Interpreting ISR Data

Ian McCrea
STFC Rutherford Appleton Lab
Oxfordshire UK

(With thanks and appreciation to Mike Lockwood)

ISR data: What to be aware of

- With ISR data, what you get out depends significantly on what you put in!
  - ...so be aware of what that is.....

- When you choose your experiment you start constraining your science
  - frequencies,
  - coding,
  - pointing/ scanning,
  - resolution

ISR data: What to be aware of

- Analysing the data implies more constraints
  - Integration times
  - Range/altitude resolution
  - Non-thermal spectra
  - Satellites, space debris, clutter
  - Fit ambiguities and covariance
  - Systematic errors due to (possibly) incorrect assumptions
    - Modelled compositions
    - Collision frequencies
    - Iteration limits
    - Convergence criteria
  - Random errors

- The danger is not to realise that these effects exist!

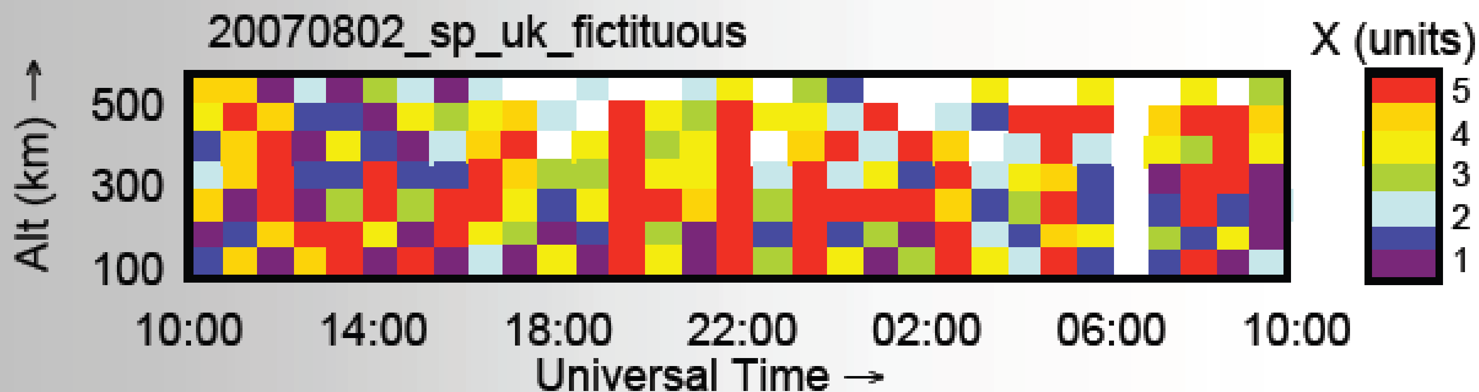
What this talk is and isn't....

- This talk is partly about some of the problems that can happen with your experiment, data integration and fitting.
- This talk is mainly to get you thinking about the physical meaning of the results, especially for high latitude radars.
- Even if you've designed a perfect experiment and done a perfect analysis, the interpretation is not necessarily simple....

Usual Summary Plot Format

These data show what? (is anyone colourblind?)

Data plotted as a function of UT of observations and altitude of range “gate”



Analysis integration time (often 1 or 5 min)

- may be too long for what you are looking for

Height resolution set by pulse coding and pointing direction of experiment

Usual Summary Plot Format

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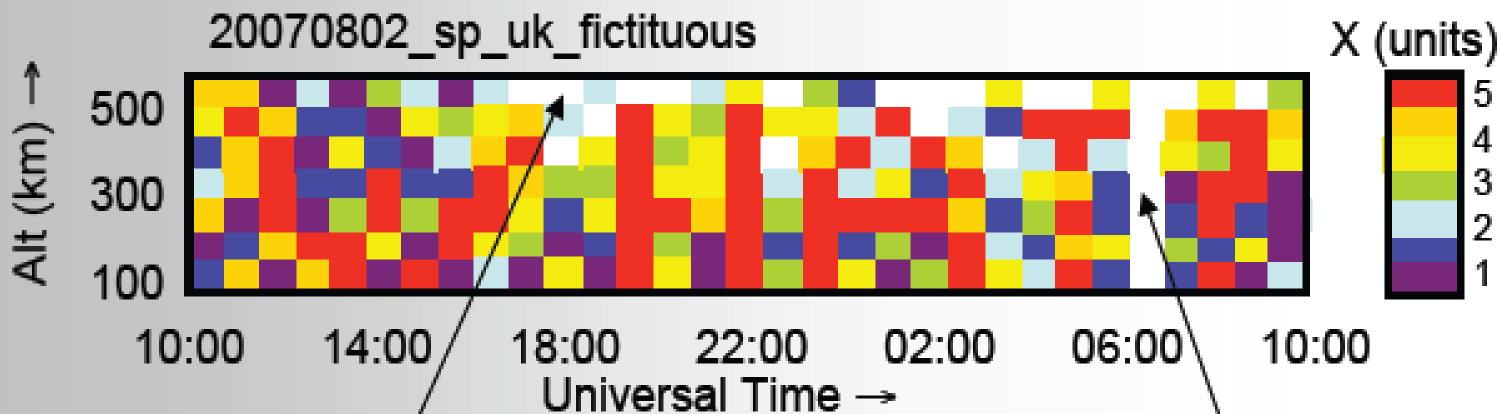


Bad data: analysis cannot fit it

•Poor signal/noise? (could increase integration time

•Too much variation in an interval (could reduce integration time)

•Coherent echo?

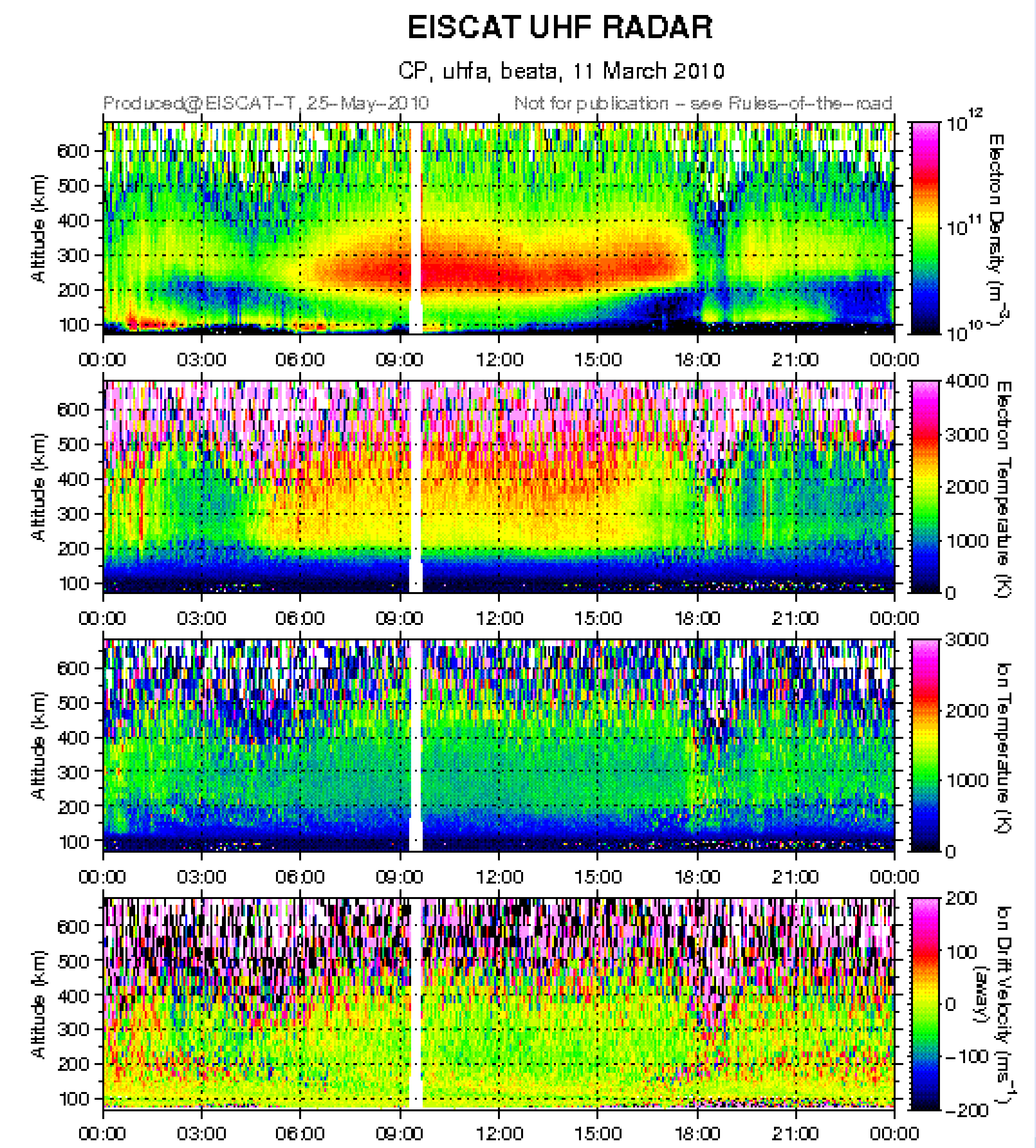
Data gap: data probably never recorded

•Commonly “crowbars” at Tromsø

•or aircraft landing at Longyearbyen

•but could be geophysical (a “NEIAL”) which analysis cannot fit

Fixed field-aligned data



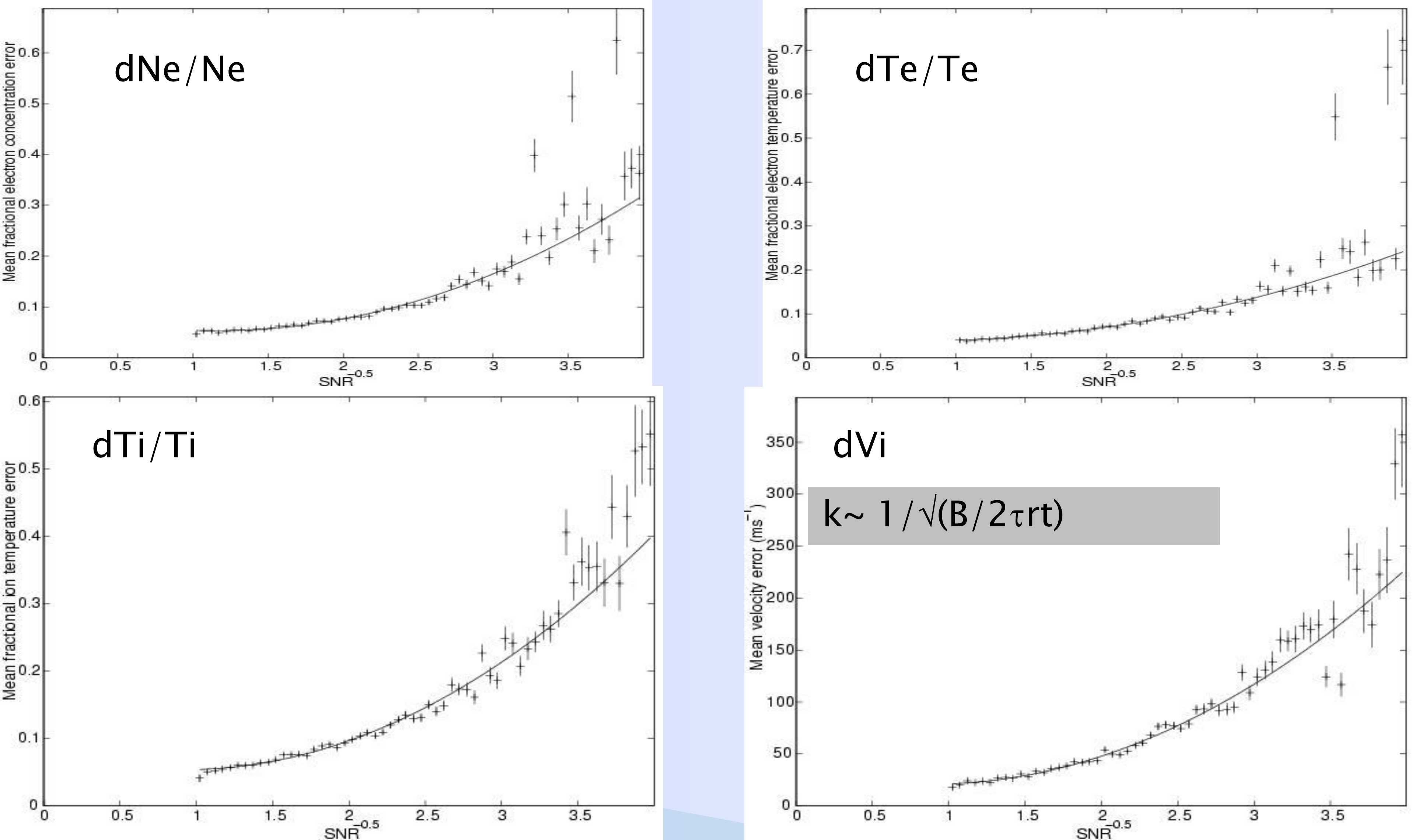
Electron number density, N_e (m^{-3})

Electron temperature, T_e (K)

Ion temperature, T_i (K)

Line-of-sight velocity, V_{los} (ms^{-1})

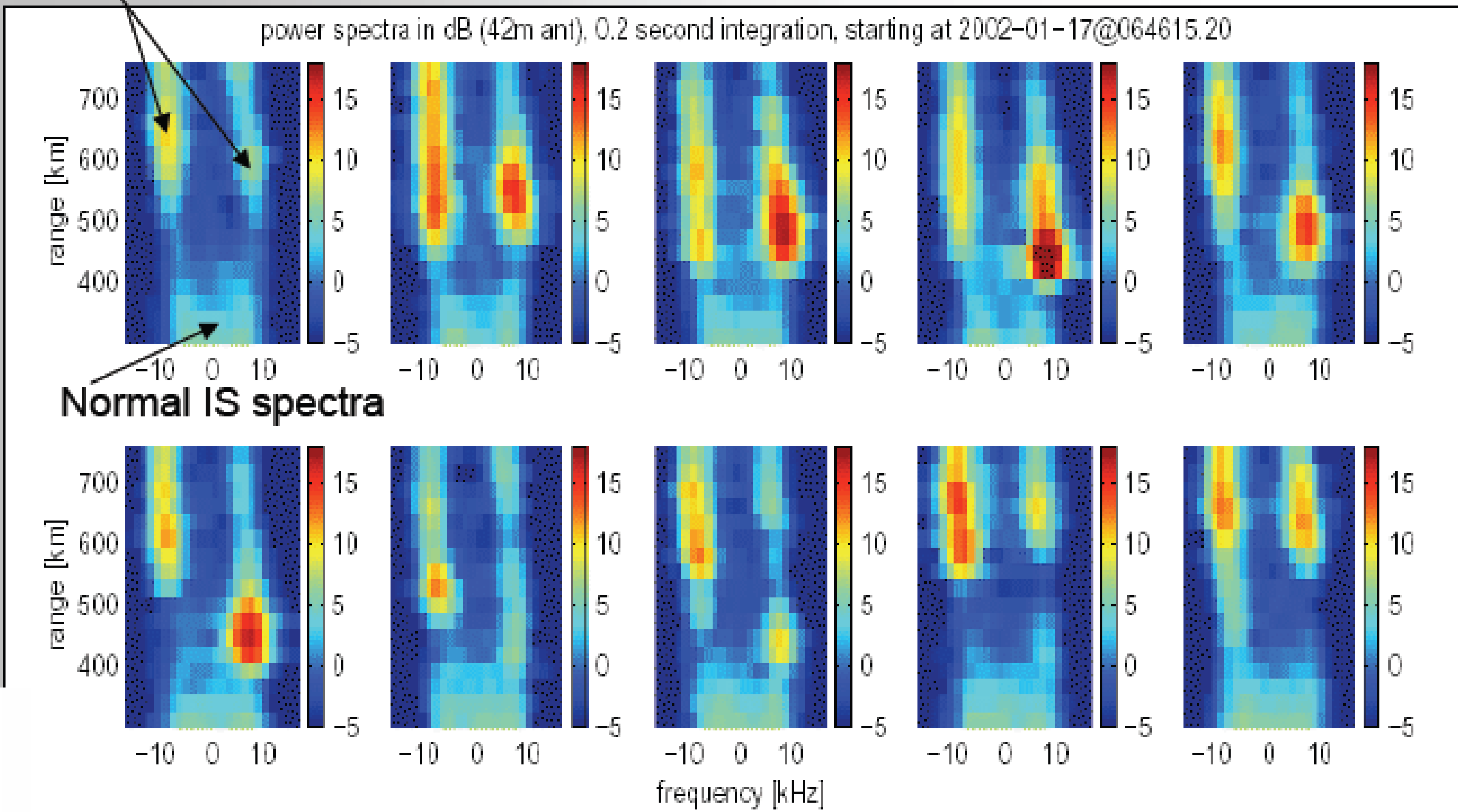
Random Errors in EISCAT (CP1) Data



Coherent echoes

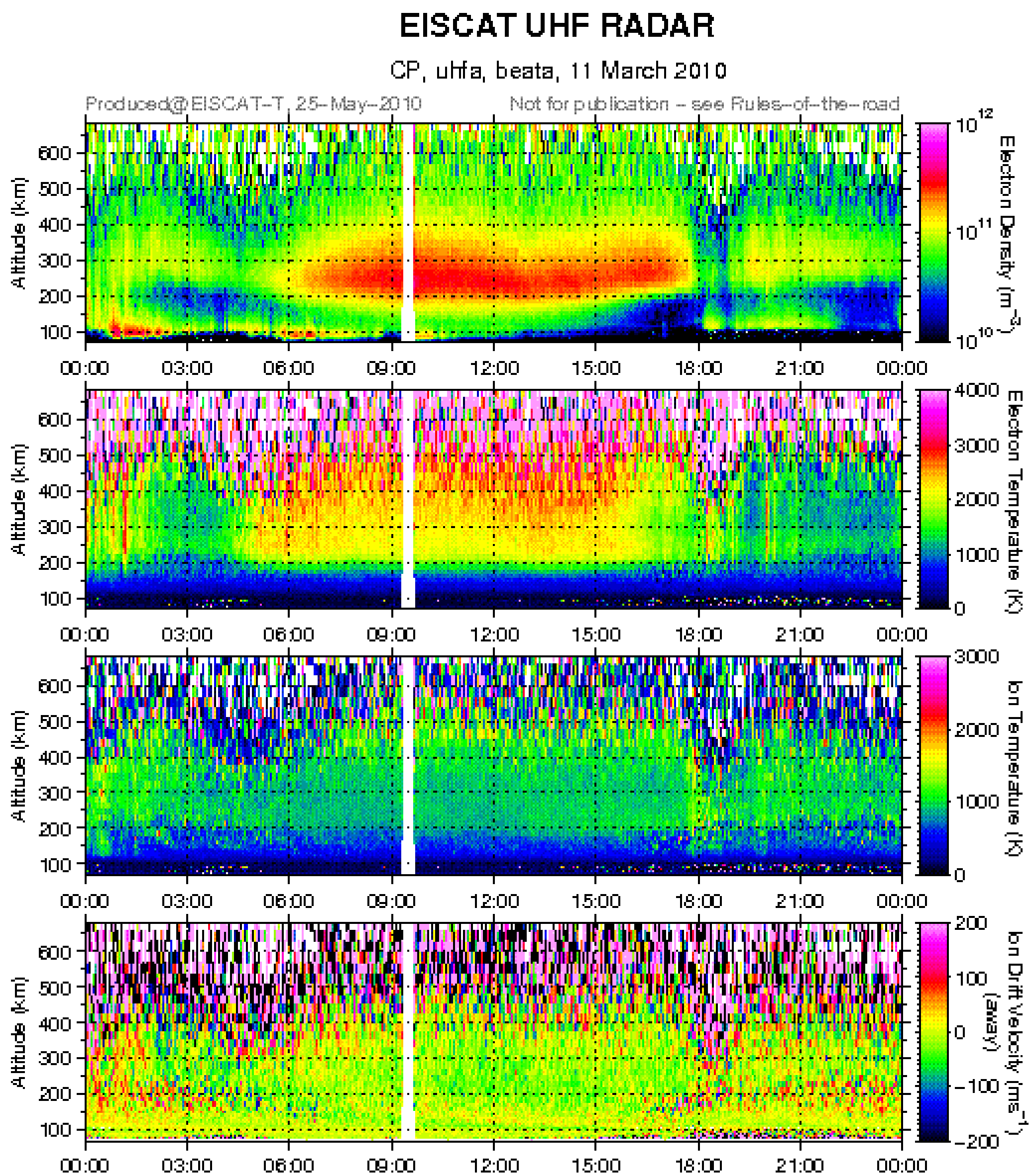
(will appear as bad data in summary plots)

Anomalous echoes



Other examples: satellites, meteor echoes, heater effects, other non-thermals..

Fixed field-aligned data



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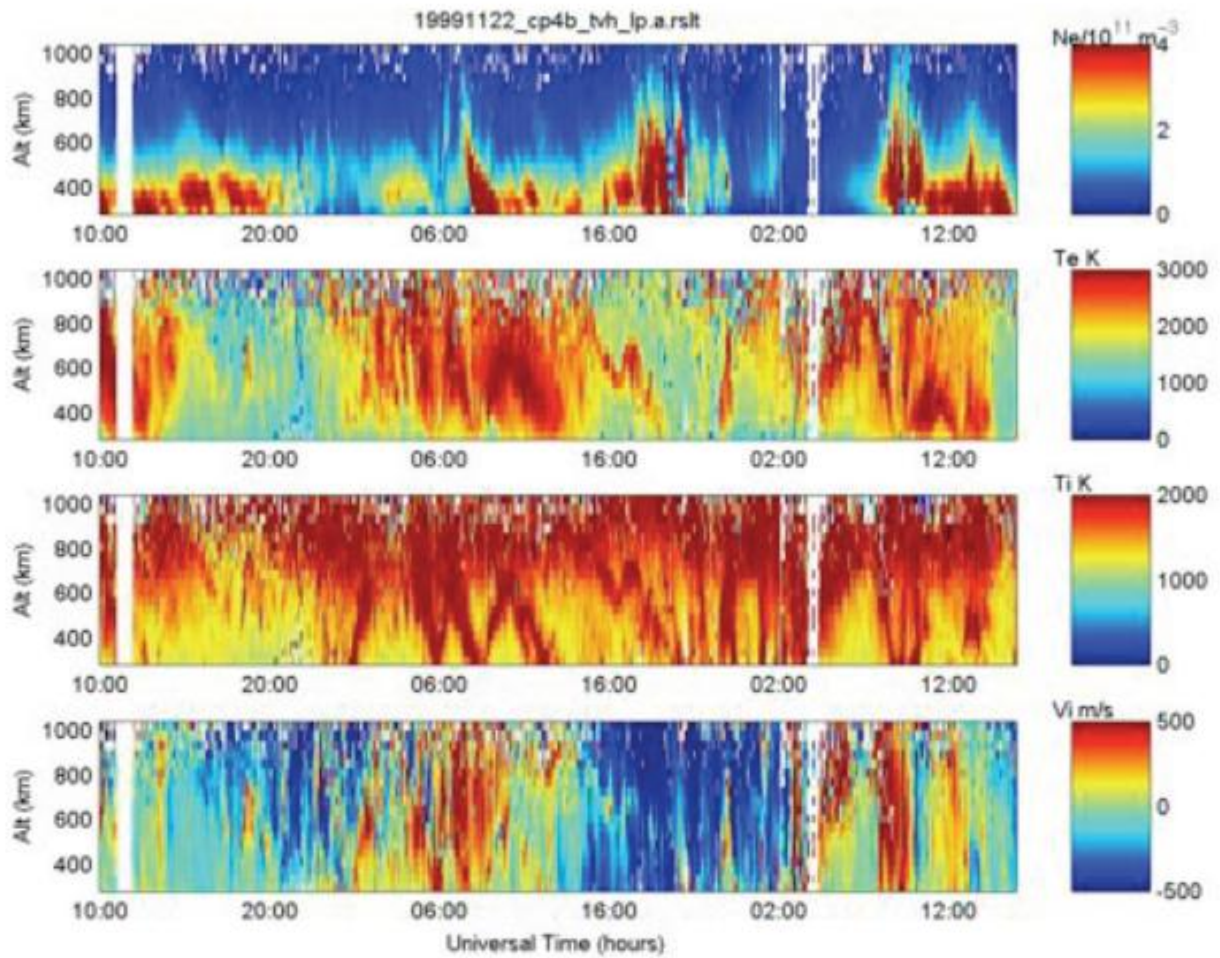
What about these data?



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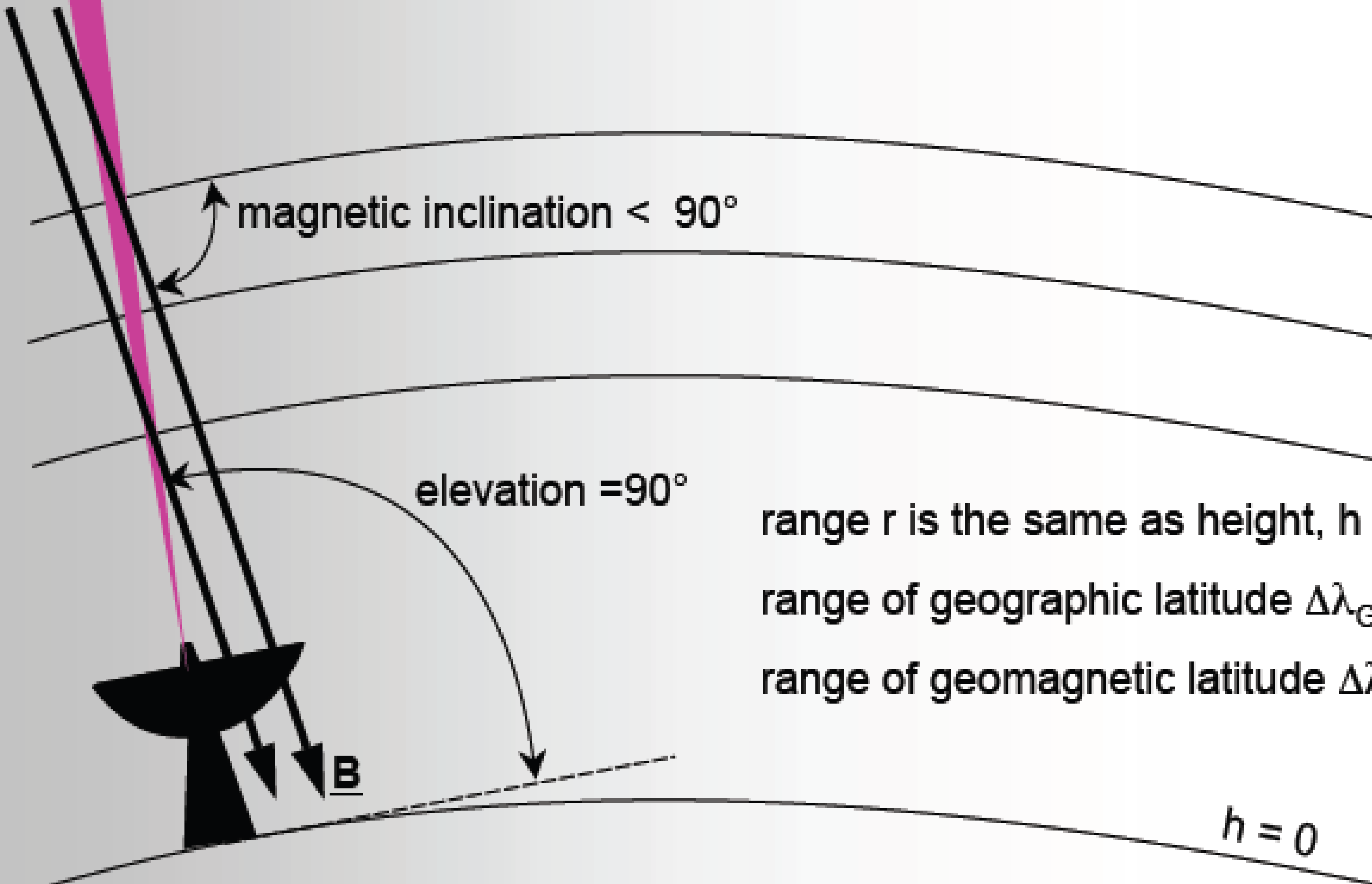
Altitude and Pointing Direction

vertical, e.g. CP7, $(r / h) = 1$, $\Delta\lambda_G = 0$, $\Delta\lambda_M > 0$



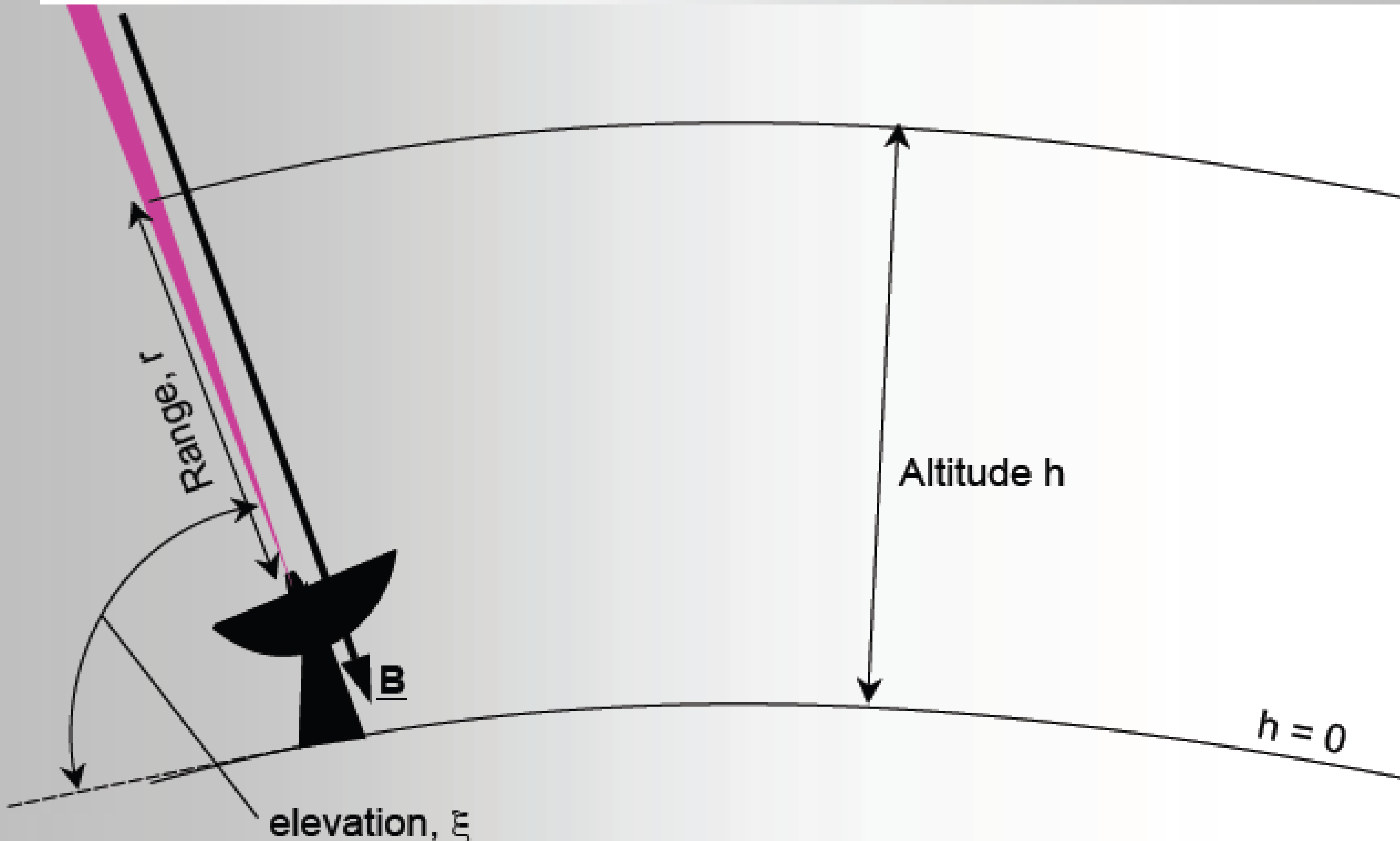
range r is the same as height, h

range of geographic latitude $\Delta\lambda_G = 0$

range of geomagnetic latitude $\Delta\lambda_M > 0$

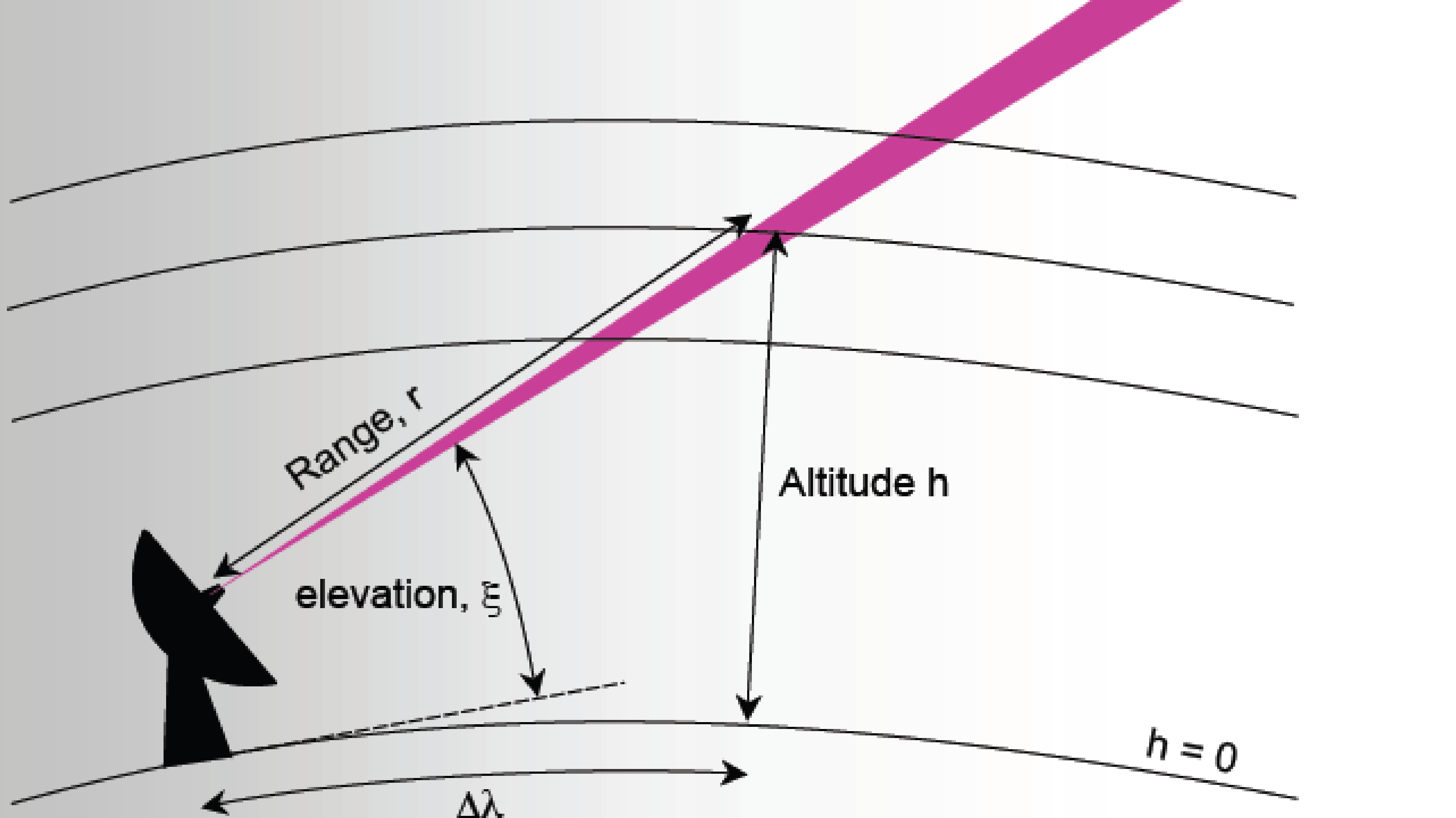
Altitude and Pointing Direction

Field-aligned, e.g. CP1, $(r / h) > 1$, $\Delta\lambda_M = 0$, $\Delta\lambda_G > 0$

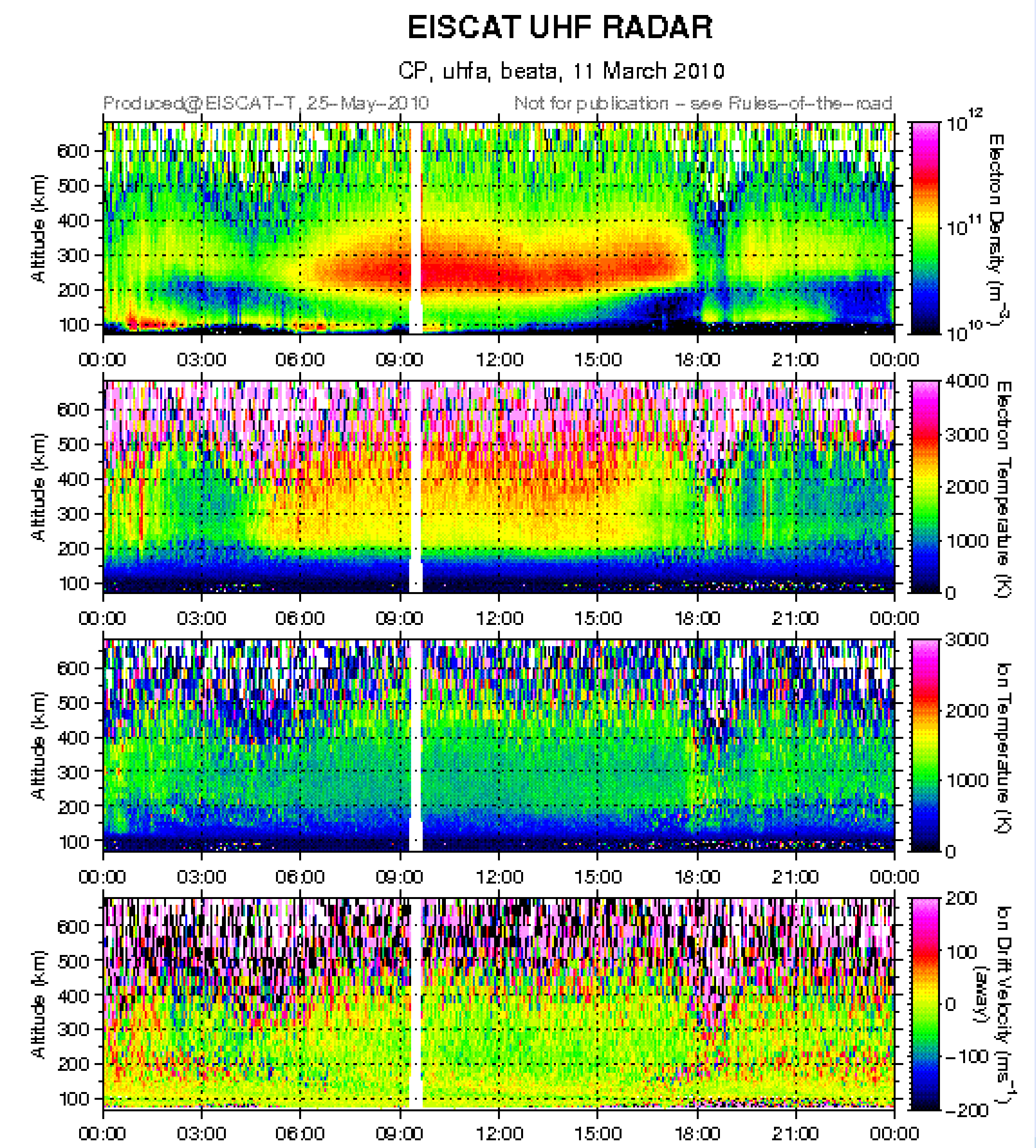


Altitude and Pointing Direction

low elevation, e.g. CP4, (r / h) is large, $\Delta\lambda > 0$



Fixed field-aligned data



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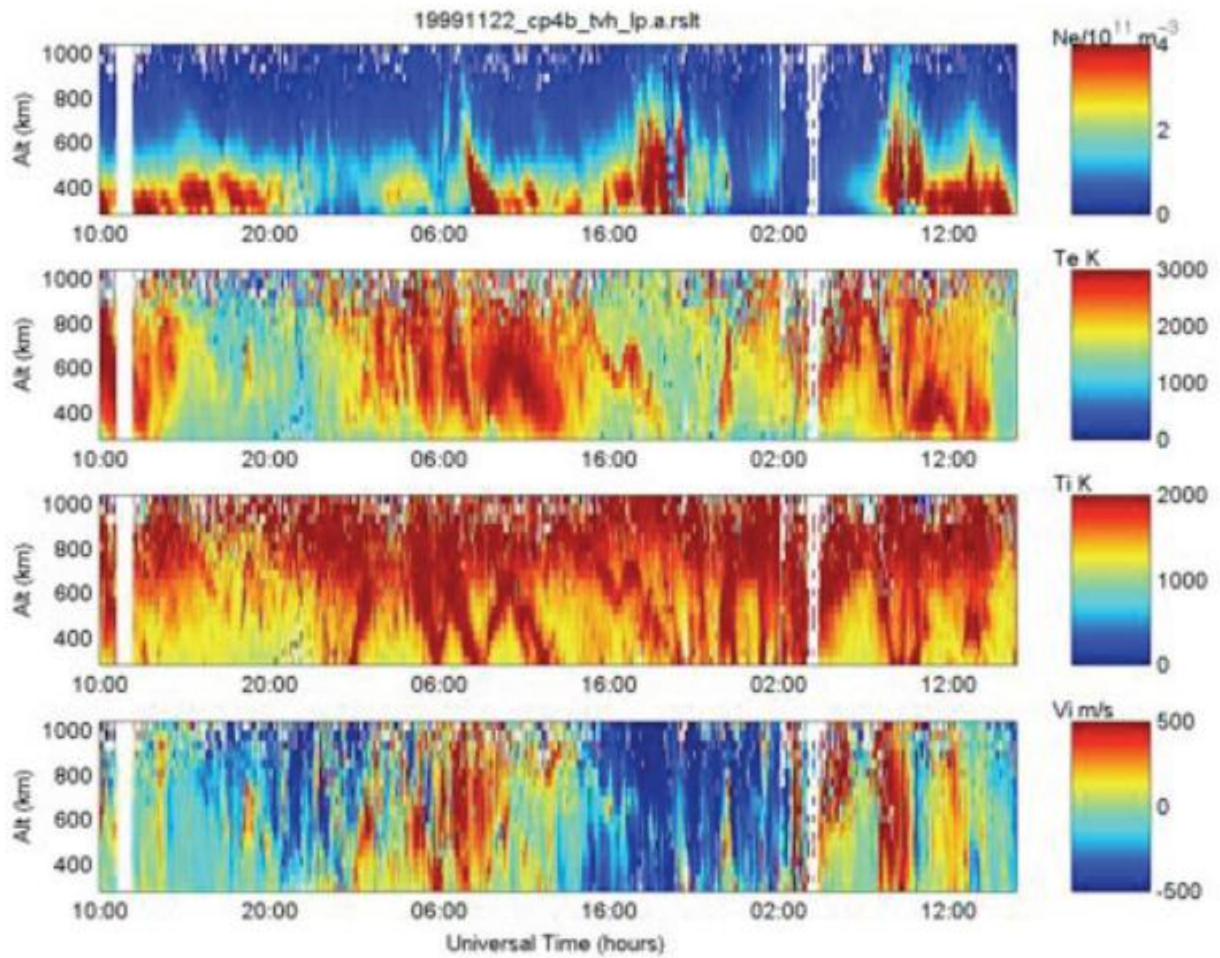

Electron number density, N_e (m^{-3})

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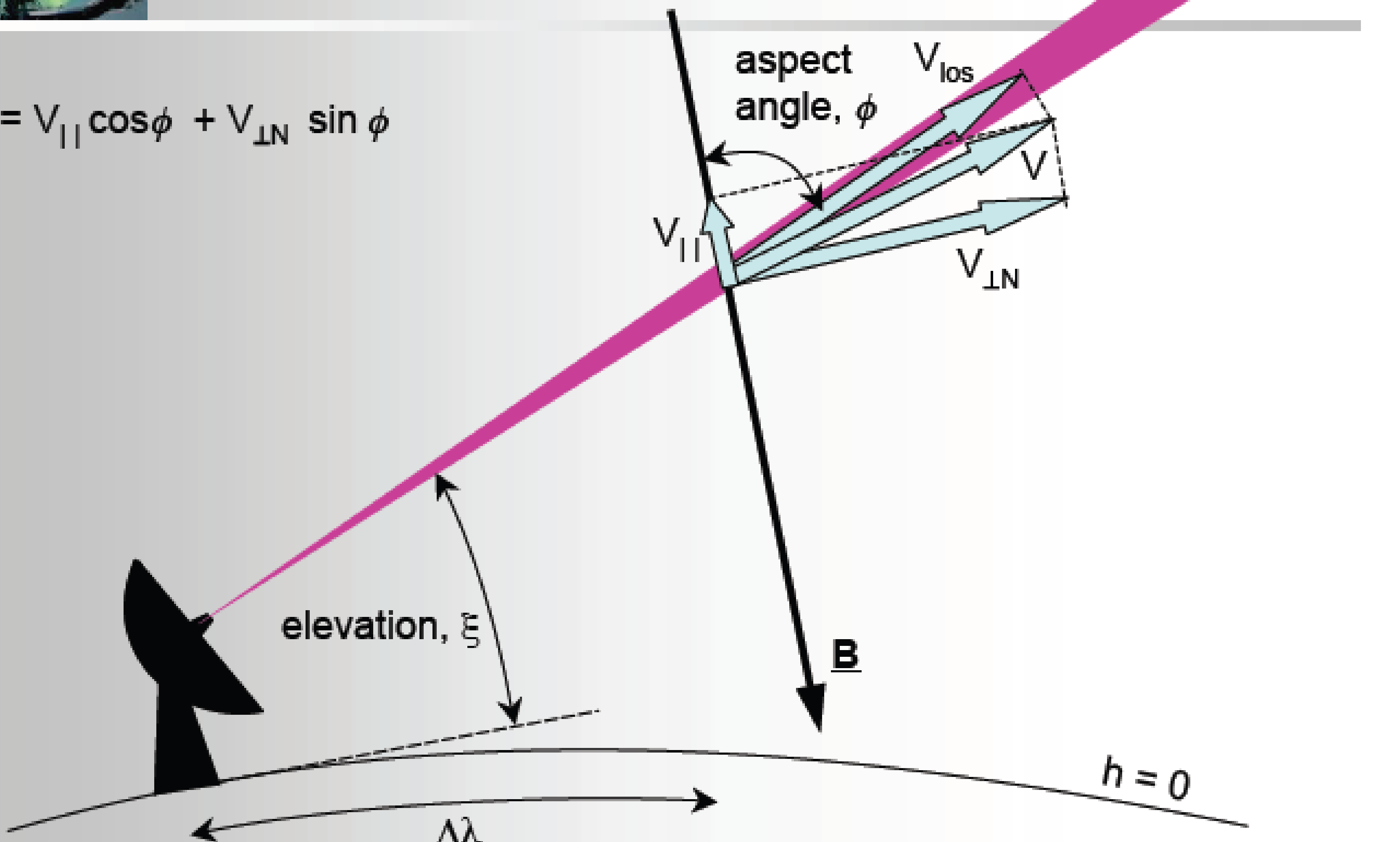
Changing Pointing Direction

Line-of-sight velocity

e.g. for a northward-pointing beam

$$V_{los} = V_{||}\cos\phi + V_{\perp N}\sin\phi$$

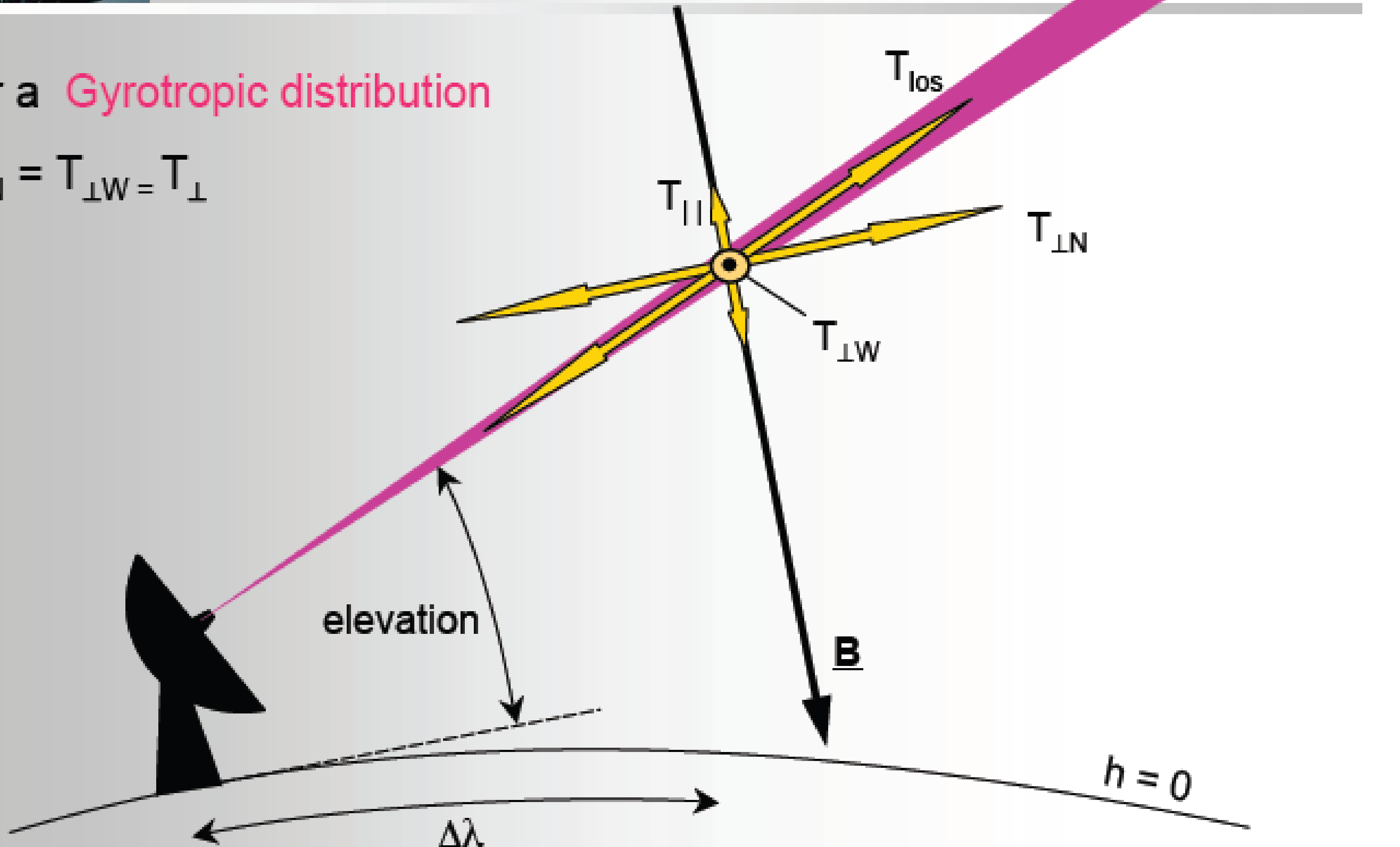


Line-of-sight temperature

e.g. for a northward-pointing beam

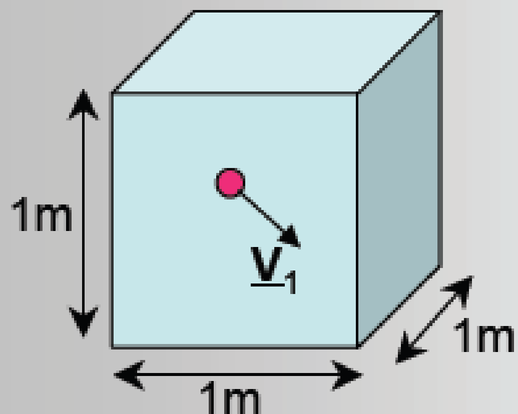
For a Gyrotropic distribution

$T_{\perp N} = T_{\perp W} = T_{\perp}$



Definition of Temperature

(distribution functions)



Number of particles in unit volume = N

In cube shown, the number density, N = 1 m^{-3}

Distribution function (or phase space density) is the number of particles in unit volume with a given vector velocity

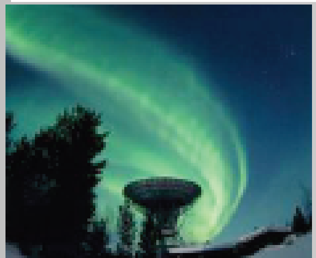
Here $f(\underline{\mathbf{V}})=1$ for $\underline{\mathbf{V}} = \underline{\mathbf{V}}_1$ but $f(\underline{\mathbf{V}})=0$ for all other $\underline{\mathbf{V}}$ (i.e., $f(\underline{\mathbf{V}})$ is a delta function in this simple case)

In general, in unit volume, the number of particles

$$\left.\begin{array}{l} \text{with X-velocity between } V_X \text{ and } V_X+dV_X \\ \text{and with Y-velocity between } V_Y \text{ and } V_Y+dV_Y \\ \text{and with Z-velocity between } V_Z \text{ and } V_Z+dV_Z \end{array}\right\} \text{ is } f(\underline{\mathbf{V}})dV_X dV_Y dV_Z = f(\underline{\mathbf{V}})d^3\underline{\mathbf{V}}$$

$$\text{Number density, } N = \int_{-\infty}^{+\infty} f(\underline{\mathbf{V}})d^3\underline{\mathbf{V}} \qquad (m^{-3})$$

Units of $f(\underline{\mathbf{V}})$ are $m^{-3} / (ms^{-1})^3 = m^{-6}s^3$



Line-of-sight temperature

(derivation courtesy Jean-Pierre St-Maurice)

For a direction that makes an aspect angle ϕ with the magnetic field, along which the velocity is V_ϕ

Definition of 1D temperature T_ϕ: $\langle V_\phi^2 \rangle = k_B T_\phi / m_i = (1/N) \int_{-\infty}^{+\infty} V_\phi^2 f(\underline{\mathbf{V}}) d^3\underline{\mathbf{V}}$

Where $f(\underline{\mathbf{V}})$ is the distribution function and $d^3\underline{\mathbf{V}} = dV_X dV_Y dV_Z$

If gyrotropic, $f(\underline{\mathbf{V}}) = f(V_X, V_Y, V_Z) = f(V_{||}, V_\perp)$

$V_\phi = V_{||} \cos\phi + V_\perp \sin\phi$

$V_\phi^2 = V_{||}^2 \cos^2\phi + V_\perp^2 \sin^2\phi + 2 V_{||} V_\perp \cos\phi \sin\phi$

Substitute

$$k_B T_\phi / m_i = \int_{-\infty}^{+\infty} V_{||}^2 \cos^2\phi\, f(V_{||}, V_\perp)\, d^3\underline{\mathbf{V}} + \int_{-\infty}^{+\infty} V_\perp^2 \sin^2\phi\, f(V_{||}, V_\perp)\, d^3\underline{\mathbf{V}}$$
$$+ 2 \int_{-\infty}^{+\infty} V_{||} V_\perp \sin\phi \cos\phi\, f(V_{||}, V_\perp)\, d^3\underline{\mathbf{V}}$$

Line-of-sight temperature

$$k_B T_\phi / m_i = \int_{-\infty}^{+\infty} V_{||}^2 \cos^2\phi \, f(V_{||},V_\perp)\, d^3\underline{\mathbf{V}} + \int_{-\infty}^{+\infty} V_\perp^2 \sin^2\phi \, f(V_{||},V_\perp)\, d^3\underline{\mathbf{V}}$$
$$+ 2\int_{-\infty}^{+\infty} V_{||} V_\perp \sin\phi \, \cos\phi \, f(V_{||},V_\perp)\, d^3\underline{\mathbf{V}}$$

If the distribution function is also symmetric along $\underline{\mathbf{B}}$

$f(V_{||},V_\perp) = f(-V_{||},V_\perp)$, so $\int_{-\infty}^{+\infty} V_{||} \, f(V_{||},V_\perp)\, d^3\underline{\mathbf{V}} = 0$ and the 3rd term in RHS of above equation is zero

Subs for $\phi = 0$ $\quad k_B T_\phi / m_i = k_B T_{||} / m_i = (1/N)\int_{-\infty}^{+\infty} V_{||}^2 \, f(V_{||},V_\perp)\, d^3\underline{\mathbf{V}}$

Subs for $\phi = \pi/2$ $\quad k_B T_\phi / m_i = k_B T_\perp / m_i = (1/N)\int_{-\infty}^{+\infty} V_\perp^2 \, f(V_{||},V_\perp)\, d^3\underline{\mathbf{V}}$

Yields

$$T_\phi = T_{||} \cos^2\phi + T_\perp \sin^2\phi$$

(c.f. $\quad V_\phi = V_{||} \cos\phi + V_\perp \sin\phi$)

3-D temperature

Three Dimensional temperature: $\boxed{3}k_BT/m_i = \langle V^2 \rangle = (1/N)\int_{-\infty}^{+\infty} V^2 f(\underline{\mathbf{V}})d^3\underline{\mathbf{V}}$

Where $V^2 = V_X^2 + V_Y^2 + V_Z^2$

$$3k_BNT/m_i = \int_{-\infty}^{+\infty} V_X^2 f(\underline{\mathbf{V}})d^3\underline{\mathbf{V}} + \int_{-\infty}^{+\infty} V_Y^2 f(\underline{\mathbf{V}})d^3\underline{\mathbf{V}} + \int_{-\infty}^{+\infty} V_Z^2 f(\underline{\mathbf{V}})d^3\underline{\mathbf{V}}$$

$$3k_BT/m_i = (k_B/m_i)\{T_X + T_Y + T_Z\}$$

Gyrotropic, so $T_X = T_Y = T_\perp$ and $T_Z = T_{||}$

$$T = (T_{||} + 2T_\perp)/3$$

The magic angle $\phi = \phi_M$ where $T = T_\phi$

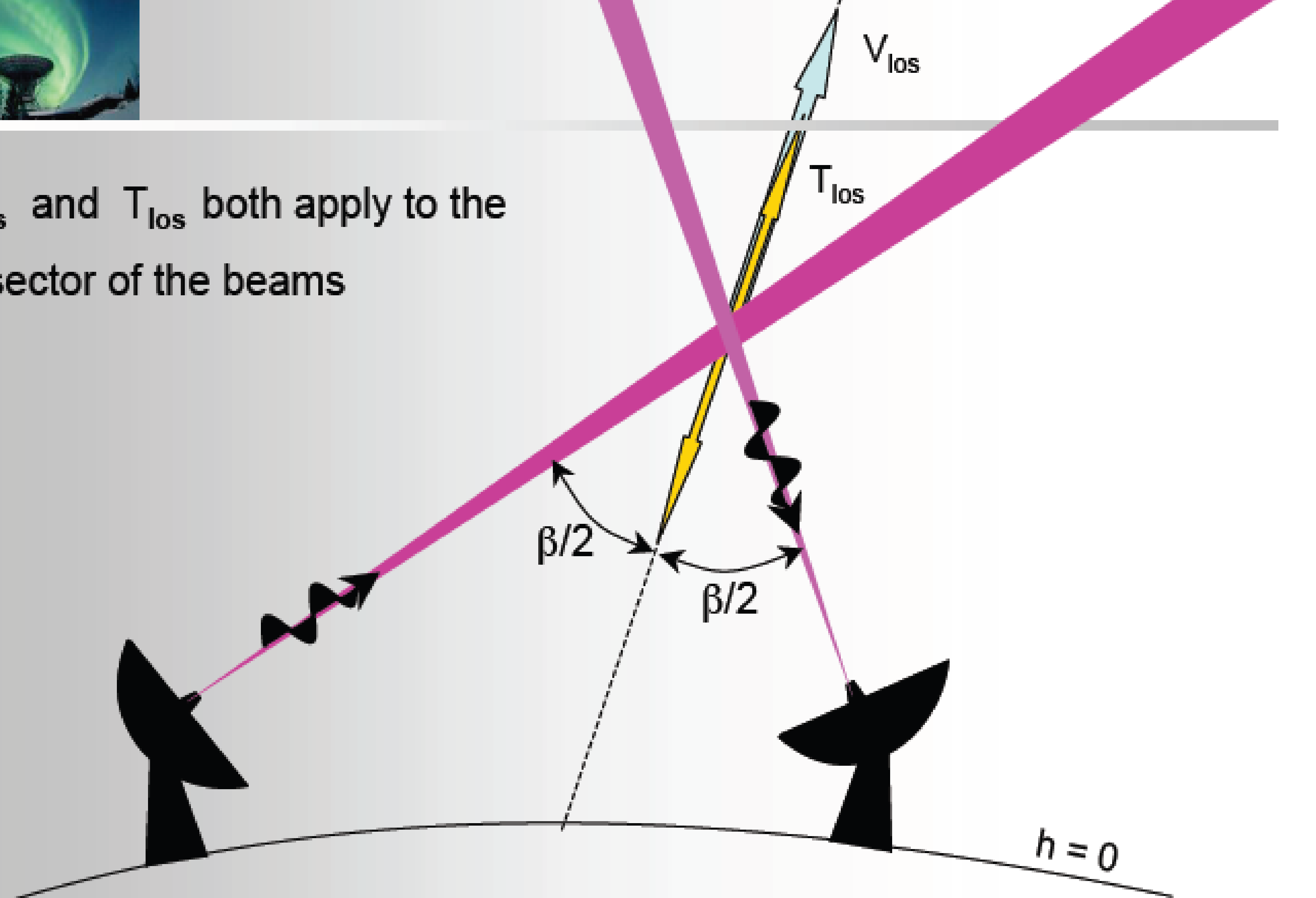
$$(T_{||} + 2T_\perp) = 3\{T_{||}\cos^2\phi_M + T_\perp \sin^2\phi_M\}$$

$$\sin(\phi_M) = (2/3)^{1/2}$$

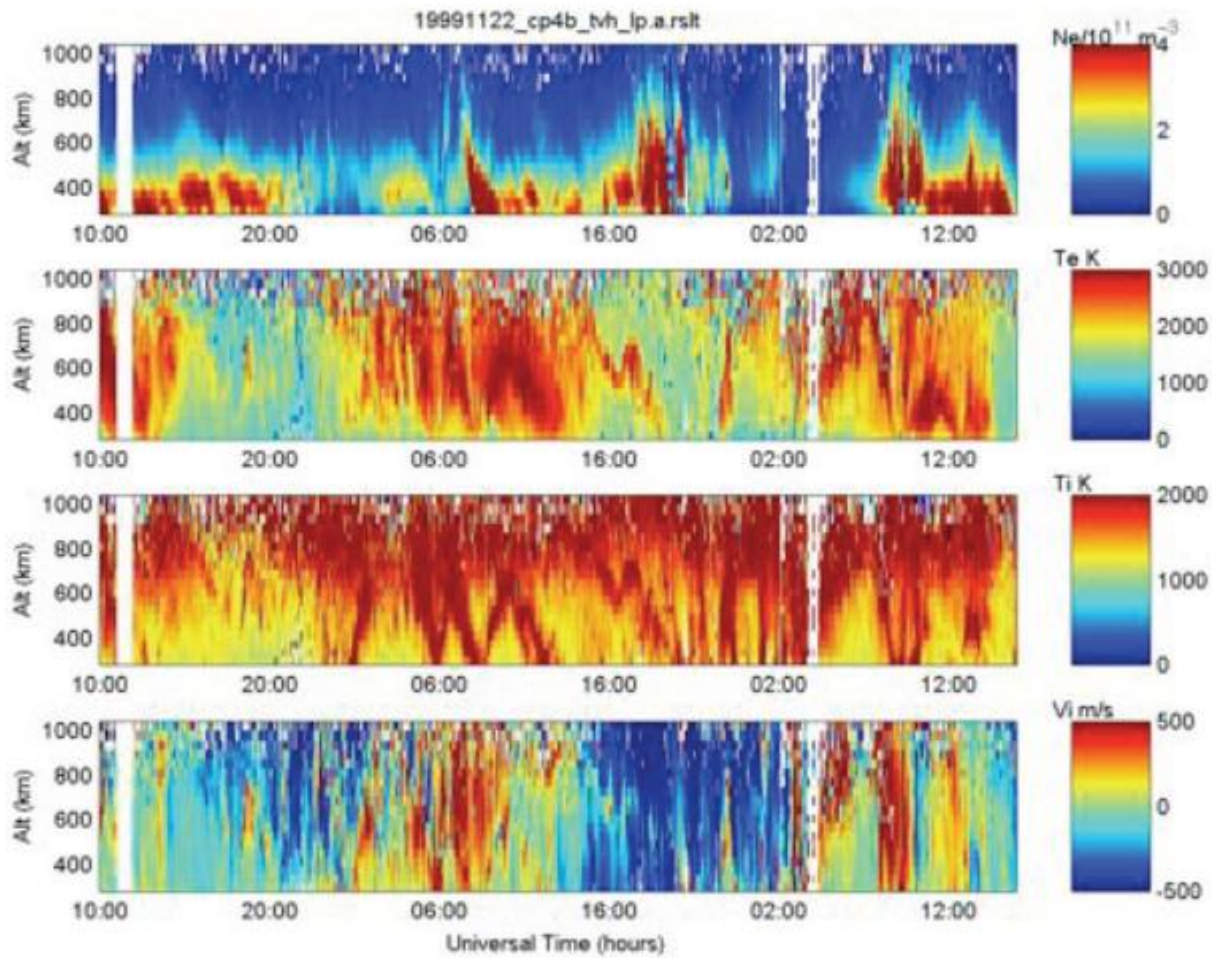
$$\phi_M = 54.7^\circ$$

Remote Site Data

V_{los} and T_{los} both apply to the bisector of the beams



What about these data?



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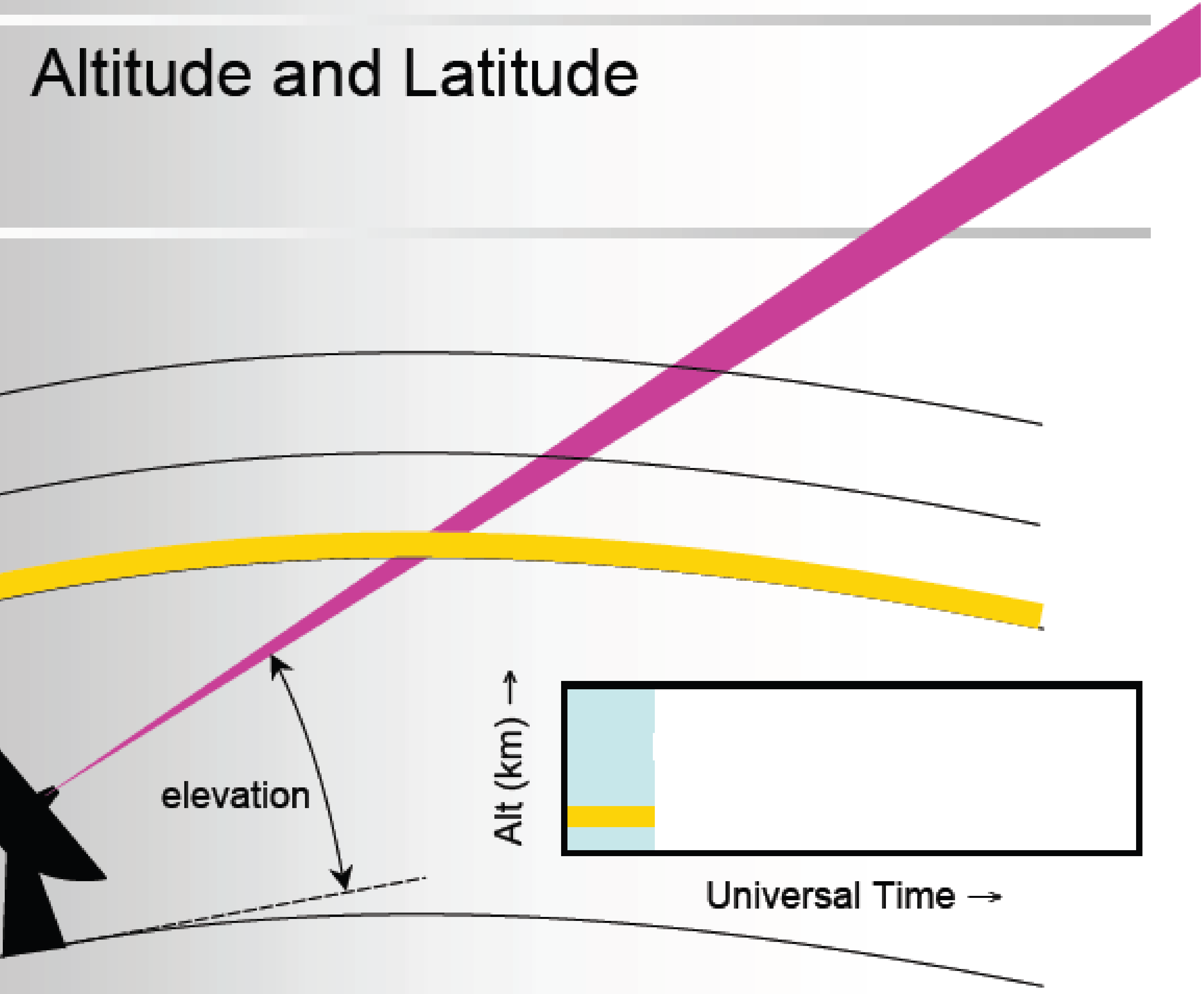
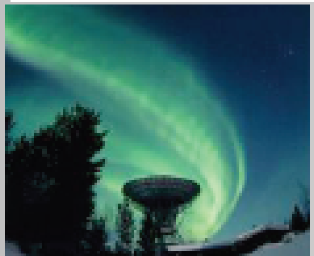
Altitude and Latitude





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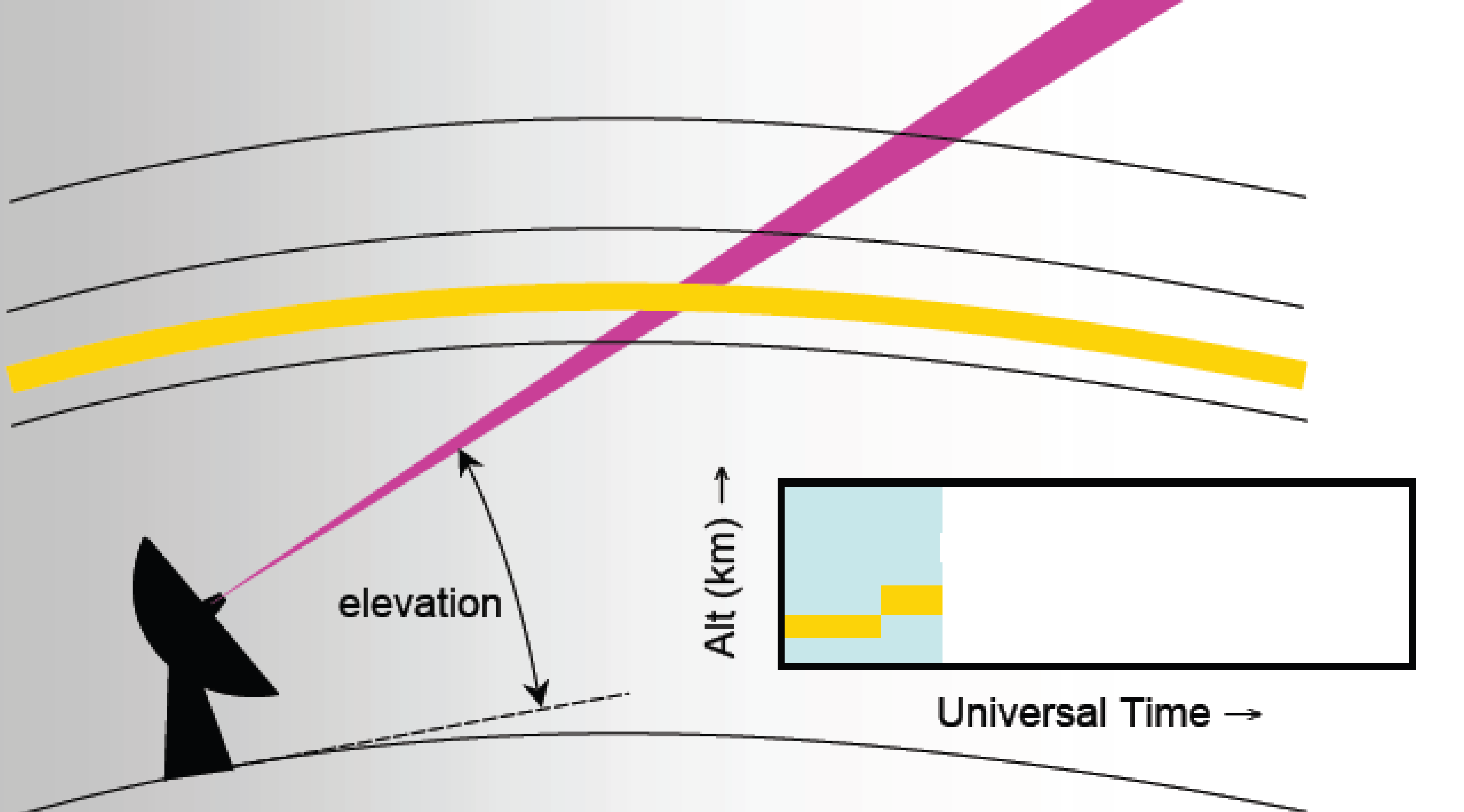

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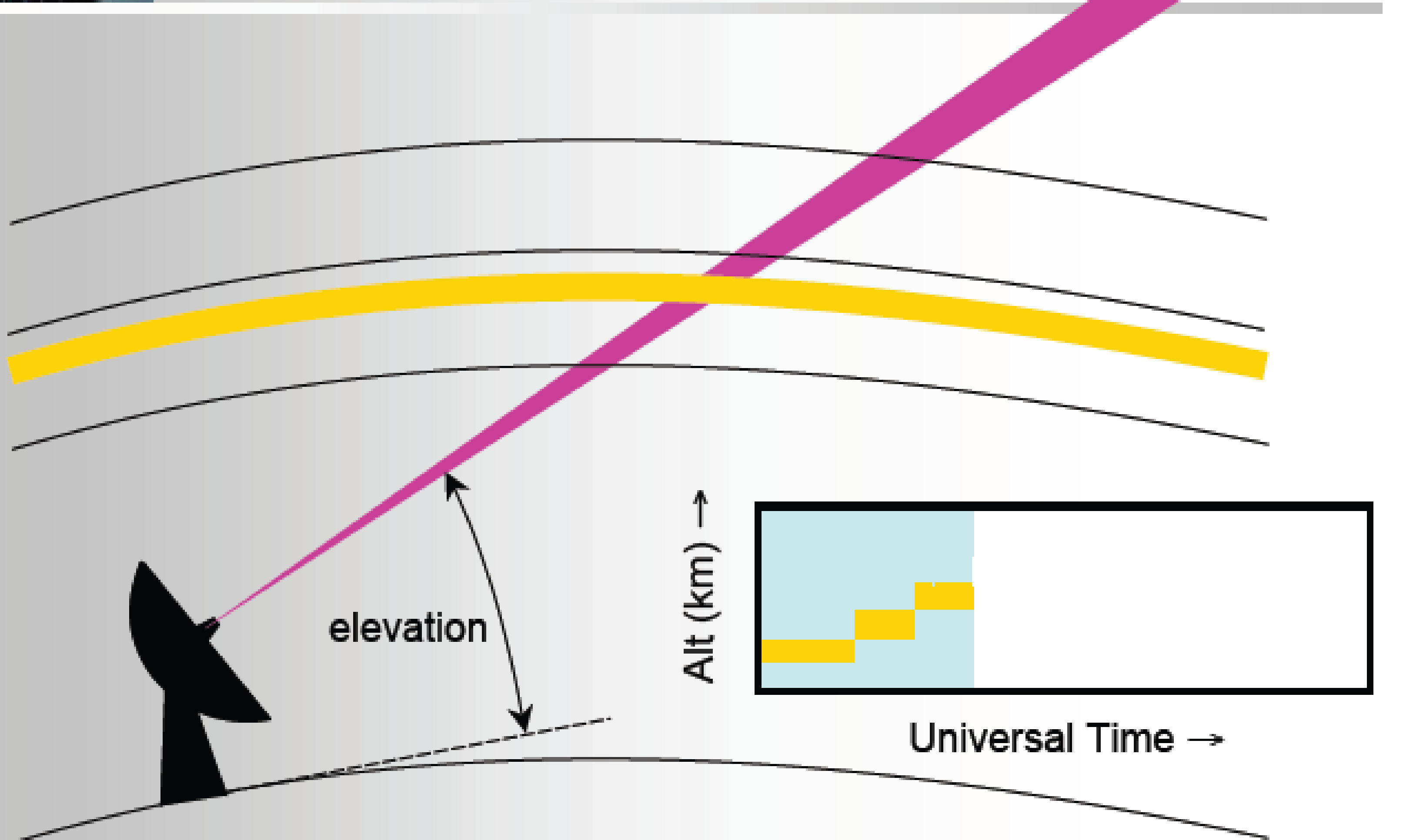

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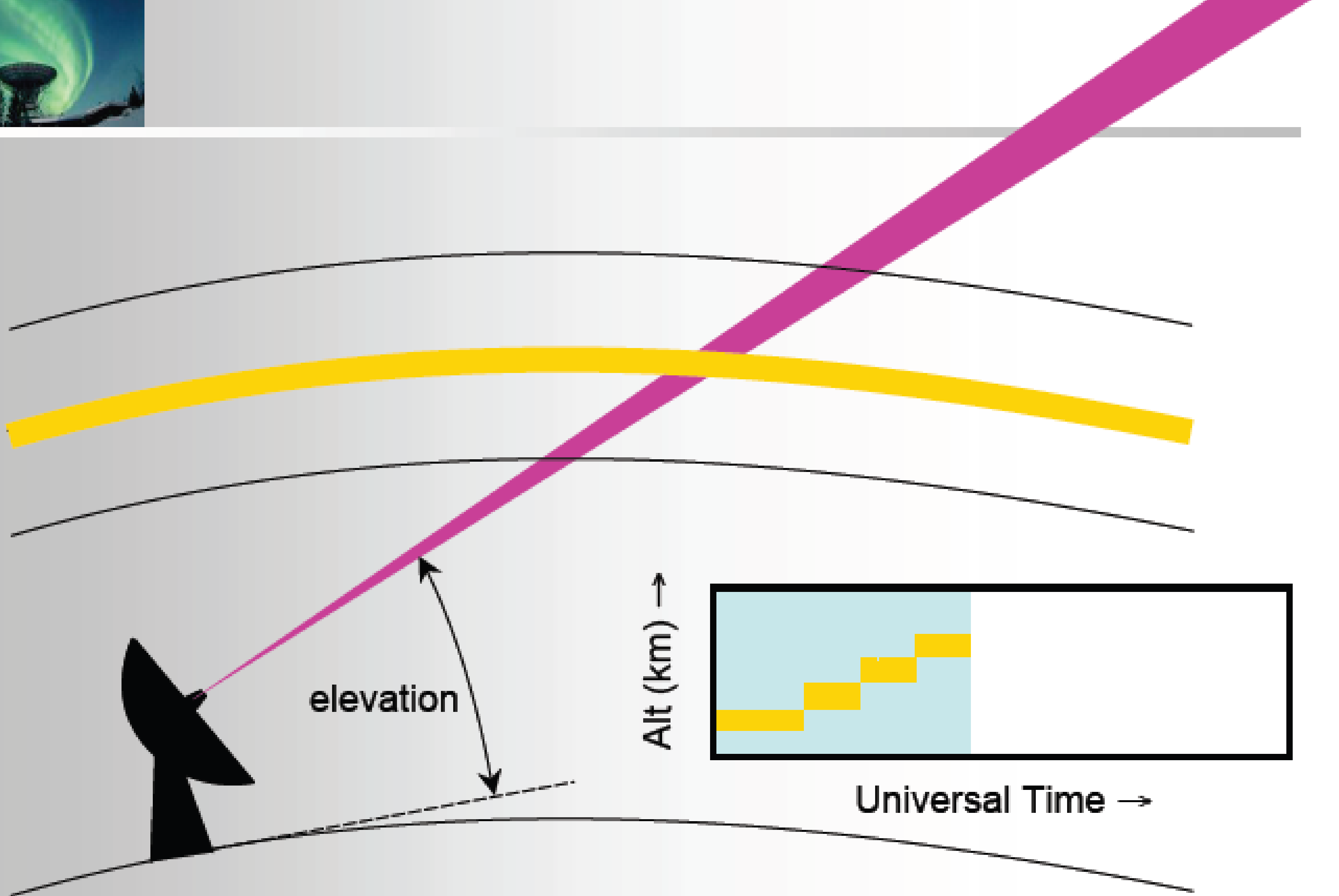

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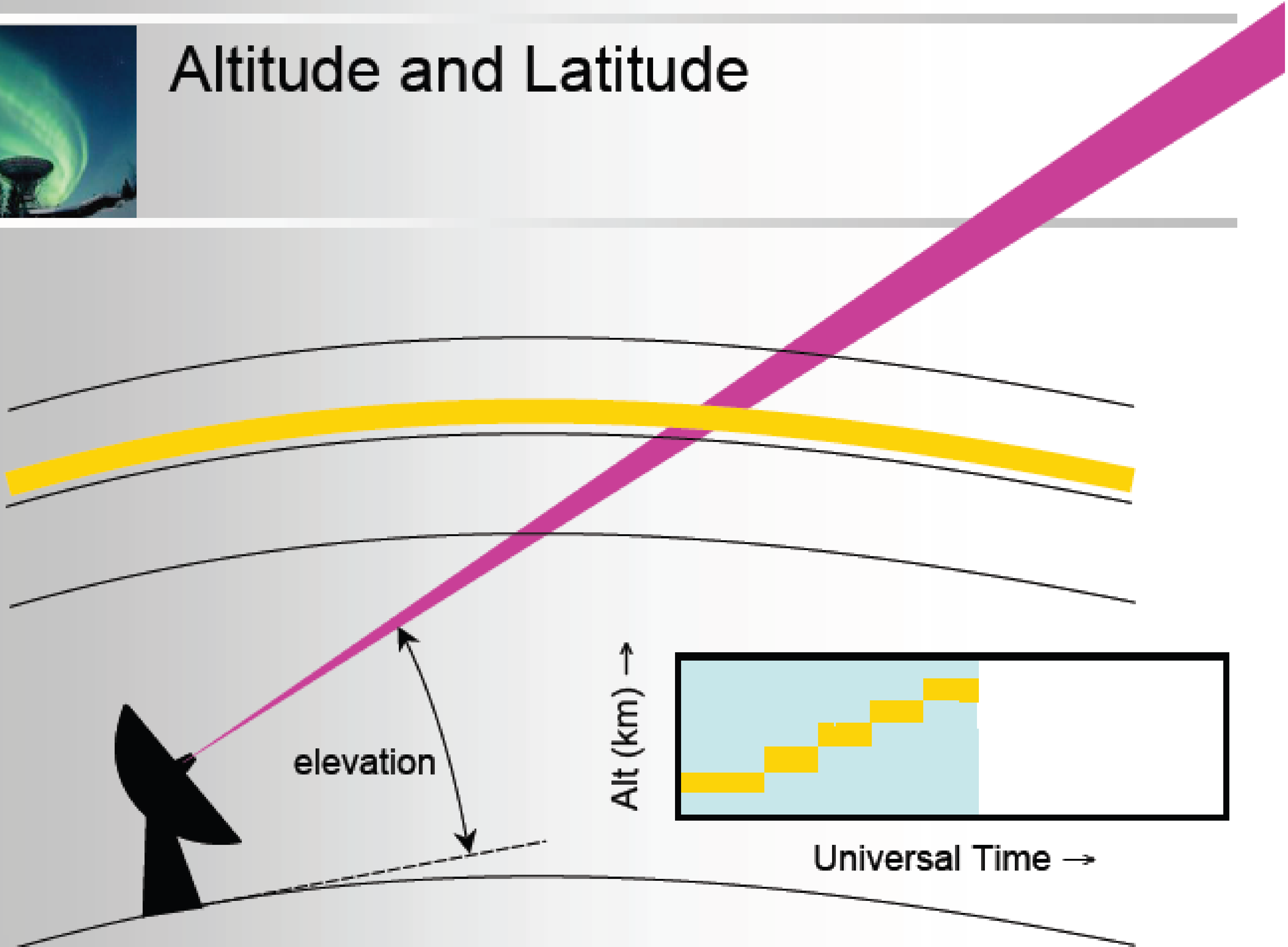

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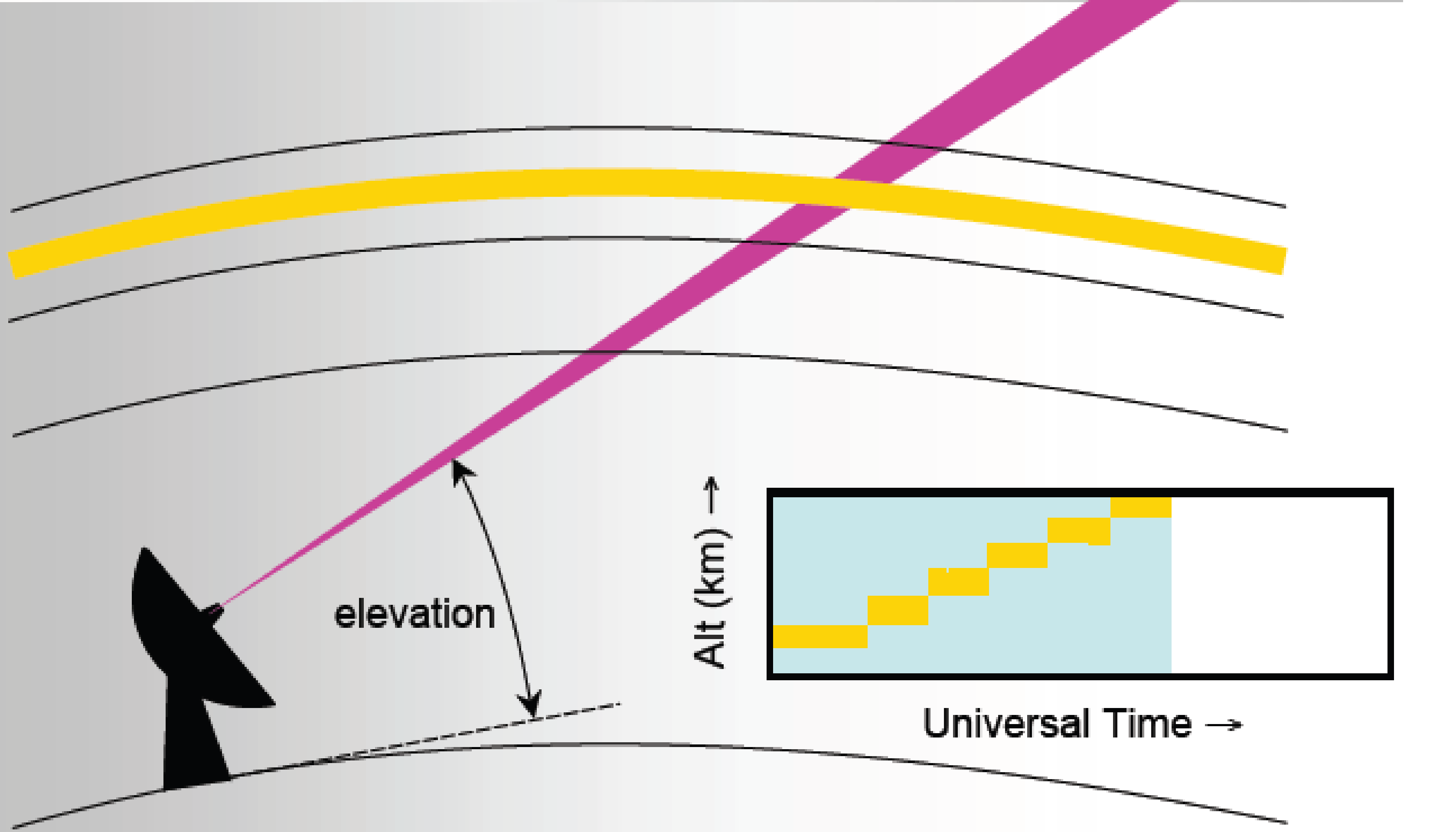

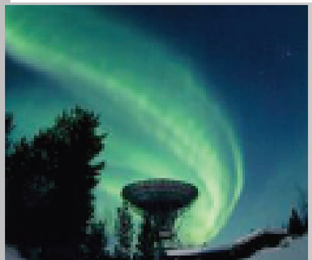

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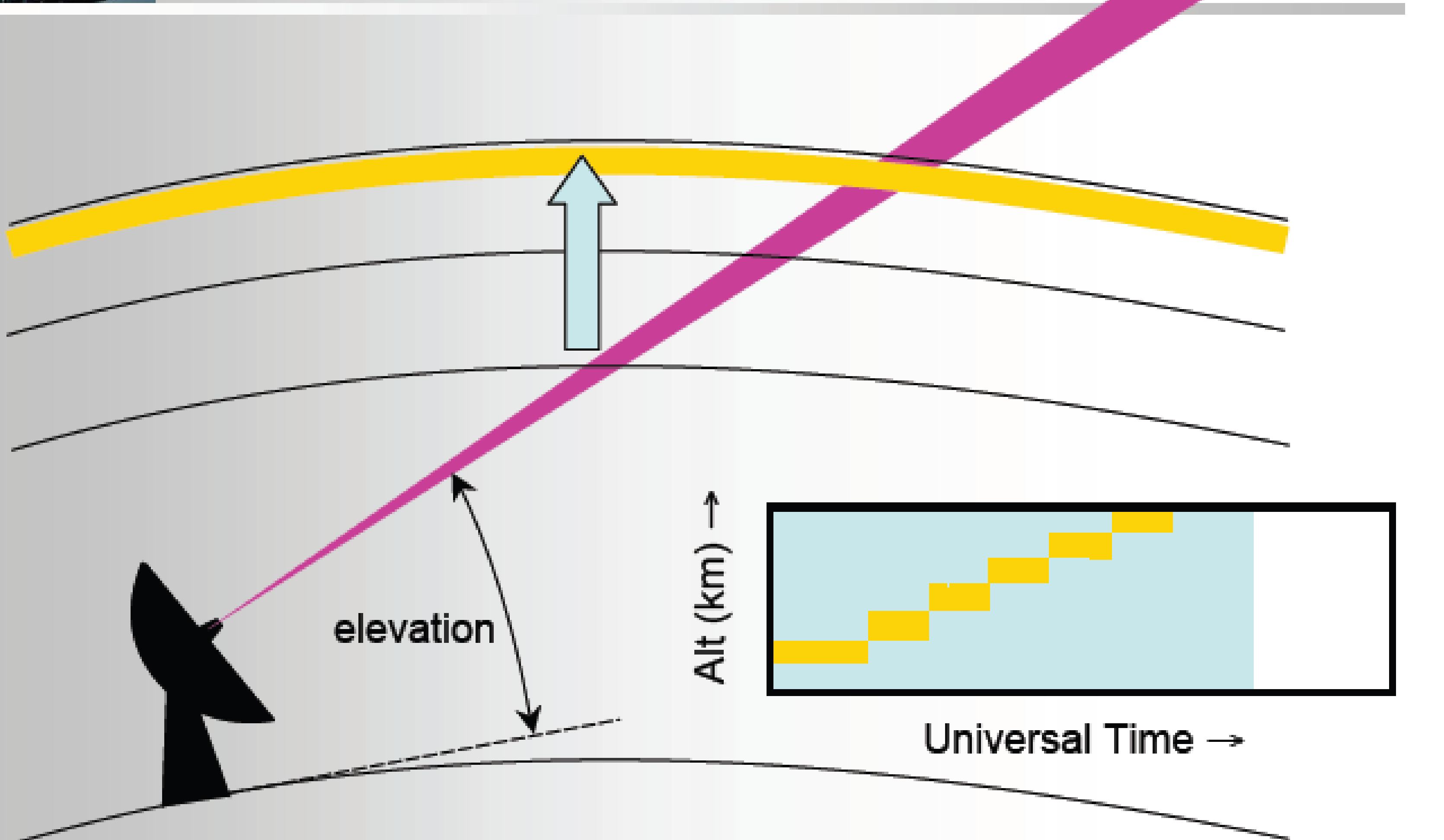

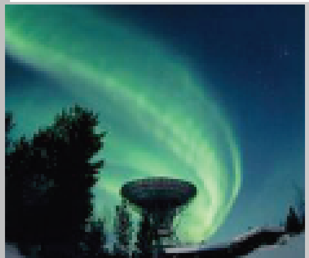

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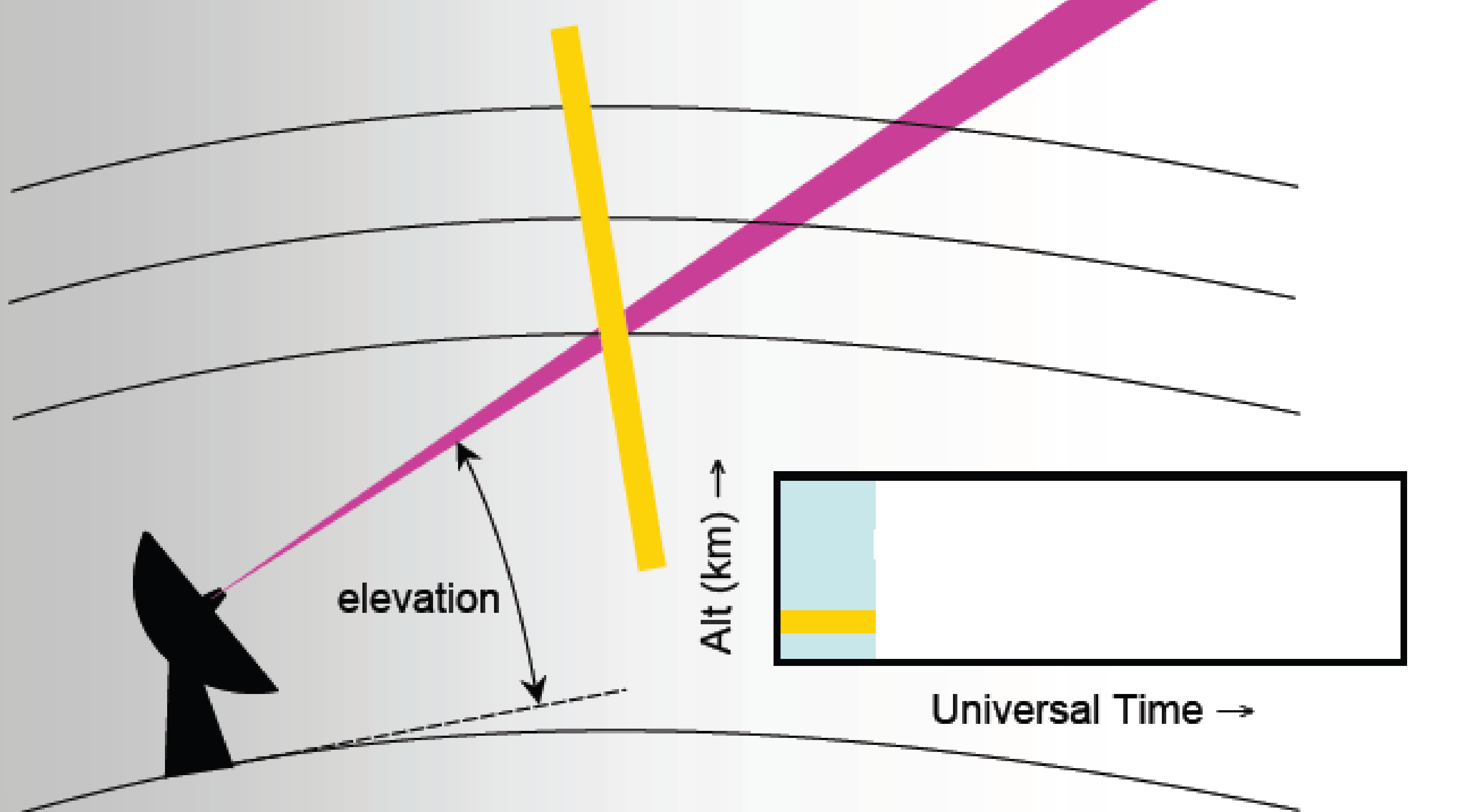

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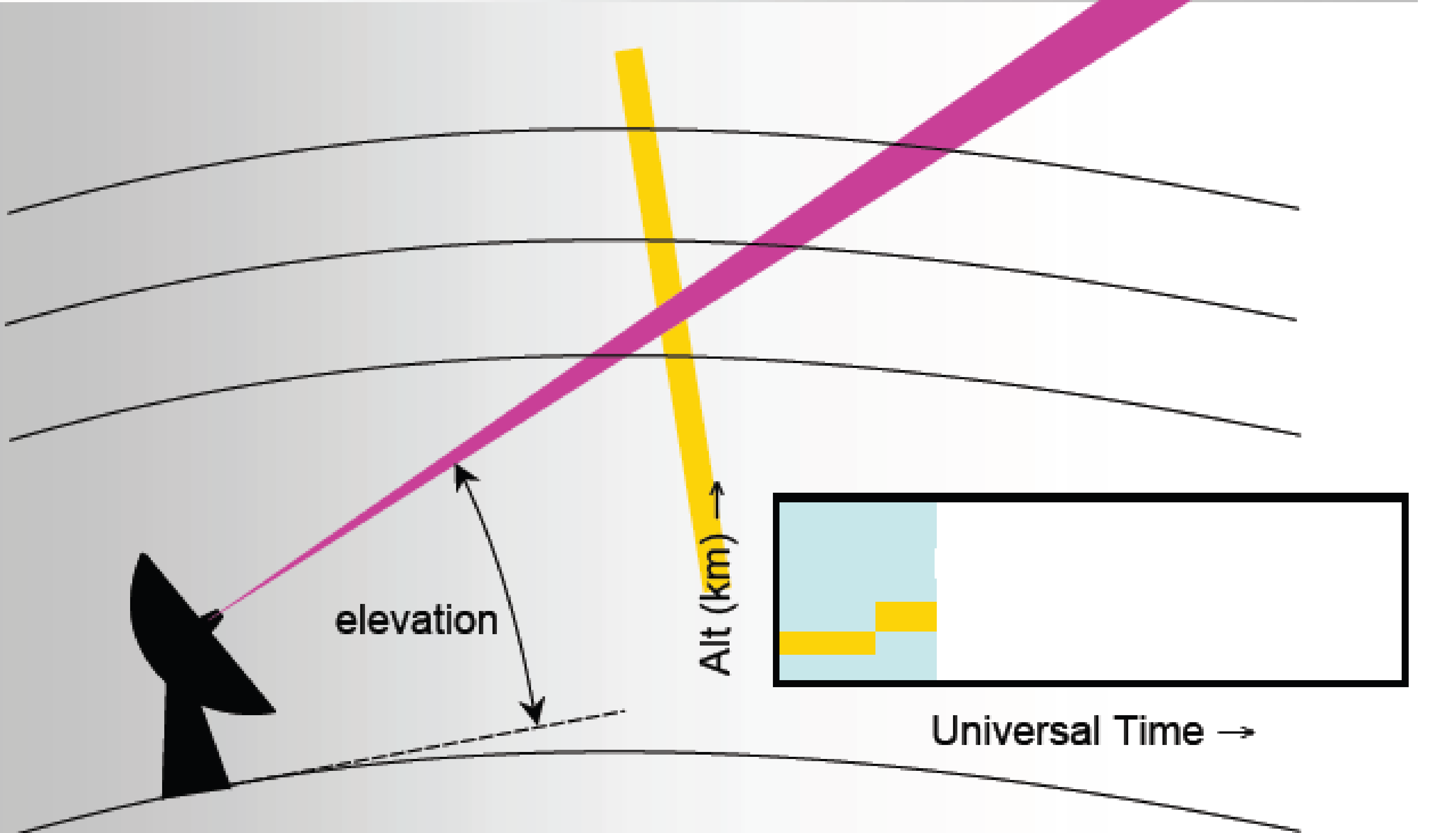

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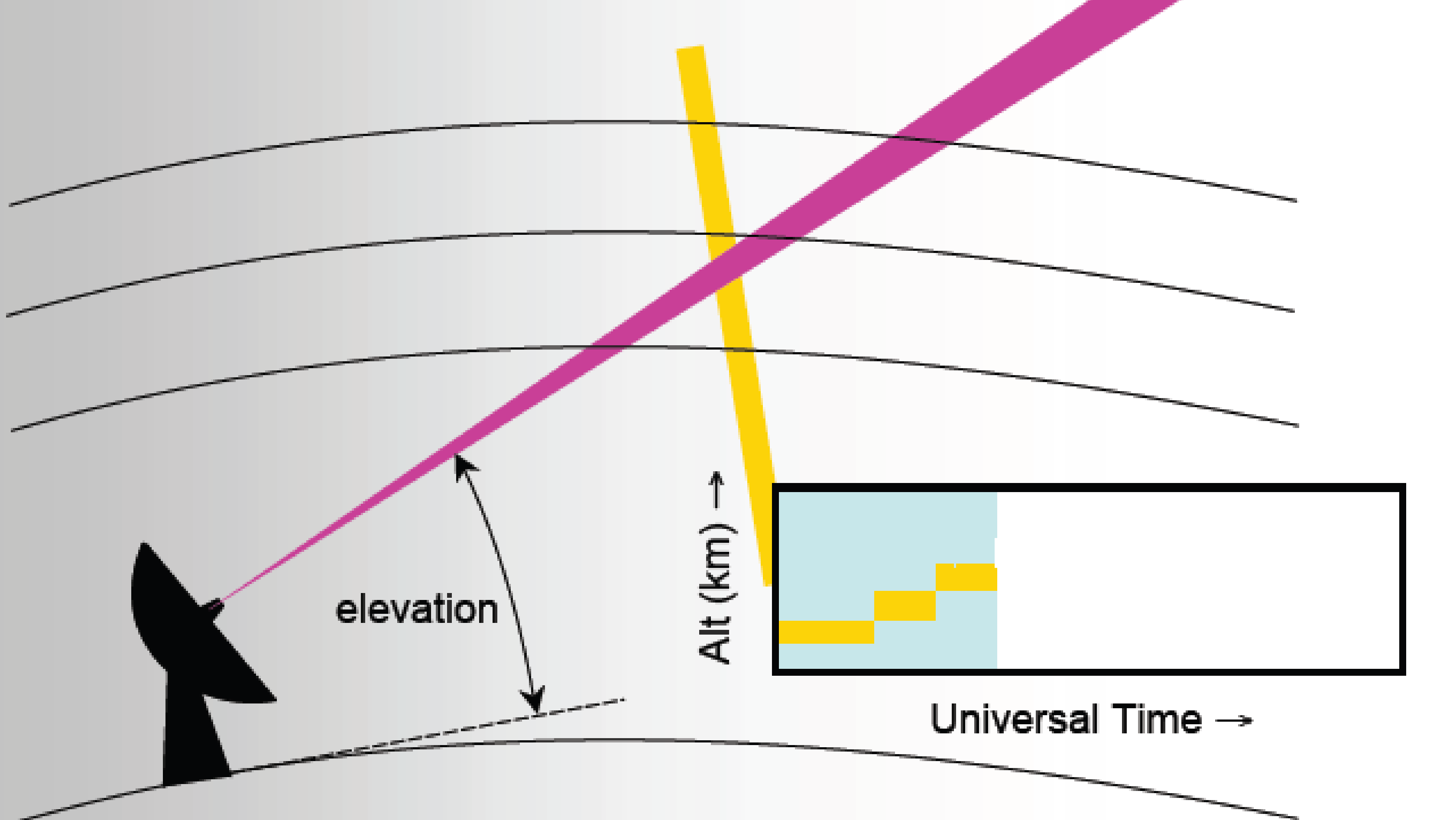

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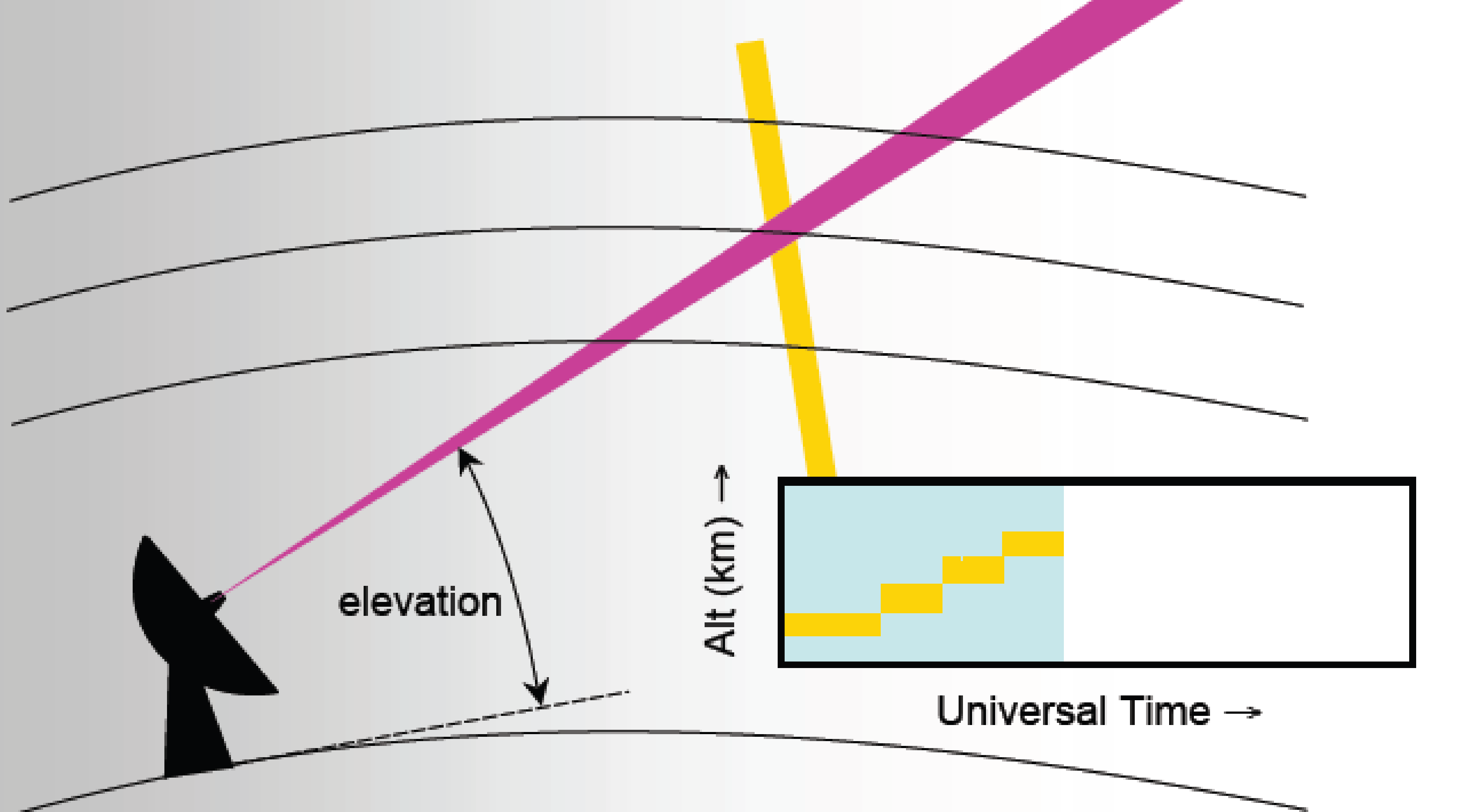

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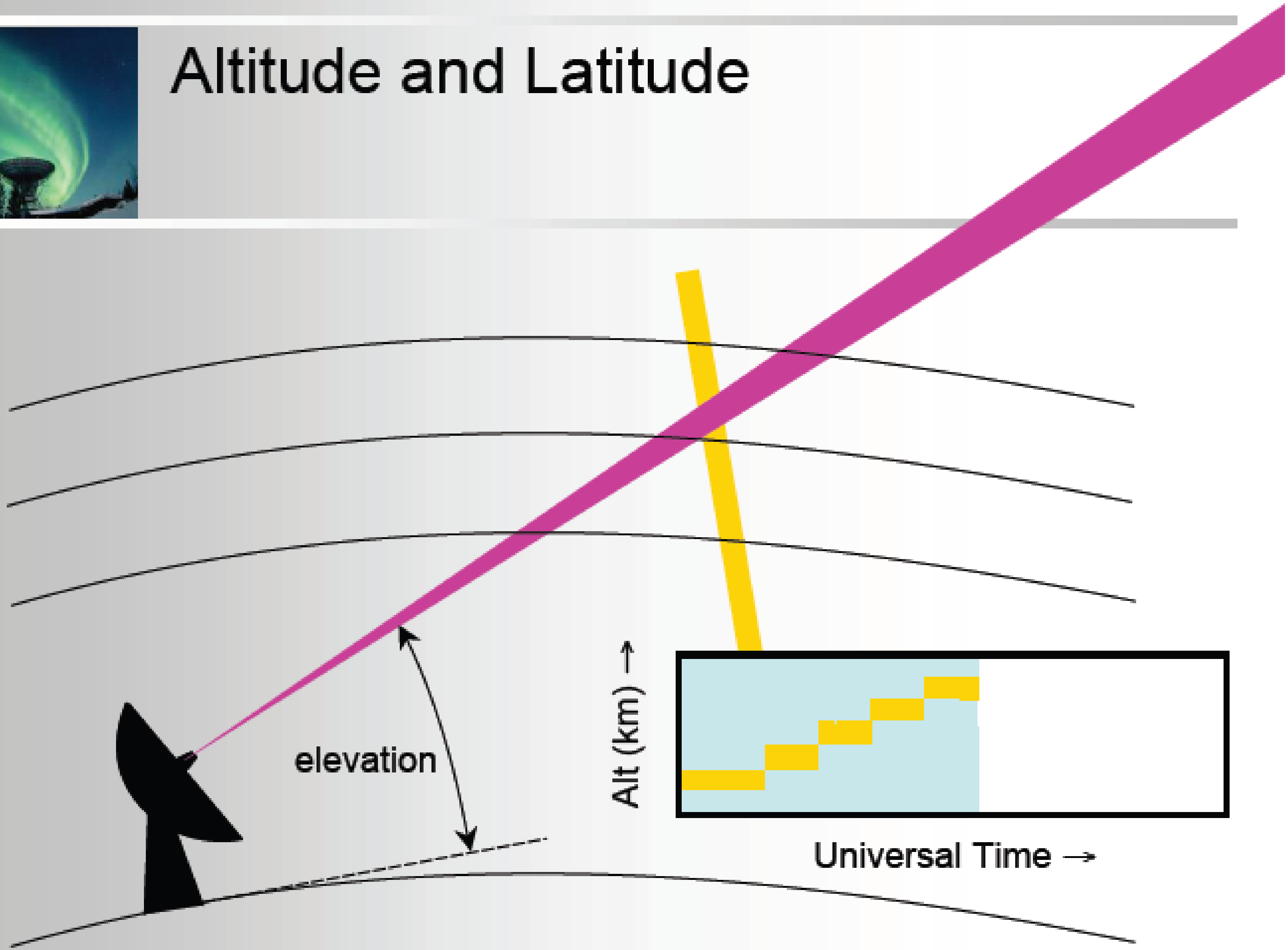

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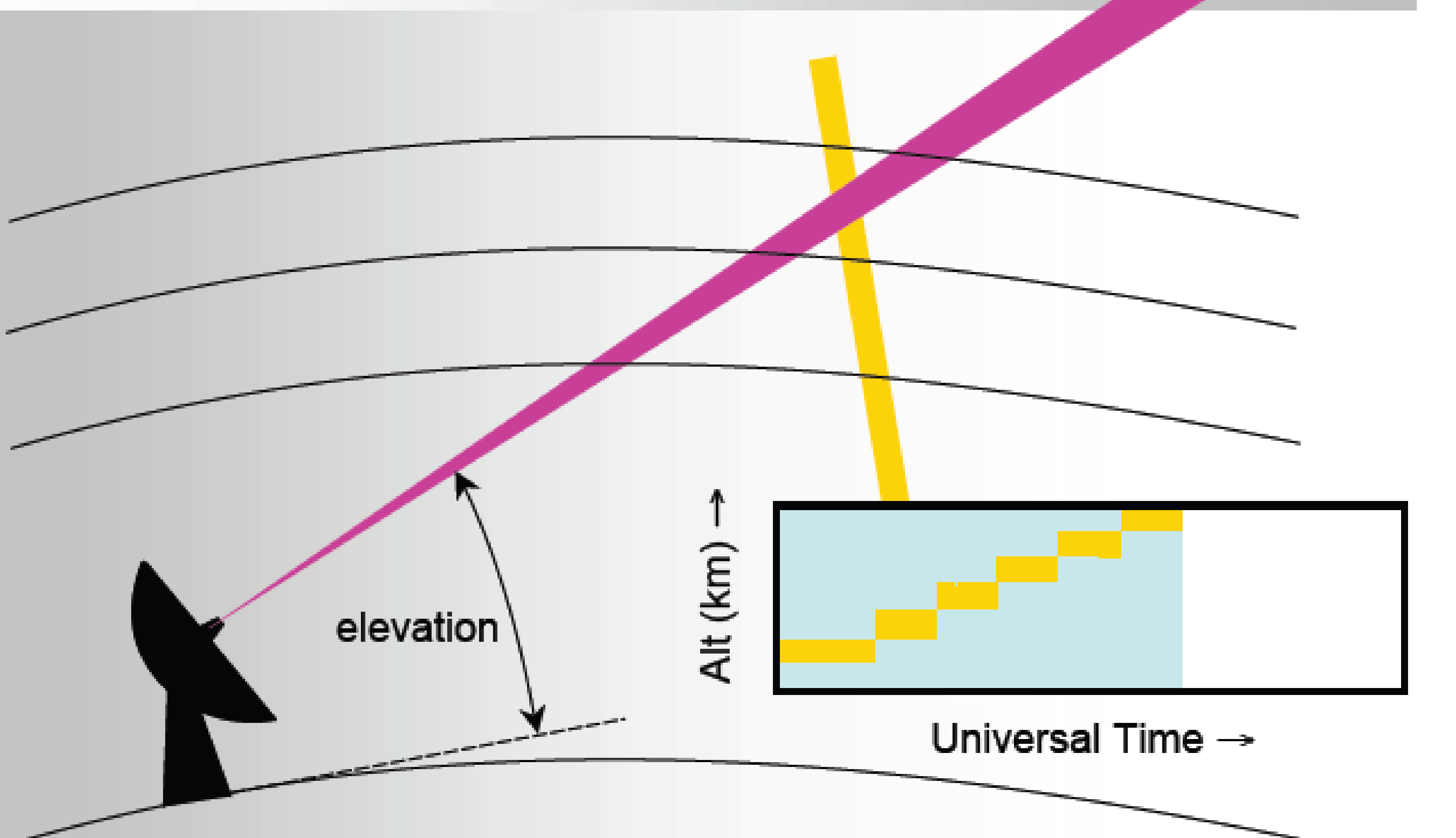

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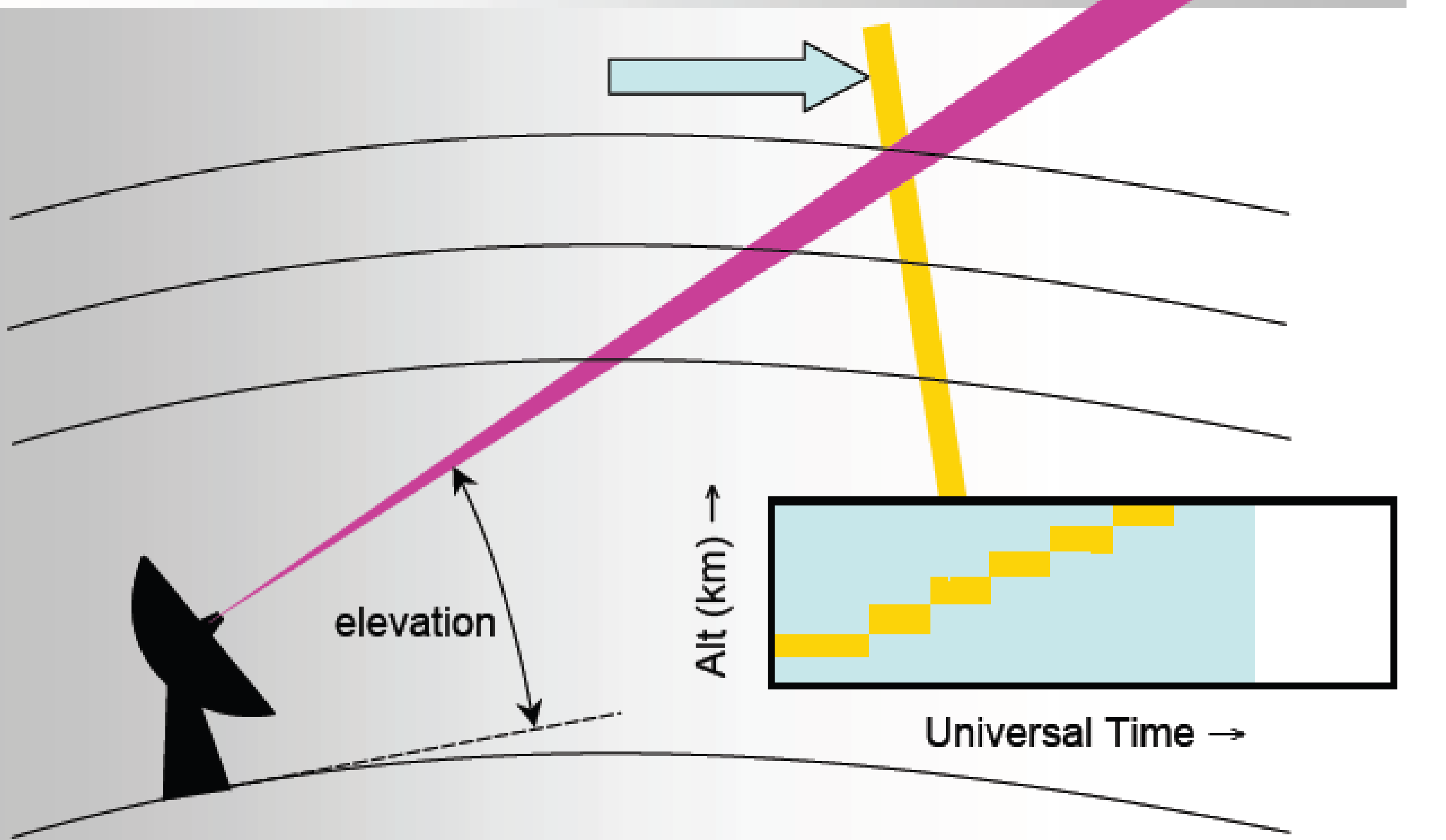
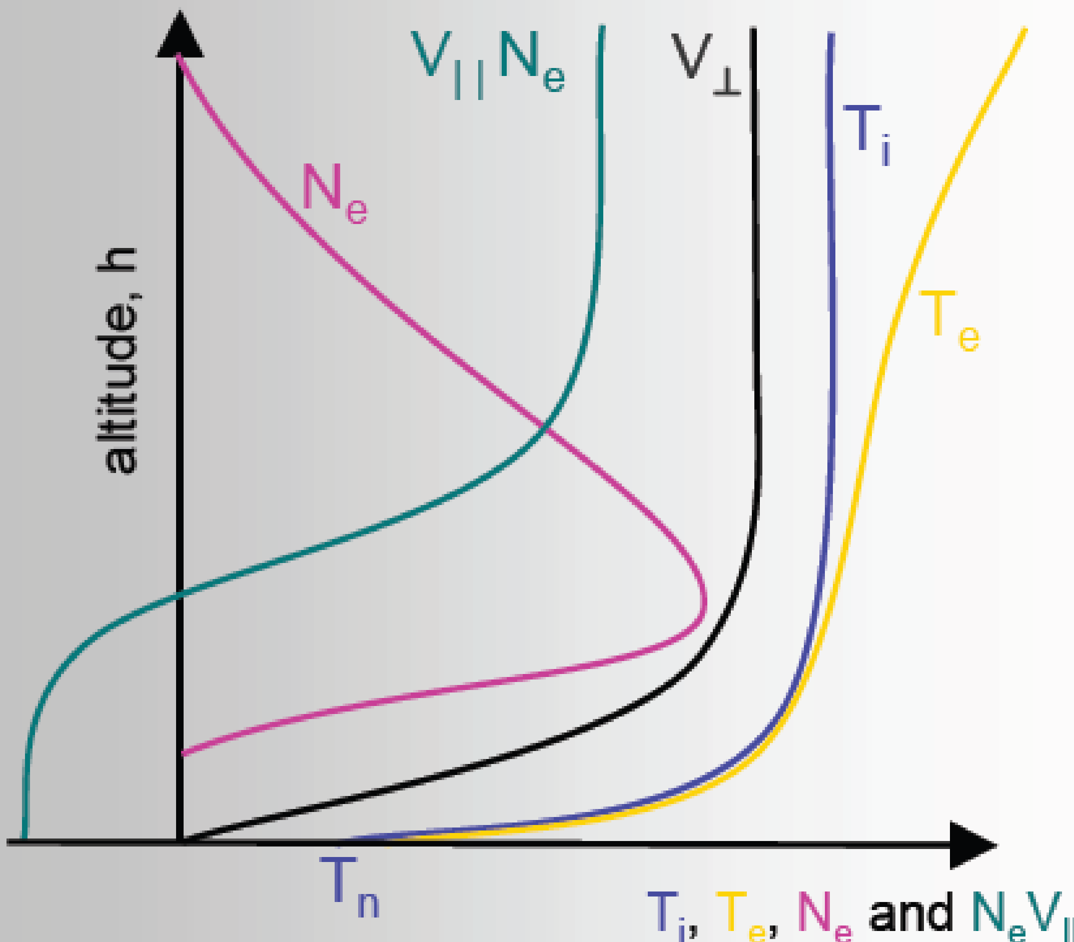


Latitude or altitude?

- How can we tell whether we are observing a latitude-dependent process or an altitude-dependent process?
- We can use our knowledge of atmospheric physics to determine which kind of variation is the more likely.
- Sometimes this is easy, because certain parameters do not change with height.

Height Profiles



T_i , $V_\perp$ and $V_{||}N_e$ are approximately independent of h above about 200 km. Thus we can identify latitudinal structures and motions in these variables

T_i Profiles

Why is T_i independent of h?

Ion energy balance equation

Time derivative $d(N_i k_B T_i)/dt$ negligible on timescales $> (1/\nu_{in}) \sim$ 1sec

Viscosity negligible on spatial scales > ~ 1km

Strictly, the divergence of heat flux $\nabla.q_i$ and the advection term $\underline{\mathbf{V}}.\nabla(N_i k_B T_i)$ are not always negligible but this is a good approximation at h < ~500km. Gives

$$Q_i - L_i = 0$$

Where the heat gained by the ion gas is the effect of collisions with the n neutral species which transfer some of their energy (of both thermal motions and bulk flow motions)

$$Q_i = \Sigma_n N_i m_i \nu_{in} \{3k_B(T_n - T_i)\, \psi_{in} + m_j\, (V_i - V_n)^2\, \phi_{in}\} / (m_i + m_n)$$

And the velocity dependent correction factors ϕ_{in} and ψ_{in} are close to unity.

T_i Profiles

Why is T_i independent of h?

Loss term L_i is heating of electron gas by collisions of ions with electrons (in fact it is a loss $L_i > 0$ if $T_e < T_i$, but another gain $L_i > 0$ if $T_e < T_i$). From same equation for electrons, for which $m_i/(m_e+m_i) \approx 1$

$L_i = - N_e \nu_{ie} \{ 3k_B(T_e-T_i) + (V_i-V_e)^2 \}$

$Q_i - L_i = 0$ gives

$T_i = T_n + (m_n/3k_B)(\phi_{in}/\psi_{in})(V_i-V_n)^2 + (\nu_{ie}/\nu_{in}) \{(m_i+m_n)/m_i\} (T_e-T_i)/\psi_{in}$

For $\phi_{in} = \psi_{in} = 1$,

O^+ ions and O atoms (F-region ionosphere), $\{(m_i+m_n)/m_i\} = 2$

$(m_n/3k_B) = 6.46 \times 10^{-4}$ kg K J^{-1} (in SI units)

Because $T_e \sim T_i$, the second term on the RHS is usually negligible

$$T_i = T_n + 6.46 \times 10^{-4} (V_i-V_n)^2$$

T_n, V_i, and V_n are all roughly independent of h – so is T_i

Perpendicular ion velocity

Why is $V_{\perp}$ independent of height above about 210 km?

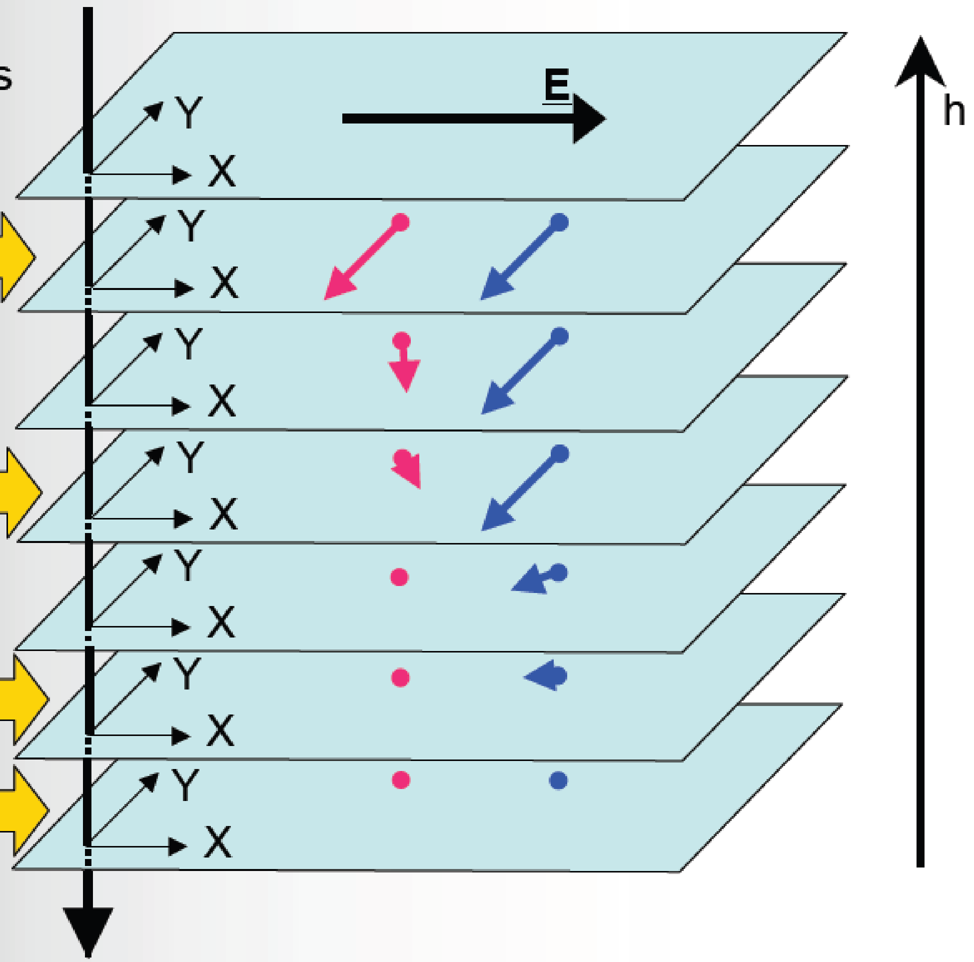
ion and electron collisions with neutrals determine their mobilities

At h > ~210 km, both ions and electrons move with velocity ($\underline{\mathbf{E}} \times \underline{\mathbf{B}}$) / B^2 – no collision effect

At h ~ 140 km, $\upsilon_i = \Omega_i$ ion motions show effect of collisions, but not electrons.

At h ~ 80 km, $\upsilon_e = \Omega_e$ electron motions also show effect of collisions. Ions do not move*

Neither electrons nor ions move*

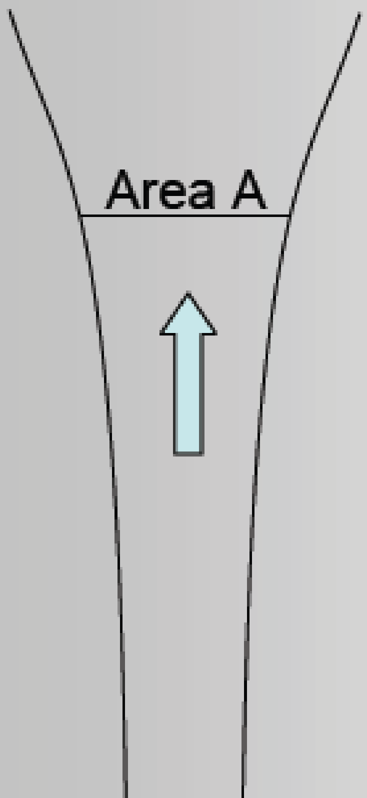


* *w.r.t. neutral gas*

Flux Profiles

Why is $N_e V_{||}$ independent of h?

Continuity equation on a flux tube



$d(N_i A V_{||})/dh = q - L$

Above h of about 200 km production q and loss L are negligible

(note we consider total ion flux so charge exchange is not a factor)

$(1/F)\ dF/dh = (1/A)\ dA/dh$

In the ionosphere A(h) is approximately constant (and is known from magnetic field model) so F is approximately constant)

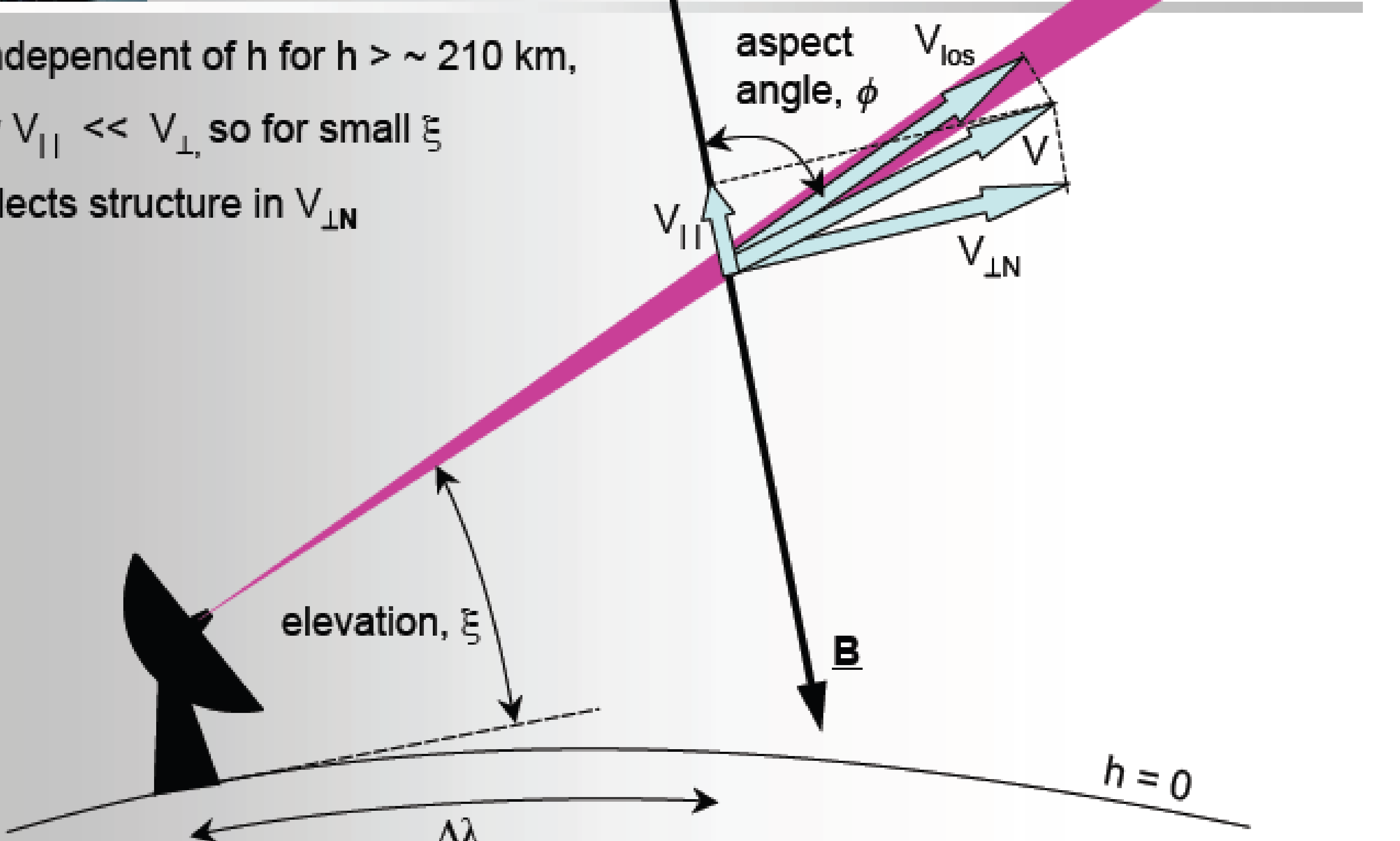
Line-of-sight velocity

e.g. for a northward-pointing beam

$V_\perp$ is independent of h for h > ~ 210 km,

usually $V_{||}$ << $V_{\perp}$, so for small ξ

V_{los} reflects structure in $V_{\perp N}$

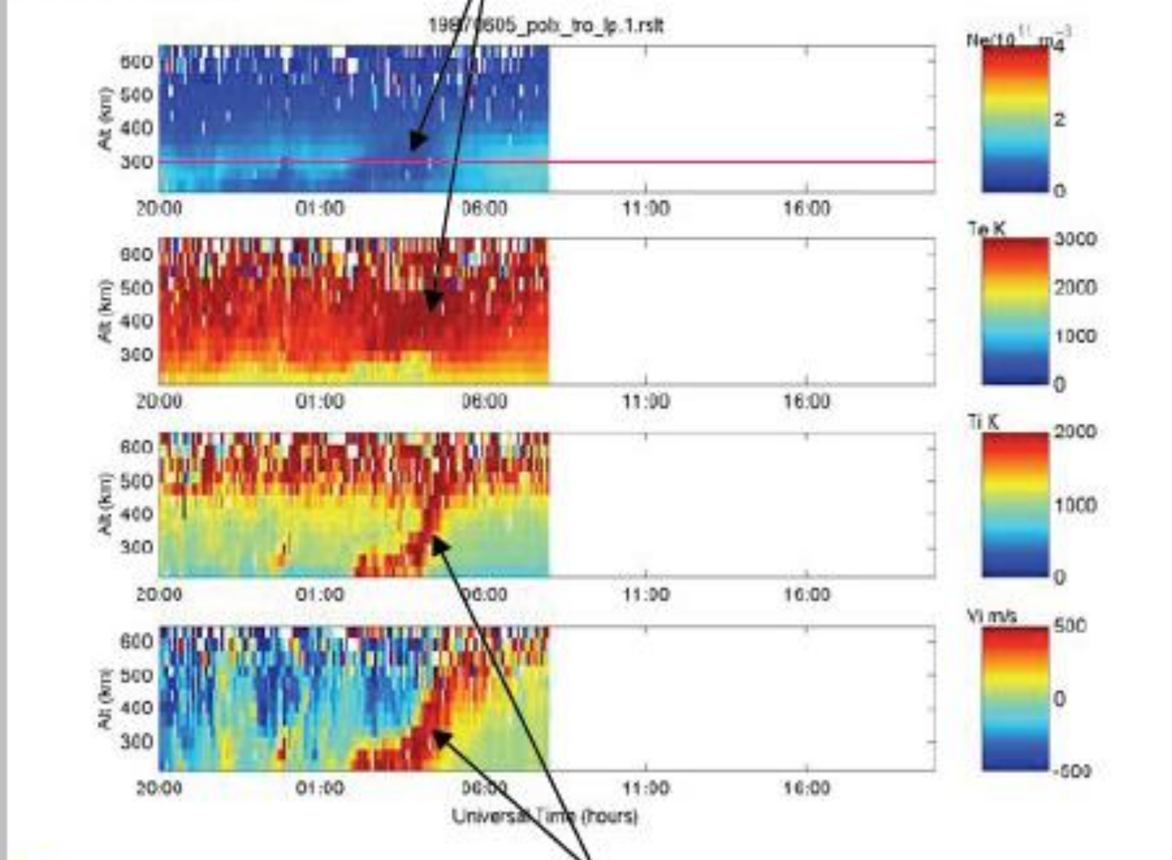


A Polar Cap Contraction

CP-4-A (UHF), azimuth 2 (points Magnetic north)

Elevation, ξ = 21°

Trough in N_e with enhanced T_e



Poleward moving event

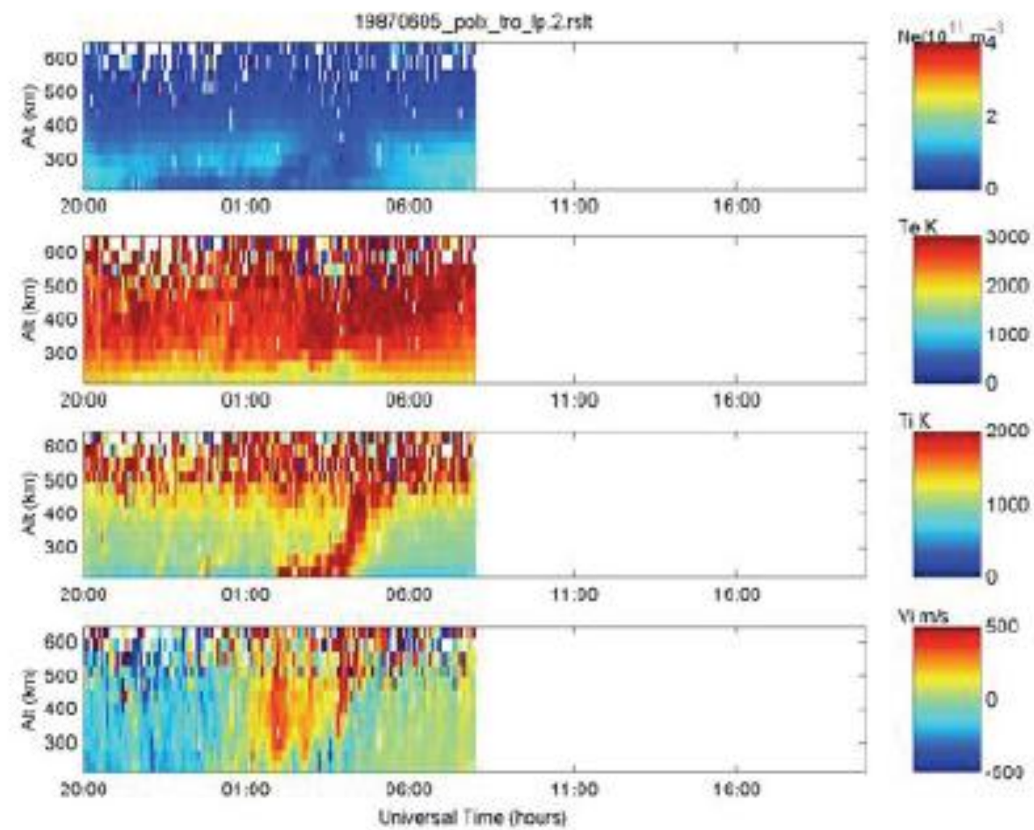
N_e and T_e - latitude structure and height structure mixed for this low elevation beam

Look at one height at a time to see time variations

T_i and $V_{los} \approx V_{\perp N}$ approx. indep. of h and so this is a latitudinal structure and it migrates poleward

A Polar Cap Contraction

CP-4-A (UHF), azimuth 1 (points 12° east of magnetic north)

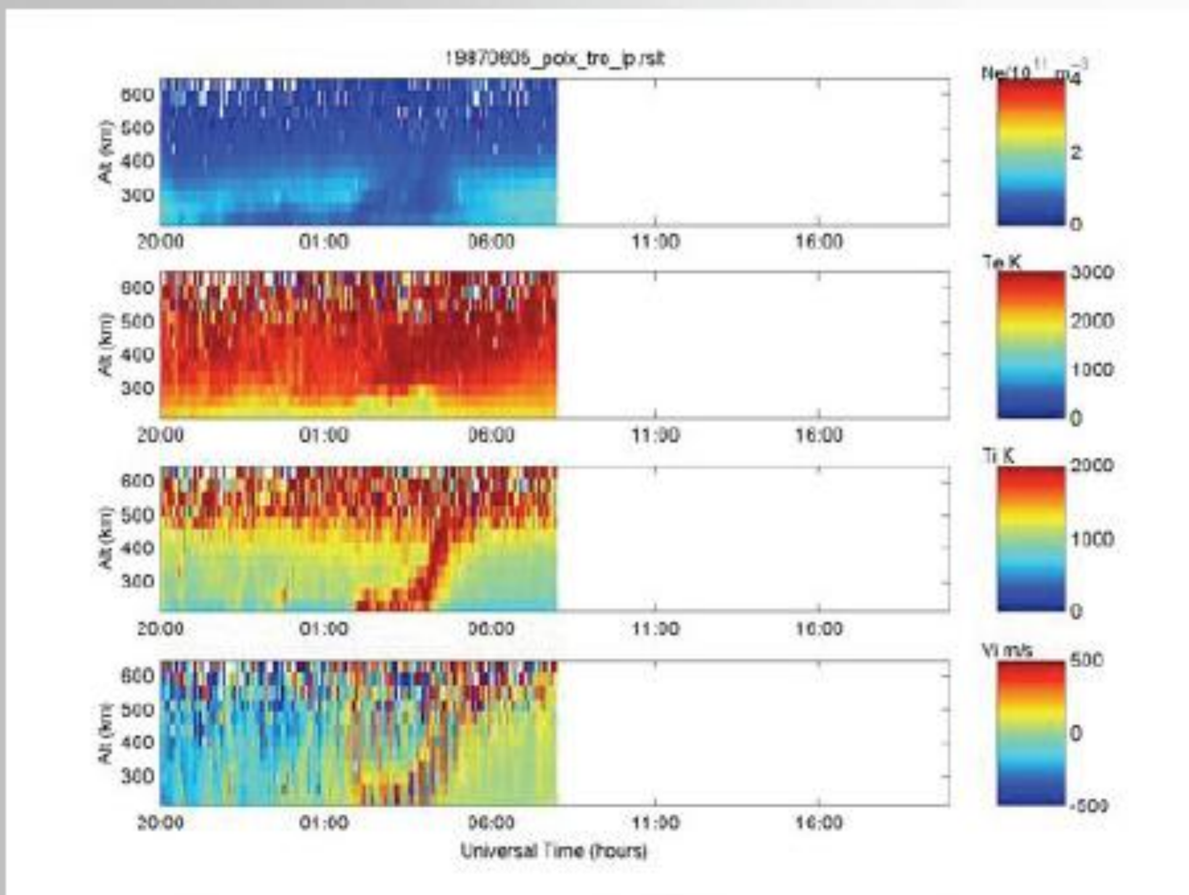


N_e, T_e and Ti show the same features as aximuth1 – gives us a orientation w.r.t. the L-shells and a minimum extent

V_{los} is quite different to that for azimuth 1 – shows either longitudinal structure or, more likely, along L-shell convection

A Polar Cap Contraction

CP-4-A, both azimuths



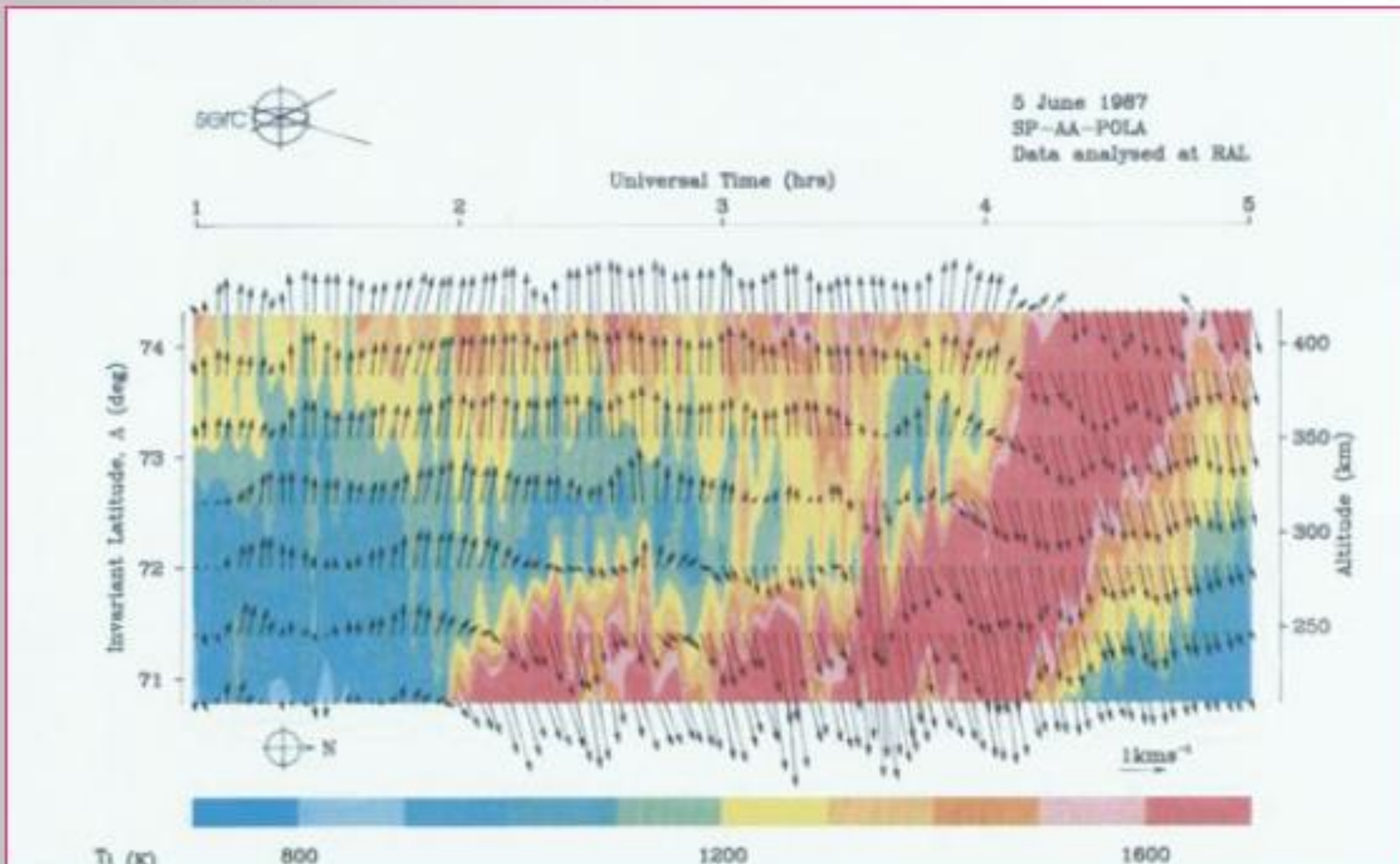
structure and differences show show best if both azimuths are interleaved on the same plot

Vertical stripes in V_{los} highlight the differences between the two beams

A Polar Cap Contraction

Beamswinging E vectors superposed on T_i plot

Note band of high T_i is only on trailing side of convection reversal boundary (OCB)



A Polar Cap Contraction

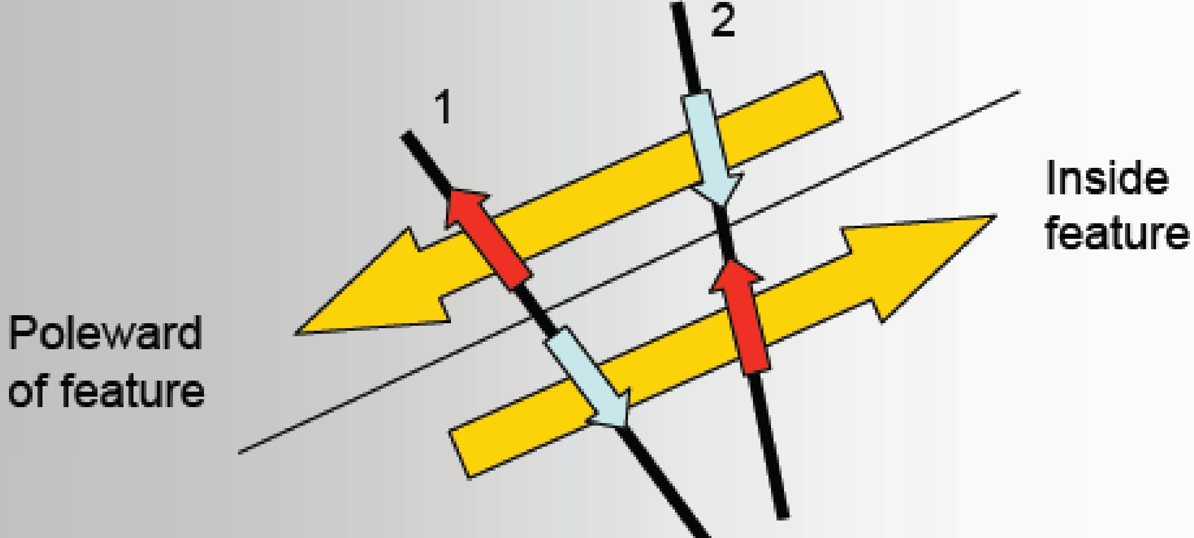
Where are we?

F-o-v is north of Tromsø (latitudes λ = 70.5 - 74.5°)

For this f-o-v MLT $\approx$ UT + 1.75 hrs

(use, e.g. http://lewes.gsfc.nasa.gov/space/cgm/cgm.html)

Poleward-moving event is at about 4:00UT, $\approx$ 5:45 MLT, i.e. near dawn

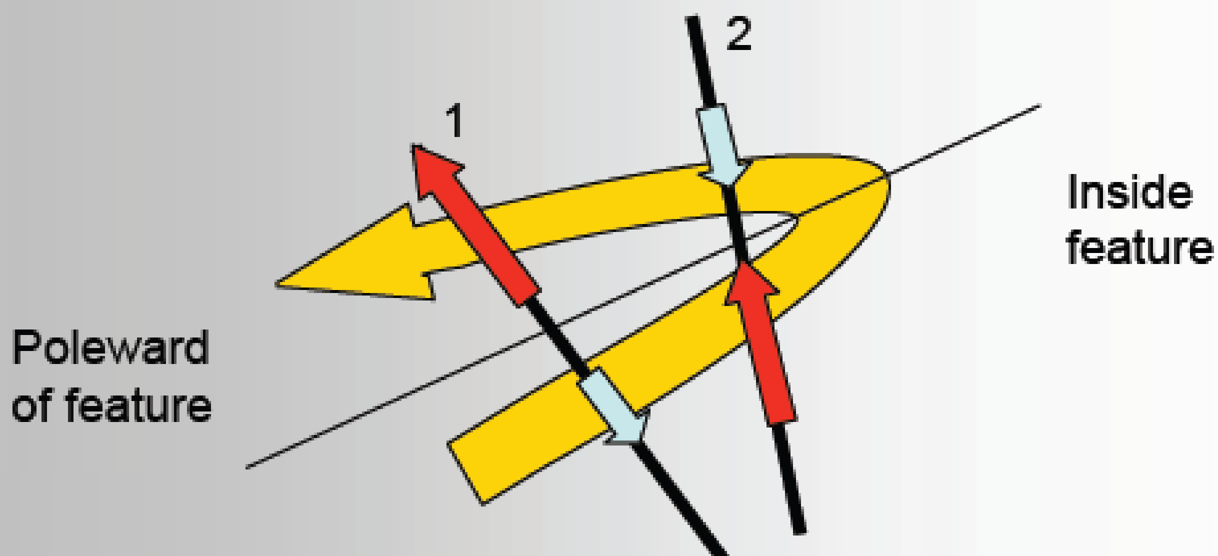


A Polar Cap Contraction

Where are we?

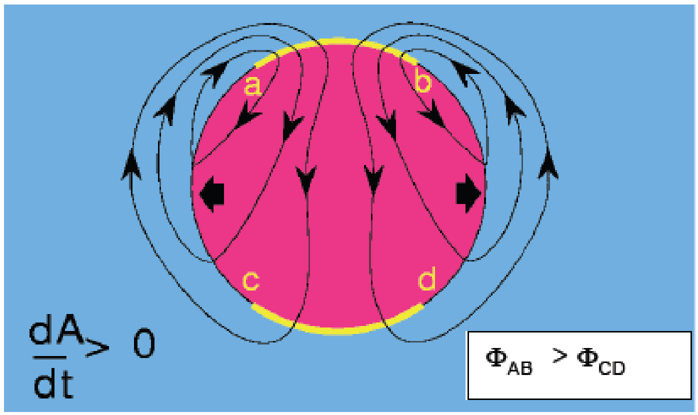
In fact there is an asymmetry in observed V_{los}, flow – as shown below

It reveals that there is flow across the convection reversal boundary

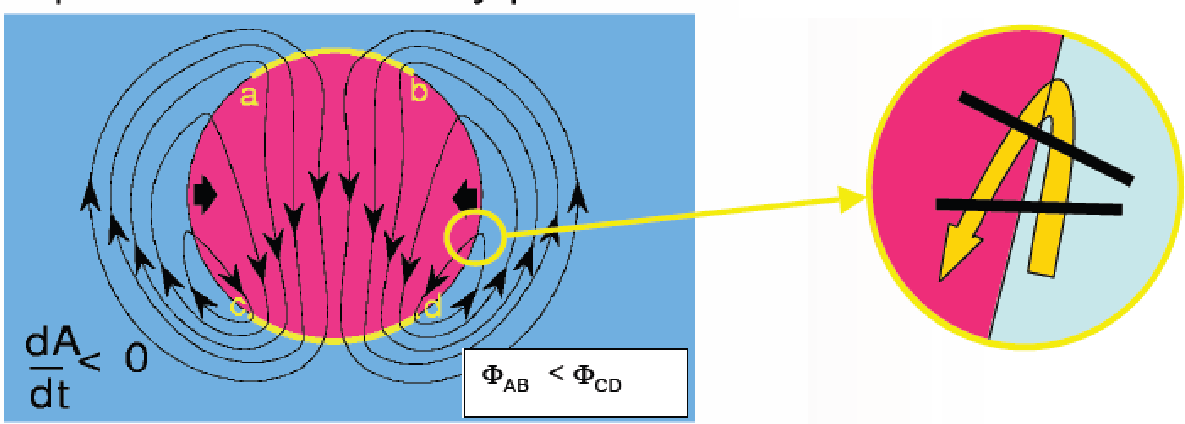


A Polar Cap Contraction
What’s going on? Substorm recovery phase

growth phase



expansion and recovery phases



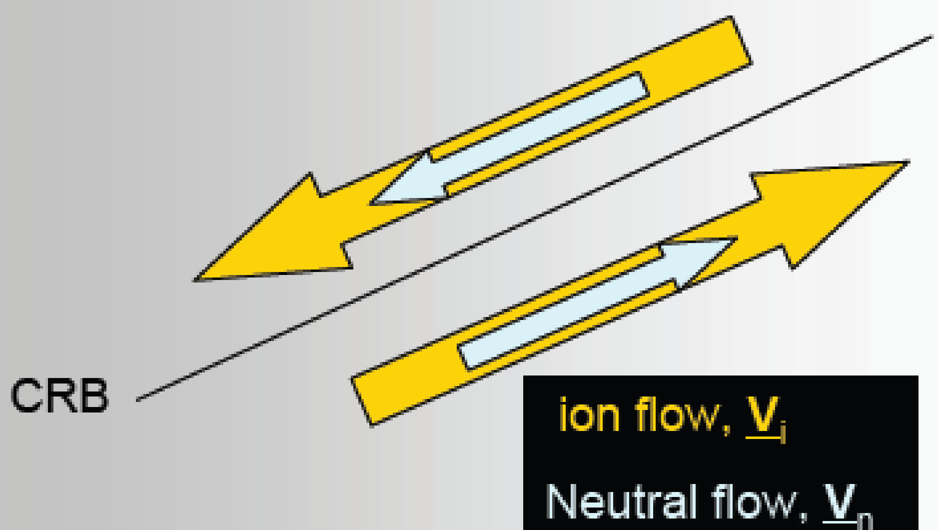
In substorm recovery phase, reconnection voltage in cross-tail current sheet (that destroys open flux) exceeds that at the dayside magnetopause (which generates open flux) and so the open polar cap contracts.

Ion-neutral frictional heating event

Caused by polar cap contraction

$T_i = T_n + (m_n/3k_B)\,|\underline{\mathbf{V}}_i - \underline{\mathbf{V}}_n|^2$

$N_n >> N_i$; means that responses in $\underline{\mathbf{V}}_n$ to changes of $\underline{\mathbf{V}}_i$ are small and slow



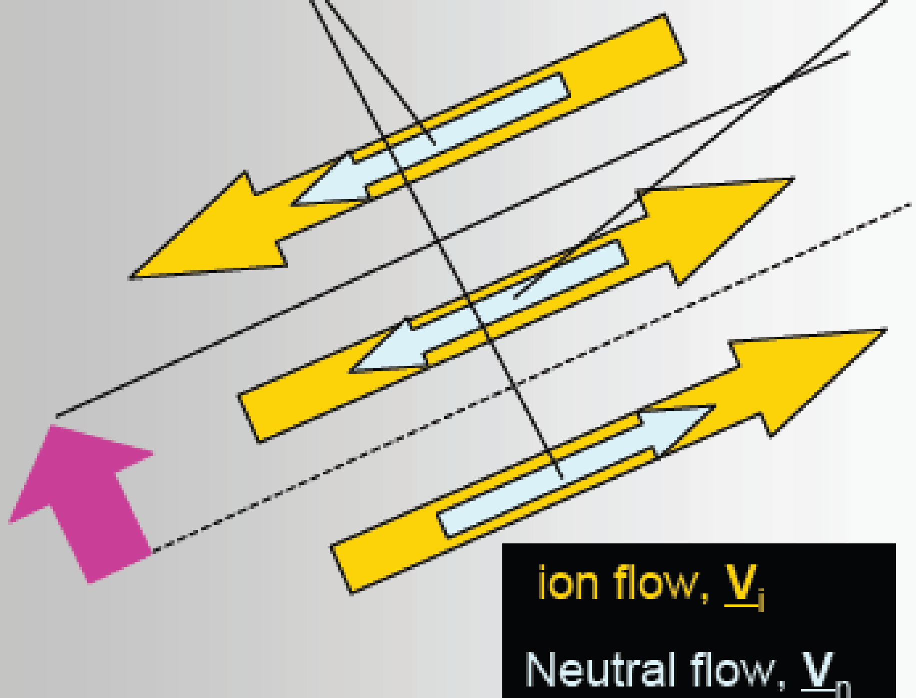
Ion-neutral frictional heating event

Caused by polar cap contraction

$T_i = T_n + (m_n/3k_B)\,|\underline{V}_i - \underline{V}_n|^2$

Boundary moves so ion flows reverse in band between old and new locations

As before $T_i \approx$ 1090 K here



Neutrals do not respond for a while. In the band $\underline{\mathbf{V}}_n = -\underline{\mathbf{V}}_i/3$

$(\underline{\mathbf{V}}_i - \underline{\mathbf{V}}_n)^2 = (4V_i/3)^2 = (16/9)V_i^2$

So this term is 4 times larger

For the typical V_i = 1 kms^{-1}

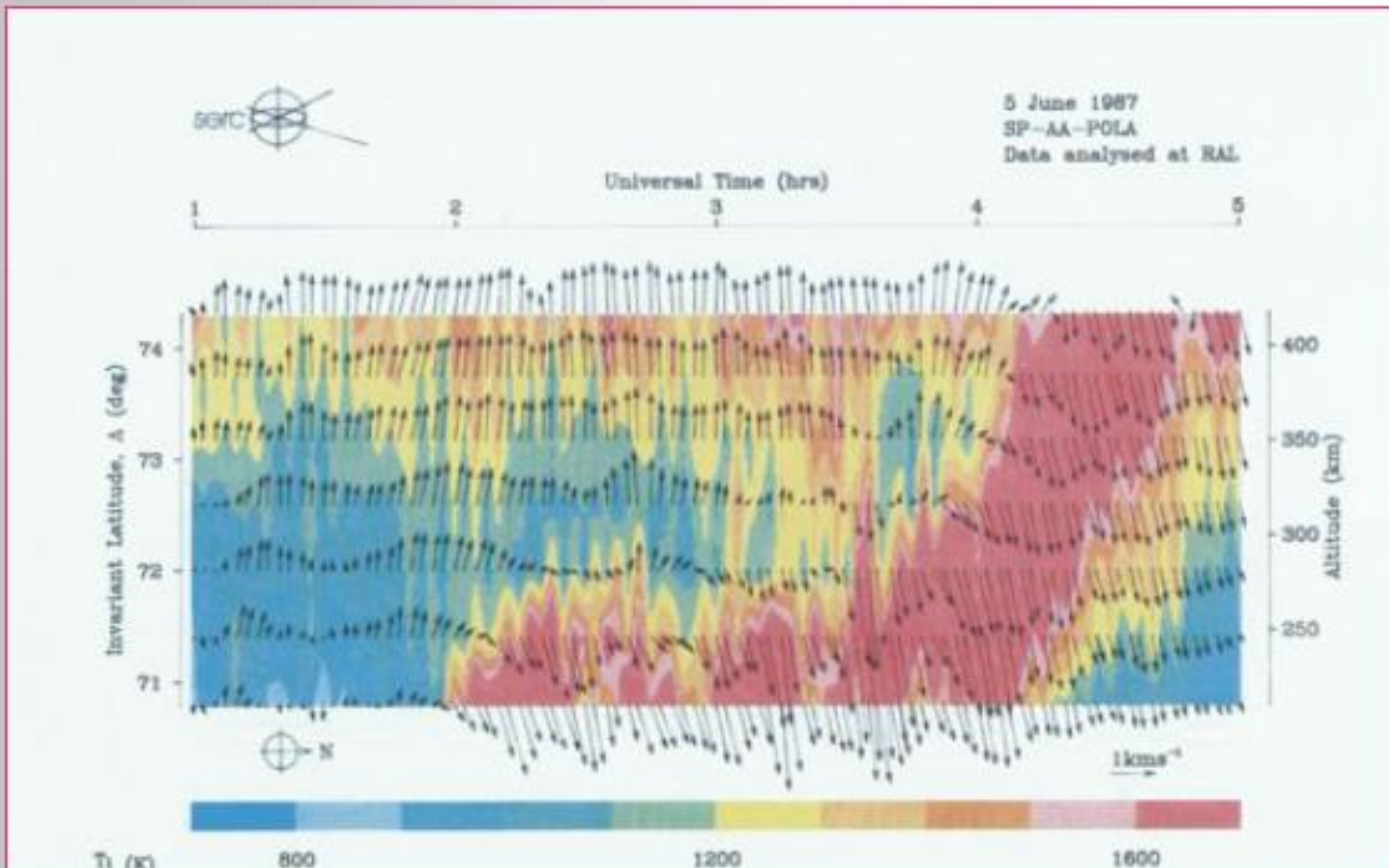
and $T_n \approx$ 800 K

eqn. gives $T_i \approx$ 1950 K

A Polar Cap Contraction

Beamswinging E vectors superposed on T_i plot

Note band of high T_i is only on trailing side of convection reversal boundary (OCB)

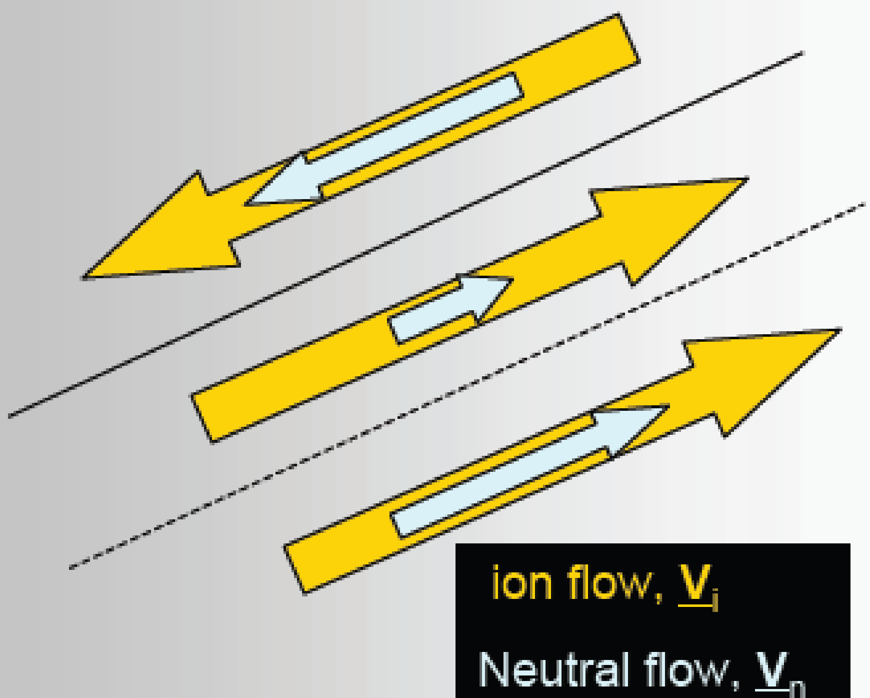


Ion-neutral frictional heating event

Caused by polar cap contraction

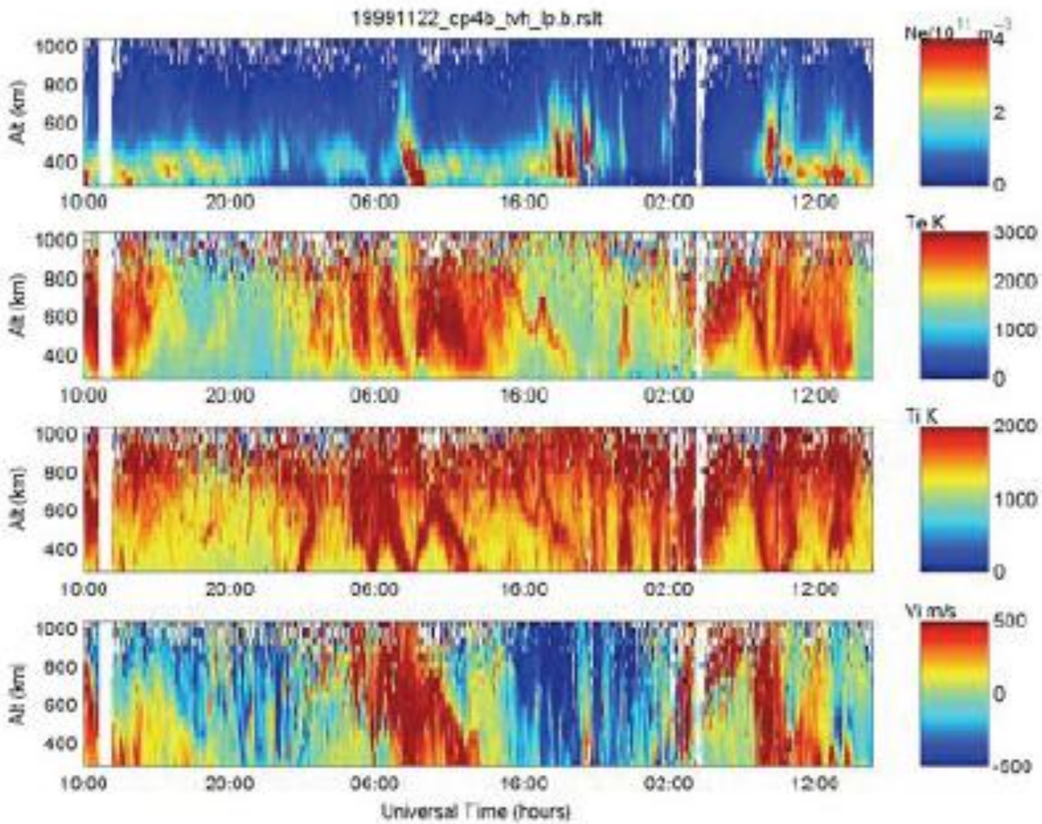
$T_i = T_n + (m_n/3k_B)\, |\underline{\mathbf{V}}_i - \underline{\mathbf{V}}_n|^2$

high Ti in this band slowly subsides as neutral begin to respond



Substorm Cycles

(in CP-4-B data)

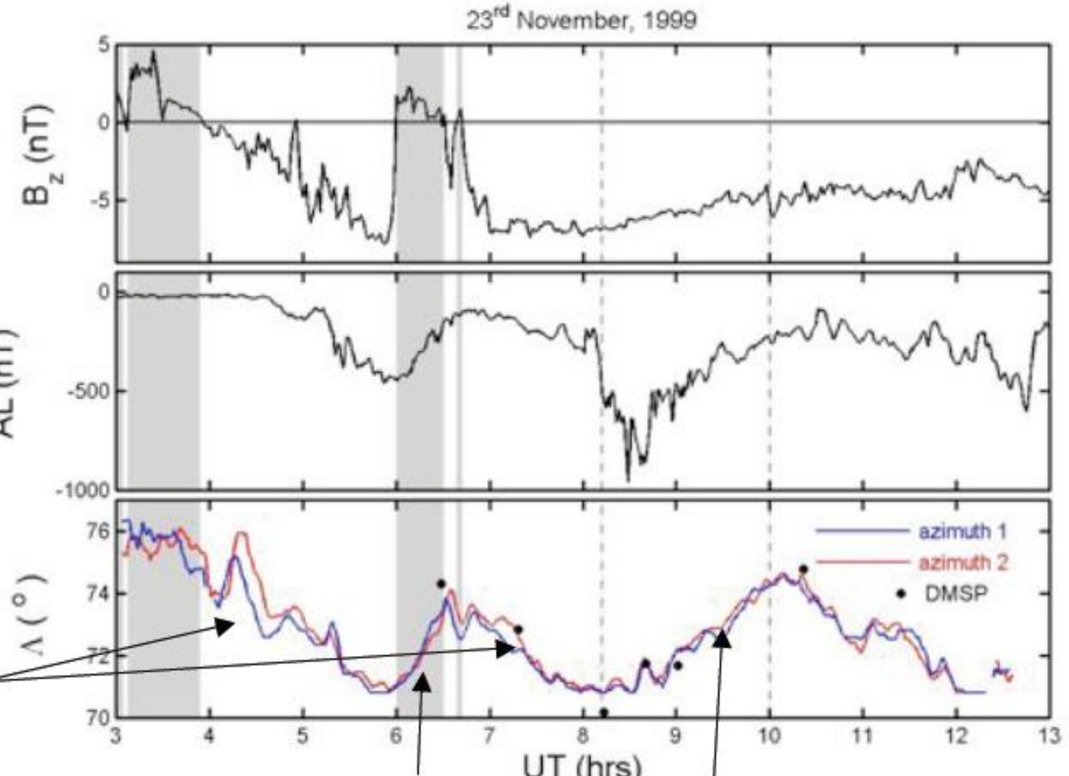


See expansions and contractions. This time MLT ≈ UT + 2.75hr

So 06-12 UT is 8:45-12:45 MLT

Substorm cycles

Use solar wind and magnetic indices to understand the radar data

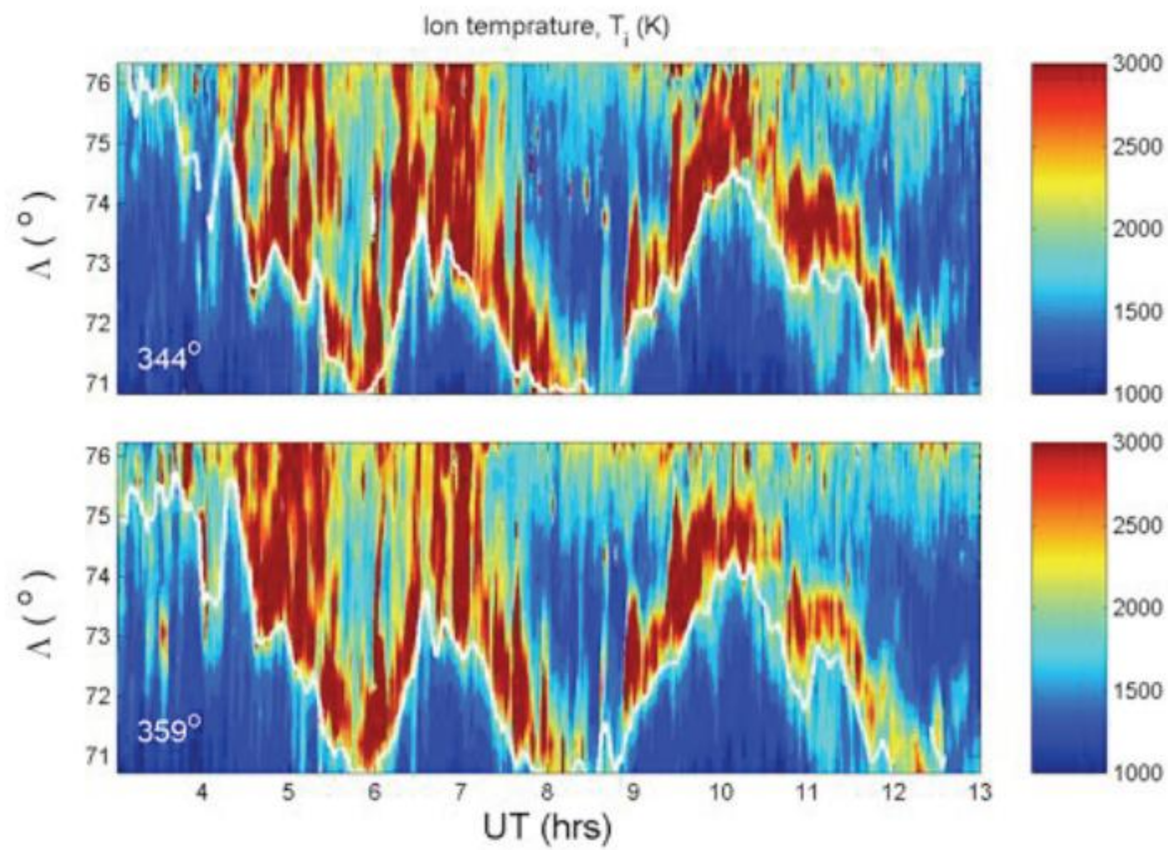


IMF $B_z < 0$ gives polar cap expansion (growth phase)

IMF turns northward and AL index shows a substorm expansion phase (polar cap contracts)

IMF stays southward and AL index shows a substorm expansion phase (polar cap contracts)

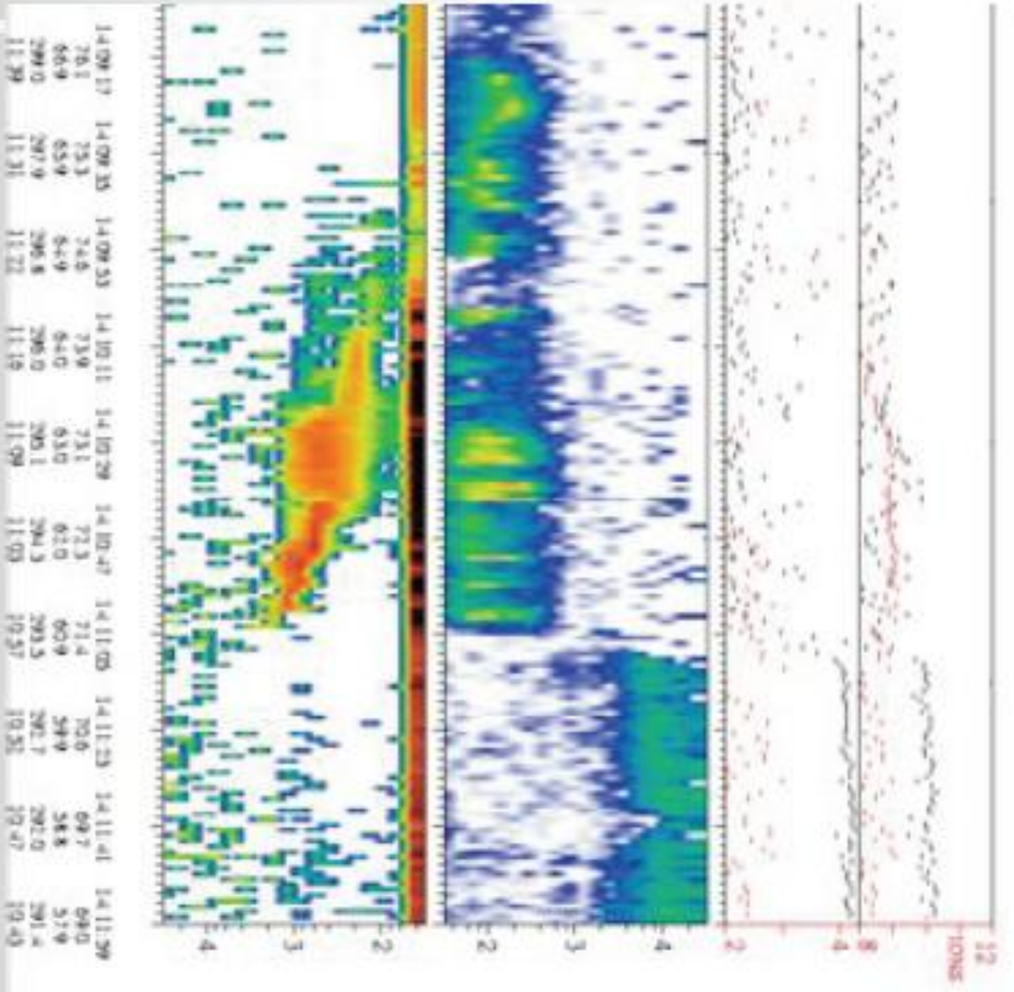
Substorm cycles
Note: changing the contour levels often helps you see an event



Inferred Open-Closed Boundary

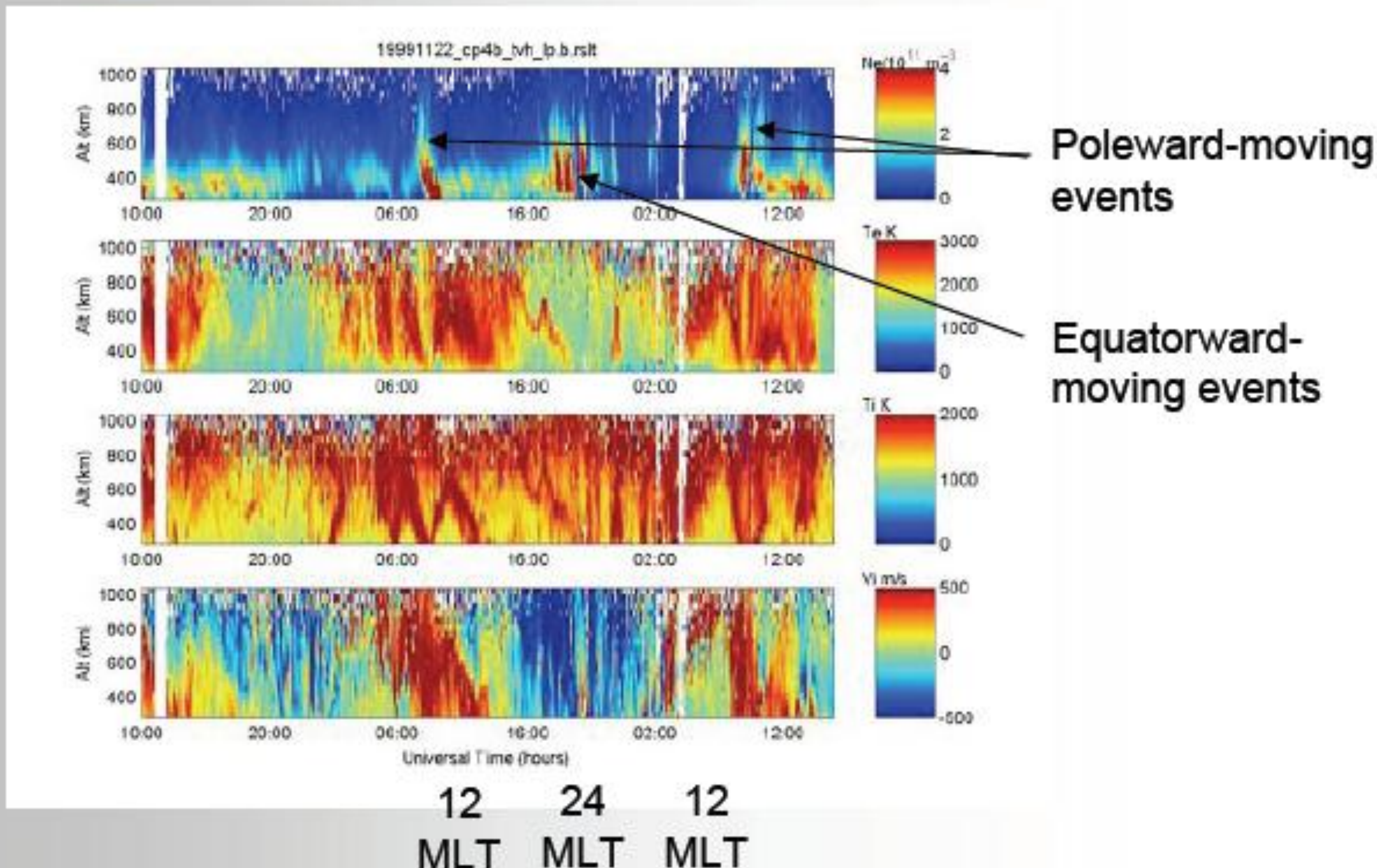
(agrees well with DMSP passes over the cusp)

ALWAYS check as much supporting data as exists from other sources as you possibly can!



Polar Cap Patches

(in same CP-4-B data)



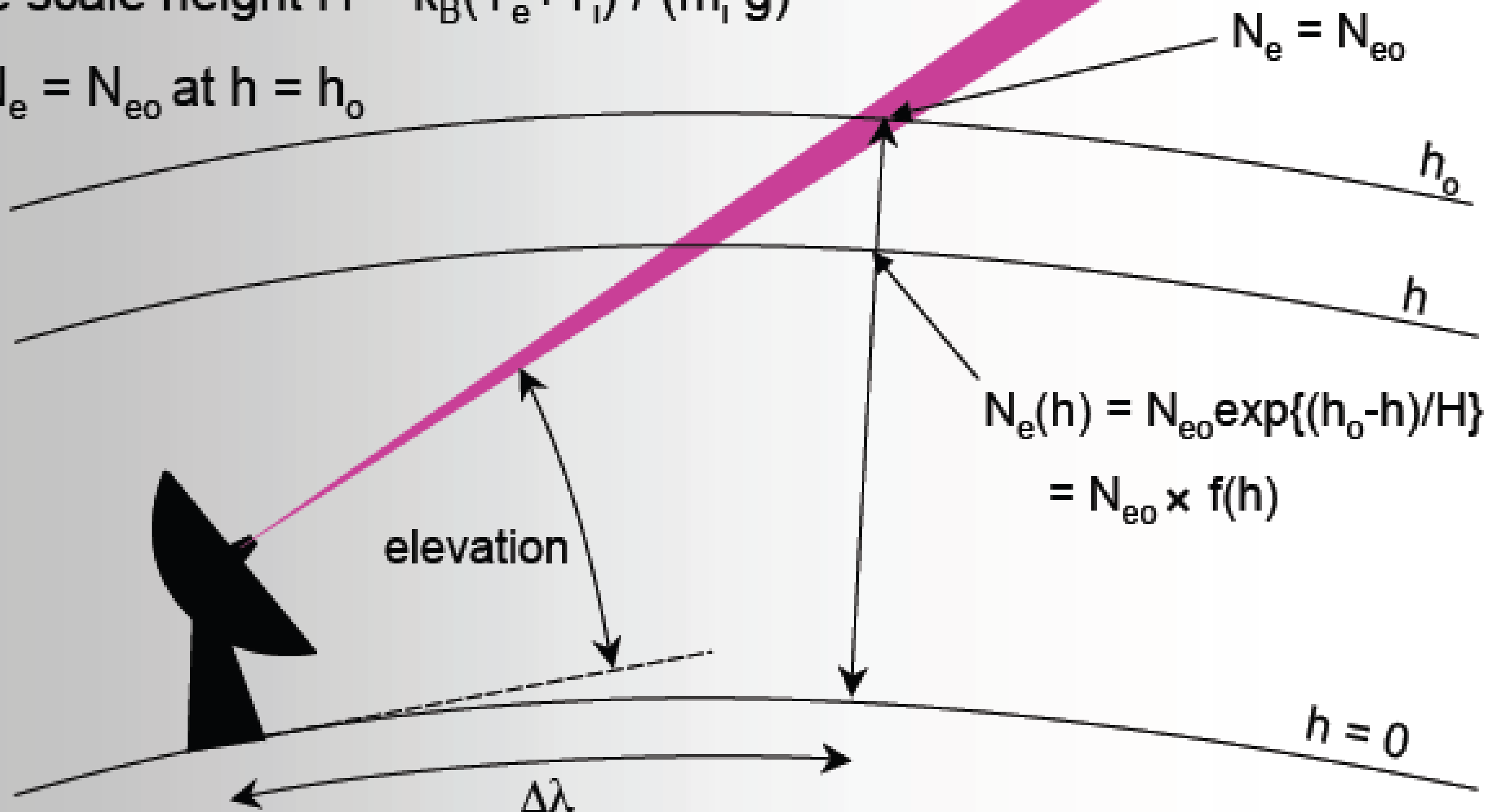
A trick to remove altitude effect in N_e

Assume diffusive equilibrium*

In diffusive equilibrium $N_e = N_{eo}\exp\{(h_o - h)/H\}$

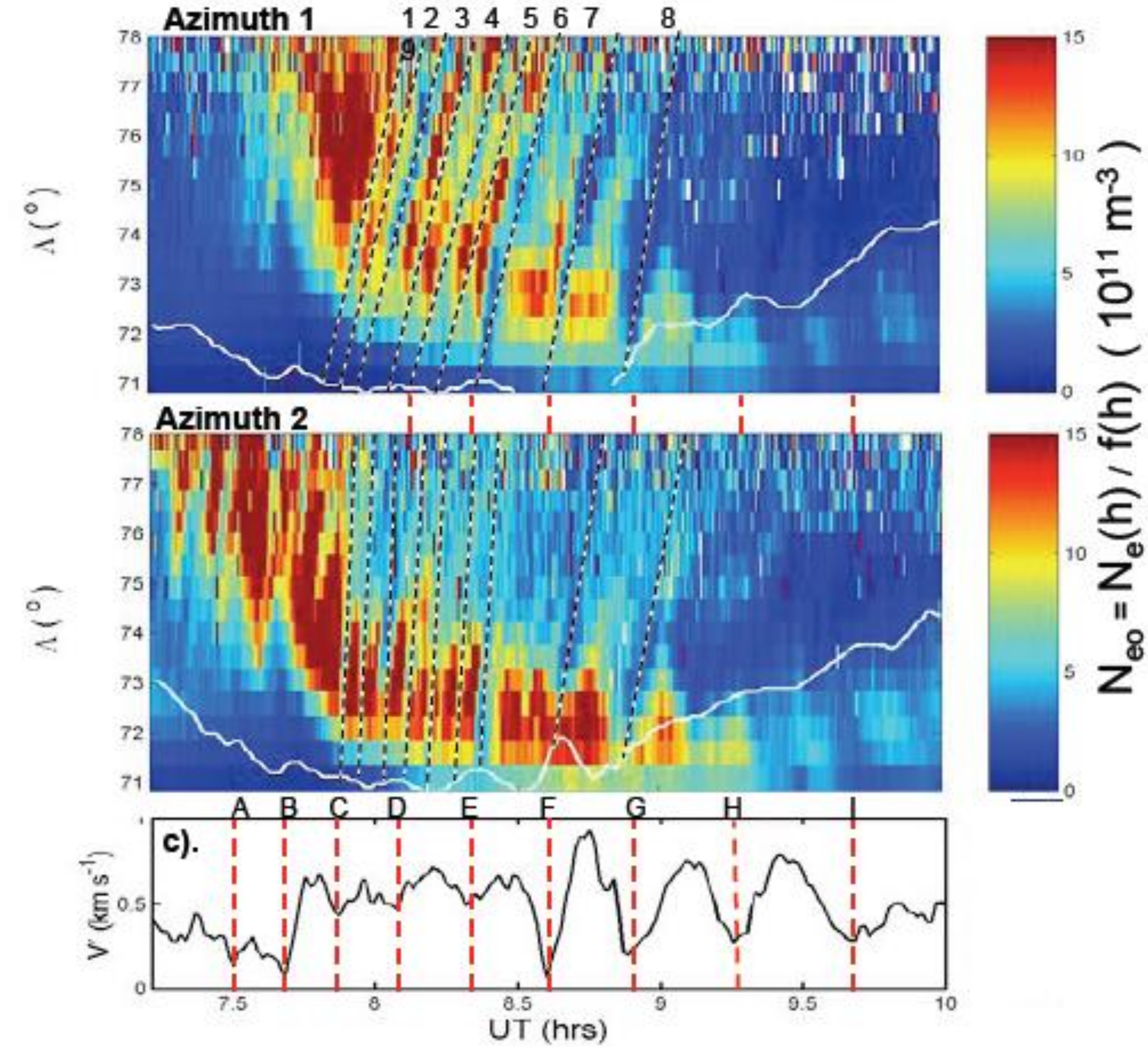
where scale height $H = k_B(T_e + T_i) / (m_i\ g)$

and $N_e = N_{eo}$ at $h = h_o$



* Not TOO bad an assumption in the lower topside

Polar Cap Patches



Observed density N_e corrected to reference height h_o by assuming diffusive equilibrium to give $N_{eo} = N_e(h) / f(h)$

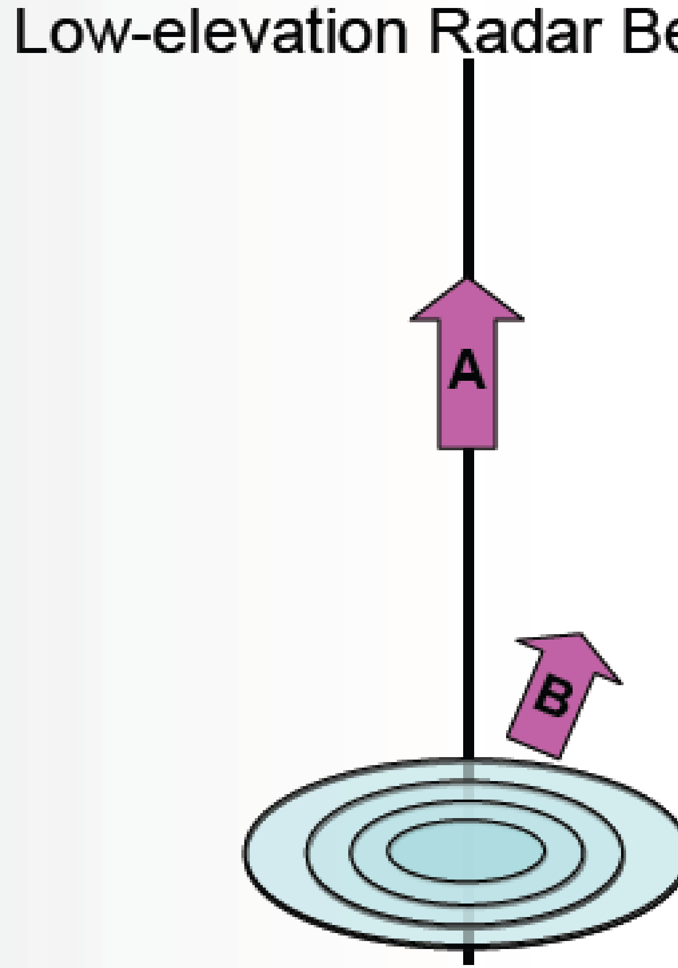
Polar Cap Patches in N_e

If N_e falls in patch as it moves poleward is it

A. because N_e is lower at greater h?

Or

B. because patch has moved in MLT?

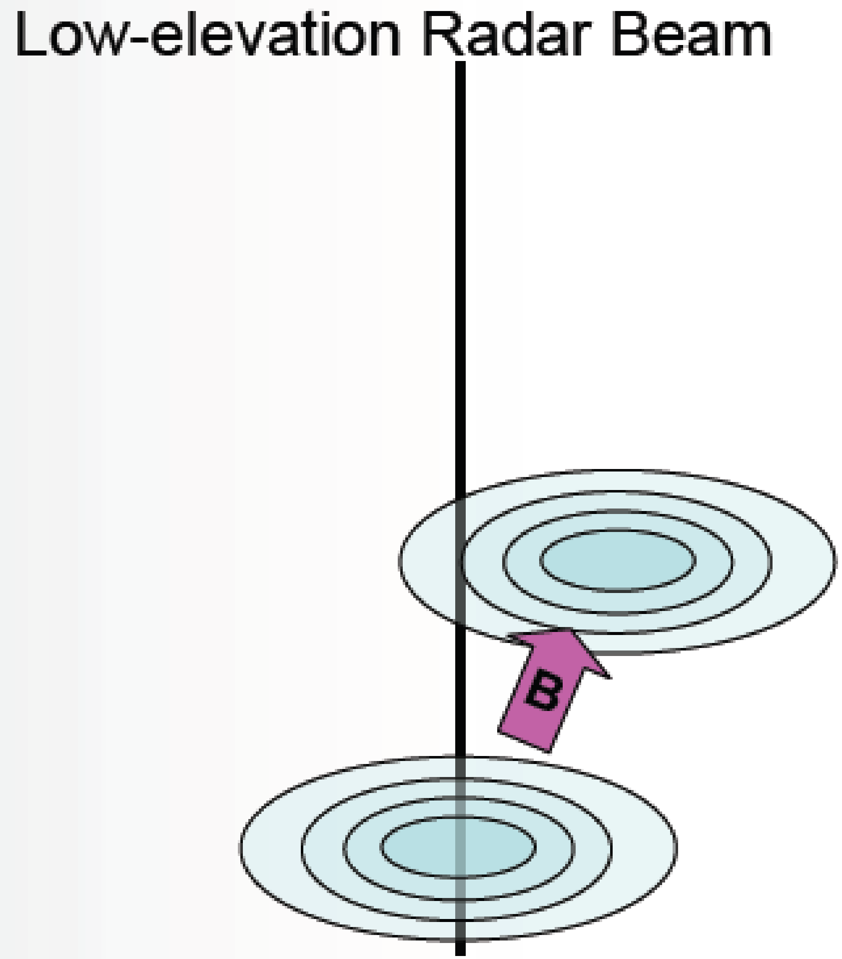


Polar Cap Patches in N_{eo}

If N_{eo} falls in patch as it moves poleward we KNOW it is

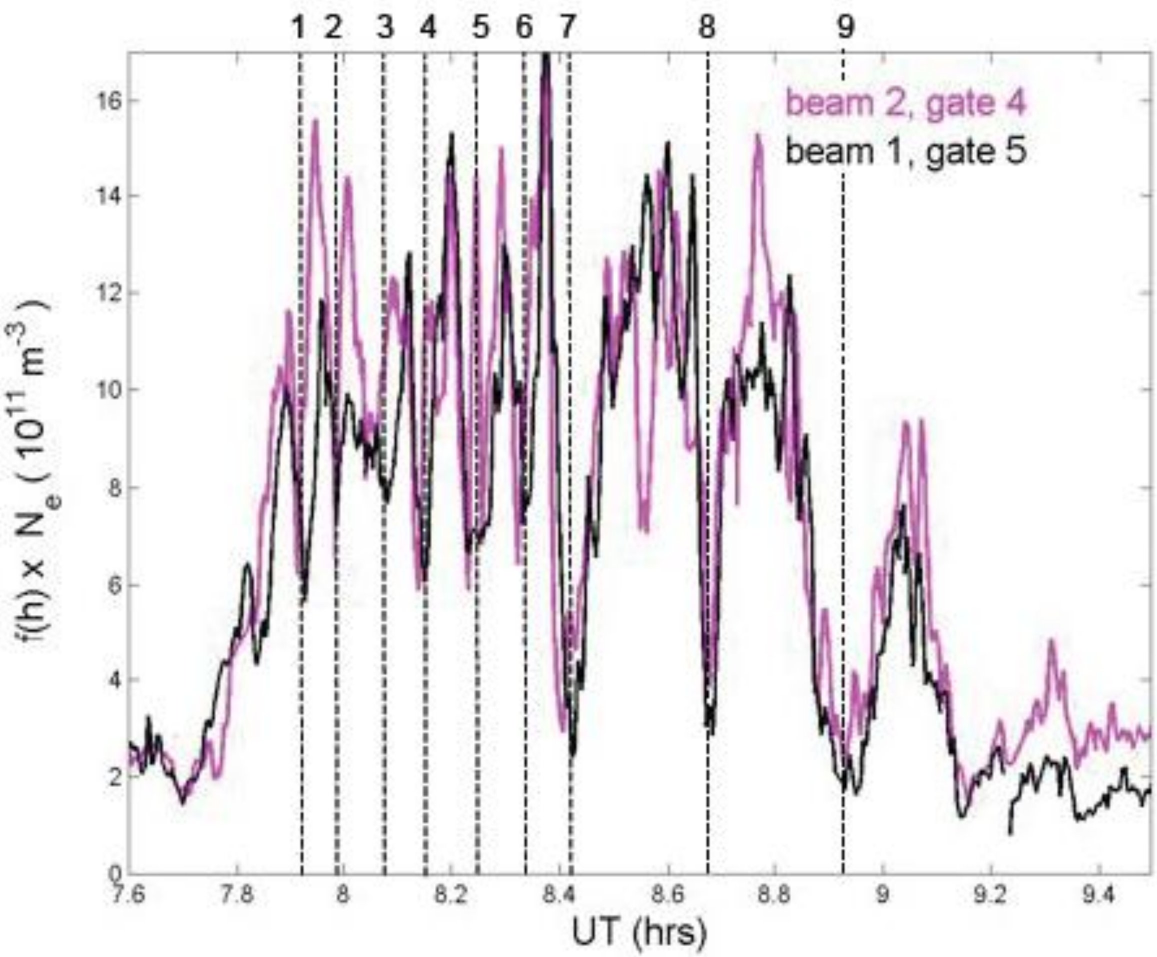
B. because patch has moved in MLT

(because N_{eo} does not depend on h)



Phase Motion $V_x = \Delta x / \Delta t$

(use lag Δt from cross-correlation)



Phase Motion $V_x = \Delta x/\Delta t$

(use lag Δt from cross-correlation)

A word of warning: you need to worry about event orientation

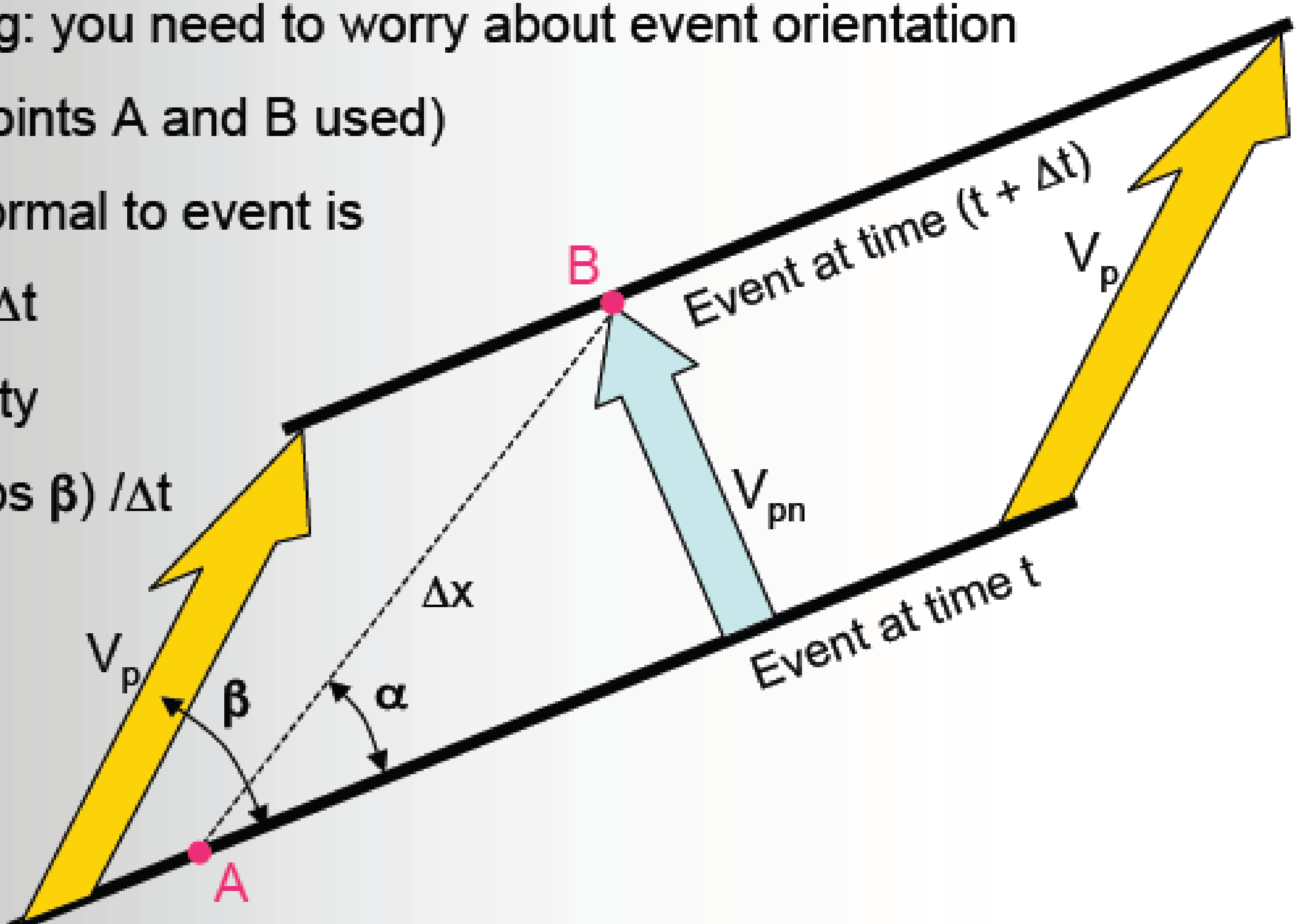
(relative to two points A and B used)

phase velocity normal to event is

$V_{pn} = \Delta x(\cos\alpha)/\Delta t$

true phase velocity

$V_p = \Delta x(\cos\alpha / \cos\beta)/\Delta t$

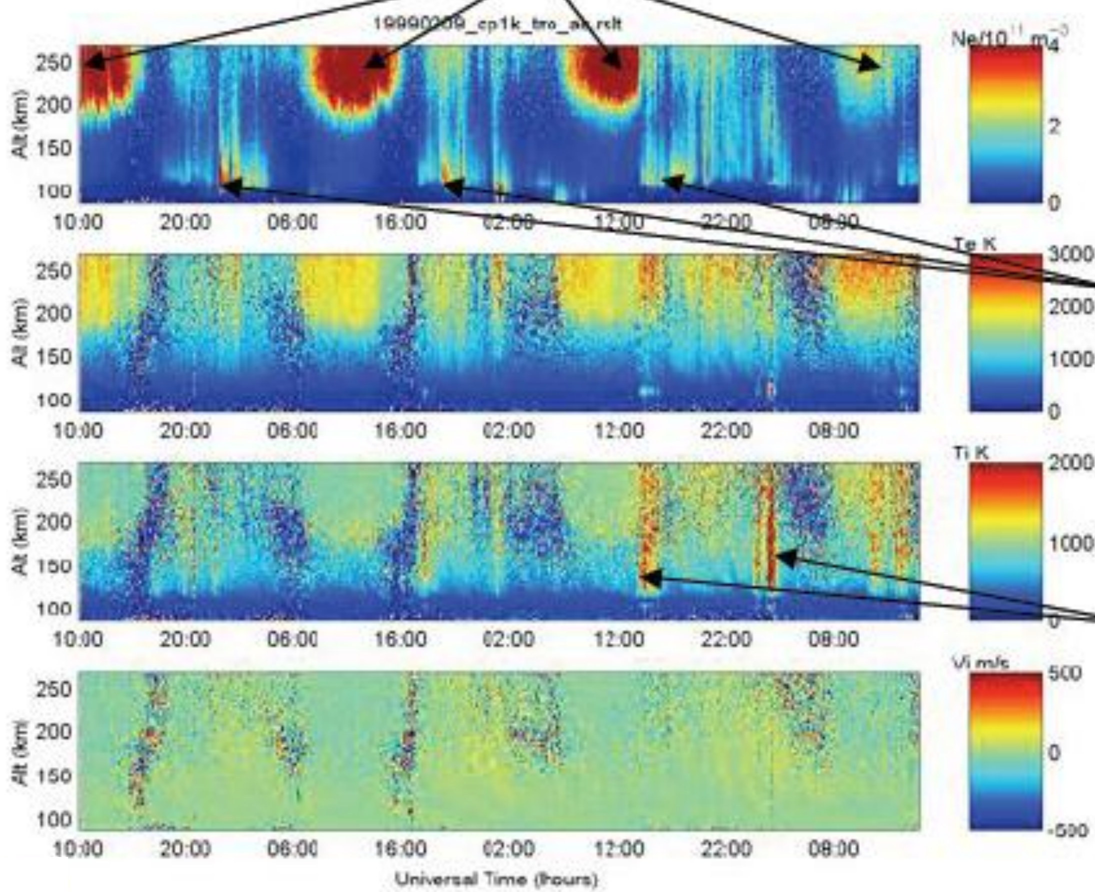


CP1 – Field-aligned

(a winter run lasting 3 days)

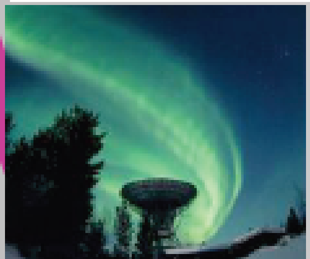
Dayside maxima in N_e (and T_e)

Note day-to-day variability in N_e

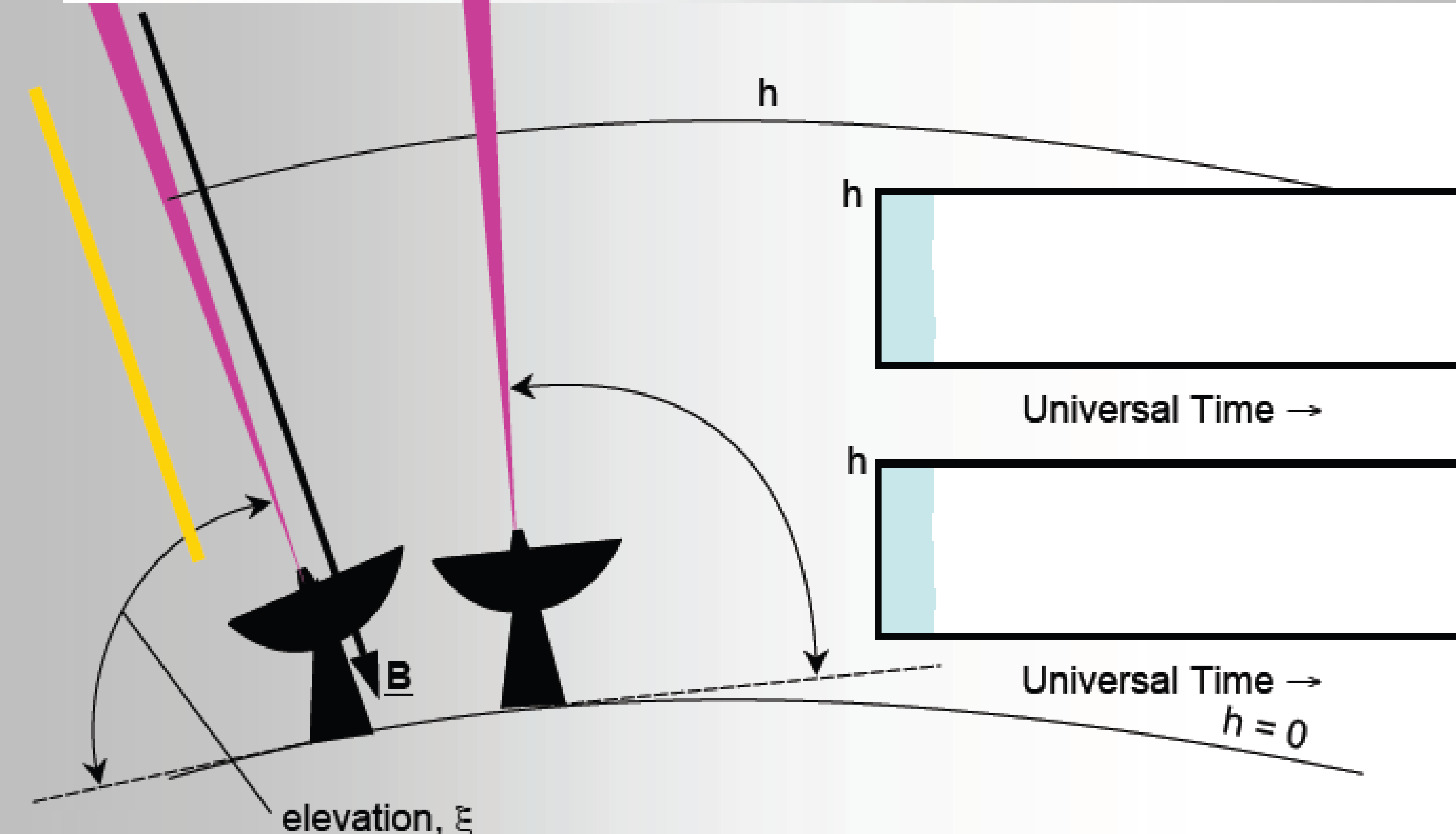


Precipitation effects

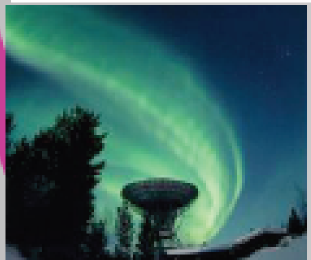
Ion heating events (Note T_i is almost independent of h at h > 130 km in events

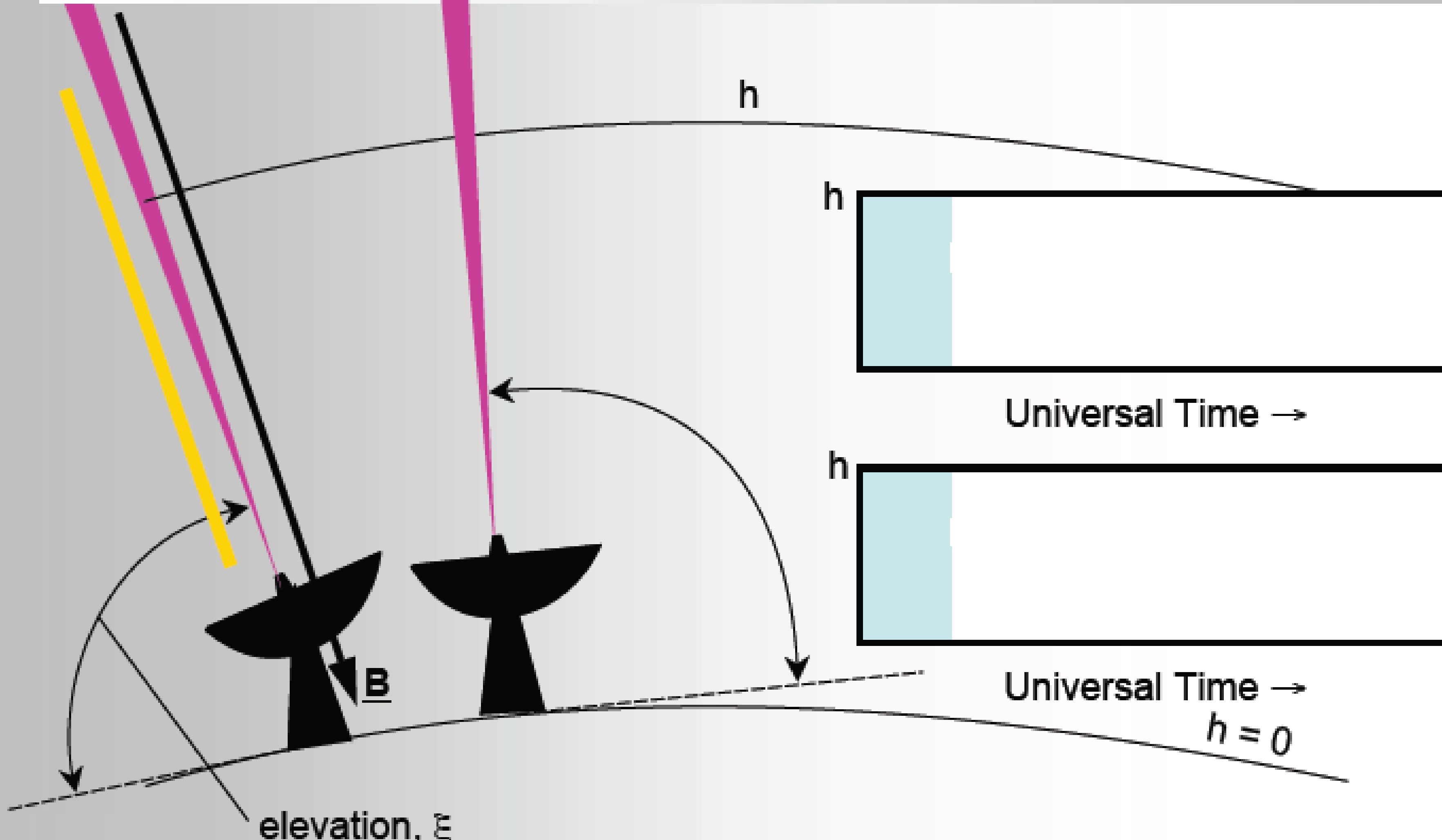


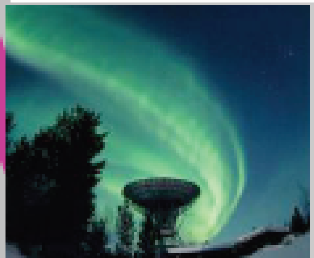
Arcs, field-aligned and vertical beams



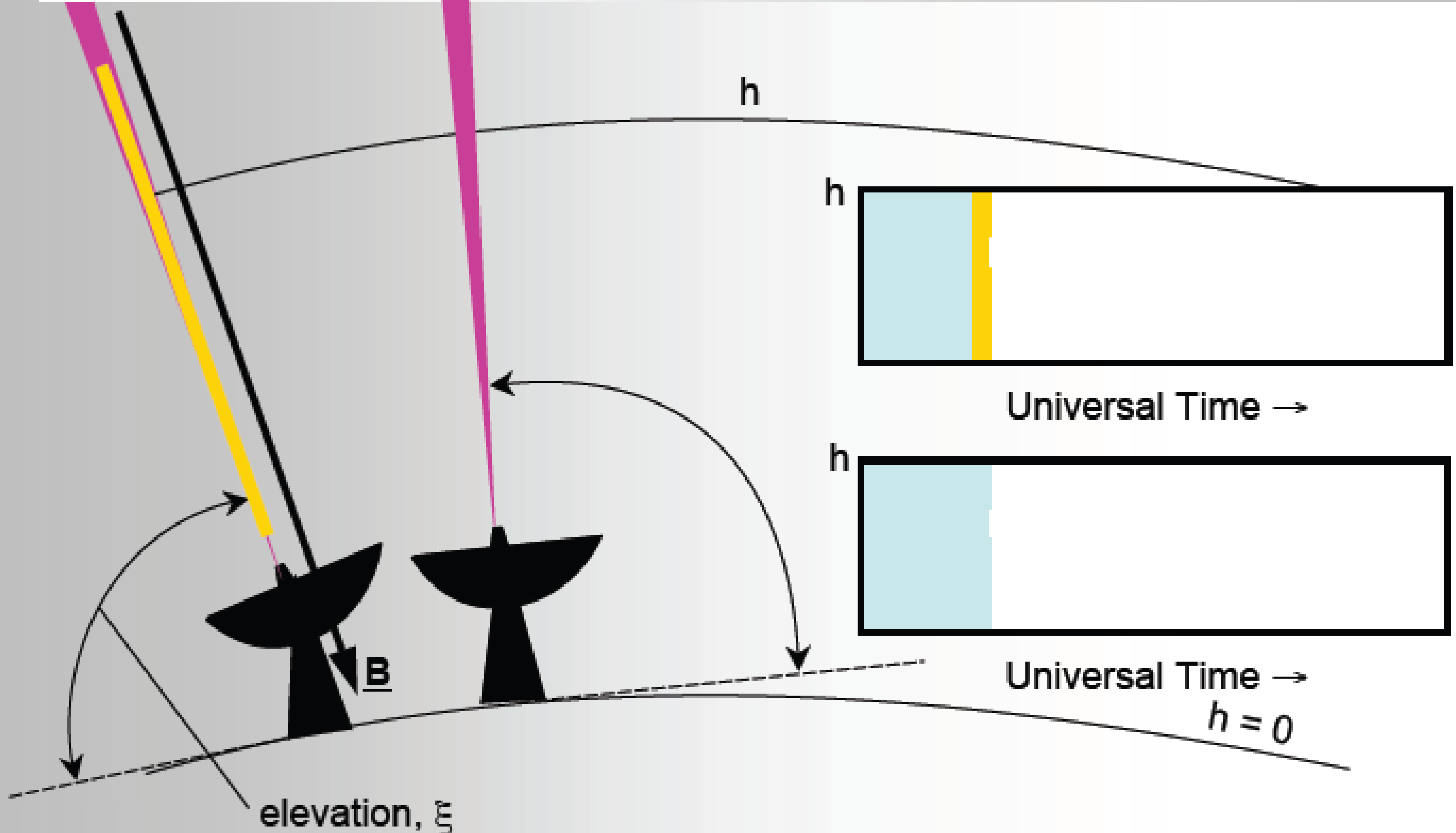
Arcs, field-aligned and vertical beams



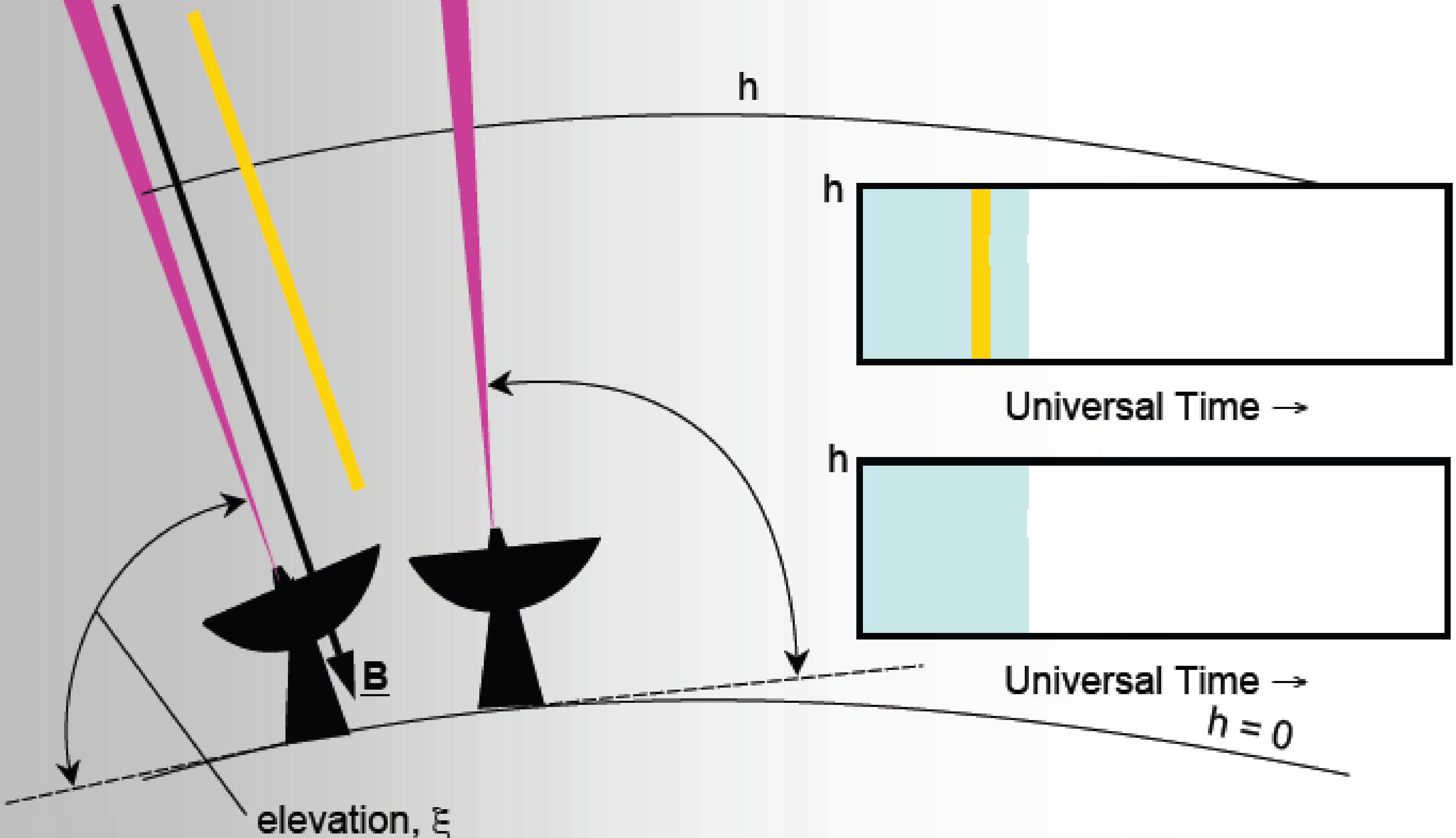




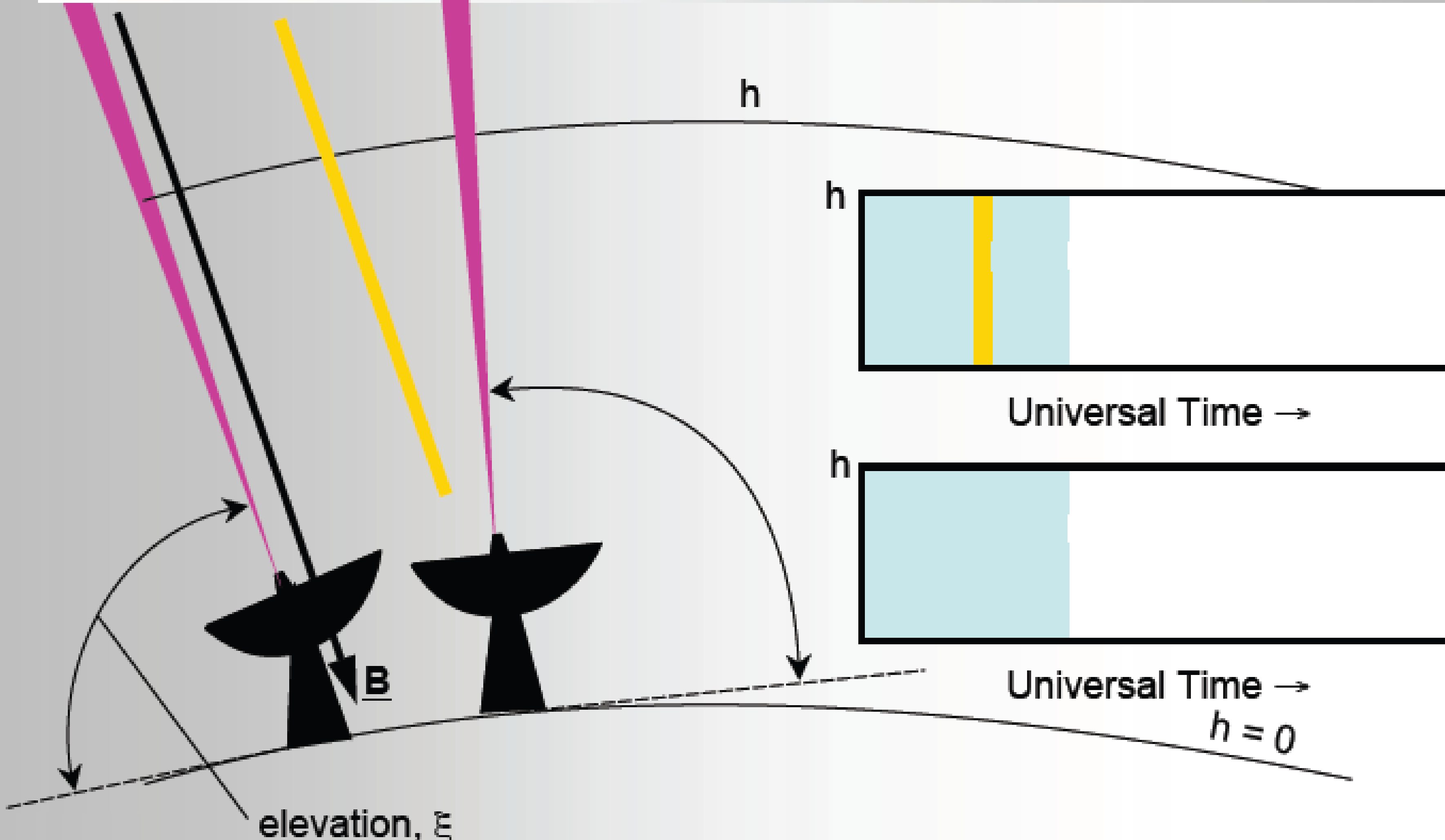
Arcs, field-aligned and vertical beams



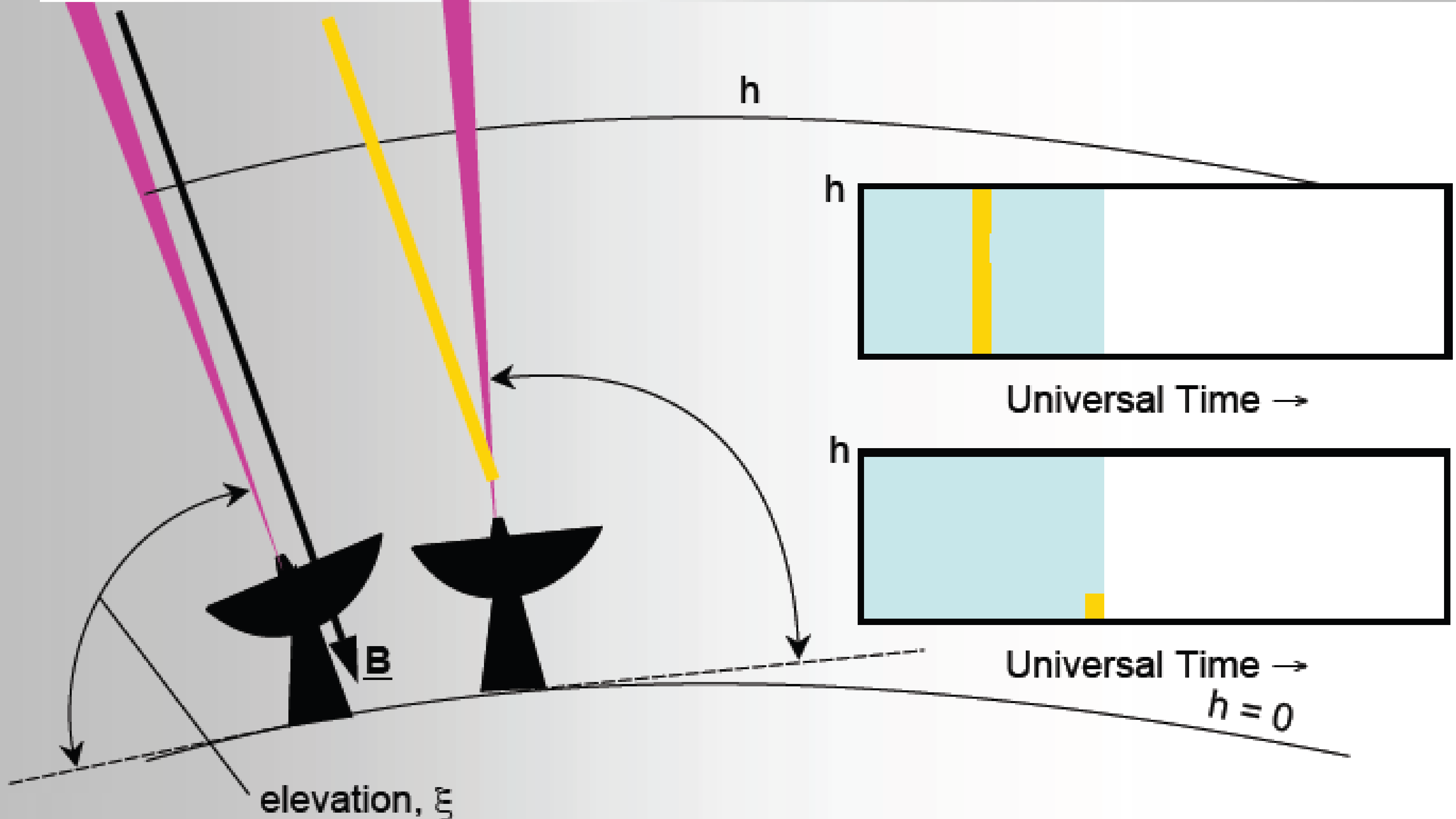
Arcs, field-aligned and vertical beams



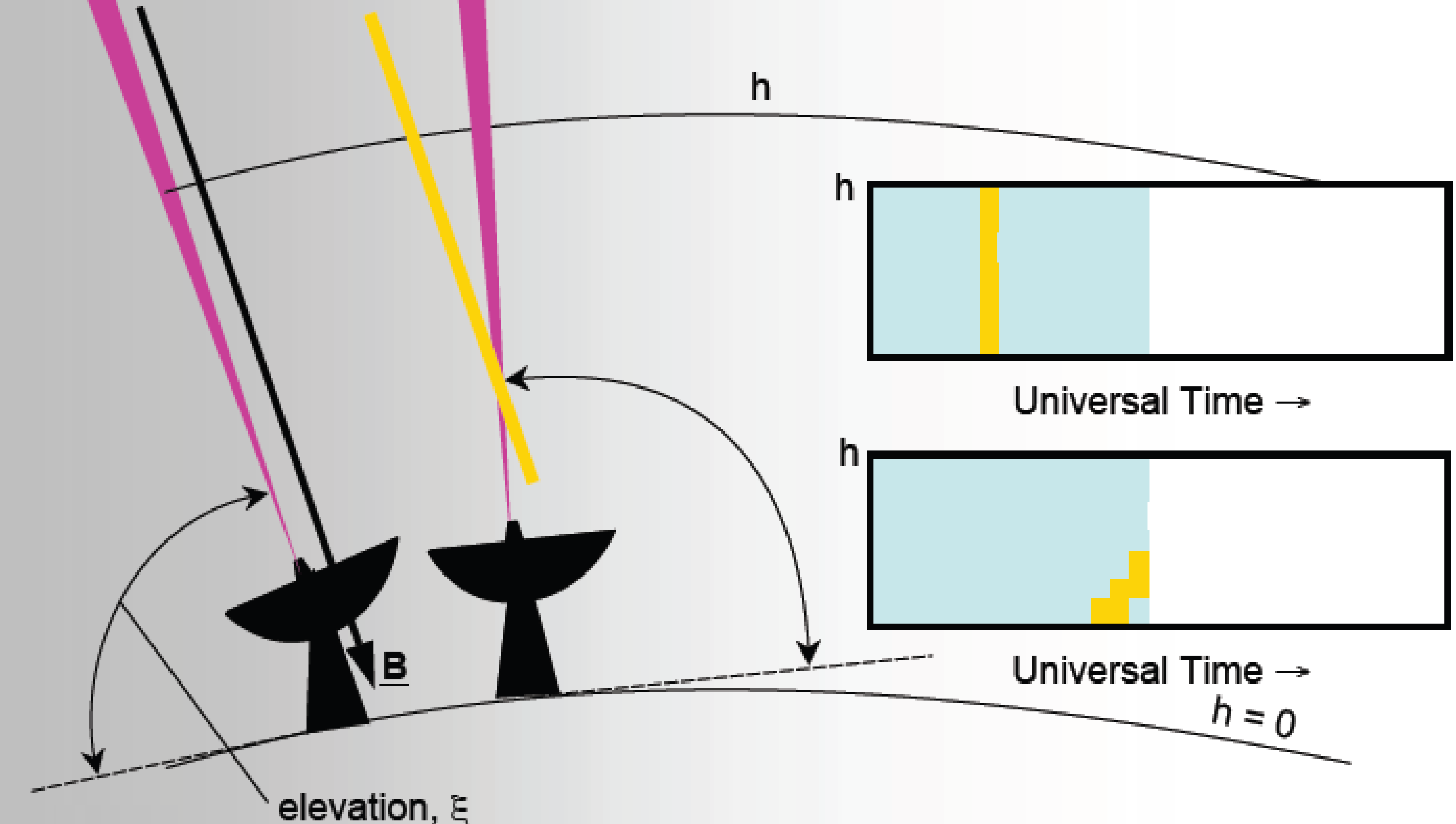
Arcs, field-aligned and vertical beams

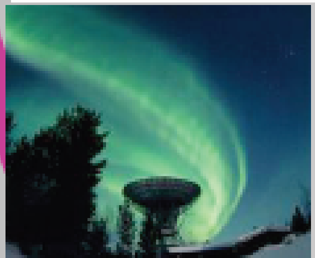


Arcs, field-aligned and vertical beams

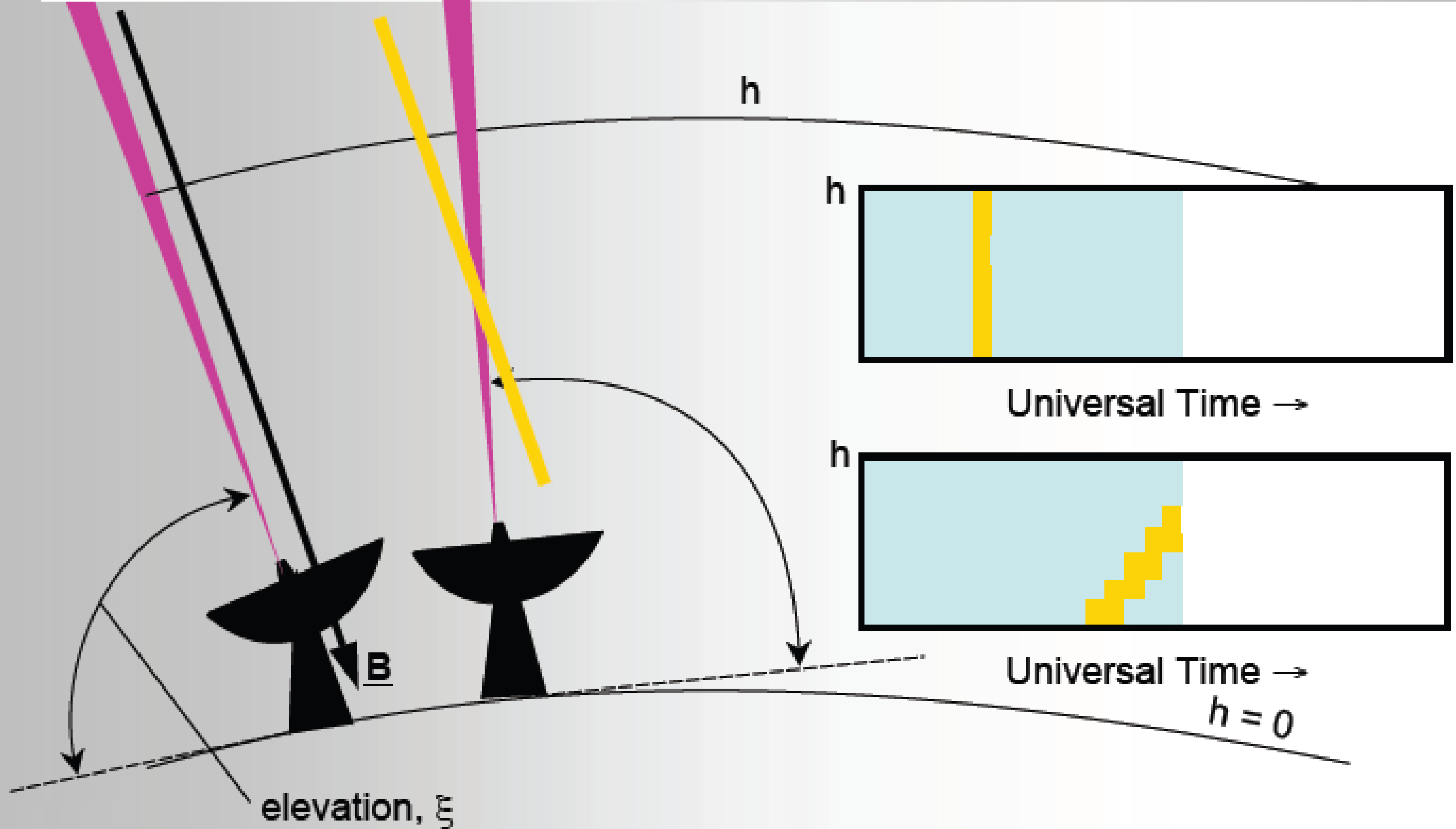


Arcs, field-aligned and vertical beams

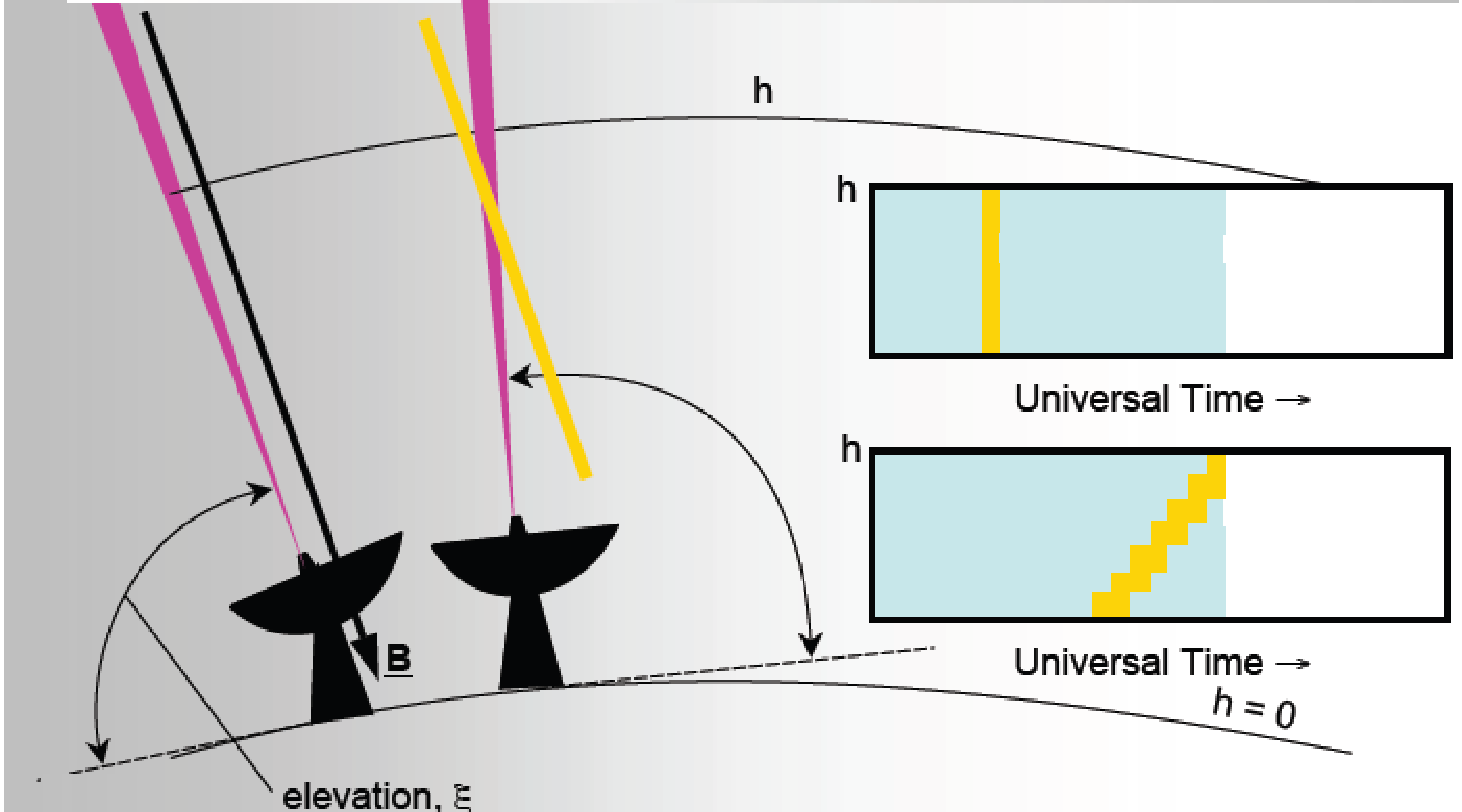




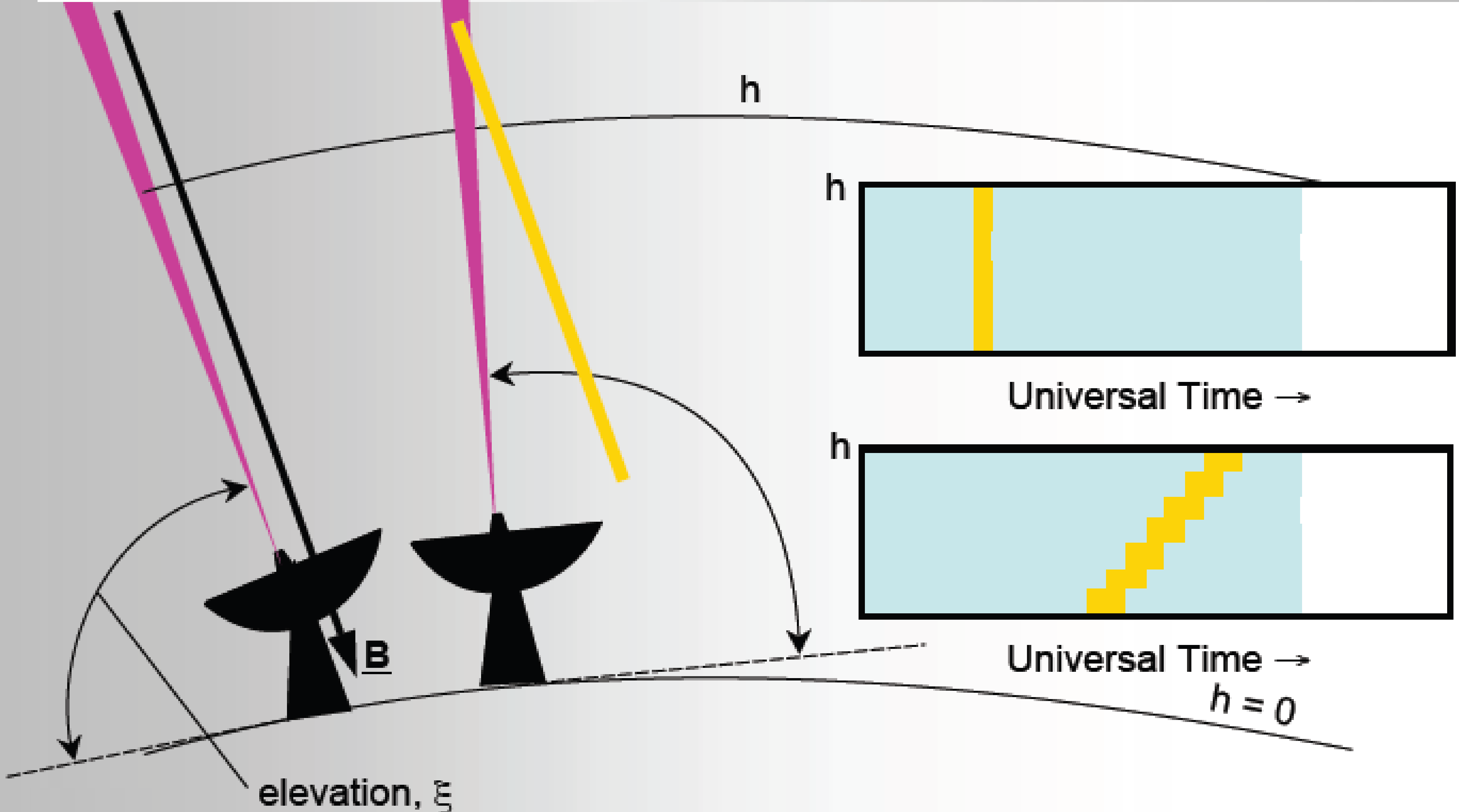
Arcs, field-aligned and vertical beams



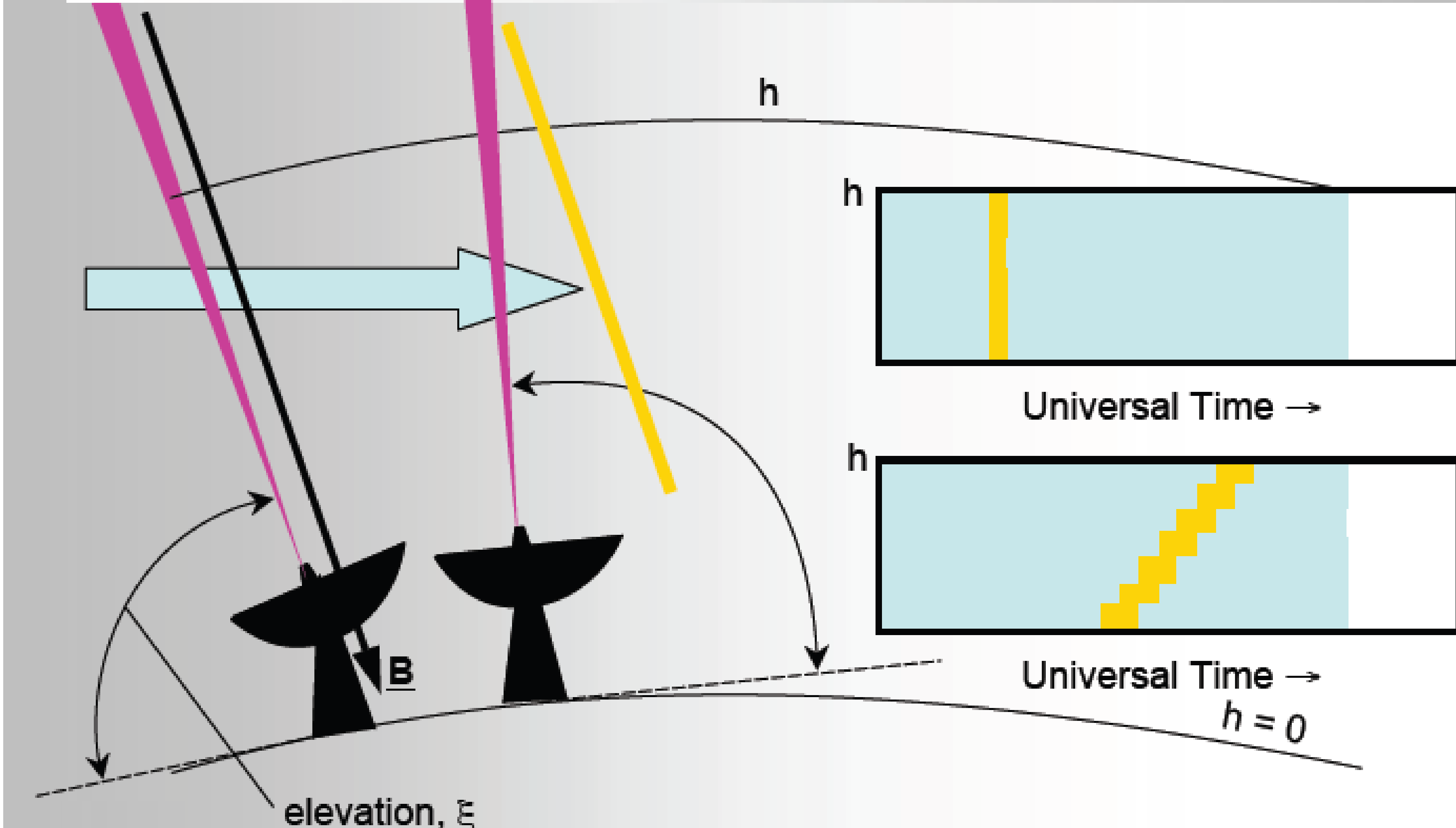
Arcs, field-aligned and vertical beams



Arcs, field-aligned and vertical beams



Arcs, field-aligned and vertical beams



A precipitation event

(the passage of an auroral arc)

The bottom of arcs are near h = 110 km.

For field-aligned beam r ≈ 120 km

EISCAT beamwidth ≈ 0.5° (FWHM), $d\theta = 0.5\pi/180$ rads

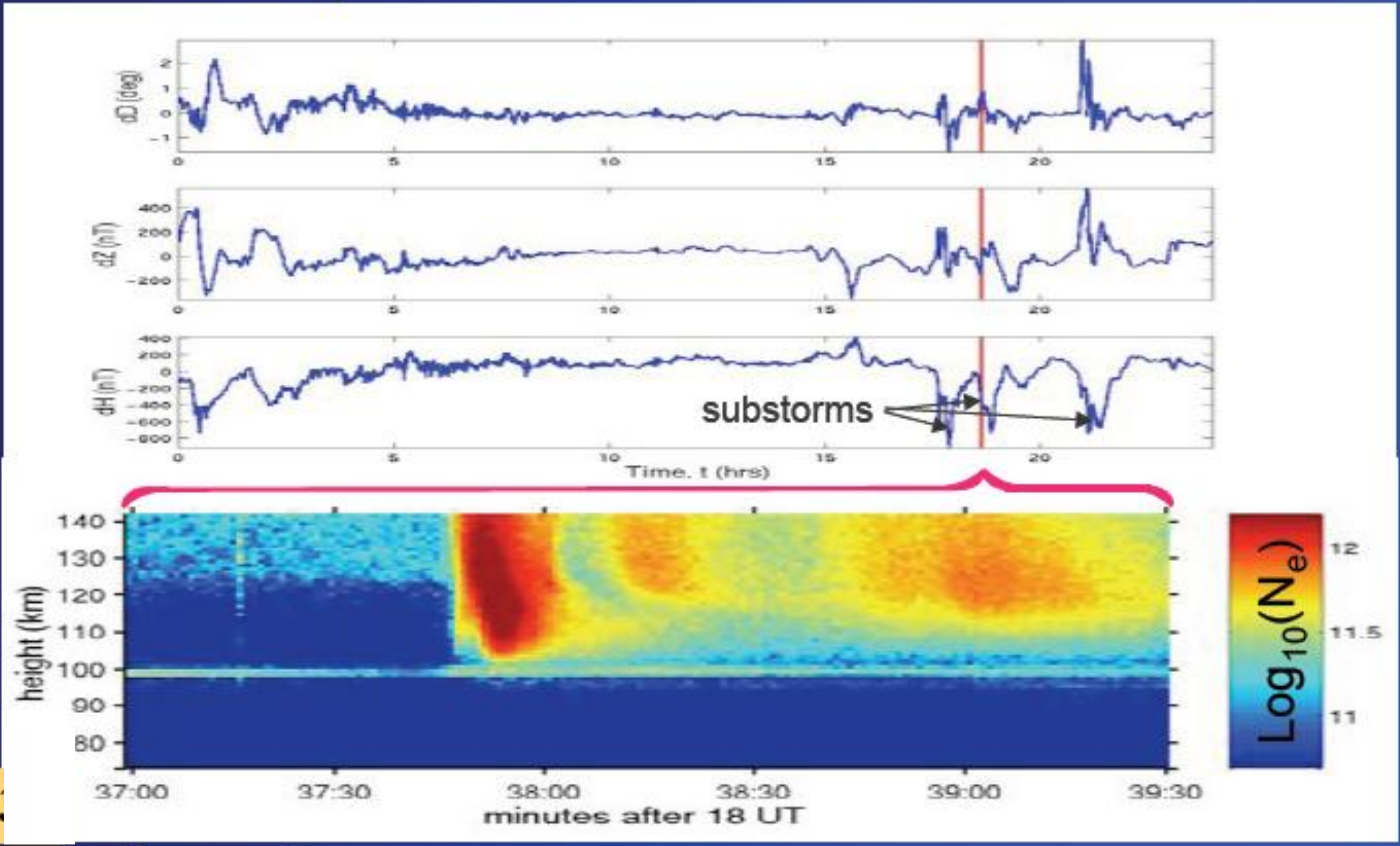
Beam diameter = $r\,d\theta$ ≈ 1 km

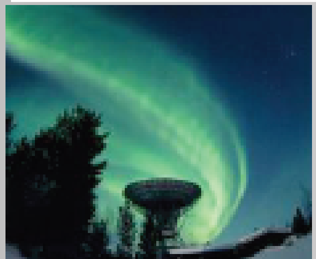
Arcs are sometimes less than 100m

Arcs can move at 5 km s^{-1} – would cross the beam in just 0.2 s

Therefore want high time resolution for arc studies

Tromsø, 30 January 1995



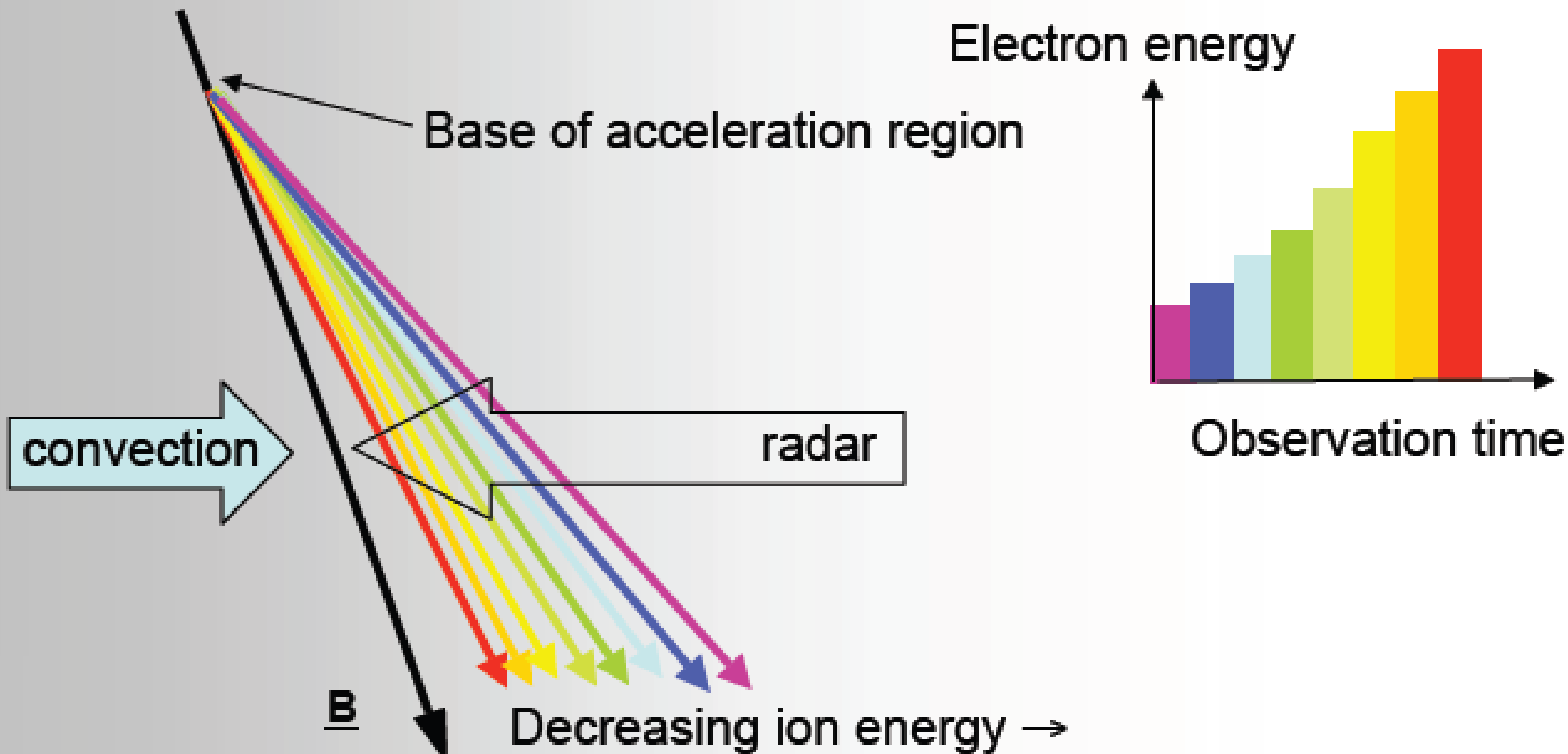


A precipitation event

(dispersion structure)

In the rest frame of the arc

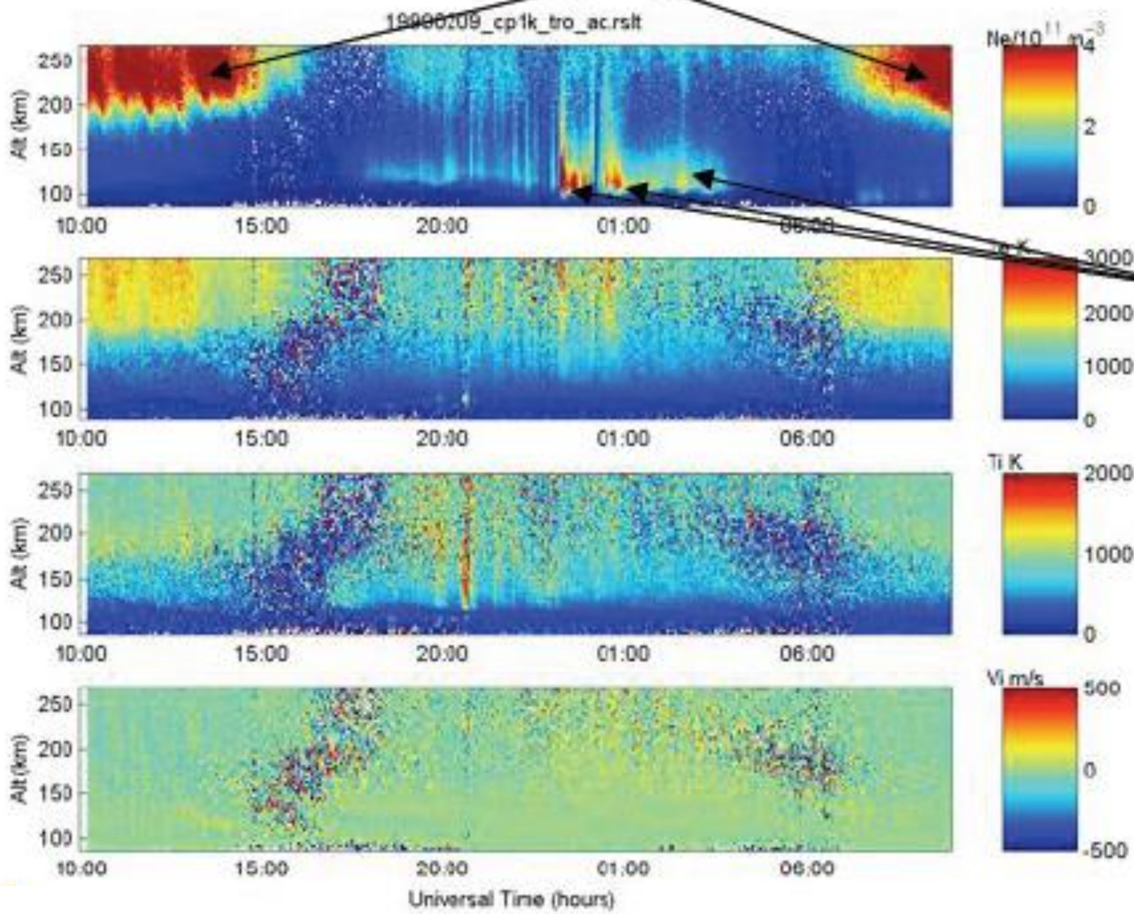
(in the radar rest frame, the arc moves over radar in same direction as convection, but is moving more slowly then convection)



CP1 – Field-aligned

(a typical winter day)

Dayside maxima in N_e (and T_e)

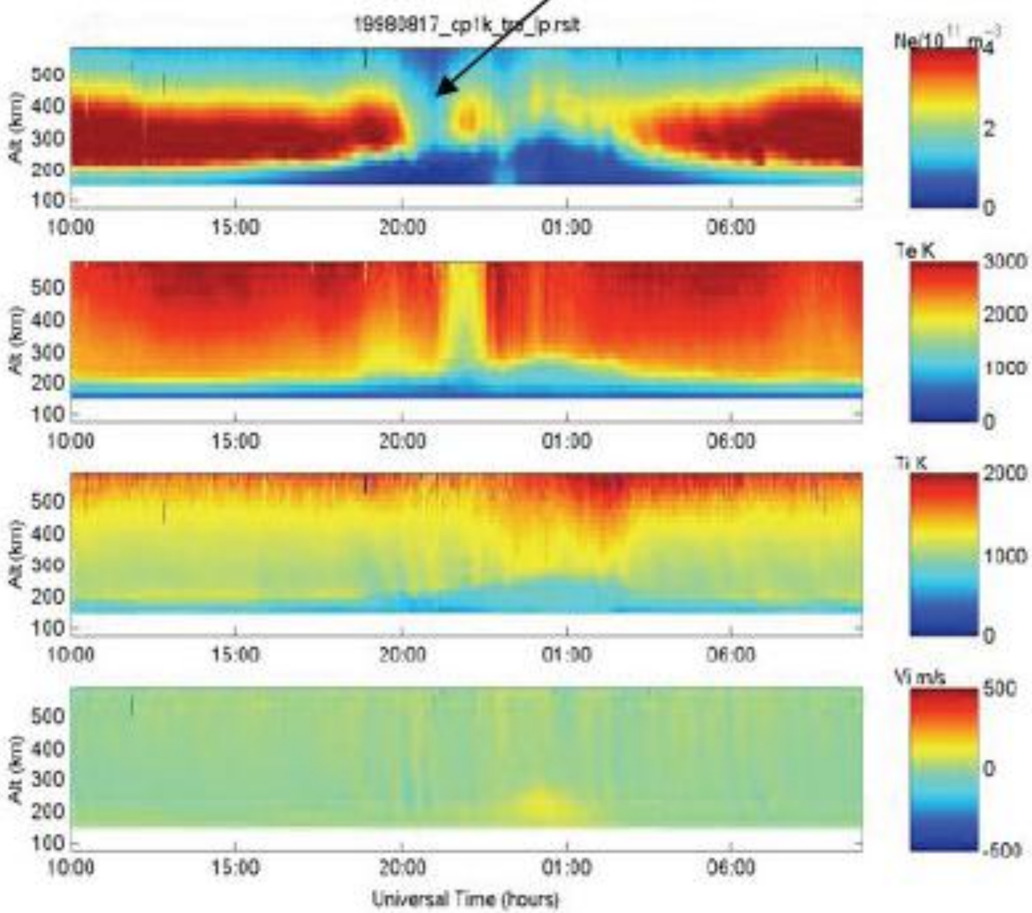


Precipitation effects

CP1 – Field-aligned

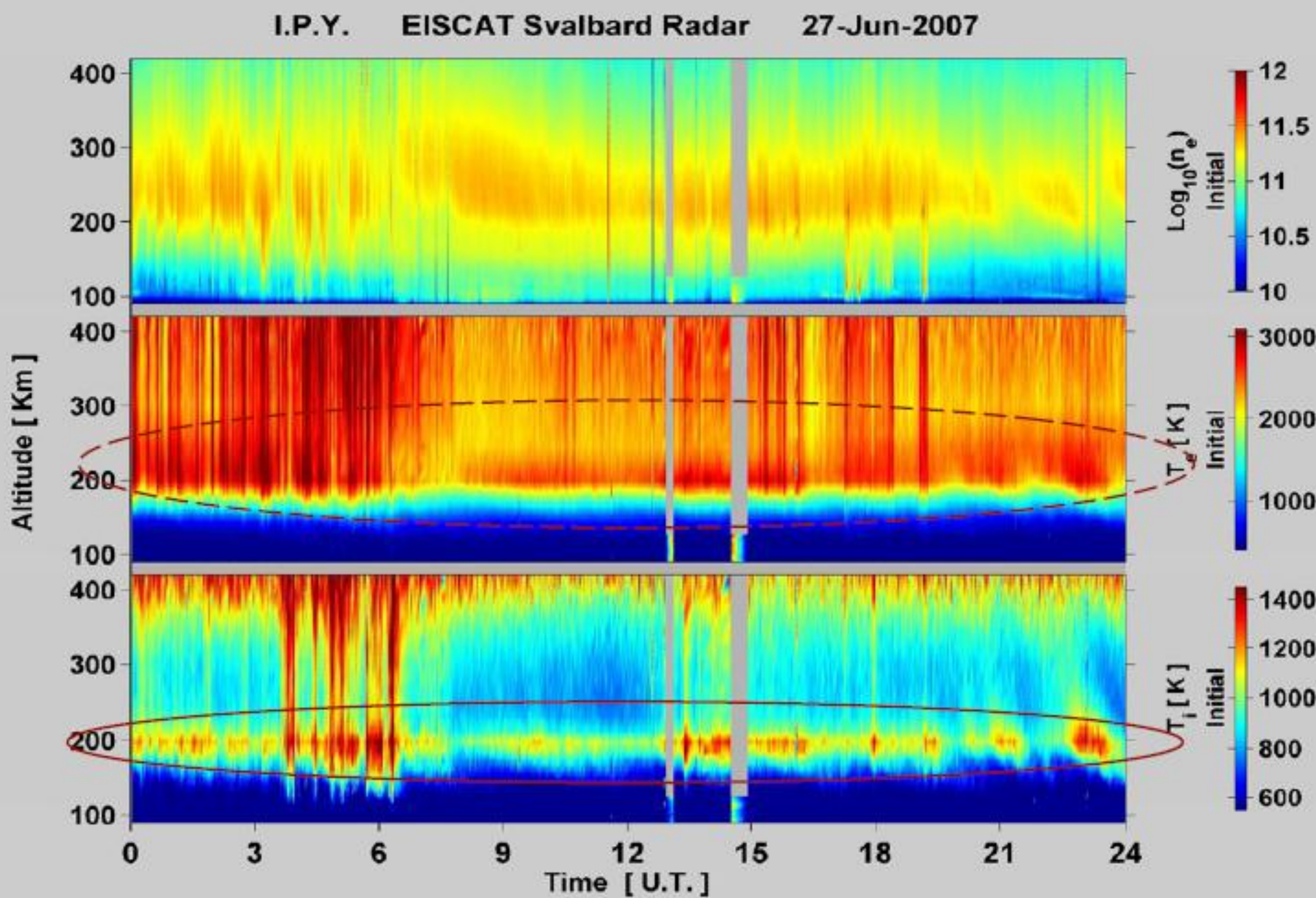
(a typical summer day)

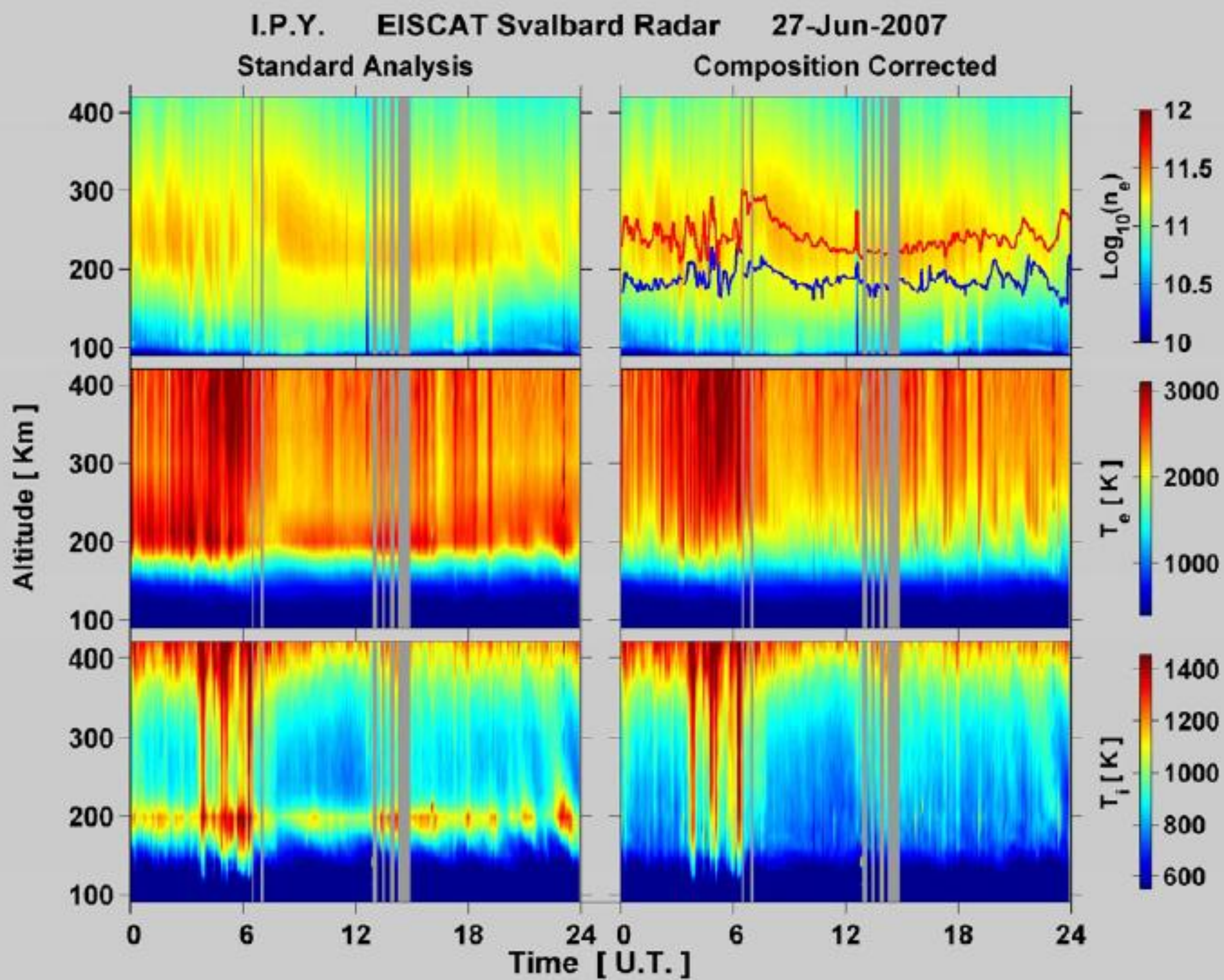
Nightside minima in N_e (and T_e)



Note T_e and, by electron ion conduction T_i are also much greater than in winter case

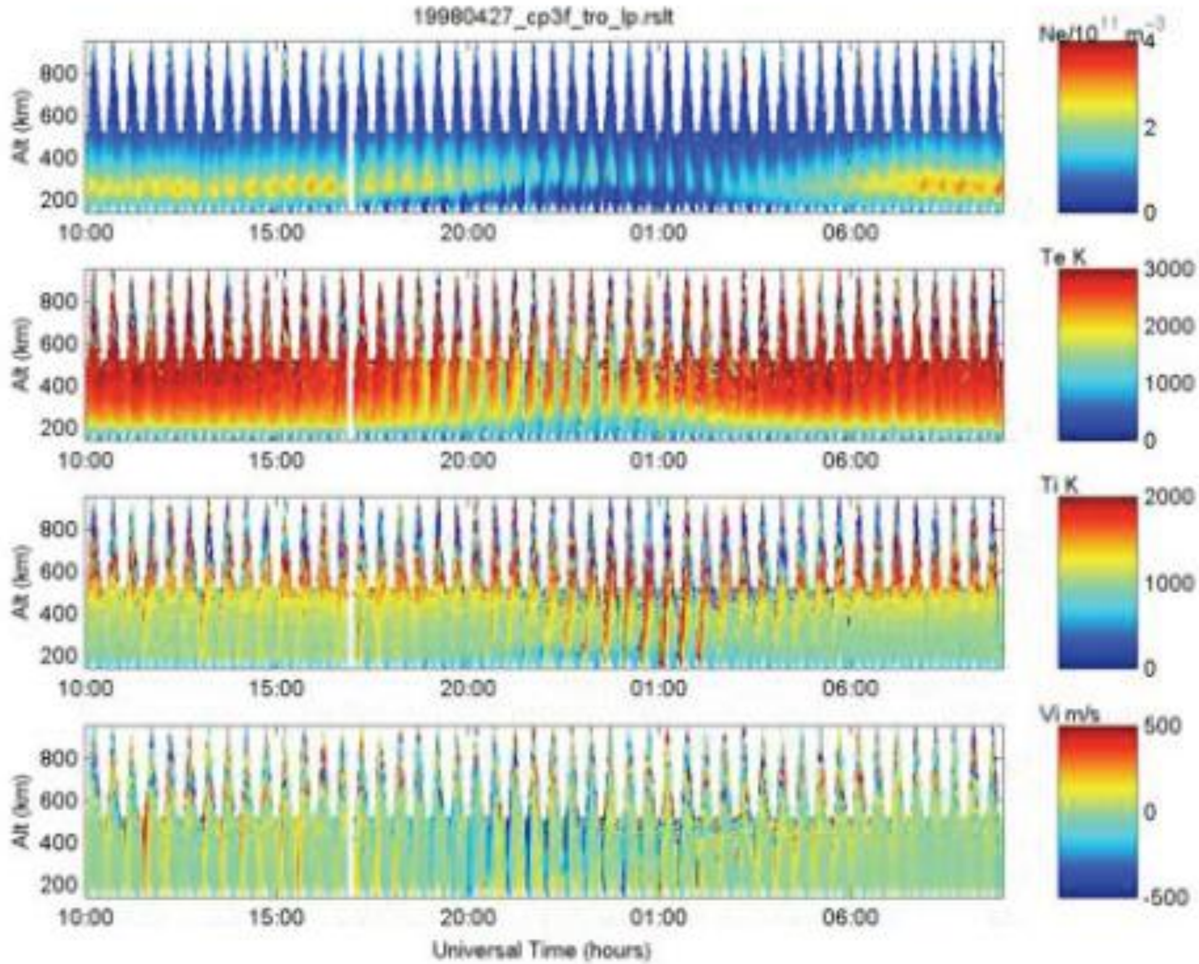
Problem of Ion Composition




I.P.Y. EISCAT Svalbard Radar 27-Jun-2007
Standard Analysis
Composition Corrected
Altitude [Km]
Time [U.T.]
Log10(ne)
Te [K]
Ti [K]
100
200
300
400
0
6
12
18
24
10
10.5
11
11.5
12
1000
2000
3000
600
800
1000
1200
1400

Large Scans (e.g. CP3)

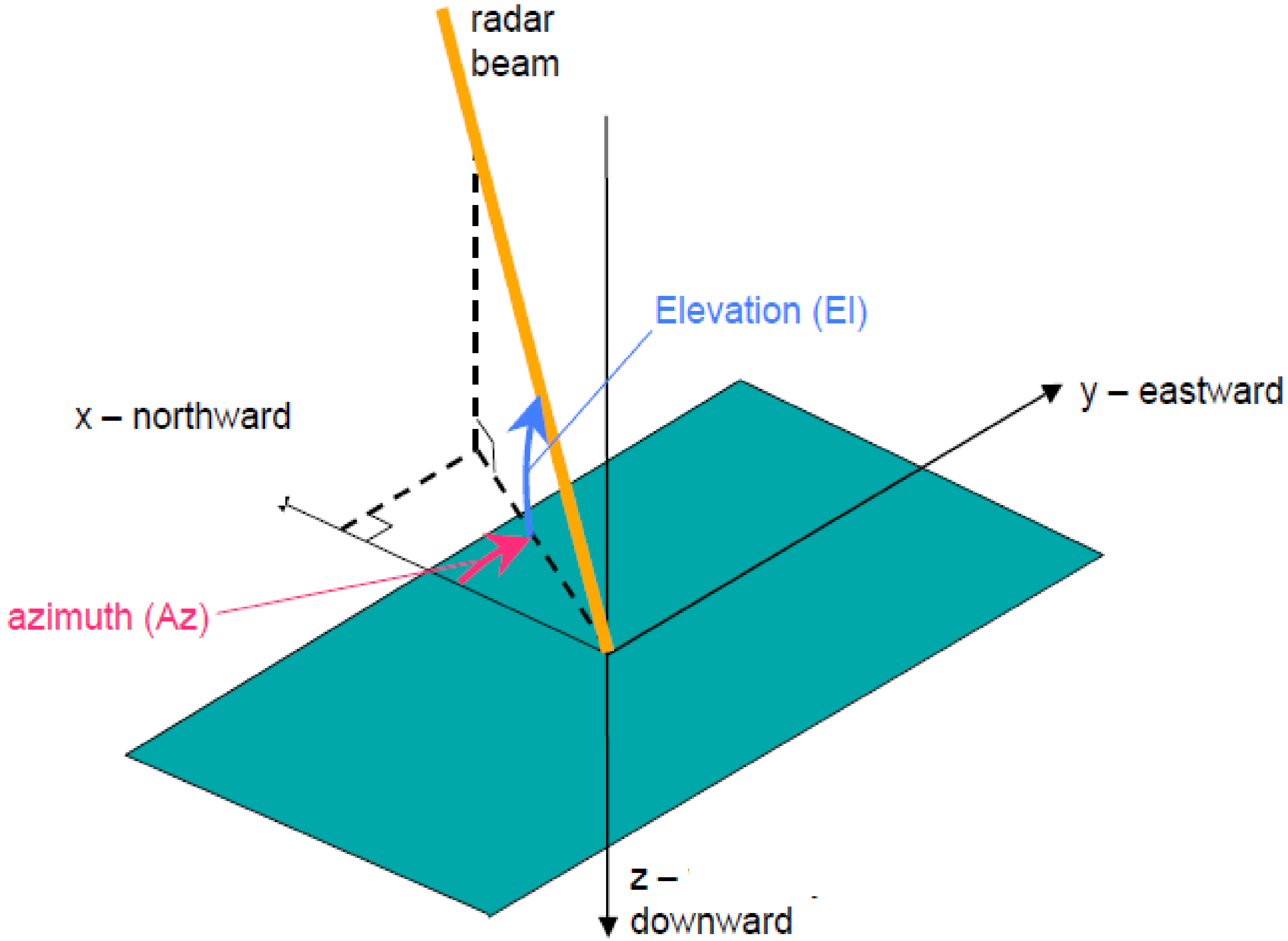
(summary plot dominated by the beam scan pattern)

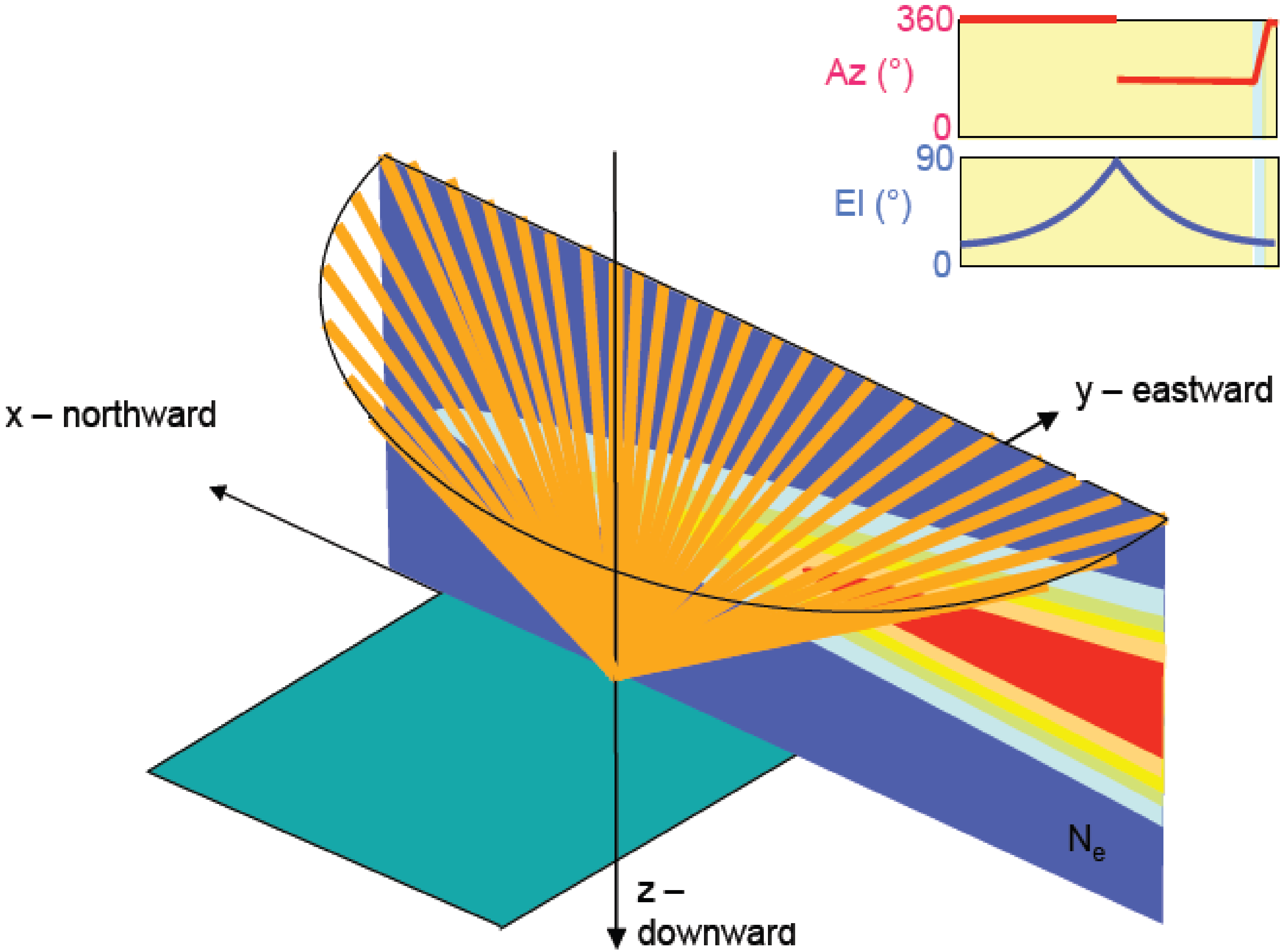


Summary plot hard to interpret because of scan pattern.

But can make out basic N_e and T_e variation as seen for CP1

Stripes with scan period (30 min) reveal latitudinal structure

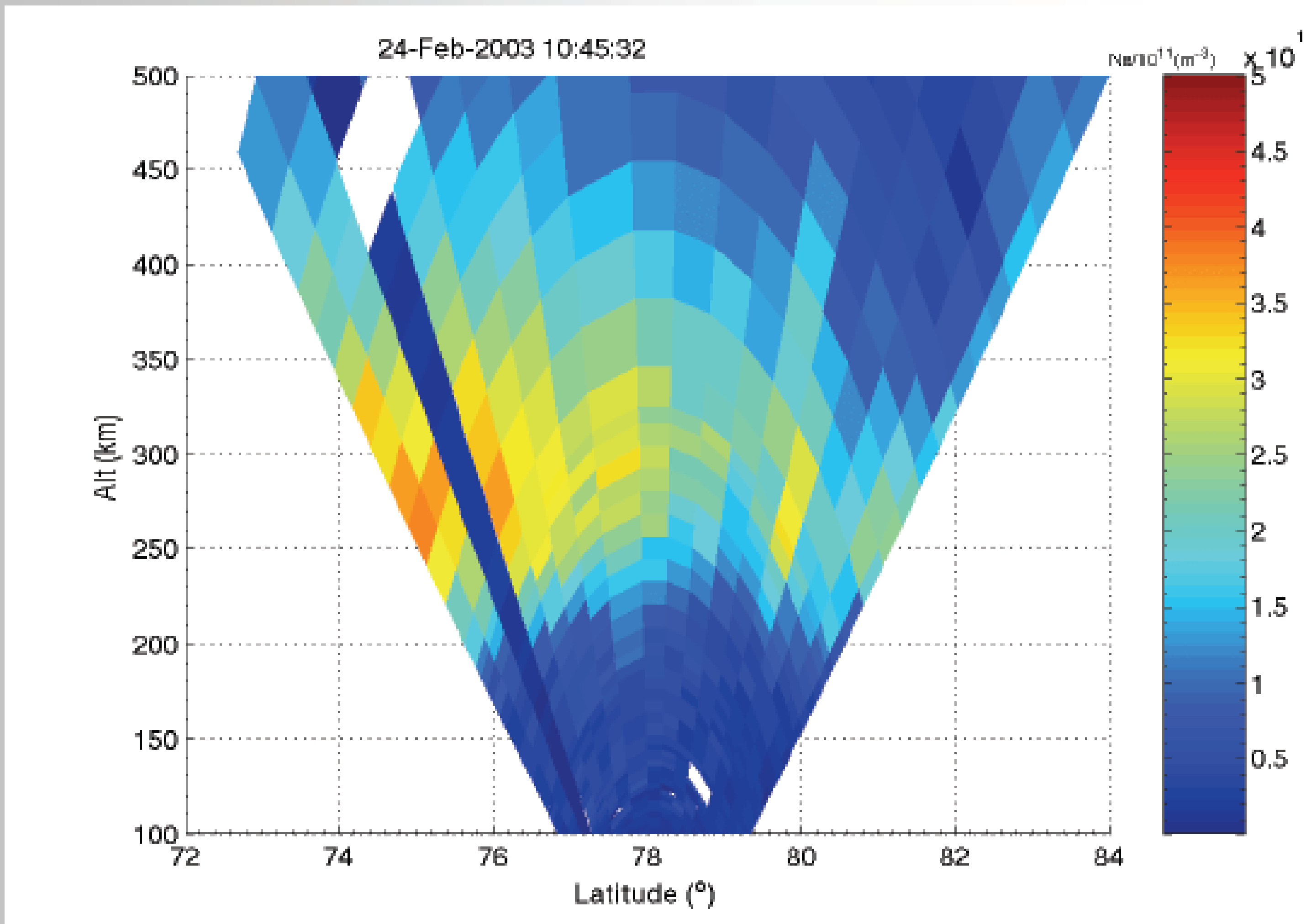

radar
beam
Elevation (El)
y – eastward
x – northward
azimuth (Az)
z –
downward



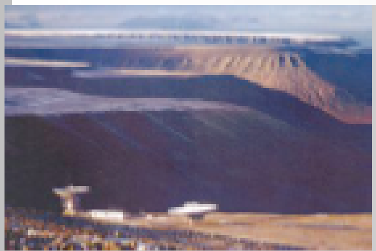
The scan can often be limited by the properties of the radar!
Scan up – spin – and scan down

Large Scans (e.g. CP3)

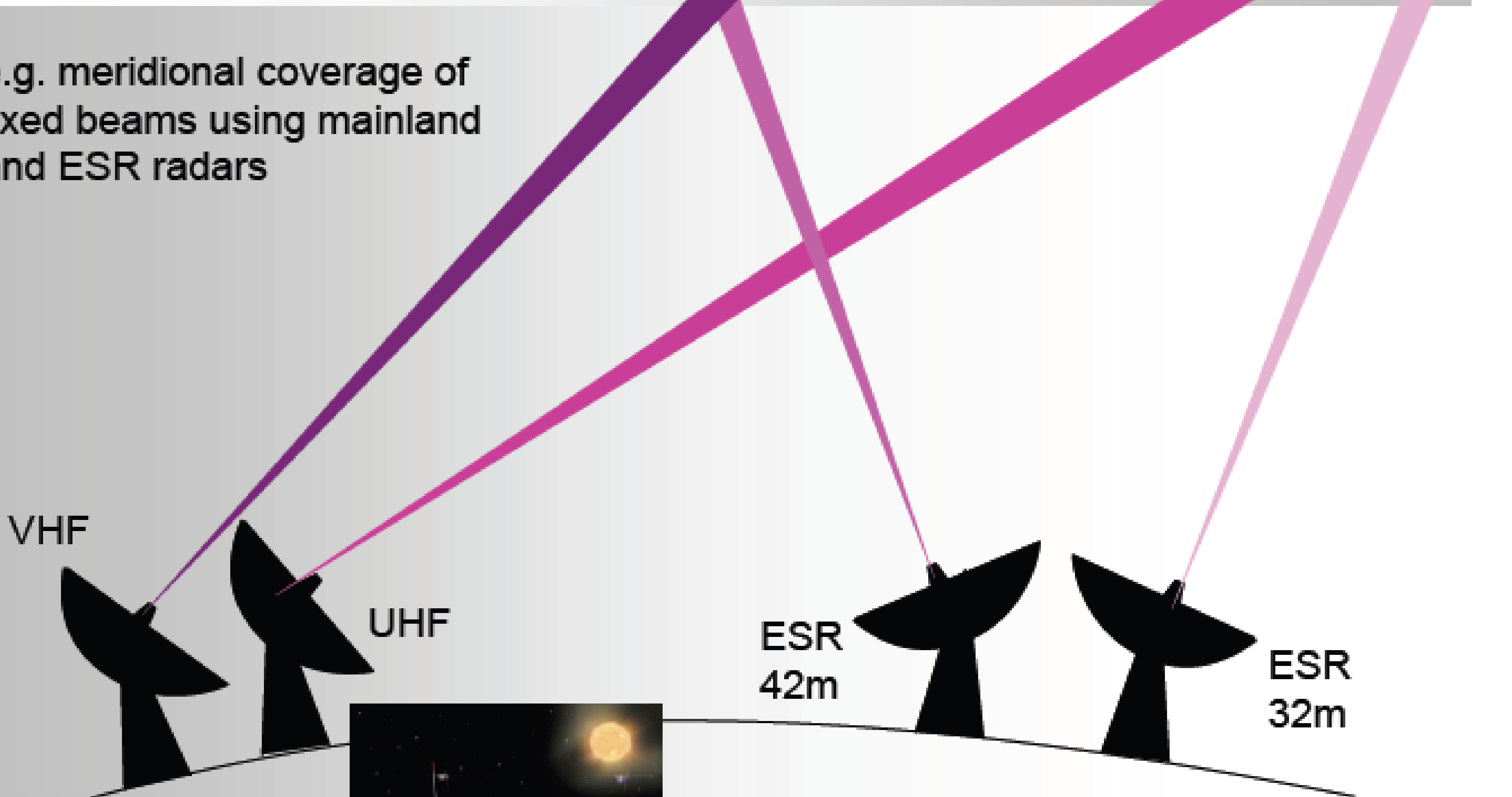
(summary plot dominated by the beam scan pattern)

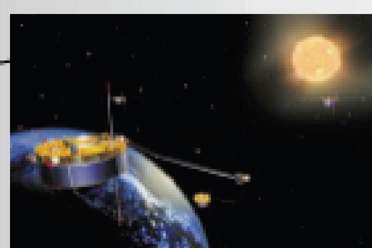


Multiple Radar use



e.g. meridional coverage of fixed beams using mainland and ESR radars





Plus you have Cluster & Doublestar, TIMED, DMSP, Fast .....

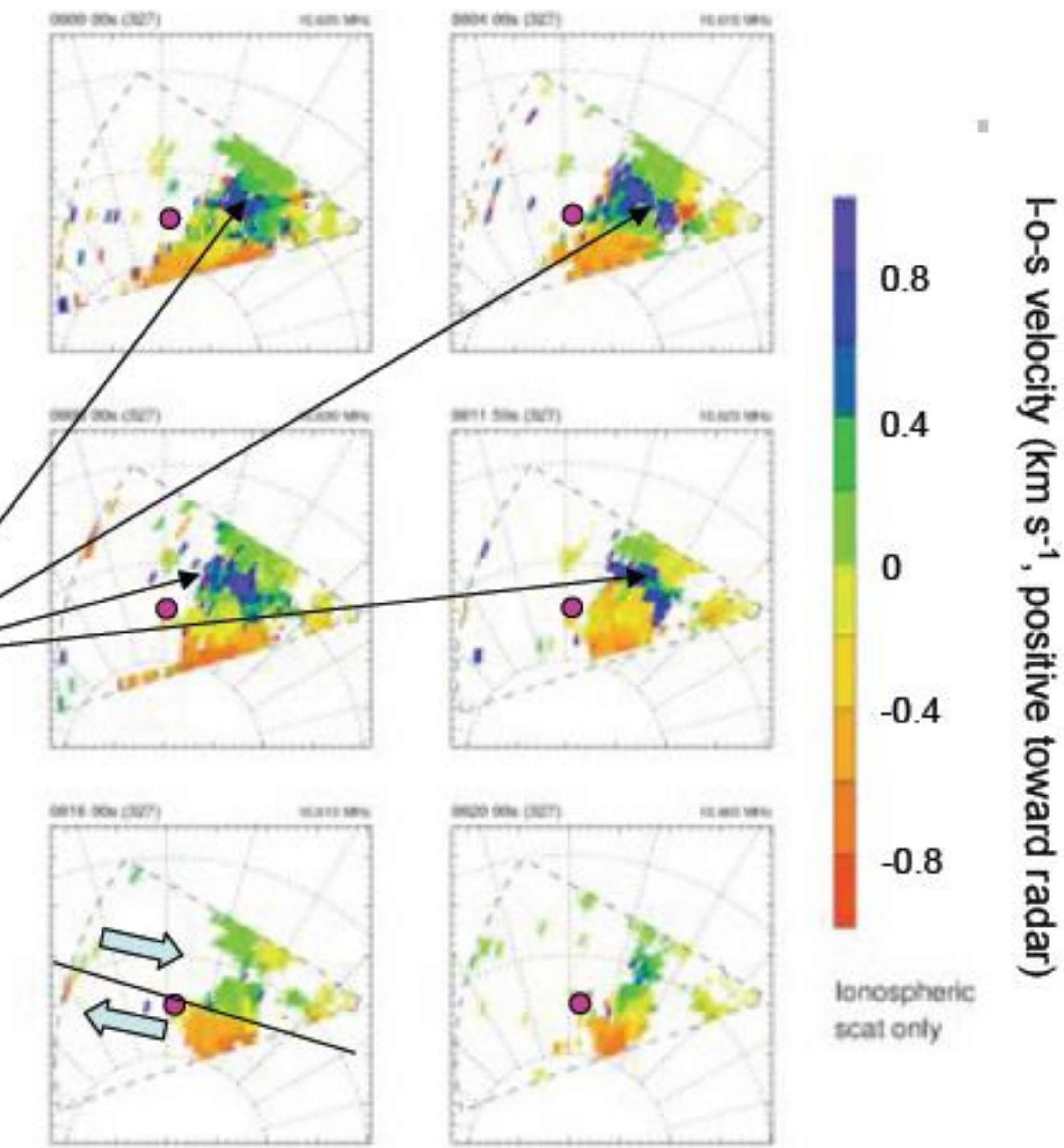
Working out where the radars were

e.g. Using Iceland CUTLASS SuperDARN HF radar

(can use IMAGE magnetometer chain & Imagers also)

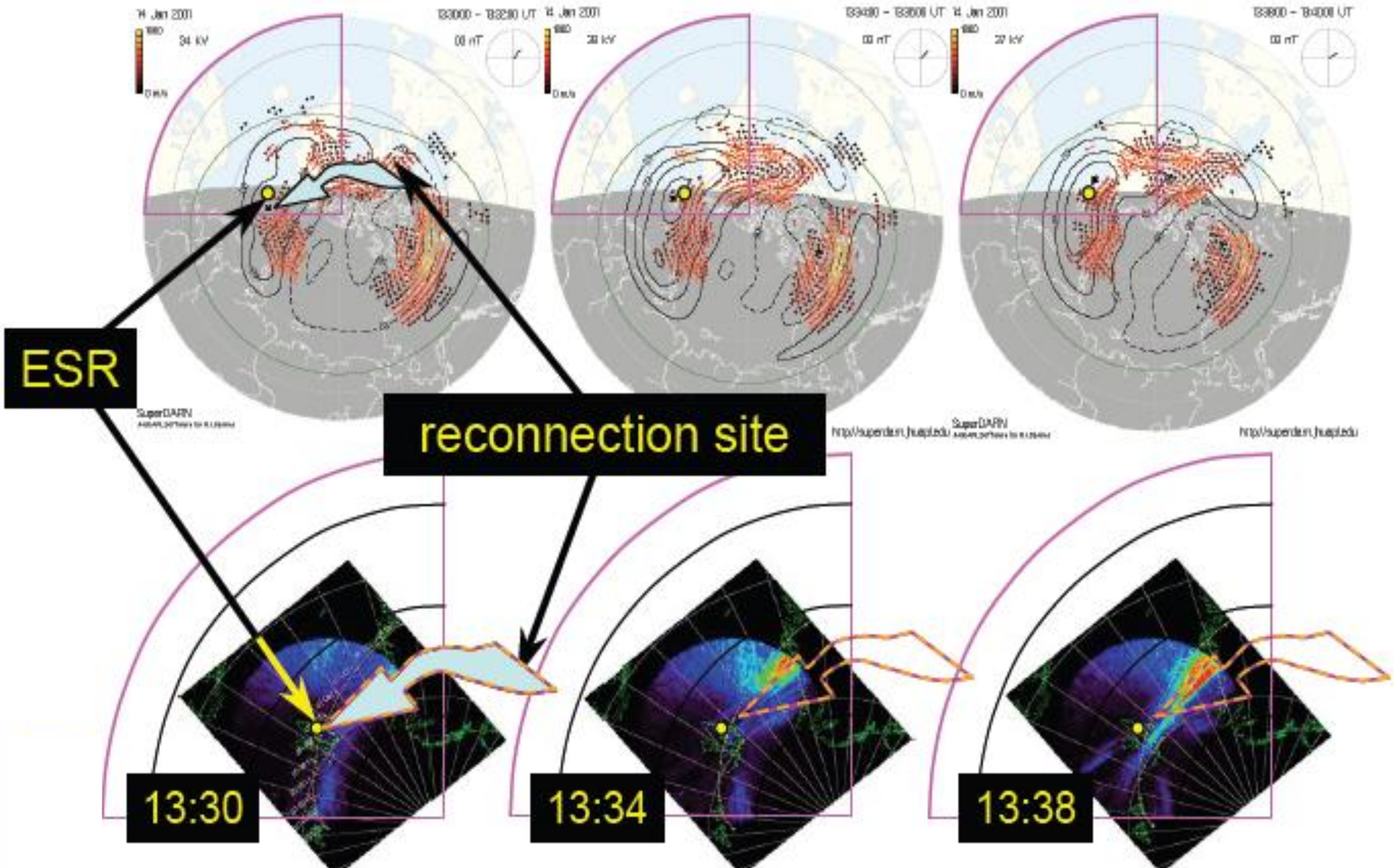
Transient westward flow burst

Here ESR is just poleward of CRB (Convection Reversal Boundary)



Putting ESR and Cluster data into context

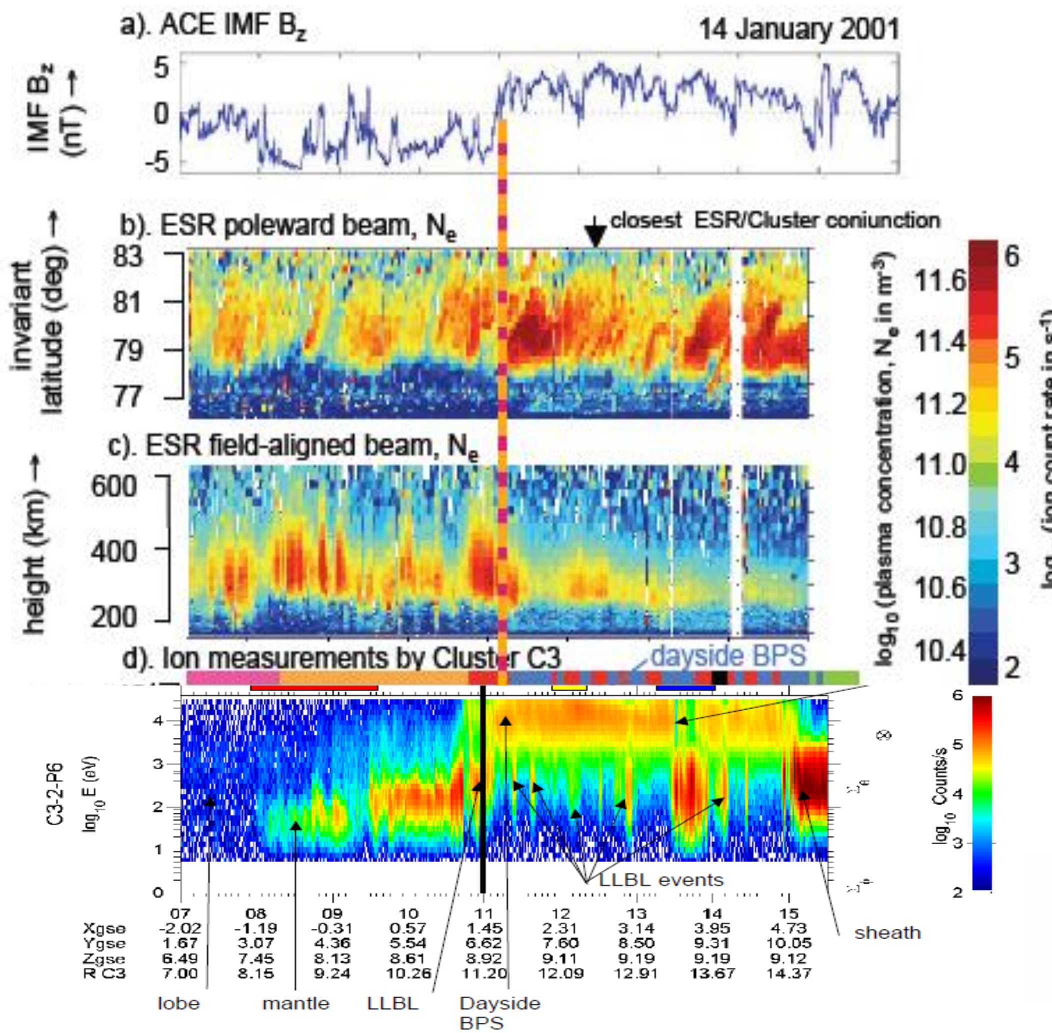
Using SuperDARN radar convection maps and imagers



Putting the field-aligned data in context

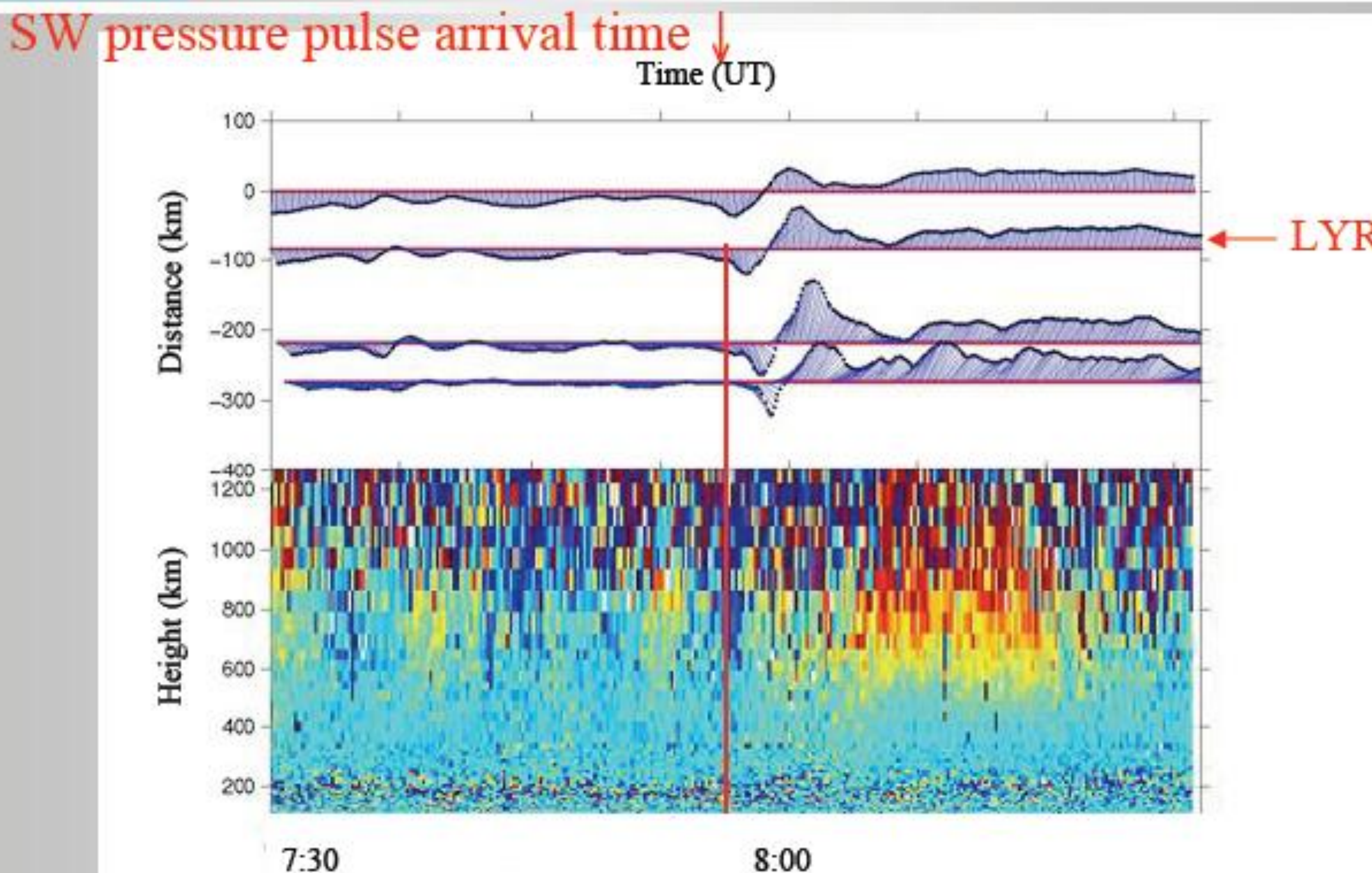
using 2 ESR beams

- effect of northward turning
- motions over radar matched to those over Cluster
- poleward-moving events shown to be caused by low-energy electron flux changes
- transient LLBL and cusp entries shown to be FTEs

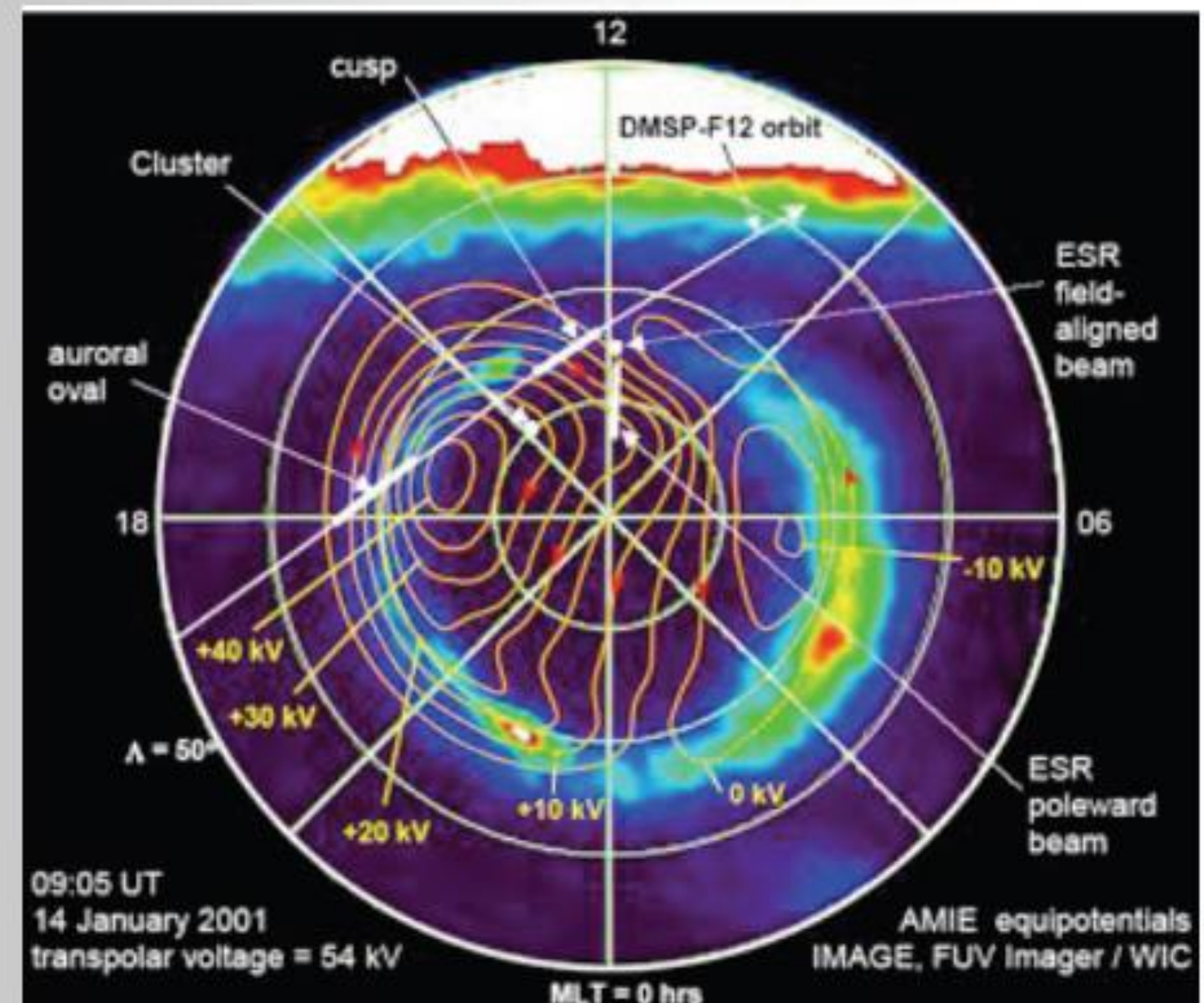


Field-aligned flows

(put into context of a TCV using IMAGE magnetometers)



Identifying the cusp (ESR)



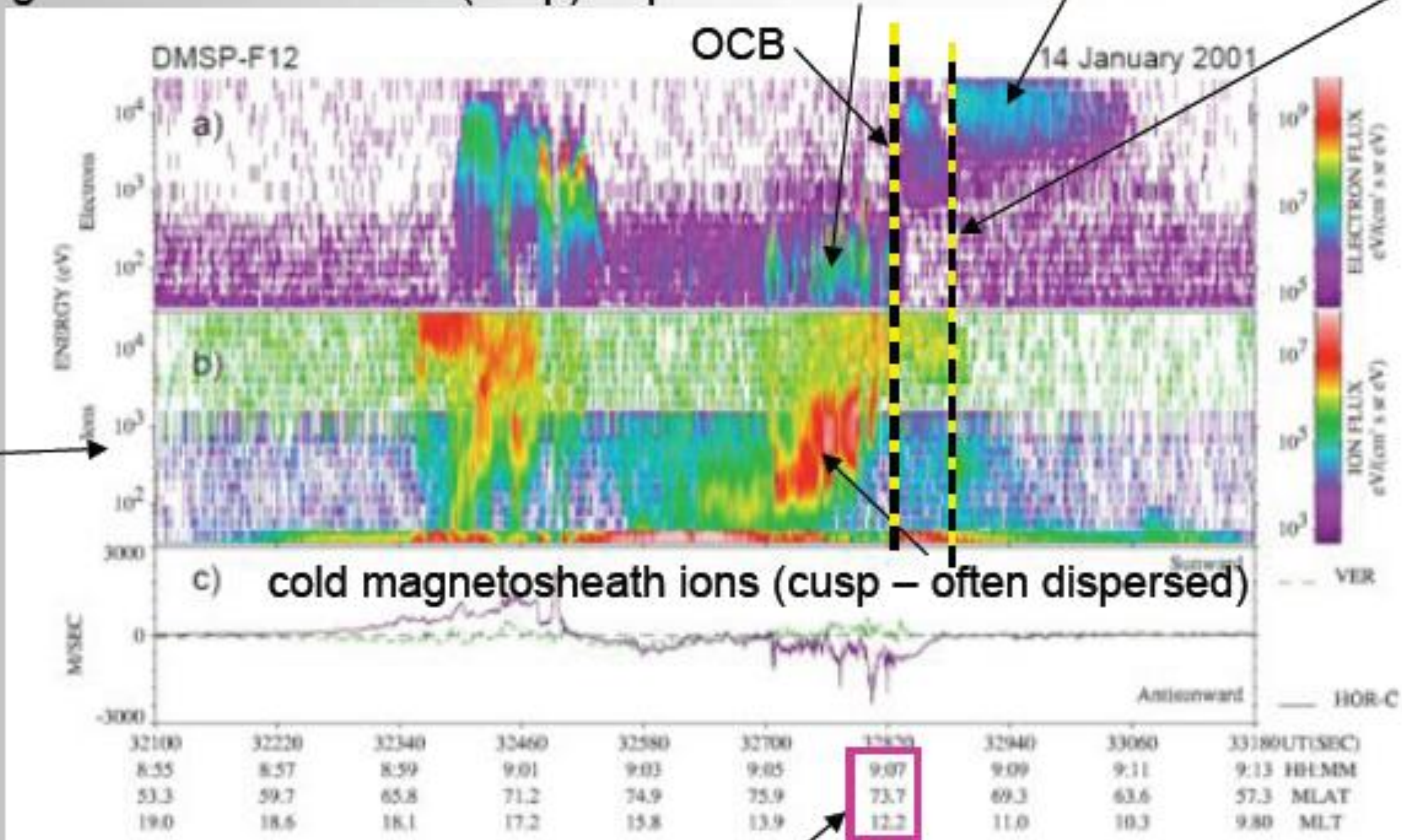
Identifying the cusp (DMSP satellite pass) and the open-closed boundary (OCB)

Hot magnetospheric electrons (not always present) - closed field lines

cold magnetosheath electrons (cusp) - open field lines

OCB

NB Ion energy scale inverted in JHU/APL summary plots

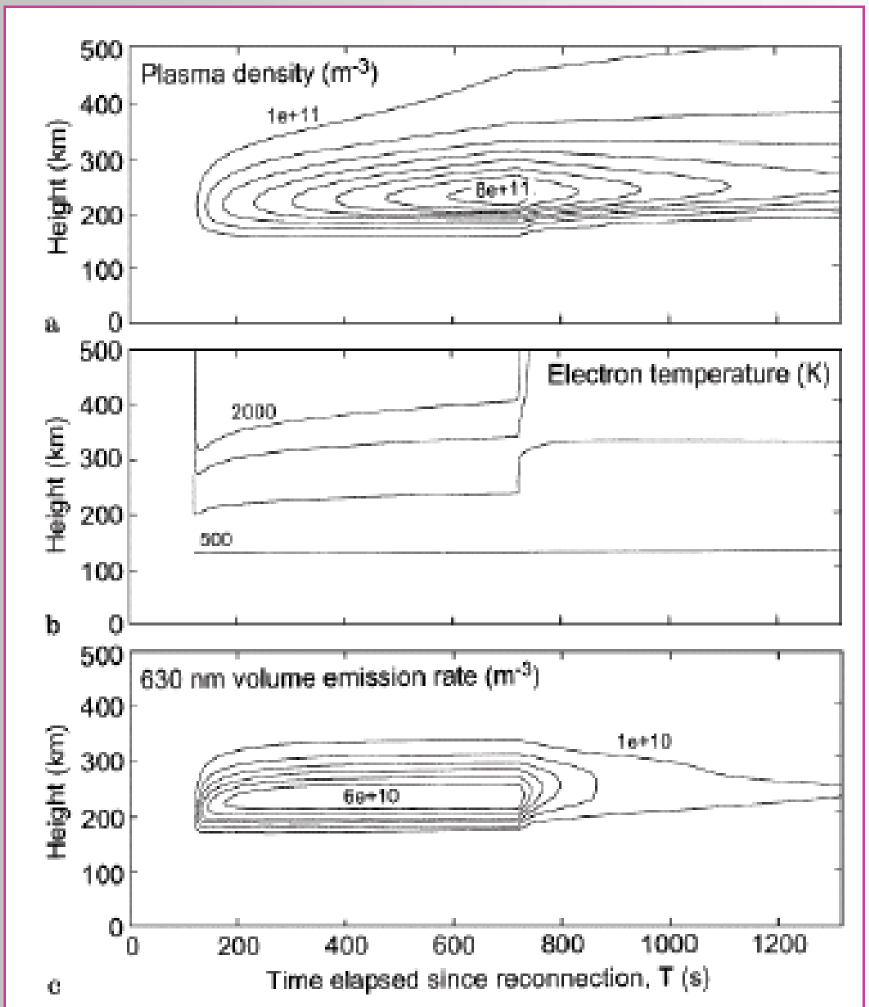


cold magnetosheath ions (cusp – often dispersed)

Electron dropout - brief second OCB intersection because it moved south

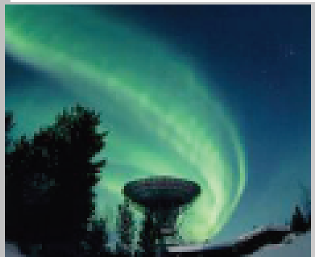
Over Svalbard: MLT-UT ≈ 2.75 hrs; latitude ≈ 75 deg (geographic)

Identifying the cusp (ESR)



Model simulations of cusp electron - precipitation effects on a newly-opened field line convecting through cusp. Precipitation is present for elapsed times since reconnection of about 150-750 s.

Davis and Lockwood, Annales Geophys., 14, 1246-1256, 1996.

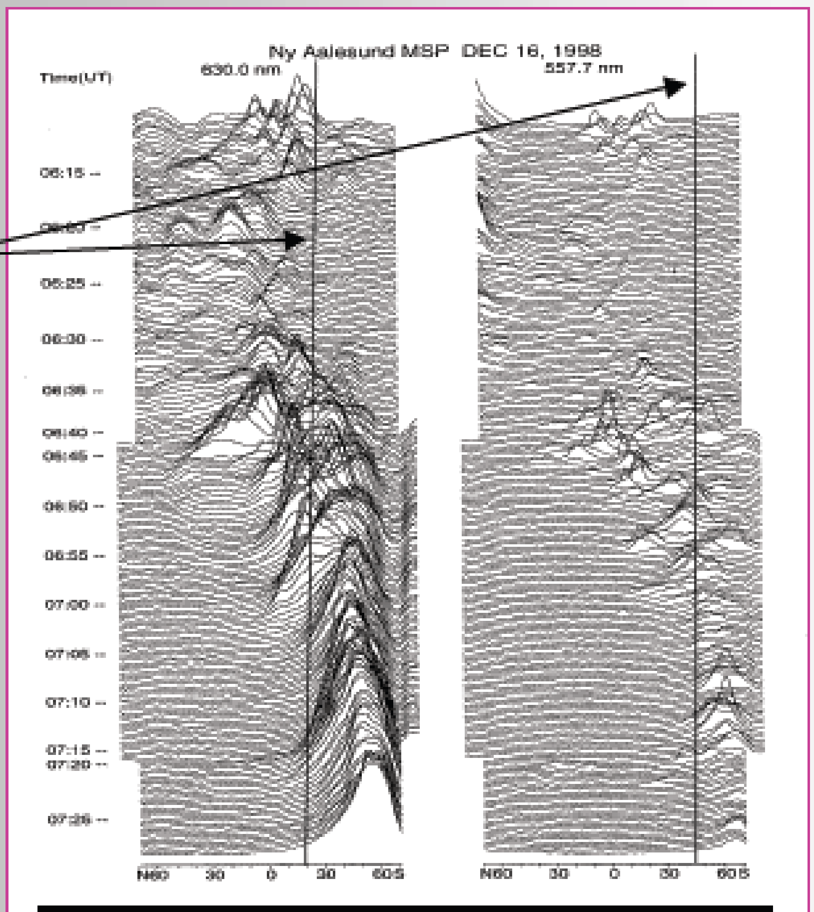


Identifying the cusp (Photometer)

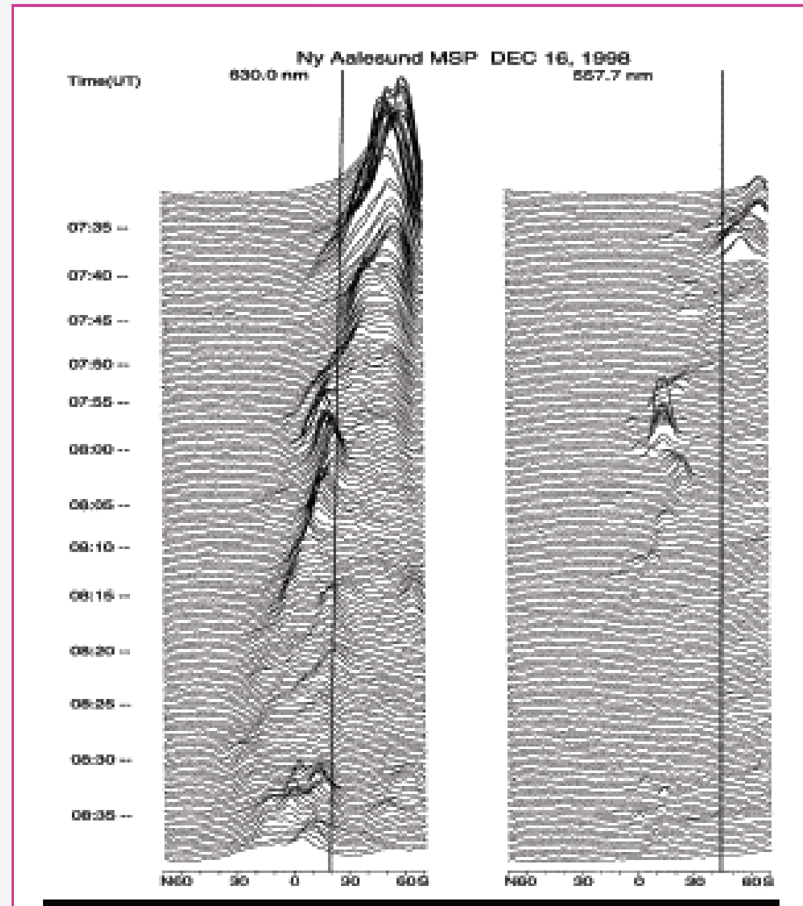
McCrea et al., Annales Geophys., 18, 1009-1026, 2000.

In cusp red line dominant, but there is always some green

Field-aligned (ESR beam)



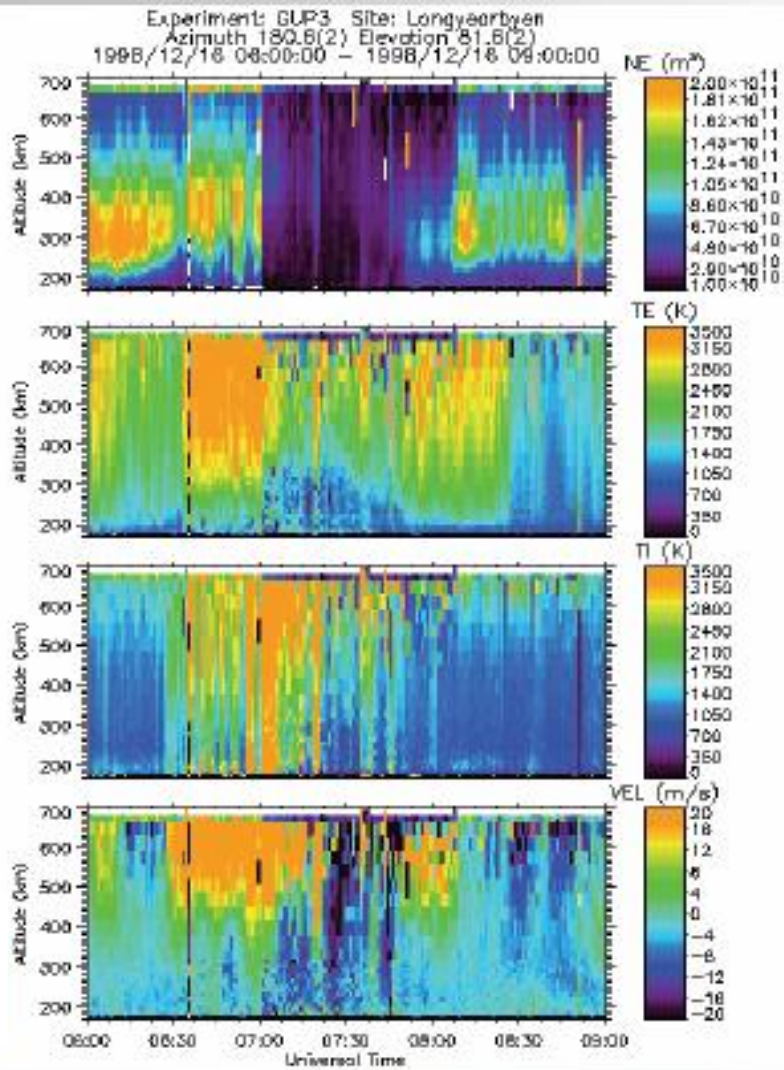
Red (630nm) Green (557.7nm)

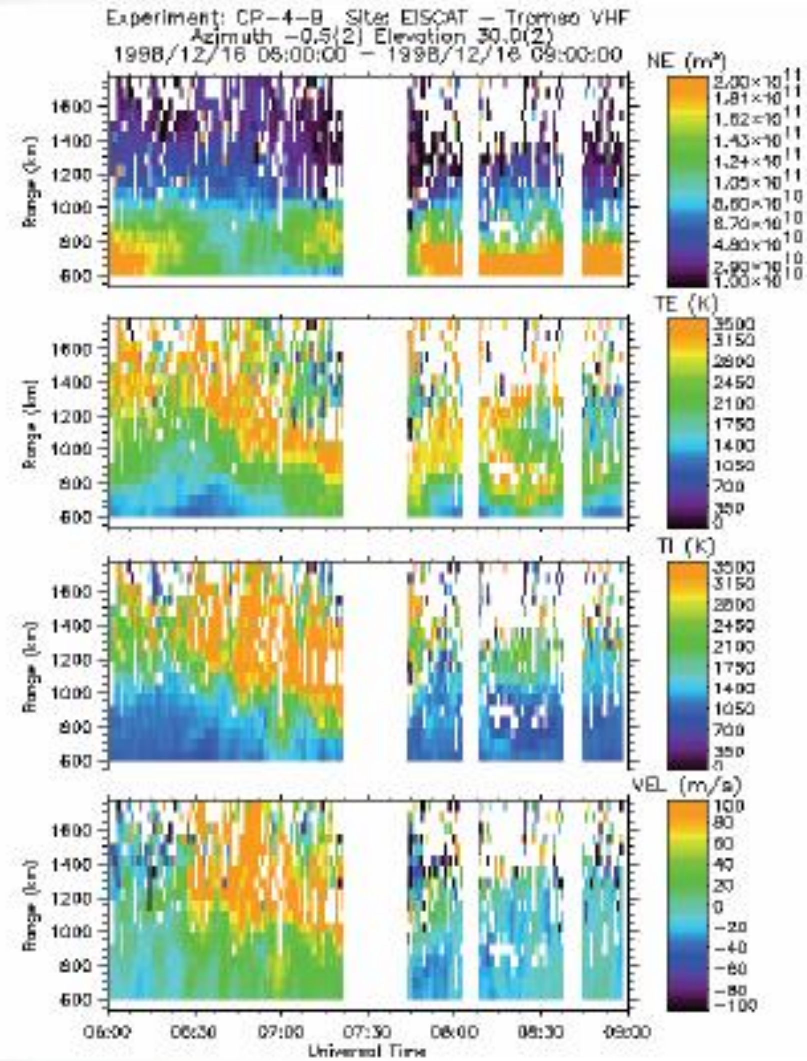


Red (630nm) Green (557.7nm)

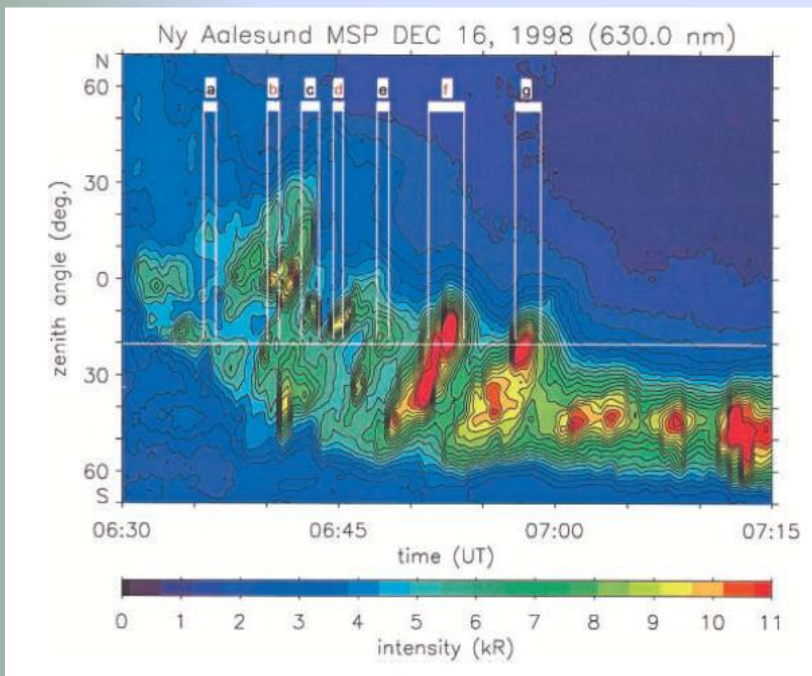
Identifying the cusp (ESR and CP4)

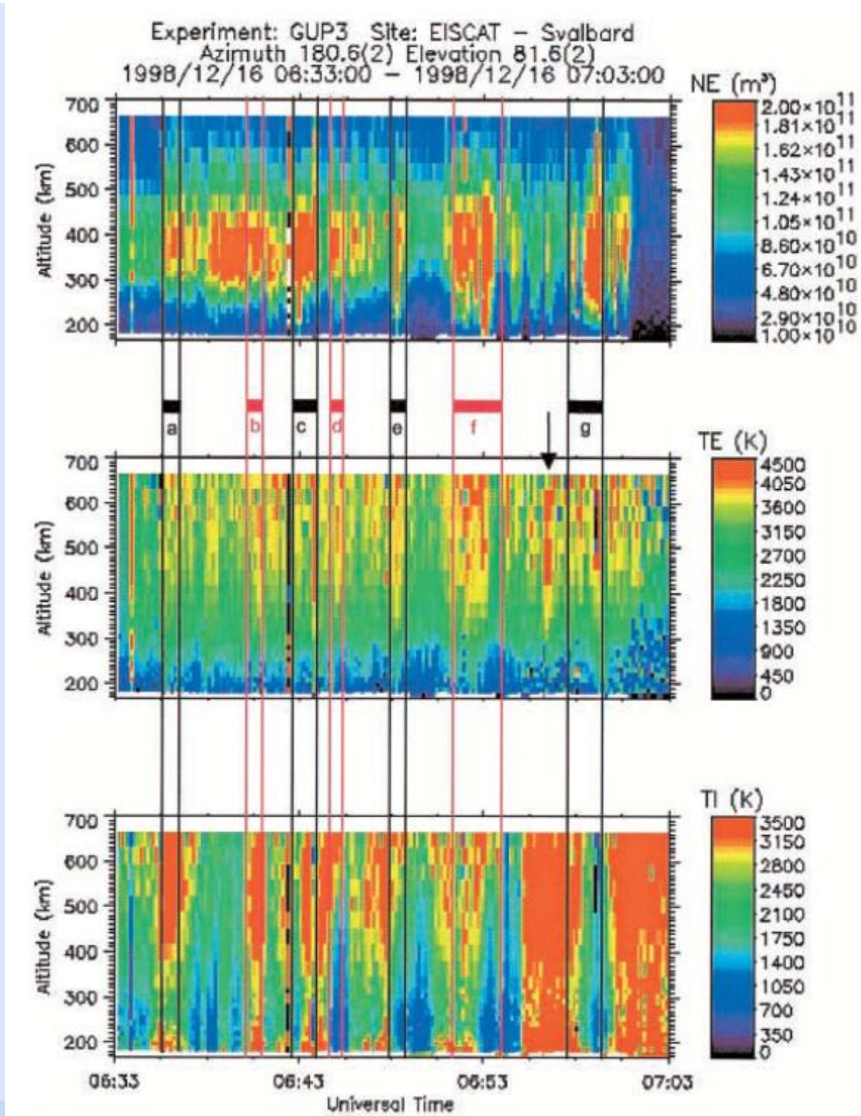
McCrea et al., Annales Geophys., 18, 1009-1026, 2000.





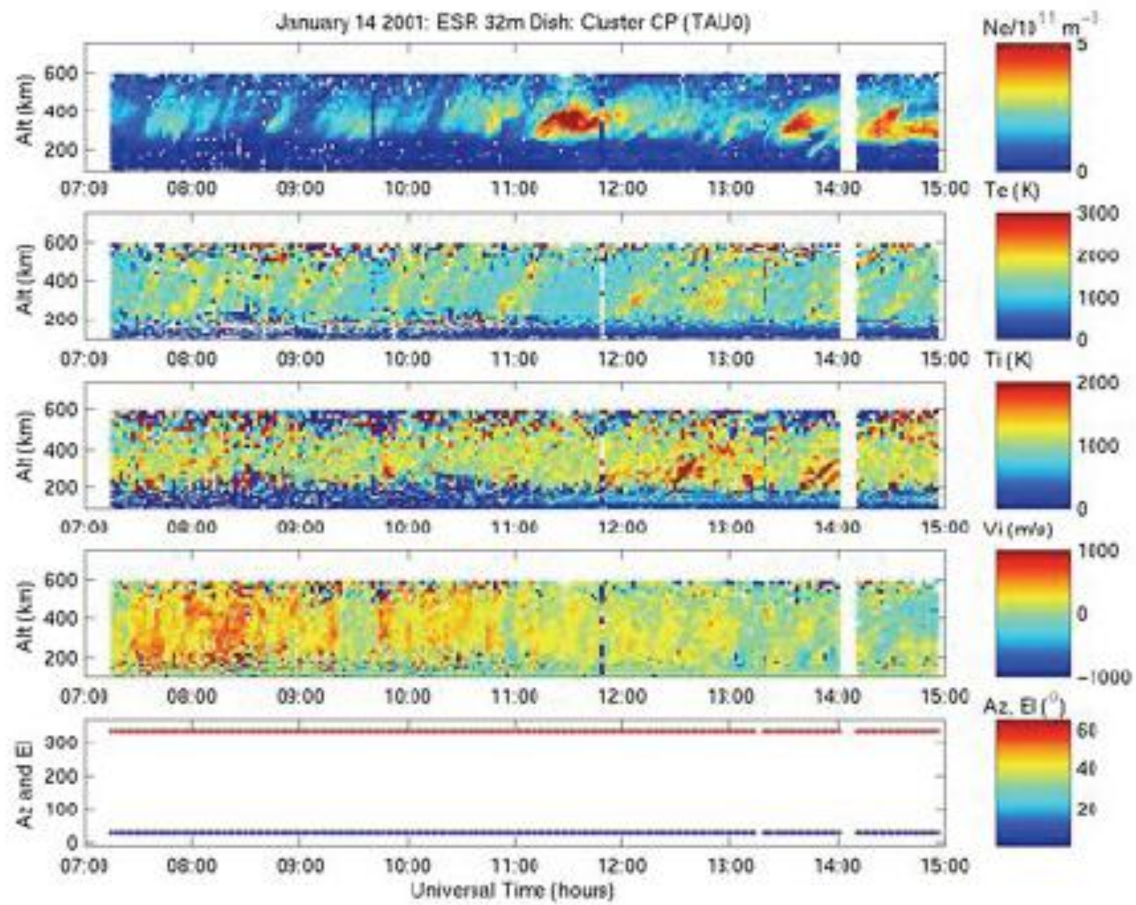
Identifying the cusp (ESR)



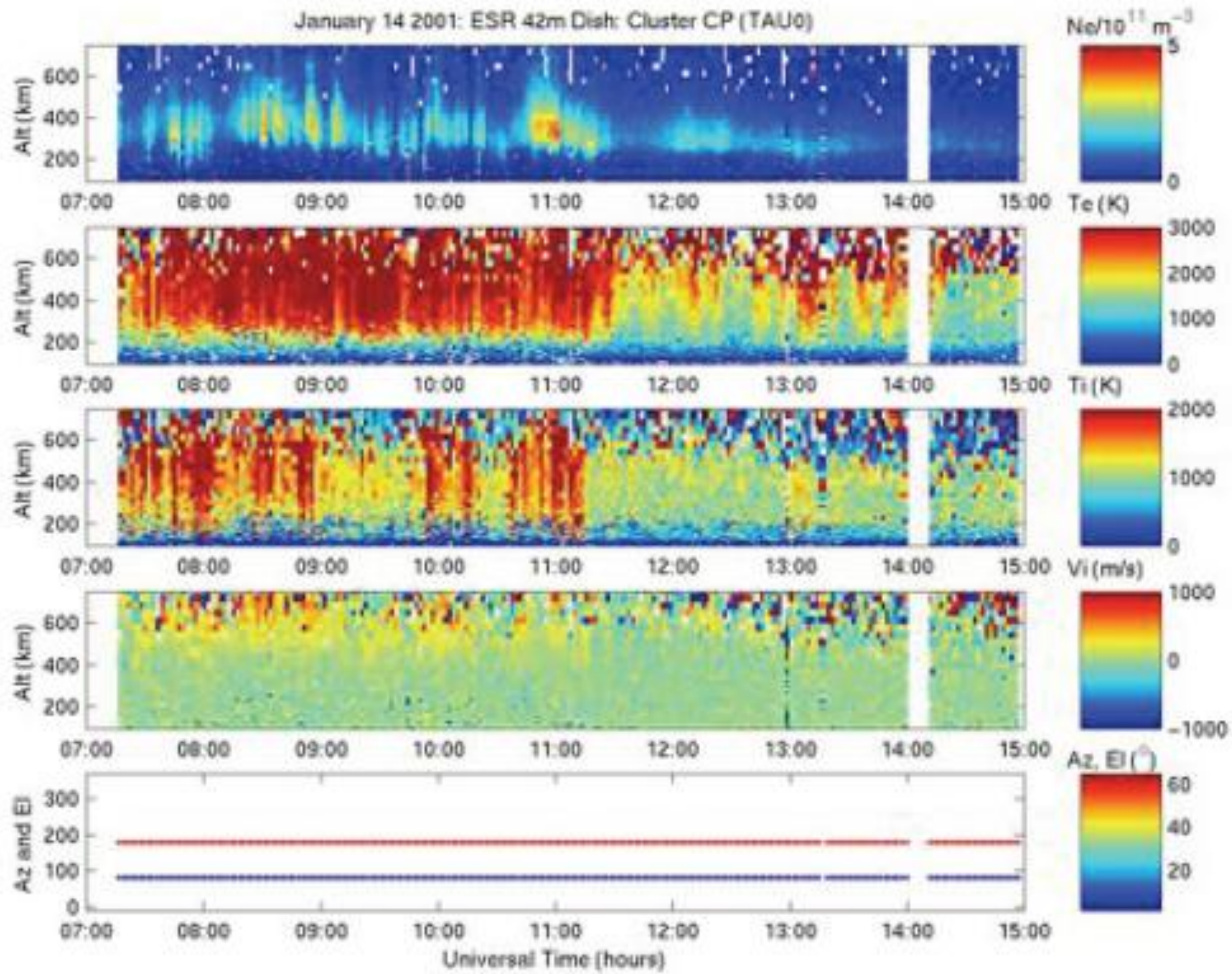


Lockwood et al, Ann. Geophys., 18, 1027-1042, 2000

Identifying the cusp (ESR 32m – looking north)

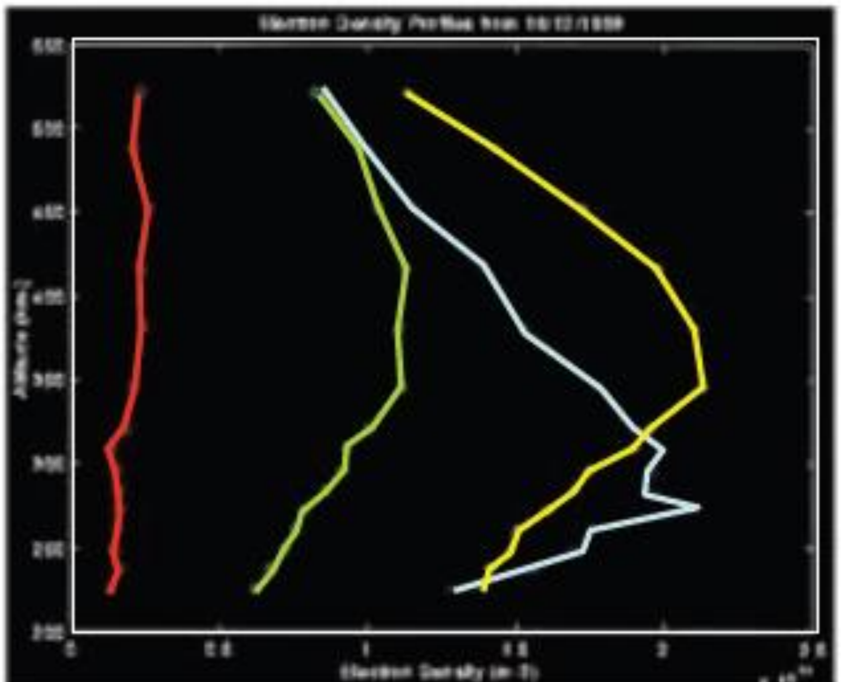


Identifying the cusp (ESR 42m – field aligned)

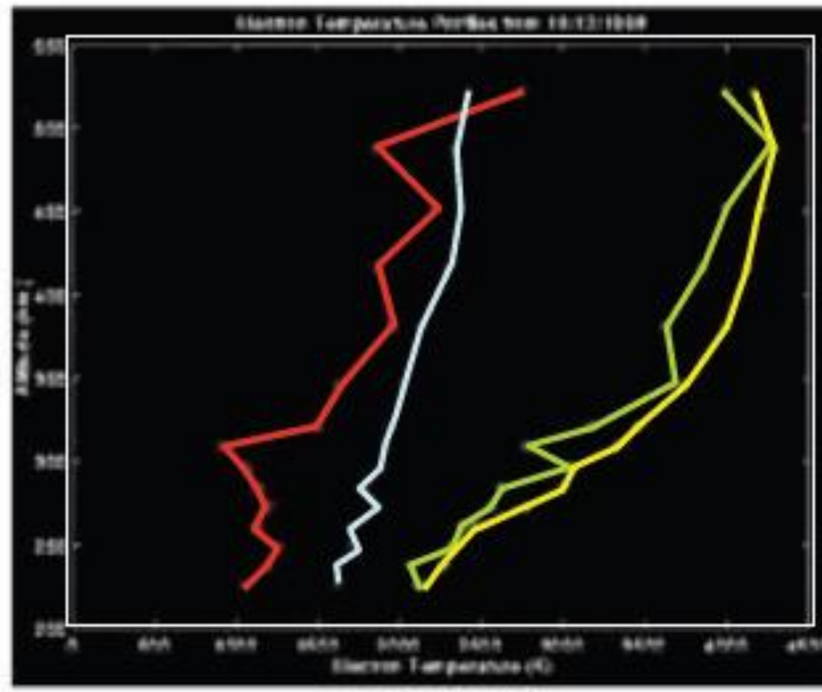


Identifying the cusp (ESR)

Plasma density profile



Electron temperature profile

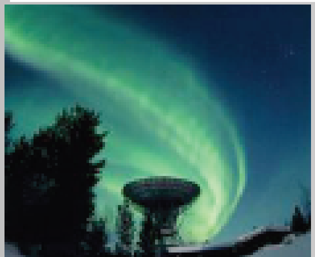


Polar Cap

Sub-auroral

Cusp – outside 630nm transient

Cusp – inside 630nm transient



Identifying the cusp (ESR)

- High F-region electron density N_e (but can be confused with EUV-enhanced polar cap patches convecting poleward)
- High Electron Temperature (patches of sub-aurorally EUV-produced plasma would not show enhanced T_e)
- Electron density highly variable in cusp – gives poleward-moving 630nm transient aurorae

Conclusions(I)

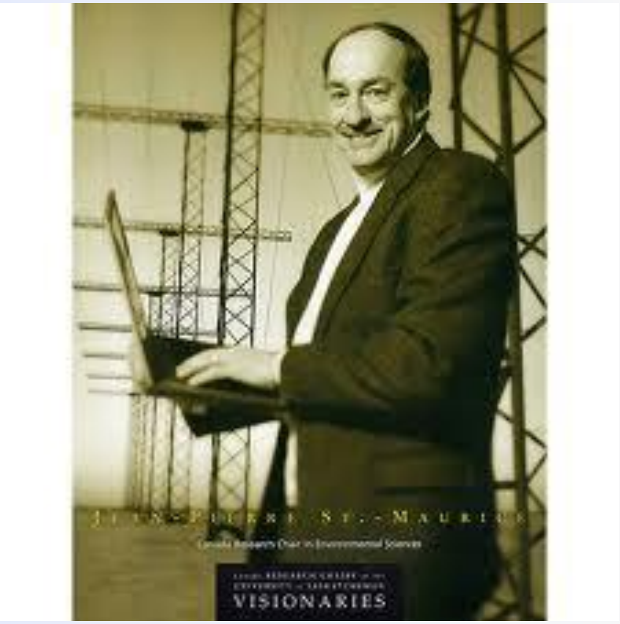
- When interpreting your data, remember....
  - The ISR technique contains ambiguities
    - Range/Doppler ambiguity is inherent
    - Noise is always present, giving uncertainty
    - Be careful of over-interpreting your data

- At high latitudes, remember....
    - Ionosphere can be highly structured in latitude and longitude
    - Ionosphere can be dynamic, e.g. responding to changing solar wind conditions
    - Looking anywhere but along B, you will convolve altitude-dependence with latitude/longitude dependence
    - Some tricks are available to test which might be which
    - Even looking field-aligned, the time series data can conditioned by latitude/longitude variation (features moving across the radar)

Conclusions(II)

- Good experiment design is critical
  - A well-designed experiment really aids understanding
  - Think about characteristic times, scale sizes of events and the measurements needed to characterise them.
  - A badly-designed experiment can produce seriously misleading conclusions (or none)
- Context is all important....
  - Remember that what you see is limited by your experiment
  - ISR is a very powerful technique, but not an oracle!
  - Using multiple radars or other diagnostics is key to determining what might be going on

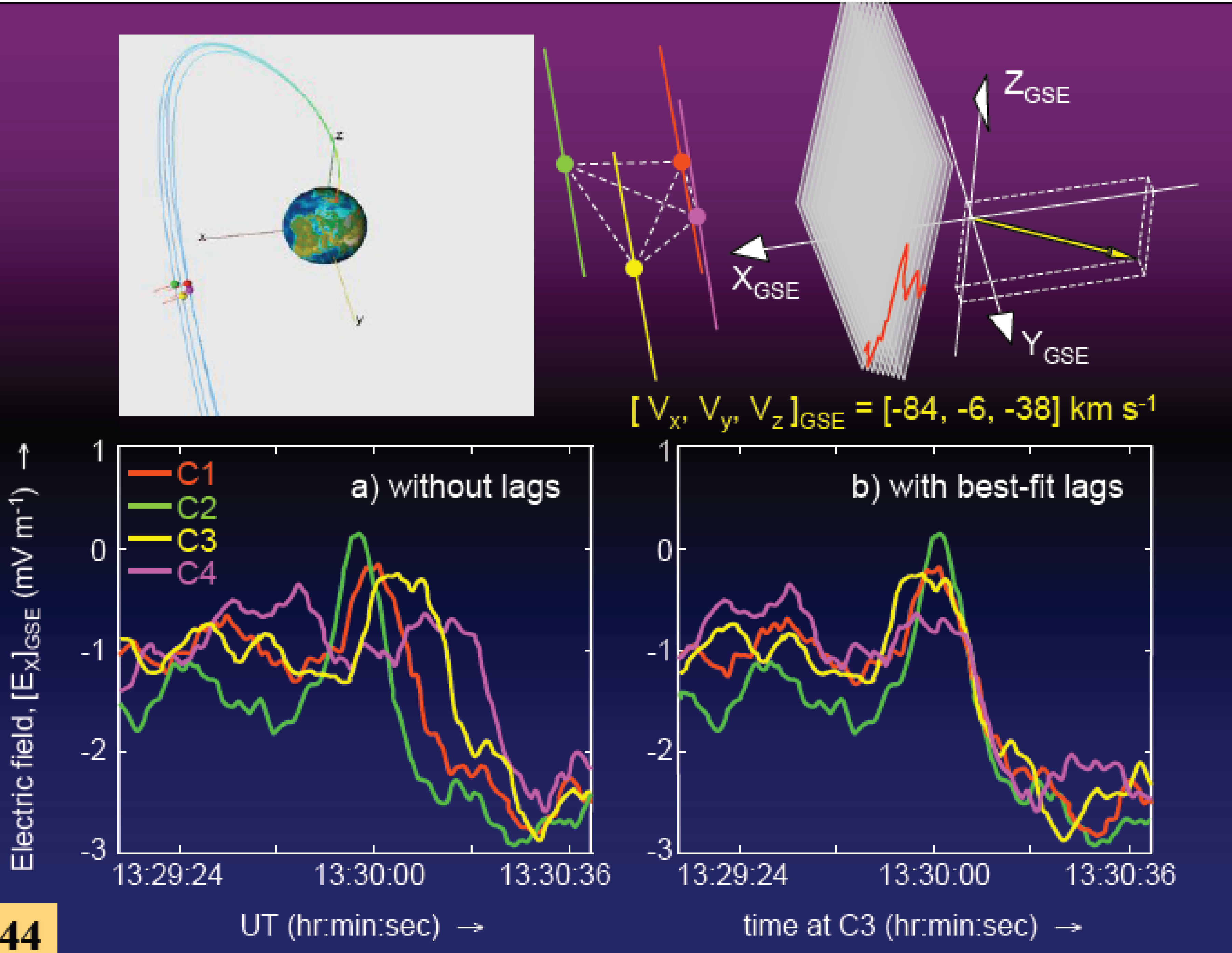
The Wisdom of JP....



- "Let the data speak!...."
- "...but don't torture it...."
- "If your torture your data enough, it will confess to anything..."

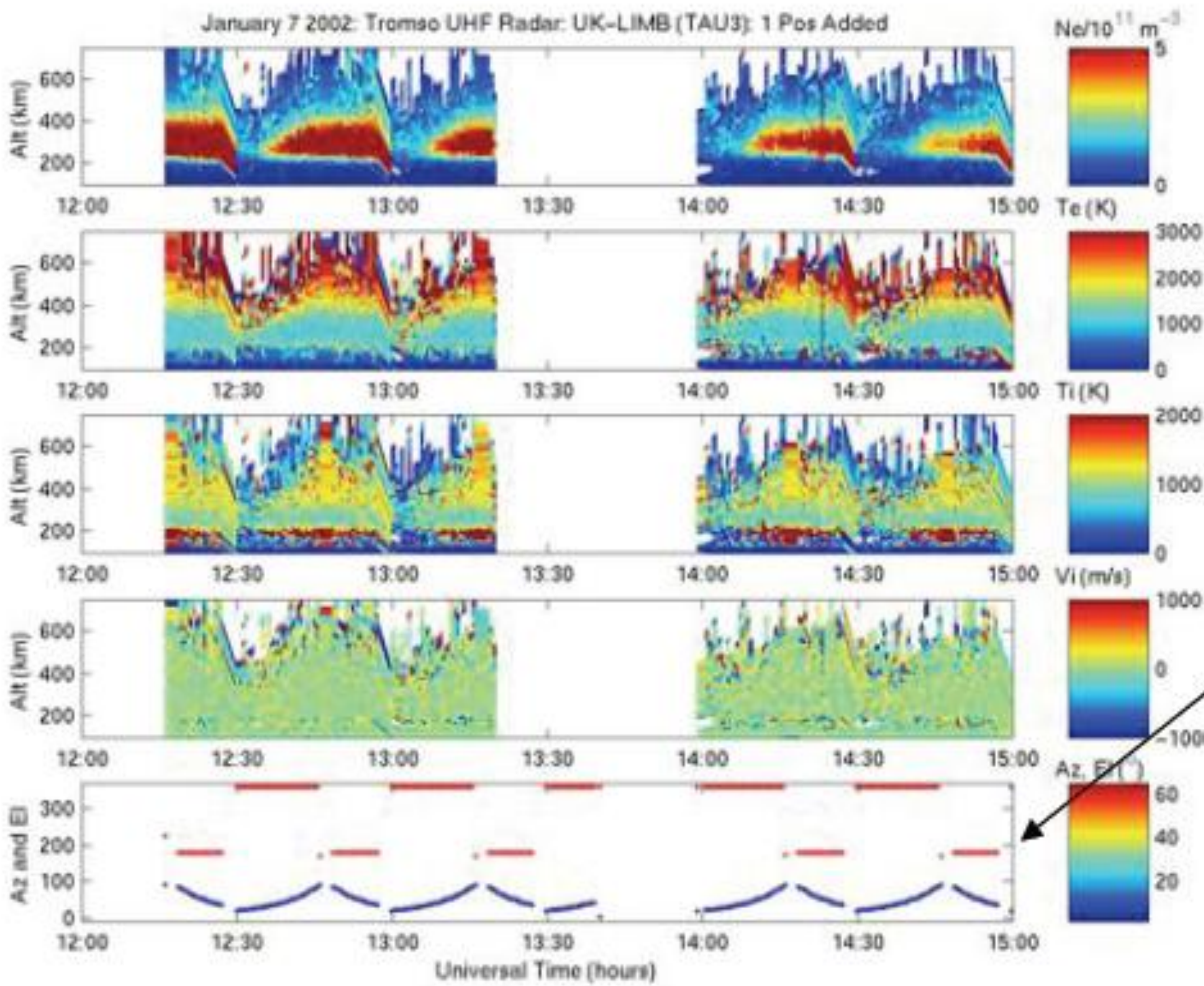
The End

(does anyone have any questions?)


Z_{GSE}
Z_{GSE}
X_{GSE}
Y_{GSE}
$[V_x, V_y, V_z]_{GSE}$ = [-84, -6, -38] km s^{-1}
Electric field, $[E_X]_{GSE}$ (mV m^{-1}) →
C1
C2
C3
C4
a) without lags
b) with best-fit lags
1
0
-1
-2
-3
13:29:24
13:30:00
13:30:36
UT (hr:min:sec) →
time at C3 (hr:min:sec) →

Special Programmes (SP)

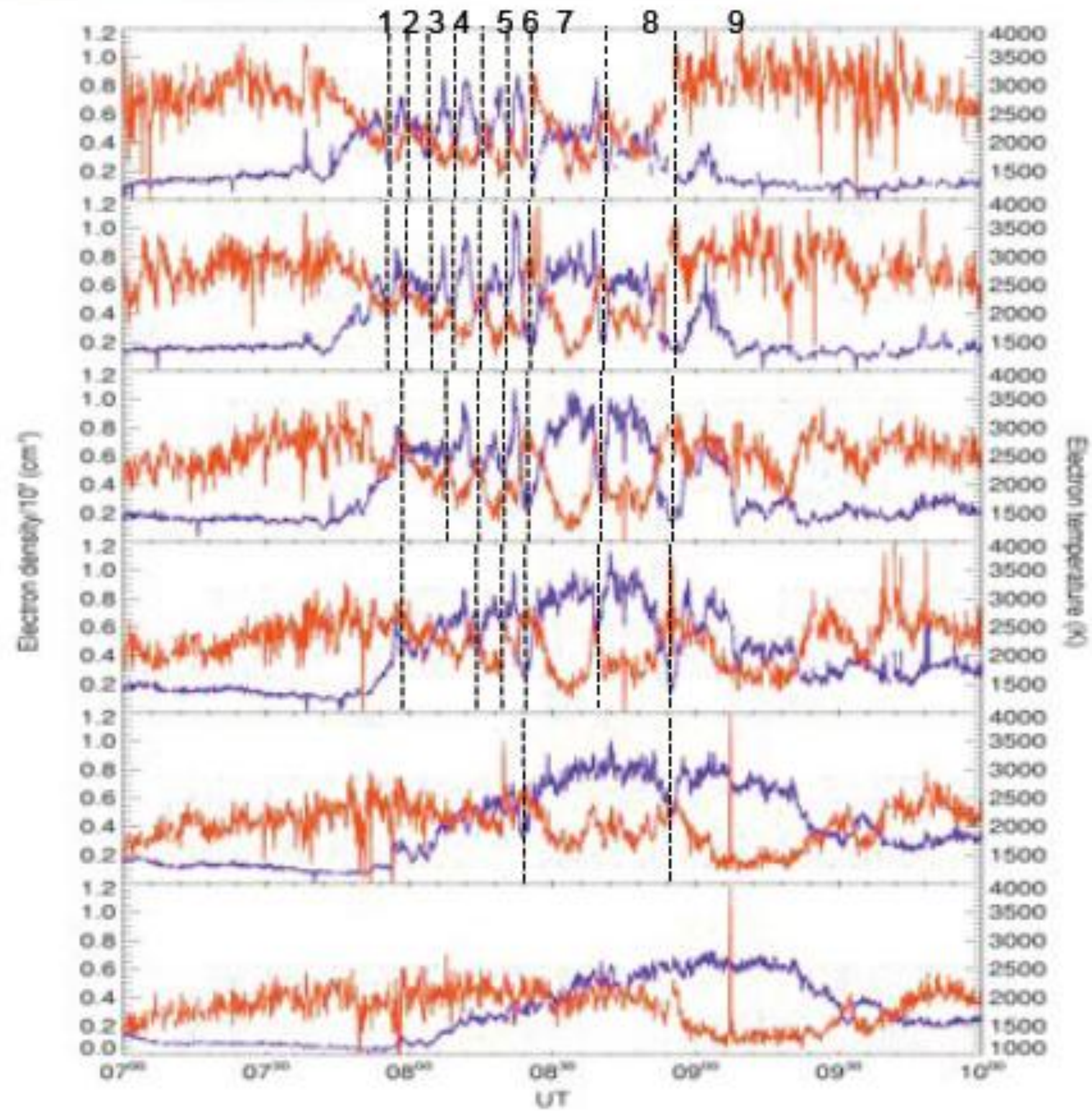
(for which we might not know beam scan pattern)



Beam pointing Panel:

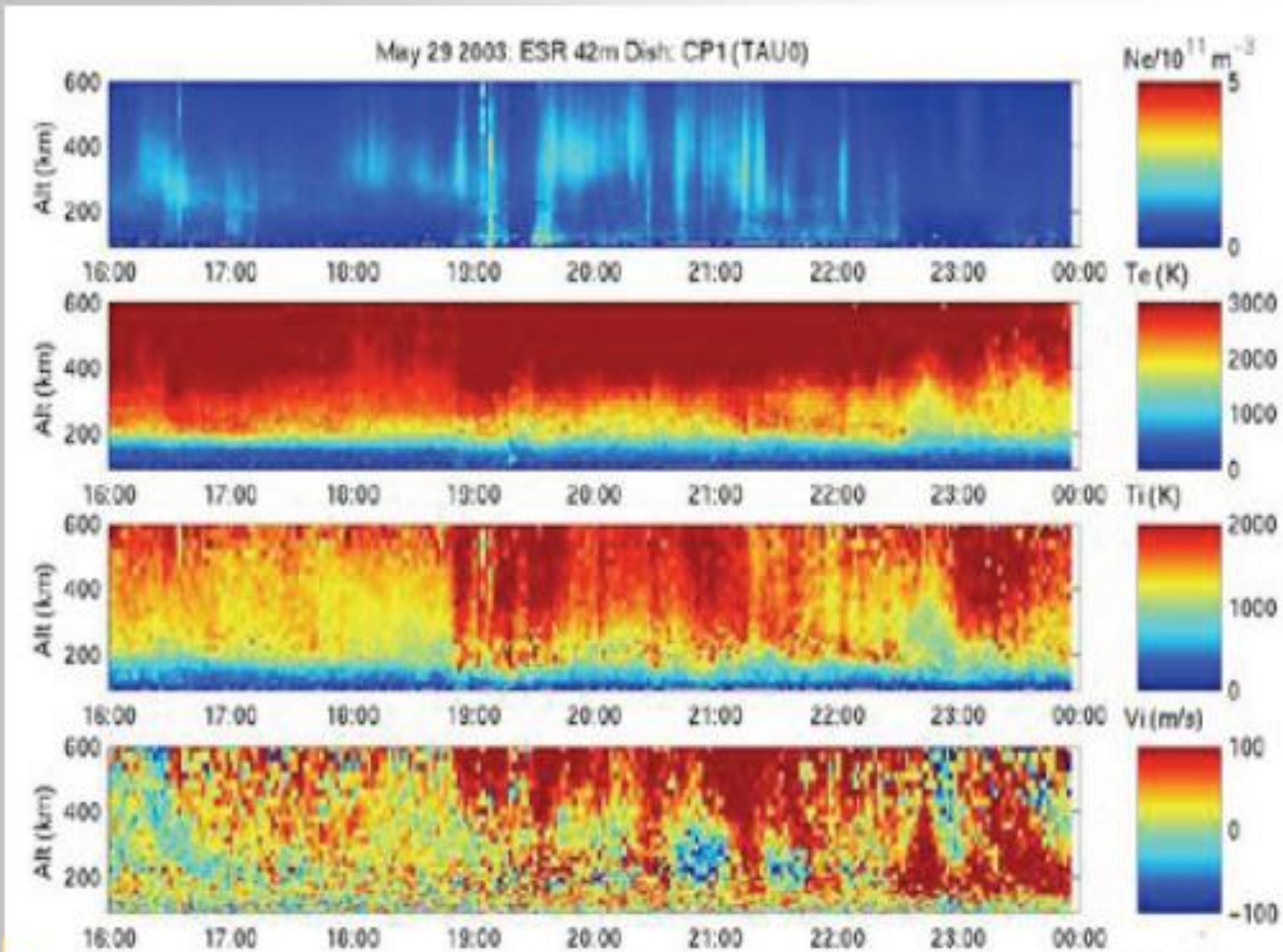
Az is the azimuth (in red), El is the elevation (in blue)

N_e – T_e anticorrelation



Field-aligned flows

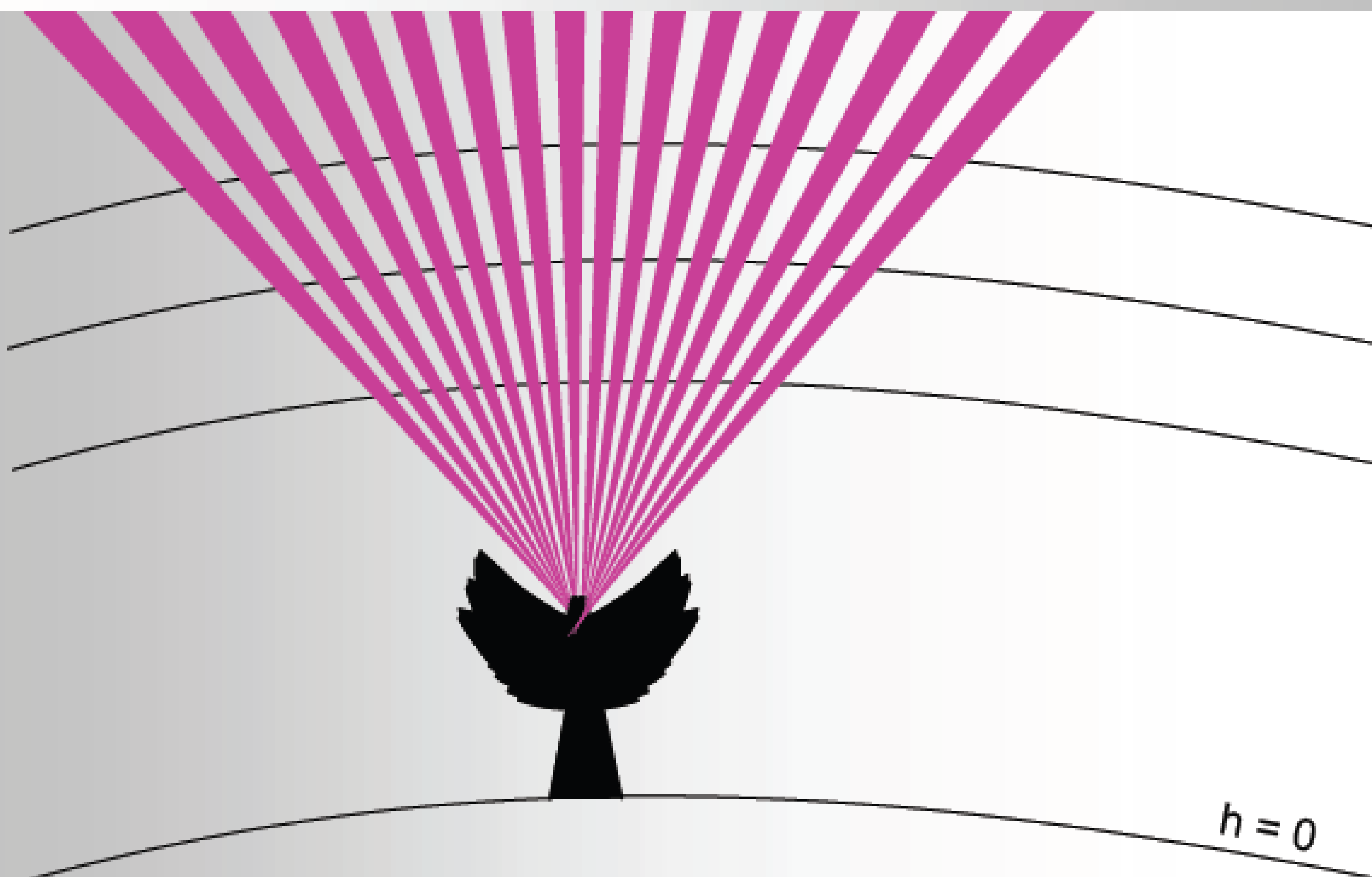
(seen using ESR)

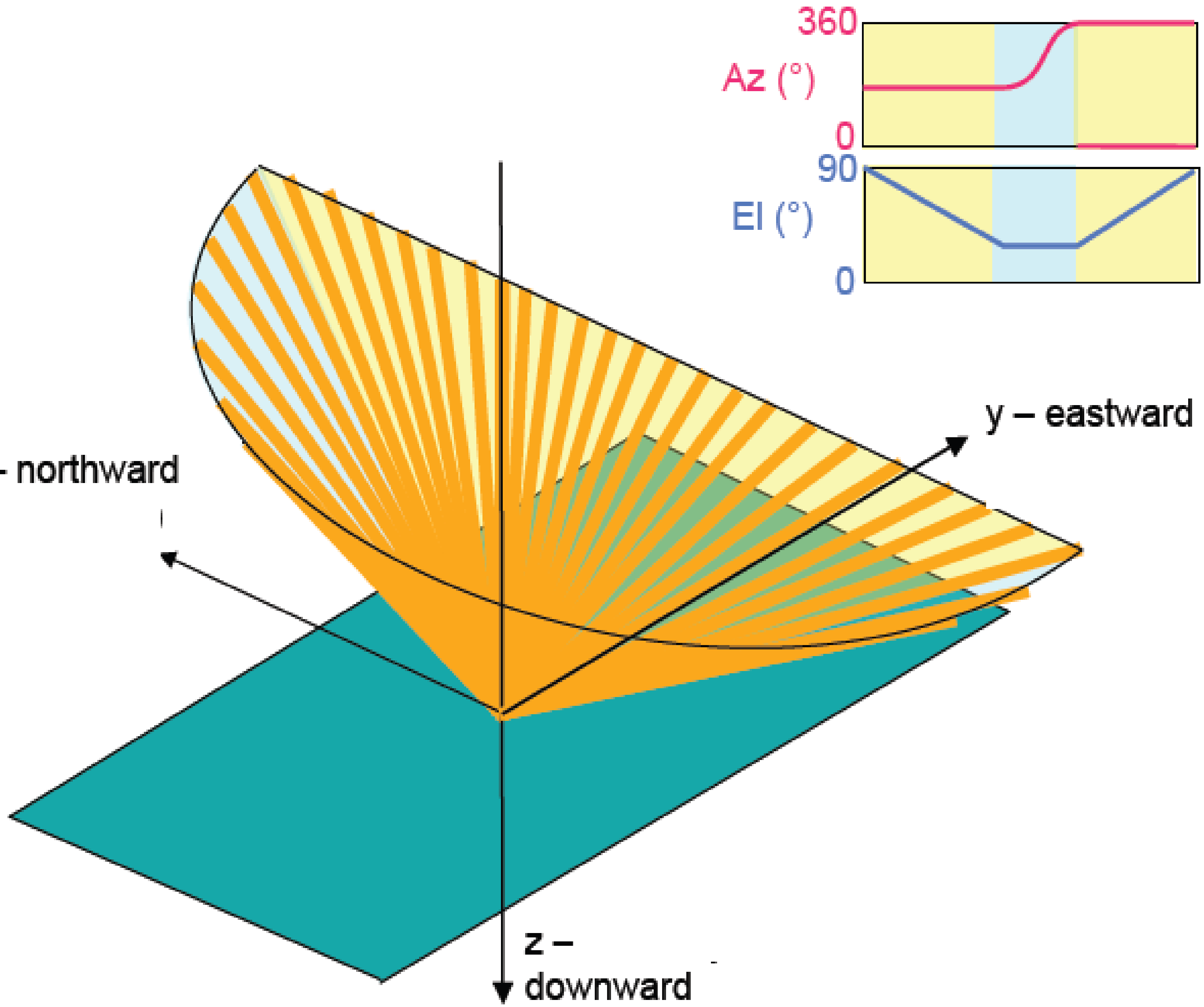


Note upflows (red away from Earth) in bottom panel

Altitude and Pointing Direction

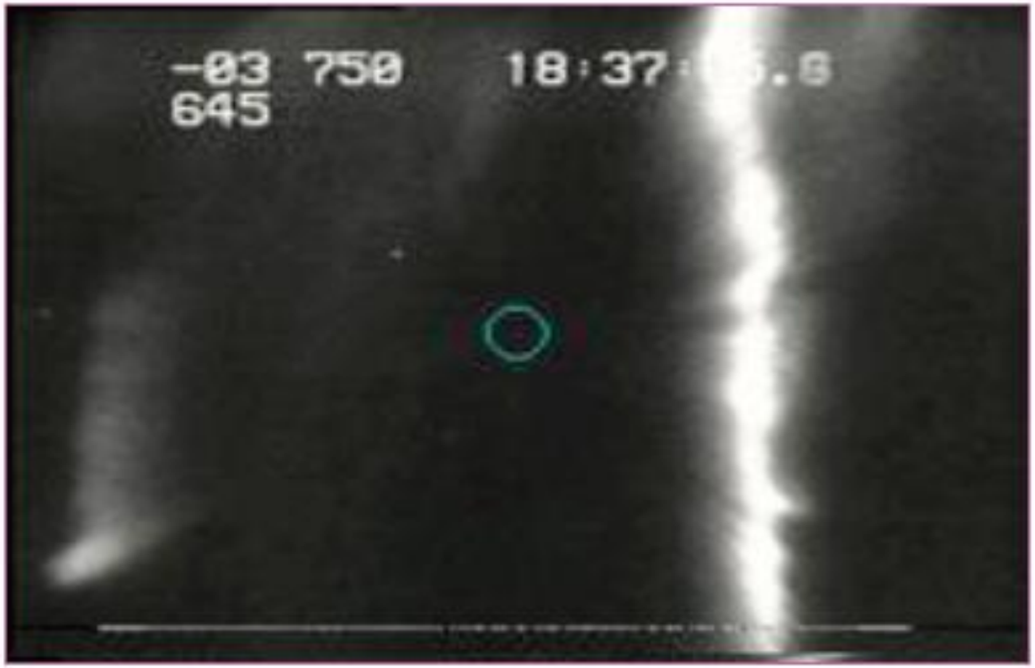
CP-3 Scan





The scan can often be limited by the properties of the radar!
Scan down – turn – and scan up

Tromsø, 30 January 1995



Note in this case, that there is dispersion – with the N_e enhanced at higher altitudes first – i.e. low energy particles arrive first!