Using Ultra-long wavelength to research absorption and distribution of free electron

Yanping Cong (SHAO)

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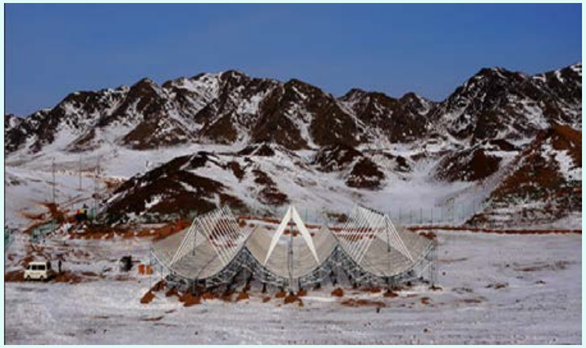
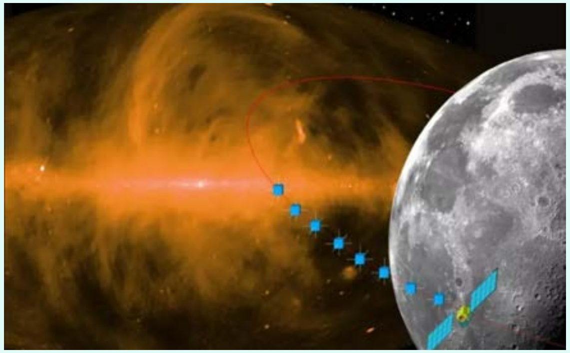
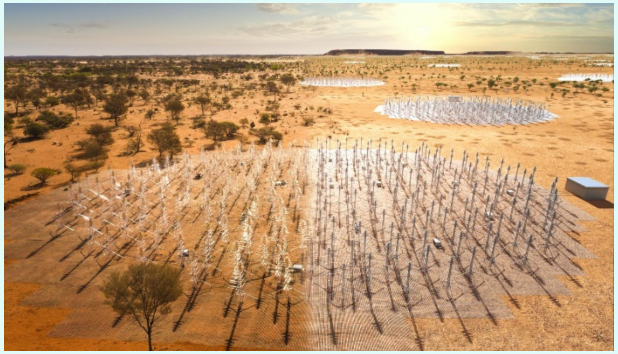






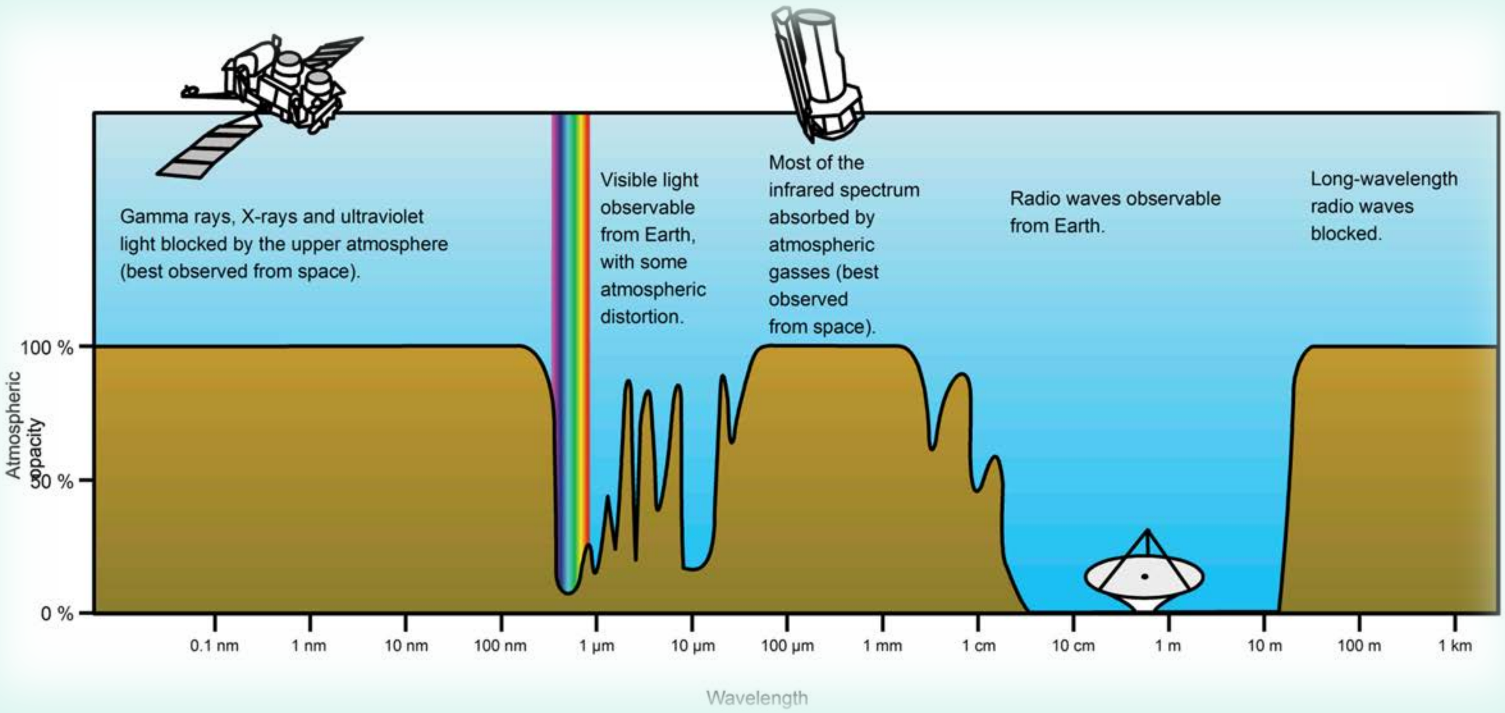
Outline

- Background
- The Ultra-long wavelength(ULW) observation
- The Sky Model with considering Absorption
- To reconstruct the 3D free electron with ULW band
- Summary

Outline

Background

- Electromagnetic waves with a wavelength of ~ 10m and above (frequency ~ 30 MHz and below).
- It is a blank observation window called the ultra-long wavelength (or ultra-low frequency) band.



Scientific goals:

- **21 cm radiation during the Dark Ages and Reionization**
- **The galactic interstellar medium**
- **The origin and propagation of co smic rays**
- **Extragalactic galaxies and radio galaxies**
- **Evolution of quasars and galaxy clusters**
- **Solar activity and planetary mag netic fields**

Challenge:

- **Ionospheric refraction and absorption**
- **RFIs on Earth**
- **FM radio**

Outline

Ultra-long observation on ground

- Australia and Canada
- 192 dipole antennas
- The array built by Reber et al., covering "one square kilometer"

Figure 10: Reber's array, north of Bothwell, in 1975 (courtesy: Grote Reber Foundation).

location: TASMANIA
Bothwell region

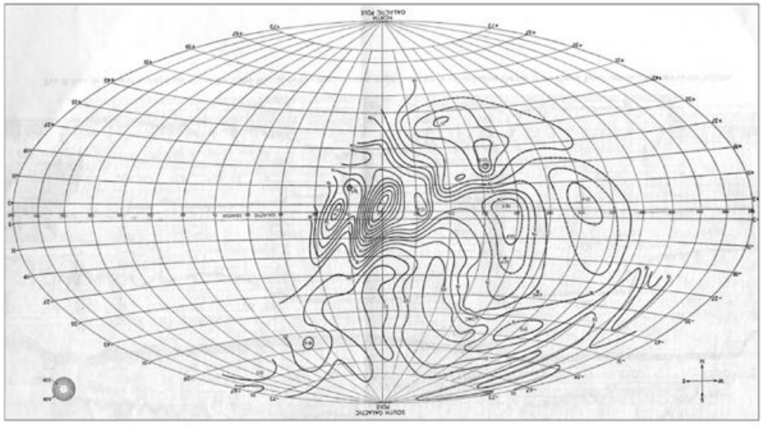
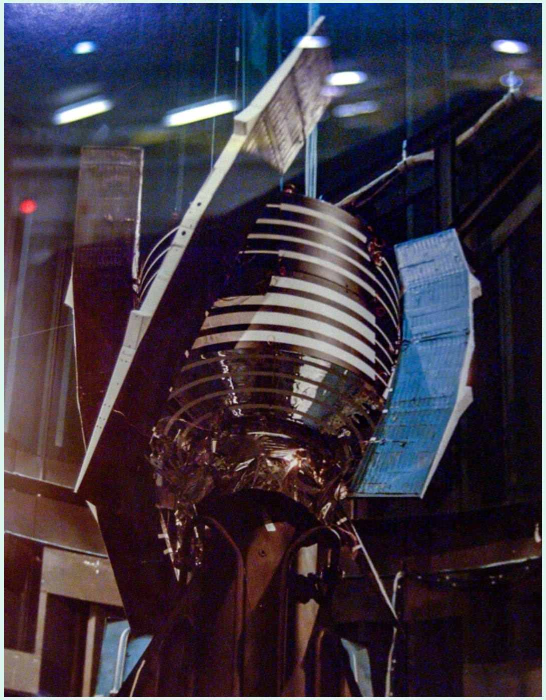
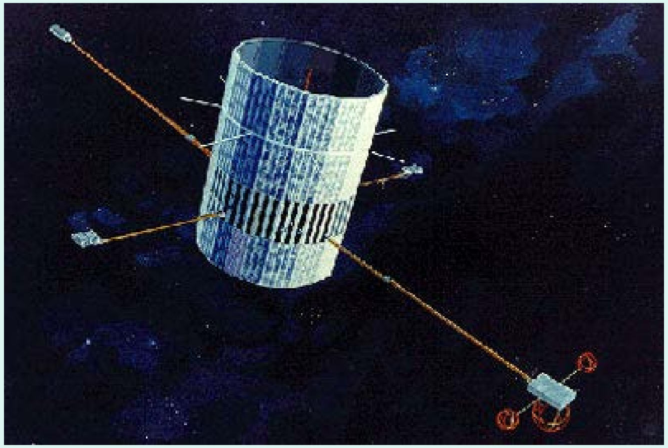


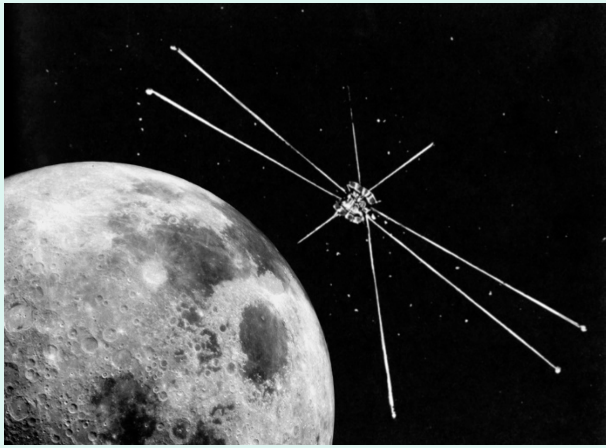
Figure 11: A 2.085 MHz contour map of galactic radio emission (after Reber, 1968: 10).

2.1 MHz（1975）

- RAE-1(1968) , IMP-6(1971), RAE-2(1973)







Interplanetary Monitoring Platform-6

Targets: energetic particles, cosmic rays, plasma, electrons, and magnetic fields

Radio Astronomy Explorer A

high-resolution space observations

- Measuring the primordial fluctuation would require large scale arrays(A_{eff}>10km^2)

- The 21cm global spectrum could be measured with single antenna and probe cosmic dawn and dark ages

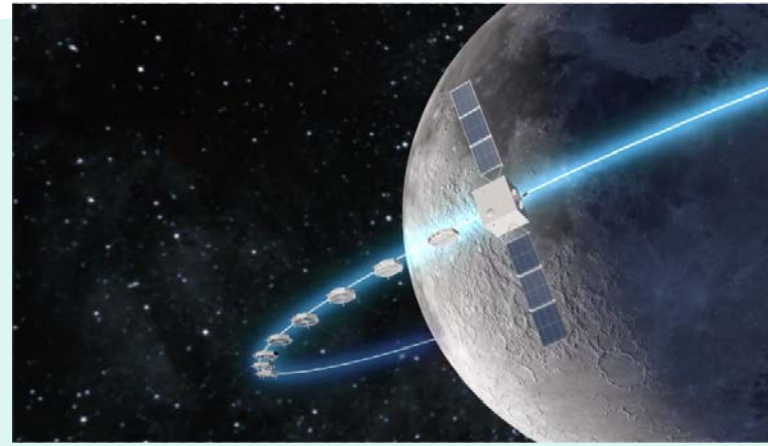


Fig.1 DSL project concept image(Chen et al.2020)

Fig.2 FARSIDE

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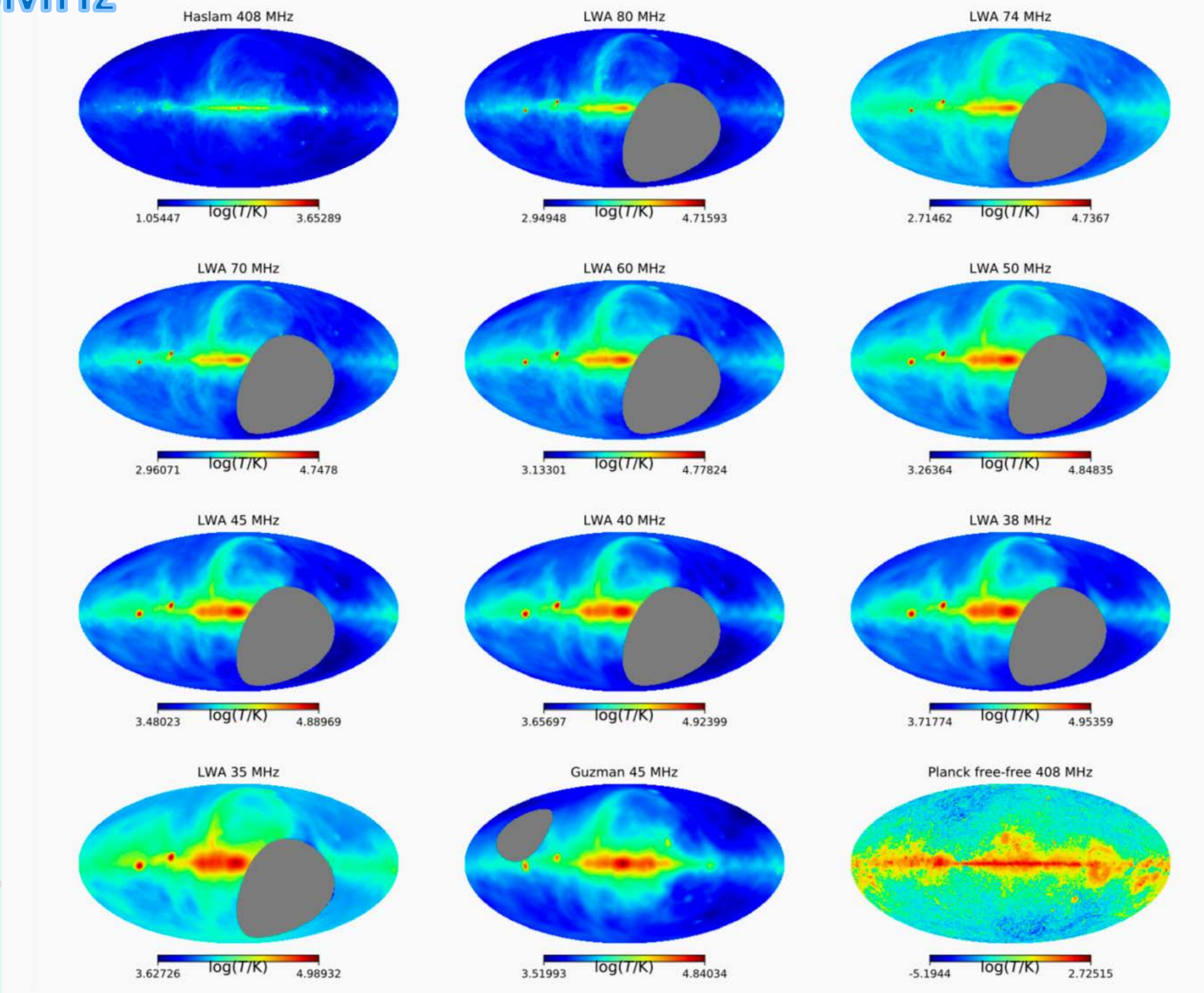
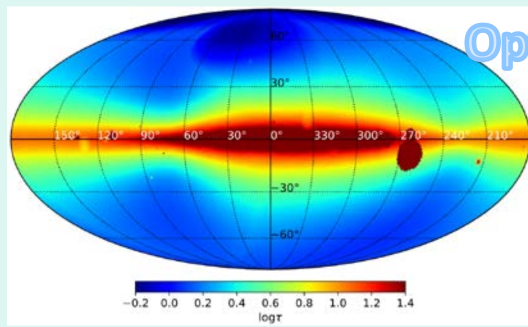
observation data in High-frequency

35MHz – 408MHz



The sky model with absorption of ISM

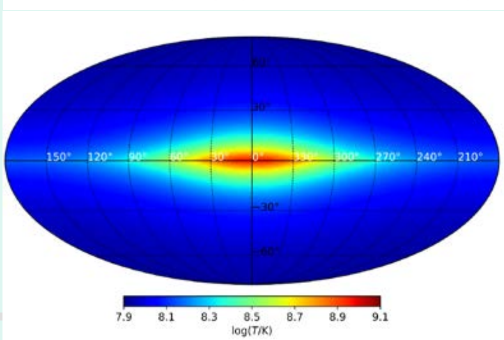
- Sky Model ---ULSA(Yanping Cong et.al. 2021)　(< 10 MHz;)
- ISM has stronger absorption for ultra-long wavelength——free-free absorption。
- The interpolated sky map represents the intrinsic characteristics of the emission source.



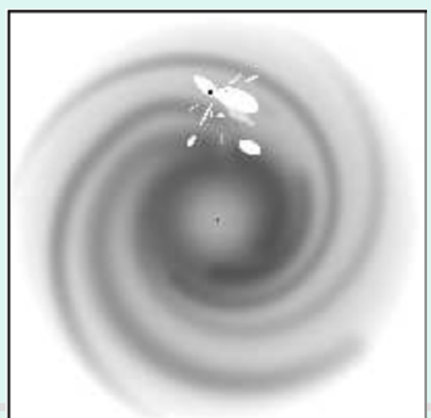
Optical depth

$$T(\nu,l,b)=T_{\rm G}(\nu,l,b)+T_{\rm E}(\nu)$$
$$=\int_0^{s_{\rm G}}\epsilon(\nu,R,Z,\phi)e^{-\tau(\nu,s)}ds+T_{\rm E}^{\rm iso}(\nu)e^{-\tau(\nu,s_{\rm G})}$$

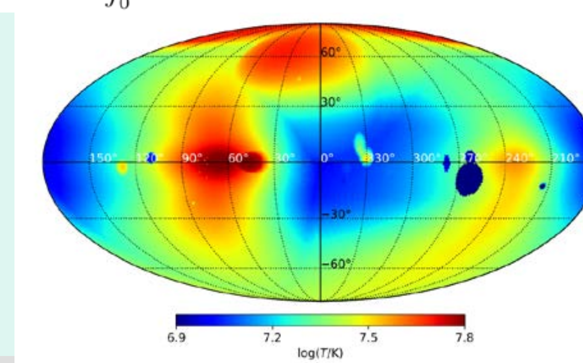
$$\epsilon(\nu,R,Z)=A\left(\frac{R+r_1}{R_0}\right)^{\alpha}e^{-R/R_0}e^{-|Z/Z_0|^{\gamma}}\left(\frac{\nu}{\nu_*}\right)^{\beta_{\rm G}}$$



3D emissivity integrated along L.o.s.



NE2001电子密度模型
J. M. Cordes&T. J. W. Lazio(2002)



The sky map on 1MHz

Spectral index

- *Constant spectral index* β = -2.51
- *Frequency dependent spectral index* $\beta = \beta_0 + \beta_1 \, exp(-\nu/\nu_1)$,
- **Direction dependent spectral index (spectral index map)**

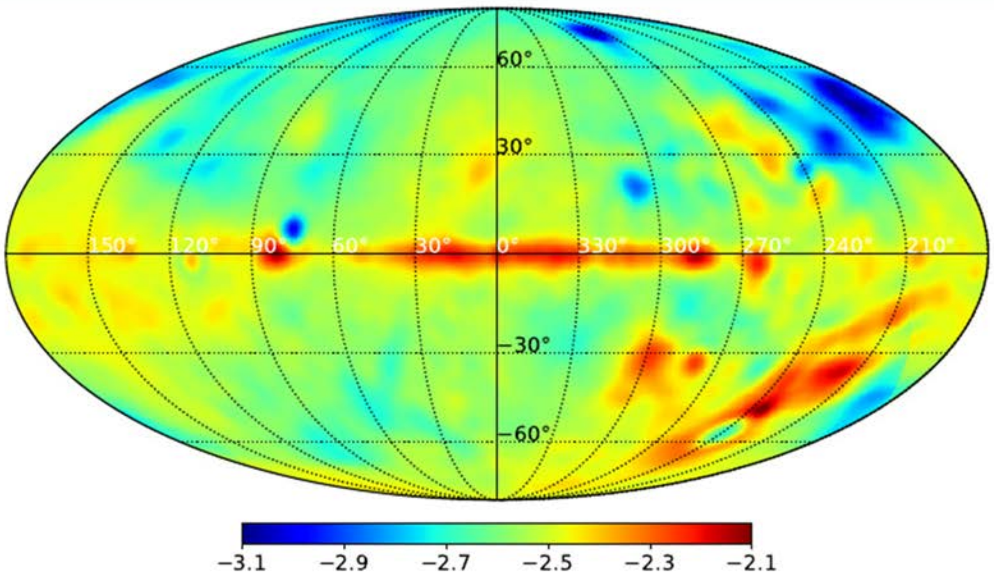


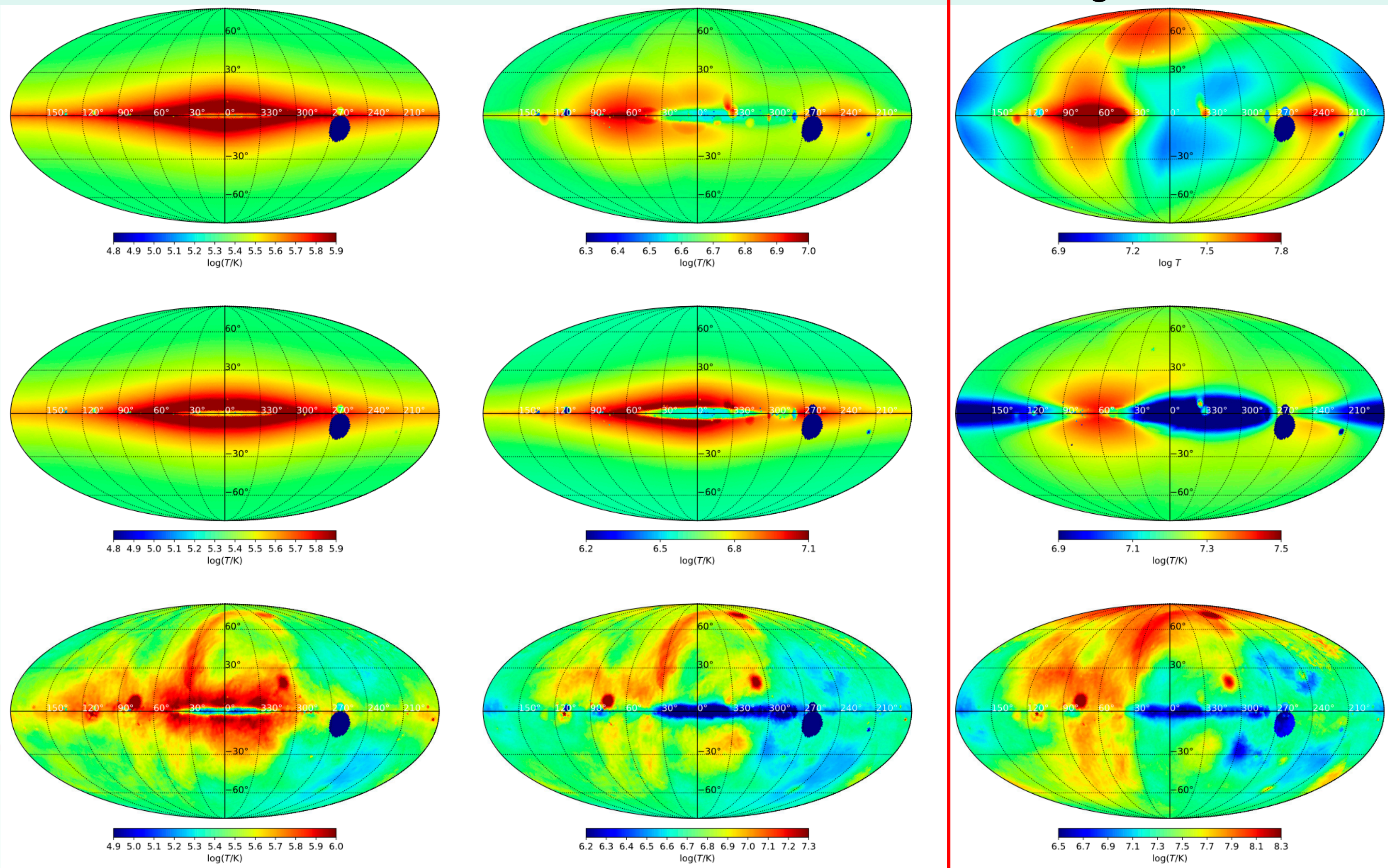
Figure 13. The spectral index map (equatorial coordinates) obtained by combining the Haslam 408 MHz map with the LWA and Guzman maps.

Top: Constant spectral index, with enhanced absorption

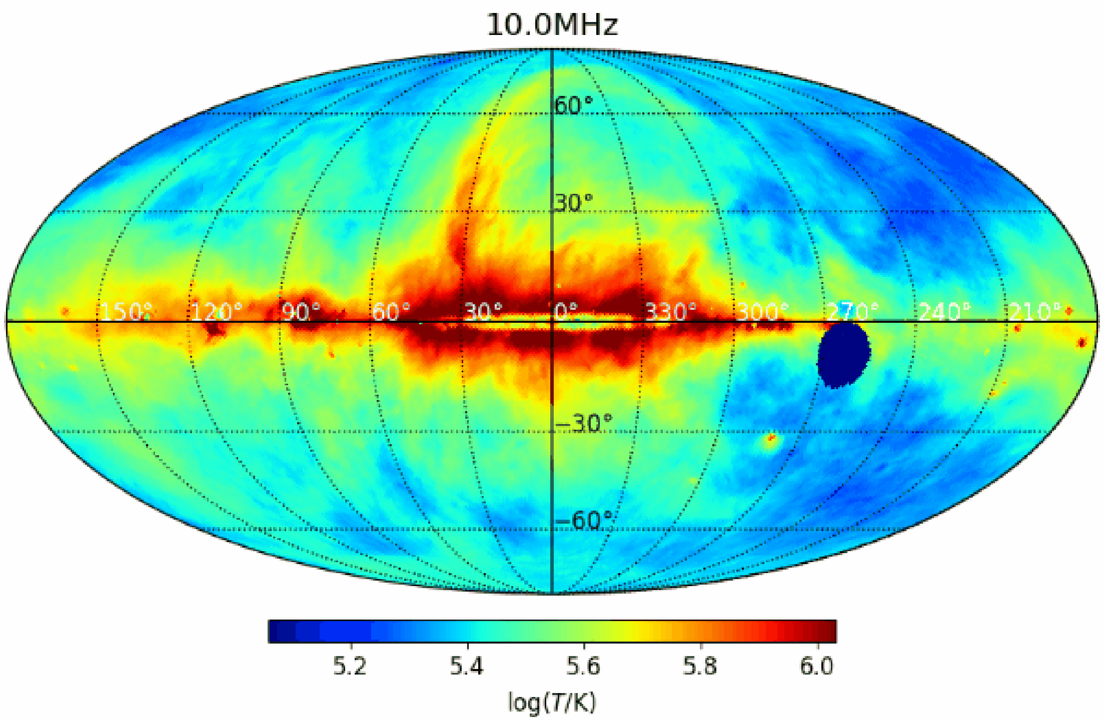
Middle: Frequency-dependent spectral index, with standard absorption

Bottom: The direction depends spectral index, with enhance absorption

Left : 10MHz | Middle: 3MHz | Right: 1MHz



Constant spectral index



summary

- we have developed an ultra-long wavelength radio sky model that is valid below ~ 10 MHz.
- We derive a cylindrical emissivity from the observed all-sky map at 408 MHz, extrapolate it to ultra-long wavelength using a power-law form, and then add the free-free absorption by th e Galactic diffuse free electrons and some small-scale dense HII regions.
- As for the absorption, at ultra-long wavelengths, the Galactic disk would become darker than higher Galactic latitude.

Outline

The tracer of large scale structure

The interstellar medium (ISM) is one of the major components of the Galaxy and consists of coronal gas, intercloud gas, diffuse clouds, dark clouds, Bok globules, molecular clouds, and H II regions (Myers 1978). The neutral hydrogen H I radiates 1420

(Hiroyuki Nakanishi & Yoshiaki Sofue(2014))

ISM	mass fraction	tracer
HI and H_2	80% of hydrogen	21cm; CO line
Dust	1%	Extinction
Hot gaseous halo	≤ 5% within 20 kpc	Metal X-ray line
WIM	30% of ISM mass	Free electron

Using absorption to research free electron

- Ionized gases in ISM have a stronger absorption of lower frequencies
- The 3D electron in each l.o.s. can be reconstructed by the absorbed ultra-long wavelength observation.

$$\frac{dI_\nu}{ds} = -\alpha_\nu I_\nu + j_\nu$$

$$\alpha_\nu \approx 3.28 \times 10^{-7} \left(\frac{T_e}{10^4\mathrm{K}}\right)^{-1.35} \left(\frac{\nu}{\mathrm{GHz}}\right)^{-2.1} \left(\frac{n_e}{\mathrm{cm}^{-3}}\right)^2 \mathrm{pc}^{-1},$$

The observation produced by ULSA

- Using ULSA (Yanping Cong et.al.) to simulate sky map
- Each l.o.s share the same fluctuation parameter

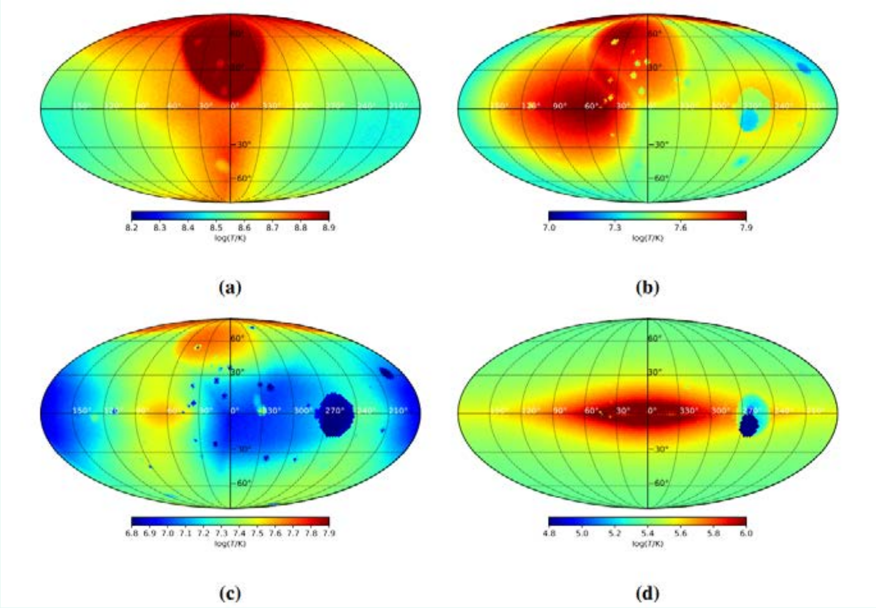


Fig.1 The simulated brightness temperature in (a) 0.1 MHz, (b) 0.5 MHz, (c) 1 MHz and (d) 10 MHz respectively

$$\epsilon(\nu, R, Z) = A\left(\frac{R + r_1}{R_0}\right)^{\alpha} e^{-R/R_0} e^{-|Z/Z_0|^{\gamma}} \left(\frac{\nu}{\nu_*}\right)^{\beta_G}.$$

- A, R_0, α, Z_0 and γ is the main parameter of model.
- $\beta_G = -2.51$
- More reality emissivity using GALPROP ? or hammurabi X ? or Dragon ? or HII region?

The reconstructed result in each l.o.s.

$$\chi^2(l,b) = \sum_{j=1}^{N_{\rm freq}} \frac{[T_{\rm sky}(\nu_j,l,b) - T_{\rm sky}^{\rm obs}(\nu_j,l,b)]^2}{\sigma_{\rm noise}^2},$$

- NSIDE = 32 and number of LoS = 12288
- The size, density and distance of Clumps can be used to improved the MCMC method。
- LoS type: Normal， Clumps，Voids。

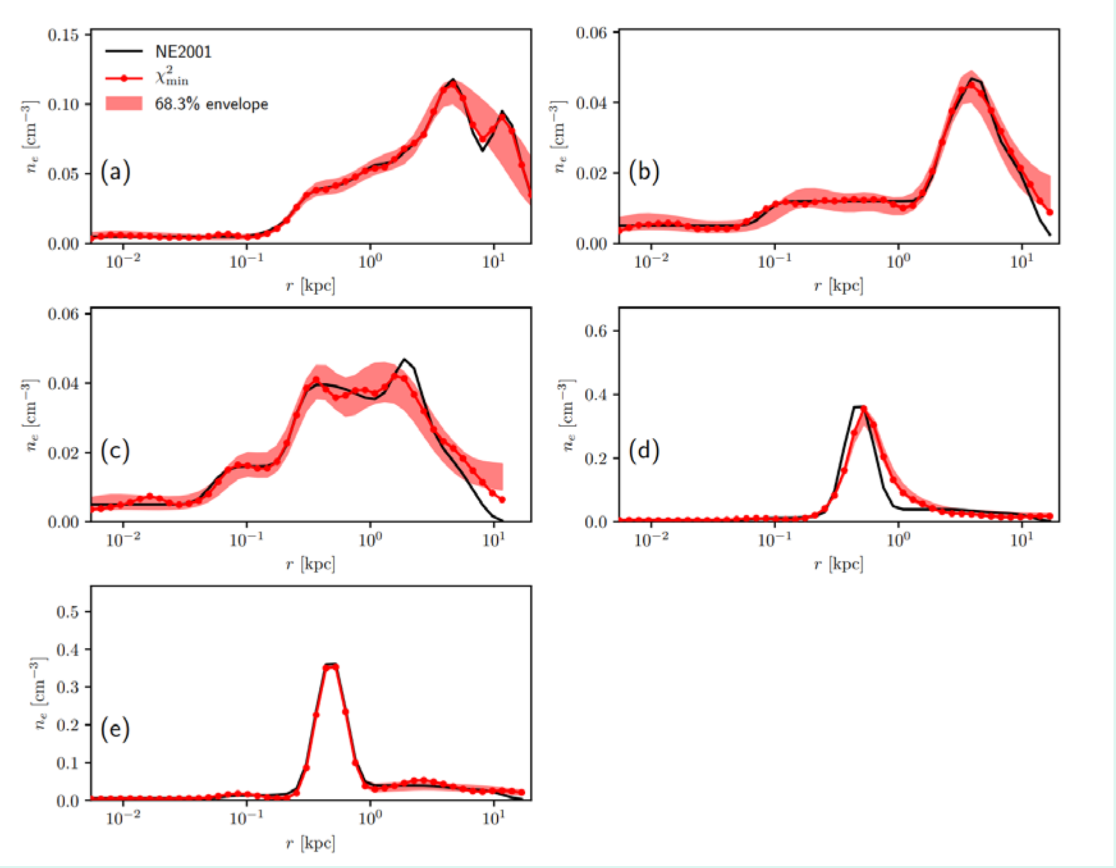


Fig.1 The reconstructed density profile of electron along 4 LoS in the Galactic plane （b = 0∘） （a） l = 2°; （b） l = 90 °; （c） l = 180 °; （d） l = 270 °， distance ~ 0.5 kpc showing the Gum nebula

The projected 3D result

- Projection from line-of-sight distance to Cartesian coordinates
- Gaussian smoothing for the 3D result.
- The higher resolution can mitigate the “stream” situation

Summary

- The ultra-long wavelength reconstruction metho d relies on diffuse emission and is therefore not li mited by the number and direction of sources.
- Ultra-long wavelength observations provide a mo re accurate tracing of the 3D Local ISM in the vici nity of the solar system.
- Once the ultralong-wavelength sky is systematica lly surveyed, we will pin down the long-lasting de bate on the distance of the NPS.

A foreground is an effect whose dependence on cosmological parameters we cannot compute accurately from first principles at the present time.