Mulitplicity-study of nearby B-type stars

using near-infrared data from ESO-VLT Archive

Christian Adam

Astrophysikalisches Institut und Universitätssternwarte
Friedrich-Schiller Universität Jena

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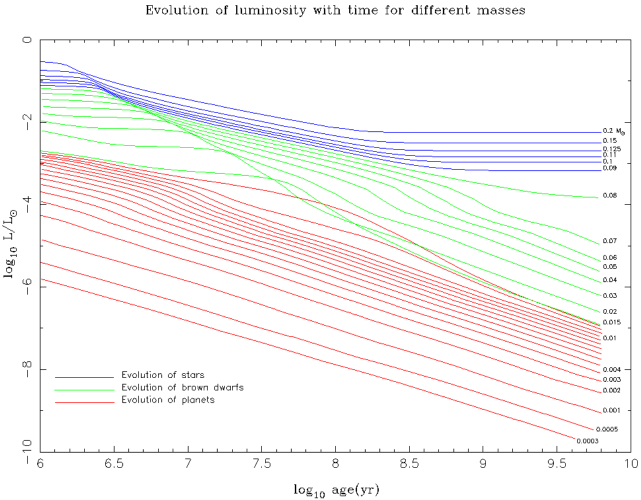
Outline

1. Why intermediate/high-mass stars?
   - principal source of heavy elements and UV-radiation
   - affect the physical, chemical, and morphological structure of galaxies (e.g Kennicutt 1998, 2005)
   - strong influence on star- and planet-formation in their environment (Bally et al. 2005)
   - and high frequency of multiplicity (But why and what is the frequency of multiplicity?)
2. Why near-infrared data?



(Burrows et al. 2001)

Search for unknown Multiplicity of B-stars in ESO/VLT-NaCo Archive Data using Direct Imaging

- increase the data sample size $\longrightarrow$ improve statistics
- estimate frequency of multiple systems among all B-stars
- "improve understanding of formation and evolution of high-mass stars and multiple systems"

Infos

- position, α_{J2000} and δ_{J2000}
- proper motion, μ_α and μ_δ
- magnitudes U, B, V, R, I, J, H and K, and spectral type B
- Parallax π

- small uncertainties in $\pi \Longrightarrow$ more precise magnitudes
- catalogs: Simbad, Vizier (Hipparcos, 2Mass)

- $\pi = 1\text{mas} \Longrightarrow$ volume-limited sample of objects d $\lesssim$ 1 kpc
- 1st: search in Simbad and Hipparcos: 8146 B-stars
- 2nd: limit sample by accuracy of Parallax

SpTyp	#	$\pi - 1\sigma_\pi \geq 1$ mas	$\pi - 2\sigma_\pi \geq 1$ mas	$\pi - 3\sigma_\pi \geq 1$ mas
B	8146	5967	3956	2600

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- 3rd: search in ESO-VLT/NaCo archive: 231 availible objects

The Reduction

- standard reduction for all data
- conicap-pipline for dark- and flat-field reduction (Devillard 1997)
- jitter algorithm used for science-data reduction

$$IMG_{SCI} = \frac{RAW_{SCI} - DARK_{SCI}}{FLAT - DARK_{FLAT}}$$

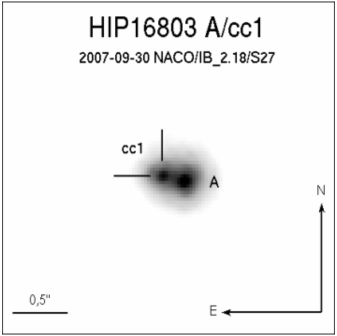
- Shift+Add $\longrightarrow$ reduced science image

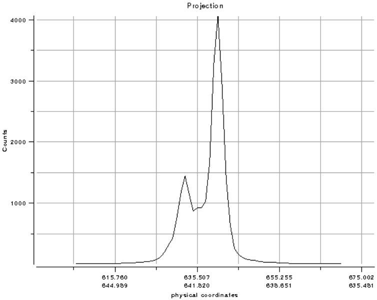
- Software: MIDAS, Sextractor, Gaia, IDL
- Howto measure the position
  1. Center of flux
  2. maximum of PSF[1]-fitting (2D-Gaussian-fit) <– used here

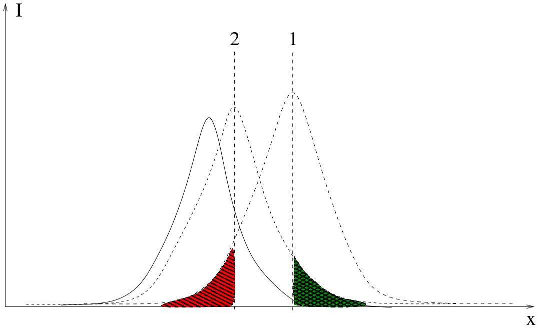
[1] PSF... Point-Spread-Function

Position of Objects

PSF Subtraction

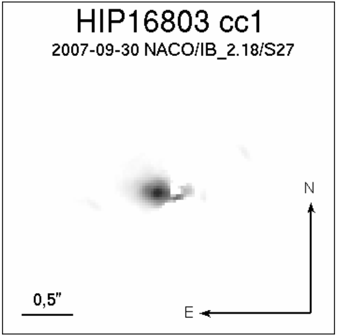


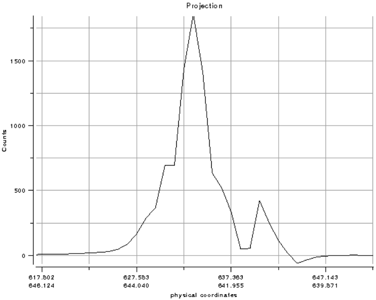


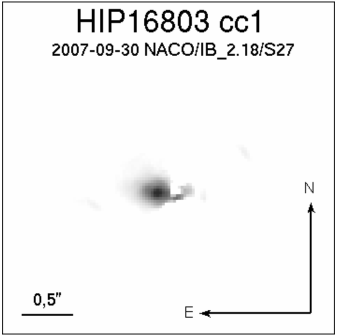


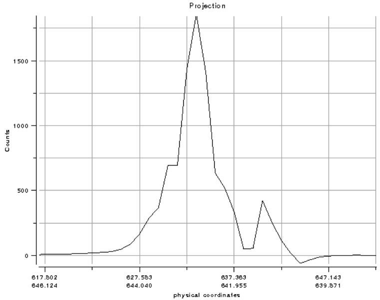
- superposition of Psf $\Longrightarrow$ shift in pixelposition
- solution: substract Psf from Image
  1. symmetric model Psf
  2. measured (”real”) Psf
- result: corrected pixelposition of objects

Position of Objects
PSF Subtraction









$x_i,\ y_i$ Position [pixel] $\longrightarrow$ Separation *sep**[pixel] & Position Angle *pa**[deg]

$$sep^* = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2}$$

$$pa^* = \arctan\left(\frac{(y_i - y_j)}{(x_i - x_j)}\right) \qquad \forall\, i \neq j$$

1. Binary with known separation and position angle
2. calculate theoretical sep and position angle for observing-date of target
3. measure sep and pos.-angle of calib.-bin. for target night

$\Longrightarrow$ Pixel-scale and rotation angle for target

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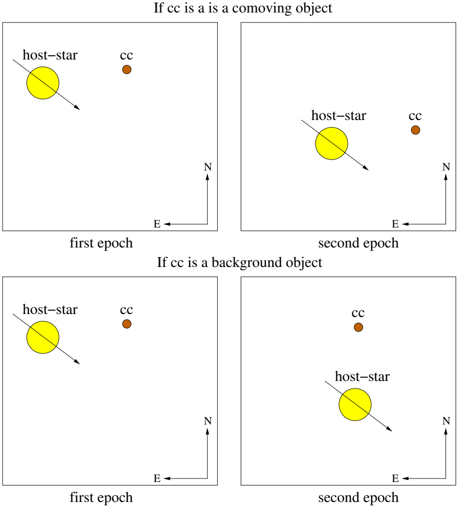
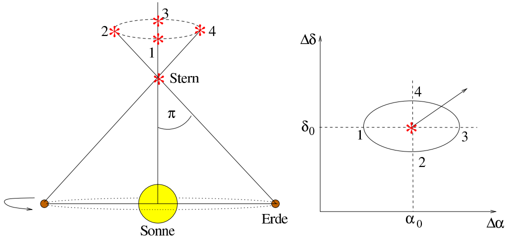
not applied, due to limited time of thesis



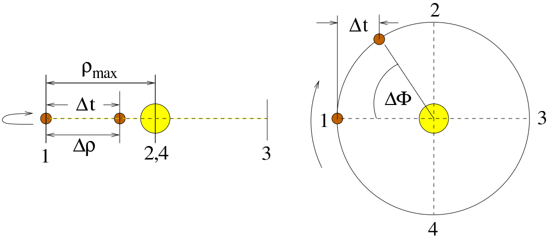
- const. sep. and pa
- ecxept changes due to orbital motion

- sep. and pa $\neq$ const.
- high probability of bg-object



- apparent motion on sky as result of superposition of:
  1. proper motion μ_{ra}, $\mu_{dec} \longrightarrow \Delta\alpha_{pm}$, $\Delta\delta_{pm}$
  2. annual motion of earth around the sun $\rightarrow \Delta\alpha_{\pi}$, $\Delta\delta_{\pi}$

$$\begin{aligned} \Delta\alpha_{bg} &= \Delta\alpha_{pm} + \Delta\alpha_{\pi} \\ \Delta\delta_{bg} &= \Delta\delta_{pm} + \Delta\delta_{\pi} \end{aligned} \Longrightarrow \begin{aligned} sep_{bg} &= \rho_{meas} + \sqrt{\Delta\alpha_{bg}^2 + \Delta\delta_{bg}^2} \\ pa_{bg} &= \Phi_{meas} + \arctan\left(\frac{\Delta\delta_{bg}}{\Delta\alpha_{bg}}\right) \end{aligned}$$

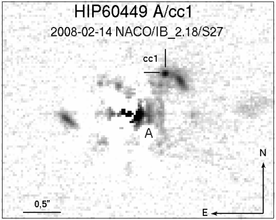


- maximum change in sep for circular edge-on orbit (left)
- maximum change in pa for circular pole-on orbit (right)
- assuming $a \approx \rho_{max} \implies P$ from 3rd. Keplers law

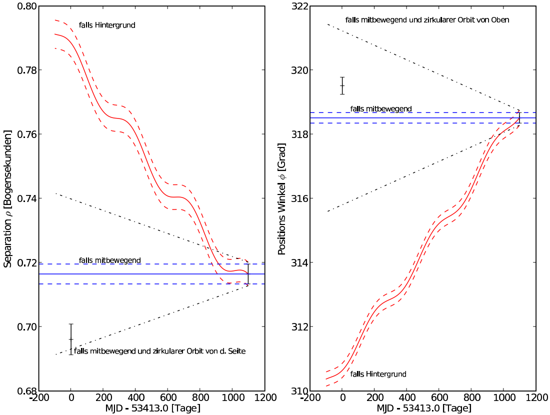
$$P \propto \sqrt{\frac{a^3}{(M_* + M_P)}}$$

$$\Longrightarrow \Delta\rho = 4 \cdot \rho_{max} \cdot \frac{\Delta t}{P}$$

$$\Longrightarrow \Delta\Phi = 360 \cdot \frac{\Delta t}{P}$$



- D = 125 pc
- SpType: B8/9V $\approx 3.7 M_\odot$ (Lang, 1992)
- $a \approx 88\,AU$, $P \approx 425$ yr



MJD	Sep [$''$]	Sep$_{bg}$ [$''$]	σ_{Sep}	P.A. [$^\circ$]	P.A.$_{bg}$ [$^\circ$]	$\sigma_{P.A.}$
53413.28742	0.6961±0.0048	0.7885±0.0043	14.3	319.5±0.3	310.6±0.2	25.6
54510.35386	0.7165±0.0031	-	-	318.5±0.2	-	-

Basic Idea

Age of system and $\Delta m \Longrightarrow$ Mass of companion candidate from evolutionary tracks, e.g. Baraffe et al. 1998, 2002

1. usefull models, e.g. Schaller et al. 1992, Claret 2007 or Bertelli et al. 2009: $L_{bol}, T_{eff} \Longrightarrow$ mass and age of host-star
2. T_{eff}: from spectral type of star (Lang, 1992)
3. L_{bol}: J, H, K magnitudes from 2MASS and plx, Vmag from Hipparcos

L_{bol}: J, H, K magnitudes from 2MASS and plx, Vmag from Hipparcos

$$A_V = \frac{(J-H)_{mess} - (J-H)_0}{c_{jv} - c_{hv}} \quad \text{where} \quad c_{jv} = \frac{A_J}{A_V} = 0.1825,\ c_{hv} = \frac{A_H}{A_V} = 0.282$$

$$M_V = m_V - 5\log\frac{r}{10\text{pc}} - A_V$$

$$M_{bol} = M_V + \text{B.C.}$$

$$L_{bol} = 10^{-0,4(M_{bol} - M_{bol,\odot})} \quad \text{where} \quad M_{bol,\odot} = 4.84\text{mag}$$

L_{bol}, T_{eff} in model $\Longrightarrow$ Age of Host-star $\Longrightarrow$ with Δm and $M_{abs,host}$: Mass of companion candidate from e.g. Baraffe et al. 2002, 1998

231 B-stars in ESO/VLT-NaCo archive
81 Stars with possible companion candidate(s)

34 : 2+ epochs

47: 1 epoch

9: unknown

⇓

25: known but
5: new triple/quad-systems

20: unknown

⇓

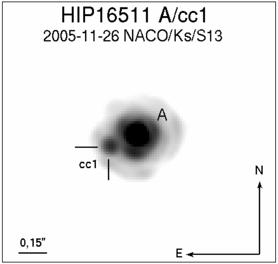
27: known

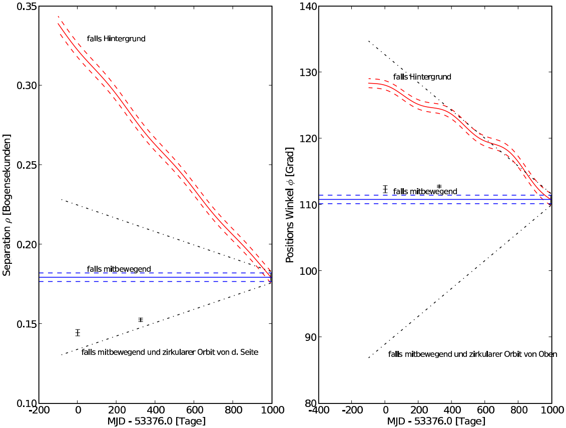
5 : high prob. cc's
4 : medium prob. cc's

future work
new obs., other sources

Results

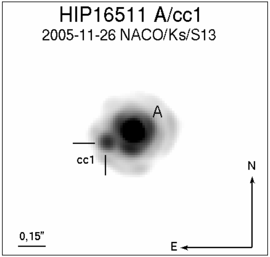
Example: HIP 16511





Epoche	PS [mas/pixel]	Φ^* [°]
2005-01-06	13.289±0.033	-0.220±0.025
2005-11-26	13.192±0.062	-0.425±0.040
2007-09-27	27.085±0.152	-0.239±0.074

- $\pi = 9.18 \pm 0.87\,\mathrm{mas} \approx 110\,\mathrm{pc}$
- B9IV: $\approx 2.5\,M_\odot$, $15 - 40\,Myr$
- $M_K = 0.67\,mag$, $\Delta m \approx 3.6\,mag$
- $sep_{\mathrm{proj.}} \approx 0.15'' \equiv 17\,AU$
- $\rightarrow$ $0.6\,M_\odot$ (Baraffe et al. 1998, 2002)



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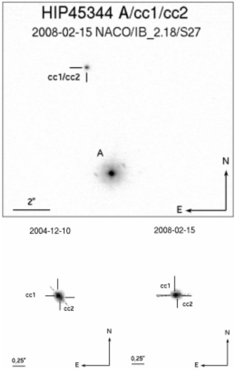
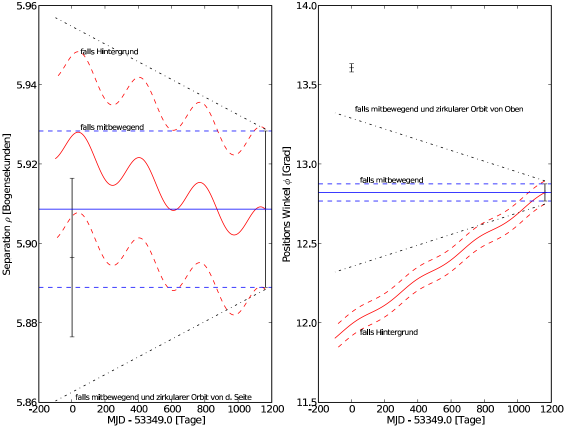
MJD	Sep [″]	Sep_{bg} [″]	σ_{Sep}	P.A. [°]	$P.A._{bg}$ [°]	$\sigma_{P.A.}$
53376.04926	0.1445±0.0020	0.3225±0.0045	35.9	112.4±0.5	128.1±0.7	18.0
53700.13878	0.1526±0.0011	0.2738±0.0041	28.7	112.8±0.2	124.5±0.7	16.0
54370.32211	0.1794±0.0027	-	-	110.8±0.6	-	-



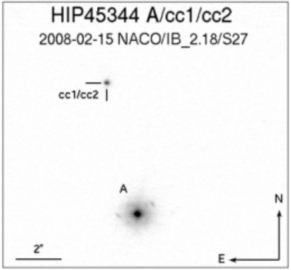


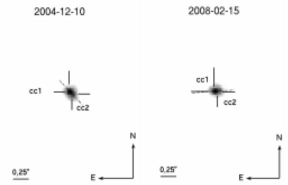
Epoche	PS [mas/pixel]	Φ^* [$^\circ$]
2004-12-10	27.079±0.091	0.004±0.021
2008-02-15	27.179±0.088	-0.200±0.022

RESULTS

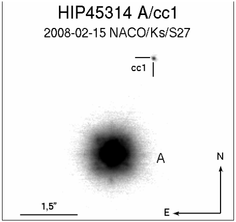
EXAMPLE: HIP 45344

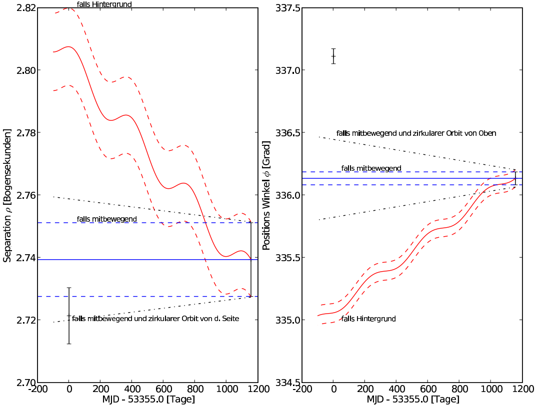
- $\pi = 5.86 \pm 0.54$ mas ≈ 170 pc
- B4V: $\approx 4\, M_{\odot}$, $\approx 16\, Myr$
- $M_K = -0.56\, mag$, $\Delta m_1 \approx 3.5\, mag$, $\Delta m_2 \approx 5.4\, mag$
- $sep_{\mathrm{proj.}} \approx 5.9'' \equiv 1000\, AU$
- $\rightarrow M_1 \approx 1.1\, M_{\odot}$, $M_2 \approx 0.3\, M_{\odot}$ (Baraffe et al. 1998, 2002)





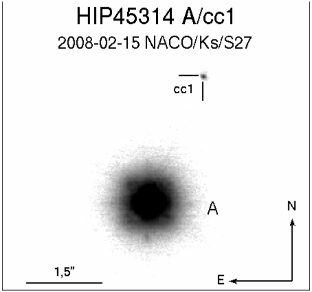
MJD	Sep [$''$]	$\mathrm{Sep_{bg}}$ [$''$]	σ_{Sep}	P.A. [$^\circ$]	$\mathrm{P.A._{bg}}$ [$^\circ$]	$\sigma_{\mathrm{P.A.}}$
53349.37686	5.8965±0.0200	5.9272±0.0203	1.1	13.6±0.0	12.0±0.1	20.4
54511.15795	5.9087±0.0197	-	-	12.8±0.1	-	-





Epoche	PS [mas/pixel]	Φ^* [°]
2004-12-16	27.038±0.088	0.112±0.053
2008-02-15	27.182±0.114	-0.178±0.025

- susp. variable, $\Delta m_{var} = 0.05\ mag$ (Kukarkin et al. 1981)
- $\pi = 6.26 \pm 0.55\,\mathrm{mas} \approx 160\,\mathrm{pc}$
- B6IV: $\approx 3.2\,M_{\odot}$, $\approx 3 - 19\ Myr$
- $M_K = 0.11\ mag$, $\Delta m \approx 6.3\ mag$
- $sep_{proj.} \approx 2.7'' \equiv 430\ AU$
- $\rightarrow M \approx$ 0.05 $- 0.5\,M_{\odot}$ (Baraffe et al. 1998, 2002)



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MJD	Sep [$''$]	Sep_{bg} [$''$]	σ_{Sep}	P.A. [°]	$P.A._{bg}$ [°]	$\sigma_{P.A.}$
53355.36407	2.7214±0.0090	2.8076±0.0124	5.6	337.1±0.1	335.1±0.1	21.3
54511.14395	2.7394±0.0118	-	-	336.1±0.1	-	-

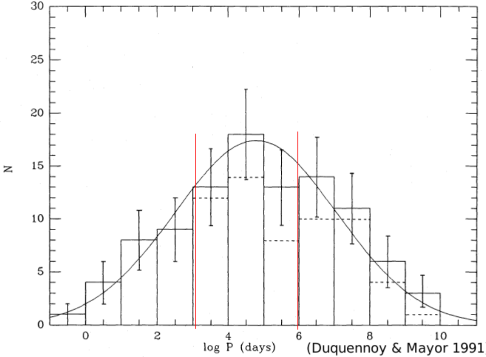
SUMMARY

- $81/231$ with companion candidate: $\approx 35\%$
- $61/81$ are known ($52 + 9$ new (here)): $\approx 75\%$
- Brown Dwarf candidate around HIP45314 A ??

(sub)stellar obj. with orbital periods from $10^2 - 10^4$ yr in NaCo-Range ($\approx 0.1'' - \approx 13''$)

- $44/164 \approx 27\%$ with same mass-(period)-range like sample (81)

1. $\Longrightarrow$ 27% of 47 1 epoch targets: 13 multiples in range
2. $\Longrightarrow$ 73% of 231 multiple: 169 multiples from SB's to long period
3. $\Longrightarrow \approx$ 75% of all B-stars are multiple ???



(Duquennoy & Mayor 1991)

$\Longrightarrow$ To be continued ...

Thank you for your attention