

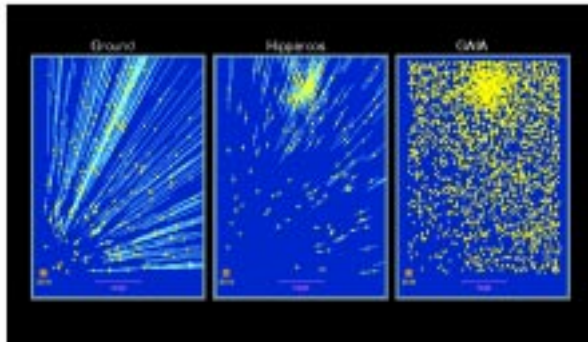
GAIA

A Stereoscopic Census of our Galaxy

GAIA Compared with Hipparcos

	Hipparcos	GAIA
Magnitude limit	12	20-21 mag
Completeness	7.3 – 9.0	~20 mag
Bright limit	~0	~3-7 mag
Number of objects	120 000	26 million to V = 15 250 million to V = 18 1000 million to V = 20
Effective distance limit	1 kpc	1 Mpc
Quasars	None	$\sim 5 \times 10^5$
Galaxies	None	$10^6 - 10^7$
Accuracy	~1 milliarcsec	4 μ arcsec at V = 10 10 μ arcsec at V = 15 200 μ arcsec at V = 20
Broad band	2-colour (B and V)	4-colour to V = 20
Medium band	None	11-colour to V = 20
Radial velocity	None	1-10 km/s to V = 16-17
Observing programme	Pre-selected	On-board and unbiased

Scientific Objectives: Performances



Improvements with respect to Hipparcos:

- accuracies by factors of 100-1000
- numbers of stars by factor $\sim 10^4$ ($\sim 30\,000/\text{sq deg}$)
- limiting magnitude (from 10-12 mag) to ~ 20 mag
- plus radial velocities and photometry
- giant leap in accessible volumes

It will advance understanding of:

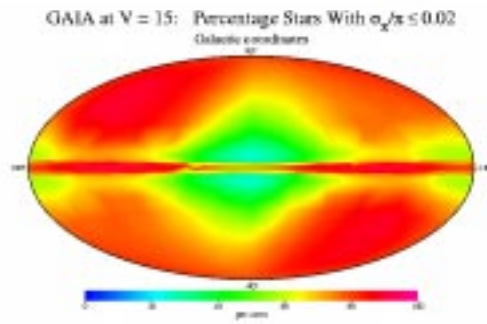
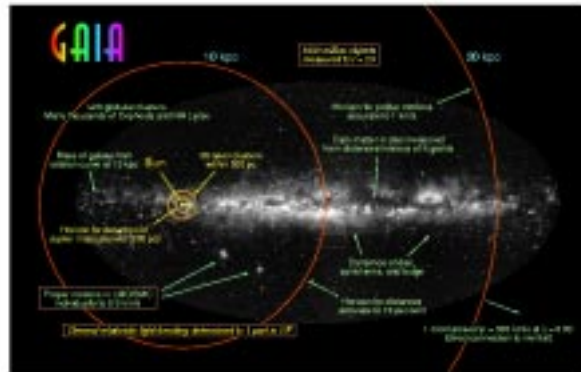
- physics and evolution of stars and planets
- kinematic and dynamical Galaxy structure
- origin and evolution of our Galaxy/Local Group

Based on Galactic models:

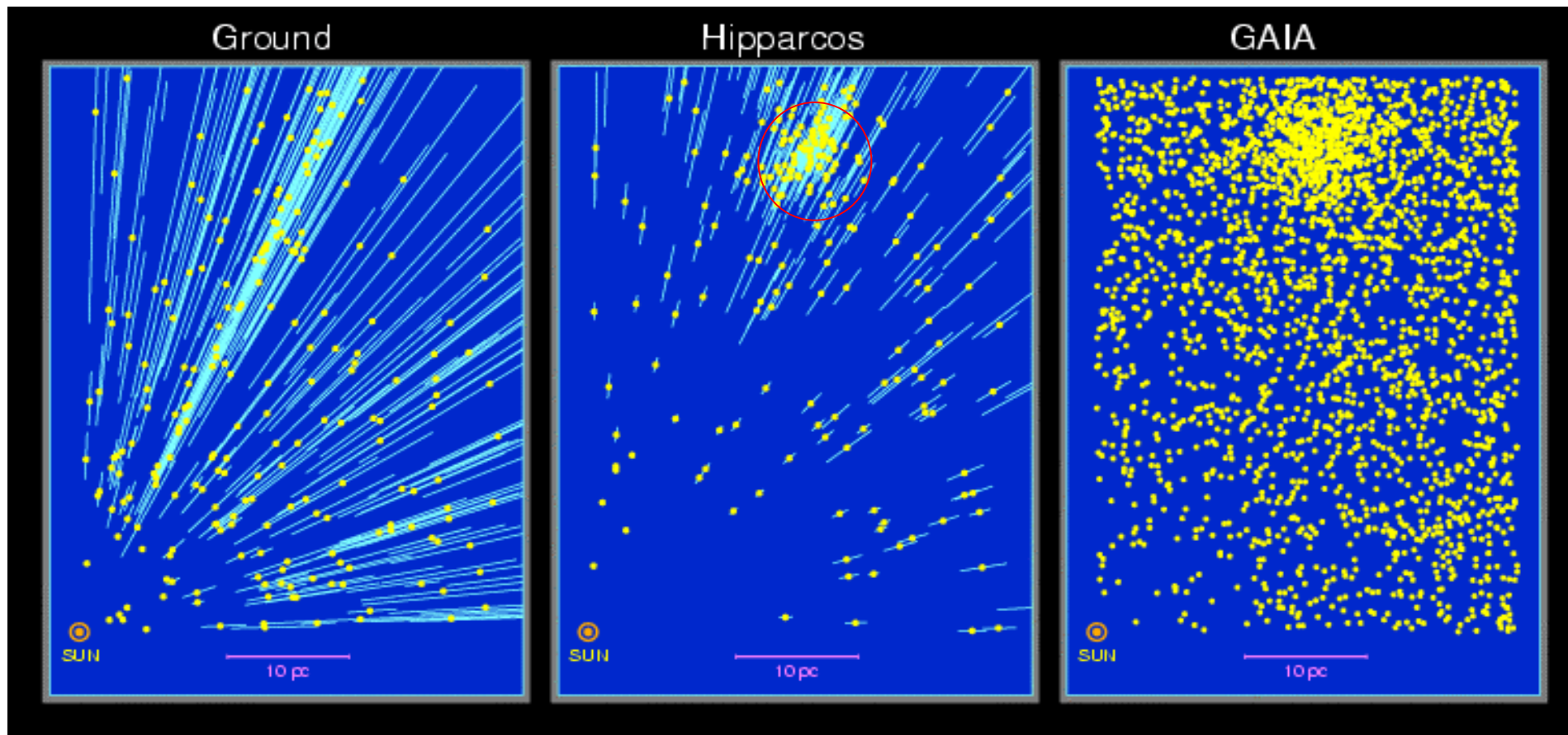
- ~ 18 million distances better than 1 per cent
- ~ 90 million distances better than 5 per cent

Special objects (examples):

- $10^6 - 10^7$ galaxies
- 5×10^5 quasars
- 10^5 supernovae
- $10^5 - 10^6$ (new) Solar System objects
- 10^8 binaries
- 200 000 disk white dwarfs
- 50 000 brown dwarfs
- 50 000 planetary systems

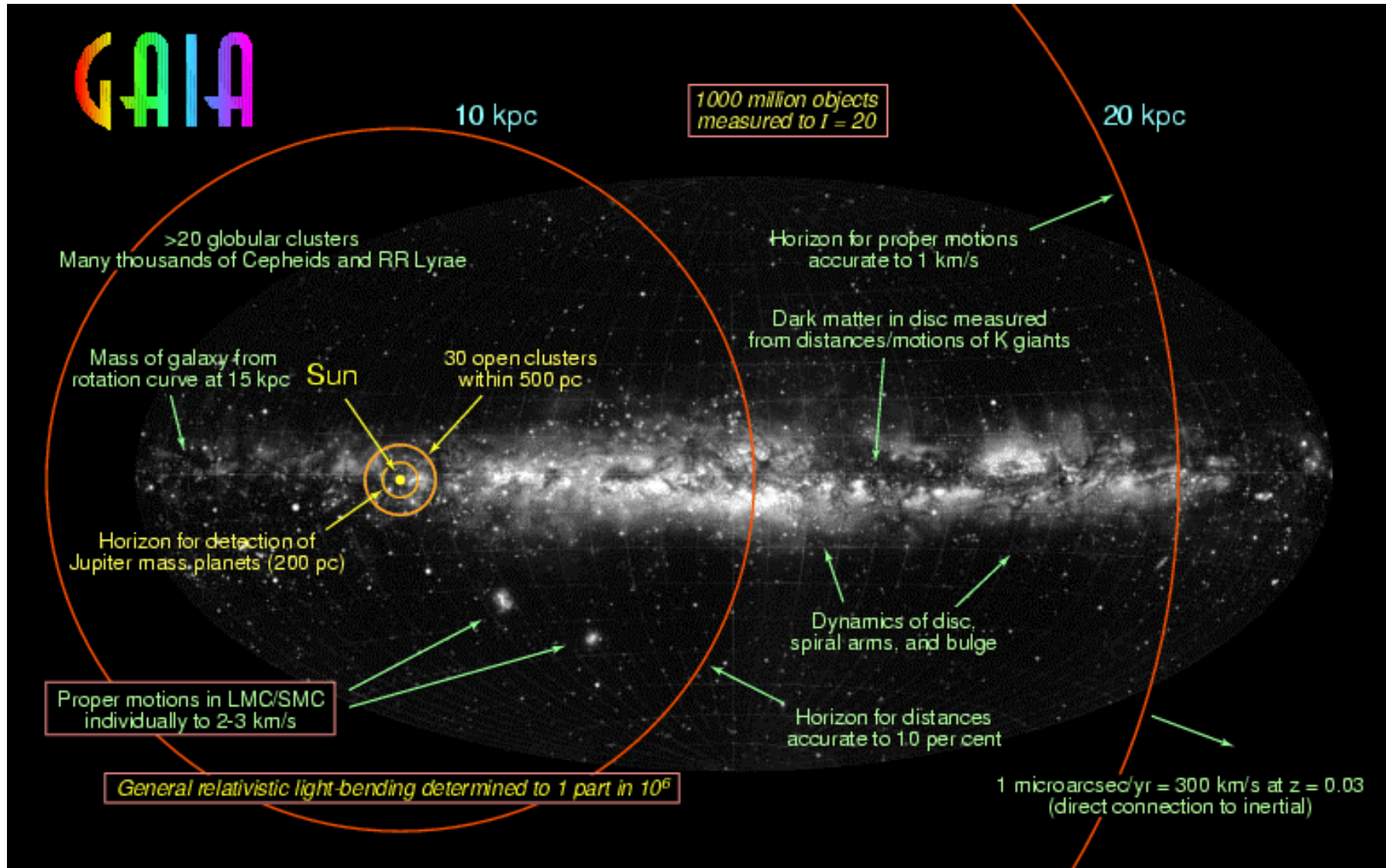


Distances from Ground, Hipparcos, and GAIA



e.g. the Hyades: distance, membership, age, dynamics,
mass segregation, evolution, main sequence, etc

GAIA Accuracies and our Galaxy



10 μ as = 10% distances at 10 kpc

10 μ as/yr = 1 km/sec at 20 kpc

Scientific Objectives

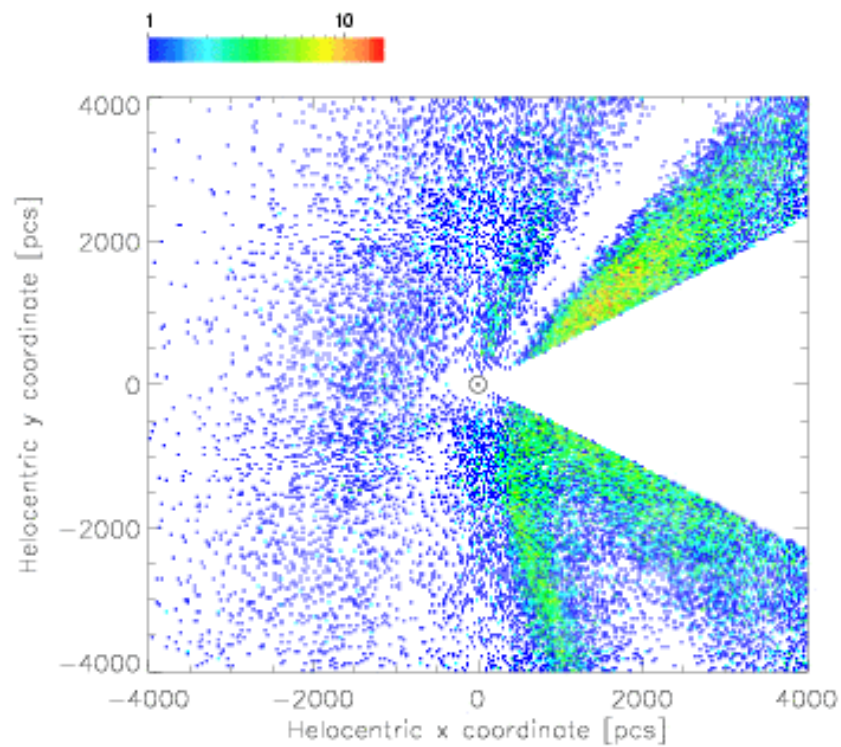
GAIA: Why a Survey to 20 mag?

Tracer		M _v	l	b	d	A _v	V ₁	V ₂	ε _T	σ _{μ1}	σ _{μ1}	σ _{π1}
		mag	deg	deg	kpc	mag	mag	mag	km/s	μas/yr	-	-
Bulge	gM	-1	0	<20	8	2-10	15	20	100	10	0.01	0.10
	HB	+0.5	0	<20	8	2-10	17	20	100	20	0.01	0.20
	MS	+4.5	1	-4	8	0-2	19	21	100	60	0.02	0.60
Spiral arms	Cepheids	-4	All	<10	10	3-7	14	18	7	5	0.03	0.06
	B-M supergiants	-5	All	<10	10	3-7	13	17	7	4	0.03	0.05
	Perseus Arm (B)	-2	140	<10	2	2-6	12	16	10	3	0.01	0.01
Thin disk	gK	-1	0	<15	8	1-5	14	18	40	6	0.01	0.06
	GK	-1	180	<15	10	1-5	15	19	10	8	0.04	0.10
Disk warp	gM	-1	All	<20	10	1-5	15	19	10	8	0.04	0.10
Thick disk	Miras, gK	-1	0	<30	8	2	15	19	50	10	0.01	0.10
	HB	+0.5	0	<30	8	2	15	19	50	20	0.02	0.20
	Miras, gK	-1	180	<30	20	2	15	21	30	25	0.08	0.65
	HB	+0.5	180	<30	20	2	15	19	30	60	0.20	1.50
Halo	gG	-1	All	<20	8	2-3	13	21	100	10	0.01	0.10
	HB	+0.5	All	>20	30	0	13	21	100	35	0.05	1.40
Gravity, K-z	dK	+7-8	All	All	2	0	12	20	20	60	0.01	0.16
	dF8-dG2	+5-6	All	All	2	0	12	20	20	20	0.01	0.05
Globular clusters	gK	+1	All	All	8	0	12	21	100	10	0.01	0.10
Satellite orbits	gM	-1	All	All	100	0	13	20	100	60	0.30	8.00

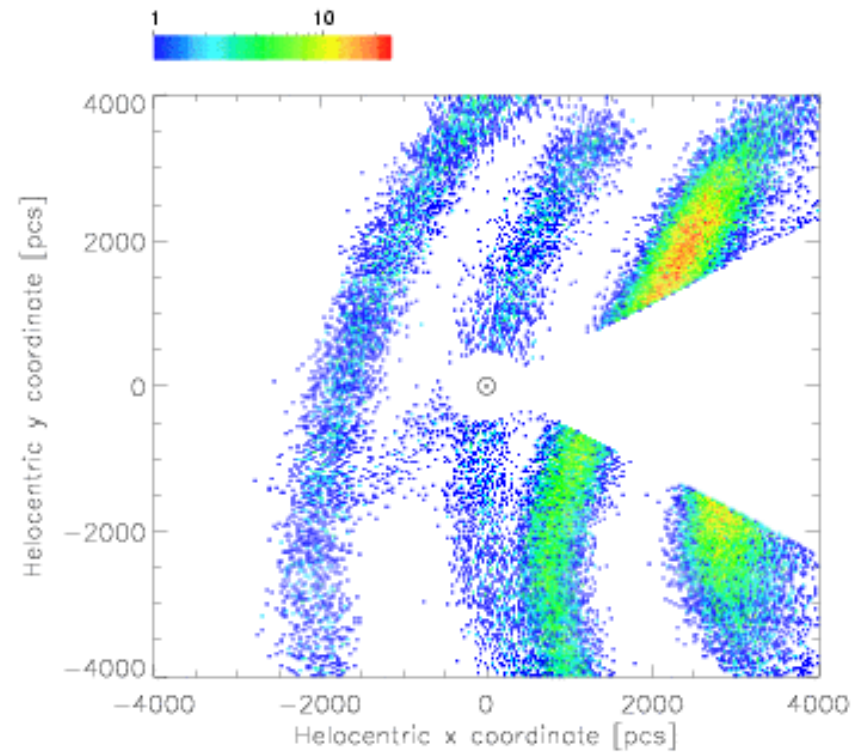
Formation and Evolution of the Galaxy

- Structure and kinematics:
 - tests of hierarchical structure formation
 - shape and figure of rotation of the bulge
 - kinematic detection and internal motions of associations, open and globular clusters, and Local Group dwarfs
 - dynamics of spiral arms and nature of the stellar warp
 - substructure in the halo, including tidal accretion debris
- Mass:
 - rotation curve from specific kinematic tracers
 - K-z studies for local dark matter
 - space motions of globular clusters, LMC/SMC, dwarf spheroidals, and other Local Group members
- Star formation history:
 - stellar populations in the main Galactic components
 - constraints on formation scenarios
 - chemical evolution

Simulations of the Galactic Plane (50,000 OB stars)

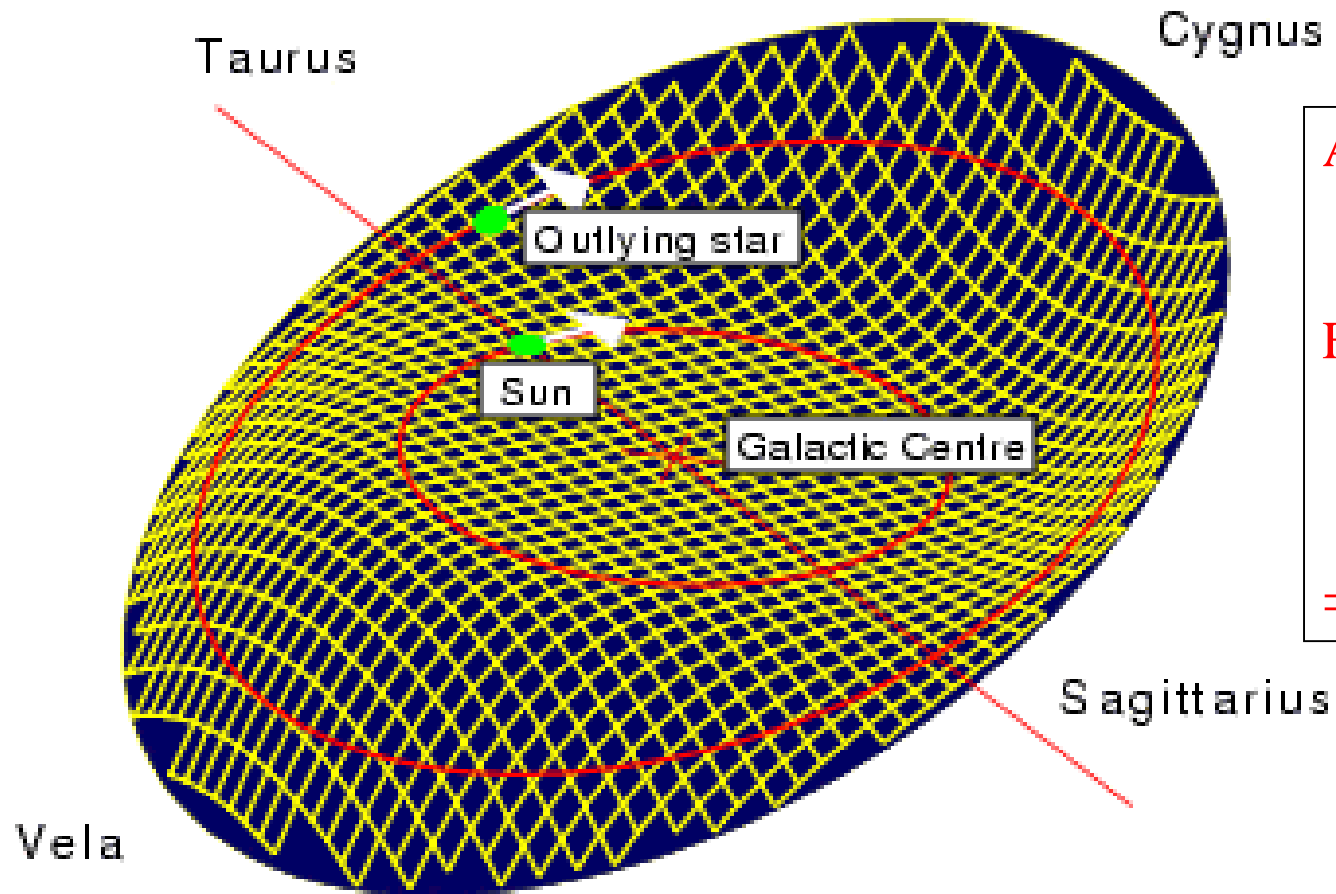


Photometric distances



GAIA distances

Galaxy Warp

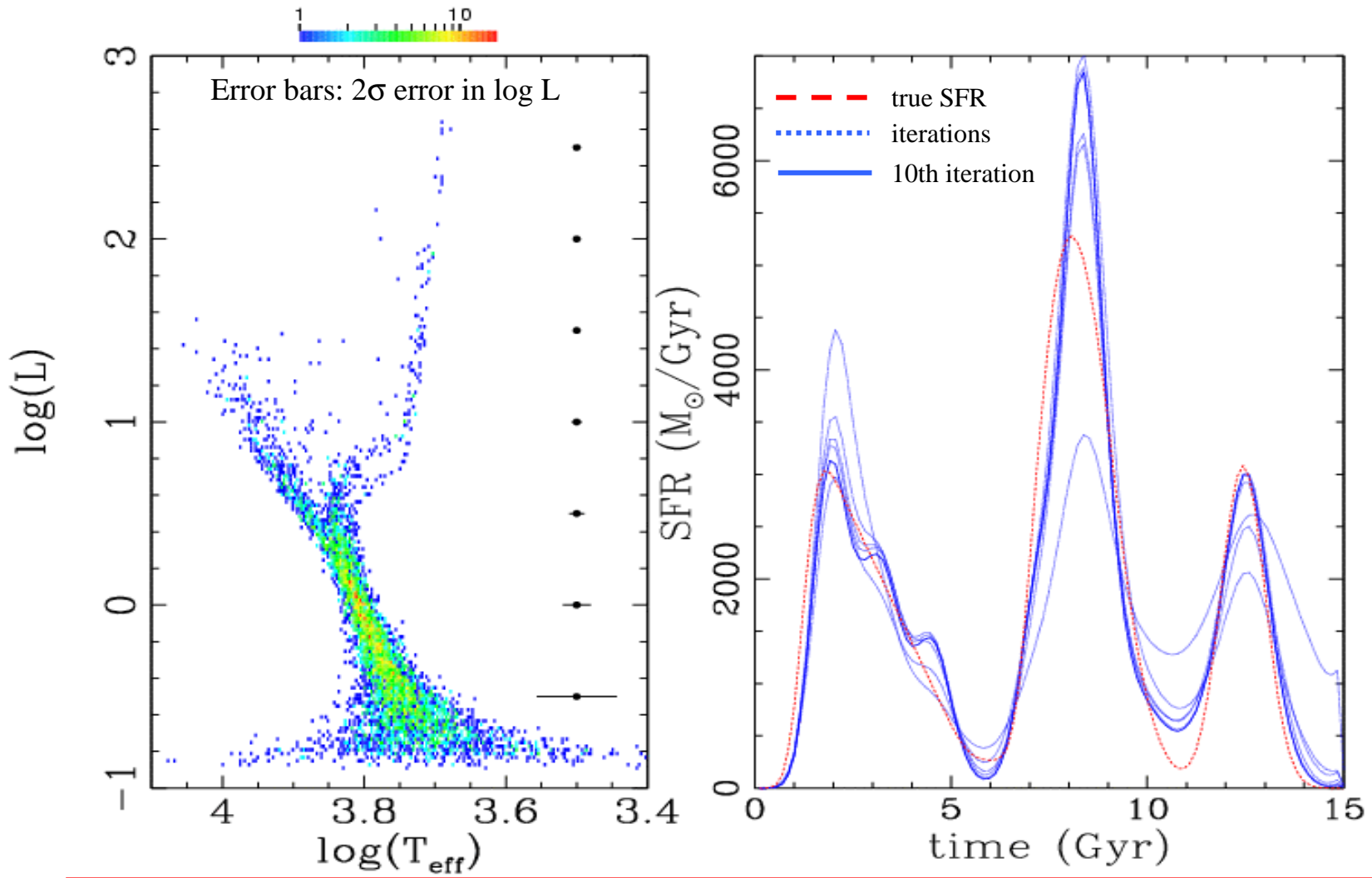


At 15 kpc:
disk rotation ~ 6 mas/yr

For a 1 kpc high warp:
 ~ 90 μ as/yr in latitude
 ~ 600 μ as/yr in longitude

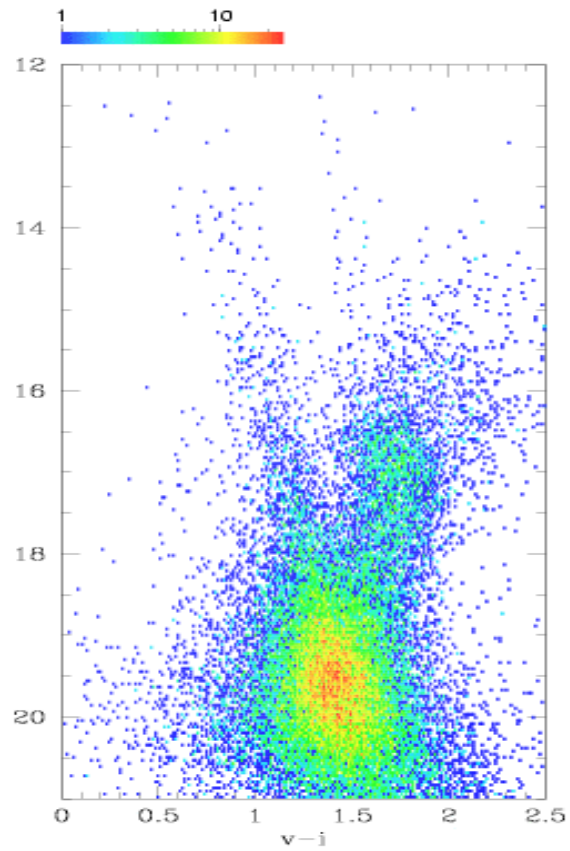
\Rightarrow easily measurable

Star Formation History

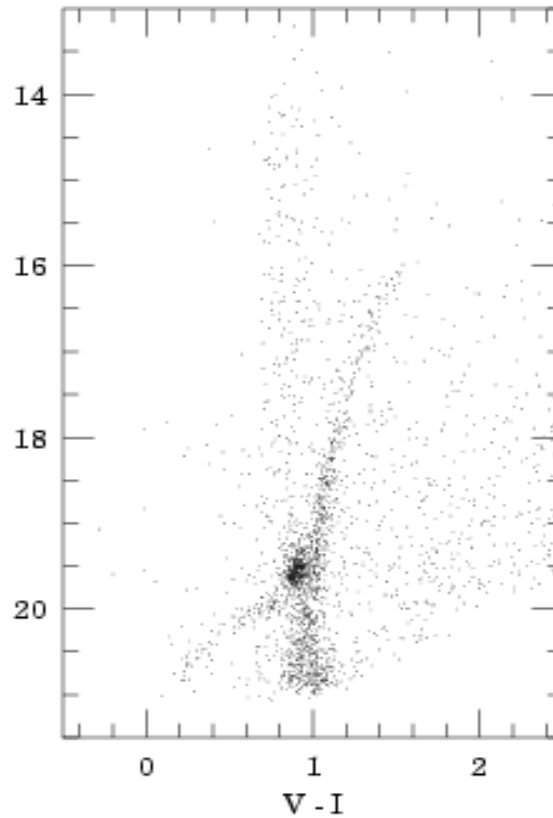


Accuracies: 10% in L and T_{eff} ; 0.2 dex in $[\text{Fe}/\text{H}]$ ($V < 17$ mag, $d < 4$ kpc) \Rightarrow ages to 10%

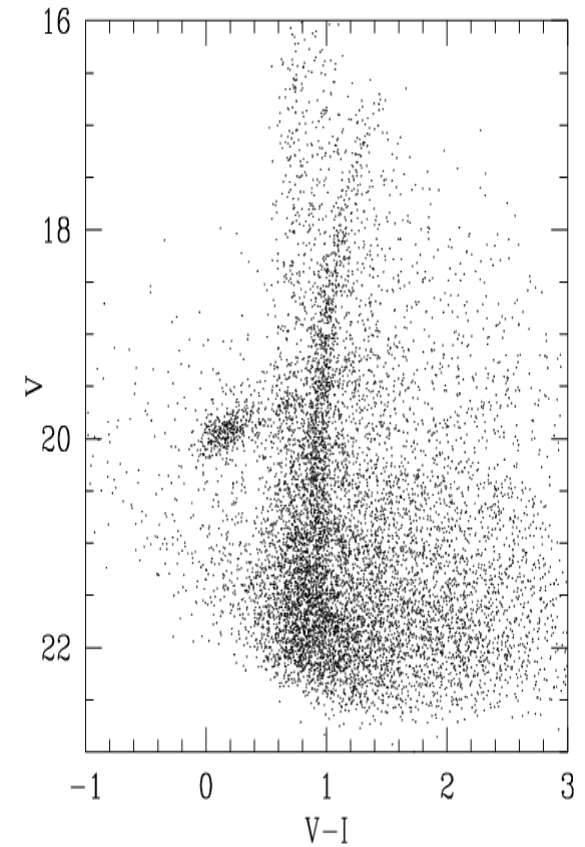
Colour-Magnitude Diagrams



Baade's Window
Bulge turnoff ~ 19.5
Mixture of young stars + foreground

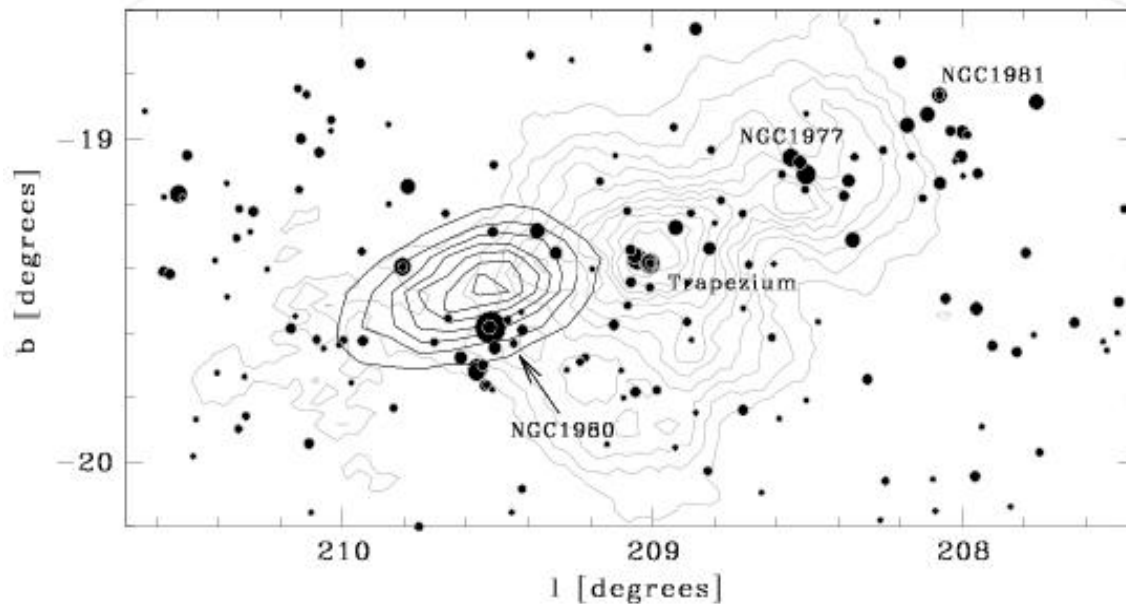
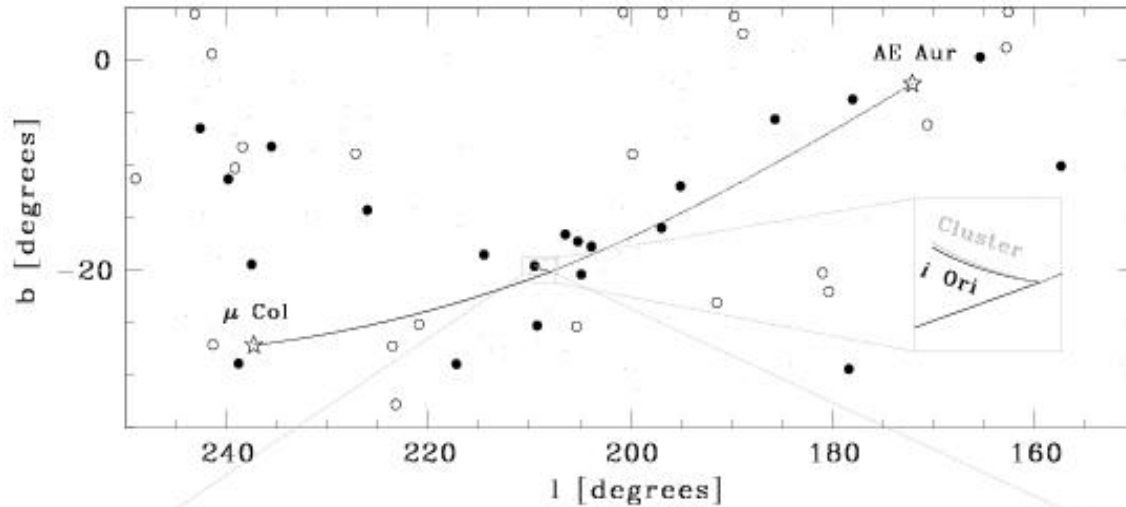


Carina Dwarf
14 x 14 arcmin
2210 stars $I < 20$ mag



Ursa Minor
(dwarf spheroidal)
few thousand * to $V = 20$

Runaway Stars



Two scenarios:

- binary supernova
- dynamical ejection

☆ = present location

● = O and B stars

AE Aur/ μ Col/*i* Ori:

$v_{OB} = 150$ km/s

$d \approx 400$ pc

Common origin:

2.5 Myr ago

$d < 1$ pc at closest approach

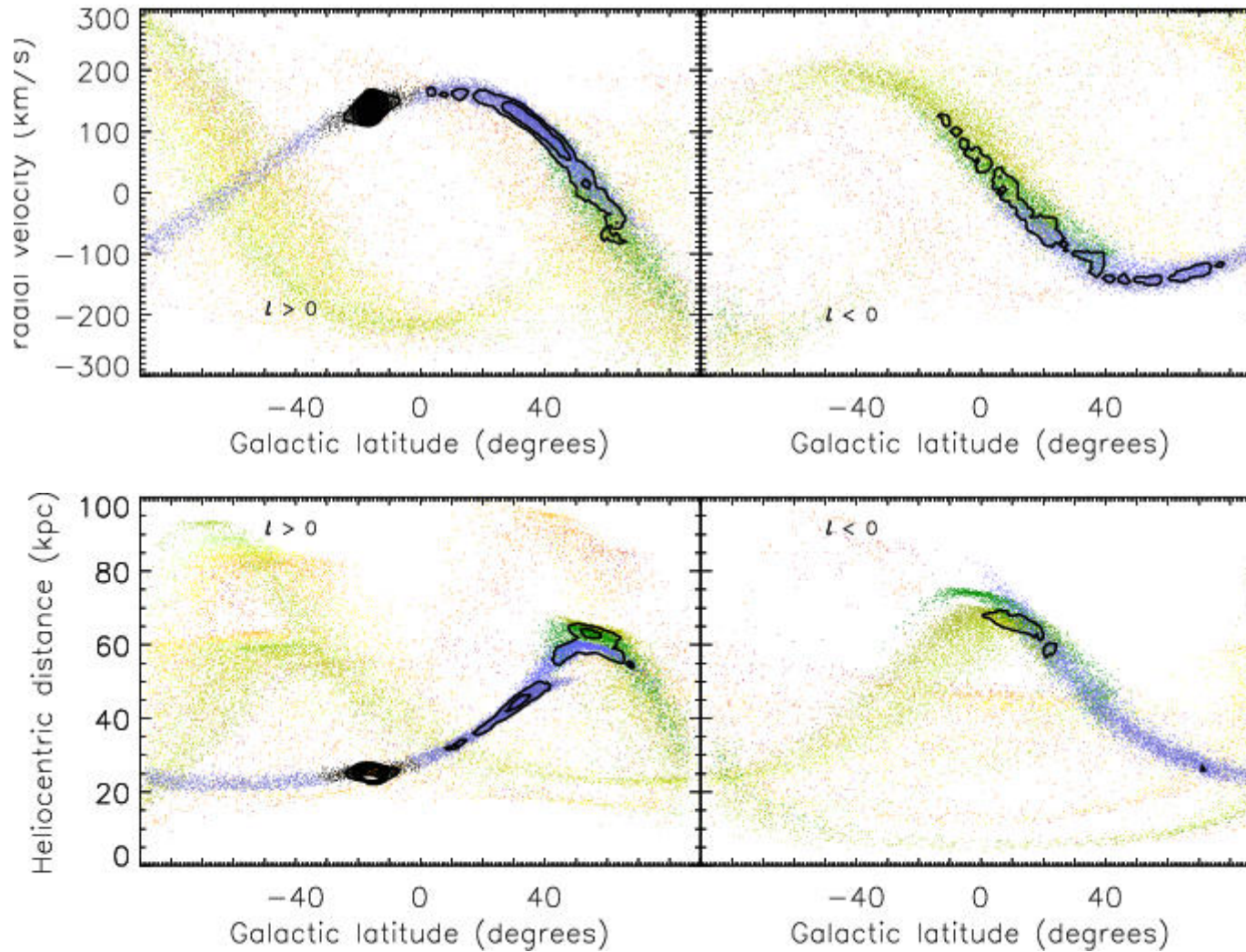
\Rightarrow binary/binary encounter

Others:

ξ Oph + PSR J1932+1059

\Rightarrow binary-supernova scenario

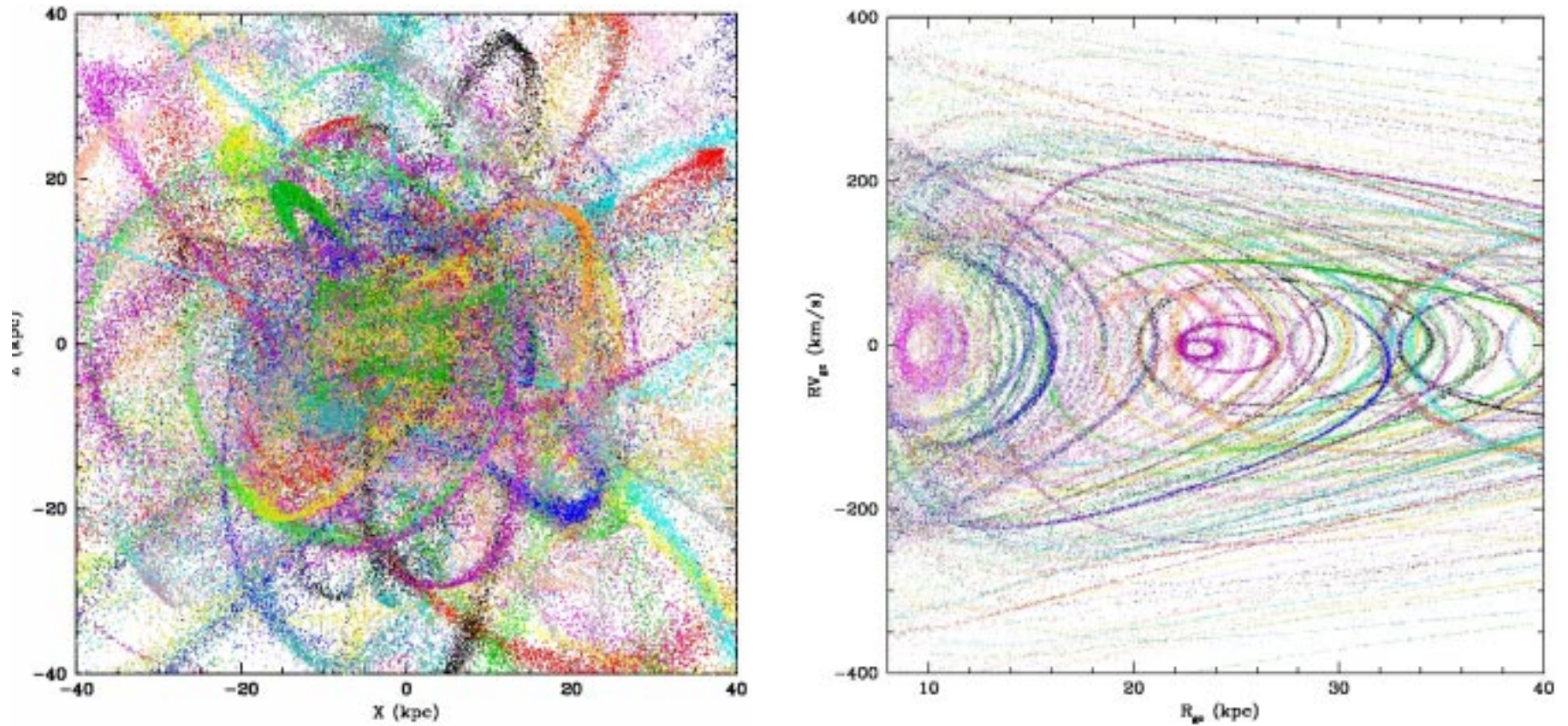
Tidal Streams



Helmi & White, 2000, AGM
Helmi et al., 1999 Nature 402, 53

Colours: different perigee passages
Sagittarius over 10 Gyr

Tidal Streams



Simulation of the baryon halo built up through accretion of 100 satellite galaxies
(P. Harding and H. Morrison, 2000, *Science* 287, 79)

Stellar Astrophysics

- Luminosity calibration throughout the HR Diagram:
 - 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
 - planetary nebulae, blue supergiants, Wolf-Rayet, novae, Mirae
 - parallax calibration of all distance indicators
 - absolute luminosities Cepheids and RR Lyrae to LMC/SMC
- Luminosity functions, mass functions, ages:
 - solar neighbourhood mass function and luminosity function
 - e.g. white dwarfs (~200,000) and brown dwarfs (~50,000)
 - clean colour-magnitude diagrams for star forming regions, open and globular clusters, and dwarf spheroidals
 - initial mass functions and dynamics in star forming regions
 - luminosity function for pre main-sequence stars
 - detection and dating of the oldest (halo) white dwarfs

Binary and Multiple Stars

- Census for constraints on star formation theories
- Orbits for $>100,000$ resolved binaries ($\rho > 20$ mas)
 - masses to 1% for $>10,000$ objects
 - wide range of separations and mass ratios
 - rare types
 - includes brown dwarfs and planetary companions

Photocentric motions:

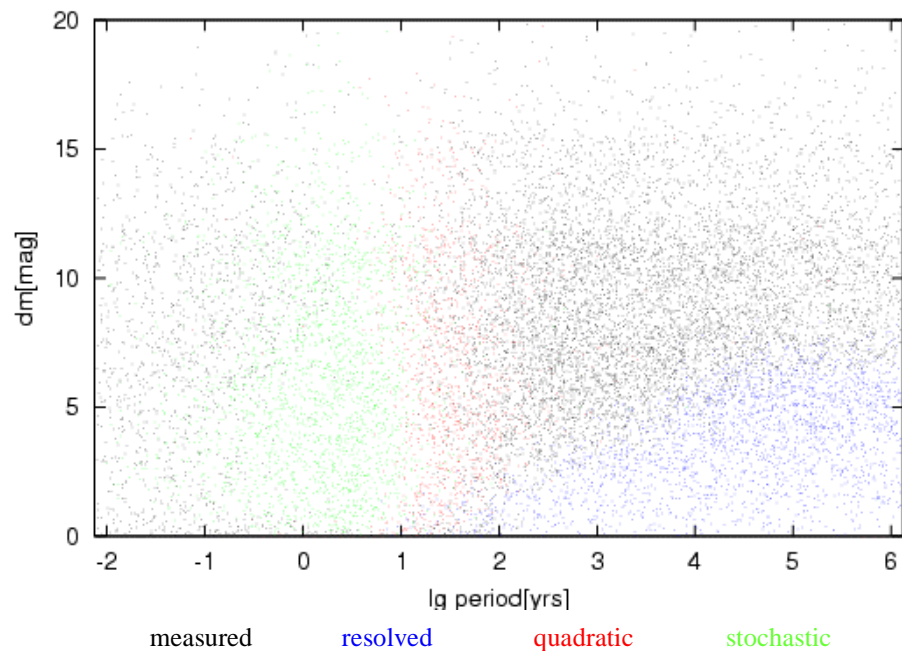
$\sim 10^8$ binaries

Photometry:

$>10^6$ eclipsing binaries

Radial velocities:

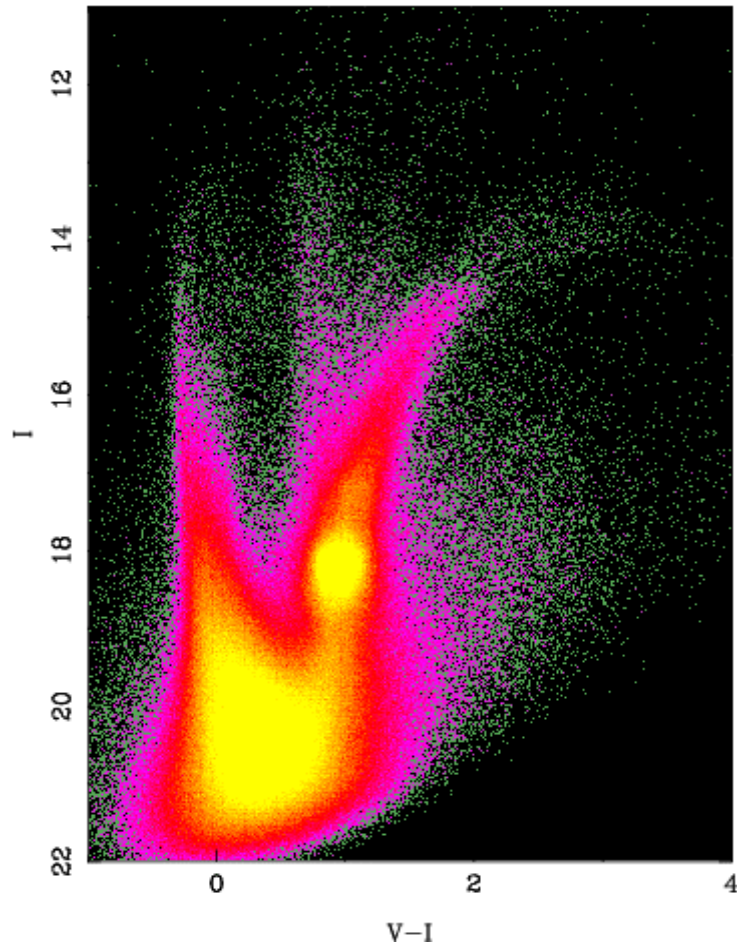
$>10^6$ spectroscopic binaries



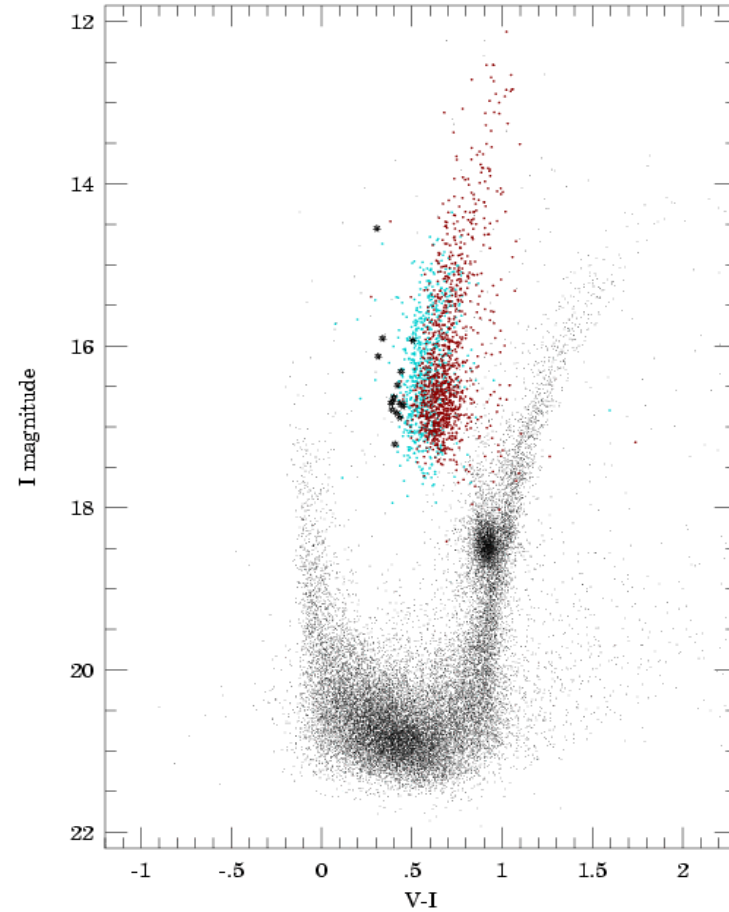
Interstellar Medium

- ISM has key role in star formation
- Optical, radio, mm observations give kinematics of warm, neutral and molecular components
- GAIA data provides dynamical model
 - ⇒ accurate density distributions for different phases
- GAIA will map:
 - HI and H₂ clouds and dust
 - inter-cloud medium
 - ionising stellar radiation field
- Providing:
 - cloud distances, including high-velocity clouds
 - pulsar distances, via improved H column densities

Magellanic Clouds

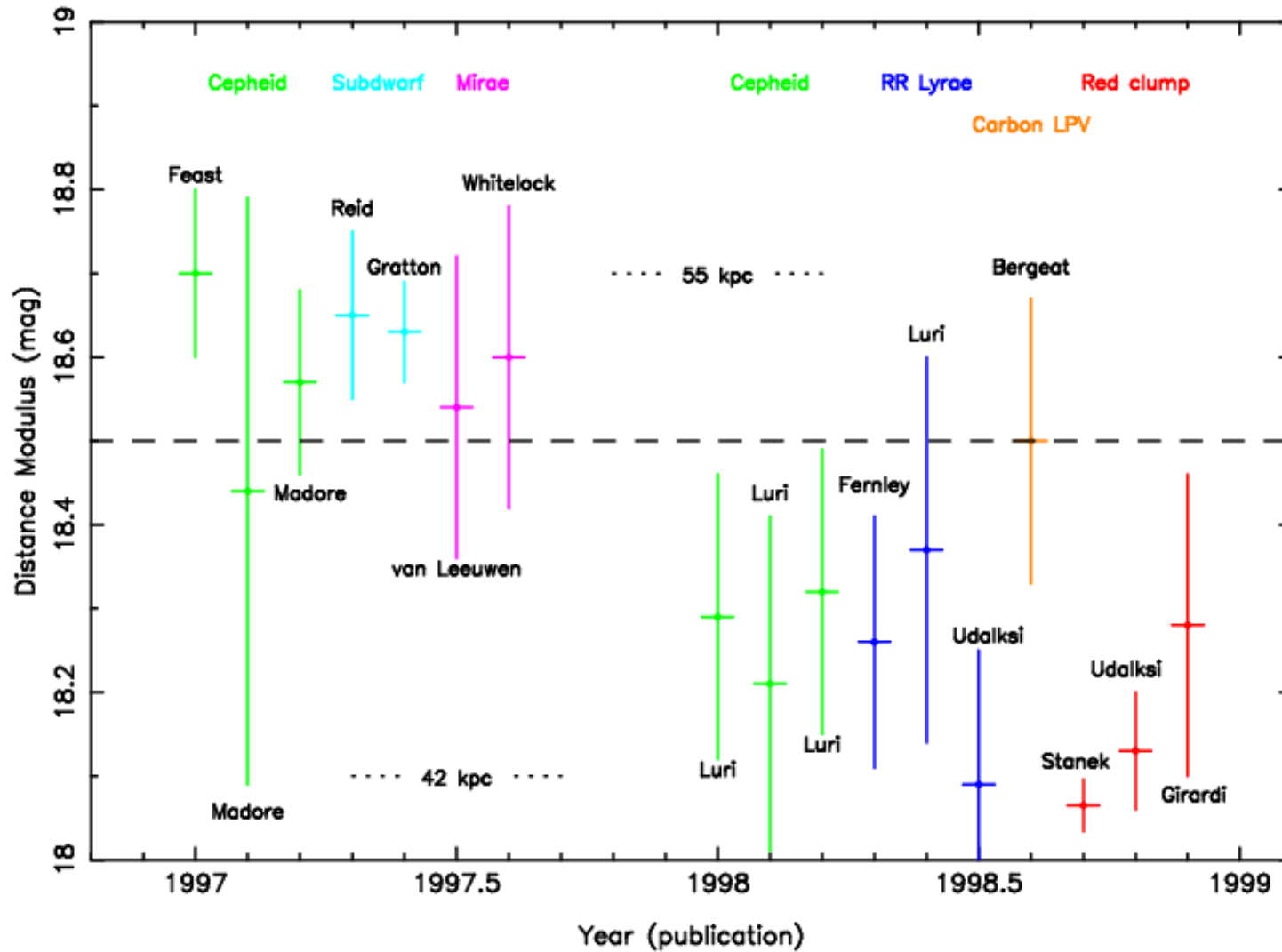


LMC: $4 \times 4 \text{ deg}^2$
2.4 million stars to $I = 20$
from Magellanic Cloud Photometric Survey
(Zaritsky et al. 1997)



SMC: $14 \times 57 \text{ arcmin}^2$
45,500 stars to $I = 20$
OGLE Cepheids according to pulsation
(Udalski et al.)

Large Magellanic Cloud: Distance Uncertainties post-Hipparcos



Reference Frames etc

Galaxies, Quasars, and the Reference Frame

- Geometric distances and orbits for nearby galaxies
- Rotational parallaxes for Local Group galaxies
- Internal dynamics of Local Group dwarfs
- Galaxy survey, including large-scale structure ($10^6 - 10^7$ objects)
- Photocentric motions of jets in active galactic nuclei
- 500,000 quasars: 'kinematic' detection + proper motion residuals
- $\sim 10^5$ supernovae
- Ω_M, Ω_Λ from numbers of multiple quasar images (3500 to 21 mag)
- Galactocentric acceleration: $0.2 \text{ nm/s}^2 \Rightarrow \Delta(\text{aberration}) = 4 \text{ } \mu\text{as}$
- Globally accurate reference frame to $\sim 0.4 \text{ } \mu\text{as/yr}$

General Relativity/Metric

- From positional displacements:
 - γ to 5×10^{-7} (cf. 10^{-5} presently) \Rightarrow scalar-tensor theories
 - effect of Sun: 1.7 arcsec; Jovian limb: 17 mas; Earth: $\sim 40 \mu\text{as}$
- 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)

Related Missions

SIM (NASA, approved):

- 10-m pointed interferometer
- launch 2005
- accuracies to 1-3 μas at 20 mag
- about 10-20 000 target stars

FAME (USNO/NASA approved):

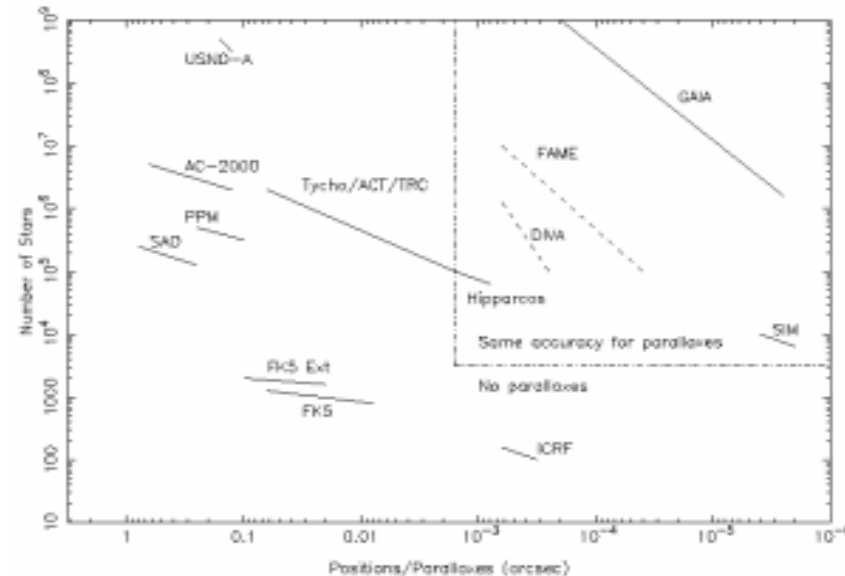
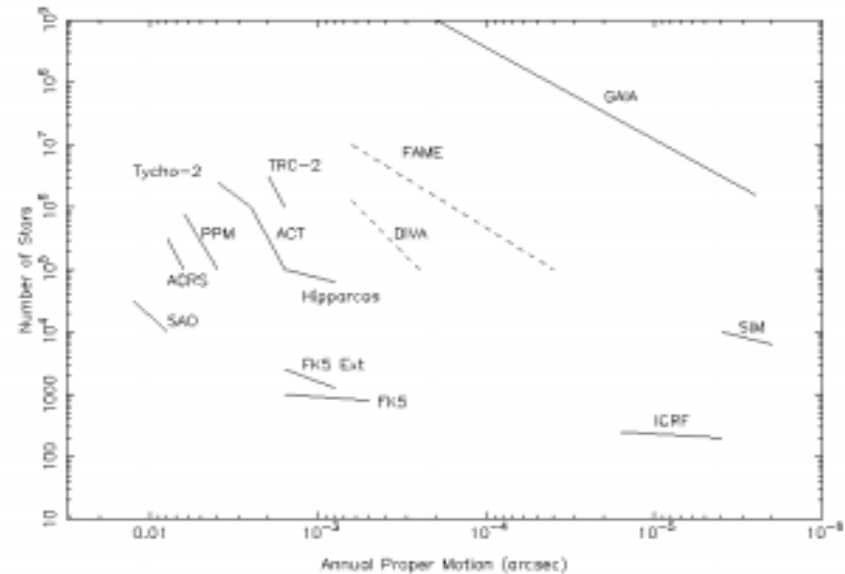
- GAIA principles, Hipparcos accuracy
- launch mid-2004
- 40 million objects to 15 mag
- 50 μas at 9 mag, 0.3 mas at 15 mag

DIVA (German national candidate):

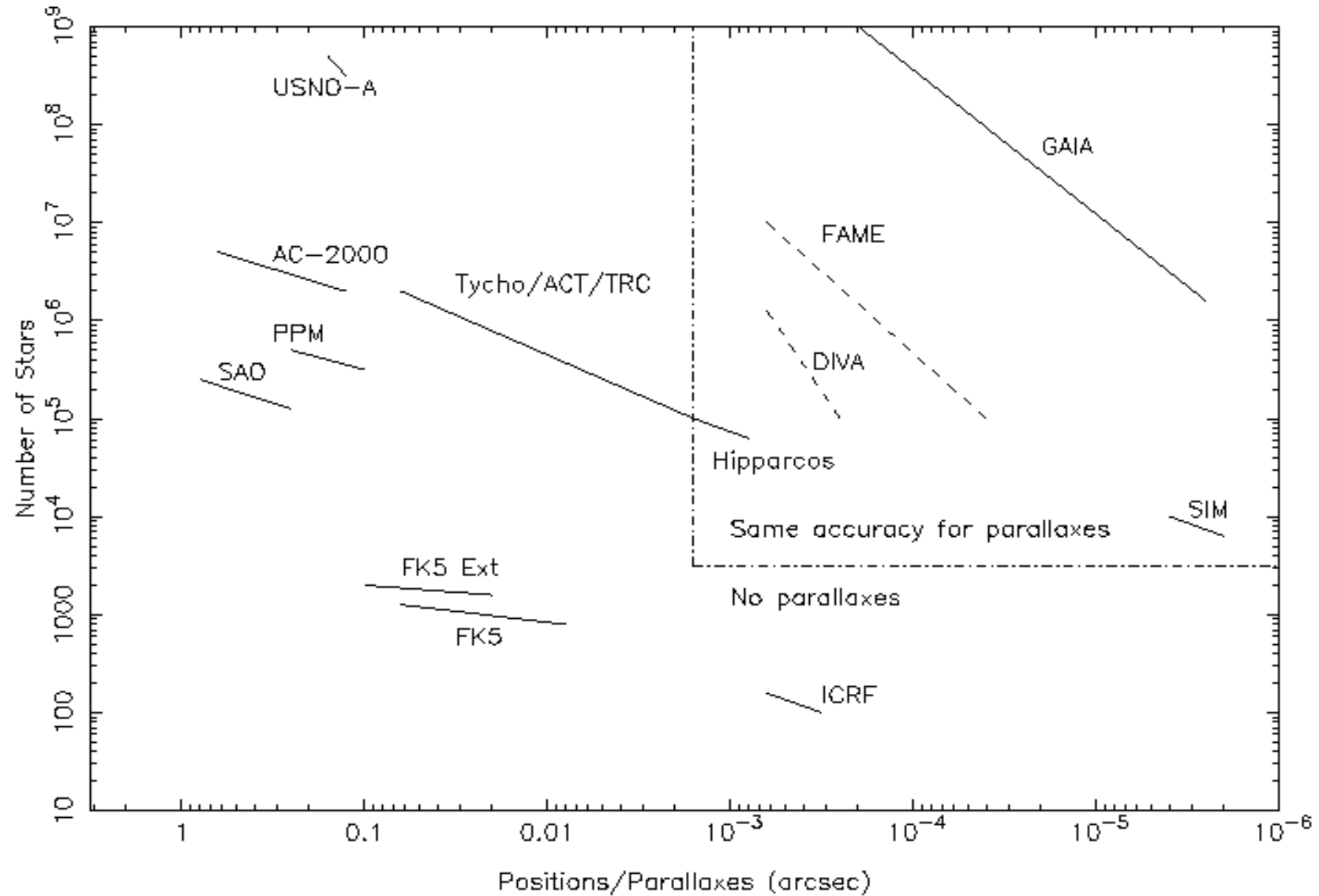
- small interferometer
- launch 2003
- 30 million objects to 15 mag
- 200 μas at 9 mag, 2 mas at 14 mag

Ground interferometric astrometry:

- NPOI, Keck, VLTI (PRIMA)



Accuracies: GAIA, FAME, DIVA

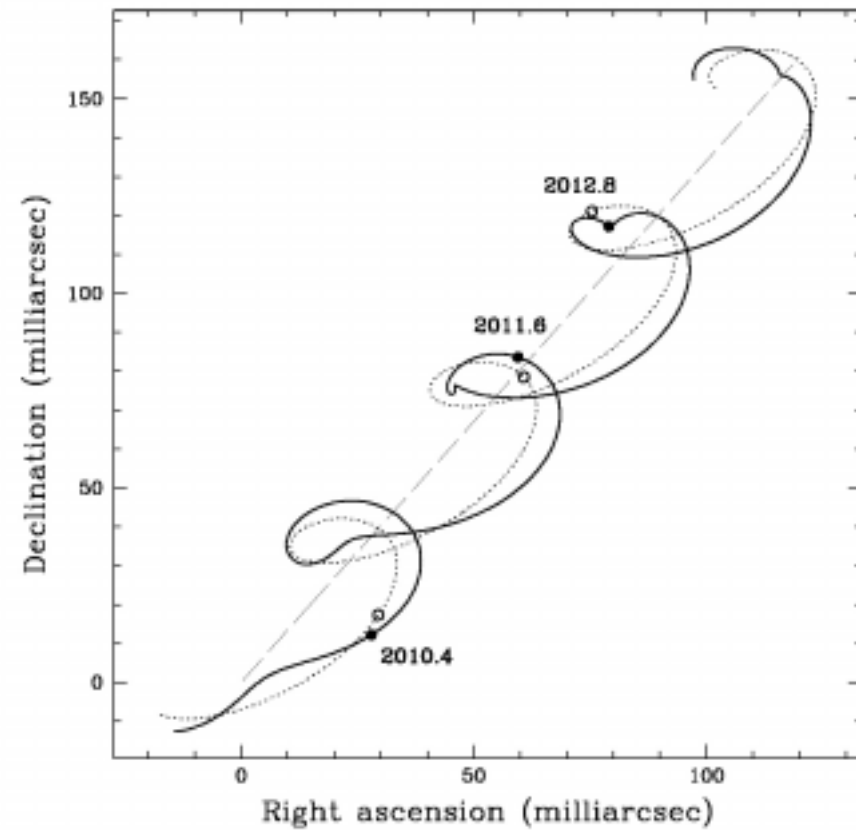
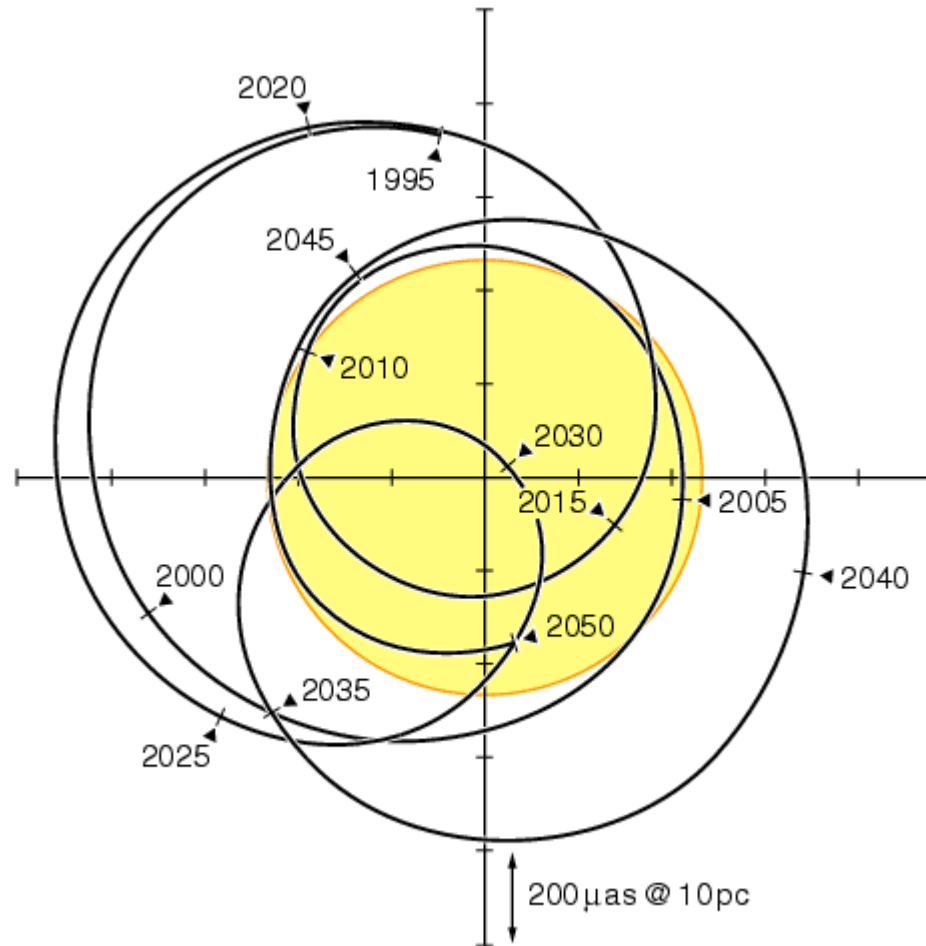


Extra-Solar Planets

Extra-Solar Planets

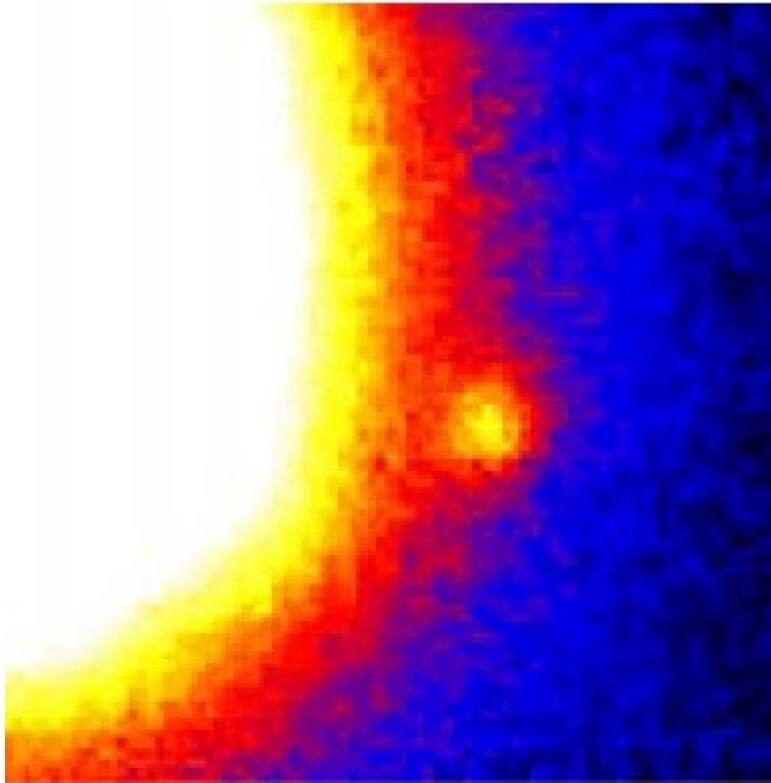
- From simulations/present knowledge:
 - 20,000- 30,000 gas giants (\sim few M_J) to 150-200 pc
 - complete census, covering $P = 2-9$ years
 - masses, rather than $m \sin i$
 - orbits for many systems
 - co-planarity of orbits for multiple systems
 - mass down to $M(\text{Uranus})$, or $10 M(\text{Earth})$ to 10 pc
 - examples:
 - 47 Uma $\alpha = 360 \mu\text{as}$
 - 70 Vir $\alpha = 160 \mu\text{as}$

Sun's Motion and Simulated Planetary Effects

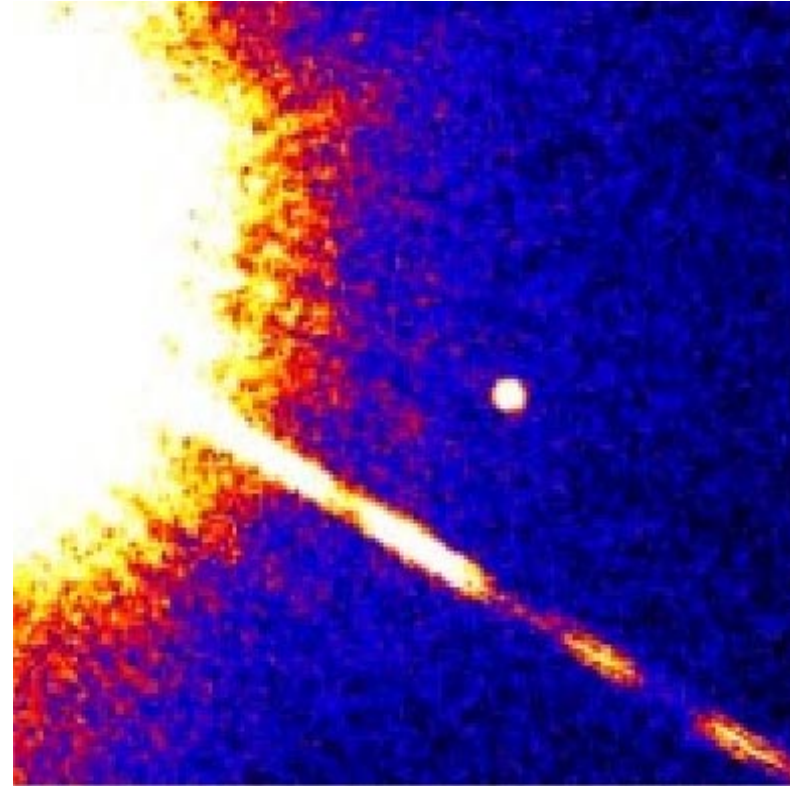


$$M = 15 M_J \quad e = 0.2 \quad a = 0.6 \text{ AU} \\ d = 50 \text{ pc} \quad \mu = 50 \text{ mas/yr}$$

Brown Dwarf Gliese 229B



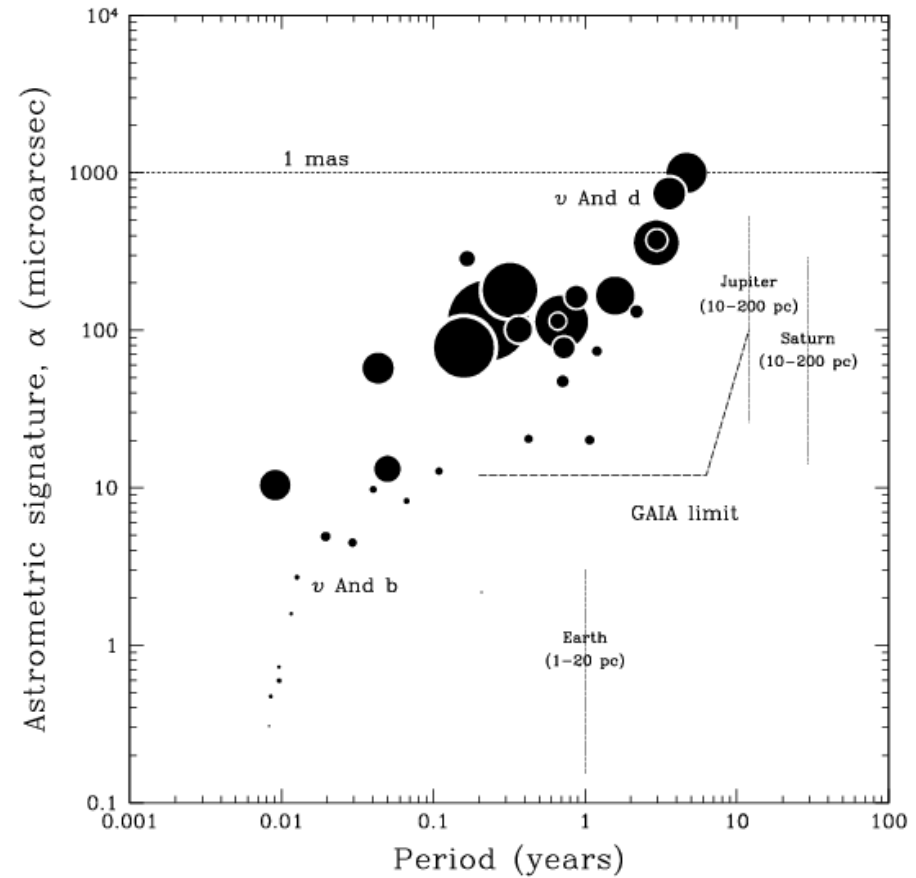
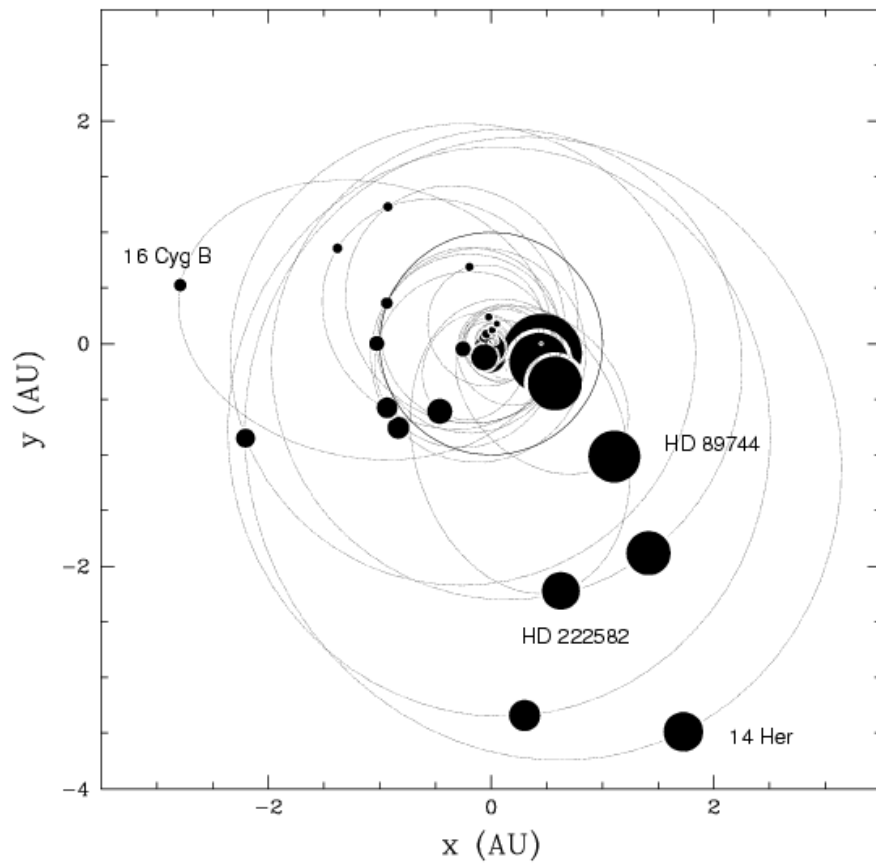
Palomar 60-inch



HST

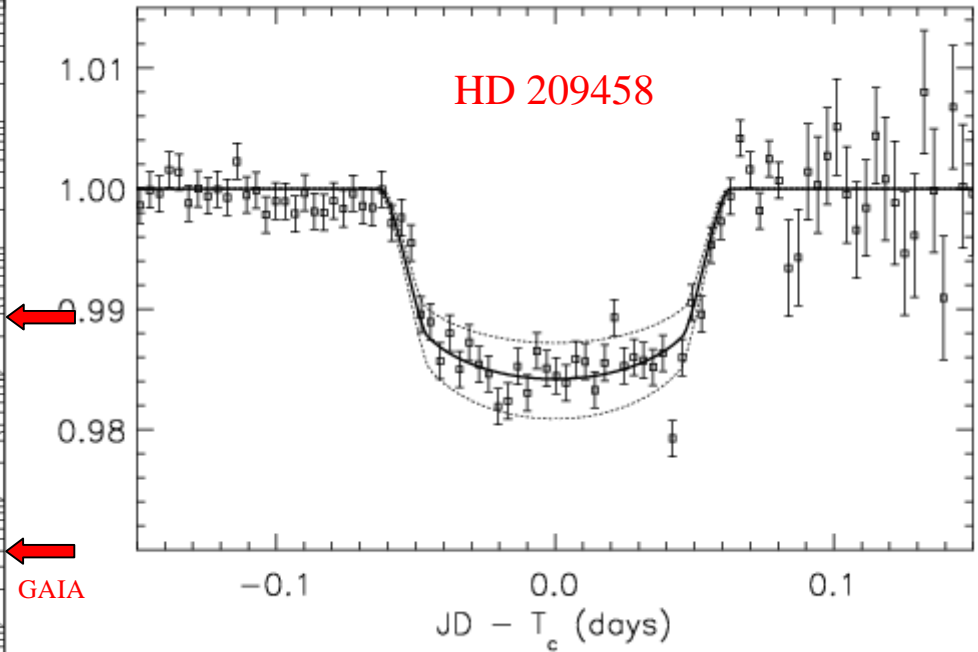
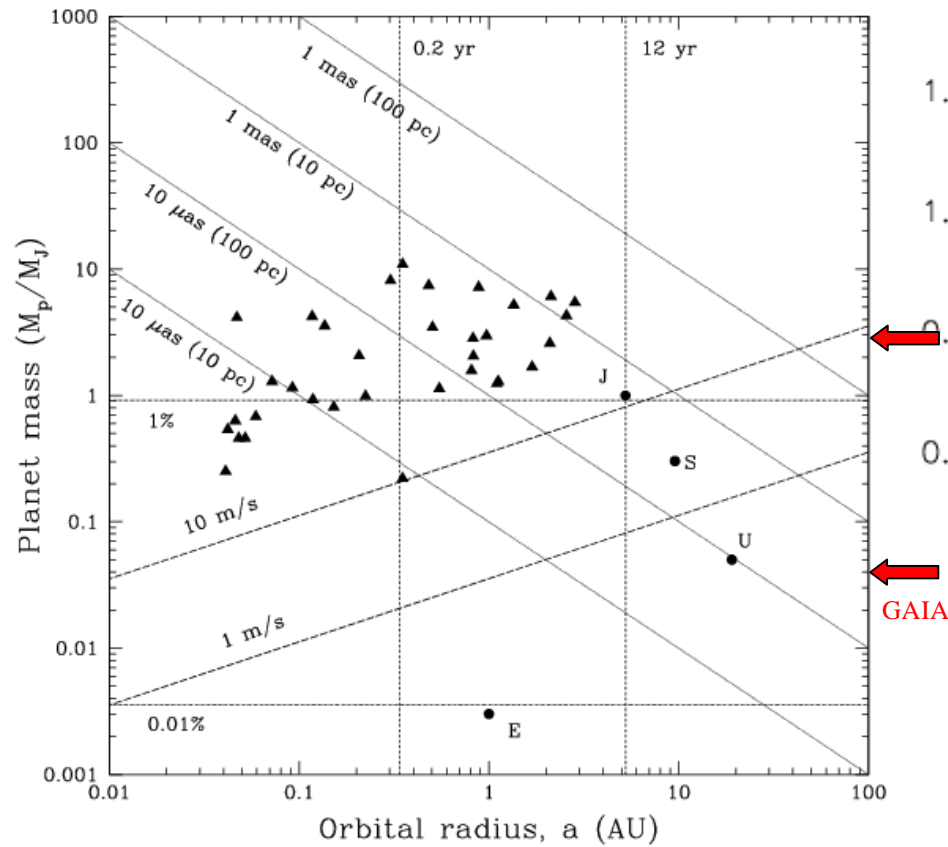
astrometric signature ~ 0.2 arcsec
orbital radius \sim Pluto; brightness ratio ~ 5000

Known planets orbits and astrometric signatures



$$\alpha = (M_p/M_s) \cdot (a_p/d)$$

Extra-Solar Planets: Detection Domains and Transits



Huge numbers of transits may be detected

Solar System Studies

Solar System

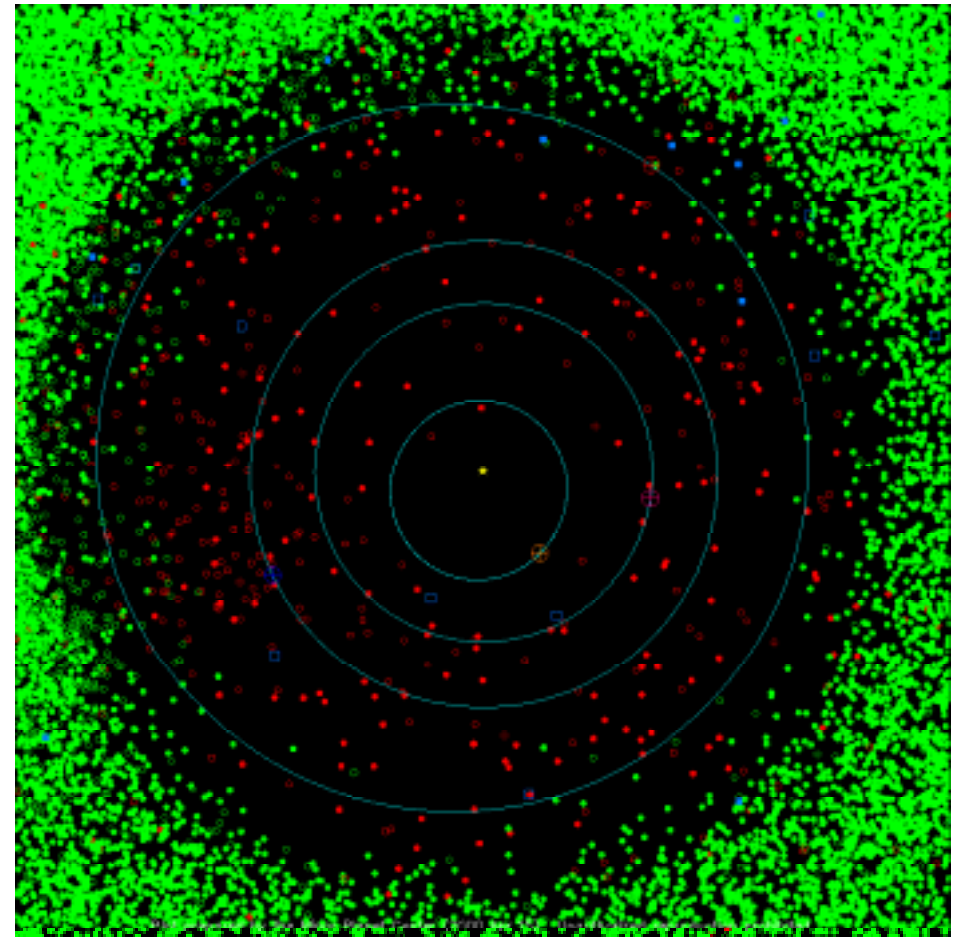
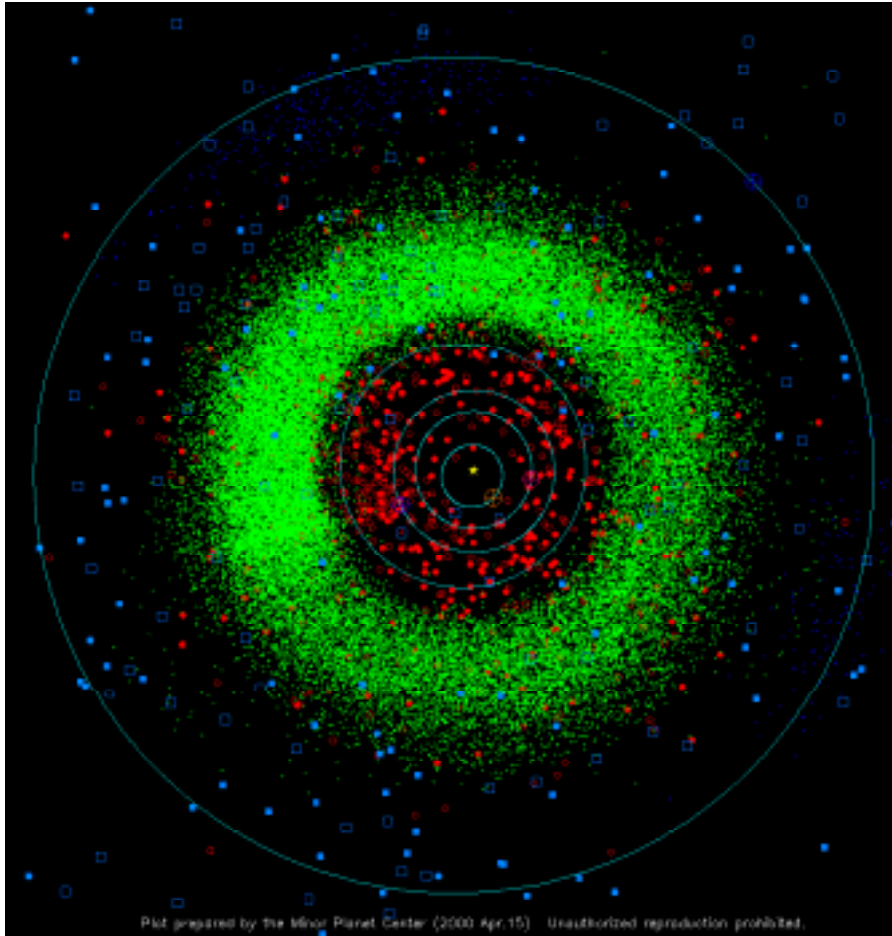
Deep and uniform detection of minor planets:

- complete to 20 mag
- discovery of $\sim 10^5 - 10^6$ new objects (cf. 65000 presently)
- populations shows limited thermal evolution since planetary accretion
- taxonomy and mineralogical composition versus heliocentric distance
- diameters for ~ 1000 asteroids + masses for ~ 100 objects
- orbits ($\times 30$ better than present, even after 100 yr) \Rightarrow occultations
- Trojan companions of Mars, Earth and Venus (cf. 2 Martians presently)
- Edgeworth-Kuiper Belt objects: ~ 300 to 20 mag + binarity + Plutinos

Near-Earth Objects:

- detection of Amors, Apollos and Atens (442: 455: 75 known today)
- 20-40% of Earth-crossing asteroids may collide with Earth (~ 10 -100 Myr)
- re-supply via Edgeworth-Kuiper Belt or Oort Cloud
- largest: 1627 Ivar and 1580 Betulia, $d \sim \text{km}$
- ~ 1600 Earth-crossing asteroids $> 1 \text{ km}$ predicted (100 currently known)
- GAIA detection: 260 - 590 m at 1 AU, depending on albedo

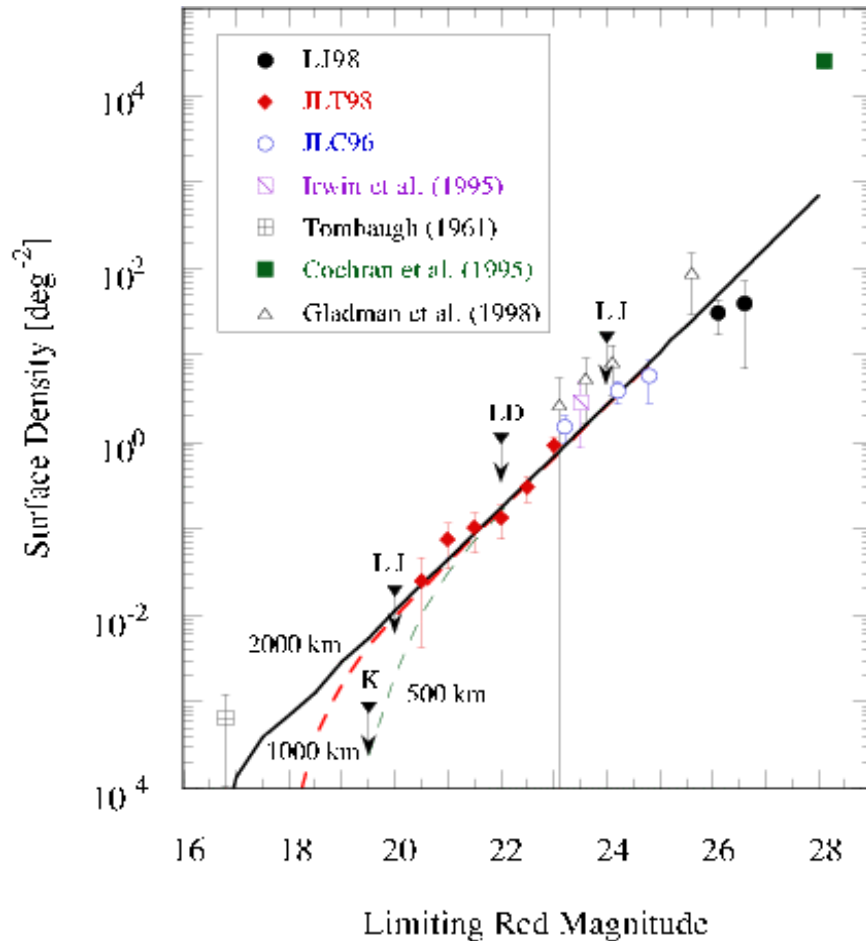
The Inner Solar System



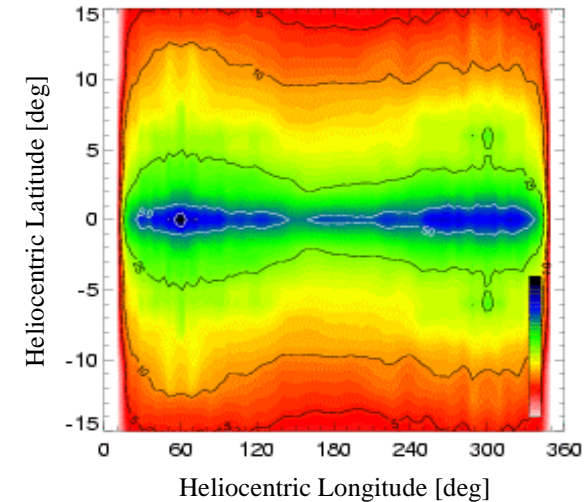
- Jupiter Trojans (610)
- numbered periodic comets
- other comets

- minor planets (numbered/multiple apparition)
- perihelia < 1.3 AU

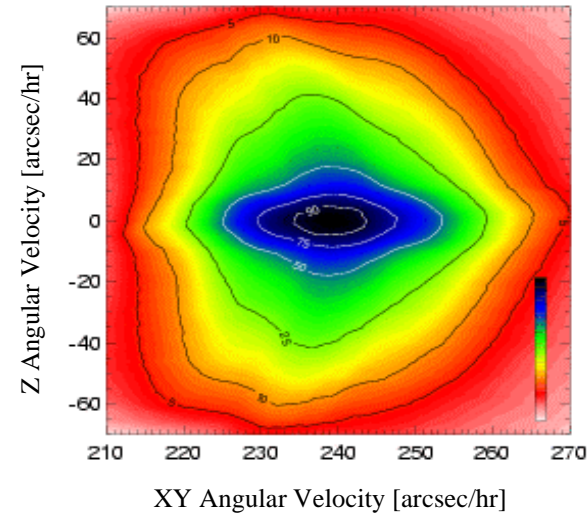
Kuiper Belt Objects and Co-Orbiting Asteroids



Surface density of Kuiper Belt Objects versus R



Co-orbiting asteroids expected in heliocentric l and b



Co-orbiting asteroids expected: proper motions wrt ecliptic (z vs. xy)

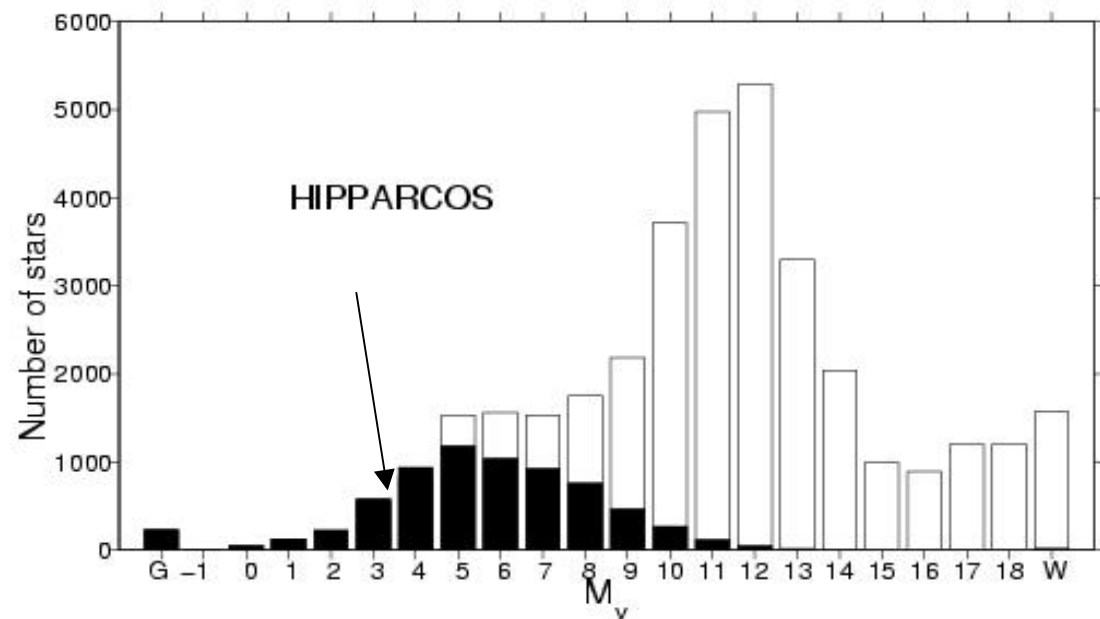
Stellar Encounters with the Oort Cloud

- Close encounters can deflect comets to inner-planetary regions
- May result in Earth-crossing cometary showers and Earth impacts
- Grouping of cometary aphelia may indicate recent star passages
- Dynamical models give decay times of 2-3 Myr
- GAIA will extend census to geological time scales (e.g. Eocene extinction)

Largest Perturbers:

In the past: Algol
2.5 pc about 7 Myr ago

In the future: Gliese 710
passes through Oort Cloud:
69000 AU in about 1 Myr



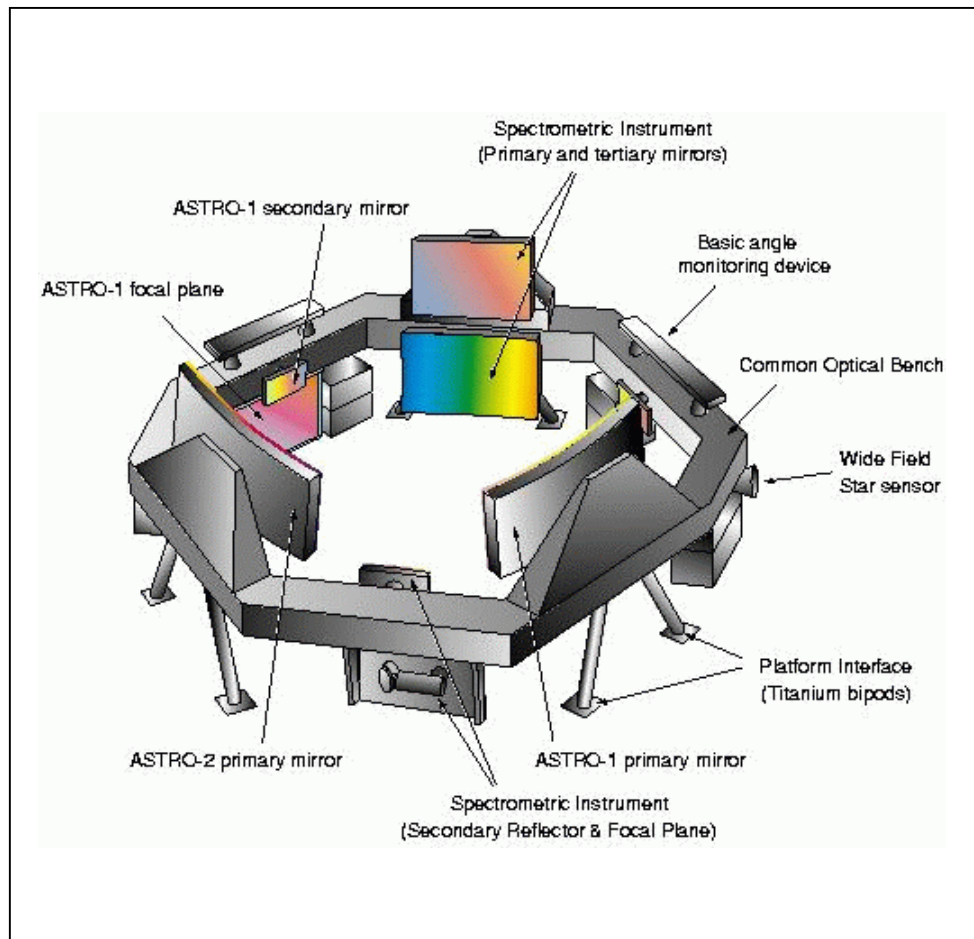
Completeness within 50 pc of the Sun: all detected by GAIA
G = giants W = white dwarfs

Payload and Spacecraft

Design Considerations

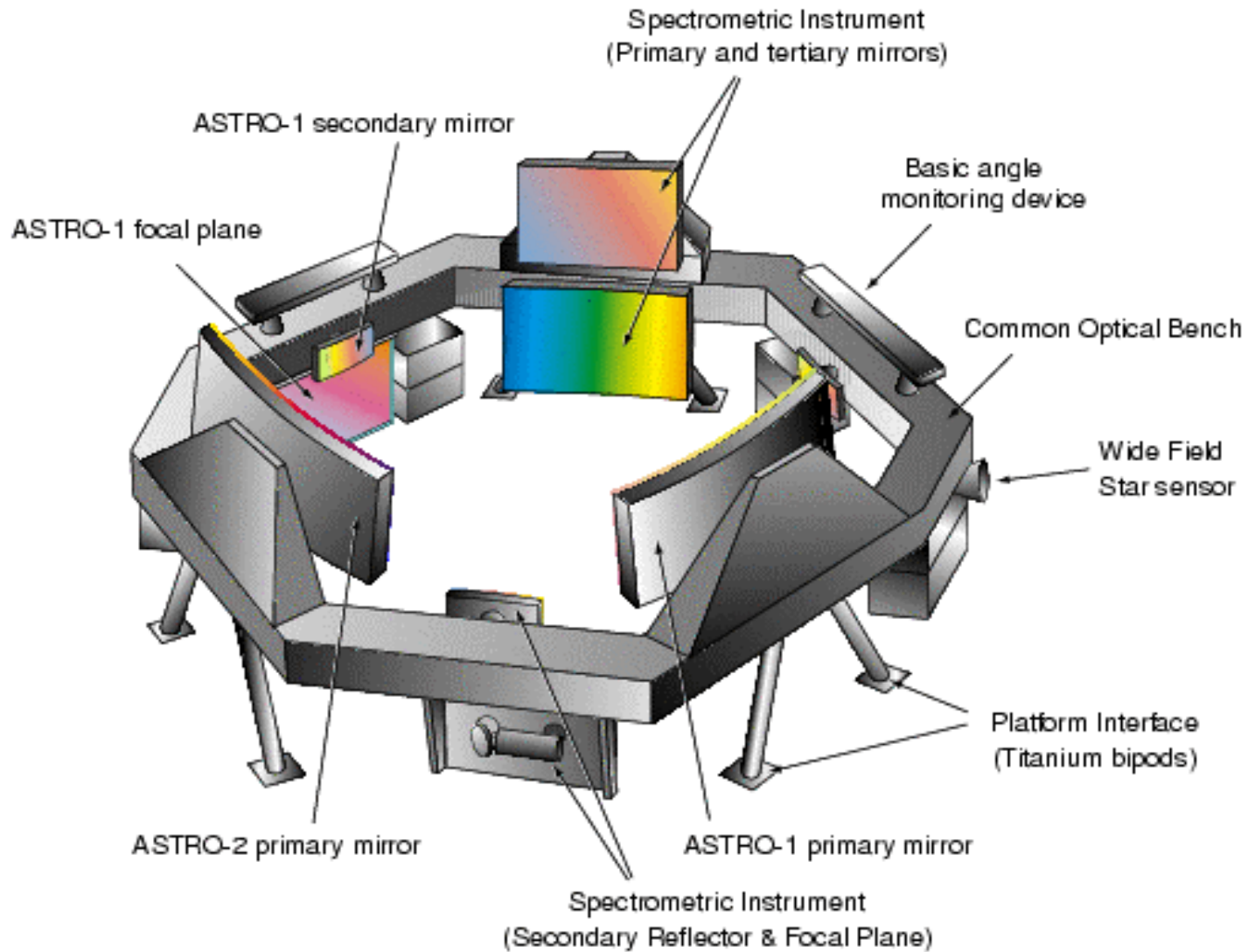
- Astrometry:
 - to $V = 20$ mag (crucial astrophysical targets)
 - complete to specified limits \Rightarrow on-board detection
 - accuracies: $10 \mu\text{as}$ at 15 mag (Survey Committee + science)
 - scanning satellite, two viewing directions
 - \Rightarrow global accuracy, optimal with respect to observing time
 - major advantages with respect to pointed missions
 - windowing reduces data from 1 Gbps to 1 Mbps
- Radial velocity ($V < 17$):
 - third component of space motion
 - measurement of perspective acceleration
 - astrophysical diagnostics, dynamics, population studies
- Photometry ($V < 20$)
 - astrophysical diagnostics (4-band + 11-band)
 - \Rightarrow extinction; $\Delta T_{\text{eff}} \sim 200 \text{ K}$, $[\text{Fe}/\text{H}]$ to 0.2 dex
 - chromaticity correction

Payload

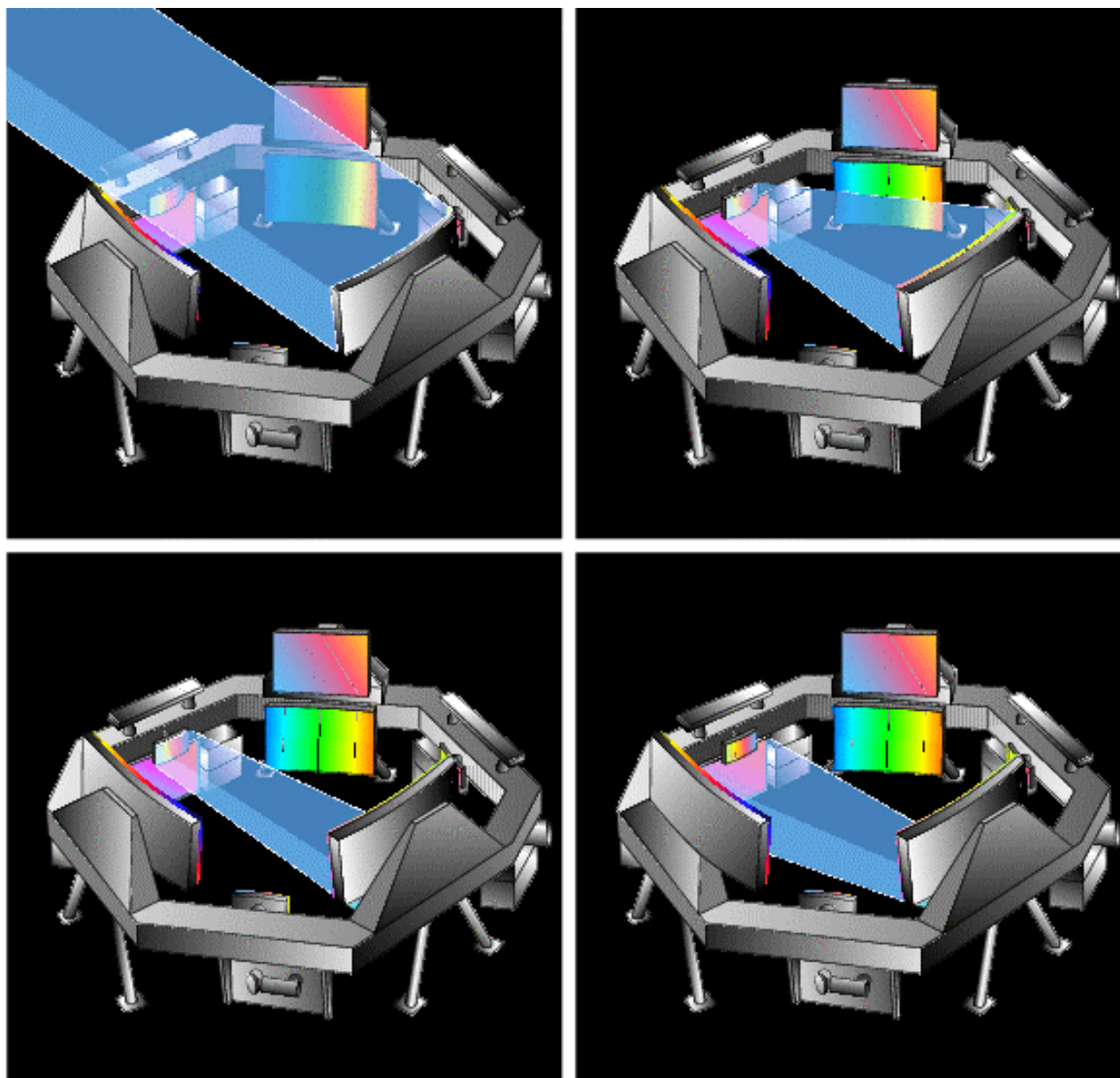


- Two astrometric instruments:
 $0.6^\circ \times 0.6^\circ$, $\gamma = 106^\circ$
- Monolithic mirrors: $1.7 \text{ m} \times 0.7 \text{ m}$
- Non-deployable, 3-mirror, SiC optics
- Astro focal planes: TDI CCDs
- Radial velocity/photometry telescope
- Astrophysically driven payload:
 - faint stars, to $V=20$ mag
 - radial velocities for dynamics
 - broad-band photometry: chromaticity
 - medium-band photometry: astrophysics
- Survey principles:
 - revolving scanning
 - on-board detection
 - complete and unbiased sample

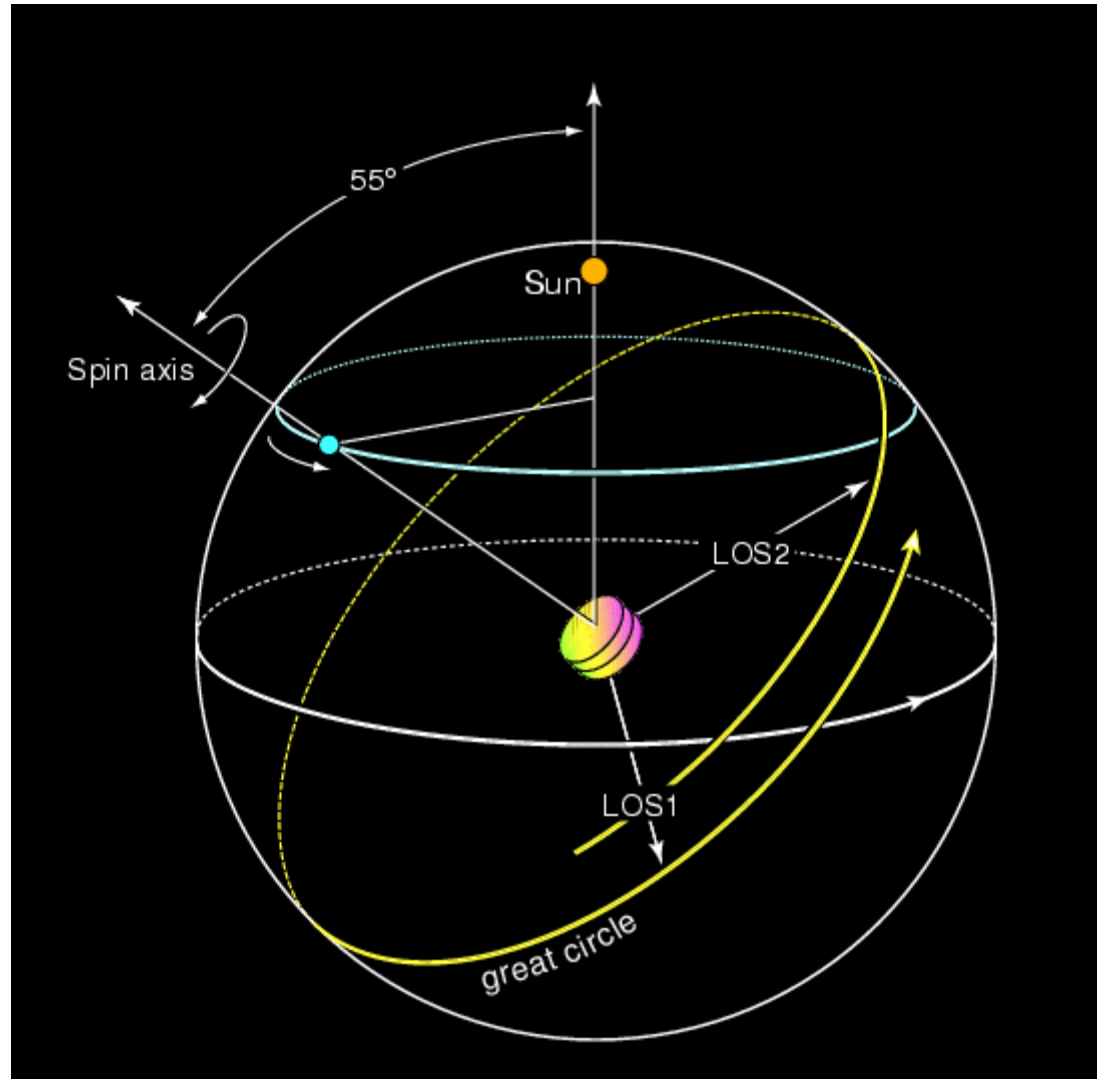
Payload Configuration



Astrometric Instrument: Light Path

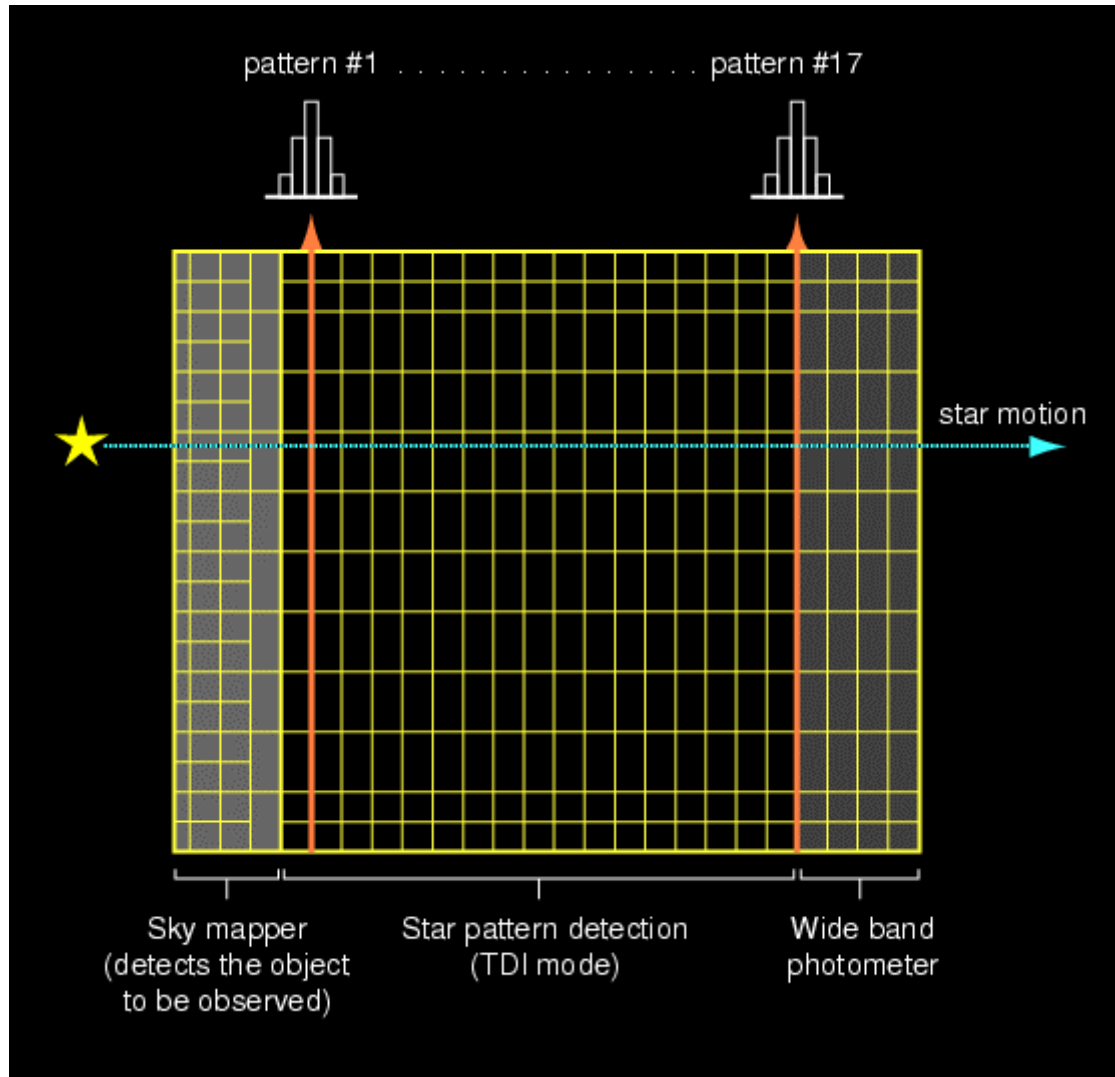


GAIA: Sky Scanning Principle



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

GAIA: 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 deg²
- 60 × 70 cm²
- CCD chips: 136
- CCDs: 2780 x 2150 pixels

Pixels:

- size: 9 x 27 μm²
- window area: 6 x 8 pixels
- flush frequency: 15 MHz
- readout frequency: 30 kHz
- total read noise: 6e⁻ rms

Broad-band photometry:

- 4 colour

On-Board Object Detection

Requirements:

- unbiased sky sampling (mag, colour, resolution, etc)
- but no all-sky catalogue at GAIA resolution (0.1 arcsec) to V~20

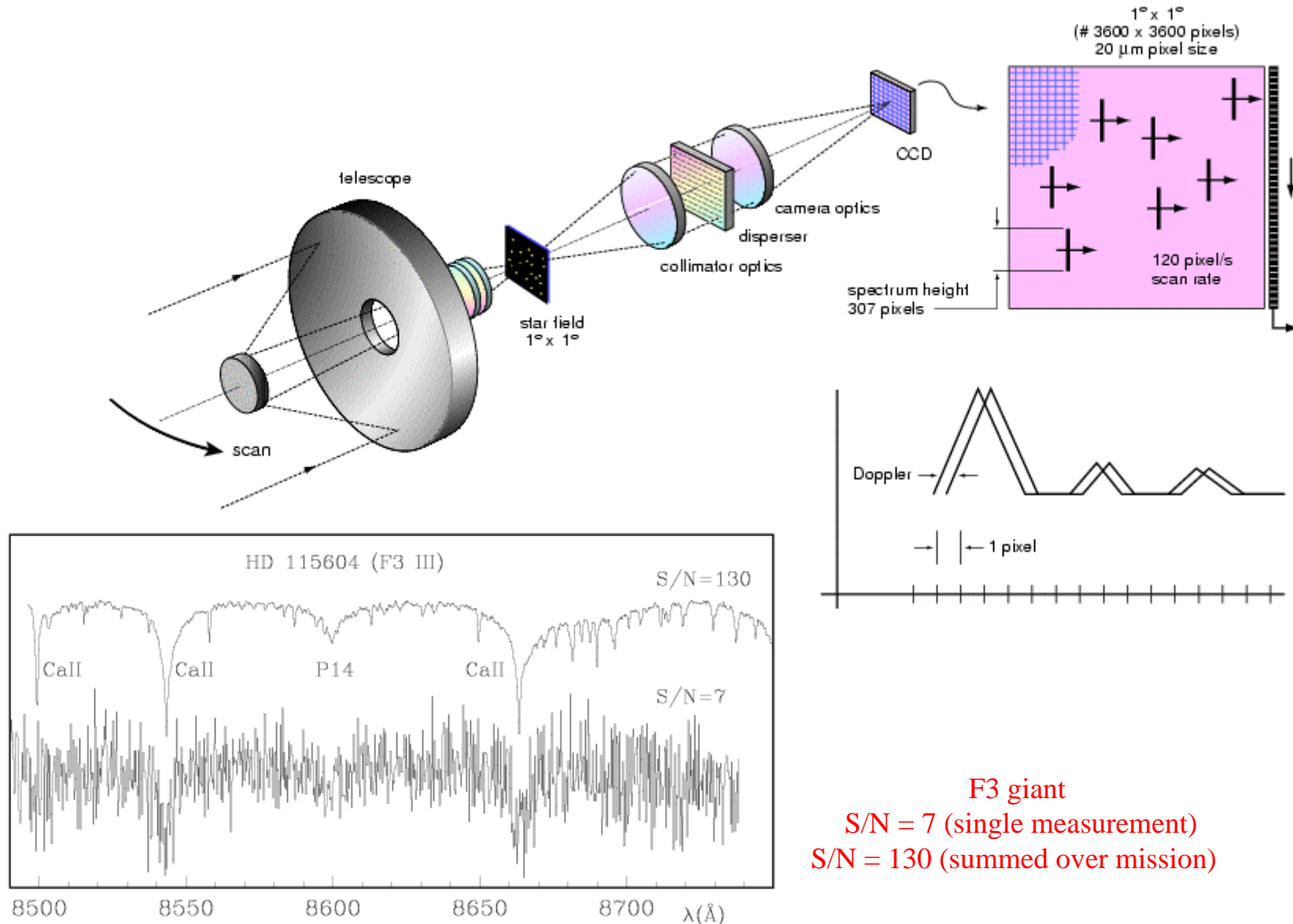
Solution: on-board detection:

- no input catalogue or observing programme
- good detection efficiency to V~21 mag
- low false detection rate, even at very high star densities
- maximum star density: ~ 3 million stars/deg² (Baade's Window)

Will therefore detect:

- variable stars (eclipsing binaries, Cepheids, etc)
- supernovae: 10^5 expected
- microlensing events: ~ 1000 photometric; ~ 100 astrometric
- low luminosity nearby stars: brown dwarfs and white dwarfs
- Solar System objects, including near-Earth asteroids and KBOs

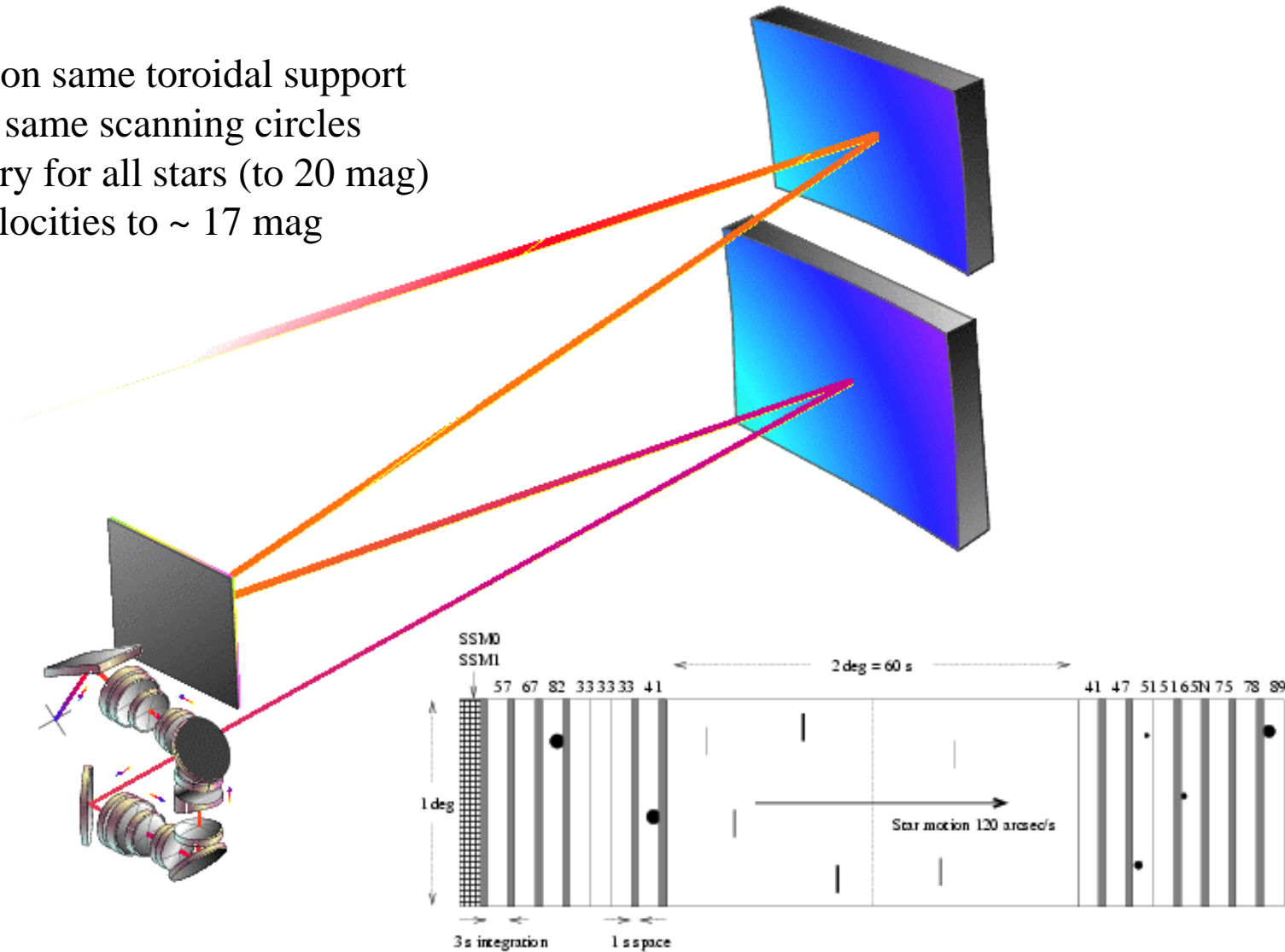
Radial Velocity Measurement Concept



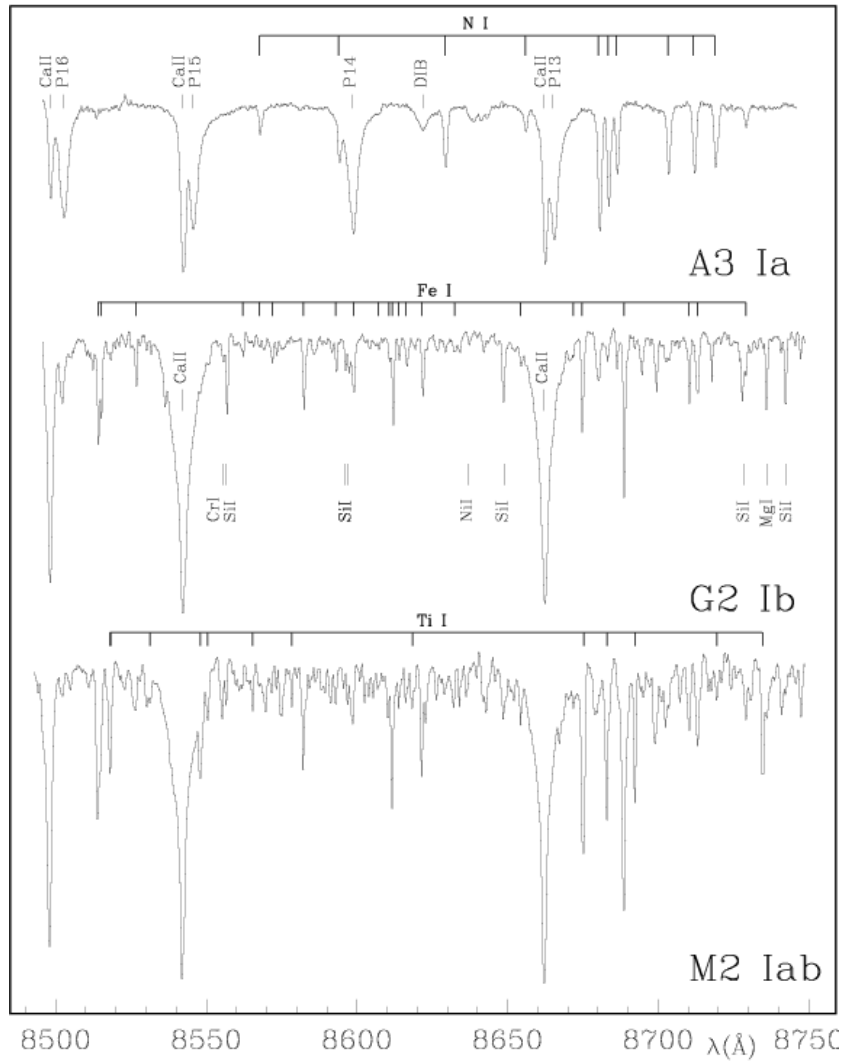
F3 giant
 $S/N = 7$ (single measurement)
 $S/N = 130$ (summed over mission)

Radial Velocity and Photometric Instrument

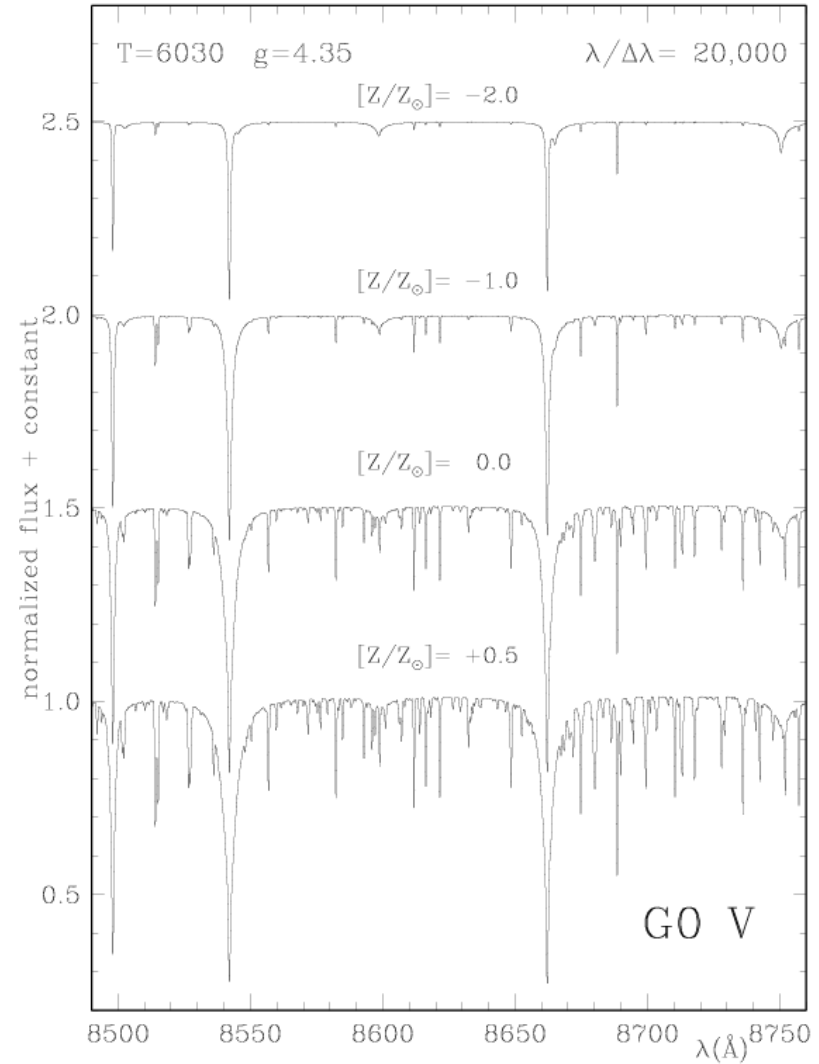
- Mounted on same toroidal support
- Observes same scanning circles
- Photometry for all stars (to 20 mag)
- Radial velocities to ~ 17 mag



Spectral Sequences around Ca II

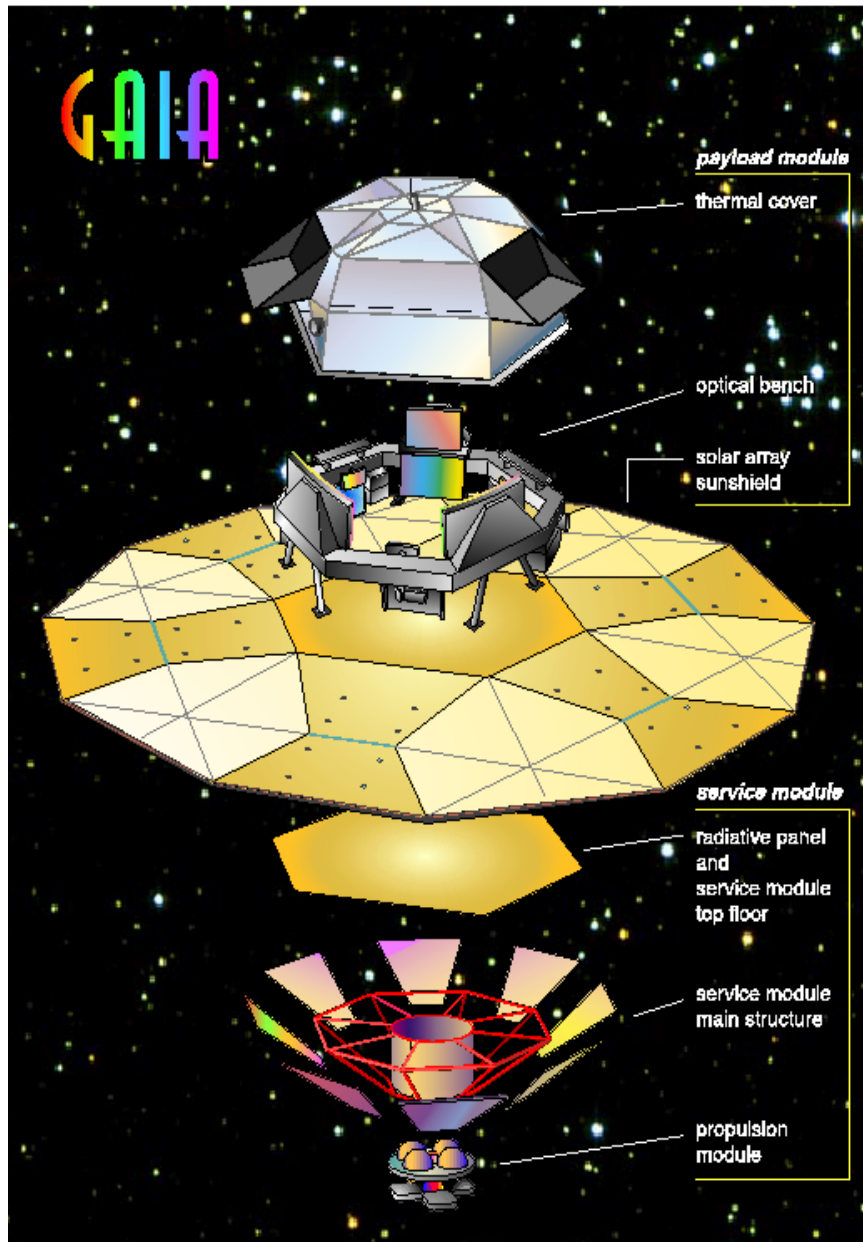


Effect of temperature: A to M stars



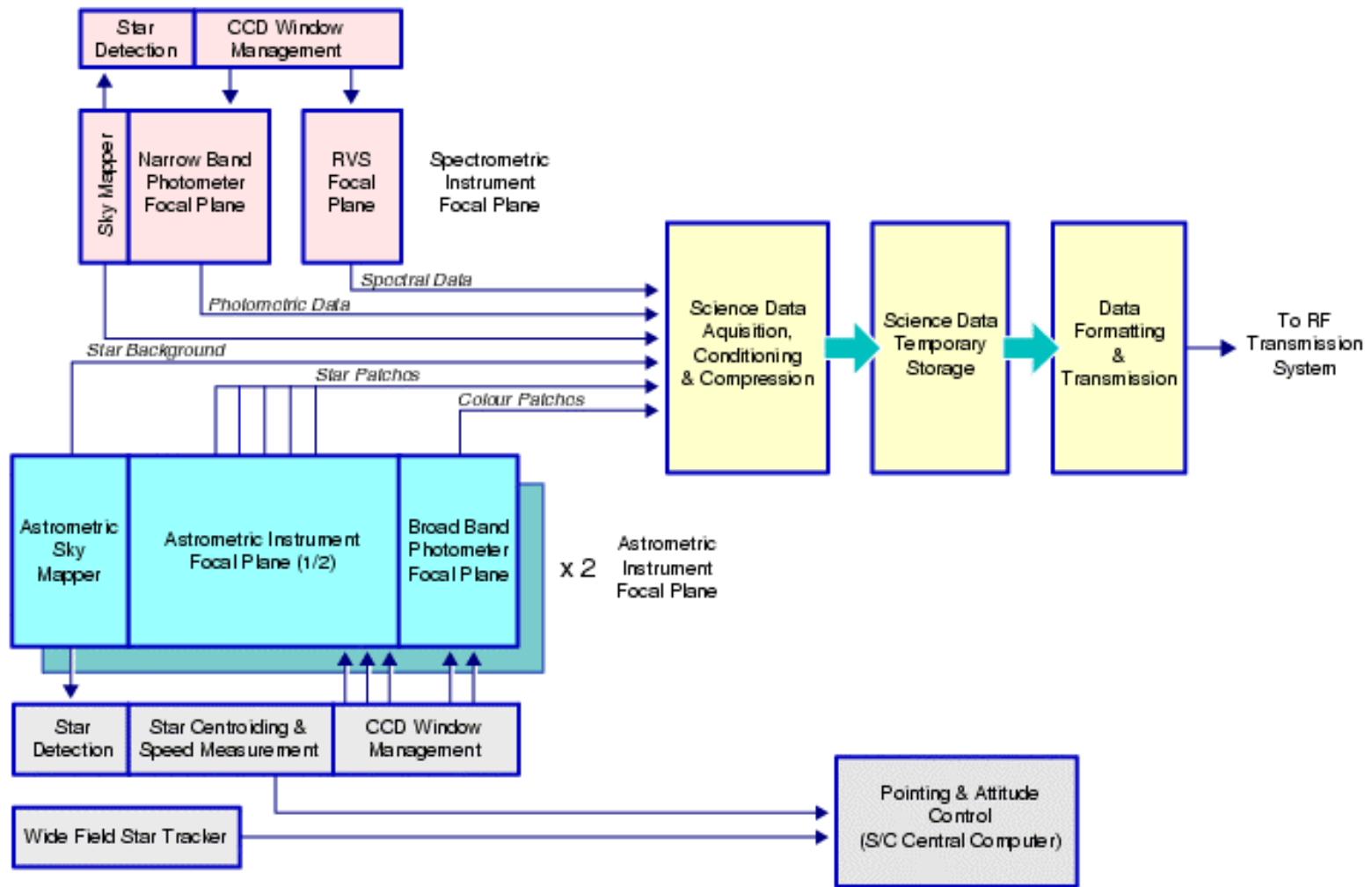
Effect of metal abundance in G stars

Satellite and System



- Launch: dual Ariane 5
- Orbit: Sun-Earth L2 (Lissajous)
- Attitude control: FEEP thrusters
- Deployable: solar array/sun-shield
- Data rate:
 - 1 Mbs⁻¹ sustained
 - 3 Mbs⁻¹ downlink (1 ground station)
- Mass: 3100 kg
 - fuel = 1000 kg; payload = 800 kg
- Power: 2600 W:
 - payload = 1500 W
- Design lifetime: 5 years
- Launch date: 2009
- ESA only mission

Data Flow on Board



Key Technical Challenges

- CCDs with necessary properties:
 - 9 μm pixels
 - large CCD focal planes with high-speed, low-noise detector chain
 - parameter trade-off (EEV) \Rightarrow first-order system design
 - small pixels + windowing + centroiding (MMS, starting Oct 99)
 - CTE/radiation effects (SIRA) \Rightarrow operating temp and trap physics
- SiC technology for mirrors and optical bench
- On-board basic-angle measurement (tests completed)
- High data rate phased-array antenna:
 - (Alcatel) \Rightarrow feasibility confirmed (3 Mbps?)
- Large deployable array/sunshield

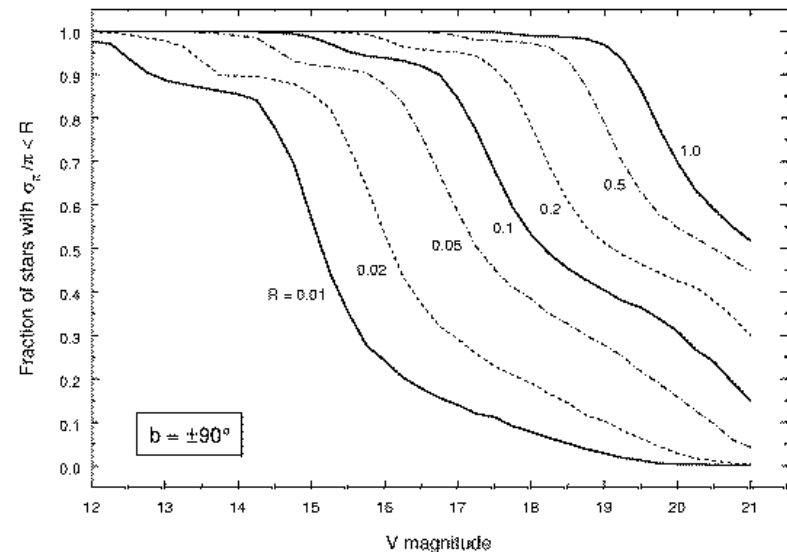
Accuracy and Data Analysis

Astrometric Accuracy

G (~V mag)	10	11	12	13	14	15	16	17	18	19	20	21	5-year accuracies in μs
Parallax	4	4	4	5	7	11	17	27	45	80	160	500	
Position	3	3	3	4	6	9	15	23	39	70	140	440	
Annual proper motion	3	3	3	4	5	8	13	20	34	60	120	380	

Derived from comprehensive analysis:

- image formation (polychromatic PSF)
- evaluation versus spectral type/reddening
- comprehensive detector signal model
- sky background and image saturation
- attitude rate errors + sky scanning
- on-board detection probability
- on-ground location estimation
- error margin of 20 per cent included
- results folded with Galaxy model



Fraction with given relative parallax error towards Galactic poles

Main Performances and Capabilities

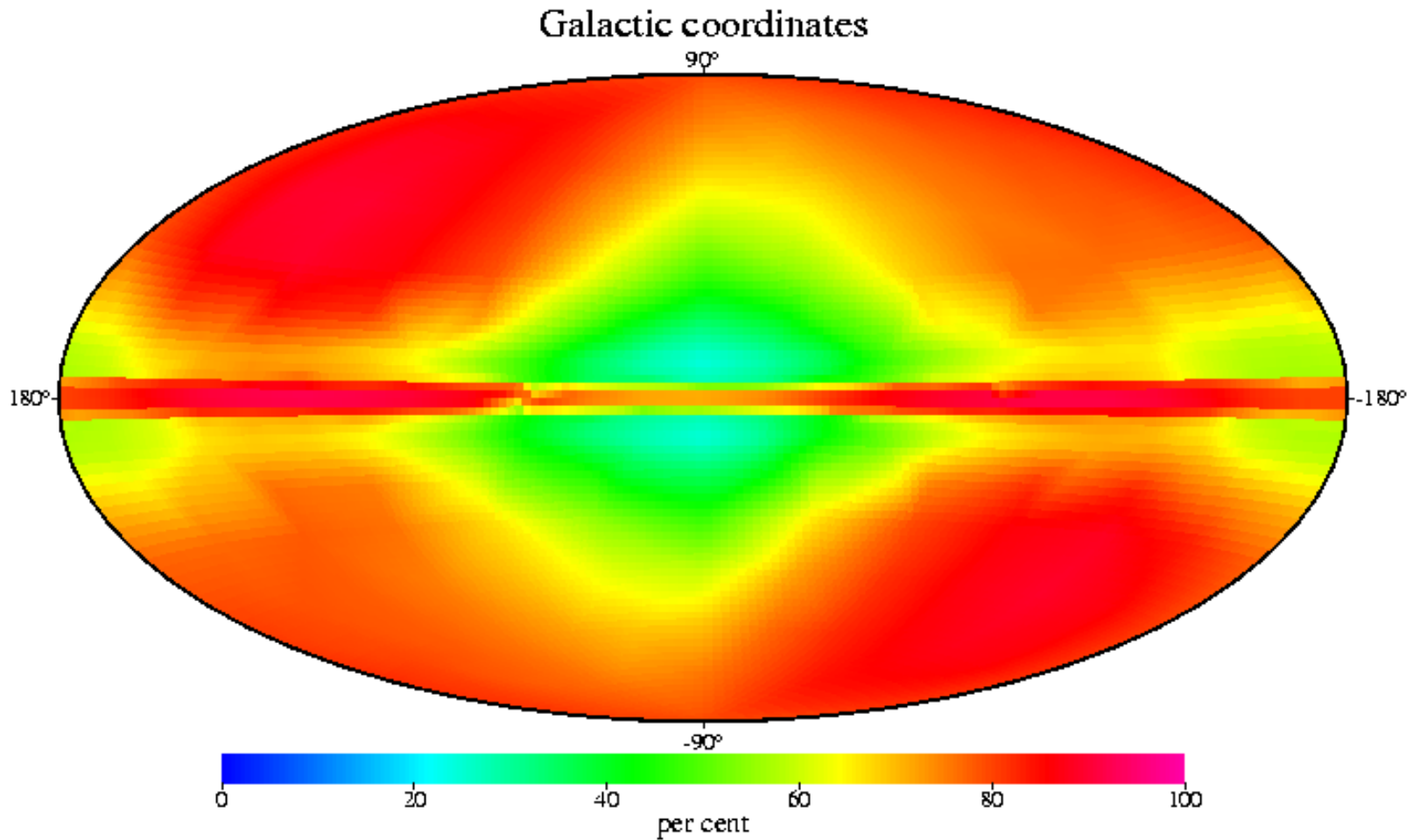
Accuracies:

- 4 μas at $V = 10$ 10 μas at $V = 15$ 0.2 mas at $V = 20$
- complete astrophysical sample: one billion stars
- 1 km/s radial velocities complete to $V = 17.5$
- sky survey at ~ 0.25 arcsec spatial resolution to $V = 20$
- multi-colour multi-epoch photometry to $V = 20$
- dense quasar link to inertial reference frame

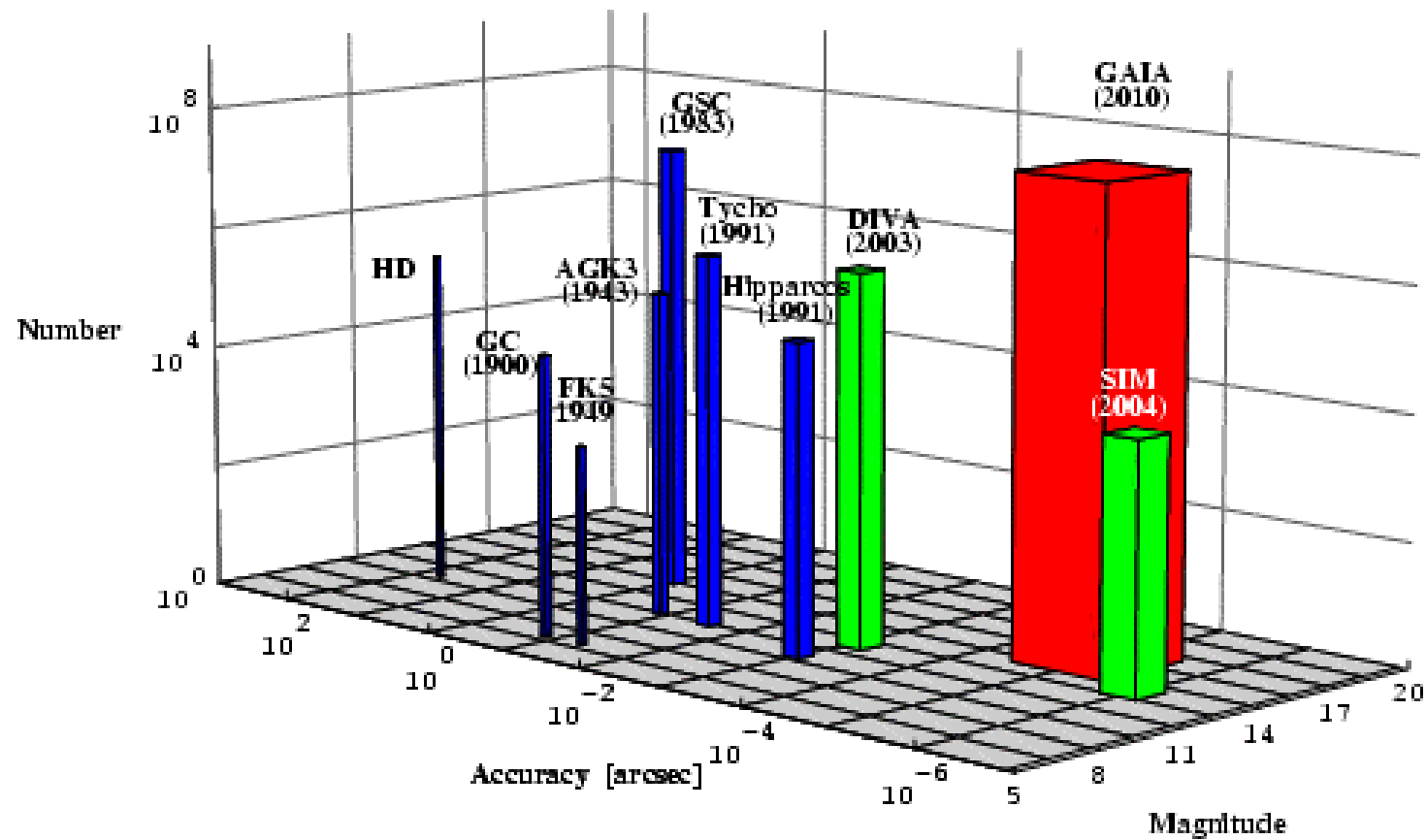
Capabilities:

- 10 $\mu\text{as} \equiv 10\%$ at 10 kpc $\equiv 1$ AU at 100 kpc
- 10 $\mu\text{as/yr}$ at 20 kpc $\equiv 1$ km/s
- \Rightarrow every star in the Galaxy and Local Group will be seen to move
- \Rightarrow GAIA will quantify 6-D phase space for over 300 million stars,
and 5-D phase-space for over 10^9 stars

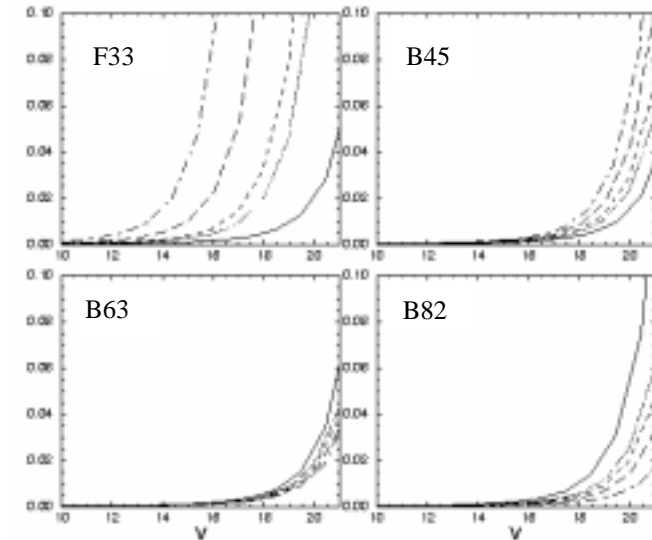
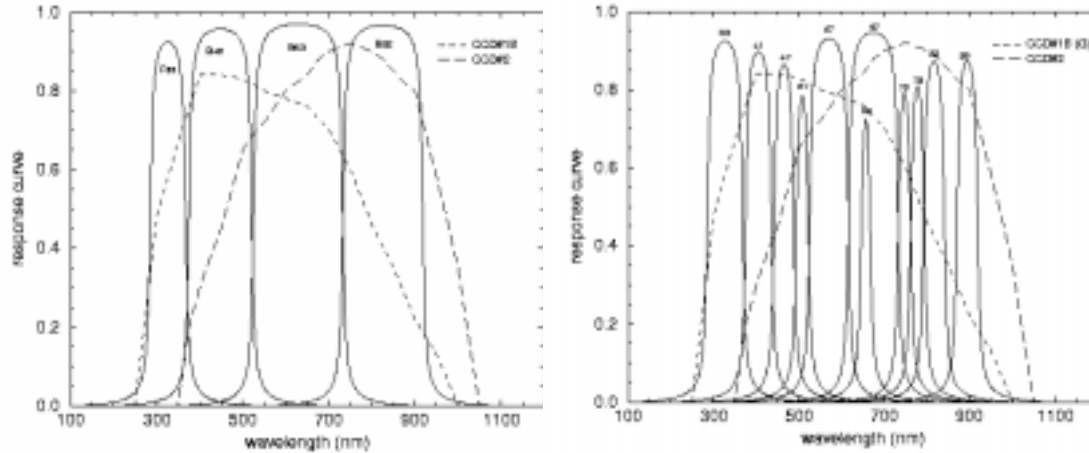
Accuracy Example: Stars at 15 mag with $\sigma_{\pi}/\pi \leq 0.02$



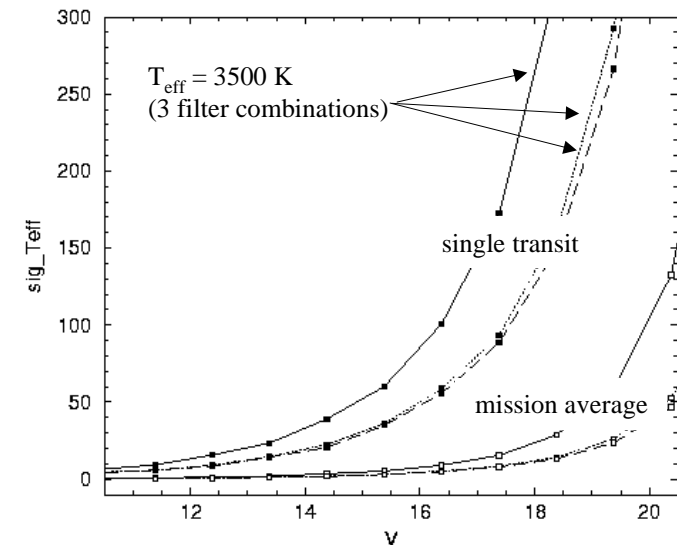
Comparison with Other Catalogues



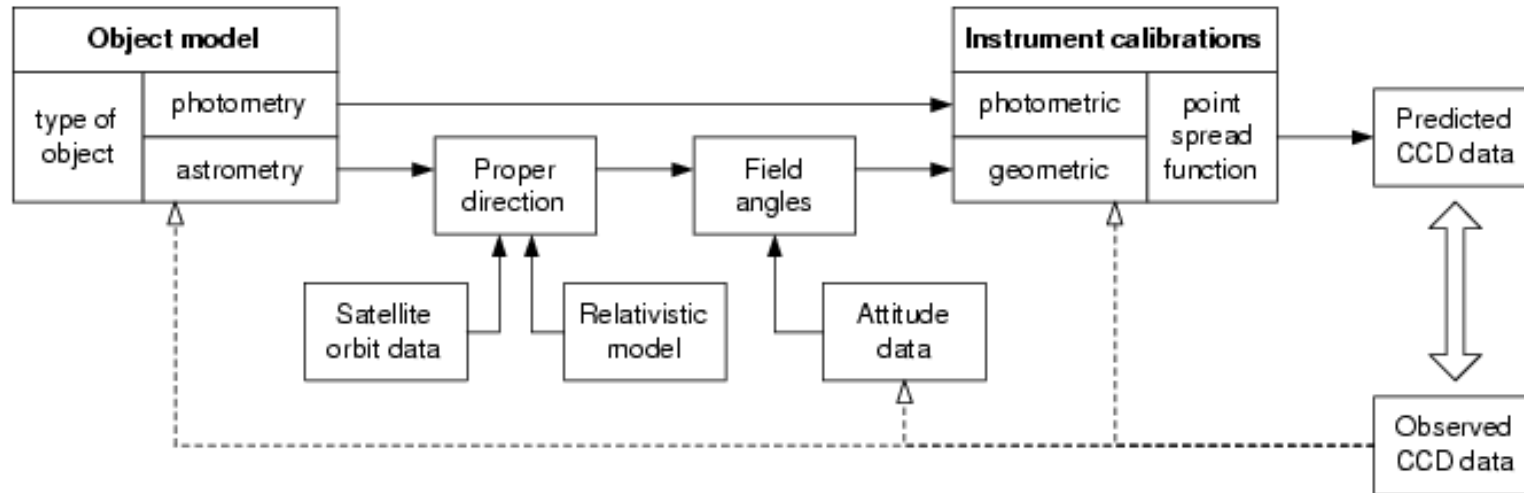
Photometric Accuracies and Diagnostics



- **Photometric system (above):**
 - optimised for astrophysical diagnostics
- **Photometric accuracy assessment (top right):**
 - photon noise, sampling, CCD response, etc.
 - single transit + mission averages (~100 transits)
- **Astrophysical diagnostics (right):**
 - ⇒ reddening, T_{eff} , [Ti/H], [M/H], etc.



Data Analysis: Concept and Requirements



Capacity: ~100 Terabytes

Overall system: centralised global iterative approach

Accessibility: quasi-random, in temporal and object domains

Processing requirements: entire task is $\sim 10^{17} - 10^{18}$ flop

Numerical: 0.1 microarcsec = 10^{-13} of a circle (64-bit marginal)

Modelling accuracy: 0.1 microarcsec demanding, but feasible

Data base structure: e.g. Objectivity (cf. Sloan)

Results: time-critical results available early (NEO, supernovae etc)

⇒ **Prototype:** Hipparcos global astrometry re-reduced successfully during concept study

Organisation etc

GAIA Science Advisory Structure

- Science Advisory Group members (1997-2000):

K.S. de Boer (Bonn)	L. Lindegren (Lund)
G. Gilmore (Cambridge)	X. Luri (Barcelona)
E. Hoeg (Copenhagen)	F. Mignard (Grasse)
M.G. Lattanzi (Torino)	P.T. de Zeeuw (Leiden)
- Associated Working Groups:
 - Science Working Group (17 members)
 - Instrument Working Group (16 members)
 - Photometry Working Group (17 members)
 - Members at Large (47 members)
- ESA:
 - O. Pace (Future Projects, Study Manager)
 - M.A.C. Perryman (Astrophysics Division, Study Scientist)

Concept and Technology Study

- **Industrial objectives (1997-2000):**
 - Demonstrate technical feasibility and design trade-offs (size, mass, accuracy)
 - Evaluate end-to-end programme costs
 - Inputs to accuracy assessment/limiting performances
 - Identify technology development requirements after selection
 - Schedule summary:
 - Invitation to Tender: April 1997
 - Selection of Matra Marconi Space (MMS, Toulouse)
 - Final industrial report: November 1998
- **Scientific objectives:**
 - Evaluate scientific drivers and spin-offs
 - Determine payload properties needed to achieve these
 - Evaluate end-to-end accuracies (astrometry, photometry, radial velocity)
 - Assess feasibility and critical points in data processing
 - Conferences/workshops:
 - Cambridge 1995, SP-379
 - Venice 1997, SP-402
 - Leiden 1998

Other/Backup/Redundant

Gaia

Galactic
Structure



Fundamental
Physics

20 Kpc

The Reference
Frame



Stellar
Astrophysics

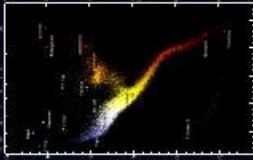
10 Kpc



Solar
System

500 pc

Star Formation
History of
the Milky Way



Binaries and
Brown Dwarfs



Extrasolar
Planets



Scientific Objectives: Implications

Galactic Structure: origin and history of our Galaxy - tests of hierarchical structure formation - inner bulge/bar dynamics - disk/halo interactions - dynamical evolution - nature of the warp - star cluster disruption - dynamics of spiral structure - star formation history - chemical evolution - distribution of dust - distribution of invisible mass - detection of tidal accretion debris - Galaxy rotation curve - disk mass profile

Star Formation and Evolution: dynamics of star forming regions - luminosity function for pre-main sequence stars - detection and categorization of rapid evolutionary phases - complete and detailed local census down to single brown dwarfs - identification/dating of oldest halo white dwarfs - age census - census of brown dwarfs in binaries

Distance Scale and Reference Frames: parallax calibration of all distance scale indicators - absolute luminosities of Cepheids - distance to the Magellanic Clouds - definition of the local, kinematically non-rotating metric

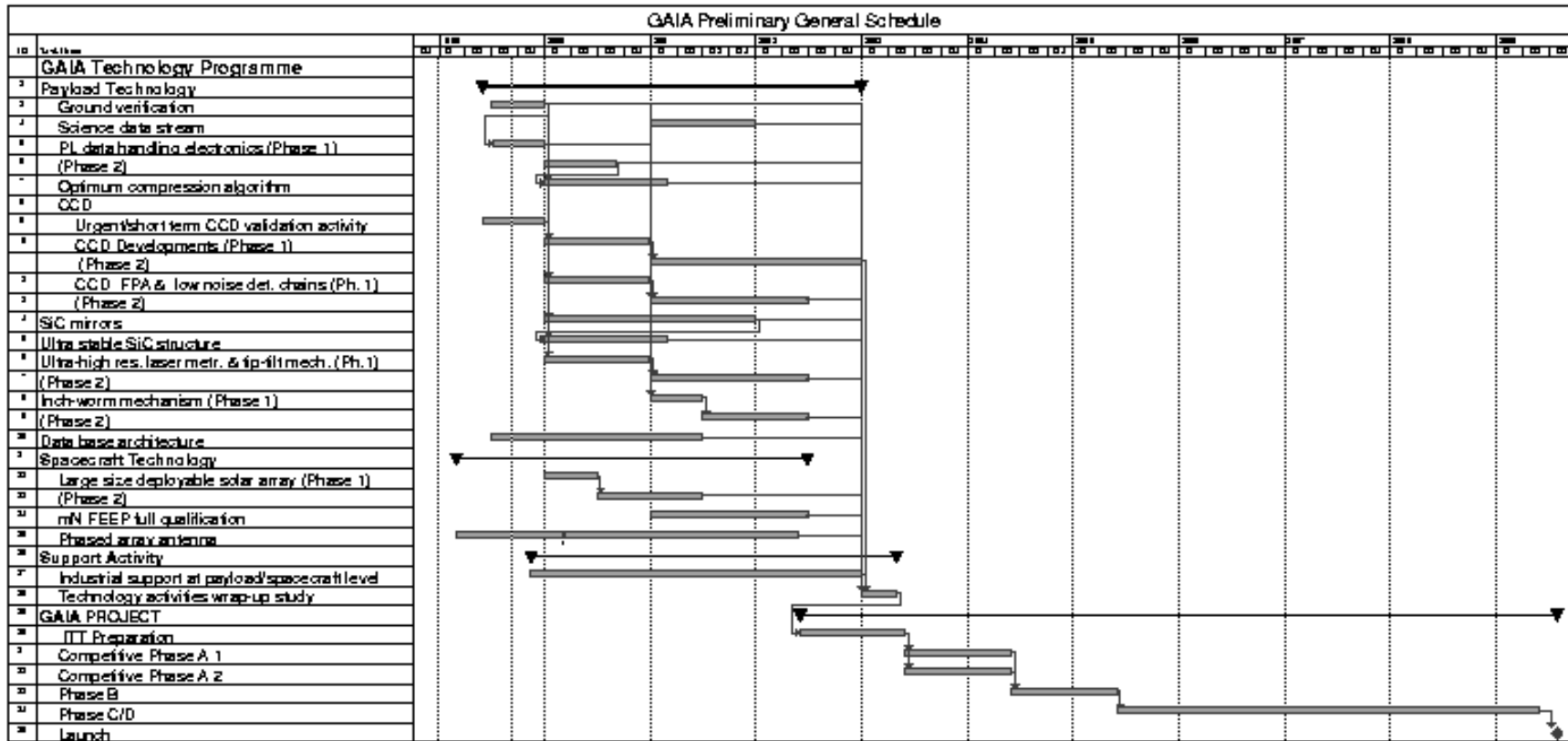
Local Group and Beyond: rotational parallaxes for Local Group galaxies - kinematical separation of stellar populations - internal dynamics of Local Group dwarfs - galaxy orbits and cosmological history - zero proper motion quasar survey - cosmological acceleration of Solar System - photometry of galaxies - detection of supernovae

Solar System: 10^5 - 10^6 new minor planets - taxonomy and evolution - disruption of Oort Cloud

Extra-Solar Planetary Systems: complete census of large planets out to 200-500 pc - orbital characteristics of several thousand planets

Fundamental Physics: determination of space curvature parameter γ to 1 part in $5 \cdot 10^{-7}$

Implementation Timescale: Technology

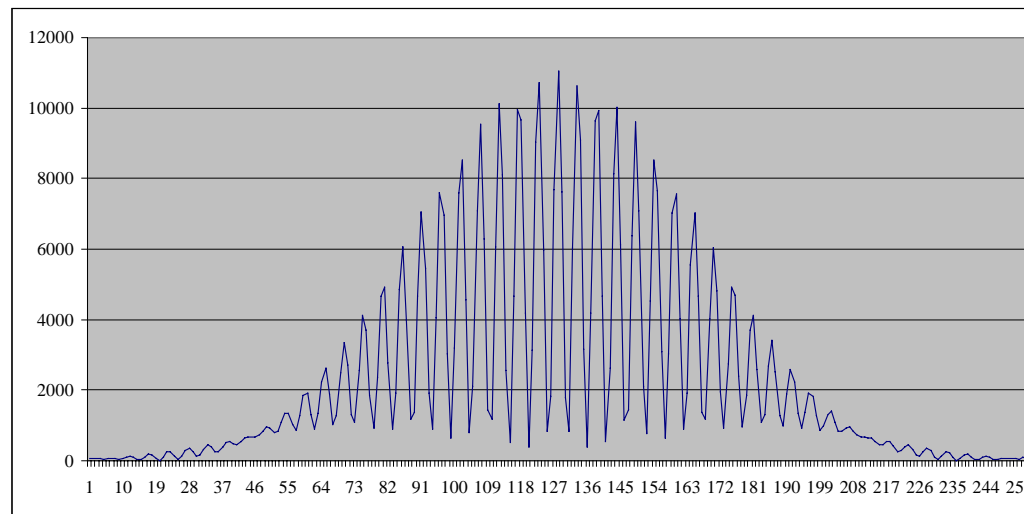


- Competitive Phase A start: mid-2003
- Phase B: mid-2004 to mid-2005
- Phase C/D: mid-2005 to mid-2009

- Launch: 3rd quarter 2009
- Transfer to L2: 6 months
- Mission duration: 5 years

Technology Studies: Basic Angle Monitoring

- TU Delft, Sep. 99:
 - ⇒ 50 pm OPD demonstrated (10 pm target)
 - ≅ 1:10 000 of fringe
 - ≅ 1:2500 pixel (9 μ m)



Interferometric Option

- Alenia Aerospazio, 1997-99, covering:
 - small-baseline interferometer, laser monitoring, active control, geostationary orbit
 - resulting disadvantages:
 - » feasibility of small pixels for sampling of interference fringes
 - » significantly (factor 10) higher data rate
 - » complexity of optical alignment, stability and control
 - » poorer sensitivity limiting of ~ 18 mag
- ⇒ not the preferred option

Implementation Timescale

Scientific Rationale for Launch ~2009

Scientific context of 2009 launch:

- photometric data available from 2010-2015
- extreme object discoveries from 2012 (preliminary) to 2017 (final), thus (e.g.):
 - ⇒ high-resolution extinction maps for comparison with Planck
 - ⇒ map star-forming regions for study with FIRST and ALMA
 - ⇒ discover transients and extreme objects for NGST (+SIM?)
 - ⇒ discover planetary systems for interferometers/next-generation ground telescopes
- scientific demand:
 - ⇒ GAIA will make the Local Group the template for galaxy evolution
 - ⇒ improved understanding of galaxy evolution (and NGST data) demands GAIA

Technology:

- GAIA technologies (CCD mosaics, FEEPs, SiC mirrors, large data bases, etc) will be ready, and are beneficial to other projects (space and ground)

Leadership and expertise:

- Europe is the acknowledged leader in this innovative science:
- build on Hipparcos investment (scientific expertise/readiness now exists in Europe)
 - ⇒ retain European leadership