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Timing Accuracy Of The GEO 600 Data Acquisition System

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Introduction

- many **search algorithms for gravitational wave (GW) signals** require input data that was **simultaneously recorded** at multiple detector sites located all over world
  - coincidence **burst detection**
  - targeted **pulsar search**
  - correlated signals from **stochastic background**
- data streams need to be **accurately time-stamped** at their origin **(offset < 30 s**
- GEO600 **data acquisition system (DAQS)** uses **"Global Positioning System"** (GPS) as a **reference for timestamping** the data
- **checking the performance of the system involves:**
  - verifying the **GPS second labels** on the one-second data segments
  - measuring the **offset and jitter** of the first sample of each data segment

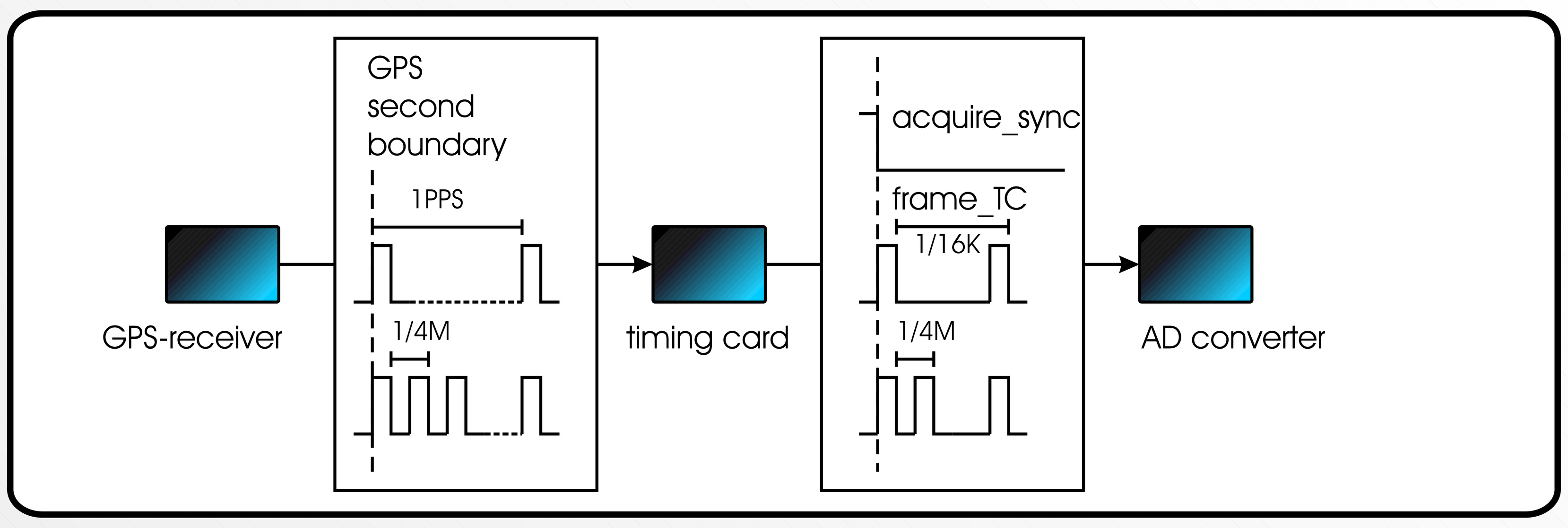

Figure 1: GEO600 Data Acquisition And Timing System

Measurements

Gross Timing Accuracy

Checking that the **GPS second labels** are not wrong by an integer number of seconds can be done by **disconnecting a signal** in the middle of a second. The disconnection time is inside the segment marked by the red line (figure 2). Looking at the data stream from the DAQS shows that the signal **disappears in the expected** one second data **segment.** This cofirms that the labels on the data are correct.

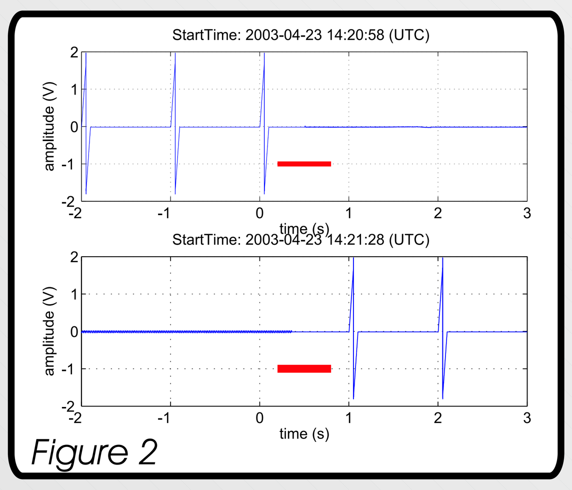

Figure 2

High Precision Measurement Of The Jitter And Offset

Measuring the **time offset and jitter** of the first sample of each data chunk to a **sub- s precision** is done by **recording a ramp signal** from a HP33120A signal generator that is triggered by a GPS/Rb unit used as reference (figure 3).
By **fitting a line** to the recorded data of the ramp and **calculating the zero-crossing** (figure 4) it is possible to determine the start of the ramp to a precision much higher than the resolution of the sample time (61 s).

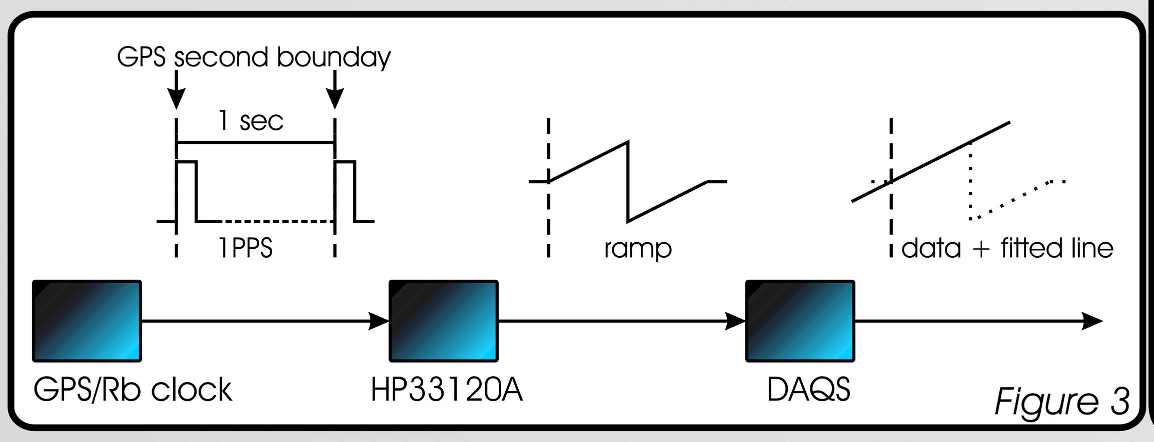

Figure 3

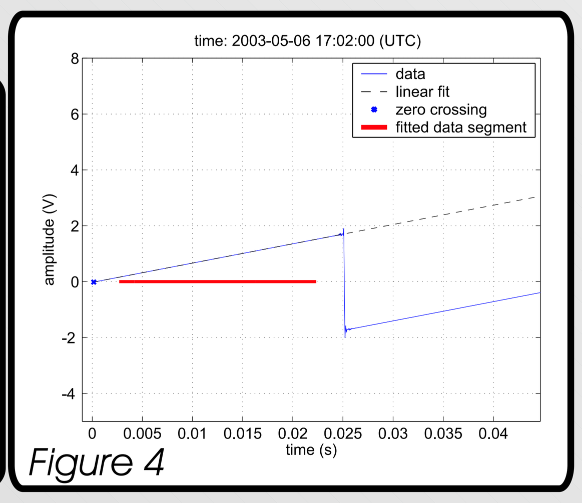

Figure 4

Analysing The Data

The **offset of the ramp signal** with respect to the first sample measured each second over a 24h time stretch can be seen in figure 5. The **histogram of the offsets** (figure 6) shows that the distribution agrees with a **Gaussian distribution**.

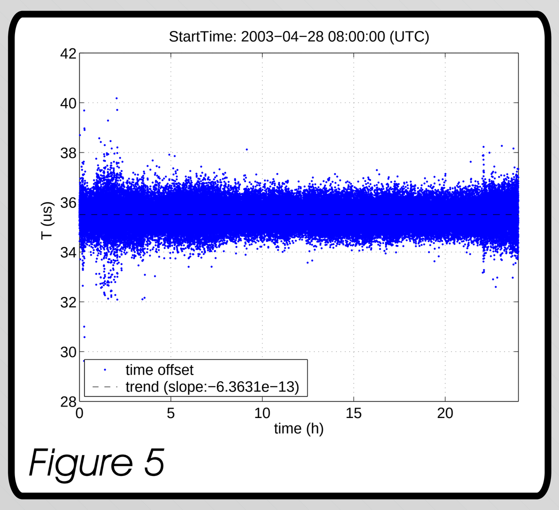

Figure 5

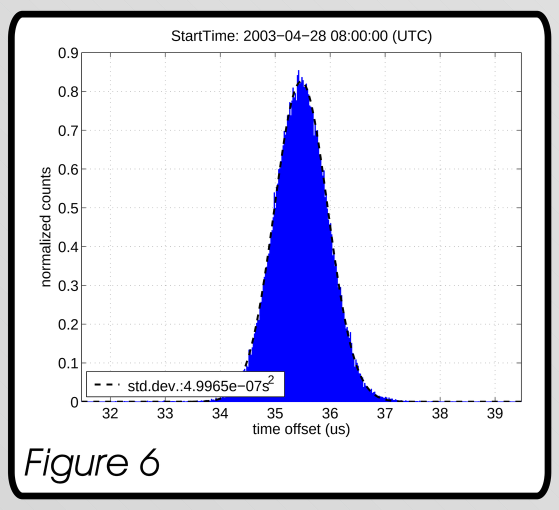

Figure 6

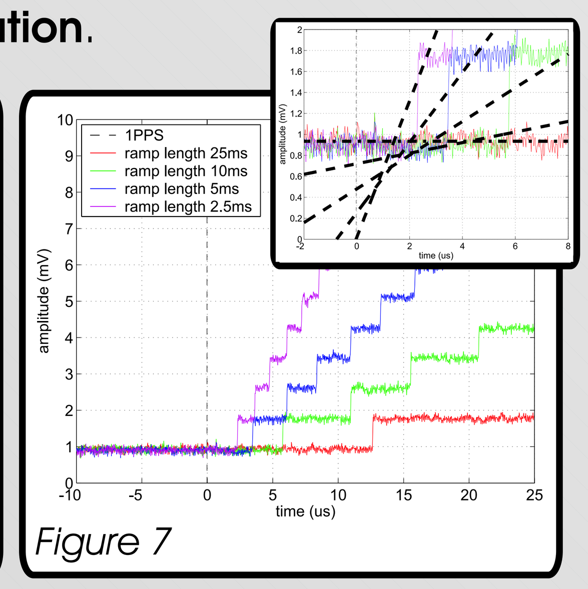

Figure 7

The measurement process of the timing offset and its variance introduces a **systematic error** that is **proportional to the length of the ramp signal** used for fitting:

- The start of the ramp signal from the generator lags behind the trigger signal by an amount that is proportional to the ramp length (figure 7).
- An error in determining the slope of the ramp leads to an error in the zero crossing estimation: A shorter (steeper) ramp signal gives a more accurate estimation.

Results

The measurement is repeated for several ramp lengths and the results for the offset and the jitter are **extrapolated** to the value for an **infinitely short ramp**. This minimizes the influence of the analysis method on the result.

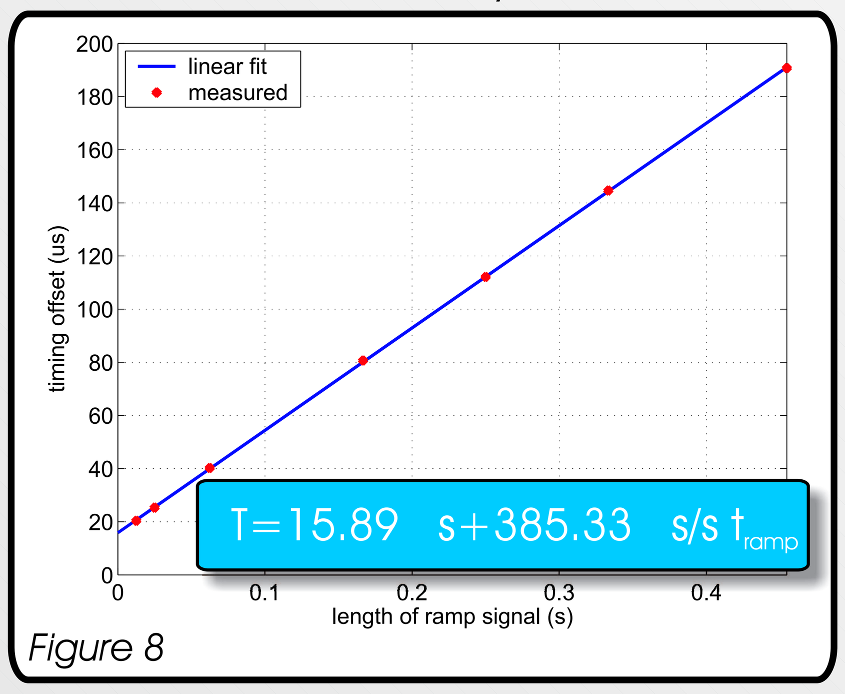

Figure 8

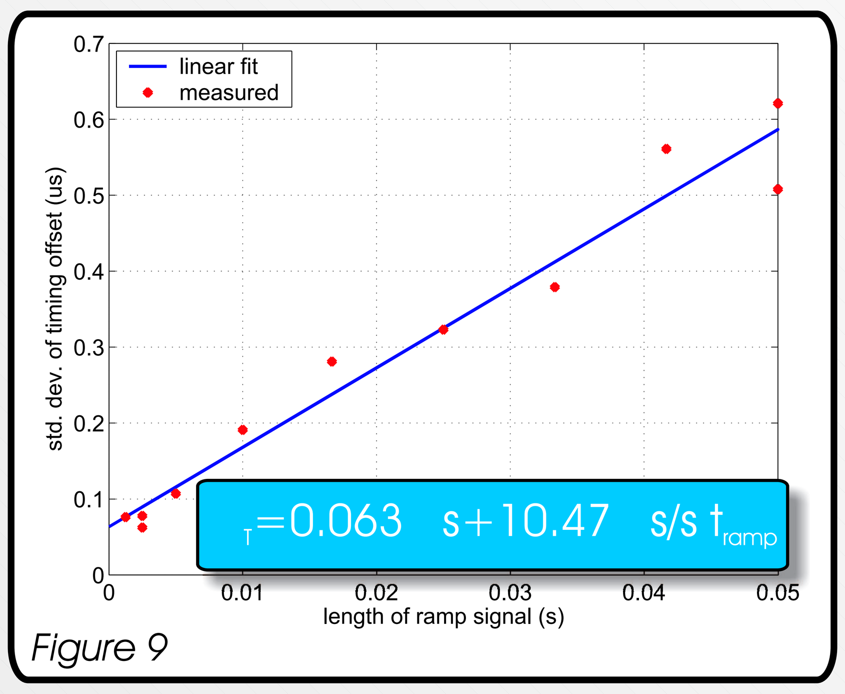

Figure 9

The measured **timing offset is 15.89 s**. This value is lower than half the sample time of 61 s, so the offset cannot be made smaller by shifting the data an integer number of samples.
The timing offsets have a **standard deviation of 63ns**.

Problems Found

The analysis revealed two problems with the time-stamping that are related to rebooting the DAQS units.

- After power cycling the DAQS unit the internal oscillator of the **GPS receiver card** needs to **reacquire the phase lock** to the GPS signal. It takes about 10 minutes before the card gives a reliable timing signal (figure 10).
- Figure 11 shows the timing offset after several software reboots and hardware reboots (power cycles) of the DAQS unit. It can be seen that after a **software reboot** the **gate delay of the AD converter (37 samples) is not removed** from the data. This causes the data to be offset by about 2.2ms. The problem was addressed by modifying the DAQS software.
- Analysis of the recorded calibration signal showed that **37 minutes of data** recorded **during S1 were affected** by the problem with the gate delay (figure 12). These stretches were then excluded from data analysis.

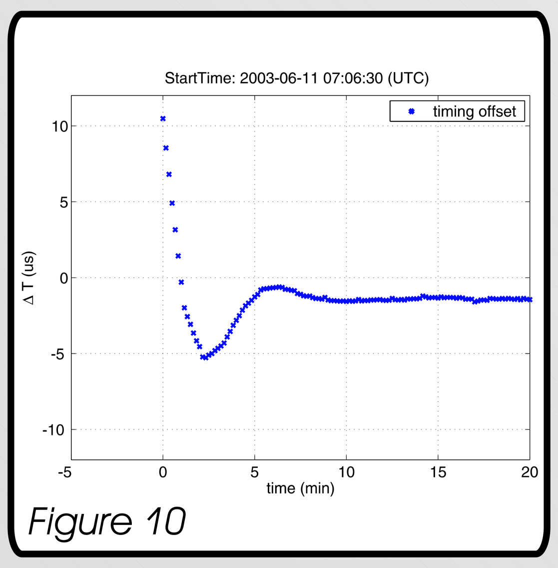

Figure 10

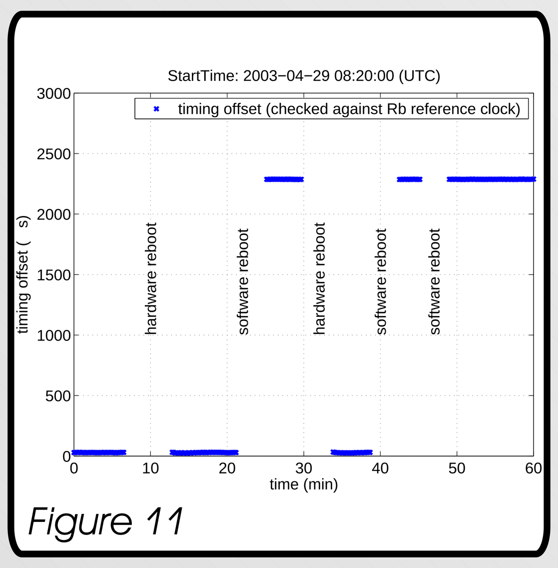

Figure 11

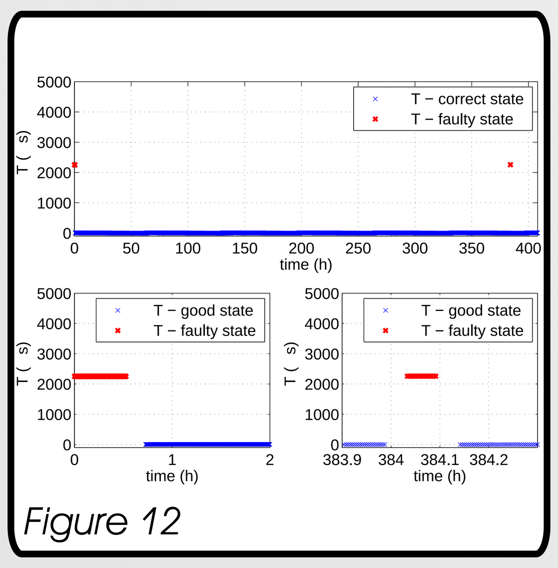

Figure 12

Estimating The Direction Of Arrival Of A GW Signal

Using a **worldwide network of GW detectors** it is possible to **estimate the direction of arrival (DOA)** of a signal: When the signal is seen by more than three detectors the DOA of the signal can be **determined from the time of arrival** (TOA) of the signal at each individual detector.
The plots on the right side show the **error of the DOA estimation** that arises from a **jitter in the timestamping** of the data at each individual detector site. It was assumed that the timing jitter on each data stream has a standard deviation of 63ns. This is the value measured for the DAQS of the GEO600 detector (see above).The plots were generated using a **Monte-Carlo simulation** running 3200 iterations for each data point.
Figure 13 shows the error in estimating the direction to the source as a function the DOA for the **detector network GEO600, LIGO (LHO and LLO) and TAMA**. Since all these detectors lie approximately in a plane parallel to the equatorial plane of the earth a strong dependance of the error on the DOA can be seen.
Figure 14 shows the DOA error after **VIRGO and ACIGA** are added to the network.

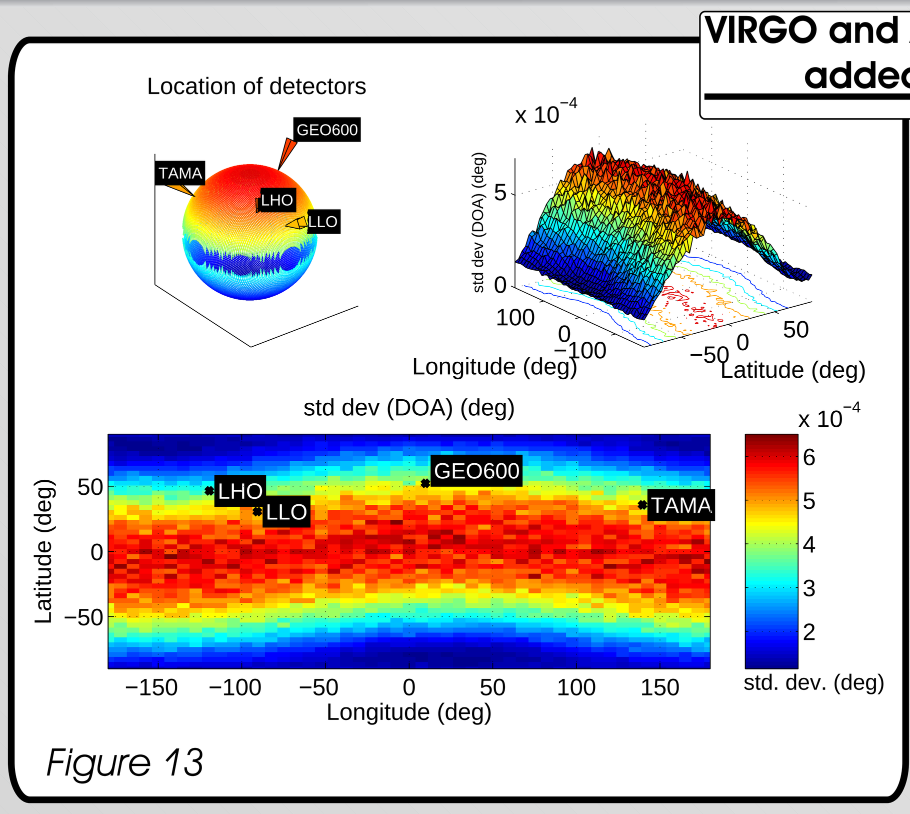

Figure 13

VIRGO and ACIGA added

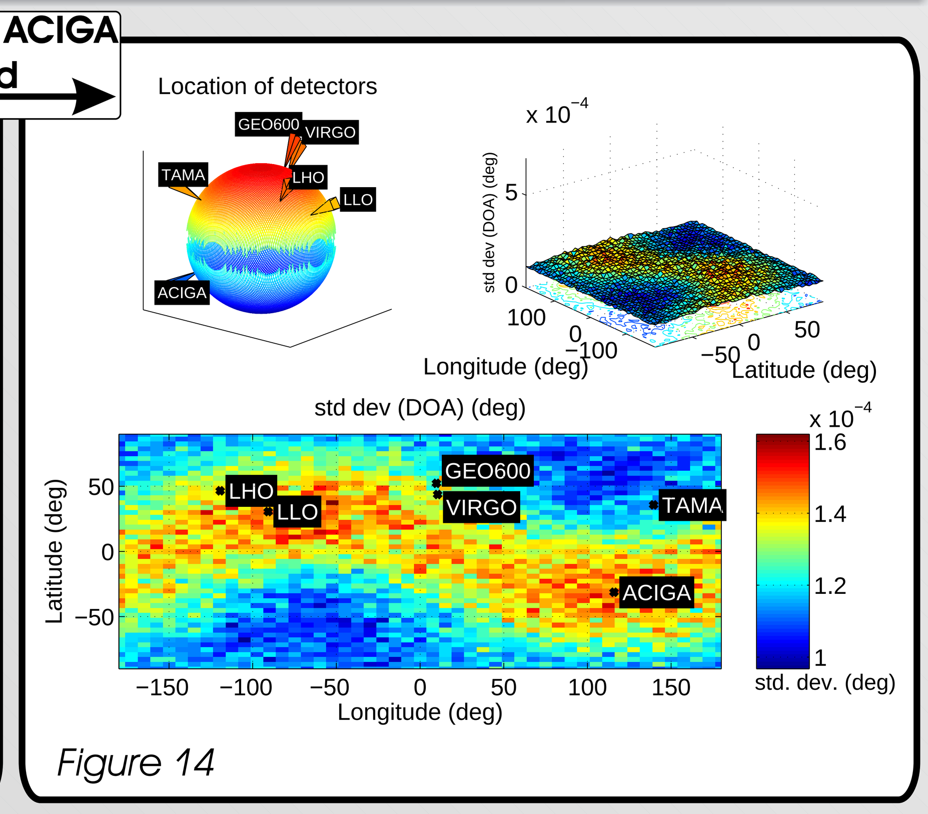

Figure 14

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GEO600 http://www.geo600.uni-hannover.de