

# Unravelling the origins of the Milky Way with Gaia

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- The formation of the Milky Way
- Galactic archaeology with Gaia
- Complementary ground based spectroscopic surveys
- The data processing consortium
- Broader impact of Gaia



gaia



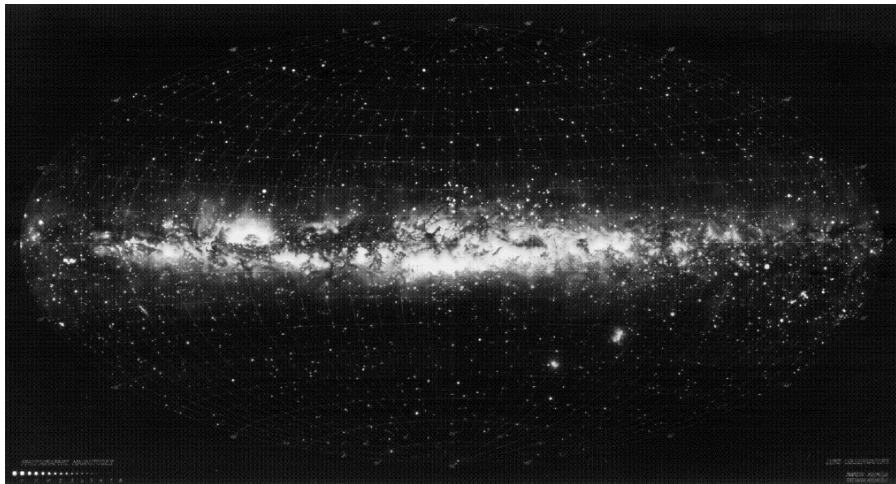


Image credit: Lund Observatory

# The Milky Way

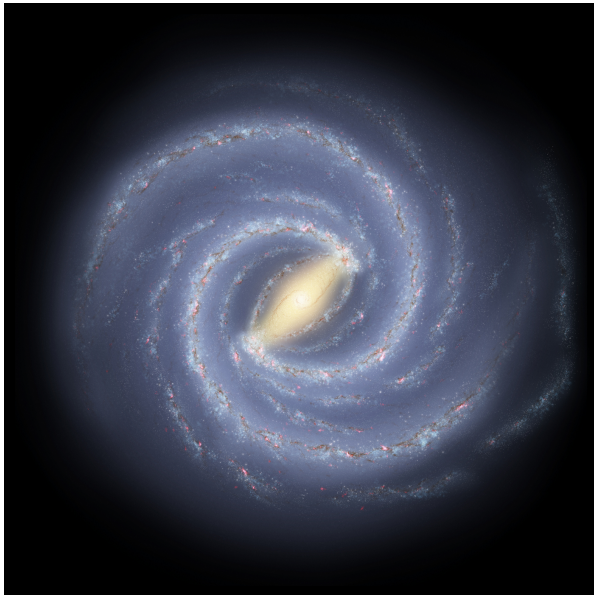


Image credit: NASA/JPL-Caltech/R. Hurt (SSC)

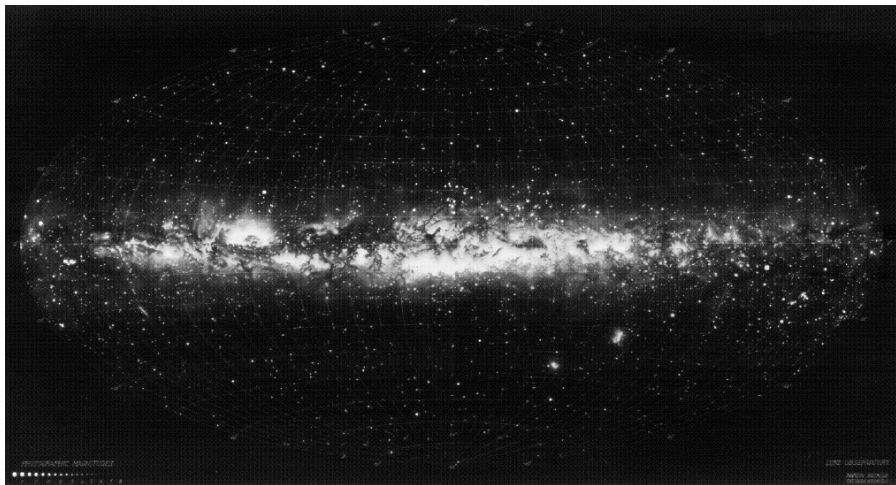


Image credit: Lund Observatory

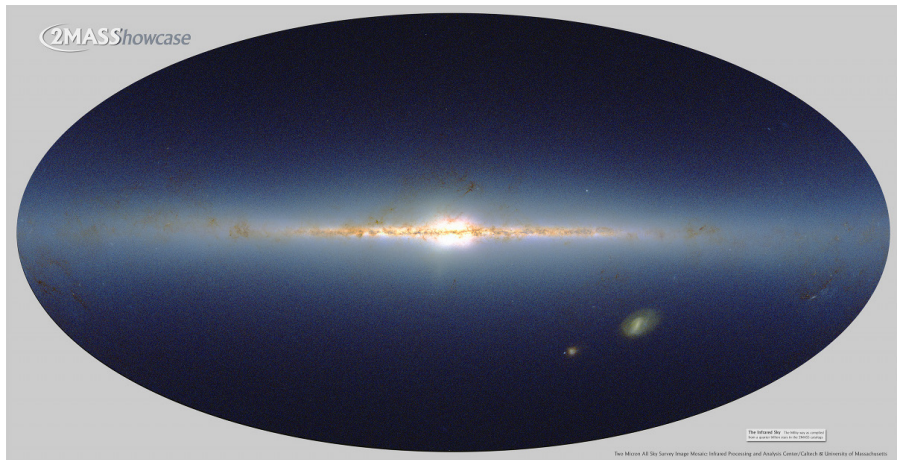
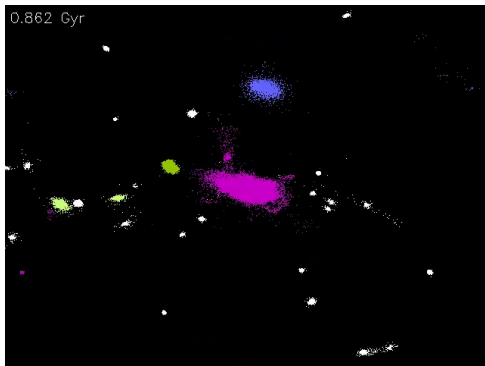


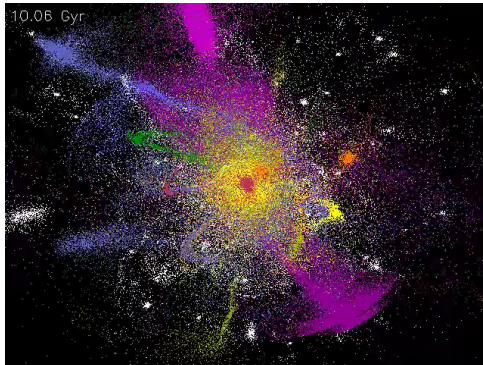
Image credit: Infrared Processing and Analysis Center/Caltech & University of Massachusetts

# How was it formed?



Movie credit: Amina Helmi, University of Groningen

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## How was it formed?



Image credit: R. Jay GaBany



## How was it formed?

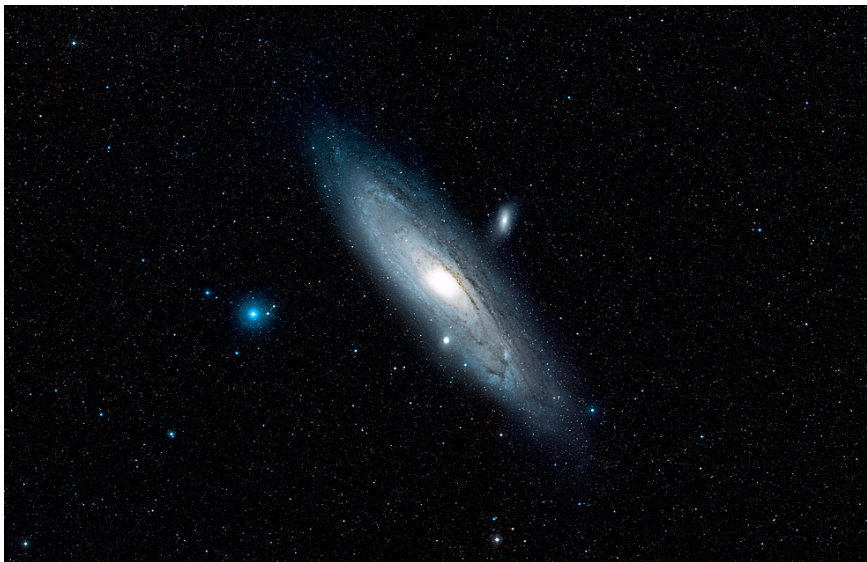


Image credit: Davide de Martin, [www.skyfactory.org](http://www.skyfactory.org)

## How was it formed?

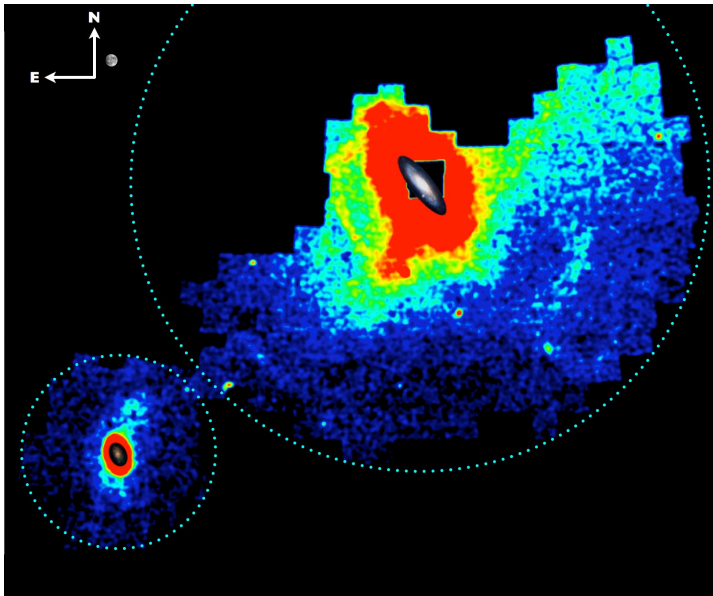
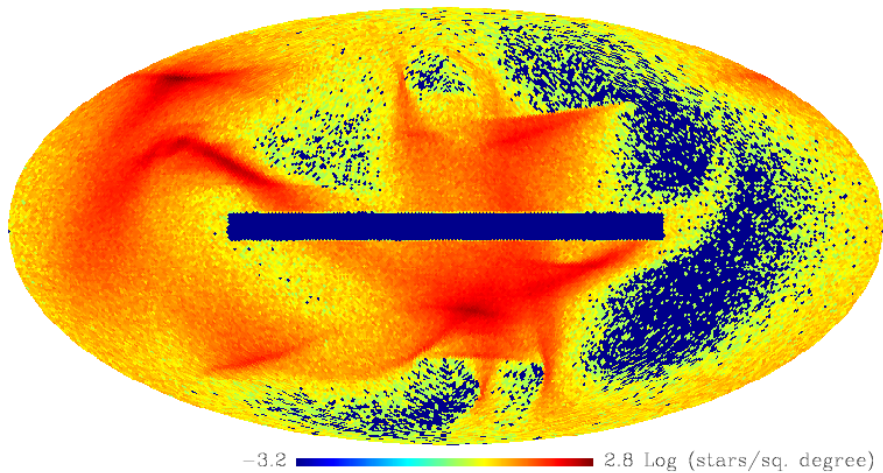
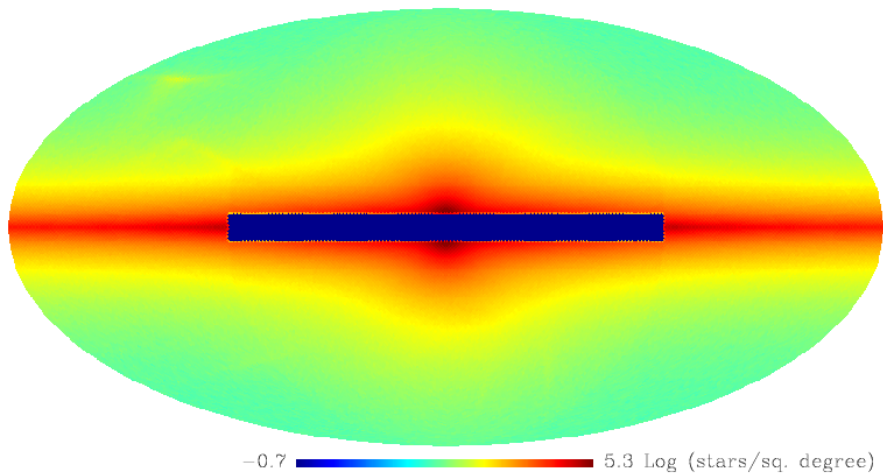
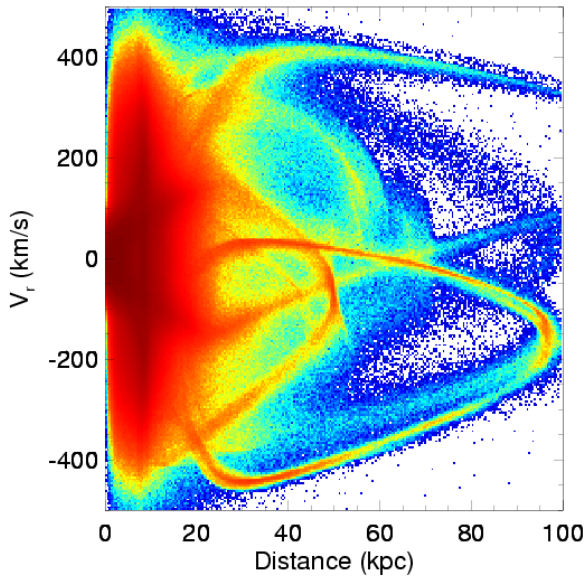


Image credit: A. McConnachie et al.







**Hypothesis:** Milky Way built up through hierarchical merging process

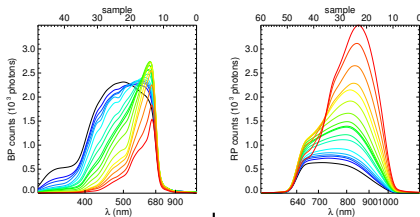


- ◆ **Where** are the building blocks of our Galaxy?
- ◆ **When** did they merge with the Milk Way?
- ◆ What was the **chemical make-up** of the building blocks?

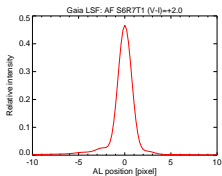


The formation history of the Milky Way can be unravelled by measuring the **location**, **motions** and **astrophysical characteristics** of its stars

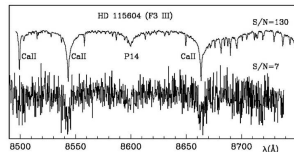
## Photometry



## Astrometry



## Spectroscopy



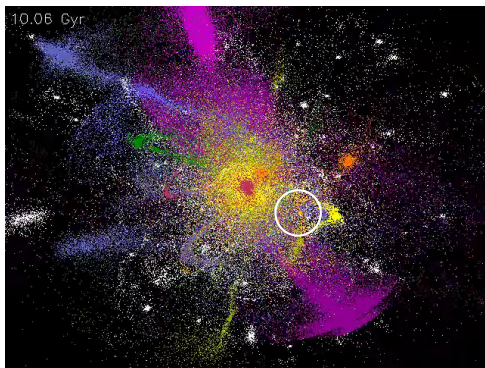
Data processing

3D positions

3D motions

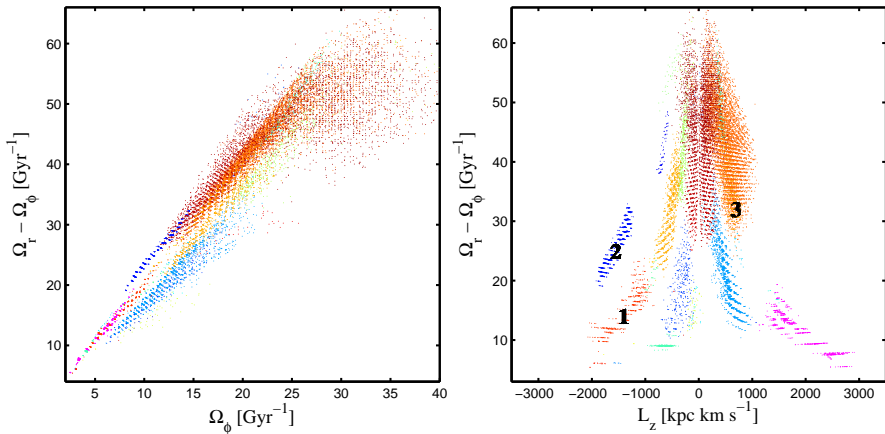
Stellar types, ages, compositions

# Unravelling the formation history of the Milky Way



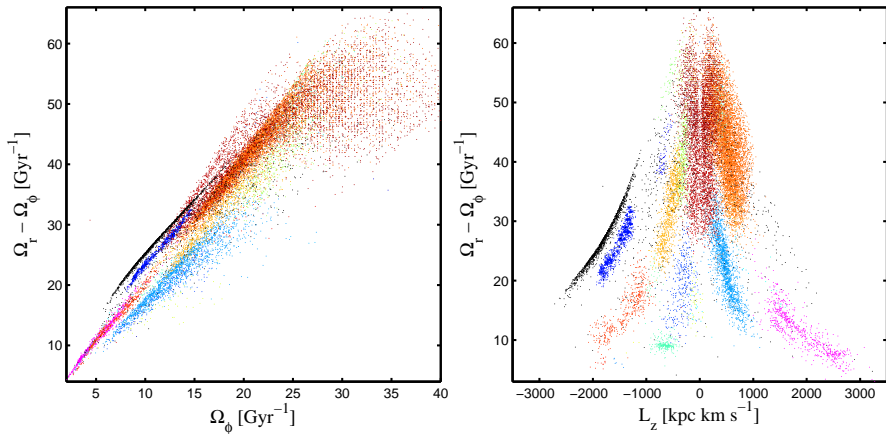


# Unravelling the formation history of the Milky Way



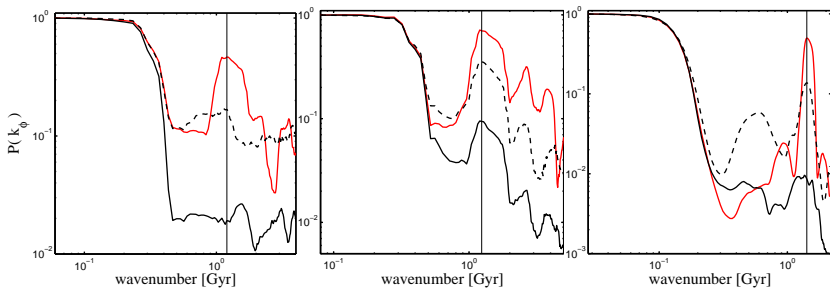
Gómez et al, 2010, MNRAS

# Unravelling the formation history of the Milky Way



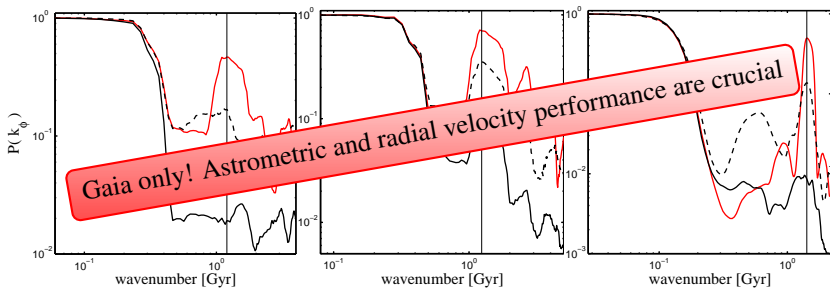
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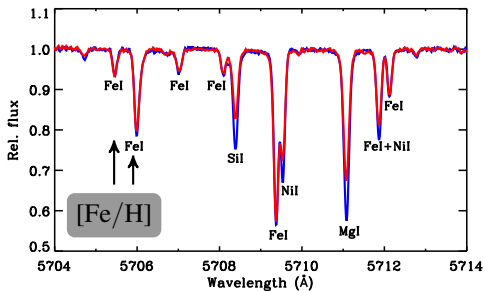
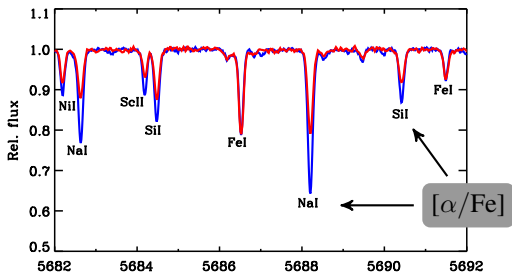


Gómez et al, 2010, MNRAS

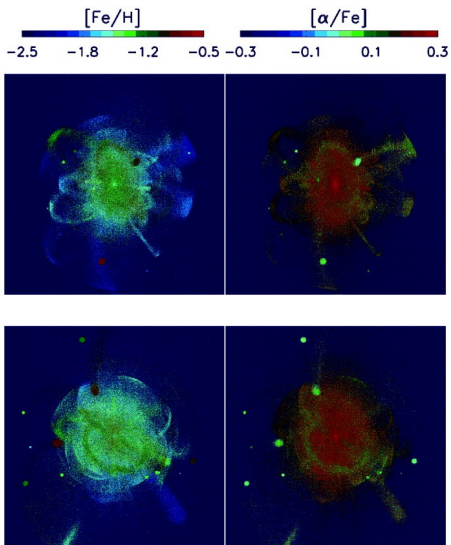
# Unravelling the formation history of the Milky Way



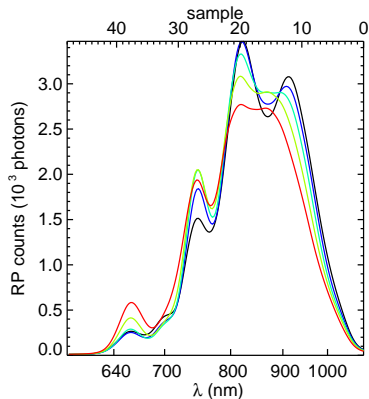
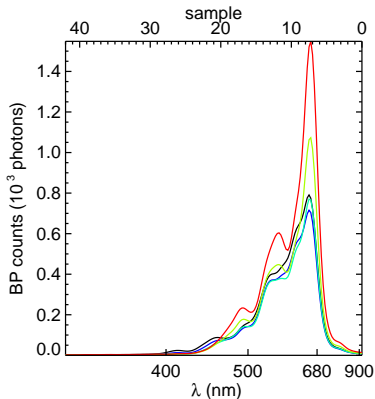
Gómez et al, 2010, MNRAS

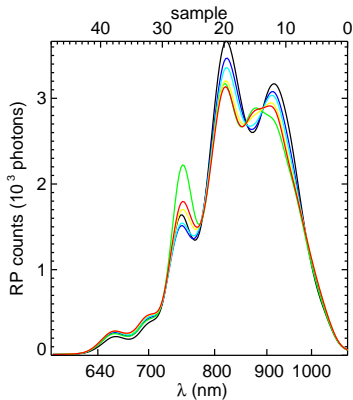
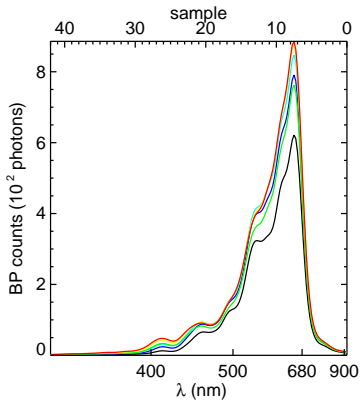


Nissen & Schuster, 2010, A&A 511, L10

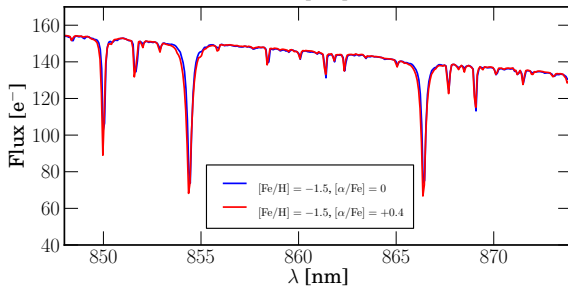
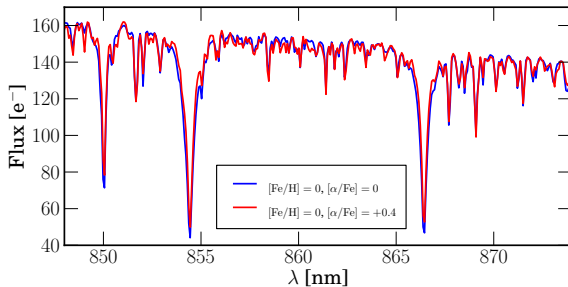


## Gaia photometry: cool star, [Fe/H] variation



Gaia photometry: cool star,  $[\alpha/\text{Fe}]$  variation



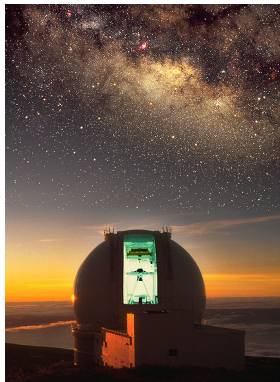
Gaia spectroscopy:  $[\text{Fe}/\text{H}]$  and  $[\alpha/\text{Fe}]$  variation

RVS spectra simulated  
by P. Sartoretti

# Large spectroscopic surveys

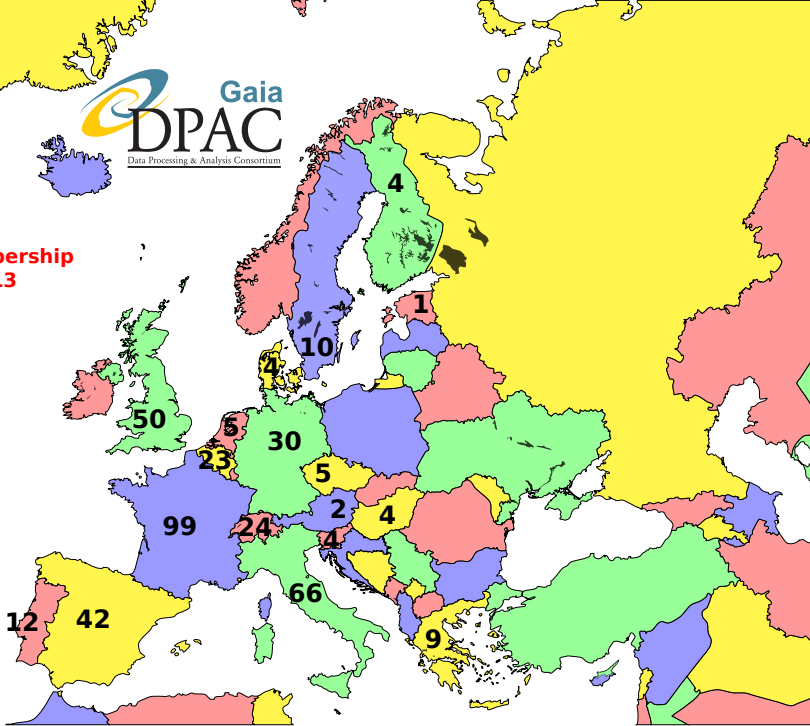


- $\sim$  Ten million star survey
- Five years on 8-m and 4-m telescopes
- $R \sim 5000$  for radial velocities at  $V > 17$
- $R \sim 20\,000\text{--}40\,000$  for chemical tagging



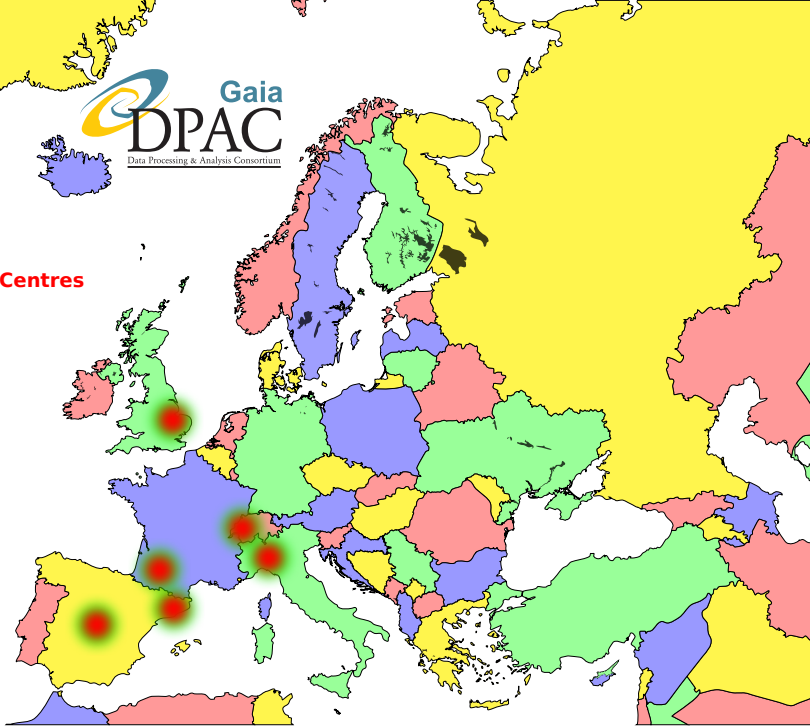
**DPAC membership  
January 2013  
432 total**

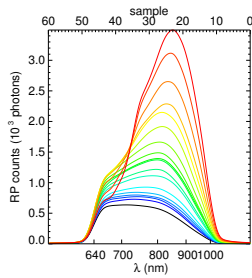
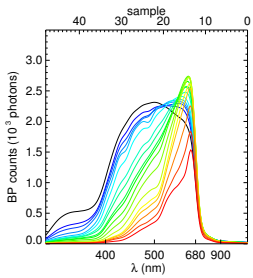
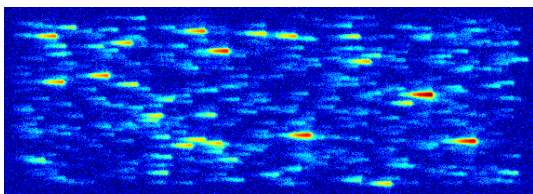
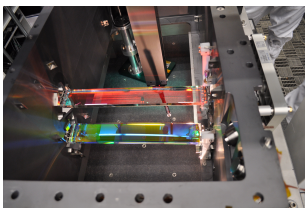
BR: 5  
CA: 1  
CL: 1  
ESA: 28  
IL: 1  
US: 2





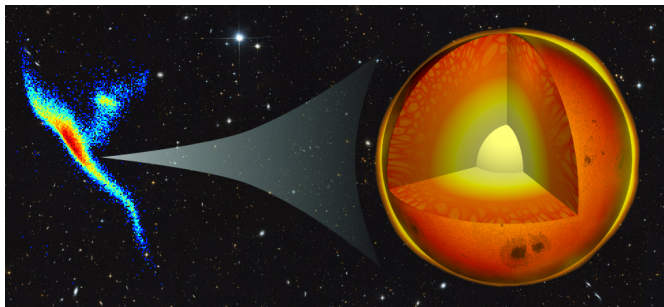
**DPAC Data Processing Centres**

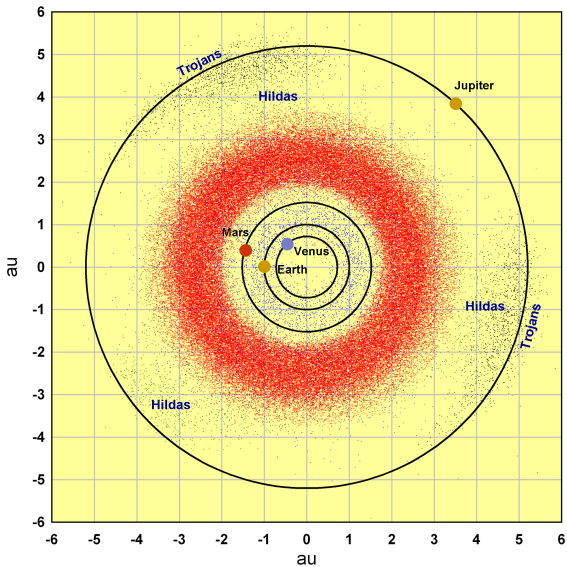




## Accurate distances across the HR diagram

- ◆ luminosity calibration
  - ▶ calibration photometric and spectroscopic distance indicators
- ◆ astrometric detection of stellar, sub-stellar and planetary companions
  - ▶ 10 000 stars with masses to 1%
- ◆ fundamental parameters for rare stellar types
- ◆ precision tests of stellar interior models and stellar evolution



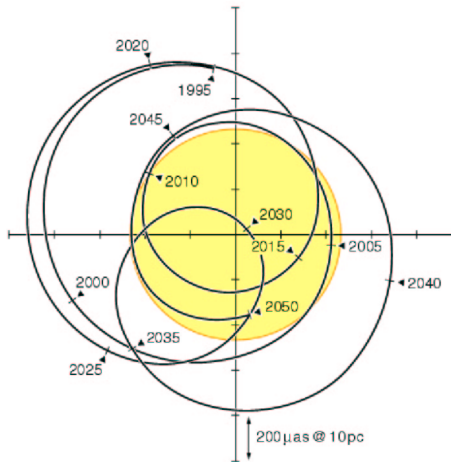


Solar system around the time of Gaia launch (courtesy F. Mignard)

- Accuracies: ground-based 0.1–1 arcsec, Gaia single measurement 0.1–1 mas
- Systematic survey down to 20 mag  $\sim 3 \times 10^5$  objects
  - ▶  $\sim 50\,000$  new objects expected
  - ▶ Observations at high ecliptic latitudes and to within  $45^\circ$  from Sun  $\rightarrow$  exotic orbits
- Orbits: for virtually all objects observed —  $\times 30$  better than now
- Masses from close encounters  $\sim 100$  masses expected
- Diameters for over 1000 asteroids: shape, density
- Photometric data in several bands: albedo, taxonomic classification
- Light curves over 5 years: rotation, pole, shape
- Space distribution vs. physical properties
- Perihelion precession for 300 planets: GR testing, solar J2



- ◆ Astrometric survey
  - ▶ monitoring of several  $10^5$  FGK stars to  $\sim 200$  pc
  - ▶ detection limits  $\sim 1 M_J$  and  $P < 10$  yr
  - ▶ complete census of all stellar types over  $P = 2-9$  yr
  - ▶ masses rather than lower limit ( $m \sin i$ )
  - ▶ multiple systems measurable
- ◆ Results expected
  - ▶ orbits for  $\sim 5000$  systems
- ◆ Photometric transits
  - ▶  $\sim 1000$  to  $10\,000$  with  $a \lesssim 1$  AU



$d <$	stars	planets
100	60 000	1500-5000
200	500 000	5000-20 000

## 1. Light deflection

- ▶ Monopole deflection from the Sun:  $\sigma_\gamma \sim 10^{-6}$   
(systematic errors remain a difficult challenge)
- ▶ First detection of a number of subtle deflection effects from the planets:  
monopole, **quadrupole**, **gravitomagnetic**

## 2. Motion of the solar system: perihelion and node precessions, quadratic deviations in the mean longitudes

$$\sigma_\beta \sim 10^{-3}, \quad \sigma_{J_2^{\text{Sun}}} \sim 10^{-7}, \quad \sigma_{\dot{G}/G} \sim 10^{-12} \text{ yr}^{-1}, \quad \sigma_\eta \sim 10^{-3}$$

## 3. Local Lorentz Invariance: Gaia is a kind of Michelson-Morley experiment

## 4. Pattern matching in proper motions and epoch astrometry:

- ▶ Solar system acceleration  $\sigma_a/a < 0.1$
- ▶ **Improved estimates** of the stochastic background of primordial low frequency gravitational waves

## 5. **Astrometric information** for the optical components of some objects that are important for other relativistic tests