A Theoretical Model of the Near-Surface Shear Layer of the Sun

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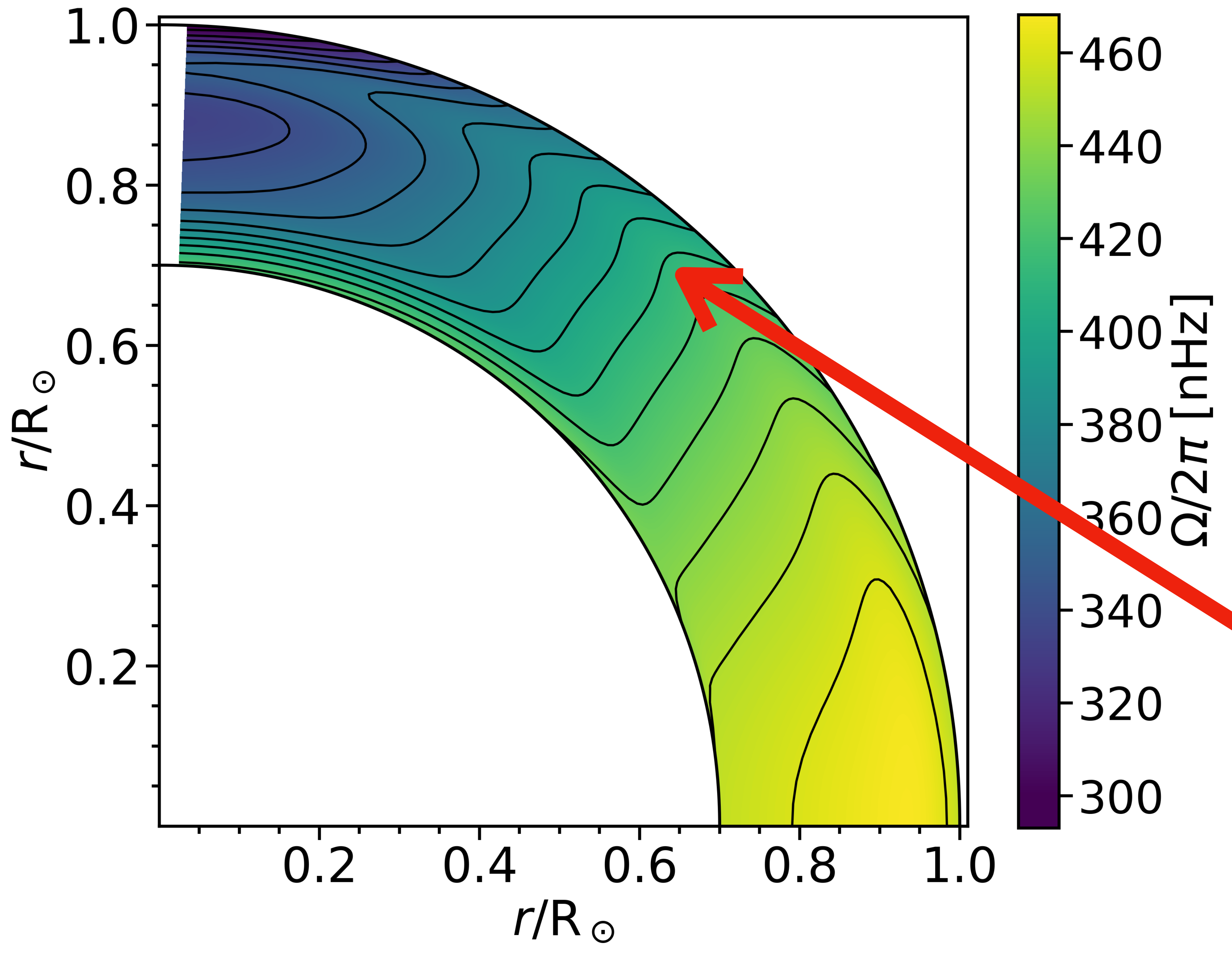
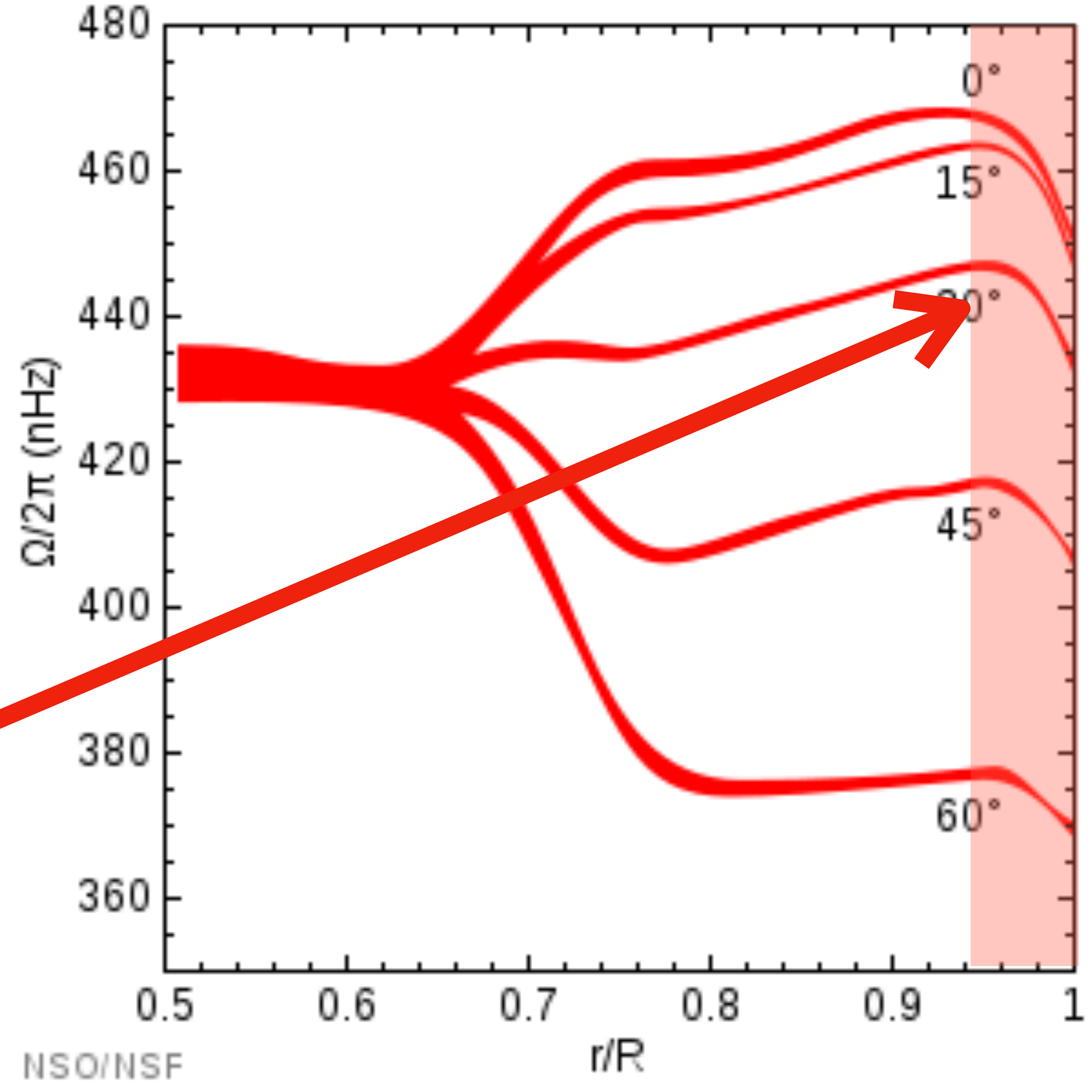
What is Near Surface Shear Layer (NSSL)?



Solar Rotation profile as measured from helioseismology

The sharp change in differential rotation profile near the photosphere is termed as NSSL

NSSL

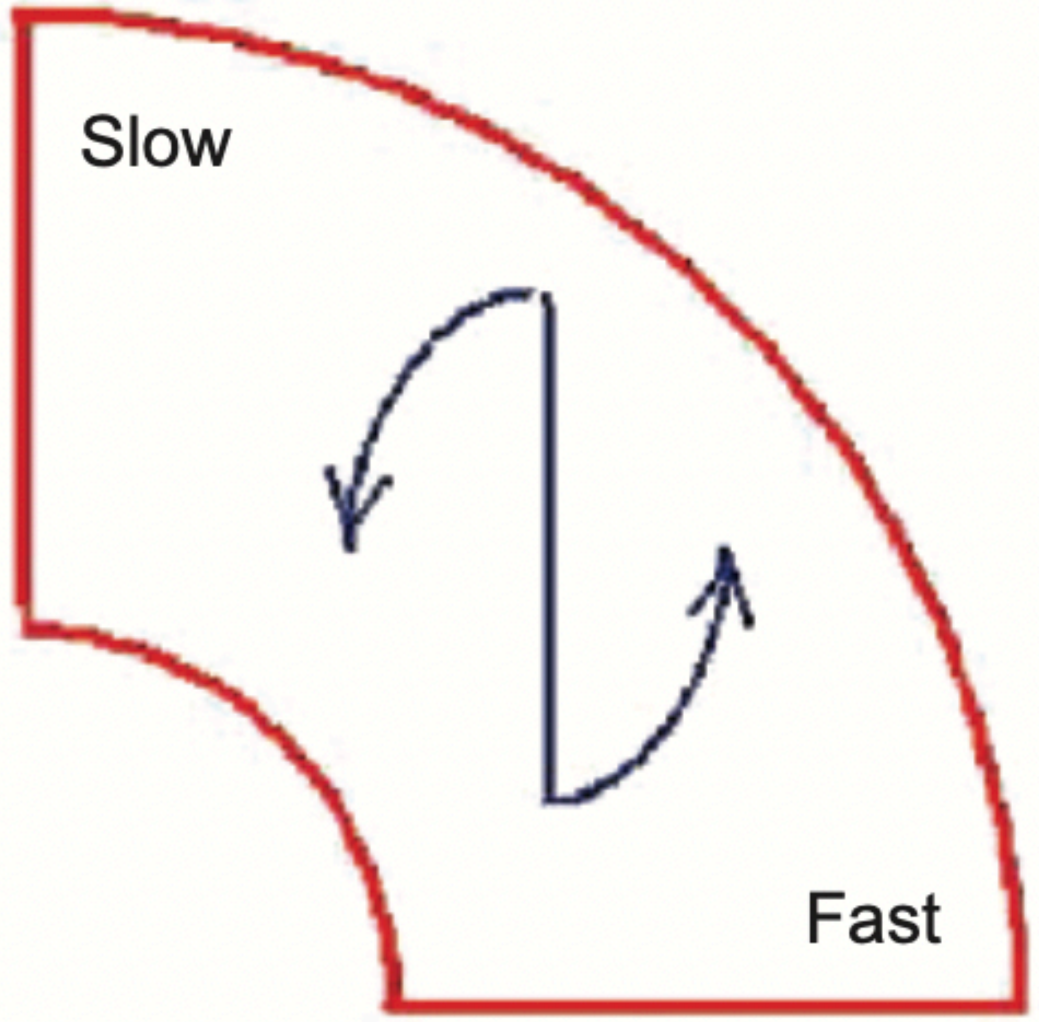


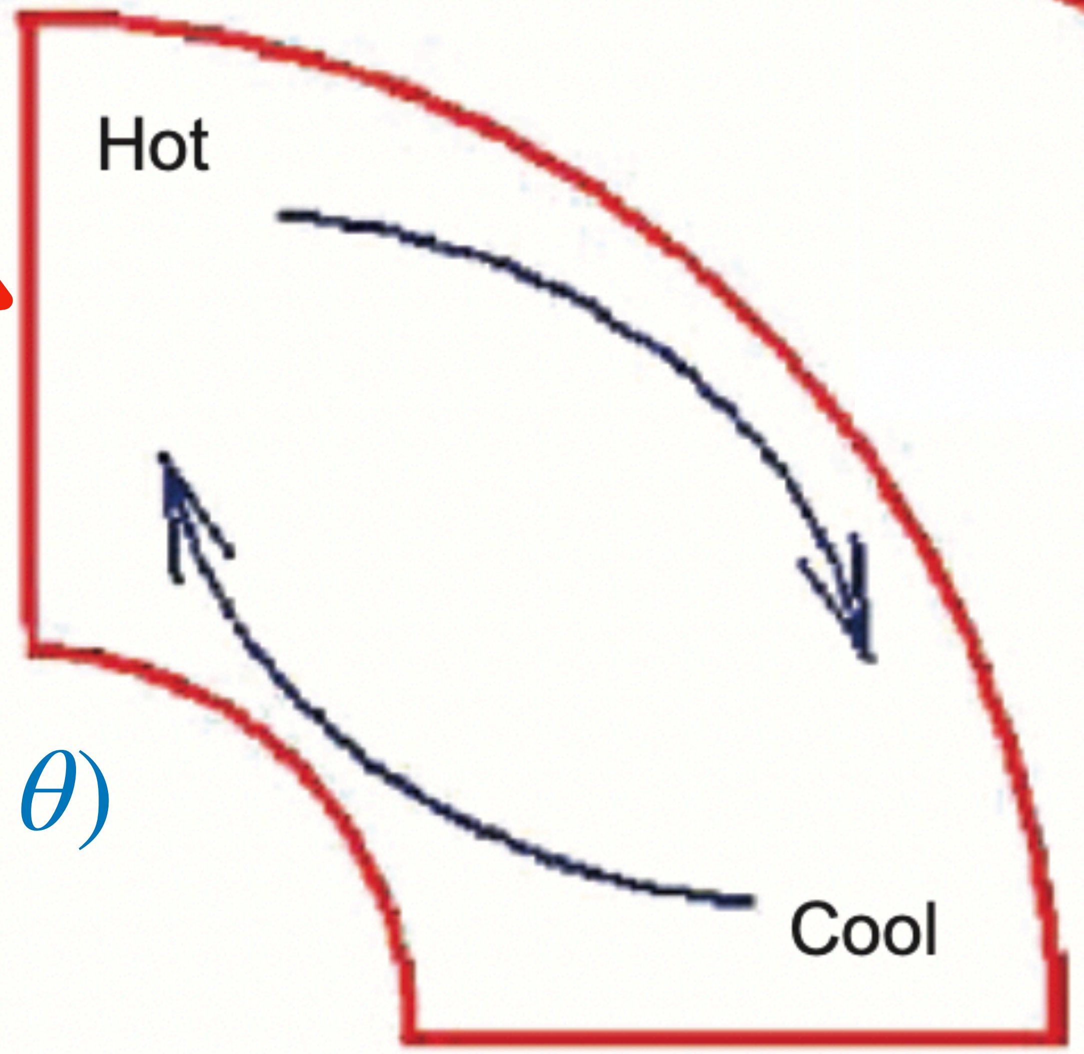
What is the Idea?

Thermal Wind Balance Equation (Choudhuri et al. ;2021)

$$r \sin\theta \frac{\partial}{\partial z}\Omega^2 = \frac{1}{r}\frac{g}{\gamma C_V}\frac{\partial S}{\partial \theta}$$

Centrifugal Term **Thermal Wind Term**





In case of ideal gas and isochoric surface

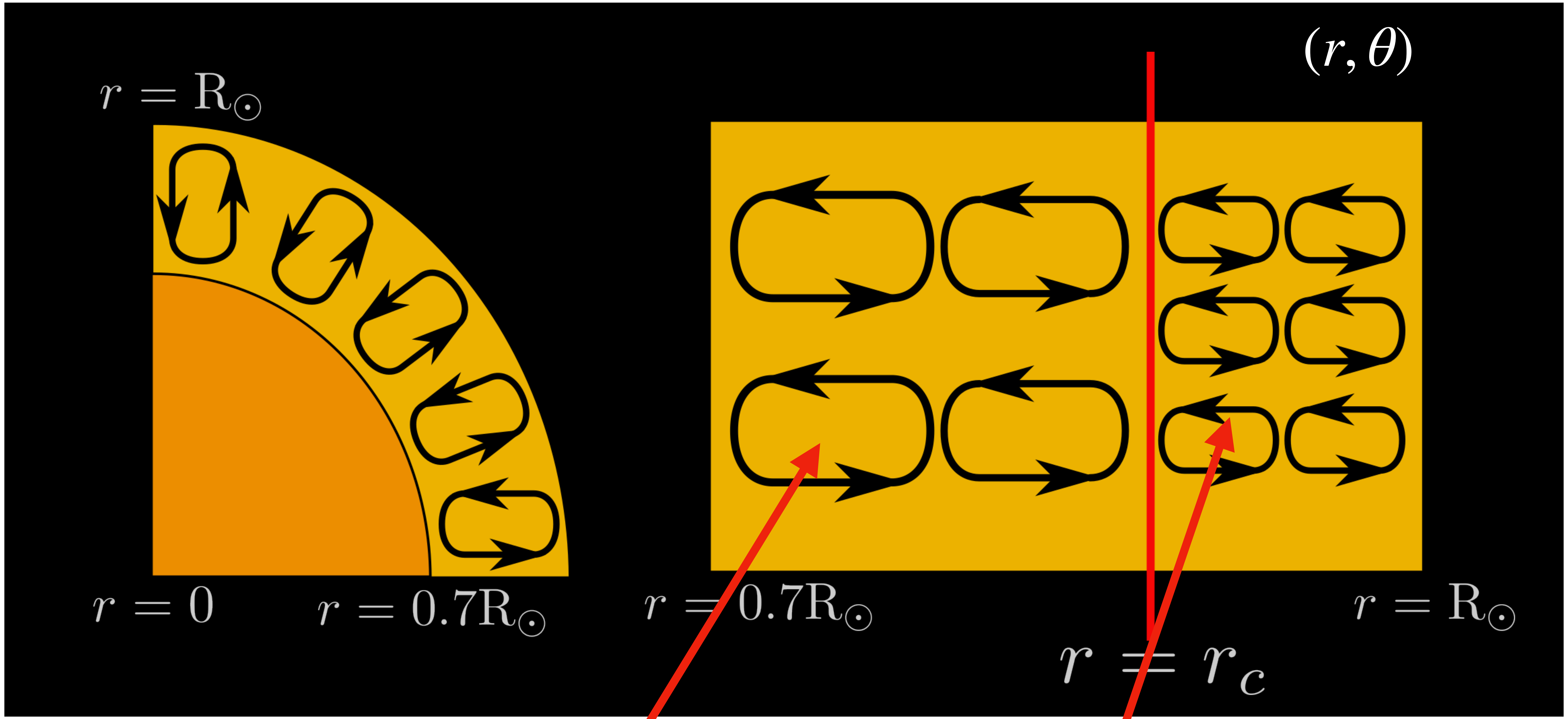
$$S = C_V \ln T - (\gamma - 1)\ln\rho + K \;\&\; T(r,\theta) = T(r,\theta=0) + \Delta T(r,\theta)$$

$$\implies \frac{\partial S}{\partial \theta} = C_V \frac{1}{T}\frac{\partial}{\partial \theta}\Delta T$$

$$r \sin\theta \frac{\partial}{\partial z}\Omega^2 = \frac{1}{r}\frac{g}{\gamma}\left(\frac{1}{T}\frac{\partial}{\partial \theta}\Delta T\right)$$

It is believed that this equation is not valid near the surface but we claimed that it is valid even near the surface !

Methodology

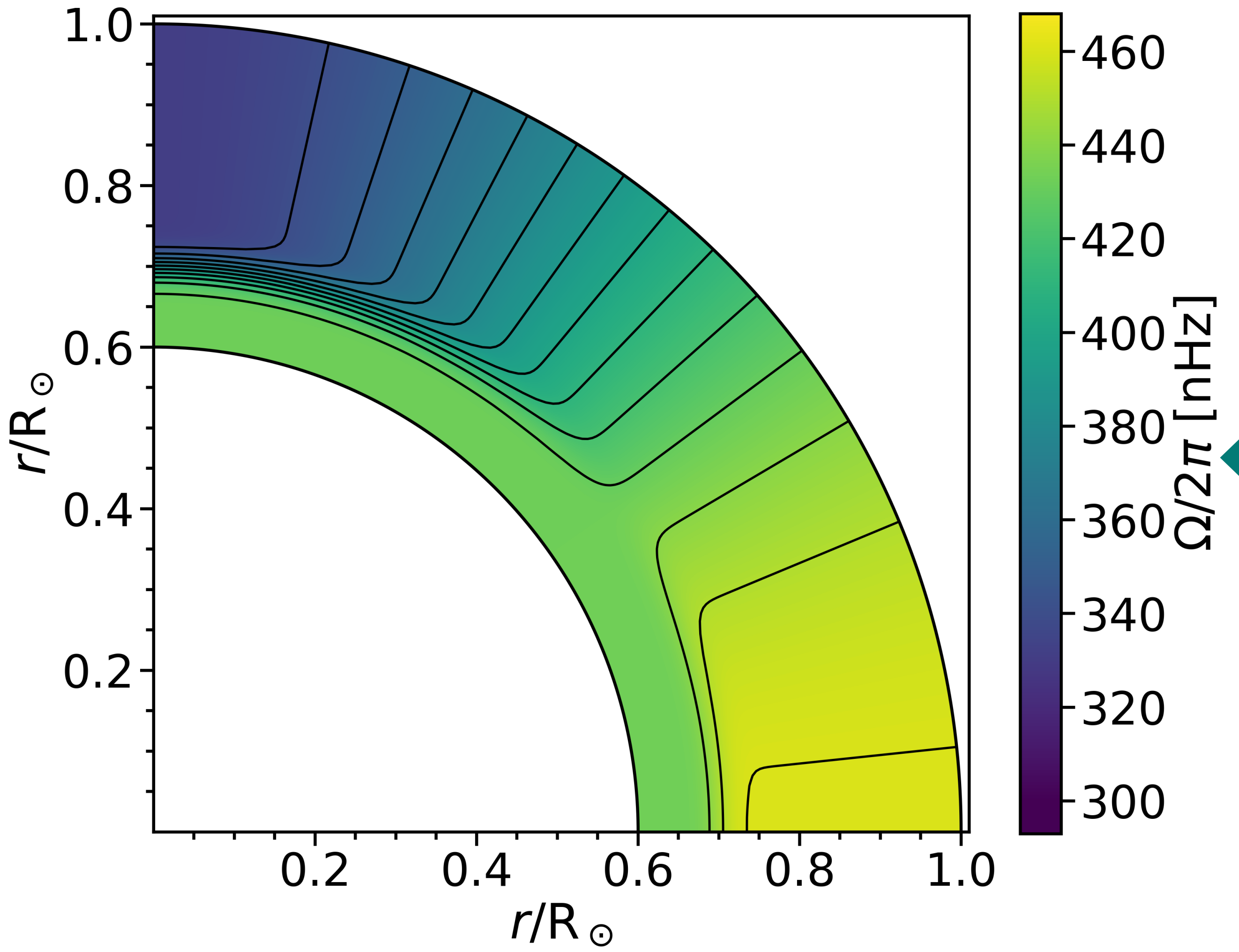


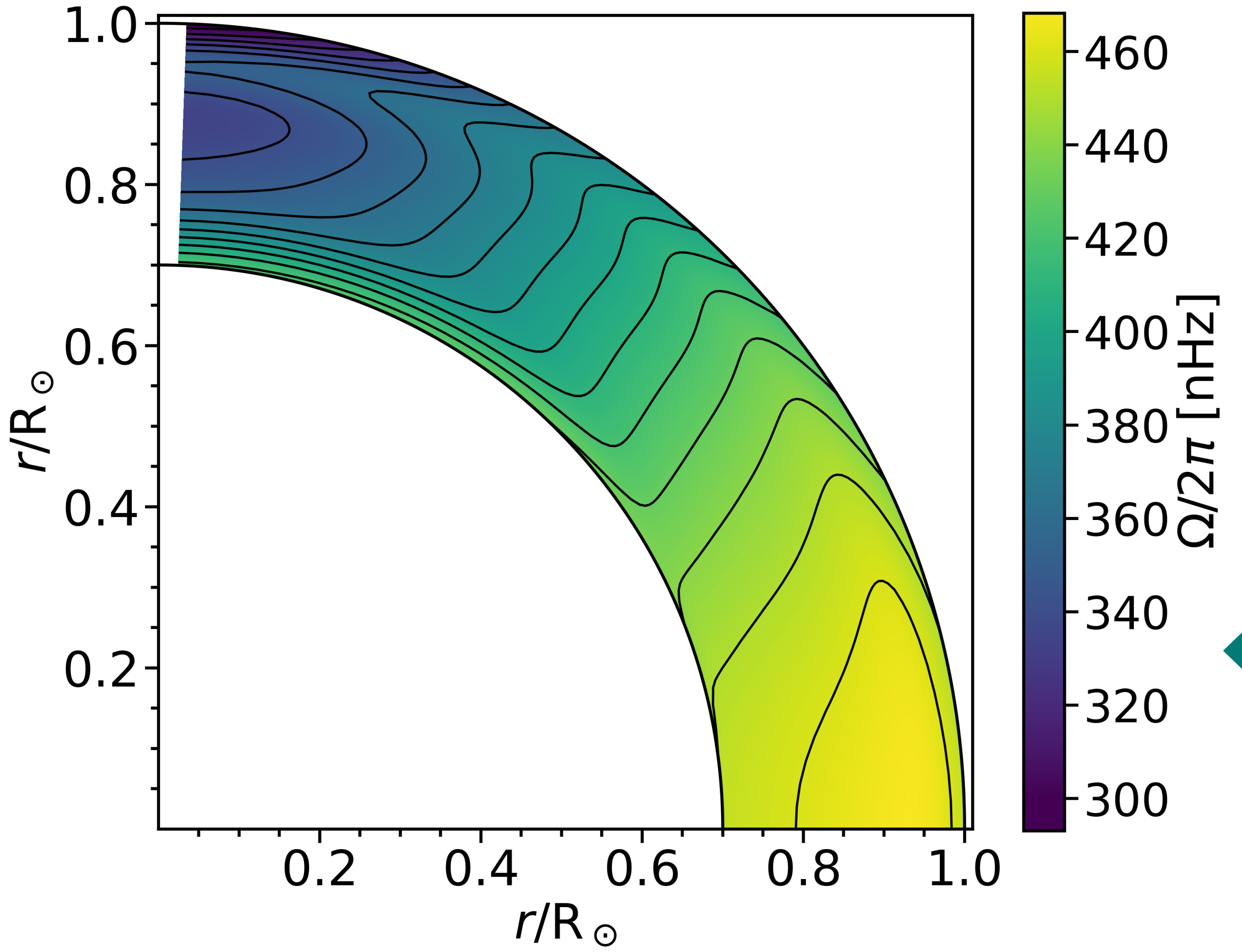
1. **Solve for ΔT for given Ω in $r < r_c$**

2. **Solve for Ω for given $\Delta T(r_c, \theta)$ in $r > r_c$**

$$\frac{1}{r}\frac{g}{\gamma}\left(\frac{1}{T}\frac{\partial}{\partial\theta}\Delta T\right) = r\sin\theta\frac{\partial}{\partial z}\Omega^2$$

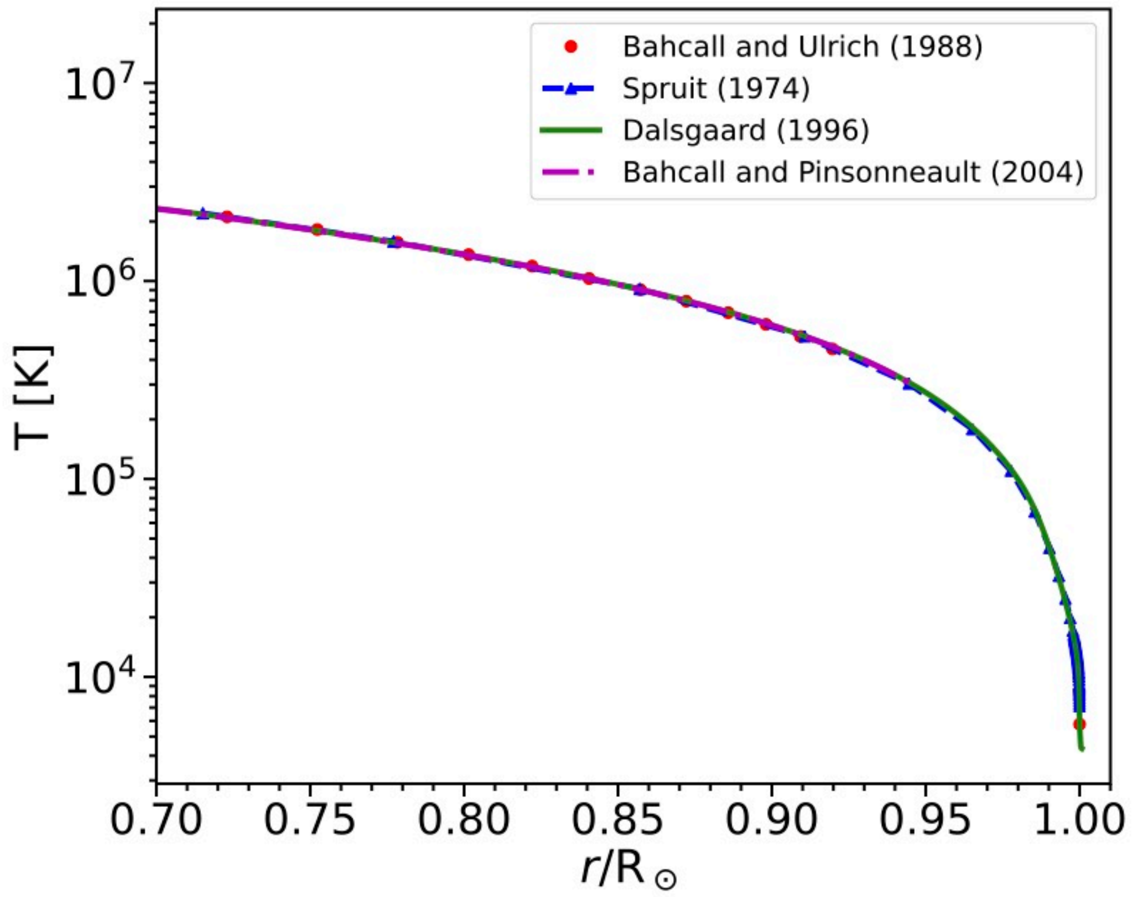
Ω based on Analytical Expression





Ω as Observed in Helioseismology

$T(r, \theta = 0)$



$$r \sin\theta \frac{\partial}{\partial z}\Omega^2 = \frac{1}{r}\frac{g}{\gamma}\left(\frac{1}{T}\frac{\partial}{\partial \theta}\Delta T\right)$$

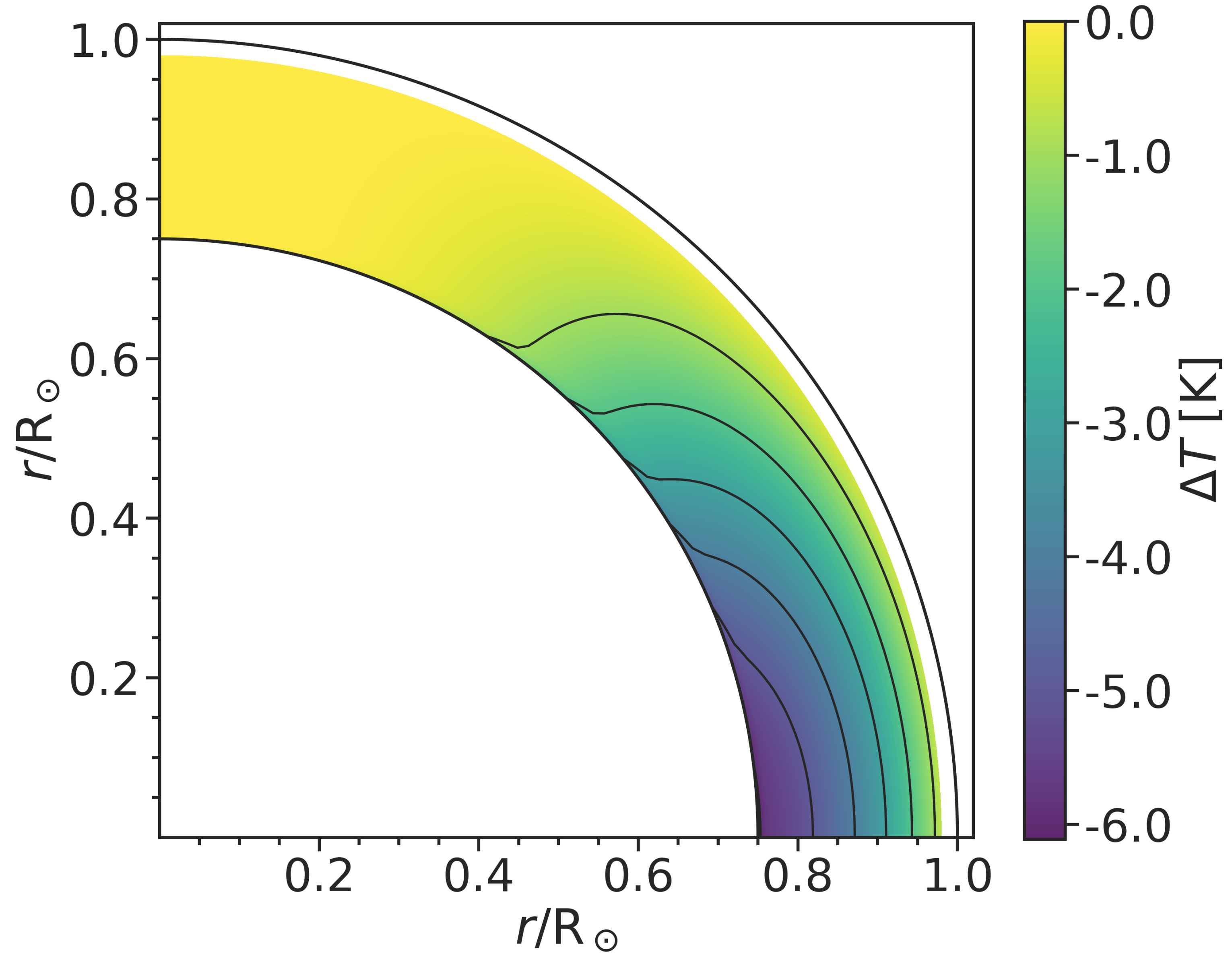
Thermal Wind Balance Equation

NSSL?

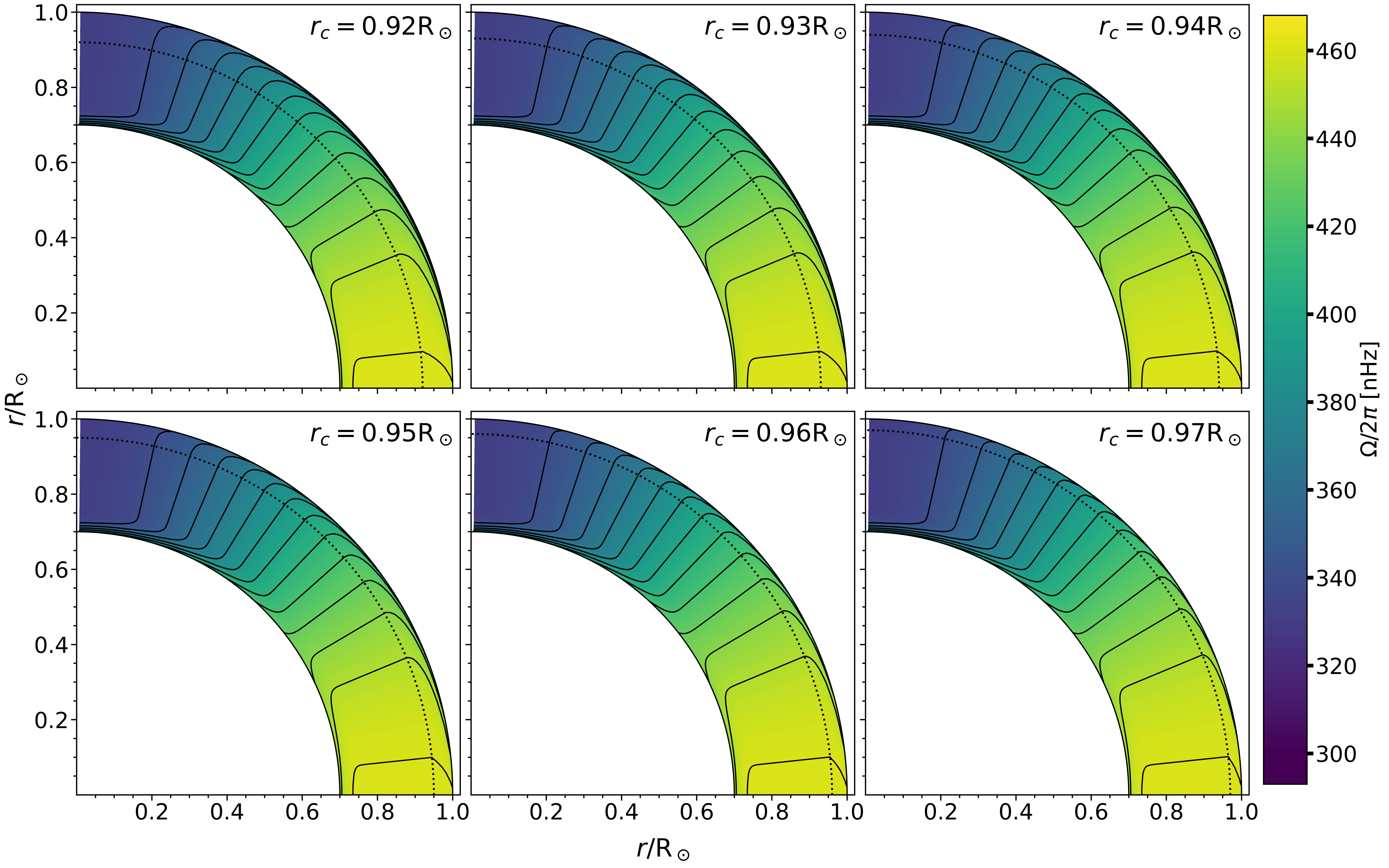
Inputs

- **Ω based on analytical expression which does not contain any signature of NSSL ((Schou et al. 1998; Charbonneau et al. 1999)**
- **Ω as observed in Helioseismology (Antia et al. ;1998, 2008)**
- **S-Model for temperature (Dalsgaard, 1996)**

NSSL Based on Analytical Expression



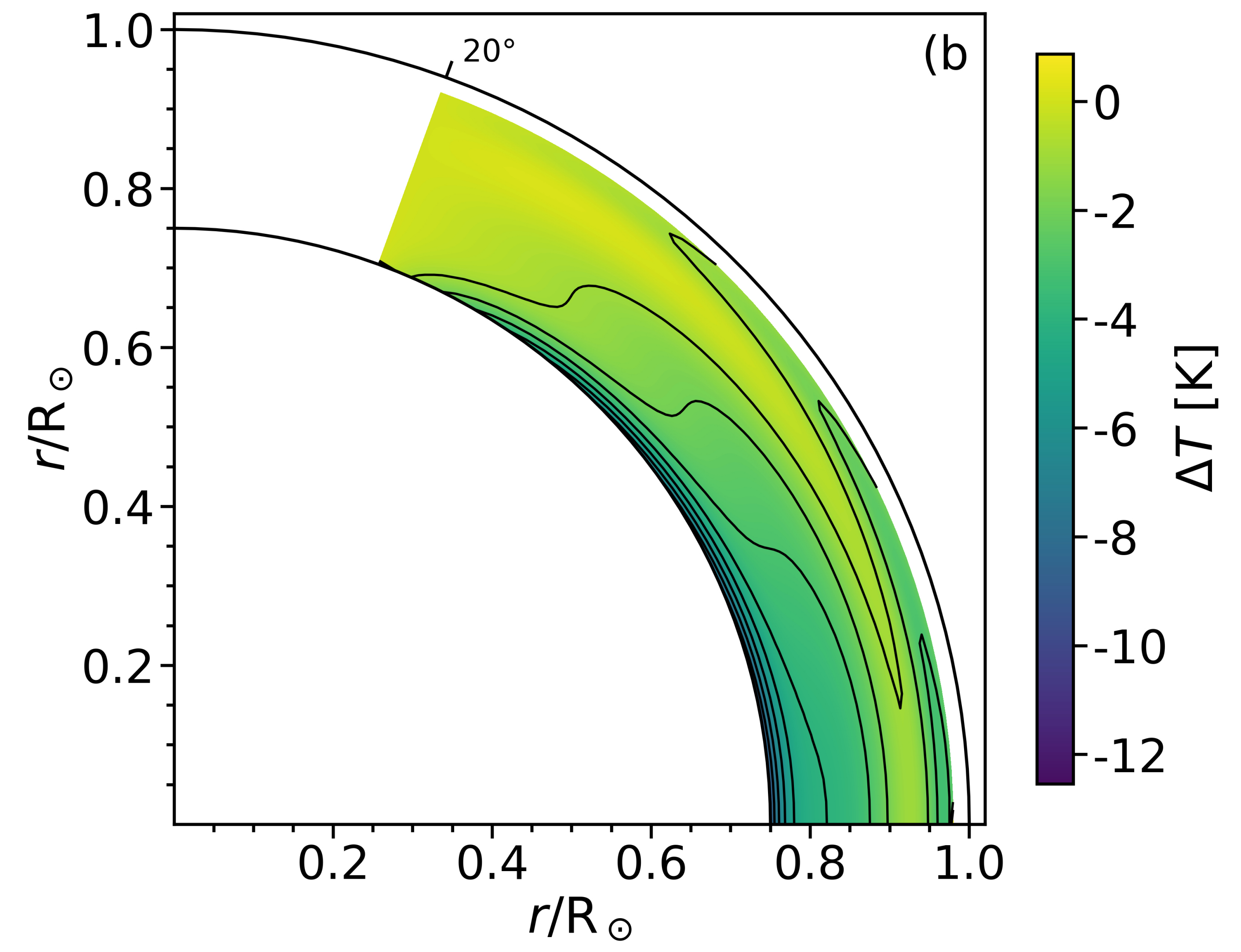
Distribution of $\Delta T(r,\theta)$ based on the analytical expression of $\Omega(r,\theta)$



Distribution of $\Omega(r \geq r_c, \theta)$ based on our model and $\Omega(r > r_c, \theta)$ as per analytical expression.

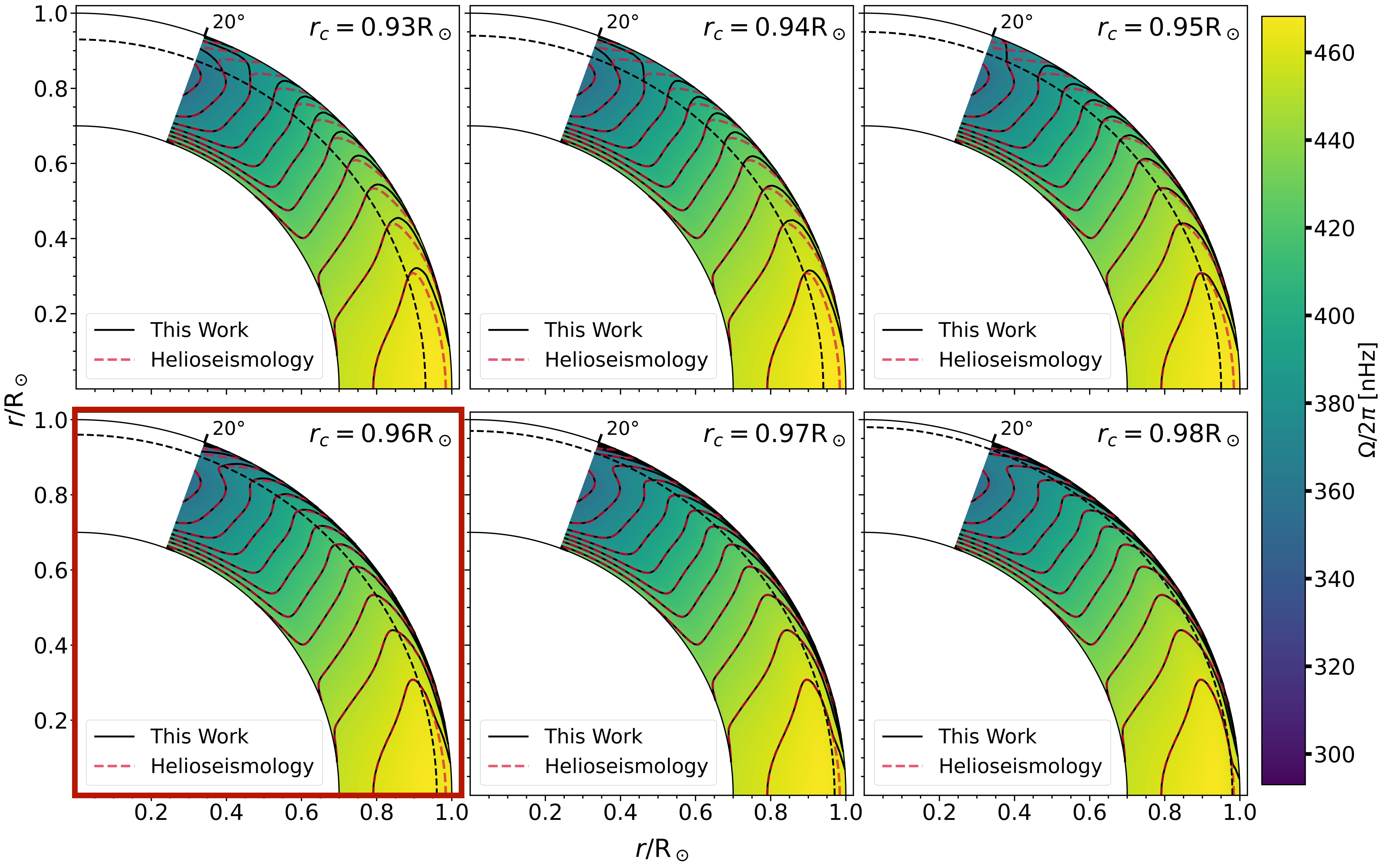
Even though our input Ω does not contains any signature of NSSL our model successfully gives a feature like NSSL.

NSSL Based on Helioseismology Data



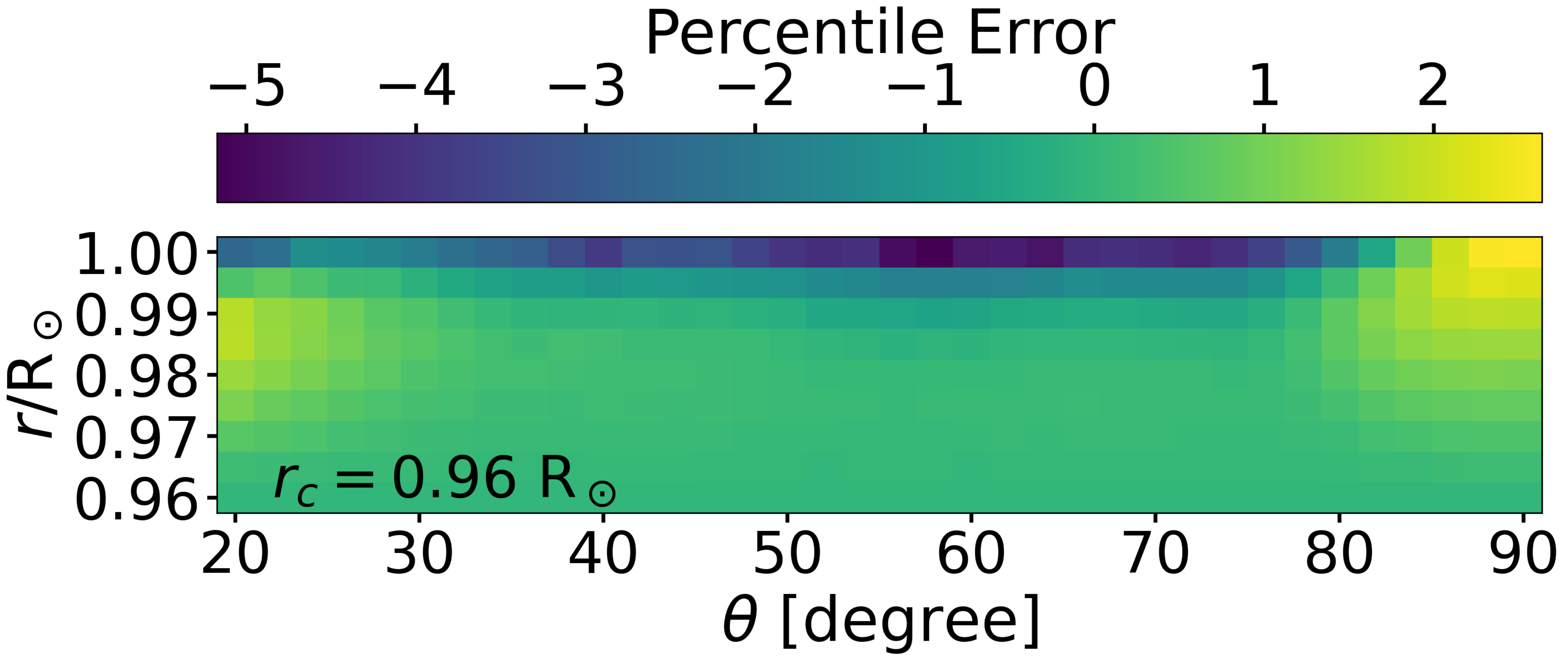
Distribution of $\Delta T(r, \theta)$ based on the Helioseismology observation of $\Omega(r, \theta)$

For $r_c = 0.96\ \mathrm{R}_\odot$ our model matches well with the observation.



Distribution of $\Omega(r \geq r_c, \theta)$ based on our model and $\Omega(r > r_c, \theta)$ as per Helioseismology observation.

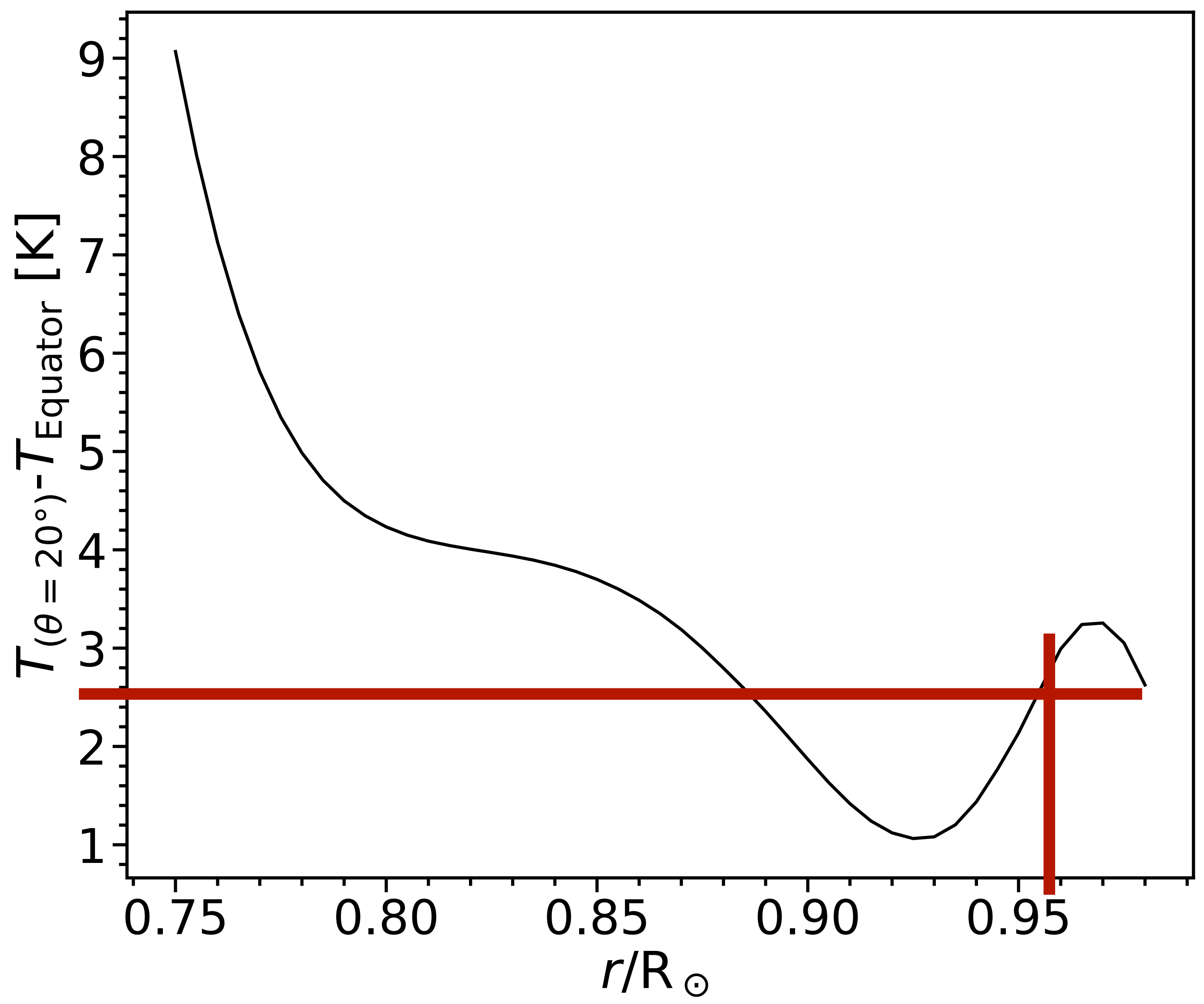
Error Estimation



r_c [R$_\odot$]	RMS
0.95	1.5%
0.96	1.3%
0.97	2.41%

Conclusion

- **For $r_c = 0.96$ R$_\odot$ our model was successfully able to produce the NSSL observed with RMS error 1.3 %**



- **For $r_c = 0.96$ R$_\odot$ the PETD also shows the agreement with the observation of *Rast et al. (2008)***