Sensitivity of large-angle method to detect deep-seated magnetic flux

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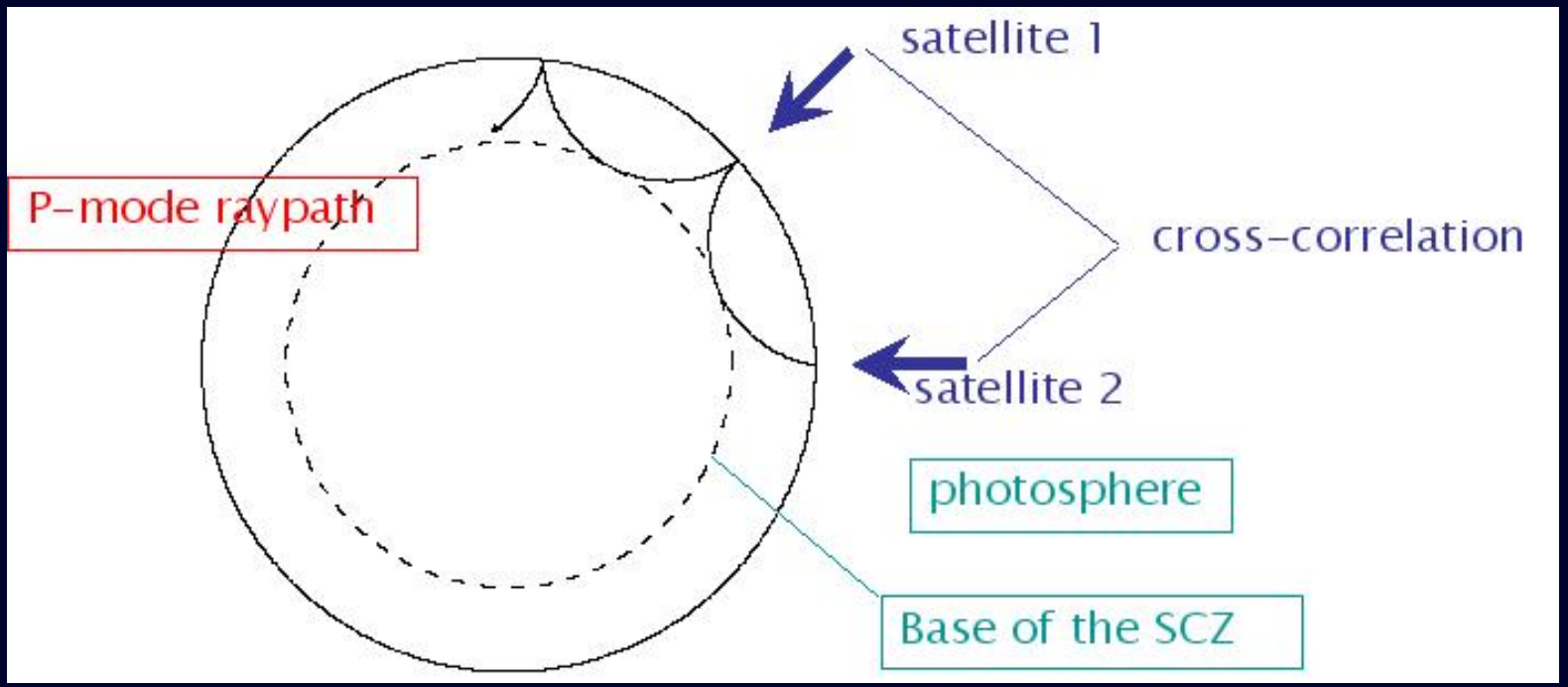
This talk is about…

- Q: Is going to high latitudes really worth it?
  - From the ‘large-angle method’ point of view

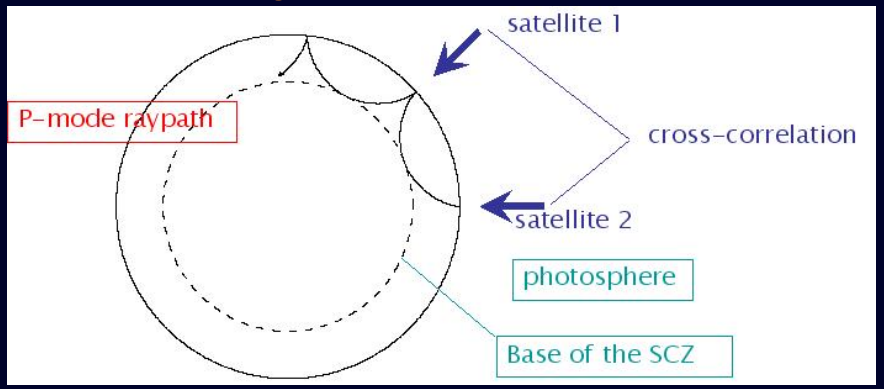
The large-angle method

- The p-mode ray paths that reach the tachocline have 45-degree skip angle



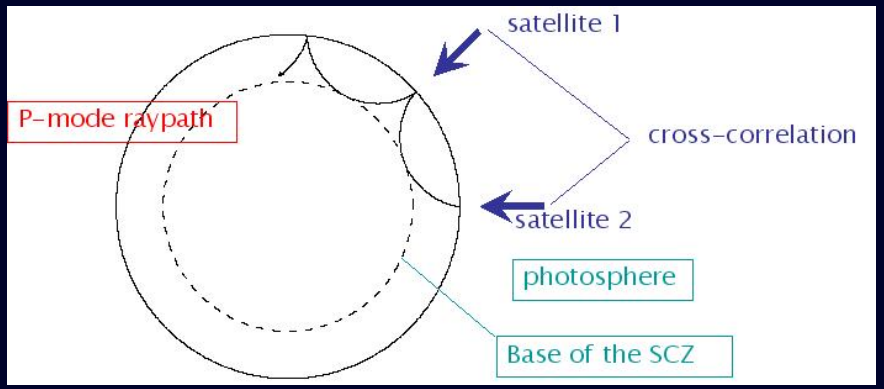
The large-angle method

- Observing solar wavefield from high latitudes improves chance of seeing anything in the *tachocline* region
- Because then we can observe Doppler signal at high latitudes without the effect of projection/foreshortening



The large-angle method

- Do we really need two vantage points?
  - People have been looking for 45-degree signal anomaly and nobody has convincingly found it
  - We may need every little extra help

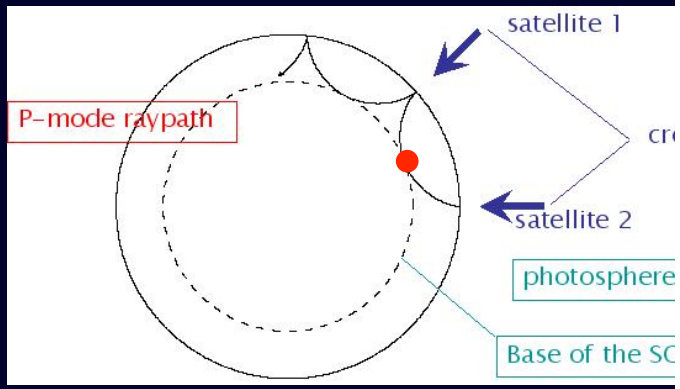


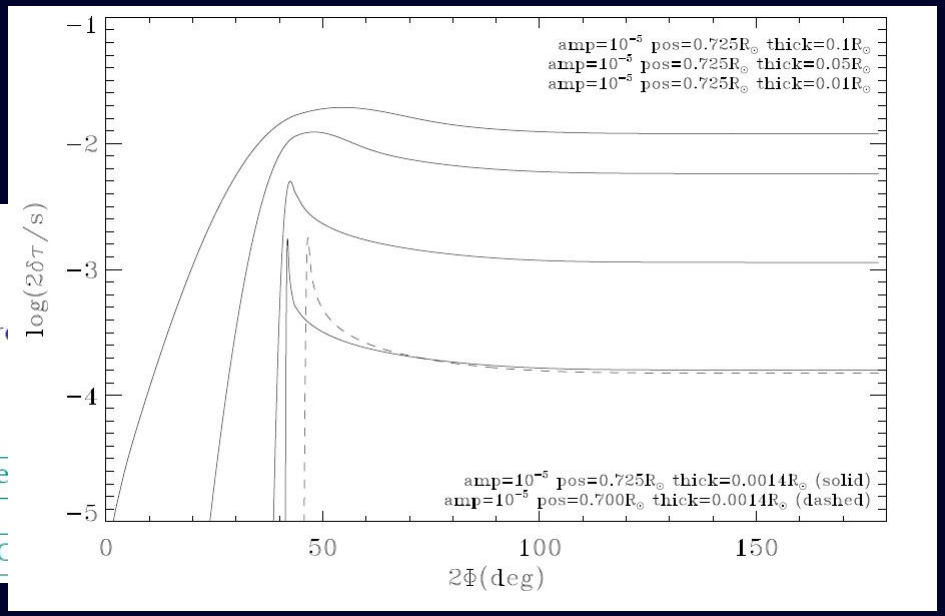
What do we expect to see anyway?

- Flux tube: ~100 kG, ~1000-km thick?
  - effective 'soundspeed' perturbation of ~10^{-5}
  - Around 30-degree latitude?
- Flow inside the flux tube: up to ~200 m/s
  - $v/c \sim 10^{-3}$, $v/r\Omega \sim 0.2$
    - amplitude large enough but probably too thin to be seen by rotation inversion
    - This flow also exhibits more transient signature when the tubes are rising
- There is the issue of uncertain cross section/filling factor

Travel-time signatures

- Rough estimates based on ray theory
  - Requires ~a few msec sensitivity for detecting flux directly by wavespeed anomaly
  - This translates to a few$\times 10^{-1}$sec sensitivity for flow





Measuring travel times

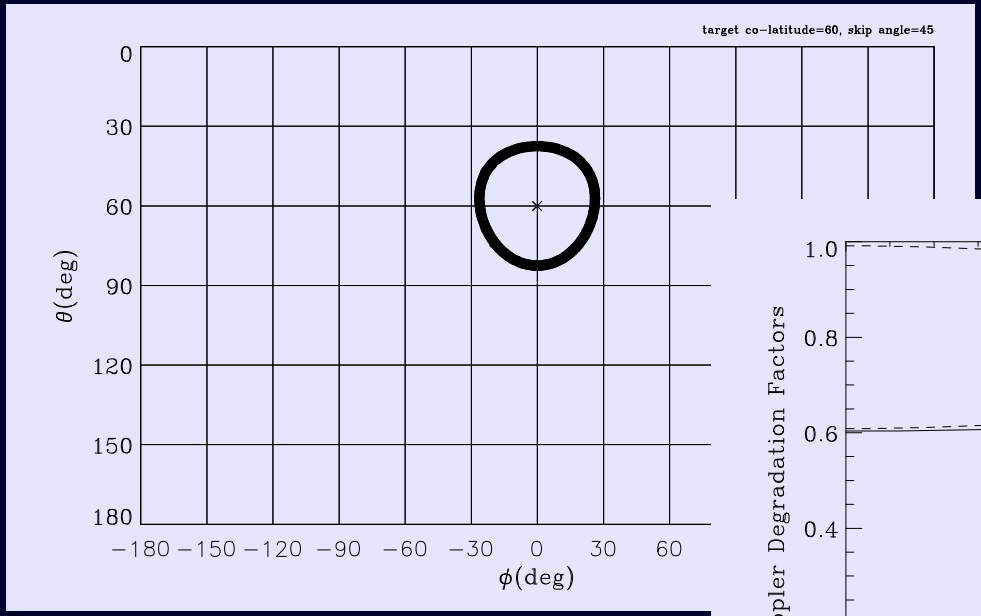
- It is not just a matter of travel-time sensitivity
  - We need a way to disentangle the signature from other sources of perturbations
  - However, for the moment, let us forget this issue
- What are the difficulties with measuring travel time with an angle?

The projection and foreshortening

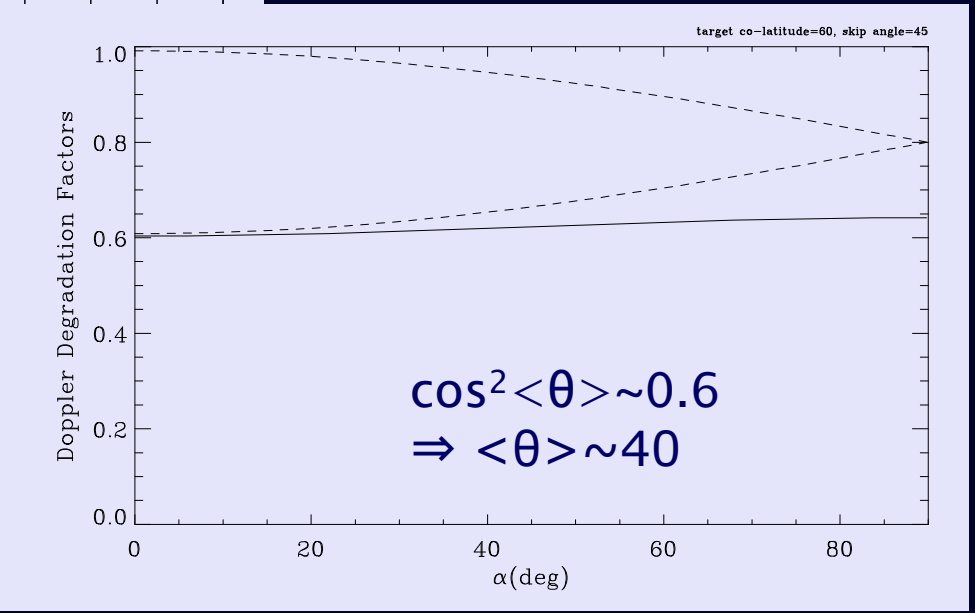
- There are two effects
  - projection: Doppler signal multiplied by cosϕ while the background hardly changes (around 3mHz anyway)
    - i.e. noisy cross-correlation function
  - foreshortening: loss of spatial resolution leads to overlaying many cross-correlation functions with different travel times
    - i.e. temporally blurred (noisy) cross-correlation function

Looking for a flux tube?

- Suppoe it is located at r/R=0.725, 30-deg latitude



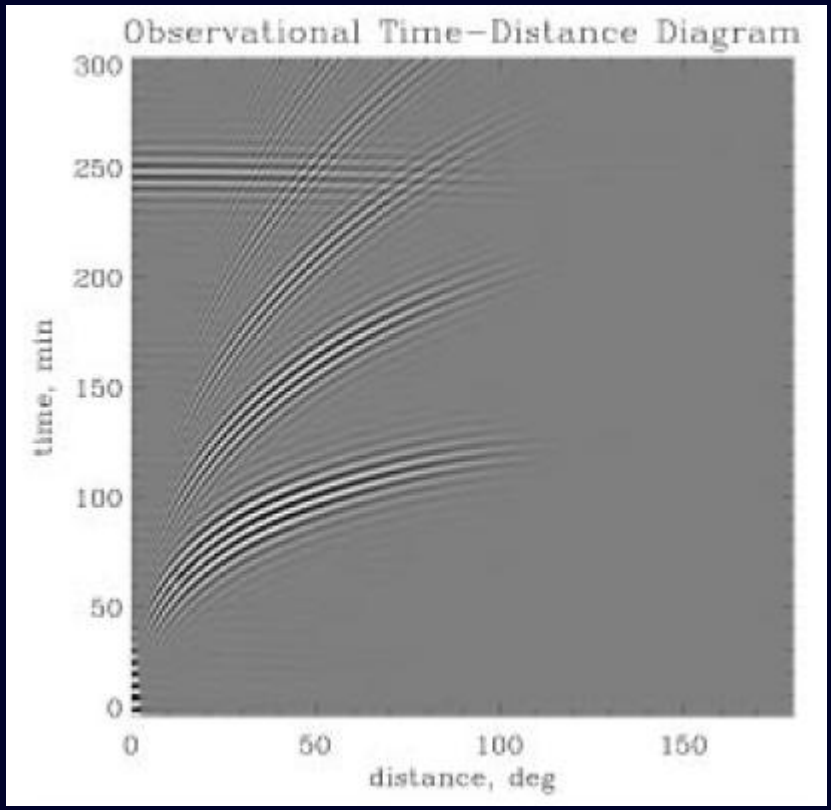
The projection angle plot



Trajectory of ray-path end points

The projection and foreshortening

- A 45-degree ray off equator: how difficult?



The projection and foreshortening

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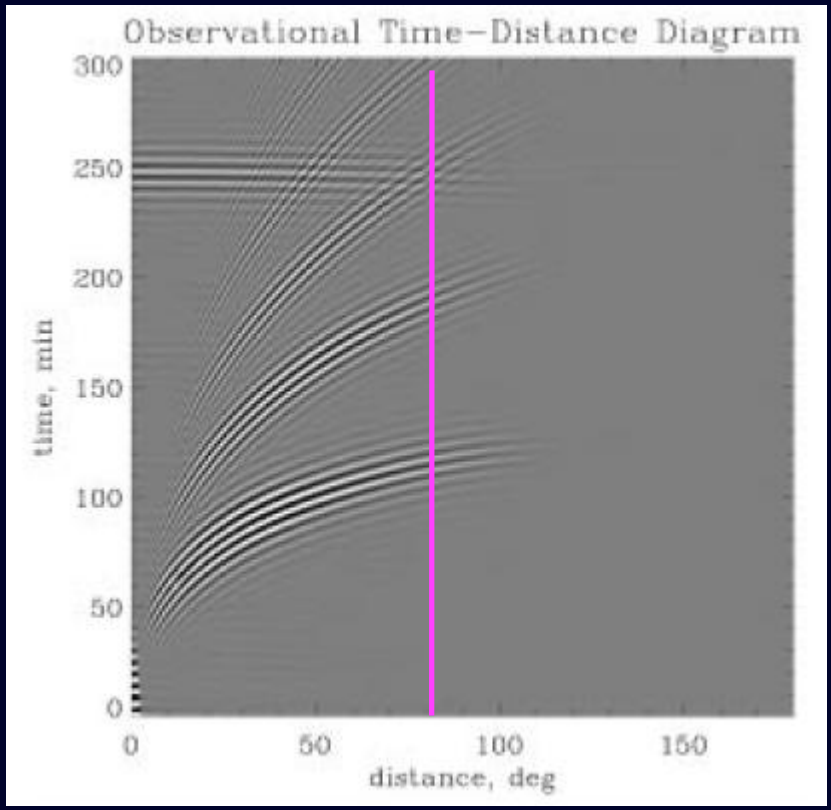


Looking for a flux tube?

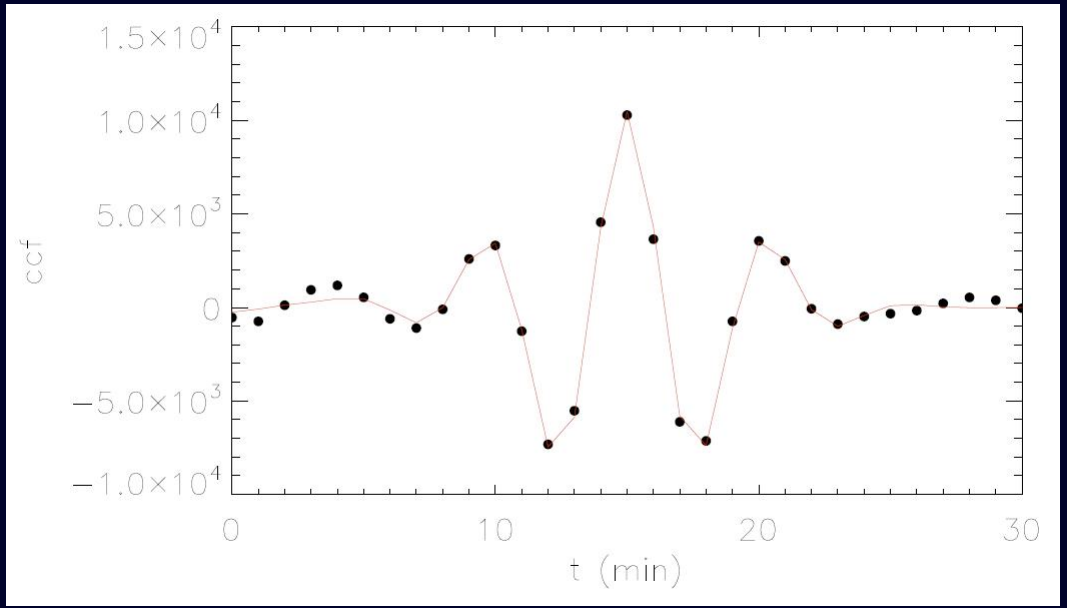
- Cross-correlation function S/N down by a factor ~1.7
- Effective resolution down by a factor 1.3
- What if the full resolution is 1 arcsec?
  - =700-km resolution (disc centre)

Simulation

- Artificially generated stochastically excited oscillation data
  - for Gabor wavelets with a background noise,
  - some proper parameters (5-min period etc)
  - some arbitrary parameters (travel time etc)
  - Prescribed spatial resolution and noise level
- These are fitted by a non-linear LS method
  - statistic is pretty close to Gaussian

Results

- Sample curve



Results

- Measurement errors (still tentative)
  - 1-min cadence, 10-day series
    - 750-km resolution, 2 per-cent noise: 1.8 sec
      - This is 1-arcsec resolution
    - 900-km resolution, 2.5 per-cent noise: 3.0sec
    - 1125-km resolution, 3 per-cent noise: 8.5 sec
      - This is the relevant case
  - 1-min cadence, 100-day series
    - Errors reduced by about factor 3
- With deep focusing, longer data sets etc, we may be able to do it

The bottom line is…

- Going to high latitudes does reduce measurement errors in travel time by a moderate factor
- This reduction *could* be crucial
  - We seem to be in a twilight zone between the land of possible and the land of impossible
    - depends on what the Sun really is doing

What if…

- What if the flux tubes are located at 40 degree?
- What if the flux tubes are located deeper?
- Don't we want to know what is taking place *beneath* the tachocline?

Then going to high latitudes is even more important, not to mention other merits of doing so

This talk was about…

- Q: Is going to high latitudes really worth it?
  - From the ‘large-angle method’ point of view
- A: Most likely YES