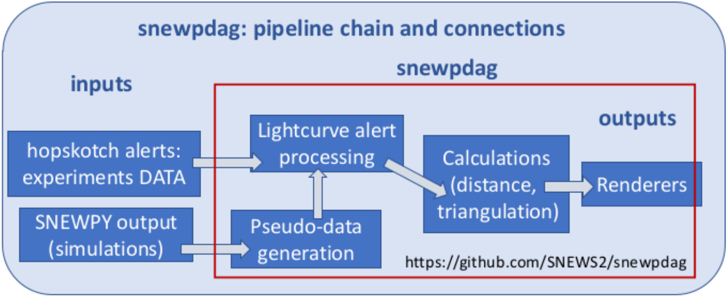
Signal prediction connection with snewpdag: generators, triangulation and distance estimate

Marta Colomer Molla
marta.colomer@ulb.be

snewpdag: will process the SNEWS time tiers data and apply different calculations (e.g. triangulation/distance)



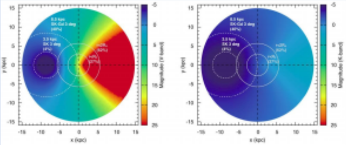
- SNEWPY connection with snewpdag: allows to evaluate expected performances and responses for different models
- snewpdag pseudo-data and calculations will be used for firedrills
- snewpdag connection with coincidence server: implemented, under testing

MOTIVATION: the multi-messenger signal

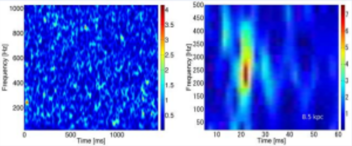
- Source position and distance using neutrinos are crucial for a successful MM follow-up
- Timing of the neutrino signal is key for those parameter estimates
- SNEWS will collect data from different experiments and send an alert to other observers

SNEWS
SUPERNOVA EARLY WARNING SYSTEM

EM observations



GW observations



- Without neutrino information (time window, pointing and distance), the MM counterparts could be missed
- SNEWS can provide it in almost real time

Outline:

1. Generators
2. Triangulation
3. Distance estimate

Data generation in snewpdag:

Two types of input data:

- Time series: event-by-event times
- Histograms: events per time bin
  - New implementation as different classes in snewpdag, treated similarly in the generator level

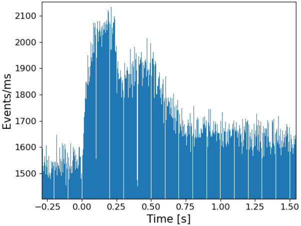
Two types of generators:

- Lightcurve simulated from expected time profile (signal+background) through poisson fluctuations
  Expected input signal for generator comes from SNEWPY output
- Signal simulated a delta peak in time (box-like shape) Bin-by-bin event rates also fluctuation through Poisson
- In both, signal can be simulated starting at any T0 and for any distance

Why generators?
The starting point is an expected number of events, not a simulated observation

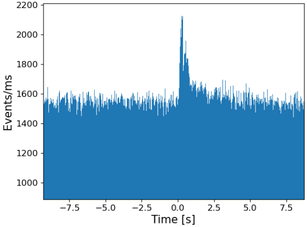
Two types of detector effects implemented:

- Dead times in the detector

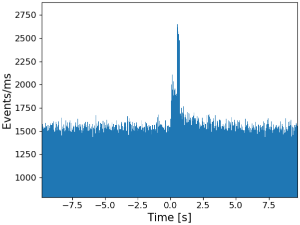


- Background/noise bursts:

Without background burst



With background glitch on top of signal



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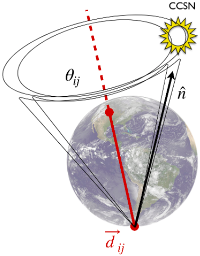
Pointing to a CCSN with triangulation

"The time delay between the signal at different detectors defines a sky region"



Steps of the procedure:

1. Signal prediction at different experiments
2. Evaluating the time delay uncertainty and bias for a given method
3. Apply triangulation!

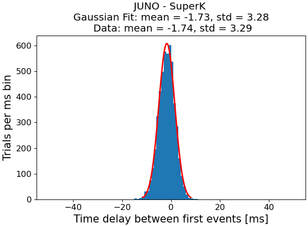
Latest updates:

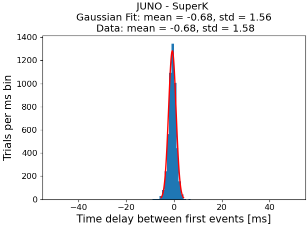
- Coordinate system: moving from GCRS to ICRS
- Correction of probability VS coincidence level output
- Ouputs: possibility to plot different skymaps in the same figure implemented in snewpdag
- First step for automatizing results sharing → implementation of pickles
- Chain completed using different models (11, 27 and 40 $M_{\odot}$) for step 1, and two methods for step 2 (matching lightcurve and 1st event time)

Example results of step 2:

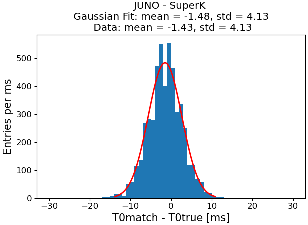
Bollig 11 $M_{\odot}$ | OConnor 40 $M_{\odot}$

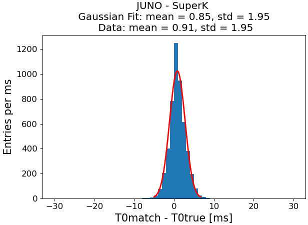
1st events method:





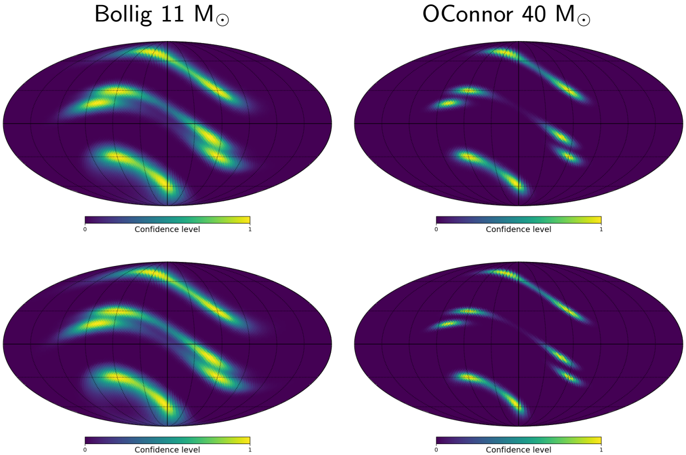
Matching lightcurves:





***NOTE: for 1st events method, IceCube performance is taken from latest results on the T0 uncertainty (ICRC 2019 proceedings)

***NOTE: for 1st events method, the distribution with real detector trigger might vary



1st events method:

Matching lightcurves:

Triangulation combining IceCube, Super-K and JUNO experiments
(Peformance compared for SN at four different locations)
Results: $http://www-pnp.physics.ox.ac.uk/~tseng/snews/$

Next steps:

- Clean-up and documentation of the code
- Using multi-order coverage maps instead of "simple" FITS
- Automatic upload of results to a server for sharing skymaps
- Including/testing more methods for obtaining the T0 and its uncertainty:
  - See next talk by Remington*
  - Bayesian blocks algorithm (proposed by Josh)
  - New idea being tested by Cal and Jeff (ongoing work):

  $\rightarrow$ use the time differences between expected and observed lighcurve from every position on the sky in a single Poisson χ^2:
  combines the method used by Ligo-VIRGO with the matiching lightcurve method (this would consider directly all uncertainties (syst+stat) on the T0 in single step)

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Reminder:

Two methods, based on observed $N50$ = number of events in the first 50 ms:

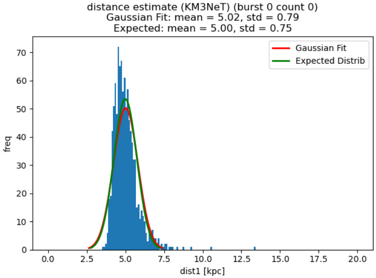
1. Using the expected signal weighted over initial mass function (IMF_{N50}):
   $d_1 = d_{\mathrm{ref}} \sqrt{\mathrm{IMF}_{N50}/N50}$
   - Lower stat uncertainty, larger model systematics
2. Linear relation between $N50$ and $f_\Delta = \frac{N50}{N(100-150)}$:
   $d_2 = d_{ref} \sqrt{N50_{fit}/N50}$, with $N50_{fit} = a \times (f_\Delta - b)$
   - Larger stat uncertainty, lower model systematics

We will give results for each method separately (no weigthed average)

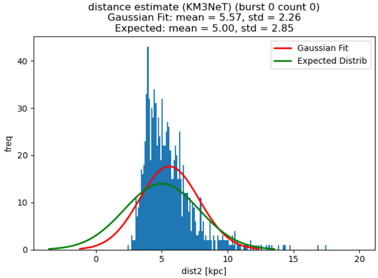
Updates:

- Using the method on additional detectors (method parameters not evaluated in paper): JUNO MM-trigger configuration and KM3NeT
- Including background: extreme case of KM3NeT
- Evaluate of main method 1 systematics from IMF uncertainty, separately from statistical uncertainty

Method 1:



Method 2:



- The distribution start deviating from Gaussian case with large background
- When moving to large distances (results here at 5kpc), fits start failing (background fluctuations larger than signal expectation)

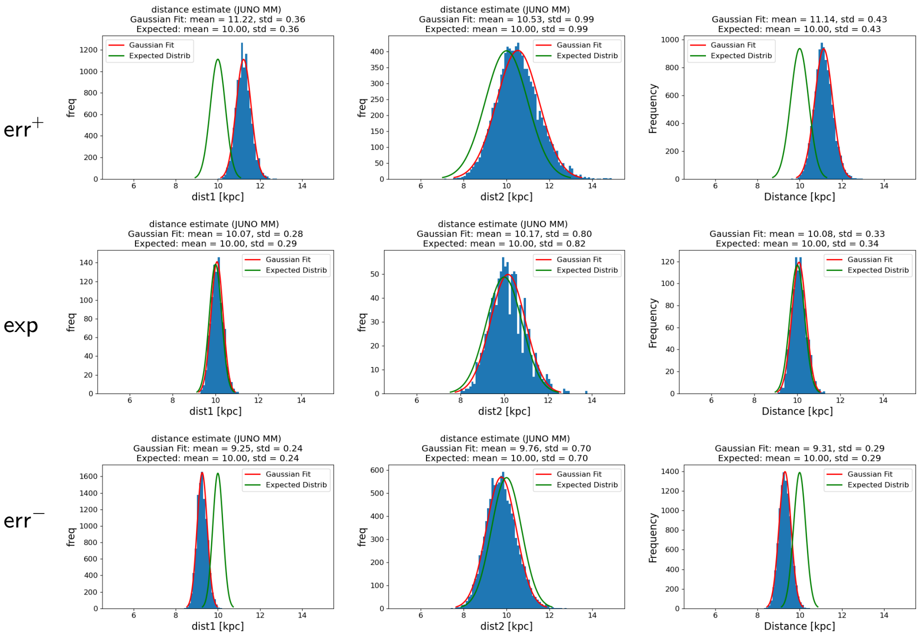
Next:

- More cross-checks on the implementation of bg

Method:

- Evaluate the mean and spread of the estimated distance distribution for three cases:
  1. Where expected N50$\simeq$IMF$_{N50}$-σ_{IMF} (err^{+})
  2. Where expected N50$\simeq$IMF$_{N50}$ (exp)
  3. Where expected N50$\simeq$IMF$_{N50}$+σ_{IMF} (err^{-})
- The shift of the mean in (err^{+}) and (err^{-}) cases gives the syst error
- The spread of the distribution for the (exp) case gives the stat error
- Sum both quadratically

Evaluation of main systematics: IMF uncertainty



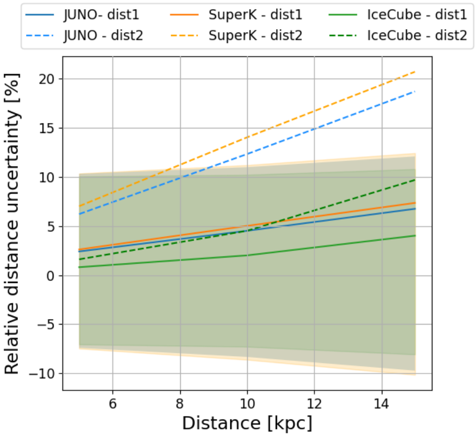


Figure: Statistical uncertainties for Methods 1 (solid) and 2 (dashed). For Method 1, the bands include the model IMF systematic error.

Next:

- Include T_0 and main Method 2 systematics

Summary

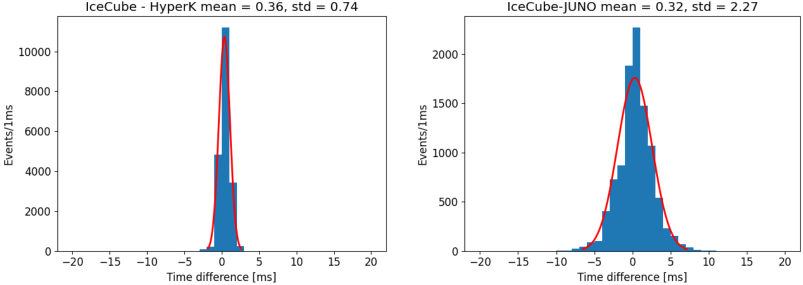
The full snewpdag chain using SNEWPY + pseudo-data with detector response + calculations (triangulation/distance) is working and mostly in shape

$\rightarrow$ **getting ready for firedrills**

Back-up

Evaluating $\sigma(\delta_t)$ and bias with lightcurve matching method and a delta peak function signal

- Number of events per time bin for IceCube: 600 signal and 1458 bg
- Number of events per time bin for JUNO: 6 signal events and 0 bg
- Number of events per time bin for Hyper-K: 160 signal events and 0 bg



$\rightarrow$ Bias below 0.5 ms and same for both pairs with this method

If we agree, I can produce skymaps with those $\sigma(\delta_t)$ and bias results for the poster