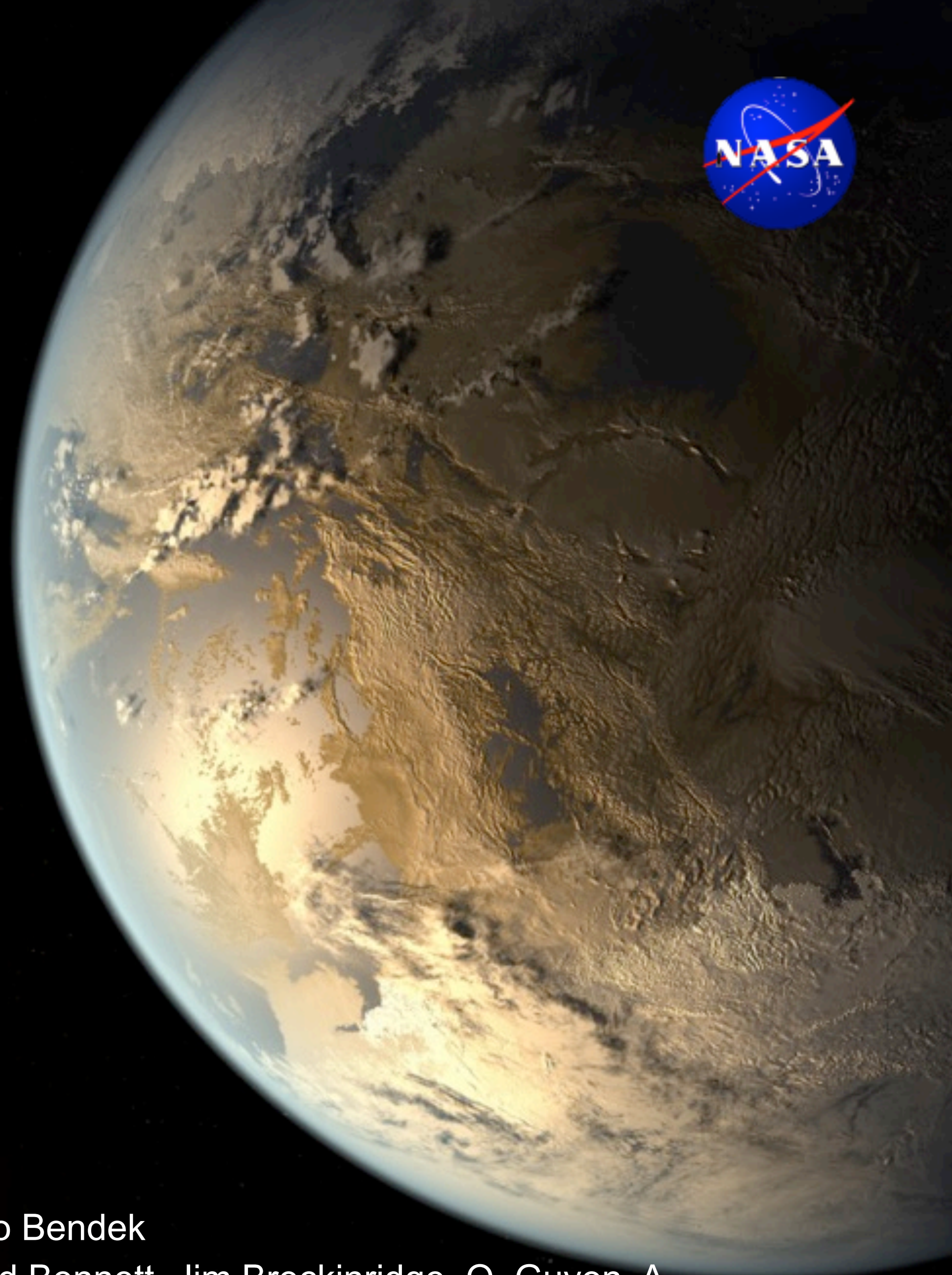
SAG-12 Astrometry for exoplanet detection



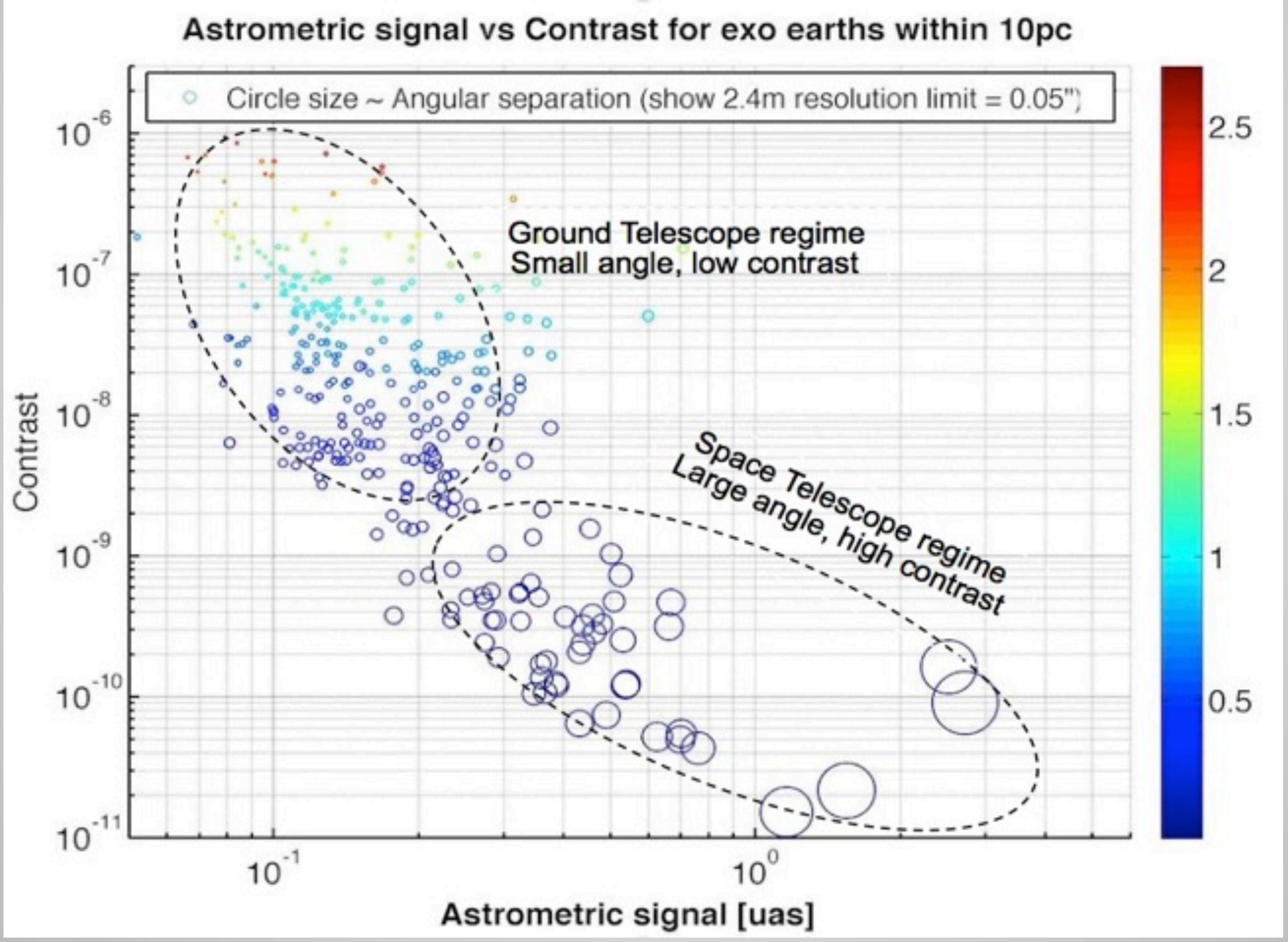
SAG-12: Chair Eduardo Bendek

Contributions from: S. Mark Ammons, Rus Belikov, David Bennett, Jim Breckinridge, O. Guyon, A. Gould, T. Henry, S. Hildebrandt, V. Makarov, F. Malbet, M. Shao, J. Sahlmann, A. Sozzetti, D. Spergel.

Image Credit: NASA Ames *Kepler 186f*

SAG-12: Motivation

- Astrometry is well suited for exoplanet detection from space



SAG-12: Goals and question

Key questions and goals that this group will address are:

1) What is the scientific potential of astrometry for different precision levels? Which planets types, confirm planet candidates.

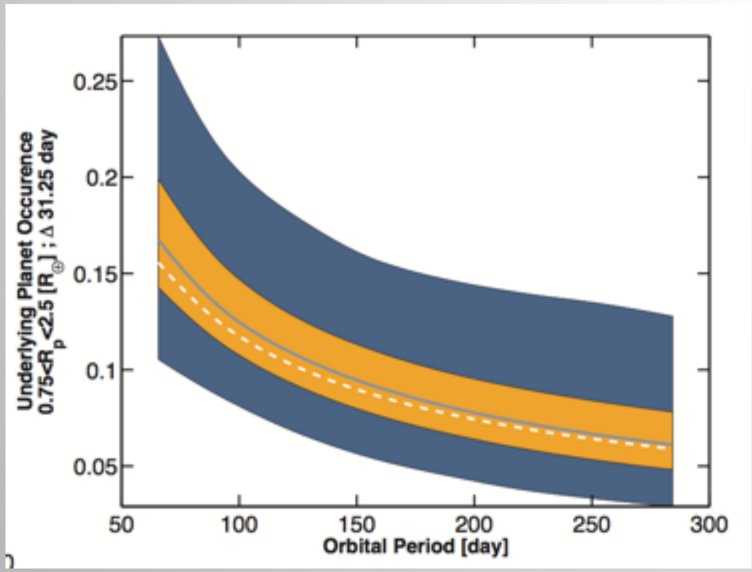
2) What are the technical limitations to achieving astrometry of a given precision? Technical challenges, observational strategies or post processing to improve the astrometry.

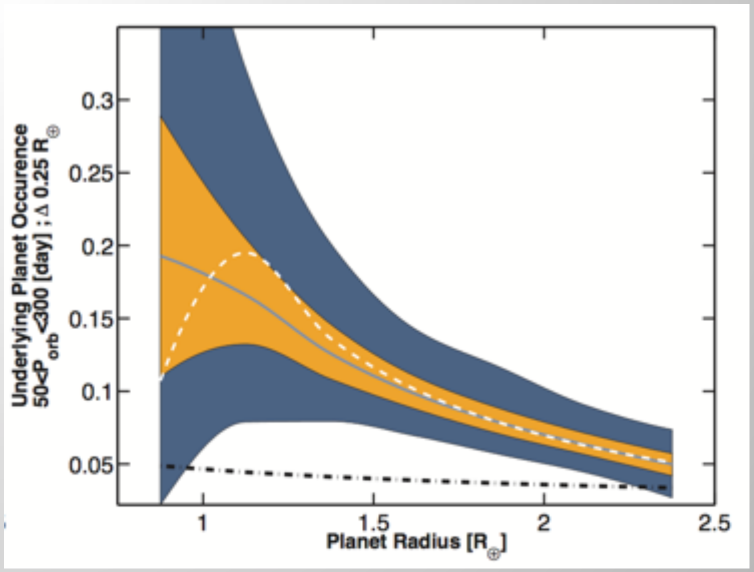
3) Identify mission concepts that are well suited for astrometry. Next mission after GAIA that will make exoplanet science possible? What are the requirements for such a mission?

4) Study potential synergies with current and future European astrometry missions. What are the available astrometric facilities to follow-up on GAIA (exoplanet-related) discoveries? Are they sufficient?

Scientific potential of astrometry

1) Terrestrial exoplanets yields using astrometry
   - Based on Terrestrial Planet Occurrence rates *(Burke et al. 2015)*
   - $0.75 < R_p < 2.5\ R_{earth}$
   - $0.50 \leq P_{orb} \leq 300$days
   - $F_o = 0.77$ planets per star (G and K)





Scientific potential of astrometry

1) Terrestrial exoplanets yields using astrometry.
   Toy model assumptions:
   - Simple first-order treatment: power law (allows analytic integration of # of planets)

$$\frac{\partial^2 N}{\partial \ln(a) \partial \ln(R)} = nR^{\alpha} a^{\beta}$$

   - α = -1 and n = 0.89: reproduces roughly the right frequency of small planets ($\zeta_{1.0}$ = 0.1 Burke et al, 2015) as well as large planets
     - Caution: a single power law is insufficient to capture real details
   - β = 0 (Bode's law), consistent with much of published literature
   - Mass radius relationship: $M = R^2$, in units of Earth
     - (valid for 1 < M < 100 Earths, see e.g. http://phl.upr.edu/library/notes/standardmass-radiusrelationforexoplanets)

Scientific potential of astrometry

Focus on terrestrial planets around nearby bright stars

- Mv < 6
- Distance <10 pc

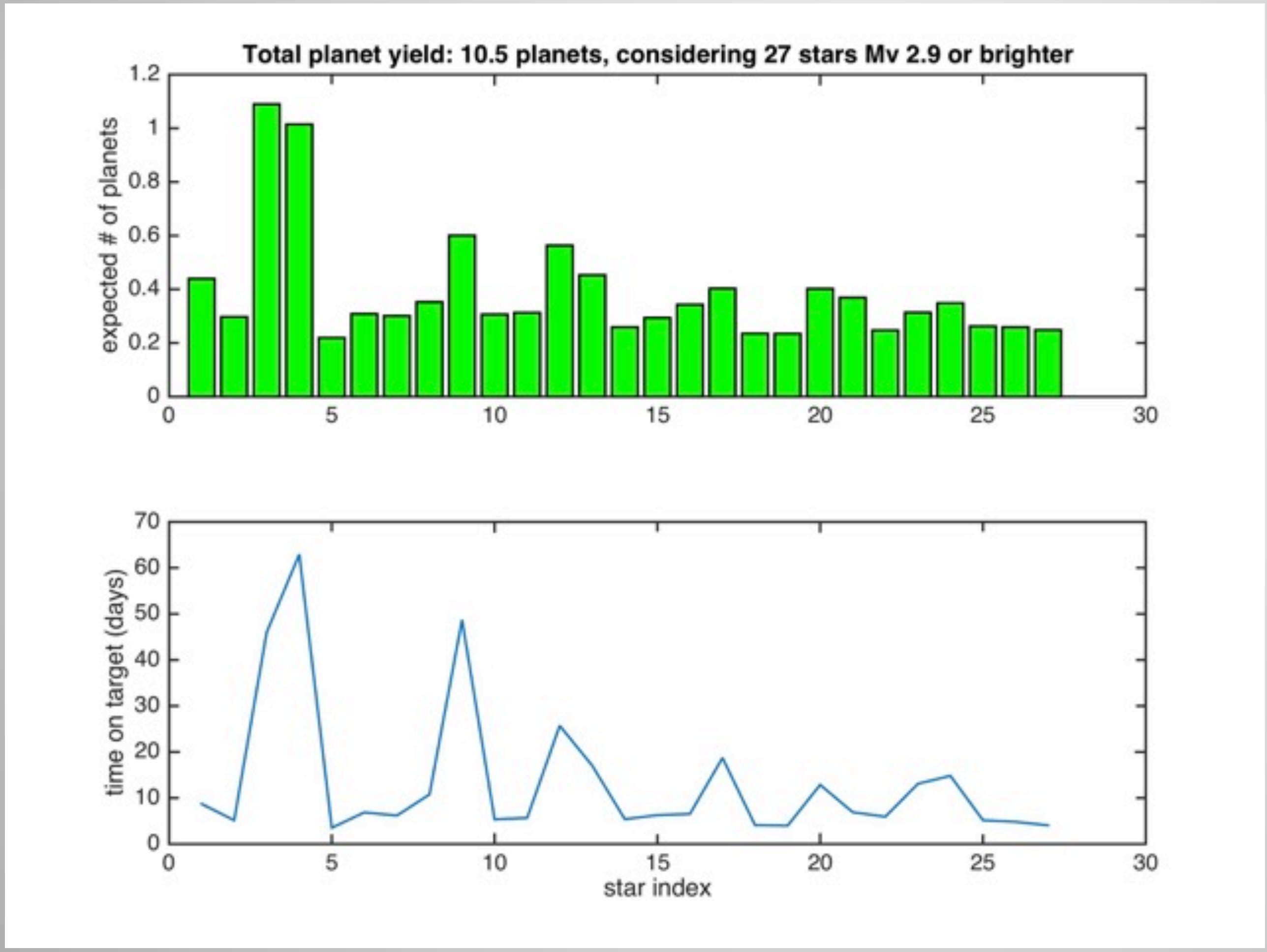
This population is not accessible/desirable by GAIA, Kepler or TESS

Implementation/Mission assumptions

- Photon noise from the target star is the only source of noise in astrometric precision
- D = 0.30;
- λ = 550e-9;
- QE = 0.003; % includes QE of all components, and throughput of diffractive mask
- $\Delta\lambda$= 400e-9; % Astrometry imaging bandwidth
- 1 year cumulative mission exposure time for astrometry targets
- Several revisits of each target throughout the mission

Scientific potential of astrometry

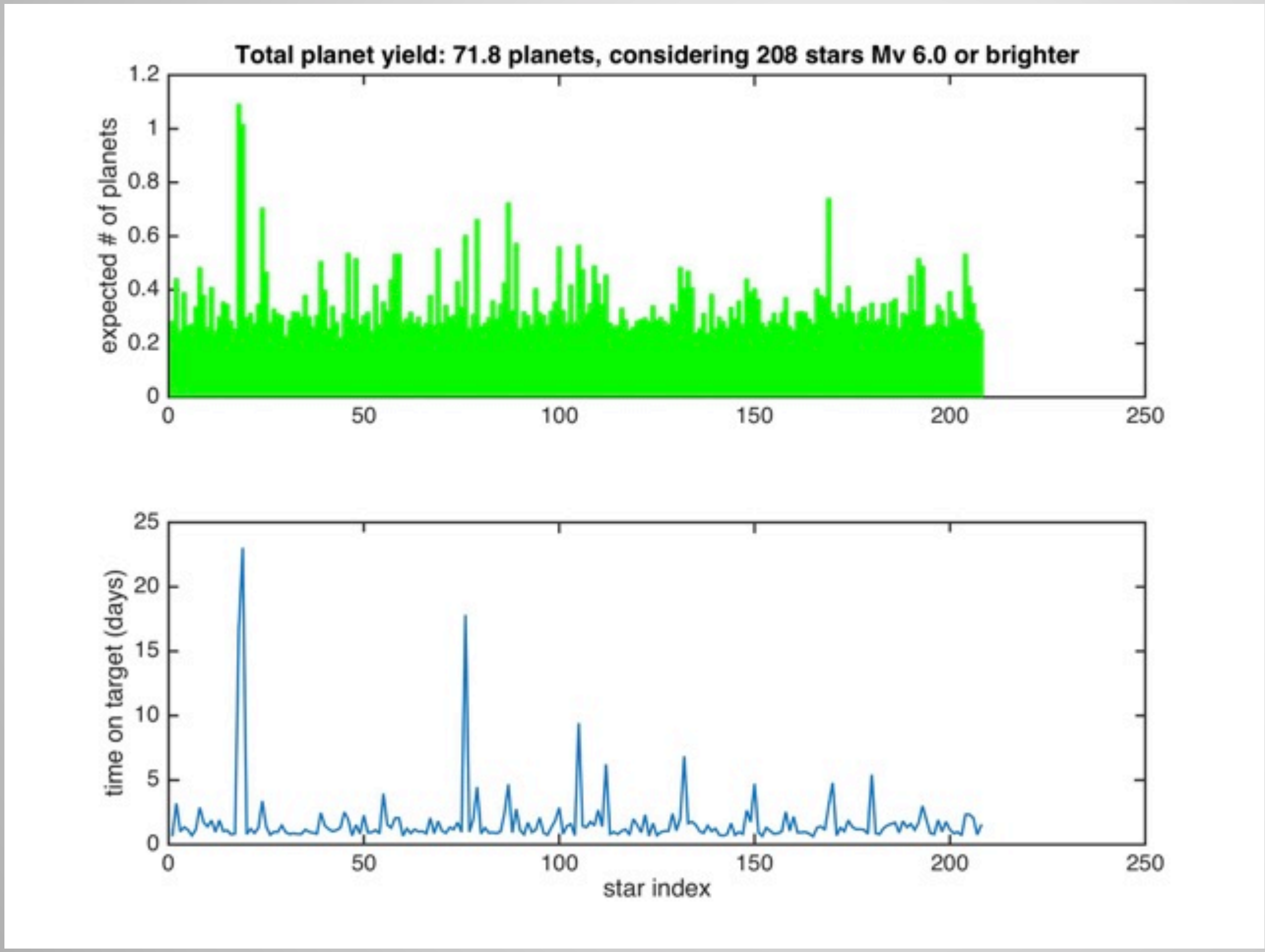
1) Astrometry exoplanet yields (Mv < 3 and 10μas)



- 27 stars
- 10.5 Terrestrial planets

Scientific potential of astrometry

1) Astrometry exoplanet yields (Mv < 6 and 10μas)



- 208 stars
- 71.8 Terrestrial planets

SAG-12: Original structure

SAG-12 sub area	Questions	Name	Org	Expertise/Interest
SAG-12.1 Astrometry with WFIRST and other missions	**1, 2, 3, 4**	David Spergel	Princeton University	Astrometry with AFTA, Science and calibration
		Mike Shao	JPL	Astrometry concepts performance comparisons, TPF, Diff Pupil, NEAT
		James Breckinridge	Caltech	Sources of systematic and random errors that limit astrometric precision
		Olivier Guyon	Univ. of Arizona	Imaging astrometry performance and modeling
		Todd Henry	GSI	Astrometry for exoplanet detection around nearby stars
SAG-12.2 European astrometry missions	**3, 4**	Johanness Sahlmann	ESA	Gaia, Exoplanet science with astrometry. Synergies between European and US missions
		Alessandro Sozzetti	INAF	Gaia Development
		Fabien Malbet	Grenoble	Theia, ultra-high precision astrometry
		Valerie Makarov	USNO	SIM/Theia
SAG-12.3 Ground and space-based astrometry synergies	**1, 2, 4**	Mark Ammons	LLNL	Science case for low-mass stars. Simulation of astrometric error budget, Anchoring error budgets to ground-based demos. Synergy with direct imagers on 8-10 meters and ELTs, comparison with Gaia's capabilities

SAG-12 Plan

SAG-12 sub area
SAG-12.1 Astrometry with WFIRST and other missions
SAG-12.2 European astrometry missions
SAG-12.3 Ground and space-based astrometry synergies

SAG 12.1 Activities and timeline

1) Kick-off (January 2015)
2) Astrometry with AFTA workshop at Princeton organized by D. Spergel.

We would like to increase the SAG activities by:

- Establish direct collaboration with WFIRST SIT
- Invite the community to participate.
- Revisit areas of interest for the SAG
- Establish monthly meetings
- Define SAG-12 completion date before the end of 2016

SAG-12.1 Astrometry with AFTA

SAG-12 sub area
SAG-12.1 Astrometry with WFIRST and other missions
SAG-12.2 European astrometry missions
SAG-12.3 Ground and space-based astrometry synergies

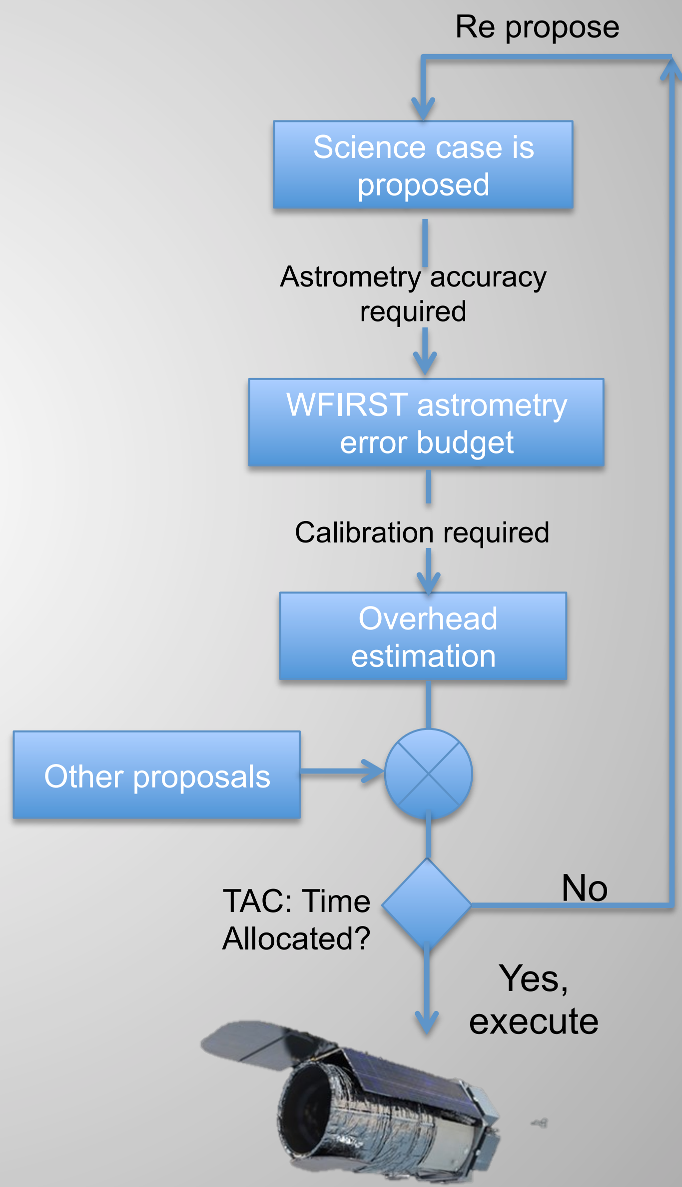
Deliverables:

- Science cases
- Error sources
- Calibration and error budget
- Science and observation trade-offs

Putting all together:

Flow diagram to assess the best scientific yield

Coordination with WFIRST SIT is necessary



SAG-12.1 Astrometry with AFTA and Other mission

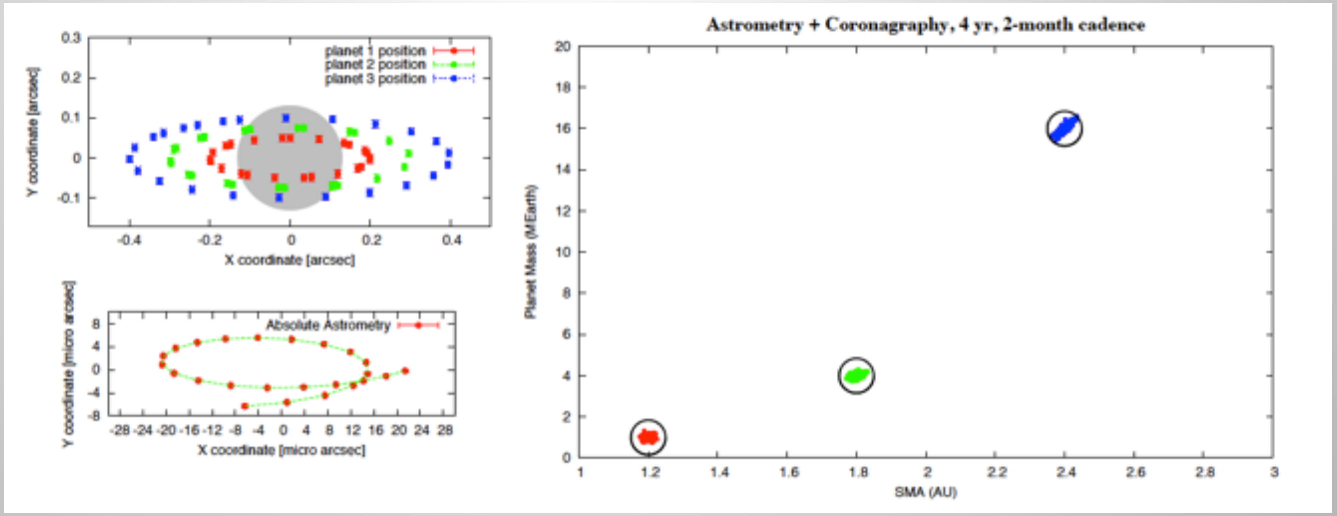
SAG-12 sub area
SAG-12.1 Astrometry with WFIRST and other missions
SAG-12.2 European astrometry missions
SAG-12.3 Ground and space-based astrometry synergies

Astrometry for other missions:

- Any coronagraphic + wide field imaging mission
- Small mission focusing on nearby stars

Can we study astrometry

- EXO-S?
- James Webb?

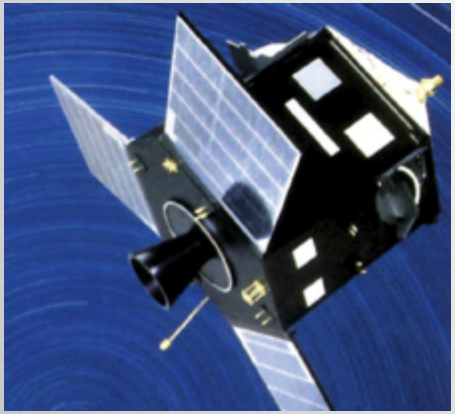


SAG-12.2 Synergies between U.S. and international astrometry efforts

3) Identify mission concepts that are well suited for astrometry. Next mission after Gaia that will make exoplanet science possible? What are the requirements for such a mission?

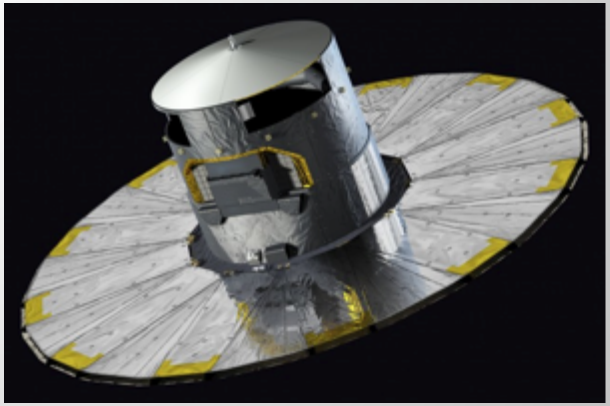
4) Study potential synergies with current and future European astrometry missions. What are the available astrometric facilities to follow-up on Gaia (exoplanet-related) discoveries? Are they sufficient?

Hipparcos – ESA 1989 - 1993



- 0.001 µas for 117,000 stars
- 0.03 as for 2.5 million stars (Tycho2)
- 2.5 million stars
- 300Ly range

GAIA ESA 2013 - 2018



- **8µas for stars $6 < m_v < 12$**
- **25µas for stars $m_v = 15$**
- 70 visits in 5 years.
- 1000 million stars, 30.000Ly range

SAG-12.3 Ground and Space based astrometry synergies (S. M. Ammons)

SAG-12 sub area
SAG-12.1 Astrometry with WFIRST and other missions
SAG-12.2 European astrometry missions
SAG-12.3 Ground and space-based astrometry synergies

Goals

1. **Science case for low-mass stars**, such as M dwarfs and brown dwarfs: **Matching planet formation theory at higher masses**, synergy with high-contrast imaging programs of brown dwarfs (using LGS).

2. **Simulation of astrometric error budget**, including use of common position-finding codes (StarFinder) and distortion correction schemes

3. **Anchoring error budgets to ground-based** demos on GeMS, ShaneAO, etc

4. **Synergy with direct imagers on 8-10 meters and ELTs**, comparison with GAIA's capabilities

SAG-12.3 Ground and Space based astrometry synergies

SAG-12 sub area

SAG-12.1 Astrometry with WFIRST and other missions

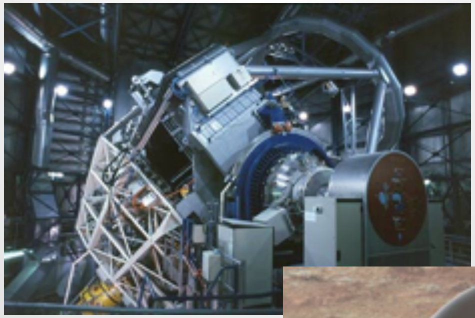
SAG-12.2 European astrometry missions

SAG-12.3 Ground and space-based astrometry synergies

Ground based telescopes astrometric performance

Observatory	**Instrument**	**Performance**	**FoV**	**Comments**	**Ref**
Gemini	GEMS+GSAOI	0.2mas monoepoch + 0.4 multi epoch	2'	Crowded wide	Neichel et al 2014 (MNRAS)
VLT	FORS	50µas	Narrow	Crowded	Lazorenko et al 2009 (A&A)
TMT	IRIS	25µas	17"x17"	Galactic center	Yelda et al 2013
EELT	MICADO	40µas	Narrow	Crowded	Trippe et al 2009

Gemini South, GEMS



VLT, FORS1, 2.

TMT, IRIS

EELT, MICADO

SAG-12 Conclusion

We are seeking for more member of the community to join:

- We will send an invitation.
- We will interact with the WFIRST SIT to optimize the work.
- We will establish a regular meting structure