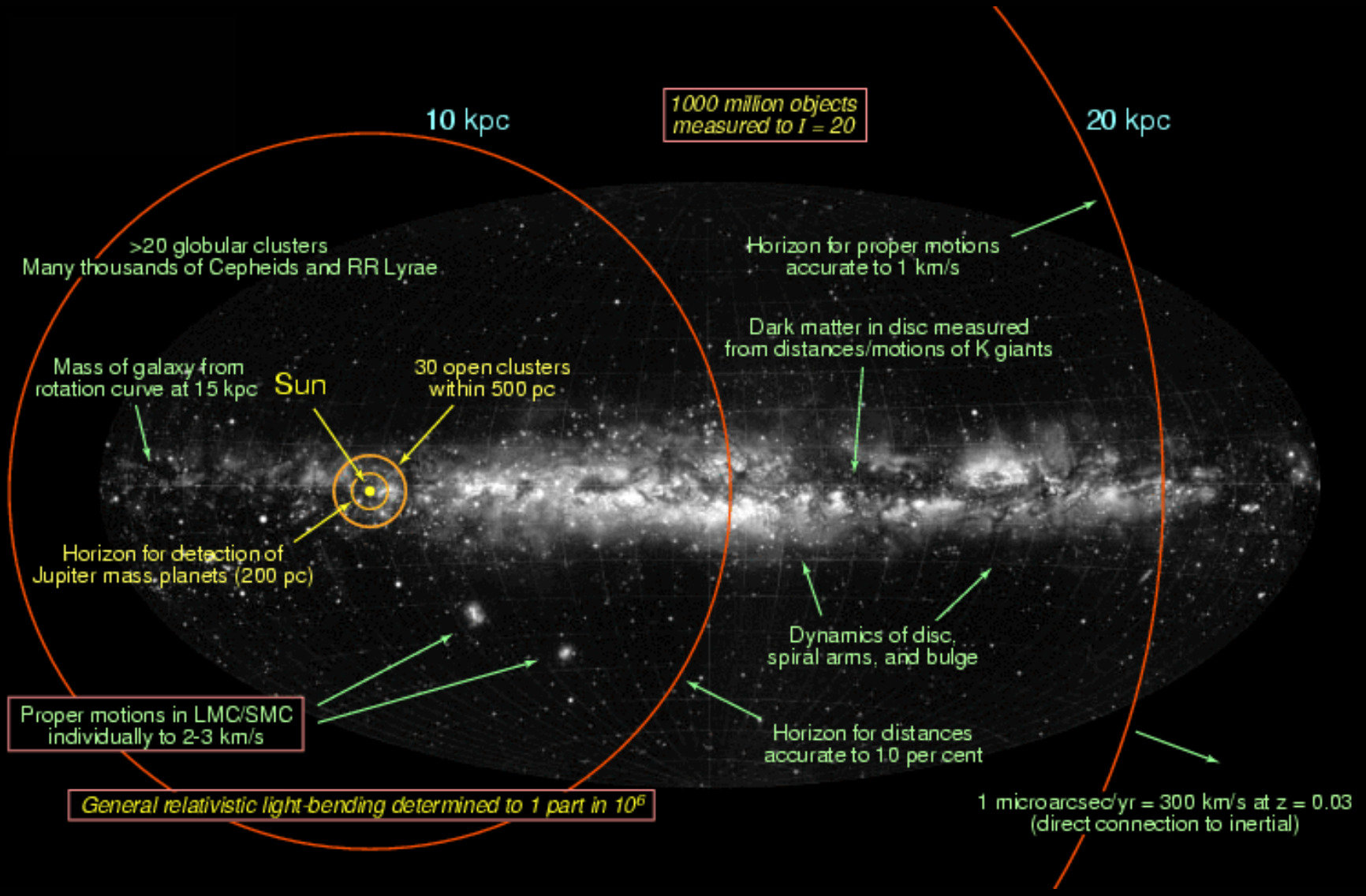
GAIA

Composition, Formation and Evolution of our Galaxy

STATUS: approved and funded. Due for launch `before 2012'
Launch goal is 2010
5-6 years operation at L2
Broad-band photometry at <0.1arcsec resolution
Medium band photometry at low resolution
Spectra/radial velocities (Ca II) for all stars V<17
Eventual astrometry for 1 billion sources
Complete photometric census to V=20


Planet Motion
(simulated: 3 years)

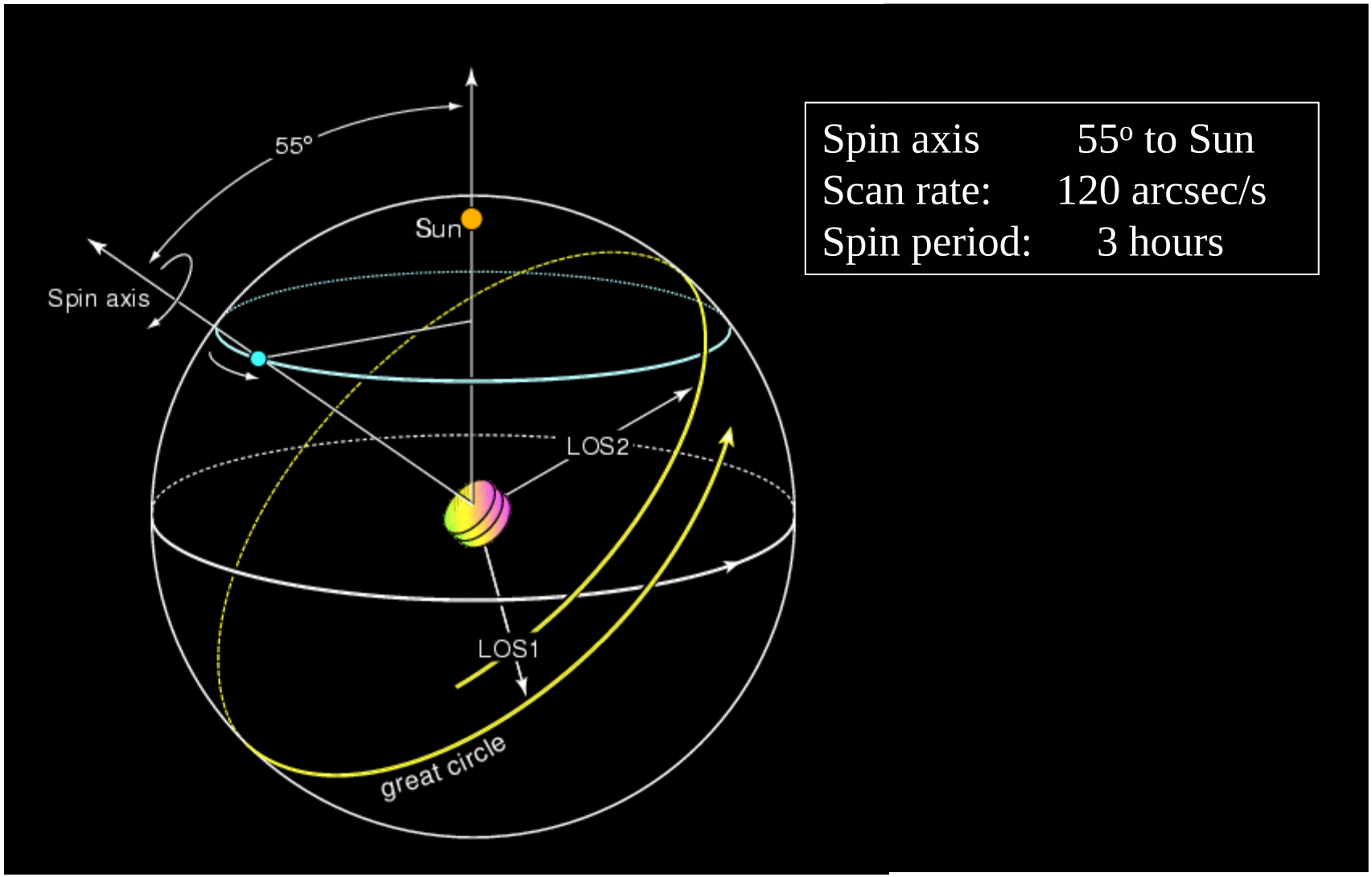
GAIA Accuracies and our Galaxy



10 μas = 10% distances at 10 kpc

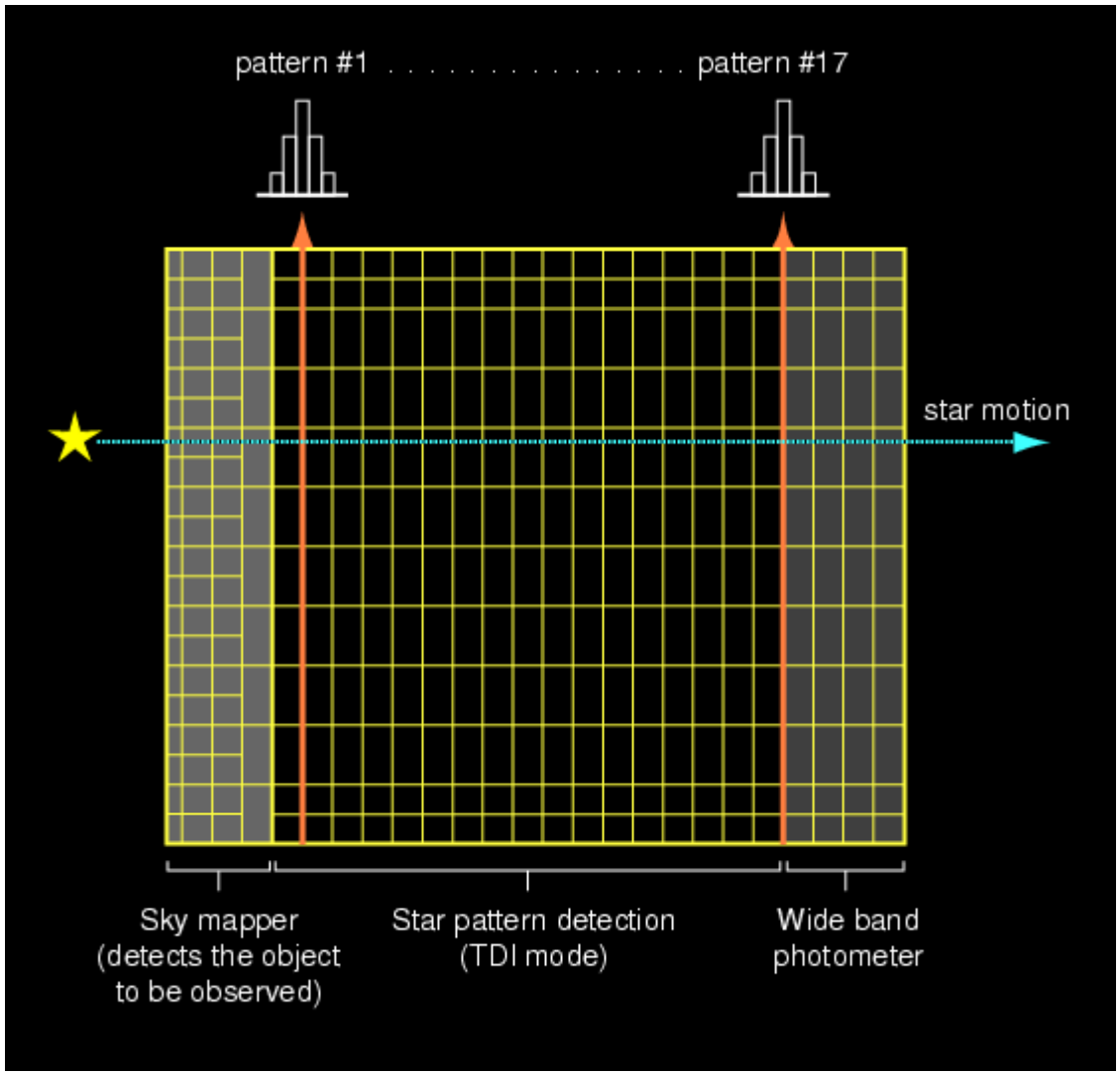
10 μas/yr = 1 km/sec at 20 kpc

Sky Scanning Principle



Spin axis	55° to Sun
Scan rate:	120 arcsec/s
Spin period:	3 hours

Astrometric Focal Plane



Sky mapper:
- detects all objects to 20 mag
- rejects cosmic-ray hits
- mag and x,y to main field

Main field:
- area: 0.3 deg^2
- size: 60 × 70 cm^2
- Number of CCD chips: 150
- CCDs: 2780 x 2150 pixels

Pixels:
- size: 9 x 27 μm^2
- flush frequency: 15 MHz
- readout frequency: 30 kHz
- total read noise: 6e^- rms

Broad-band photometry:
- 4 colour

Main Performances and Capabilities

Accuracies:

- 4 μas at V = 10 10 μas at V = 15 0.2 mas at V = 20
- radial velocities to few km/s complete to V = 17.5
- sky survey at ~0.1 arcsec spatial resolution to V = 20
- multi-colour multi-epoch photometry to V = 20
- dense quasar link to inertial reference frame

Capabilities:

- 10 μas ≡ 10% at 10 kpc ≡ 1 AU at 100 kpc
- 10 μas/yr at 20 kpc ≡ 1 km/s

⇒ every star in the Galaxy and Local Group will be seen to move

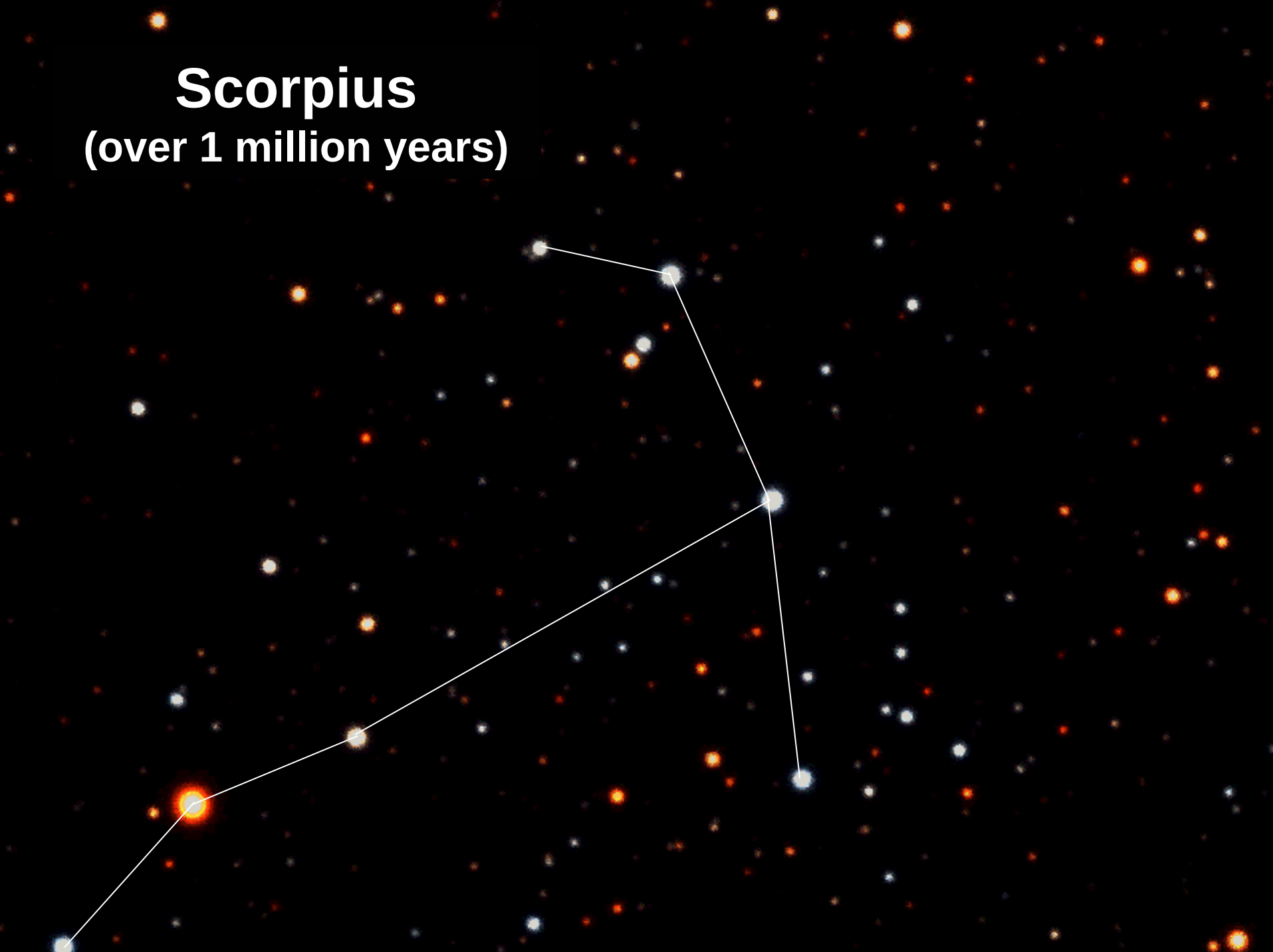
⇒ GAIA will quantify 6-D phase space for over 300 million stars, and 5-D phase-space for over 10^9 stars

And an interesting data reduction challenge….

GAIA: Key Science Objectives

- Structure and kinematics of our Galaxy:
  - shape and rotation of bulge, disk and halo
  - internal motions of star forming regions, clusters, etc
  - nature of spiral arms and the stellar warp
  - space motions of all Galactic satellite systems
- Stellar populations:
  - physical characteristics of all Galactic components
  - initial mass function, binaries, chemical evolution
  - star formation histories
- Tests of galaxy formation:
  - dynamical determination of dark matter distribution
  - reconstruction of merger and accretion history

$\Rightarrow$ Origin, Formation and Evolution of the Galaxy


Scorpius
(over 1 million years)

GAIA: Studies of the Solar System

Deep and uniform detection of all moving objects:

- complete to 20 mag
- discovery of ~10^5 - 10^6 new objects (cf. 65,000 presently)
- taxonomy and mineralogical composition versus heliocentric distance
- diameters for ~1000 asteroids
- masses for ~100 objects
- orbits: 30 times better than present, even after 100 years
- Trojan companions of Mars, Earth and Venus
- Edgeworth-Kuiper Belt objects: ~300 to 20 mag + binarity + Plutinos
- Near-Earth Objects:
  - e.g. Amors, Apollos and Atens (442: 455: 75 known today)
  - ~1600 Earth-crossing asteroids > 1 km predicted (100 currently known)
  - GAIA detection: 260 - 590 m at 1 AU, depending on albedo

GAIA: Discoveries of Extra-Solar Planets

- Large-scale detection and physical characterisation
- 20,000- 30,000 giants to 150-200 pc

  e.g. 47 UMa: astrometric displacement 360 μas
- complete census of all stellar types (P = 2-9 years)
- masses, rather than lower limits (m sin i)
- orbits for many (≈5000) systems
- relative orbital inclinations for multiple systems
- mass down to 10 M_{Earth} to 10 pc

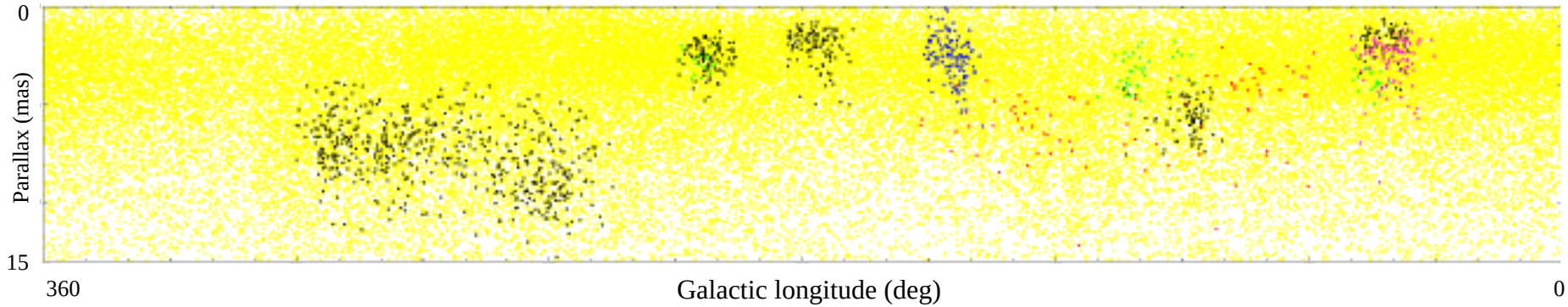
Stellar Astrophysics

- Comprehensive luminosity calibration, for example:
  - distances to 1% for 18 million stars to 2.5 kpc
  - distances to 10% for 150 million stars to 25 kpc
  - rare stellar types and rapid evolutionary phases in large numbers
  - parallax calibration of all distance indicators
    e.g. Cepheids and RR Lyrae to LMC/SMC

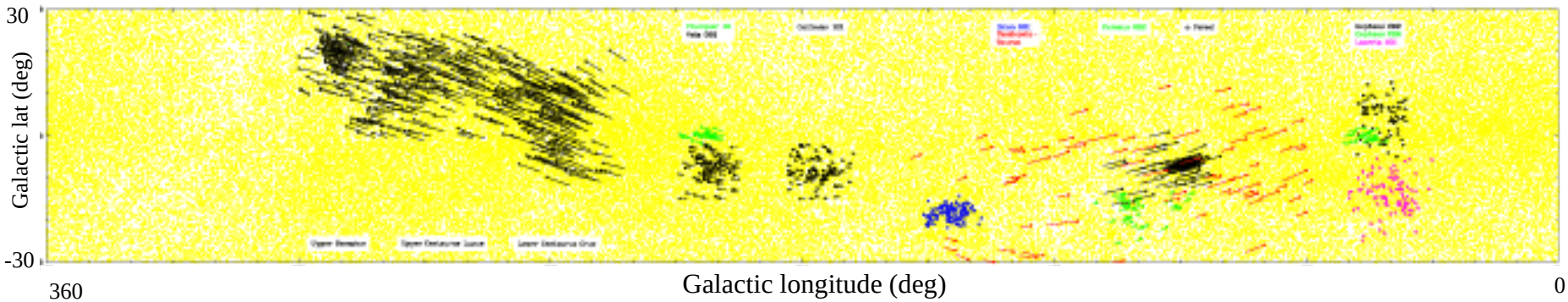
- Physical properties, for example:
  - clean Hertzsprung-Russell sequences throughout the Galaxy
  - solar neighbourhood mass function and luminosity function
    e.g. white dwarfs (~200,000) and brown dwarfs (~50,000)
  - initial mass and luminosity functions in star forming regions
  - luminosity function for pre main-sequence stars
  - detection and dating of the oldest (disk and halo) white dwarfs

Structure of Star Forming Regions

Parallaxes of OB association members (Hipparcos)



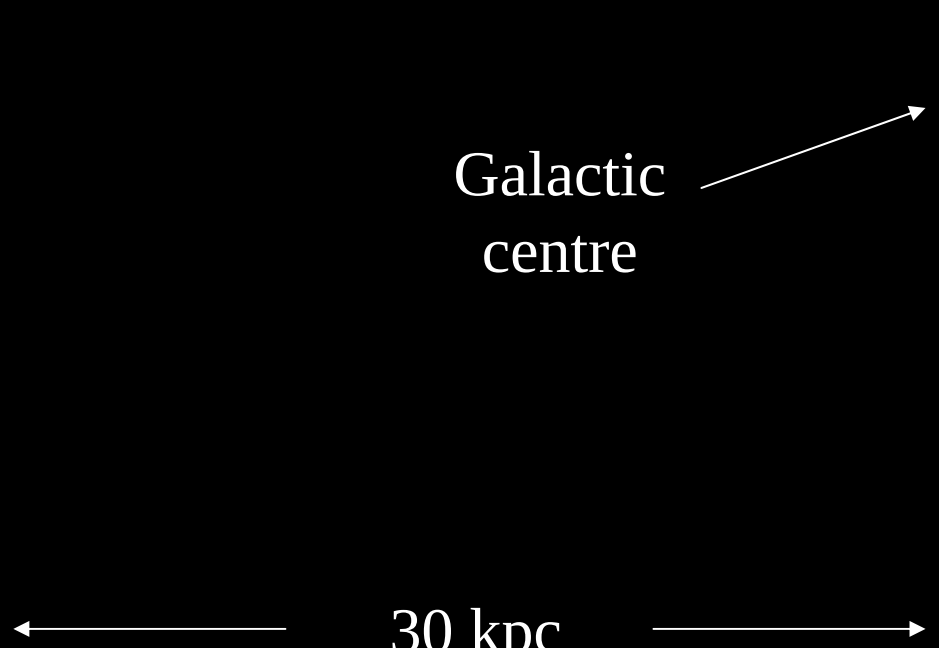
Positions and proper motions of selected members



GAIA will allow:

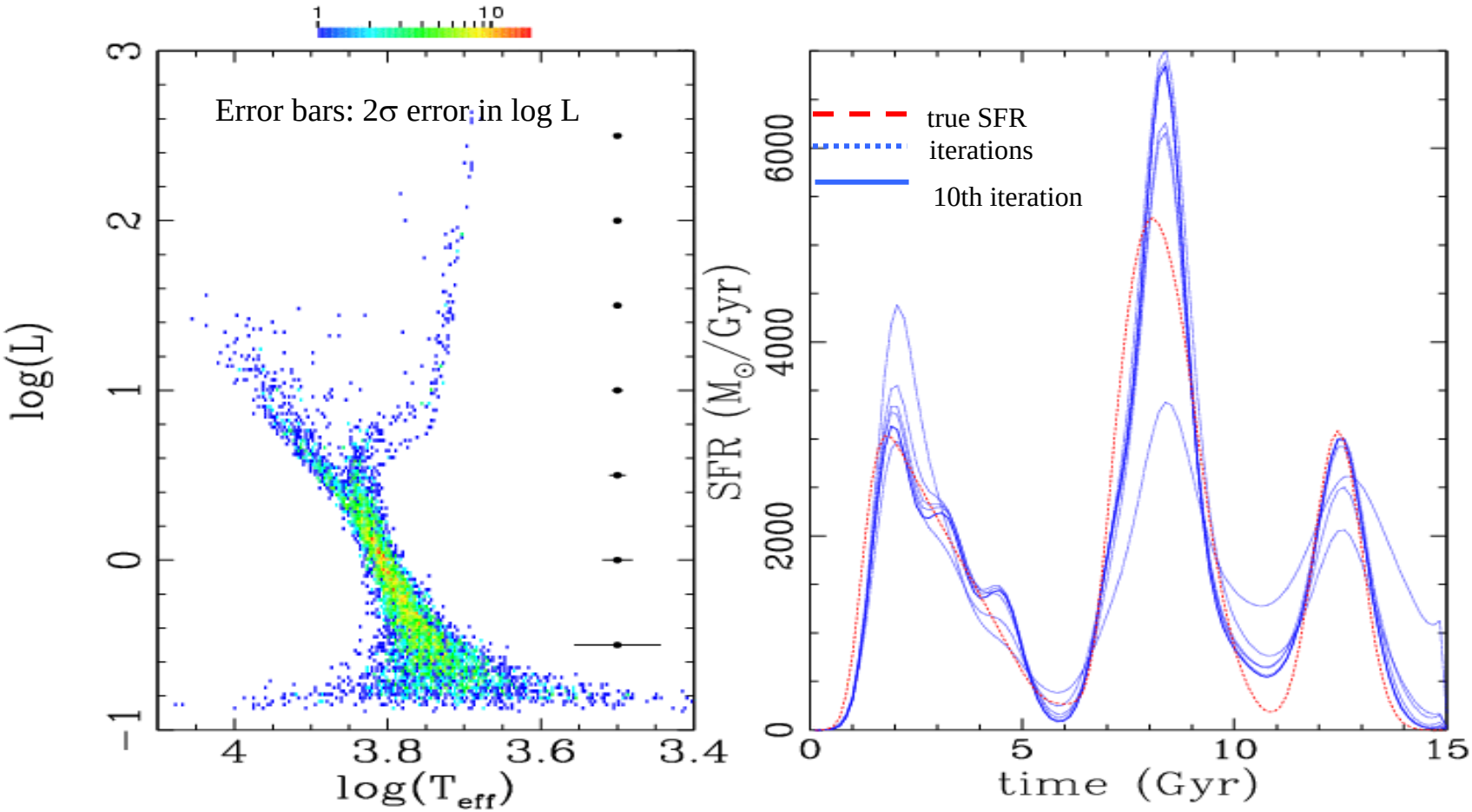
- detection of stellar groups across the Galaxy
- tracing back of orbits to time and location of formation

Halo Satellite Disruption



Captured galaxy:
- satellite mass: 4×10^8 M_o
- pericentre: 7 kpc
- simulation over 3 Gyr

Star Formation History



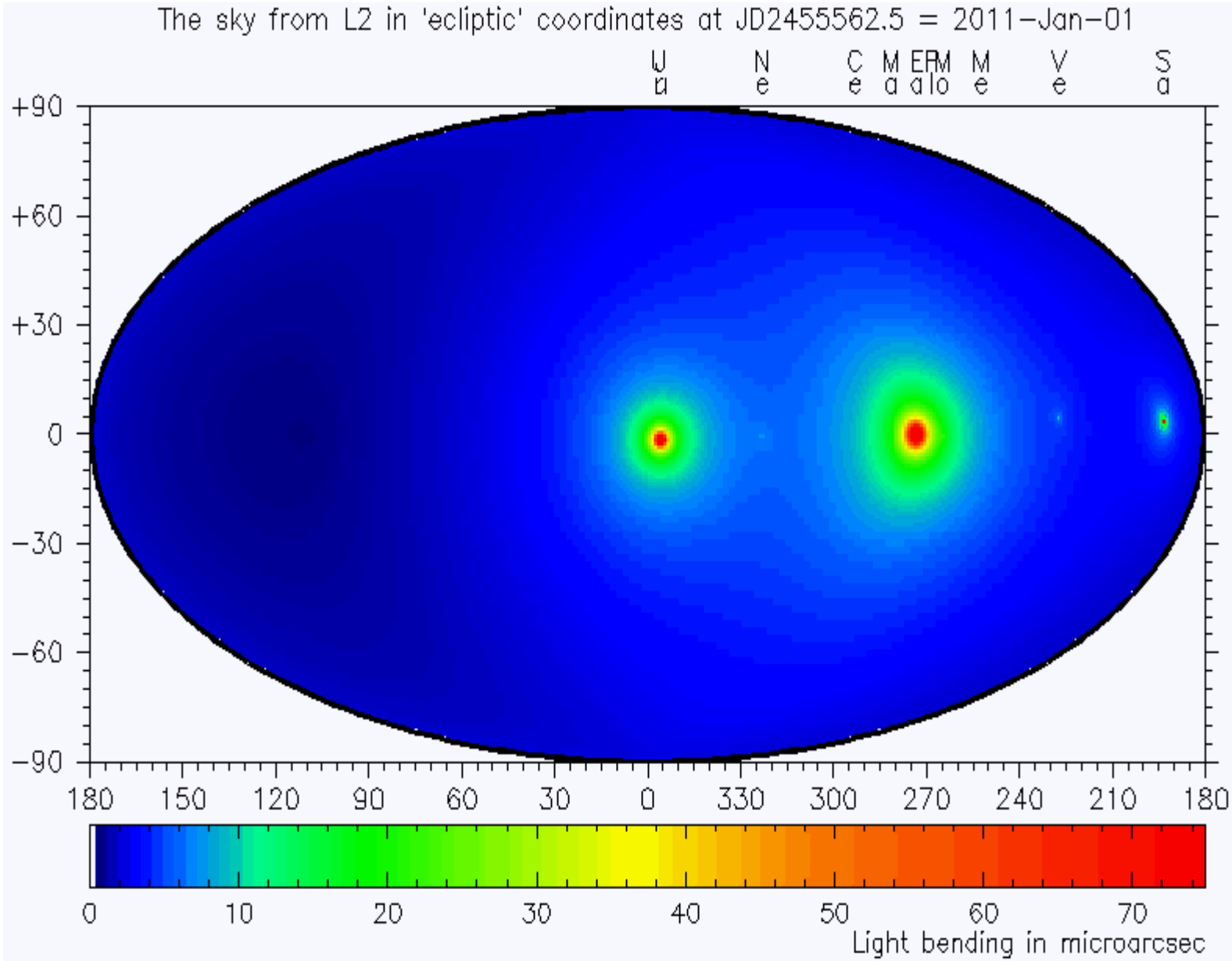
⇒ GAIA will yield L, T_{eff}, [Fe/H], and ages throughout the Galaxy

Galaxies, Quasars, and the Reference Frame

- Parallax distances, orbits, and internal dynamics of nearby galaxies
- Galaxy survey, including large-scale structure
- ~500,000 quasars: kinematic and photometric detection
- ~100,000 supernovae
- Ω_M, Ω_Λ from multiple quasar images (3500 to 21 mag)
- Galactocentric acceleration: 0.2 nm/s^2 $\Rightarrow$ Δ(aberration) = 4 μas/yr
- Globally accurate reference frame to ~0.4 μas/yr

General Relativity/Metric

- From positional displacements:
  - γ to 5×10^{-7} (cf. 10^{-5} presently) $\Rightarrow$ scalar-tensor theories
  - effect of Sun: 4 mas at 90^{o}; Jovian limb: 17 mas; Earth: ~40 μas
- From perihelion precession of minor planets:
  - β to 3×10^{-4} - 3×10^{-5} ($\times$10-100 better than lunar laser ranging)
  - Solar J_2 to 10^{-7} - 10^{-8} (cf. lunar libration and planetary motion)
- From white dwarf cooling curves:
  - dG/dT to 10^{-12} - 10^{-13} per year (cf. PSR 1913+16 and solar structure)
- Gravitational wave energy: $10^{-12} < f < 10^{-9}$ Hz
- Microlensing: photometric (~1000) and astrometric (few) events
- Cosmological shear and rotation (cf. VLBI)


The sky from L2 in 'ecliptic' coordinates at JD2455562.5 = 2011-Jan-01
U
N
C
M
E
R
M
M
V
S
+90
+60
+30
0
-30
-60
-90
180
150
120
90
60
30
0
330
300
270
240
210
180
0
10
20
30
40
50
60
70
Light bending in microarcsec

GAIA Observatory: Early Science

- **Continuously throughout the mission:**
  - broad-band photometry
  - medium-band photometry
  - radial velocity spectroscopy

=> VARIABLES, INTERESTING OBJECTS,
SOLAR SYSTEM SOURCES, SUPERNOVAE,…

⇒ A REAL-TIME VIDEO OF THE SKY at 0.1arcsec resolution...

Summary

GAIA will determine:

- when the stars in the Milky Way formed
- when and how the Milky Way was assembled
- how dark matter in the Milky Way is distributed

GAIA will also make substantial contributions to:

- stellar astrophysics
- Solar System studies
- extra-solar planetary science
- cosmology
- fundamental physics

http://www.rssd.esa.int/GAIA/

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GAIA: the European Observatory