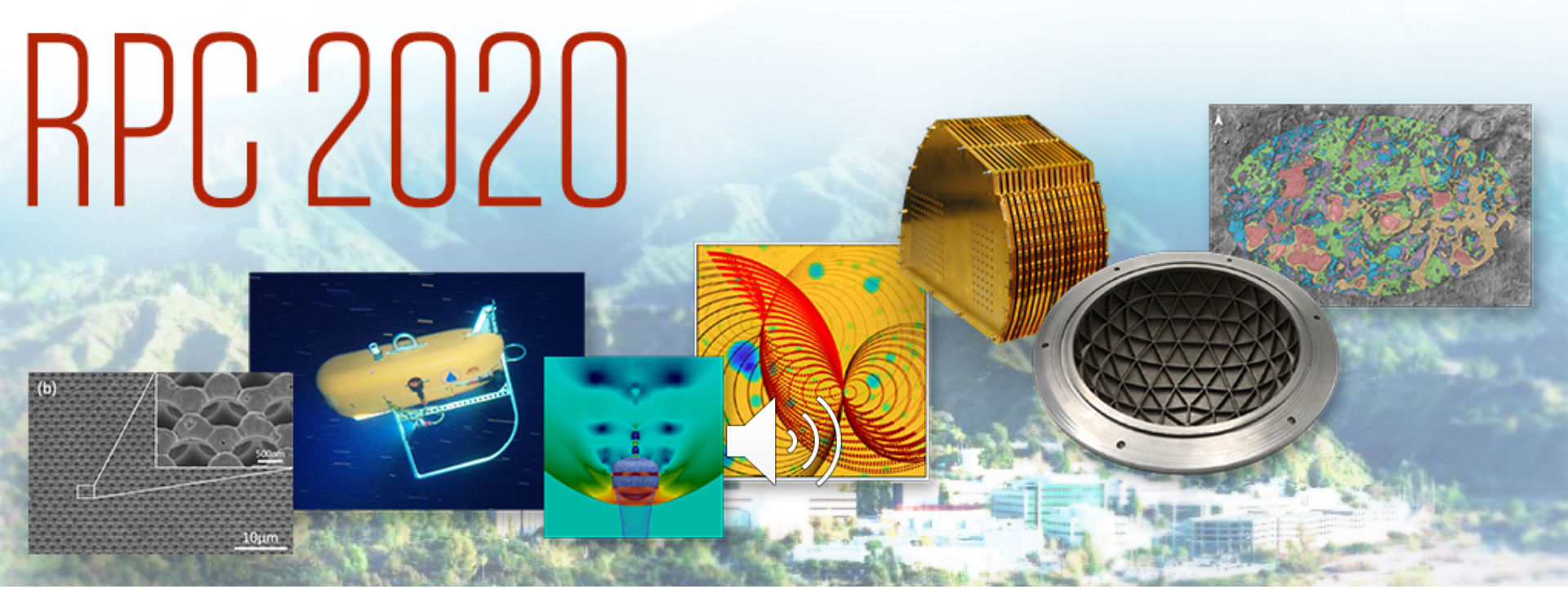
RPC 2020



Virtual Research Presentation Conference

Task Title: DSN Solar Monitoring: Developing a high angular resolution mapping capability for combining single dish & interferometric data

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Program: Spontaneous Concept)

Assigned Presentation #RPC 067

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Tutorial Introduction

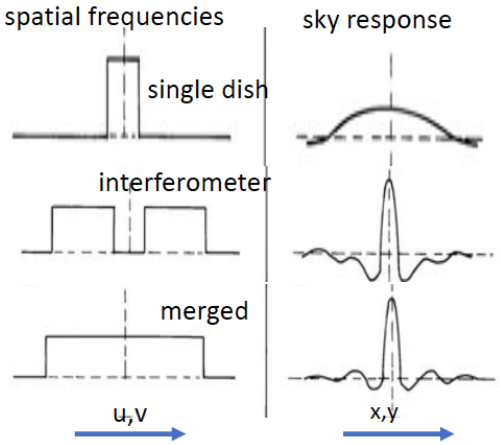
Abstract: *The Goldstone-Apple Valley Radio Telescope (GAVRT), a retired 34-m DSN antenna (DSS28), is being used in partnership between JPL and the Lewis Center for Educational Research (LCER), with K-12 students actually controlling the telescope to make maps of the sun at 4 wavelength bands between 3 and 14 GHz. The GAVRT single dish maps have the entire full disk information but little on the small-scale structures (e.g. above sunspots). In contrast, the interferometer maps observed at the Extended Owens Valley Solar Array (EOVSA) contain no full disk information but only on small scale structures. In the current era of the Parker Solar Probe, GAVRT solar patrol could play a still larger role with a demonstrated capability to combine its maps with EOVSA to achieve high fidelity, high-resolution full disk solar maps. Under this RTD effort we have developed the strategy and the necessary tools to merge GAVRT single dish and EOVSA interferometer maps. Here we present an example highlighting the intrinsic merits of reconstructing full disk maps with higher resolution.*

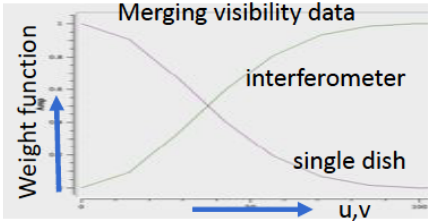
- GAVRT solar patrol has the capability to produce daily maps of the sun multiple times, every 20-30 minutes, during each +/-30 days of PSP perihelion passage.
- EOVSA (http://ovsa.njit.edu/) makes daily (8 hr full synthesis) maps of the sun collecting visibility (u-v) data on 78 baselines (using thirteen 2.1 m dishes) at 1- 18 GHz.
- Merging EOVSA and GAVRT map data allows reconstruction of high resolution (8" -18 ") full disk maps
  - overcoming the limitations of low r resolution (2.6′ to 10′) in the GAVRT maps.
  - alleviating the short spacings problem for EOVSA.

High fidelity full disk solar mapping by merging interferometer & single dish data

- At radio wavelengths it is a challenge imaging the large scale full solar disk (30 arcmin) along with small scale features such as active regions above sunspots or flares (< 1arcmin).
- While interferometers provide high spatial resolution on small scale structures (corresponding to high spatial frequencies: u,v spacings) single dish provides low spatial resolution on largest scale structures (corresponding to short u,v spacings).
- The sun's disk (30′ diameter) has its first null of visibility (J_0 Bessel function or Airy pattern) near uv ~100λ which is not adequately sampled in the EOVSA data
- GAVRT 34-m provides fully sampled short spacings, e.g <15λ at 14 GHz which are derived by Fourier transforming the map which is then merged to the EOVSA u-v data to reconstruct full disk high-resolution map
- To meet the growing need for solar patrol (high resolution full disk maps at cm radio wavelengths) it is essential to merge data over a wider range of all available spatial frequencies (u,v spacings)
- Relevance to NASA & JPL: (i) Ground based observatory support for Parker Solar Probe (PSP): Upcoming PSP Perihelion #7 (January 21, 2021); Last #24 on June 19, 2025. (ii) Solar monitoring as GAVRT educational K-12 curriculum.
- It is time critical to develop this state-of-the-art approach to produce improved EOVSA (interferometer) images of sun's full disk adding GAVRT (single dish map) to overcome the limitations of the missing short spacings.

Why merge?

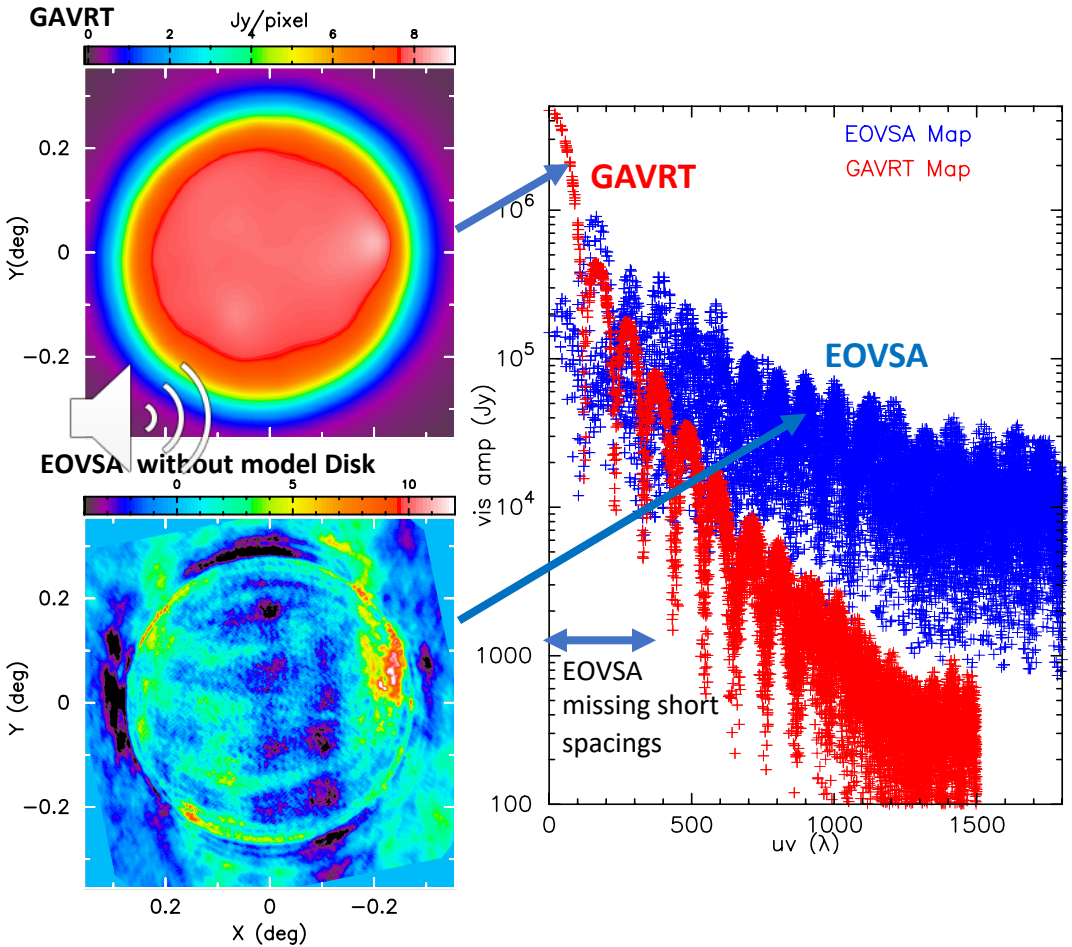




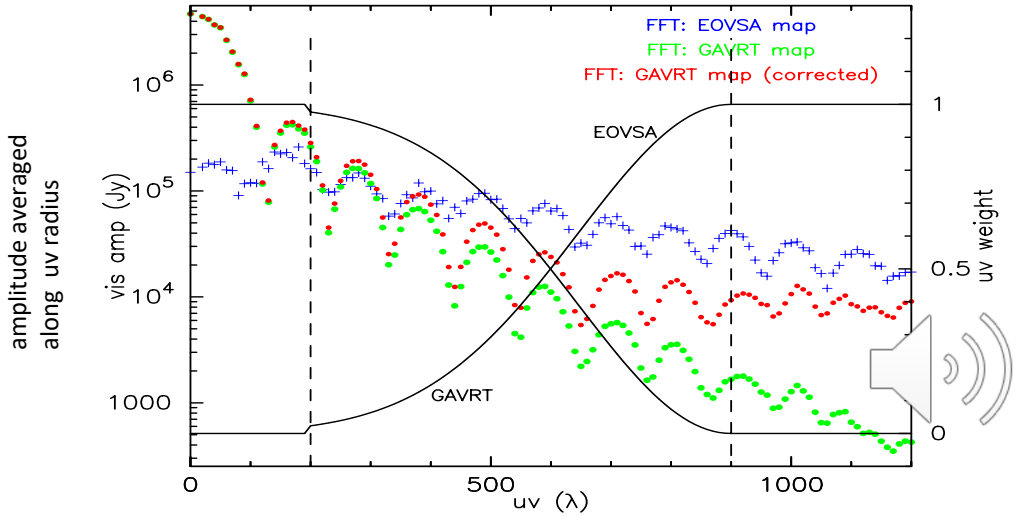
Velusamy et al. (1995), Braun & Walterbos, (1985); Stanimirovic, (2002)

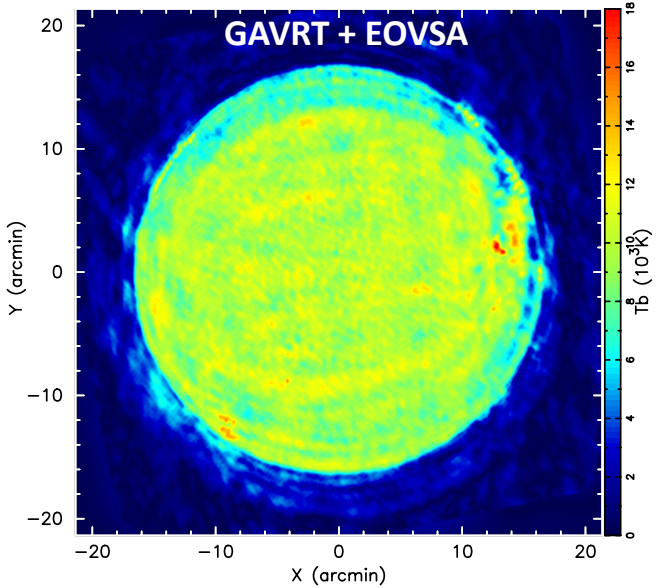
Methodology–Visibility Data

- GAVRT map *(top image)* of the sun at 14 GHz (2.2 cm) with 2.6 arcmin antenna beam was made using the data observed on Jan 30 2020 17 to 22 UT
- EOVSA interferometer map *(bottom image)* at 13.9 GHz, specially made for us in *suncasa* using all baselines (uv data), but without adding theoretical model disk emission. This map represents a 8 hr synthesis around 20:00 UT on Jan 30 2020. (*courtesy:* Sijie Yu, New Jersey Institute of Technology).
- Note Jan 30 2020 includes PSP perihelion Encounter #4.
- The complex visibilities as function of spatial frequencies (u,v) are derived by Fourier Transforming the images using 4096 x 4096 array forward FFT. *(right panel)*
- The missing short spacings are assessed by comparing the single dish and interferometer visibility amplitudes at spacings uv < 1500λ.
- Note the dark areas (-ve brightness) in EOVSA map is consequence of missing short spacings



Methodology: Visibility Data Merging



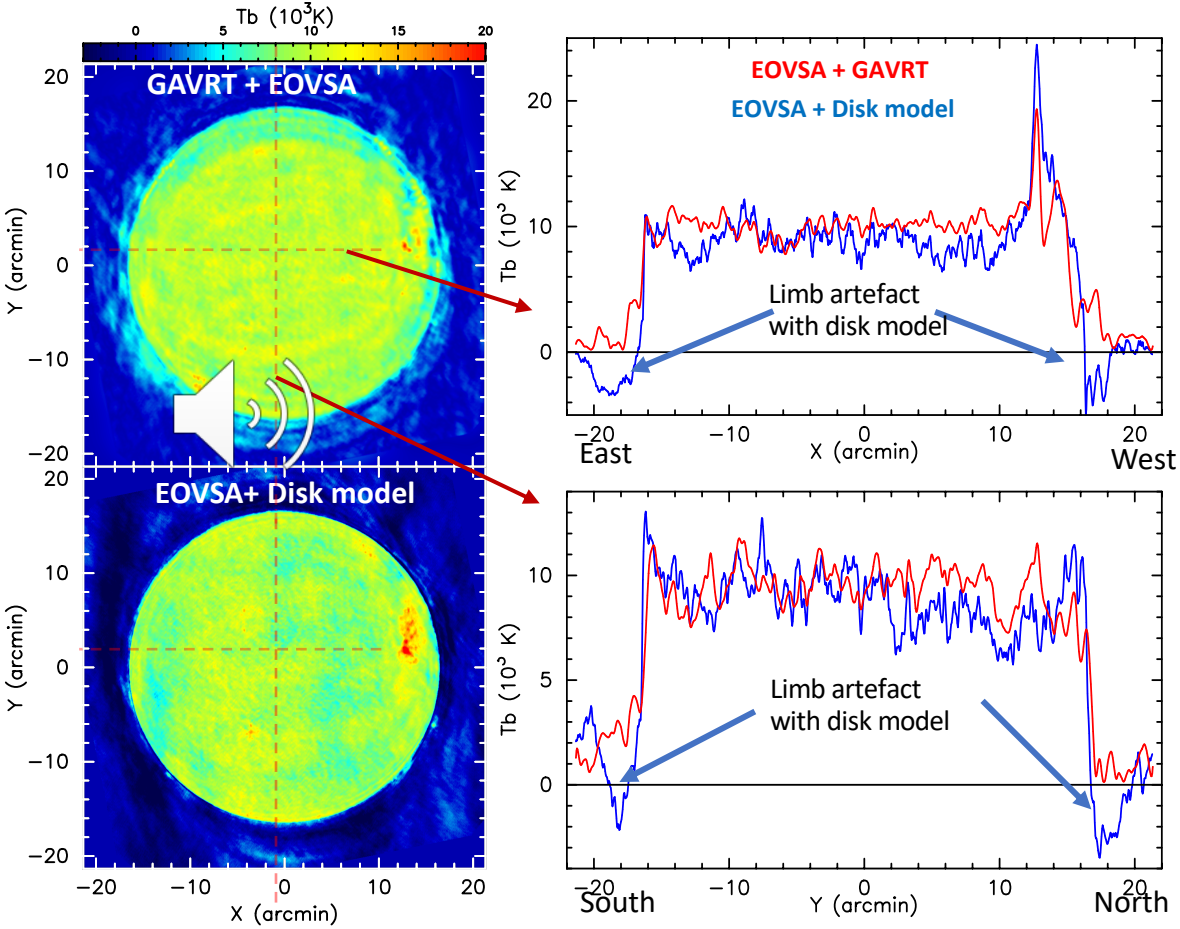


- GAVRT visibilities from Fourier transforming the map (shown in green)
- GAVRT visibilities corrected for spectral sensitivity: dividing by Fourier transform of the 34-m antenna beam (shown in red)
- ESOVA visibilities (shown in blue) were obtained by Fourier transforming the map produced by using all uv data without disk model
- The dashed lines show the usable shortest (EOVSA) and the longest (GAVRT) baselines (uv range)
- GAVRT and EOVSA visibilities are merged applying weighting functions as shown by the solid lines.

- The final map (shown in right) is reconstructed by Fourier transforming the merged visibilities (uv data) using 4096 x 4096 array inverse FFT.
- The merged image essentially brings both the GAVRT and EOVSA maps together, preserving the features of single dish and interferometer data.
- challenge of the best way to transition from GAVRT data to EOVSA UV data needs more exploring

Results: merged *vs* EOVSA pipeline

- The map reconstructed by merging single dish and interferometer uv data (top image) is compared with 13.9 GHz EOVSA map nominally produced by all uv data along with theoretical model for disk emission(bottom image): http://www.ovsa.njit.edu/wiki/index.php/Full_Disk_Simulations
- The E-W and N-S scans along the dashed lines with 8 arcsec beam (right panels) bring out quantitatively the differences between the maps.
- Adding single dish achieves notable improvements over disk model
  - Limb is reconstructed with higher fidelity in the GAVRT + EOVSA map
  - Preserve limb brightening while reducing the artefacts (bowl of –ve brightness).
  - Active region is reproduced well, very compact, as seen in the high uv data without any artefacts resulting from from shorter spacings in EOVSA data.



Results -2: Future Plans

- This exploratory effort shows promise of high resolution image reconstruction of GAVRT maps by adding interferometer (EOVSA) data
- To further validate GAVRT- EOVSA map merger by expanding the analysis to
  - understand the best way to transition from GAVRT data to EOVSA uv data
  - All 4 GAVRT bands between 3 and 14 GHz
  - On days when many active regions are present, especially one near the center and one at the limb
- Work with EOVSA team at Center for Solar-Terrestrial Research, New Jersey Institute of Technology (NJIT)
  - GAVRT maps replacing the need to adding theoretical disk model
  - To evaluate amplitude and phase calibration of the EOVSA visibilities, especially at shorter spacings
  - Combine GAVRT visibility directly with EOVSA uv data (in stead of using the processed map) and process the merging, re-imaging and clean all within *SunCasa* software.
  - Plan coordinated observations during PSP perihelion encounters to evaluate the relevance of merged full disk map data from space missions perspective
  - To process map merger routinely whenever GAVRT solar patrol observations are made
  - To create a resource for solar full disk radio maps at centimeter wavelengths for community use
  - *Future proposals to support Parker Solar Probe magnetic field data by connecting surface magnetograms with the magnetic field at various heights*
  - A peer review publication

Publications and References

References:

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