

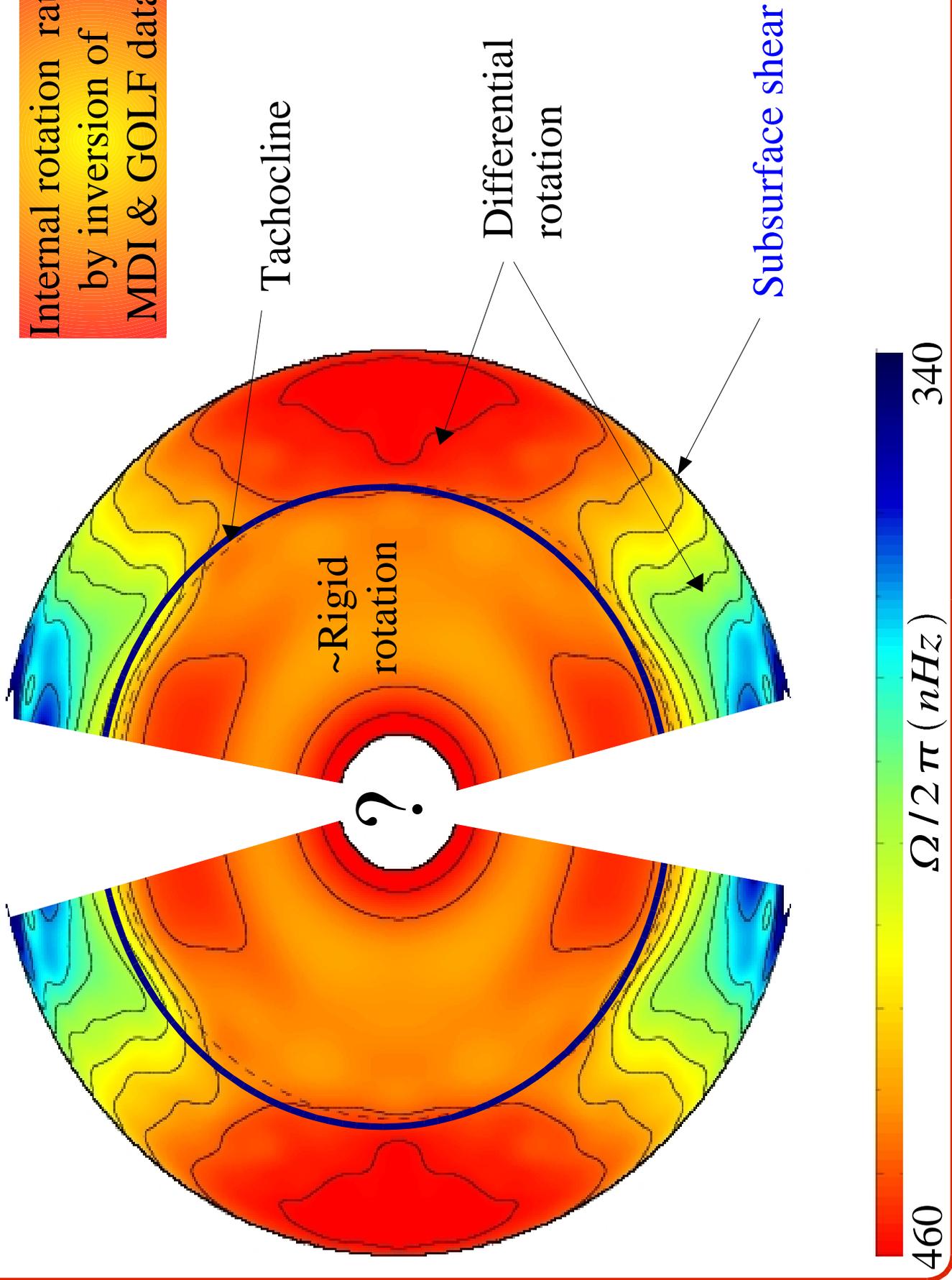
New constraints on the dynamics of the solar sub-photospheric layers from high resolution helioseismology:

The sub-photospheric radial shear

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- ◆ Interest and limitation of previous measurements (Surface feature tracking / Global Helioseismology)
- ◆ The sub-surface radial shear from MDI f-modes observations.
- ◆ The First GONG synoptic flow map from ring-diagram analysis
- ◆ The sub-surface radial shear from GONG & MDI ring-diagram analysis

Internal rotation rate
by inversion of
MDI & GOLF data



The subsurface radial shear: interests

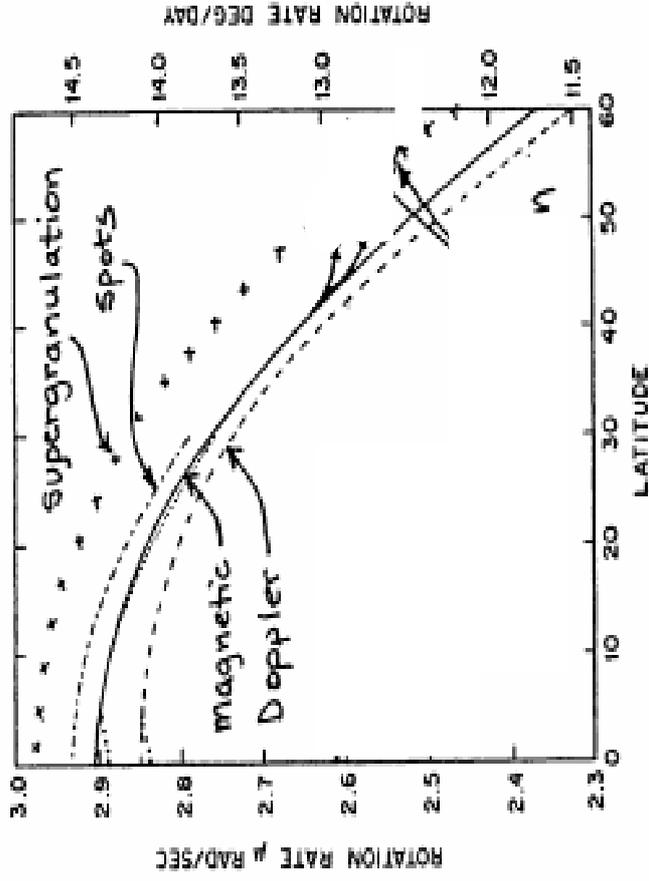
1) From dynamo theories

- > Original assumption of Babcock (1961) $d\Omega/dr > 0$
- > In order to match the observed patterns of activity $d\Omega/dr < 0$
(*Stix 1976, Gilman 1974*)
- > In most recent circulation dominated dynamo models $d\Omega/dr = 0$ at the surface (*Dikpati & Charbonneau 1999, Küker, Rüdiger & Schultz 2001*)

2) Supergranulation layer models and simulations

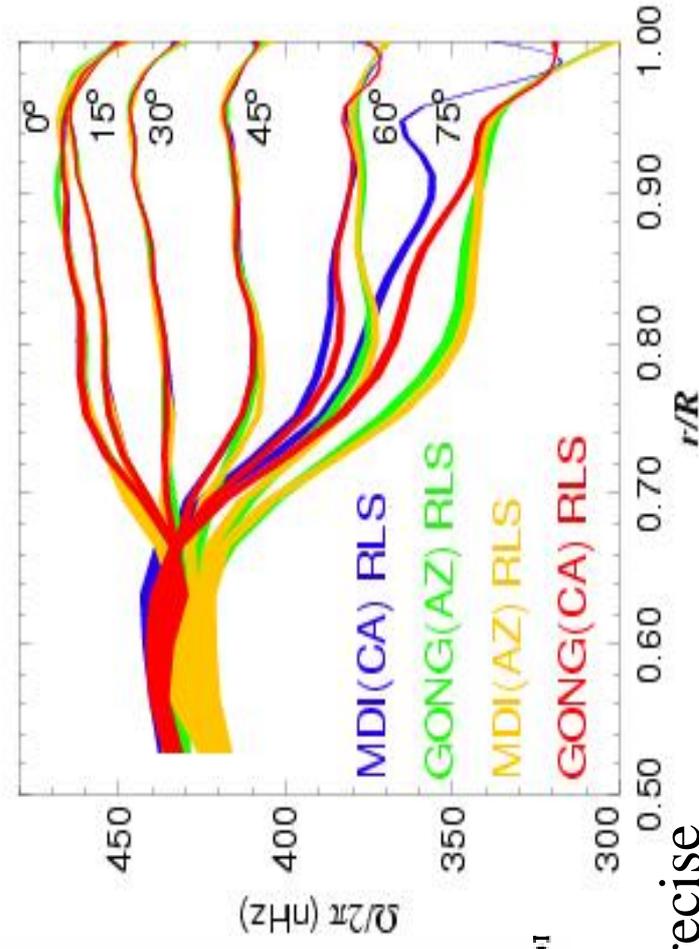
- > Conservation of angular momentum per unit mass $\sim \Omega r^2 \sin\theta$
 $\Rightarrow d\ln\Omega/d\ln r = -2$
(*Foukal and Jokipii, 1975, Gilman and Foukal, 1979*)
- > Numerical simulations in shallow spherical shells (0.94-0.98R)
(*DeRosa, Gilman, Toomre, 2002*)
outward transport by viscous diffusion $\Rightarrow d\ln\Omega/d\ln r \sim -1$

Previous measurements: surface features tracking and Global Helioseismology



Solar rotation profiles using various indicators

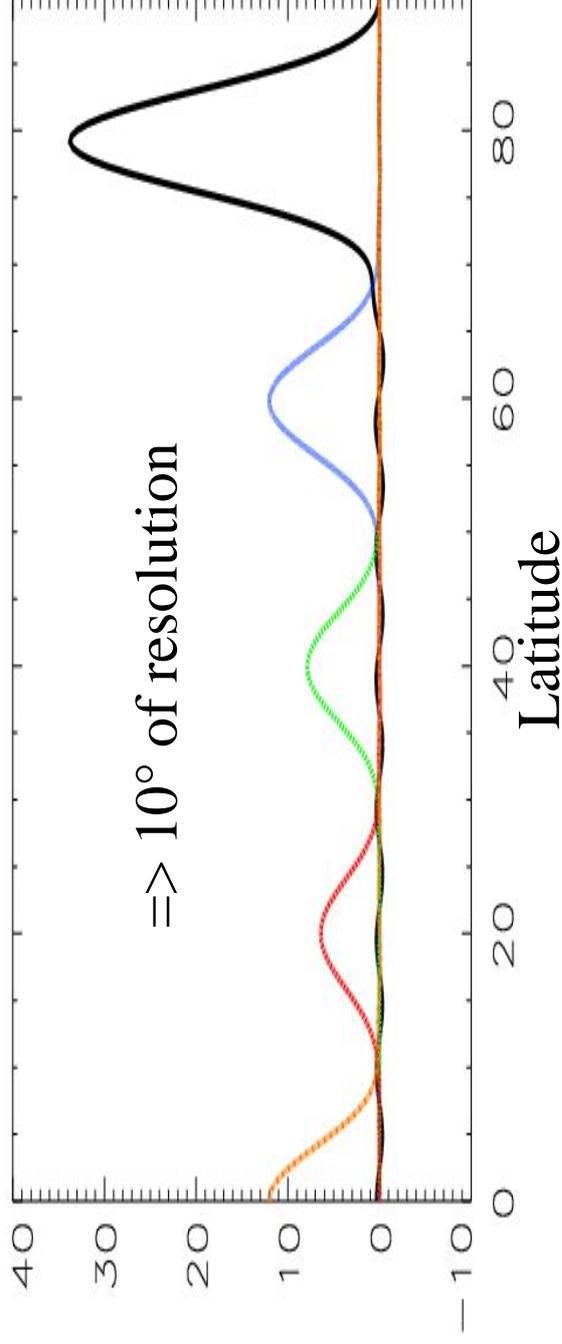
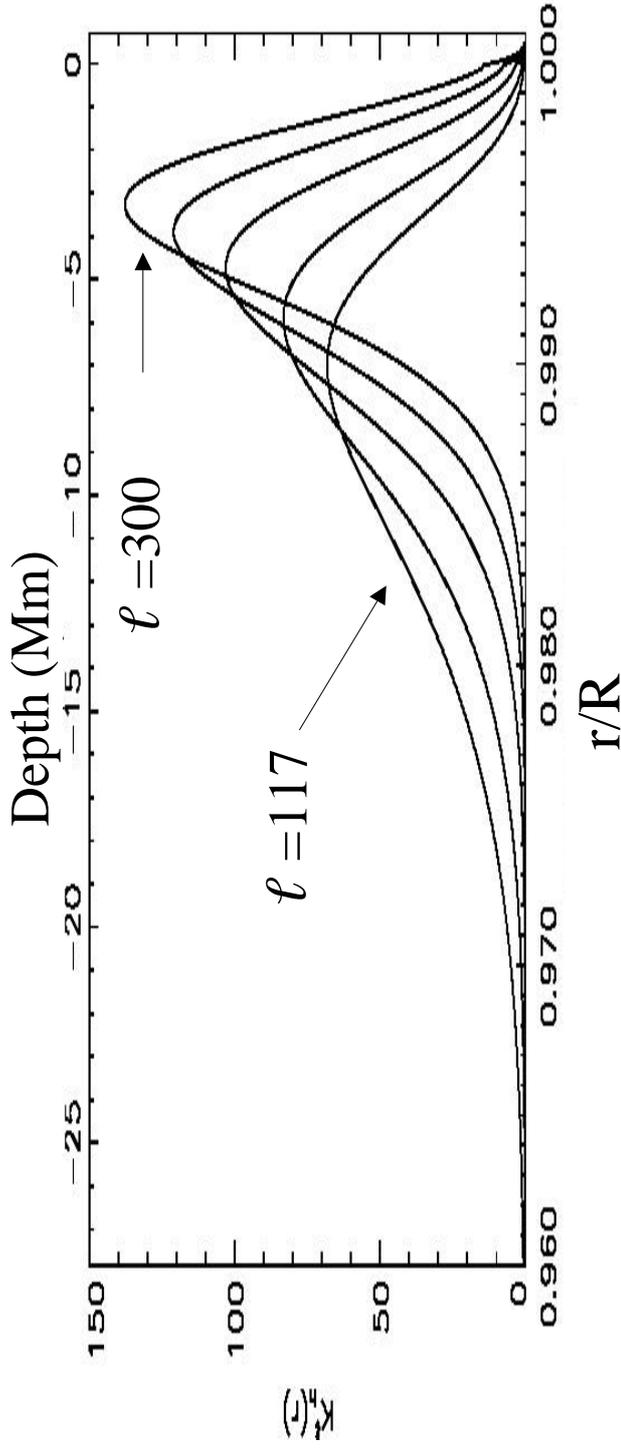
=> Maximum near 0.95R but no precise value for the radial gradient and its latitudinal dependence



Schou et al. 2002

**THE SURFACE LAYERS FROM
MDI f-MODES OBSERVATIONS**

MDI f-modes



Surface radial gradient as a function of latitude

Angular momentum

$$\sim \Omega r^2$$

Conservation in the supergranulation layer

would imply

$$d \ln \Omega / d \ln r = -2$$

Gradient Sign

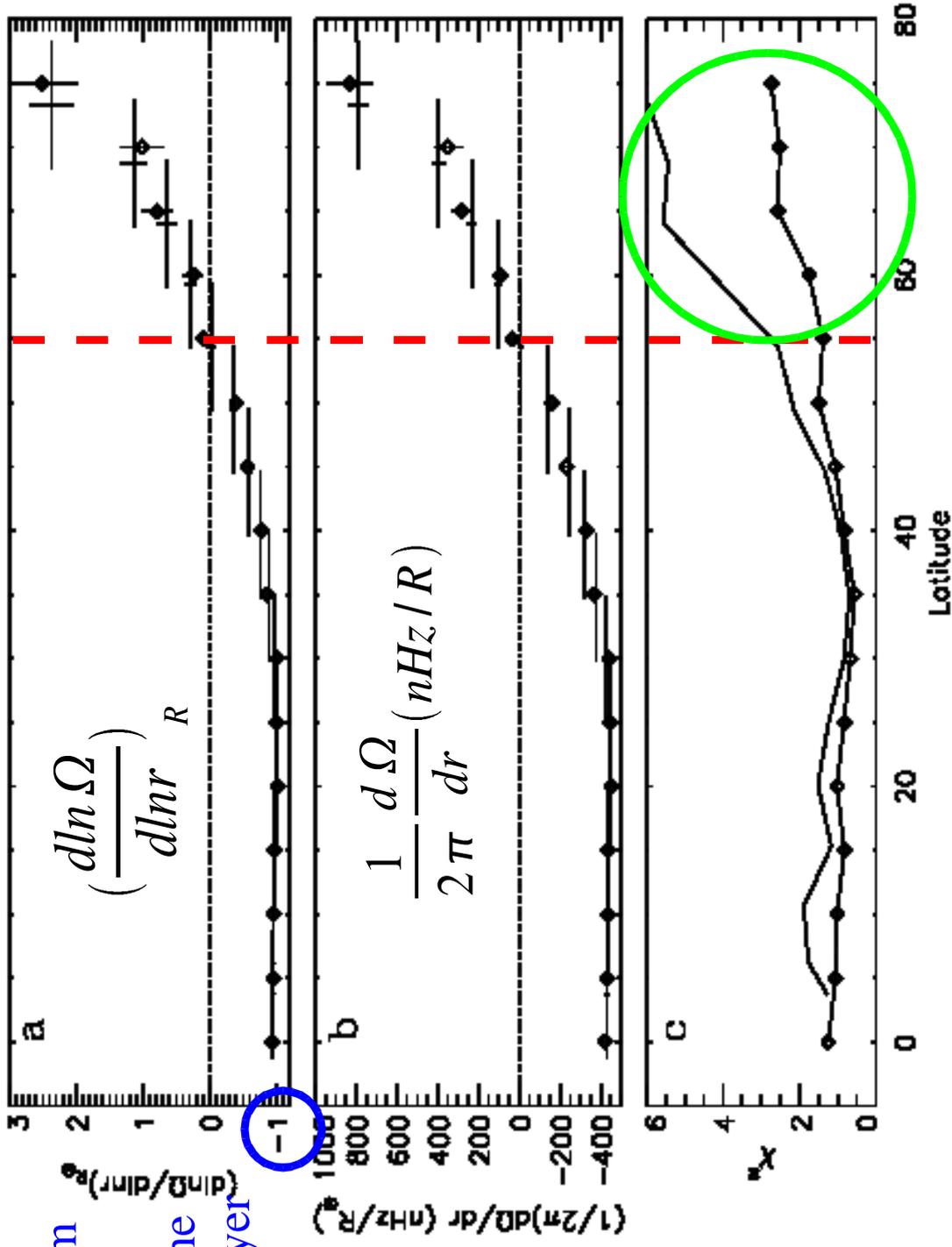
reversal at

55° of

latitude

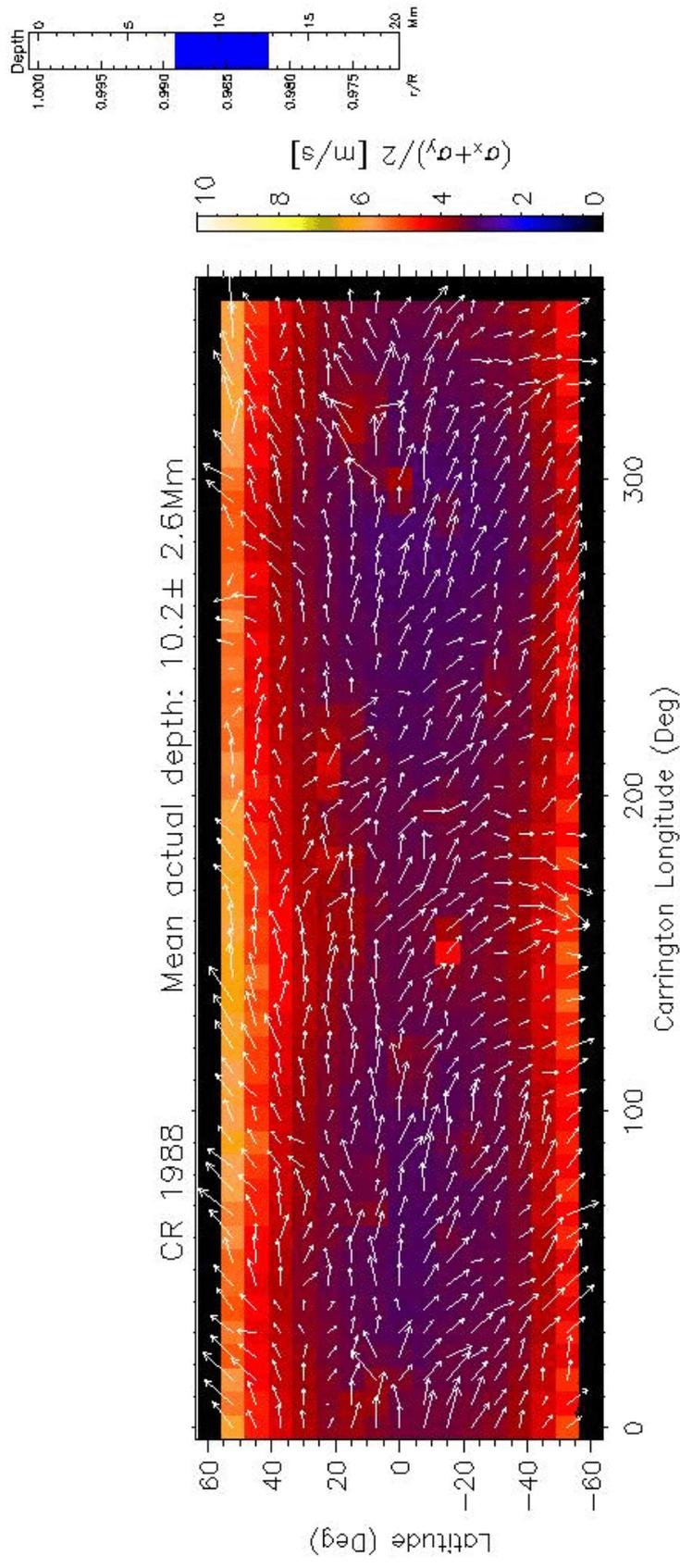
• $\chi^2 > 2$ above

65°

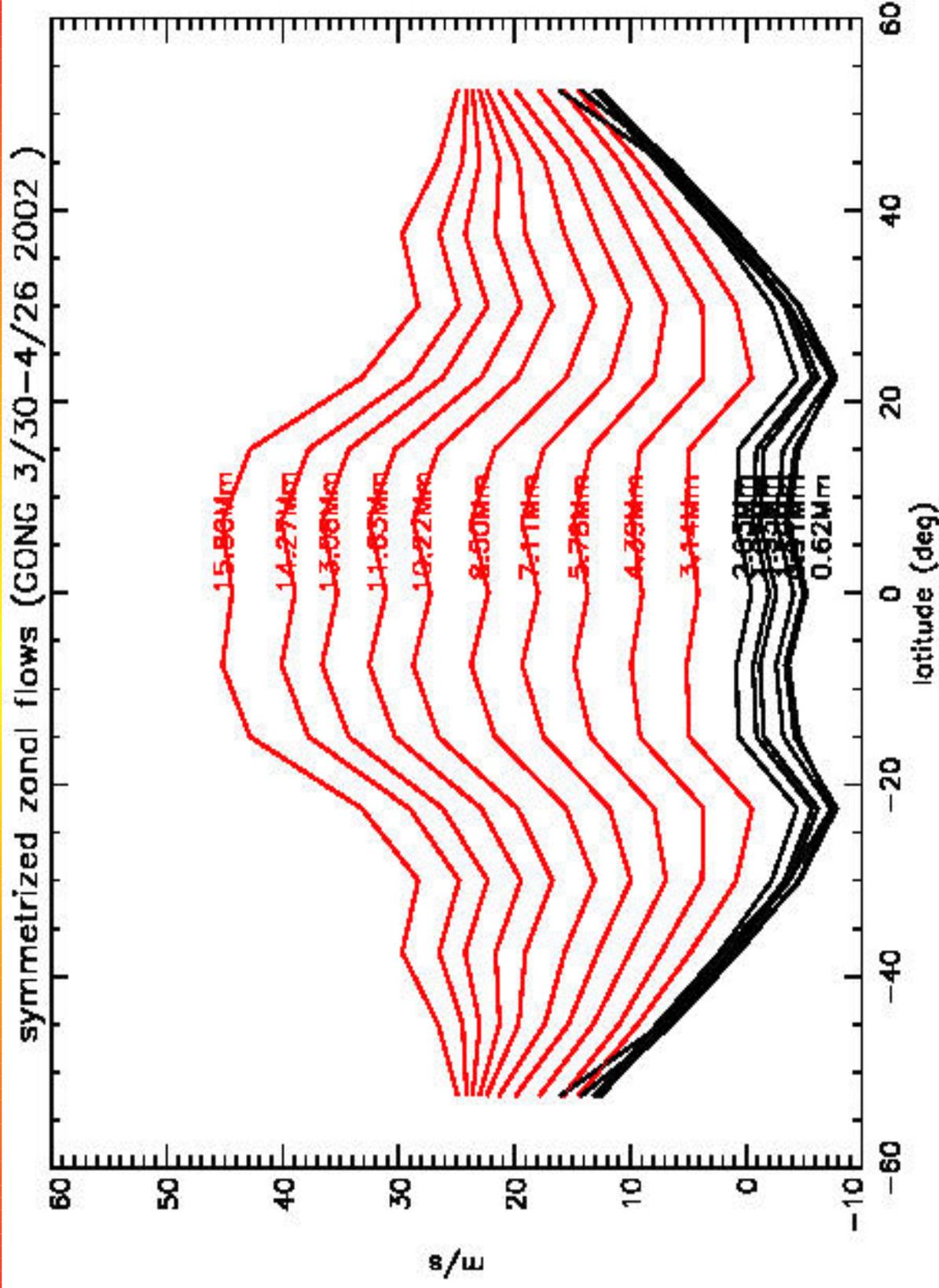


**SUB-PHOTOSPHERIC FLOW MAPS
FROM RING DIAGRAM ANALYSIS**

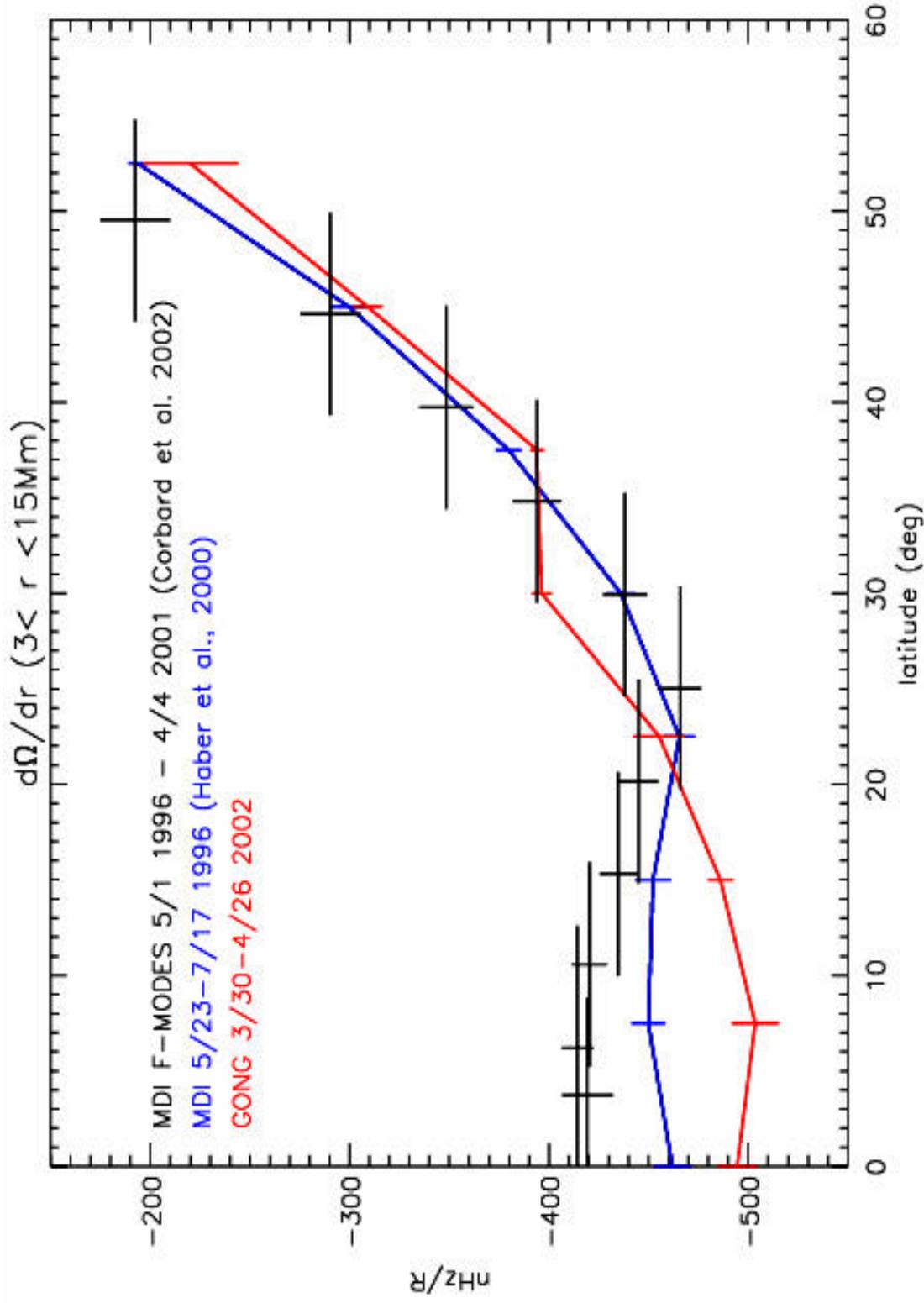
First GONG synoptic flow maps



Mean zonal flow CR 1988



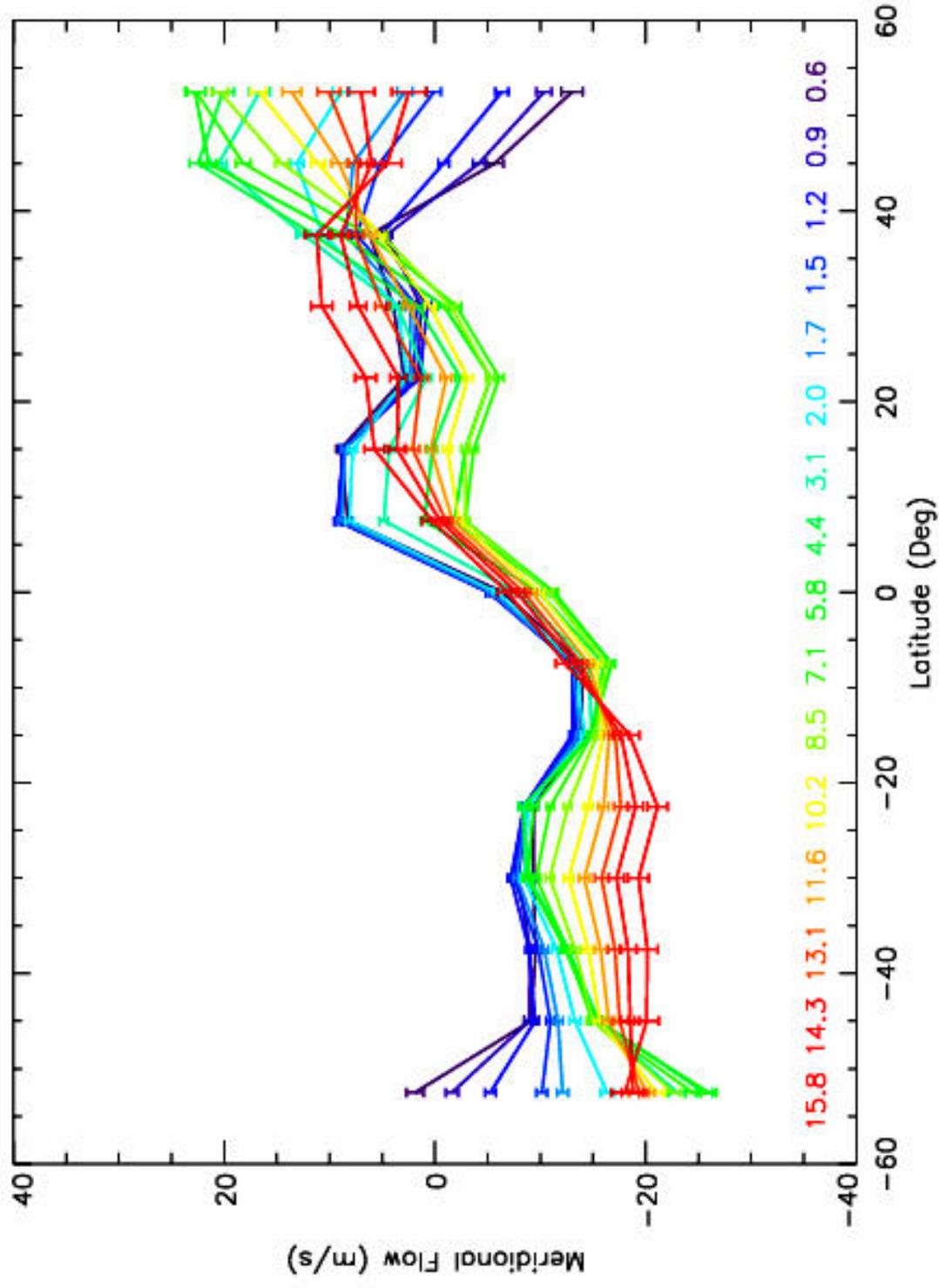
Subsurface radial shear



Conclusion

- ➡ At low latitude ($<40^\circ$) the negative gradient ~ 400 to 500 nHz/R is a robust feature and is such that $d\ln\Omega/d\ln r$ is close to -1
 - \Rightarrow it is compatible with the current numerical simulation of the supergranulation.
- ➡ There is a strong evidence for a different behavior at low and high latitudes (positive gradient above 55 degree ?)
 - \Rightarrow Are surface plasma rates or ring diagram analysis reliable above 55° ? Are f-modes $l > 250$ splittings reliable ?
- ➡ Implication for the dynamo theories ? (Dikpati, Corbard, Thompson & Gilman 2002)
 - \Rightarrow The surface radial shear can contribute to the production of toroidal fields but we can not close a dynamo loop directly in the near-surface layer.
- ➡ The GONG synoptic flow maps that are now available are new important diagnostic tools, giving not only the symmetric part of zonal flows but also N/S components, the meridional circulation, correlation with magnetograms.

Meridional Flows



Synoptic Flow Map + Magnetograms

