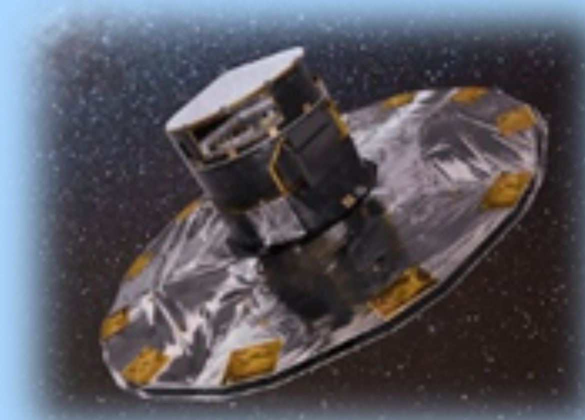
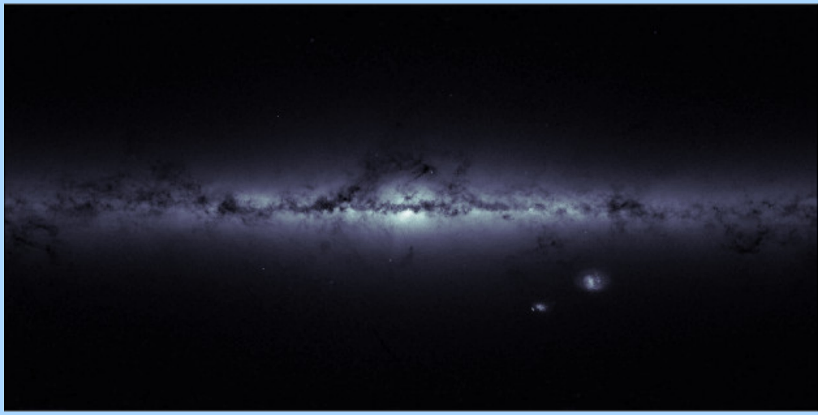
Preparing for the analysis of Gaia's astrometric data releases.

William van Altena
Yale University



Gaia's general goals

- Investigate the origin and subsequent evolution of the Milky Way.
  - Census of 10^9 stars in our Galaxy
  - Develop the most accurate 3D map of Galaxy
    - Map from Gaia scans >>



Gaia's general goals

- Galactic Structure
  - Determine magnitudes, colors, positions and tangential velocities for stars and star clusters brighter than m = 20 – about 10^9 stars.
  - Determine spectroscopic data (metallicity, distance, extinction and radial velocities for stars brighter than m = 15 – about 150×10^6 stars.

What can we use Gaia's DR1 for?

- Systematic corrections to existing catalogs
  - Use DR1 positions for faint stars and TGAS proper motions for bright stars
  - Existing catalogs will have completely different systematic errors from TGAS
    - Except where the existing catalogs used Tycho as a source of positions.
  - Evaluate corrections for 2MASS, UCAC4, URAT, SPM & NPM, USNO-B, XPM, PPMXL, etc.

The Magellanic Clouds

- Absolute proper motion of the Clouds
  - Are they bound to the Milky Way?
- Relative proper motion of the two Clouds
  - Are they orbiting each other? First pass?
- Membership of different types of stars in various regions of the Clouds.
- Clusters in the MC

Galactic structure and the TGAS pms

- TGAS pms are a little bit more precise than ground-based cats, but should have different systematic errors.
- Local galactic structure
  - Gould's Belt, Rotation, Expansion?
  - Kinematic characteristics of Pops I, II & III?
  - Open Cluster absolute pms and membership
  - Globular Clusters – crowding may be a problem

Galactic structure and future Gaia pms

- Rotation rate of the Galactic bulge and kinematics of the Galactic bar
- Rotation of the Galactic halo and kinematics of its substructures
- Distances and ages of the globular clusters
- Tracing of the inner and outer spiral structure
- Accurate orbits and astrometric membership of globular clusters and their tidal structures

Milky Way dwarf galaxies

- Many dwarf galaxies have been discovered from the deep Sky Surveys.
- Need to understand their kinematics: lifetimes in orbit until destruction, etc.
- From accurate orbits we can integrate backwards in time to get information on their "origins"

Binary stars

- DR1 positions will add data points to some of the existing binaries
- Future releases will add an enormous amount of data for separations > 0.1”
- Speckle interferometry
  - Continue observations of important close binaries
  - Search for companions to Gaia objects where possible confusion in the astrometric parameters exists

Minor Planets and Comets

- Many new Minor Planets have been detected
- Combine the DR1positions with existing data to help improve orbits

Local Group galaxies

- Once future releases of Gaia proper motions are available we will be able to study the internal motions in the Local Group

How can we best utilize DR1?

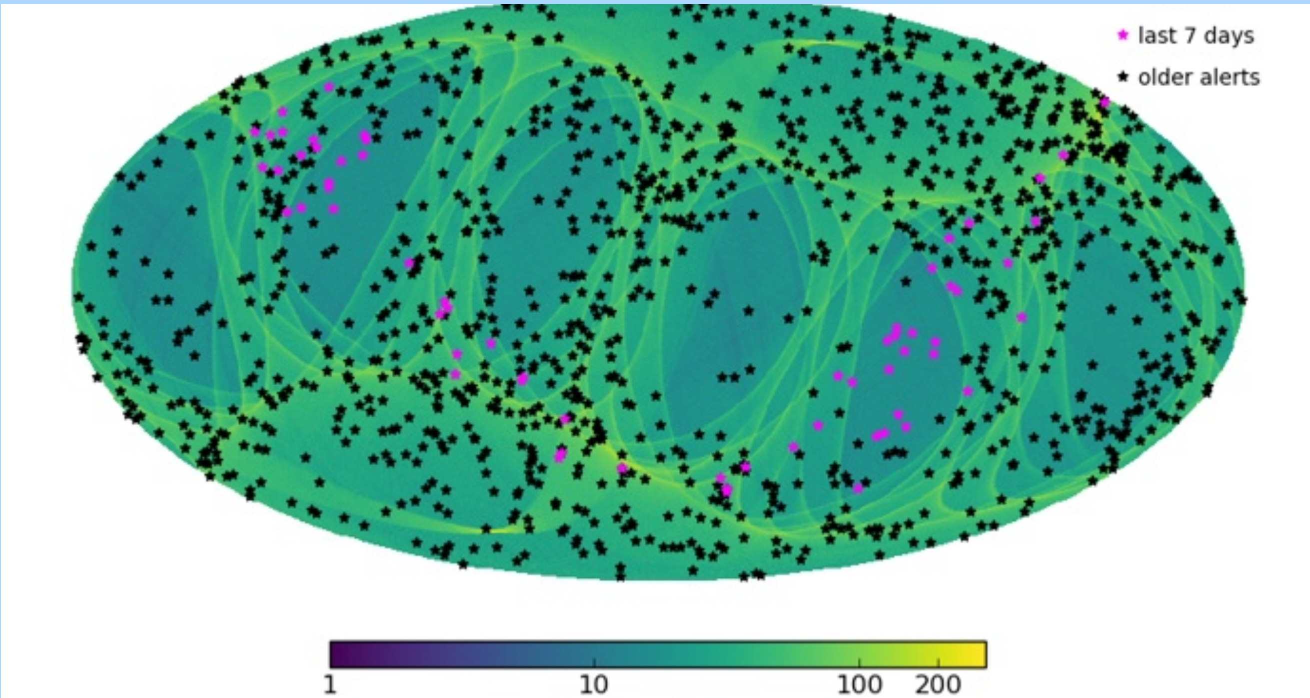
- Gaia DR1 and future releases are unique opportunities to dramatically advance our astronomical research:
  - "Ground-breaking" data available at our desktop computers!
  - Opportunities to compete at the international level without special access to large telescopes!
  - How can we prepare ourselves to take advantage of Gaia?

Things that: “go bump in the night”

Gaia Photometric Science Alerts

(http://gsaweb.ast.cam.ac.uk/alerts)

Gaia photometric science alerts as of 21 September



What astrometric skill-sets do we need to develop?

- Gaia was designed to make major advances to our knowledge of the structure, dynamics and kinematics of our Milky Way Galaxy.
  - We need to update our skill-sets in astrometry and statistics as detailed in René Méndez and Anthony Brown's chapters on those subjects
    - Ch 22:Galactic structure astrometry,
    - Ch 16:Statistical astrometry, in:

      Astrometry for Astrophysics

Star Clusters

- Membership, distances and ages of the globular clusters.
- Internal kinematics and dynamics of the open and globular clusters
  - Kinematic distances
- Kinematics and origins of:
  - Tidal Streams in the Galactic halo
  - Star streams in the Galactic disk
- See detailed discussions in, Imants Platais:
  - Ch 25:Star Clusters

Binary and Multiple Stars

- High resolution astrometry is needed to search for unresolved binaries in the Gaia observations that can perturb their positions, parallaxes and proper motions.
- Gaia parallaxes will yield many stellar masses accurate to 1-2% level – a revolution in our understanding of the stellar mass-luminosity relation.
- Introductions to these topics by Andrea Ghez, Andreas Glindemann, Elliott Horch and Dimitri Pourbaix, in:
  - Ch 10:Astrometry with ground-based diffraction-limited imaging
  - Ch 11:Optical interferometry
  - Ch 23:Binary and multiple stars
  - Ch: 24:Binaries: HST, Hipparcos and Gaia

Systematic corrections to existing catalogs

- Existing catalogs will have completely different systematic errors from Gaia
- Background on this topic is given by: Norbert Zacharias and Carlos López in:
  - ADeLA 2016: The URAT Project, by NZ
  - Ch 20:Astrometric Catalogs: concept, history and necessity.

Solar System Astrometry

- Discovery, cataloging, orbit computation and dynamics of Minor Planets, Kuiper-Belt objects and Comets
- Dynamical improvement of reference frame
- Asteroid masses from near encounters
  - Shapes and sizes from stellar occulations
- Post-Gaia ground-based follow up observations will be vital for this field
- Introduction to this topic by Francois Mignard, in
  - Ch 26:Solar System Astrometry

What are the Characteristics of DR#1?

The Tycho-Gaia Astrometric Solution

Median Astrometric uncertainties (precisions)

	All TGAS sources	Hipparcos stars
G magnitude	11.0 mag.	8.3 mag.
Position	0.3 mas	0.3 mas
Parallax	0.3 mas	0.3 mas
Proper motion	1.3 mas/yr	0.07 mas/yr

Note that the above are precisions and systematic errors several times larger may exist, especially in local areas as noted in the next slide.

Sources of Gaia Astrometric Errors

- Input parameters:
  - Relativistic & aberration corrections
  - Spacecraft & solar system ephemeris
- Instrumental calibration problems
  - Point Spread Function (PSF) variation
  - Sky background & noise variations
  - Uncorrected “Basic-Angle” variations
  - Uncorrected or changing optical field-angle distortion
  - Spin-synchronous errors
- Objects
  - Binary stars, i.e. not all are point-like objects
  - Flux variation, e.g. photometrically variable stars, emission line variation

Sky-Scanning Principle

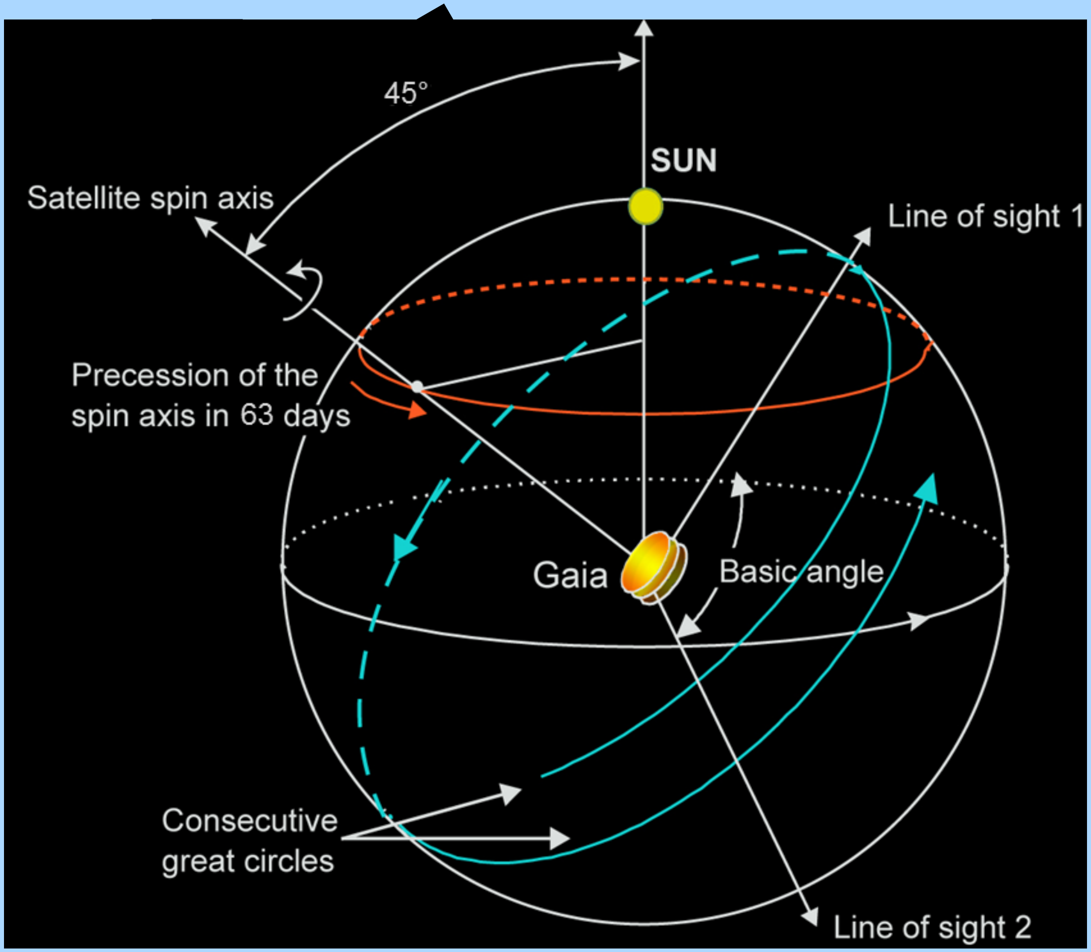


Figure ESA

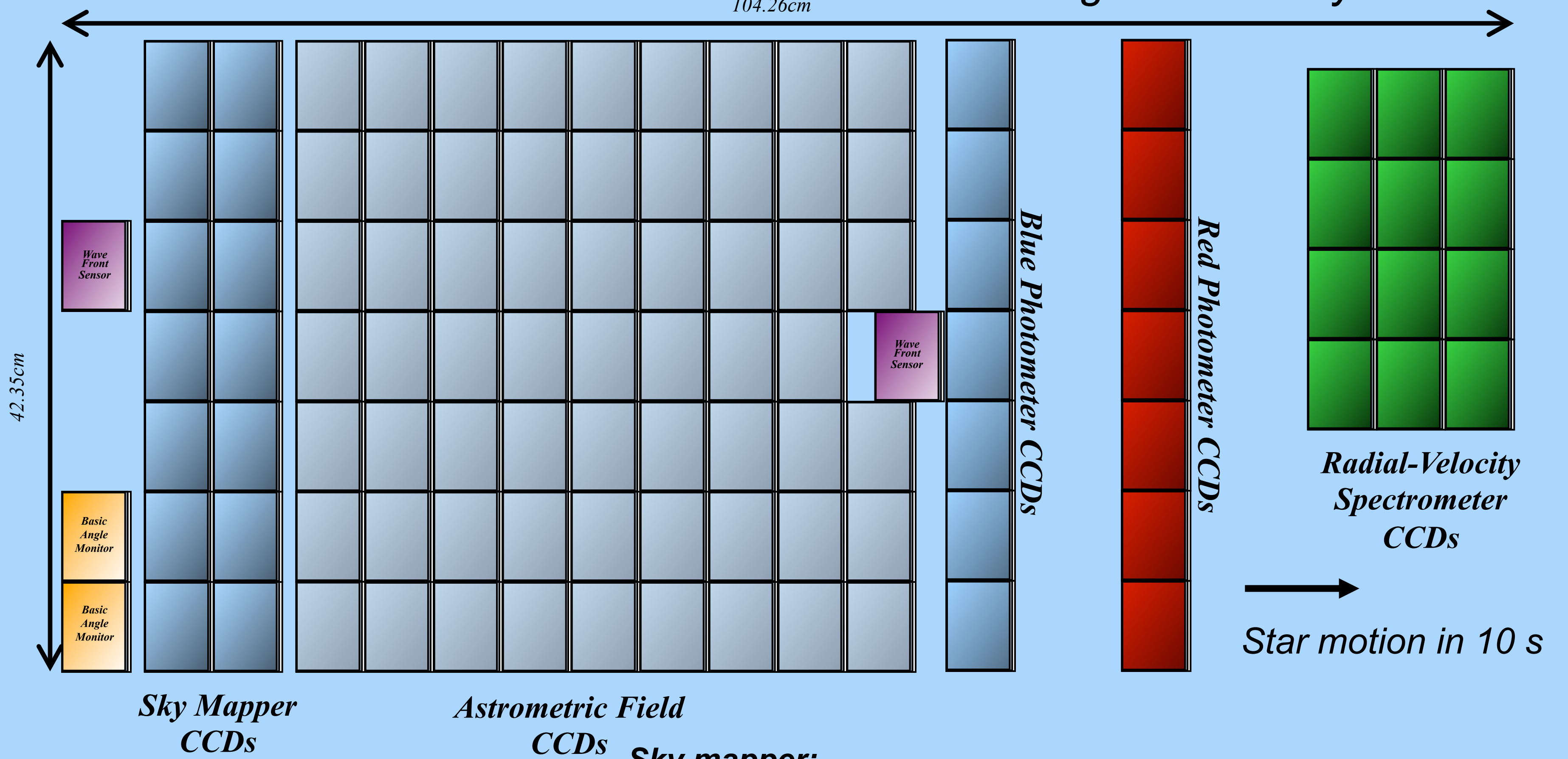
Spin axis	*45° to Sun*
Scan rate:	*60 arcsec s^{-1}*
Spin period:	*6 hours*

Background on the Sky-Scanning Principle

- Background on Gaia, coordinate systems and measurement system reductions can be found in the following chapters by: Lennart Lindegren, Nicole Capitaine &Magda Stavinschi, Zheng Hong Tang & William van Altena
  - Ch 2:Astrometric Satellites
  - Ch 7:Celestial Coordinate Systems and Positions
  - Ch 19:From Measures to Celestial Coordinates

Focal Plane

Figure courtesy Alex Short



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 G=20 mag
- rejects cosmic-ray events
- field-of-view discrimination

Astrometry:

- total detection noise ~ 4 e^-

Photometry:

- spectro-photometer
- blue and red CCDs

Spectroscopy:

- high-resolution spectra
- red CCDs

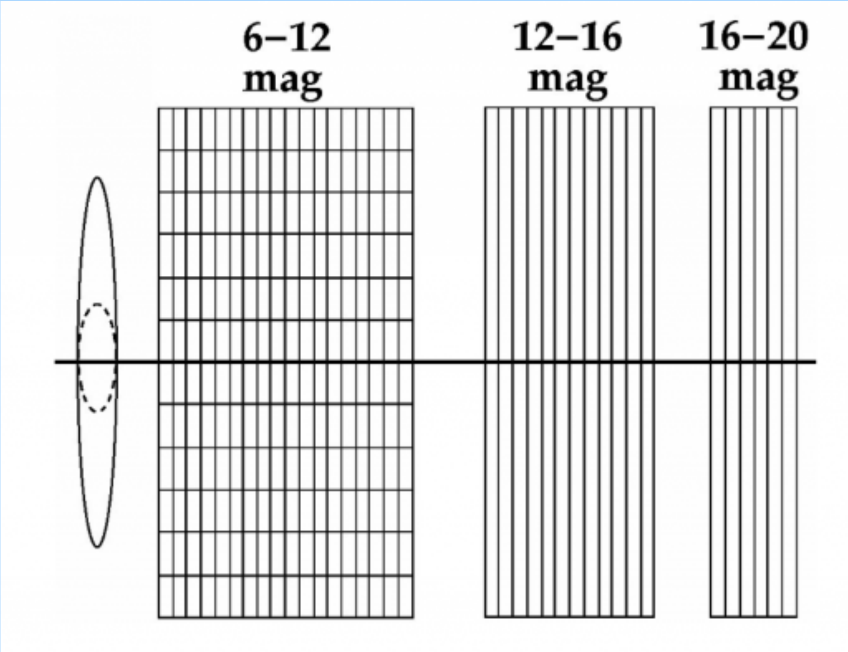
Gaia scanning – time-delayed integration

- Objects drift across the CCDs in the Gaia focal plane
  - Charge accumulates and is transferred in synchronism with the rotation of the satellite.
  - Depending on the brightness of the object the integration is terminated in one of 12 steps
    - This procedure may lead to position errors that are a function of the magnitude, estimated to be about 0.2 mas. In the DR1 data
- For more details see: Steve Howell and David Rabinowitz,
  - Ch 14:CCD Imaging Detectors
  - Ch 15:Using CCDs in the time-delay integration mode

Gaia's Sky Mapper

- Sky mapper resolution
  - along-scan/across scan

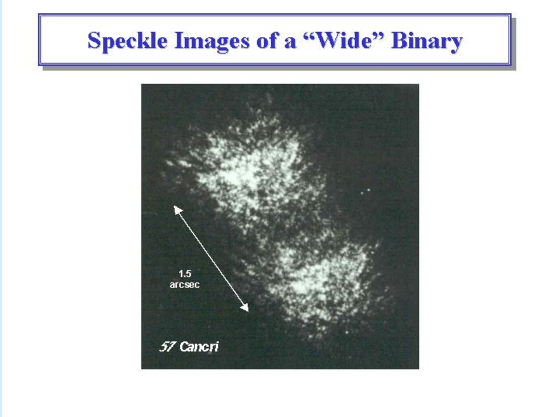
  0.23” x 0.70” (doubles?)
  - Many scans at random angles give 0.1” resolution
  - Systematic errors from close binaries, crowded fields & local sky background variations
- Speckle observations to detect binaries

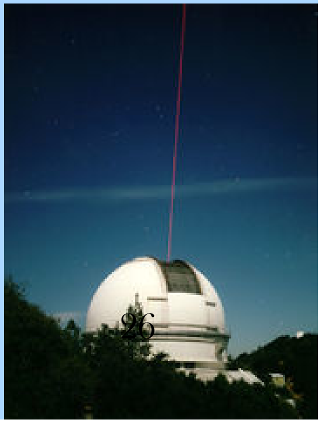


Window Size Depends on Brightness – Image: ESA

Dealing with Gaia's limited resolution

- Speckle and Adaptive optics searches for Gaia's unresolved doubles that may effect astrometry
- For more details see: Andrea Ghez
  - Ch 10: Astrometry with ground-based diffraction-limited imaging

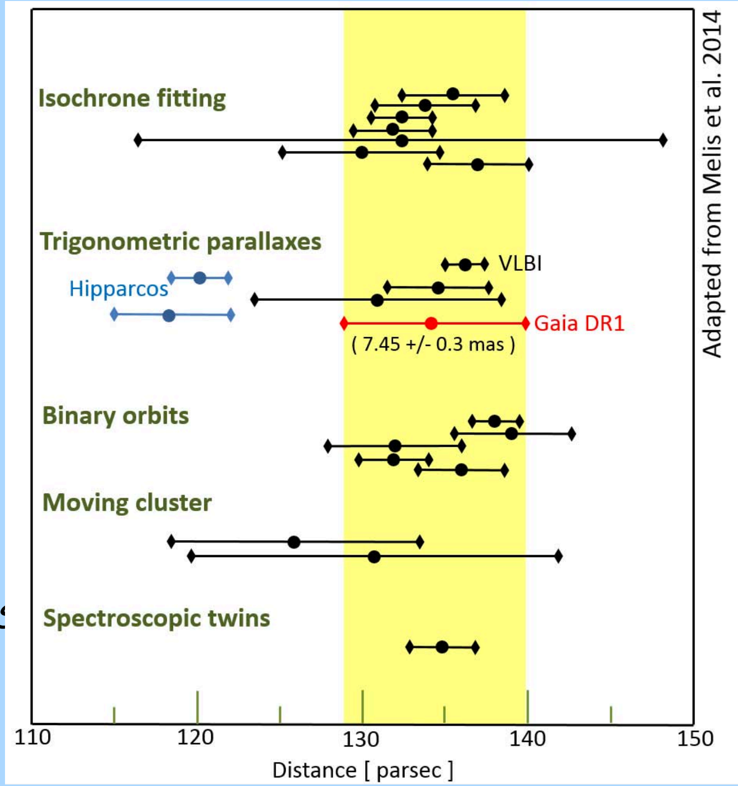




Spin Synchronous Gaia Errors

- Spin-synchronous errors
  - Field-of-view = 0.75×0.75^0
  - Uncorrected errors within the FOV, e.g. time-variable optical field-angle distortion might remain.
  - <u>**Large-number averaging will not work within the FOV**</u>
    - Several degrees radius – DR1
      - $\pm\sigma_\pi$(random) ±0.3 mas (systematic)
    - Less than 2 degrees radius – DR1
      - $\pm\sigma_\pi$(random) ±1 mas (systematic)

Pleiades cluster parallax



A.G.A. Brown, et al., A&A, aa29512-16.

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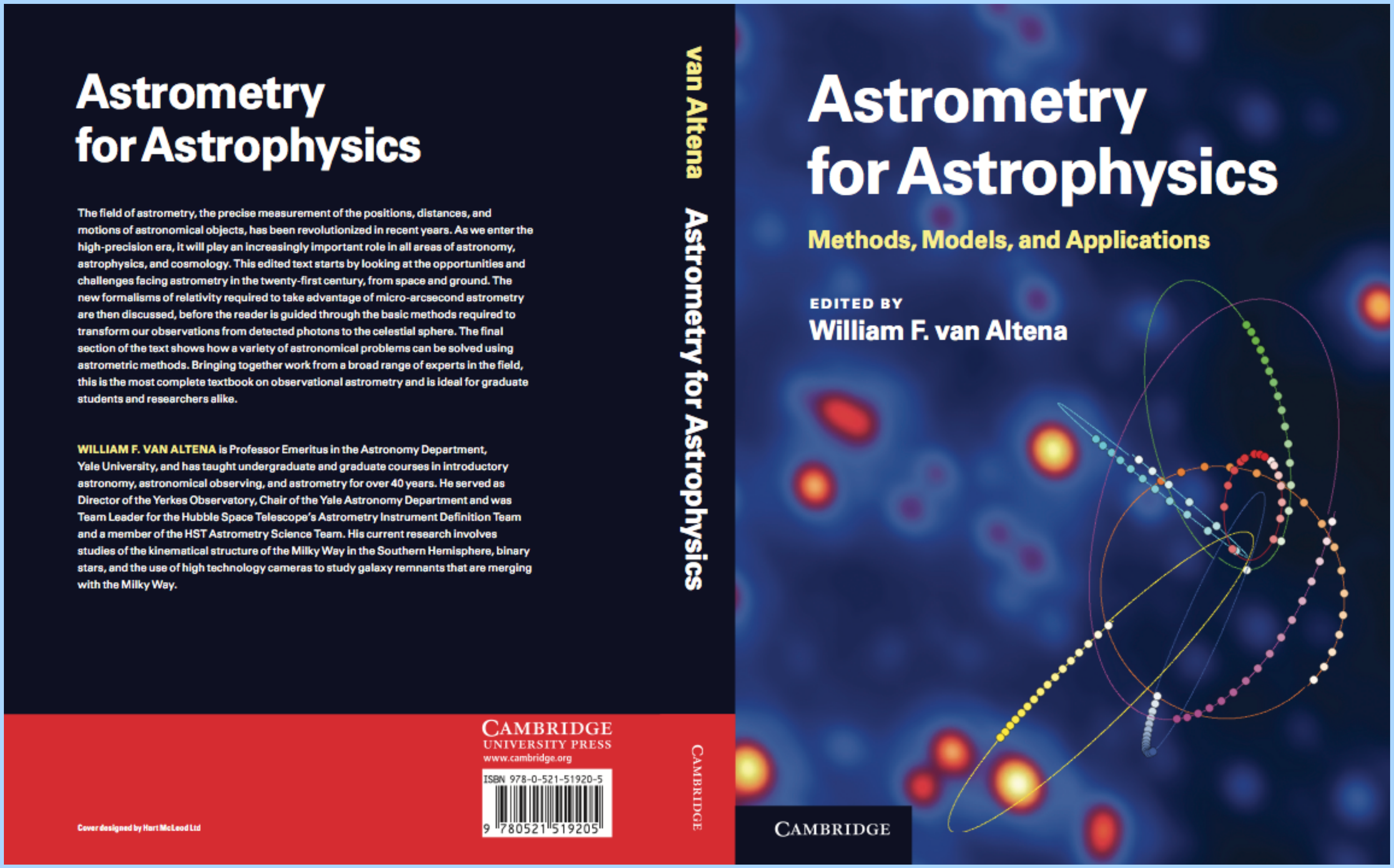
Summary

- Gaia DR1 and future releases are unique opportunities to dramatically advance our astronomical research:
  - "Ground-breaking" data is available at our desktop computers!
  - Opportunities to compete at the international level without special access to large telescopes!
  - We must prepare ourselves now to take advantage of Gaia.

Acknowledgements

- Alejandro Garcia for his outstanding work in organizing this Conference and its organizers who invited me to present this talk.
- Apologies to all that I wasn't able to attend in person!
- European Space Agency & its contractors that developed Gaia and our European Gaia colleagues, all of whom have provided us with an outstanding facility for astrometric research.

The Introductory Astrometric textbook designed to help you understand Gaia data



http://www.astro.yale.edu/vanalten/book.htm