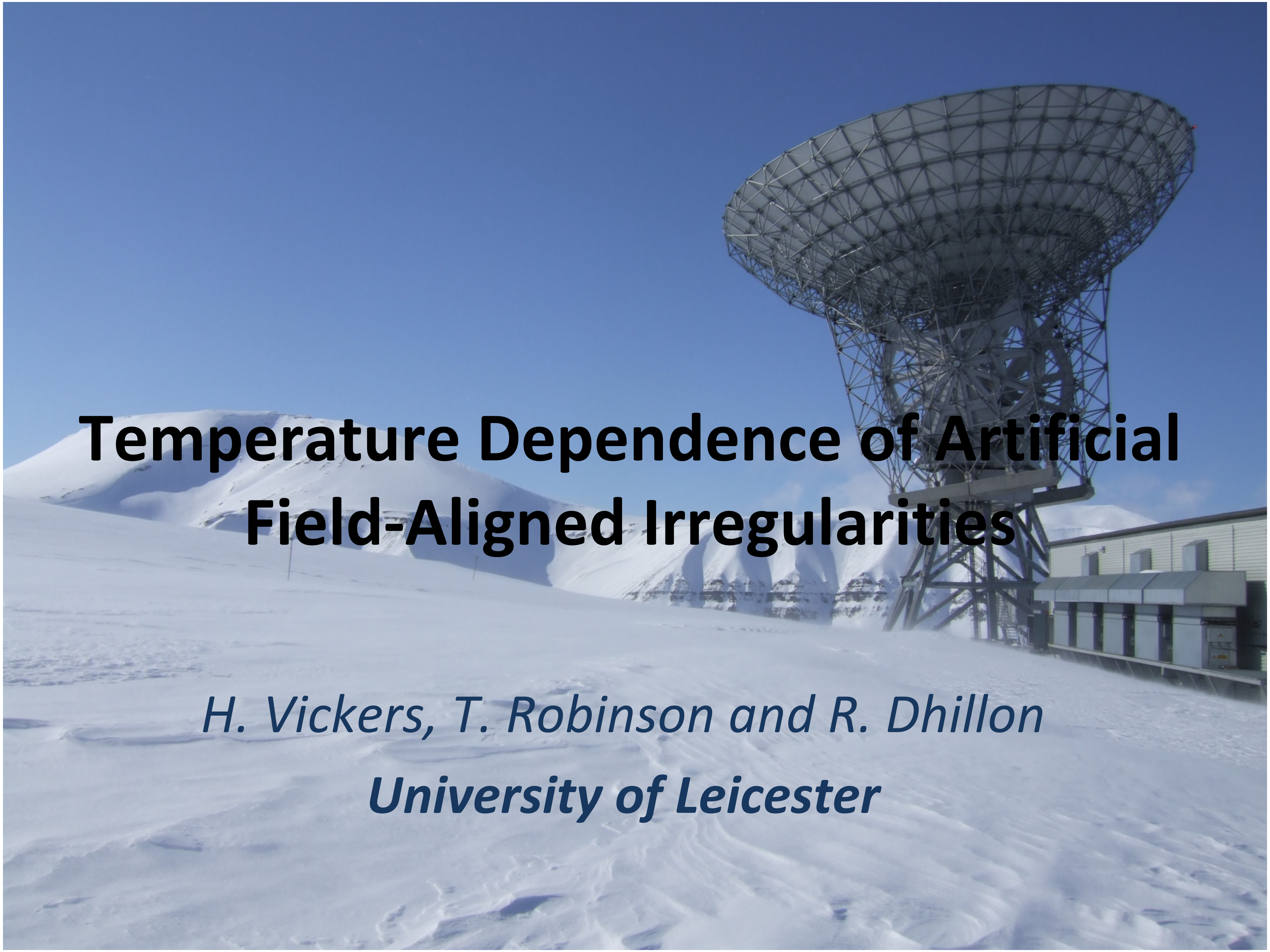

Temperature Dependence of Artificial Field-Aligned Irregularities

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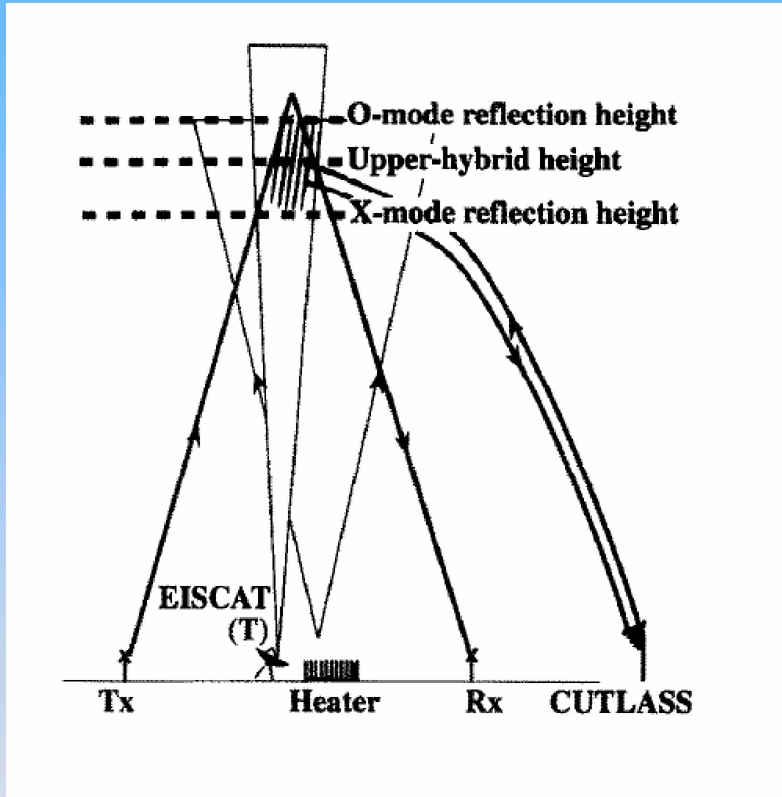
Overview

- Ionospheric heating experiments
- Incoherent Scatter technique
- Modelling the electron temperature (Te) during heating experiments
- Field-aligned irregularities (FAI): temperature dependence
- CUTLASS backscatter & relation to growth and decay times of FAI
- Future work

Ionospheric Modification & Diagnostics

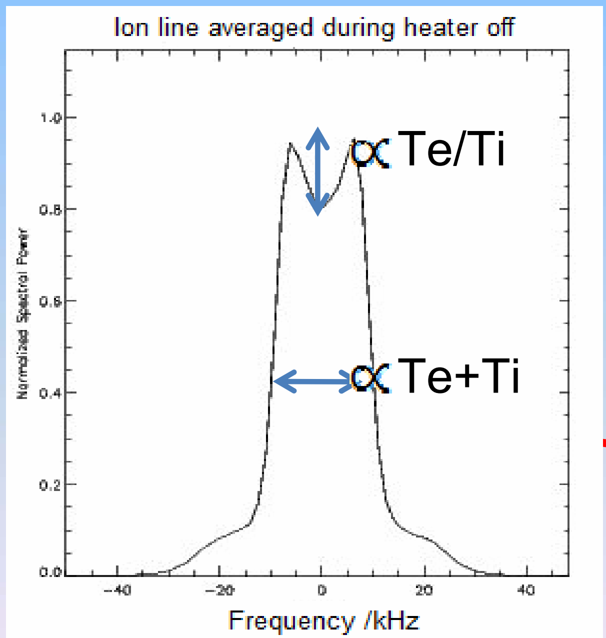
- EISCAT Heater, N. Norway : HF waves at 3.85-8MHz in O-, X-modes.
- Plasma turbulence excited as instability thresholds exceeded = strong heating, conduction away from source at UH height along **B** → field aligned irregularities (FAI) develop
- EISCAT UHF (933MHz). IS analysis used to infer plasma parameters
- CUTLASS (8-20MHz) Wave s Bragg-scattered from single height over extended horizontal range
- DOPE: Doppler Pulsation Experiment, 4-5MHz, monitors anomalous absorption



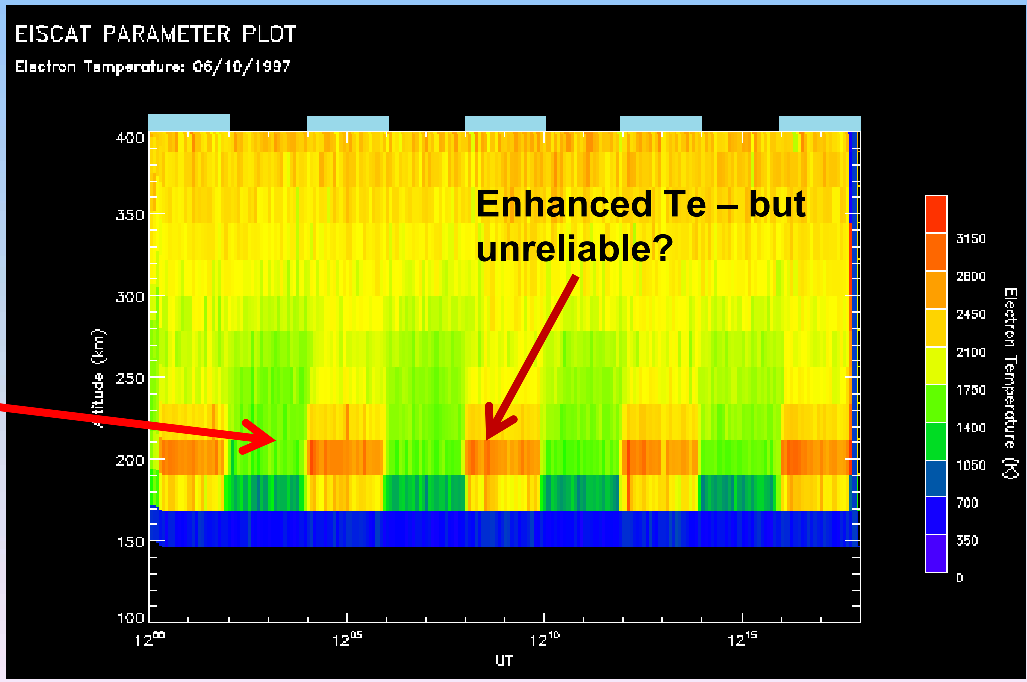
Schematic from Fig.1b, *Robinson et al., 1998*

EISCAT Analysis

- Radar receives scatter from natural waves in the plasma in thermal equilibrium (Maxwellian) due to thermal fluctuations
- Fits curve to power spectrum to get best fit parameters
- During heating, plasma becomes non-Maxwellian



Typical ion-acoustic spectra when heater off

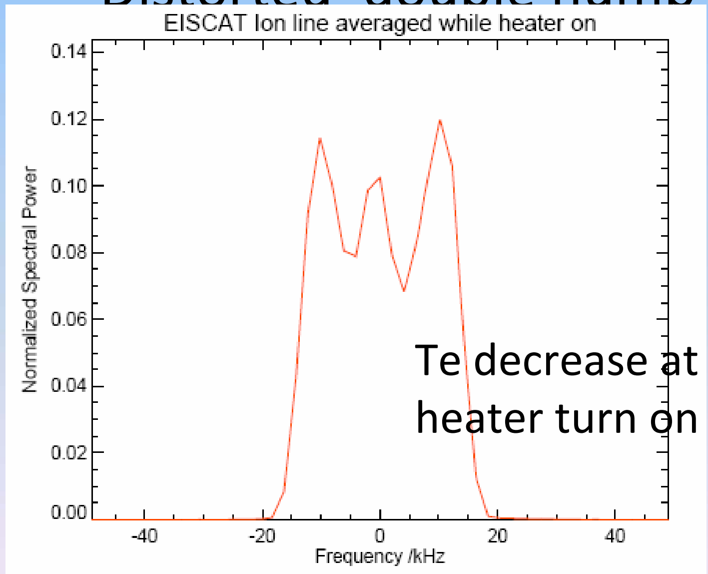


‘Ion Line overshoot’

- Parametric Decay Instability (PDI) drives plasma turbulence at heater reflection height

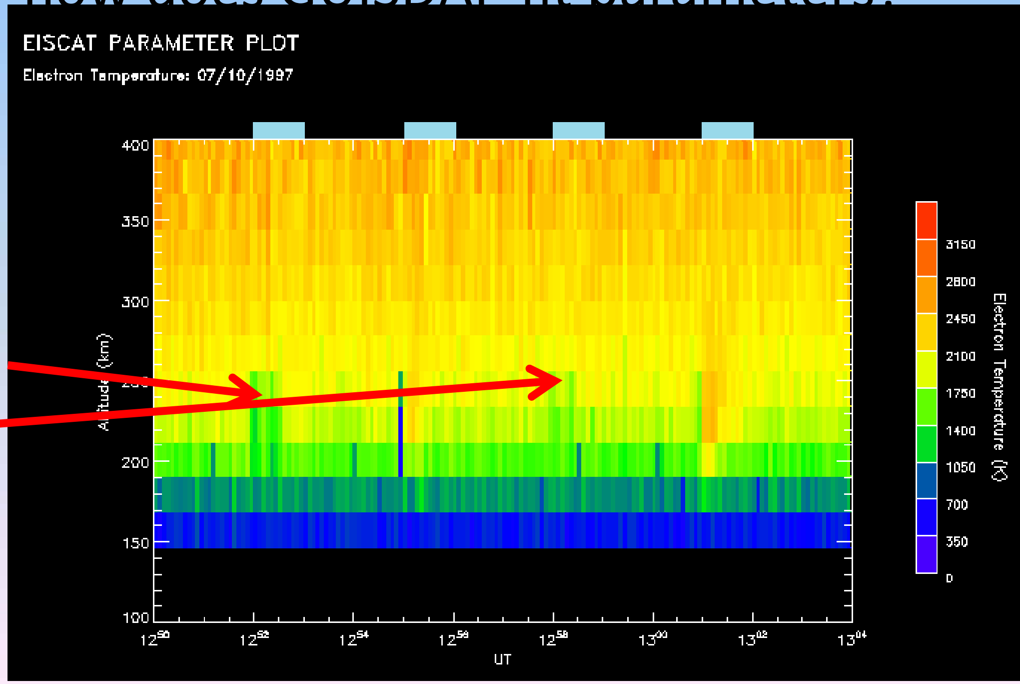
→ Enhanced ion-acoustic waves

- Oscillating Two-Stream Instability (OTSI) or purely growing mode (PGM) → Spectrum contains central peak in first few seconds only
- No present theory for Te under thermally ‘chaotic’ conditions
- Distorted ‘double hump’ – how does GUISDAP fit parameters?



Example of ion line at turn on

Te decrease at heater turn on



Modelling the Te Profile

- ‘Modified’ Epstein and Chapman functions used to model height profile of Te change during heating:

$$f_{eps} = A\frac{e^{\frac{X(z)}{B2(k,z)}}}{\left(1+e^{\frac{X(z)}{B2(k,z)}}\right)^2} + G \qquad f_{chap} = Ae^{\left(1-\frac{X(z)}{H}-e^{-\frac{X(z)}{H}}\right)} + G$$

$$B2(z) = B0 + kz \qquad X = z - z_m \qquad H(z) = H0 + kz$$

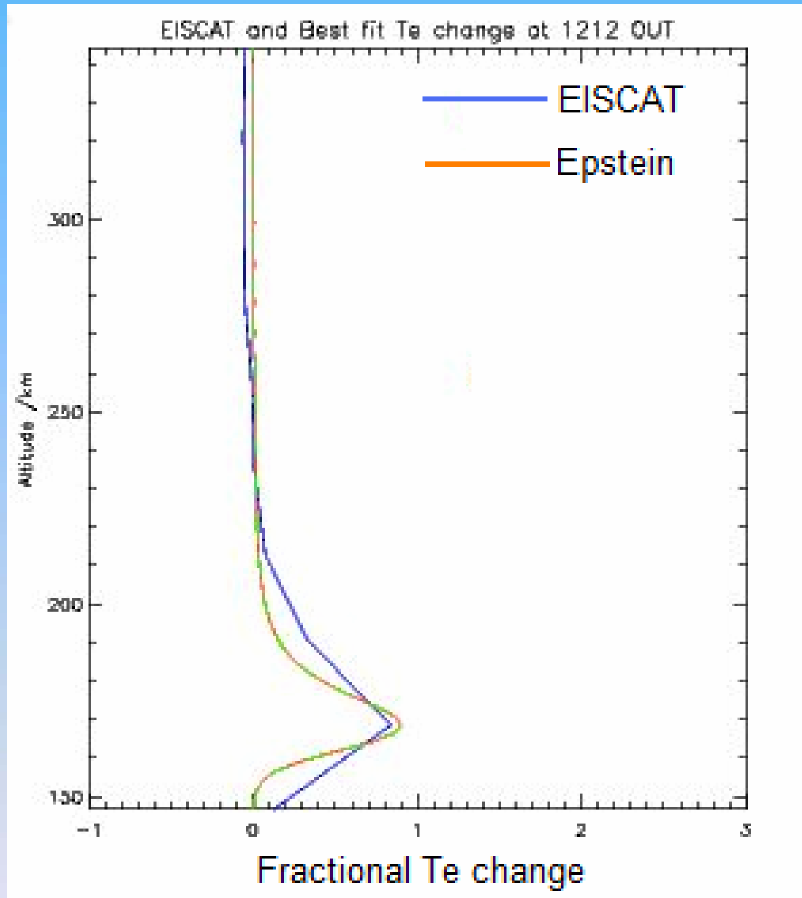
- 4 free parameters (A, G, k, B0/H0)
- Fitting to ΔTe profiles – get model estimate at peak ΔTe height

$$\Delta T_e = \frac{T_e - T_0}{T_0}$$

- Trial parameters varied simultaneously, least squares technique applied until variance of model from real profiles minimized

Model vs. EISCAT: agreements

- Assumed Te outside interaction altitude are reliable, if inferred from non-distorted I-A spectra
- Best fit Te estimated at peak height when real Te at peak height is 1) included, 2) excluded in calculation of variance i.e. Complete profile or only data above / below peak height
- Implemented profile fitting so far for ~***90 heating periods*** between 1996-2002 at Tromso



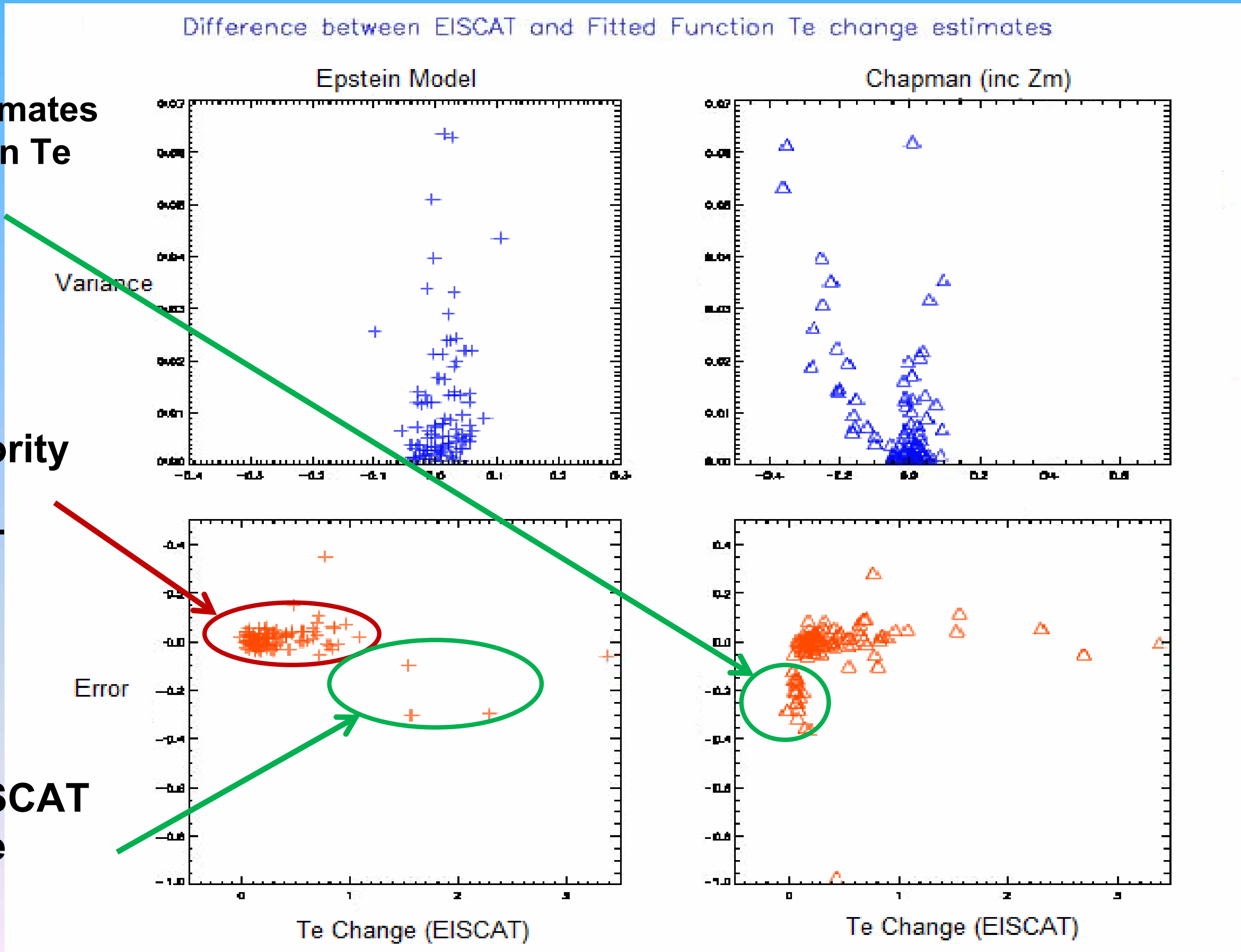
-Fits to profiles for data at heater switch-on⟶ ΔTe derived from distorted spectra
-Fits to data averaged from 20s to end of cycle (no PGM) ⟶ large scale ΔTe

Statistics

Cluster of estimates < EISCAT when Te change ≈ 0

Error in majority of estimates from EISCAT close to 0

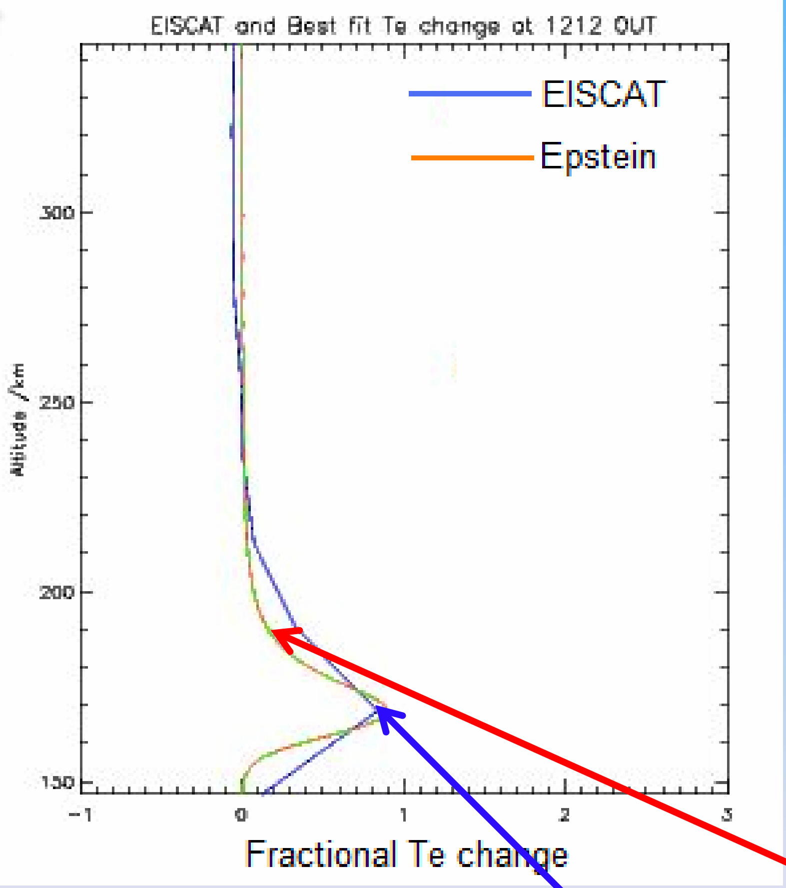
Model < EISCAT at largest Te changes



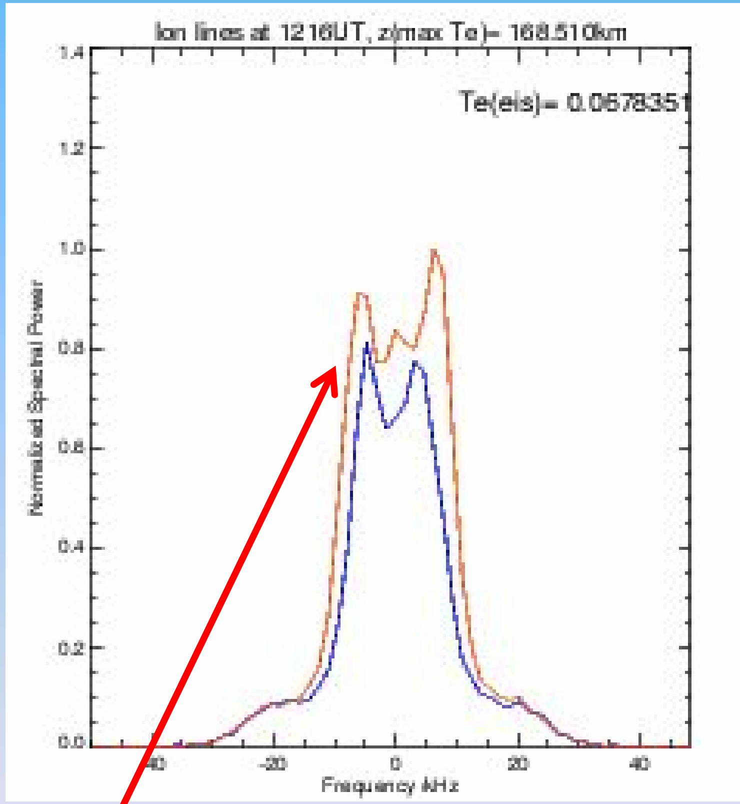
Results

- Majority of estimates with error close to 0 show good agreement between model and EISCAT
- Model fits predict *lower* ΔTe at largest ΔTe
- ‘Anomalous’ cluster at small ΔTe where Chapman estimate is lower than EISCAT
- Not enough data points a very large ΔTe (UHF) to make reliable conclusions
- Is max ΔTe really a good proxy of interaction height (Zm), where ion line overshoot occurs?
- Cases where power profiles maximise at different height to max ΔTe. Power profile resolution ≈ 4-5km, ΔTe at ≈ 22km

Model vs. EISCAT: discrepancies



Ion lines at heater switch on



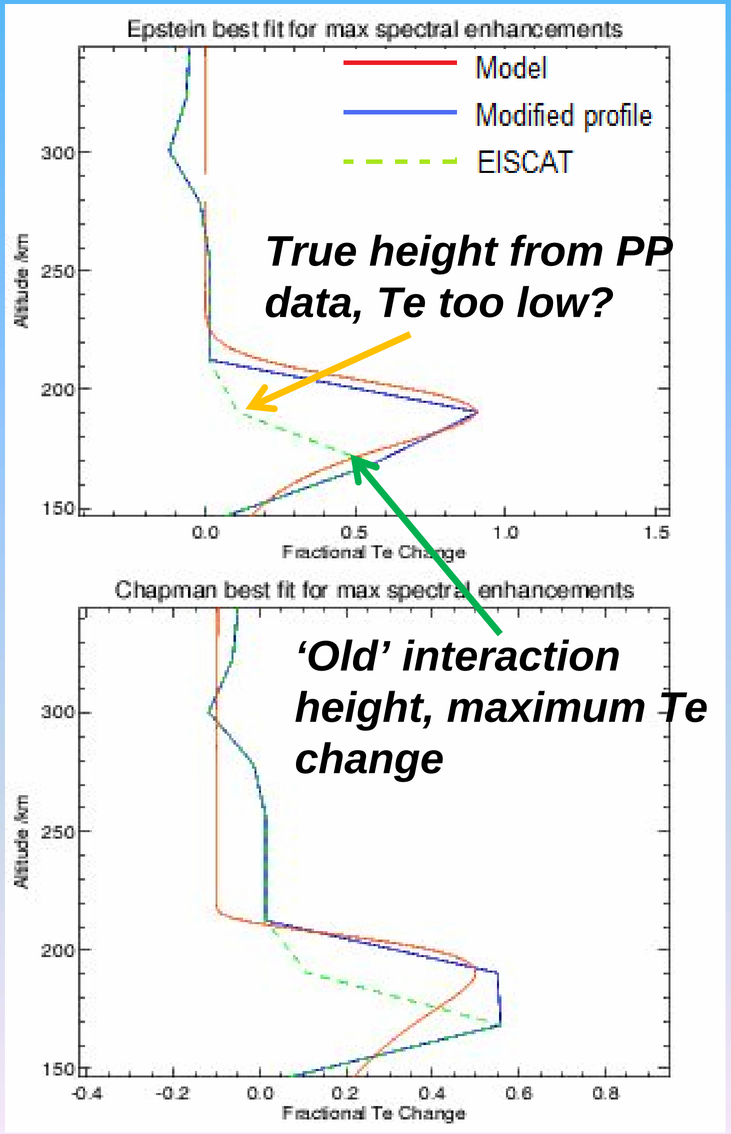
Epstein fits

Model-fitted interaction height

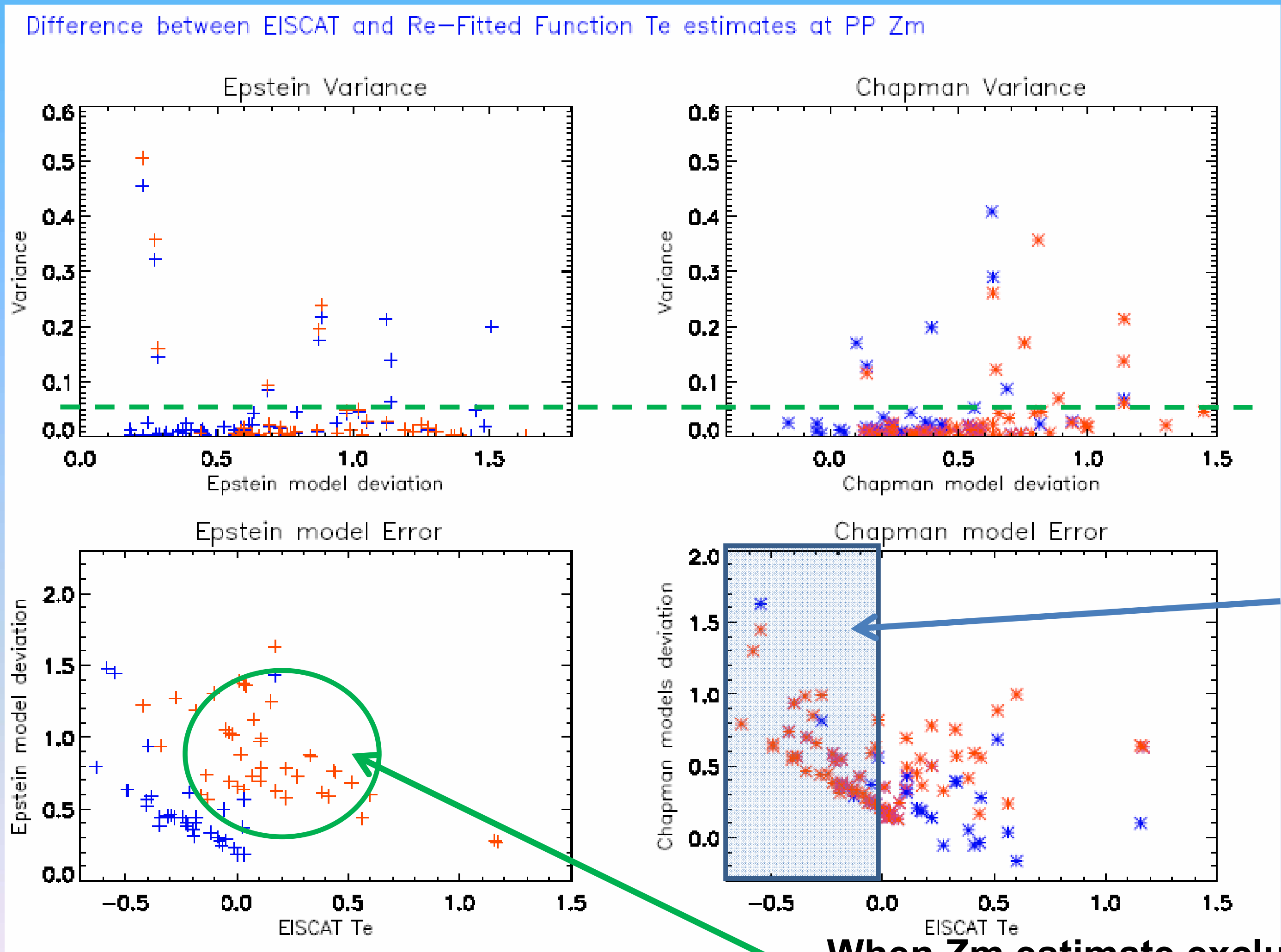
'Real' interaction height?

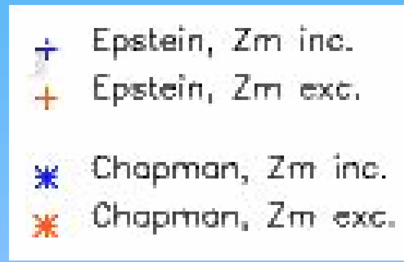
Re-fitting the Profiles

- Height of max. in power profile data at ‘turn on’ time
- Closest altitude to Te data determined (but Te and PP not at same height resolutions)
- Corrected peak altitude passed into Epstein/Chapman fitting routine, new peak Te allowed to vary as a free parameter until variance minimized
- ‘Re-fitting’ check for all 90 Te profiles at turn on AND also averaged (‘steady state’) profiles



Re-fitting to ‘turn-on’ profiles





Majority of estimates have full profile variance within 5%

Estimates where EISCAT Te at turn on < background Te before

When Zm estimate excluded, deviation from EISCAT is higher

Field-Aligned Irregularities

- EM heater ('pump') wave mode-converted to electrostatic (upper hybrid) waves at UH height → Thermal Parametric Instability (TPI) excited
  - → Beating of EM/ES waves = plasma heating
  - → Net motion of electrons along **B** = field-aligned irregularities at UH height
  - → Density depletions - can scatter low power radio waves ('anomalous absorption') + trap UH waves = enhanced heating
- Grow to many km along B, few m across B
- Significant effect on electron dynamics
- Ultimate goal to make comparison between Tromso and SPEAR (polar cap ionosphere, greater variability) → lower power facility

FAI Rise and Decay

- Characteristic growth & decay rates of FAI strongly dependent on electron temperature:

$$\tau, \tau_0 = \frac{1}{\gamma} \qquad \gamma \sim \frac{q_1 E_0^4}{N^2 D_1} \qquad D_1 = 27 D_{\parallel} (T_{e0} + T_{i0})^2$$

$$\gamma_0 = -1.8 D_{\perp} k^2$$

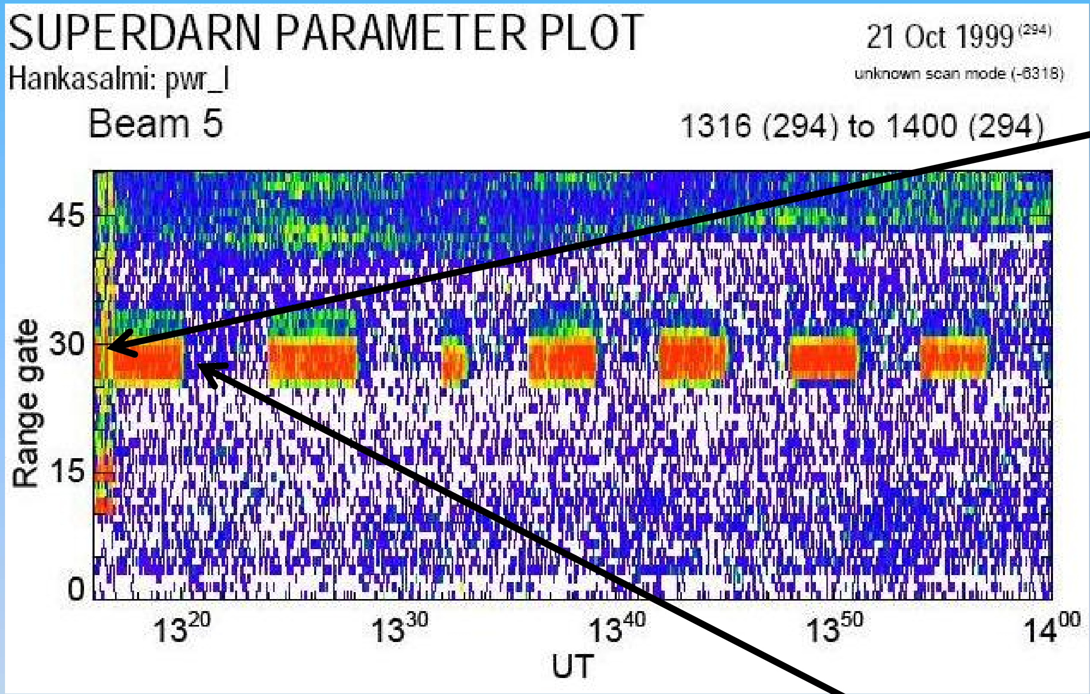
- Thermal conduction coefficients obtained from EISCAT data

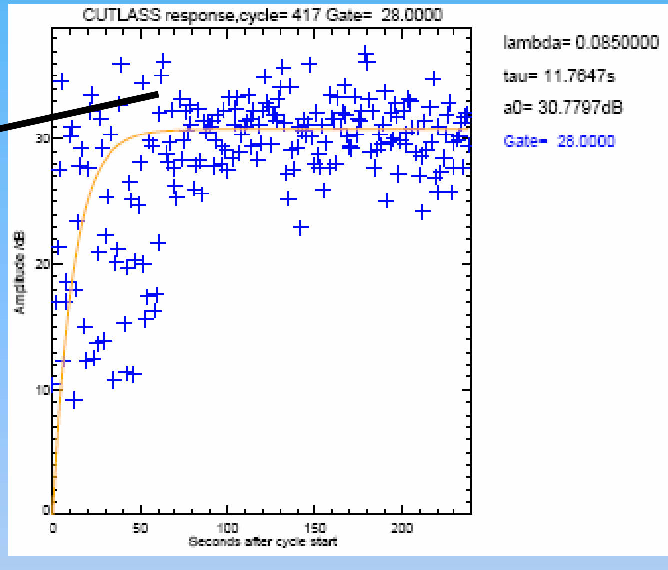
$$D_{\perp} = \frac{k_B T_{e0} \nu}{m_e \, \Omega^2} \qquad D_{\parallel} = \frac{k_B T_{e0}}{0.51 m_e \nu}$$

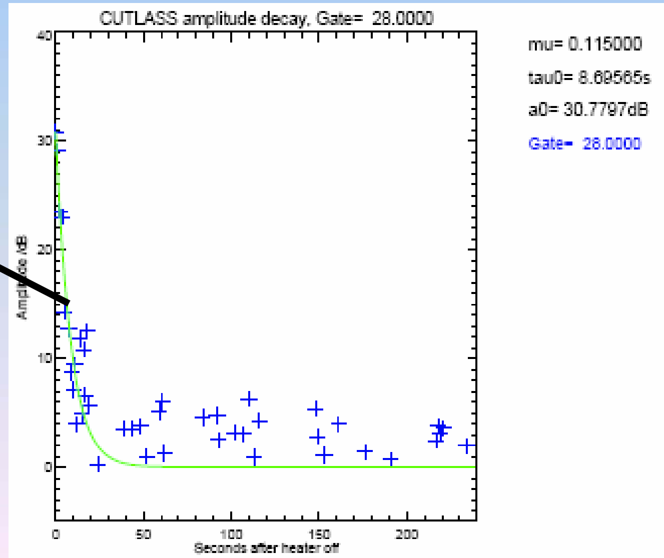
- Model rates from CUTLASS backscatter, **k** is fixed – check consistency of EISCAT data

$$\tau \propto {T_{e0}}^3$$

Fitted curves

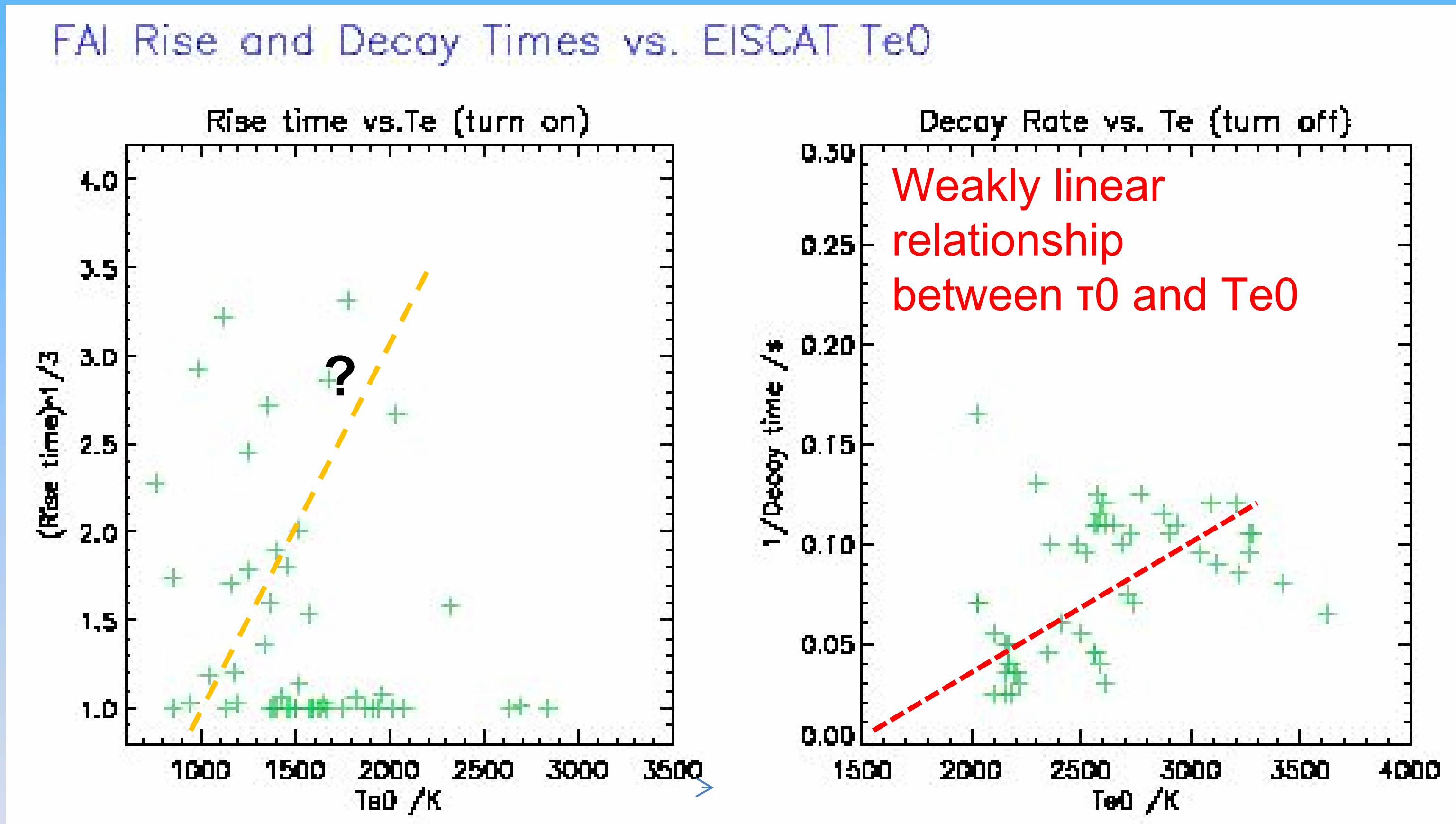






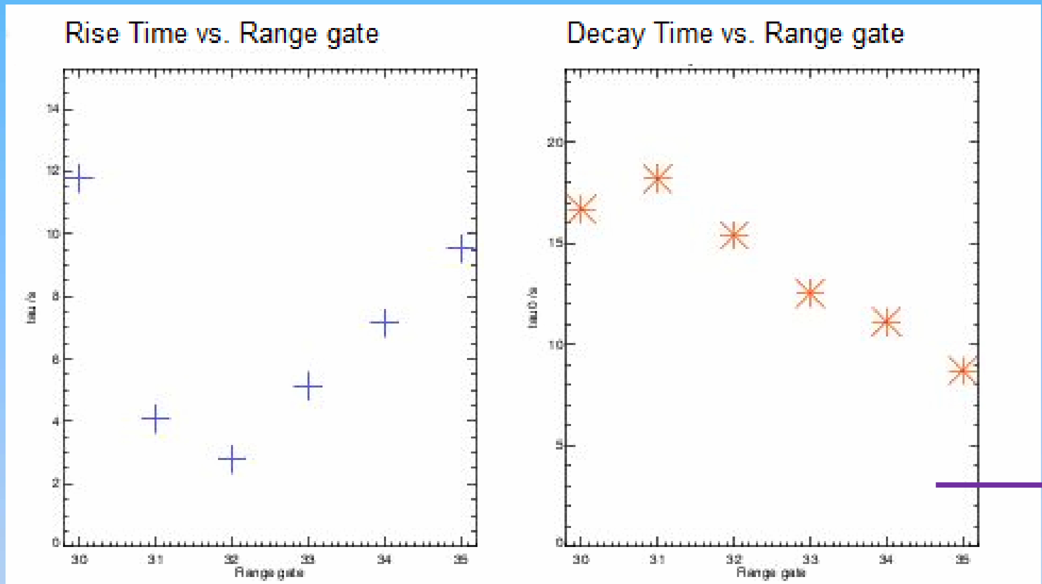
- Time to steady-state amplitude time
- Least-squares fitting procedure for heater-on and heater-off
- 'Growth' of form $A = A_0(1 - e^{-\tau_1 t})$
- 'Decay' form $B = B_0 e^{-\tau_0 t}$

Experiment vs. Theory



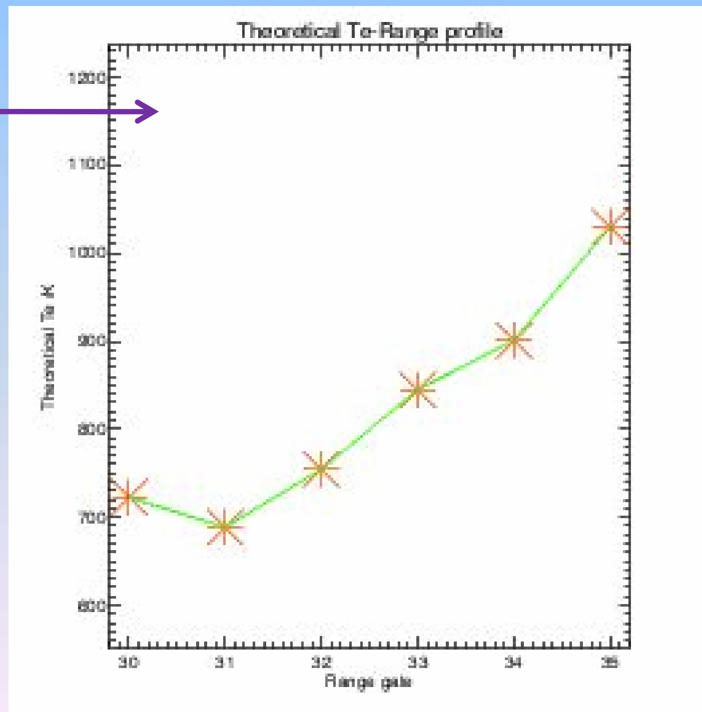
$$\gamma \sim \frac{1}{\tau} \propto \frac{1}{T_{e0}{}^{3}} \rightarrow T_{e0} \propto \tau^{1/3} \qquad \gamma_0 \sim \frac{1}{\tau_0} \propto T_{e0}$$

Theoretical Te Range profile



Decay time independent of heater E field

Te from theory much lower than EISCAT inferred values



1/Rise time ~ E_0^4 → range-dependence

$$D_\perp = \frac{k_B T_{e0} \nu}{m_e \ \Omega^2} \qquad \nu_e = 5.8x10^{-11} N_n T_{e0}^{5/6}$$

$$\Rightarrow T_{e0}(r) = \left(\frac{m_e \Omega_e^2 \gamma_-(r)}{10.44x10^{-11} N_n k_B k^2} \right)^{6/11}$$

Further work

- Te fitting for LOTS more heating cycles + estimate growth & decay rates for more CUTLASS 'patches' - test theory
- Check correlation between model Te and τ (rise time)
- EISCAT scanning experiments: check how data fit with theoretical Te-range profiles → need to modify model?
  - Te0 assumed constant for $\tau 0$ estimates; but Te decreases after heater turned off → ***time-dependent decay rate***
  - Te 'decay' rate will determine effective FAI decay rate
  - Lower –than-expected Te from theory may correspond to $\tau 0$ representative of latter stage decay?
- Simple exponential decay curve not very accurate for time-dependent decay rate