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

WP6

JRA2 Advanced Instrumentation Development

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

Task 1

Improvements of techniques of image slicers for 2D spectroscopy

(IAC lead, WO, NAOJ)

Task 2

Microlens-fed spectrograph

(MPS)

(Heritage of previous SOLARNET and GREST projects and fundamental for the definition of innovative instrumentation for EST)

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

Task 1

Improvements of techniques of image slicers for 2D spectroscopy

Goal: increase the spatial resolution, which can only be achieved by having thinner slicers (100 → 30-70 microns)

Two strategies will be followed to that aim:

- glass slicers (to be produced by WO)
- metallic slicers (to be produced by NAOJ)

The two alternatives will be pursued and compared in order to decide the best option for EST.

They will be tested at the lab and the best slicer will be tested at GREGOR telescope.

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

Task 2

Microlens-fed spectrograph

Goal: increase the field of view

Requirements

- Larger number and smaller microlenses are needed
- 30k × 30 k detector would be needed → FoV splitting + sensor mosaic
- Challenge: data handling, reduction and restoration

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

Task 3

Design concept of a Narrow-Band Tunable-Filter Imager for EST

(UNITOV lead, IAC, INAF, KIS, SU, BDP E&M)

Goal: define the optimum configuration of the EST Narrow-Band Tunable-Filter Imagers

1. Configuration trade-offs
   - telecentric or classical mount
   - lens, mirrors or catadioptric system
   - plane or 3D set-up
2. Optical design
   - optical performance
   - stray light analysis

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

Task 4

Absolute high precision polarization measurements
(USI/IRSOL)

Goal: Technique to measure absolute (linear and circular) polarisation, with high spatial resolution and applicable to solar telescopes with large aperture

Technique based on combined slow+fast modulation

1. Analytical study of optimum modulation schemes
2. Tests to explore the strengths and limitations of the method
3. Design and construct a prototype system for GREGOR
4. Telescope tests

SOLARNET

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

Closest Deliverables/Milestones

Del./Ms. Number	Del./Ms. Title	Lead Beneficiary	Del./Ms. Date
D6.1	Image slicer design	IAC	13
D6.2	Ability to manufacture thin glass slices	WO	14
D6.3	Ability to manufacture thin metallic slices	NAOJ	14
D6.7	Field splitter design and MLA specs	MPG	14
D6.12	Review of the scientific requirements of Narrow Band Imager	UNITOV	12
MS10	Validation of the ability to manufacture thin metallic and glass slices	IAC	13

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

WP6

JRA2 Advanced Instrumentation Development

sWP6.1

Improvements of techniques of image slicers for 2D spectroscopy

Carlos Dominguez, on behalf of the sWP team

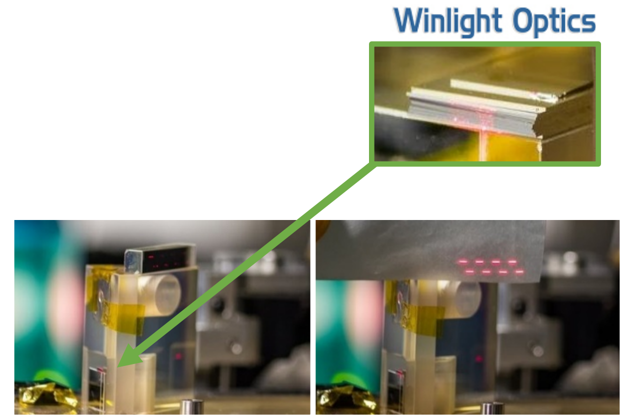
SOLARNET GA Meeting
Prague, 23 January 2020

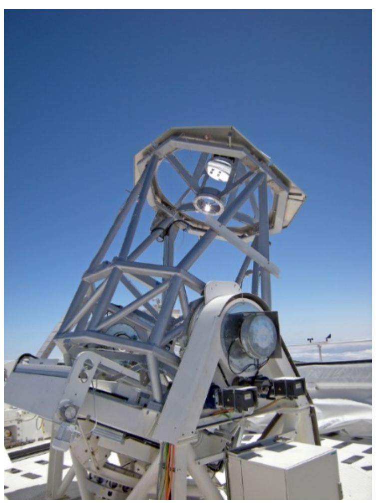
SOLARNET

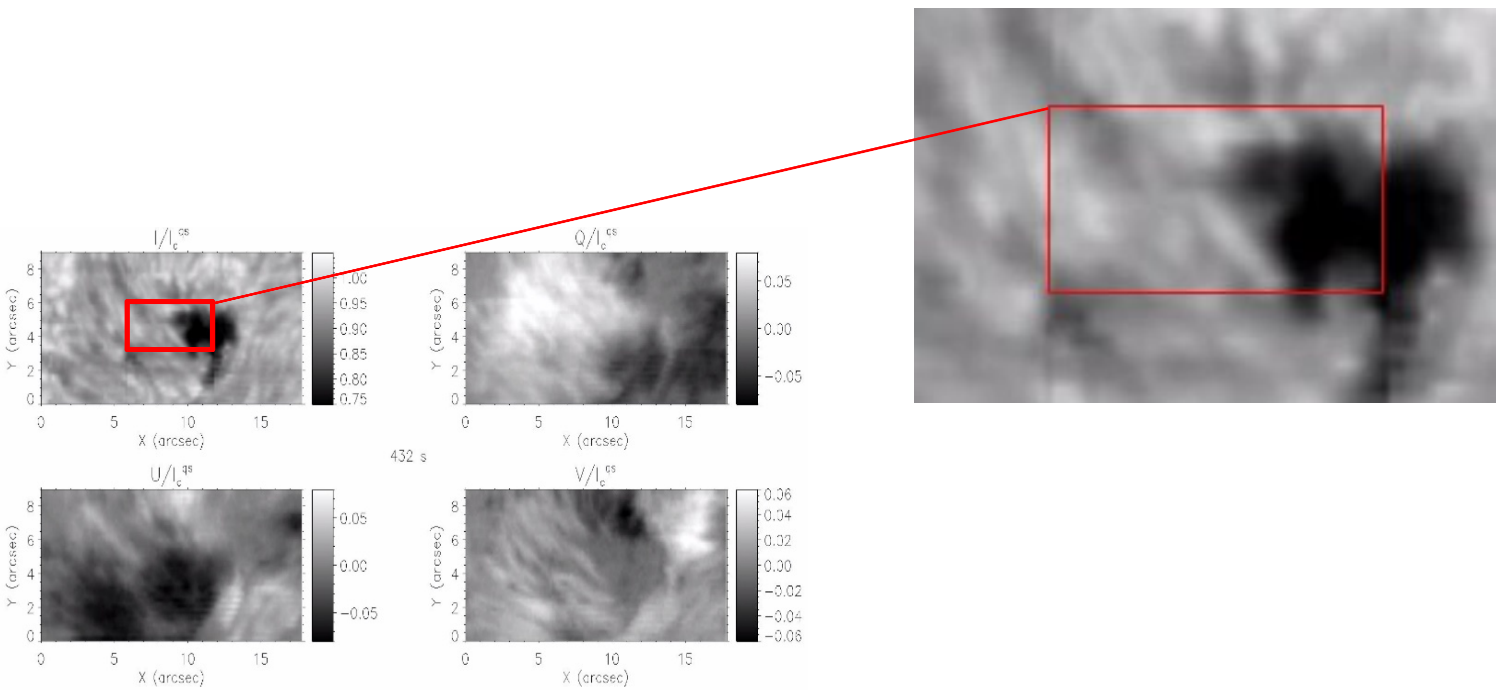
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

sWP 6.1 Introduction

SOLARNET-FP7 Prototype for IFU (1st Image slicer)
GREST Design for multi-slit IFU
SOLARNET-H2020 Prototype for thinner slicers







SOLARNET

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

sWP 6.1 Objective

- Increase the spatial resolution
  - Feasibility of thinner slicers
    - Zerodur slicers: go <100 microns --> 70
    - Metallic slicers: go <50 microns --> 35
  - Manufacture and test prototype

sWP 6.1 Partners:

INSTITUTO DE ASTROFISICA DE CANARIAS · IAC

Winlight System

Winlight Optics

NAOJ

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

sWP 6.1 Milestones

Milestone	Date (month)	Deliverable	Lead beneficiary
Design of the image slicers	13	6.1	IAC
Validation of the ability to manufacture thin glass slices	14	6.2	WO
Validation of the ability to manufacture thin metallic slices	14	6.3	NAOJ-NINS
Manufacture of the glass slicers	37	6.4	WO
Manufacture of the metallic slicers	37	6.5	NAOJ-NINS
Integration with the reimagination optics	39	6.6	IAC
Performance of image slicers	48		

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

Optical design (IAC)

- Based on the experience from previous designs
- Thinner slicers
- Could be coupled to the spectrograph GRIS
- Two designs:
  1) metallic image slicer
  2) Zerodur image slicer

Magnification	1
Illumination type	Telecentric
Main wavelengths	1083nm & 1565nm
Number of output slits *	1-2
Detector size *	1020 x 1024 pixels
Pixel size *	18 microns

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

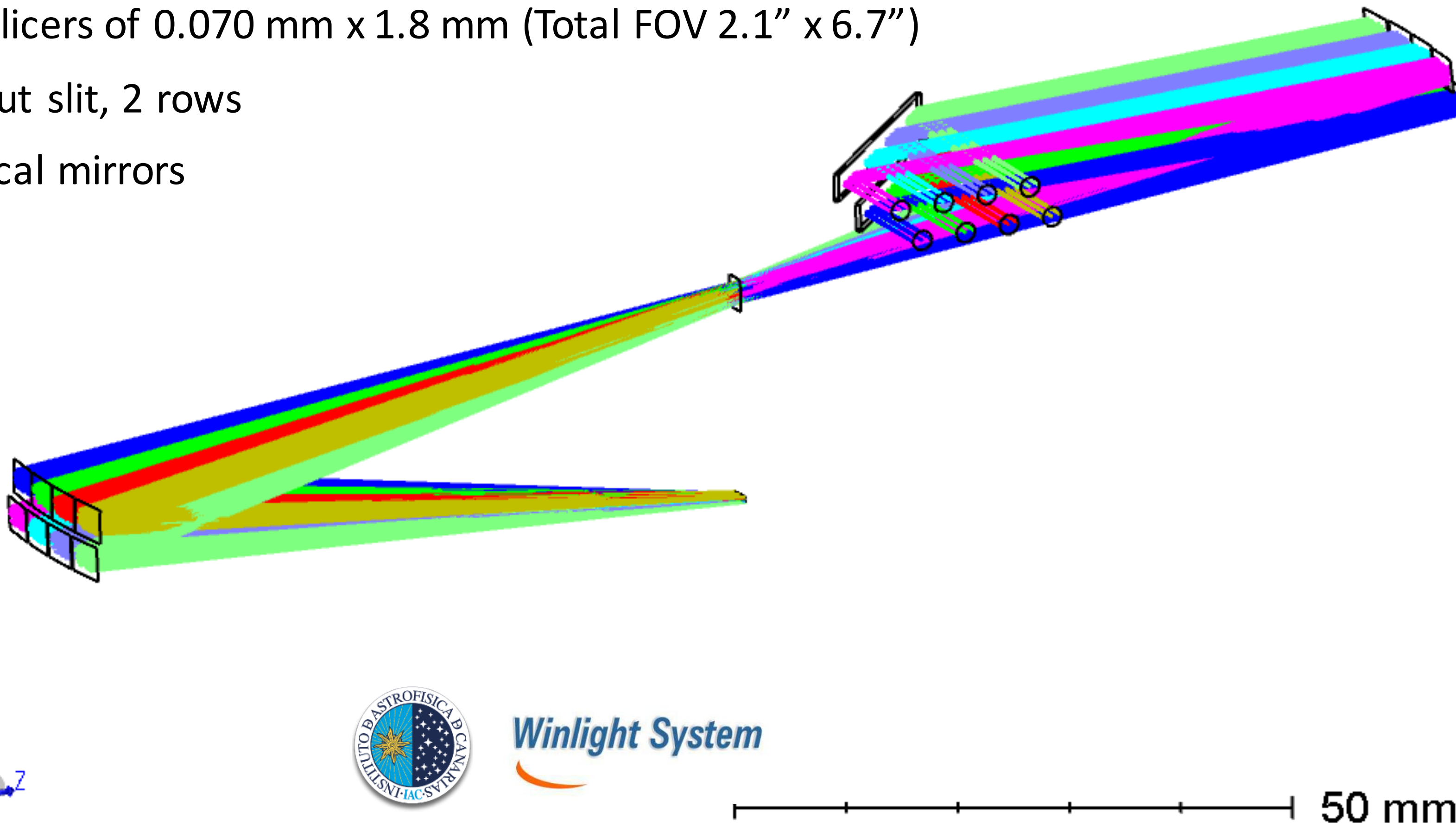
Optical design: Zerodur image slicer (IAC in coordination with WO)

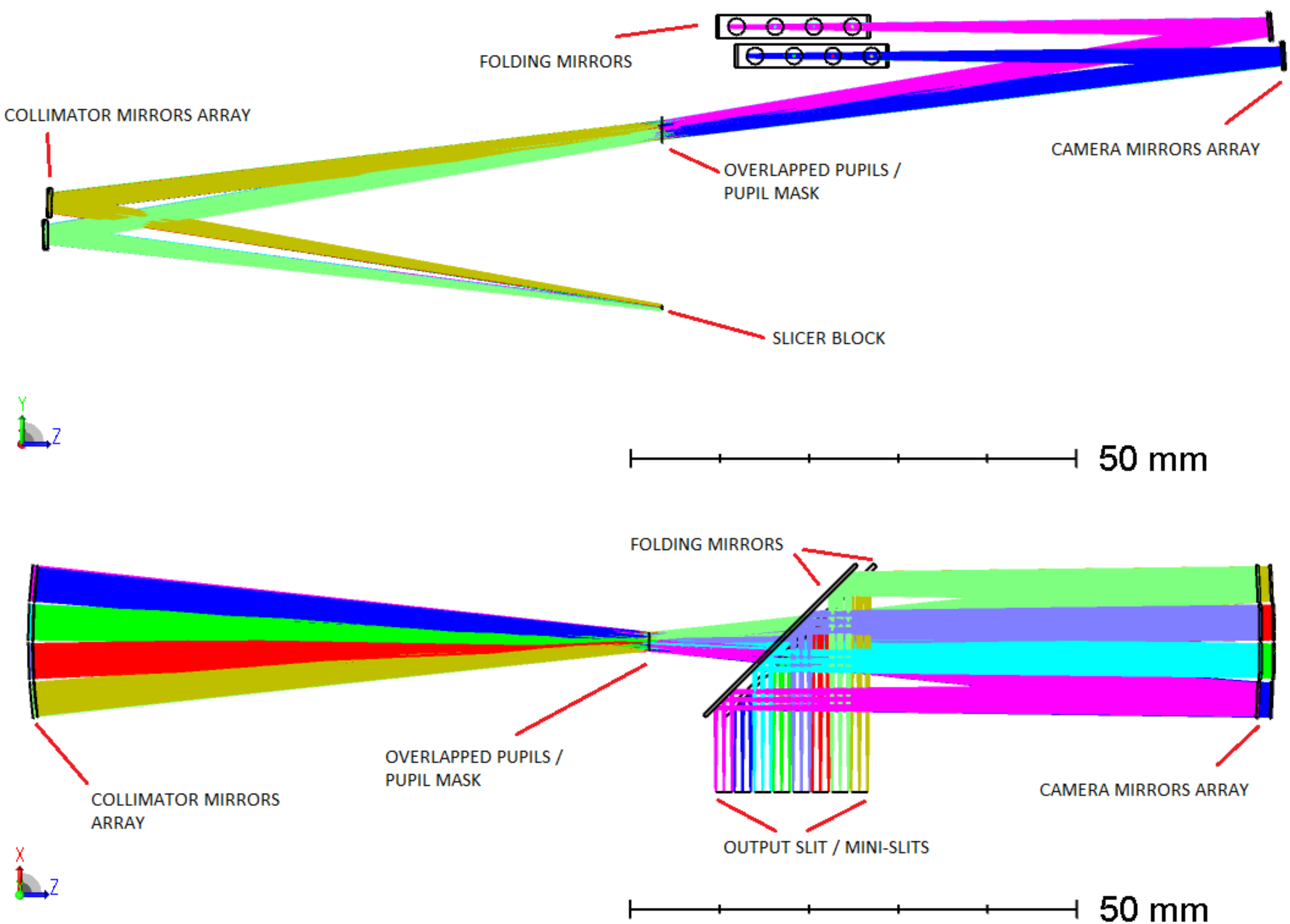
Slicers thickness: 70 micron

8 flat slicers of 0.070 mm x 1.8 mm (Total FOV 2.1" x 6.7")

1 output slit, 2 rows

Spherical mirrors




FOLDING MIRRORS
COLLIMATOR MIRRORS ARRAY
CAMERA MIRRORS ARRAY
OVERLAPPED PUPILS /
PUPIL MASK
SLICER BLOCK
Y
Z
50 mm
FOLDING MIRRORS
OVERLAPPED PUPILS /
PUPIL MASK
COLLIMATOR MIRRORS
ARRAY
CAMERA MIRRORS ARRAY
OUTPUT SLIT / MINI-SLITS
X
Z
50 mm

SOLARNET

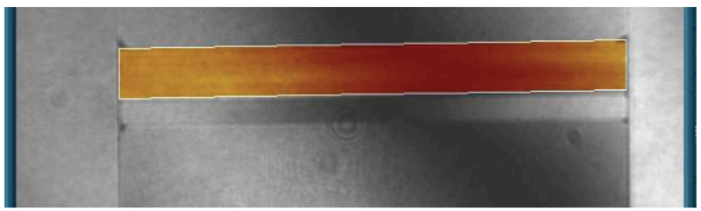
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

WO ability to manufacture thin glass slices

Working with 50 and 70 micron slices

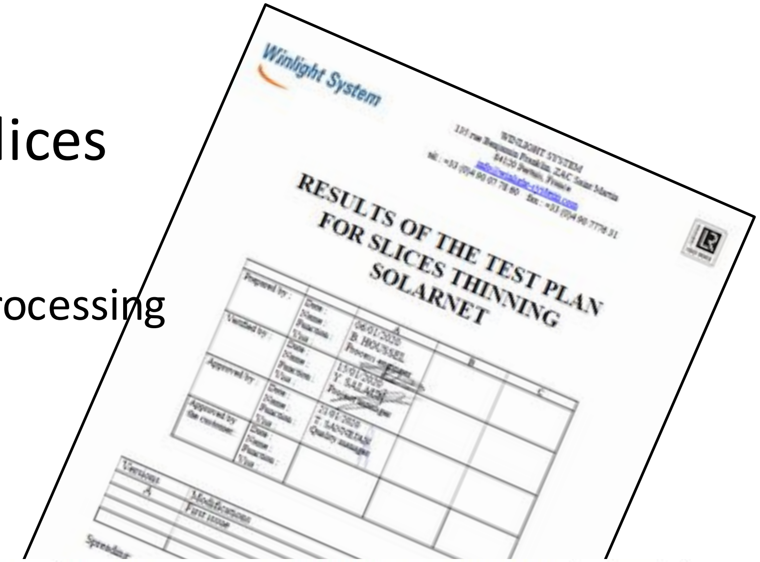
Tests of geometry, SFE and roughness during the processing

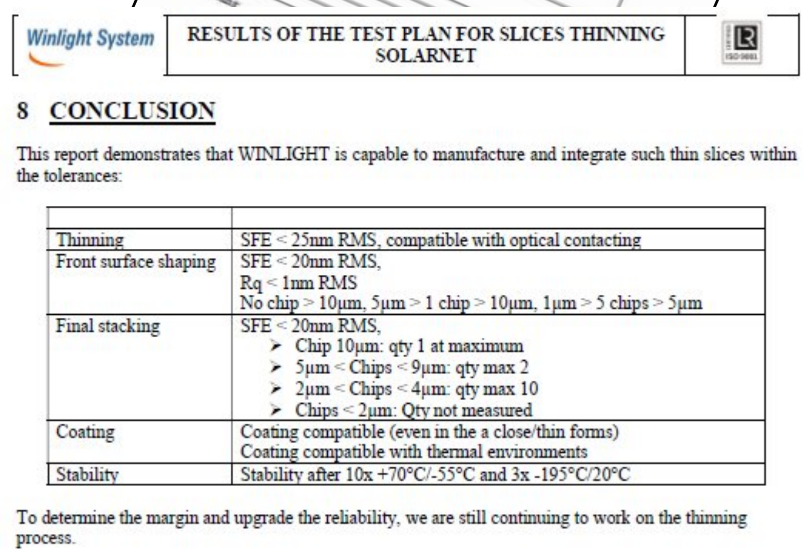
Very good results with 70 micron



Measurement of a stack of 14 slices Measurement of a stack of 23 slices (scale ≈ 10)

Flatness measurement of a stack of 14 slices – full aperture





Winlight System | RESULTS OF THE TEST PLAN FOR SLICES THINNING SOLARNET

8 CONCLUSION

This report demonstrates that WINLIGHT is capable to manufacture and integrate such thin slices within the tolerances:

Thinning	SFE < 25nm RMS, compatible with optical contacting
Front surface shaping	SFE < 20nm RMS, Rq < 1nm RMS No chip > 10µm, 5µm > 1 chip > 10µm, 1µm > 5 chips > 5µm
Final stacking	SFE < 20nm RMS, ➤ Chip 10µm: qty 1 at maximum ➤ 5µm < Chips < 9µm: qty max 2 ➤ 2µm < Chips < 4µm: qty max 10 ➤ Chips < 2µm: Qty not measured
Coating	Coating compatible (even in the a close/thin forms) Coating compatible with thermal environments
Stability	Stability after 10x +70°C/-55°C and 3x -195°C/20°C

To determine the margin and upgrade the reliability, we are still continuing to work on the thinning process.

Winlight System

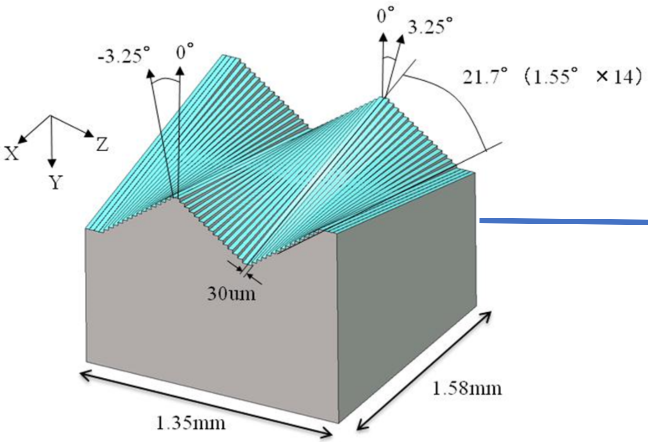
This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

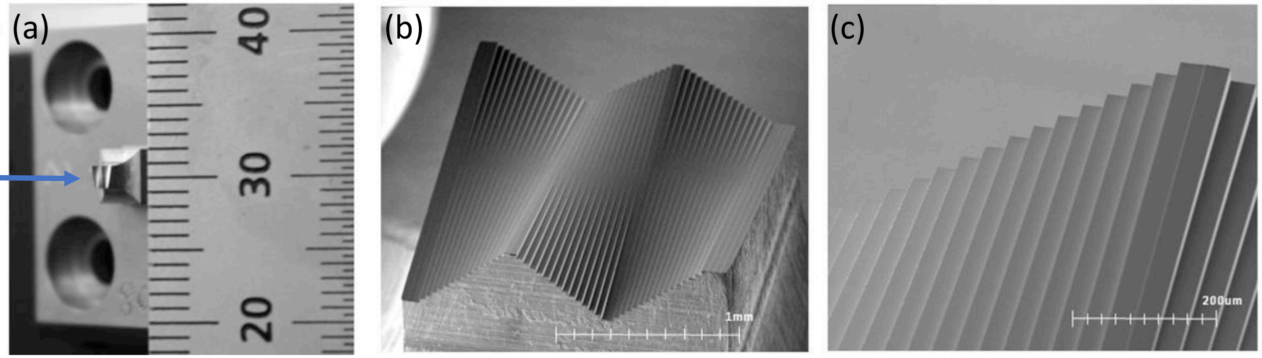
NAOJ -NINS ability to manufacture thin metallic slices

- Re-evaluation of the 1st prototype metal-mirror slicer
- Collaboration in the optical design
- Got a research grant for the fabrication of metallic image slicer. Delivery due: mid-February, 2020

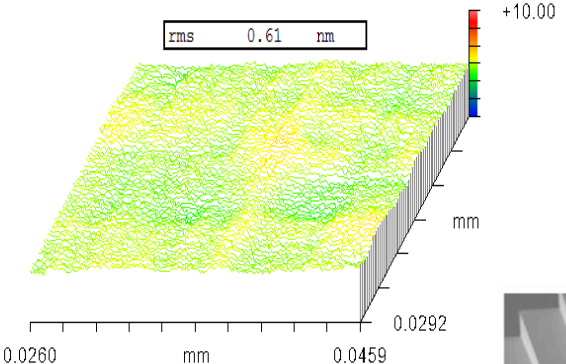
	1st prototype slicer
Substrate	Invar
Array	15x3
Slicer surface figure	Flat
One slicer size	0.03x1.56 mm
Accuracy of width	±1 µm
Edge sharpness	≦1 µm
Flatness	≦20 nm PV (Y), ≦55 nm PV (X)
Micro-roughness	≦1.3 nm RMS
Coating	Protected silver

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

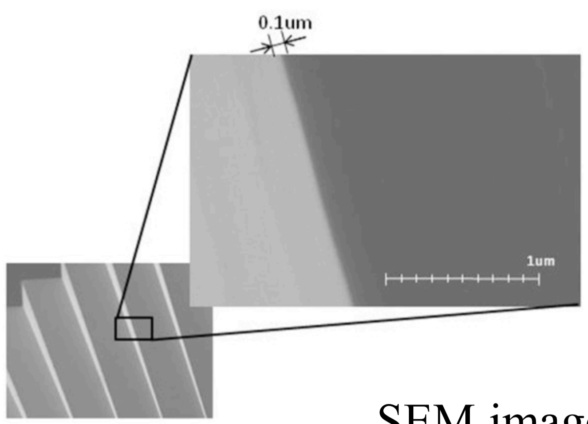


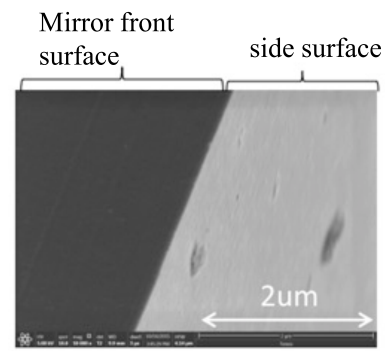


Picture and the scanning electron microscope (SEM) images (X50, X200)

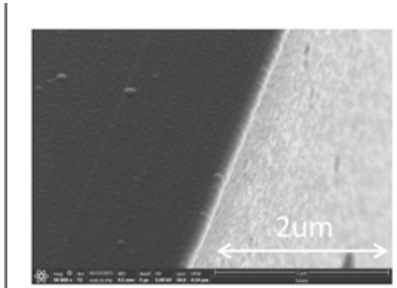


Surface roughness





Before silver coating



After silver coating

SEM image (X50000) of an edge quality of the micro slicer mirrors

SOLARNET

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

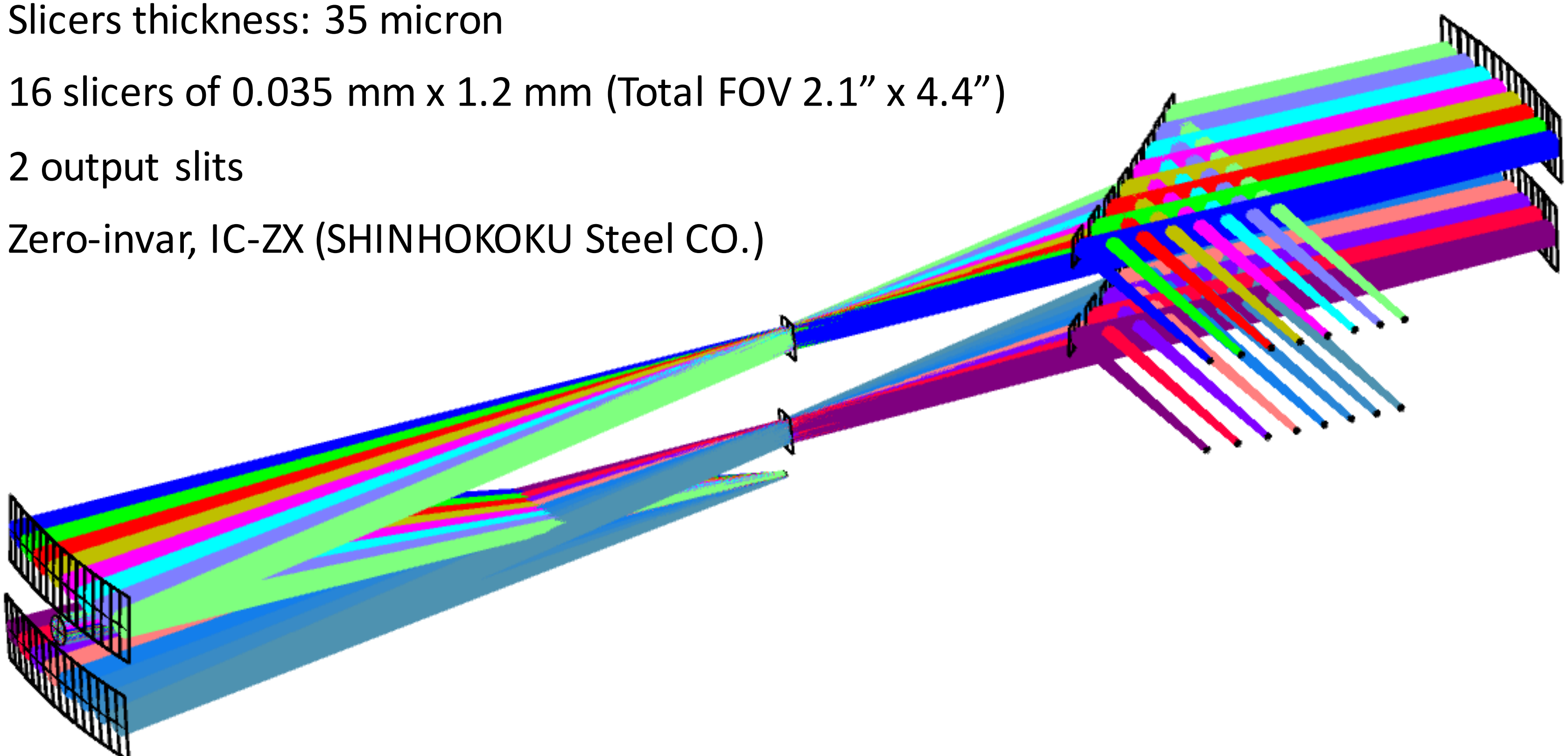
Optical design: metallic image slicer (IAC and NAOJ-NINS)

Slicers thickness: 35 micron

16 slicers of 0.035 mm x 1.2 mm (Total FOV 2.1” x 4.4”)

2 output slits

Zero-invar, IC-ZX (SHINHOKOKU Steel CO.)

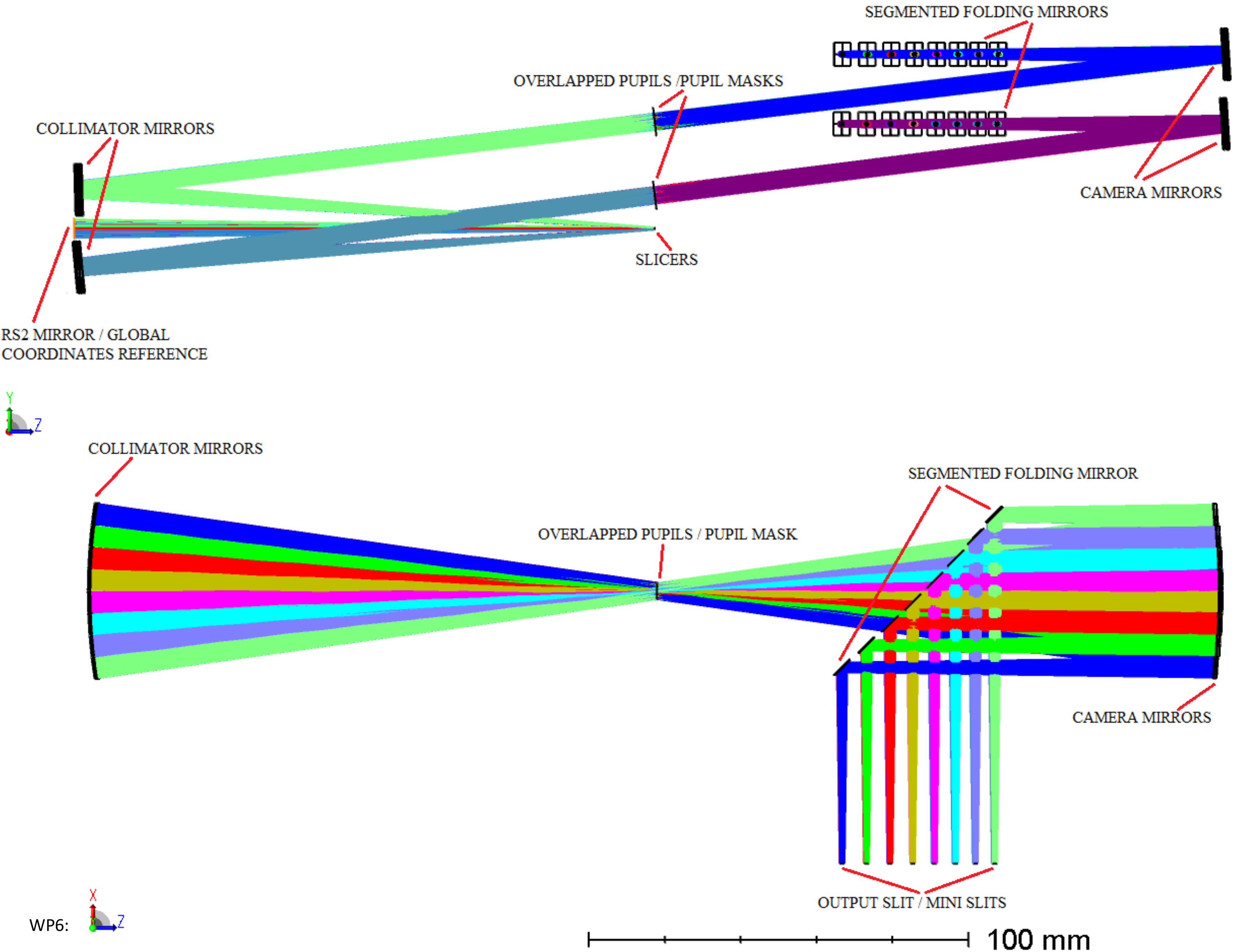


100 mm

WP6

NAOJ

ean
ogramme



SEGMENTED FOLDING MIRRORS
OVERLAPPED PUPILS /PUPIL MASKS
COLLIMATOR MIRRORS
CAMERA MIRRORS
SLICERS
RS2 MIRROR / GLOBAL
COORDINATES REFERENCE
Y
Z
COLLIMATOR MIRRORS
SEGMENTED FOLDING MIRROR
OVERLAPPED PUPILS / PUPIL MASK
CAMERA MIRRORS
OUTPUT SLIT / MINI SLITS
X
Z
WP6:
100 mm

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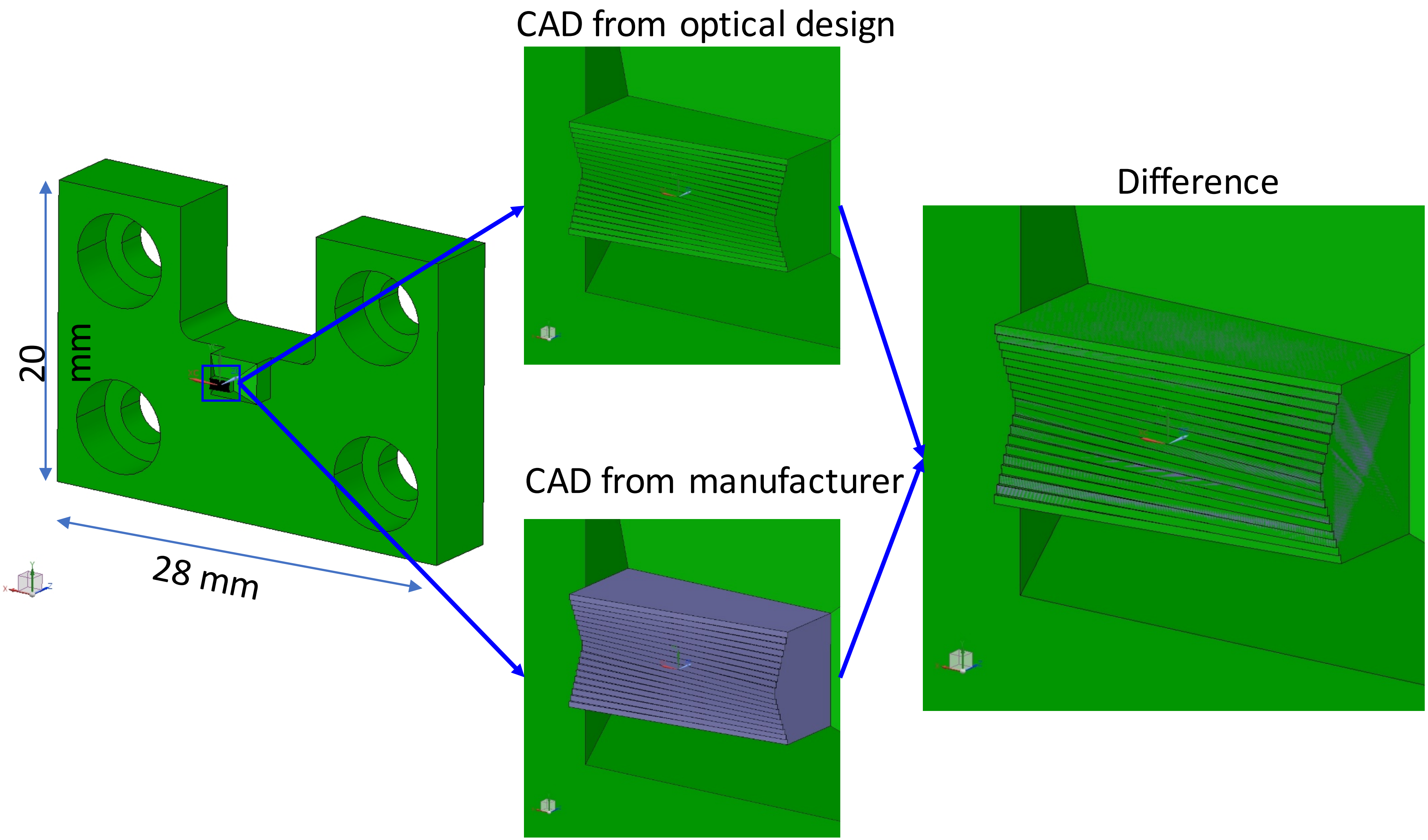


This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 824135.

sWP 6.1 Status:

- ✓ Optical design of the image slicers
- ✓ WO report on the ability to manufacture thin glass slices
- ✓ NAOJ-NINS is already fabricating a new prototype

Next steps

- Tolerance analysis (new optical engineer)
- Manufacture of image slicers
- Design of reimagination optics
- Tests

Integrating High Resolution Solar Physics

Report on Absolute high-precision polarization measurements

Solarnet General Assembly Meeting

January 23, 2020

F. Zeuner, D. Gisler & **M. Bianda**

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

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

Method

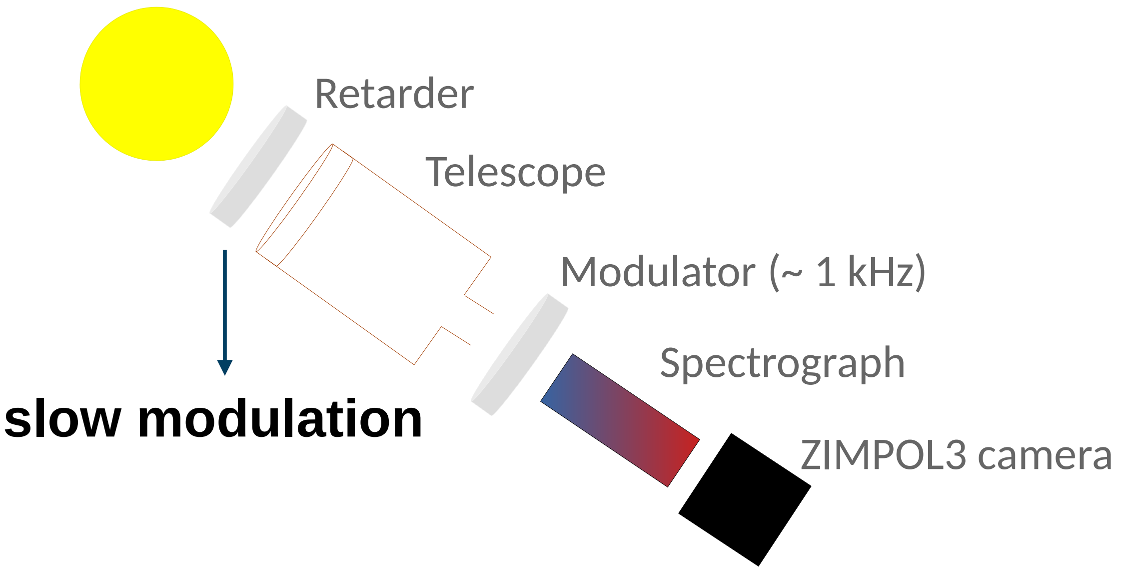
Absolute high-precision spectropolarimetry requires to minimize:

- seeing-induced cross-talk (SIC)
- telescope polarization
- telescope-induced cross-talk
- post-focus instrument errors

} → telescope calibration

Optimal position: **in front of the telescope**

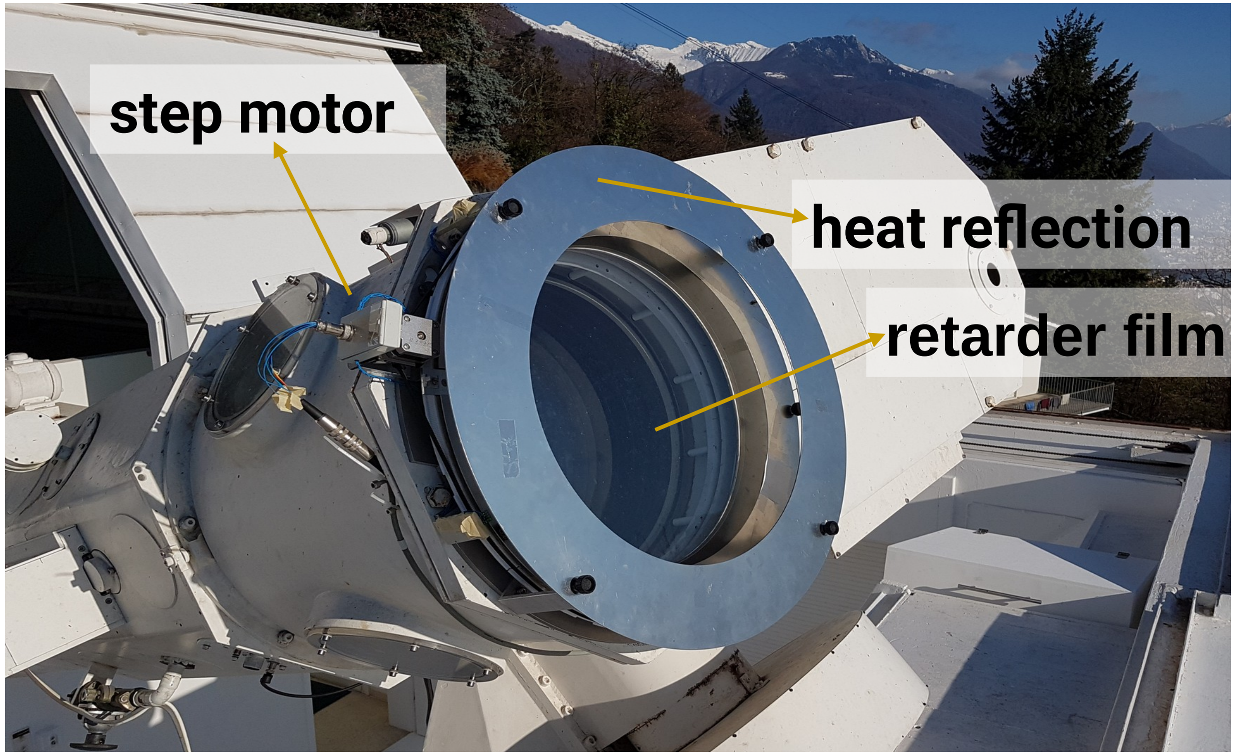
Current setup at IRSOL



- SIC minimized by *fast modulation* (modulator + ZIMPOL3)
- telescope calibration by *slow modulation* (automatically rotated zero-order retarder film)

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

Telescope Calibration Unit (TCU) setup at IRSOL



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

Method

Problem:

Aperture-size **achromatic, homogeneous λ/2 retarders** are unavailable.

In general, retardence δ(λ,x,y) depends on wavelength and position within the retarder.

IRSOL solution:

- cheap retarder film
- 8 angle positions of TCU (22.5° per step)
  → to correct for additional cross-talk induced by zero-order retarder
- up to now, only *Q* and *U* are correctable
- wavelength range **3800 Å – 8000 Å** with retardations 0.4-0.6

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

Method

pros:

- first correction in front of the telescope
- broad wavelength range with cheap device
- correction of cross-talks and offsets induced by telescope and post-focus instruments

→ allows for **absolute** high-precision spectropolarimetry

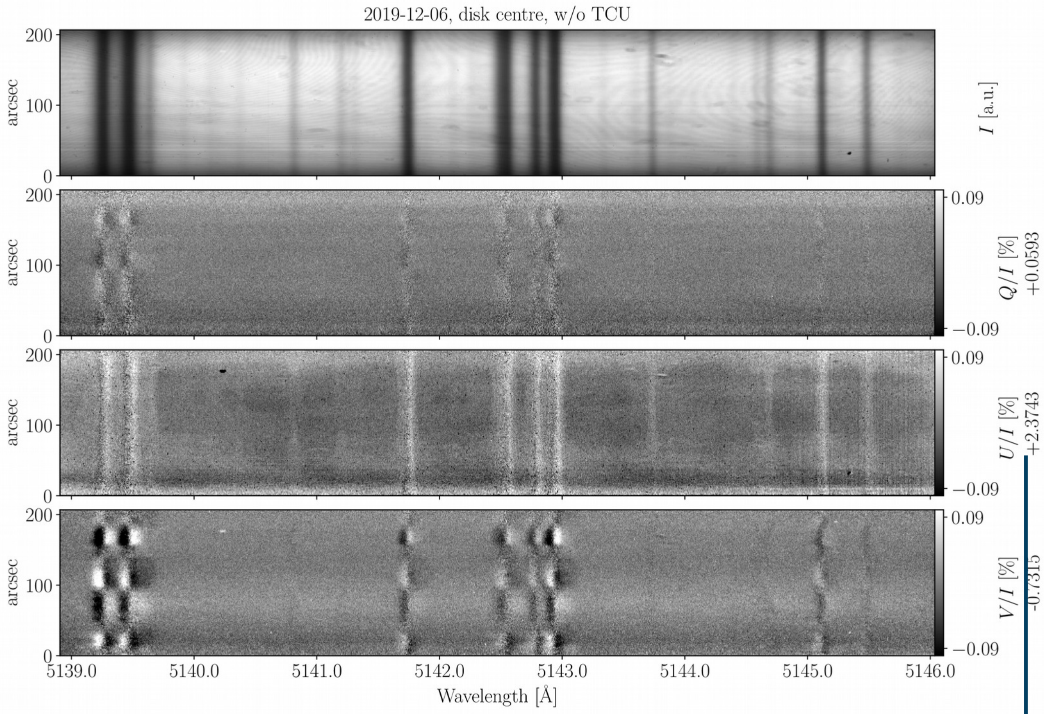
cons:

- slow second modulation (measurement cycle length ~min)
- low spatial resolution
- reduction of efficiency
- up to now, only *Q* and *U* are corrected

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

Example: C_2 lines ~5140 Å (IRSOL synoptic program)

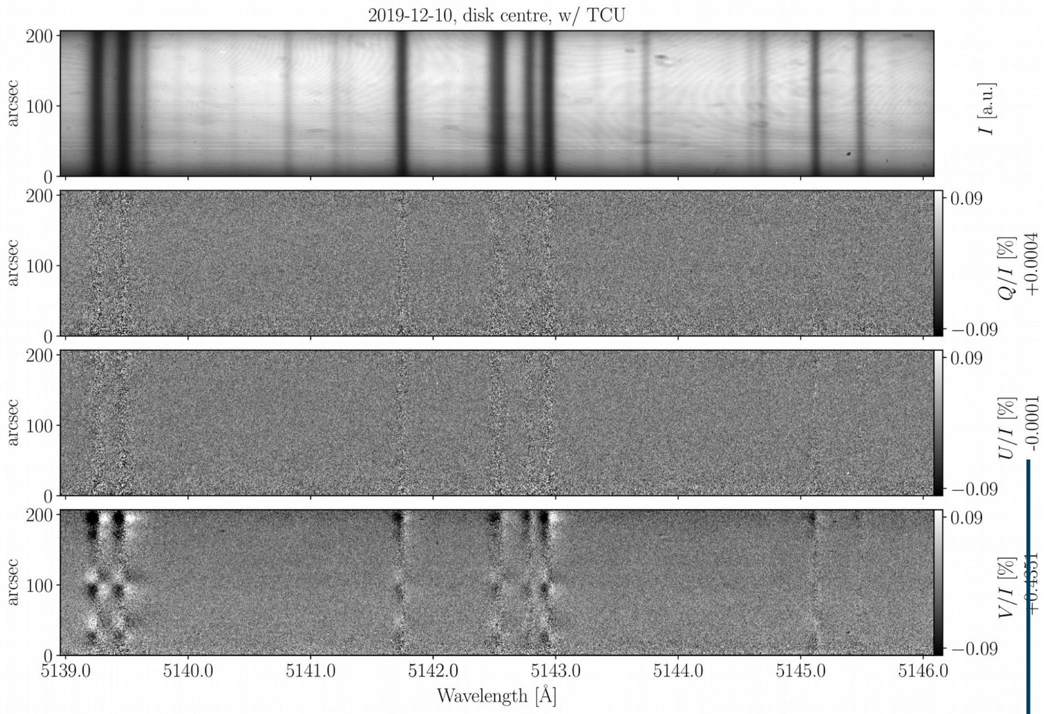
w/o TCU



Q offset	**6·10^{-4}**
U offset	**2·10^{-2}**

telescope induced polarization offset up to ~10^{-2}

w/ TCU



Q offset	**4·10^{-6}**
U offset	**1·10^{-6}**

removed, <10^{-5}

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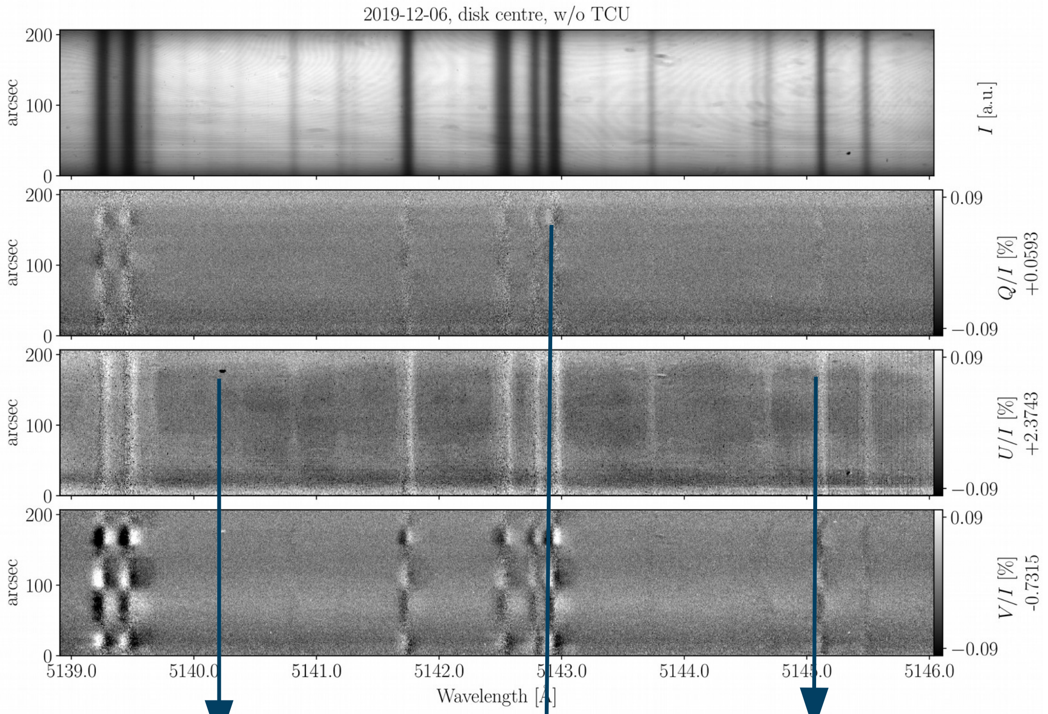
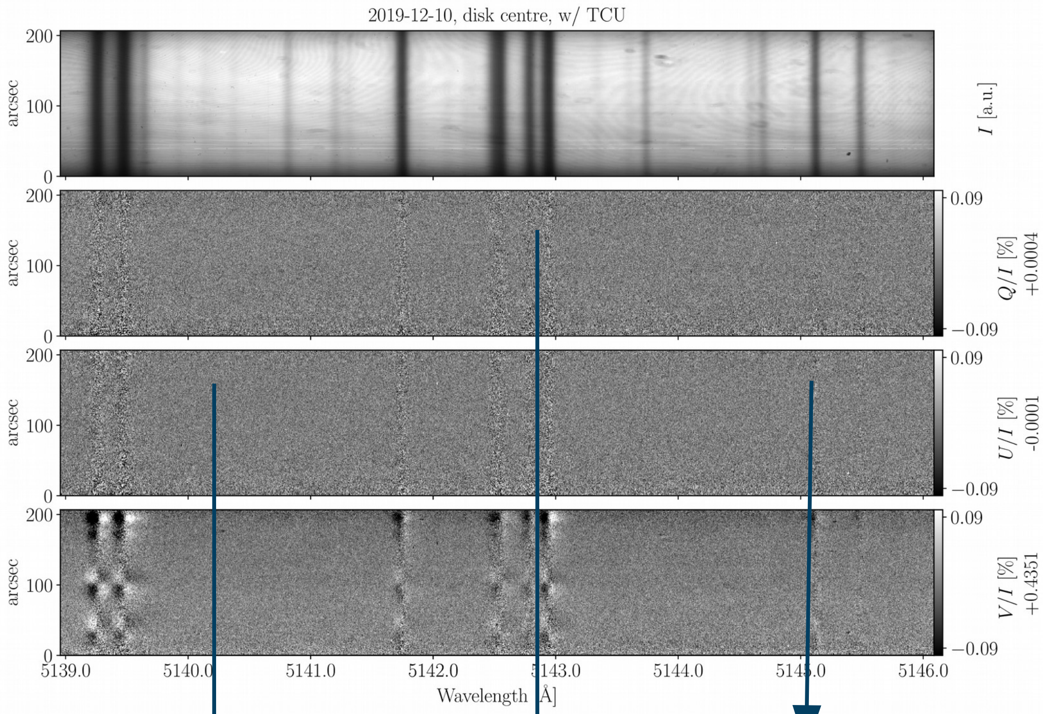
Example: C_2 lines ~5140 Å (IRSOL synoptic program)

w/o TCU



w/ TCU



camera defects

telescope induced
Stokes *V* cross-talk

Stokes *I* cross-talk

removed

removed

removed

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

Planned work for 2020:

- Finding **optimal modulation scheme** by analytically studying the method
- Extensive testing of the method in **different wavelength** regimes
- Limits of method regarding the **spatial resolution**
- Extent method to correct for **full Stokes**
- First planning to extent the method to **GREGOR** telescope

Integrating High Resolution Solar Physics

Report on WP6.2-Microlens Spectrograph

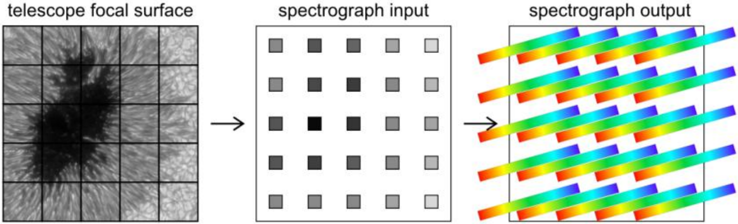
Solarnet 2nd General Assembly Meeting
2020.01.23

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

Michiel van Noort

SOLARNET-I: MiHI prototype

Integral Field instrument: High spatial and spectral resolution without the usual compromises



Principle: "The incredible shrinking pixel"

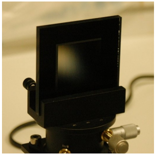
- Demagnify pixels using double sided microlens array
- Prototype: "Plug-in" for TRIPPEL at the SST
- FOV 8.3" $\times$7.5"
- Spectral range: $\sim$5Å.

MiHI prototype @ SST

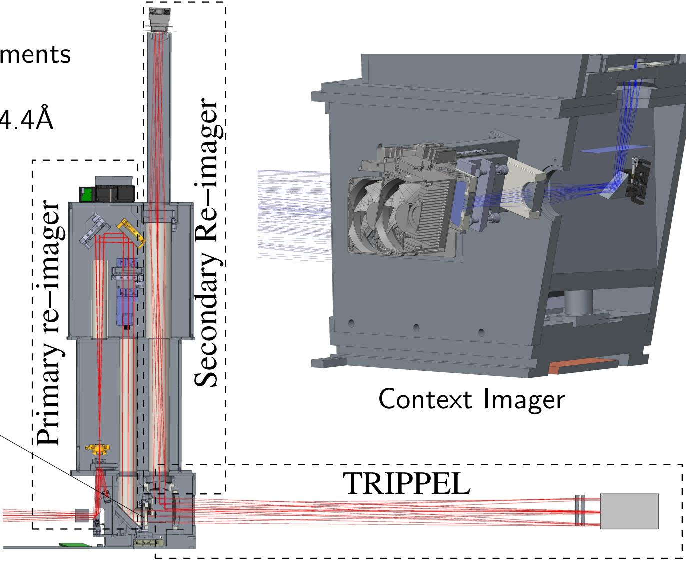
128×115 elements
(8.3" ×7.5")

Bandwidth: 4.4Å

R ≈ 330000

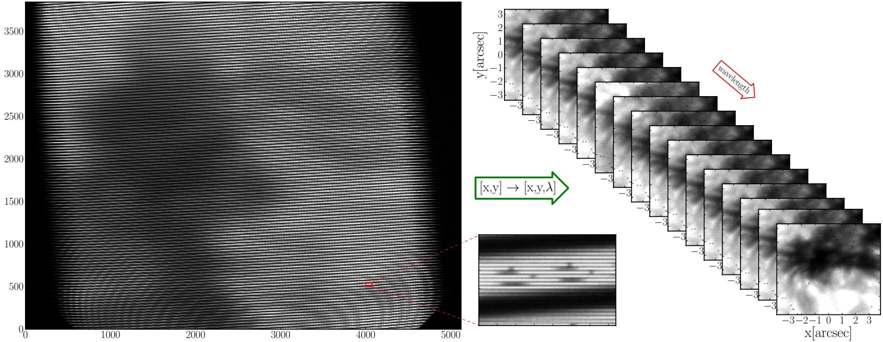


MLA



Context Imager

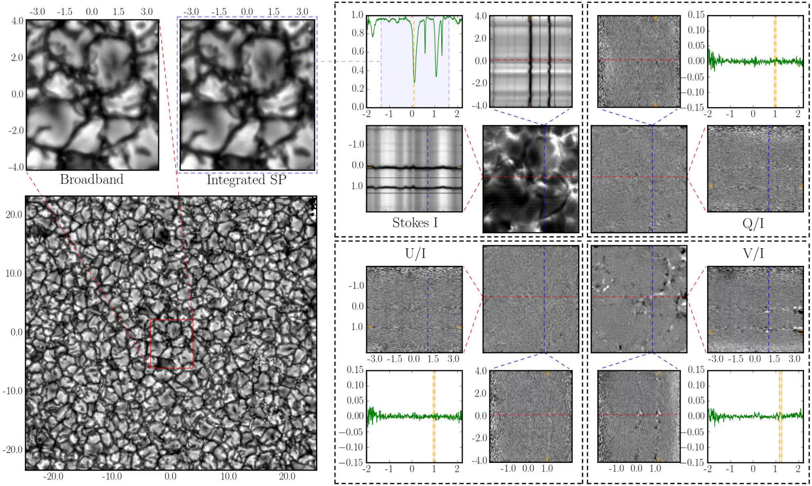
Reducing the data



- Data are challenging to reduce!
- Moiré pattern due to "beat" of pixel and MLA grids
- Difficult to obtain flatfield correction
- Difficult to calibrate spectrally (telluric lines)

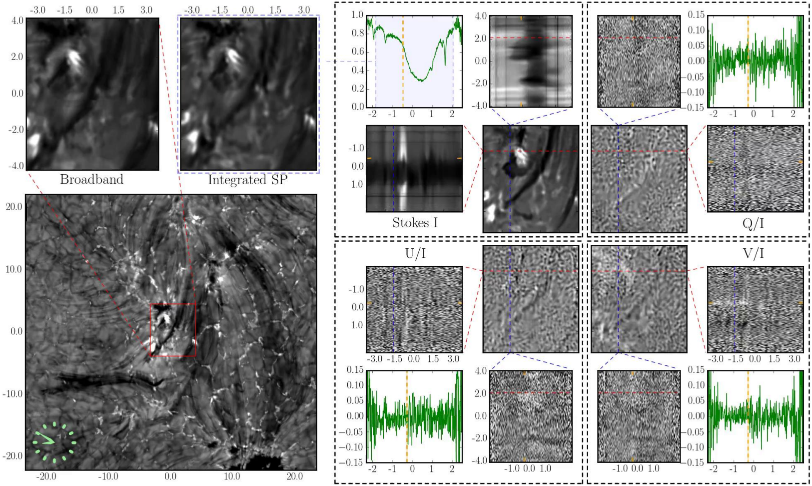
MFBD + Spectral Restoration + MiHI Single Beam (2017)

- FeI@6302Å: Quiet Sun at disk center



MFBD + PD + MiHI Dual Beam (2018)

- H-α: Active region loop



Beyond prototype

Prototype shows potential, but:

- Limited FOV (128x128 "pixels")
- Limited spectral range ($\sim$300 bins)

This is not sufficient for telescopes with an aperture $> 1\,\mathrm{m}$

Scaling properties not favorable!

Doubling in all dimensions:

- Optically: 256x256x300 already "not trivial"
- Sensor: 12k x 10k @ 100fps not available (yet)
- IR: a long way off

... and this is still much too small!

This sub-WP: Segmenting the focal plane

Two main approaches possible

- Single instrument observes split field (segment detectors only)
- Identical instruments observe segments of the focal plane (fully segmented): optically easier

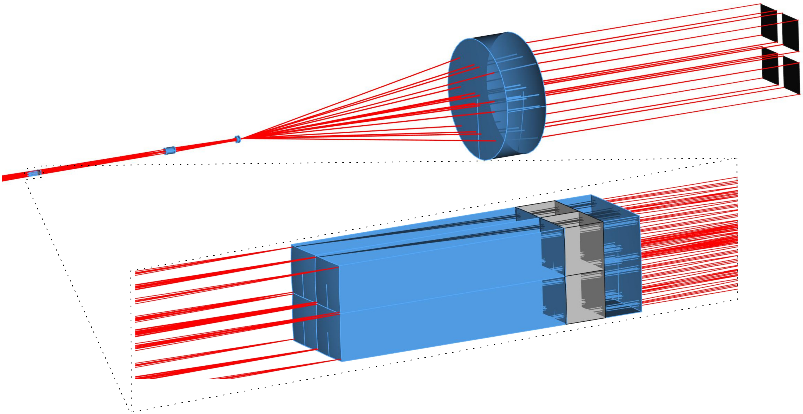
Potential problems:

- splitting artefacts in the focal plane $\longrightarrow$ purely optical
- differences in instrumental response $\longrightarrow$ include in calibration
- shift in the sampling of the image plane $\longrightarrow$ include in image restoration

Planned approach:

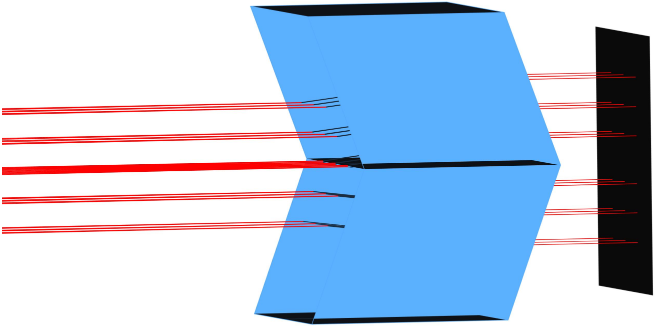
- build physical setup to generate test data
- improve calibration methods
- adapt image restoration software to include this information

Optical segmentation: Micro-splitter



- Easy to extend
- Edge effects?
- Errors scale with the image (stability!)

Optical segmentation: Macro-splitter



- Slow beam: optically much easier
- Minimal edge effects
- Errors not amplified
- Large optics: many segments difficult & expensive

This method was chosen for test setup

Calibration

- [Space dependent] Instrumental PSF
- Improved instrumental coordinate mapping
  - time variable
  - influenced by the instrumental PSF
- Segment alignment
- Flatfield: main structure from instrument: dust & scratches, Moiré fringes, sensor imperfections
  - calculated from high contrast image
  - different contributions difficult to separate
  - very few valid assumptions can be made about the data
- Spectral calibration
  - Telluric lines?
  - Absorption lines from gas cell?
  - Fabri-Pérot?
  - Laser Comb?

Image restoration

Using “spectral restoration” technique:

- use “synchronized” SJ camera to obtain PSF[s]
- use PSF[s] to describe formation of data elements (linear)
- solve linear system
- shift in image sampling $\rightarrow$ shift PSF

Large field: [much] more CPU time $\rightarrow$ optimize wavefront sensing

- Optimize existing codes (MOMFBD)
- New techniques (Machine Learning?)

Longer term (beyond SOLARNET?): Solve fully forward:

- using “raw” data
- solving Stokes parameters directly
- deconvolve spectrally

sub-WP Status (Jan 2020)

- Optical designs are [more than] 6 months behind due to difficulties in hiring an optical engineer
  - D61: Splitter designed and type selected (finished)
  - D61: MLA design (in progress)
- Calibration: forward modeling software exists, can fit coordinates and simplified PSF
  - Forward modeling software (finished)
  - Fit coordinates and simplified PSF (in progress)
  - Obtain good flatfield information (TBD)
- Image restoration:
  - Machine Learning MFBD (in progress)
  - D62: Restore single segment ([mostly] complete)
  - D63: Restore multiple segments (TBD)

Integrating High Resolution Solar Physics

Report on Absolute high-precision polarization measurements

Solarnet General Assembly Meeting

January 23, 2020

F. Zeuner, D. Gisler & **M. Bianda**

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

SOLARNET

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Method

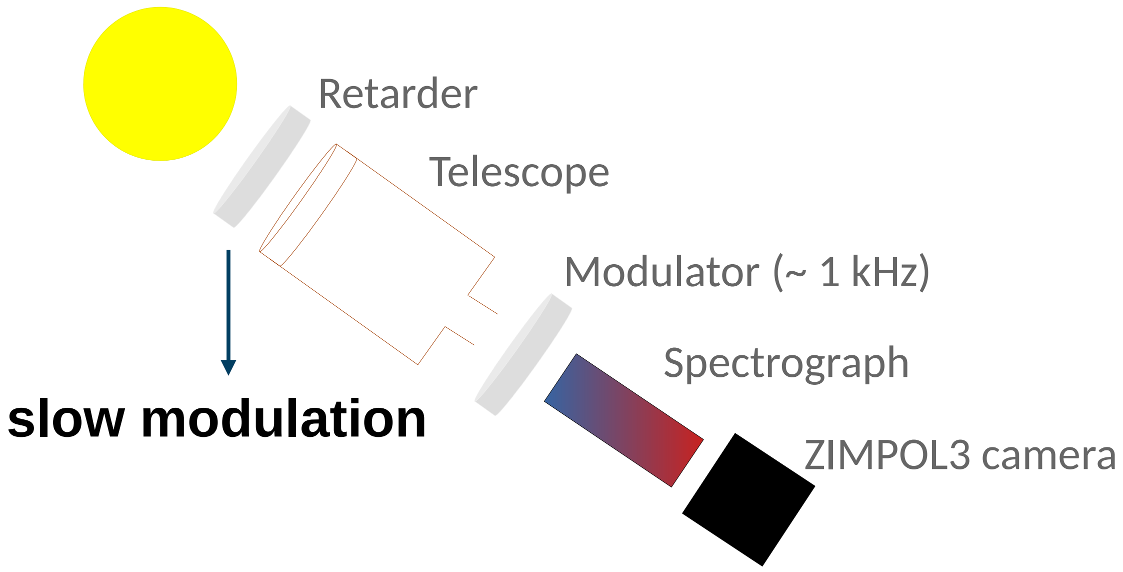
Absolute high-precision spectropolarimetry requires to minimize:

- seeing-induced cross-talk (SIC)
- telescope polarization
- telescope-induced cross-talk
- post-focus instrument errors

} → telescope calibration

Optimal position: **in front of the telescope**

Current setup at IRSOL



- SIC minimized by *fast modulation* (modulator + ZIMPOL3)
- telescope calibration by *slow modulation* (automatically rotated zero-order retarder film)

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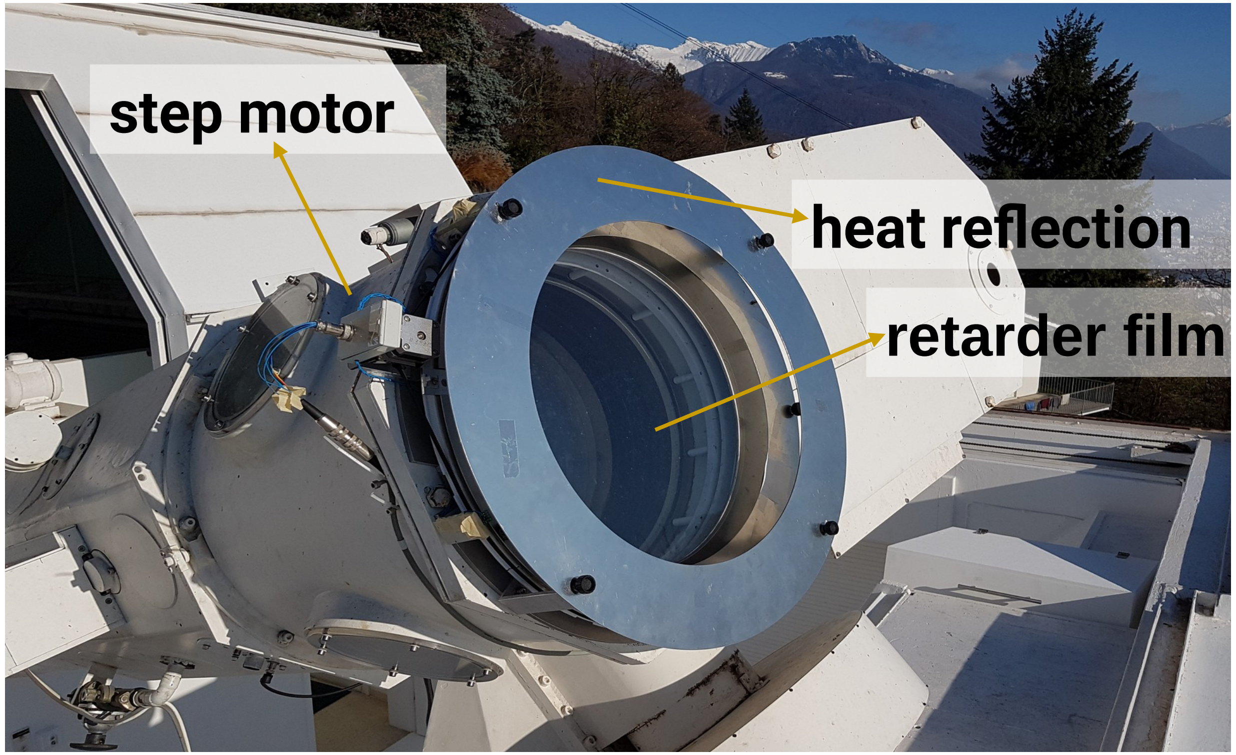
Telescope Calibration Unit (TCU) setup at IRSOL



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Problem:

Aperture-size **achromatic, homogeneous λ/2 retarders** are unavailable.

In general, retardence δ(λ,x,y) depends on wavelength and position within the retarder.

IRSOL solution:

- cheap retarder film
- 8 angle positions of TCU (22.5° per step)
  → to correct for additional cross-talk induced by zero-order retarder
- up to now, only *Q* and *U* are correctable
- wavelength range **3800 Å – 8000 Å** with retardations 0.4-0.6

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pros:

- first correction in front of the telescope
- broad wavelength range with cheap device
- correction of cross-talks and offsets induced by telescope and post-focus instruments

→ allows for **absolute** high-precision spectropolarimetry

cons:

- slow second modulation (measurement cycle length ~min)
- low spatial resolution
- reduction of efficiency
- up to now, only *Q* and *U* are corrected

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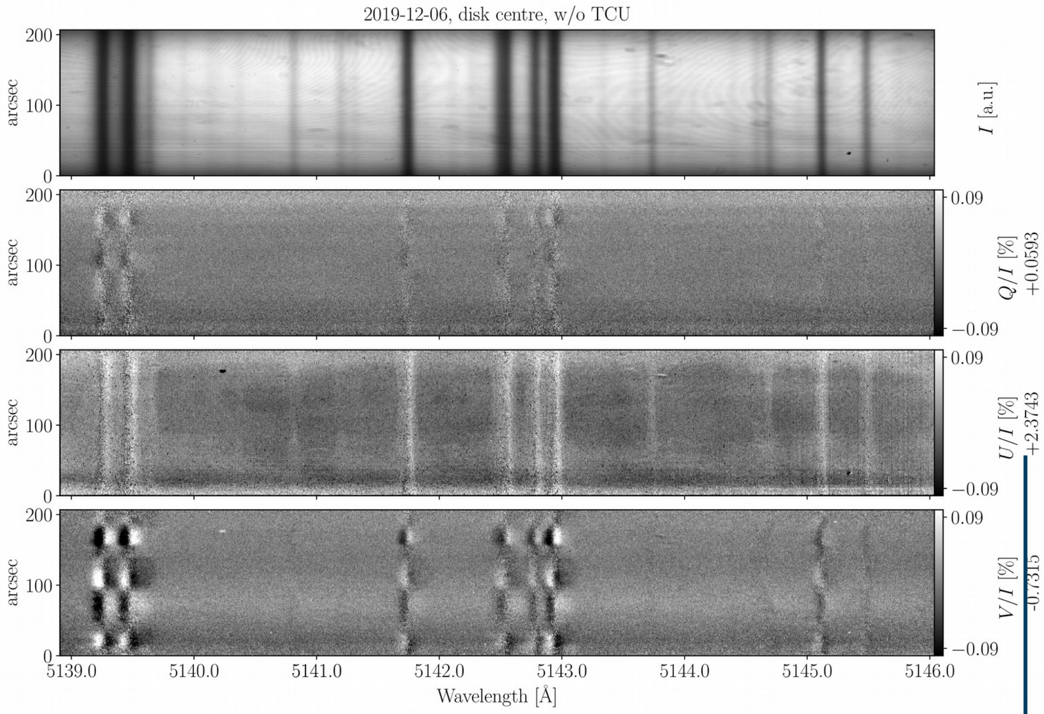
Example: C_2 lines ~5140 Å (IRSOL synoptic program)

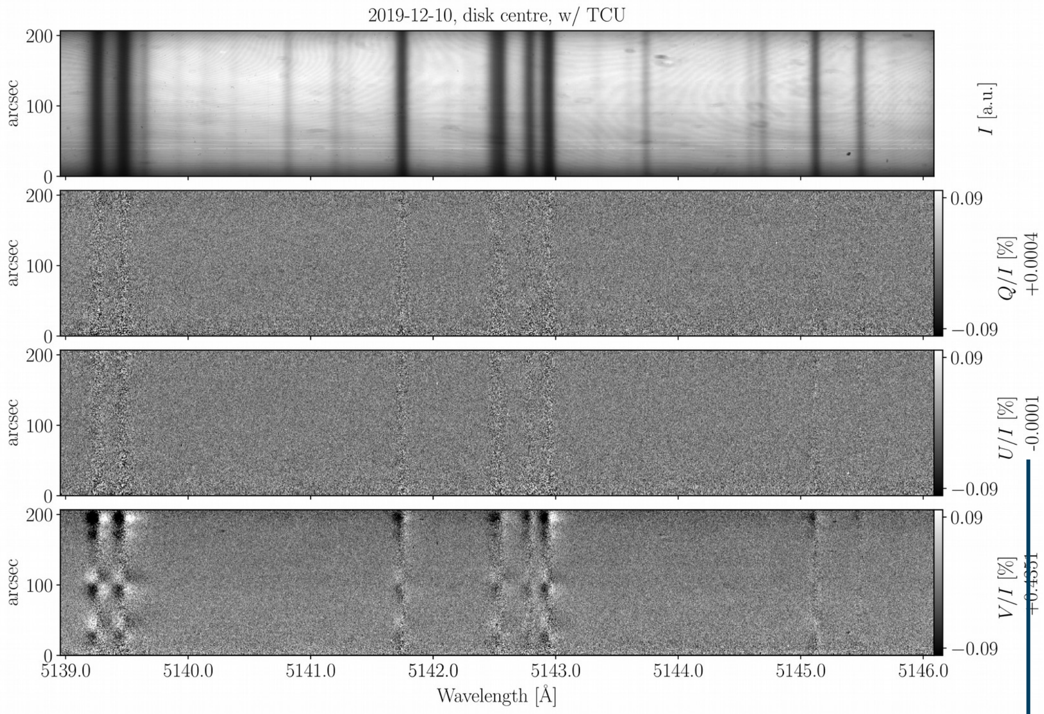
w/o TCU



Q offset	**$6 \cdot 10^{-4}$**
U offset	**$2 \cdot 10^{-2}$**

telescope induced polarization offset up to ~10^{-2}

w/ TCU



Q offset	**$4 \cdot 10^{-6}$**
U offset	**$1 \cdot 10^{-6}$**

removed, <10^{-5}

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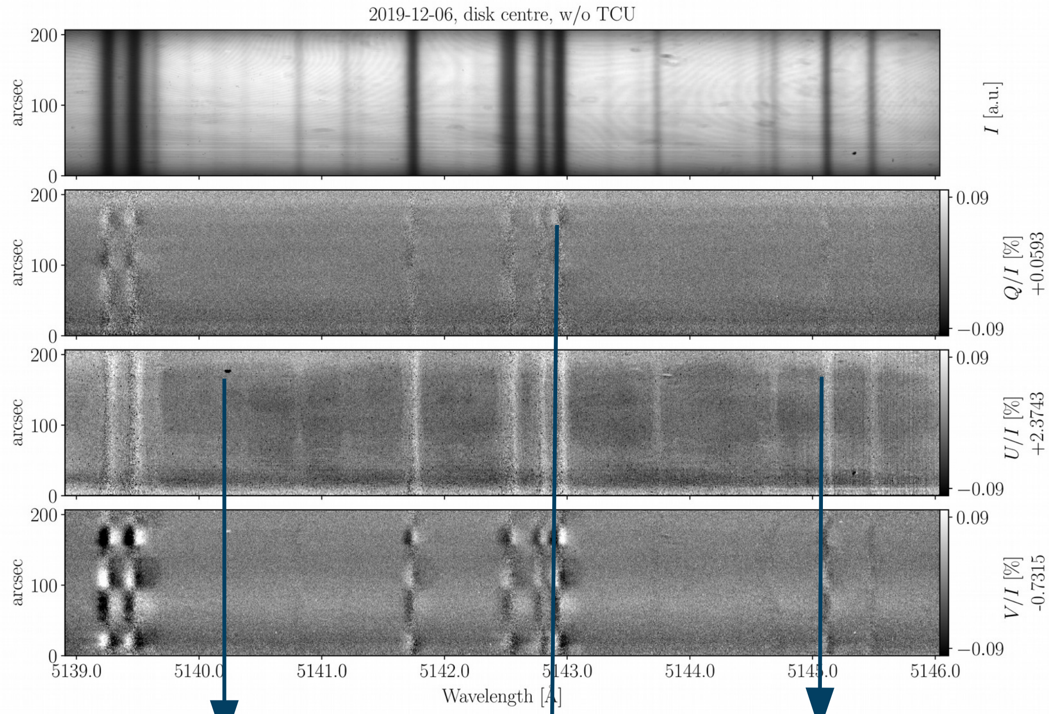
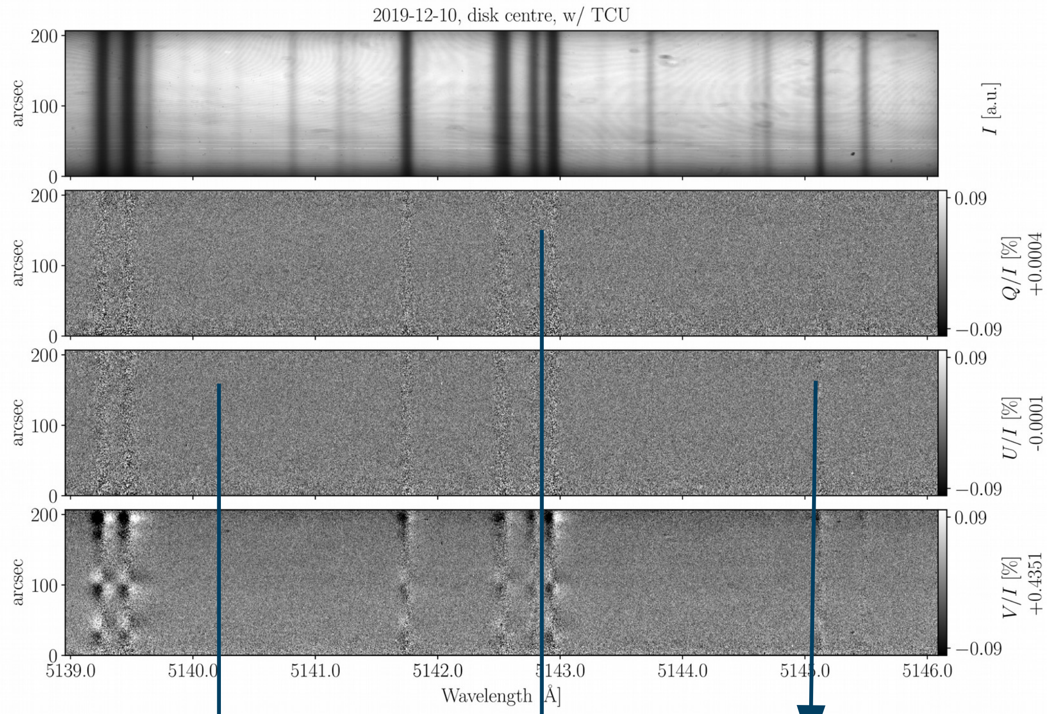
Example: C_2 lines ~5140 Å (IRSOL synoptic program)

w/o TCU



w/ TCU



camera defects

telescope induced
Stokes *V* cross-talk

Stokes *I* cross-talk

removed

removed

removed

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Planned work for 2020:

- Finding **optimal modulation scheme** by analytically studying the method
- Extensive testing of the method in **different wavelength** regimes
- Limits of method regarding the **spatial resolution**
- Extent method to correct for **full Stokes**
- First planning to extent the method to **GREGOR** telescope