Relativistic aspects of Gaia mission

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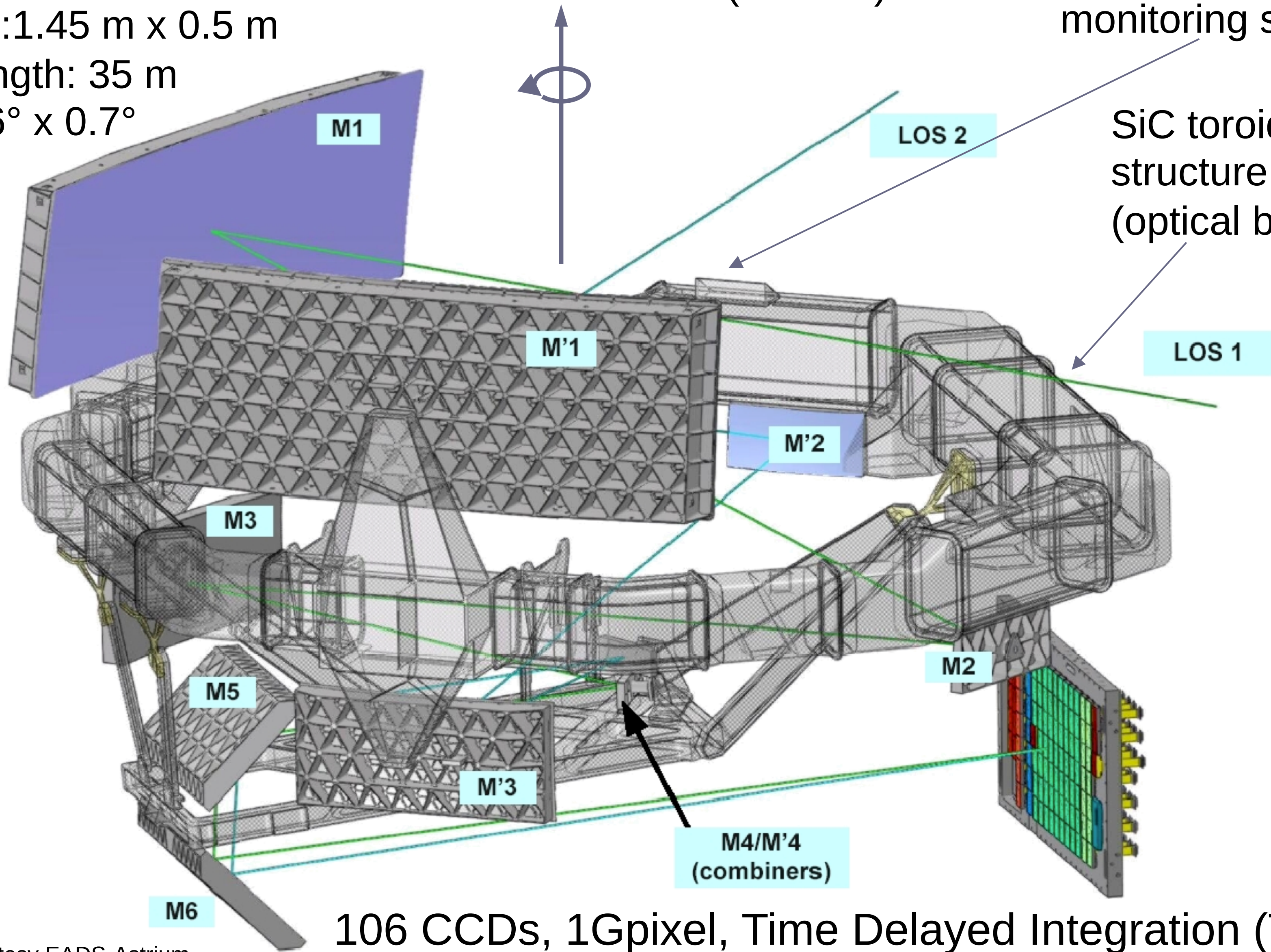
Gaia telescope

Astrometry, photometry of all 10^9 sources up to 20 mag (+spectroscopy)

2 SiC primary mirrors at 106.5°
Aperture:1.45 m x 0.5 m
Focal length: 35 m
FOV: 1.6° x 0.7°



106 CCDs, 1Gpixel, Time Delayed Integration (TDI)

Figure courtesy EADS-Astrium

Gaia: payload ready for launch (2013)

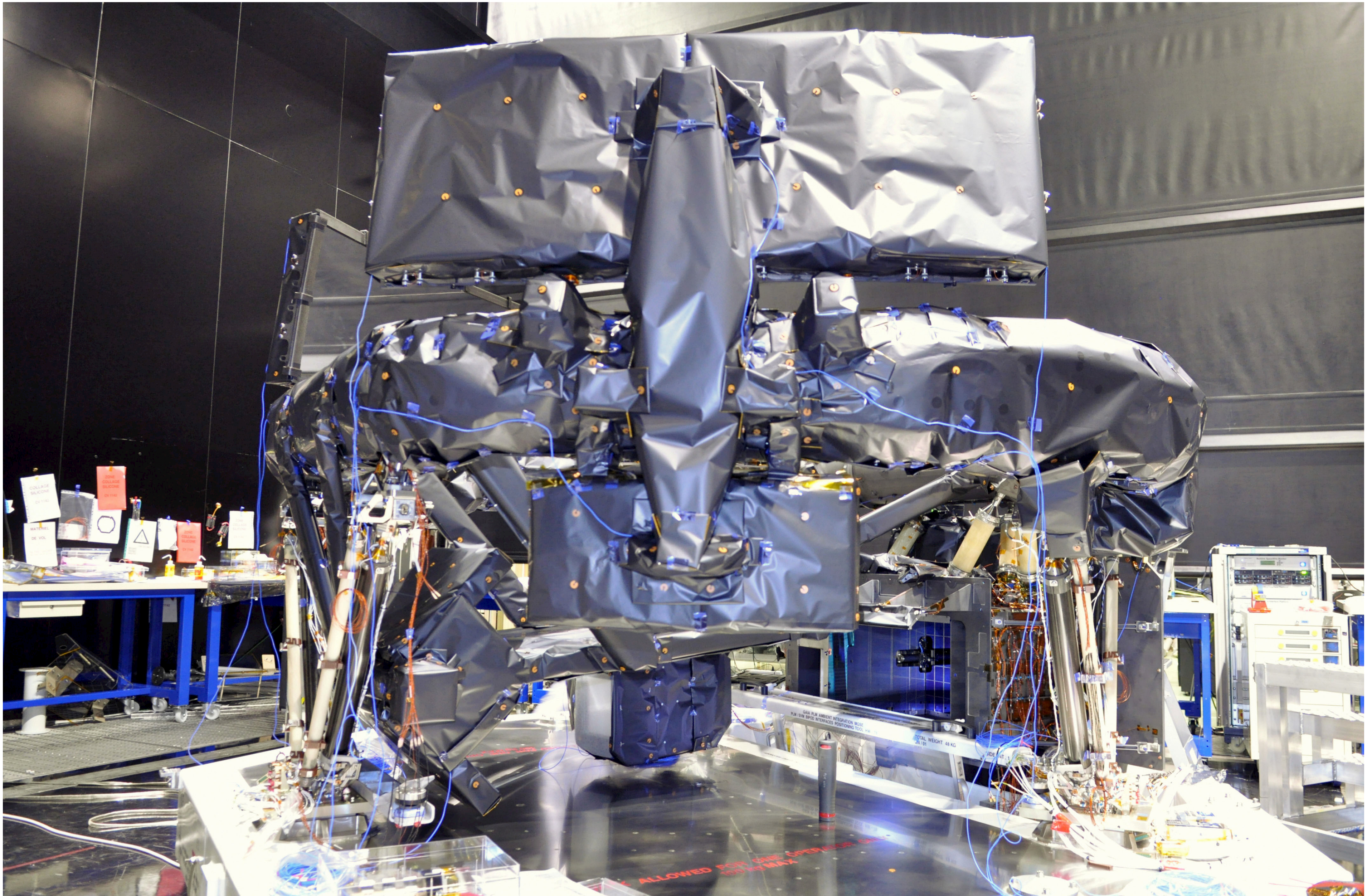


Figure courtesy EADS-Astrium

Gaia launch:
19 December 2013

Figure courtesy Arianespace

The first “historical” image from Gaia

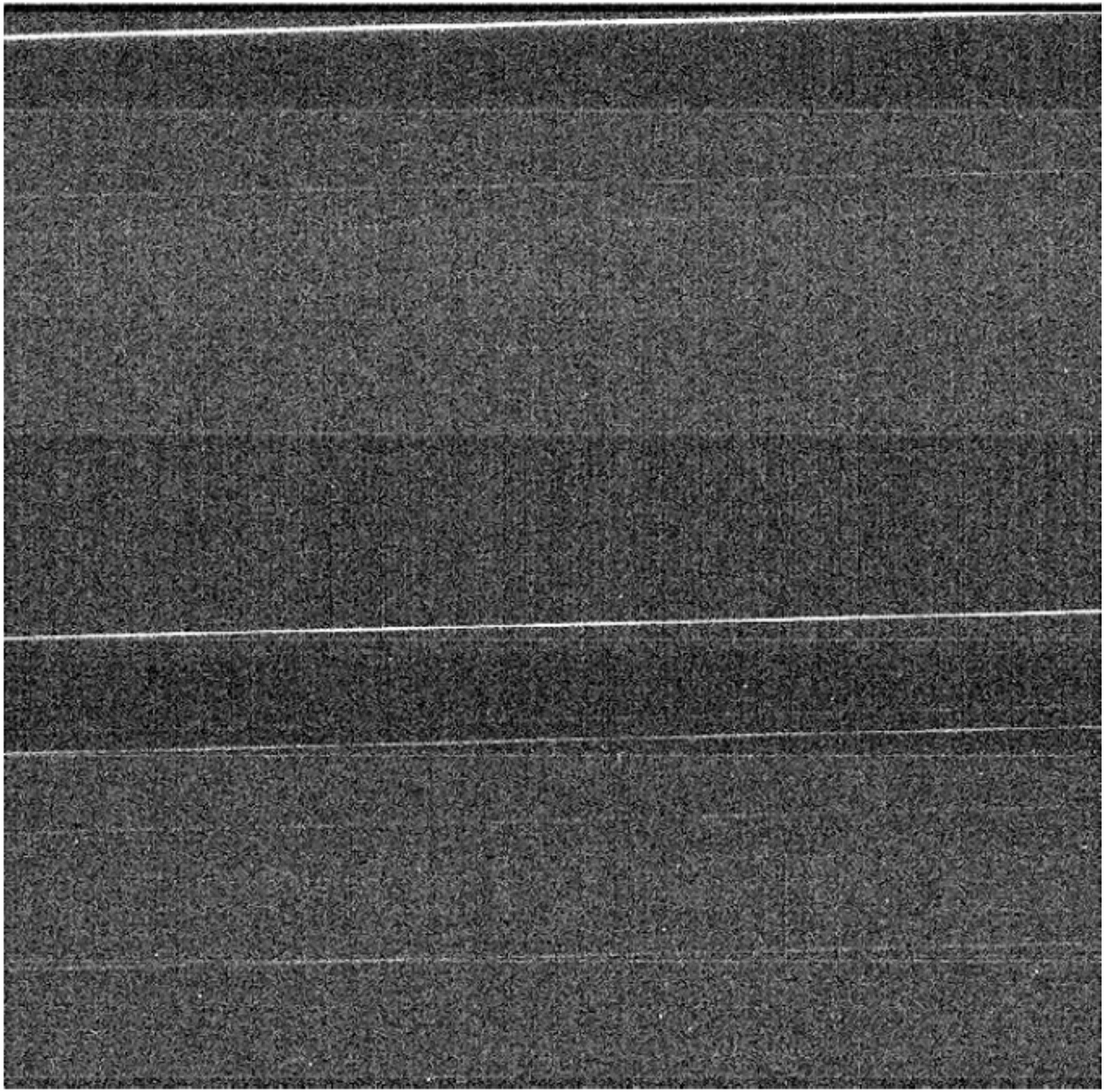
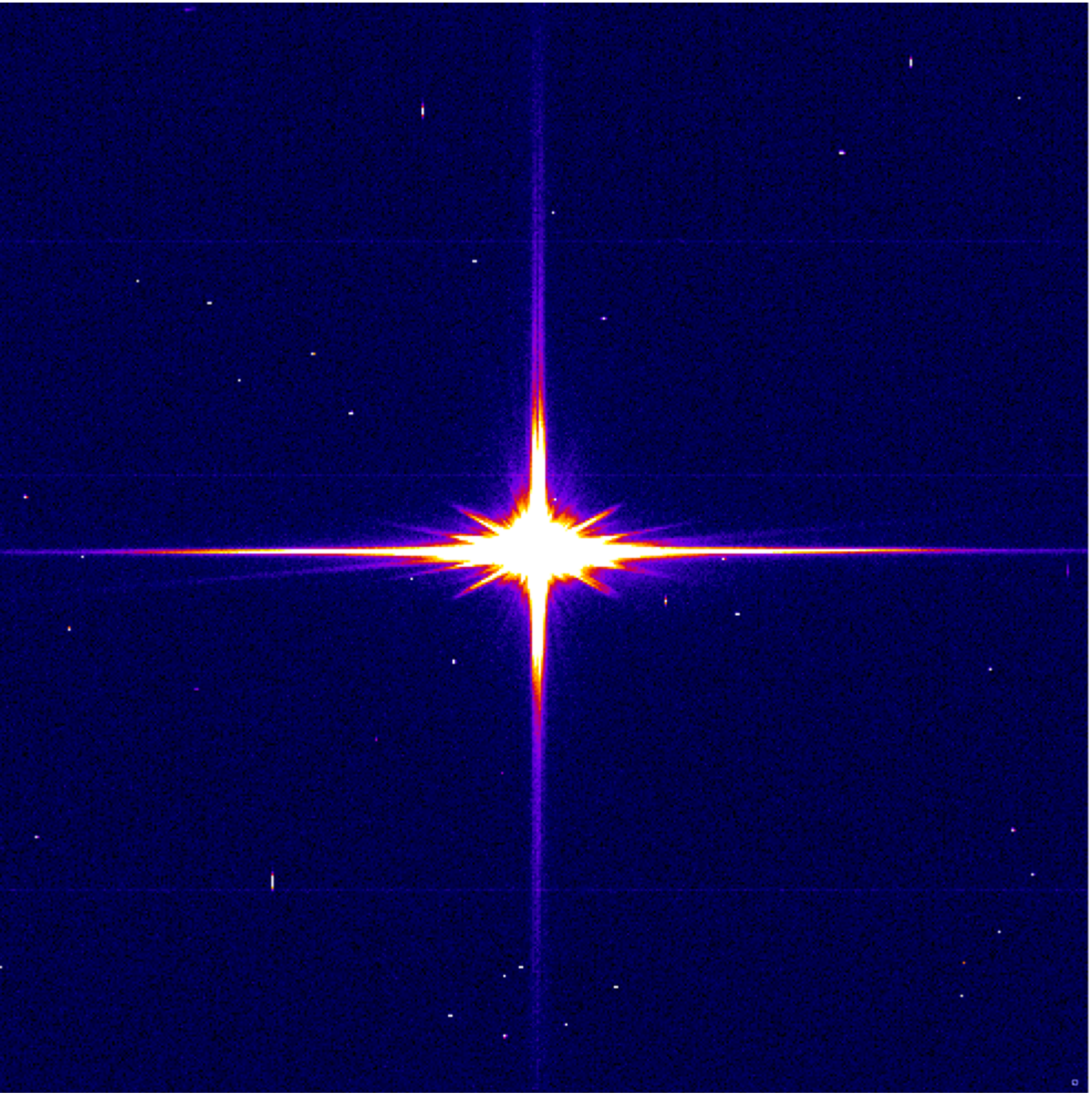


Image reconstruction C. Crowley (ESA Gaia-SOC)

Gaia not spinning,
not focused

“First light”



A random bright star,
before focusing

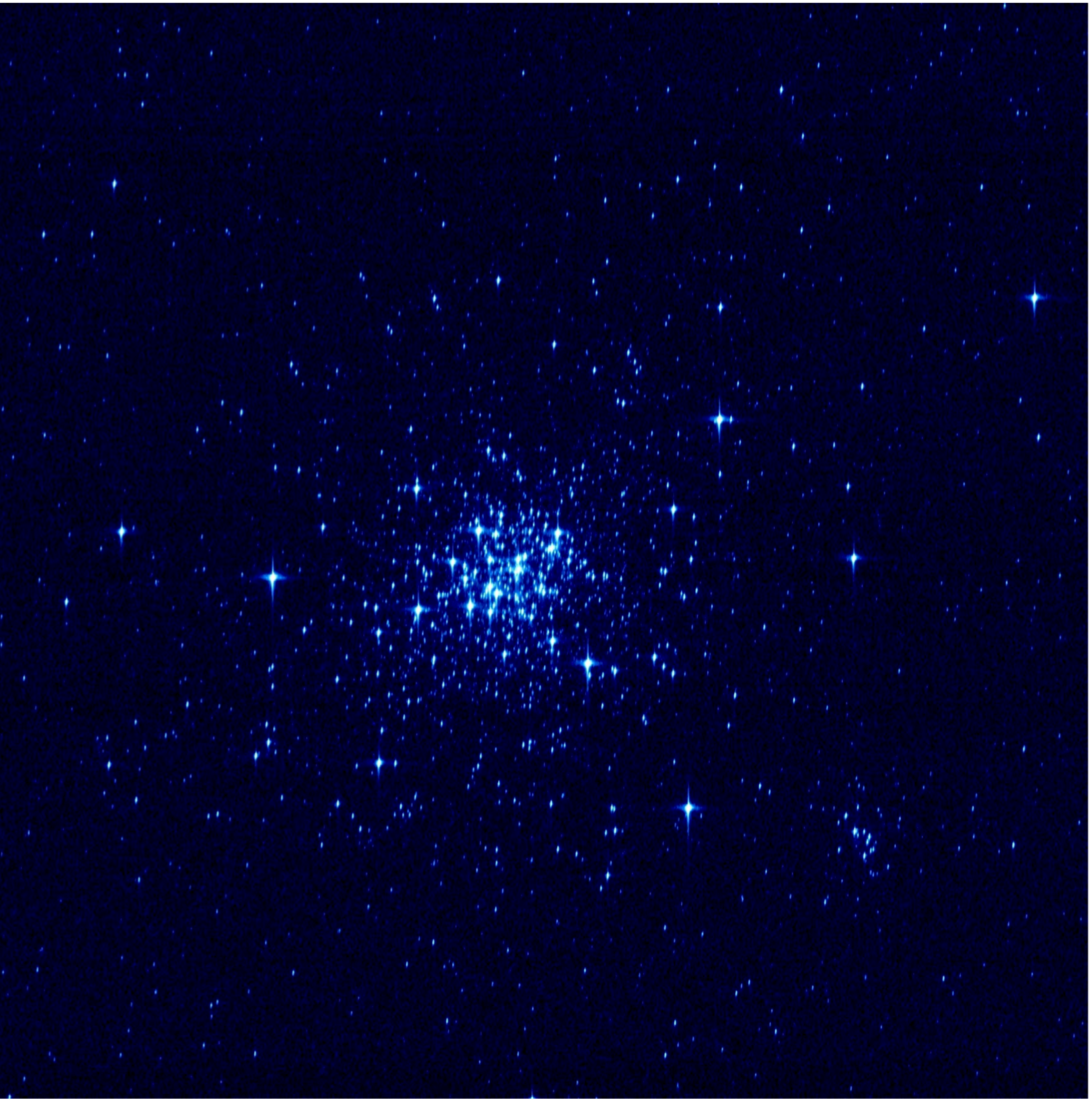
Sadalmelik
("Luck of the king”)
= Alpha Aquarii

SpT = G2 Ib

V = 2.94 mag

2.85 s integration time

First released PR image: a stellar cluster



NGC 1818:

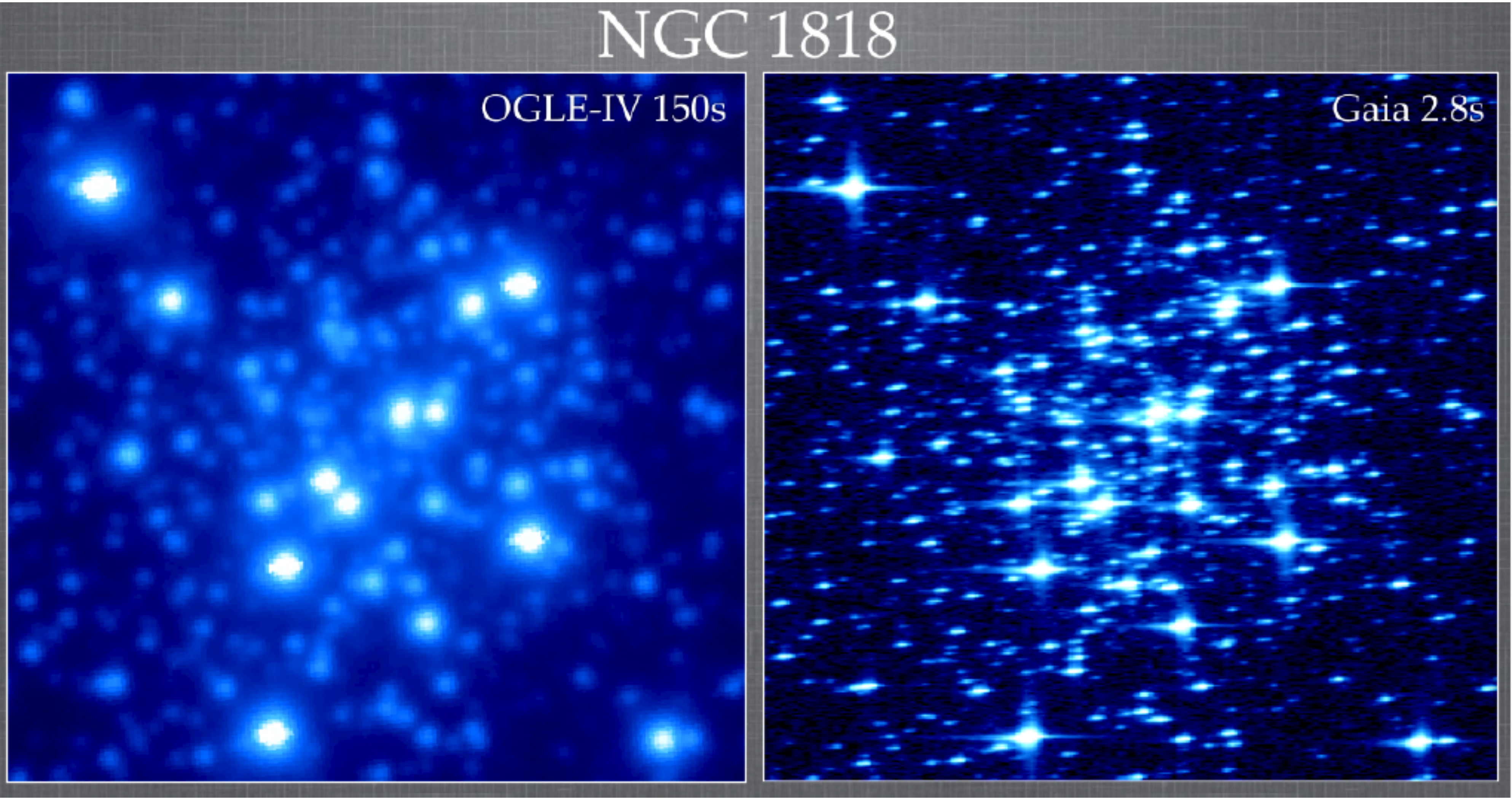
2.85 s integration time

212 x 212 arcsec^2

image ESA/DPAC/Airbus DS

(processed and cleaned by J. Sahlmann)

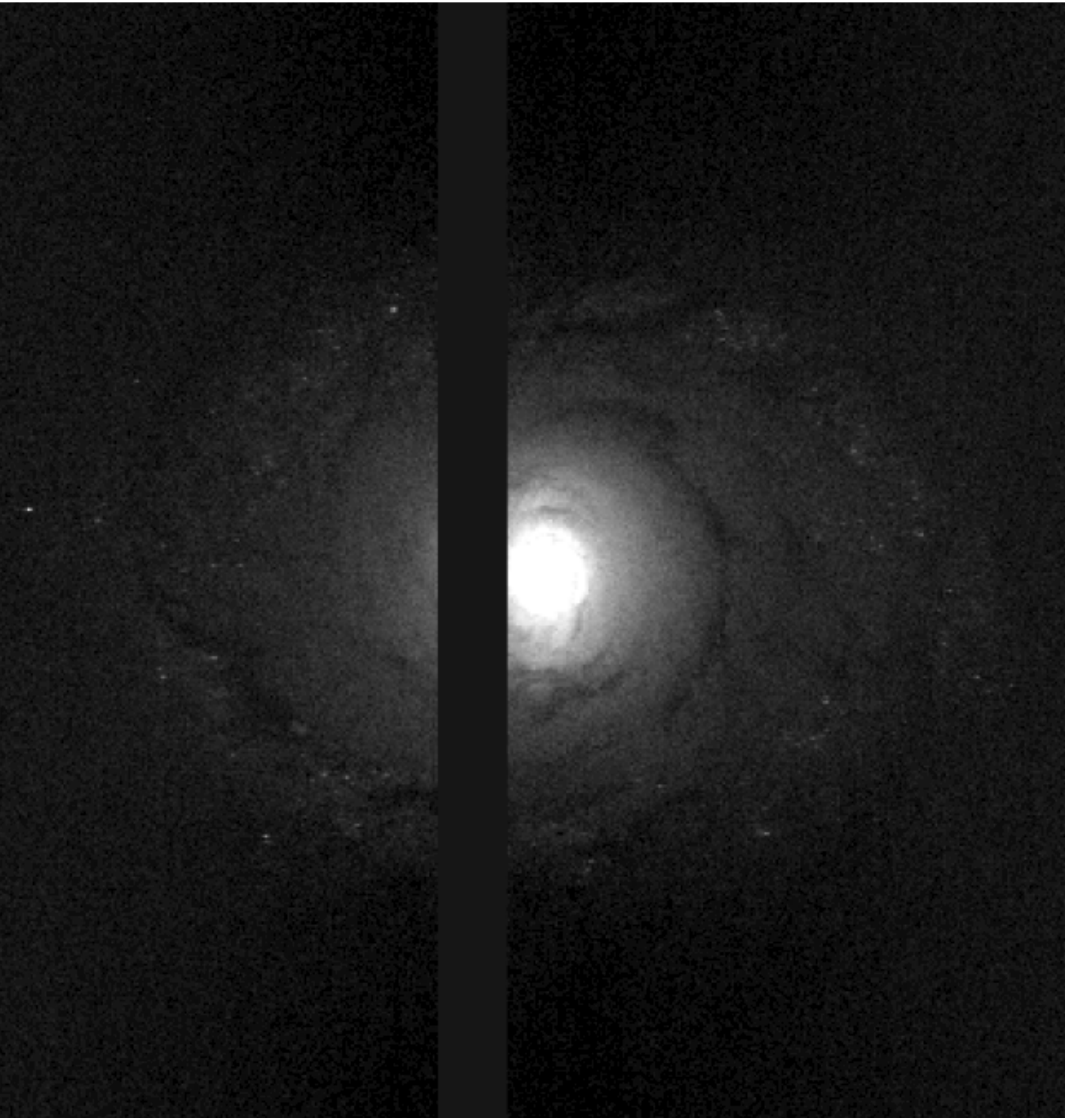
First released PR image: a stellar cluster



Comparable telescopes (1.3 m): from the Earth and from space

Image courtesy Łukasz Wyrzykowski

A galaxy…



M84

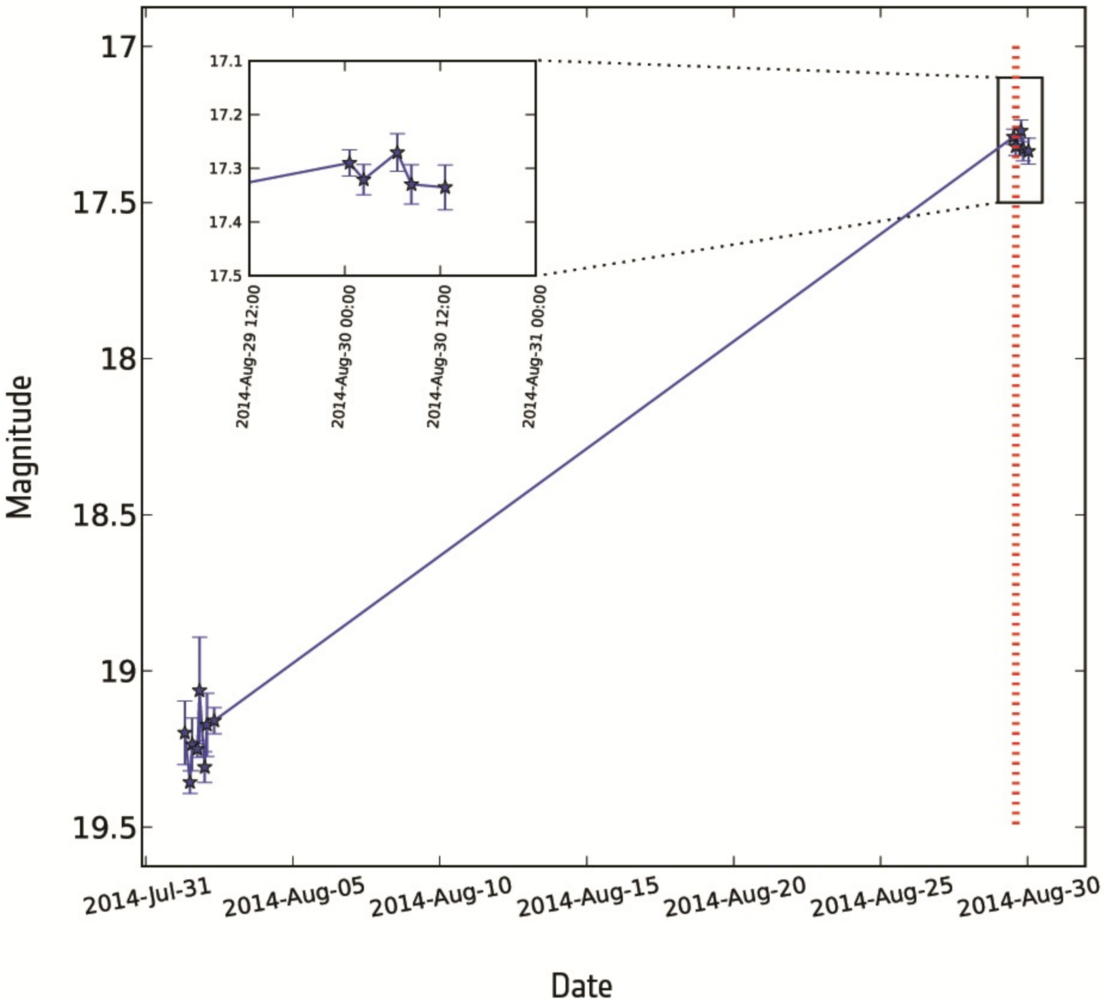
again in 2.85 sec

ALL THESE IMAGES ARE TAKEN FOR TEST PURPOSES

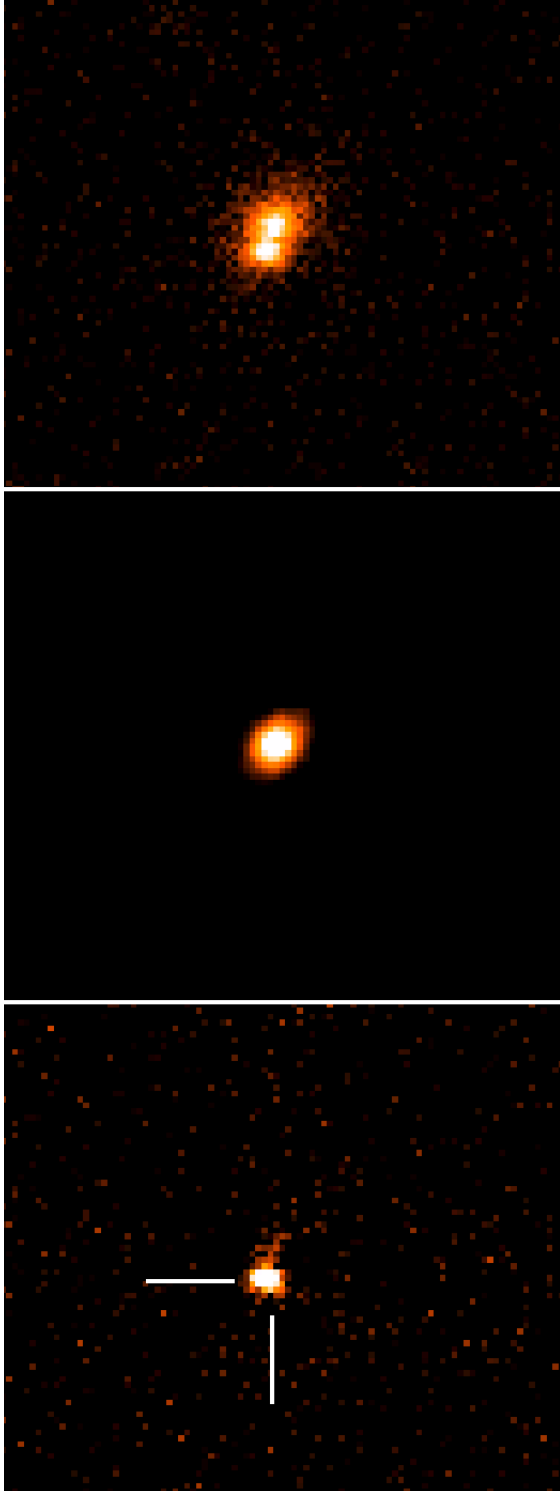
Gaia does not take images in normal operations!

The first discovery: 12.09.2014 a supernova Gaia2014aaa

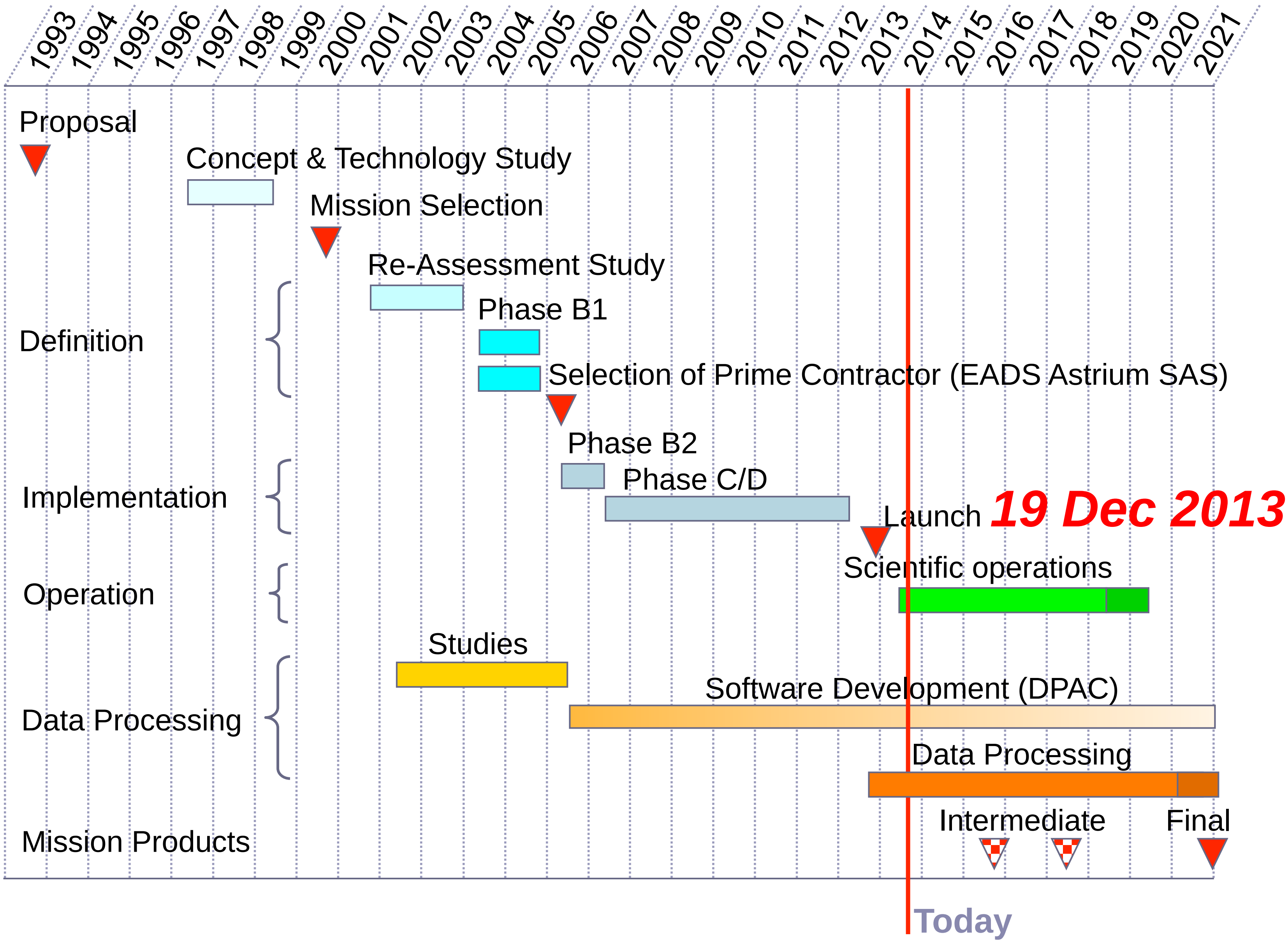
Increase of the flux from a galaxy:
hand-picked from the standard science alert pipeline



M. Fraser/S. Hodgkin/L. Wyrzykowski/H. Campbell/N. Blagorodnova/
Z. Kostrzewa- Rutkowska/Liverpool Telescope/SDSS



Schedule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2014
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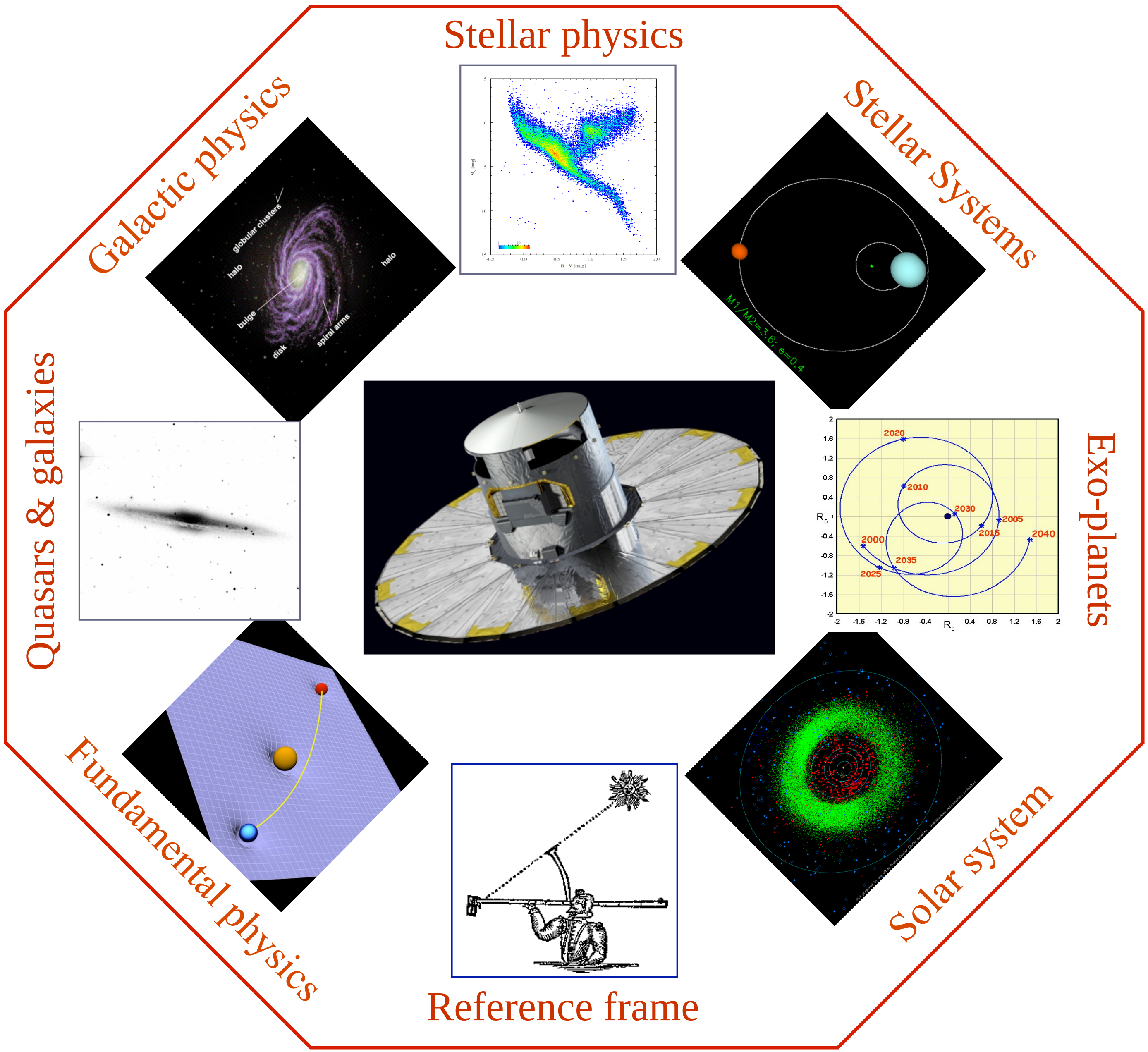
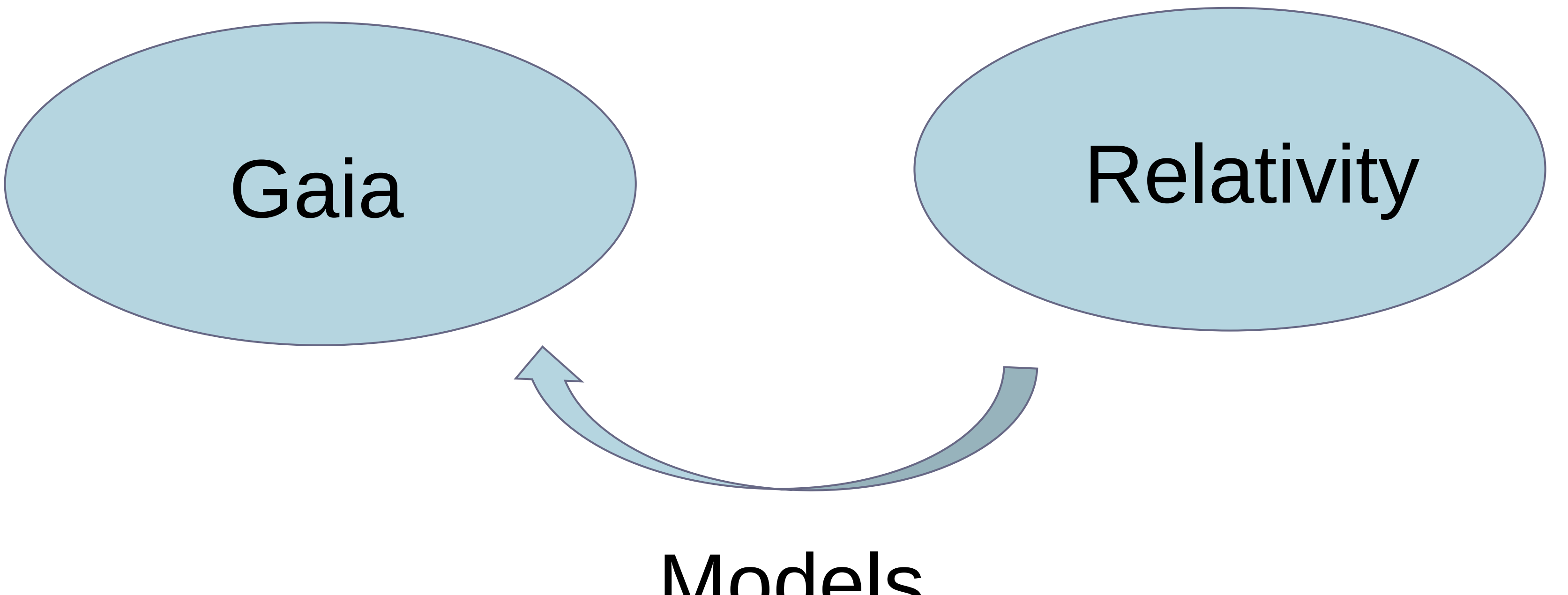
2018
2019
2020
2021
Proposal
Concept & Technology Study
Mission Selection
Re-Assessment Study
Definition
Phase B1
Selection of Prime Contractor (EADS Astrium SAS)
Phase B2
Implementation
Phase C/D
Launch 19 Dec 2013
Scientific operations
Operation
Studies
Software Development (DPAC)
Data Processing
Data Processing
Intermediate
Final
Mission Products
Today

Gaia: goals


Stellar physics
Stellar Systems
Exo-planets
Solar system
Reference frame
Fundamental physics
Quasars & galaxies
Galactic physics


Gaia
Relativity
Models

Major components of the model

1. IAU 2000 relativistic framework (Soffel et al. 2003) form the basis for the Gaia data processing

2. Relativistic model for astrometric observations (Klioner 2003, 2004)

   - Lorentz transformations for aberration

   - Deflection of light: monopole (post- und post-post-Newtonian),
     quadrupole, gravitomagnetic terms
     up to 17 bodies routinely, more if needed

   - BCRS definitions of parallax, proper motion, etc.

   - Relativistic definition of observables and the attitude

3. Relativistic model for the synchronization of Gaia atomic clock and TCB

   - GCRS, BCRS, Gaia proper time, relativistic propagation, …

Consistency of all aspects of the mission should be monitored

Clock calibration: observational data (simplified)

Gaia clock: OBT_k

onboard delay

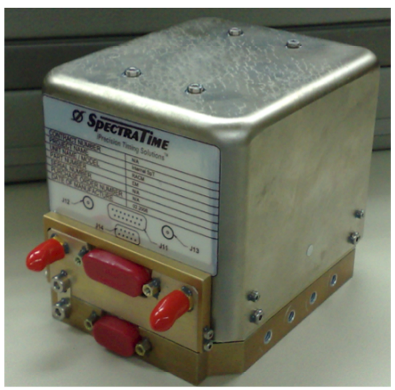
propagation delay

station delay

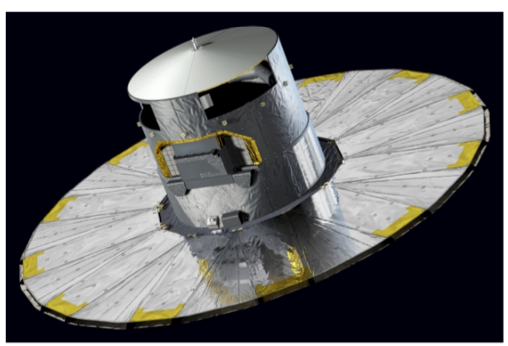
Ground clock: UTC_k

Phase Array Antenna

Cebreros dish

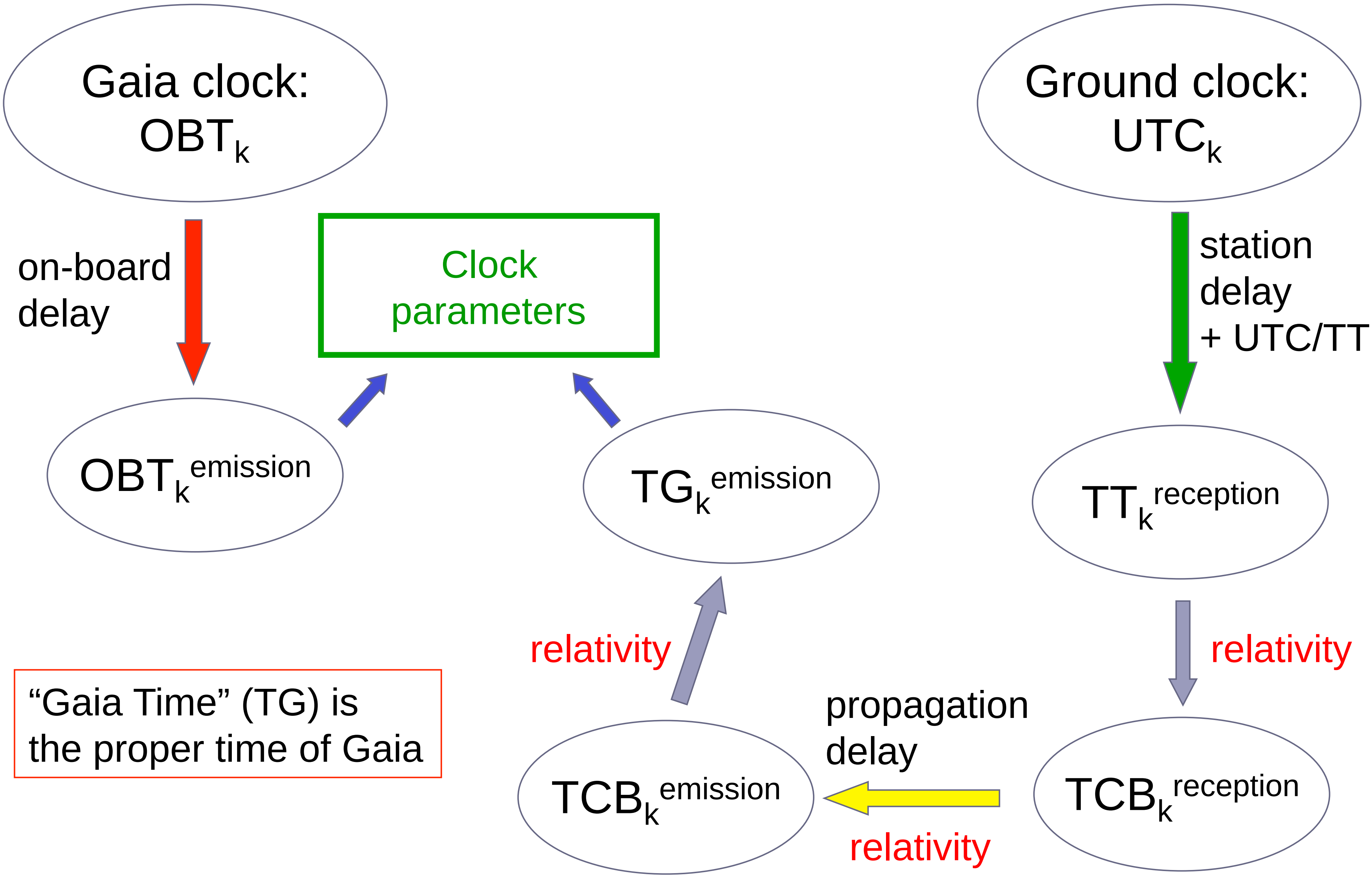


Rb clock counting On-Board Time (OBT)

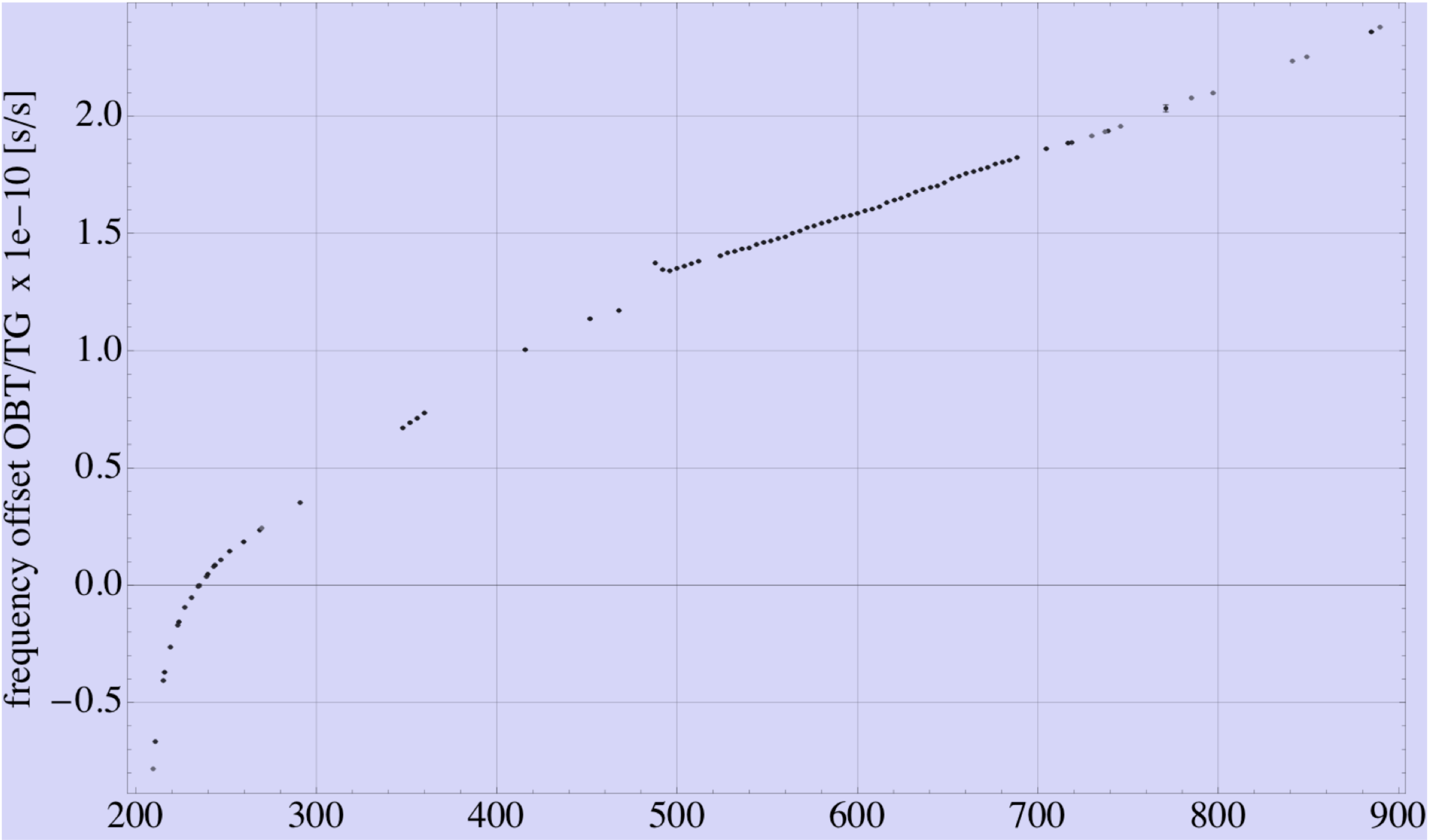


FINAL RESULT:
the Time Couples (UTC_k, OBT_k)

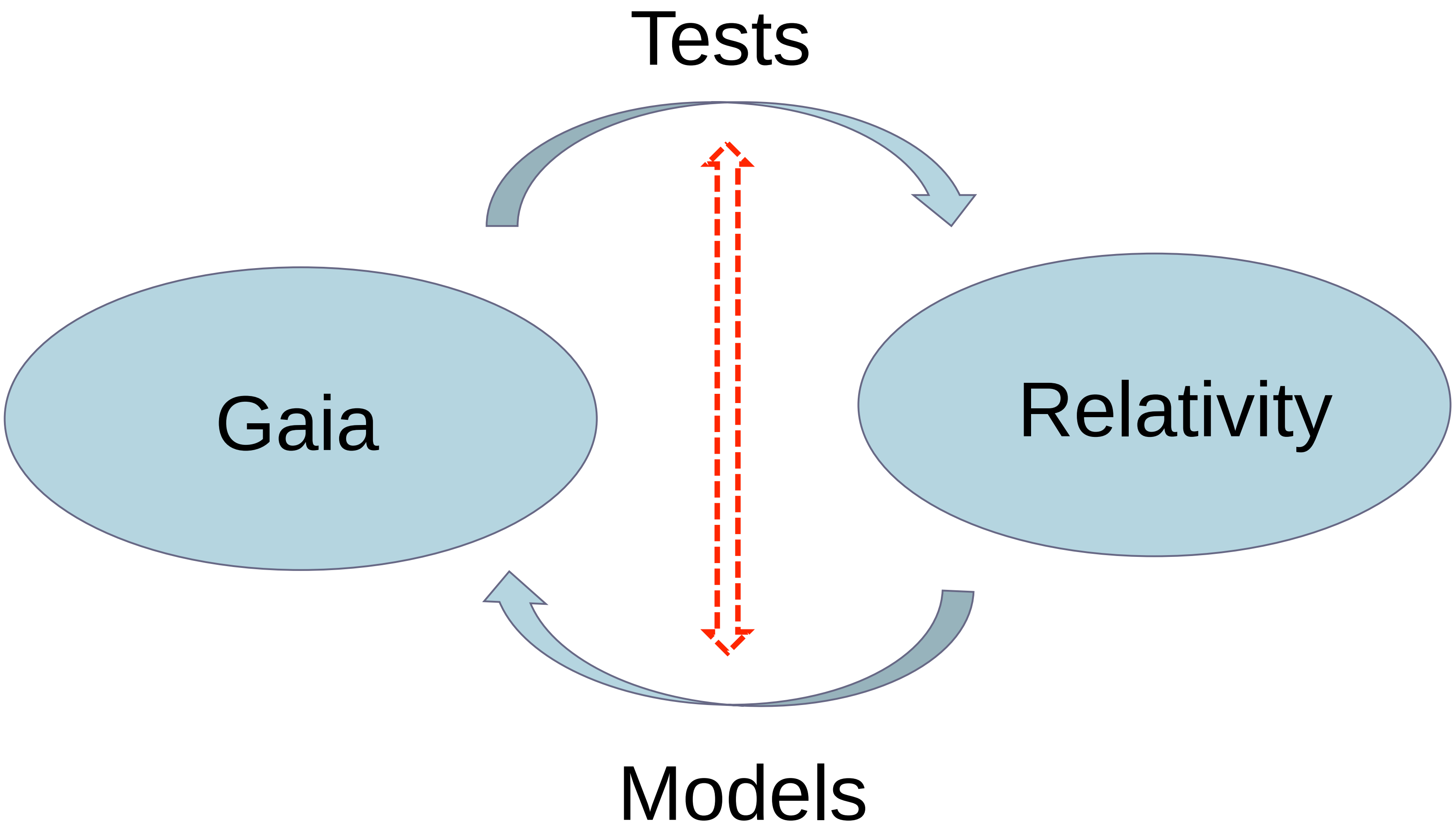
High-accuracy clock model



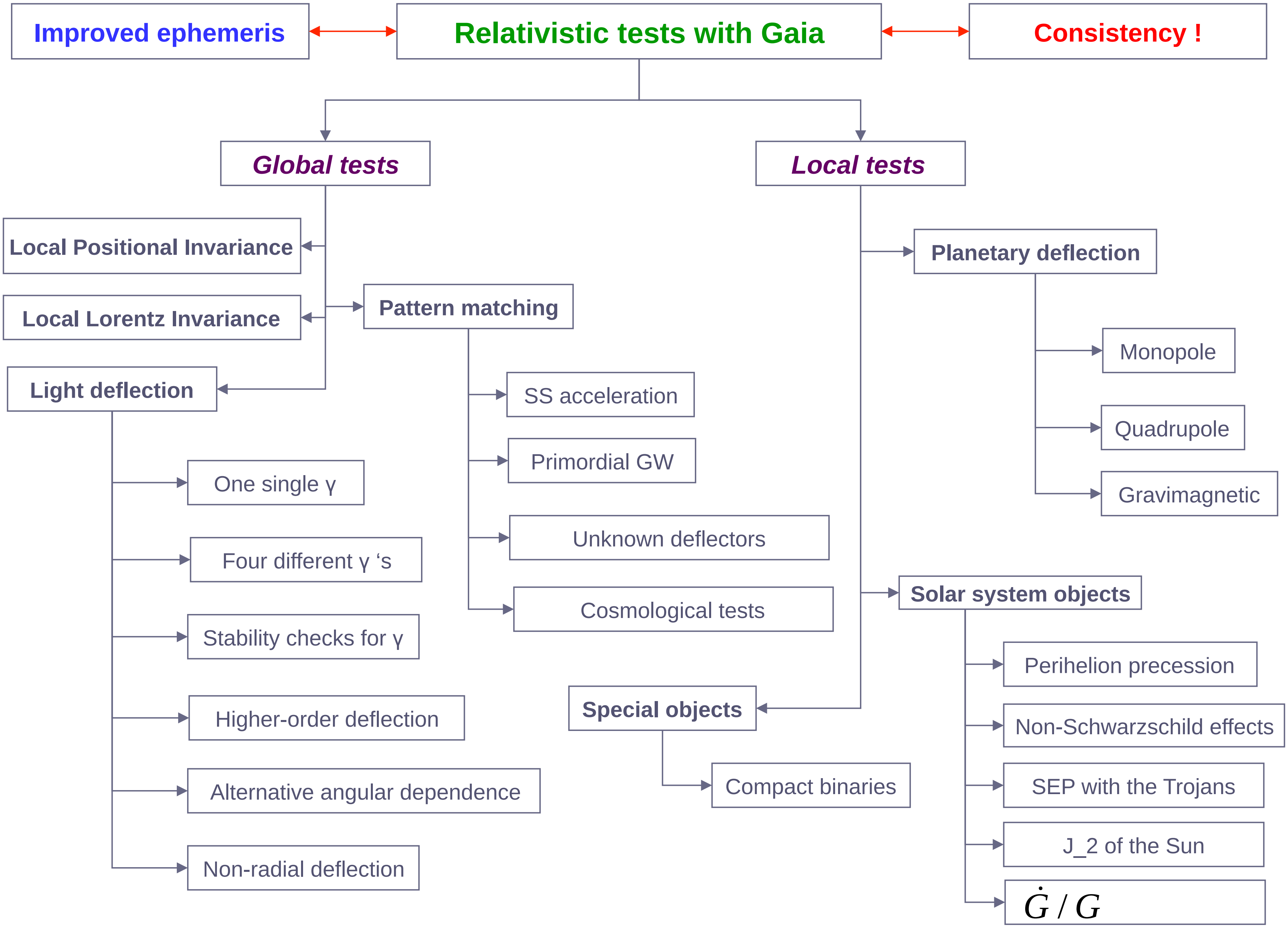
Gaia clock behaviour



After taking the relativity into account:
we see the clock behaviour as expected from laboratory experiments

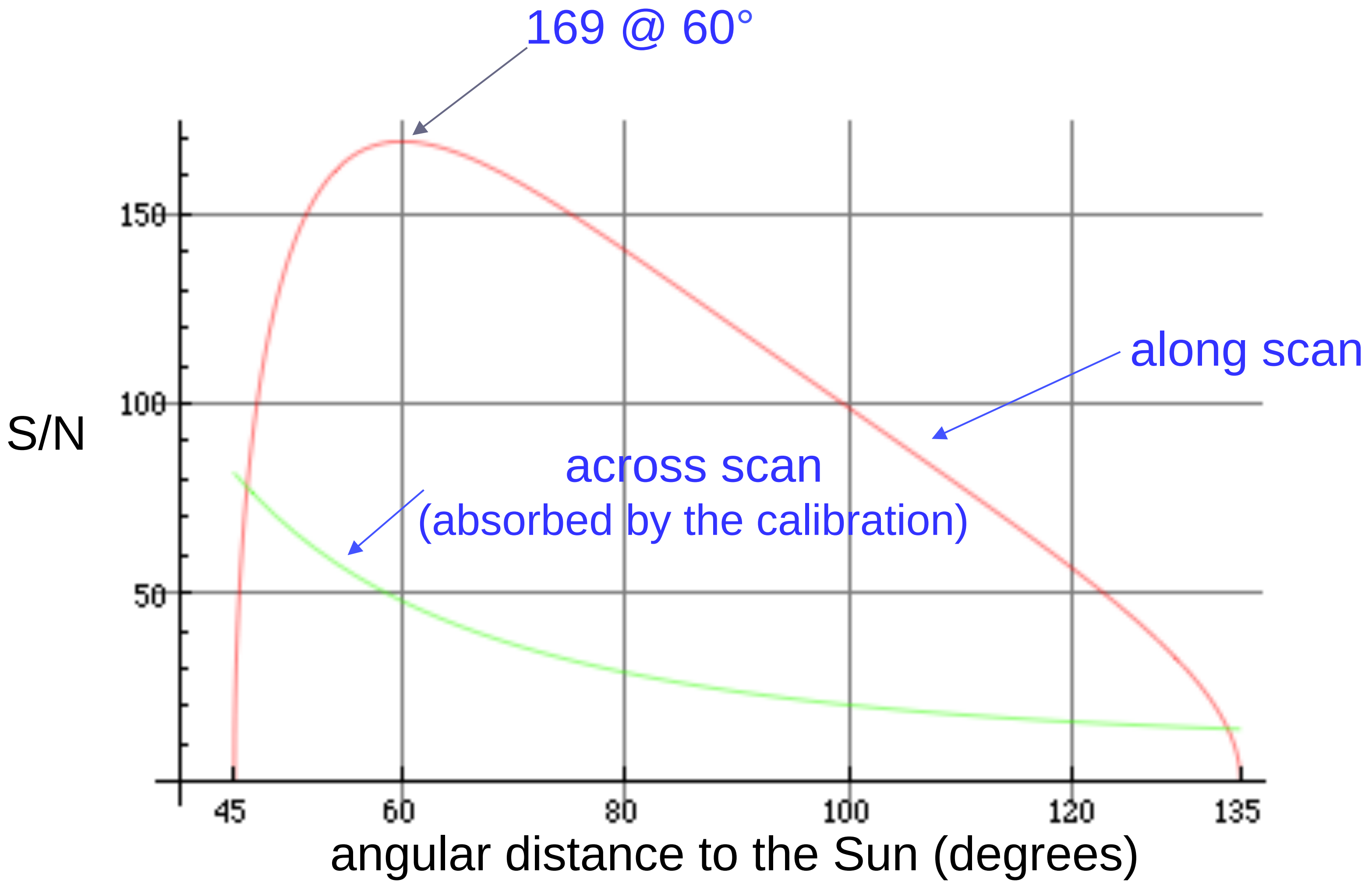


Each relativistic effect used in the models can be used to test GR



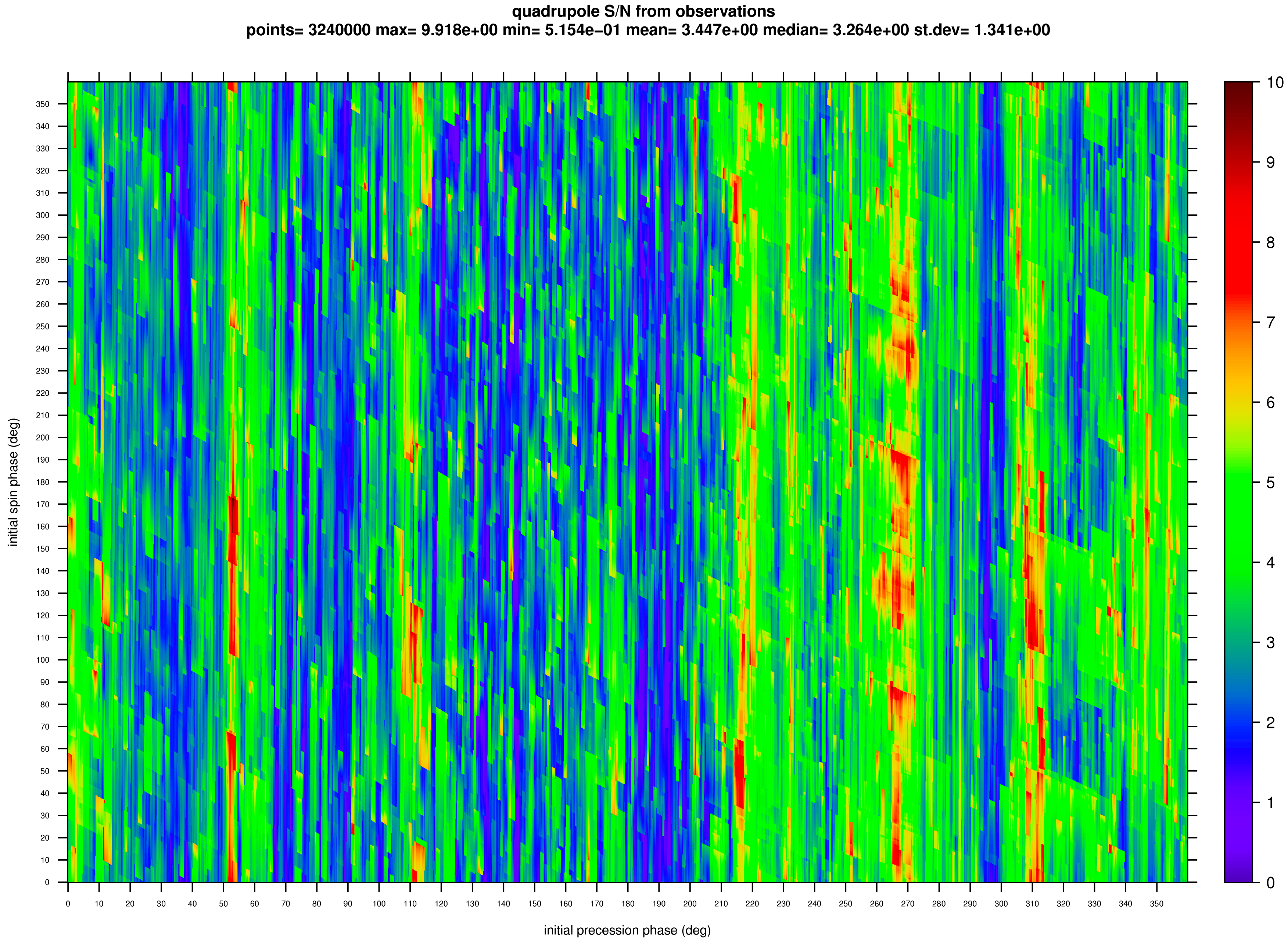
Improved ephemeris
Relativistic tests with Gaia
Consistency !
Global tests
Local tests
Local Positional Invariance
Local Lorentz Invariance
Pattern matching
Light deflection
SS acceleration
Primordial GW
Unknown deflectors
Cosmological tests
One single γ
Four different γ ‘s
Stability checks for γ
Higher-order deflection
Alternative angular dependence
Non-radial deflection
Planetary deflection
Monopole
Quadrupole
Gravimagnetic
Solar system objects
Perihelion precession
Non-Schwarzschild effects
SEP with the Trojans
J_2 of the Sun
$\dot{G}/G$
Special objects
Compact binaries

Gaia sensitivity to the gravitational light deflection due to the Sun

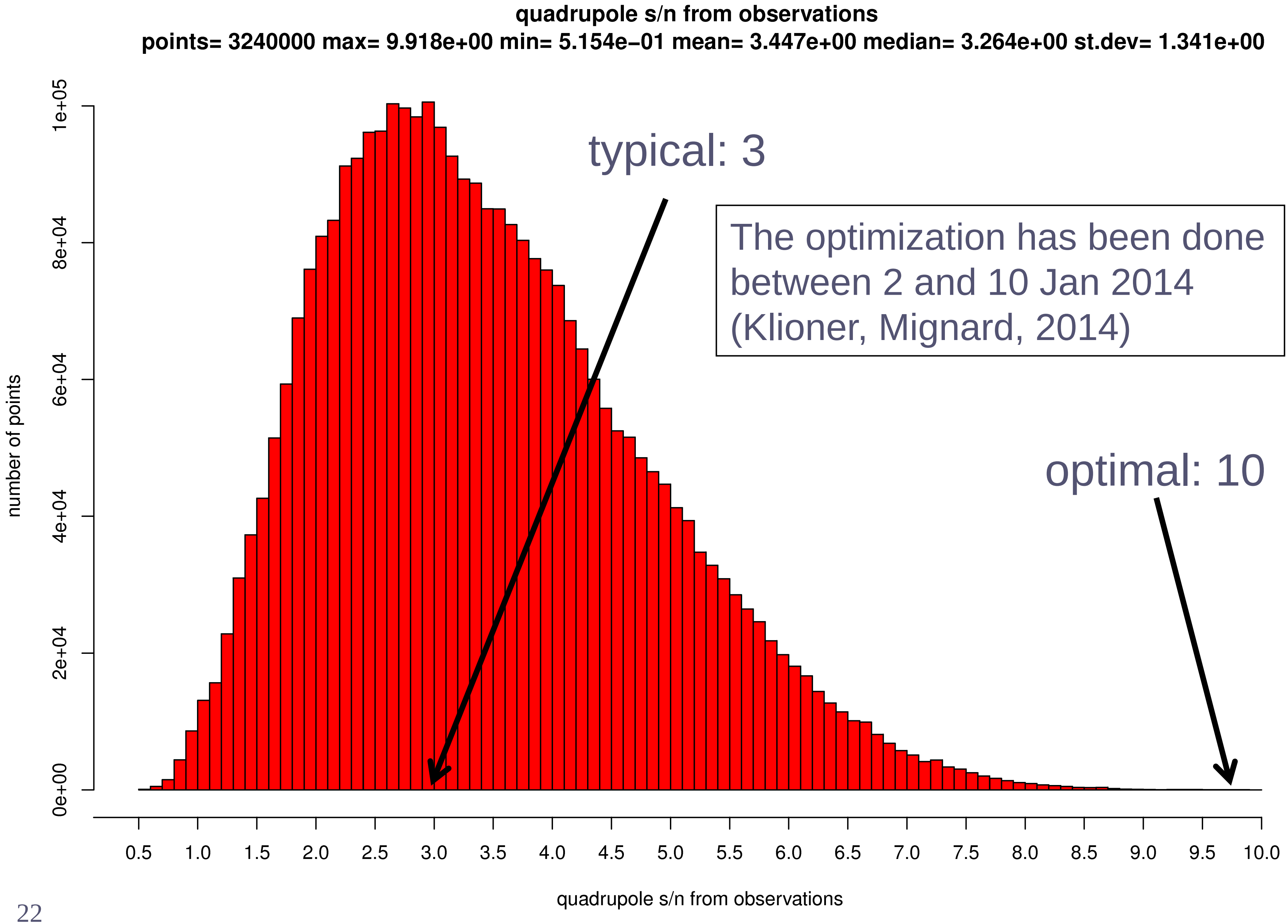


about 80 observations for each of 10^9 sources…

Accuracy of the quadrupole deflection test as function of two free parameters of the Gaia scanning law



Optimization does bring a major improvement



The optimization has been done between 2 and 10 Jan 2014 (Klioner, Mignard, 2014)

GR-relevant tests with Gaia: solar system and beyond

1. Monopole light deflection
2. Quadrupole light deflection (a few sigmas – detection)
3. Local Lorentz Invariance – a big (and expensive ☺) “Michelson-Morley”
4. post-Newtonian equations of motion with asteroids
5. acceleration of the solar system
6. masses of black holes and neutron stars in binaries
7. ultra-low frequency gravitational waves: v < 6 nHz
8. gravitational waves from quasi-stationary sources
   (binary supermassive black holes): 6 nHz < v < 0.2 mHz

Backup slides

Gaia: hardware problems

- Gradual throughput decrease

  reason: unexpected water in the spacecraft which slowly evaporates and condenses as ice on the (cold) mirrors
  remedy: periodic (once per several months) heating of the payload
  consequences: about 1 month of additional dead time per year

- Excessive stray light in some parts of the focal plane

  reason: not fully understood; small manufacturing errors of the sunshield?, …
  remedy: none; might become better after decontamination
  consequences: lower accuracies for stars G>16

- Larger variations of the BA (basic angle) are measured by the BA monitor

  reason: unknown
  remedy: BA monitor; studies ongoing
  consequences: hopefully none, but…

Gaia: expected astrometric accuracy

http://www.cosmos.esa.int/web/gaia/science-performance

End-of-mission parallax:

	B1V	G2V	M6V
$V-I_C$ [mag]	-0.22	0.75	3.85
Bright stars	5-14 µas (3 mag < V < 12 mag)	5-14 µas (3 mag < V < 12 mag)	5-14 µas (5 mag < V < 14 mag)
V = 15 mag	26 µas	24 µas	9 µas
V = 20 mag	600 µas	540 µas	130 µas

Other parameters:

$$
\begin{aligned}
\sigma_0 &= 0.743 \cdot \sigma_\Pi; \\
\sigma_{\alpha*} &= 0.787 \cdot \sigma_\Pi; \\
\sigma_\delta &= 0.699 \cdot \sigma_\Pi; \\
\sigma_\mu &= 0.526 \cdot \sigma_\Pi; \\
\sigma_{\mu\alpha*} &= 0.556 \cdot \sigma_\Pi; \\
\sigma_{\mu\delta} &= 0.496 \cdot \sigma_\Pi,
\end{aligned}
$$

The predicted errors vary over the sky…