

Future of Observational Helioseismology

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Overview



- **Why bother?**
- **Ground vs. space**
- **Some proposed projects**
- **Conclusion**

Why Bother?



- **Utilitarian purposes**
 - E.g. space weather predictions
- **More of the same**
 - How similar are solar cycles?
 - Better coverage
 - More statistics on active regions
 - But \sqrt{N} increases very slowly
 - Factor of 2 over GONG/MDI/HMI requires a lifetime of observations
- **Something different**

So What Can We Do Differently?



- **Current limitations:**
 - Brain power – hard to fix
 - Systematics, non-optimal analysis techniques, ...
 - Limited signal to noise
 - S/N is a limiting factor at low frequencies
 - Would like to see g modes and other low frequency modes
 - Excitation/realization noise
 - Linewidth sets a limit
 - o Limiting factor near peak of power
 - o At least in the standard damped oscillator model with frequent excitation
- **So what to do?**
 - Multiple lines/height in atmosphere
 - Increased spatial resolution
 - Better spatial coverage
 - Vector velocities

Multiple Height and Line Observations



- **Signal to noise depends on height/observable**
- **Various systematic effects are also height dependent**
 - Perhaps we can understand them?
- **Granulation (noise) and oscillations (signal) have different dependence**
 - Can various observations be combined to improve S/N?
- **Can we detect excitation event in some observable or combination?**
 - If so we may be able to beat realization noise

Increased Spatial Resolution

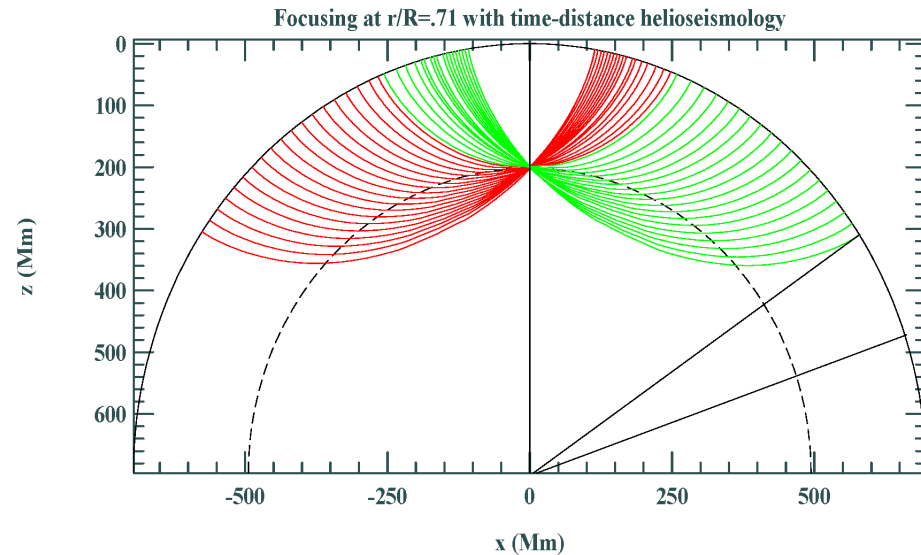
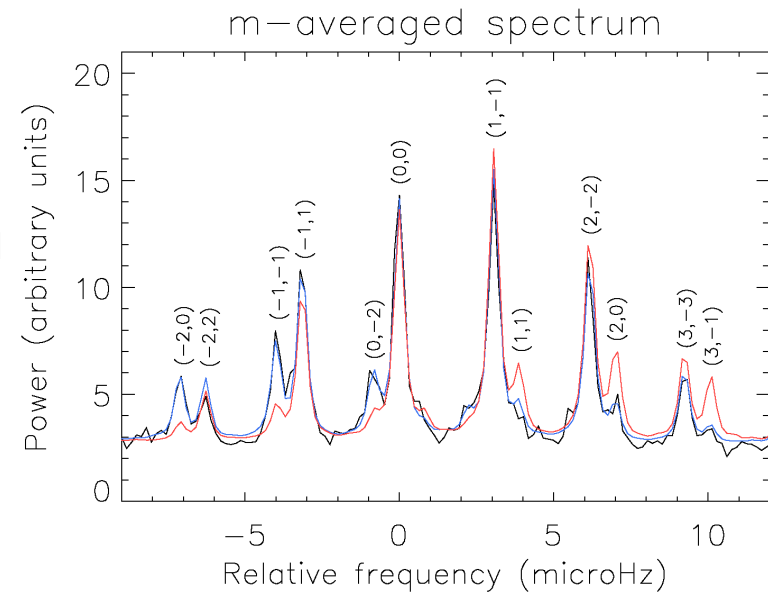


- **Already close to desired resolution(?)**
 - But perhaps being able to go even closer to the limb is desirable?
 - Anything interesting above the acoustic cutoff?
- **Can granulation and modes be separated?**
 - Perhaps some clever trick can be used
- **Can we see excitation events and characterize them?**
 - Much of the excitation is believed to be generated in intergranular lanes
- **Sunrise**
 - Poor coverage, small field
- **Ground based**
 - Various (NST, ATST)
 - Generally poor spatial and temporal coverage
 - But excellent resolution
- **Space based**
 - Can provide both high resolution and good coverage

Better Spatial Coverage



- **Only see about 1/3 of surface from (near) Earth**
 - Seeing the whole Sun will increase S/N
 - Few years of whole surface may not beat decades of 1/3
 - Not clear that g modes are right below the noise level
 - Reduced leaks - systematics will likely decrease



Vector Velocities



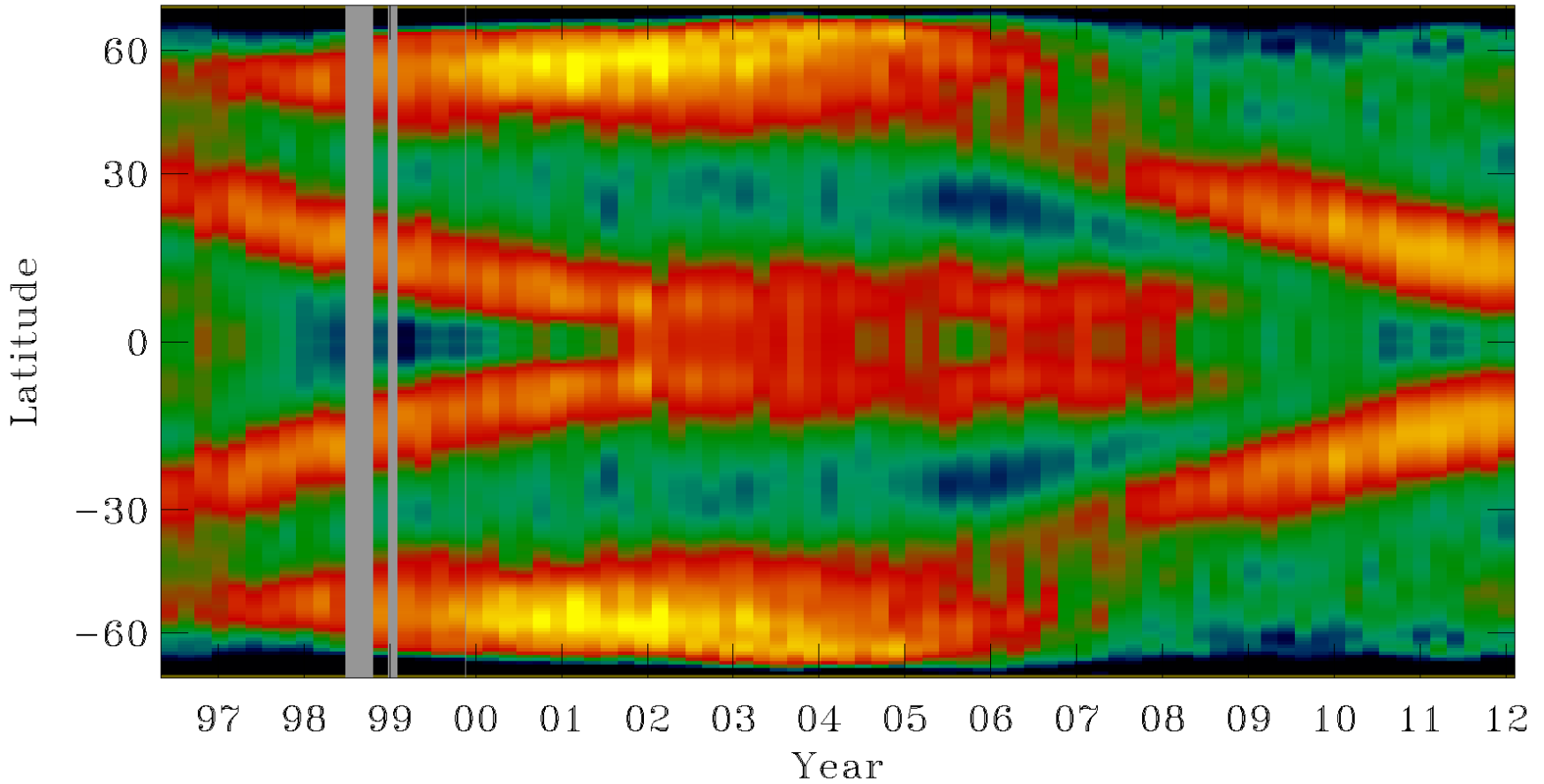
- **Multi view point observations will allow us to determine vector velocity**
- **Usual arguments about granulation/modes and excitation events apply**

- **Resolution**
 - Very difficult to cover all desired degrees from the ground
 - At least in full disk. AO can, in principle, do smaller fields of view very well
 - But much science does not need high resolution
- **Temporal coverage**
 - Seems that ground observations should work
 - Visible – No need for UV or the like
 - Networks can and have been built (e.g. BiSON, IRIS, GONG, TON)
 - But 95+% duty cycle (MDI/HMI) probably requires 10+ sites. But is that needed?
- **Stability**
 - It is very difficult to provide uniform high quality time-series from the ground
 - Atmospheric transparency fluctuations, seeing, telluric lines, thermal effects, ...
- **See only one side of Sun from ground**
- **But:**
 - Space is costly! And takes a long time!
 - Easy to fix things on the ground. At best difficult to fix things in space!
 - Data return is a major problem

Changes in Solar Rotation Rate



Zonal flows from MDI+HMI f modes



Outer 1%. Relative to smooth variation with latitude. +/- 9m/s.

Ground Based Projects



- **Some running and future single site projects**
 - E.g. MOTH, HELLRIDE
- **Two current networks:**
 - GONG
 - Running fine. Some \$\$\$ problems. Could b extended for a long time.
 - BISON
 - Single pixel, so does not address most science objectives
- **One(?) future network project**
 - SPRING
 - Multi height
 - Will provide continuity
 - Lots of work ongoing
 - No funding commitment



- **Two current helioseismology projects**
 - SOHO
 - MDI, GOLF, VIRGO
 - MDI is still running but not taking data. Could be restarted.
 - SDO
 - HMI is running happily
 - o No technical showstoppers
 - o Funded to mid 2015. Will likely get funded for another 5 years. Then uncertain, but likely
 - AIA
 - o Some science here too
- **One non-dedicated**
 - Hinode
 - Very small FOV



- **Solar Orbiter/PHI is only project under construction**
 - Currently being constructed
 - Launch around 2018
 - Will provide different viewing angles
 - Will look from high(er) latitude
 - Very little data return
 - Short observing periods
 - See talk by Löptien



- **Many proposed projects**
 - Some primarily helioseismology, others not
 - See next few pages
 - In random order
 - Incomplete
 - See ISSI review by Sekii, Appourchaux, Fleck and Turck-Chieze
 - From whom I have stolen some material

- **L5/EASCO**
 - Various versions and funding schemes considered.
 - From partial to comprehensive instrument packages
 - JPL and GSFC versions.
 - Observing from roughly Sun-Earth L5 point, 40-90 degrees away
 - Primarily space weather
 - Could be combined with L4 for better coverage
- **SAFARI**
 - Proposed multiple times by groups overlapping with the above
 - Would be parked at L3, 180 degrees away from the Earth
 - Various packages proposed
- **SAI**
 - Cubesat being proposed (6U)
 - Will fly MOF and demonstrate technology
 - Drift orbit at 1AU to of order 30 degrees
 - Short lifetime

- **SPI and Polaris**
 - Proposed for US Decadal Survey and ESA Cosmic Visions
 - >75 degree inclination near polar orbit around 0.48AU
 - Solar sails
 - Comprehensive instrument package
- **Solaris**
 - Smaller version of the above
 - Minimal payload including Doppler/magnetograph
 - Part of longer term solar sail development program
- **Telemachus**
 - Similar, but using Jupiter gravity assist to reach high inclination

- **4PI**
 - Proposed for Decadal Survey
 - As name indicates it would cover the entire surface
 - 4 spacecraft
 - Various payload options
- **Solar-D**
 - The mission formerly known as Solar-C Plan B
 - Moderately comprehensive package
 - >40 degree inclination
 - Ion engine propulsion
- **GOLD/GOLF-NG**
 - Improved GOLF instrument
 - Multiply points across line
 - Targeted at low degree modes (especially g-modes)

Conclusion



- **Continuity needs to be ensured**
 - **New observations are still needed**
 - **Multi height observations represent one direction**
 - **Multi viewpoints another**
 - **Some can be done ground based**
 - **Others require space**
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- **“... there is no future visible at present.”**
 - Out of context quote from speaker declining to give a talk about this subject.