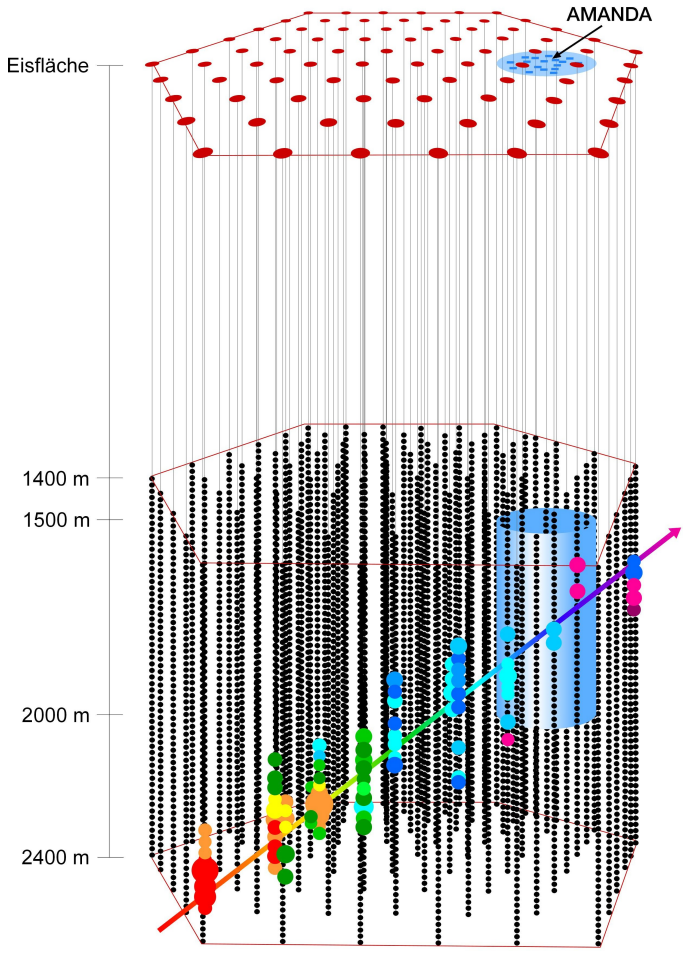
Multiwavelength Search for Transient Neutrino Sources with IceCube's Follow-up Program



Nora Linn Strotjohann
for the DESY Real-Time Group

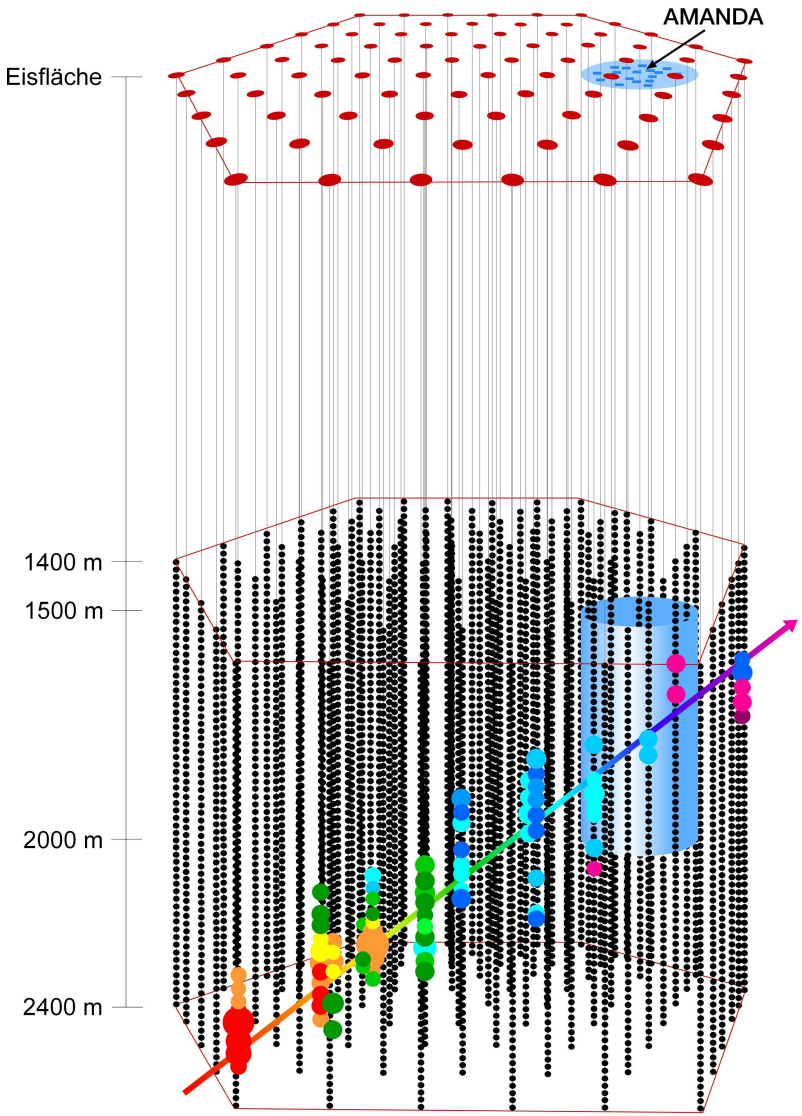
GROWTH Meeting at Caltech,
July 26th 2016

HELMHOLTZ ASSOCIATION

GROWTH
Global Relay of Observatories Watching Transients Happen

DESY

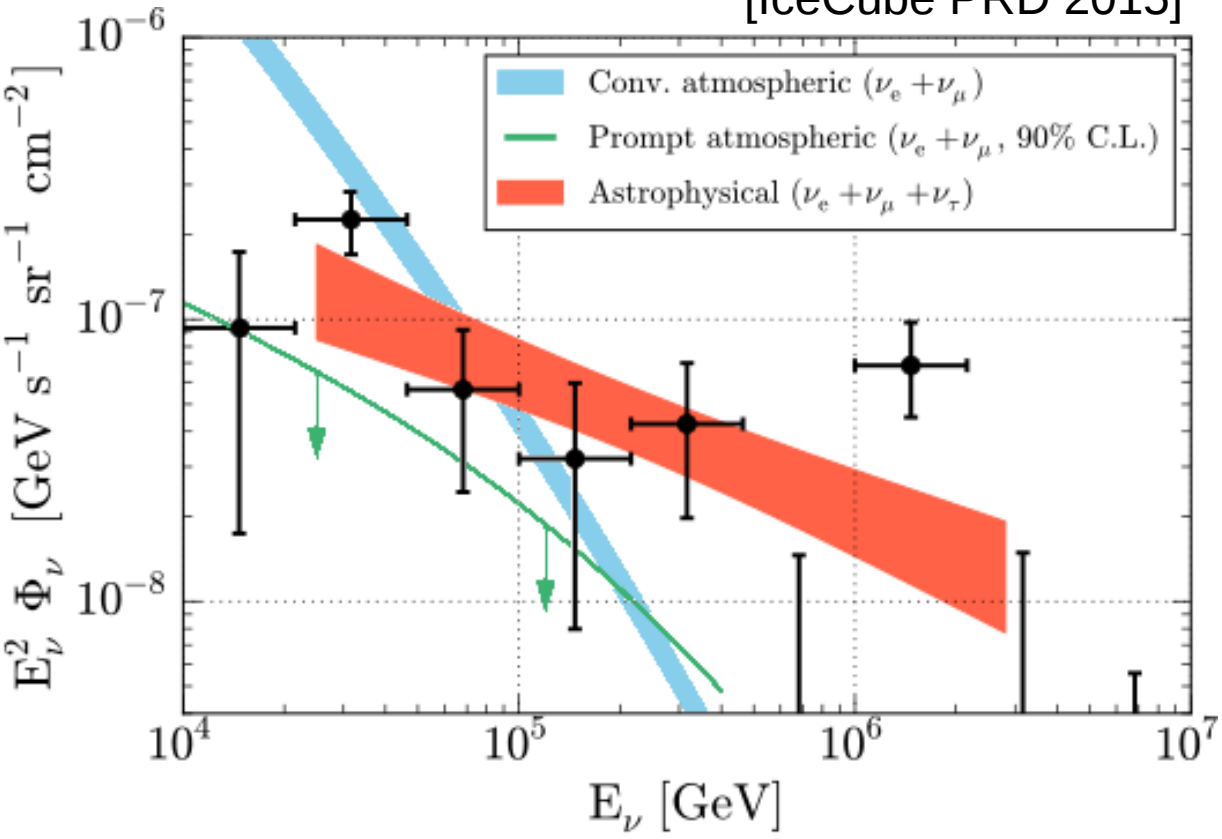
The IceCube Neutrino Observatory



- 1 km^3 detector in Antarctic glacier
- 5160 optical modules on 86 strings
- Cherenkov light of secondary particles detected
- energy range: 10 GeV – 10 PeV

Astrophysical ν flux discovered at highest energies

[IceCube PRD 2015]



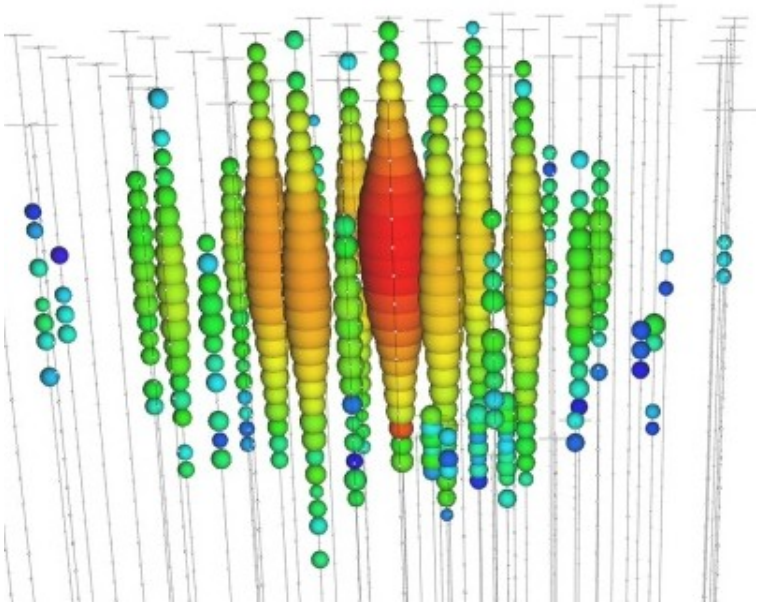
> best fit in combined analysis: $E^{-2.5}$ [IceCube PRD 2015]

> arrival directions consistent with extragalactic origin

> no sources identified so far

Event Topologies

Cascade-like events

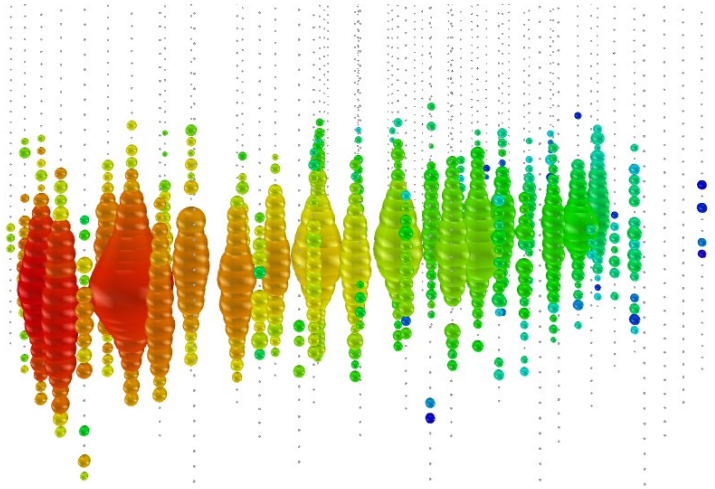


> charged current interactions: ν_e and ν_τ

> neutral current interactions

> good energy measurement

Track-like events



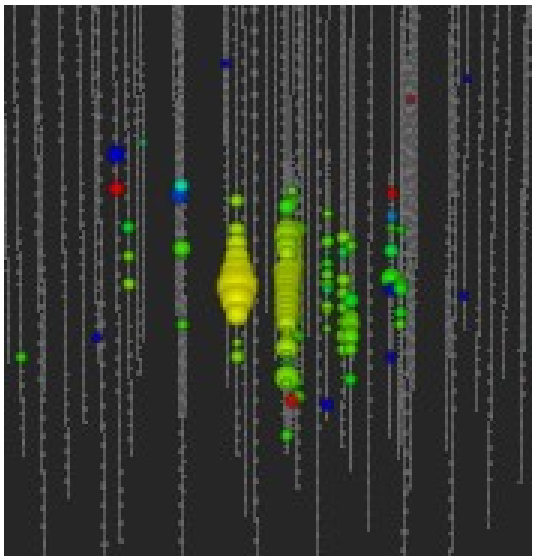
> charged current interactions: ν_μ

> good angular resolution of 1°

→ used in point source searches

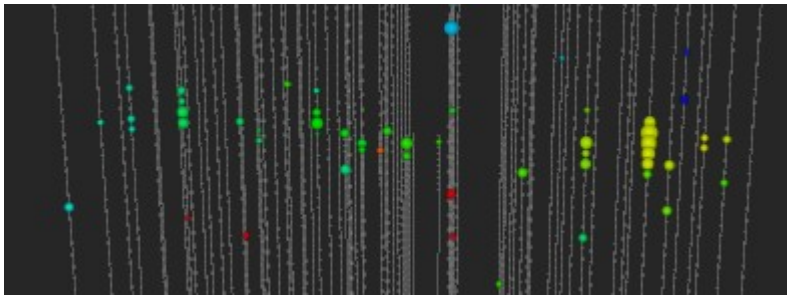
Event Topologies

Cascade-like events



- charged current interactions: ν_e and ν_τ
- neutral current interactions
- good energy measurement

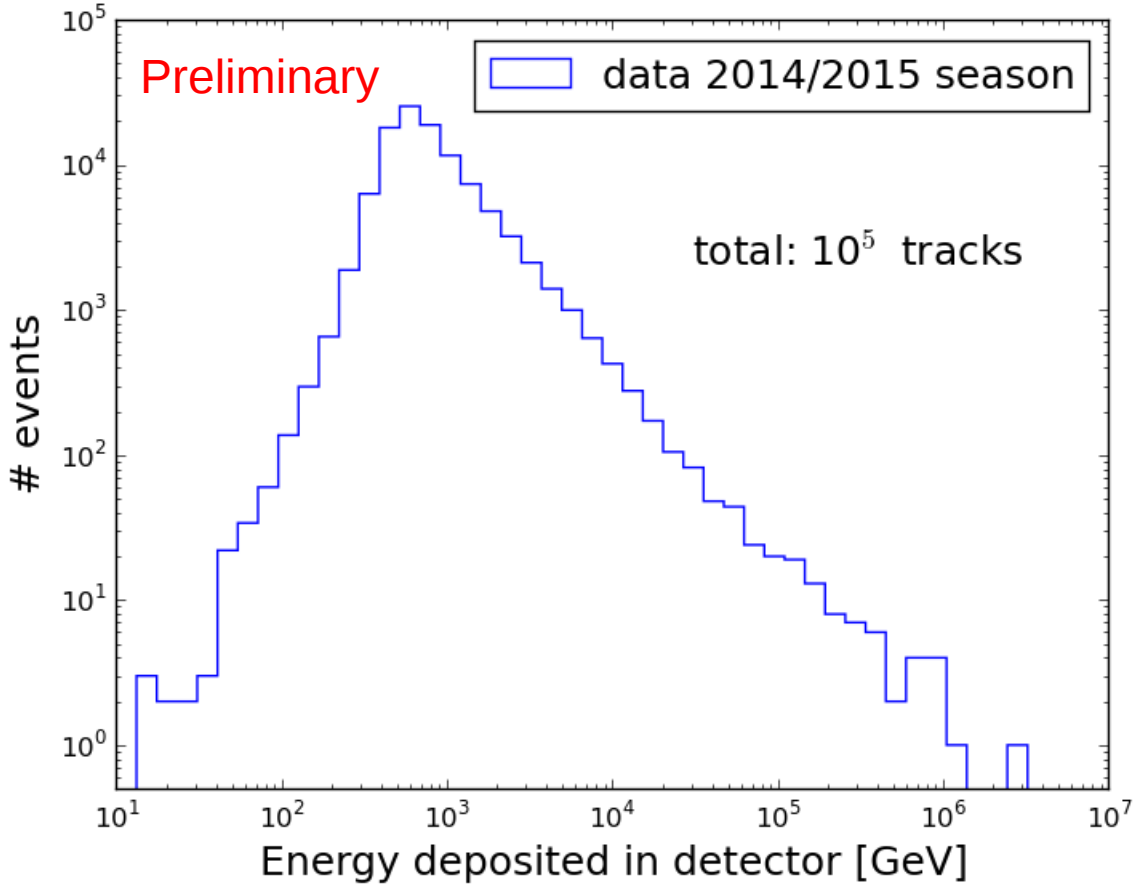
Track-like events



- charged current interactions: ν_μ
- good angular resolution of 1°

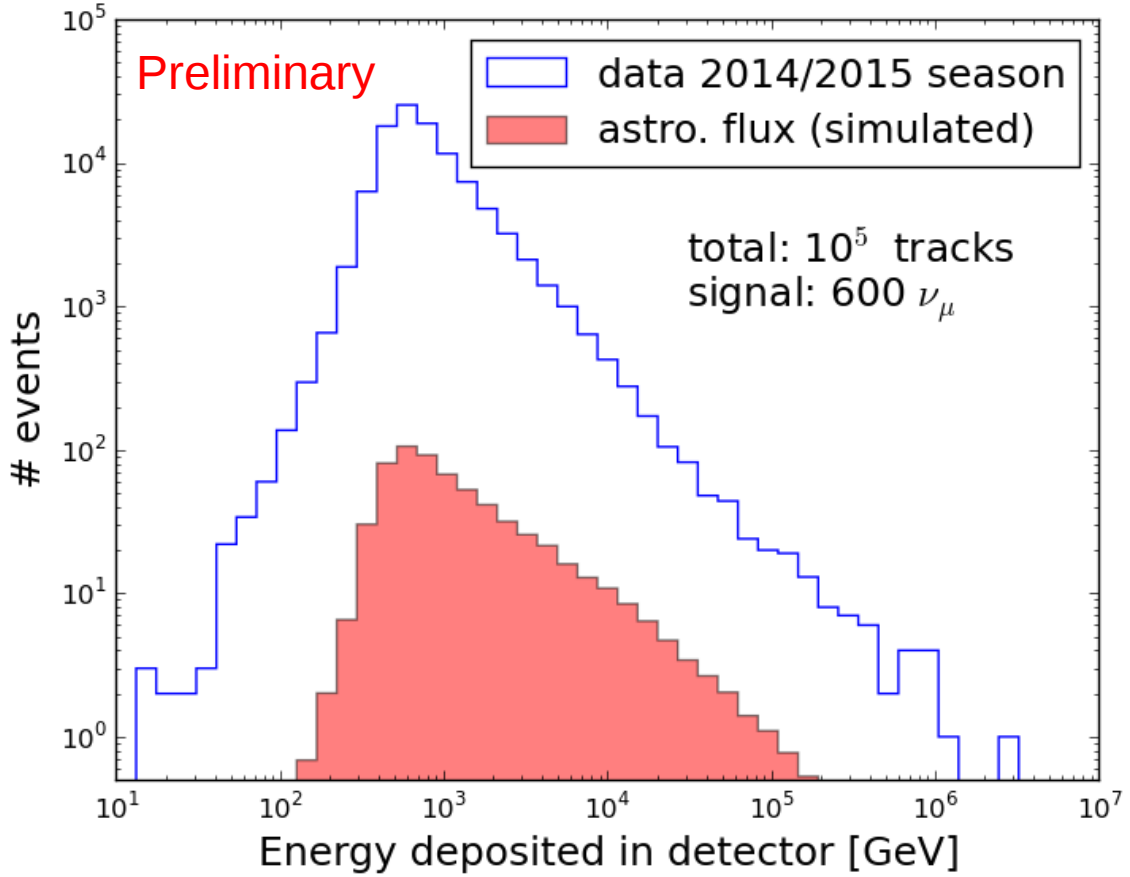
  → used in point source searches

Event Selection of the Follow-up Program



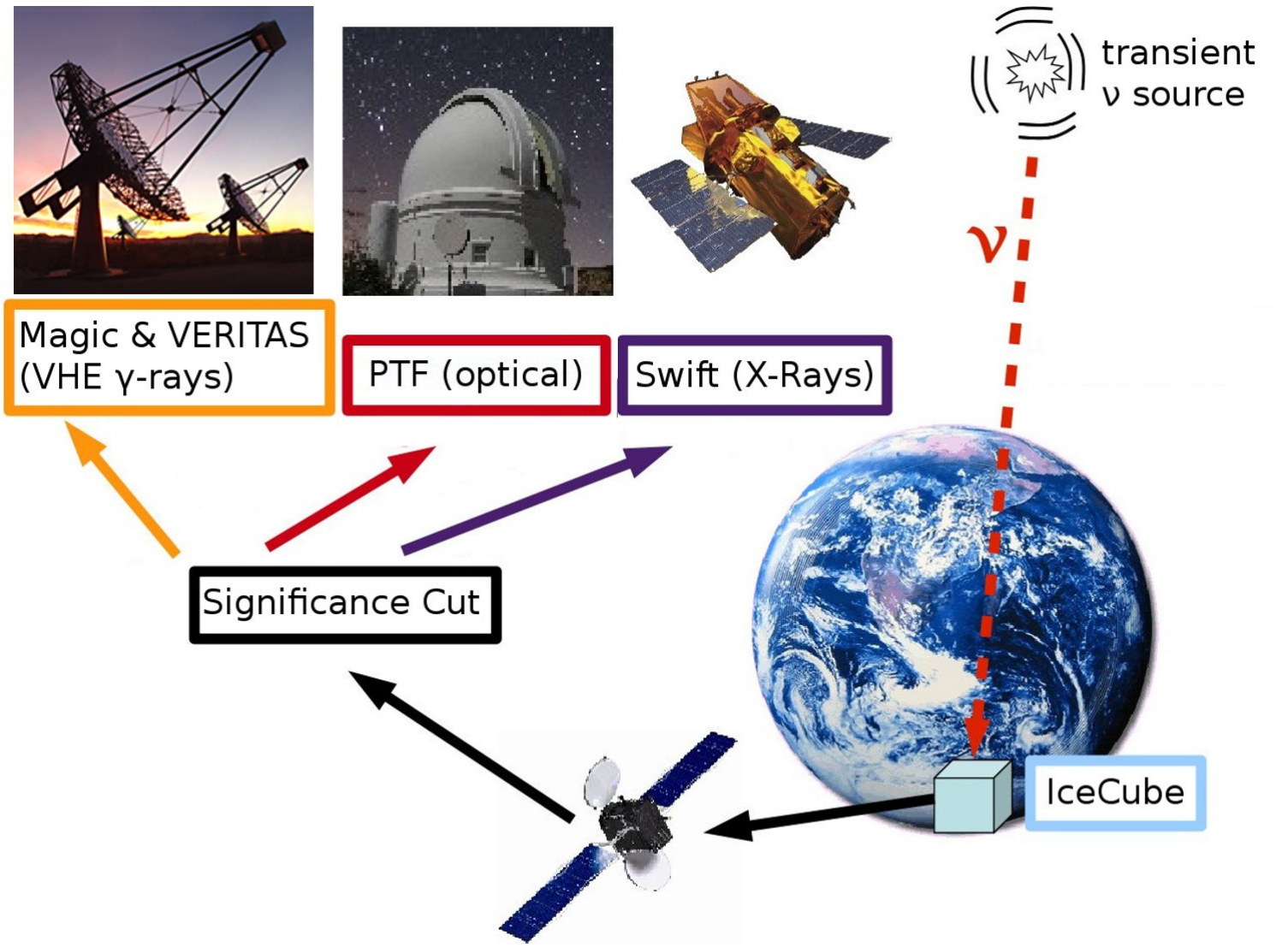
> well reconstructed tracks from Northern sky: 100 000 events per year

Event Selection of the Follow-up Program



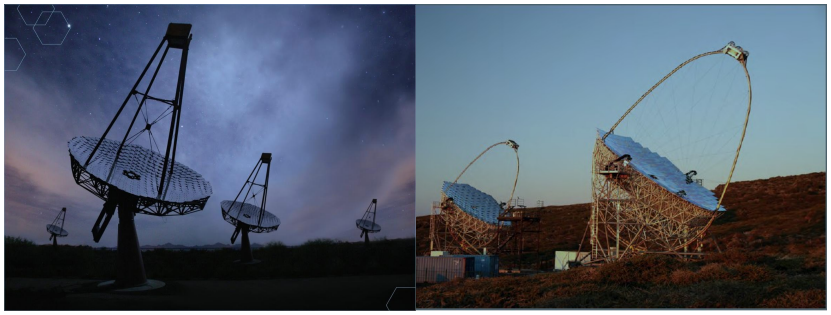
- well reconstructed tracks from Northern sky: 100 000 events per year
- extrapolated astrophysical flux: ~600 ν_μ per year
- search for transient sources using multiplets

The Follow-up Program

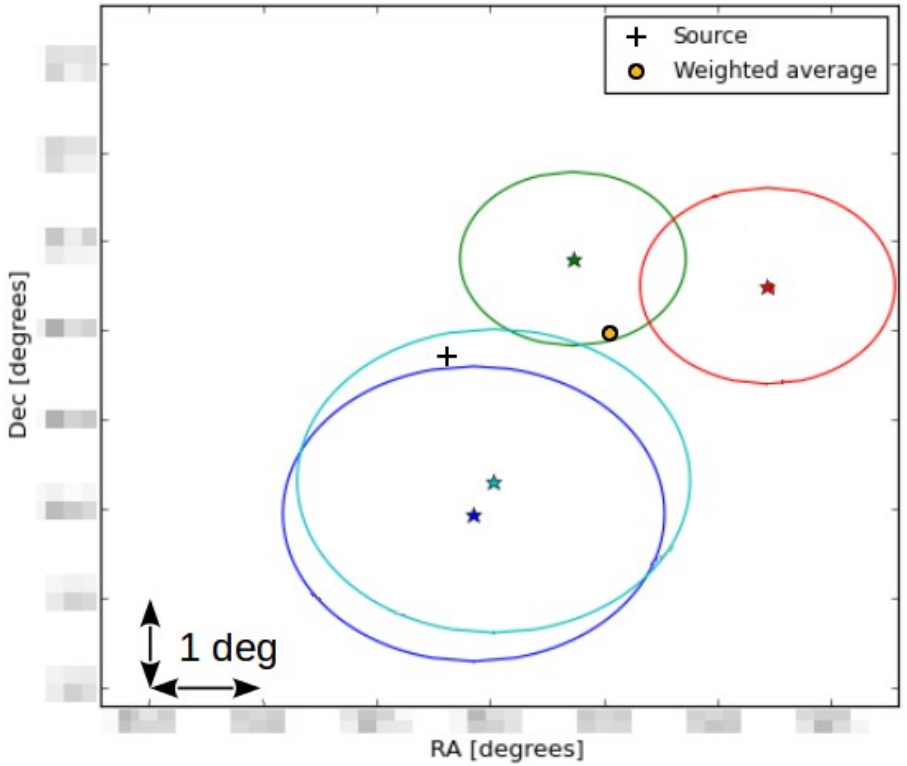


Gamma-ray Follow-up

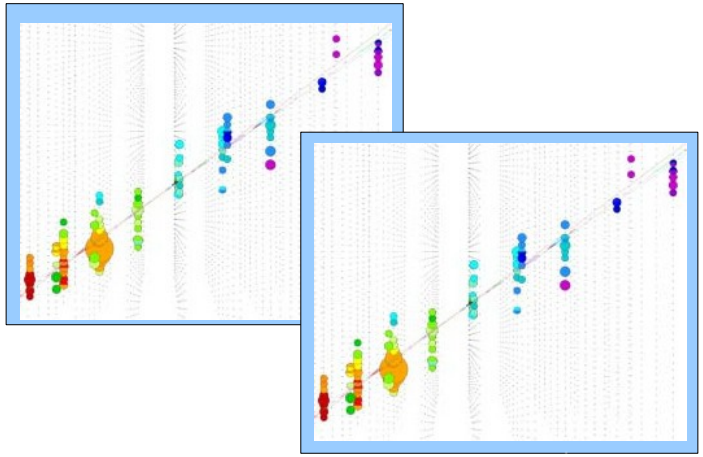
- search for flares with imaging air cherenkov telescopes
  - Magic: 1 alert/year
  - VERITAS: 3 alerts/year



- look for neutrinos from a predefined list of sources
- time window: up to 3 weeks
- recent alert:
  - 4 ν within 1.2 days
  - consistent with a potential VHE gamma source



The Optical and X-ray Follow-up



- select all well reconstructed tracks from Northern sky

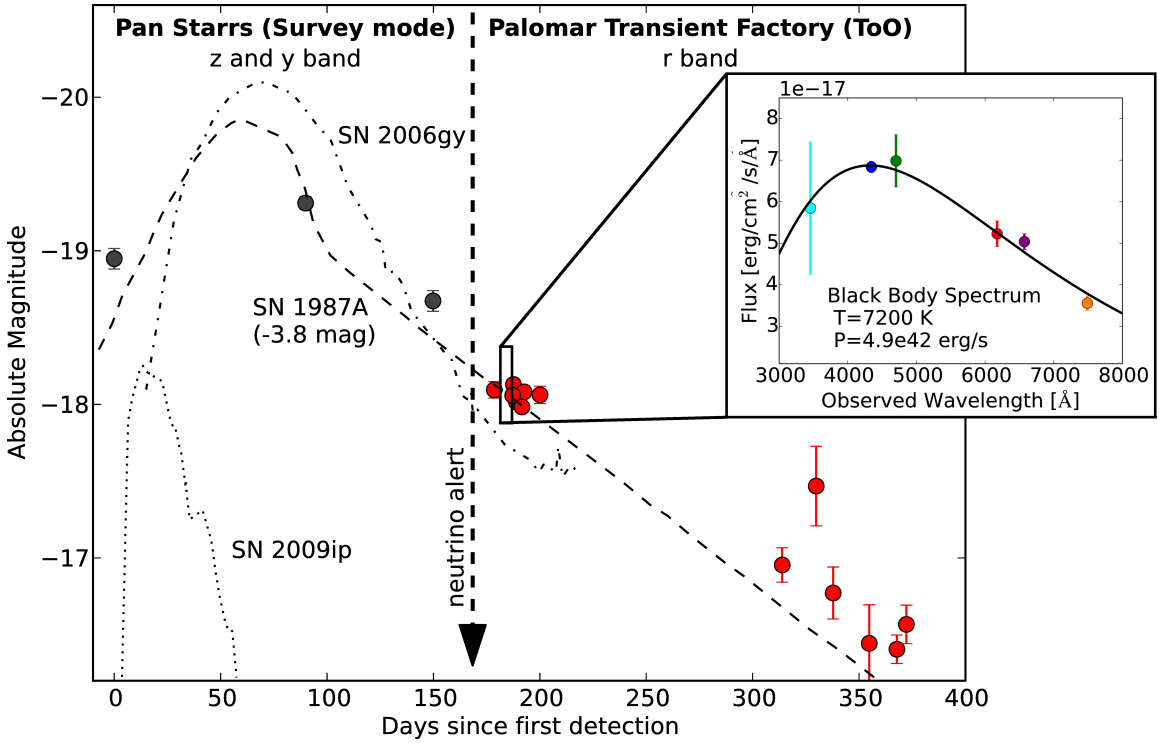
- 2 or more tracks from similar direction ($\Delta\Psi<3.5°$) within 100s

  → **sensitive to short transients: SNe with choked jet and GRBs**

- most significant alerts are sent to telescopes (7 to PTF, 3 to Swift)

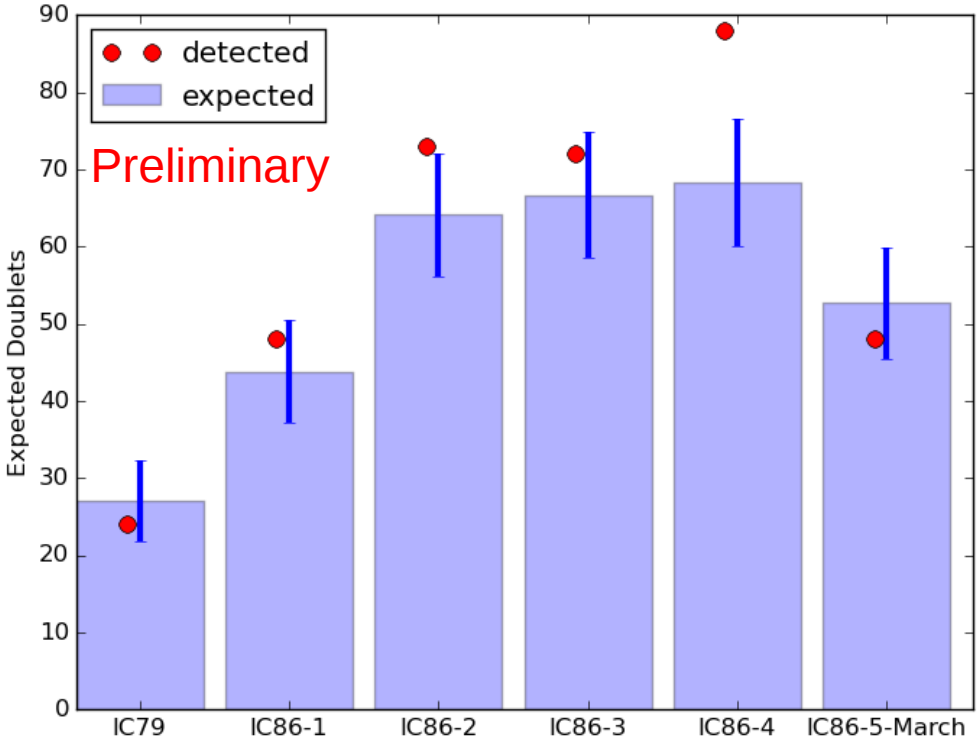
Detected supernovae

- most significant alert lead to discovery of PTF12csy, a fading SN IIn [IceCube+PTF+Swift+Panstarrs APJ 2015]
- such an alert + CCSN: expected every 50 years → **~2σ significance**



- unclear why a ν burst would happen half a year after SN explosion
- several coincidences of SNe with less significant alerts
- challenge to identify interesting detections

Alerts detected so far



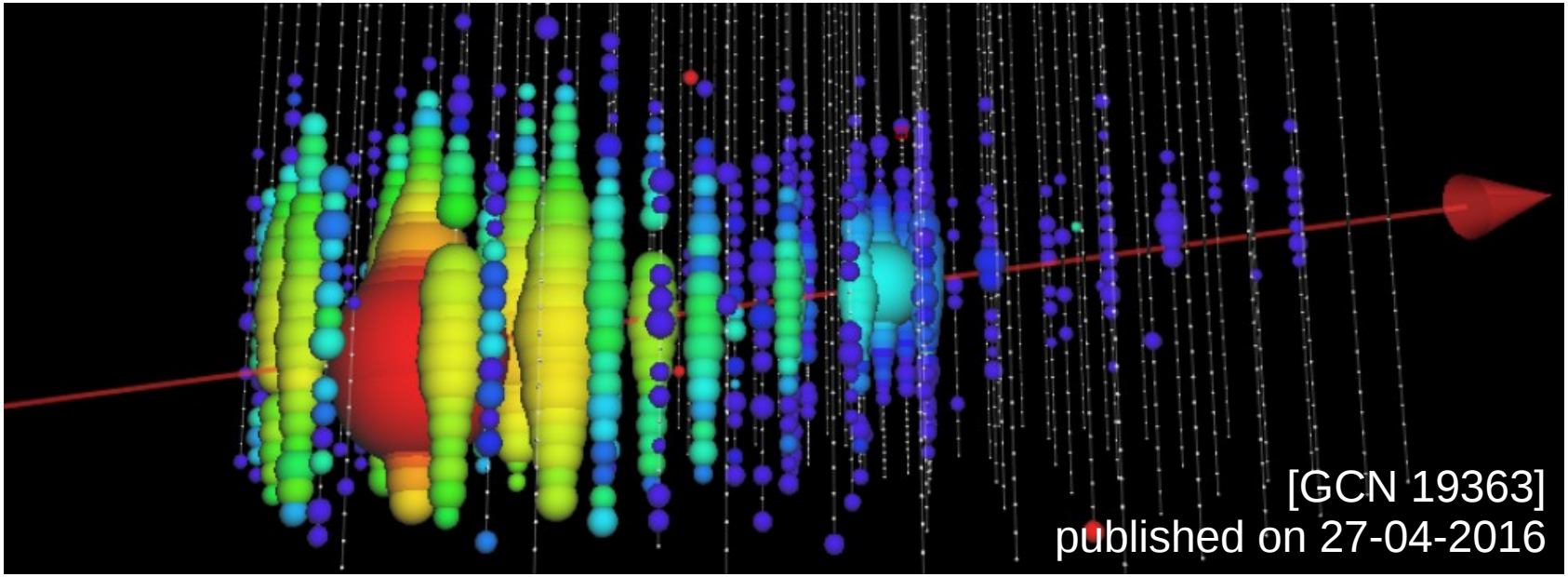
- 323 doublets expected from background, 353 detected (9% more => 1.7 σ) → consistent with background

  → limits very bright short transients (paper in preparation)

- at most 2 out of 6 most significant alerts per year can be from signal

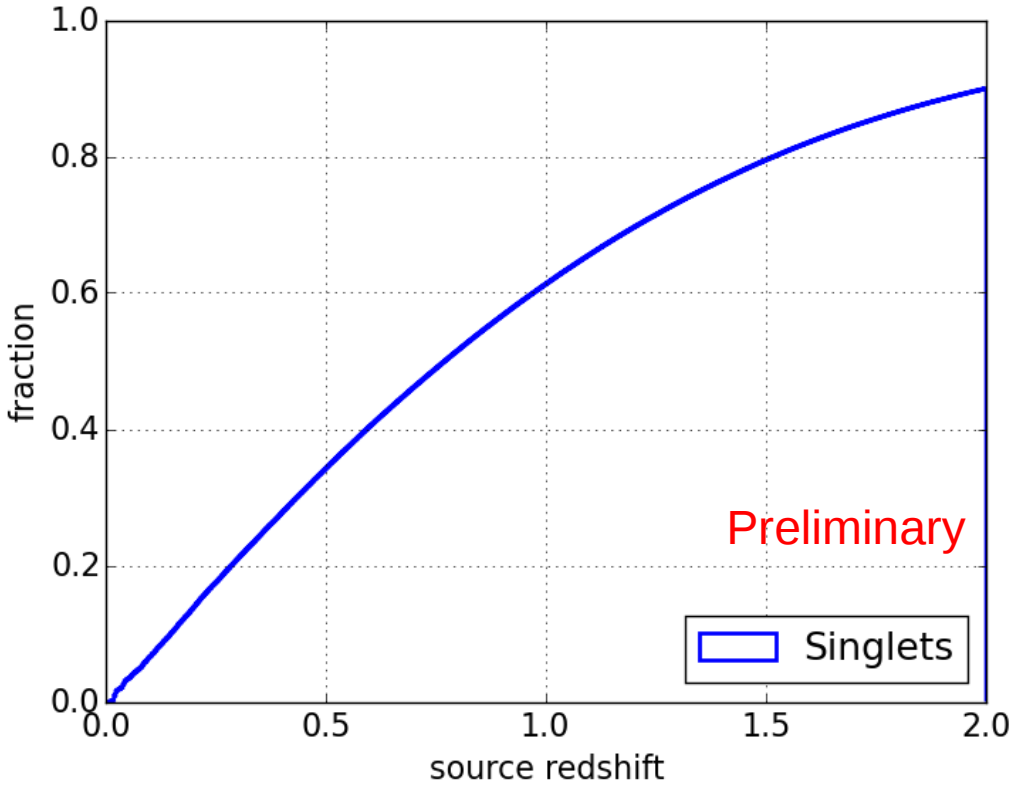
High-Energy Singlet Alerts

- high-energy single track events published in real-time via GCN:
  - **starting tracks** (running since April 2016): 1 out of 4 is astrophysical
  - **through-going tracks** (upcoming): 2 out of 4 are astrophysical
- first event found in April 2016



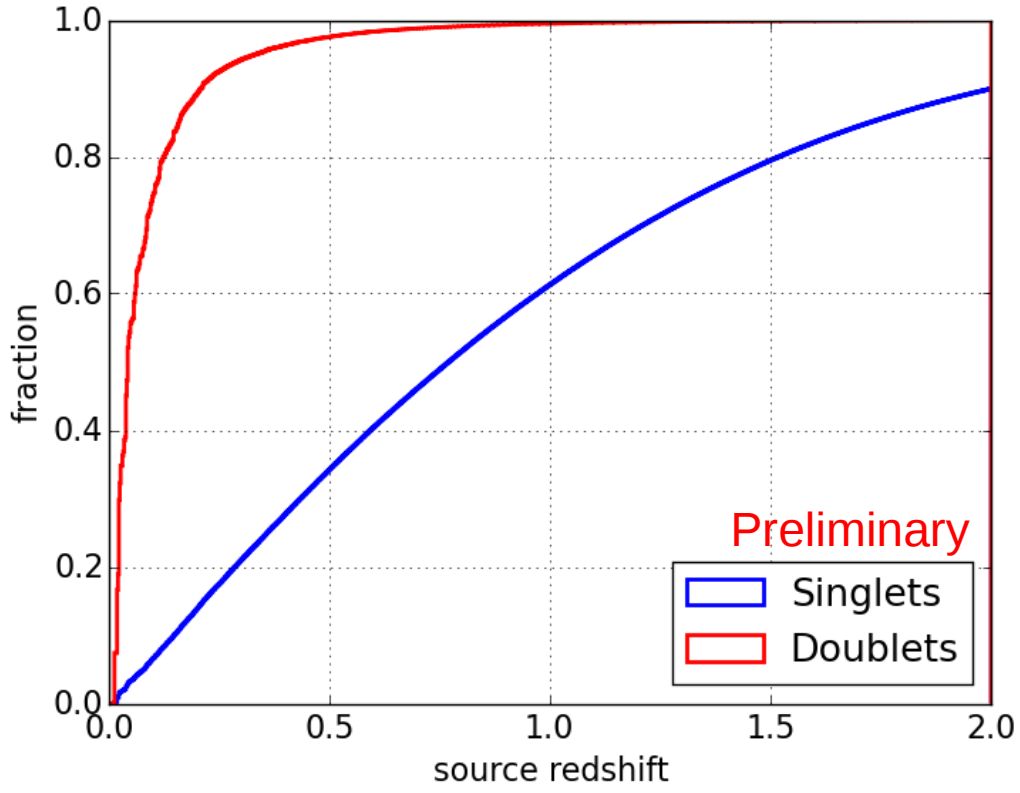
Counterpart distances

> assuming sources follow the star formations rate from Madau et al. 2014 [Arxiv:1403.0007]

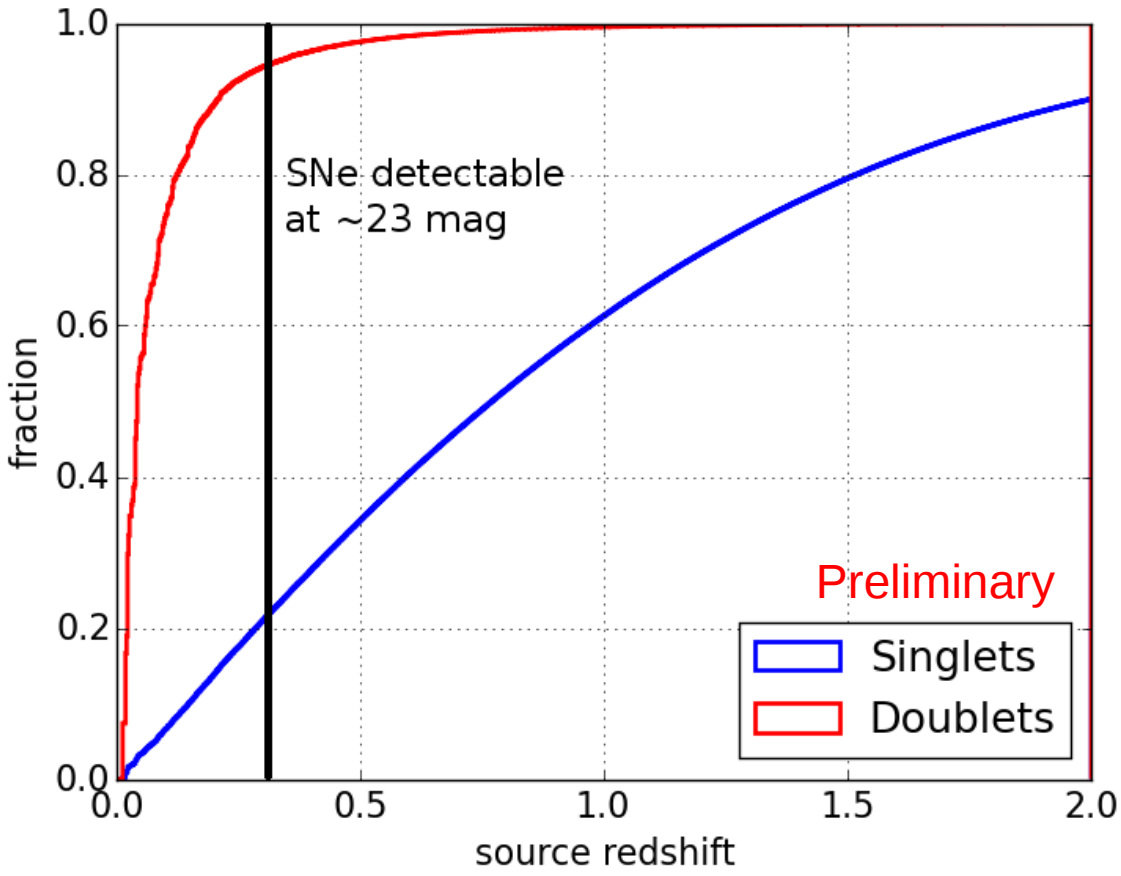


Counterpart distances

- assuming sources follow the star formations rate from Madau et al. 2014 [Arxiv:1403.0007]
- doublet rate depends on source density
  bright sources: (10^{-6} Mpc^{-3} yr^{-1}) yield upper limit on source distance



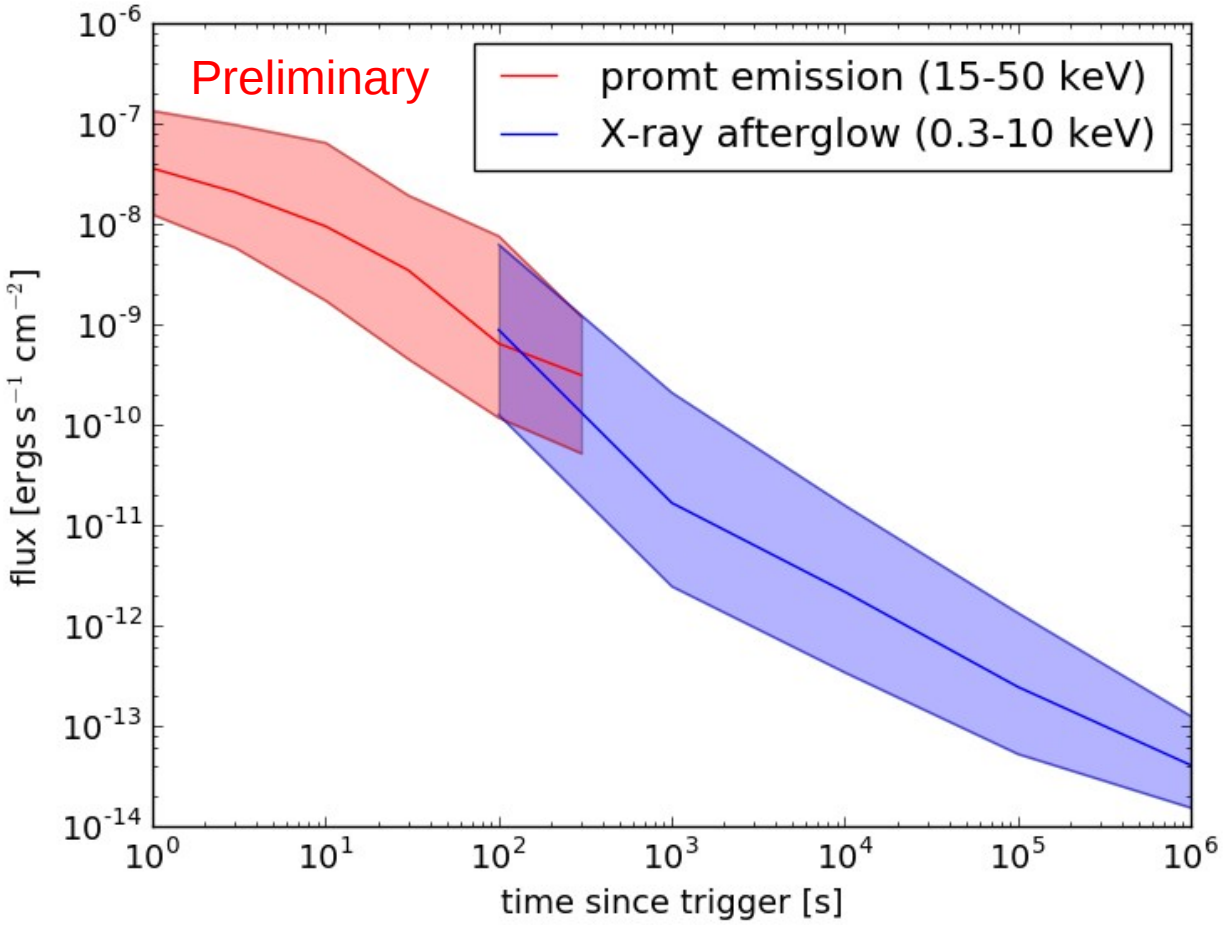
Search for electromagnetic counterpart: Supernovae



> **singlets:** majority of SNe are too far away to be detectable

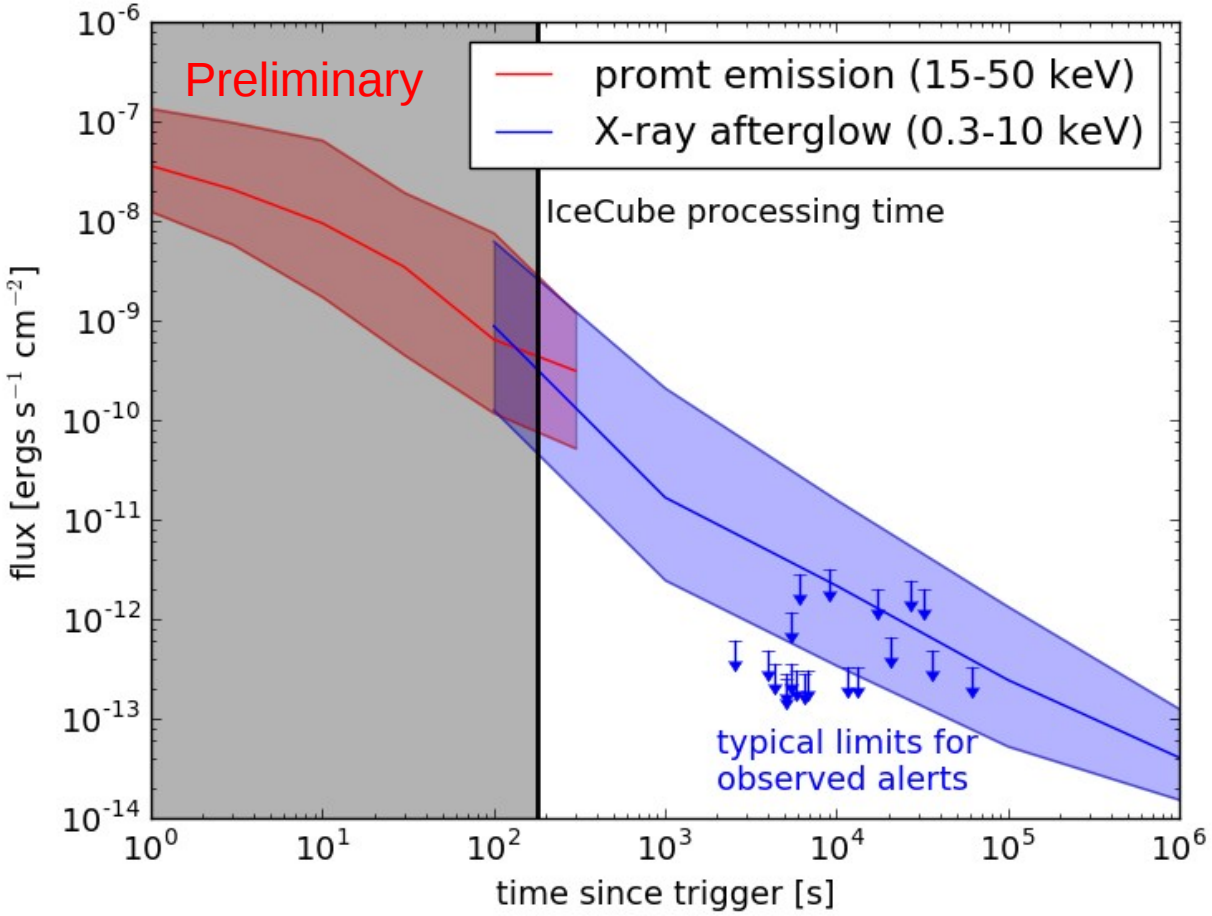
> **doublets:** close-by source should be detectable

Search for electromagnetic counterpart: GRBs



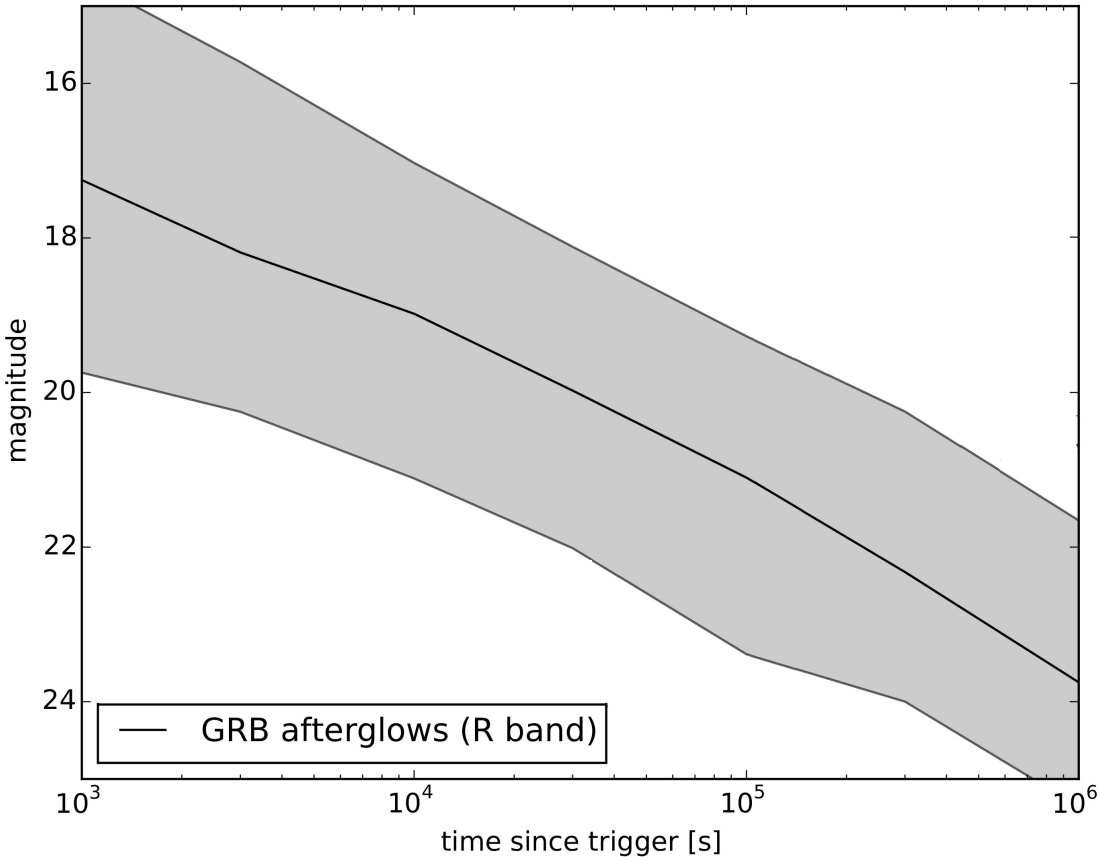
> shaded band contains 80% of all GRBs detected by Swift BAT and XRT

Search for electromagnetic counterpart: GRBs



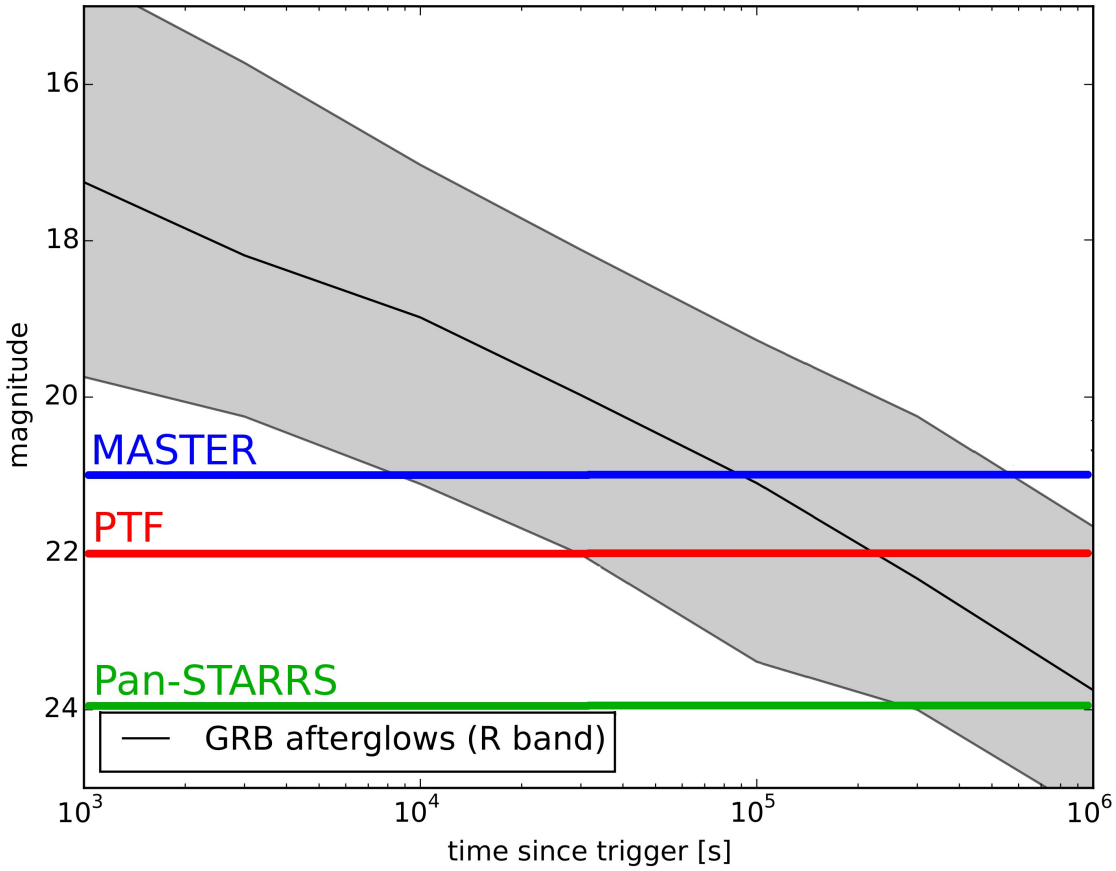
- promt emission too short (IceCube processing time ~3min)
- X-ray afterglows would have been detectable for alerts sent so far [Evans et al., MNRAS, 2015]

Search for electromagnetic counterpart: GRBs



> shaded band: R-band GRB afterglows
(data provided by D.A. Kann; see e.g. [Kann et al., 2011, ApJ])

Search for electromagnetic counterpart: GRBs



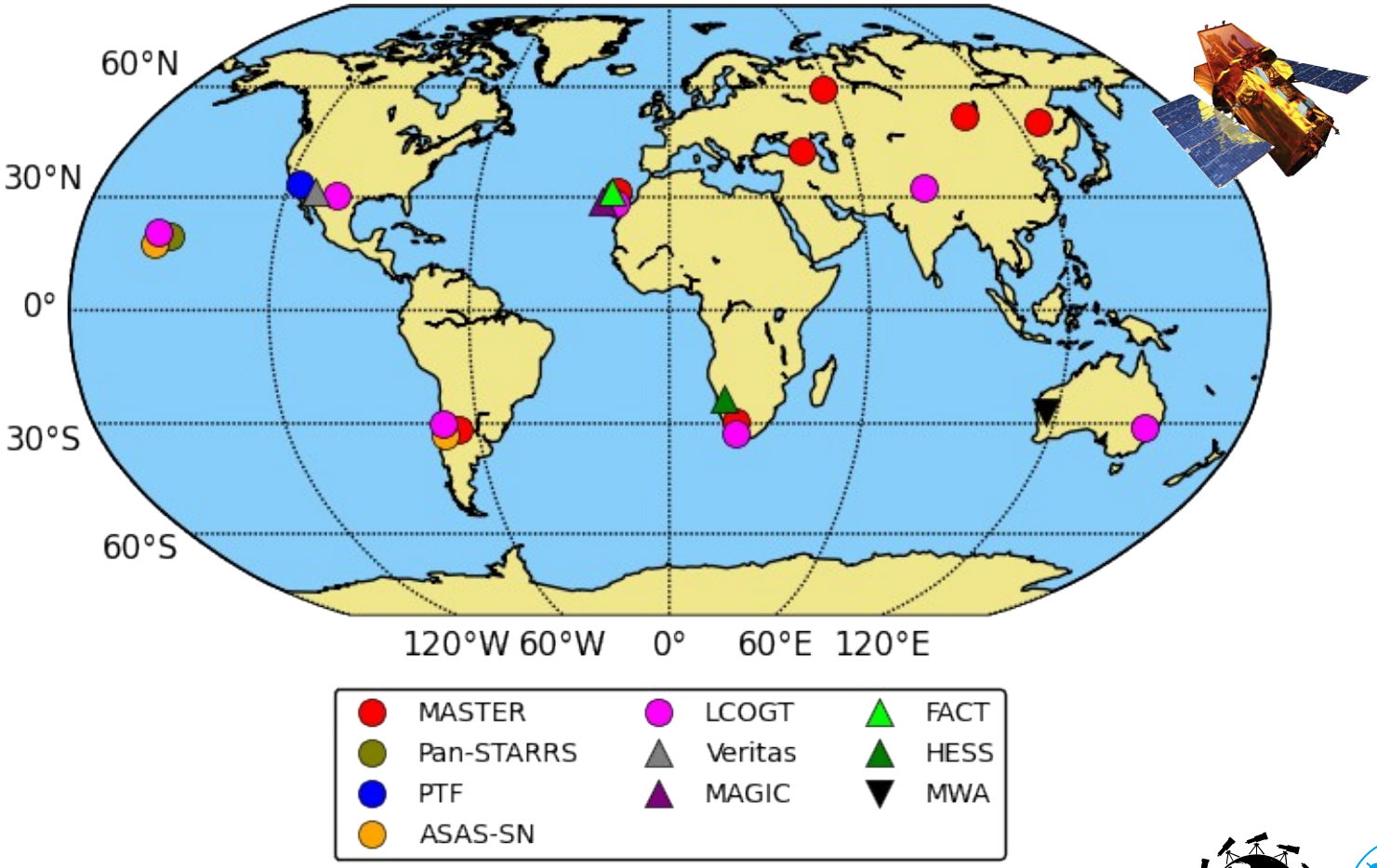
> only detectable if bright

> very quick follow-up needed → telescopes at several sites (MASTER)

Future Strategy

> continue to follow up the most significant multiplets

> quick follow-up needed to check whether transient is coincident with ν



Differences between IceCube alerts

	astrophysical events [yr^{-1}]	source type	median source z	announced
Doublets	0 - 2 out of 6	short transient	close-by z = 0.05 or less	privately (MoU required)
Singlets (starting & through-going)	3 out of 8	transient or steady source	far away z = 0.7	publicly via GCN

> singlet stream has a large astrophysical contribution

> however the counterparts are most likely far away

Summary

- IceCube can trigger real-time follow-up observations for single or multiple neutrinos
- multiplet alert rates consistent with background during past 6 years
  → can set limits on bright short transients
- several likely coincident SNe found
- good constraints on explosion time boost significance
- increase follow-up network to get better data
- detection of high-energy tracks now announced publicly via GCN