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Is the Earth Flat?

or...

Four considerations for the Copernican Academy

Michael Perryman

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1. Is the Earth flat? No, of course not !

- Answered by the Hellenistic Greeks ~300 BCE:
  - travelling further south: southern constellations rise higher above the horizon
  - during a lunar eclipse: the shadow of the Earth on the Moon is circular
  - Earth's circumference: determined from length of Sun's shadow at different locations
- Any remaining doubt was put to rest by Copernicanism (mid-1500s):
  - Sun: now at the *centre* of the solar system
  - Sun's distance: improvements from the Transit of Venus in the 1600s, 1700s, 1800s
  - Newton's laws of gravity: provided a mathematical foundation, as well as great predictive power
  - but... the 'revolution' in thinking took decades for full acceptance... was Earth really moving through space?
- A spheroidal Earth orbiting the Sun explains a vast range of natural phenomena:
  - seasons on Earth, precession and nutation, motions of planets, eclipses, planetary transits, stellar occultations, the orbit of artificial satellites, Earth's interior, etc, etc, etc...
  - more 'subtle' effects: stellar and Galactic aberration, and relativistic precession of Mercury's orbit, etc, etc...
  - very compelling (but harder to explain): lunar libration, due to changes in perspective and rotation

Flat Earth Society (1956)... with roots to Samuel Rowbotham (1865)

YouGov Polls (internet market research and data analytics):

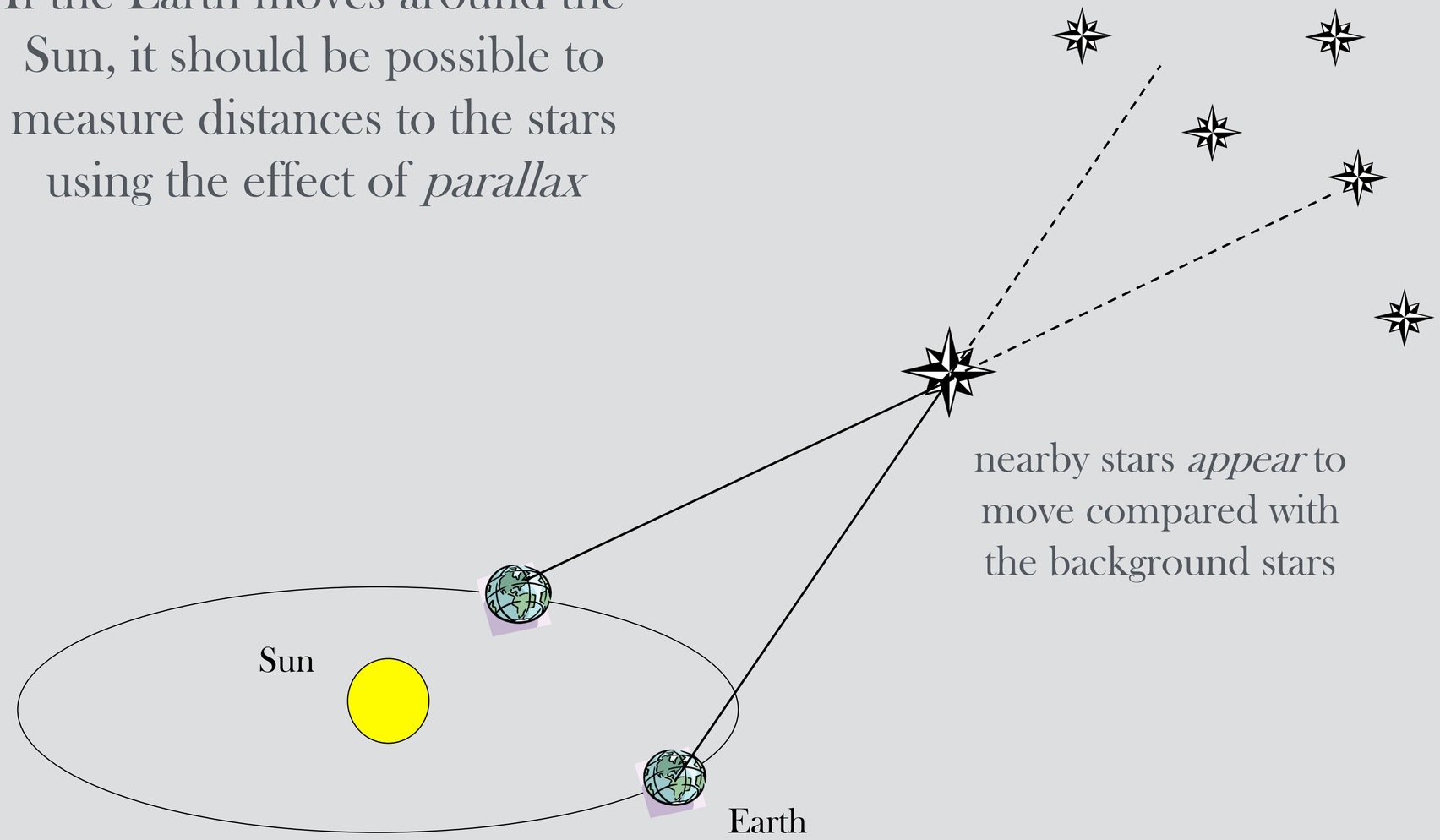
- USA 2018:
  - only 84% said with certainty that the Earth is a globe (16% 'unsure')
  - the fraction is even lower amongst young people, at 64% (36% 'unsure')
- UK 2019:
  - 3% think the Earth is flat; 5% say it's probably (but not definitely) flat
  - 16%... the moon landing was probably (12%) or definitely (4%) staged
  - 20%... vaccinations have harmful effects which are not being fully disclosed
  - 33% aged over 55 think the threat of climate change is over-exaggerated

Why do some people cling to the idea that the Earth is flat?

- less about the shape of the Earth, and more about how 'big science' is communicated ?
- ideas/institutions are too large and complex for any individual to easily comprehend ?
- no understanding of the 'scientific method' ⇒ a mistrust of anything not easily verified personally ?
- perhaps amusing in the case of the Flat Earth, but more of concern in the case of vaccines, climate change, ...

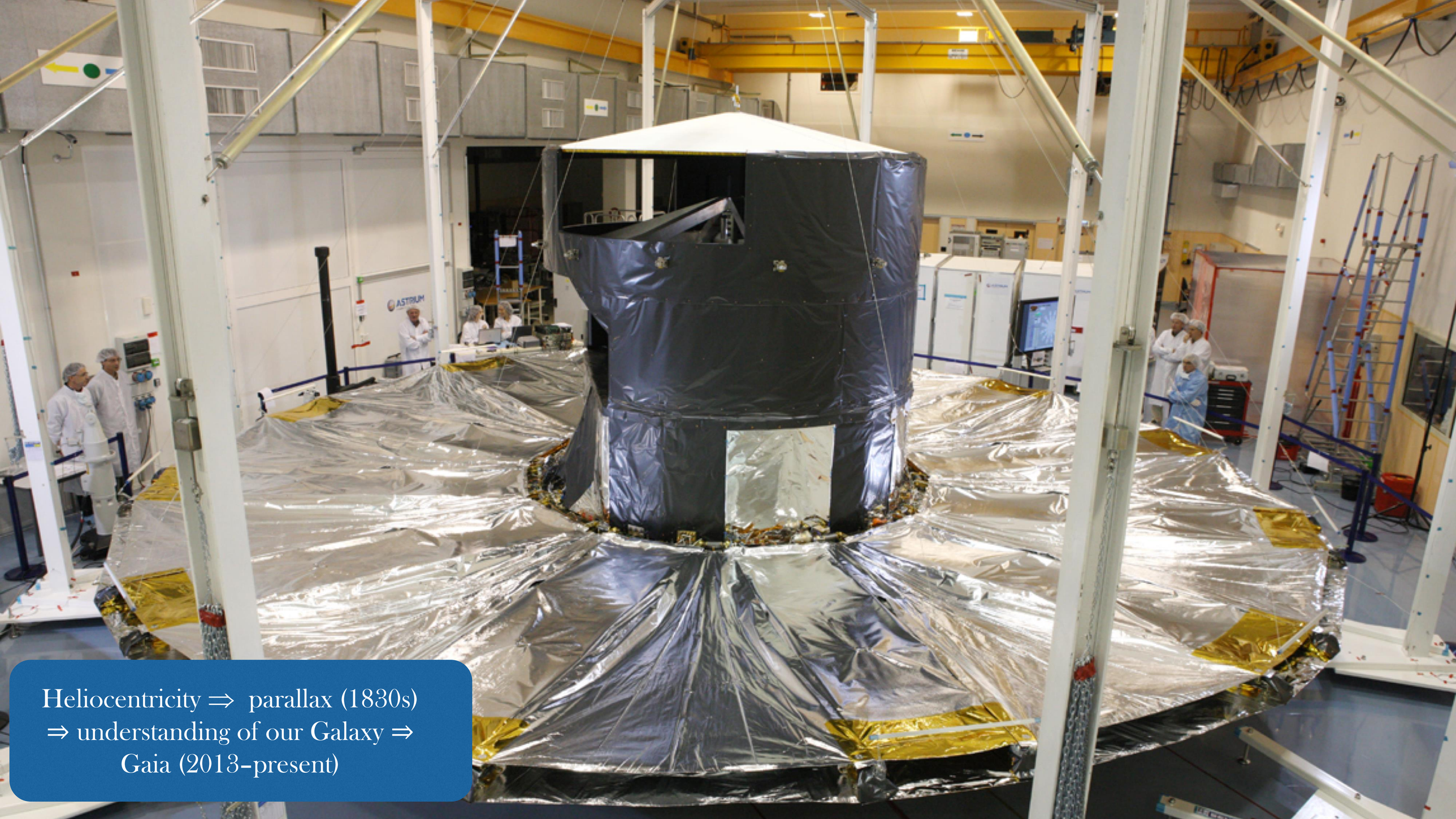
1: Do scientists need to communicate even better to keep wider society 'on side' ?

If the Earth moves around the Sun, it should be possible to measure distances to the stars using the effect of *parallax*



nearby stars *appear* to move compared with the background stars

measured for the first time, after 250 years, in the 1830s



Heliocentricity ⇒ parallax (1830s)
⇒ understanding of our Galaxy ⇒
Gaia (2013–present)

Gaia: stars within 200 pc
over 1.5 million years
(25,000 years per second)

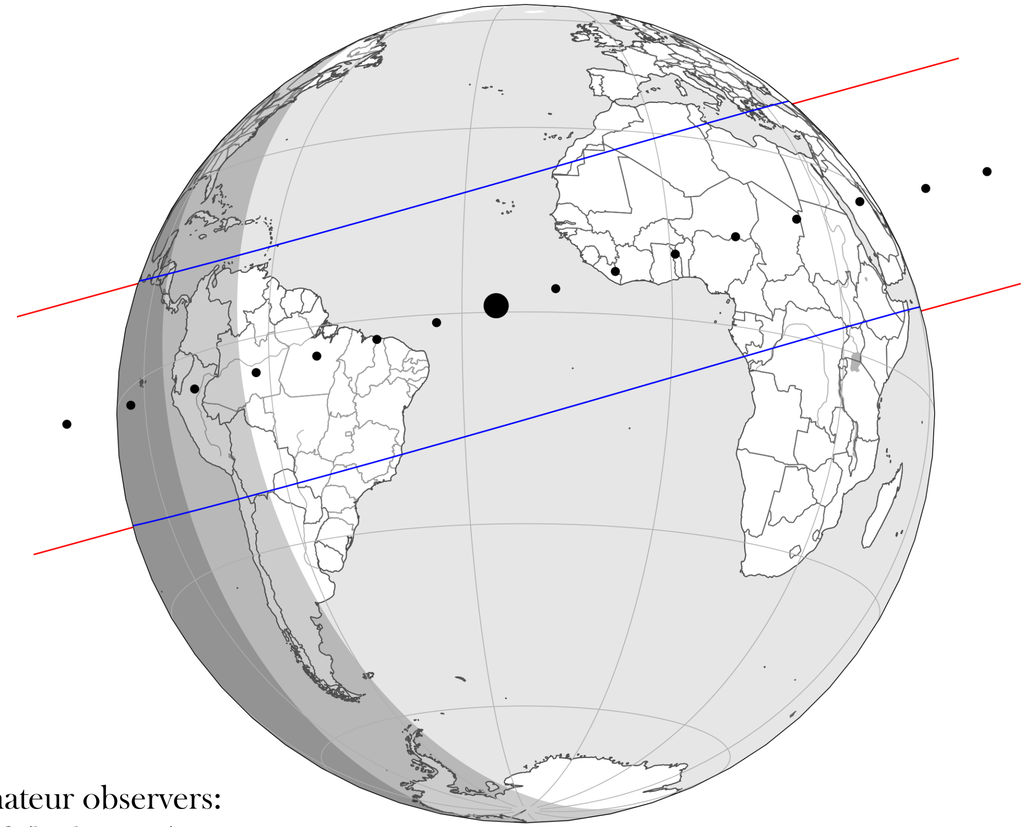
Jacqueline Faherty (AMNH)

Copernicanism in 2023 with Gaia
... two examples

(1) Solar system occultations

Two billion moving stars + 160,000 moving asteroids gives:

- a dense network of accurate positions and motions of both
- positions of both can be projected years into the future
- occultations of minor solar system bodies can be scheduled



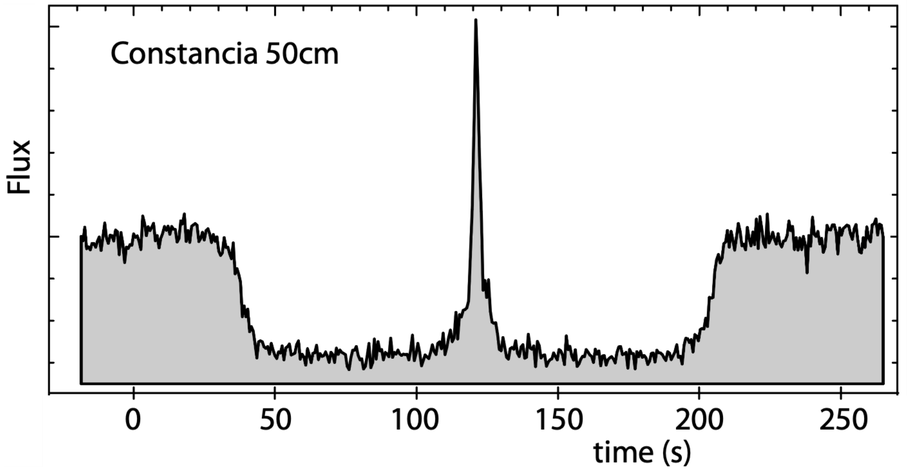
Coordination of amateur observers:
https://lesia.obspm.fr/lucky-star/

What:

- before Gaia: a few occultation events per year
- predictions 'wrong' by hours, and thousands of km !
- thousands per year now predictable/observable
- prediction accuracy: within 10 seconds

Examples:

- first observations of Europa (9.5 mag), 31 Mar 2017:
  a = 1562.0 ± 3.6 km, b = 1560.4 ± 5.7 km
- rings: Chariklo (Centaur) and Haumea (dwarf planet)
- seasonal changes of Pluto's atmosphere
- Triton: atmospheric 'flash', 5 Oct 2017

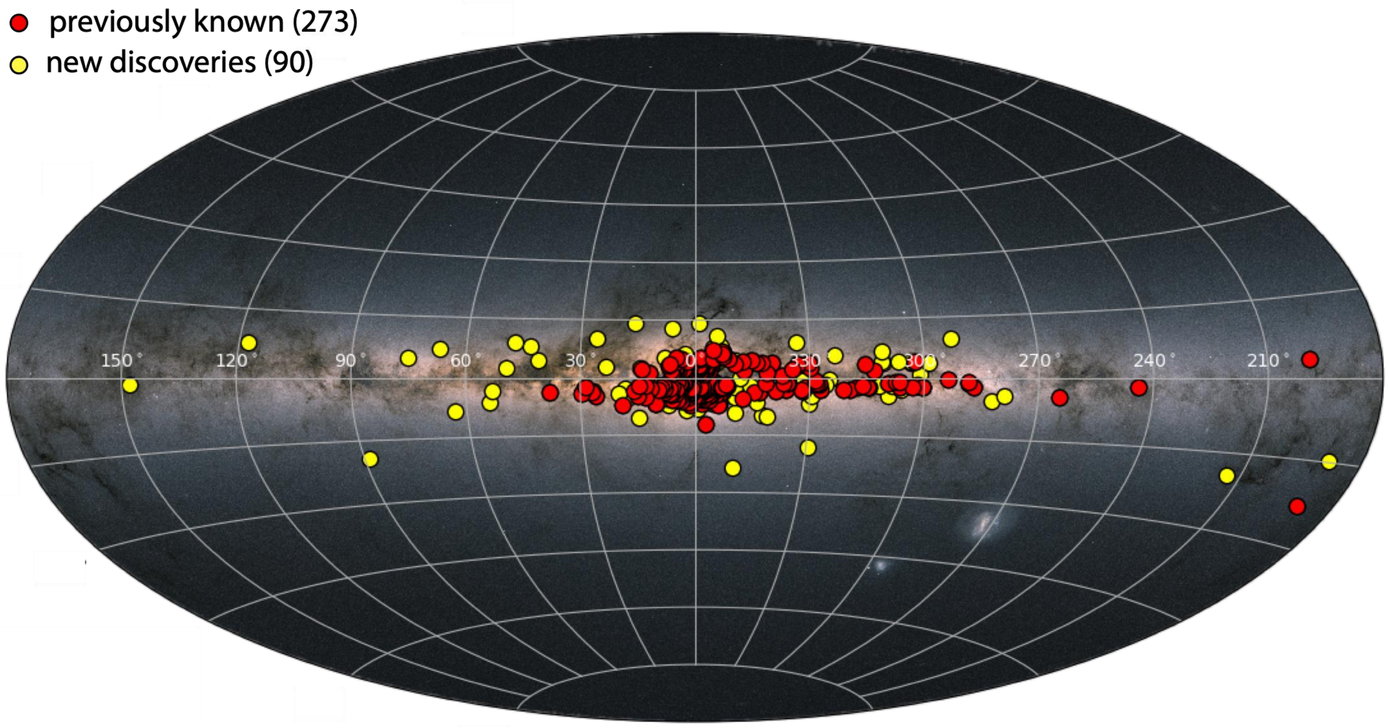


Triton
Constancia (P)
5 Oct 2017
Rui Gonçalves

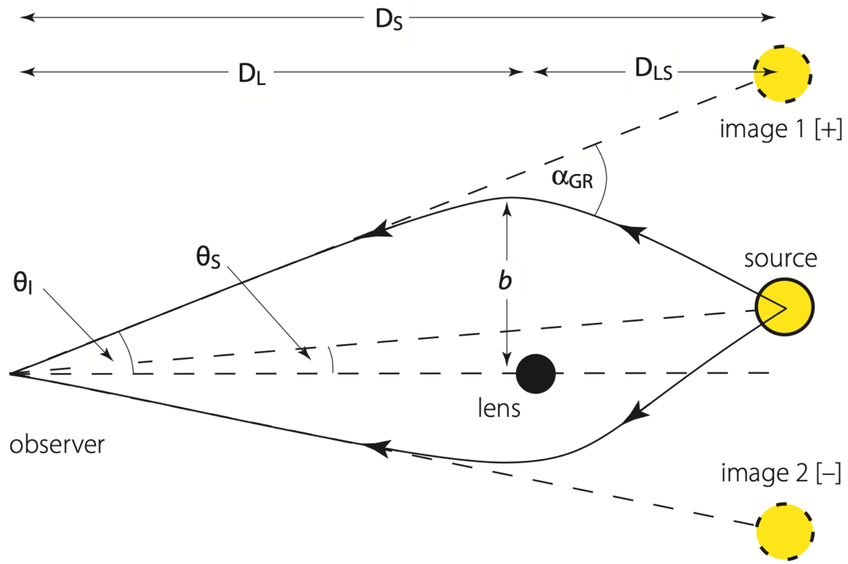
What prospects of a
Flat Earth proponent
predicting these ?!

(2) Microlensing

If the observer (Gaia), some star at intermediate distance (lens), and some distant background star (source) align precisely, then the light from the background star can be strongly magnified!

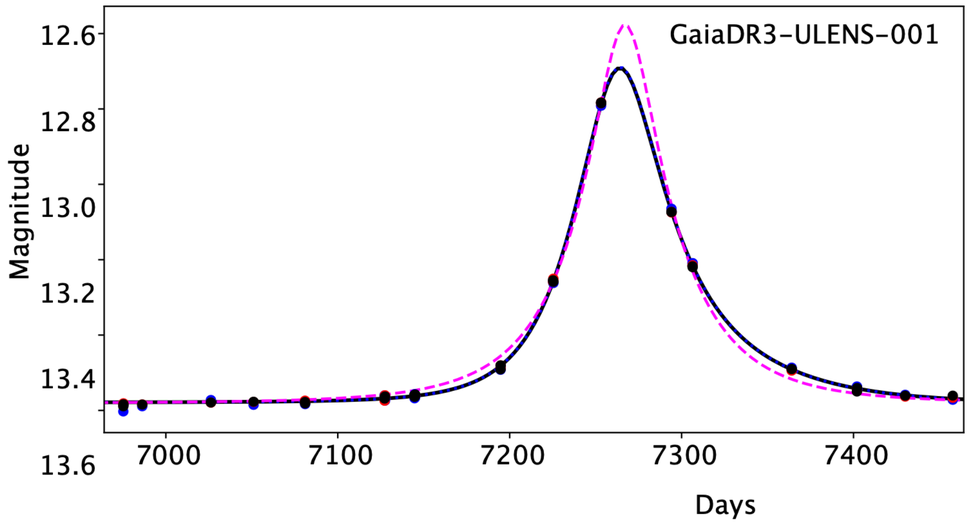


While thousands have been found from ground,
Gaia is discovering more, all across the sky



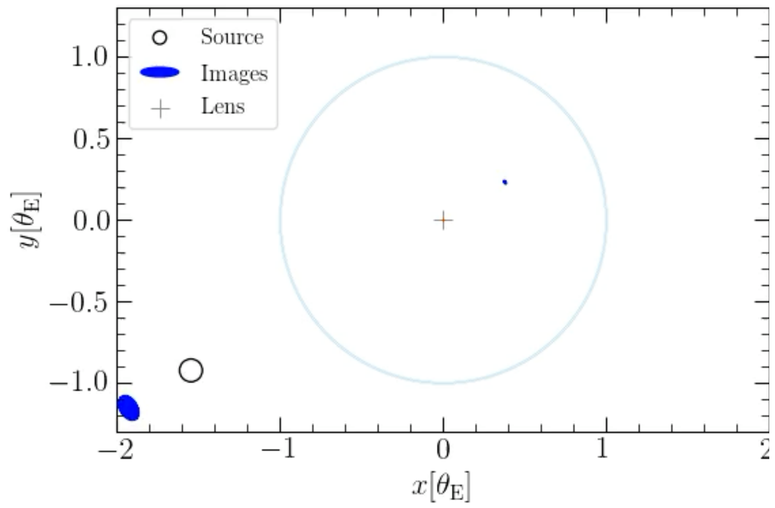
The first of Gaia's discoveries

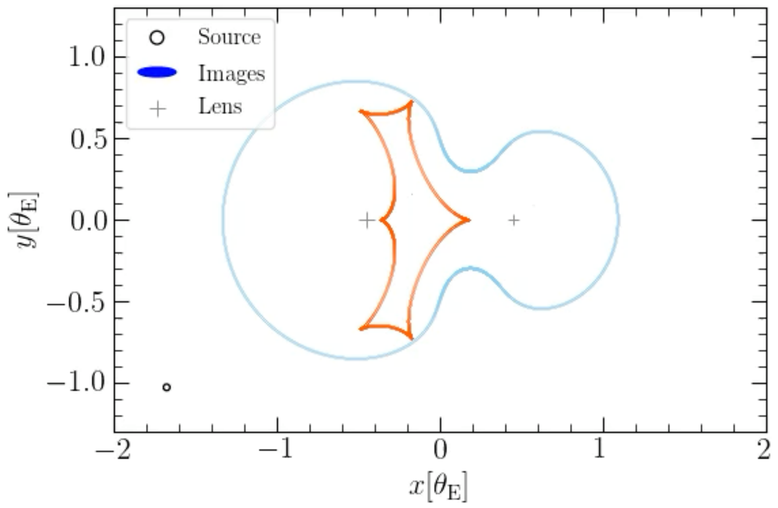
(Wyrzykowski et al., 2022)

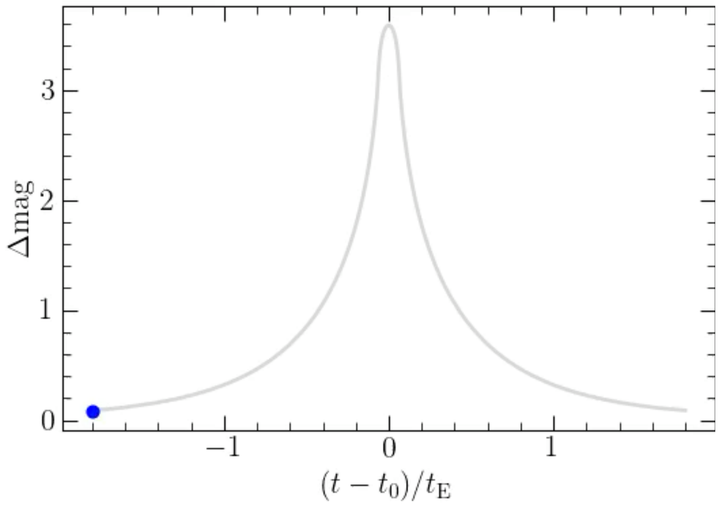


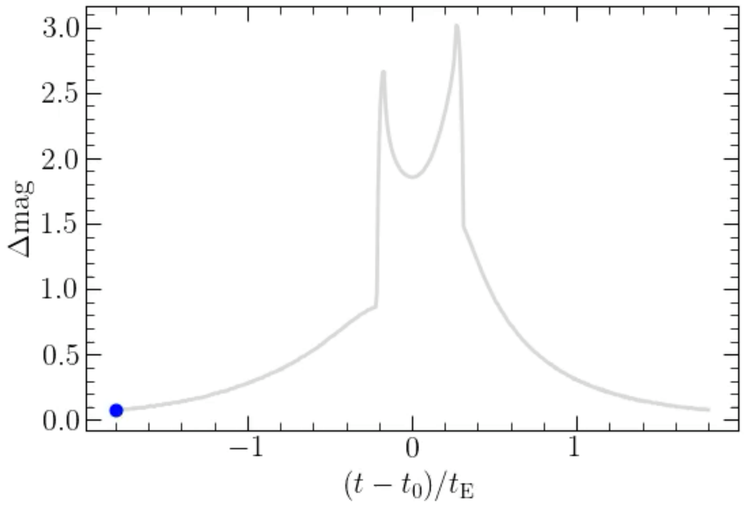
These animations, with different lens–source geometries, show what's happening during observations by Gaia

Animations by Kris Rybicki, University of Warsaw

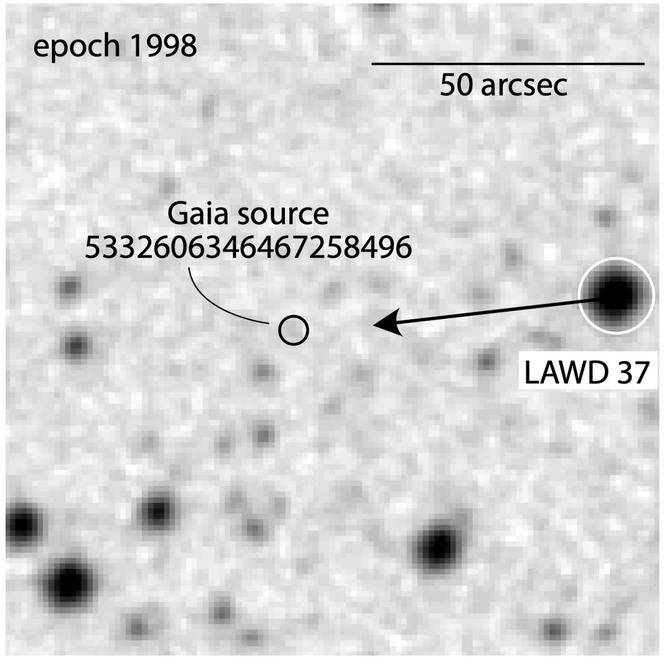




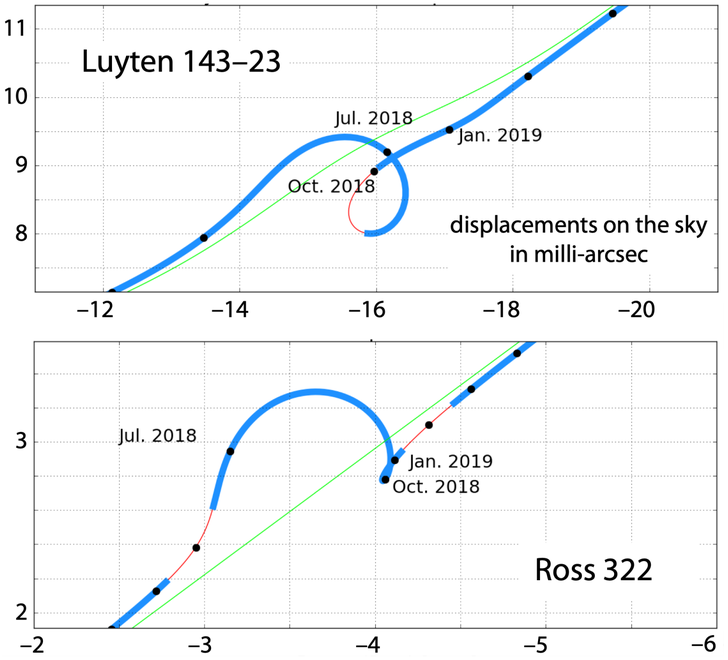




Predicting microlensing



Astrometric microlensing

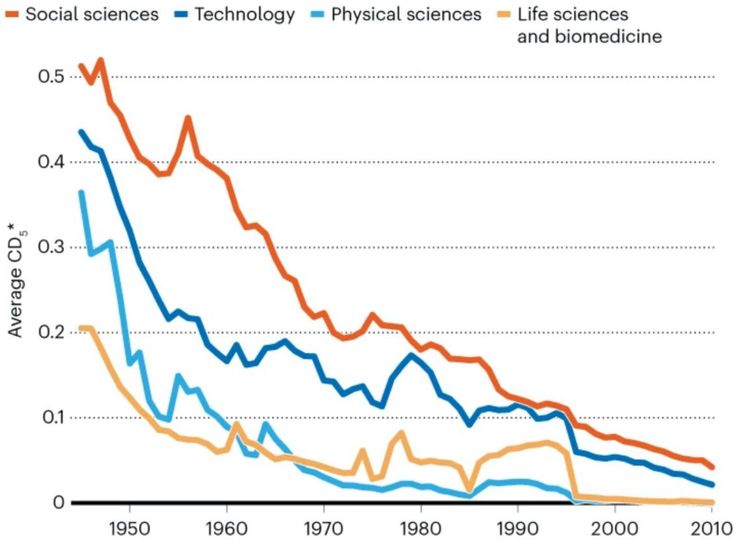


2. What kind of science lies ahead?

- Since the start of my own career in 1977:
  - pace of advance has not slowed: astronomy is discovering ever more complex and bizarre phenomena
  - ahead: plenty of scope for new discoveries, and great opportunities for researchers and educators

- It does not seem that we are approaching the 'end of science':
  - particle physics: will there be a unified theory of matter and energy?
  - cosmology: how (and why) was our Universe created?
  - evolutionary biology: how did life begin, and does it exist elsewhere?
  - neuroscience: what are the processes that give rise to consciousness?

- But 'disruptive' science has *fallen* by 90% (1945 to 2010):
  - Park et al (2023): 45 million papers and the disruptive index (CD)
  - disruptiveness declined in all of the analysed research fields
  - disruptive is not inherently good; incremental is not necessarily bad
  - but... not particularly clear what is going on



2: What sort of research should be encouraged in future?

3. Collaboration

Some observations:

- modern projects are often too large for individual states to undertake alone
- that was one of the motivations for establishing ESA and ESO
- not only financially driven, but also by intellectual/industrial contributions… ESA missions involve hundreds of scientists, thousands of engineers
- also for industry, where key competences are often concentrated in individual member states
- economists recognise the economic capital of (scientific) collaborations: networks, training, stimulation
- all collaborations come with other complexities… Henk van der Hulst (Leiden, 1918–2000) made the remark that *"Doing science on your own is very difficult… doing it in collaboration with others is even harder"*
- in big projects, cost and schedule overruns are common: part of the problem (I think) is that there is little attention given to passing on organisational and sociological experience acquired in the past

3: International collaborations are crucial, but benefit from their proper 'management'

4. Fundamental science and economic growth

Arguments for major investments in science (and space science) include:

- unexpected/applied spin-offs, technology development, industrial, political, societal/cultural, economic
- scientists often argue that knowledge is important for its own sake, and can be more vague when it comes to the wider benefits for society
- such arguments are easy to ignore, and budgets (e.g. in space) can be scaled back faced with other priorities
- since the 1960s, economists have tried to measure economic 'returns' (GDP) accruing from *basic* research
  - OECD (2009) estimated return factors: UK 1.9, Norway 4.7, US (industry) 4.9, NASA 7.0
  - in 'endogenous growth' (Solow–Swan) economics, technological progress is generated by accumulation of knowledge
  - Max Planck's Peter Gruss (2012): "*80% of economic growth in industrial countries results from the development of new technologies*"

4: Arguments for funding of 'basic research' (cf. applied research) can be economic as well as cultural

To conclude

I have touched on aspects of: education, research directions, collaboration, and economics

I have written more on these and other aspects of Gaia (mainly science): www.michaelperryman.co.uk

Some science highlights from Gaia:

- H-R diagram: white dwarf crystallisation and M dwarf convective/radiative transition [42]
- the nearest (480 pc) black hole in a non-interacting binary [101]
- a dynamical distance to the Galactic centre (8.23±0.12 kpc) [111]
- hypervelocity stars as probes of supermassive black holes and the halo [22]
- the first exoplanets, amongst 50,000 *predicted* [78]

Thank you!

And some more closely tied to cosmology:

- the spiral in the (z, vz) phase plane of solar-neighbourhood stars, due to Sag dwarf [75]
- orbits of dwarf spheroidals and other Local Group galaxies [31]
- detection of our motion around the Galaxy through Galactic aberration [32]
- multiple halo streams, relics of the tidal accretion of the Milky Way [71]
- deceleration of the pattern speed of our Galaxy's bar due to halo friction [112]