Determining properties of the solar atmosphere by inversion

Emily Atkinson & Han Uitenbroek

Image Credit: JAXA/NASA

Introduction

- Focusing on observing efficiency, not computational efficiency
- Spectral range vs. rate

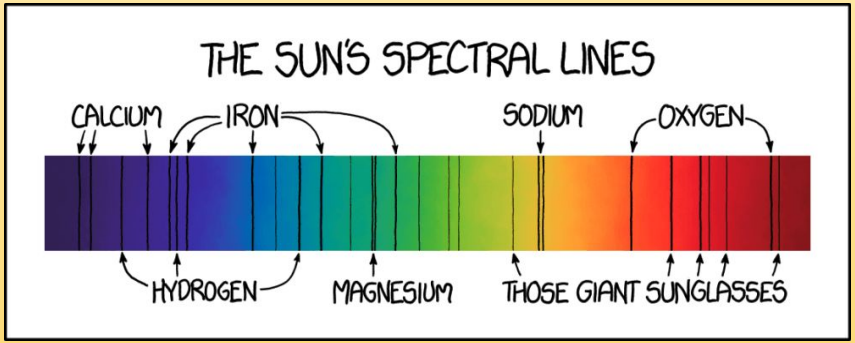

Image credit: xkcd

Image Credit: NSO

Stokes' Profiles

- I, total intensity of light
- Q, linearly polarized light
- U, light polarized at 45°
- V, circularly polarized light

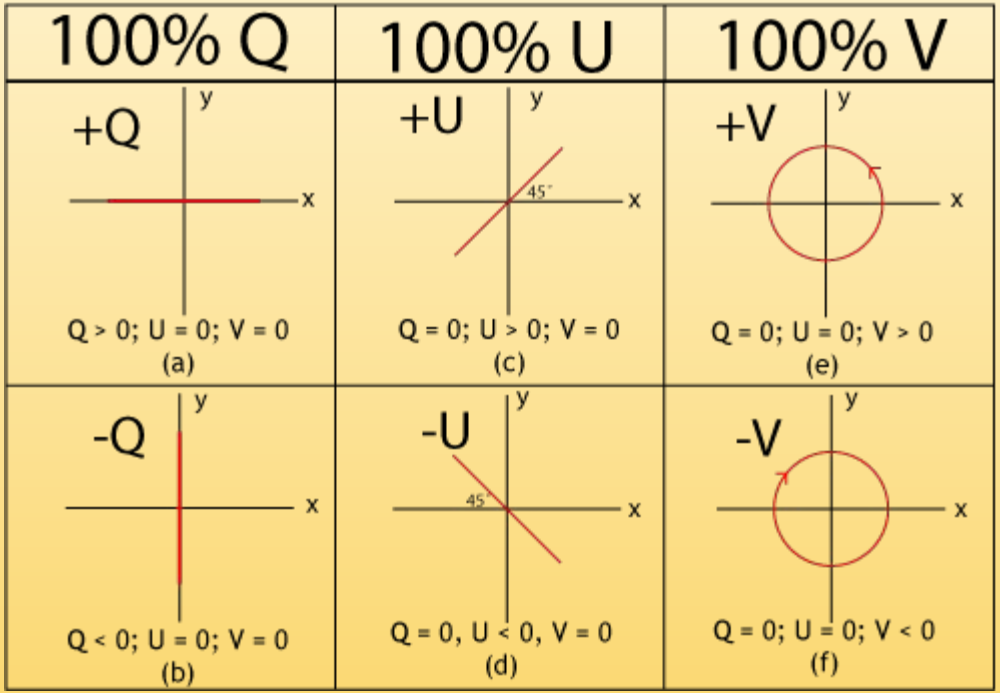

Image Credit: Dan Moulton

SIR

- One of many inversion codes
- Two modes:
  - Synthesis
  - Inversion

sir.trol
~/Source/SIR/Tests/Fine

```
Number of cycles          (*):3         ! (0=synthesis)
Observed profiles         (*):profile.per !
Stray light file             :          ! (none=no stray light contam)
PSF file                     :          ! (none=no convolution with PSF)
Wavelength grid file      (s):wavelength.grid ! (none=automatic selection)
Atomic parameters file       :LINES     ! (none=DEFAULT LINES file)
Abundances file              :THEVENIN  ! (none=DEFAULT ABUNDANCES file)
Initial guess model 1     (*):guess.mod  !
Initial guess model 2        :
Weight for Stokes I          :1               ! (DEFAULT=1; 0=not inverted)
Weight for Stokes Q          :1                 ! (DEFAULT=1; 0=not inverted)
Weight for Stokes U          :1                 ! (DEFAULT=1; 0=not inverted)
Weight for Stokes V          :1                 ! (DEFAULT=1; 0=not inverted)
AUTOMATIC SELECT. OF NODES?  :0,0,1                ! (DEFAULT=0=no; 1=yes)
Nodes for temperature 1      :2,5,*
Nodes for electr. press. 1   :
Nodes for microturb. 1       :0,1
Nodes for magnetic field 1   :1,4,8
Nodes for LOS velocity 1     :1,4,6
Nodes for gamma 1            :1,4,8
Nodes for phi 1              :1,4,8
Invert macroturbulence 1?    :1                ! (0 or blank=no, 1=yes)
Nodes for temperature 2      :
Nodes for electr. press. 2   :
Nodes for microturb. 2       :
Nodes for magnetic field 2   :
Nodes for LOS velocity 2     :
Nodes for gamma 2            :
Nodes for phi 2              :
Invert macroturbulence 2?    :                 ! (0 or blank=no, 1=yes)
Invert filling factor?       :                 ! (0 or blank=no, 1=yes)
Invert stray light factor?   :                 ! (0 or blank=no, 1=yes)
mu=cos (theta)               :1.                 ! (DEFAULT: mu=1. mu<0 => West)
Estimated S/N for I          :100              ! (DEFAULT: 1000)
Continuum contrast           :                 ! (DEFAULT: not used)
Tolerance for SVD            :                 ! (DEFAULT value: 1e-4)
Initial diagonal element     :                 ! (DEFAULT value: 1.e-3)
Splines/Linear Interpolation :               ! (0 or blank=splines, 1=linear)
Gas pressure at surface 1    :             ! (0 or blank=Pe boundary cond.
Gas pressure at surface 2    :          ! (0 or blank=Pe boundary cond.
Magnetic pressure term?      :0                 ! (0 or blank=no, 1=yes
NLTE Departures filename     :               ! blank= LTE (Ej. depart_6494.dat'
```

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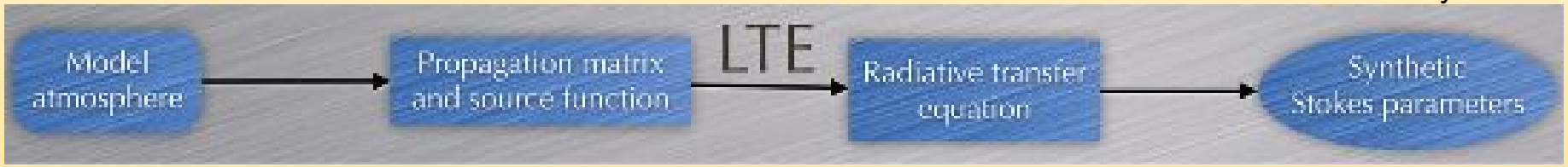
SIR

Synthesis



Inversion

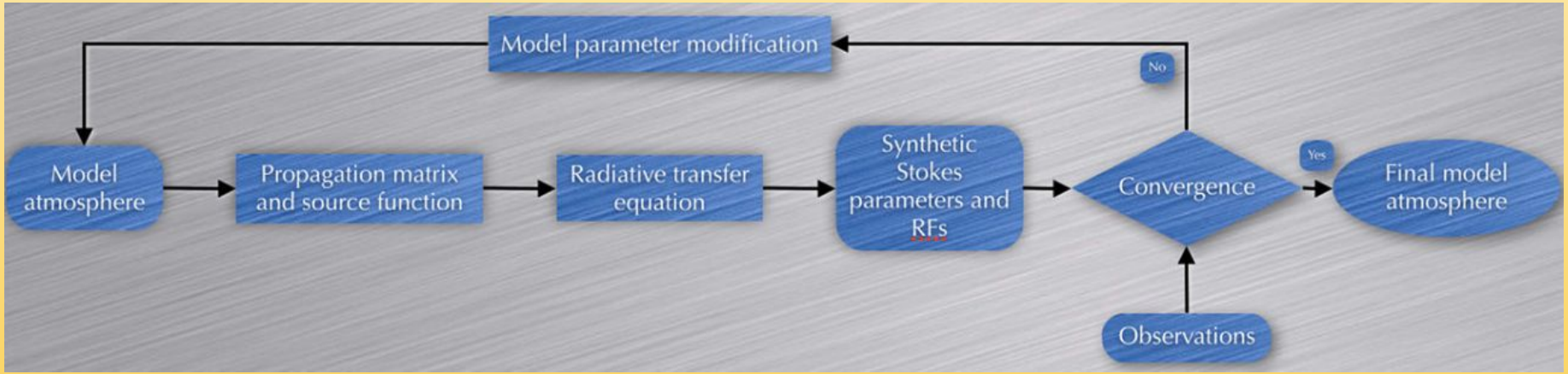
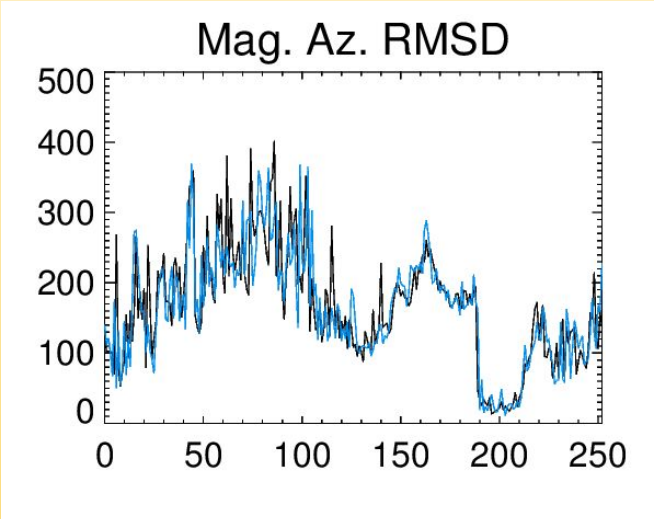


Image Credits: del Toro Iniesta, J.C., & Ruiz Cobo, B.

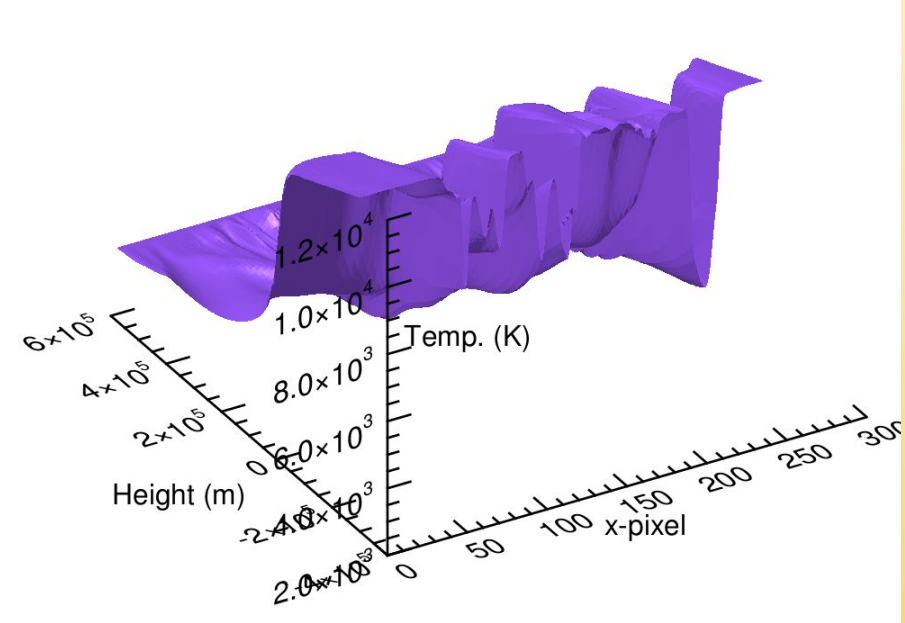
Calculation of accuracy

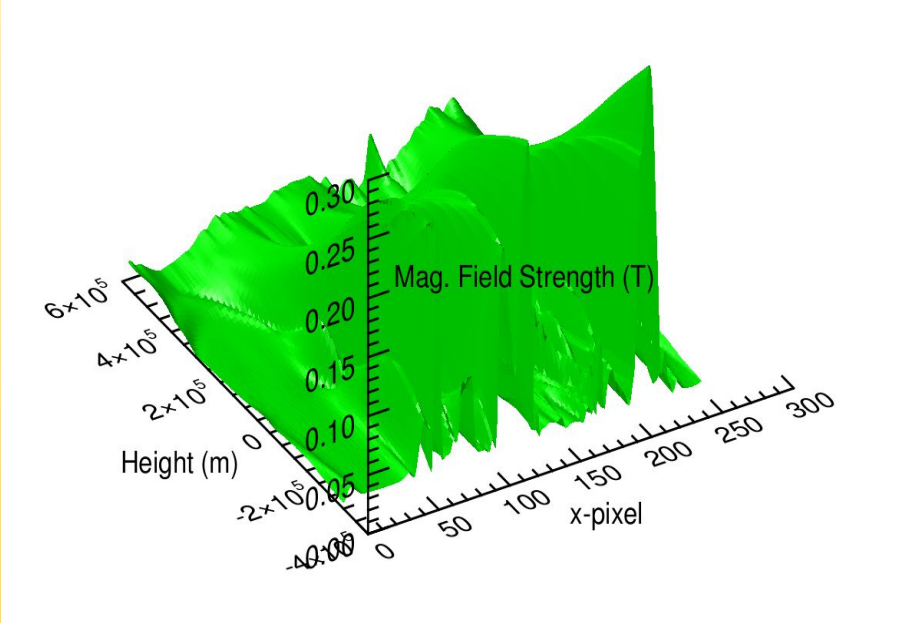
$$\text{RMSD} = \frac{\sqrt{\sum_{i=0}^{n}(x_{syn} - x_{inv})^2}}{\sqrt{n}}$$

- Relative values, not absolute



Model Atmosphere 1





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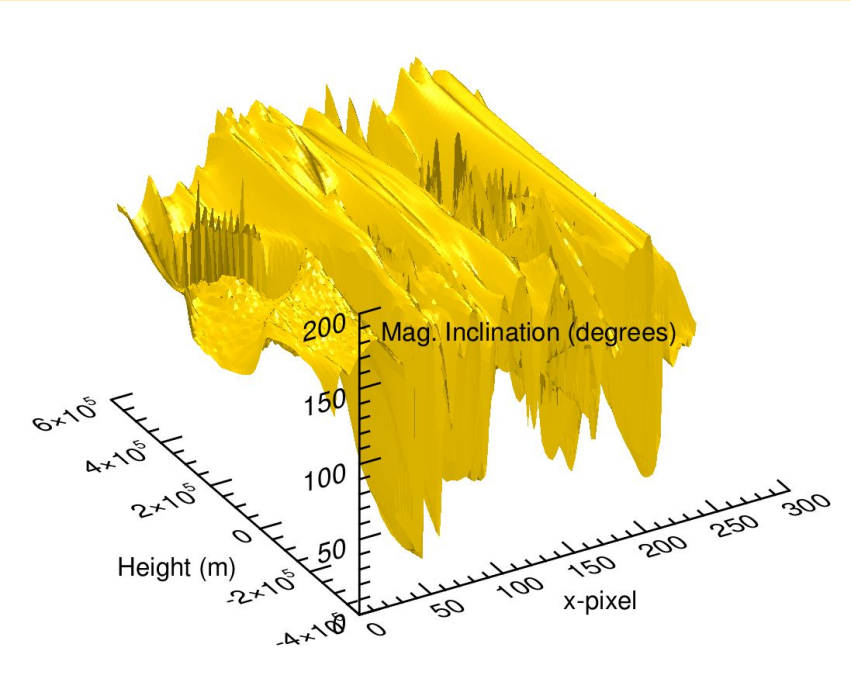
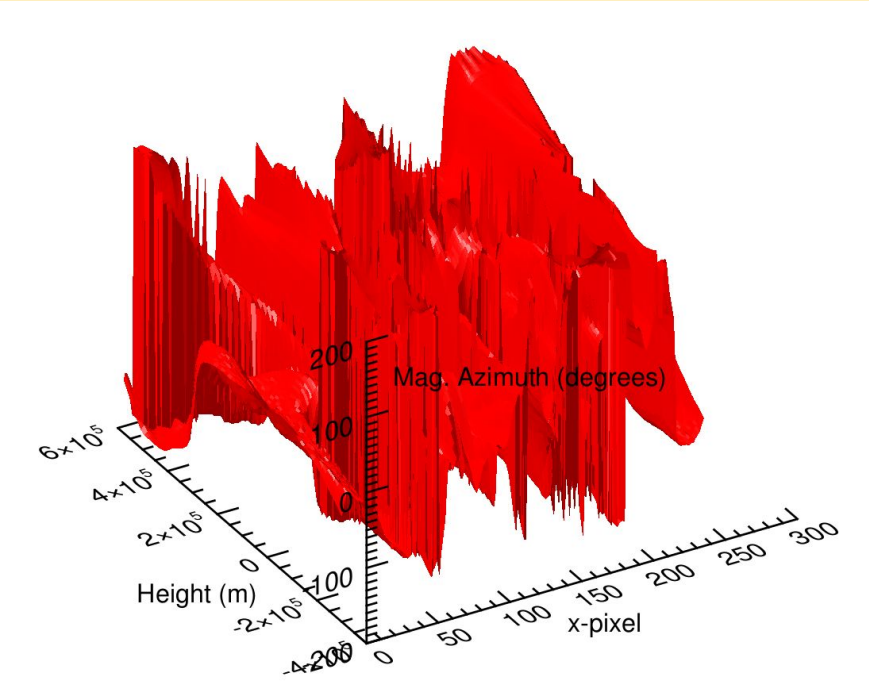
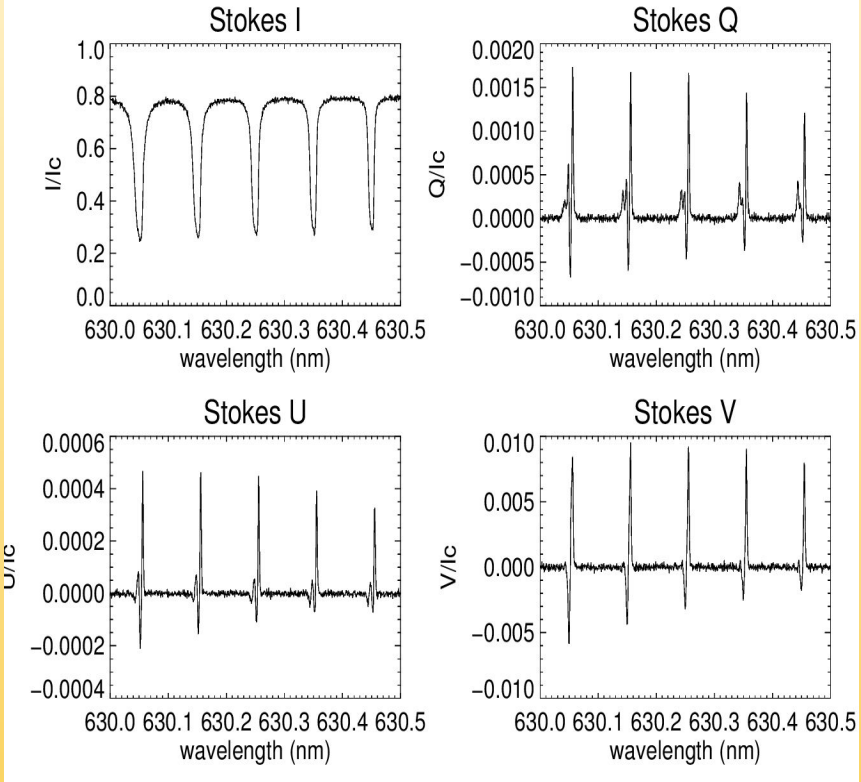
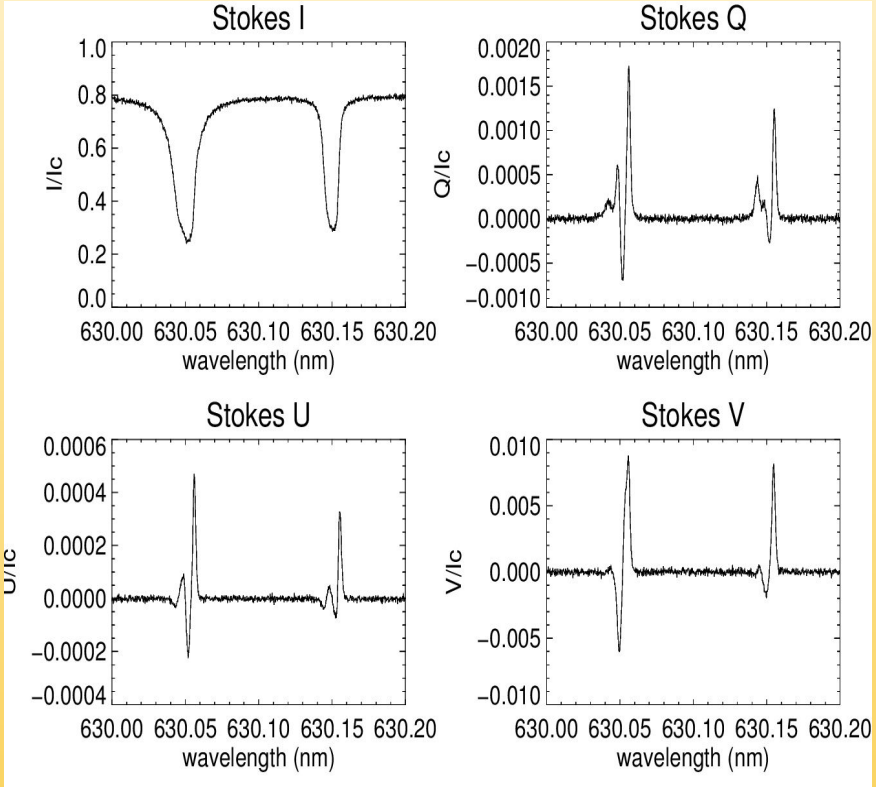




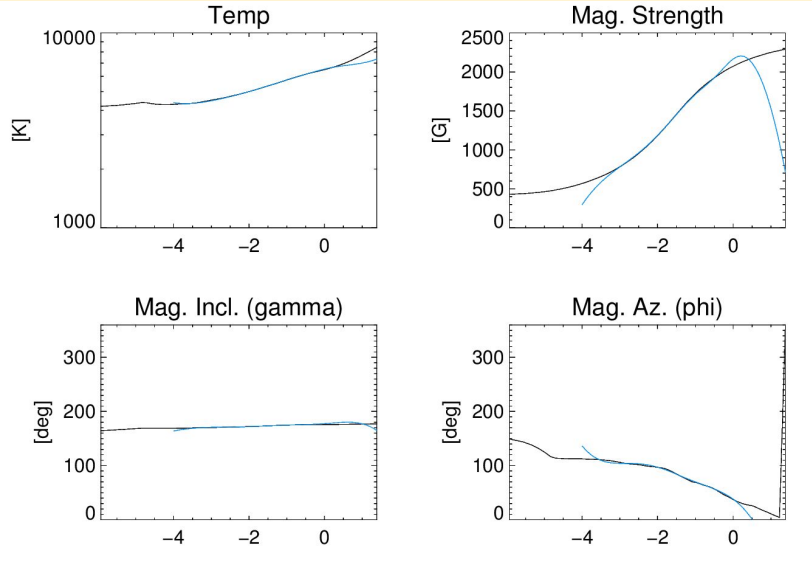
Spectra Examples





Conditions for Inversion

- Three 2D model atmospheres
- Two initial guess atmospheres
- 3, 4 or 7 inversion cycles
- Nodes for T, B, γ, ϕ
- 10 inversion trials total



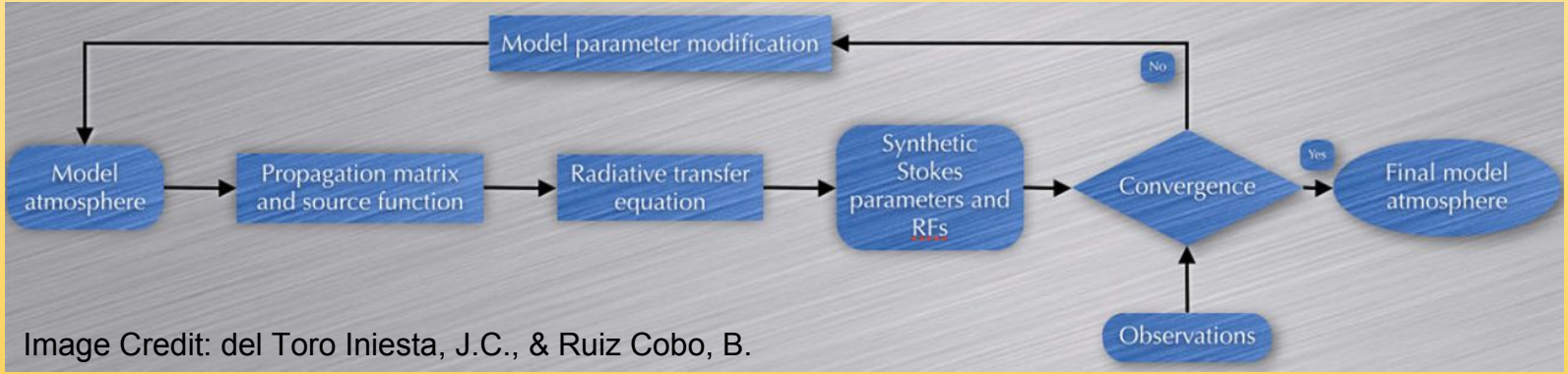


Image Credit: del Toro Iniesta, J.C., & Ruiz Cobo, B.

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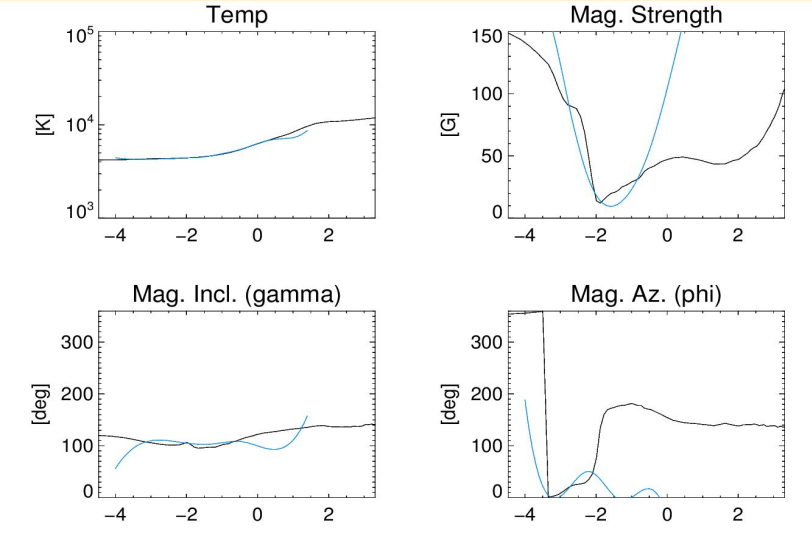


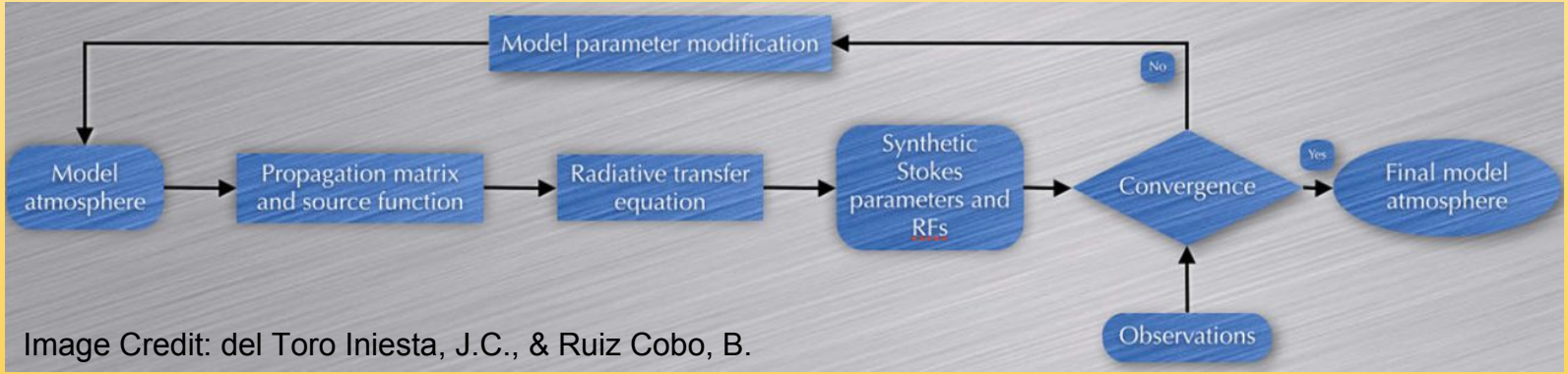
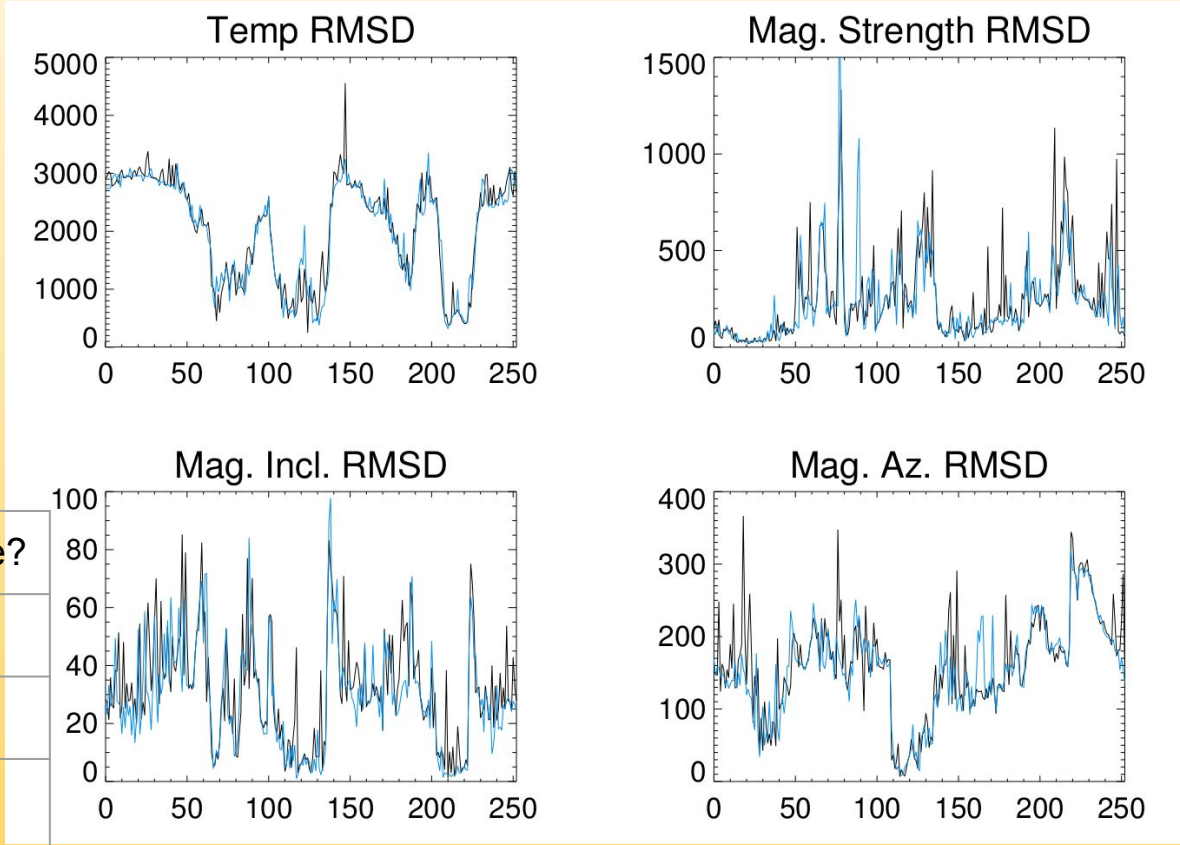


Image Credit: del Toro Iniesta, J.C., & Ruiz Cobo, B.

Inversion 1

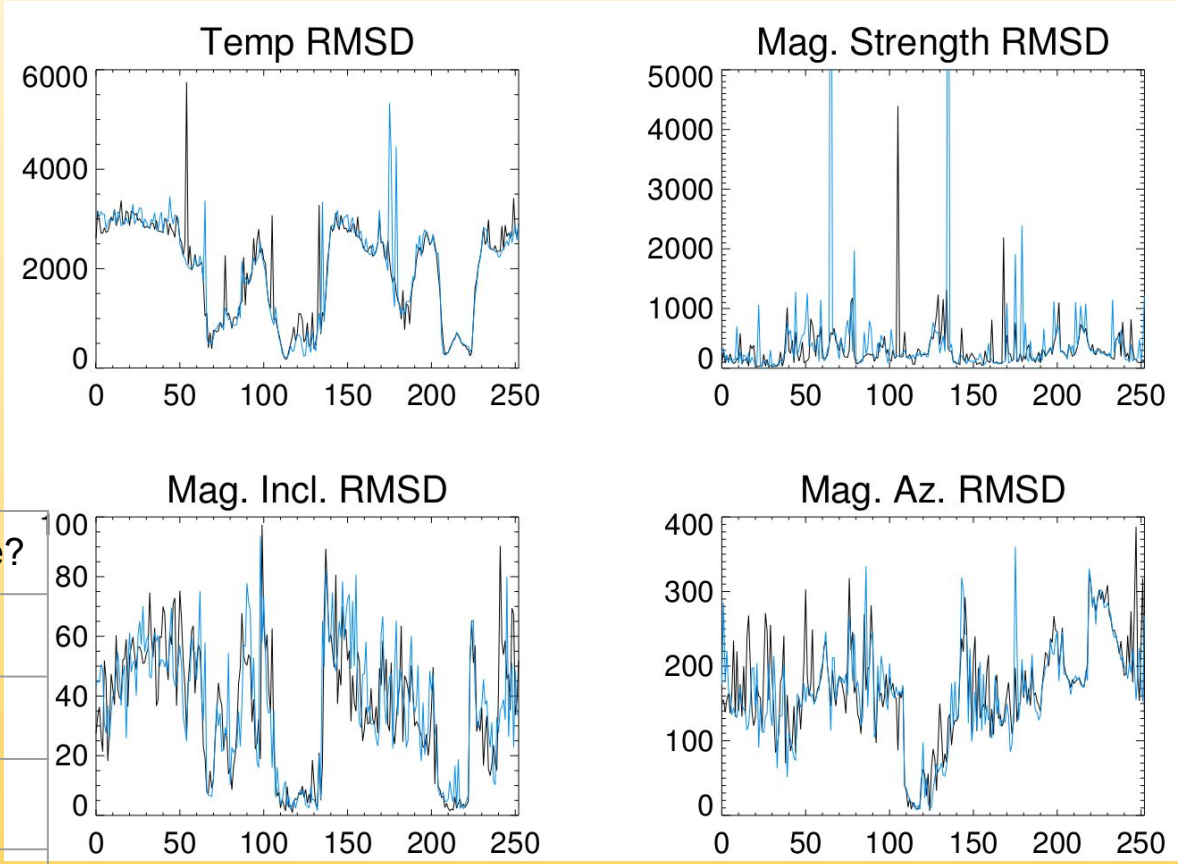
- Atmosphere 1
- Guess mod 1
- 3 cycles



Parameter	% Diff	Coarse or Fine?
T	1.62	Coarse
B	9.03	Coarse
γ	10.2	Coarse
ϕ	4.32	Coarse

Inversion 3

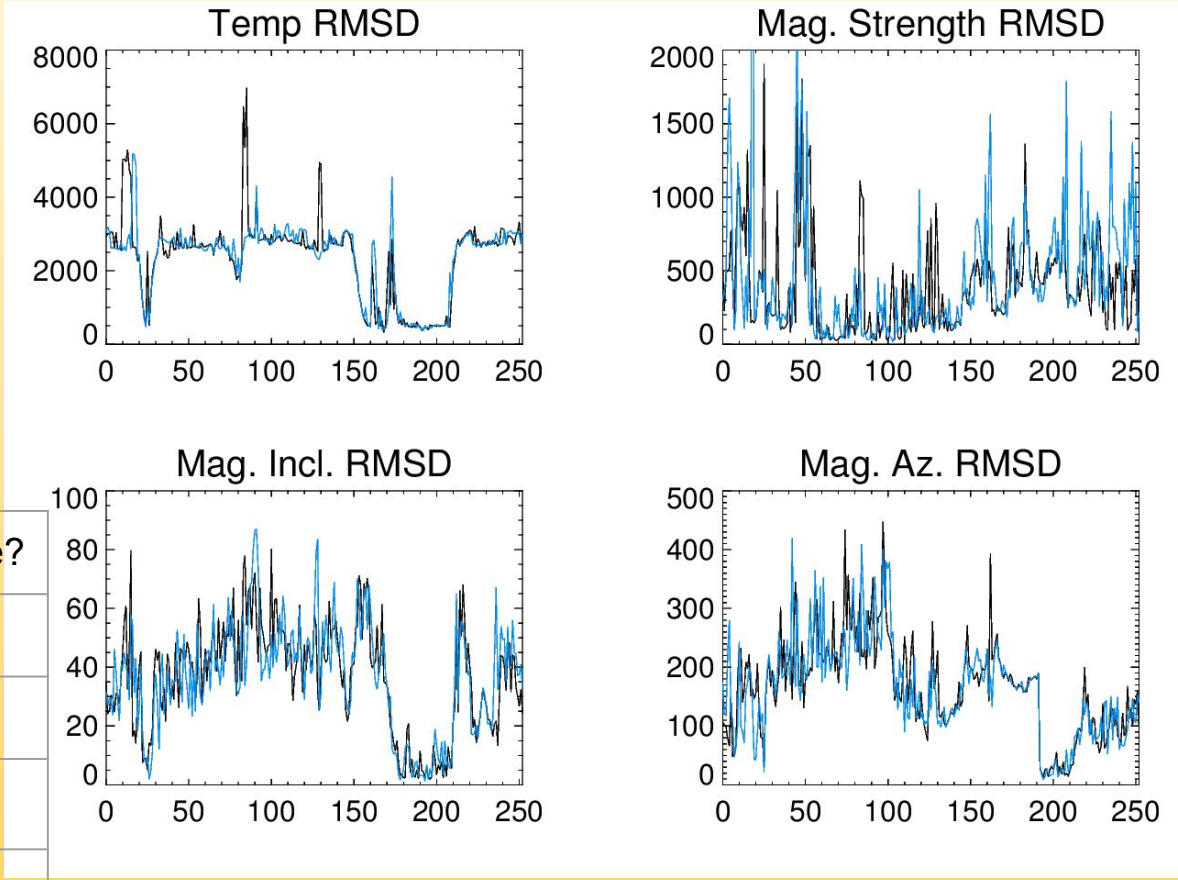
- Atmosphere 1
- Guess mod 2
- 3 cycles



Parameter	% Diff	Coarse or Fine?
T	0.34	Neither
B	33.6	Fine
γ	2.31	Fine
ϕ	3.79	Coarse

Inversion 5

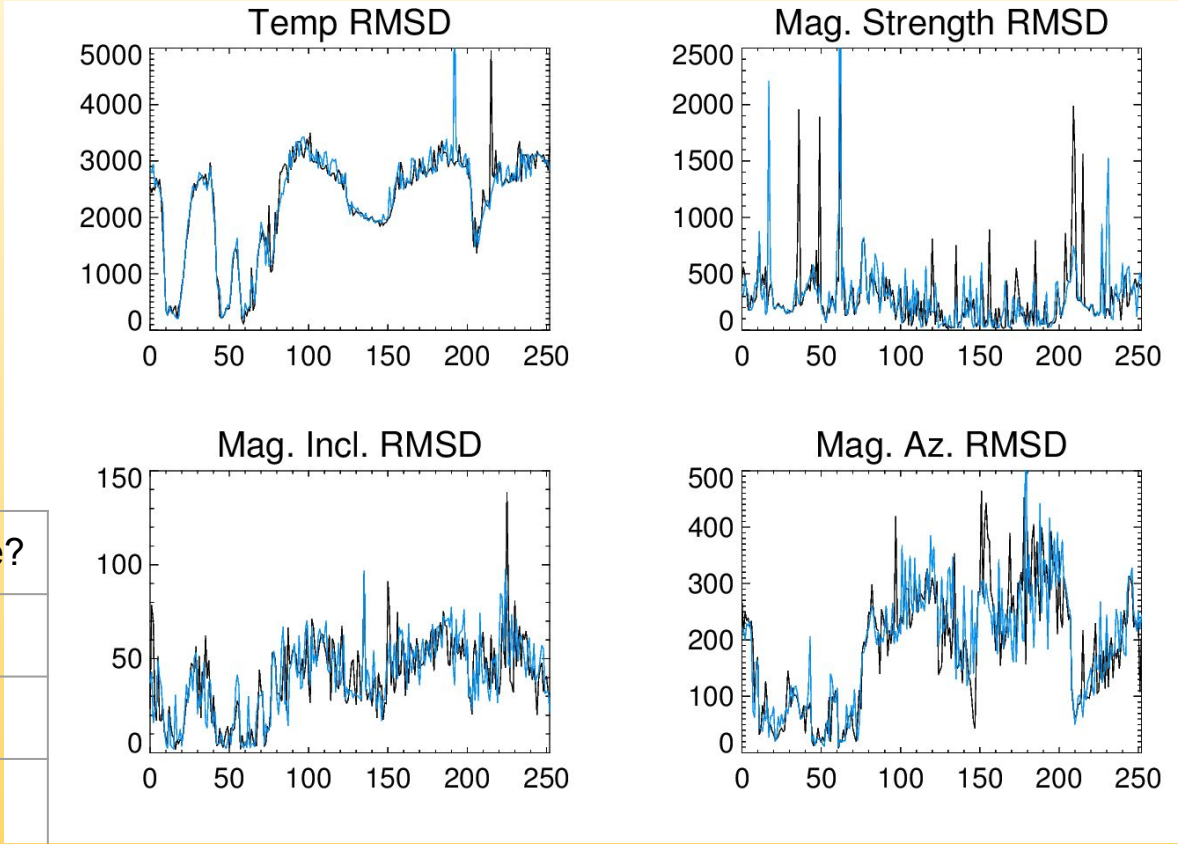
- Atmosphere 2
- Guess mod 1
- 4 cycles



Parameter	% Diff	Coarse or Fine?
T	0.28	Neither
B	0.74	Neither
γ	0.98	Neither
ϕ	1.33	Coarse

Inversion 8

- Atmosphere 3
- Guess mod 1
- 4 cycles



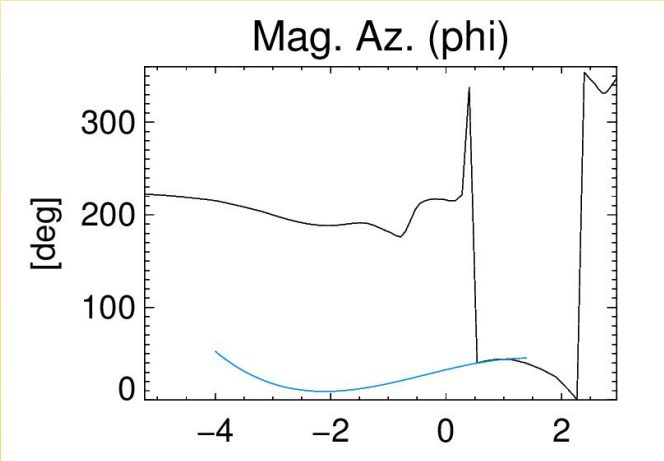
Parameter	% Diff	Coarse or Fine?
T	0.58	Neither
B	6.85	Coarse
γ	2.49	Fine
ϕ	0.86	Neither

Conclusions

- With 1% cutoff: Fine - 10, Coarse - 18, Neither - 12
- With 1.5 % cutoff: Fine - 7, Coarse - 11, Neither - 22
- Sample type should not be chosen based on ability to invert

Future Work

- Fix ϕ in SIR
- Change S/N ratio
- Use real data



References

[1] Bellot Rubio, L.R. 2003, Inversion of Stokes profiles with SIR, (Freiburg: Kiepenheuer-Institut für Sonnenphysik).
[2] Ruiz Cobo, B., & del Toro Iniesta, J.C. 1992, ApJ, 398, 375.
[3] Landi Degl'Innocenti, E. & Landolfi, M., "Description of Polarized Radiation," in *Polarization in Spectral Lines*. Dordrecht, The Netherlands: Kluwer, 2004, pp. 15-28.
[4] del Toro Iniesta, J.C., & Ruiz Cobo, B., "Inversion of the radiative transfer equation for polarized light," 2016, Living Rev. Sol. Phys. 13:4
[5] Stein, R. F. \& Nordlund, A. 1998, ApJ, 499, 914.
<http://comp.astro.ku.dk/Twiki/view/CompAstro/StaggerCode>

Thanks for listening!

Questions?