A luminous measuring tape

A different approach to taking students to the Milky Way and beyond with Gaia

Arndt Latusseck
Gymnasium Josephinum, Hildesheim
Haus der Astronomie, Heidelberg
arndt.latusseck@josephinum.net
2021/06/02

„How can we gather knowledge about the 3D structure of the local universe?“

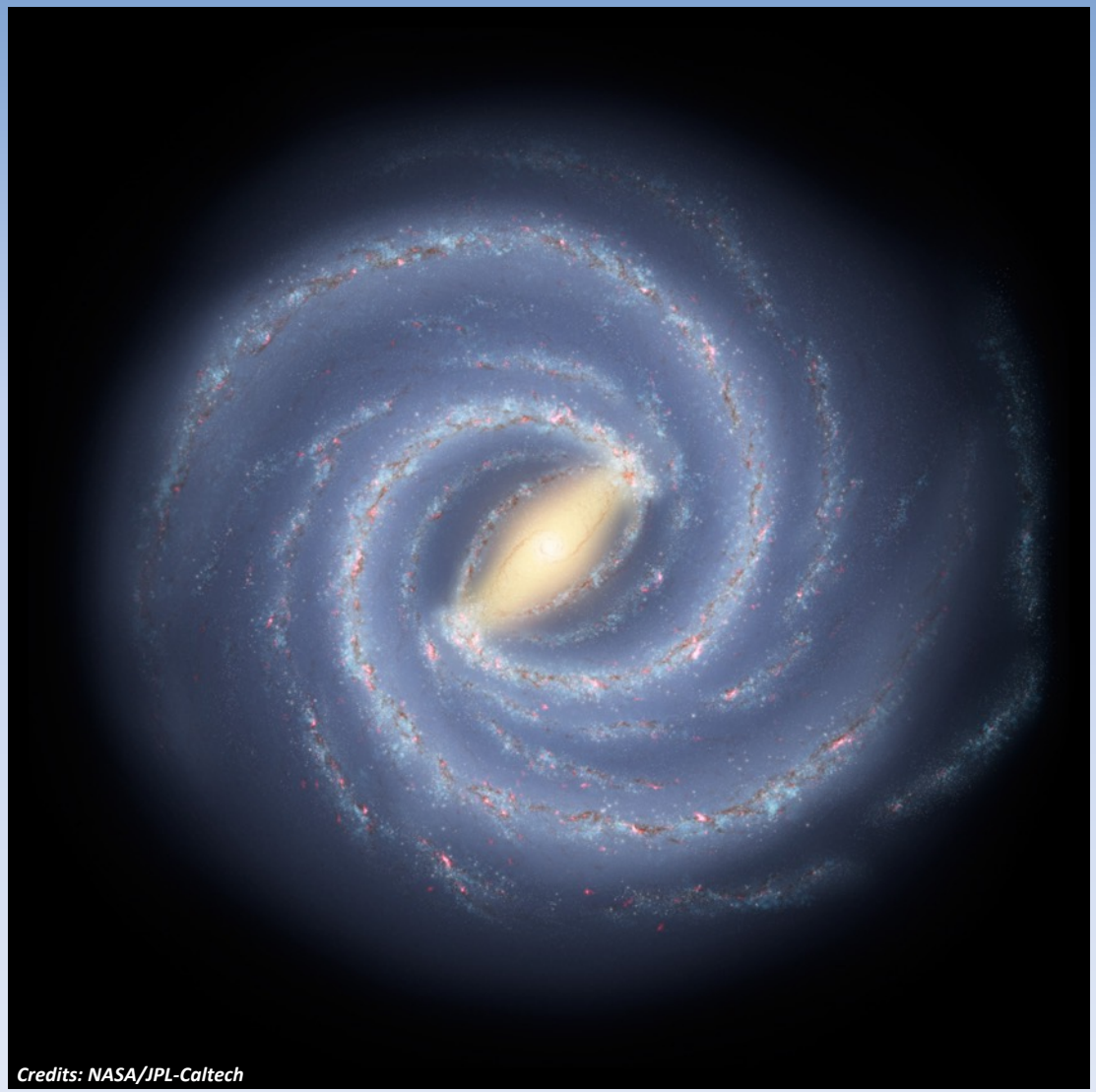
„3D structure“ ➔ Distance to important structure markers must be known

„*Astrometry first*“?

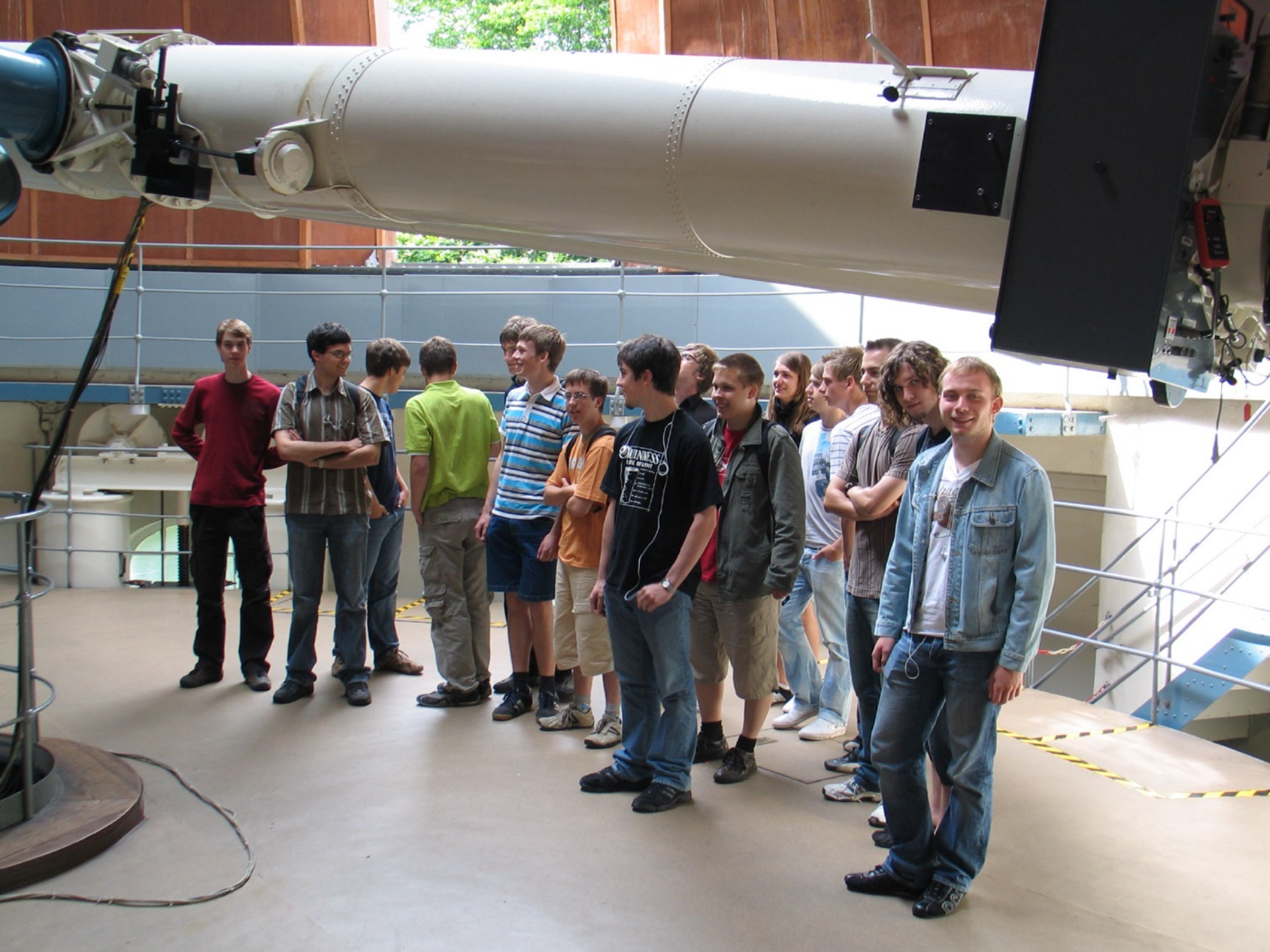
But what about high school student‘s perspective?

What is their background?
None

What ist their inspiration?
Pure curiosity



Credits: NASA/JPL-Caltech



Using the student‘s view: Let them marvel – let them measure – let them learn

„What‘s in a picture?“

1) star counts

2) apparent brightness / color

3) position → parallax

Star counts are easily performed without prior knowledge (could even be done without catalogues!).
Stellar brightness (and color – CI) is the first and easiest *stellar property* measurable by students ;
position and parallax follow up (concept of RA/Dec or l/b).
Remember: Distance is the first *derived* stellar property, thus not immediately apparent!

The fundamental question

„What can students learn about our local galactic volume by just using stellar brightness and color?“

Objective remains unchanged:

- **Develop a general concept of distance measurement techniques to the Milky Way and beyond using Gaia data – <u>avoiding positions and parallaxes as long as possible</u>**

Secondary objectives:

- Let students follow the learning process of classical astronomy:
  Herschel/Kant – Kapteyn – Oort – modern days
  (Remember: The early astronomers had no useable astrometric data / available techniques apart from stellar statistics and photometry)
- Develop a relative distance scale of objects in the Milky Way and beyond
- Finally link the relative distances to a common zero point

What‘s needed?

+

+

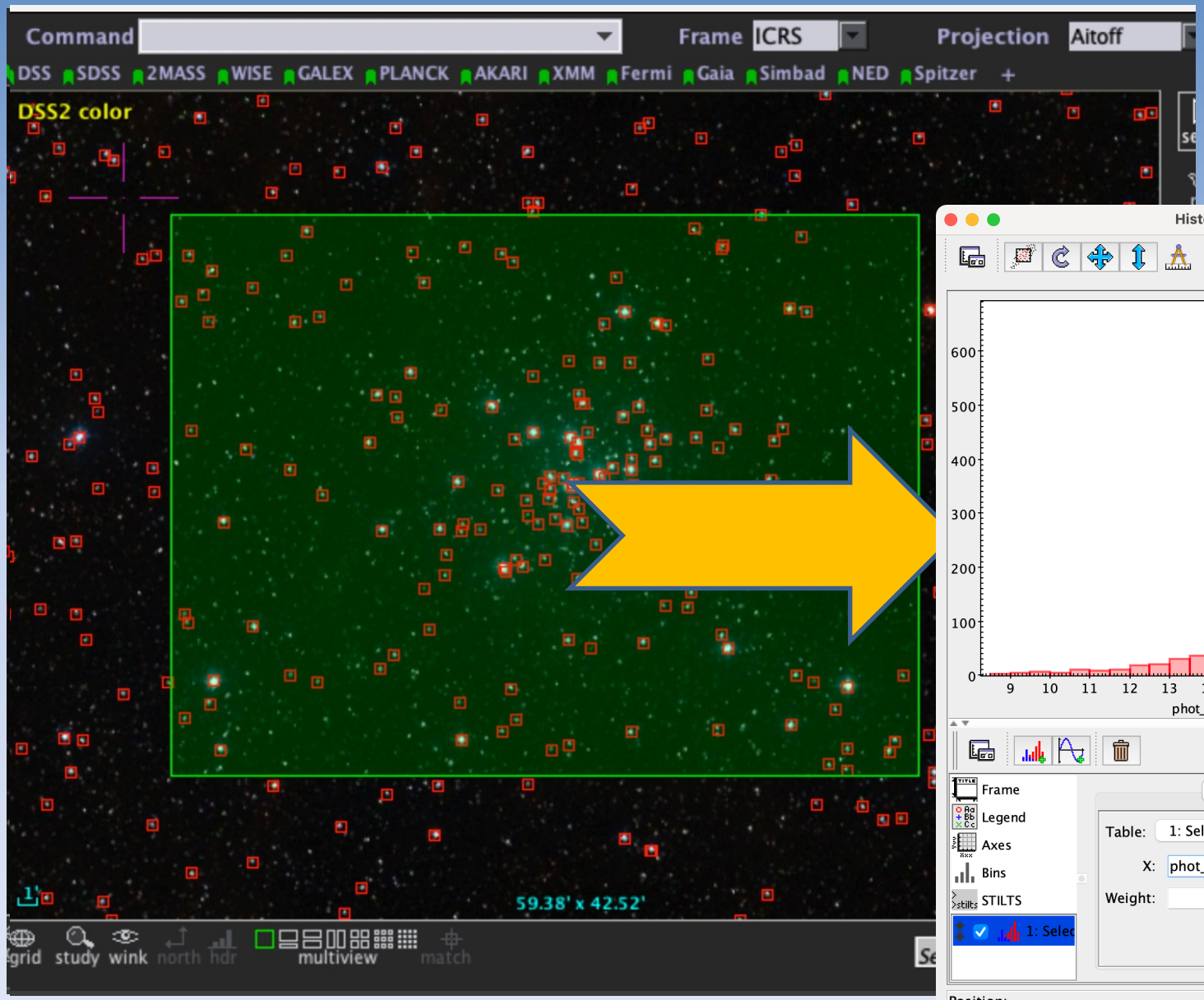
The data (DR2)
„static data“

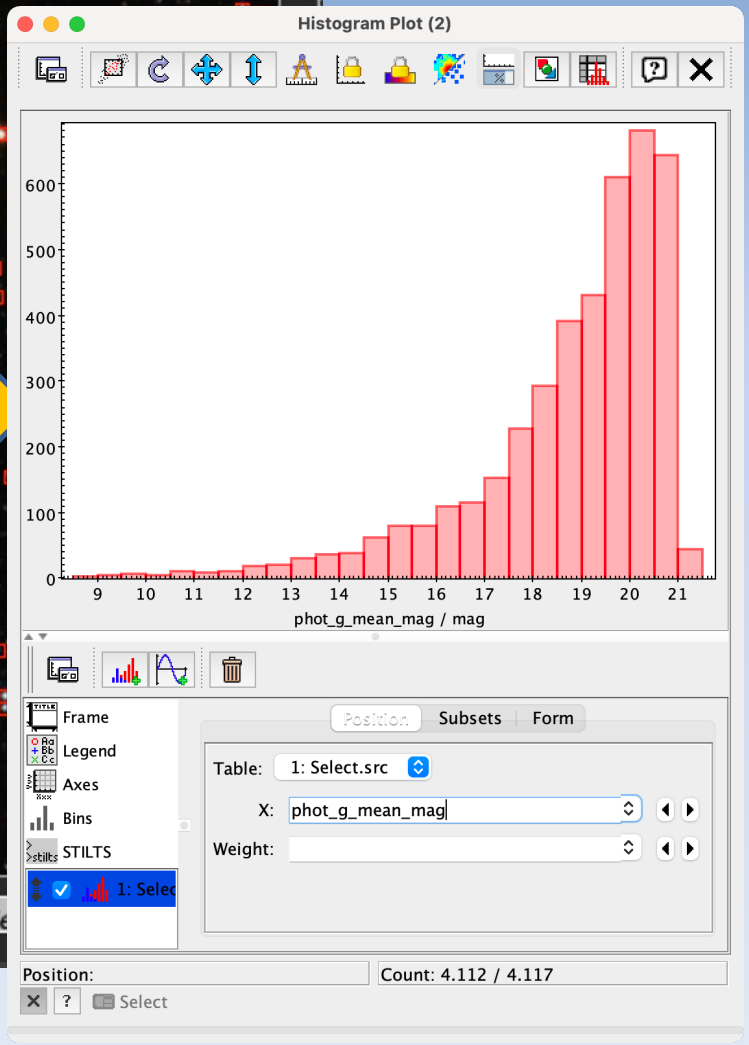
The observatory

The workbench

Prerequisites:

Simulating „real“ quantitative observations: Gaia /Aladin / topcat



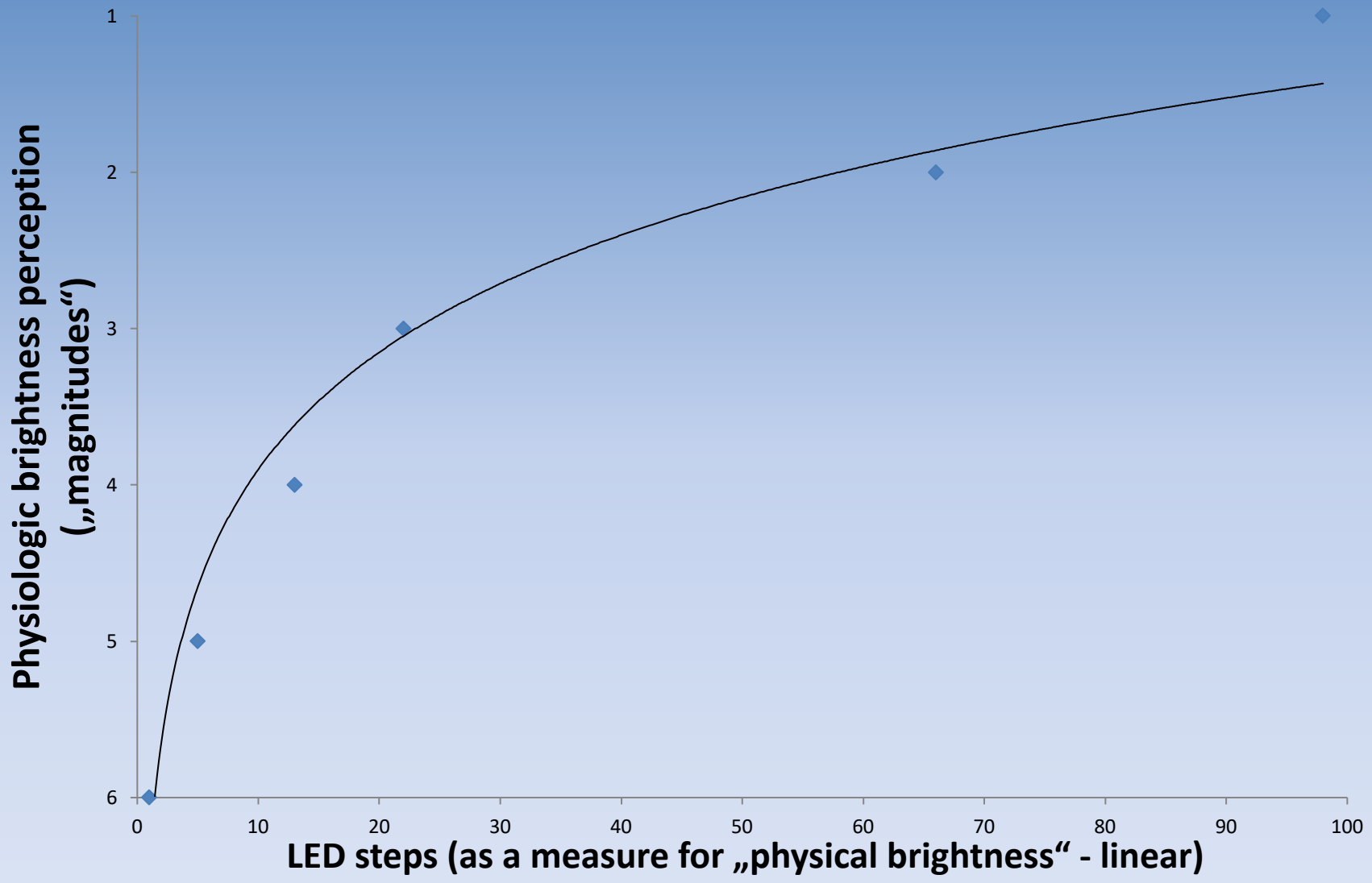


Using stellar brightnesses – introducing the magnitude system

s://apod.nasa.gov/apod/image/1301/M35-DW.jpg

Linking physical to physiological brightness: “Magnitude box“

Project: Physiological Weber-Fecher law with the Magnitude Box



Introducing the relative distance modulus

Concepts:

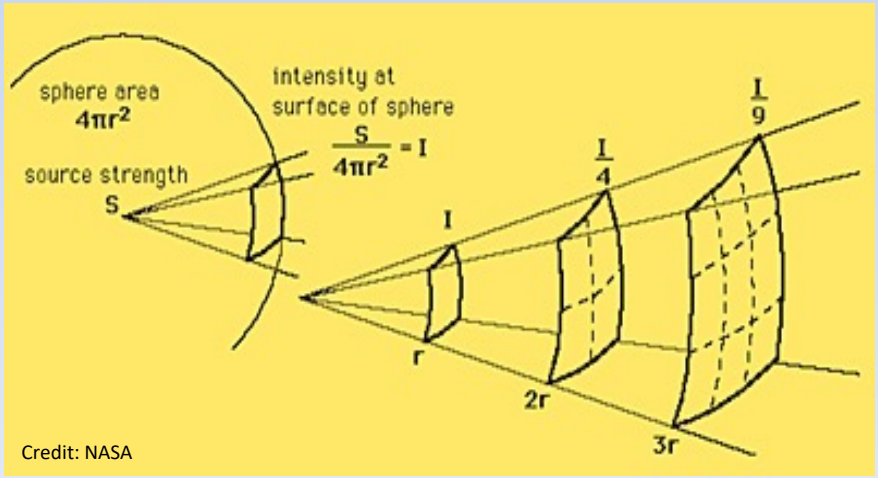
- Apparent stellar brightness links (linear) physical brightness with Magnitude system

Pogson's law (from Magnitude Box):

$$\frac{I_1}{I_2} = 2.512^{m_2 - m_1}; \qquad m_2 - m_1 = -2.5 \lg\left(\frac{I_1}{I_2}\right)$$

By applying the $\frac{1}{r^2}$ law, we obtain the **relative distance modulus**

$$\frac{r_2}{r_1} = \sqrt{2.512^{m_2 - m_1}}$$

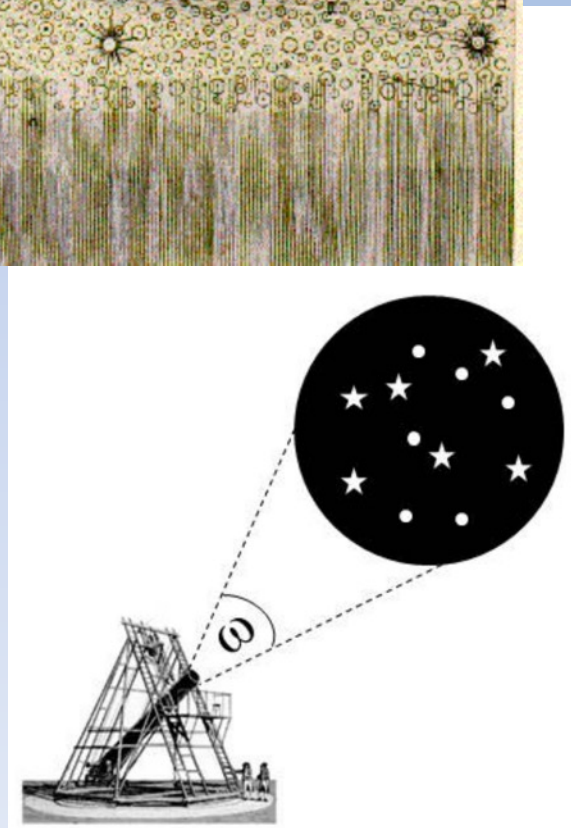


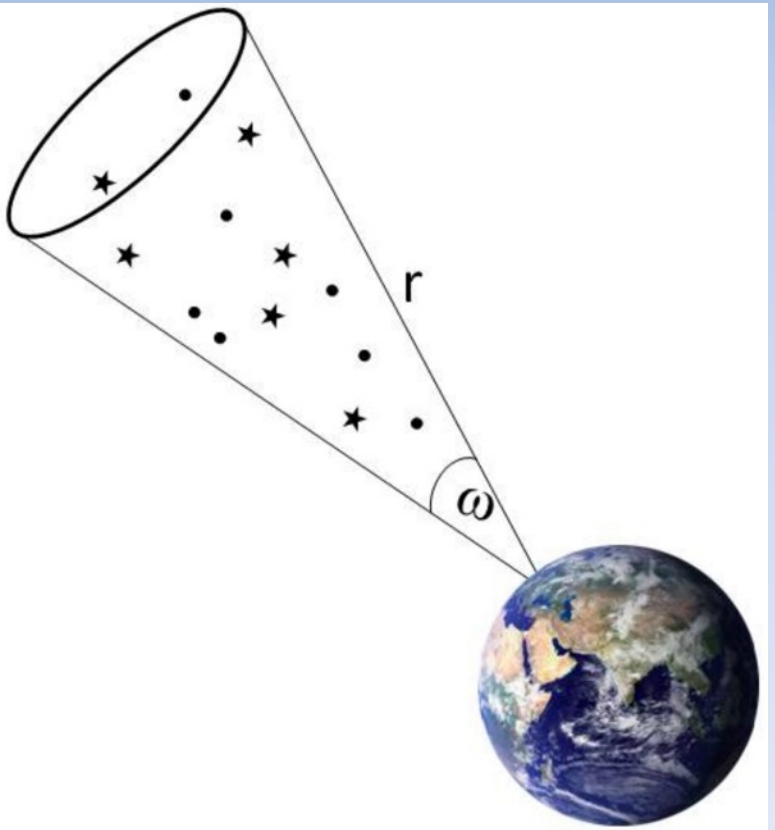
Project ideas with Gaia...

Project: William Herschel‘s Milky Way (1785)

Prior knowledge: Just star numbers, topcat; no stellar (apparent) brightnesses

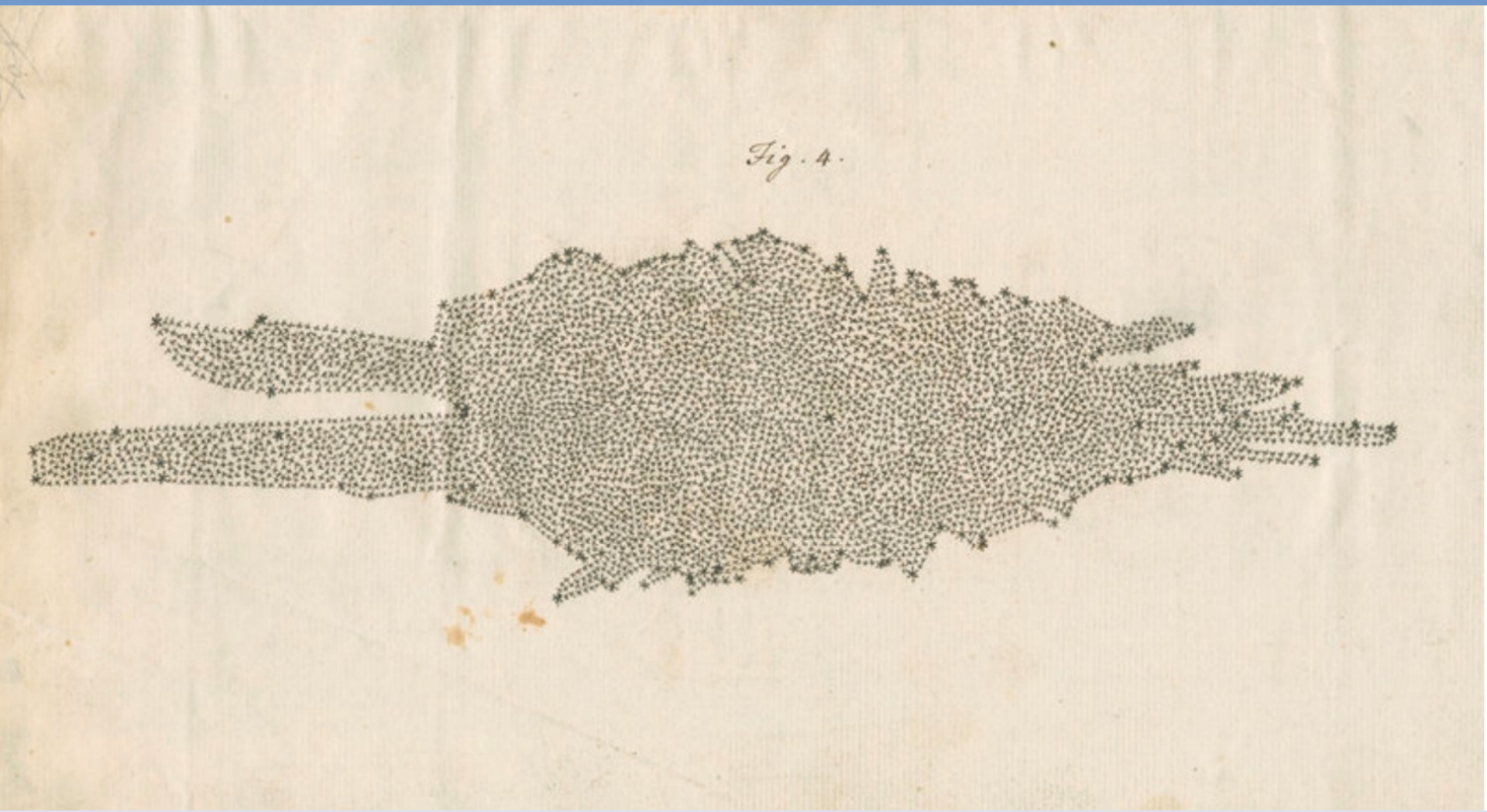
Herschel‘s „star gauges“





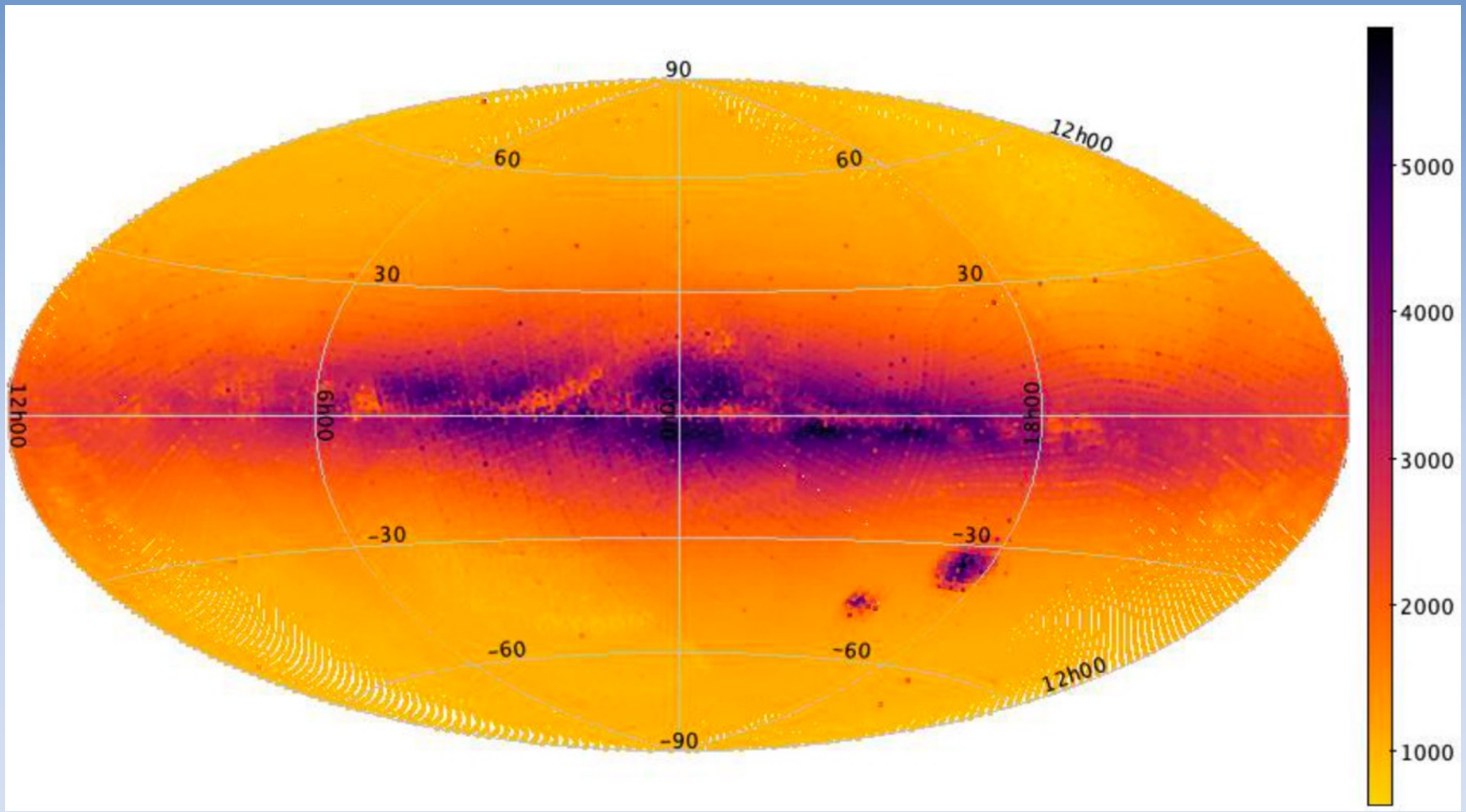
Project: William Herschel‘s Milky Way (1785)

Herschel‘s iconic Milky Way map:



Project: William Herschel‘s Milky Way (1785)

Star density map with Gaia‘s DR2 and healpix tiles



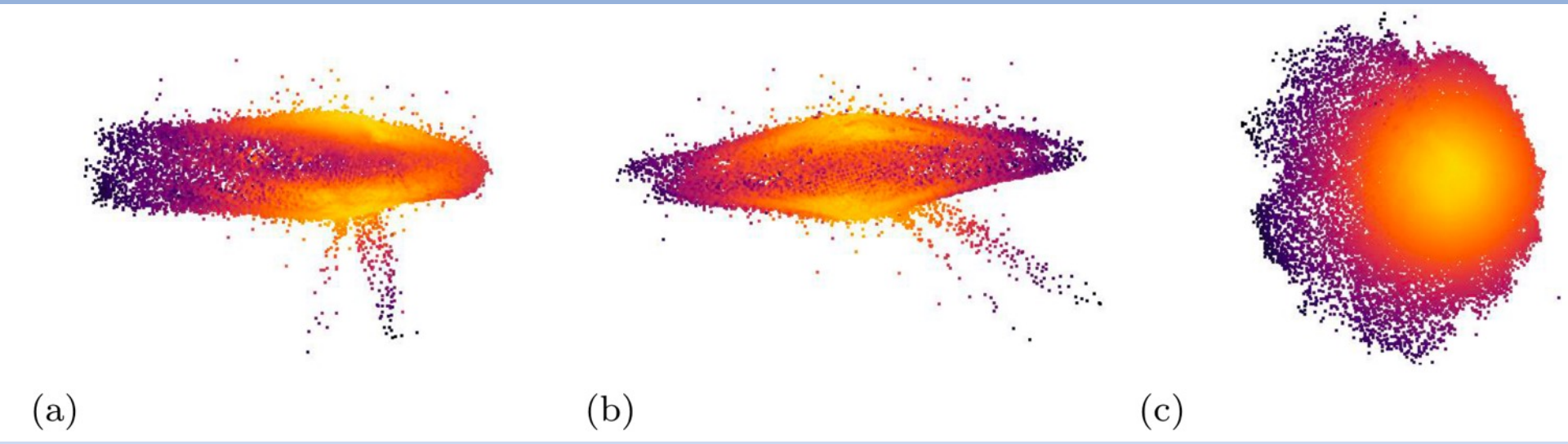
$$V \approx \frac{1}{3}\pi r^3 tan^2\omega$$

$$r = k \times \sqrt[3]{\frac{3N}{\pi tan^2\omega}}$$

Star numbers / Gaia DR2 Healpix n=64

Project: William Herschel‘s Milky Way (1785)

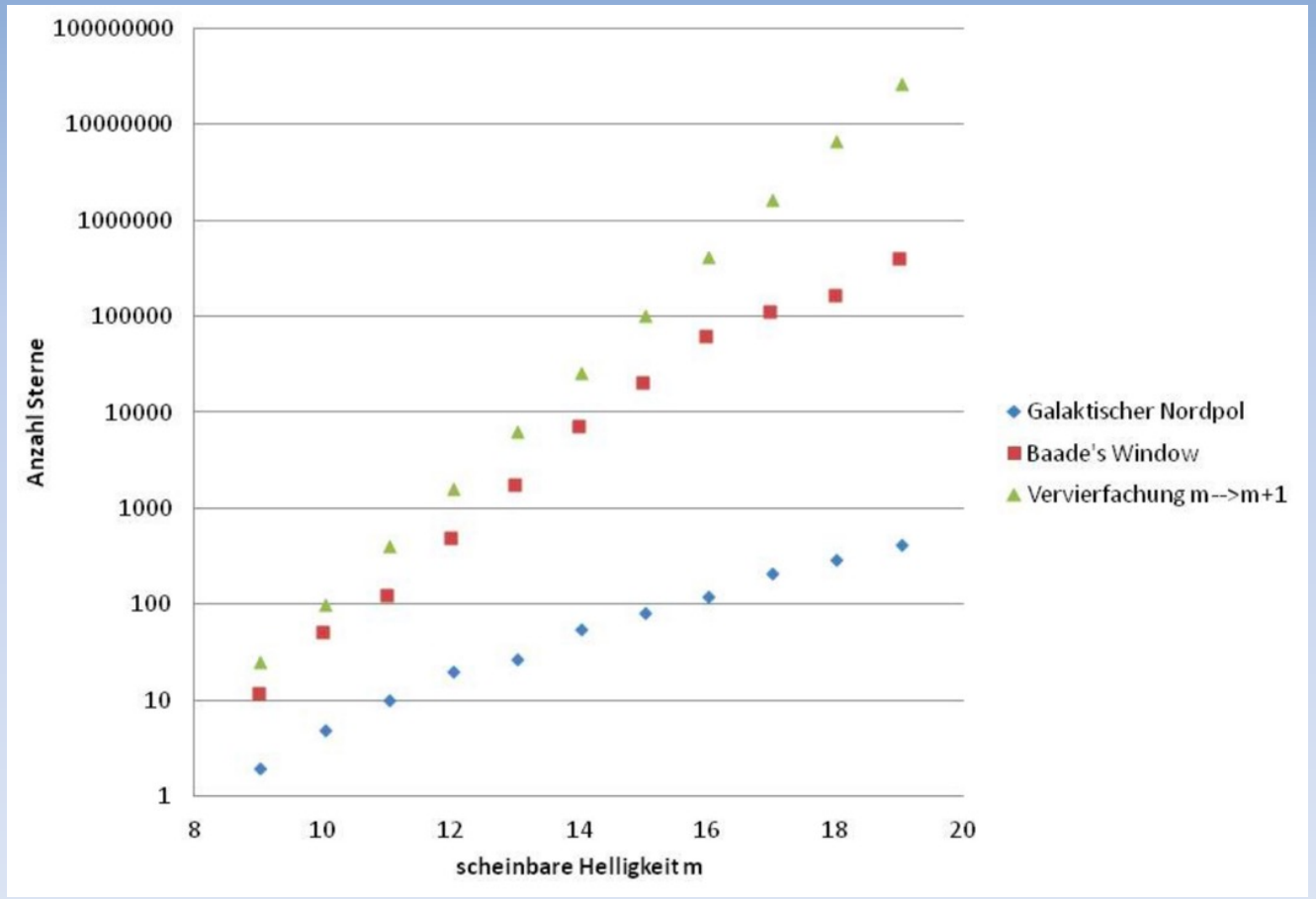
The result: A 3D „Herschel Milky Way“



Project: Kapteyn-Universe (1905) and first hints to interstellar absorption

Prior knowledge: Apparent brightness (magnitude scale), Aladin, topcat

Star numbers *N* in an ideal, homogenic Milky Way (constant star density)
in a certain field of view grow with increasing apparent magnitude *m* (green curve):
$N(m) \sim 4^m$

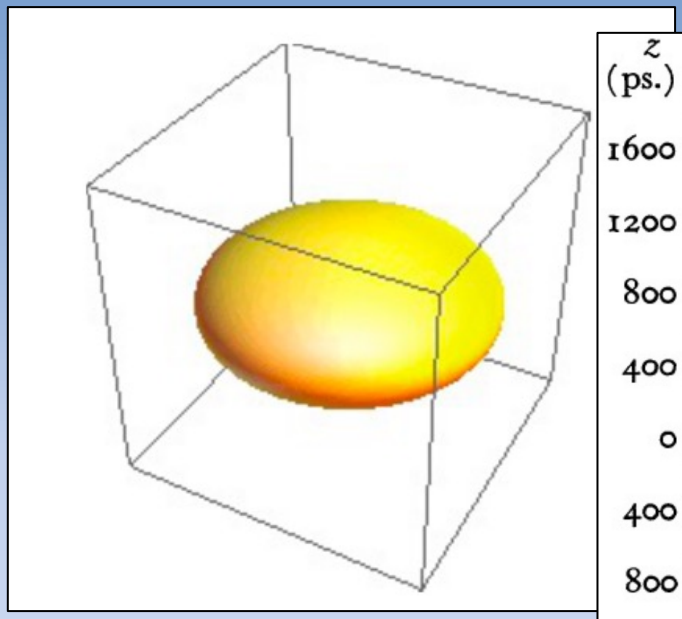


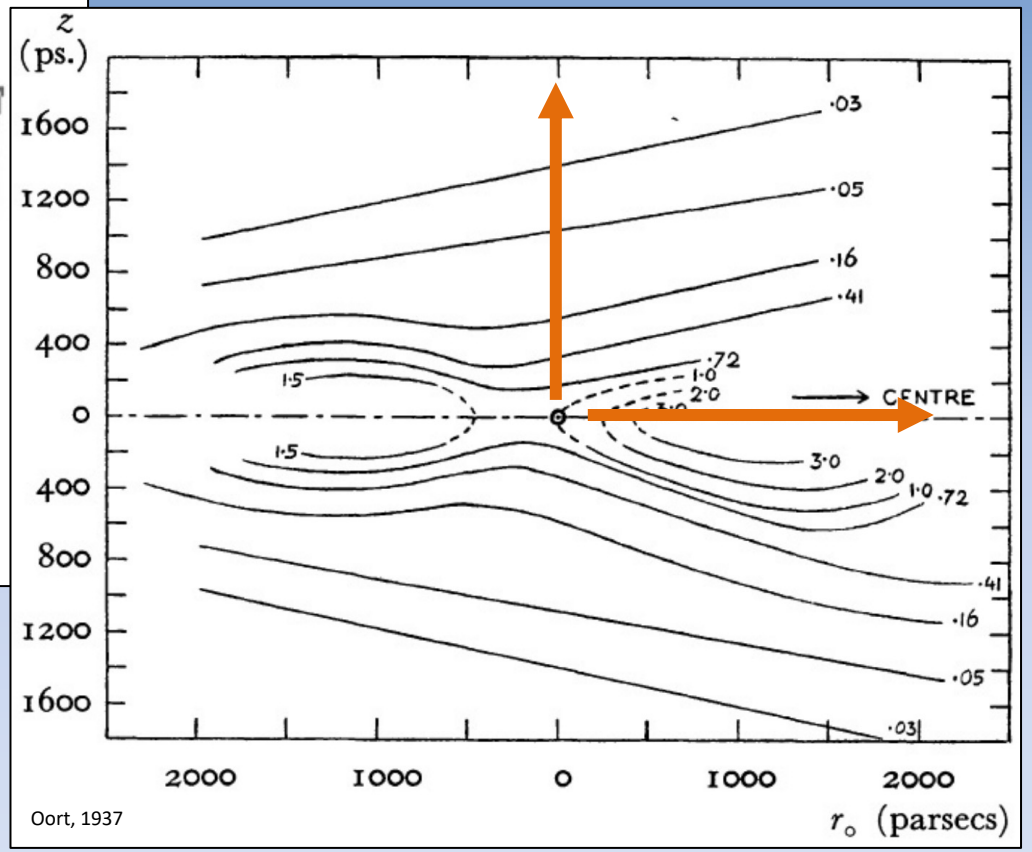
Star numbers in Baade‘s window (MW plane, red, 1deg fov): $N(m) \sim 3^m$

Star numbers at North Galactic Pole (blue, 1deg fov): $N(m) \sim 1{,}63^m$

Project: Kapteyn-Universe (1905) and first hints to interstellar absorption

Apparent consequence of slower number growth:
Star numbers seem to decrease in every direction away from the sun (*Kapteyn universe*).





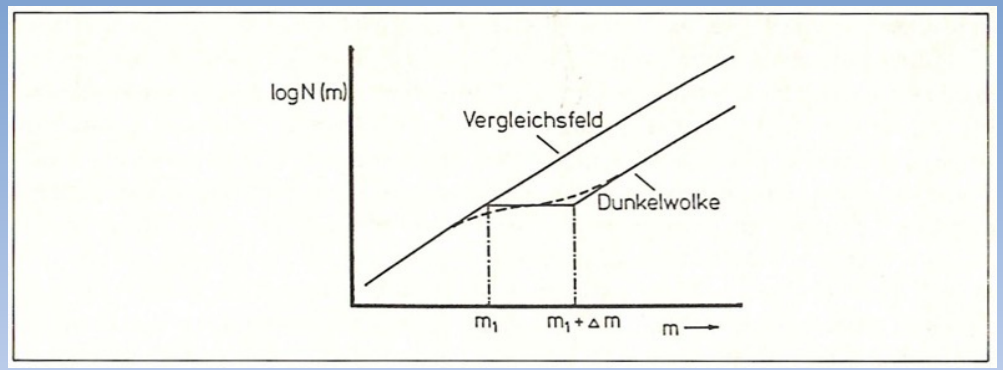
And they do! But only perpendicular to the galactic plane (exponential law).

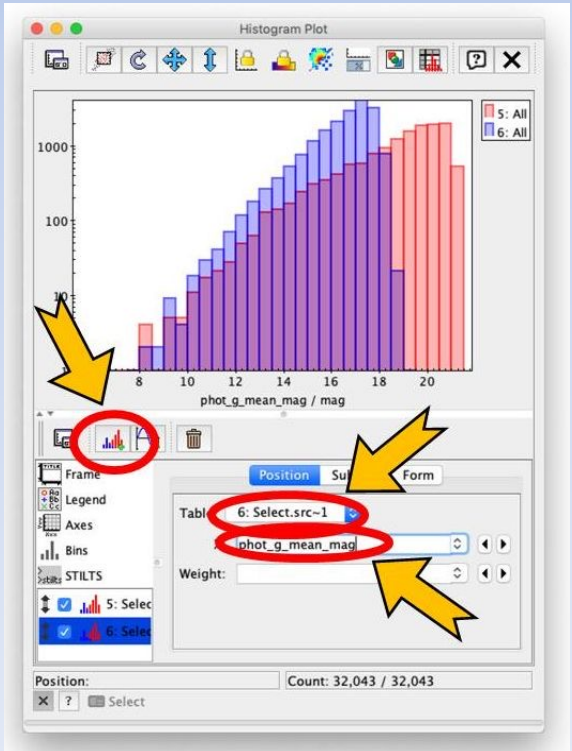
Galactic plane: Something‘s wrong... it‘s interstellar absorption!

Project: Wolf Diagrams: More evicende for interstellar absorption

Prior knowledge: Apparent brightness (magnitude scale), Aladin, topcat

Compare two adjacent fields: One „dark“ field, one „bright“ field
Result: Vacancies in certain areas of the Milky Way are caused by obscuration





Core concept:
comparing like with like

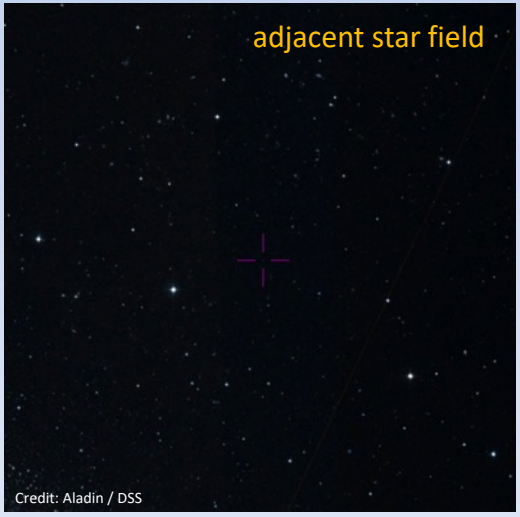
s://apod.nasa.gov/apod/image/1301/M35-DW.jpg

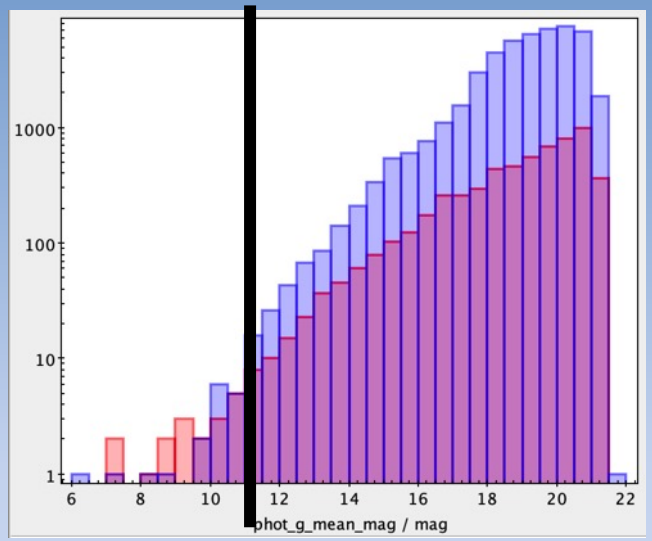
Project: Relative distance of two globular clusters (*comparing like with like*)

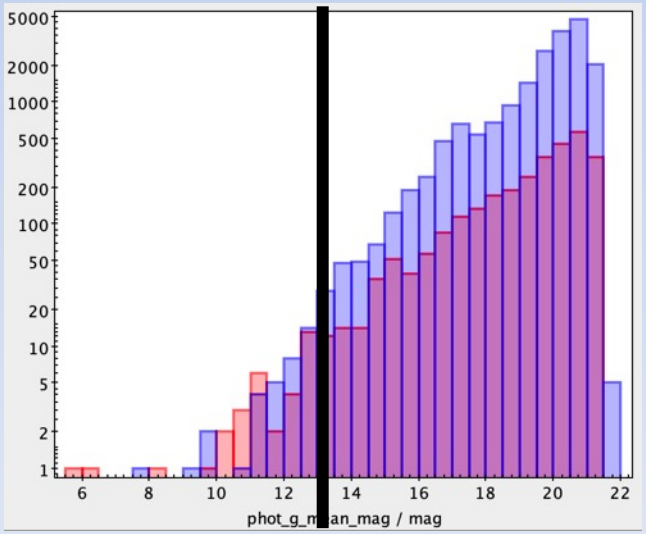
Prior knowledge: Apparent brightness (magnitude scale), Aladin, topcat

Hypothesis: All globular clusters are similar.

We compare the brightest stars of globulars M13 and M53. How can we find them?





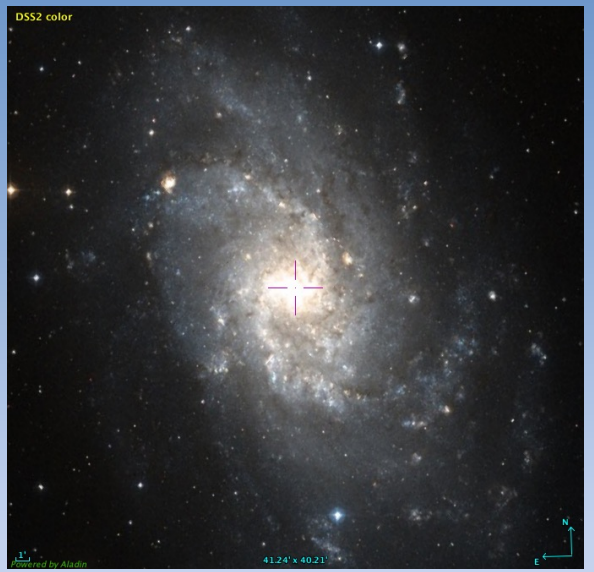


$$m_2 - m_1 \approx 2\,mag \quad \rightarrow \frac{r_2}{r_1} = \sqrt{2.512^{m_2 - m_1}} \approx 2.5$$

Catalogue values: $\frac{r_2}{r_1} \approx 2.63$

Project: Relative distances of four spiral galaxies (*comparing like with like*)

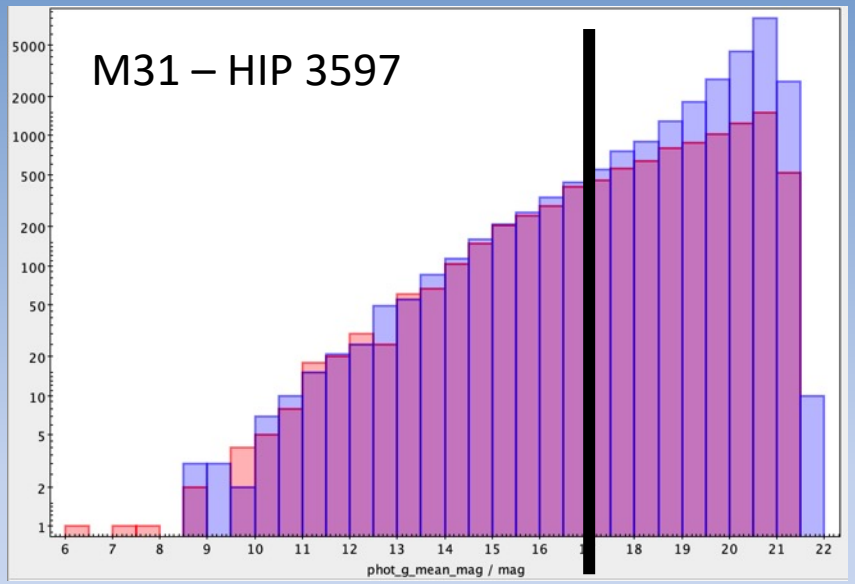
Prior knowledge: Apparent brightness (magnitude scale), Aladin, topcat

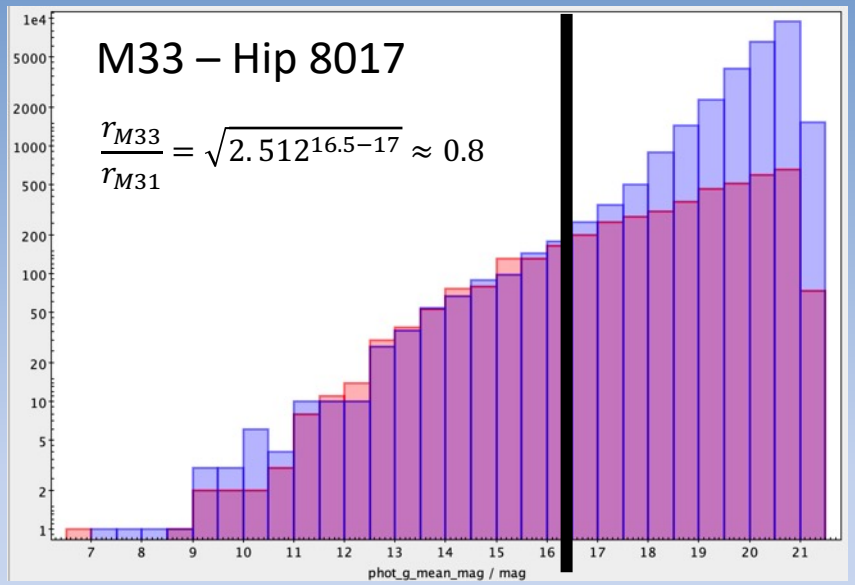


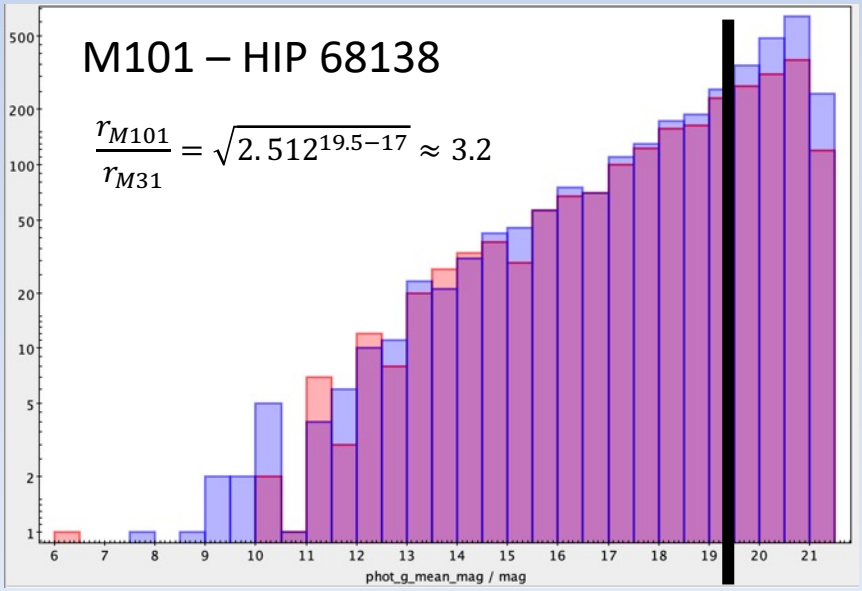
Project: Relative distances of four spiral galaxies (*comparing like with like*)

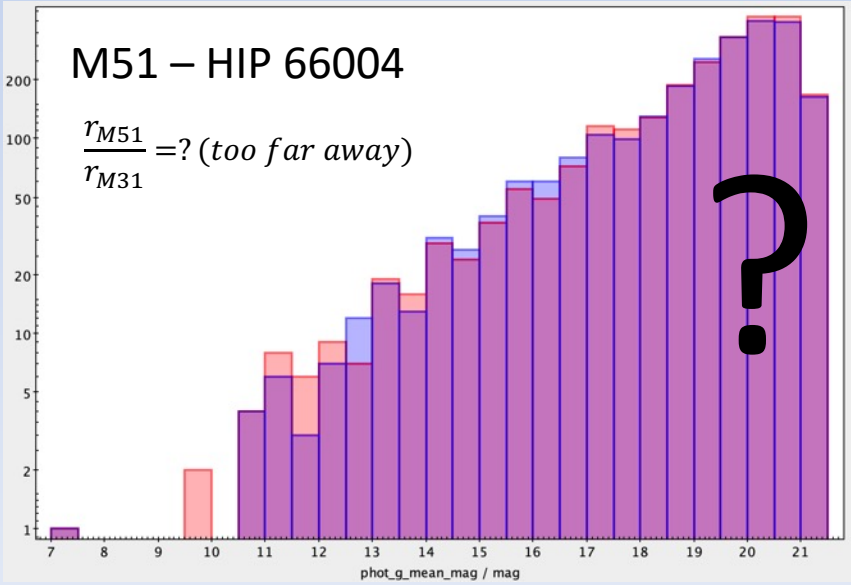
Prior knowledge: Apparent brightness (magnitude scale), Aladin, topcat

„Adjacent star field method“ similar to globular distances...





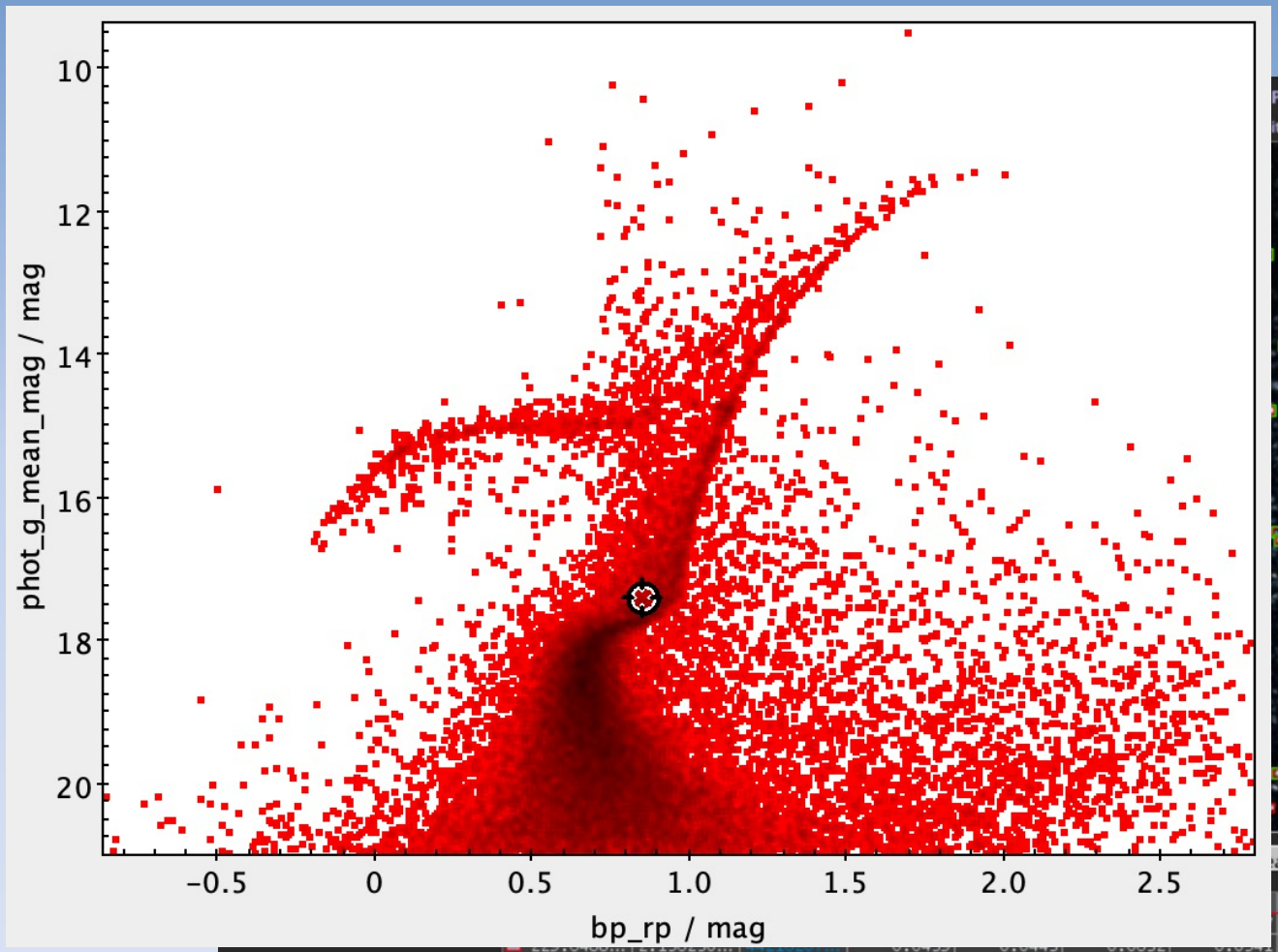


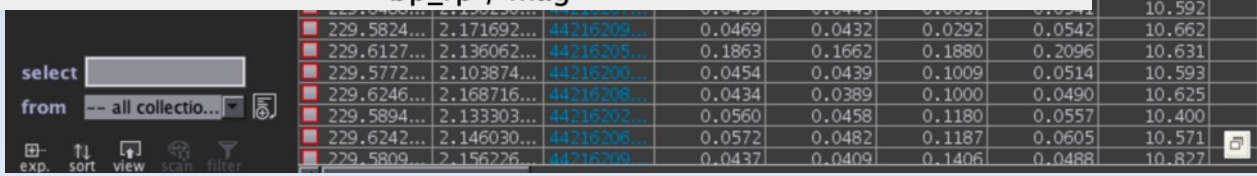


Photometry project: Discovering the HRD

Prior knowledge: Apparent brightness (magnitude scale), colour (CI), Aladin, topcat

Let students discover the HRD – by themselves ➔ CMD as a mere *observational* feature

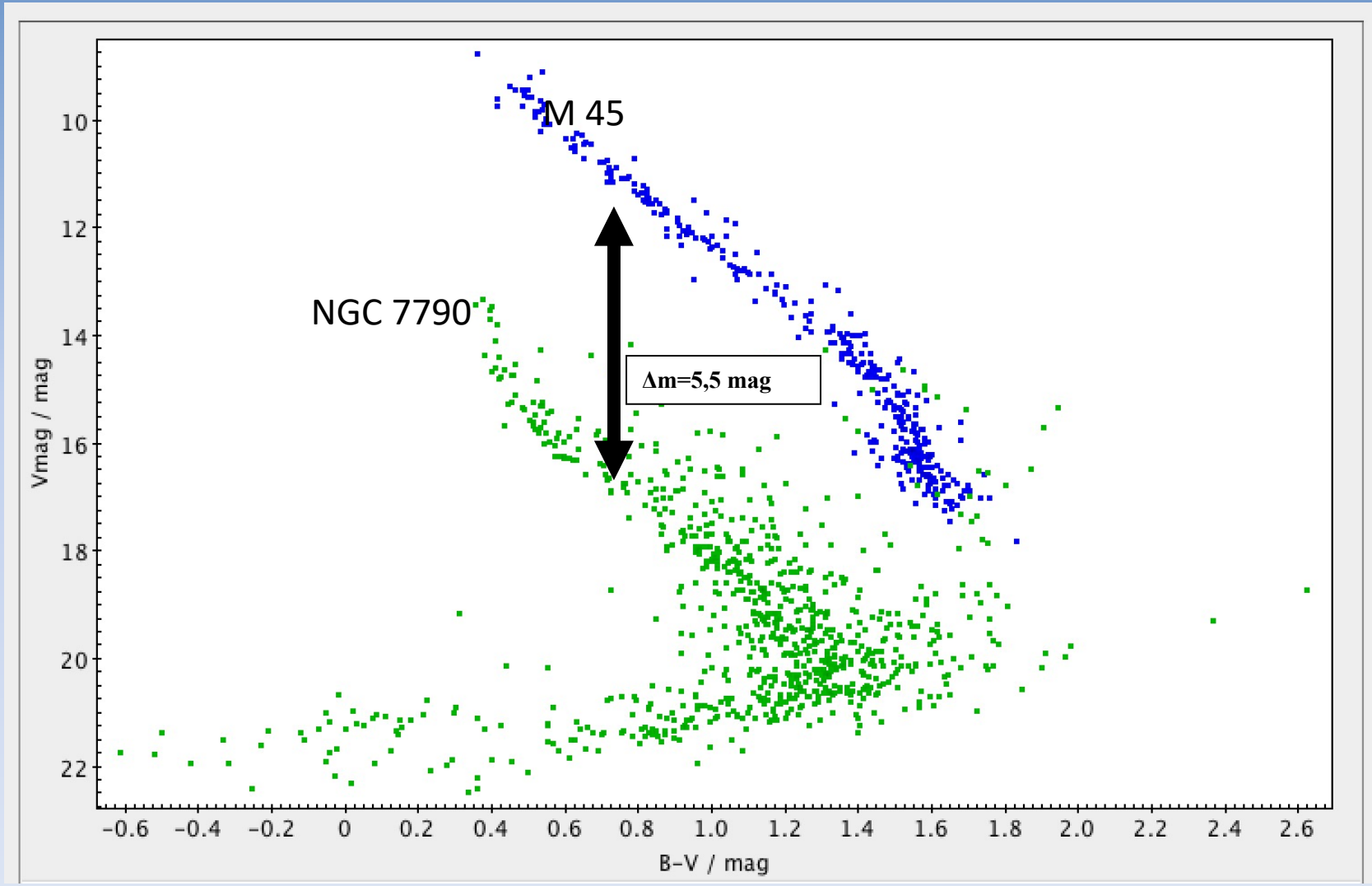




Project: Relative distance of M45 and NGC7790 (*comparing like with like)*

Prior knowledge: Apparent brightness (magnitude scale), colour (CI), Aladin, topcat

Relative distance of M45 and NGC7790

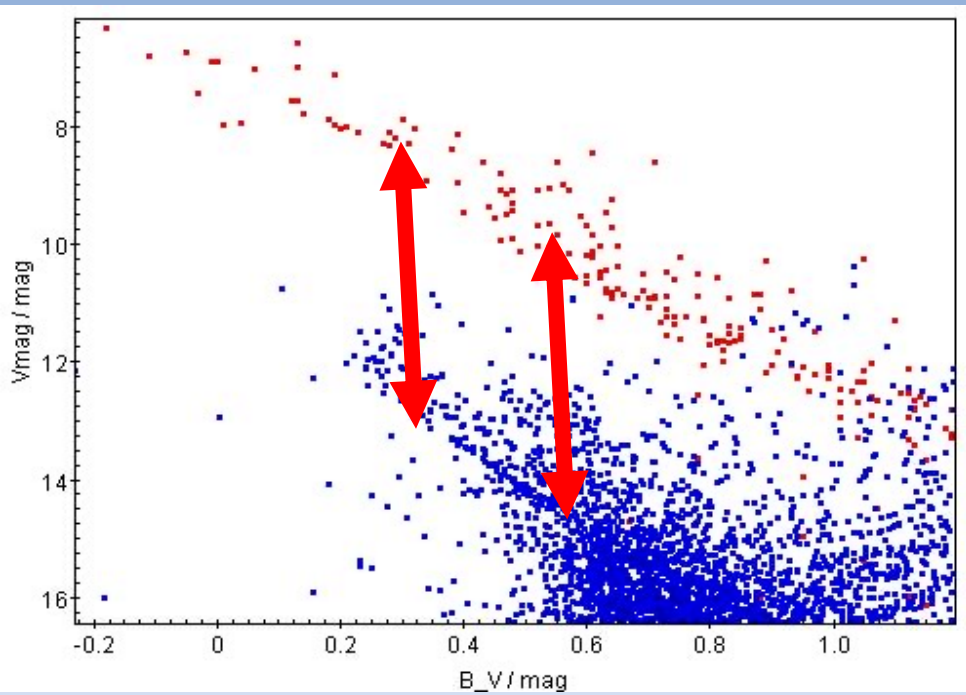


Relative distance modulus (remember: no zero point): $m_2 - m_1 = 5,5;$ $\frac{r_2}{r_1} \approx 12,5$

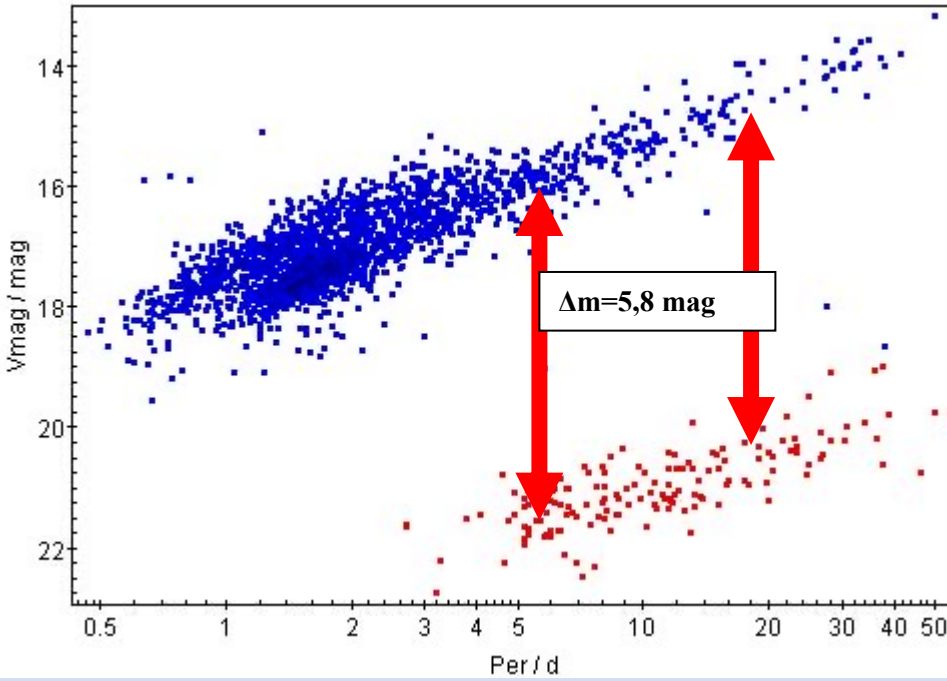
Project (non-Gaia): Using stellar subgropus for relative distance measurements *(comparing like with like)*

Sub-populations: Cepheids

comparison of two open cluster CMDs



comparison of two
period-luminosity diagrams (SMC, M33)

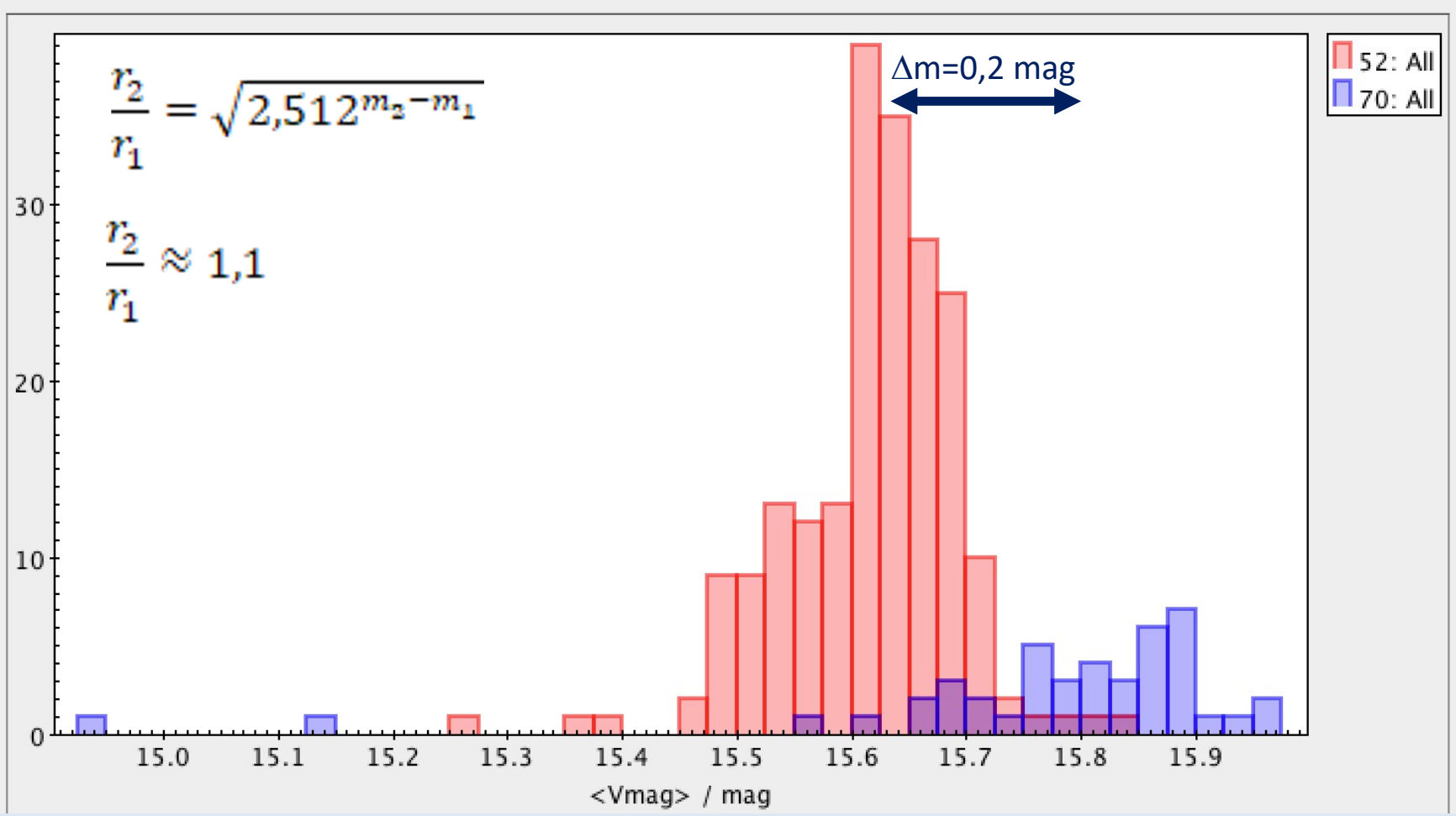


$$\frac{r_2}{r_1} = \sqrt{2{,}512^{m_2 - m_1}} \qquad \frac{r_2}{r_1} \approx 14{,}5$$

Project (non-Gaia): Using stellar subgropus for relative distance measurements *(comparing like with like)*

Sub-populations: RRLyr stars

Relative distances of M3 (red) and M15 (blue)



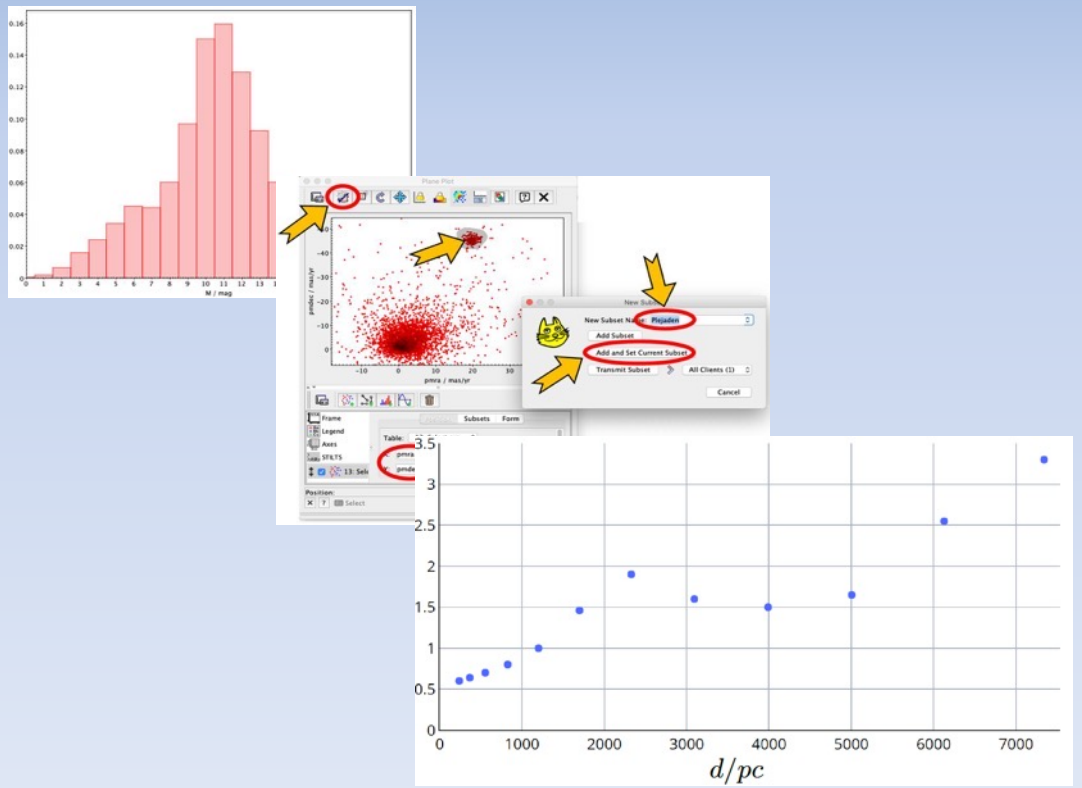
Outlook

Now that the students have learned about measuring relative distances on a galactic scale with Gaia data, the next step would be to link them to absolute distances. Only then can the structure of the Milky Way be revealed quantitatively. This is the moment when Gaia‘s trigonometric parallaxes become important.

Once the concept of **absolute magnitudes** has been introduced, the students may proceed to more advanced topics.

<u>Further student projects include:</u>

- Revealing the stellar luminosity function in the solar neighbourhood
- Getting deeper insights into the structure of open cluster CMDs
- Finding density maxima in the stellar distribution in certain directions (Scutum cloud)



Summary

- Use basic stellar statistics to let students practise concepts of data evaluation / data mining
- Let them use Gaia‘s catalogues as their primary scientific data source
- Let them get as close to „real observing“ (through Aladin) as possible.
- Let students discover basic structures, as cluster CMDs, as a result of observation, rather than theorization
- Make use of the principle *compare like with like*
- Introduce absolute distances only after the relative dimensions of the Milky Way have been established.