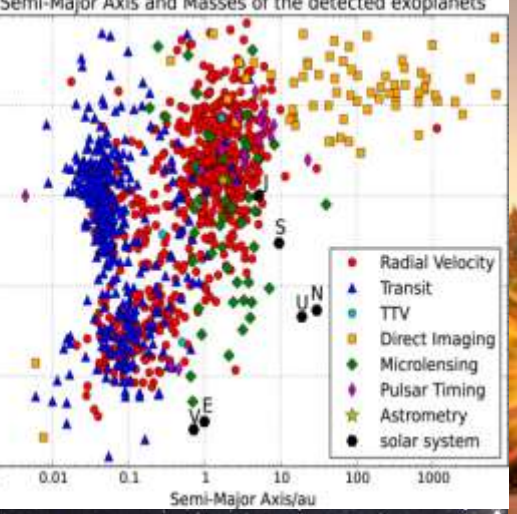
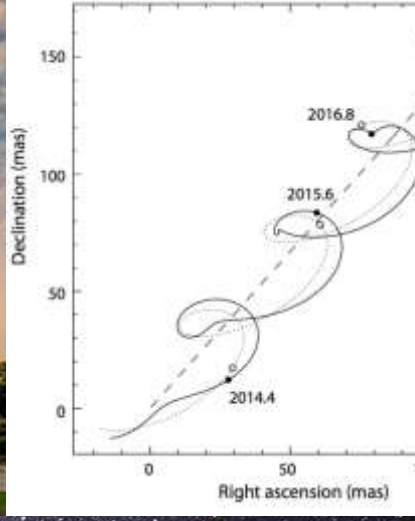
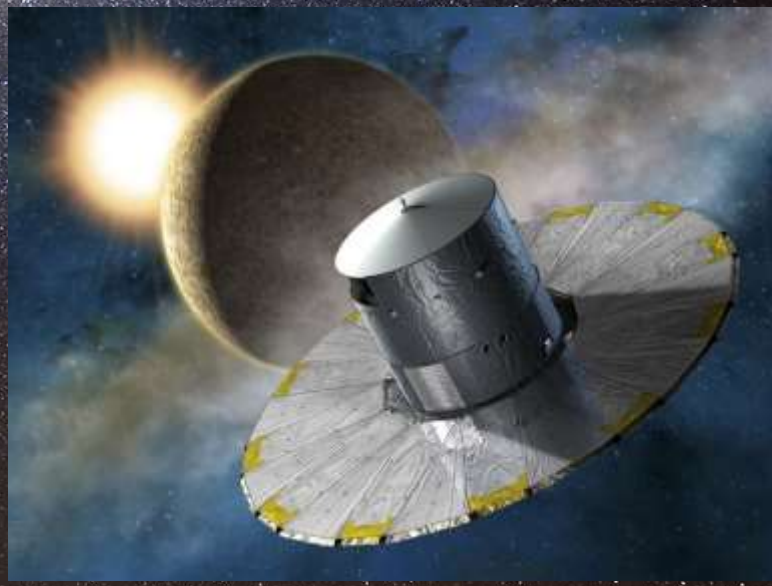


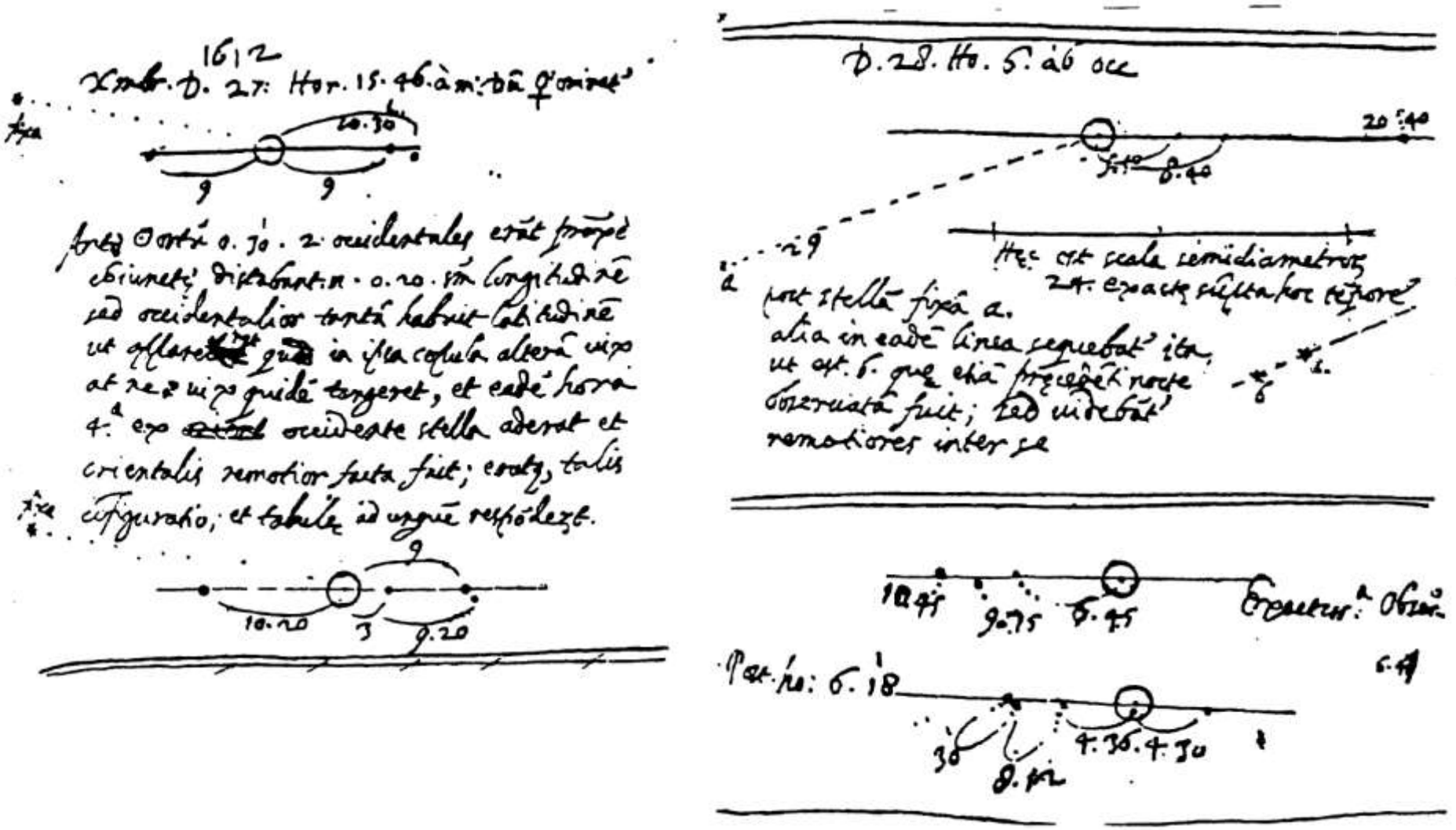


Astrometry in Italy



A. Sozzetti
INAF - Osservatorio Astrofisico di Torino
(with help from M.G. Lattanzi, G. Piotto, R. Smart)

Astrometry and Planets in Italy



1612 -1613: Galileo's discovery of Neptune! Only, he probably did not know…

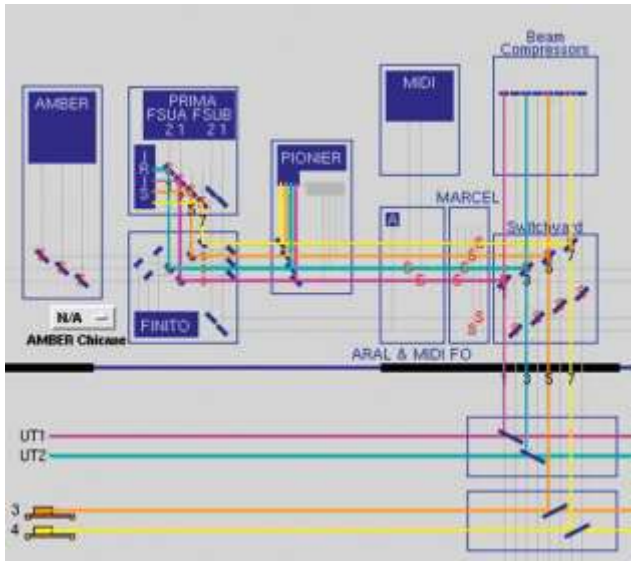
The Last (Few) Decades

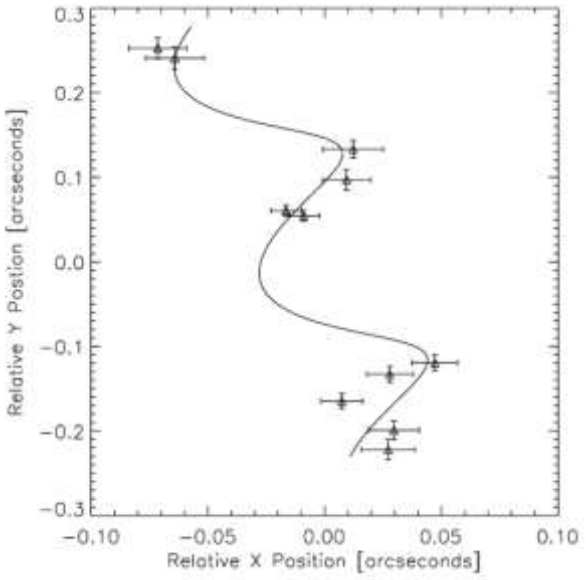
- Science driven applications of astrometry in the optical (mostly)
- Global and relative measurements of astrometric observables (e.g. time intervals, angular directions and their change with time, optical path-length differences between the two arms of an interferometer) from the ground and in space
- Determination of fundamental kinematic (distance, space motion) and physical (mass, radius) quantities
- Three classes of relevant contributions and leadership: design and technology development and applications, numerical preparatory work, data analysis and interpretation

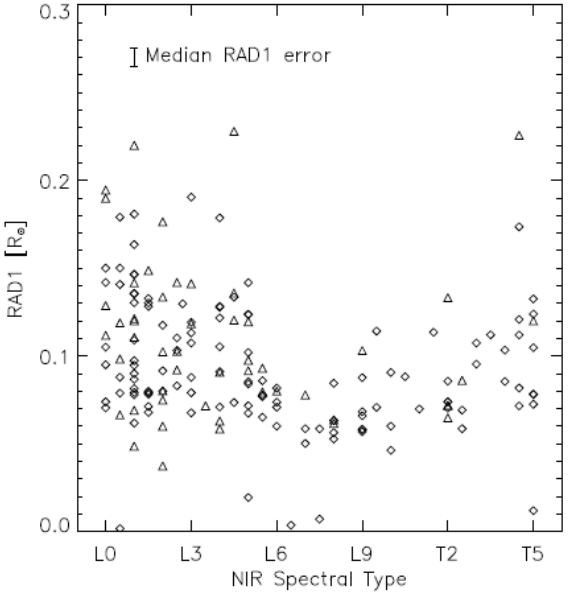
Ground-based astrometry

- Leadership of the FINITO Consortium (M. Gai PI) that provided ESO VLTI with the first-generation high-frequency fringe tracker and Fringe Sensor Units (Under TAS-I Prime contractor to ESO, M. Gai PI).

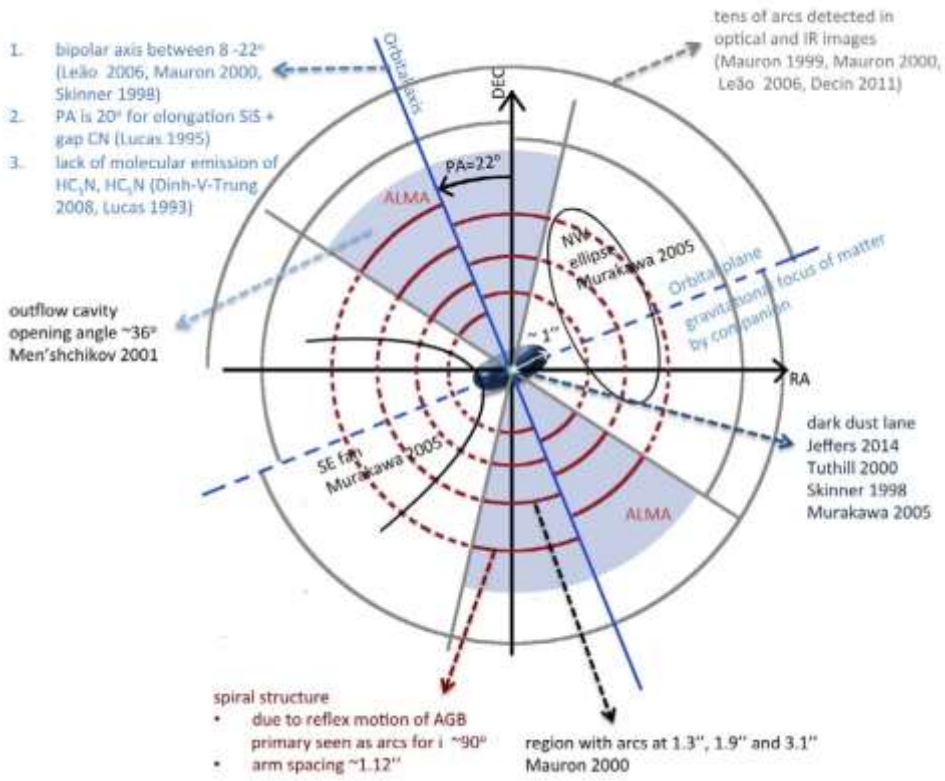
- Leadership of a long-term (20 yr) suite of programs (TOPP (Smart et al. 2003; Sozzetti et al. 2017), PARSEC (Smart et al. 2013), NPARSEC (Smart et al. 2018)) for the determination of relative parallaxes of cool (M type) and ultra-cool (L & T type) dwarfs

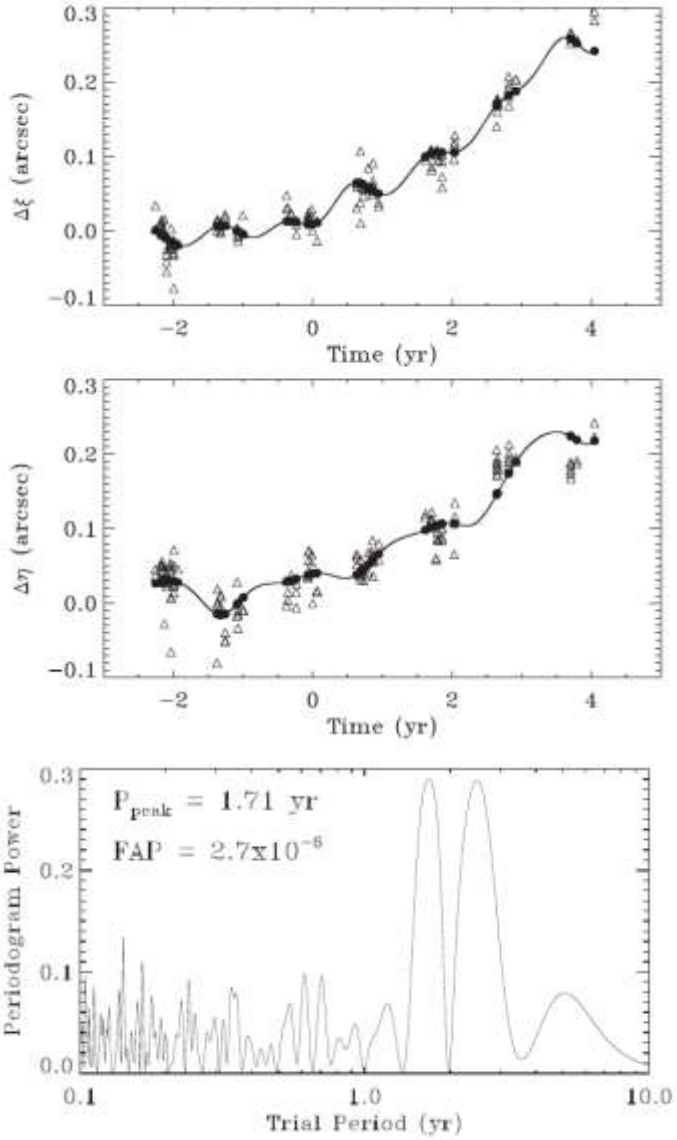






CW Leonis Astrometry





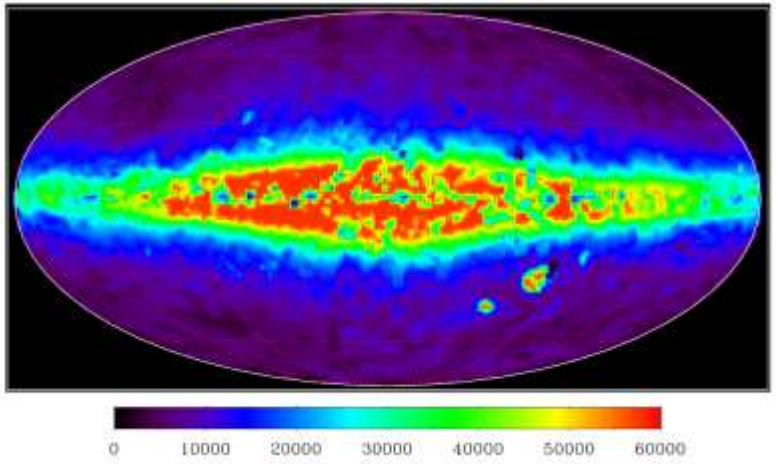
Evidence for orbital motion of CW Leonis via detection of VIM effects (Sozzetti et al. 2017)

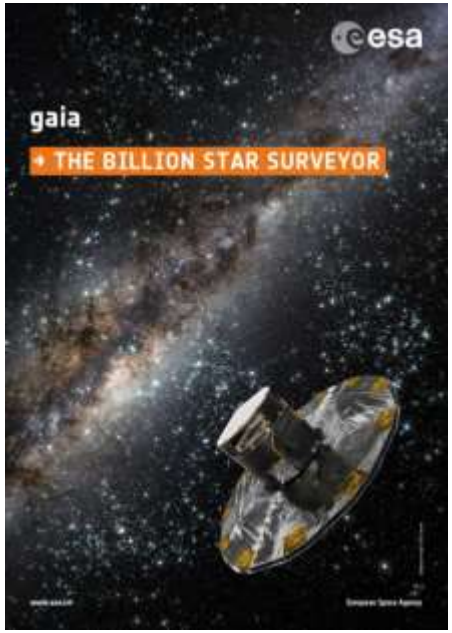
Space Astrometry

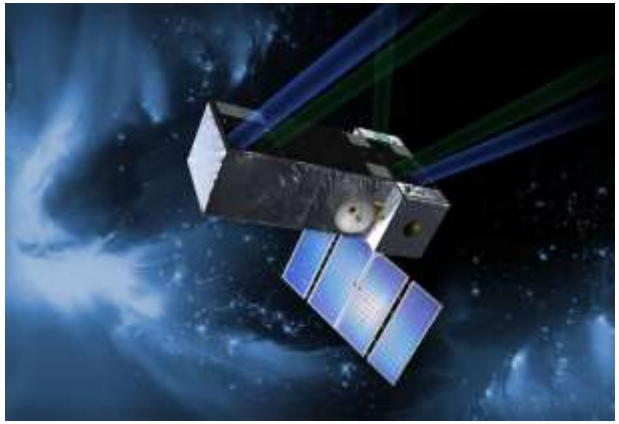
- Astrometric catalogs to enable astrophysics from space-borne facilities such as HST (Lasker, Lattanzi et al. 2008) and EUCLID (PI Drimmel INAF-OATo)

- Global astrometry (Hipparcos, and then Gaia)

- Narrow-field (interferometric) astrometry (HST, but also Gaia!, and then SIM, SIM Lite, NEAT, Theia…)







mas Astrometry: HST

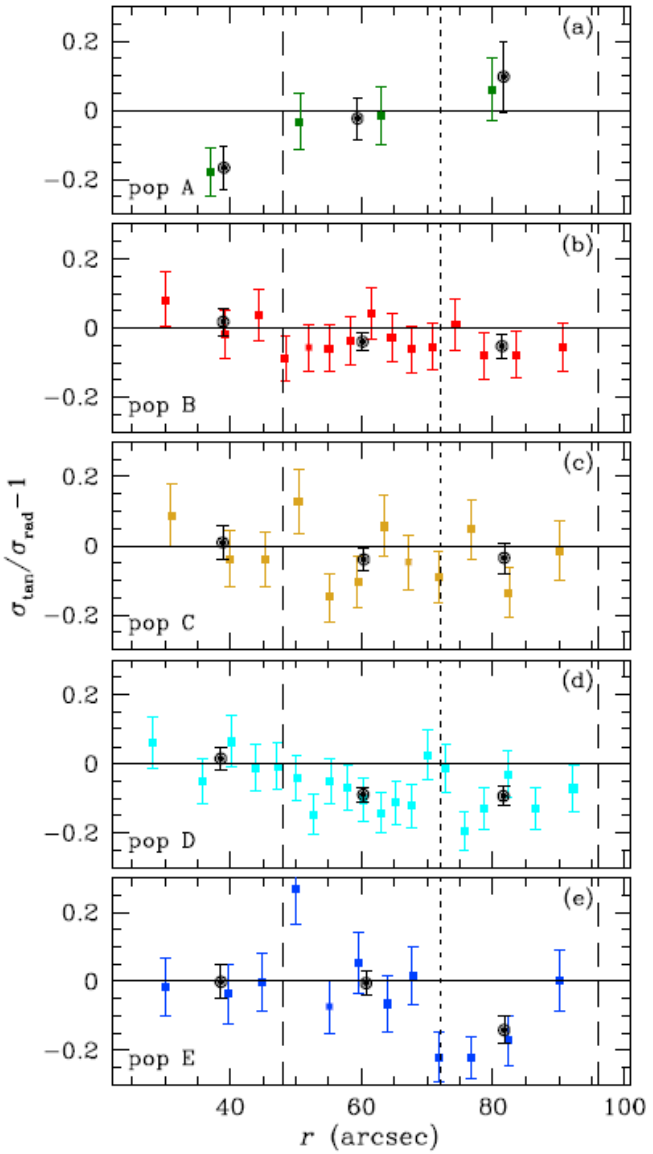
- Development of the scientific capability of HST FGS (Bernacca et al. 1993; Lattanzi et al. 1994; Tanga et al. 2003)

- Interferometric angular diameters of Mira variables with FGS (Lattanzi et al. 1997)

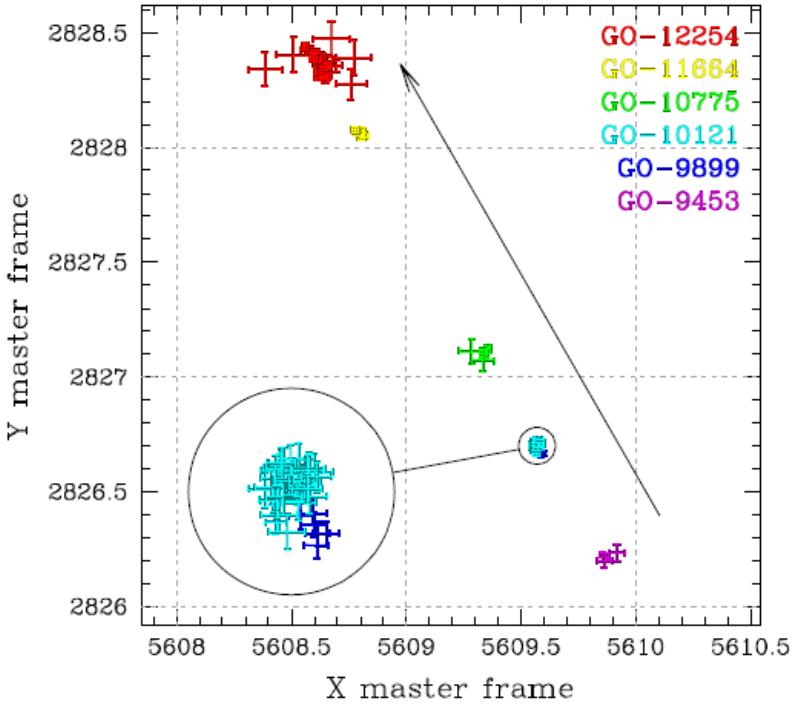
- Internal kinematics of Globular Clusters (HST Legacy Treasury program) with WFC3 (GO 13297, Piotto et al. 2015 and following)

- Measurement of light deflection from Jupiter's quadrupole moment with WFC3 in spatial scanning mode (GO 14666, S. Casertano PI, A. Riess, U. Abbas, B. Bucciarelli, M. Crosta et al. INAF-OATo). 50 μas precision achieved…

Accurate PMs



Bellini et al. (2015)



HST PM surveys of GCs:

- up to 27th mag in the inner regions
- Accurate membership, internal kinematics
- Double main sequences (tangential velocity dispersion differences between 1G and 2G stars)

mas Astrometry: Hipparcos

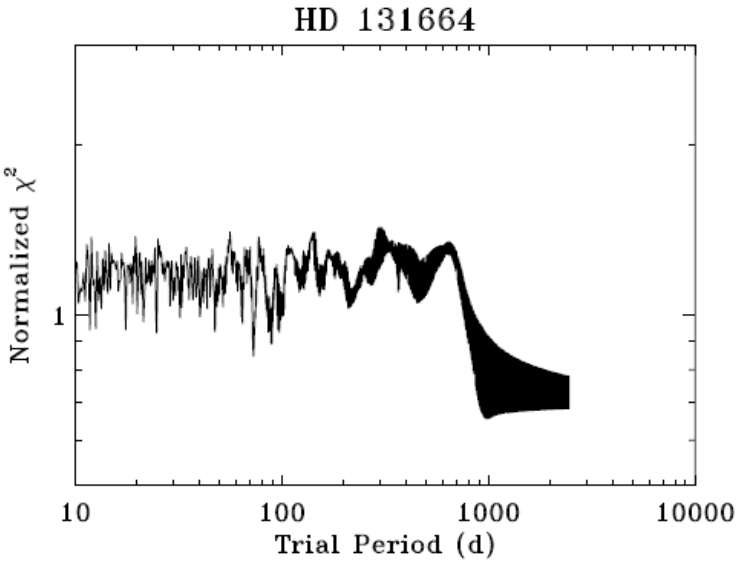
• Institutes involved: UniPd, CISAS Pd OAPd, OATo, UniBo, PoliTo, CSATA Bari, INO Firenze, PoliMi, CSS Torino, CNR Frascati

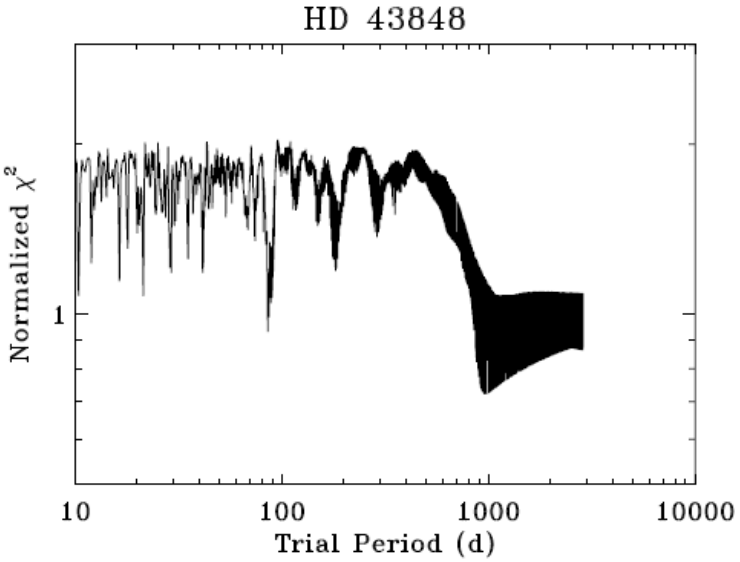
• Leadership of system and mission analysis during industrial feasibility study, 1977. Promotion of mission approval by ESA/SPC (1979-80).

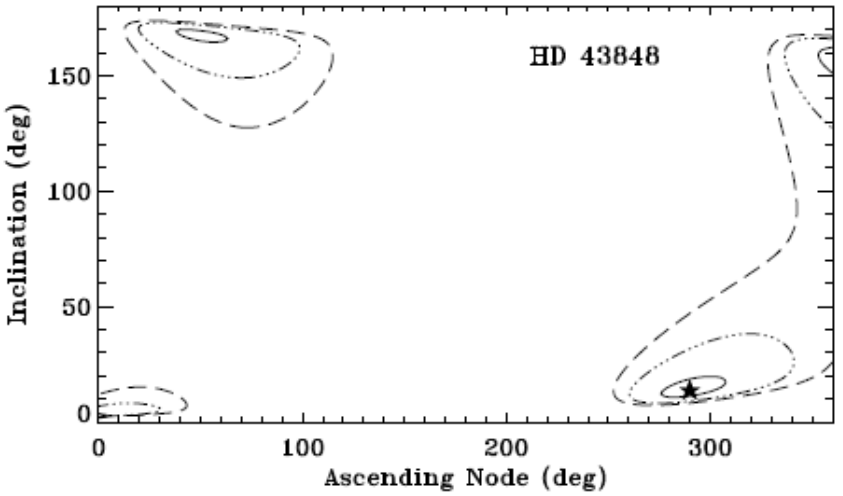
• Major contributions and tasks in the FAST Consortium: optical modelling, main grid and star mapper data reduction, attitude determination, sphere solution, double star reduction and modeling, modeling of minor planets.

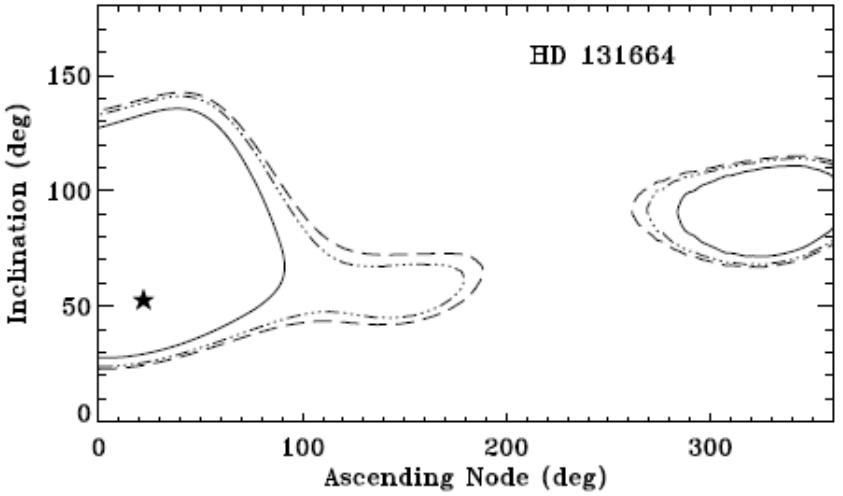
• Major contributions to the Hipparcos Project: comparison of attitude determinations by FAST and NDAC. Preparation of double star reductions in FAST. Membership of the Hipparcos Science Team and of the FAST Steering Committee.

Orbits with Hipparcos



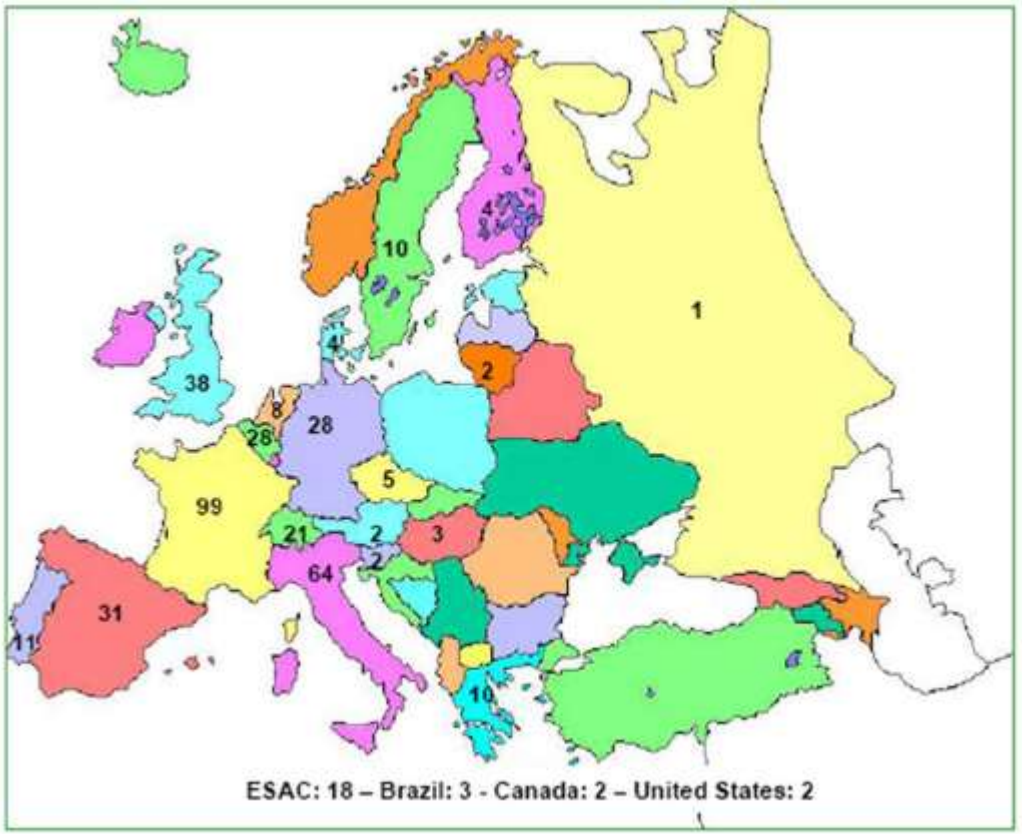






Sozzetti & Desidera 2010

10 μas Astrometry: Gaia



~ Italy's contribution to DPAC is second best, contributing close to 20% of total effort
~ 25 FTE/yr of staff personnel (spread over just more than 60 people) + 12 FTE/yr of contract personnel

CU3 Core Processing: AVU

- Independent (DPAC internal) validation of the baseline all-sky global astrometric solution (AGIS). Three sub-systems: AIM, BAM, GSR

- **AIM:** pipeline processing of data in the astrometric fields with different methods and monitoring of the evolution of the main (astrometric) electro-optical system (Busonero, Lattanzi et al. 2014; Gai, Busonero et al. 2013, 2017)

- **BAM:** pipeline processing of data from the Basic Angle Monitoring Device (BAMD), and monitoring of the evolution of the basic angle between FOVs over all time scales (Riva, Lattanzi et al. 2014; Gai, Riva et al. 2017)

- **GSR:** independent reconstruction of the Celestial Sphere as defined by the primary sources (common to baseline AGIS). It implements the fully relativistic astrometric model RAMOD (e.g., Crosta et al. 2017; Vecchiato et al. 2018)

- All (daily and cyclic) AVU operations are executed at DPCT, built and run by ALTEC (Torino) and INAF-OATo (for ASI).

- First results of the AGIS-GSR comparison expected for DR3 (2021)

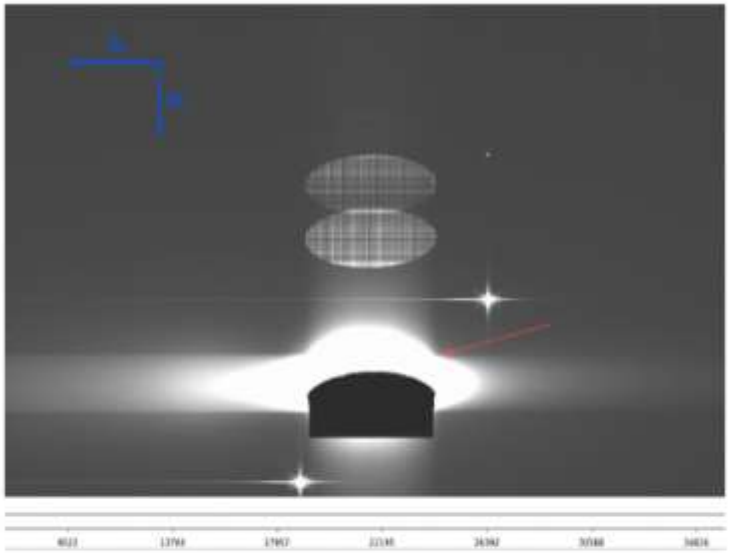
GAIA GAREQ-DIFF

(Crosta & Mignard, 2006; Crosta et al. 2008, **GAIA-C3-TN-INAF-MTC-003-1**; Abbas, Bucciarelli et al, **PASP** 2017; Abbas; Bucciarelli, et al. 2017, **GAIA-C3-TN-INAF-UA-005-01.**)

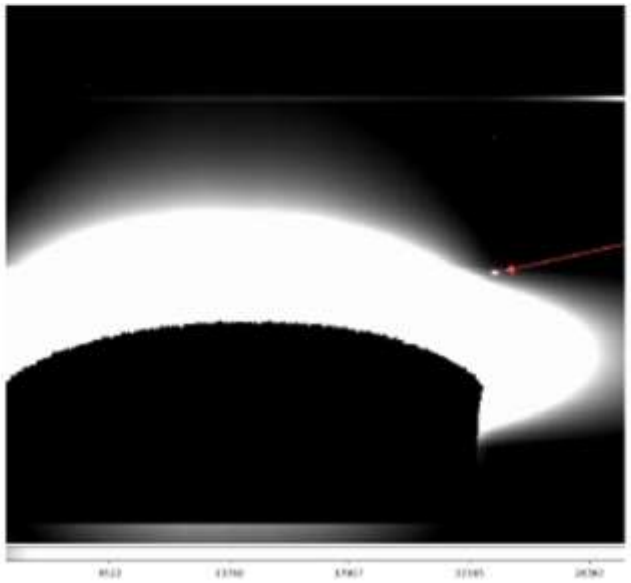
Based on on-board detections during the GAREQ event **of Feb 2017** (Pixel SM data from Gaia, Crowley et al. 2017)

Observations for the **closest transit of the Target star** at angular **separation of 6.73" from Jupiter's limb** seen on 2017-02-23T02:55:01.694

Combine different target fields In a differential astrometric analysis of the target obs. (INAF-OATo lead, developed via the DPCT@ALTEC)



Section of the SM image around Jupiter for the closest transit. The location of the target star is shown by the red arrow.

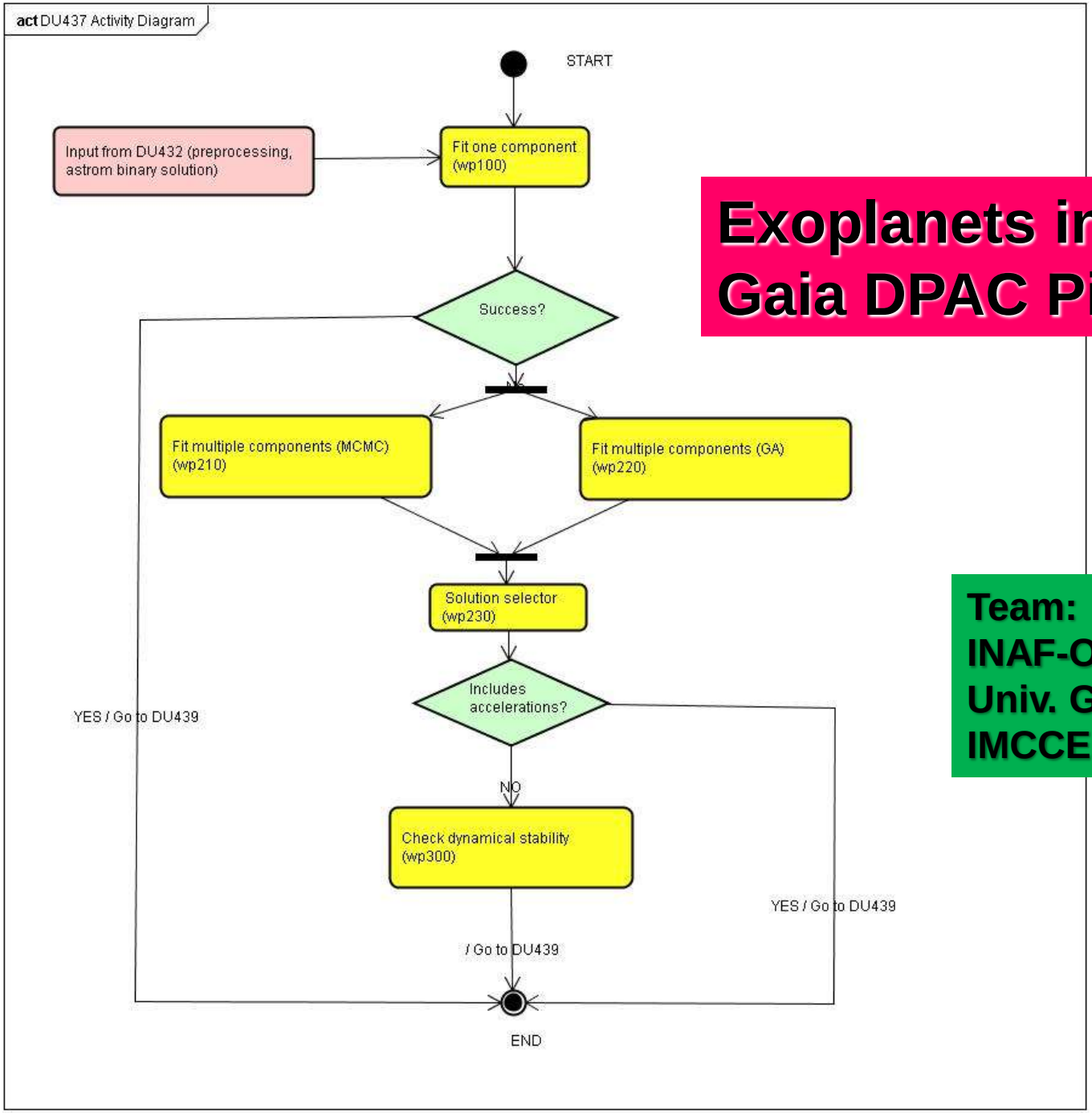


A zoom-in to the top image for the closest transit. The target star is visible just outside the saturated region.

Image credit ESA/Gaia/DPAC/C. Crowley

CU4-NSS

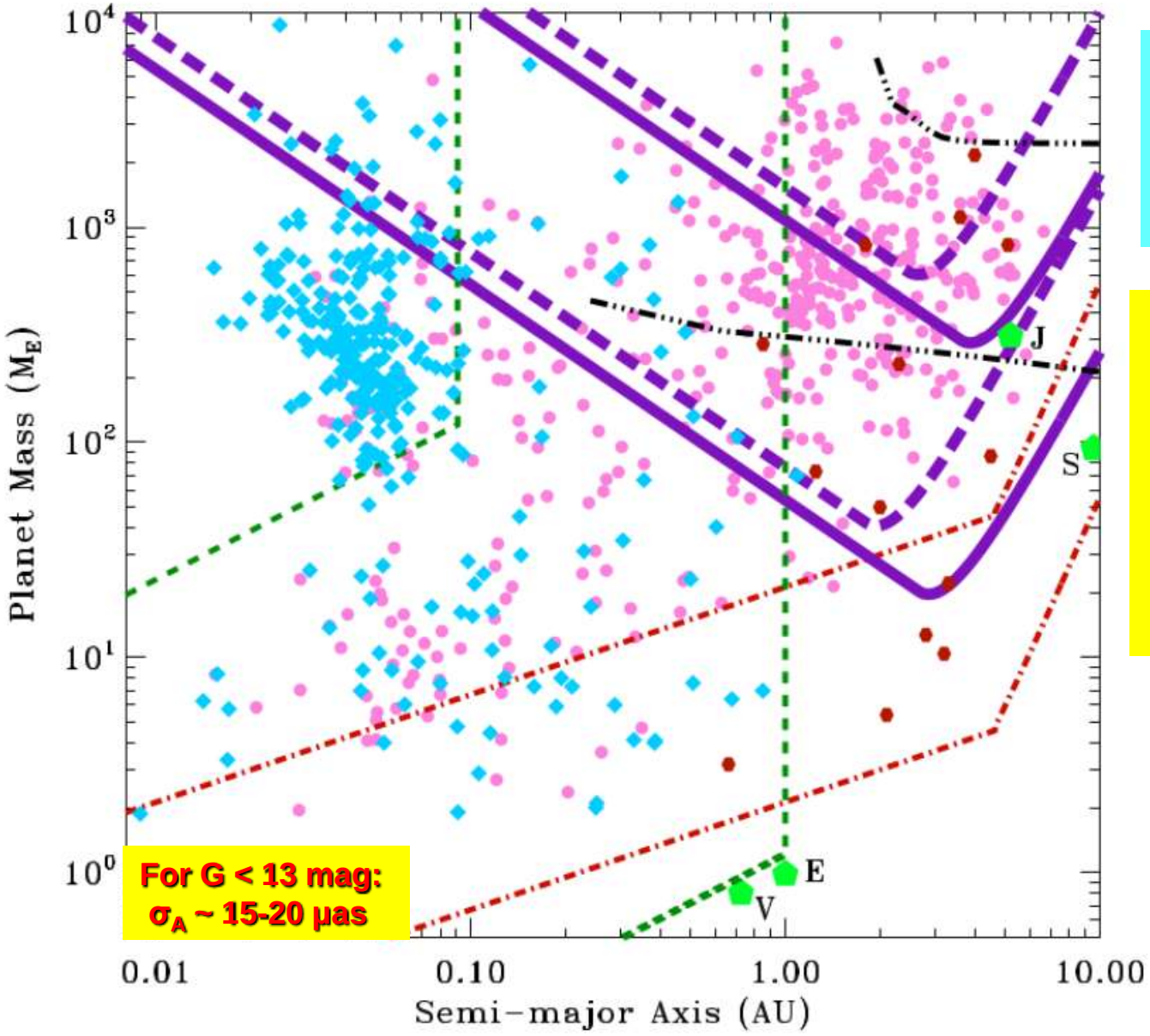
- CU4-NSS handles astrometric, photometric and spectroscpic modeling of non single stars (including exoplanet orbits)
- It requires input of non-well-behaved stellar samples
- CU3 has produced a first set based on the 5-parameters astrometric solution for DR2
- NSS are modeled based on highly calibrated data: not trivial!
- First NSS processing results thus expected for DR3 (2021)



Exoplanets in the Gaia DPAC Pipeline

Team:
INAF-OATo (Lead).
Univ. Geneva (CH),
IMCCE (FR)

Gaia Discovery Space

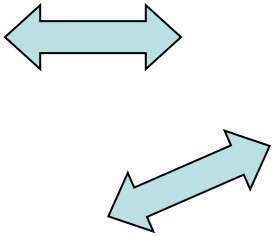


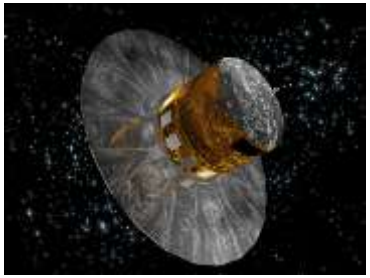
Unbiased, magnitude-limited planet census of maybe 10^6-10^7 stars

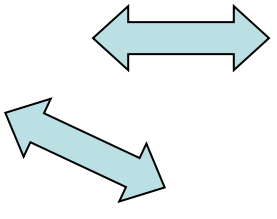
On the order of >10^4 NEW gas giants (< 15 M_{JUP}) around A through M dwarfs Numbers might as much as triple for a 10-yr mission

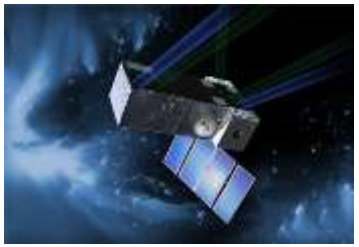
Lattanzi et al. 2000,
Sozzetti et al.2001
Casertano et al. 2008
Sozzetti et al. 2014
See also:
Perryman et al. 2014
Sahlmann et al. 2014

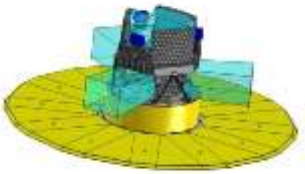
Gaia: a ‘Synergy’ Machine

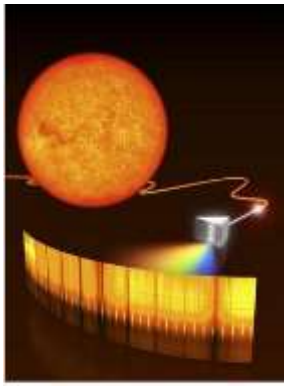












- **Gaia & spectroscopic characterization observatories (e.g., JWST)**
- **Gaia & transit surveys from the ground (e.g., WASP, HAT, MEarth, APACHE, NGTS) and in space (CoRoT, Kepler, TESS, PLATO) -> Giacobbe’s talk**
- **Gaia & direct imaging observatories (e.g., SPHERE/VLT, PCS/E-ELT)**
- **Gaia & RV programs (HARPS(-N), ESPRESSO, CARMENES, etc.) -> Giacobbe’s talk**
- **Gaia & ground-based and space-borne astrometry (TOLIMAN!)**

1 μas Astrometry, or less

A) Numerical preparatory work:

- First assessment of astrometric (single and multiple) planet detection capabilities of the Space Interferometry Mission (Sozzetti et al. 2002, 2003)

- Direct involvement in the double-blind tests program to assess the ability of SIM-Lite to detect Earth-like planets in multiple-planet systems (JPL Contract, S. Casertano,. A. Sozzetti PIs)

- Double-blind tests campaign for assessing the potential of the proposed NEAT and Theia astrometric obsevatories to measure dynamical masses of temperate Earths and Super Earths around the nearest main-sequence stars to the Sun

B) **High-level involvement:**

- Co-I, PI, and Co-PI of the proposed M3, M4, and M5 ESA missions NEAT, Theia, GAME, and AGP
- Main responsibility for the definition of the exoplanet science case for the NEAT and Theia missions

A Perspective

- Strong experience in complex (astrometric) data processing, big-size datasets handling and archiving (e.g., DPCT@ALTEC)

- Strong experience in instrument design as applied to positional measurements **-> Gai's, Riva's talks**

- Long-term experience and leadership in astrophysical applications of astrometry

- Leadership in the soon-to-come program of astrometric detection of exoplanets with Gaia

- Strong experience in preparatory numerical work and in actual data analysis and interpretation of complex, and across-techniques, astrophysical signals due to exoplanets **-> Damassos's, Pagano's talks**

- Important/strategic/multidisciplinary synergies with research institutes (e.g, INRIM) and industrial partners (e.g. TAS-I, ALTEC) **-> Several upcoming talks**

The Italian community with expertise in astrometry has potentially a lot to offer!