Current spectropolarimeters to measure stellar magnetic fields

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Contents

- How to measure magnetic fields?
- Regression method

  → Low resolution spectropolarimeters : FORS1,…
- Stokes profiles and LSD

  → High resolution spectropolarimeters : Musicos, Narval, Espadons,…
- Regression (low R) vs Zeeman profiles (high R)
- Which polarimeter should you use?

How to measure magnetic fields?

Spectropolarimetry :

Measure the Zeeman effect

- circular polarisation (Stokes V) is enough to detect a stellar field

- circular+linear polarisation (QUV) is needed to reconstruct a detailed magnetic map

Measure the Hanle effect?

not done yet for stars other than the Sun…

How to measure magnetic fields?

Spectropolarimetry :

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Important features of spectropolarimeters

- Focus : Cassegrain or Nasmyth
- No spurious polarization (crosstalk, fringes)
- Achromaticity

} taken care of by instrument team

- Resolution : low or high
- Efficiency

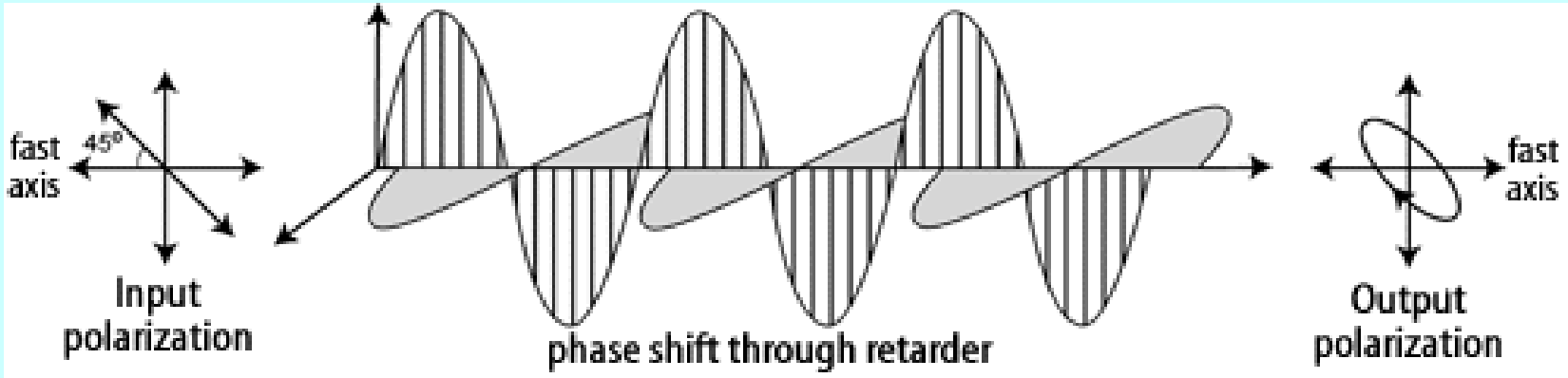
→ Trade of between R and S/N

- Wavelength domain (echelle spectro, LSD)

} your choice

Necessary ingredients of a spectropolarimeter

Wave plate:

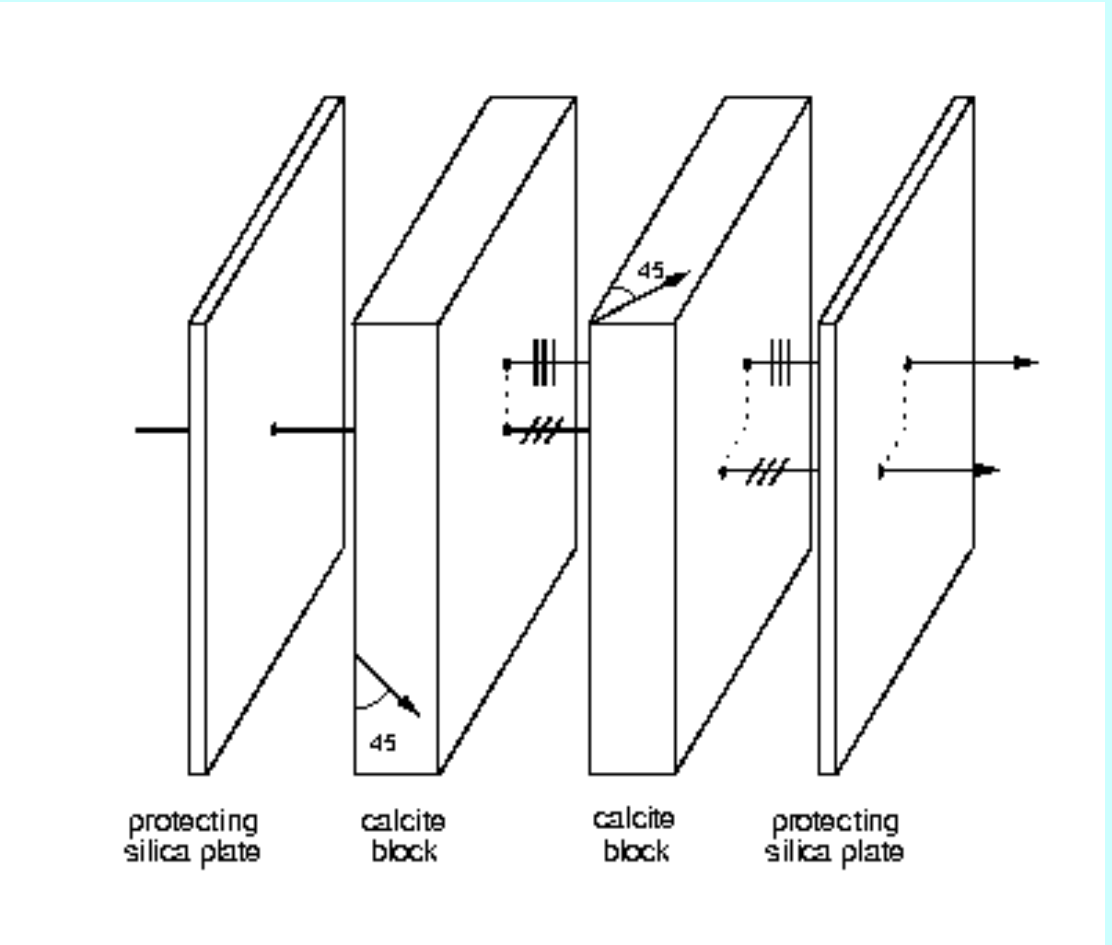


Create a phase delay between 2 beams

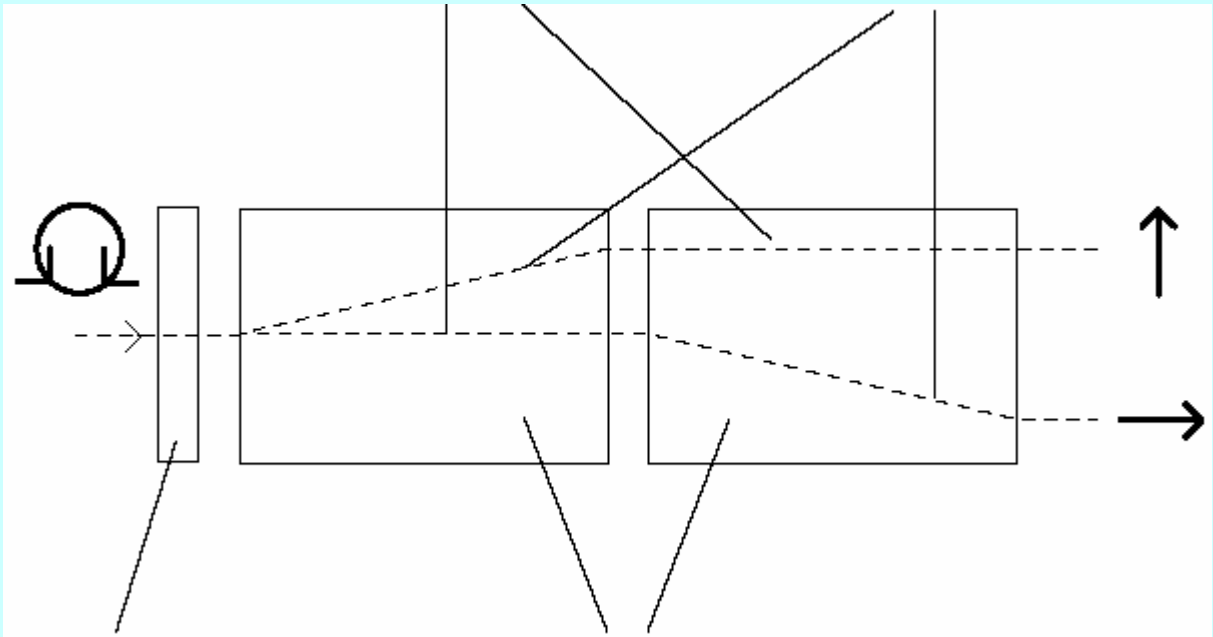
Analyser / Beamsplitter:

Separate spatially the 2 states of orthogonal polarization

e.g. calcite bloc, Savart plate



- For Stoves V we have to measure 2 circular polarization (left and right)
- For each circular state we have to measure 2 linear states



Measurements

1 exposure = 2 orthogonal states of linear polarization

But several exposures needed to measure 1 Stokes parameter:

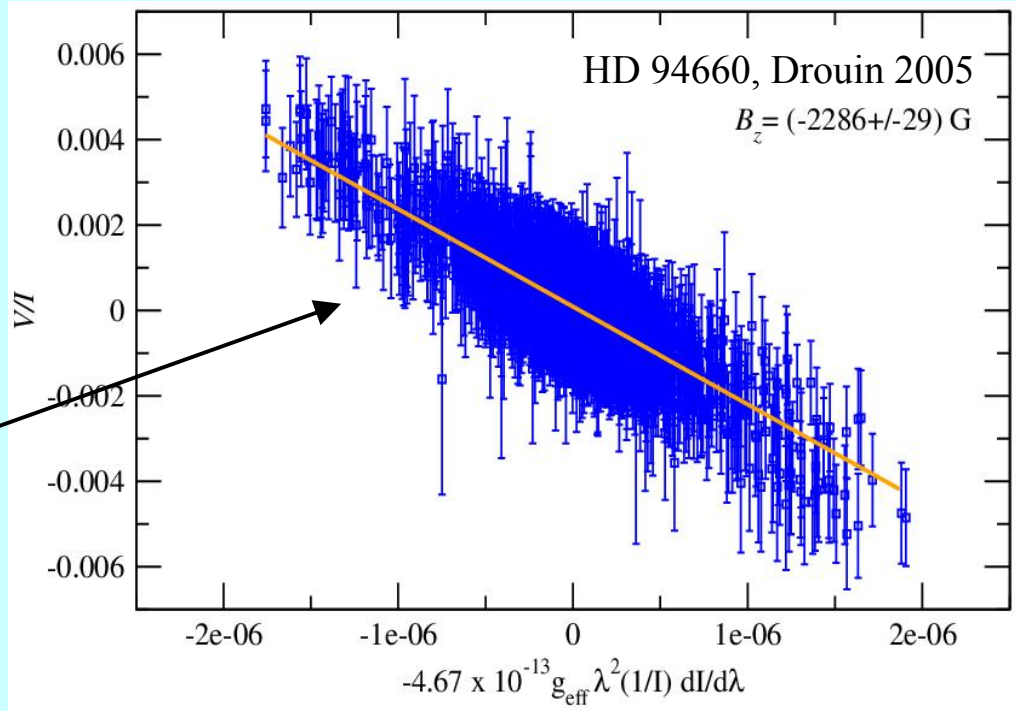
- either same path but consecutive measurements
- or simultaneously but different path
- or… switch path and repeat measurements → beam exchange

e.g. with Espadons/Narval: 1 circular (V) polarization measurement = 4 subexposures; 1 linear (QU) measurement = 8 subexposures

Regression method

(Bagnulo et al. 2002)

Slope proportional to mean longitudinal magnetic field



$$V/I = 4.67 \times 10^{-13}\ g_{eff}\ \lambda^2/I\ dI/d\lambda \quad x \quad B$$

- low resolution spectropolarimeter
- one unblended line studied at a time (Hα, Hβ…)
- extension of photoelectric method *(Angel & Landstreet 1970):* measures difference between blue and red wings circular polarisation

Regression method

(Bagnulo et al. 2002)

$$V/I = 4.67 \times 10^{-13}\ g_{eff}\ \lambda^2\ 1/I\ dI/d\lambda \times B$$

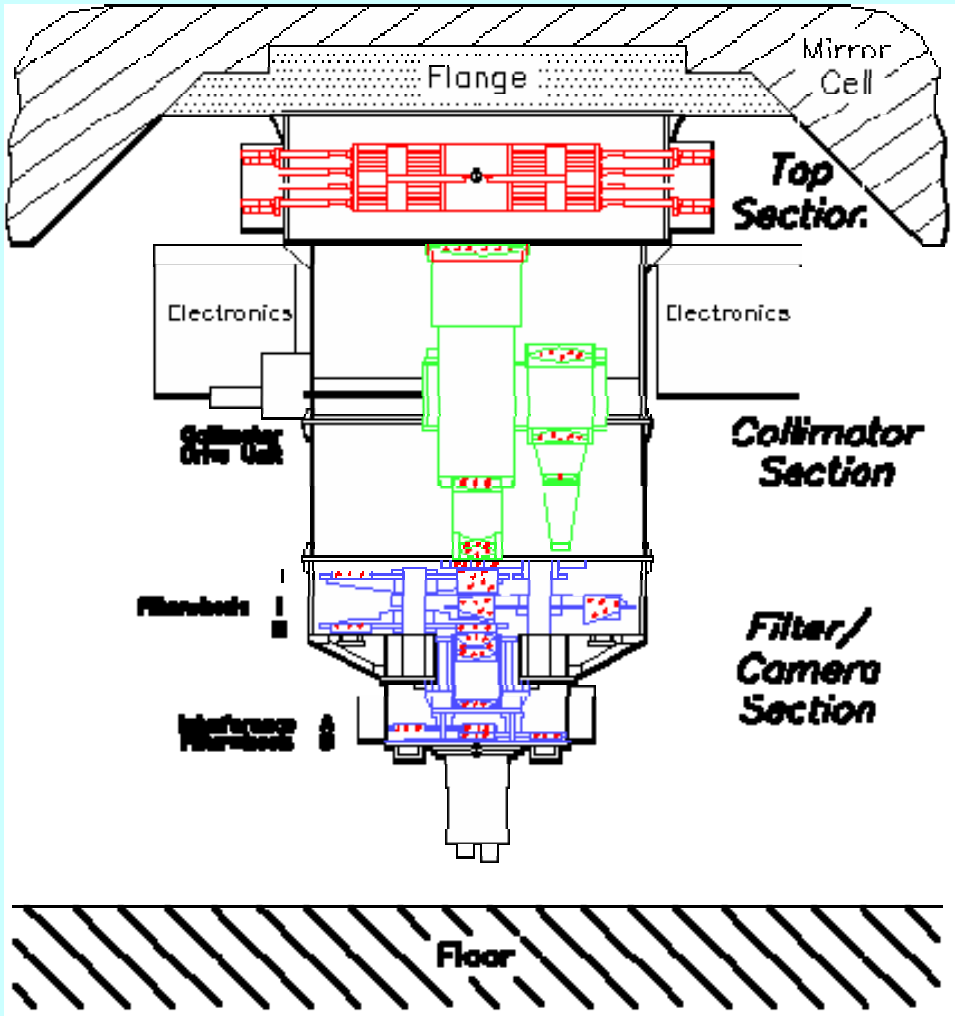
< 0.1 / Å
for BA stars

→ need S/N ~ 10000 for error bar of 100 G!

→ use several H lines + sum exposures

→ if field small enough, use also metallic lines

FORS1@VLT



At UT2 Cassegrain focus

FORS1@VLT :

- Spectropolarimetric mode R=260-1700

- Mag-limit: V=17-19

- multi-object

- Instrumental polarization 0.01% (Bagnulo et al. 2002)

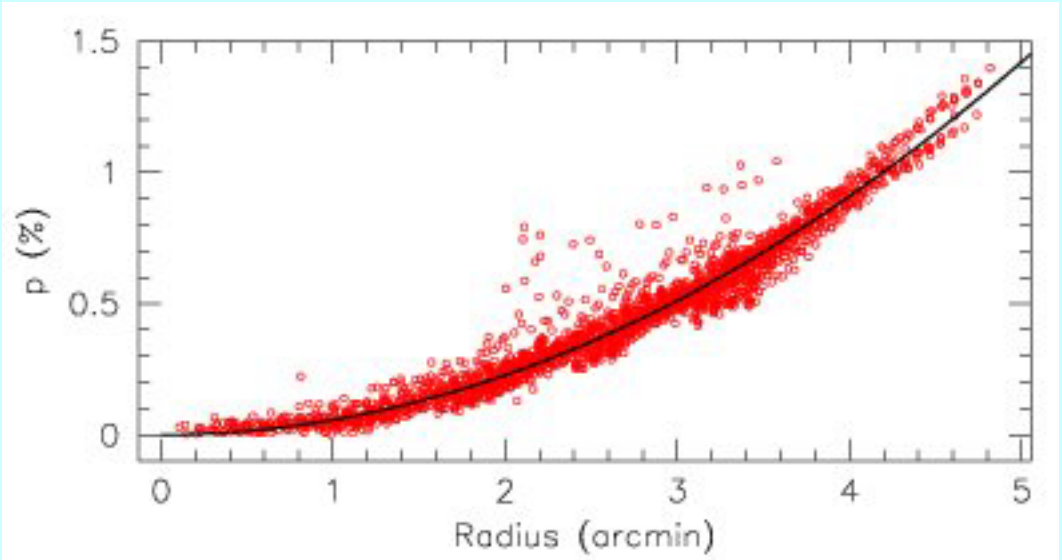
- new CCD mosaic E2V detector optimized for blue

- new high throughput filters

But :

- Fringes at $\lambda > 650$ nm

- Spurious polarization if object off-centered



ISIS@WHT

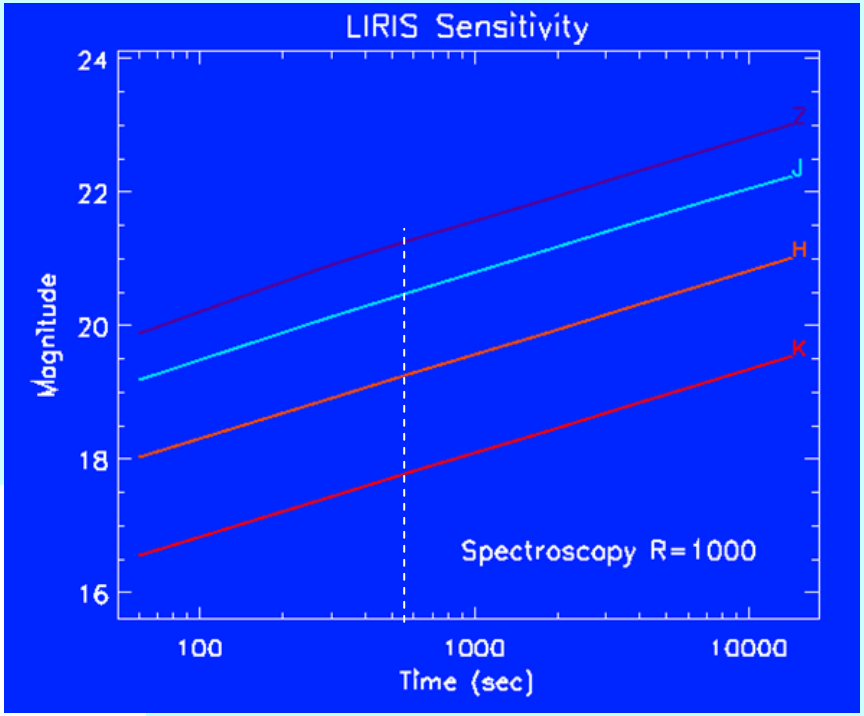
- R = 5000
- λ = 378-448 nm + red domain
- Accuracy 300G for B=12 mag

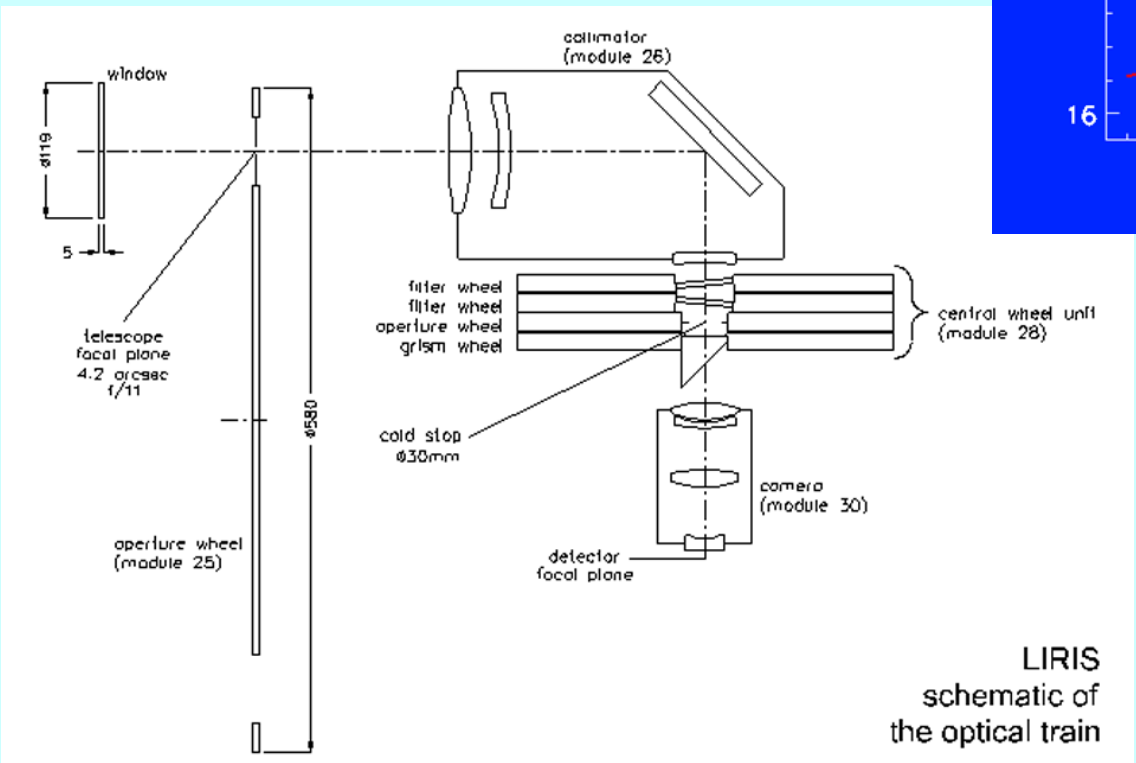
4.2m

Leone et al. 2007

LIRIS@WHT

- from 2008A on
- near-IR (ZJHK)
- low resolution R = 1000-2500

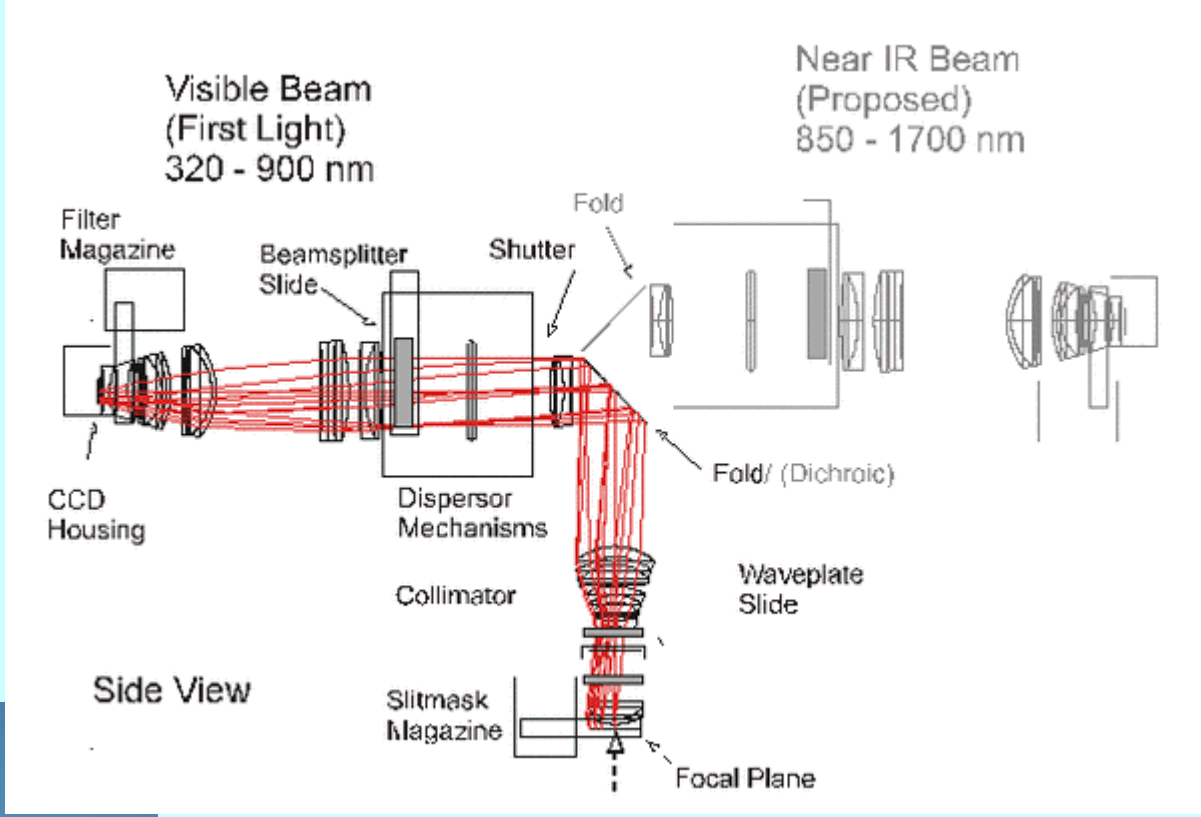




LIRIS
schematic of
the optical train

PFIS/RSS@SALT

Buckley et al. 2005



11m

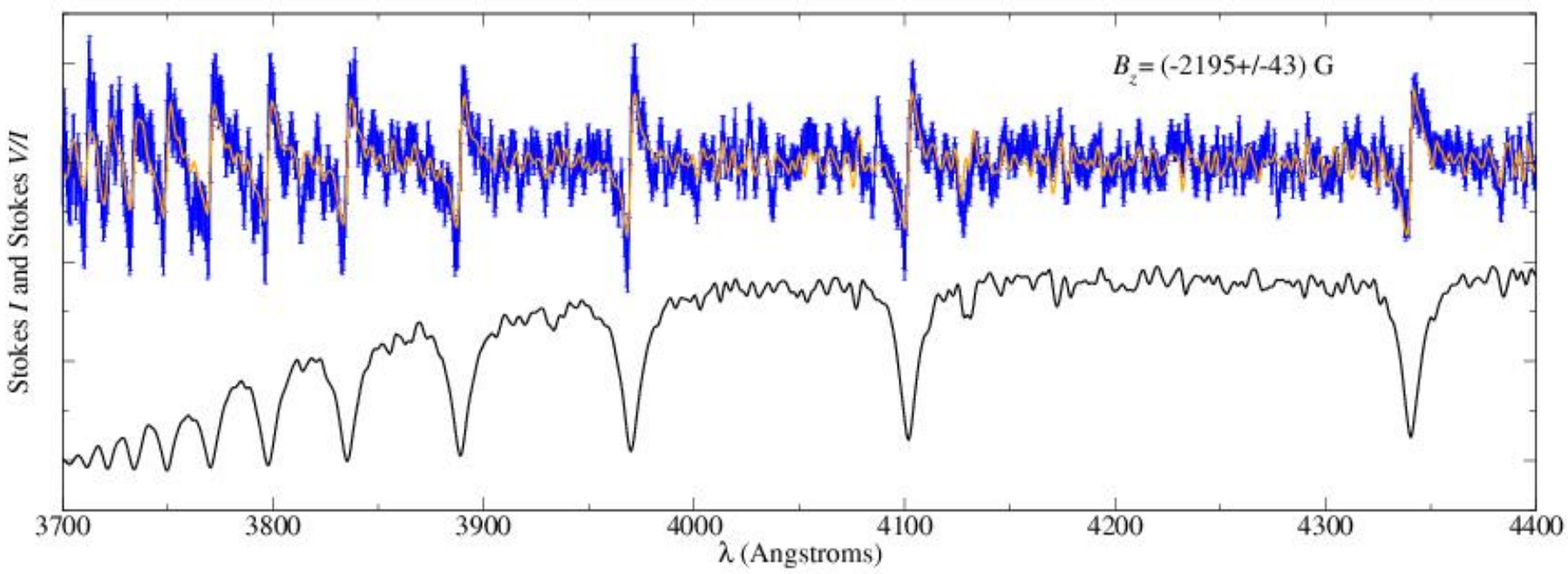
- R = 500-10000

- λ = 320 (UV) - 900 nm
→ planned 1700 nm (IR)

- multi-objet

Stokes profiles LR

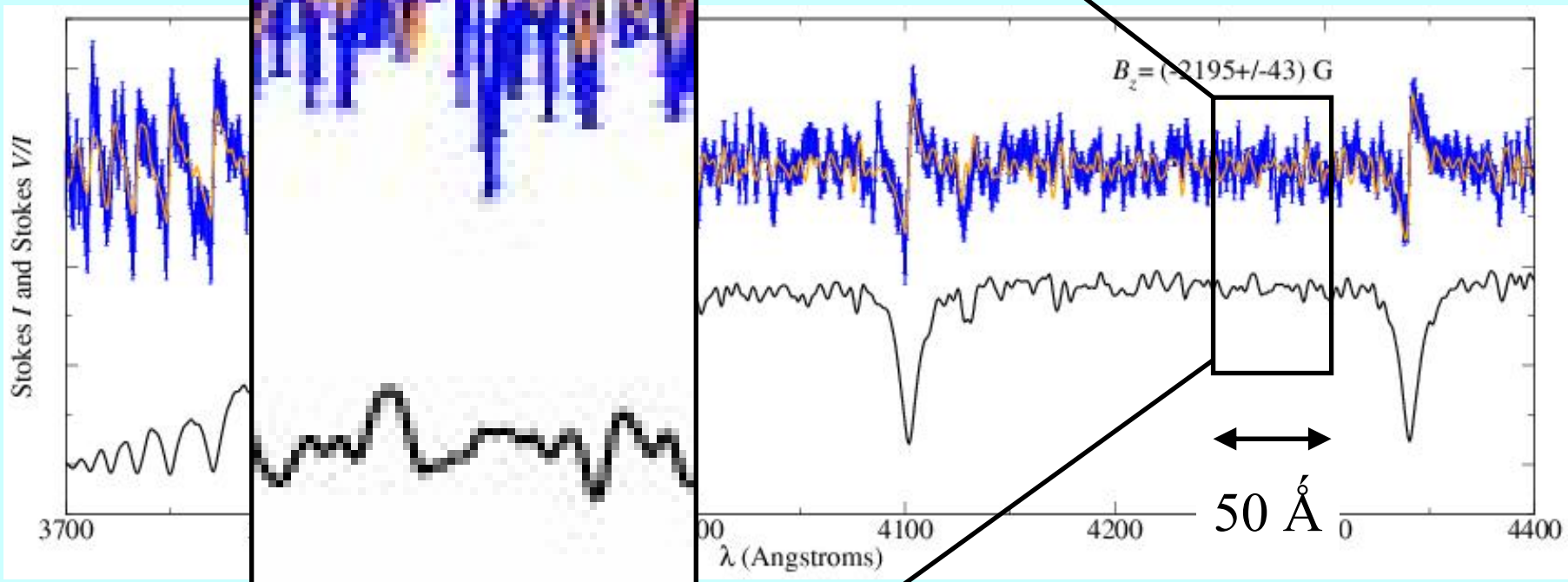
Low resolution FORS1 spectrum



Drouin 2005

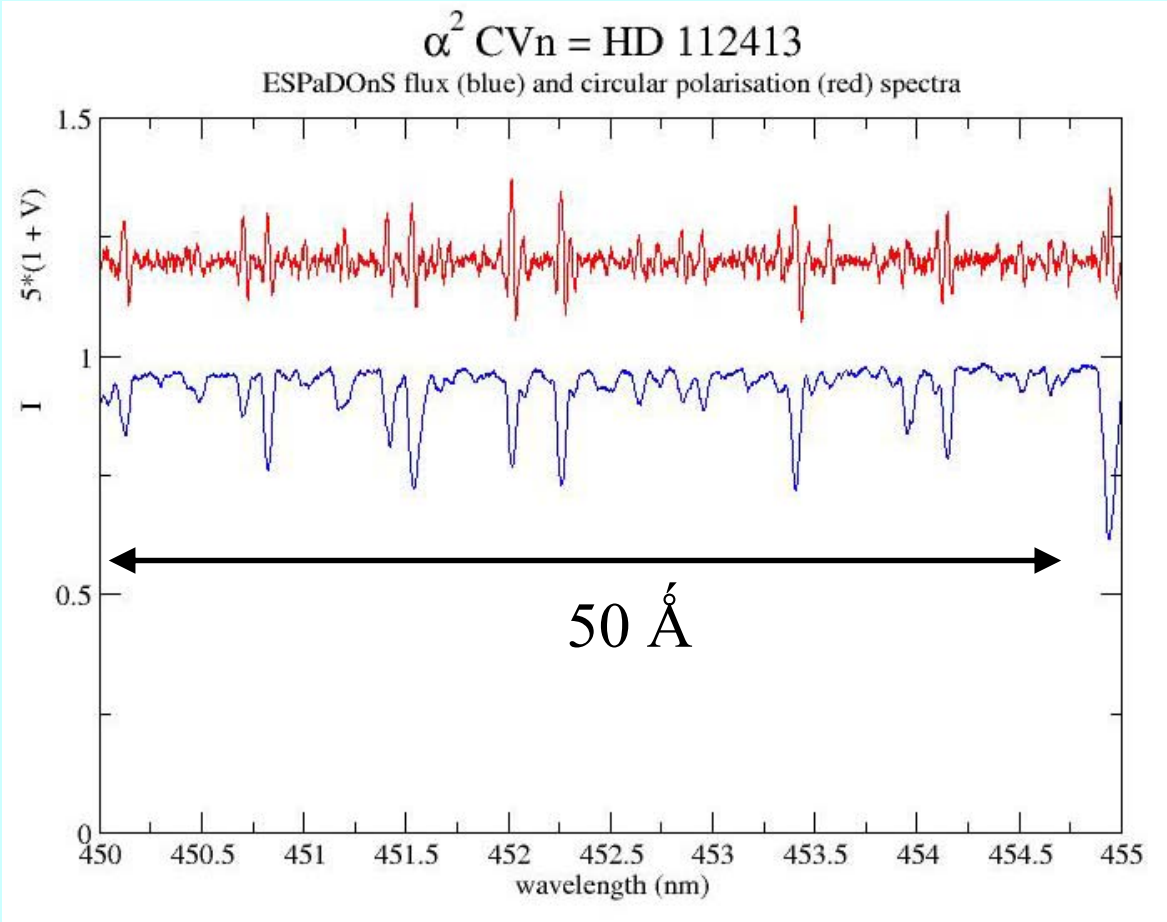
kes profiles LR

Low resol um



Drouin 2005

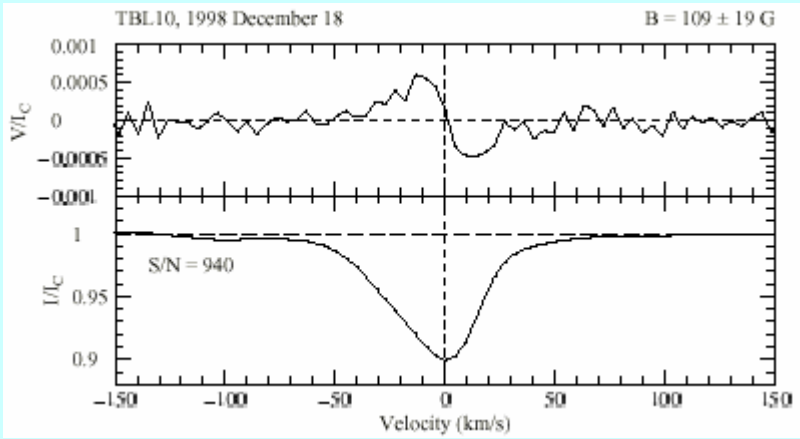
Stokes profiles HR



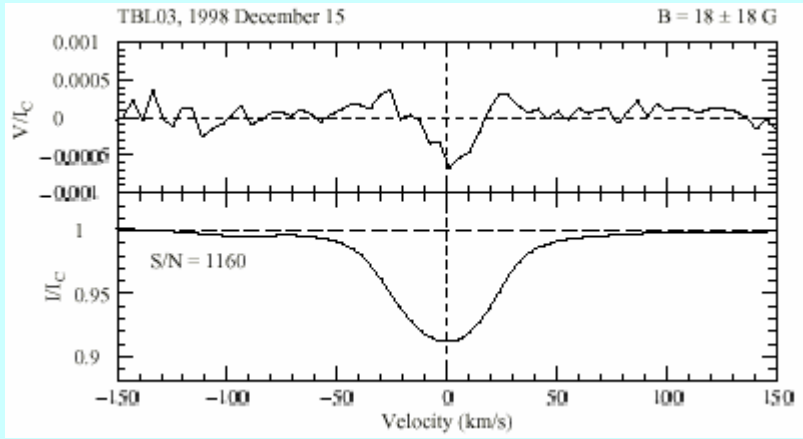
J. Landstreet

- high resolution spectropolarimeters
- measures difference between 2 circular polarisation states

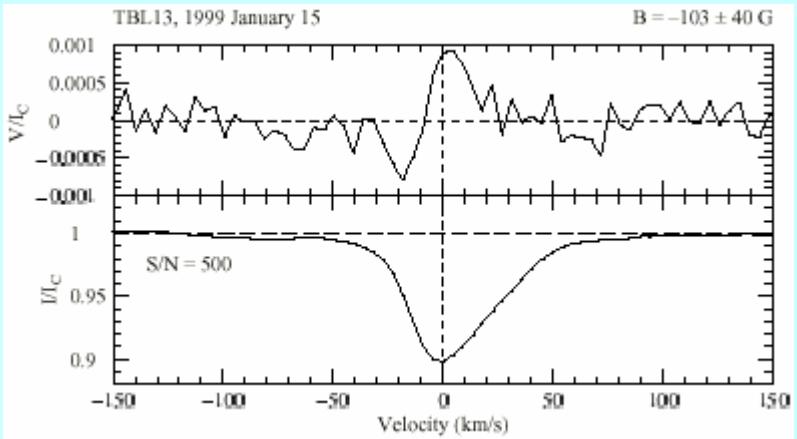
Variation of Stokes V with rotation period



B maximum



B = 0

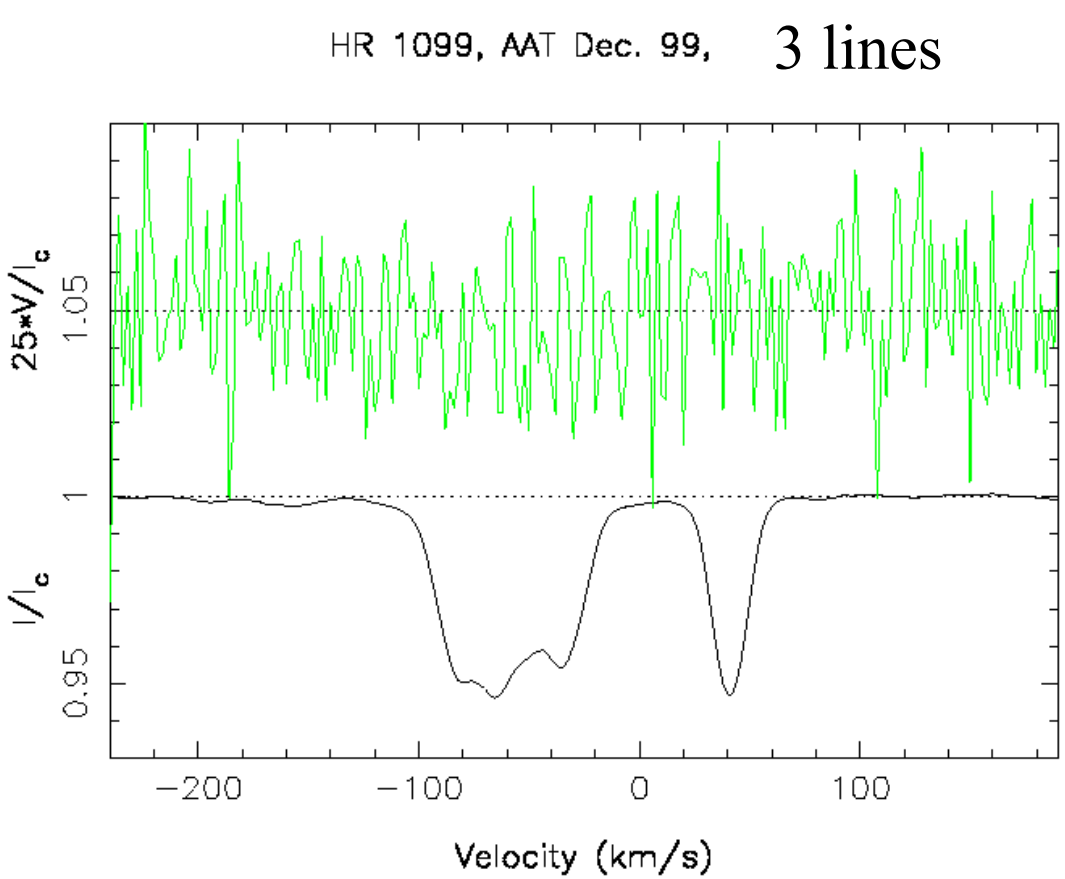


B minimum

β Cep

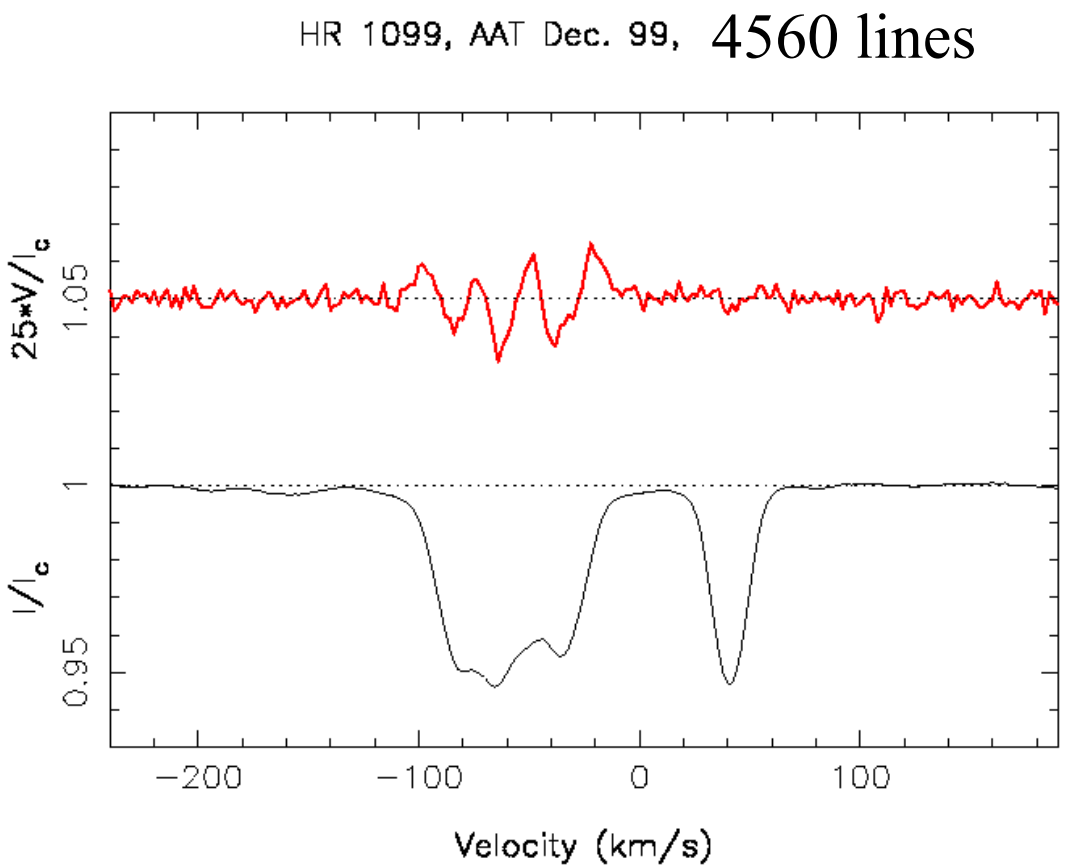
Henrichs et al. 2000

LSD (Least Square Deconvolution) method *(Donati et al. 1997)*



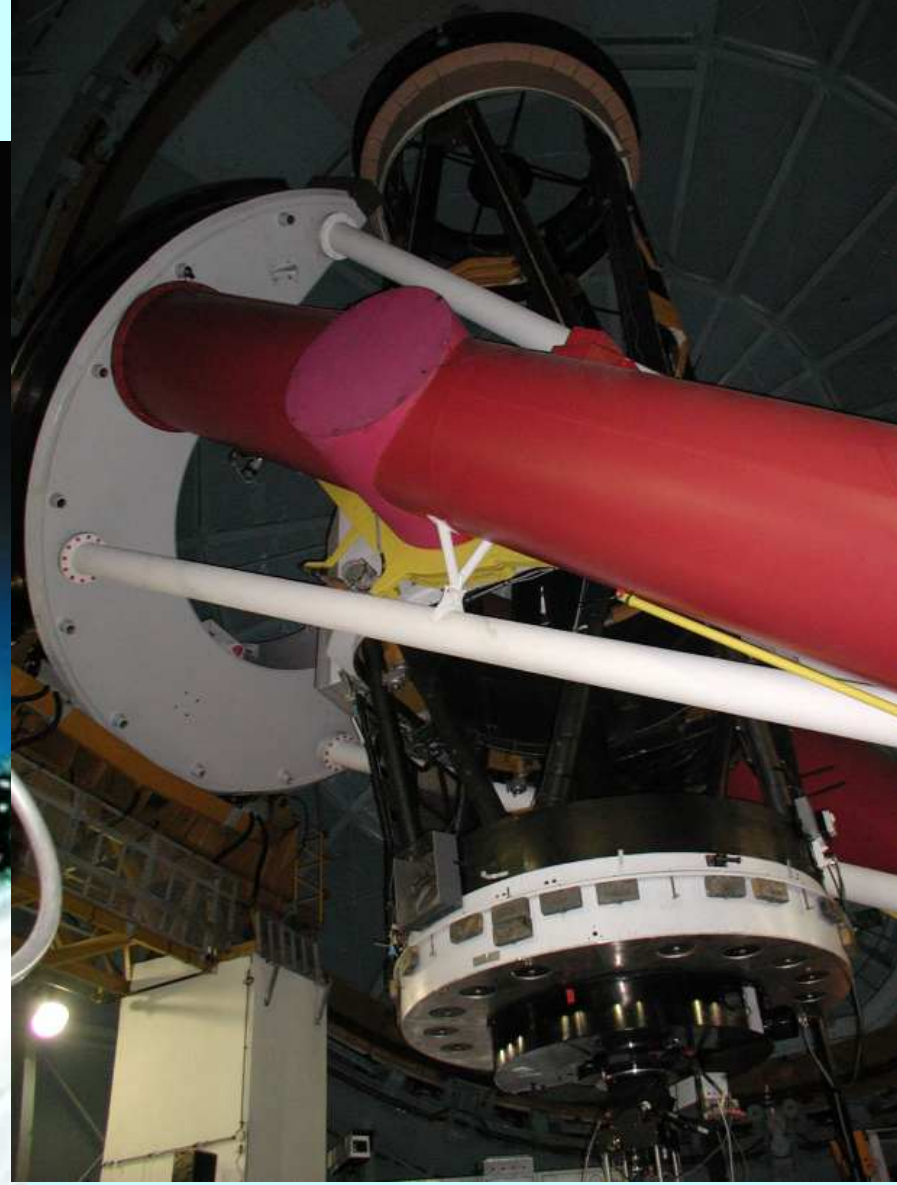
- all lines used at the same time

LSD (Least Square Deconvolution) method *(Donati et al. 1999)*



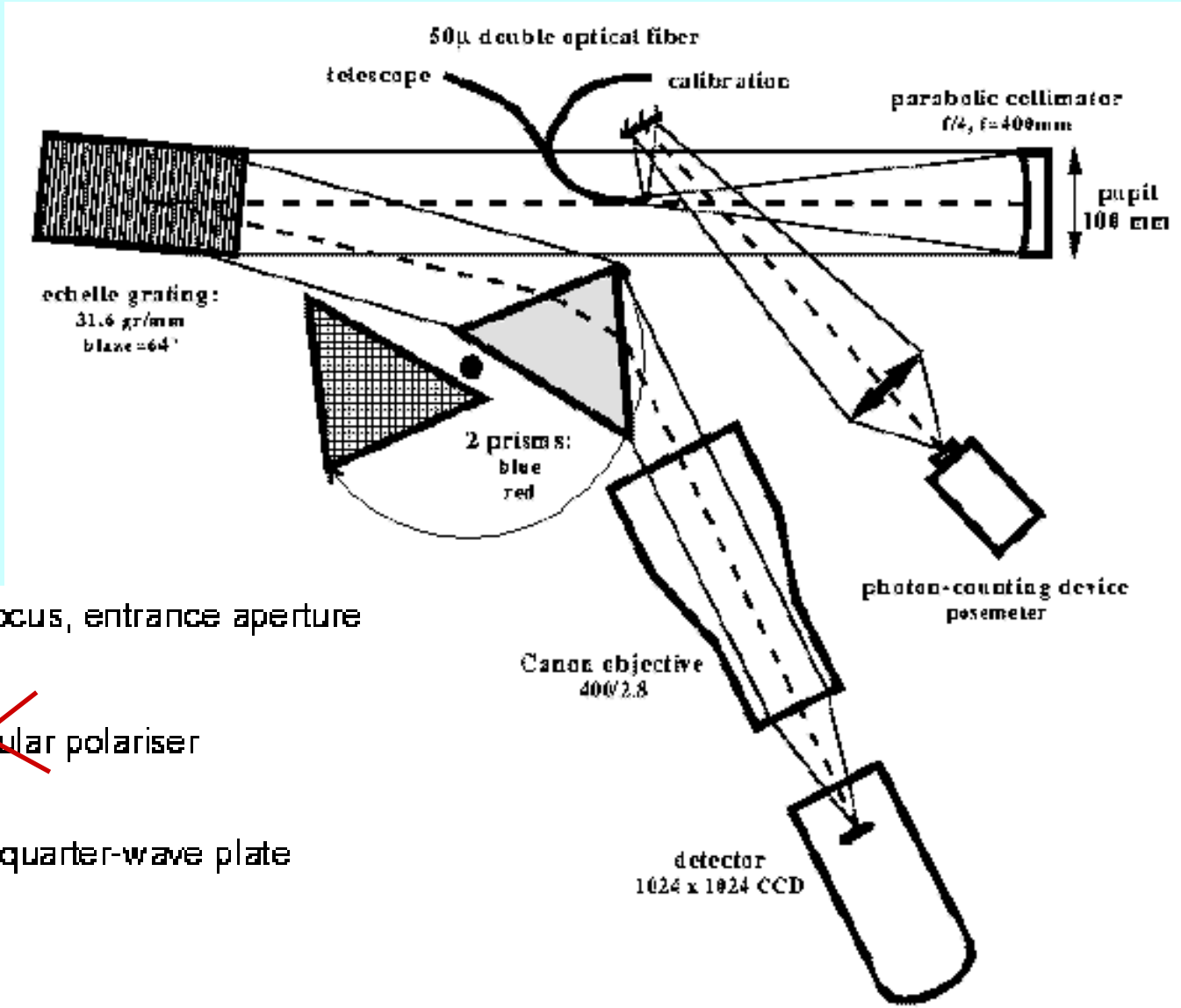
- all lines used at the same time

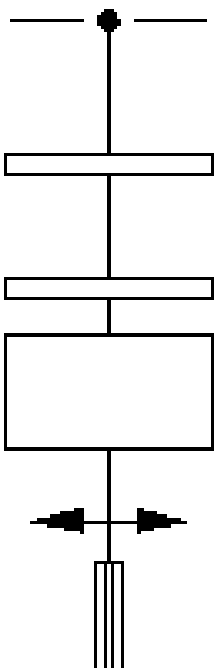
at TBL, Pic du Midi



2m

Musicos@TBL





Cassegrain focus, entrance aperture

Linear or ~~circular~~ polariser

Half-wave or quarter-wave plate

Beamsplitter

Focal reducer f/25 - f/2.5

Optical fibres

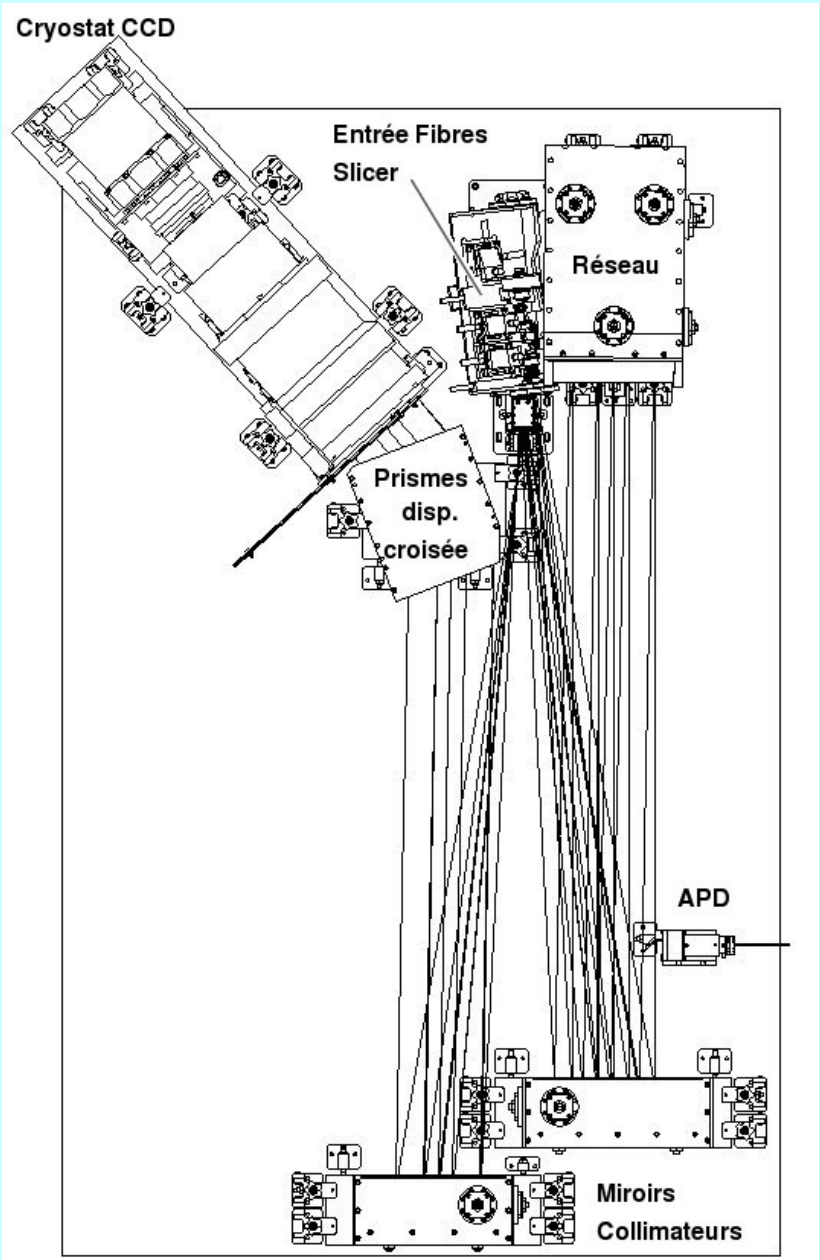
Musicos@TBL

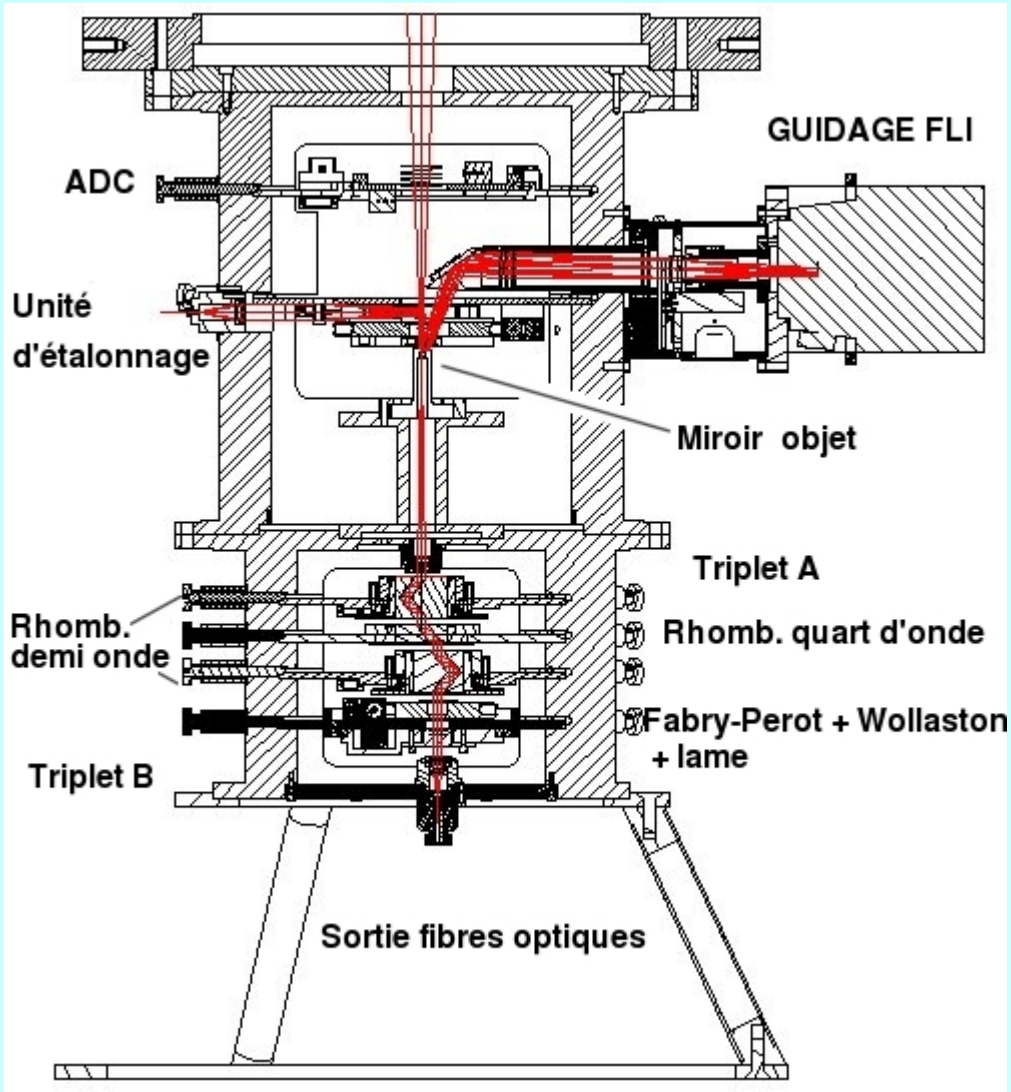
- R=35000
- Spectropolarimetric mode: λ = 400-700 nm
- Accuracy (circular) < 0.002%

→First HR spectropolarimeter to measure weak magnetic fields in stars

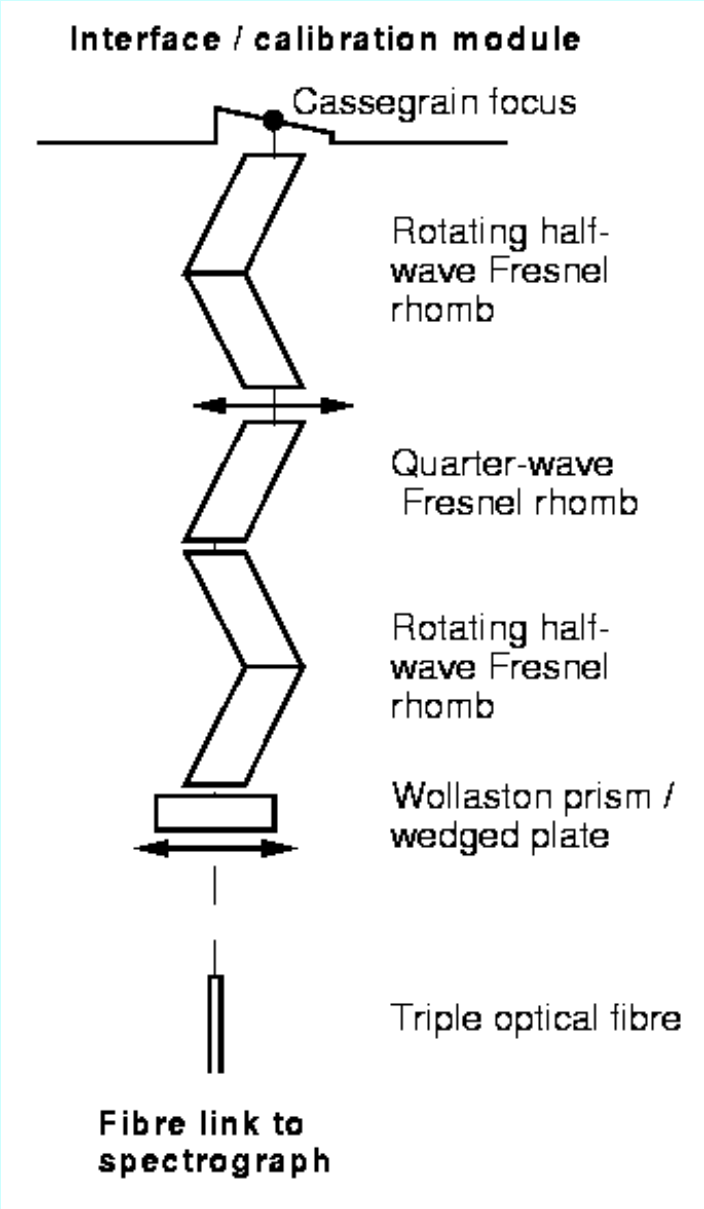
not available anymore…

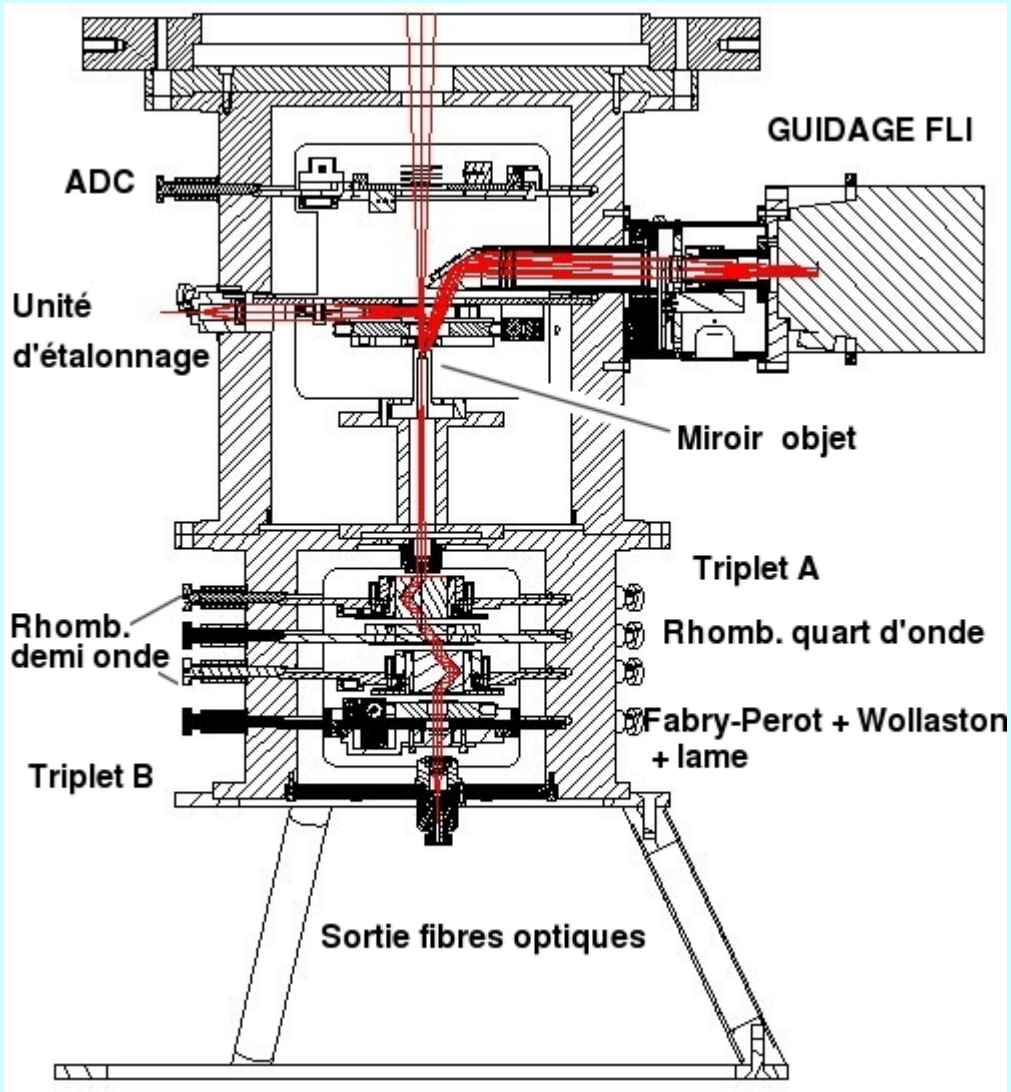
Narval@TBL


Cryostat CCD
Entrée Fibres
Slicer
Réseau
Prismes
disp.
croisée
APD
Miroirs
Collimateurs


GUIDAGE FLI
ADC
Unité
d'étalonnage
Miroir objet
Triplet A
Rhomb.
demi onde
Rhomb. quart d'onde
Fabry-Perot + Wollaston
+ lame
Triplet B
Sortie fibres optiques

Narval@TBL


Interface / calibration module
Cassegrain focus
Rotating half-wave Fresnel rhomb
Quarter-wave Fresnel rhomb
Rotating half-wave Fresnel rhomb
Wollaston prism / wedged plate
Triple optical fibre
Fibre link to spectrograph


GUIDAGE FLI
ADC
Unité d'étalonnage
Miroir objet
Triplet A
Rhomb. demi onde
Rhomb. quart d'onde
Fabry-Perot + Wollaston + lame
Triplet B
Sortie fibres optiques

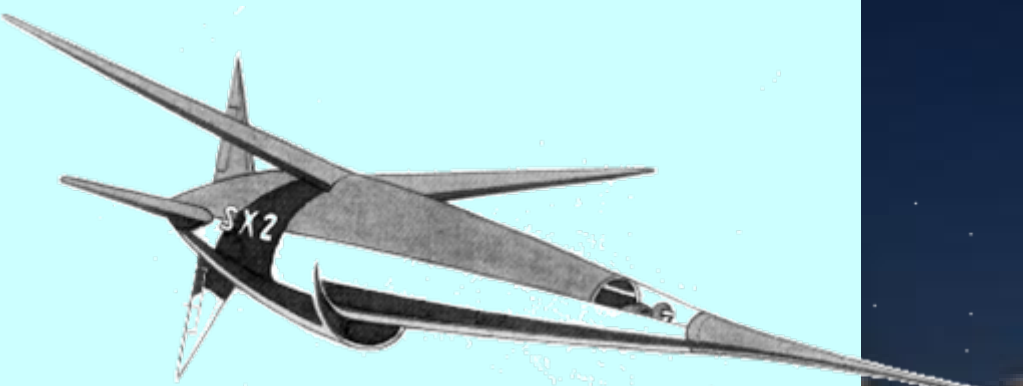
Narval@TBL

- R = 65000
- λ = 375-1050 nm
- much higher efficiency than Musicos

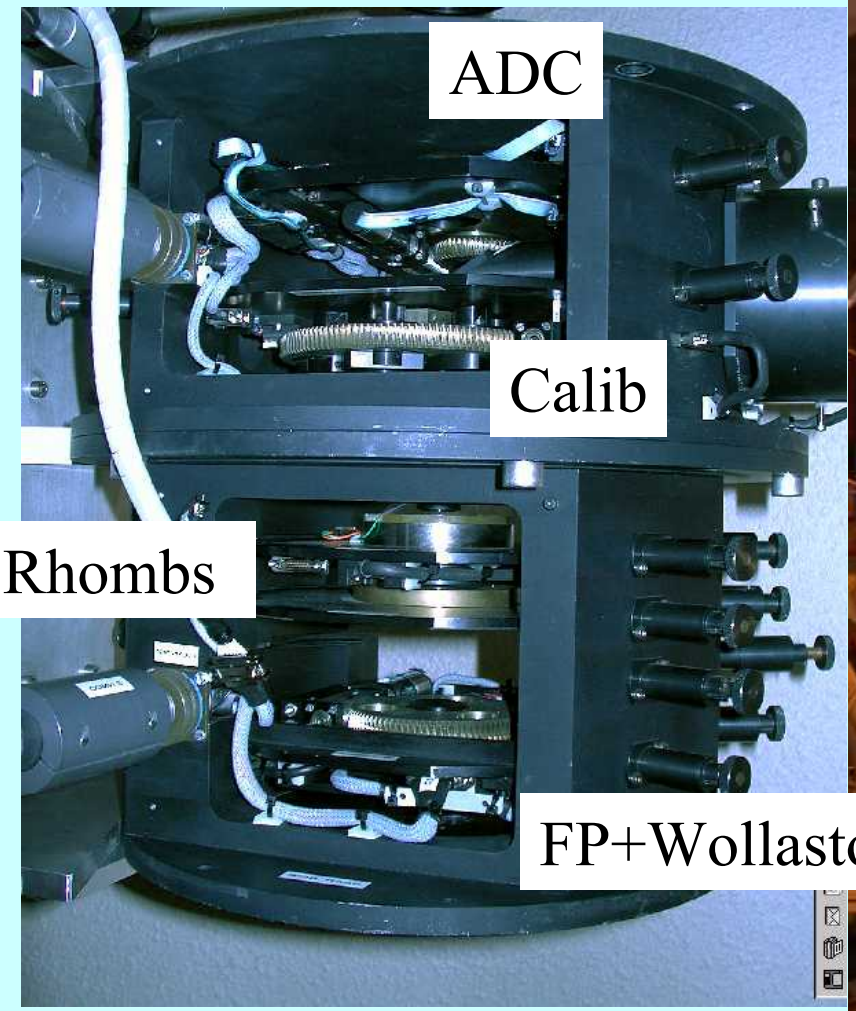
- Crosstalk (birefingence stress) < 1%
- Fringing < 0.05% (in principle… but high amplitude fringes at red λ due to unstable temperature of the CCD)

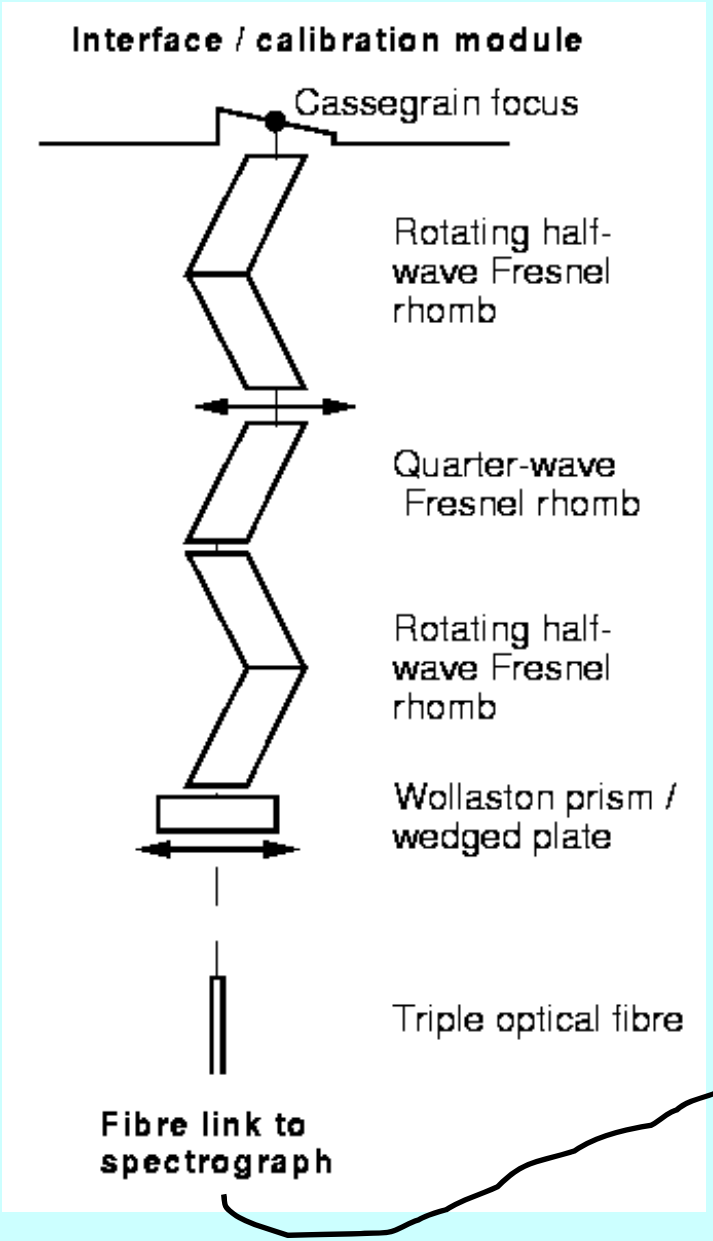
at CFHT in Hawaii

3.6m



ESPaDOnS@CFHT

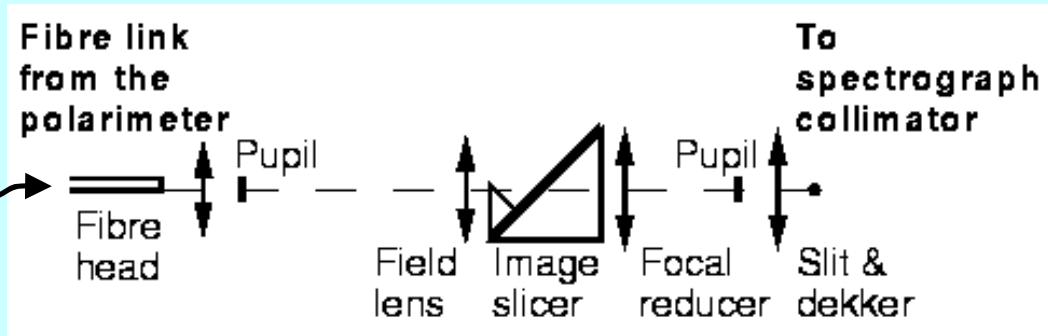




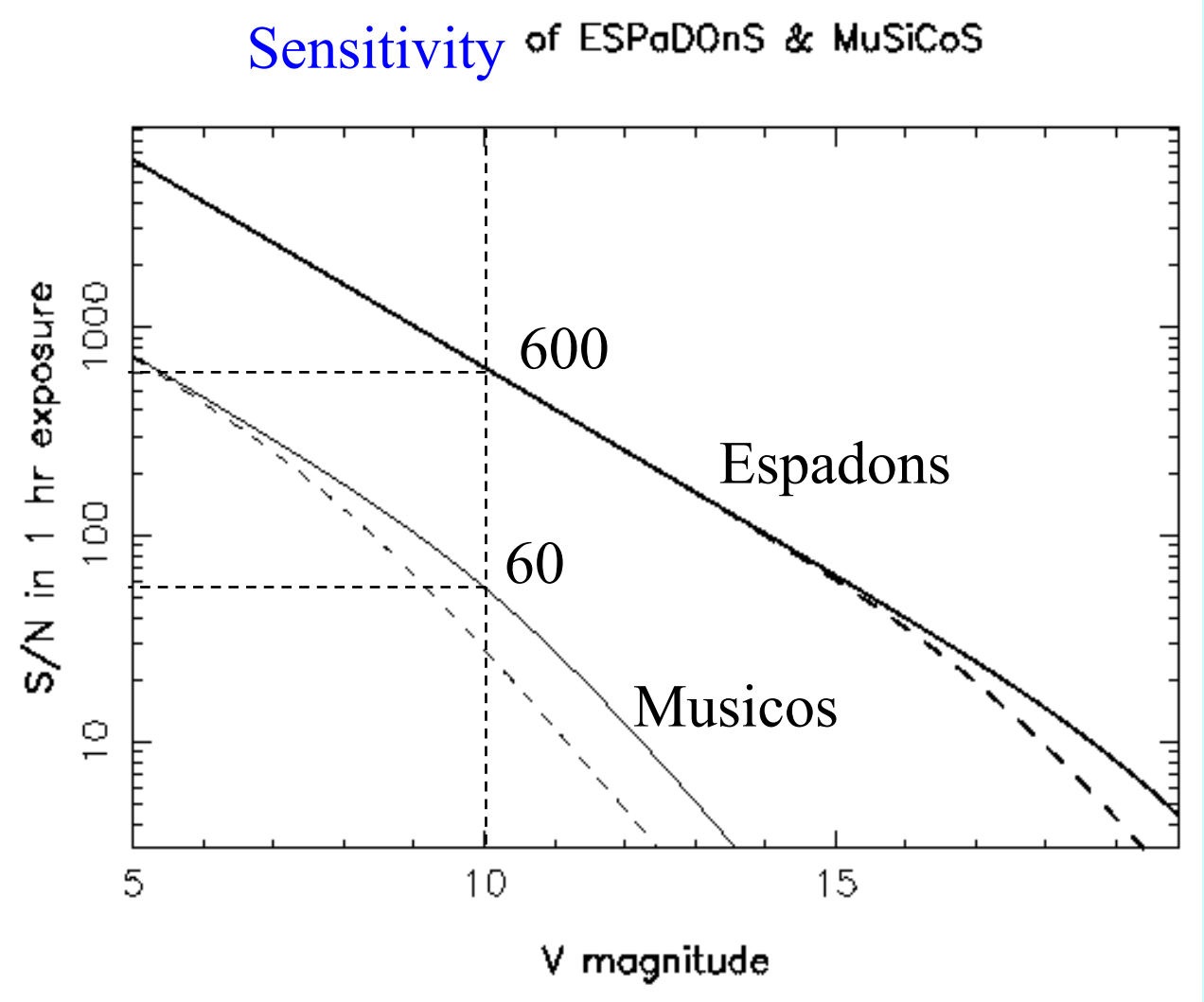
ESPaDOnS@CFHT

- R = 68000
- λ = 370-1050 nm (3 gaps : 923, 962, 1005 nm)
- QSO mode (from 2008A on)

- Crosstalk : 20% → 7% → 2-3%



Musicos vs Espadons



Throughput :

Musicos 0.5%

Espadons 12%

Narval 15%

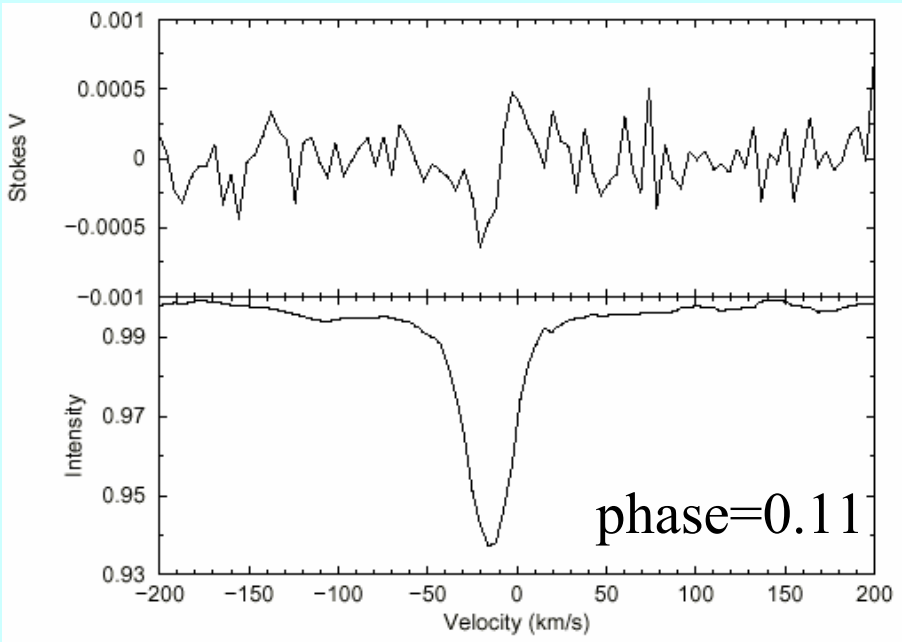
>25 times better!

+ gain in LSD from wavelength coverage

Musicos vs Espadons

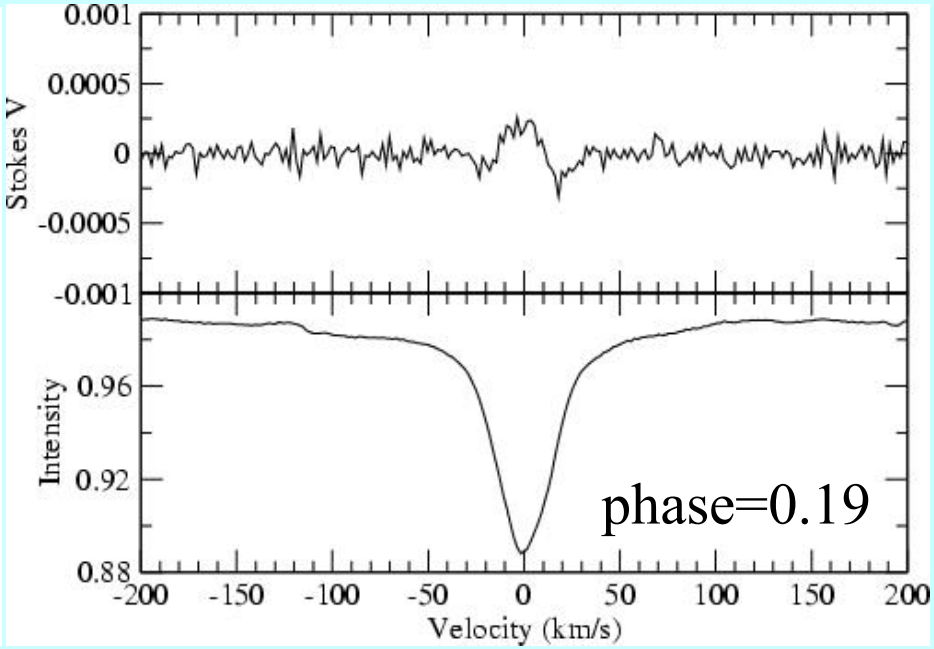
In practice : the SPB star ζ Cas

MUSICOS: 4*7 min



Neiner et al. 2003

ESPADONS: 4*2 min

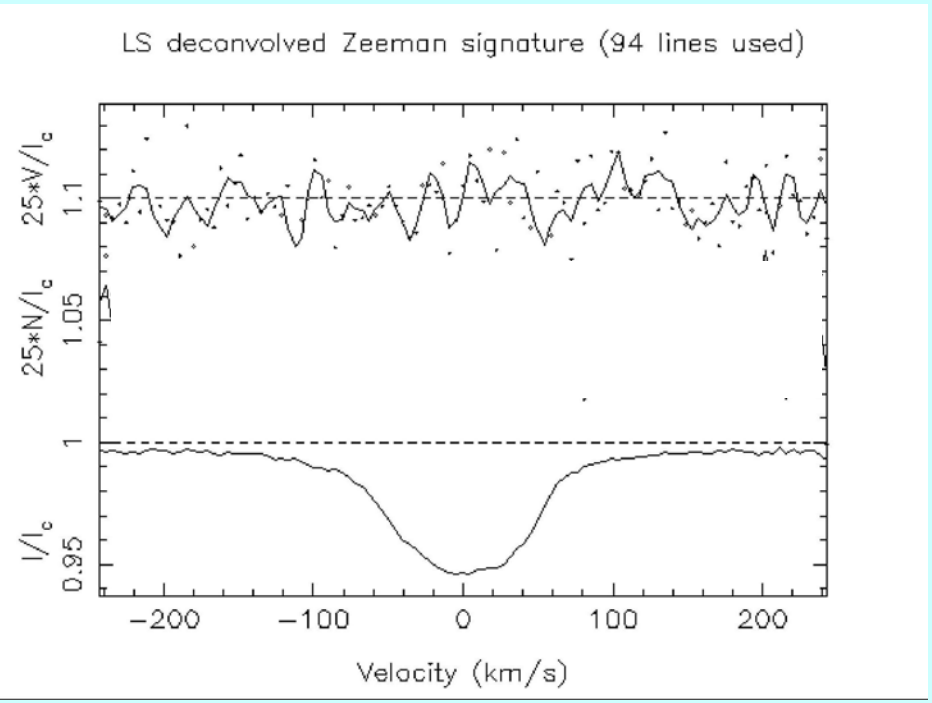


Espadons Commissioning

Musicos vs Narval

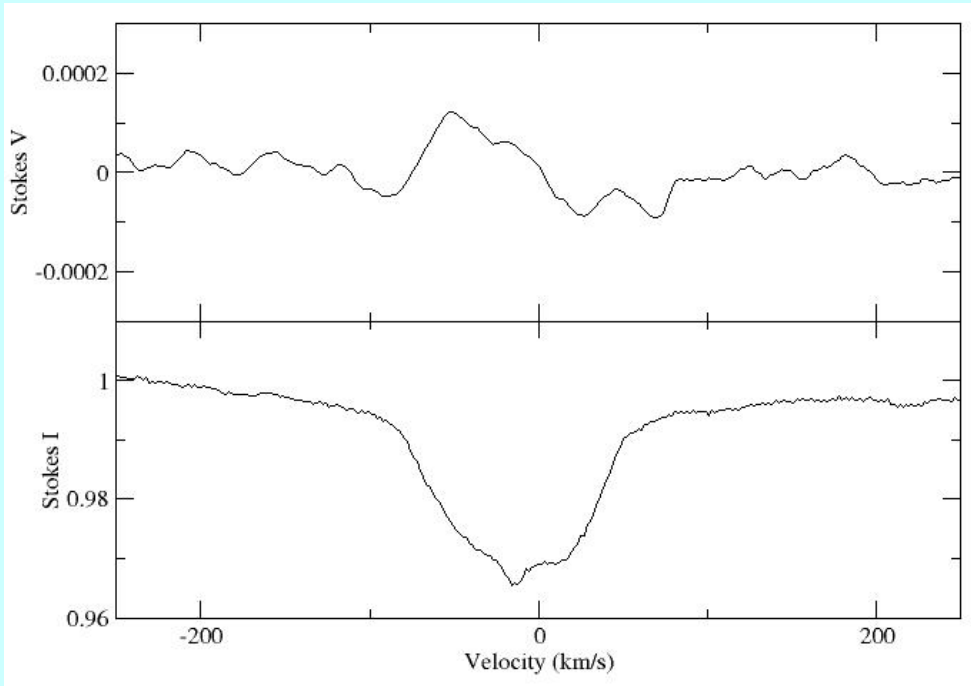
In practice : the β Cep star V2052 Oph

MUSICOS: 4*12 min



Neiner et al. 2003

NARVAL: 4*7 min



Neiner et al. 2007

UCLES&Semel-pol@AAT

Siding Spring

3.9m

UCLES&Semel-pol@AAT

- Visitor polarimeter (M. Semel) attached to UCLES
- Cassegrain focus
- R = 70000
- λ = 430-715 nm

→ Southern hemisphere!

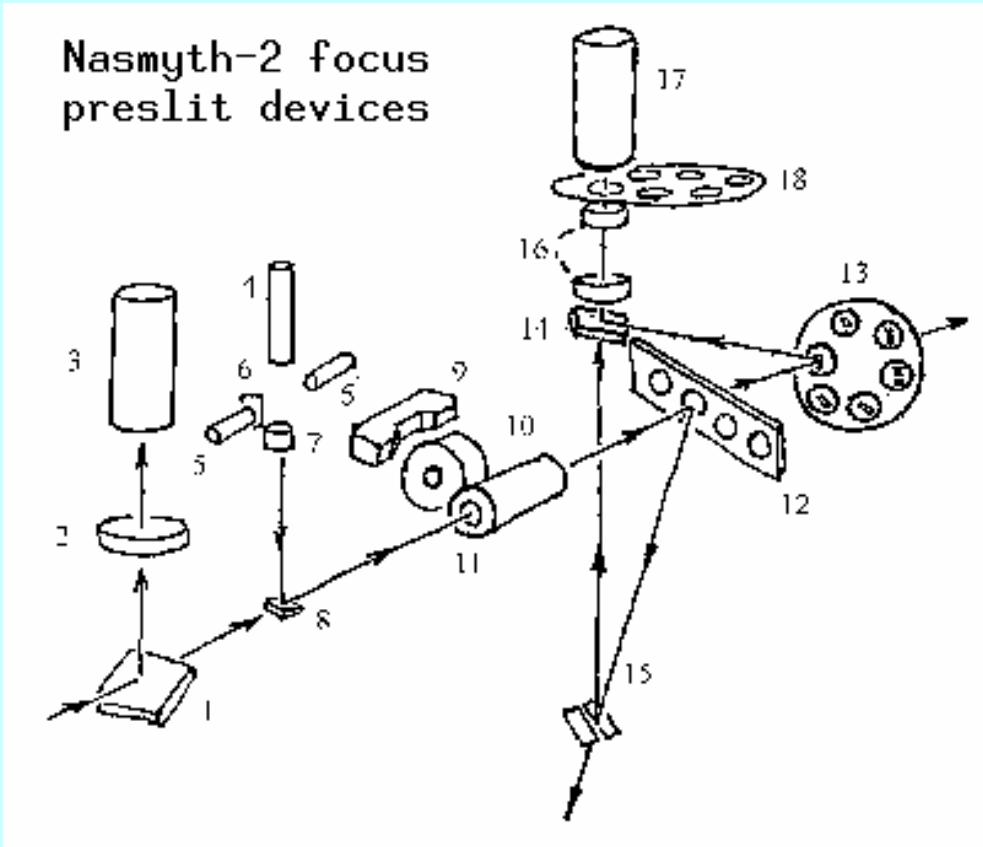
UES&Semel-pol@WHT

- Visitor polarimeter attached to UES
- R = 50000
- λ = 300-1100 nm
- at Nasmyth

4.2m

NES@BTA/SAO (Russia)

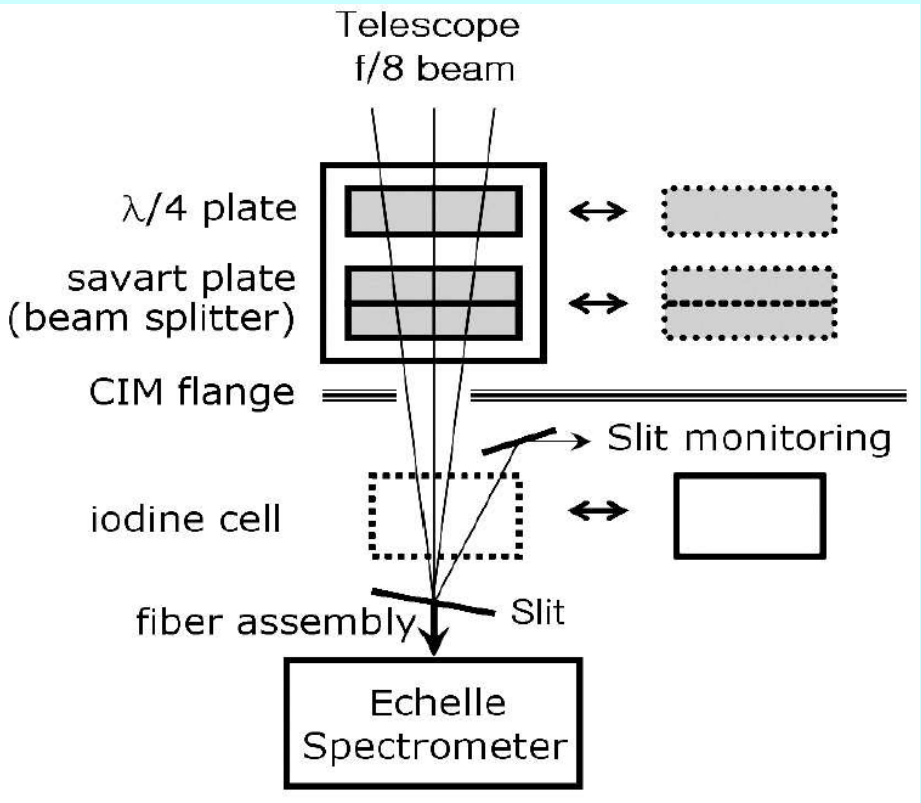
- at Nasmyth
- R=60000
- λ = 350-500 or 470-610 nm

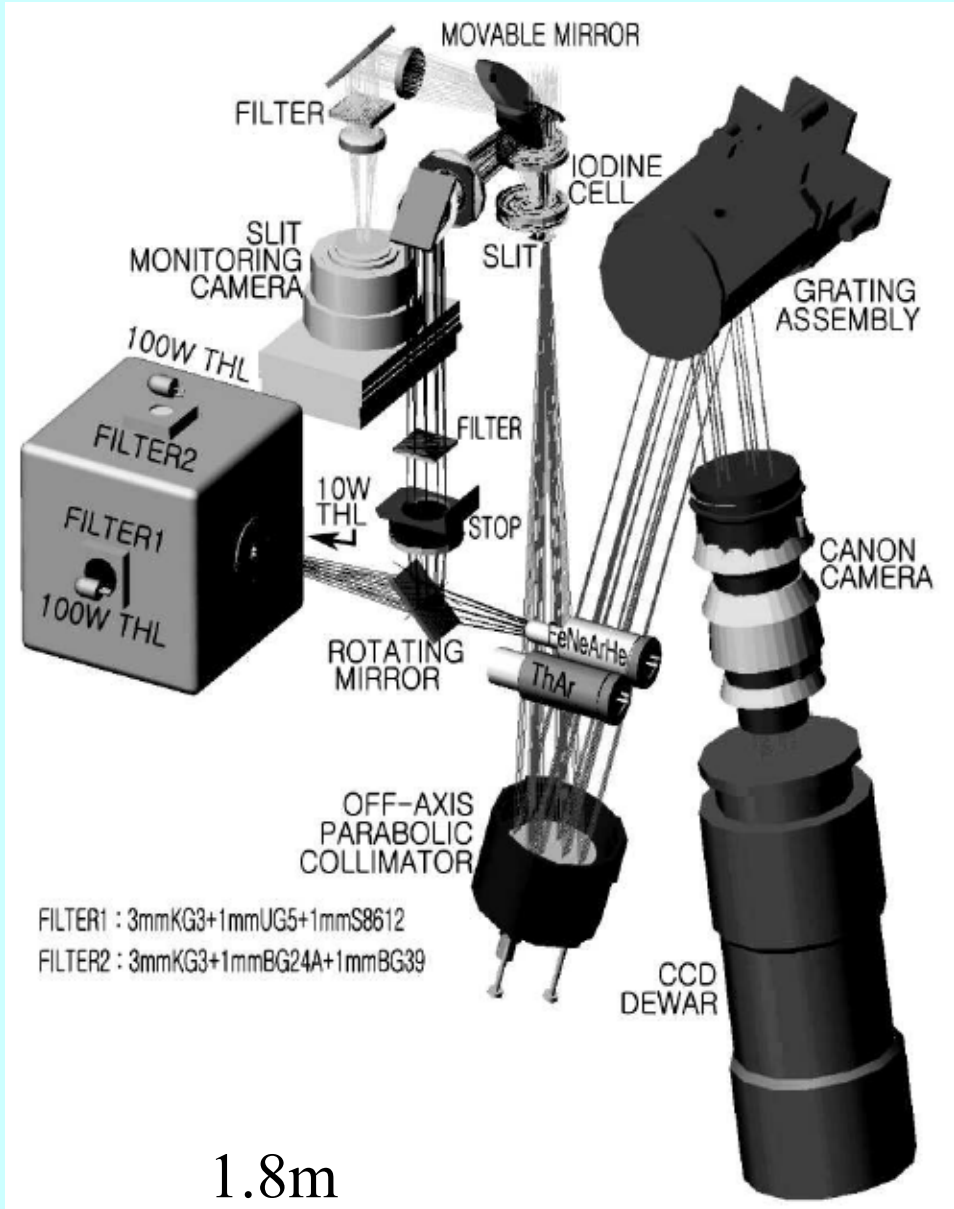


6m

BOES@BOAO (Korea)

- R = 30000-90000
- λ = 350-1050 nm





Which polarimeter should you use to measure the magnetic field of your pet stars?

- Detection of the field : circular (V) is enough
- Full detailed mapping : circular+linear (QUV) is needed

- Strong field (e.g. Ap stars) → low resolution + regression method is enough

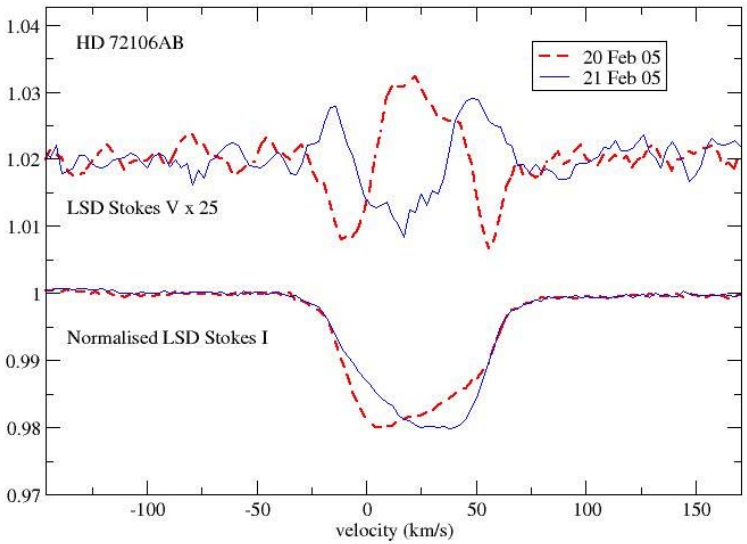
- Weak field (e.g. O stars) → high resolution + LSD

Regression method vs Zeeman profiles

HD 72106

- with FORS1 *(Drouin 2005)*: Prot~2d, surface B=200 ± 45 G
- with Espadons *(Wade et al. 2005)*: surface B~1kG, large scale dipolar field

Espadons



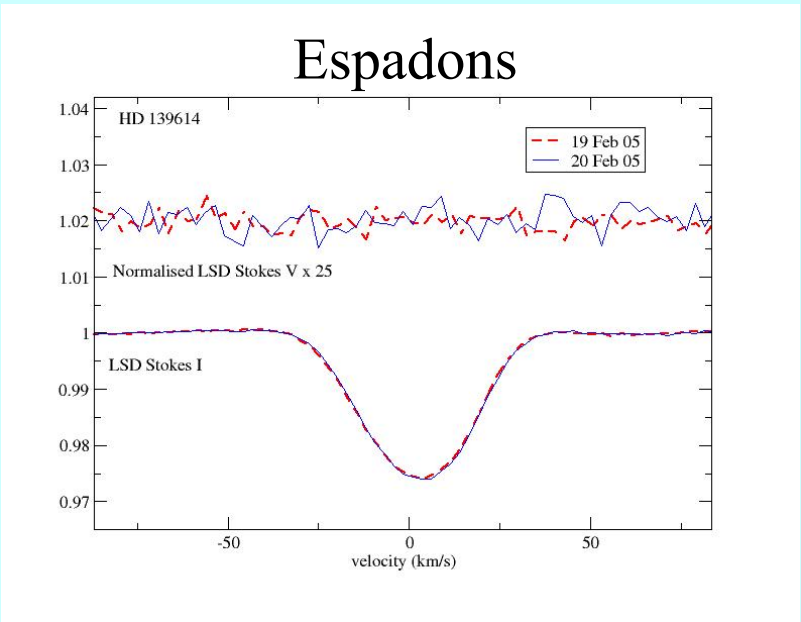
Wade et al. 2005

and HD 139614 ???

- detected magnetic by *Hubrig et al. 2004*: FORS1 data: Bz = -450 ± 93G
- contested by *Wade et al. 2005*: reanalysed FORS1 data: Bz = -110 ± 70G
- reconfirmed by *Hubrig et al. 2005*: new FORS1 data: Bz = -116 ± 34G
- rejected by *Wade et al.*: Espadons observations: Bz = -20 ± 25G

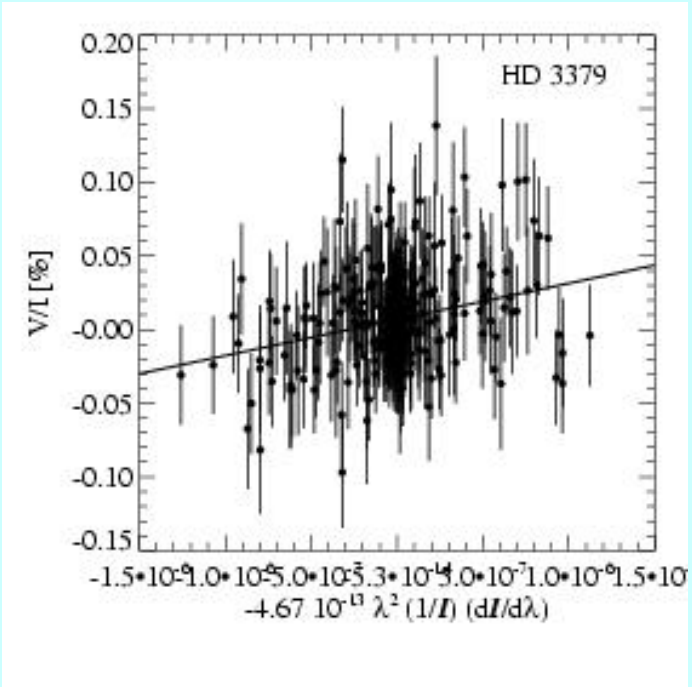
→ FORS1: magnetic signature in the Balmer lines but not in the metal lines

→ no Zeeman signature with Espadons

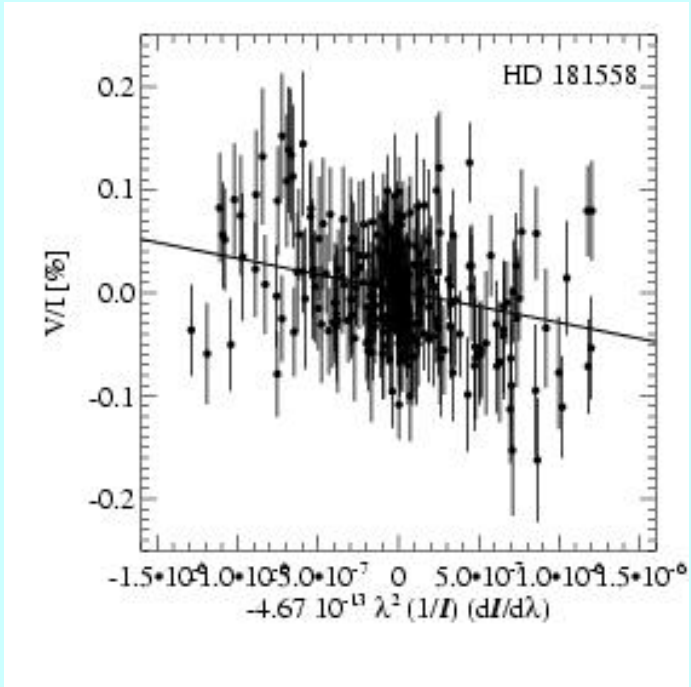


→ be careful with FORS1! spurious signatures can be confused with weak magnetic signatures! Careful data reduction is needed! *(Drouin 2005)*

Ten other magnetic SPB stars detected with FORS1 (Hubrig et al.)



Bz = 245 ± 57 G



Bz = -311 ± 69 G

not detected with Narval (except one?)…

Spectropolarimeters

When?	Instrument	Where?	Size	Range (nm)	R
1999	VLT/FORS1	Chile	8m	330-1100	1000
2006	SALT/PFIS	SouthAfrica	11m	320-900	5000
2007	WHT/ISIS	Spain	4.2m	378-448+red	5000
2008	WHT/LIRIS	Spain	4.2m	nIR	2000
1995	AAT/UCLES/Semel	Australia	3.9m	430-715	70000
2001	SAO/BTA/NES	Russia	6m	470-610	60000
2005	WHT/UES/Semel	Spain	4.2m	300-1100	50000
2005	CFHT/ESPADONS	Hawai	3.6m	370-1050	65000
2006	TBL/NARVAL	France	2m	380-1000	65000
2007	BOAO/BOES	Korea	1.8m	350-1050	60000

Spectropolarimeters

When?	Instrument	Where?	Size	Range (nm)	R
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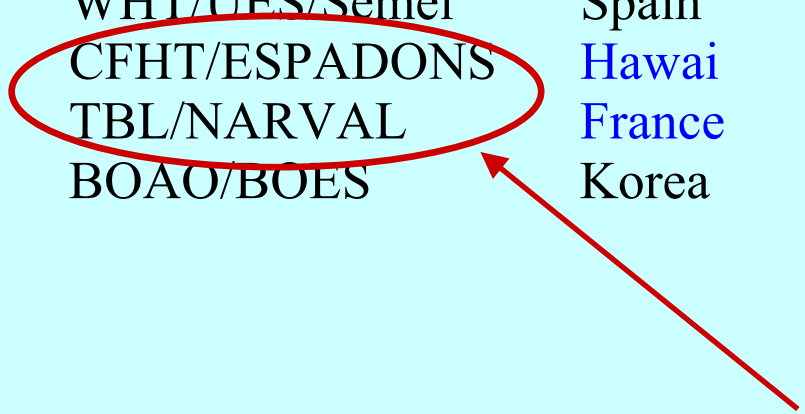
2006	SALT/PFIS	SouthAfrica	11m	320-900	5000
2007	WHT/ISIS	Spain	4.2m	378-448+red	5000
2008	WHT/LIRIS	Spain	4.2m	nIR	2000
1995	AAT/UCLES/Semel	Australia	3.9m	430-715	70000
2001	SAO/BTA/NES	Russia	6m	470-610	60000
2005	WHT/UES/Semel	Spain	4.2m	300-1100	50000
2005	CFHT/ESPADONS	Hawai	3.6m	370-1050	65000
2006	TBL/NARVAL	France	2m	380-1000	65000
2007	BOAO/BOES	Korea	1.8m	350-1050	60000



Espadons and Narval observations

French pressure: CFHT/Espadons 8 → 5 → 3
TBL/Narval 3

Proposal deadlines: CFHT/Espadons last week… → ~March 20th
TBL/Narval October 24th

New for Narval@TBL:
- Now more Opticon time available on TBL for non-French programs: 20 nights/semester
- New proposal system NorthStar http://voparis-northstar.obspm.fr

Espadons Large Program

Call for LP at CFHT : deadline for LoI on October 15th

> 200h over 8 semesters → > 4-5 nights / semester

Espadons community will propose 4-5 LP on Espadons:

- Massive stars
- Low-mass stars
- Stellar formation with B
- Magnetic interaction between stars and planets

→ Only one big group (French+Canadian): no direct competition (but competition with Megacam and WIRcam LPs)

→ Legacy database

Want to join?... please contact J-F Donati.

Conclusion

- Nowadays there are many spectropolarimeters available (also other wavelengths)

- French community has major asset: Espadons/Narval

- Observing in spectropolarimetry is easy (follow the recipee, fully reduced at telescope)

- Magnetism is a priority of PNPS

→ go for it!!!