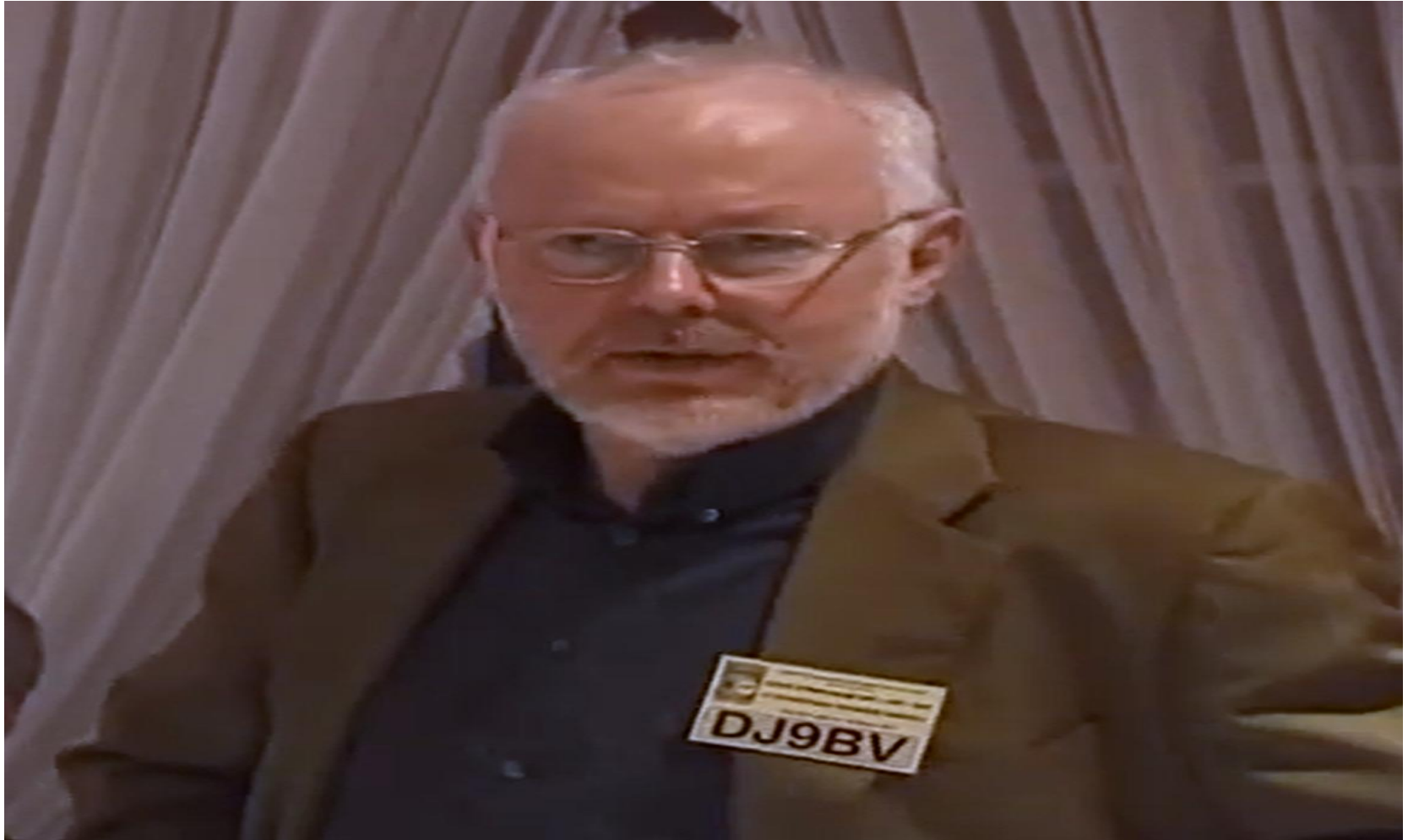


**Beyond DJ9BV-
A high-resolution antenna
temperature calculator
'Skynoise'**

John Sager G8ONH & John Regnault G4SWX

© J Sager & J Regnault 2026

Rainer Bertelsmeier DJ9BV (SK)

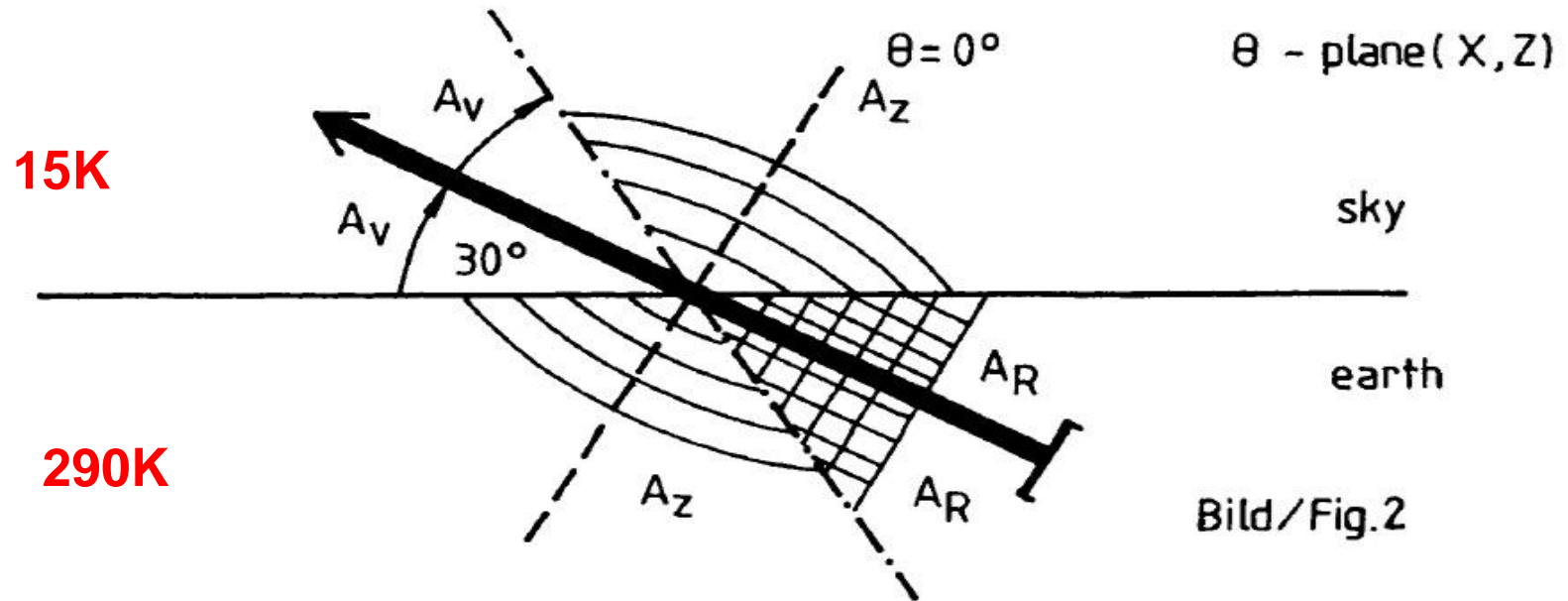


DJ9BV's Approximation of Antenna Temperature 1987 (a)

A Simulation of antenna array properties

- Produced using NEC2 simulations with 3-degree steps in Φ & ϕ on a Sun 3/160 workstation.
- By comparison a modern Core i7 as used by G4SWX for NEC4 simulations is >10,000 times faster in raw computing performance.
- ~100 minutes in 1987 for 3-degree steps vs <10 secs in 2026 for 1-degree steps in Φ & ϕ including a 4NEC2 software wrapper.

DJ9BV's Approximation of Antenna Temperature 1987 (b)



$$T_A = \frac{A_v T_{sky}}{A} + \frac{A_z T_{sky}}{2A} + \frac{A_z T_{earth}}{2A} + \frac{A_r T_{earth}}{A}$$

So we arrive at:

$$T_A = T_v + T_z + T_r \quad (3)$$

with

"Forward temperature": $T_v = \frac{A_v T_{sky}}{A}$

"Sidelobe temperature": $T_z = \frac{A_z \cdot (T_{sky} + T_{earth})}{2A}$

"Backward temperature": $T_r = \frac{A_r T_{earth}}{A}$

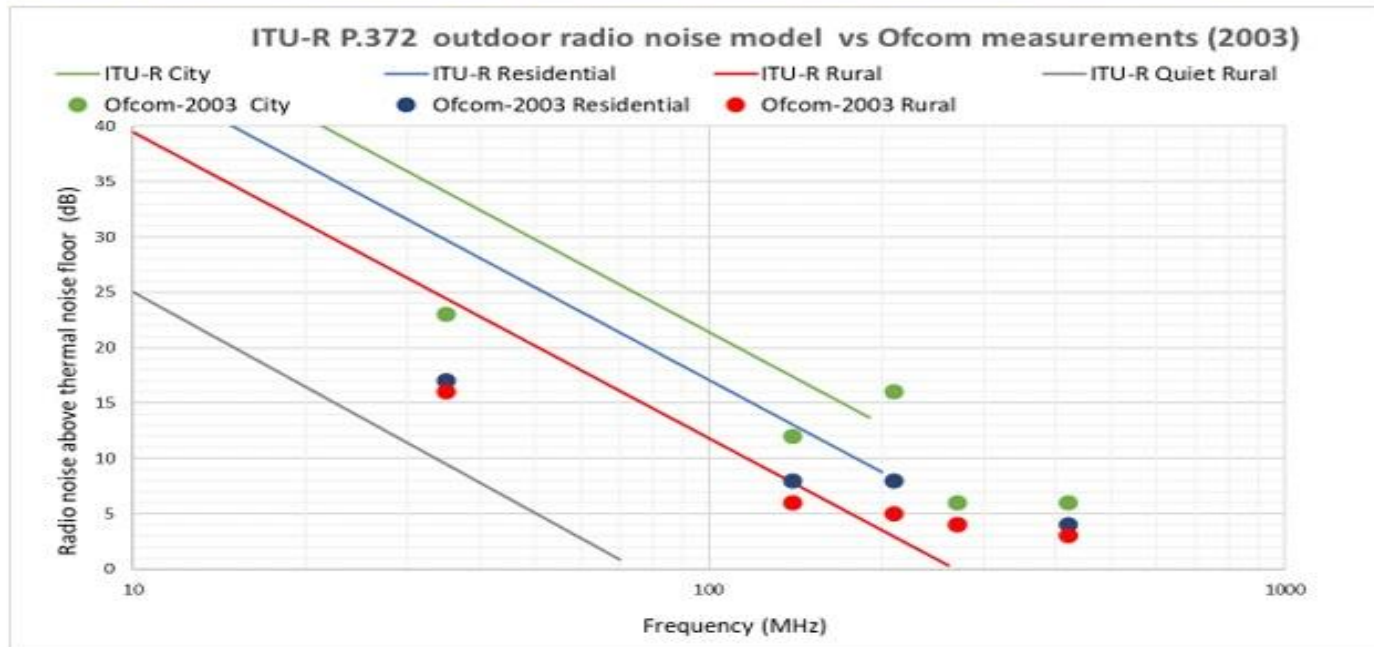
Satisfactory on 432MHz but Elsewhere?

- The approximation is good on 432MHz when $T_{\text{sky}} \ll T_{\text{ground}}$
 - i.e. $T_{\text{sky}} = 15\text{K}$ & $T_{\text{ground}} = 290\text{K}$
 - Rear end clutter \approx front lobe + 1st sidelobes
- Significant errors on 144MHz where T_{sky} is of the same order as T_{ground} .
 - i.e. $T_{\text{sky}} = 200\text{K}$ & $T_{\text{ground}} = 290\text{K}$
 - Front lobe + 1st sidelobes \gg rear end clutter
- Irrelevant on 50MHz where $T_{\text{sky}} \gg T_{\text{ground}}$
- Some have played with T_{sky} and T_{ground} numbers to produce tables!

Choice of Ground Noise Temperature?

- Some have proposed using figures based upon ITU-R P.372
- This model is a statistical model for a grounded monopole antenna
- Not a directive array at some height above ground
- Whilst it can be recalculated for the main lobe at a given height
- Not easy for the sidelobes with different ground angles.
- **~290K is the most appropriate choice**

Figure 9: Comparison of ITU-R P.372 prediction method with Ofcom's 2003 measurements



Other Software

- **Antenna Noise Temperature Calculator**

By R Galluscak OM6AA et al

DUBUS 3/2009

- **Used CST Microwave Studio or FEKO antenna data**
- **Used tables of environmental noise**
- **Useful for dishes rather than Yagi arrays**

Sky Temperature References

- **Haslam et al (1982) 408MHz all-sky survey**
 - Basis of most subsequent VHF/UHF datasets
- **Platania et al. (2003)**
 - Removed instrumental artifacts from Haslam data
- **Remazeilles et al. (2015)**
 - The chosen data set for this project
 - Re-processing of Haslam with modern algorithms
 - Available on NASA's Lambda server
- **Lawson et al. (1987)**
 - Extragalactic noise corrections
- **Irfan & Puglisi (2025)**
 - Recent spectral index figures

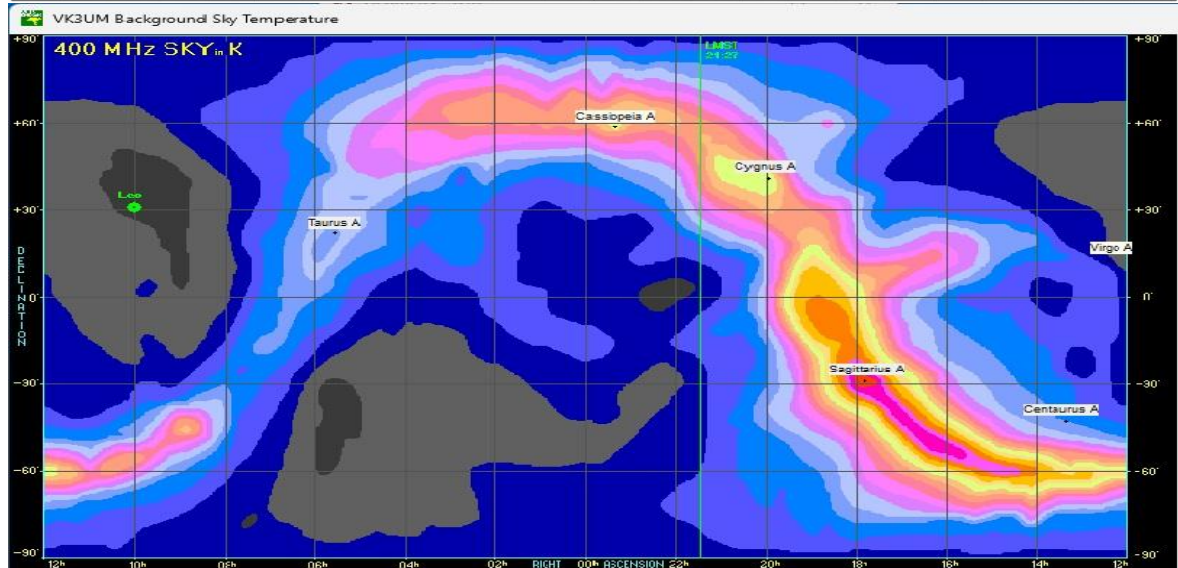
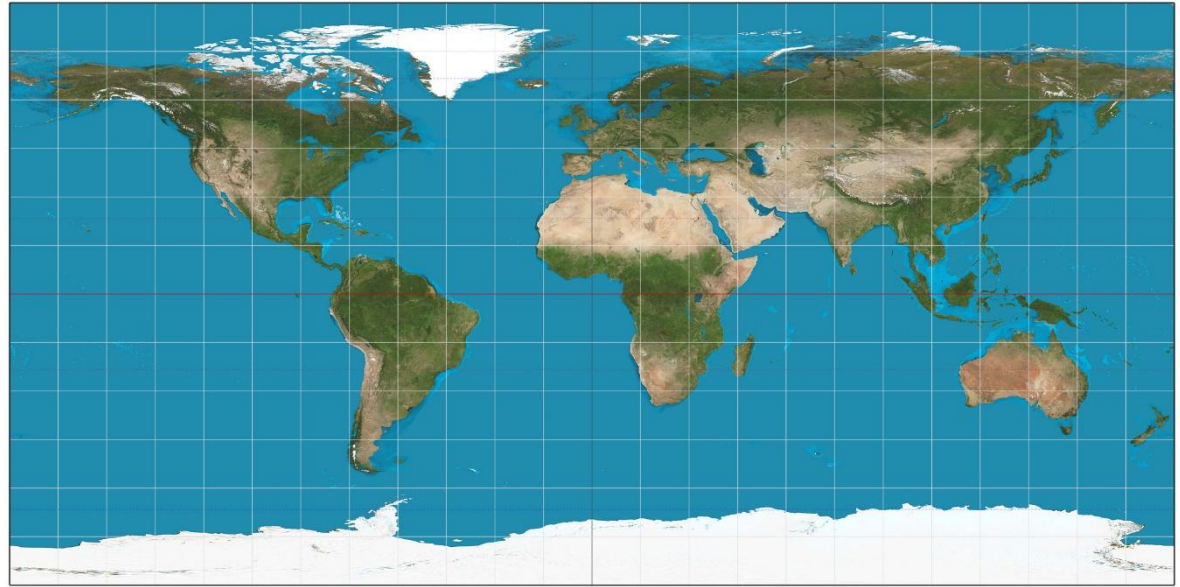
Map Projections - 1

Equirectangular Projection

Invented by Marinus of Tyre about AD100

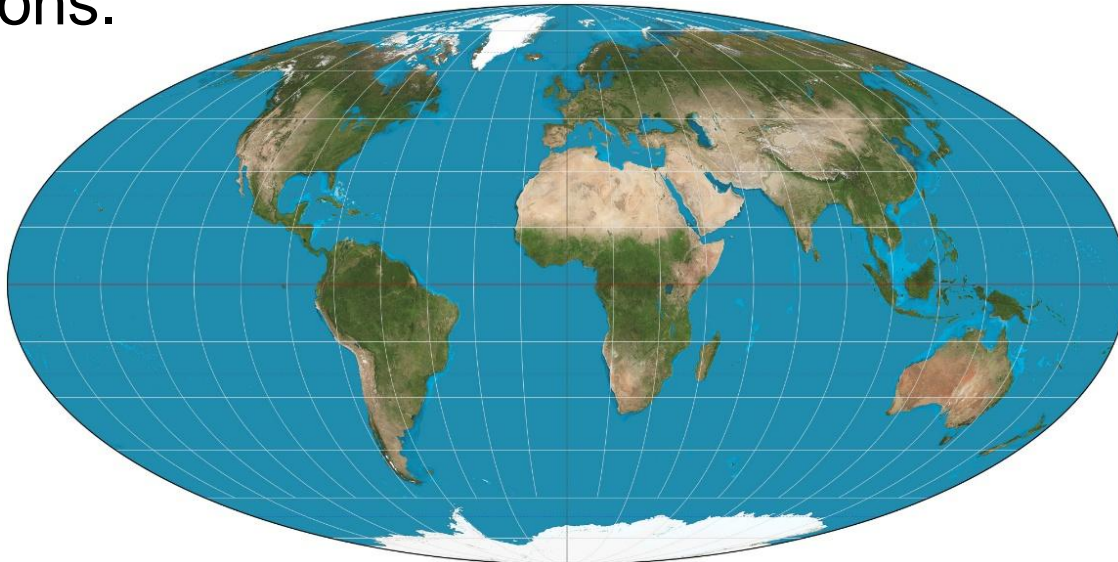
Familiar but:

- Significant distortion
- Inefficient data usage



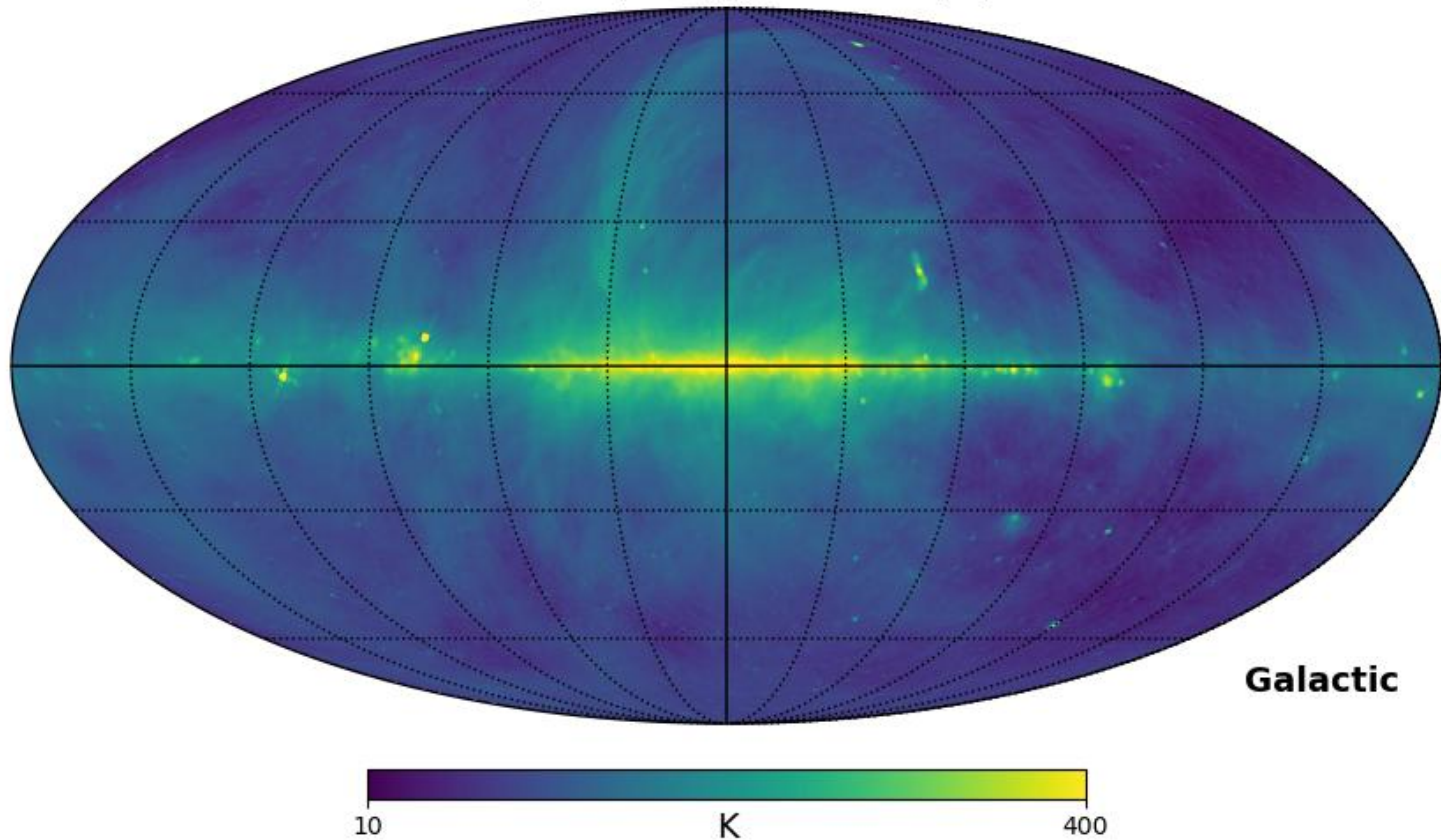
Map Projections - 2

- The **Mollweide** projection is an equal-area, pseudo-cylindrical map projection generally used for maps of the world or celestial sphere.
- The projection was first published by mathematician and astronomer Karl Brandan Mollweide in 1805.
- The projection trades accuracy of angle and shape for accuracy of proportions in area, and as such is used where that property is needed, such as maps depicting global distributions.



Map Projections -3

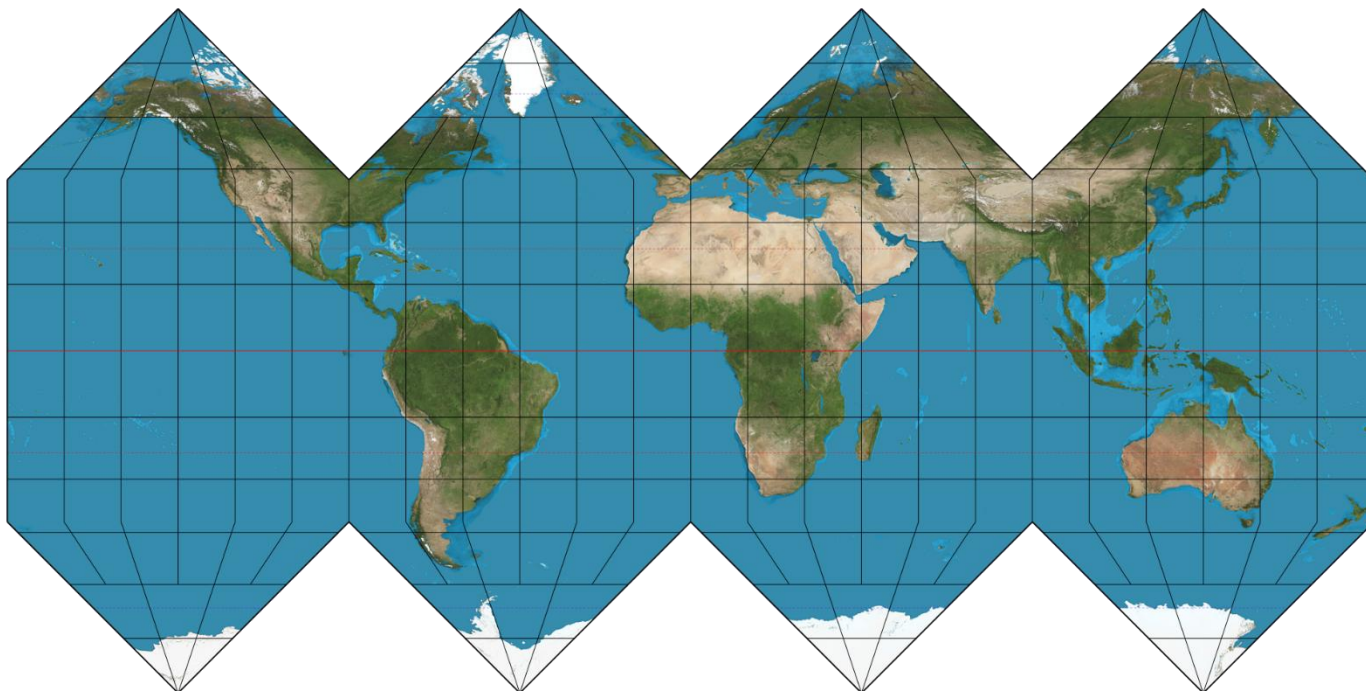
408MHz Sky Temperature in Mollweide projection



This is the sky map produced from the Haslam 408MHz data as reprocessed by Remazeilles downloaded from the NASA server.

Map Projections - 4

- **HEALPix**, an acronym for Hierarchical Equal Area isoLatitude Pixelisation of a 2-sphere, is an algorithm for pixelation of the 2-sphere and the associated class of map projections.
- This pixelisation algorithm was devised in 1997 by Krzysztof Gorski at the Theoretical Astrophysics Center in Copenhagen



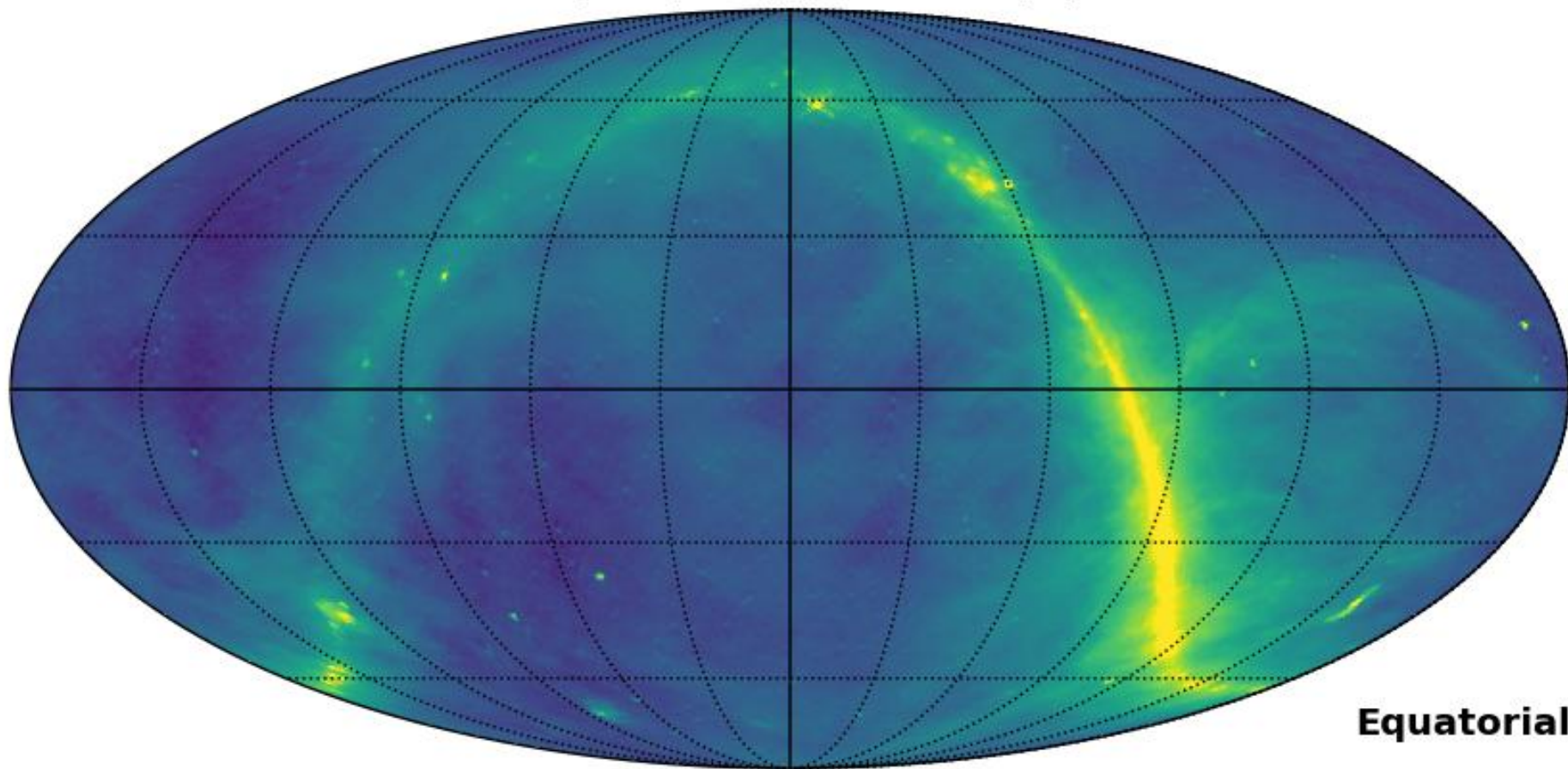
HEALPix
projection of
the world.

Producing Derived Sky Temperature Maps

- HEALPix data format,
- Reference epoch: J2000
- Remazeilles sky map in HEALPix
- Each point is Equal Area on sphere
- 3M data points in Galactic coordinates
- Reduced to 197K in Equatorial coords (RA,Dec)
- $T_{144} = kT_{408} + Ca$; $k = (408/144)^{2.56}$
- $T_{432} = kT_{408} + Cb$; $k = (408/432)^{2.617}$
- C(a,b) extragalactic noise corrections
- Map files produced for both 144MHz & 432MHz

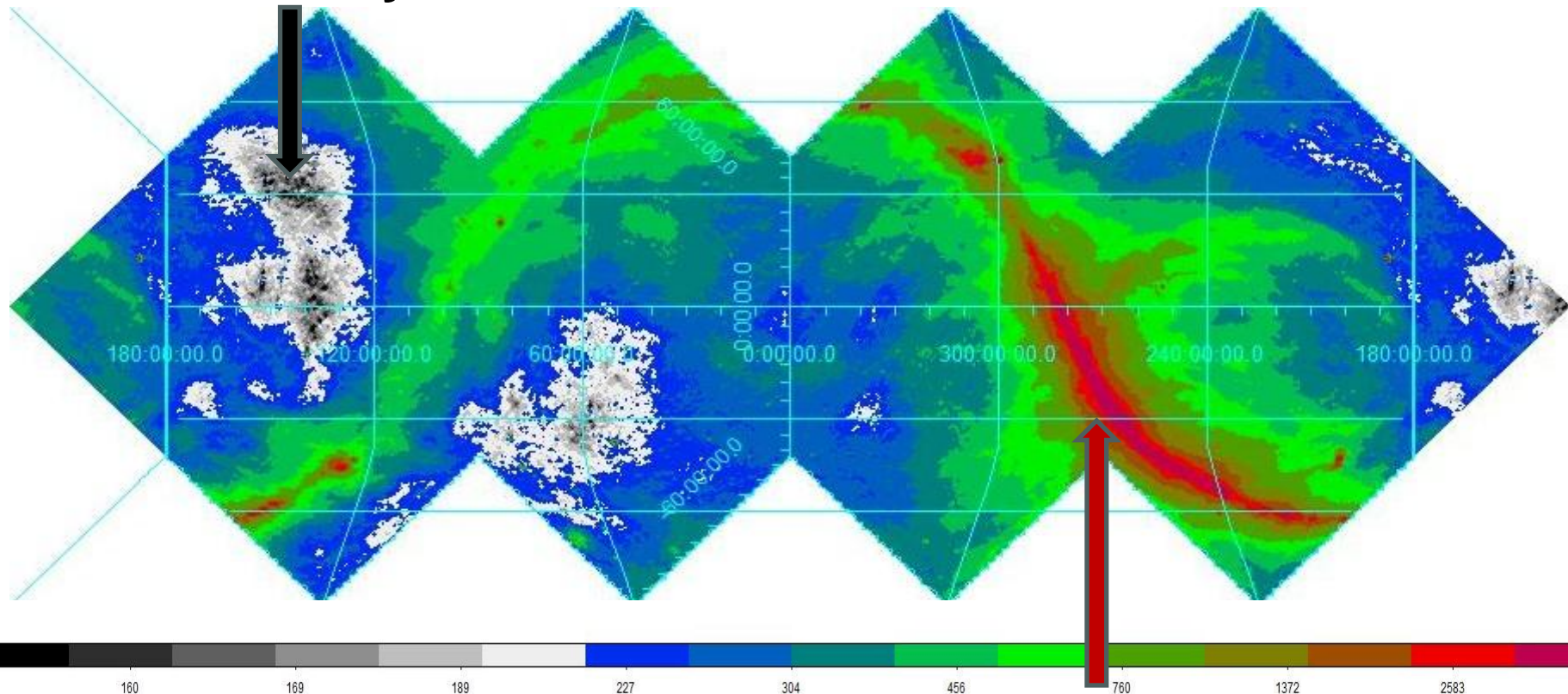
144MHz Sky Temperature Mollweide Projection

144MHz Sky Temperature in Mollweide projection



144MHz HEALPix Sky Noise Map

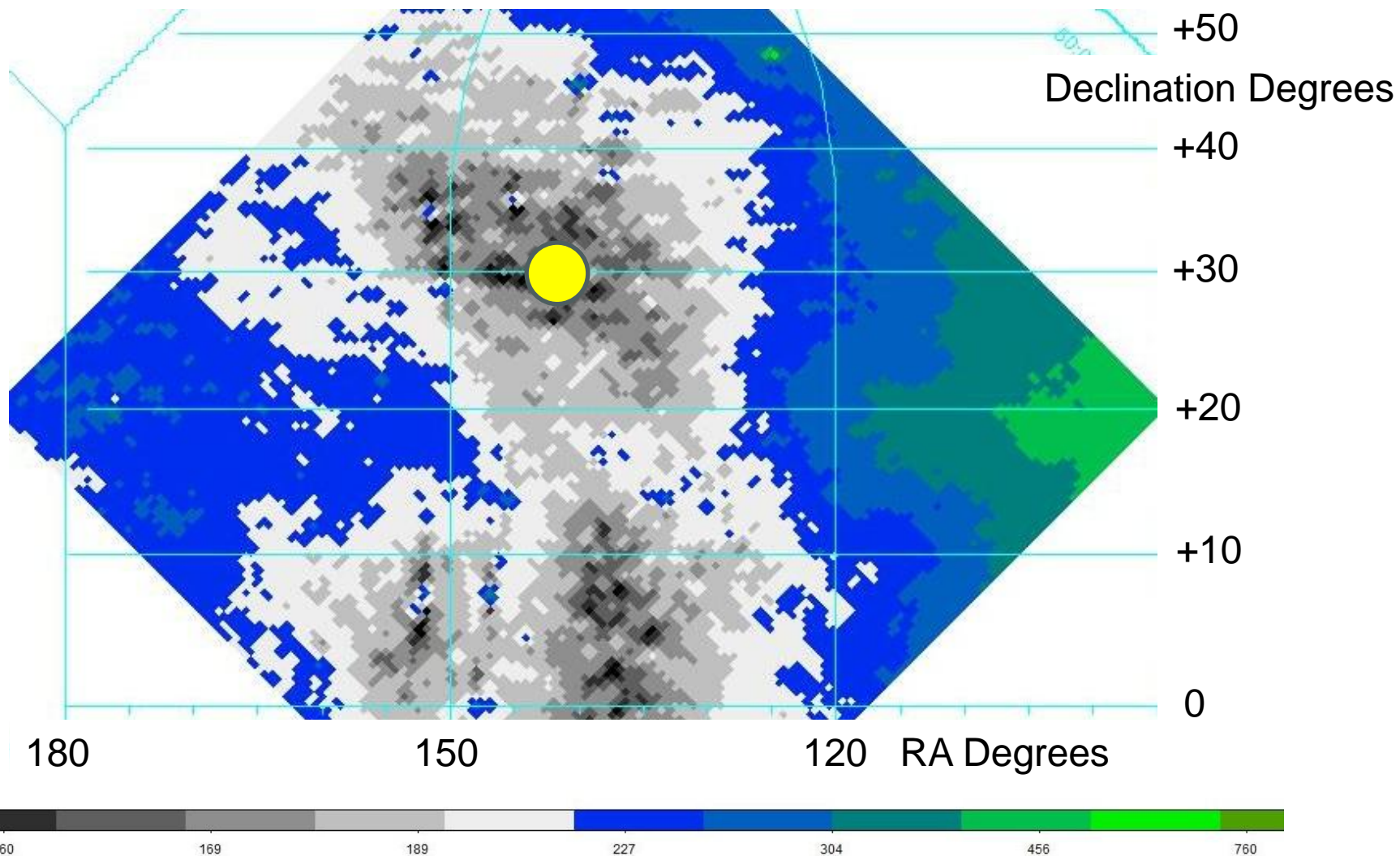
Quietest Sky ~170K



Noisiest sky ~6000K

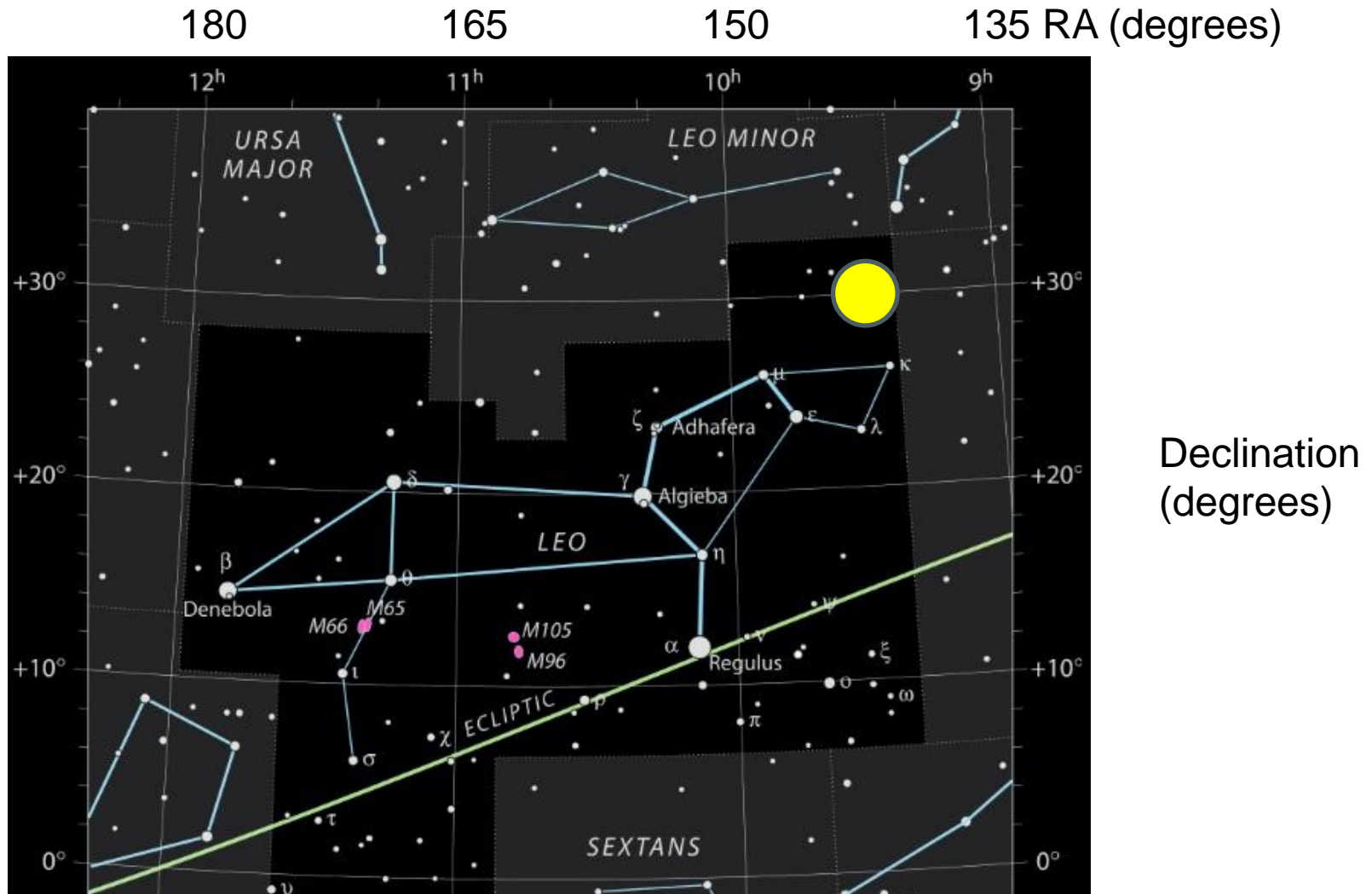
RA is 0 to 360 degrees
Dec is -90 to +90 degrees

144MHz Quiet Sky



 = position to beam at quietest sky ~170K 142 RA +30 Dec

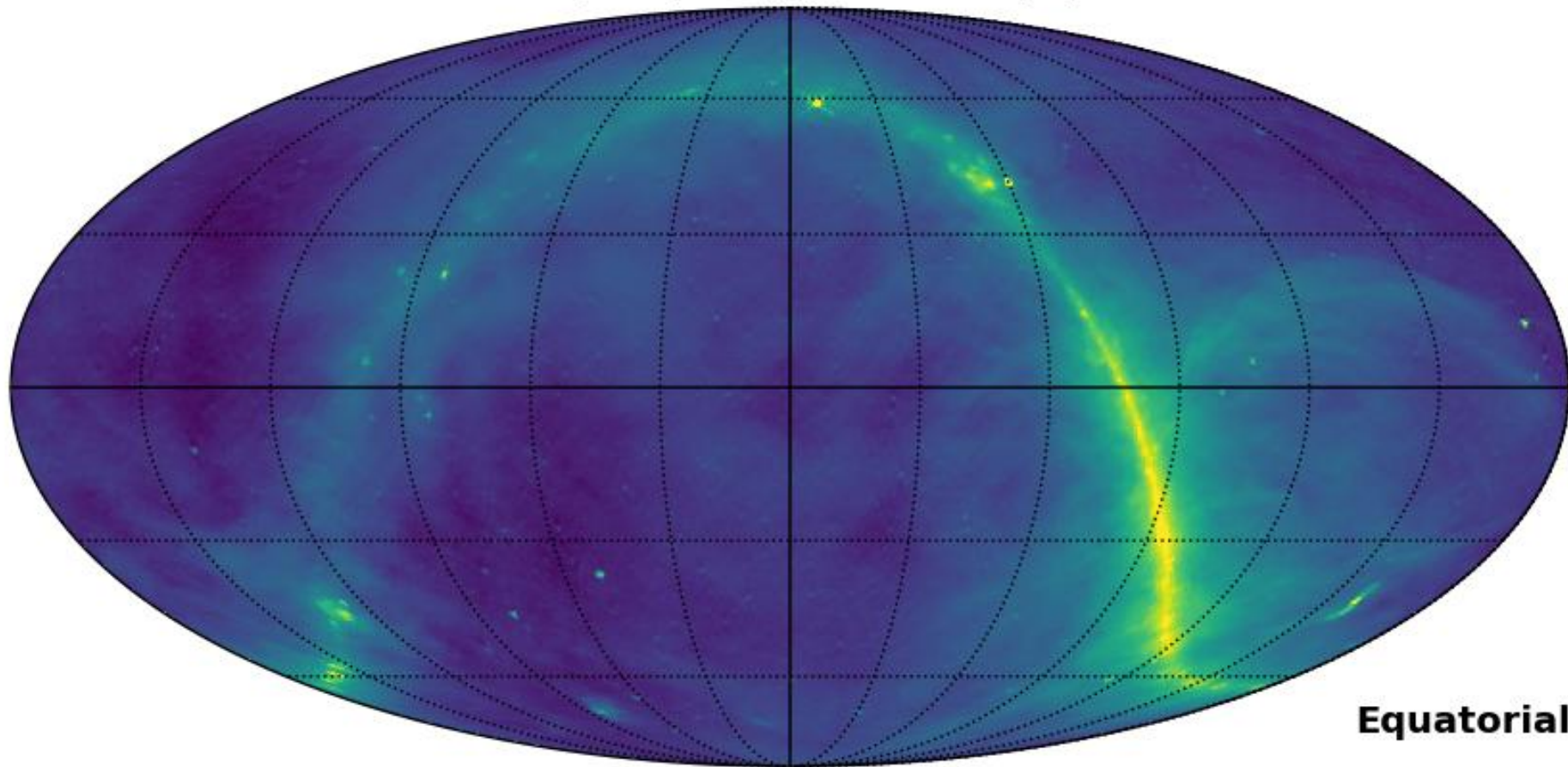
Beaming at Leo?



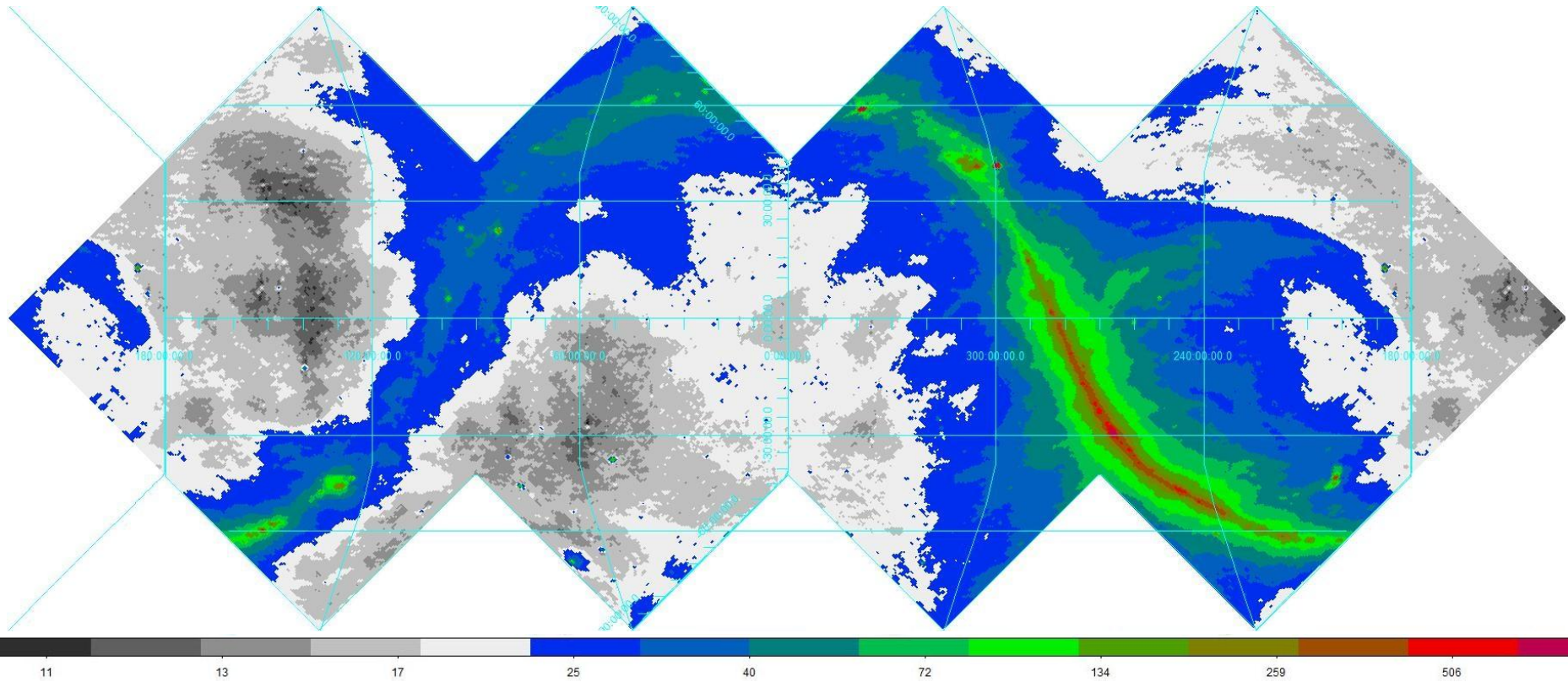
☀ = position to beam at quietest sky 142 RA +30 Dec

432MHz Sky Temperature Mollweide Projection

432MHz Sky Temperature in Mollweide projection



432MHz HEALPix Sky Noise Map



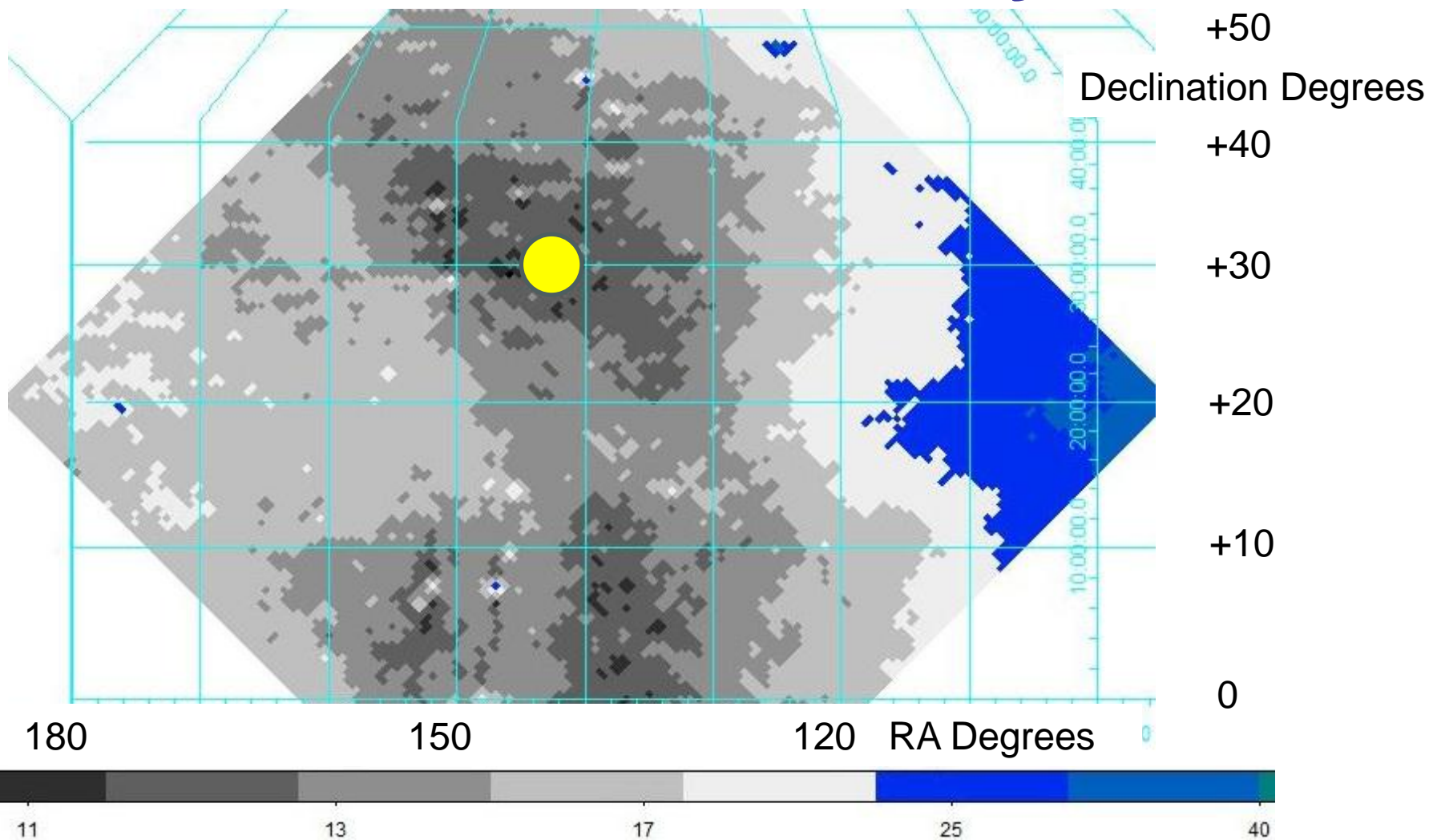
RA is 0 to 360 degrees

Dec is -90 to +90 degrees

Quietest sky ~11K

Noisiest sky ~1200K

432MHz Quiet Sky



 = position to beam at quietest sky ~11K 142 RA +30 Dec

Skynoise An Improved Method of Calculating Antenna Noise Temperature

Written in Python

- Numpy for array/matrix arithmetic
- Astropy-healpix for interpolation
- Reads NEC model vectors (ϕ, θ) , then calculates RA, Dec for each from QTH Lon, Lat, Antenna Az, El, Time
- Interpolates temperatures (T) from sky data set with RA, Dec arrays
- Reads gain (G) from NEC data
- Integrates 360 degrees Az and 180 degrees El (+/- 90)

$$T_{ant} = \frac{\sum_{\phi=0}^{359} \sum_{\theta=0}^{180} T(\phi, \theta) G(\phi, \theta) \sin(\theta)}{\sum_{\phi=0}^{359} \sum_{\theta=0}^{180} G(\phi, \theta) \sin(\theta)}$$

Temperature for vectors below horizon set to 290K

<https://pypi.org/project/skynoise>

Calculation of Antenna Noise Temperature

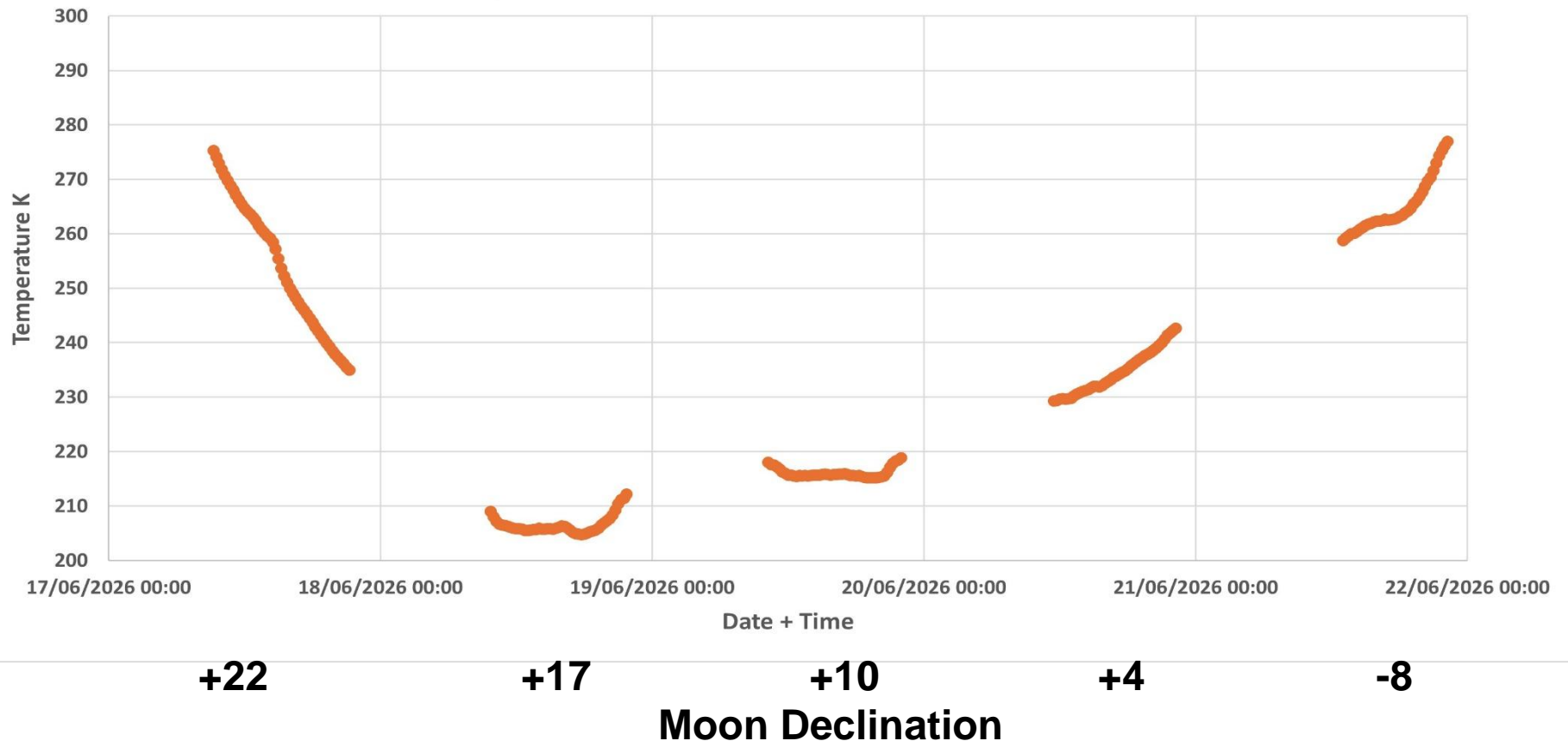
- Whilst beaming at quiet sky
- Whilst beaming at the moon
 - A month of moon passes
 - Elevation above 10 degrees
 - Ground reflections are not included
 - Moon noise is not included
 - Sun position/noise contribution is not included
- More revealing of Yagi antenna array performance than any existing method.

Calculated Antenna Temperature

June 2026 17-22nd Moon Passes

G4SWX 4 X 15OWL 144MHz array in JO02RF

Antenna Temperature Moon 17-22nd June 2026 144MHz 15OWL
Stacking distance is DL6WU calculated



There will be a lot more detail in the 2nd part of the presentation

Beyond DJ9BV – Skynoise Program

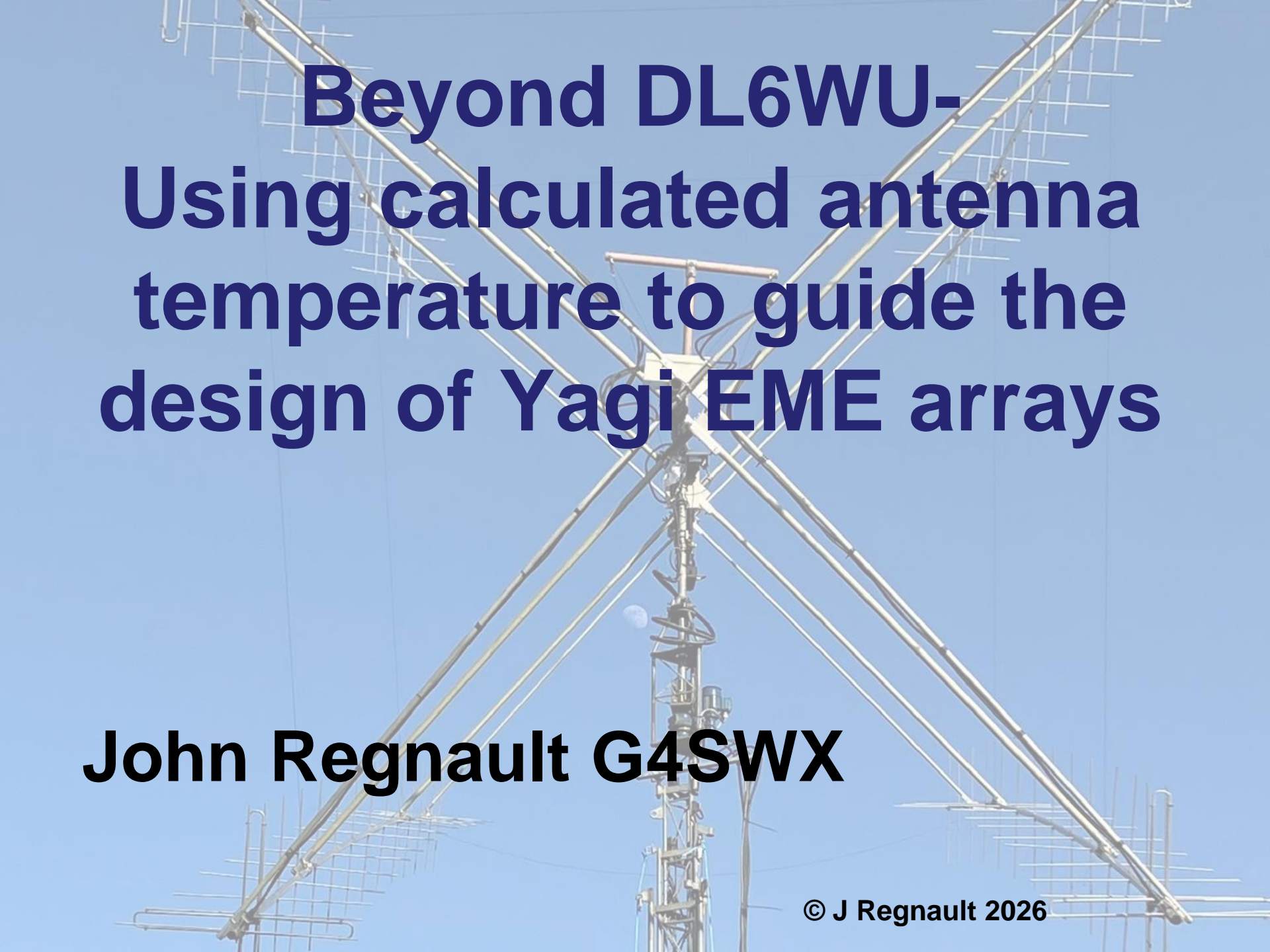
- Takes a NEC model output file computed for one-degree steps.
- Computes the integration of the pattern against new sky temperature maps (144 & 432MHz).
- Produces a calculated antenna temperature.
- Can then be further applied for the moon position during moon passes.

Questions on Part 1?

- <https://pypi.org/project/skynoise>

The screenshot shows the gskynoise.py application window. It features several data panels:

- File Selection:** Buttons for "NEC File" and "Ini File".
- Frequency:** A checkbox for "432MHz" which is currently unchecked.
- Time (UTC):** 10:16:58
- LMST:** 21:27:07.2
- Antenna (Top):**
 - RA: 259.6°
 - Dec: 30.0°
- Antenna (Bottom):**
 - Azimuth: 269.0°
 - Elevation: 40.0°
- Moon (Left):**
 - Azimuth: 264.6°
 - Elevation: -23.6°
- Moon (Right):**
 - RA: 220.8°
 - Dec: -21.7°
- Temperature:** 564.1K

A large Yagi EME antenna array is shown against a clear blue sky. The array consists of a central vertical mast with a spiral antenna at the top, and several long, thin boom arms extending outwards. Each boom arm has multiple horizontal elements. A small, crescent moon is visible in the sky behind the central mast.

Beyond DL6WU- Using calculated antenna temperature to guide the design of Yagi EME arrays

John Regnault G4SWX

100 Years of Yagi-Uda Antennas

Hidetsugu Yagi and Shintaro Uda



Guenter Hoch DL6WU (SK)



What Did DL6WU Publish in 1979?

- **Defined optimum spacing for stacking directional antennas**

$$D_{\text{opt}} = \lambda / (2 * \sin(\theta/2))$$

Where θ is the 3dB single antenna beamwidth

He also proposed:

- **The first side lobe will be approximately 13dB down on the main beam**
- **It may be acceptable in many cases to reduce the spacing to 0.75 of D_{opt}**
- **However @ D_{opt} first Yagi sidelobes are ~-11dB**
- **Below 0.8 D_{opt} the higher order sidelobes grow significantly.**

Beyond DL6WU- this talk:

- **Define using Skynoise and a NEC model, the antenna temperature of a 4 Yagi EME arrays against 'quiet sky'.**
- **Study 144 & 432MHz antenna temperature & G/T with stacking distances.**
- **Calculate the antenna temperature and G/T during a number of moon passes, 144 & 432MHz.**
- **Compare a few Yagi designs on 144 & 432MHz during several moon passes.**
- **Extrapolation of results to 50, 220 & 1296MHz.**

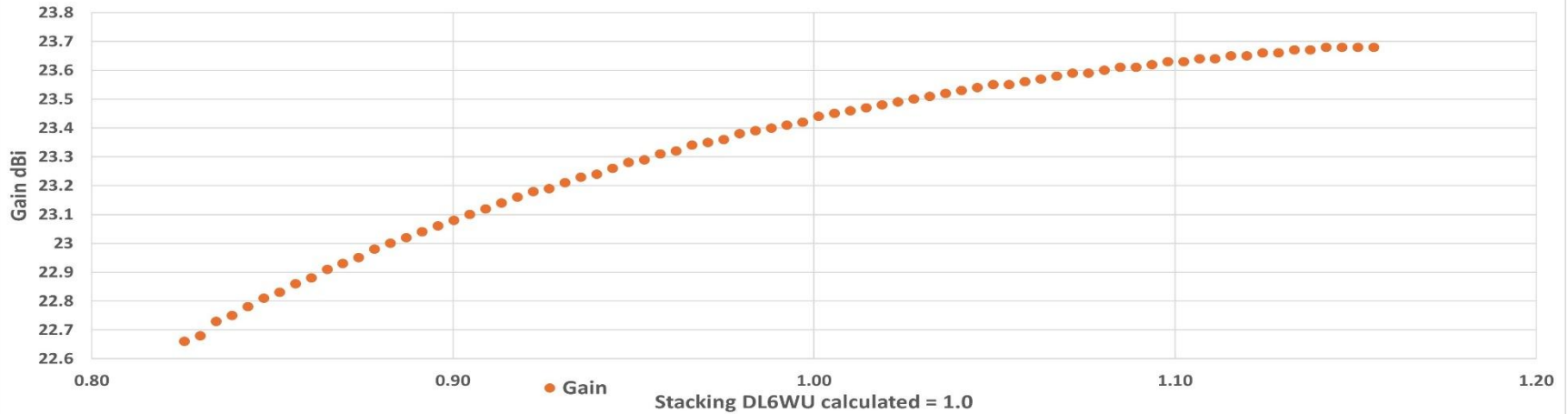
To Simplify Things – a little!

- **Four Yagi antennas are stacked with equal V & H distances. Normal for X-pol arrays.**
- **Antenna patterns modelled with NEC4 with 1-degree resolution, 18 segments/half wave.**
- **DL6WU stacking distance calculated from a single Yagi Vertical polarisation pattern.**
- **Antenna Temperature calculated at 45-degrees elevation from JO02RF beaming at 142 RA 30 Dec**
 - 30-degrees elevation is not adequate (results later)
- **Ground temperature is taken as 290K**
 - other numbers lack proof of provenance!

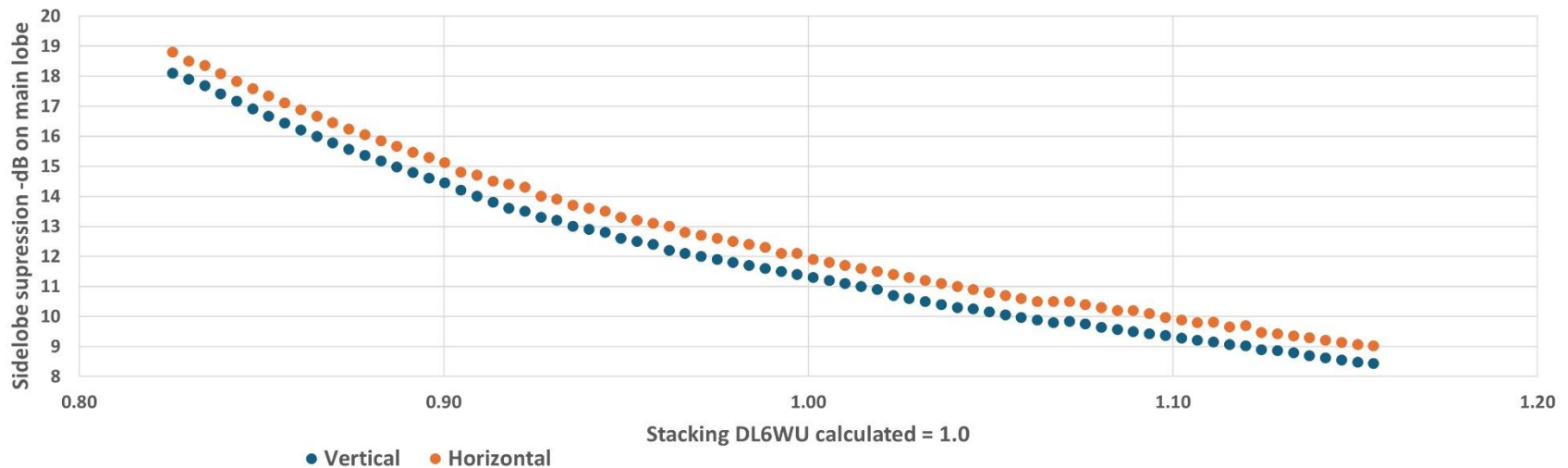
Modelled Gain & Sidelobes

4 X G4SWX 15OWL 144MHz

G4SWX 144MHz 4 X 15 OWL Gain vs Stacking (DL6WU calculated = 1.0)

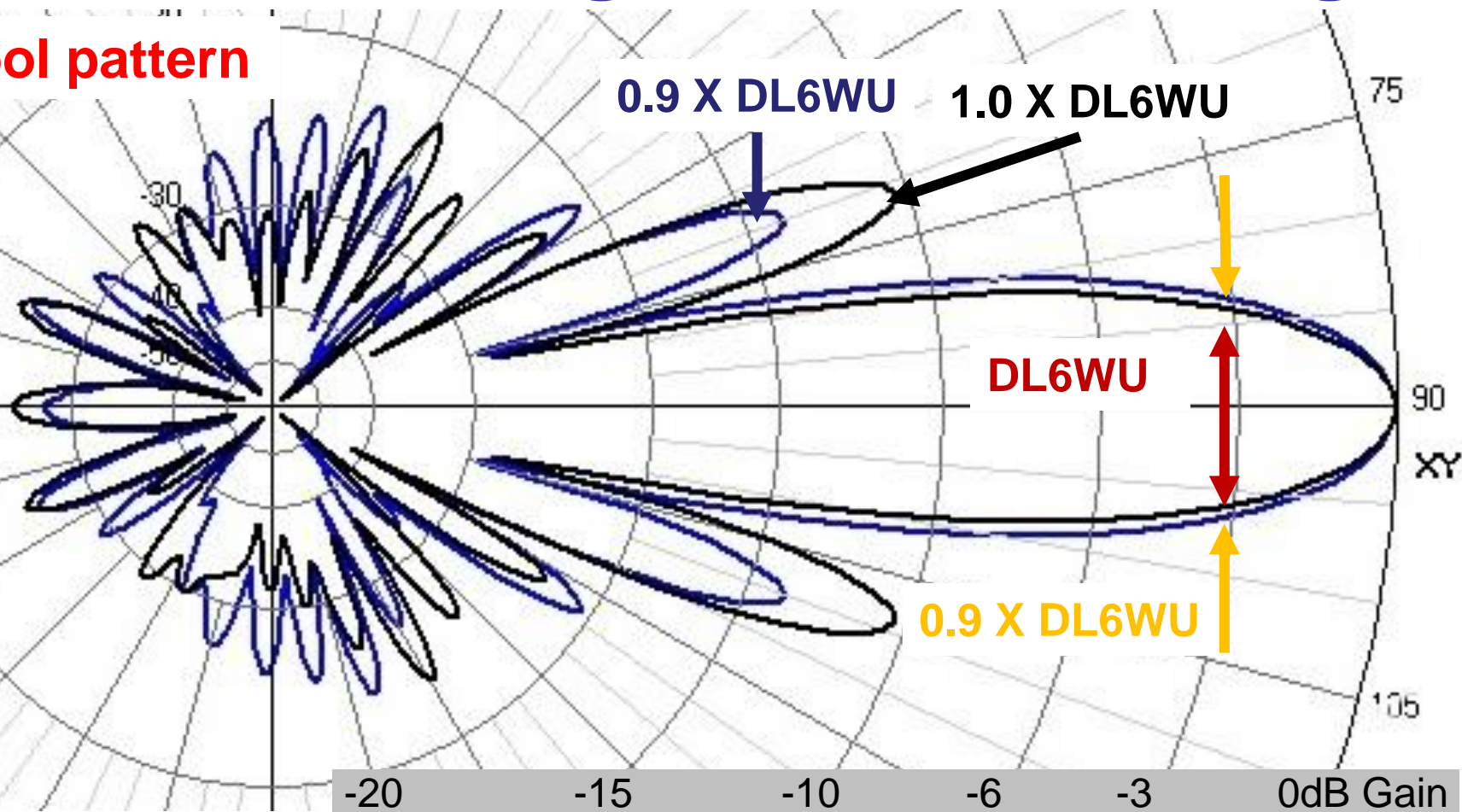


G4SWX 144MHz 4 X 15 OWL Sidelobe Supression vs Stacking (DL6WU calculated = 1.0)



Pattern Changes With Stacking

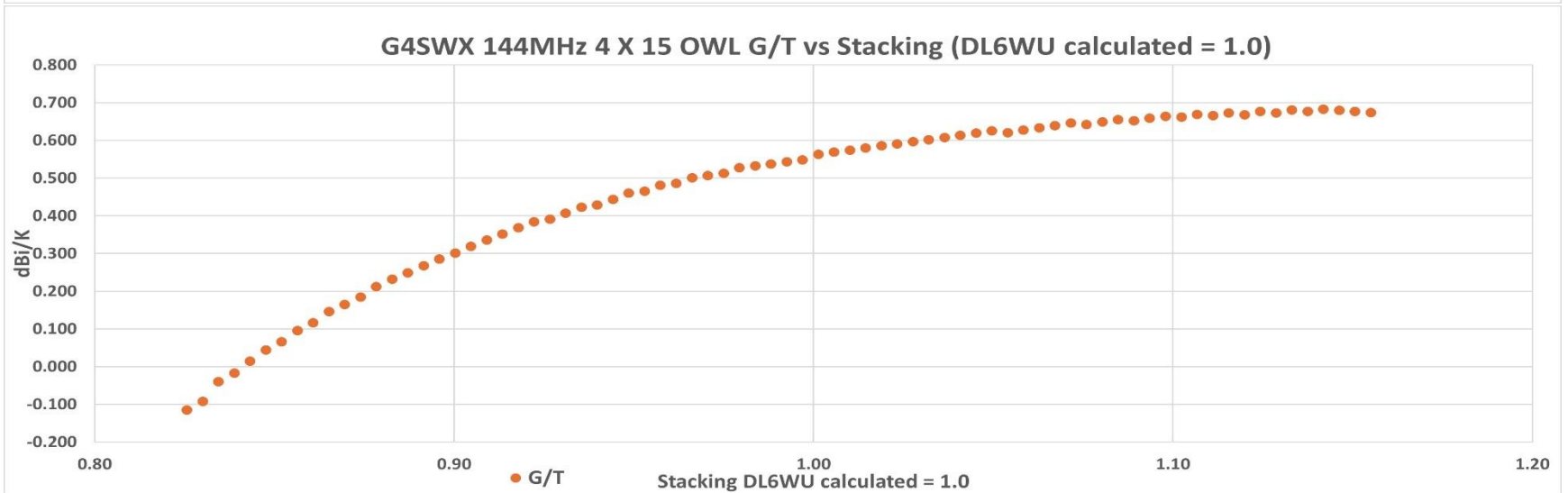
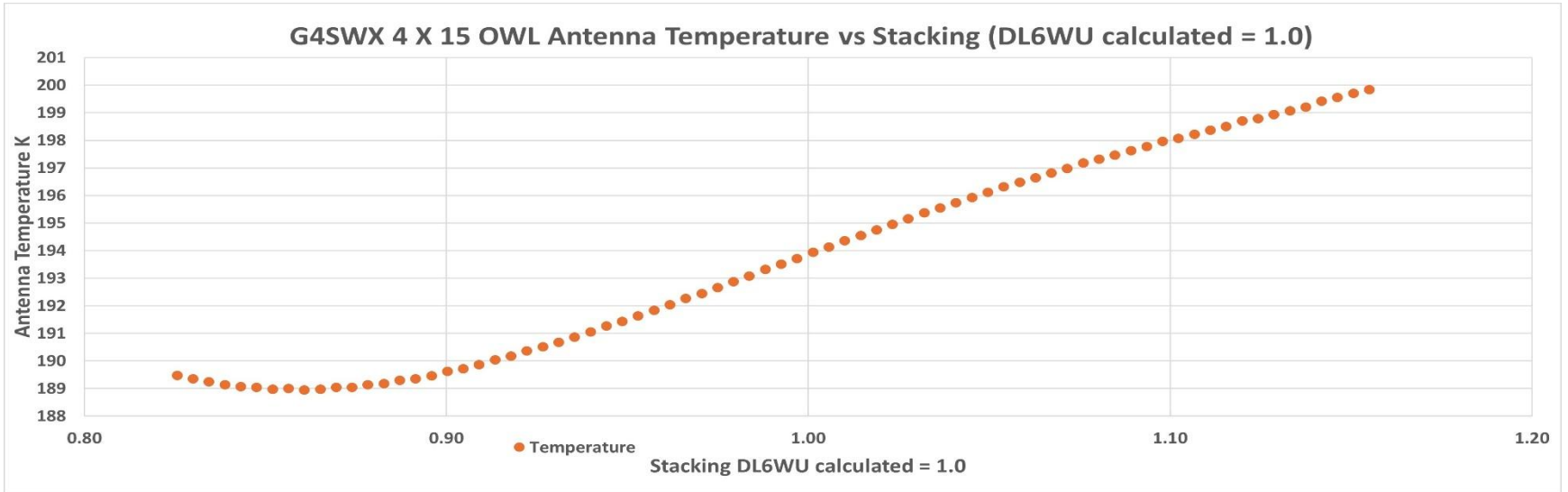
V-pol pattern



- Reducing the Yagi stacking from DL6WU calculated to 0.9 X DL6WU
- The first order sidelobes reduce from ~ -11 dB to ~ -14 dB
- The main lobe increases in area by 20%
- Antenna temperature is a function of both!

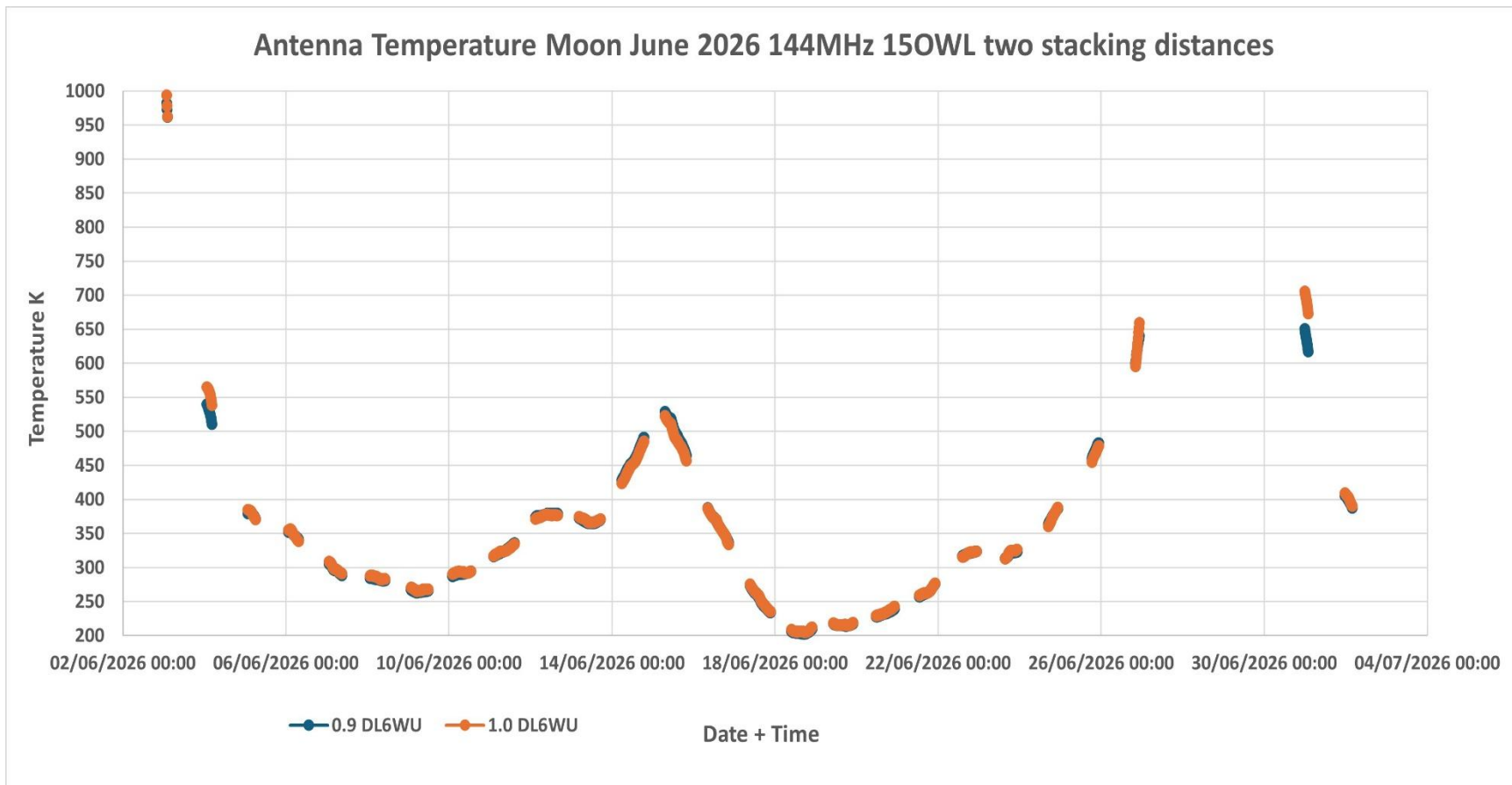
Calculated Antenna Temperature & G/T

4 x G4SWX 15 OWL 144MHz



Calculated Antenna Temperature

Moon passes June 2026 4 X G4SWX 15OWL 144MHz



All Calculations:

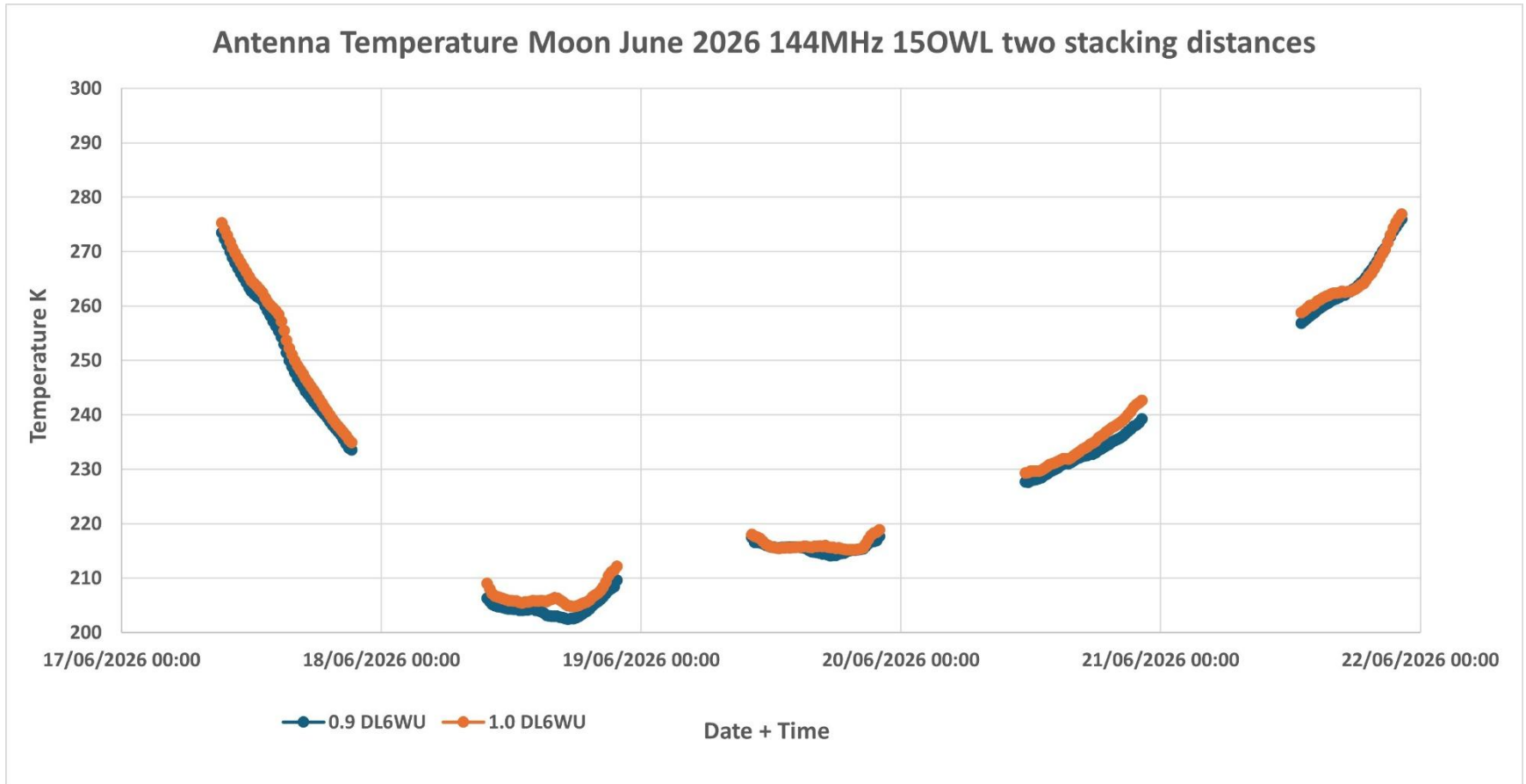
Location JO02RF when moon is above 10 degrees elevation

No compensation for moon temperature

Position of the Sun is not included

Calculated Antenna Temperature

Moon passes 17-22 June 2026 4 X G4SWX 15OWL 144MHz



All Calculations:

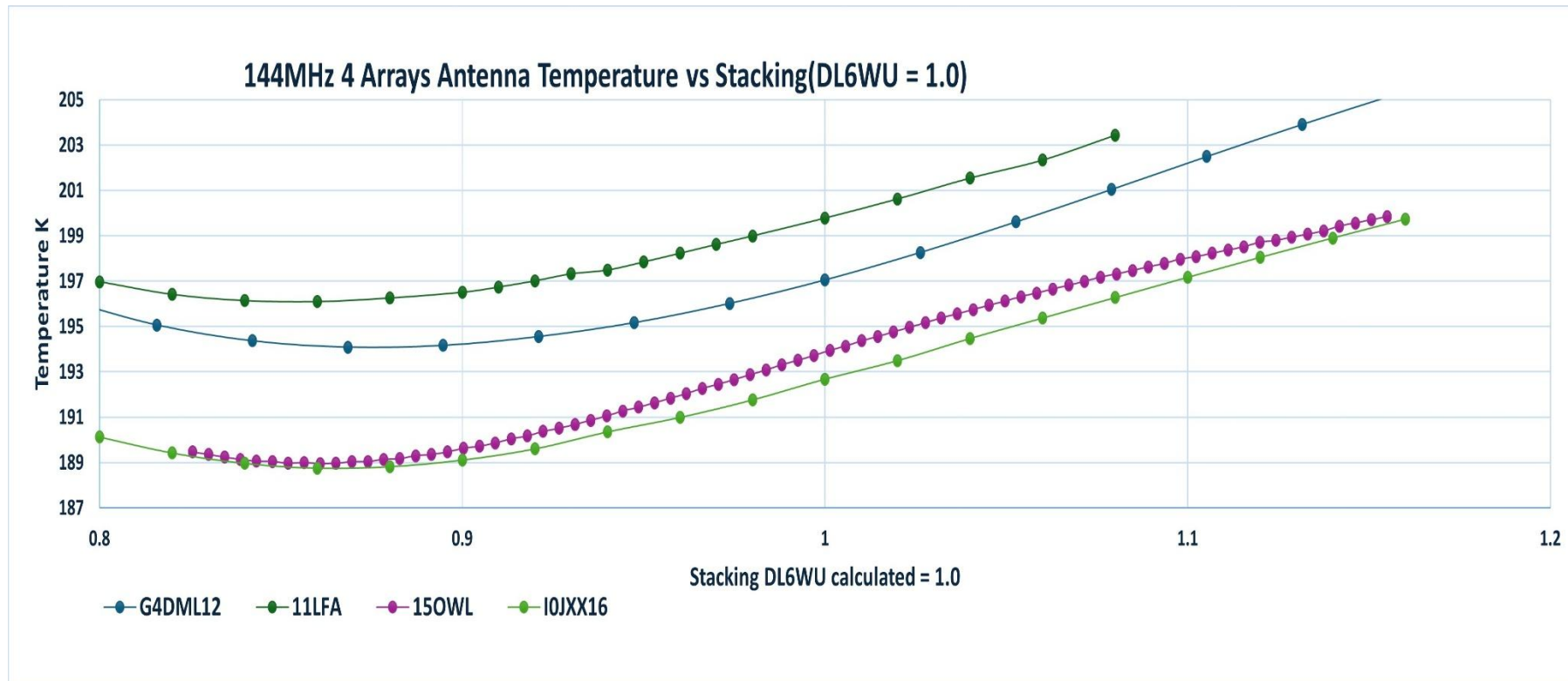
Location JO02RF when moon is above 10 degrees elevation

No compensation for moon temperature

Position of the Sun is not included

Calculated Antenna Temperature

4 different 144MHz arrays



7K max difference @ DL6WU stacking = 1.0

Little between IOJXX16 (G4SWX old) and 15OWL (G4SWX new)!

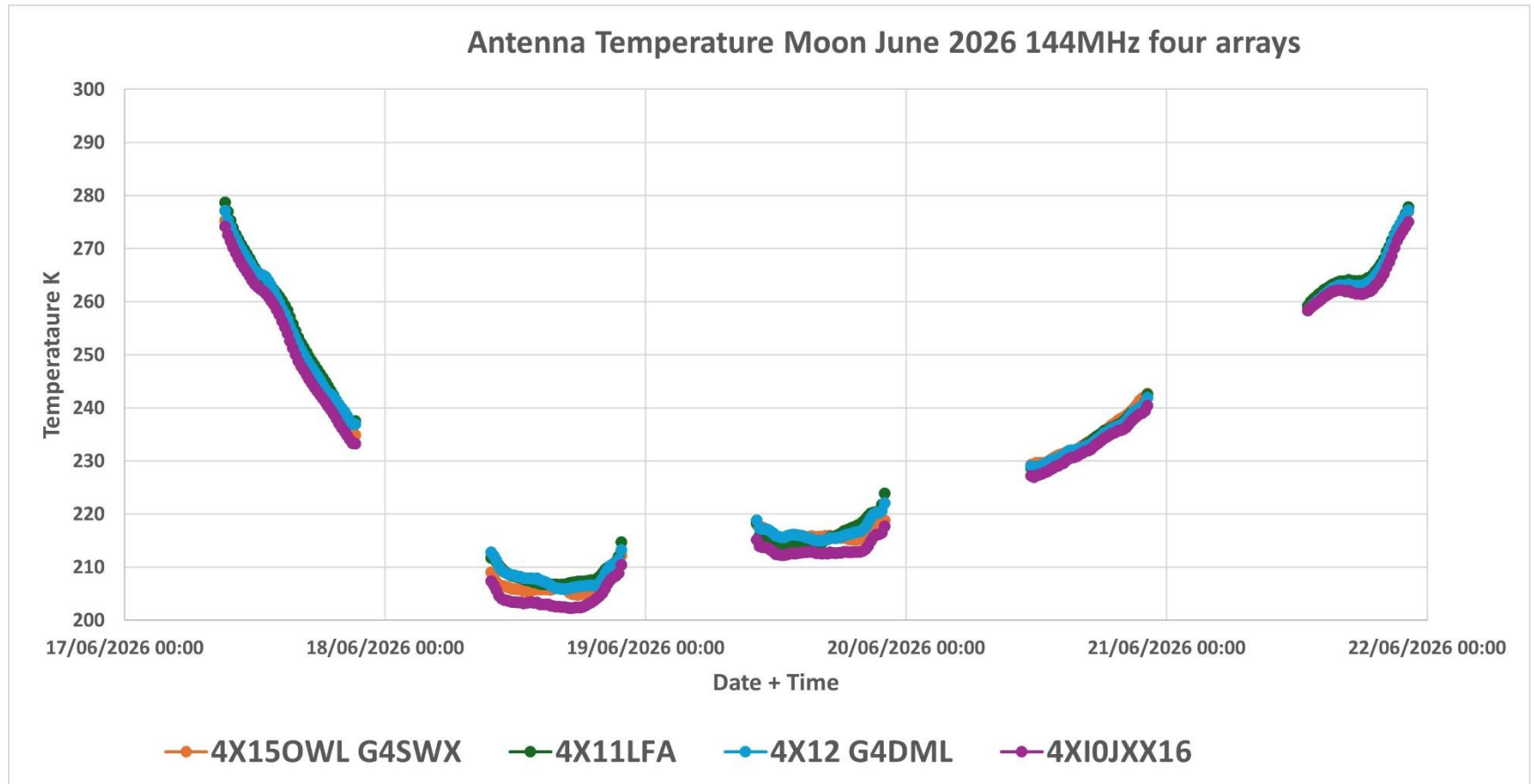
Longer Yagis: 15OWL(5.4WL), IOJXX16(4.48WL) have a smaller main lobe spots than shorter ones G4DML12 (3.4WL), 11LFA (3.27WL)

All have minimum antenna temperature @~0.87 X DL6WU stacking

Calculated Antenna Temperature

Moon passes 17-22 June 2026

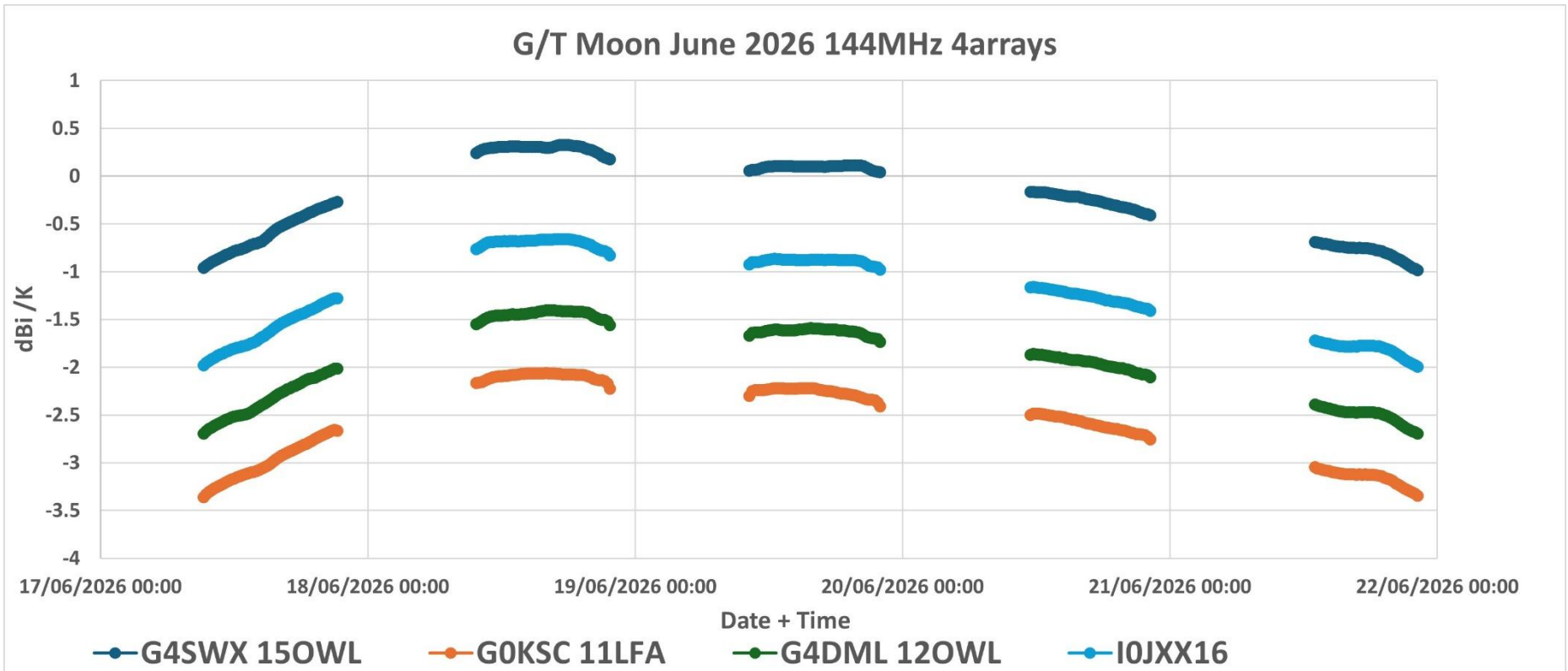
four different 144MHz arrays



144MHz Antenna G/T

Moon passes 17-22nd June 2026

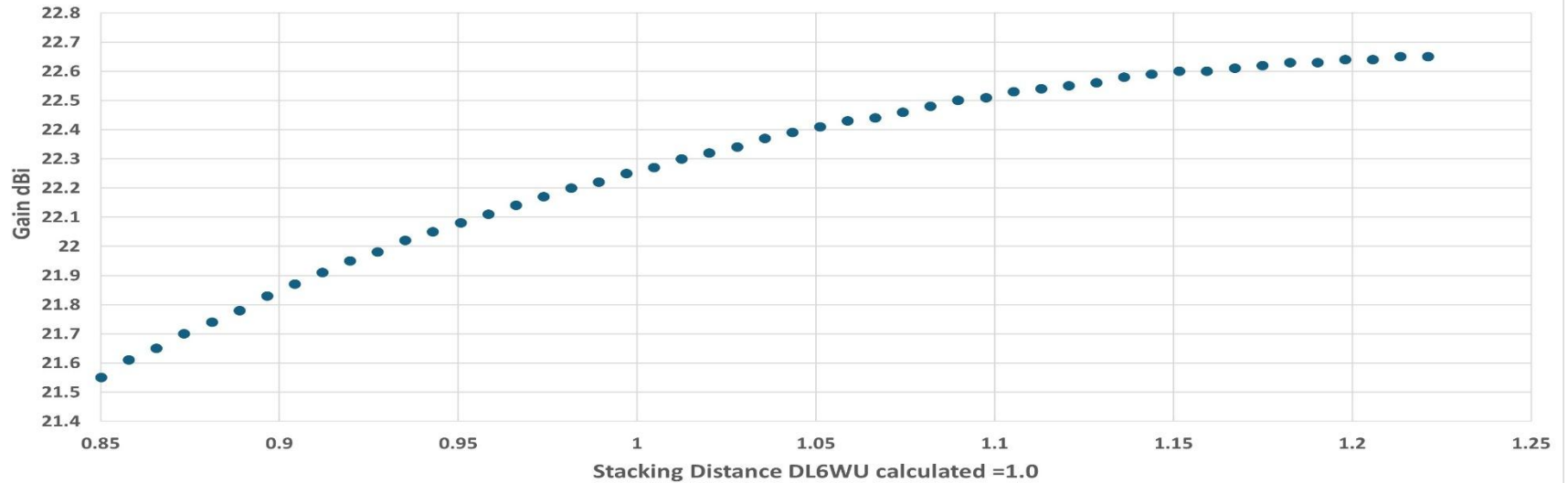
4 different arrays



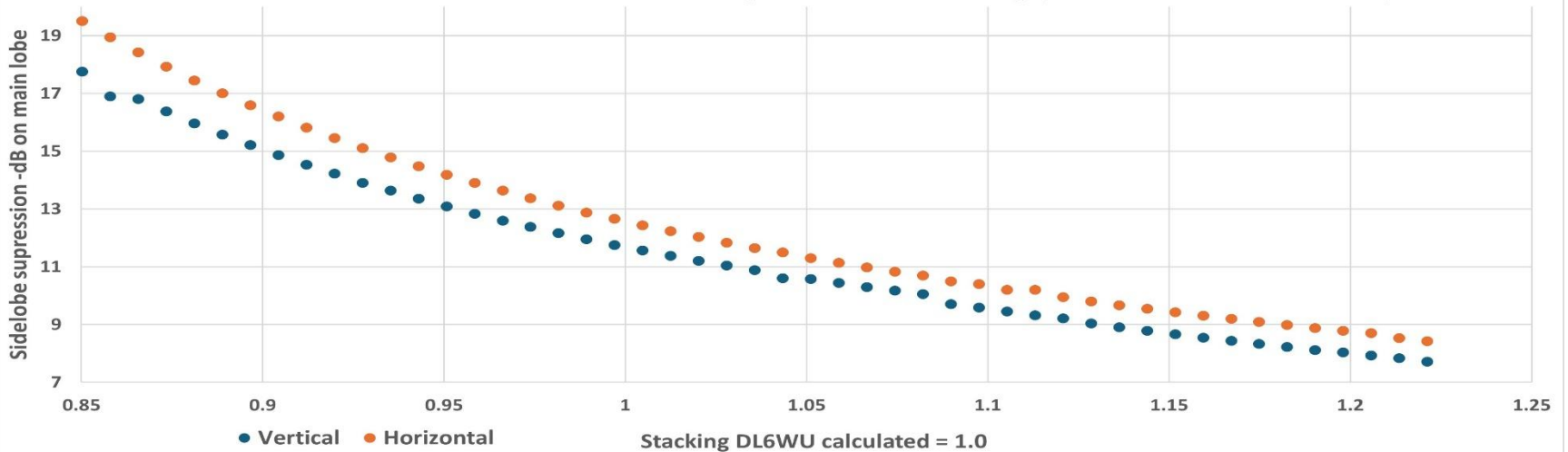
Modelled Gain & Sidelobes

4 X 15 WD5AGO 432MHz

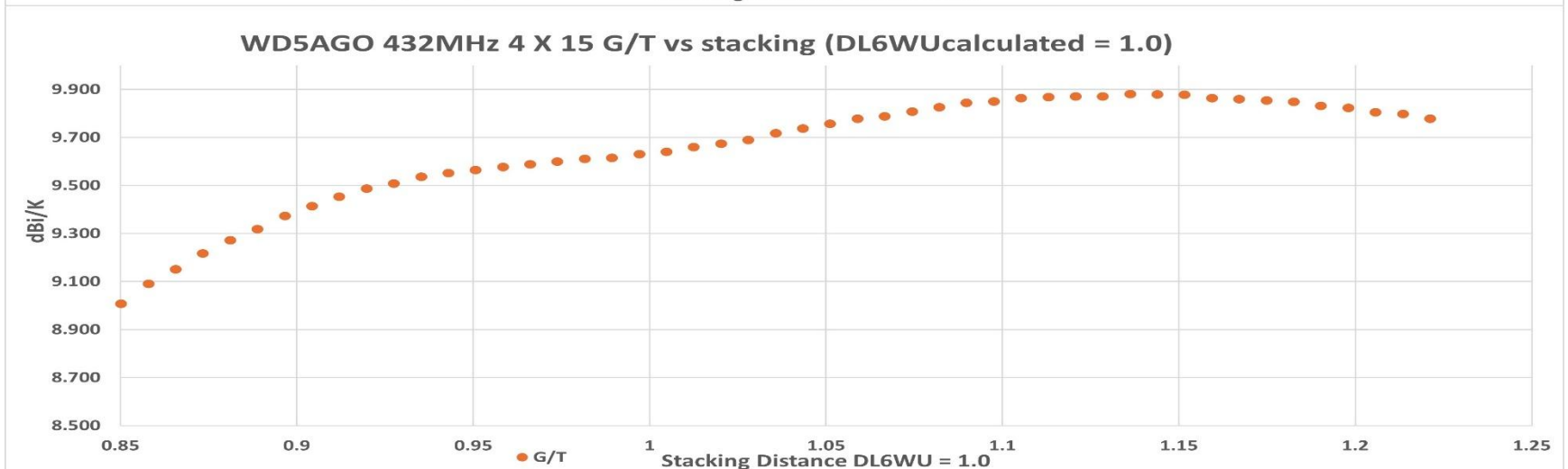
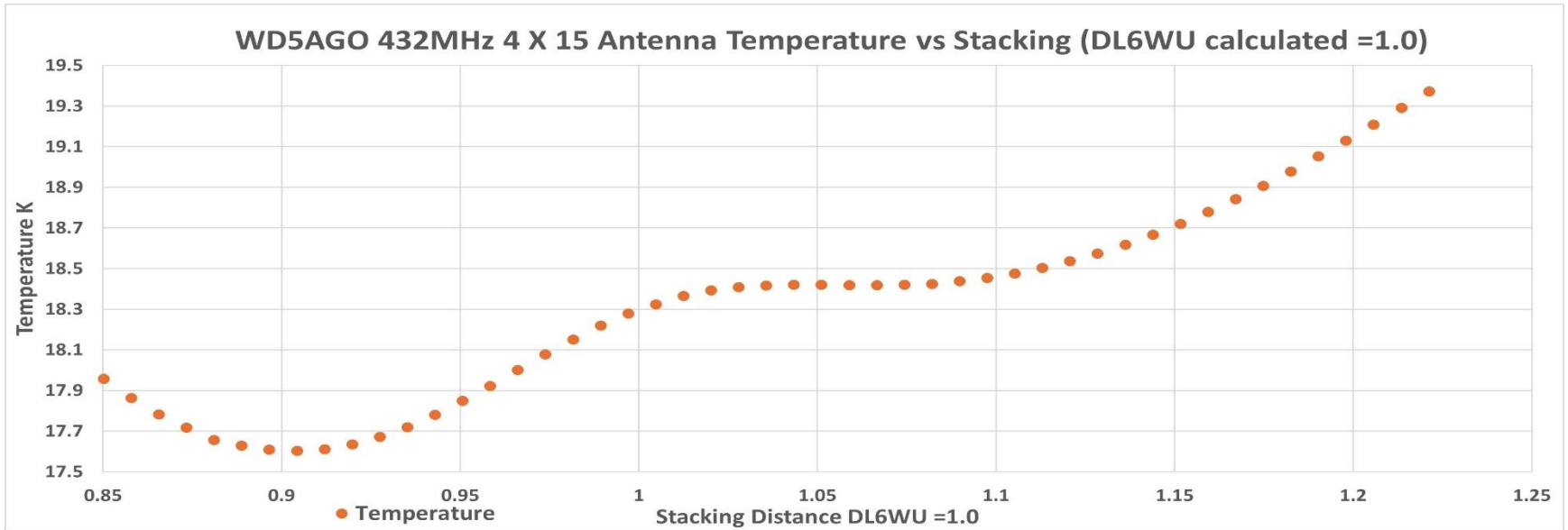
WD5AGO 432MHz 4 X 15 Gain vs Stacking (DL6WU calculated = 1.0)



WD5AGO 432MHz 4 X 15 Sidelobe Supression vs Stacking (DL6WU calculated = 1.0)



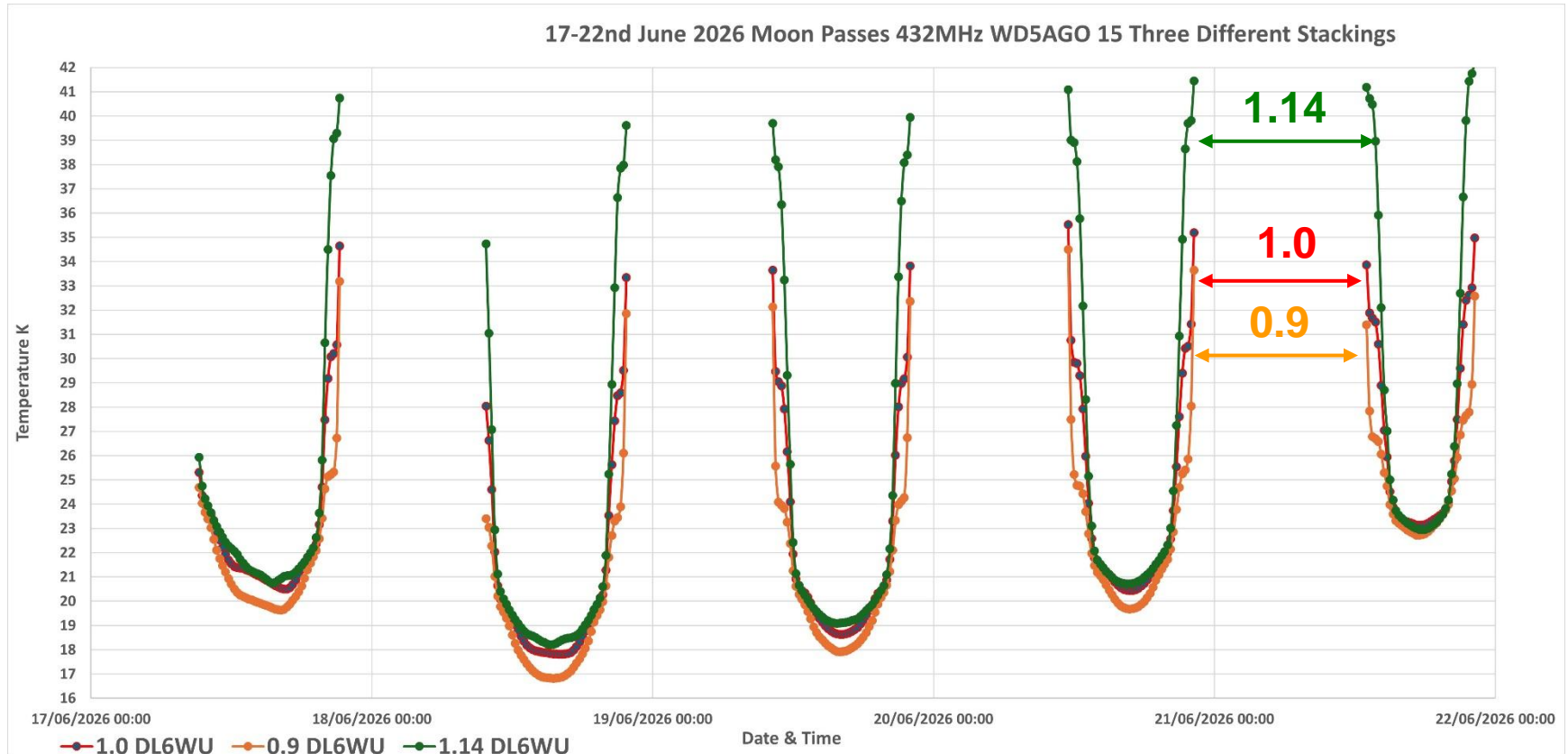
Calculated Antenna Temperature & G/T 4 X 15WA5ADO 432MHz



Calculated Antenna Temperature

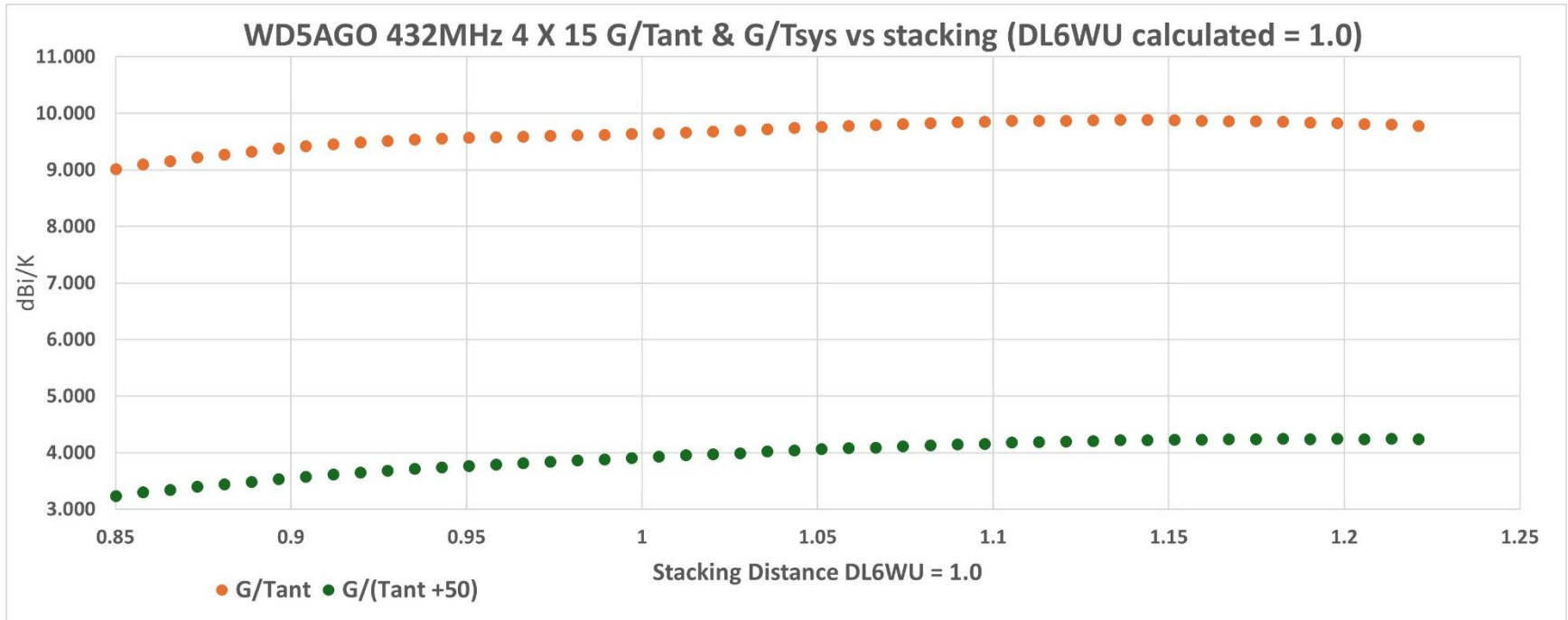
Moon passes 17-22nd June 2026

4 X 15 WD5AGO 432MHz Three different stacking distances



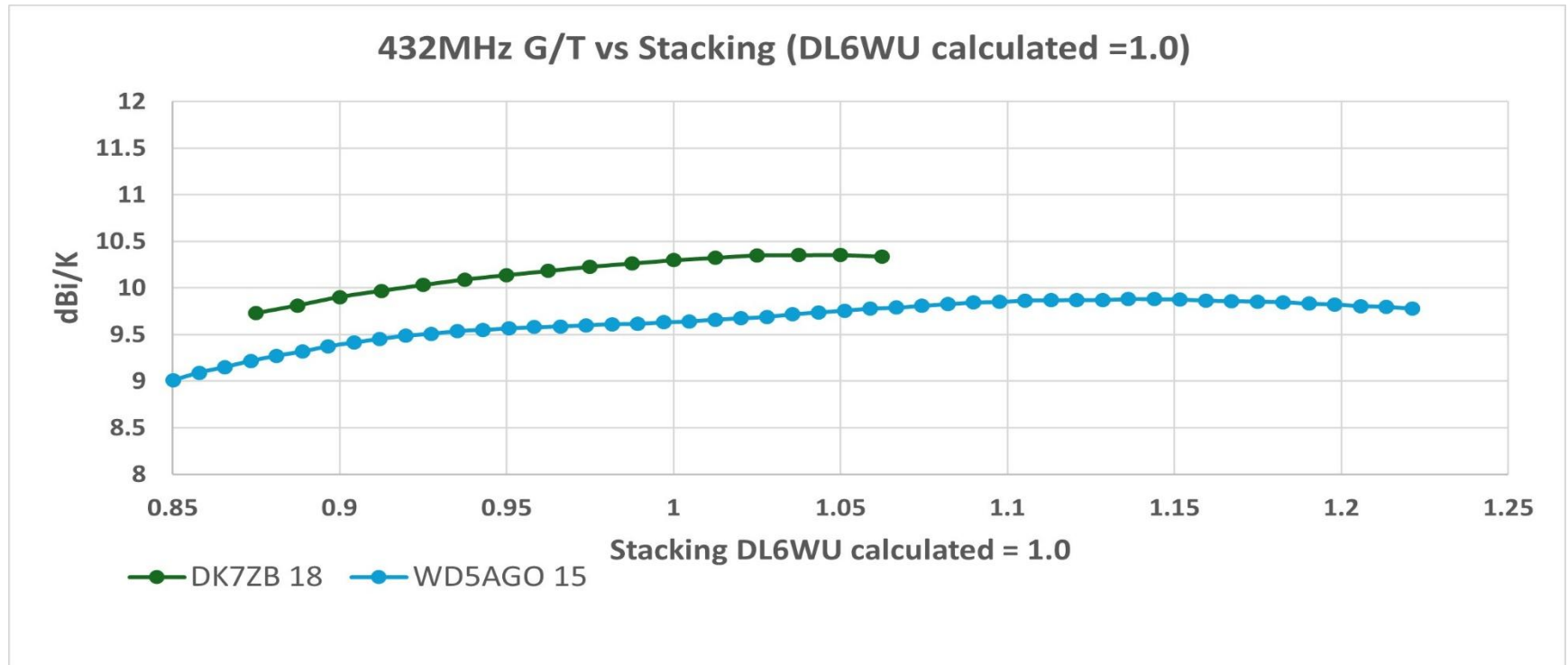
- The impact of the different stacking distances becomes very clear when it is viewed over several moon passes.
- At low elevations from moonrise and towards moonset wider stacking results in significantly increased antenna temperature.

432MHz Adding in receiver noise temperature to G/T



- The impact of adding in the receiver noise temperature, for instance 50K, including feed lines is overwhelming.
- All improvements including; lower loss feeders and cooled phemt preamplifiers are worth considering.

432MHz G/T Two Arrays

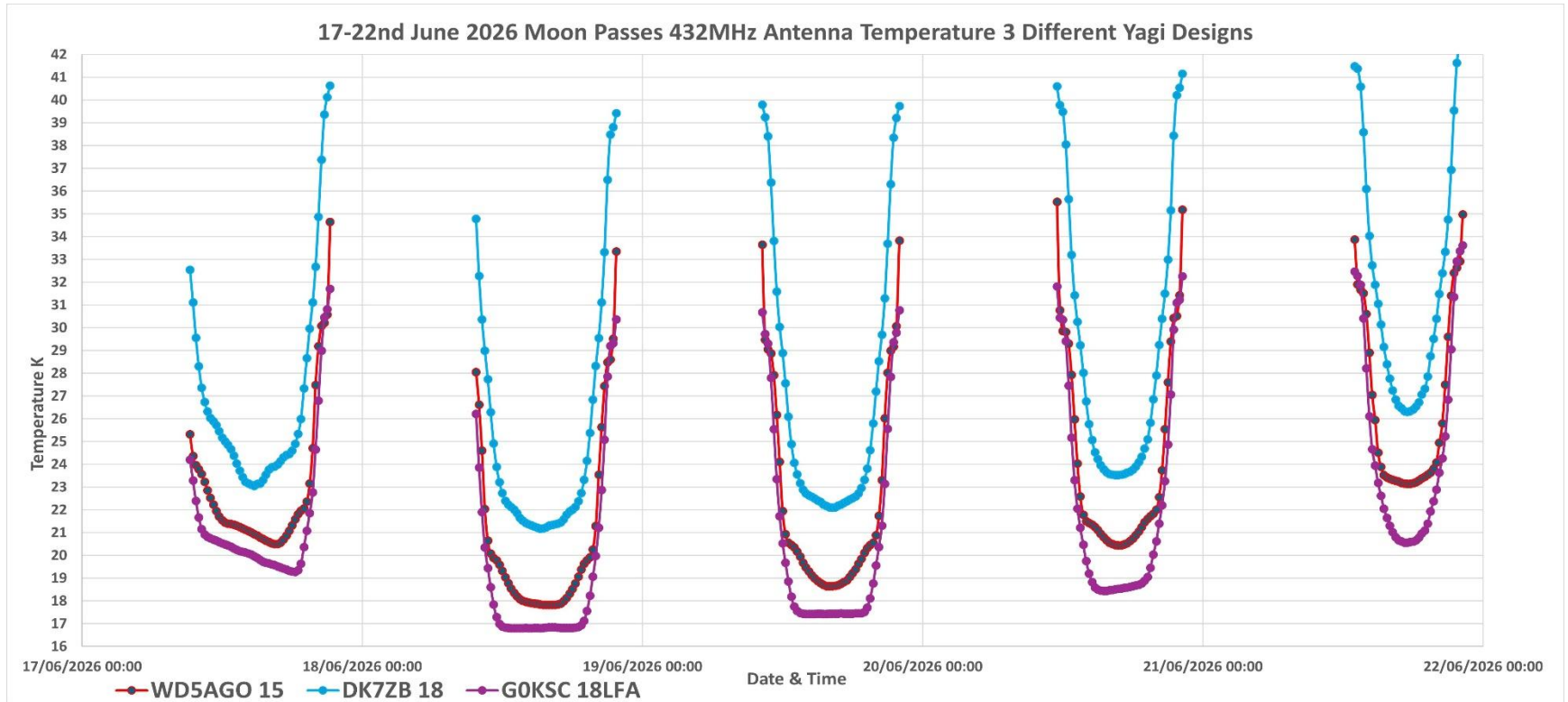


- On 432MHz G/T really matters. Using DL6WU calculated stacking the DK7ZB 18 ele has 1.37dB more modelled gain than the WD5AGO 15 ele
- However, this reduces to 0.7dB G/T advantage because of the 3K lower noise temperature of the WD5AGO 15 ele

432MHz Antenna Temperature

Moon passes 17-22nd June 2026

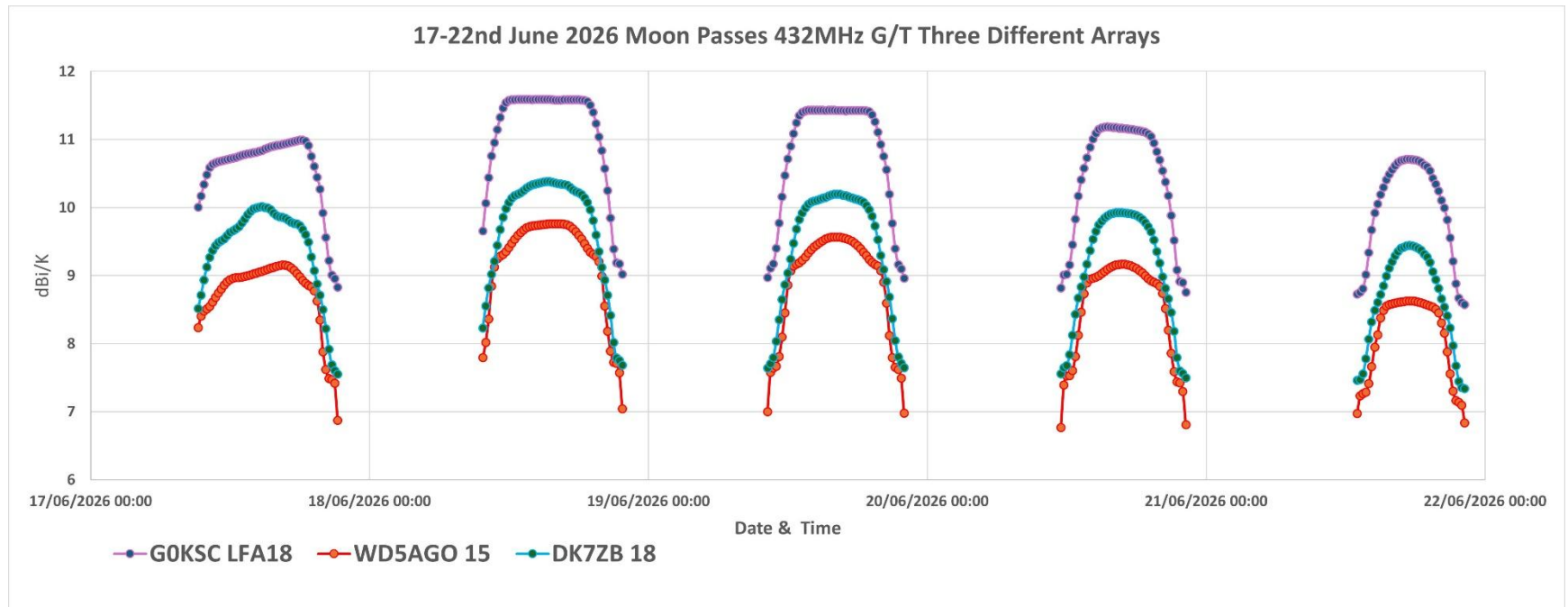
3 different arrays



- It can be seen again that the lower antenna temperature arrays have far better performance at low elevations

432MHz G/T

Moon passes 17-22nd June 2026 3 different arrays



- Here the G0KSC 18LFA is clearly well ahead. It has higher gain and lower antenna temperature than both of the others.
- Even at low elevations at the start and end of moon passes the performance of this array is excellent

Optimum G/T

On 144MHz and below it hardly matters – gain is the dominant issue

On 50MHz G/T calculations are irrelevant for EME

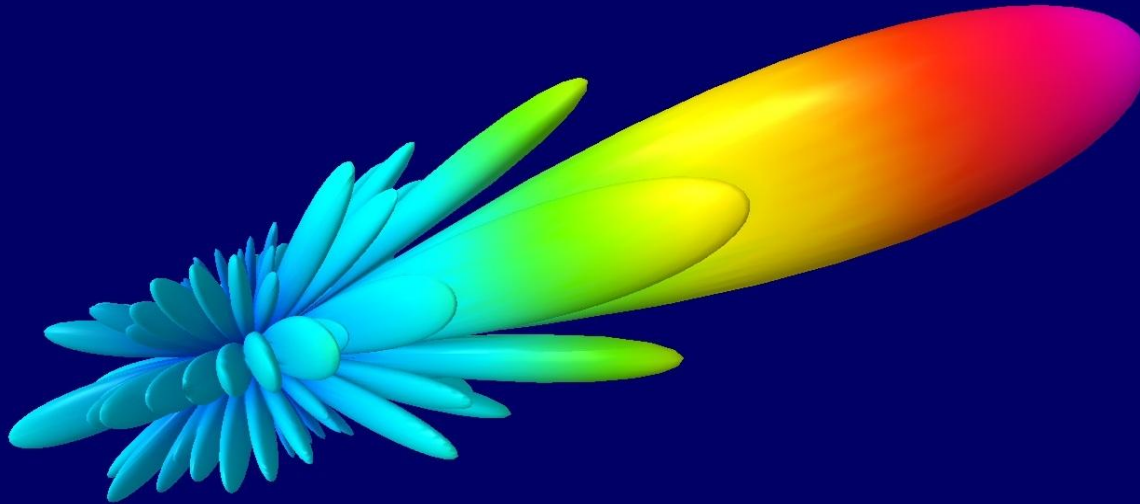
On 432MHz and above, it is a critical measure - both gain and antenna temperature are important

On 1296MHz –use a dish!



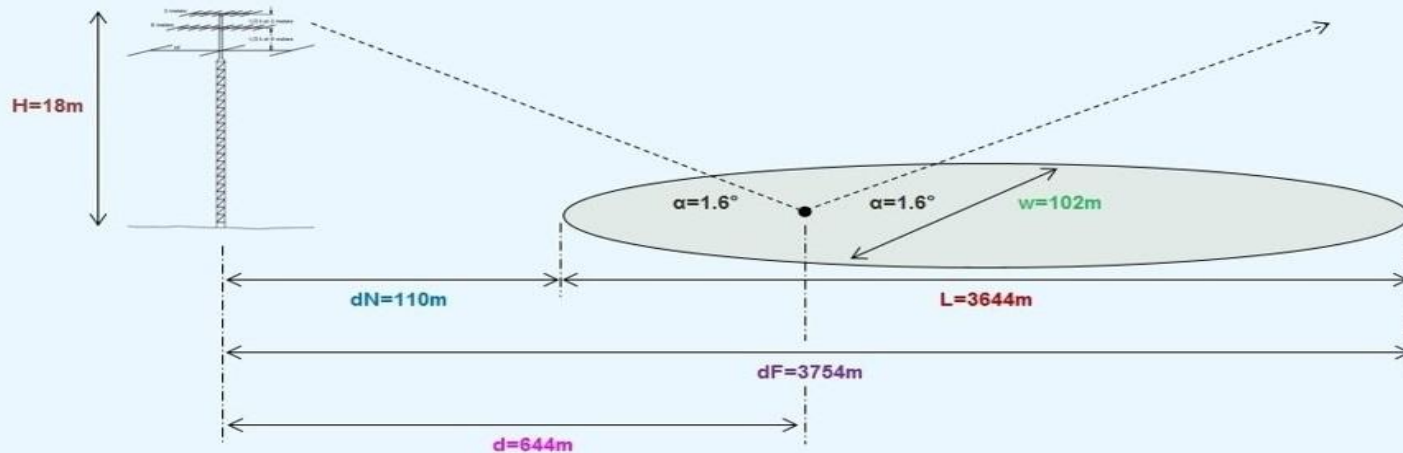
Ground Reflections!

Sidelobe ground gain is significant on 50 & 144MHz



Fresnel Zone Geometry for the 1st Elevation Lobe

ON4KHG ground-gain



Stacking Decisions


- On 144MHz 1st vertical sidelobe ground gain can significantly increase antenna temperature at ~20-degrees elevation.
- On 432MHz ground gain is lower due to surface roughness (less specular = scattered).
- G/T loss at close stacking is less than raw gain loss(~70%).
- On 432MHz sidelobes dominate antenna temperature under 30 degrees elevation.
- On both bands stacking at DL6WU calculated stacking is a good compromise but only above 30-degrees elevation on 432MHz.

What have I discovered?

- **Calculated antenna temperatures were a little lower than had been expected using previous data.**
- **Minimum calculated antenna temperature at 45-degrees elevation occurs at 0.87 X DL6WU calculated Yagi stacking. 144 & 432MHz**
- **G/T at 45 degrees elevation is maximum at ~1.1 X DL6WU calculated Yagi stacking. 144 & 432MHz**
- **On 144MHz Antenna temperature & G/T are not critical when tracking the moon! – forward gain rules**
- **432MHz is a far more complex situation**
 - **Sidelobes really matter under 30 degrees elevation**
 - **G/T makes a significant difference**
 - **But receiver temperature(including feeders) rules!**

What Next?

- **More detailed results in upcoming DUBUS magazine article.**
- **Building Skynoise into moontrackers to give predicted and real-time antenna temperature for any NEC modelled array.**
- **Production of 220 & 1296MHz sky maps. 50MHz is not required!**
- **Better prediction of 2-station EME S/N.**
- **Design of some better 432MHz Yagi arrays.**
- **Some leisurely EME operating!**

A large, complex metal antenna structure, likely a Yagi-Uda array, is shown against a clear blue sky. The structure consists of multiple long, thin metal rods extending outwards from a central vertical mast. A small, crescent moon is visible in the sky behind the central mast. The text "Thank You & Any Questions?" is overlaid in blue, and "John G4SWX" is overlaid in black below it.

**Thank You
&
Any Questions?**

John G4SWX