Plan A:

Helioseismology Requirements

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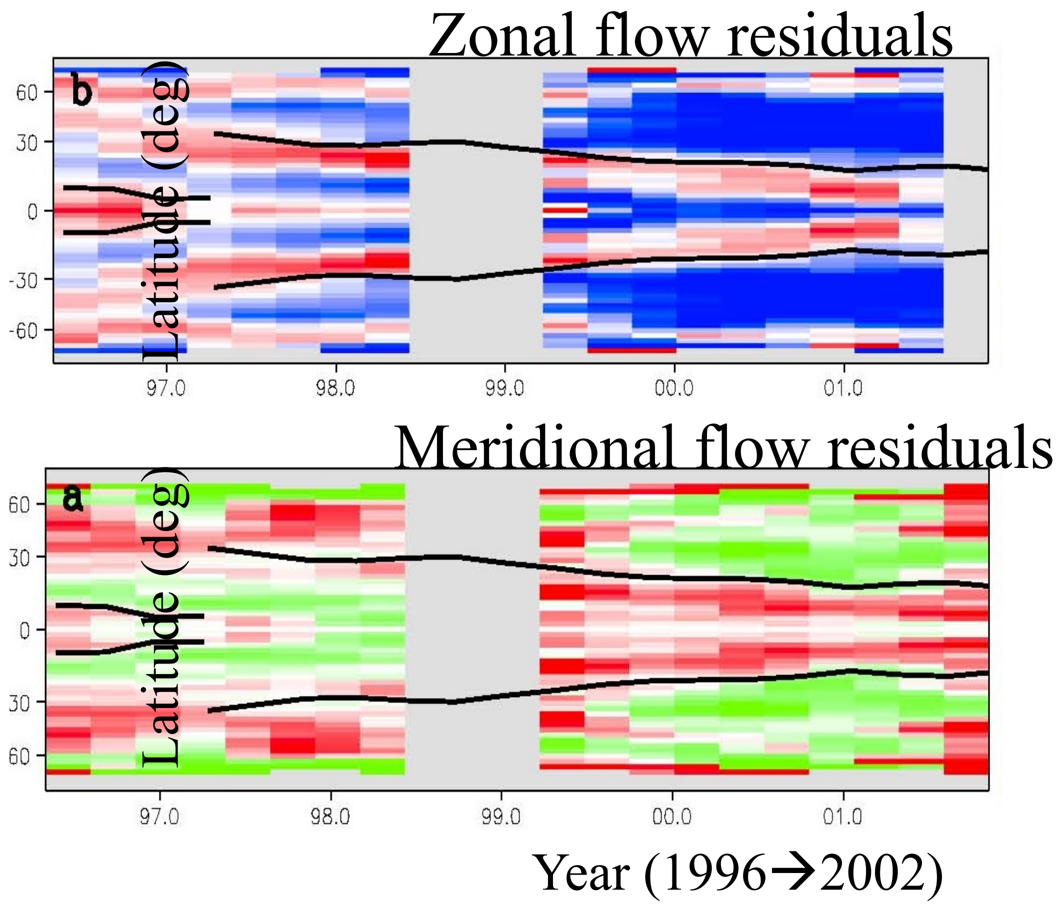
Outline

The key scientific questions addressed by Plan A and helioseismology have been presented.
In short, we need to measure flows and other inhomogeneities deep in the convection zone and at high latitudes (unknown territory).

Topics:
1. Measurable flows
2. How large should the inclination of the orbit be?
3. Stereoscopic helioseismology
4. Telemetry rate?
5. Some other basic requirements for helioseismology

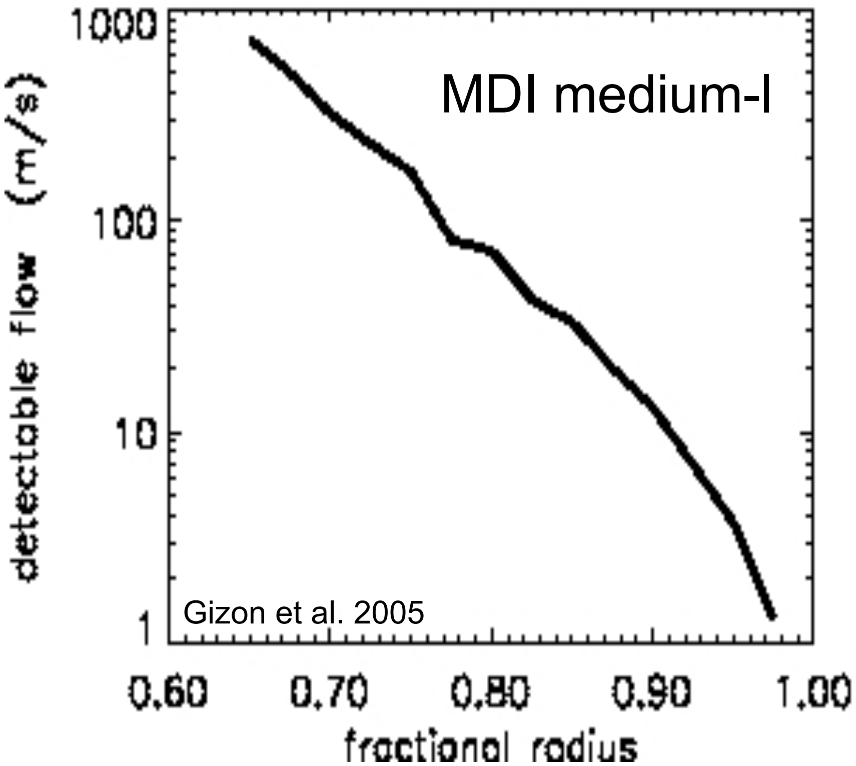
MDI medium-l data (256x256 pixels)
One local helioseismology measurement every 3 months

Random noise ~1-2 m/s, systematic errors <?

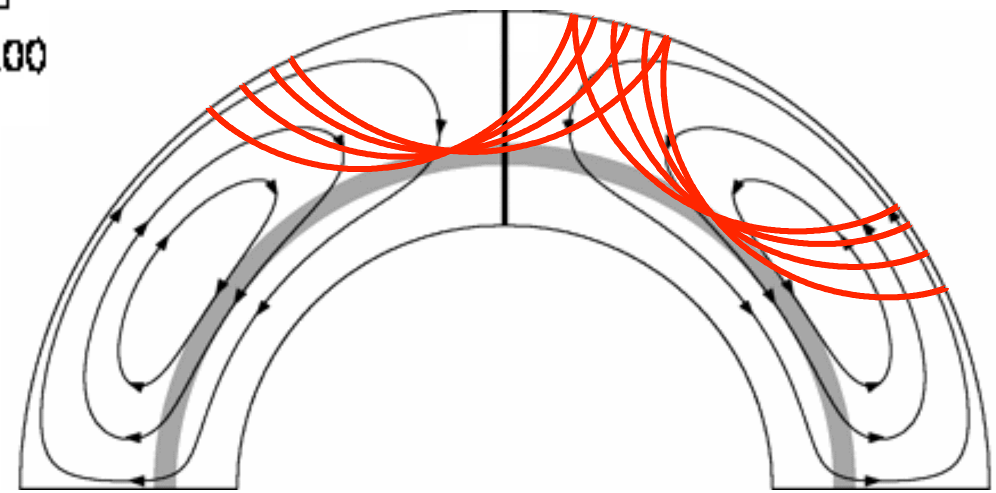


Plots of residuals of rotation and meridional circulation after subtraction of a long-term average.
About 50 Mm deep.
Valid up to 50 deg latitude. Beck et al. (2002) find +/- 5 m/s temporal changes.

High latitudes??



Detectable flow in one month of observations using deep focusing time-distance helioseismology (10 x 12 deg^2 resolution)



How inclined should the orbit be?

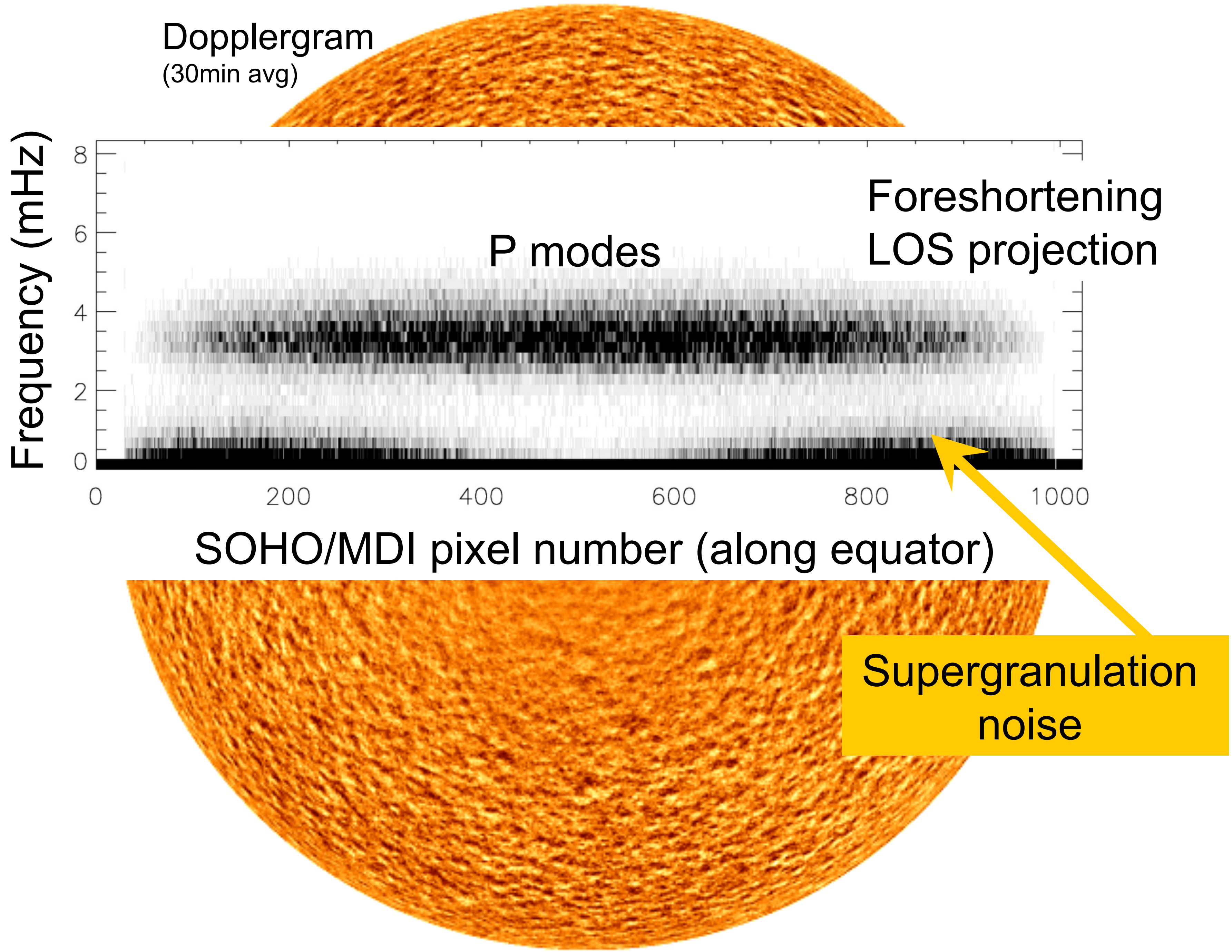
Inclination is needed

1. To beat foreshortening, projection effects, and convection noise. 30 deg.
2. To probe the deep convection zone in the polar regions. Prolate tachocline? 45/2 deg.

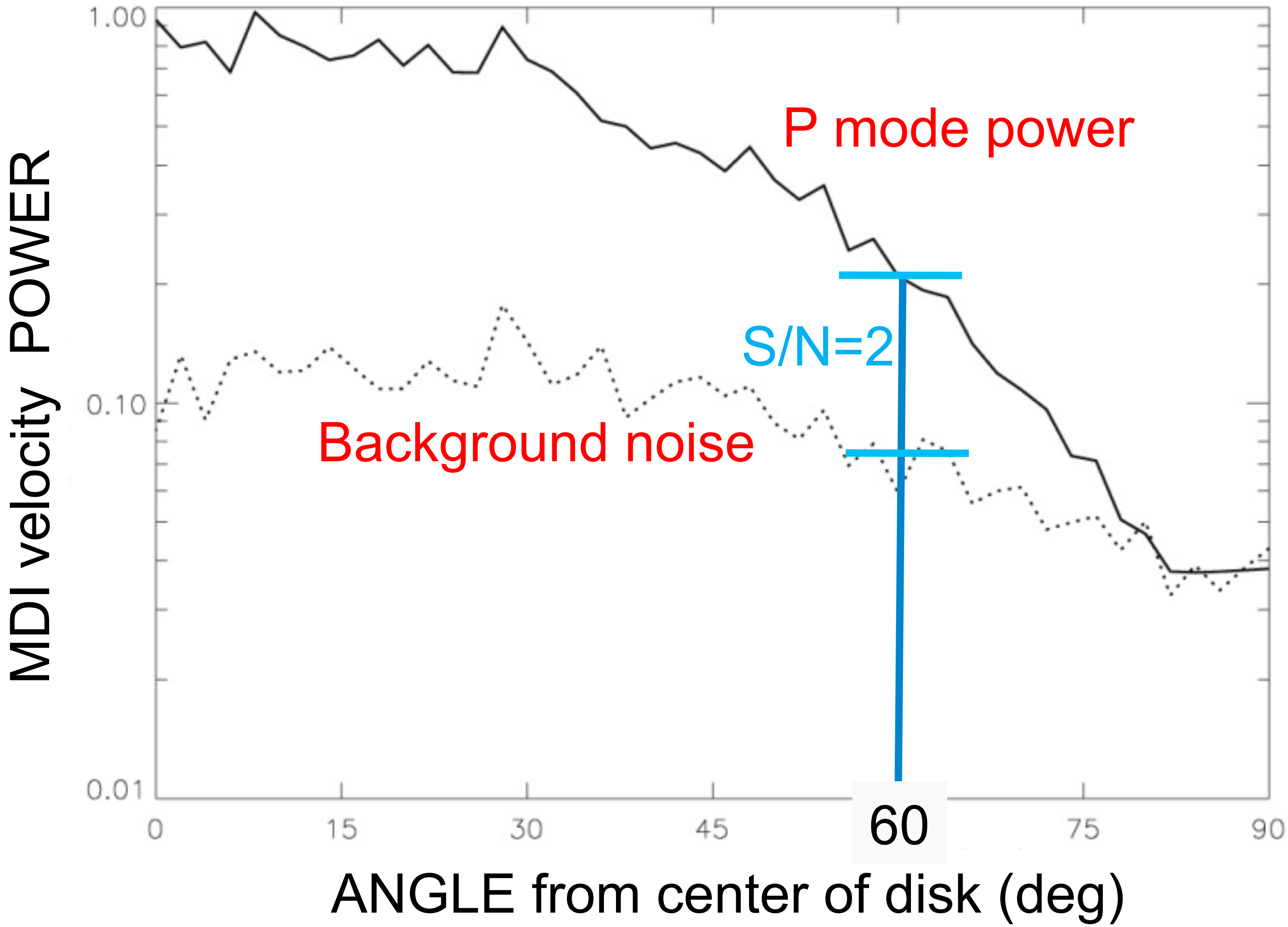
   (Less stringent requirement from T. Sekii.)

→30 + 45/2 = 45 + 7.5 deg

Inclination wrt Ecliptic > 45 deg



Dopplergram
(30min avg)
Frequency (mHz)
8
6
4
2
0
P modes
Foreshortening
LOS projection
0
200
400
600
800
1000
SOHO/MDI pixel number (along equator)
Supergranulation
noise



MDI velocity POWER
1.00
0.10
0.01
P mode power
S/N=2
Background noise
0
15
30
45
60
75
90
ANGLE from center of disk (deg)

Several vantage points: 'Stereoscopic' helioseismology

- SDO/HMI, Solar Orbiter, GONG
- Out-of-Ecliptic views and/or large Earth-Sun-S/C angles
- New possibilities for helioseismology

Non-overlapping regions:

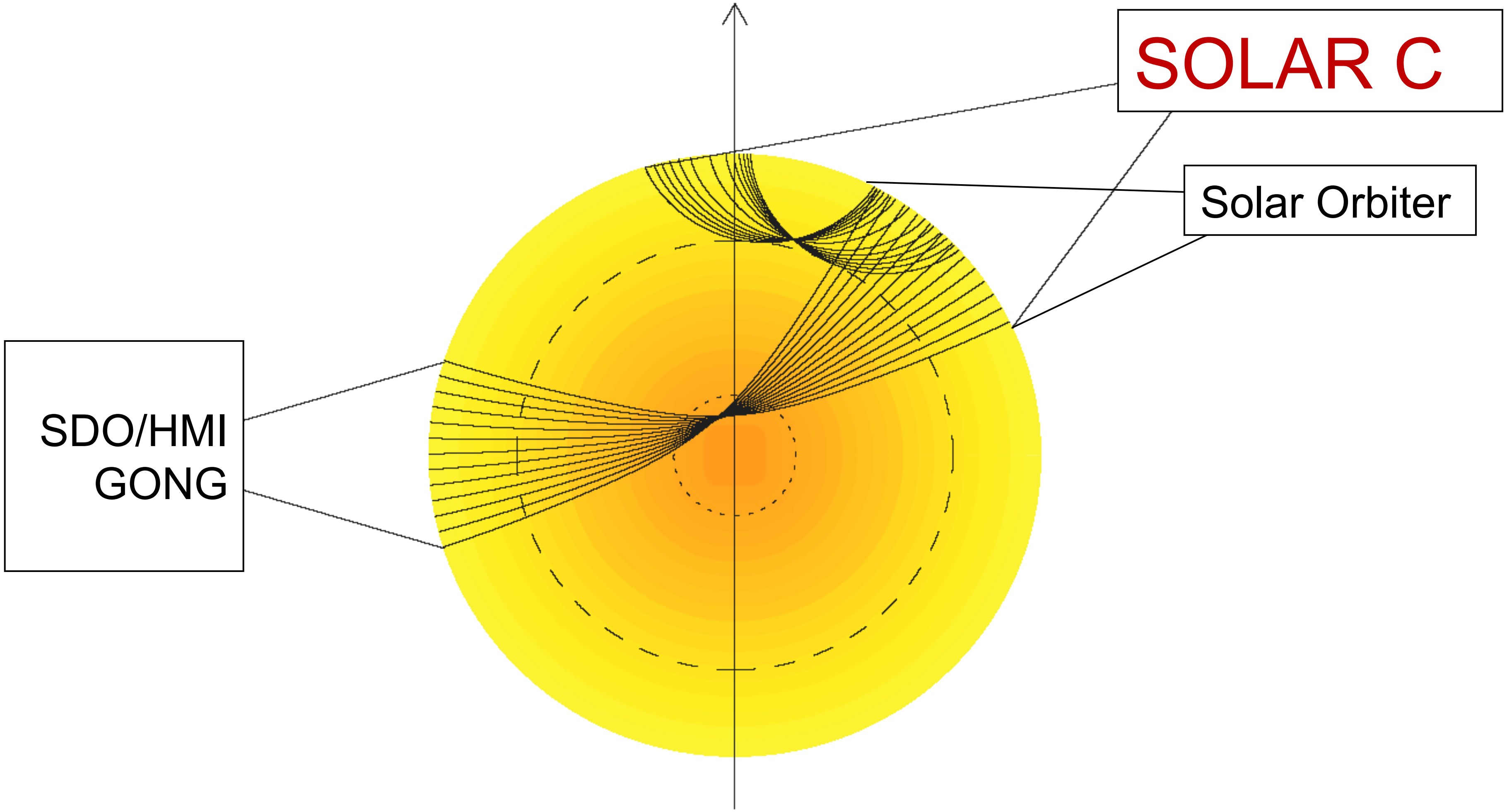
Global helioseismology: At high frequencies, spatial leaks are reduced whatever the degree. Error reduction for certain mode frequencies. At low frequencies, SNR is the issue, not the leaks.

Local helioseismology: A new game! New single-skip ray paths can be considered, even ray paths that go through the core. <u>Regions on the Sun can be tracked over a longer time.</u> Noise reduction for larger target depths.

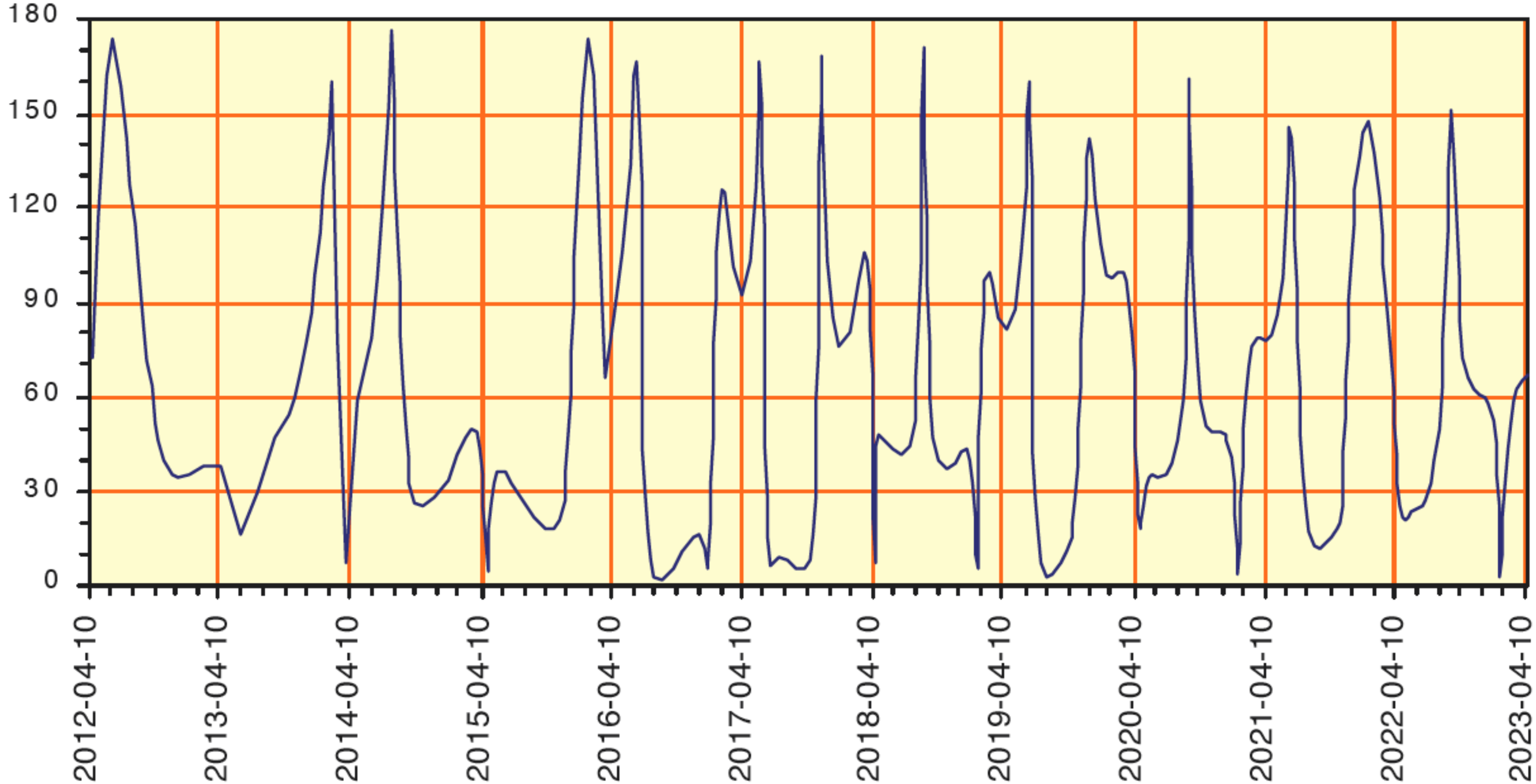
Same region seen from two or several viewing angles:

Reduction of random noise.

In principle, with three observations of the los Doppler velocity, it should be possible to reconstruct the velocity vector. Since oscillations and convection have different geometrical properties, it may be possible to partially decoupled the two. This may lead to a large increase in the oscillation S/N at low frequencies (can be tested using numerical simulations). Implications for g-mode searches?

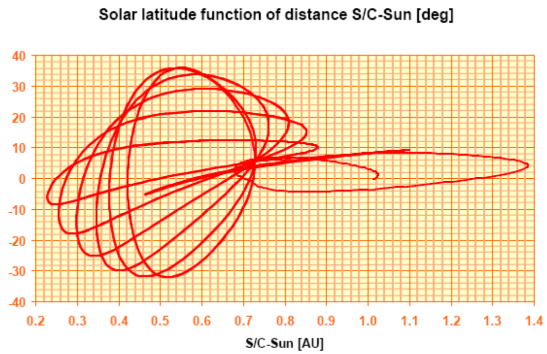

SOLAR C
Solar Orbiter
SDO/HMI
GONG

Solar Orbiter   Sun-S/C-Earth Angle
(not the latest plan)



SO orbit inclination:

progressively increases to 37 deg at the end of the extended mission. Sun-S/C distance varies a lot.



The choice of orbit is very important:

•High inclination to the Ecliptic (>45 deg) during at least one/two months per orbit for several orbits.

• Launch time (overlap with SDO and SO, and some observations near solar minimum).

•Smoothly varying S/C-Sun distance.

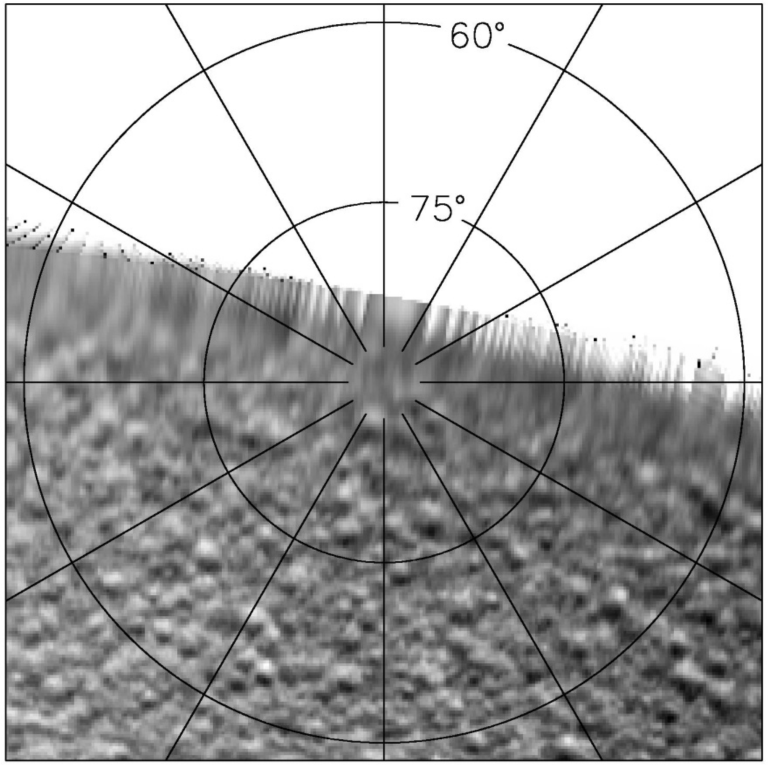
•Large S/C-Sun-Earth angles if possible…

Object	Spatial resolution *	Observation time
Core	~0.01 R	As much as possible
Meridional circulation, rotation	~0.01 R	Months to years
Tachocline ** (flows 20-100 m/s)	~0.01 R	years
Farside calibration **	~0.01 R	months to years
High resolution local helioseismology	0.002 R	days to weeks

*A resolution of 0.01 R means a pixel spacing of 0.005 R = 3 Mm → 512^2 pixels
** Courtesy of C. Lindsey

256x256 pixels may be enough

A lot more than helioseismology can be done with high-resolution Dopplergrams



Flows can be measured from direct Doppler measurements, and from the motion of supergranules or small magnetic features.
And much much more.

Requires high resolution, but not at full temporal cadence.

Thus it is useful to have a big CCD and to also transmit high-resolution images at low cadence.

MDI Doppler image showing view of South pole

Basic requirements for helioseismology

- Observables:
  - LOS velocity (or possibly intensity for several lines)
  - LOS magnetic field, continuum intensity
- Field of view: full disk
- Camera: say 2000^2 pixels
- Cadence and spatial resolution:
  - 60 sec for LOS velocity images ‘binned’ down to 512^2 pixels
  - Less often (every hour?), V, B and I at full resolution
- Data coverage:
  - As long as possible (years)
  - As continuous as possible (>90% duty cycle)
- Telemetry >20 kb/s, all the time.

  (12 b)*512^2/(4/pi)/(60 s)/2.2=18.7 kb/s
  12 kb/s if only Fourier coefficients of interest
  + telemetry for high-resolution low-cadence images.
- Clock precision and image stabilisation system must be excellent for stereoscopy.
- Orbit inclination >45 deg