SAG-12 Astrometry for exoplanet detection

SAG-12: Chair Eduardo Bendek

Image Credit: NASA Ames
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)
   • $0.75 < R_p < 2.5 \text{ R}_{\text{earth}}$
   • $0.50 \leq P_{\text{orb}} \leq 300 \text{ days}$
   • $F_0 = 0.77$ 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)

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

• \(\alpha = -1\) 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

• \(\beta = 0\) (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

- $M_v < 6$
- 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
- $D = 0.30$;
- $\lambda = 550e-9$;
- $QE = 0.003$; % 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 ($M_v < 6$ and $10\mu$as)

- 208 stars
- 71.8 Terrestrial planets
### SAG-12: Original structure

<table>
<thead>
<tr>
<th>SAG-12 sub area</th>
<th>Questions</th>
<th>Name</th>
<th>Org</th>
<th>Expertise/Interest</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SAG-12.1</strong></td>
<td>1, 2, 3, 4</td>
<td>David Spergel</td>
<td>Princeton University</td>
<td>Astrometry with AFTA, Science and calibration</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mike Shao</td>
<td>JPL</td>
<td>Astrometry concepts performance comparisons, TPF, Diff Pupil, NEAT</td>
</tr>
<tr>
<td></td>
<td></td>
<td>James Breckinridge</td>
<td>Caltech</td>
<td>Sources of systematic and random errors that limit astrometric precision</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Olivier Guyon</td>
<td>Univ. of Arizona</td>
<td>Imaging astrometry performance and modeling</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Todd Henry</td>
<td>GSI</td>
<td>Astrometry for exoplanet detection around nearby stars</td>
</tr>
<tr>
<td><strong>SAG-12.2</strong></td>
<td>3, 4</td>
<td>Johanness Sahlmann</td>
<td>ESA</td>
<td>Gaia, Exoplanet science with astrometry. Synergies between European and US missions</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Alessandro Sozzetti</td>
<td>INAF</td>
<td>Gaia Development</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Fabien Malbet</td>
<td>Grenoble</td>
<td>Theia, ultra-high precision astrometry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Valerie Makarov</td>
<td>USNO</td>
<td>SIM/Theia</td>
</tr>
<tr>
<td><strong>SAG-12.3</strong></td>
<td>1, 2, 4</td>
<td>Mark Ammons</td>
<td>LLNL</td>
<td>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</td>
</tr>
</tbody>
</table>

*ExoPag 13, Kissimmee, FL, Jan 4, 2016*
SAG-12 Plan

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

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

ExoPag 13, Kissimmee, FL, Jan 4, 2016
Astrometry for other missions:
- Any coronagraphic + wide field imaging mission
- Small mission focusing on nearby stars
Can we study astrometry
- EXO-S?
- James Webb?
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 \( \mu \)as for 117,000 stars
- 0.03 \( \mu \)as for 2.5 million stars (Tycho2)
- 2.5 million stars
- 300Ly range

**GAIA ESA 2013 - 2018**
- 8\( \mu \)as for stars \( 6 < m_v < 12 \)
- 25\( \mu \)as for stars \( m_v = 15 \)
- 70 visits in 5 years.
- 1000 million stars, 30,000Ly range
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

### Ground based telescopes astrometric performance

<table>
<thead>
<tr>
<th>Observatory</th>
<th>Instrument</th>
<th>Performance</th>
<th>FoV</th>
<th>Comments</th>
<th>Ref</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gemini</td>
<td>GEMS+GSAOI</td>
<td>0.2mas monoepoch + 0.4 multi epoch</td>
<td>2'</td>
<td>Crowded wide</td>
<td>Neichel et al 2014 (MNRAS)</td>
</tr>
<tr>
<td>VLT</td>
<td>FORS</td>
<td>50µas</td>
<td>Narrow</td>
<td>Crowded</td>
<td>Lazorenko et al 2009 (A&amp;A)</td>
</tr>
<tr>
<td>TMT</td>
<td>IRIS</td>
<td>25µas</td>
<td>17&quot;x17&quot;</td>
<td>Galactic center</td>
<td>Yelda et al 2013</td>
</tr>
<tr>
<td>EELT</td>
<td>MICADO</td>
<td>40µas</td>
<td>Narrow</td>
<td>Crowded</td>
<td>Trippe et al 2009</td>
</tr>
</tbody>
</table>

---

ExoPag 13, Kissimmee, FL, Jan 4, 2016
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