KSTAR ECEI diagnostics and fluctana code

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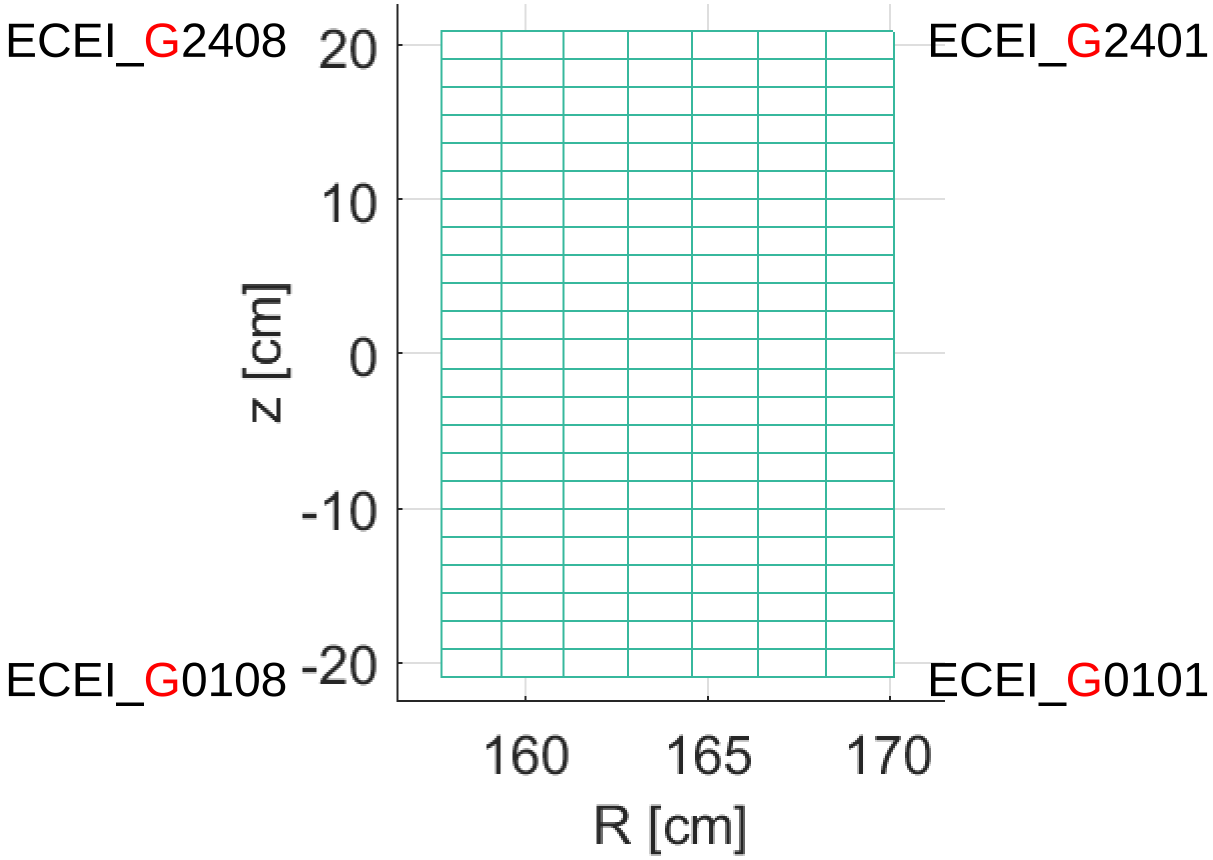
The KSTAR ECEI channel numbering

- There are three ECEI systems (L, H, G), and each has 24 (vertical) x 8 (radial) = 192 channels
- For example, the ECEI G system channel numbering



The ECEI data analysis and fluctana code

- The ECEI measures 2D local electron cyclotron emission intensity ($\propto$ local electron temperature when optical depth is large)
- MHD instability research
  - Mode number identification *Lee RSI 2016*
  - Plasma displacement estimation for MHD mode growth/decay rate *Choi RSI 2016*
- Turbulence research
  - Spectral analysis *Choi APS 2011 & 2015, Lee PRL 2016, Choi NF 2017*
  - Statistical analysis
- fluctana
  - 'adv_analysis' (matlab) developed in 2011; significantly improved in 2012—2014 (ack: Dr. S. Zoletnik and Prof. Y.-c. Ghim); being re-written in Python

Introduction to spectral methods used in fluctana

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Spectral analysis

- Cross power spectral density (FFT)
- Coherence (FFT)
- Cross phase / wavenumber (FFT)

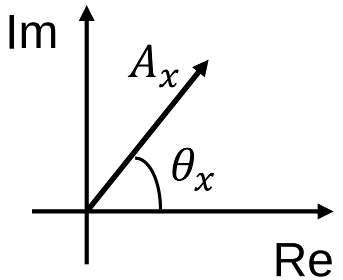
Cross power spectral density (CPSD) and cross phase

- Definition
  - For two time series data $x(t)$ and $y(t)$
    Let $X(f)$ and $Y(f)$ be the Fourier transform of $x(t)$ and $y(t)$, respectively.
  - CPSD is defined as
    $$\langle X(f)Y^*(f)\rangle$$
    where $\langle\ \rangle$ denotes an ensemble average
- Meaning
  - $X(f) = A_x(f)\, e^{-i\theta_x(f)}$
    $A_x(f)$ is (sinusoidal) amplitude of $x(t)$ at given f
    $\theta_x(f)$ is (sinusoidal) phase of $x(t)$ at given f
  - $X(f)Y^*(f) = A_x\,(f)A_y\,(f)\, e^{-i(\theta_x(f)-\theta_y(f))}$
    $A_{xy}\,(f) = A_x\,(f)A_y\,(f)$ is product of amplitudes
    $\theta_{xy}(f) = \theta_x(f) - \theta_y(f)$ is cross phase (phase difference btw of $x(t)$ and $y(t)$)

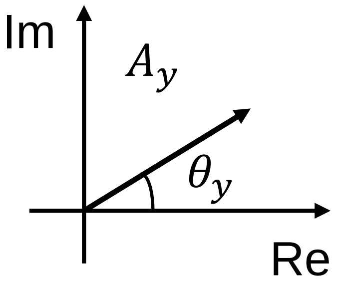
Cross power spectral density (CPSD) and cross phase

- $\langle X(f)Y^*(f)\rangle = \dfrac{X_1(f)Y_1^*(f)+\ldots+X_N(f)Y_N^*(f)}{N}$

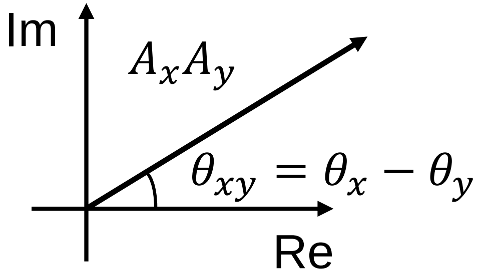
$X(f)$



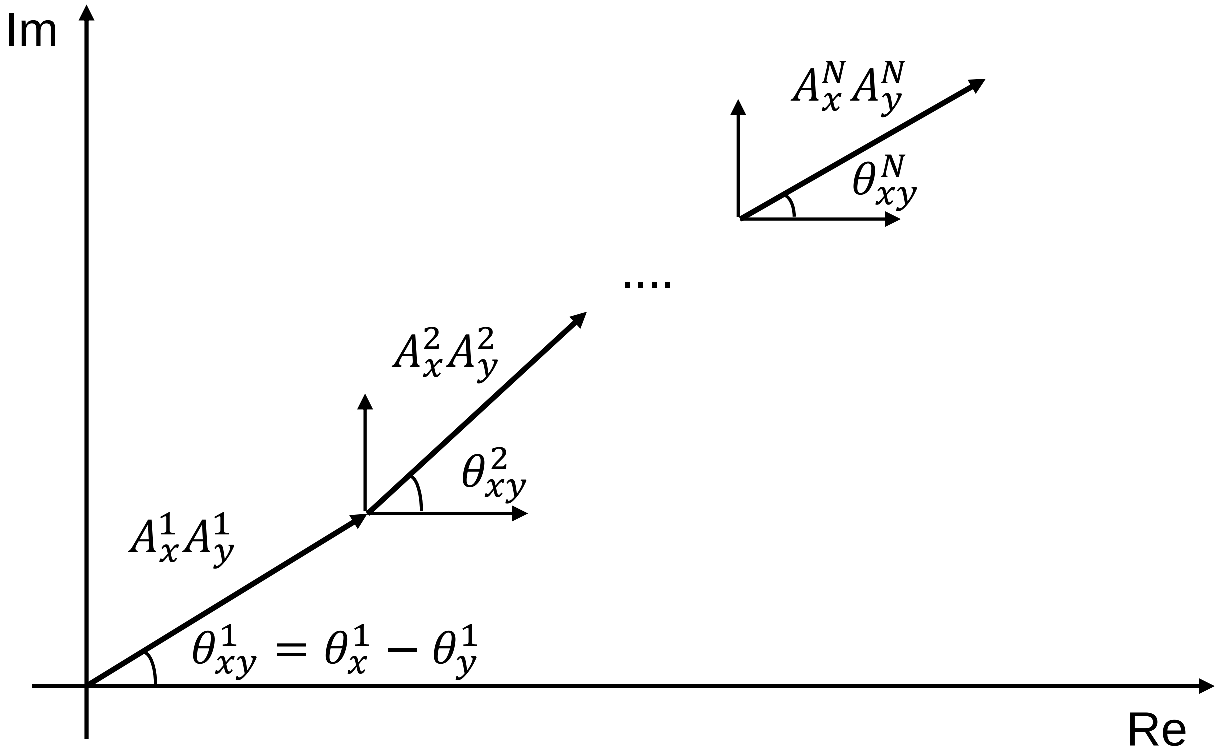
$Y(f)$



$X(f)Y^*(f)$



$X_1(f)Y_1^*(f)+\ldots+X_N(f)Y_N^*(f)$



Non-coherent (random phase) (including noise) components will be canceled out for a large N

Coherence

- Definition
  - Normalized CPSD

$$\frac{|\langle X(f)Y^*(f)\rangle|}{\sqrt{\langle X(f)X^*(f)\rangle\langle Y(f)Y^*(f)\rangle}}$$

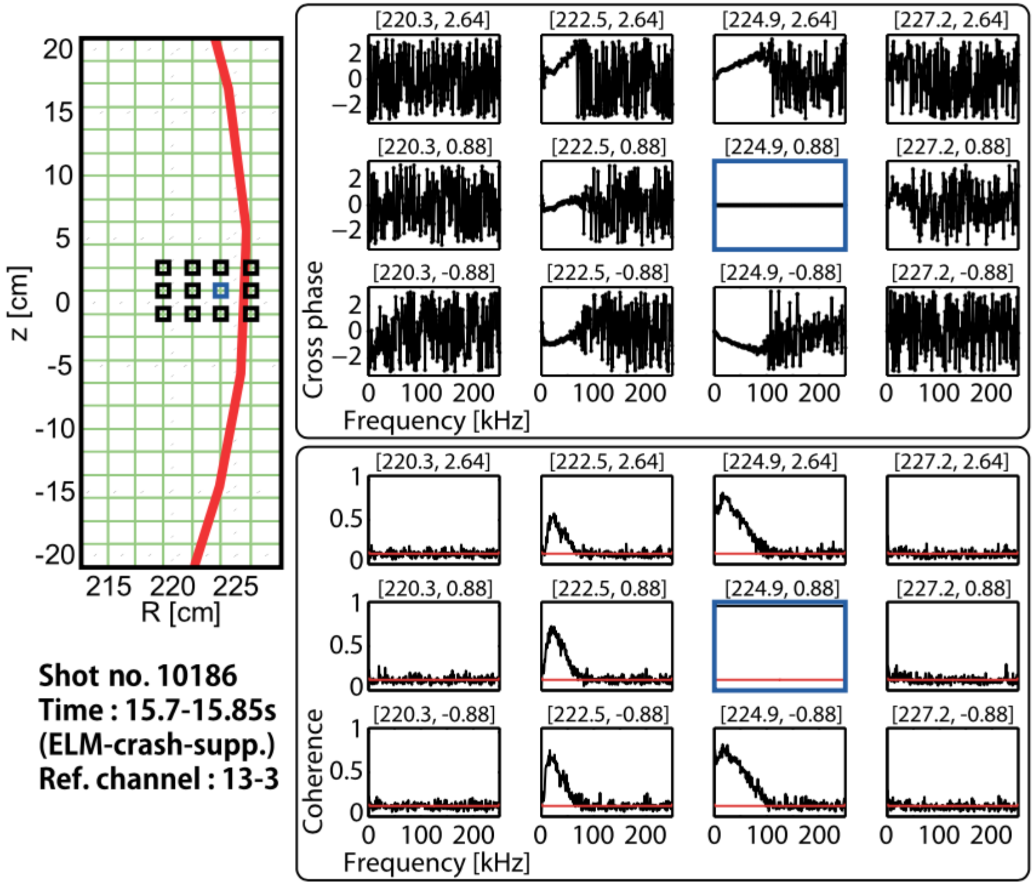
    where $\langle X(f)X^*(f)\rangle$ is auto power spectral density

- Meaning
  - It means the coherent (constant θ_{xy}) power fraction over total power (0—1)
  - In contrast to CPSD, it is normalized by total power, and so a large power non-coherent (remaining) component is safely excluded
  - It is also useful when the background noise level (or the channel position) is not stationary

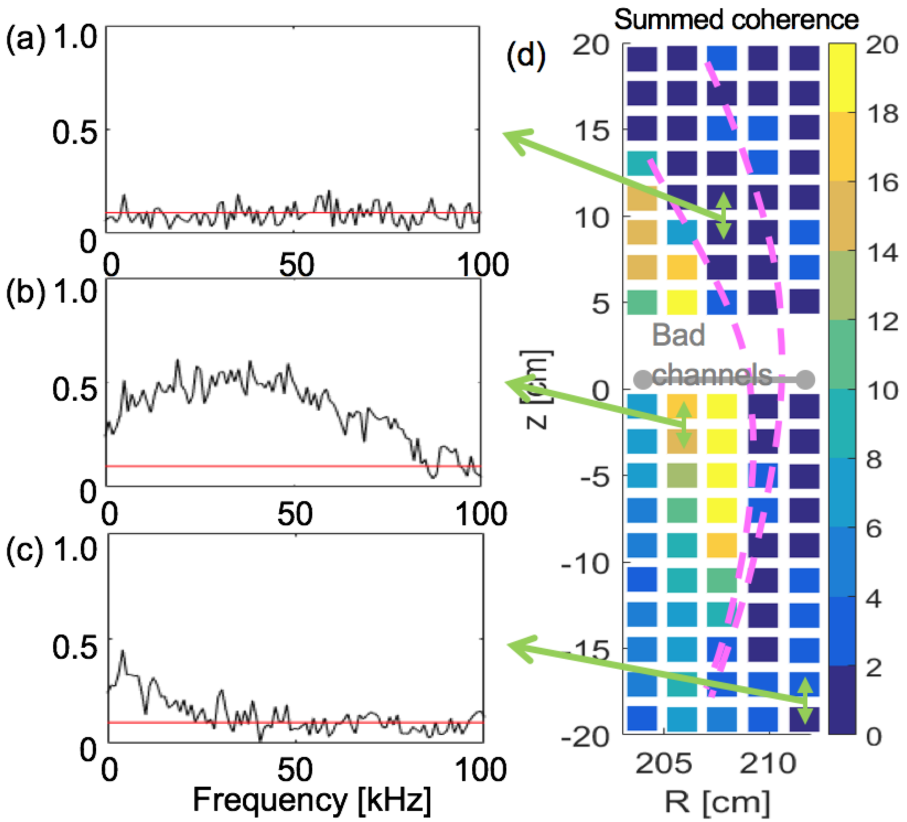
Coherence

- Application
  - Turbulence near pedestal, q=2, ...

Lee PRL 2016

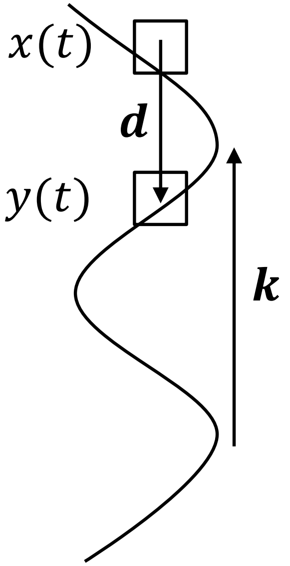


Choi NF 2017

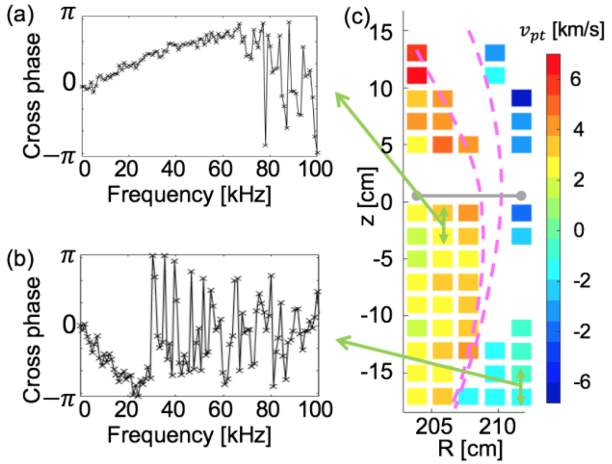


Local cross phase or wavenumber

- Definition
  - For two signals from two separated channels, $\theta_{xy}(f) = \boldsymbol{k} \cdot \boldsymbol{d}$ is local cross phase where $\boldsymbol{k}$ is wavenumber vector and $\boldsymbol{d}$ is separation vector



- Meaning
  - Wavenumber can be estimated using above relation
  - It is a local dispersion relation and the phase velocity is $v_p = \frac{\omega}{k} = \frac{2\pi f}{\theta_{xy}/d} = \frac{2\pi f}{\theta_{xy}} d$
- Application



Choi NF 2017