The Thermal Structure of Sunspots from Ring Diagram Inversions

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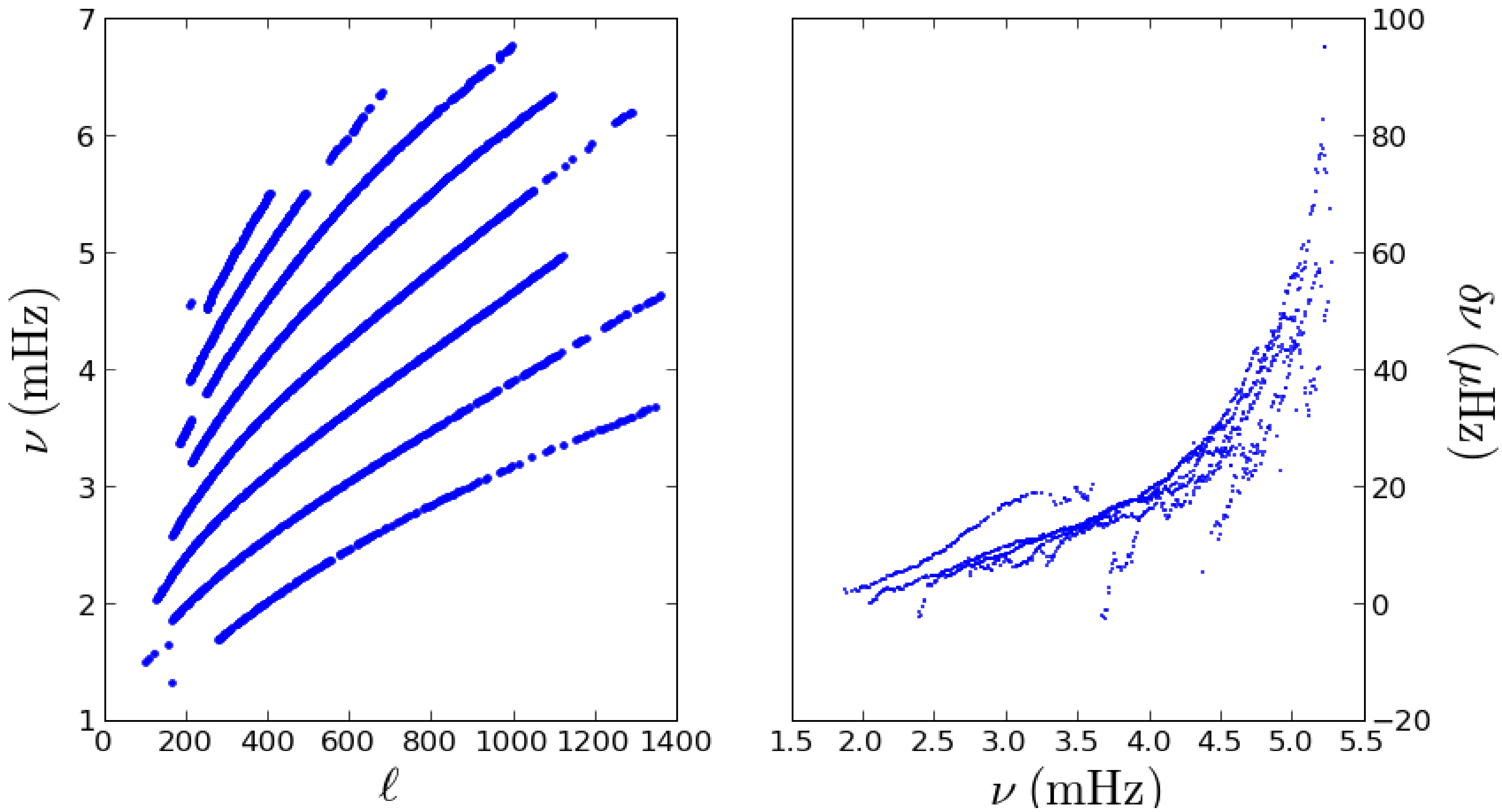
Introduction

- Measuring the thermodynamic properties of the regions under sunspots is critical to understanding the nature and evolution of active regions.
- 3D power spectra (ring diagrams) can be inverted like global mode helioseismic data sets
- This has been done on small samples of active regions:
    - Sound speed is depressed near the surface ($>0.99R_{solar}$) but enhanced deeper down (e.g. Basu et al. 2004, Bogart et al. 2008)

Current Sample

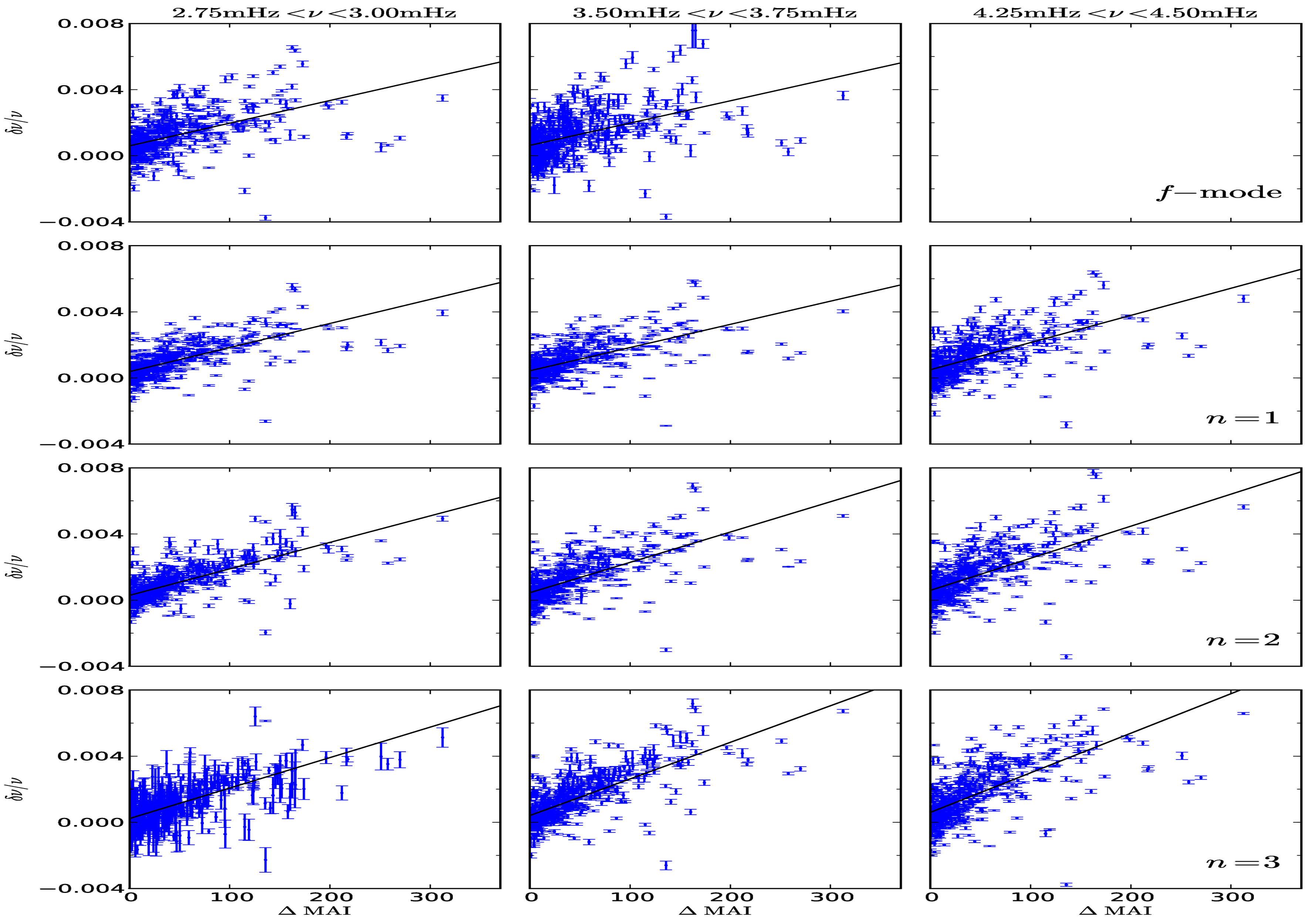
- ~350 active regions from solar cycle 23
- Rings from MDI full-disk Doppler data
- 16x16 patches, tracked for 8192 minutes
- Active region coordinates taken from NOAA catalog, 1 or 2 nearby quiet regions chosen for comparison
- Ridges are fit using code described in (Basu et al. 1999)
- Characterized by Magnetic Activity Index (MAI; Basu et al. 2004)

A Ring



7
6
5
4
3
2
1
0
200
400
600
800
1000
1200
1400
ν (mHz)
ℓ
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
100
80
60
40
20
0
−20
$\delta\nu$ (μHz)
ν (mHz)

Frequency differences

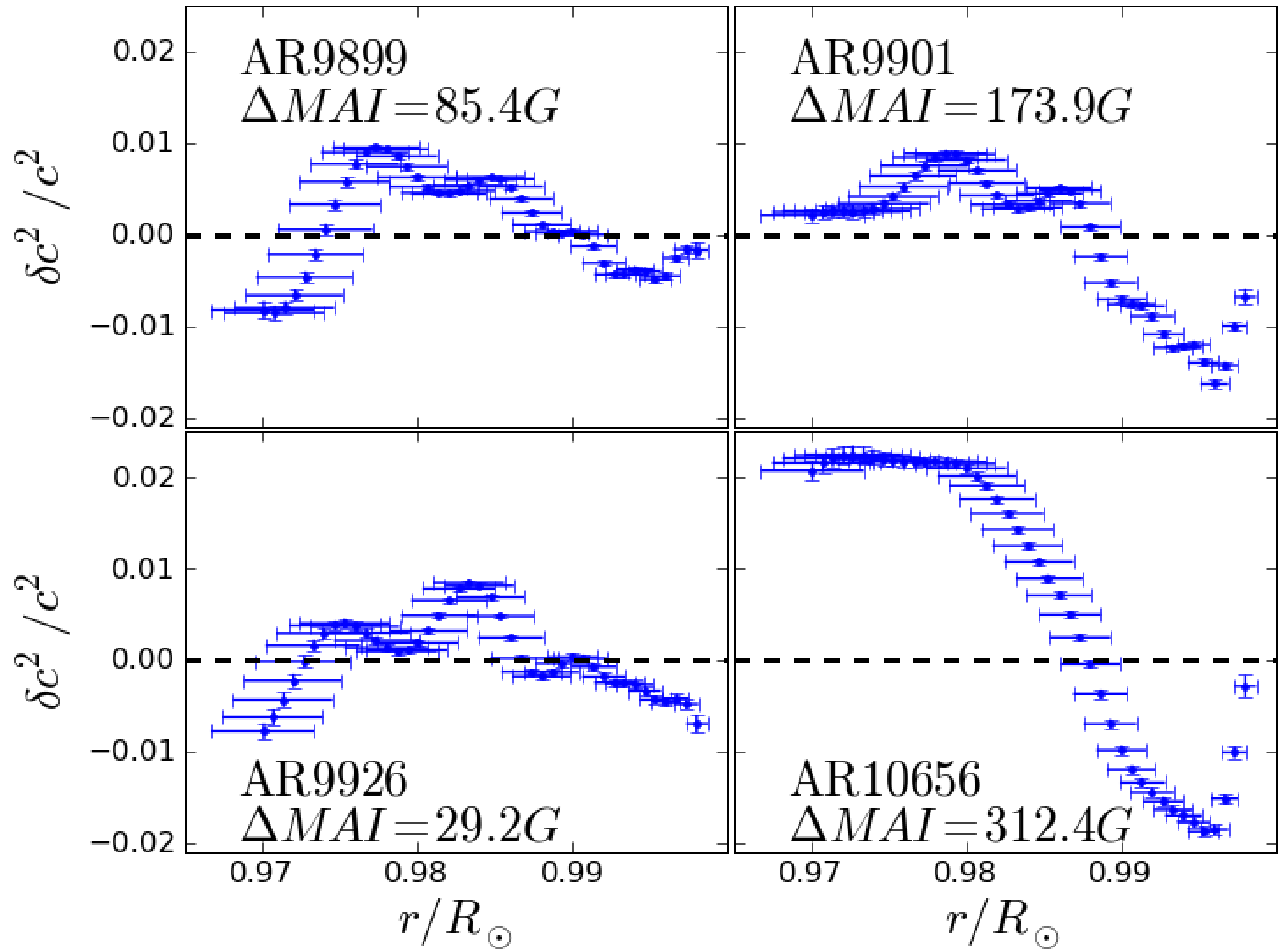


Inversions

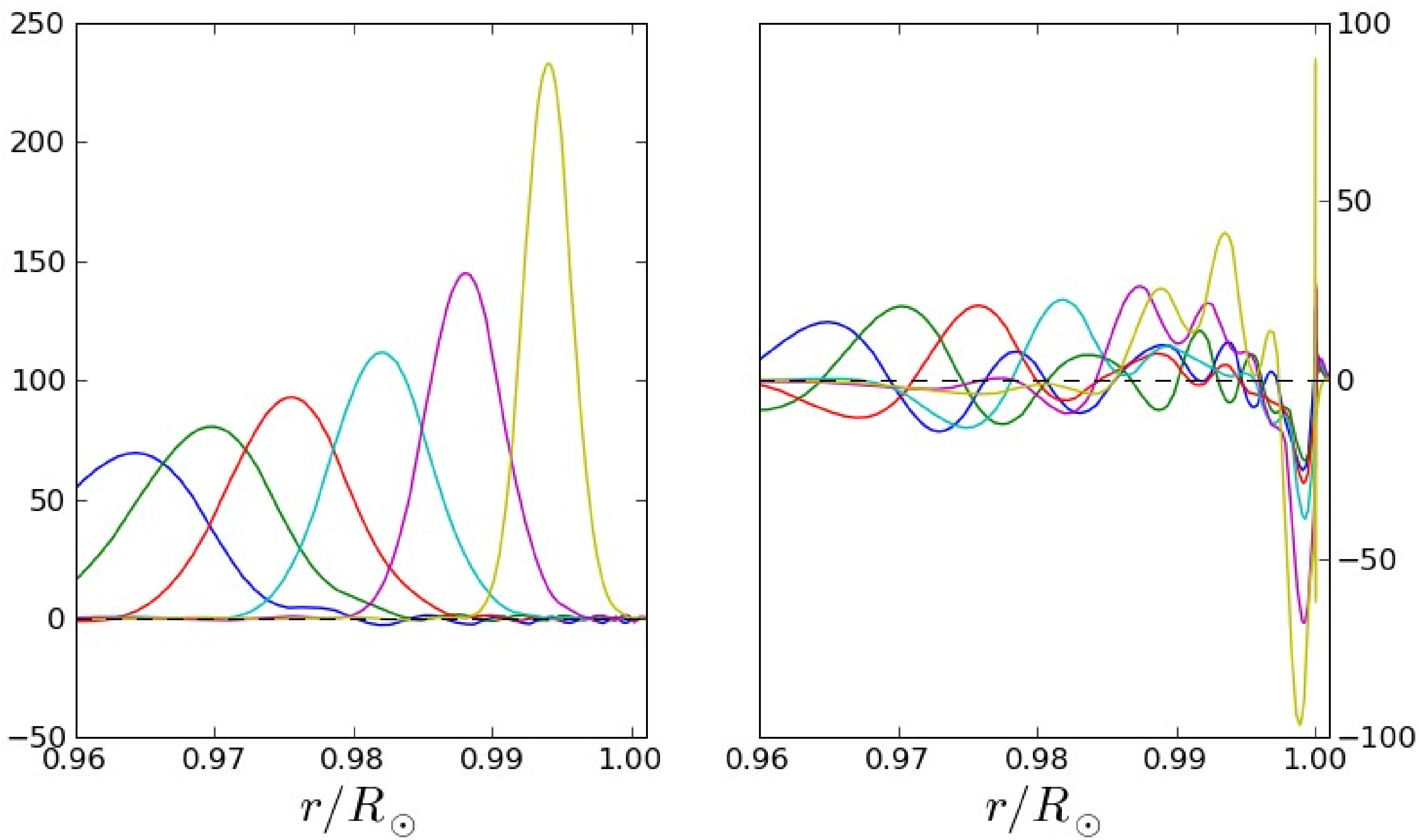
- Subtractive Optimally Localized Averages (SOLA) inversions of frequency differences between active and quiet regions

- 4 usual free parameters: target width, error suppression, cross term suppression, surface term

Sound Speed Inversions

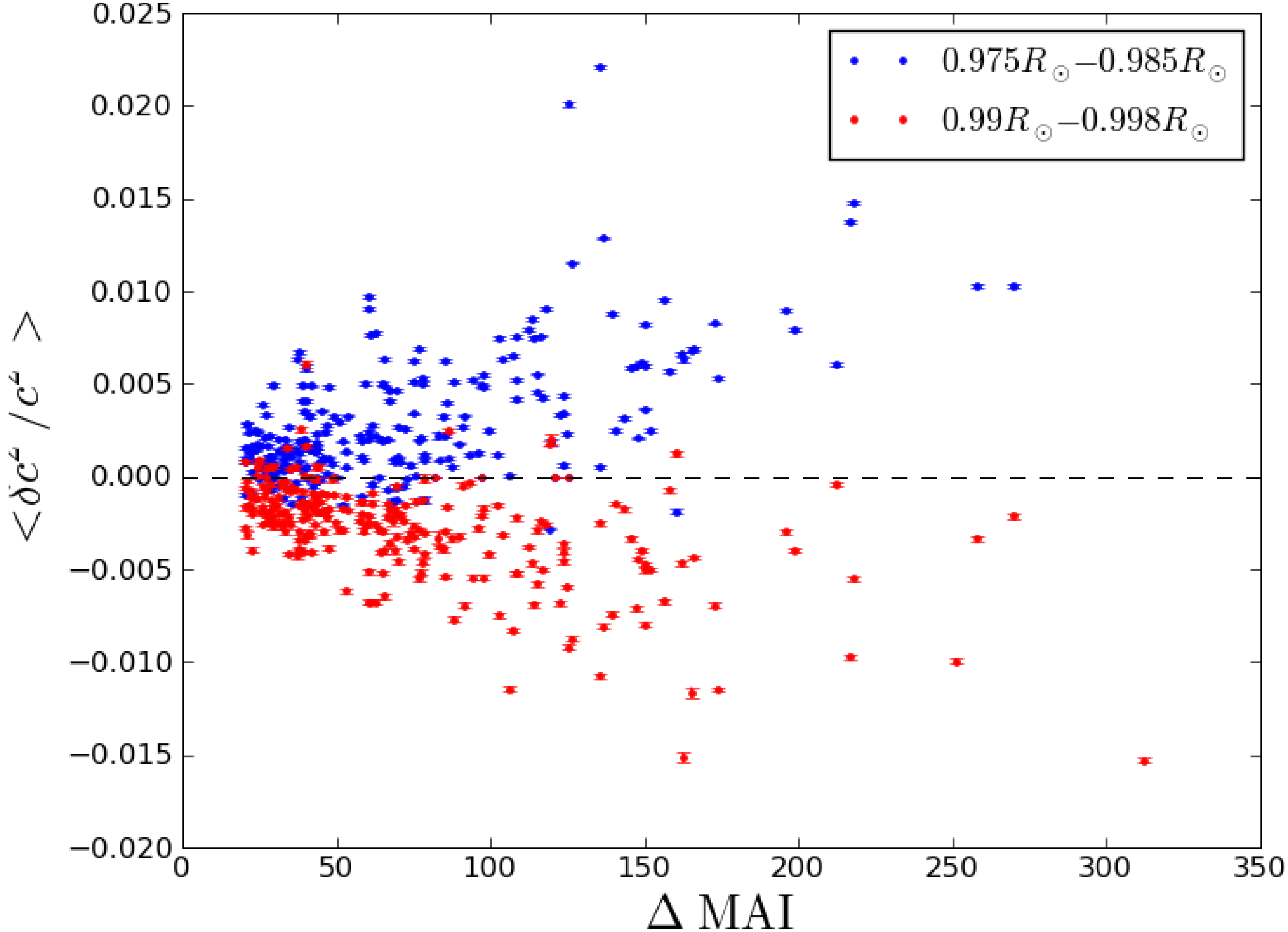


Kernels

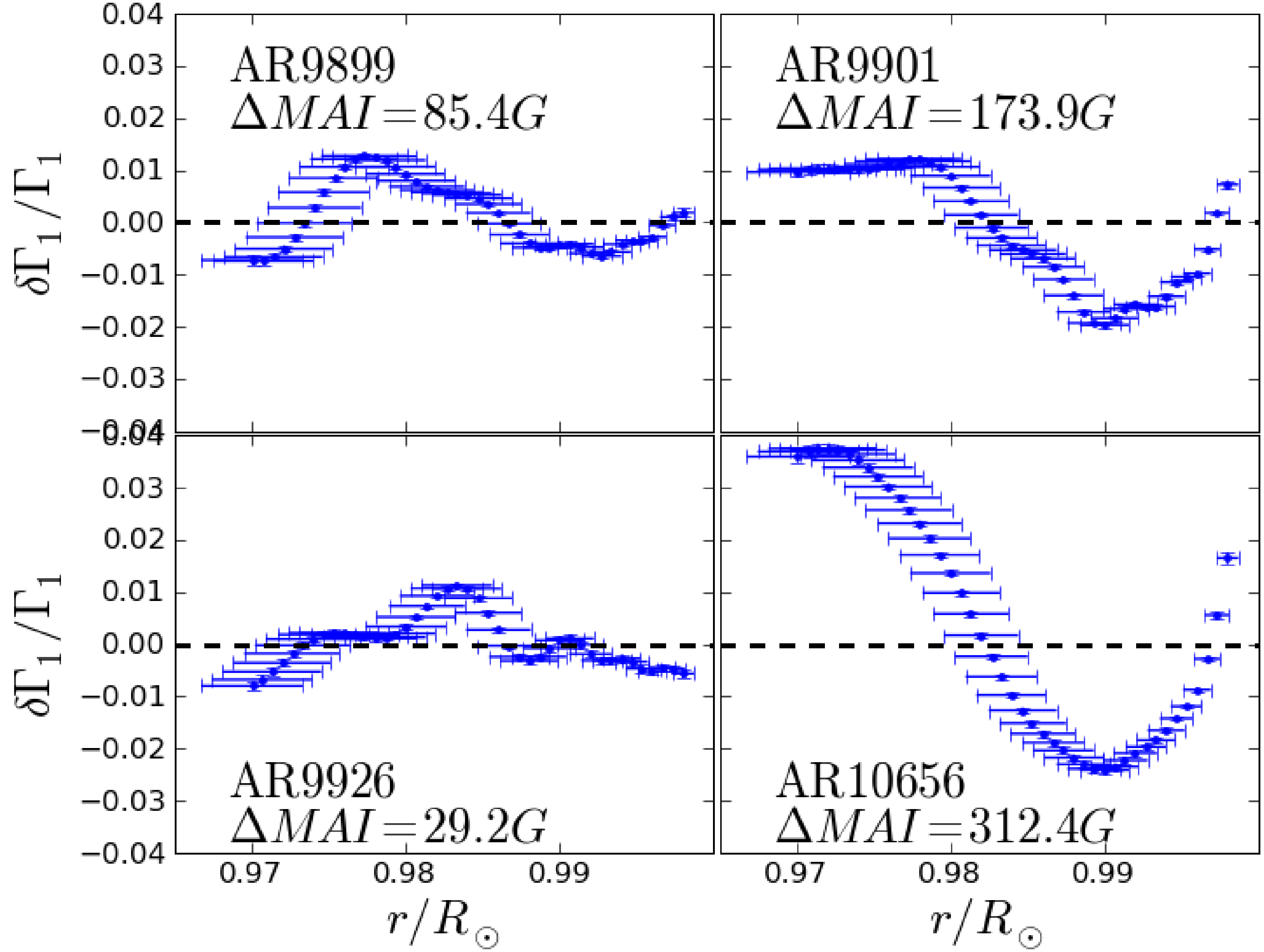


250
200
150
100
50
0
−50
0.96
0.97
0.98
0.99
1.00
$r/R_\odot$
100
50
0
−50
−100
0.96
0.97
0.98
0.99
1.00
$r/R_\odot$

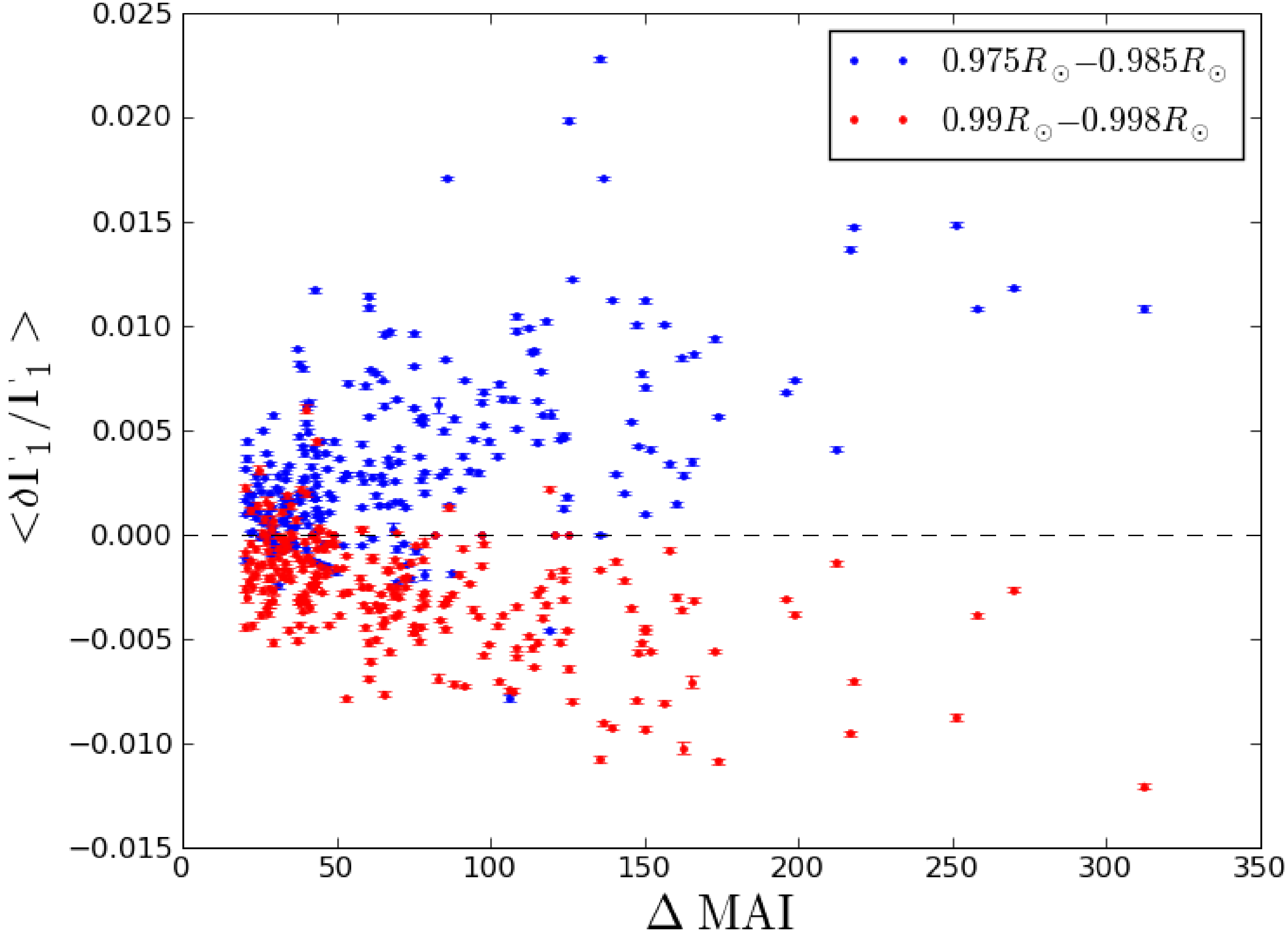
Sound Speed Averages over Depth



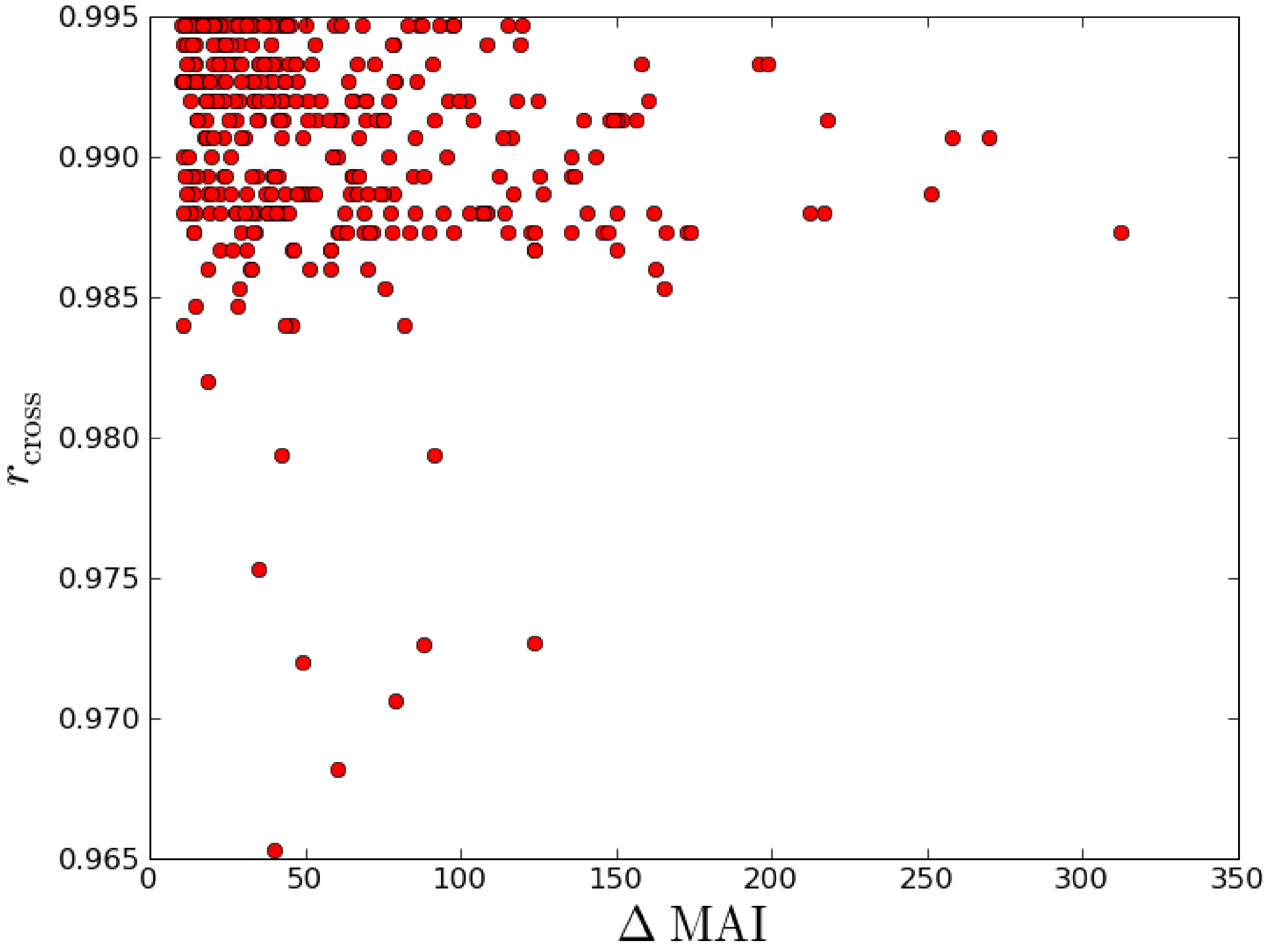
Adiabatic Index (Γ_1)



Adiabatic Index averages



Cross-over points



Conclusions

- Sound speed and adiabatic index inversions are consistent with earlier results on smaller samples:
  - Sound speed and adiabatic index depressed at shallow depths
  - Enhanced at deeper depths
- Cross-over point shows no obvious dependence on active region strength
- Work is ongoing