# Solar Orbiter PHI - RTE Inverter - science products

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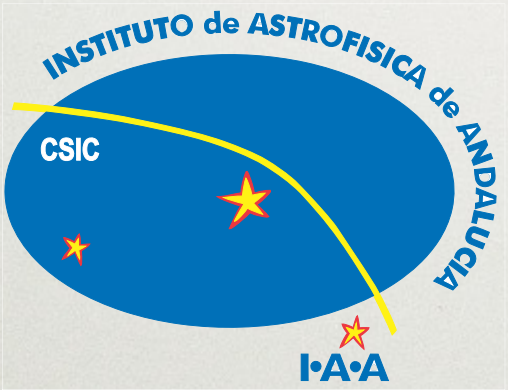



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# Radiative transfer equation (RTE) inverter

- Facts:
  - ➡ Solar Orbiter will have elliptical orbit during which there are periods of very low telemetry
  - ➡ Telemetry is very much expensive
  - ➡ Many of the Solar Orbiter scientific goals require a precise measurement of the plasma flows (Doppler shifts) and of the vector magnetic field (strength and orientation).

- Approach:
  - ➡ Make most* of the "scientific analysis" of the data onboard -> the most efficient compression strategy.
  - ➡ RTE inverter concept was born

*raw data will also be available for several scientific objectives



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# Radiative transfer equation (RTE) inverter

- PHI has two telescopes:

  - ➡ The Full Disk Telescope (FDT) will provide Stokes images of the Sun with a sampling of 3.5 arsecond per pixel, at perihelion.
  - ➡ The High Resolution Telescope (HRT) Stokes images sampling will reach 0.5 arcseconds per pixel.
  - ➡ All data will be recorded by a 2kx2k pixel camera with a maximum cadence of one minute and a polarimetric sensitivity of $10^{-3}$.

  - ➡ We want to provide the solar community with Doppler images and vector magnetic field maps with a quality comparable to or better than, at least, that of HMI aboard SDO.

- How do we do it in practice?

# Radiative transfer equation (RTE) inverter

- Precursors in space:
  - ➡ The SOHO/MDI instrument has been the first in successfully making such measurements from space:
    - Na D l 589.6 nm line and the classical estimates to measure the longitudinal component of the magnetic field ($B_{LOS} = B \cos\gamma$) and the line-of-sight velocity ($v_{LOS}$).

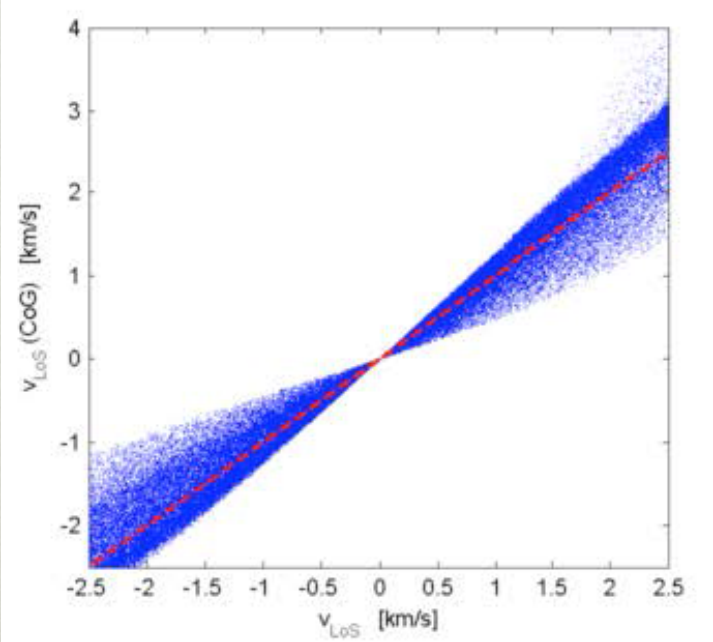
$$v_{LOS} = \beta_v \frac{\lambda_+ + \lambda_-}{2} \qquad B_{LOS} = \beta_B \frac{\lambda_+ - \lambda_-}{2}$$

  - ➡ The SDO/HMI instruments goes a step forward and **inverts the RTE**: "The idea is to compare the observed Stokes profiles with the **Milne-Eddington solution** to the radiative transfer equation for polarized radiation and then modify the set of parameters on which such solution depends until a best fit is obtained".
  - ➡ The ME approach is perhaps, the most trustful means for plasma magnetic fields and velocities estimations

# Radiative transfer equation (RTE) inverter

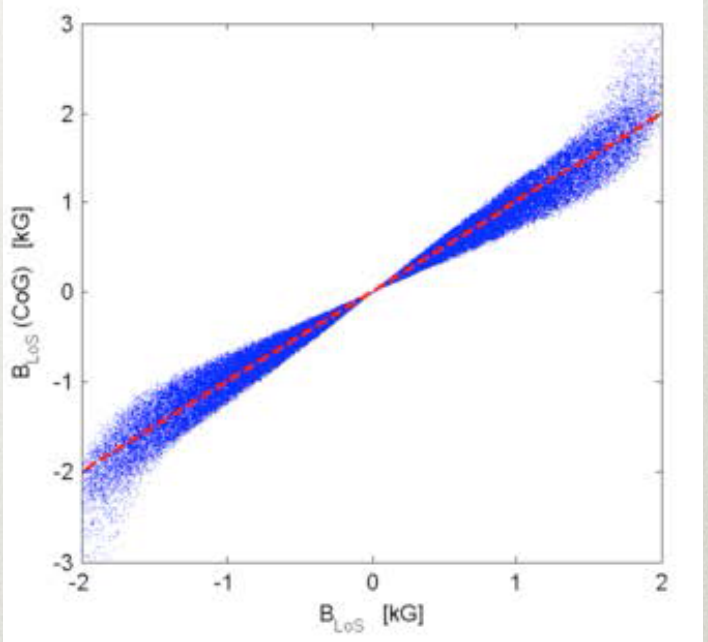
- Both, HMI and PHI, use the Fe I 617.3 nm spectral line because its relatively insensitive to the temperature stratification and because its Landé factor (2.5, normal Zeeman triplet) is large enough to ensure a good magnetic sensitivity.
- Classical estimates, like c.o.g., Fourier tach., etc., are quite robust and reliable (Orozco Suárez, Bellot Rubio, & Del Toro Iniesta 2010)

$$v_{LOS} = \beta_V \frac{\lambda_+ + \lambda_-}{2}$$




Reference

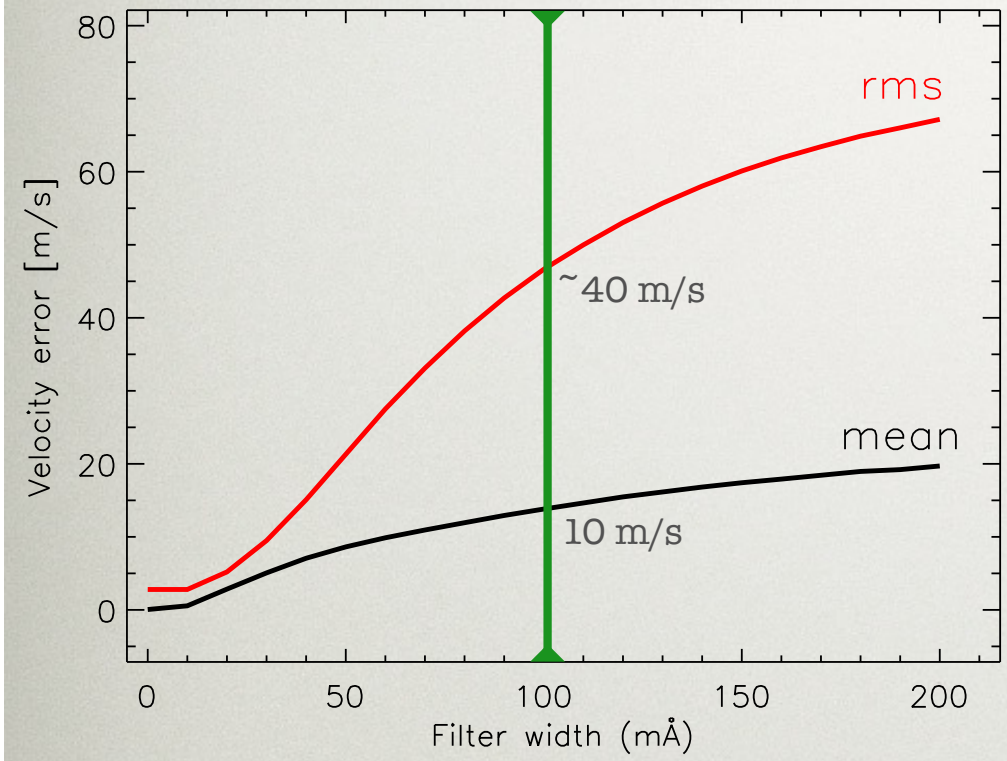
$$B_{LOS} = \beta_B \frac{\lambda_+ - \lambda_-}{2}$$

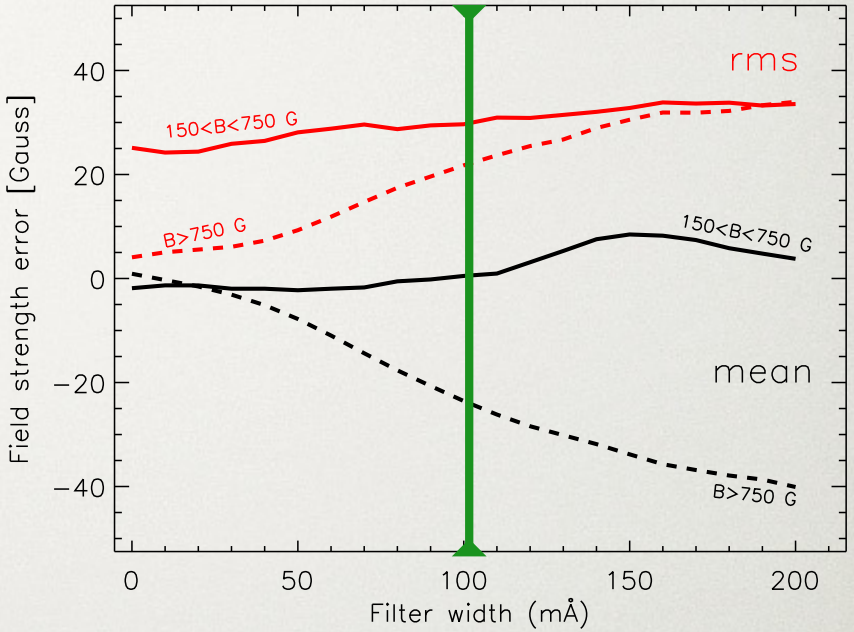


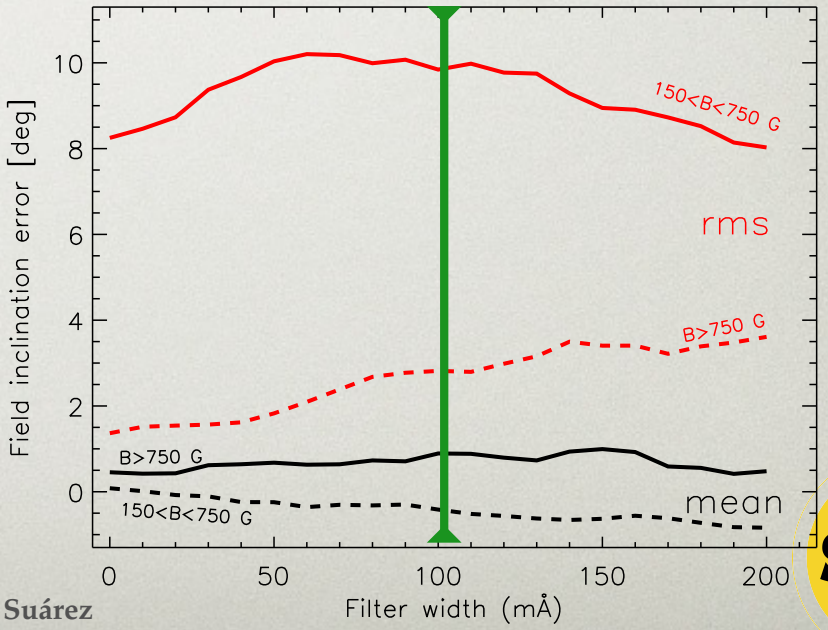

Reference

# Radiative transfer equation (RTE) inverter

- Using the Milne-Eddington inversion approach is better:

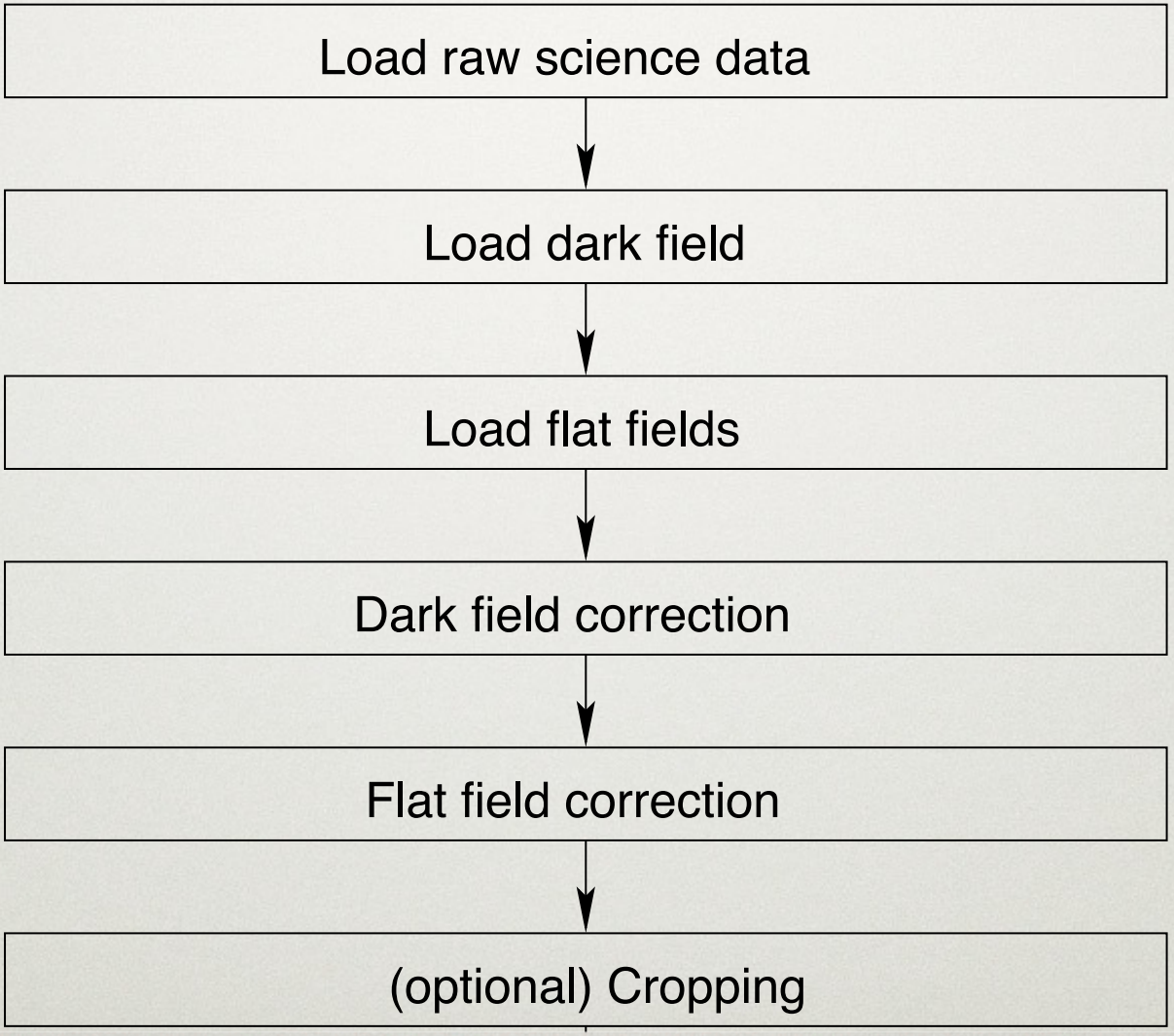


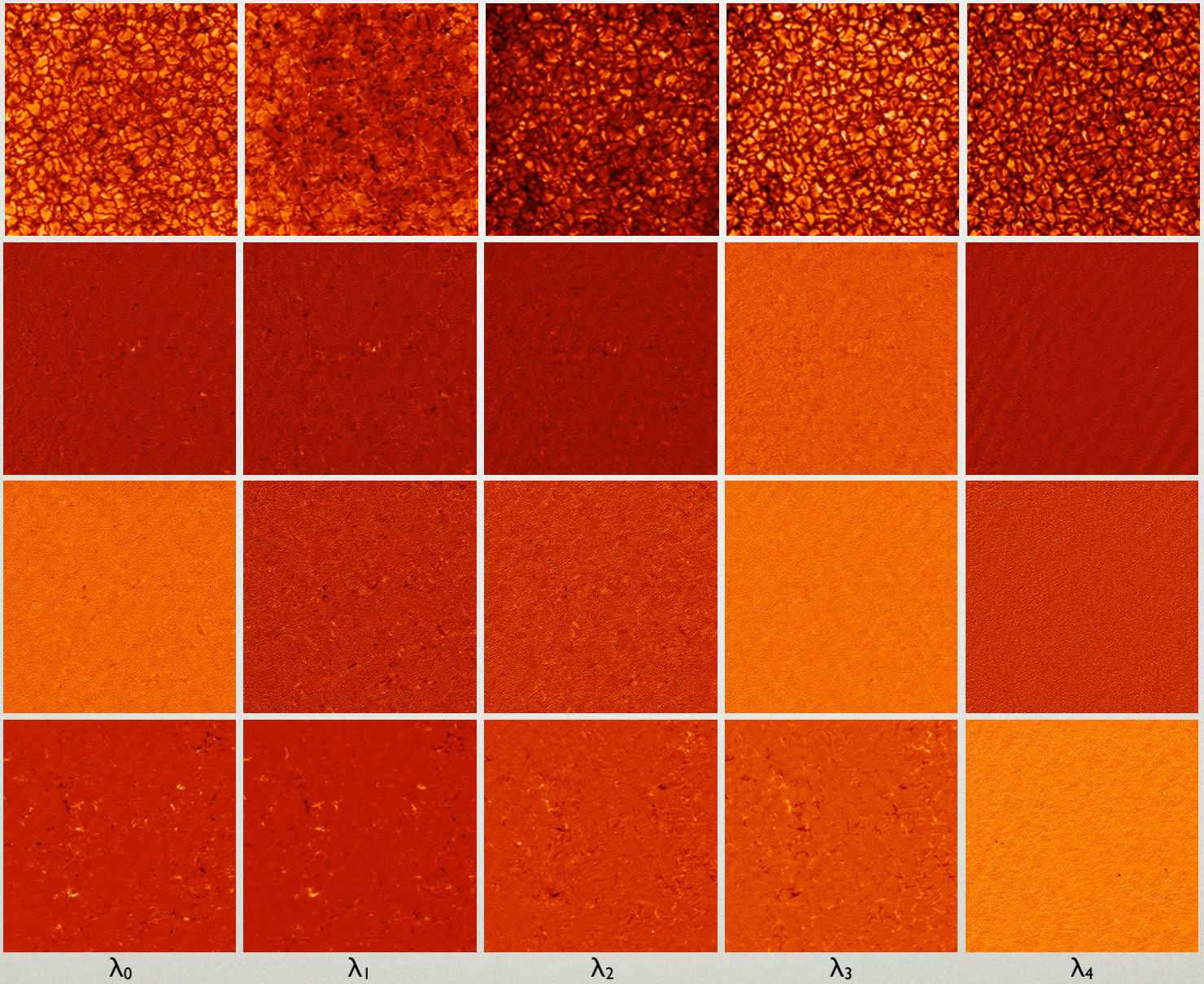
# Radiative transfer equation (RTE) inverter

- Data preprocessing:



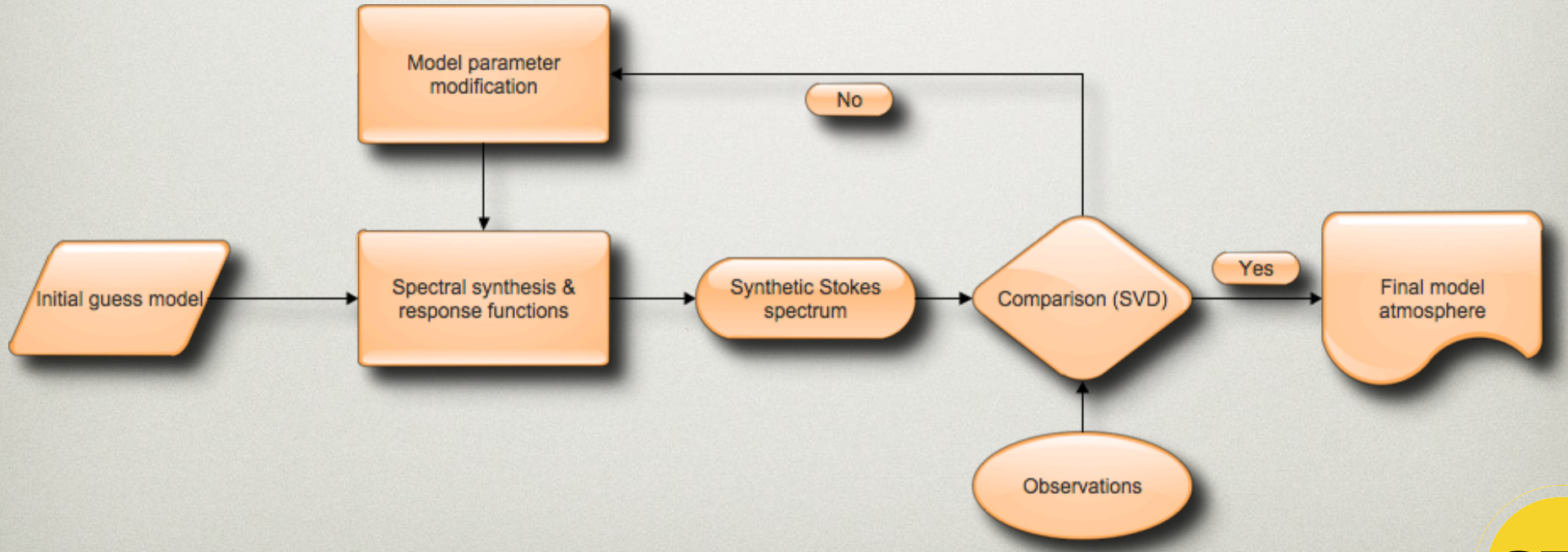
# Radiative transfer equation (RTE) inverter

## Four Stokes profiles + 6 wavelength points



# Radiative transfer equation (RTE) inverter

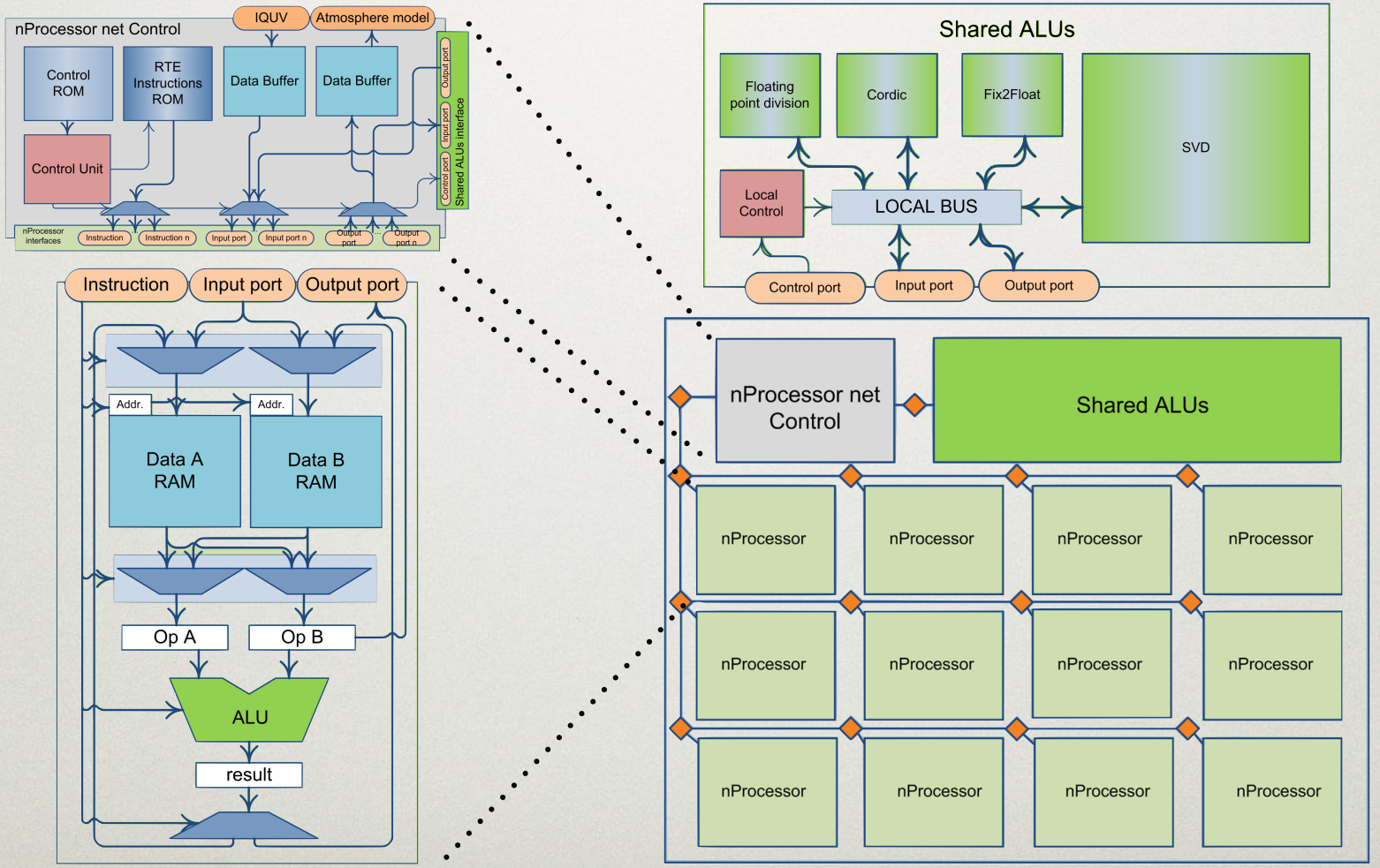
- RTE concept: The 4 polarization states times 6 wavelengths, are translated* into five solar physical quantities, namely the plasma line-of-sight velocity, the three components of the vector magnetic field (strength, inclination relative to the line of sight, and azimuth) and the continuum intensity.
- The RTE follows the implementation by Orozco Suárez & Del Toro Iniesta (2007).




* A full description of inversion procedures can be found in Del Toro Iniesta & Ruiz Cobo (2016).

# Radiative transfer equation (RTE) inverter

- Specific **firmware** design working on one of the FPGAs in the DPU (Cobos Carrascosa et al. 2014, 2015, 2016a,b; Cobos Carrascosa 2016).
- **RTE is 1.7 times faster than VFISV (HMI code) in 50 computers**



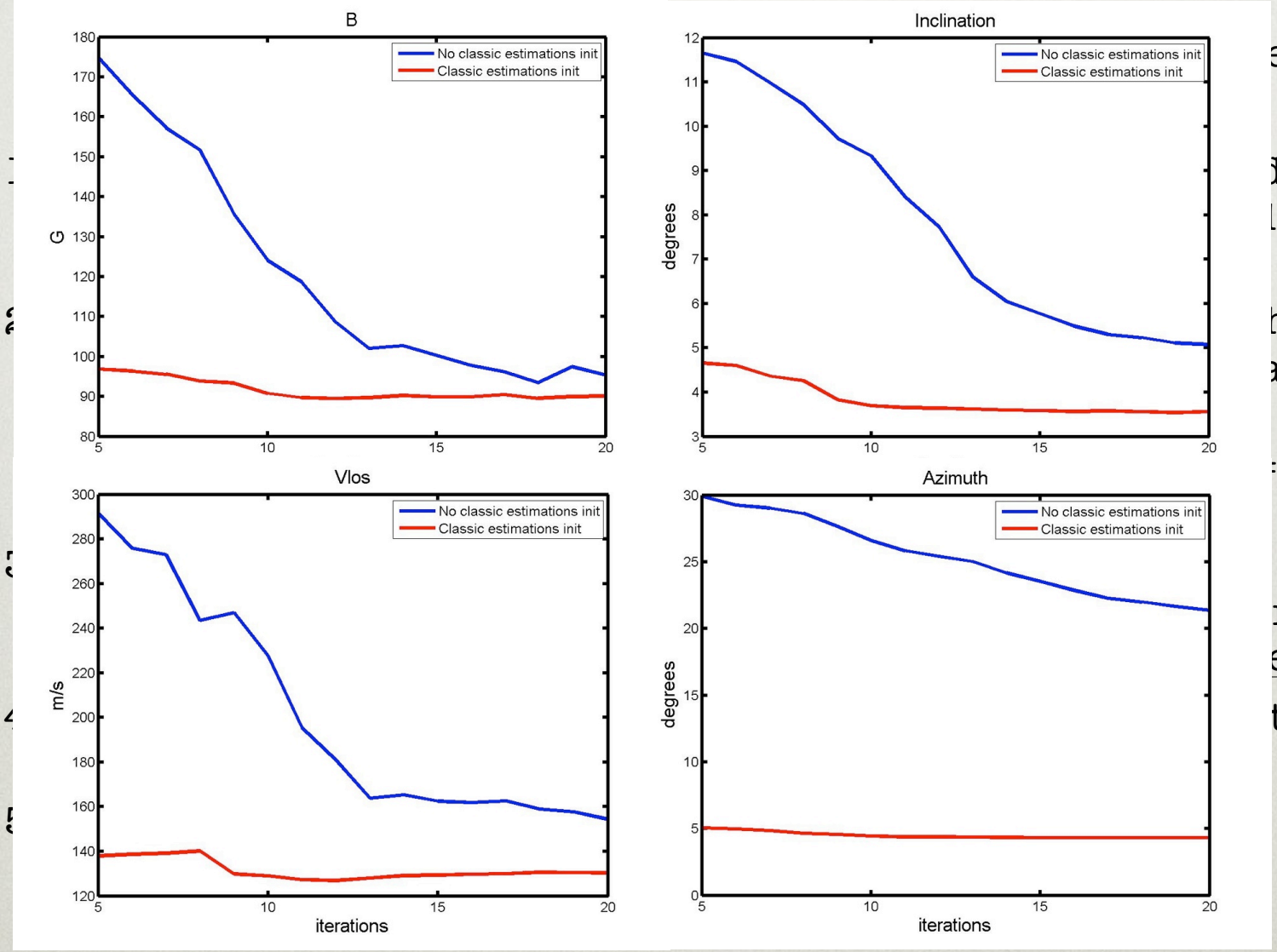
# Radiative transfer equation (RTE) inverter

- The RTE inverter assumes a single homogeneous magnetic component in the pixel.
- It also takes into account the spectral transmission of the instrument.
- There are **five modes** in which the inverter can be executed

1. **RTE inversion**: The inverter infers the vector magnetic field and the velocity using the ME approximation and an ad-hoc initial model atmosphere.
2. **Classical estimations**: The inverter infers $B_{LOS}$ and $v_{LOS}$ using the center of gravity technique as introduced by Semel (1967) (see also Rees & Semel 1979). The field strength is obtained through the weak-field approximation (Landi Degl'Innocenti & Landolfi 2004). This mode is not iterative.
3. **RTE inversion with classical estimations**: The classical estimations are used to get initial estimates of the free parameters that are then fed into the RTE inversion algorithm. (default mode.)
4. **Longitudinal**: The inverter delivers $B_{LOS}$ and $v_{LOS}$ using the center of gravity technique.
5. **No polarization modulation**: The RTE delivers $v_{LOS}$ only.

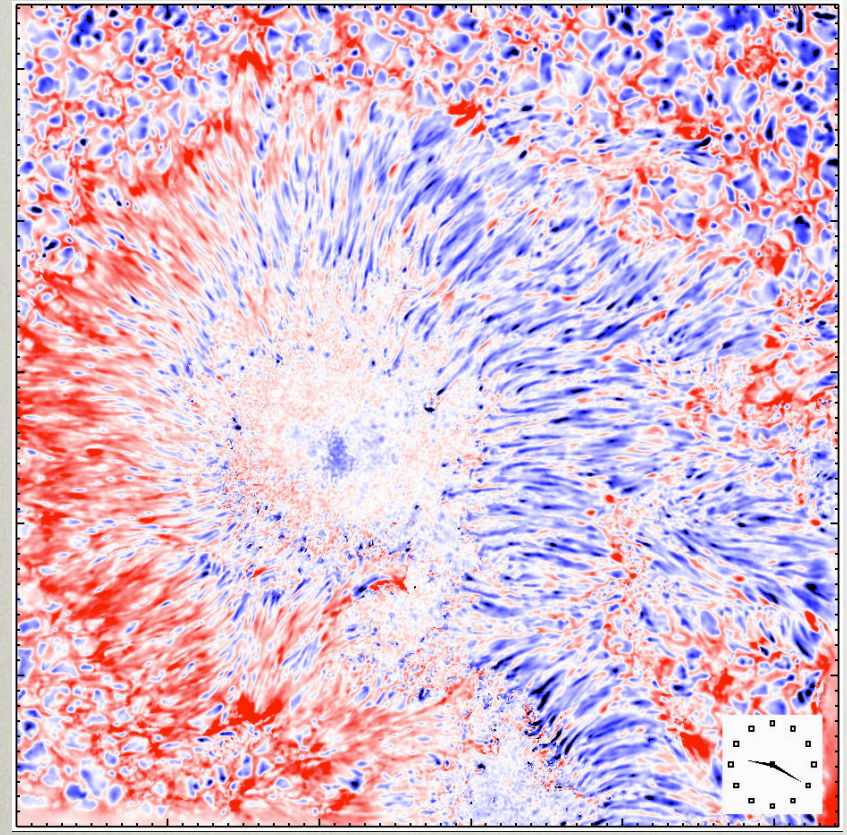
# Radiative transfer equation (RTE) inverter

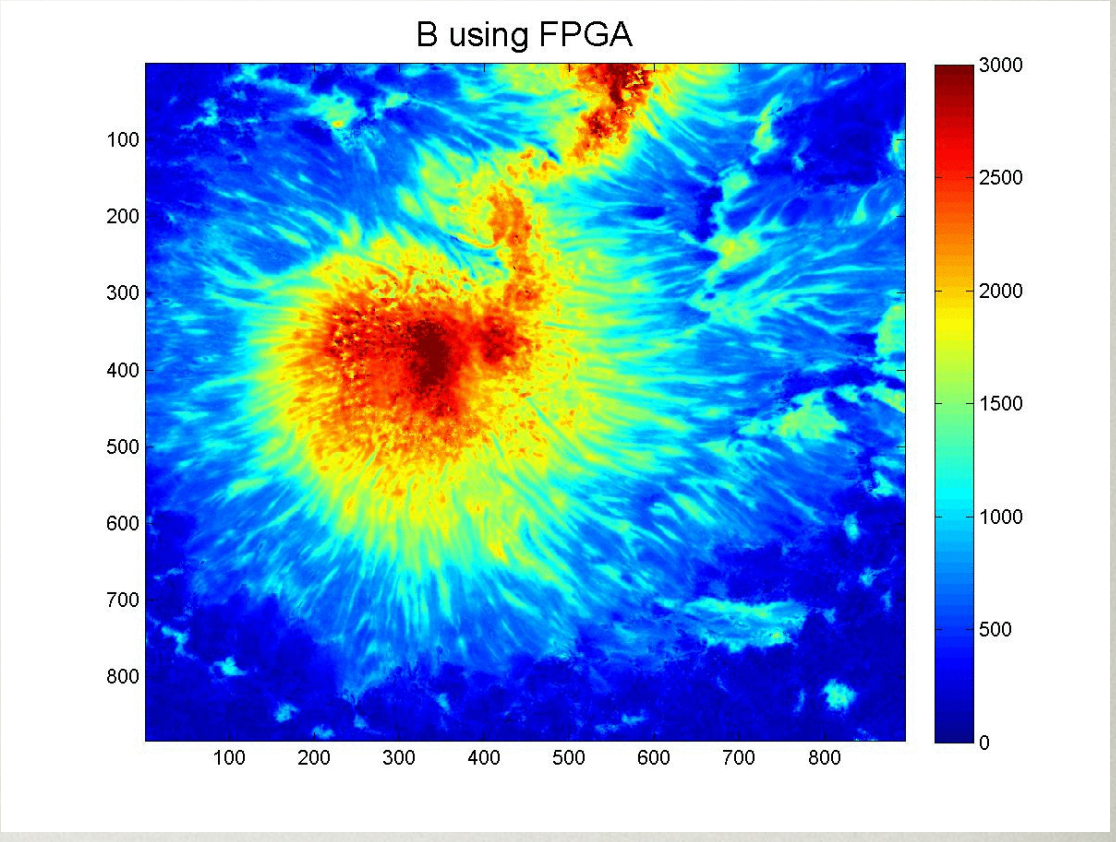
- The RTE inverter assumes a single homogeneous magnetic component in the pixel



# Radiative transfer equation (RTE) inverter

- Examples





# Radiative transfer equation (RTE) inverter

- Yesterday's question: what we would like from METIS?