Surveying the Galaxy

ESA's upcoming Gaia mission

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gaia

Gaia DPAC
Data Processing & Analysis Consortium

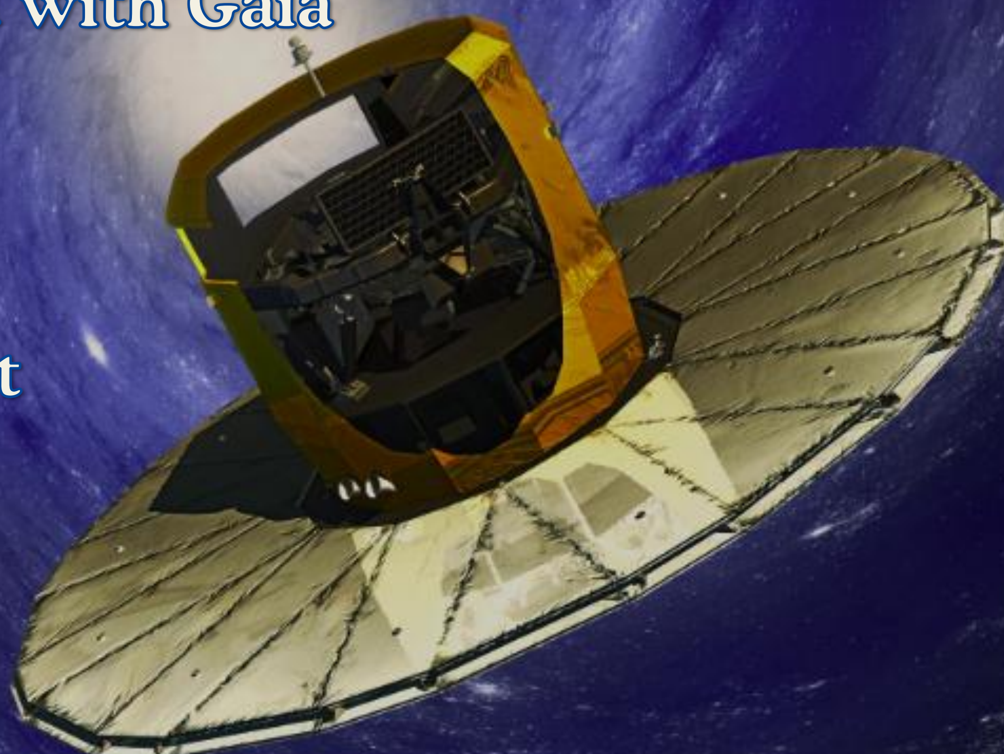
RYMDSTYRELSEN
Swedish National Space Board

Predicting the future...

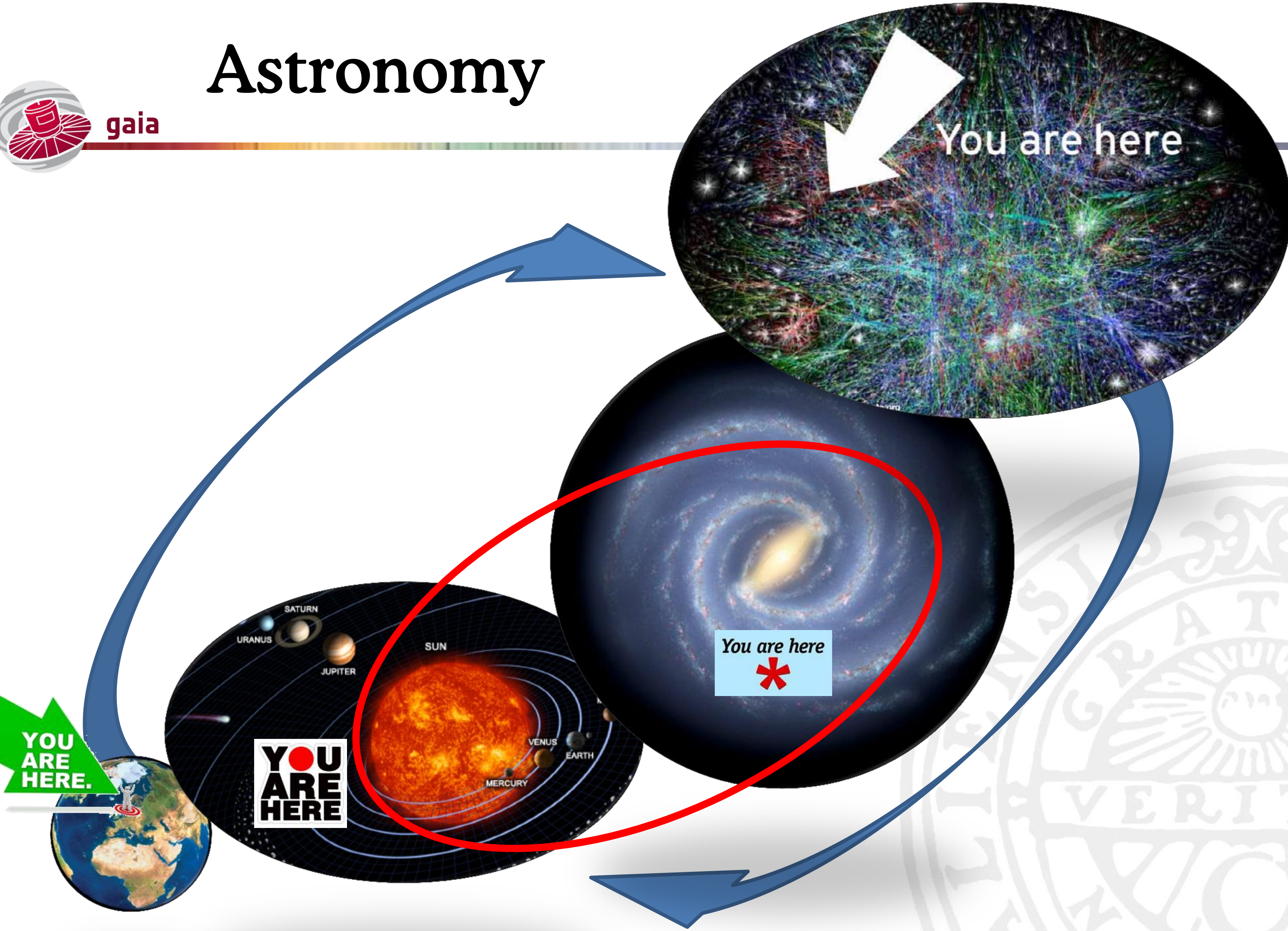
*It is always wise to look ahead,
but difficult to look farther
than you can see.*

Outline of this talk

- ⋆ Where we stand with the Galaxy
- ⋆ Where we stand with Gaia
- ⋆ Challenges
- ⋆ Scientific impact



Astronomy

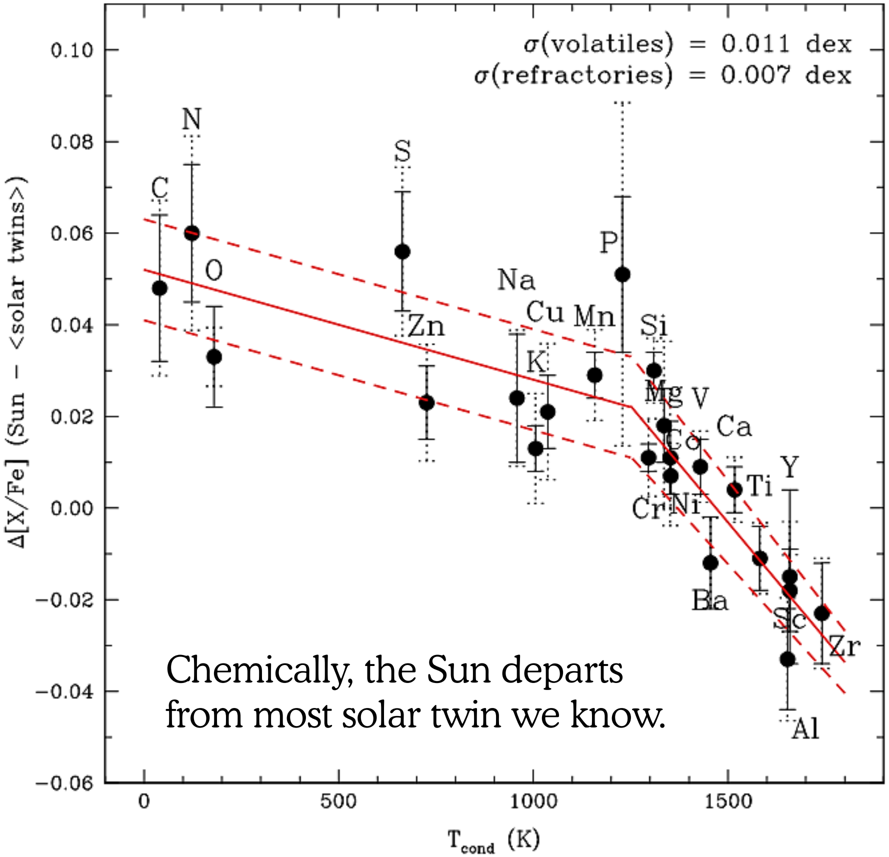

You are here
You are here
*
SATURN
URANUS
JUPITER
SUN
VENUS
EARTH
MERCURY
YOU ARE HERE
YOU ARE HERE.

The Milky Way Galaxy

The Sun is a normal G2 V stars.

Maybe, but it is unusually massive (most stars are M dwarfs) and it departs systematically from field solar twins in its chemical composition

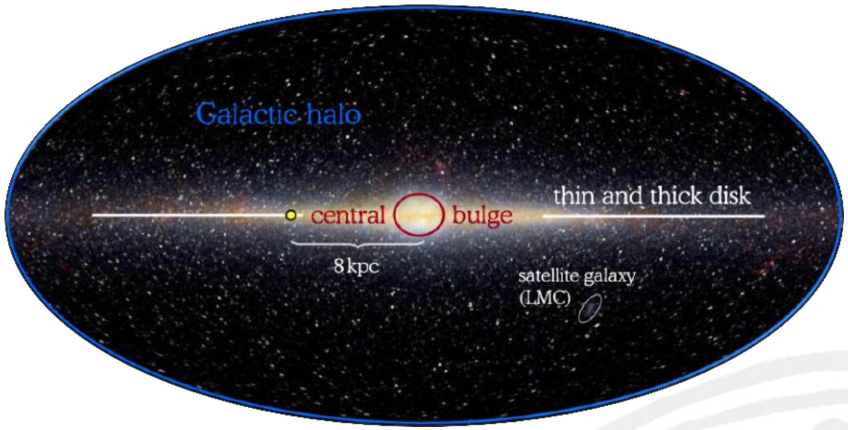
(but cf. Önehag *et al.* (2011) for a solar twin in the open cluster M 67).



Meléndez *et al.* (2009)

The Milky Way Galaxy

The Sun is a normal G2 V stars. (*Maybe.*)



The Milky Way is a normal (barred) spiral.

Probably, but its primary satellites are unusually luminous and star-forming: the Magellanic Clouds

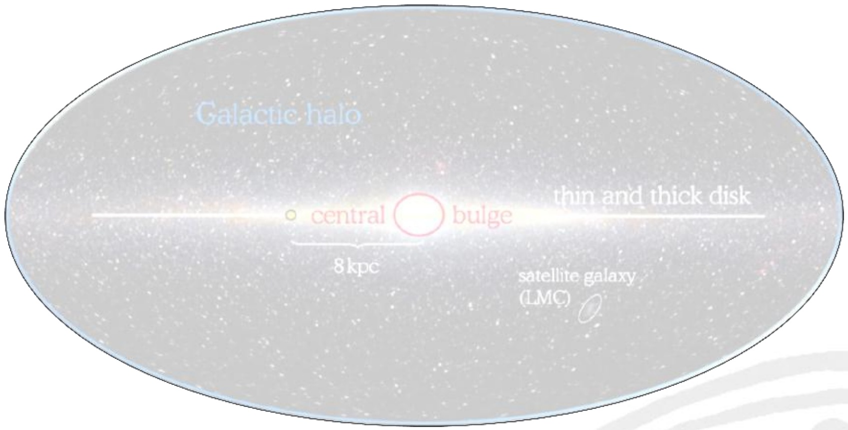
(cf. Holmberg 1969)

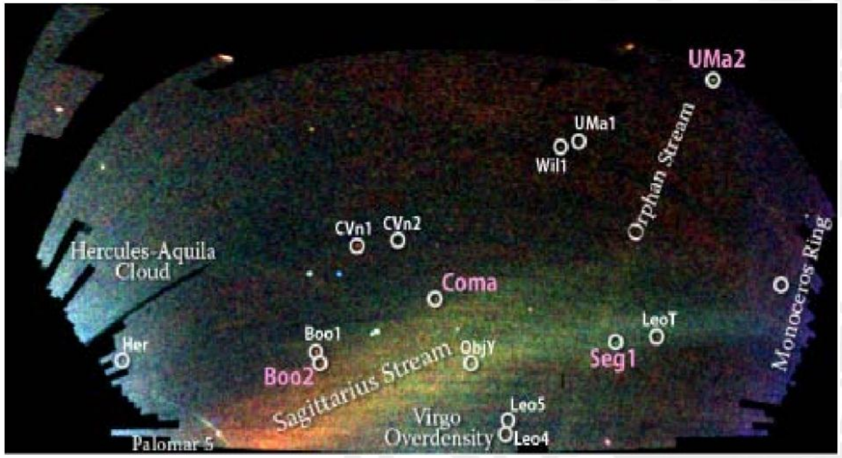
The Milky Way Galaxy

The Sun is a normal G2 V stars. (*Maybe*.)

The Milky Way is a normal (barred) spiral. (*Probably*).

The Milky Way is a typical result of DM-driven hierarchical structure formation (?).





Belokurov *et al.* (2006)

Some milestones on the way

Halo stars (chemically: Chamberlain & Aller 1951)

2 local stars

The Thick disk (photometrically: Gilmore & Reid 1983)

12500 stars

The Solar neighboorhood (chemically: Edvardsson *et al*. 1993)

189 stars

The Thick disk (chemically: Fuhrmann 1998; Bensby *et al*.)

10+ stars, now 100s

Definition of the Bulge population

dozens of stars

(Rich, McWilliam, Fulbright; Ryde; Bensby)

1000s of stars

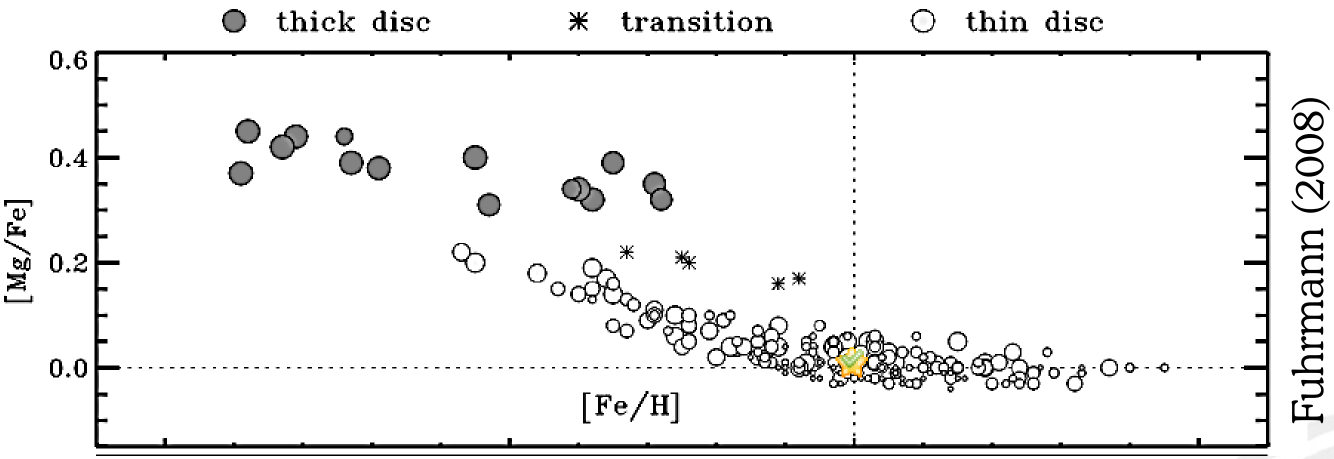
Inner/outer halo (SDSS-SEGUE: Carollo *et al*. (2007), but see Schönrich *et al*. 2011)

Lessons learnt?

Discoveries often local/ with poor statistics,

but a clear tendency towards a more statistically sound global view of Galactic populations.

Is there a Thick disk?



A unique population in terms of its chemistry, dynamics and age!

The Astrophysical Journal, 751:131 (6pp), 2012 June 1
doi:10.1088/0004-637X/751/2/131

THE MILKY WAY HAS NO DISTINCT THICK DISK

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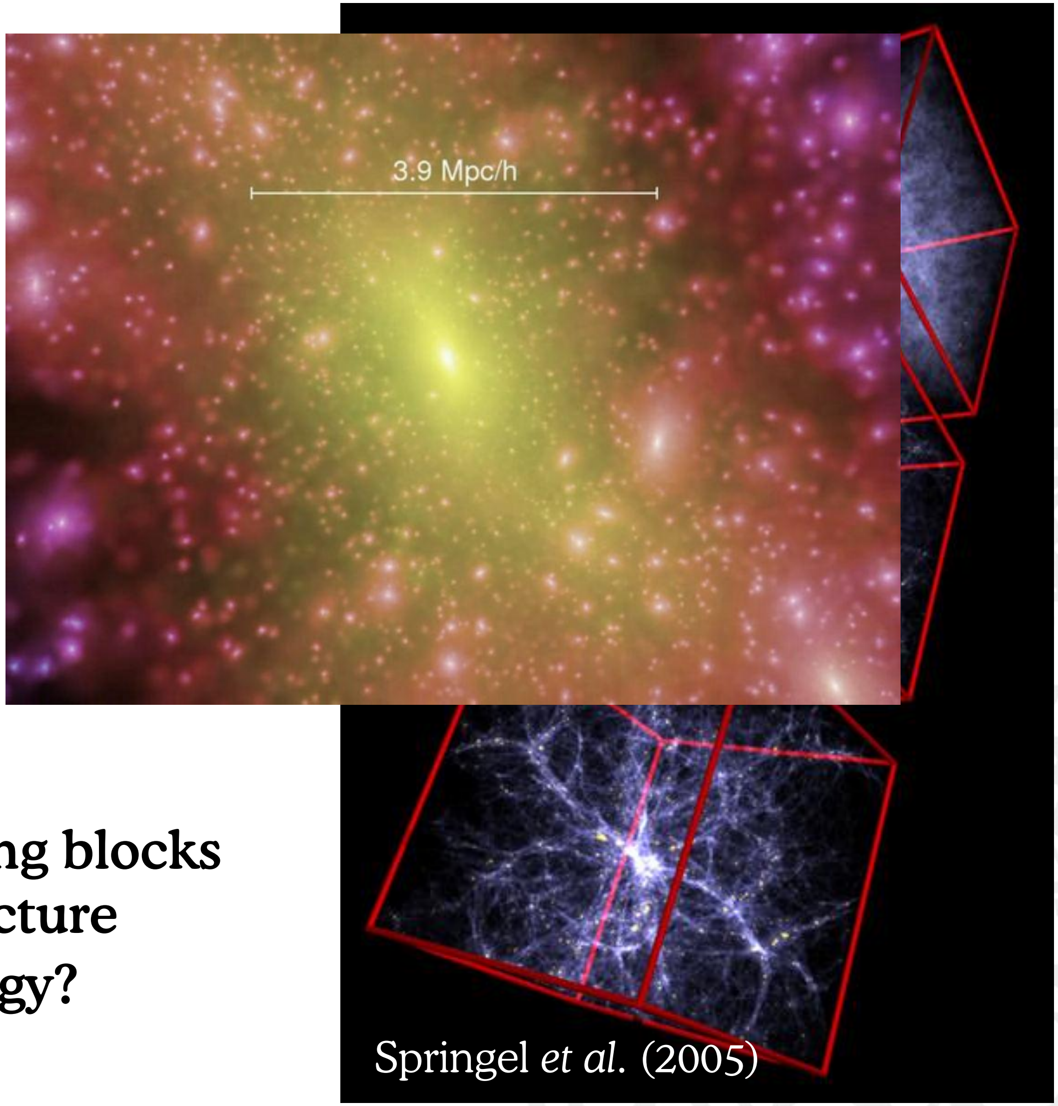
Received 2011 December 6; accepted 2012 March 30; published 2012 May 15

Doing chemo-dynamics with Gaia

High Precision Parallax
Collecting Satellite

(1989-1993)



Springel *et al.* (2005)

Where are the 100s of building blocks predicted by DM-driven structure formation in ΛCDM cosmology?

A prerequisite

Are dynamical/chemical properties of stars conserved?

Yes (or the most part).

Dynamics: interactions with specific structures (e.g. the bar) can lead to changes in the orbits.

Chemistry: Giant stars dregde up processed material from the interior; stars can receive matter from a companion; atomic diffusion can change the surface composition.

Gaia in a nutshell (2013 – 2018)

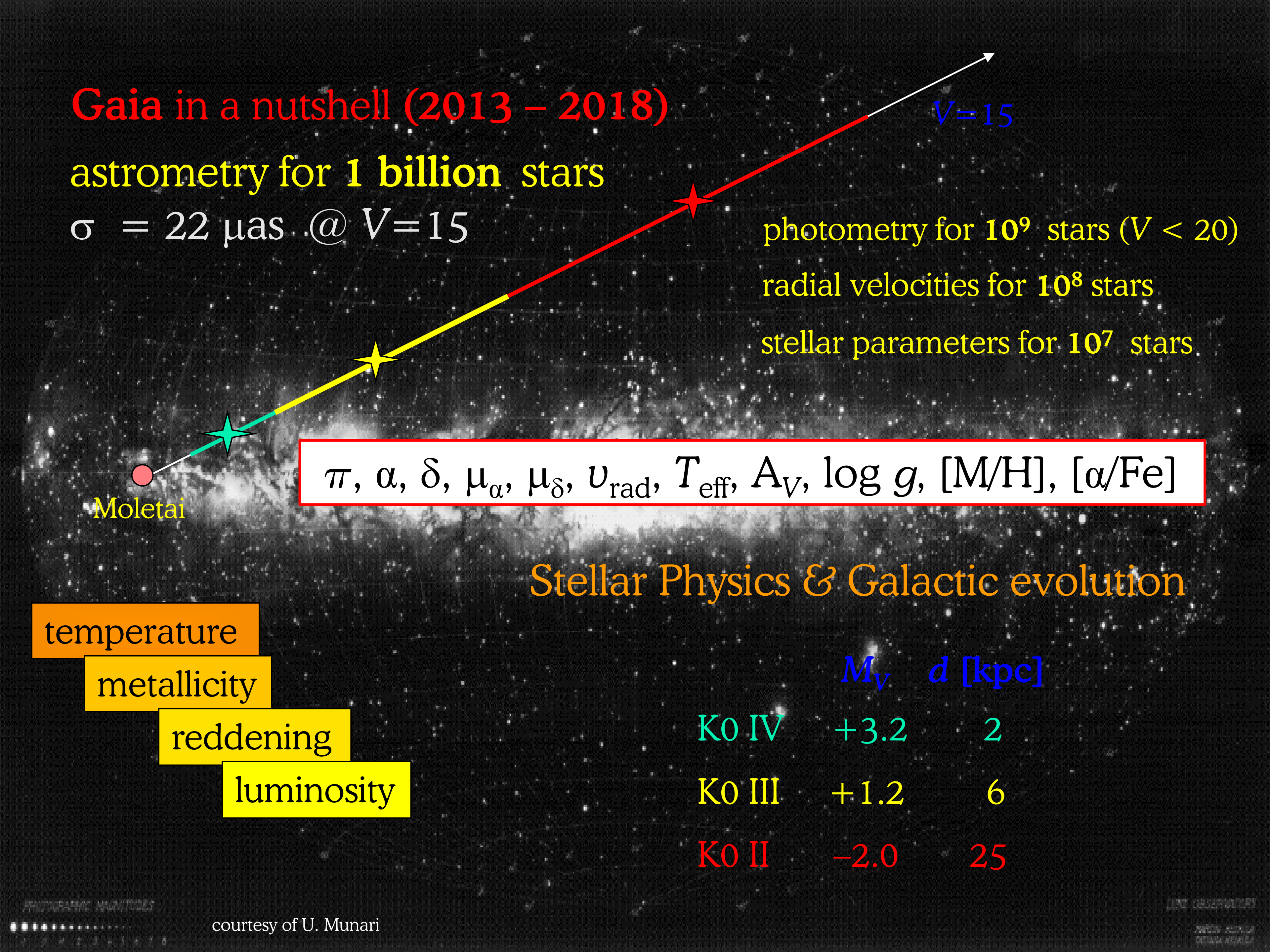
astrometry for **1 billion** stars

$\sigma = 22\ \mu as$ @ $V=15$

photometry for $\mathbf{10^9}$ stars ($V < 20$)

radial velocities for $\mathbf{10^8}$ stars

stellar parameters for $\mathbf{10^7}$ stars



π, α, δ, μ_α, μ_δ, υ_{rad}, T_{eff}, A_V, $\log g$, [M/H], [α/Fe]

Stellar Physics & Galactic evolution

- temperature
- metallicity
- reddening
- luminosity

	M_V	d [kpc]
K0 IV	+3.2	2
K0 III	+1.2	6
K0 II	–2.0	25

courtesy of U. Munari

How does it work?

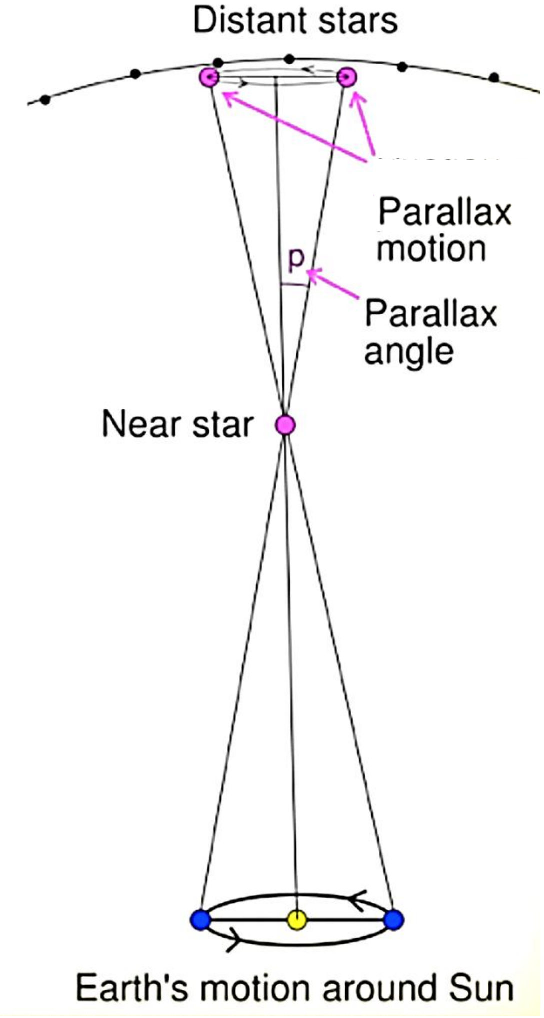
$$\pi[\text{arcsec}] = 1/d[\text{pc}]$$
$$(1\ \text{pc} = 3.26\ \text{ly})$$

Parallax of nearest star: $\pi = 0.7687$ arcsec
$= 768700\ \mu$as

Parallax of Galactic centre: $\pi = 118\ \mu$as

Parallax of nearest satellite (LMC): $\pi = 20\ \mu$as

Gaia best accuracy: $\sim 10\ \mu$as
(“resolving a coin on the Moon”)



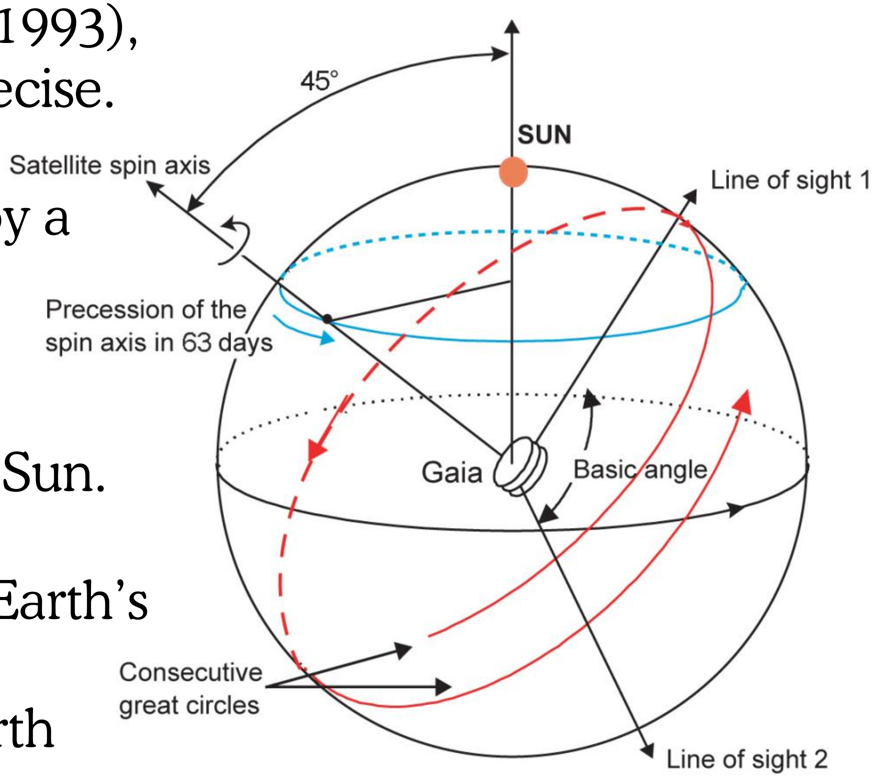
μas astrometry from space

Same principle as HIPPARCOS (1989-1993), but two orders-of-magnitude more precise.

Two telescopes with LOSs separated by a 106.5° basic angle.

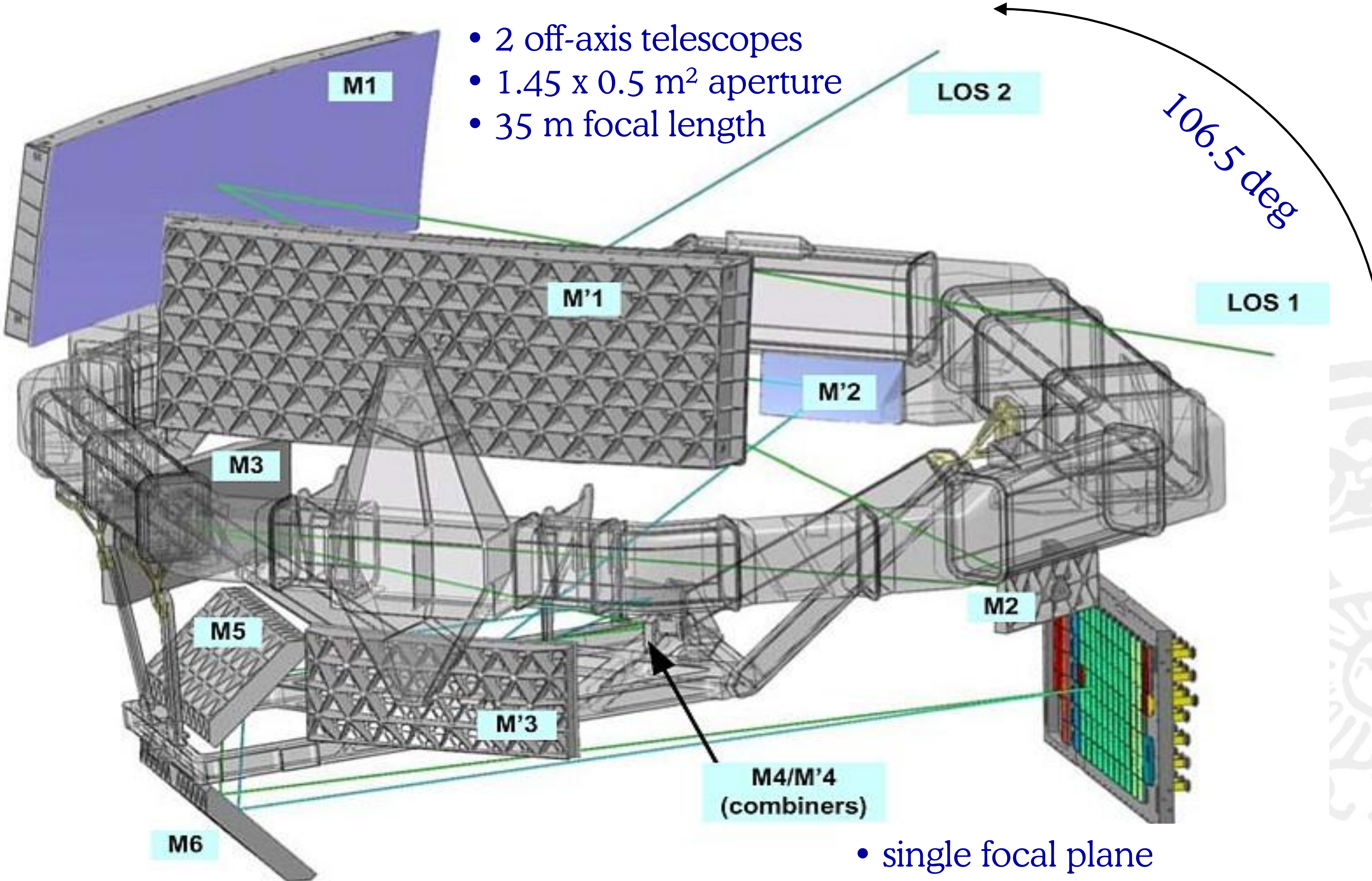
Observe the whole sky by having the satellite's spin axis precess around the Sun.

The ideal place for this: L2 outside of Earth's orbit, 1.5 million km away.
Lissajous orbit around L2 avoiding Earth eclipses during 6 years.
Transfer to L2: 4 month (eclipse-free)



Gaia's telescopes

gaia



• single focal plane
• 106 CCDs totalling 938 Mpixels
• 0.93 x 0.42 m²

Gaia's focal plane

gaia

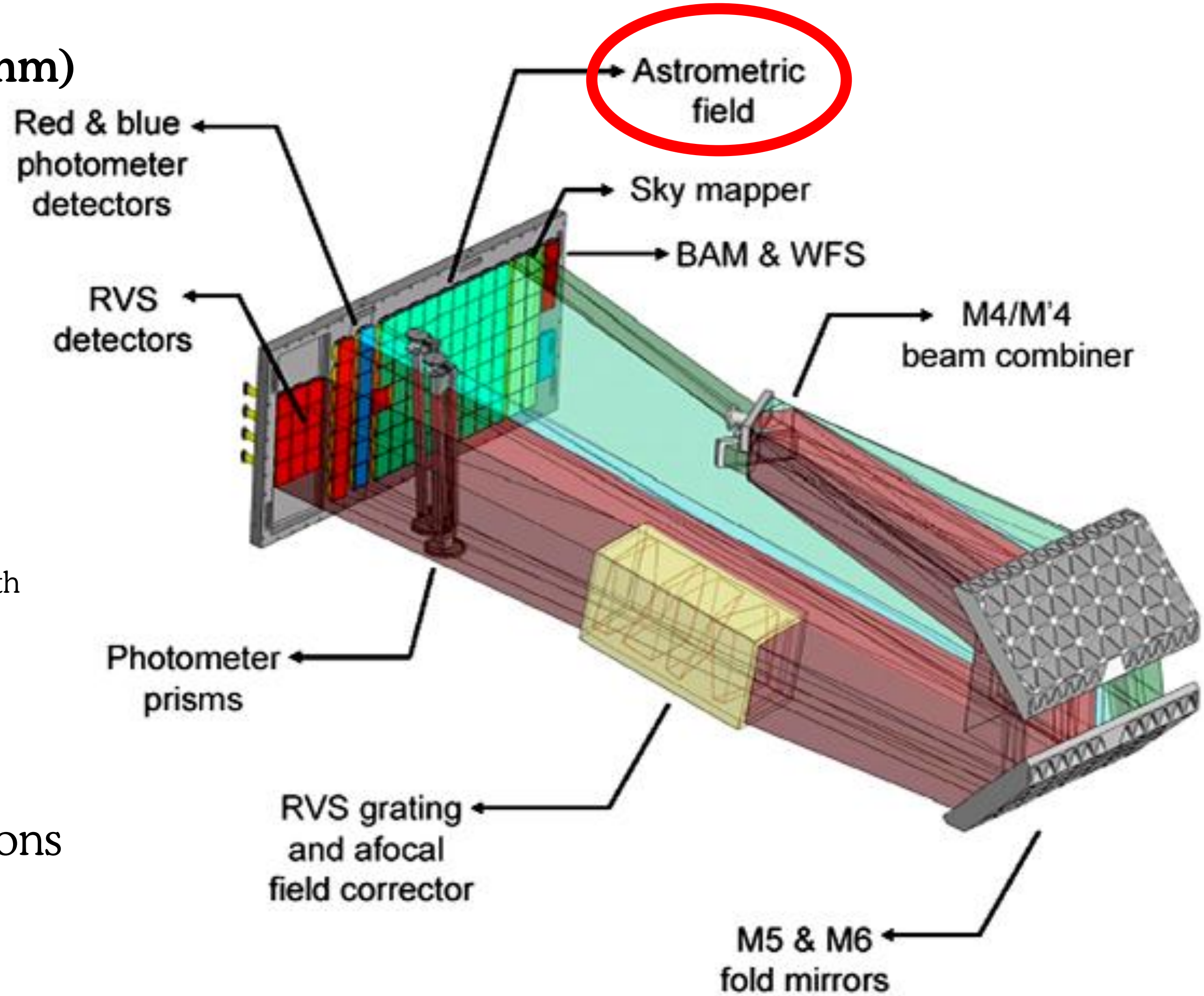
BP/RP (330–1050 nm)

80 pixels in two arms (blue and red) with dispersions between 50 Å and 300 Å.

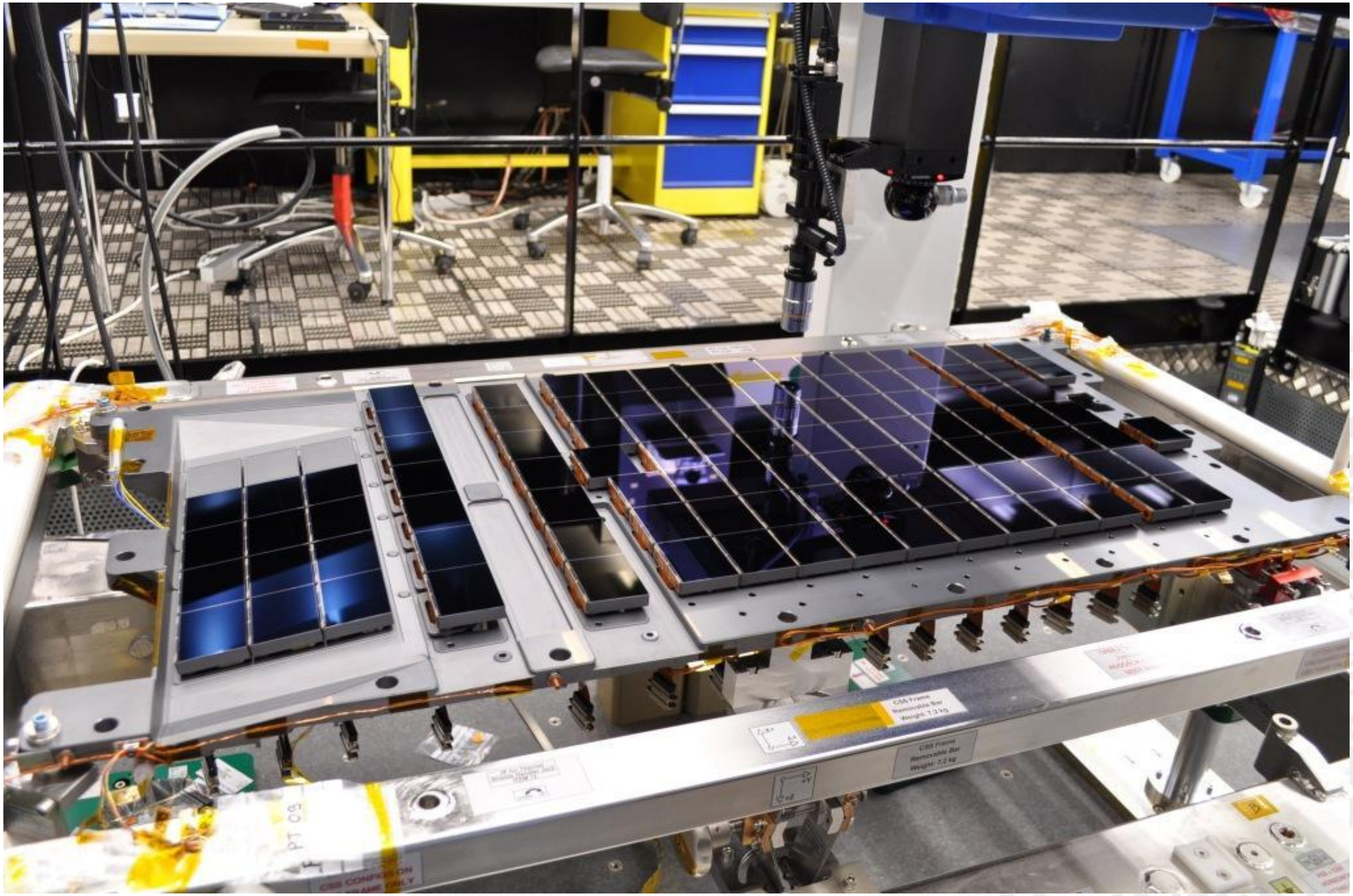
RVS (847–874 nm)

R=11500 down to 11th magnitude,
5500 below.

Typically 80 observations over 5 years (binarity, variability!).

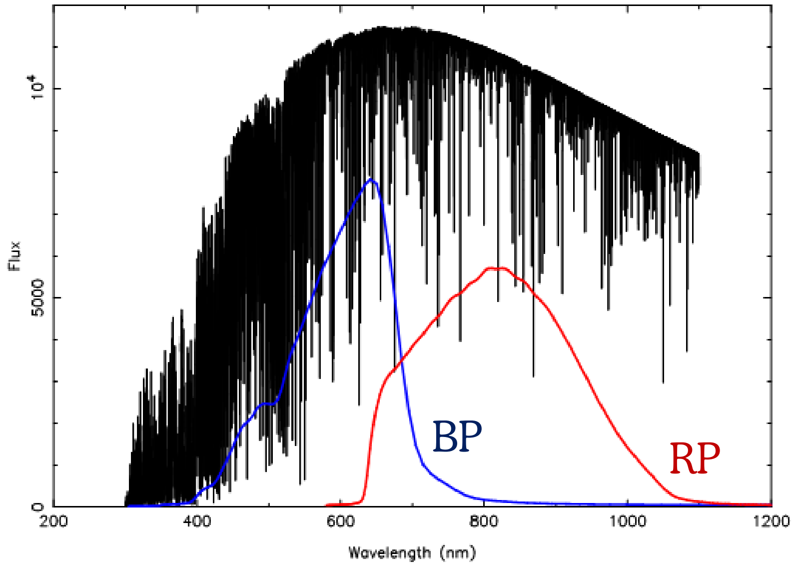


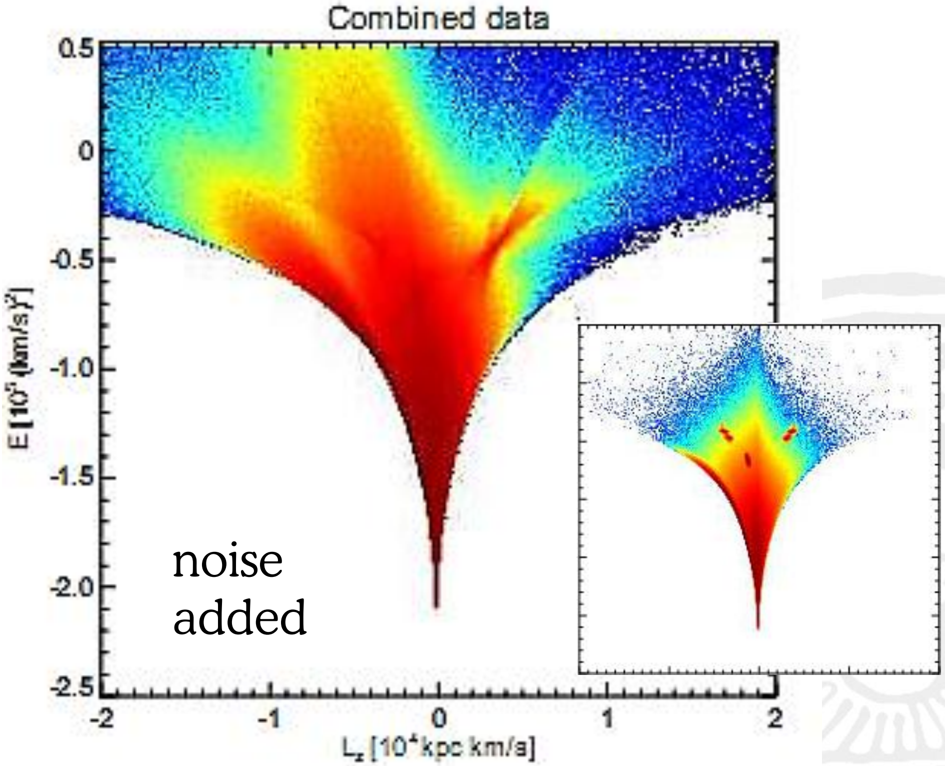
Gaia's CCDs



What Gaia will not provide

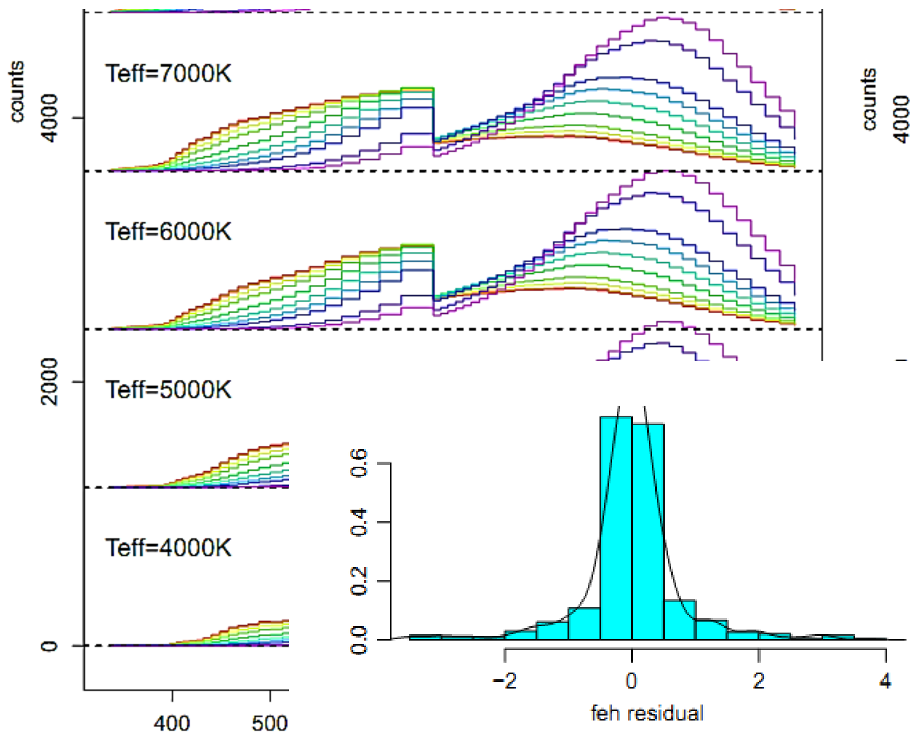
- Radial velocities below $V \approx 15$
- Chemical abundances below $V \approx 14$
- Good T_{eff} / A_V decoupling

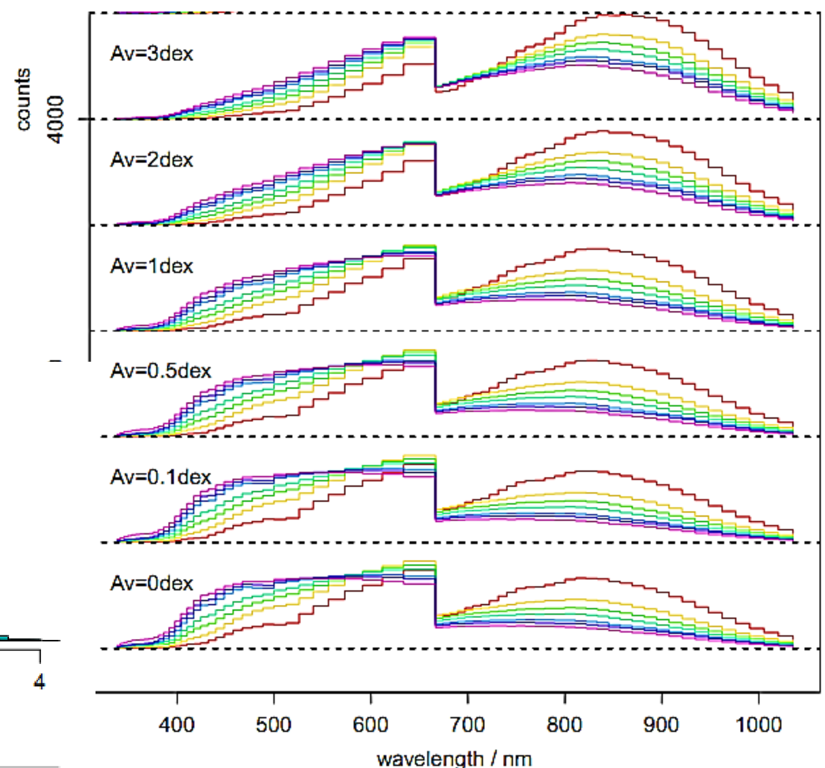


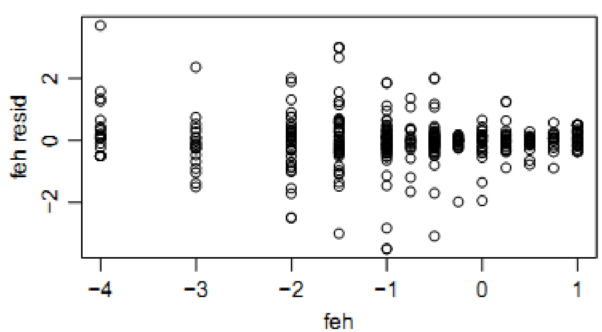


Brown *et al.* (2005)

Astrophysical parameter degeneracies







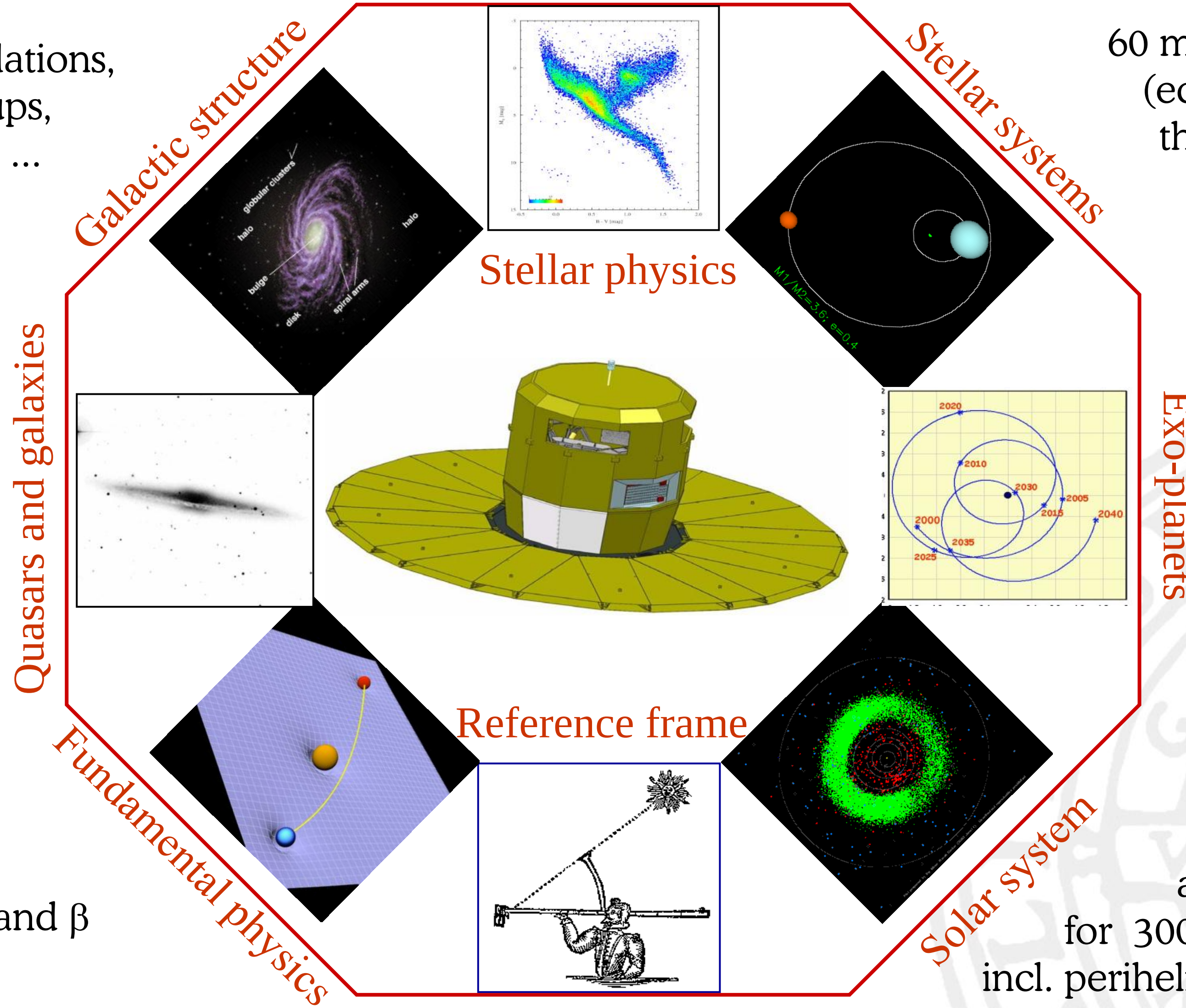
Bailer-Jones (2009:
GAIA-C8-TN-MPIA-CBJ-048)

σ = ([M/H] residual) ≈ 0.5

Known science highlights

Stellar populations,
moving groups,
the bar, DM, …

60 million binaries,
(eclipsing ones!);
the Sun's cradle



500 000
quasars
(RF!)

10s of
1000s
(with
different
biases)

PPN γ and β

accurate orbits
for 300000 asteroids,
incl. perihelion precession

Best ever optical ICRF

Expect the unexpected!

Knowledge beyond astrometry

Need to collect **complementary information** only photometry/spectroscopy can provide to

- reach the desired astrometric accuracy,
- complete the 6D phase-space information with υ_{rad},
- reach Gaia's Galactic-evolution science goals.

  E.g., the identification of Galactic building blocks in the outer halo cannot be achieved on kinematics alone (Brown *et al.* 2005).

Ground-based *follow-up*

The Gaia-ESO Survey (2011-2016)

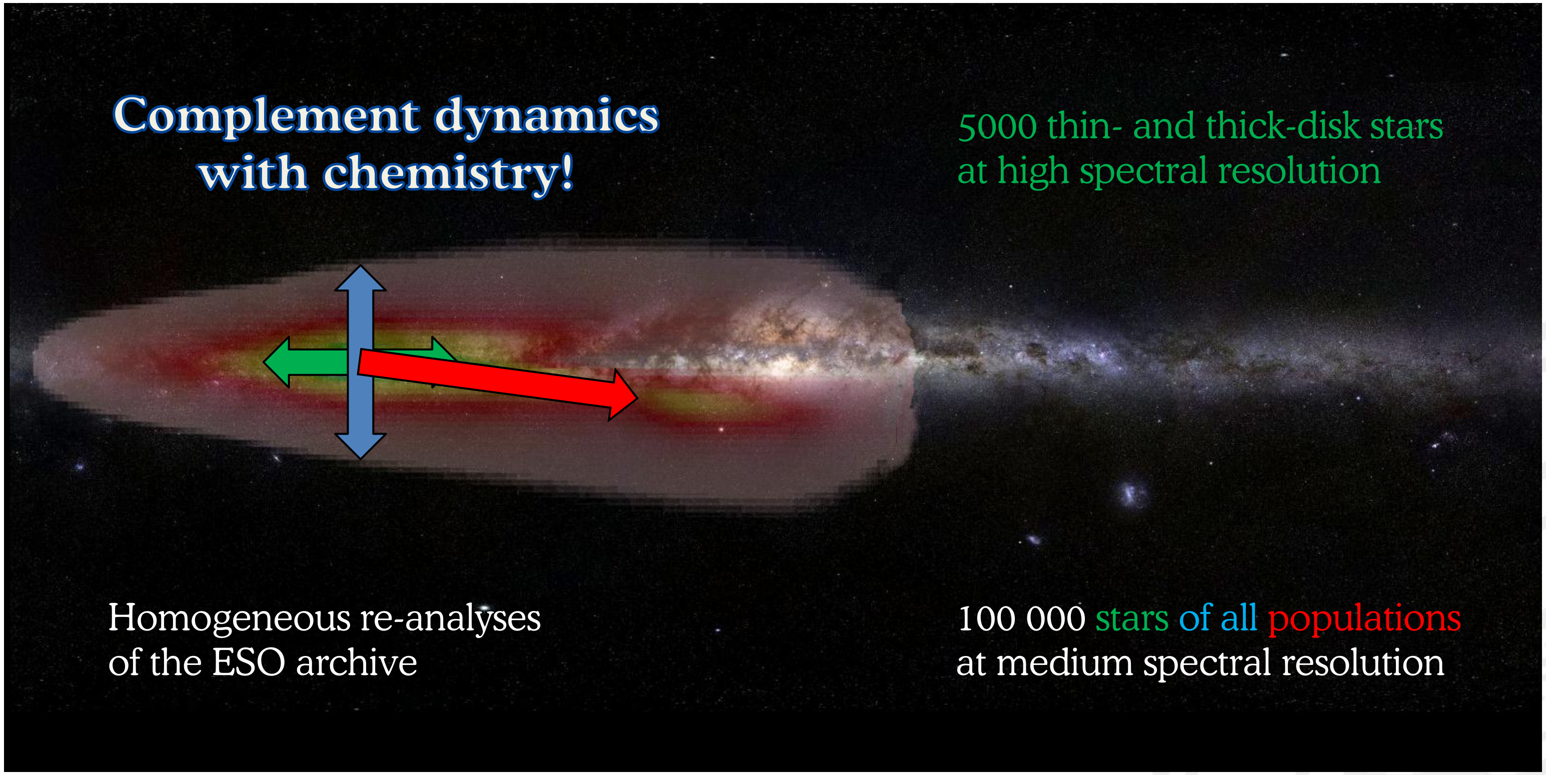
300 nights at the *Very Large Telescope* to obtain observations of 10^5 stars of all mature Galactic populations *in-situ*.

value of observing time: 30 M€

The Gaia-ESO survey: Galactic Astrophysics via VISTA Imaging, Gaia Astrometry, and Eso SpectrOscopy

PI: Gerry Gilmore[1]
Steering Group: James Binney[2], Piercarlo Bonifacio[7], Annette Ferguson[3], Sofia Feltzing[19], Eva Grebel[12], Amina Helmi[13], Geraint Lewis[23], Alejandra Recio-Blanco[4], Hans-Walter Rix[10], Matthias Steinmetz[11], Nic Walton[56]
CoI: C. Allende Prieto[16], T. Antoja[13], J. Alves[42], F. Arenou[7], M. Asplund[37], C. Babusiaux[7], C. Bailer-Jones[10], B. Barbuy[39], M. Bellazzini[15], V. Belokurov[1], T. Bensby[19], O. Bienayme[8], J. Bland-Hawthorn[23], A. Brown[14], J. Caballero[31], E. Caffau[7,12], F. Calura[55], L. Casagrande[37], N. Christlieb[12], C. Chiappini[11], M. Colless[24], M. Correnti[15], M.Cropper[5], J. Drew[6], S. Van Eck[48], B. Edvardsson[20], N.W. Evans[1], K. Eriksson[20], B. Famaey[8], M. Fellhauer[21], I. Ferreras[5], F. Figueras (& Spanish Gaia network)[17], G. Fiorentino[13], C. Flynn[23], P. Francois[7], K. Freeman[25], B. Gaensicke[47], F. Garzòn[16], S. Geier[52], D. Geisler[21], B. Gibson[55], J. Gonzalez Hernandez[16], A. Gomboc[27], A. Gomez[7], M. Groenewegen[34], F. Grundahl[49], B. Gustafsson[20], P.Hadrava[54], D. Hadzidimitriou[29], N. Hambly[3], P. Hammersley[33], M. Haywood[7], U. Heber[52], G. Hensler[42], V. Hill[4], S. Hodgkin[1], R. Ibata[8], M. Irwin[1], R. deJong[11], P. Jonker[50,51], A. Jorissen[48], D. Katz[7], D. Kawata[5], S. Keller[25], R. Klement[10], A. Koch[53], M. Kontizas[29], S. Koposov[1], A. Korn[20], P. Koubsky[54], R. Lallement[32], P deLaverny[4], B. Lemasle[13], K. Lind[37], P. Lucas[6], H. Ludwig[12], T. Lueftinger[42], J-B. Marquette[35], G. Matijevic[27], R. McMahon[1], I. Minchev[11], D. Minniti[36], L. Monaco[21], D. Montes[18], M.J. Monteiro[46], N. Mowlavi[41], A. Mucciarelli[45], U. Munari[30], R. Napiwotzki[6], G. Nelemans[51], J. Palous[54], E. Pancino[15], J. Penarrubia[1,39], G. Piotto[30], H. Posbic[7], A. Quirrenbach[12], C. Reyle[9], N. Robichon[7], A. Robin[9], F. Royer[7], G. Ruchti[37], A. Ruzicka[54], S. Ryan[6], N. Ryde[19], N. Santos[46], L.M. Sarro Baro[44], L. Sbordone[33,37], R. Schönrich[37], G. Seabroke[5], S. Sharma[23], G. De Silva[24], M. Smith[1,43], C. Soubiran[9], S. Sousa[46], E. Tolstoy[13], C. Turon (& French Gaia network)[7], M. Walker[1,38], K. Venn[26], R. Wyse[28], M. Zoccali[36], D. Zucker[22], T. Zwitter[27]
[1]IoA Cambridge, UK; [2]Theoretical Physics, Oxford, UK; [3]Edinburgh, UK; [4]OCA Nice, France; [5]MSSL, UCL, UK; [6]U Herts, UK; [7]Obs Paris, France; [8]Obs Strasbourg, France; [9] Obs Besancon, France; [10]MPIA, AIP Potsdam, Germany; [12]ZAH Univ. Heidelberg Germany; [13]Kapteyn Inst. iden, Nl; [15]INAF Bologna, Italy; [16]IAC, Canary Islands, Spain; [17]Univ Barcelona, ain; [19]Lund Univ, Sweden; [20]Uppsala Univ, Sweden; [21]Univ Concepcion, Chile; lia; [23]Univ Sydney, Australia; [24]AAO, Australia; [25]ANU, Australia; [26]Univ Vic- bliana, Slovenia; [28]Johns Hopkins Univ, USA; [29]Univ Athens, Greece; [30]INAF e Astrobiologìa, Madrid, Spain; [32]LATMOS/IPSL, Versailles, France; [33]ESO; Paris, France; [36]Univ. Catolica, Chile; [37]MPA, Garching, Germany; [38]CfA, USA; Univ Sao Paolo, Brazil; [41]Obs de Geneve, Switzerland; [42]IoA Univ Vienna, Aus- ina; [44]UNED, Madrid, Spain; [45]Univ Bologna, Italy; [46]CAUP Porto, Portugal; B, Brussels, Belgium; [49]Univ Aarhus, Denmark; [50]SRON, Nl; [51]Univ. Nijmegen, gen-Nuernberg, Germany; [53]Univ Leicester, UK; [54]Ast Inst Acad Sci, Prague, cs, Preston, UK; [56]GREAT Chair, ESA Gaia GST.

Gaia, Gaia-ESO and...



Major upcoming/future efforts include APOGEE, HERMES and 4MOST.

Gaia and Gaia research…