Measurement of Ion Transport Driven by Magnetic Fluctuations in MST Edge

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It has long been expected that magnetic fluctuation driven ion radial particle flux ($<\tilde{j}_{i\|}\tilde{b}_r>/eB$) in MST is large. Measurement, however, shows it to be small. Magnetic fluctuation driven electron, and total charge radial flux, ($<\tilde{j}_{e\|}\tilde{b}_r>/eB$) and $<\tilde{j}_{\|}\tilde{b}_r>/eB$), have been measured using insertable probes. The magnetic fluctuation driven flux for total charge is measured as being small, indicating ambipolar particle flux, while for electrons it is measured as being large. This is inconsistent with the measurement of magnetic fluctuation driven radial ion flux. A robust upper bound can be placed on magnetic fluctuation driven ion flux, leading to the conclusion that the electron and/or charge flux measurments, both of which agree with prior well established measurements, must be flawed.

*Work surported by U.S. D.O.E.

Outline

Motivation: Expectations for Magnetic Fluctuation Driven Ion Transport

Discussion of Magnetic Fluctuation Driven Ion Transport

Comparison of Magnetic Fluctuation Driven Electron and Charge Transport

Discussion of Inconsistency in Transport Measurements

Discussion of Diagnostics

Conclusions

Motivation

Magnetic fluctuation driven particle transport in MST has been measured to be ambipolar, in agreement with expectation.

Magnetic fluctuation driven electron transport has been measured to be large.

It has been expected that magnetic fluctuation driven transport of ions would be large.

Magnetic fluctuation driven ion transport was measured to test this expectation.

Magnetic Fluctuation Driven Ion Transport is Expected to be Large.

The magnetic fluctuation driven electron flux, Γ_e has been measured[2] in the MST edge to be large.

Magnetic fluctuation driven particle transport is expected to be ambipolar ($\Gamma_i \sim \Gamma_e$) since:

The magnetic fluctuation driven charge flux, Γ_q, has been measured[1] to be much much smaller than the electron flux.

Tearing modes dominate the magnetic fluctutions in RFPs. The phase relationship of $\tilde{\mathbf{j}}_{\parallel}$ and $\tilde{\mathbf{b}}_r$ for tearing modes leads to the expectation that $\Gamma_q = 0$.

In other words: $\Gamma_q = \Gamma_i - \Gamma_e$, Γ_e large, Γ_q small => Γ_i large

[1] W. Shen, et al., Phys. Rev. Lett. **68** (1319), March 1992.
[2] M. R. Stoneking, et al., Phys. Rev. Lett. **73** (549), July 1994.

Ion Transport Driven by Magnetic Fluctuations is Small

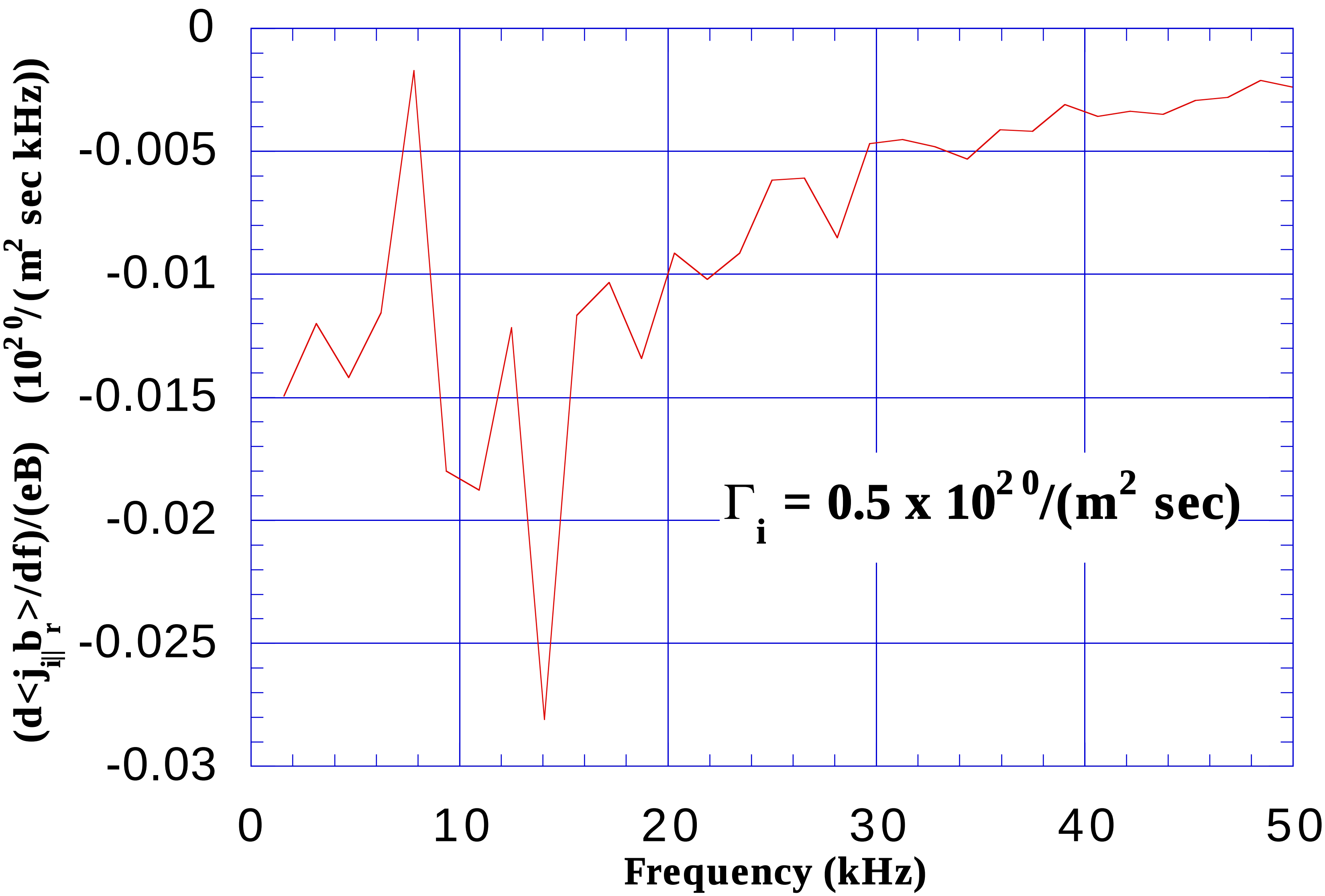
@ r/a = .86

$$\Gamma_i = \langle \tilde{j}_{i||} \tilde{b}_r \rangle / eB = 0.5 \times 10^{20} / m^2 s$$

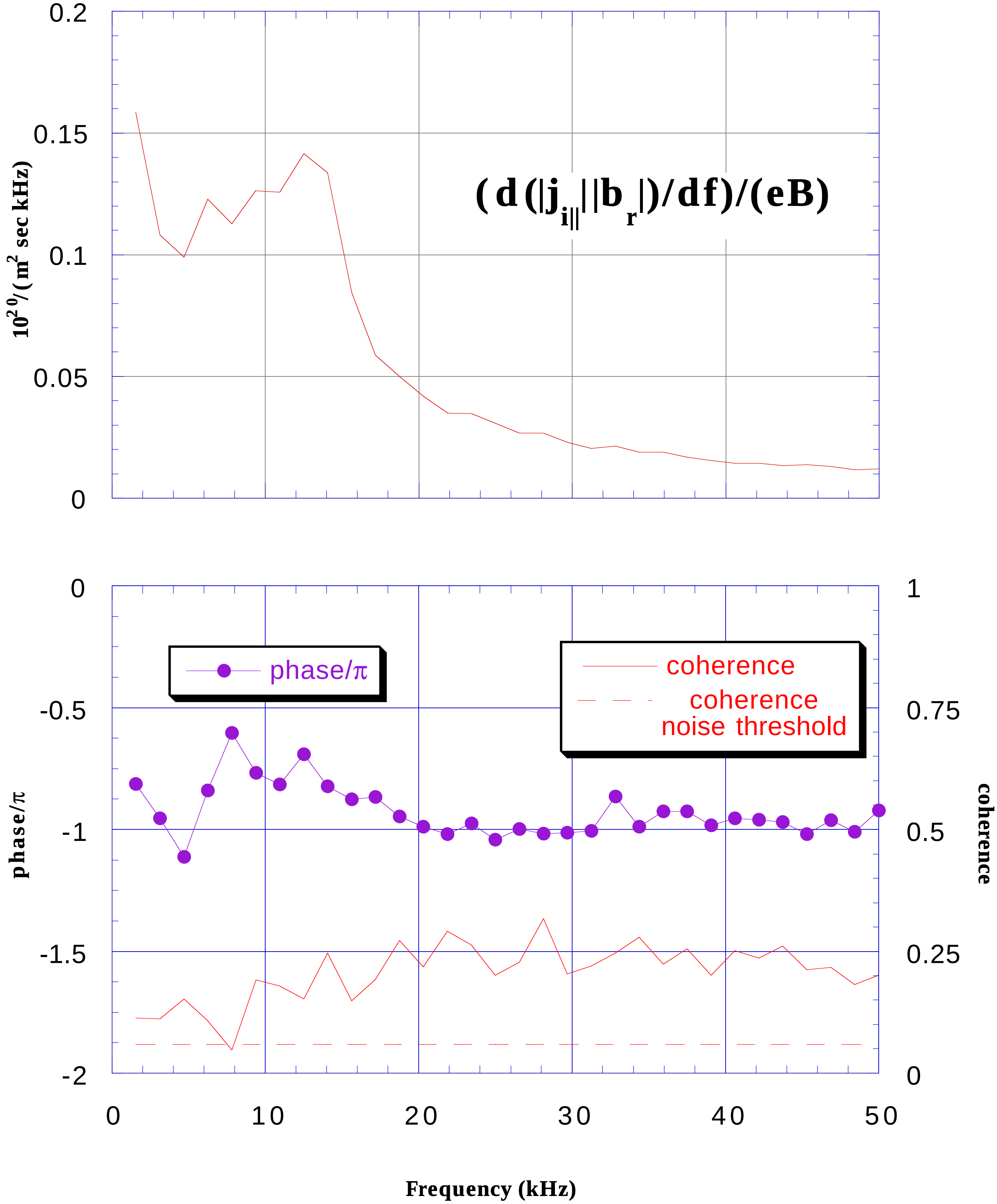
$$(|\tilde{j}_{i||}||\tilde{b}_r| / eB \sim 3 \times 10^{20} / m^2 s,\ \gamma \sim .14, \phi \sim -\pi)$$

Total particle transport is estimated to be ~10-50x10^{20}/m^{2}s.

Ion Transport at r/a = .86



Ion Transport Spectral Characteristics at r/a = .86



Measured $\tilde{b}_r$-Driven Flux for Electrons Much Greater than for Total Charge

(@ r/a = .86)

$$\Gamma_e = \langle \tilde{j}_{e\|} \tilde{b}_r \rangle / eB = 12\times10^{20}/m^2 s$$

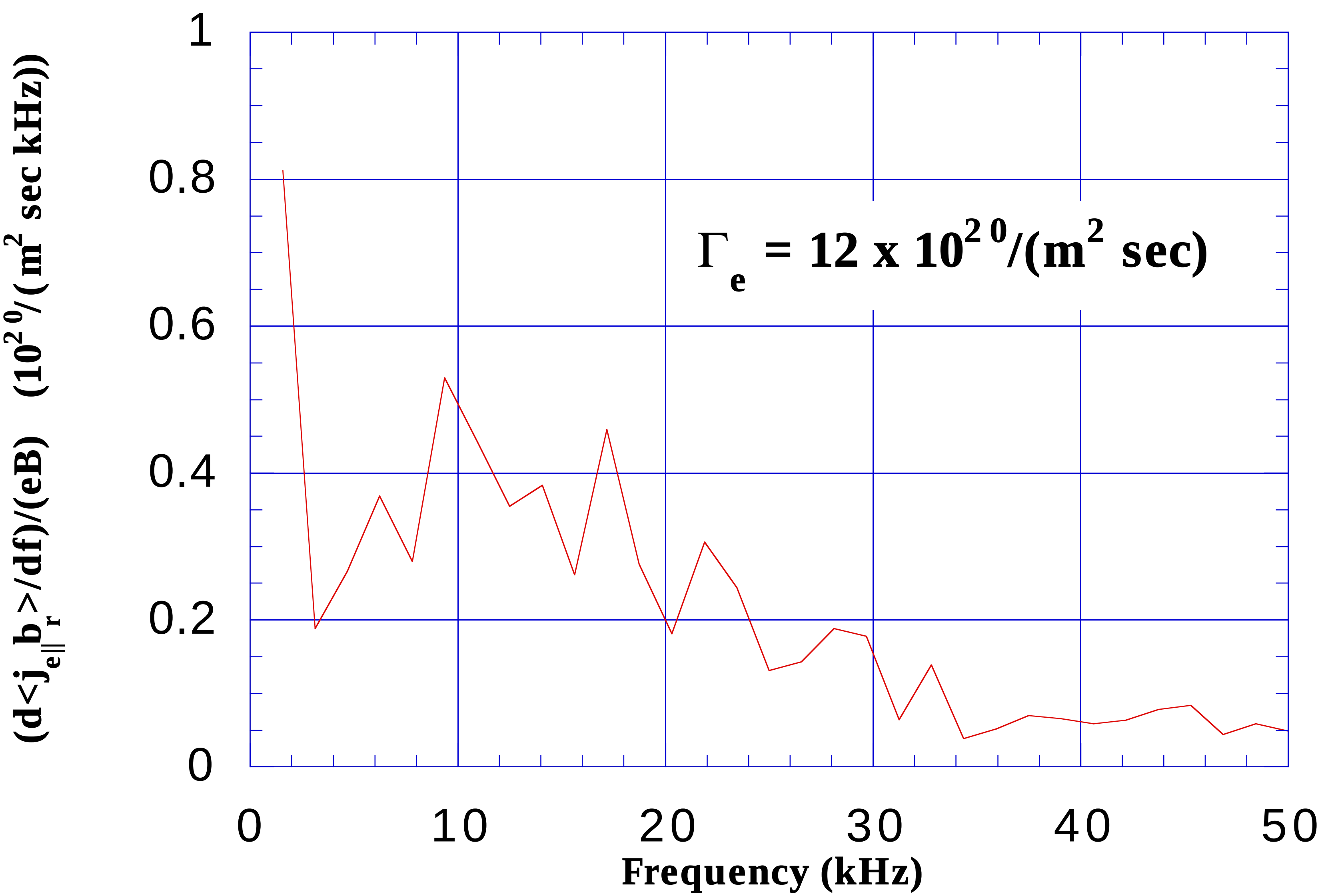
$(|\tilde{j}_{e\|}||\tilde{b}_r|/eB \sim 74\times10^{20}/m^2 s,\ \gamma \sim .16, \phi \sim 0)$

$$\Gamma_q = \langle \tilde{j}_{\|} \tilde{b}_r \rangle / eB = 3\times10^{20}/m^2 s$$

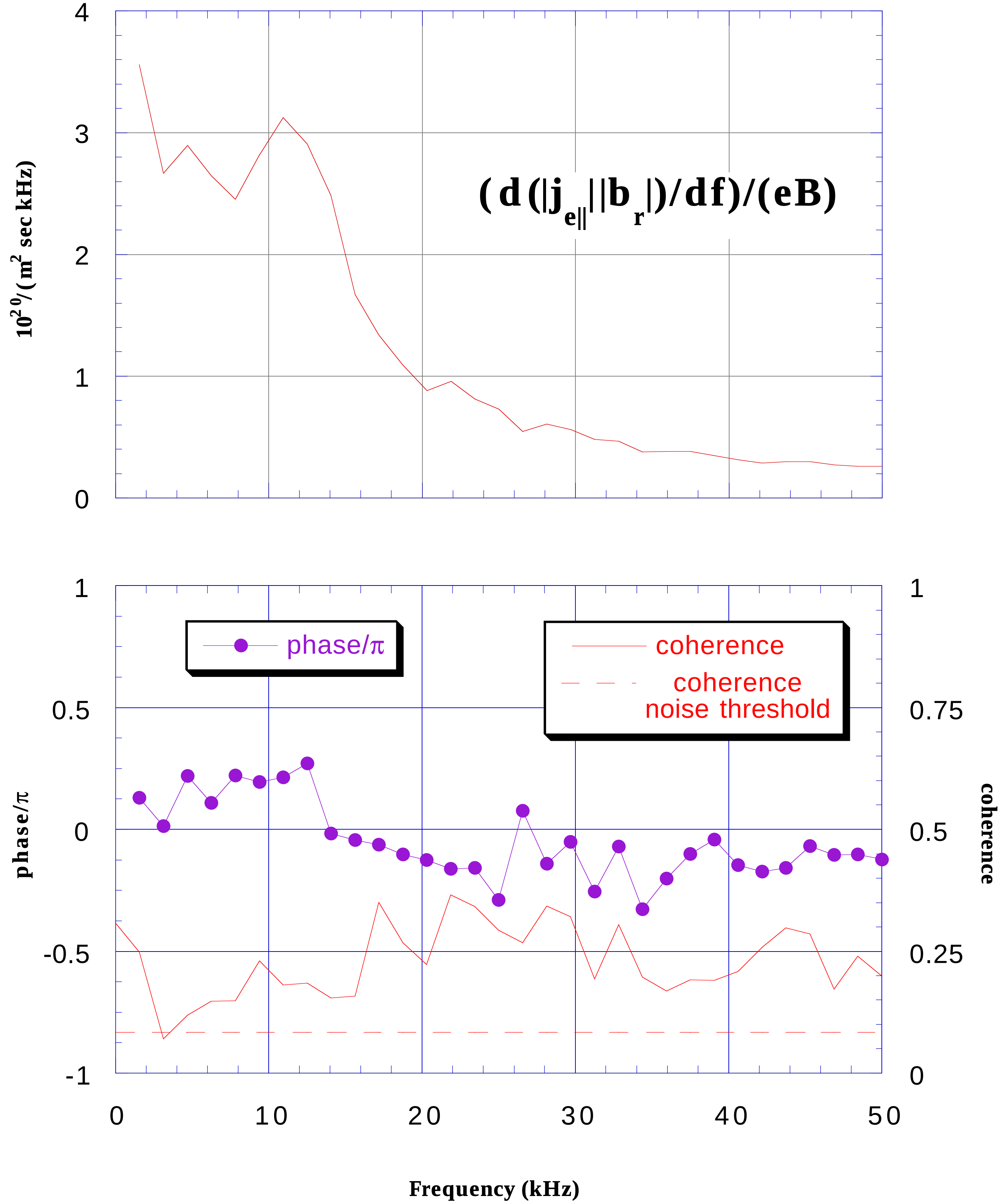
$(|\tilde{j}_{\|}||\tilde{b}_r|/eB \sim 42\times10^{20}/m^2 s,\ \gamma \sim .12, \phi \sim -(.3)\pi)$

Difference between Γ_e and Γ_q is due to difference of phases of $\tilde{j}_{e\|}$ and $\tilde{j}_{\|}$ relative to $\tilde{b}_r$. Phase for Γ_q is near $\pi/2$, so Γ_q has large relative uncertainty.

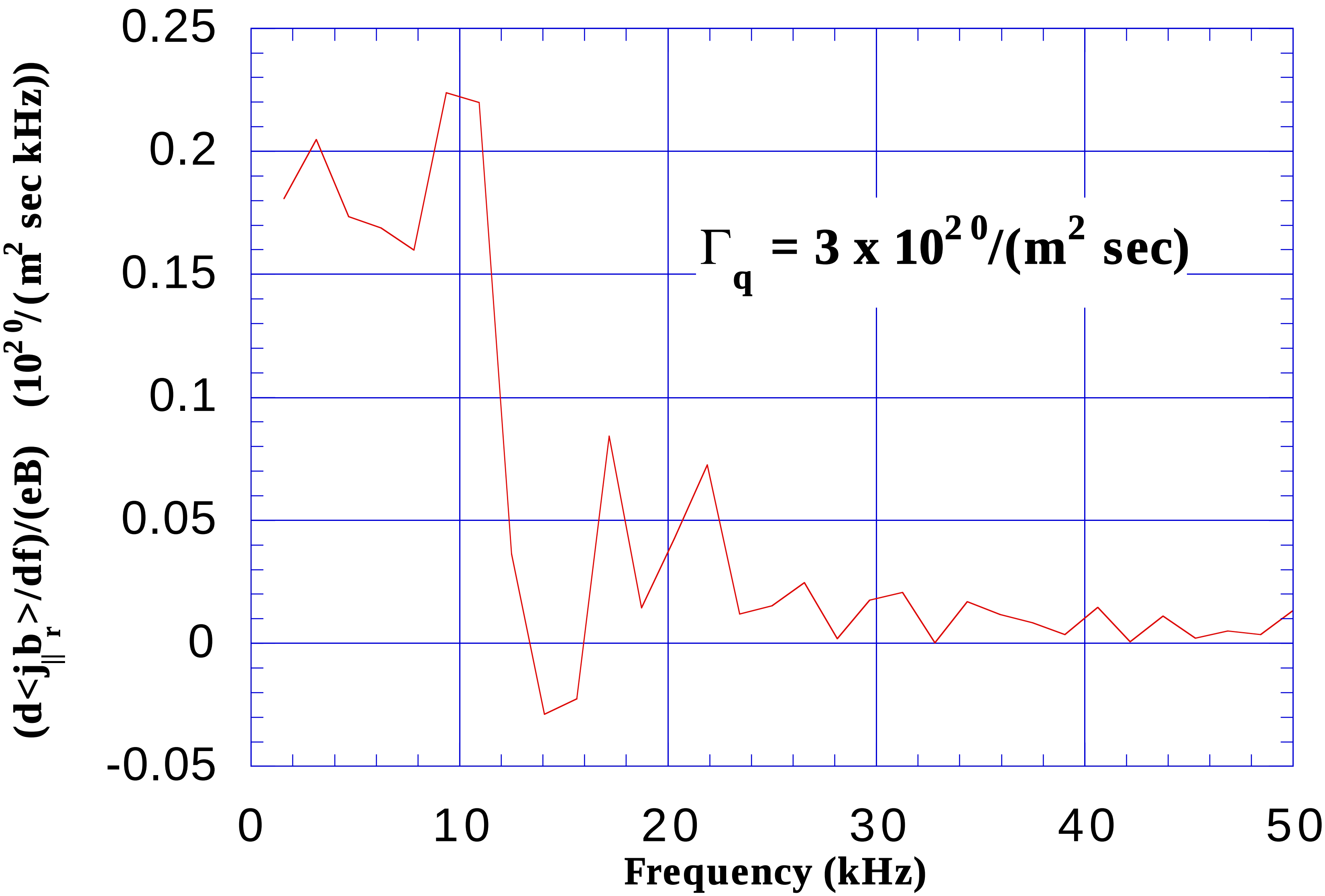
Electron Transport at r/a = .86



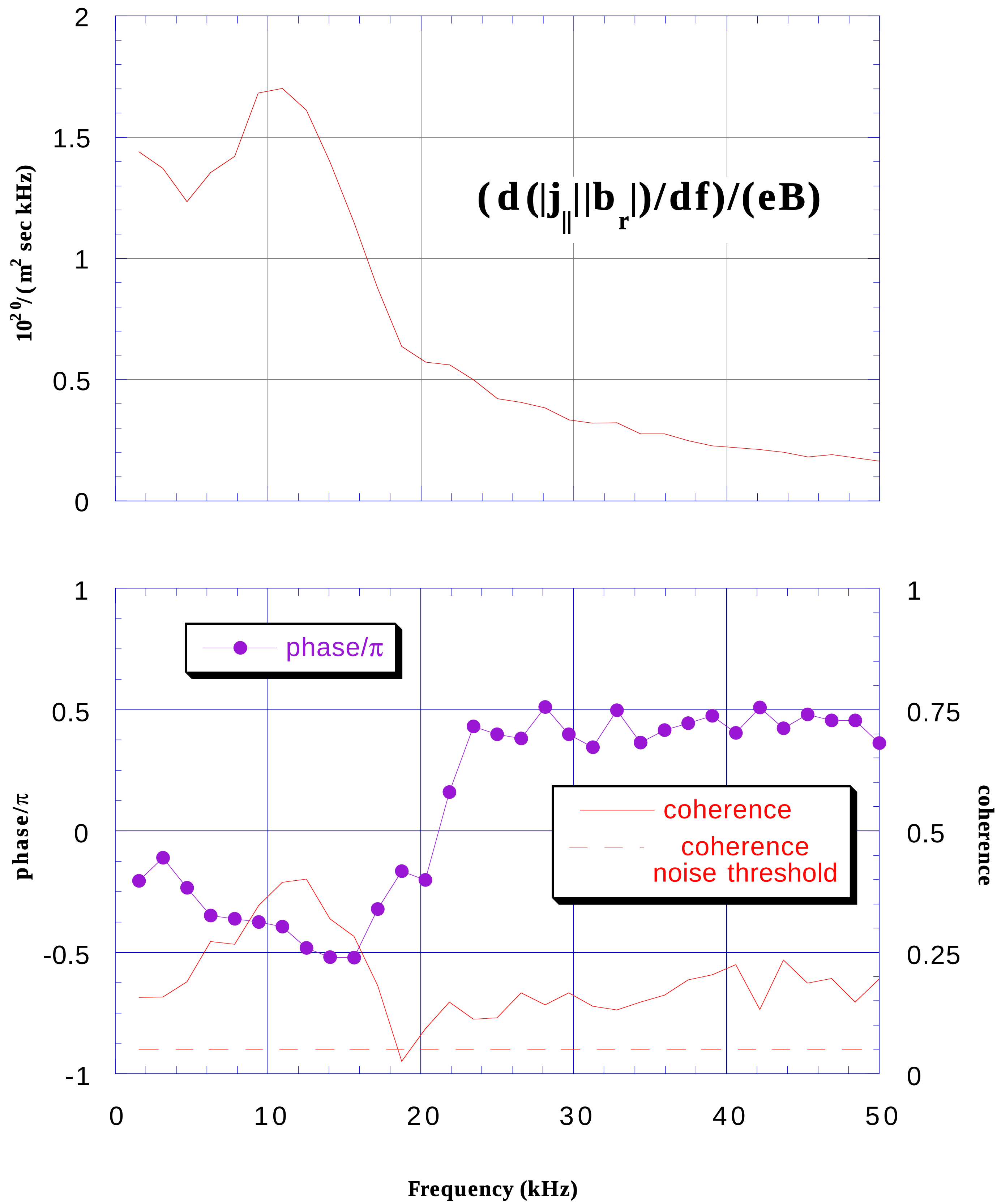
Electron Transport Spectral Characteristics at r/a = .86



Charge Transport at r/a = .86



Charge Transport Spectral Characteristics at r/a = .86



Inconsistency in Transport Measurements

Measurements of Γ_i, Γ_e and Γ_q do not yield $\Gamma_i - \Gamma_e = \Gamma_q$

$|\tilde{j}_{i\|}|$ and $|\tilde{b}_r|$ place an upper bound on Γ_i $(\max |\Gamma_i| \sim |\Gamma_q|)$

Since $\Gamma_e >> \Gamma_q$, no error in $\langle \tilde{j}_{i\|} \tilde{b}_r \rangle$ could account for inconsistency.

Measurements of Γ_e and/or Γ_q are flawed

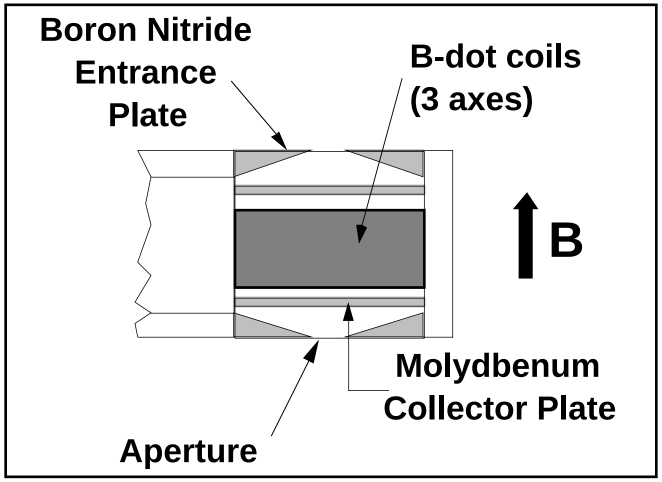
Measurement Techniques

Measurement of Γ_e, Γ_i

The magnetic fluctuation driven cross surface flux of species α is given by

$$\Gamma_\alpha = \langle \tilde{j}_{\alpha\|} \tilde{b}_r \rangle / eB$$

< > indicates a flux surface average, achieved by averaging over an ensemble of many time records taken at a single location. α refers to ions or electrons.



$\tilde{j}_{\alpha\|}$ can be measured using the Flux Probe (FP)

The FP is oriented to collect current parallel to the magnetic field.

The collectors are biased to repel electrons or ions.

$J_{\|\alpha}$ is obtained from difference of the collector currents divided by their respective aperture areas.

The aperture is wide-angle and shallow to reduce ion gyroradius effects on ion collection.

$\tilde{b}_r$ is measured simultaneously by a coil inside the probe head.

Measurement of Γ_q

$\Gamma_q = \langle j_\| \tilde{b}_r \rangle / eB$ is measured with an insertable Rogowskii with a built in $\tilde{b}_r$ coil.

Potential Flaws in Diagnostics

FLOW PROBE

Probe <u>interrupts parallel current</u>, which may self-consistently <u>modify probe measurement</u>. In particular, current collection by probe may locally change ambipolarity contraint. Probe also modifies trajectories of oscillating particles.

<u>Probe may ablate, producing local plasma.</u> In the presence of fast electrons (which have a strongly drifted distribution) ablation would be assymetric, so that <u>local plasma is seen by probe as a current source</u>. Fast electrons may correlate with magnetic flucuations so that <u>locally generated current may be seen as electron transport</u>.

ROGOWSKII

Rogowskii <u>geometry</u> may result in <u>scrape off</u> of significant fraction of <u>ions</u> that would otherwise pass through. This would cause <u>electrostatic barrier</u> to passage of low energy <u>electrons</u>. Such a barrier would vary with ion density, which may correlate with magnetic fluctuations. This would could lead to a corruption of the measurement of charge transport.

Approaches to Resolving Measurement Inconsistency

Build modified Rogowskii to reduce or eliminate geometric effects on measured current density.

Controlled comparison of Rogowskii and Flow Probe using electron gun.

Conclusions

$\tilde{b}_r$-driven ion transport is much smaller than total particle transport.

There is an inconsistency in the measurements of Γ_i, Γ_e and Γ_q.

Γ_e and/or Γ_q. measurements must be flawed.