EE- and BB- mode signatures of Single Phase Turbulence *also* Their Variations on the Sky

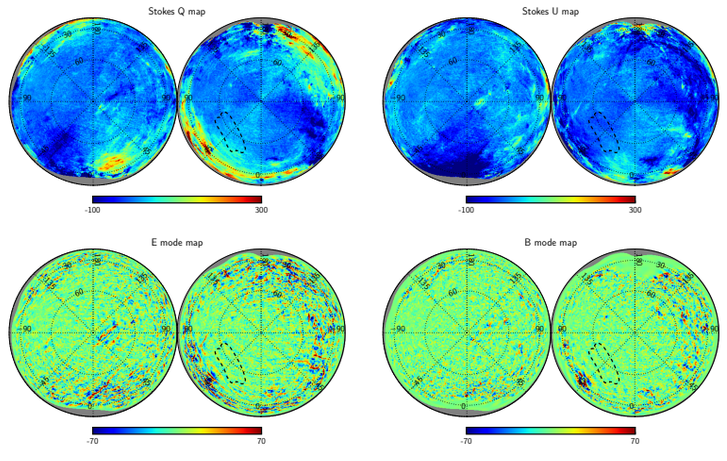
David Collins, Florida State University
2017-11-28, *UCSD CMB Foregrounds Workshop*
with
Kevin Huffenberger (FSU)
Aditya Rotti (FSU)
Corey Brummel-Smith (Georgia Tech)
Marc Kamionkowski (Johns Hopkins)

and less directly
Blakesley Burkhart (CfA)
Kye Stalpes (FSU)
Alex Lazarian (Madison)
Alexei Kritsuk (UCSD)
Paolo Padoan (Barcelona)
Hui Li (LANL) Hope Chen (CfA)
Alyssa Goodman (CfA)
Phil Meyers (CfA)
Mike Norman (UCSD)

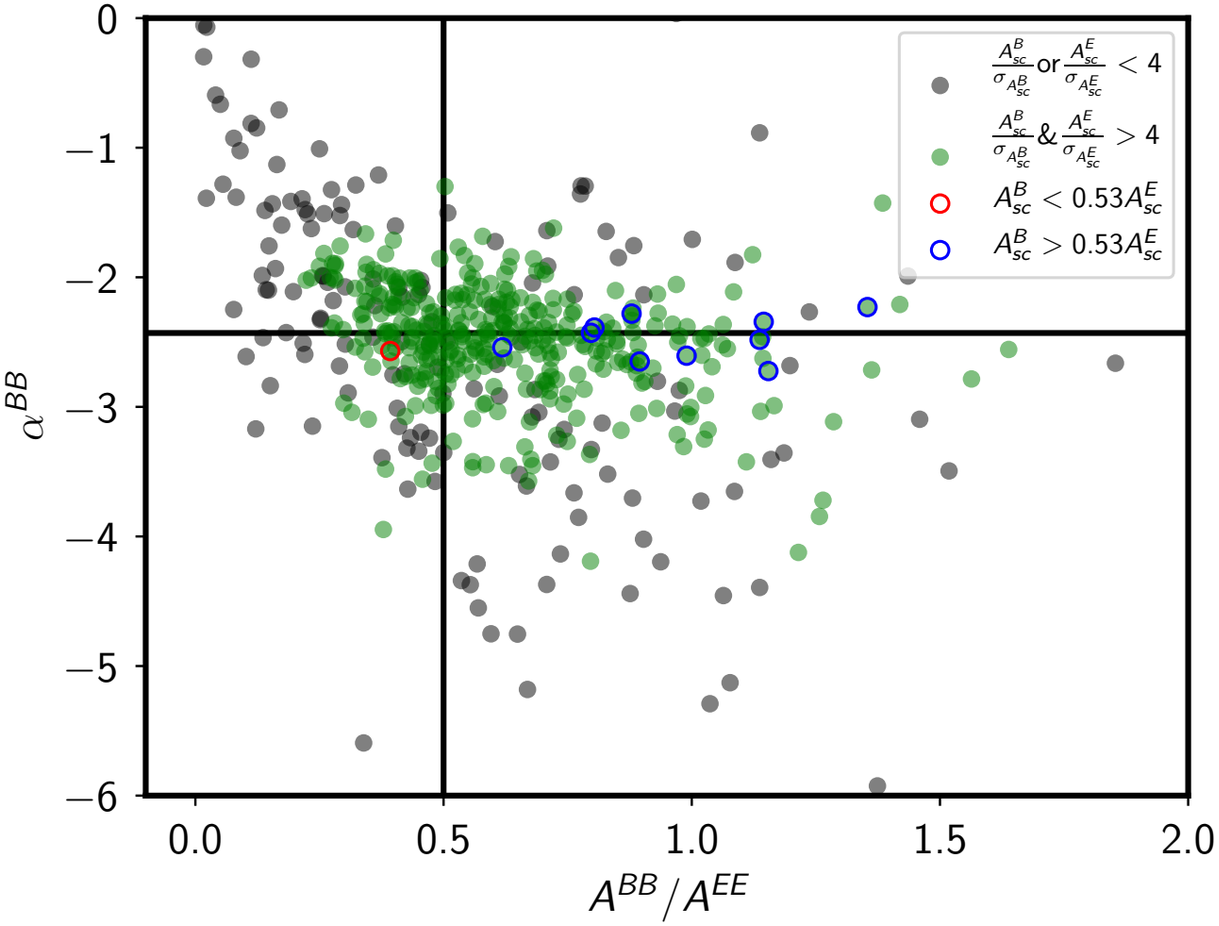
Outline

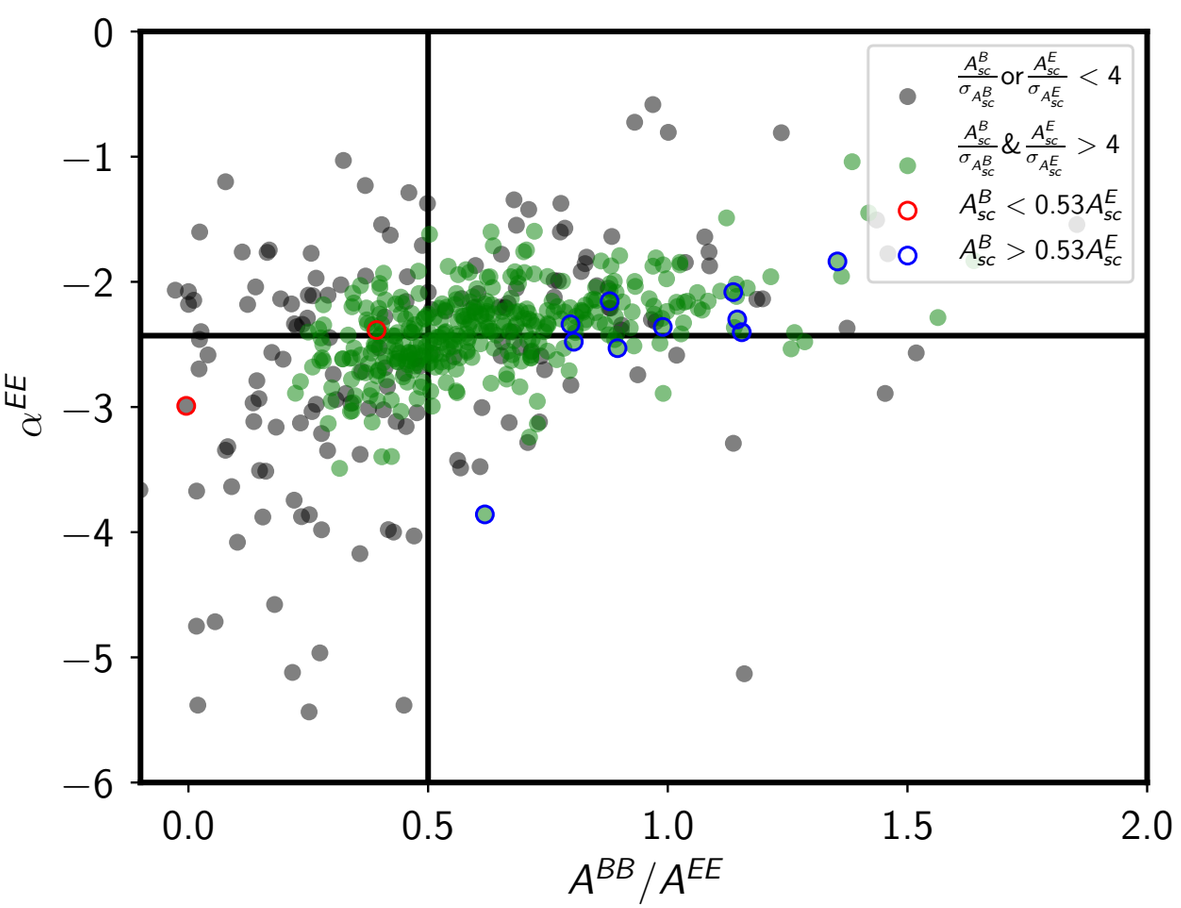
- Using the simplest model that Alex won't yell at me for, We'll look at how
  - B-power to E-power **ratio**
  - and B and E **slopes**.
  - vary with **Alfven** and **Sonic** Mach Numbers
  - And on the actual sky with **Planck**
- This is work in progress, feedback is welcome.

Slope and Ratio



- Variations from Real Life
- From 11 degree patches from Planck, above l=35 deg.
- Colors indicate statistical significance.



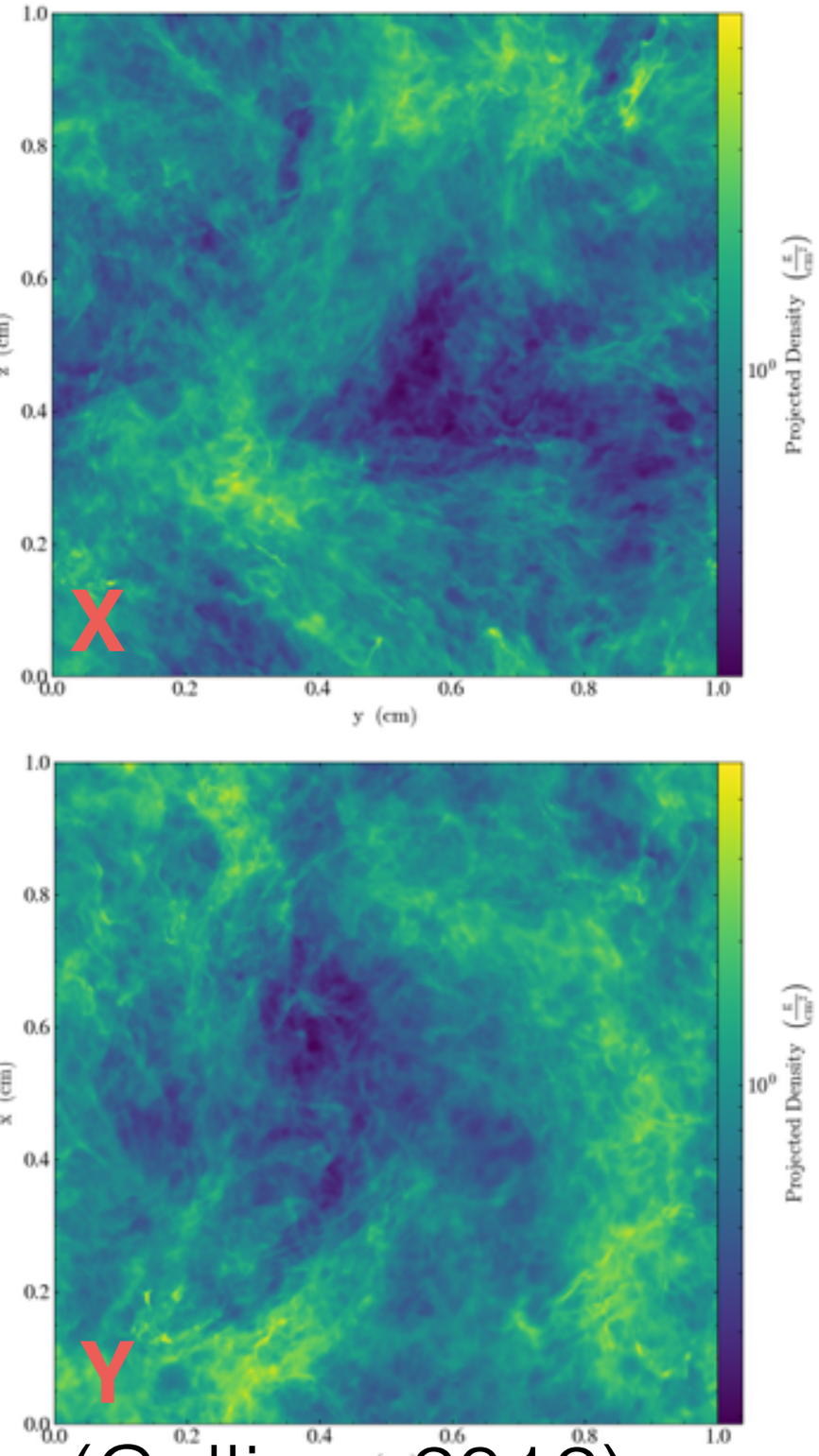


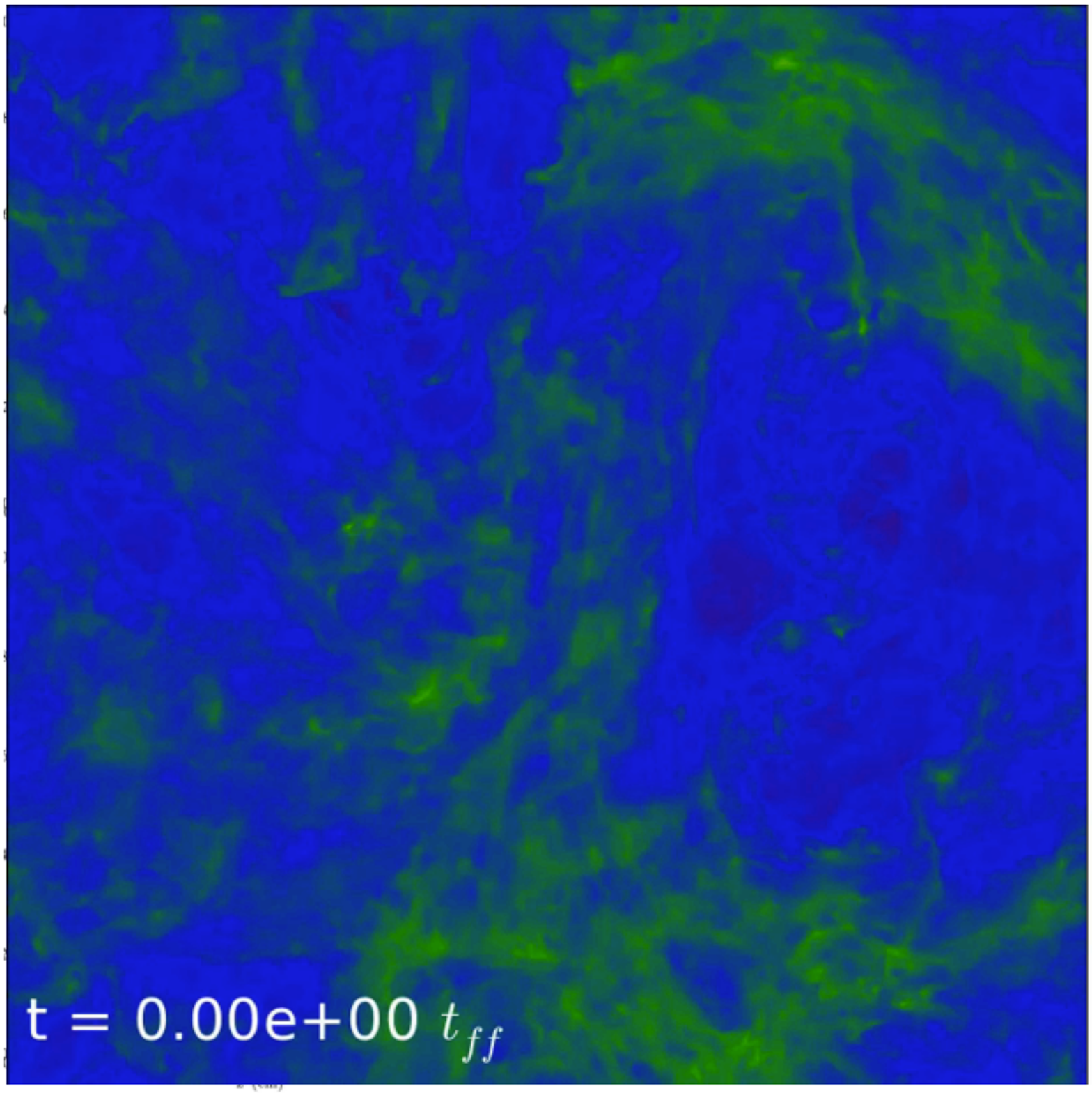
(Rotti et al in prep)

“Simplest” Thing to Do:

- MHD Turbulence in a Box.
  - Begins with Uniform Density, Magnetic Field.
  - Adds kinetic energy in large modes
  - Structures cascade to smaller scales by v.grad v
  - Density/Magnetic/Velocity correlations and spectra are self-consistent.
- I already had some such simulations from some Molecular Cloud work…

Ms=9, Ma=9, 512^3+4, CT

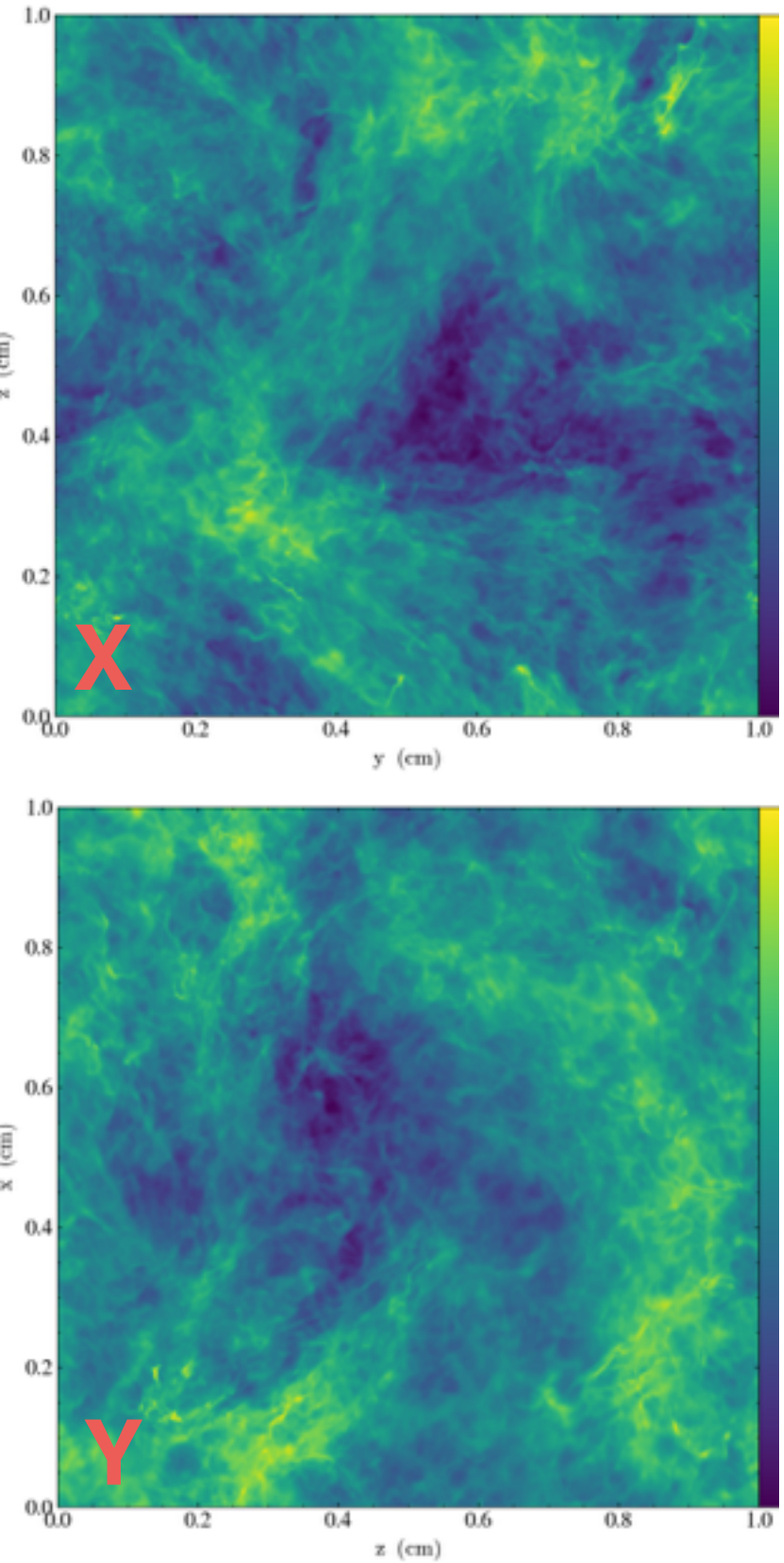


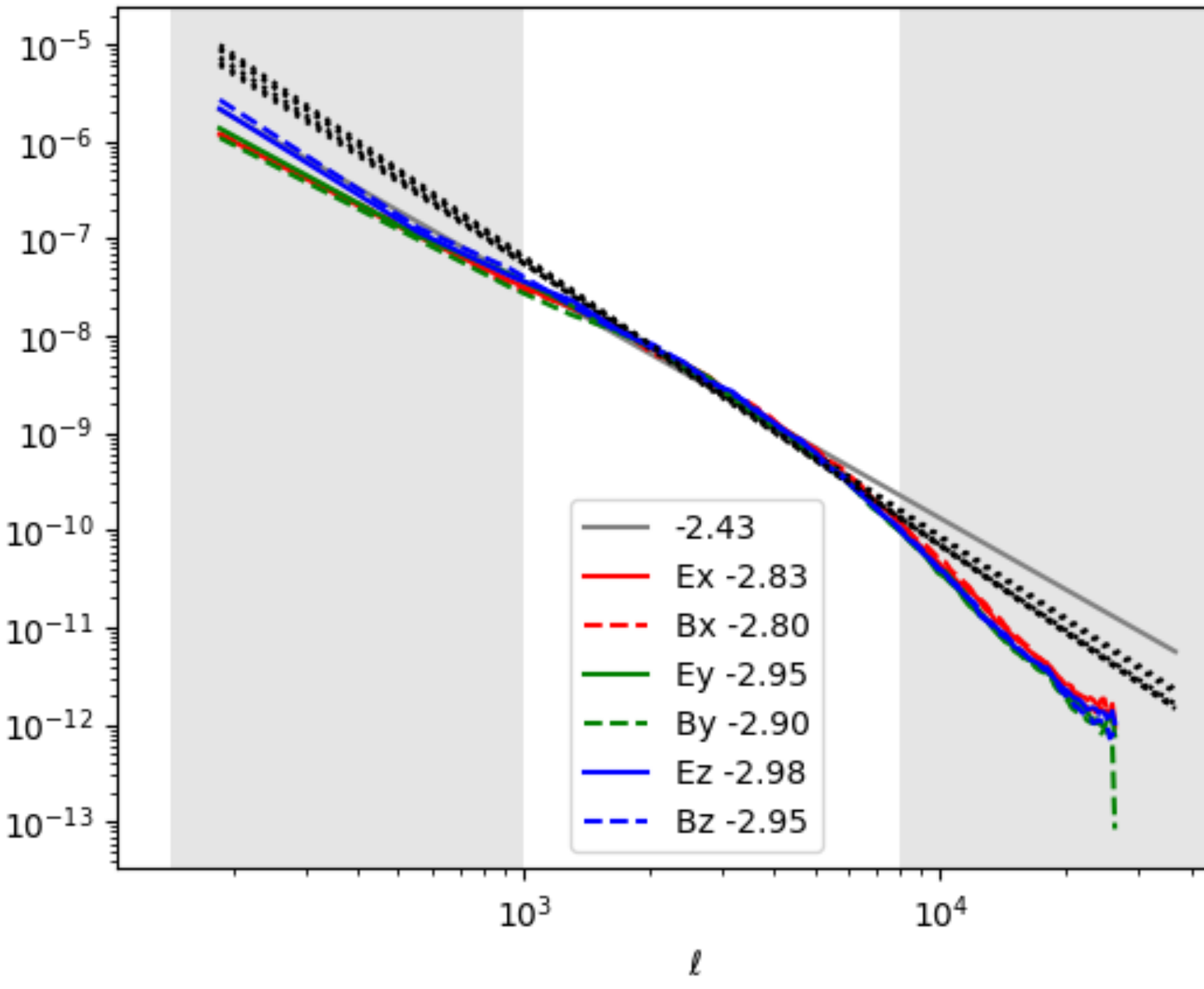


(Collins+2012)

Ms=9, Ma=9

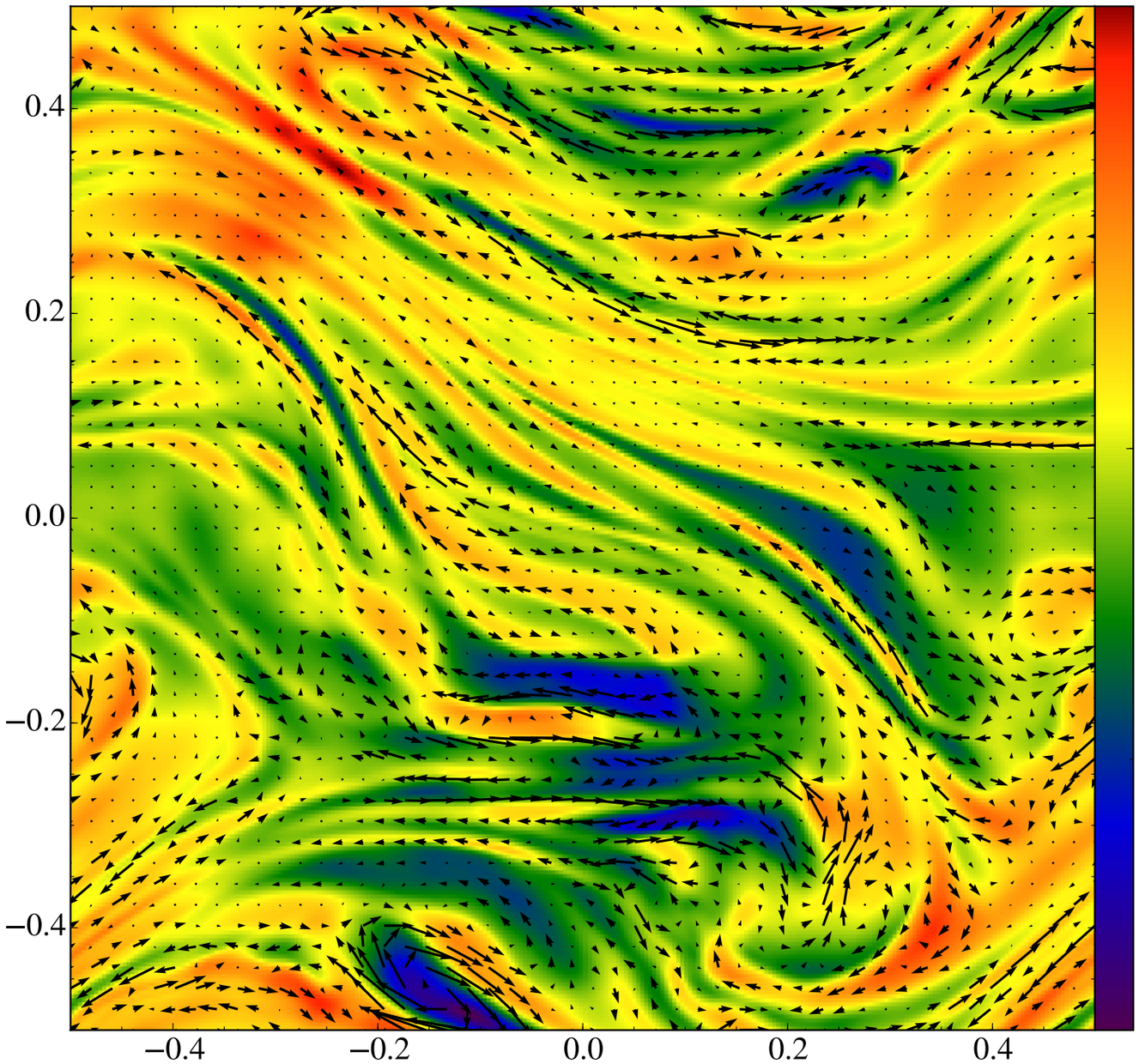
Slope is good
Ratio is Bad

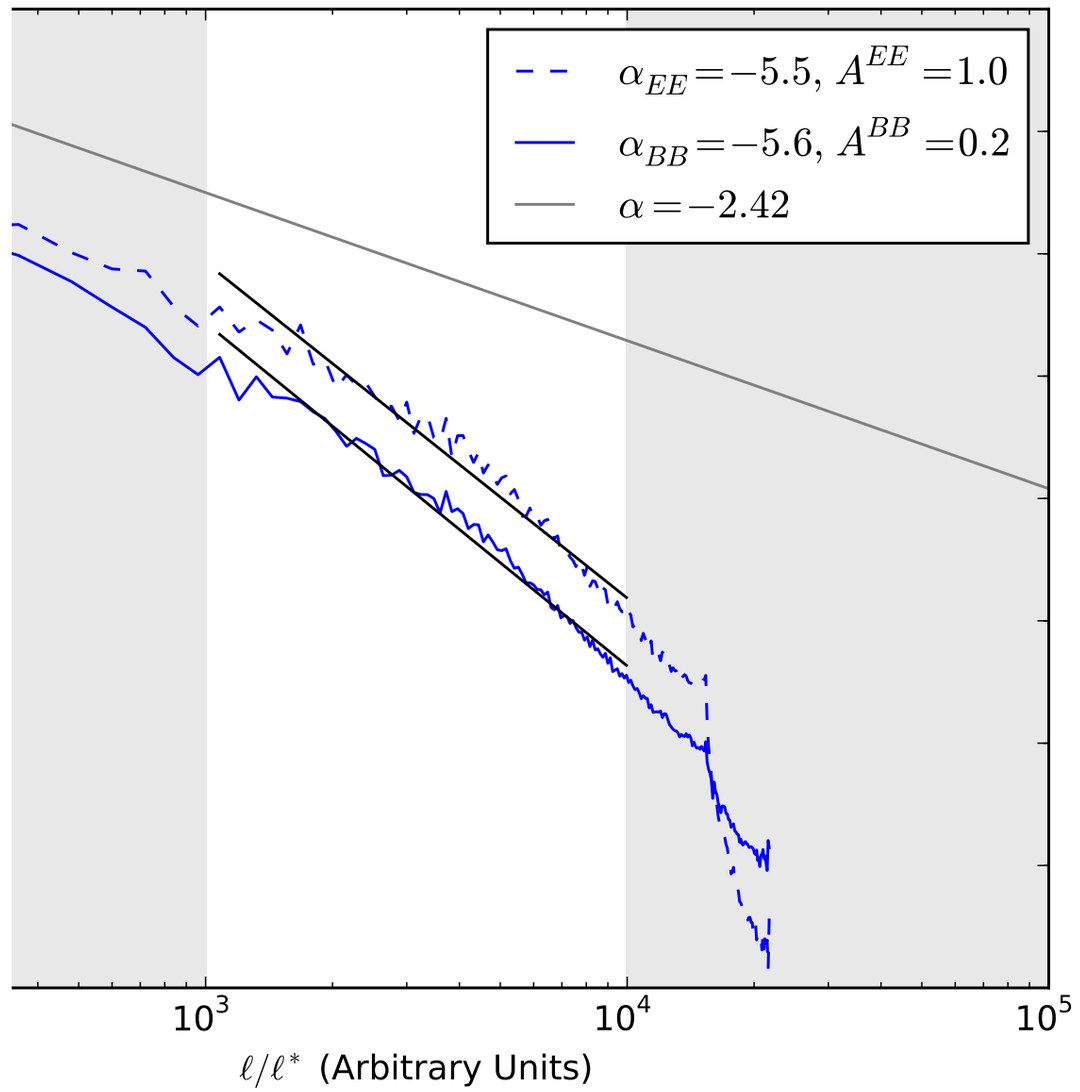




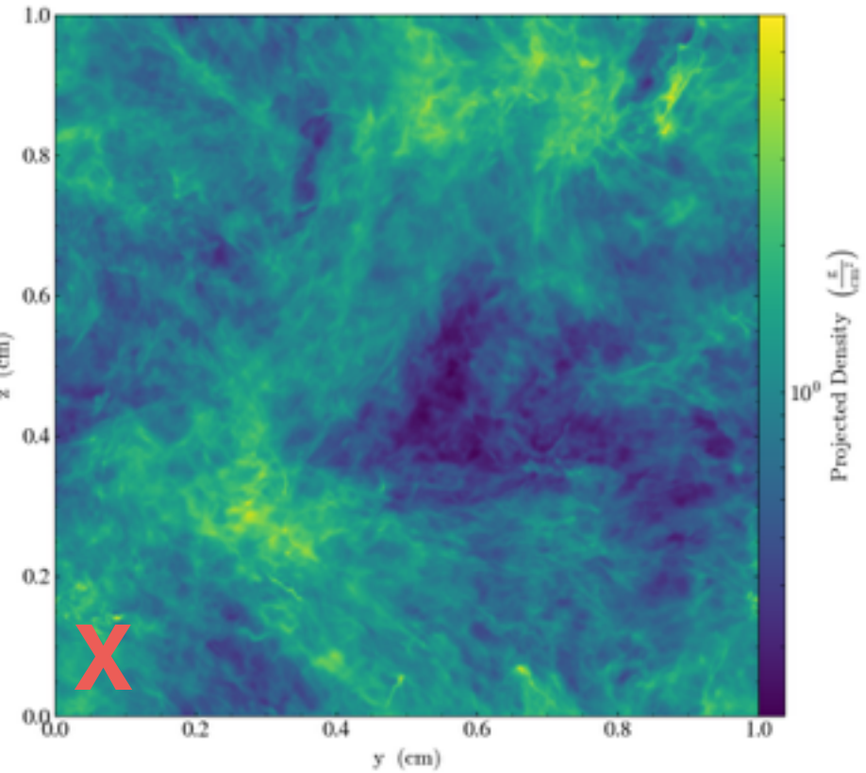
Ms = 0.6, Ma = 0.3

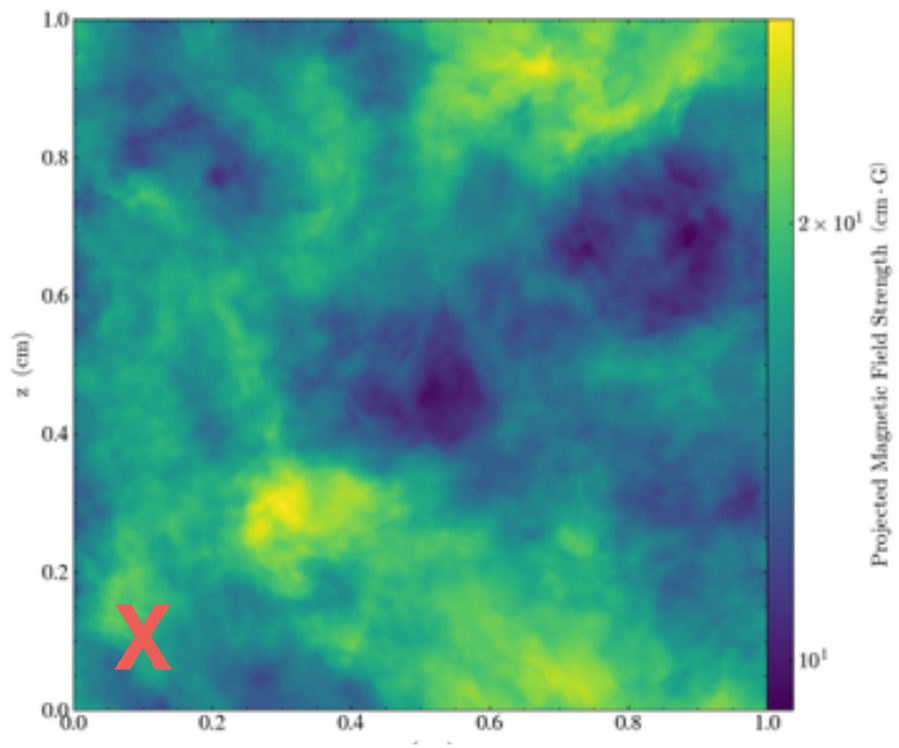
Slope is good
Ratio is Good



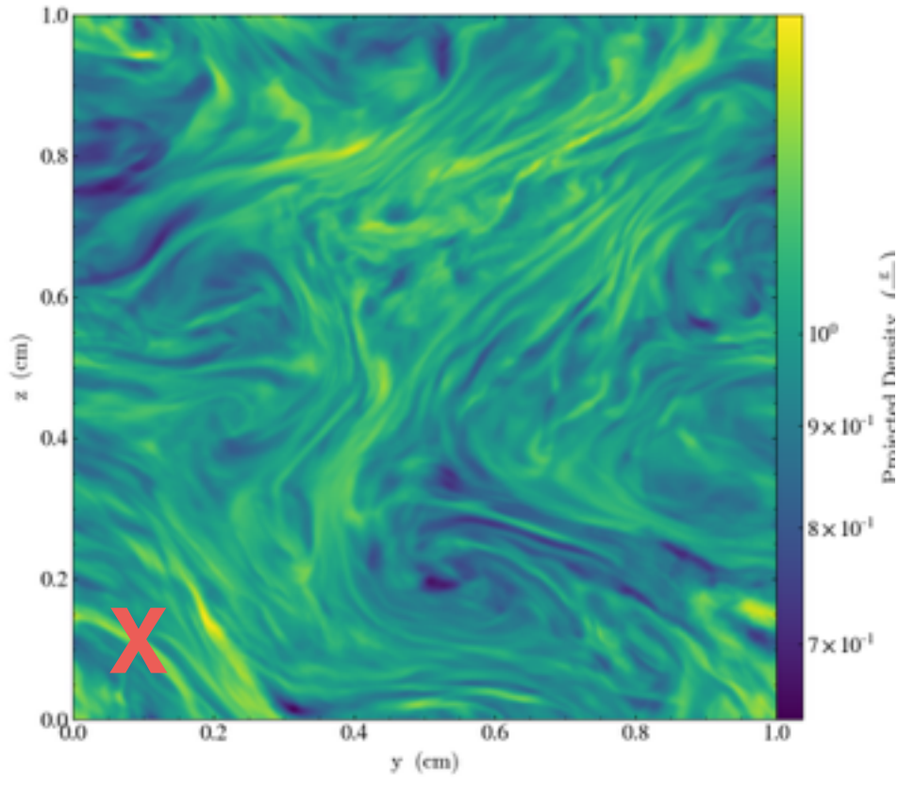


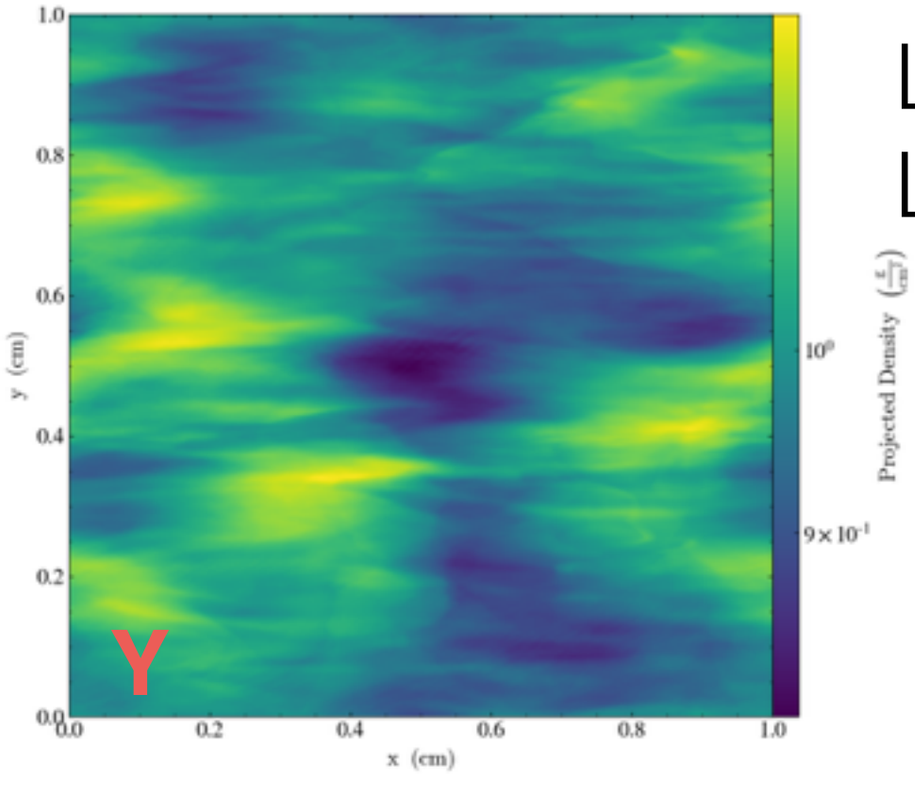
Vary Ma, Ms, Gamma





High Sonic Mach,
High Alfven Mach





Low Sonic Mach,
Low Alfven Mach

Fake Data: 27(ish) sims

- Enzo, Driven MHD Turbulence
  - Some Dedner, some CT
- 512^3/256^3
- Ma, Ms vary *(Please remind me if this hasn't been sufficiently described)*
- Three EOS: Actually Isothermal: Gamma=1.001; Gamma=5/3
- Driven at large scale
  - 2/3 power in Solenoidal modes (mostly)
  - Stochastic forcing of Federrath. et al 2008 (mostly)

Several series of runs

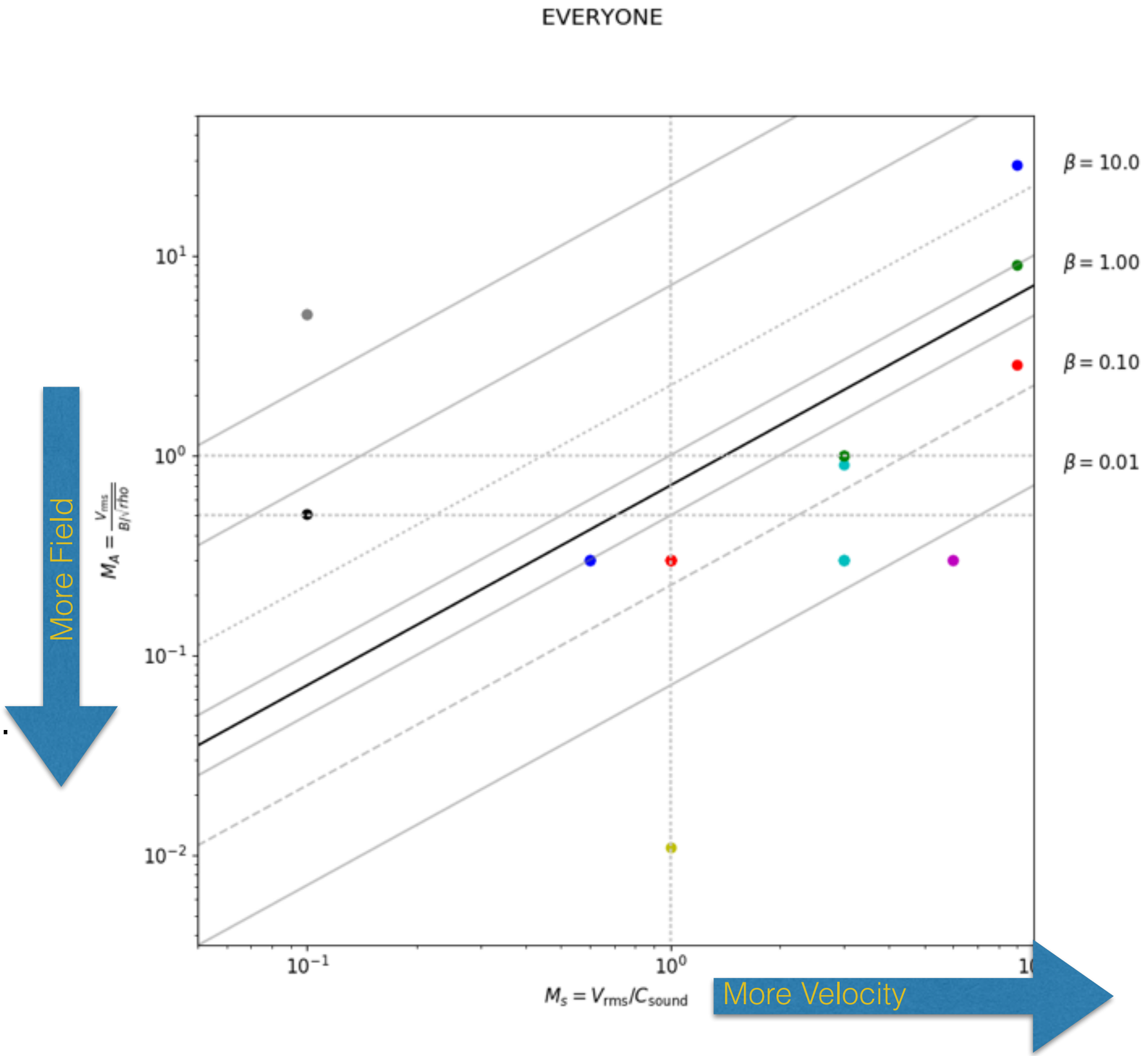
- *ax* 512 CT Isothermal (crashed, so, grain of salt)
- *ac* 512 dedner 1.001
- *ab* 256 dedner 1.001
- *aa* 256 dedner 5/3
- *az* 512 dedner 5/3
- *b* 512+4 levels of AMR, CT, Isothermal, Gravity

Parameter Space: Target

- Ma =
  Velocity vs
  Magnetic Velocity
  V/(B/sqrt(rho))

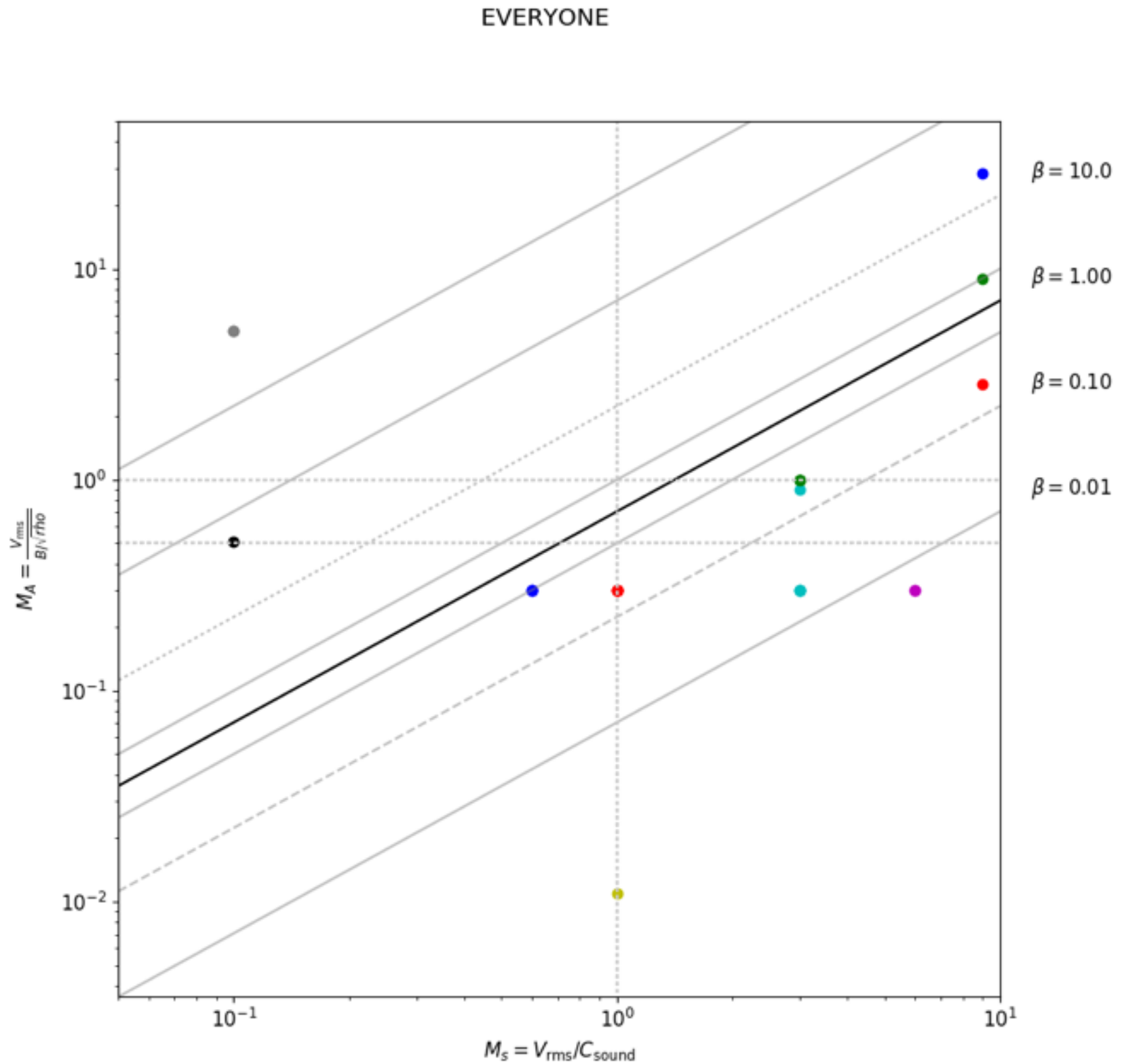
- Mach =
  Velocity vs.
  Sound Velocity
  V/Cs, Cs^2=T

- Plasma Beta =
  Thermal Pressure vs.
  Magnetic Pressure
  (rho T/B^2)



Parameter Space: Target

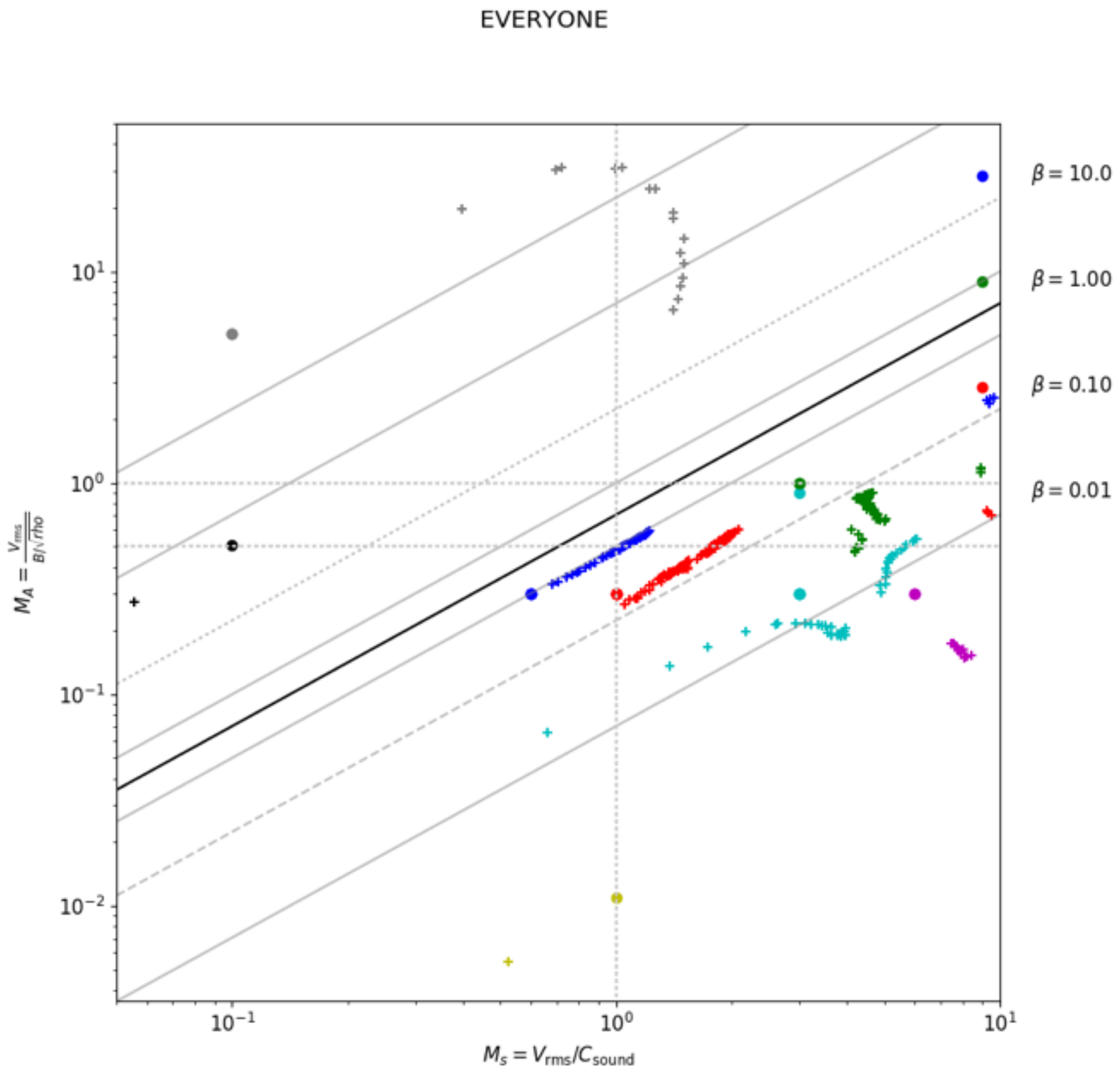
- $Ma^2 = \langle v^2 \rangle / \langle va^2 \rangle$
- Kandel+2017: Ma<0.5
- Density and Magnetic distributions and correlations increase to the bottom right (e.g. Burkhart et al 2009)
- Cost increases to the bottom right.
- *Not all of these points are finished cooking, so, grain of salt.*



Parameter Space: Actual

- Look at individual snapshots for t> 1 tcross.

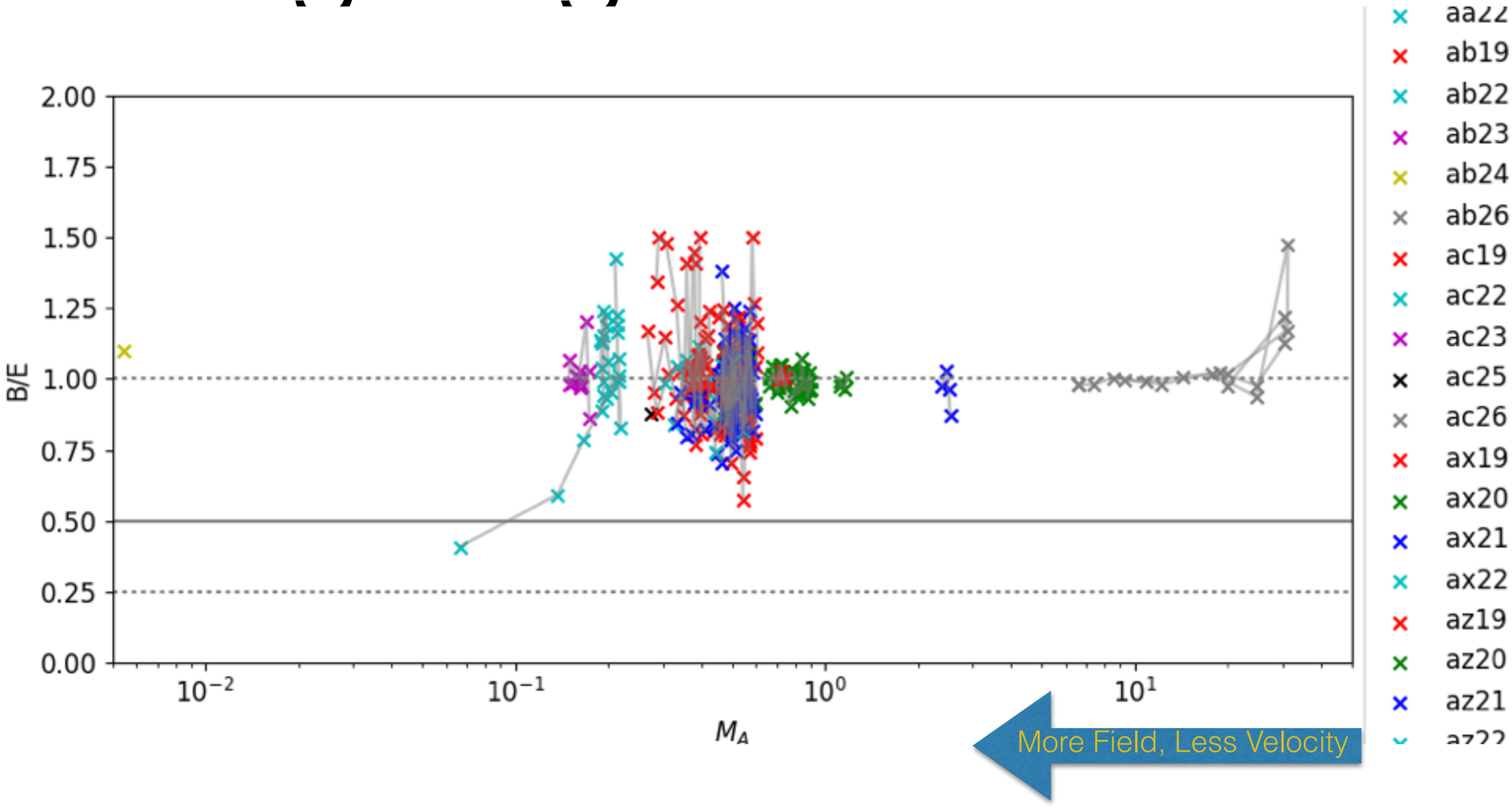
- Rather than averaging.



Variation of Slope and Ratio with

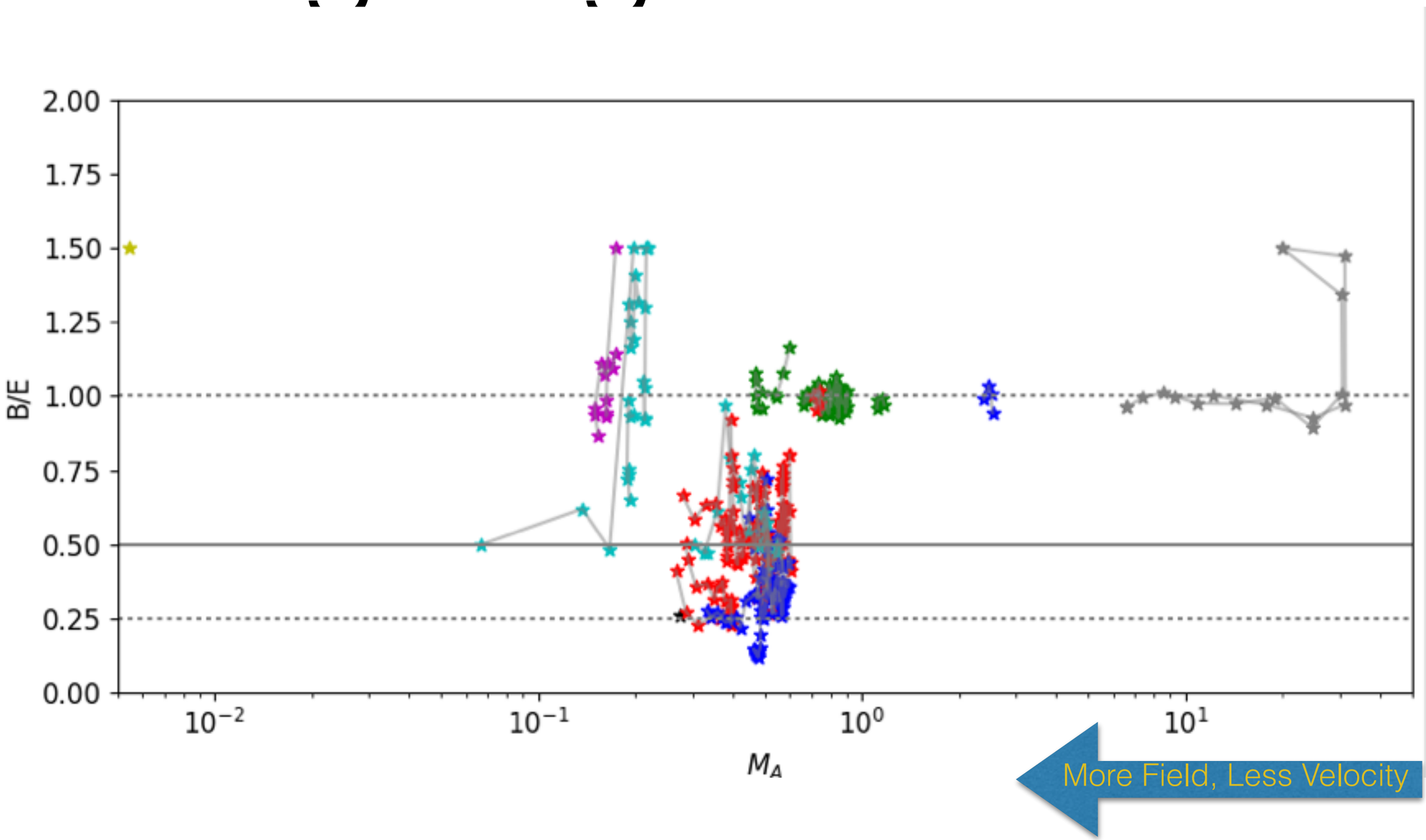
- Viewing Angle
- Alfven Mach Number
- Mach Number

Viewing Angle: Ratio



Only from X projections, along the mean field.
Clusters heavily around ONE.

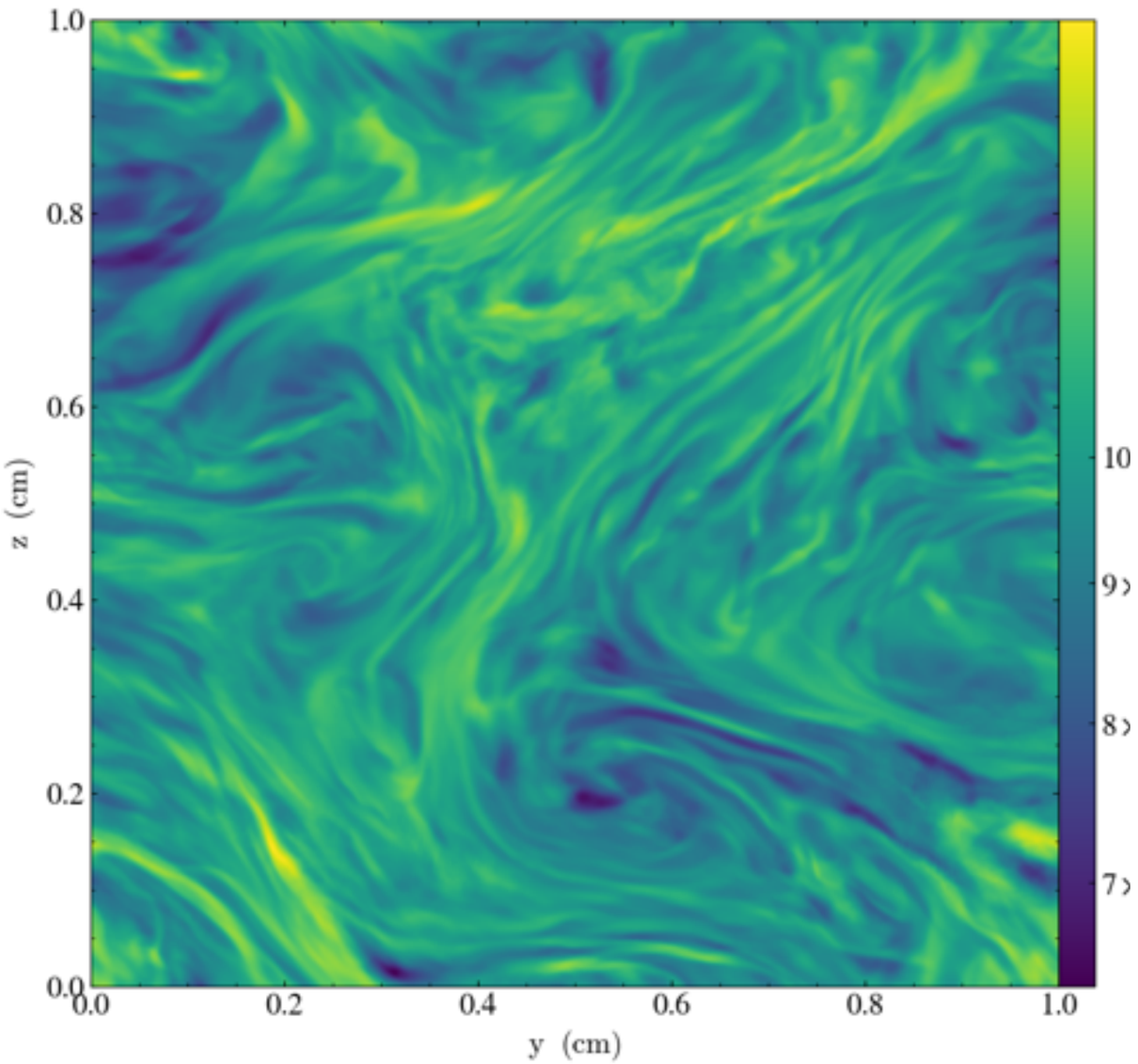
Viewing Angle: Ratio

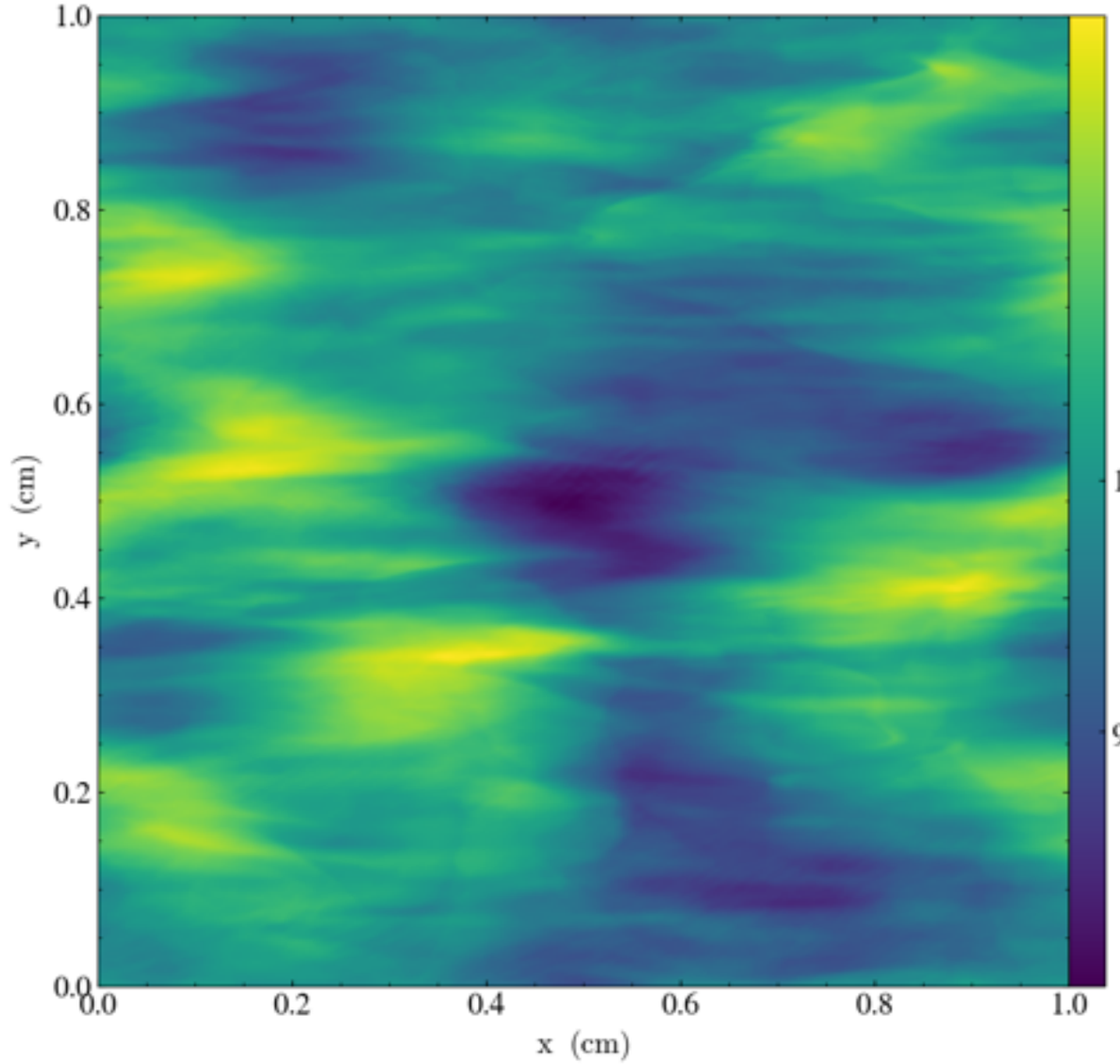


Only from Y projections. Now many sims DO cluster around 0.5

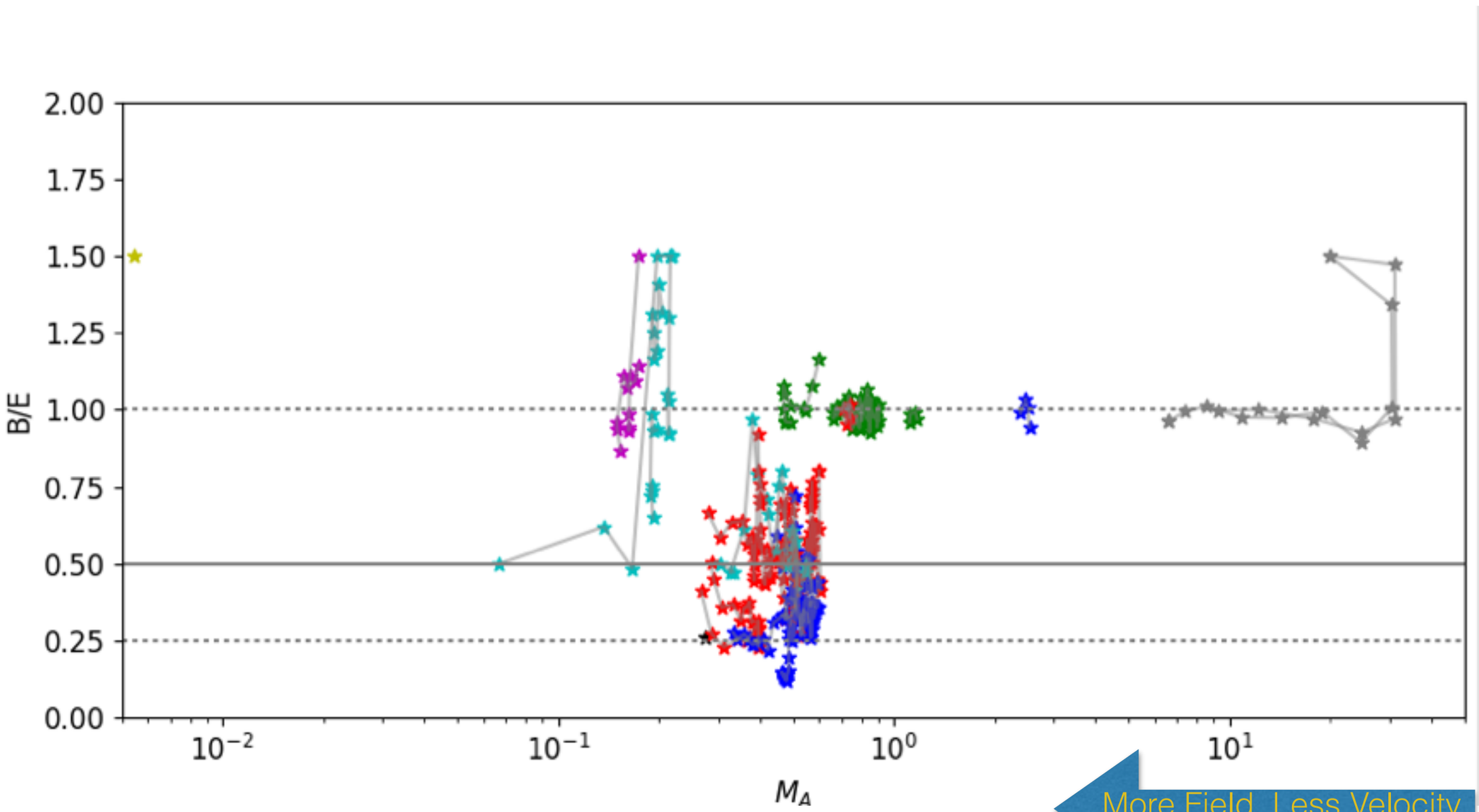
Why?

- Very Sub-Alfvenic, Trans-Sonic



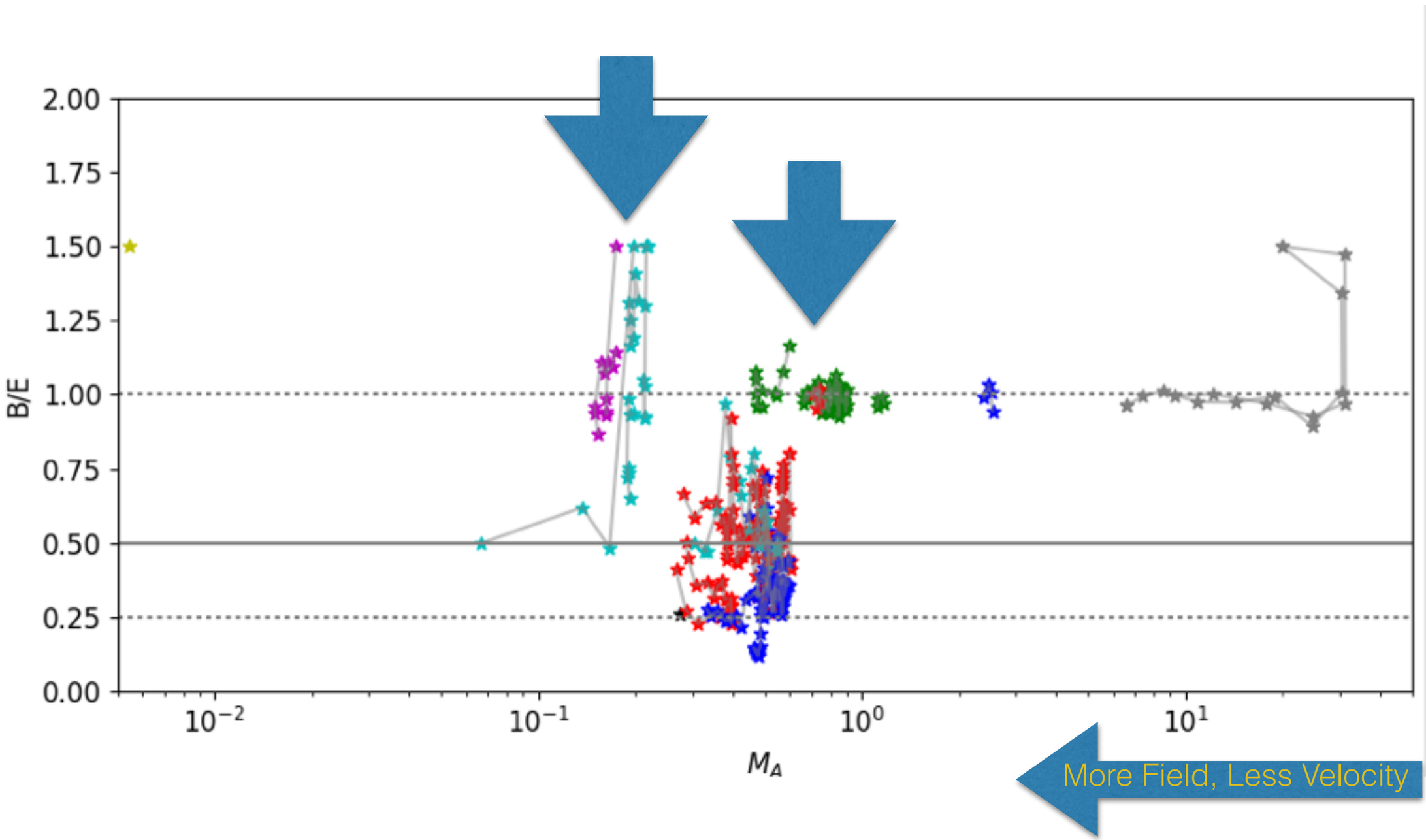


Alfven Mach Number



Same plot, but now we talk about the Alfven Mach Number. Clearly low Ma is *necessary* but *not sufficient.*

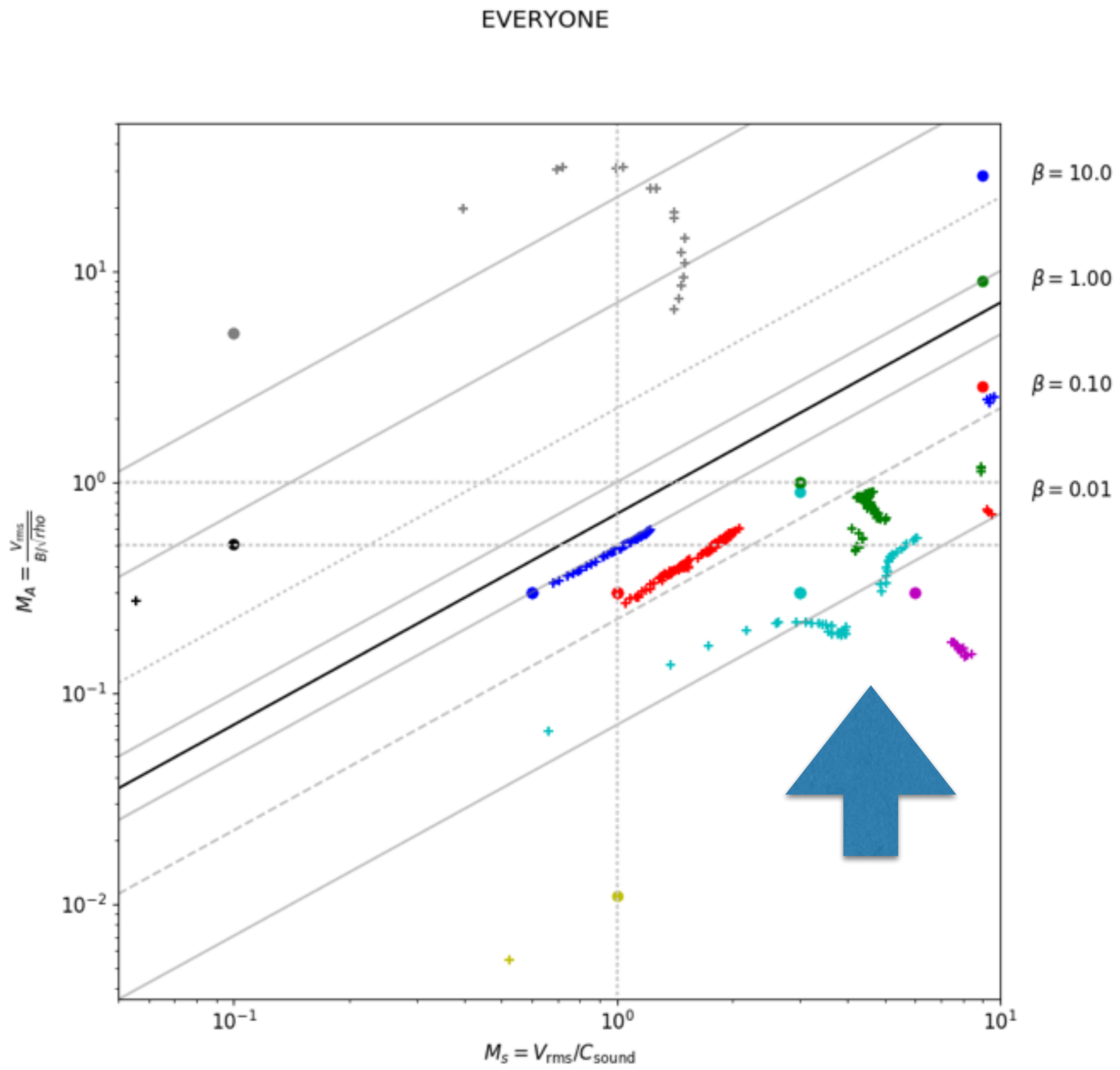
Alfven Mach Number



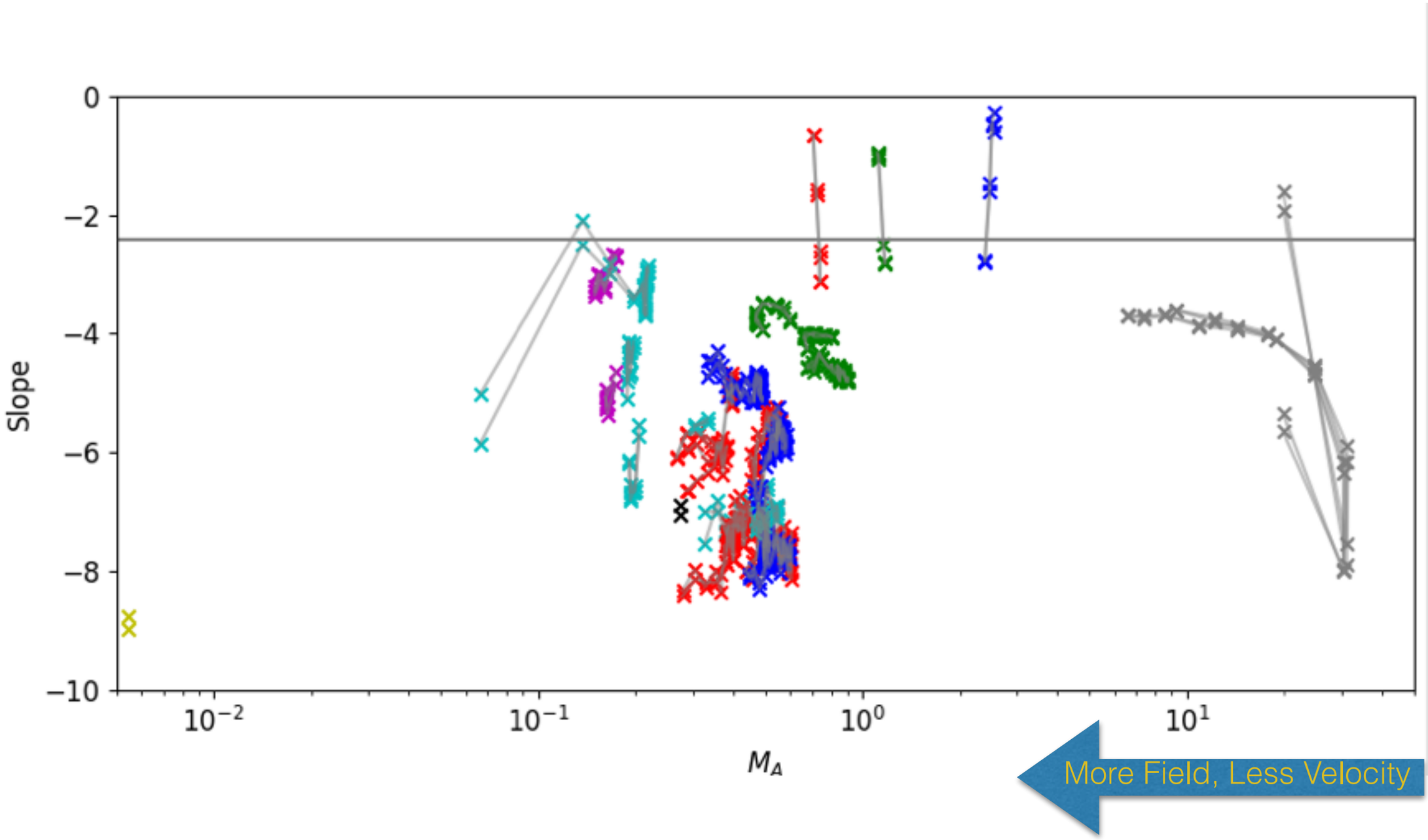
What's up with these ones?

Parameter Space: Actual

- They’re all a lot supersonic
- The green ones are not Sub-Alfvenic enough (?)

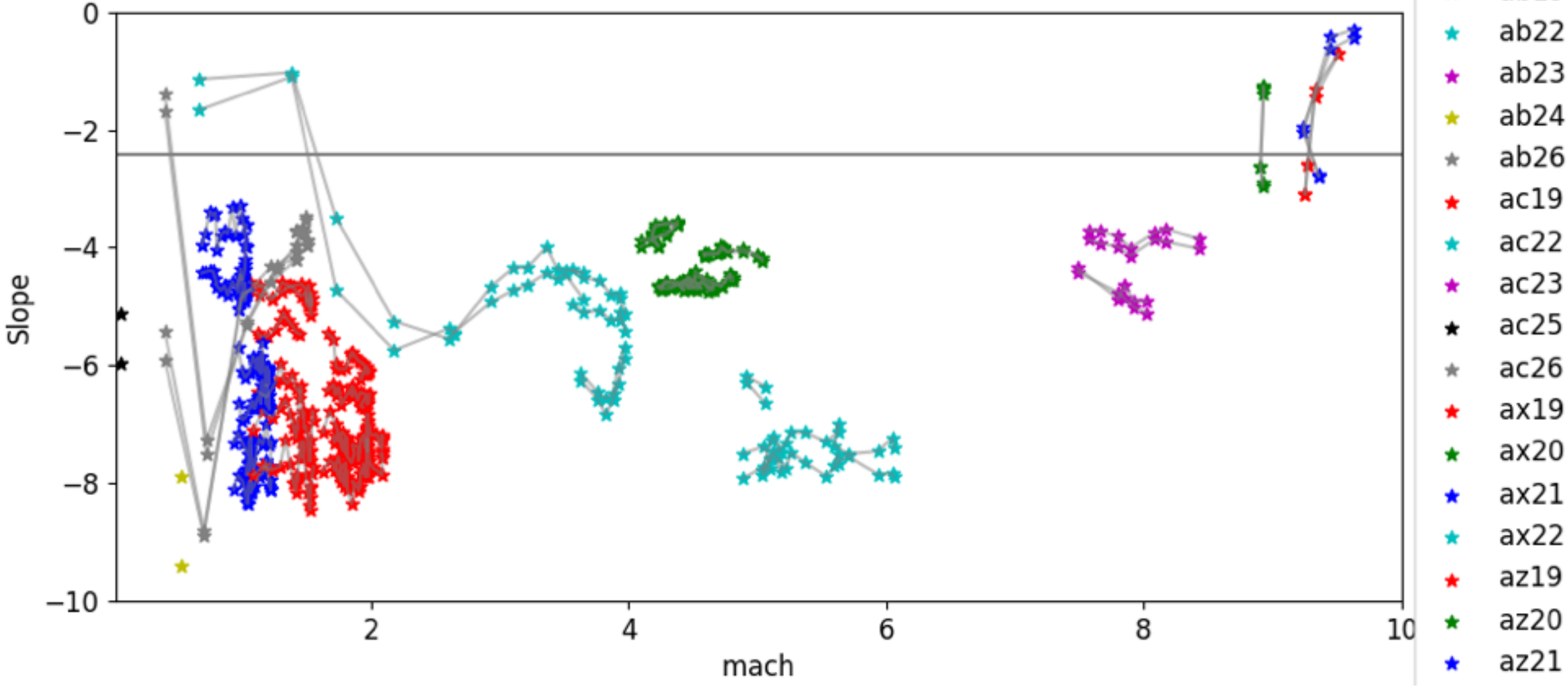


Alfven Mach Number vs. Slope



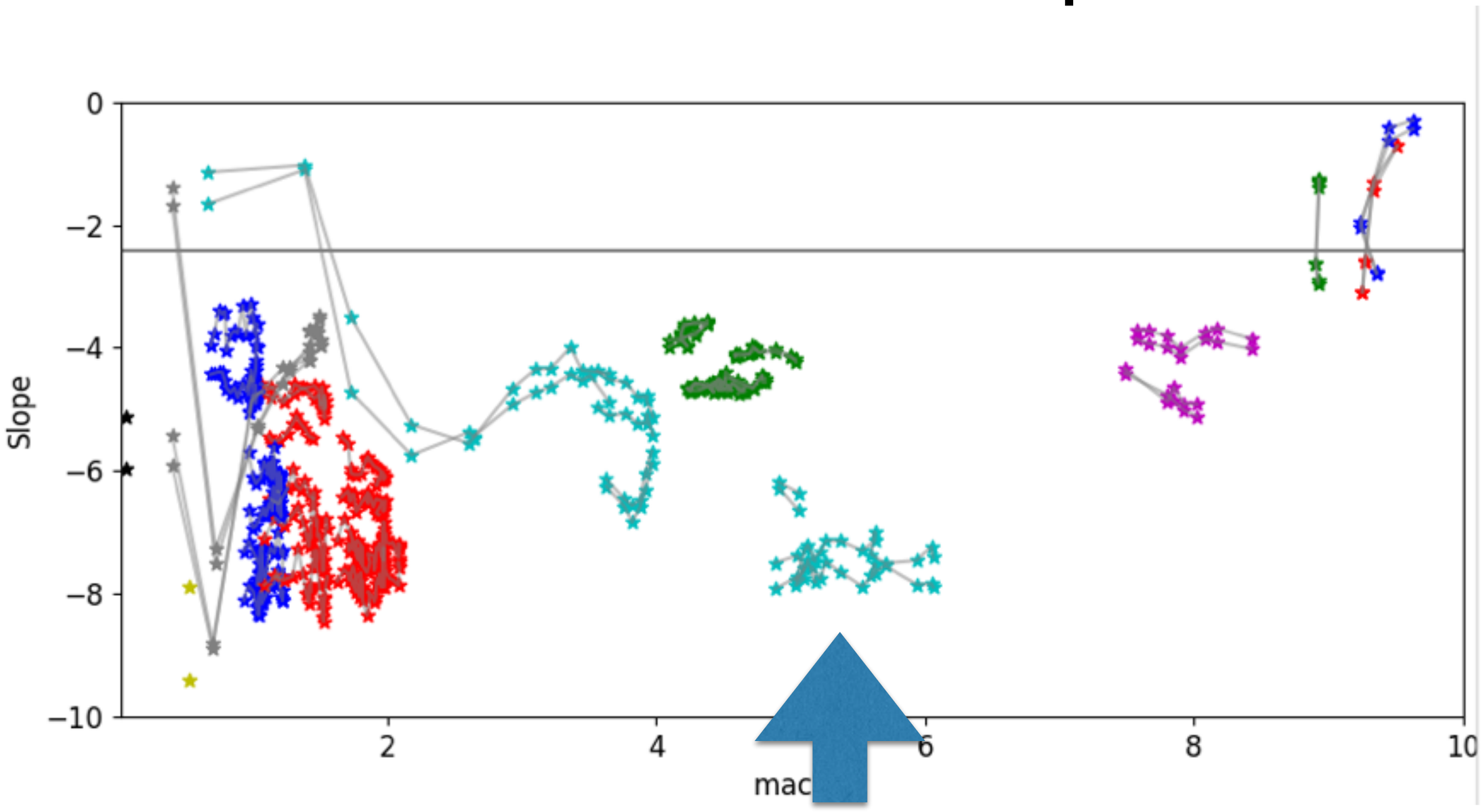
Can’t say much? More in a second.

Mach Number: Slope



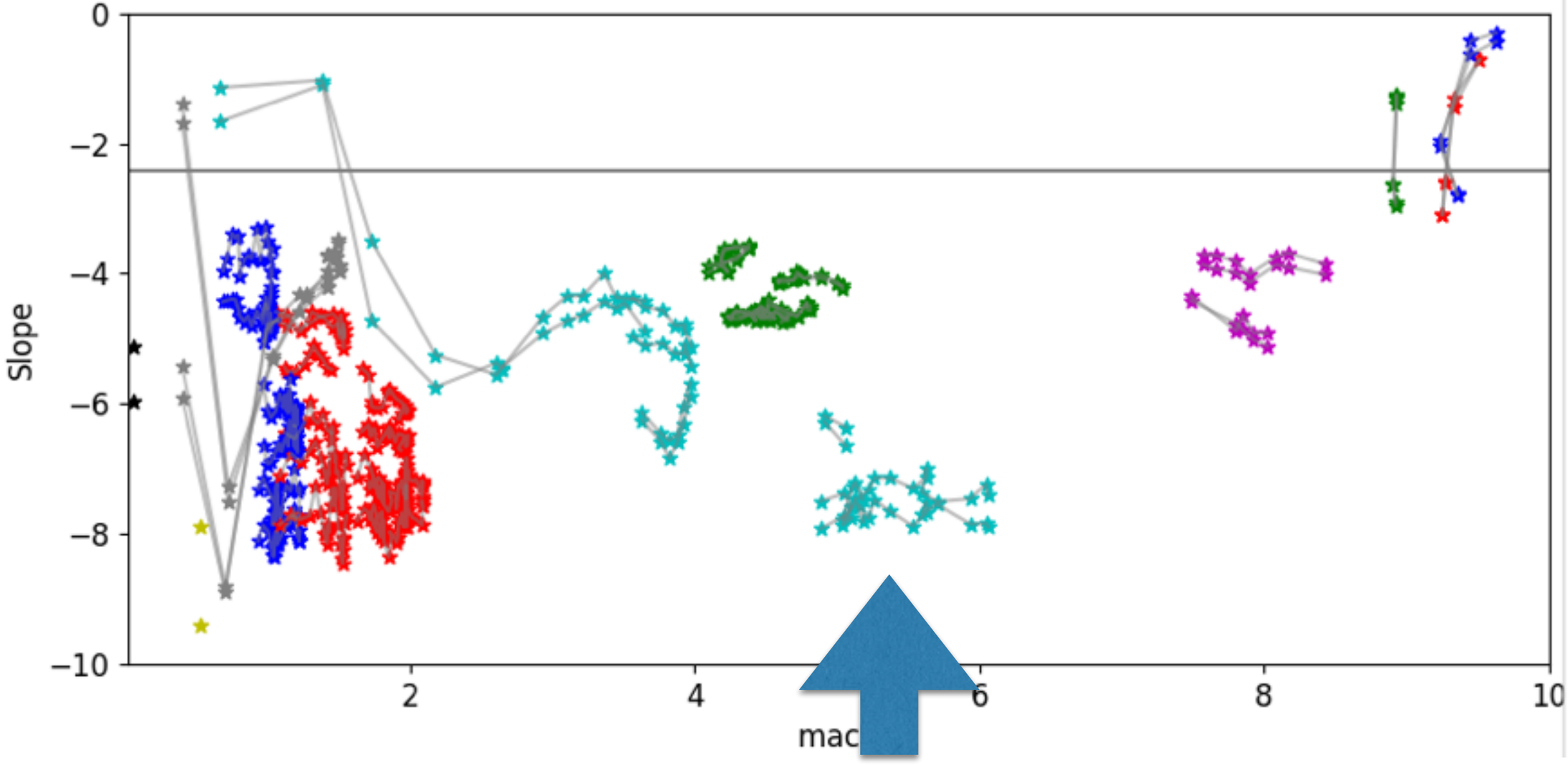
Almost an increasing trend.
What about these?

Mach Number: Slope



Almost an increasing trend.
What about these?

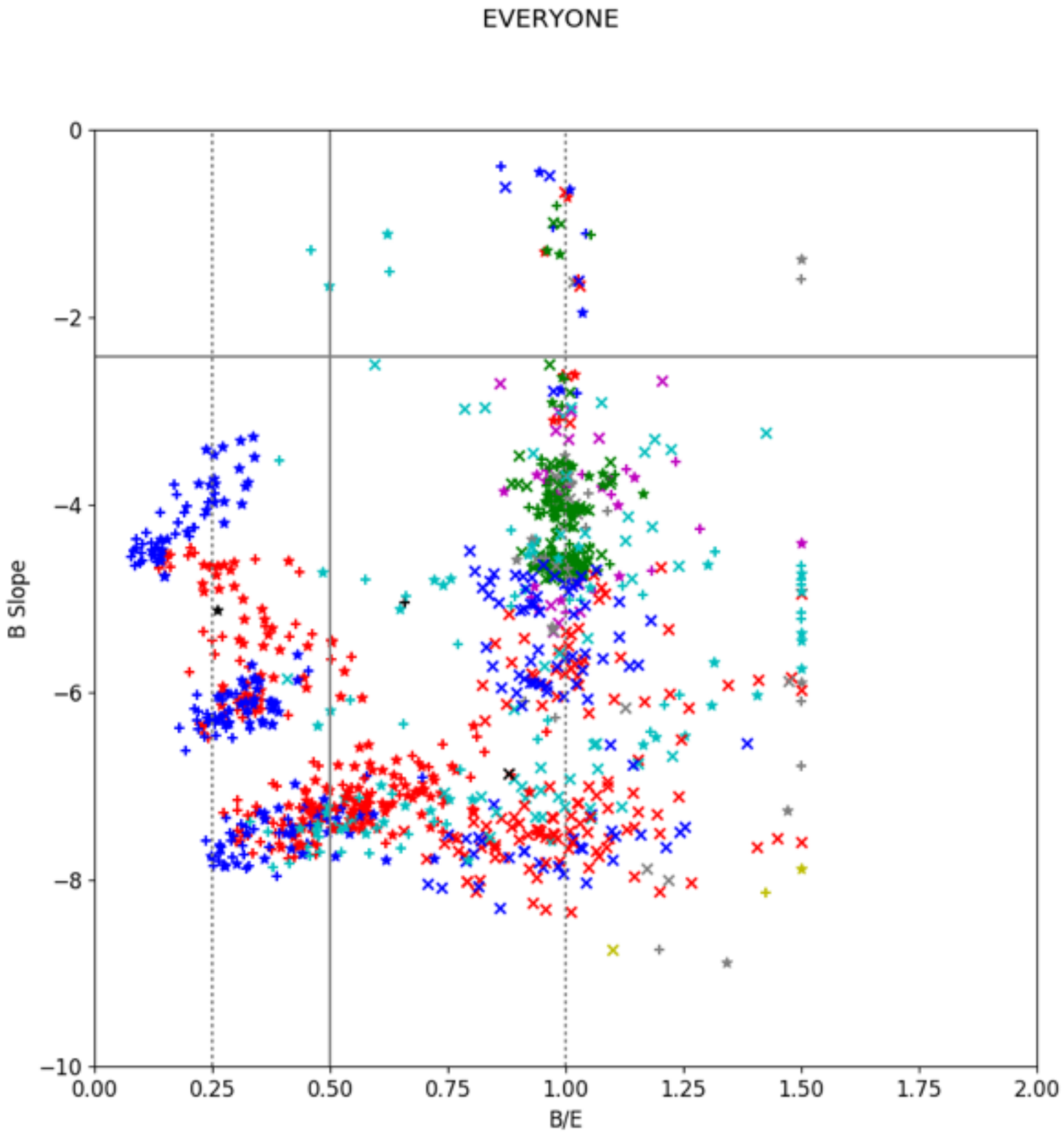
Mach Number: Slope



These have gamma 5/3.
Less compressible.

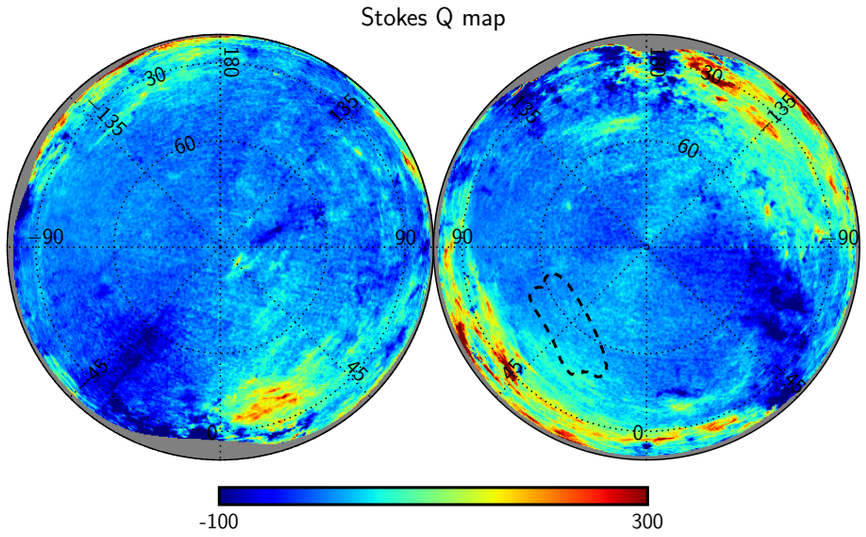
Put it all together

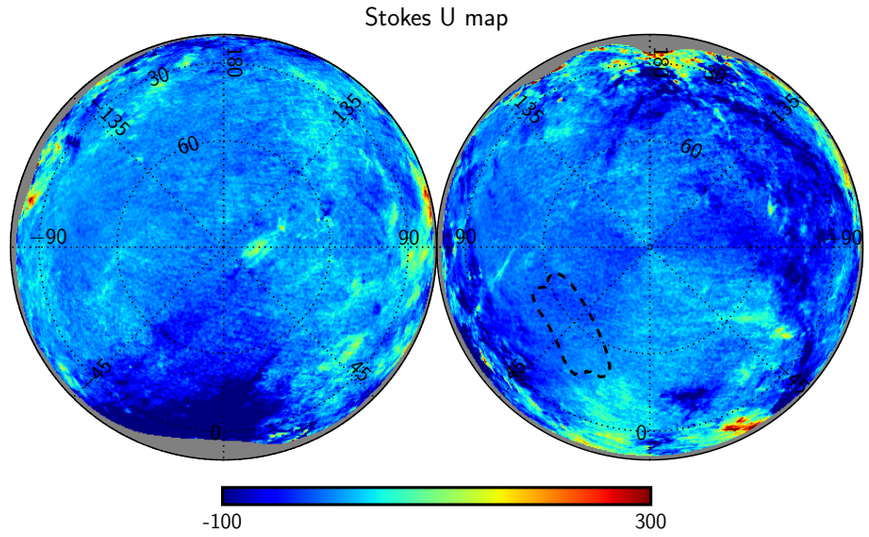
- Is disappointing.
- We get nothing at the crossroads.
- Why?
  - Resolution/ simulation
  - Physics

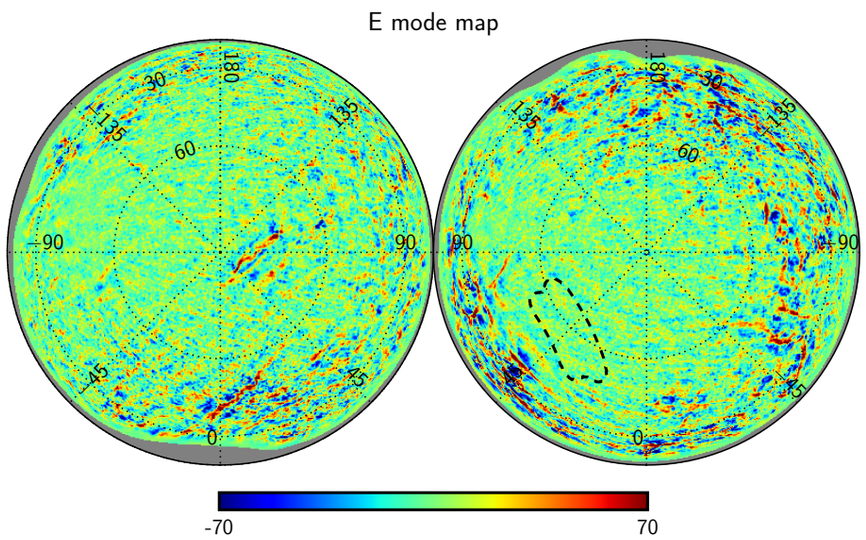


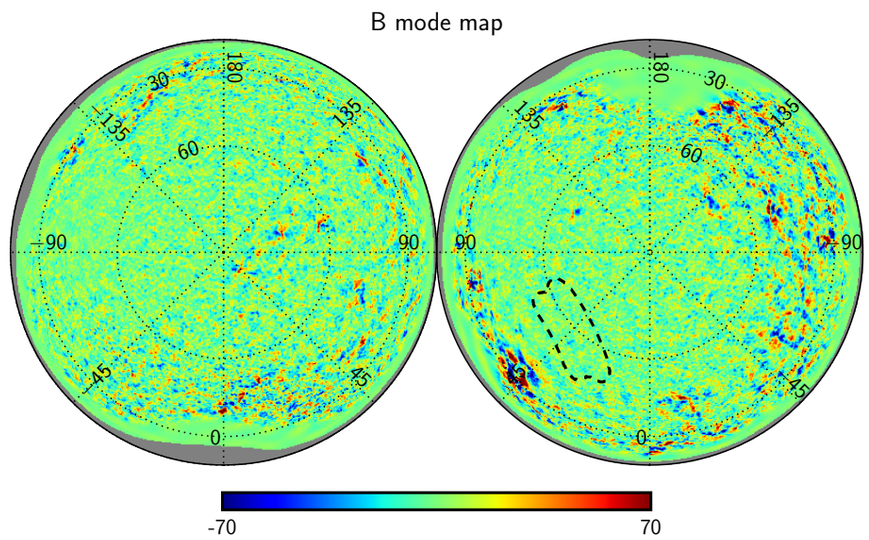
E/B

- Come from Q,U
- Inherently correlations between field alignment and density.
- 353 GHz









(Rotti et al 2018)

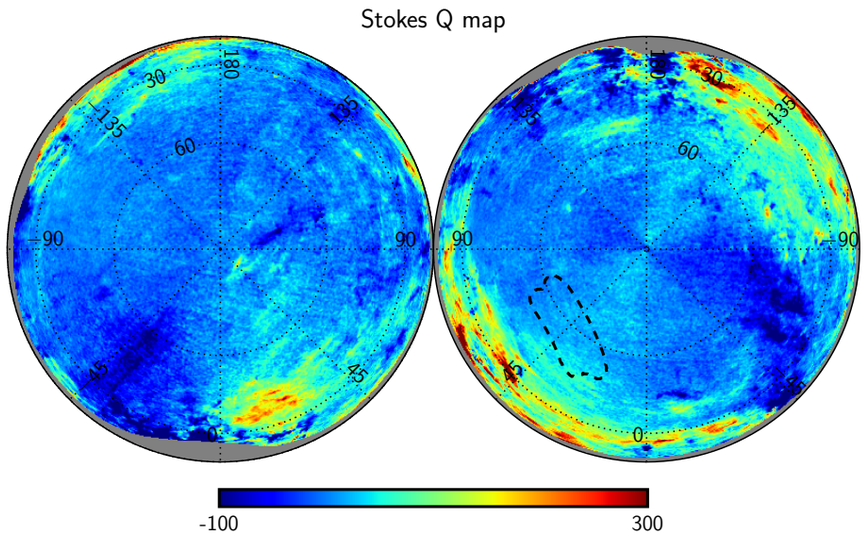
Examine Variation

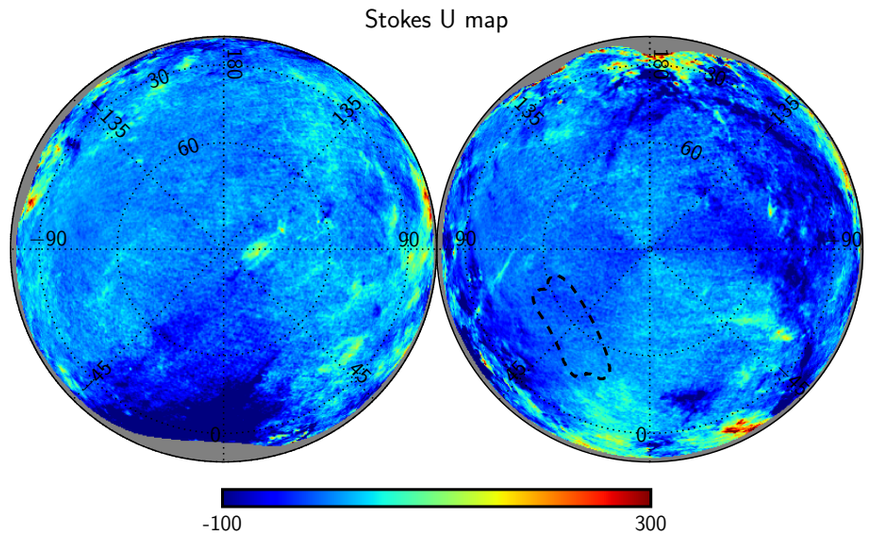
- Cut small patches, fit E&B spectra

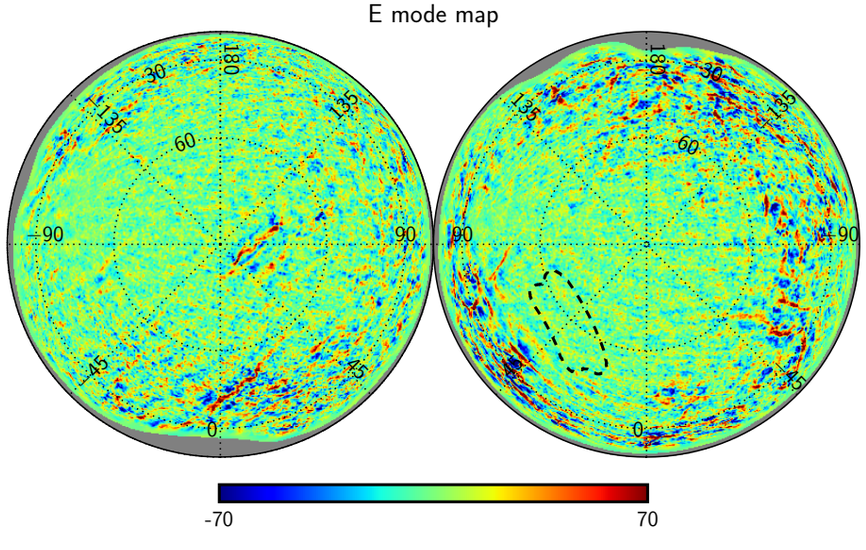
- 11.3 deg disks
  512 pixels

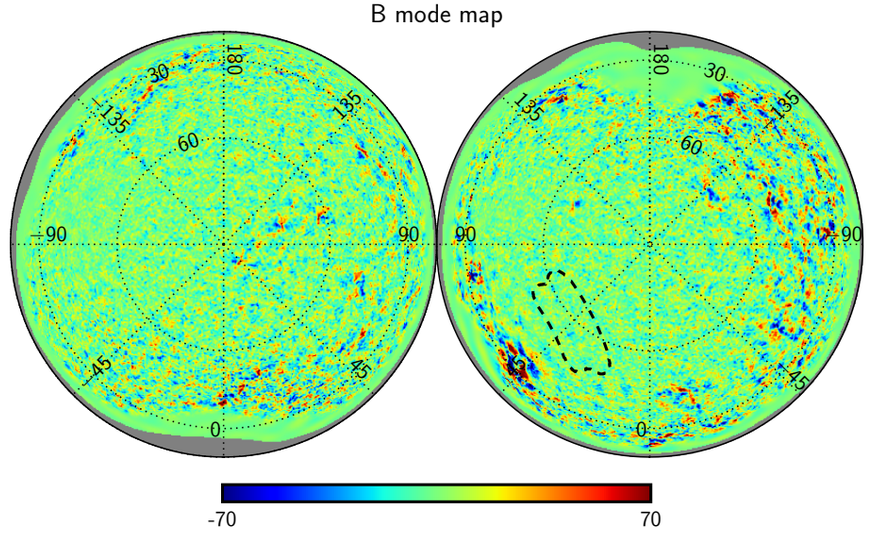
- b> 35 deg

(Rotti et al 2018)



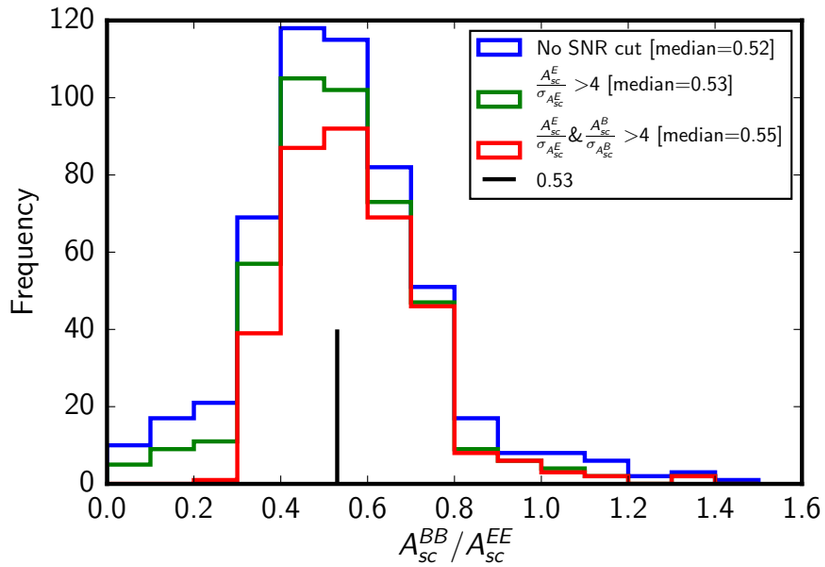




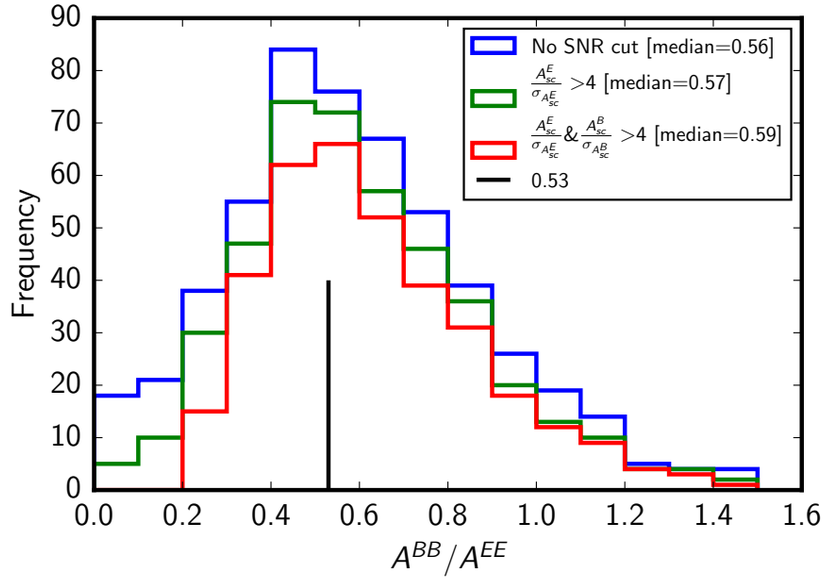


Some variation

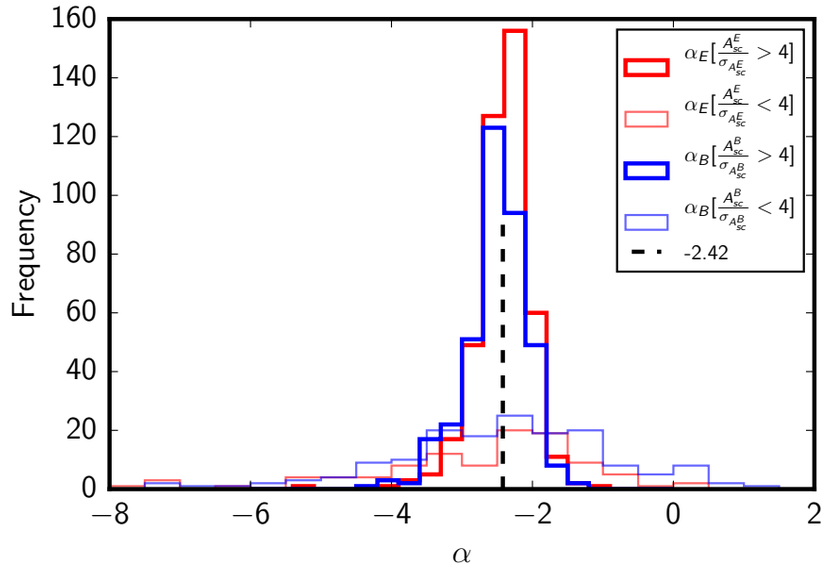
- Slopes and Ratios for various noise cuts, two fit methods



Constant slope ($\alpha = -2.43$)

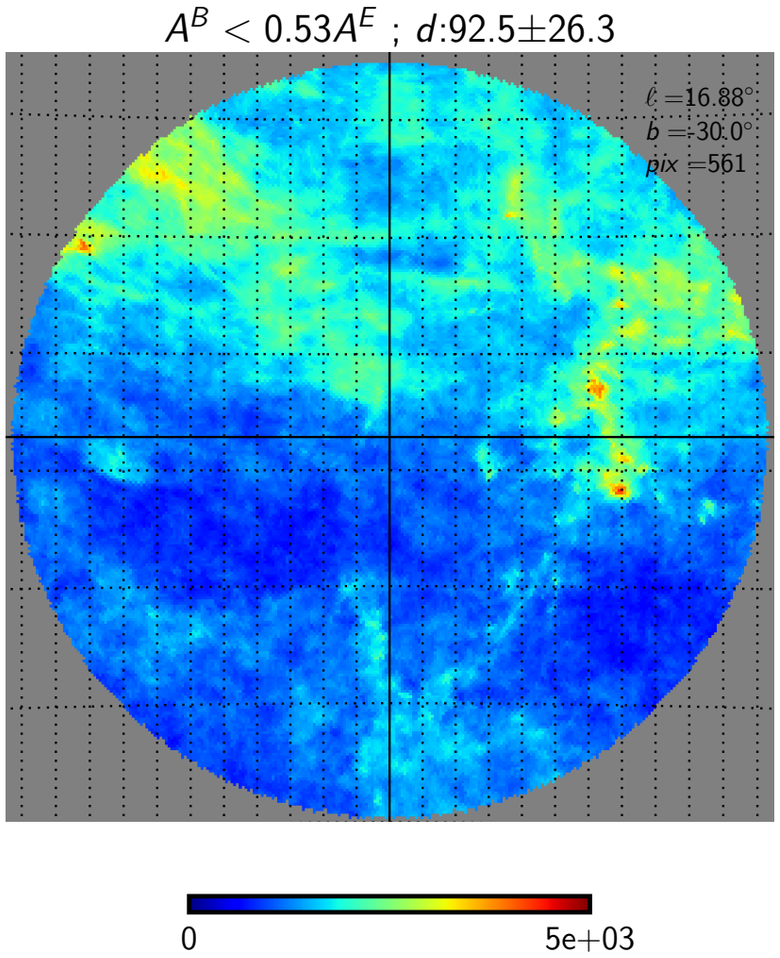


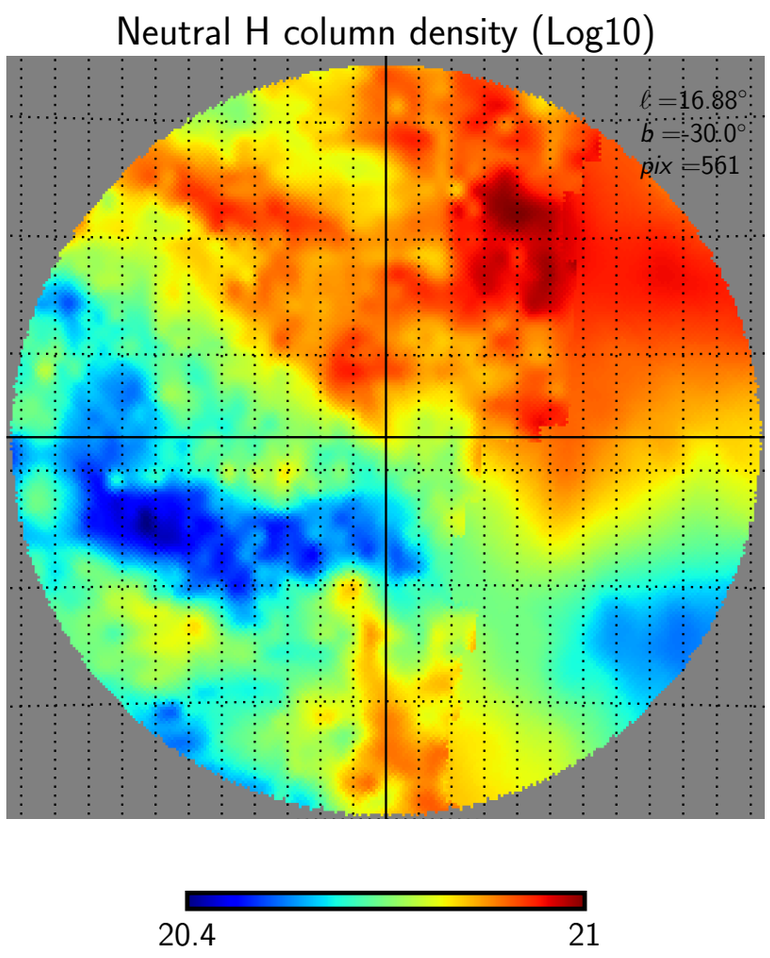
Varying slope

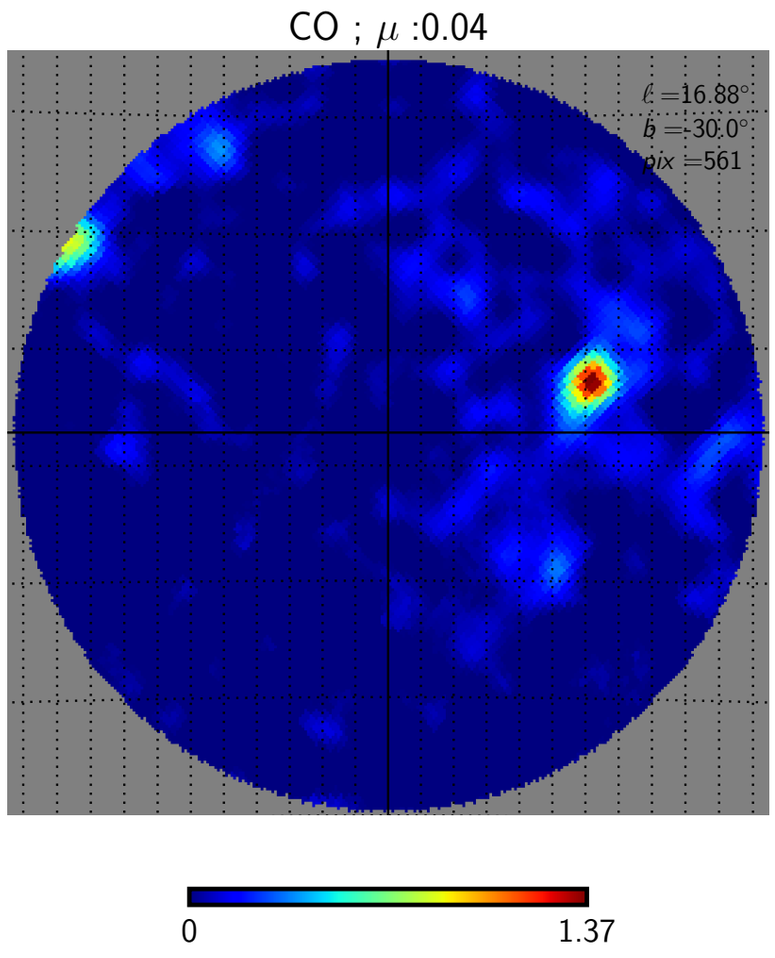


α

Too Much E: B/E = 0.34







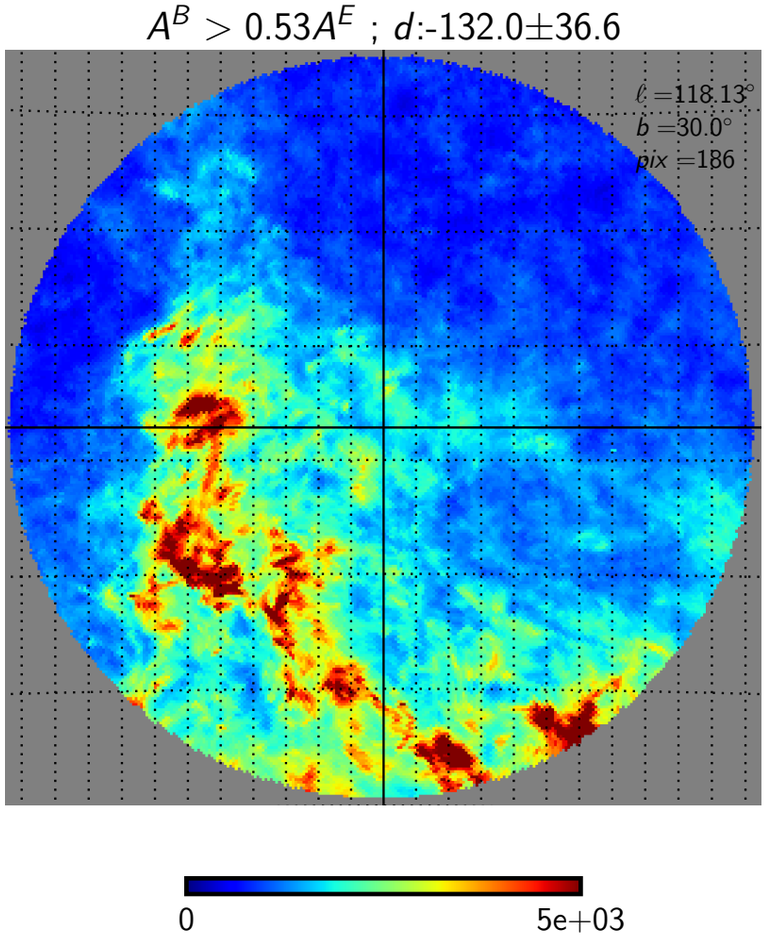
Temperature

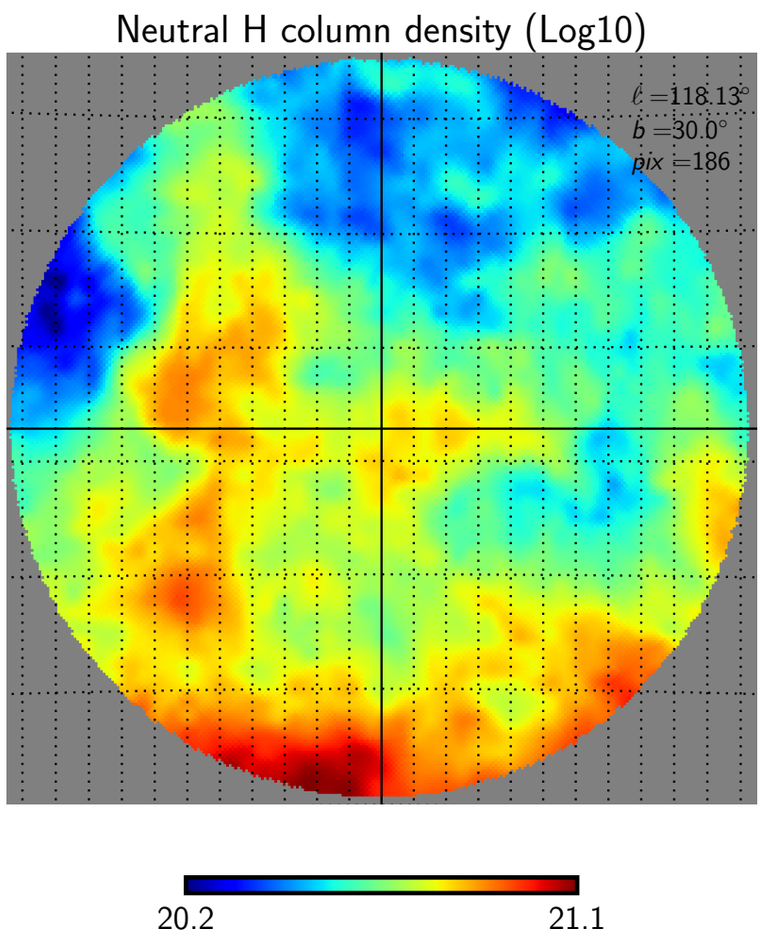
Neutral Hydrogen

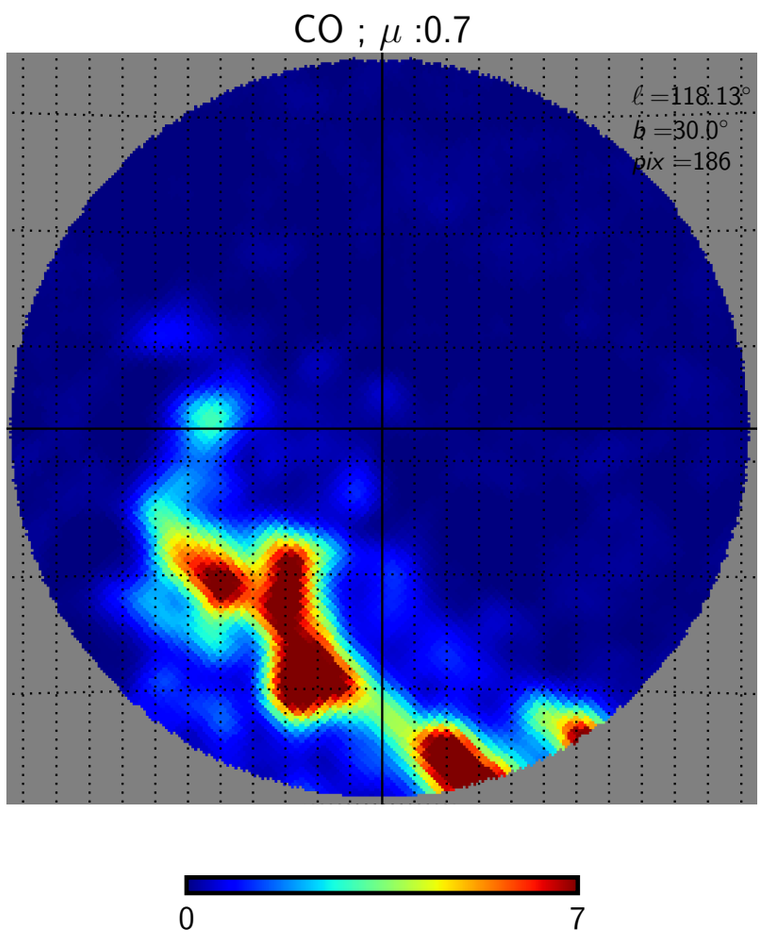
CO

(figure 6 top row)

Too Much B: B/A = 0.77







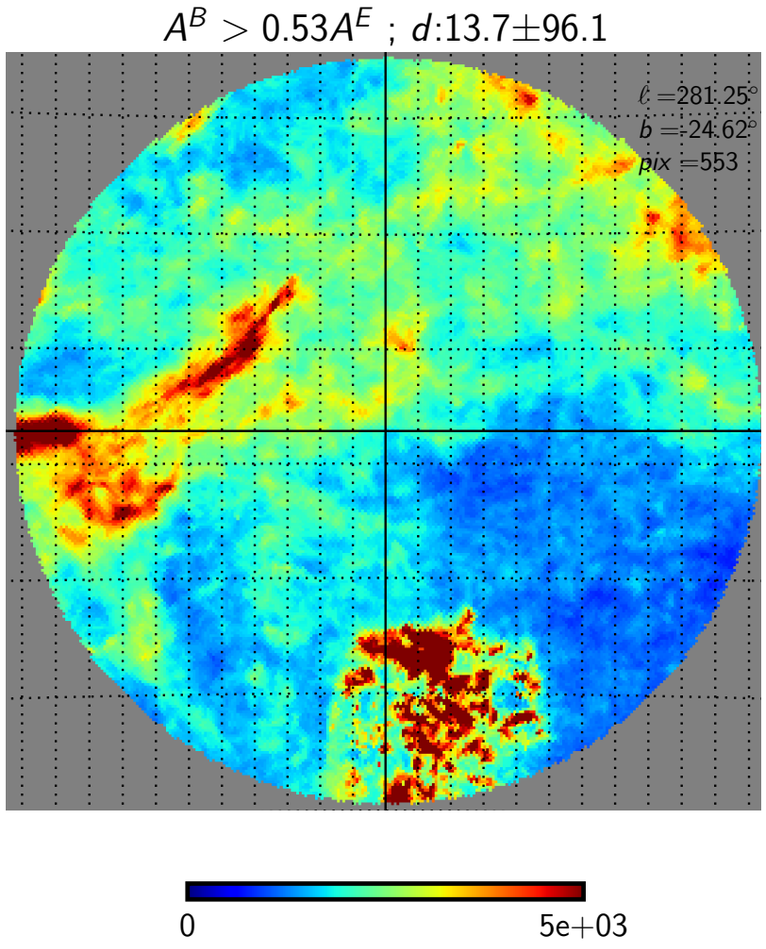
Temperature

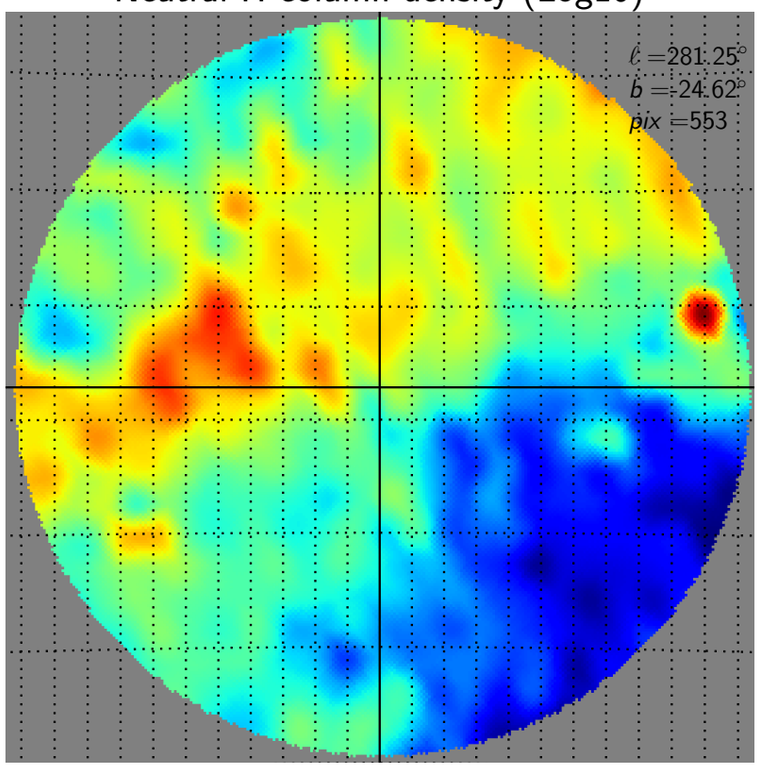
Neutral Hydrogen

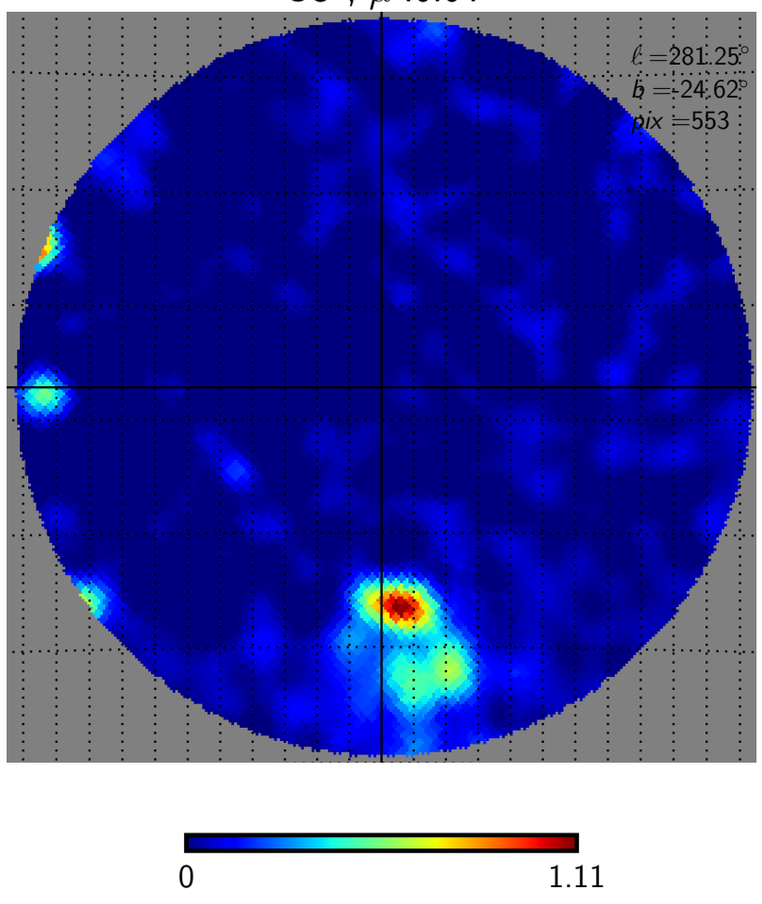
CO

(figure 7 bottom row)

Wrong Slope: alpha_B=-1.8, alpha_E = -1.5







Temperature

Neutral Hydrogen

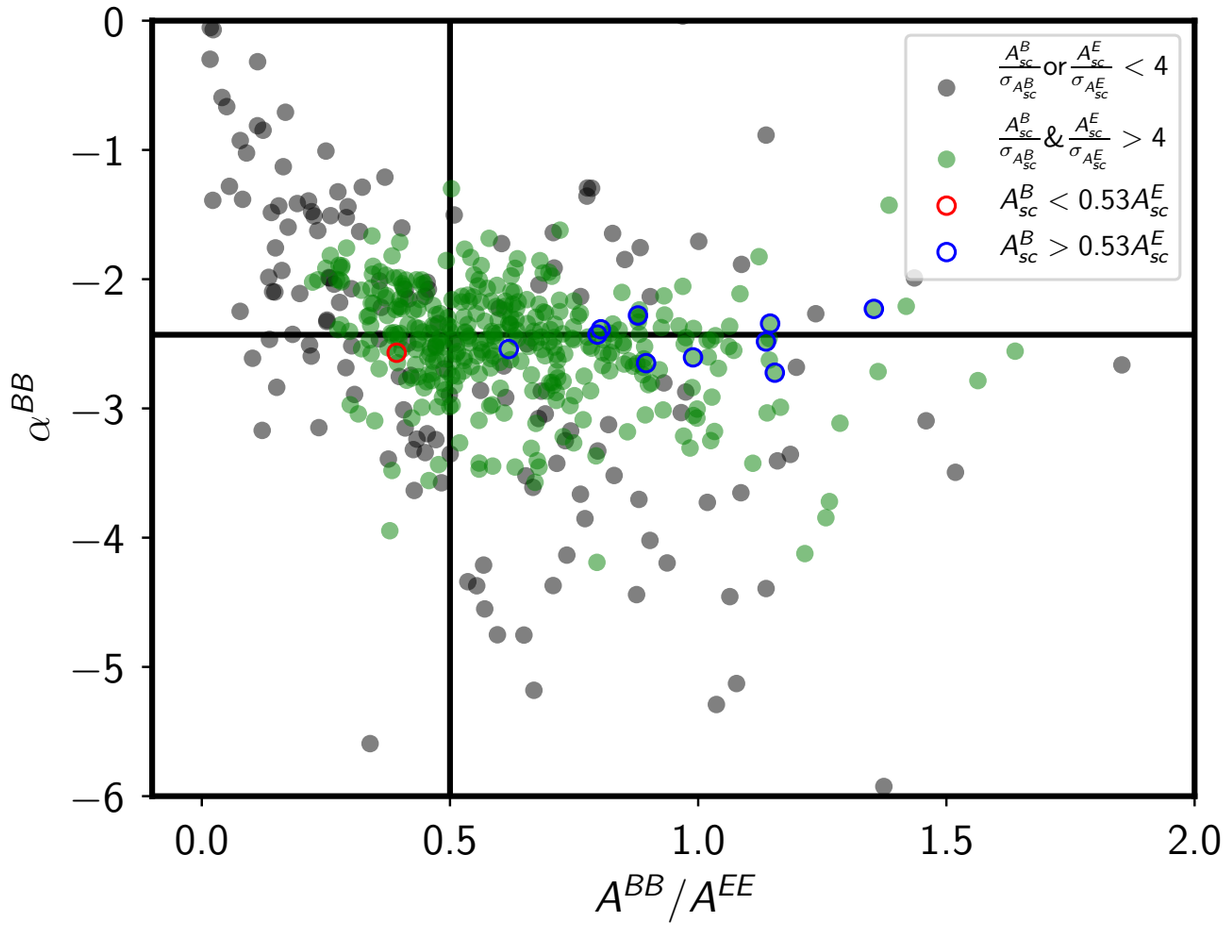
CO

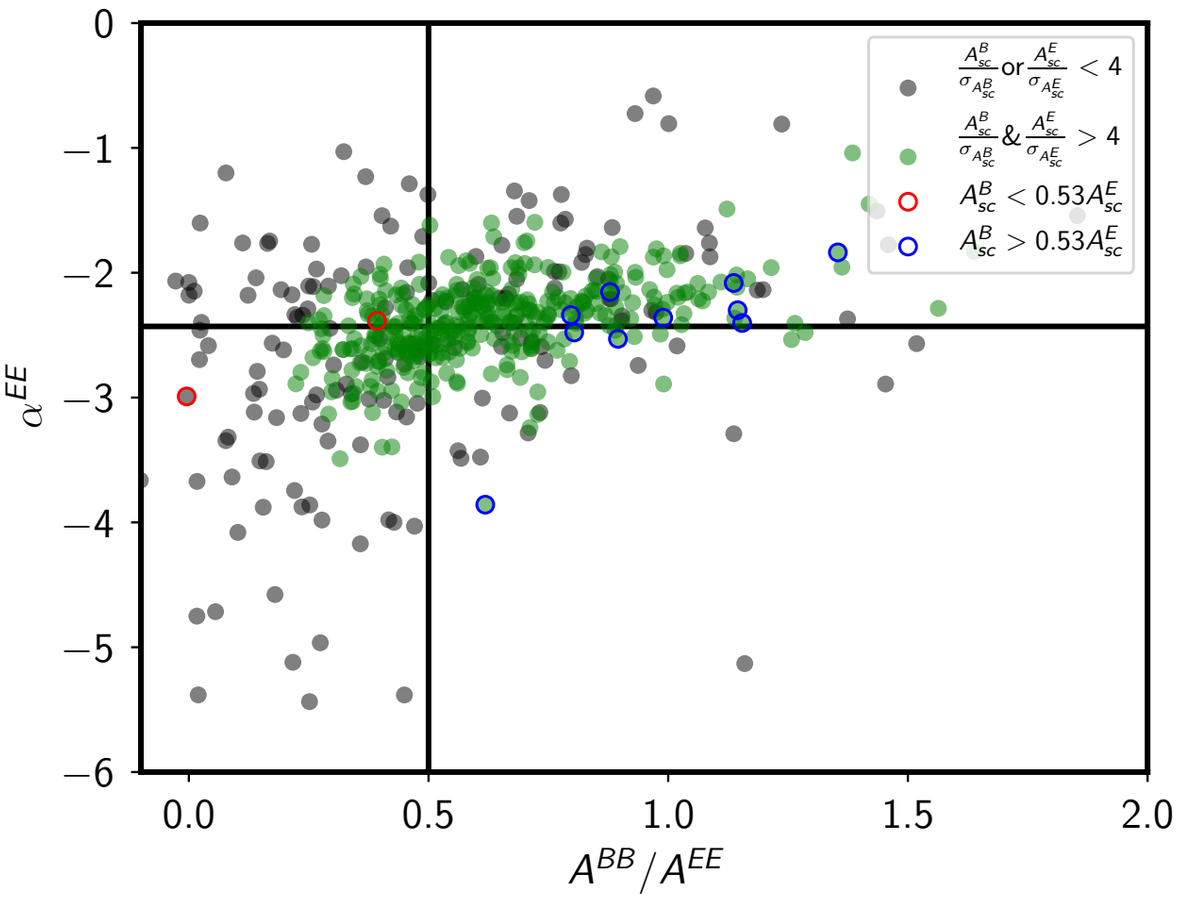
AB/AE = 0.52

(figure 10 top row)

In one plot

- Colors indicate statistical significance.





General Takeaway

- Matching B/E ratio requires Sub-Alfvenic Turbulence.
    - Makes intuitive sense: more H, more long skinny things, more flow along the field.
    - Perhaps this is not sufficient?
- Matching slope requires supersonic motions, very compressible (Gamma < 1, or perhaps a more reasonable equation of state)
- Could Be
    - Compressibility and power ratio work against one another?
    - Resolution?
    - Missing Physics?
    - PEBKAC?
- What conditions do you need?
    - I also don’t know, but I know some things that don’t work.