UNIVERSITY of OULU
Sodankylä Geophysical Observatory

KAIRA RIOMETRY

Derek McKay-Bukowski

PROPAGATION

$$n^2 = 1 - \frac{X}{1 - iZ - [\frac{Y_\perp^2}{2(1-X-iZ)}] \pm [\frac{Y_\perp^4}{4(1-X-iZ)^2} + Y_\parallel^4]^{\frac{1}{2}}}$$

Appleton-Hartree Equation

PROPAGATION

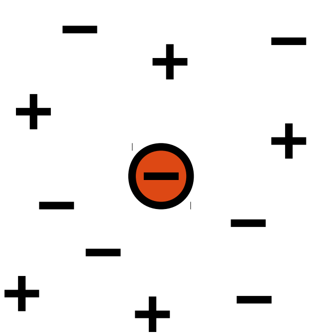
$$n^2 = 1 - \frac{X}{1 - iZ - [\frac{Y_\perp^2}{2(1-X-iZ)}] \pm [\frac{Y_\perp^4}{4(1-X-iZ)^2} + Y_\parallel^4]^{\frac{1}{2}}}$$

$$X = \omega_\mathrm{N}^2/\omega^2; \quad Y = \omega_\mathrm{B}/\omega; \quad Y_\parallel = \omega_{\mathrm{B}_\parallel}/\omega; \quad Y_\perp = \omega_{\mathrm{B}_\perp}/\omega; \quad Z = \nu/\omega;$$

ω_N ω_B υ

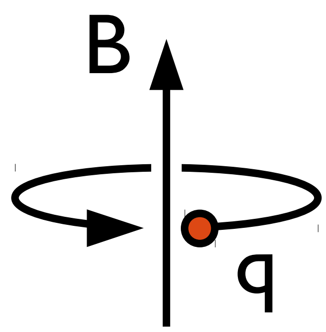
Plasma frequency

ω_N



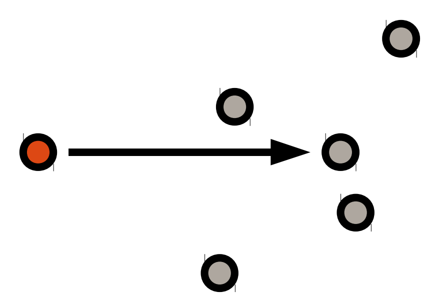
Gyro frequency

ω_B



Collision frequency

ν



PROPAGATION

$$n^2 = 1 - \frac{X}{1 - iZ - [\frac{Y_\perp^2}{2(1-X-iZ)}] \pm [\frac{Y_\perp^4}{4(1-X-iZ)^2} + Y_\parallel^4]^{\frac{1}{2}}}$$

$$X = \omega_\mathrm{N}^2/\omega^2; \quad Y = \omega_\mathrm{B}/\omega; \quad Y_\parallel = \omega_{\mathrm{B}\parallel}/\omega; \quad Y_\perp = \omega_{\mathrm{B}\perp}/\omega; \quad Z = \nu/\omega;$$

$$n^2 = 1 - \frac{X}{1 - iZ} = 1 - \frac{\omega_\mathrm{N}^2}{\omega(\omega - i\nu)}$$

$$n^2 = 1 - \frac{X}{1 - iZ} = 1 - \frac{\omega_{\mathrm{N}}^2}{\omega(\omega - i\nu)}$$

Complex $$n = \mu - i\chi$$

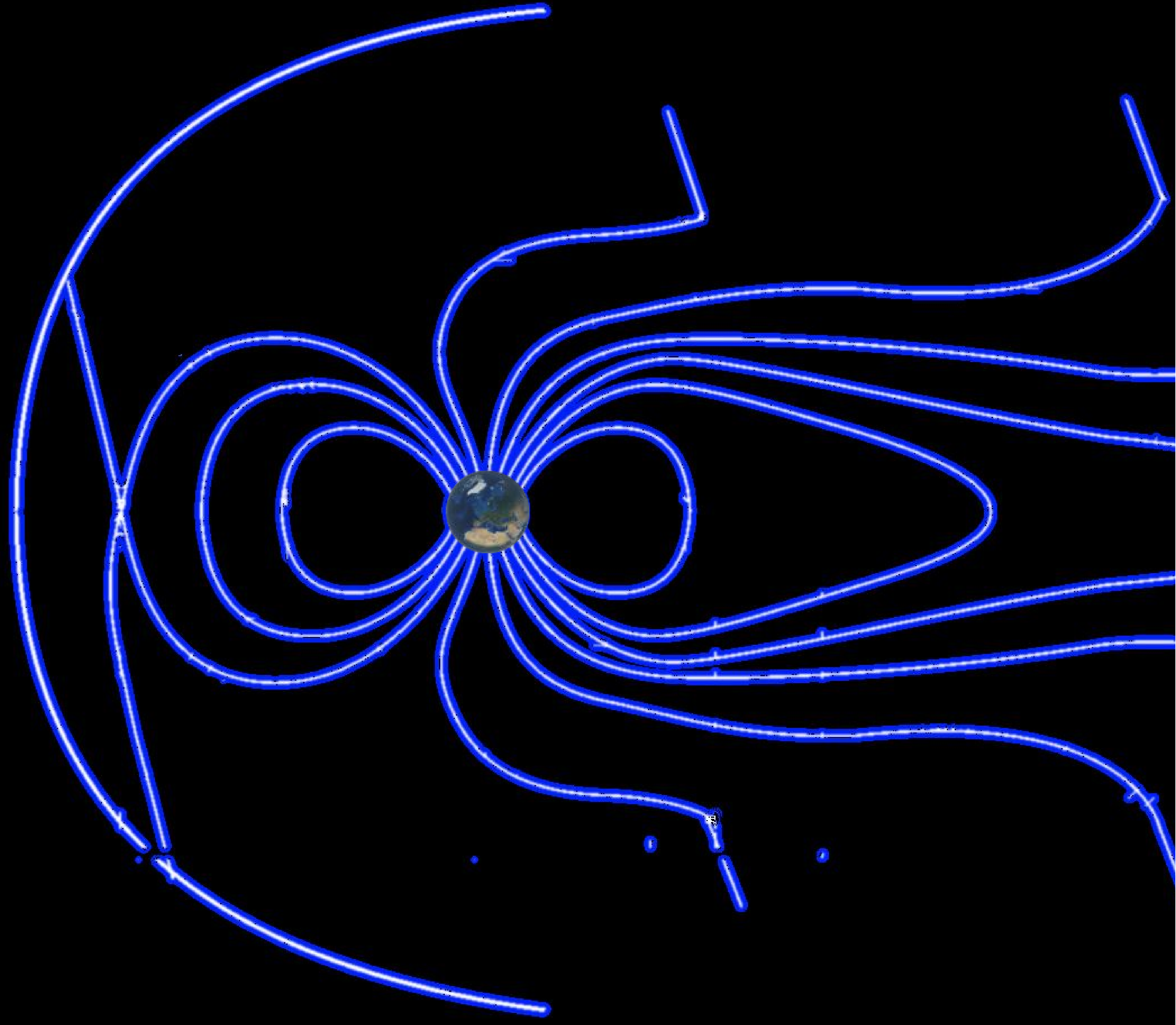
Exp. decay $$\exp(-x\chi\omega/c)\cos\omega(t - x\mu c)$$

Abs. coeff $$\kappa = \frac{\omega}{c} \cdot \frac{1}{2\mu} \cdot \frac{XZ}{1 + Z^2} = \frac{e^2}{2\epsilon_0 mc} \cdot \frac{1}{\mu} \cdot \frac{N_{\mathrm{e}}\nu}{\omega^2 + \nu^2}$$

Riometry Eqn. $$A = 4.5 \times 10^{-5} \int \frac{N_{\mathrm{e}}\nu}{\omega^2 + \nu^2}\ dx\ (\mathrm{dB})$$

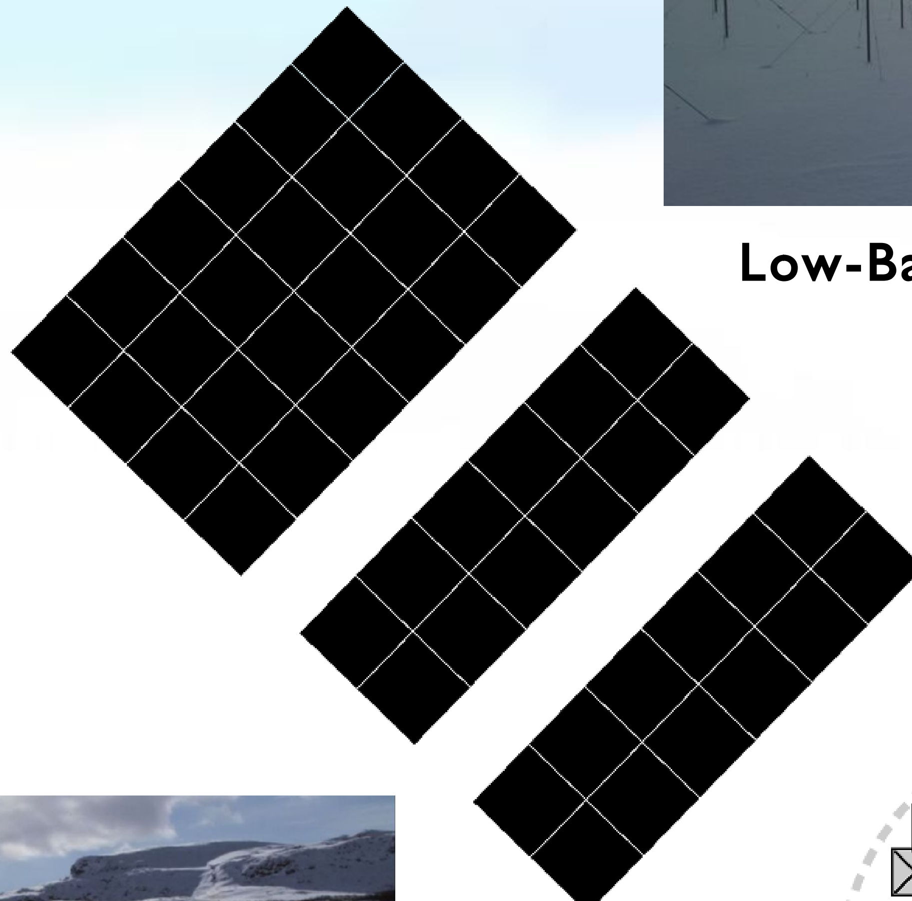
CAUSES

- D-region, free electrons
- Collisional plasma, chemically complicated
- Multiple sources of ionisation
  - Lyα ionises NO
  - EUV ionises $O_2(^1\Delta g)$
  - Hard X-ray and EUV ionise O_2 and N_2
  - Galactic cosmic rays
  - Solar particle and auroral precipitation

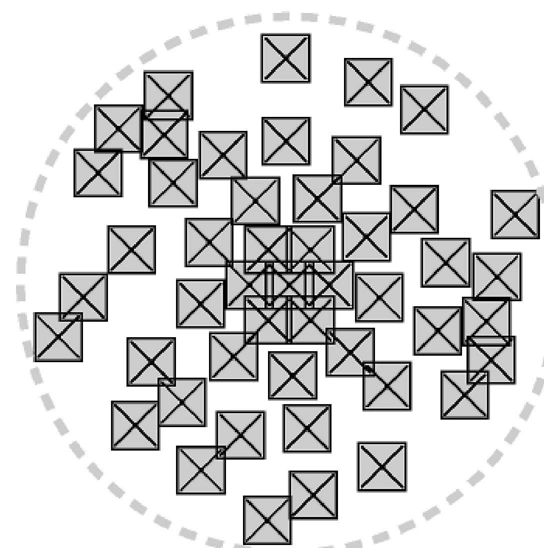


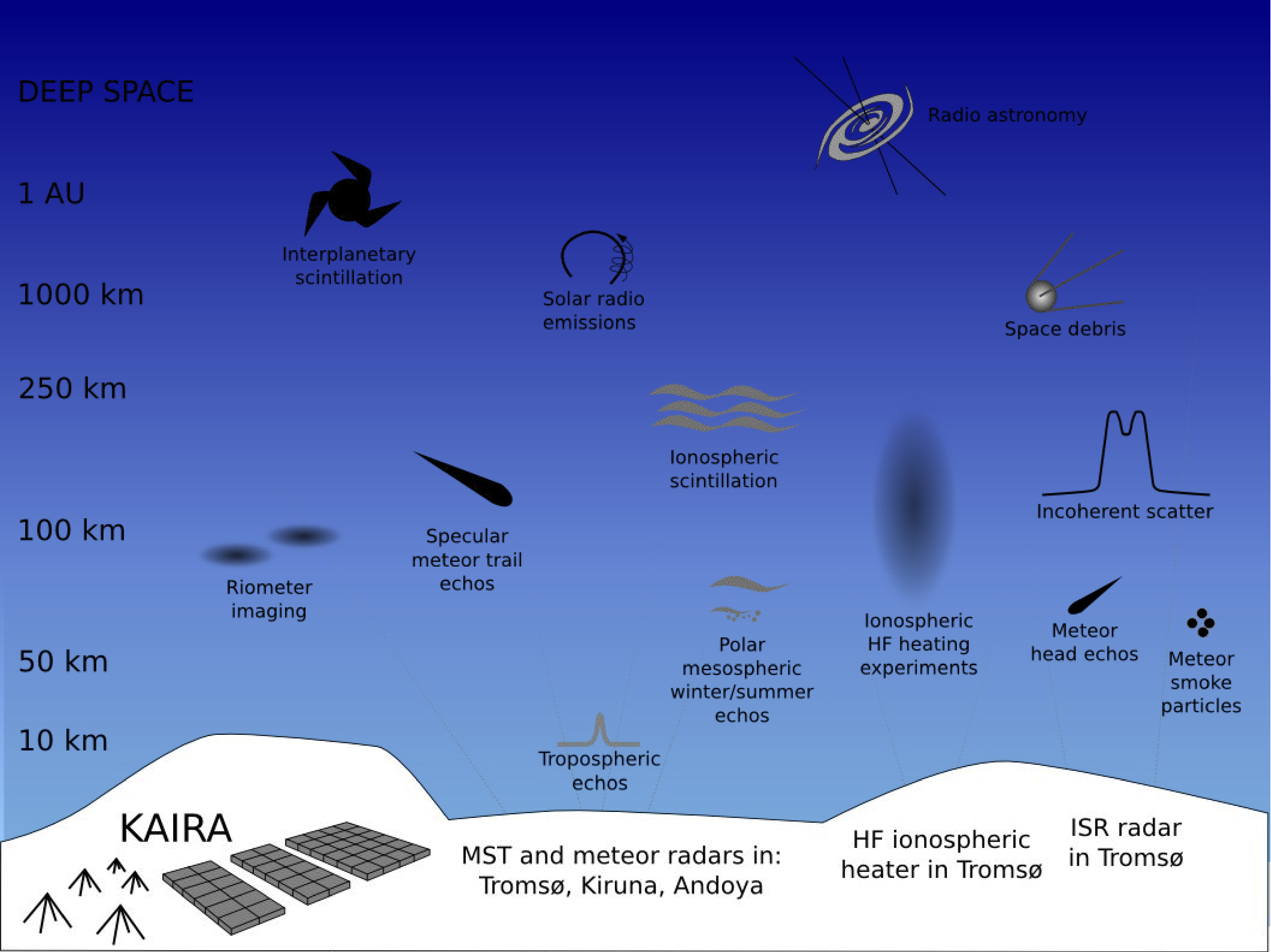
KAIRA

Low-Band Antenna (LBA) array
34 m diameter
48 aerials
10-90 MHz



High-Band Antenna (HBA) array
51m x 31 m
48 tiles
110-270 MHz




DEEP SPACE
1 AU
1000 km
250 km
100 km
50 km
10 km
Radio astronomy
Interplanetary scintillation
Solar radio emissions
Space debris
Ionospheric scintillation
Incoherent scatter
Specular meteor trail echos
Riometer imaging
Ionospheric HF heating experiments
Polar mesospheric winter/summer echos
Meteor head echos
Meteor smoke particles
Tropospheric echos
KAIRA
MST and meteor radars in:
Tromsø, Kiruna, Andoya
HF ionospheric heater in Tromsø
ISR radar in Tromsø

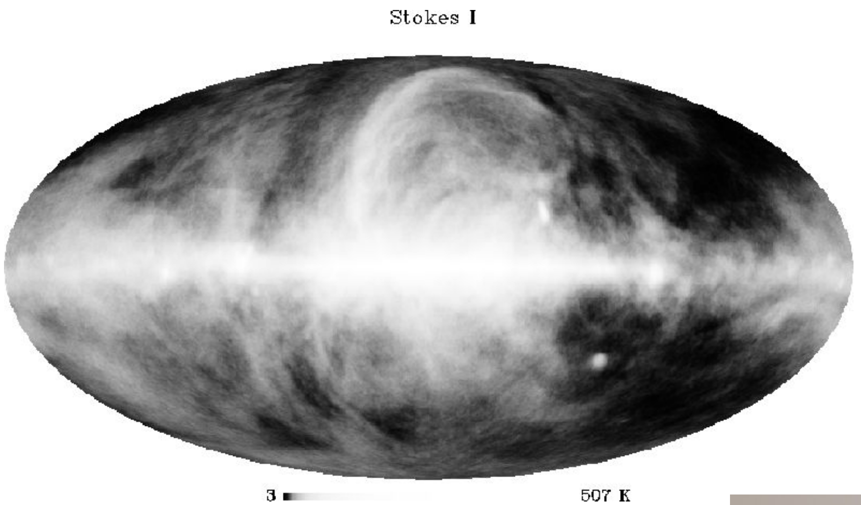
RIOMETRY

Riometry Absorption Eqn.

$$A = 4.5 \times 10^{-5} \int \frac{N_{\mathrm{e}}\nu}{\omega^2 + \nu^2}\, dx \ (\mathrm{dB})$$

Observed Absorption

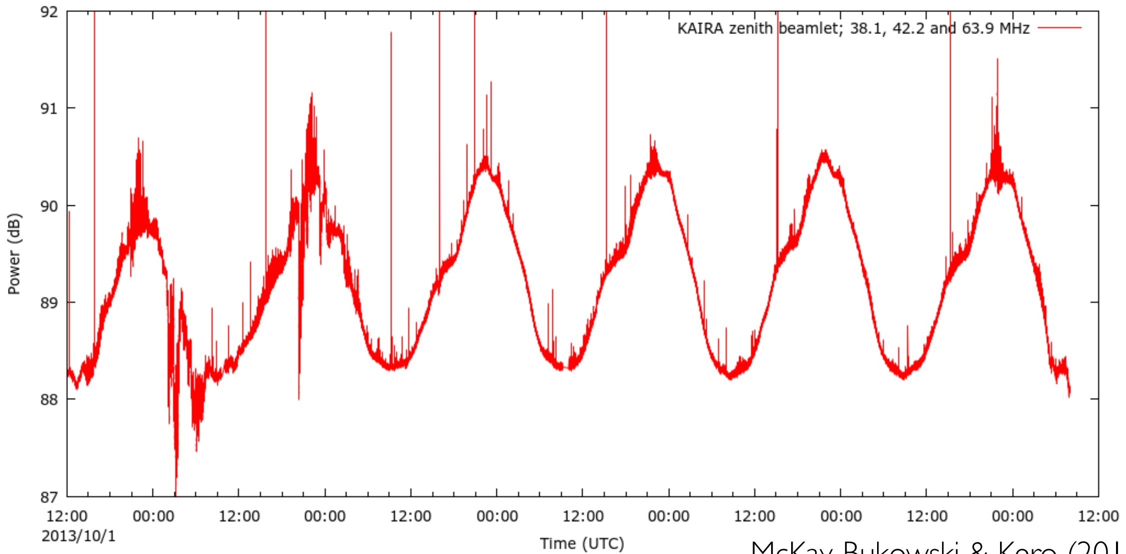
$$A = 10 \log_{10}(P_{\mathrm{q}}/P)$$



Giardino et al., A&A 387, 82-97 (2002).

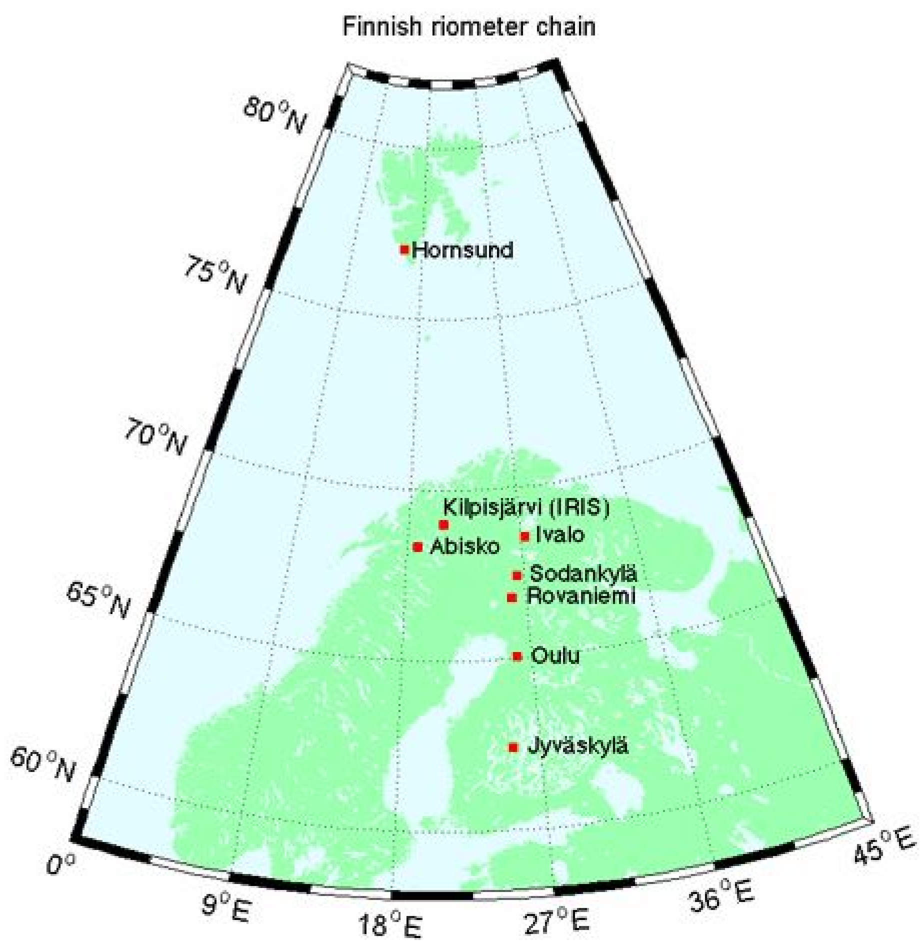
Gal.Synch

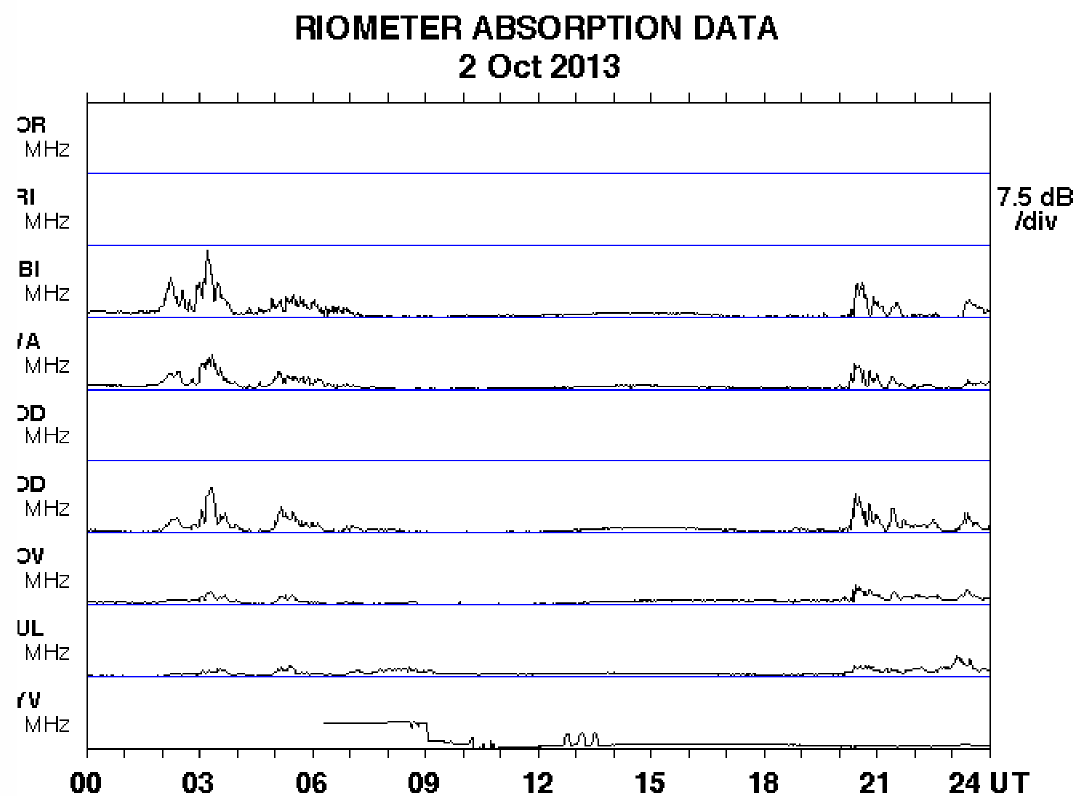
KAIRA



McKay-Bukowski & Kero (2013)

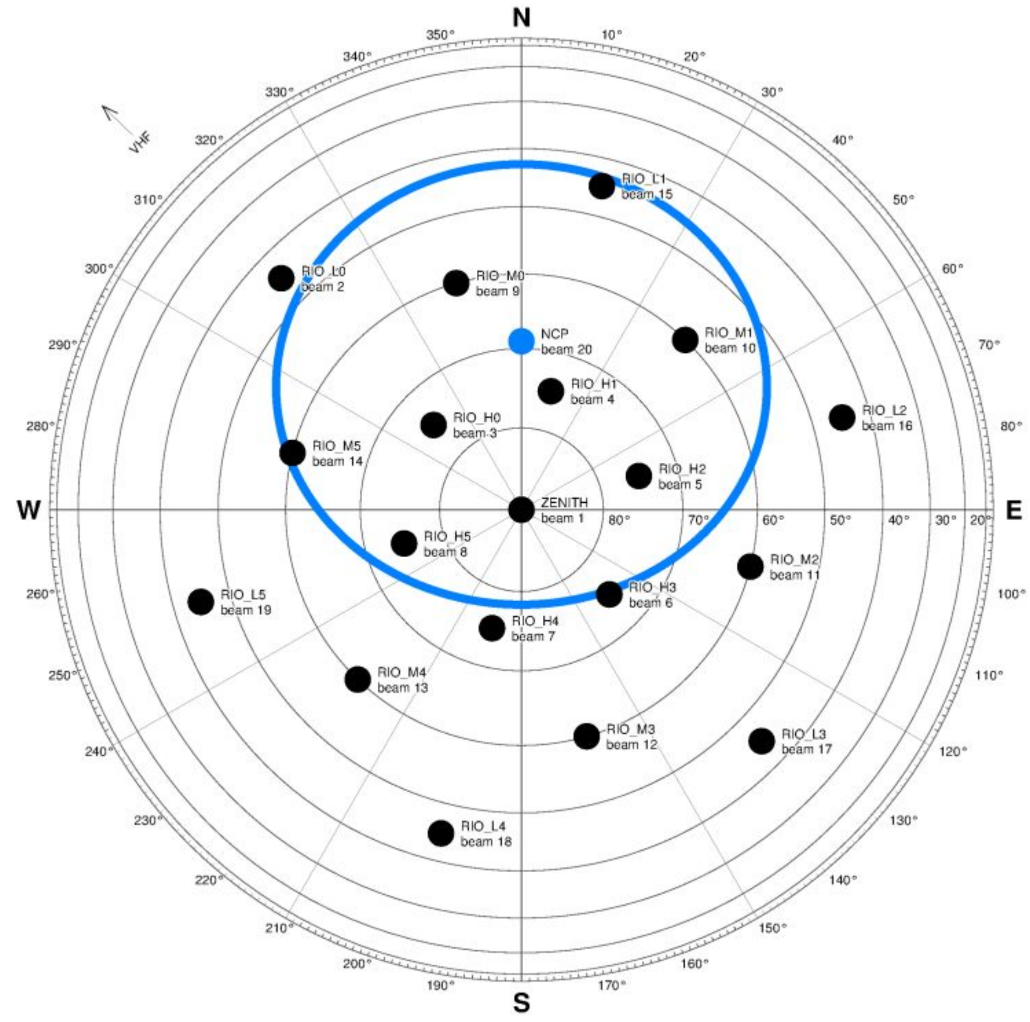
However, this is already being done by the SGO riometer chain





Raita, et al.

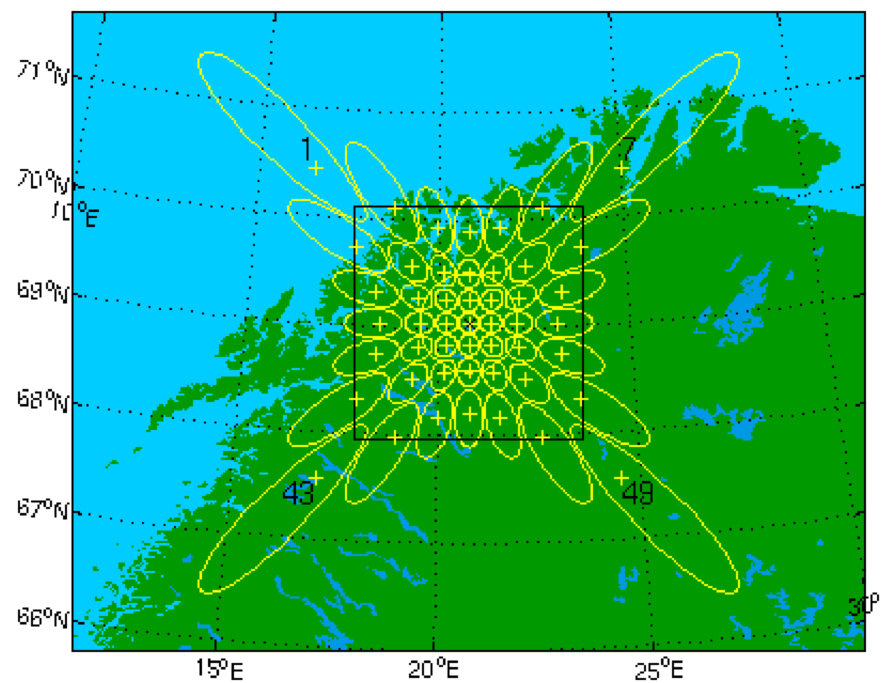
MULTIBEAM



McKay-Bukowski & Kero (2013)

However, this is already being done by the IRIS multibeam riometer

38.1 MHz
49 antennas
7x7 matrix
49 beams



Plot: Dept. Phys, U.Lancs Photo: McKay-Bukowski

LOFAR

More stable

Nicer beam shape

Steerable beams

Better, but not ground-breaking...

However, there are two innovations

1 MULTI-FREQUENCY

Riometry Eqn. $$A = 4.5 \times 10^{-5} \int \frac{N_{\mathrm{e}}\nu}{\omega^2 + \nu^2}\, dx \ (\mathrm{dB})$$

This is an inverse problem!

Kero, Vierinen, Virtanen *et al.* (2013)

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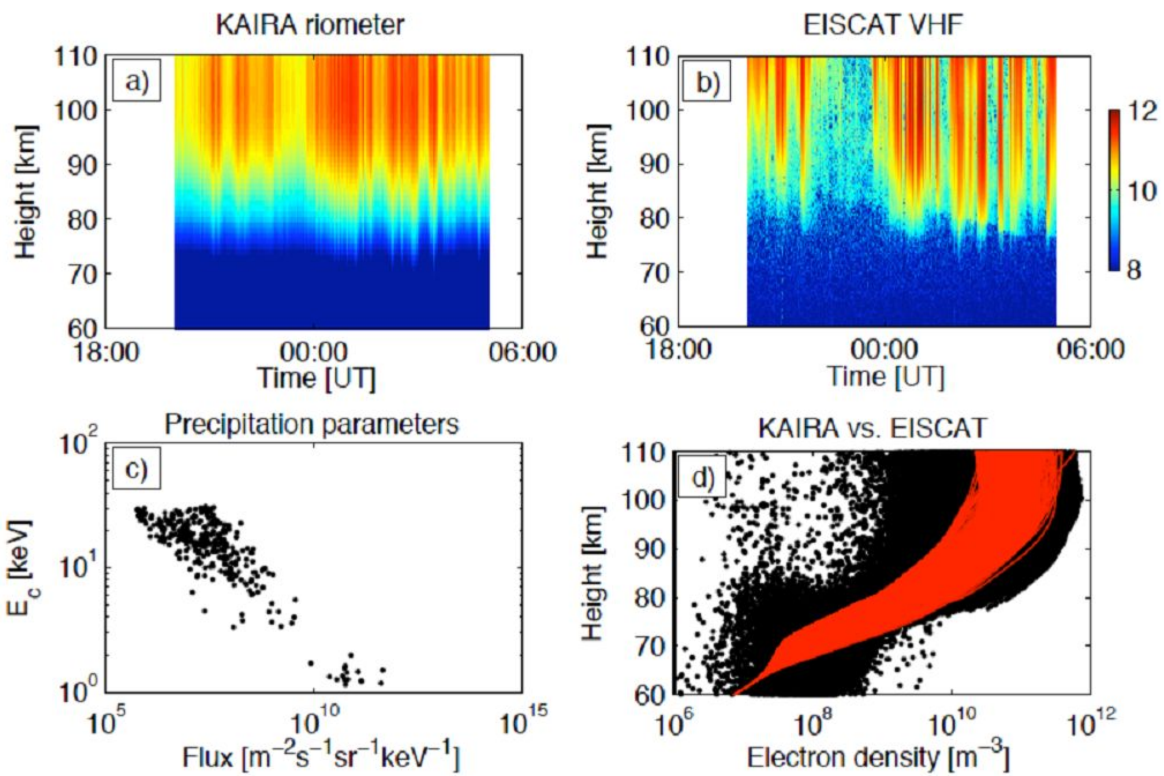
Riometry Eqn. $$A = 4.5 \times 10^{-5} \int \frac{N_{\mathrm{e}}\nu}{\omega^2 + \nu^2}\, dx\ (\mathrm{dB})$$



Kero, Vierinen, Virtanen *et al.* (2013)

2 INTERFEROMETRY

2 INTERFEROMETRY

Like riometry, but in 2D

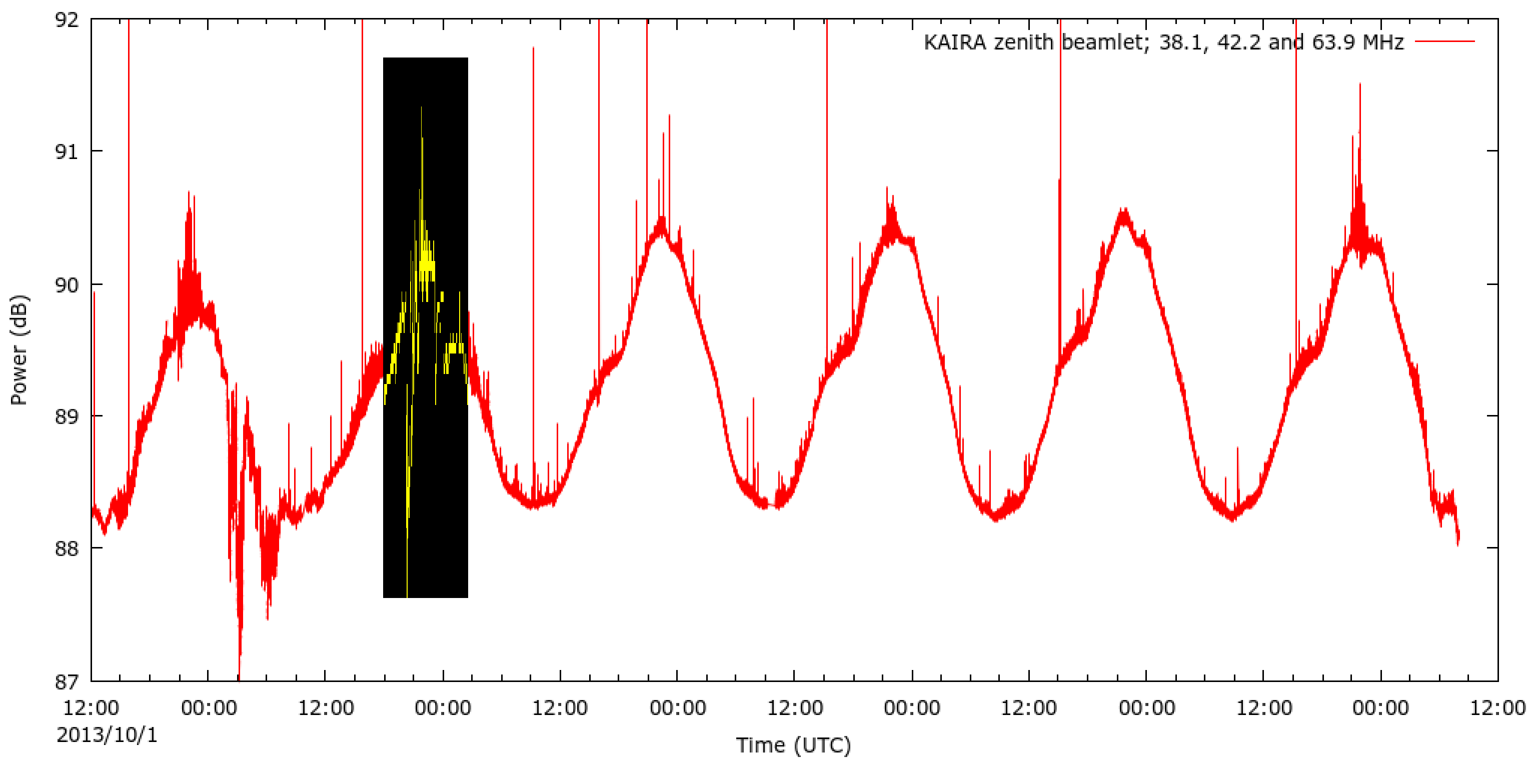
vCZ theorem

Build up QSP

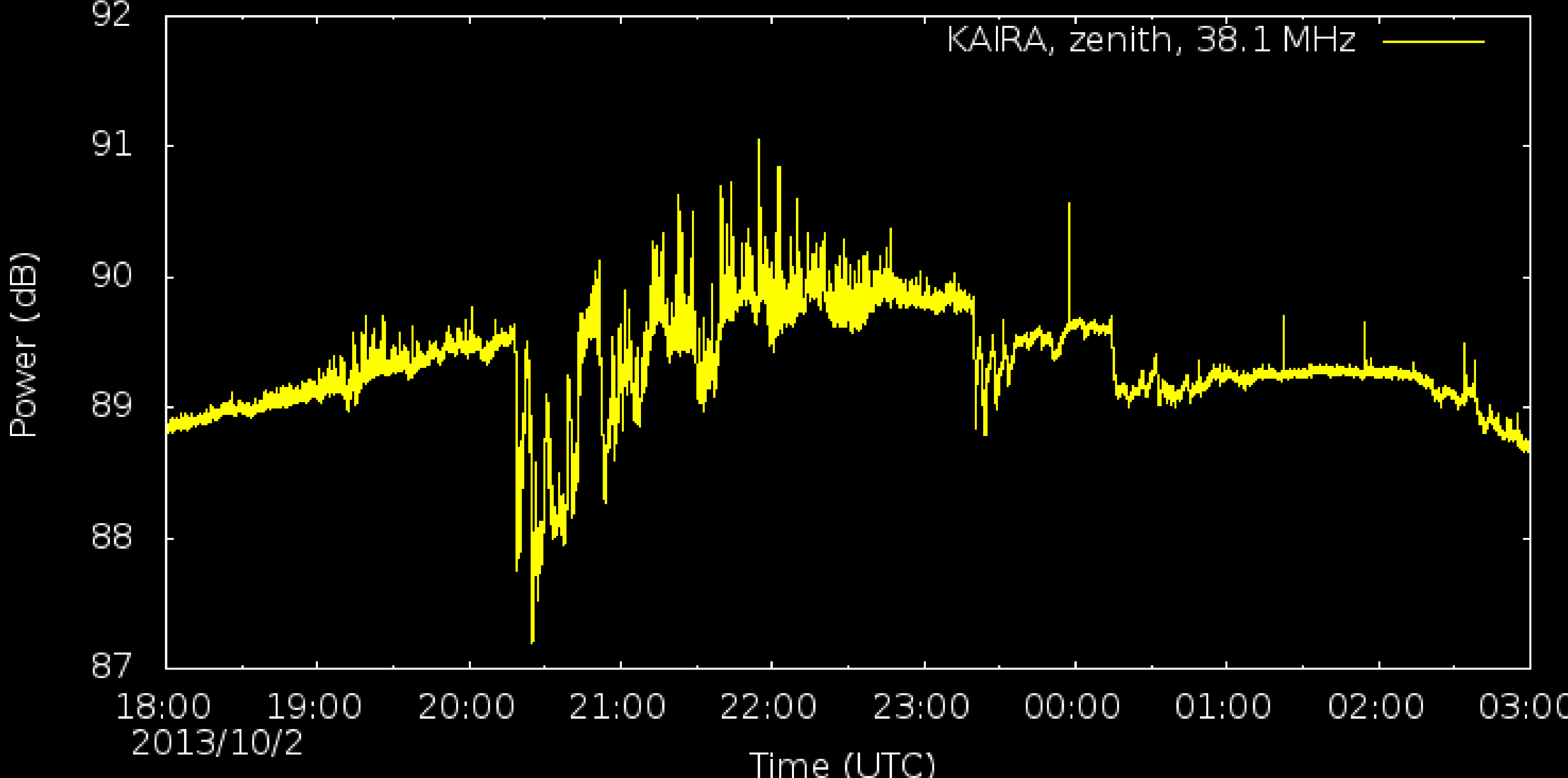
Derive Abs.

Data July-October 2013 at 38.1 MHz

Shown here: 01-08 Oct 2013



McKay-Bukowski, *et al.* (2013)



KAIRA, zenith, 38.1 MHz
Power (dB)
92
91
90
89
88
87
18:00
2013/10/2
19:00
20:00
21:00
22:00
23:00
00:00
01:00
02:00
03:00
Time (UTC)

+ ADVANTAGES

All-sky

All-weather

All-season

+ ADVANTAGES

All-sky
All-weather
All-season

− DISADVANTAGES

Resolution
Single-frequency (at the moment)

FUTURE

Multi-frequency, interferometry

Multi-station (Finland, ILT)

Improved Inverse Problem algorithms

Improved ionospheric models

Applications (space, aviation, forecasting)

CONCLUSIONS

Inverse problem → electron densities

All-sky inteferometric riometry

Viable for all-season auroral monitoring

Noise ↔ Data

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Thank you!

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