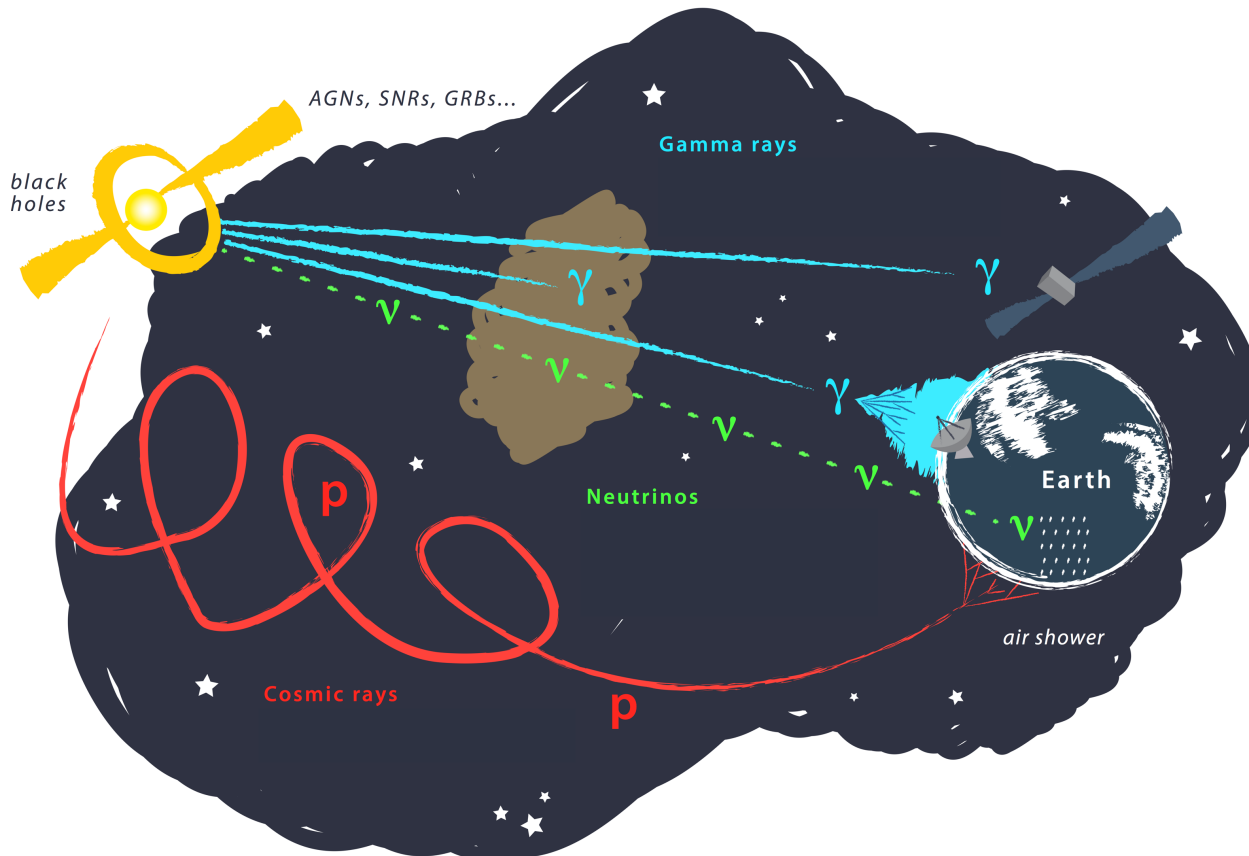
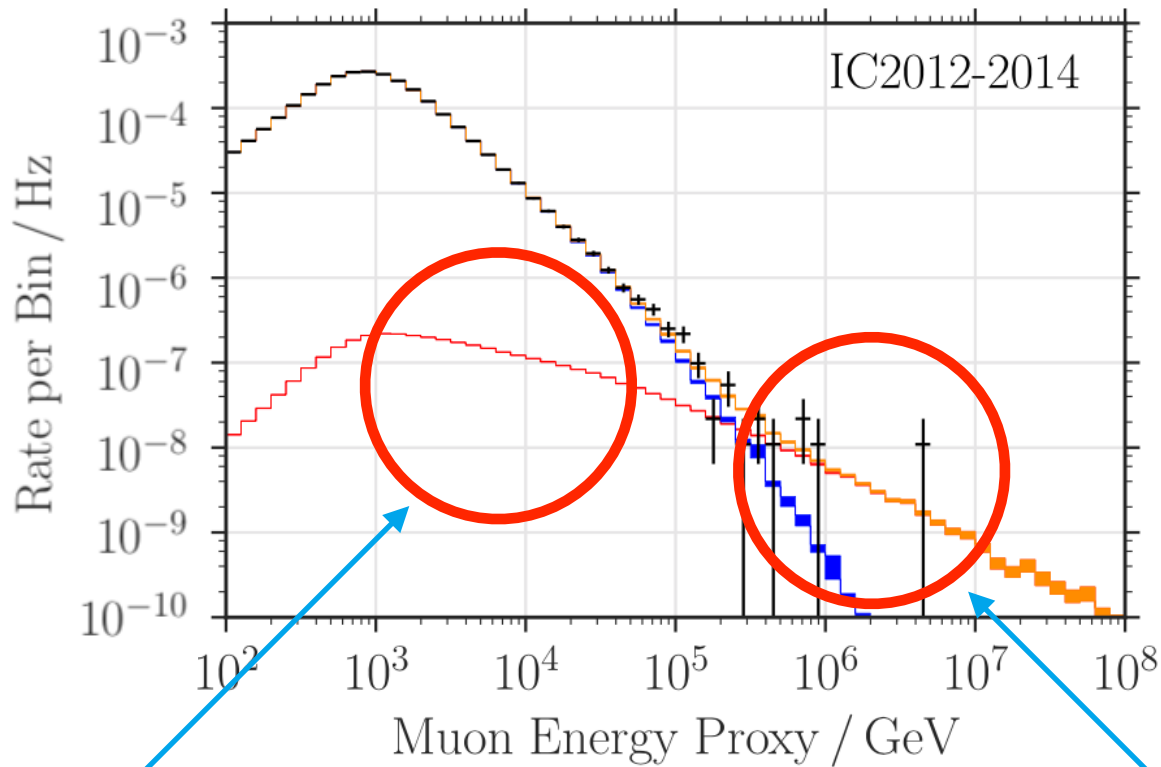


AMPEL - ZTF/IceCube program



Ludwig Rauch
Berlin, 23.05.2019

Optical Follow-Up Program of High-Energy Neutrinos



Continuous:

Build catalogue by collecting many transients

Triggered:

Target of Opportunity program

Neutrino Target of Opportunity program

- > We received ~7 IceCube alerts since start of ZTF
- > One could be followed-up: no interesting candidates identified
- > Reasons for non-observations: Sun distance too close, IceCube retractions, ZTF offline

Type	date	RA	Dec	Error	Comments
Doublet	2018-06-11 23:36:04.87	255.63	13.32	0.90	observed
EHE	2018-09-08 19:59:31.84	145.77	-2.52	0.34	Sun distance 22.68 deg
HESE	2018-10-14 11:52:19.07	225.18	-34.79	1.22	Sun distance 35.73 deg
EHE	2018-10-23 16:37:32.65	269.84	-8.89	0.29	camera down
HESE	2018-10-31 02:02:51.41	182.79	-68.39	1.22	retracted
HESE	2019-01-24 03:44:35	307.19	-32.29	1.23	Sun distance 13 deg
HESE	2019-03-31 06:55:43	337.79	-21.08	2.624	Sun too close

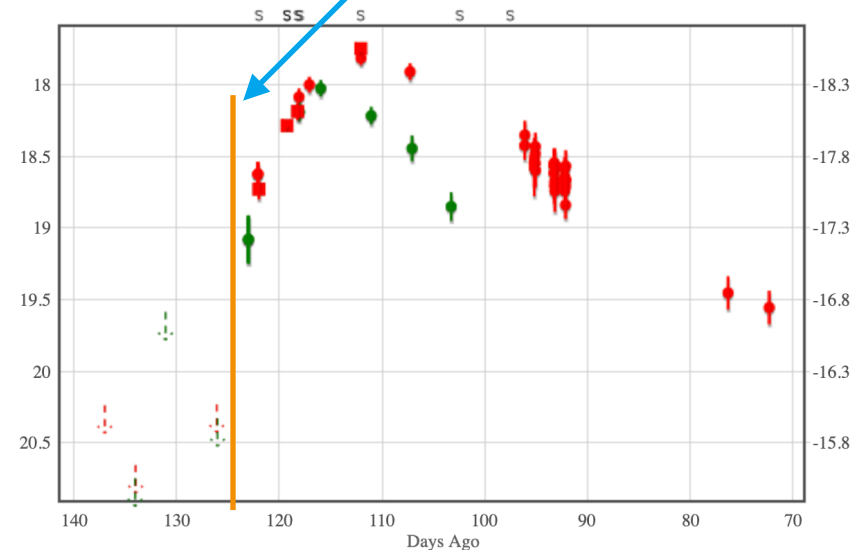
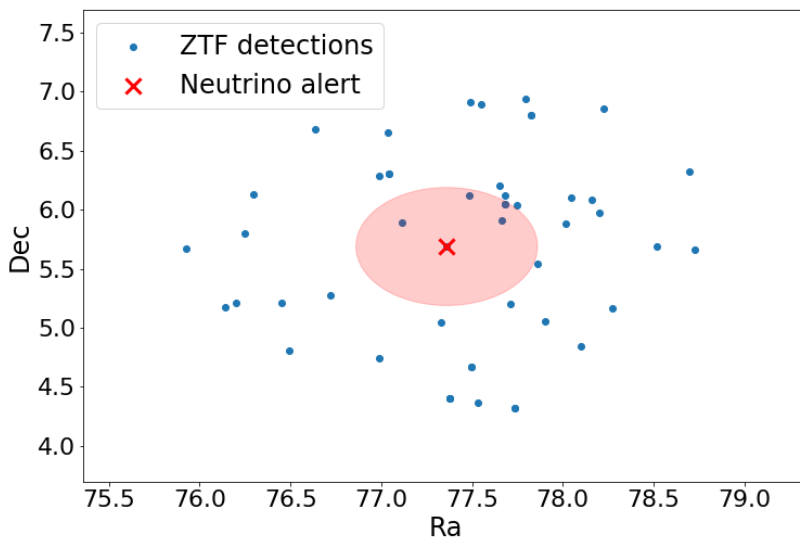


AMPEL ToO filter (T0):

AMPEL follow up analysis:

- Neutrino detection triggers search
- Cone search in neutrino uncertainty contour
- Require no prior photometric detections of object

E.g. Neutrino emission at explosion time

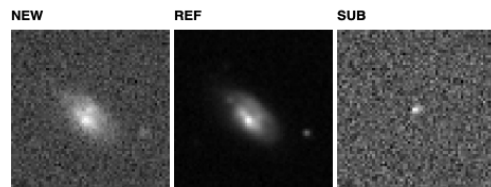


Real-time Neutrino Correlation with IceCube

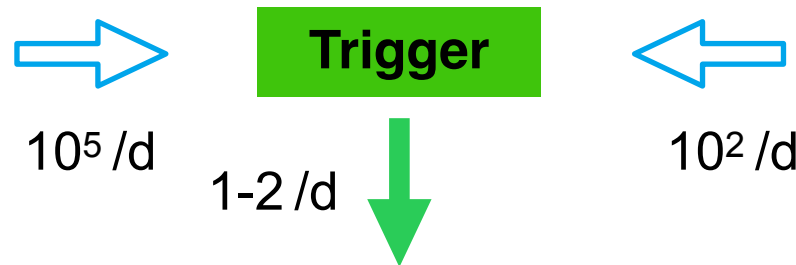
Alert Management, Photometry and Evaluation of Lightcurves: AMPEL



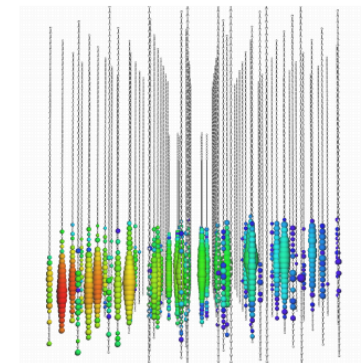
Transient positions from ZTF



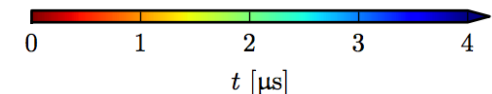
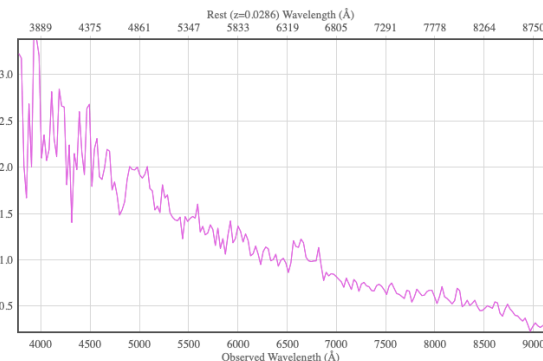
Novel realtime alert management and trigger software



Neutrino tracks from IceCube



Transient Spectrum



Primary filter (T0)

Filter: Primary data reduction applied to all alerts

Parameters

```
# number of previous detections
# minimum duration of alert detection history [days]
# maximum duration of alert detection history [days]
# real bogus score from machine learning
# sextractor FWHM (assume Gaussian) [pix]
# Difference: magap - magpsf [mag]
# number of bad pixels in a 5 x 5 pixel stamp
# distance to nearest solar system object [arcsec]
# minium distance from galactic plane. Set to negative to disable cut.
#search radius for GAIA DR2 matching [arcsec]
# significance of proper motion detection of GAIA counterpart [sigma]
# significance of parallax detection of GAIA counterpart [sigma]
# min gmag for normalized distance cut of GAIA counterparts [mag]
# max gmag for normalized distance cut of GAIA counterparts [mag]
# maximum allowed noise (expressed as significance) for Gaia match to be trusted
# maximum distance to closest PS1 source for SG score veto [arcsec]
# maximum allowed SG score for PS1 source within PS1_SGVETO_RAD
# reject alerts if the three PS1 sources are all within this radius [arcsec]
```

Information contained in alert

Automatic GAIA match

Automatic PanStarrs match



Correlation of two data streams (T2)

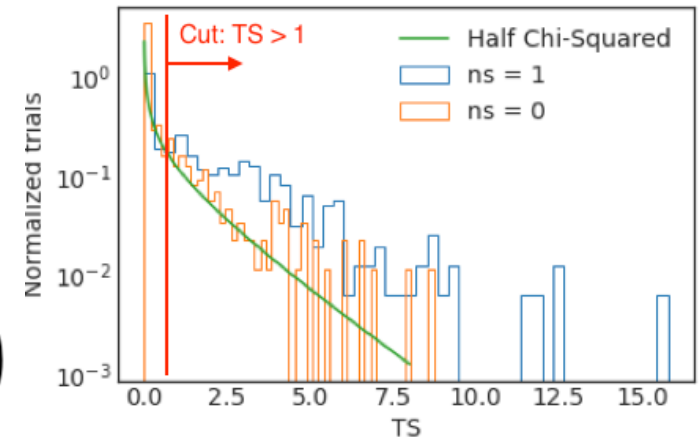
Perform maximum likelihood analysis

Maximum likelihood function

$$\mathcal{S}(E_\nu, \Delta T, \Delta\Psi, \sigma) = \underbrace{\frac{1}{2\pi\sigma^2} e^{(\Delta\Psi)^2/(2\sigma^2)}}_{\text{Position}} \cdot \underbrace{\epsilon_{\text{sig}}(E, \theta, \gamma)}_{\text{Energy}} \cdot \underbrace{\text{Box}(t_{\text{start}}, t_{\text{end}})}_{\text{Time}}$$

$$\mathcal{B}(E_\nu, \Delta T, \Delta\Psi) = \underbrace{\frac{\mathcal{P}(\sin\theta)}{2\pi}}_{\text{Position}} \cdot \underbrace{\epsilon_{\text{BG}}(E, \theta)}_{\text{Energy}}$$

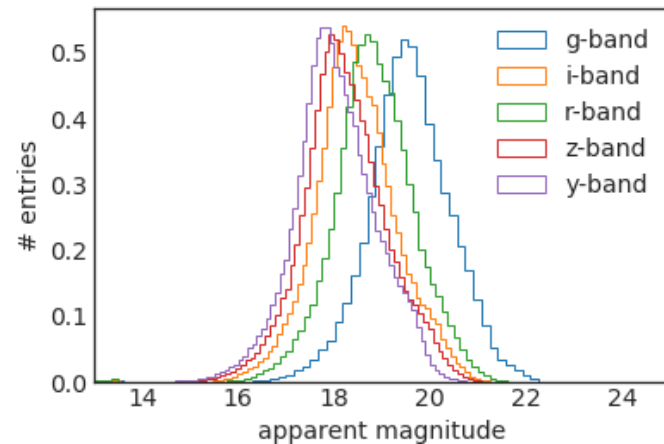
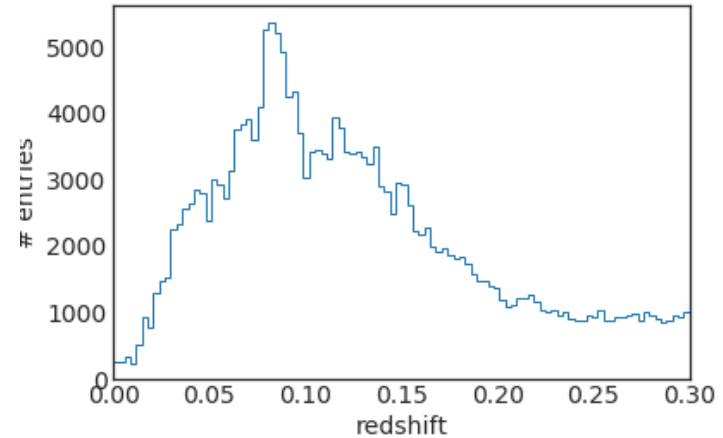
$$TS = -2 \log \frac{\mathcal{L}(\text{ns})}{\mathcal{L}(\text{ns} = 0)} = -2 \sum_{i=0}^N \log \left(1 + \frac{\text{ns}}{N} \left(\frac{\mathcal{S}}{\mathcal{B}} - 1 \right) \right)$$



Photometric redshift estimation (T2)

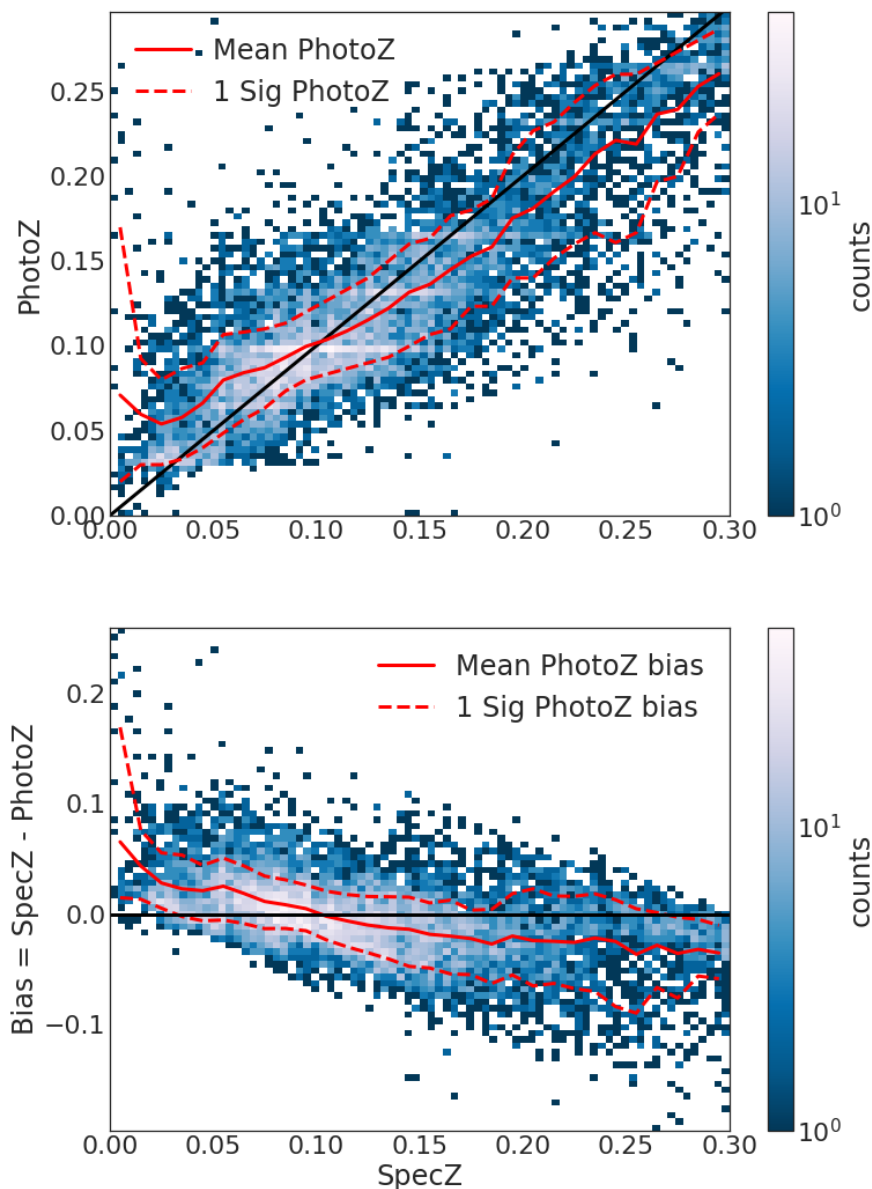
- SDSS and BOSS data
- $> 3 \times 10^6$ Galaxies with spectroscopic redshift estimation and photometric data for u,g,r,i,z filters
- No full sky coverage
- But good for training machine learning algorithms

➔ **Use Pan-STARRS catalogue for photometric data (g,r,i,z,y)**



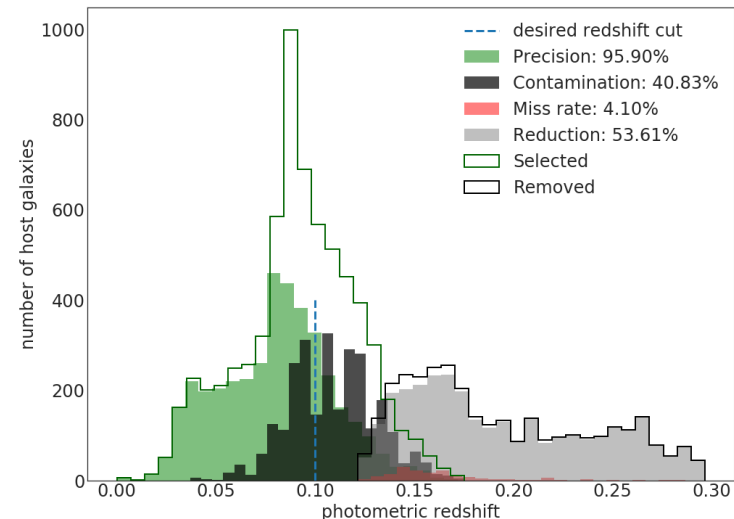
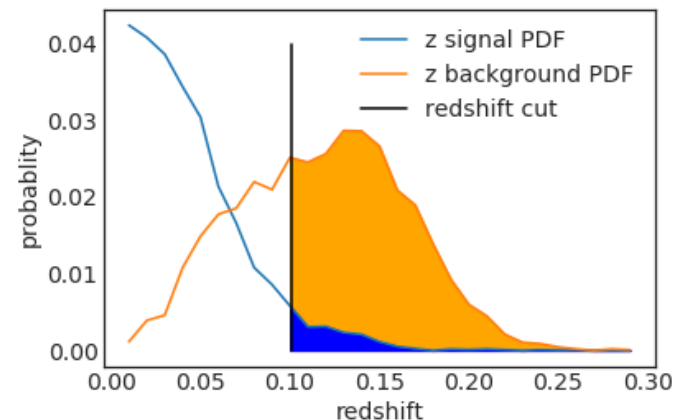
Results on training data

- Code is based on ANNZ2 package (developed by Iftach Sadeh et al.)
- Uses 100 random configurations of hyper parameters for boosted decision trees
- Trained BDTs are weighted according to their performance
- Software is embedded into AMPEL and optimised for computational speed.
- On average 0.5s per calculation
- Results on training data comparable to other results even though we are missing the u-band



Photometric redshift (T2)

- > Use photometric redshift for signal and background discrimination
- > At redshifts larger than $z=0.1$:
 - > Background: $\sim 62\%$
 - > Signal $< 5\%$
- > Due to uncertainties of the redshift estimate we consider the error pdf
- > Redshift cut on integral: Area of error pdf should be larger than 80% above a value of 0.1
- > Using the area reduces the background rejection efficiency but minimises false negative rate



Transient selection is pushed to GROWTH marshal (T3)

ZTF18aakebhi AGN

13:44:19.60 +51:26:24.5

206.081850 +51.440145

Note: 0.2" from ZTF18aakebod

[View another](#)

OVERVIEW
PHOTOMETRY
SPECTROSCOPY
OBSERVABILITY
EXAMINE
FINDING CHART

NEW
REF
SUB
SDSS
PS1

AUTO ANNOTATIONS

[2019 Feb 12 AMPELBOT \[saved_by_id\]](#): Correlating Icecube and ZTF

[2019 Feb 12 AMPELBOT \[saved_by_id\]](#): AmpelTNS

[2019 Jan 24 fremling \[Reference\]](#): 2018-03-05 08:58:55 to 2018-04-10 09:01:13

[2018 Nov 29 fremling \[IAU name\]](#): AT2018bjcp

[2018 Aug 07 sjoert \[saved_by_id\]](#): ZTFBH Nuclear

[2018 Jun 04 annayqho \[passed_filter\]](#): Red Transients

[2018 May 22 cenko \[passed_filter\]](#): Nuclear Transients

[2018 May 09 yiyang \[NED_GALEX_auto\]](#): NUV: 19.27 +- 0.133 mag, FUV: 19.731 +- 0.241 mag (2MASX J13441957+5126244, 0.136", [reference])

[2018 May 09 yiyang \[NED_redshift_auto\]](#): 0.0629 +- 1.1e-05 (2MASX J13441957+5126244, 0.136", [reference])

[2018 May 09 yiyang \[SDSS_specz_auto\]](#): 0.0629 +- 1.08e-05 (0.152", GALAXY AGN, [reference])

[2018 May 09 yiyang \[SDSS_photz_auto\]](#): 0.0612 +- 0.0132 (0.152", [reference])

[2018 May 09 yiyang \[passed_filter\]](#): ZTF Science Validation

[Auto Annotation Submission Form](#)

COMMENTS

[2019 Feb 12 AMPELBOT \[comment\]](#): AMPEL Neutrino PhotoZ 0.043 Delta -0.023 +0.053

[2019 Feb 12 AMPELBOT \[comment\]](#): AMPEL Neutrino T3.1.603

[2018 May 22 sjoert \[classification\]](#): AGN

[2018 May 22 sjoert \[info\]](#): Milliquas match: broadtype=NX; ref=PGC

[2018 May 22 sjoert \[info\]](#): From Portsmouth: sigma=182.3+/-5.7; BPT=Seyfert

[2018 May 09 yiyang \[redshift\]](#): 0.06292

$r = 18.9 (0.1 \text{ d})$ | [Upload New Photometry](#) | [Upload New Spectroscopy](#)

DM (approximate) = 37.22

First saved in partnership data.

ADDITIONAL INFO

NED

TNS

SNEx

SIMBAD

VizieR

HEASARC

SkyView

MPCChecker

Extinction

CFHT

IPAC

DSS

WISE

Subaru

VLT

FIRST

CRTS

ADS

iPTF Marshal

LegacySurvey

CURRENT FOLLOWUP REQUEST

Requester	Instrument	Start Date	End Date	Program	Priority	Status
sfrederick	SEDM	2018-08-29	2018-09-05	Nuclear Transients	1	IFU:ACCEPTED

ADD FOLLOWUP

Instrument:

Add a Comment:

Attach File: no file selected

Type:

SEND AN ALERT

Soft Alert (email)

Hard Alert (email + SMS)

Add to Favorites

Subscribe to this Target (daily digest)

Subscribe to this Target (immediate alerts)



AMPEL supports two types of neutrino programs:

Target of Opportunity

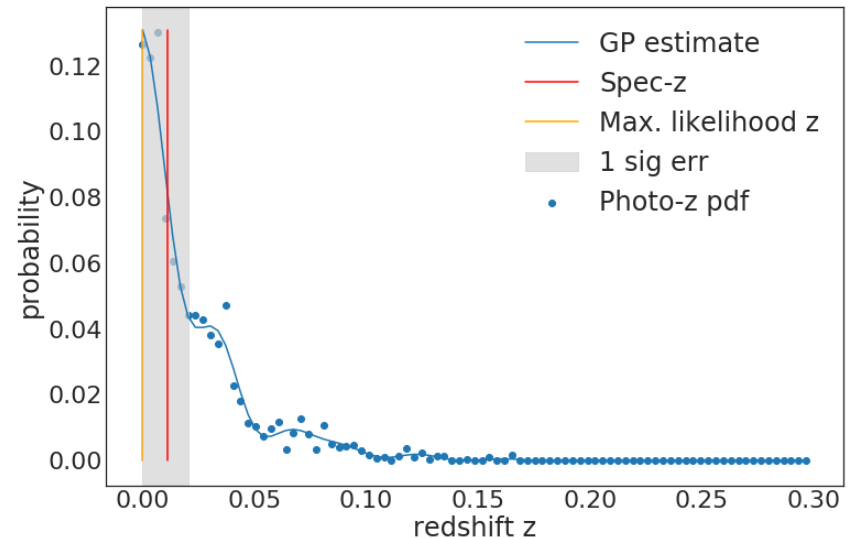
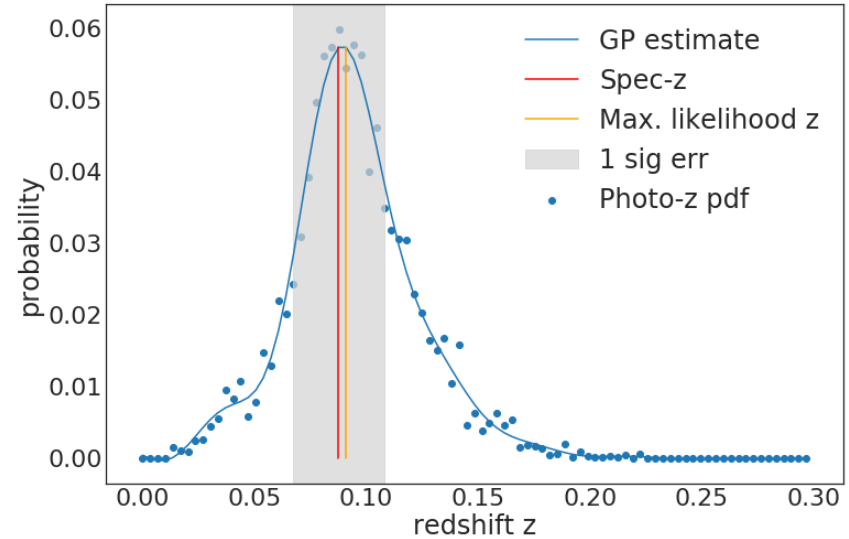
- Low rate of high-energy neutrinos
- High cadence of ZTF (3 days) allows to search for fast fading transients
- Spectroscopic classification available
- Large field of view to consider full error circles

Stacking Analysis

- Continuous search for transients
- High rate of low-energy neutrinos
- Complete and magnitude limited transient catalogue

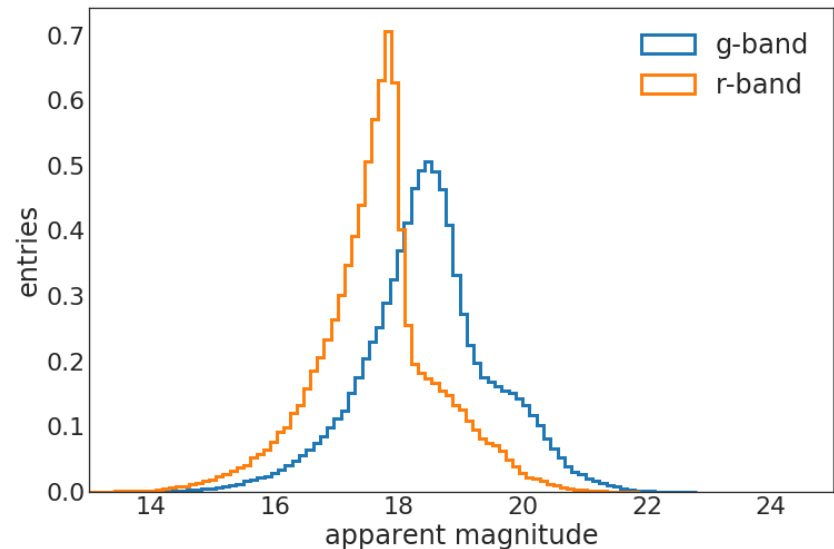
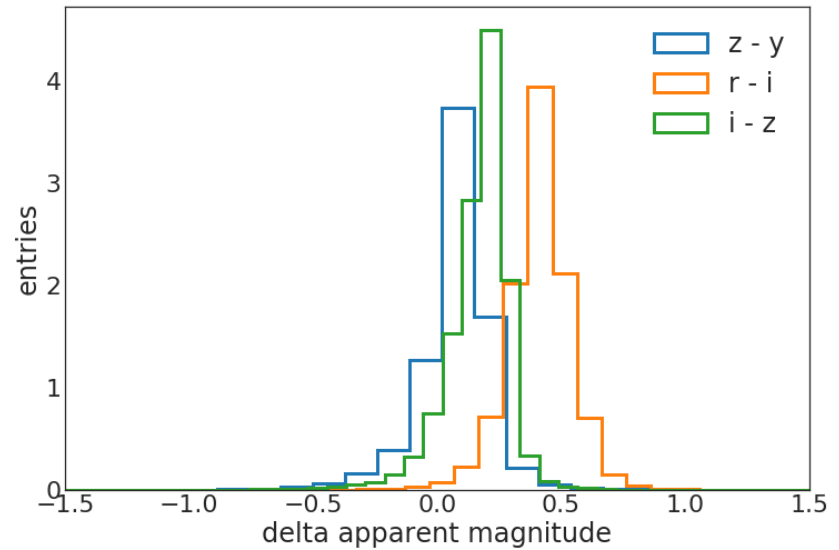
Uncertainty probability density function

- Uncertainty pdf estimated by KNN method:
 - Use 100 nearest neighbours in feature space
 - Use scatter of estimates as uncertainty estimation
- Photo-z estimation challenging at the boundaries at low redshifts ($z=0$) and high redshifts ($z=0.3$)
- Upper lower limits of the redshift can still provide viable information for transient selection!



MLM input parameters

- Photometry: g,r,i,z,y
- Input parameters (all Kron mag.)
 - g
 - r
 - z-y
 - r-i
 - i-z
- Possible improvements:
- Galex catalogue (two more bands)
- Use other parameters e.g. galaxy size



Future ToO neutrino stream

Neutrino alert stream:

> GOLD:

- > 50% probability of astrophysical origin
- > ~10 events per year

> BRONZE:

- > 30% probability of astrophysical origin
- > ~18 events per year

> Expected number of ZTF follow ups

- > Only 50-75% of the 28 (due to sun distance, retractions, ...)

