Astrometric search for extrasolar planets

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Astrometric Signal

\[ \text{a}_{\text{wobble}} [\text{AU}] = \text{a}_{\text{comp}} [\text{AU}] \left( \frac{M_{\text{comp}}}{M_{\text{star}}} \right) \]
Astrometric Signal

\[ a_{\text{wobble}} \, [\text{AU}] = a_{\text{comp}} \, [\text{AU}] \, \frac{M_{\text{comp}}}{M_{\text{star}}} \]

Astrometric Signal (circular orbit)

\[ \Theta \, [\text{mas}] = 2 \times a_{\text{wobble}} \, [\text{mas}] = 1.91 \times \frac{a_{\text{comp}}}{[\text{AU}]} \, \frac{[\text{pc}]}{d} \, \frac{M_{\text{comp}}}{[M_{\text{J}}]} \, \frac{[M_{\odot}]}{M_{\text{star}}} \]
Astrometric Signal (circular orbit)

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Example

Jupiter with Sun seen from 5 pc / 100 pc: \[ \Theta = 2 \text{ mas} / 0.1 \text{ mas} \]

Earth with Sun seen from 5 pc: \[ \Theta = 1.2 \mu\text{as} \]
Exoplanet Detection - Sensitivity

- Θ(50 pc) = 1 mas
- Θ(10 pc) = 100 µas
- Θ(5 pc) = 1 µas
- K = 10 m/s
- K = 1 m/s
- K = 10 cm/s
- ∆F / F ≃ 1 %
- ∆F / F ≃ 0.1 %
- ∆F / F ≃ 0.01 %

(data from exoplanet.eu)
First Detection of an Astrometric Companion

Friedrich Wilhelm Bessel (1784-1846)

1844
periodic perturbation in the proper motions of Sirius and Procyon

Conclusion
existence of unseen companion orbiting the star

Sirius A, Sirius B
Parallax, Proper Motion, Acceleration, and Orbital Motion of Barnard’s Star

Peter van de Kamp

Sprout Observatory, Swarthmore College, Swarthmore, Pennsylvania
(Received 31 December 1968)

Twenty-four early plates (1916–1919) and thirty consecutive years of photographic observations of Barnard’s star covering the interval 1938–1967 confirm orbital motion with a period of 25 years and semi-axis major of 0".0275. The total number of plates is 3036, with 10 452 exposures, taken on 766 nights, with a total weight of 2056. Assuming a value of 0.15 ☉ for the mass of Barnard’s star, the mass of the companion is found to be 0.0016 ☉, or 1.7 times the mass of Jupiter.
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- Sproul refractor (diameter: 61 cm, focal length: 10.9 m)
- never confirmed by other groups (Gatewood et al., 1973)
- detection of systematic errors (Hershey, 1973)
Hubble Space Telescope (launch: 1990)
Currently the only telescope, which already delivers successful applications of astrometry regarding exoplanets.

- Gl 876 b (Benedict et al., 2002)
- 55 Cnc d (Mc Arthur et al., 2004)
- Epsilon Eridani b (Benedict et al., 2006)
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Spaced based Astrometry

HD 33636 b
RV planet candidate with $M \sin i = 9.3 \, M_J$

Bean et al. 2007 determined with astrometry a true mass of $M_{\text{true}} = 142 \pm 11 \, M_J$. 

Tristan Röll (AIU Jena)
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Astrometric Exoplanet Search at the AIU Jena

Targets

nearby stellar multiple systems (distance < 100 pc)
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### Telescope and Instruments
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- single 8 m apertures (VLT and SUBARU)
# Astrometric Exoplanet Search at the AIU Jena

## Targets

nearby stellar multiple systems (distance < 100 pc)

## Telescope and Instruments

- single 8 m apertures (VLT and SUBARU)
- AO assisted NIR imager
Astrometric Exoplanet Search at the AIU Jena

### Targets

nearby stellar multiple systems (distance < 100 pc)

### Telescope and Instruments

- single 8 m apertures (VLT and SUBARU)
- AO assisted NIR imager
- NIR narrow band filter
Astrometric Exoplanet Search at the AIU Jena

Targets

nearby stellar multiple systems (distance < 100 pc)

Telescope and Instruments

- single 8 m apertures (VLT and SUBARU)
- AO assisted NIR imager
- NIR narrow band filter

Calibration

old globular cluster (47Tuc and M15)
Astrometric Exoplanet Search at the AIU Jena

"Wobble"-Orbit

„Wobble“-Orbit
Astrometric Exoplanet Search at the AIU Jena

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„Wobble“-Orbit
First Target System: HD 19994 A&B

- **P**_{binary} \geq 1400 \text{ years}
- distance \approx 22.6 \text{ pc}
- M_A \approx 1.34 M_\odot, \quad M_B \approx 0.4 M_\odot

RV planet candidate HD 19994 Ab
Mayor et al. (2004)

- P_{pl} \approx 535 \text{ days}
- a_{pl} \approx 1.4 \text{ AU}
- m \sin i \approx 1.7 M_{Jup}

Expected Astrometric Signal:
- \Theta(\iota = 90^\circ) \approx 150 \mu\text{as}
- \Theta(13 M_{Jup}) \approx 1.2 \text{ mas}
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HD 19994 A&B - Astrometric measurements

HD19994 A & (BC) - Separation

Sep [pixel]

HD19994 A & (BC) - Delegation Measurements

Deviation [mas]

Residual [µas]

Time [MJD]

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Astrometric search for exoplanets
HD 19994 B&C - Speckle Interferometry

HD19994 B & C - Separation

(speckle interferometry program written by Rainer Köhler)

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HD 19994 B&C - Radial Velocity (CRIRES, VLT)

HD1994 B & C - RV

m_{comp} / M = 0.605
Ecc = 0.36
Inc [deg] = 108.63
P [days] = 378.1
a_{total} [AU] = 0.97
\omega [deg] = 335.9

(radial velocity data by Andreas Seifahrt and Jacob Bean)
HD 19994 B - Wobble Orbit

\[ P \text{ [days]} = 378.07 \pm 0.64 \]

\[ m_C \text{ [M}_\odot] = 0.326 \pm 0.012 \]

\[ M_B \text{ [M}_\odot] = 0.54 \pm 0.014 \]

\[ \text{Inc [deg]} = 108.58 \pm 0.51 \]

\[ \text{Ecc} = 0.36 \pm 0.014 \]

\[ d \text{ [pc]} = 20.11 \pm 0.30 \]

\[ 0 - 2 - 4 - 6 \]

\[ 2 \quad 4 \]

\[ X_{\text{app}} \text{ [mas]} \]

\[ Y_{\text{app}} \text{ [mas]} \]

(S \leftrightarrow N)

Astrometric search for exoplanets
HD 19994 is a triple system, harboring one exoplanet

- P [days] = 378.07 ± 0.64
- mC [M☉] = 0.326 ± 0.012
- MB [M☉] = 0.54 ± 0.014
- Inc [deg] = 108.58 ± 0.54
- Ecc = 0.36 ± 0.014
- d [pc] = 20.11 ± 0.30
Exoplanet Detection - Sensitivity

Astrometric search for exoplanets

(data from exoplanet.eu)
Earth’s Atmospheric Turbulence’s

(by Tyson: “Introduction to Adaptive Optics”)

\[
\begin{align*}
\theta_0 \text{ (μrad)} &\quad f_G \text{ (Hz)} \\
(\text{cm}) &\quad r_0 \text{ (cm)} \\
\lambda \text{ (μm)} &
\end{align*}
\]
Extreme case: Two blackbodies with $T_{\text{eff}} = 2000 \, \text{K}$ and $T_{\text{eff}} = 20000 \, \text{K}$
Differential Chromatic Refraction

ESO Ks Filter

ESO NB2.17 Filter

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HD 19994 A&B - Astrometric measurements

HD19994 A & (BC) - Position Angle

Angle [deg]

Deviation [deg]

Residual [deg/1000]

Time [MJD]

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Astrometric search for exoplanets
HD 19994 B&C - Speckle Interferometry

HD19994 B & C - Position Angle

Time [MJD]

Residual [deg]

(speckle interferometry program written by Rainer Köhler)

Tristan Röll (AIU Jena)  Astrometric search for exoplanets