Sky-position reconstruction abilities for different ET geometries and layouts

Alexander Dietz
Benoit Mours

Outline

- Overview: What is the goal
- Technical details
  - Detector network
  - Observed quantities
  - Methods used
- Preliminary results
  - Tests with S6 injections
  - Results for different ET configurations
- Outlook

Outline

- Overview: What is the goal
- Technical details
  - Detector network
  - Observed quantities
  - Methods used
- Preliminary results
  - Tests with S6 injections
  - Results for different ET configurations
- Outlook

Overview

- Investigate the ability of different ET geometries to reconstruct the sky position
  - Assume LV detectors exist with (enhanced) advanced configuration
  - Using ET's in different locations, lengths, L-shape, triangle, ...
  - Using a 'signal'
  - Output: area on the sky

Outline

- Overview: What is the goal
- Technical details
  - Detector network
  - Observed quantities
  - Methods used
- Preliminary results
  - Tests with S6 injections
  - Results for different ET configurations
- Outlook

Technical Implementation

- Using self-made code: pyET.py
  - Can choose noise curve (LIGO-I, advanced, ETB,ETC)
  - Can define any detector with any arm directions, lengths and location
  - Can create a 'network' of detectors
  - Calculates the SNR of a signal (VIR-027A-09):

$$\rho = 1.56 \times 10^{-19} \left(\frac{\mathcal{M}}{M_\odot}\right)^{5/6} \left(\frac{Mpc}{r}\right) f_{geo} \sqrt{\int_{f_{low}}^{f_{ISCO}} \frac{f^{-7/3}}{S_h(f)} df}$$

  - Calculates the time-of-arrival for any network, location, etc
  - Uses a finite grid of sky points

Technical Implementation

- Using self-made code: pyET.p
  - Can choose noise curve (LIGO ... C)
  - Can define any detector w... engths and location
  - Can create a 'netw
  - Calculates th ... 027A-09):

$$\rho = \ldots \left(\frac{Mpc}{r}\right) f_{geo} \sqrt{\int_{f_{low}}^{f_{ISCO}} \frac{f^{-7/3}}{S_h(f)} df}$$

  - ...e-of-arrival for any network, location, etc
  - U... grid of sky points

Code still needs to be cross checked!

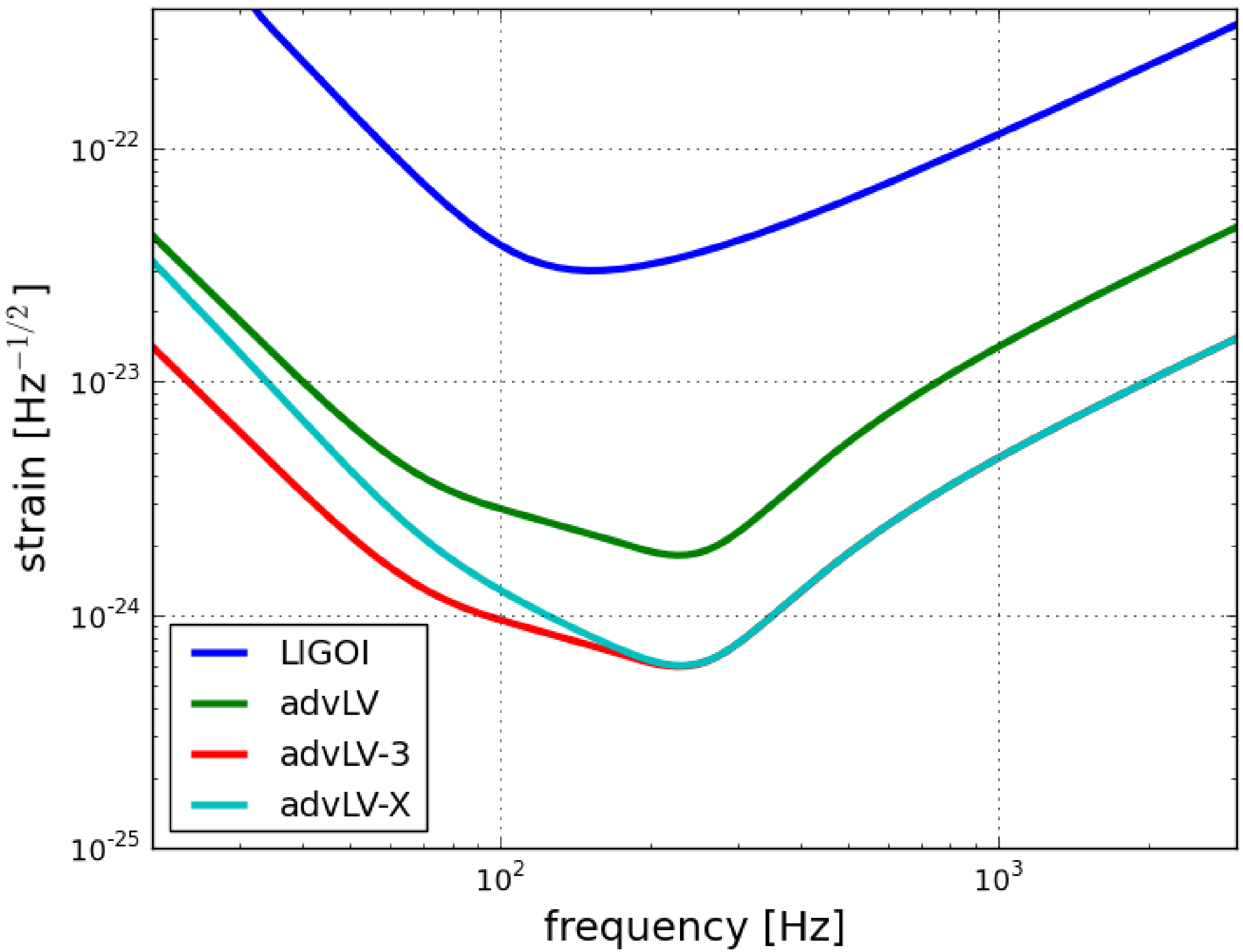
All results preliminary

Detector Network

- Assume LIGO+Virgo online
  - with enhanced advanced configuration
  - f_{low} = 30 Hz
- Probably advanced detectors running in Japan (J1) (and Australia)
- Different ET geometries: (f_{low} = 3Hz, ET-B noise curve)
  - Δ at Geo-site (L=10 km)
  - L at Geo site and L in Black Forest (L=7.5 km)
  - L at Geo site and L in Hungary (L=7.5 km)

Detector Network

- Assum
  - with (
  - f_{low} =
- Probab
  (and Au
- Differe
  - Δ at (
  - L at (
  - L at (



Signal parameters

- **Masses**: 1.4, 10.0, 50.0 $M_{\odot}$
- **Sky location**: random location on the sky
- **Source parameters**: random orientation and inclination
- **Distance:** 100 Mpc

➔this gives a list of "*observed quantities*"

Observed quantities

- Select a detector network with a noise PSD
- Select a signal with parameters (as described before)

➔"Observed quantities": *(masses assumed to be known)*

- SNR inclusively the error $\Delta\rho = 1 + 1\% \times \rho$ Intrinsic error / Calibration error
- Time-delays of the signal between the detectors
- Error on the time delay:
  - Given the SNR and its error: calculate maximum SNR mismatch

    $$q = \frac{\rho - \Delta\rho}{\rho + \Delta\rho}$$

  - Calculate mismatch by introducing a time-shift:

    $$\rho_c(t) = \int_{f_{low}}^{f_{ISCO}} df \; \cos(2\pi f t) \frac{f^{-7/3}}{S_n(|f|)} \qquad \rho = \sqrt{(\rho_c^2 + \rho_s^2)}$$

  - Find the time t at which $\rho_c(t) \equiv q$

Observed quantities

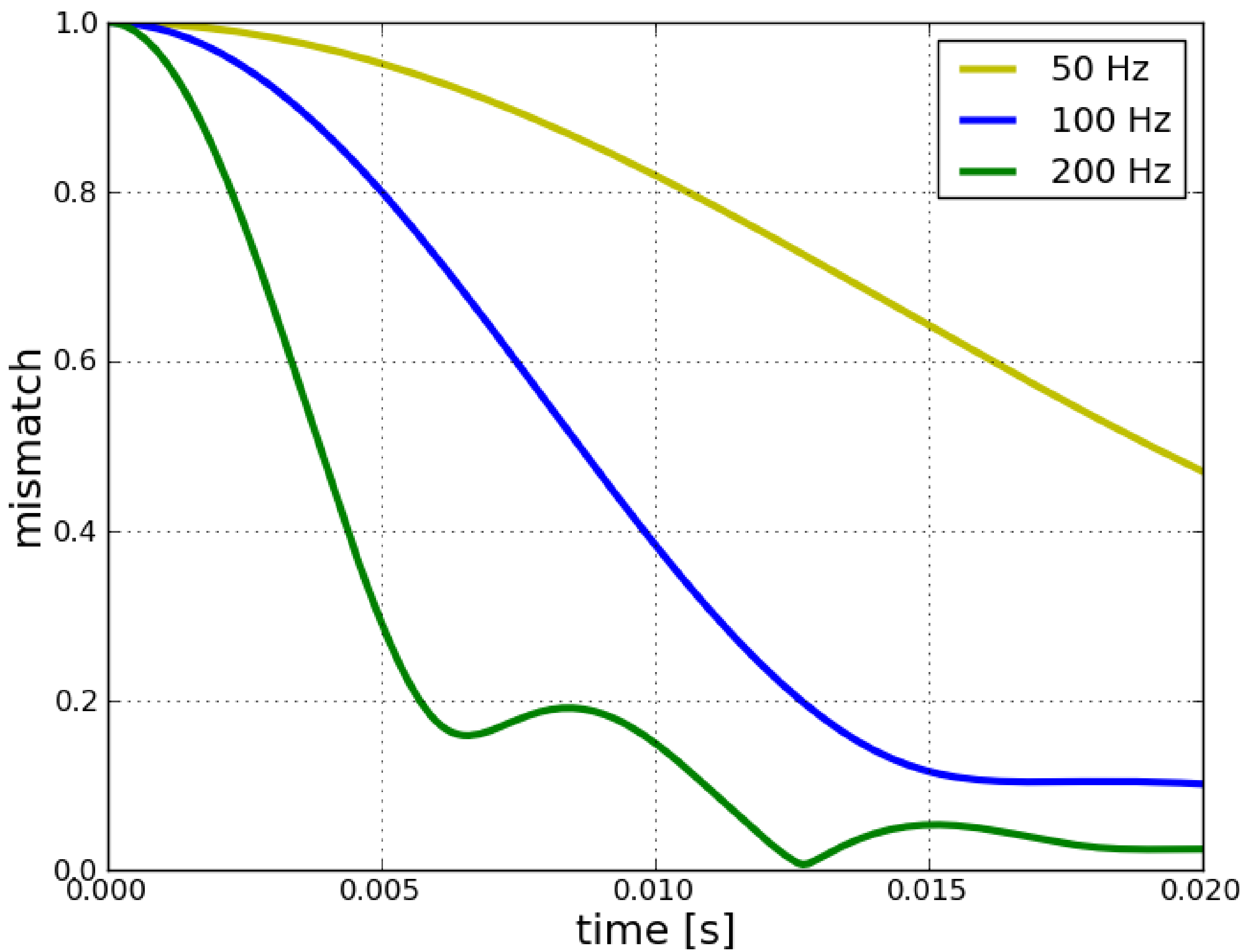
- Sel
- Sel)

➔“Ol

error

ion error

s low

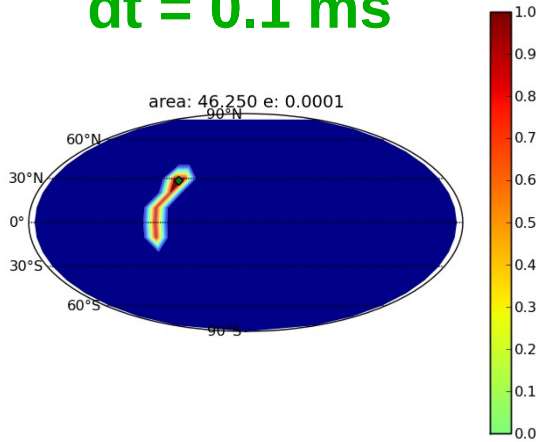


Sky Location procedure

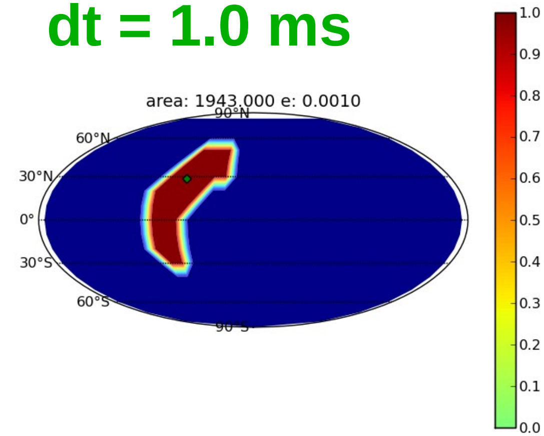
- Divide the sky in equal-sized areas (SkyPoints)
- For a given signal/network/noise:
  - Reject any SkyPoint inconsistent with the **timing of the arrival time of the signal** (allowing 2 sigma error)
  - Keep only the remaining points which contain the true location with 90%, **as deduced from the SNR values.**

Effect on the timing error

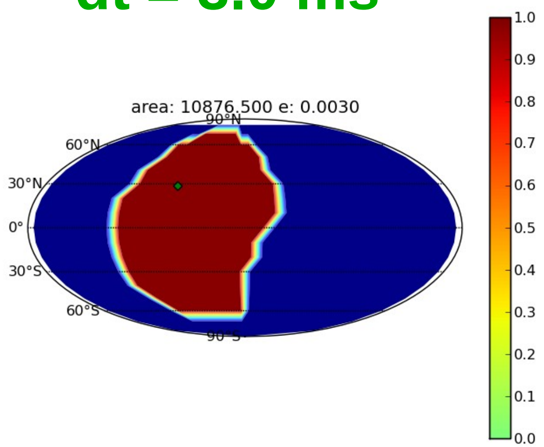
dt = 0.1 ms



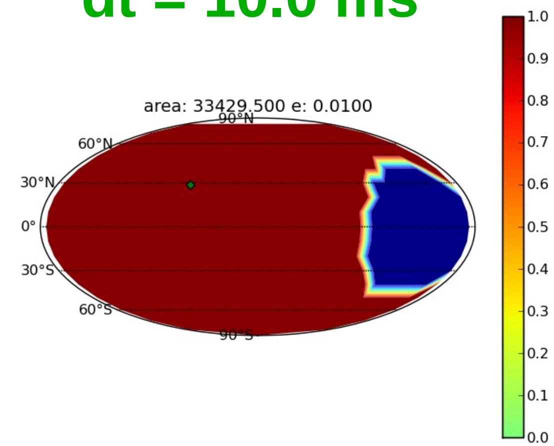
dt = 1.0 ms



dt = 3.0 ms



dt = 10.0 ms



Using the amplitude

- Assumption: Masses known (i.e. template-bank)
- Unknown: Distance, sky location, source orientation
- Take the SNRs of two detectors: $t = \frac{\rho_1^2 - \rho_2^2}{\rho_1^2 + \rho_2^2}$
  → Quantity independent of distance
- SNR depends on antenna factors: $\rho^2 = \frac{\sigma^2}{D_{\mathrm{eff}}^2} = \frac{\sigma^2}{r^2}\left(F_+^2\, H_+^2 + F_\times^2\, H_\times^2\right)$
- Choose fixed sky location (SkyGrid), do some maths:

$$\psi = \frac{1}{4}\left(-\arcsin\left(vu\right) - \phi\right)$$

polarization

depends on inclination

depends on t

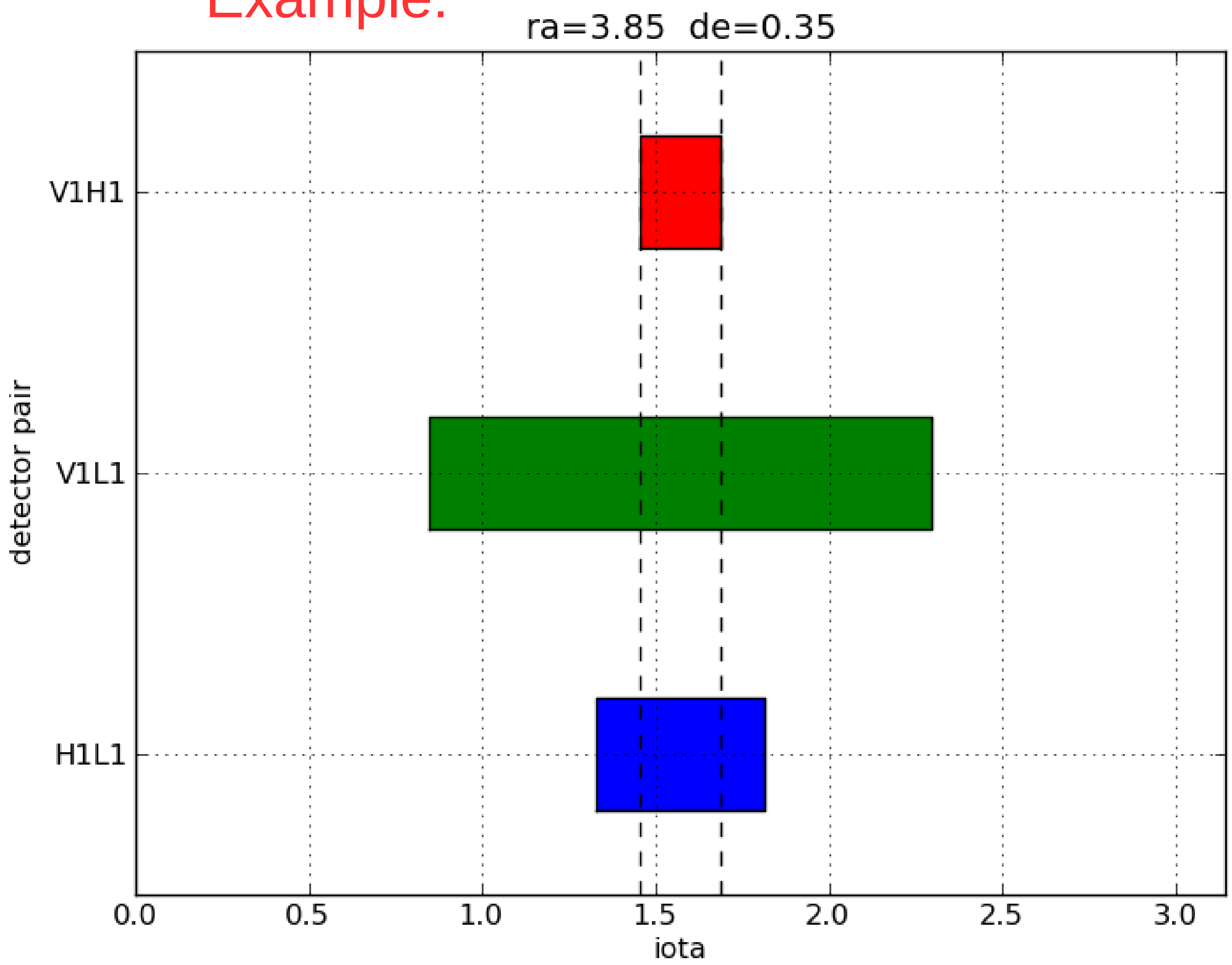
Find the range of iota for which a solution exists

Using the amplitude

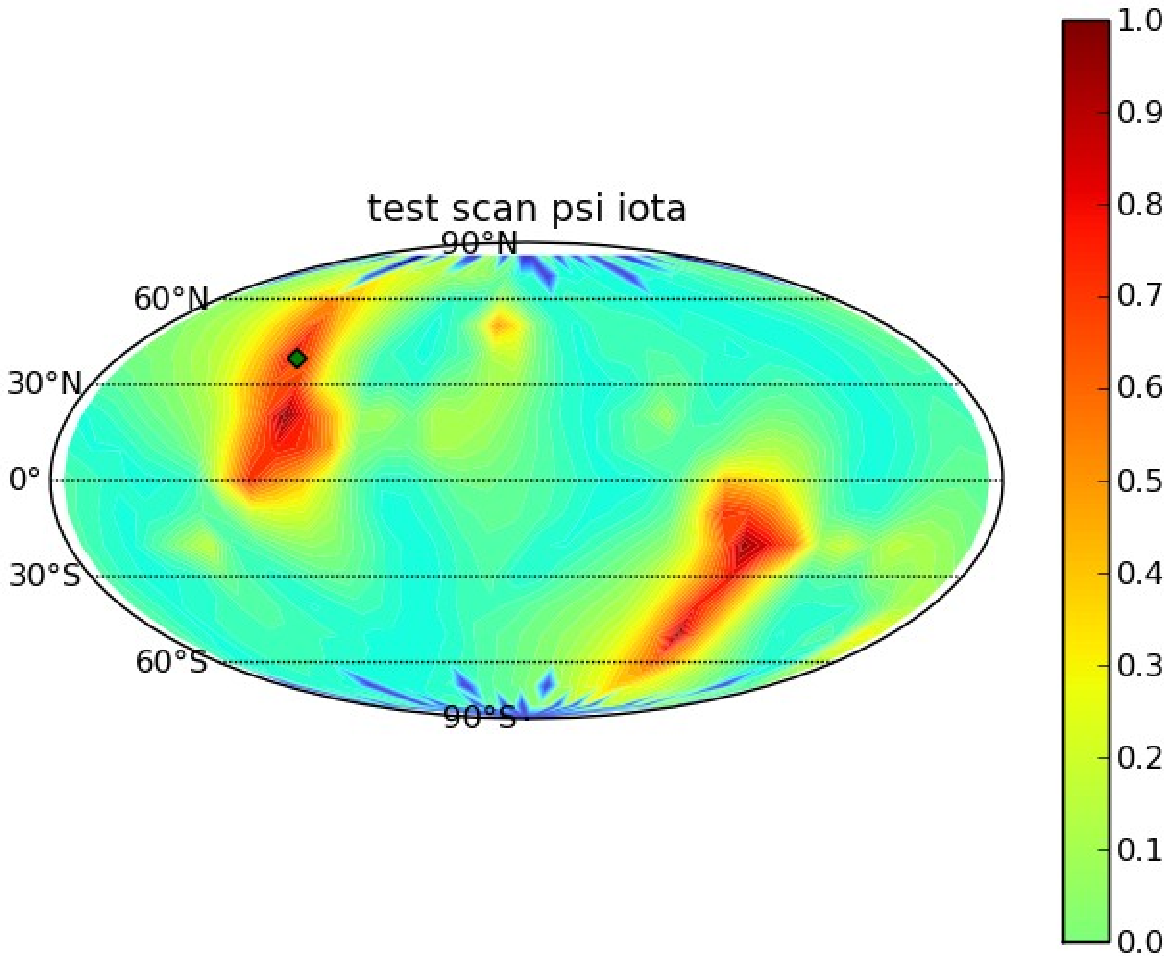
- Ass
- Unl
- Tak
  → (
- SN
  ant
- Ch

pol

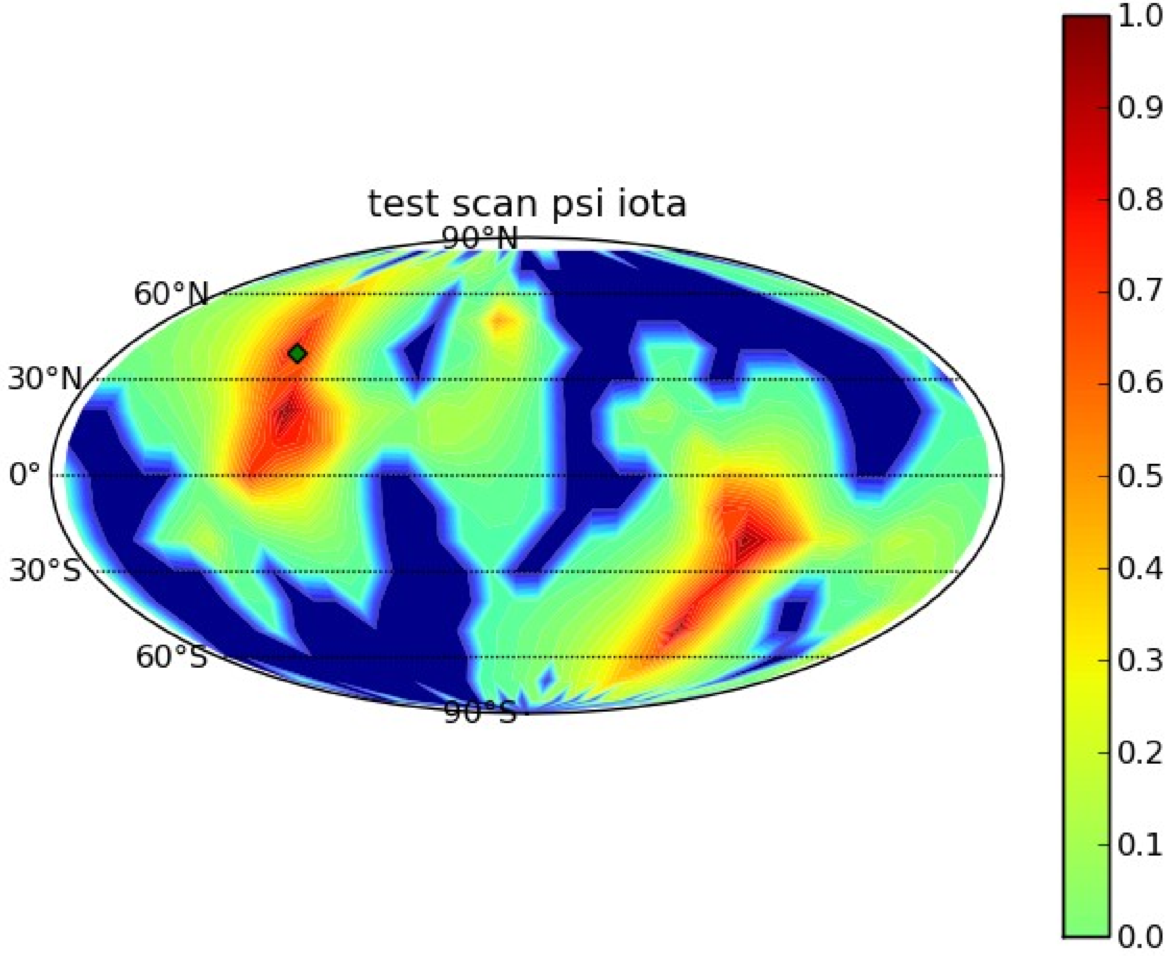
Example:



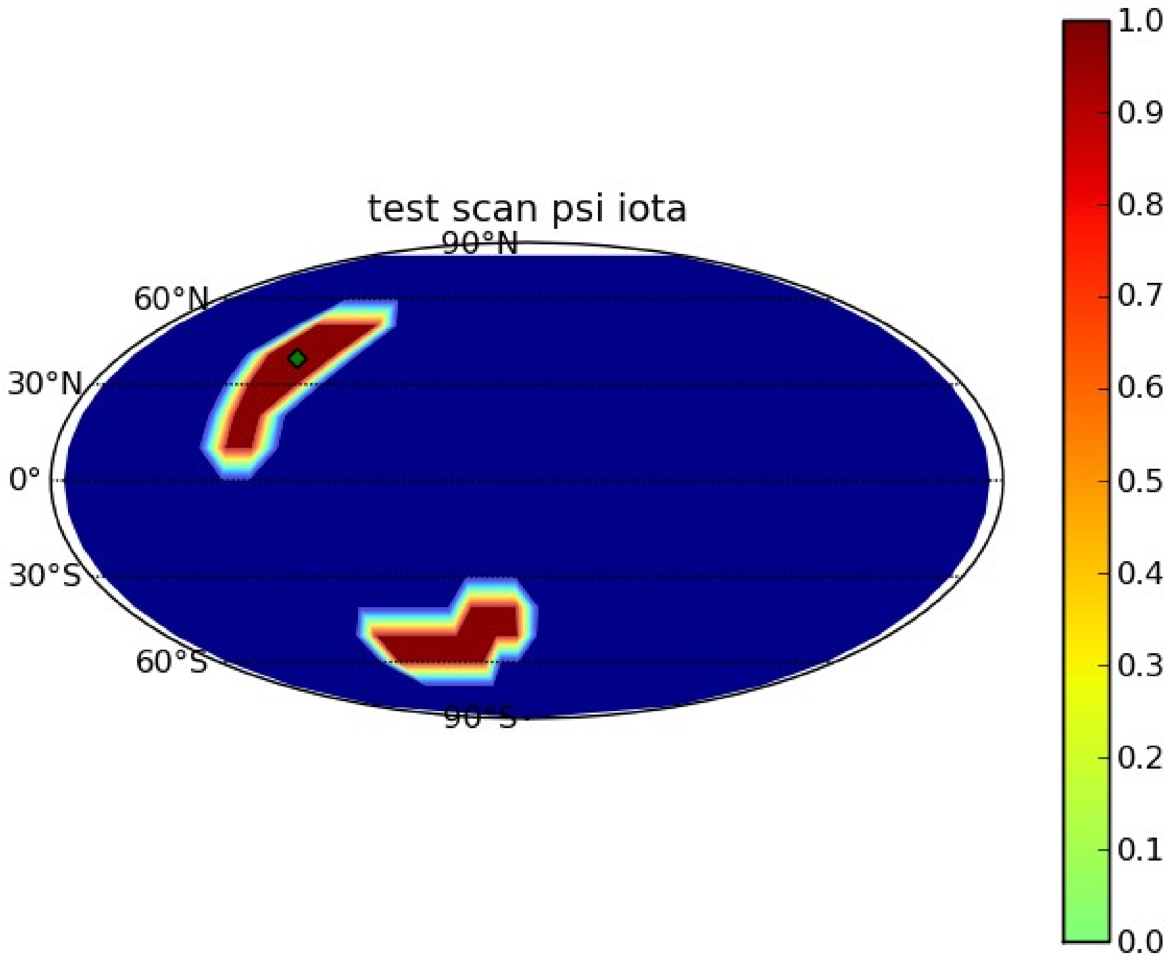
Example: Iota segment whole sky



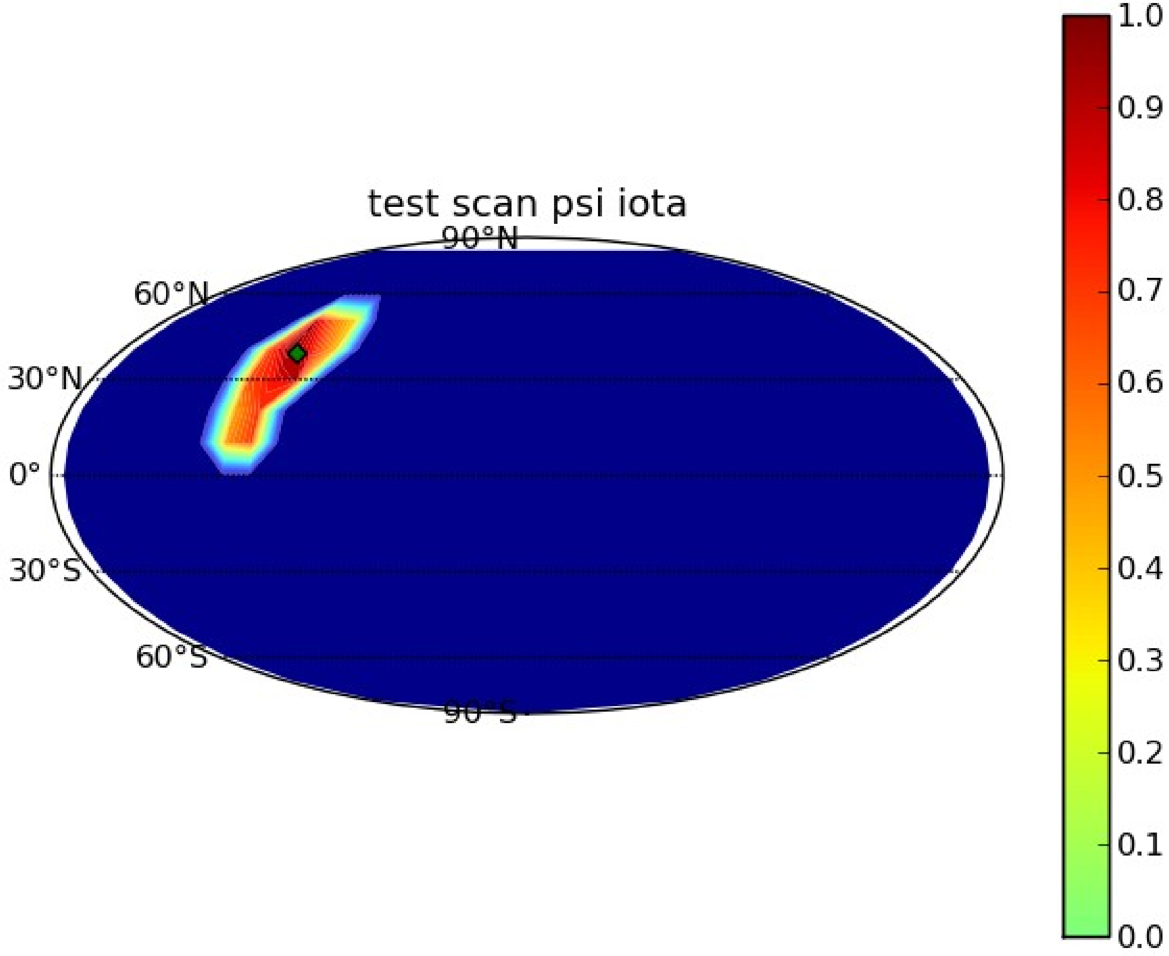
Example: iota segment > 90%



Example: Only Timing



Example: Timing+amplitude



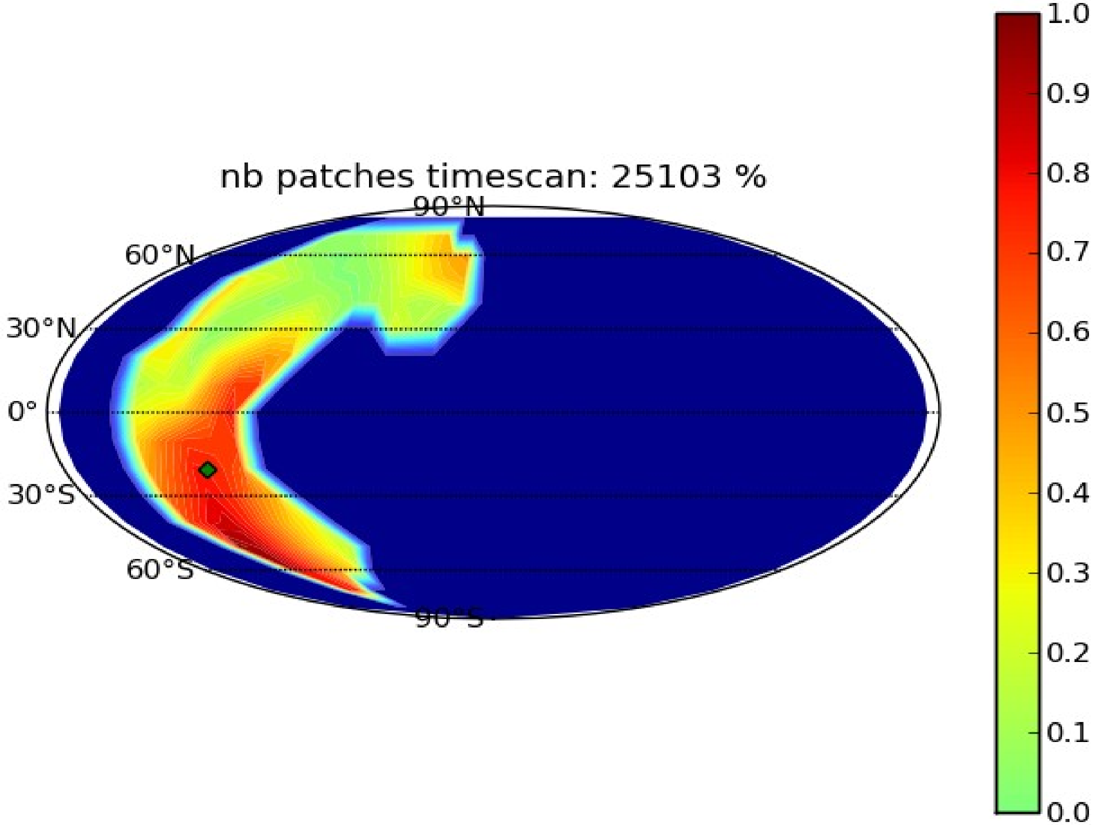
Outline

- Overview: What is the goal
- Technical details
  - Detector network
  - Observed quantities
  - Methods used
- Preliminary results
  - Tests with S6 injections
  - Results for different ET configurations
- Outlook

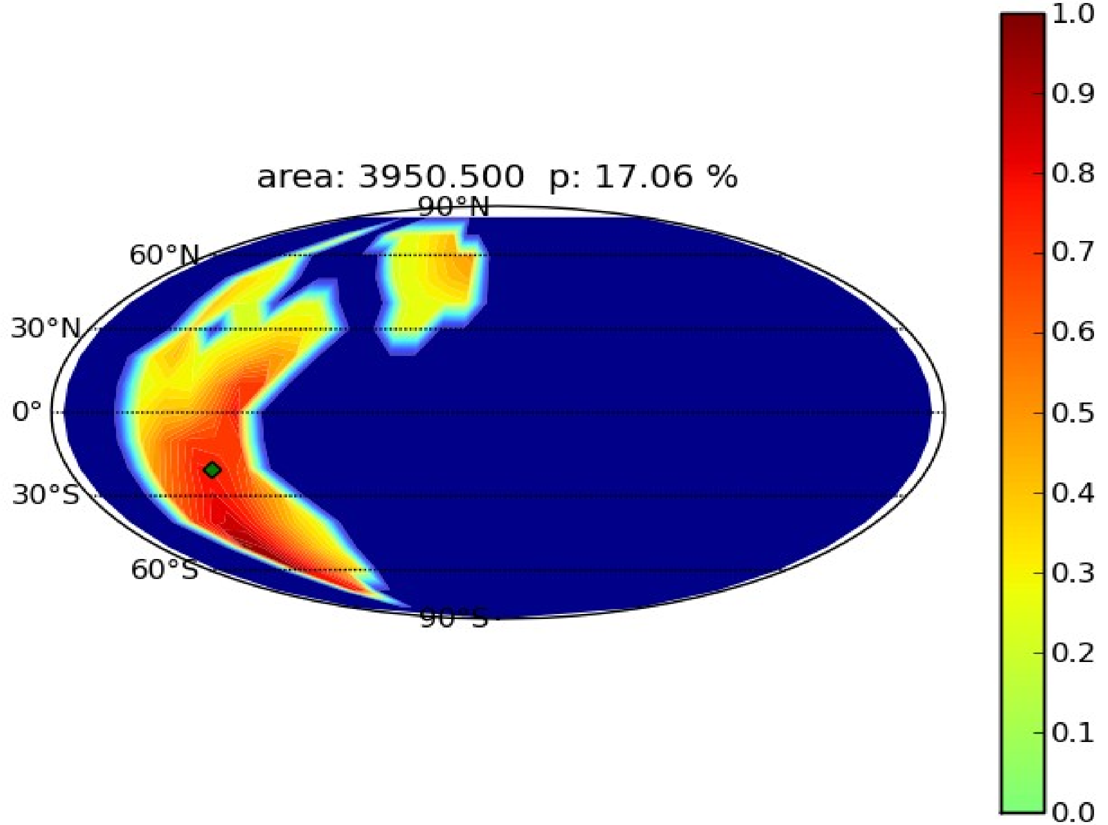
Testing the method: SW injections

- Using MBTA software injections from S6
- All data in a text file
- Using reconstructed masses and end-time
- Correcting end-time to fixed frequency

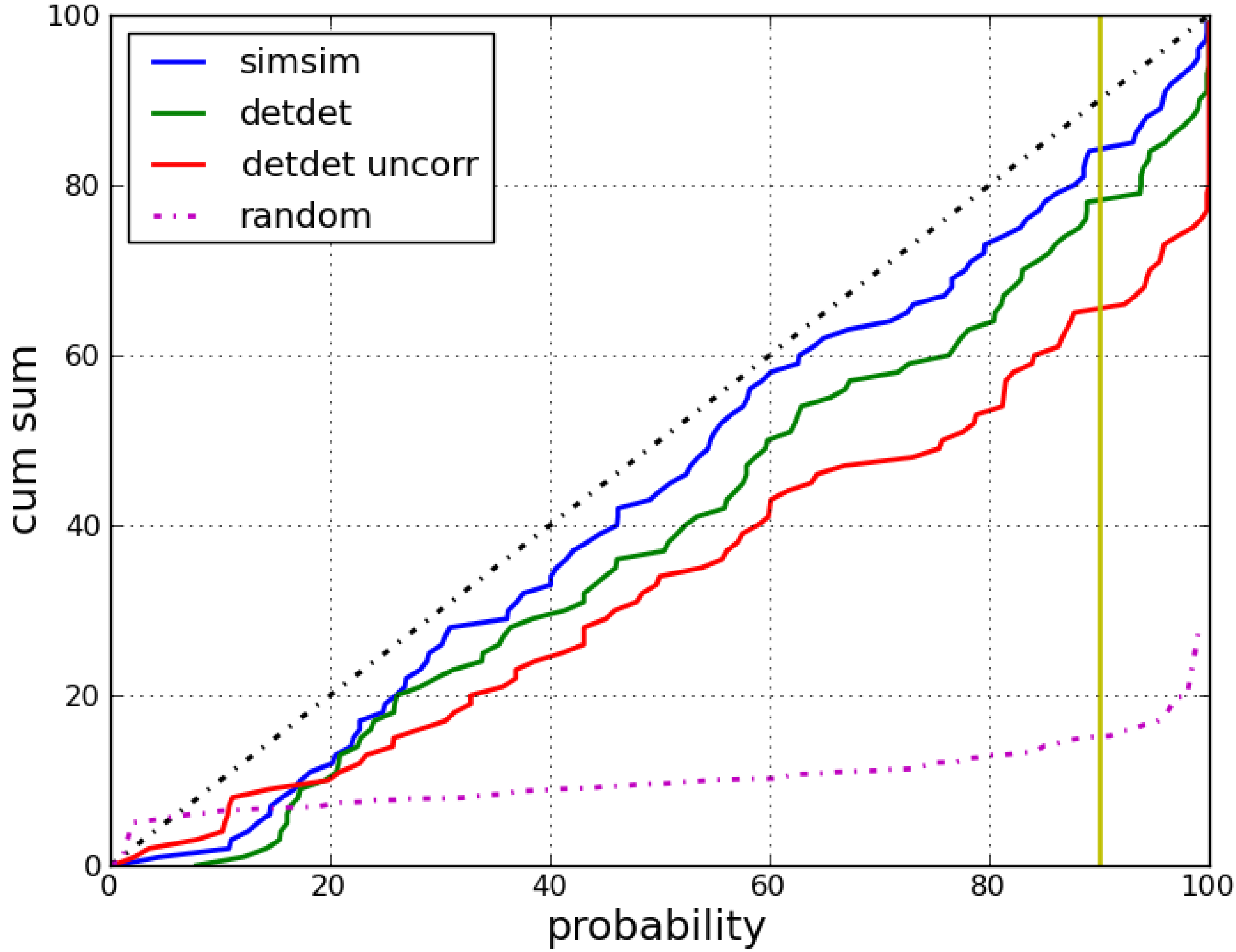
Example: Only timing



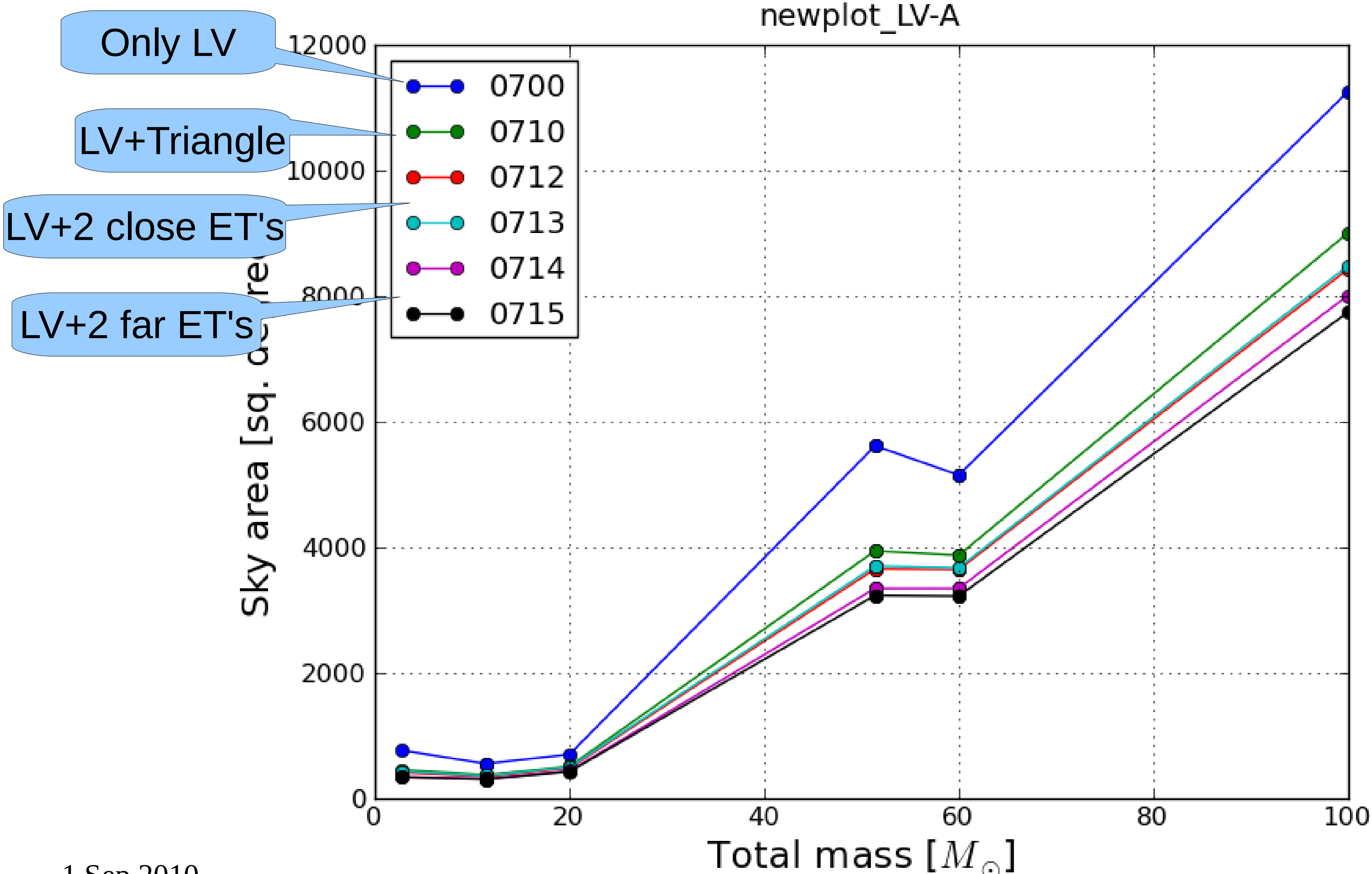
Example: Timing & Amplitude



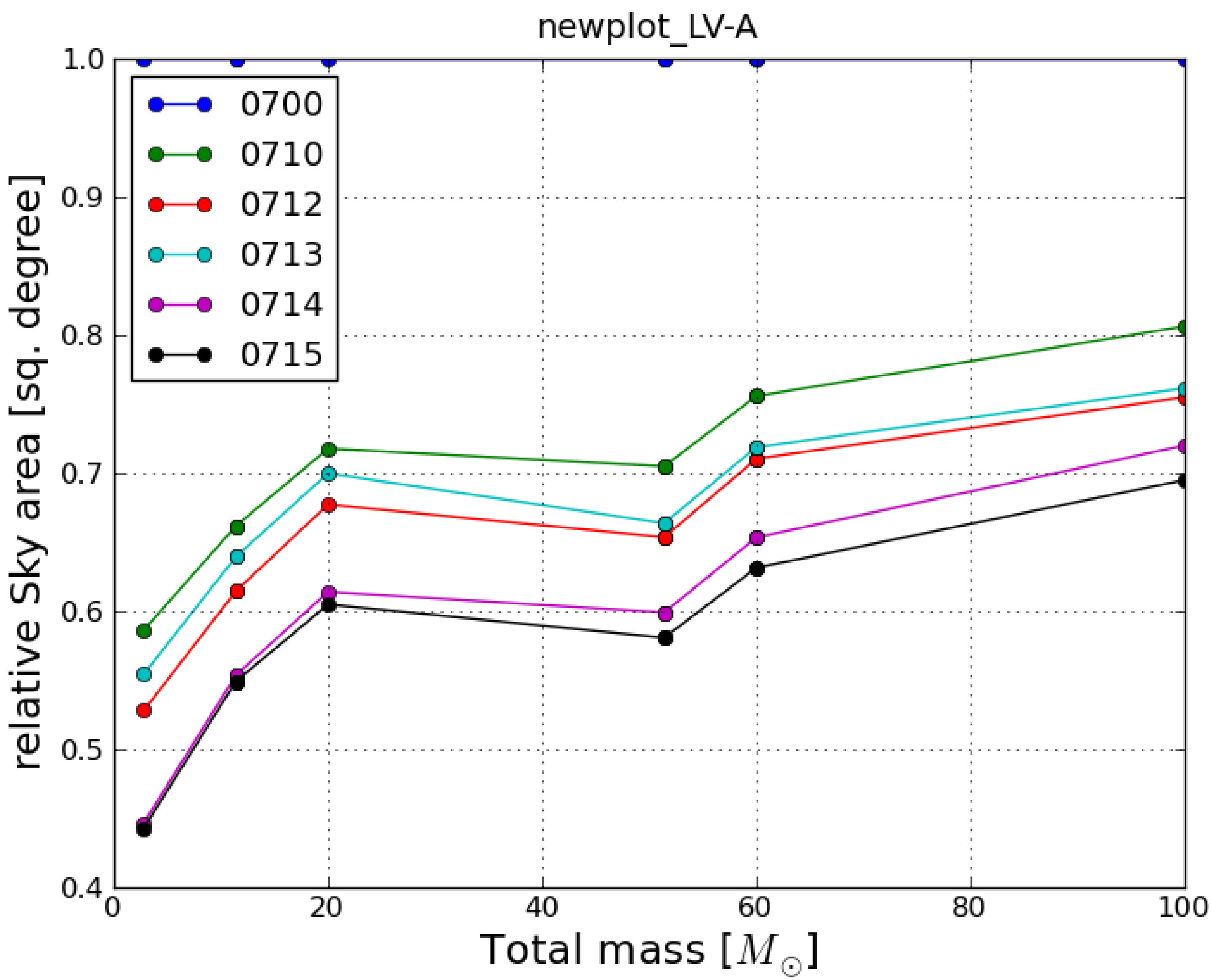
Summary of 100 trials



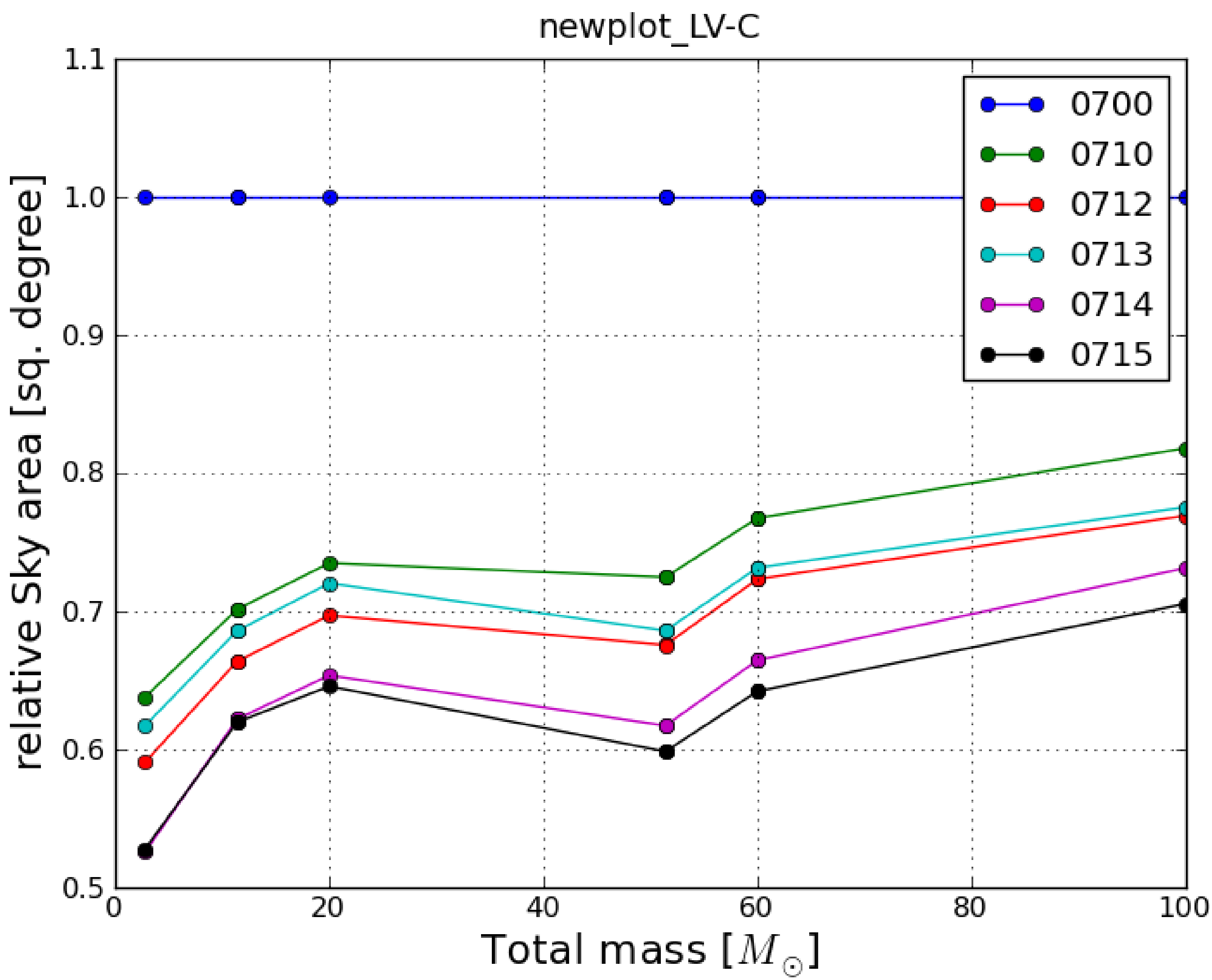
Area of LV network + ET



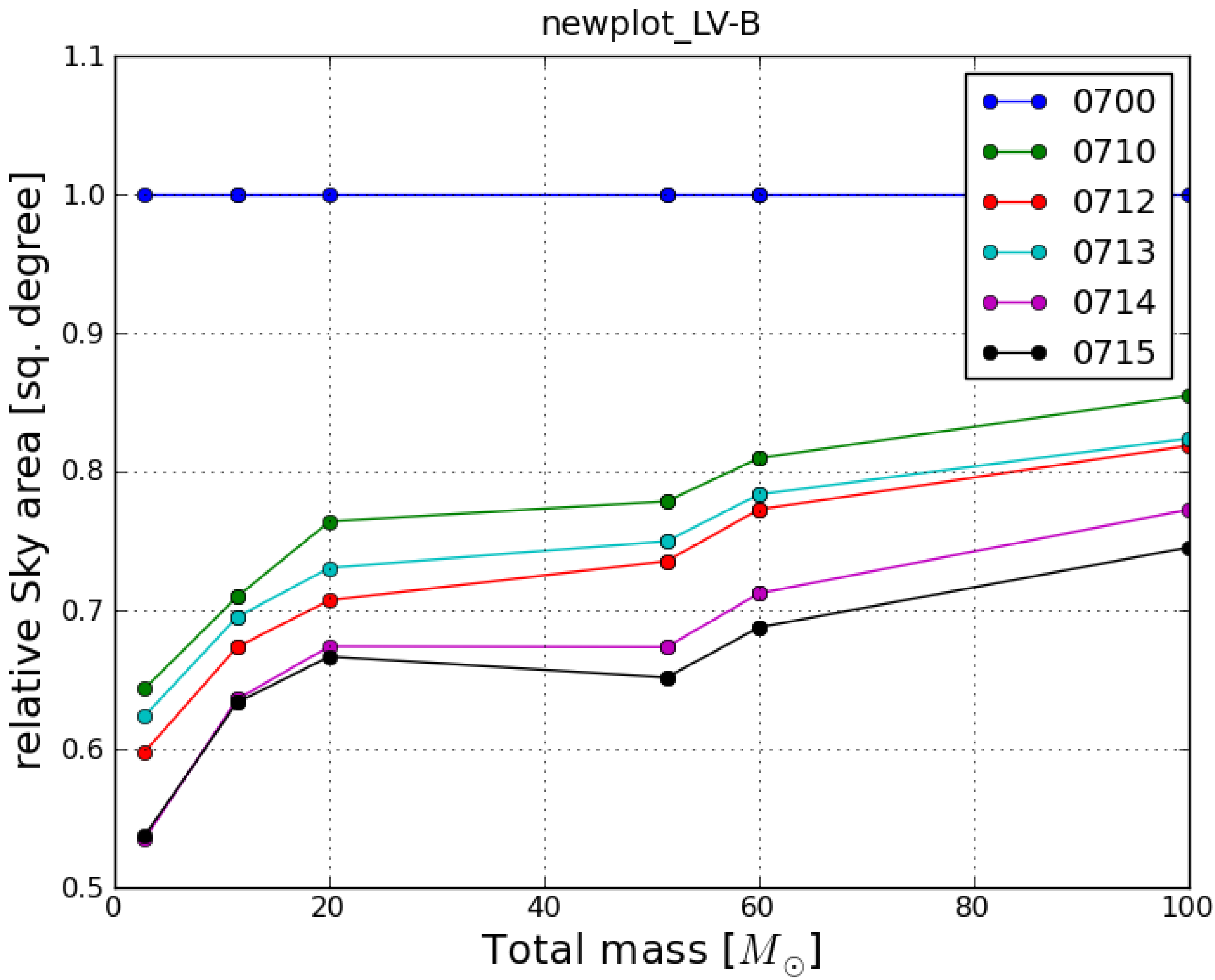
Relative area of LV + ET (advLV)



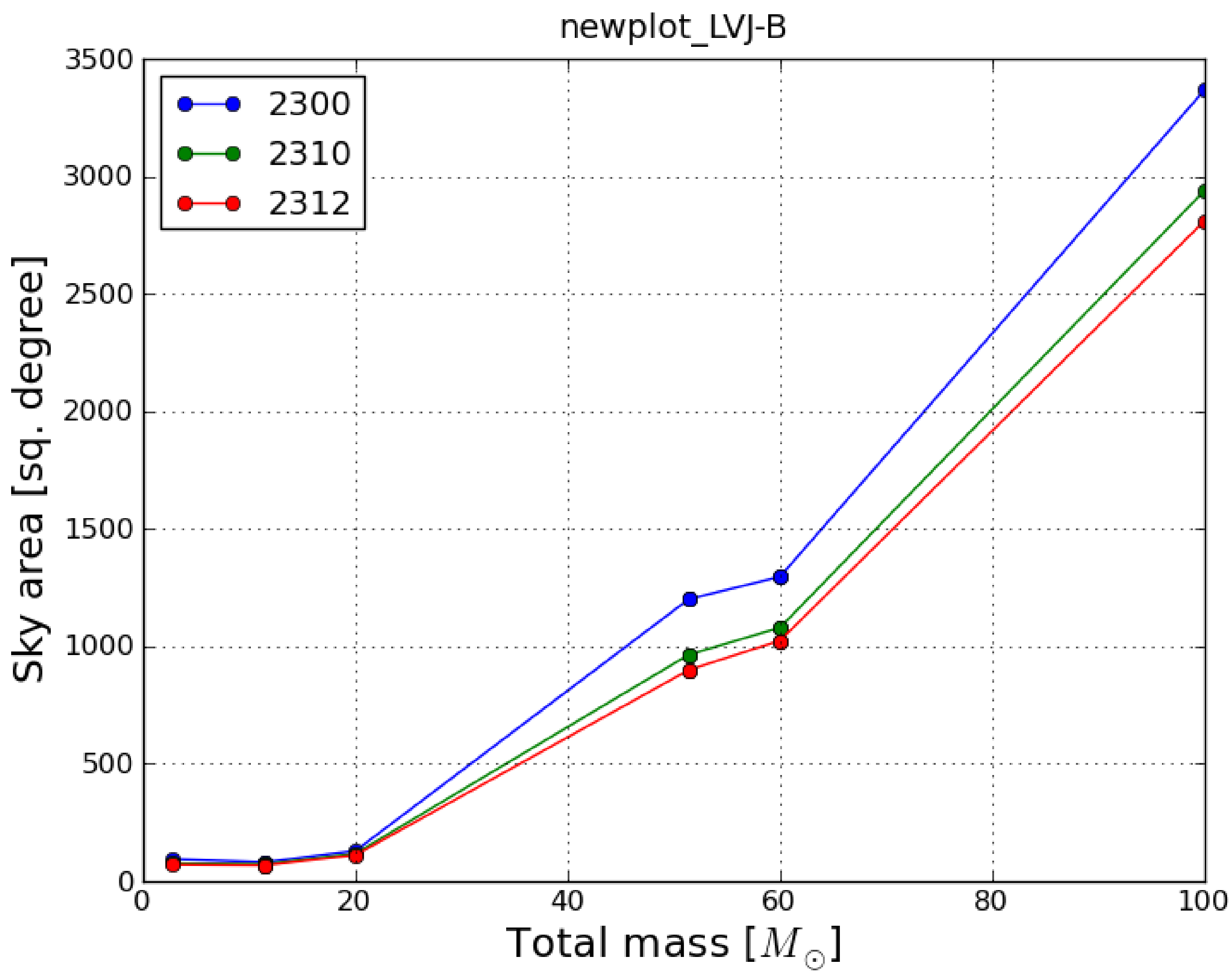
Relative area of LV + ET (advLV-X)



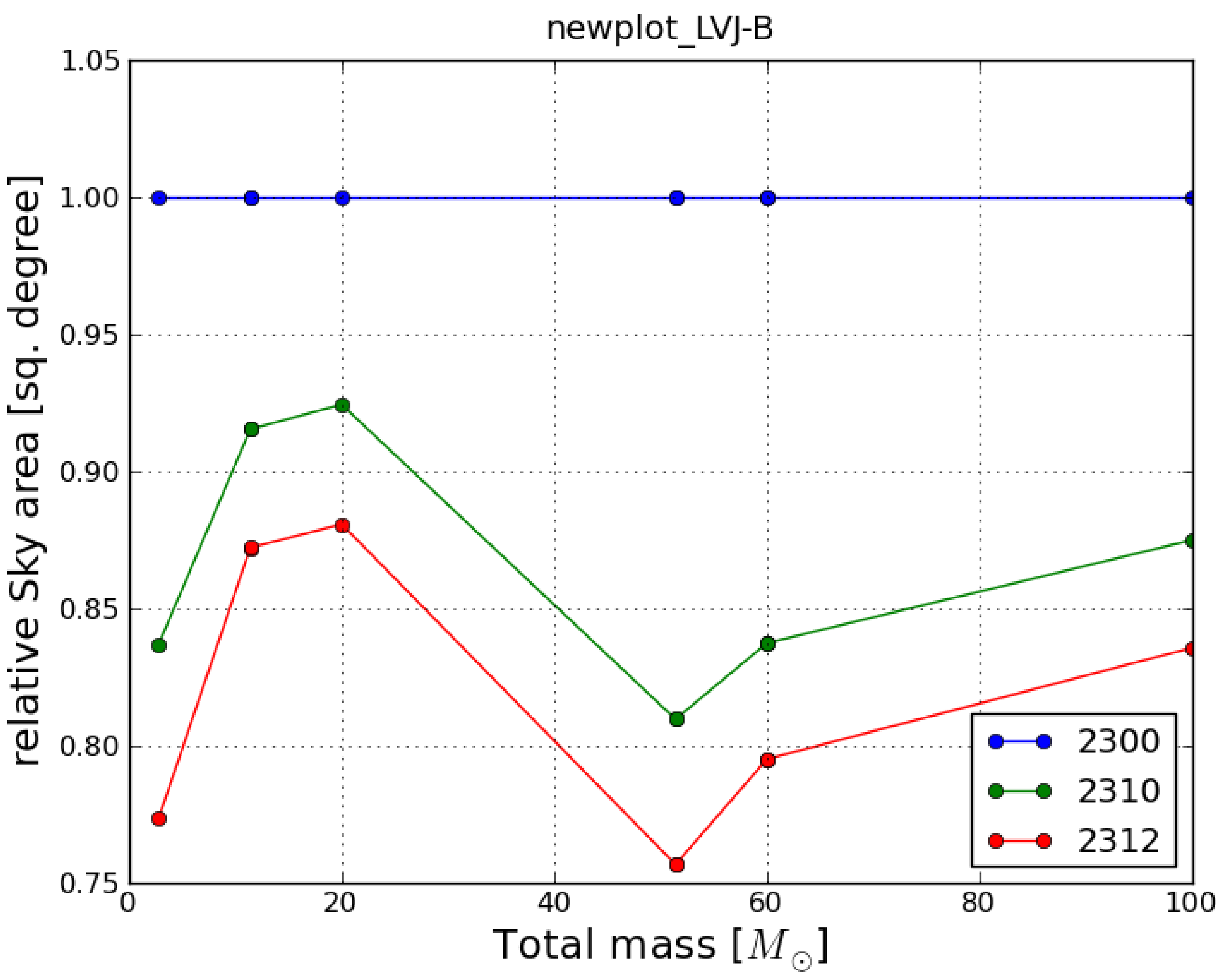
Relative area of LV + ET (advLV-3)



Relative area of LVJ + ET (advLV-X)



Relative area of LVJ + ET (advLV-X)



Conclusion

- When running (enhanced) advanced LV detectors:
  - Localization capabilities does not improve significantly (0.5-0.9 reduction of area)
  - Area reduction seems best for small masses.
  - Two L-instruments farther away slightly better than one Triangle instrument
  - Rotation of the two L's: insignificant
- Not taken into account:
  - Duty factor with ET as additional detector.
  - Observation time with 3/4 detectors.
  - Rotation of earth

Outlook

- *Verify the code and algorithms*
  - Compare with **ET-C noise curve** (i.e. Xylophone)
  - Investigate behavior for **high mass systems**
  - Include rotation of earth (A 10/10 source will be in band for 20 minutes for f=3 Hz).
  - Double check the results with MC methods