New science on the second electron gyro-harmonic

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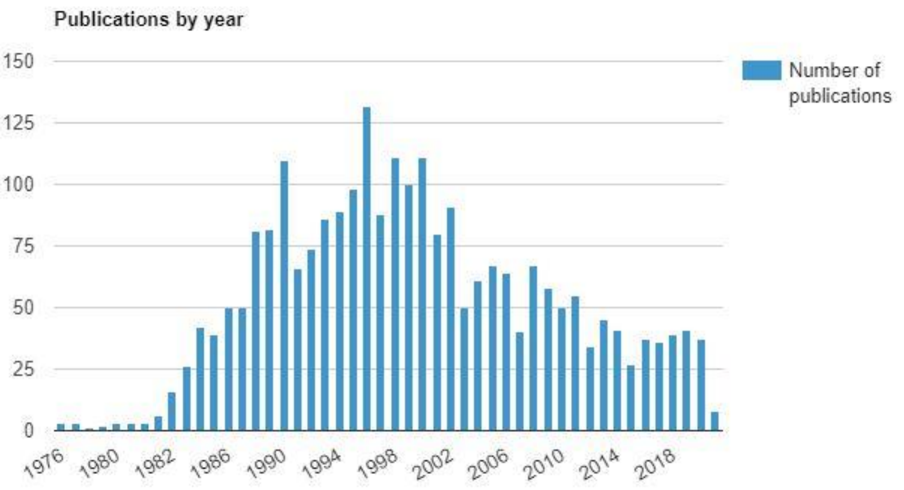
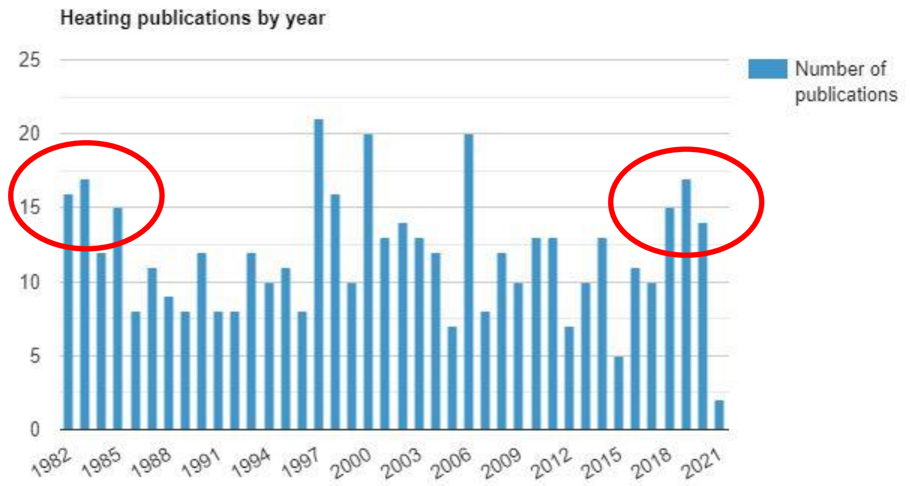
The HAARP and HIPAS Heaters in the USA have shown there is new science on the second electron gyro-harmonic. The EISCAT Heater used to have this capability. EISCAT has the advantage of incoherent scatter radar diagnostics. The case is made to convert the (super-)Heater to operate at 2.7 MHz, which will also make night-time and solar minimum experiments more successful.

EISCAT & Heater publications



Total = 2345



Total = 478

Electron gyro-frequency at EISCAT

Height (km)	B (nT)	2 GH (MHz)
100,0	51284,8	2,87
110,0	51071,9	2,85
120,0	50860,0	2,84
130,0	50649,1	2,83
140,0	50439,3	2,82
150,0	50230,6	2,81
160,0	50022,8	2,80
170,0	49816,1	2,78
180,0	49610,4	2,77
190,0	49405,7	2,76
200,0	49202,1	2,75
210,0	48999,4	2,74
220,0	48797,8	2,73
230,0	48597,2	2,72
240,0	48397,5	2,71
250,0	48198,9	2,69
260,0	48001,2	2,68
270,0	47804,5	2,67
280,0	47608,8	2,66
290,0	47414,0	2,65
300,0	47220,2	2,64

$$f = \frac{qB}{2\pi m}$$

2GH ≈ 2.7 MHz

3GH ≈ 4.05 MHz

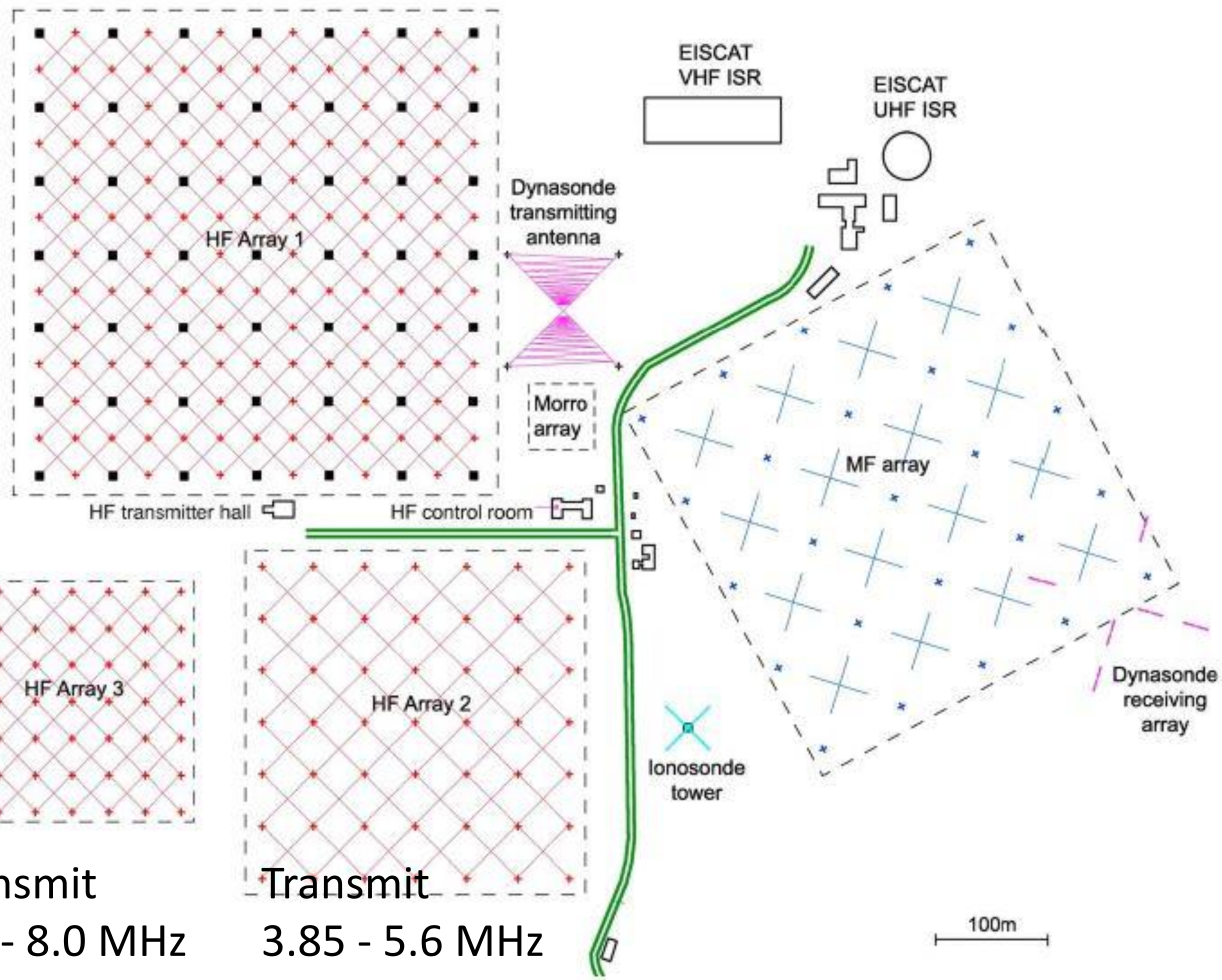
4GH ≈ 5.4 MHz

5GH ≈ 6.75 MHz

6GH ≈ 8.1 MHz

Heater – pre-1986
Max Planck Institute

Transmit
2.75 - 4.0 MHz
Gain = 24 dB



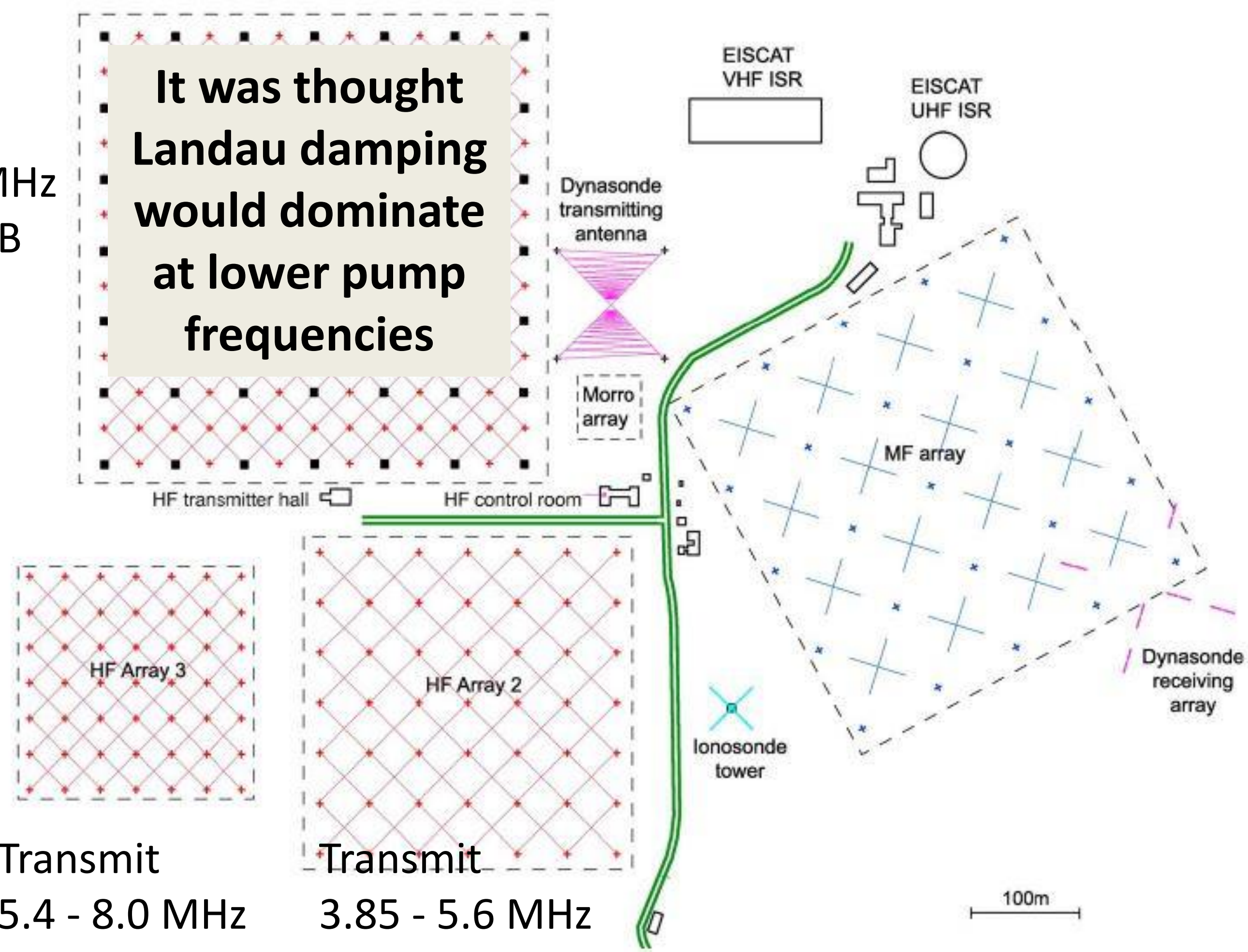
Transmit
5.4 - 8.0 MHz
Gain = 24 dB

Transmit
3.85 - 5.6 MHz
Gain = 24 dB

Heater – pre-1986
Max Planck Institute

Transmit
2.75 - 4.0 MHz
Gain = 24 dB

It was thought Landau damping would dominate at lower pump frequencies



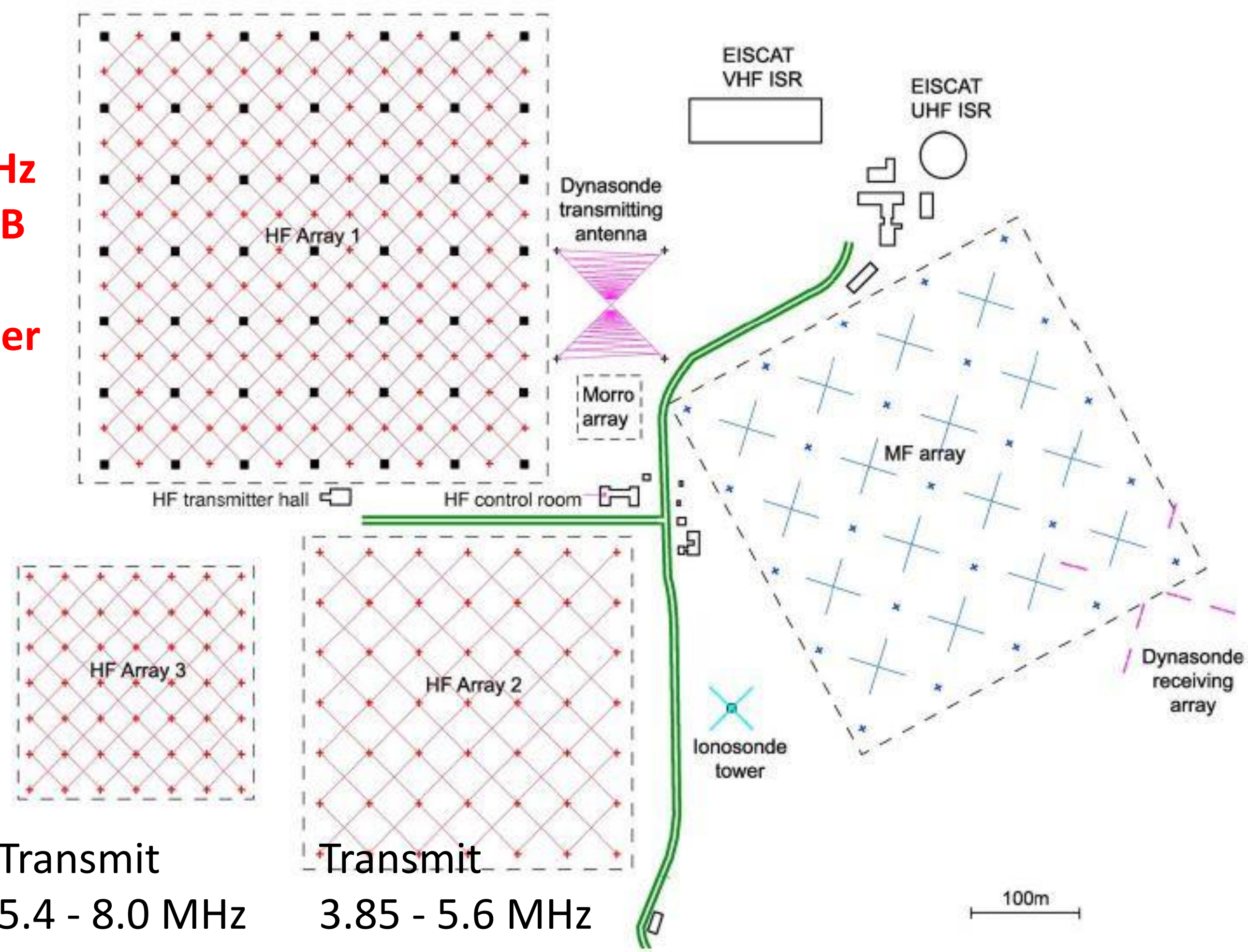
Transmit
5.4 - 8.0 MHz
Gain = 24 dB

Transmit
3.85 - 5.6 MHz
Gain = 24 dB

Heater – post-1990 EISCAT

Transmit
5.4 - 8.0 MHz
Gain = 30 dB

Super-Heater



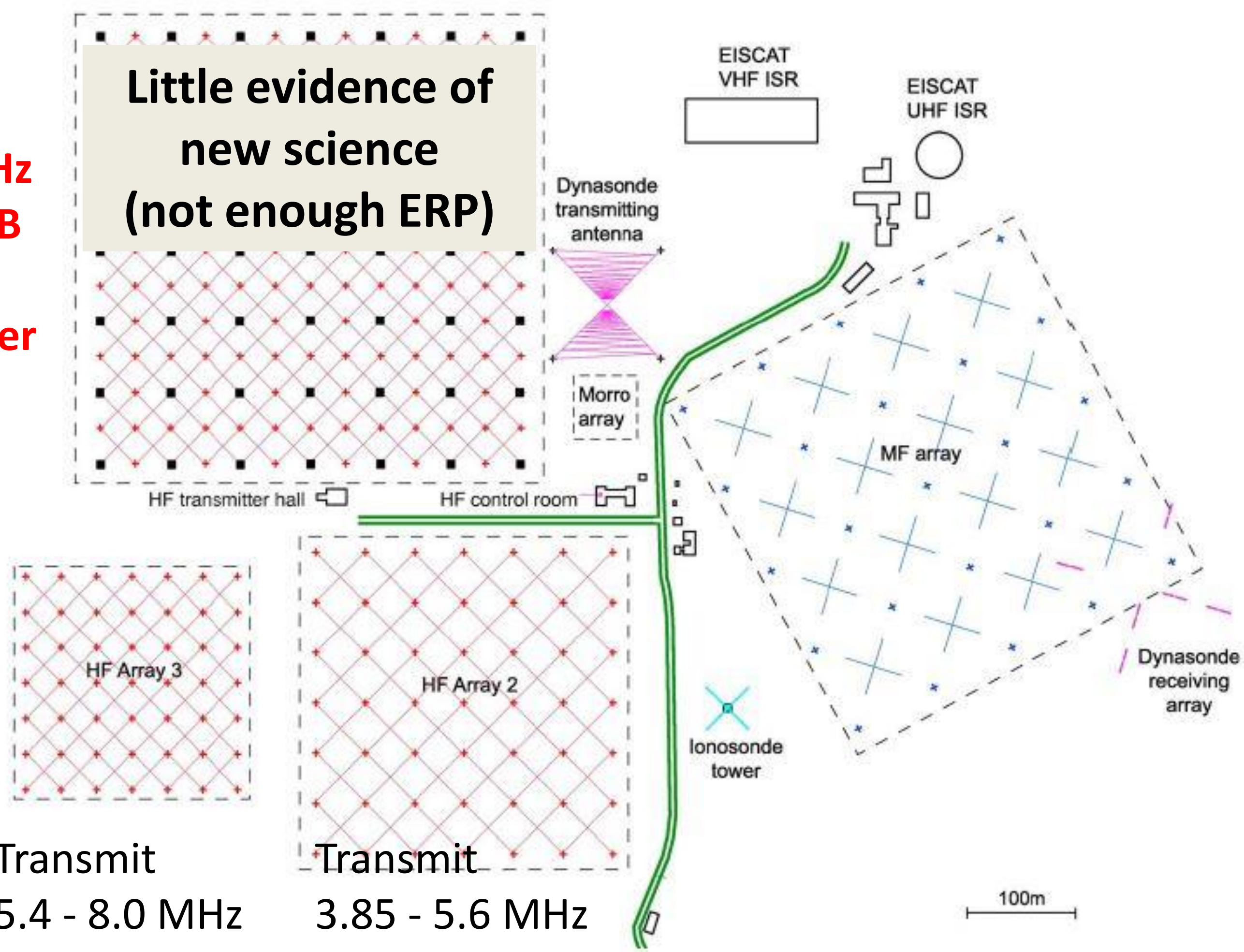
Transmit
5.4 - 8.0 MHz
Gain = 24 dB

Transmit
3.85 - 5.6 MHz
Gain = 24 dB

Heater – post-1990 EISCAT

Transmit
5.4 - 8.0 MHz
Gain = 30 dB

Super-Heater



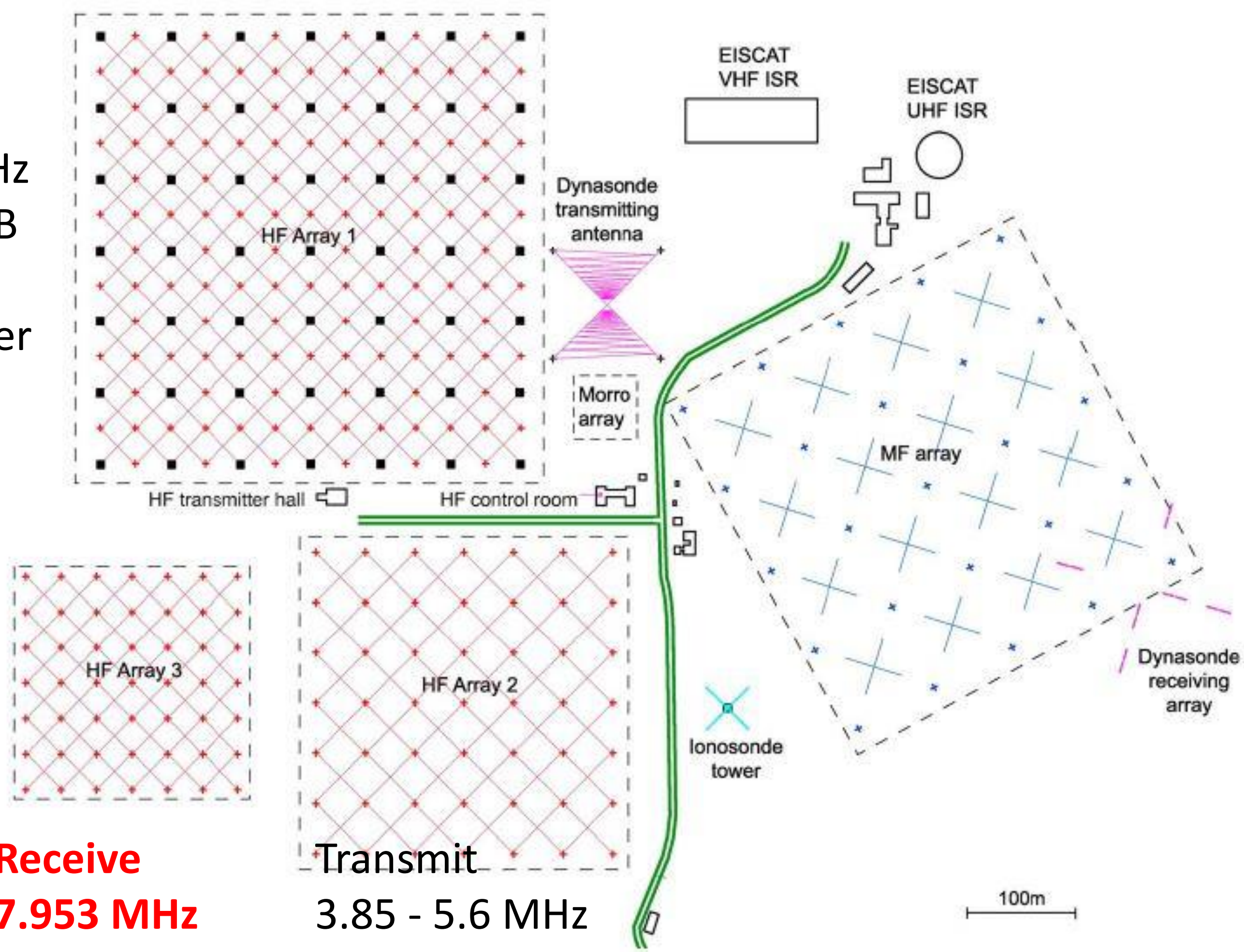
Transmit
5.4 - 8.0 MHz
Gain = 24 dB

Transmit
3.85 - 5.6 MHz
Gain = 24 dB

Heater – post mid-2013 EISCAT

Transmit
5.4 - 8.0 MHz
Gain = 30 dB

Super-Heater



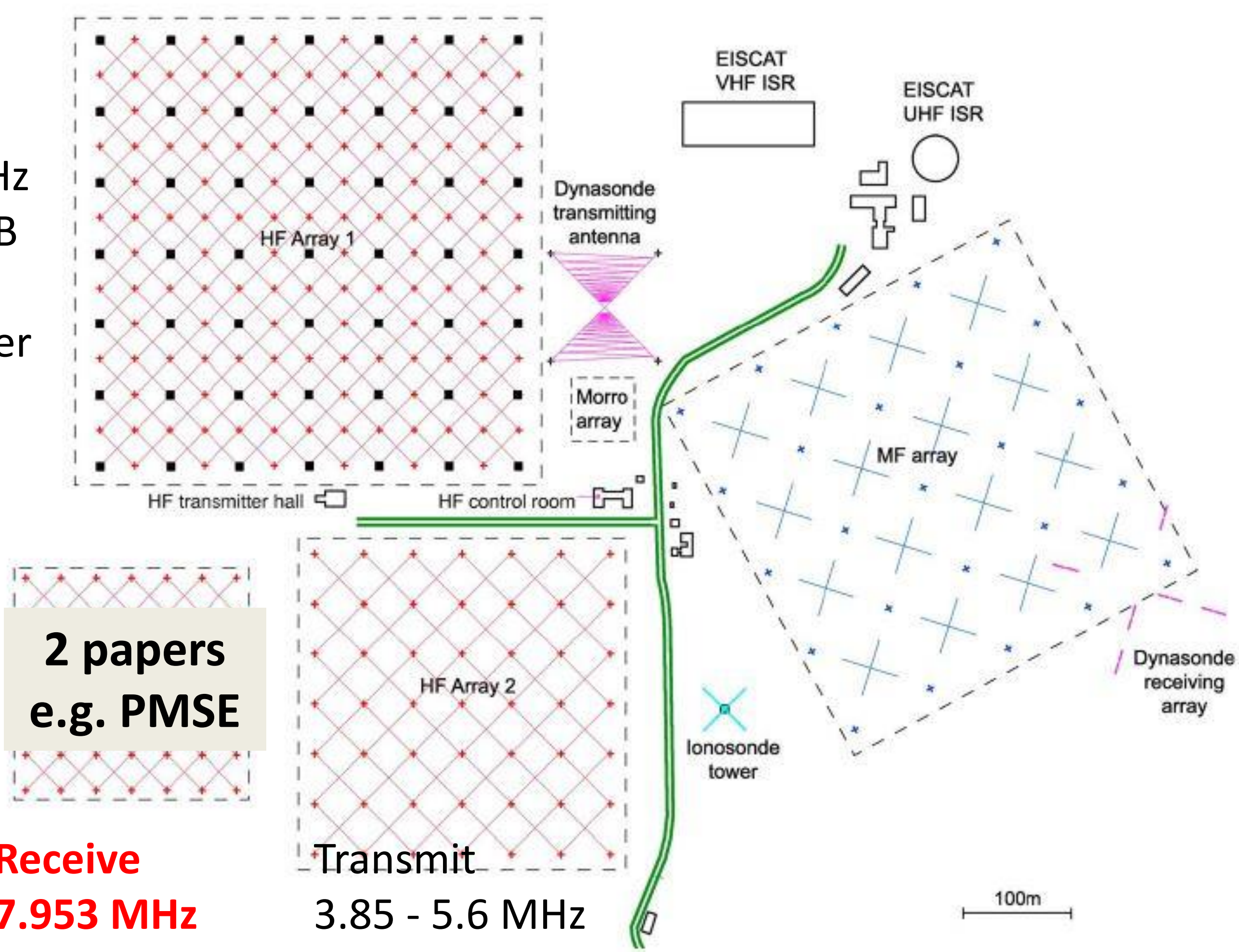
Receive
7.953 MHz
Gain = 24 dB

Transmit
3.85 - 5.6 MHz
Gain = 24 dB

Heater – post mid-2013 EISCAT

Transmit
5.4 - 8.0 MHz
Gain = 30 dB

Super-Heater



2 papers
e.g. PMSE

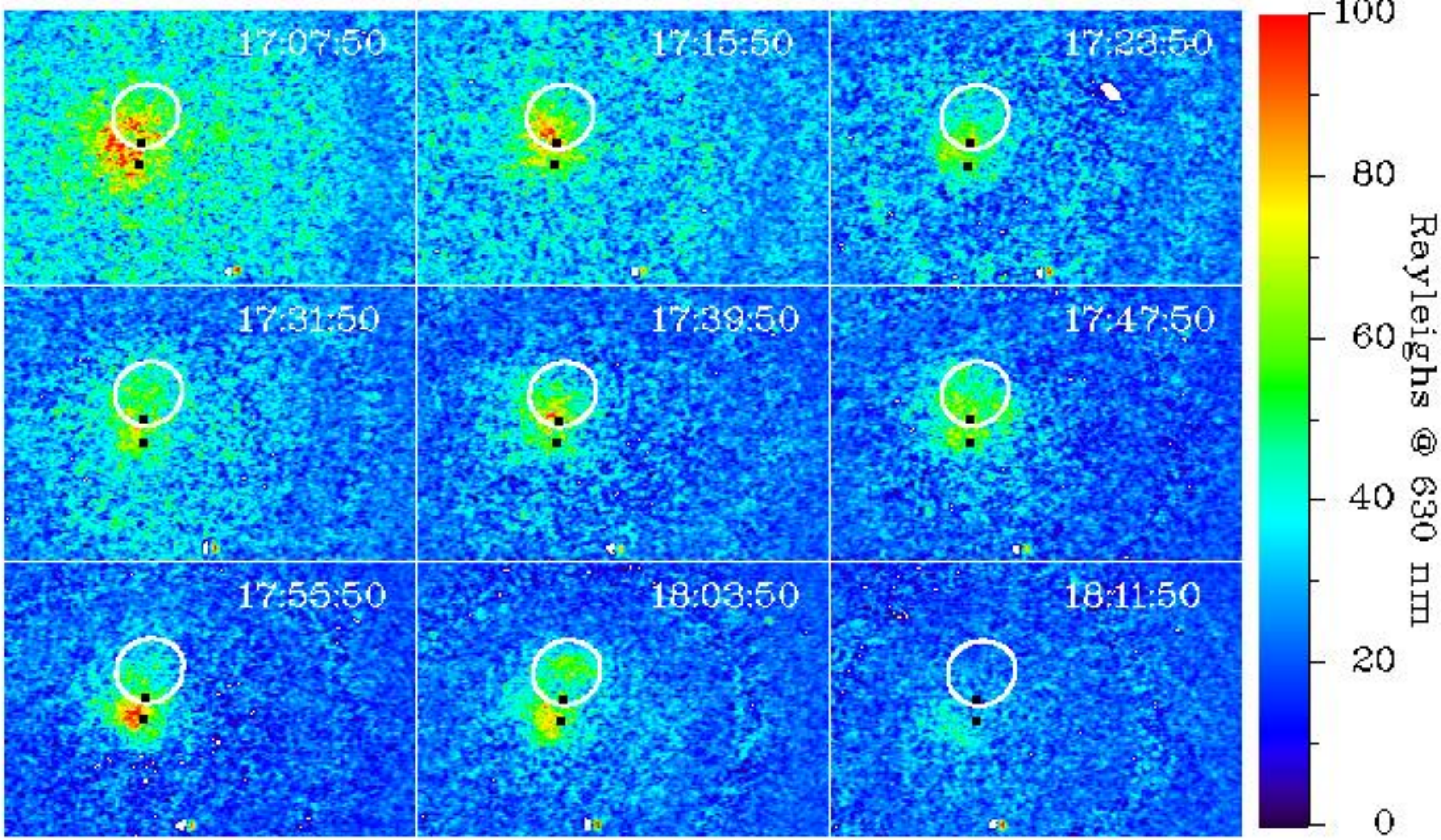
Senior et al.,
GRL, 2014,
doi:10.1002/
2014GL060703

Receive
7.953 MHz
Gain = 24 dB

Transmit
3.85 - 5.6 MHz
Gain = 24 dB

Second recording of artificial auroras at EISCAT

21/2/1999   4.04 MHz   ERP = 70 MW

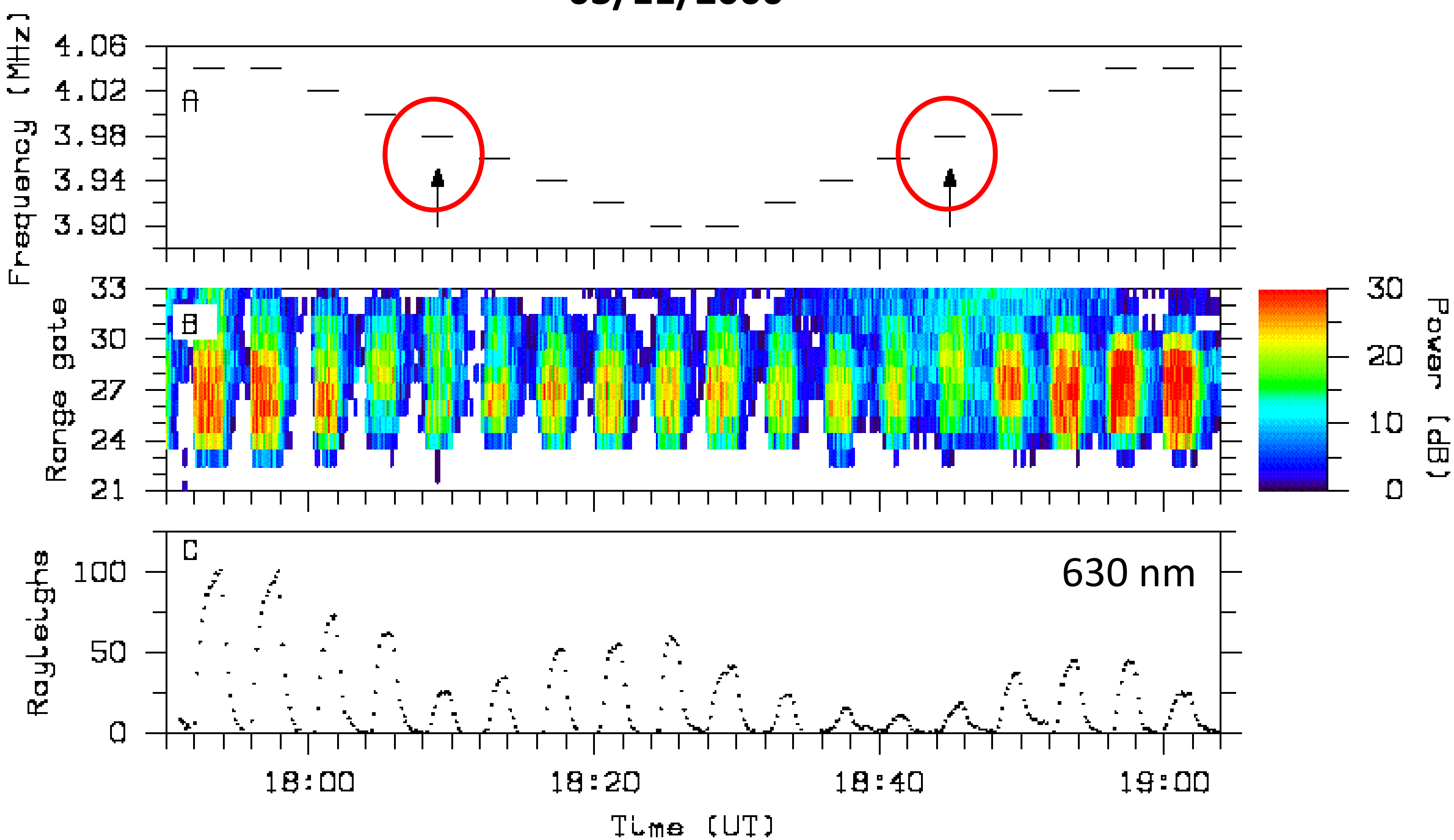


Kosch et al., GRL, 27, 2817-2820, 2000

Gyro-harmonics (upper-hybrid resonance)

03/11/2000

Super-DARN



Kosch et al., GRL, 29, 2112-2115, 2002

First 2GH artificial auroras

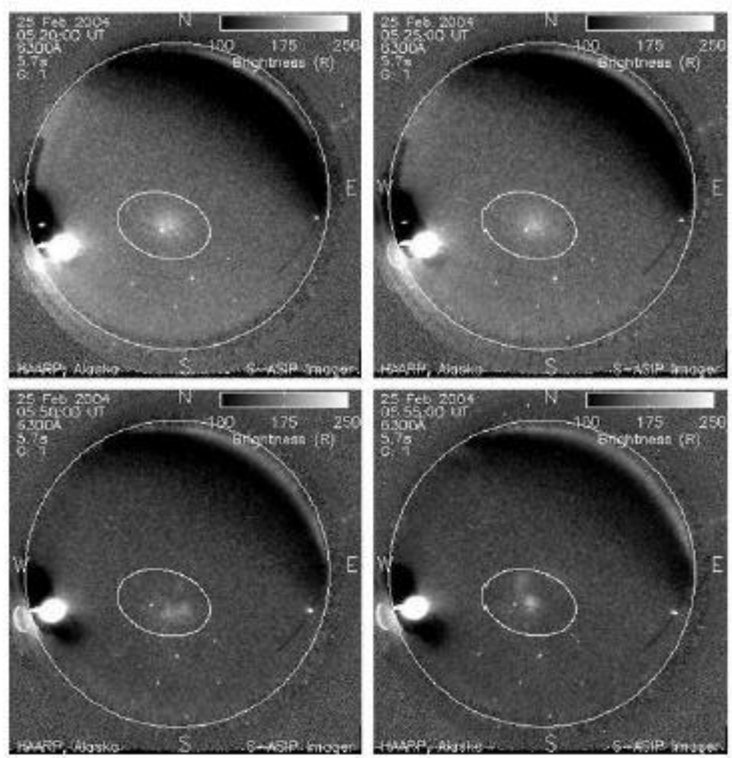


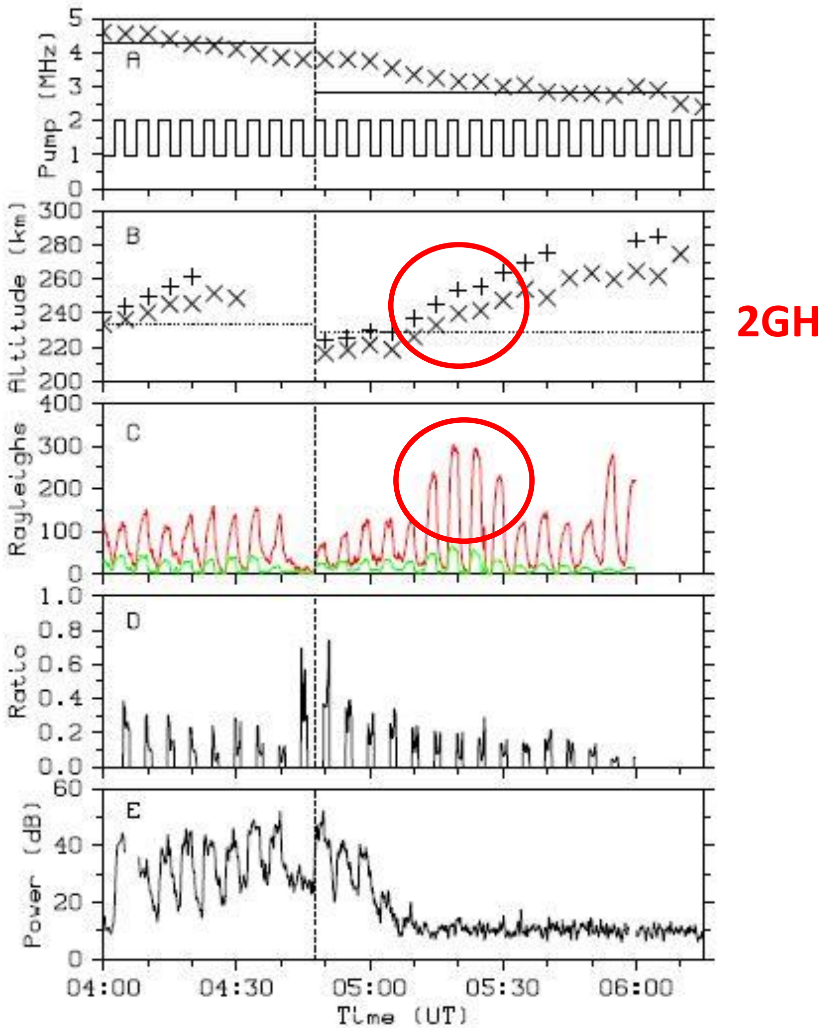
Fig. 2. Example images of the calibrated artificial optical emissions at 630 nm from the HAARP all-sky imager. The large circle is the horizon. The smaller oval denotes the HAARP beam −3 dB locus. The bright white disk near the south-west horizon is the moon. The faint arc near the north-east horizon is a natural aurora. The white spots correspond to stars. The top two panels show images from pumping close to the second gyro-harmonic. The bottom two panels show images from pumping just above the ionospheric critical frequency.

HAARP 2.85 MHz

ERP = 11 MW

Kosch et al.,
AG, 23, 1585–1592, 2005

First 2GH artificial auroras



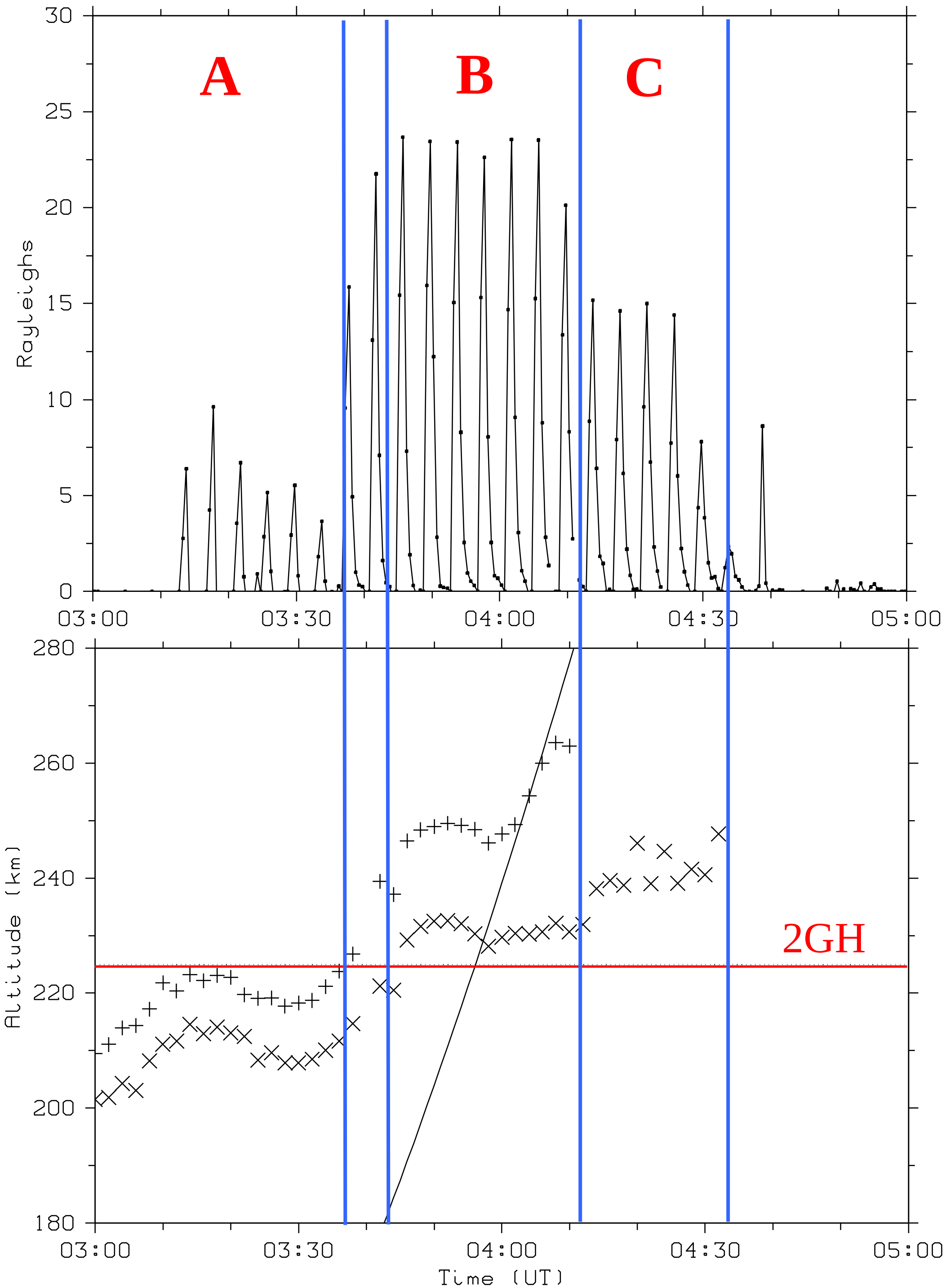
HAARP 2.85 MHz

04/02/2005

ERP = 11 MW

Kosch et al.,
AG, 23, 1585–1592, 2005

Fig. 1. Results from 25 February 2004. The vertical dashed line in all panels separates the third (left) and second (right) gyro-harmonic parts of the experiment. Panel A shows the pump frequency used (solid lines), ionospheric critical frequency (×) and pump cycle (square waves). Panel B shows the altitude of the respective gyro-harmonics (dotted lines), the pump wave reflection altitude measured by the Digisonde (+), and the upper-hybrid resonance altitude (×). Panel C shows the calibrated optical emission enhancement above background for 630 (red line) and 557.7 (green line) nm. Panel D shows the ratio of I(557.7)/I(630). Panel E shows the Kodiak radar backscatter power at 10 MHz.



HAARP

04/02/2005

630 nm

2.85 MHz

A: $PDI_L + PDI_{EB}$

B: $PDI_L + PDI_{UH} + TPI$

C: $PDI_{UH} + TPI$

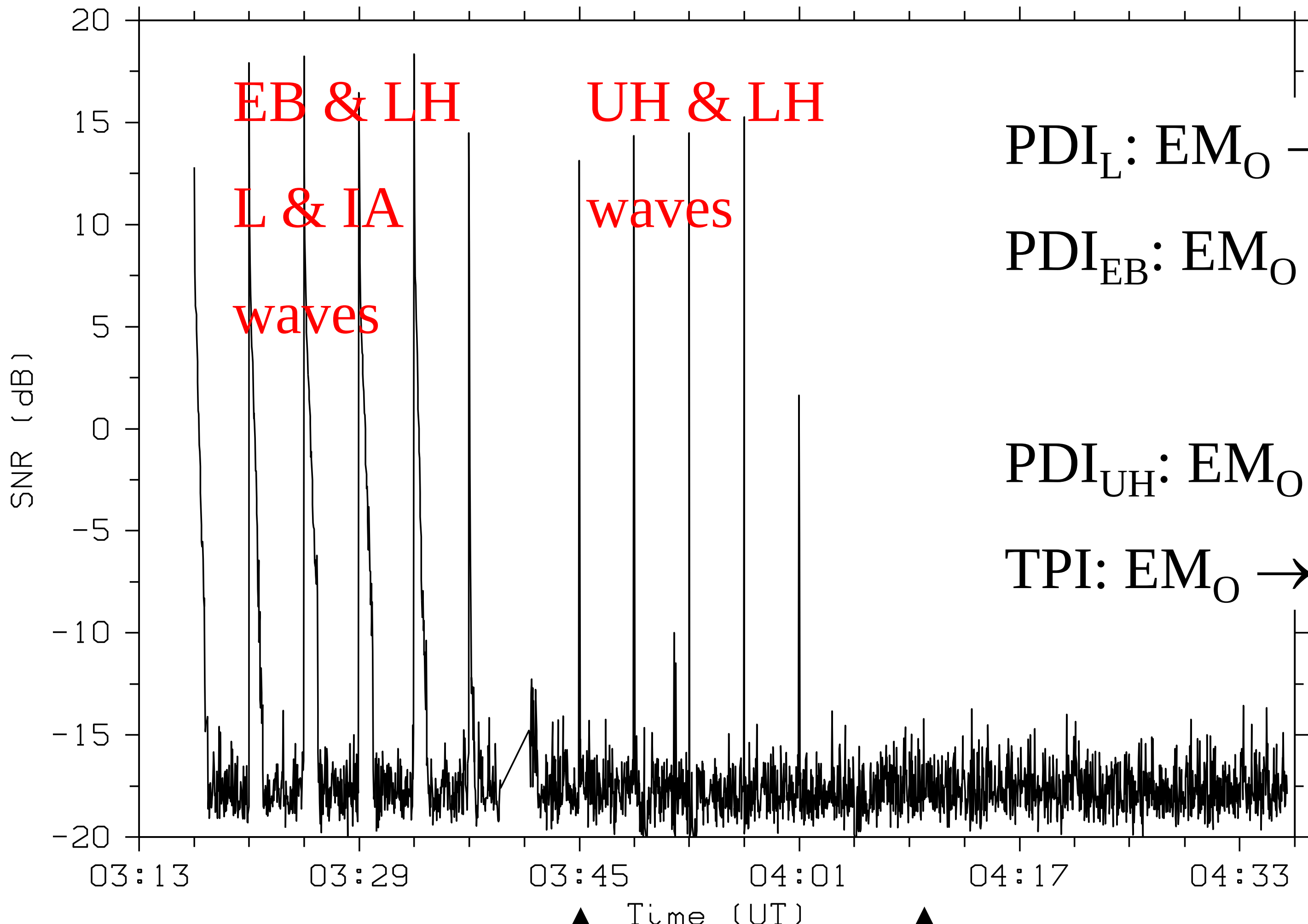
PDI_L: $O \rightarrow L + IA$

$PDI_{UH/EB}$: $O \rightarrow UH/EB + LH$

TPI: $O \rightarrow UH + \Delta n_e$

HAARP 04/02/2005

MUIR plasma-line (450 MHz)



PDI_L: $EM_O \rightarrow L + IA$

PDI_{EB}: $EM_O \rightarrow EB + LH$

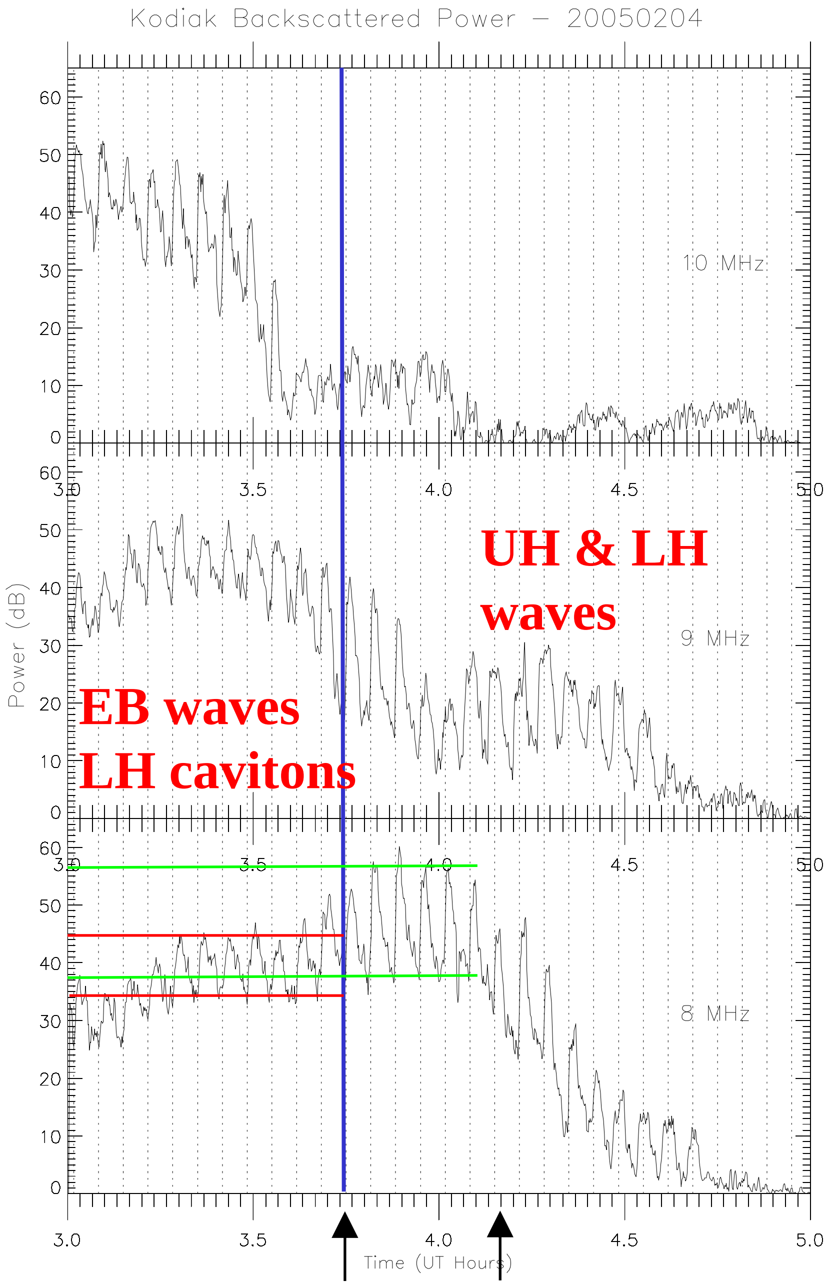
PDI_{UH}: $EM_O \rightarrow UH + LH$

TPI: $EM_O \rightarrow UH + \delta n_e$

2[nd] gyro = 03:45 UT

04:10 UT = foF2

Kosch et al., JGR, 2007, 10.1029/2006JA012146



2nd gyro = 03:45 UT

04:10 UT = foF2

HAARP 04/02/2005

2.85 MHz

Kodiak SuperDARN

$PDI_{UH/EB}$: $EM_O \rightarrow UH/EB + LH$

TPI: $EM_O \rightarrow UH + \delta n_e$

Kosch et al., JGR, 112, A06325, doi:10.1029/2006JA012146, 2007

First (and only) ISR data on 2GH

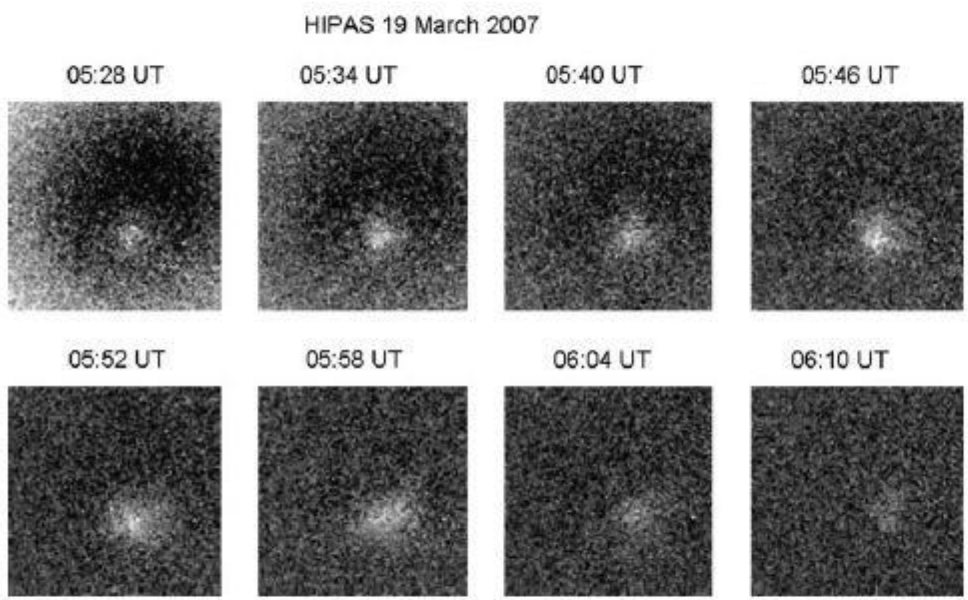


Fig. 2. Un-calibrated background-subtracted images of the pump-induced artificial optical emissions at 630 nm taken from HIPAS at the end of each continuous wave pump pulse. The field of view is ~45°. North and west are to the top and right of the images, respectively. The "halo" apparent in the earlier images is an artifact of background subtraction caused by declining twilight.

Kosch et al., JASTP, 71, 1959–1966, 2009

Distance PFISR-HIPAS (Alaska) = 41 km

First (and only) ISR data on 2GH

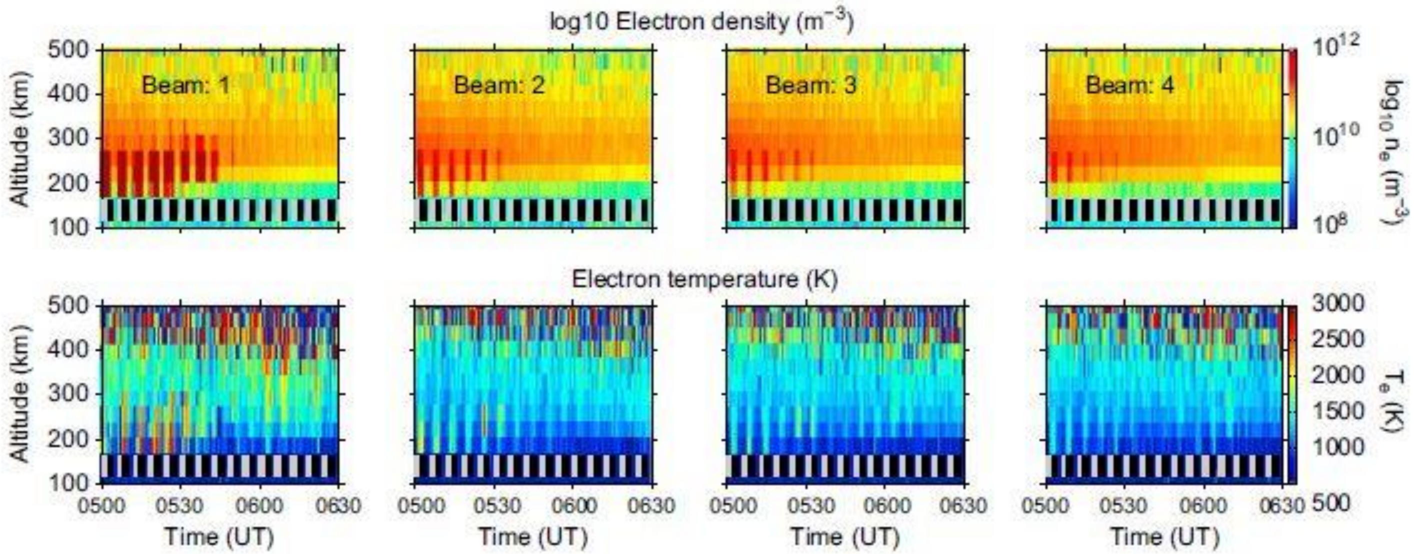


Fig. 4. Poker Flat Incoherent Scatter Radar observations of electron density (upper panels) and electron temperature (lower panels) with altitude in 4 different look directions from long-pulse data, post-integrated to 30.72 s. HIPAS was operated in pulsed (grey panels) and continuous wave (black panels) modes with other periods having no transmissions.

Kosch et al., JASTP, 71, 1959–1966, 2009

First (and only) ISR data on 2GH

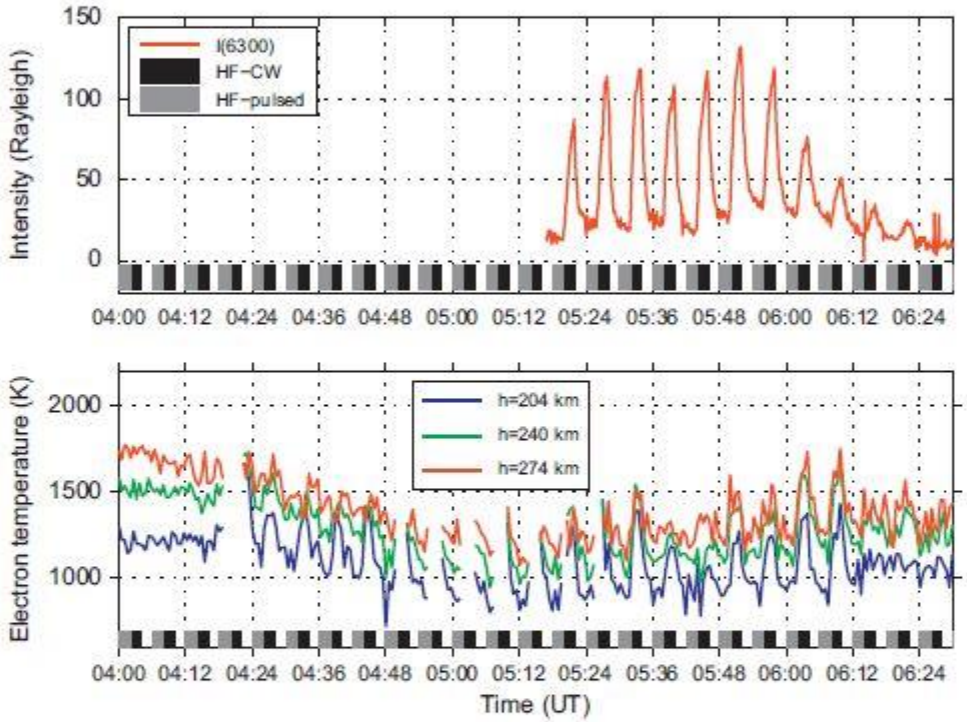
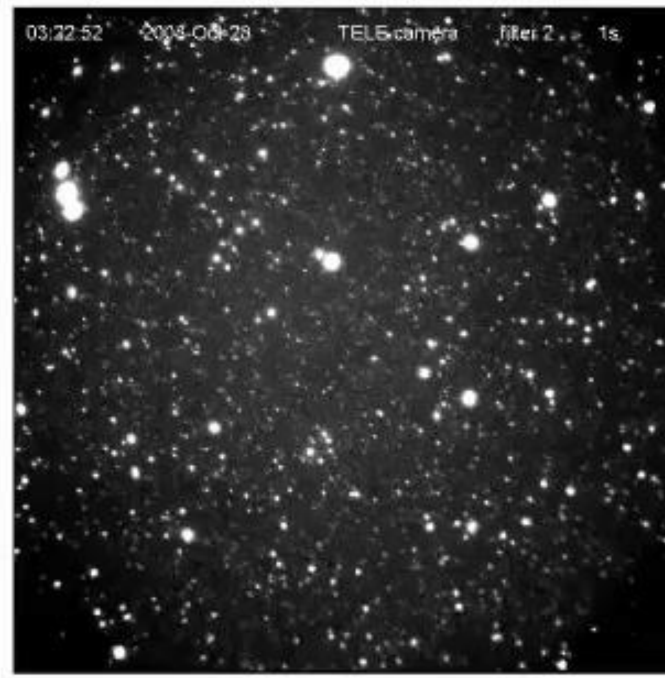


Fig. 5. Calibrated background-subtracted intensity of the pump-induced artificial optical emissions at 630 nm (upper panel). Electron temperature taken from the 3 long-pulse PFISR beams intersecting the HIPAS pump beam at 3 different altitudes, post-integrated to 30.72 s (lower panel). HIPAS was operated in pulsed (grey panels) and continuous wave (black panels) modes with other periods having no transmissions.

Kosch et al., JASTP, 71, 1959–1966, 2009

Small scale structures (2GH)

HAARP 20081028 @ 5577 A



First Narrowband SEE at EISCAT

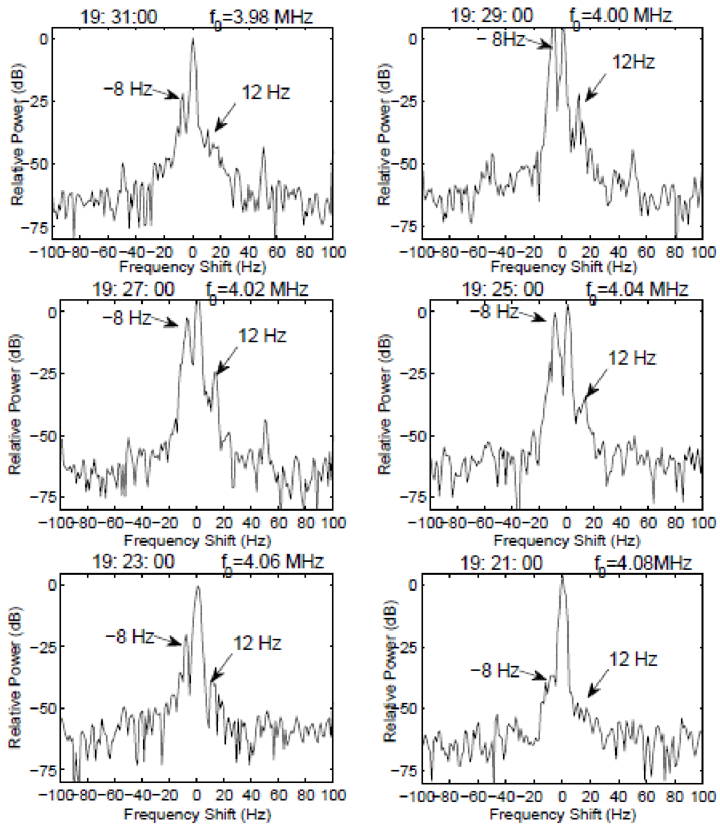


Figure 1. Narrowband SEE frequency spectra of HF scattered signals showing strong emission lines at 8–12 Hz using the EISCAT HF transmitter operating at varying pump frequencies near $3f_{ce}$ during 19:20–19:32 UT on 3 July 2012. The heating beam points towards the magnetic zenith direction with 1 min on/off duty cycle.

Fu et al., AG, 33, 983–990, 2015

Optical opportunities
Minimum pump frequency (4 MHz)

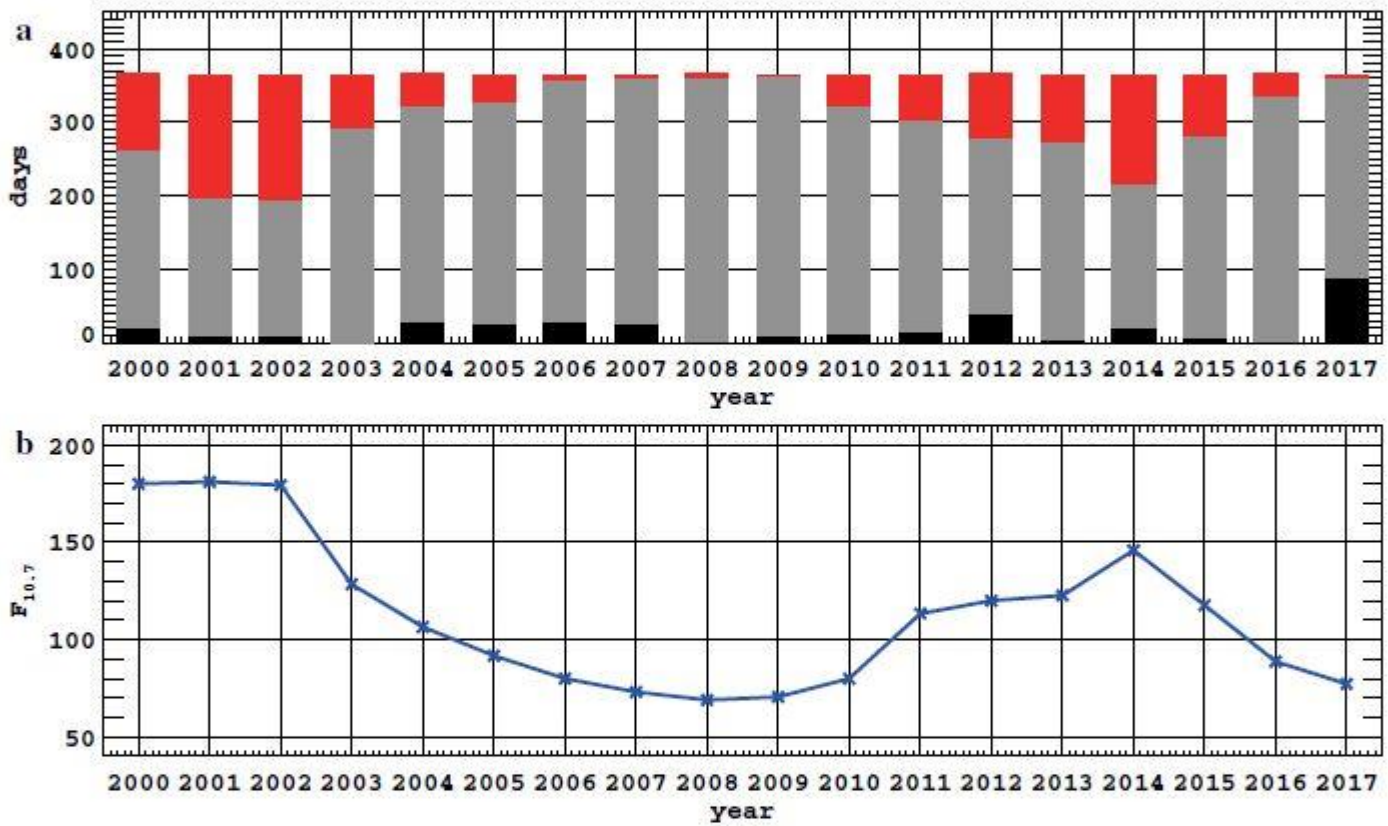


Fig. 9 **a** Year-to-year variations in the number of possible days for conducting artificial aurora experiments from 2000 to 2017. The red bars indicate possible days, the gray bars indicate days in which conducting the experiments is not possible, and the black bars indicate days when there are no data. **b** Year-to-year variation in 1-year-averaged $F_{10.7}$ from 2000 to 2017

Tsuda et al., EPS, 2018, https://doi.org/10.1186/s40623-018-0805-9

Optical opportunities
Minimum pump frequency (2.7 MHz)

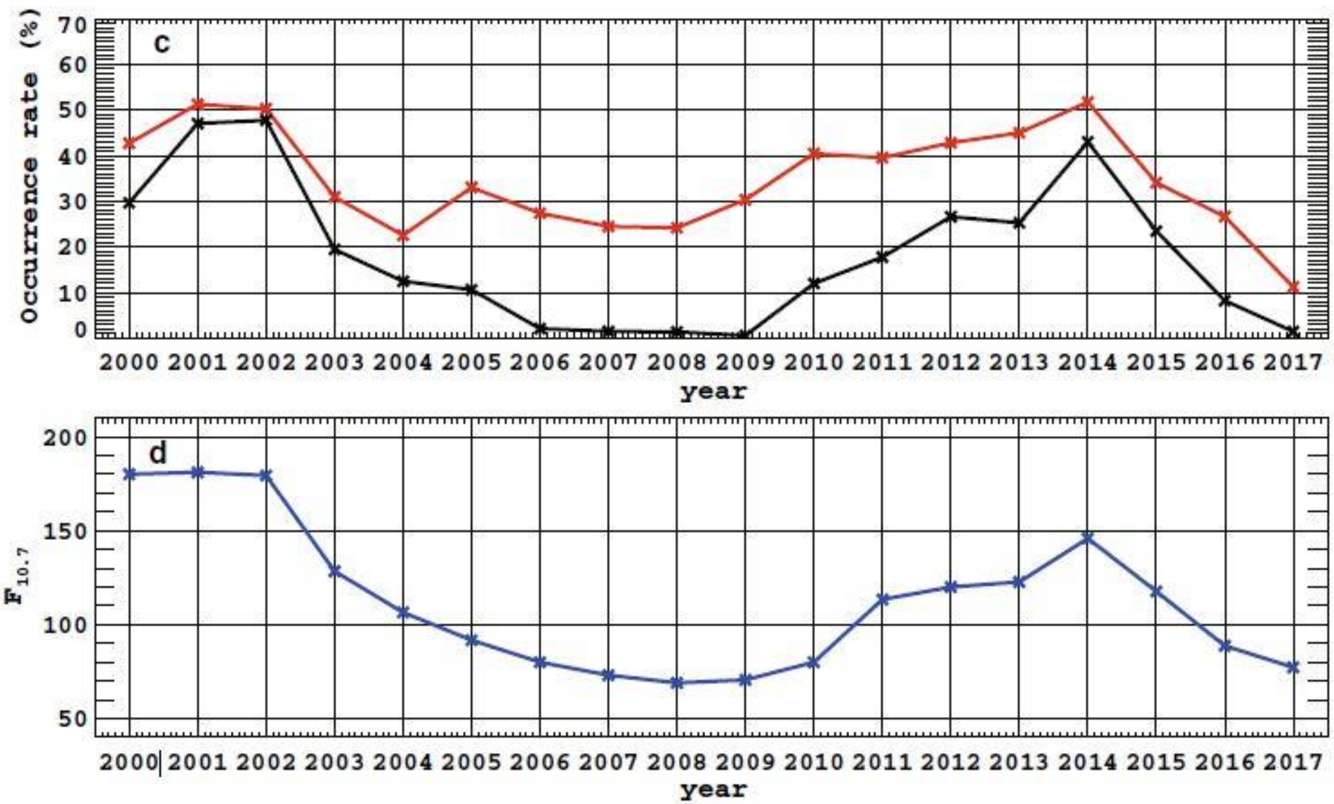
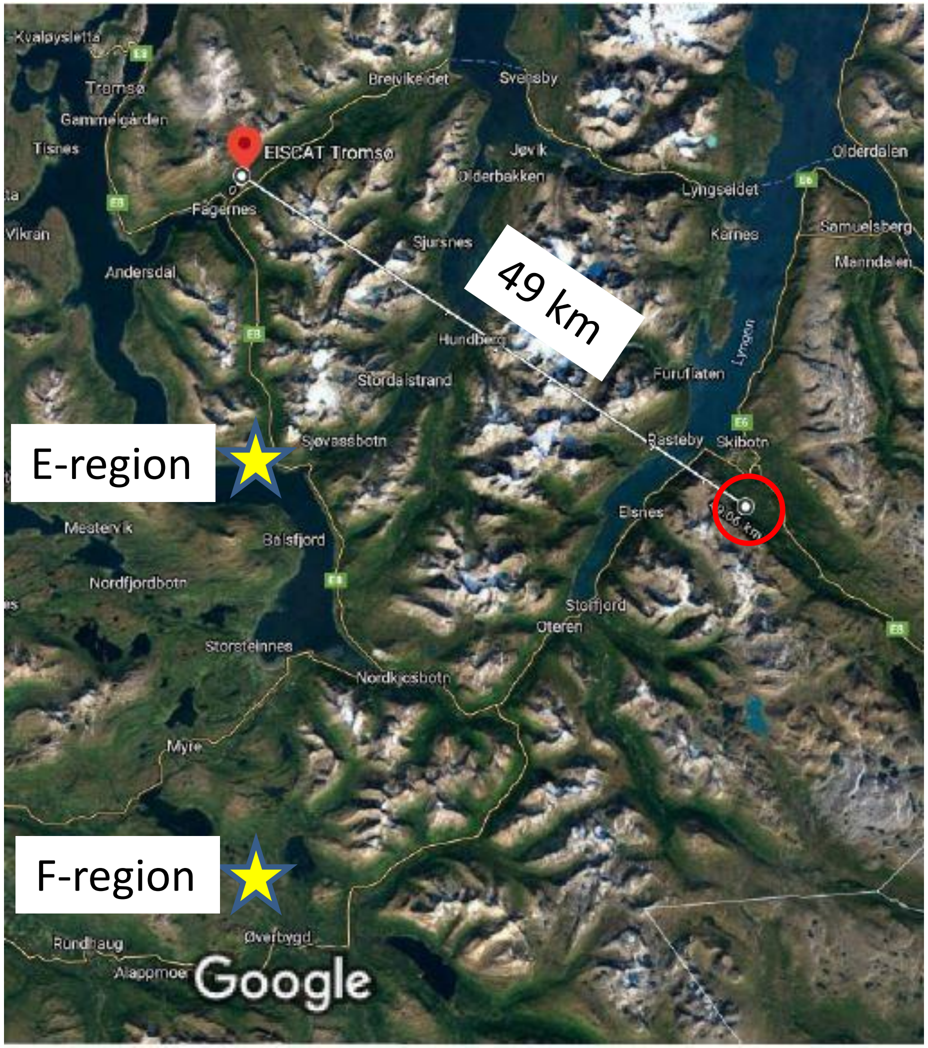


Fig. 7 **a** Year-to-year variations in the number of possible days for conducting artificial aurora experiments from 2000 to 2017, in the case of 2.7-MHz frequency. The red bars indicate possible days, the gray bars indicate days in which conducting the experiments is not possible, and the black bars indicate days when there are no data. **b** Same as **a**, but in the case of 4-MHz frequency (Tsuda et al. 2018). **c** Year-to-year variation in the occurrence rate of possible days for conducting artificial aurora experiments from 2000 to 2017. The red indicates results in the case of 2.7-MHz frequency, and the black indicates results in the case of 4-MHz frequency. **d** Year-to-year variation in 1-year-averaged $F_{10.7}$ from 2000 to 2017

Tsuda et al., EPS, 2018, https://doi.org/10.1186/s40623-018-0864-y

E3D viewing angles



Heater field-aligned

F-region (250 km):
E3D elevation = 77°

E-region (100 km):
E3D elevation = 67°

Heater vertical

D-region (85 km):
E3D elevation = 60°

Conclusion

- ~2.72 MHz is the 2^{nd} gyro-harmonic at EISCAT
- Heater transmitters can operate on 2.7 MHz
- Heater waveguides can operate on 2.7 MHz
- **Need to convert SuperHeater antennas**

- New F-region science – plasma resonance (e.g. NSEE)
- New F-region science – Small scale structures
- New D-region science – e.g. PMSE/PMWE?
- New diagnostic angles (not field-aligned)

- Better night-time/winter opportunities (optics)
- Better solar minimum opportunities (PMSE)

Thank you