Broadening-function technique: new tool in the quest for exoplanets

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Intro

- CCF technique: classical approach to obtain extremely precise RVs in the quest for extrasolar planets

$$ccf(x) = \int_{-\infty}^{\infty} f(k)\, g(k-x)\, dk$$

- Advantageous for slowly-rotating stars
- Recent improvement (Lagrange et al., 2009): CCF with the average spectrum of the target itself

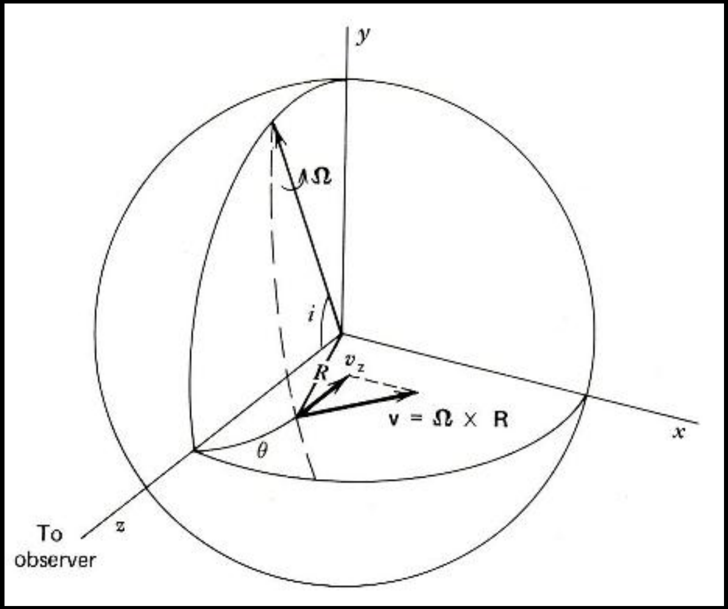
BF function basics

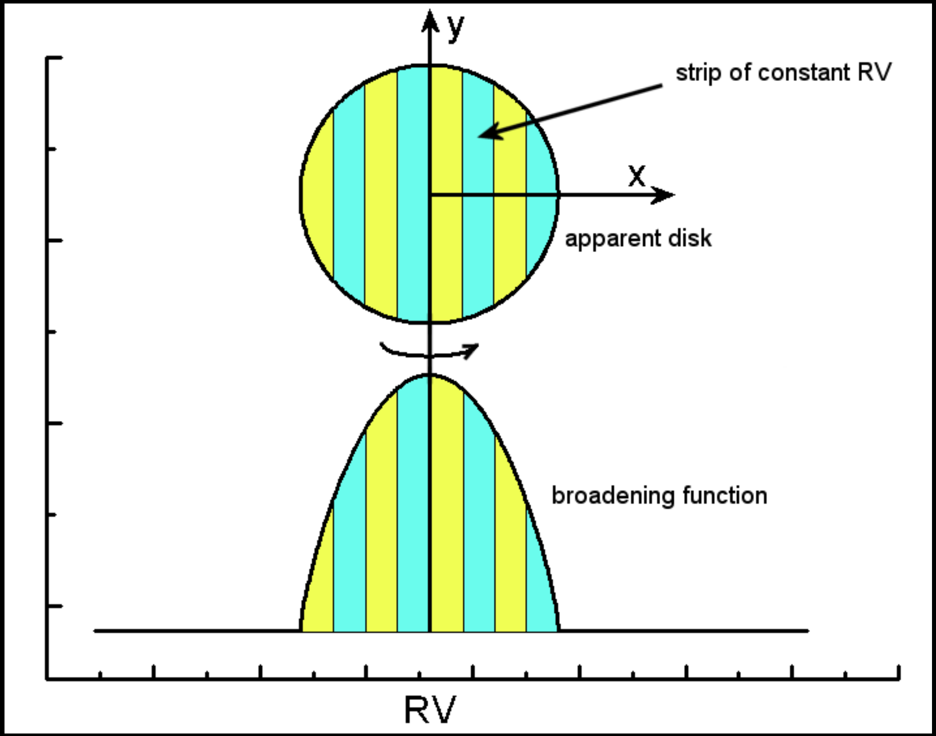
- BF originated & elaborated by Slavek M. Ruciński (DDO, UofT)
- BF is a function mapping sharp-line template spectrum to rotationally broadened spectrum
- Basic interpretation: BF is the Doppler image of star/stellar system: it gives dependence of flux on radial velocity
- In case of solid-body rotation (tidally-locked binaries also) BF is 1D image of star
- Similar to CCF, BF uses information from the whole spectrum
- “Sweet spot” of BF technique for exoplanet search are moderately-rotating A to F-type dwarfs

Solid-body rotation & BF

$$\vec{v} = \vec{\Omega} \times \vec{r}$$

$$\frac{\Delta\lambda c}{\lambda} = v_z = x\Omega \sin i$$



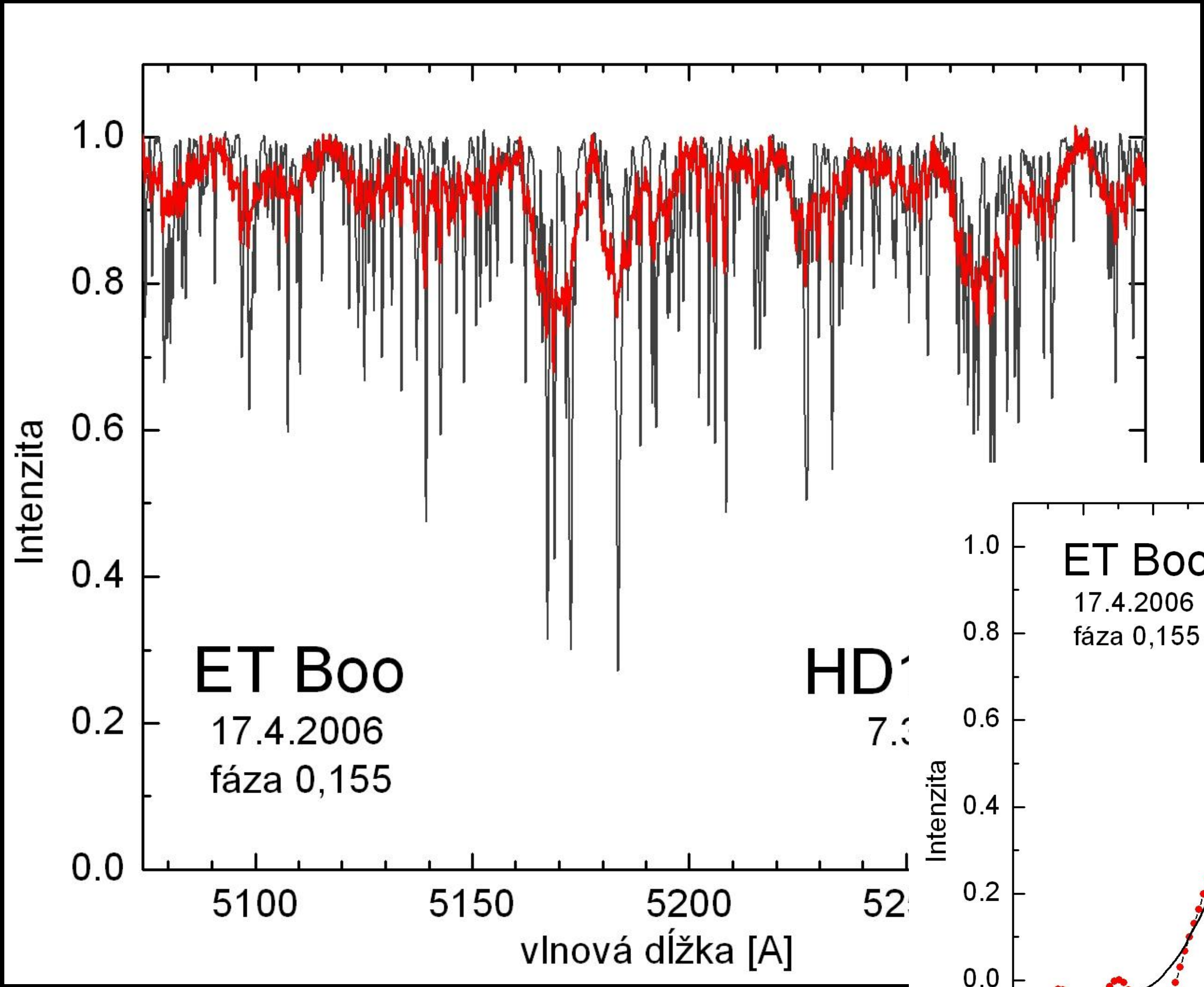


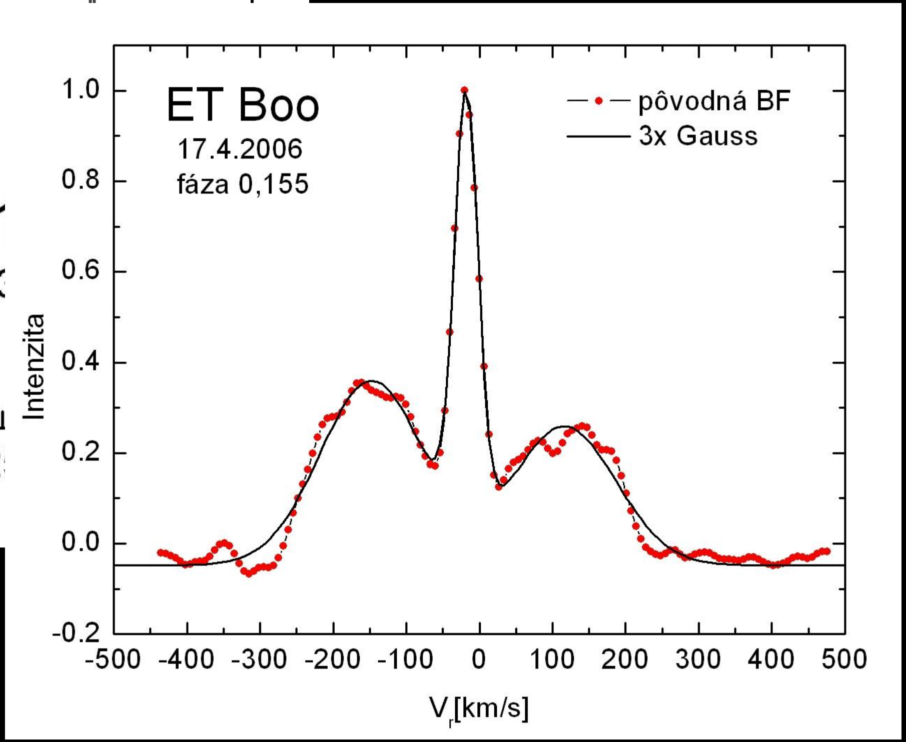
$$I = I_0 + A\frac{(1-w)\sqrt{1-\frac{(x-x_0)^2}{R^2}} + \frac{1}{4}\pi w\left[1-\frac{(x-x_0)^2}{R^2}\right]}{(1-w)+\frac{1}{4}\pi w}$$

BF = rotational profile for a single star

ET Boo

DDO, UofT



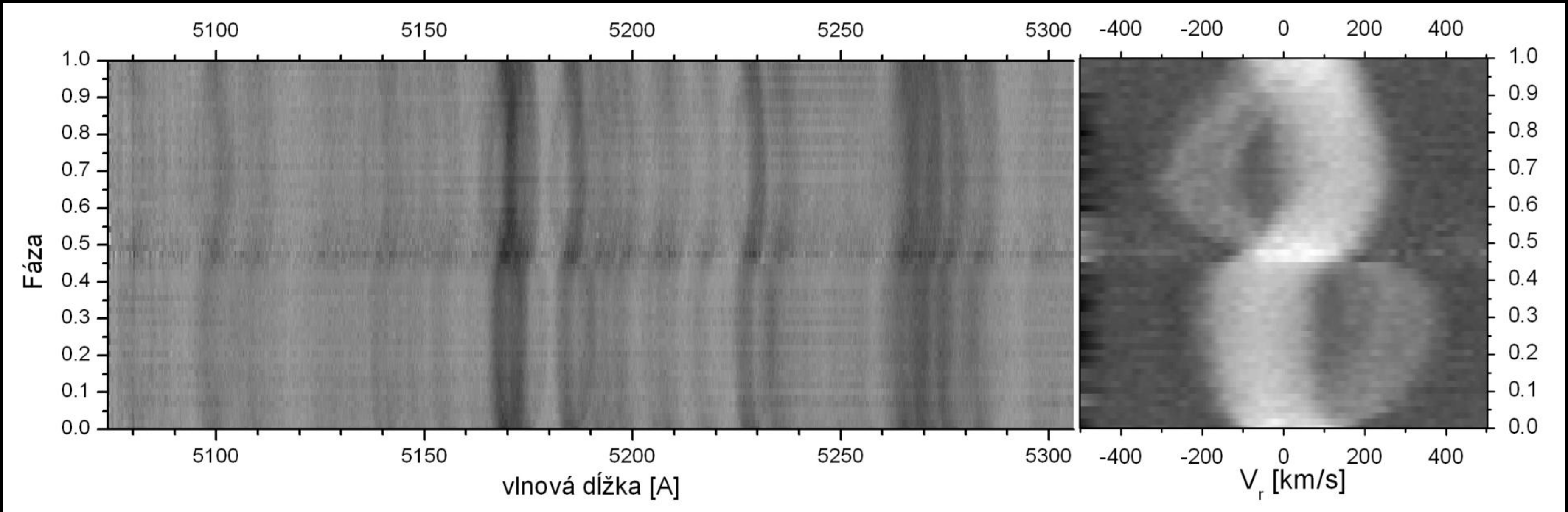


HD102870 template

Computing BF

$$o(x) = \int s(y) bf(y - x) dy$$

- In real and discrete data the last integral can be written as summation and results in MANY linear equations for BF, best solved by the SVD method



Cons & pros

CCF

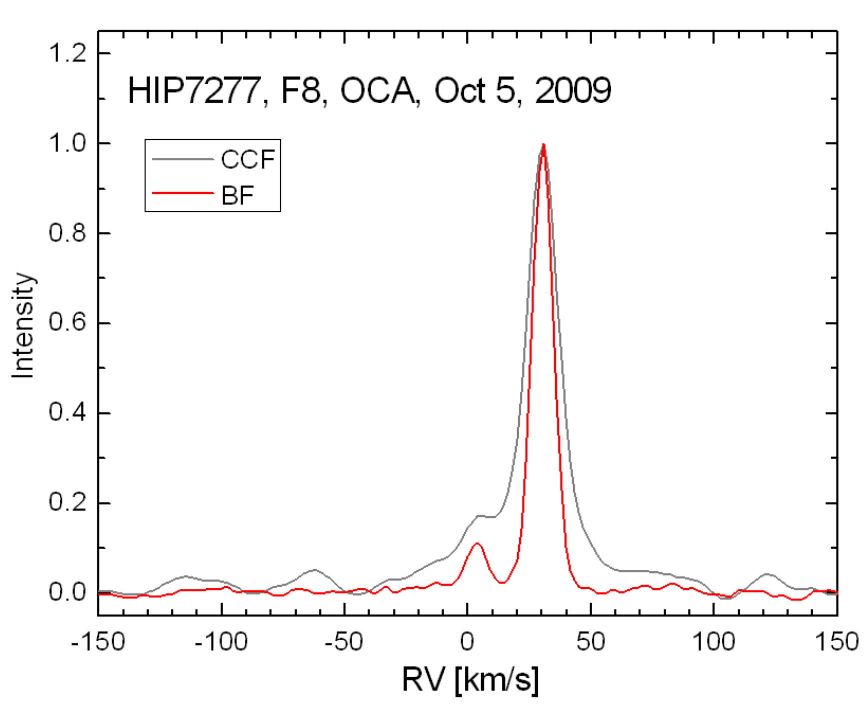
+fairly easy to compute: direct problem

–no easy interpretation

–indirect interpretation: bisector method

+no systematic errors if the average spectrum used as a template

–loses spectral resolution



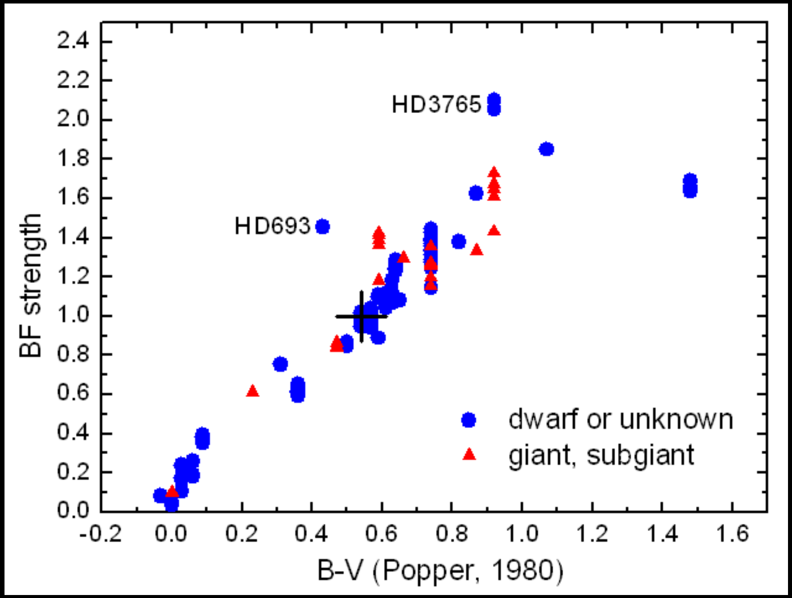
BF

–fairly hard to compute: inverse problem

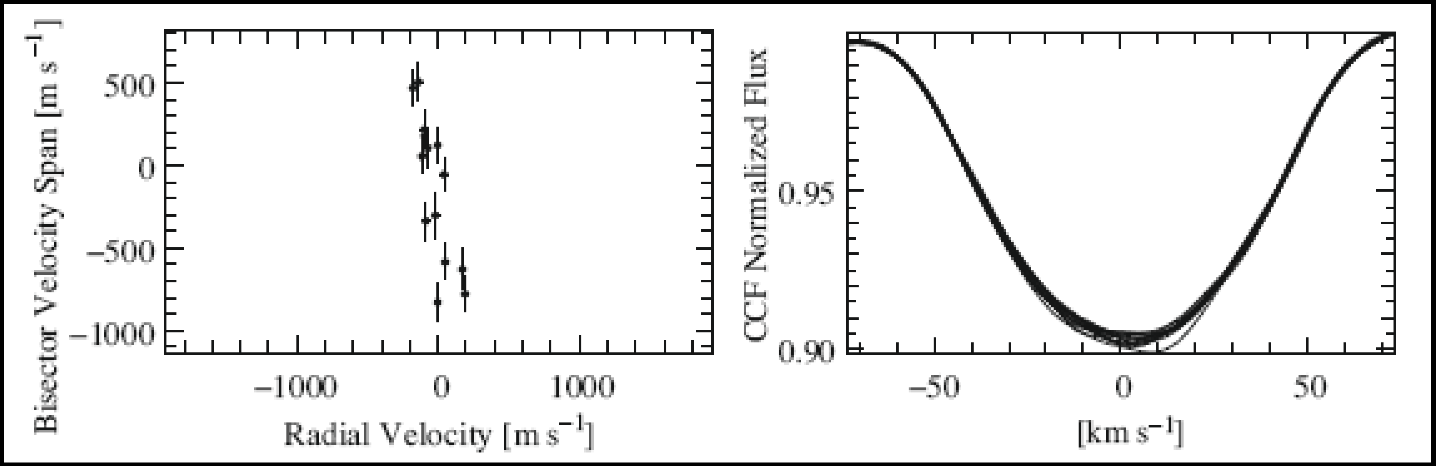
+straightforward interpretation and modeling

+preserves spectral resolution ➔ easy detection of spots, pulsations, asymmetries, multiplicity

+enables simple spectral classification based on the BF integral

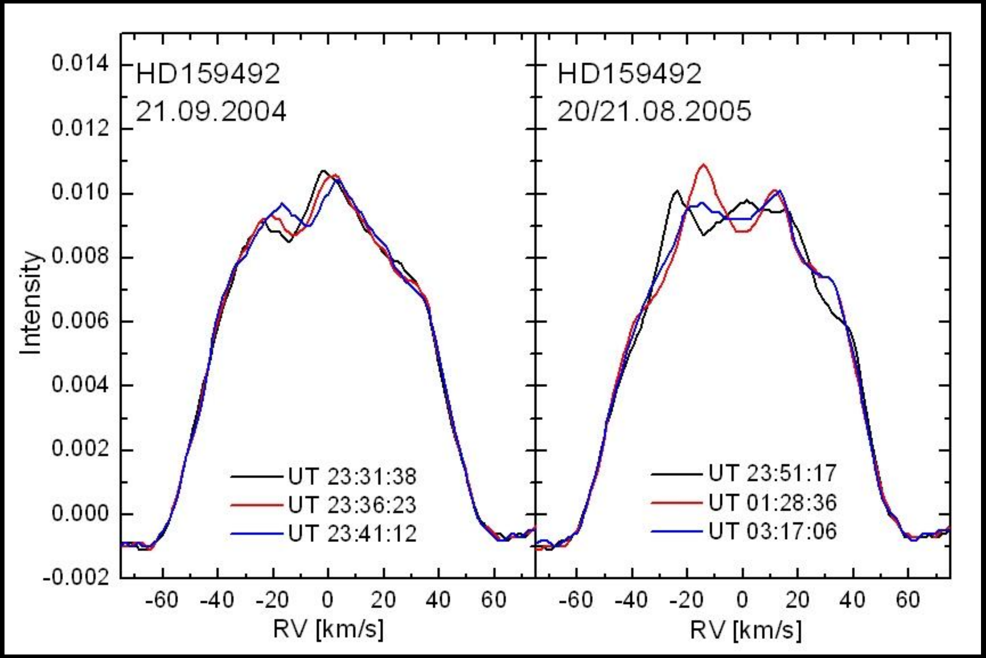


Non-radial pulsations: CCF vs. BF (HARPS data)

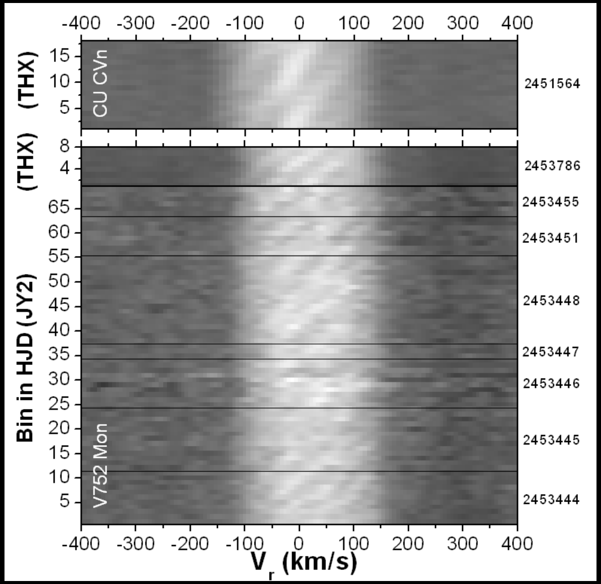


CCFs

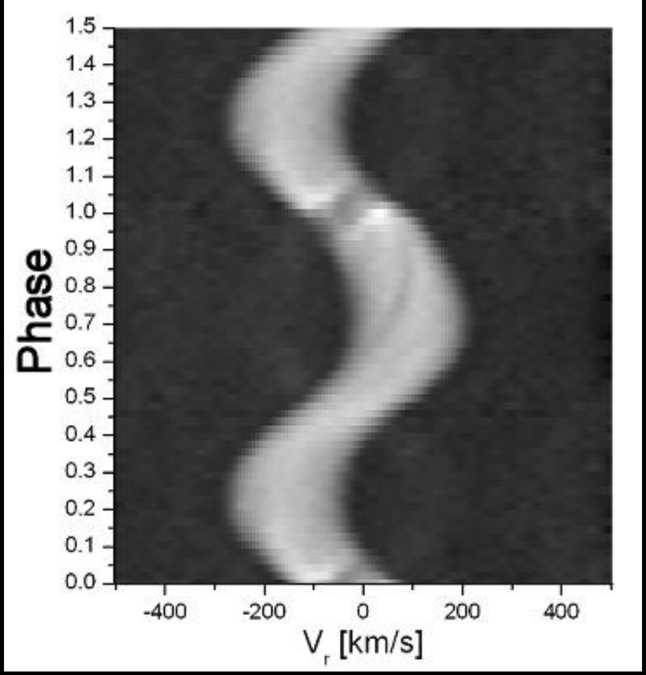
BFs

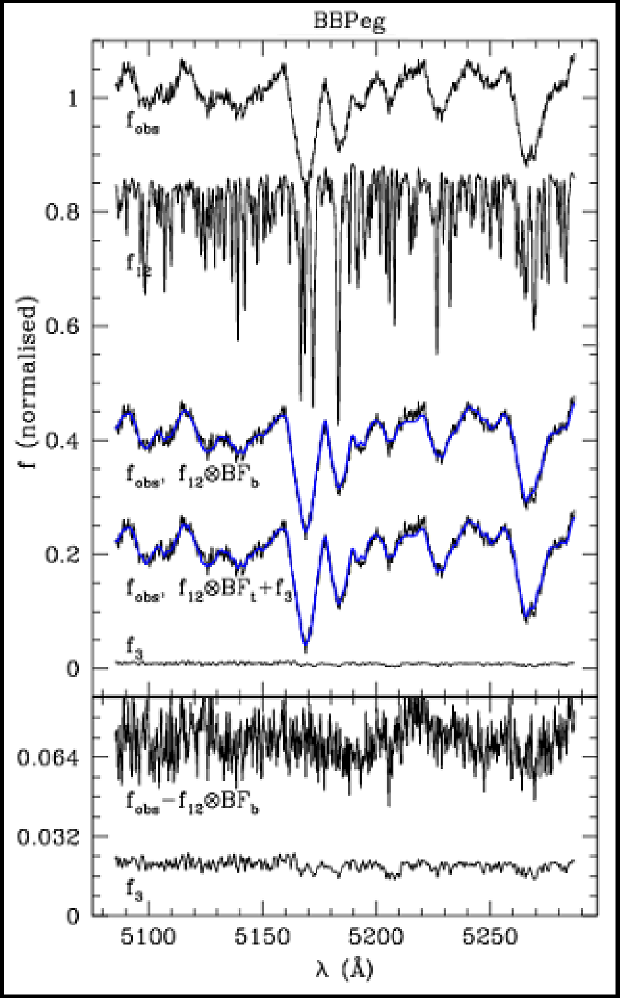


➔ BF enables to exclude spurious detections !!!



Detection of spots on XY UMa, late-type spotted binary, UofT (Pribulla et al., 2007)





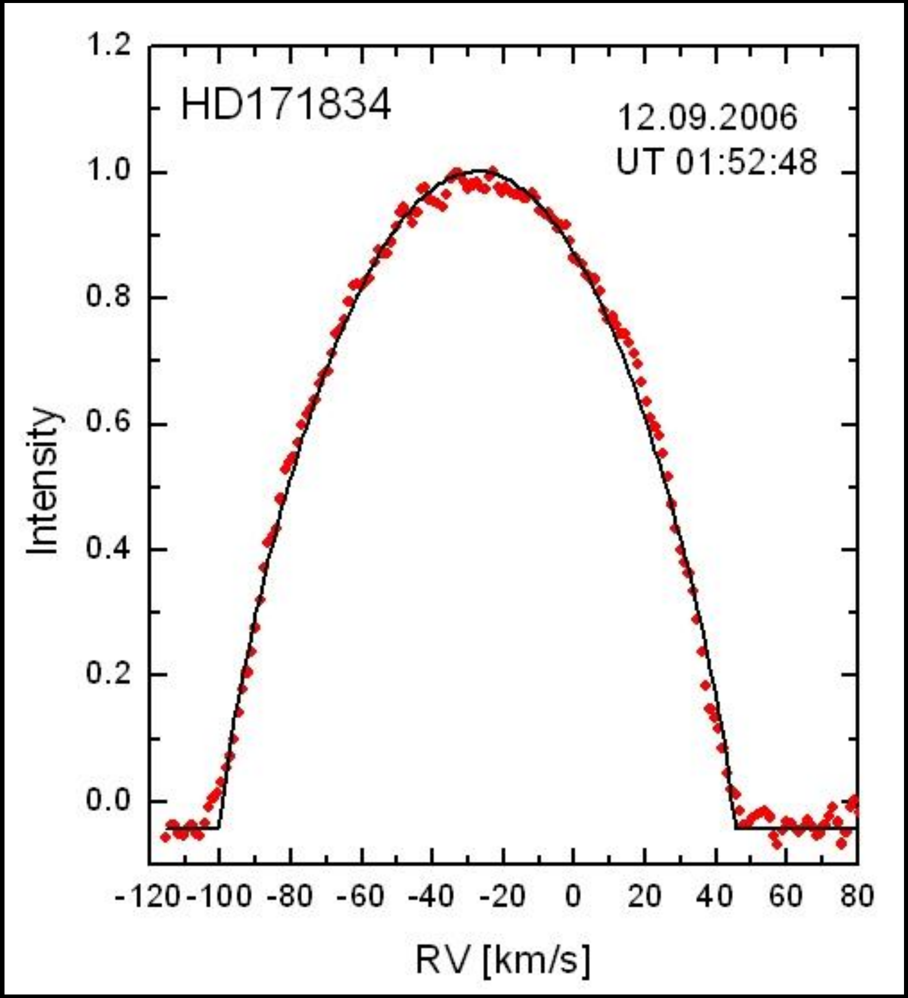
Two late A-type non-radial pulsators, UofT (Pribulla et al., 2010)

Detection of late-type companions (D'Angelo et al., 2006)

Applications of the BF technique

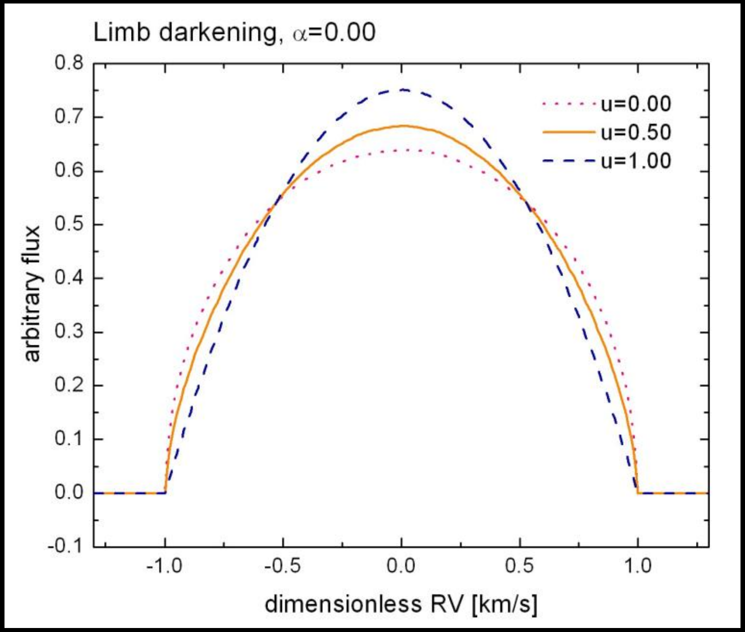
Precise RVs

Fitting rotational profile to BF of a single star

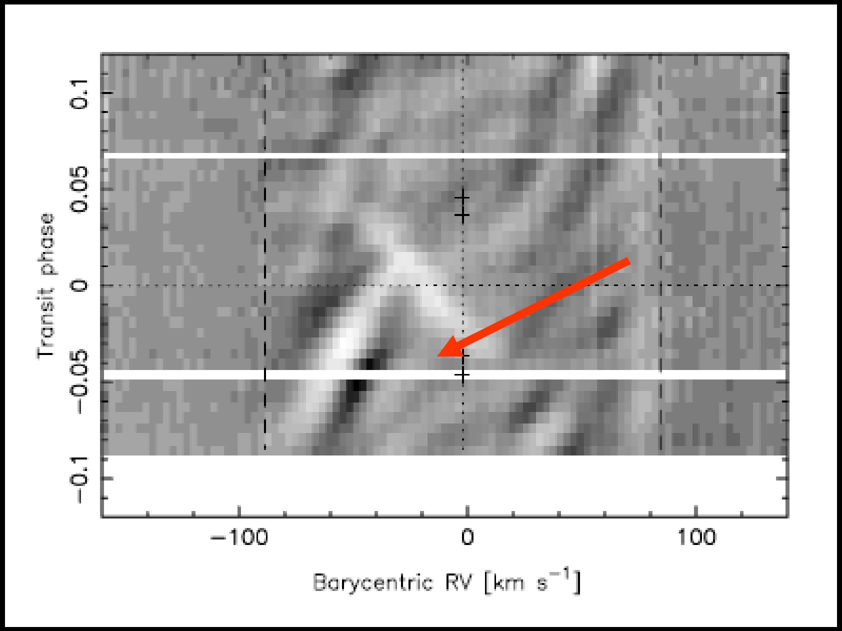


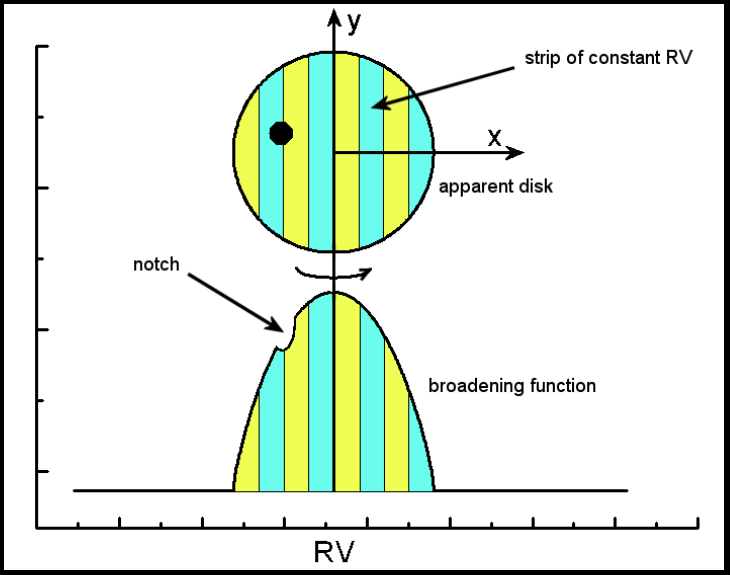
BF enables reliable determination of v sin i

precise RV for moderately to rapidly rotating stars

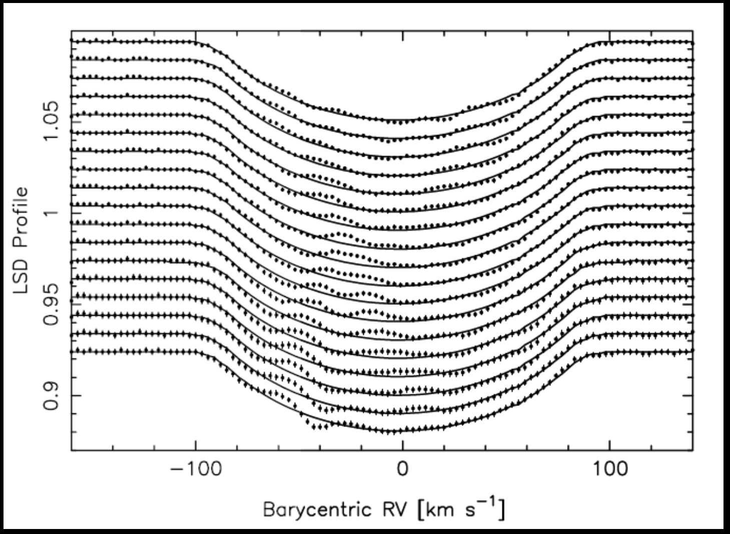


Tomography of exoplanet transits





- group Collier Cameron applied similar method to WASP 3, WASP 33
- BF ⇔ least-squares deconvolved profile
- If v sin i >> c/R ➔ Detection of transiting planets using BF possible
- Depth of notch $\propto R_p/R_s$, while depth of phot. transit $\propto (R_p/R_s)^2$



Conclusions/ Future plans

- BF is useful to: (i) precisely determine RV of rapid rotators, (ii) directly detect binarity/multiplicity, non-radial pulsations or late-type companions ➔ quickly excluding spurious cases (iii) detect/study transiting exoplanets
- Plans: Reanalysis of ESO archive data using the BF technique: (i) detection of additional components to known parent stars (ii) higher RV precision for fast rotators (iii) finding false detections

IAU symposium 282, July 18-22, 2011

From Interacting Binaries to Exoplanets: Essential Modeling Tools

venue: AI SAS, Tatranská Lomnica

SOC: M. Richards, I. Hubený et al.

LOC: Pribulla et al.

Ďakujem !

(Thank you !)