Toward real-time inversion of SPRING Stokes observations (WP8.3.2)

Luis Bellot Rubio, Juan P. Cobos
Instituto de Astrofísica de Andalucía (IAA-CSIC)

SPRING observations

7. ESTIMATION OF THE EXPECTED DATA RATE OF SPRING

We describe here the expected data rates for one node of the network which follow from the Scientific Requirement Document (SRD).

Combining the science requirements defined in Section 3 of the SRD we arrive at the following specifications: The Sun has to be observed in full-disk mode with a spatial resolution of 1 arc second and a temporal cadence of 10 s in photospheric velocity and intensity as well as in the line-of-sight magnetic field and the full-vector magnetic field. Five spectral lines should be observed with the same temporal cadence at 20 wavelength-bins per line. For a full-disk image of the Sun, a resolution of 1 arc sec can be achieved with a 2048 x 2048 pixel^2 CCD.

Specifications of the expected observations:

- 2k x 2k camera, 16 bits
- Five spectral lines
- 20 wavelength bins per spectral line
- Cadence: 10 sec
- Full Stokes vector (=4 components)

SPRING observations

Table 3.1: List of observables and the detailed observing parameters as required by different science goals.

S. No	Science Goal	Justification	Observables Req.	Observing parameters
1.	**Synoptic Magnetic Fields:**Long-term monitoring of solar magnetic fields	Solar magnetic cycle, relation with internal flows, solar dynamo	Vector Magnetometry of the full solar disk in multiple sensitive solar spectral lines	FOV: Fulldisk Spatial Res: 1arcsec Spectral Res: 100mA Temporal Res: Few per day Spectral Lines: Fe I 6173, Fe I 6302, Fe I 5250, Ca II 8542, He I 10830, Fe I 1.5 micron
2.	**AR evolution and Transient Events:** Solar Flares, flux emergence and cancellation, Helicity flux, free energy evolution in Active Regions	Understanding magnetic origin of solar flares, flare precursors, driving coronal MHD simulations for space weather predictions, estimate of magnetic free energy and helicity.	High cadence vector magnetic fields of the full solar disk in multiple spectral lines	FOV: Fulldisk Spatial Res: 1 arcsec Spectral Res: 100 mA Temporal Res: one per 10 minute Spectral Lines: Fe I 6173, Fe I 6302, Fe I 5250, Ca I 8542, He I 10830, Fe I 1.5 micron
3.	**Helioseismolog**	Internal flow structure	Velocity maps of	FoV: Full disk + prominences

SPRING observations

	y:Solar internal flows and waves in solar atmosphere	and its variation with solar cycle, impact on dynamo action, properties of acoustic and magnetoacoustic waves in solar atmosphere, subsurface structure of active regions, meridional flows	the full solar disk in multiple spectral lines	Spatial Res: 1 arcsec Spectral Res: 100 mA Temporal Res: One velocity map per line per 30 seconds Spectral lines: See Table 1.2 below**
4.	**Solar Awareness:** Total and Spectral solar irradiance (TSI, SSI)	Monitor Sun-as-a-star spectral properties, magnetic activity and its signatures on radiative output.	Spectrophotometry of unresolved solar radiation.	FOV: Unresolved Solar light Spatial Res: Unresolved Spectral Res: 20 mA Temporal Res: One per day
5.	**Context Imager** for Upcoming Large Aperture Telescopes.	Provide complementary information over larger FOV to support small FOV observations by future large aperture telescopes	High resolution imaging in different broad and narrow spectral bands, including continuum images	FOV: Full disk Spatial Resolution: 0.5 arcsec (after post processing) Spectral Resolution: broad band (0.25 to few Angstroms) Temporal Resolution: Few per minute or as demanded by coordinating observer.

Deriving physical parameters from observations

- Full Stokes inversions
- Only photospheric lines
- Simple Milne-Eddington atmosphere
- 1 magnetic component in the pixel (+ filling factor?)
- 9 (10) physical parameters extracted from each line

- Baseline code: MILOS (Orozco Suárez et al. 2010)
  - Used for inversion of Solar Orbiter PHI data on FPGAs
  - Written in IDL
  - Speed: ~150 pixels/s
  - Inverting 4 million pixels with one core would take 7.5 h!!!

Planned solution I

- Code acceleration and optimization
  - Version in C++
  - Profiling
  - Optimization of time-consuming routines (SVD, convolution)
  - Efficient I/O
- We already have preliminary working version: C-MILOS
- Speed goal: 1500-2000 pixel/s (1 core)
- Inversion of full-disk image would take 285 s (8 cores)

Still insufficient to handle 10 s cadence and 3 lines!!

Planned solution II

- Paralellization of C-MILOS
- Based on MPI
- Will allow the use of multi-core workstations, servers or clusters
- 250 cores needed to invert full-disk image in 10 s
- 750 cores needed to invert 3 lines at 10 s cadence

Very expensive from a computational point of view

Planned solution III

GPU implementation of C-MILOS

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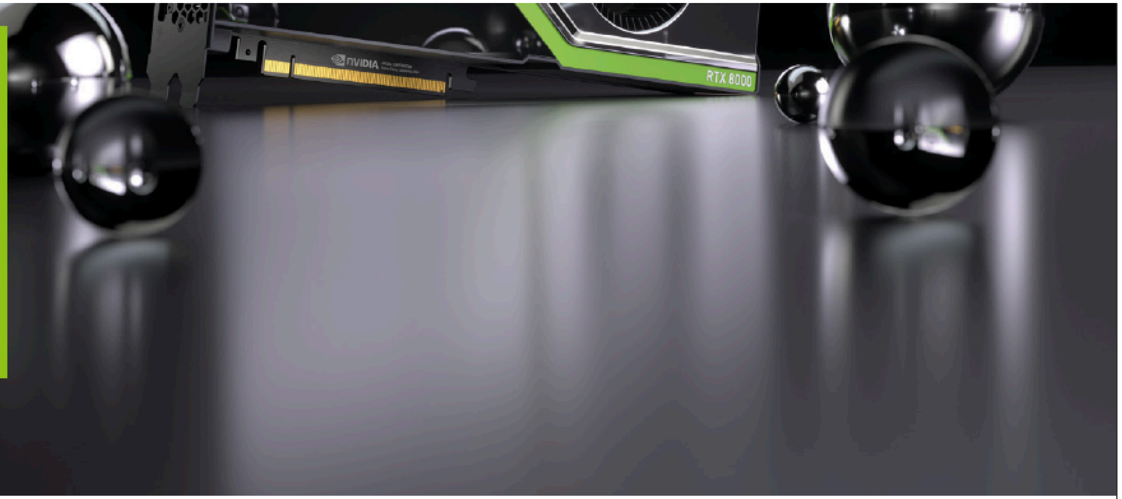

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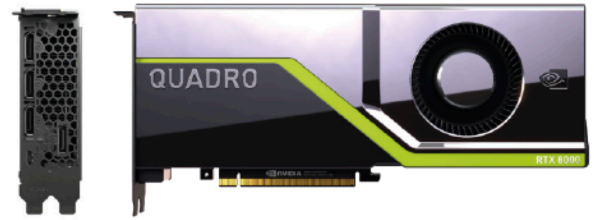

SPECIFICATIONS

GPU Memory	48 GB GDDR6
Memory Interface	384-bit
Memory Bandwidth	672 GB/s
ECC	Yes
NVIDIA CUDA Cores	4,608
NVIDIA Tensor Cores	576

WP8.3.2 Tasks

T4. Stokes inversion code. Selection of model atmosphere, inversion setup and data products. Selection of input/output format and implementation of I/O interfaces.

T5. Stokes inversion code profiling and optimization, with a focus on very time-consuming processes such as singular value decomposition (SVD), Voigt function evaluation, and convolution (FFT vs direct calculation).

T6. Stokes inversion code parallelization. A parallel version will be developed for execution on multi-core machines (workstations, HPC clusters). This will give us a scalable code capable of inverting the data, provided sufficient computing CPUs are available.

T7. Towards real-time Stokes inversions. To boost the performance further and achieve near real-time applicability, a solution based on Graphical Processing Units (GPUs) will be investigated. The optimized inversion code will be used to study critical aspects of a GPU implementation, such as data transfer rates, memory allocation, and speed. We will examine the advantages of CUDA versus OpenCL and will select the most appropriate platform for the development of GPU code. A preliminary design for GPU architectures will be proposed based on these studies.

Comments and questions

- Fully calibrated observations are needed for inversion
- Who will develop pipeline(s)?
- What cadence is really needed? Makes a huge difference!
- Use simple diagnostic methods and approximations instead of Stokes inversion? E.g., COG, weak field?
- How to analyze chromospheric lines?
- Data format: are FITS cubes acceptable?
- We do not have test full-disk data except from HMI...