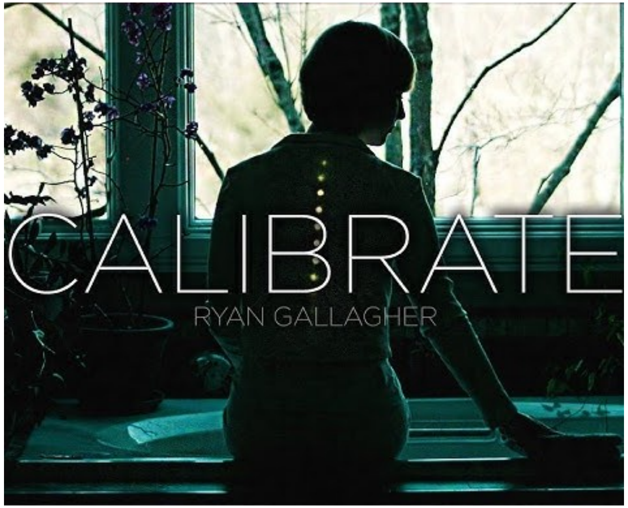
# SII software school: Lesson 3




your SII analysis

T. Hassan on behalf of
the magic_spysii dev team

European Research Council
Established by the European Commission

Ciemat
Centro de Investigaciones
Energéticas, Medioambientales
y Tecnológicas

# IACT-SII: Lesson I & II wrap up

- Downloading/synchronizing data, and “reducing” it should be a piece of cake now
- Visualizing binary data should also be easy, and the user should understand the meaning of most parameters plotted
- Analyzers should have, more or less, an idea of the information that each level of analysis contains
- Analyzers are able to perform the analysis of any star they like

**Although most likely, you don’t know yet what you are doing!**

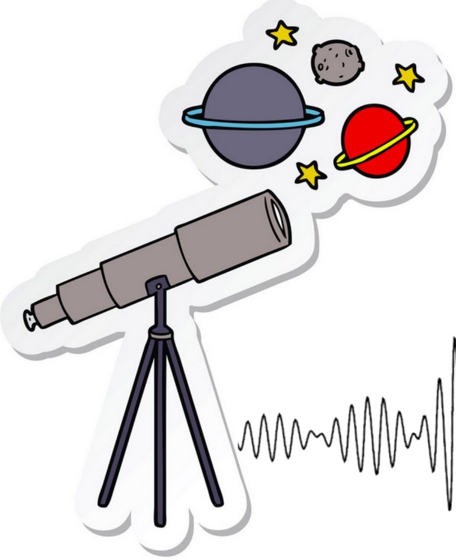
**And that is ok!**

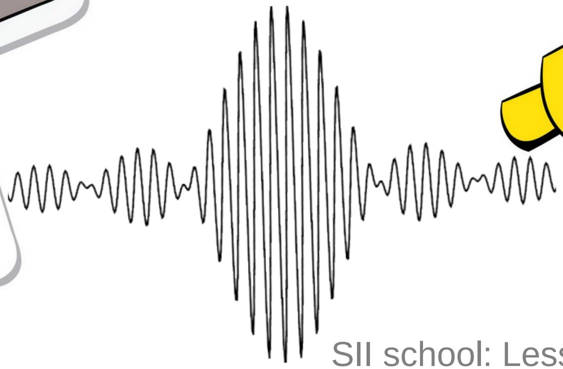
# IACT-SII: Lesson III

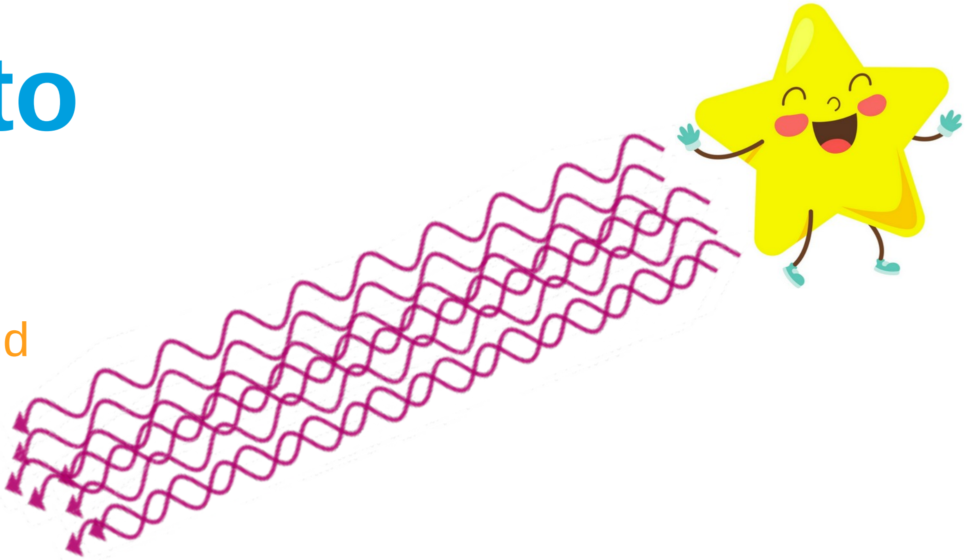
- Review basic concepts of interferometry (you will start needing them now)
- Understand the meaning of zero-baseline correlation
  - How to generate a “ZBC calibration file”
  - How to use it
- Side step: first steps towards MAGIC-LST analysis:
  - Which runs have MAGIC+LST1 data?
  - How do I download LST DC reports?

# Gentle introduction to interferometry

Amazing angular resolution, but hard to understand

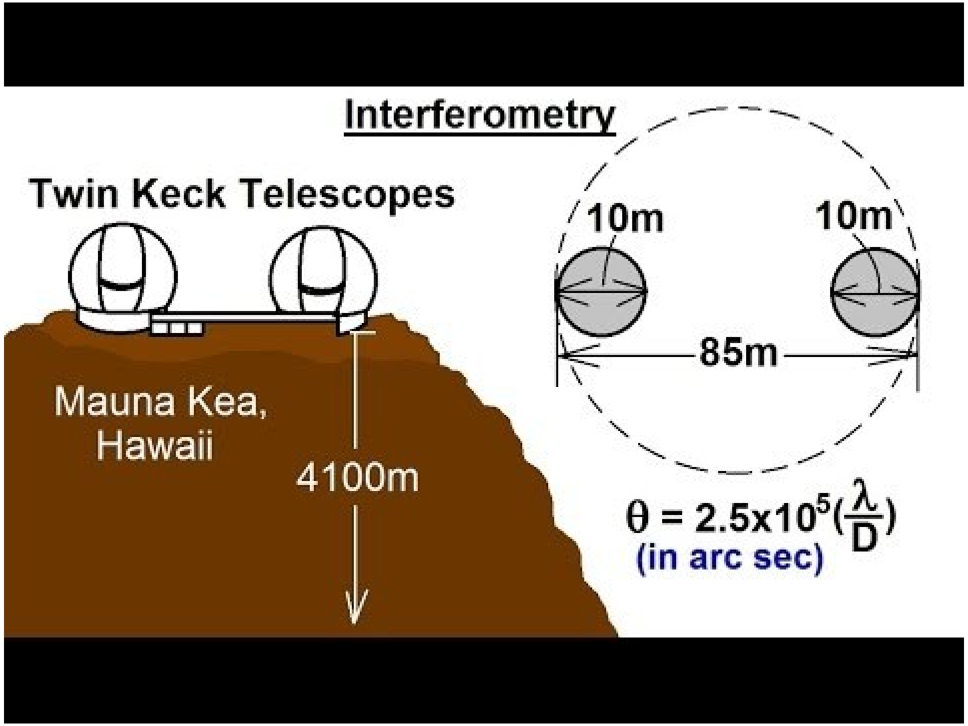






# Principle of interferometry

- A technique to reach unprecedented angular resolution, by using several separated telescopes “working as one”




But how do they work?

# Introduction to SII: The very basics

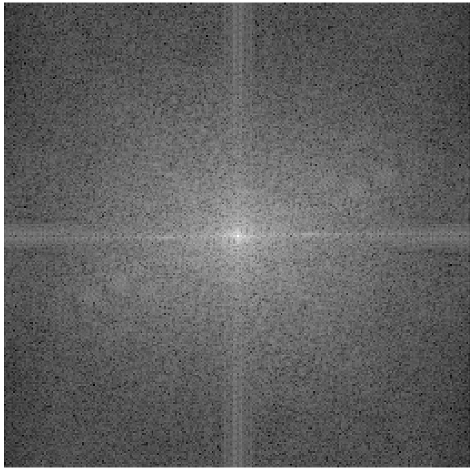
Glasses improve our angular resolution

# Introduction to SII: The very basics

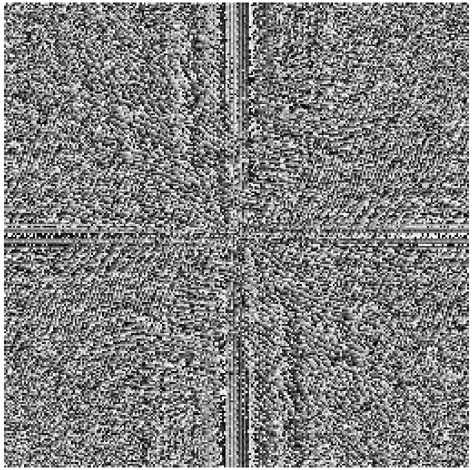
What would happen if these glasses allowed us to see the **Fourier space**?

# Introduction to SII: The very basics

We would (quite literally) look at a **complex** universe



**Intensity**



**Phase**

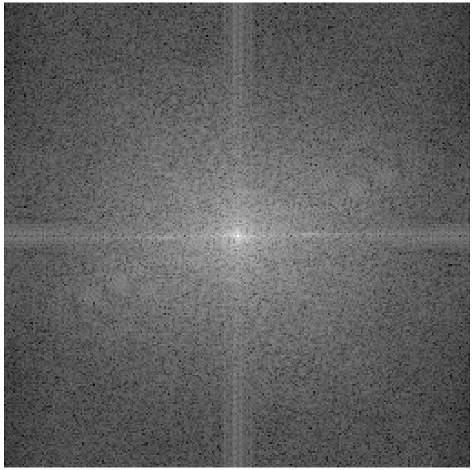
# Introduction to SII: The very basics

2D FFT$^{-1}$

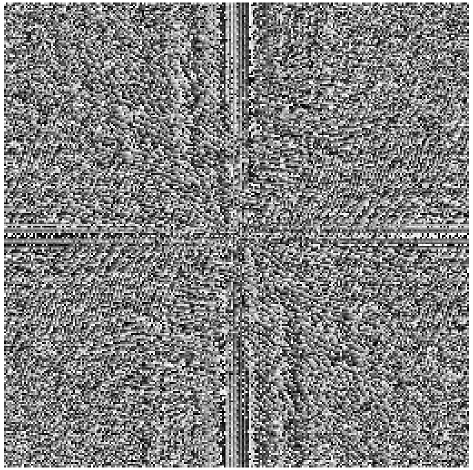
Looking at the complex Fourier space is good enough:

You have all the information!

2D FFT

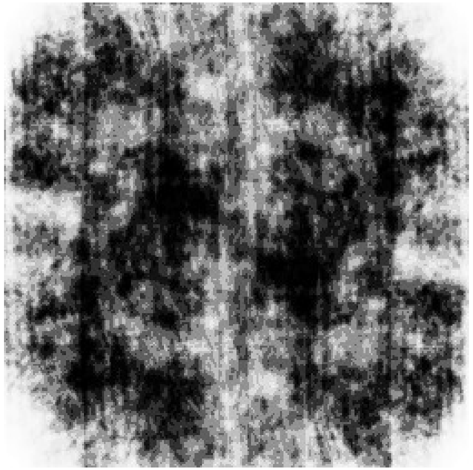


Intensity



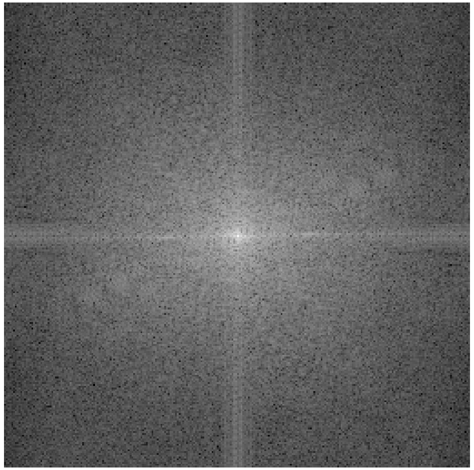
Phase

# Introduction to SII: The very basics



2D FFT$^{-1}$

Phase is important!



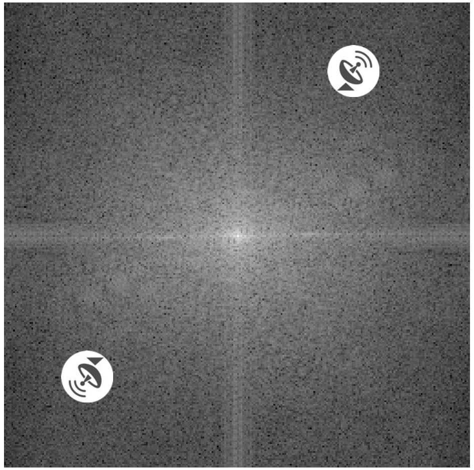
**Intensity**

?

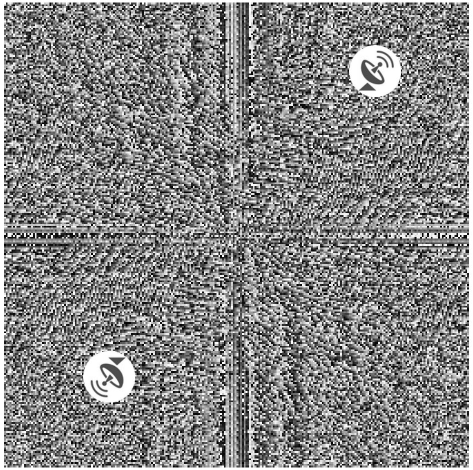
**Phase**

# Introduction to SII: The very basics

An interferometer is something very similar to these "Fourier" glasses



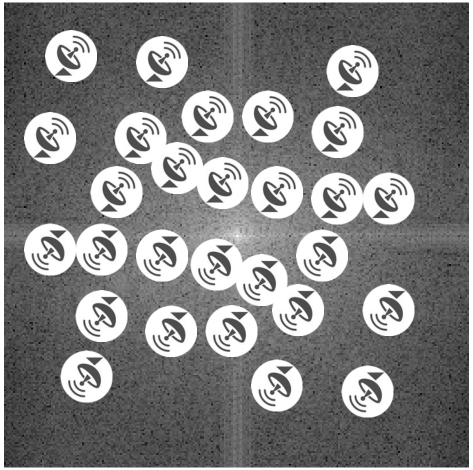
Intensity (u,v)



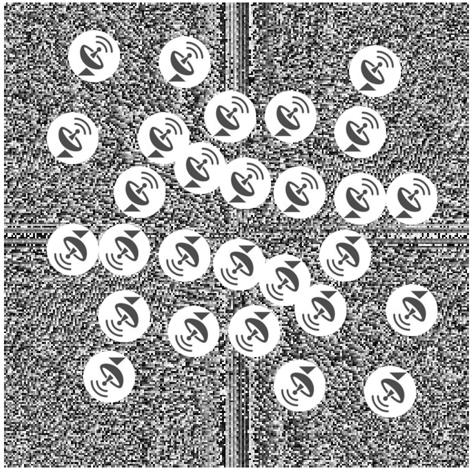
Phase

# Introduction to SII: The very basics

More telescopes → more information from the Fourier space → more spacial information → better imaging



**Intensity (u,v)**



**Phase**

# SII analysis theory

- Van Cittert-Zernike Theorem:

$$g^{(1)}(u, v, 0) = \int\int I(l, m) \mathrm{e}^{-2\pi(lu+mv)} \mathrm{d}l\mathrm{d}m$$

# SII analysis th

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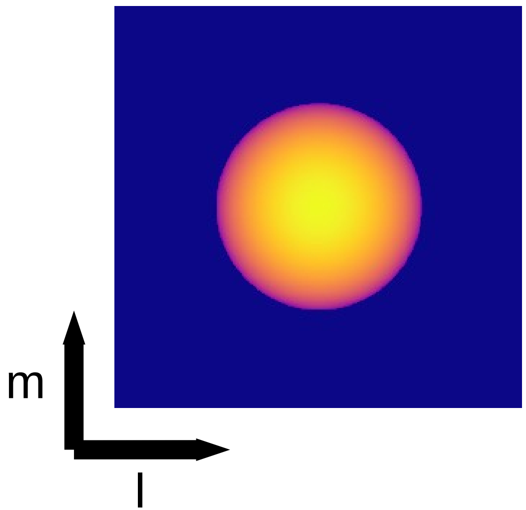
Sky model



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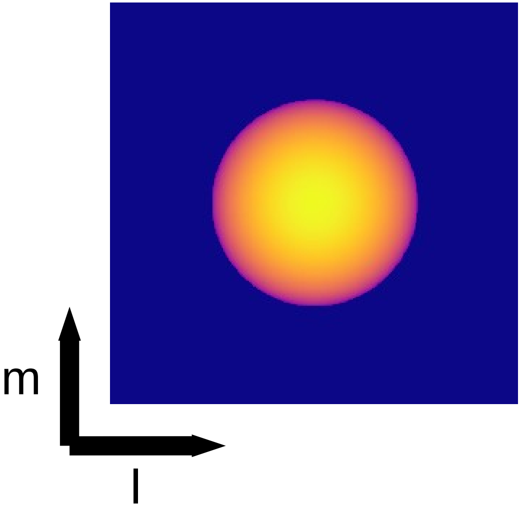
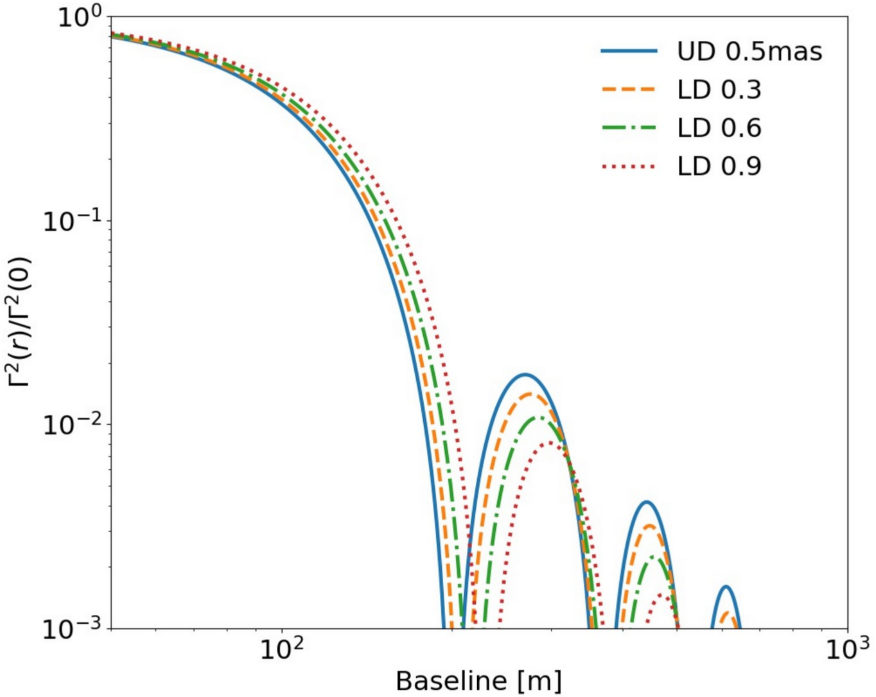
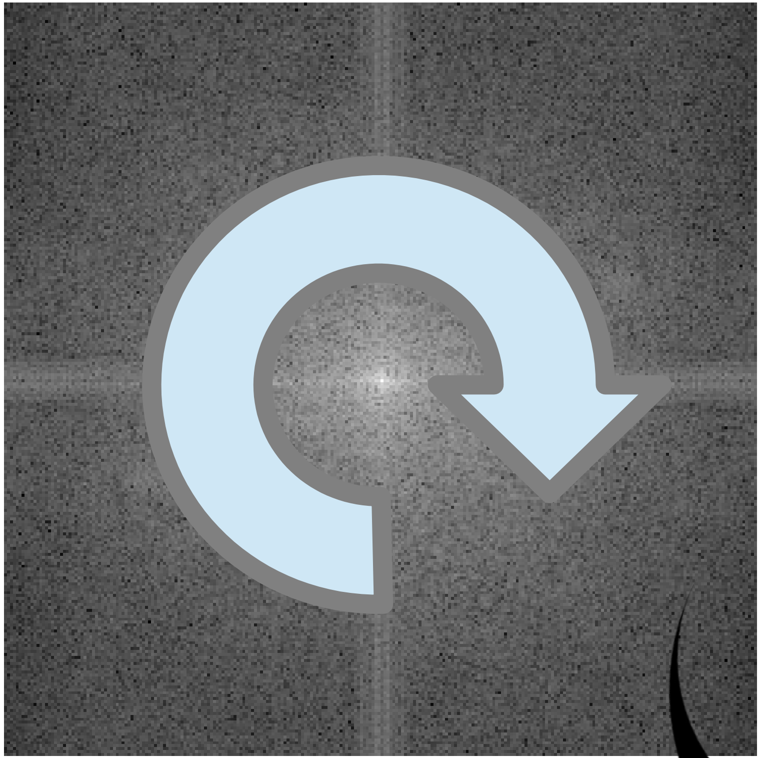
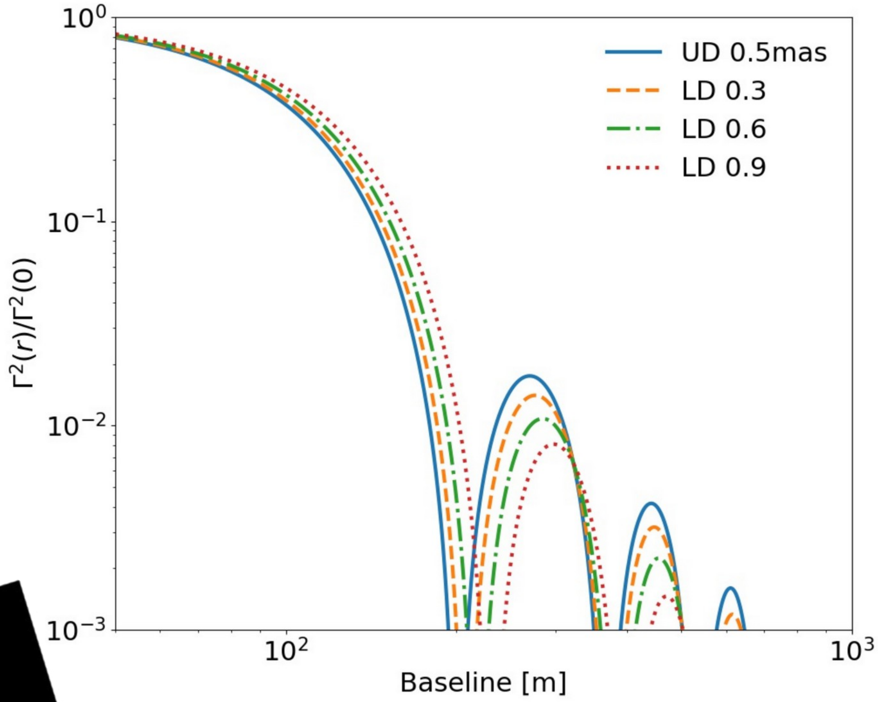



$$g^{(2)}(u,v,t) = 1 + |g^{(1)}(u,v,t)|^2$$

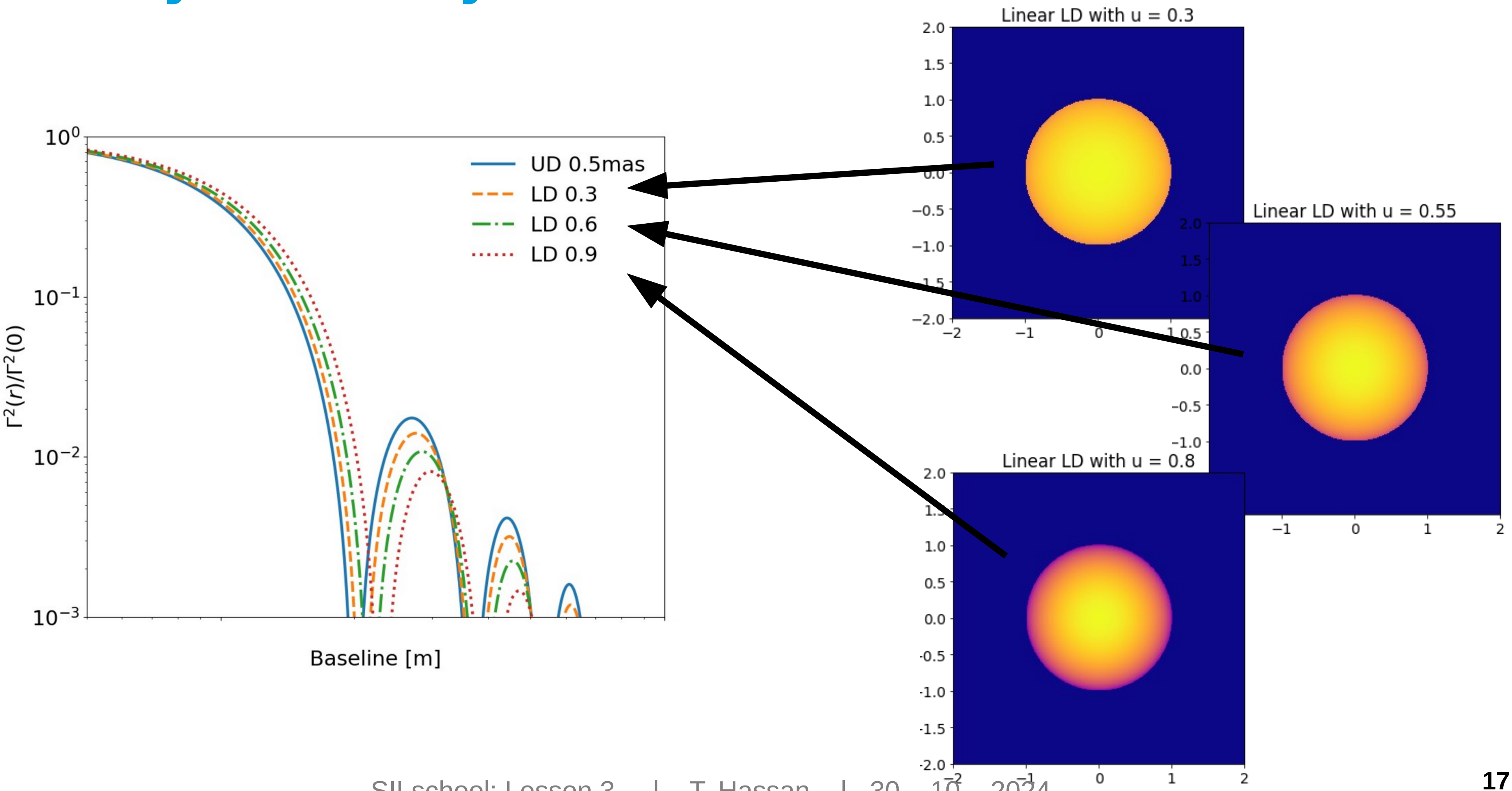


# V² vs baseline: radially symmetric UV models



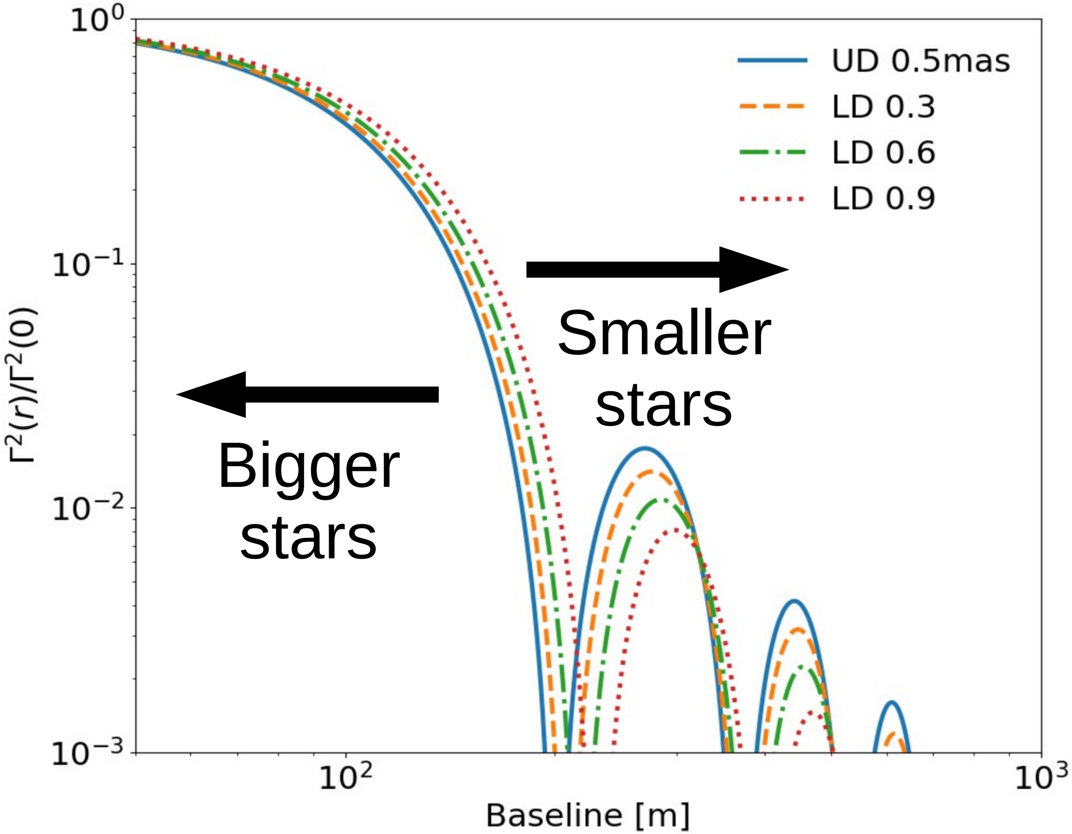


# SII analysis theory



# SII analysis theory

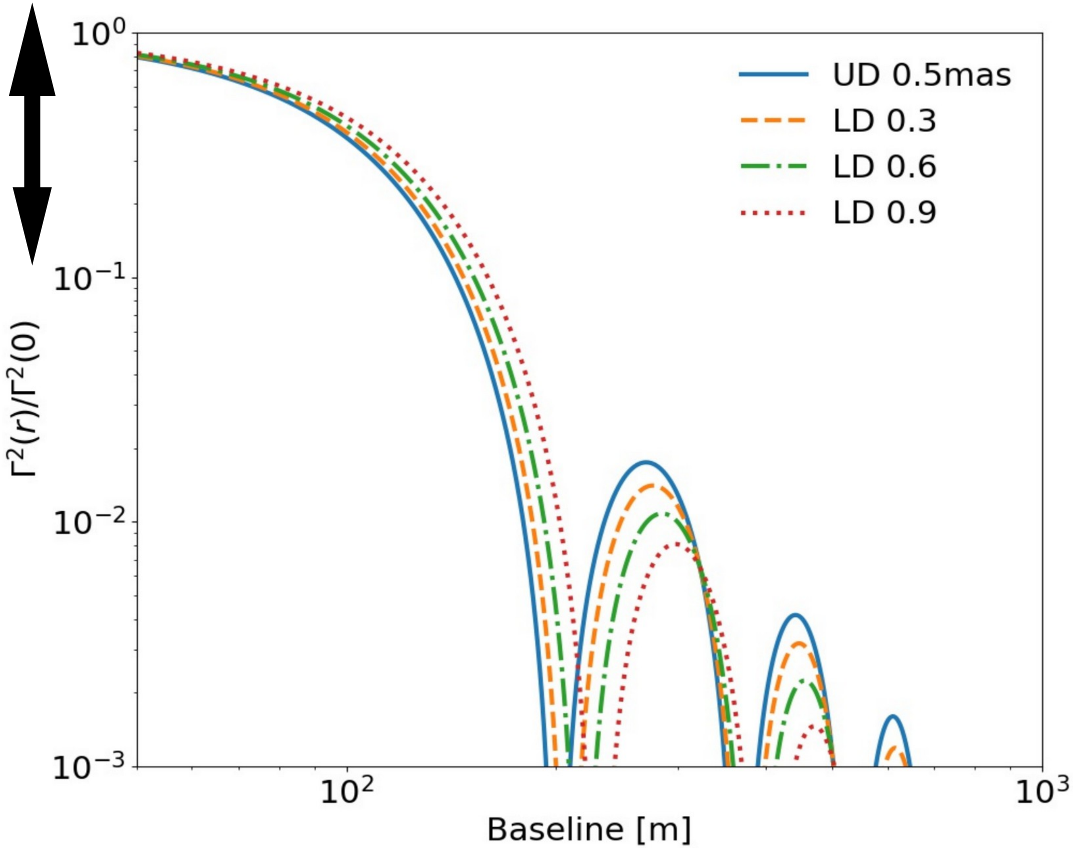
- These models generally have 2 free parameters:



# SII analysis theory: zero-baseline correlation

- These models generally have 2 free parameters:

Correlation expected at 0 distance



# SII analysis theory: zero-baseline correlation

- These models generally have 2 free parameters:

  1) Diameter of the measured star

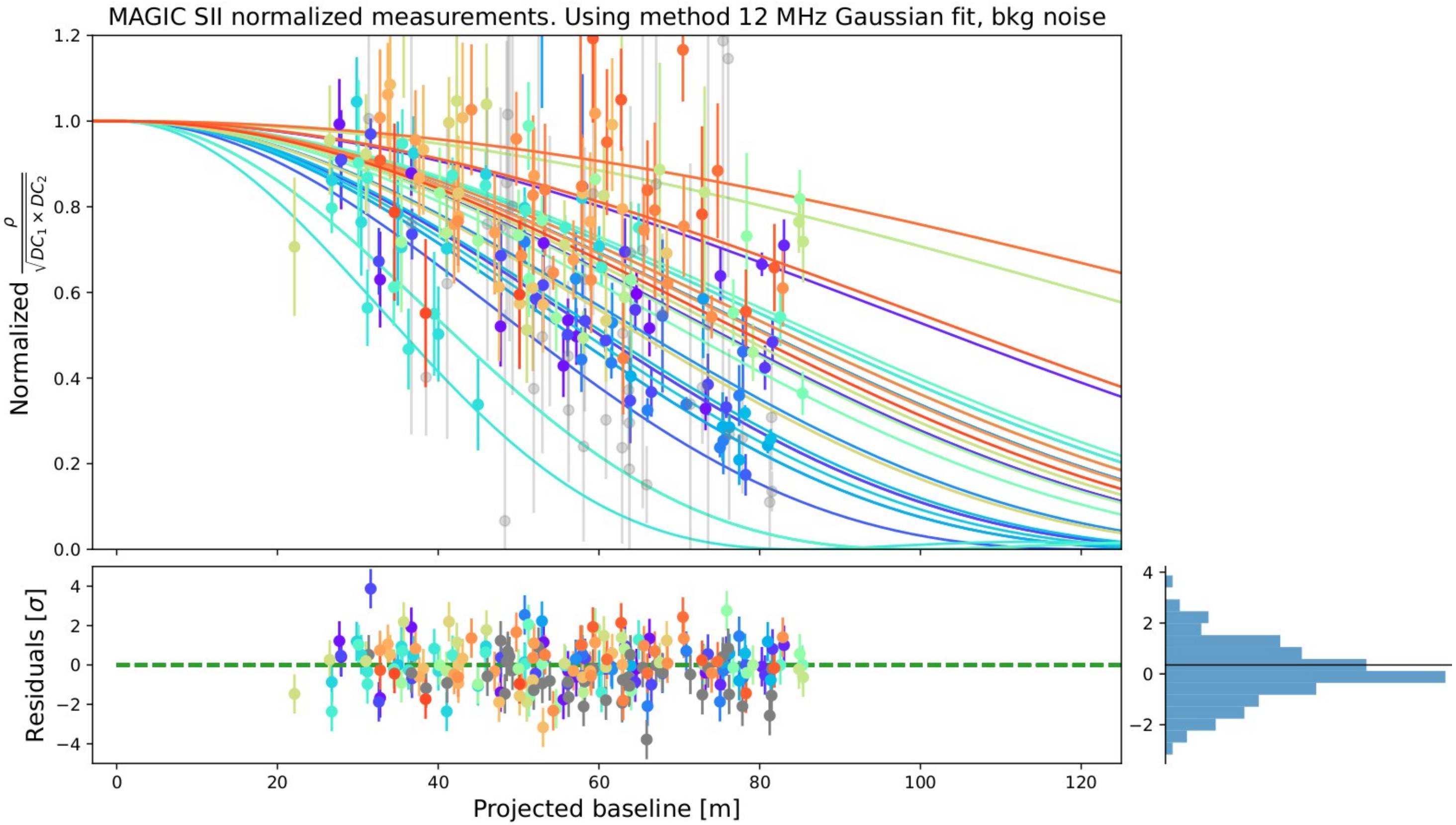
  2) Normalization parameter (zero-baseline correlation)

- Zero-baseline correlation is **fixed by your hardware setup**, and mainly depends on optical and electronic bandwidth

  - In our case, as we use DC reports to normalize the correlation, pixel gains also affect ZBC

# SII analysis theory: zero-baseline correlation

- During the peformance paper work, all sources were consistent with **a single ZBC**:



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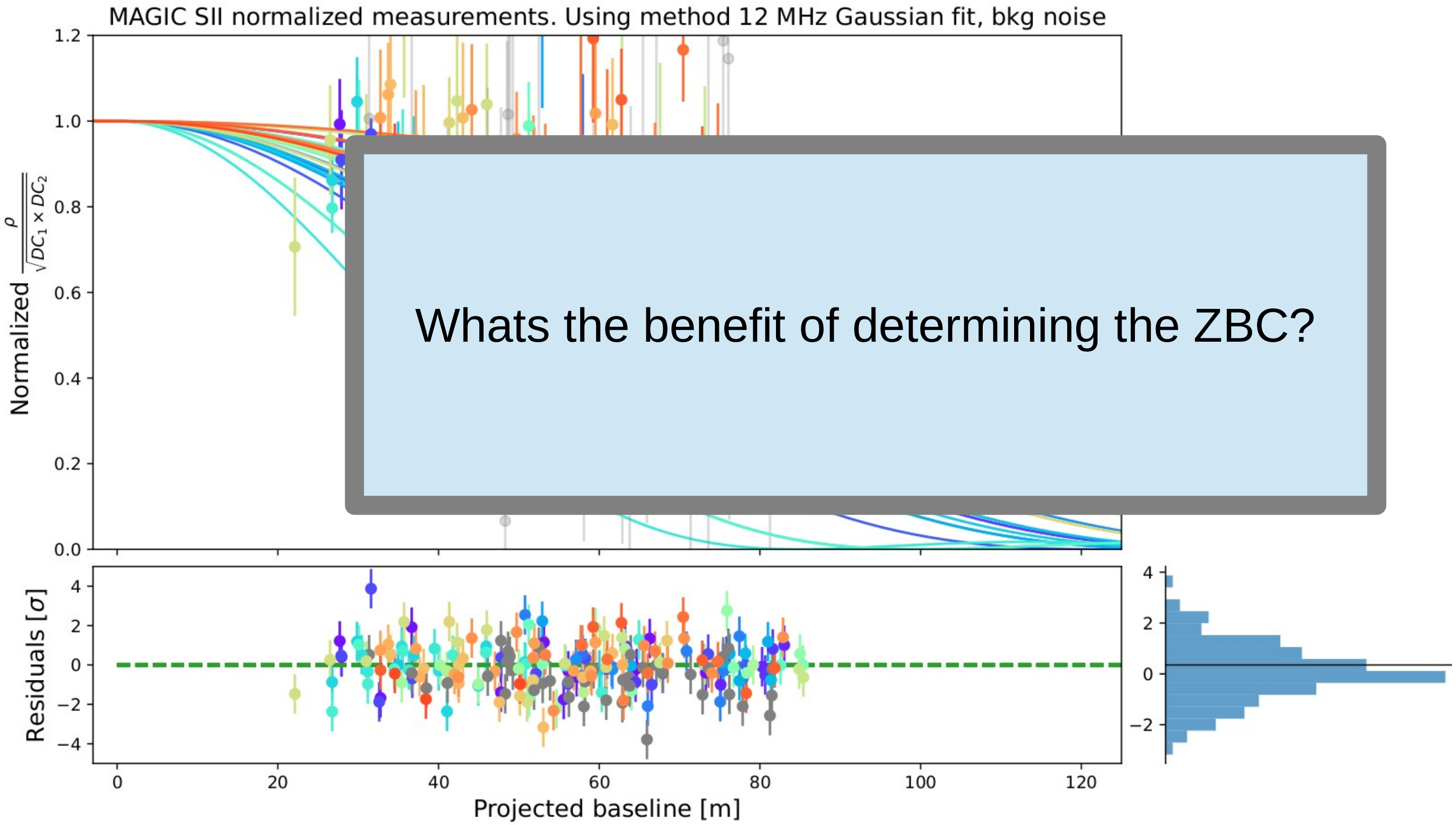
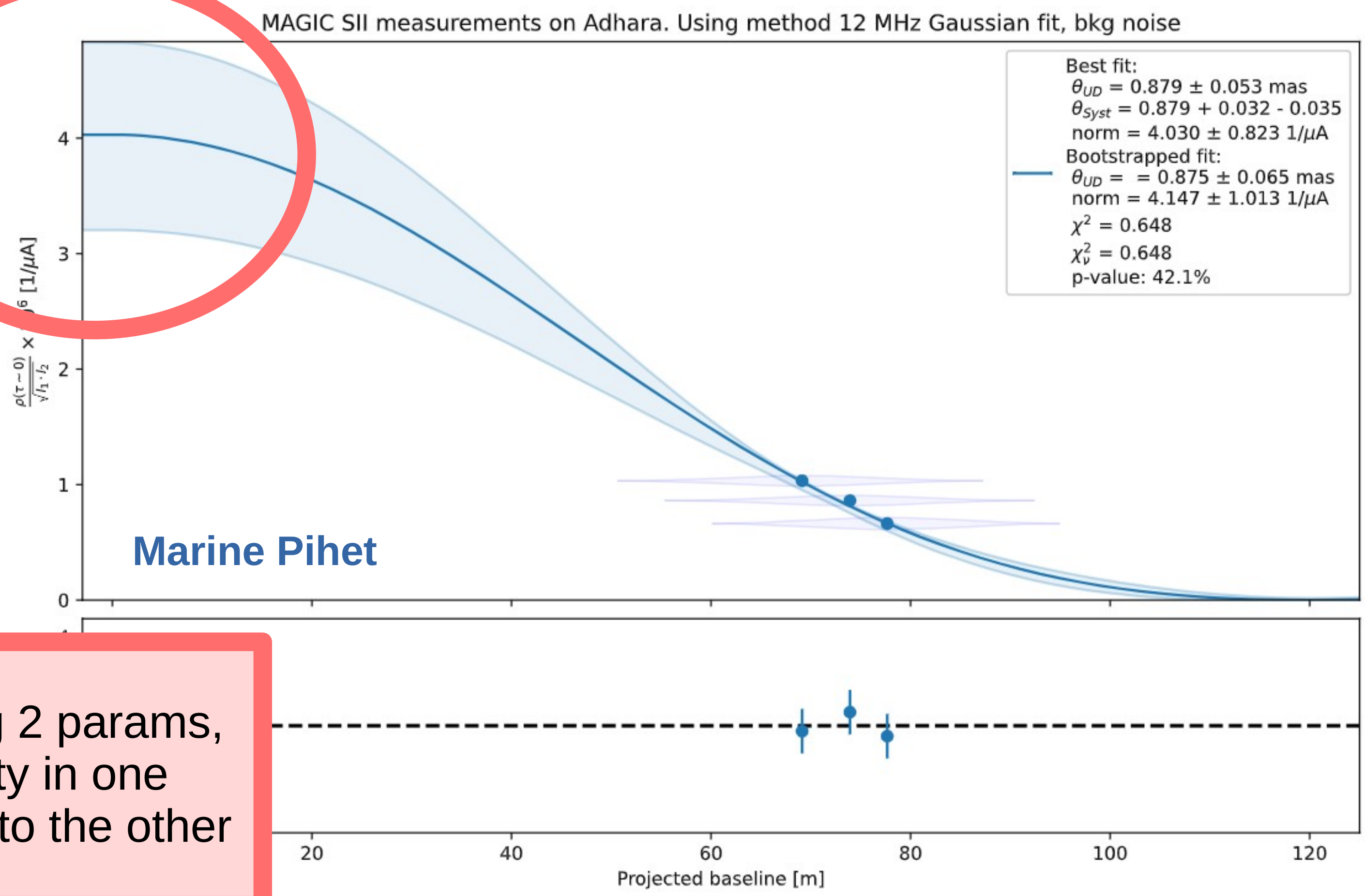


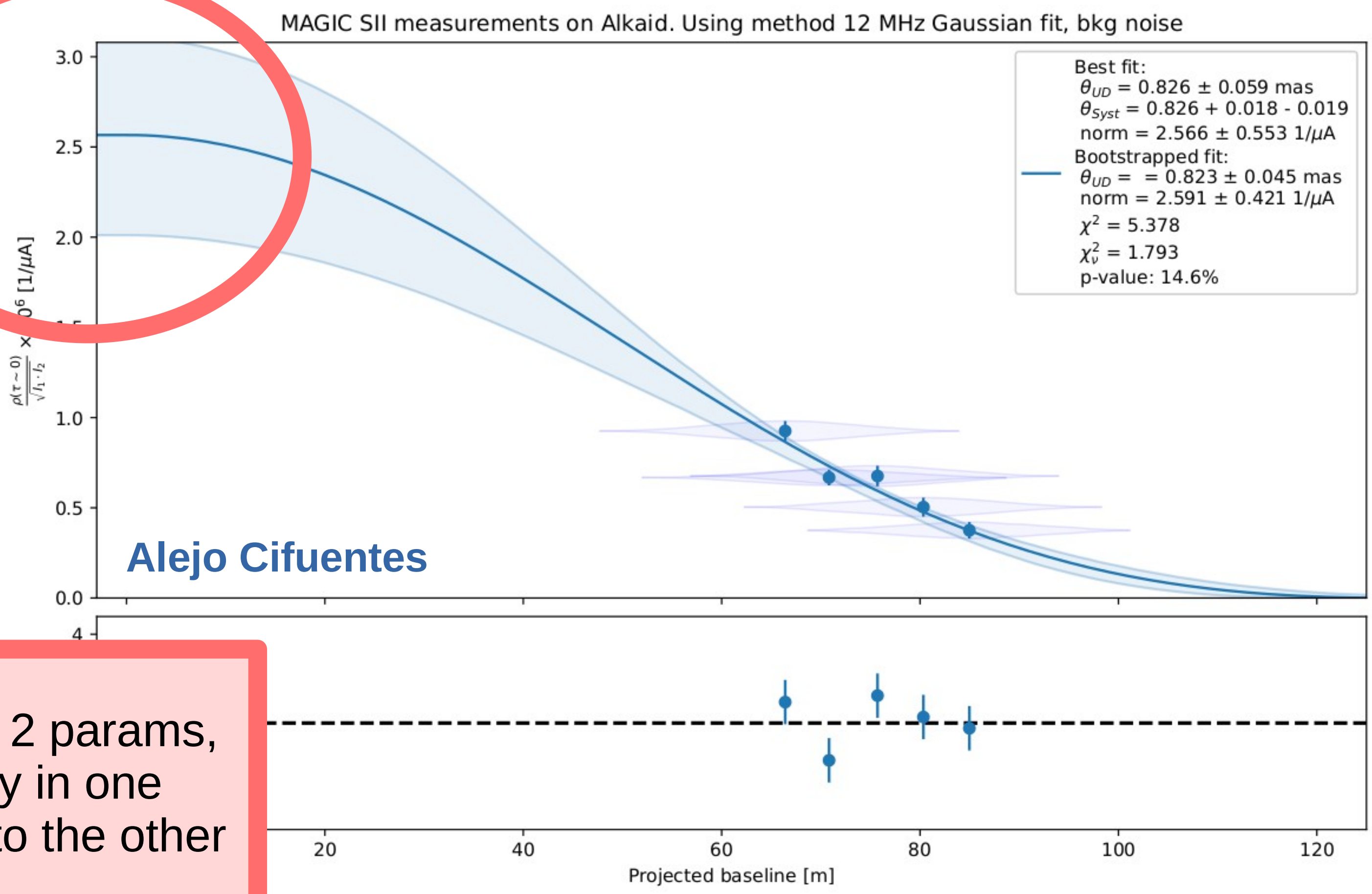

Whats the benefit of determining the ZBC?

# ZBC: Adding a ZBC to an analysis




When fitting 2 params, uncertainty in one propagates to the other

# ZBC: Adding a ZBC to an analysis

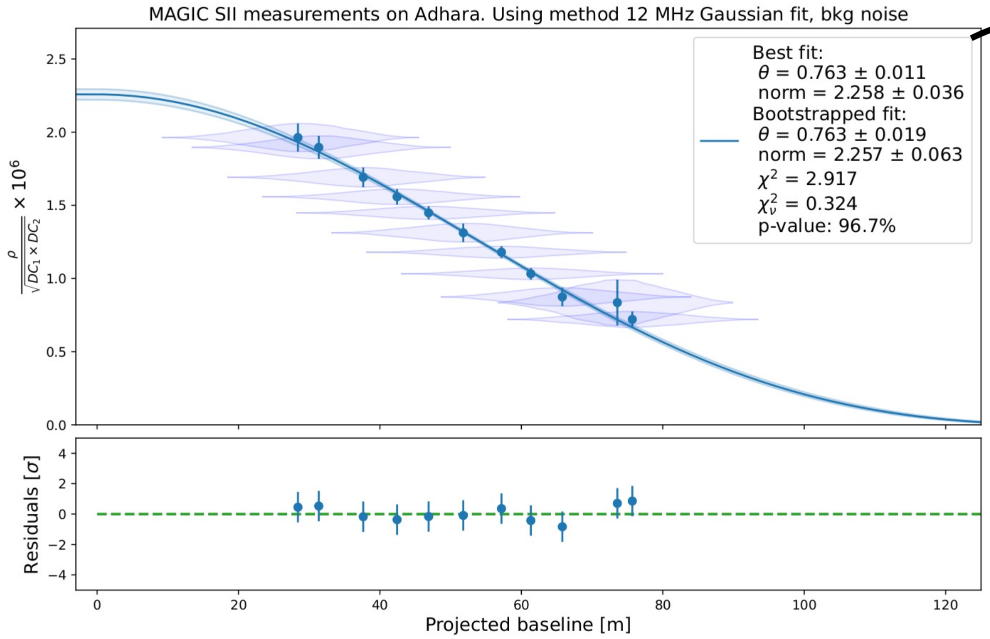



When fitting 2 params, uncertainty in one propagates to the other

# ZBC: Create your own ZBC calibration file

- magic_spysii allows to extract all information related to the ZBC from an analysis, and use it over other analyses

- The way to do this is trivial: once you have an analysis with good ZBC...




```
> extract_zbc_file [ANALYSIS FILE].pkl
```

This executable will generate a file caled: zbc_[ANALYSIS FILE].pkl

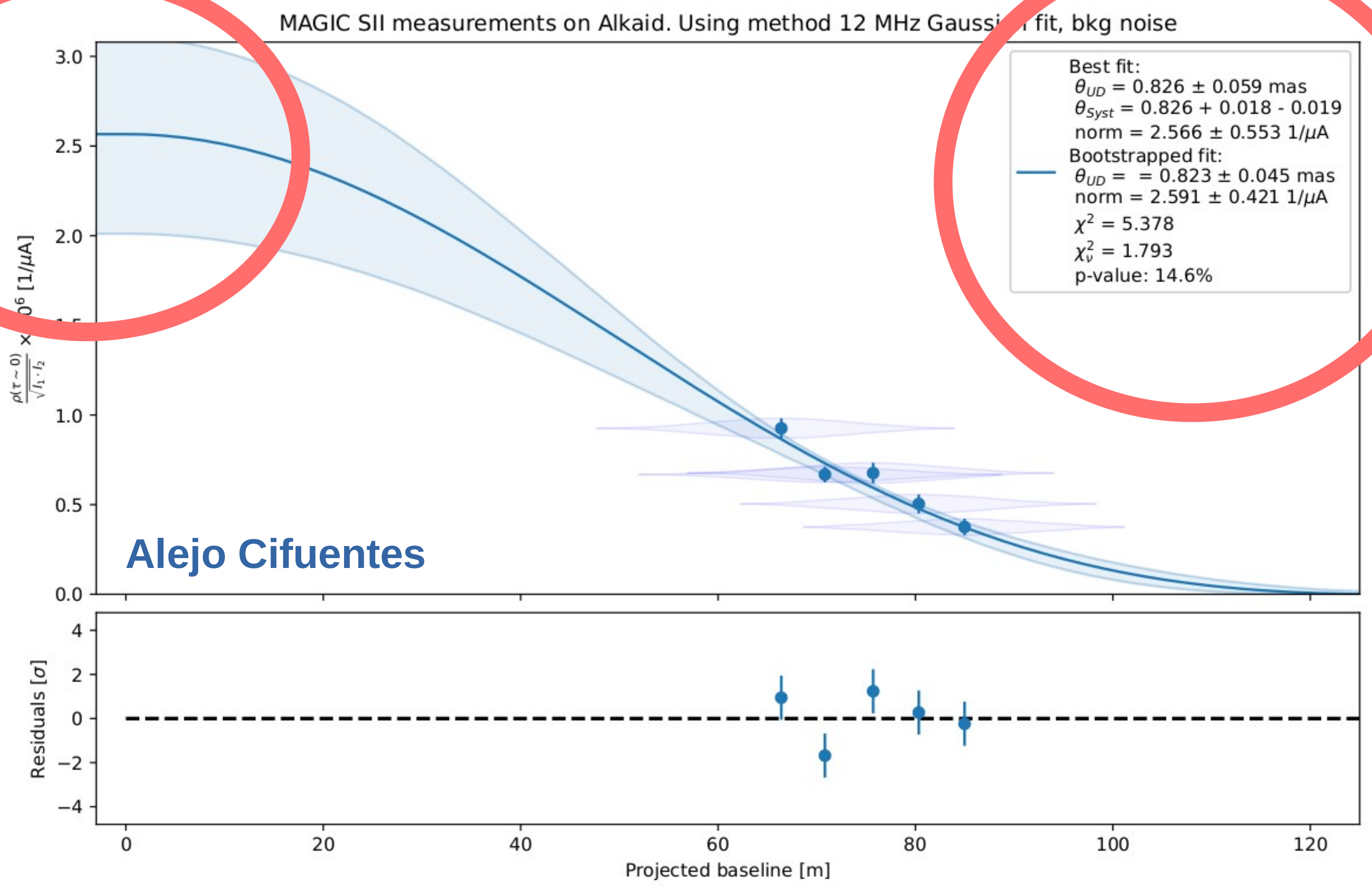
# ZBC: Use your ZBC calibration file

• Obviously you should not use the extracted ZBC on the same source, but you can use it on any other! How?

> sii_production config_file.yml

```
...
# The following are the parameters used at the "analysis" level:
analysis:
  # In case you want to add a ZBC measurement to the analysis, set the
  # [path]/[filename] of the pkl file here. If not,
  # set as None. This is considered the calibration of the system, and impacts
  # strongly on the resulting diameter.
  add_zbc: [PATH_TO_ZBC_FILE]/zbc_Adhara_M1-251_M2-251.pkl
...
```

# ZBC: Adding a ZBC to an analysis



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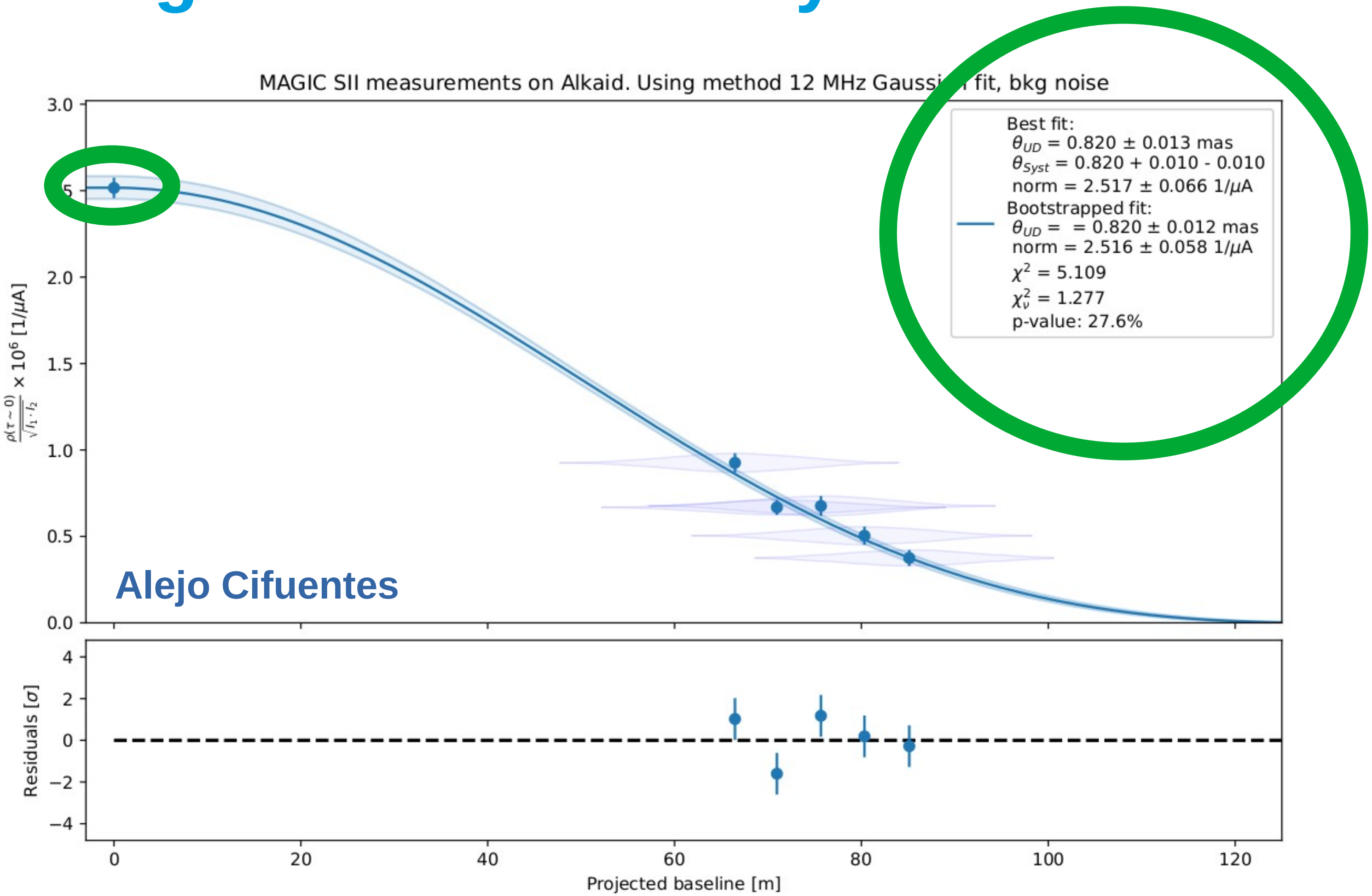

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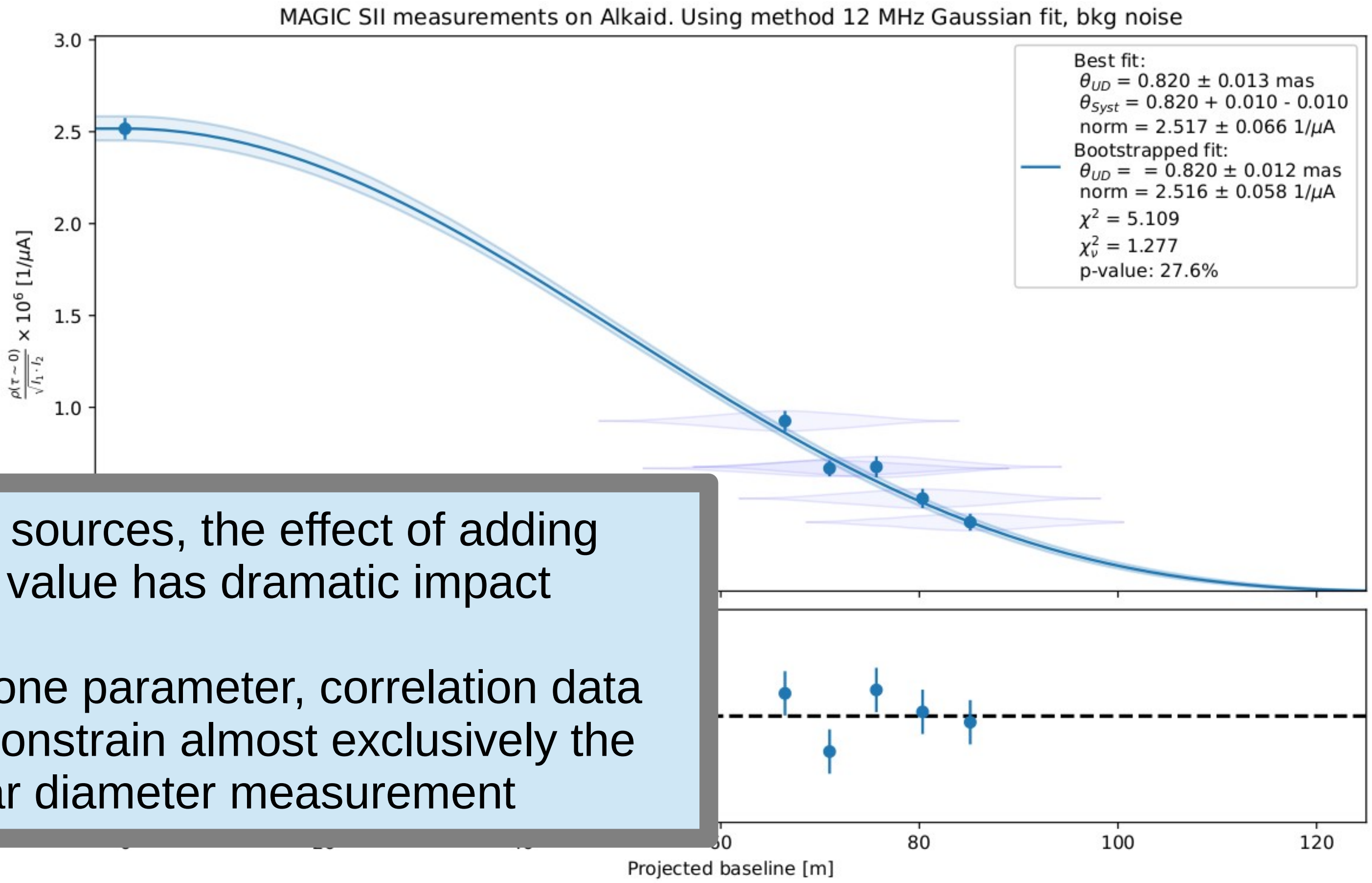


For many sources, the effect of adding a ZBC value has dramatic impact

By “fixing“ one parameter, correlation data is used to constrain almost exclusively the stellar diameter measurement

# ZBC: Things to remember

- As stated before, ZBC is fixed by **the hardware setup**.

  What does this mean?

  - Measuring the correlation between different pixels (e.g. 251-251 vs 260-260) may lead to small differences in ZBC → better not to combine 251 and 260 pixels

  - Differences between MAGIC pixels may be small, but MAGIC vs LST pixels will be **very different** → definitely never combine

  - PMTs degrade with time, so we expect ZBC to evolve over month/year timescales

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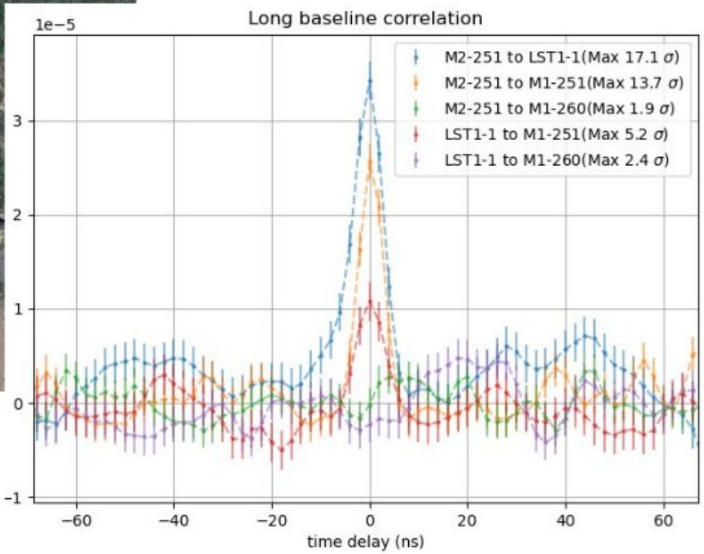
# MAGIC-SII → MAGIC-LST1-SII


Remember we have 3 telescopes now!!

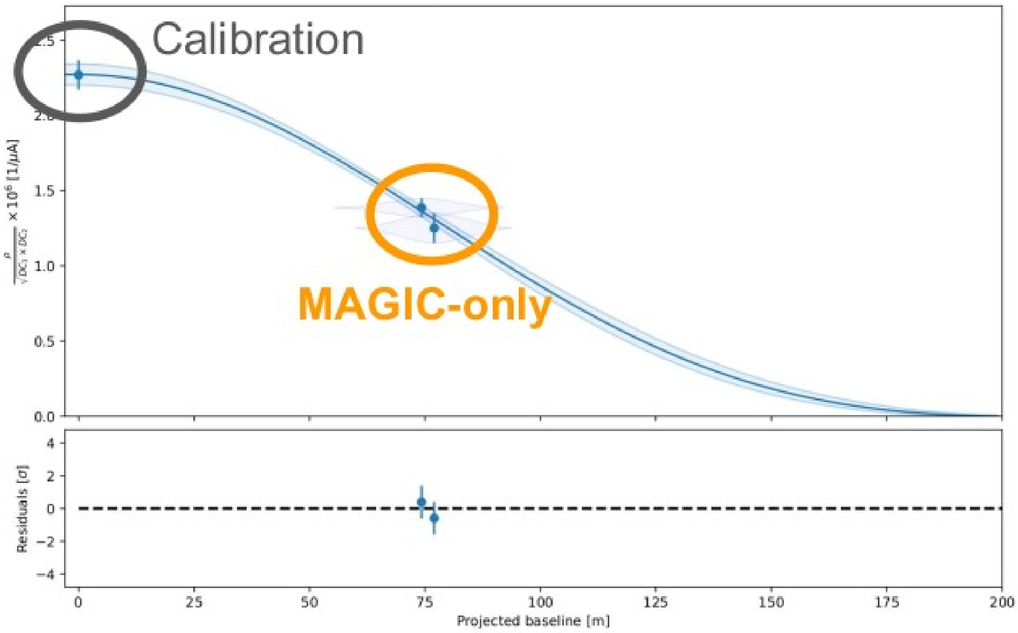
(and soon more will be coming)



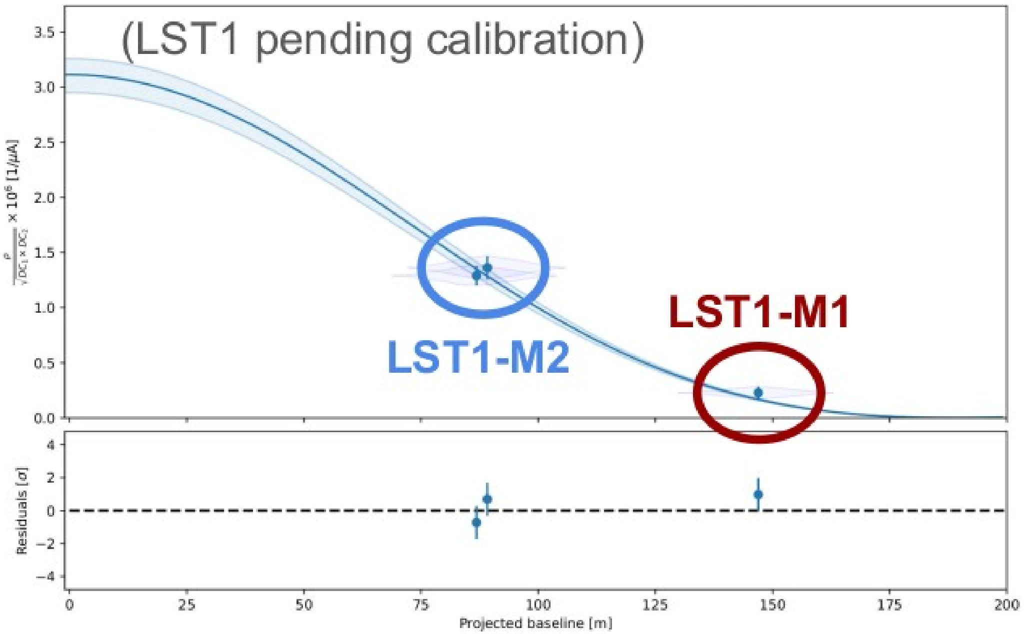
# MAGIC-SII → MAGIC-LST1-SII

- During MAGIC+LST1 observations we get 3 simultaneous correlations at the same time:

MAGIC-only measurement




MAGIC-LST1 measurements



# IACT-SII: Lesson III wrap up

- It is trivial to extract ZBC measurements from analysis files, and use these calibration ZBC files into other analyses

- Different ZBCs are expected from different pixels, so it is adviced to **never combine different pixel combinations into a single analysis**

  - Each different pixel pair should be analyzed differently
  - ZBC may not be perfectly stable: if you analize data over years, **careful**!

- MAGIC+LST1 data

# MAGIC+LST1: DISCLAIMER

- **CAREFUL!**
  - MAGIC+LST1 analysis is very recent, and still needs to be polished
  - Time-delay correction is “more or less” correct, but definitely needs to be improved (correlation signals won’t be nicely located at 0 yet)
  - Don’t trust these results yet. They did not undergo the long validation process of MAGIC-only data
  - Help to improve this analysis would be much appreciated!

# MAGIC+LST1: First steps

- The same way as with standard MAGIC data, the first step is to download data and DC reports
  - As soon as LST1 was connected to the correlator, we added the “LST1” tag in the raw files, but knowing which runs have LST1 pointing to a star **is not trivial**
  - Simplest method: Just check a file, that contains a list of all MAGIC+LST1 runs **magic_spysii/data/joint_magic-lst1_run_list.txt**

# MAGIC+LST1: First steps

- Easy to check which nights contain MAGIC+LST1 data:

joint_magic-lst1_run_list.txt

```
2024_09_15, Spectrum_XCorr_acc-6C4A-LST1-joint_500MSa_Buff_50Ohm_200mV_5min_del-Per_10002_20002_20240915T004358
2024_09_15, Spectrum_XCorr_acc-6C4A-LST1-joint_500MSa_Buff_50Ohm_200mV_5min_gam-Peg_10002_20002_20240914T230329
2024_09_15, Spectrum_XCorr_acc-6C4A-LST1-joint_500MSa_Buff_50Ohm_200mV_5min_gam-Peg_10002_20002_20240914T230835
2024_09_15, Spectrum_XCorr_acc-6C4A-LST1-joint_500MSa_Buff_50Ohm_200mV_5min_gam-Peg_10002_20002_20240914T231341
2024_09_15, Spectrum_XCorr_acc-6C4A-LST1-joint_500MSa_Buff_50Ohm_200mV_5min_gam-Peg_10002_20002_20240914T231846
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2024_09_15, Spectrum_XCorr_acc-6C4A-LST1-joint_500MSa_Buff_50Ohm_200mV_5min_gam-Peg_10002_20002_20240914T233403
2024_09_15, Spectrum_XCorr_acc-6C4A-LST1-joint_500MSa_Buff_50Ohm_200mV_5min_gam-Peg_10002_20002_20240914T233908
2024_09_15, Spectrum_XCorr_acc-6C4A-LST1-joint_500MSa_Buff_50Ohm_200mV_5min_gam-Peg_10002_20002_20240914T234414
2024_09_15, Spectrum_XCorr_acc-6C4A-LST1-joint_500MSa_Buff_50Ohm_200mV_5min_gam-Peg_10002_20002_20240914T234919
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2024_09_15, Spectrum_XCorr_acc-6C4A-LST1-joint_500MSa_Buff_50Ohm_200mV_5min_gam-Peg_10002_20002_20240914T235930
```

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  - As soon as LST1 was connected to the correlator, we added the “LST1” tag in the raw files, but knowing which runs have LST1 pointing to a star **is not trivial**

  - Simplest method: Just check a file, that contains a list of all MAGIC+LST1 runs **magic_spysii/data/joint_magic-lst1_run_list.txt**

  - Once you identify the nights you want to analyze, you need to download (again, **manually**!) LST1 DC reports

# MAGIC+LST1: First steps

- As with MAGIC DC reports, they need to be contained within each observing night

- The location of the reports is, from any machine with access to the fefs: ***/fefs/onsite/monitoring/cameraLST1/clusco/reports***

- So, in order to download reports from one night, you may:

```
 # For example, on night 2024_09_16, we make sure we have all reports from
the 15th and 16th:
 > scp tcs01:/fefs/onsite/monitoring/cameraLST1/clusco/reports/2024/monitor-
240915*.txt $MAGICSIIDATA/2024_09_16/
 > scp tcs01:/fefs/onsite/monitoring/cameraLST1/clusco/reports/2024/monitor-
240916*.txt $MAGICSIIDATA/2024_09_16/
```

# MAGIC+LST1: First MAGIC+LST1 analysis

- Once you have both MAGIC and LST1 DC reports, you have everything you need to start analyzing M1-LST1 and M2-LST1 correlation channels

    - In addition to M1-M2 productions, also launch the 2 additional productions (the same way, with `sii_production`)

    - Note the baseline coverage of these new correlation pairs may be very limited, and not enough to evaluate ZBC correlation properly

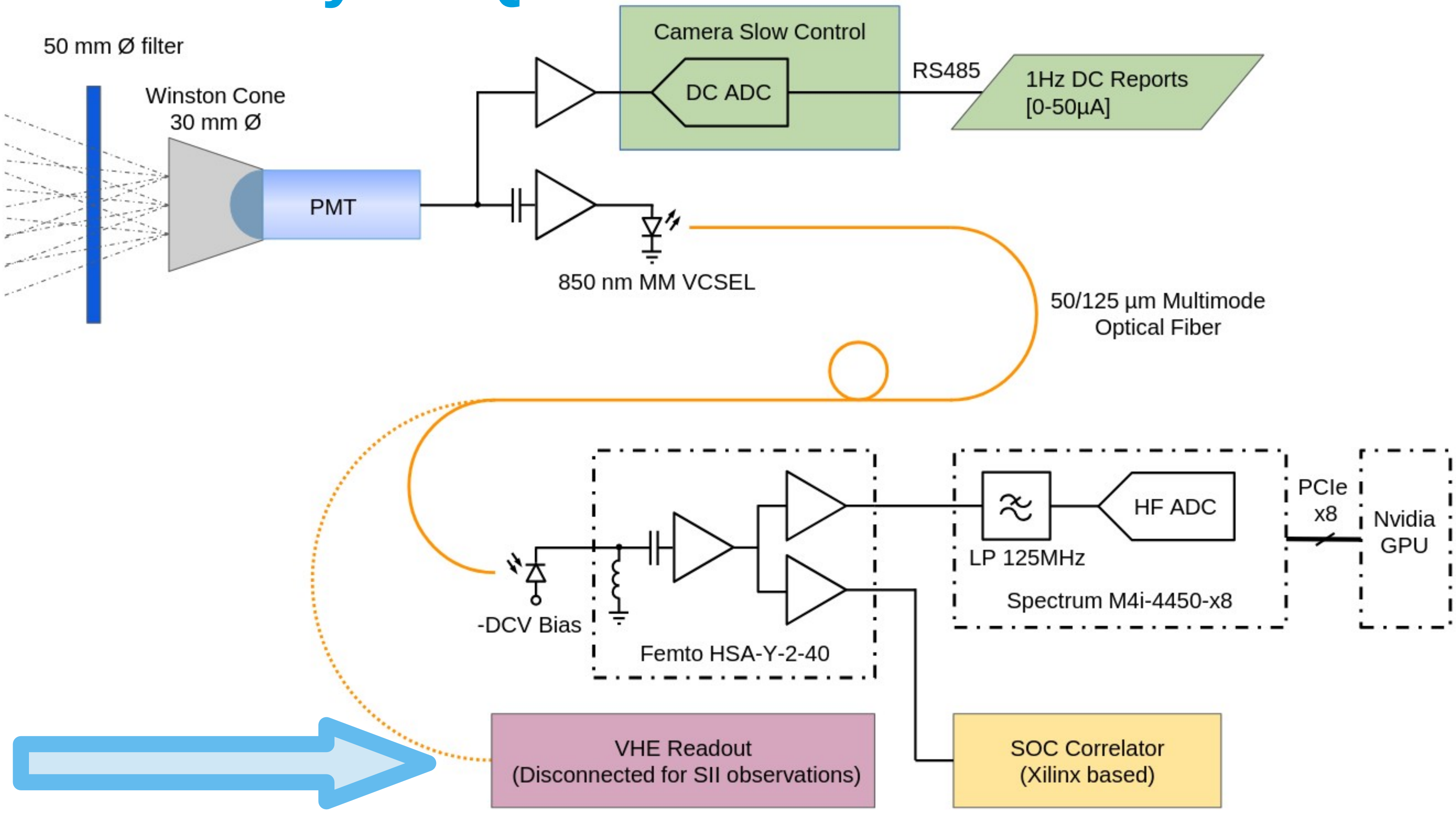
    - As time-delay correction is not yet perfect, correlation signals may be "far" from 0 (up to 8/9 ns). This means you may need to modify the default values within the config file: `peak_fitting_parameters → time_delay_bounds`

# IACT-SII: Lesson III – Proposed exercises

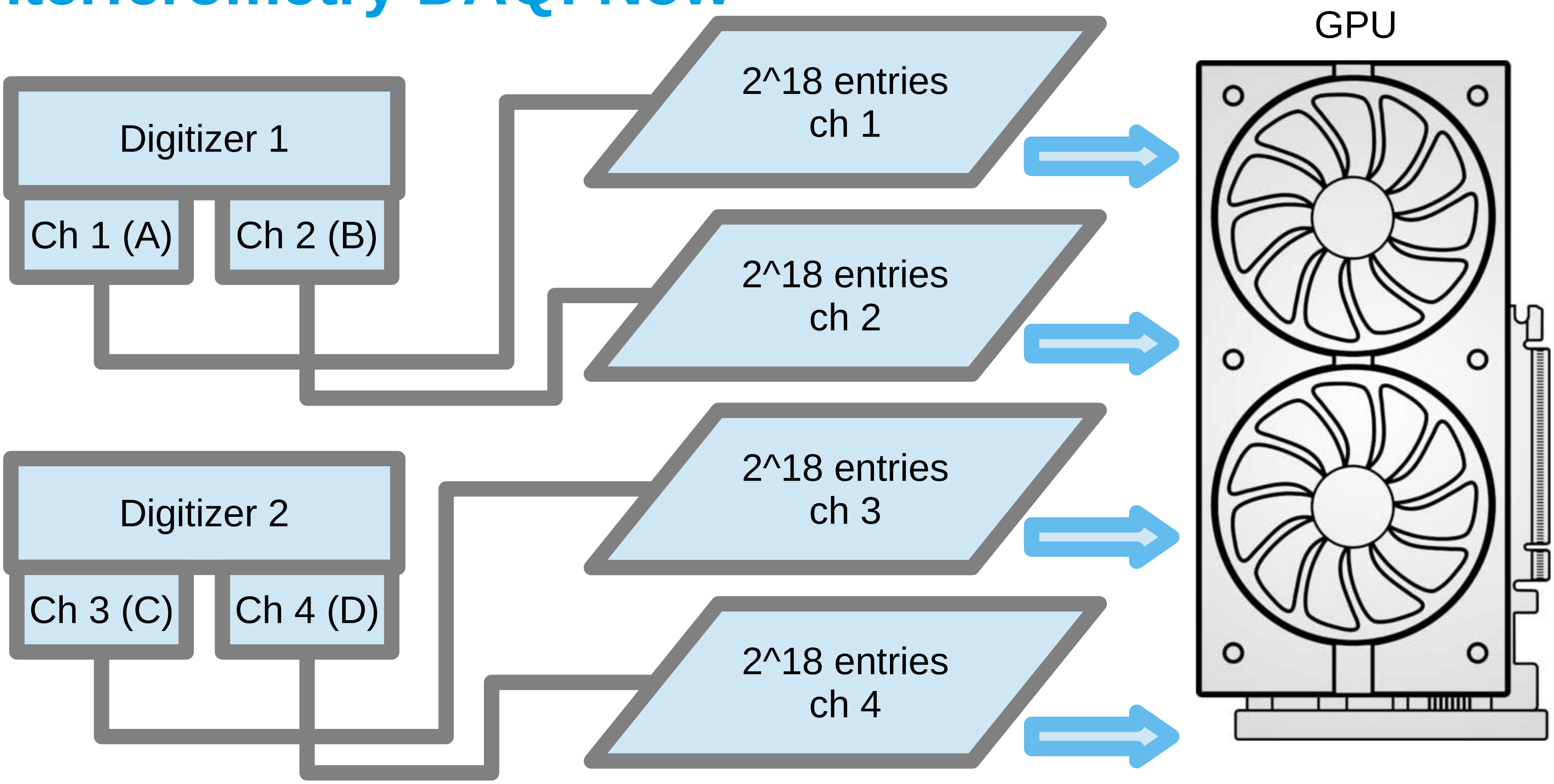
- Download more nights from Adhara (“chronologically”), ensuring you increase its baseline coverage
    - This should significantly improve ZBC determination
- Extract it’s ZBC using the executable
- Use the new ZBC calibration file to analize another source. Also try to analize the source without the ZBC. See the difference!
- Identify nights of MAGIC+LST1 data, and download some DC reports from the night. Pick a source (with MAGIC+LST1 data), and perform 3 analyses, one from each correlation pair


BACKUP

# Interferometry DAQ

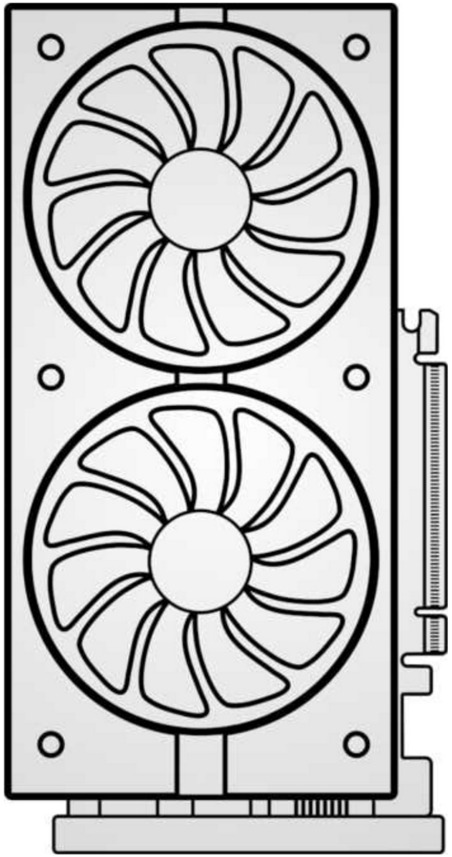


# Interferometry DAQ: Now



# Interferometry DAQ: Now

GPU



- 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**