Astrometry

Future Directions for Interferometry

Tucson

Nov. 13-15, 2006
An answer in search of a Question?

- Astrometry provides unique lever on many important astrophysical questions. Some examples:
  - Exoplanets
  - Galactic Center
  - Stellar Mass, Distance & Luminosity
- Interferometry is particularly well-suited to astrometry. In fact, it may be what interferometers do best...
Types of Astrometry

• "Wide-Angle": Over entire sky, atmospheric effects are uncorrelated.
  • ~1-5 milli-arcsecond performance.

• "Narrow-Angle": Less than ~1 arc-minute, atmospheric errors subtract out (mostly)
  • 20 micro-arcsecond performance.

• "Very Narrow Angle": Targets are close enough to be in FOV of single beam combiner, though at different delays. Atmosphere stabilized with fringe tracking.
  • 5-20 micro-arcsecond performance for 0.1-1 arcsecond separations.
Atmospheric limits to a narrow-angle measurement

Results from the Mark III scaled to 1 hour integration

Mauna Kea Model values seeing = 1"

PTI Results (1999)

South Pole

Error (\(\mu\text{as in 1 h}\))

B = 1.2 m
B = 12 m
B = 110 m

PTI Results (1999)
Narrow-Angle Astrometry: Exoplanets

- Astrometry is complementary to RV - better at longer periods.
- Provides inclination, mass.
- Need ~10 micro-arcseconds to be competitive with RV.
- Traditionally these have been the targets for “dual-star” systems (PRIMA, KOA)
Very Narrow-Angle Astrometry: Exoplanets in Binaries

- Very narrow angle astrometry could be applied on one of several arrays, with ~500 targets in a representative sample (here assuming 1.8-m apertures).

- Targets would all be speckle binary systems brighter than mK ~ 8
  - Allows higher precision in shorter time than using background references.
Binary Orbits

• With 20 micro-arcsecond astrometry on 0.2 arcsecond binaries we have the precision to revolutionize stellar astronomy (0.01%).

• At PTI, we have begun to observe several known “speckle” binary systems (e.g. HD 202275).

• Results compare favorably with previous data.

• Can determine apparent orbital geometry to ~0.2 % with ~20 points, 1/5th of the orbit.

• \( a = 0.2319 \pm 0.0004 \) arcseconds.
Young Stars in the GC

- orbits constrain BH, DM, GR,...

- current state of the art: ~0.25 mas astrometry

- KI/VLTI: ~30 µas astrometry

(Ghez et al. 2005)
accuracy: 1 in $10^4$!
Weinberg et al. 2005

Astrometric Precision (mas)

10

1

0.1

0.01

0.001

1

10

Signal to Noise

GR: prograde precession
Dark matter: retrograde precession
BH Spin: frame dragging

a = 1000 AU, e = 0.9 (S0-2)
a = 1700 AU, e = 0.97 (S0-16)

30 μas
Other GC Science

• Dark matter detection via orbital perturbations: IMBHs?
• Astrometry of SgrA* flares
• Eventually... black hole spin
Dome C Location
Interferometer Sensitivity

- **Astrometry (~20 x – if free air turbulence ~0)**
  - Depends ~ \( \text{int}(h^2C_n^2) \) so low elevation seeing helps.
  - Extremely Long baselines possible.
  - Large isoplanatic angle required to avoid photon limit.

- **Differential Phase (~20 x @ 2 \( \mu \text{m} \))**
  - Water vapor limited sensitivity ~ \( \sigma_{\text{PWV}}/\text{SNR} \sim 25/\text{SNR} \).
  - Photon limited with phase referencing ~ 20 \( \mu \text{rad} \)
    \( (K_{\text{magn}} = 5, 10 \text{ min int}, 1.8 \text{ m telescope, 10\% throughput}) \).

- **Background limited sensitivity (~75x @ 2 \( \mu \text{m} \))**
  - Improvement ~ \( \text{NEP}_{T_1}\text{NEP}_{T_2} \times \sqrt{\tau_0} \sim 4.7 K_{\text{magn}}, 2.5 N_{\text{magn}} \)

All interferometer modes are dramatically improved!
The Importance of the Free Air Turbulence

• Ordering of scientific priorities.
  • Which is the most important observing mode?
  • If potential for astrometric accuracy < 1 μ" then astrometry might be the top priority.

• Profound effect on instrument design.
  • ~ 1 μ" class astrometry may require siderostats.
  • Telescope pivot error tolerances become ~ 1 μm for ~ 1 μ" astrometry.
<table>
<thead>
<tr>
<th>Site</th>
<th>$r_0$ (500nm)</th>
<th>$f_c$</th>
<th>$\theta_0$</th>
<th>$\sigma_\delta$ (100m, l’, 1hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mauna Kea</td>
<td>20 cm</td>
<td>80 Hz</td>
<td>1.6“</td>
<td>60 $\mu$as</td>
</tr>
<tr>
<td>South Pole</td>
<td>6 cm</td>
<td>35 Hz</td>
<td>34”</td>
<td>8 $\mu$as</td>
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<tr>
<td>Dome C</td>
<td>20 cm</td>
<td>2.5 Hz</td>
<td>380”</td>
<td>0.5 $\mu$as</td>
</tr>
</tbody>
</table>
Impact of Recent NASA Actions

• With the Outrigger Array gone, there is currently no astrometric facility planned for the Northern Hemisphere.

• With SIM delays there is an opportunity to get the jump on some very interesting science from the ground.