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Milne-Eddington Stokes Inversion for Spectro-Polarimeter (SP)

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Objective of this sub-project

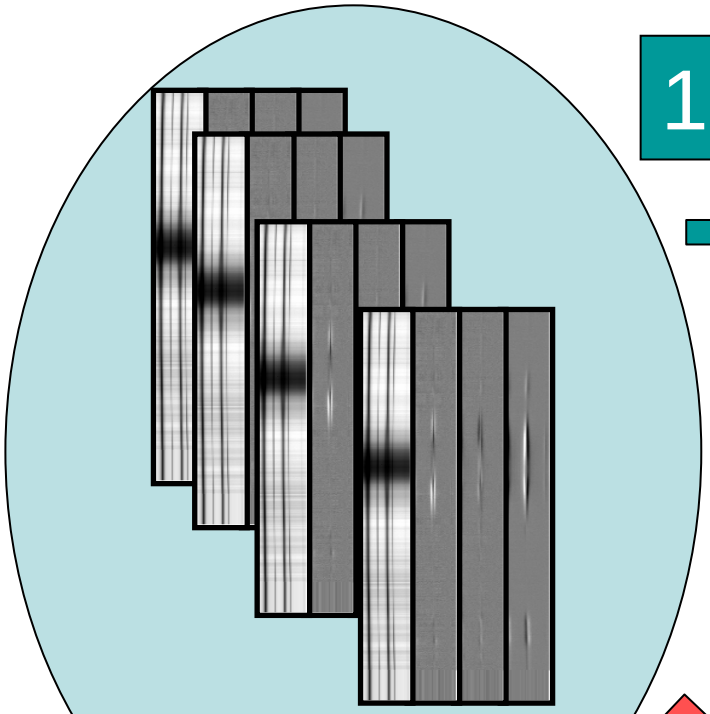
Development of a profile-fitting program based on the Milne-Eddington model

- It is for generating data-maps of the magnetic fields for the usage of the quick analysis. The maps will be released on the data server in the SOLAR-B Science Center.
- It will be a template for the development of the software that is for more sophisticated fitting procedure of the Stokes-profile analysis.

Development of the new code

- The HAO “inversion” code is one of the best famous codes for the Milne-Eddington-model fitting.
  - It is a very efficient and powerful code. However, ...
    - It is very complicated. Hard to understand the calculation flows.
    - Basically it assumes an input data format suitable for the ASP.
- We develop a new code under the following guiding principles.
  - The basic algorithm will be the same as that of the HAO code.
  - FITS file I/O
  - Fast enough to use for daily processing of the B-field maps
  - Portable to various architectures.
  - Easy to follow the procedures in the code.
- The code is developed by modifying and extending
  - PIKAIA by the HAO group
  - MELANIE by H. Socas-Navarro

Outline of the fitting procedure



Calibrated Stokes profiles

(I/O of Fits format by Shimojo)

1. genetic algorithm

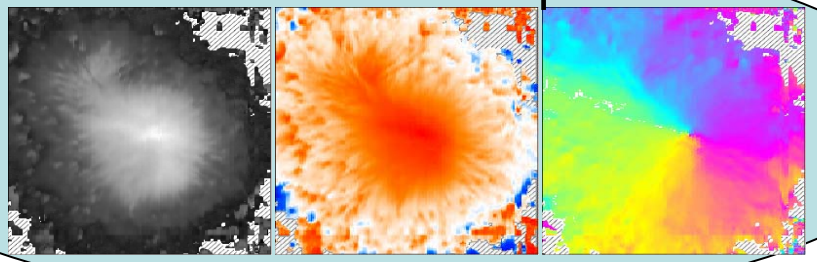
(by Katsukawa)

Initial-guess parameters

2. Fitting the Stokes profiles by the nonlinear least-square method (Levenberg-Marquardt method)

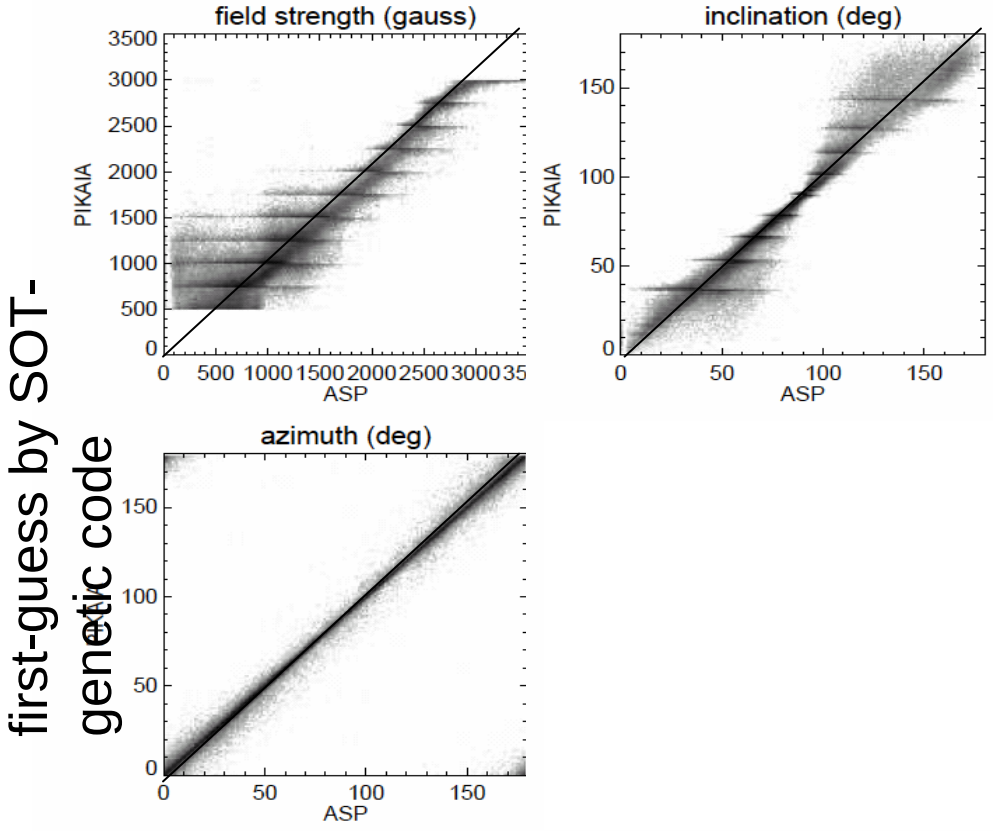
(by Yokoyama)

Vector field maps



Derivation of initial-guess data by the genetic algorithm

- Genetic algorithm is a search technique by iterating the generation, the selection and the mutation of solutions.
- Robust but slow.
- Our strategy
  - Based on PIKAIA by HAO group
  - simplify the profile-calculation procedures
  - reduce # of free-parameters
  - reduce # of used points in the profile data
- performance:15msec/pixel @ Intel Xeon 3.6GHz



"correct" solution (Final fitting results by the HAO inversion code)

Nonlinear least-square fitting of the Stokes profiles

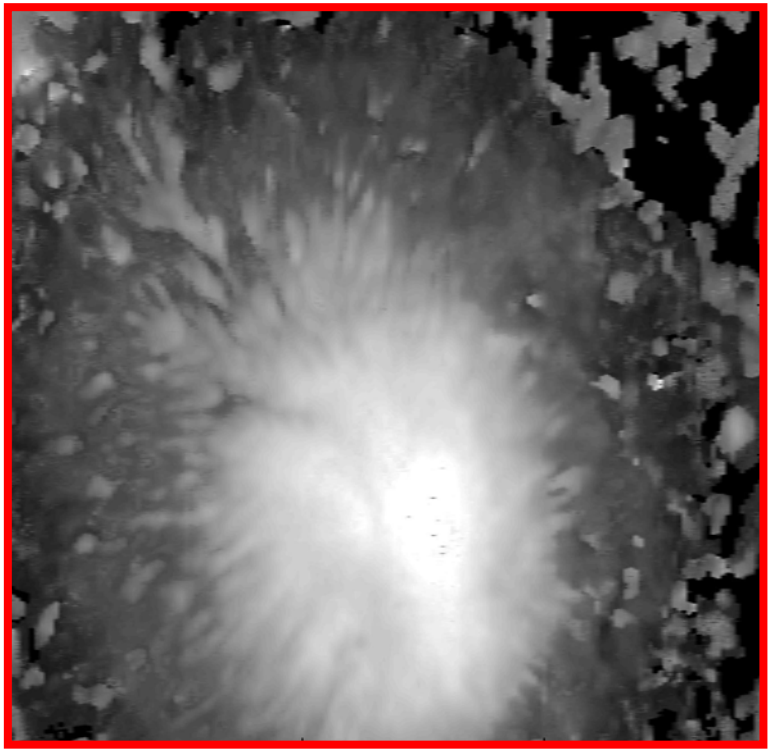
- Nonlinear least-square fitting (Levenberg-Marquardt method) is done to obtain the final results.
- Development strategy
  - based on MELANIE by Socas-Navaro (performance: >100msec/pixel)
  - tune as much as possible
    - relax the convergence condition
      - MELANIE: iterate while the residual ($\chi 2$) is decreasing
      - SOT-fit: iterate while the reduction rate of the residual is greater than 1%
    - Remove the redundant calculations
      - calculations of Voigt functions
    - Optimize the value of parameters (e.g. λ) in the Levenberg-Marquardt method
    - etc. etc.
- Performance: 15-25msec/pixel @ Intel Xeon 3.6GHz
- Still there remain bugs....

Nonlinear least-square fitting of the Stokes profiles

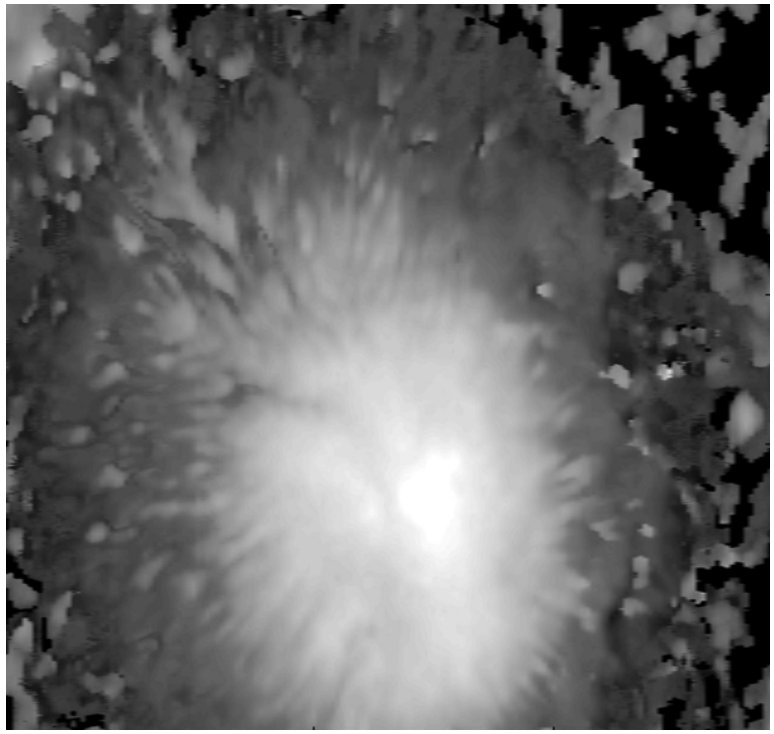
- Fitting free parameters (12 parameters)
  - Field strength
  - Field inclination
  - Field azimuth
  - Doppler shift
  - Doppler width
  - Damping parameter
  - Line strength
  - Source function
  - Source function gradient
  - Macro-turbulence
  - Stray-light fraction (filling factor)
  - Stray-light shift

Test 1/2

- A test fitting is done by using the dataset observed by ASP.
- Performance: 30msec/pixel (Intel Xeon 3.6GHz) for (genetic plus fitting) procedures. It takes 8 hrs for generating a (1k*1k-pixels) map.



results by the SOT-fit

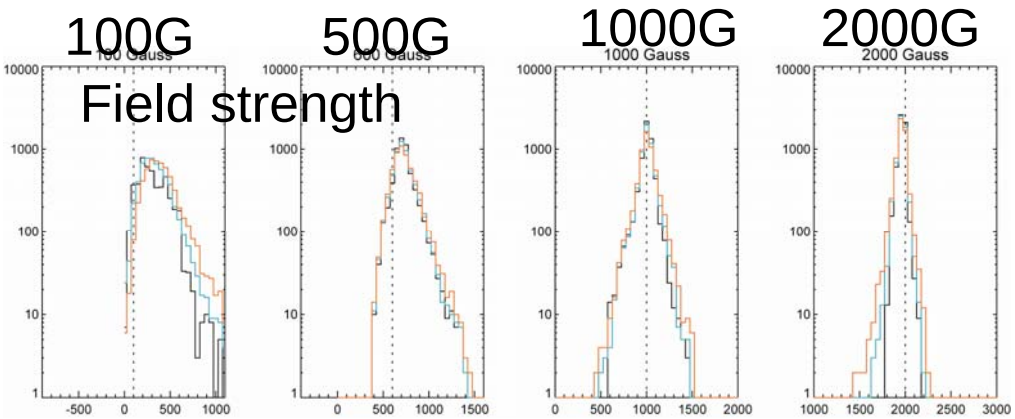


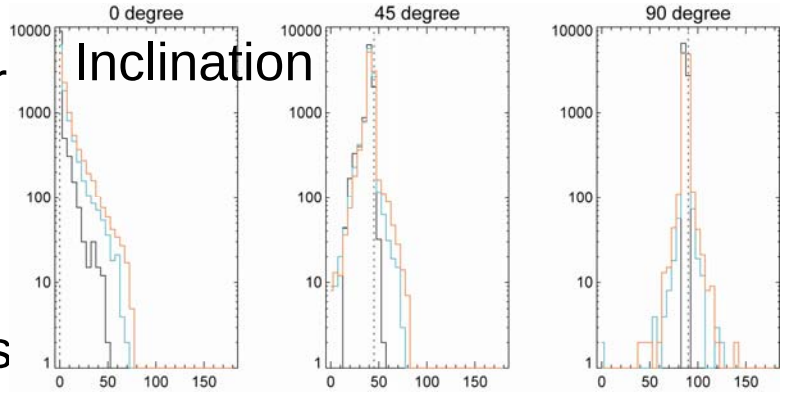
results by the HAO code

Test 2/2

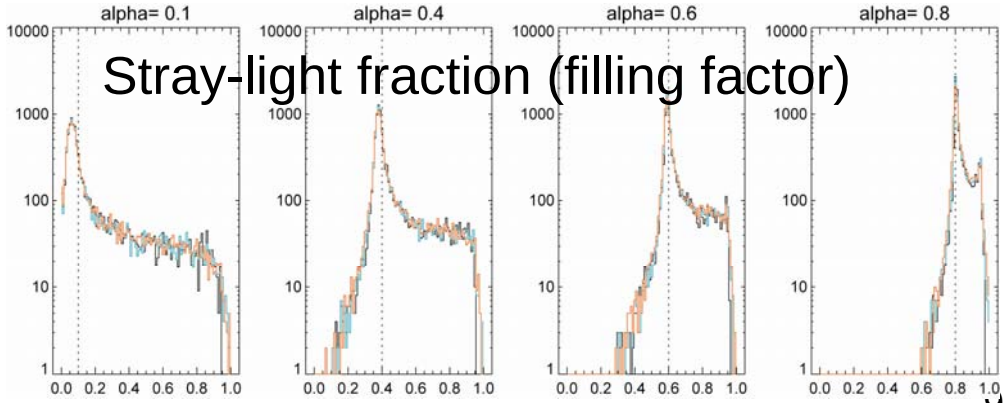
- Fit the test model profiles that are generated by using the known sets (~100,000 sets) of parameters and by using the Milne-Eddington model with additional noise on them.
- The fitted results distribute near the “correct answer”. The degree of scatter increases as increasing the noise level.
- On the other hand, there seems to be a systematic fitting error when the correct field strength is less than ~500 Gauss. In this case, there is a tendency of the overestimation of the field strength.

noise level: 0%, 0.1%, 0.2%





Vertical dotted lines : “Correct answer”



Summary

- We are developing a profile-fitting program based on the Milne-Eddington model.
- The obtained maps are roughly consistent with those by HAO code.
- The performance is 30 msec / pixel. This rate is enough to produce magnetic field maps from the downlinked data of SOT/SP without a long delay.
- There still remain bugs and some issues to be solved.