# Holistic spectroscopy

## Extracting spectra by means of perfect image reproduction

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GALAH
GALactic Archaeology
with HERMES

# The Idea

High precision spectroscopy is best practiced with a complete understanding of the instrument's point spread function (PSF) and its effects.

No spectrograph is perfect and especially highly multiplexed instruments suffer from PSF variations and instabilities.

These are expensive instruments and some investment into a good PSF monitoring system and advanced analysis can benefit most science cases.

We developed an algorithm that forward models an observed field of spectra when the PSF is known extremely well. Spectra can be extracted, or science can be performed in the image domain altogether [Kos+ 2018].

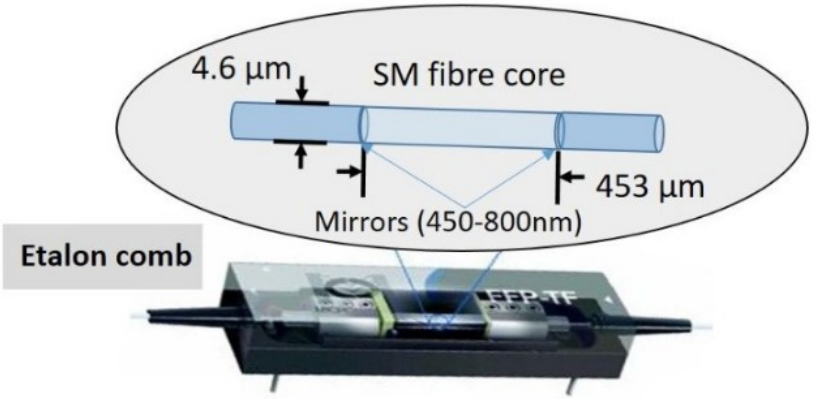
+ Improve the nominal resolution.
+ Remove variable resolution, produce Gaussian LSF.
+ Fix cross talk.
+ Observe bright and dark objects in a single frame.

– Computationally intensive (but easily paralelised).
– Need for precise, bright, rapid PSF monitoring system.
– Science in the image domain would be tedious and hard to manage.
– Doesn't play well with machine learning (yet?).

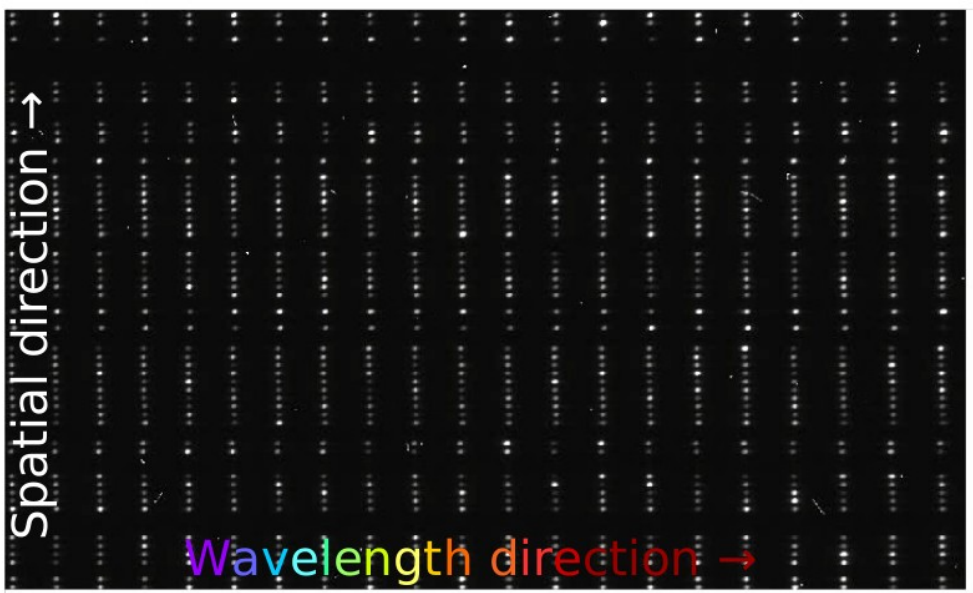
# Measuring the 2D PSF

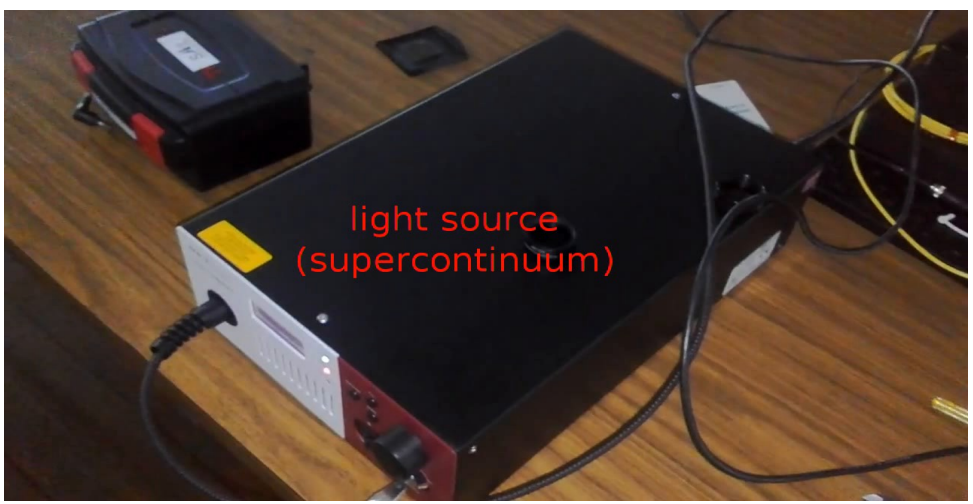
In our experiment, the PSF was measured by injecting the light from a photonic comb directly into the fibres of the HERMES spectrograph at the AAT.

We used an etalon photonic comb with *FSR*=300 GHz, *Finesse*=40.
It was locked to a Rb laser for stability [Bland-Hawthorn+ 2017].




Several talks showed ESPRESSO and HARPS spectra with a track of a comb pattern. MOS probably need a separate exposure.

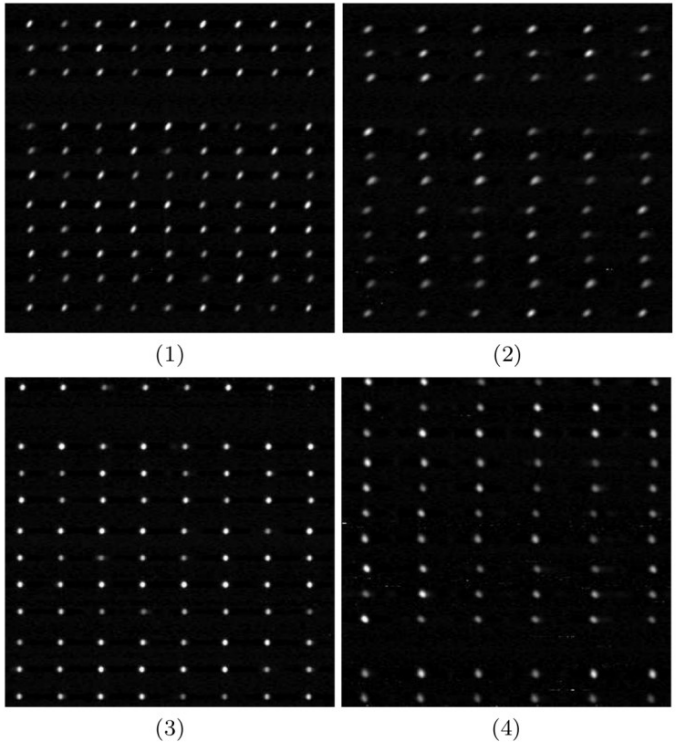


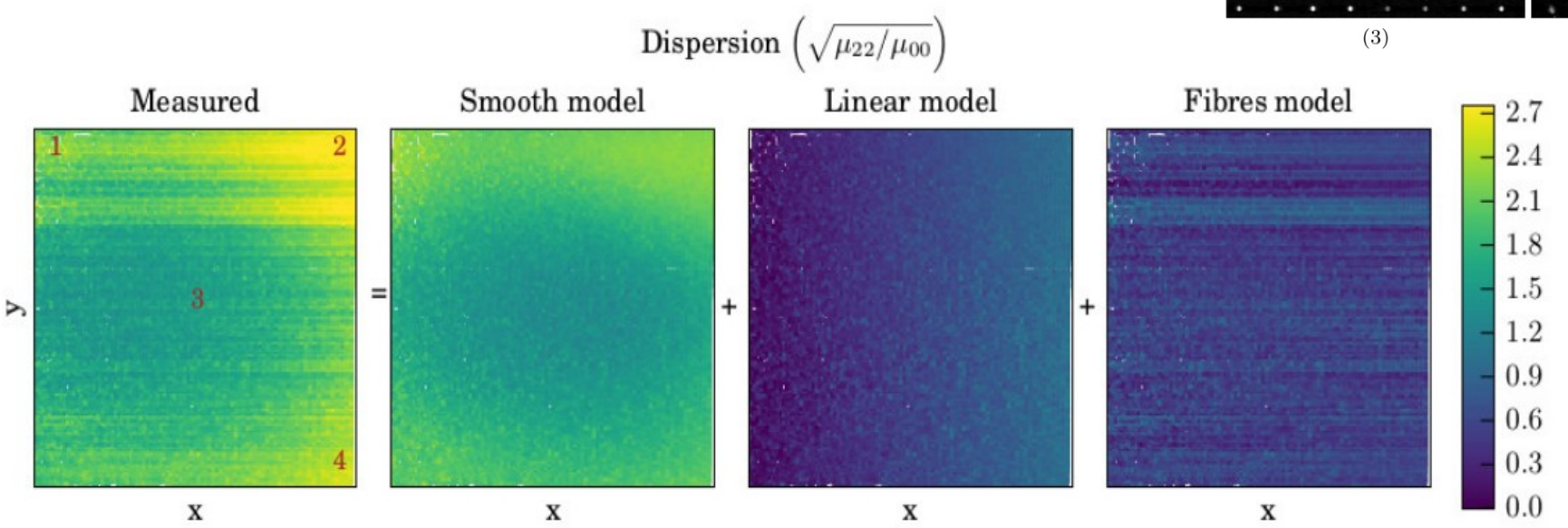



# PSF parametrisation

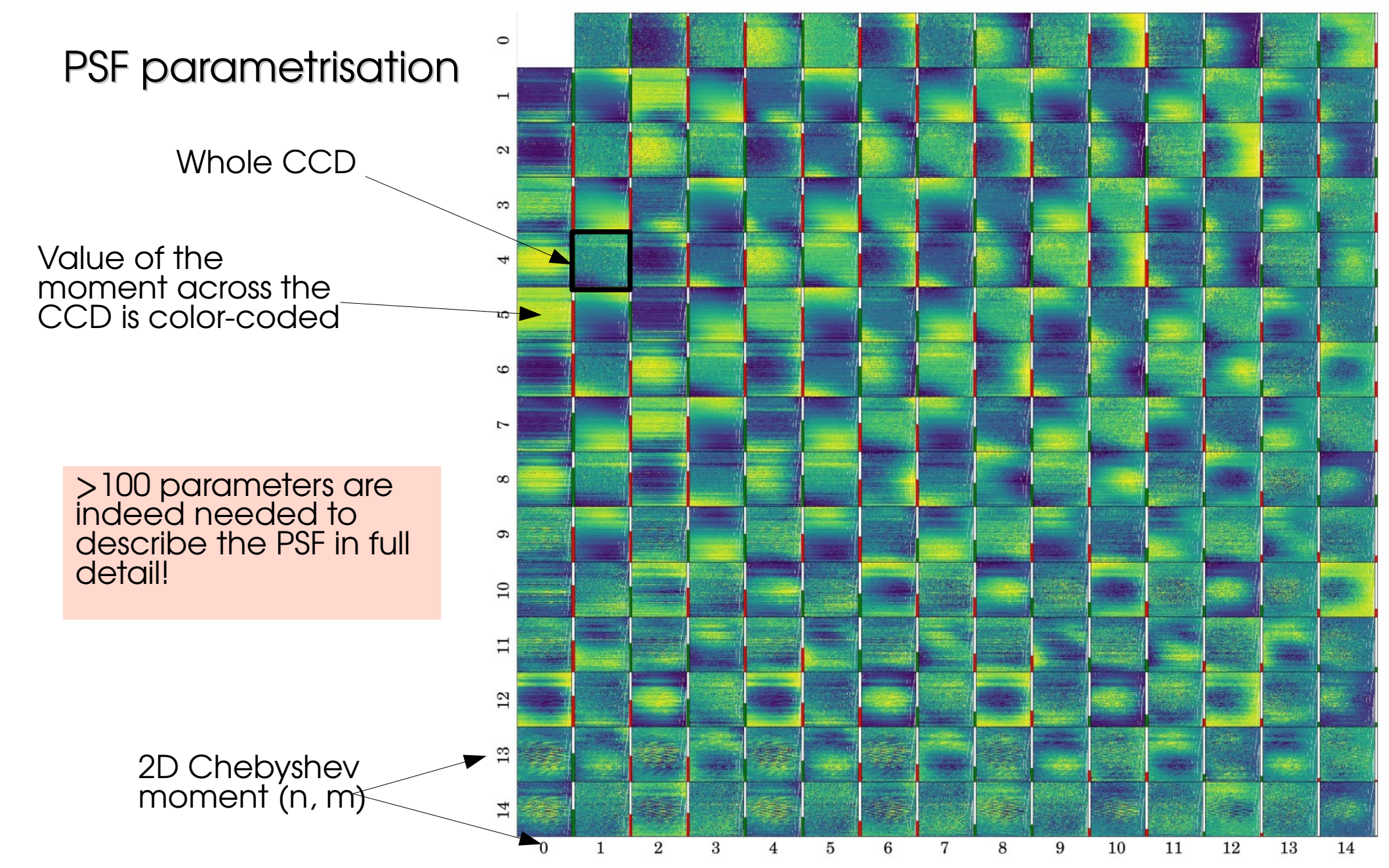
PSF is measured at a finite number of points on the CCD. The PSF is represented by 2D Chebyshev moments. Each moment is interpolated throughout the field.

PSF at any position on the CCD can be generated very fast (basic arithmetic and look-up tables) from these moments and so can the reconstructed image.

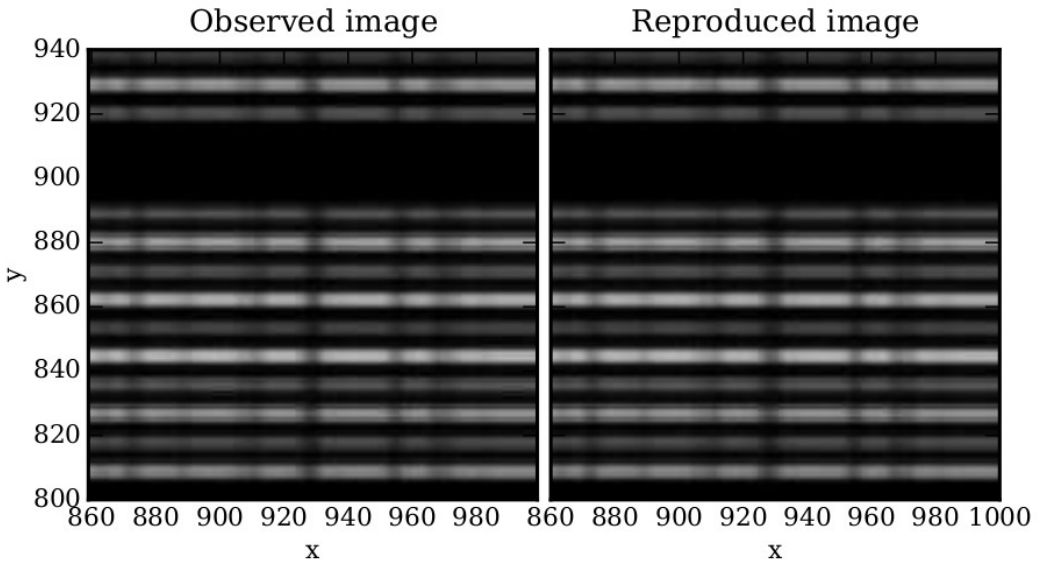


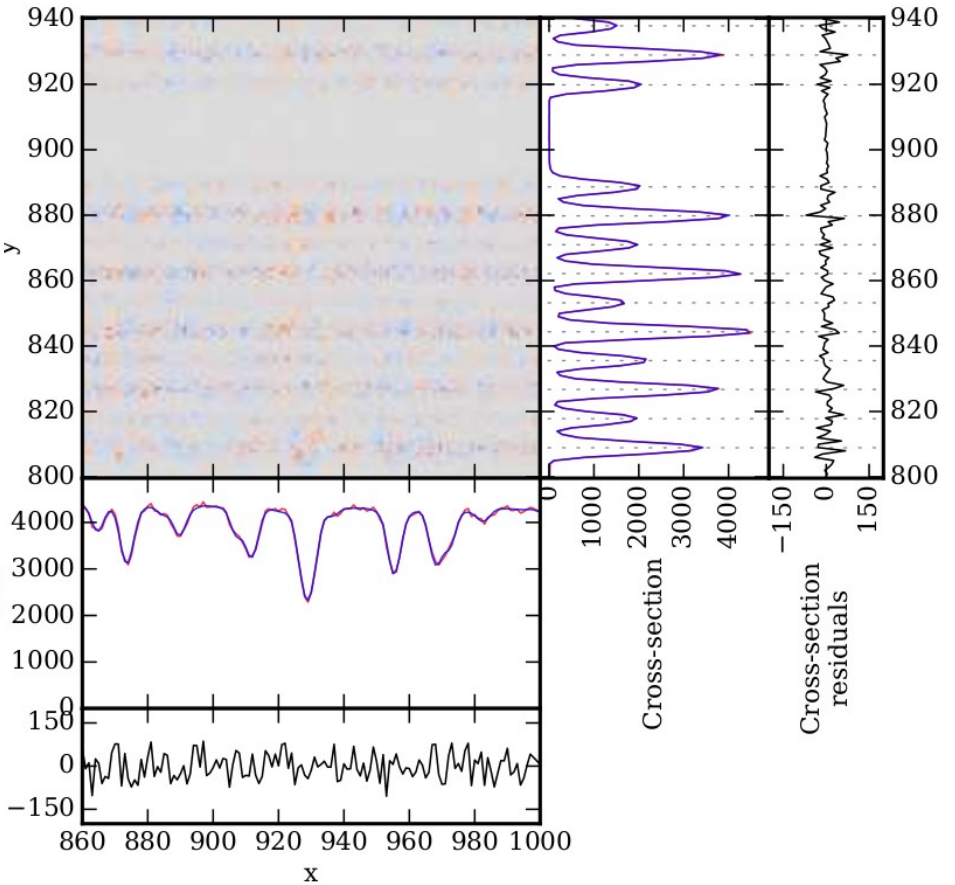



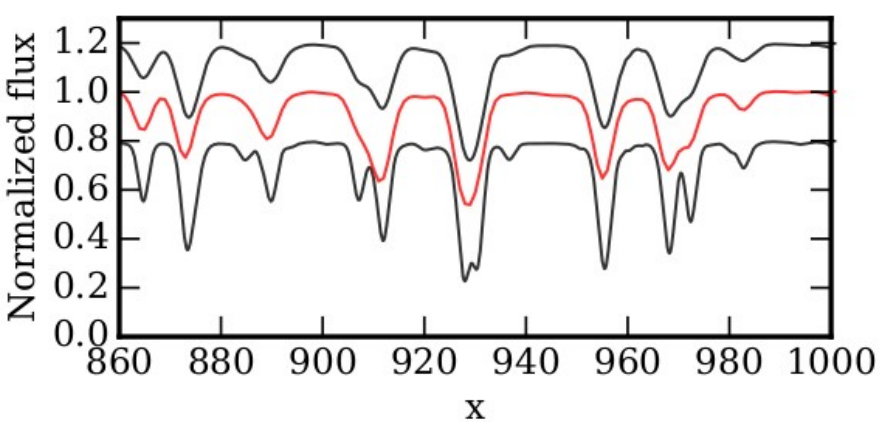
# PSF parametrisation



# Image reproduction



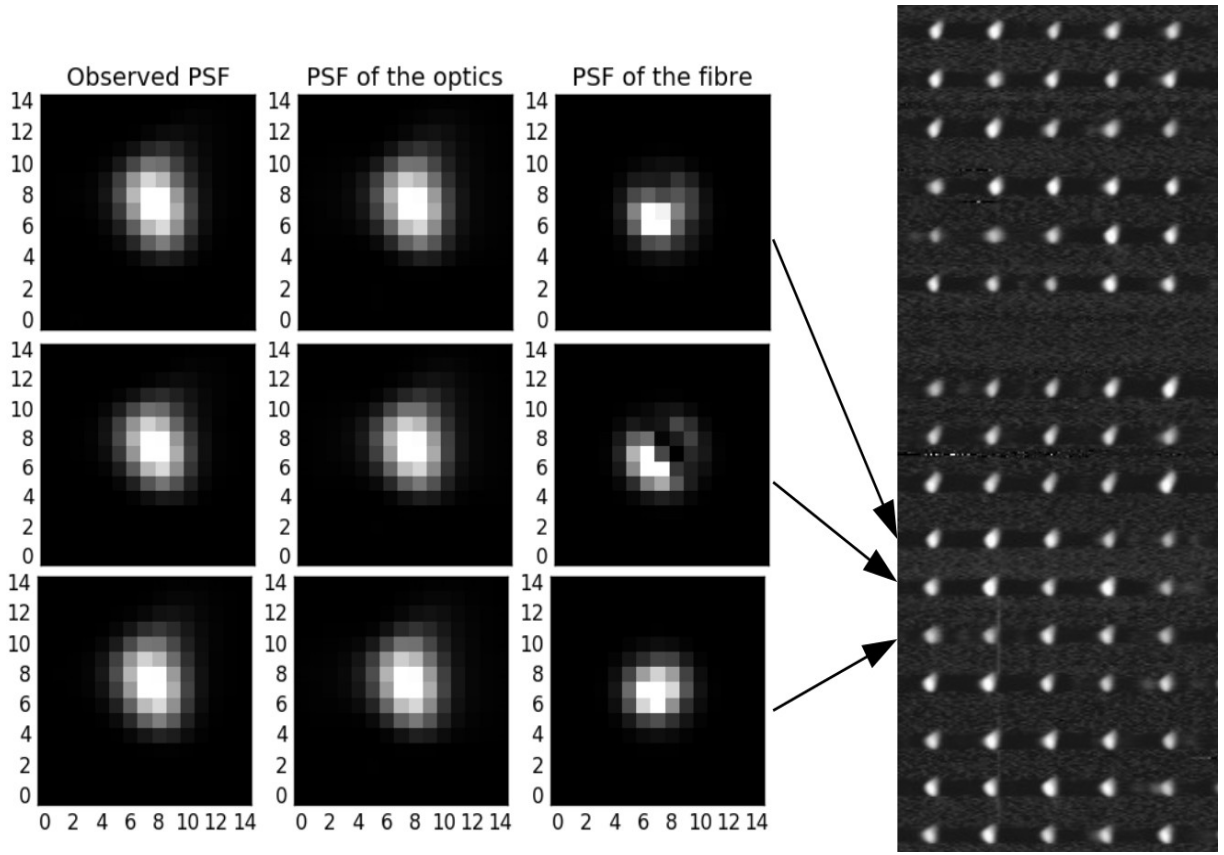

Even a small improvement in resolution benefits crowded blue spectra (e. g. Rb and Pb lines discussed by Valentina)

# Image reproduction

Decomposition of moments into the source of aberrations allows us to monitor the health of the instrument.

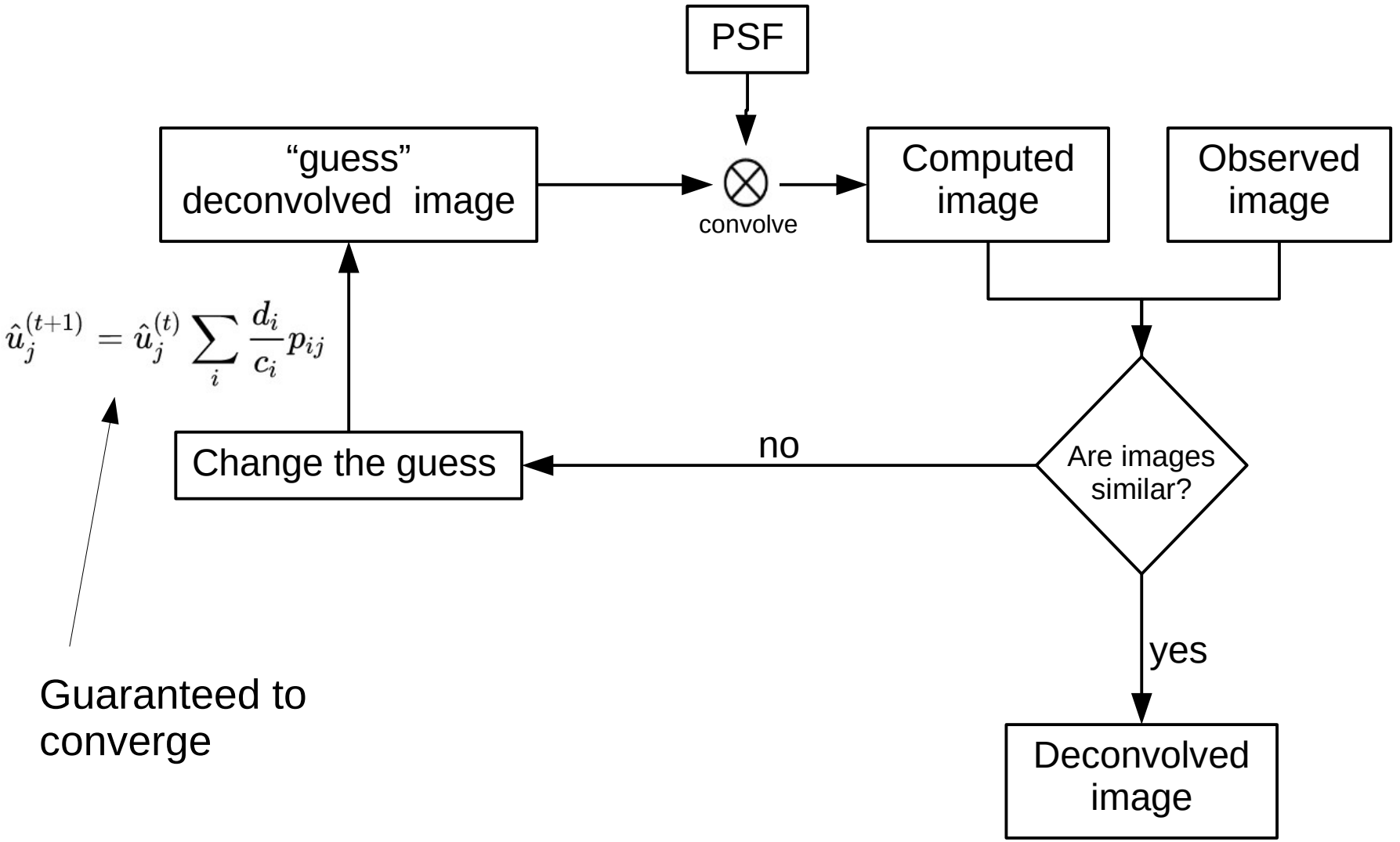
Imagine the impact on differential spectroscopy of wide binaries (e. g. Keith's talk) or in clusters.

PSF precision and stability is essential in the studies of ultraprecise spectral line profiles (e. g. Michaels's fine structure constant or hiperfine transitions from Gabriele's talk)

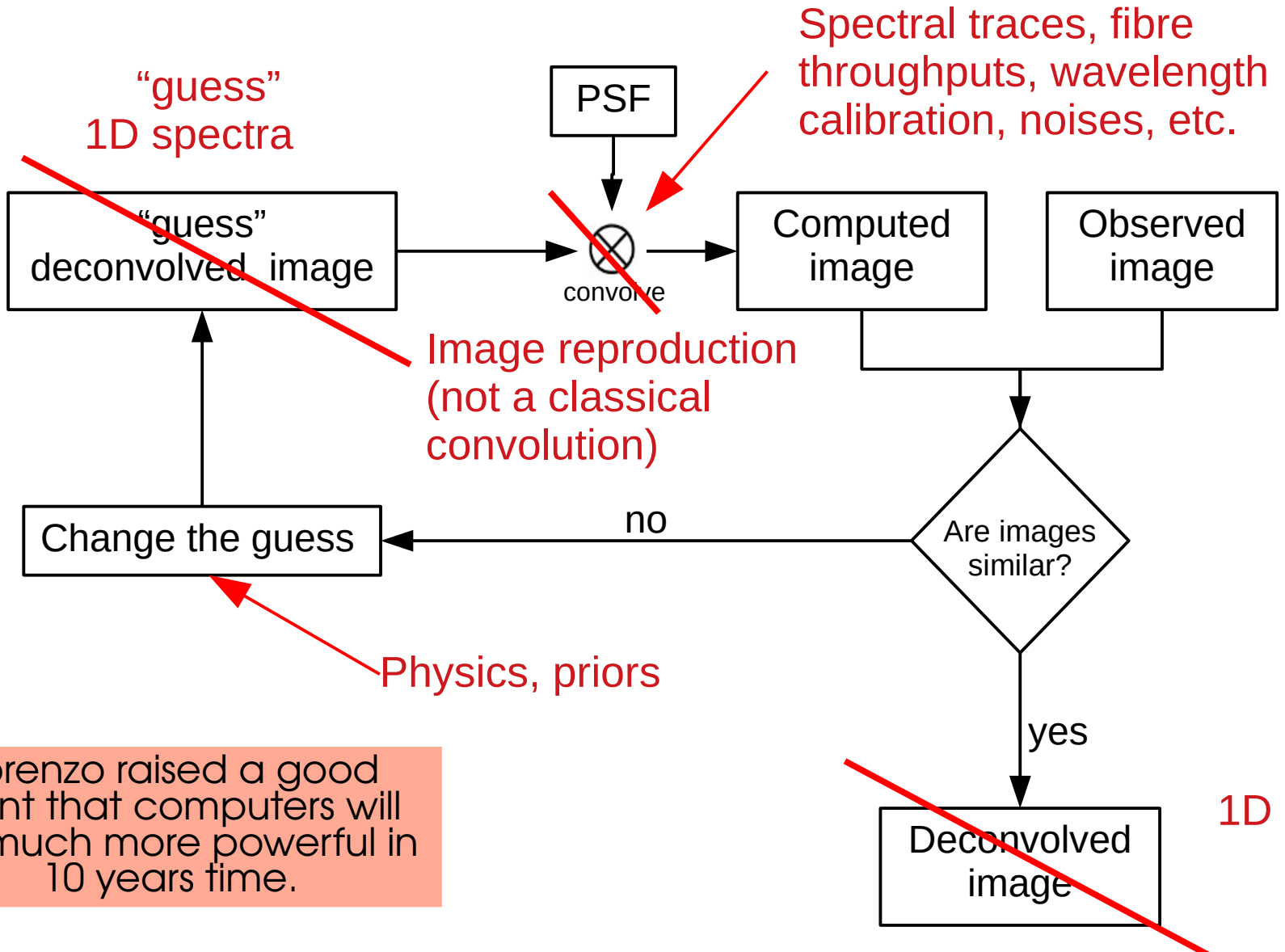



This has a similar effect as echelle orders have on lines, like Vardan discussed.

# Richardson-Lucy algorithm



# Our forward modeling algorithm



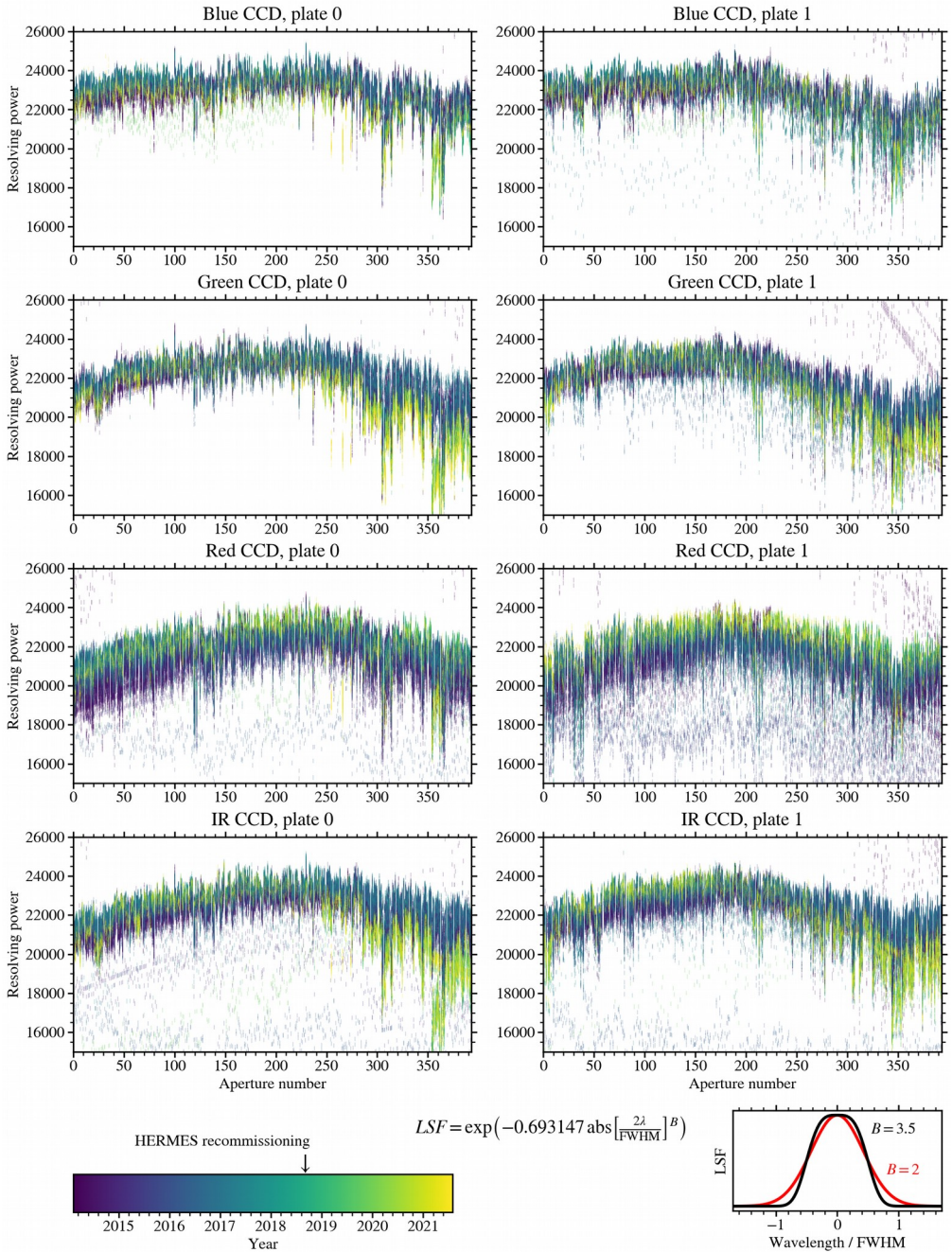

Lorenzo raised a good point that computers will be much more powerful in 10 years time.

# Applications in the GALAH survey (coming in DR4)

We do not have the infrastructure to perform the previous algorithm regularly.

Comb measurements help us transition into arc-only calibration. Cross talk profiles and the resolution profile is measured from arc frames, but the fitted functions are selected and constrained based on the comb maps.

Resolution precision is better than 500 at R=28 000 (variation over the field is 6000).



# Conclusions

Optics and photonics of combs is progressing very fast. Combs should be a defacto calibration sources for HRMOS.

Poor performance of some combs in blue/UV and low power will hopefully be solved in the near future.

Make better and more calibration frames than needed. Spectra can be reduced again, but calibration frames can only be taken once.

Remember algorithms from 10 years ago? Many new algorithms and approaches to data processing will be in use in the next 10 years.

Will we have a conference in 10 years, discussing a R>100 000 MOS spectrograph?

A big step can be done with clever data processing right now!