Wide Binaries in Gaia

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IAU Symposium 330:
Astrometry and Astrophysics in the Gaia Sky
Nice, France

Julio Chanamé (PUC)
Marcel Agüeros (Columbia)
Sirius A/B System

(A) the apparent motions relative to background stars of Sirius (A), its companion (B) and the center of mass of the system (C)

(B) Orbital motions of Sirius A and B relative to center of mass

Motions of Sirius A and B (binary star system)

Image Credit: Michael Rulison

Right Ascension

Declination

Bond et al. (2017)
Proper Motions from Photometric Plates

Laser Scanning Microdensitometer

Willem Luyten

IAU Colloquia 5:
Coordination of Observing Techniques of Visual Double Stars
Nice, France September 1969

Newcomb (1971)
Wide Binary Science

**Galactic Structure**
Wide binaries are fragile, sensitive to structure

**Stellar Dynamics**
Triple system dynamics

**Stellar Astrophysics**
Components are co-eval, independent, same metallicity
Initial-Final Mass Relation

Zhao et al. (2012)
Initial-Final Mass Relation

Zhao et al. (2012)

Andrews et al. (2015)
Initial-Final Mass Relation

We are limited by data quality and small sample sizes!!
Wide Binaries using TGAS

TGAS Characteristics:
- 2 million stars
- Minimum separation ~ 2"
- Bias at separations <10"
- g mag < 12

Our Goal: Match on 5 Dimensions of Phase Space
- Position
- Proper motion
- Parallax
- Correlated uncertainties
- No radial velocities (yet)

Andrews et al.  
ArXiv: 1704.07829
Method - Bayesian Priors

Random alignment prior
\[ \propto \rho(\hat{x})^2 \]

Density in position and proper motion phase space

Binary prior
\[ \propto f_{\text{bin}} \rho(\hat{x}) \]

Binary fraction

Andrews et al.
ArXiv: 1704.07829
Method - Random Alignment Likelihood

Probability = density x area

The area of an infinitesimally thin annulus is $2\pi r dr$

Position

Proper Motion

$d\theta$

$d\Delta \mu$
Method - Binary Likelihood

- Binary Likelihood
- Random Alignment
- Binary
- Log ΔV (km/s)
- Parallax (mas)
- Proper Motion (mas/yr)
- Log s (AU)
A Catalog of Only Random Alignments

Shift the catalog by:
- +1° in declination
- +3 mas/yr in right ascension
- +3 mas/yr in declination

Example from
Lepine & Bongiorno (2007)
A Catalog of **Only** Random Alignments

Shift the catalog by:
- +1° in declination
- +3 mas/yr in right ascension
- +3 mas/yr in declination

Example from
Lepine & Bongiorno (2007)
Results

Only Random Alignments

![Graph showing the relationship between distance (pc) and projected separation (AU). The graph includes lines for different angular separations (θ) and a distance of 1 pc.]
Results

Only Random Alignments

Catalog of TGAS Wide Binaries
Results

6196 Wide Binaries
For pairs with projected separations <4x10^4 AU, contamination is roughly 5%
Orbital Separation Distribution

Power law:

\[ P(a) \sim a^{-1.6} \]
RAVE Radial Velocity Test

Only Random Alignments

Catalog of TGAS Wide Binaries

\[ P > 0.990 \]

(40)

\[ P > 0.990 \]

(292)
Triple Systems

“more than 25% of [common proper motion] components are spectroscopic or astrometric binaries themselves.”

Makarov et al. (2008)

Chanamé et al. (in prep)
Wide Binary Metallicity Comparison

Decidera et al. (2006)
RAVE Metallicity Comparison

Pearson $r = 0.35$
Spearman $\rho = 0.42$
Kendall $\tau = 0.31$

Andrews et al. (in prep)
We identify binaries at smaller proper motions
Catalog Comparison

TGAS is biased below 10”
No pairs closer than 2”

de Bruijne et al. (2015)
Catalog Comparison

<table>
<thead>
<tr>
<th>Angular Separation (“”)</th>
<th>Apparent Magnitude</th>
<th>Proper Motion (mas/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1 10^1</td>
</tr>
<tr>
<td>1 10^1</td>
<td>1</td>
<td>1 10^2</td>
</tr>
<tr>
<td>1 10^2</td>
<td>1</td>
<td>1 10^3</td>
</tr>
<tr>
<td>1 10^3</td>
<td>1</td>
<td>1 10^4</td>
</tr>
</tbody>
</table>

SDSS | Hipparcos | TGAS

Dhital et al. (2010) | Shaya & Olling (2011) | This work

N = 1342 | N = 543 | N = 6197

SDSS g mag | V mag | Gaia g mag

Future data sets will go much deeper

Future depth
Conclusions

• We have found over 4000 wide binaries with separations <4x10^4 AU and contamination < 5%.

• There is lots of potential science:
  - stellar triples
  - stellar abundances
  - galactic structure

• We will likely find 2 orders of magnitude more wide binaries in future Gaia catalogs

• N^2 scaling makes this problem very challenging in DR2

See details on the ArXiv: 1704.07829
Extra Slides
Detecting Orbital Velocities

Proper Motion

Parallax

\[ \frac{\Delta \mu}{\sigma_{\Delta \mu}} \]

\[ \frac{\Delta \varpi}{\sigma_{\Delta \varpi}} \]
Cluster Dissolution

Model 1

Simulate open cluster dispersal

Model 2

Kouwenhoven et al. (2010)
Cluster Dissolution

- Kouwenhoven et al. (2010)
- Model 1
- Simulate open cluster dispersal

- Elliott & Bayo (2016)
- See also Alonso-Floriano et al. (2015)
- Cluster Dissolution
Binaries become unbound due to passing stars and the Galactic tide.
Öpik’s Law

Region 1
“Small” Separations

Region 2
“Large” Separations

Probability

$P(a) \sim a^{-1.6}$
power law

Angular Separation ("")
Öpik’s Law only consistent at small separations

Öpik’s Law:

\[ P(a) \sim a^{-1.6} \]

power law

Angular Separation (")

Region 1
“Small” Separations

Region 2
“Large” Separations
Wide Binary Science

Galactic Structure
- Weinberg et al. (1985) - Binary stars dissipate over time
- Bahcall & Tremaine (1985) - MACHOs cannot be larger than 2 Msun
- Yoo et al. (2004) - MACHOs cannot be form dark matter in the Milky Way
- Penarrubia et al. (2016) - Constrain dark matter in nearby ultrafaint galaxies

Stellar Dynamics
- Kouwenhoven et al. (2010) - Formed from dissolution of stellar clusters
- Reipurth & Mikkola (2012) - Formed from dynamical unfolding of stellar triples
- Andrews et al. (2016) - Constrain Lidov-Kozai mechanism
- Tokovinin (2017) - Formed from bound, nearby star-forming cores

Stellar Astrophysics
- Bonfils et al. (2005) - Calibrate M-dwarf metallicities
- Garcés et al. (2011) - Calibrate stellar chromospheric ages
- Andrews et al. (2015) - Constrain the Initial-Final mass relation
Clustered Pairs

Oh et al. (submitted)
Random Alignments - Radial Velocities

![Graph showing ΔRV/σRV vs Log s(AU) and N vs Log s(AU)]
Method Test - rNLTT
Open Clusters

We remove 12 open clusters:

- Pleiades
- Coma Ber
- Hyades
- Praesepe
- α Per
- IC 2391
- IC 2602
- Blanco I
- NGC 2451
- NGC 6475
- NGC 7092
- NGC 2516
Cross-Matching with LAMOST - Radial Velocities
Cross-Matching with LAMOST - Metallicities
Gaia for Planets

Image Credit: ESA Gaia