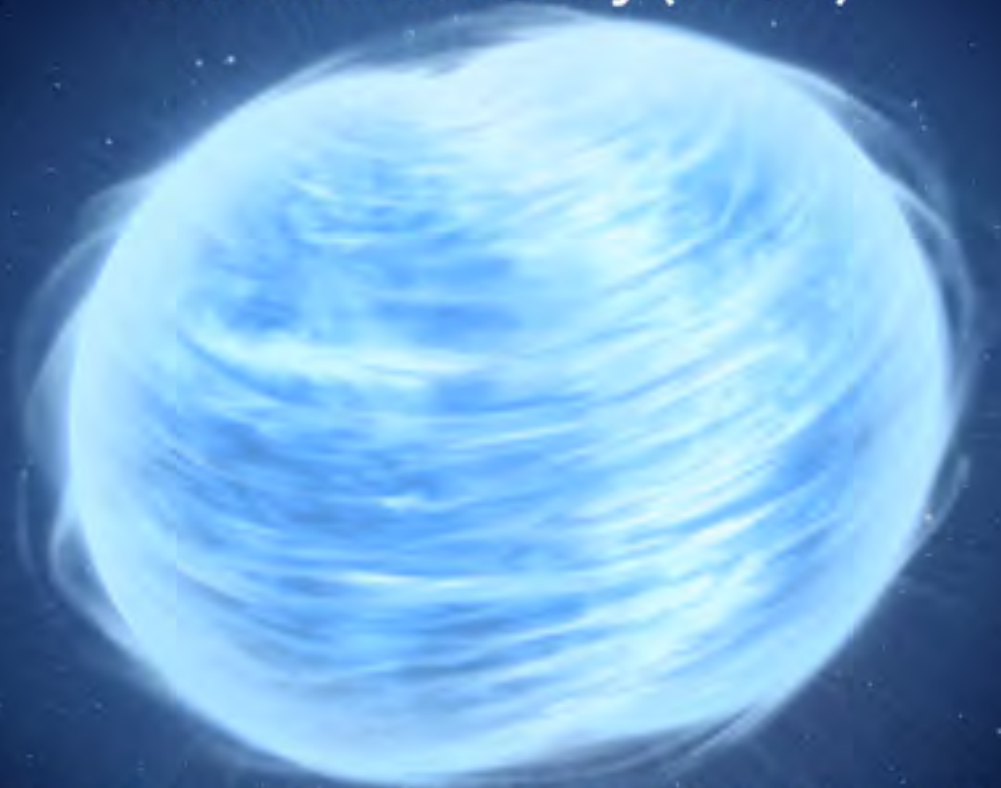
VLBI astrometry on binary systems in the AB Doradus moving group

Dr. Rebecca Azulay (MPIfR)



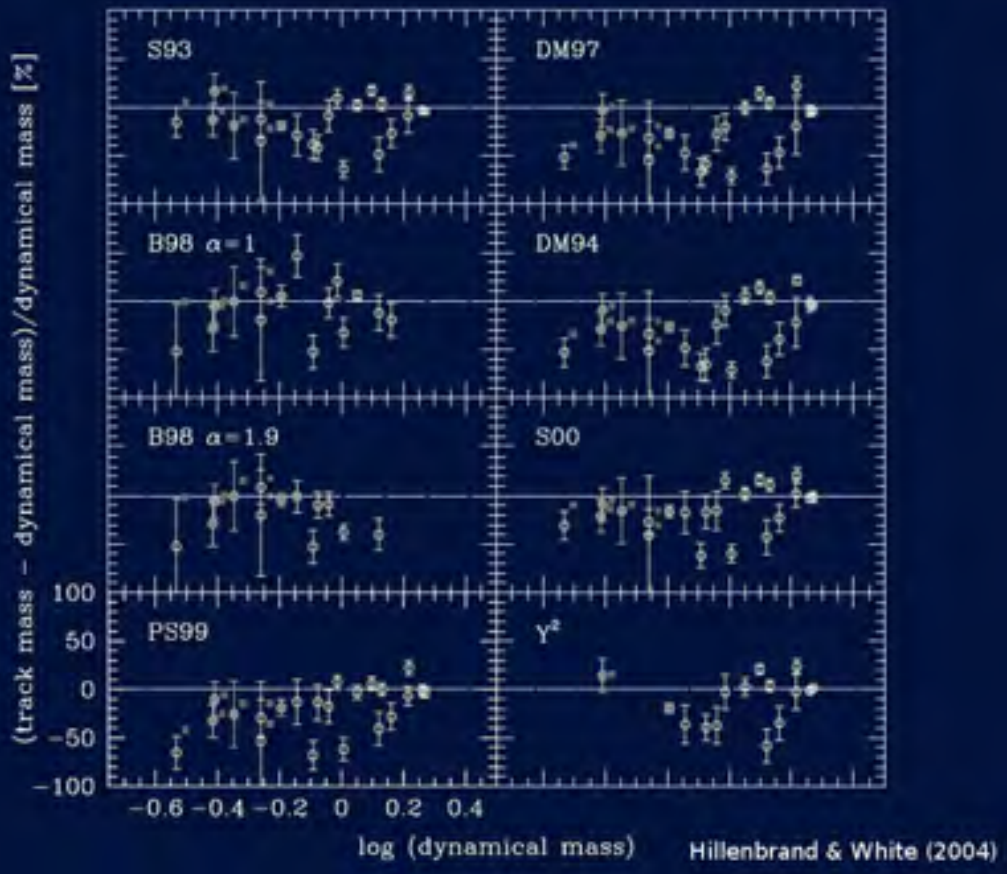
Co-authors: J. C. Guirado, J. M. Marcaide, E. Ros, I. Martí-Vidal, E. Tognelli

MIT Haystack Observatory Workshop
November 1-3, 2017
Westford, Massachusetts, USA

Content

- Introduction
  - Evolutionary models
  - AB Doradus moving group
- Observations
  - Analysis and data reduction of AB Dor B
  - Analysis and data reduction of HD 160934
- Conclusions and Outlook

Evolutionary models



PMS evolutionary models systematically **underpredict** the dynamically determined masses by **10%–30%**. Binary stars in young, nearby moving groups offer an opportunity to increase the number of PMS stars with dynamically determined masses.

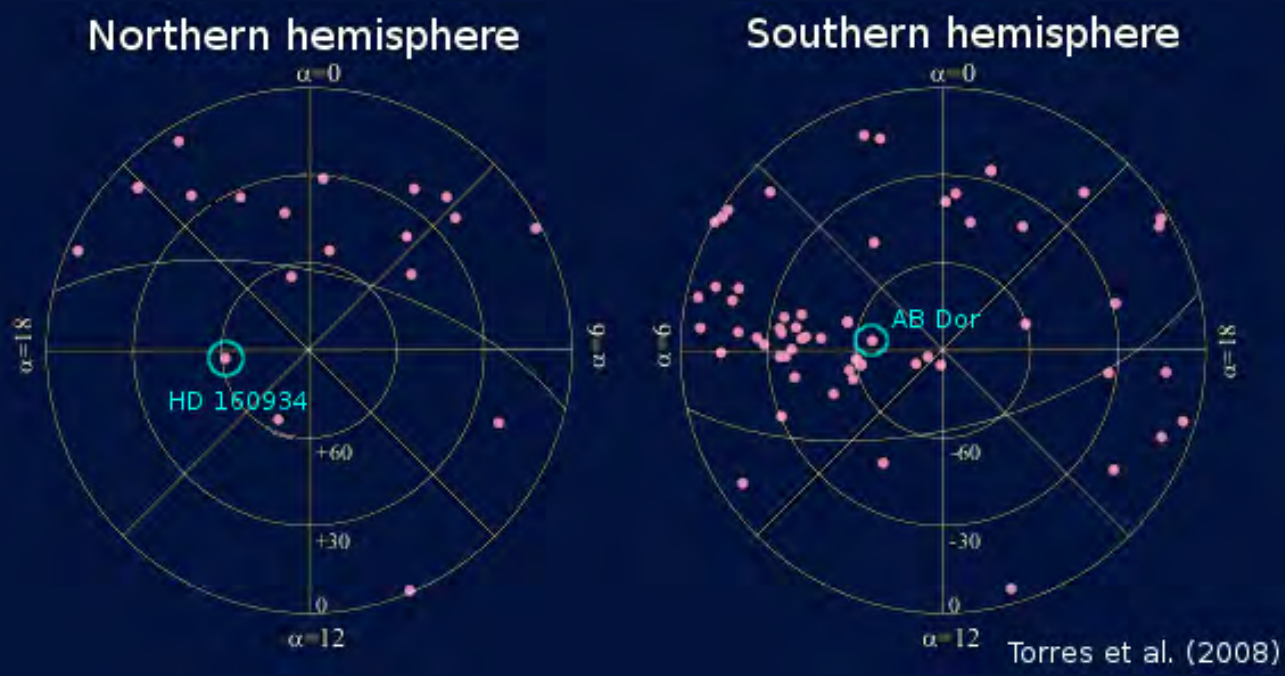
Moving groups

A **moving group** is an association of stars moving in a coherent way through the galaxy that proceed from the same cloud of gas and share relevant properties as its kinematics, its chemical composition, and, specially, its age.

Several of these groups have been discovered.

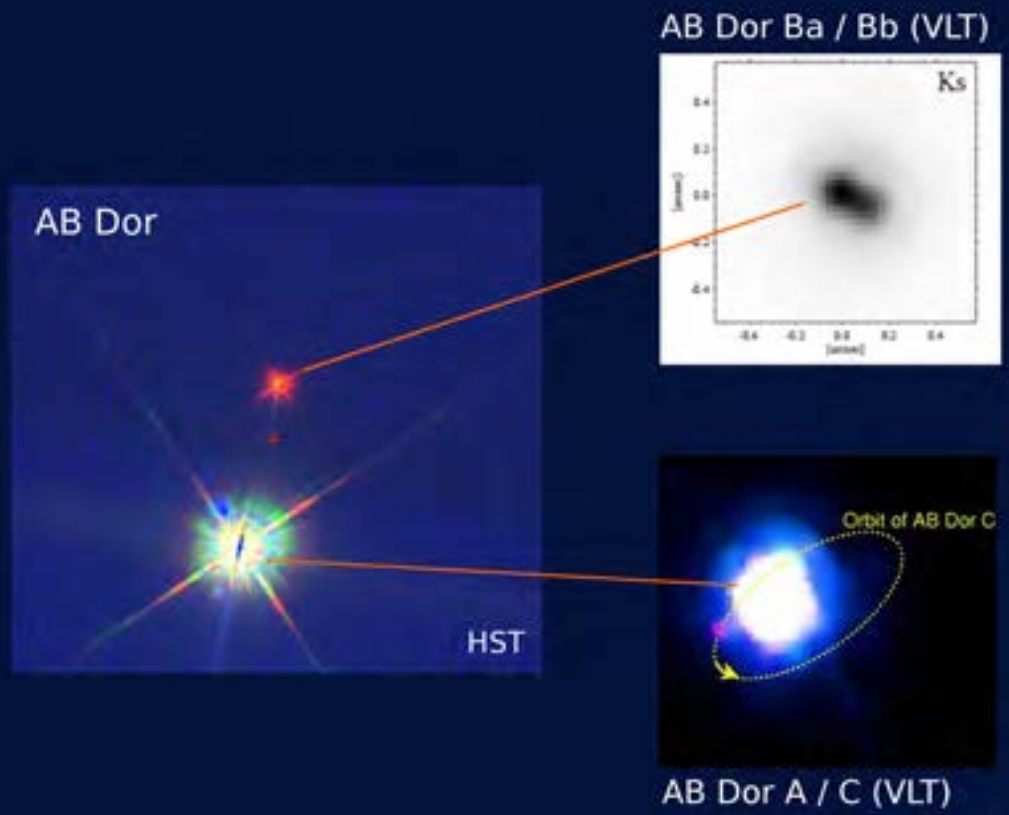
Name of the group	Age (Myr)	Distance (pc)	Number of members
TW Hydrae (TWA)	8–12	40–62	22
β Pictoris (βPMG)	12–22	18–40	48
Tucana-Horologium (THA)	20–40	38–51	44
Columba (COL)	20–40	26–63	41
Carina (CAR)	20–40	11–42	23
Argus (ARG)	30–50	15–48	64
AB Doradus (AB Dor-MG)	70–120	15–50	89

AB Doradus moving group



- It is the closest moving group (mean distance to the Sun, 30 pc).
- Its age is reasonably well determined (50-120 Myr).
- It presents radio emission in some of its active members.
- It has members in the northern and in the southern hemispheres.

AB Doradus stellar system



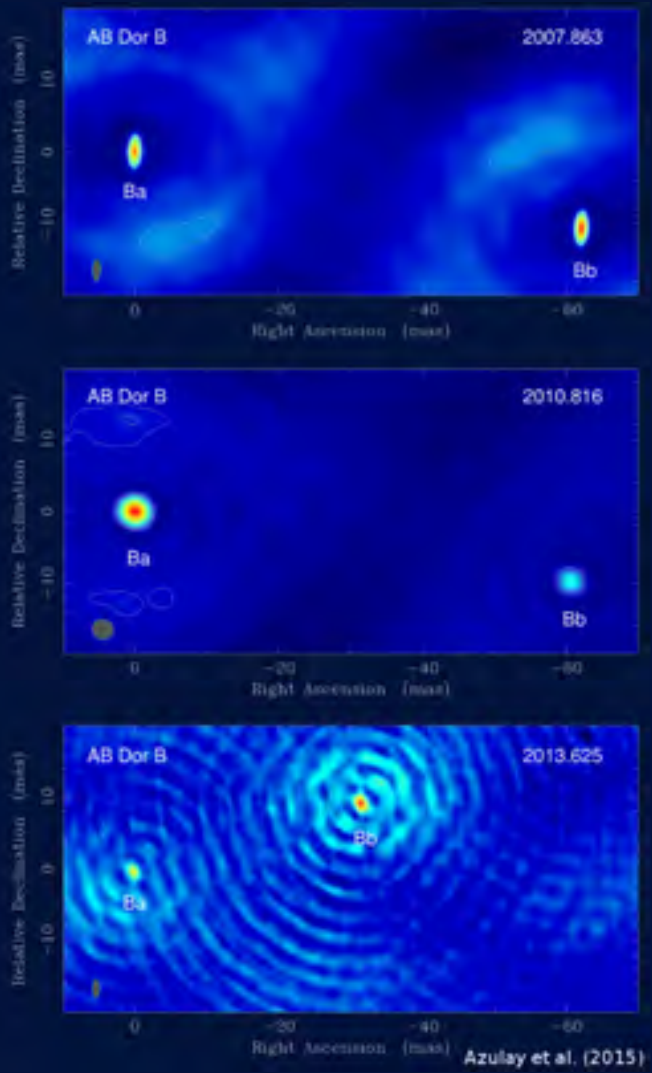
- The system has two pairs of stars separated 9″: AB Dor A/AB Dor C and **AB Dor Ba/AB Dor Bb**. It is placed at a distance of ∼15 pc.
- AB Dor Ba and AB Dor Bb are separated ∼0.″05. The star has a high rotation rate and strong radio emission.

AB Doradus B observations

We observed this target with the technique of phase-referencing (AB Dor B/0516-621, separated 3.6°) in three different epochs with the **LBA** at 8.4 GHz:

- 2007 November 11
- 2010 October 25
- 2013 August 16

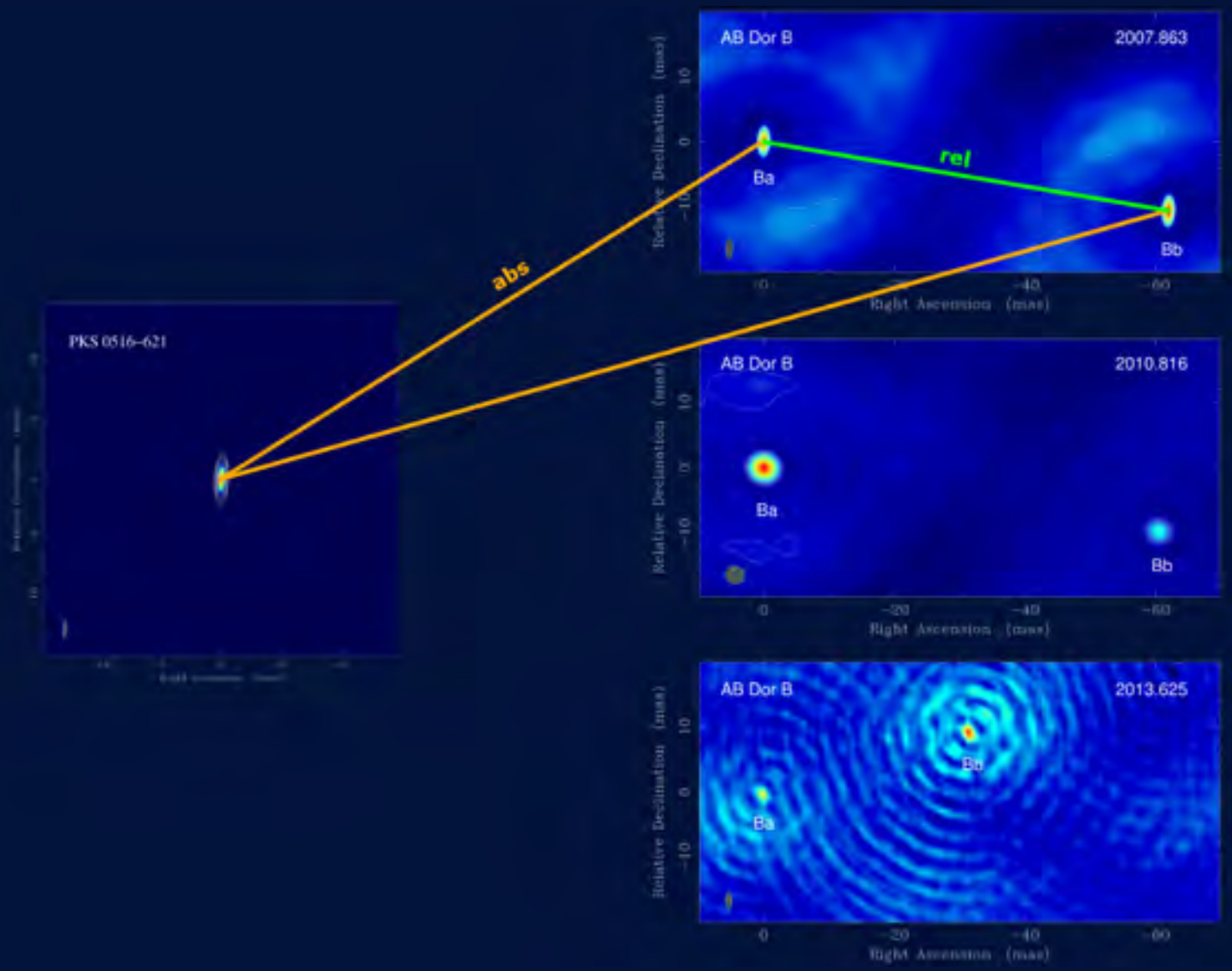
- Target: AB Dor B

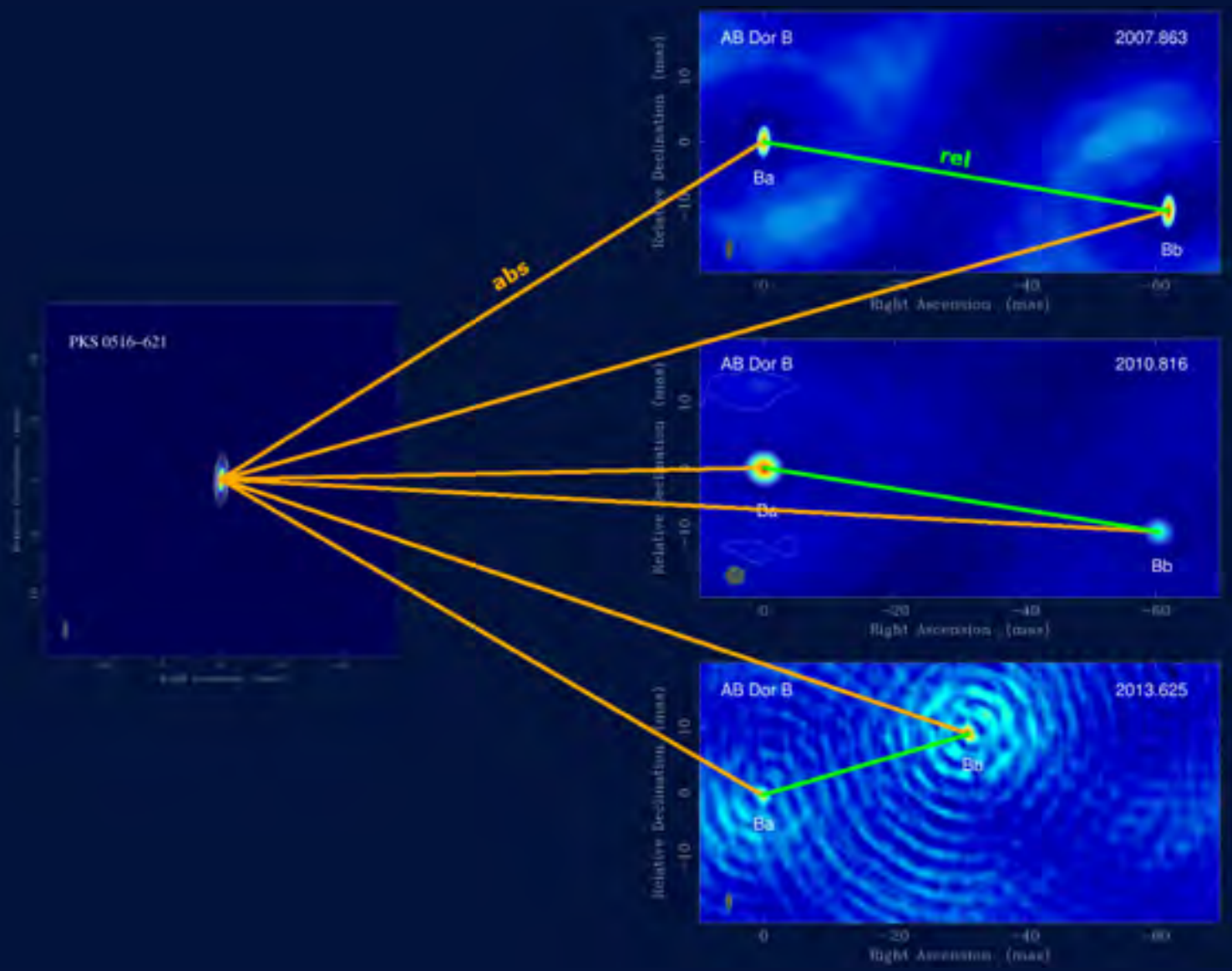


Flux Ba: **0.82 mJy**
Flux Bb: **0.88 mJy**

Flux Ba: **1.39 mJy**
Flux Bb: **0.60 mJy**

Flux Ba: **0.63 mJy**
Flux Bb: **0.92 mJy**


PKS 0516−621
abs
AB Dor B
2007.863
rel
Ba
Bb
Relative Declination (mas)
Right Ascension (mas)
AB Dor B
2010.816
Ba
Bb
Relative Declination (mas)
Right Ascension (mas)
AB Dor B
2013.625
Bb
Ba
Relative Declination (mas)
Right Ascension (mas)


PKS 0516−621
abs
AB Dor B
2007.863
rel
Ba
Bb
AB Dor B
2010.816
Ba
Bb
AB Dor B
2013.625
Bb
Ba

Relative positions AB Dor Bb − AB Dor Ba

Epoch	Instrument	$\Delta\alpha$ (mas)	$\Delta\delta$ (mas)	Reference
2004.098	VLT (IR)	-56.3 ± 1.8	-34.5 ± 1.6	Jason et al. (2007)
2005.019	VLT (IR)	-54.8 ± 3.5	-24.4 ± 3.6	Close et al. (2007)
2005.909	VLT (IR)	-66.7 ± 3.0	-4.0 ± 3.0	Wolter et al. (2014)
2008.650	VLT (IR)	9.6 ± 3.0	-16.4 ± 3.0	Wolter et al. (2014)
2008.855	VLT (IR)	-61.3 ± 3.0	-9.9 ± 3.0	Wolter et al. (2014)
2008.967	VLT (IR)	-61.5 ± 3.0	-24.8 ± 3.0	Wolter et al. (2014)
2009.003	VLT (IR)	-57.3 ± 3.0	-26.7 ± 3.0	Wolter et al. (2014)
2009.131	VLT (IR)	-45.6 ± 3.0	-32.7 ± 3.0	Wolter et al. (2014)
2007.863	**LBA (radio)**	**-62.0 ± 0.1**	**-10.5 ± 0.1**	**This work**
2010.816	**LBA (radio)**	**-60.3 ± 0.7**	**-9.7 ± 0.7**	**This work**
2013.625	**LBA (radio)**	**-31.3 ± 0.1**	**9.3 ± 0.3**	**This work**

Absolute positions AB Dor B (LBA)

Epoch	Component	RA (h min s)	Dec (° ′ ″)
1992.685	Bb	5 28 44.41973 ± 0.00060	-65 26 47.0047 ± 0.0021
1993.123	Ba	5 28 44.40441 ± 0.00080	-65 26 46.9869 ± 0.0028
2007.863	**Ba**	**5 28 44.57761 ± 0.00008**	**-65 26 45.1002 ± 0.0010**
	Bb	**5 28 44.56766 ± 0.00008**	**-65 26 45.1107 ± 0.0010**
2010.816	**Ba**	**5 28 44.61098 ± 0.00009**	**-65 26 44.71316 ± 0.0008**
	Bb	**5 28 44.60130 ± 0.00014**	**-65 26 44.7229 ± 0.0008**
2013.625	**Ba**	**5 28 44.63954 ± 0.00005**	**-65 26 44.2920 ± 0.0009**
	Bb	**5 28 44.63453 ± 0.00013**	**-65 26 44.2827 ± 0.0008**

Parameters for AB Dor B

Astrometric parameters

Parameter	
α_0 (h m s):	5 28 44.48396 $\pm$ 0.00022
δ_0 ($^\circ$ $'$ $''$):	$-$65 26 46.0573 $\pm$ 0.0013
μ_α (s yr^{-1}):	0.01054 $\pm$ 0.00012
μ_δ (arcsec yr^{-1}):	0.1287 $\pm$ 0.0005
Q_α (s yr^{-2}):	0.000008 $\pm$ 0.000001
Q_δ (arcsec yr^{-2}):	$-$0.00010 $\pm$ 0.00005
π (arcsec):	0.0664 $\pm$ 0.0005

Orbital parameters

Parameter	
P (yr)	0.986 $\pm$ 0.008
$a_{\rm rel}$ ($''$)	0.052 $\pm$ 0.002
$a_{\rm Ba}$ ($''$)	0.028 $\pm$ 0.002
$a_{\rm Bb}$ ($''$)	0.025 $\pm$ 0.002
e	0.6 $\pm$ 0.1
Ω ($^\circ$)	270 $\pm$ 15
i ($^\circ$)	121 $\pm$ 5
ω($^\circ$)	54 $\pm$ 20
T_0:	2003.68 $\pm$ 0.05

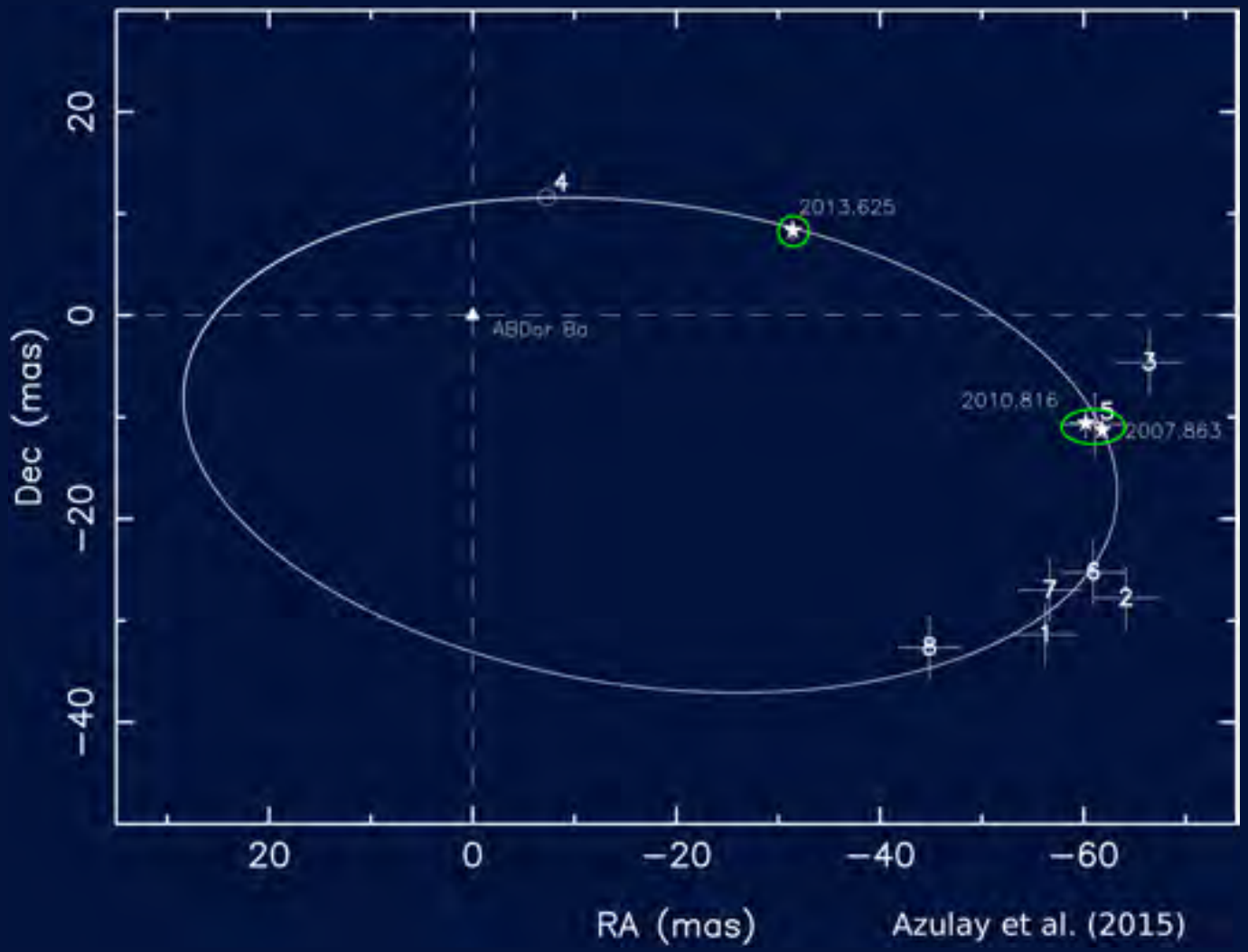
From Kleper's third law we know that:

$$\frac{(a''_{\rm rel} \cdot d_{pc})^3}{P^2} = (m_{\rm Ba} + m_{\rm Bb})_\odot \qquad \frac{(m_{\rm Ba})^3_\odot}{(m_{\rm Ba} + m_{\rm Bb})^2_\odot} = \frac{(a''_{\rm Bb})^3}{P^2}$$

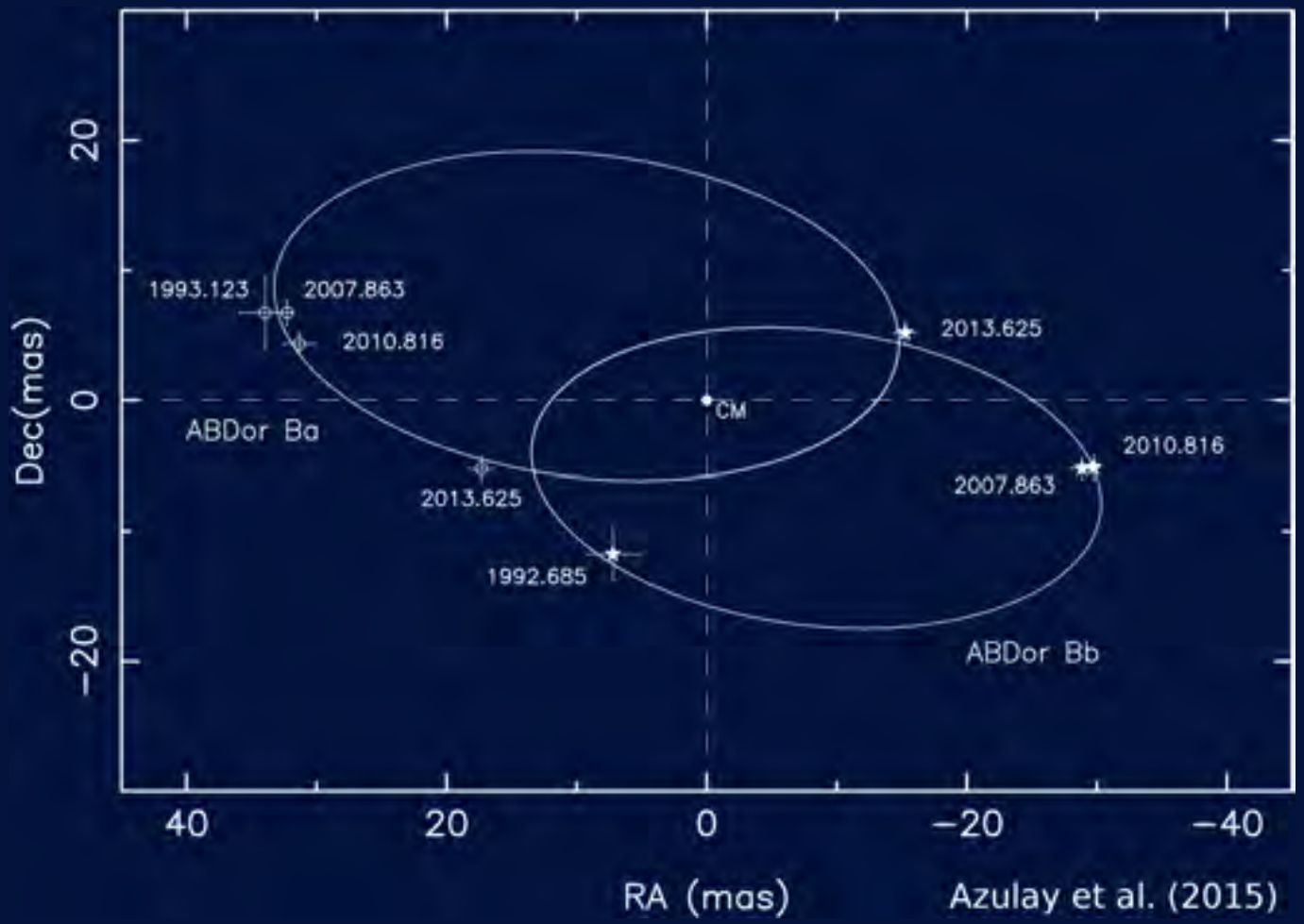
with $a''_{\rm rel}$ and $a''_{\rm Bb}$ in arcsec, d_{pc} in pc, P in yr, and $m_{\rm Ba} + m_{\rm Bb}$ and $m_{\rm Ba}$ in solar units.

The sum of the masses of both components is $0.53 \pm 0.05\ M_\odot$.
The mass of the component Ba is $0.28 \pm 0.05\ M_\odot$.
The mass of the component Bb is $0.25 \pm 0.05\ M_\odot$.

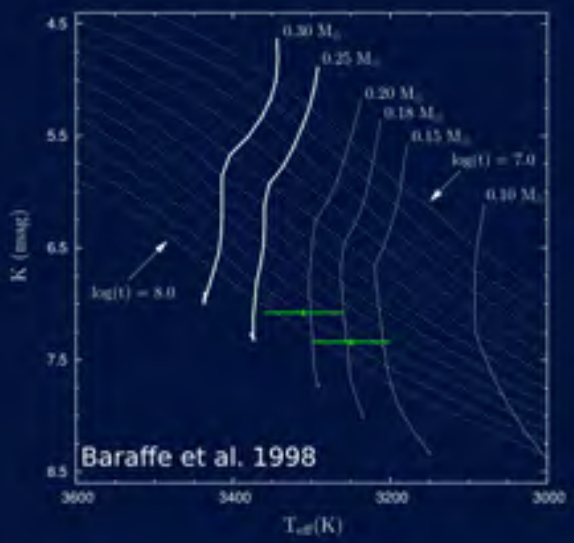
Relative orbit of the binary AB Dor B.

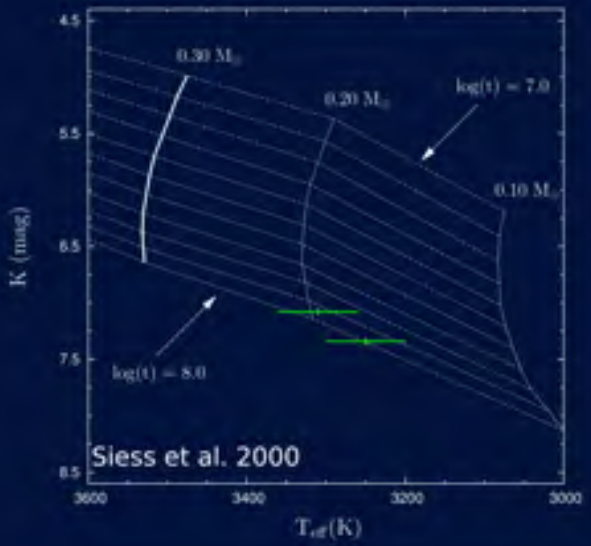


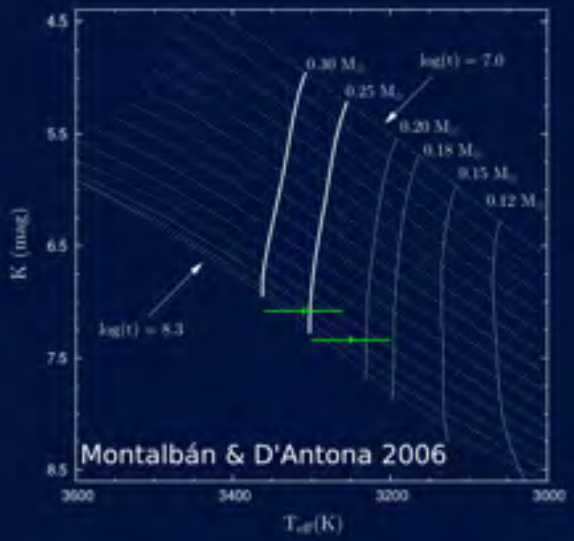
Absolute orbits of the components AB Dor Ba and AB Dor Bb.

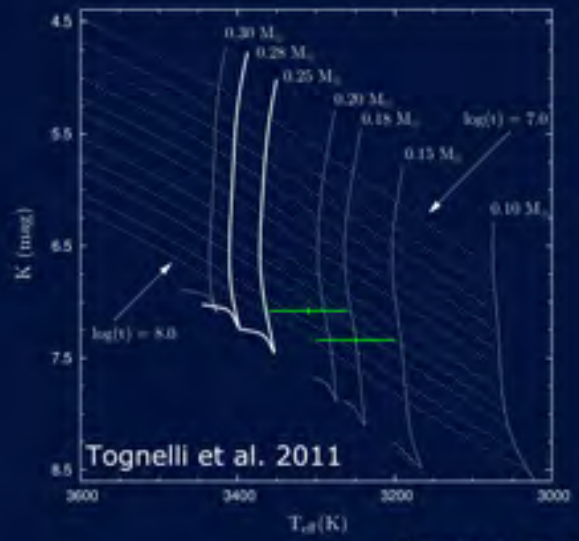


Theoretical models









Azulay et al. (2015)

Masses:

	Underprediction BCAH98	Underprediction S00	Underprediction MD06	Underprediction TDP12
AB Dor Ba	$\sim$30%	$\sim$40%	$\sim$10%	$\sim$30%
AB Dor Bb	$\sim$30%	$\sim$40%	$\sim$10%	$\sim$30%

Age:

- **BCAH98**: between **50-100 Myr**; coevality.
- **S00**: between **65-125 Myr**; non-coevality.
- **MD06**: between **100-125 Myr**; coevality.
- **TDP12**: between **50-100 Myr**; coevality.

HD 160934 stellar system

HD 160934 is a very active young star with spectral type K7Ve, placed at a distance of ∼33 pc with a high rotation rate.

It is a tertiary system:

- **HD 160934 A**
- HD 160934 B
- **HD 160934 c**

The components A and c are separated a distance of ∼0.2". HD 160934 B is at a distance of ∼8.7" from the primary pair.

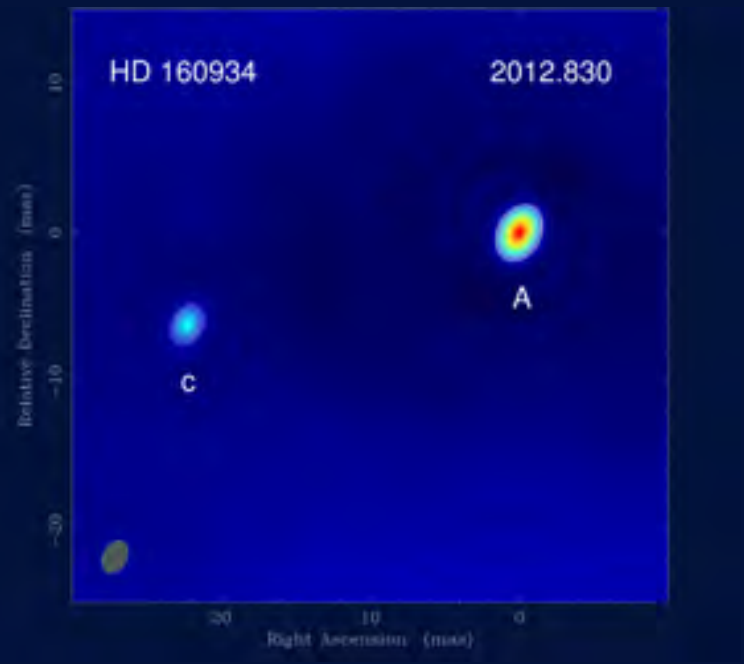
Hormuth et al. (2007)

HD 160934 observations

We observed this target with the technique of phase-referencing (HD 160934/J1746+6226, separated 1.5°) in three different epochs with the EVN at 5 GHz.

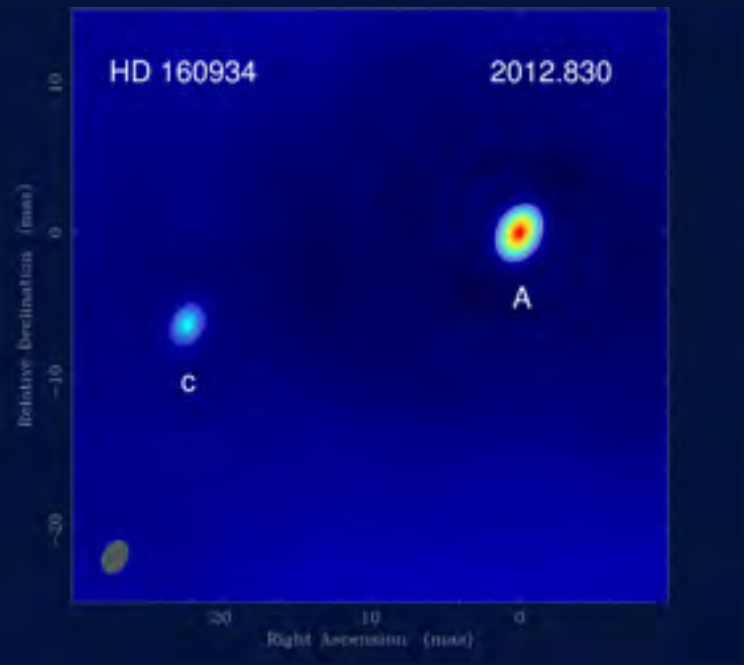
- 2012 October 30
- 2013 May 23
- 2014 March 5

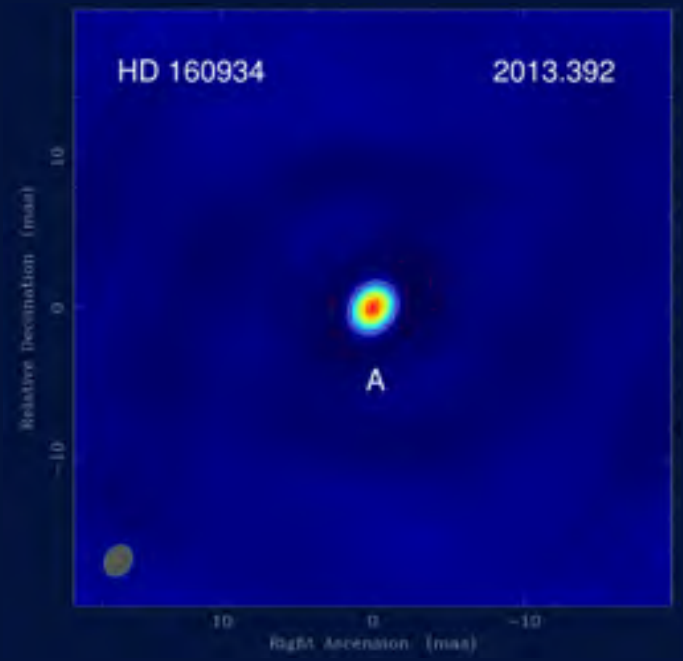
- Target: HD 160934



Flux A: **0.16 mJy**
Flux c: **0.06 mJy**

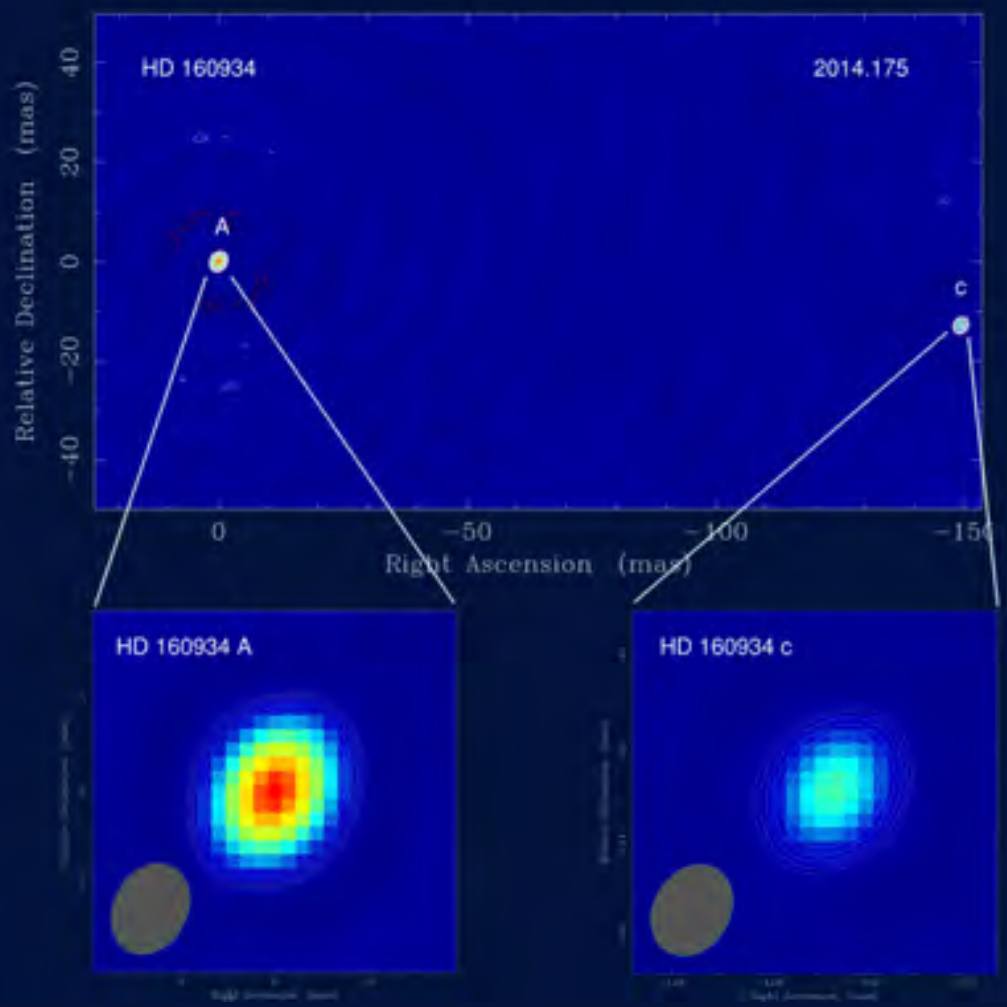
- Target: HD 160934





Flux A: **0.16 mJy**
Flux c: **0.06 mJy**

Flux A: **0.05 mJy**



Flux A: **0.13 mJy**, Flux c: **0.06 mJy**.

Relative positions HD 160934 A − HD 160934 c

Epoch	Instrument	$\Delta\alpha$ (mas)	$\Delta\delta$ (mas)	Reference
1998.098	AstraLux (IR)	154.3 ± 0.9	-14.8 ± 0.5	Hormuth et al. (2007)
2005.296	Gemini (IR)	212.9 ± 2.0	5.6 ± 2.6	Lafrenière et al. (2007)
2006.518	AstraLux (IR)	214.9 ± 1.0	-3.4 ± 1.0	Hormuth et al. (2007)
2006.712	Gemini (IR)	217.9 ± 2.0	-4.9 ± 2.6	Lafrenière et al. (2007)
2008.477	Palomar (IR)	-169.1 ± 0.3	-9.7 ± 0.3	Evans et al. (2012)
2010.318	Keck (IR)	64.6 ± 0.3	-23.5 ± 0.3	Evans et al. (2012)
2011.310	Keck (IR)	-6.3 ± 0.3	-18.9 ± 0.3	Evans et al. (2012)
2012.830	**VLBI (Radio)**	$\mathbf{-22.3 \pm 0.1}$	$\mathbf{6.2 \pm 0.2}$	**This work**
2014.175	**VLBI (Radio)**	$\mathbf{149.3 \pm 0.1}$	$\mathbf{12.9 \pm 0.2}$	**This work**

Absolute positions HD 160934 (EVN)

Epoch	Instrument	RA (h min s)	Dec (° ′ ″)
2012.830	**A**	**17 38 39.59830 ± 0.00016**	**61 14 16.6077 ± 0.0010**
	c	**5 28 44.56766 ± 0.00008**	**-65 26 45.1107 ± 0.0010**
2013.403	**A**	**17 38 39.60667 ± 0.00016**	**61 14 16.6865 ± 0.0010**
2014.175	**A**	**17 38 39.61159 ± 0.00016**	**61 14 16.6882 ± 0.0010**
	c	**5 28 44.63453 ± 0.00013**	**-65 26 44.2827 ± 0.0008**

Determination of orbital parameters and masses

Parameters for HD 160934

Astrometric parameters

Parameter	
α_0 (h m s):	17 38 39.6349 $\pm$ 0.0002
δ_0 ($^\circ$ $'$ $''$):	+61 14 16.0238 $\pm$ 0.0015
μ_α (s yr^{-1}):	$-$0.0025 $\pm$ 0.0002
μ_δ (arcsec yr^{-1}):	0.0469 $\pm$ 0.0002
π (arcsec)$^{\mathrm{c}}$:	0.0314 $\pm$ 0.0005

Orbital parameters

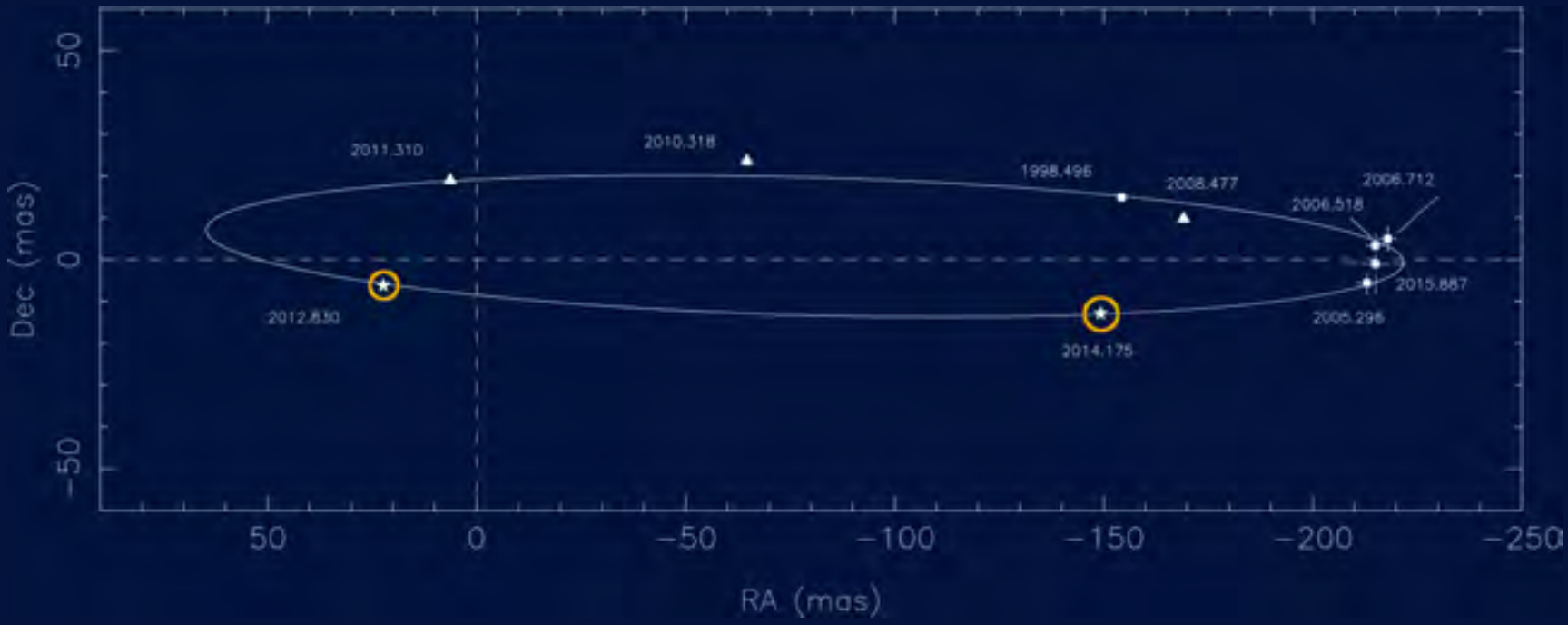
Parameter	
P (yr):	10.26 $\pm$ 0.08
a_{rel} ($''$):	0.1554 $\pm$ 0.0008
a_{A} ($''$):	0.0603 $\pm$ 0.0014
a_{c} ($''$):	0.0952 $\pm$ 0.0014
e:	0.64 $\pm$ 0.03
i ($^\circ$):	82.72 $\pm$ 0.12
ω_{c} ($^\circ$)$^{\mathrm{d}}$:	37.7 $\pm$ 0.5
Ω ($^\circ$):	266.74 $\pm$ 0.12
T_0:	2002.4 $\pm$ 0.1

The sum of the masses of both components is $1.15 \pm 0.10\ M_\odot$.

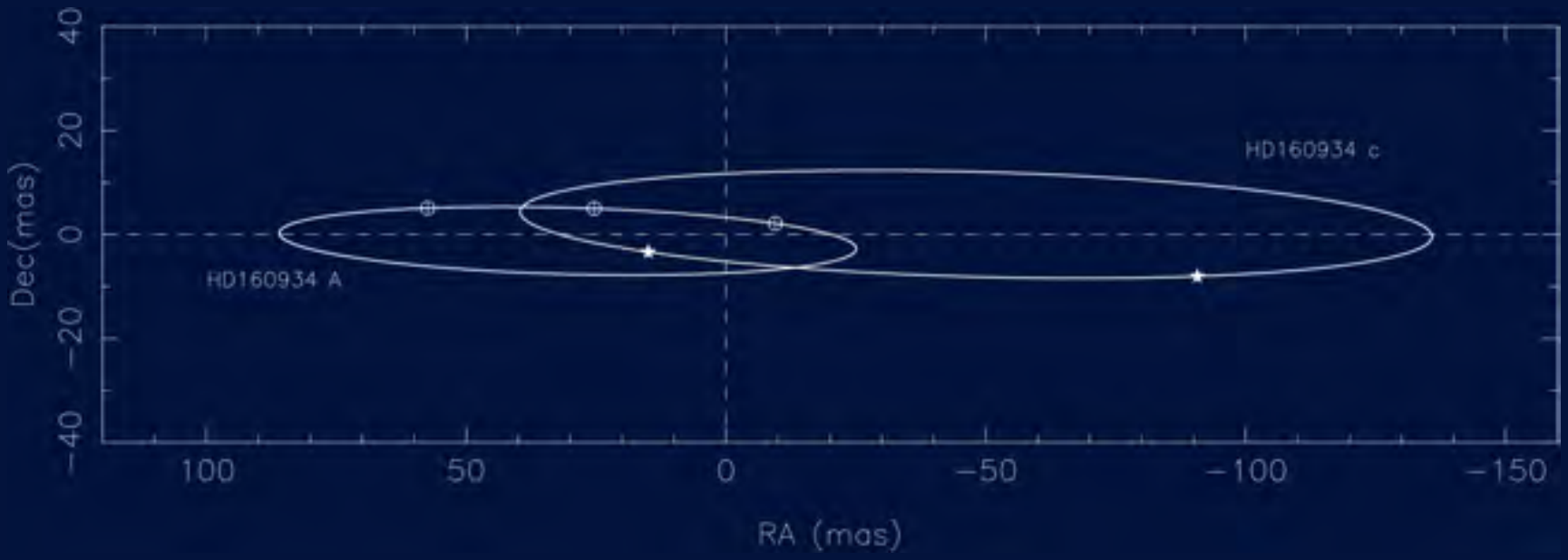
The mass of the component A is $0.70 \pm 0.07\ M_\odot$.

The mass of the component c is $0.45 \pm 0.04\ M_\odot$.

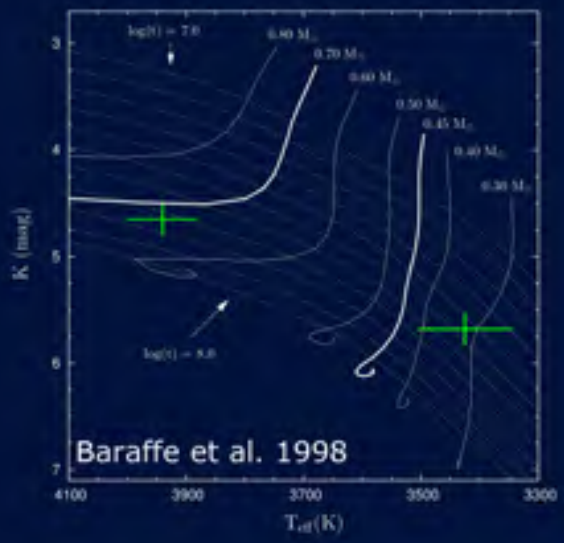
Relative orbit of the binary HD 160934.

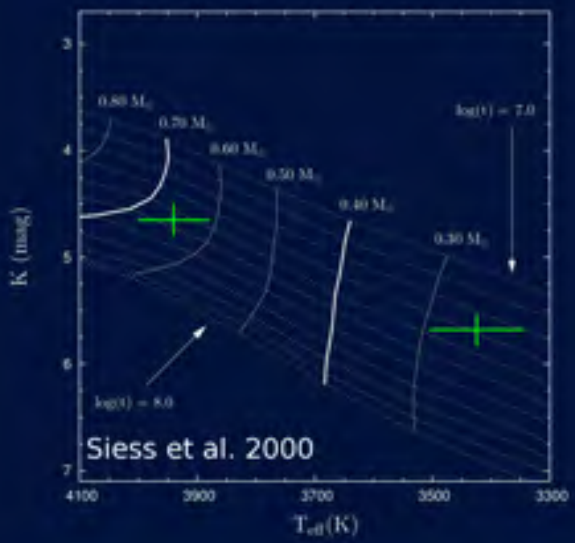


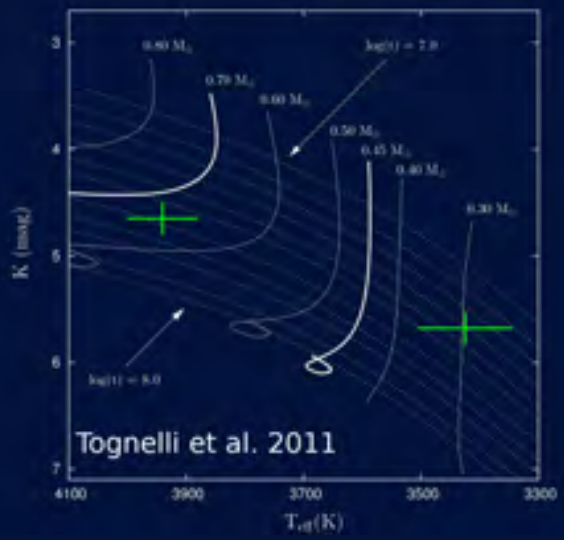
Absolute orbits of HD 160934 A and HD 160934 c.

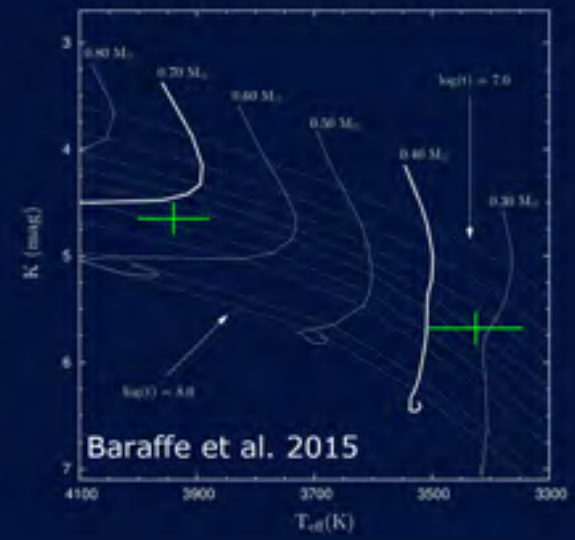


Theoretical models









Masses:

	Underprediction BCAH98	Underprediction S00	Underprediction TDP12	Underprediction BHAC15
HD 160934 A	$\sim$10%	$\sim$10%	$\sim$10%	$\sim$10%
HD 160934 c	$\sim$20%	$\sim$40%	$\sim$30%	$\sim$20%

Age:

- **BCAH98**: both stars younger than **65 Myr**.
- **S00**: both stars younger than **40 Myr**.
- **TDP12**: both stars younger than **50 Myr**.
- **BHAC15**: both stars younger than **50 Myr**.

Conclusions

We have presented the results of our study of several PMS stars belonging to the AB Dor-MG, with a special focus in VLBI.

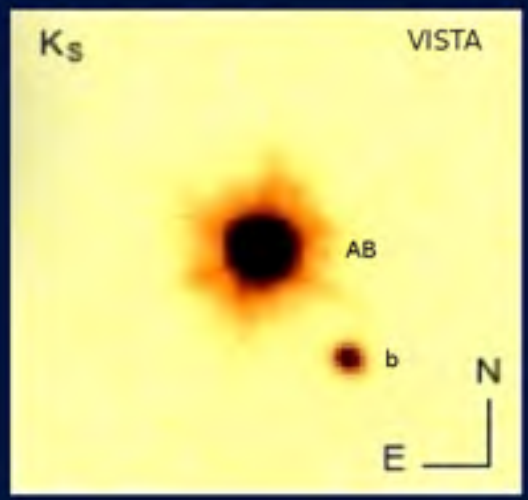
- **We detected, for the first time, the compact radio emission originated from each component of the PMS binary systems AB Dor Ba/Bb, HD 160934 A/c.** The stars emit at radio wavelengths by gyrosynchrotron emission.
- **We have estimated the dynamical masses of AB Dor Ba/Bb, and HD 160934 A/c** with a combined analysis of our VLBI data and previously-published NIR relative positions.
- **We have found observational evidence that PMS evolutionary models underpredict the mass of PMS stars by a 10−40%.** This result is consistent with the studies published by other authors.

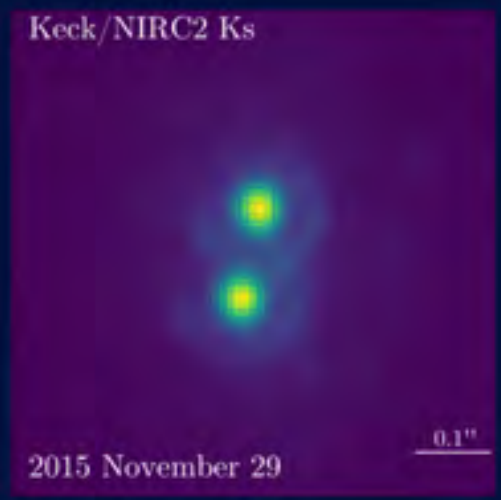
Outlook

The nearby planetary system VHS 1256-1257

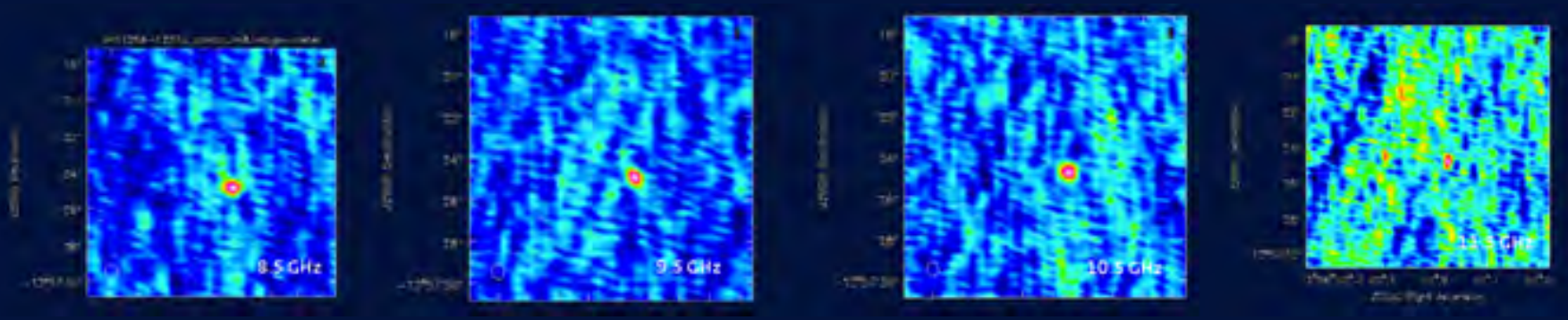
System of 150-300 Myr placed at 12 pc.

- **Components AB:** M7.5 brown dwarfs, 65 M_{Jup}
- **Component b:** L7 companion, 11 M_{Jup}





- **VLA observations**
  - **8.4 GHz (4 GHz bandwidth).** Map of non-thermal detection of the primary brown dwarfs.
  - **1.4 GHz.** Detect non-thermal radio emission of the planetary object (analizing data).
- **EVN observations**
  - **1.4 GHz.** Three epochs to detect non-thermal radio emission of the primary brown dwarfs, obtain a precise orbit, and dynamical masses determination (analyzing data).



Thank you for your attention

My email: **azulay@mpifr.de**

More details in:

- Azulay et al. 2014, A&A Vol.561, idA38
- Azulay et al. 2015, A&A Vol.578, idA16
- Azulay et al. 2017, A&A Vol.602, idA57
- Azulay et al. 2017, A&A Vol.607, idA10
- Guirado et al., A&A (in preparation)