The mass excess in the systems of wide visual double stars on the basis of apparent motion parameters method, Hipparcos parallax and WDS data.

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Abstract. The formula for determination of the minimal value of the total mass of visual double star components is derived on the basis of Apparent Motion Parameters method. To apply this formula, the trigonometric parallax $\mathbf{p_t}$ and the apparent motion parameters (distance $\boldsymbol{\rho}$, position angle $\boldsymbol{\theta}$, apparent relative velocity $\boldsymbol{\mu}$ and its direction $\boldsymbol{\psi}$ at a fixed epoch T_o, and also $\boldsymbol{\rho_c}$ – the radius of curvature of the observed short arc of the apparent motion near T_o) are to be known. We assume that Hipparcos parallax is determined with a good precision. We selected 129 wide pairs ($\rho \geq 2''$, $p_t \geq 0.01''$, observed arc is enough for ρ_c determination) from WDS catalog for investigation. We conclude that for 13 stars the value of minimal mass M_{min} is more than may be expected from mass luminosity relation $M_{SP\text{-}L}$. Possible explanations include invisible satellites or some peculiarities.

Key words: stars: binaries: visual – stars: fundamental parameters (masses)

Introduction.

The method of apparent motion parameters (AMP), applied to determining the orbits of visual binaries on the basis of the short arc of observations (Kiselev and Kiyaeva, 1980), can be used for estimating the lowest limit for the sum of the component masses without determining the orbit. A necessary condition for this work is a reliable knowledge of the trigonometric parallax $\mathbf{p_t}$ and the following apparent motion parameters: distance $\boldsymbol{\rho}$, position angle $\boldsymbol{\theta}$, visual relative velocity $\boldsymbol{\mu}$ and its direction $\boldsymbol{\psi}$ at a fixed epoch T_o, and also $\boldsymbol{\rho_c}$ – the radius of curvature of the observed short arc of the apparent motion near T_o.

The mass estimate can be easily derived from the key formula of the AMP method

$$r^3=k^2(\rho\rho_c/\mu^2)\,|\sin(\psi-\theta)|$$

Here **r** is the spatial separation between components A and B, expressed in AU, $\mathbf{k^2= 4\pi^2(M_A+M_B)}$ – the dynamical constant of astrocentric motion, expressed in $(AU)^3(yr)^{-2}$, masses, $\mathbf{M_A}$ **and** $\mathbf{M_B}$, are expressed in solar mass.
Clearly, $\mathbf{r \geq \rho/p_t}$. Then

$$M_A+M_B \geq (\rho\mu)^2/(4\pi^2\rho_c p_t^3\,|\sin(\psi-\theta)|) = M_{min}$$

We have applied this formula to the long series of Pulkovo 26-inch refractor visual double stars observations and revealed 7 stars having $\mathbf{M_{min}}$ more than the masses obtained from the mass-luminosity relation $\mathbf{M_{SP\text{-}L}}$. It is known that 4 of them are multiple stars. Therefore we assume that other stars may be also multiple or anomalous stars, and further study of them is desirable (Kiselev, Kiyaeva, 2003).

Selection of the stars for investigation.

We applied the same technique to wide pairs from the WDS catalog. The selection of the stars was done using the first and last observations of the all stars included in the WDS catalog, according to the following criteria:

1) Distance ρ is more than 2”.
2) Parallax from Hipparcos catalogue is more than 0.01”.
3) The observed arc satisfy to the following condition:

$$0.03 \le \mu(\Delta T)/(2\pi\rho)) \le 0.1,$$

that is, observations cover the arc of about from 10^o to 30^o so that at least the orbit curvature may be determined, although the orbit elements and masses can not be determined.
4) Number of positions is more than 20.

We assume that these stars have an elliptical orbit, therefore,

$$\rho/p_t \le r \le 2k^2/v^2.$$

Hence, $$M_A+M_B \ge \rho\mu^2/(8\pi^2 p_t^3)=M_o$$

We have rejected the binaries with M_o>20, and thus we have confined the problem to normal stars only. The rejected 616 stars are either optical pairs or possibly have errors in their first or last observations. There may be interesting anomalous starts among them, however, and we plan to investigate them later on. As a result, 129 stars were selected for analysis.

The series of observations for these 129 visual double stars were taken from WDS database, and we appreciate Dr. Mason’s help very much.

The curvature radius determination is the most difficult part. We used four different methods of calculation. The error of $\boldsymbol{\rho_c}$ shows us the dispersion of their values. Unfortunately, the dispersion of different heterogeneous XIX century observations is too high and the curvature isn’t determined for many binaries.

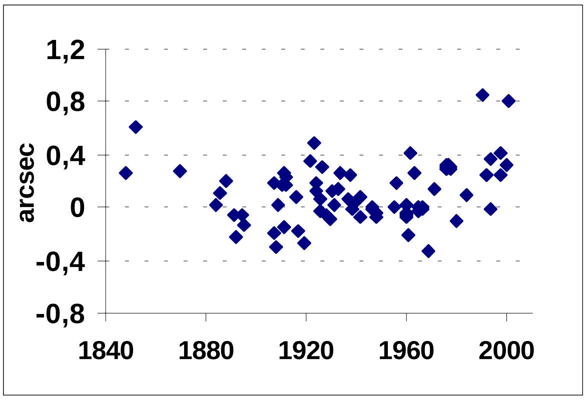
Results.

Here we present only 14 stars for which the apparent motion parameters may be determined reliably enough and $\mathbf{M_{min}}$>$\mathbf{M_{SP\text{-}L}}$. The curvature radius is determined with different precision for different stars. Therefore we present also the graphs which illustrate deviations of positions from rectilinear orbital motions (a possibility to determine the curvature). The error of $\mathbf{M_{min}}$ depends of the errors of $\boldsymbol{\rho_c}$ and $\mathbf{p_t}$.

There are 3 stars, marked by *(ADS 8048, 8250 and 12145), which are included in the multiple stars catalog (MSC, Tokovinin, 1997), data of MSC is in agreement with our results for ADS 8250 and 12145. The number of observations for ADS 8048 (N=35) isn’t enough to be sure in the result.

The most interesting stars are absent in MSC. May be, they have still undiscovered invisible satellites or some peculiarities. Among them we reveal 2 stars – ADS 7446, 9701– for which our results are the most reliable.

ADS 3188 = WDS 04246+3358



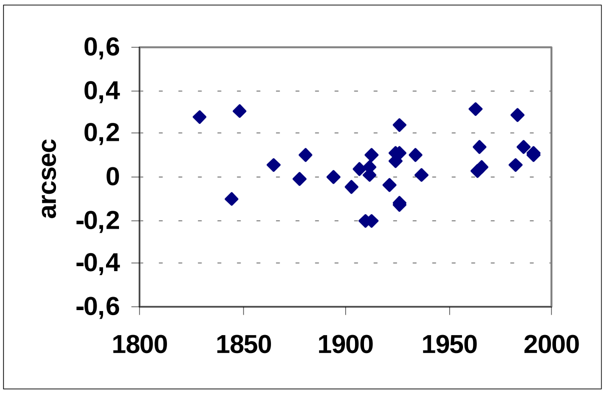
m_A=5.8 m_B=9.6
SP_A= F4IV-V SP_B= –
p_t=0.0240±0.0091”

$\mathbf{M_{SP\text{-}L} \approx 2.2}$ [Sun]

N=85 1847-2004 T_o=1924.0
ρ=4.43±0.03” θ=36.03±0.031°
μ=0.0189±0.0007”/yr ψ=303.6±2.1°
ρ_c=3.7±0.3”

$\mathbf{M_{min}=3.4\pm0.5}$

ADS 6513 = WDS 08010+2335



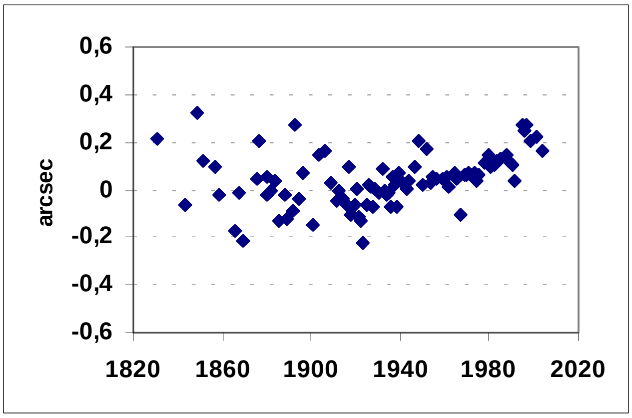
m_A=6.51 m_B=9.95
SP_A=K1III-IV SP_B= –
p_t=0.0118±0.0010”

M_{SP-L}≈3.0[Sun]

N=32 1828-1991 T_o=1910.2
ρ=2.48±0.05” θ=329.04±0.74°
μ=0.0063±0.0008”/yr ψ=181.9±6.2°
ρ_c=1.4±0.2”

M_{min}=4.9±2.0

ADS 7446 = WDS 09379+7305



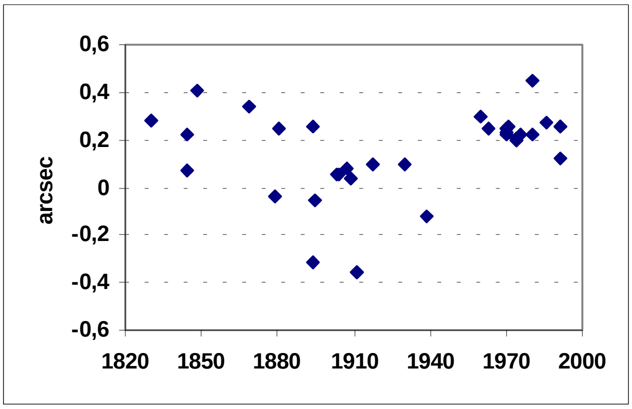
m_A=6.39 m_B=6.58
SP_A=F1IV SP_B=F2V
p_t=0.0144±0.0011”

M_{SP-L}≈3.4[Sun]

N=78 1833-2003 T_o=1918.4
ρ=5.054±0.018” θ=131.61±0.13°
μ=0.0063±0.0002”/yr ψ=34.4±2.8°
ρ_c=0.7±0.1”

M_{min}=12.1±3.4

ADS 8048 = WDS 11047-0413 *



m_A=7.64 m_B=10.25
SP_A=G5V SP_B=M0V
p_t=0.0406±0.0014”

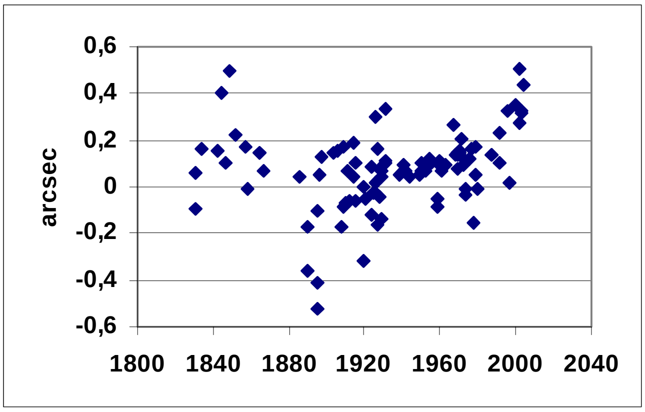
M_{SP-L}≈1.4[Sun]

N=35 1829-1991 T_o=1910.7
ρ=11.227±0.045” θ=216.50±0.17°
μ=0.0127±0.0005”/yr ψ=271.8±2.7°
ρ_c=1.5±0.4”

M_{min}=6.1±1.8

MSC data: the triple system, masses – 0.9+0.47+0.45=1.82[Sun]

ADS 8250 = WDS 11387+44507 *



m_A=6.50 m_B=8.37
SP_A=G0V SP_B=K2V
p_t=0.0429±0.0010”

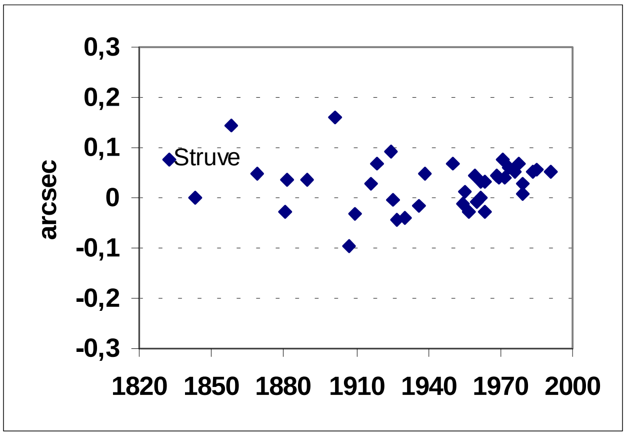
$M_{SP\text{-}L}$≈1.8[Sun]

N=104 1830-2004 T_o=1893.7
ρ=9.970±0.019” θ=258.14±0.10°
μ=0.0206±0.0003”/yr ψ=114.9±0.9°
ρ_c=6.4±0.5”

M_{min}=2.3±0.2

MSC data: the triple system, masses – 1.1+0.74+0.31=2.15[Sun]

ADS 8450 = WDS 12115+5325



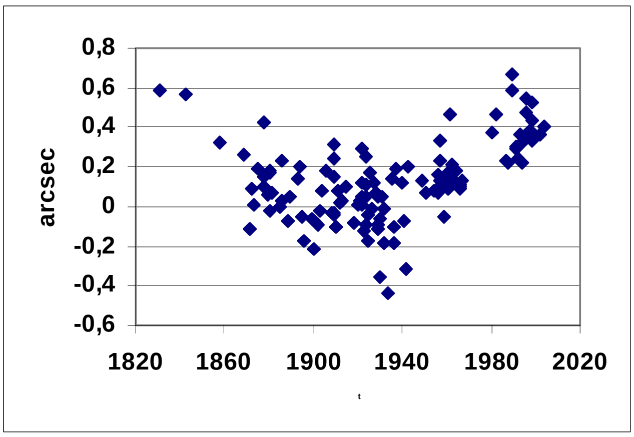
m_A=7.96 m_B=8.14
SP_A=K2 SP_B=G9
p_t=0.038±0.004”

$M_{SP\text{-}L}$≈1.7[Sun]

N=39 1832-1991 T_o=1913.0
ρ=12.140±0.041” θ=222.23±0.07°
μ=0.0164±0.0006”/yr ψ=208.7±1.1°
ρ_c=18.2±3.0”

M_{min}=4.3±1.6

ADS 9192= WDS 14165+2007



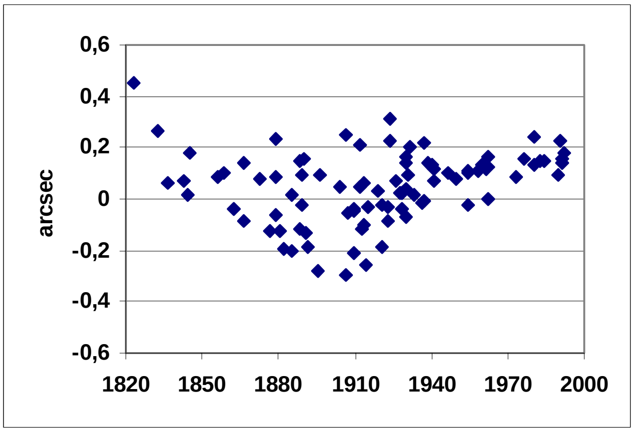
m_A=6.25 m_B=8.39
SP_A=F6V SP_B= –
p_t=0.0310±0.0008”

$M_{SP\text{-}L}$≈2.0[Sun]

N=128 1830-2003 T_o=1917.0
ρ=4.288±0.017” θ=169.41±0.12°
μ=0.0139±0.0003”/yr ψ=99.6±1.6°
ρ_c=1.3±0.1”

M_{min}=2.4±0.3

ADS 9237 = WDS 14226-0746



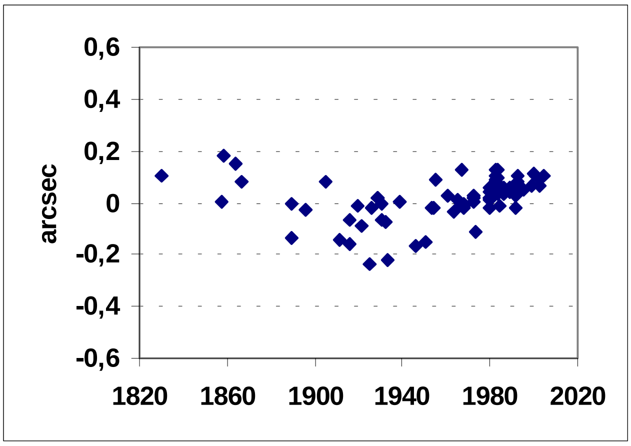
m_A=6.82 m_B=6.84
SP_A=G0V SP_B=G0V
p_t=0.0228±0.0019"

M_{SP-L}≈2.5[Sun]

N=94 1822-1991 T_o=1907.3
ρ=5.574±0.021" θ=169.55±0.14°
μ=0.0074±0.0004"/yr ψ=214.7±2.7°
ρ_c=1.1±0.1"

M_{min}=4.8±1.5

ADS 9346 = WDS 14410+5757



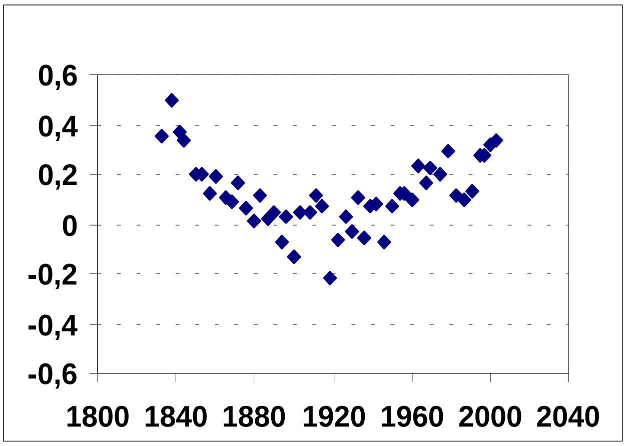
m_A=7.03 m_B=7.90
SP_A=K0 SP_B= –
p_t=0.0189±0.0009"

M_{SP-L}≈2.5[Sun]

N=80 1830-2004 T_o=1917.0
ρ=7.592±0.022" θ=42.69±0.11°
μ=0.0088±0.0002"/yr ψ =134.5±3.2°
ρ_c=3.2±0.8"

M_{min}=5.2±1.5

ADS 9701 = WDS 15348+1032



m_A=3.80var m_B=4.84
SP_A=F0IV SP_B=F0
p_t=0.0155±0.0008"

M_{SP-L}≈5.5[Sun]

N=405 1831-2004 T_o=1913.0
ρ=3.741±0.022" θ=184.00±0.04°
μ=0.0120±0.0002"/yr ψ=136.5±1.0°
ρ_c=1.8±0.2"

M_{min}=10.3±2.2

Note: the 3 years means (49 positions) were used

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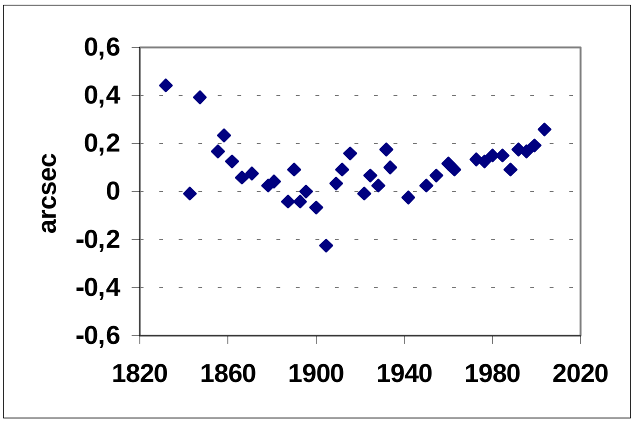
ADS 9842 = WDS 15559-0210



m_A=6.77 m_B=8.46
SP_A=G0 SP_B= –
p_t=0.0265±0.0011”

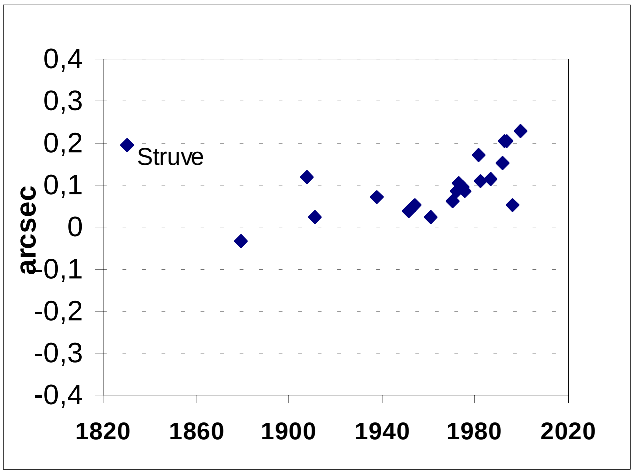
M_{SP-L}≈2.0[Sun]

N=153 1831-2004 T_o=1913.9
ρ=5.871±0.008” θ=338.01±0.11°
μ=0.0172±0.0002”/yr ψ=61.7±0.9°
$ρ_c$=4.2±0.2”

M_{min}=3.3±0.4

Note: the 3 years means (39 positions) were used.

ADS 10329 = WDS 17033+5935



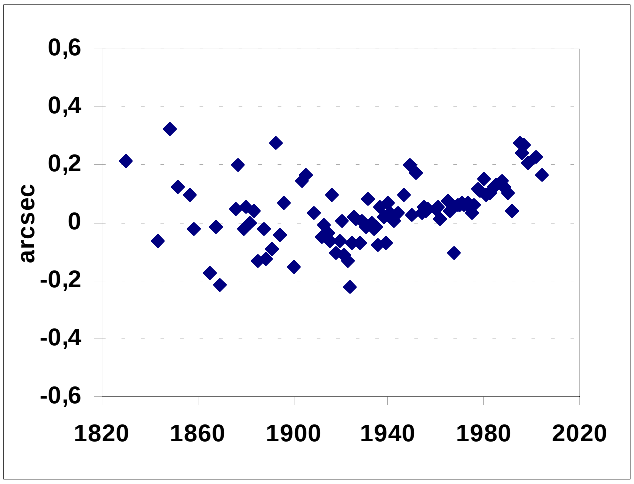
m_A=8.61 m_B=10.34
SP_A=K5 SP_B=M0
p_t=0.0397±0.0016”

M_{SP-L}≈1.3[Sun]

N=37 1830-1999 T_o=1914.8
ρ=12.010±0.024” θ=49.41±0.12°
μ=0.0146±0.0003”/yr ψ=333.2±2.9°
$ρ_c$=4.0±0.6”

M_{min}=3.1±0.6

ADS 12145 = WDS 19111+3847 *



m_A=8.15 m_B=8.07
SP_A=G6V SP_B=G7V
p_t=0.0205±0.0012”

M_{SP-L}≈2.0[Sun]

N=229 1830-2003 T_o=1917.1
ρ=4.256±0.007” θ=36.72±0.06°
μ=0.0157±0.0001”/yr ψ=325.1±0.8°
$ρ_c$=4.3±0.6”

M_{min}=3.2±0.7

MSC data: the quadruple system, masses – (1.18+0.85)+(0.80+0.56)=3.39[Sun]

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