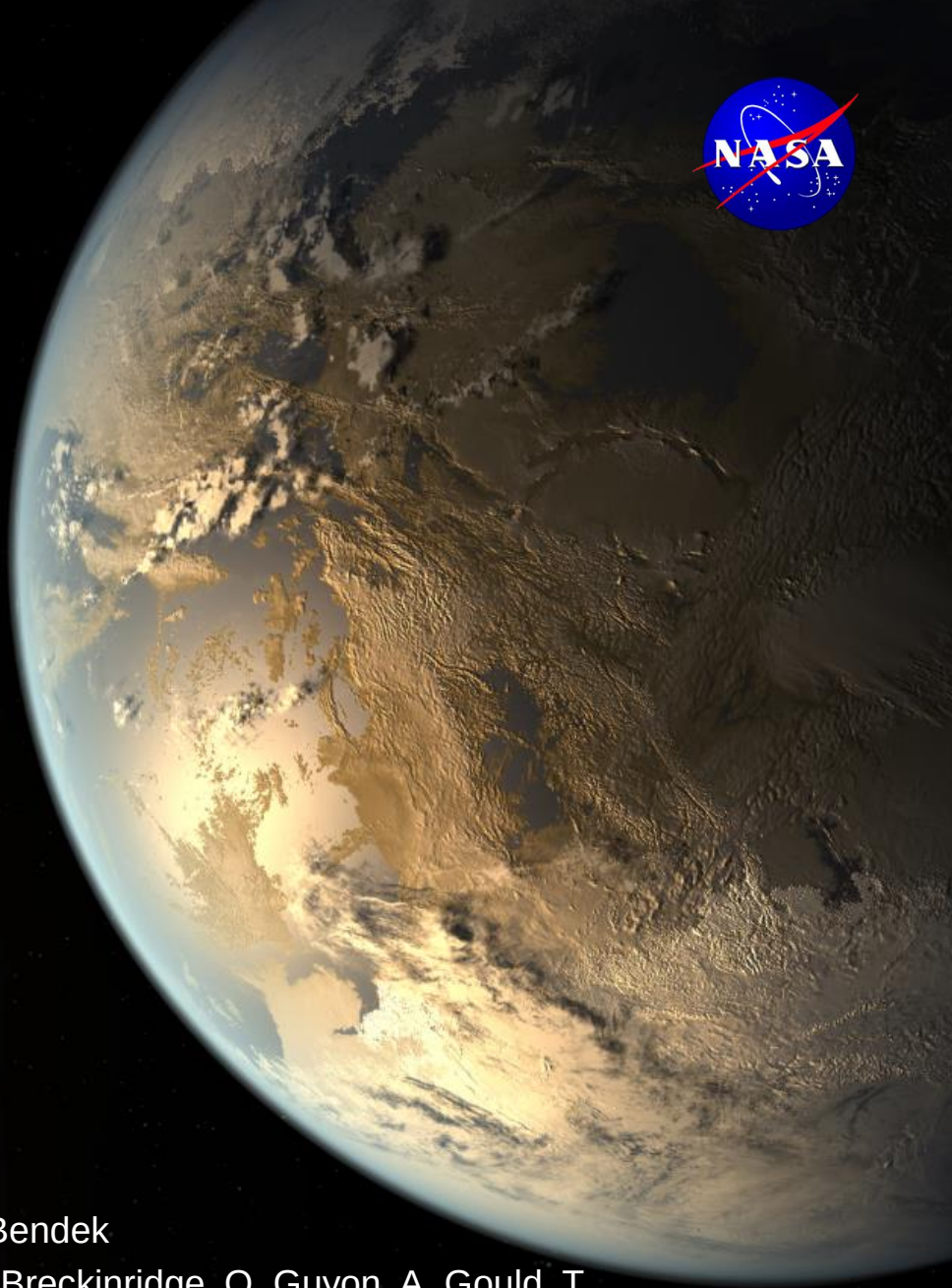
SAG-12 Astrometry for exoplanet detection



SAG-12: Chair Eduardo Bendek

Contributions of: S. Mark Ammons, 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: Astrometry for exoplanet detection and characterization

- Potential to play an important role in the detection and characterization of exoplanets (**mass, inclination**).
- **Complement high-contrast** direct imaging surveys by allowing for improved yields.
- **Sub-microarcsecond** astrometry allows measurement of the mass and orbits of **Earth-mass planets** within 10pc.

  1μas < required for earth-like measurements

  10μas enables super-earths and Neptunes
- Complementary tool for characterizing the **demographics** of nearby planetary systems.
- **Sensitivity increases with semi-major axis**, in contrast to radial velocity and transit surveys. (WIYN, Transit spectroscopy telescopes)

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?

SAG-12: Original structure

SAG-12 sub area	Questions	Name	Org	Expertise/Interest
SAG-12.1 Astrometry with AFTA and other missions		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-12.1 Astrometry with AFTA

SAG-12 sub area
SAG-12.1 Astrometry with AFTA 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.
3) Status report at AbSiCon in June 2015 (Now)
4) Planed completion by Q1 2016

SAG-12.1 Astrometry with AFTA

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Astrometry with AFTA workshop at Princeton University organized by D. Spergel.

- May 6th, 2015
- About 25 members of the community
- Conclusions:

  - Wide range of astrometry related science cases.
  - High-sensitivity of science case v/s astrometric accuracy.
  - Significant work on detector calibration.
  - Observation strategies are key on optimizing accuracy.

SAG-12.1 Astrometry with AFTA and other missions

SAG-12 sub area
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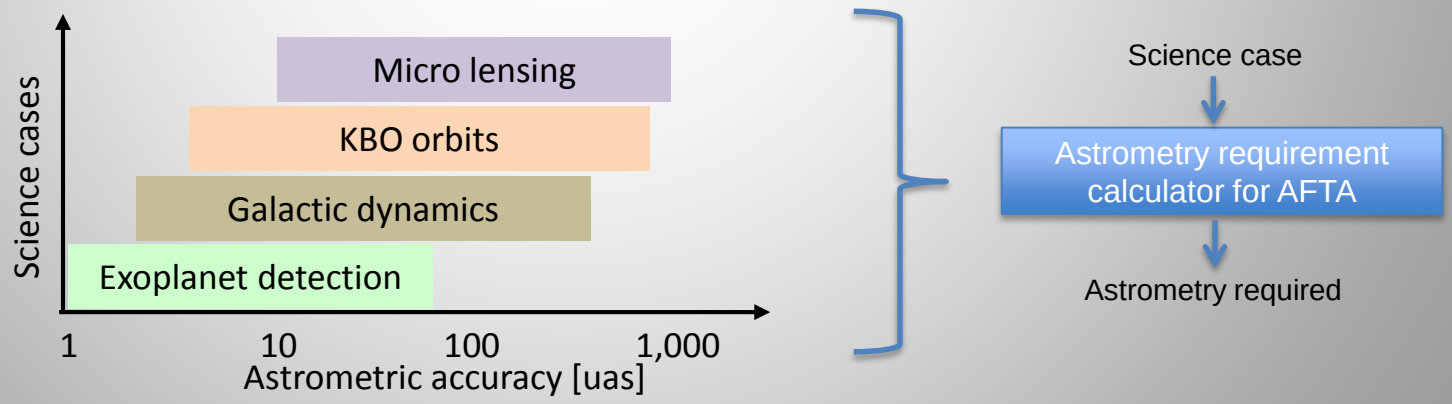
SAG-12.3 Ground and space-based astrometry synergies

1) Define science drivers for astrometry and photometry with WFIRST (i.e. Talks by Spergel, Gehrels, Bennett, Gould)

1.1) Find and define precision astrometry science cases.
1.2) Classify them as a function of astrometry required.
1.3) Identify WFIRST niche.



Notional plot, does not necessarily reflect real science required performance.

SAG-12.1 Astrometry with AFTA and other missions

SAG-12 sub area
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2) Astrometry error budget

2.1) Detector effects (i.e. Talks by Shao, Hildebrand, Shapiro)

- PSF centroiding over wide field (~1/100th of a pixel) Shao
- Detector pixel spatial and temporal variations (Hildebrand)
- Charge repulsion (Shapiro)
- Inter-detector and inter-pixel motion (Shao)
- Detector mounting back plane calibration

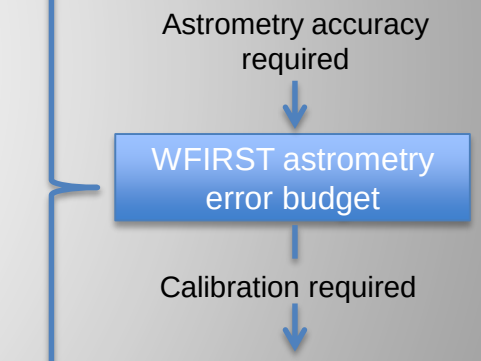
25cm wide SiC (CTE 4ppm) focal plane. 0.01˚K gradient can cause detector motion equivalent to ~100μas

2.2) PSF modeling and centroiding over wide field

- Dynamic and static aberrations over FoV

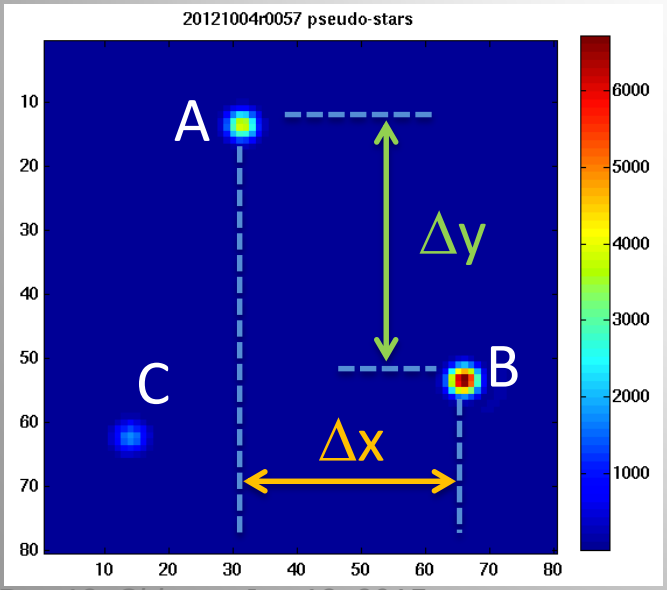
2.3) Telescope distortion (Bendek, Guyon,

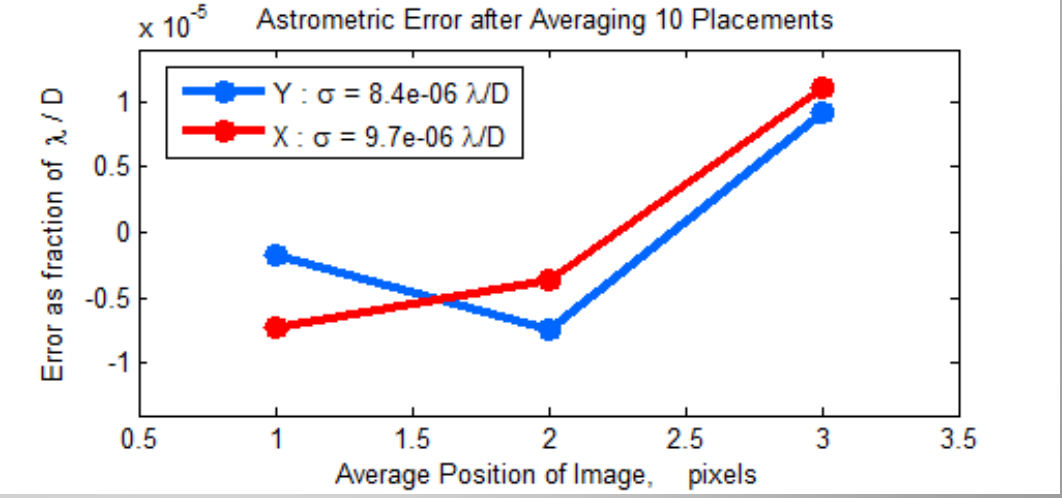
- Rigid motion of optical elements



Centroiding Test 10^{-5} λ/D (By M. Shao)

- Three diff limited spots are moved across multiple pixels on a backside CCD. The separation of the images should not change.
- Images were oversampled (3.5~4 pixels / λ/D). Images were moved ~30 positions. The separation of the two images (A B) were constant to 1e-5 l/D when 10 positions were averaged. Astrometry with a single image was ~1.2e-4 pixels.

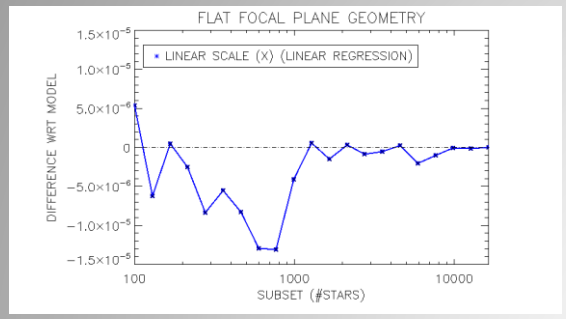


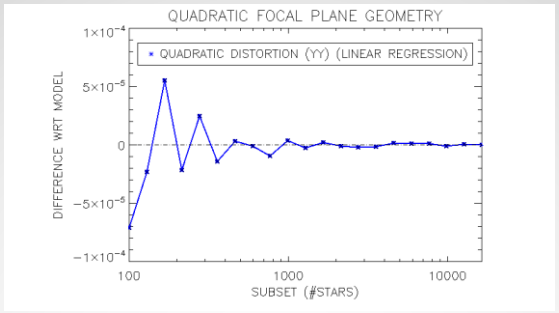


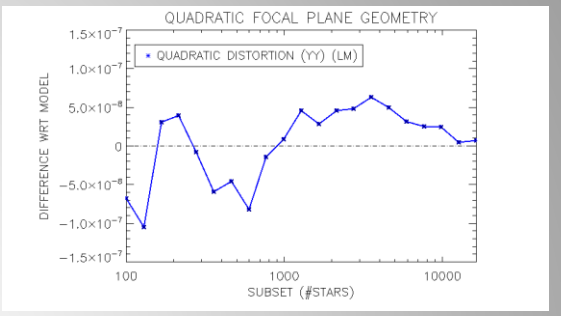
SAG-12.1 Astrometry with AFTA: EFFECT OF DETECTOR NOISE IN ASTROMETRY

By SERGI R HILDEBRANDT (JPL/CALTECH)

CONVERGENCE OF COEEFICIENTS WITH THE NUMBER OF STARS

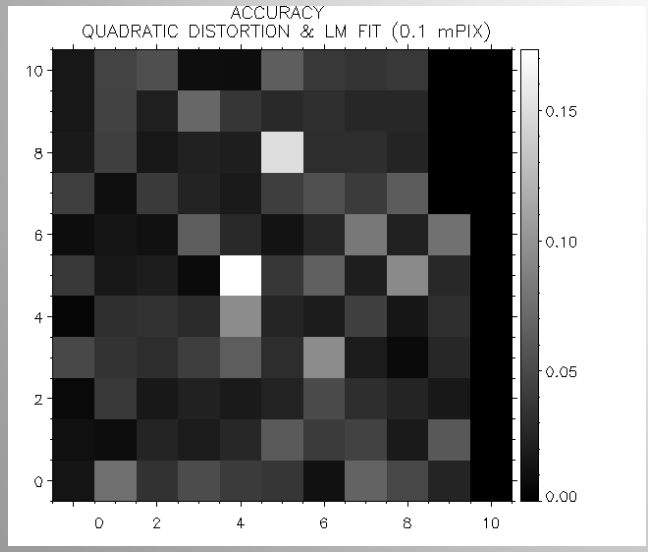






STUDIED BOTH **ACCURACY**: SYSTEMATIC EFFECTS AND **PRECISION**: STATISTICAL ERRORS FOR SEVERAL MAGNITUDES AND ACROSS THE FOCAL PLANE.

RESULTS: Median values for each of the 106 noise types

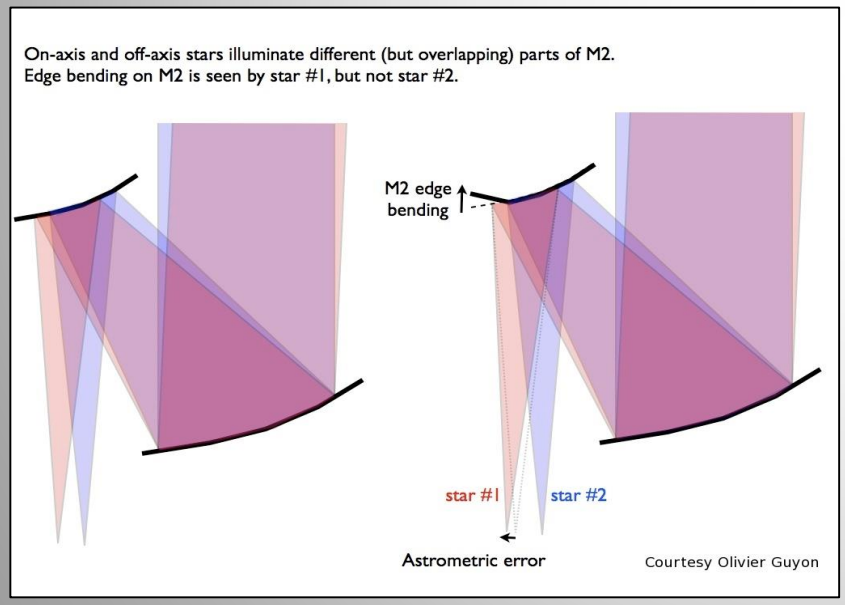


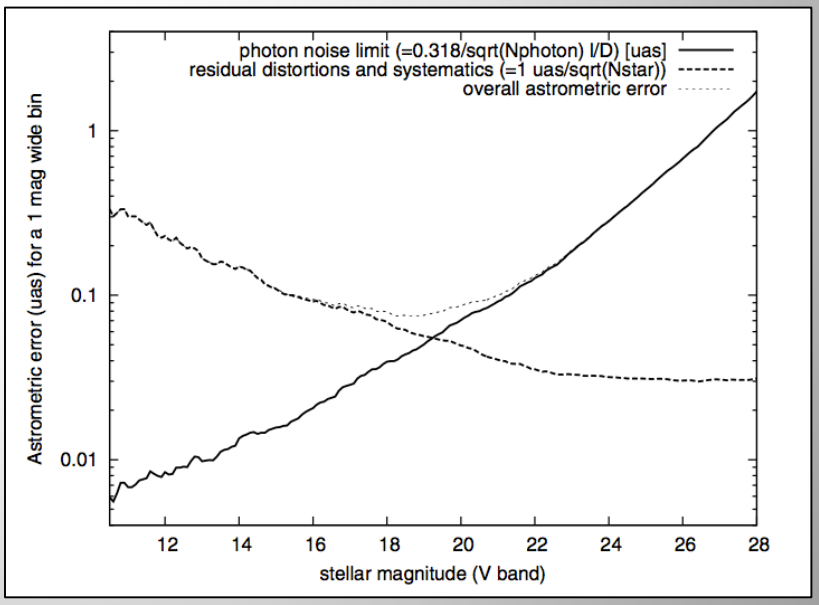
GENERAL CONCLUSIONS:

- **GOOD NEWS FOR ASTROMETRY**
- **EFFECTS OF ORDER 0.1 `MILLIPIXEL' (m<24, H FILTER).**
- **IDEAL ASTROMETRIC LIMIT OF SCAN MODE ASTROMETRY WITH WFIRST = 0.1 mPIX (DAVID N. SPERGEL)**
- **MORE REALISTIC SIGNAL UNDER STUDY**

SAG-12.1 Astrometry with AFTA: Optical distortions (Guyon, Bendek)

- How distortions affect astrometry
  - Cause local plate scale changes
  - Bias the astrometric measurements
  - Impact on multi-epoch astrometry





SAG-12.1 Astrometry with AFTA and other missions

SAG-12 sub area
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SAG-12.2 European Astrometry Missions
SAG-12.3 Ground and space-based astrometry synergies

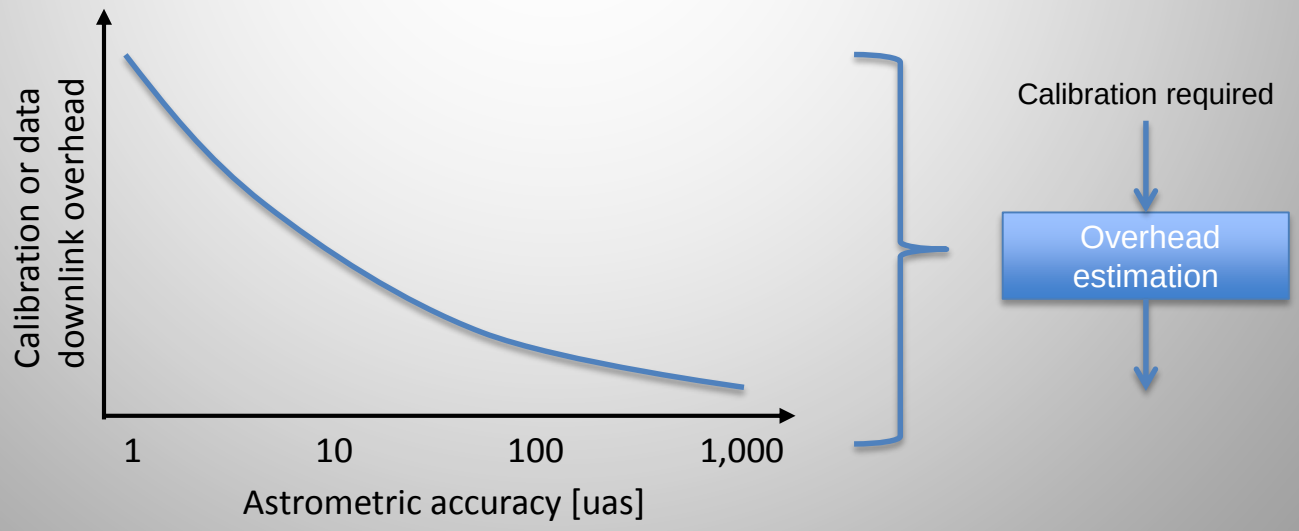
3) Identify calibration strategies and trade offs

3.1 ***Science yield trade off v/s calibration*** (i.e. scanning)

3.2 ***Calibration v/s bus capabilities*** (i.e. data rate)

3.3 Prepare **Astrometry error budget** per observation strategy

- Spiders diffraction?
- GAIA absolute reference
- PASS Scanning
- Star fields



SAG-12.1 Astrometry with AFTA and other missions

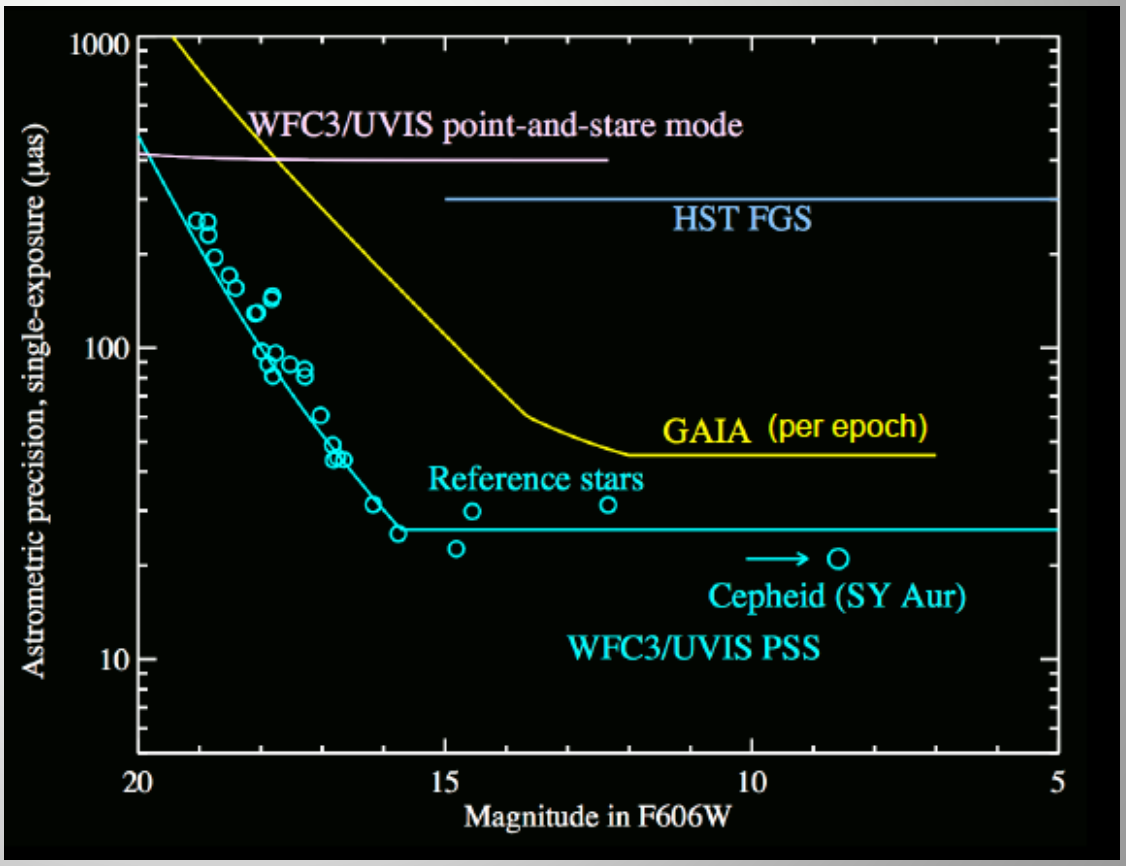
Other missions: HST Astrometry (From Adam Reiss)

Wide field

- WFC3/UVIS Point and stare mode ~ 400μas
- HST FGS ~ 300μas

Narrow field

- Precision Astrometry with Spatial Scanning ~25μas



SAG-12.1 Astrometry with AFTA

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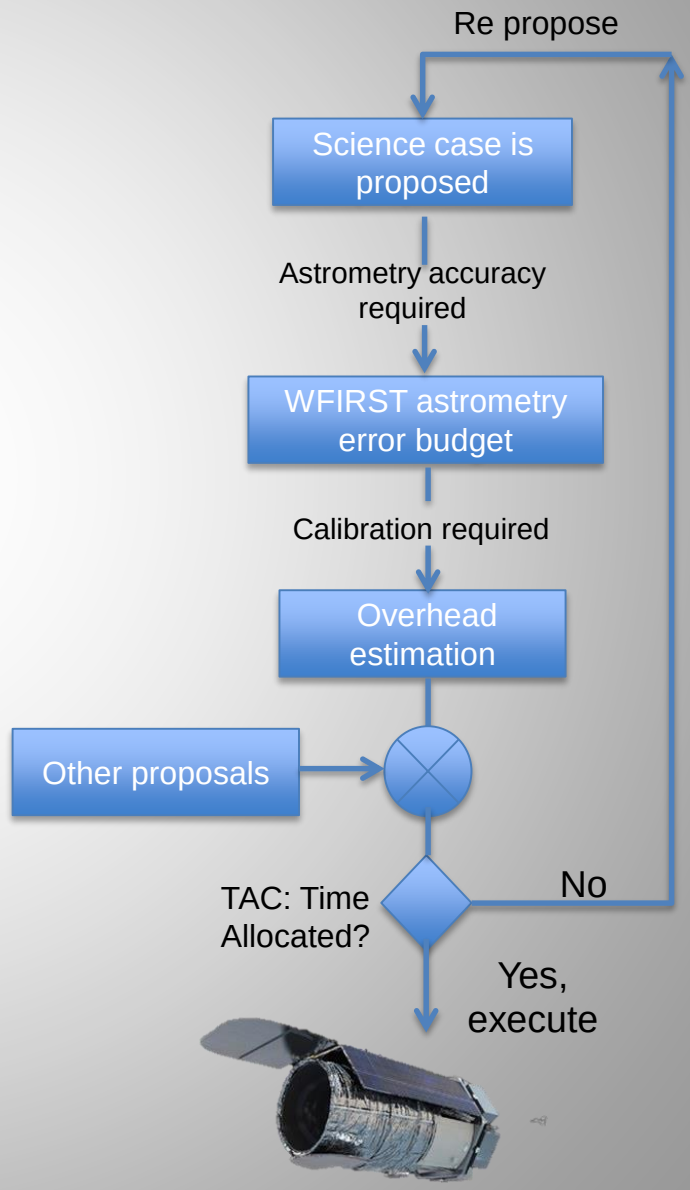
Deliverables:

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

Putting all together:

Flow diagram to assess the best scientific yield



SAG-12.1 Astrometry with AFTA and Other mission

SAG-12 sub area
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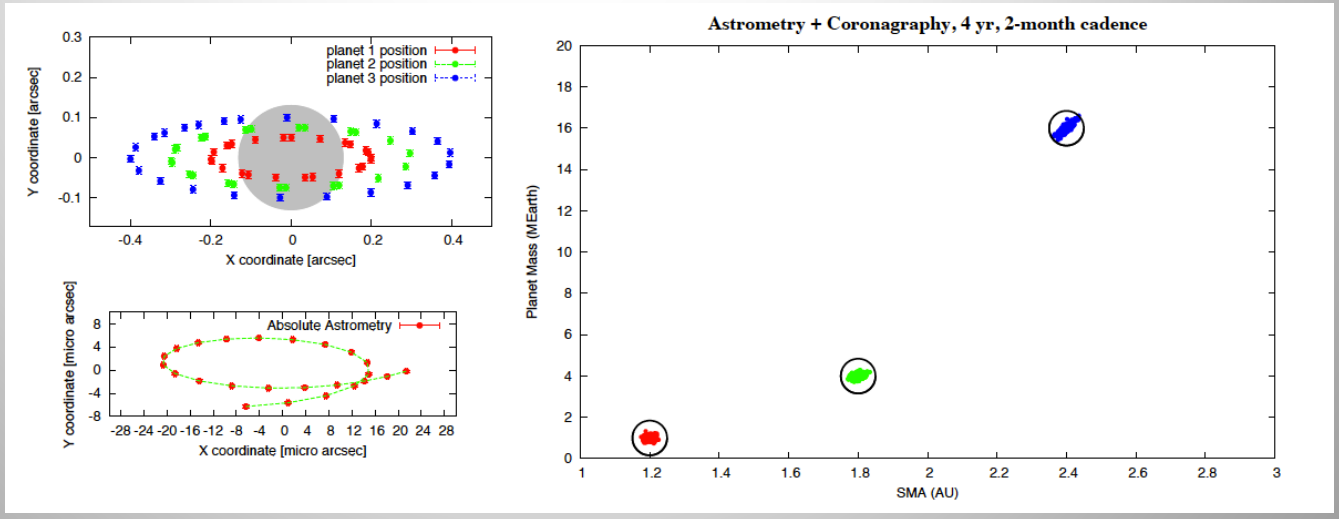
SAG-12.3 Ground and space-based astrometry synergies

Astrometry for other missions:

- Any coronagraphic + wide field imaging mission

Can we study astrometry

- EXO-S?
- James Webb?

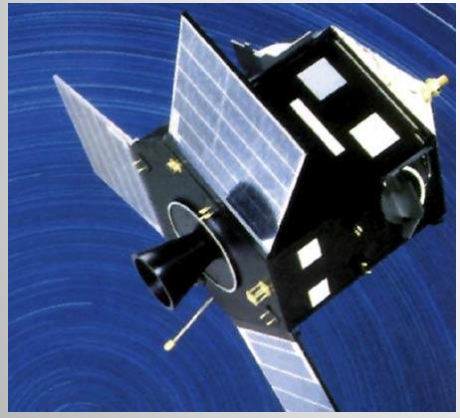


SAG-12.2 Synergies between U.S. and international astrometry efforts

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?

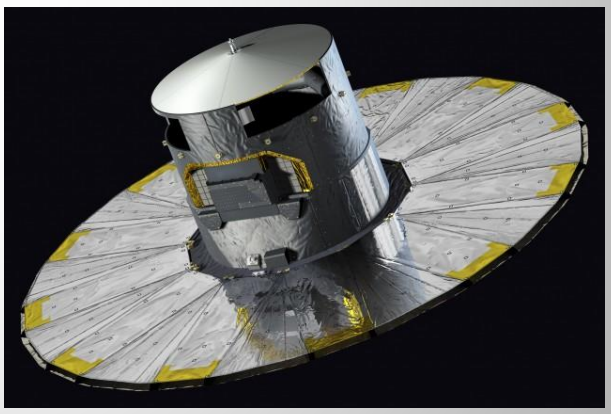
4) Study potential synergies with current and future European astrometry missions. What are the available astrometric facilities to follow-up on Gaia (exoplanet-related) discoveries? Are they sufficient?

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 areas

SAG-12.1 Astrometry with AFTA 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

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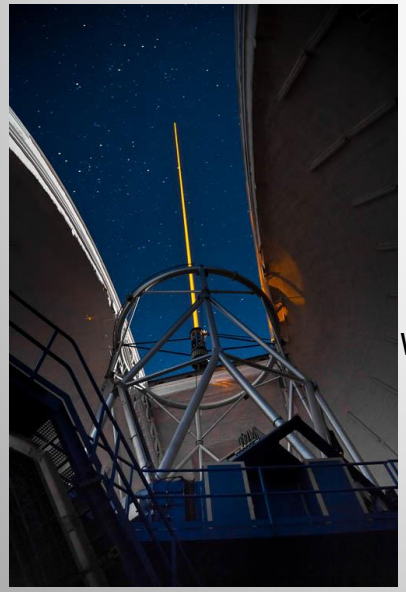
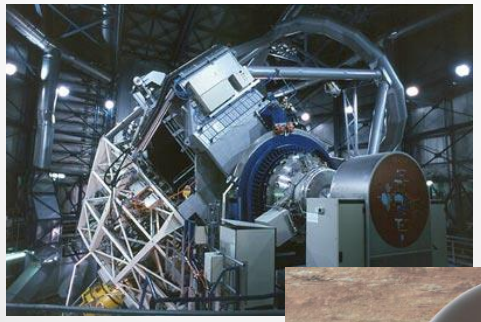
SAG-12.3 Ground and space-based astrometry synergies

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

Conclusion

SAG-12 Astrometry is making progress

- Sub-areas has been identified
  - ***Strong emphasis*** in Astrometry with AFTA
  - Synergies with international missions
  - Ground and Space based astrometry