Velocity Detection of Plasma Patterns from 2D BES Data

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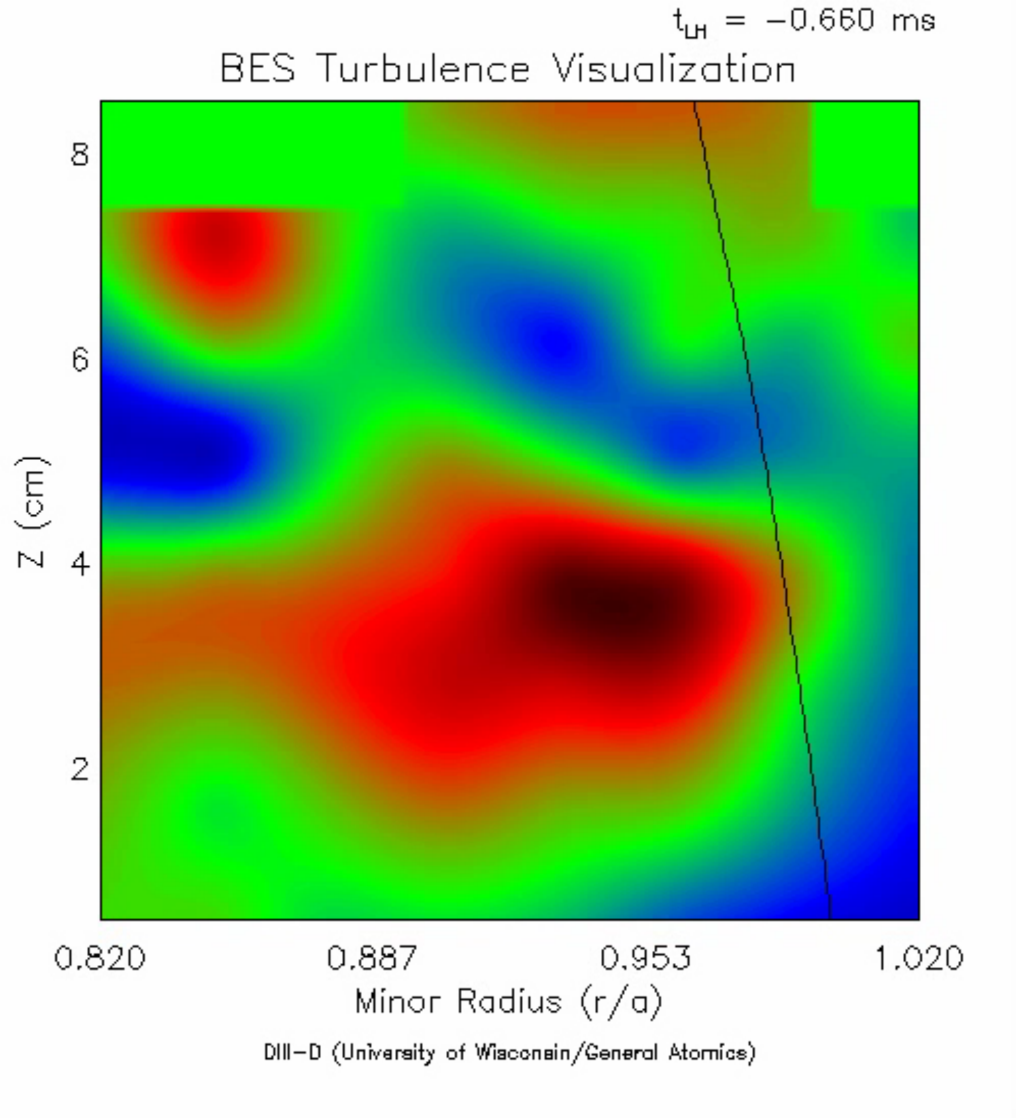
28, February, 2011

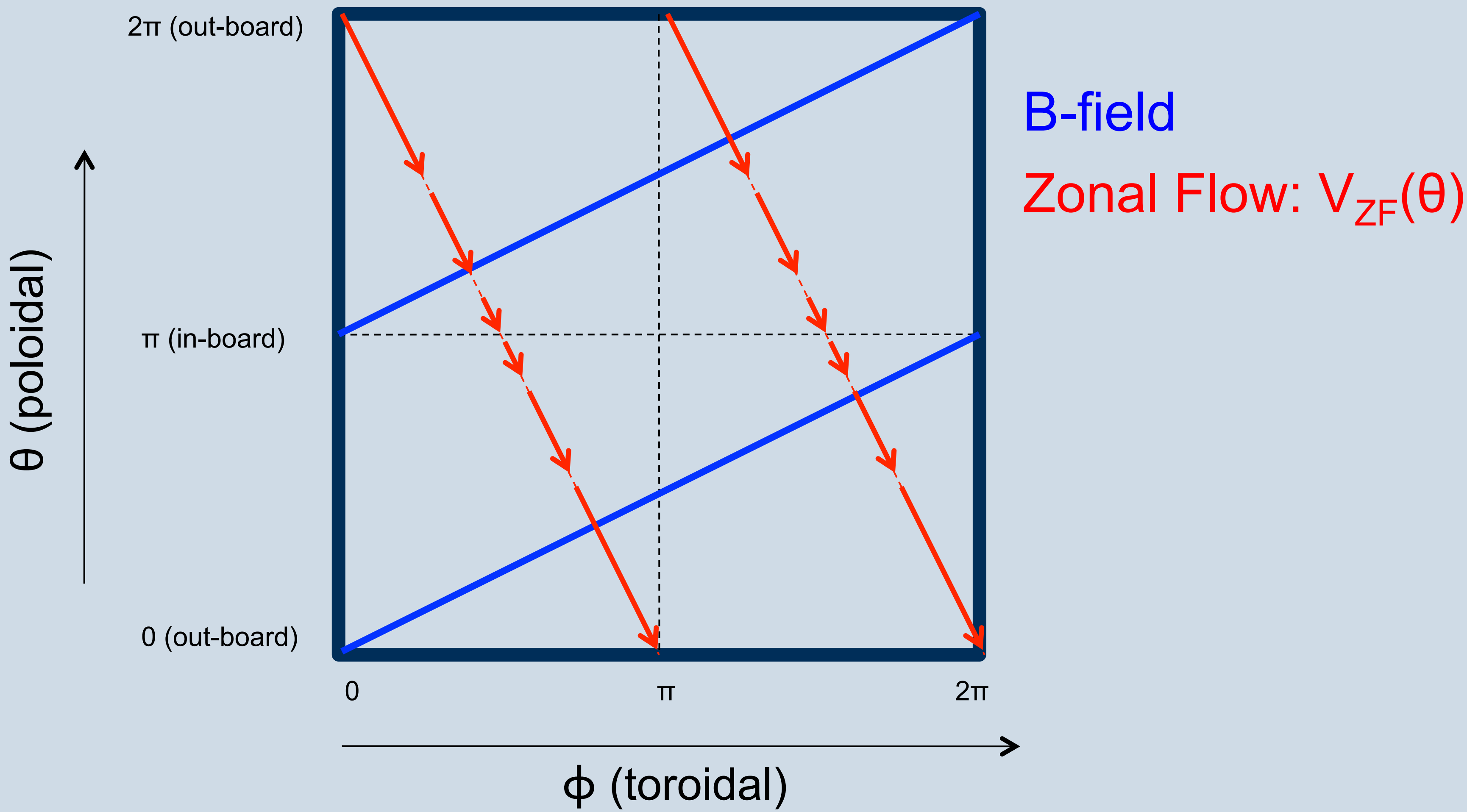
Quantity BES measures is Density Fluctuation.



Contents

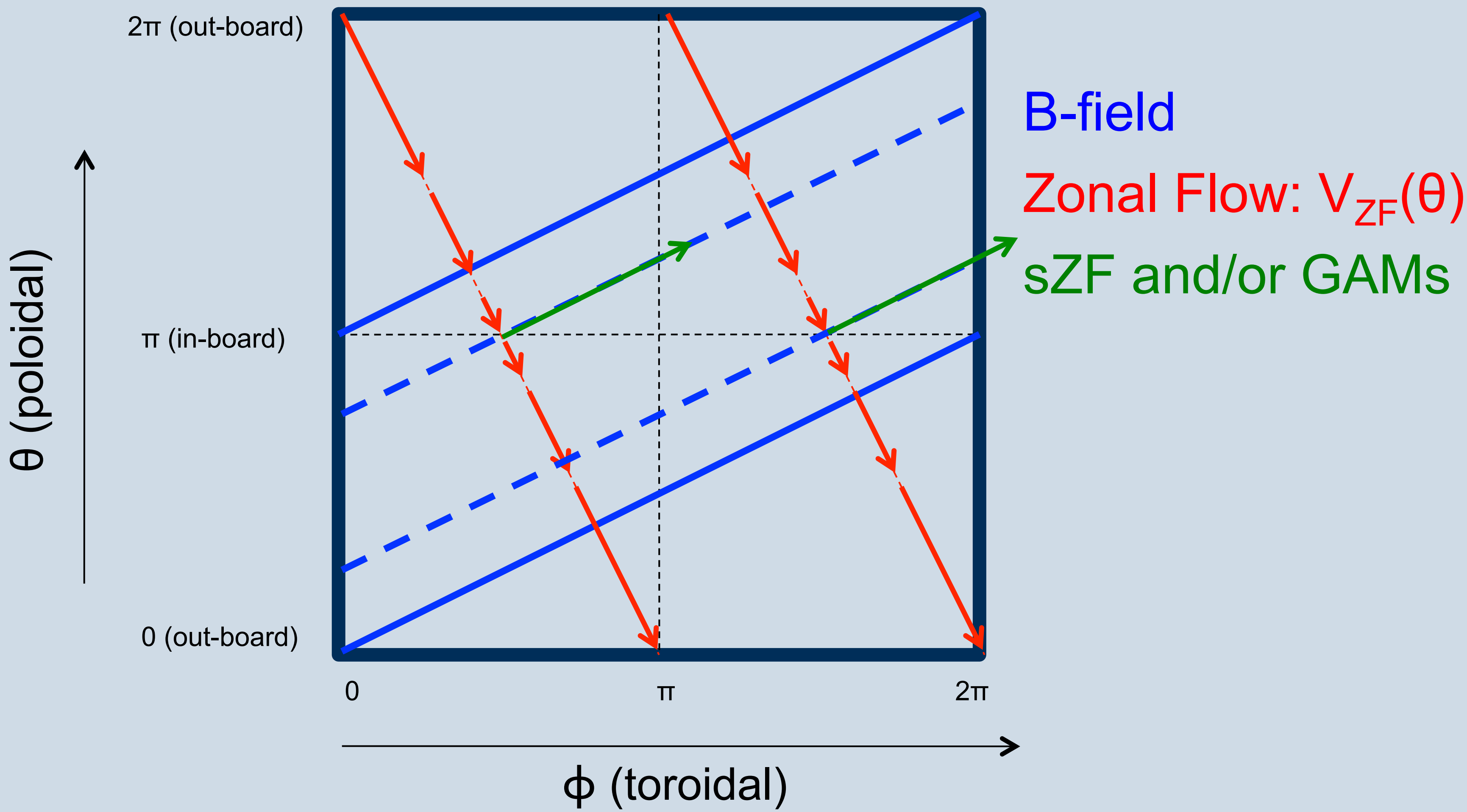
ZFs are not divergence free in a tokamak.

A Flux Surface (q=2 surface)



So, consequences are generating sZF and/or GAMs.

A Flux Surface (q=2 surface)



Structure of GAMs: (m, n) = (0, 0) and (1, 0)

Both modes have the same temporal behavior:

$$\omega_{GAM}^2 = \frac{C_S^2}{q^2 R^2}\left(1 + 2q^2\right)$$

Spatial structure of GAMs

$$\tilde{\phi}_{GAM}^{m=1} \sim \varepsilon \tilde{\phi}_{GAM}^{m=0}$$

where ε is the inverse aspect ratio.

$$\tilde{\phi}_{GAM}^{m=1} \sim -\sin(\theta)$$

Winsor et al. Phys. Fluids 11, 2448 (1968)

Density response to GAMs

Temporal behavior of density fluctuation:

$$\omega_{GAM}^2 = \frac{C_S^2}{q^2R^2}\left(1+2q^2\right)$$ because this is slow phenomena.

Due to m = 0 mode of GAM:

$$\tilde{\phi}_{GAM}^{m=0} \rightarrow \text{Polarization Drift} \rightarrow \text{Density fluctuation}$$

$$\rightarrow \tilde{n}_{GAM}^{m=0} \sim \left(k_r\rho_i\right)^2 \tilde{\phi}_{GAM}^{m=0}$$

Due to m = 1 mode of GAM:

$$\tilde{\phi}_{GAM}^{m=1} \rightarrow \text{e}^{-} \text{ Boltzmann Response} \rightarrow \text{Density fluctuation}$$

$$\rightarrow \tilde{n}_{GAM}^{m=1} \sim \tilde{\phi}_{GAM}^{m=1} \sim \varepsilon\tilde{\phi}_{GAM}^{m=0}$$

Detecting $\tilde{n}_{GAM}$ using 2D BES

$$\tilde{n}_{GAM} = A_{m=0}\exp(i\omega_{GAM}t) - A_{m=1}\sin(\theta)\exp(i\omega_{GAM}t)$$

- BES cannot detect *m*=1 mode of $\tilde{n}_{GAM}$ because observation position is mid-plane.
- How about m= 0 mode of $\tilde{n}_{GAM}$?

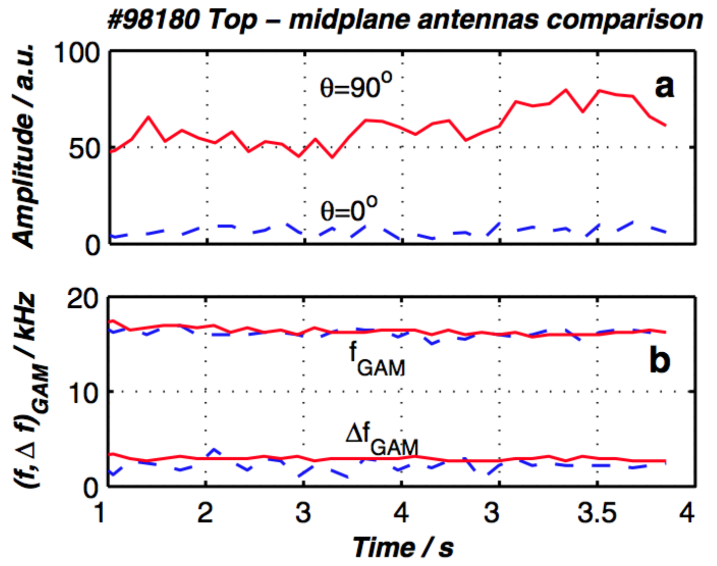


FIG. 4 (color online). (a) Comparison of the GAM amplitude at top (solid line) and midplane (dashed line) position. (b) Center frequency and FWHM of the GAM peak.

Krämer-Flecken et al. Phy. Rev. Lett. 97, 045006 (2006)

BES can detect GAMs from motions of ñ.

To the perpendicular direction on a given flux surface:

$$\tilde{v}_{\perp GAM}^{m=0} = \left(-k_r \tilde{\phi}_{GAM}^{m=0}\right)/B$$

$$\tilde{v}_{\perp GAM}^{m=1} = \left(-k_r \tilde{\phi}_{GAM}^{m=1}\right)/B$$

These induce oscillating perpendicular motion of ñ.

To the radial direction:

$$\tilde{v}_{r\,GAM}^{m=0} = \frac{\omega_{GAM}}{\omega_C B} k_r \tilde{\phi}_{GAM}^{m=0}$$

$$\tilde{v}_{r\,GAM}^{m=1} = \left(-k_\theta \tilde{\phi}_{GAM}^{m=1}\right)/B_\Phi$$

These induce oscillating radial motion of ñ.
But, their magnitudes may be small.

Conclusion I

As physicists, we want to know

- how zonal flows are generated.
- how they suppress turbulence.

First, we need to confirm existence of zonal flows.

↓

Try to observe ñ associated with zonal flows. → In general, not easy.

↓

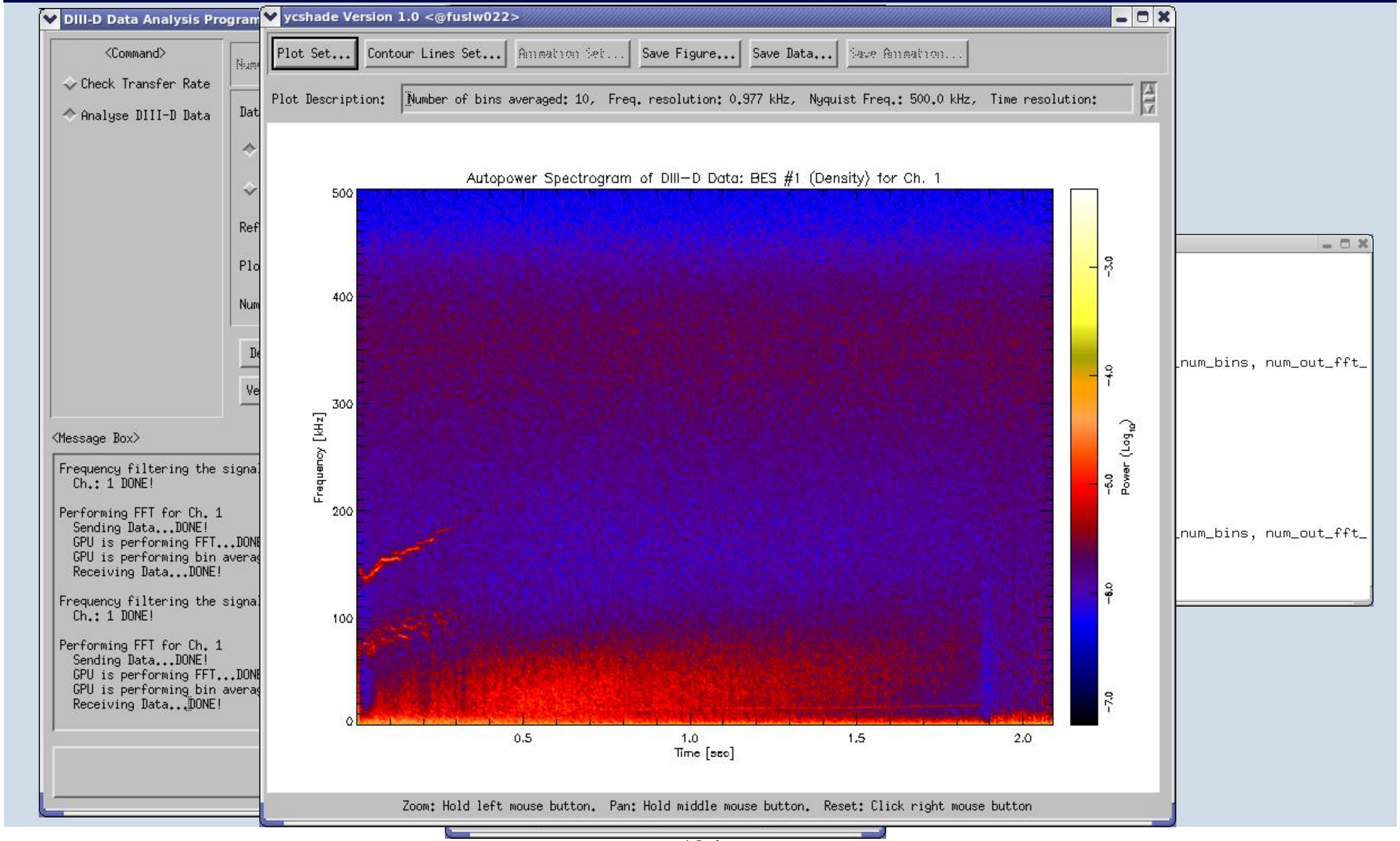
Try to observe ñ associated with GAMs. → Hard with BES at the midplane

↓

Try to observe GAM induced motions of ñ → Possible with BES

Contents

Statistical analyses are performed on a GPU.



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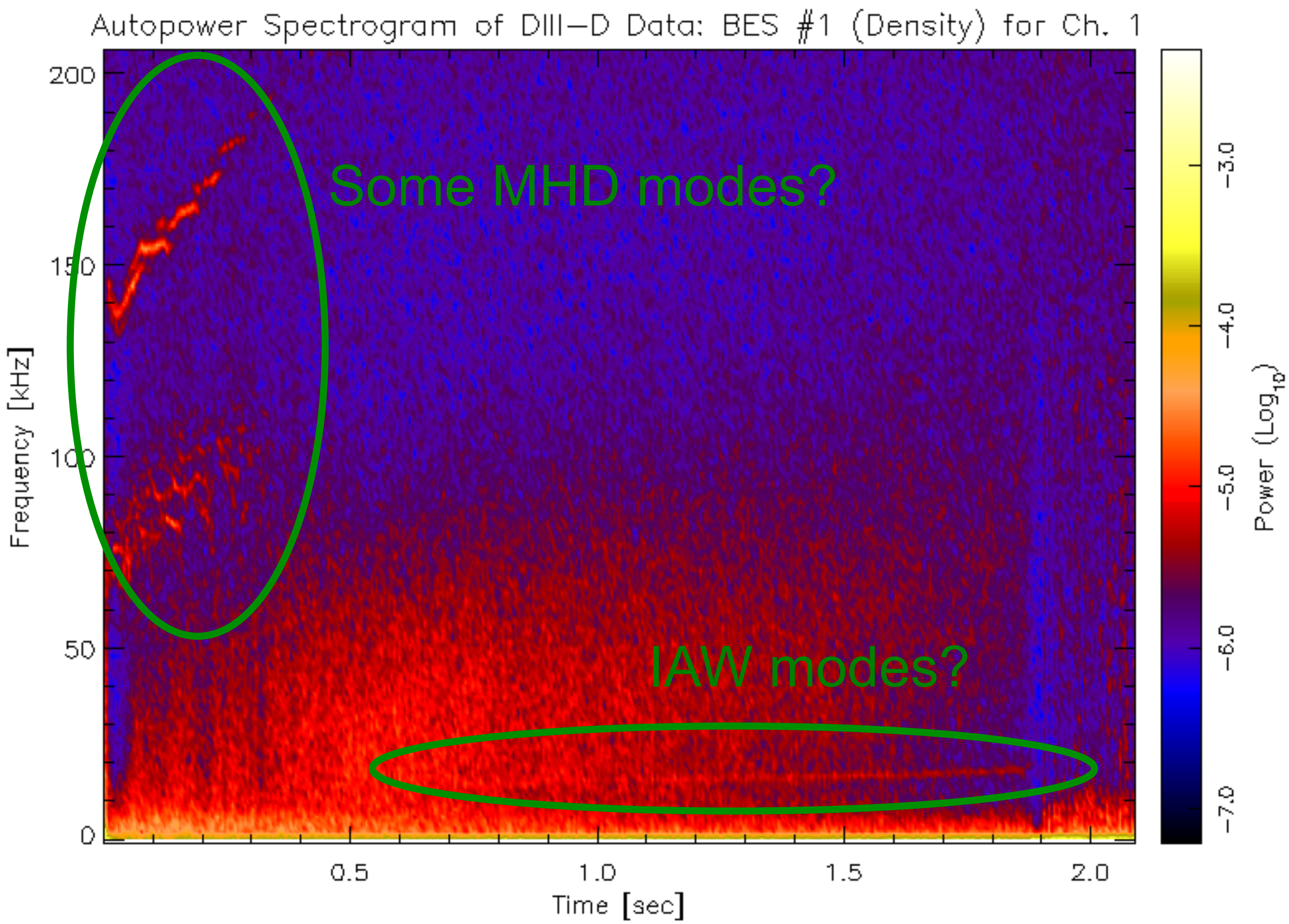
DIII-D BES Data

I have two sets of data which each consists of

- 7 poloidally separated channesl
- with 11 mm separation
- for about little bit more than ~ 2 seconds worth
- with 1MHz sampling frequency

Data Set #1: Density spectrogram (Ch.1)



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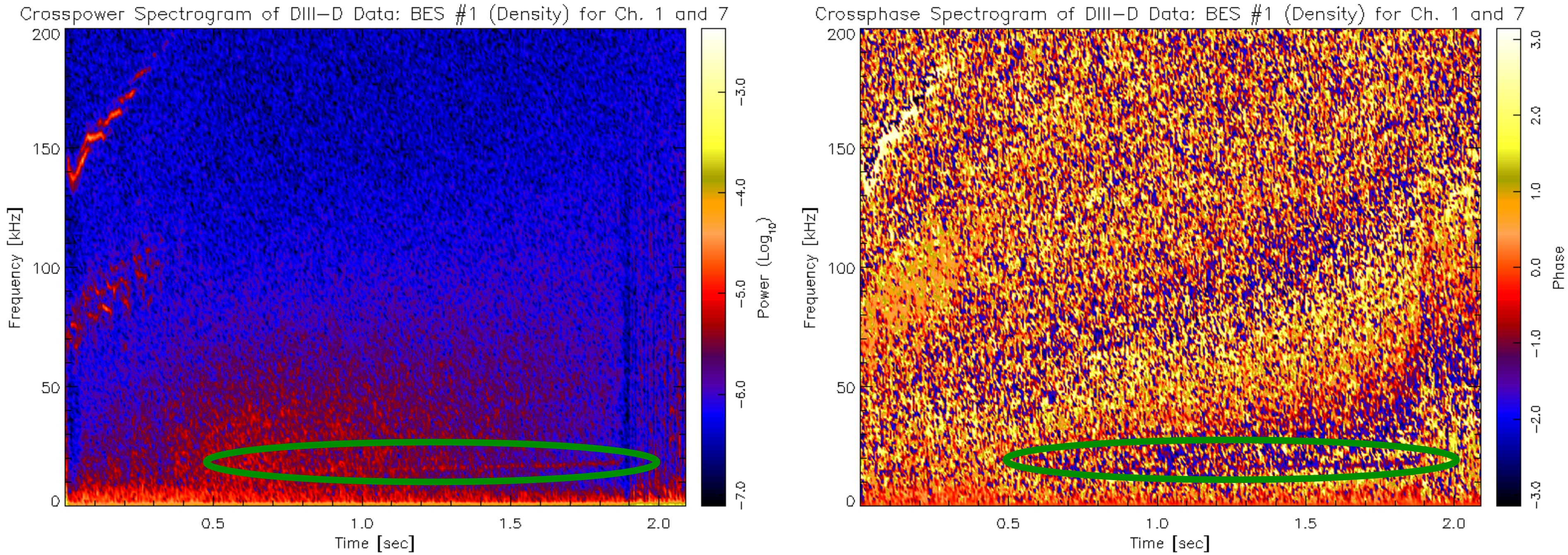
Data Set #1: Density spectrogram (Ch.1 and 7)



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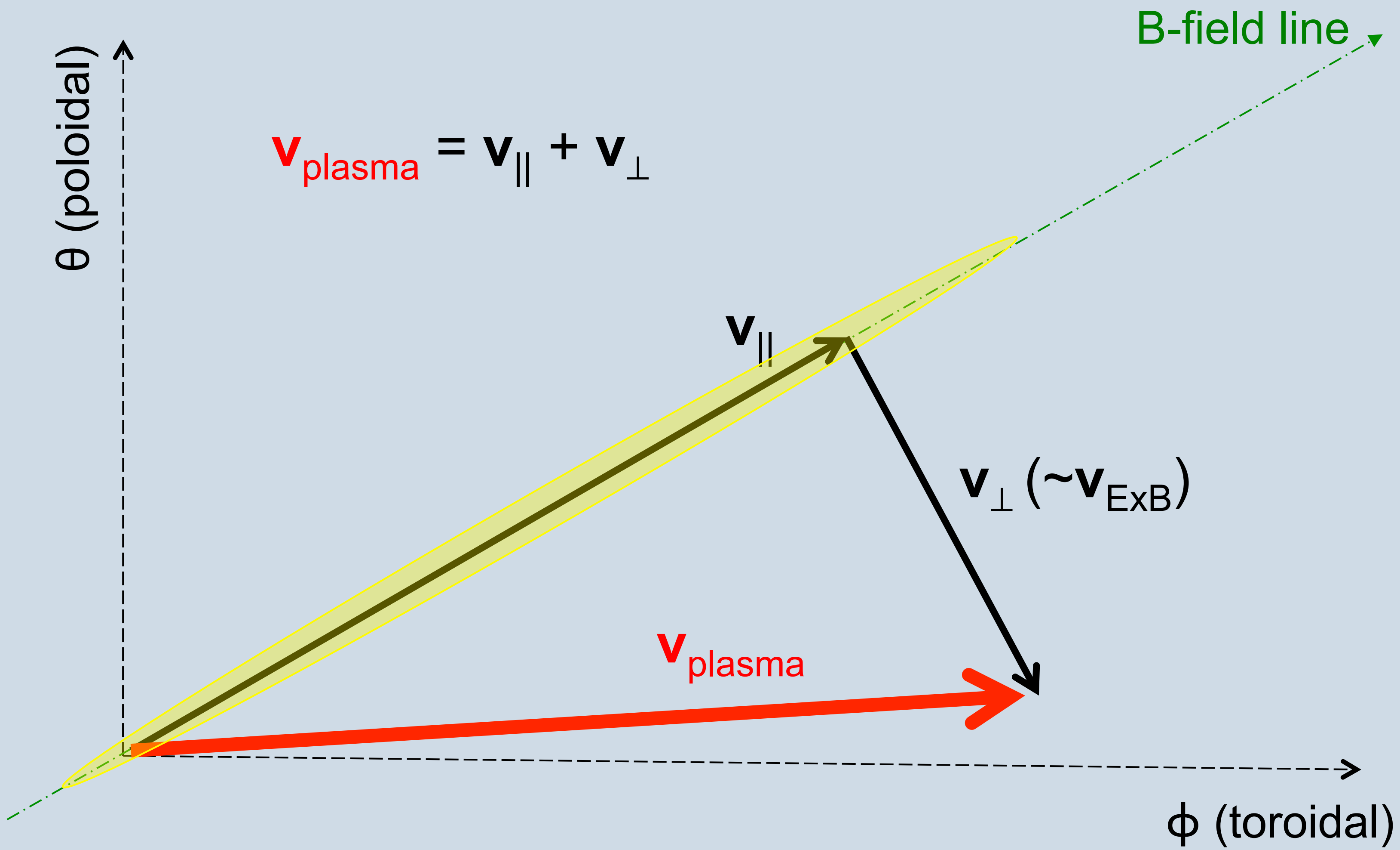
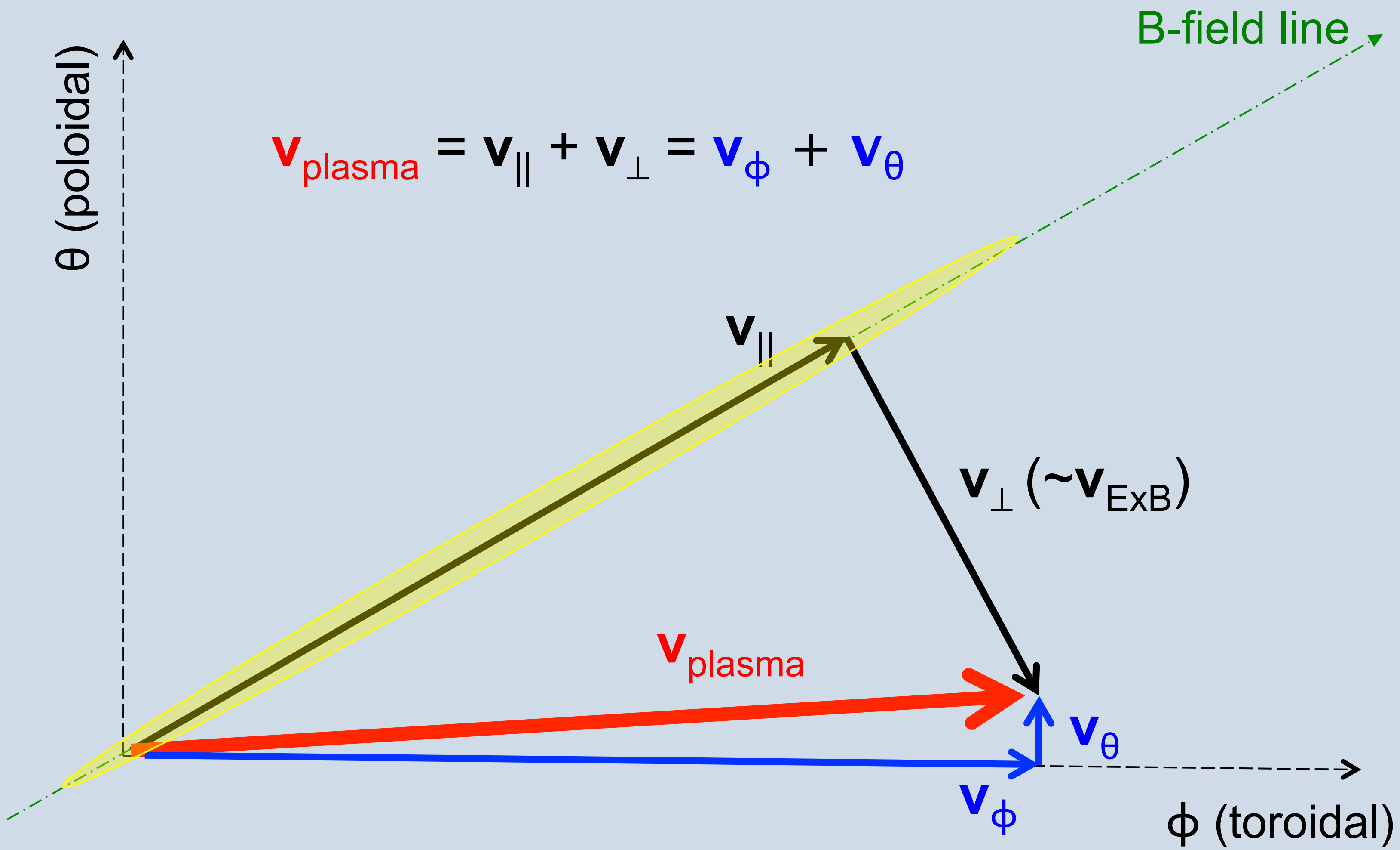
Contents

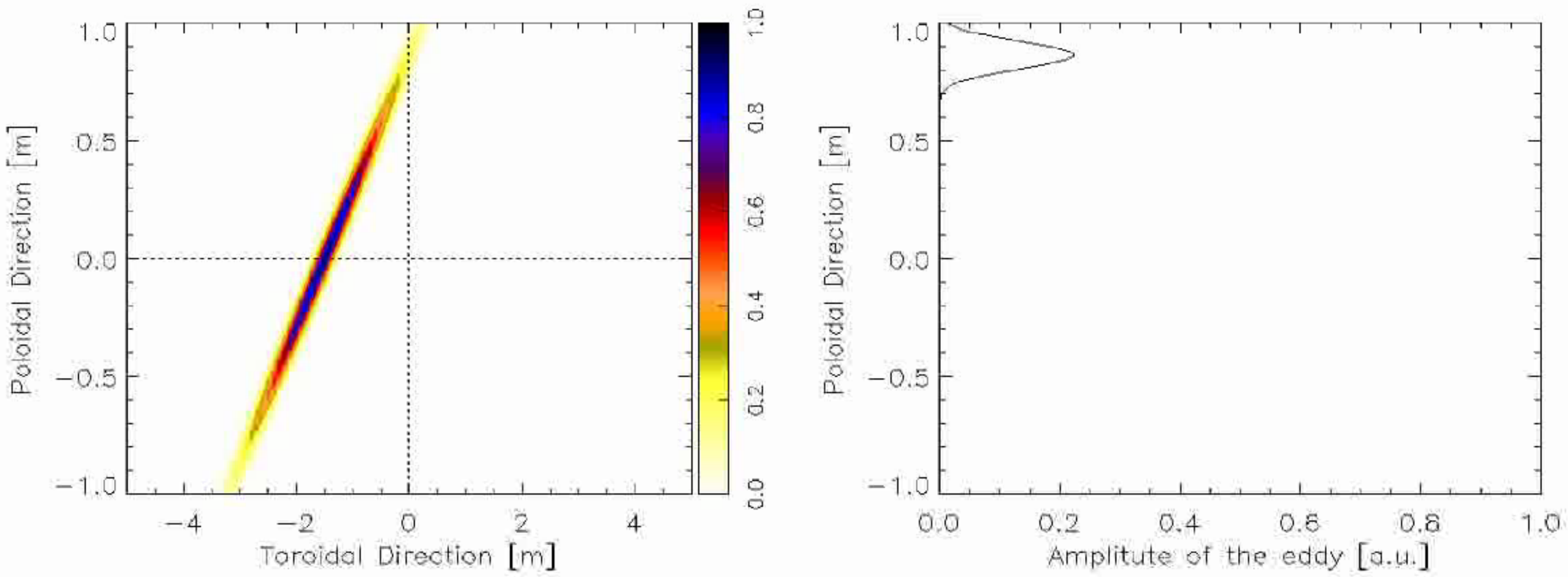
Mean flows in a tokamak is mostly toroidal.



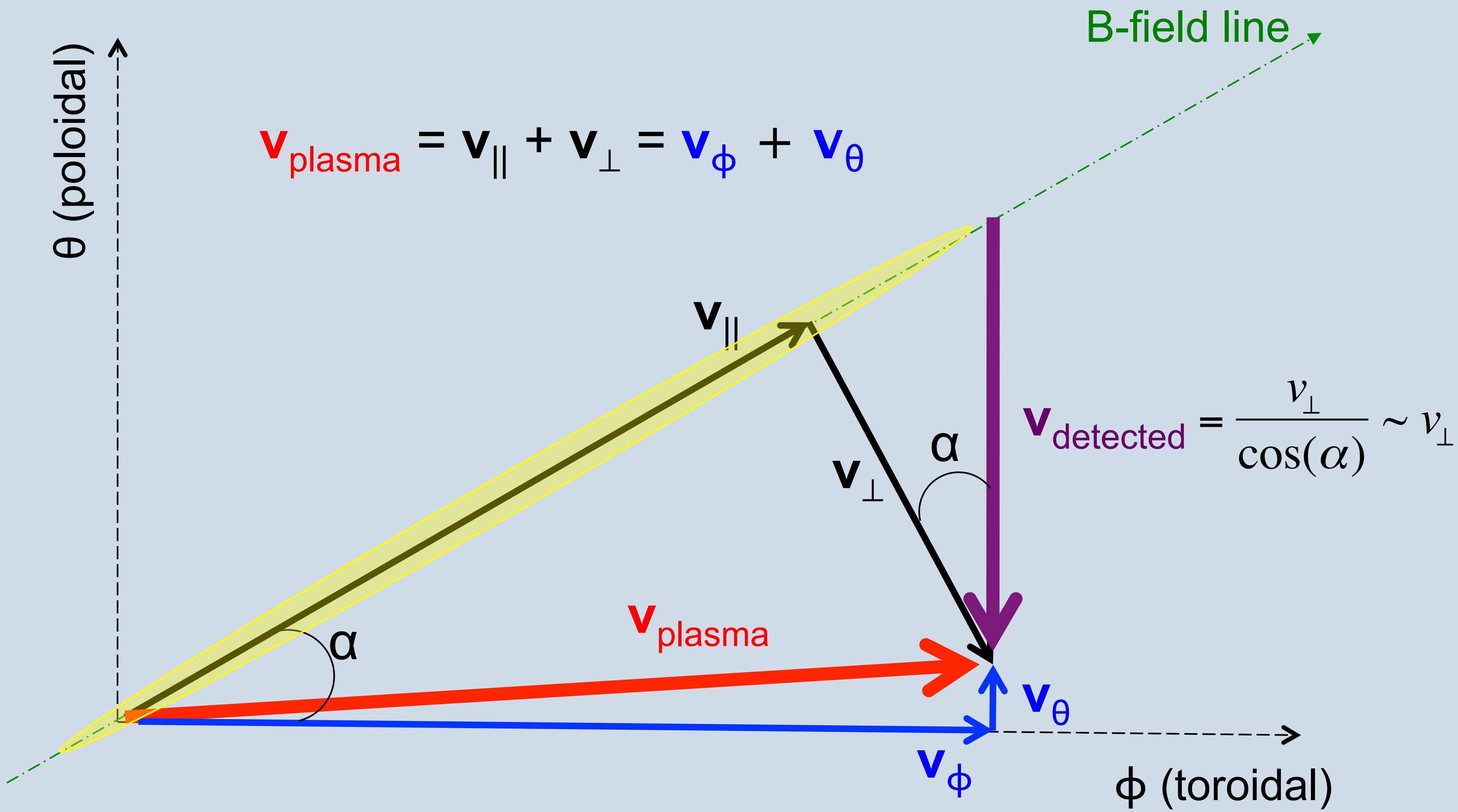
Mean flows in a tokamak is mostly toroidal.



Poloidal motion: mostly 'barber pole' effect.



Poloidal velocity from barber shop effect is close to ExB drift velocity.



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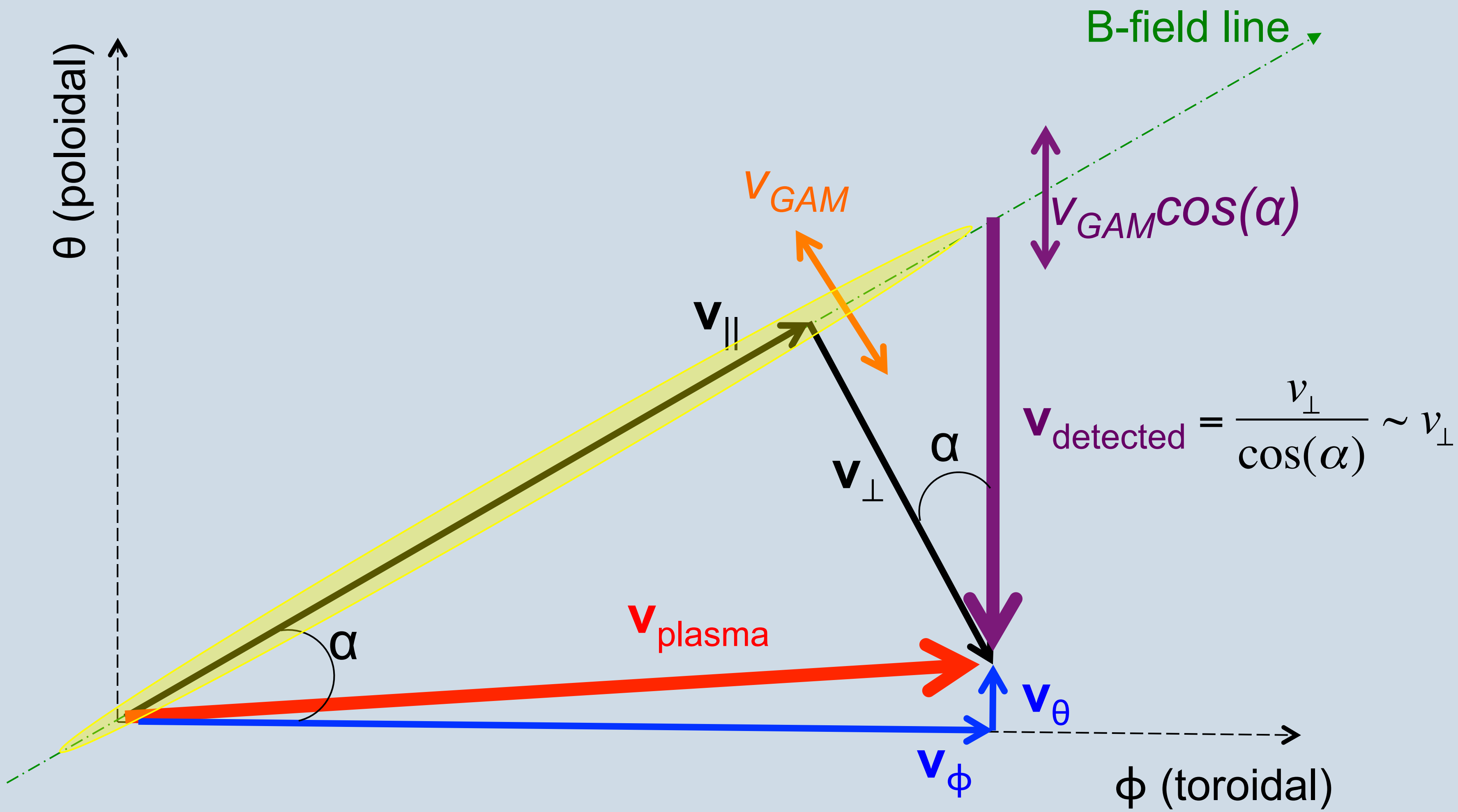
In addition, we have GAM induced velocity.



Conclusion III

We have to be careful when we say 'poloidal motion' of a plasma in a tokamak measured by BES.

- ✓ Poloidal motion of plasma → small (on the order of diamagnetic flow)
- ✓ Poloidal motion of patterns → can be on the order of ExB flow (due to 'barber pole' effect)

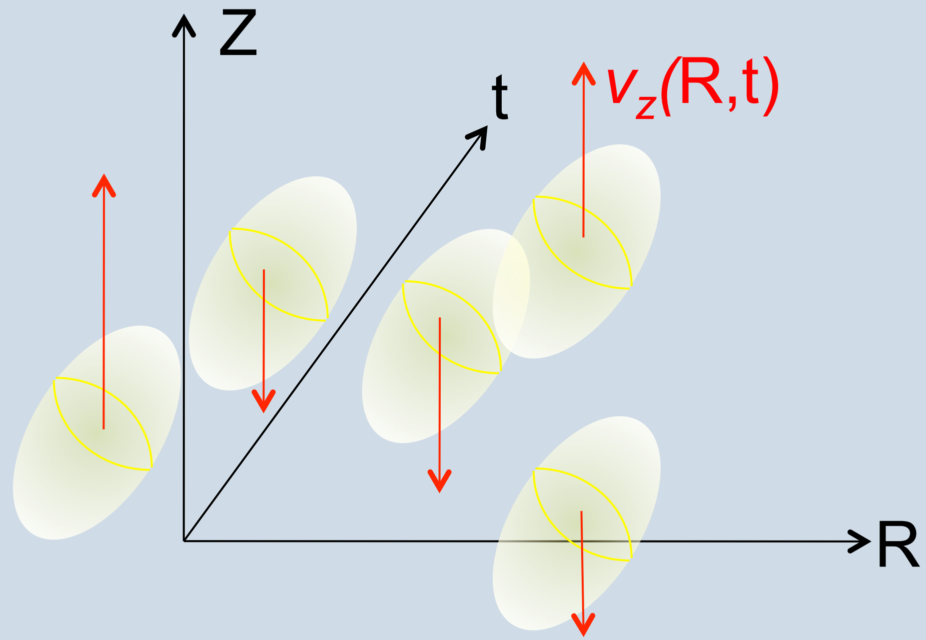
Contents

1. Brief description of zonal flows, sZFs, and GAMs
2. Density fluctuation from DIII-D data using CUDA
3. Meaning of measured velocity from 2D BES data
4. Detectable range of velocity
    a) How the study is performed.
    b) Mean flow
    c) Temporally fluctuation flow (i.e. GAMs)
5. Velocity measurements from DIII-D Data
6. Conclusion

Eddies generated by using GPU (CUDA programming)

Equation to generate 'eddies'

$$\tilde{n}(R,z,t) = \sum_{i=1}^{N} A_i \exp\left[-\left(\frac{(R-R_i)^2}{2\lambda_R^2} + \frac{(z+v_z(R,t)(t-t_i)-z_i)^2}{2\lambda_z^2} + \frac{(t-t_i)^2}{2\tau_{life}^2}\right)\right]\cos\left[2\pi\frac{z+v_z(R,t)(t-t_i)-z_i}{\lambda_z}\right]$$

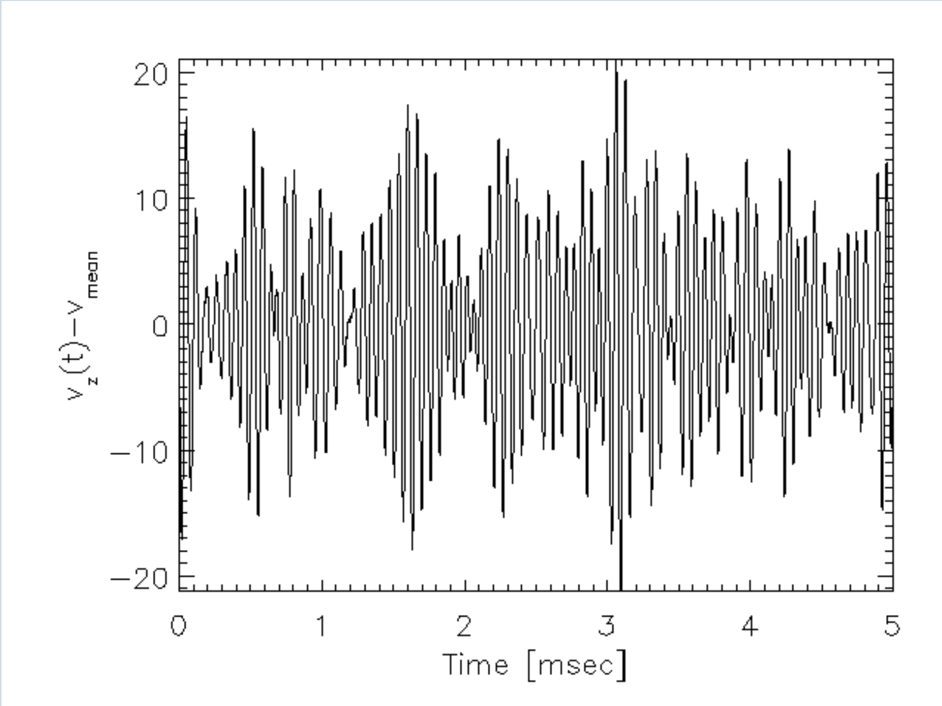


Assumed that eddies have Gaussian shapes in R, z, and t-directions plus wave structure in z-direction.

$v_z(R,t)$ is set to have sheared and GAM induced flows.

$$v_z(R,t) = \tilde{v}_z(R,t) * \exp\left[-\frac{t^2}{\tau_{GAM}^2}\right]\sin(2\pi f_{GAM}\, t)$$

$$v_{mean}(R) = \lim_{T\to\infty}\frac{1}{T}\int_0^T v_z(R,t)dt \quad \text{and} \quad v_{GAM}(R) = \sqrt{\lim_{T\to\infty}\frac{1}{T}\int_0^T dt\left[v_z(R,t) - v_{mean}(R)\right]^2}$$



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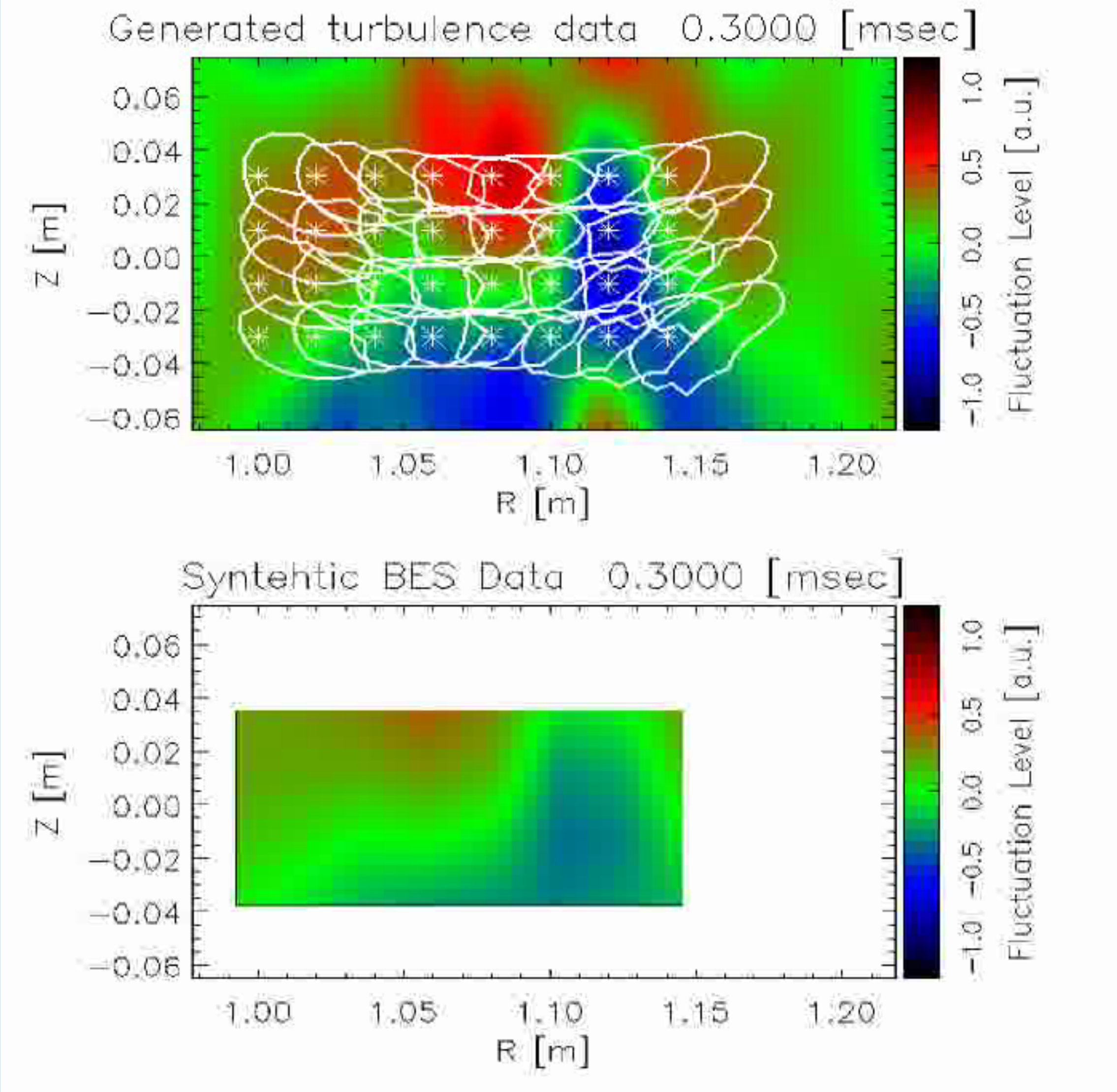
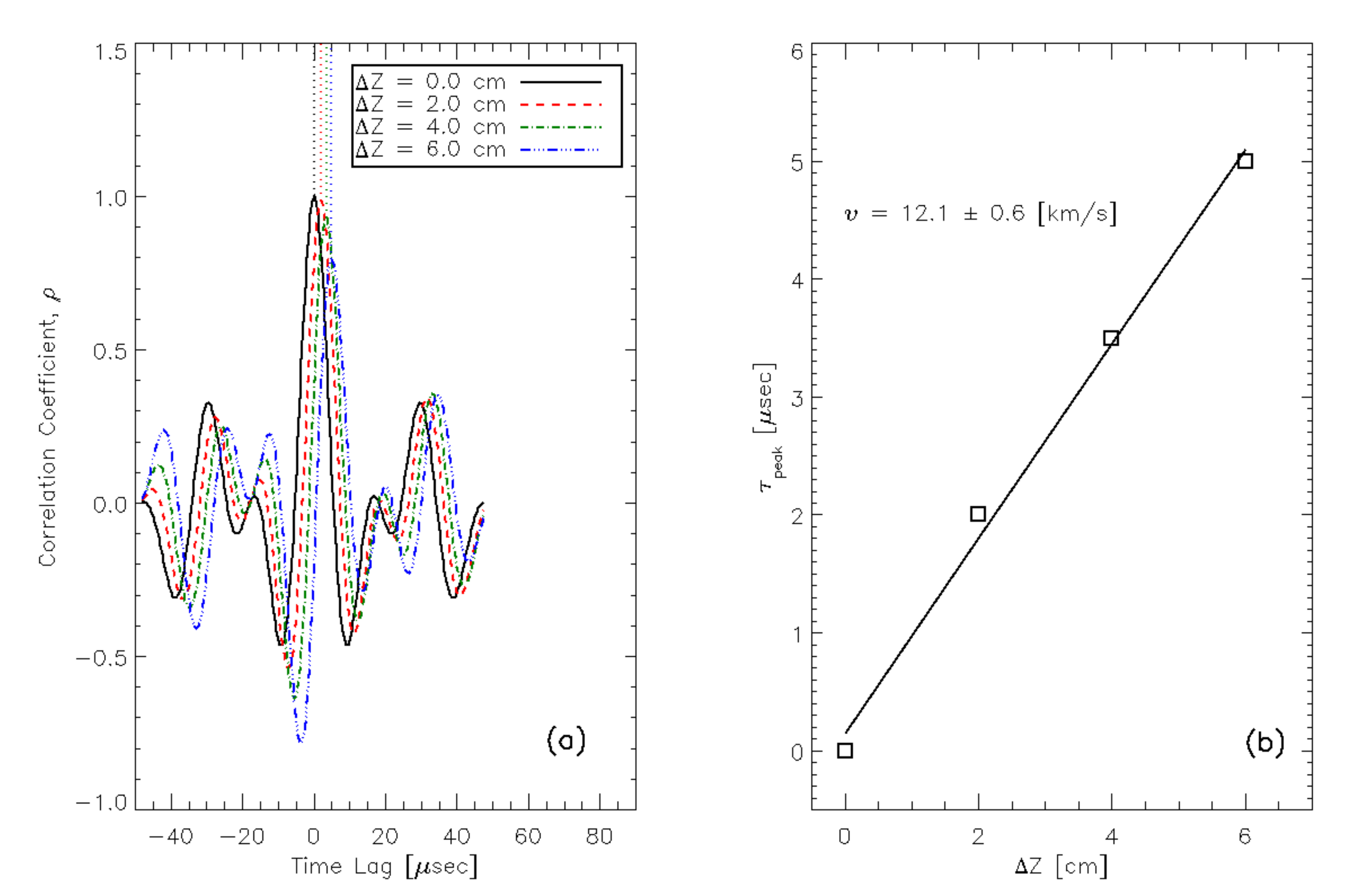
Synthetic BES data are generated by using PSFs and generated eddies.



$v_z(t)$ is estimated using the CCTD method.



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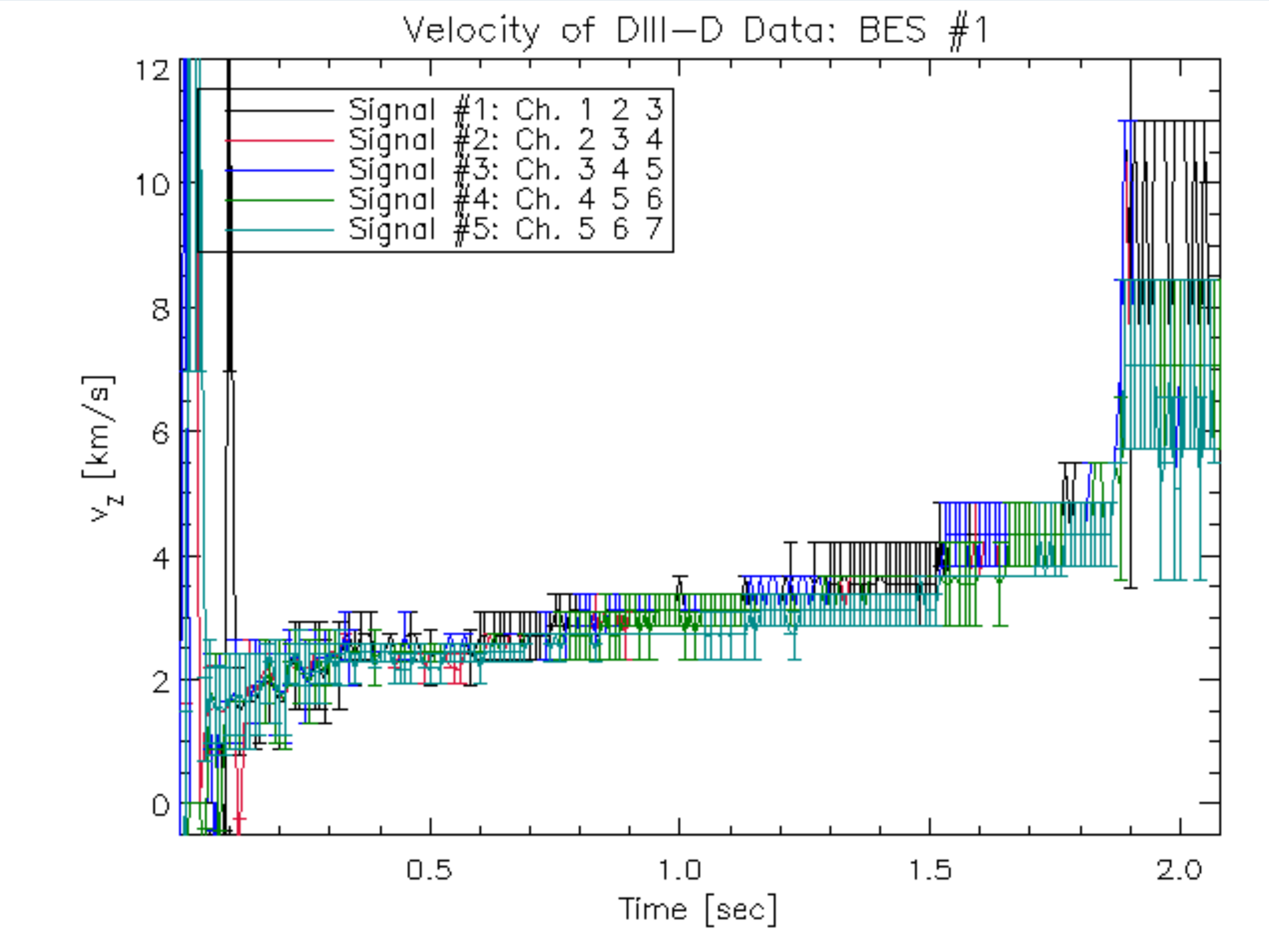
Data Set #1: Mean $v_z(t)$ of plasma patterns

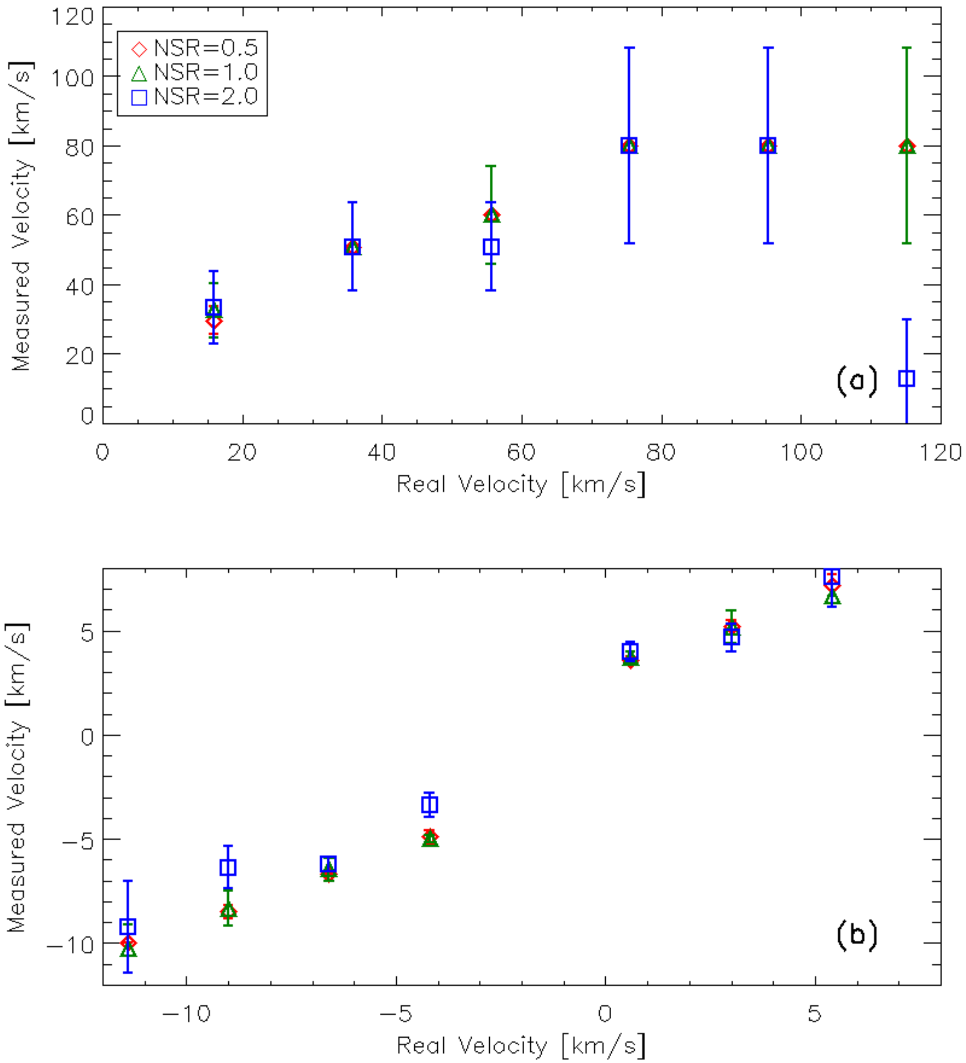


Back-of-envelope calculation of detectable range of mean velocity using CCTD method

- ✓ Sampling Frequency: 2 MHz → 0.5 usec
- ✓ Adjacent channel distance: 2.0 cm
- ✓ Farthest apart channel distance: 6.0cm
- ✓ Life time of an eddy: 15 usec (This plays a role in lower limit. i.e. before an eddy dies away, it needs to be seen by the next channel.)

	Upper Limit	Lower Limit
Using adjacent Channel	40 km/s	1.3 km/s
Using Farthest apart channels	120 km/s	4.0 km/s
Numerical Results	~ 80 km/s	~ 5 km/s

Numerical results of detecting mean velocities.



Upper limit

Lower limit

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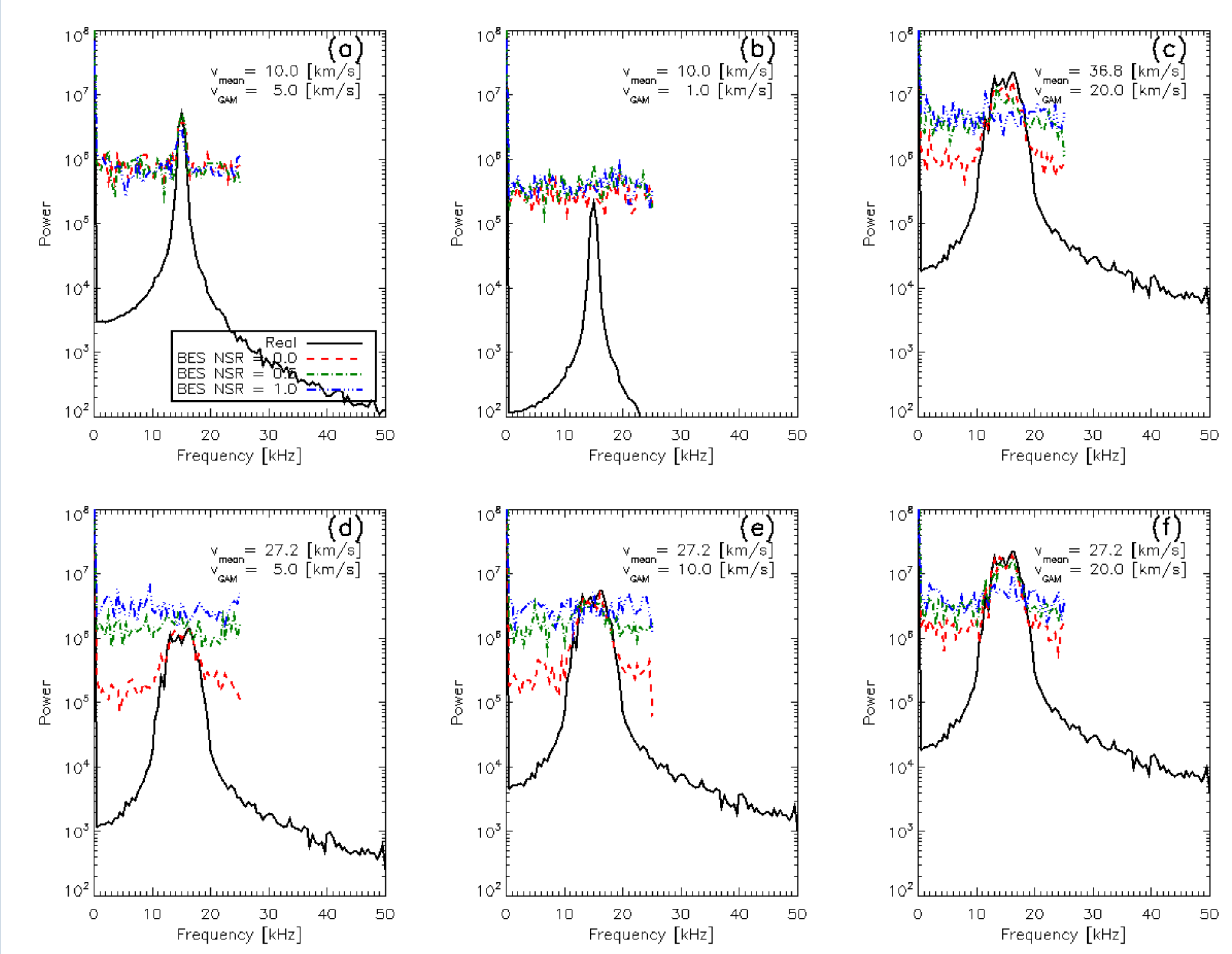
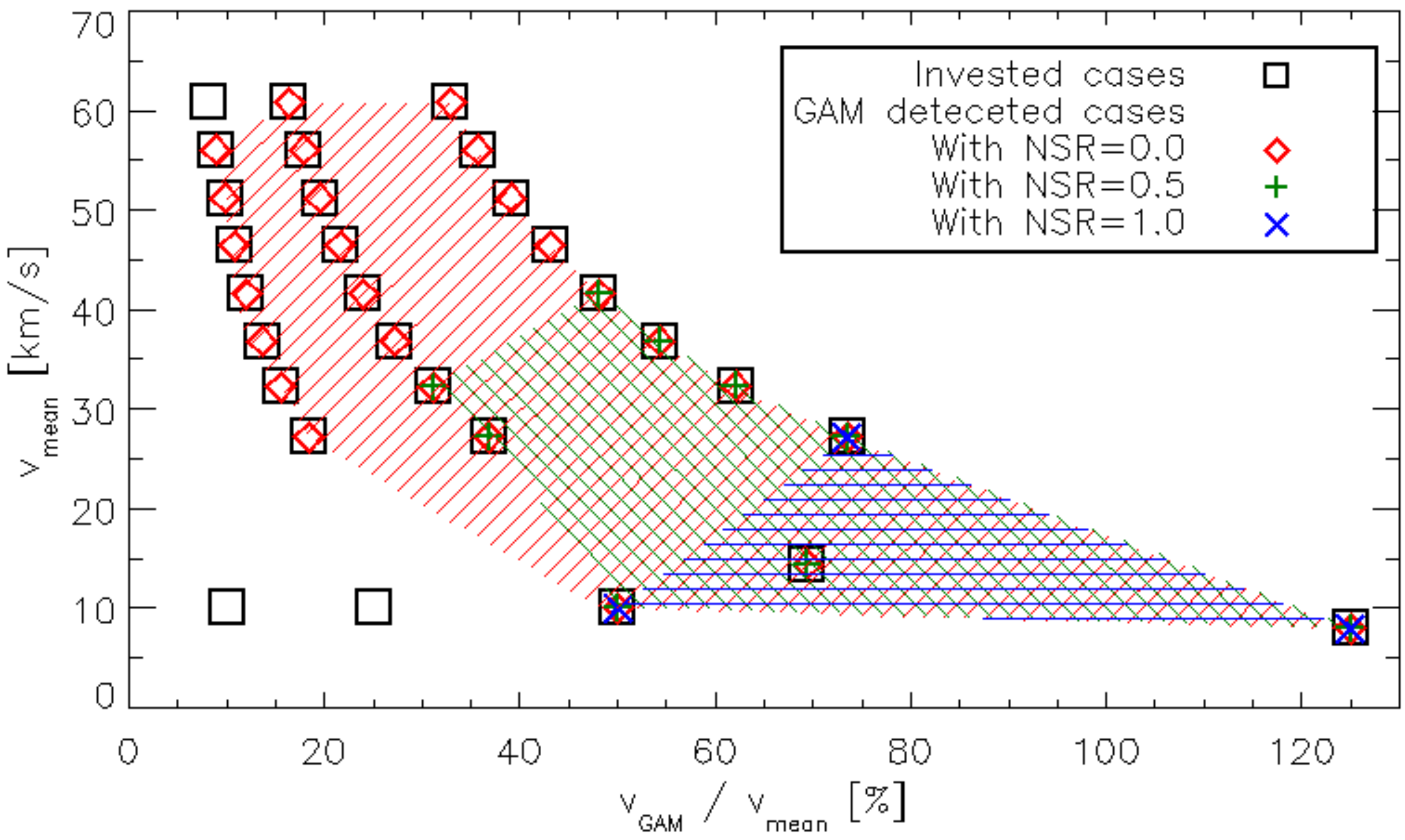
Numerical results of detecting fluctuating velocities.



Numerical results of detecting fluctuating velocities.



Conclusion IV

- ✓ We saw upper and lower limits of detectable mean flow velocity using BES with CCTD technique.

  - Upper Limit is set by
    1) Sampling frequency
    2) Distance from a channel to next one
  - Lower Limit is set by
    1) Life time of a structure
    2) Distance from a channel to next one

- ✓ We saw that
  - The worse the NSR, the harder to detect GAMs
  - the faster the mean flow, the harder to detect GAMs

Contents

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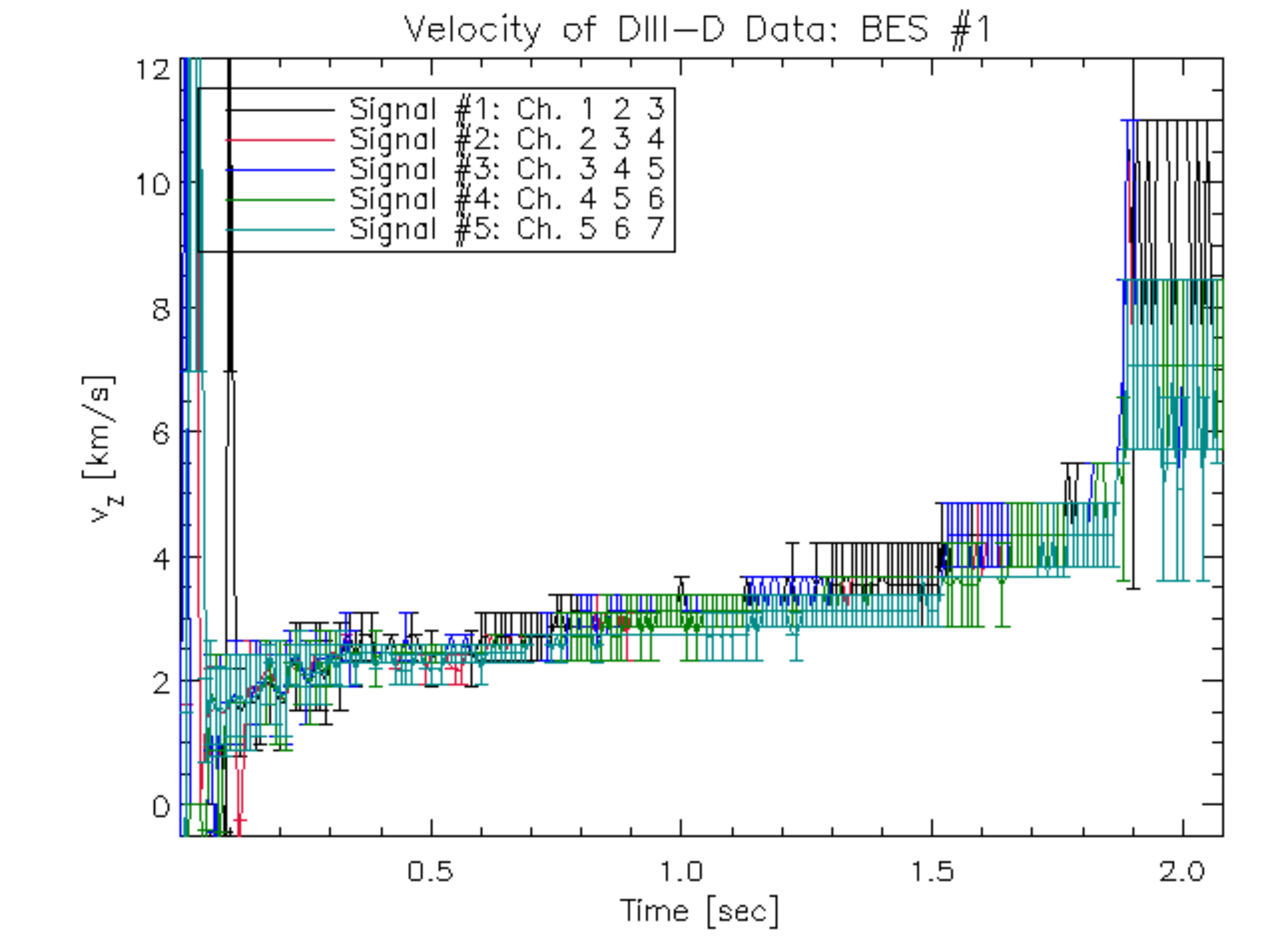
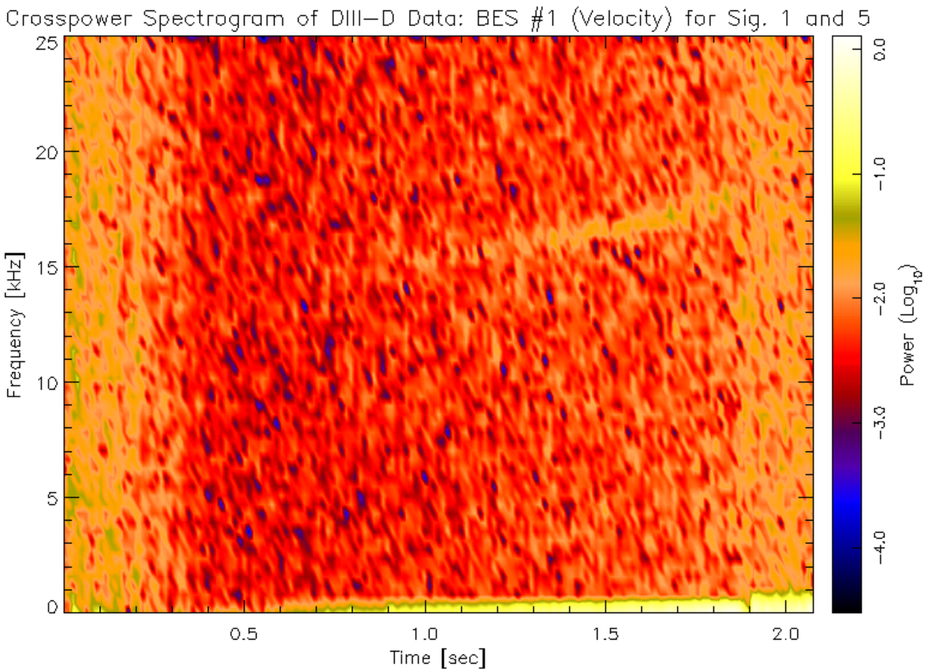
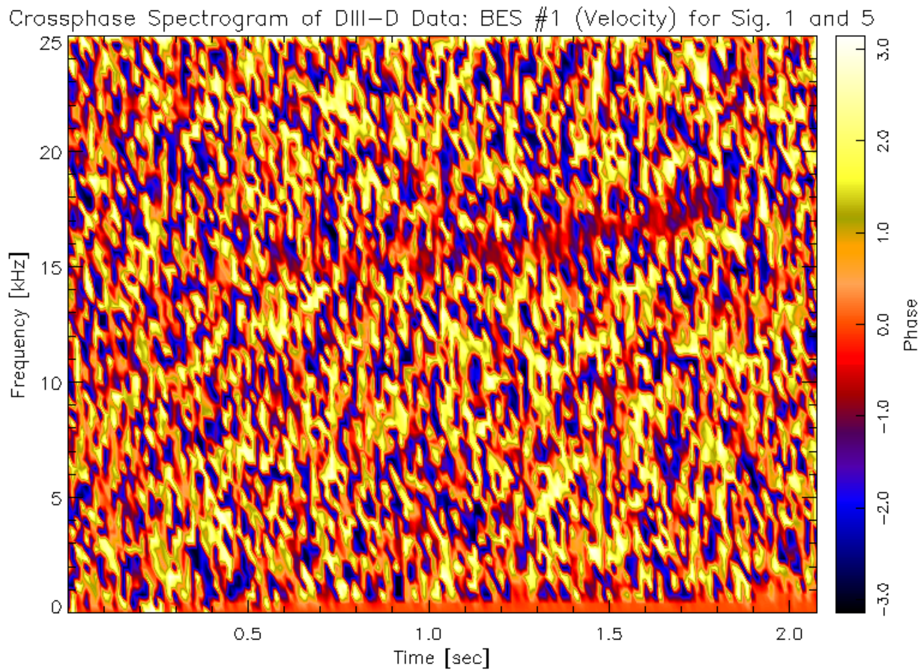


Data Set #1: Fluct. $v_z(t)$ of plasma patterns

Density is filtered 50.0 kHz < *f* < 100.0 kHz before $v_z(t)$ is calculated.





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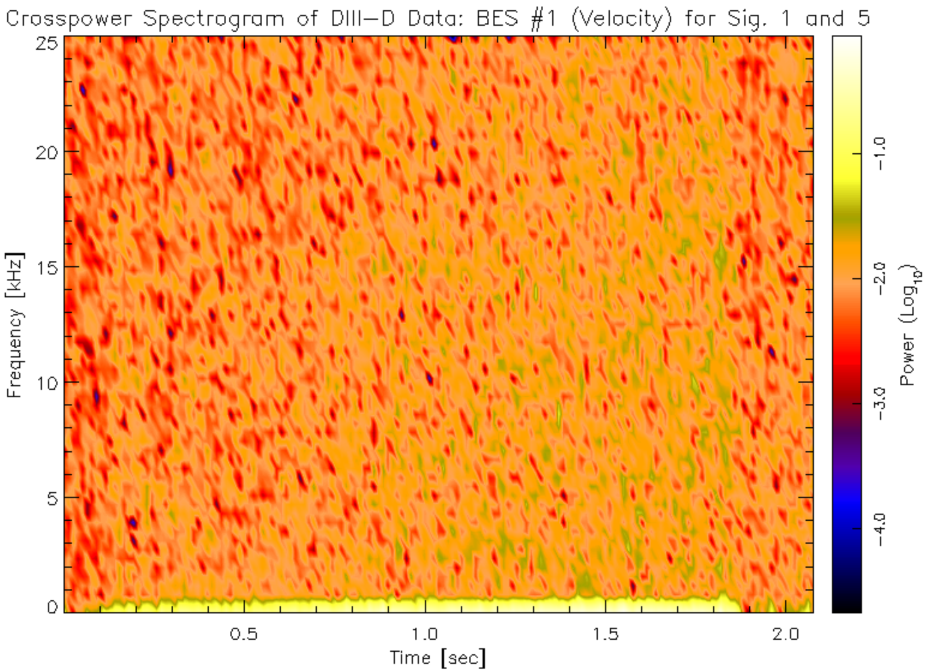
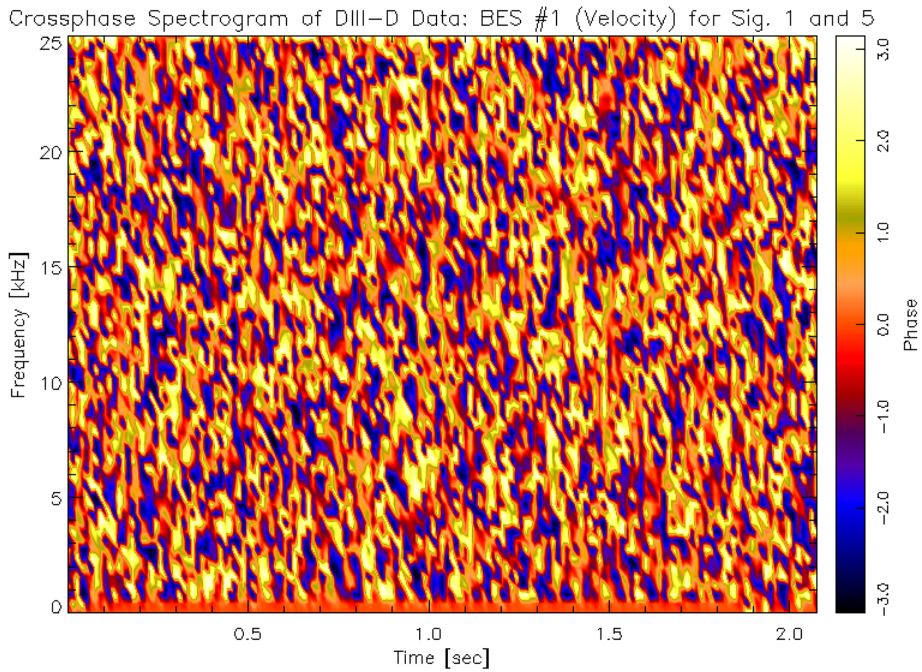
Data Set #1: Fluct. $v_z(t)$ of plasma patterns

Density is filtered 0.0 kHz < *f* < 30.0 kHz before $v_z(t)$ is calculated.





Conclusion V

- ✓ As we just saw, detecting GAM features are not straight forward.

  - It may be helpful to consider radial motions as well since we have radial motions of eddies due to

    1) Polarization drift
    2) Finite poloidal wave-number associated with m=1 mode of GAM

    → However, we do not know whether these radial motions are big enough to be seen by the 2D BES.

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Final Conclusions

1. Discussed about ZFs, sZFs, and GAMS.
   - ✓ Because of the observation positions of 2D BES, we use GAMs to "confirm" the existence of zonal flows.

2. Discussed the meaning of poloidal velocities seen by the 2D BES.
   - ✓ BES sees poloidal motions of 'plasma patterns' rather than bulk plasmas.

3. Discussed detectable ranges of poloidal motions using the CCTD method.
   - ✓ Mean v_z: sampling freq., ch. separation dist., lifetime of eddies.
   - ✓ Fluct. v_z: NSR levels, v_{GAM}/v_{mean}.

4. DIII-D data showed that we have to be careful for detecting GAM-like features.

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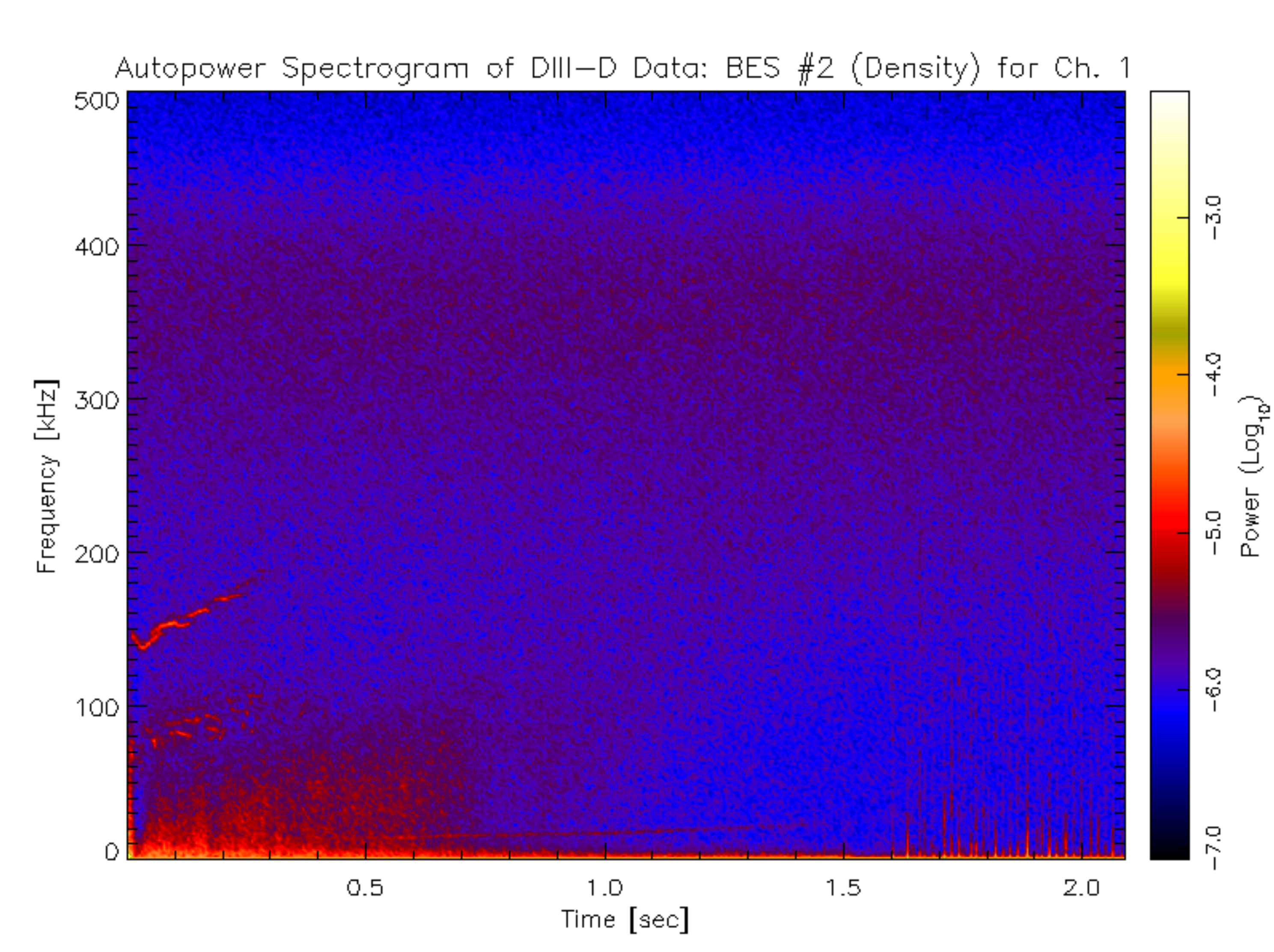
Data Set #2: Density spectrogram (Ch.1)



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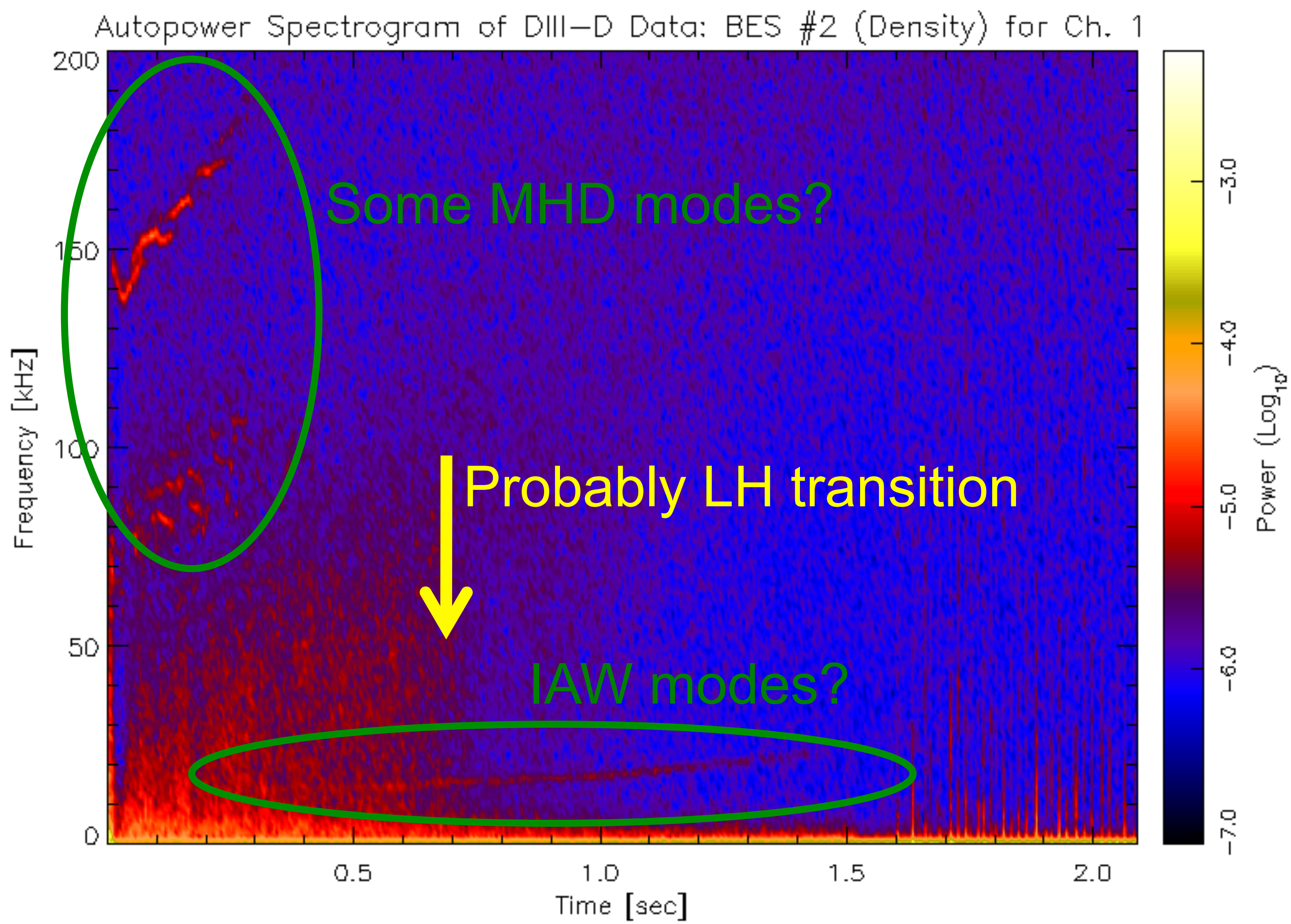

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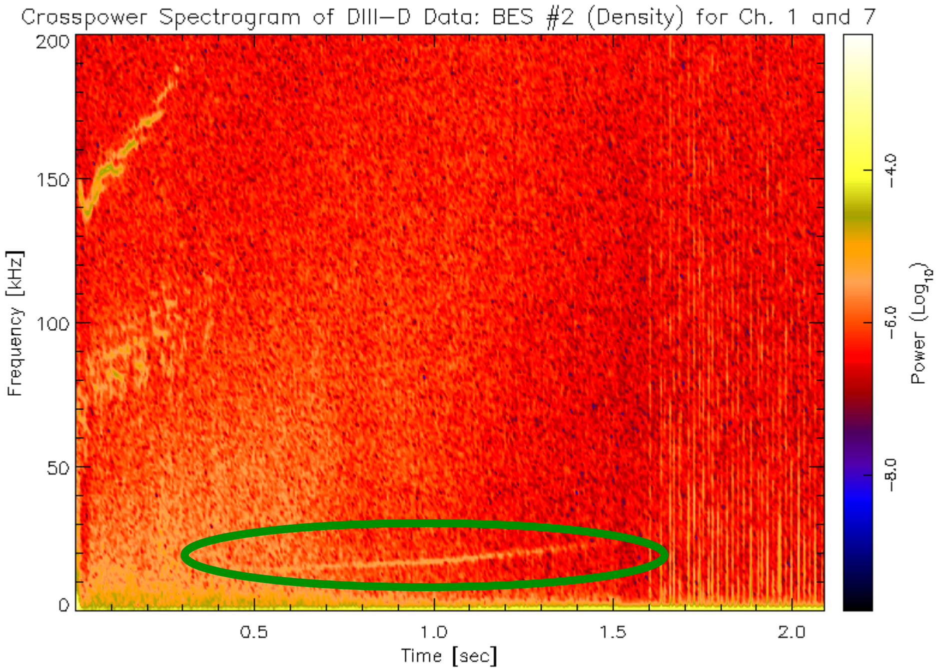
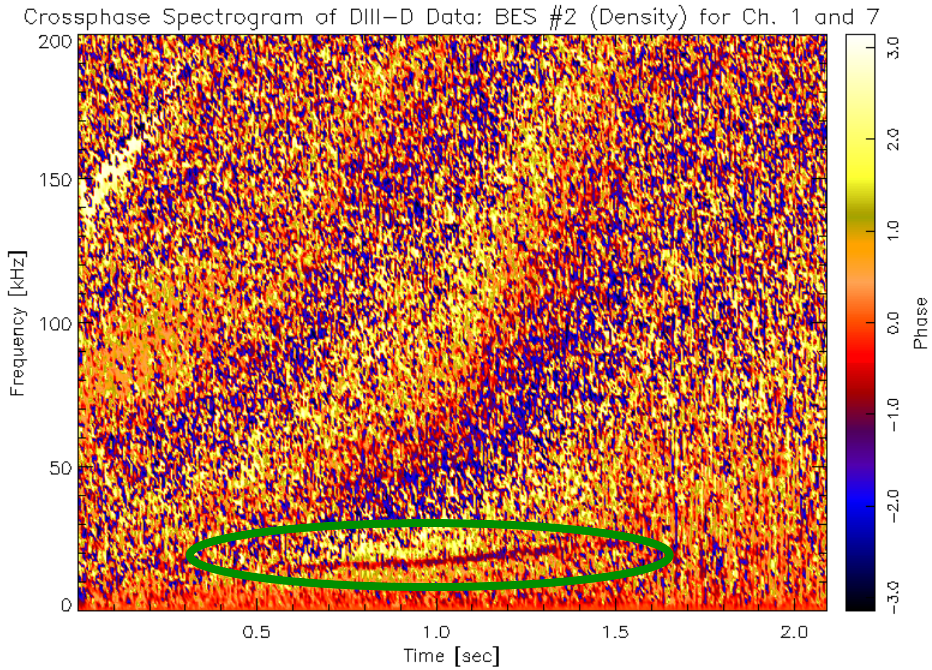
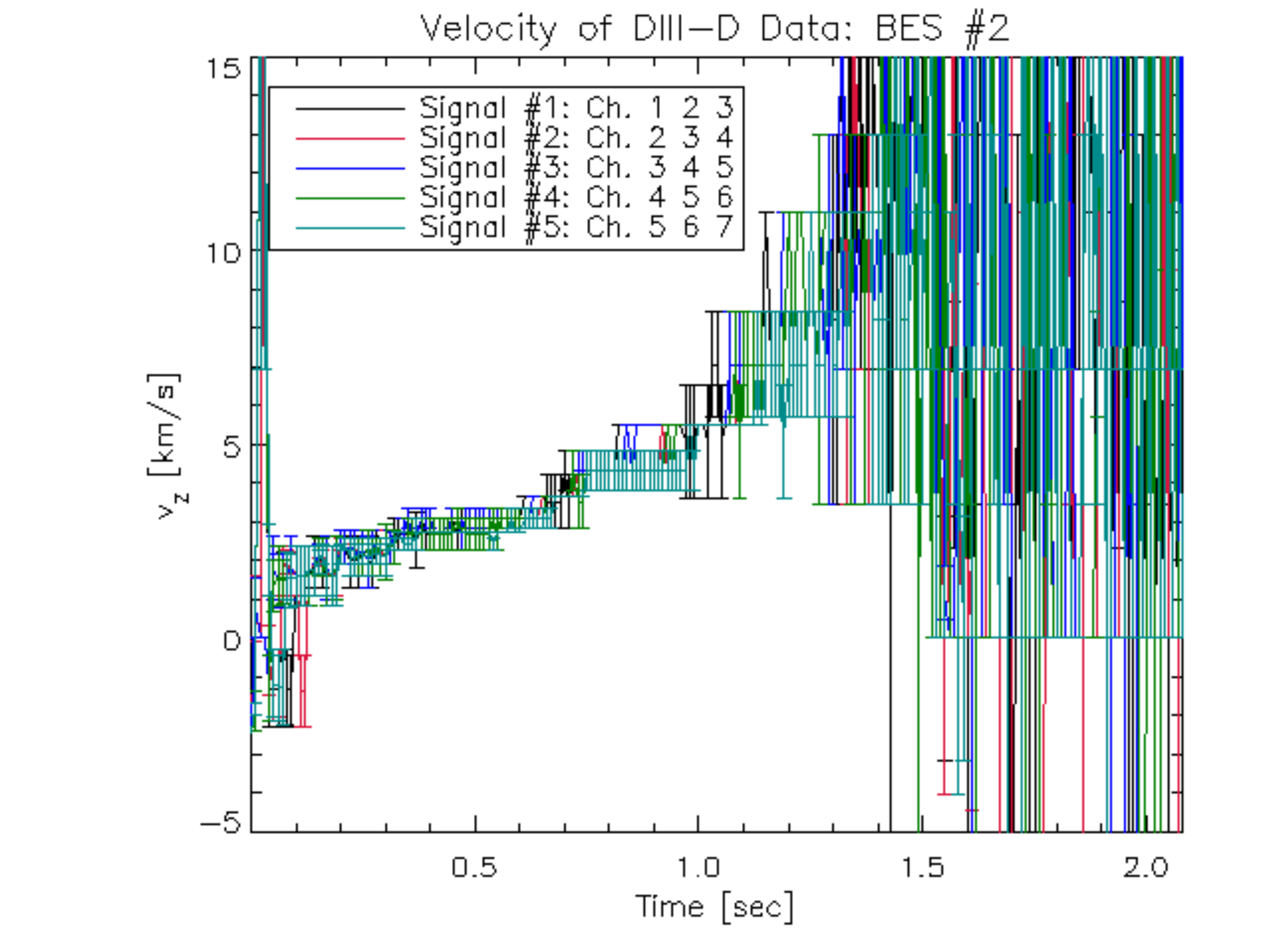


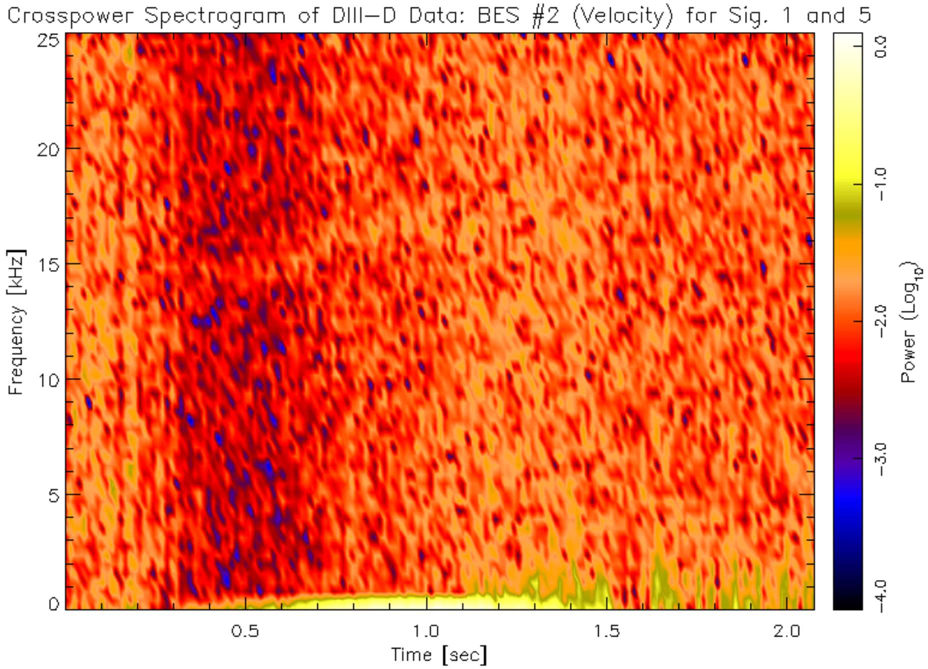


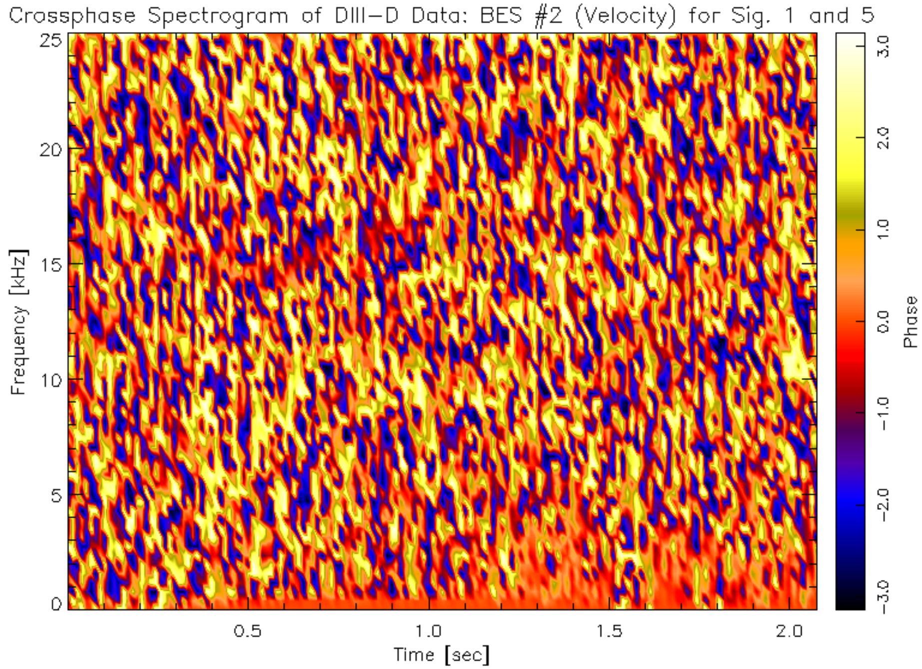
Data Set #2: Mean $v_z(t)$ of plasma patterns



Data Set #2: Fluct. $v_z(t)$ of plasma patterns

Density is filtered 50.0 kHz < *f* < 100.0 kHz before $v_z(t)$ is calculated.





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