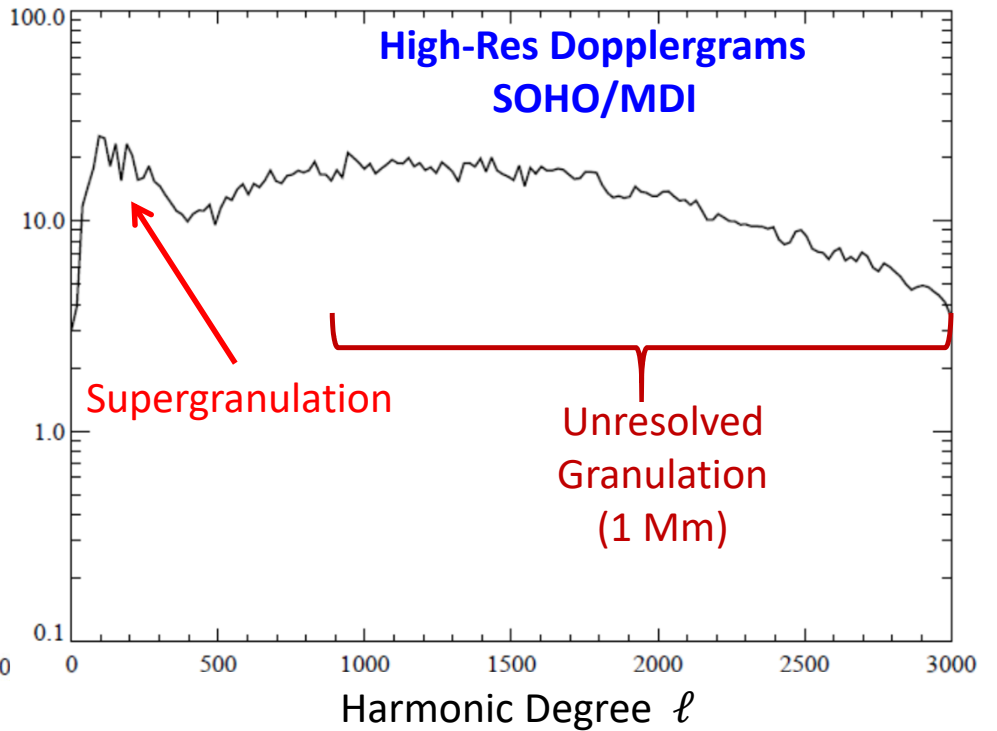
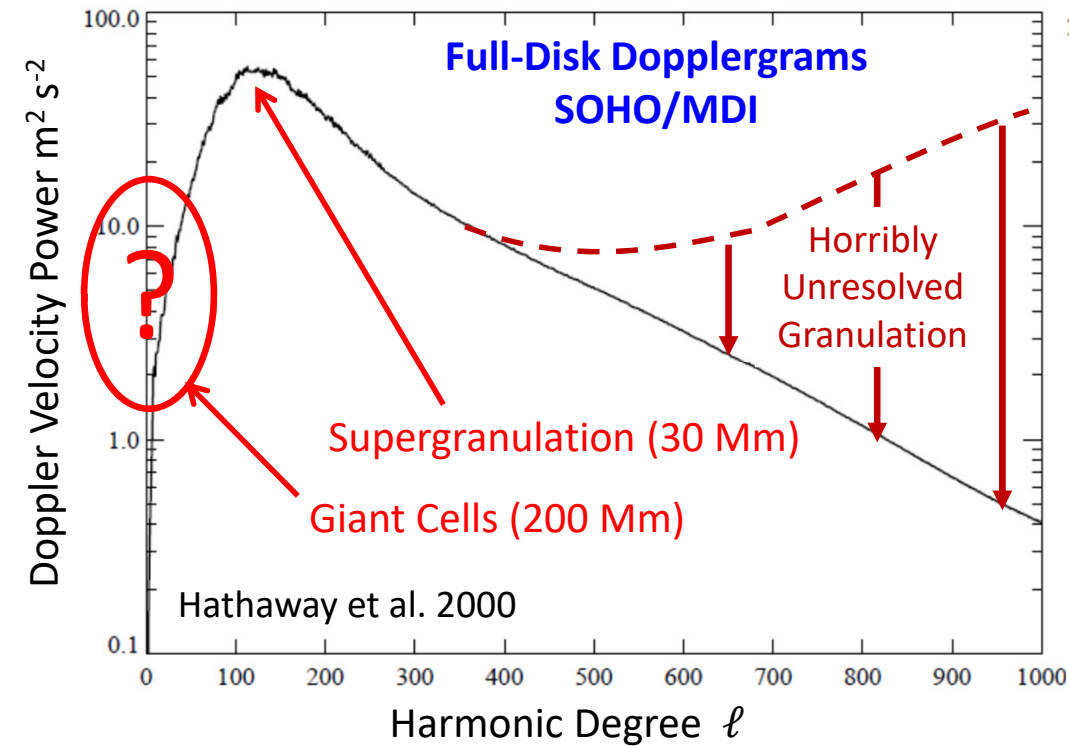


Observational Update on the Convective Conundrum

Bradley W. Hindman
University of Colorado Boulder

The Original Convective Conundrum (No Giant Cells ! Bah!)



Velocity power at the surface lacks large-spatial scale motions.

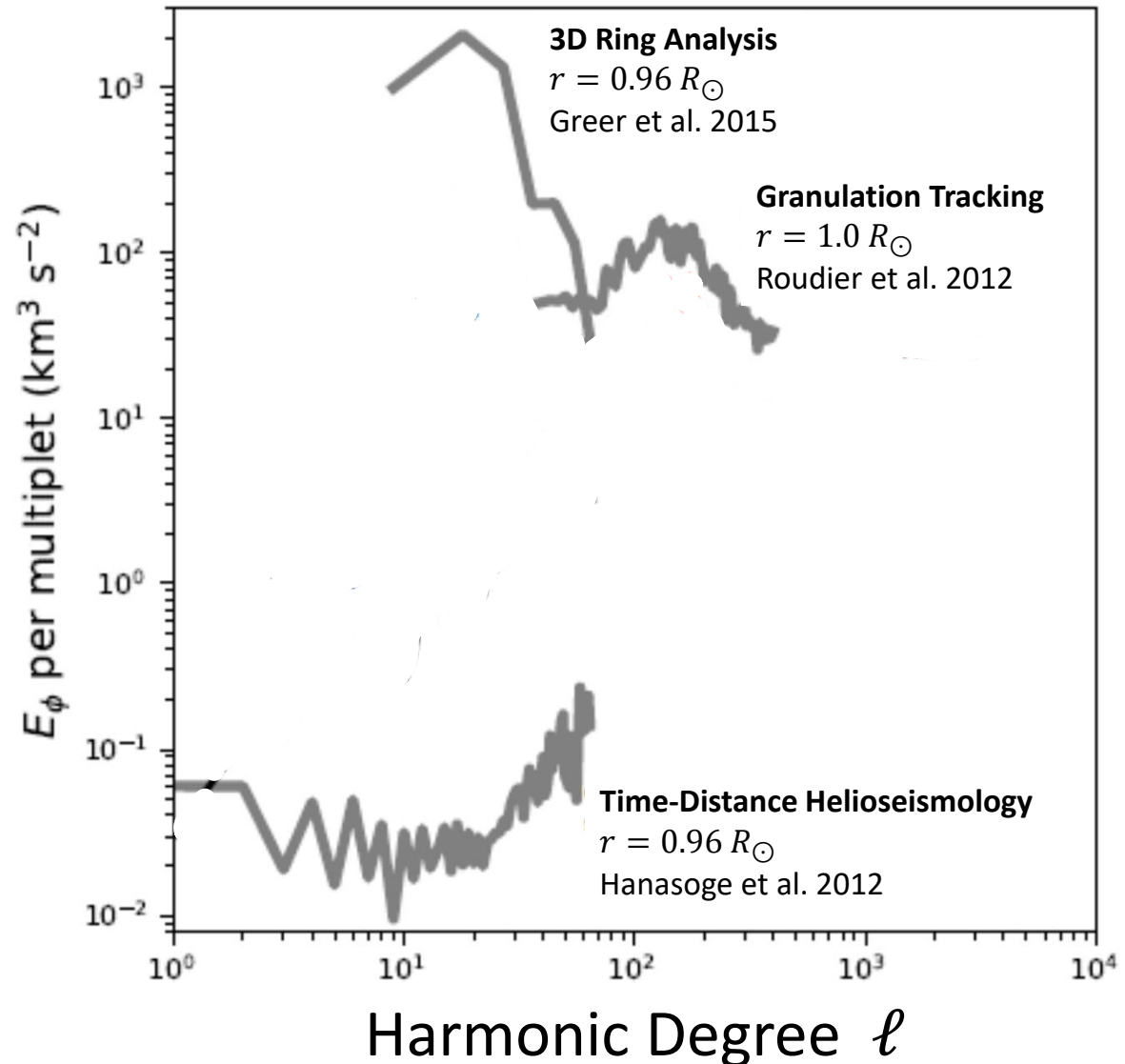
Granulation: 1 Mm or $\ell \sim 3000$
 Supergranulation: 30 Mm or $\ell \sim 100$
 Giant Cells: 200 Mm or $\ell \sim 10$

Convective Conundrum Continued (Bah! Bah!)

As originally posed, two distinct helioseismic methods produced very different results for the speed of the Sun's convection. The velocity power differed by 3 orders of magnitude.

$$\frac{\text{Ring Analysis}}{\text{Time - Distance}} > 1000$$

from Proxauf 2021

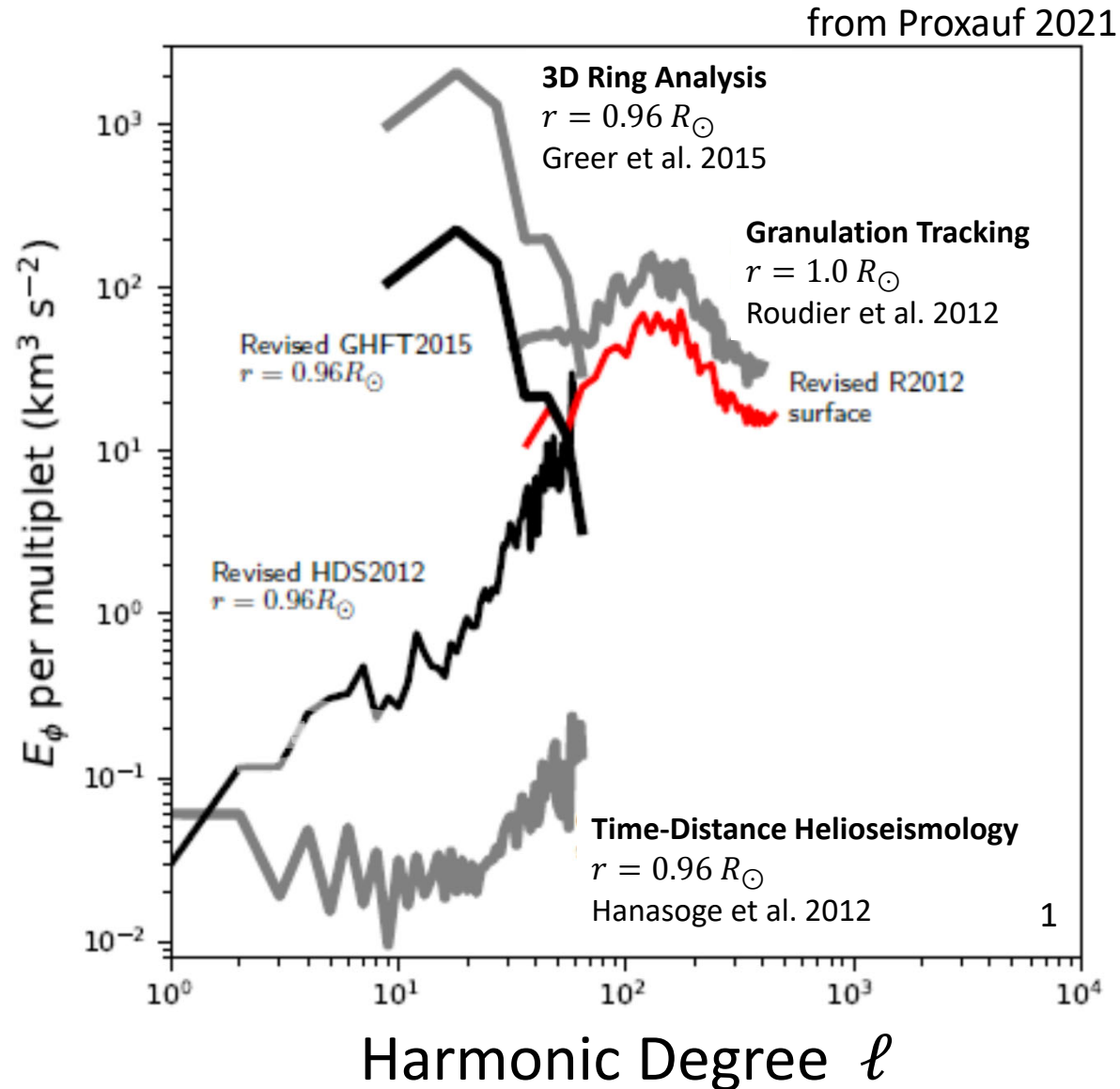


Original Convective Conundrum

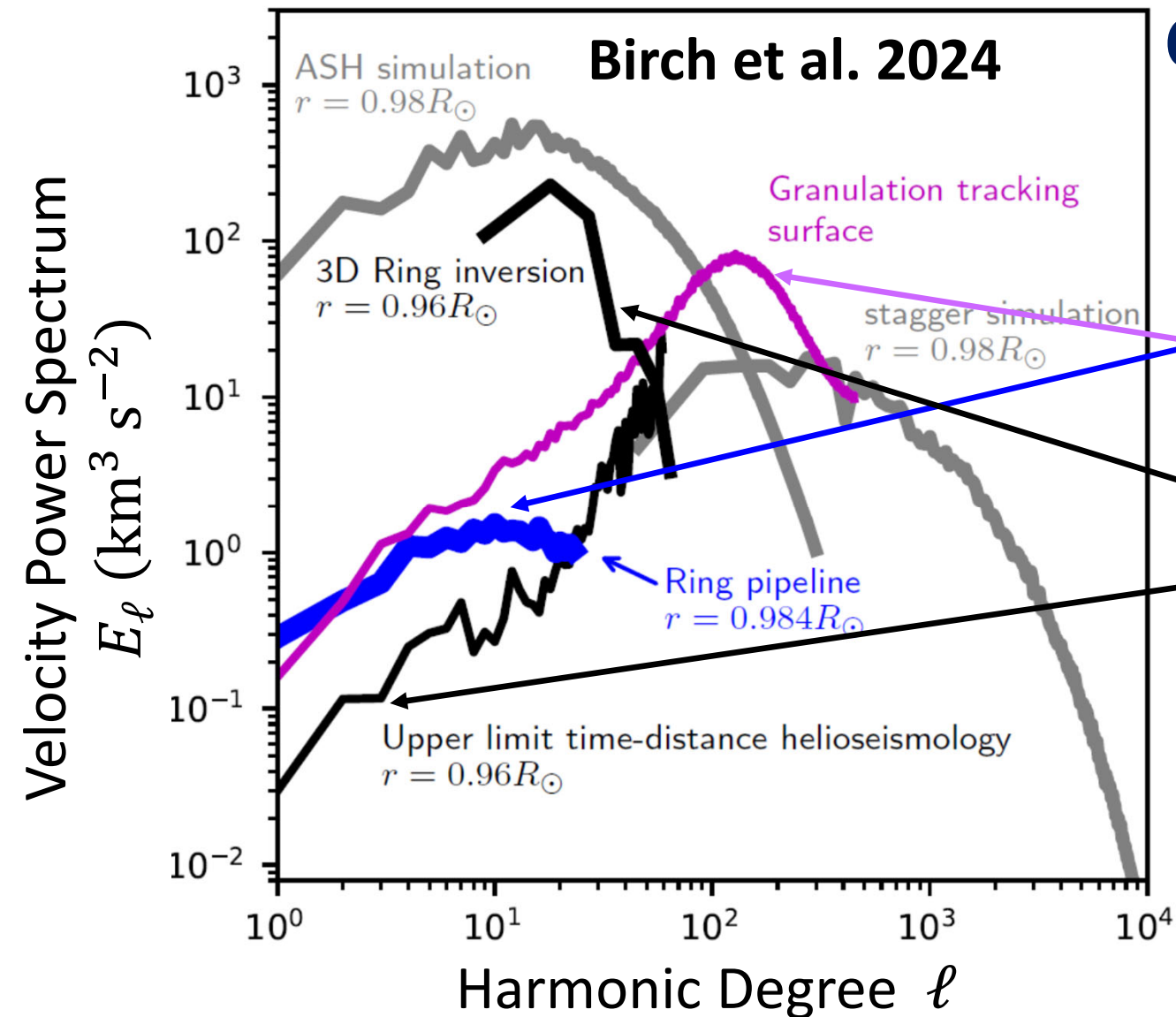
After performing a careful comparison which

- 1) homogenized definitions
- 2) fixed small errors

Observations still disagree



Convective Spectrum of the Sun



Proxauf et al. 2021

Greer et al. 2015

Hanasoge et al. 2012

After performing a careful comparison which

- 1) homogenized definitions
- 2) fixed small errors

Observations still disagree

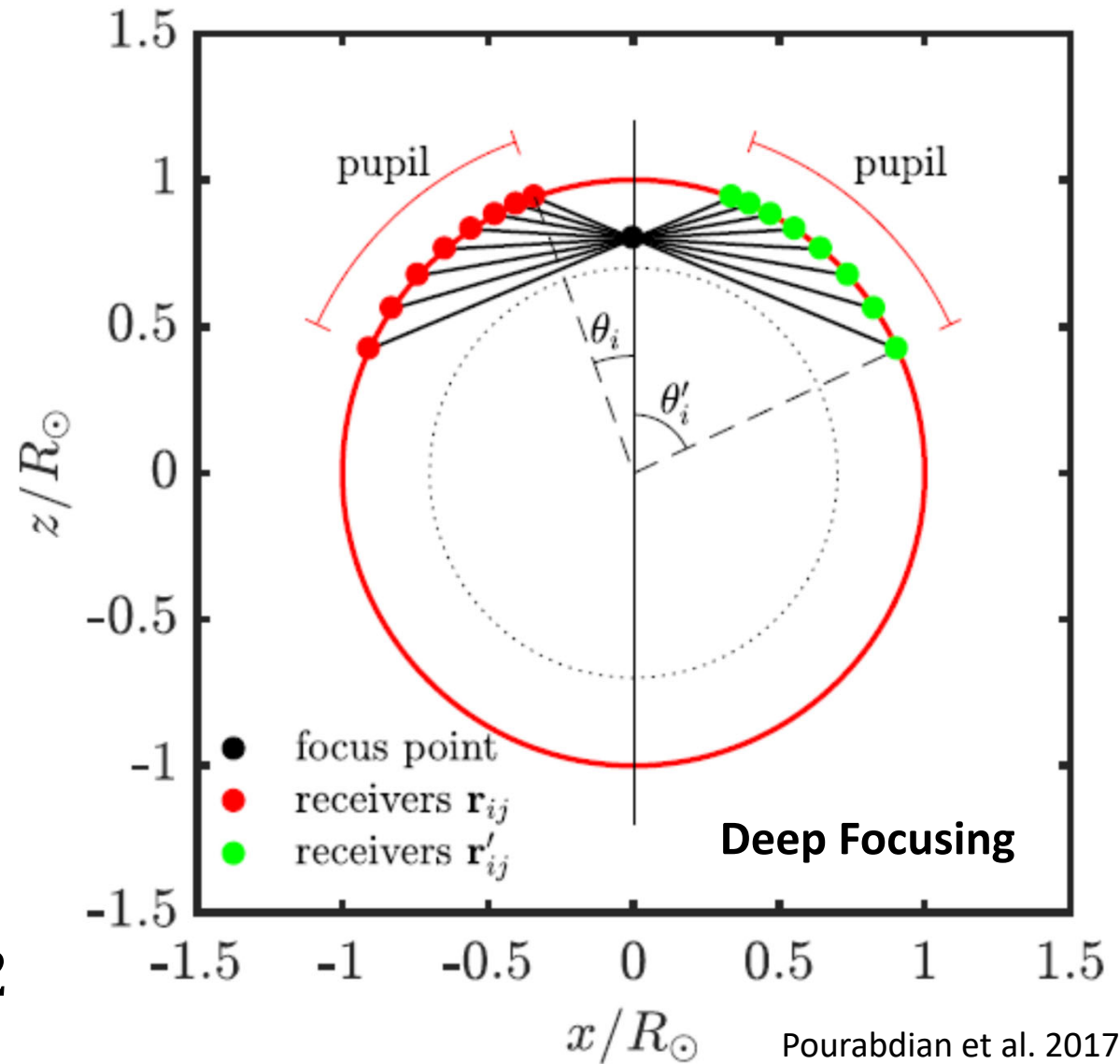
Time-Distance Helioseismology

$$v_\ell = \frac{\delta\tau_\ell}{C_\ell} \left(\frac{S}{N} \right)$$

The velocity is estimated from the travel-time difference (east-west component):

Calibration factor = C_ℓ

Signal-to-Noise Ratio = $S/N \sim 0.2$



Noise Estimates

Noise Model

$$\sigma_{\delta\tau}^2 = S^2 + \frac{N^2}{T}$$

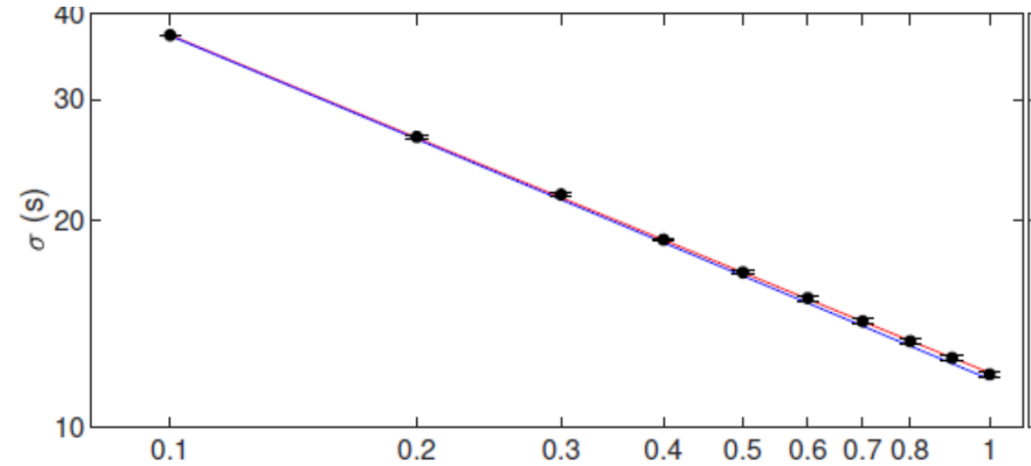
Standard Deviation of the travel-time differences

Signal

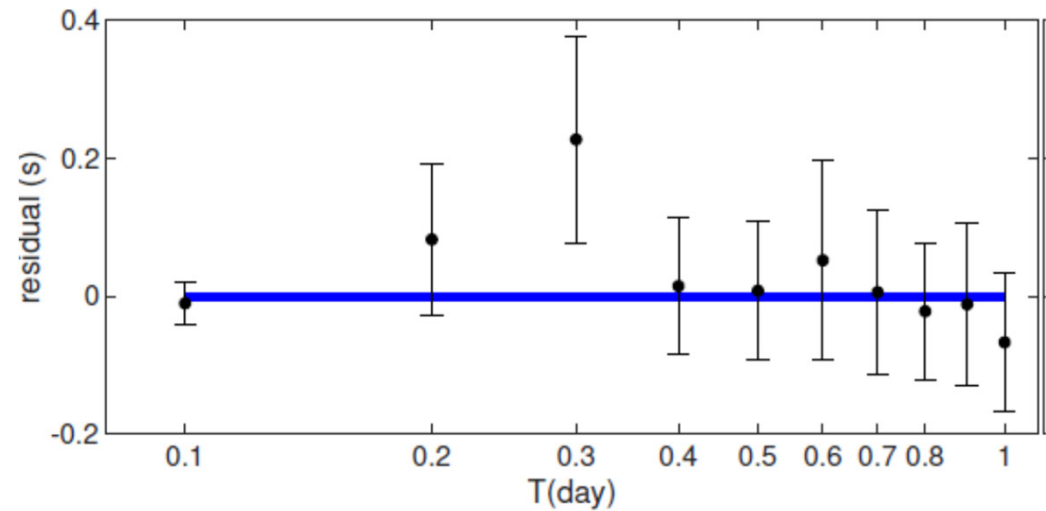
Averaging Duration

Noise

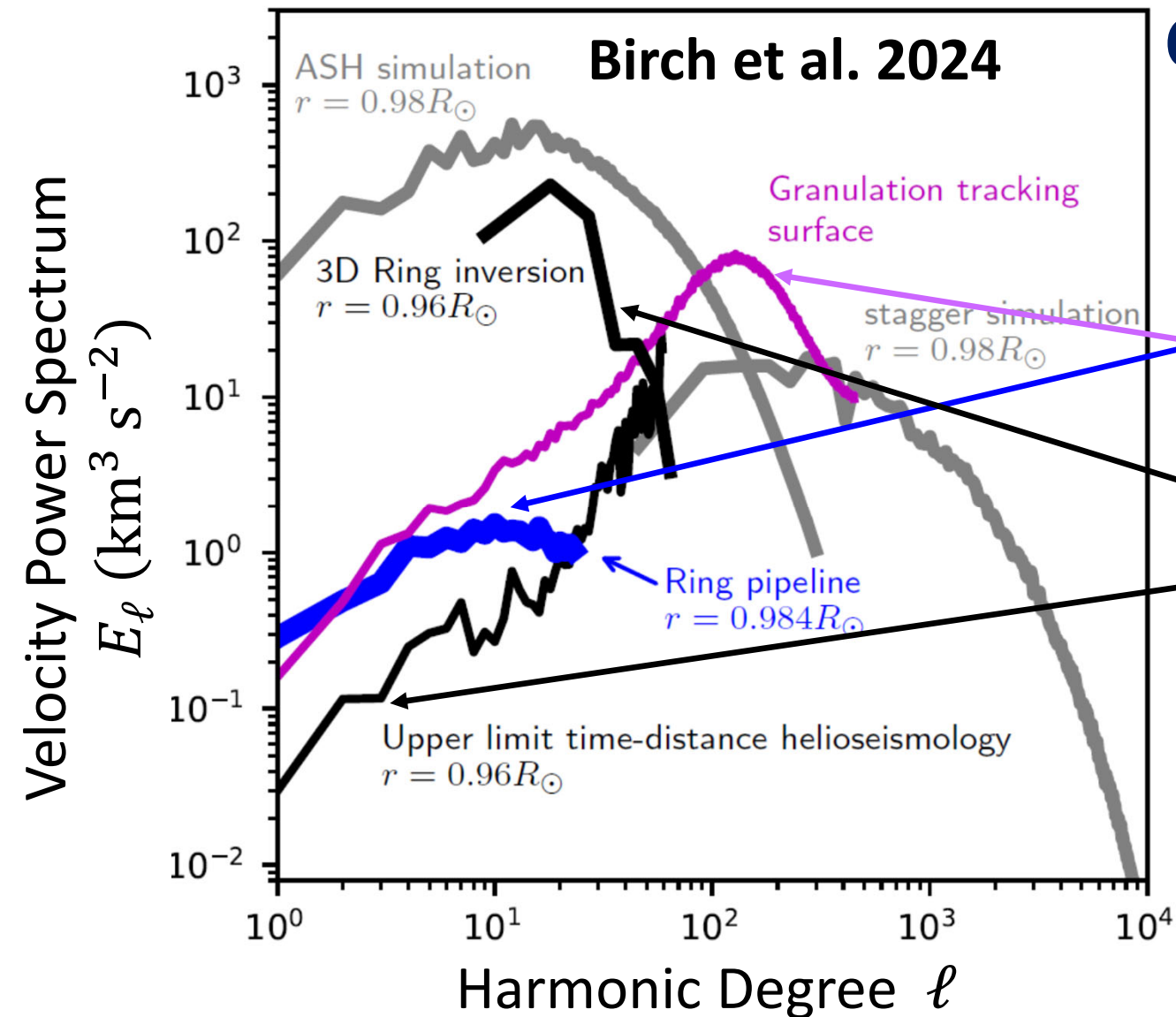
$$\frac{S}{N} \sim 0.2$$



Variance of the Velocity Field



Convective Spectrum of the Sun



Proxauf et al. 2021

Greer et al. 2015

Hanasoge et al. 2012

After performing a careful comparison which

- 1) homogenized definitions
- 2) fixed small errors

Observations still disagree

Outstanding Issues

Differential Rotation in the Convection Zone

- The models of Hotta et al. 2021,2022 do a fine job of reproducing the Sun's differential rotation profile
 - Can these results be reproduced in models with a different diffusion scheme?
 - Is magnetism truly necessary to restructure the meridional circulation in a fruitful way? (Geostrophic turbulence?)
 - The convective spectrum is still wrong – the surface amplitude is still too large.
- Where is the latitudinal temperature gradient expected from thermal wind balance?
 - Perhaps the balance fails in the Near-Surface Shear Layer?
 - . . . or in the radiative boundary layer?

