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
Ground vs. Space

- **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 thing one 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
**Space Based Projects - Current**

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

- **One non-dedicated**
  - Hinode
    - Very small FOV
Space Based Projects - Future

- 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
Space Based Projects - Future

• **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
Space Based Projects - Future

• **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
Space Based Projects - Future

• **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

- “...there is no future visible at present.”
  - Out of context quote from speaker declining to give a talk about this subject.