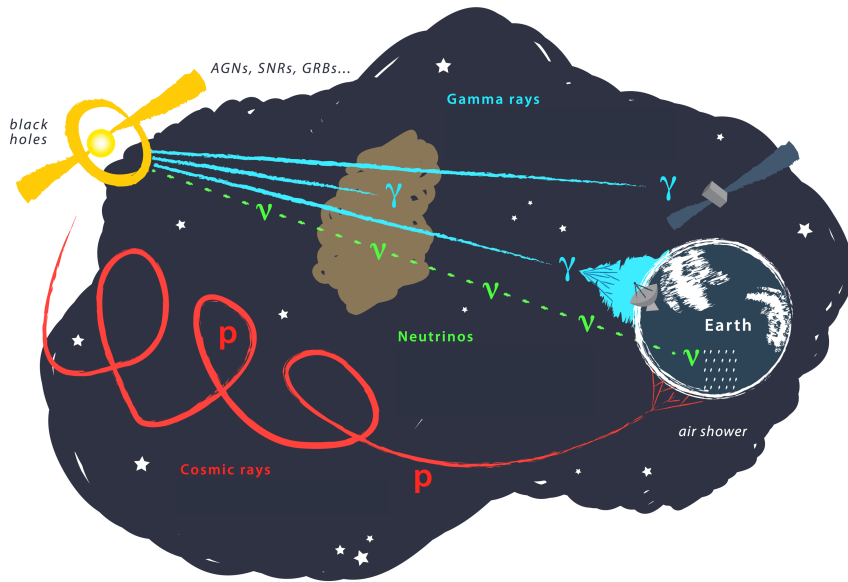


Searching for Optical Counterparts to High-Energy Neutrino Sources with the Zwicky Transient Facility



Ludwig Rauch
TeVPA 2018
Berlin, 29.08.2018

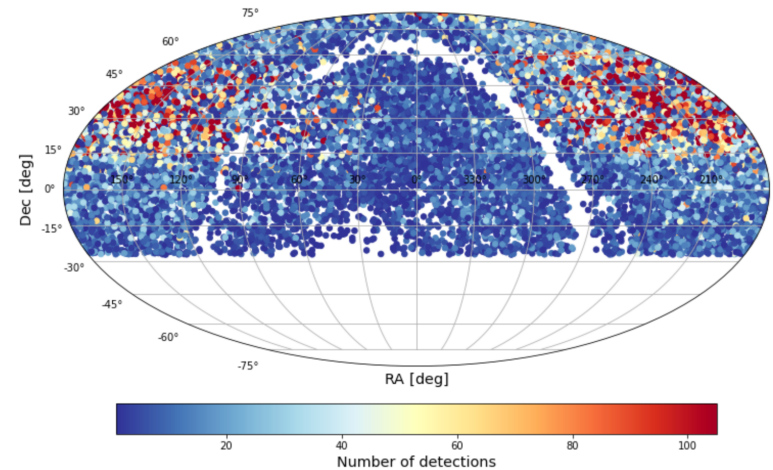
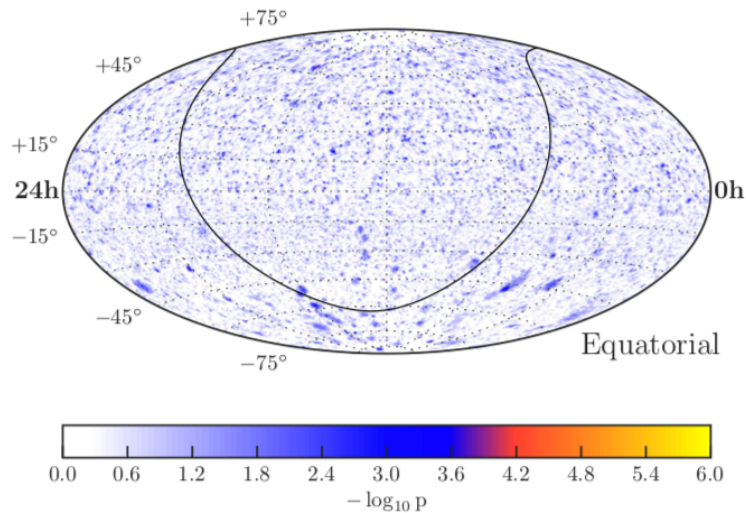
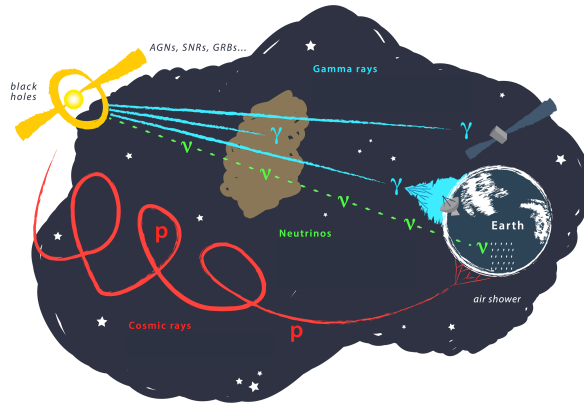
HELMHOLTZ
Young Investigators



ICECUBE
SOUTH POLE NEUTRINO OBSERVATORY



The Idea in Short

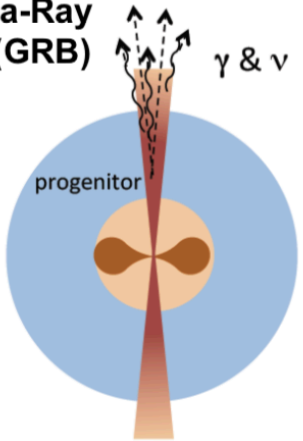


Combine two northern sky surveys in realtime

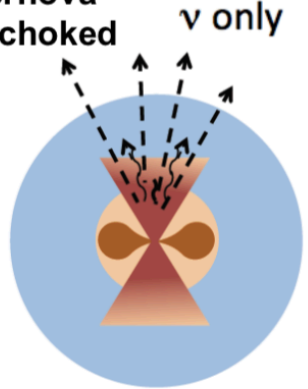


Neutrino Source Candidates

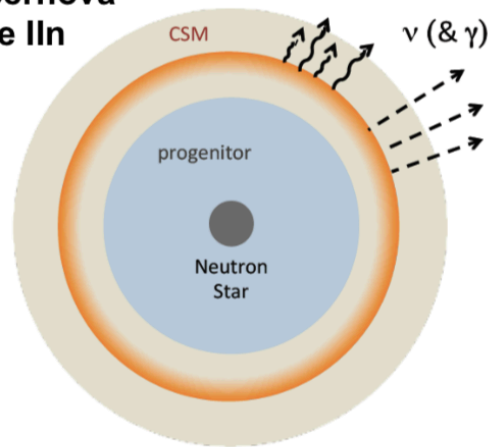
Gamma-Ray Burst (GRB)



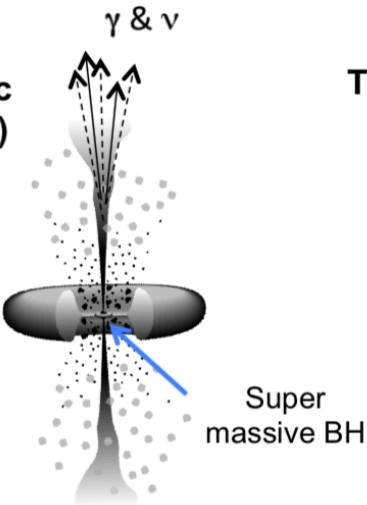
Supernova with choked jets



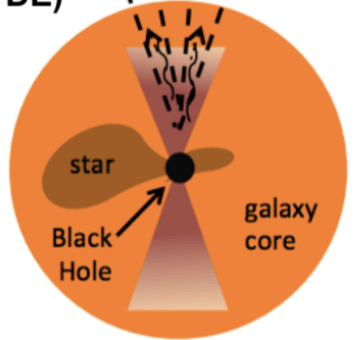
Supernova Type II_n



Active Galactic Nucleus (AGN)

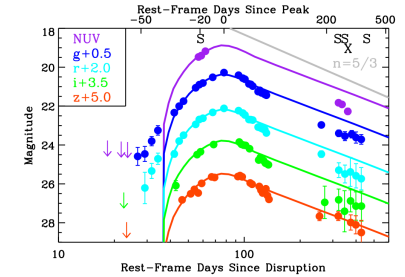


Tidal Disruption event (TDE)

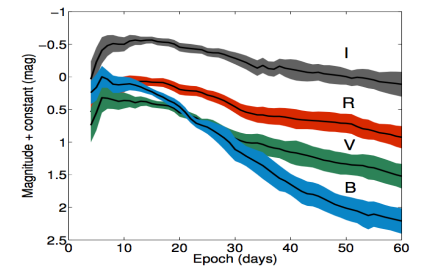


Expected Time Scales of Transients

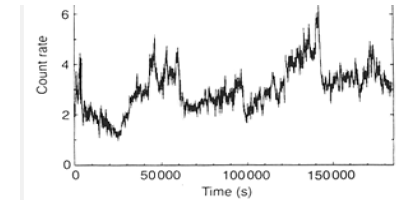
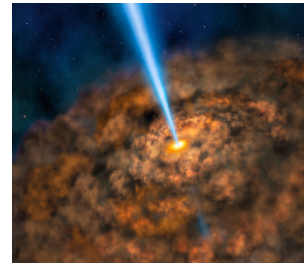
Tidal disruption events ~1d - 100d



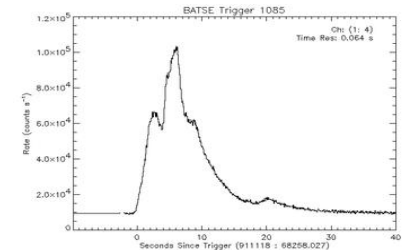
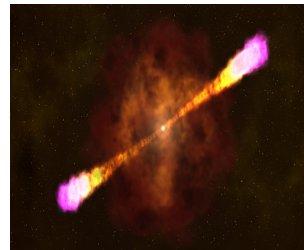
Supernovae ~100d



Active galactic nuclei ~1h - 10d



Gamma ray bursts ~10s - 100s

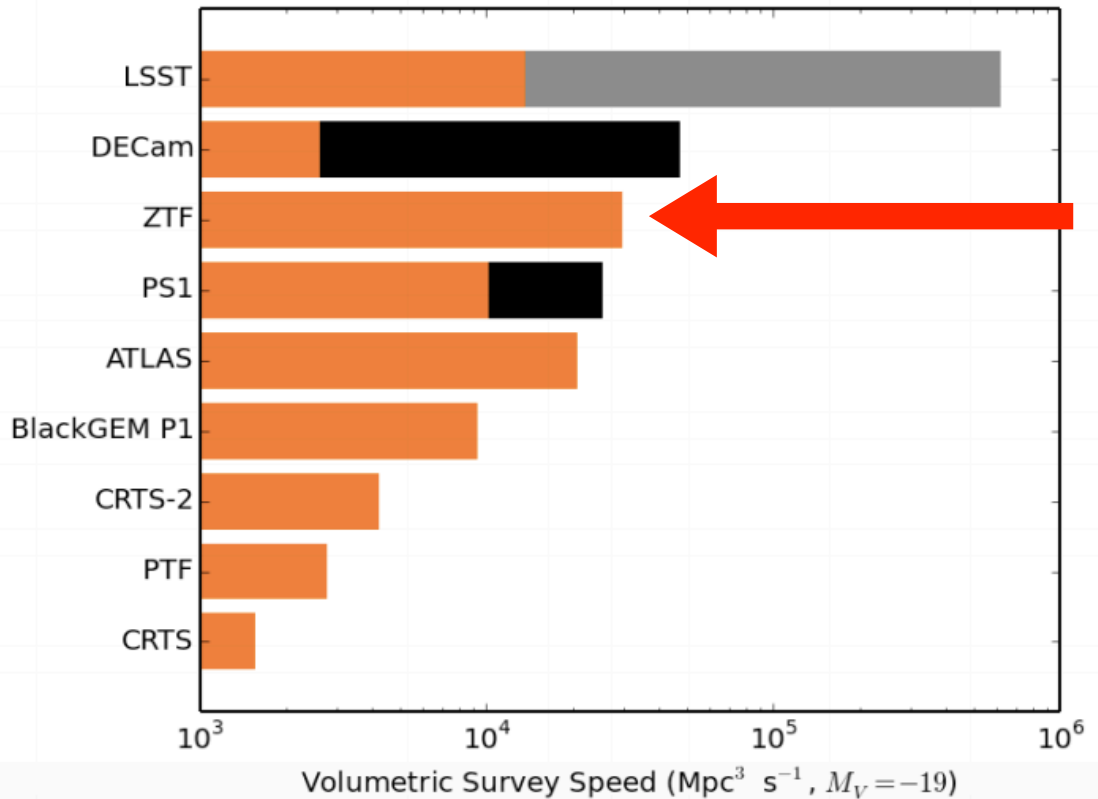


Current / Future Optical Surveys

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



ZTF Spectroscopically-Accessible Transients



ZTF provides:

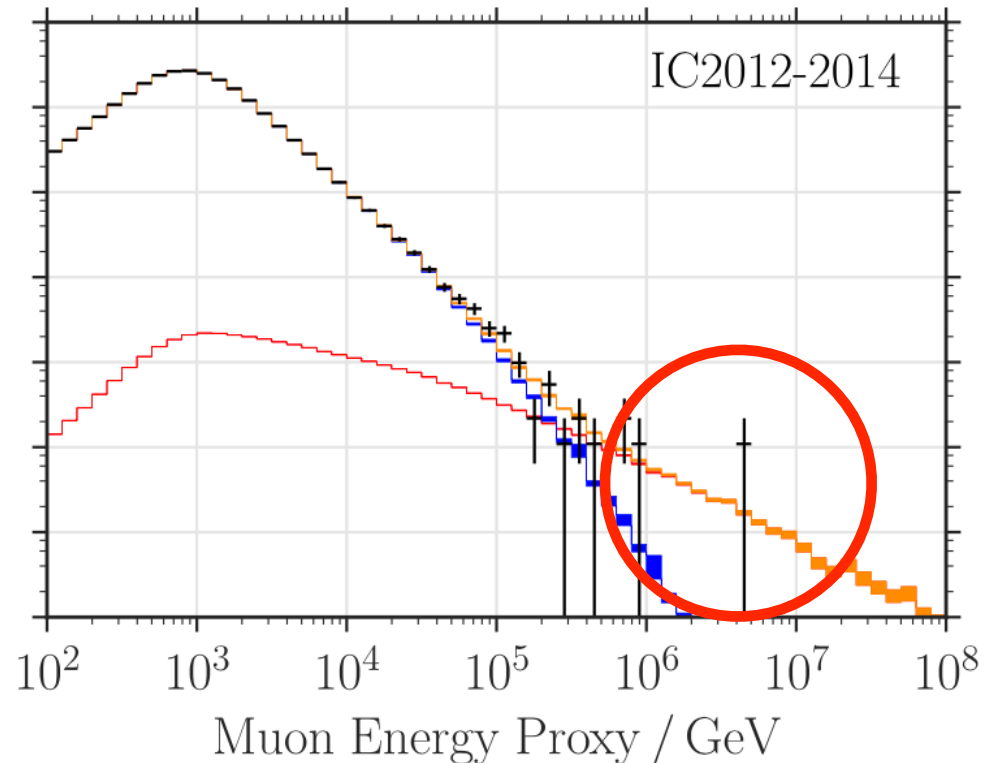
- Unprecedented catalogue of transients up to ~ 20.5 mag
- Complete set of lightcurves for source identification
- All-sky coverage (3π in 8h)
- Cadence approx. 3 days
- On site spectrograph (SED-machine)
- Additional spectroscopic time available on other telescopes

 Spectroscopically-accessible

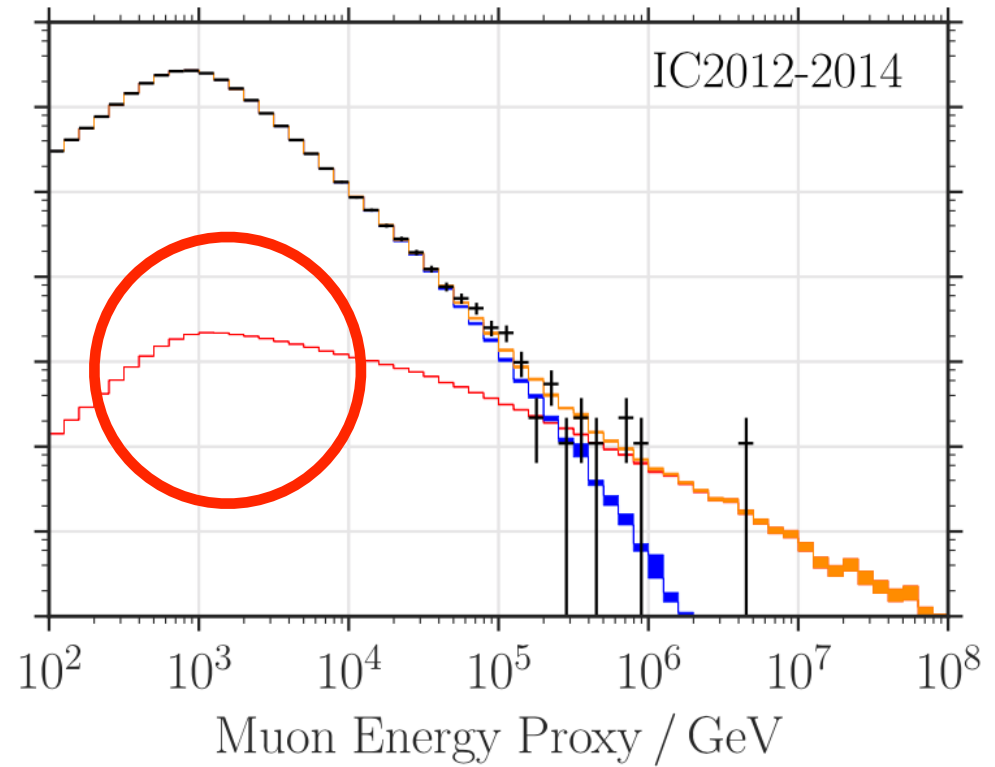
Optical Follow-Up Program of High-Energy Neutrinos

Target of Opportunity

- Follow-up of high-energy neutrinos (TeV, PeV) for early time information of transient
- Track events: (~ 1 deg, ~ 10 /year)
 - ~1 pointing of ZTF covers the neutrino error circle
- Public high-cadence data increases information about the late-time evolution of the lightcurve
- Spectroscopic typing of all selected transients possible



Search for Low-Energy Neutrino Sources ?



Real-time Neutrino Correlation with IceCube

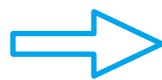
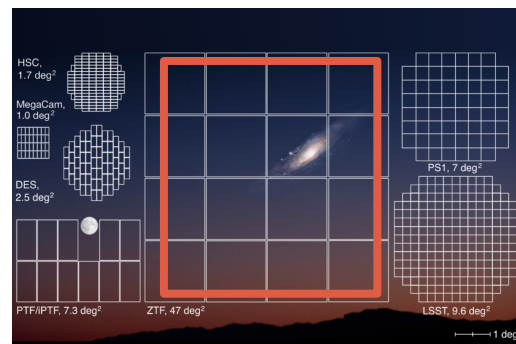
Alert Management, Photometry and Evaluation of Lightcurves: AMPEL



Transient positions from ZTF

Novel realtime alert management and trigger software

Neutrino tracks from IceCube



$10^5 / d$

Trigger



$10^2 / d$

$1-2 / d$

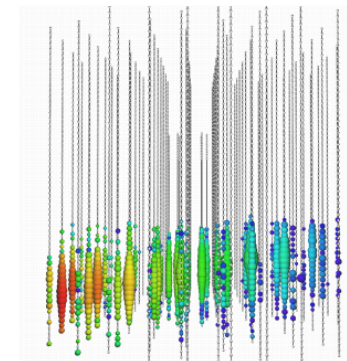
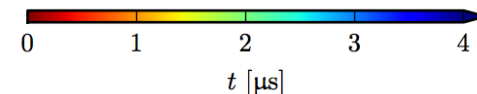
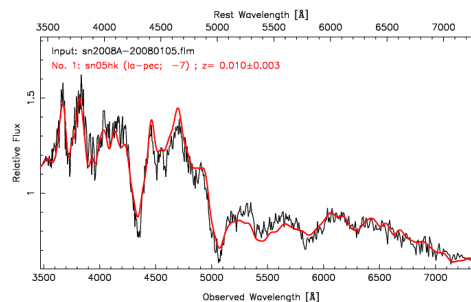


Illustration:
Transient Spectrum



Real-time Neutrino Correlation: Primary Transient Selection

Short transients (GRB-like)

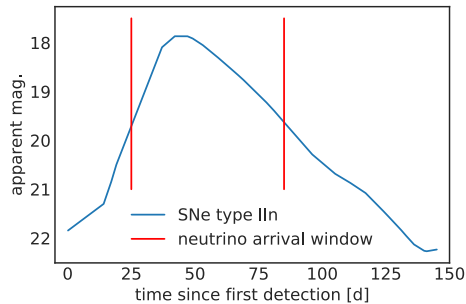
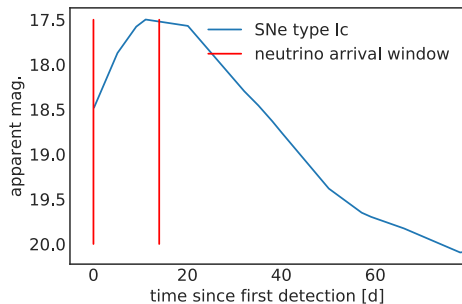
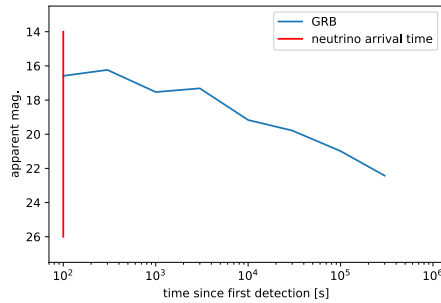
- More than 2 detections in $< 12\text{h}$
- Falling lightcurve
- Realtime maximum likelihood calculation of test statistic

Medium length transients (SN Ic, Kilonova)

- Time window of 2 weeks
- More than 3 optical detections

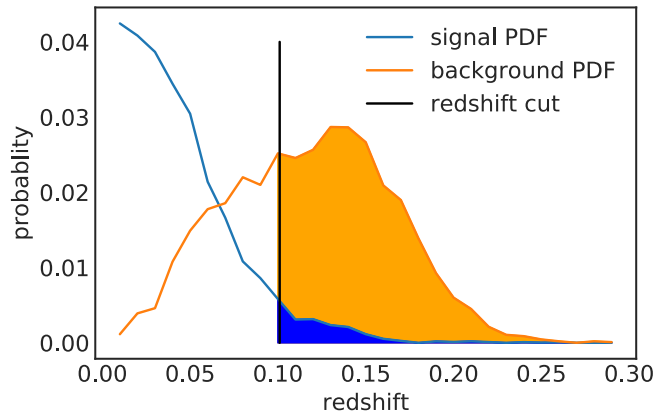
Long transients (SN IIn, SLSN, TDE, AGN)

- Time window of 8 weeks
- More than 5 optical detections



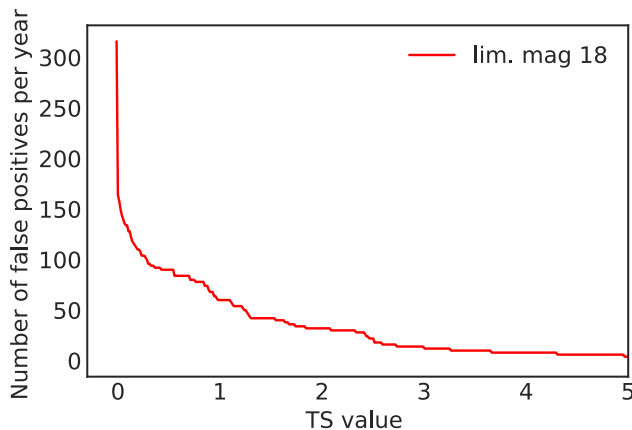
Real-time Neutrino Correlation: Search for Counterparts

Background discrimination:



- Trained neural network estimates redshift of host galaxy
 - Neutrino counterparts (signal) show generally smaller redshifts
- **Enables rejection of transients showing no significant neutrino emission (background)**

Spectroscopic follow-up



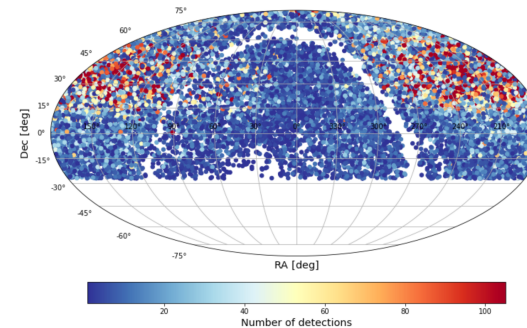
- Real-time maximum likelihood calculation
- Statistical excess between neutrino and optical counterpart will trigger spectroscopic follow-up
- Optimised on false positive rate of < 100 triggered spectra per year.

Real-time Neutrino Correlation: Goal

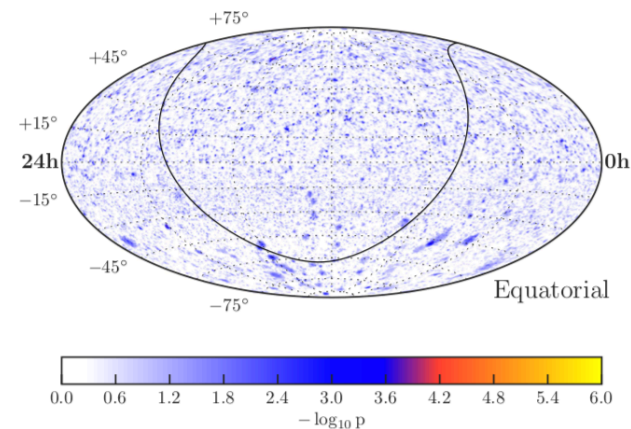
Offline Stacking Analysis

- ZTF transient catalogue:
 - Complete (magnitude-limited) catalogue
 - Fast-fading transients can be detected
 - Well-sampled lightcurves
 - Spectroscopical classification available
- IceCube neutrino sky map
 - Large statistics of high-energy neutrino events

ZTF transient catalogue



IceCube neutrino sky map



Current Status: Commissioning

Current status:

- ZTF camera and alert stream online
- Software for online correlation and alert management (AMPEL)
- Spectrograph at Palomar Observatory (SED-m)



ToO Program:

- ToO: First successful follow-up

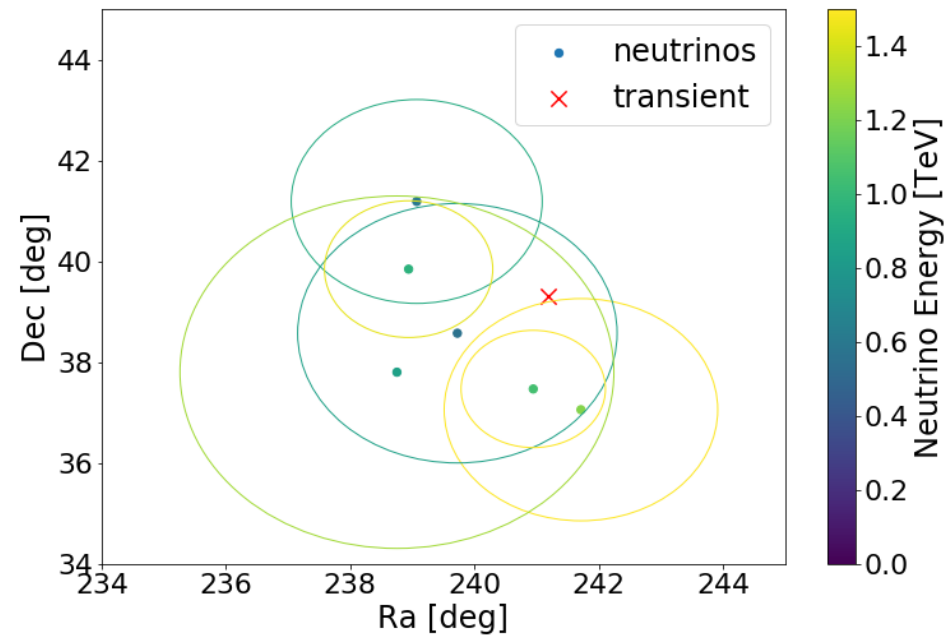


Real-time neutrino correlation:

- IceCube neutrino stream
- Commissioning: validation of transient selection via maximum likelihood estimation
- Start of neutrino science data acquisition with ZTF



Illustration: Transient selection via likelihood ratio



Summary

ZTF transient catalogues and ToO program allows for improved and novel analyses

Target of Opportunity

- Low rate of high-energy neutrinos
- High cadence of ZTF (3 days) allows to search for fast fading transients
- Spectroscopic classification available
- Large field of view to consider full error circles

Stacking Analysis

- High rate of low-energy neutrinos
- Complete and magnitude limited transient catalogue