Filter Transmission: Wavelength and Spatial Dependence

- Objective: to determine the phase and contrast maps of the tunable elements; to infer the non-tunable transmission profile as a function of the location on the CCDs

- Requirements:
  - IPD: noise on Doppler velocity: 25 m/s (quiet Sun), dynamic range: ±6.5 km/s, ripples of front window and blocker filter: less than 1% of the maximum transmittance
  - CPS: baseline filter design with a 76 mA FWHM, central wavelength of 6173 A (Fe I line), filter range of 680 mA
  - Precision to reach on the contrasts: an error of 10% produces a zero-velocity offset <1 m/s and an increase in the Doppler velocity noise <7.8% (averaged MDI-like algorithm, 6 positions)

- Precision to reach on the phases: 0.25^o produces a zero-velocity error <4.4 m/s and an increase in the Doppler velocity noise <0.05% (averaged MDI-like algorithm, 6 positions)

- Test Configuration:
  - Light sources: dye laser, lamp, sun through heliostat
  - Target: circular target whose size is the angular diameter of the Sun (solar radius 960.66''= 23.056 mm on the CCDs)
  - Wave-meter to measure dye laser wavelength
  - Device to record laser intensity
  - Stimulus telescope
  - Air-to-vacuum corrector ?

- Description: 3 different tests to be performed

  dye laser test (1^{st} test to be performed if possible)

  - ✓ We parametrize the tunable part of the filter: we want to determine phases and contrasts of E1 and the 2 Michelsons
  - ✓ We want to infer the non-tunable transmission profile by interpolation

  lamp test

  - ✓ We expand the non-tunable filter transmission profile into its Fourier series: we want to determine the corresponding Fourier coefficients

  (initial) sunlight test

  - ✓ We parametrize the tunable part of the filter: we want to determine the phases of E1, M1, and M2, to be able to co-tune the filter. Then we want to obtain a first Dopplergram

- Test Plan:

<u>for the laser test</u>

- ✓ Measurements in Obsmode & Calmode, in air
- ✓ Light source: dye laser illuminating a circular target whose size is the solar angular diameter. Target in the focal plan of the stimulus telescope
- ✓ Test sequence:

  At a wavelength close to 6173 A, we run a 27-position detune sequence: we learn how to co-tune the elements

  Then at each laser wavelength (32 in the range [-3.5,+3.5] A) we run a 10-position co-tune sequence
- ✓ Wavelength and intensity of the laser must be recorded
- ✓ Only the tuning 1/2-wave plates are rotated, not the polarizer

<u>for the lamp test</u>

- ✓ Obsmode and Calmode, in air

- Light source: lamp + stimulus telescope
- Test sequence: we run a 27-position detune sequence
- Spectral properties and stability of the lamp must be known

for the sunlight

- In air, first in Calmode (to determine the phases), then in Obsmode (to obtain a Dopplergram)
- Light source: sun through heliostat
- Test sequence: we run a detune sequence several times a day (for the “colored-cone” effect, and for the throughput test)
- The solar p-angle must be determined and recorded at the date and time of the test
- The Fe I line central wavelength must be determined independently

- Data analysis

  <u>for laser test</u>:

  - ✓ Regularized least-squares to fit for the parameters (phases & contrasts) of the tunable filter; interpolation to infer the non-tunable transmission profile (cubic spline interpolation)
  - ✓ Averaging of the 4096x4096 data maps by blocks of 32x32 to increase the S/N ratio
  - ✓ Laser line assumed to be a delta function
  - ✓ Use the spatially-averaged blocker filter + front window profile

  <u>for lamp test</u>:

  - ✓ Use the spatially-averaged blocker filter+ front window profile, the FSRs, contrasts, and phases of the tunable elements (obtained by laser test), and the parameters/ or inferred profile of the non-tunable part

- Expand the non-tunable part into Fourier series and fit for the coefficients: this provides information in the wavelength range [-2 FSR_{NB}, +2 FSR_{NB}] and for 8 frequencies in the range [0, 7/4/FSR_{NB}]; gives access to the blocker+front window fringes

For sunlight test

- Images are rotated according to the p-angle
- In Calmode: fit for the relative phases (assuming contrasts=1). The solar line depth and width (Gaussian profile) are fitted for, or we just scale an observed line profile. All the relative phases are then spatially averaged
- In Obsmode: fit for the solar line central wavelength assuming contrasts = 1 and using previously determined phases

- STOL status: to be written

Filter Transmission: Angular Dependence

- Objective: to determine the wavelength drift maps as a function of the angle of incidence of light rays. For the tunable filter elements we express the drift as a phase, for the non-tunable profile we just measure this drift

- Requirements:
  - IPD: noise on the Doppler velocity: 25 m/s (quiet Sun), dynamic range: ±6.5 km/s

- Configuration:
  - Light source: dye laser
  - Target: circular target whose size is the angular diameter of the sun
  - Stimulus telescope
  - PCU (with hole plate)

- **Description**: a non-zero incidence angle *i* produces a wavelength drift proportional to i^2. We want to determine the drift = f(*i*) parabola and characterize any azimuthal dependence
- **Test plan**:

  in Calmode

  - ✓ Light source: dye laser + stimulus telescope to produce collimated light, in air
  - ✓ For each incidence angle (6 in the range [-0.28^o,$+0.28^o$] + 0 ?): we select 3 (?) laser wavelengths and for each wavelength we run a detune sequence
  - ✓ 2 series of measurements should be performed with angles varying up/down and then left/right
  - ✓ The specific angles can be selected by moving the HMI instrument legs

- At each leg position, the exact angle value can be retrieved by taking an image of the laser dot in Obsmode

In Obsmode

- Light source: dye laser illuminating a circular target whose size is the angular diameter of the sun + stimulus telescope
- A plate with a hole will be placed as close as possible to the front window: the radial distance of the hole to the plate center corresponds to a specific incidence angle *i.* The plate will be rotated to access the azimuthal dependence. An image taken in Calmode will give us the value of *i*.

- Data Analysis:
- Regularized least-squares to fit for the phase shifts of the tunable elements as a function of *i*
- Least-squares to fit for the drift on the non-tunable profile
- STOL status: to be written

Filter Transmission: Throughput

- Objective: to determine the overall transmittance of the HMI filter system as a function of the location on the CCDs, in order to fix the exposure time
- Requirements:
  - ✓ CPS: requires a cadence of 50s for a co-tuning sequence
  - ✓ IPD: exposure time < 700 ms
- Description:
  - ✓ We want to know the fraction of input intensity transmitted through the instrument to the CCDs by comparing the input solar continuum intensity with the output (measured) continuum intensity

- Configuration:
  - ✓ Light source: Sun through heliostat
  - ✓ A photometer
- Test Plan and Data analysis:
  - ✓ The wavelength and spatial dependence sunlight test must have been performed prior to this test: thus we have already fitted for the solar continuum intensity measured by the instrument at different times of the day. Using a computer code returning the altitude of the Sun at these specific times, we can extrapolate the atmospheric extinction coefficient
  - ✓ We need to determine the transmission coefficient of the heliostat (using a photometer at the entrance and the exit of the heliostat)
  - ✓ We calculate the intrinsic solar brightness
  - ✓ The ratio between intrinsic solar brightness (in photon flux) and measured solar brightness gives us the instrument throughput
- STOL status: to be written

Still Needed Before we Perform the Tests ?

- Circular target whose size is the angular size of the Sun
- Wave-meter to record the dye laser wavelengths
- Device to record the dye laser intensity
- Algorithm to compute the Fe I line central wavelength in Calmode
- Plate with a hole for the angular dependence test
- Front window + blocker filter spatially averaged transmission profile
- Test of the stability of the lamp
- Algorithm to determine the orientation of the solar rotation axis on the filtergrams obtained with sunlight through the heliostat