Comparing Ca II IR Triplet to Ca II H&K for activity studies

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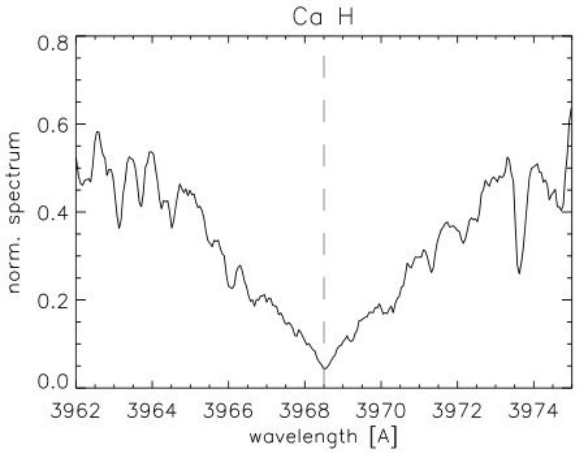
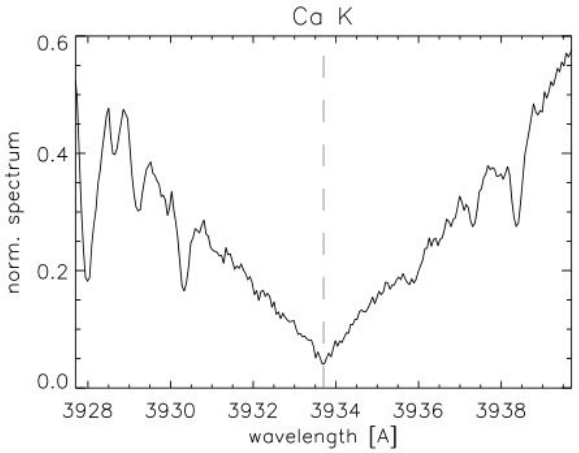
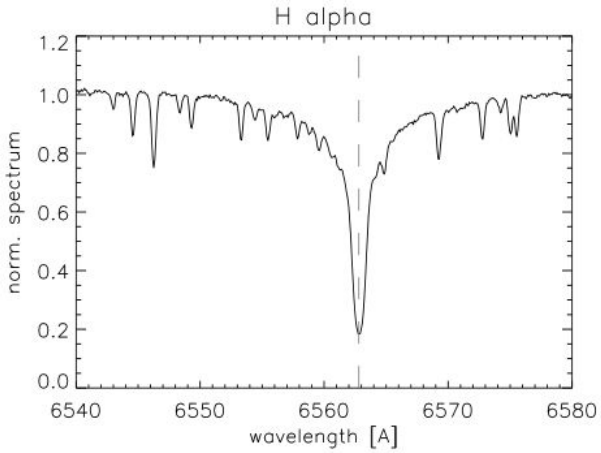
DER FORSCHUNG | DER LEHRE | DER BILDUNG

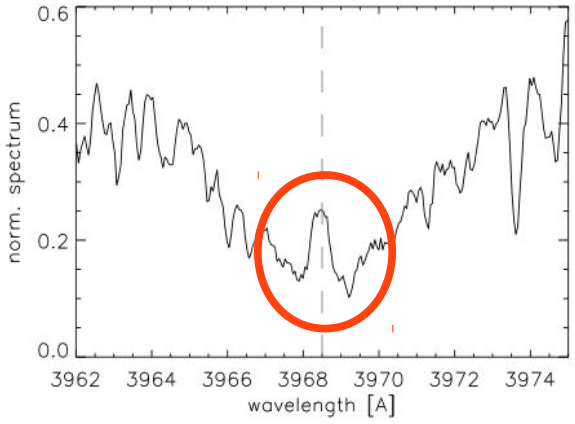
We look at two different sets of Ca II lines + Hα that are sensitive to magnetic activity:

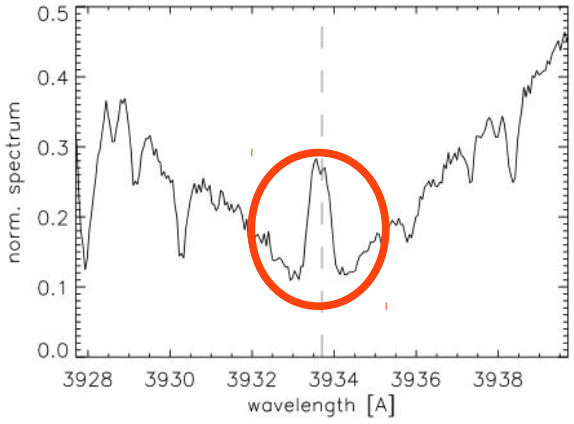




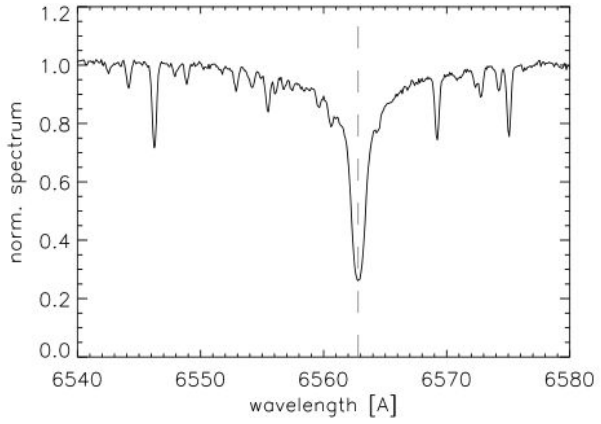


HD124570 (inactive) - F8V





HD190771 (active) - G2V



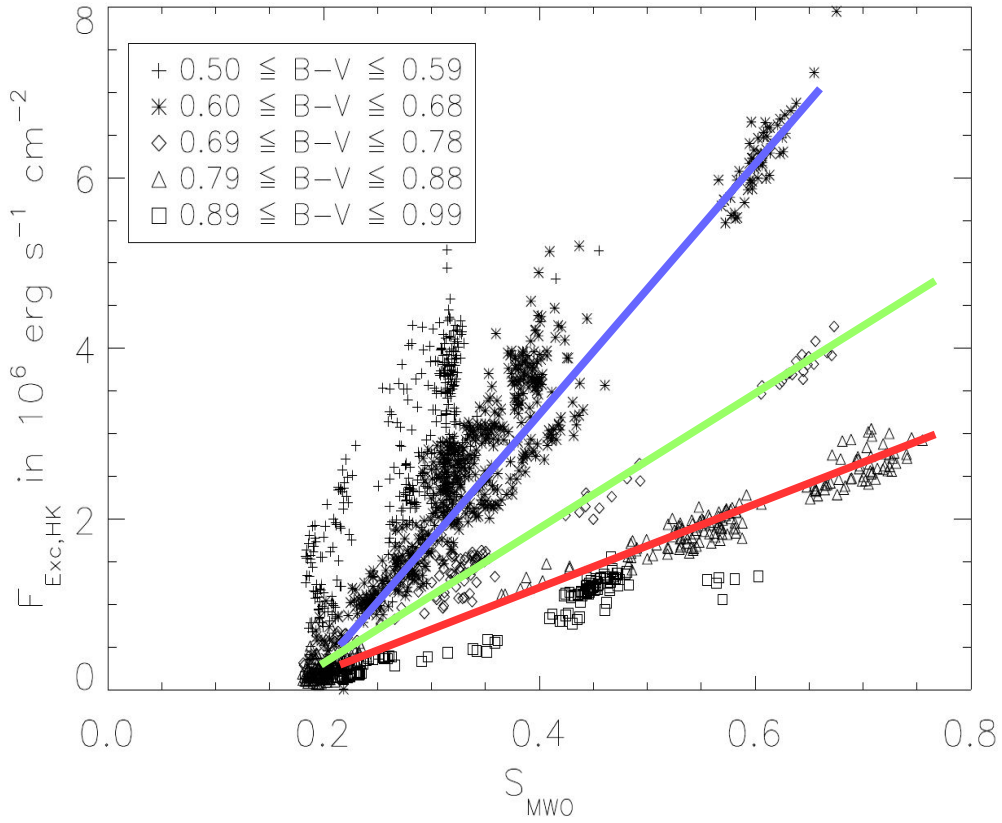
Many activity indicators **derived** from Ca II H & K:

$$S = \frac{N_H + N_K}{N_v + N_b}\alpha$$

Mount-Wilson S-Index S_{MWO}:

Compares **countrates** in- and outside the H&K-lines

→ Easy to measure
Lots of data available (e.g. Baliunas (1995))!



However:

Different stellar types follow different relations!

→ Can be difficult to compare two stars

Another index with two differences:

1) Take the actual “interesting” **flux**

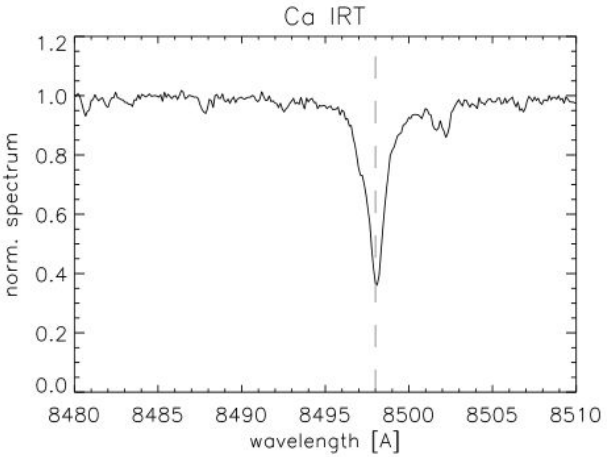
$$R'_{\mathrm{HK}} = \frac{F_{\mathrm{HK}} - F_{\mathrm{HK,phot}}}{\sigma T_{\mathrm{eff}}^4}$$

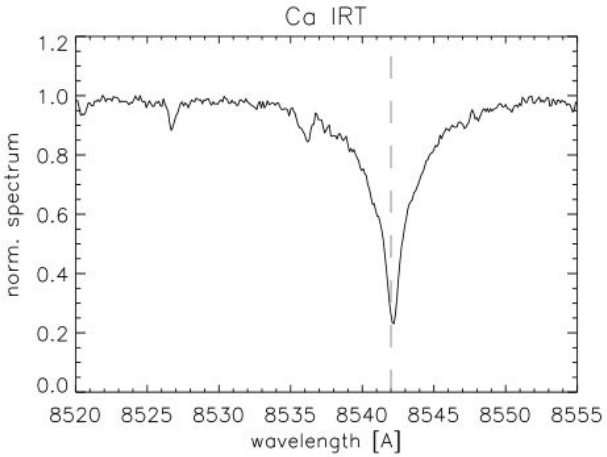
2) **Normalize** for different stellar types

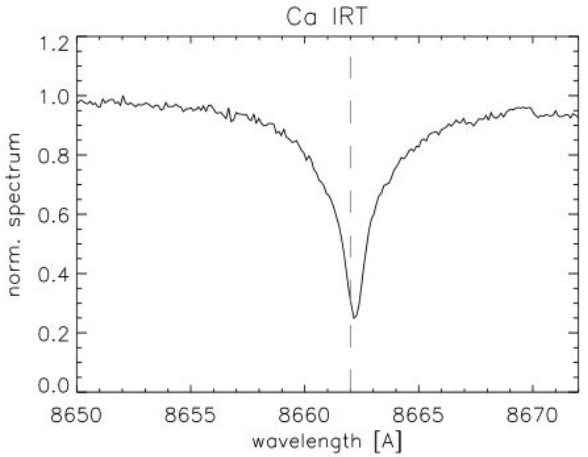
More **robust** and better way to compare different stars!

→ Can be estimated from S_{MWO}.

Also known: Ca II IRT lines are sensitive to activity! (e.g. Andretta et al (2005))







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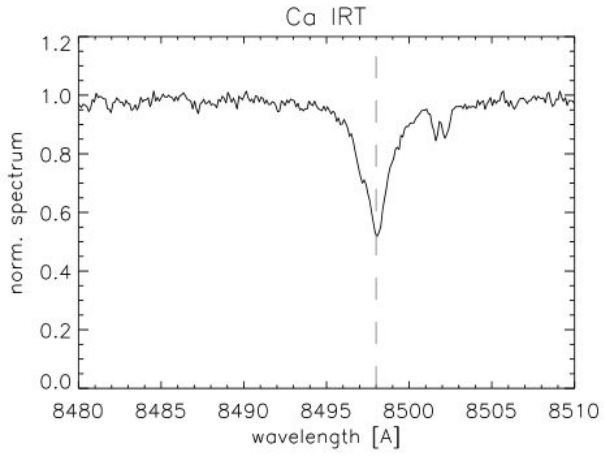
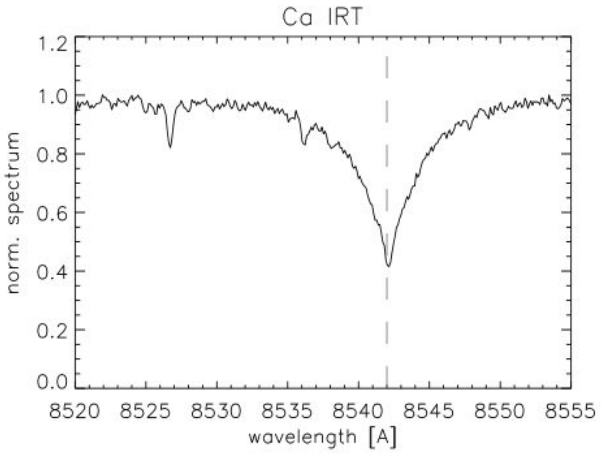
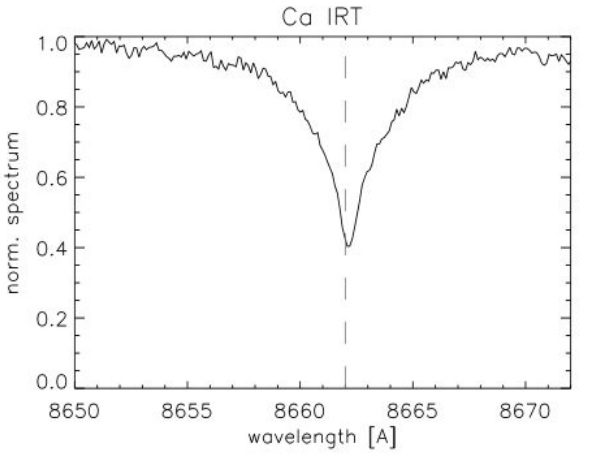






Spectral range of GAIA: 8470 A to 8740 A

→ **No** Ca H and K lines → No S-Index
No H alpha

→ Large number of spectra that **only** include the Calcium Infrared Triplet (IRT)!

→ What can we learn specifically from the Ca IRT?
Can we “convert” the Ca IRT to other indicators?

Go through the archive and take observations of
Main-sequence stars with type F, G and K
(and ignore the ones with the bad camera):

Type	# Stars	# Obs.
F	20	656
G	31	968
K	19	426
Total	71	2050

Large number of **simultaneous** observations!

→ **No scatter** from temporal variation (that can be huge!)

Unfortunately, had to remove a few more (possible binaries, low SNR in the lines,...)

→ 56 Objects with 1550 Observations

⟶ **Large sample of simultaneous observations – TIGRE advantage!**

How to determine the **excess flux**? (=The flux left after removing the “inactive parts”)

Take the best spectrum of an inactive, slowly rotating star of similar parameters
(that will only include the “inactive parts”)

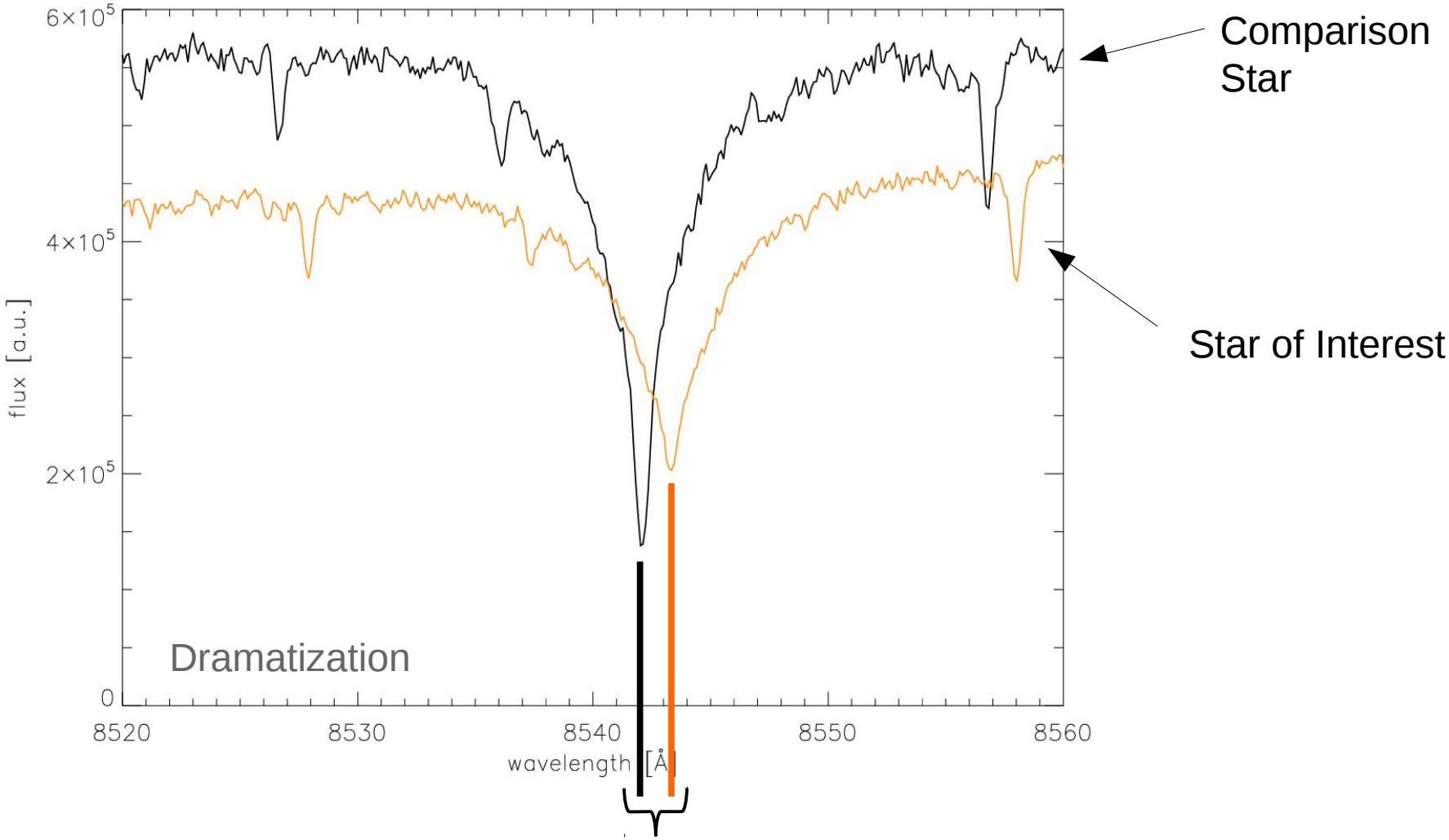
Name	*B-V*	log *g*	[Fe/H]	*v* sin *i*	Name	*B-V*	log *g*	[Fe/H]	*v* sin *i*
HD 100180	0.57(1)	4.25(1)	-0.06(1)	3.59(1)	HD 10307	0.62(1)	4.32(1)	0.03(1)	4.07(1)
HD 10700	0.72(1)	4.48(1)	-0.50(1)	1.60(2)	HD 115617	0.70(1)	4.39(1)	-0.01(1)	3.90 ± 0.90(3)
HD 117176	0.71(1)	3.97(1)	-0.06(1)	4.83(1)	HD 124570	0.58(1)	4.05(1)	0.08(1)	3.00(4)
HD 126053	0.63(1)	4.43(1)	-0.38(1)	3.08(1)	HD 12846	0.66(1)	4.38(1)	-0.26(1)	2.20(5)
HD 143761	0.60(1)	4.25(1)	-0.22(1)	3.00(4)	HD 146233	0.65(1)	4.42(1)	0.03(1)	4.07(1)
HD 157214	0.62(1)	4.31(1)	-0.40(1)	3.15(1)	HD 159332	0.45(1)	3.85(1)	-0.23(1)	5.00(6)
HD 168009	0.60(1)	4.23(1)	-0.01(1)	3.00(4)	HD 178428	0.70(1)	4.25(1)	0.14(1)	1.50(7)
HD 186427	0.65(1)	4.32(1)	0.07(1)	2.18 ± 0.50(5)	HD 187691	0.56(1)	4.26(1)	0.10(1)	3.00(4)
HD 19373	0.59(1)	4.21(1)	0.08(1)	3.15(1)	HD 216385	0.48(1)	3.95(1)	-0.29(1)	3.00(4)
HD 34411	0.62(1)	4.22(1)	0.08(1)	3.15(1)	HD 38858	0.64(1)	4.48(1)	-0.22(1)	2.61(1)
HD 42618	0.66(1)	4.46(1)	-0.11(1)	4.40(8)	HD 43587	0.67(1)	4.29(1)	-0.04(1)	2.98(1)
HD 45067	0.53(1)	4.01(1)	-0.09(1)	5.00(6)	HD 50692	0.56(1)	4.45(1)	-0.13(1)	1.89(1)
HD 739	0.40(1)	4.27(1)	-0.09(1)	4.40(9)	HD 75732	0.87(1)	4.41(1)	0.28(1)	2.27(1)
HD 89269	0.66(1)	4.41(1)	-0.19(1)	0.80(5)	HD 95128	0.62(1)	4.30(1)	0.01(1)	3.15(1)

References. (1) Martínez-Arnáiz et al. (2010); (2) Jenkins et al. (2011); (3) Ammler-von Eiff & Reiners (2012); (4) Takeda et al. (2005); (5) Marsden et al. (2014); (6) Bernacca & Perinotto (1970); (7) Mishenina et al. (2012); (8) McCarthy & Wilhelm (2014); (9) Schröder et al. (2009);

Criteria: Similar in B-V, then [Fe/H], then log g.

Note: There is a rather large gap in B-V at ~0.8!

How to determine the **excess flux**? (=The flux left after removing the “inactive parts”)



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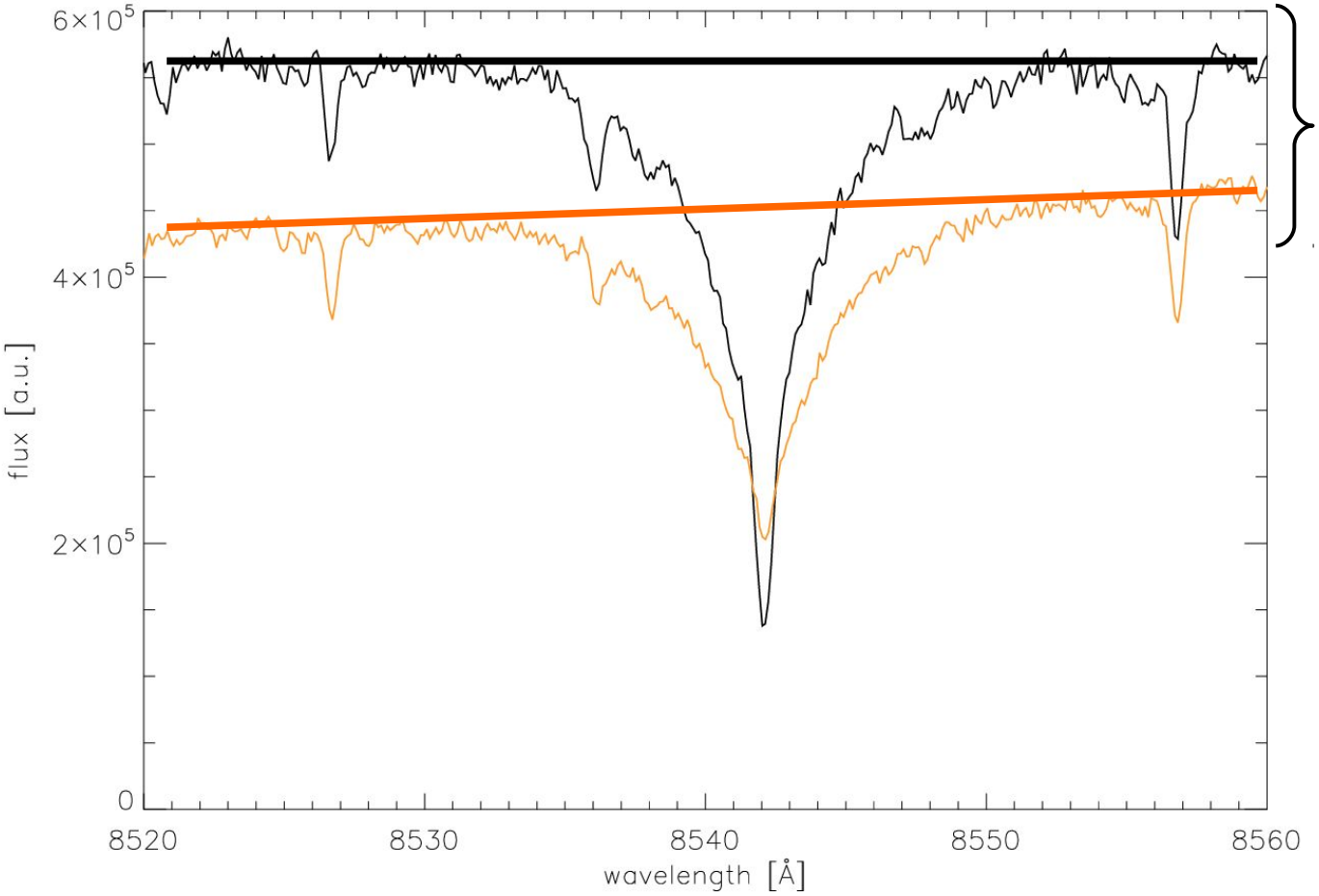
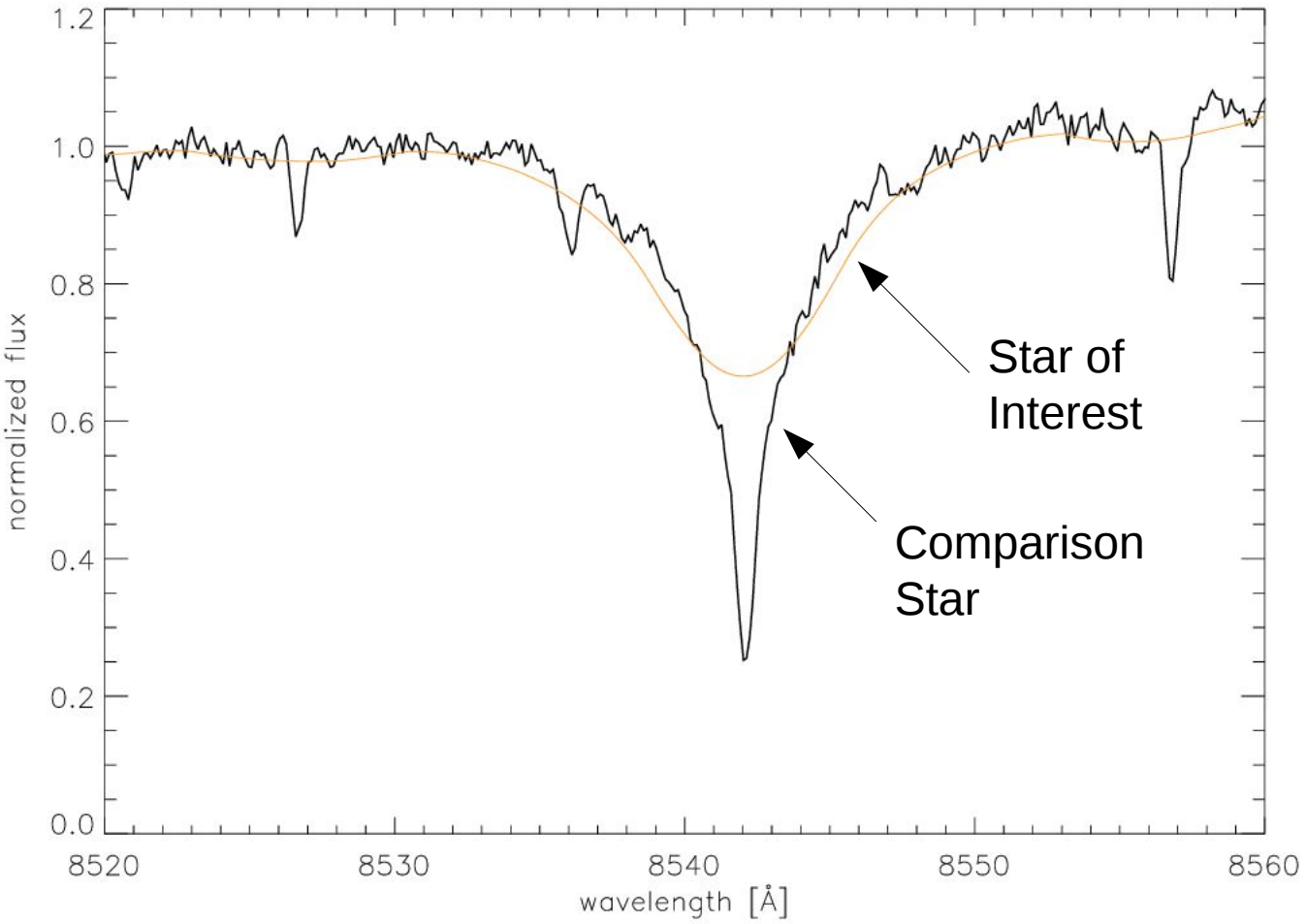


Continuum at different level

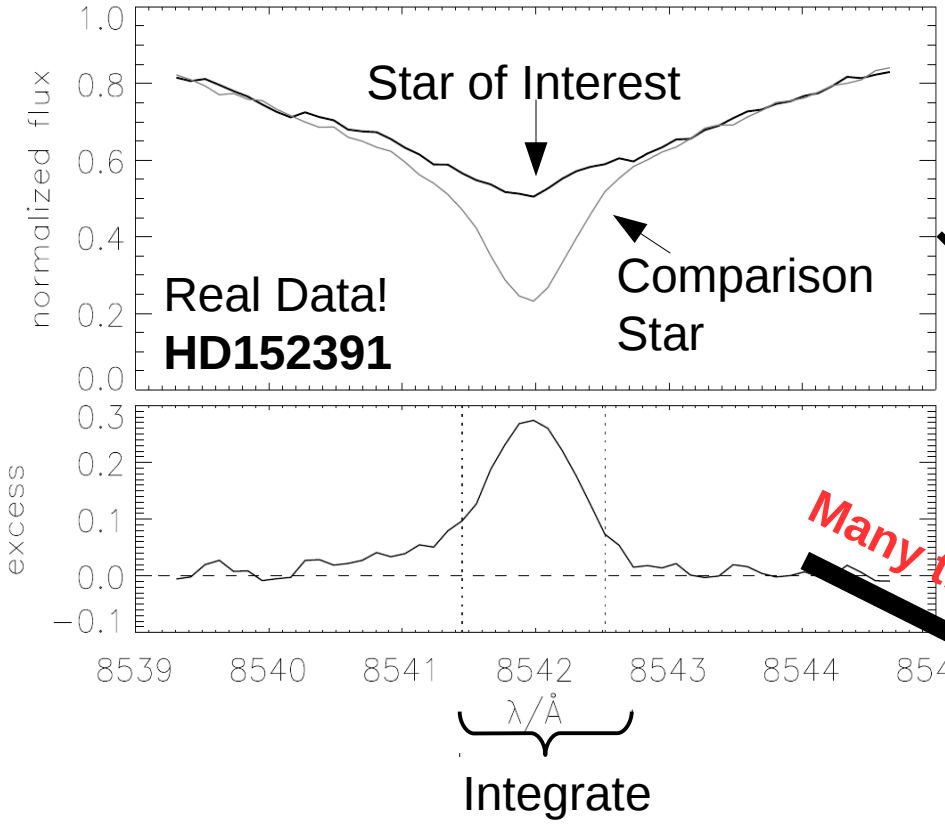
Normalize!

How to determine the **excess flux**? (=The flux left after removing the “inactive parts”)



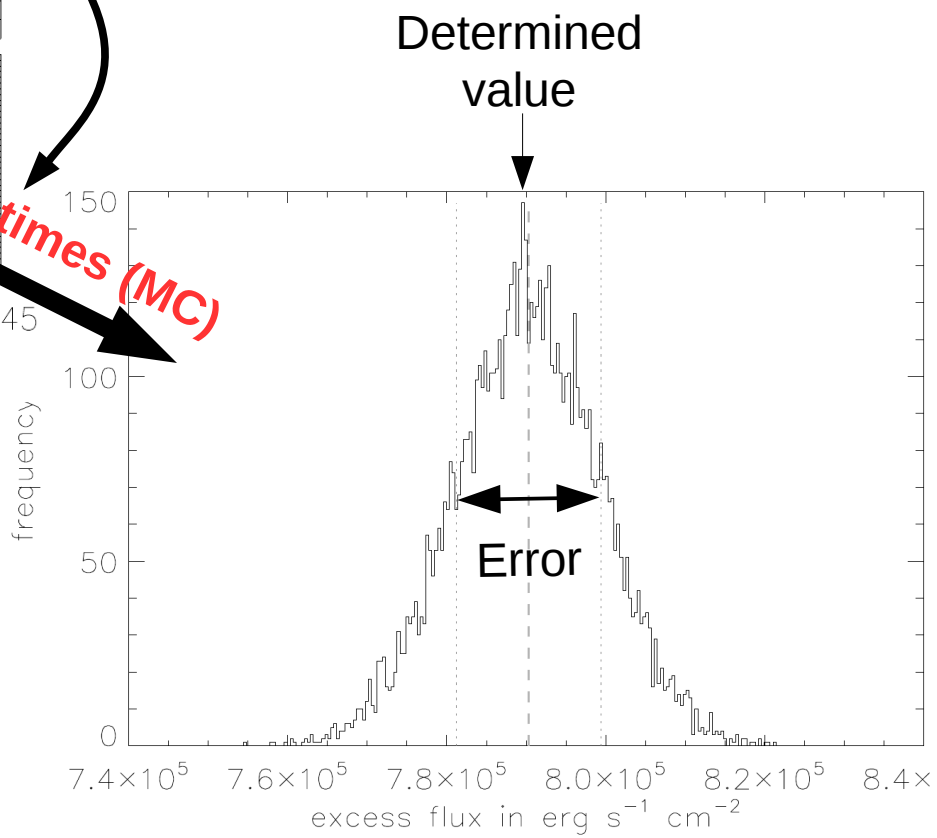
Often necessary: **Rotational broadening** of Comparison Star!

How to determine the **excess flux**? (=The flux left after removing the “inactive parts”)



Subtract to obtain **excess**!

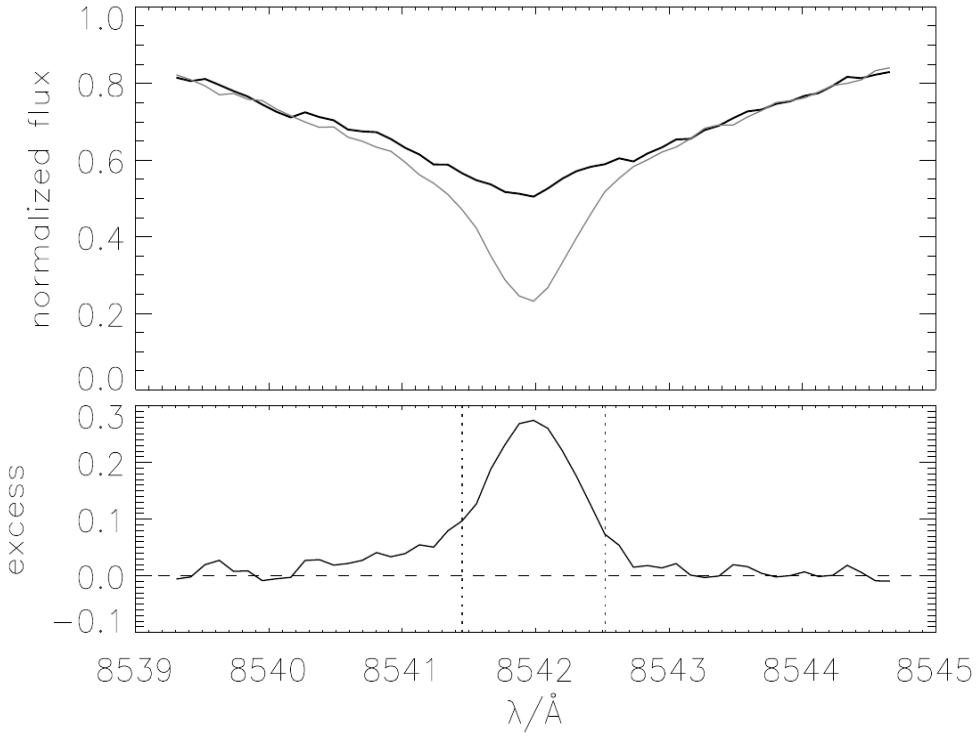
Many times (MC)



Vary parameters within their errors (esp. rot. Velocity!) to get **distribution**:

Approach also allows investigating the distribution of the excess! (position, width, shape...)

Spectrum was **normalized**, so the result is technically in Angstrom!



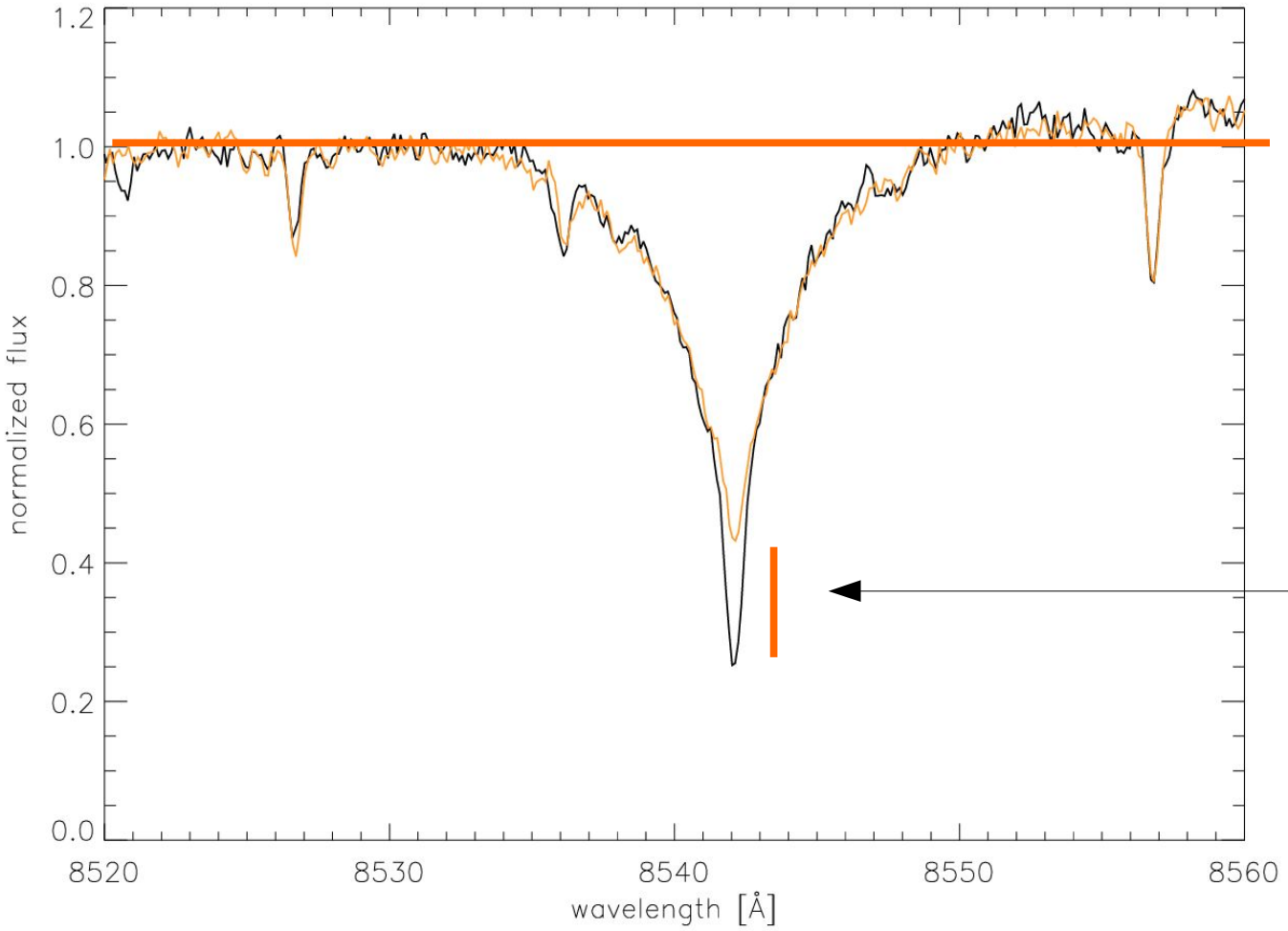
$$\int_{\lambda_0-\Delta}^{\lambda_0+\Delta} \underbrace{(F(\lambda) - f(\lambda))}_{\text{Normalized: Unit = 1}} \, \mathrm{d}\lambda \quad \rightarrow \text{Unit = [m]}$$

Busà et al (2007): ΔW_{IRT}

Busà et al (2007) compared to **models**! Two objects also in our sample:

ΔW_{IRT} matches in both cases within 1 σ!

Spectrum was **normalized**, so the result is technically in Angstrom!



Knowing the value in physical units **here**...

...gives you the scale to determine this!

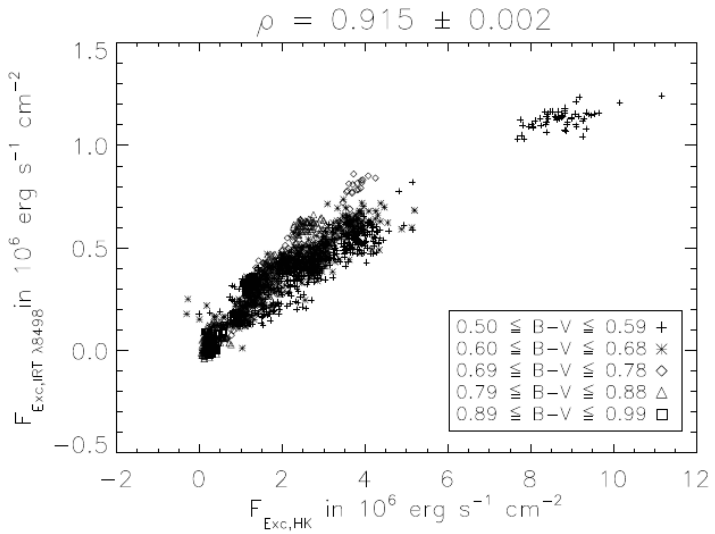
Could be done e.g. with models.

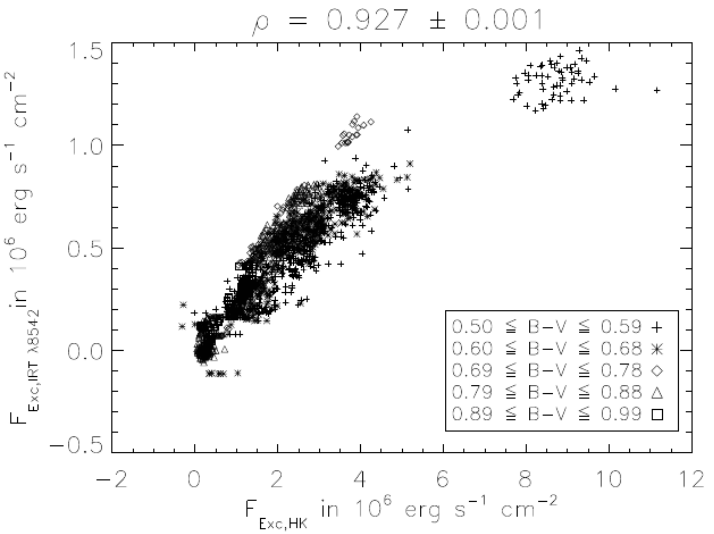
We used relations from Hall (1996) to convert to erg s^{-1} cm^{-2}

Note that different approaches give somewhat different results...

Obtained Excess Flux in this fashion for six lines (Ca II H&K+IRT, Hα). Good correlations across the board:

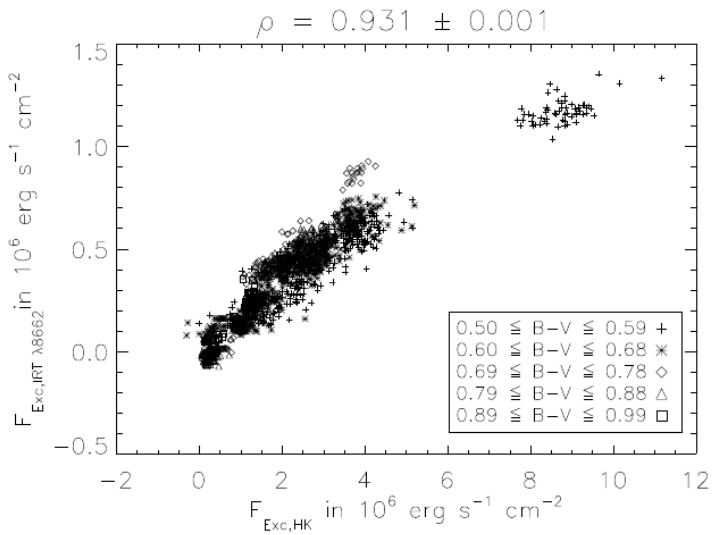
8498A

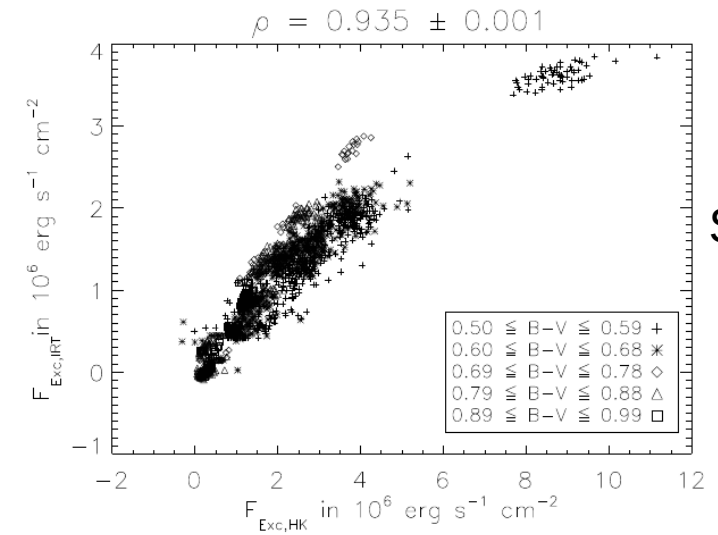




8542A

8662A

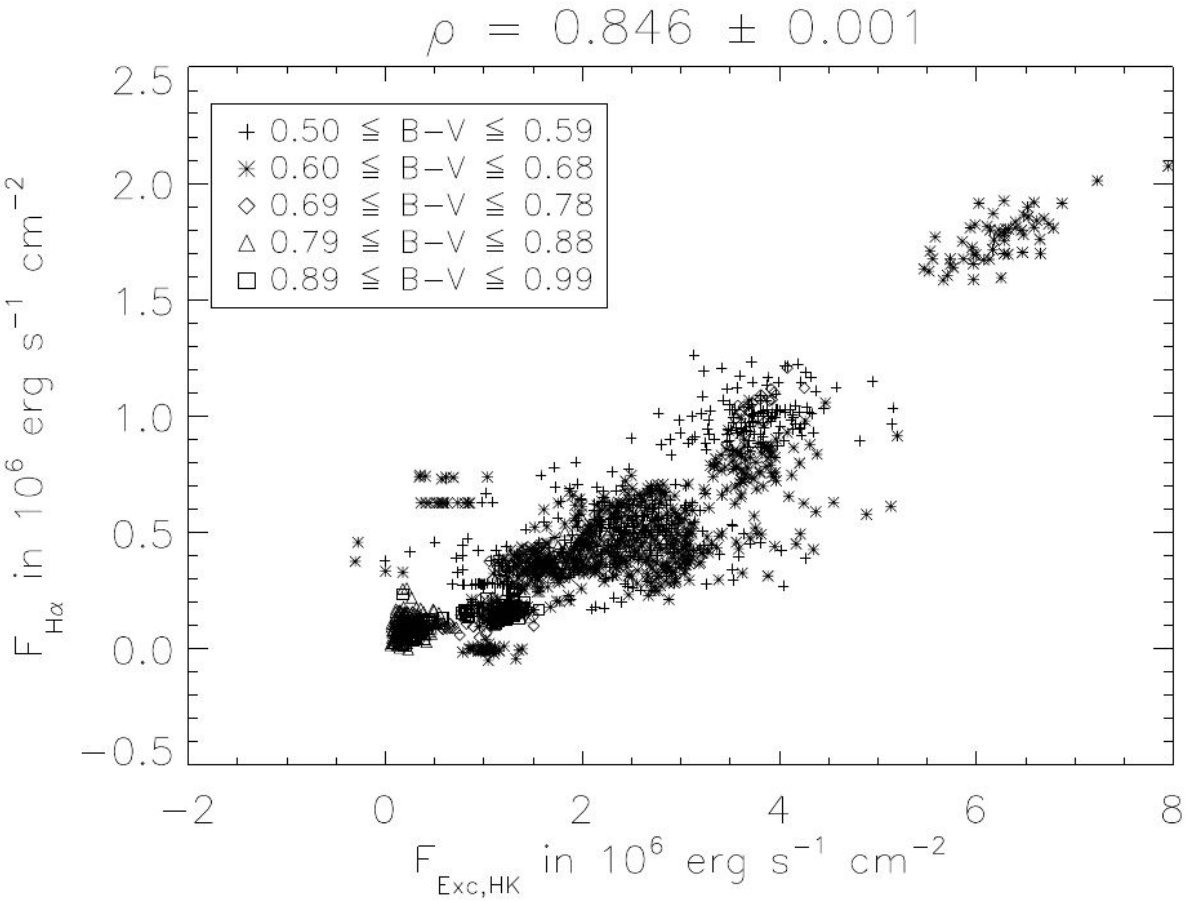




Summed up

Great correlation of > 0.9!

Obtained Excess Flux in this fashion for six lines (Ca II H&K+IRT, Hα). Good correlations across the board:



Hα:
Does correlate slightly worse,

Relation seems less linear!

You can **estimate** Ca II H&K-based indicators from **Ca II IRT measurements**!

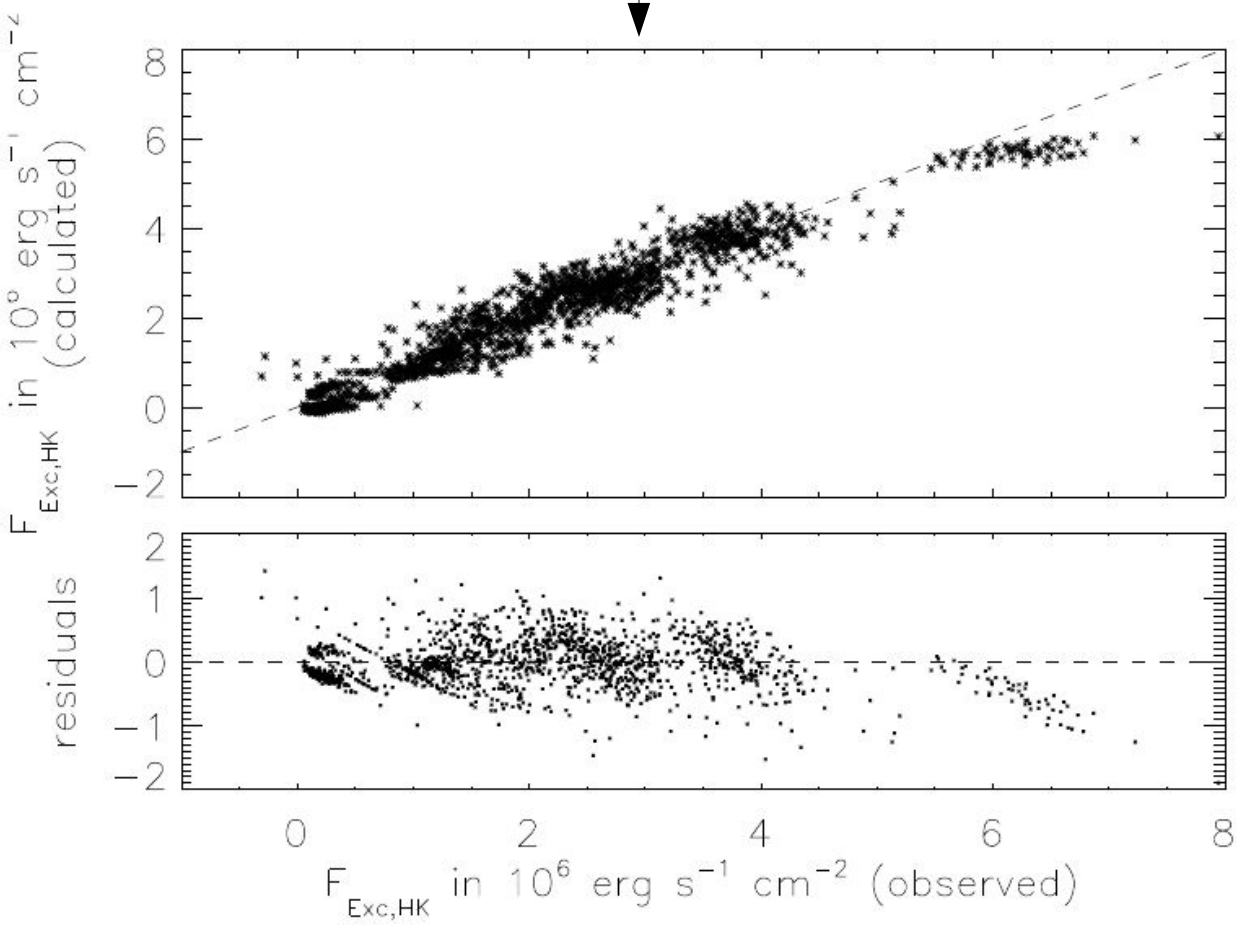
$$F_{\mathrm{Exc,HK}} = (3.021 - 1.911 \cdot (B - V)) \cdot F_{\mathrm{Exc,IRT}}$$

1) Take only observations with specific B-V

2) Fit linear relation to obtain coefficients

Now we have **one set of coefficients for each B-V**

3) Now fit relation to coefficients as function of B-V!



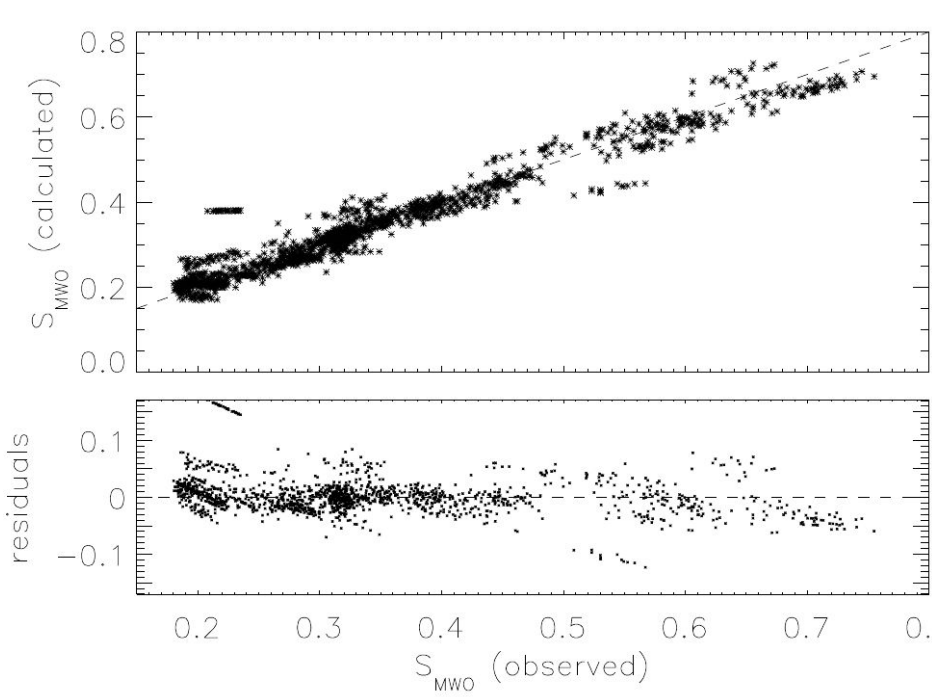
Errors: ~4×10^5 erg s^{-1} cm^{-2}

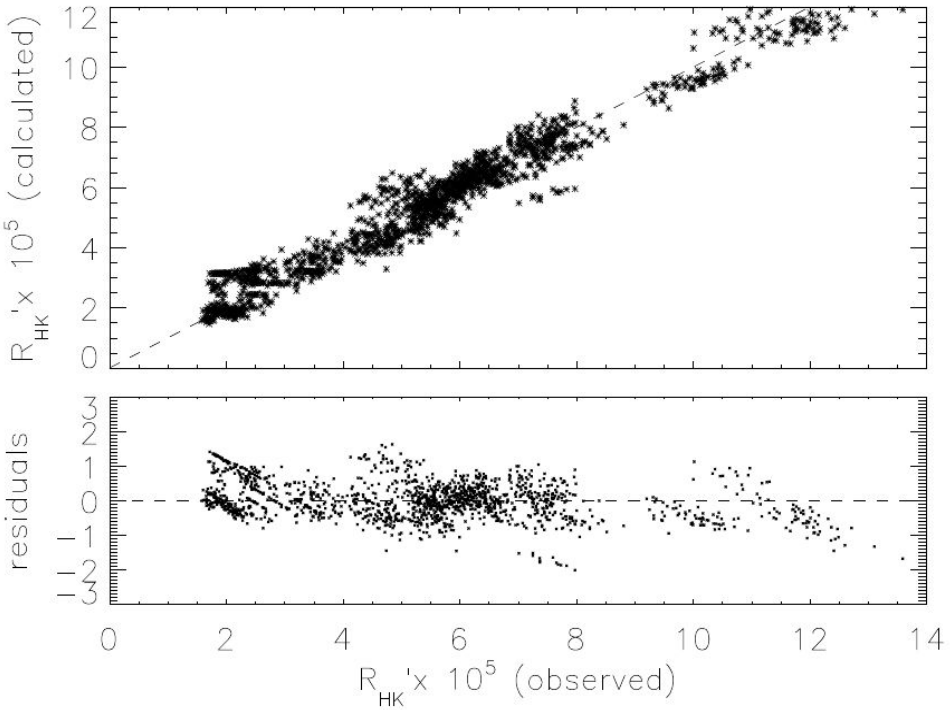
(This avoids introducing a Bias due to the very uneven sampling in B-V)

Somewhat more complicated relations for converting to S_{MWO} or R'_{HK}:

$$
\begin{aligned}
S_{\mathrm{MWO}} &= m \cdot F_{\mathrm{Exc,IRT}} + b, \text{ with} \\
m &= 0.741 \cdot 10^{-6} - 2.772 \cdot 10^{-6}(B-V) + \\
&\quad 3.543 \cdot 10^{-6}(B-V)^2 - 1.157 \cdot 10^{-6}(B-V)^3 \\
b &= -0.300 + 1.642 \cdot (B-V) - \\
&\quad 1.918 \cdot (B-V)^2 + 0.795 \cdot (B-V)^3
\end{aligned}
$$

$$
\begin{aligned}
R'_{\mathrm{HK}} &= m \cdot F_{\mathrm{Exc,IRT}} + b, \text{ with} \\
m &= 1.597 \cdot 10^{-10} - 5.551 \cdot 10^{-10}(B-V) + \\
&\quad 7.303 \cdot 10^{-10}(B-V)^2 - 2.864 \cdot 10^{-10}(B-V)^3 \\
b &= -1.907 \cdot 10^{-4} + 7.947 \cdot 10^{-4}(B-V) - \\
&\quad 9.911 \cdot 10^{-4}(B-V)^2 + 4.072 \cdot 10^{-4}(B-V)^3
\end{aligned}
$$

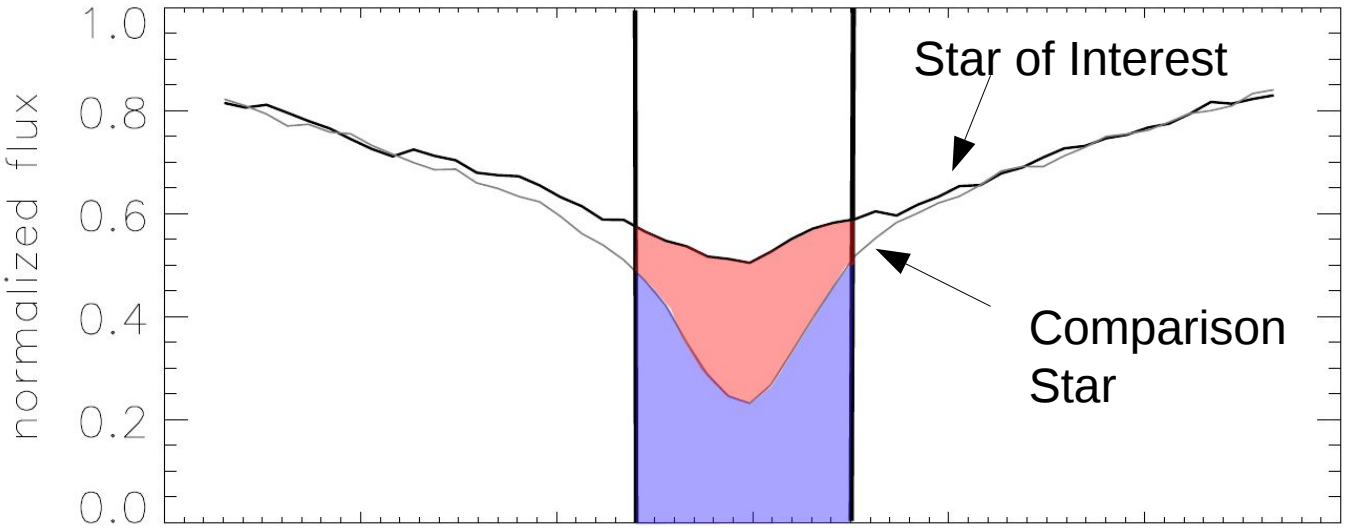




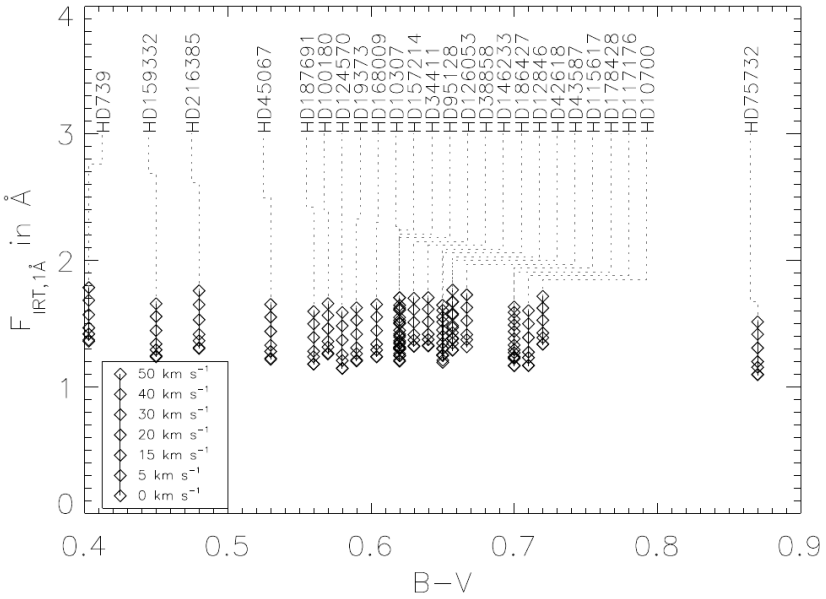
Errors: ~ 6%

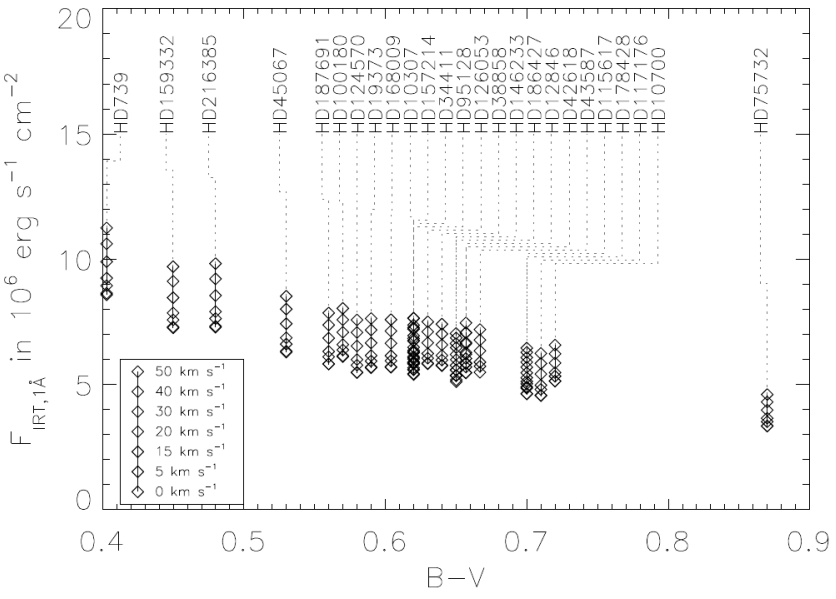
Get Excess fluxes “quickly”

Subtraction procedure is technically not necessary if only interested in excess flux!



To get the **excess flux**, integrate your spectrum (red+blue), and subtract estimate of photospheric+basal contribution (blue region)!



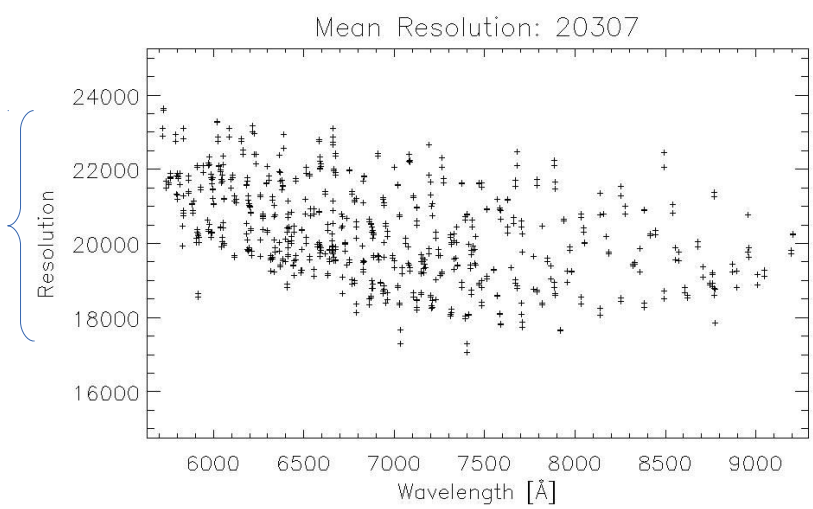


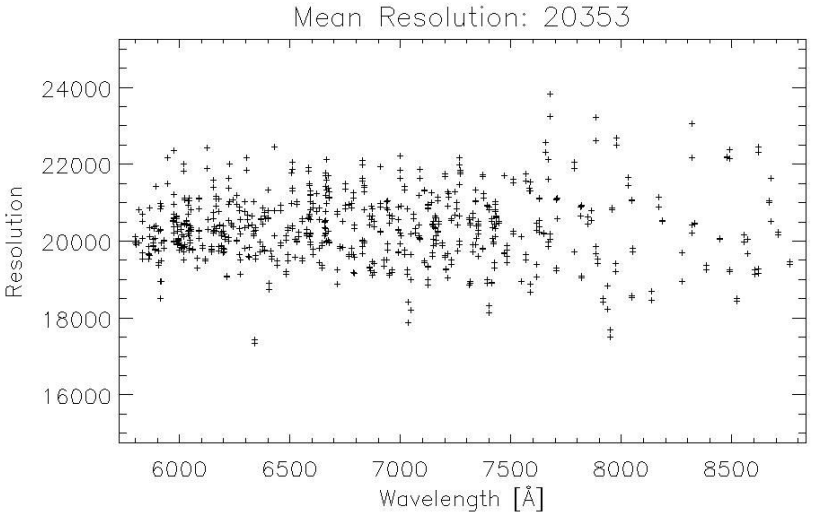
Things you might want to look out for:
(That you may not know about)

- Resolution:

The resolution varies by ~ 15% (or more..?), even quite sudden at times!

17000 ~ 23000





- Wavelength shifts:

Can be physical (you should know if that's the case) or nonphysical (small shifts due to inaccuracies). Might not be a problem.

TIGRE's **large sample** of **simultaneous** Ca II H&K and Ca II IRT observations show:

- They are **well correlated** and feasible as **activity indicator!**

- It is possible to find **conversion relations**:
→ You can use them to compare activity measured from GAIA data to old archival data!
→ If you don't have something to compare to, you can **estimate it** still

Next:

- More reliable comparing to **models**
(plus: Determining stellar parameters!)

- Comparing binary systems & searching for phase-activity relations!

Thank you for your attention!