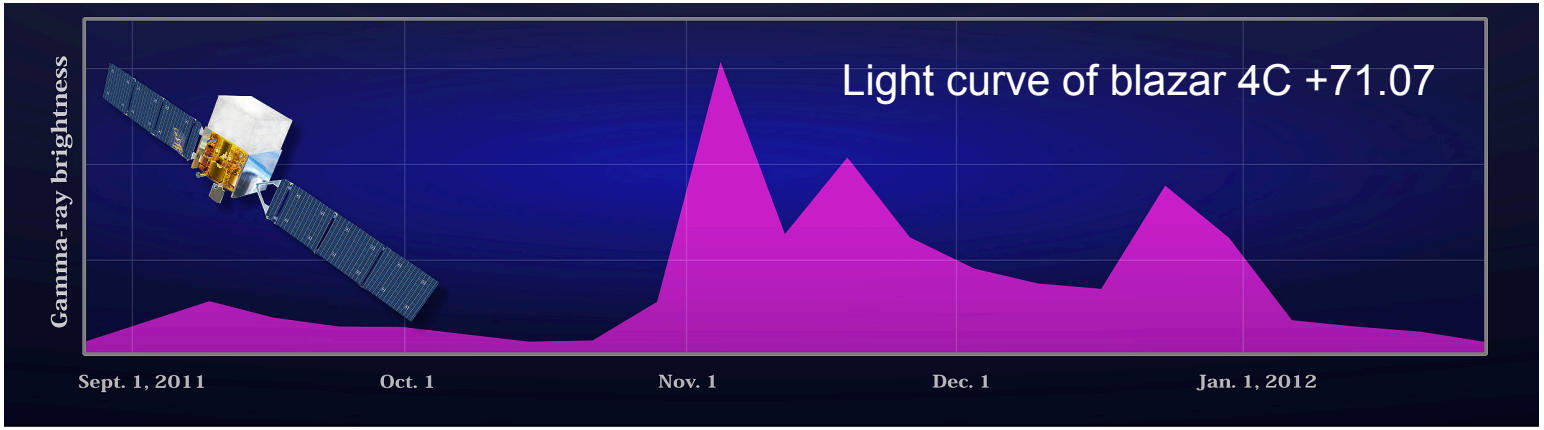
IceCube A&A 539, A60 (2012)

Expected EM Counterparts







Online Neutrino Event Selection

Need to suppress atmospheric background

- Clusters in time
- High-energy Events

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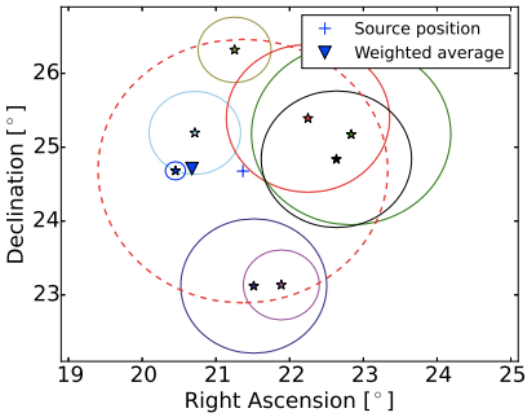
- High-energy Events



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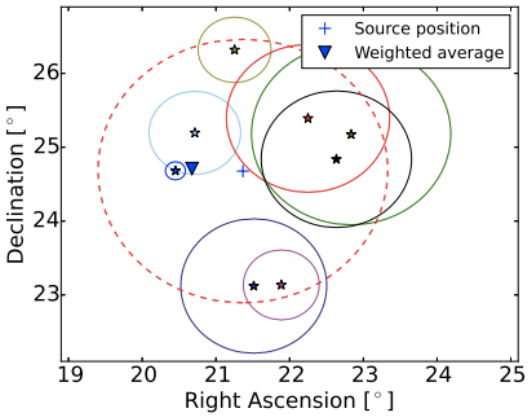
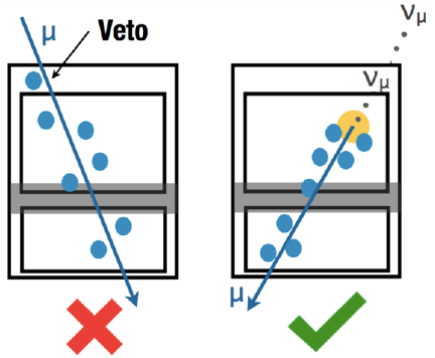


- High-energy Events
  - High-energy starting tracks (HESE)



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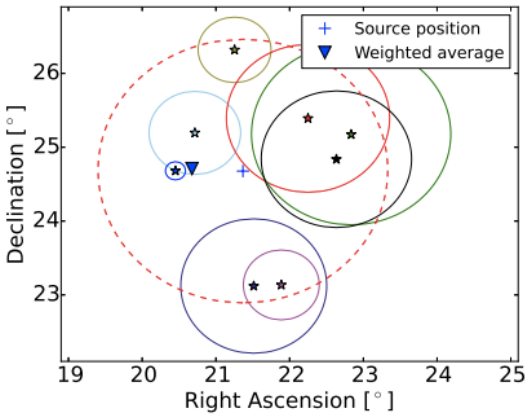

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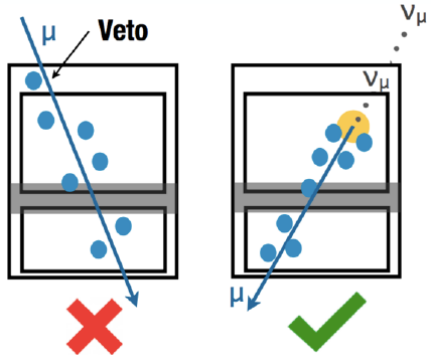
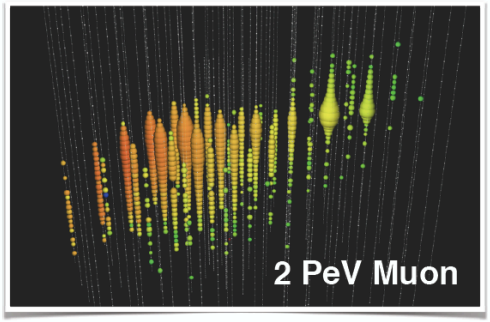
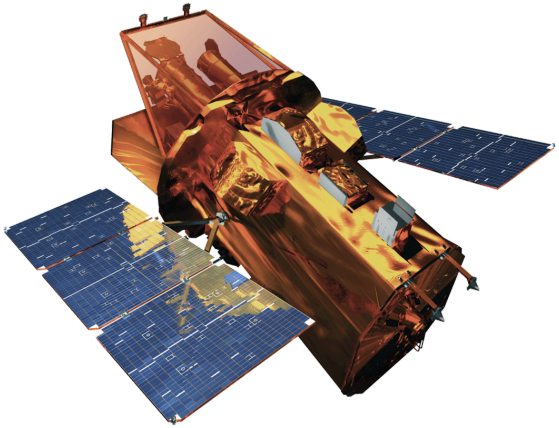


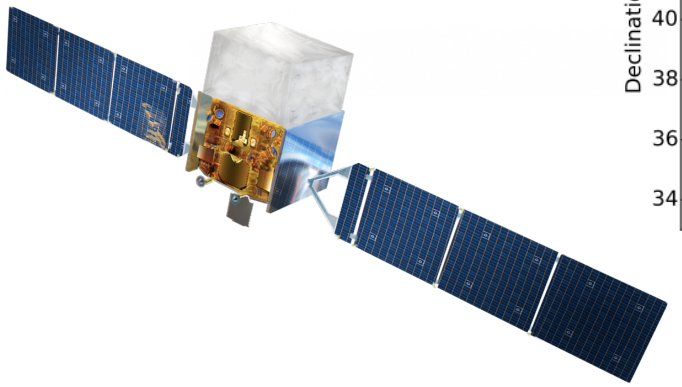
  - Extremely high-energy events (EHE)

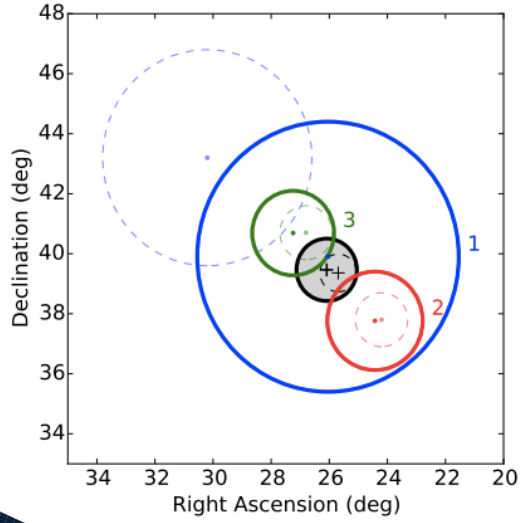


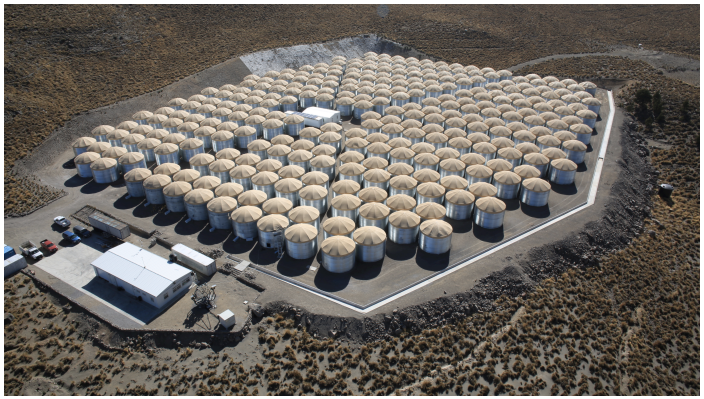
Three Neutrinos detected within 100 sec

- Expected from background once every 13.7 yrs





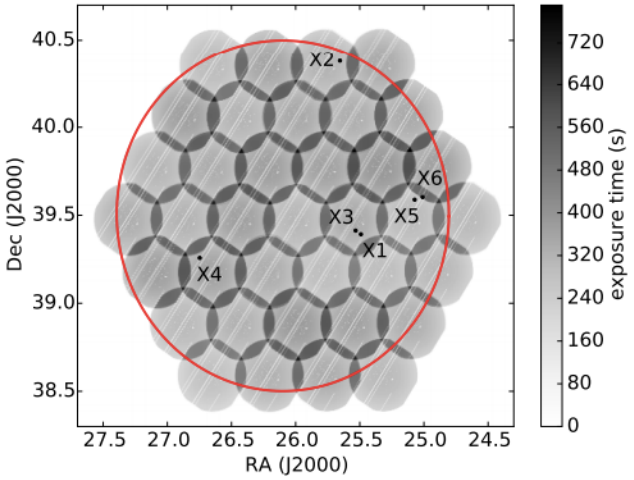


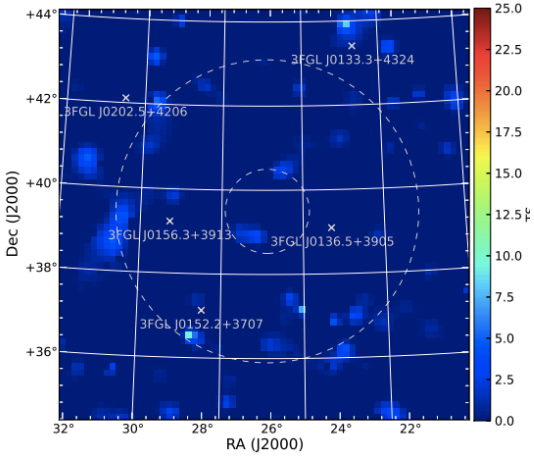


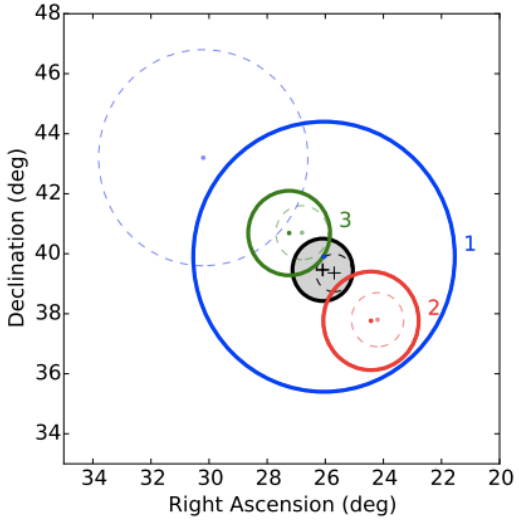
IceCube, ASAS-SN, AMON, Fermi, VERITAS, HAWC, LCO, Swift, MASTER, arXiv:1702.06131

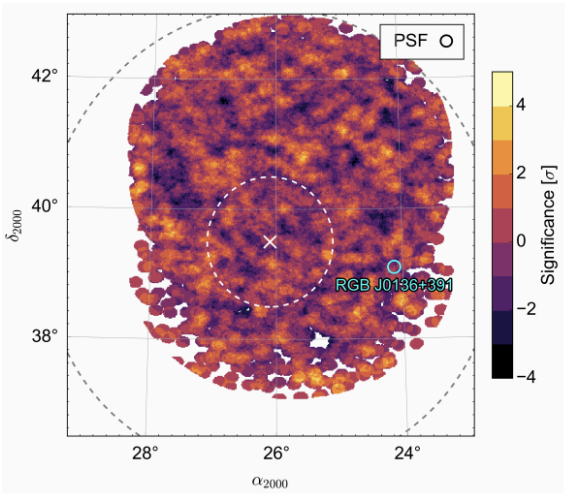
Three Neutrinos detected within 100 sec

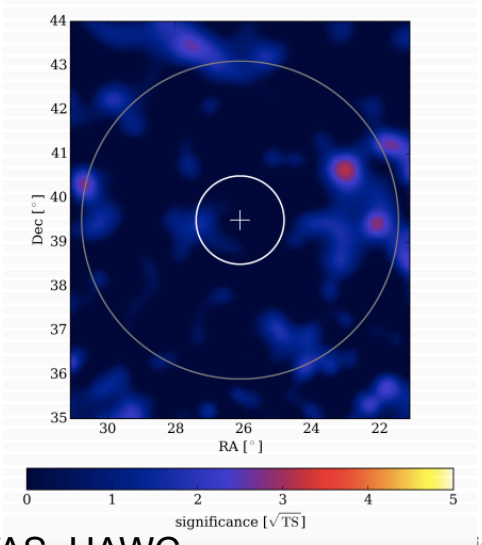
- Expected from background once every 13.7 yrs







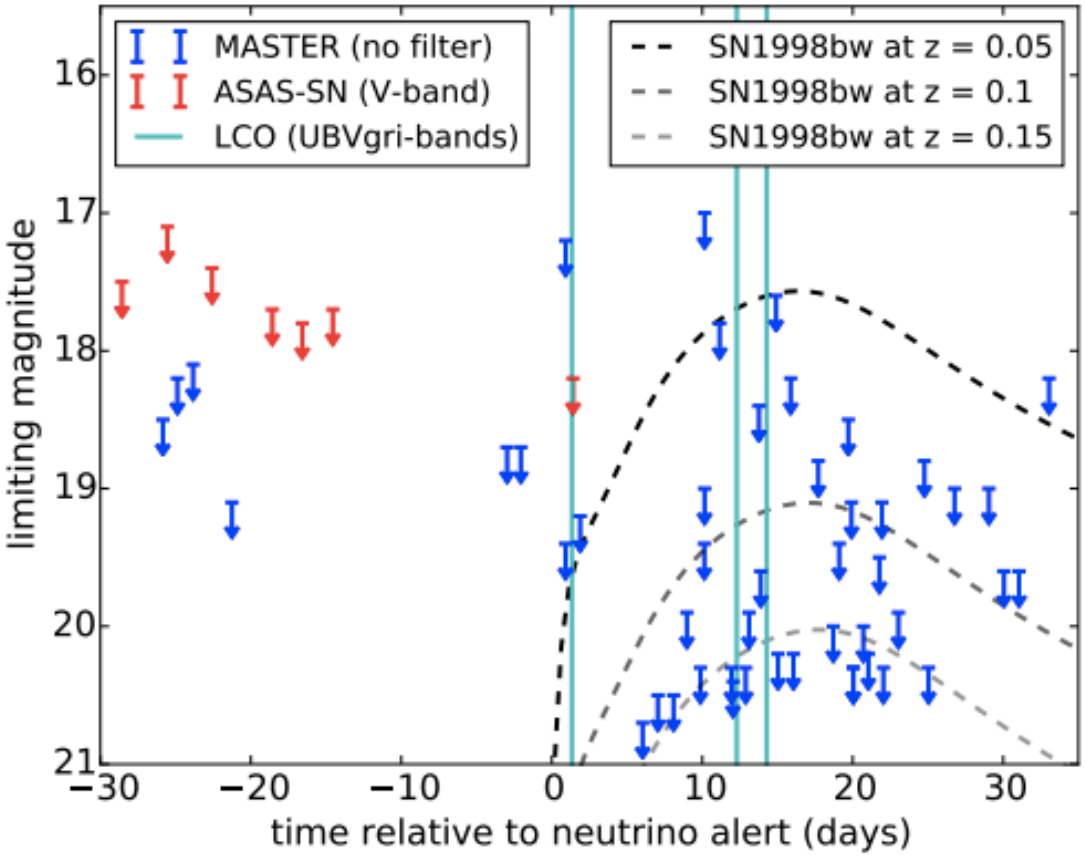




IceCube, ASAS-SN, AMON, Fermi, VERITAS, HAWC, LCO, Swift, MASTER, arXiv:1702.06131

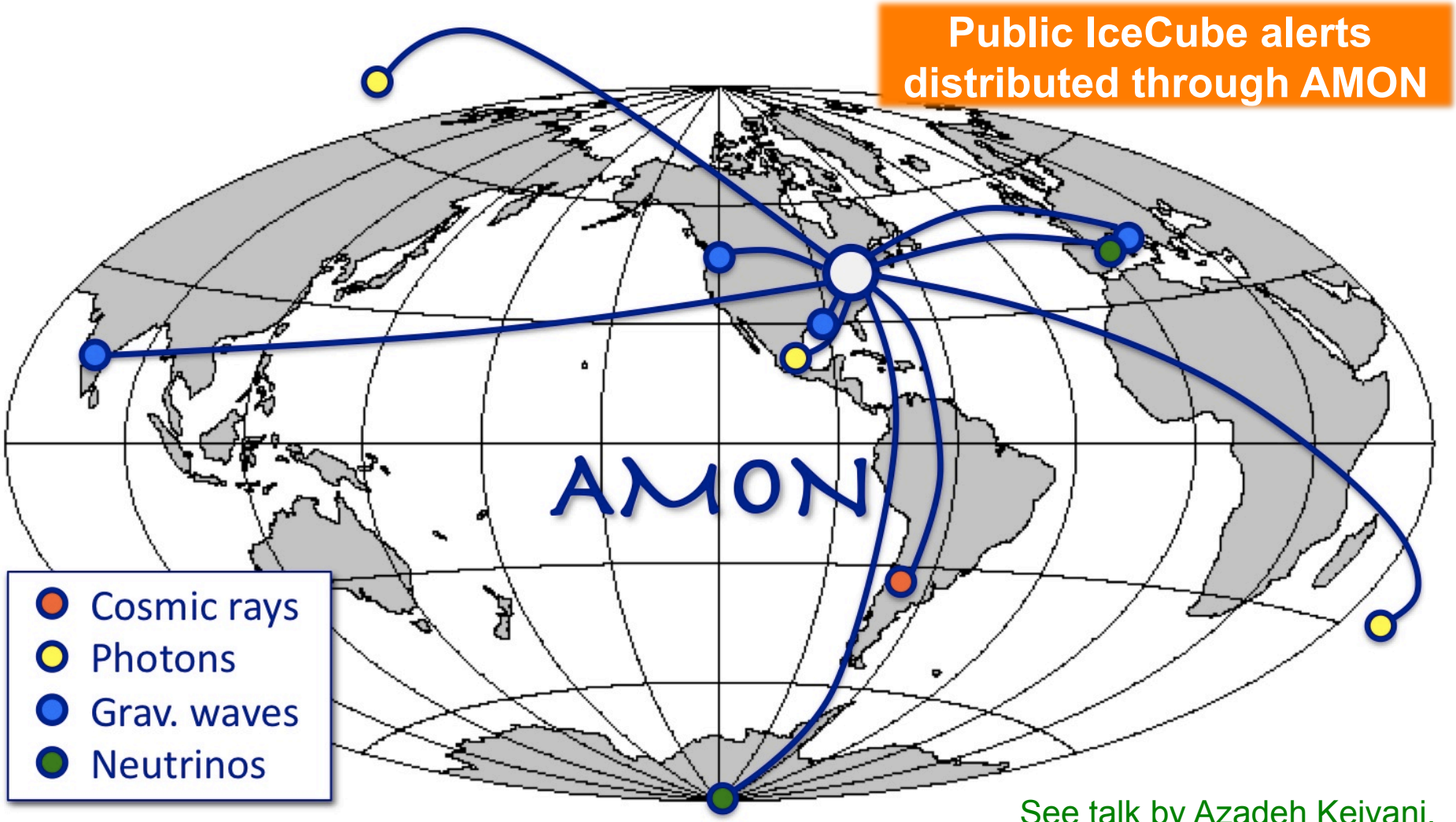
Three Neutrinos detected within 100 sec

- Results: no obvious counterpart found



IceCube, ASAS-SN, AMON, Fermi, VERITAS, HAWC, LCO, Swift, MASTER, arXiv:1702.06131

Astrophysical Multimessenger Observatory Network (AMON)



http://amon.gravity.psu.edu
Smith et al., Astropart. Phys., 45 (2013)

See talk by Azadeh Keivani, James Delaunay

First HESE/EHE Alerts

Date	Type	RA	Dec	50% Error
2016/04/27	HESE	240.6°	9.3°	0.6°
2016/07/31	EHE + HESE	214.5°	-0.3°	0.35°
2016/08/06	EHE	122.8°	-0.7°	0.11°
2016/08/14	HESE	200.3°	-32.4°	0.48°
2016/11/03	HESE	40.8°	12.6°	0.42°
2016/12/10	EHE	46.6°	15.0°	0.3°
2017/03/03	HESE	305.2°	-26.6°	0.5°
2017/03/21	EHE	98.3.1°	-14.5°	0.3°
2017/05/06	HESE	221.8°	-26.0°	1.2°

Alerts sent publicly via GCN through AMON

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2017/03/03	HESE	305.2°	-26.6°	0.5°
2017/03/21	EHE	98.3.1°	-1	
2017/05/06	HESE	221.8°	-2	

Alerts sent publicly via GCN through AMON

optical

Telescope	Results
iPTF	3 transients, all AGN
MASTER	No detection
Pan-STARRS	7 SN candidates

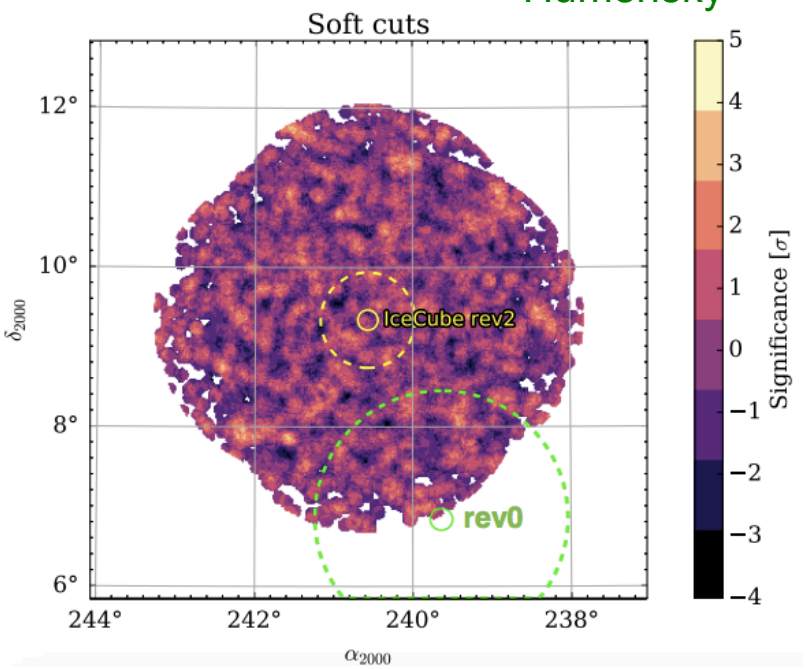
gamma-rays

Telescope	Results
IPN	No detection
Fermi-LAT	5 unrelated blazars
Fermi-GBM	No detection
FACT	No detection
VERITAS	No detection
HAWC	No detection
MAGIC	No detection

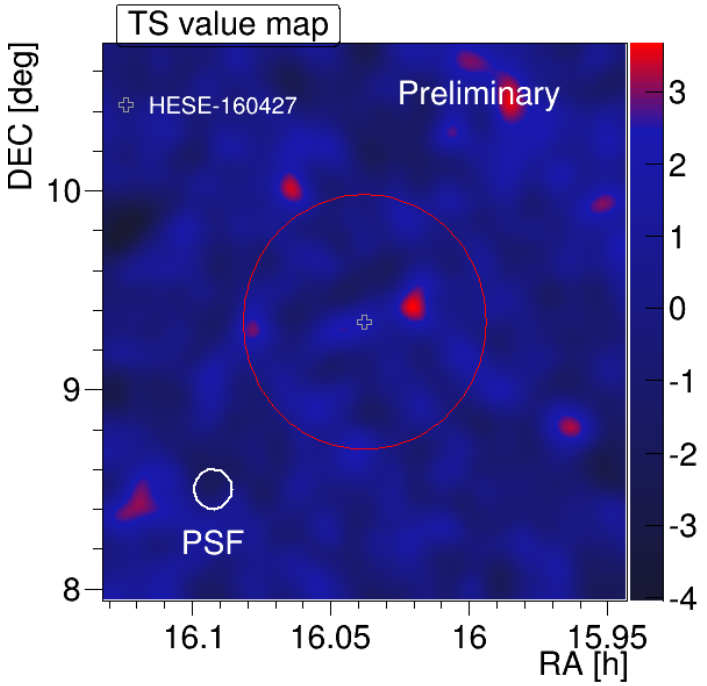
Gamma-Ray Follow-Up of Public Alerts

- All operating Cherenkov Telescopes observed
  - H.E.S.S.: automatic follow-up in < 2min
  - VERITAS: automatic follow-up in 112 sec
  - FACT
  - MAGIC

See talk by B. Humensky

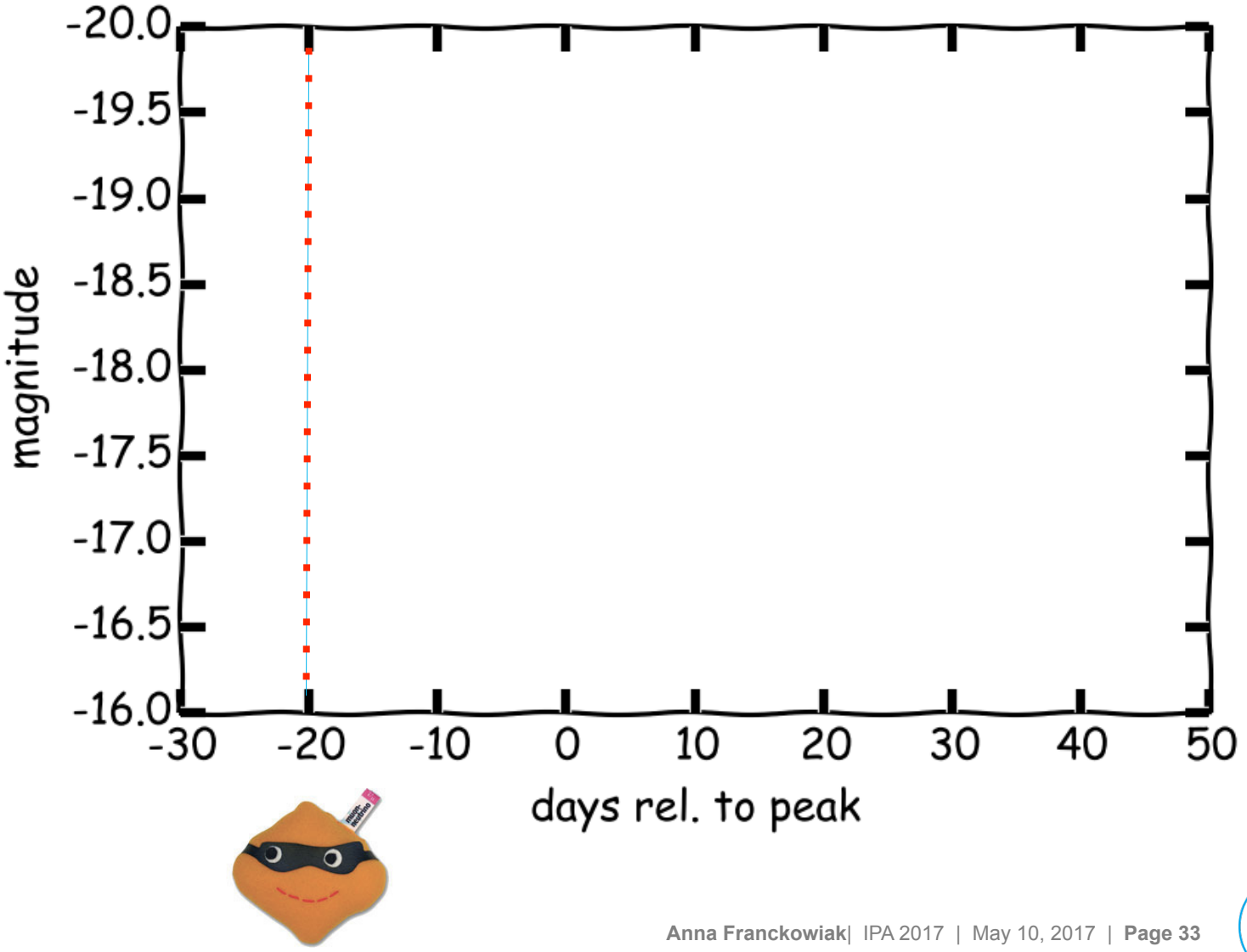


M. Santander for the VERITAS Coll., ICHEP 2016



D. Gora et al. for the MAGIC Coll., Neutrino 2016

What could we learn if we would find a supernova counterpart?



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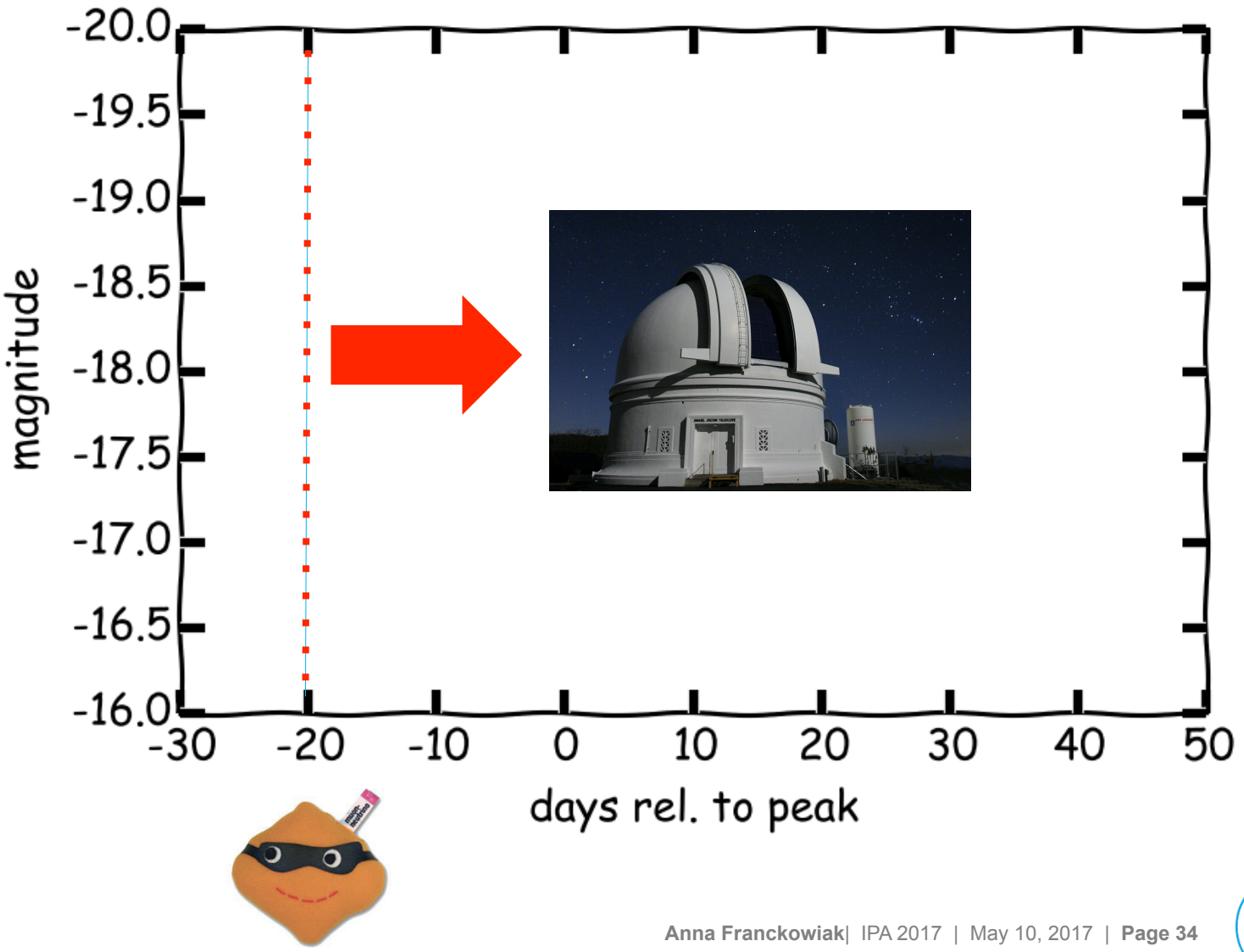

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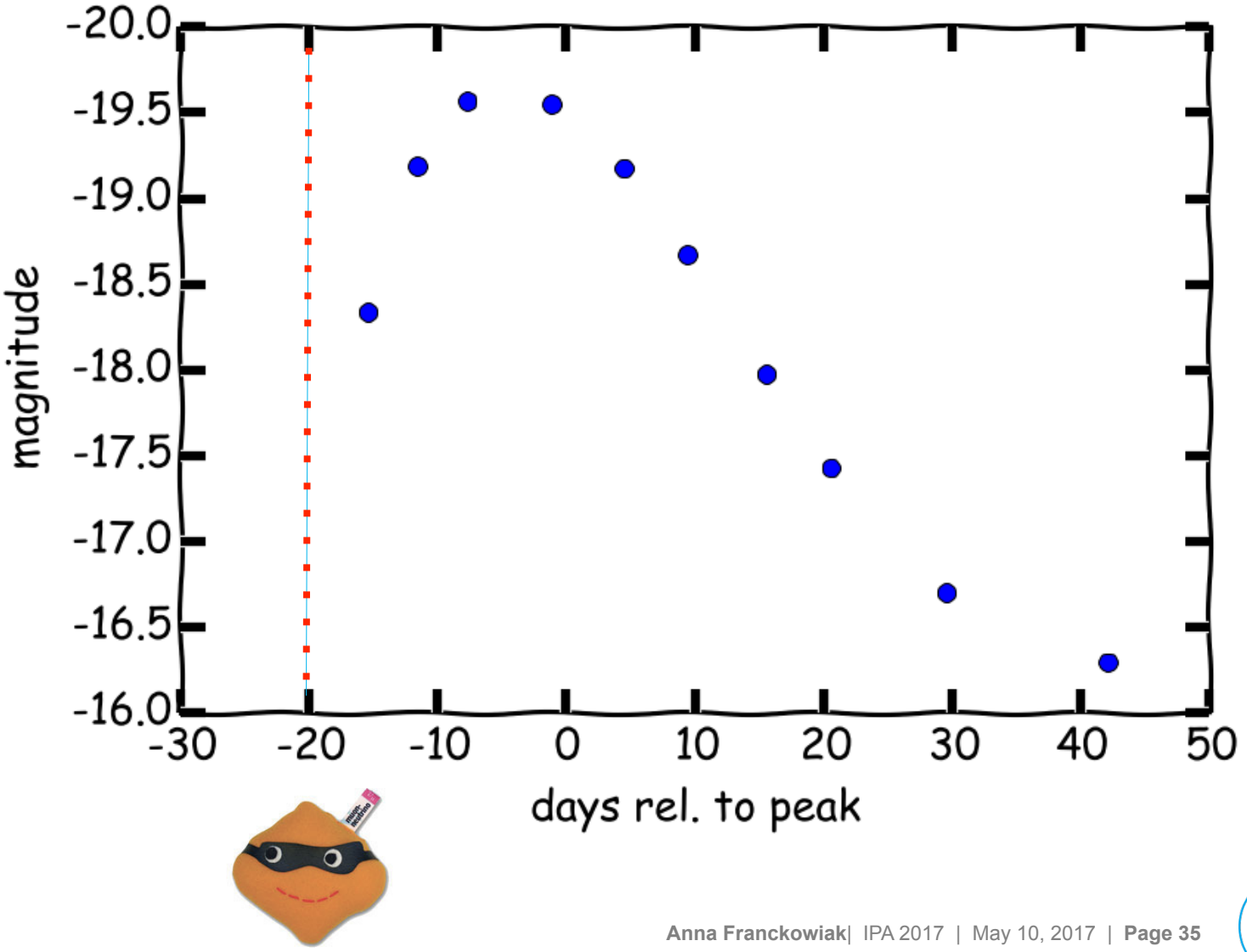

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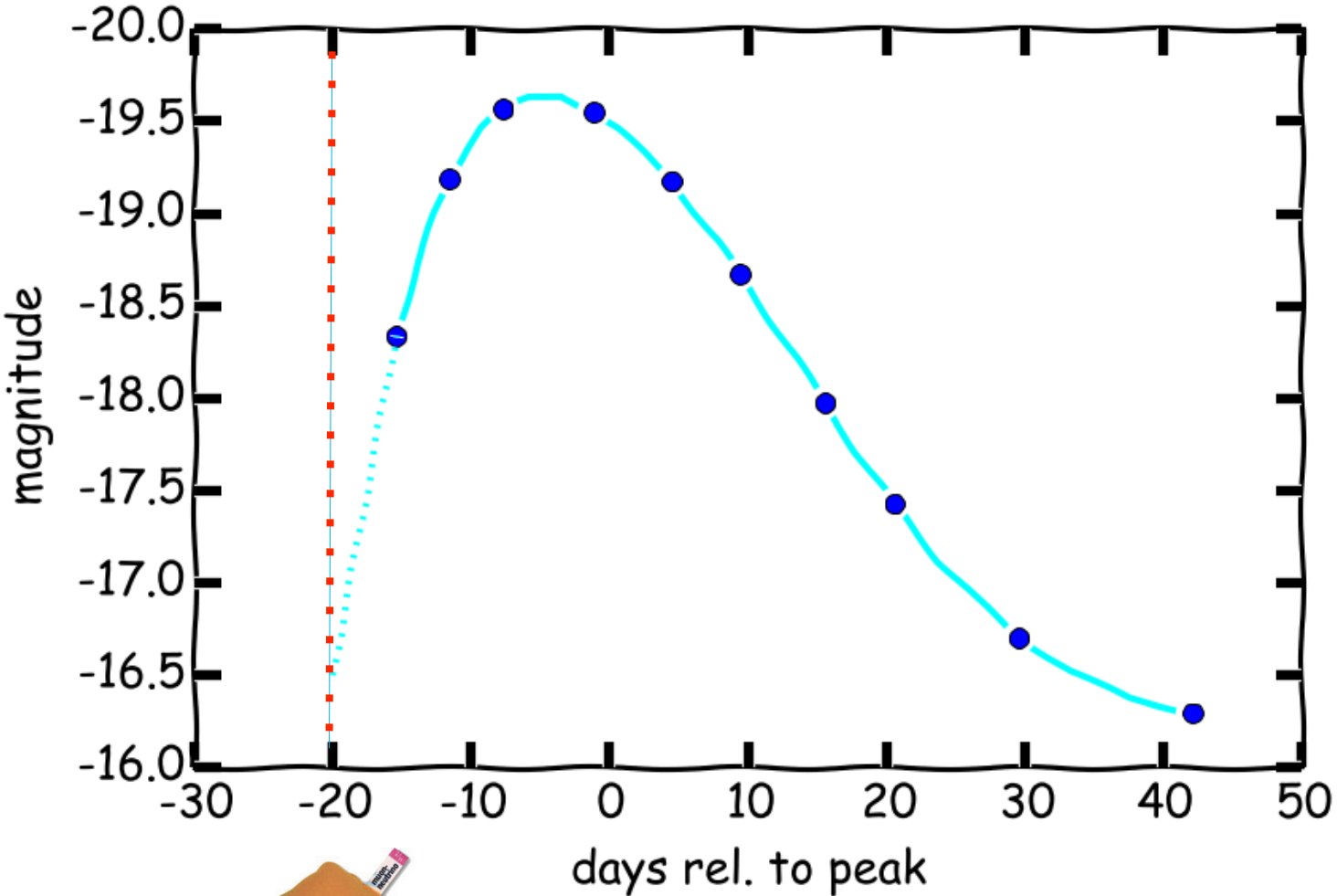

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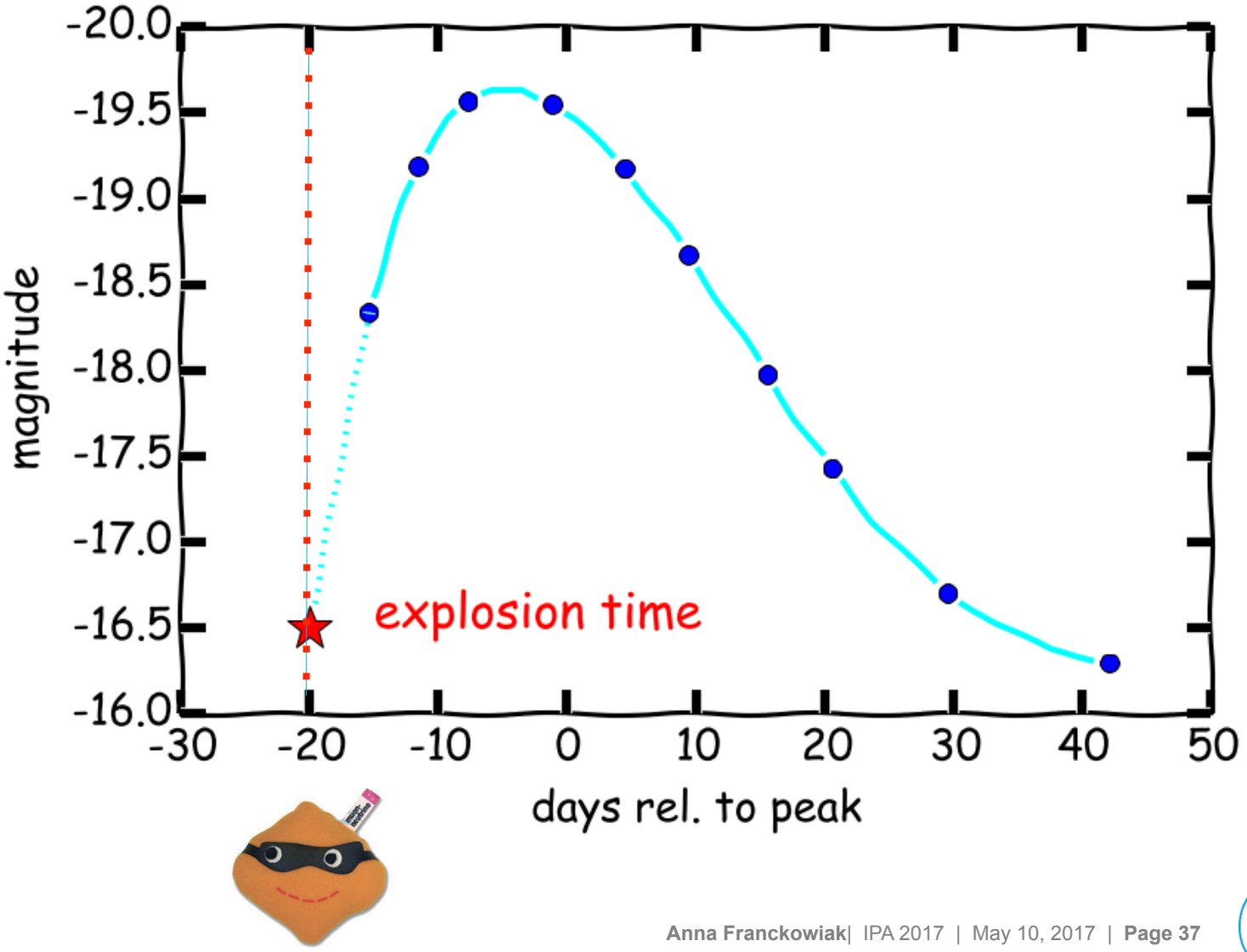

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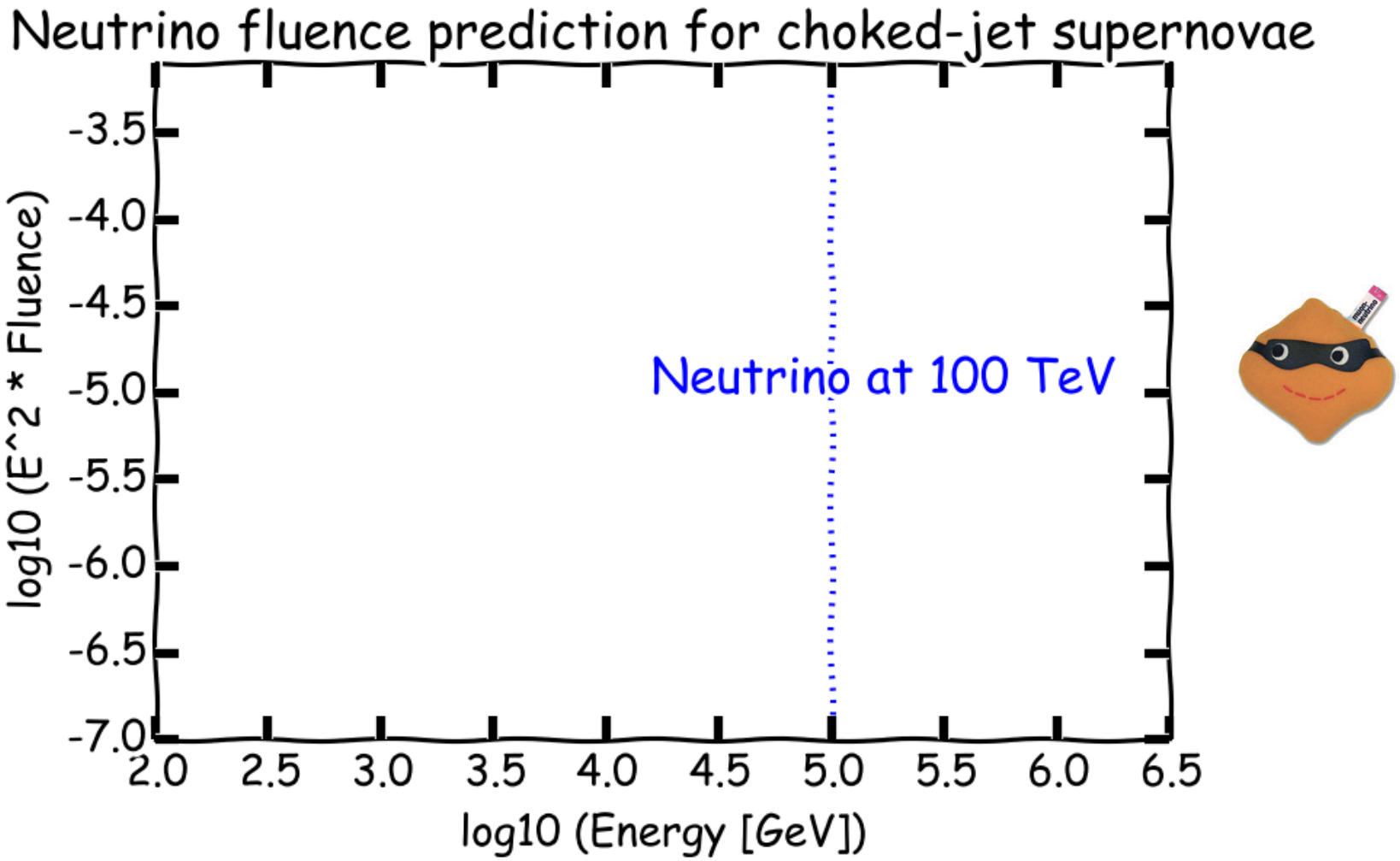

Adopted from Tamborra & Ando, PRD 93, 053010 (2016)

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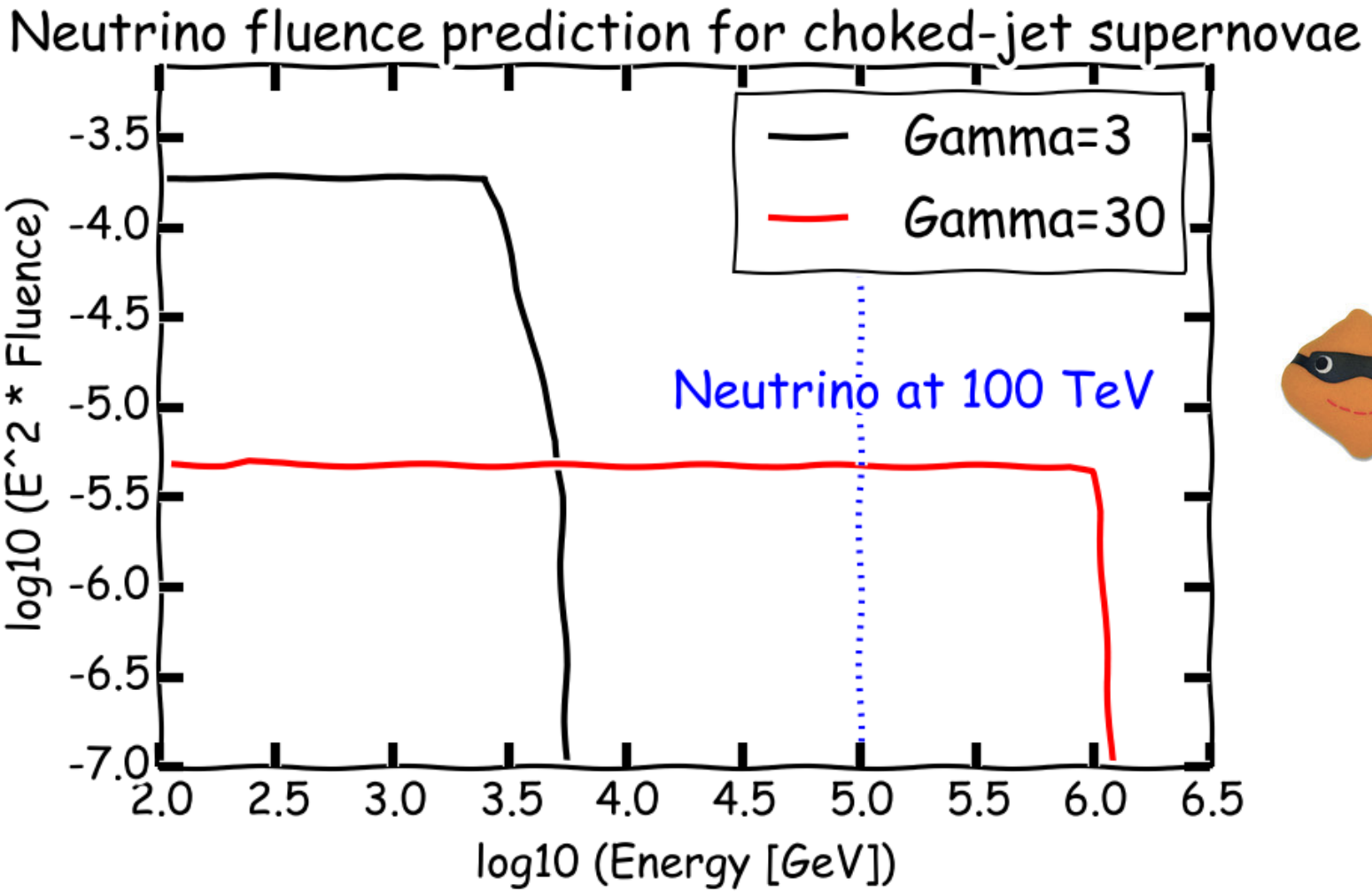

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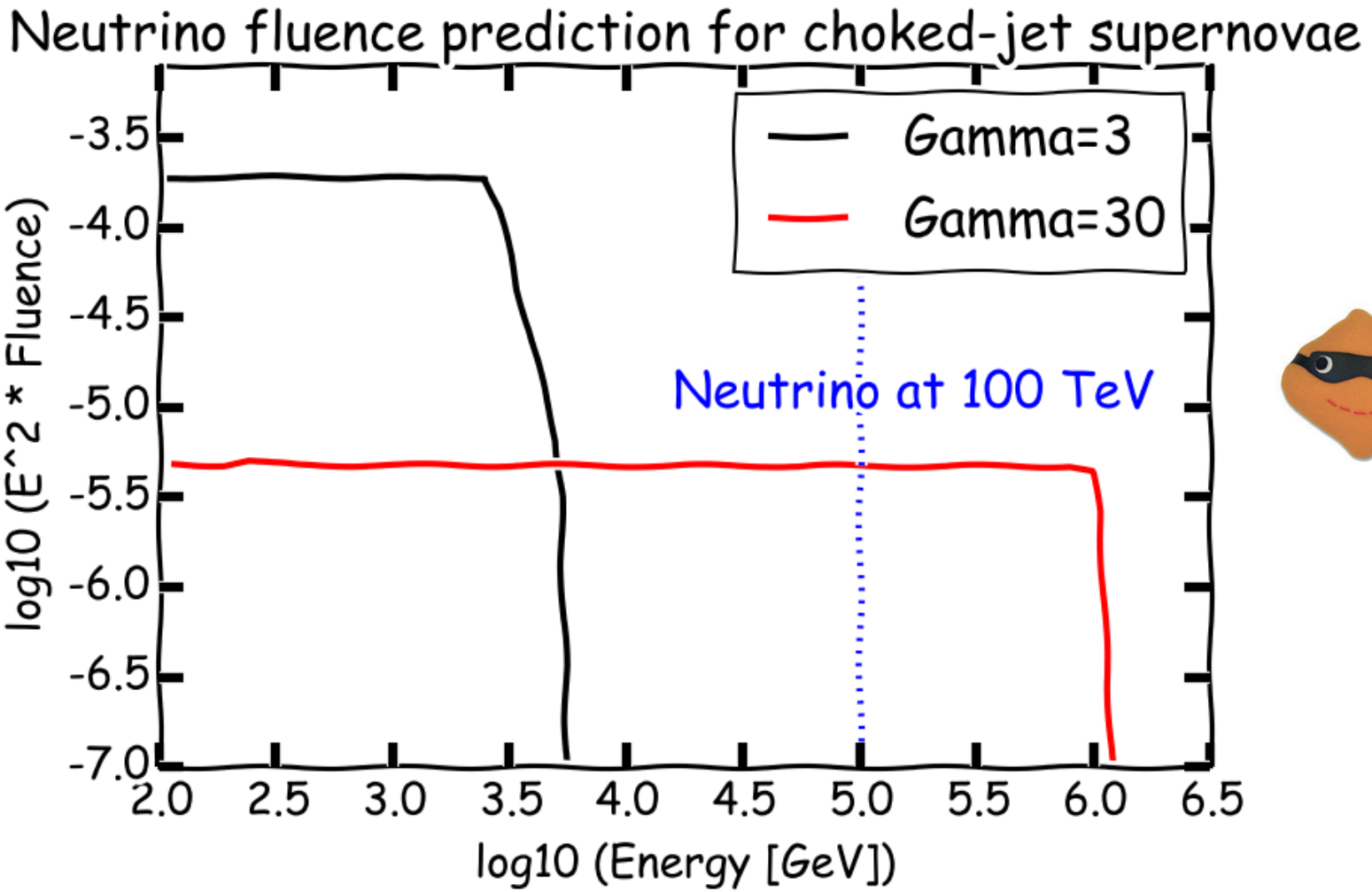


Adopted from Tamborra & Ando, PRD 93, 053010 (2016)

Set lower limit on boost Lorentz factor of choked jet

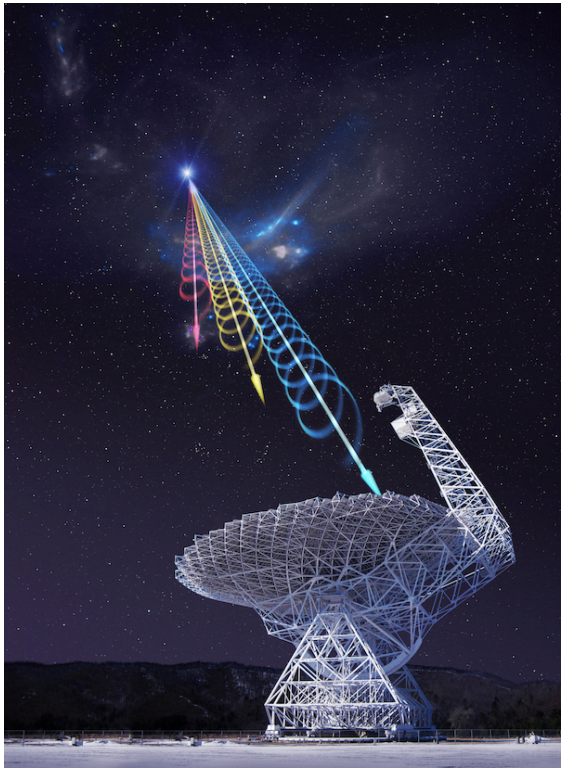
Fast Radio Bursts

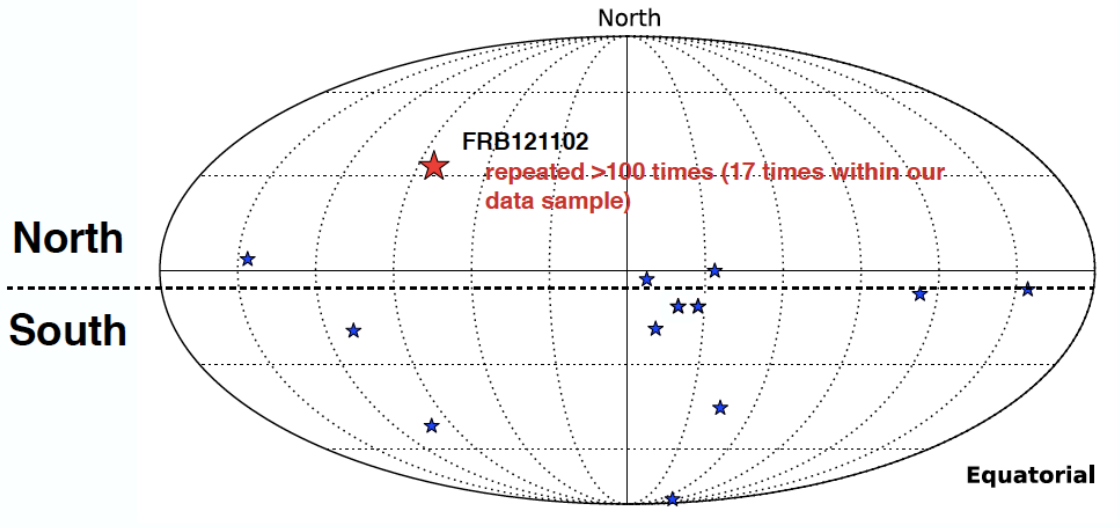
Many possible models: some are possible neutrino sources (e.g. magnetar/SGR hyperflares)

S. B. Popov and K. A. Postnov, arXiv1307.4924
Halzen *et al.*(2005) asto-ph/0503348

See talk by S. Fahey

No excess found from 29 bursts (13 unique locations)
25 time windows tested: 10 ms, 20 ms, 40 ms, … , 0.97 days, 1.94 days

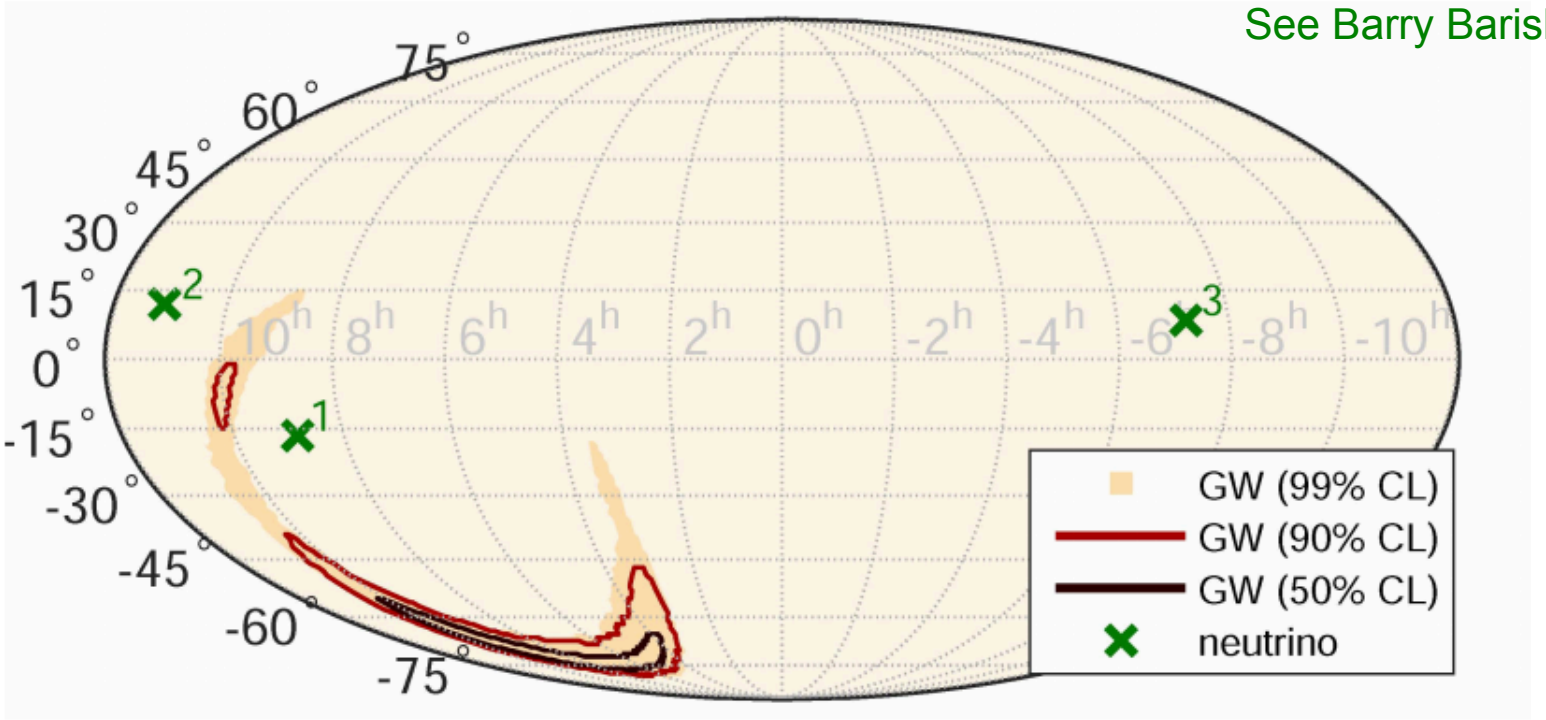




Gravitational Waves (GW) and Neutrinos

Search for neutrinos from GW150914 in ANTARES and IceCube data
→ no counterpart found

See Barry Barish's talk



Neutrino could help to constrain direction and teach us about the GW source environment

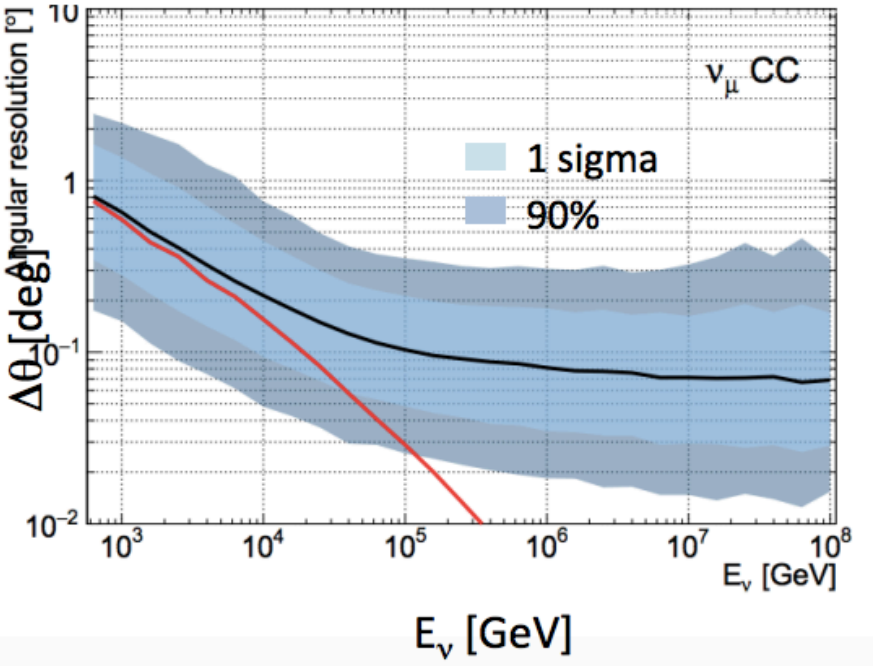
LIGO, Virgo, ANTARES, IceCube
Phys. Rev. D 93, 122010 (2016)


The Future
NEXT EXIT

Future Neutrino Detectors: IceCube Gen2 / Km3NET / GVD

- Larger volume → more astrophysical events
- Better angular resolution → improved correlation with multi-messenger data

KM3NET angular resolution



See talk by Paschal Coyle and Marek Kowalski

Future EM Observatories

- ZTF (**optical**)
  - First light in summer 2017, 0.5 y of commissioning phase
- LSST (**optical**)
  - Site construction began in 2015
  - engineering first light in 2019, science first light in 2021

Catalogs of supernova, tidal disruption events

- eROSITA (**X-rays**)
  - launch in spring 2018
- SKA (**radio**)
  - First data 2019, full array in 2023

AGN catalog → probe AGN core models

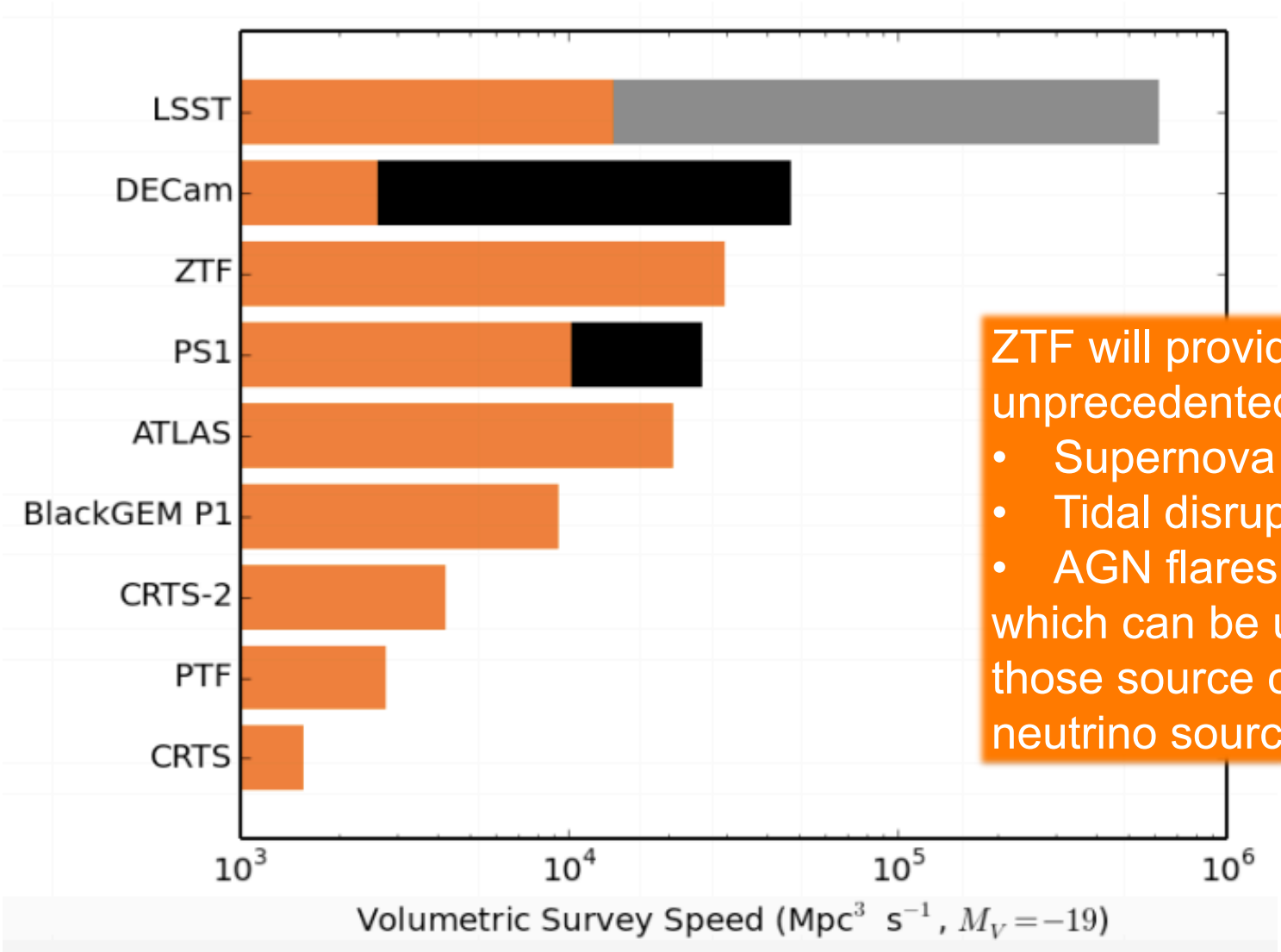
- CTA (**gamma-rays**)
  - Begin of operations in 2018, complete array in 2023

Blazar flares, Galactic sources

Current / Future Optical Surveys

ZTF can scan the entire Northern sky every night to 20.5 mag

ZTF will reach world-leading speed in finding spectroscopically-accessible transients



ZTF will provide an unprecedented catalog of

- Supernova
- Tidal disruption events
- AGN flares

which can be used to probe those source classes as neutrino sources

Conclusion

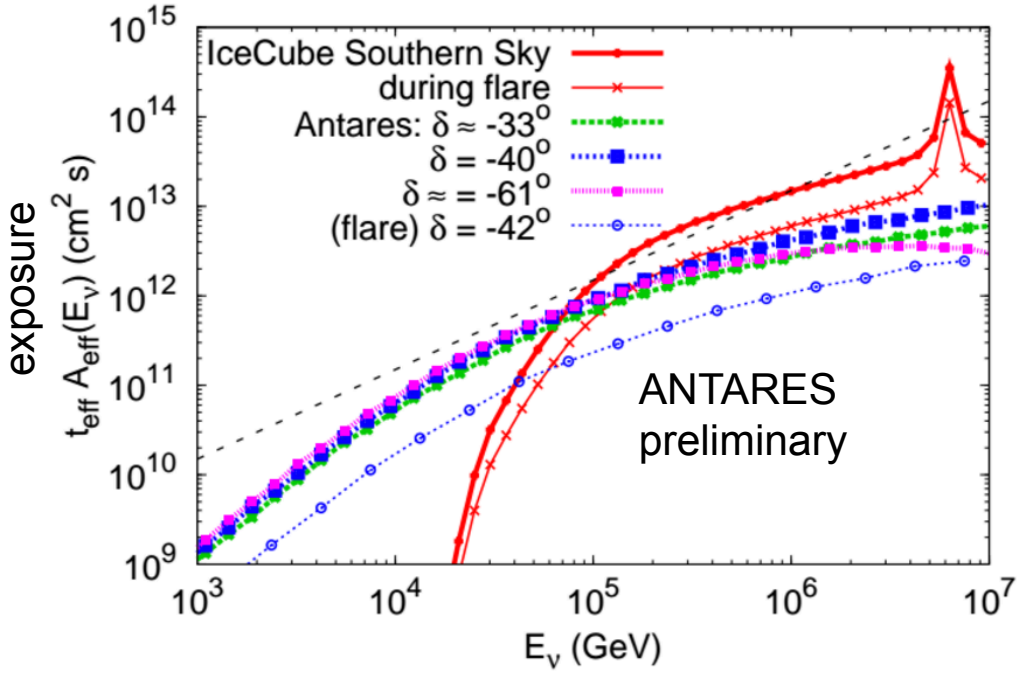
- Transient source classes could be main contributors to diffuse neutrino flux
- Models can be probed with multi-messenger observations
- Some scenarios already excluded
- Remaining ones are extensively studied
- Future EM survey instruments will improve sensitivity

Stay tuned!

Backup

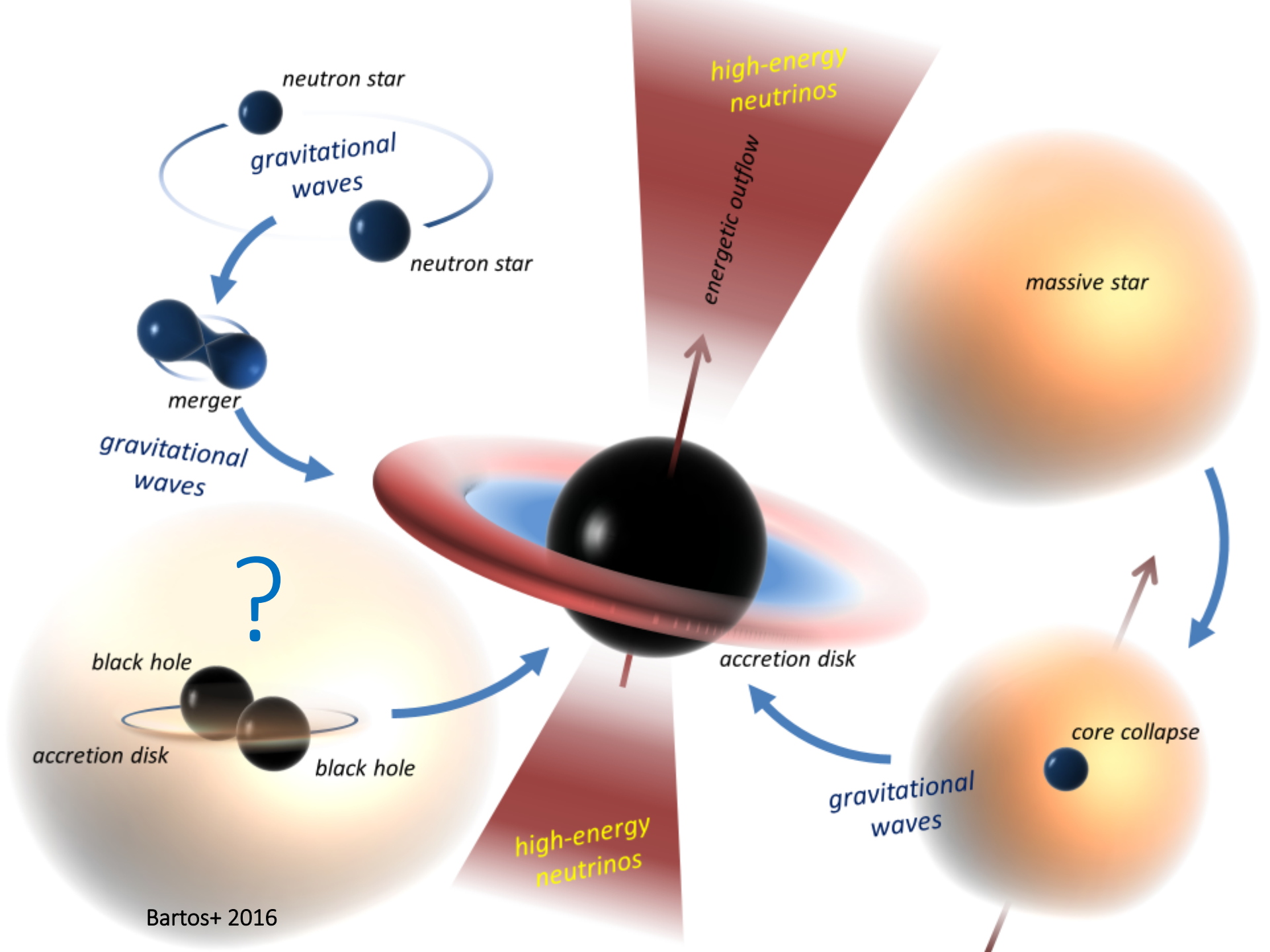
Constraining the Possible Neutrino Spectra of High-Fluence Blazars with ANTARES

- Point-source search with 406-days of ANTARES data at position of PKS B1424−418
  - Flux limit (90% CL): 4.2×10^{-8} GeV cm^{-2} s^{-1}



Very steep neutrino spectrum excluded

ANTARES, A&A Lett. 576, 2015
M. Kadler on behalf of the TANAMI and ANTARES Coll. presented at ICRC 2015

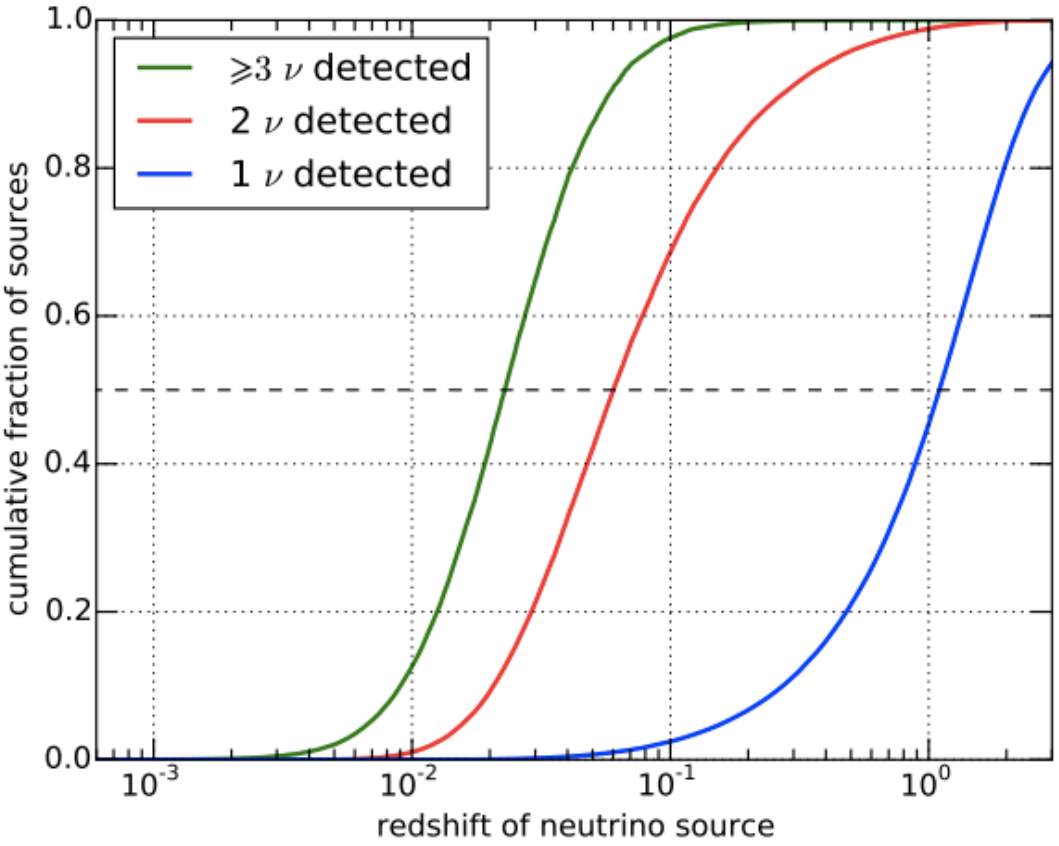

neutron star
gravitational waves
neutron star
merger
gravitational waves
high-energy neutrinos
energetic outflow
massive star
?
black hole
accretion disk
black hole
accretion disk
high-energy neutrinos
core collapse
gravitational waves

Bartos+ 2016

Online Neutrino Event Selection

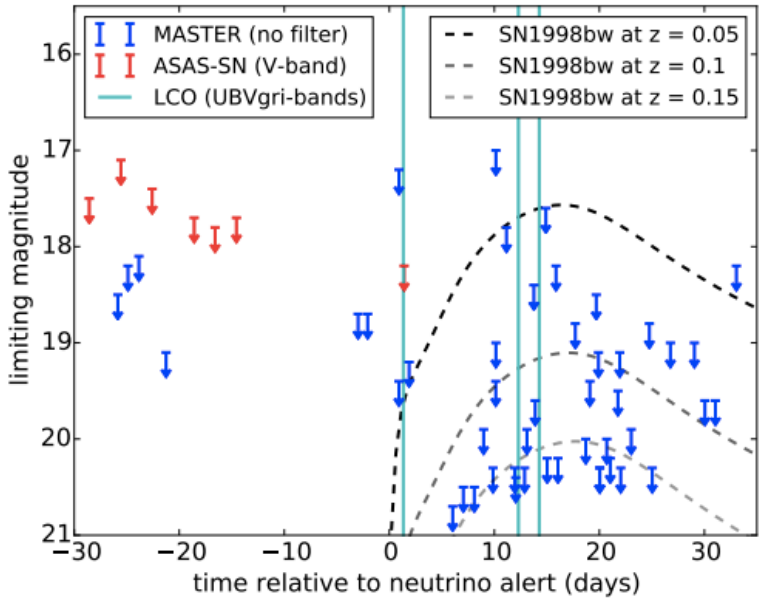
Need to suppress atmospheric background

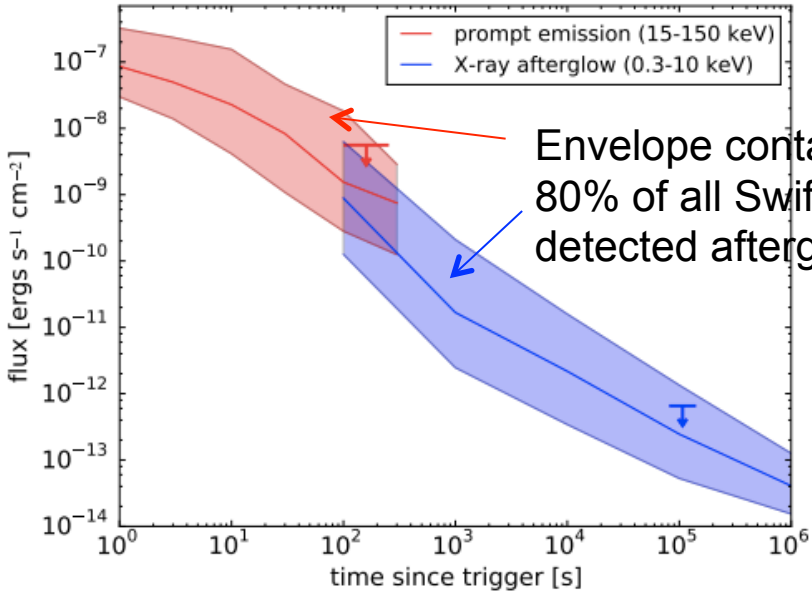
- Clusters in time
- High-energy Events



Three Neutrinos detected within 100 sec

- Results: no obvious counterpart found





Envelope containing 80% of all Swift detected afterglows

IceCube, ASAS-SN, AMON, Fermi, VERITAS, HAWC, LCO, Swift, MASTER, arXiv:1702.06131