This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

WP8: Solar Physics Research Integrated Network Group - SPRING

Solarnet Kick-Off Meeting

Brussels, January 24, 2019

Markus Roth, Leibniz-Institut für Sonnenphysik

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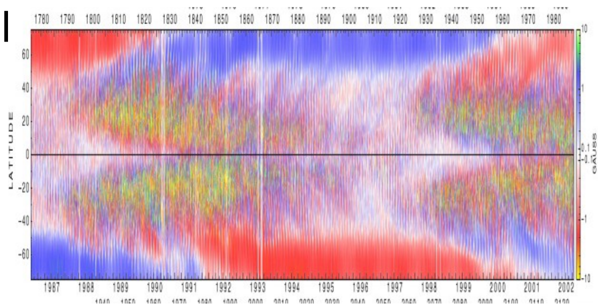
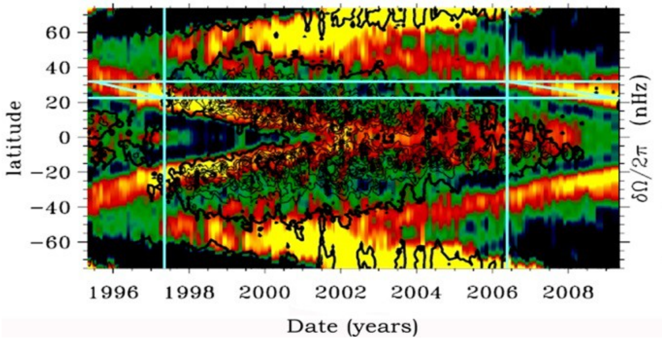
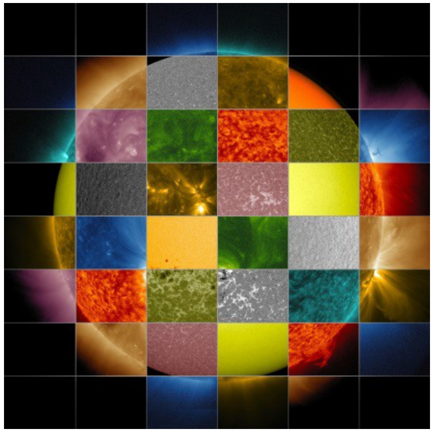
he Need for Synoptic Observations of the Su





- **Long term monitoring of the solar magnetic fields**
  - to understand solar dynamo
  - evolution with solar cycle (polar and active region fields)
  - Active region evolution for space weather studies
  - surface flows via feature tracking
- **Long term monitoring of velocity fields**
  - subsurface flows via helioseismology
  - solar cycle variations and relationship to solar dynamo
  - Flows beneath emerging flux regions and active regions for space weather studies
- **Context imaging for next generation high-res telescopes such as DKIST and EST**
  - Large scale effects (flares, filament eruptions) of small scale events such as flux emergence
  - Technically the fulldisk image could support the pointing system



Current synoptic facilities cannot serve all these new demands!

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Solarnet FP7: Work on Solar Physics Research Integrated Network Group (SPRING) started

Objective: Development of instrumentation for large field-of-view observations of the Sun with a network of solar telescopes in support of observations with existing
high-resolution solar telescopes (either isolated or in a coordinated way).

Technical Requirements / Future synoptic telescopes should provide

- Full-disk Doppler velocity images
- Full-disk vector magnetic field images
- Full-disk intensity images
- Measurements of quantities relevant for space weather

- Provide the above data products in a variety of wavelengths
- Provide the above data products at a high cadence (≤ 60 seconds)
- Provide the above data products at a spatial resolution of 1″ (0.5″ pixels)
- Provide the above data products at least 90% of the time
- Provide the above data products for at least 25 years
- Complement space missions

Participants:

KIS, IAC, INAF, MPS, QUB, AISAS, AIASCR, IGAM, UoB, NSO, HAO

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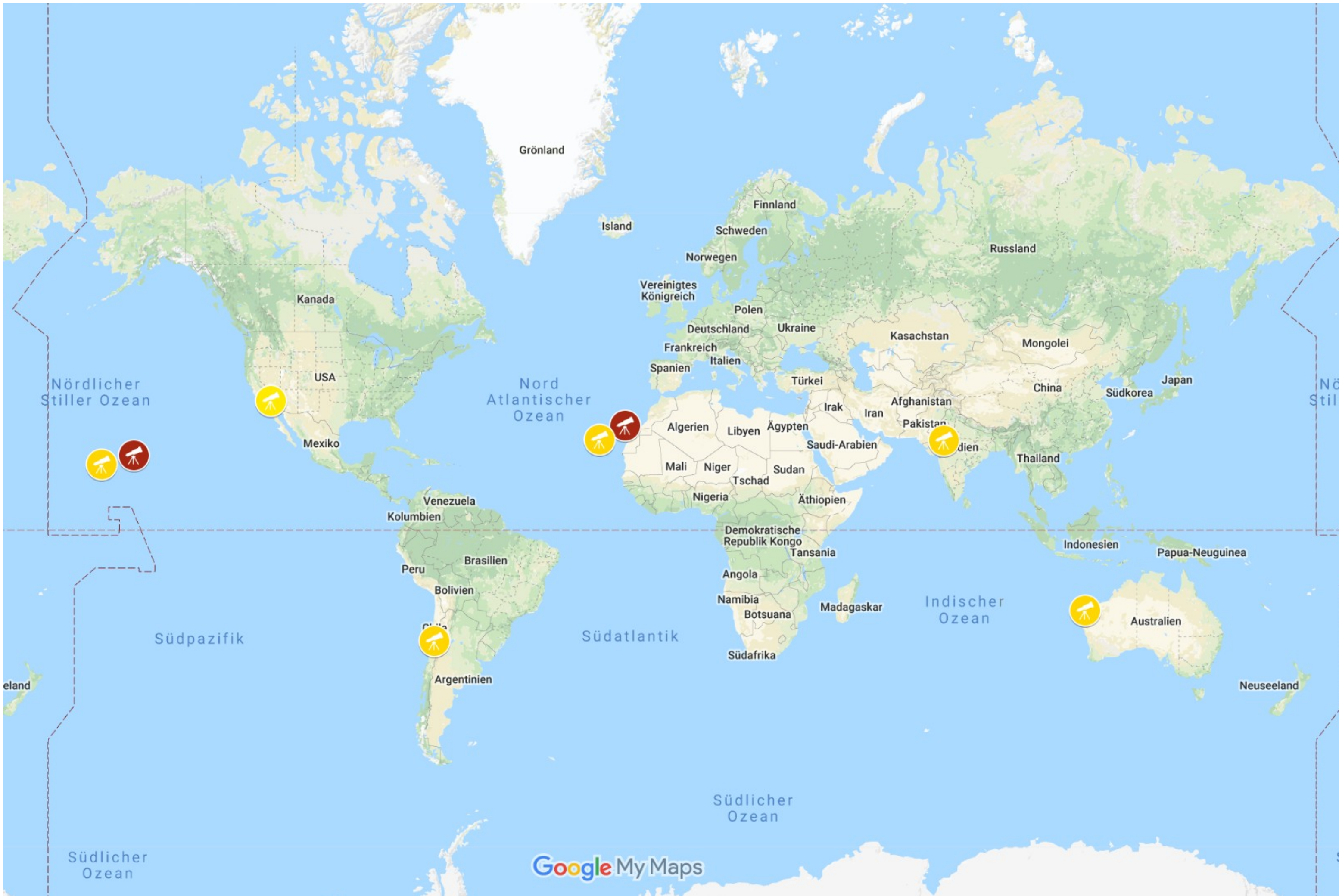
International Dimension



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Science Goal: Long-term behavior of solar magnetism
Front-end Design Concept

SNR Req: Accurate spectropolarimetry of the solar magnetic fields typically requires SNR in Stokes measurements

- Q,U,V/I_{cont} □

~ 1000 for photospheric fields, and

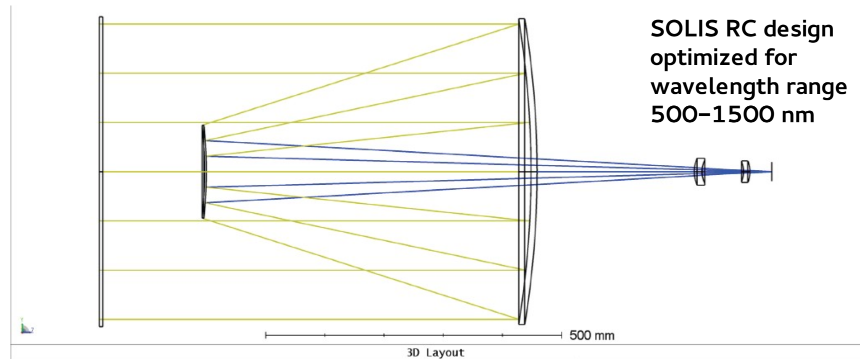
~10000 for chromospheric magnetic fields

Other requirements:

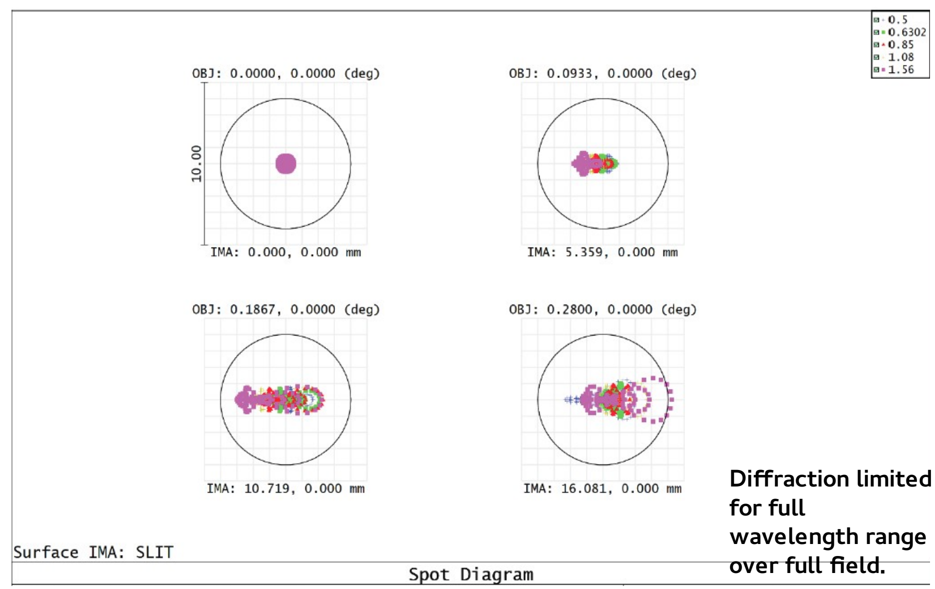
- Spatial sampling: 1 arcsec/pix (2arcsec res.; 2kx2k)
- Spectral Res.: 200,000
- Temporal: every 2-3 hours /Fulldisk
- Spectral lines: in photospheric and chromospheric spectral lines (525.0, 617.3, 630.2, 589.6, 854.2, 1083.0 nm, and 1.5 micron)

Front-end telescope design:

- D=50 cm; Polarization free; Helium filled
- Ritchey-Chretien Design with secondary as tip-tilt
- Wavelength range: 500-1500 nm
- Diffraction limited over full field
- Cooled secondary



SOLIS RC design optimized for wavelength range 500-1500 nm



Diffraction limited for full wavelength range over full field.

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Science Goal: Long-term behavior of solar internal flows
Front-end Design Concept

For Doppler measurements in different spectral lines:
One only needs moderate sized aperture

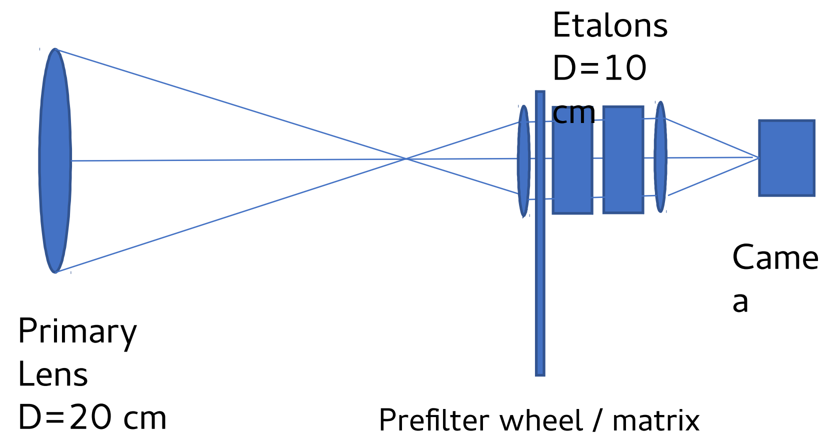
Most of photospheric lines:
Sensitivity of 10 m/s can be reached with an aperture size of 20 cm
Chromospheric lines one needs to integrate more photons.

Temporal cadence requirement:
dictates that a tunable filter with high throughput, such as Fabry-Perot interferometer, must be used.

To achieve the requirements of
- multiple lines
- velocity sensitivity
- SNR
- and the fact that different cameras and etalons will be needed for infrared measurements

We split the instruments into two Identical setups, one for visible (500–750nm) and another for infrared (800–1500nm)

Optical Setup:
Achromatic Doublet
D=20-25 cm
f/D=10
Relay optics: Achromatic wide field



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Objectives

- Translate the technical concept for SPRING developed under SOLARNET FP7 into a preliminary design.

The key scientific areas supported by this facility are:

- 1. Solar awareness (arc-second resolution context images)
- 2. Synoptic magnetic fields (activity complexes, solar magnetic cycle)
- 3. Synoptic velocity fields (surface and interior dynamics, wave phenomena, helioseismology)
- 4. Transient events (flares, active region evolution, space weather)

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Activities

The next steps required towards building such a network are

- WP8.1 Design of the mounting and telescopes
- WP8.2 Design and proto-typing of the post focus instruments
- WP8.3 Definition of the data processing pipelines

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8.1 Design of telescopes and instrument platforms

Partners: AMOS, KIS, AURA, UCAR, ASU, INAF, USFD, UNITOV

One telescope is required for precise magnetic field measurements of the full-disk

- A 50cm telescope is needed to allow a signal-to-noise in Stokes Q, U, and V of 1000 for photospheric lines, and 10000 for chromospheric lines
- Optimized for wavelengths between 0.38 to 1.56 microns

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8.1 Design of telescopes and instrument platforms

In addition full-disk imaging telescopes in parallel to provide data

- in white light and in several wavelength ranges in the blue (3933 – 5434 Angstroms), red (5890 – 6768 Angstroms) and infrared (8542 – 15648 Angstroms)
- with a cadence of 10 s

Further requirements are

- Compactness
- polarization free symmetric optical design
- active tip-tilt corrector built into the system.

Recent thoughts: Such a concept could be realized by a Ritchey-Chretien type design with an entrance aperture of 26 cm, a focal length of 333 cm, which gives an f/D ratio of 13.

Industrial partners: AMOS & BDP

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8.2 Post-focus instrumentation

Partners: KIS, UNITOV, INAF, USFD, AURA, UCAR, BDP E&M

Select the first-light instruments for

- magnetic field and velocity measurements

Magnetograph:

- synoptic full disk measurements of the Sun at all polarization states sufficiently well enough to derive the full magnetic field vector in areas of weak (i.e., quiet Sun) and strong (i.e., sunspots) magnetic field
- with moderate spatial and temporal resolution (1 arc second pixel size and one hour cadence), changing to flare mode (cadence 10 min) in case of an event

Proposed concept is a multi-plex slit spectrograph linked to the 50 cm telescope.

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8.2 Post-focus instrumentation

Doppler Imager:

- Enabling improved and continued measurements for studying
  - the surface
  - internal dynamics and interior structure

The proposed concept is to link Fabry-Perot interferometers to the three smaller full-disk telescopes for the three wavelength ranges.

Plan: Usage of VTT & HELLRIDE to build up a prototype for full-disk observations

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8.3 Data Recording and Processing

Partners:
CSIC-IAA, KIS, NSO, INAF, UNITOV, UNICT, USFD, UCAR, ORB,UNIGRAZ, ASU, SKOLTECH

8.3.1 Lucky Imaging

(ORB, UNIGRAZ, INAF, NSO)

Aim:

- Develop Lucky imaging techniques to improve the effective resolution that can be obtained by SPRING observations
- Required resolution: 1 arcsec

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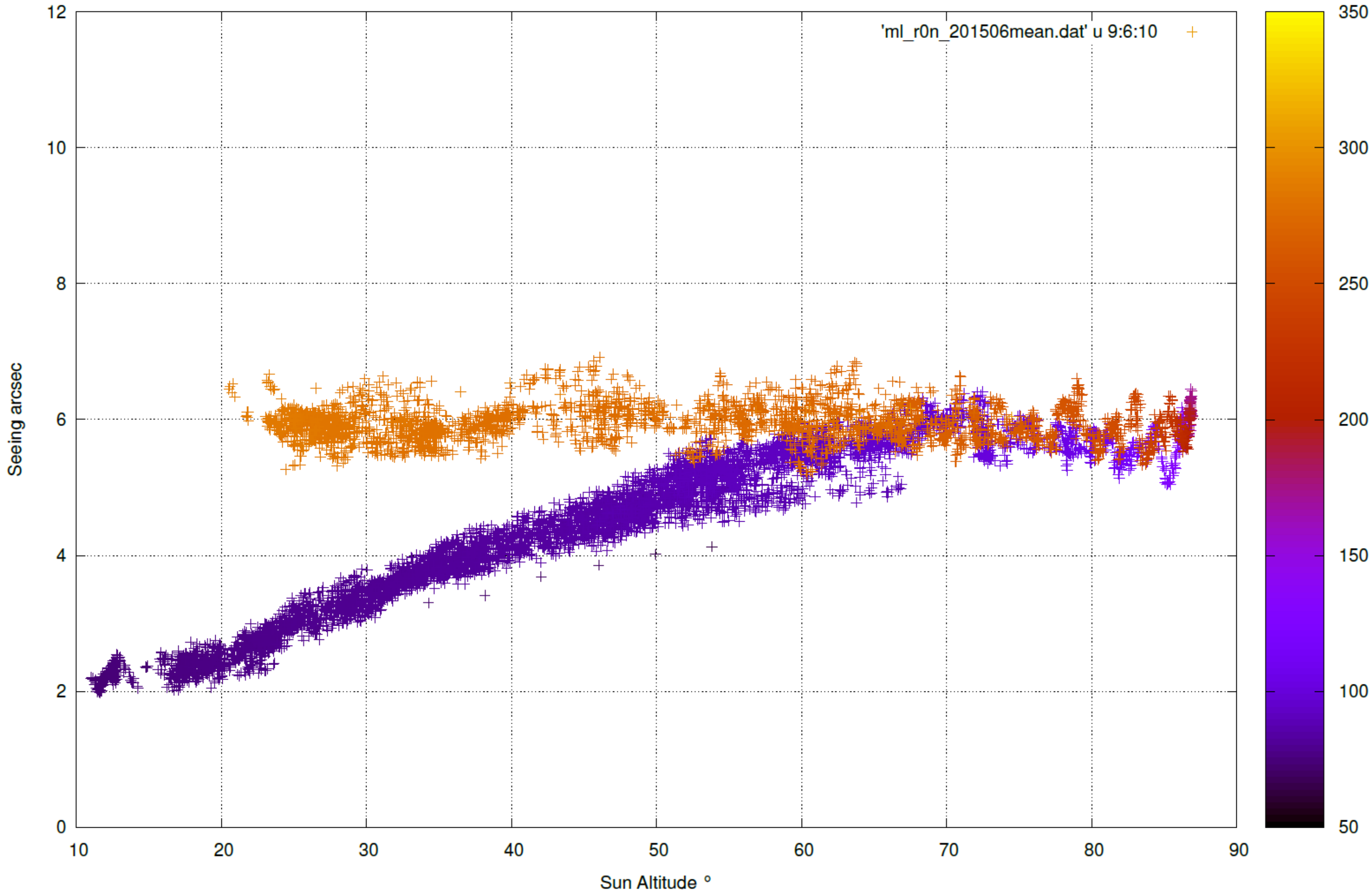
e.g. seeing quality at one of the GONG sites

Mauna Loa



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8.3 Data Recording and Processing

- **8.3.2 Data Calibration, Merging, and Inversion**
  (KIS, CSIC-IAA, NSO, USFD, QUB, ASU, UNIGRAZ, INAF, UNITOV, UNICT)
- Given the defined spatial, spectral and temporal resolution of the post-focus instruments, the data rate of the SPRING network is high.

Challenge:

- provide science-ready data in near real-time.

Development work:

- running software solutions with code acceleration and parallelization for
  - the real-time calibration of the raw data
  - continuous merging of the time-series when switching observing sites
  - Stokes inversion of the polarimetric data of the multiplexed slit spectrograph and the Doppler Imagers.

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8.3 Data Recording and Processing

- **8.3.3 Data Homogenization & Automatic Flare Detection** (UNIGRAZ, SKOLTECH, ORB, NSO, INAF, UNITOV, UNICT, ASU)

Development work:

- Algorithms to homogenize the full-disk solar images from different SPRING network stations, in order to
  - provide continuous high-quality context observations
  - real-time triggers of dynamic observing targets (like flares) for the high-resolution observations

Make use of two high-performance clusters at SKOLTECH (Russia) to which we will get guaranteed access for use in the SOLARNET project.

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Human effort

Participation per Partner

Partner number and short name	WP8 effort
1 - KIS	36.00
6 - INAF	18.00
7 - UNITOV	18.00
8 - UNICT	4.00
9 - CSIC	19.00
13 - USFD	4.00
15 - QUB	4.00
16 - ASU	12.00
17 - ORB	21.00
21 - UNI GRAZ	22.00
22 - Skoltech	24.00
28 - AURA	24.00
31 - BDP E&M	12.00
35 - AMOS	18.00
Total	236.00

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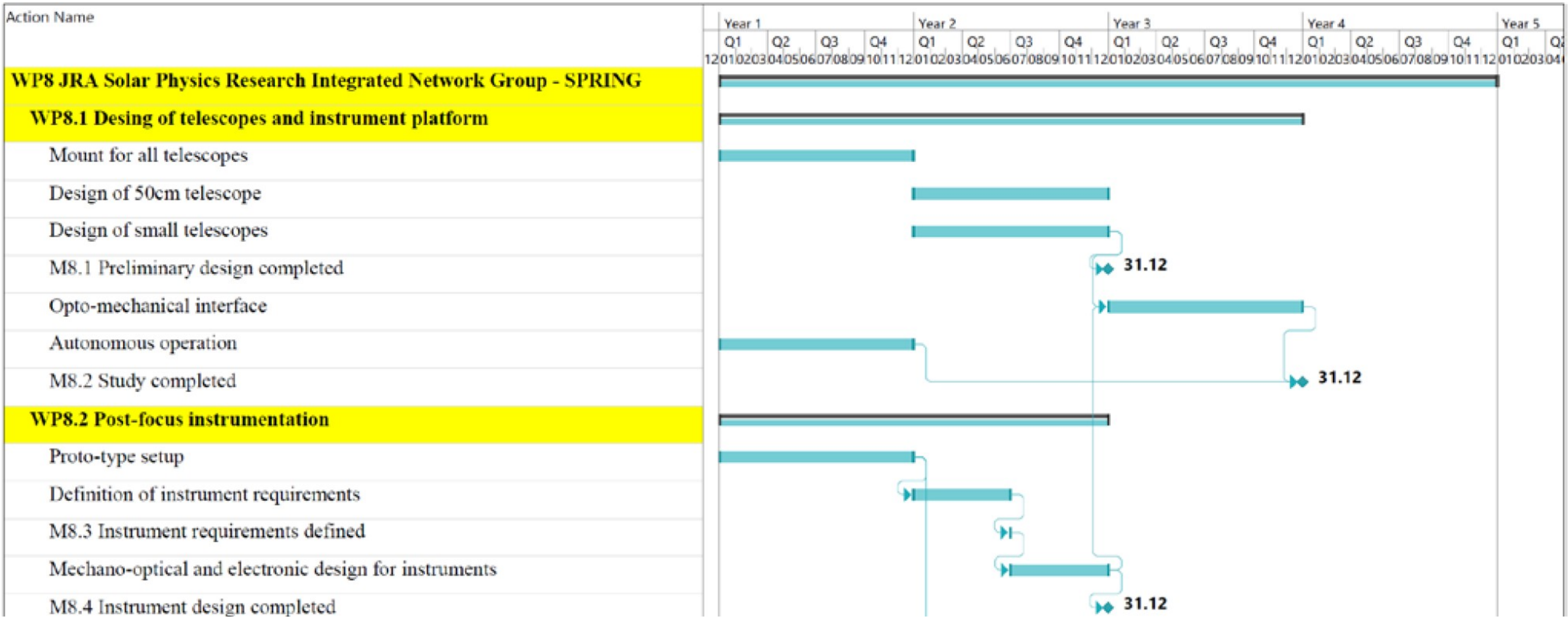
Timeline



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Timeline

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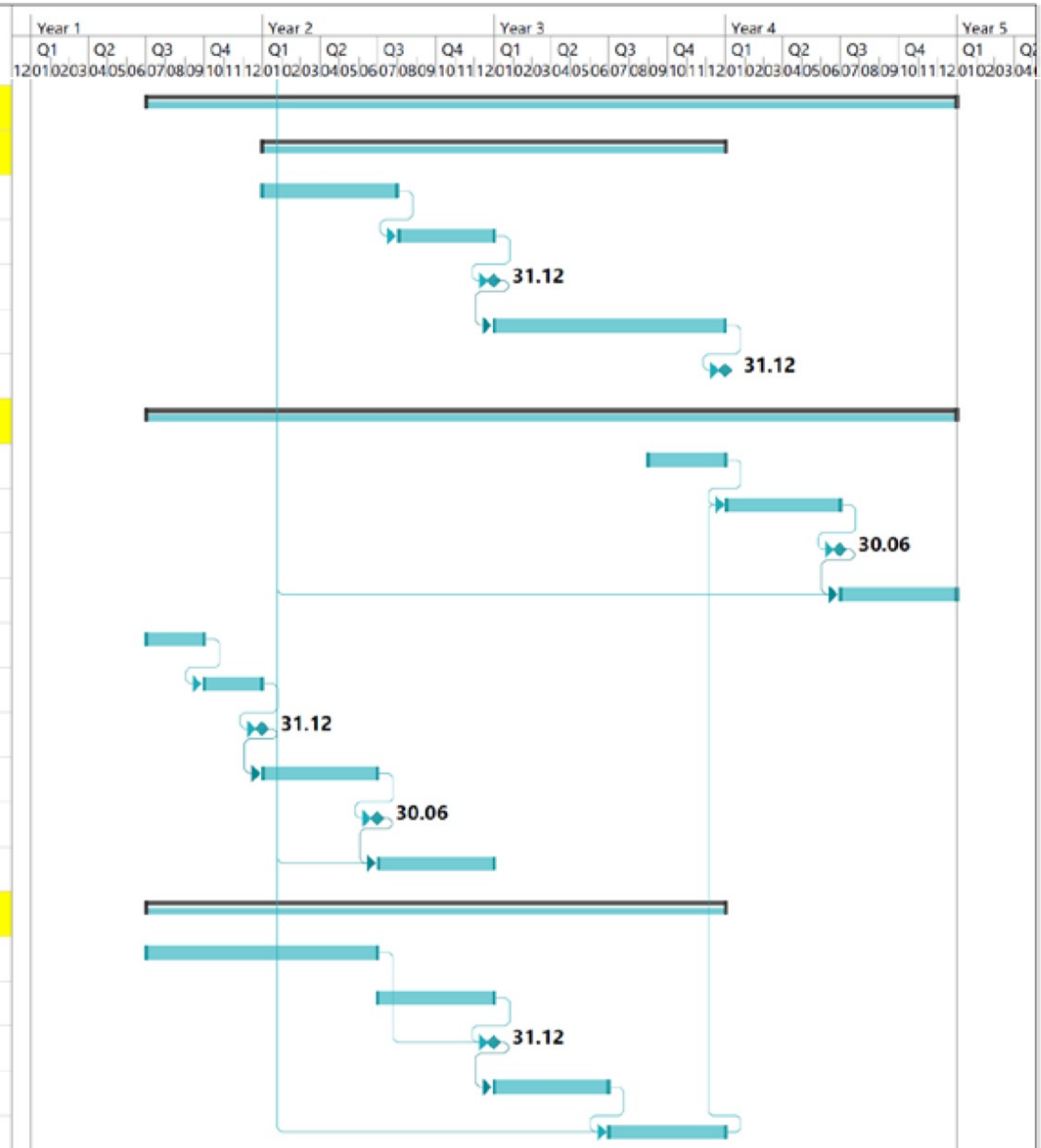
Action Name

- **WP8.3 Data recording and processing**
  - **Lucky Imaging**
    - Algorithm development
    - Lucky Imaging tests
    - M8.5 Lucky Imaging pipeline operationa on archival data
    - Application on Prototype data
    - M8.6 Lucky Imaging pipeline is prototyped on SPRING instrument data
  - **Data Calibration and Inversion**
    - Select test data set for merging
    - Procedures to calibrate and merge data
    - M8.7 Code ready
    - Integration of high-res and synoptic data
    - Stokes inversion code - definition phase
    - Stokes inversion code profiling and optimization
    - M8.8 Stokes inversion code in C completed
    - Stokes inversion code parallelization
    - M8.9 Parallel version of Stokes inversion code completed
    - Towards real-time inversions
  - **Data Homogenization & Automatic Flare Detection**
    - Image processing algorithm development
    - Algorithm for image quality quantification and characterization
    - M8.10 Algorithms written
    - Testing of algorithms
    - Application to prototype data



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Deliverables

Deliverable Number[14]	Deliverable Title	Lead beneficiary	Type[15]	Dissemination level[16]	Due Date (in months)[17]
D8.1	Report on optical and mechanical design of telescope and mounting	35 - AMOS	Report	Public	24
D8.2	Preliminary design for front-end telescope and mounting including schematics	35 - AMOS	Report	Public	42
D8.3	Design for post-focus instrumentation (Dopplergraph and magnetograph)	1 - KIS	Report	Public	42
D8.4	Technical feasibility report on rationale and results of the quasi real-time Lucky-Imaging data-reduction pipeline at ROB	17 - ORB	Report	Public	24
D8.5	Report on Demonstration Platform and results of Lucky-Imaging using multi-instrument data	17 - ORB	Report	Public	42
D8.6	Software for Stokes inversion	9 - CSIC	Demonstrator	Public	24
D8.7	Report on preliminary design of GPU implementation of inversion code	9 - CSIC	Report	Public	30
D8.8	Software for data calibration, data merging	1 - KIS	Other	Public	48
D8.9	Report on rationale and results of the data homogenization and multi-instrument flare detection developed and tested on archival data	21 - UNI GRAZ	Report	Public	30
D8.10	Report on data homogenization of SPRING prototype data and feedback to calibration sub-WP	21 - UNI GRAZ	Report	Public	42

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Milestones

Milestone number[18]	Milestone title	Lead beneficiary	Due Date (in months)	Means of verification
MS20	Preliminary telescope design completed	35 - AMOS	24	Presentation of design concepts (cf. WP 8.1)
MS21	Design study of telescopes and instrumental platform completed	35 - AMOS	36	Design study completed; thermomechanical design for validation. (cf. WP 8.1)
MS22	Post-focus instrument requirements defined	1 - KIS	18	Optical setup tested on working proto-type instruments. (cf. WP 8.2)
MS23	Instrument design completed	1 - KIS	24	All post-focus systems validated and parameters for opto-mechanical interface defined. (cf. WP 8.2)

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First Steps

- Organize a meeting to coordinate work
  - Participation of all partners from Solarnet + further international partners
  - Synchronize with further ongoing activities, e.g. NSO seeks for own money to contribute
- Location of meeting in Freiburg