SII software school: Lesson 2

analysis

T. Hassan on behalf of
the magic_spysii dev team

European Research Council
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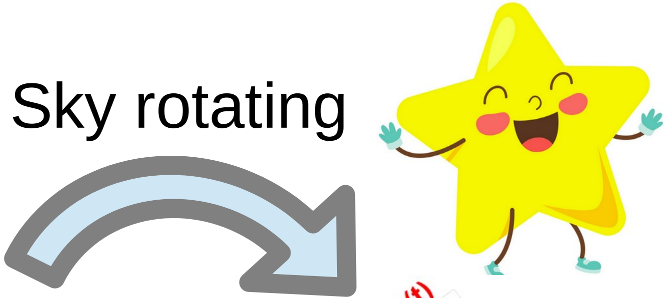
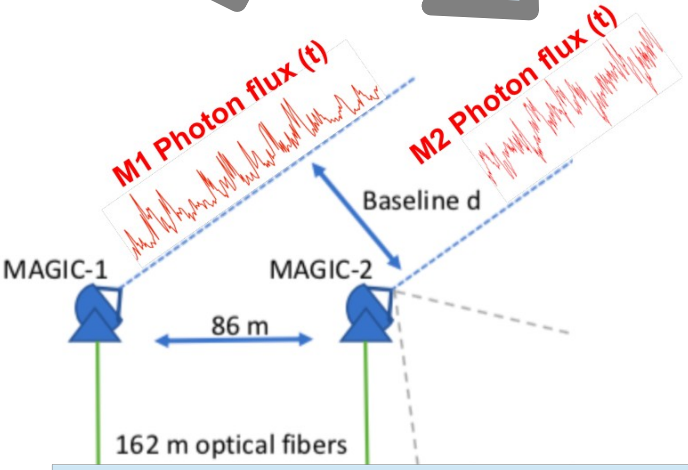
Ciemat
Centro de Investigaciones
Energéticas, Medioambientales
y Tecnológicas

From last week: Correlation signals

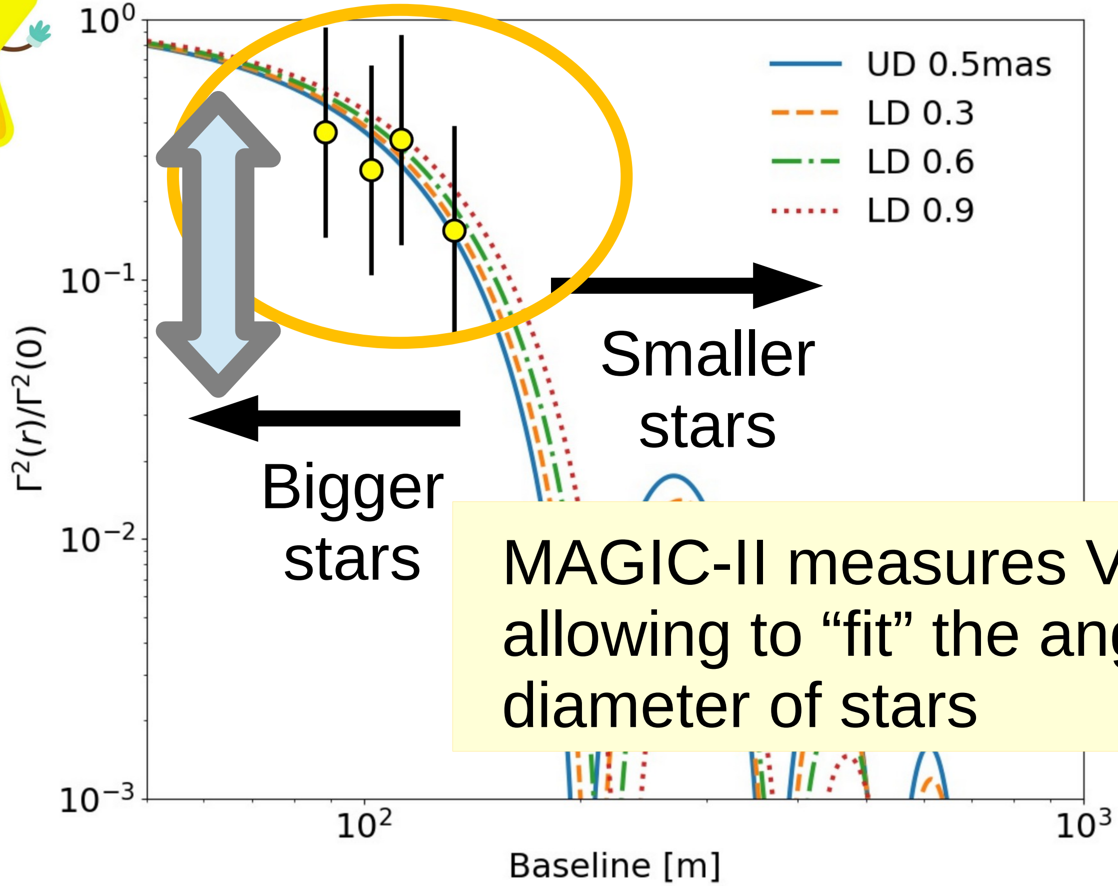
Sky rotating





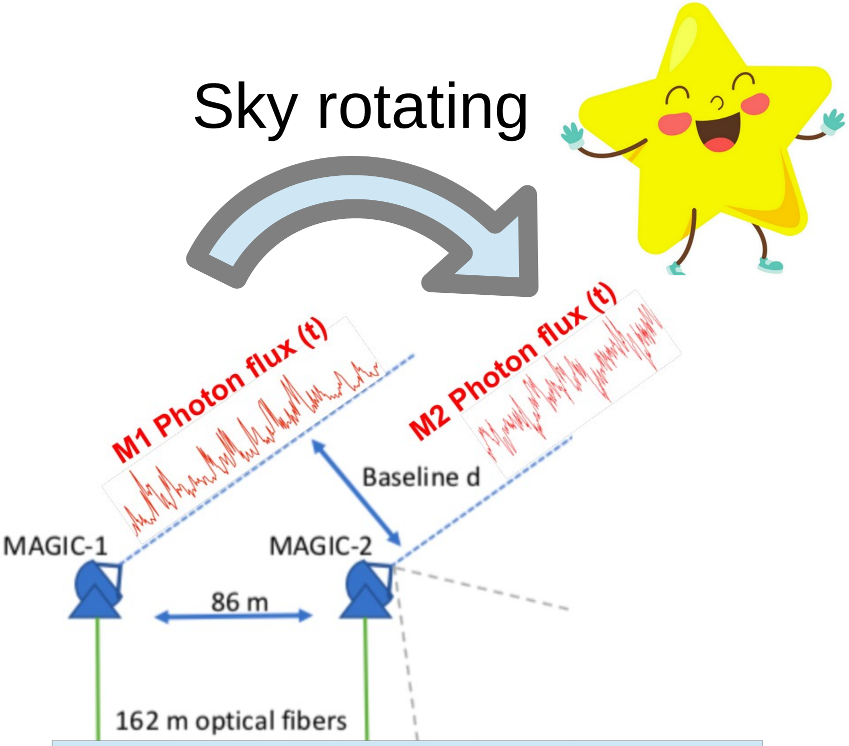
MAGIC-II correlator (digitizers + GPUs)

MAGIC-II observations

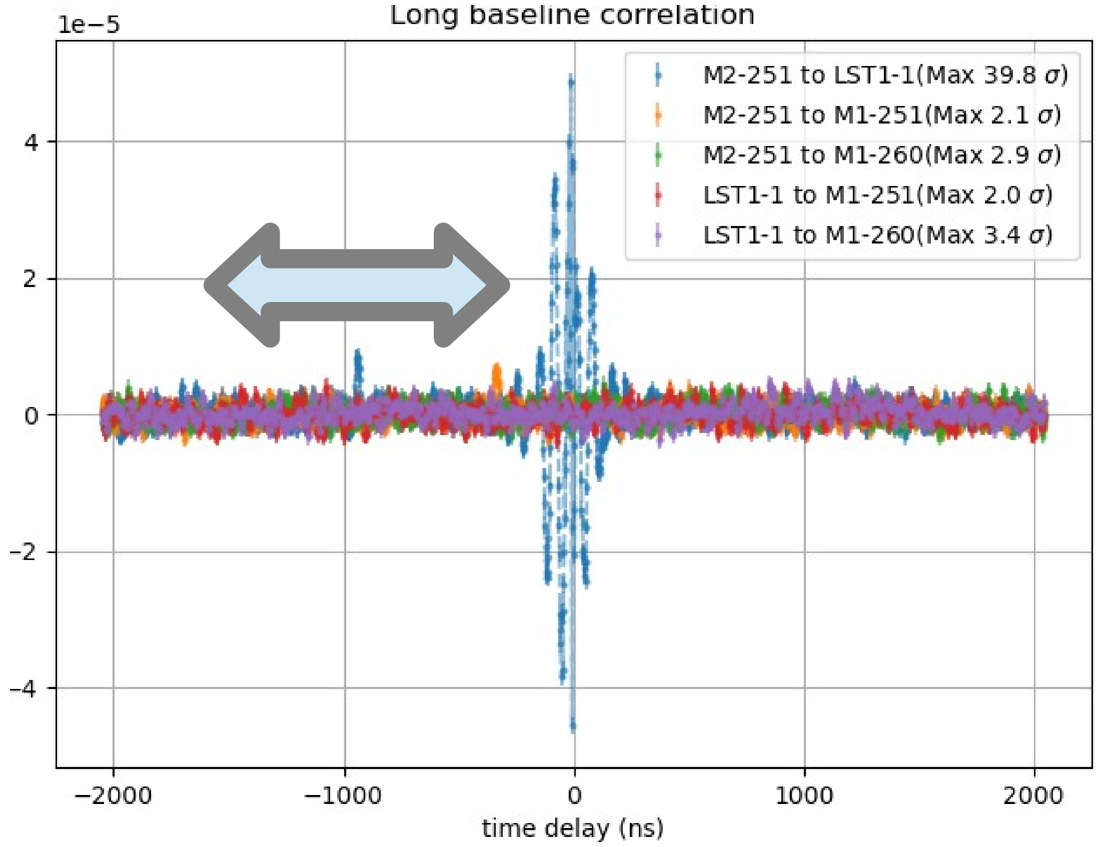


MAGIC-II measures V², allowing to “fit” the angular diameter of stars

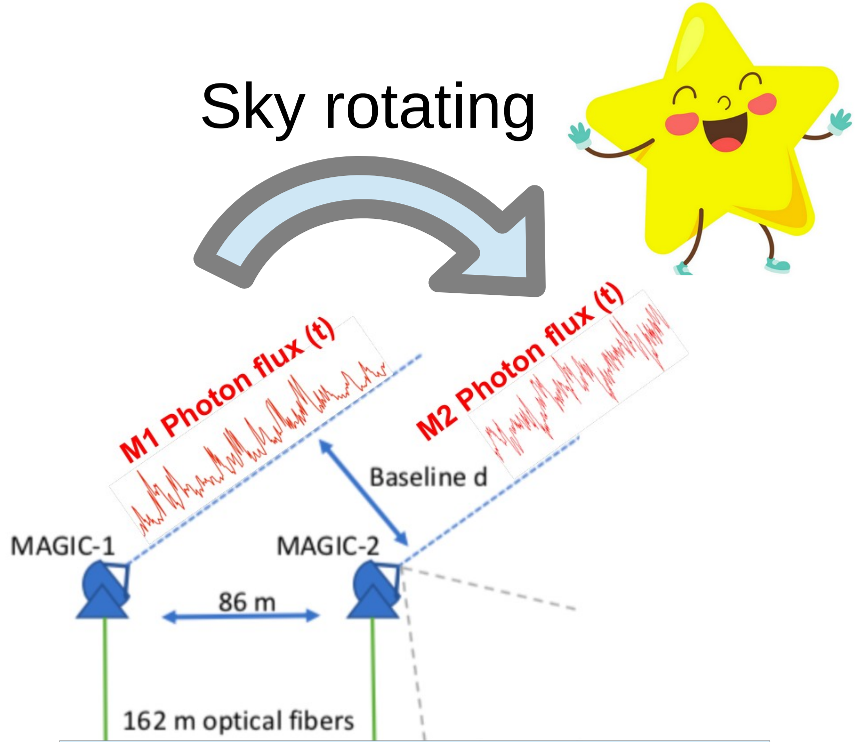
From last week: Correlation signals

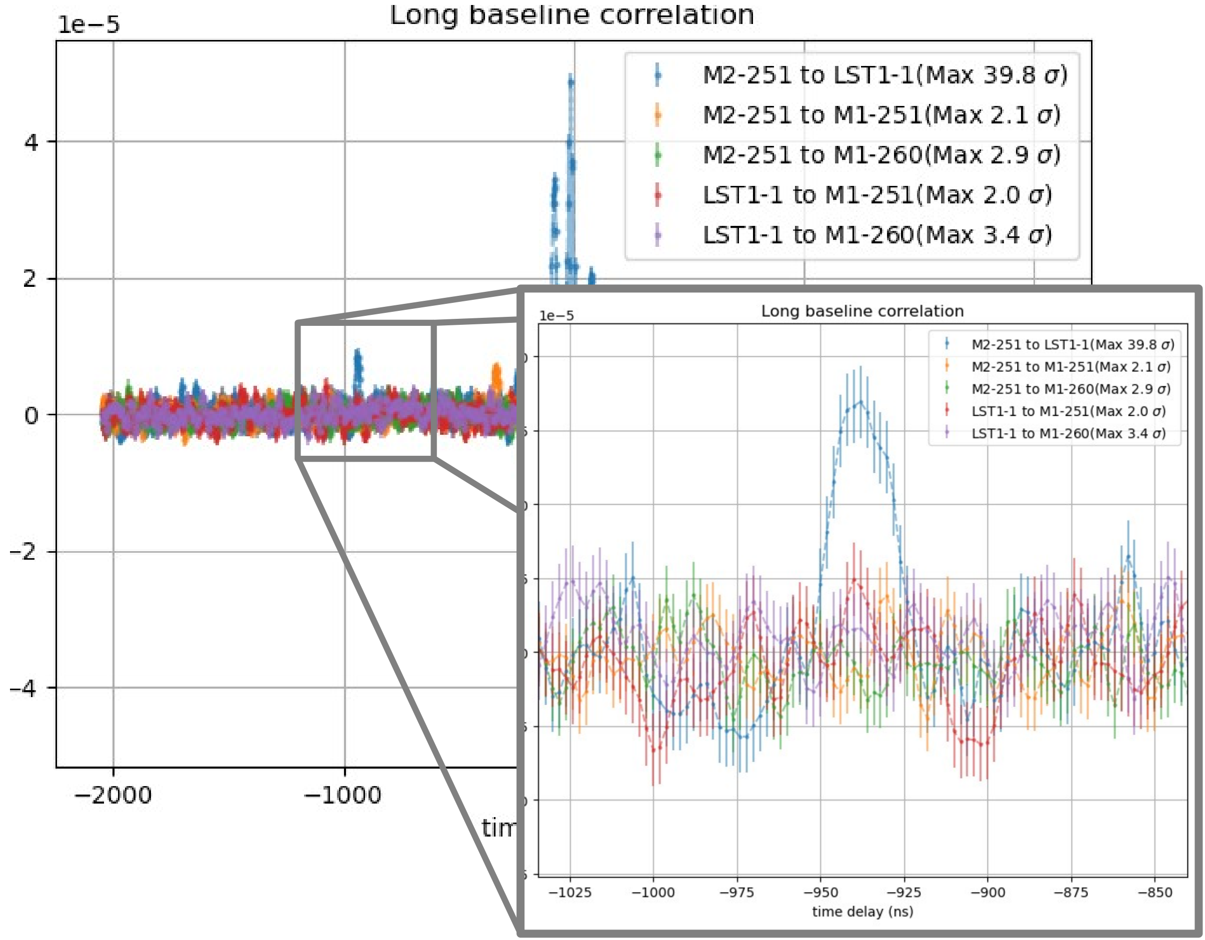


MAGIC-II correlator
(digitizers + GPUs)



From last week: Correlation signals





MAGIC-II correlator
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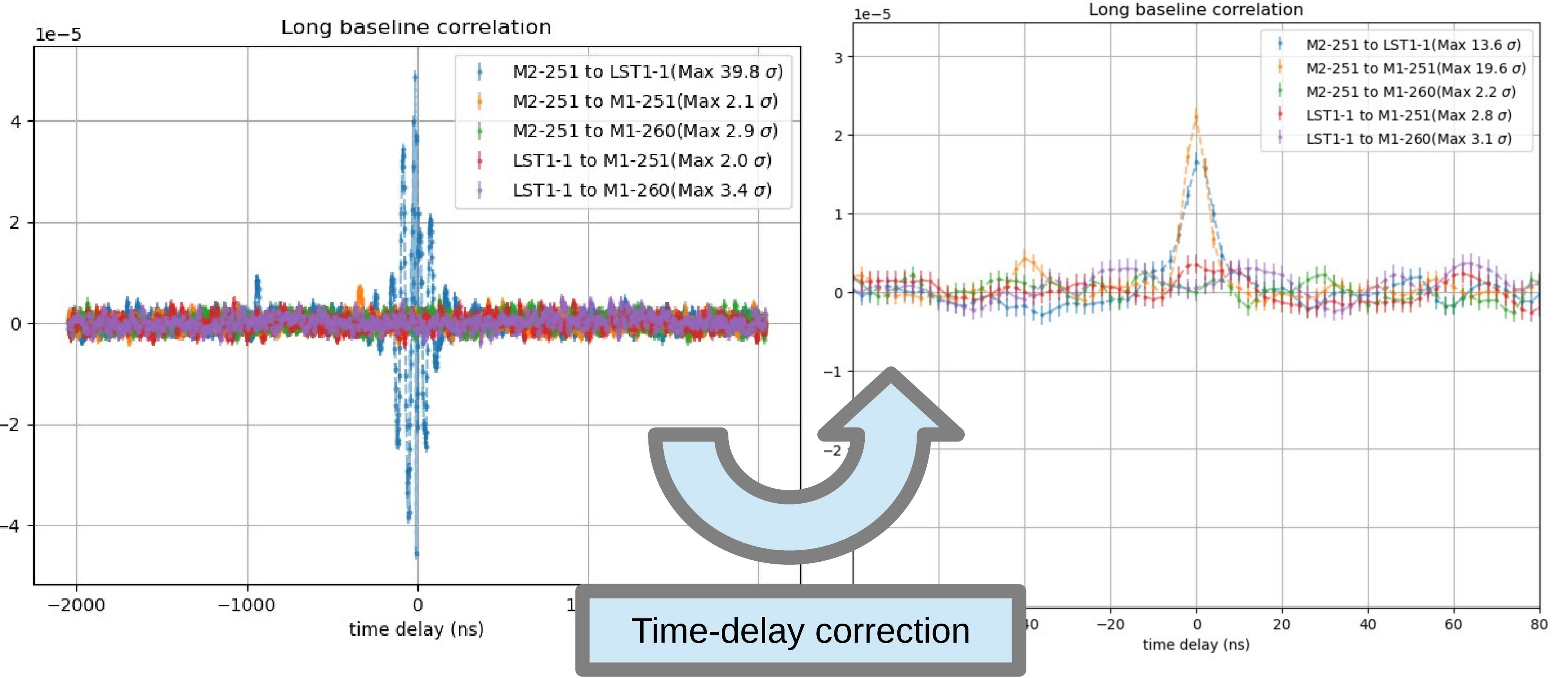
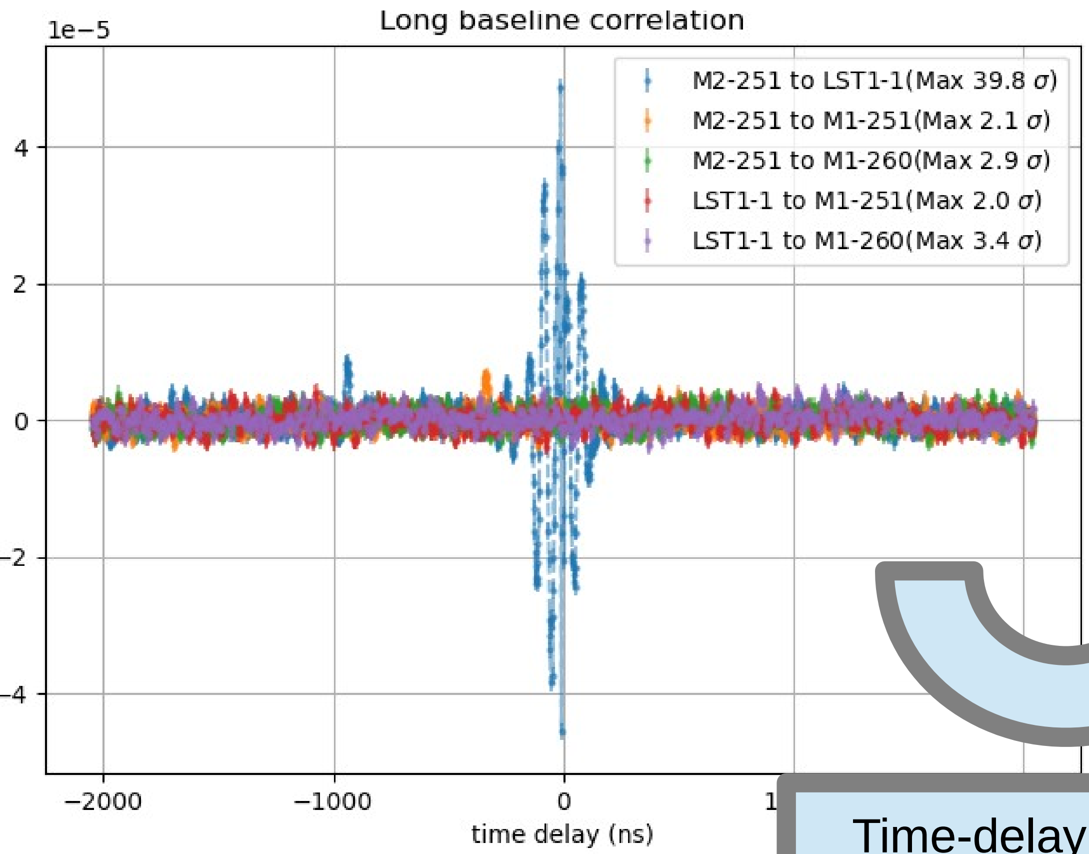
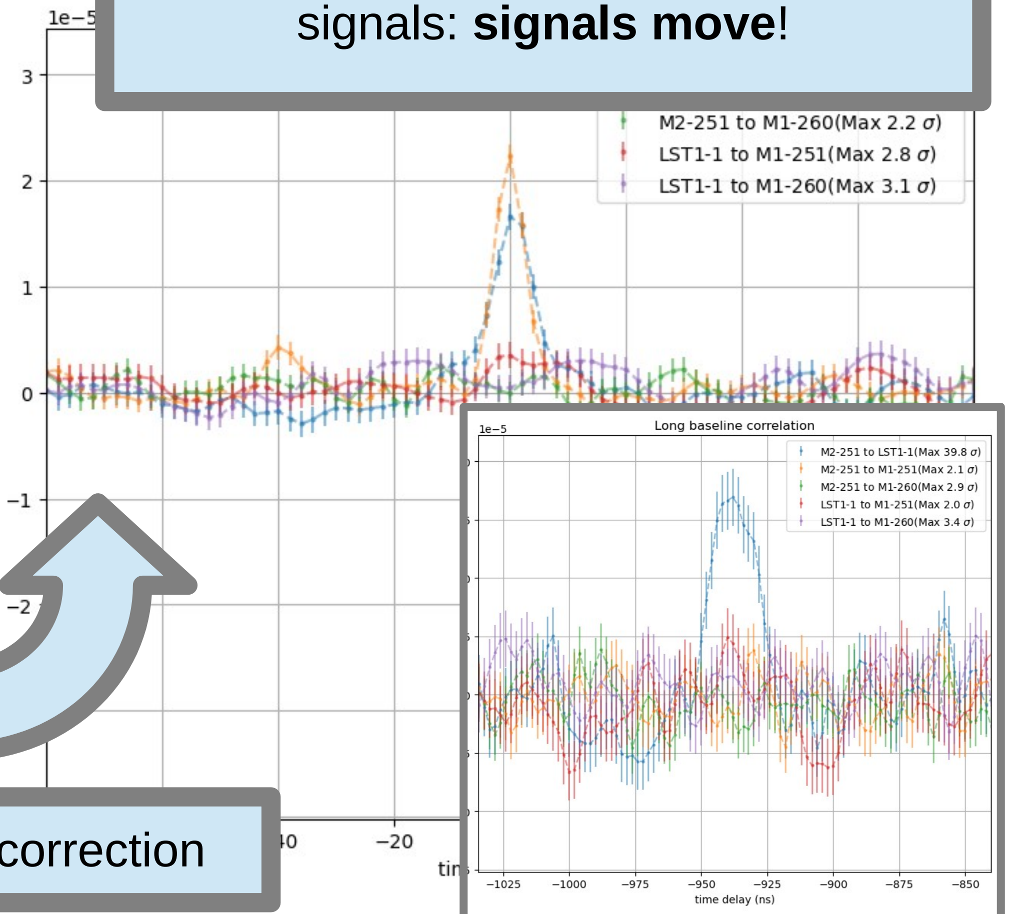


From last week: Correlation signals



Note the different **width** of both signals: **signals move**!



Time-delay correction

IACT-SII: Lesson I wrap up

- Binary files contain signal statistics plus correlation arrays (over a broad delay range)

- Following *magic_spysii* documentation you should now be able to:

  - **Download/synchronize raw data** and camera reports into your $MAGICSIIDATA folder
  - Plot the content of individual or multiple “averaged” runs, and see clear correlation signals
  - Draw the DCs and Hvs of any synced night
  - Tinker with binary data, understand how it is stored and what kinds of binary data exist

IACT-SII: Lesson II

- Points to be covered in lesson II:
  - Understand magic_spysiii analysis data flow:
    - Analysis stages
    - Data products produced
  - Run your first analysis!
    - This will create run-wise run reports, as well as your first stellar-diameter measurements!

IACT-SII: Lesson II

- Points to be covered in lesson II:

magic_spysii documentation   Installation | User Guide | Tutorials | API reference   Search Ctrl + K   Choose version

User Guide > SII data flow

Section Navigation

- Sync and reduce data
- Check raw data
- **SII data flow**
- Running an analysis
- Calibration analysis
- Source analysis

On this page

- Single run reduction
- Analysis data flow
- Combined analysis

Show Source

SII data flow

At this point, the user should be able to sync and reduce interferometry data from their favourite target into their $MAGICSIIDATA folder. This section describes the flow of data, with an overall description of each stage of an interferometry analysis.

Single run reduction

As briefly introduced in the previous section, each raw binary run is reduced via the *reduce_binaries* (current data with *reduce_binaries_6C*) script. Each .bin file will generate several .pkl files, depending on the amount of valid correlations found in the data. Some examples:

1) A .bin file contains MAGIC-only data using a full-mirror configuration (all starlight focussed into a single pixel, e.g. pixel 251), the only valid cross-correlation from the 6 computed will be the correlation between M1-251 -> M2-251. Therefore 4 auto-correlations and 1 cross-correlation will be stored as .pkl files.

IACT-SII: First, let’s learn the language

- Channel: Digitized signal in the DAQ. We currently have 4 chanels (2 entries per card) and the pixels connected to those channels change with time

- Correlation pair/channel: specific pair of pixels used for a correlation (e.g. M1-251 → M2-251, M1-260 → M2-260 or M1-251 → LST1-1)

- Frame: Each correlation array the DAQ stores. In 2021, each frame integrated ~0.5 ms, while now each frame integrates 0.25 s

- Zero-baseline correlation (ZBC): maximum correlation measured by the system. Should be a constant of the system. As our visibility is calibrated with DCs, our ZBC has units (1/uA), and therefore is subject to PMT degradation (gain slowly changes with time for a fixed HV).

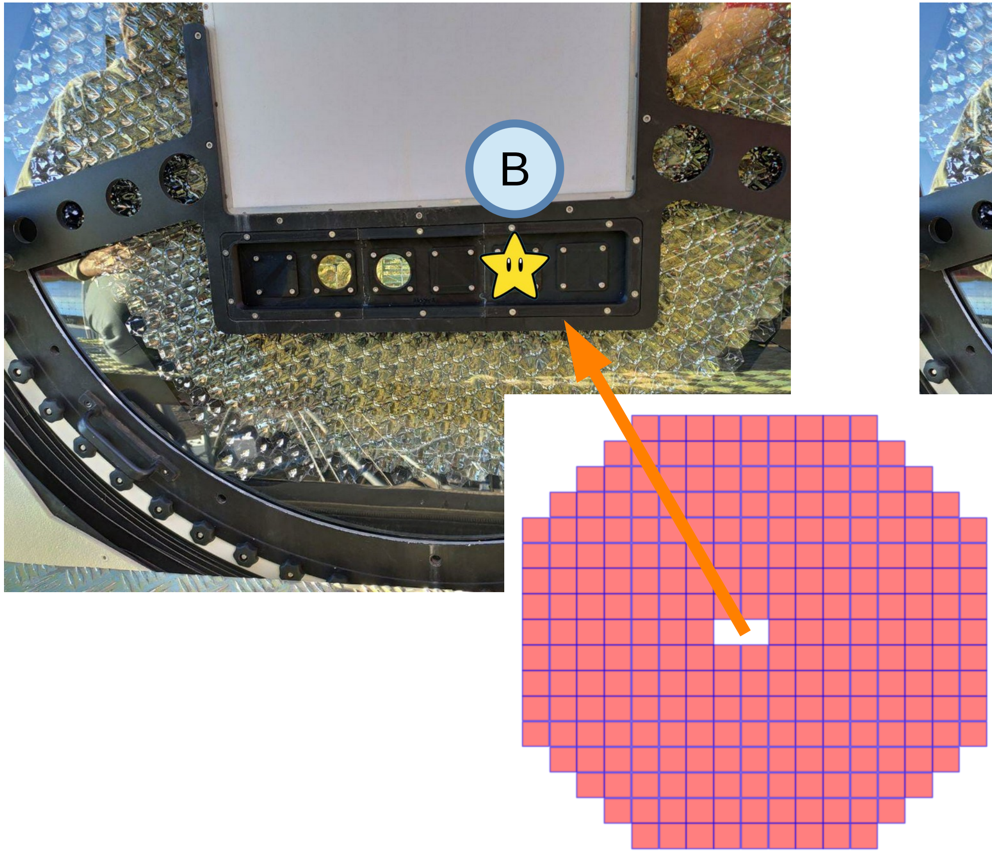
Interferometry data flow: reduce_binaries

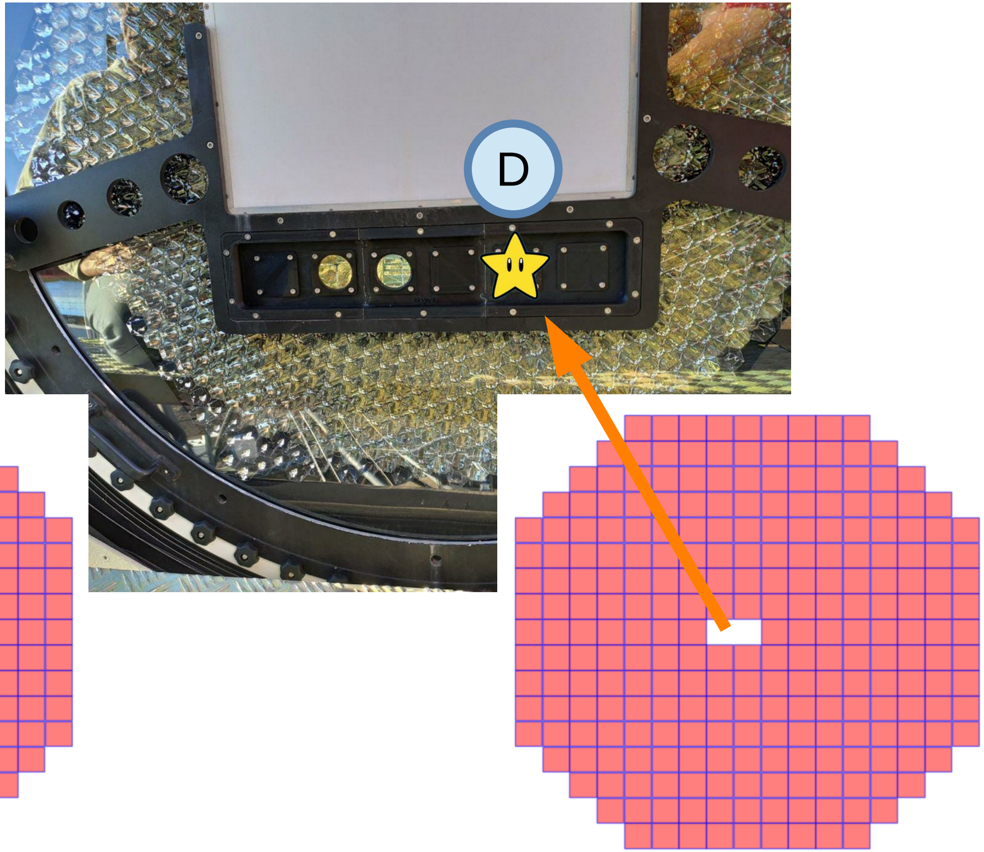
- As you saw, during the sync stage one can directly compute the "reduce_binaries" script to generate correlation-pair-wise pickle files

- The program is smart enough to compute only the relevant pickle runs
  - Remember we have many kinds of data!
    - Full mirror (to pixels 251 or 260)
    - Chessboard
    - Sub-mirrors
    - MAGIC+LST1 (current setup)

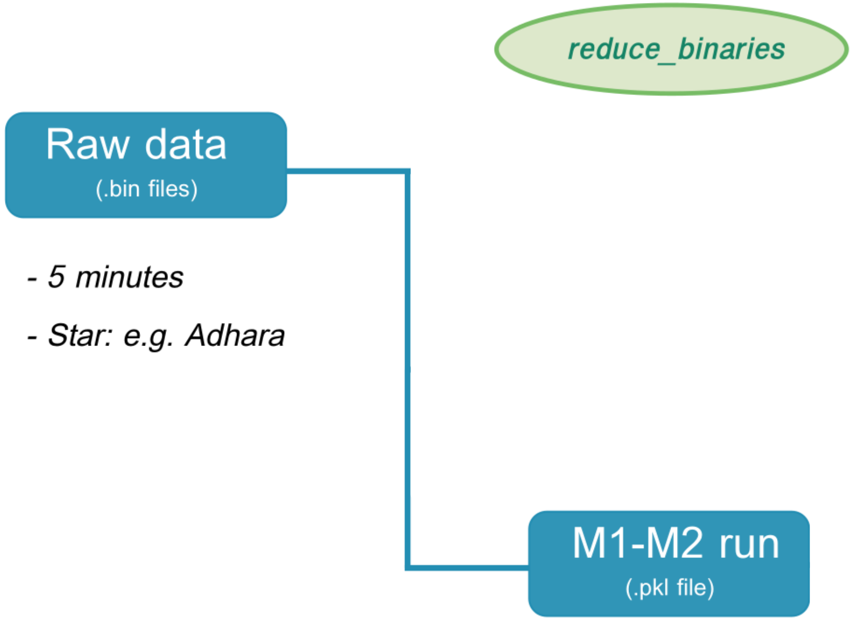
As a non expert, I recommend these configurations

MAGIC-SII setup: Full mirror



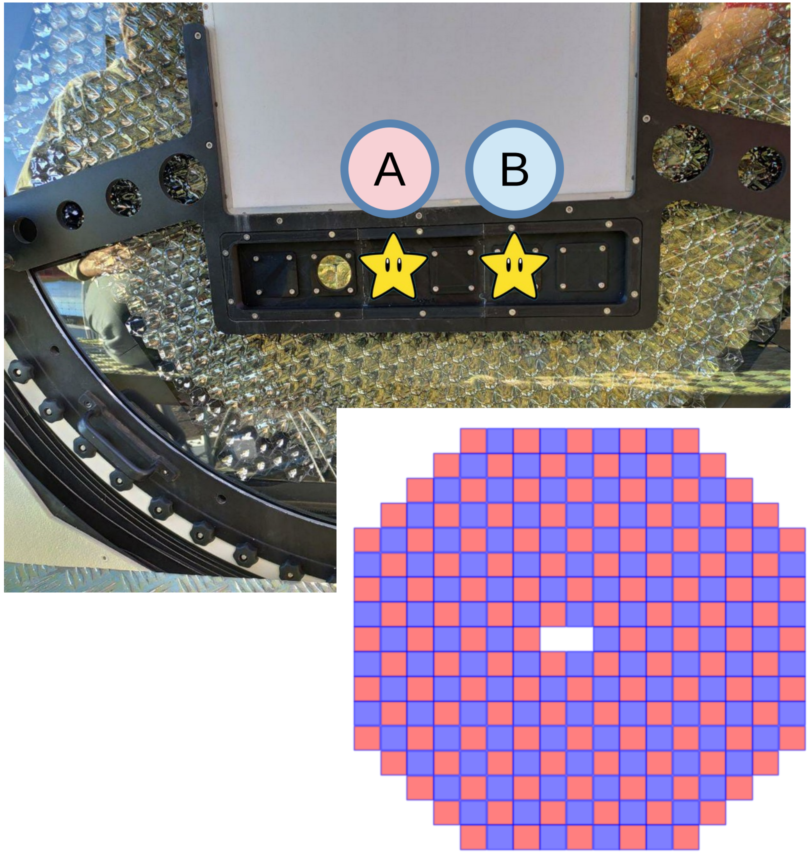


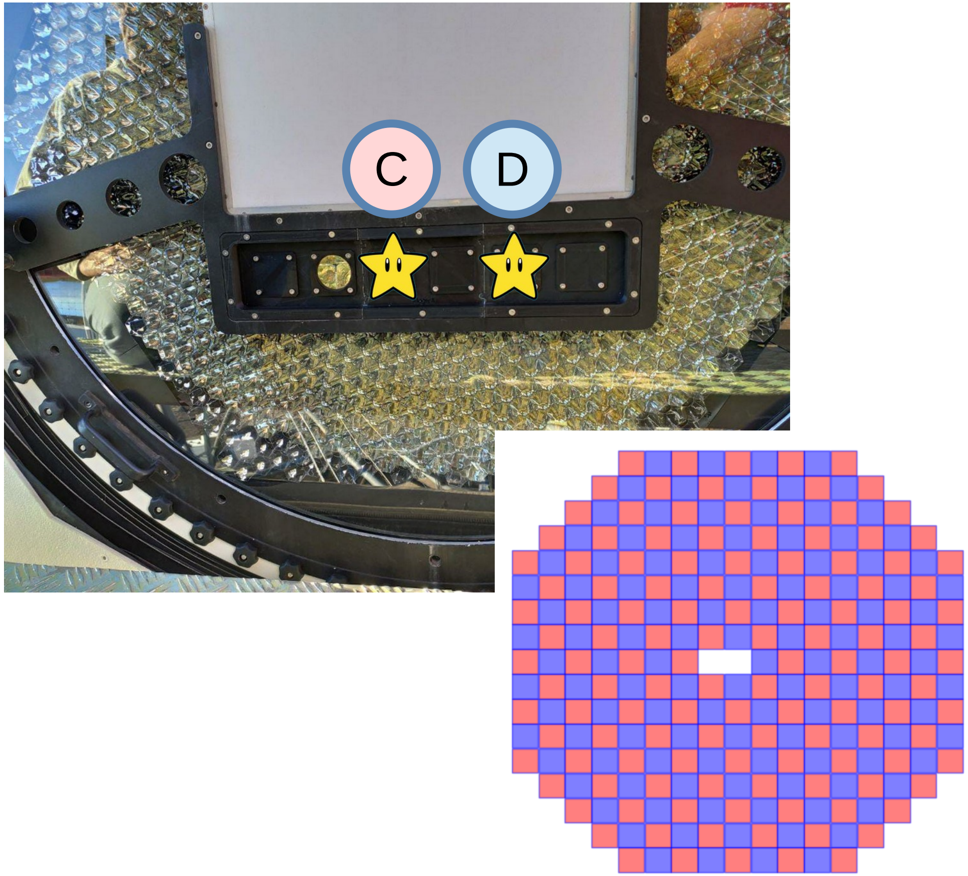
Interferometry data flow: reduce_binaries



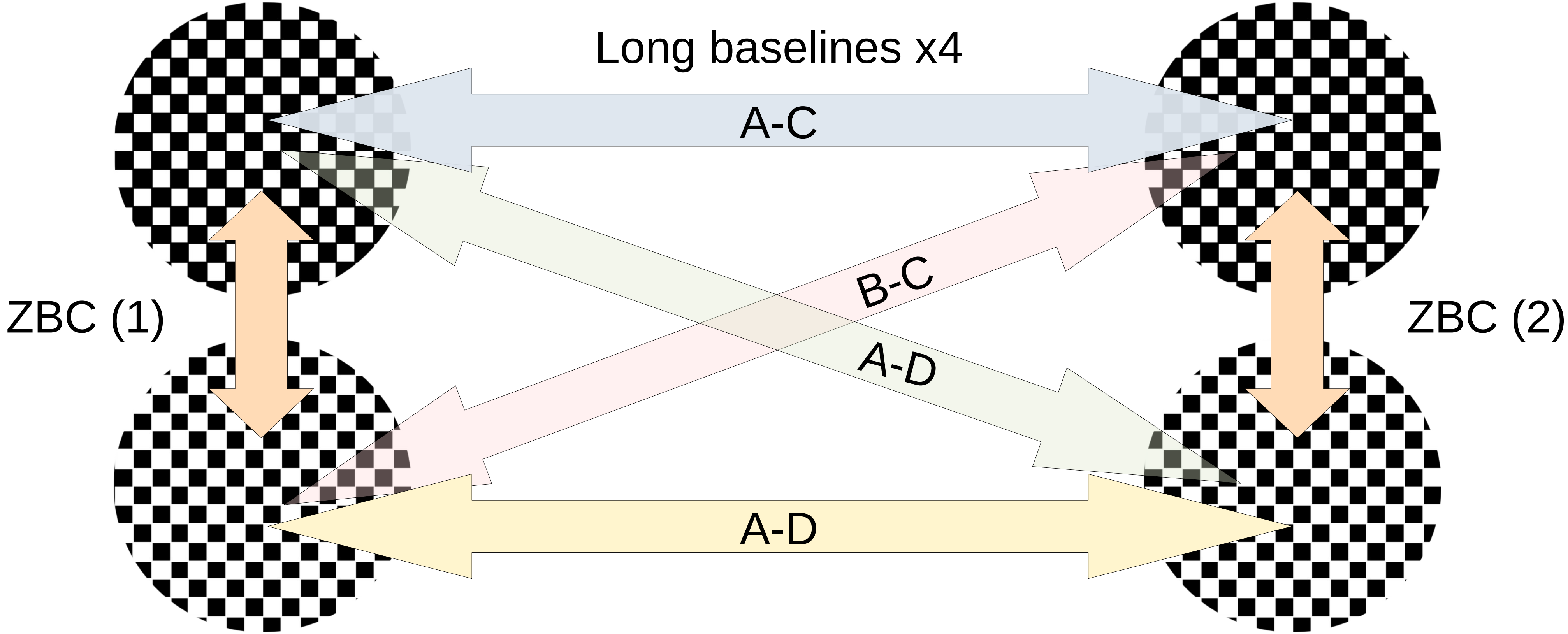
- Example 1: MAGIC-only full-mirror data
  - Only one possible correlation between the 2 signal pixels
  - May be of any combination (M1/M2 pixels 251/260)

MAGIC-SII setup: chessboard mode

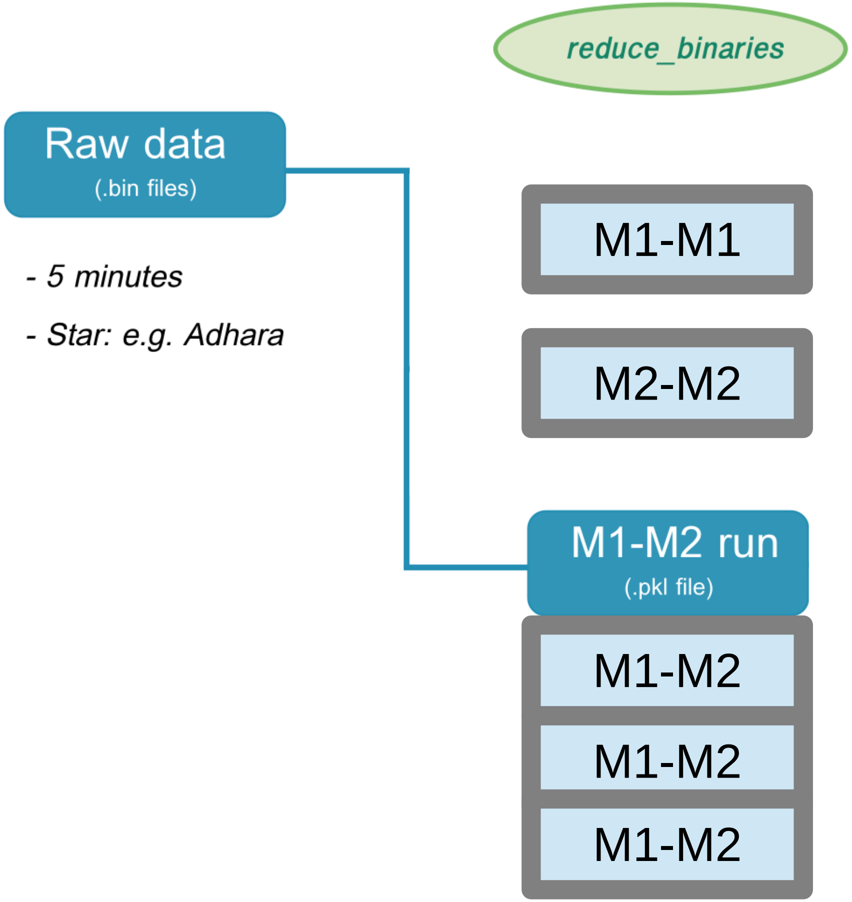




MAGIC-SII setup: chessboard mode

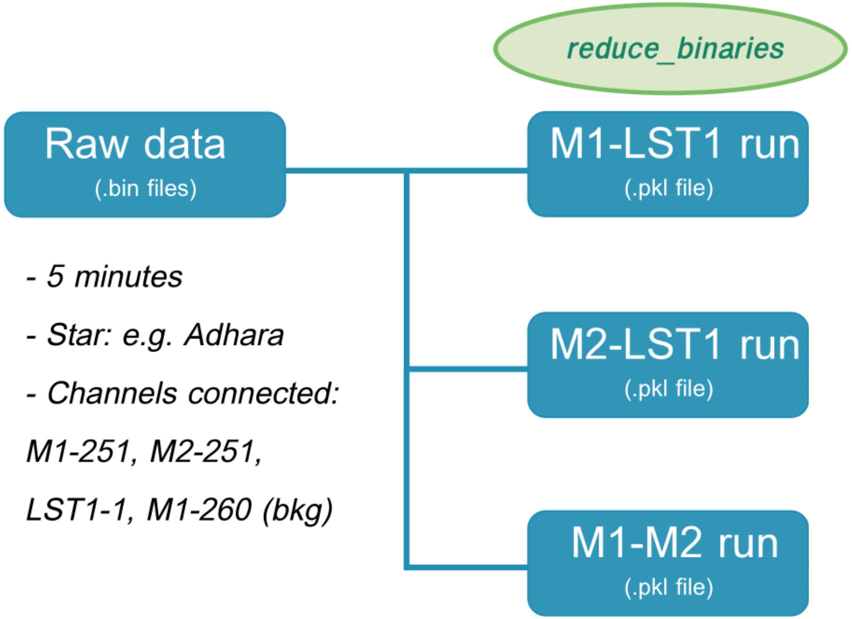


Interferometry data flow: reduce_binaries



- Example 2: MAGIC-only chessboard data
  - 6 different possible correlation between the 4 signal pixels
  - 4 long-baseline corr.
  - 2 short-baseline corr.
  - Signal to noise is significantly worse than full-mirror data

Interferometry data flow: reduce_binaries



- Example 3: MAGIC-LST1 full-mirror data
  - 3 signal pixels → 3 corr
  - May be of any combination (M1/M2 pixels 251/260)

Performance paper reminder: visibility

- Reminder on how we compute V^2 measurements:

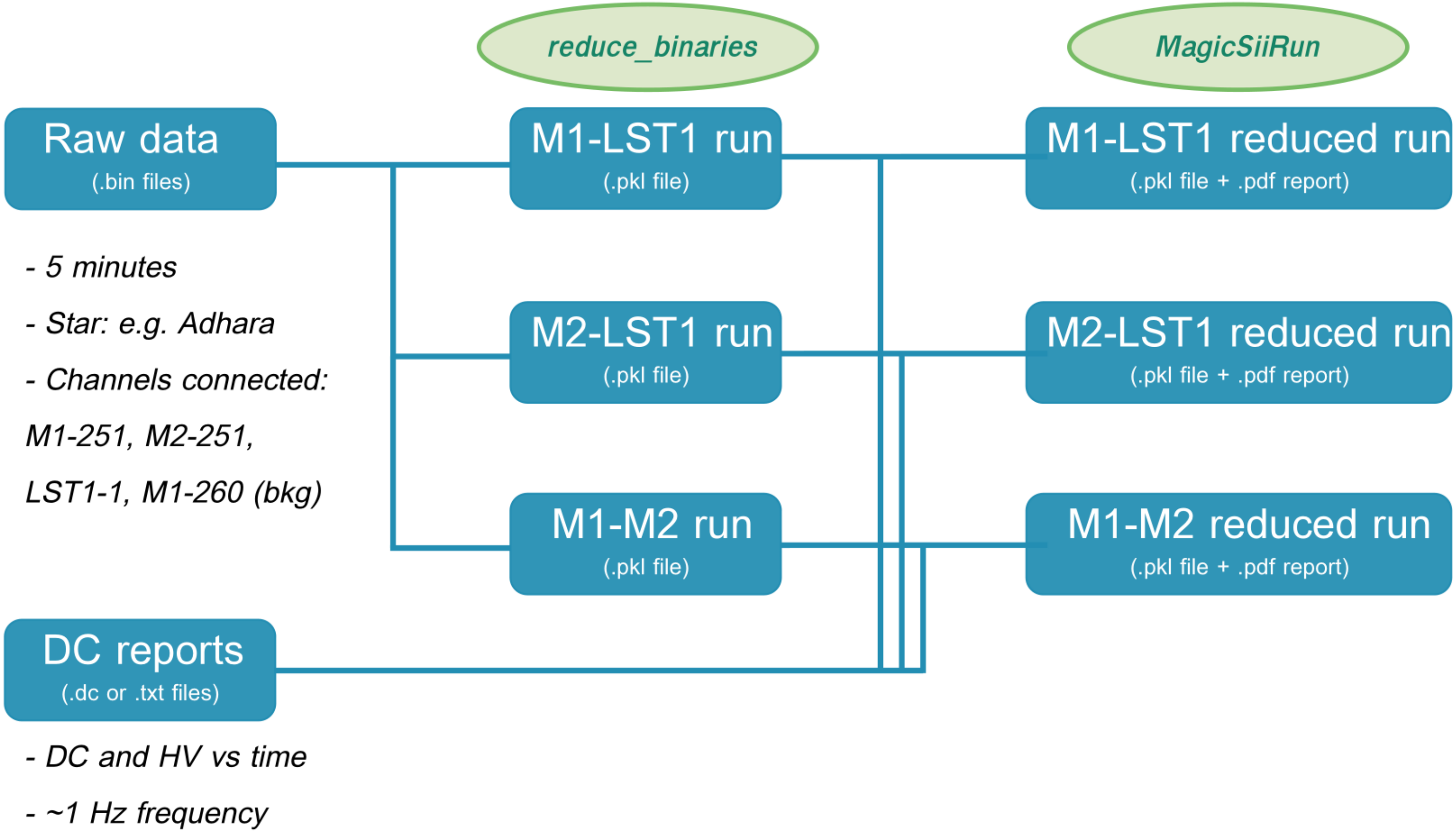
$$c = K \frac{\rho(\tau_0)\beta\sqrt{G_1 G_2}}{\sqrt{DC(Star)_1 DC(Star)_2}}$$

  - DCs need to be proportional to photon flux @ the PMT
  - Beta accounts for the ratio between DC(Star) and DC(NSB)
  - Gain corrections are needed if combining observations with different HV (not very common, but always checked)
  - Rho @ tau 0 is the amplitude of the correlation signal

Interferometry data flow: run-level analysis

- Run-wise analysis stage, computed by the ***MagicSiiRun*** class:
  - Computes time-delay correction (time of flight + hardware delay)
  - Applies time-delay correction → correlations signals expected at 0 ns
  - Combines data and DC reports:
    - Interpolates DC reports to frame's times
    - Computes DC(NSB) and DC(Star)
    - Calibrates frames with DC(star)

Interferometry data flow: run-level analysis



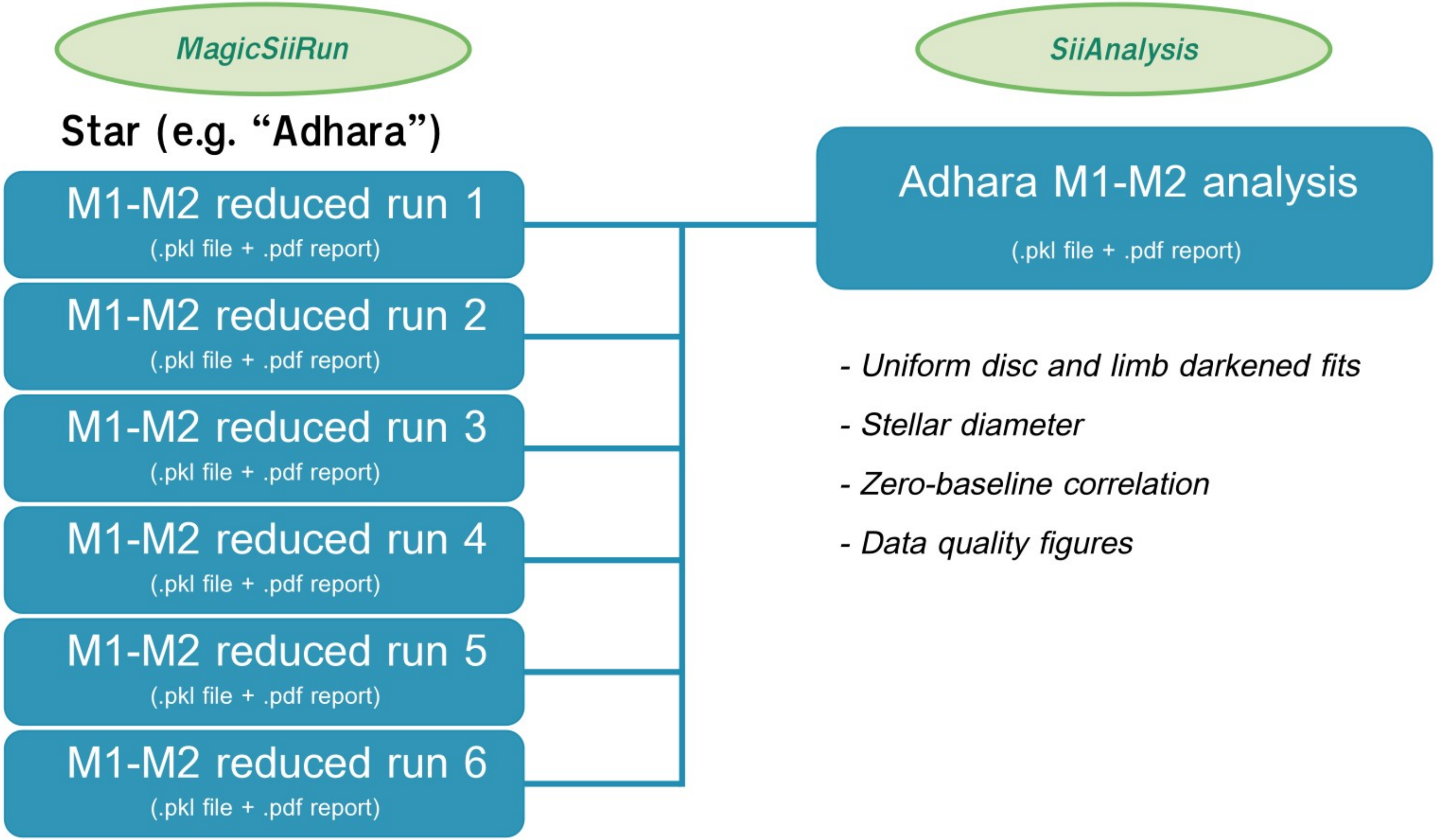
Interferometry data flow: run-level analysis

- **Tarek's hands on** a SII run report file (2024-03-20):
  - Show DC and std dev vs time figures
  - Show correlation signal plots (also before/after time-delay correction)
  - Show UV tracks

Interferometry data flow: source-level analysis

- Source-wise analysis stage, computed by the `SiiAnalysis` class:
  - Loads all runs from the selected star
  - Bundles data in baseline (in case of 1D analysis) or UV (2D analysis)
  - Combines correlation data from a each “bin” (in baseline or UV) and compute the amplitude of the signal and its uncertainty (V^2 measurements).
  - Fit V^2 measurements to a uniform disc or limb darkened model. In case of 2D analysis, also fit to an ellipse (fast rotator model).
  - Store results both in a .pkl file, and a .pdf report file

Interferometry data flow: source-level analysis



Interferometry data flow: source-level analysis

- **Tarek's hands on** an analysis results file: Adhara vs Mirzam
    - Understand baseline "binning"
    - Understand calibration and V^2 measurement
    - Identify stellar diameter measurement
    - Understand uncertainties

Interferometry data flow: production

- Production class (`SiiProduction`): helping class to launch analyses:
  - Read the configuration file and pass all the configuration parameters to each analysis
  - Find the nights of observations in which files from the selected source exist (surviving selection criteria)
  - Launch all analyses requested from the config file: either sequentially execute them or paralelize them via condor (works at pic!)
- **Entry point of most analyzers to the analysis:**

  the `sii_production` executable

Interferometry data flow: production

SiiProduction

```
> sii_production [config file]
```

Configuration file
(.yml file)

- *Top level class to execute multiple analyses*
- *Configuration file used*
(similar to MARS .rc files)
- *Paralelization: analysis-wise condor jobs*

SiiAnalysis

Adhara M1-M2 analysis
(.pkl file + .pdf report)

Adhara M1-LST1 analysis
(.pkl file + .pdf report)

Adhara M2-LST1 analysis
(.pkl file + .pdf report)

Mirzam M1-M2 analysis
(.pkl file + .pdf report)

Interferometry data flow: production

- **Tarek's hands on** the production config file sample:
  - Show yaml format (not .rc files)
  - Describe the hierarchy of the 3 analysis levels: run, analysis and production
  - Show relevant variables, and those that (for now) should not be changed by non experts
  - Show the `sii_production` executable
  - Show location of the example config file

IACT-SII: Lesson II wrap up

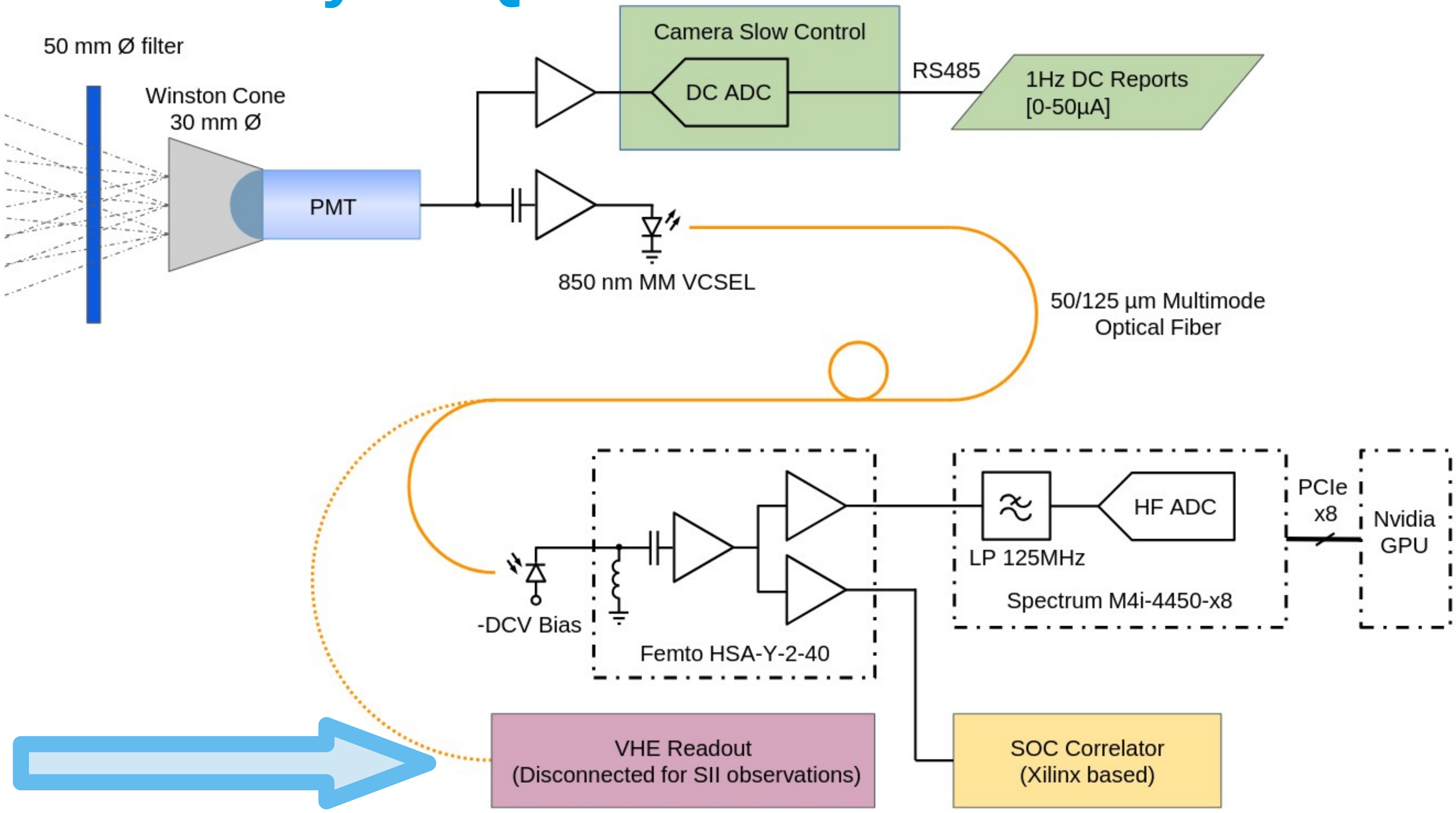
- Binary files are reduced, storing each starlit correlation pair as pickle files
- The analysis is very simple:
    - One class handles run-wise analysis
    - One class handles source-level analysis
    - Launching an analysis is simple! Fill an analysis configuration file and launch it!
- Later more advanced/complex stages of the analysis will be explained in the future

IACT-SII: Lesson II – Proposed exercises

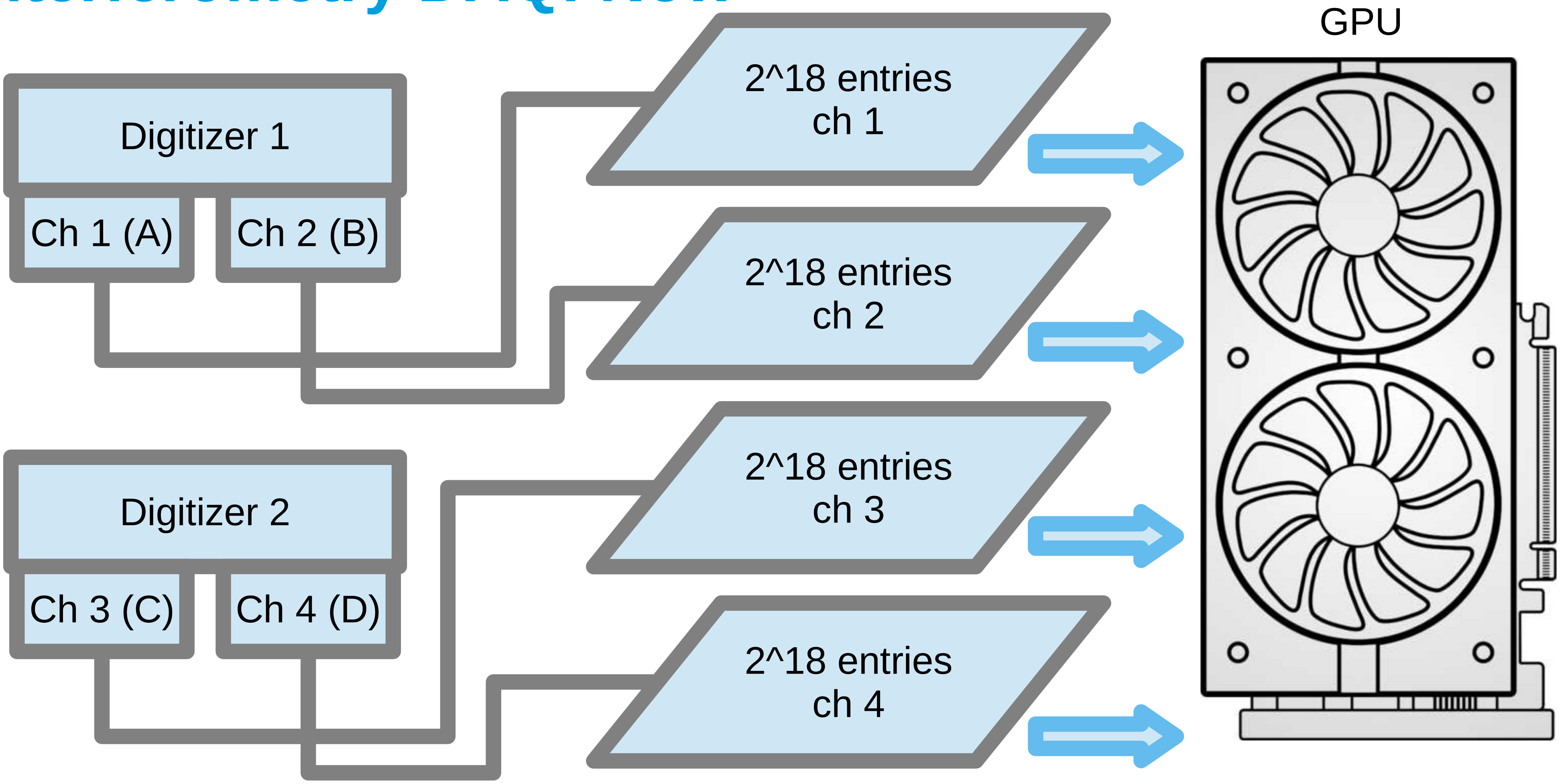
- Launch an analysis of **Adhara**, making sure you only select files with a single correlation pair (for now, MAGIC-only correlations!)
  - Check measured diameter: is it consistent with the performance paper?
  - Check the figures of the results pdf. Do you understand most plots?
  - **ExPeRt level**: check pickle results file. Do you make any sense out of it?
- Sync data from another star. Run an analysis of that other star.
  - Do these results make sense?


BACKUP

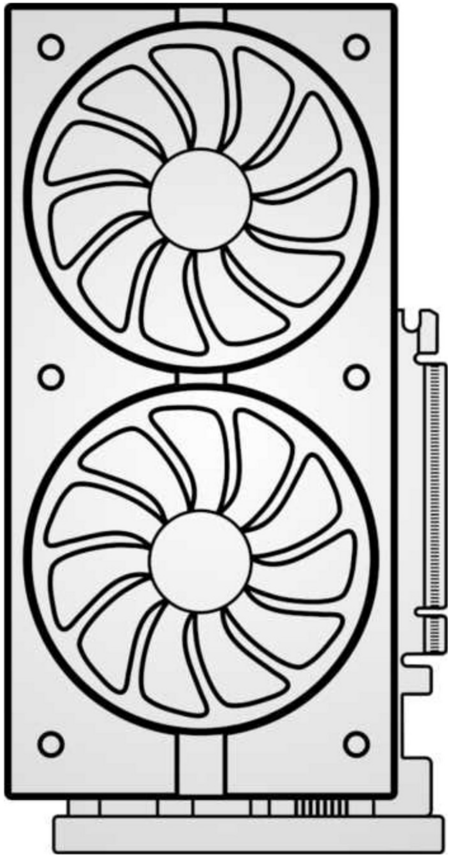
Interferometry DAQ



Interferometry DAQ: Now



Interferometry DAQ: Now



- Current DAQ computes:
  - Cross-correlation between each channel pair (via FFTs)
  - Auto-correlation of each channel
  - Certain useful parameters (mean and std dev of each channel)
- Current DAQ “accumulates” these, and writes the average correlation/mean/std dev every 500 cycles

ZBC: The constant of our system

- From HB&T, we know that the expected correlation:

$$\overline{c(d)} = \langle \Delta i_1(t) \Delta i_2(t) \rangle = e^2 A^2 \alpha^2 n^2 |\gamma_d(0)|^2 \Delta\nu \Delta f \qquad (4.28)$$

- After dividing by the flux, the remaining correlation should be:

$$\frac{\overline{c(d)}}{flux} \propto \frac{|\gamma_d(0)|^2}{\Delta\nu\Delta f}$$

- But as with our setup, our “flux” is the DCs (different gain than the correlation):

$$\frac{\overline{c(d)}}{\sqrt{DC^1 DC^2}} \propto \frac{|\gamma_d(0)|^2}{\sqrt{G^1{}_{DC} G^2{}_{DC}}\,\Delta\nu\Delta f}$$

Any time evolution in the DC gain will be a **systematic**