Leibniz-Institut für Astrophysik Potsdam

PCA tool for High-Resolution Echelle Spectroscopy Analysis

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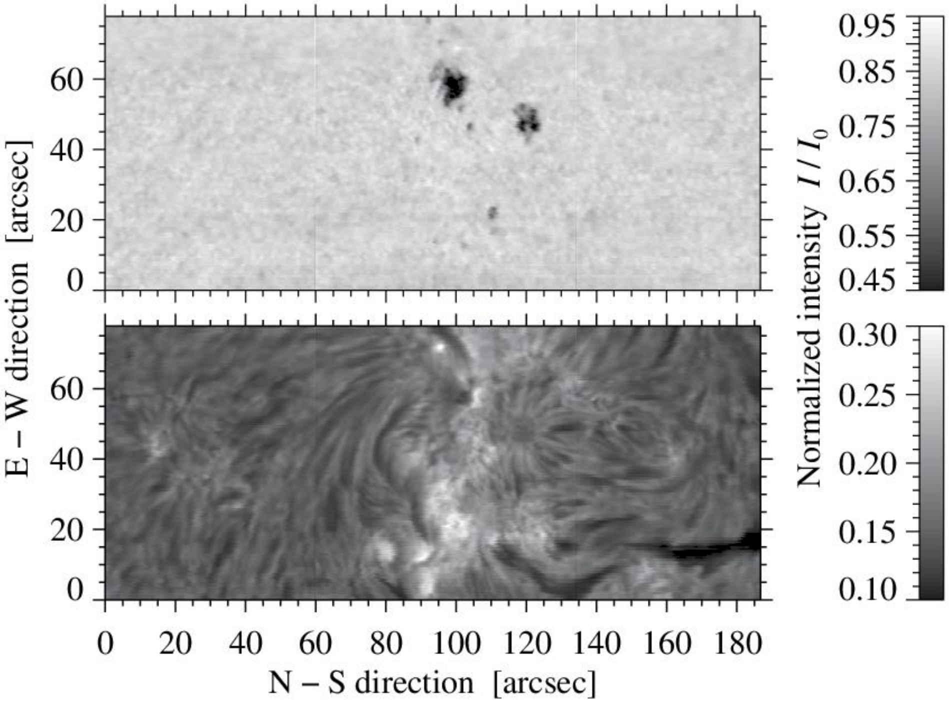
Motivation

- Application of the Principle Component Analysis in processing spectroscopic observations
- Classic Cloud Model as a training data basis
- Develop a data-pipeline which incorporates various functions and procedures:
  - make use of iterative PCA
  - minimize human interaction
  - create a unified protocol for bulk processing of high-resolution echelle spectra
- Analysizing high-resolution observations of strong chromospheric absorption lines
  - Physical maps
  - Cloud Model inversions

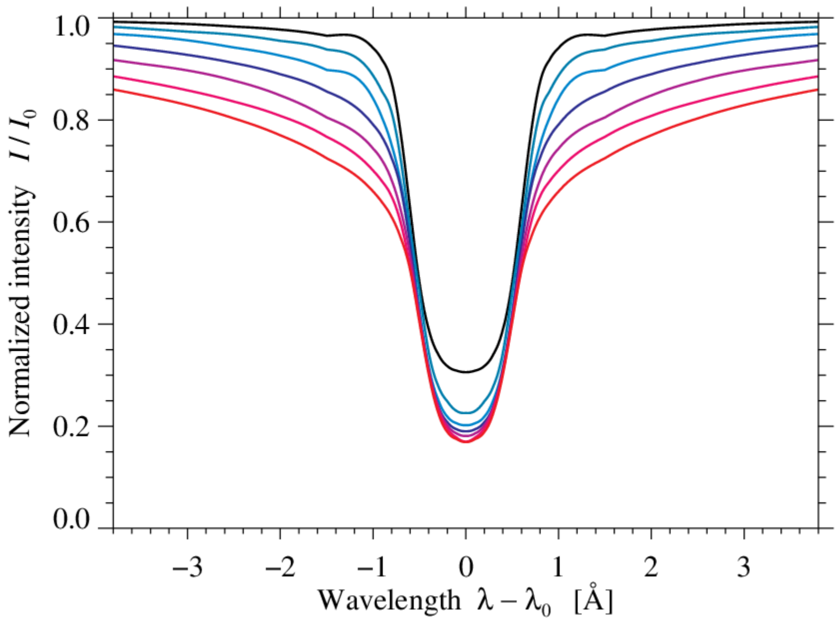
Observations

- 70-cm Vacuum Tower Telescope, at the Observatorio del Teide, Tenerife, Spain
- Echelle spectrograph
- Wavelenght range: 655.9 nm – 657.1 nm
- Dispersion: 0.6 pm pixel^{-1}
- Lline of interest: Hα λ656.28 nm
- Active region: NOAA 11126
- Coordinates: S32.6° and E5.5°
- FOV: 78.0″ x 186.9″
- Date and time: 18 November 2010, 10:22 UT
- Observed features: two small decaying *sunspots* and a *filament*



Preparing Observed Spectra

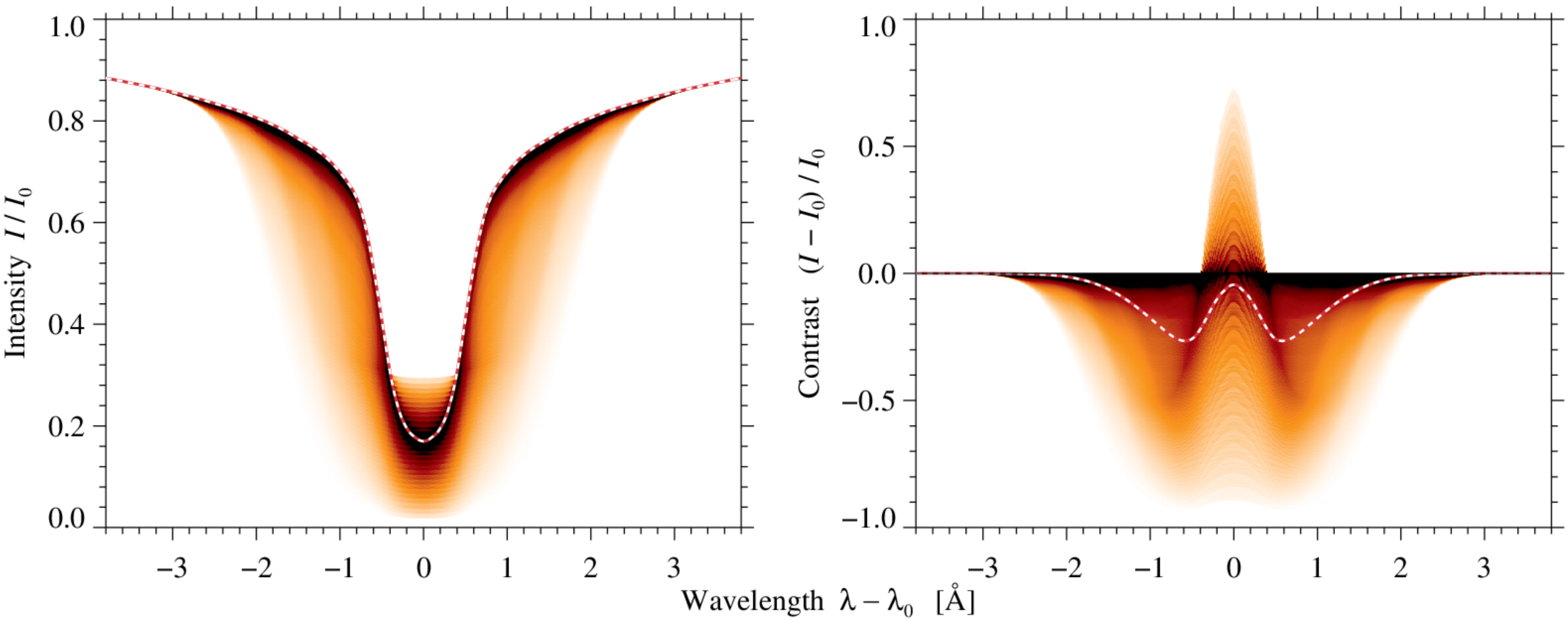
- ❑ Continuum intensity correction
- ❑ Compute quiet-Sun profile from observations:
  - ❑ Hα CLV data as a template
  - ❑ Identifying quiet-Sun profile from observations
  - ❑ Extract ± 3Å around the line-core
- ❑ Adjust the observed profiles to fit quiet-Sun profiles
- ❑ Basic line properties properties:
  - ❑ continuum intensity
  - ❑ line-core intensity and position
  - ❑ absolute contrast
- ❑ Compute contrast profiles using corrected spectra and quiet-Sun profiles from each data set



The original Hα absorption profiles observed and described in David (1961). Colors correspond to the six μ values: 1.0 (*red*), 0.8 (*magenta*), 0.6 (*purple*), 0,436 (*indigo*), 0.312 (*blue*), 0.28 (*teal*), and 0.141 (*black*)

Cloud Model Training Data Basis

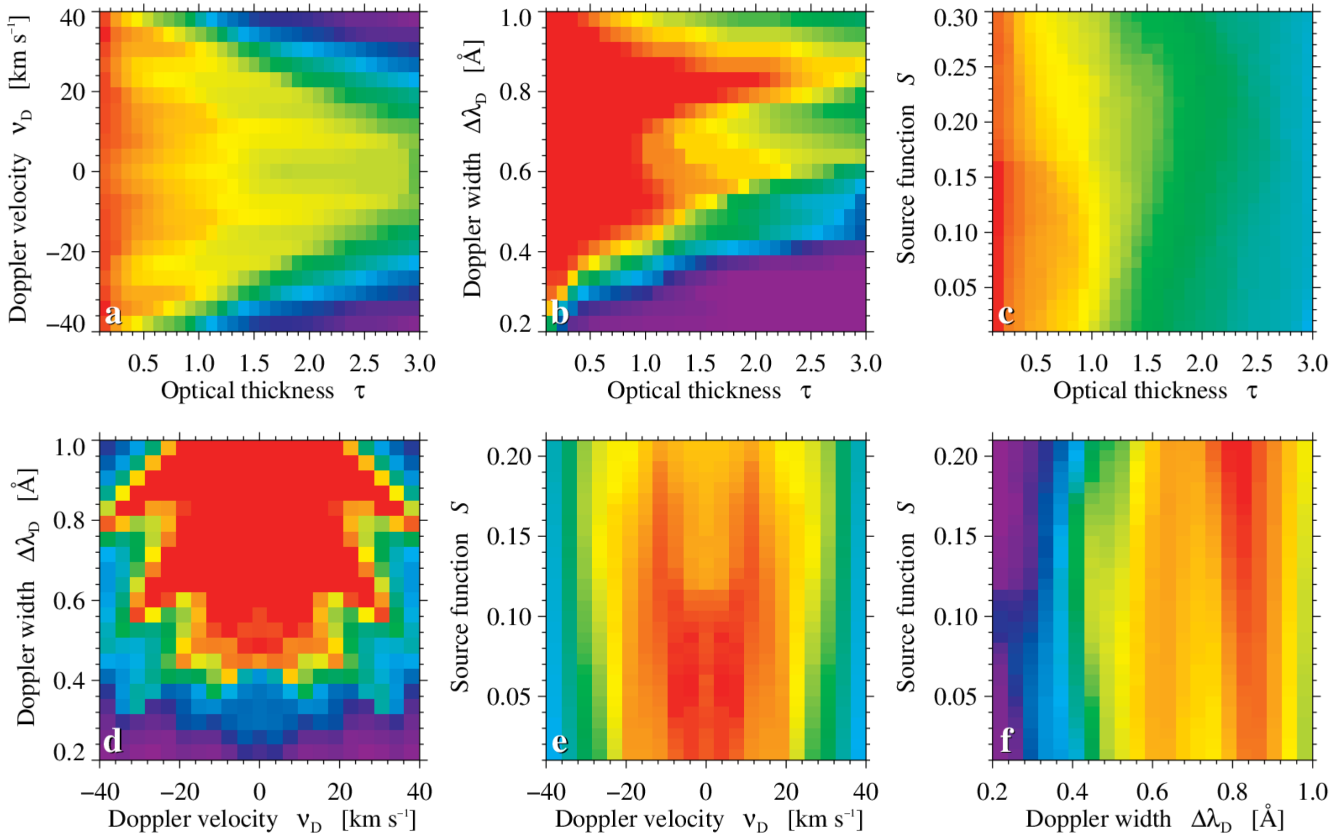
- The Classic Cloude model (Beckers, 1964)
  - Use Hα center-to-limb observations (David, 1961) as a starting point for creating a training model data set



The initial Hα spectra density distribution of the CM training data base. The next step involves ***applying PCA*** and ***refinement procedure*** to reduce number of profiles which will be used in inverting the observed Hα profiles .

Cloud Model Training Data Basis

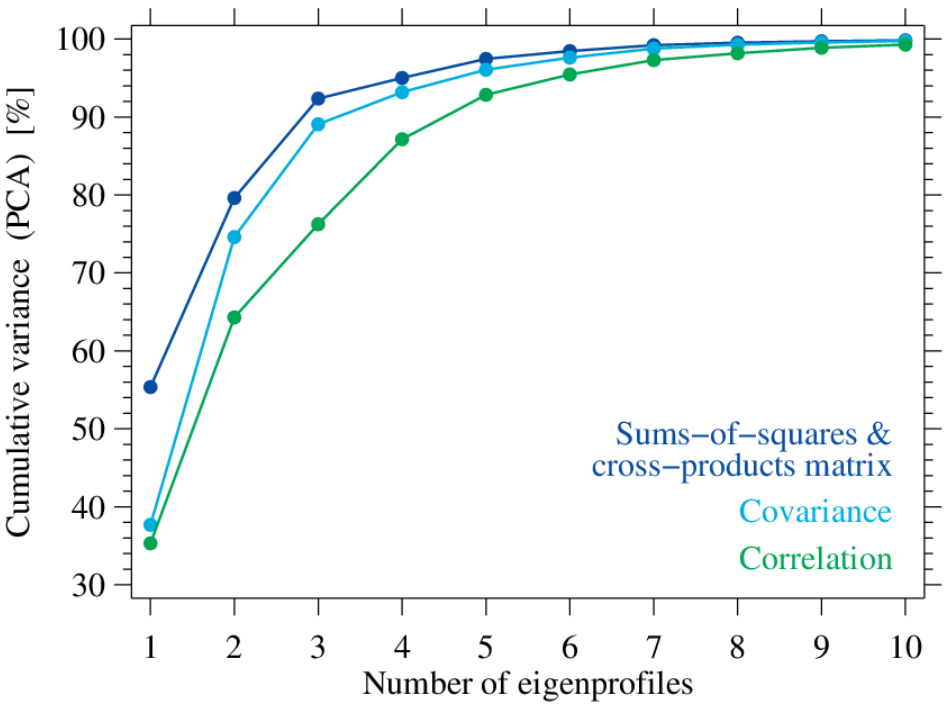
- The classic CM has four adjustable parameters:
  - optical thickness, Doppler velocity, Doppler width, and source function



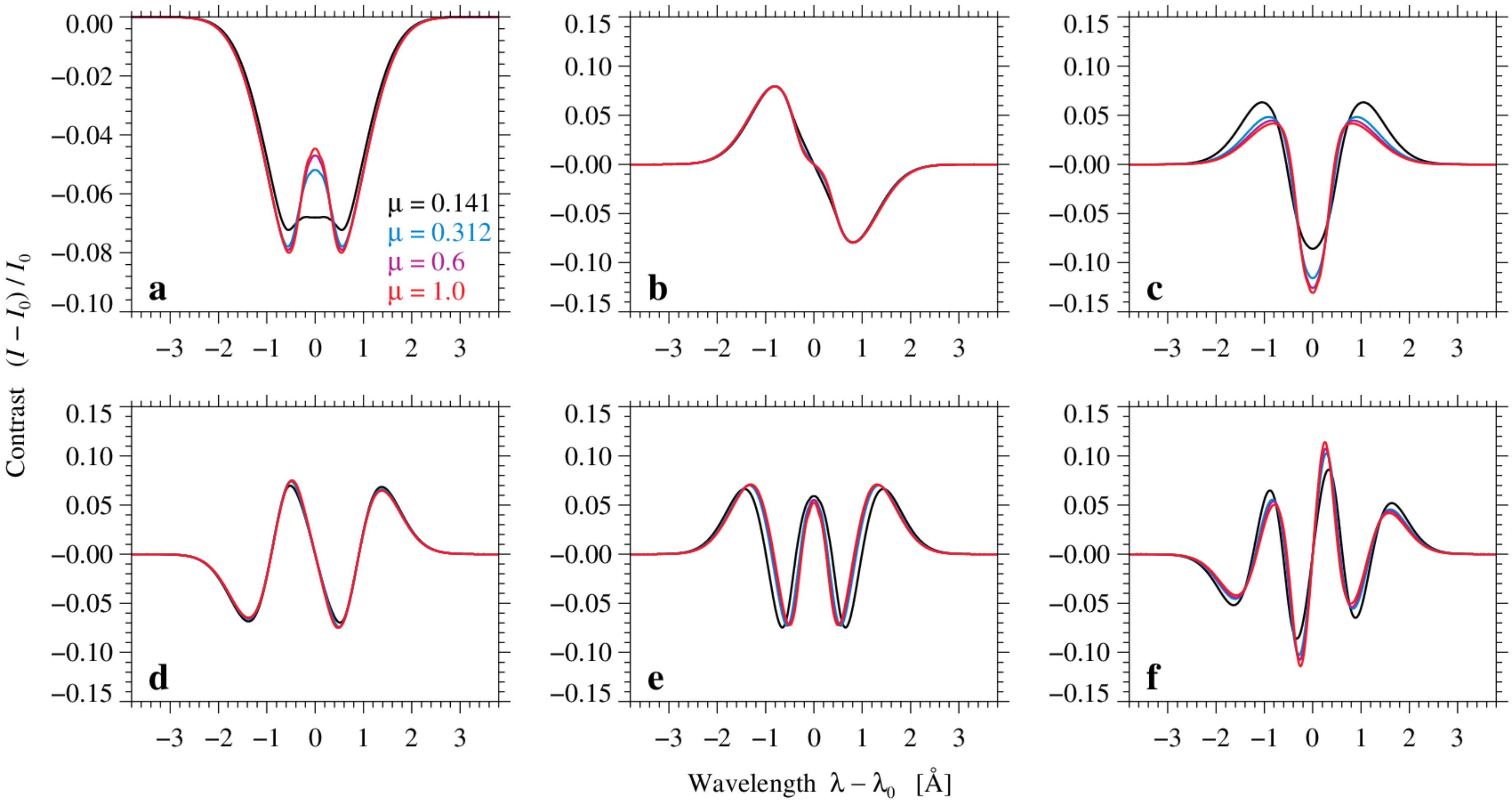
2D histograms displaying the six possible projections of the four-dimensional parameter space of the CM basis allow to evaluate the relation between the basic physical parameters and to trace the reasonable model thresholds.

Principle Component Analysis

- Applying pattern recognition technique in spectral analysis
- Importance of choosing the matrix mode
- What is the power of the Principle Component Analysis?
  - Describe data variability
  - Dimensionality reduction
  - Highlight the elements with most relevant information in a given data set
- PCA and Singular Value Decomposition
  - reducing noise in spectral observations often contaminated with telluric lines

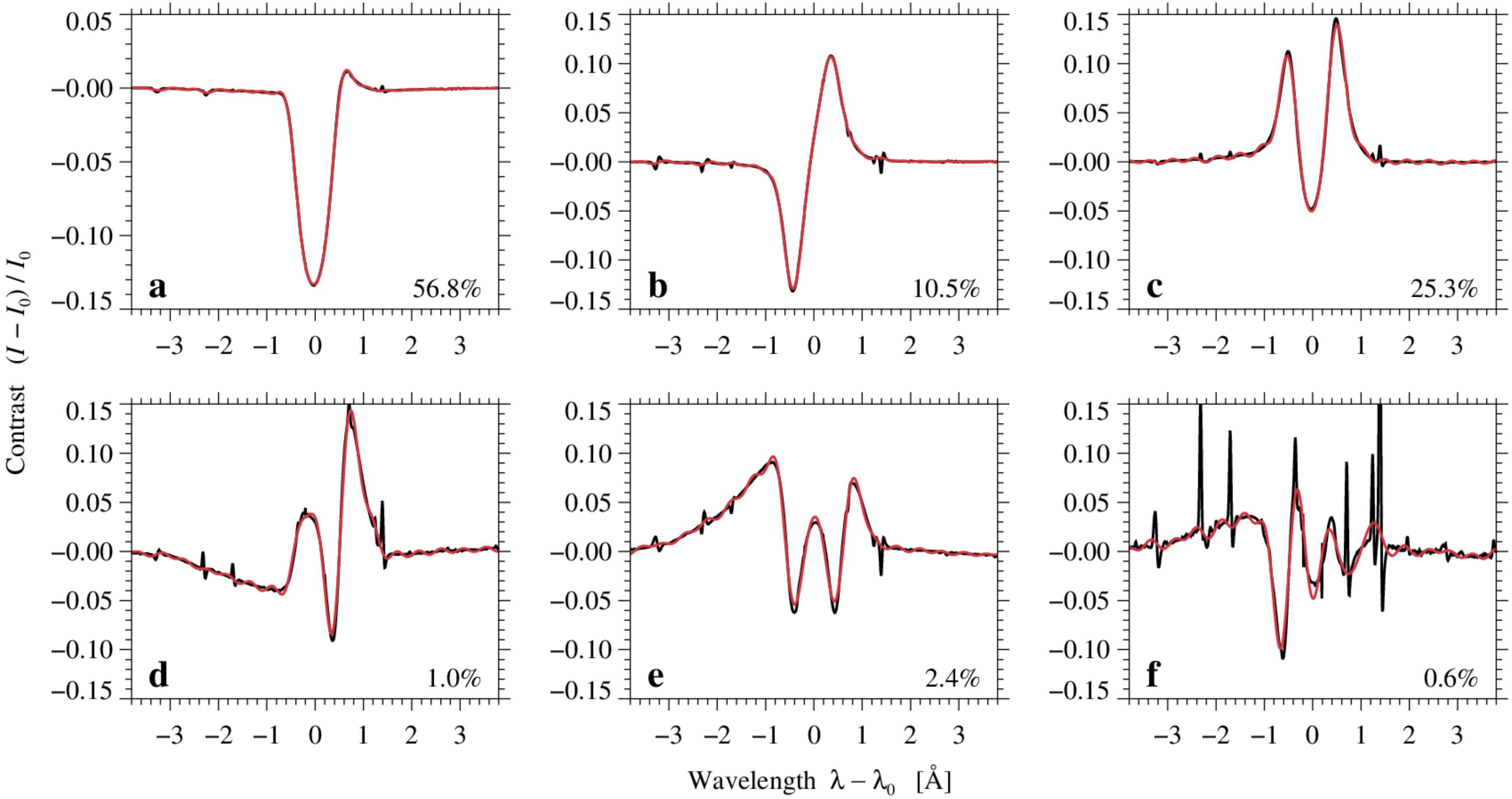


PCA and CM basis



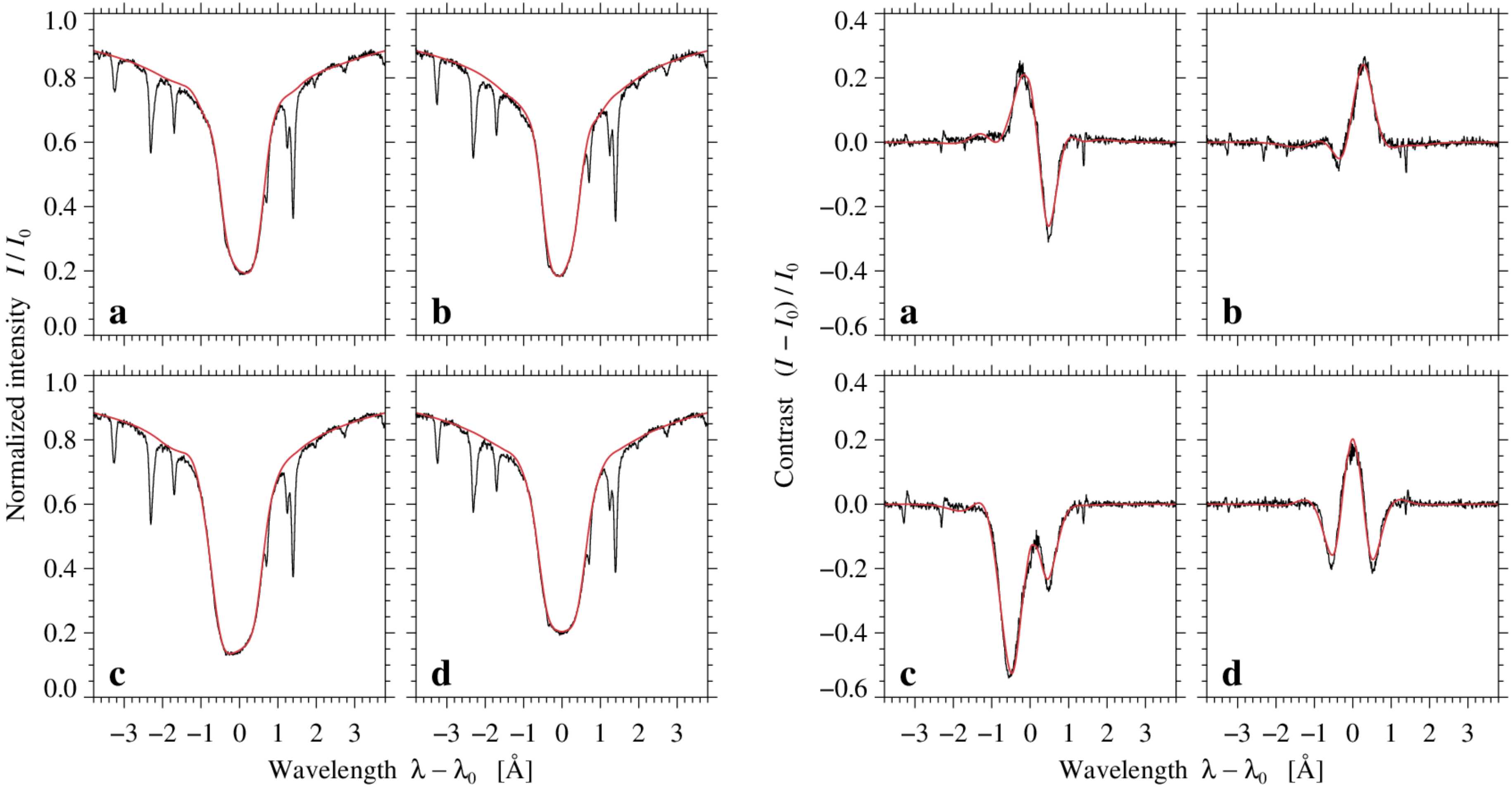
The first six eigenprofiles derived by applying PCA to the original Hα CLV observations. The first one presents the most prominent features in the data, the rest are arranged with respect to the number of minima and maxima.

PCA denoising of the real contrast profiles



The first six eigenprofiles obtained by applying PCA to the observed high-resolution echelle spectra. These are used to recreate most of the observed features. The red smooth profiles are obtained after PC decomposition and using the result for profile reconstruction.

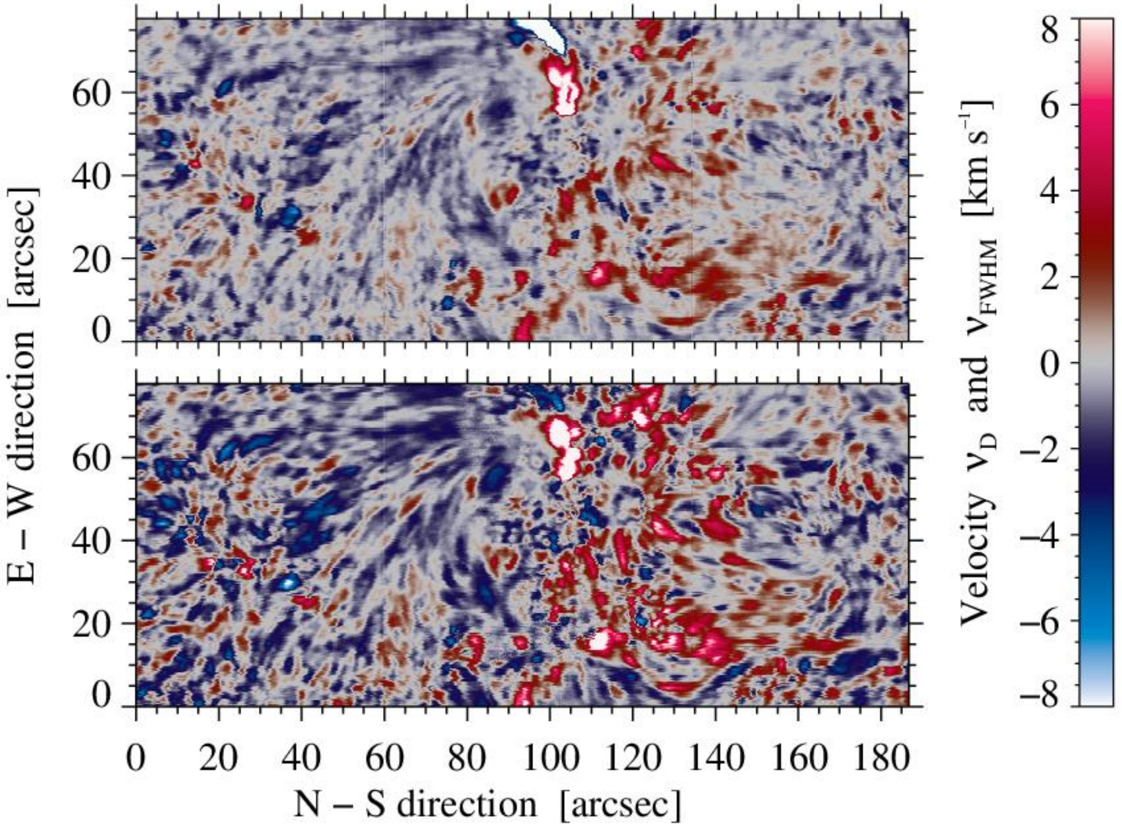
PCA decomposition and data denosing



Using the first 10 eigenprofiles, we are able to reconstruct the various features found in the observed spectra, e.g., blue and red shifted profiles, as well as, narrow and broad profiles and their corresponding contrast profiles.

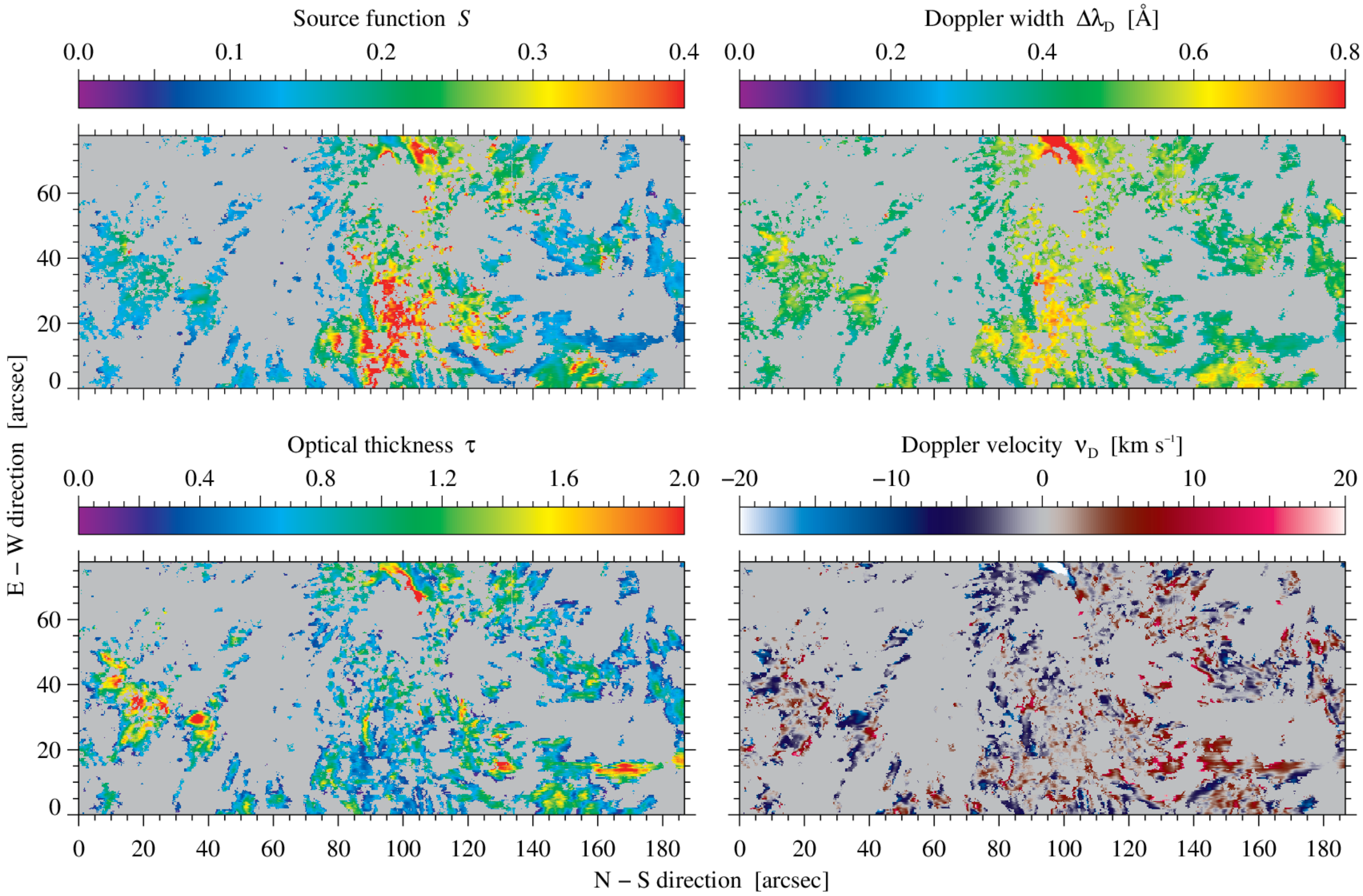
Physical Maps

- Three different sets of profiles are used as an input for computing physical maps from various parameters of the observed spectra:
  - original spectra
  - data denoised using PCA from observed spectra
  - data denoised using PCA from CM basis
- Physical maps:
  - absolute contrast
  - equivalent width
  - various methods for computing LOS velocities
  - bisectors
  - FWHM



Line-of-sight velocity maps computed from parabola fit of the line-core (bottom) and by using the FWHM (top). This allows us to trace the motion in the vicinity of the sunspots and the filament.

Cloud Model Inversion Maps



Maps of the four CM parameters inferred from the inversion of Hα profiles. In principle these four parameters can be computed either from from PCA decomposed contrast profiles using the cloud model database or using the original data.

Conclusion:

- **Uniform procedure for bulk processing of high-resolution echelle spectral data**
- **Exploiting iterative PCA approach**
  - refining training Cloud Model data base
  - refining CM inversion
  - denoising observed spectra
- **Facilitates the investigation of complex and dynamic fine structures in the solar chromosphere**
- **Results:**
  - Three input options for accurate physical maps
  - CM inversions

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Thank you for your attention!