Improved analysis of SONG spectra?

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Overview

- **Something about oscillations and spectra**
- **Normal way of fitting**
  - And why this is not ideal
- **SVD analysis**
  - And how that may be used to improve things
- **What does this mean for SONG?**

- **This is largely a review of Schou, 2018, A&A, 617, 111.**

Warning!

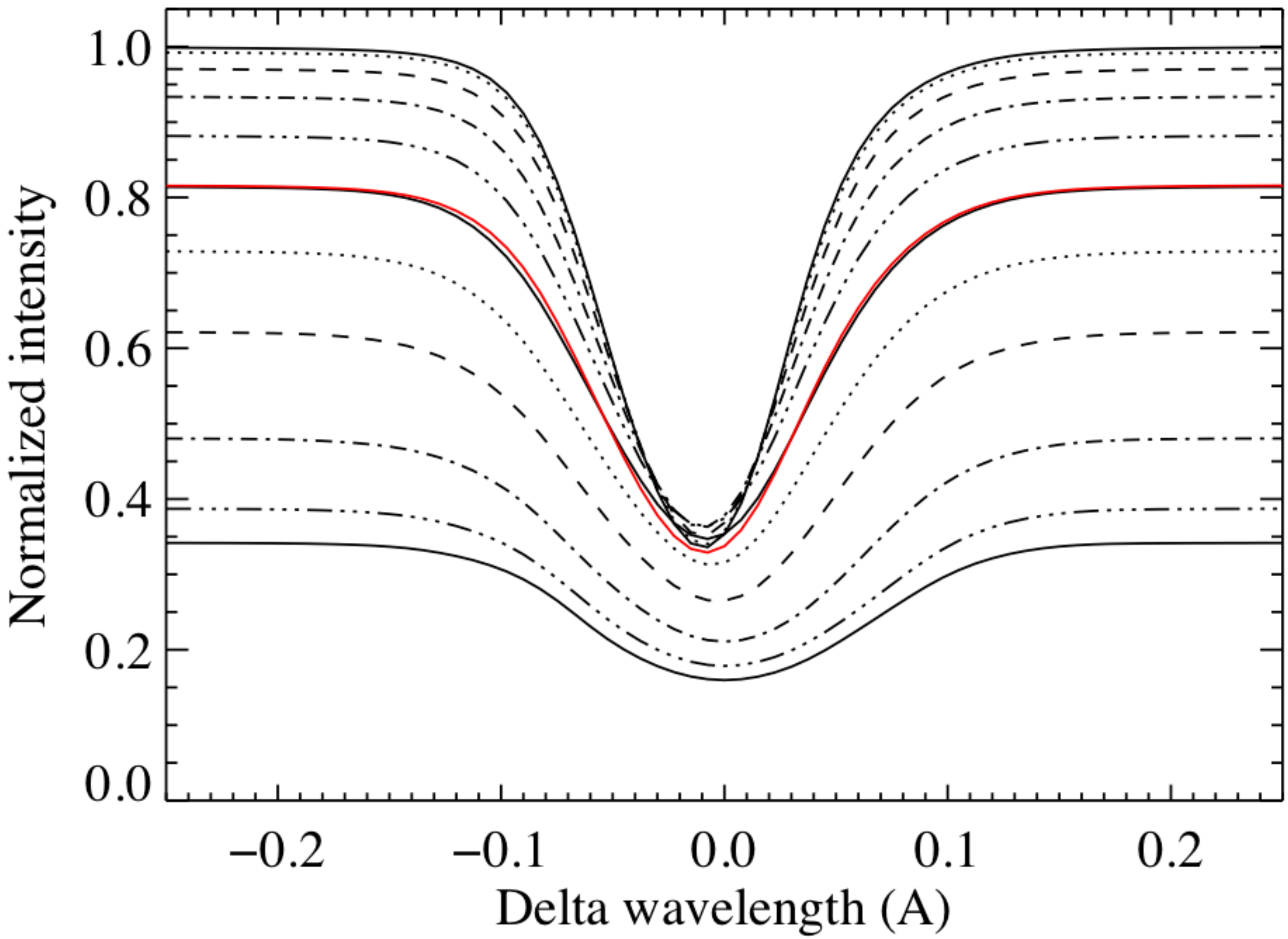
- From the referee:
- The motivation for the paper is strong. The SONG network will bring spectroscopic observations of stellar oscillations. Most asteroseismic observations have been photometric (e.g. Kepler). Schou?s paper introduces new (and arguably superior) methods for analyzing and understanding spectroscopic measurements of oscillations.
- [. . .]
- I recommend that it be rejected.

- Schou, 2018, A&A, 617, 111

Oscillations and spectra

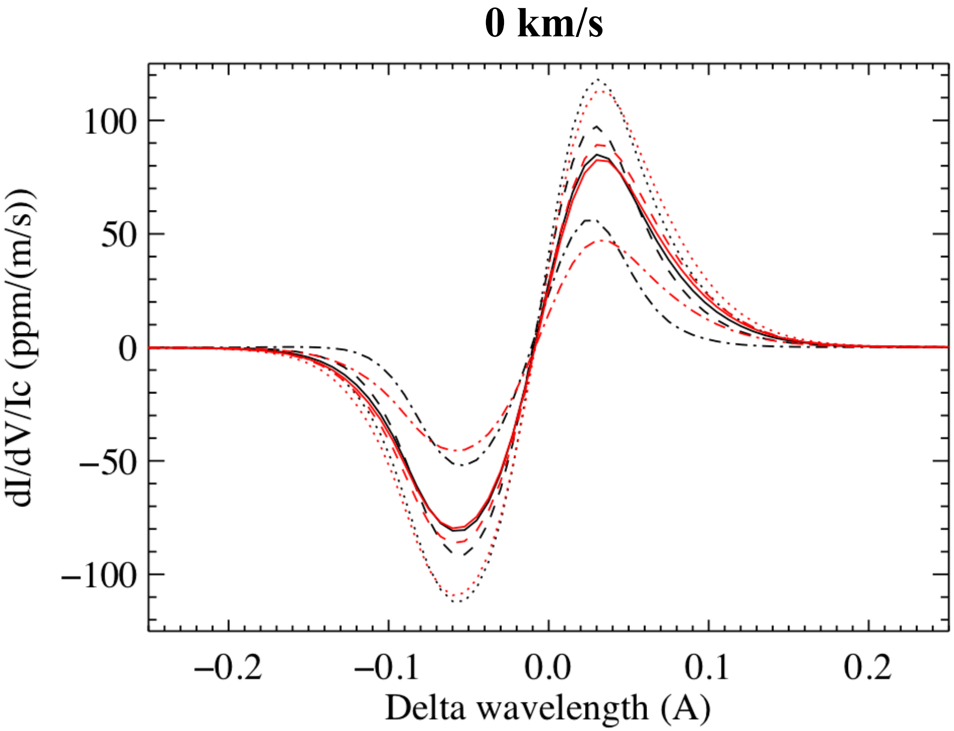
- **The horizontal part of the eigenfunctions are well approximated by spherical harmonics**
  - Radial velocity at fixed height is close to a Ylm
  - The horizontal velocities are close to derivatives of a Ylm
    - But small for solar-like oscillations at low degrees
  - The thermodynamic perturbations at fixed height are close to a Ylm
- **Spectral lines depend on observing angle**
  - Largely through different observing height
  - Good estimates can be obtain from simulations
  - Given perturbations to thermodynamics and velocity, spectral perturbations may be computed
    - But we don't know how to estimate the perturbations
    - Constant velocity with height is probably not too horrible an approximation
    - Thermodynamics is tough
- **To get spectral perturbations things need to be integrated over the disk**

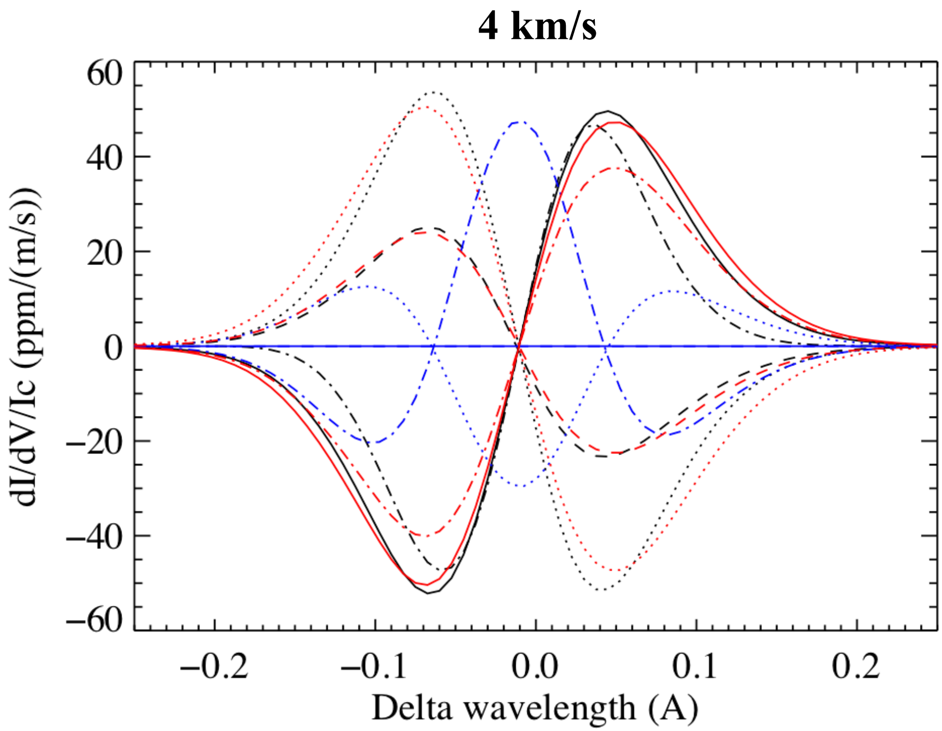
Simulated solar spectra



Spectral perturbations

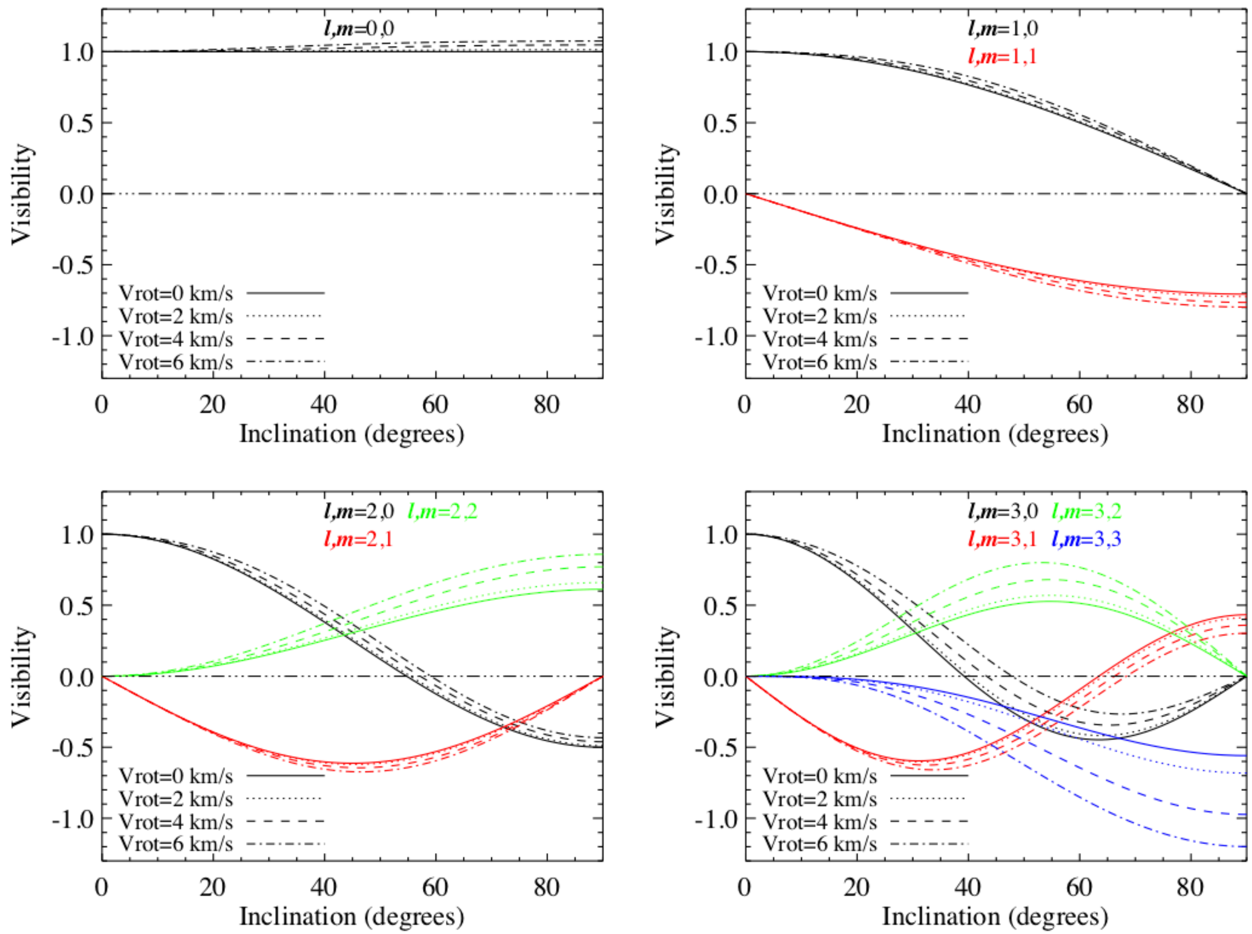
- **Results depend on rotation**
  - Black is perturbations for symmetric (cos mφ)
  - Blue for antisymmetric (sin mφ)
  - Red is derivative



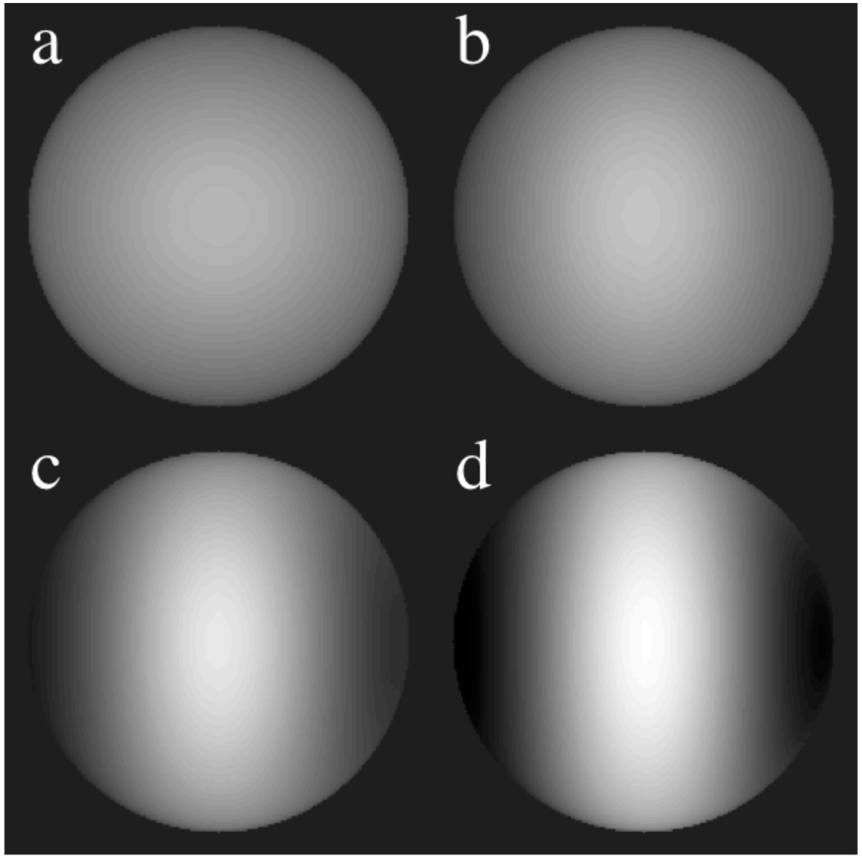


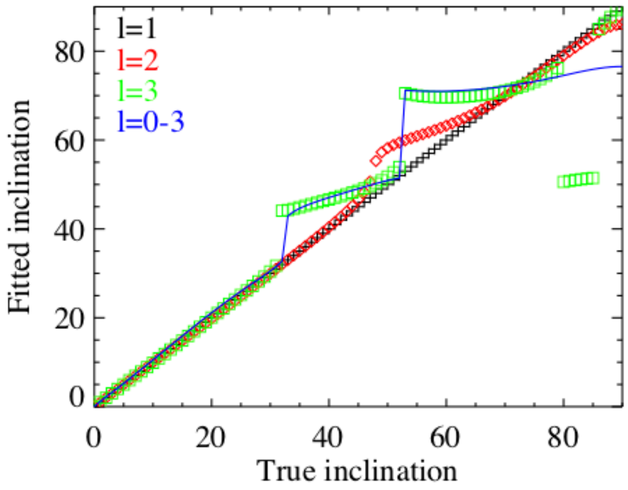
Normal way of fitting

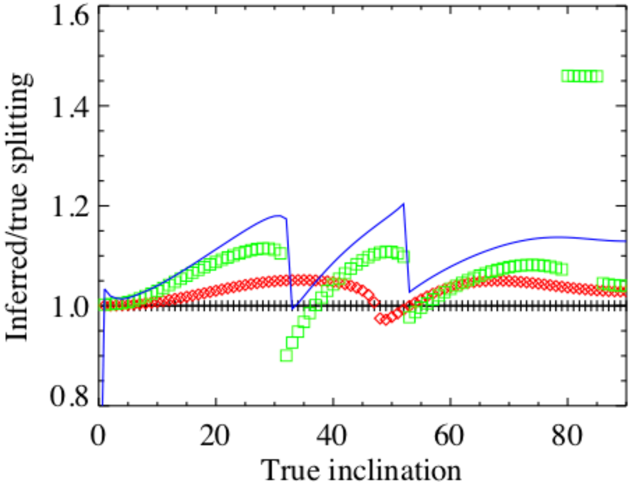
- Assume that at pure Doppler shift is a good approximation
- You can use planet finding codes (cross-correlation)
- But as just shown this is a poor approximation



More cross-correlation results

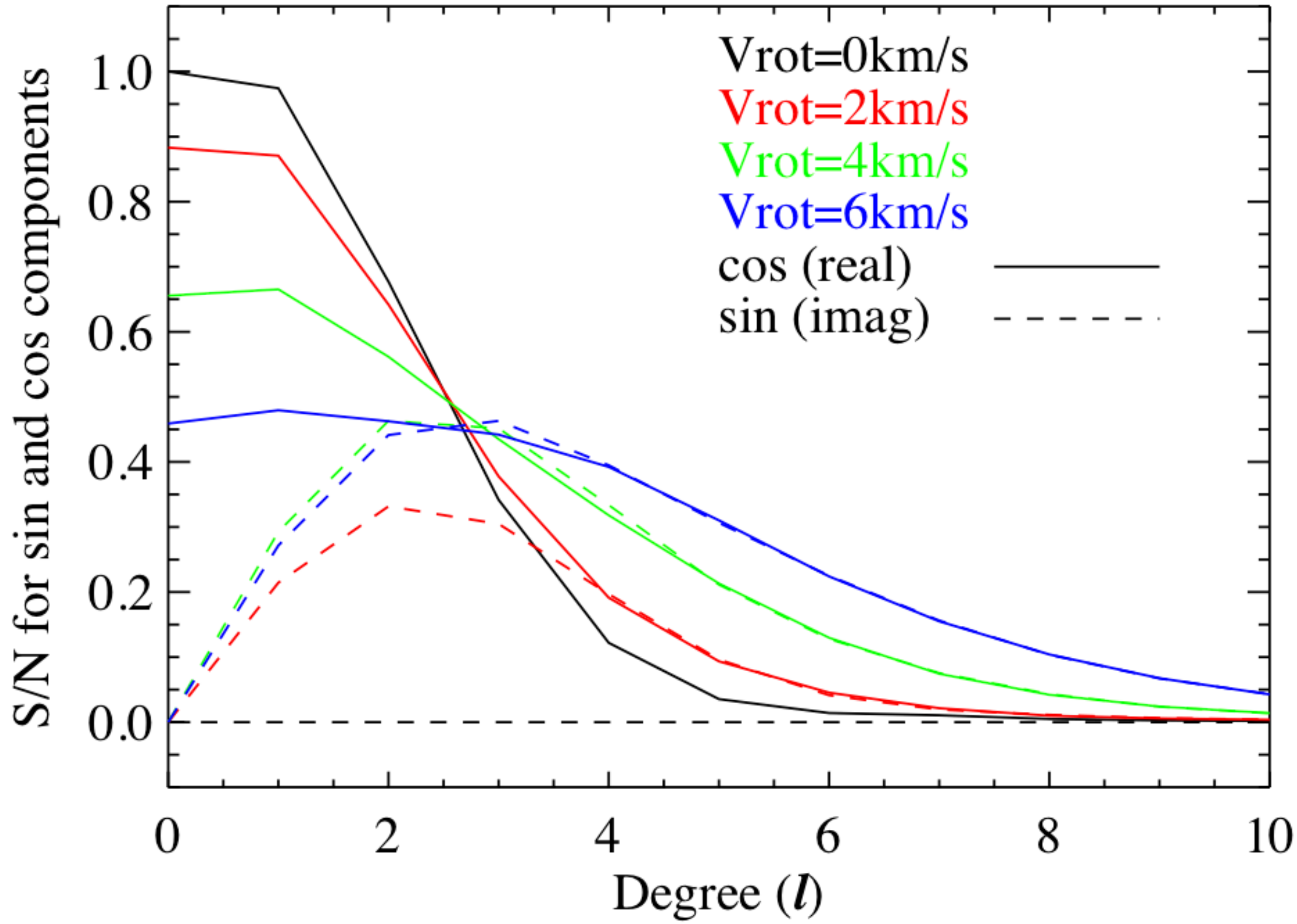






Least squares fit

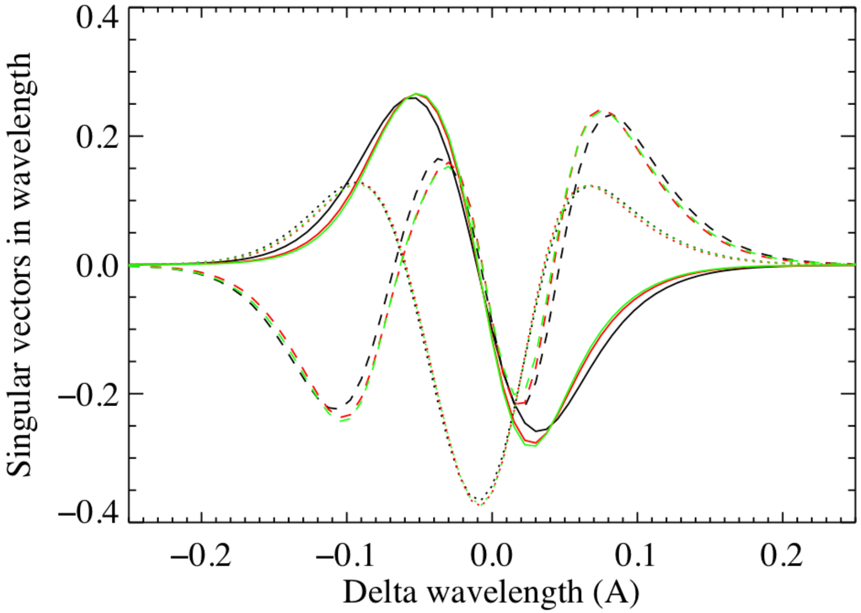
- **We could fit the expected signals for each mode to the spectra**
  - But each mode is different, which is inconvenient
  - On the other hand it does improve the situation

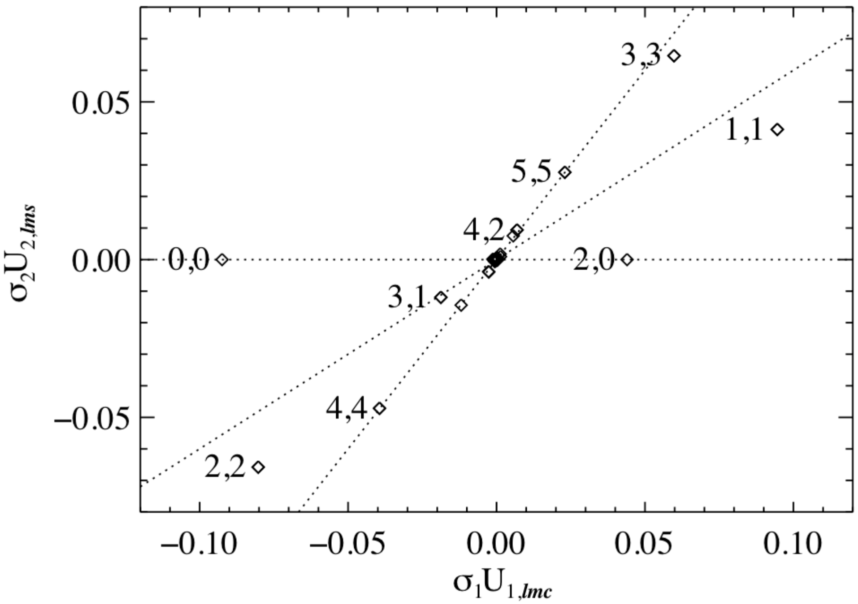


SVD based analysis

- **The perturbations from different modes are different**
  - But not very
- **So let's try an SVD on the expected perturbations**
  - That is write all the perturbations as a linear combination of a few terms
  - Optimized to limit the number of terms while retaining as much information as possible
- **Turns out that 3 terms capture essentially all the available information**
  - First is roughly Doppler
  - Second is roughly linewidth
  - Third is roughly line asymmetry
- **More modes can be detected**
- **Some amount of mode identification can be done**
- **Prograde and retrograde modes can be separated**

SVD - continued





Implications for SONG

- **Should fit for other quantities than Doppler**
  - May need to check a few details first
    - Spectrograph PSF
    - Presence/use of Iodine lines
    - …
- **May want to consider stars with optimal Vsini**
- **More work for all**…

- **Linewidth observations have been done in the past**
- **You should also ask me about how to improve spectrographs!**

Spectrograph design

A Different Type of Spectrograph

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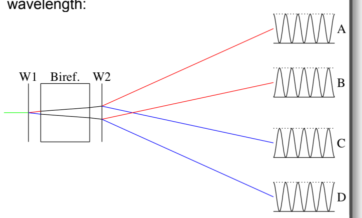
Abstract: A persistent problem with spectrographs, especially those designed for radial velocity searches, has been to achieve the required stability.
Generally the calibration has been performed by introducing a calibration signal on top of the stellar spectra, either in the form of absorption lines (e.g. using an Iodine cell) or emission lines (e.g. a ThAr lamp or a laser comb).
Unfortunately these solutions have a number of problems, including removing signal, adding photon noise, unresolved lines, poor spectral coverage and cost.
Here I present an outline of an alternative approach, based on techniques used in solar instrumentation, which does not add or remove any light and which provides a near perfect wavelength coverage.

Background: As mentioned above it is necessary to calibrate spectrographs by introducing a calibration signal. Desirable features of those include not degrading the S/N (no photons added or subtracted), covering the entire spectrum, that the stellar light and calibration signal follow each other through the relevant parts of the instrument and that it is itself inherently stable or can be easily calibrated. None of the current methods have all of these features.

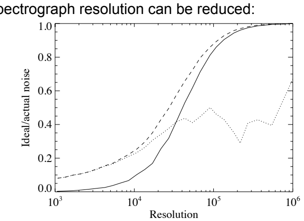
Basic idea: One way to achieve the desired features would be to split the light into two or more narrowly spaced beams, without loss of light and with each beam multiplied by a fixed pattern in wavelength:



Cartoon of how a single (~telecentric) beam (green) can be split up into beams with two different (red and blue) modulation patterns imposed. Angles are exaggerated.

These beams can then be passed through a regular cross dispersed echelle spectrograph creating narrowly spaced copies of each order multiplied by one of two different calibration patterns. Notice that the transmissions sum to 1 and that there is no net loss of light.

Implementation: This all sounds good, but how can this be implemented in practice?
W1/2 are Wollaston prisms, sending the horizontal and vertical polarization in different directions.
The central element can either be a birefringent element (i.e. a Lyot element) or an imaging Michelson, in either case rotating the polarization by an amount changing with wavelength. Both have been used extensively in solar physics and are known to have extremely good stability.
A side effect of adding such an element is that the spectrograph resolution can be reduced:



Spectrograph performance as a function of resolution without (solid) and with (dashed) the addition of the calibration elements. Performance is relative to a perfect infinite resolution spectrograph calculated from an FTS spectrum of the Sun between 600nm and 625nm.

Conclusion: Clearly this idea still needs some development. Having said that the added pieces are well understood and tested. The back end spectrograph is also largely unchanged. The main change will be a change in the cross dispersion and likely an increase in the CCD area.
Note that some of the ideas have been discussed by Erskine.

Spectrograph design - continued