

Detecting solar-like
differential rotation
by
Doppler imaging ?

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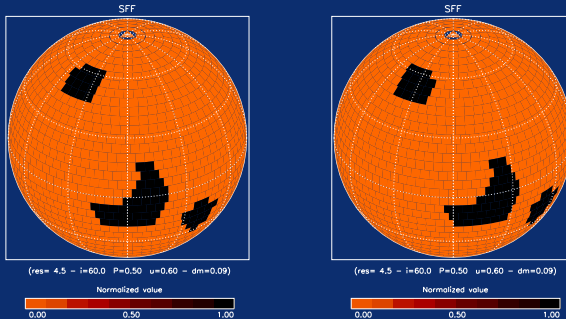
Hamburger Sternwarte

Almhütte January 2001

Outline

- I. Sunspots \approx Starspots ?
- II. Solar Differential Rotation
- III. Stellar Surface Differential Rotation
- IV. Doppler Imaging
- V. APPENDIX

Detecting solar-like differential rotation by Doppler imaging ?

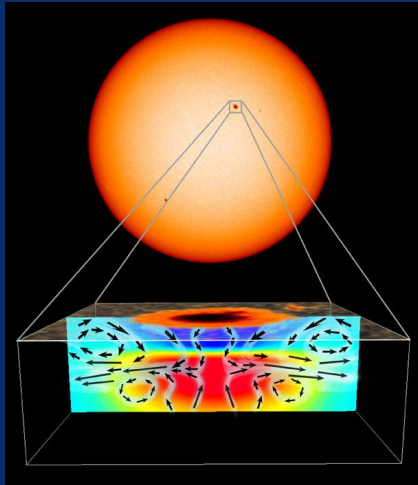


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I. Sunspots \approx Starspots ?

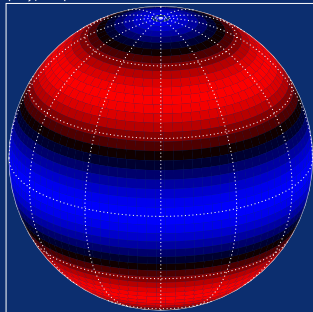
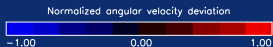
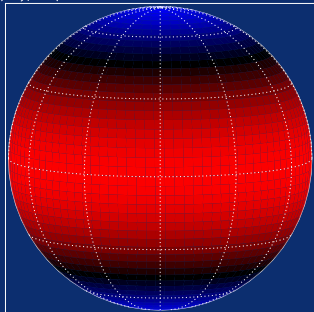


Zhao et al 2001, Hurlburt & Rucklidge 2000

II. Solar Differential Rotation

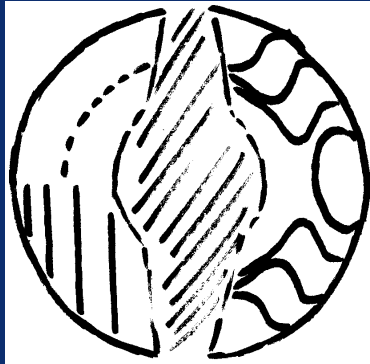
Why not ?

$\cos^2(\theta)$ -type (res= 3.6 - i=83.0 P=0.00 u=0.00 - dm=do6) $2(2+\theta)$ -type (res= 3.6 - i=67.5 P=0.00 u=0.00 - dm= Inf)



Surface rotation laws

Solar Differential Rotation I



Some conceivable patterns
of solar interior rotation

Solar Differential Rotation II



No rigid rotation (Biermann 1951)

Solar Differential Rotation III



No isorotation-cylinders
(eg. Schou et al 1998)

Solar Differential Rotation IV

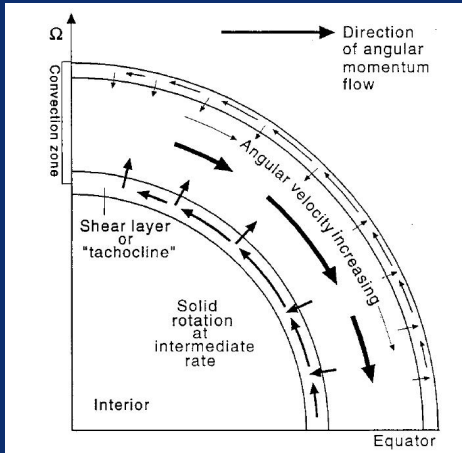
How ?

Solar Differential Rotation V

It's impossible to ignore the details.

(William Blake, freely adapted)

Dynamic equilibrium of angular momentum



Net angular momentum flow
in the SCZ (Gilman 2000)

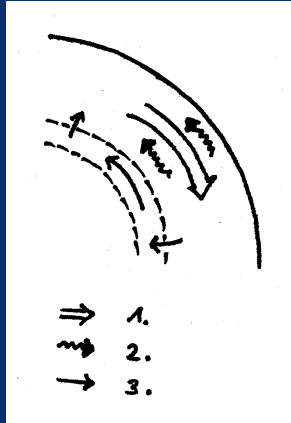
Conceivable angular momentum transporters in the SCZ (Solar Convection Zone)

- Reynolds stresses
(turbulent viscosity / giant cell convection)
- Maxwell stresses
- Meridional circulations
- Wave motions (gravity / Alfvén)

Main angular momentum transporters in the bulk of the SCZ

- ✓ Reynolds stresses
(turbulent viscosity / giant cell convection)
- ✗ Maxwell stresses
- ✓ Meridional circulations
- ✗ Wave motions (gravity / Alfvén)

One Scenario ...

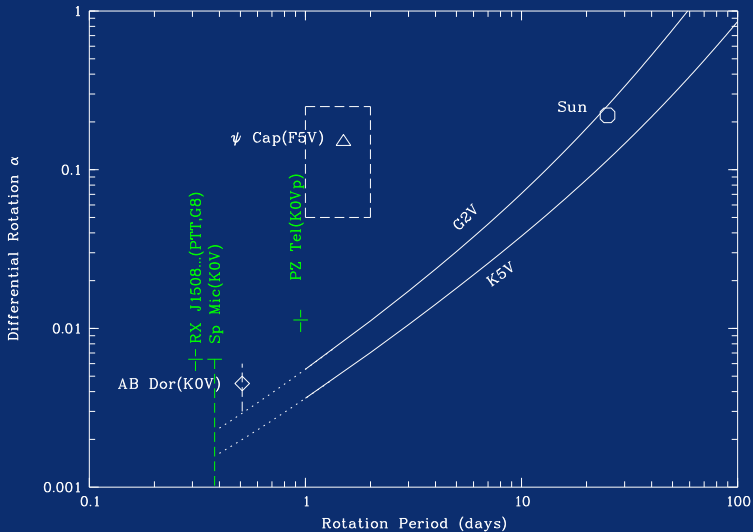


... of angular momentum transport in the SCZ
(based on Kitchatinov & Rüdiger 1995)

III. Stellar Surface Differential Rotation

?

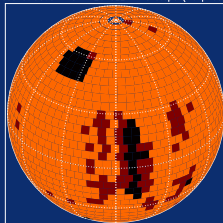
Stellar Surface Differential Rotation I



(based on Kitchatinov & Rüdiger 1999)

IV. Doppler Imaging

Reconstruction from 20 CLEANlike steps (40 phases)

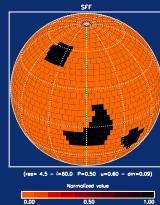
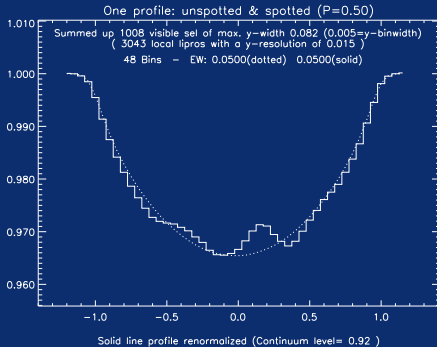


(res= 4.5 - i=60.0 P=0.50 u=0.60 - dm= lat)

Normalized value

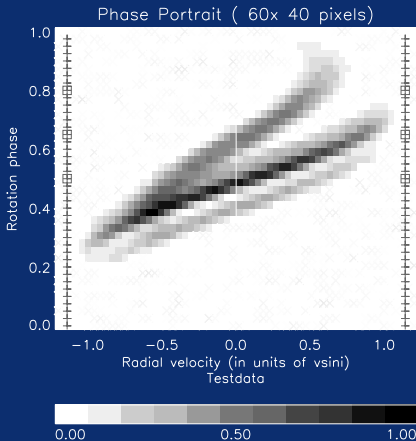


DI: Basic Idea I

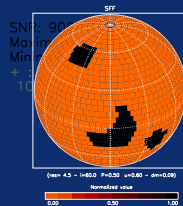


Line profile deformation: single phase

DI: Basic Idea II



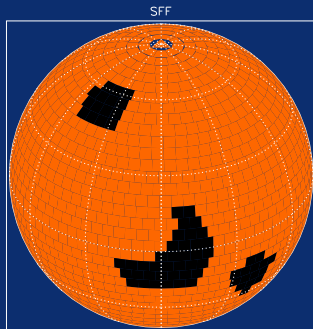
Inclination: 60.0
Limbdarkng: 0.60



Line profile deformations: time-series



CLDI: Current status & limitations

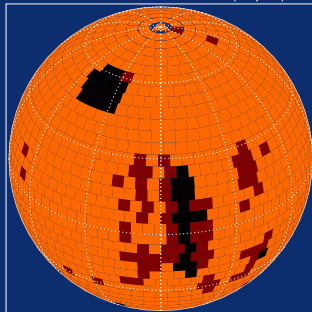


(res= 4.5 - i=60.0 P=0.50 μ =0.60 - dm=0.09)

Normalized value



Reconstruction from 20 CLEANlike steps (40 phases)



(res= 4.5 - i=60.0 P=0.50 μ =0.60 - dm= Inf)

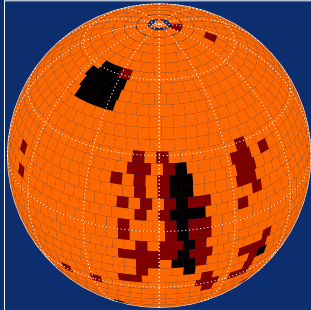
Normalized value



CLDI-reconstruction of favourable synthetic spectra

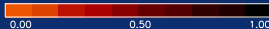
CLDI: Detecting Differential Rotation ?

Reconstruction from 20 CLEANlike steps (40 phases)

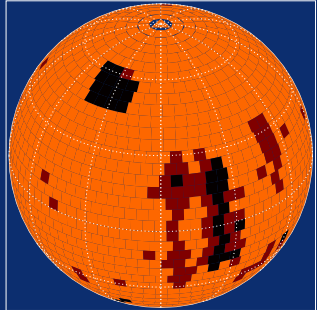


(res= 4.5 - i=60.0 P=0.50 u=0.60 - dm= Inf)

Normalized value



Reconstruction from 18 CLEANlike steps (40 phases)



(res= 4.5 - i=60.0 P=0.50 u=0.60 - dm= Inf)

Normalized value



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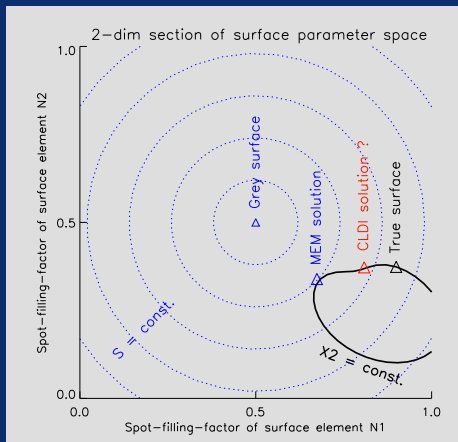
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- Detecting solar-like differential rotation
- Sunspots \approx Starspots ?
- Solar Differential Rotation
 - Why not ?
 - Solar Differential Rotation I
 - Solar Differential Rotation II
 - Solar Differential Rotation III
 - Solar Differential Rotation IV
 - Solar Differential Rotation V
 - Dynamic equilibrium of angular momentum
 - Conceivable angular momentum transporters in the SCZ (Solar Convection Zone)
 - Main angular momentum transporters
 - One Scenario ...
- Stellar Surface Differential Rotation
 - Stellar Surface Differential Rotation I
- Doppler Imaging
 - DI: Basic Idea I
 - DI: Basic Idea II
 - CLDI: Current status & limitations
 - CLDI: Detecting Differential Rotation ?
- APPENDIX
 - CLDI: Why ?
 - Sun: Surface differential rotation
 - Solar Interior: Rotation
 - Solar Model: Meridional Flow
 - Solar Model: Rotation laws

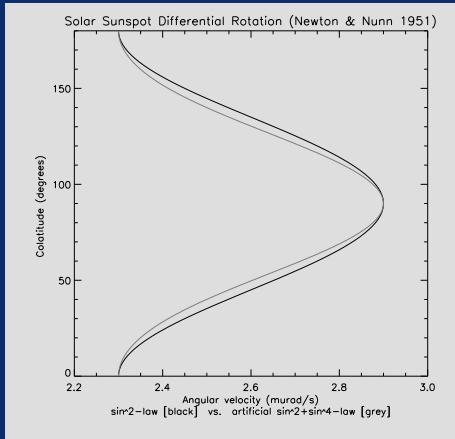
V. APPENDIX

CLDI: Why ?



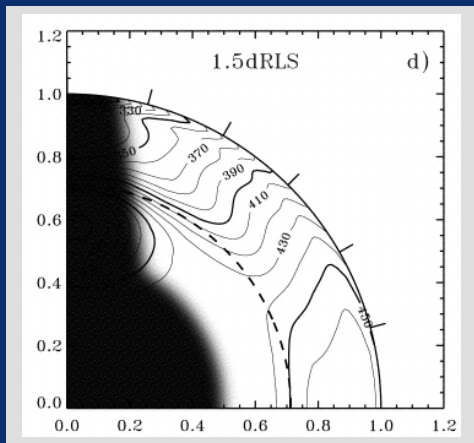
Different solutions for one measured time-series of spectra

Sun: Surface differential rotation



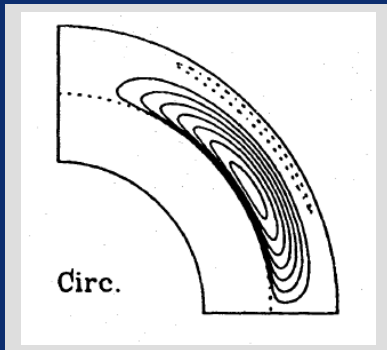
Angular velocity as function
of colatitude (extrapolated)

Solar Interior: Rotation



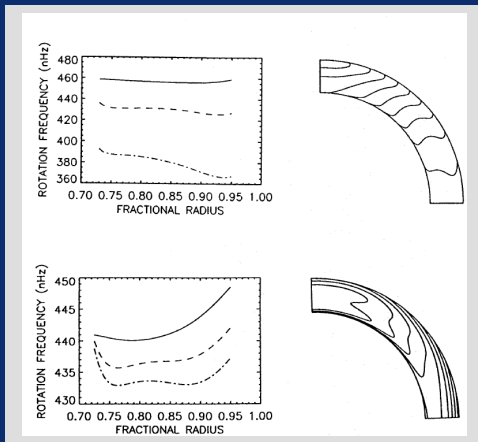
Inversion of helioseismic data (SOHO SOI-MDI)
Shaded area has no reliable information
(Fig. 3 of Schou et al. 1998)

Solar Model: Meridional Flow



Full lines mean anticlockwise circulation
(Fig. 1 of Kitchatinov & Rüdiger 1995)

Solar Model: Rotation laws



Top/Bottom: Including / ignoring thermodynamics
Computation is limited to the CZ
(Fig. 3 of Kitchatinov & Rüdiger 1995)