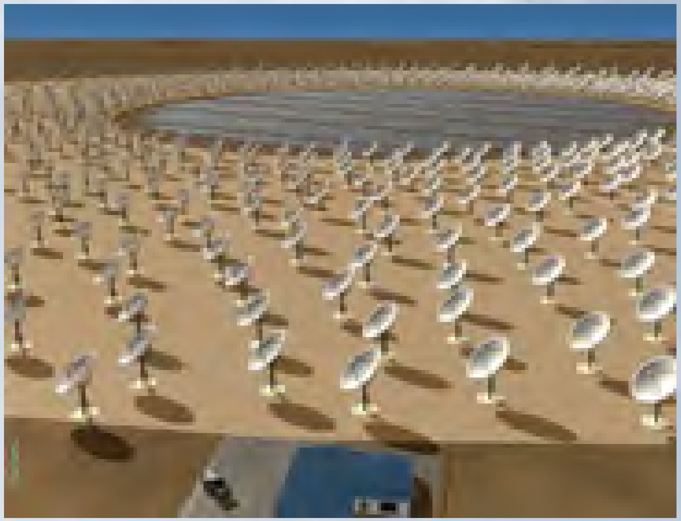
Australian Government
Bureau of Meteorology

# Radio Astronomy and the Ionosphere

John A Kennewell, Mike Terkildsen



*CAASTRO EoR Global Signal Workshop*

November 2012

Australian Government
Bureau of Meteorology

# THE IONOSPHERE

- UPPER ATMOSPHERIC PLASMA

  - The ionosphere is a weak (1%) variable plasma

  - It exists from about 80 to 1000 km altitude

  - Peak ionisation @ 300 km ($10^{10}$ - $10^{13}$ $e^-/m^3$)

- VARIABILITY

  - controlled by solar EUV / X-ray flux

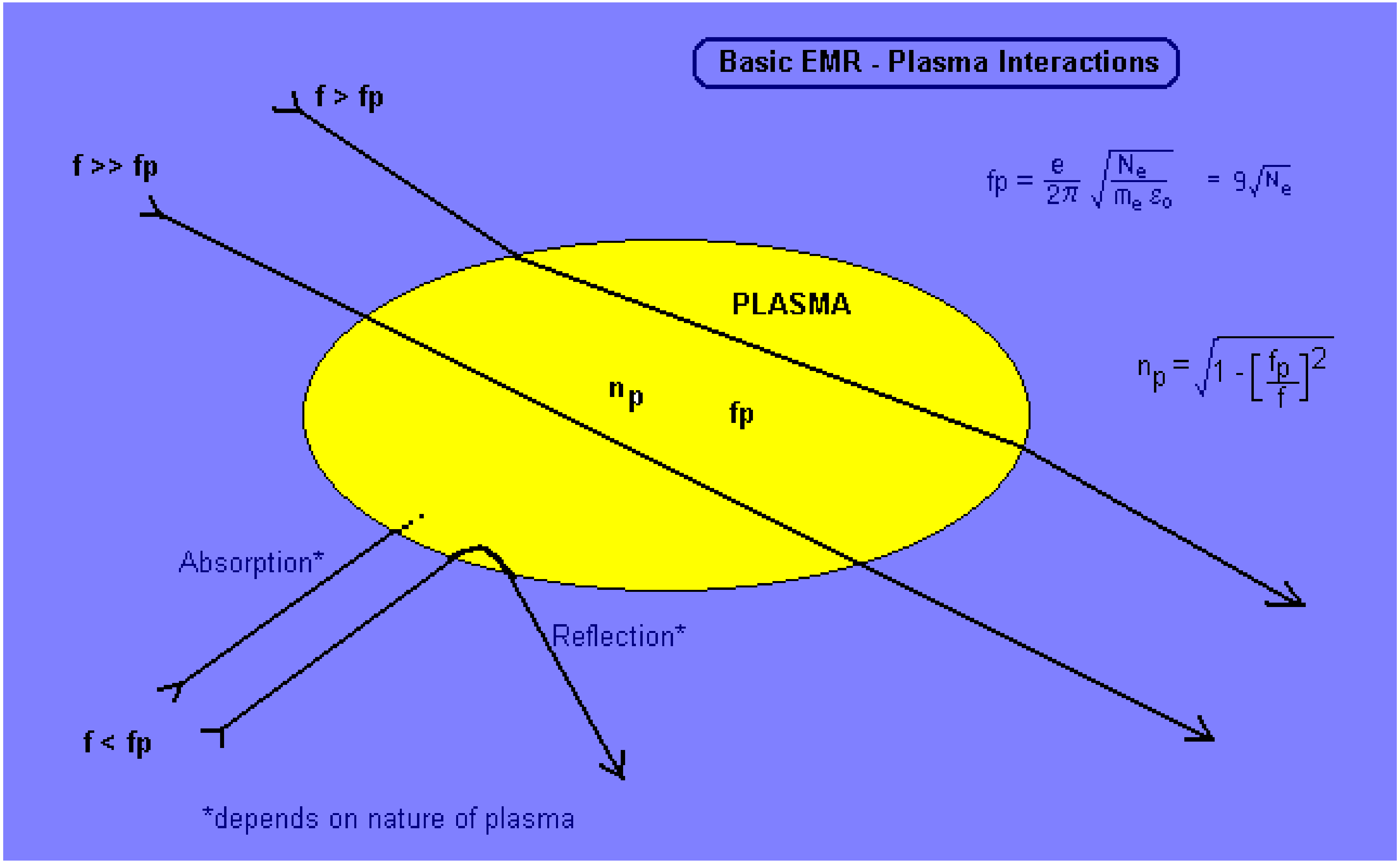
  - strongly influenced by the magnetosphere

- DISTURBANCES

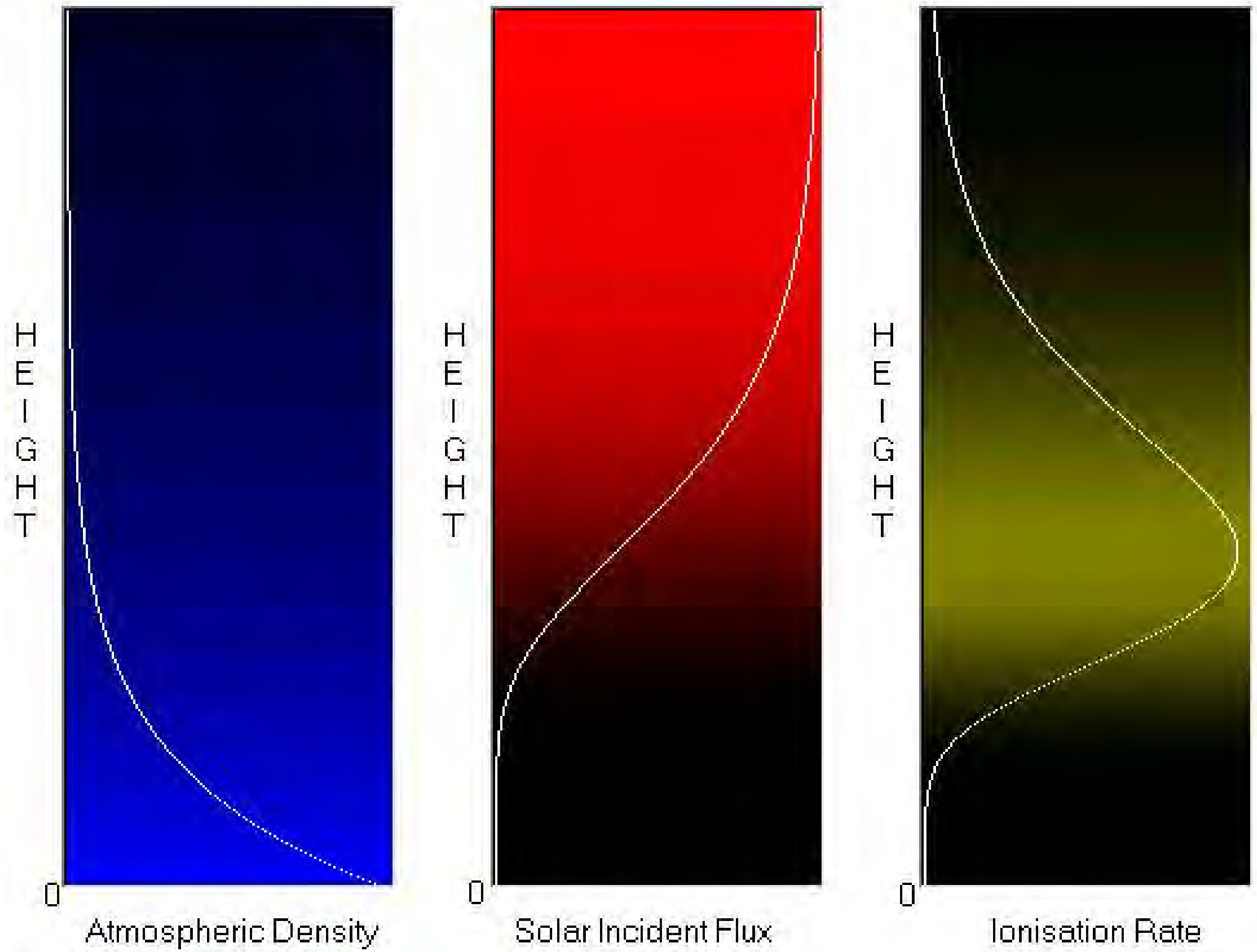
  - geomagnetic and solar

  - dynamic interactions with neutral atmosphere

# THE IONOSPHERE

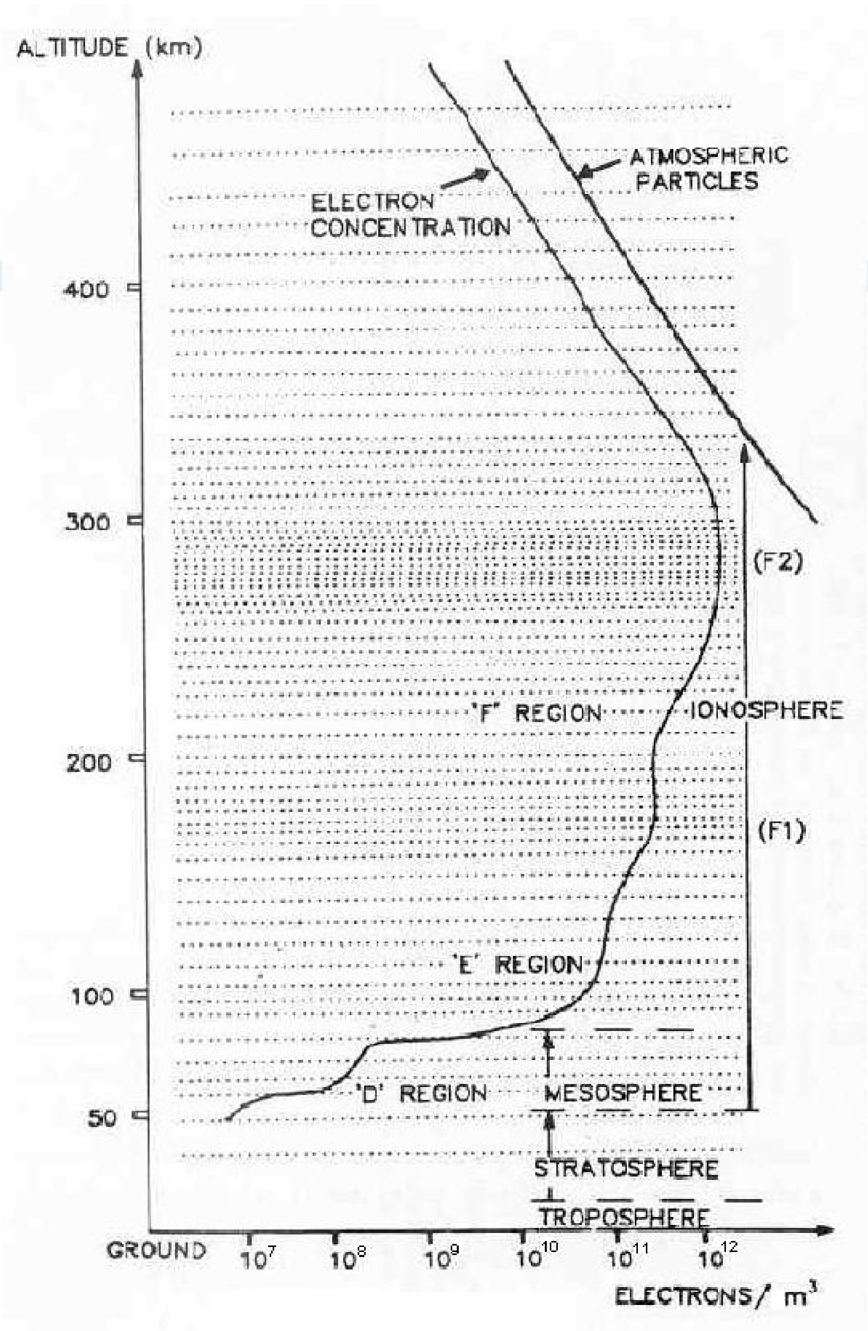


# FORMATION OF THE IONOSPHERE



Australian Government
Bureau of Meteorology

# TYPICAL IONOSPHERIC DAYTIME PROFILE



# IONOSPHERIC EFFECTS ON RADIO ASTRONOMY

- FIRST ORDER EFFECT

  - Plasma opacity

- SECOND ORDER EFFECTS

  - Refraction

  - Dispersion

  - Faraday Rotation

- THIRD ORDER EFFECTS

  - Scintillations

  - Decoherence

  - Variable refraction

  - Phase stability

- FOURTH ORDER EFFECTS

  - Emission / Radiation

Australian Government
Bureau of Meteorology

# FIRST ORDER EFFECT

- PLASMA OPACITY

  - plasma is opaque to radio waves below $f_c$

  - $f_c = 9 \sqrt{N_e}$

  - typical ionosphere $10^{10} < N_e < 10^{13}$ el/m$^3$

- AFFECTED FREQUENCIES

  - $f_c$ at zenith (typically 10 MHz max at MRO)

  - up to 5 $f_c$ at lower elevation (~ 50 MHz max)

- RADIO ASTRONOMY FIELDS

  - low frequency solar

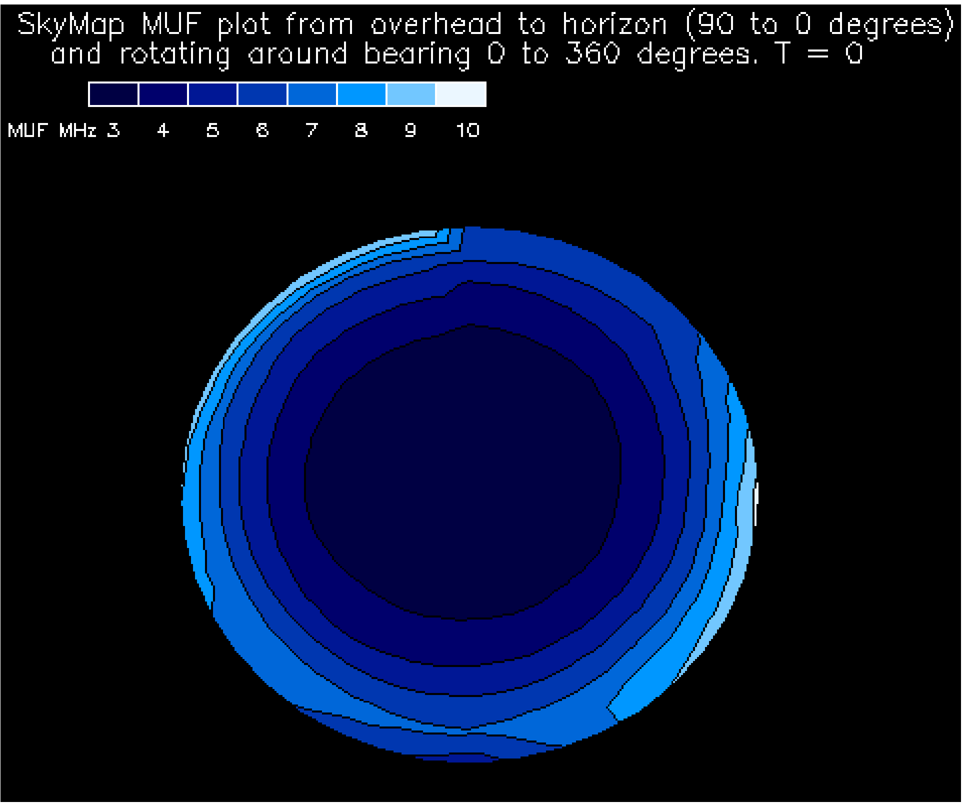
  - transients in interplanetary medium

  - jovian

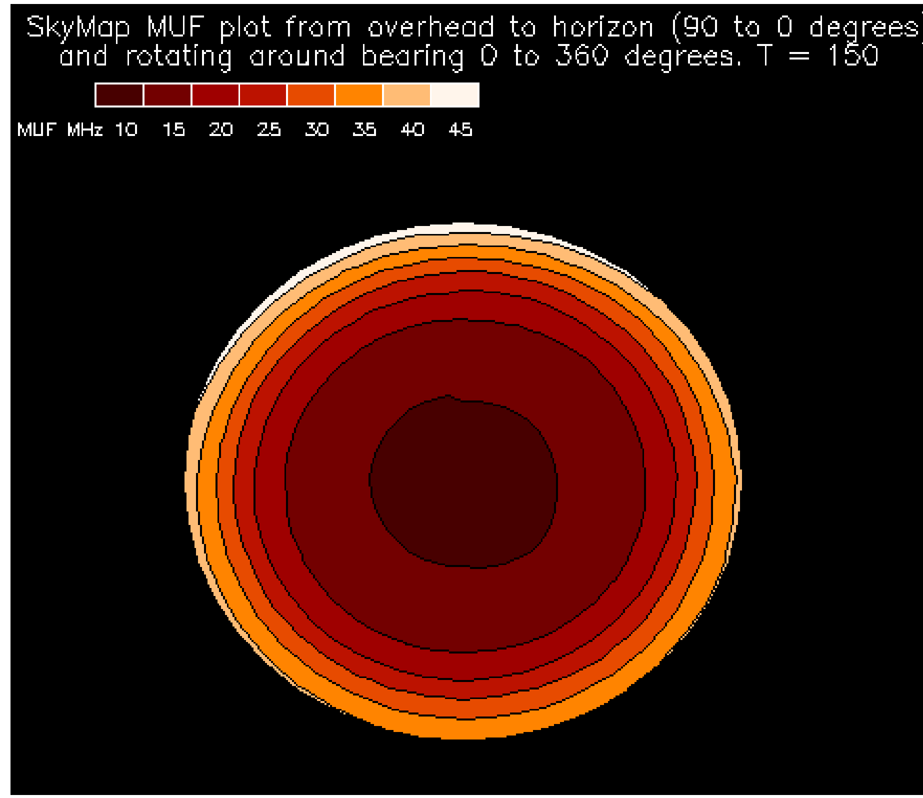
  - EoR if $z > 30$

# FIRST ORDER EFFECT - GRAPHICS

Australian Government
Bureau of Meteorology




Minimum ionosphere




Maximum ionosphere

# SECOND ORDER EFFECTS - QUIET IONOSPHERE

- REFRACTION

  - position changes / uncertainties

  - typically 1.5' at 100 MHz

- DISPERSION

  - pulse delay

  - typically 1.5 $\mu$sec at 100 MHz

  - may be significant below 1 GHz

- FARADAY ROTATION

  - polarisation change

  - typically 10 radians at 100 MHz

# THIRD ORDER EFFECTS - DISTURBED IONOSPHERE

- SCINTILLATIONS

  - image degradation

- VARIABLE REFRACTION

  - image distortion

- PHASE STABILITY

  - positional changes, decorrelation

- DECOHERENCE

  - long baseline effects (VLBI)

Significant effects for f<1 GHz        Very significant for f<100MHz

Fortunately at MRO (mid-latitudes) disturbances are generally small

Australian Government
Bureau of Meteorology

# FOURTH ORDER EFFECTS

- PLASMA RADIATION / EMISSION

  - the ionosphere is a hot plasma (~ 1500 K)

  - any emission is extremely small

  - however may be significant for EoR measurements

    (looking for a 25 mK change)

# TYPICAL IONOSPHERIC CHANGES IN RA MEASURES

| Quantity | Typical value<br><br>@ 100MHz | Frequency Dependence |
|---|---|---|
| Refraction | 1.5 arcminutes | $1/f^2$ |
| Polarisation | 10 radians | $1/f^2$ |
| Phase change | 1000 radians | $1/f$ |
| Path length | 500 metres | $1/f^2$ |
| Absorption | 0.01 dB | $1/f^2$ |

Australian Government
Bureau of Meteorology

# COLUMNAR ELECTRON DENSITY UNITS

- SI UNIT

  - the SI unit of columnar electron density is electrons/$m^2$

- IONOSPHERIC UNIT

  - this is the TECU or 'total electron content unit'

  - 1 TECU = $10^{16}$ electrons/$m^2$

- THE RADIO ASTRONOMY UNIT

  - the DM or Dispersion Measure in parsecs/$cm^3$

  - 1 DM (parsecs/$cm^3$) ~ 3 x $10^{22}$ electrons/$m^2$

    ~ 3 million TECU

  - Interstellar DM for pulsars 10's to 100's

- IONOSPHERIC TEC RANGE

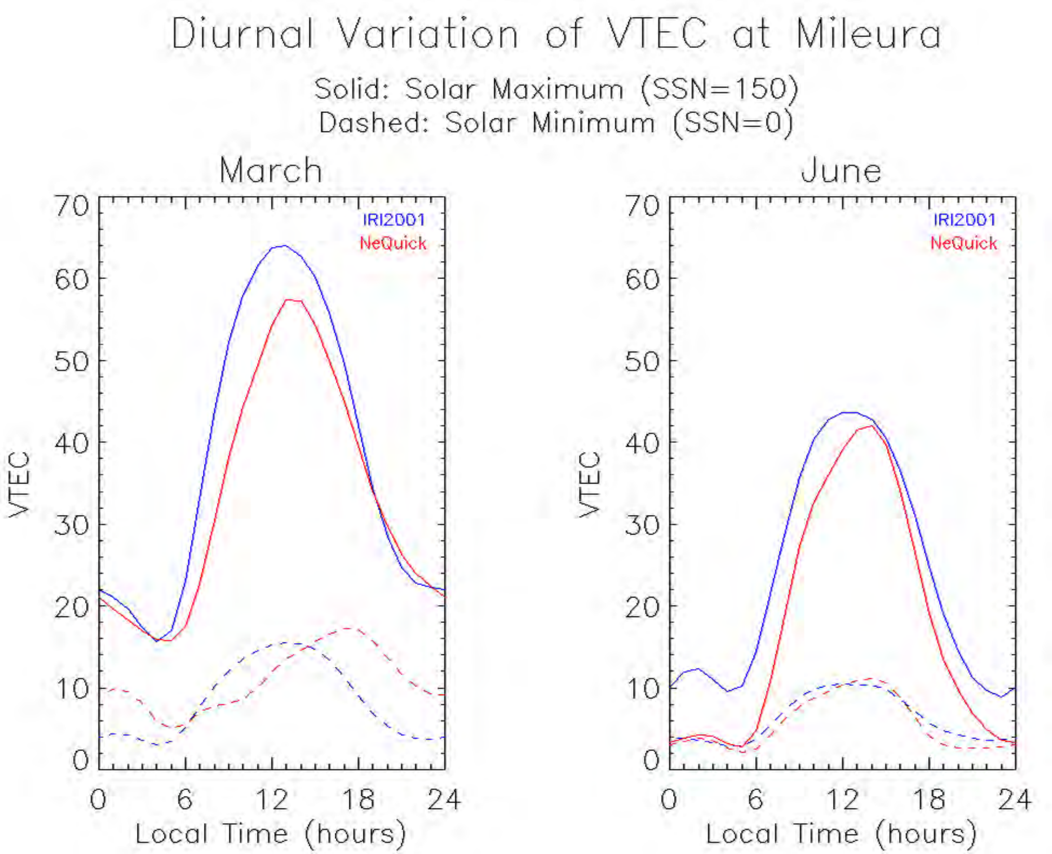
  - VTEC from 1 to 100 TECU

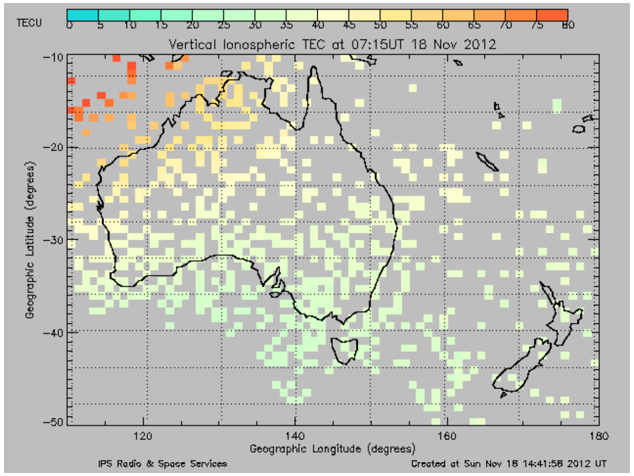
  - STEC may go to 500 TECU

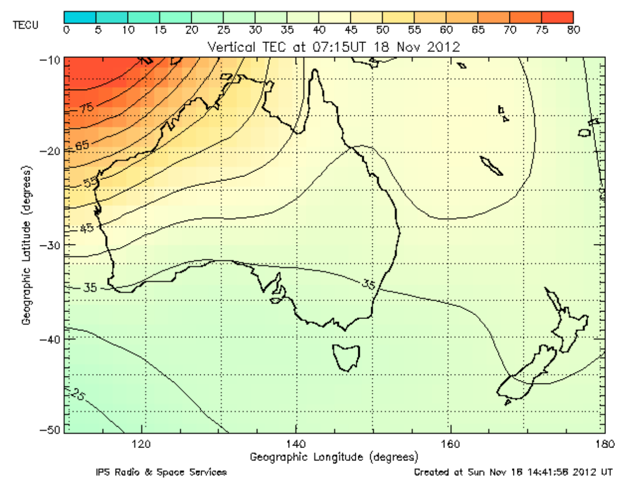
  - Ionospheric DM usually insiginificant

Australian Government
Bureau of Meteorology

# IONOSPHERIC TEC VARIATION



Australian Government
Bureau of Meteorology

# ROTATION MEASURE UNITS

- In Radio Astronomy rotation measure RM is measured in units of rad $m^{-2}$.
- Ionospheric RM ~ 1 rad $m^{-2}$
- Most RA sources have RM's much larger than the typical ionospheric RM

# SCINTILLATION COMPARISON

Ground-based radio astronomy observes three different scintillation sources:

| **Region** | **Timescale** | **Critical Source Size** |
|---|---|---|
| Ionosphere | 30 seconds | < 10' |
| Interplanetary (IPM) | 1 second | < 2" |
| Interstellar (ISM & IGM) | Days, months, years | ? (only GHz signals?) |

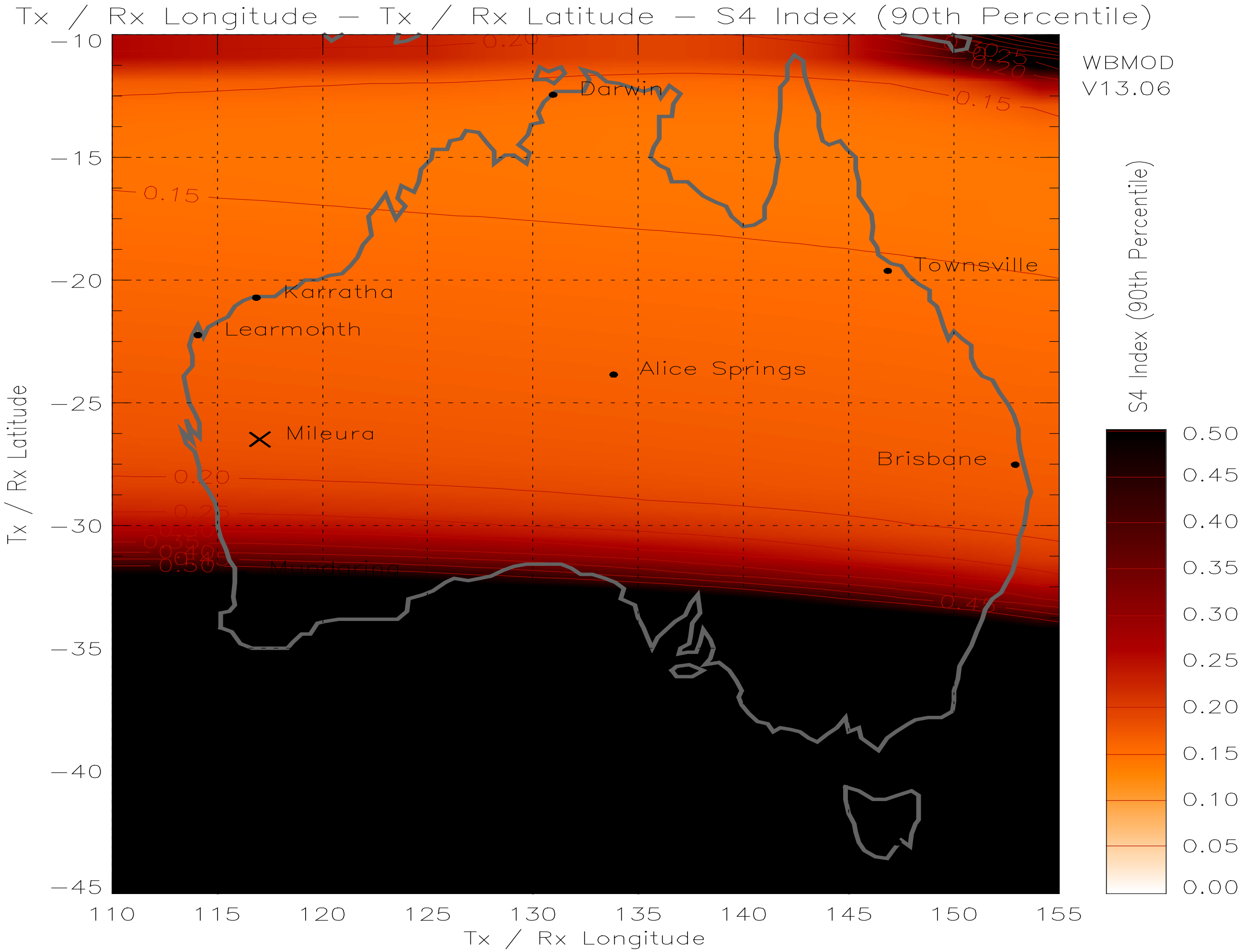
The table above refers to a frequency of 100 MHz.

Australian Government
Bureau of Meteorology

# IONOSPHERIC SCINTILLATION

$$(S_4)^2 = (\langle I^2\rangle - \langle I\rangle^2) / \langle I\rangle^2$$

$S_4$ is the square root of the normalised variance of the signal intensity




S4 scintillation index for worst case conditions - very high sunspot number and severe geomagnetic storm in progress.

Australian Government
Bureau of Meteorology

# EXTREME EXAMPLES

- Although ionospheric plasma adds negligible dispersion to pulsar signals, the dispersion of very narrow pulses (eg 1 ns) expected to result from neutrino impact on the lunar regolith is very significant.

- Although we would not expect the ionosphere to effect transionospheric signals at 24 GHz, it is in fact now the largest source of error (~1cm) in highly accurate VLBI.

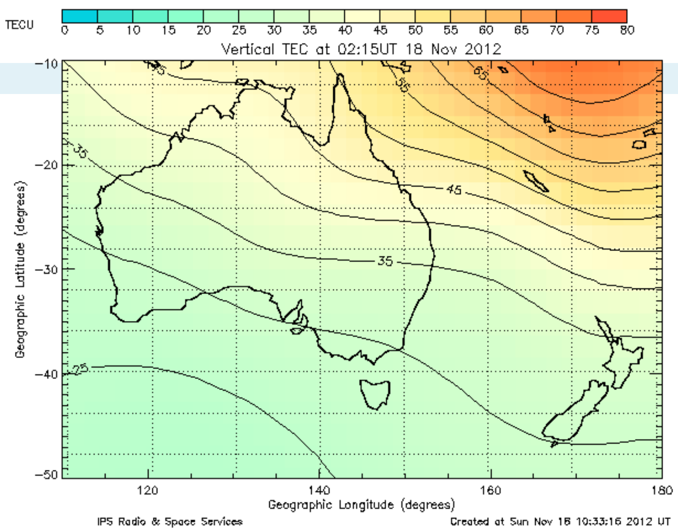
Australian Government
Bureau of Meteorology

# EPOCH OF REIONISATION

- Looking for an extremely small spectral change (~ 25 mK) in a sky temperature of 100's to 1000's K (latter when f < 100 MHz)
- We really do not know how the ionosphere will effect this measurement
- Inhomogeneitieis across the sky (these will vary with time and may average out?)
- Even the very small emission from a hot plasma may be important?

Australian Government
Bureau of Meteorology

# IONOSPHERIC SUPPORT FOR RA




**http://www.ips.gov.au/Satellite**

CLIMATOLOGY

- to allow project planning

ARCHIVE DATABASE

- values of TEC (GPS-derived) and S4
- quick look ionospheric maps and detailed time series (post processed and near real time)
- help in assessing data quality
- help in data reduction/analysis

DEDICATED SUPPORT

- for specific projects
- eg LUNASKA, high accuracy VLBI