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INTERMITTENCY AND ANISOTROPY IN THE INERTIAL RANGE: ANOTHER TEST OF CRITICAL BALANCE

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INTRODUCTION

Field-aligned anisotropy appears to be a ubiquitous property of plasma turbulence. In the inertial range of solar wind MHD turbulence, it appears to be consistent with Goldreich and Sridhar's critical balance. However, this is hard to prove conclusively.

Here, we present the **first measurements of the anisotropy of intermittency** in the MHD inertial range. We use the data to produce a new necessary, but not sufficient, test of critical balance. Our results are **consistent with critical balance but cannot exclude other possibilities**. An unambiguous proof of critical balance still eludes us.

AN ADDITIONAL TEST OF CRITICAL BALANCE

We know that turbulence is intermittent: to study this, we need to use higher order measures, such as structure functions, than second order techniques like power spectra. Here, we use wavelets to look at the intermittency of the fluctuations as a function of field/flow angle.

- If the fluctuations are critically balanced, the intermittency level should not vary with field/flow angle because we are sampling the same population of fluctuations at every angle
- If the fluctuations are composed of two populations parallel and perpendicular to the field, the intermittency level can vary with angle

This is what we test in this work, using third and fourth order wavelets.

POWER AND SPECTRAL INDEX ANISOTROPY

We have previously used second order wavelets to calculate power levels as a function of both scale and angle to the magnetic field:

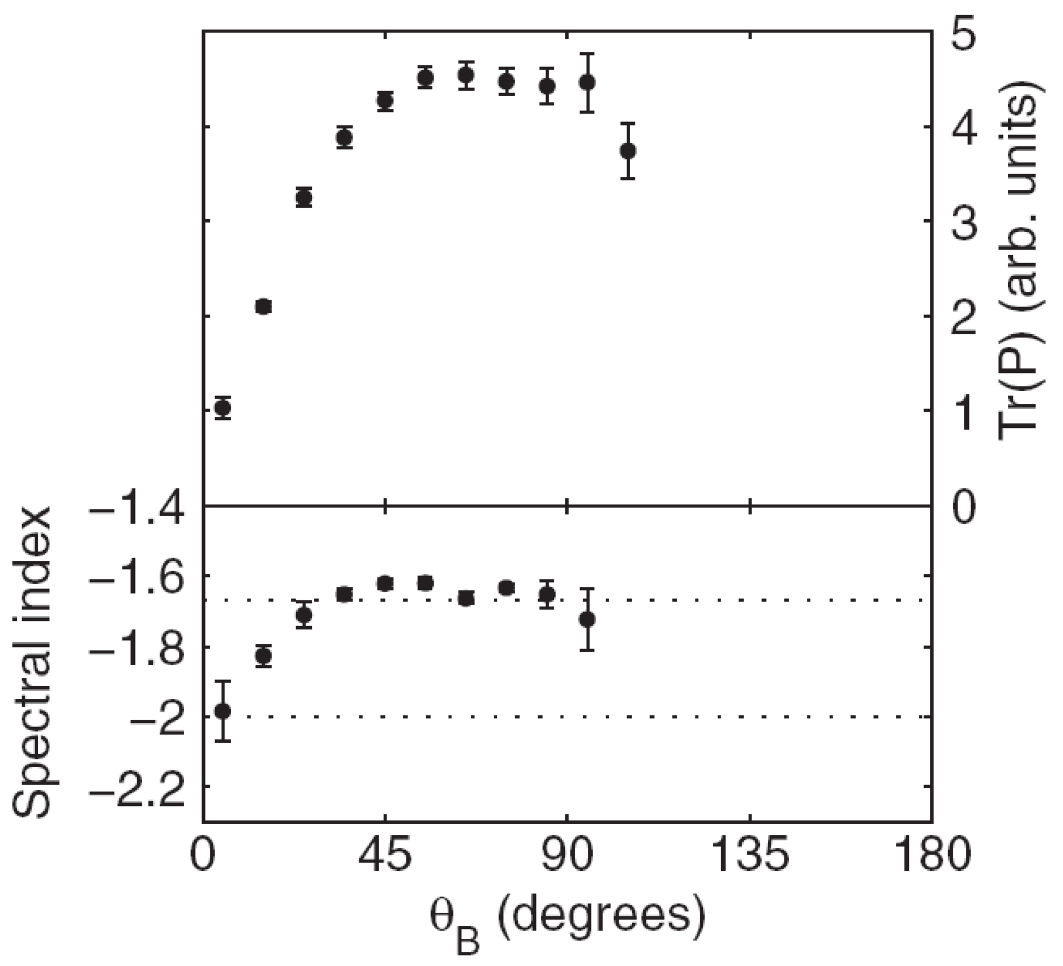

Figure 1. Power and spectral index of magnetic field fluctuations as a function of field-flow angle. The increase in power towards θ_B=90° shows that there is more power in wavevectors at large angles to the local magnetic field than parallel to it. The steepening of the spectral index from 5/3 at large angles to 2 at small angles is **consistent with, but not proof of, a critically balanced cascade**. From Horbury et al., Phys. Rev. Lett., 2008.

IS THE MHD CASCADE CRITICALLY BALANCED?

In the past, solar wind turbulence anisotropy has often been interpreted in terms of two components: "slab" (wavevectors parallel to the field) and "2D" (wavevectors perpendicular to the field). The change in spectral index with angle in Figure 1 is consistent with a critical balance cascade, but also with a population of slab waves with a spectral index of 2 and 2D waves with a 5/3 spectral index.

We do not have an analytical form of the power/angle curve in Figure 1 for critical balance and it seems that it will be very hard to prove that critical balance is operating in solar wind turbulence using these data. We want to find additional, stronger tests for critical balance in the solar wind.

HIGHER ORDER WAVELETS

Usual two-point wavelets are second order, like the second order structure function. We can, however, calculate higher order wavelets too and here we are calculating the third and fourth order moments.

This lets us, in essence, calculate higher order structure functions and how they depend on field/flow angle, so producing the first measure of the anisotropy of intermittency. In the inertial range, these moments are power laws of the time lag, τ :

$$s(\tau, m) \approx \tau^{g(m)}$$

It is how the exponent g(m) varies with angle to the field, for various moments m, that is of interest.

RESULTS

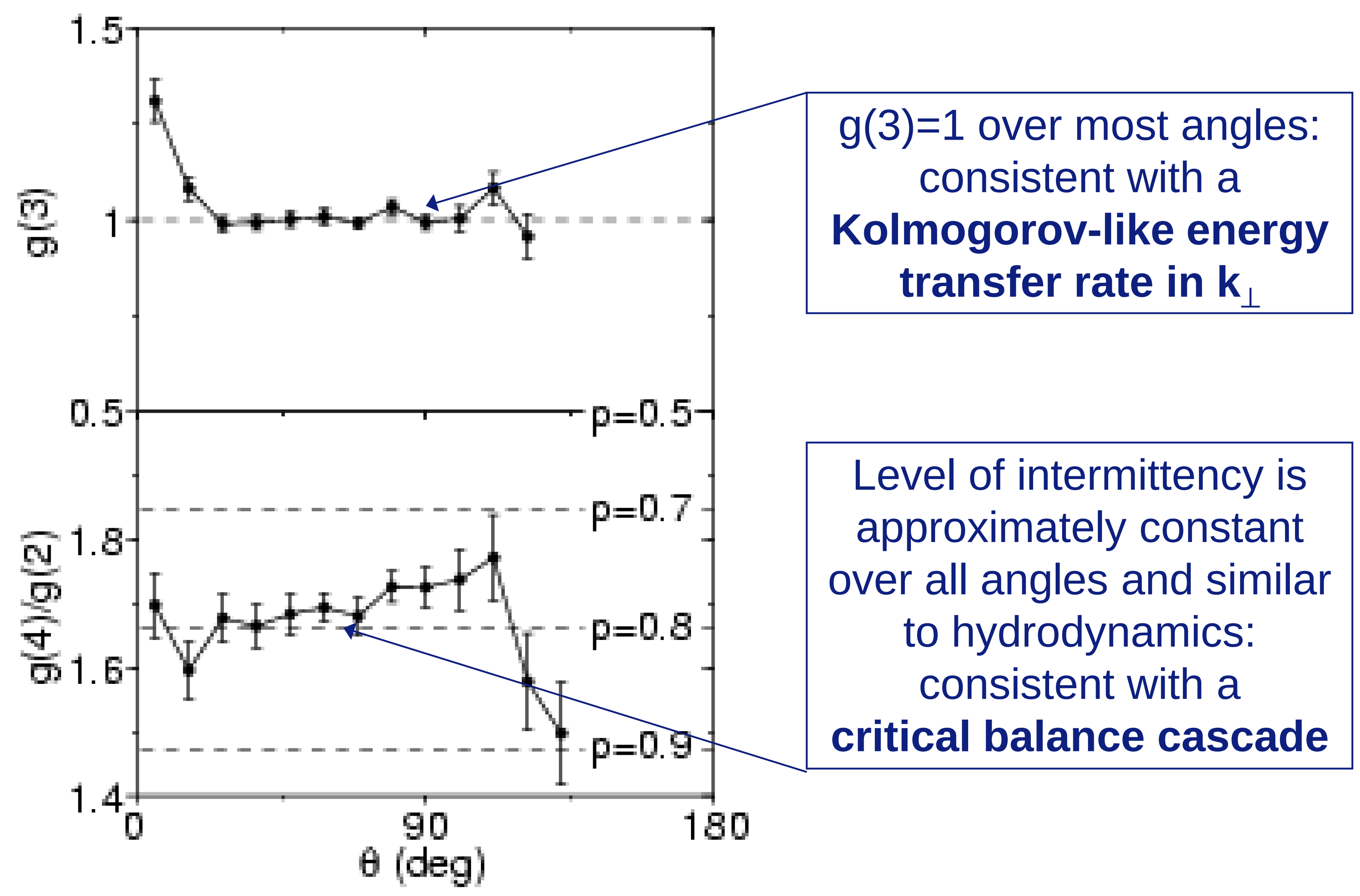

Figure 2. Top panel: third order structure function scaling as a function of sampling direction relative to the field. This is 1 for most angles, but higher (steeper scaling) at small angles. This is consistent with the variation in spectral index with angle seen in Figure 1

Bottom panel: Ratio of fourth to second order structure function scalings. This is a measure of the level of intermittency. Although errors are large, and values beyond θ=90º should be ignored, the intermittency seems to be roughly constant and in particular there is no evidence of a significant change at small θ, in contrast to that for g(3).

DISCUSSION

Kolmogorov-like cascade – The third order structure function has a unity exponent for large field-flow angles , which is what is predicted for a Kolmogorov-like cascade. This is consistent with a Goldreich and Sridhar (1995) critically-balanced cascade.

No angular variation in intermittency levels – Crucially, intermittency levels (g(4)/g(2)) do not vary with angle. If we were seeing two separate turbulence populations in parallel and perpendicular wavevectors, this need not be the case, but we think that it has to be so for critical balance. This invariance of intermittency with angle is therefore a **necessary but not sufficient** test for critical balance.

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