White Paper for Neutrino Follow-up - Reply to Referee

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Since we rely mainly on the public survey, the different Strawman options do not influence our program. As will be discussed below, we will require between 5h and 13h of ToO time each year, or in average between 0.8 and 2min each night (for comparison with the allocated ToO time).

In the following we address the comments / concerns of the referees. The referee's questions are highlighted in bold font.

1) It is said, but not quantified, that the advantage of ZTF is the availability of recent visits of the same field. The Q then becomes: what is maximum acceptable time elapsed since the last visit to the field for it to be worthwhile for ToO triggering?

A ToO trigger will *always* be worthwhile, even without previous observations. This can be seen e.g. considering searches for GRB afterglows and nearby or bright supernovae. For the latter case the ToO observations of the rise-time will be able to determine the explosion time without prior observations. However, for transients close to the detection limit or with very rapid rise-times, previous constraints will be extremely useful in separating these from pre-existing transients.

2) 60% of the candidate events will have a good localization, below 1 deg, in which case other (deeper) surveys will be more efficient. This is not discussed at all. It would be important to understand the full picture of IceCube follow-up.

In addition to ZTF we work with the Russian telescope network MASTER (limiting mag ~ 20.5), Pan-STARRS (limiting mag 22) and Blanco/DECam (limiting mag 24). We proposed to observe 4 of the public neutrino alerts with Blanco/DECam during their next observing run from August 2017 to January 2018. Pan-STARRS observes the public IceCube alerts (currently 8 / year) if they are visible from Hawaii.

Depending on weather and direction of the neutrino event, it might not be observable from Hawaii or Chile. Since early photometric data is crucial for estimating the explosion time of the SN, a large network of follow-up instruments is important for the success of the program. We only ask for few early ToO observations immediately after the neutrino alert - a few days after the alert the cadence of the public survey would be sufficient to sample the light curve.

3) In section 2.3 it says "we prefer to cover parts close to the horizon". I am not sure which horizon is meant here. Are we talking the horizon seen from South Pole?

Indeed, this refers to the horizon seen from the South Pole. Determined by the geometry of the detector our effective area is largest close to the horizon (see Fig. 1).

4) Spectroscopic follow-up with SEDM: this section is a bit unclear to me. Most CC SNe at $z \sim 0.08$ will be detected several days after explosion and there is a very wider range in abs magnitudes among CC SNe. Furthermore, the sky coverage is likely limited to 15 thousand sq. deg, every 3 nights. The proposers should do a much more careful assessment of the SEDM needed.

In the following we present a more careful study. We use the measured CCSN rates out to redshift of 2.5 by the CANDLES and CLASH survey combined with rates from the literature [Fig. 6 in Strolger and et al., 2015]. For type Ia SNe we rely on measurements from Fig. 11 in Rodney and et al. [2014]. We assume an absolute magnitude of -19.25 and -17.5 for Type Ia and CC SNe respectively with a variation of $\Delta mag = 0.5$ (1.0) for Type Ia (CC) SNe Richardson et al. [2014]. We integrate over redshift shells to get the number of sources per redshift bin.

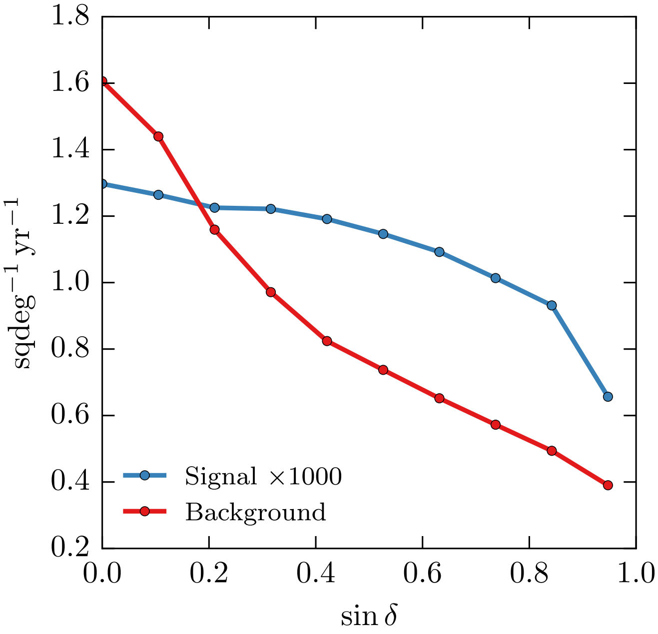

Figure 1: Neutrino event rates in IceCube. The effective area of the detector is largest at 0° declination, and decreases towards the North Pole.

We will monitor the light curve increase for all sources in spatial coincidence with a neutrino, and for those sources where the estimated explosion date matches the neutrino trigger we will obtain spectroscopy at maximum. We assume that this requirement reduces the number of sources by $\Delta T/365$ assuming an uncertainty of the explosion time of $\Delta T = 5$ days. Since we need at least 3 data points to be able to detect a rise in the light curve, we will be able to detect SNe with apparent peak at 19.5, so we can find them ∼1 week before peak at ZTF's limiting magnitude of 20.5 mag.

Furthermore we predict 160 muon neutrino candidates per day in the Northern hemisphere with an angular uncertainty of 1 sqdeg. In addition we assume that only 1/3 of the Northern sky will be scanned in the public survey.

The following table shows the number of CC and Type Ia SNe we expect to randomly line up with one of the 160 neutrino candidates (see also Fig. 2). We have requested time at VLT and ePESSTO to spectroscopically follow-up dim sources, while we propose to observe all sources, which get brighter than magnitude 19 with the SEDm. Assuming a limiting magnitude of 19.0 for the SEDm, we require 2 spectra every three days. Note that many of those transients will already be typed by other groups (i.e. the Type Ia group).

mag	CCSNe/day	Ia SNe/day	total/day
<19.0	0.29	0.41	0.70
<19.5	0.57	0.79	1.36

I doubt that the total time required for ToO is only 4 hr/yr. But it would be a worthy goal even if the ToO time is 3-4 times more in case the program can accommodate the neutrino event rates of ~ 20/yr by IceCube.

We assume that we will send out 20 neutrino alerts per year, of which 12 have a good angular resolution $< 1°$, while the remaining 8 have a worse resolution $1 - 15°$. For each alert we require 5 epochs in the first night and 2 each in the following nights. We then assume that the regular survey will cover the field every 3rd night. For the well-reconstructed events we need only one pointing, while for the other once up to 4 pointings might be required. Assuming each exposure is 30s plus 15s overhead we end up at $(5+4) * 45s * (12 + 4 * 8)$

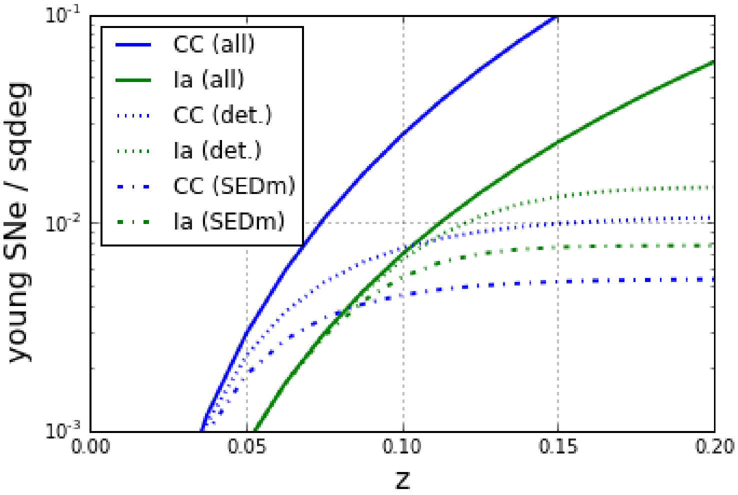

Figure 2: Expected rate of young supernovae ($\Delta T = 5\,\text{days}$) within 1 sqdeg, assuming an absolute magnitude of -19.25 (-17.5) and a Gaussian variation of the absolute magnitude with sigma of $\Delta m = 0.5$ (1.0) mag for Type Ia (CC) supernovae. The solid line shows all SNe, while the dotted line shows SNe detected by ZTF and the dashed-dotted line those accessible by the SEDm.

= 5h. If we cannot assume that the ToO field is monitored by the survey, we need to add the continuous observation of the field every 3rd night for 3 weeks requiring additional 8h, i.e. 13h per year in total.

References

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