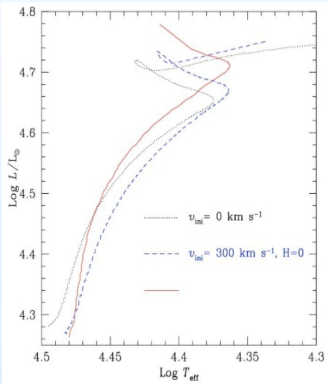
B fields in OB stars (BOB): first results of the survey

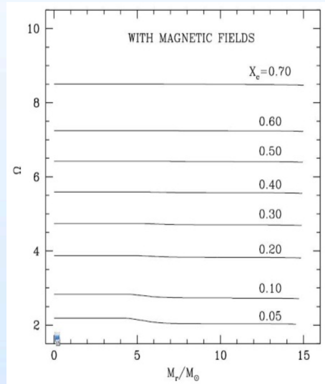
On behalf of the BOB collaboration:

Morel, T., Castro, N., Fossati, L., Hubrig, S., Langer, N., Przybilla, N., Schöller, M., Arlt, R., Barbá, R., Briquet, M., Carroll, T., de Koter, A., Dufton, P. L., González, J. F., Hamann, W.-R., Herrero, A., Ilyin, I., Irrgang, A., Kharchenko, N., Kholtygin, A., Maíz Apellaniz, J., Mathys, G., Nieva, M.-F., Oskinova, L., Piskunov, A., Reisenegger, A., Sana, H., Schneider, F., Scholz, R., Simon Díaz, S., Spruit, H., and Yoon, S.-C.

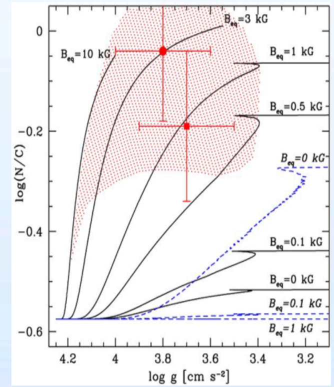
Effects of magnetic fields in massive stars



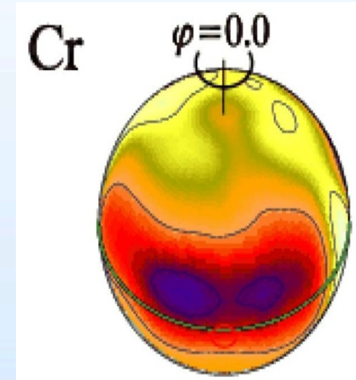
Evolution



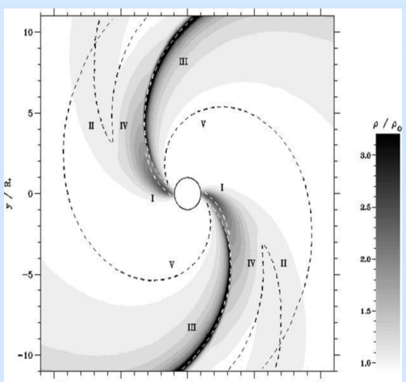
Magnetic braking
Rotational profile



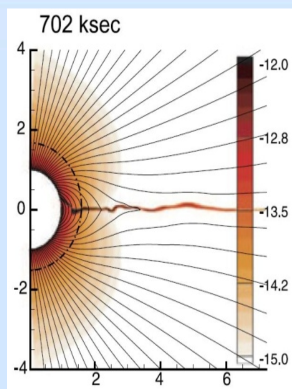
Internal mixing



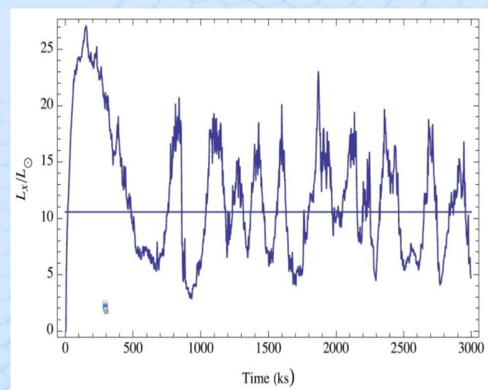
Inhomogeneous abundances
at the surface



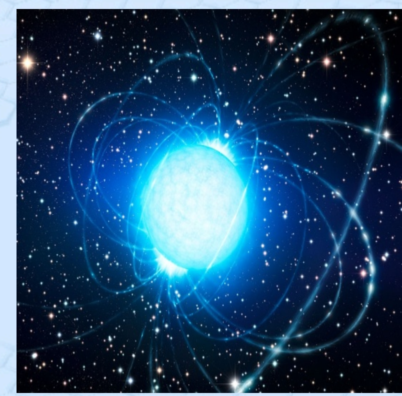
Seed perturbations for large-scale
wind structures (CIRs, …)



Channeling of
stellar wind



X-ray properties



End products
(magnetars, γ ray bursts, …)

Origin of magnetic fields in massive stars

Fossil (e.g., Braithwaite & Spruit 2004)

Predictions: *Long-lived and simple topology (mostly dipolar). Field with similar incidence and properties as Herbig Ae/Be stars.*

Merger or mass-transfer event (e.g., Ferrario et al. 2009; Wickramasinghe et al. 2014)

Predictions: *Dearth of magnetic stars in close binaries.*

Dynamo acting in radiative zone (e.g., Spruit 2002) or subsurface convection layers (e.g., Cantiello & Braithwaite 2011)

Predictions: *Time dependent and at small spatial scales. Stronger in more massive stars for second scenario.*

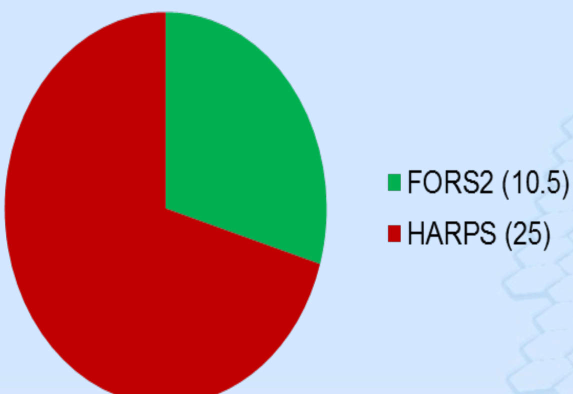
The B fields in OB stars (BOB) project

A total of 35.5 nights allocated over 2.5 years (ESO P91-P95) on FORS2 and HARPSpol

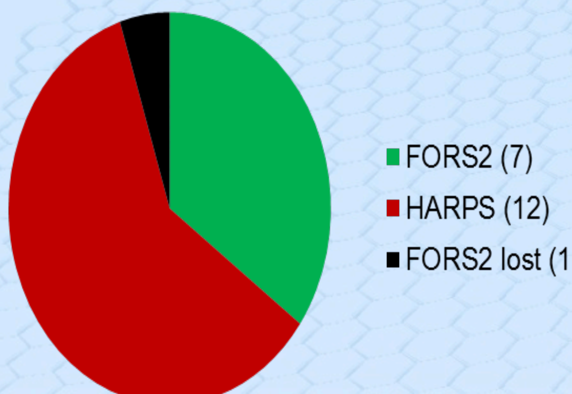
Survey biased towards slow rotators to enhance field detectability.

For both FORS2 and HARPS, data reduction and analysis carried out completely independent by two groups (Bonn and Potsdam).

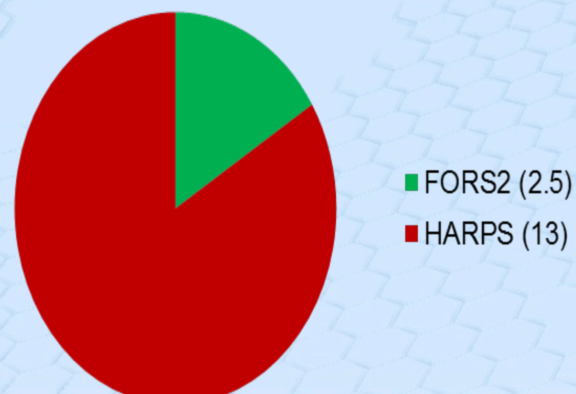
Nights allocated (35.5)



Nights completed (20)



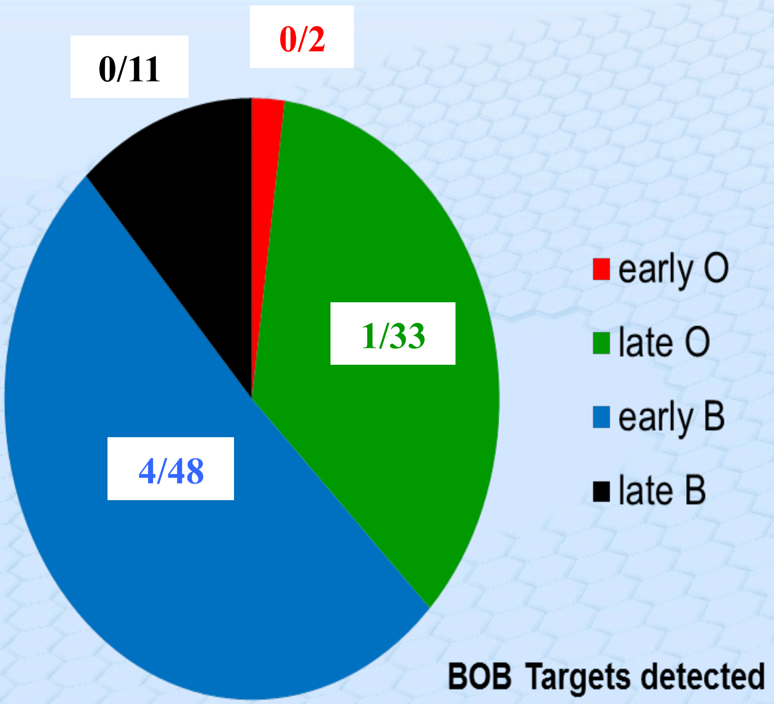
Nights remaining (15.5)



The B fields in OB stars (BOB) project

	MiMeS	BOB
Stars surveyed	**~525**	**94**
New firm detections	**~35**	**5**
Detection rate	**7±1%**	**~5%**

But ~15 candidates are still being followed up: detection rate may be (slightly) revised upwards

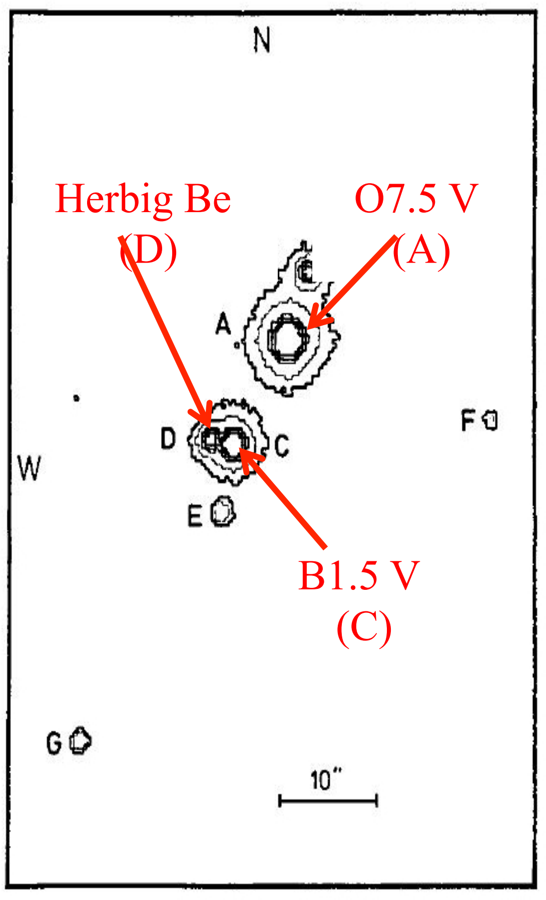


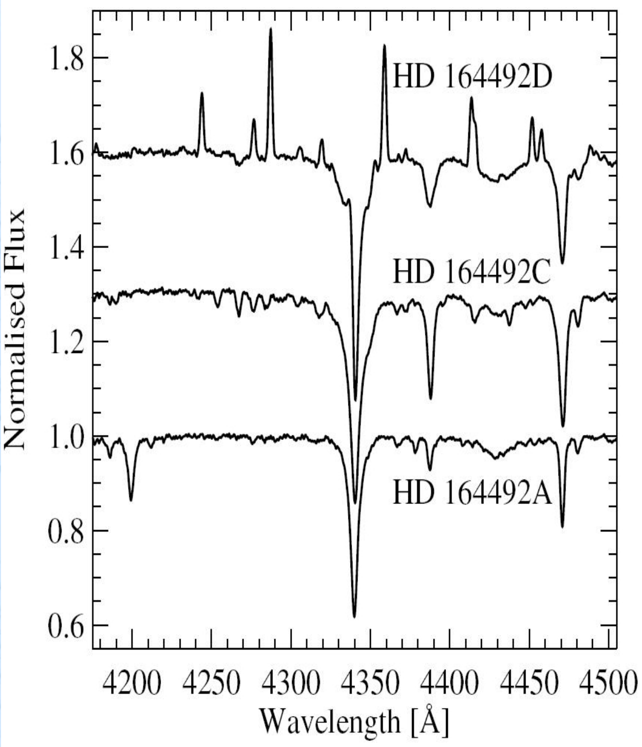
A young, magnetic binary in the Trifid Nebula

The Trifid Nebula is one of the youngest star forming regions.

Seven components identified in the central system HD 164492 (Kohoutek et al. 1999).

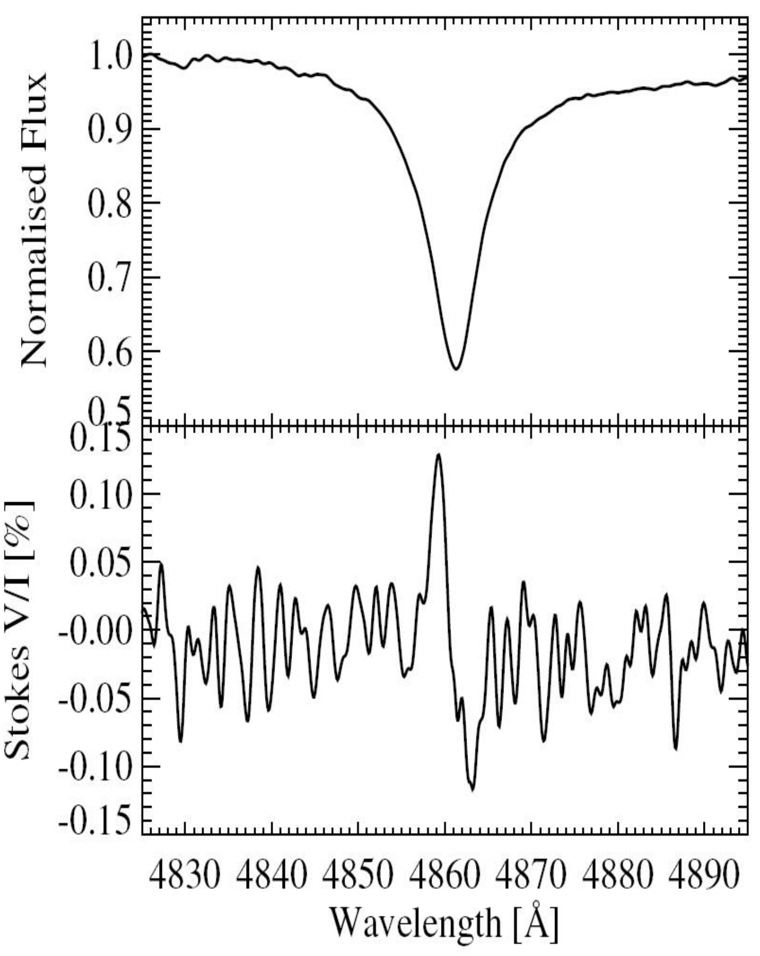
The three brightest components were observed: A, C, and D.





Hubrig et al. (2014)

A young, magnetic binary in the Trifid Nebula



Hubrig et al. (2014)

Clear magnetic signal in the FORS2 V/I spectrum of HD 164492C obtained on 2013 April 9.

Two fully independent (and consistent) magnetic field determinations:

Bonn:

$\langle B_z \rangle_{all} = 523 \pm 37$ G

$\langle B_z \rangle_{hyd} = 600 \pm 54$ G

Potsdam:

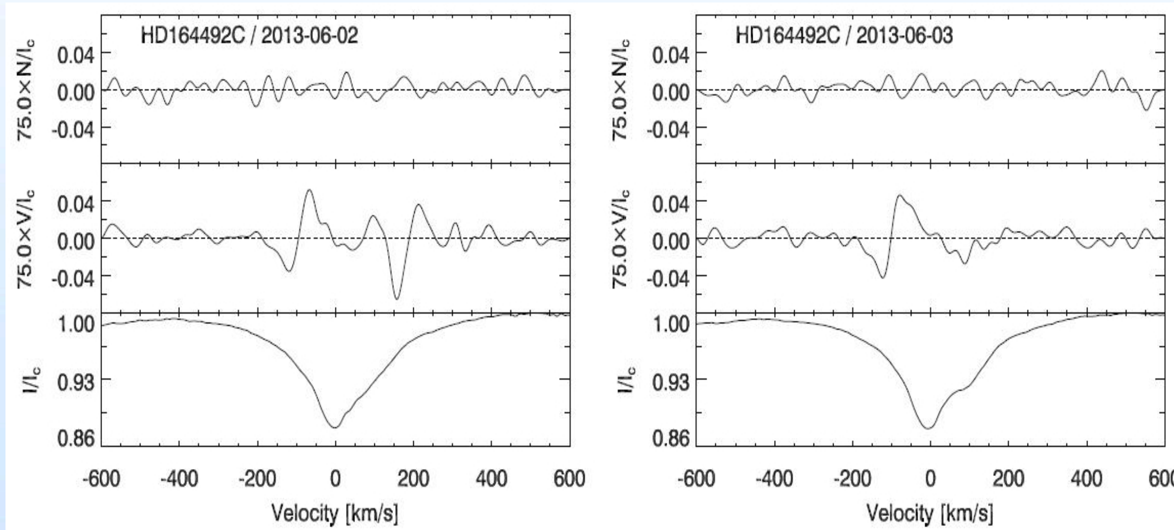
$\langle B_z \rangle_{all} = 472 \pm 44$ G

$\langle B_z \rangle_{hyd} = 576 \pm 60$ G

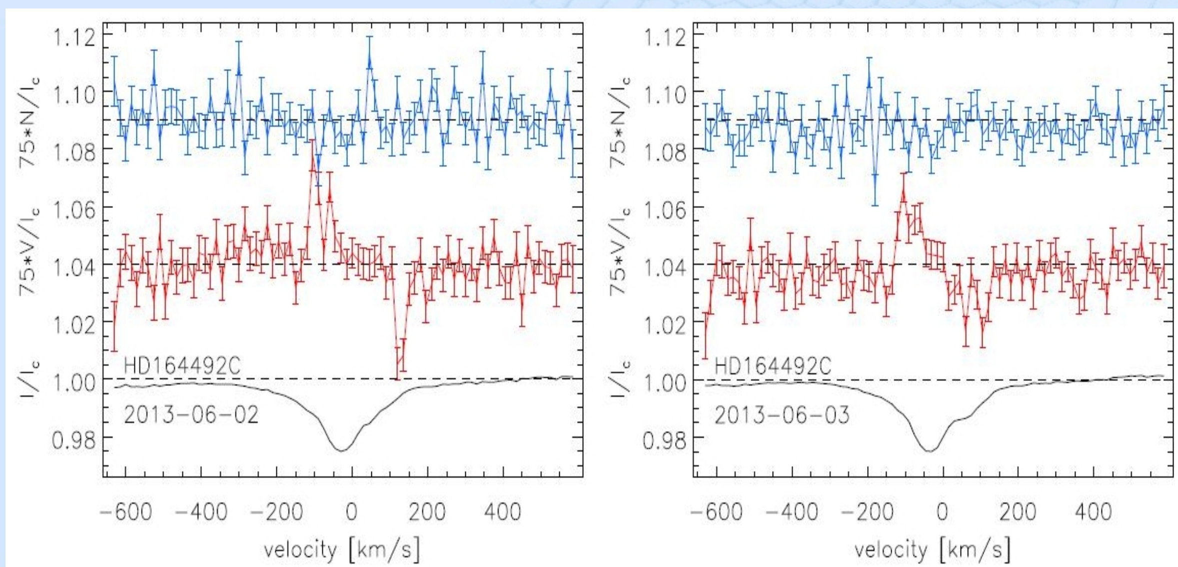
A young, magnetic binary in the Trifid Nebula

HARPS observations on 2013 June 2 and 3. Detection of a magnetic field of **500−700 G** on the first night and **400−600 G** on the second night with two techniques. False Alarm Probability < 10^{-10} for both methods.

Analysis with the Singular Value Decomposition (SVD) technique (Carroll et al. 2012) using He I and metal lines.



Least Square Deconvolution (LSD; Donati et al. 1997, Kochukhov et al. 2010).



Hubrig et al. (2014)

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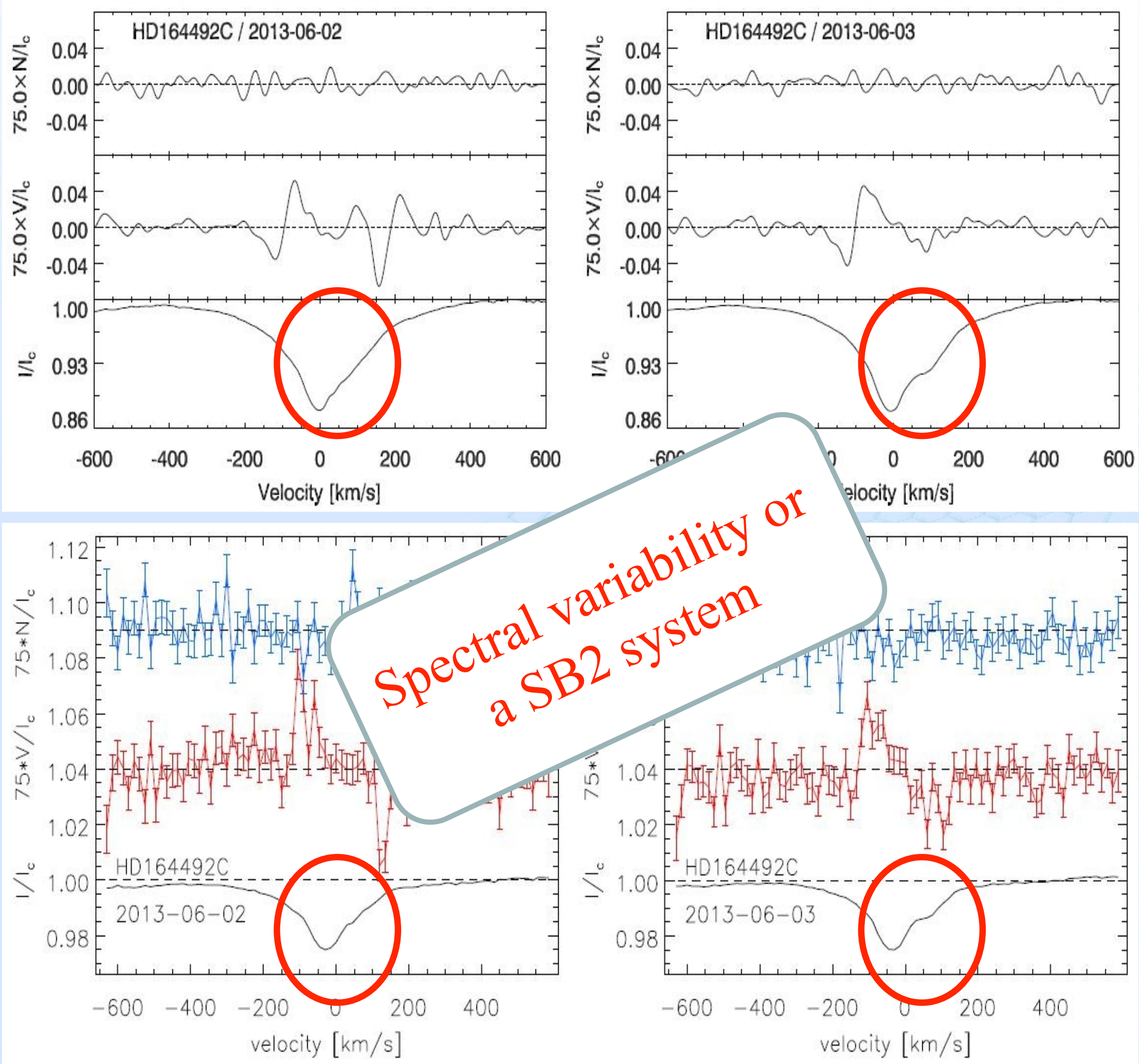
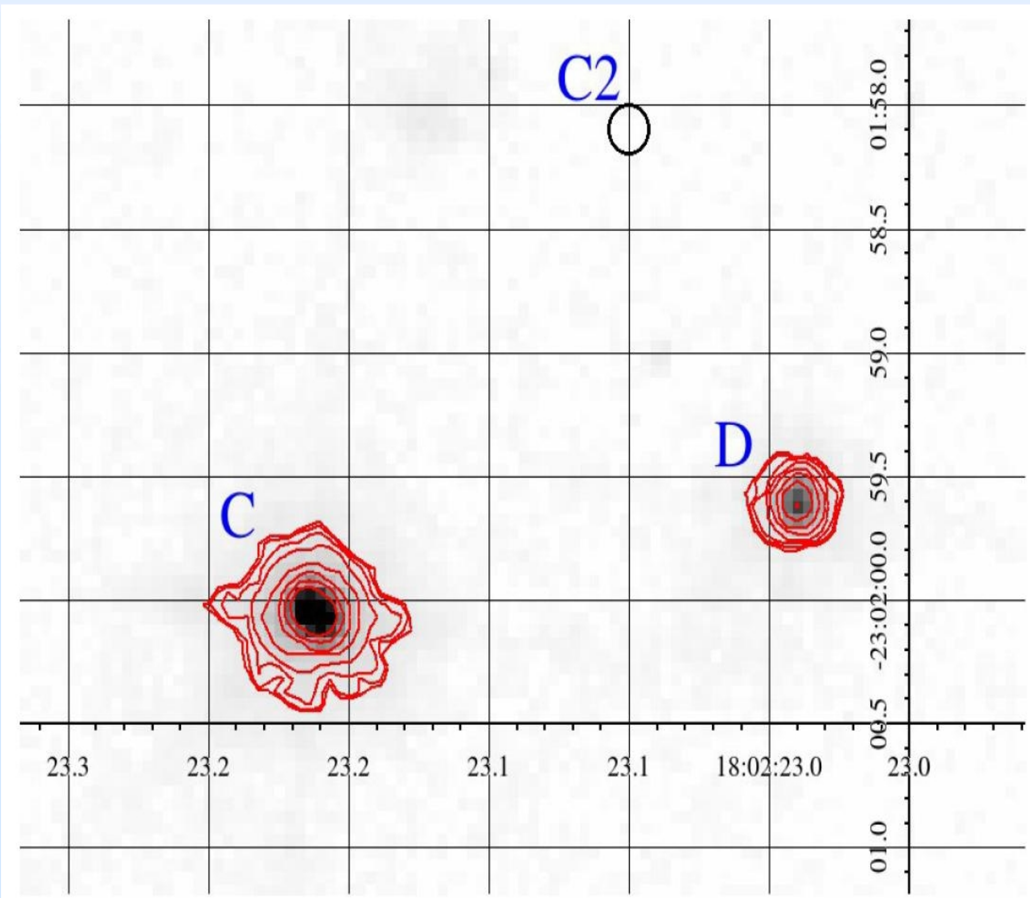


Hubrig et al. (2014)

A young, magnetic binary in the Trifid Nebula

Indications for a companion to source C from an elongated PSF in HST WFPC2 image of its surroundings



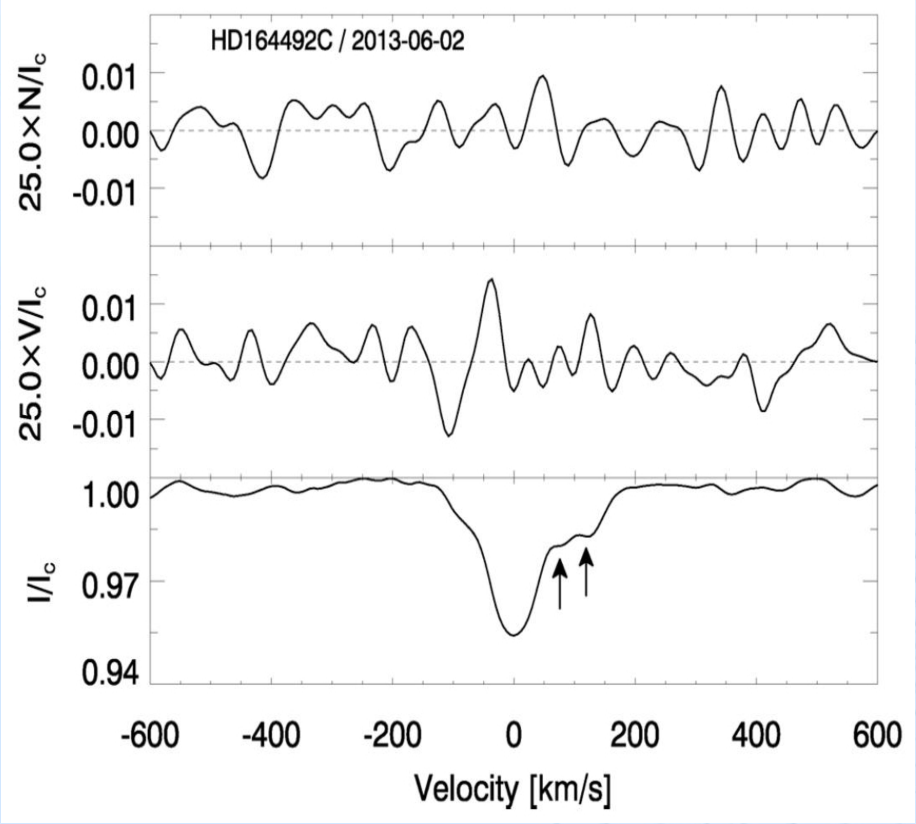
C, D, and C2: X-ray sources detected by *Chandra* (Rho et al. 2004).

Hubrig et al. (2014)

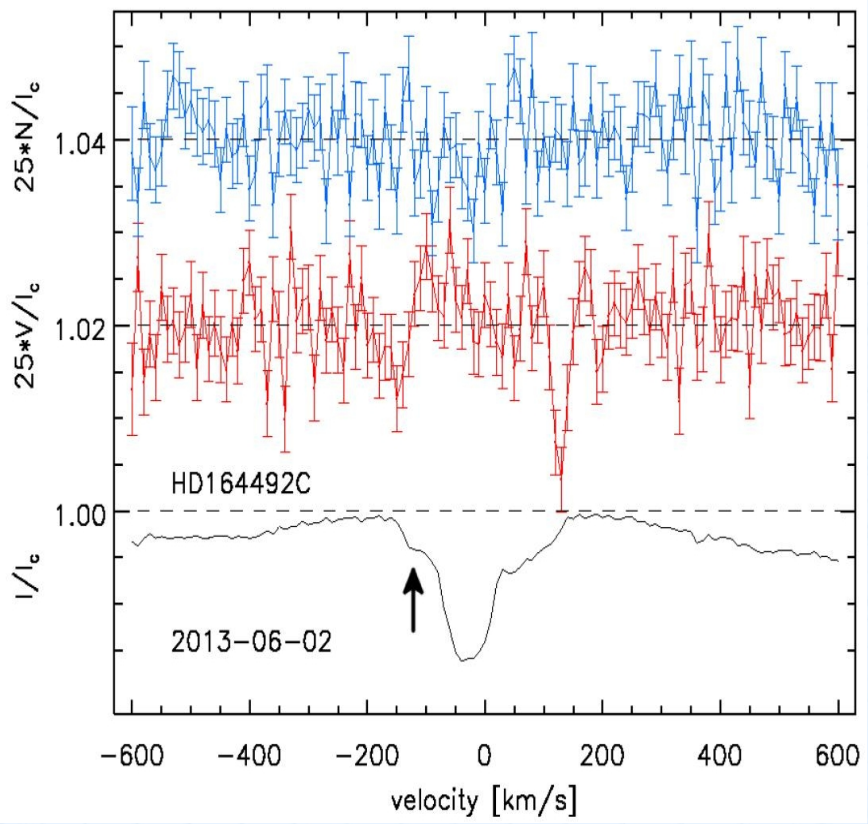
A young, magnetic binary in the Trifid Nebula

Is HD 164492C actually a multiple system?

SVD – only Si III lines



LSD – no He I lines



Hubrig et al. (2014)

HD 54879: A magnetic O9.7 V star

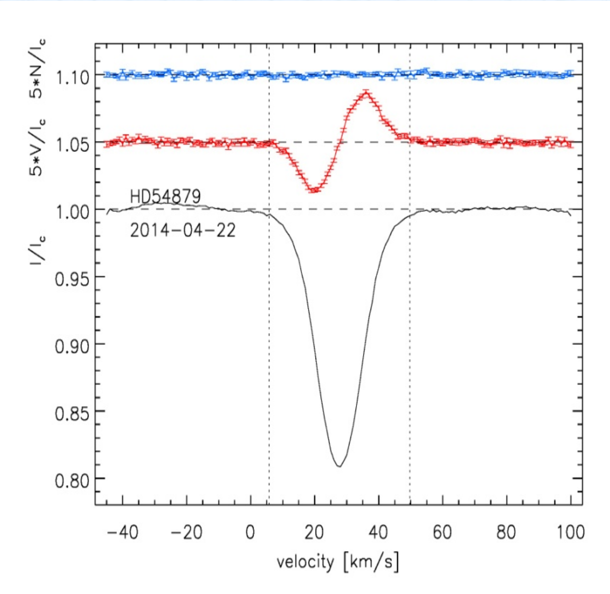
FORS2 observations

			Hydrogen lines		All lines	
			V	N	V	N
Detection	07 02 2014	Bonn	−654±111	23±80	−503±56	70±46
		Potsdam	−639±121	−16±119	−460±65	76±66
	08 02 2014	Bonn	−978±104	−35±81	−653±50	40±4
		Potsdam	−877±91	−102±105	−521±62	23±63

HARPS observations

ND: FAP > 10^{-3} MD: 10^{-5} < FAP < 10^{-3} DD: FAP < 10^{-5}

		V		N	
22 04 2014	Bonn	**−592±7**	**DD**	**−20±7**	**ND**
	Potsdam	**−584±15**	**DD**	**−22±10**	**ND**



HD 54879: A magnetic O9.7 V star

FORS2 observations

Hydrogen lines

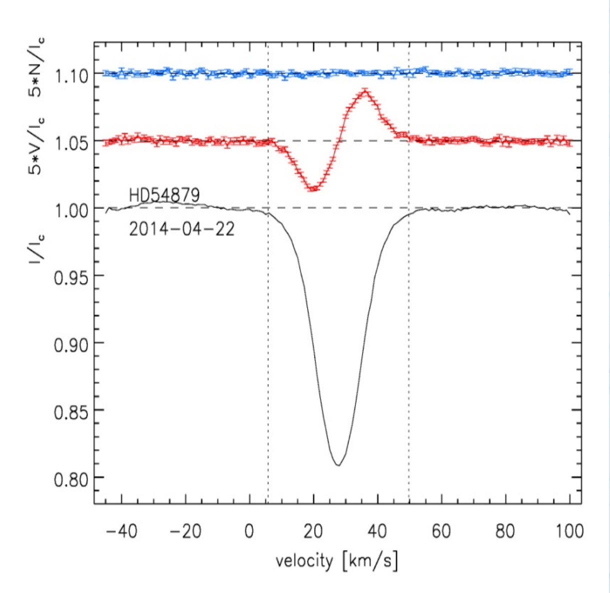
			V	N		N
Detection	07 02 2014	Bonn	−654±111	[illegible]	[illegible]±56	70±46
		Potsdam	−639±[illegible]	[illegible]	−460±65	76±66
	08 02 2014	Bonn	[illegible]	[illegible]81	−653±50	40±4
		Potsd[illegible]	[illegible]	[illegible]102±105	−521±62	23±63

Dipolar field > 2.1 kG

HARPS obser[illegible]

ND: FAP > 10^{-3} [illegible] 0^{-5} < FAP < 10^{-3} DD: FAP < 10^{-5}

		V		N	
22 04 2014	Bonn	**−592±7**	**DD**	**−20±7**	**ND**
	Potsdam	**−584±15**	**DD**	**−22±10**	**ND**



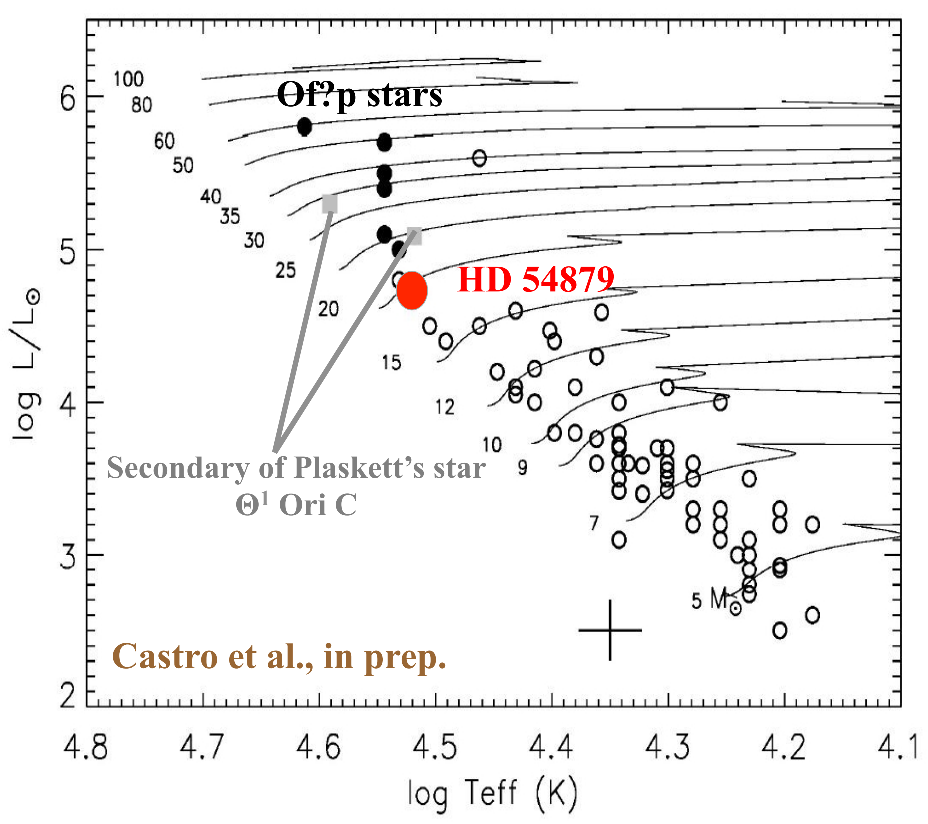
HD 54879: A magnetic O9.7 V star

Output of spectral synthesis with FASTWIND

Teff = 33000±1000 K
logg = 4.00±0.10
vsin*i* = 7±2 km s^{-1}
vmacro = 8±3 km s^{-1}
logQ = −11.0±0.1

Fundamental parameters and evolutionary stage from BONNSAI (Schneider et al. 2014)

logL/Lsun = 4.69±0.15
R/Rsun = 6.74±0.97
M/Msun = 18.6±1.7
Age = 4.0±1.0 Myrs



No evidence for spectral peculiarities or abundance anomalies/spots
Expected to support a centrifugal magnetosphere

CPD −57 3509: A σ Ori E analogue?

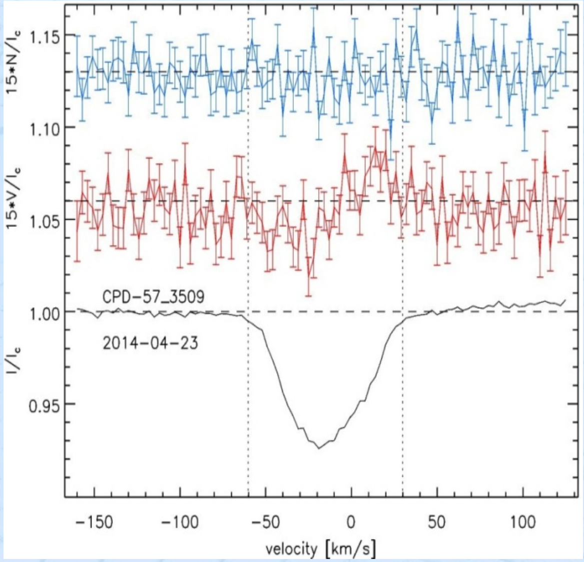
FORS2 observations

		Hydrogen lines V	Hydrogen lines N	All lines V	All lines N
No detection	06 02 2014 Bonn	−356±127	−362±122	−144±78	−39±78
	Potsdam	−287±126	−372±138	−39±76	−75±82
Detection	07 02 2014 Bonn	660±120	−120±107	711±62	68±60
	Potsdam	694±108	−116±104	618±61	16±62
No detection	01 06 2014 Bonn	−71±75	−53±75	40±46	−51±47
	Potsdam	−19±71	−28±86	87±54	−45±59
Detection	02 06 2014 Bonn	1050±93	−85±61	943±43	2±39
	Potsdam	979±68	−108±77	920±48	2±50

HARPS observations

ND: FAP > 10^{-3} MD: 10^{-5} < FAP < 10^{-3} DD: FAP < 10^{-5}

	V		N	
23 04 2014 Bonn	**−557±73**	**DD**	**76±72**	**ND**
Potsdam	**−492±78**	**DD**	**−59±59**	**ND**



CPD −57 3509: A σ Ori E analogue?

FORS2 observations

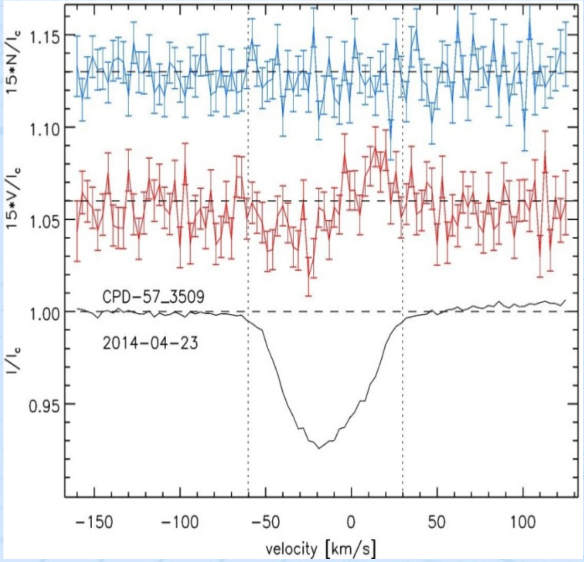
			Hydrogen lines		All lines	
			V	N	V	N
No detection	06 02 2014	Bonn	−356±127	−362±122	−144±78	−39±78
		Potsdam	−287±126	−372±138	−39±76	−75±82
Detection	07 02 2014	Bonn	660±120	[illegible]	[illegible]	[illegible]
		Potsdam	694±108	[illegible]	[illegible]	[illegible]
No detection	01 06 2014	Bonn	−71±75	[illegible]	[illegible]	[illegible]
		Potsdam	−19±71	[illegible]	[illegible]	[illegible]
Detection	02 06 2014	Bonn	1050±93	−85±61	943±43	2±39
		Potsdam	979±68	−108±77	920±48	2±50

High consistency of measurements

HARPS observations

ND: FAP > 10^{-3} MD: 10^{-5} < FAP < 10^{-3} DD: FAP < 10^{-5}

		V		N	
23 04 2014	Bonn	−557±73	DD	76±72	ND
	Potsdam	−492±78	DD	−59±59	ND



CPD −57 3509: A σ Ori E analogue?

FORS2 observations

		Hydrogen lines		All lines	
				V	N
06 02 2				144±78	−39±78
				39±76	−75±82
07 02 2				711±62	68±60
	Potsdam	694±108	−116±104	618±61	16±62
01 06 2014	Bonn	−71±75	−53±75	40±46	−51±47
	Potsdam	−19±71	−28±86	87±54	−45±59
02 06 2014	Bonn	1050±93	−85±61	943±43	2±39
	Potsdam	979±68	−108±77	920±48	2±50

No detection

Detection

No detection

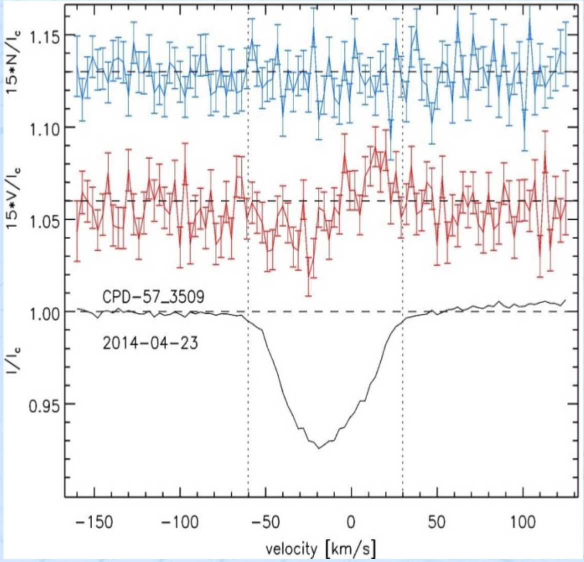
Detection

Strong, daily variations of the field

HARPS observations

ND: FAP > 10^{-3} MD: 10^{-5} < FAP < 10^{-3} DD: FAP < 10^{-5}

		V		N	
23 04 2014	Bonn	**−557±73**	**DD**	**76±72**	**ND**
	Potsdam	**−492±78**	**DD**	**−59±59**	**ND**



CPD −57 3509: A σ Ori E analogue?

Dipolar field > 3.1 kG

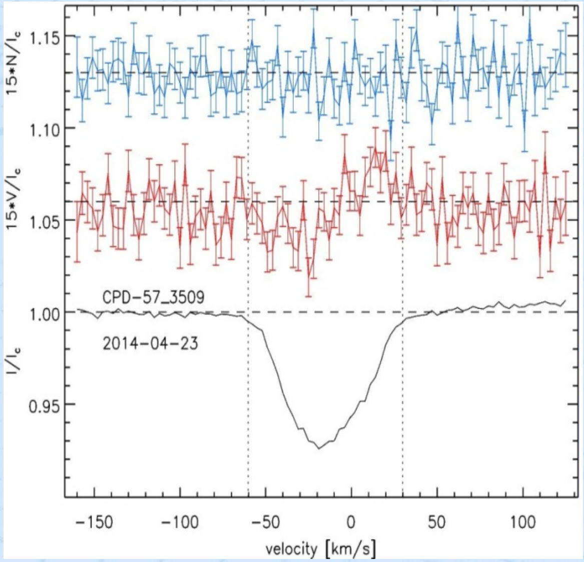
FORS2 observations

			Hydrogen lines		All lines	
			V	N	[illegible]	N
No detection	06 02 2014	Bonn	−356±127	−362±122	[illegible]	39±78
		Potsdam	−287±126	−372	[illegible]	75±82
Detection	07 02 2014	Bonn	660±120	[illegible]	62	68±60
		Potsdam	694±	[illegible]	618±61	16±62
No detection	01 06 2014	Bonn	[illegible]	75	40±46	−51±47
		Potsd	[illegible]	28±86	87±54	−45±59
Detection	02 06 2014	B	3	−85±61	943±43	2±39
		[illegible]	79±68	−108±77	920±48	2±50

HARPS obs

ND: FAP > 10^{-3} MD: 10^{-5} < FAP < 10^{-3} DD: FAP < 10^{-5}

		V		N	
23 04 2014	Bonn	**−557±73**	**DD**	**76±72**	**ND**
	Potsdam	**−492±78**	**DD**	**−59±59**	**ND**



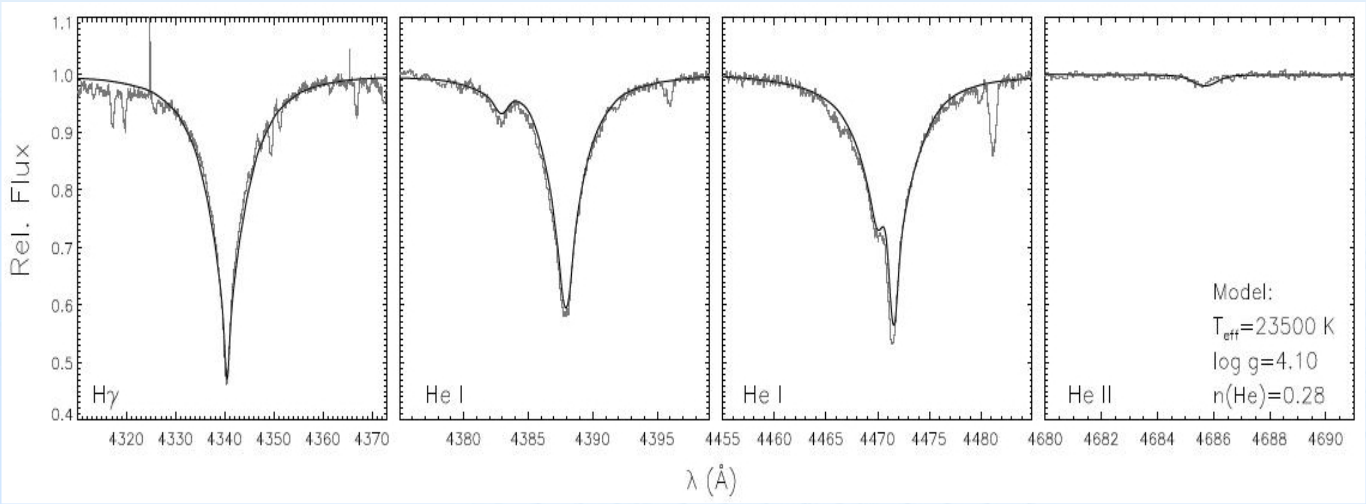
CPD −57 3509: A σ Ori E analogue?

Star in NGC 3293 (cluster age ~10 Myrs)

Output of spectral synthesis with DETAIL/SURFACE

Teff ~ 23500 K logg ~ 4.1

vsini ~ 35 km s^{-1} **He/H ~ 0.28**

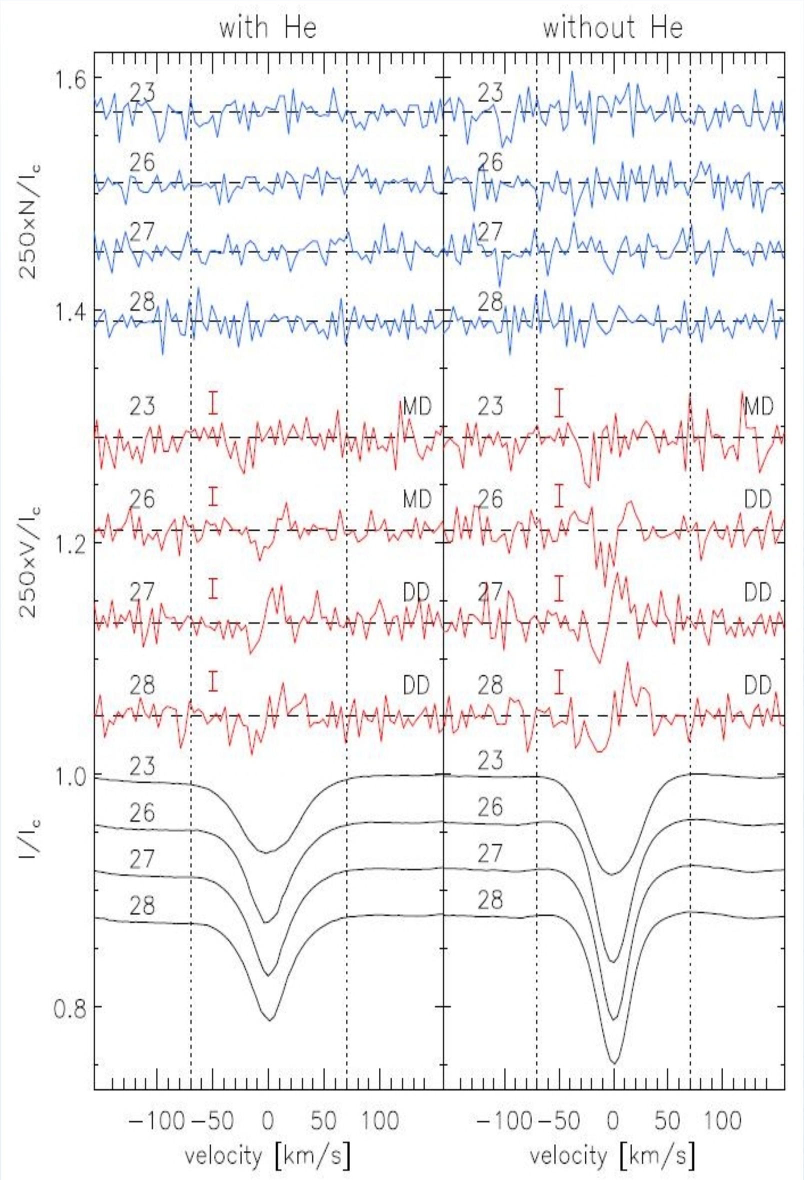


Przybilla et al., in preparation

Star evolved throughout ~30% of its main-sequence lifetime
One of the most evolved He-rich stars with a tight age estimate
Will provide constraints on the evolution of stars with magnetically-confined stellar winds
Still unclear whether CPD −57 3509 is a σ Ori E analogue (e.g., X-ray properties unknown)

Detection of weak fields in early B-type stars

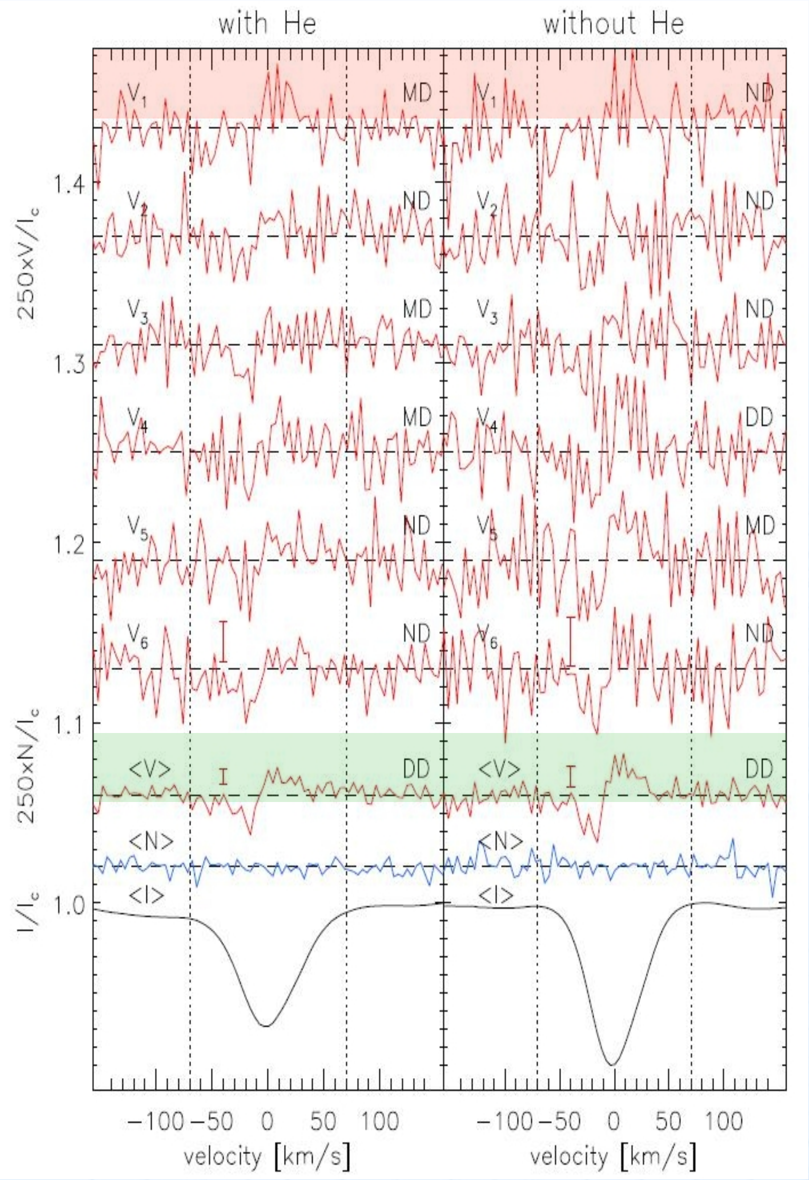
β CMa



Observations in December 2013

Detection of weak fields in early B-type stars

β CMa

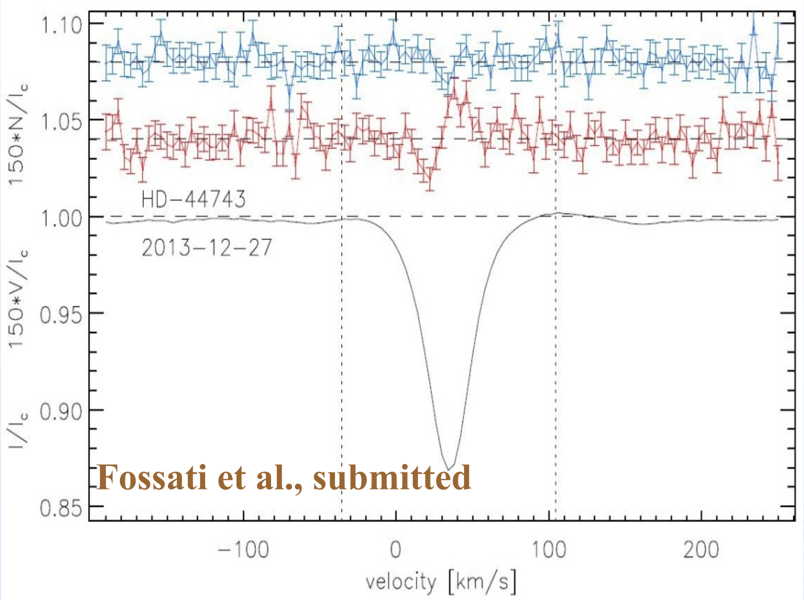


Pulsations may affect field measurements (e.g., Hubrig et al. 2011)

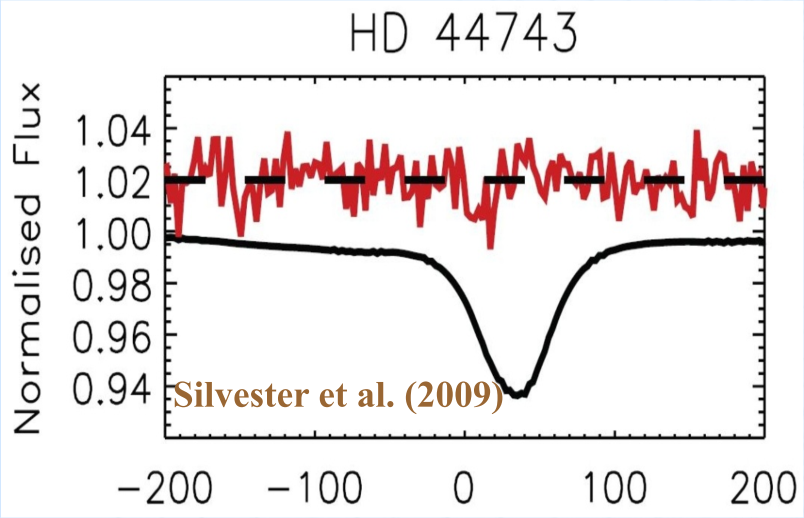
Consecutive observations in April 2014 (free from effects of pulsations)

Detection of weak fields in early B-type stars

β CMa



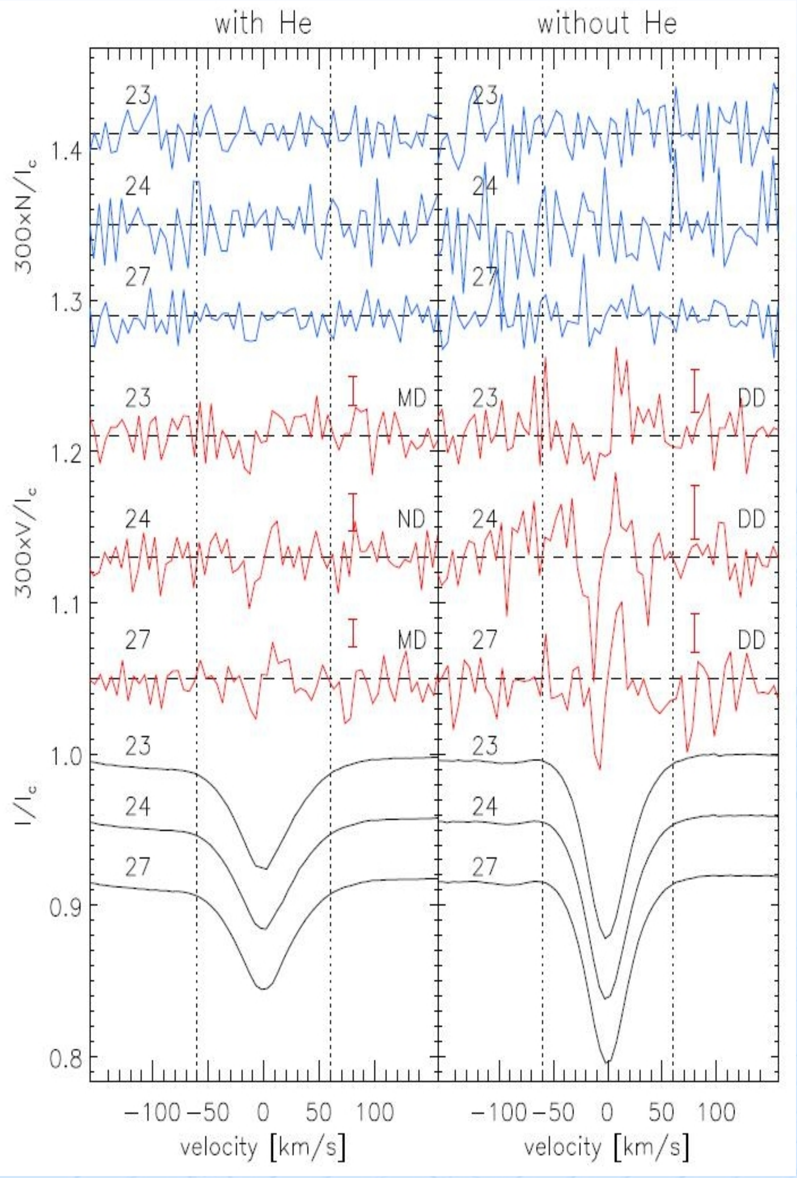
S/N ~ 900



S/N ~ 400

Detection of weak fields in early B-type stars

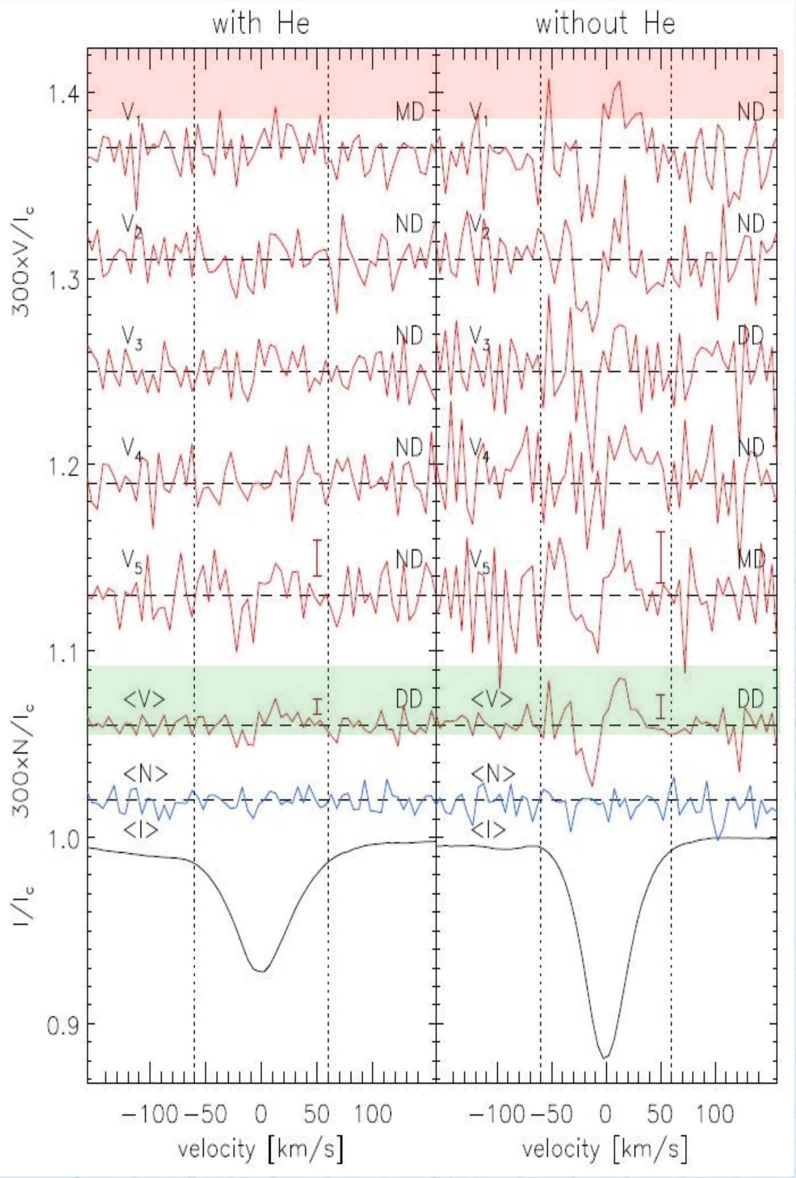
ε CMa



Observations in December 2013

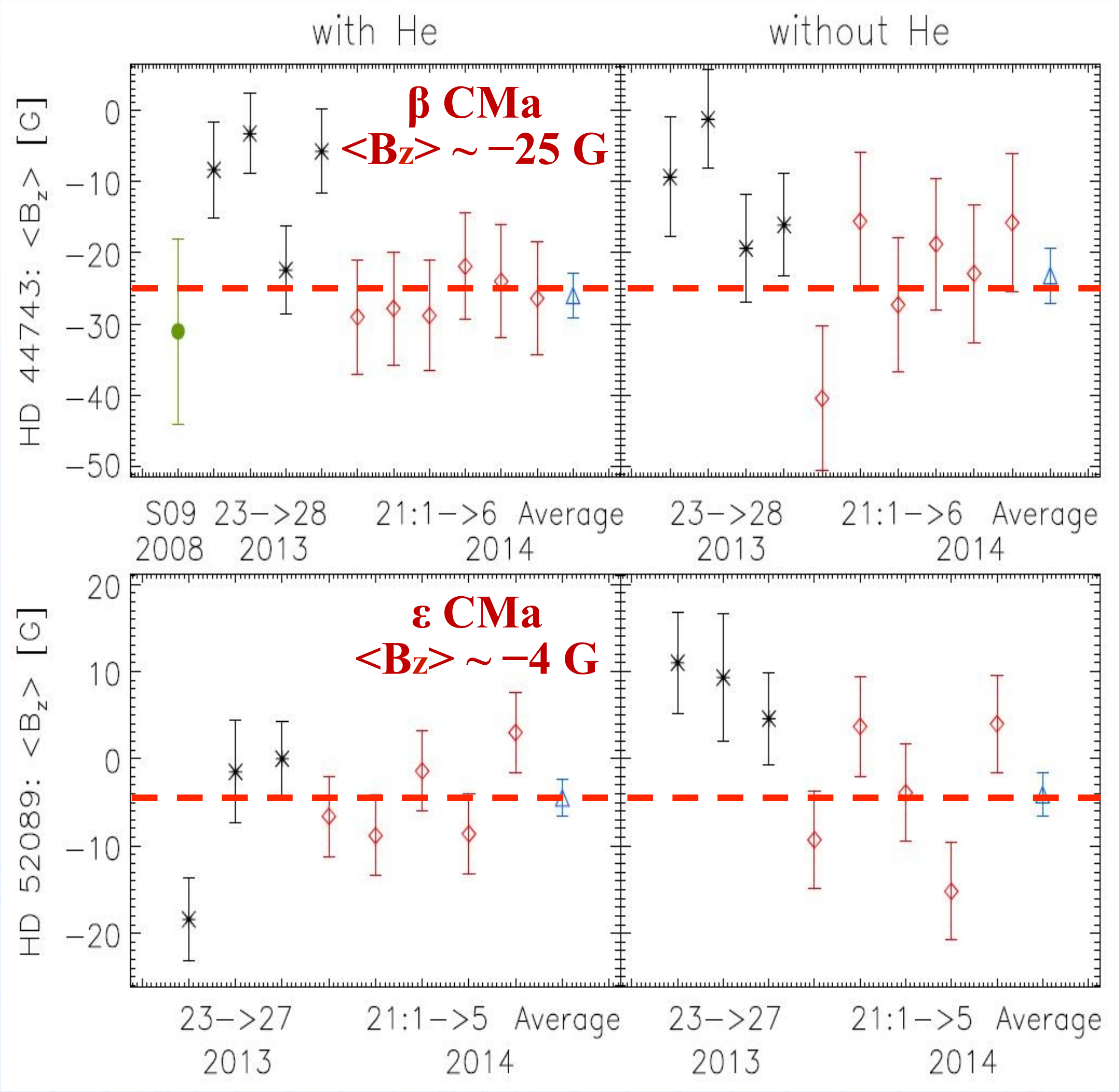
Detection of weak fields in early B-type stars

ε CMa



Consecutive observations in April 2014

Detection of weak fields in early B-type stars



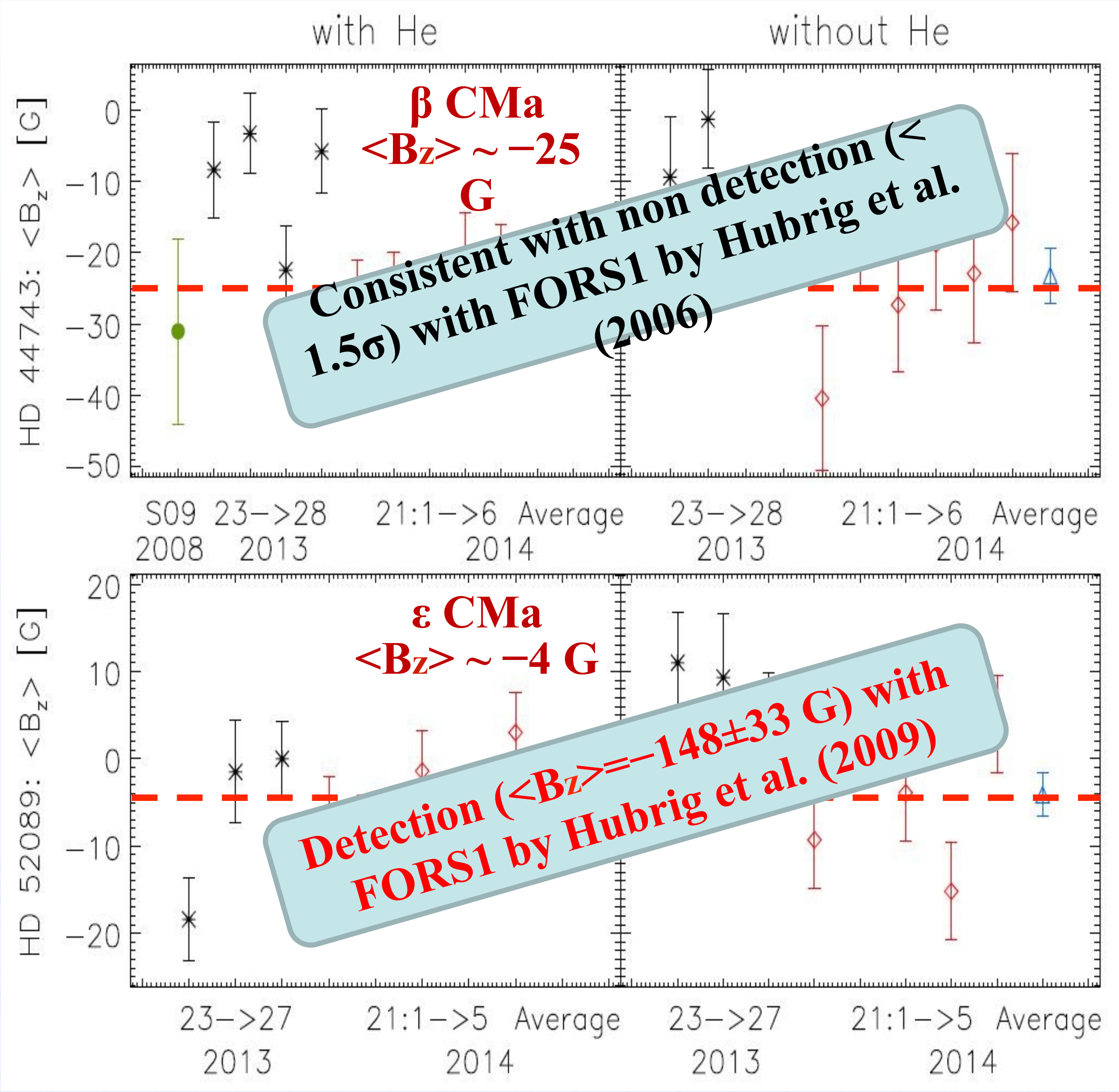
Silvester et al. (2009)

BOB December 2013

BOB April 2014

Average BOB April 2014

Detection of weak fields in early B-type stars



Silvester et al. (2009)

BOB December 2013

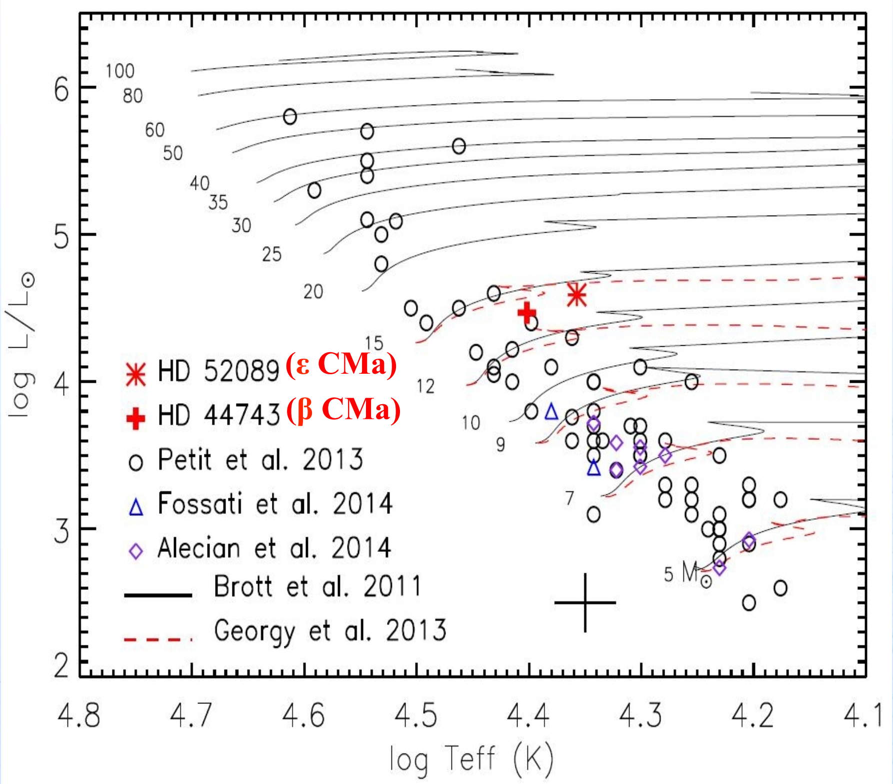
BOB April 2014

Average BOB April 2014

Detection of weak fields in early B-type stars

Output of spectral synthesis with DETAIL/SURFACE and Geneva evolutionary tracks (Irrgang et al. 2014)

	β CMa	ε CMa
Teff [K]	25230±510	22770±470
logg	3.66±0.10	3.38±0.10
vsin*i* [km s^{-1}]	27±2	< 9
M [Msun]	13.7±1.5	14.0±1.2
R [Rsun]	9.1±1.3	12.7±1.9
Age [Myrs]	~12.0	~12.0
Nitrogen	Normal	Mildly enriched



Seismic study of β CMa (Mazumdar et al. 2006)

P_{rot} = 18.6±3.3 days: i = 61 (+29−15)°

Not seen pole-on

Weak field variations during 5 days (one third of rotation period):

Magnetic field axis likely nearly aligned with rotation axis

Conclusions

- Observations of ~100 OB stars carried out so far with both FORS2 and HARPS.
- Only very few targets in common with MiMeS: complementary survey.
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Conclusions

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- Confirmation that the occurrence of fields above the detectability threshold (~100-200 G) is low in massive stars. *However, exact estimation of incidence rate still pending (may be revised upwards).*
- Discovery of a young, massive magnetic binary in the Trifid Nebula (Hubrig et al. 2014). Unclear at this stage whether only one or more components are magnetic.
- Strong case for presence of a weak field in β CMa. Conclusions for ε CMa rely on reality of stronger detection with FORS1 in 2007 (Hubrig et al. 2009).

No evidence in massive stars for the "magnetic desert" claimed for intermediate-mass stars (e.g., Aurière et al. 2007)?