SIR Exercises

Download exercises from:

https://github.com/BasilioRuiz/SIR-course

SIR Exercises: Goals

The main goals are:

Ex 1: Testing and first contact with synthesis, inversion and result visualization
Ex 2: HINODE data. Analysis of strong and symmetric signals. How many nodes should be used? Is it always better to use many nodes? Weights of Q, U & V
Ex 3: Error bars and uncertainties determination
Ex 4: SPINOR data. How to select lines in a large spectral region. Using macro- and micro-turbulence. Gradients determination.
Ex 4 bis: Optional. Strong asymmetries and use of stray-light.
Ex 5: HINODE data. High signal to noise profiles. Extremely weak linear polarization signal but large asymmetries.
Ex 6: Stokes V with 3 lobes. One versus 2 components inversions.
Ex 7: IBIS profiles: high spatial resolution bad modest spectral sampling. Introducing points in the spectra that will not be consider in the chi^2
Ex 7bis: Optional, because the topic was covered by ex 7 but with CRISP data. Strong asymmetric profiles and use of stray light. Very high spatial resolution bad poor spectral resolution.
Ex 8: FIRS profiles. How reliable are the obtained gradients in different solar scenarios?
Ex 9: Inversion of gas pressures. Sensitivity to gas pressure. How to evaluate the Response functions (RF) to gas pressure from the RF to temperature and electronic pressure.

Exercise 1

Spectral synthesis and inversion of synthetic profiles

- Use HSRA model to synthesize Stokes profiles with
    1. constant B, inclination and v_{LOS} (e.g., 1 kG, 60º, 2 km/s)
    2. constant v_{LOS}, gradients of B and inclination
    3. gradients of B, inclination and v_{LOS}

- Invert profiles from (3.), starting from initial guess model with flat stratifications of B, v_{LOS} , and inclination (modify hsra11.mod)
    - 1 node in B, v_{LOS}, inclination
    - 2 nodes in B, and v_{LOS} inclination

```
IDL> read_model,'hsra11.mod',logtau,T,pe,mic,B,V_LOS,gamma,phi,z,pg,rho,mac,filling,stray
IDL> B=1000+400.*logtau          &   v=2.e5+0.*logtau       & gamma=60.+  0.*logtau

IDL> write_model,'model1.mod',logtau,T,pe,mic,B,V_LOS,gamma,phi,z,pg,rho,mac,filling,stray
```

Exercise 2

Inversion of profiles from dark-cored penumbral filament.

• Hinode/SO observations with SNR~1000, no telluric lines, 2 lines Fe I 630.1 & 630.2 nm. Strong, symmetric signals.

1. What kind of model would you use to invert them?
2. Can the fit be improved with more nodes in T? (use 2 cycles!)
3. What happens with 2 nodes in B and v_{LOS}?
4. What happens with 10 nodes in B and v_{LOS}?

If no instrumental PSF is available, use macroturbulence to mimic its effect (i.e, invert v_{mac})

Use more weight for Q, U and V to force better fits to those parameters

Exercise 3

Error estimation and Region of sensitivity.

- Evaluate the error bars for magnetic field strength, inclination and azimuth for the last inversion of Exercise 2

- Evaluate the region of sensitivity of the azimuth.

SIR writes the error bars in a .err file that you can read using:

IDL> read_model,' [   ].err',logtau,T_err,p_err,mic_err,B_err,V_LOS,gamma,phi,z,pg,rho,mac,filling,stray

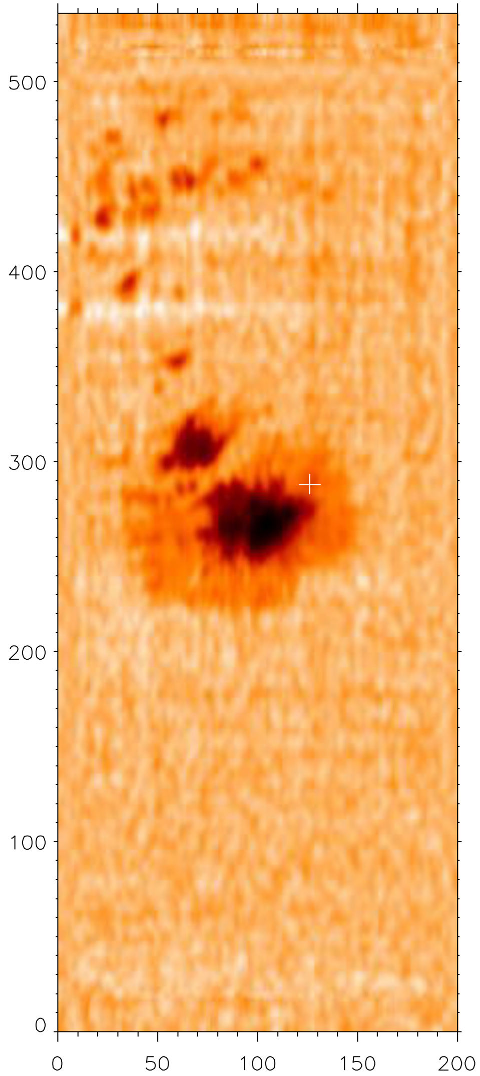
And the region of sensitivity by:

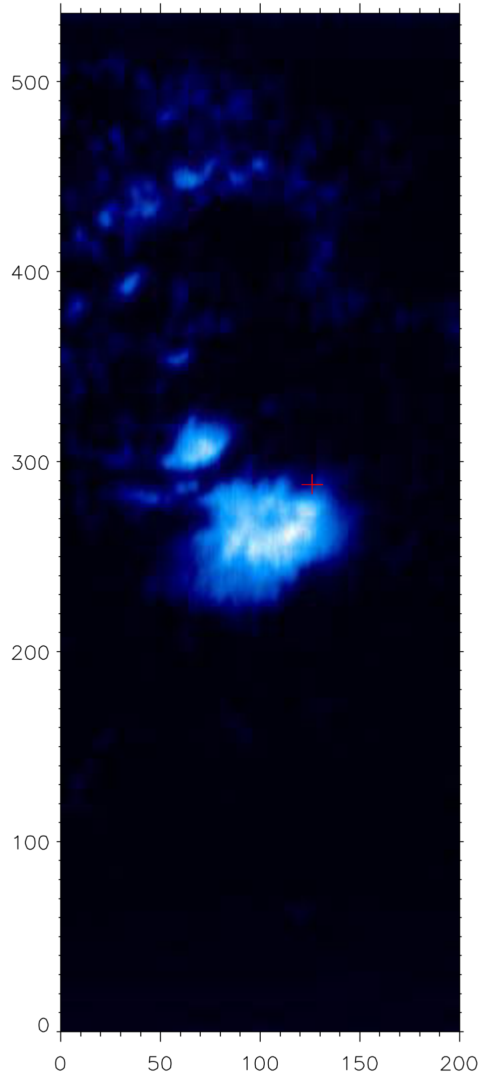
IDL> sensitivity, Stokes_obs,Stokes_syn,model,RF,logtau,uncertainties

Exercise 4

Inversion of SPINOR data

SPINOR: Spectro Polarimeter for Infrared and Optical Regions (NSO/HAO)
@ Dunn Solar Telescope on Sacramento Peak





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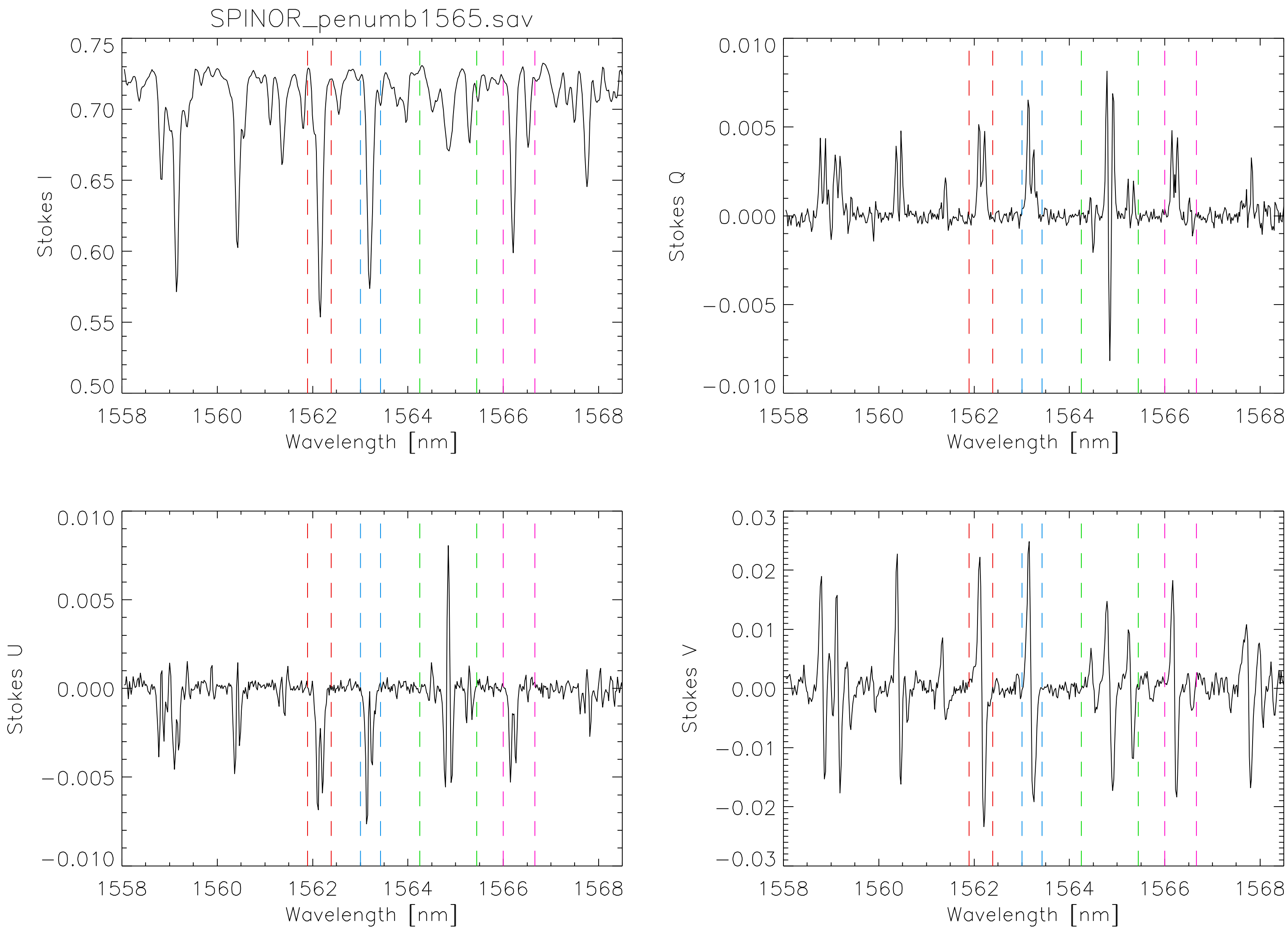


Exercise 4

Inversion of SPINOR data

SPINOR: Spectro Polarimeter for Infrared and Optical Regions (NSO/HAO)
@ Dunn Solar Telescope on Sacramento Peak

Multiline inversion including blends

1. Select the spectral regions around the Fe I lines:
   1562.1, 1563.2, 1564.5 (blended with 64.85 & 65.29), 1566.2 (blended with 66.5)
2. Write the profile and grid files
3. Invert, including micro- and macro-turbulence (because we have not used PSF). Use 2 cycles to obtain gradients (because we have several lines), increasing number of nodes in 2nd cycle.

Exercise 4 bis

Inversion of facular profiles in quiet Sun.

Advanced Stokes Polarimeter (HAO) observations, averaged over facular region, SNR~10000, but poor spatial resolution.
Two lines Fe I 630.1 and 630.2 nm (plus telluric lines!) .
Strong signals, large Stokes V area and amplitude asymmetries.

1. What kind of model would you use to invert them?
2. Use two cycles, increasing number of nodes in 2nd cycle.
3. Invert stray-light fraction, micro- and macro-turbulence.

We invert Stokes I and V only, so vertical fields should be assumed.
Use large negative number (e.g., -2) in profiles to ignore blends in Stokes I during inversion .
Use instrumental PSF and macroturbulence at the same time.
Use stray light profile.
Use weights of 10 and 100 for Stokes V.

Exercise 5

Inversion of quiet-Sun internetwork.

Hinode/SP observations at disk center, integrated for 6 min, SNR~10^5, still high spatial resolution.
Two lines Fe I 630.1 and 630.2 nm
Extremely weak signals, but linear polarization clearly seen.
Large asymmetries.

1. What kind of model would you use to invert them?
2. Use three cycles with increasing number of nodes.
3. Invert stray-light fraction, microturbulence (flat stratification).
4. Interpret resulting model .

No need for macroturbulence when high-resolution data are inverted using telescope PSF
Use following weights: 1,4,4,4

Exercise 6

Inversion of sunspot penumbral profiles near PIL

Hinode/SP observations with SNR~1000, no telluric lines, two lines Fe I 630.1 and 630.2 nm.
Strong signals, but Stokes V profile with three lobes...

1. What kind of model would you use to invert them?
2. One-component model with opposite magnetic along LOS? Two-component model?
3. Try both!

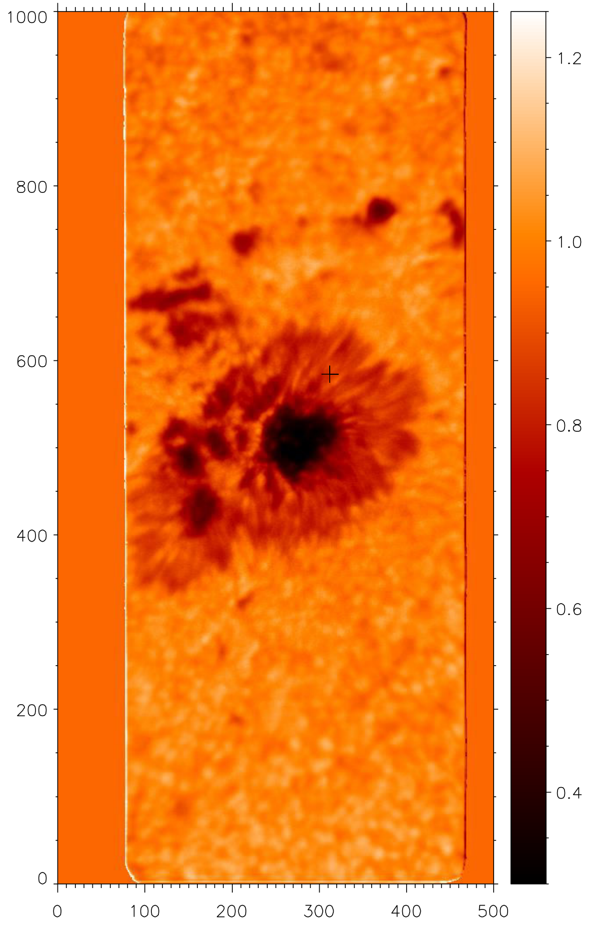
Inversion of these profiles will not be easy. Do your best!
Give more weight to Stokes V to force better fits. Increase weight with cycle.
Use instrumental PSF and macroturbulence at the same time.
If everything fails, use superpowers....

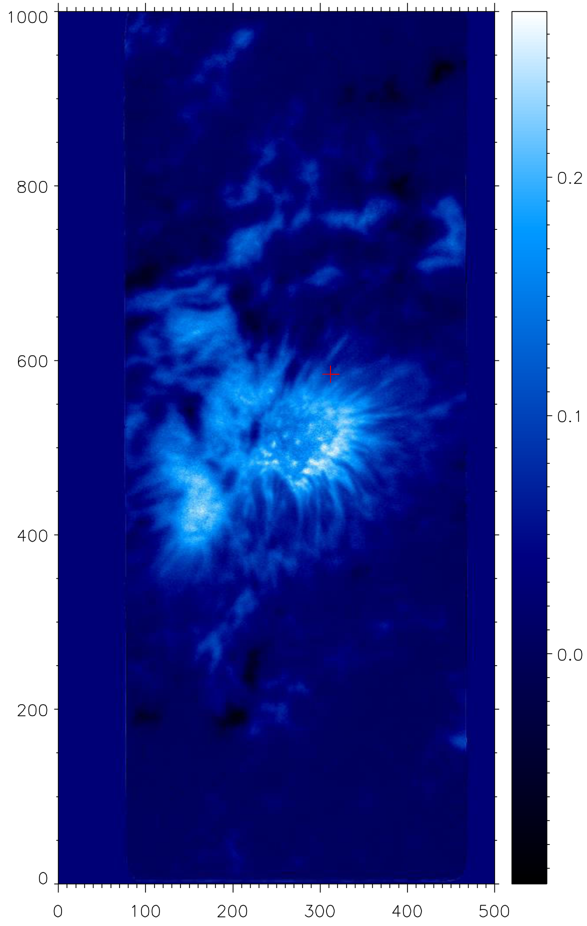
Exercise 7

Inversion of IBIS profiles

IBIS: Interferometric Bidimensional Spectropolarimeter (INAF_Arcetri OBS/NSO)
@ Dunn Solar Telescope on Sacramento Peak

Penumbra observed at Fe I 6173 A

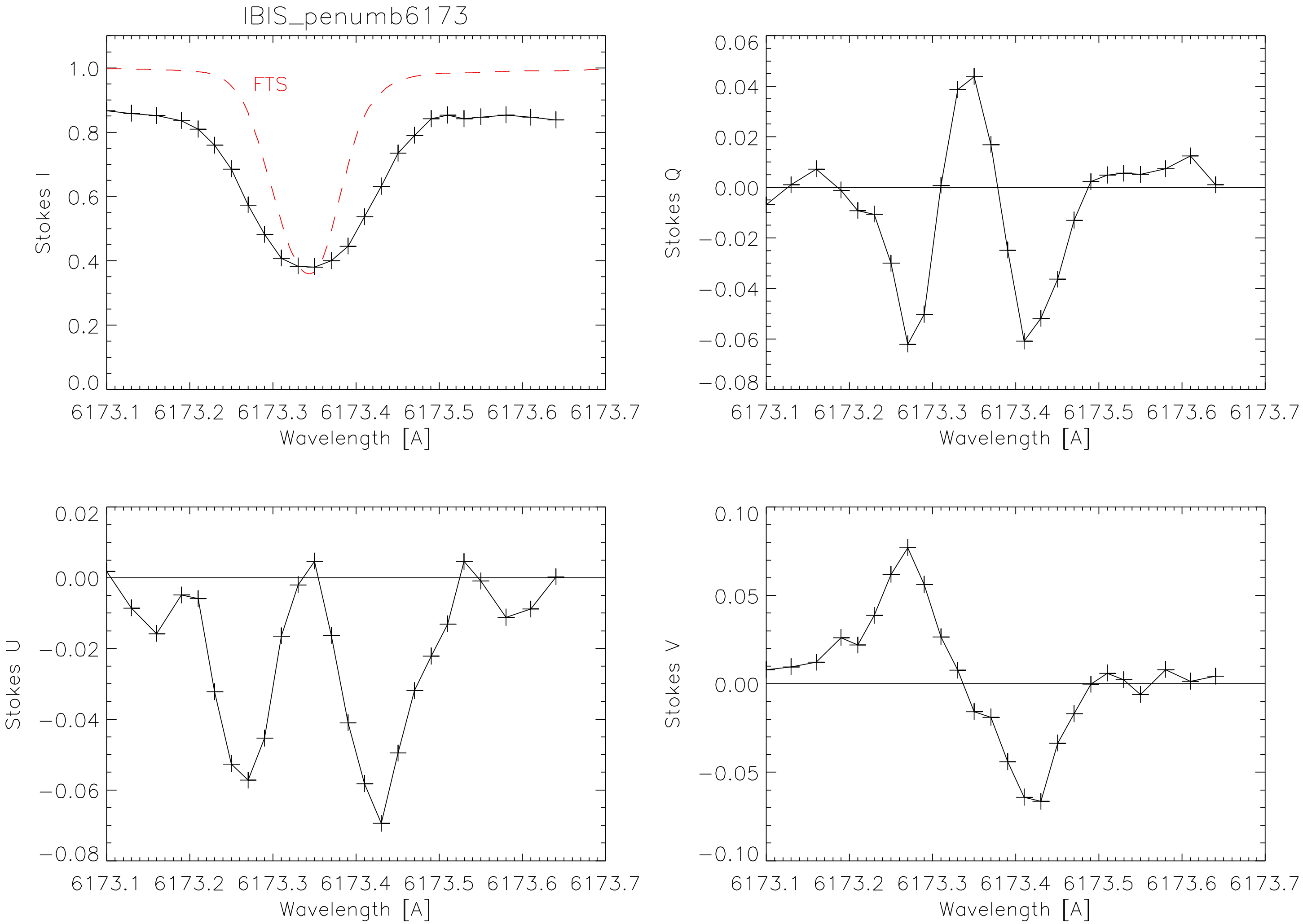




Exercise 7

Inversion of IBIS profiles

IBIS: Interferometric Bidimensional Spectropolarimeter (INAF_Arcetri OBS/NSO)
@ Dunn Solar Telescope on Sacramento Peak



Exercise 7

Inversion of IBIS profiles

IBIS: Interferometric Bidimensional Spectropolarimeter (INAF_Arcetri OBS/NSO)
@ Dunn Solar Telescope on Sacramento Peak

High spatial resolution

1. Profiles are not equally spaced in wavelength: interpolate to a 10 mA resolution and write a "-1" over the new points
2. The profiles are wider than FTS: Consider to include the spectral PSF and a macroturbulence.

Example of Stokes profiles observed with a Fabry-Pérot interferometer.
High spatial resolution, but modest spectral resolution (20-30 mA at 617 nm).
To include points in the profile you can use:

```
IDL> introduce_points,x,si,sq,su,sv, x1,si1, sq1,su1,sv1
```

Where x is the old grid and x1 the new one

Exercise 7bis

Inversion of CRISP profiles from sunspot penumbrae

SST/CRISP observations with SNR~500, sequential spectral sampling of Fe I 617.3 nm (30 wavelengths in ~30 s)
Strongly Doppler-shifted polarization profiles

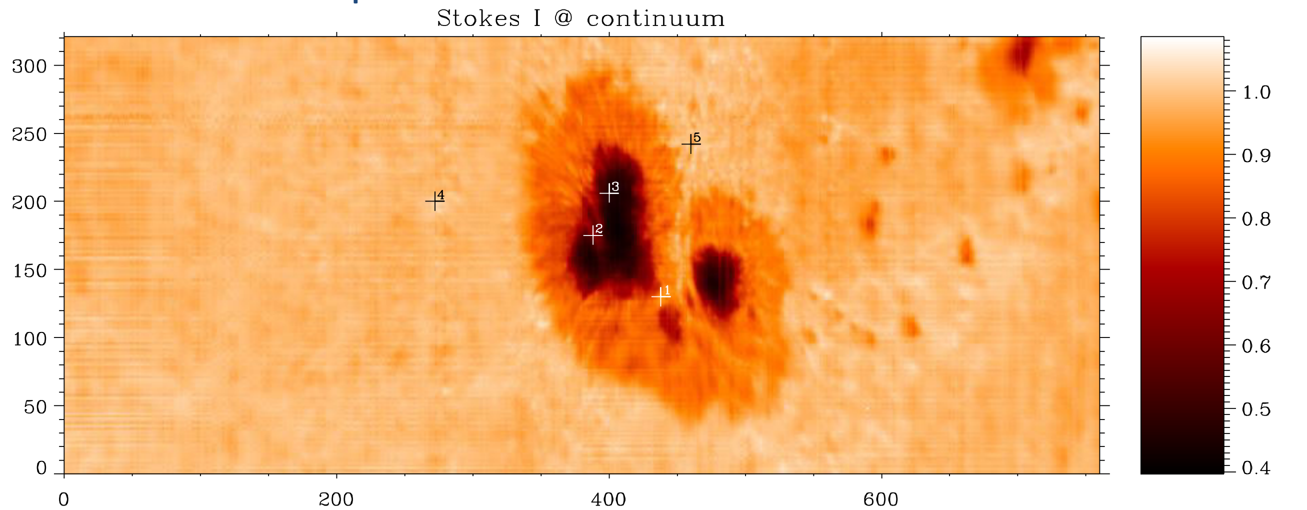
1. What kind of model would you use to invert them?
2. Include stray-light contamination, and a small weight for Q & U stokes profile (for instance: 10, 0.1,0.1,10)

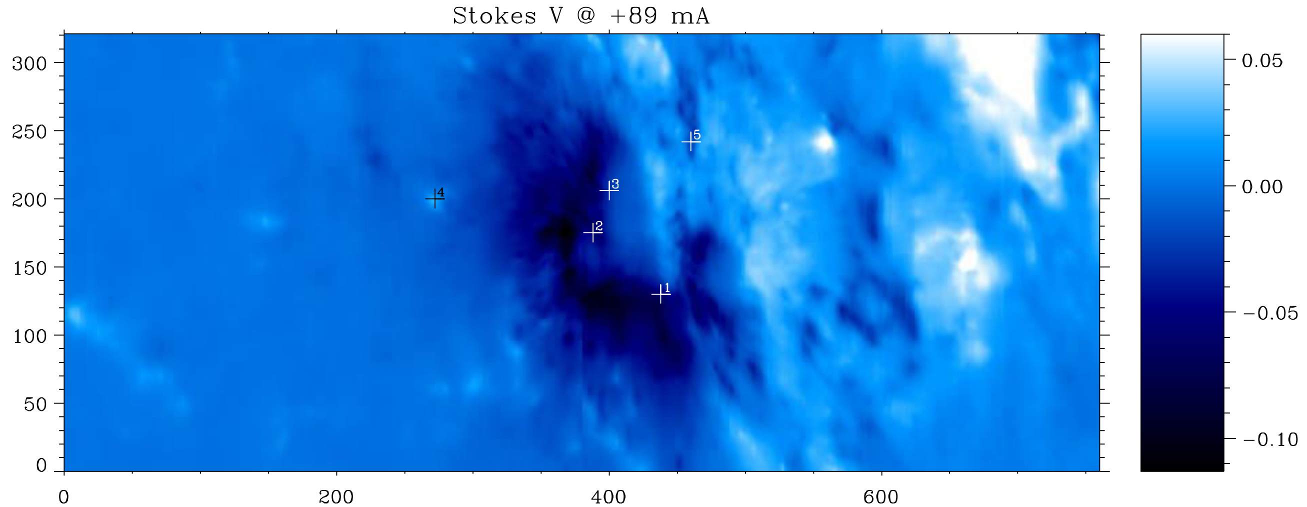
Example of Stokes profiles observed with a Fabry-Pérot interferometer.
Extremely high spatial resolution, but modest spectral resolution (~50 mA at 617 nm).
Sequential sampling of line means first and last wavelengths are observed ~30 s apart.

Exercise 8

Inversion of FIRS profiles

FIRS: Facility Infrared Spectropolarimeter (Univ. Hawai'i/NSO)
@ Dunn Solar Telescope on Sacramento Peak





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Inversion of FIRS profiles

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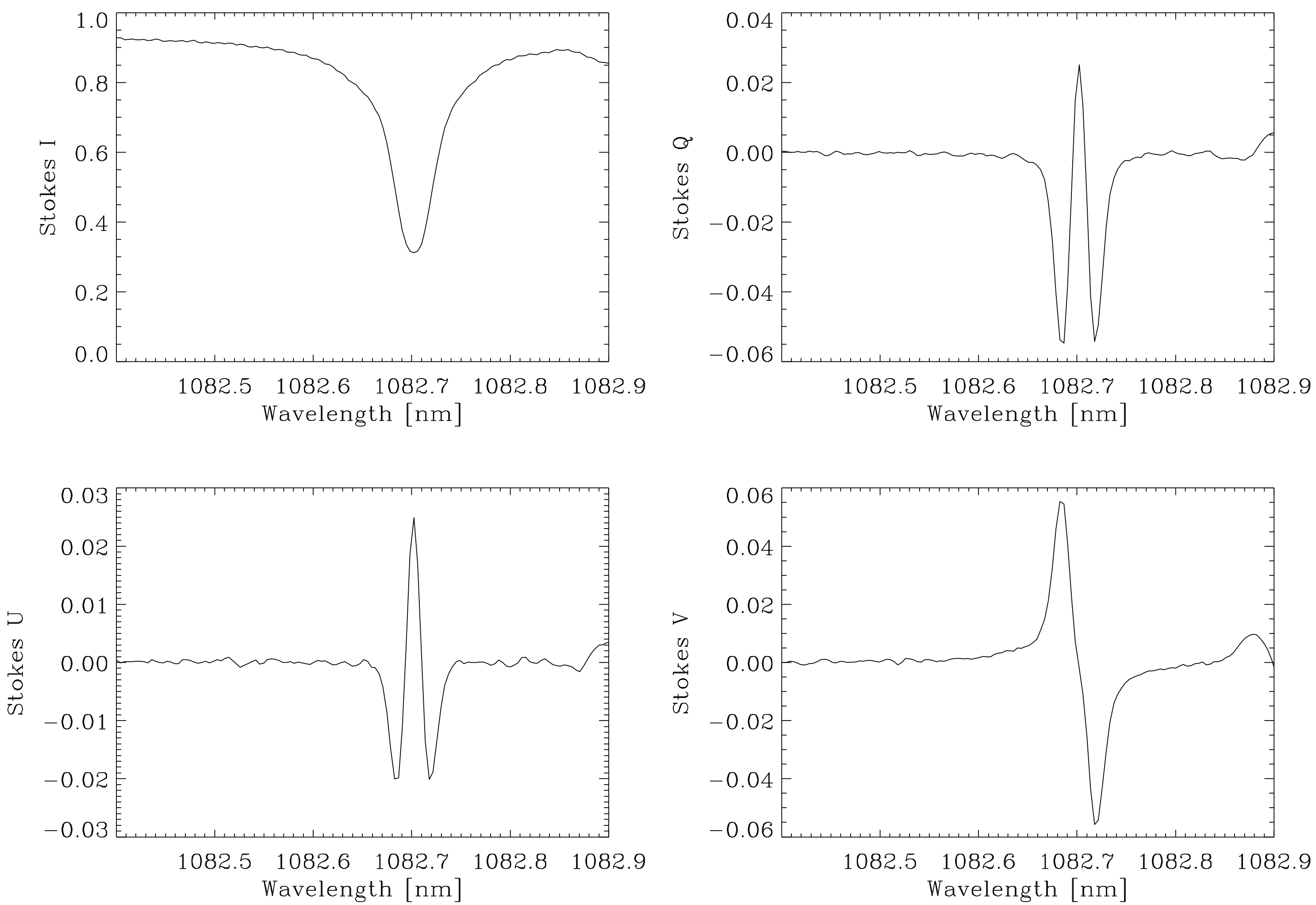

Exercise 8

<u>Inversion of FIRS profiles</u>

FIRS: Facility Infrared Spectropolarimeter (Univ. Hawai'i/NSO)
@ Dunn Solar Telescope on Sacramento Peak

1. Invert the 5 profiles of the pixels marked on the map. Try to determine gradients of B and V_LoS in the second cycle.

2. Are these gradients reliable?

Exercise 9

Inversion of Gas Pressure (simulated data)

We have selected the spectral region 614.7 – 615.1 containig Fe I, Fe II, Ti & V lines, because they show different sensitivity to T & Pg

1) I have perturbed the VALC model introducing a 10% perturbation in T & Pg, and synthetized the profiles. Try to recover T and Pg perturbations by inverting the simulated profiles.

2) I have included a velocity perturbation. Try to recover T, Pg and v_{LOS} perturbations.

3) Determine the region of maximum sensitivity (the logtau range) to relative perturbation of Pg using the Response Functions of T and Pe. Which is the minimum S/N ratio we would need in order to recover a Pg perturbation of around a 10%?

- For the case 2) use several cycles, first inverting T & Pe in Hydrostatic Equilibrium and later allow also for Pe perturbations.
- Evaluate the RF to T & Pe. You can read it using:
  IDL> read_RF_nomag, 'guess_4.rpe' ,rpe ,ntau, nlam
  To evaluate RF to Pg apply the chain rule. You can calculate dPg/dPe and dPg/dT by using
  IDL> Pgderivatives,T,Pe,Pg,dlogPgdT,dlogPgdPe
  This programs calls to the fortran program Pgderivatives_i.x. To compile this program (in the SIR folder):
  make fc=gfortran Pgderivatives_i.x or make Pgderivatives_i.x (if you use the ifort compiler)
  To get the RF to relative perturbation multiply the RF by the parameter.
- Evaluate, for each optical depth, the maximum response (RF at the wavelength at which |RF| is max).