Meter to Decameter Wave Spectral Radio Heliograph

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Outline

1. Scientific Objectives
2. Present Instruments
3. Specifications
4. System Design
5. Key technologies
6. Summaries
Scientific Objectives for the Solar-interplanetary sub-system of Meridian II project

With the terrestrial instruments, detect the solar intense activities, including the solar flare, CME, interplanetary shock wave, non-thermal particles, solar winds, etc. in the space between the solar surface to the Earth (0-215 R⊙); study the disturbance, coupling mechanism, energy transfer mechanism of the interplanetary and terrestrial space impacted by the solar activities.
Earth

Sun

Flare

Non-thermal particles

CME

Solar Wind

Shock Wave

Mingantu Meter - Decameter Wave Radio Heliograph, 30-240MHz (~1-5 Rs)

Solar Radio Burst
Project Significance

- Meter-Decameter Wave Spectral Radio Heliograph is an important part of the Solar-interplanetary sub-system of Meridian II project;
- Combined with MUSER, it can achieve a solar radio spectral imaging system at the frequency range from centimeter to decameter.
- The system will be a solar radio detecting system with the capability of high-temporal, high-spectral and high-spatial resolutions in the widest frequency band. It can do the full monitoring for the disturbance source in interplanetary space.
Scientific Objectives

- So far, it is a big scientific gap in the world to dedicatedly observe solar radio bursts with high-performance images in the frequency range of meter and decameter wavelengths.
- This frequency is just covered the important space of CMEs and non-thermal particles’ propagation, acceleration and evolutions, which strongly disturbs and impacts on the interplanetary and terrestrial space, and may trigger the disastrous space weather events.
- Therefore, it is most necessary to build a new solar radio telescope operating in the frequency of meter and decameter wavelength and with high temporal, spectral, and spatial resolutions.
Solar Radio Emission

\[ \nu_p = 8.98 \times 10^3 \sqrt{n_e} \]
\[ \nu_{\tau=1} \approx 0.5 n_e T_e^{-3/4} L^{1/2} \]
\[ \nu_B = 2.8 \times 10^6 B \]

(\text{Gary, 1999})

(1) Bremsstrahlung
(2) Gyroresonance
(3) Coherent emission
\[ \star \text{ Plasma emission} \]
\[ \star \text{ ECME} \]
Solar and Galactic radio emission flux

Frequency (MHz)

Flux density (W m⁻² Hz⁻¹)

Wavelength (m)

30GHz 3.0GHz 300MHz 30MHz 3MHz 300kHz

Type II, Type III, Spikes, etc.

Bursts (max.)

Type IV

Moving

Max. Min.

Galactic background

Quiet Sun

Slowly varying component

Storms
# Present solar radio heliograph

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Frequency</th>
<th>Time resolution</th>
<th>Frequency resolution</th>
<th>Polarization</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>MUSER</td>
<td>0.4-2.0GHz 2.0-15.0GHz</td>
<td>25ms 206ms</td>
<td>25MHz 25MHz</td>
<td>R,L</td>
<td>2016</td>
</tr>
<tr>
<td>NoRH</td>
<td>17GHz 34GHz</td>
<td>100ms 100ms</td>
<td>33.6MHz</td>
<td>R,L</td>
<td>1984</td>
</tr>
<tr>
<td>SSRT</td>
<td>5.70GHz</td>
<td>100ms</td>
<td>-</td>
<td>-</td>
<td>1996 Upgrade</td>
</tr>
<tr>
<td>NRH</td>
<td>150-450MHz</td>
<td>100ms</td>
<td>10 freqs 0.7MHz</td>
<td>-</td>
<td>1987 Upgrade</td>
</tr>
<tr>
<td>GRAPH</td>
<td>40-150MHz</td>
<td>256ms</td>
<td>1MHz 1 freq</td>
<td>-</td>
<td>1997</td>
</tr>
</tbody>
</table>
Present solar radio imaging telescope

1. Ultra-wide Band: 0.40-15.0GHz
2. High resolution:
   Spatial, 1.4-51.6”,
   temporal, 25-200ms,
   frequency, 25MHz.
3. High-speed spectral imaging: 584, imaging with ~200ms
4. Dual-circular polarization: L & R
Present solar radio imaging telescope

SSRT

NoRH

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Present solar radio imaging telescope

Gauribidanur Radio Heliograph

NRH

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Main Specification

- Frequency: 30MHz－240MHz
- Antenna: 100 LPDA antenna
- Longest Baseline: 3000m
- Frequency Resolution: 1MHz～5MHz
- Temporal Resolution: 100ms
- Spatial Resolution: 1.7’ @240MHz－14.0’ @30MHz
- Polarization: I、Q、U、V
Frequency: 30MHz—240MHz

- Solar radio emissions below 150MHz locate the area from 1 to 5 Rs, where the solar events including CME, non-thermal particle and solar wind are produced and accelerated, it is crucial to systematically monitor this area.
- Covering the full frequency band that can be observed on the ground with the Daocheng Circular Array together, the overlap frequency can be used to mutually testified.
Antenna

- LPDA, Most used and mature;
- Based on the simulations, 100 antennas are enough to get good images;
- Simple mechanism, cheap.
Polarization: I, Q, U, V

- For crossed linearly polarized feeds
  \[ v_{pp} = \frac{1}{2} g_{ip} g_{kp}^*(I + Q \cos 2\chi + U \sin 2\chi), \]
  \[ v_{pq} = \frac{1}{2} g_{ip} g_{kq}^*((d_{ip} - d_{kq}^*)I - Q \sin 2\chi + U \cos 2\chi + jV), \]
  \[ v_{qp} = \frac{1}{2} g_{iq} g_{kp}^*((d_{kp}^* - d_{iq})I - Q \sin 2\chi + U \cos 2\chi - jV), \]
  \[ v_{qq} = \frac{1}{2} g_{iq} g_{kq}^*(I - Q \cos 2\chi - U \sin 2\chi). \]

- 4 cross-correlations can be used to measure the antenna polarization performance;
- Decrease the crosstalk requirement of antenna polarization;
- For the signal with polarization unknown, 4 cross-correlations can be used to measure the full Stokes parameter, I, Q, U, V.
System Composition

- 100 LPDA;
- Calibration unit (124 LPDA), also used as spectrometer;
- 124 LPDA, beam-forming.
Array Configuration

- Design principle: UV coverage, Beam Characteristic, Image quality, Engineering Implementation;

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Array Design

- Fully take advantage of the present location and condition.
Antenna Design

- Antenna: LPDA
- Frequency: 30—240MHz
- Polarization: Dual-linear
- Gain: ≥5dB (50MHz以上)
- VSWR: ≤2.5
- Right ascension: -95° ~ +95°
- Decline: -30° ~ +30°

L × W × H = 3.0m × 3.0m × 3.0m, much smaller than the half-wavelength antenna

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Antenna receiver design

- Frequency: 30MHz ~ 240MHz
- LNA NF: < 1.5dB
- IF band: ~100MHz
- Isolation: ≥70dB
- Flatness: ±1.5dB
- Attenuator: 30dB, adjustable
Digital Receiver Design

- **AD Acquisition**: AD, BF filter, Fringe stop, 2bit quantization, Delay compensation.
- **Synchronization Module**: Sampling clock.
- **Correlator module**: 4 correlator, Cos output, Sin output.
Monitoring system
Data Processing Unit Design

1. Storage server
2. Monitor
3. HP computing server
4. Harddisk array
5. Tape library
Calibration Unit Design

- 124 LPDA, 16 groups;
- 7 antenna summing, improve gain;
- Without tracking.
MUSER OS

d-10-145-200-28:bin yyh$ ./museros
Environment file: /Users/yyh/museros/resource/xml/system.xml

Version 1.0.0-REL (r1)
Compiled on: Wed 2016/2/8 12:39:00 UTC
Current IPython Version: 4

Muser <1>:
## Observation Mode

<table>
<thead>
<tr>
<th>Order</th>
<th>Observation Mode</th>
<th>Description</th>
<th>Temporal</th>
<th>Detection Area</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Normal Obs mode</td>
<td>Full frequency band, full time</td>
<td>second</td>
<td>0-5R⊙</td>
<td>30MHz-240MHz</td>
</tr>
<tr>
<td>2</td>
<td>Frequency Selection mode</td>
<td>Frequency selection</td>
<td>second</td>
<td>0-5R⊙</td>
<td>30MHz-240MHz, Certain Frequency</td>
</tr>
<tr>
<td>3</td>
<td>Night Obs mode</td>
<td>Observe radio source for calibration and difference sciences</td>
<td>second</td>
<td>Radio sources</td>
<td>30MHz-240MHz</td>
</tr>
</tbody>
</table>
## Data Archive

<table>
<thead>
<tr>
<th>Level</th>
<th>Data name</th>
<th>Description</th>
<th>Format</th>
<th>Time resolution</th>
<th>Data Volume (MB)</th>
<th>Online or not?</th>
<th>Produced by data center?</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Image raw data</td>
<td>Raw output, visibility, time, spectrum</td>
<td>Self-define</td>
<td>1 min</td>
<td>2TB</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>0</td>
<td>Spectral raw data</td>
<td>Raw output, time, spectrum</td>
<td>Self-define</td>
<td>Each min</td>
<td>1GB</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>1</td>
<td>Standard image format</td>
<td>Normal data format, time, visibility</td>
<td>FITS</td>
<td>5 min</td>
<td>1GB</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Image production</td>
<td>Customer data, time, solar radio image</td>
<td>FITS</td>
<td>5 min</td>
<td>3.6GB</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Spectral production</td>
<td>Customer data, time, spectrum</td>
<td>FITS</td>
<td>Each min</td>
<td>1GB</td>
<td>Yes</td>
<td>否</td>
</tr>
</tbody>
</table>

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Thanks!