Frédéric Arenou, Daniel Hestroffer

Pas de deux

Pas de Deux

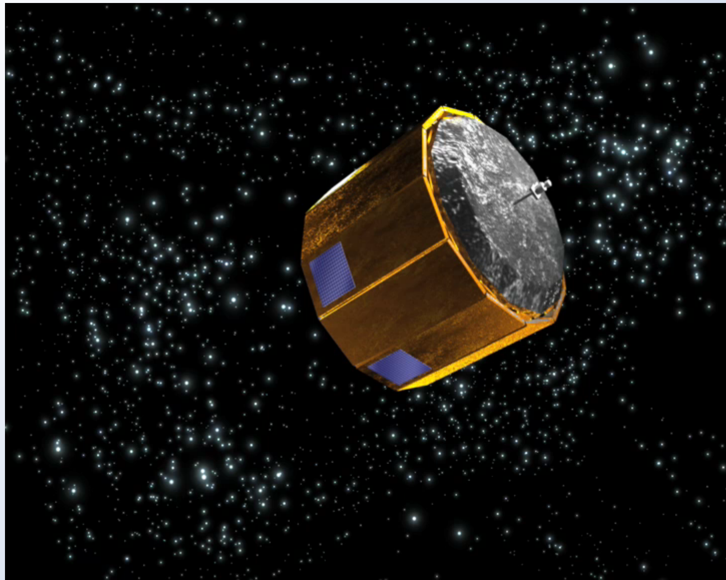
- Motivation
  - Common problems between SSO/ESP/NSS
    - Stellar binaries, exoplanets, binary asteroids need orbits
  - Gaia perspective
    - Orbits: hundreds? (SSO), thousands (ESP) or millions (NSS)
- Meeting Challenge
  - Different communities!
- Sessions
  - Presentation by subject
  - Photometry
  - Spectroscopy
  - Various methods & techniques
- Thanks
  - Gaia Research for European Astronomy Training (GREAT)
  - Action Spécifique Gaia (INSU/CNRS)
  - Observatoire de Paris

A short presentation

Gaia

Gaia Summary

- ESA mission building on the Hipparcos heritage
- Astrometry, Photometry and Spectroscopy
- Launch June 2013
- Satellite including the payload by industry (Astrium, Toulouse) data processing by scientists (DPAC)
- Science Alerts early on
- First intermediate release in about two years into routine operations



www.rssd.esa.int/Gaia

Science Topics

- Structure and dynamics of the Galaxy
- The star formation history of the Galaxy
- Stellar astrophysics
- Binaries and multiple stars
- Brown dwarfs and planetary systems
- Solar system
- Galaxies, Quasars and the Reference Frame
- Fundamental physics: General relativity

Payload and Telescope

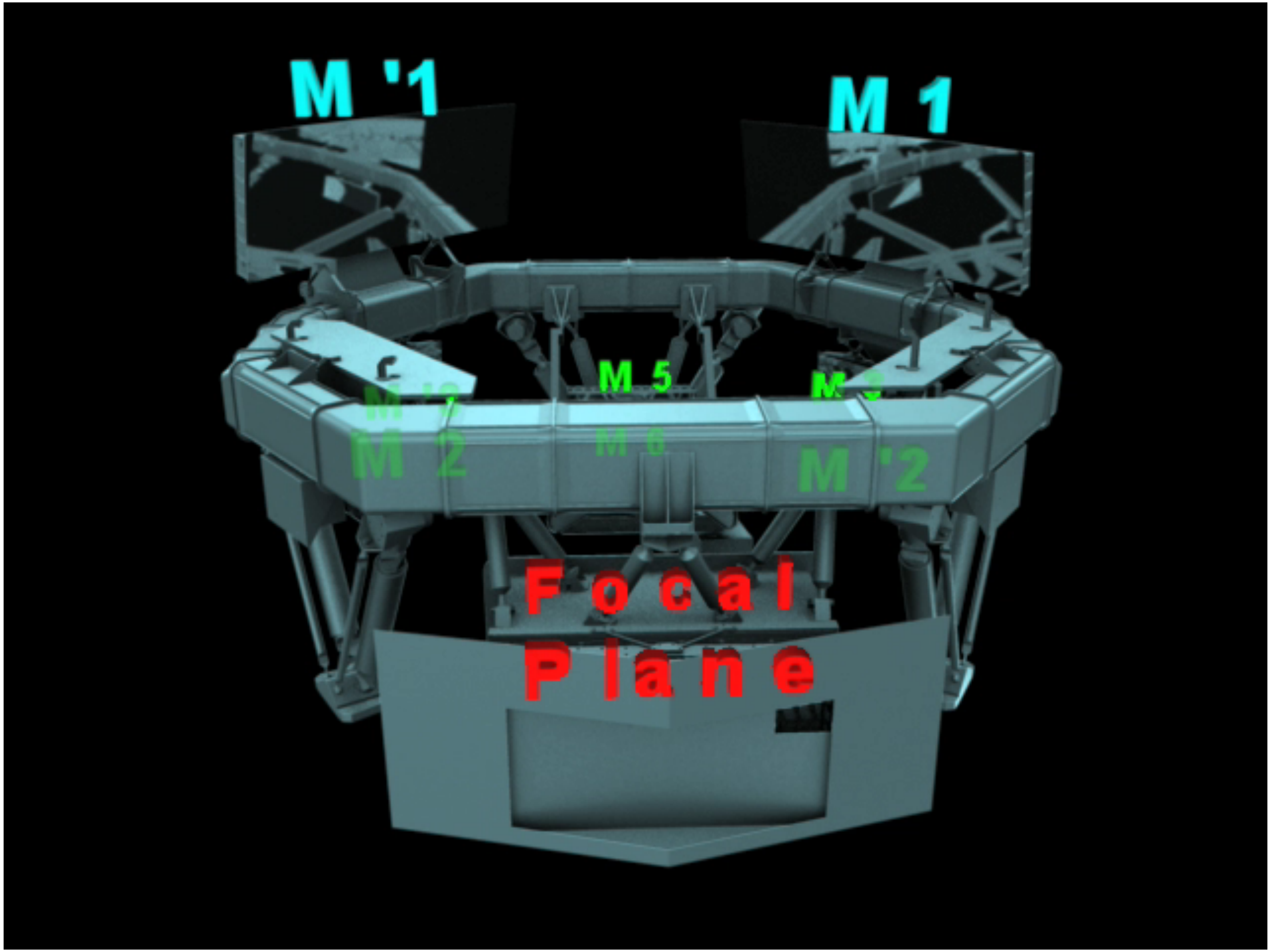
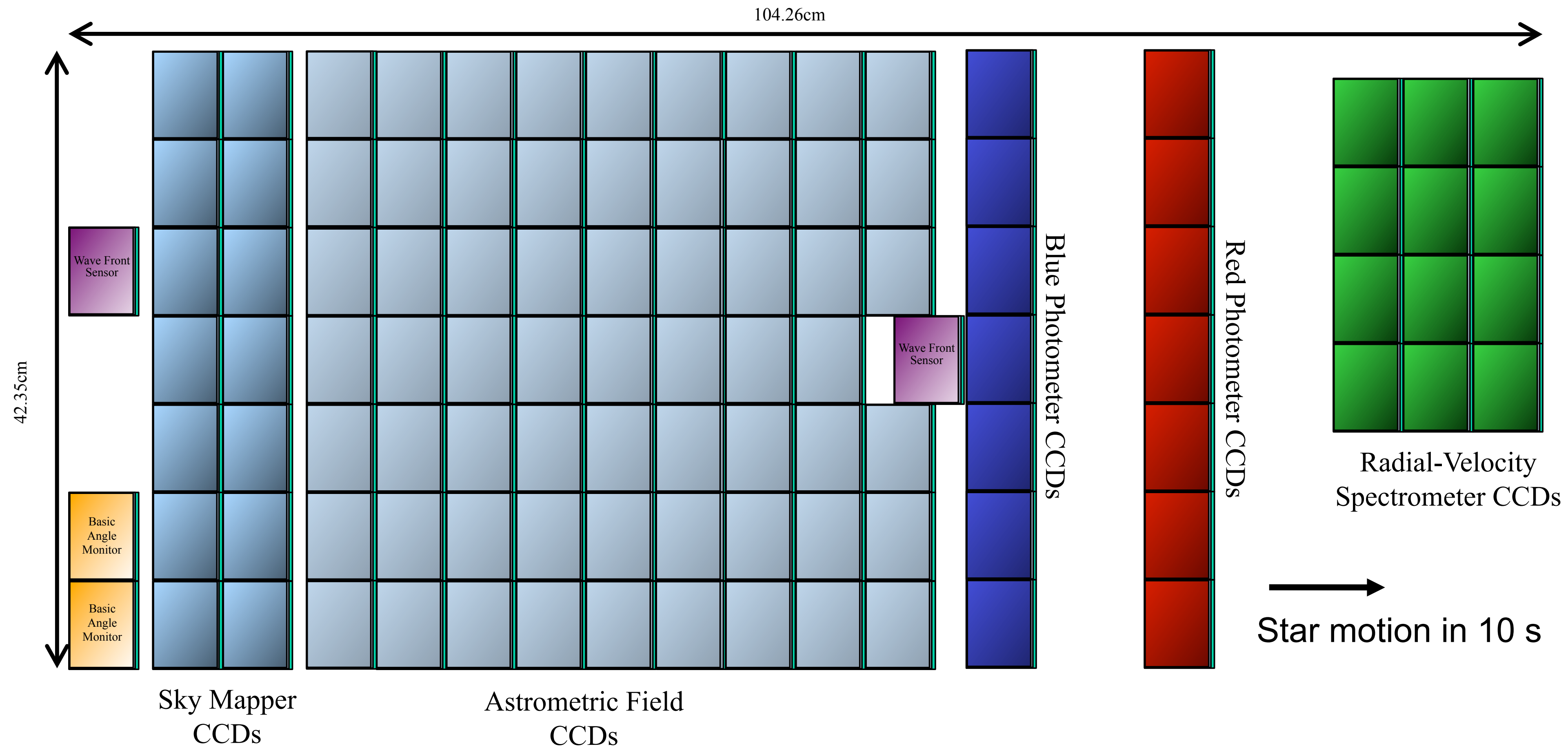


Figure courtesy Alex Short

Focal Plane



Total field:

- active area: 0.75 deg^2
- CCDs: 14 + 62 + 14 + 12 (+ 4)
- 4500 x 1966 pixels (TDI)
- pixel size = 10 µm x 30 µm
  = 59 mas x 177 mas

Sky mapper:

- detects all objects to 20 mag
- rejects cosmic-ray events
- field-of-view discrimination

Astrometry:

- total detection noise ~ 6 e$^-$

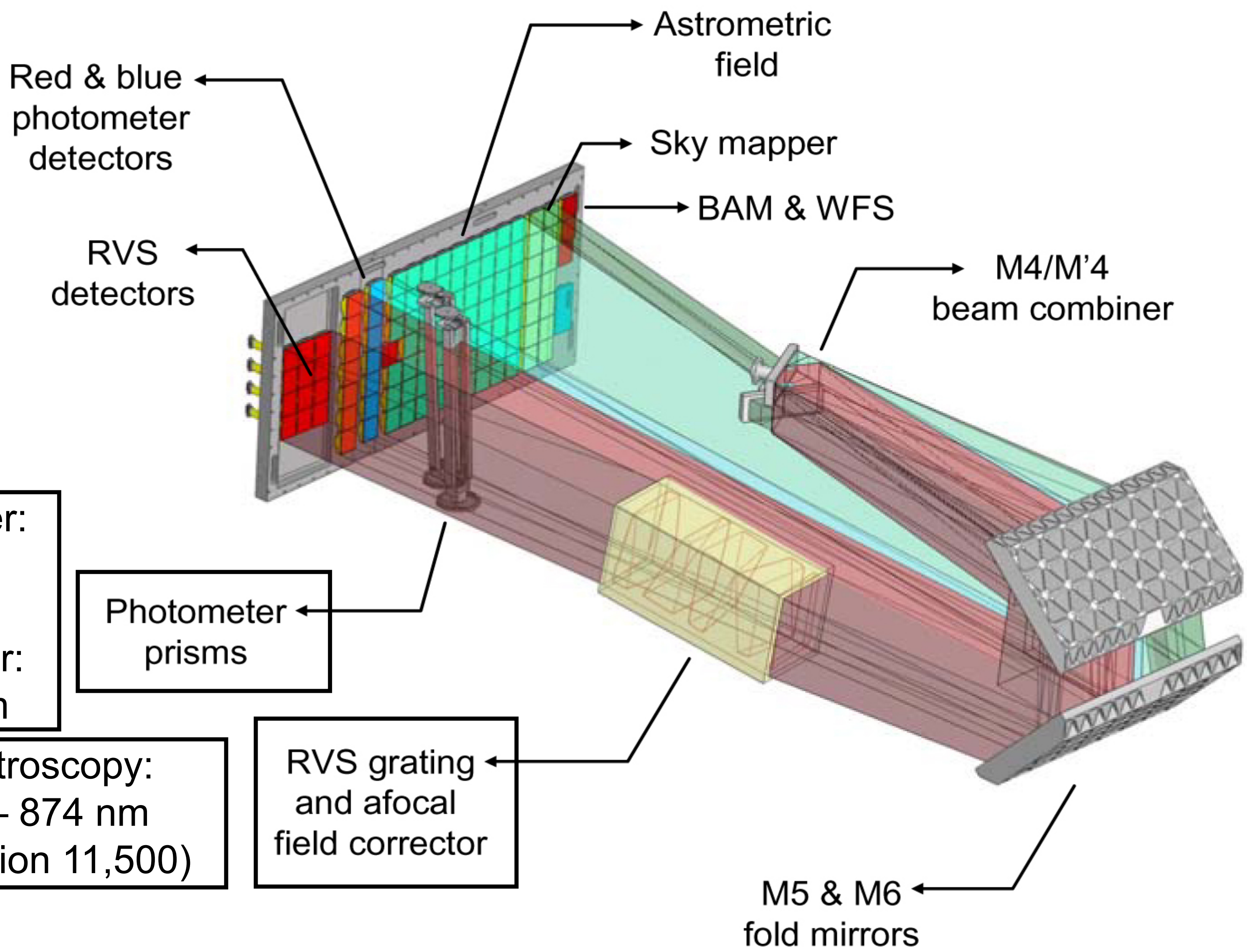
Photometry:

- spectro-photometer
- blue and red CCDs

Spectroscopy:

- high-resolution spectra
- red CCDs

Photometry/Spectroscopy Measurement Concepts



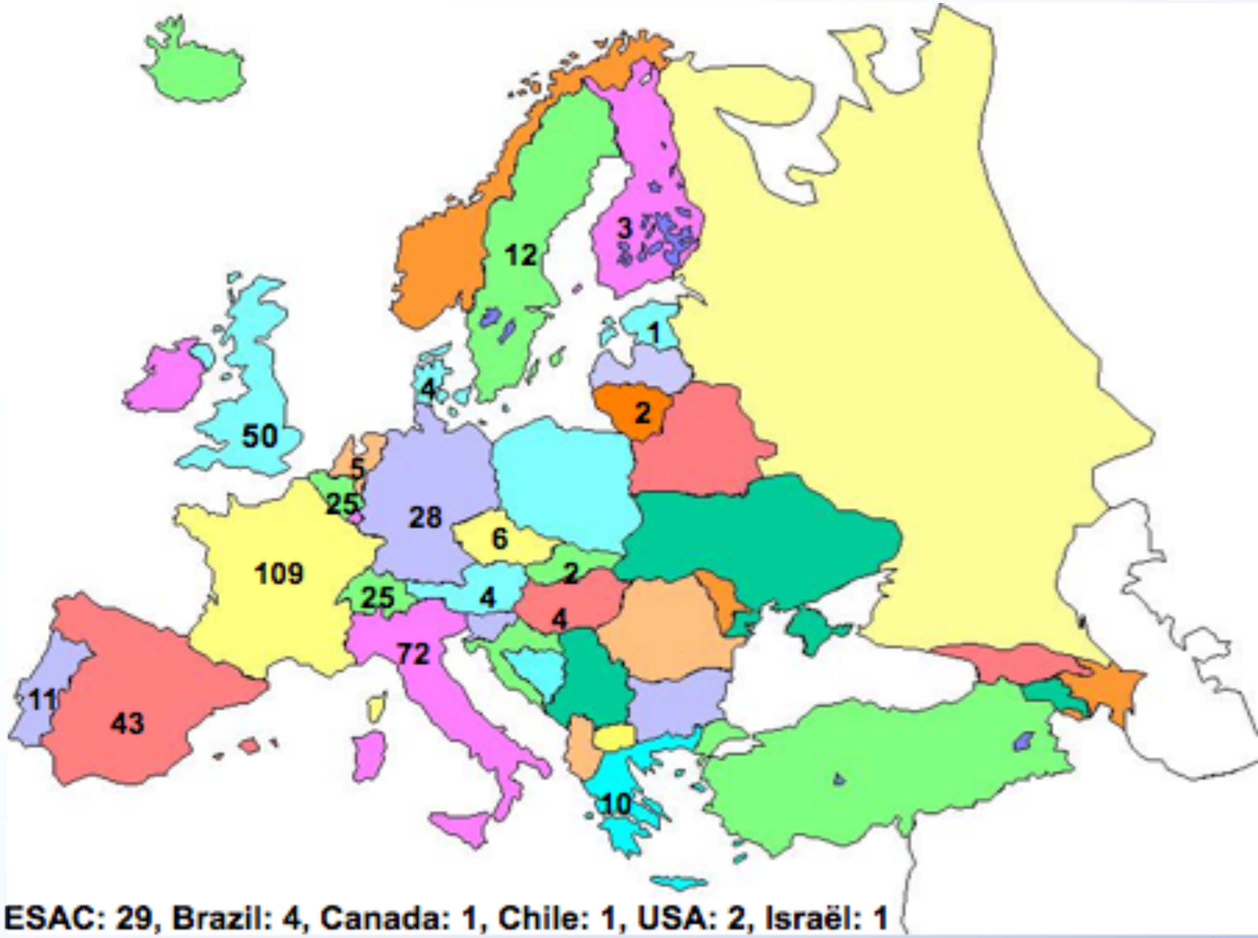
Blue photometer:
330 – 680 nm

Red photometer:
640 – 1000 nm

Spectroscopy:
847 – 874 nm
(resolution 11,500)

Figure courtesy EADS-Astrium

Data Processing



Units (CU)

e average 70

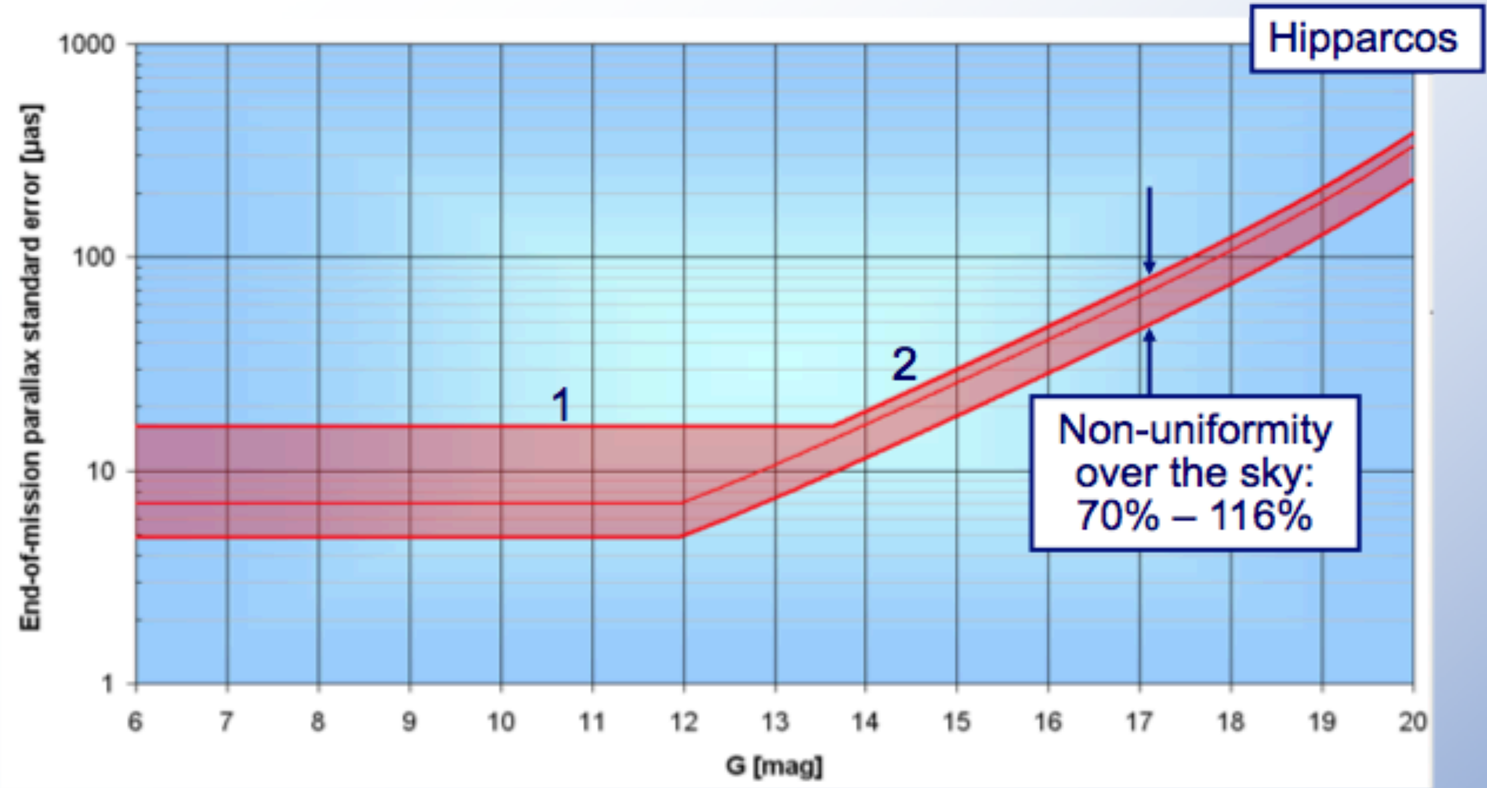
lion stars a

asurements a

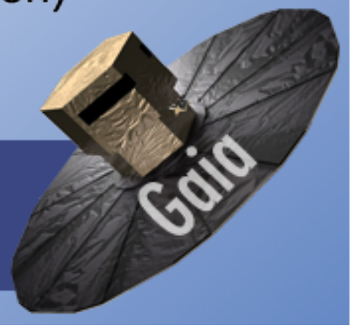
e. 10 million

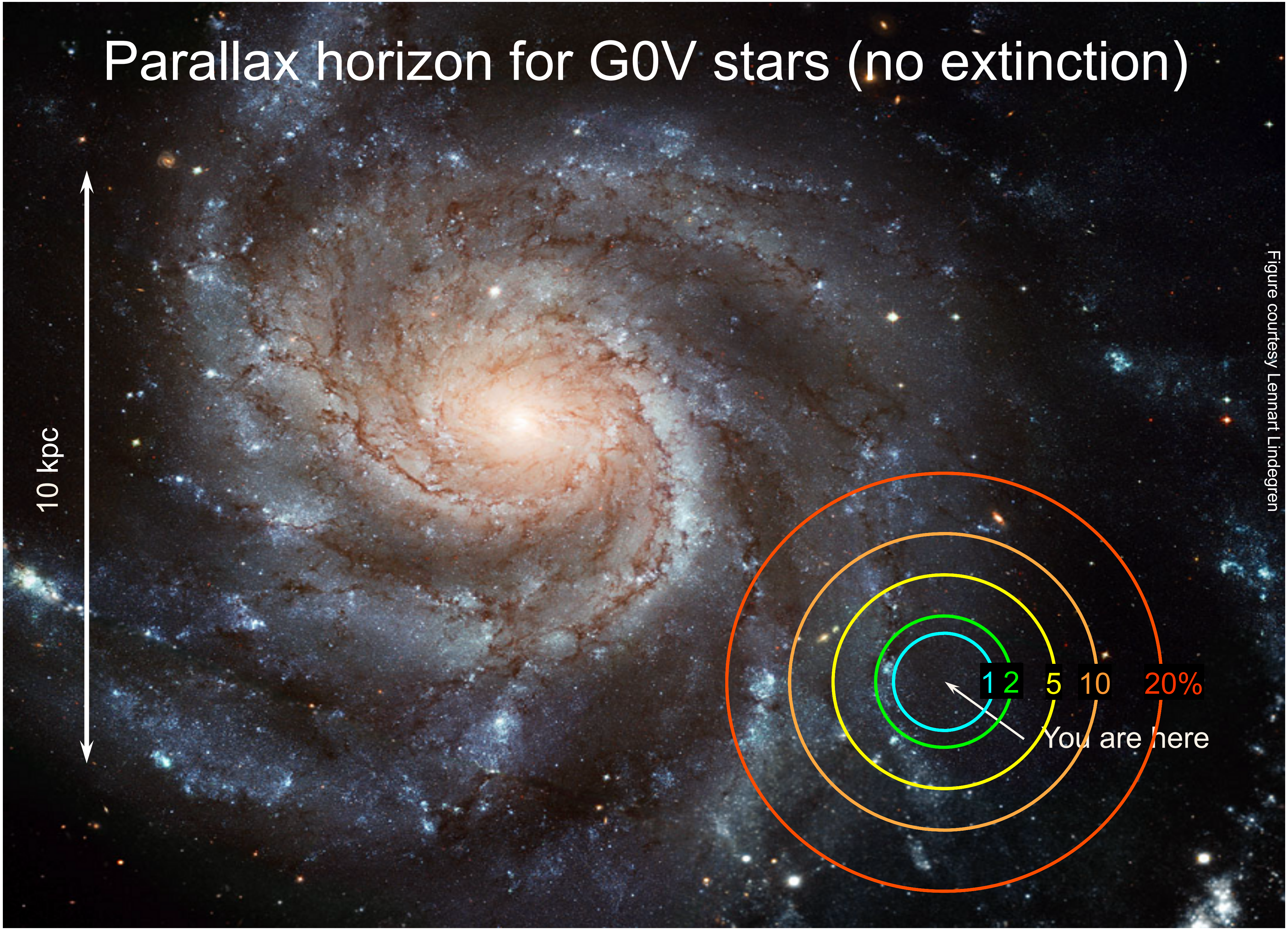
Courtesy from T. Prusti, Gaia PS

Astrometry

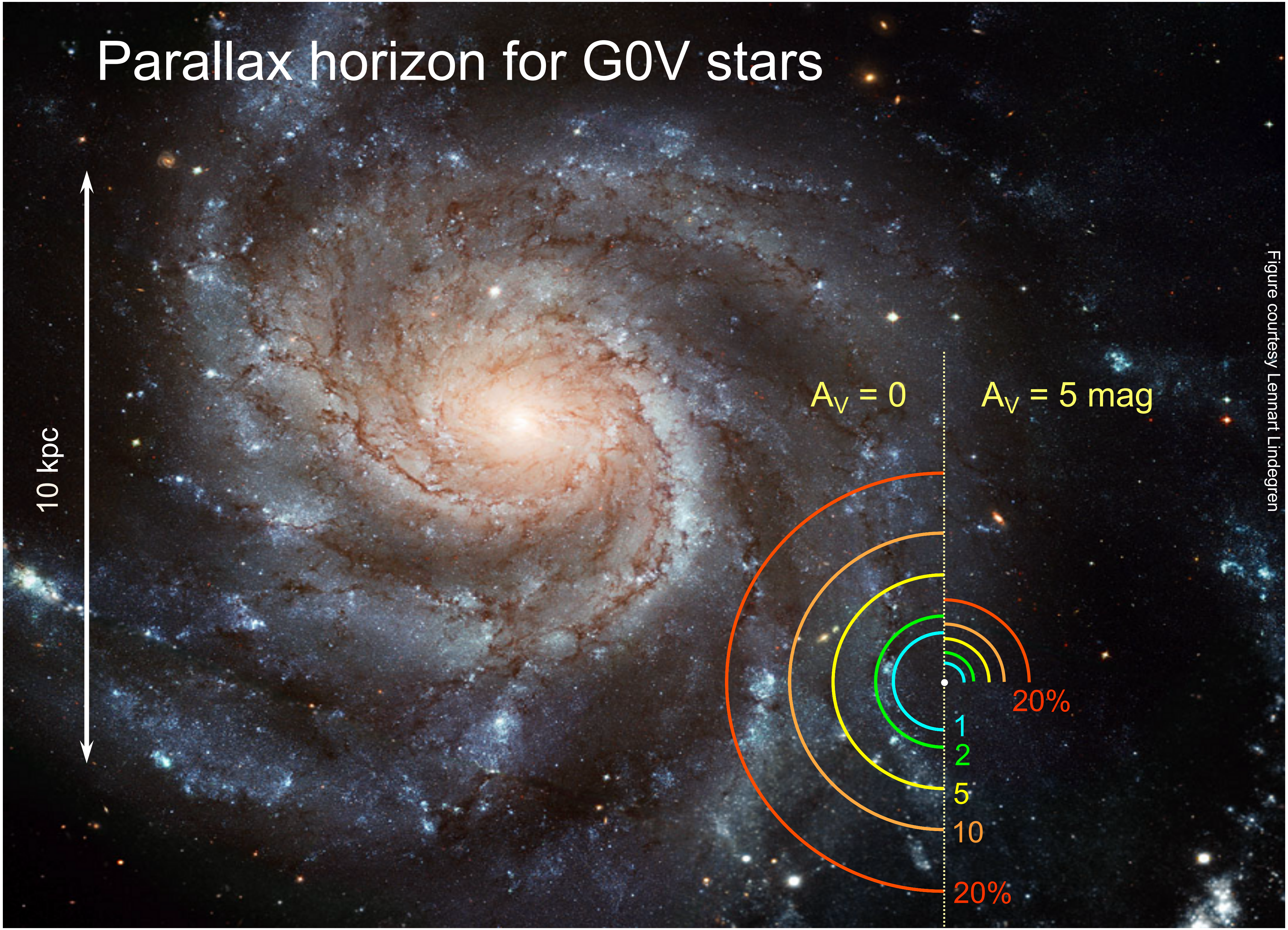


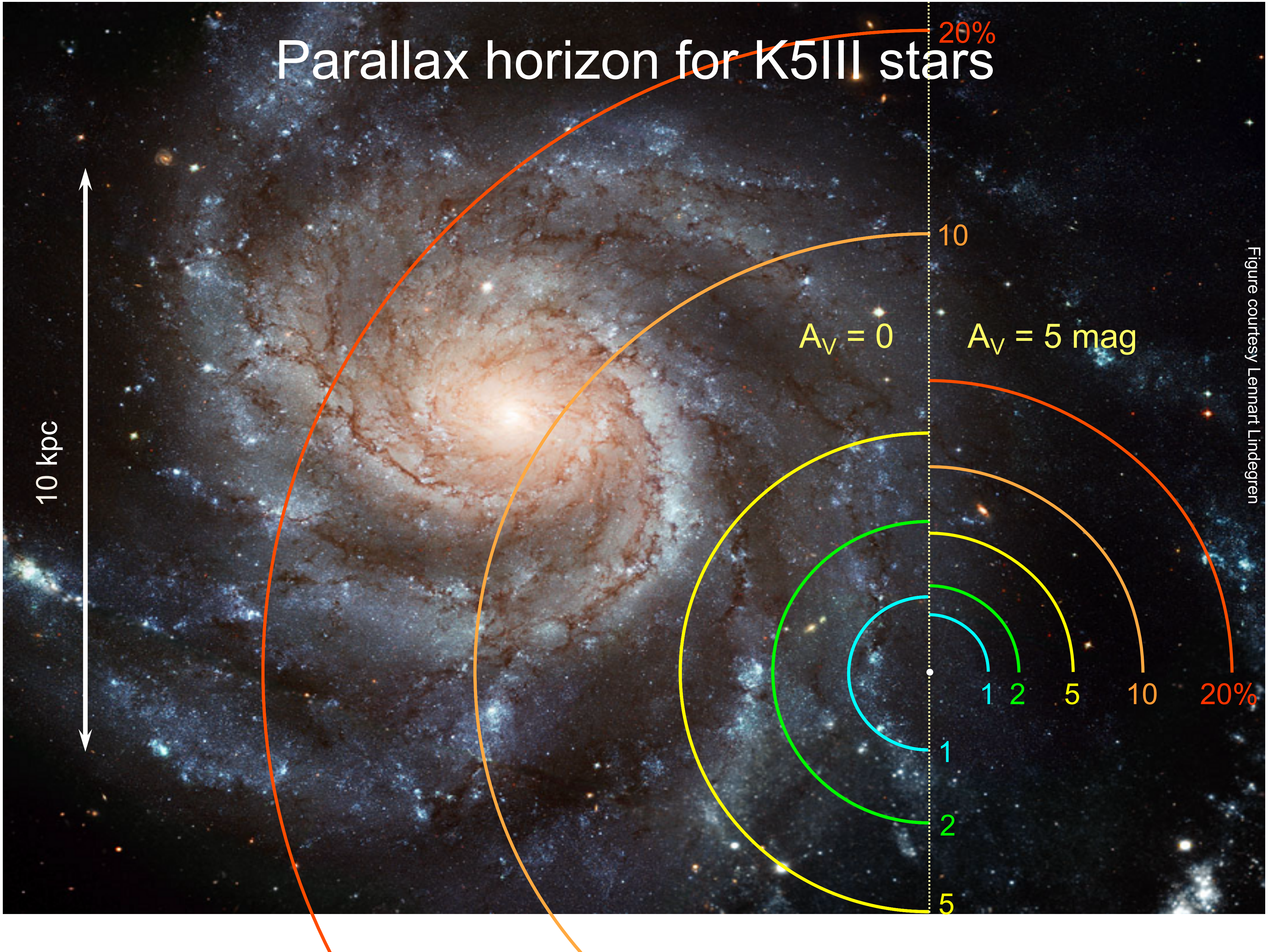
1. 6 < G < 12: bright-star regime (calibration errors, CCD saturation)
2. 12 < G < 20: photon-noise regime, with sky-background noise and electronic noise setting in around G ~ 20 mag





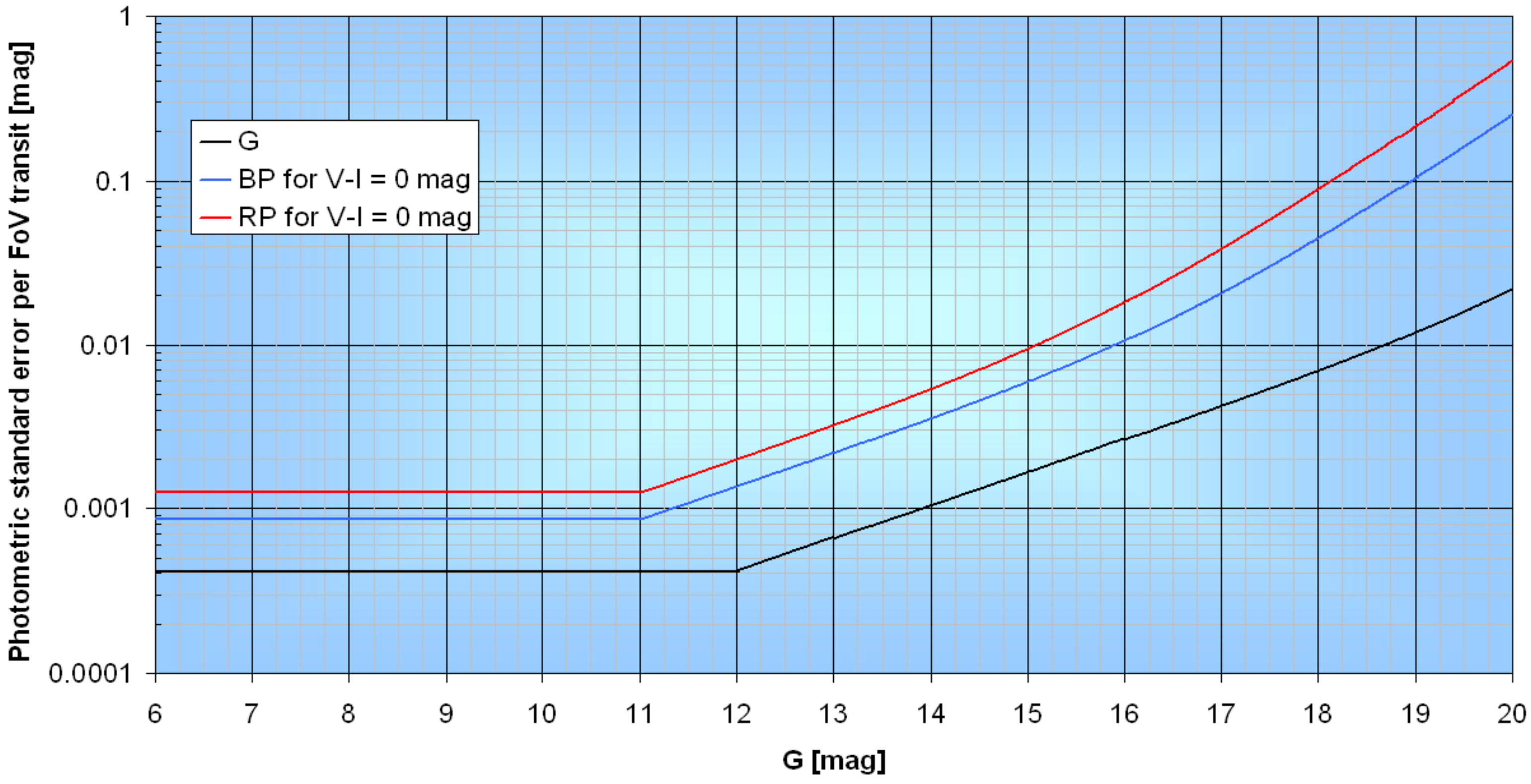
Parallax horizon for G0V stars (no extinction)
10 kpc
1
2
5
10
20%
You are here
Figure courtesy Lennart Lindegren


Parallax horizon for G0V stars
10 kpc
A_V = 0
A_V = 5 mag
20%
1
2
5
10
20%
Figure courtesy Lennart Lindegren



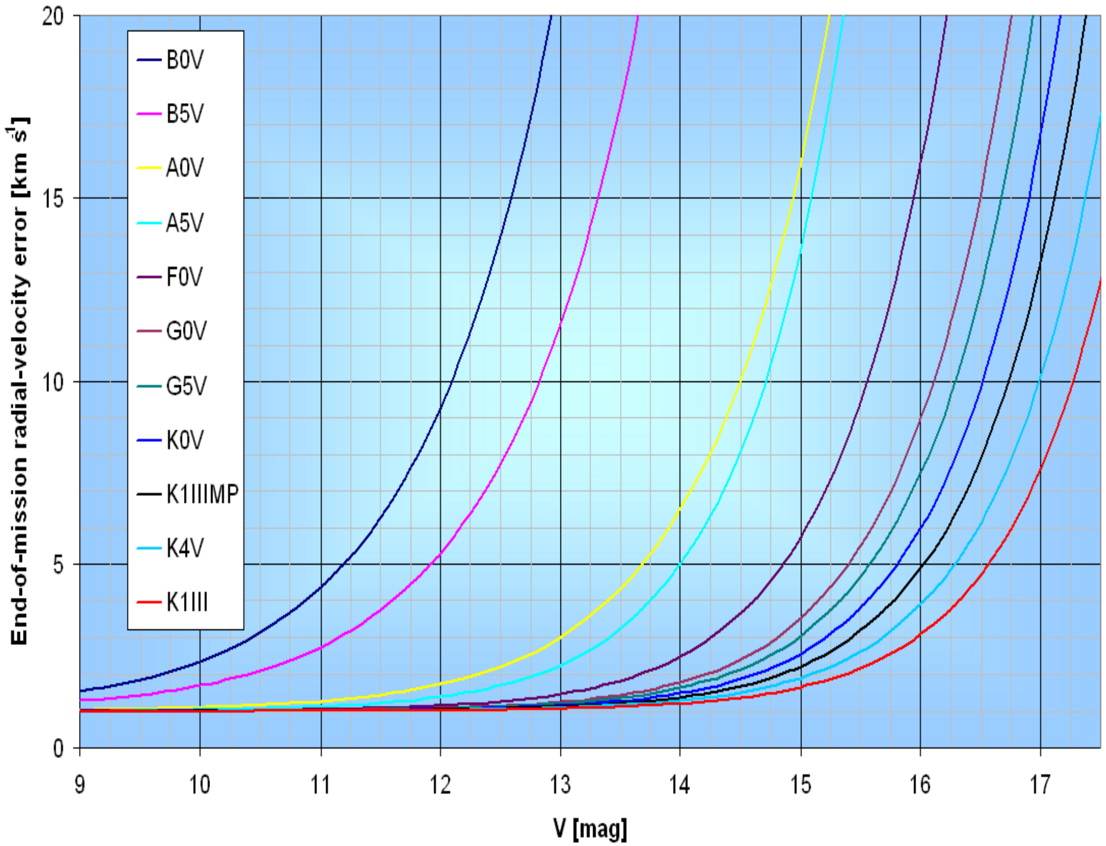
Parallax horizon for K5III stars
20%
10
$A_V = 0$
$A_V = 5$ mag
10 kpc
1
2
5
1 2 5 10 20%
Figure courtesy Lennart Lindegren

Transit level integrated photometry



Courtesy from T. Prusti, Gaia PS

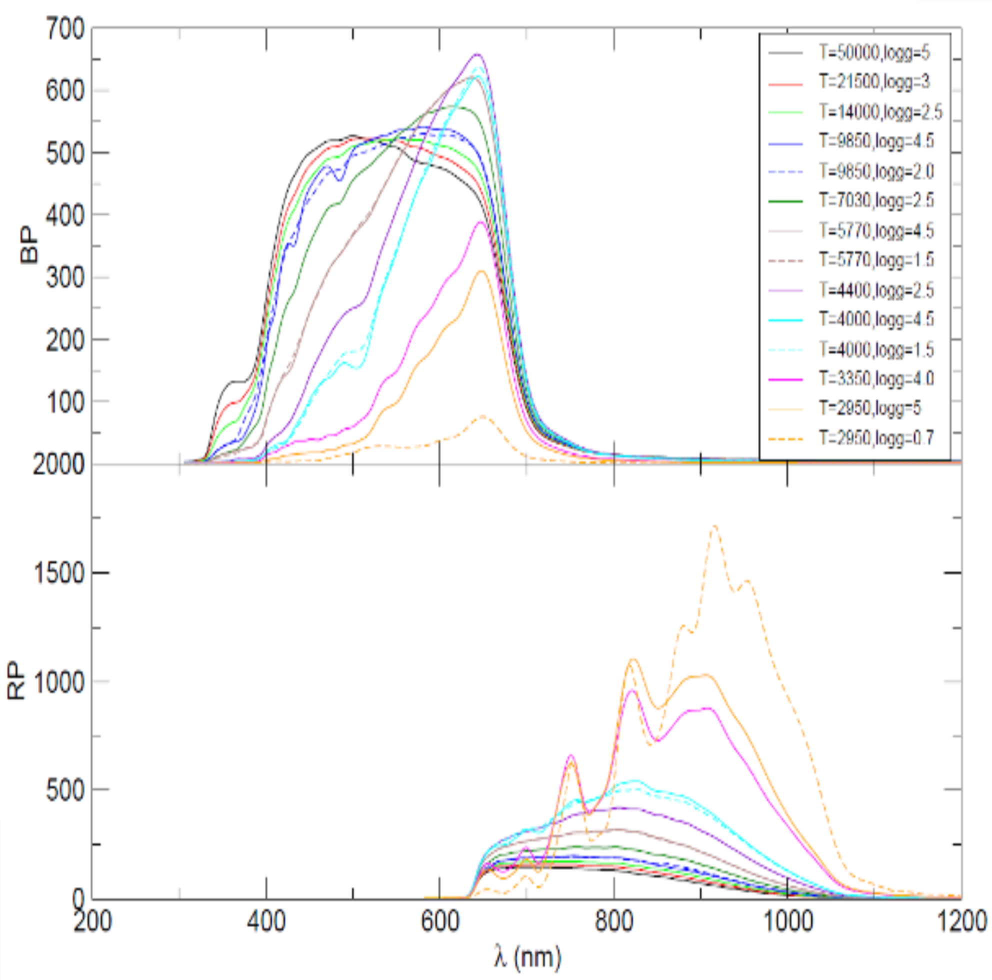
Spectroscopy



End of mission radial velocity precision

- Interstellar reddening, atmospheric parameters, and rotational velocities, for stars brighter than $G_{RVS} \approx 12$ mag (~5 million stars)
- provide element abundances for stars brighter than $G_{RVS} \approx 11$ mag (~2 million stars)

Spectro-photometry



- Illustrative spectra for G=15 mag stars (Jordi et al. 2010)
- Goals at G=15 mag e.g. extinction within 0.1mag, surface gravity 0.2dex, metallicity 0.2dex and effective temperature within 200K (Bailer-Jones 2010)

Orbital Zoo

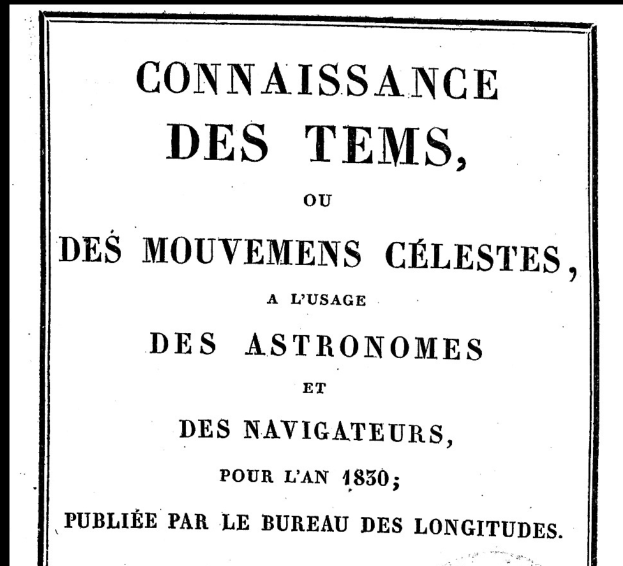
Various kind of binary stars

First binary stars

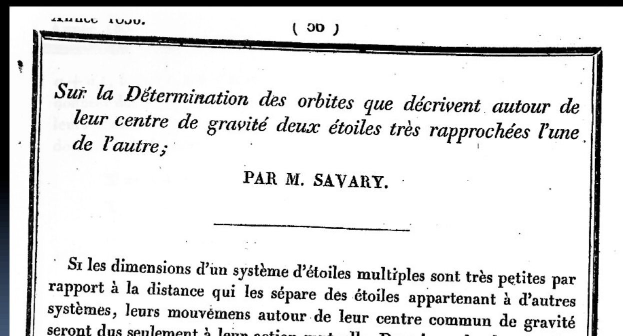
- Ptolemy first mentioned a 'double star'
  - "Quæ in oculo [of Sagitarius] est nebulosa et bina" ($\nu_{1,2}$ Sgr)
- First telescopic double
  - Benedetto Castelli, to his old master Galileo Galilei, on January 7, 1617: "una delle belle cose che siano in cielo" (Mizar?)
- First confirmation of the existence of visual binaries by W. Herschel on July 1st, 1802
  - Binary stars: "…remain united by the bond of their mutual gravitation toward each other"
  - While looking for parallaxes! (suggestion from Galileo Galilei)
    - Herschel measures a large number of couples, beginning on November 11, 1776 with θ1 Orionis,

Orbit of visual binaries

- Why is this meeting organised here ?
  - Simple: here, the first orbit of a binary star was computed
- First method of orbit computation
  - By Félix Savary (1827)
  - Librarian-observer then giving courses of astronomy and "social arithmetic"
  - First "numerical application" with ξ Ursae Majoris, 60yr period, found by Herschel on May 2, 1780



CONNAISSANCE DES TEMS, OU DES MOUVEMENS CÉLESTES, A L'USAGE DES ASTRONOMES ET DES NAVIGATEURS, POUR L'AN 1830; PUBLIÉE PAR LE BUREAU DES LONGITUDES.

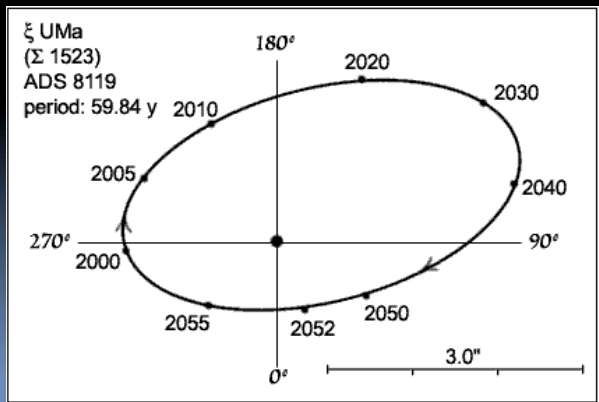


(56)

Sur la Détermination des orbites que décrivent autour de leur centre de gravité deux étoiles très rapprochées l'une de l'autre;

PAR M. SAVARY.

Si les dimensions d'un système d'étoiles multiples sont très petites par rapport à la distance qui les sépare des étoiles appartenant à d'autres systèmes, leurs mouvemens autour de leur centre commun de gravité seront dus seulement à leur

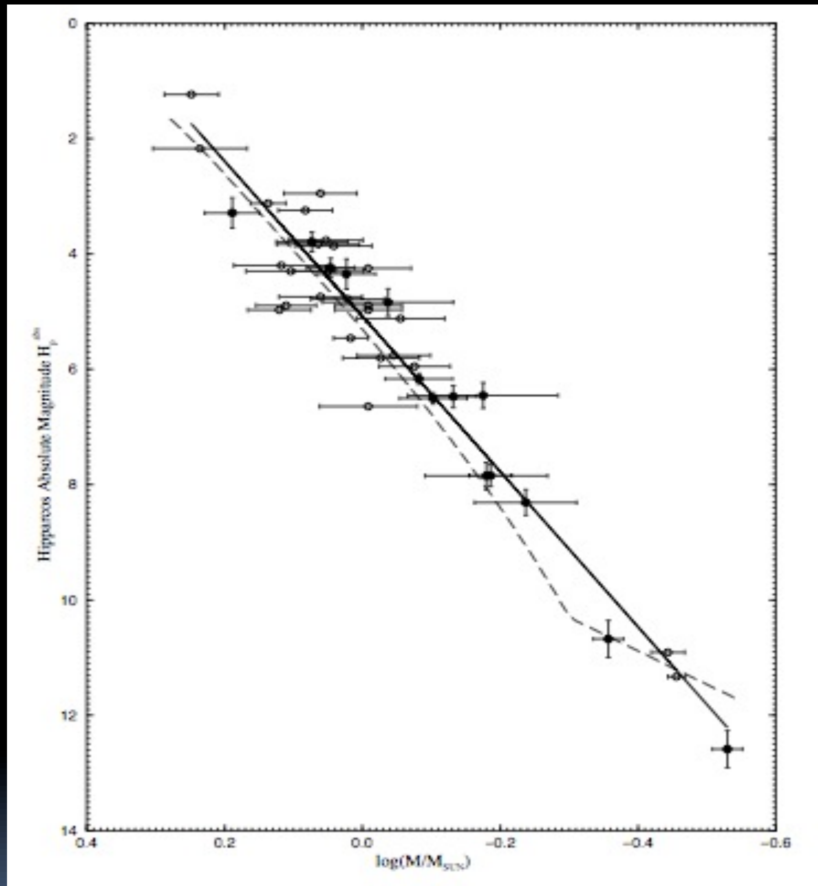


Orbit complementarity

	Eclipsing	Spectroscopic	Astrometric	Visual
Typical period range	hour-month	day-decade	year-century	year-century
Inclination	yes	no	yes	yes
Semi-major axis	a_1+a_2 (radius unit)	$a_1\sin(i)$ (km) $a_2\sin(i)$ if SB2	a_0 (angle)	a_1+a_2 (angle)
Masses		$M^3_{1,2}\sin^3(i)/(M_1+M_2)^2$ $M_{1,2}\sin^3 i$ if SB2		$(M_1+M_2)\ \varpi^3$

Astrometric + SB2 binaries

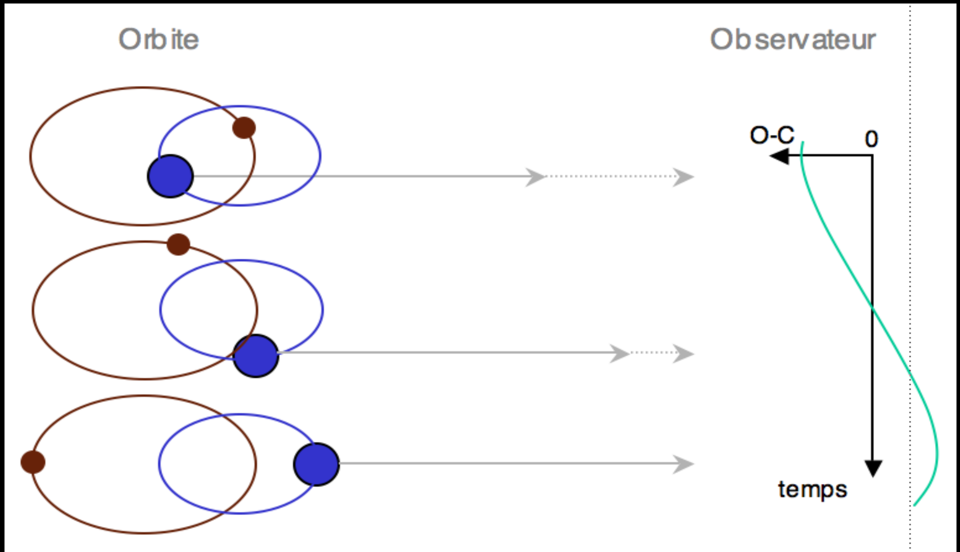
- Hipparcos unresolved binaries
  - Still, the magnitude of each component can be found from orbit when SB2
- Photocenter motion
  - Depends on mass-ratio q and magnitude difference Δm
  - $a_0=a_1[1-(1+q^{-1})(1+10^{0.4\Delta m})^{-1}]$
- What is known
  - q and $a_1$sin*i* from spectro
  - a_0 and sin*i* from astrometry
  - So masses and Δm can be known



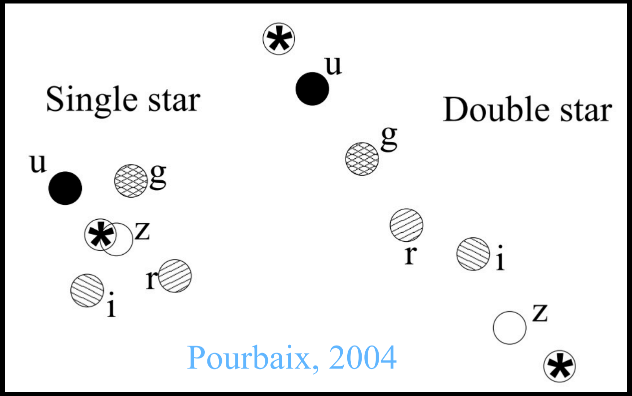
Absolute magnitude vs Mass for 7 SB2

Light-travel time binaries

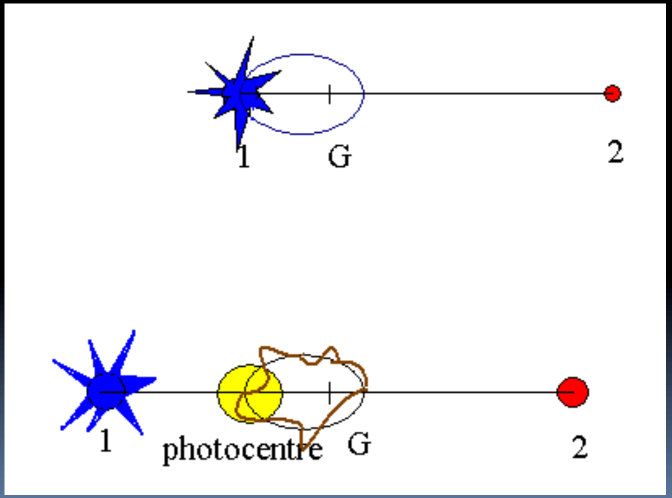
- Clocks in orbit
- Example: R CMa
  - Known as eclipsing binary
  - And acceleration solution in Hipparcos
  - Combining LTT with astrometry gives
    - P ≈ 91 yr
    - $M_3 \approx 0.5\ M_{sun}$



Many other detection methods…

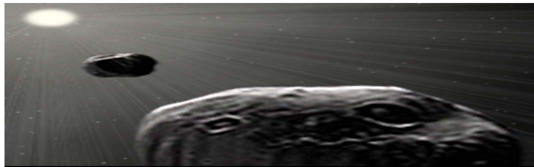


- Colour-induced movers ^
  - Components with different colours+ different filters gives a different photocentre
- Occultation doubles
- Variable-induced movers →
  - When one component is variable



Computation of orbits

- A lot of different methods…
  - Savary (1827), Encke (1830), J. Herschel (1833, 1850), Mädler (1835), Villarceau (1847), Klinkerfues (1855), Thiele (1860), Kowalsky (1873), Glasenapp (1889), Mlodziejowky (1890), Zwiers (1896), Lhose (1909), Hellerich (1925), Henroteau-Stewart (1925), Nassau&Wilkins (1927), Russell (1933), … …, Olevic (2004), Hestroffer (2005), Asada (2007)
  - See Docobo's poster
- Even creating virtual points!
  - Savary (1827): example ("invent" 4 points which are convenient!)
  - Valbousquet (1979): Gleitpunkte (create additional dummy points)
  - Hestroffer (2005): M.C. (create millions of new points)
  - What next ?



Orbit computations…

IS THIS ORBIT REALLY NECESSARY?*

W. H. VAN DEN BOS
Lick Observatory, University of California

Some years ago I made the unfortunate statement: "Orbit computation leaves nothing to be desired. Whenever a double star has been adequately measured—and not infrequently long

Research Note

Is this orbit really necessary? (III)

On the use of Hipparcus double-star measurements for orbit computation

J. Dommanget
Observatoire Royal de Belgique, avenue Circulaire, 3, B-1180 Bruxelles, Belgium

Received 10 June 1994 / Accepted 9 December 1994

- We hope that the answer from this meeting will be « yes! »

Binaries in our Solar System

Another Zoo…

General Introduction

(a tale from the XXth century)

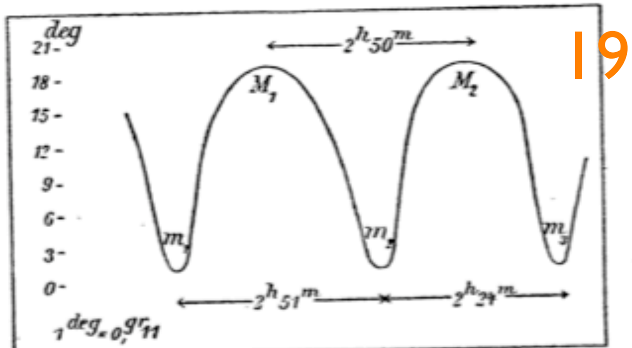
History

- Asteroids book
  - van Flandern (1979)
- based on lightcurve (e.g. eclipsing binary kind)
  - Andre (1901)

Sur le système formé par la Planète double (433) Eros.

Par M. *Ch. André.*

…s observations que nous avons pu faire …umineuse d'Eros m'ont amené à penser … ainsi que cette courbe elle même*) (fig.) et démontre qu'en effet la variation lumineuse ne s'effectue pas suivant une …e oscillation, mais suivant une oscillation double, chaque …iode de la variation se composant de deux branches.



  - Weidenschilling et al. (1989)

History

- Asteroids book – Satellites of asteroids
  - van Flandern et al. (1979)
- based on lightcurve (e.g. eclipsing binary kind)
  - Andre (1901)
- based on stellar occultation observations
  - A possible satellite of Lucina? (Arlot et al. 1976)
- based on hydrostatic equilibrium shapes
  - Weidenschilling 1981 ; Farinella, Zappalà et al. 1981
- based on bi-lobated shapes
- based on doublet craters
- -> surveys gave no evidence (e.g. Kerr 1987, Storr 1999)

History

- Asteroids II book – Do asteroids have satellites?
  - Weidenschilling et al. (1989)
- Asteroids III book – Asteroids *Do* have satellites
  - Merline et al. (2002)

1989

DO ASTEROIDS HAVE SATELLITES?

STUART J. WEIDENSCHILLING
Planetary Science Institute

PAOLO PAOLICCHI
Università di Pisa

and

VINCENZO ZAPPALÀ
Osservatorio Astronomico di Torino

A substantial body of indirect evidence suggests that some asteroids have satellites, although none has been detected unambiguously. Collisions between asteroids provide physically plausible mechanisms for the production of binaries, but these operate with low probability; only a small minority of asteroids are likely to have satellites. The abundance of binary asteroids can constrain the collisional history of the entire belt population. The allowed angular momentum of binaries and their rate of tidal evolution limit separations to no more than a few tens of the primary's radii. Their expected properties are consistent with failure to detect them by current imaging techniques.

2002

Asteroids *Do* Have Satellites

William J. Merline
Southwest Research Institute

Stuart J. Weidenschilling
Planetary Science Institute

Daniel D. Durda
Southwest Research Institute

Jean-Luc Margot
California Institute of Technology

Petr Pravec
Astronomical Institute of the Academy of Sciences of the Czech Republic

Alex D. Storrs
Towson University

After years of speculation, satellites of asteroids have now been shown definitively to exist. Asteroid satellites are important in at least two ways: (1) They are a natural laboratory in which to study collisions, a ubiquitous and critically important process in the formation and evolution of the asteroids and in shaping much of the solar system, and (2) their presence allows to us to determine the density of the primary asteroid, something which otherwise (except for certain large asteroids that may have measurable gravitational influence on, e.g., Mars) would require a spacecraft flyby, orbital mission, or sample return. Binaries have now been detected in a variety of dynamical populations, including near-Earth, main-belt, outer main-belt, Trojan, and transneptunian regions. Detection of these new systems has been the result of improved observational techniques, including adaptive optics on large telescopes, radar, direct imaging, advanced lightcurve analysis, and spacecraft imaging. Systematics and differences among the observed systems give clues to the formation mechanisms. We describe several processes that may result in binary systems, all of which involve collisions of one type or another, either physical or gravitational. Several mechanisms will likely be required to explain the observations.

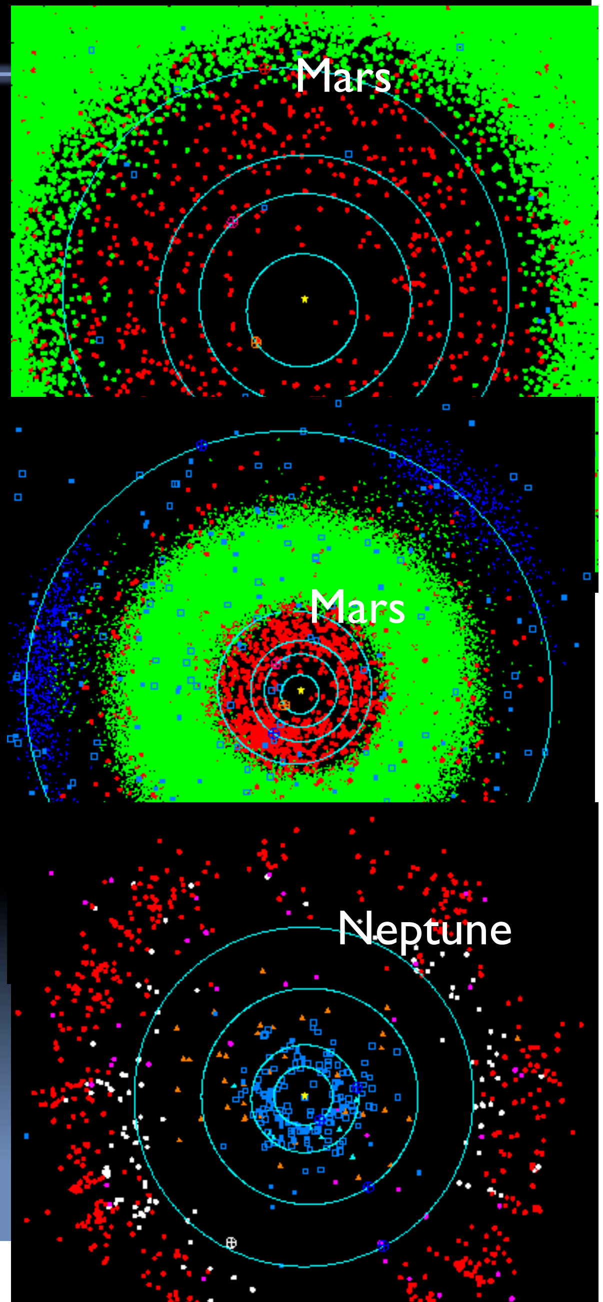
History

- What happened in between?
- 1993 space probe Galileo en route to Jupiter
  - Ida/Dactyl first direct evidence, yet fortuitously
  - Chapman et al. (1995)
- 1997/98 photometry — periods and eclipses
  - Pravec et al. (1998)
- 1998 first ground-based direct imaging
  - Merline et al. (1999)
- 2000 detection by radar
  - Margot et al.. (2002) - Ostro et al. (2006)
- 2002 among the TNO
  - Veillet at al. (2002)
- not mentioning Pluto/Charon (1987) Nyx+Hidra+P4 2011

Populations

Binaries in the Solar System

- ❑ Near-Earth objects (NEO/NEA)
- ❑ Main belt asteroids (MBA)
- ❑ Trojans
- ❑ Centaurs
- ❑ Trans-Neptunian objects (TNOs)
- ❑ Different systems
  - ❑ Low/high mass ratio
  - ❑ Low/large eccentricity
  - ❑ Families ; Multiple (triple)

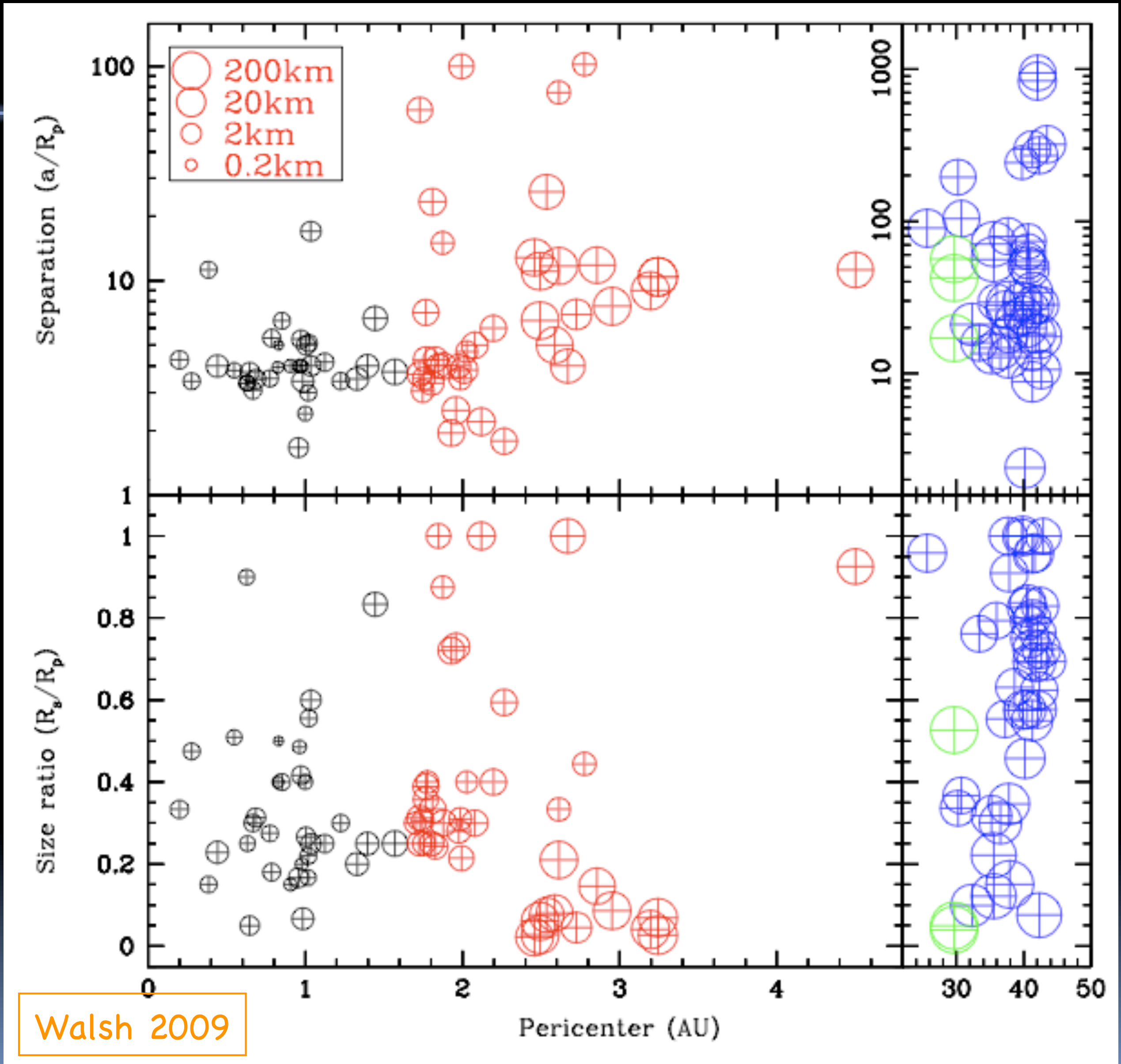


Populations

Binaries in the Solar System

- -Black NEO
- -Red MBA
  - +Trojans
- -Blue TNO
  - Pluto (green)

Note the scales



Populations

- Formation
  - various scenarii for different types NEOBs, MBBs, TNBs
  - rotational fission (YORP), tidal break-up, post-collision re-accumulation, capture (exchange, chaos assisted CAC), ...
- Evolution
  - tides, Kozai resonance, ...
- Use of orbit
  - Predict separation/position for further obs (e.g. spectro, occultation)
  - Orbit characterisation help shed light on formation theories
  - Physical parameters: the total (individual) mass, interior, ...

Populations

Binaries in the Solar System

type	imaging, ground-based	imaging, space-based	radar	photometric lightcurve
near-Earth asteroids	0 (0)	0 (0)	23 (25)	14 (14)
Mars crossers	0 (0)	0 (0)	0 (0)	14 (14)
main belt asteroids	17 (21)	4 (4)	0 (0)	54 (56)
Jupiter Trojans	2 (2)	0 (0)	0 (0)	2 (2)
trans-Neptunian objects	14 (15)	60 (64)	0 (0)	1 (1)
total	33 (38)	64 (68)	23 (25)	86 (87)

Main techniques/instruments

- Adaptive Optics (AO)
  - VLT, Keck, Gemini, etc. (MBA, Trojan, TNO)
- Space-based
  - HST (faint TNO)
- radar
  - Goldstone, Arecibo (NEO)
- Photometry
  - small telescopes network (NEO, small MBA)
- Occultation
  - portable telescopes network (so far MBA)

Talks

- **J.-L. Margot** (inv.)
  - resolved AO, radar, orbit det & evolution
- **W. Grundy** (inv.)
  - resolved HST, orbit, statistical inversion
- **P. Scheirich** (inv.)
  - photometry, orbit
- **V. Lainey** (inv.)
  - multiple system, orbit adjustment
- **Dagmara O.** (tech.)
  - orbit MCMC
- **F. Colas** (tech.)
  - density
- **A. Compère** (tech.)
  - orbit perturbed
- **A.H. Parker** (tech)
  - survey
- **A. Thirouin** (tech.)
  - astrometry
- D. Hestroffer (tech.)
  - orbit,statistical

Monday, October 10

Opening

09:30-10:00 Forewords (F. Arenou + D. Hestroffer)
10:00-10:30 When size matters (D. Pourbaix + P. Tanga)

10:30-11:00 Coffee Break

Session: Solar system binaries

11:00-11:30 Solar system binaries and triples : properties, origin, and evolution (J.-L. Margot)
11:30-12:00 Resolved binaries among TNOs, statistical inversion (W. Grundy)
12:00-12:20 Discovery and Characterization of Trans-Neptunian Binaries in Large-Scale Surveys (A. H. Parker)

13:00-14:30 Lunch (Lunch tickets behind your badge)

Session: Extrasolar planets

14:30-15:00 Occurrence of Planets with radius and period (G.Marcy)
15:00-15:30 High-precision RV measurements in the GAIA era (D. Queloz)
15:30-15:50 Astrometry and Exoplanets Characterization: Gaia and its Pandora's Box (A. Sozzetti)

15:50-16:20 Coffee Break

Session: Binary stars

16:20-16:50 Speckle interferometry of binary stars (B. Mason)
16:50-17:10 The mass-ratio distribution of binary stars (H.M.J. Boffin)
17:10-17:30 Binaries with A-type primaries - A comparison between dynamical masses and theoretical models (R.J. De Rosa)

Cocktail 18:00, Bâtiment Perrault, salle Cassini

Tuesday, October 11

Session: Photometry

09:00-09:30 Eclipsing binaries: why, how, and what next? (J. Southworth)
09:30-10:00 Orbit determination of eclipsing binary asteroids from photometry (P. Scheirich)
10:00-10:30 Kepler and Orbiting Triples : Pas de Trois (D. W. Latham)

10:30-11:00 Coffee Break

11:00-11:30 Photometric detection of non-transiting short-period binaries through the BEaming, Ellipsoidal and Reflection effects in Kepler and CoRoT lightcurves (T. Mazeh)
11:30-11:50 Binaries densities from light curves and stellar occultations (F. Colas)
11:50-12:10 Towards an Automated Processing of Gaia Eclipsing Binaries (C. Siopis)

Session: Radial velocities

12:10-12:40 Stellar wobble in triple star systems (A.C.M. Correia)

13:00-14:30 Lunch (Lunch tickets behind your badge)

14:30-15:00 Probing exoplanet population synthesis models with large samples of RV (and Gaia astrometric) orbits (C. Mordasini)
15:00-15:20 Spectroscopic binary processing within Gaia DPAC (Y. Damerdji)
15:20-15:40 When will we be able to discover exosatellites? (P. P. Campo)
15:40-16:00 Extending the GAIA planet catch by combining with precise radial velocities (M. Neveu)

16:00-16:30 Coffee Break

Session: Associated problems and technics

16:30-17:00 Planetary satellites as a N-body problem in the solar system (V. Lainey)
17:00-17:30 Precision measurements for binary pulsars (M. Kramer)
17:30-17:50 Astrometry of TNOs to characterize astrometric binaries in the solar system (A. Thirouin)

Wednesday, October 12

09:00-09:20 Orbital inverse problem and binary asteroids (D.A. Oszkiewicz)

09:20-09:40 Could Gliese 22 Bb be detected by direct imaging? (M. Andrade)

09:40-10:00 Limitation of the TTV technique for the detection of new planets (G. Boué)

10:00-10:20 Dynamical analysis of the nu Octantis planetary system (K. Gozdziewski)

10:20-10:50 Coffee Break

10:50-11:10 Interferometry, spectroscopy and high-precision astrometry of the bright eclipsing binary Delta Velorum (P. Kervella)

11:10-11:30 Approximation of the gravitational potential of a non spherical asteroid : application to binary and triple asteroidal systems (A. Compère)

11:30-11:50 Astrophysical noise in the astrometric detection of exoplanets (J. Schneider)

11:50-12:10 Orbital characterisation of binaries from Monte Carlo inversion (D. Hestroffer)

13:00-14:30 Lunch (Lunch tickets behind your badge)

Workshop

Orbital couples : "*Pas de deux*" in the Solar System and the Milky Way

Paris, October 10-12, 2011

Some conclusions

- D. Queloz:
  - "Finding planets is just like picking mushrooms: when you find one, you find others"
  - "When you do not have enough points to have a meaningful histogram, use a cumulative histogram!"
- D. Latham:
  - "My wife thanks the organisers for inviting me!"
- T. Mazeh
  - "Röemer discovered in France that light is finite, but could obtain to be on a stamp in Denmark only"
- M. Kramer
  - "We can measure a period with the atto second uncertainty"

Final remarks

- Presentations can be put on the web:
  - USB key or send by mail to hestro or fred arenou
- Proceedings
  - 4 pages or 6 pages (cf. template)
  - doc, pdf, or latex (if you bring the wine next time)
  - deadline December 31 (OK, make it in 2012… January 1st)
- Outcome
  - Discussion - interactions?
  - Another meeting? IAU, other topic, … ?
  - Ménage à trois ? (A. Quirrenbach, A. Harris: (in)stability)