

# On the center-to-limb variation of radio brightness at millimeter wavelengths

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**Aim:** To study distribution of radio brightness over the solar disk and radio radius at mm wavelengths

- **Model:**

3D R-MHD simulations of the Oslo group: <http://sdc.uio.no/search/simulations>

ENW -24 x 24 x 17 Mm<sup>3</sup>, two opposite polarities, mimics ENW

CH -24 x 24 x 17 Mm<sup>3</sup>, no large-scale MF, mimics CH

- **Data:** compilation of historical and recent measurements, including **ALMA** (Alissandrakis et al. 2017, Selhorst et al. 2019)

## Why is it important to study solar CLV and radius at submm/mm?

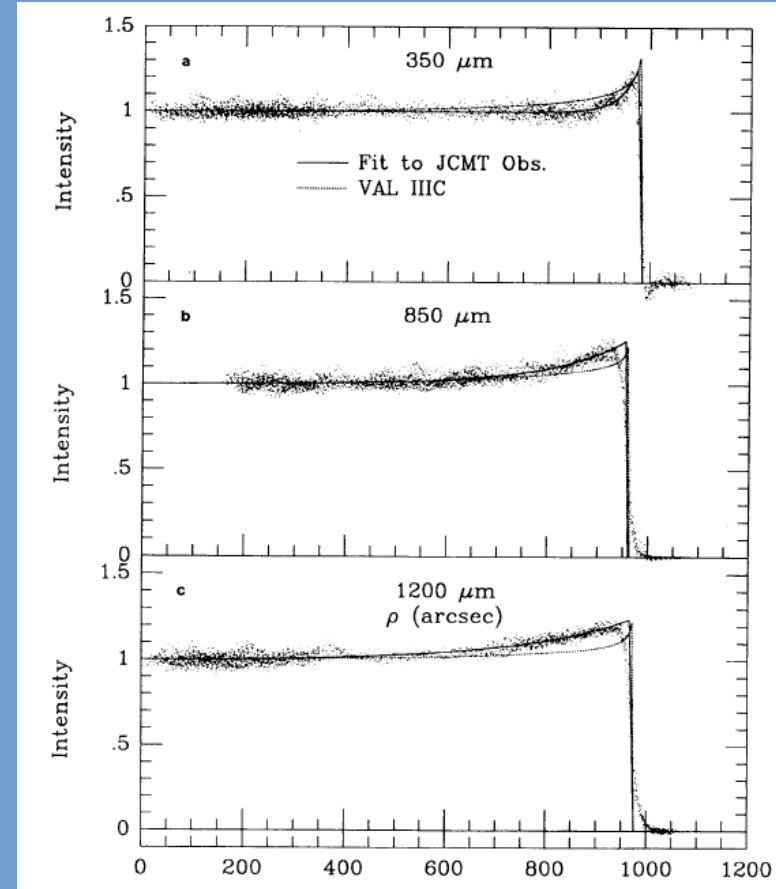
- Mm radiation probes chromospheric conditions, diff. heights with diff.  $\lambda$ . Moving toward the limb is similar to observing at longer  $\lambda$  at the disk center

$$T_b(\lambda, \mu) = T_b\left(\frac{\lambda}{\sqrt{\mu}}, 1\right)$$

- **Measuring CLV** we gain information about the vertical structure of the solar chromosphere

- **Measuring Radius** - we gain information about the heights above photosphere where mm radiation is generated

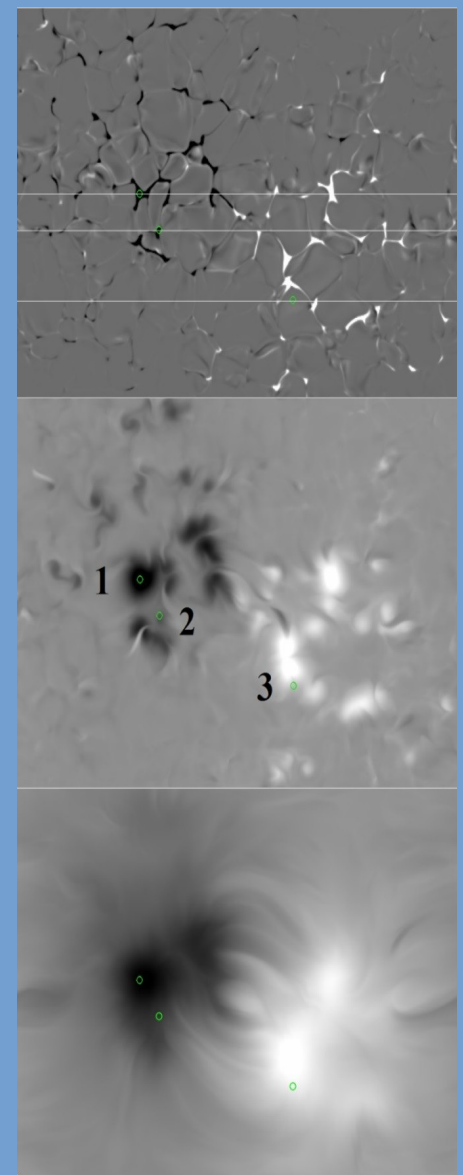
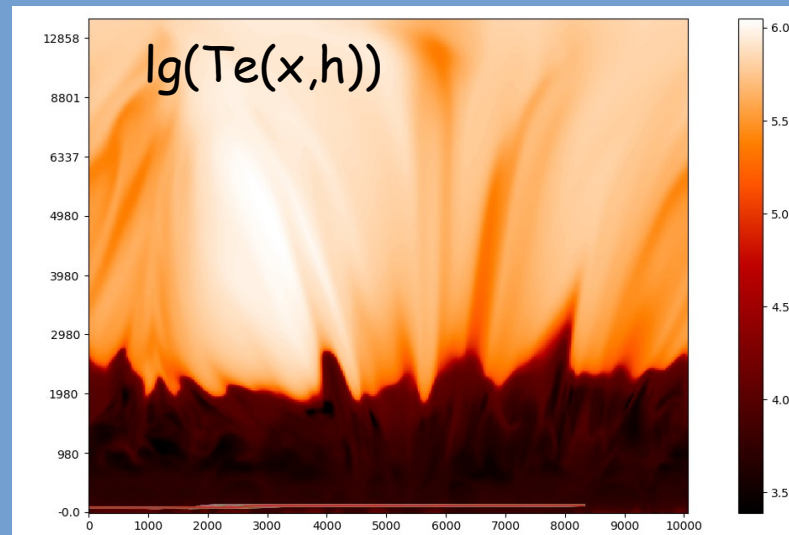
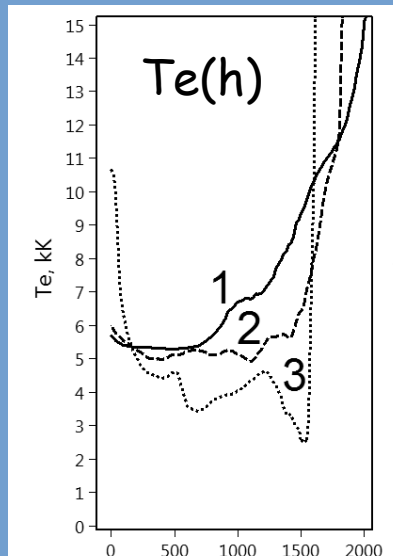
-Both provide valuable tools for atmospheric modeling



JCMT obs, Lindsey et al. 1995

# Types of model atmospheres from the 3D cubes:

- 1) **1-component plane-parallel**: 1D height profiles of Te, Ne
- 2) **inhomogeneous** : 2.5D cuts through the 3D model cube, repeated multiple times to fill the solar disk



## CLV from inhomogeneous models

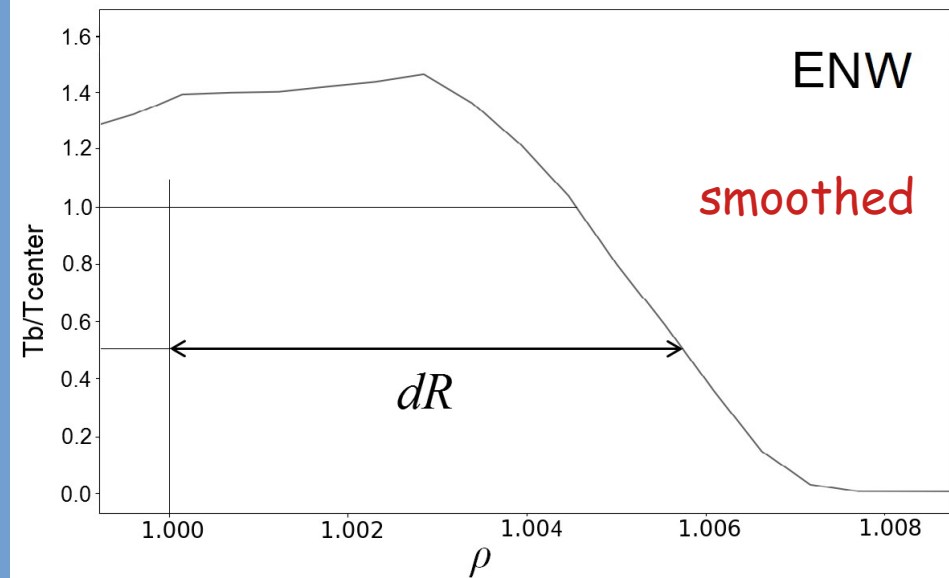
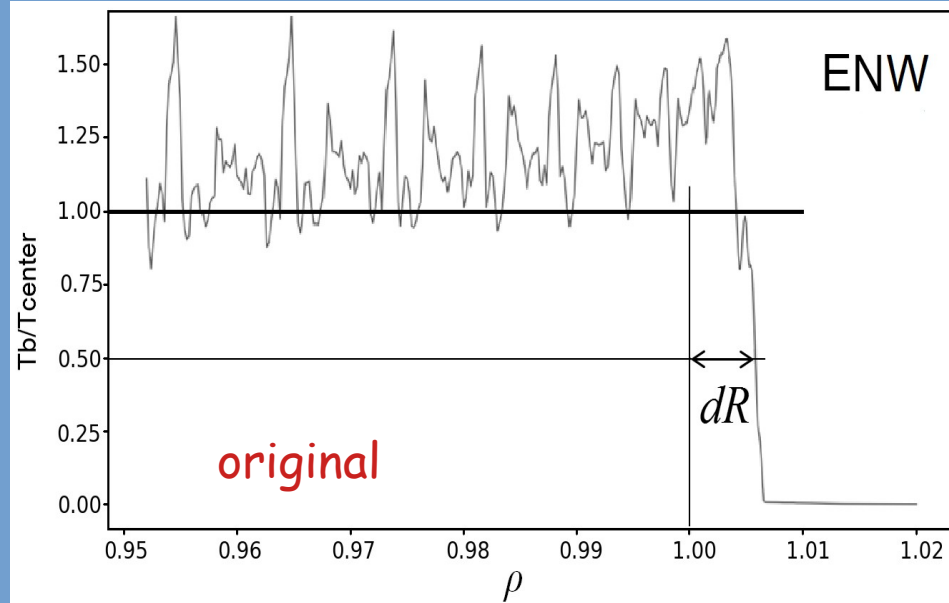
- fine structure in Tb distribution, affects evaluation of limb brightening and radius
- Smoothing is required, but we are averaging over inhomogeneities, limb: 2" at 3mm (ALMA cy4)

### Results:

- no significant CLV is seen up to 0.95Rsun
- no abrupt (>100%) limb brightening, values are smaller than for plane-parallel models
- Similar results for ENW and CH, plus CLV for CH shows bigger Tb amplitudes

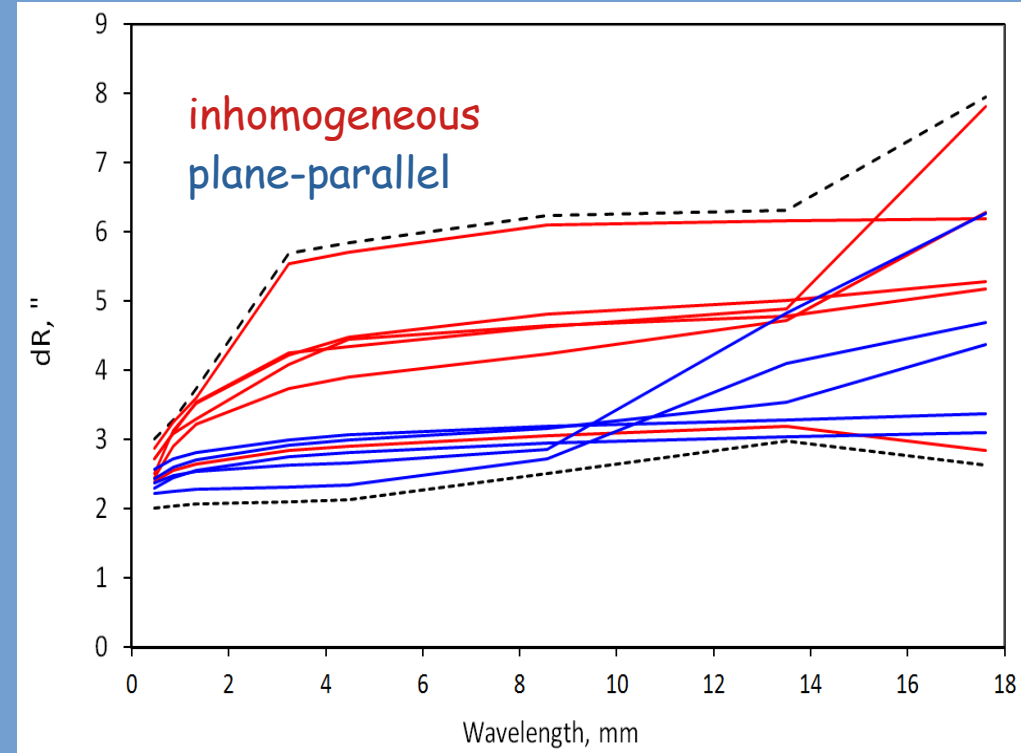
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## Results: Radio radius for ENW model

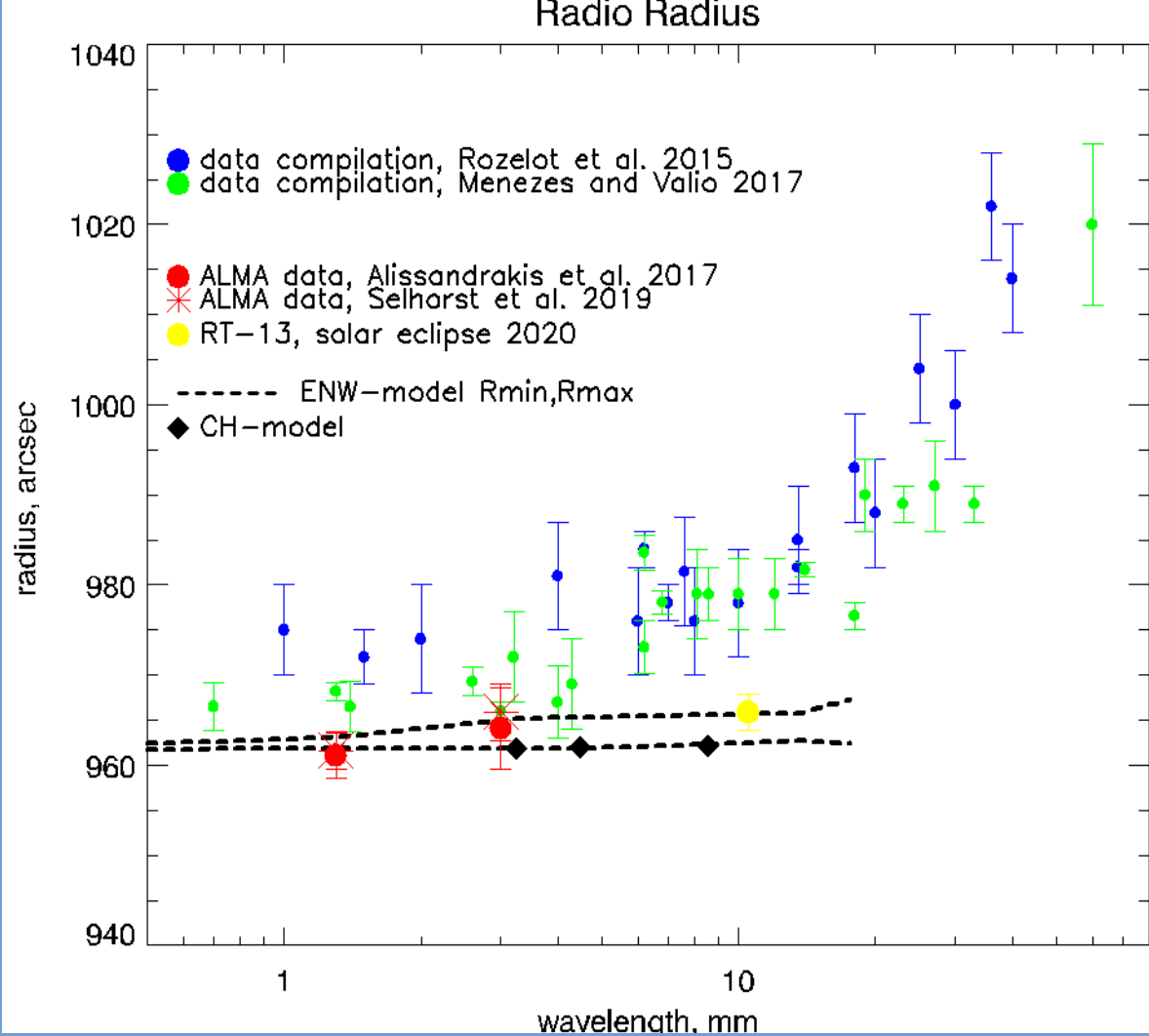
- At mm wavelengths the excess over the optical radius is in the range of (3-6)" for inhomogeneous models (red) and (2-3)" for plane-parallel (blue)
- The full range of calculated R values is shown with black dotted lines
- CH values are smaller  $\sim$  (2-3)"



## Comparison with observations

The full range of calculated R values is shown with black dotted lines

- Historical R values are significantly higher: (5-12)''
- Recent ALMA observations (Alissandrakis et al. 2017, Selhorst et al. 2017) are in agreement with the results of this work
- Recent RT-13 eclipse observations at 10mm are in agreement with the results of this work



## Comparison with observations (cont.)

Possible reasons for discrepancy between historical observations and modeling results:

- Historical measurements are highly inhomogeneous (different instruments, different methods, dependence of results on the solar cycle phase)
- The model is still far from being realistic

The future is in high-resolution measurements with ALMA, which are able to provide separate estimates for various chromospheric structures, network and internetwork (ref. the talk by Prof. Alissandrakis)

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