Helioseismology and Thoughts About a Magnetic and Doppler Imager Instrument

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Overview

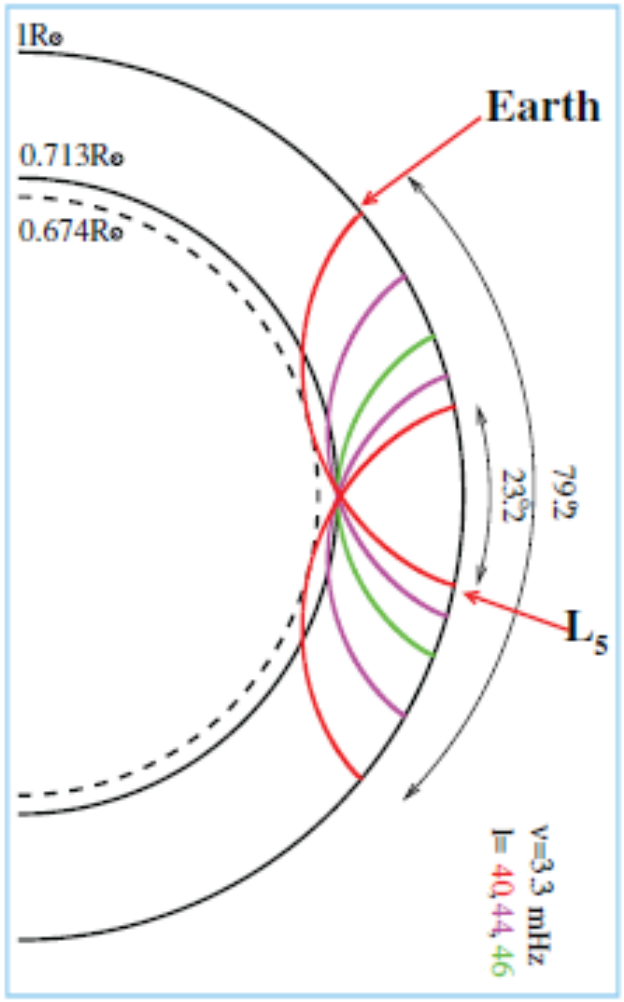
- **A bit of helioseismology**
- **Requirements**
  - Helioseismology
  - Instrument
- **Instrument Design**
  - General
  - MDI/HMI
    - And a derived design
  - PHI – Separate presentation
- **Conclusion**

Helioseismology

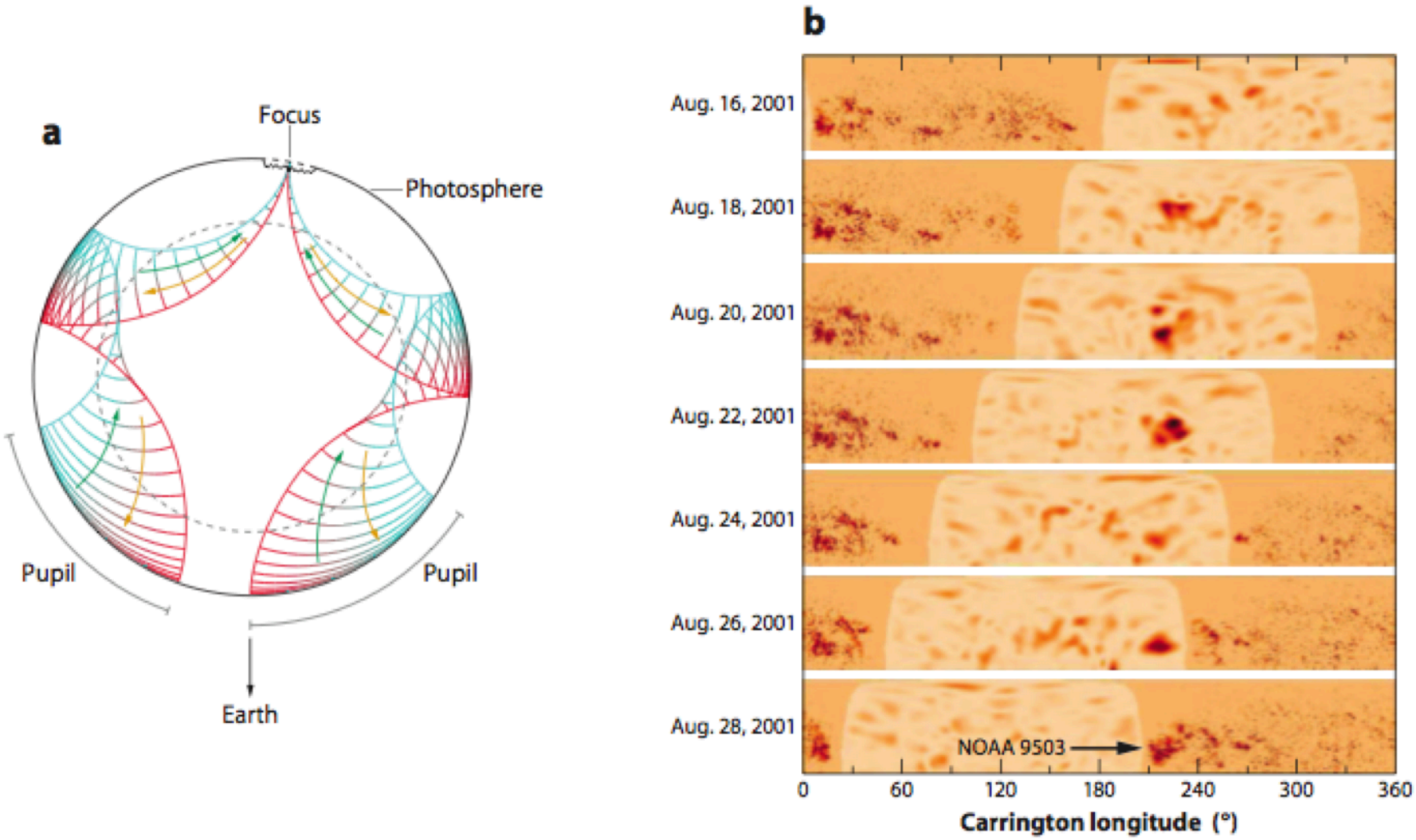
- **Study of the solar interior using (mostly) sound waves**
- **Waves are excited by near surface convection**
- **Reflected at surface**
- **Generally observed in surface Doppler shift**
- **Global mode analysis in terms of global resonant modes**
  - Good for large scale structure and flows
- **Local seismology using – see next slides**
- **Able to determine sound and flow speeds very well**
  - E.g. solar rotation
- **Some sensitivity to density**
- **Magnetic effects in principle observable**
  - But there are many complications

Helioseismology - Local

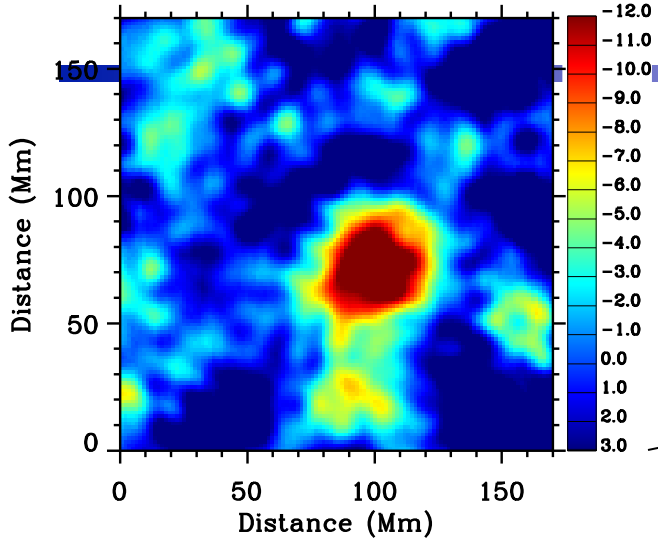
- **Time-distance**
  - Cross correlates signals at different points on the surface
  - Attempts to map interior in 3D
- **Other methods**
  - Ring diagrams, holography, etc.
- **Great success in seeing activity on far side of the Sun**
- **Active regions detected before emergency**
  - Controversial result
- **Information on near surface**
  - E.g. supergranulation



Farside Imaging



Results of AR 10488



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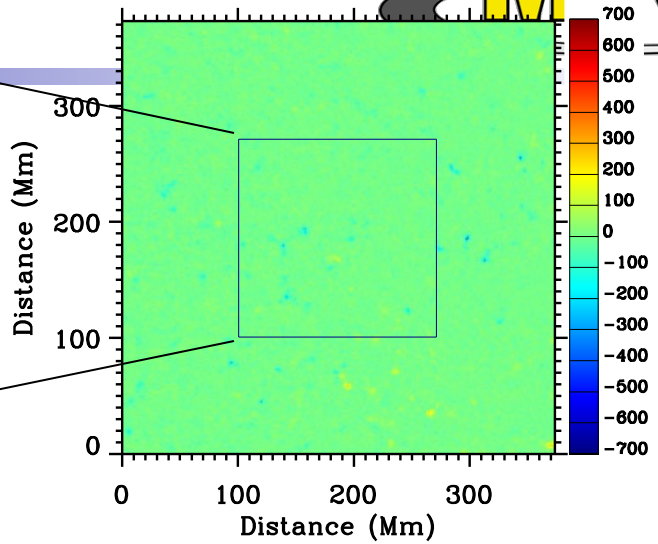

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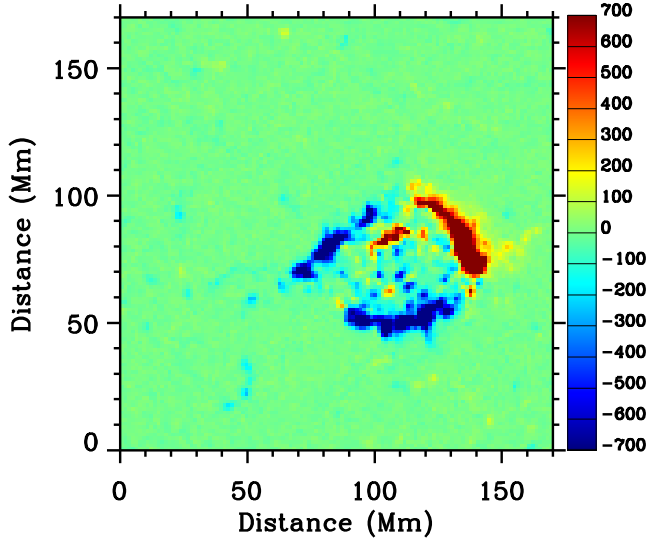

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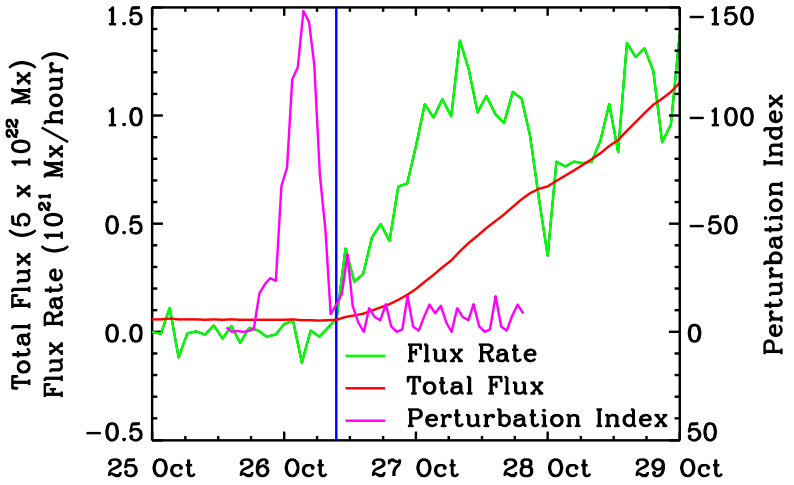


Courtesy Stathis Ilonidis –
Controversial!

Helioseismic Science Objectives

- **Near-Surface Rotation, Meridional Circulation, and Solar-Cycle Variations**
- **Deep and Large-Scale Solar Dynamics**
- **Deep Convection and Giant Cells**
- **Active Regions and Sunspots**
- **Physics of Oscillations**
- **Largely from Löptien et al., 2014 for Solar Orbiter**
- **L5 would improve on these**
  - Better spatial coverage gives better statistics
  - Longer observations of each active region
  - Longer ray paths available for time-distance
  - Vector velocities
- **Even larger improvements in combination with Solar Orbiter**
  - Which unlike L5 has a variable geometry

Magnetic Fields

- **Covered by others**
  - Don't make the STEREO mistake!
- **Surface field can be extrapolated to determine field higher in atmosphere**
  - Vector field is better than LOS
  - It is difficult to extrapolate from high beta at photosphere to the chromosphere and above
- **Vector field now done with HMI. However**
  - Transverse field is much noisier than LOS
  - Transverse has 180 degree ambiguity. Partially resolved using various constraints
  - Poor spatial coverage for field extrapolation of regions near limb and global fields
- **L5 improves this situation**
  - Gets two field components over common area with Mlos only
    - Three components at times when combined with Solar Orbiter
  - Generally resolve ambiguity over common area
  - Increases spatial coverage of relevant regions

Instrument Requirements

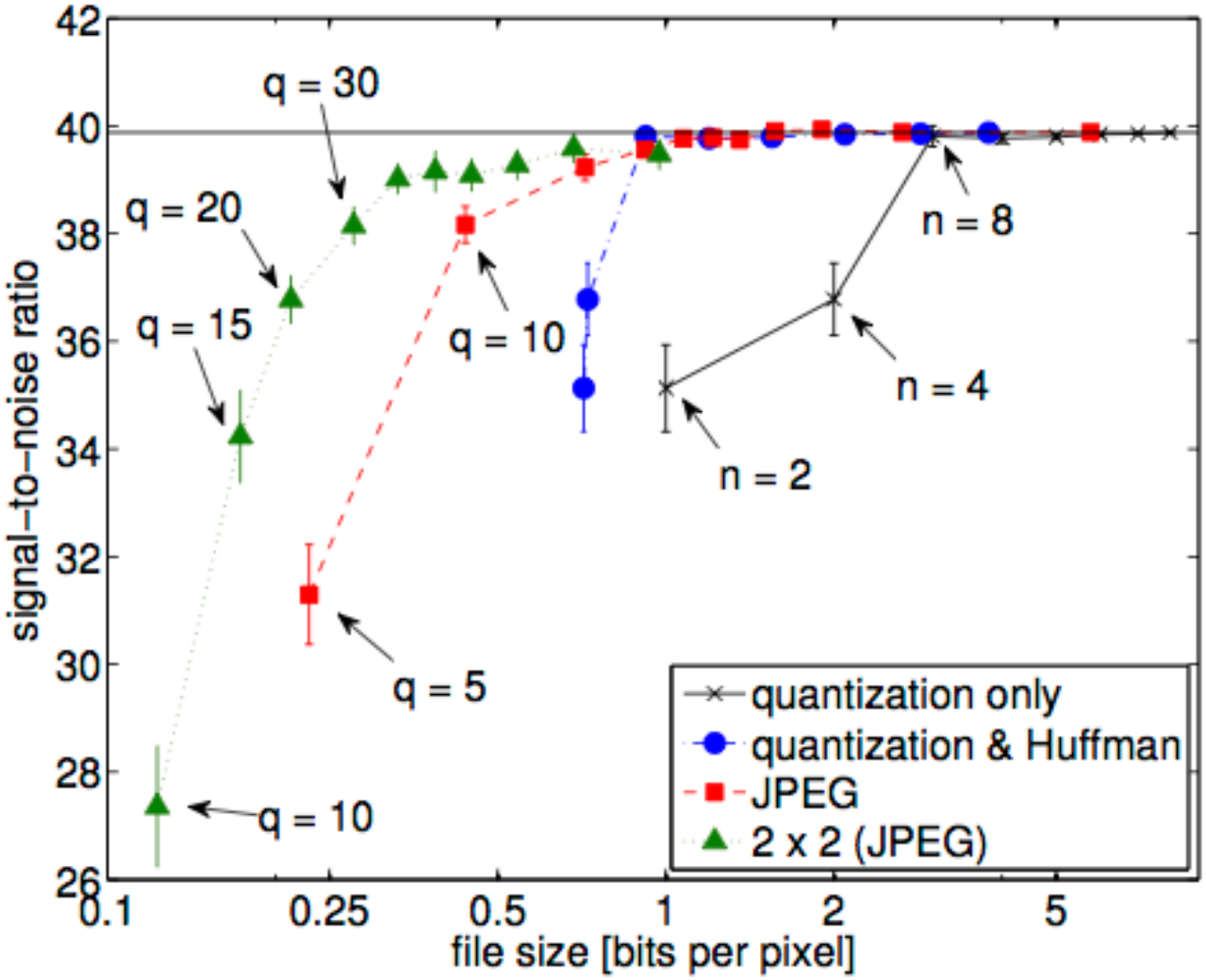
- **Magnetograms at 1024x1024 pixels (within factor of 2)**
- **Full disk only. No need for high resolution**
- **Critically sampled images**
- **V, I and Mlos**
- **Possibly vector field (largely a telemetry issue)**
- **Doppler at 60s or better cadence**
- **Minimize telemetry requirements at fixed science => onboard processing**
- **Note that measuring Doppler and field is essentially the same from an instrumental point of view**

- **The BIG issue is telemetry!**
  - We have made substantial progress on compression
  - Most other items are straightforward

Instrument Design – General Considerations

- **Various technologies available**
  - SOHO/MDI and SDO/HMI have operated for 15 and 5 years, essentially flawlessly
    - SDO/HMI not operational but has lots of redundancy
  - Solar Orbiter/PHI is being built and has qualified all new technologies. 2018 launch
- **Imaging optics**
  - Well understood
- **Polarization selection**
  - MDI and HMI use rotating waveplates
  - PHI uses liquid crystals
- **Detectors**
  - CCDs (MDI/HMI) vs. CMOS APS (PHI)
- **Onboard processing**
  - MDI did a lot
  - HMI very little
  - PHI will do a lot. Including use of reprogrammable FPGAs, inversions and compression

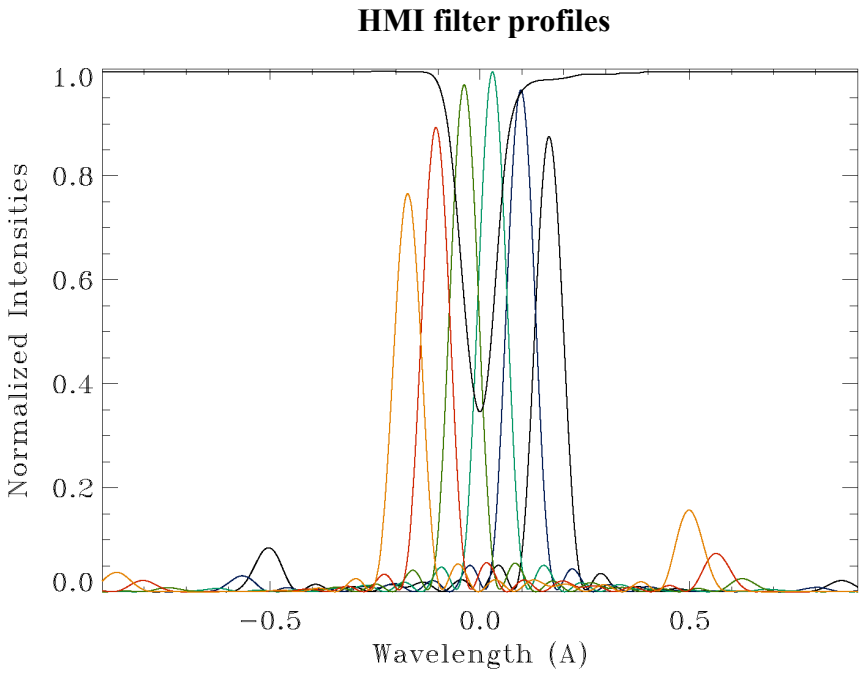
Compression



Löptien, et al., 2014, A&A 571, A42

Design – Wavelength Tuning

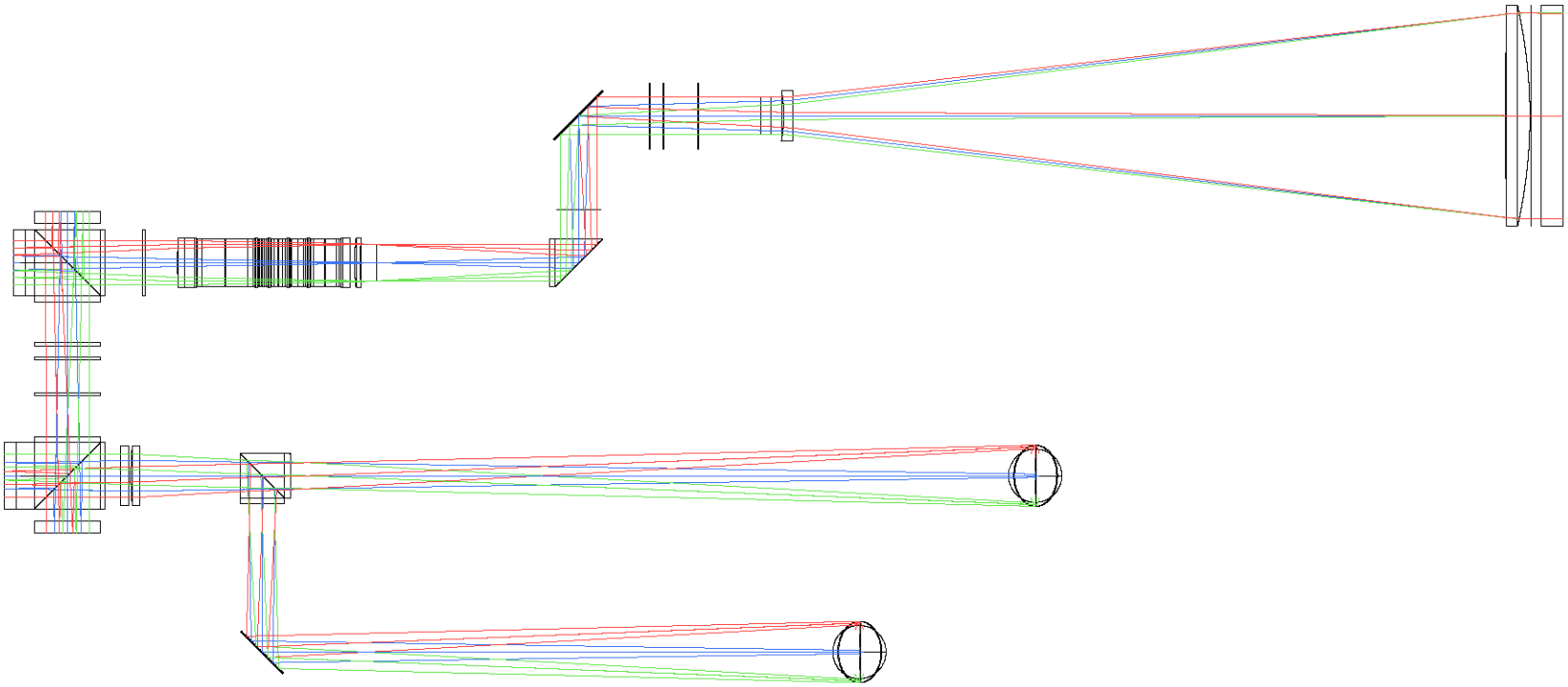
- **Lyot/UBF/Michelsons**
  - Tune several elements to scan line
    - •Rotating waveplates – stable – MDI and HMI
    - •Electro-optical devices – no moving parts
- **Fourier Tachometer**
  - Single Lyot or Micelson for tuning – simple
  - Fourier Tach and GONG
- **Fabry-Perot**
  - Use Fabry-Perot for tuning
    - •Typically electro-optical – no moving parts
  - –PHI has space qualified these
- **MOF**
  - Vapor (Na or K) in cell+magnetic field
    - •Simple, stable, poor dynamic range
  - Mt. Wilson
- **The above all require various other windows and prefilters**



Possible Instrument Design

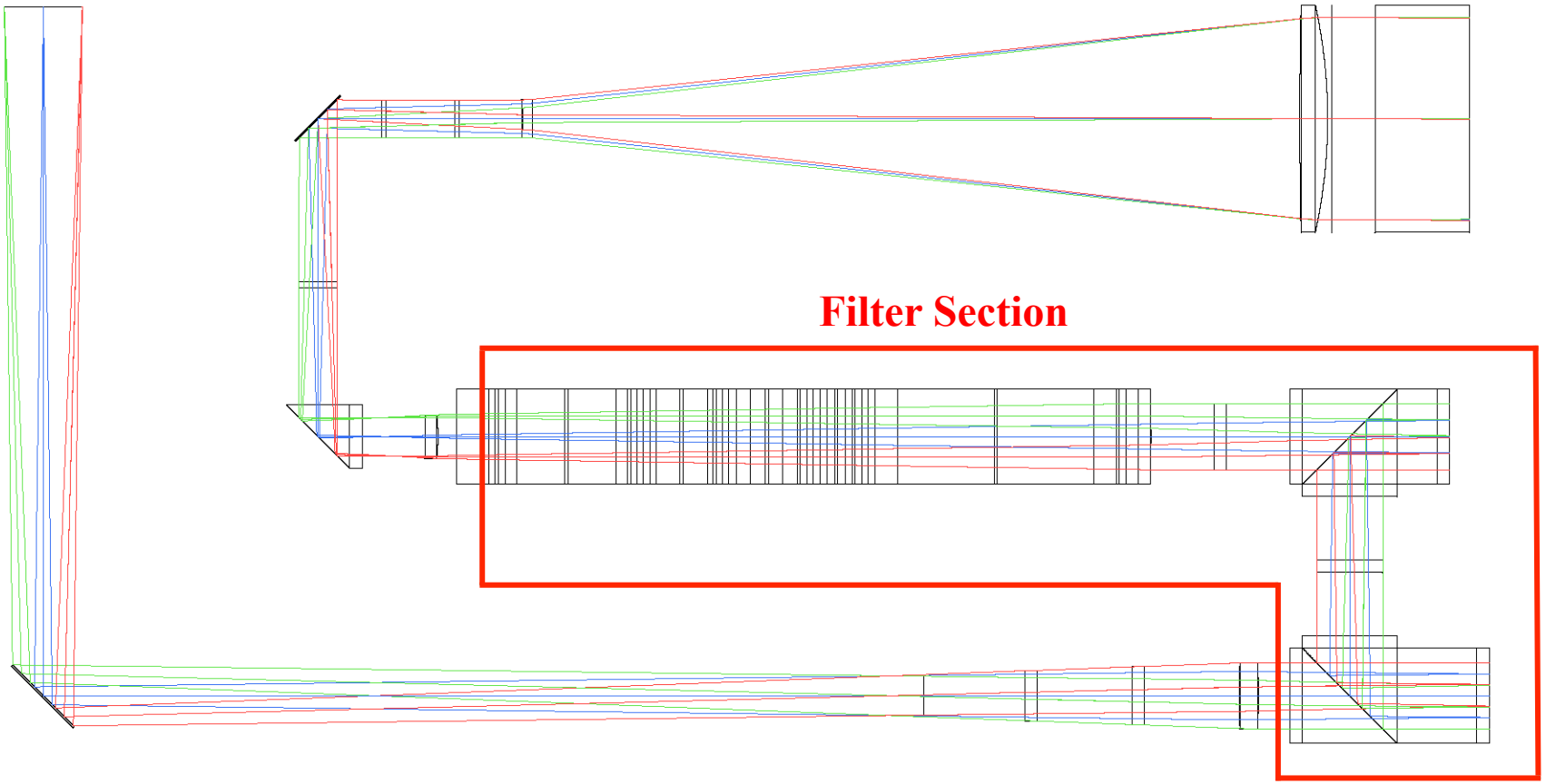
- **Shrink HMI**
- **Simple proven design. HMI in turn based on MDI**
  - High TRL. MDI and HMI have worked for years in similar environment
- **Lower resolution (4” vs. 1”) results in smaller aperture.**
  - Lyot filter length does not reduce, so reduction limited
  - Resolution is main mass driver
- **Fewer pixels (1024x1024 vs. 4096x4096)**
  - Smaller image. Shorter effective focal length
  - Likely main power driver
- **Data processing electronics needed**
  - MDI did it. PHI will
- **The developments for PHI will improve many of these substantially**
  - How high a TRL do you want?
  - How many years of ops?

HMI Layout



Size: 1050mm x 465mm

Possible Layout



Size: 235mm x 117mm

PHI

- **See separate presentation!**
  - Courtesy of Achim Gandorfer, Johann Hirzberger, and many others
- **Much more complicated instrument than needed for L5**
  - Worse environment – gets closer to the Sun
  - Challenging data return
  - Will go close to the Sun and significantly out of the ecliptic
- **Qualification of**
  - $LiNbO_3$ Fabry-Perot tuning
    - Including high voltage
  - LCVRs for polarization selection
  - CMOS APS sensors
  - Reprogrammable FPGAs doing the needed processing
  - Extensive work on onboard processing
  - Extensive work on compression and effects on science
- **Offers potential for significant reduction of resource use**
- **Being built – launch in 2018**

Conclusion

- **You need a magnetograph!**
  - Don’t repeat the STEREO mistake!
- **You should also have a Doppler images!**
  - But it is basically the same instrument
- **No technical issues**
  - MDI, HMI and PHI provide a lot of experience
  - Experience exists in both the US and Europe
- **Low mass and power**
  - Substantial reduction possible using PHI technology
- **Data rate can be modest**
  - Has been investigated in detail for PHI
  - Depends on science/ops objectives