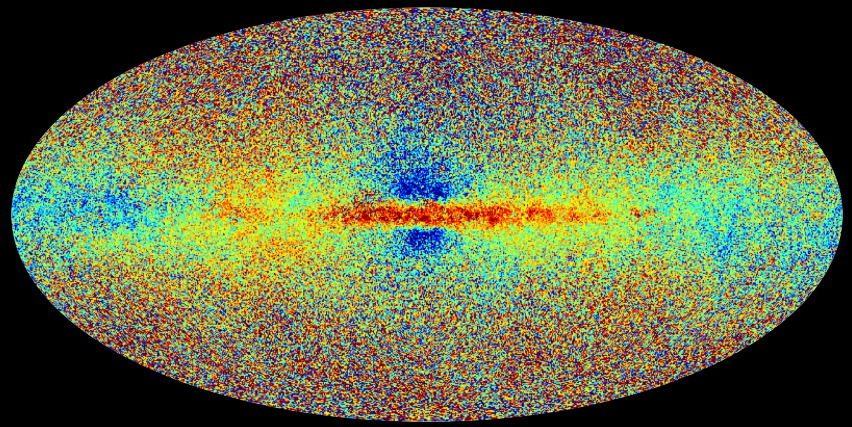
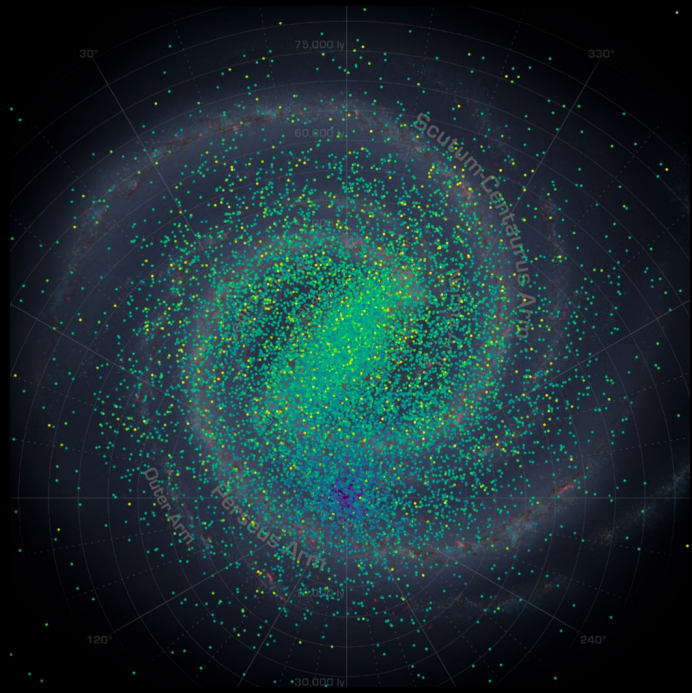
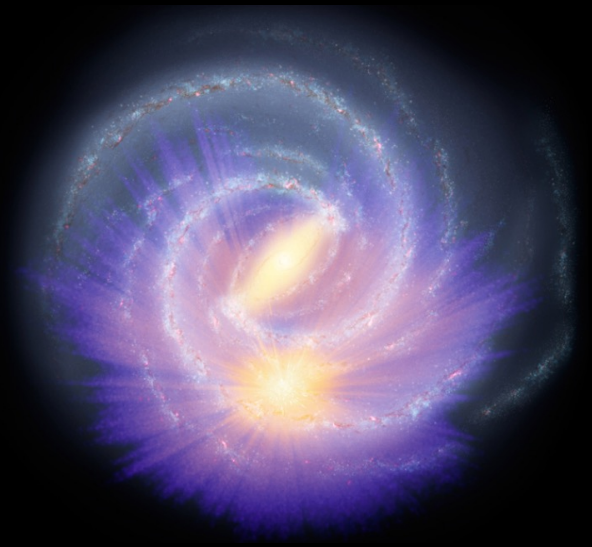
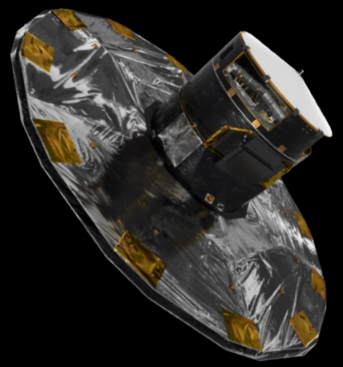
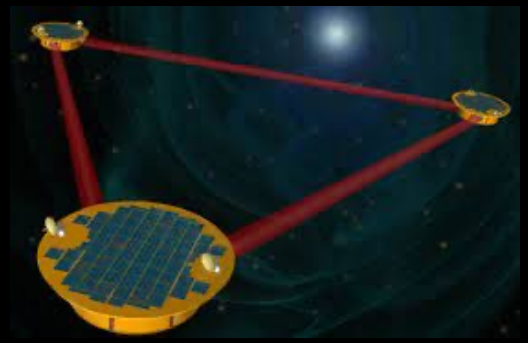
Gaia mission: lessons learned *(personal view)*







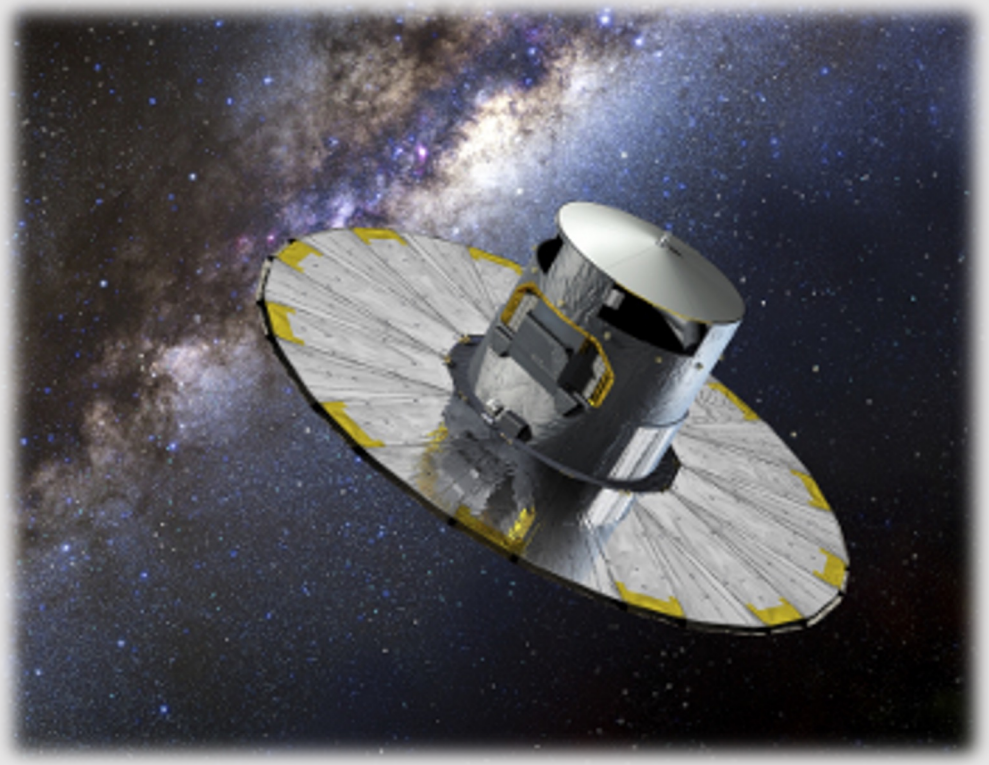


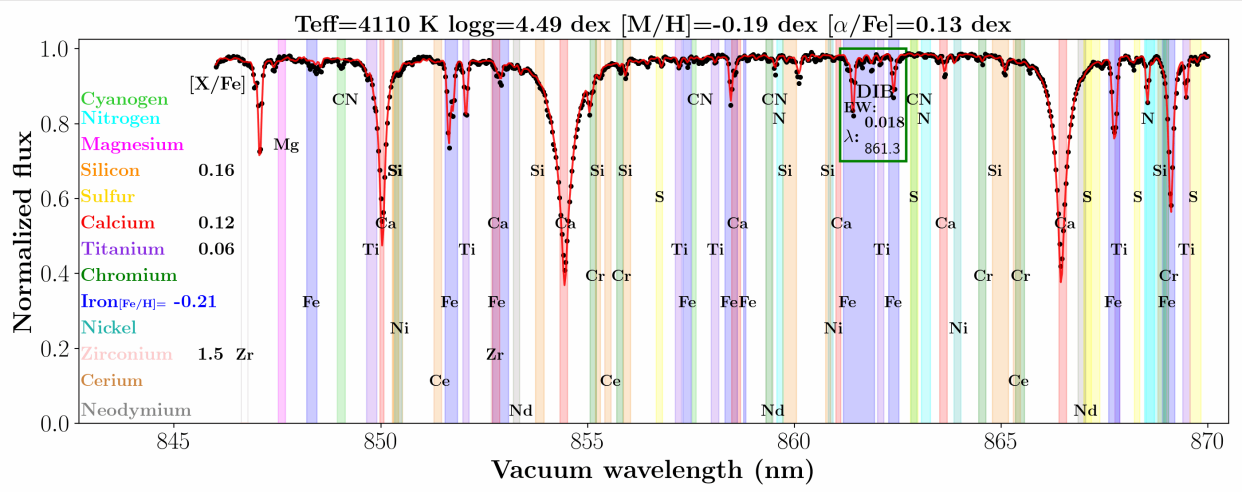


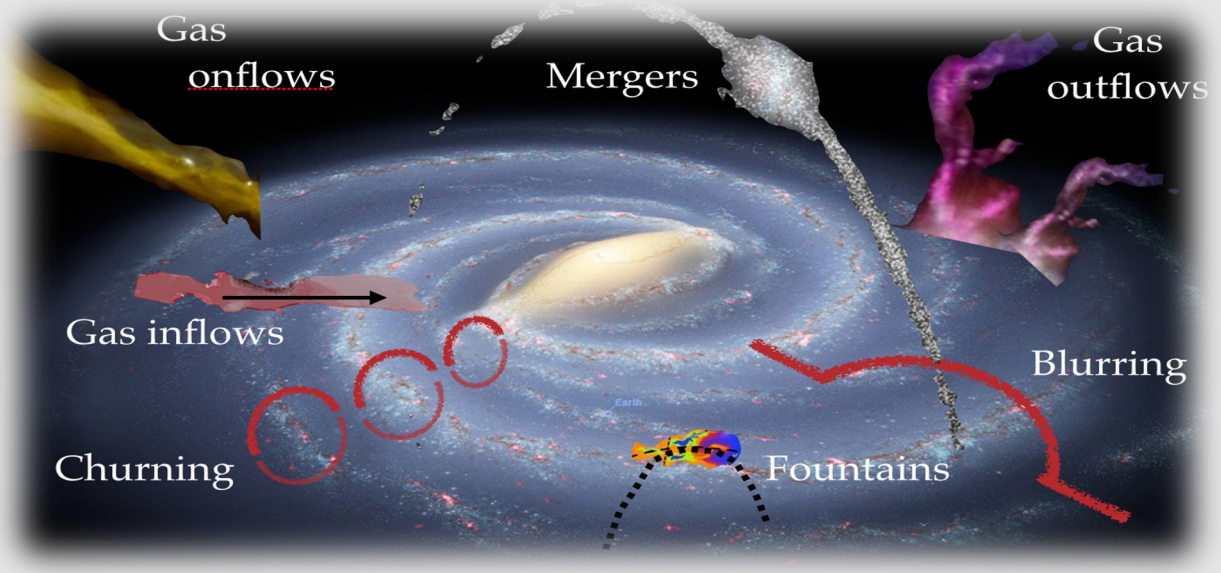
Alejandra Recio-Blanco
Observatoire de la Côte d'Azur – 12th June 2023

Outline of the talk

1. The expected and the unexpected
2. Keys of the Gaia revolution
3. Synergies Gaia-LISA







Credits:ESA/GAIA/DPAC-CU8-CU6 Recio-Blanco and the GSPspec team

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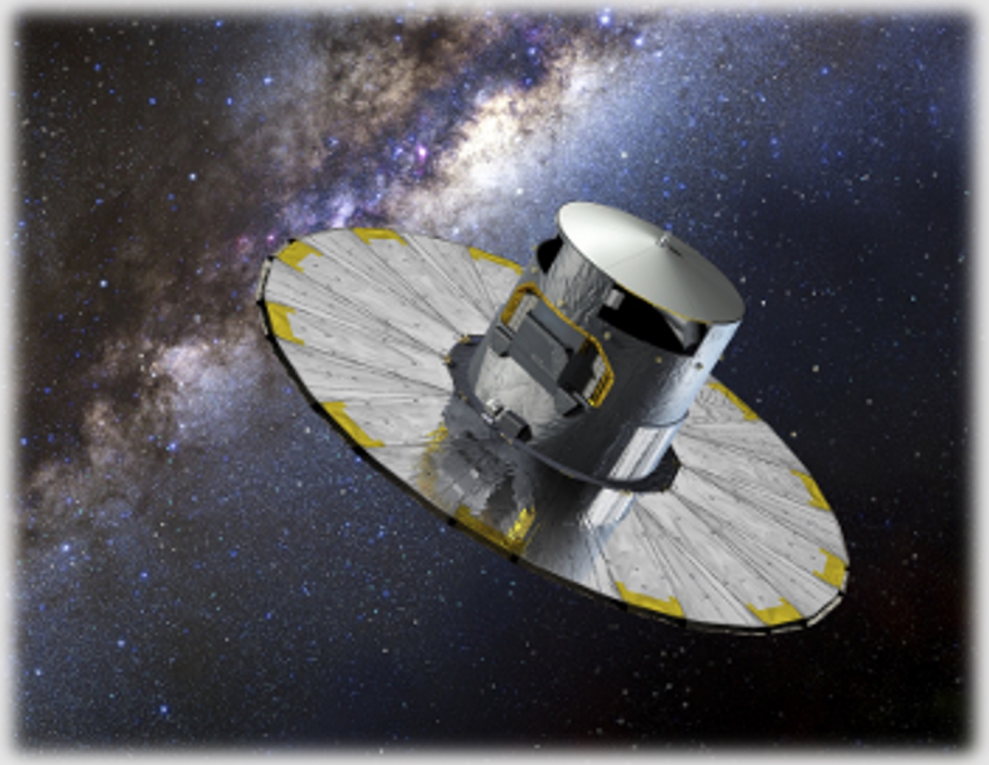
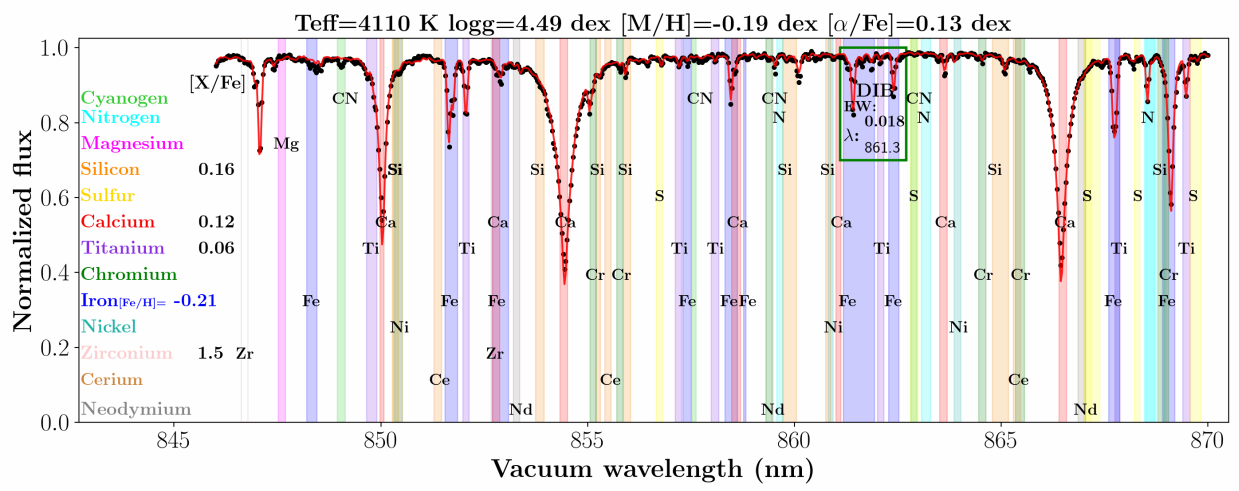
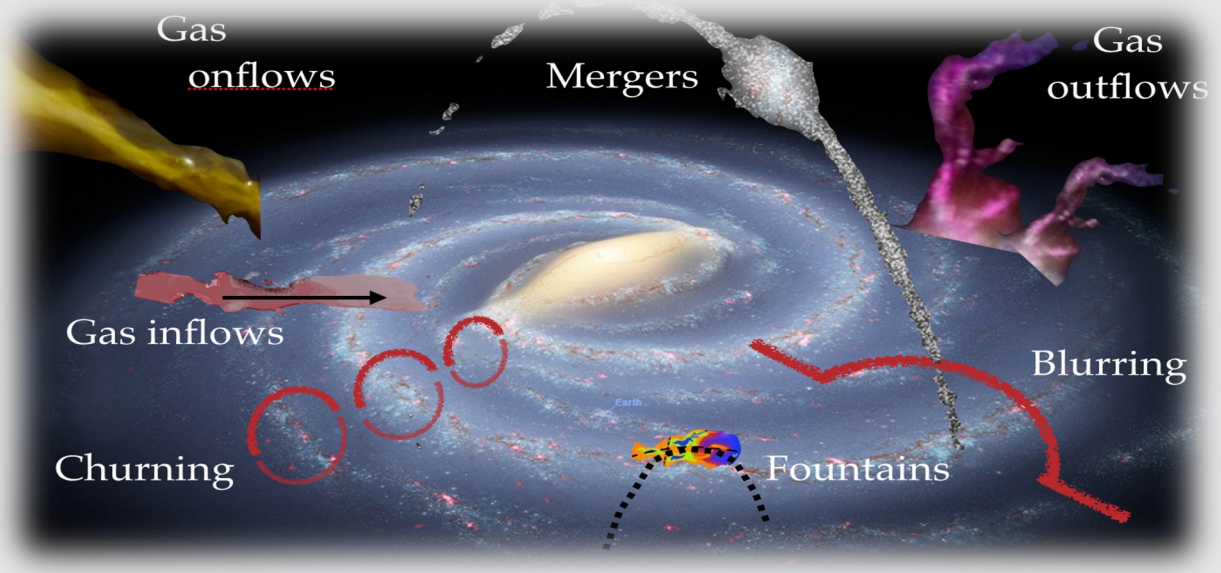




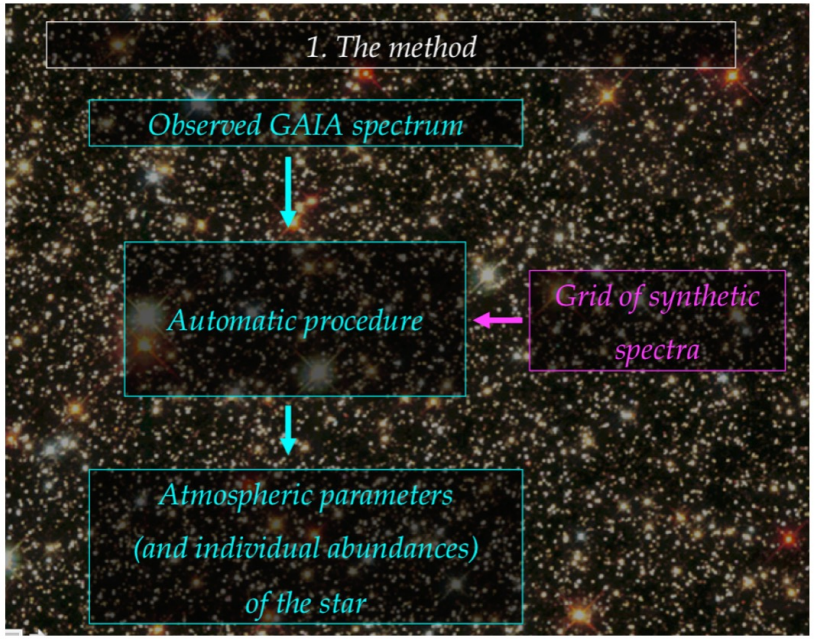


Credits:ESA/GAIA/DPAC-CU8-CU6 Recio-Blanco and the GSPspec team

Photo during ESA external fellowship

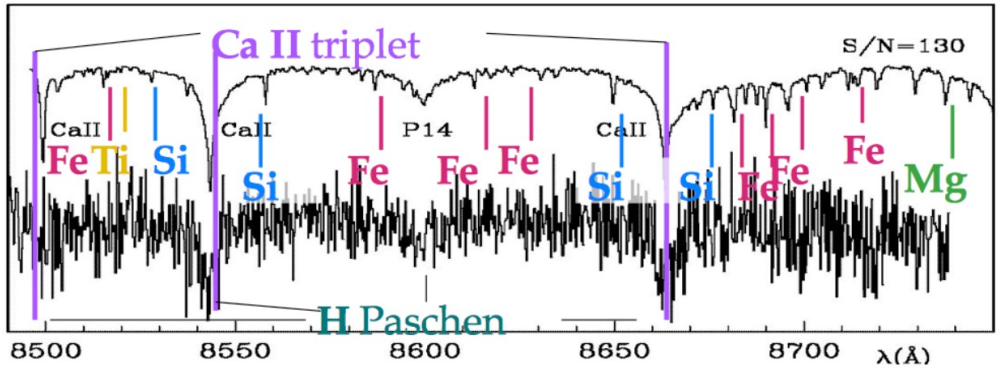
copy-right Eric Lagadec (PhD student)!

Workshop 7 RVS Working Group, 11-12 Dec 2003



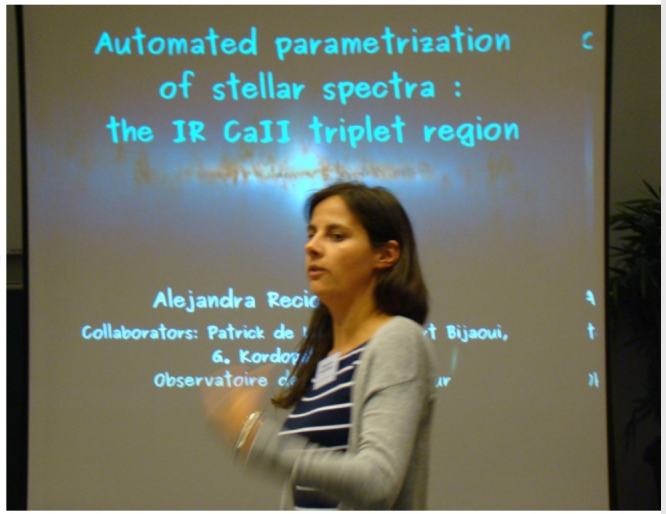
DPAC creation in 2006 **First CU8 DPAC meeting**

Generalized Stellar Parametrizer – Spectroscopy (GSP-spec) GWP-S-823-0000



Alejandra Recio-Blanco *on behalf of the GSP-spec group*
Nice, 16-17 March 2006

POURQUOI,
POURQUOI,
POURQUOI ?



Brussels, 2011

When we started, automated spectra parameterization practically did not exist… and almost nobody cared!

1. The expected and the unexpected

Success in the expected

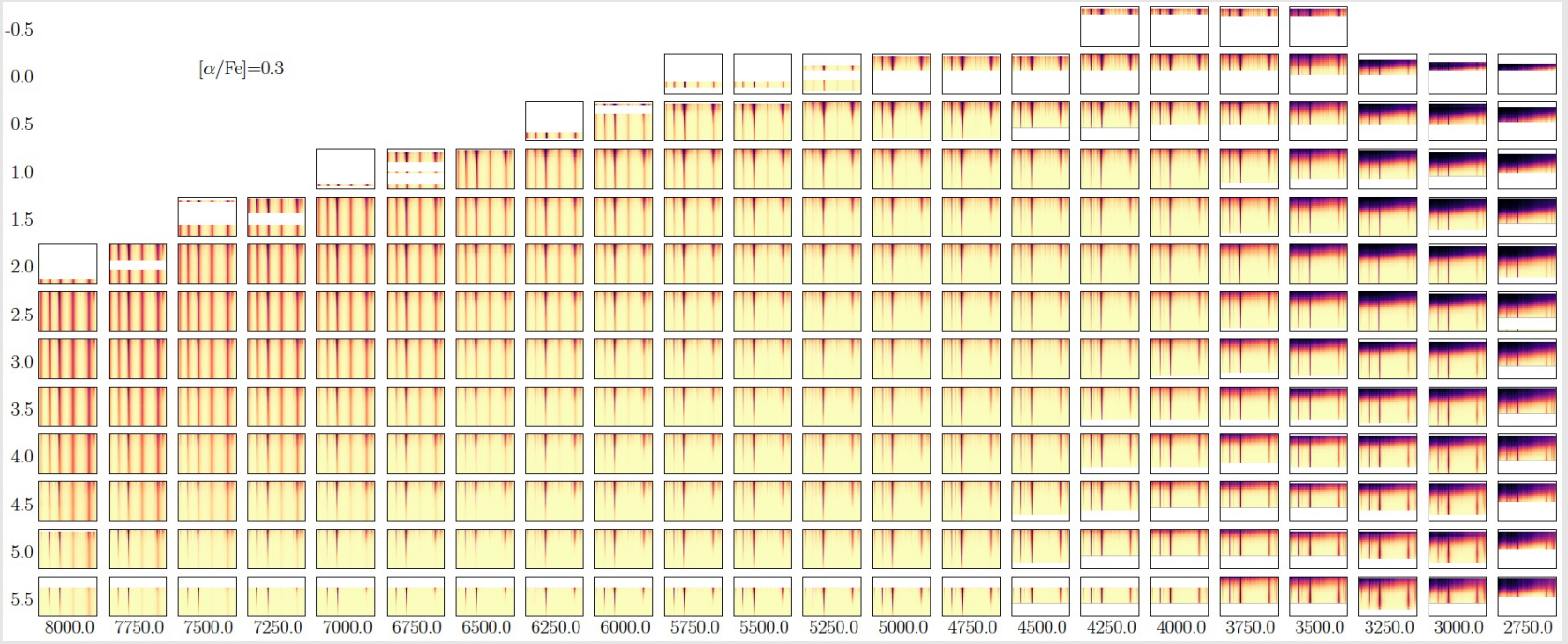
- Confirmed success of the astrometric observations

  Ground breaking results with a strong impact in many fields of astrophysics

1. The expected and the unexpected

Success in the expected

- Confirmed importance of building up on existing expertise (e.g. data analysis, Hipparcos mission,...)
  It allows to be more efficient, even pioneers in some aspects
- Confirmed importance of investment in modeling/simulations
  Crucial to prepare the pipelines and to understand the results!



MARCS atmosphere models + turbospectrum

1. The expected and the unexpected

Success in the expected

- Support from CNES and its data processing centre is a key of the success
  - CNES teams always supportive, helping to implement as much as possible all our (sometimes crazy) ideas. They are brilliant people !
  - CNES support in PhD thesis, post-docs and engineers **is crucial before and during operations.**

Merci !!!

1. The expected and the unexpected

Expected difficulties

- VERY strong pressure on the teams.
- VERY long term engagements.
- Problems detected in the payload when operations start (e.g. stray-light)
- Hard dead-lines can be imposed...
- Misbehaviour (including harassment) happens. It is important to quicky have a code of conduct and reference people for these aspects.

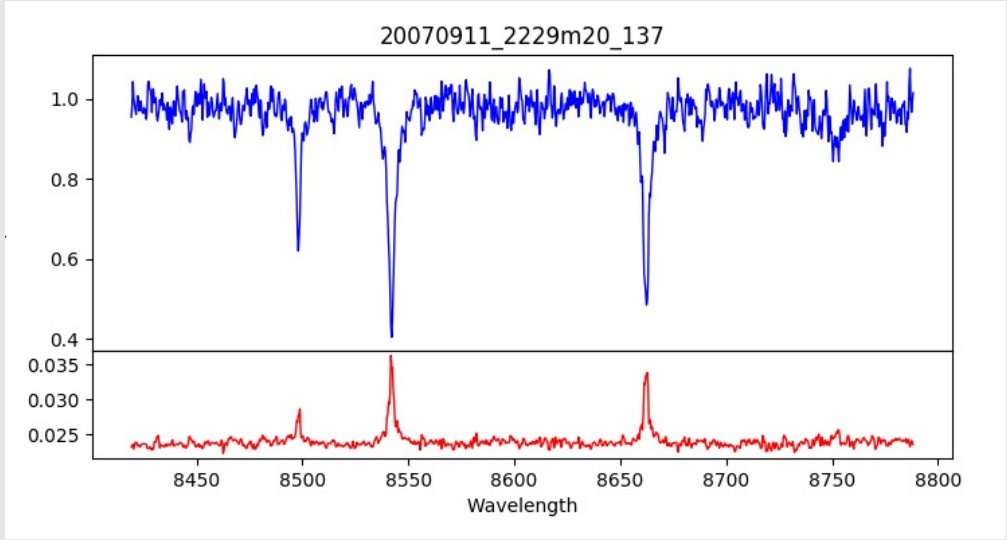
1. The expected and the unexpected

Success in the unexpected

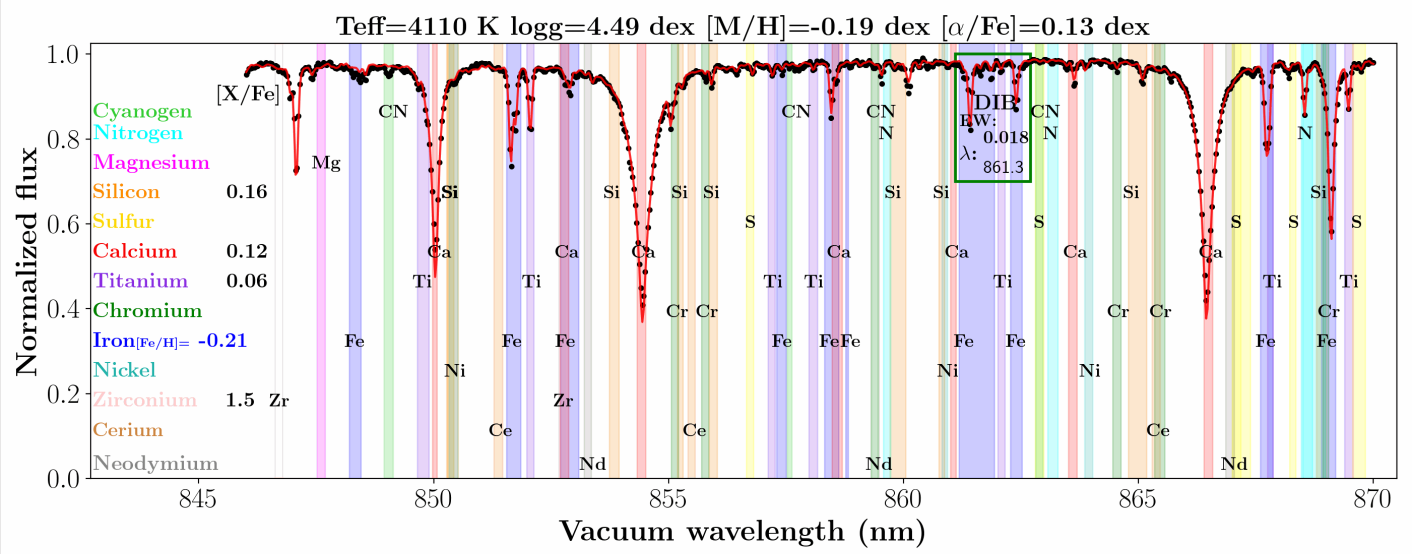
- Pessimistic predictions about spectroscopic data quality and derived products

Biased by ground-based experience with similar instrumental configurations

Ground-based RAVE data



Gaia RVS data



Real data are much better than expected -> high precision in RVs, astrophysical parameters, chemical abundances, ...

1. The expected and the unexpected

Important

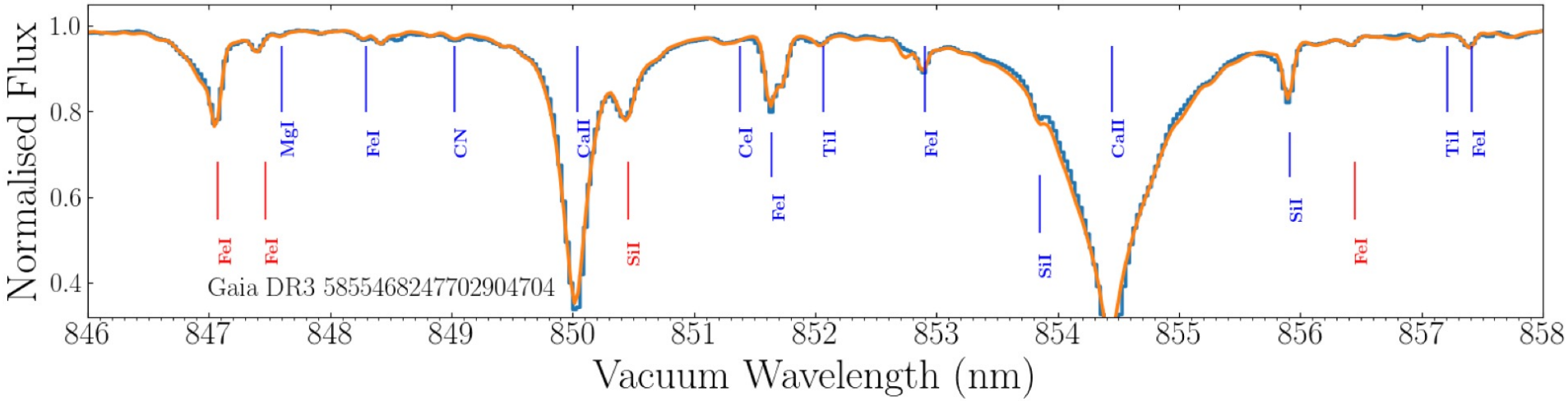
SPACE data $\neq$ ground based data

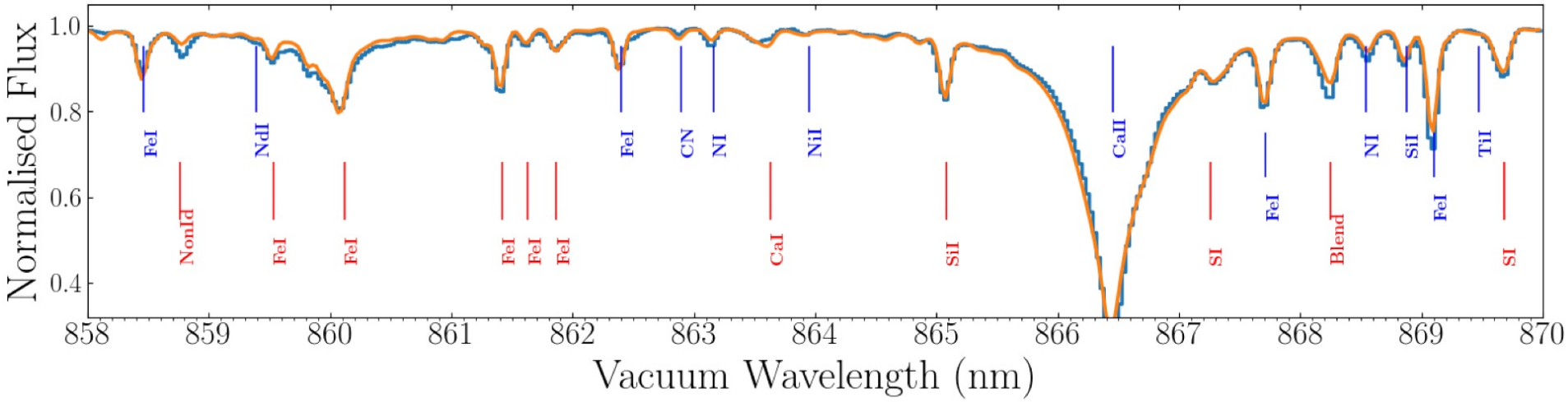
- Continuous observations for years (34 months for DR3, ~25 000 h of continuous observations)
- Stable conditions (no atmosphere)
- Very good control and modeling of systematics
- Extremely homogeneous treatment
- High number statistics providing hundreds of thousands of high SNR (>150) data

Parametrization quality comparable to ground-based surveys of higher spectral resolution and wavelength coverage.

1. The expected and the unexpected

High quality spectra: **continuous observations for 3 years, no atmosphere, control of systematics, ...** Gaia is not a ground-based survey!





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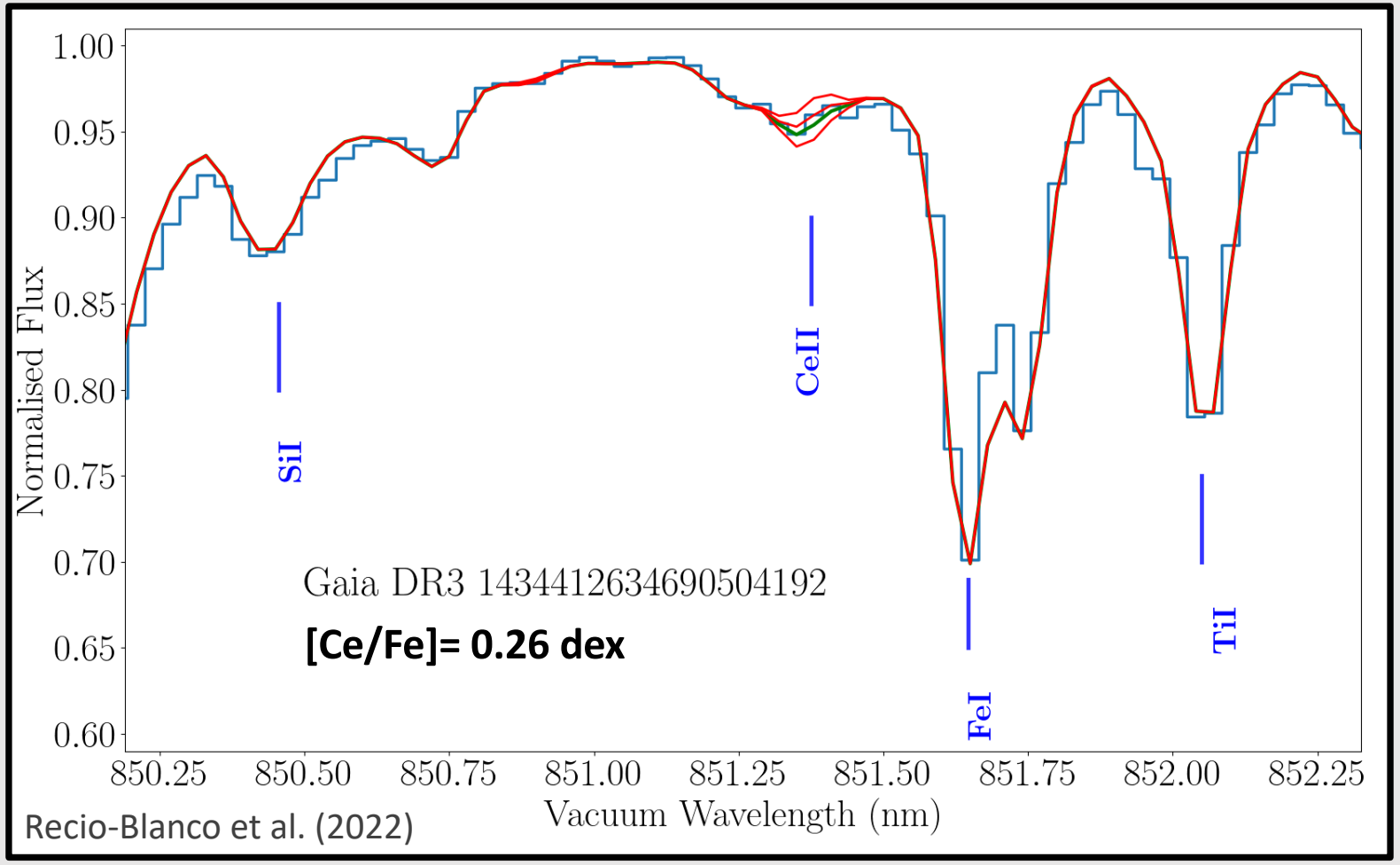


Heavy elements ex. Cerium

1. The expected and the unexpected

Unexpected difficulties

- Too optimistic predictions about some products (e.g photometric parameters)

Pre-launch simulations not realistic enough?

- Important world-wide crisis (covid!) right before a crucial data release

Gaia was not locked down, but we were!! (with young children, or completely alone...)

- Analysis of key objects (e.g. standard candles, black holes) spread over CUs/WPs not interacting with each other in a standard analysis flow.

Creation of new specific Task Forces composed of cross-CU teams

Slide from the Standard Candles Task Force kick off meeting (Resp. ARB)

Would these people have worked together if they had been Gaia DPAC members?

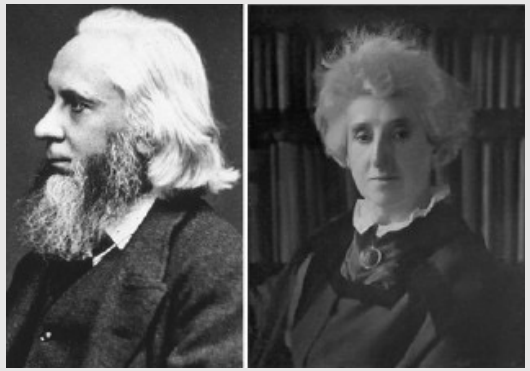
Friedrich W. Bessel (CU3)

Annie J. Cannon (CU8)

Antonia Maury (CU4)

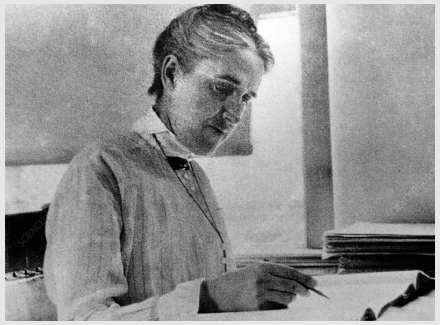
Ejnar Hertzsprung (CU5)

Henry N. Russel (CU5)



William and Margaret Huggins (CU6)

Cecilia Payne (CU8)



Henrietta Leavitt (CU7)

Edwin Hubble (CU9)

Angelo Secchi (CU6)

The Harvard "computers" (DPCC)

Harlow Shapley (CU7)

Outline of the talk

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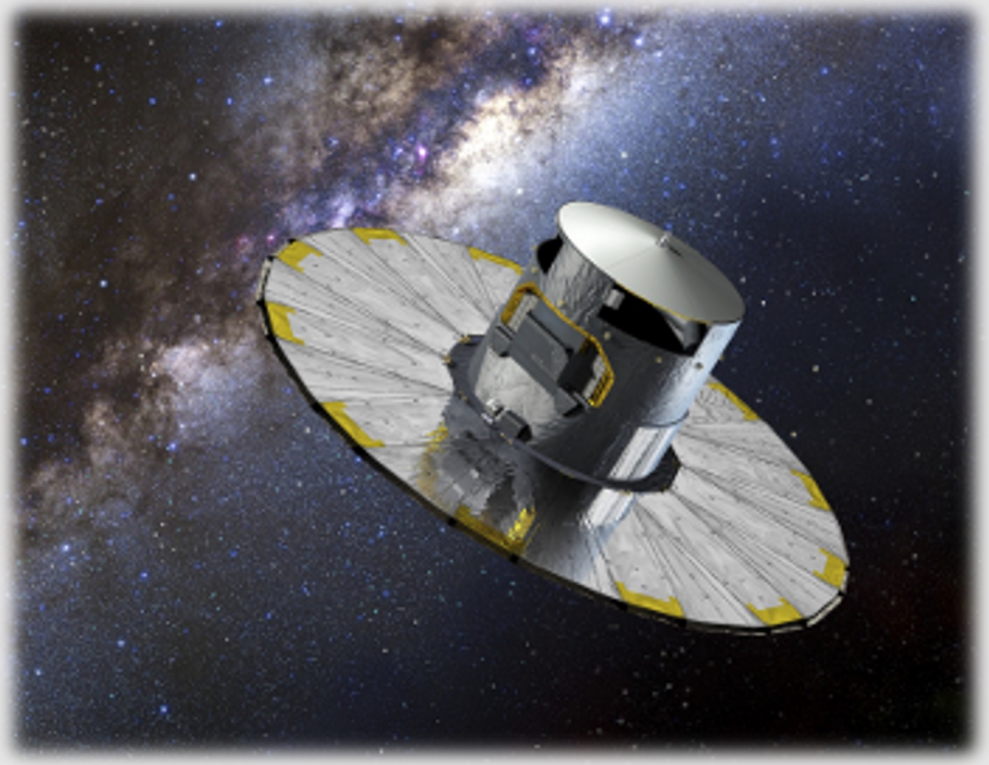
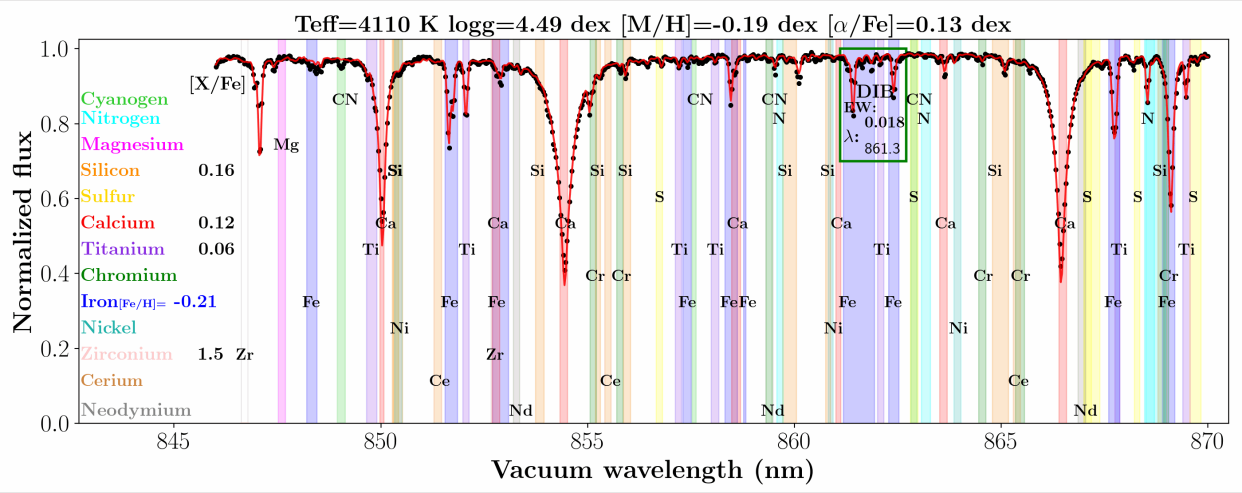
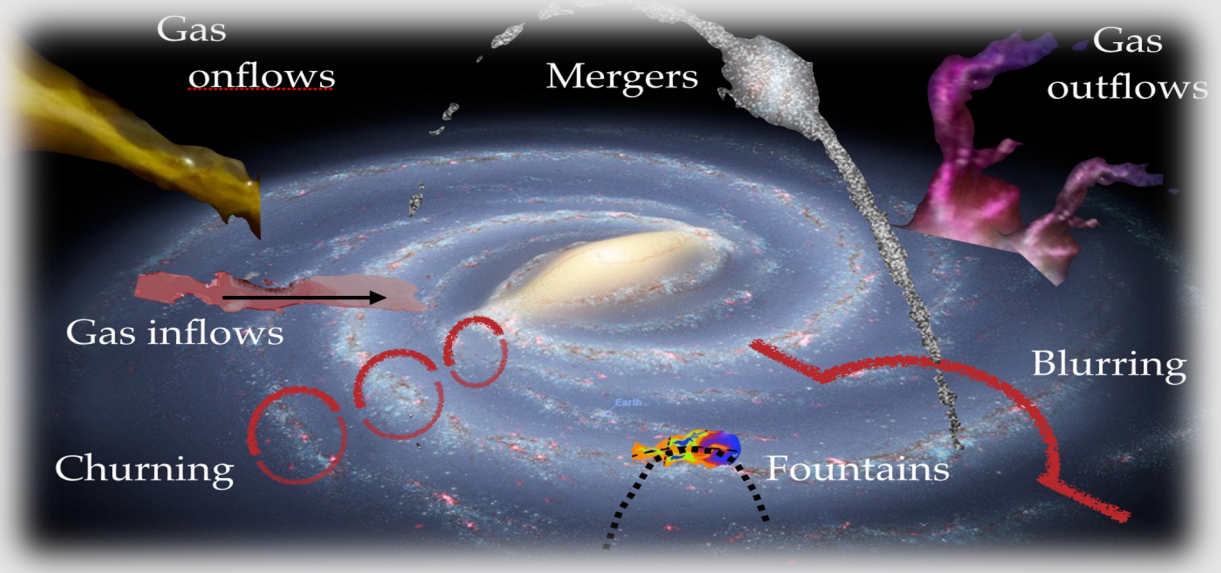
3. Synergies Gaia-LISA







Credits:ESA/GAIA/DPAC-CU8-CU6 Recio-Blanco and the GSPspec team

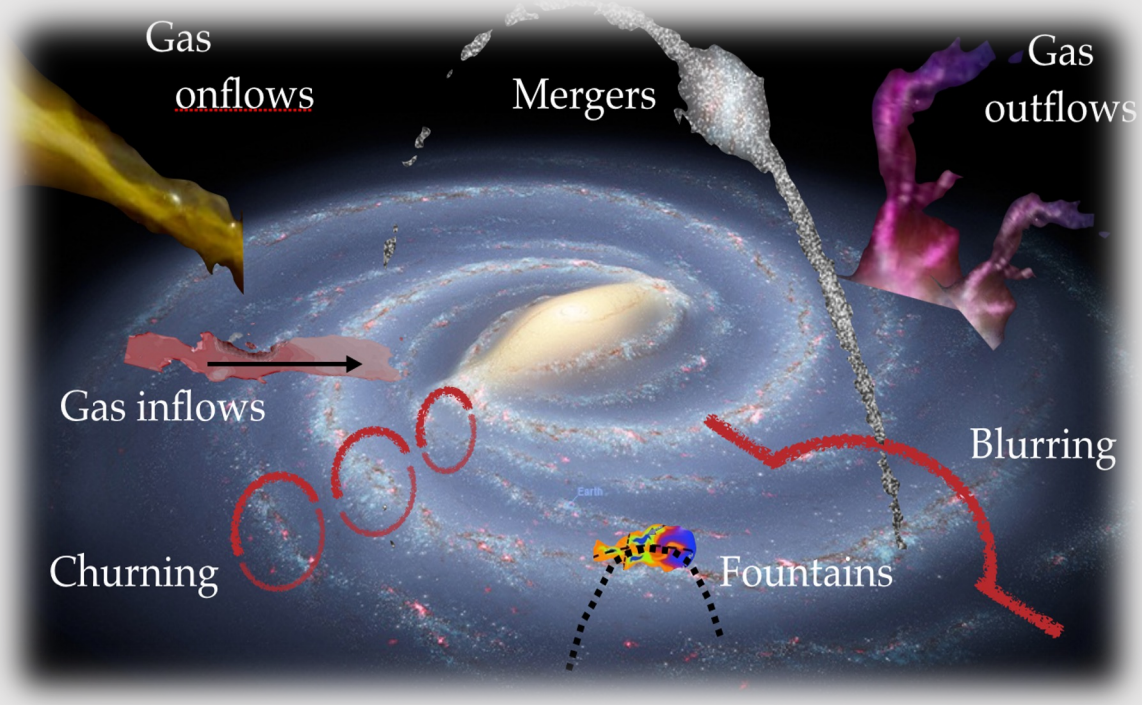
Gaia revolutions: roots and keys

Gaia combines the **astrometric** approach of **classical astronomy** with the **physical** approach of **modern astrophysics.**

Detailed evolution of the Galaxy in its environment

This is enhanced by:

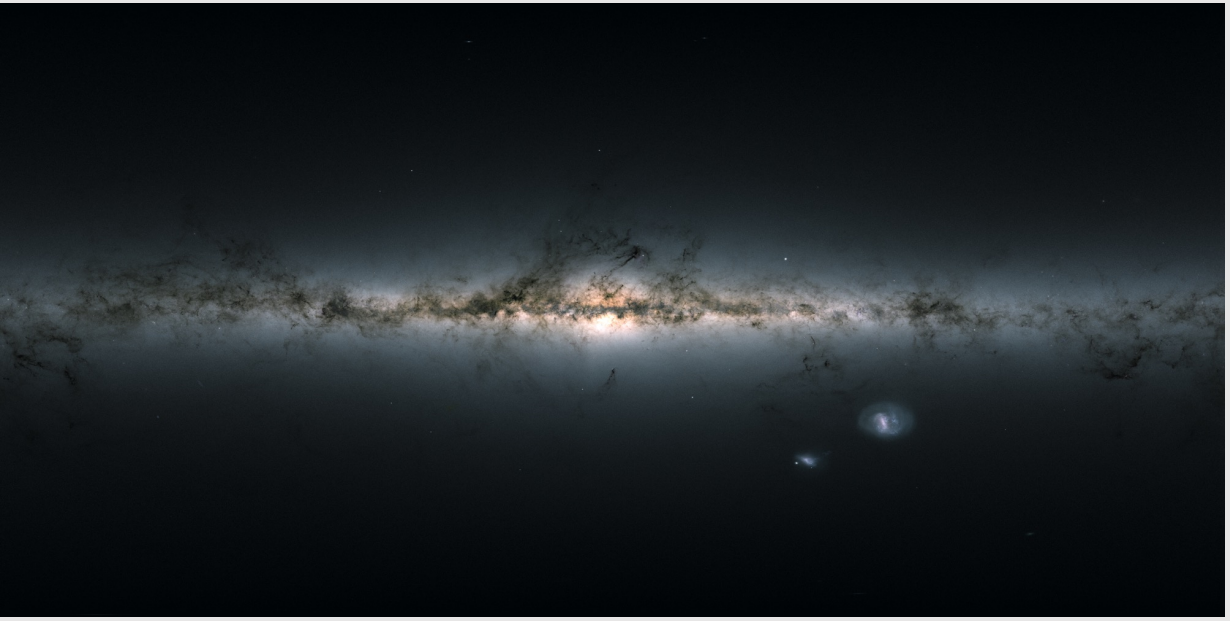
- High number statistics
- High precision
- Time series observations

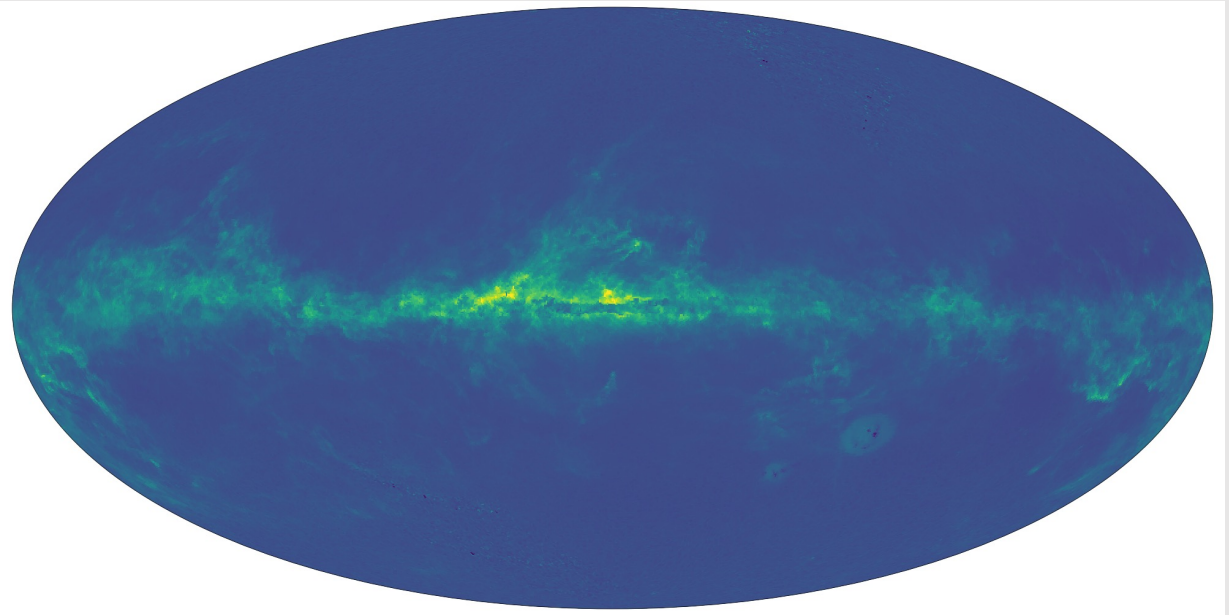


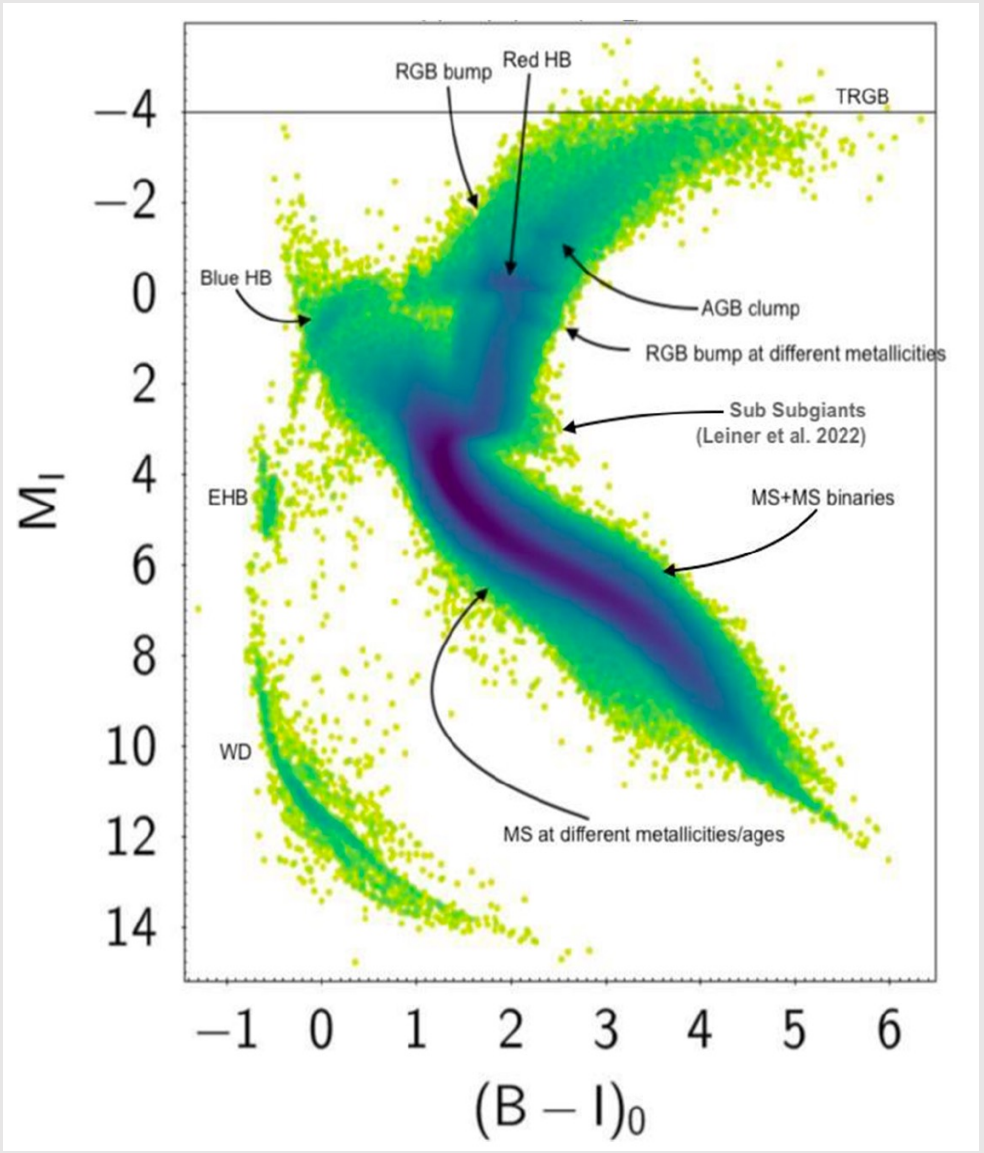
The keys of the Gaia revolution

- Parallaxes: the depth of the sky...
- Number statistics: 1.8 billion stars (astrometry+photometry)
  33 million stars (spectroscopy) Nb increasing!

Photometry





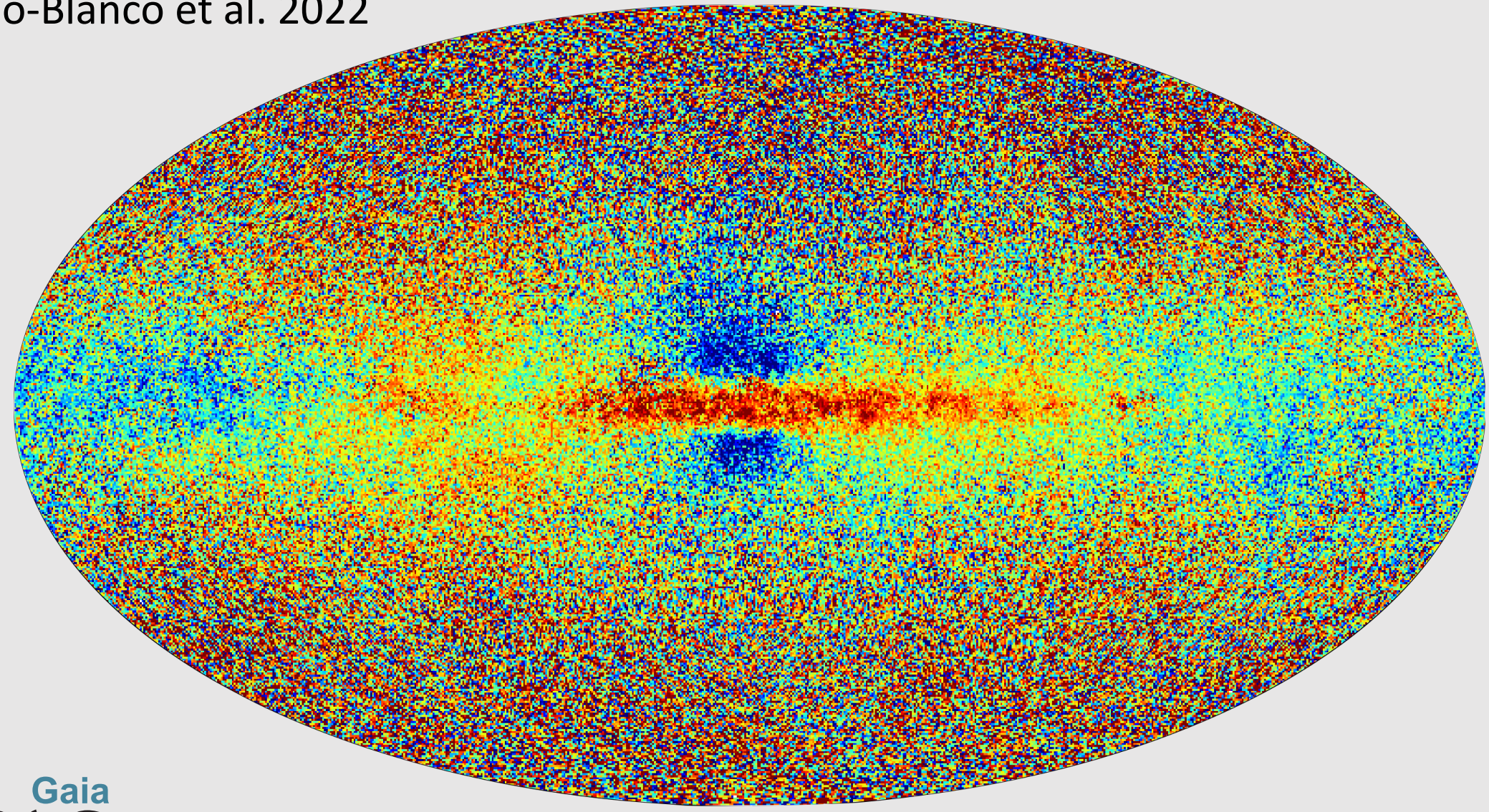


Gaia Collaboration, Montegriffo et al. 2022

Gaia DR3: 5.6 milion stars with chemo-physical parameters

Spectroscopy

Recio-Blanco et al. 2022



Gaia Collaboration, Recio-Blanco et al. 2022

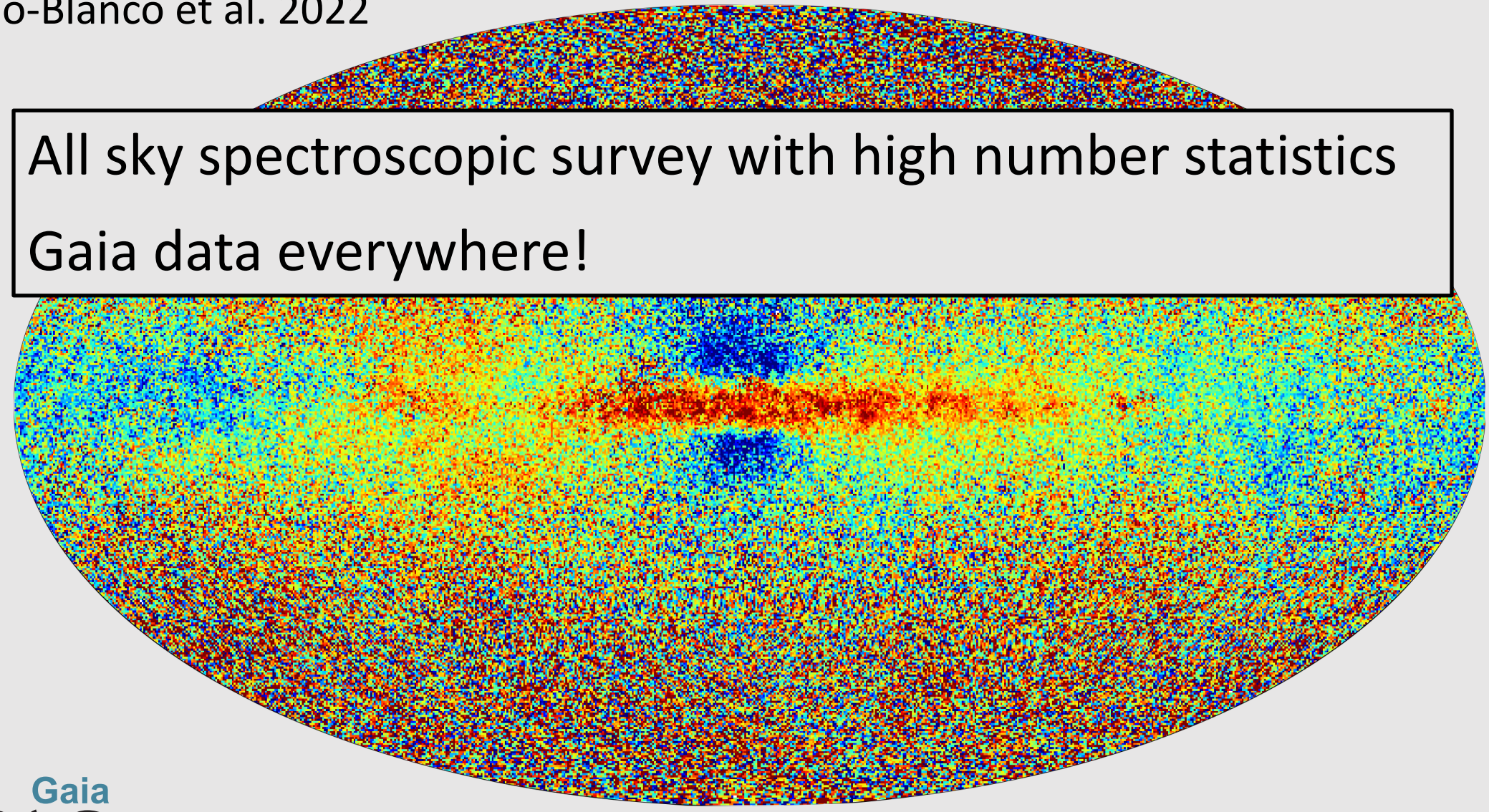
Gaia DR3: 5.6 milion stars with chemo-physical parameters

Spectroscopy

Recio-Blanco et al. 2022

All sky spectroscopic survey with high number statistics

Gaia data everywhere!



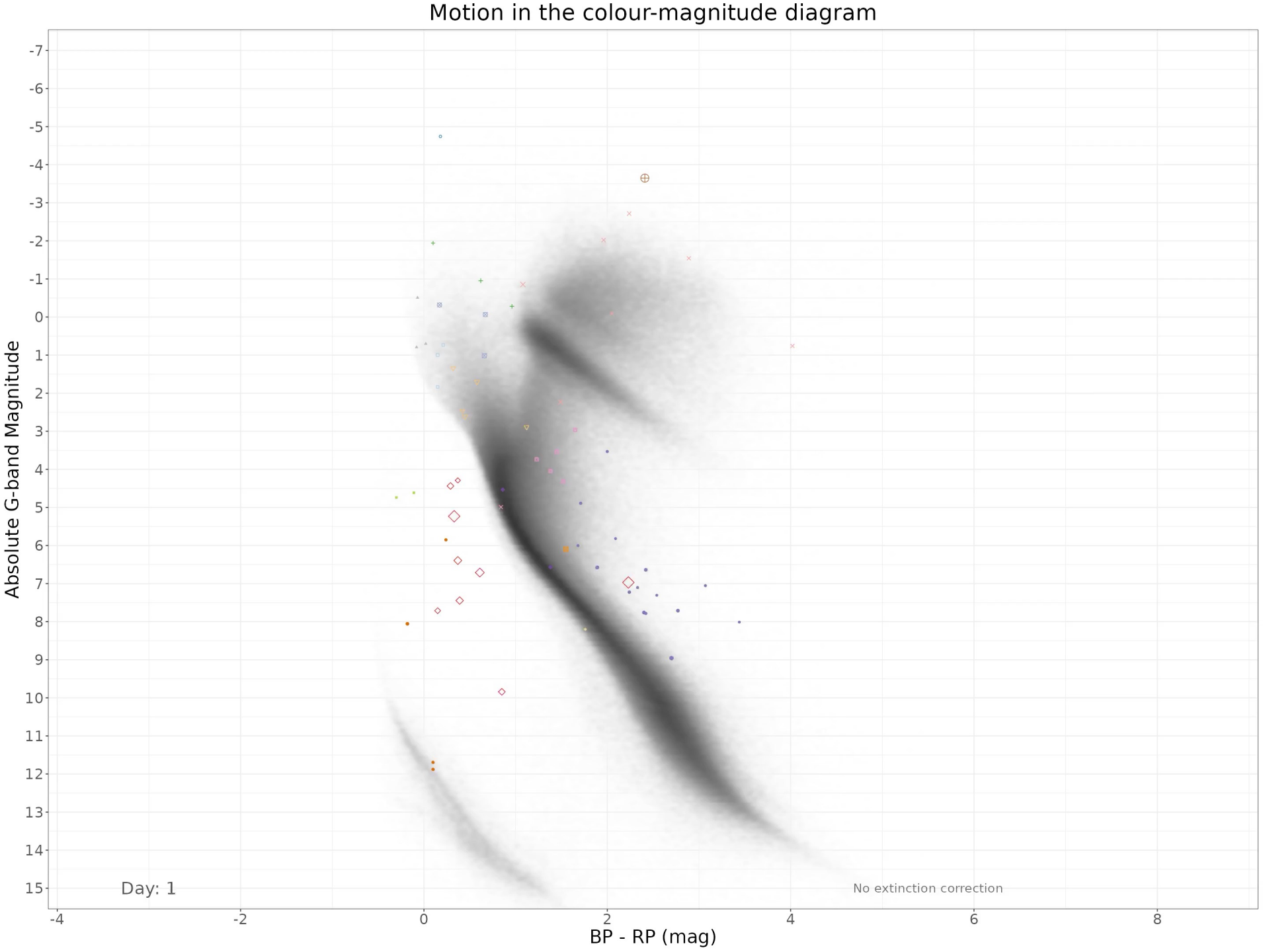
Gaia Collaboration, Recio-Blanco et al. 2022

The keys of the Gaia revolution

- **Parallaxes: the depth of the sky...**
- **Number statistics:** 1.8 billion stars (astrometry+photometry)
  33 million stars (spectroscopy) Nb increasing!
- **Stability and precision:** space observations (no Earth's atmosphere)
  extremely good control of systematics

The keys of the Gaia revolution

- **Parallaxes: the depth of the sky...**
- **Number statistics:** 1.8 billion stars (astrometry+photometry)
  33 million stars (spectroscopy) Nb increasing!
- **Stability and precision:** space observations (no Earth's atmosphere)
  extremely good control of systematics
- **Time-series (**continuous observations for years): **evolution!**
  - Proper motions
  - Solar System acceleration
  - Stellar variability
  - Binaries and their orbital solutions



Time-series over 34 months
Continuous observations!

Types

- ACV|CP|MCP|ROAM|ROAP|SXARI
- ACYG
- BCEP
- BE|GCAS|SDOR|WR
- CEP
- CV
- DSCT|GDOR|SXPHE
- ECL
- ELL
- EP
- LPV
- MICROLENSING
- RCB
- RR
- RS
- SDB
- SOLAR_LIKE
- SPB
- SYST
- WD
- YSO

Eyer et al. et al. 2022

Gaia DPAC

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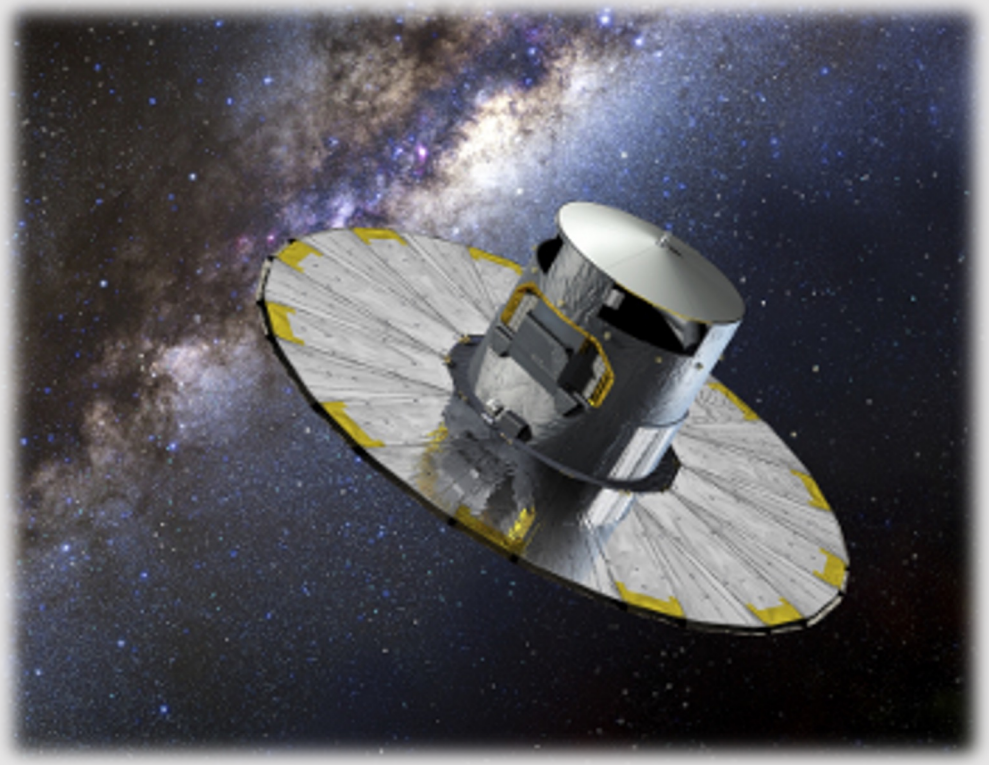
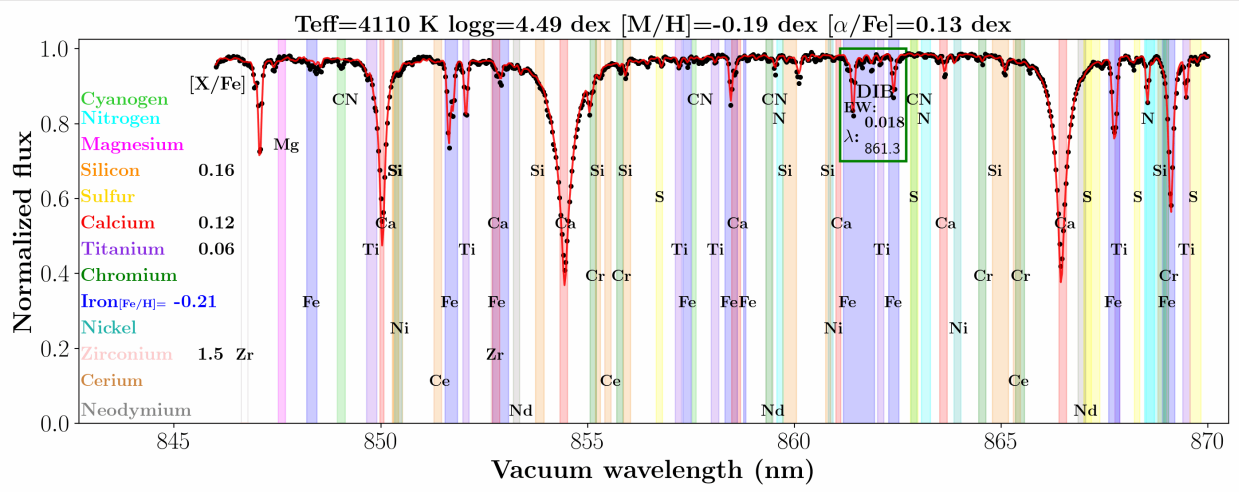
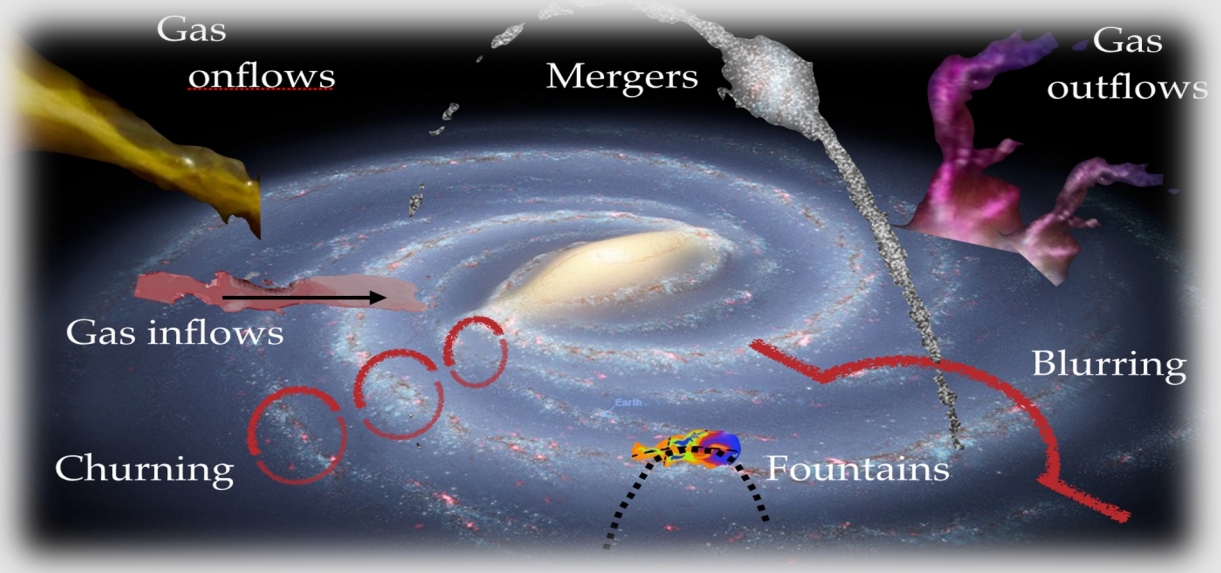
3. Synergies Gaia-LISA



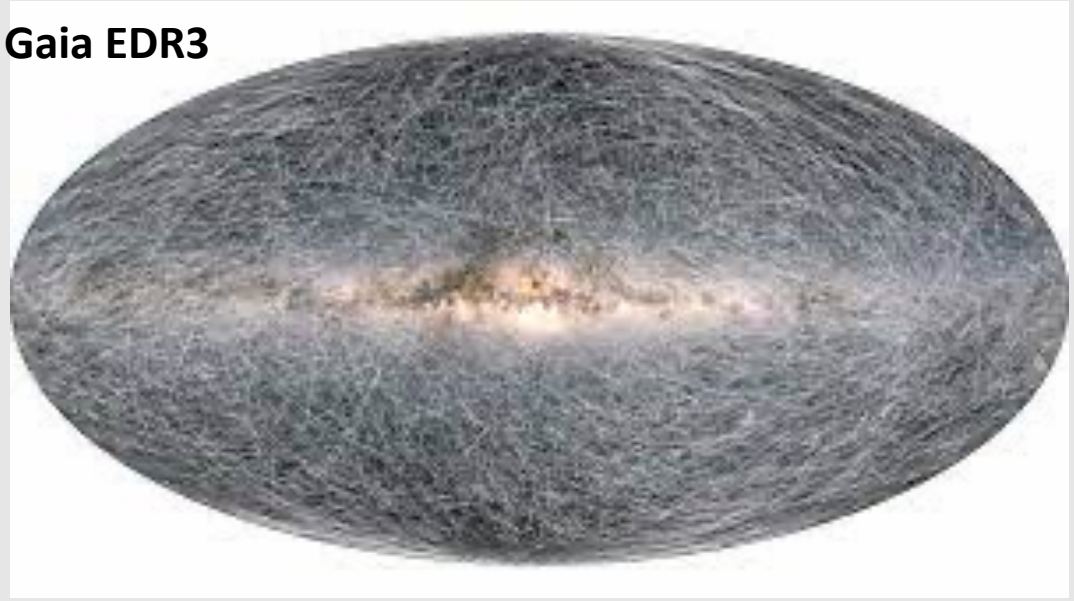


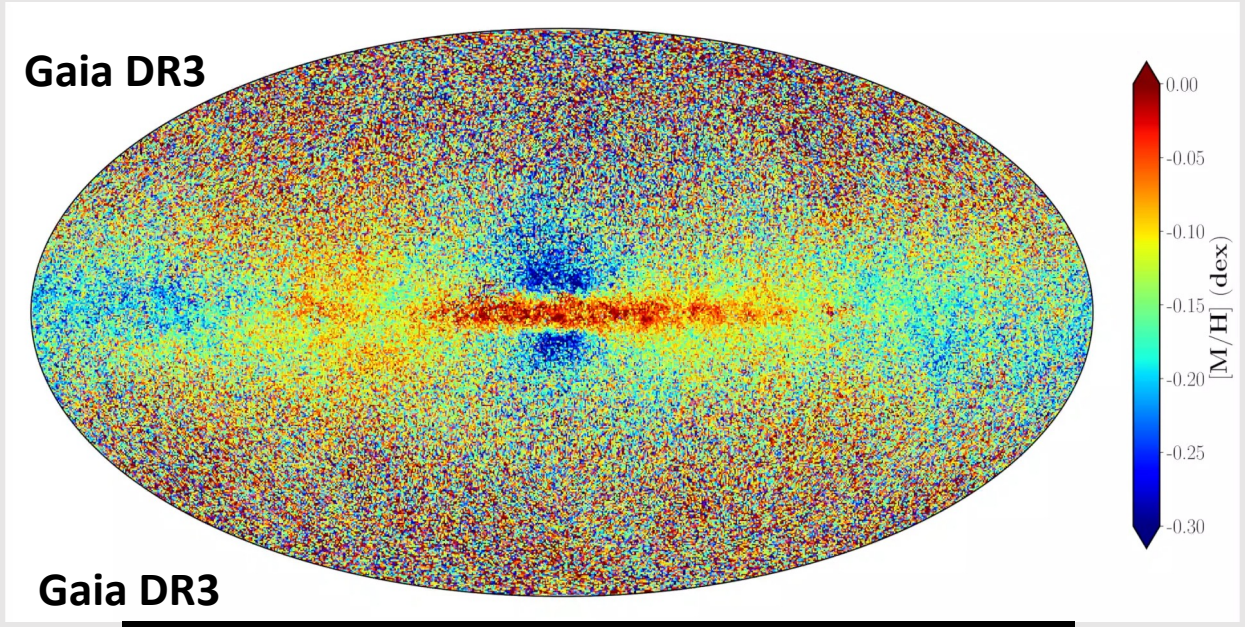


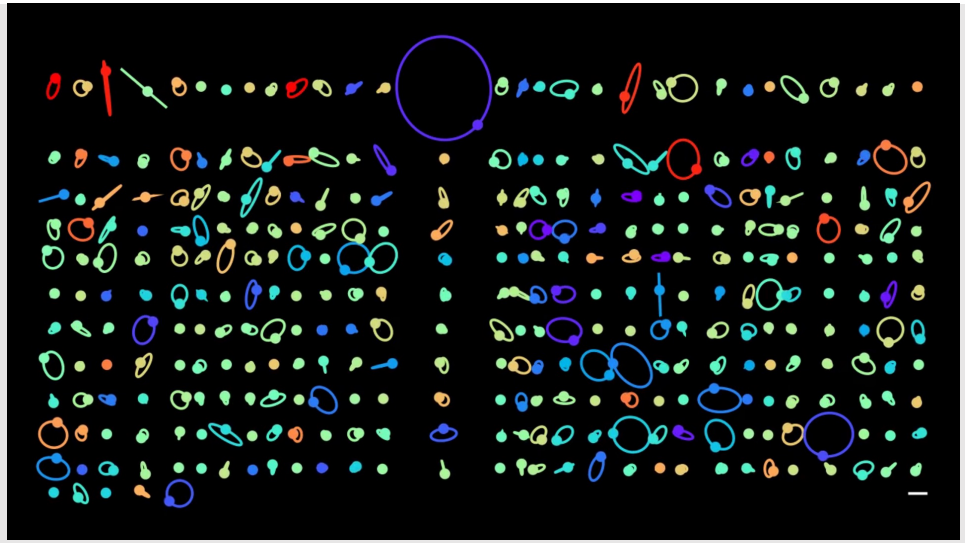
Credits:ESA/GAIA/DPAC-CU8-CU6 Recio-Blanco and the GSPspec team

Synergy between LISA and Gaia

Gaia Collaboration, Recio-Blanco et al. (2022)





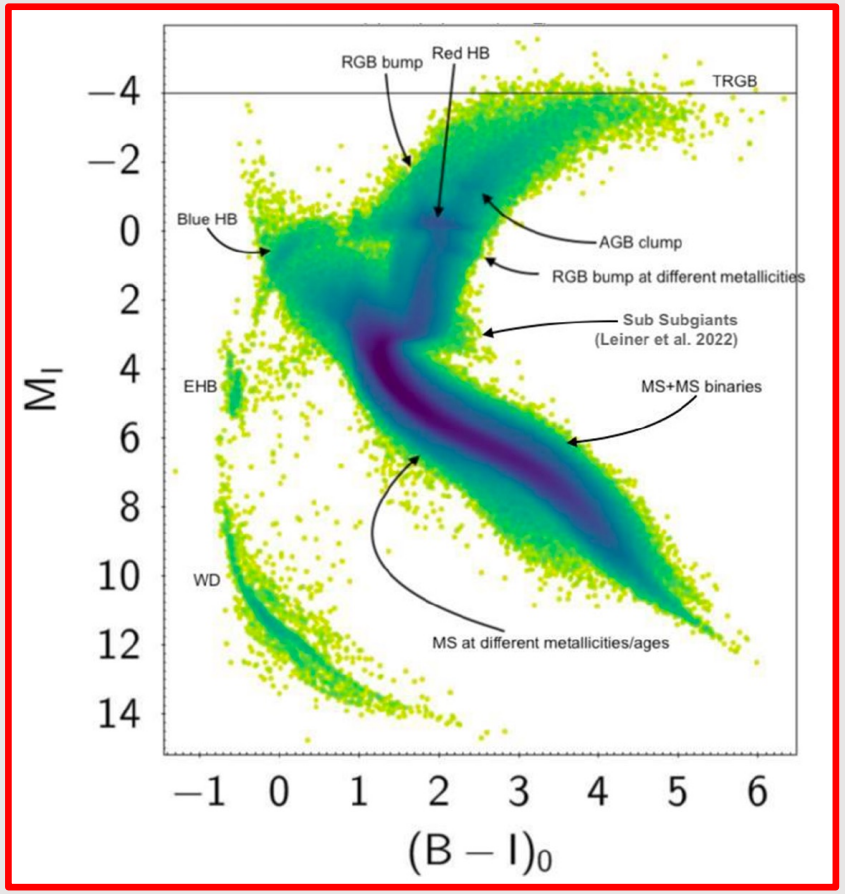


Gaia Collaboration, Arénou et al. (2022)

Synergy between LISA and Gaia

Binaries and compact objects

Gaia Collaboration, Montegrifo et al. (2022)



Gaia Collaboration, Arénou et al. (2022)

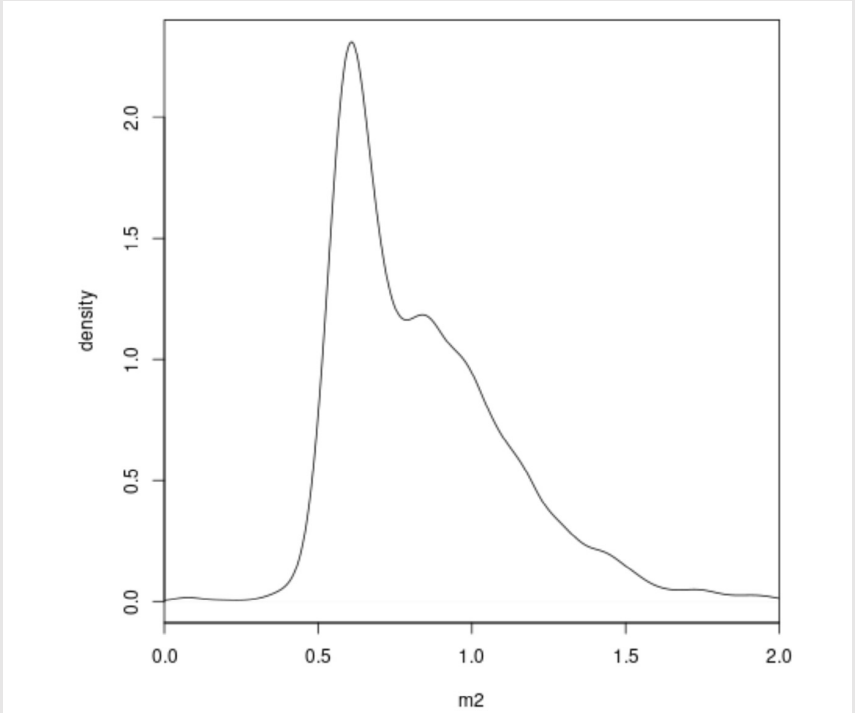


Fig. 17. Distribution of the secondary mass of astrometric solutions with `fluxratio_upper` = 0 in Table 3.

Synergy between LISA and Gaia

Binaries and compact objects

Gaia Collaboration, Arénou et al. (2022)
M. Barstow et al.

Big improvement expected in DR4!

NSS catalogues

Table	nss_solution_type	Solutions	Description
nss_acceleration_astro	Acceleration7	246 947	Second derivatives of position (acceleration)
	Acceleration9	91 268	Third derivatives of position (jerk)
nss_two_body_orbit	Orbital	134 598	Orbital astrometric solutions
	OrbitalAlternative*	629	Orbital astrometric, alternative solutions
	OrbitalTargetedSearch*	533	Orbital astrometric, supplementary external input list
	AstroSpectroSB1	33 467	Combined orbital astrometric + spectroscopic solutions
	SB1 or SB2	186 905	Orbital spectroscopic solutions
	EclipsingSpectro	155	Combined orbital spectroscopic + eclipsing solutions
	EclipsingBinary	86 918	Orbits of eclipsing binaries
nss_non_linear_spectro	FirstDegreeTrendSB1	24 083	First order derivatives of the radial velocity
	SecondDegreeTrendSB1	32 725	Second order derivatives of the radial velocity
nss_vim_fl	VIMF	870	Variable-induced movers fixed

Synergy between LISA and Gaia

Binaries and compact objects

Gaia Collaboration, Arénou et al. (2022)
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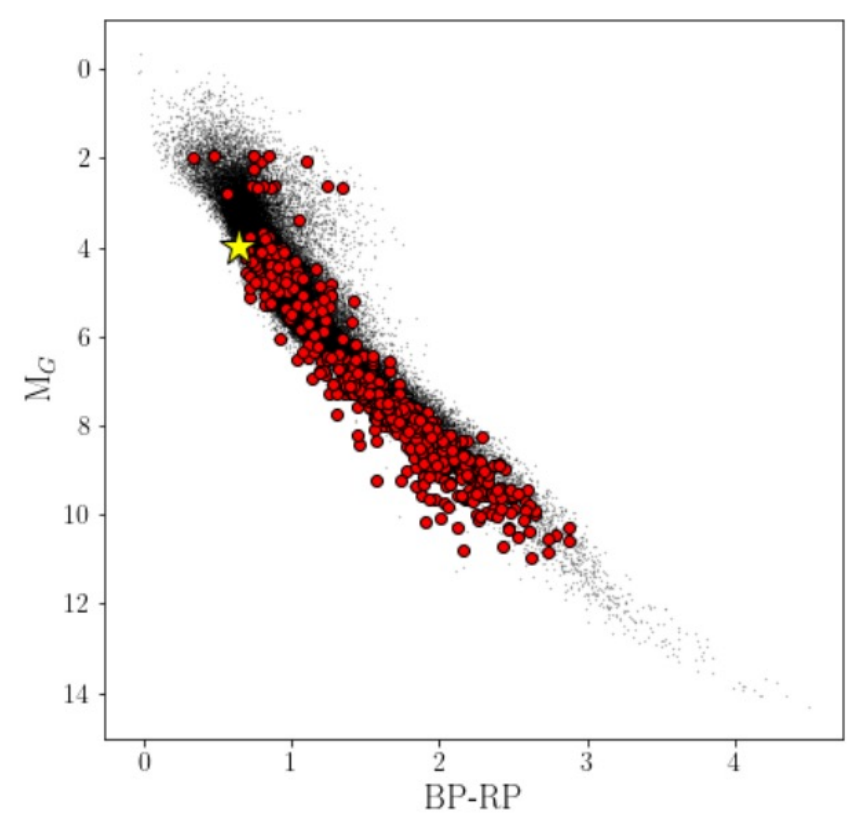
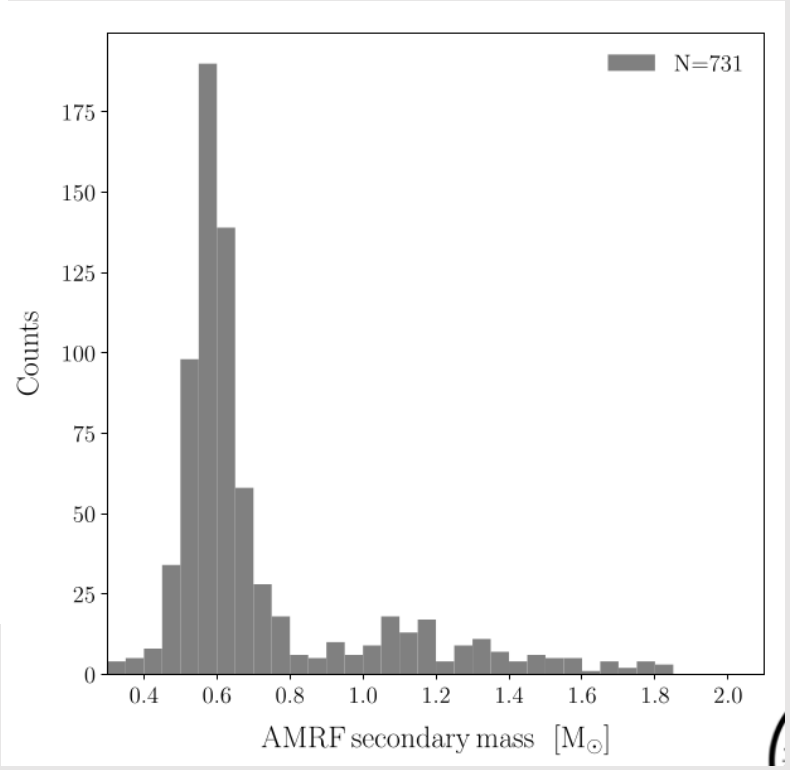


Compact objects

- Range of possible solutions – which systems may contain WDs, NSs or BHs?
- SB1 – hidden companion
- Eclipsing
- Orbital
- SB2 – only as a 3rd component



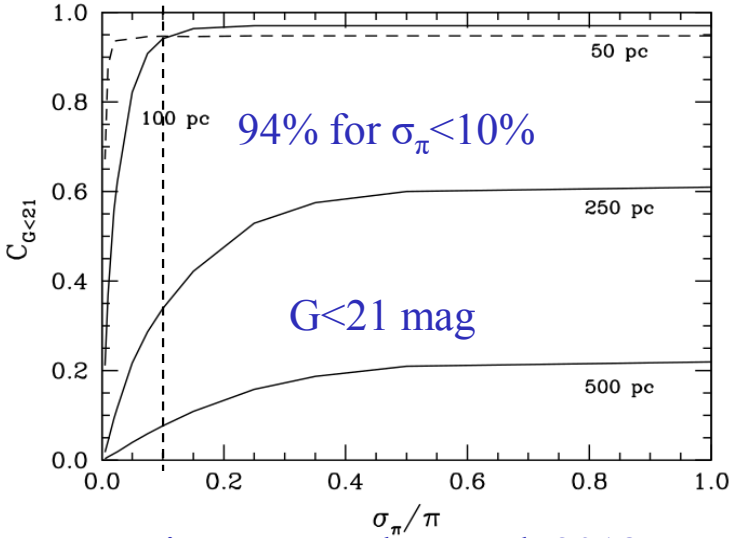
Synergy between LISA and Gaia

Binaries and compact objects

Big improvement expected in DR4!

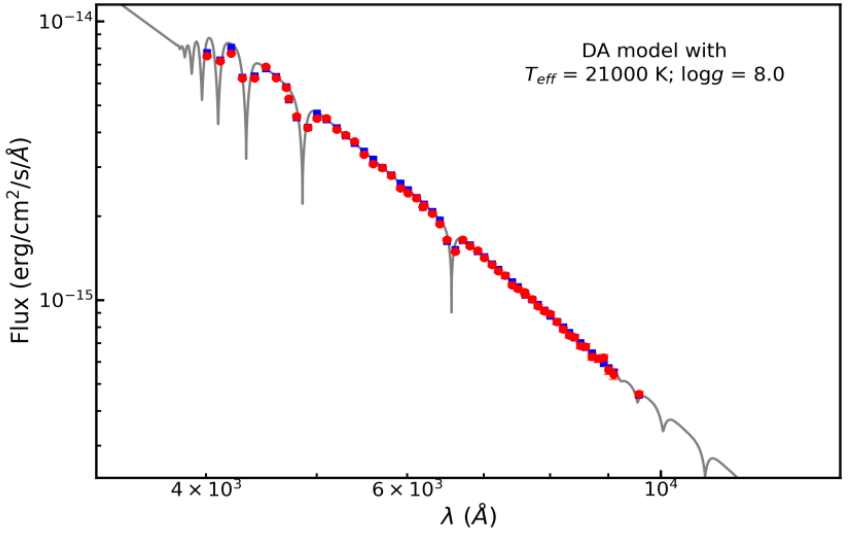
- Jiménez-Esteban et al. 2018 → 100 pc WD sample is almost complete
- Gaia-DR3 has provided ~100,000 low-resolution spectra of WDs

Completeness



Jiménez-Esteban et al. 2018

Gaia DR3 3020668542435696512

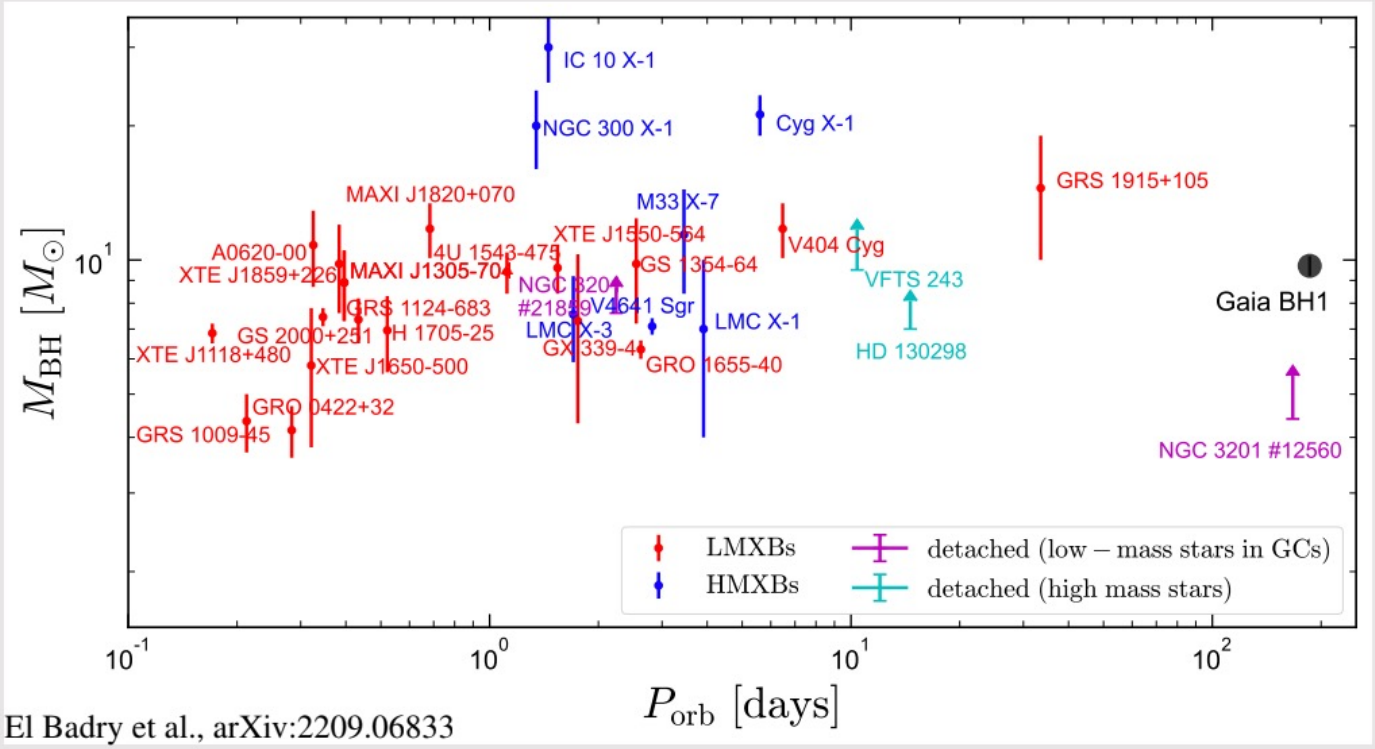


Synergy between LISA and Gaia

Binaries and compact objects

New dedicated Task force !

Gaia BH1



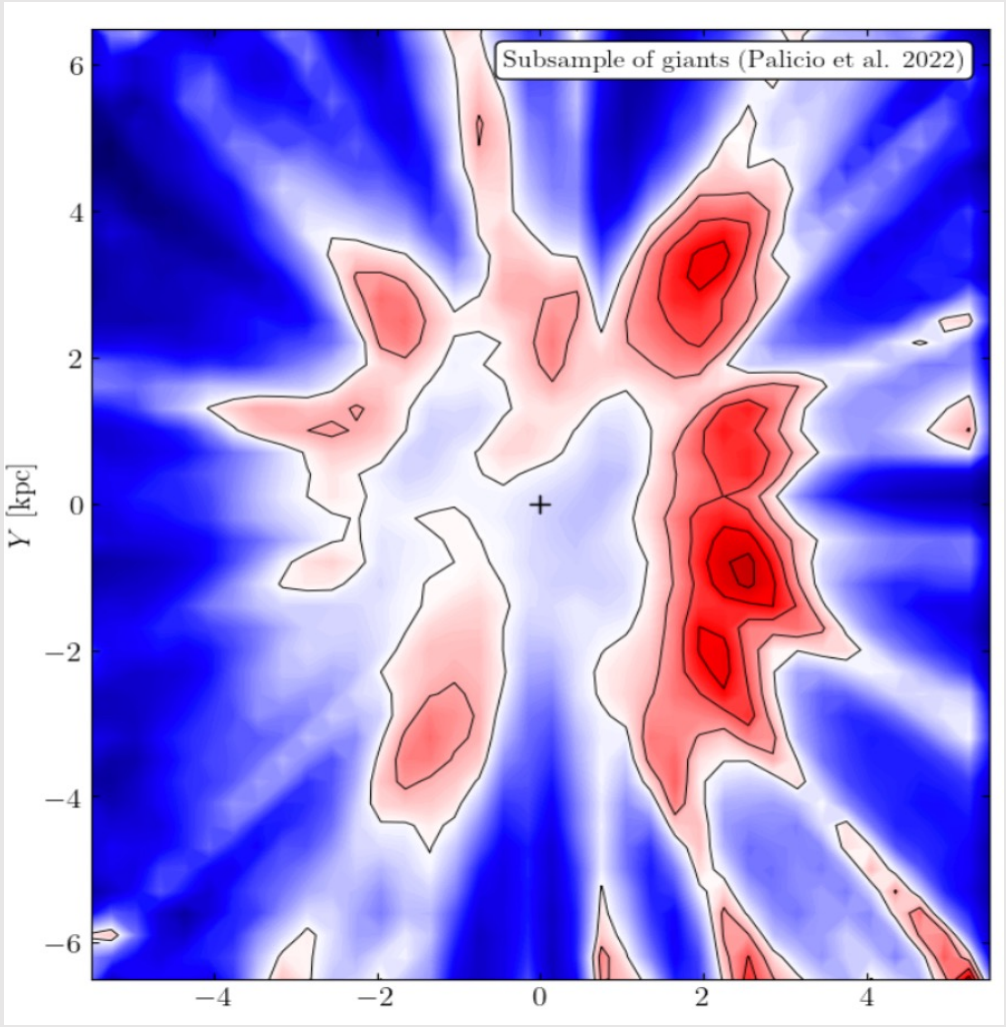
- Unique system among the known black holes: solar type star on wide orbit around dormant BH
- Evolutionary path to make such systems is unclear
- Gaia DR4 may uncover dozens more cases

Synergy between LISA and Gaia

Other important information

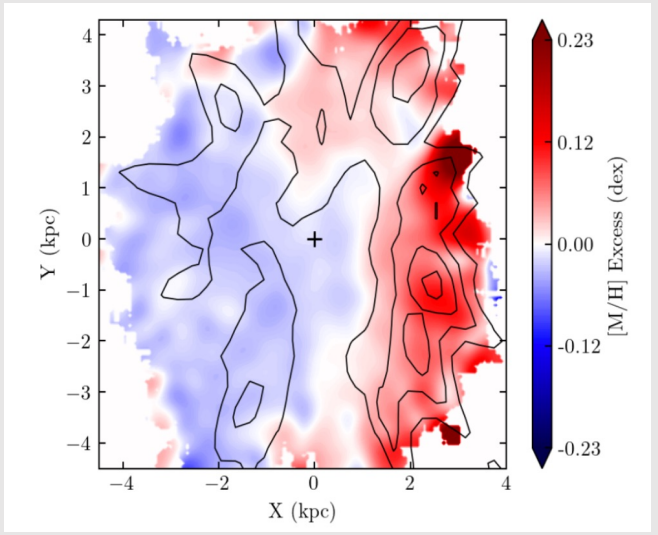
- Binarity estimates on different Galactic populations
- Characterisation of WD progenitors through the Galaxy
- Large scale, high statistics (~100 million stars in DR5) metallicity catalogues to constrain models
- Detailed Galaxy characterisation to improve LISA predictions

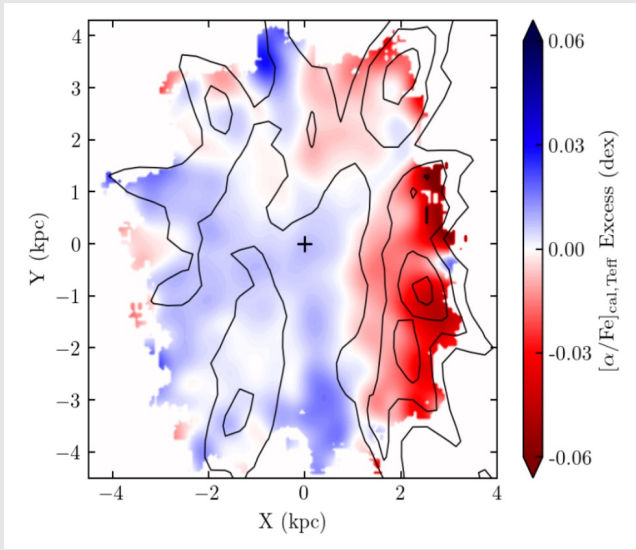
Revising LISA white paper predictions with Gaia DR3 data



Adapted from Palicio et al. (2023a)
by M. Barbillon

Spiral arms detected in stellar density and chemical abundances for old stars (Age>1Gyr)





Barbillon et al., in prep.

Gaia-LISA PhD thesis starting in Sept. 2023.

A (personal) final comment

Research is not part of a ground-segment data analysis consortium, but...

- Research is crucial to really understand the data products
- Research is essential to correctly prioritize the data analysis (there are always choices to make, we can not do everything)

Solutions (compliant with publication policies) exist :

- Science verification work (e.g. Gaia Collaboration papers)
- Support to teams to do research with public data (post-docs, PhDs)