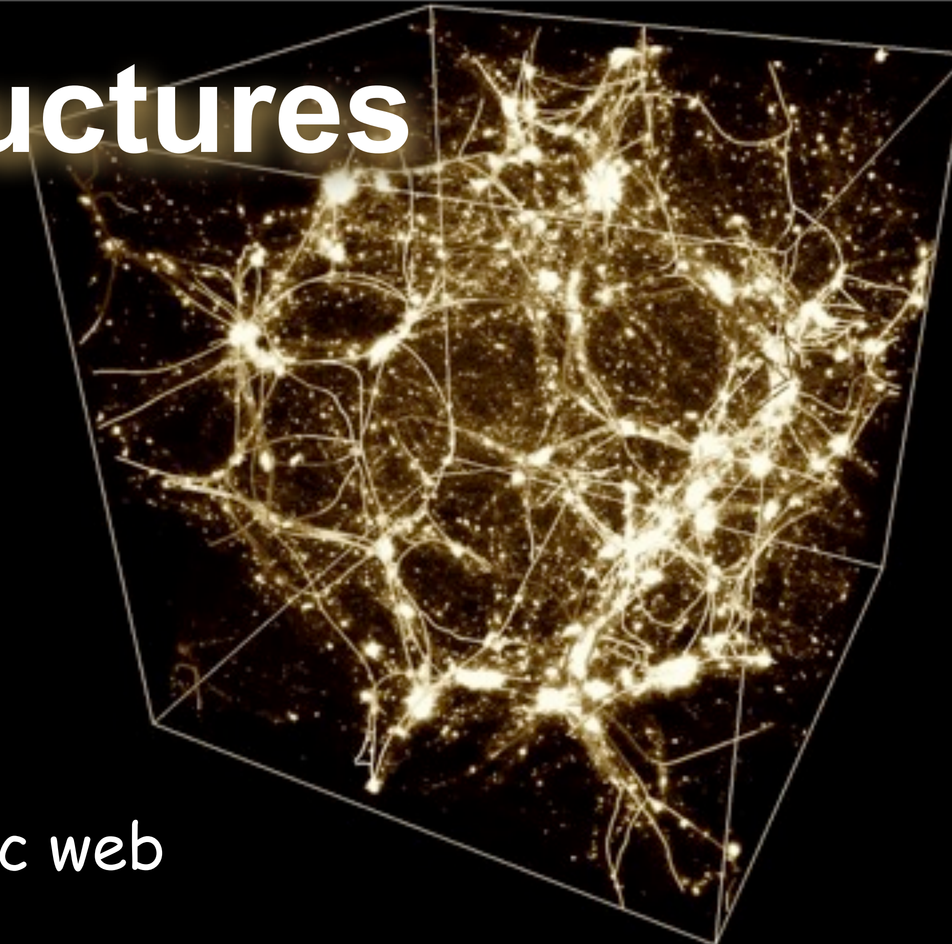
Connecting Large Scale Structures to galactic spin



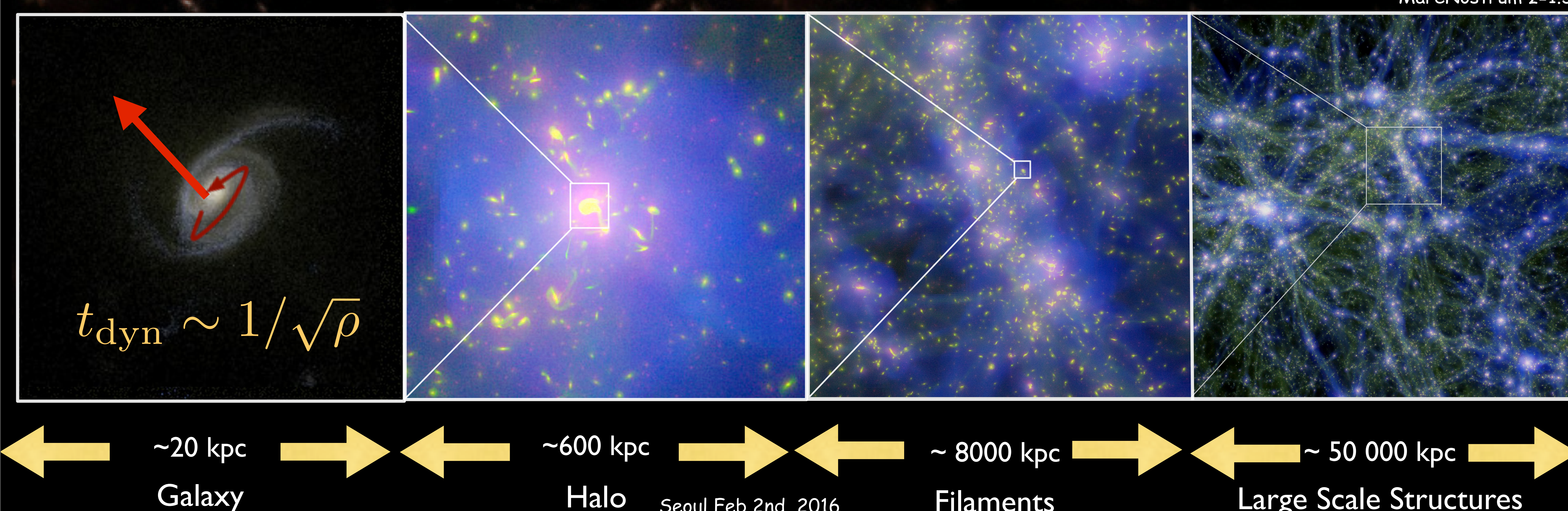
Christophe Pichon

KIAS /IAP

Can we predict the **spin** of galaxies **on** the cosmic web **from first principles**?

S. Codis, C. Laigle, T. Kimm D. +Horizon/Spin(e) Collaboration

MareNostrum z=1.55



Seoul Feb 2nd 2016

Outline

- **How do dark halo's spin flip relative to filament**
- **What is the geometry of spin near saddle?**
- **Why does it induce a transition mass:**
- **Lagrangian & *Eulerian* theory?**

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Why do we care?

- *Weak lensing*
- AM stratification drives **morphology**
- Galaxy formation is *not* a 1D manifold

(c)Taysun Kimm +E. Pharabod

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- **Lagrangian & *Eulerian* theory?**

Why do we care?

- *Weak lensing*
- AM stratification drives **morphology**
- Galaxy formation is *not* a 1D manifold

Where galaxies form does matter, and can be traced back to ICs.
Flattened filaments generate point-reflection-symmetric AM/vorticity distribution:
they induce the observed spin transition mass

PART I

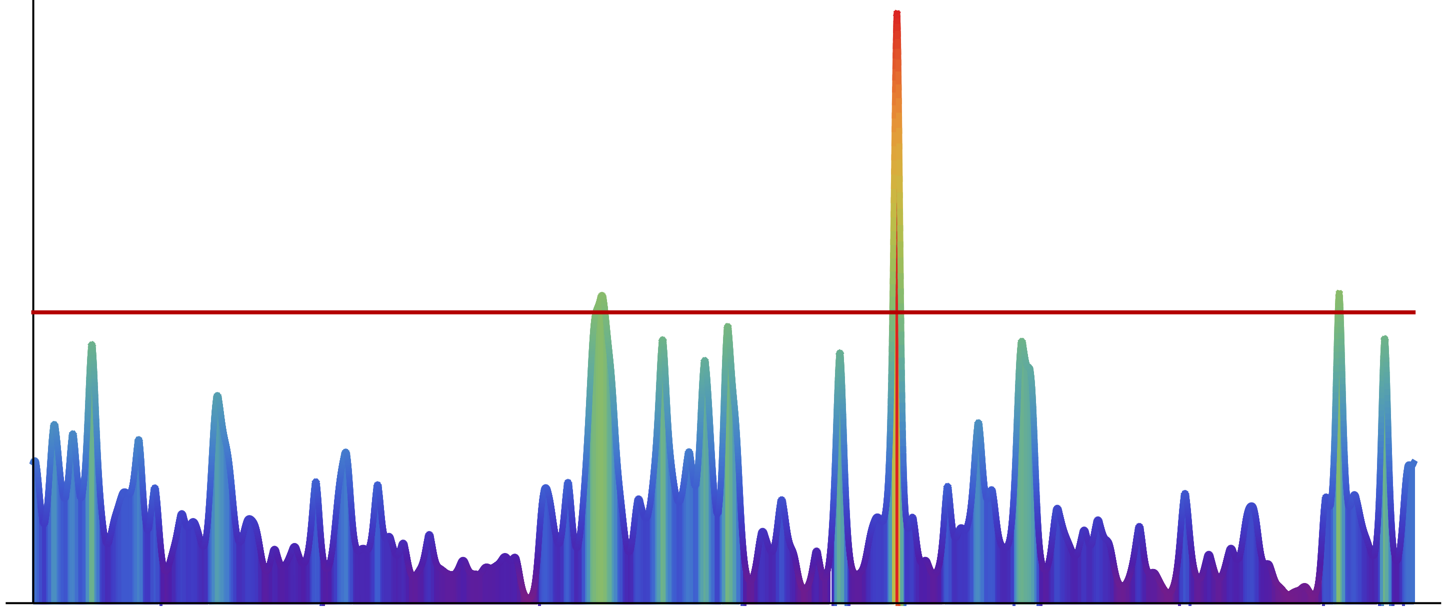
What's happening on large scales?

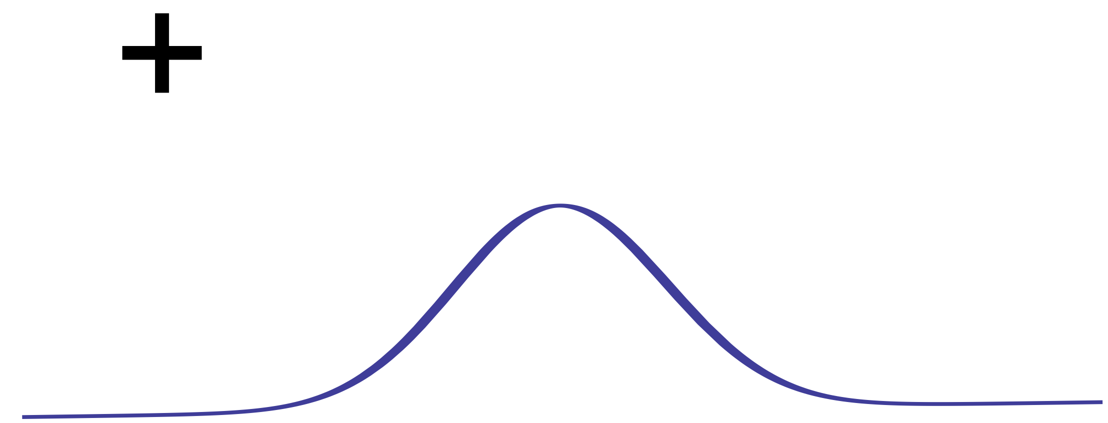
How is the cosmic web woven?

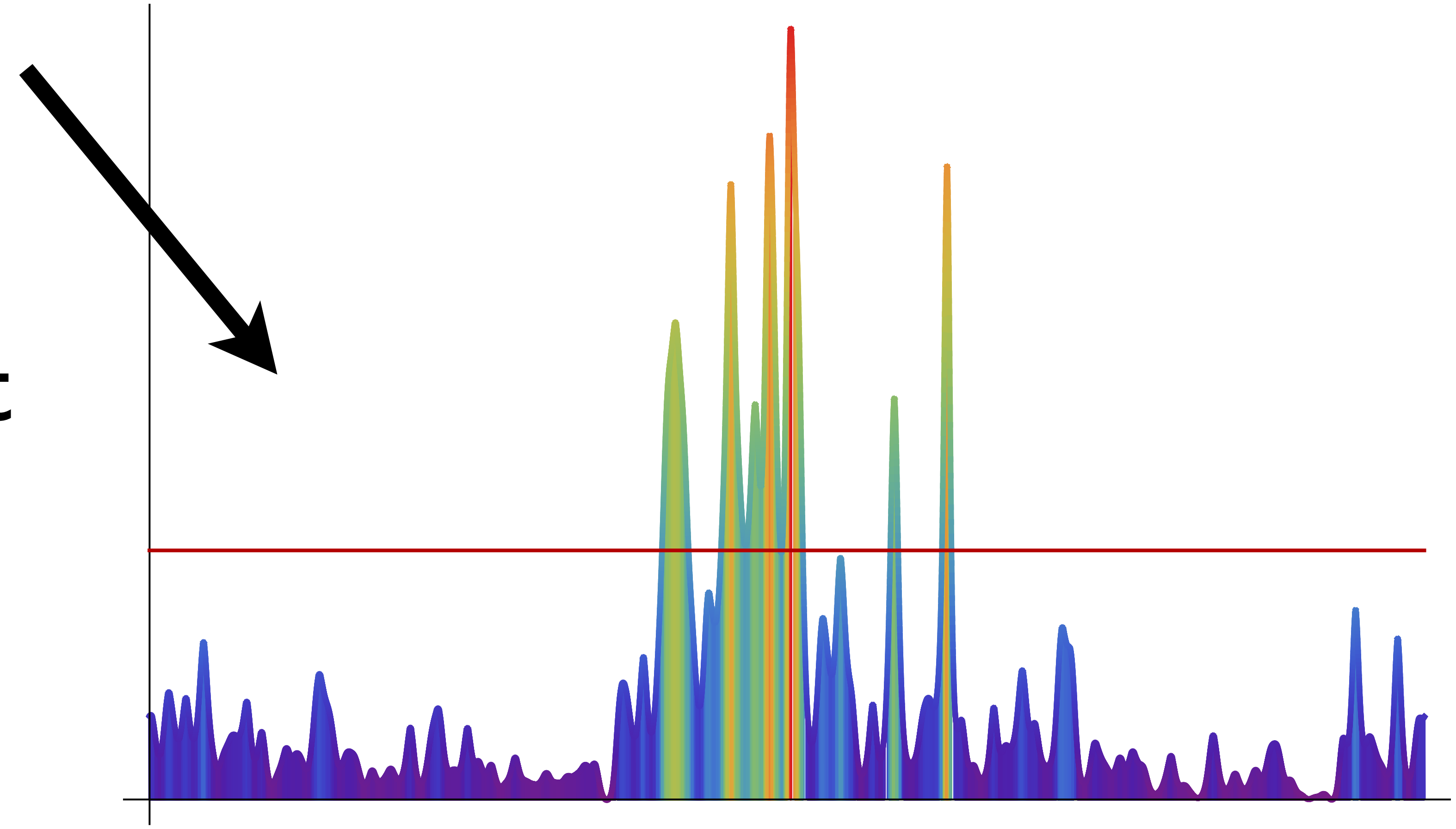
i.e Where do galaxies form in our Universe?

What are the dynamical implications?

dark halos don't form anywhere



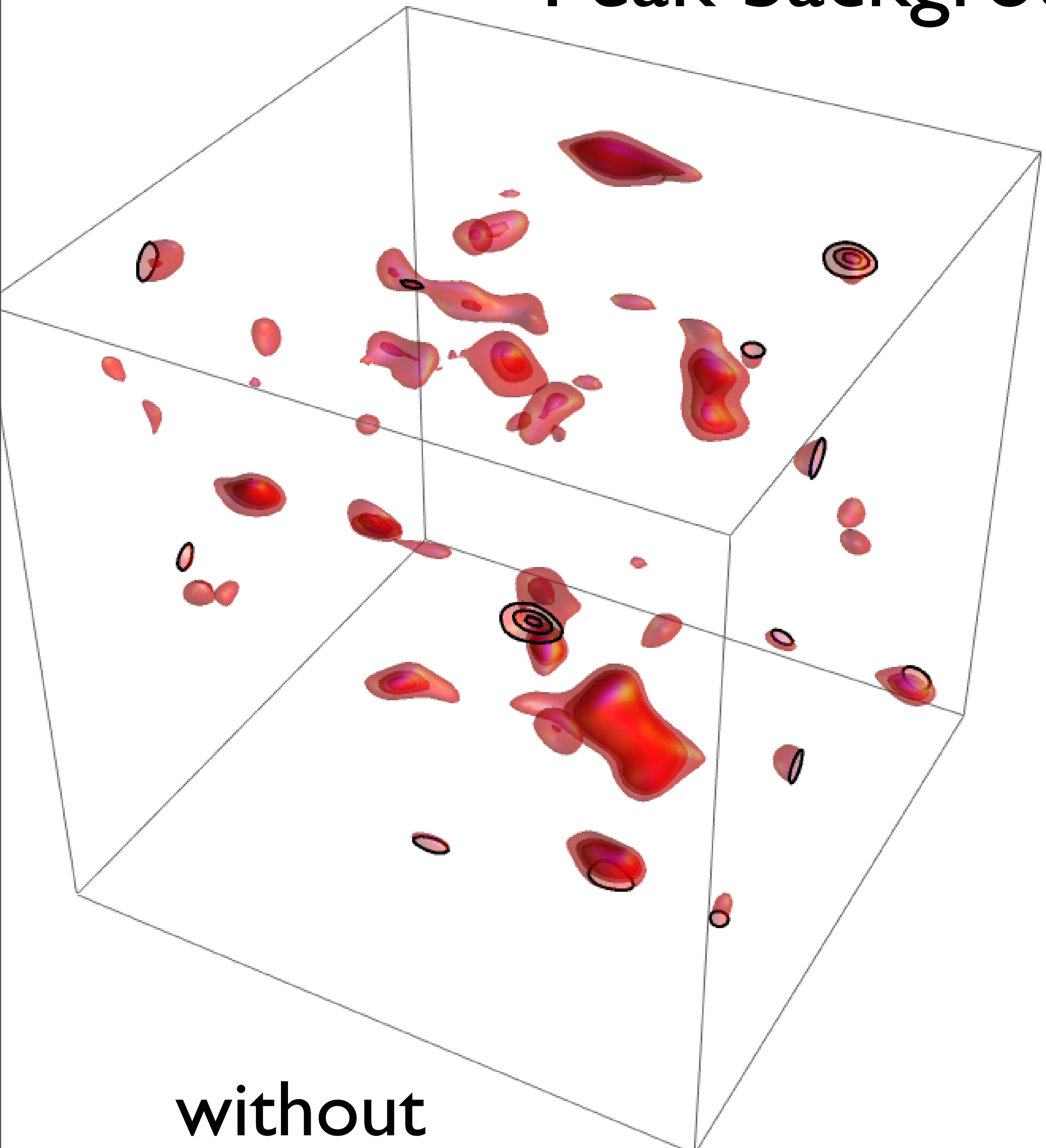


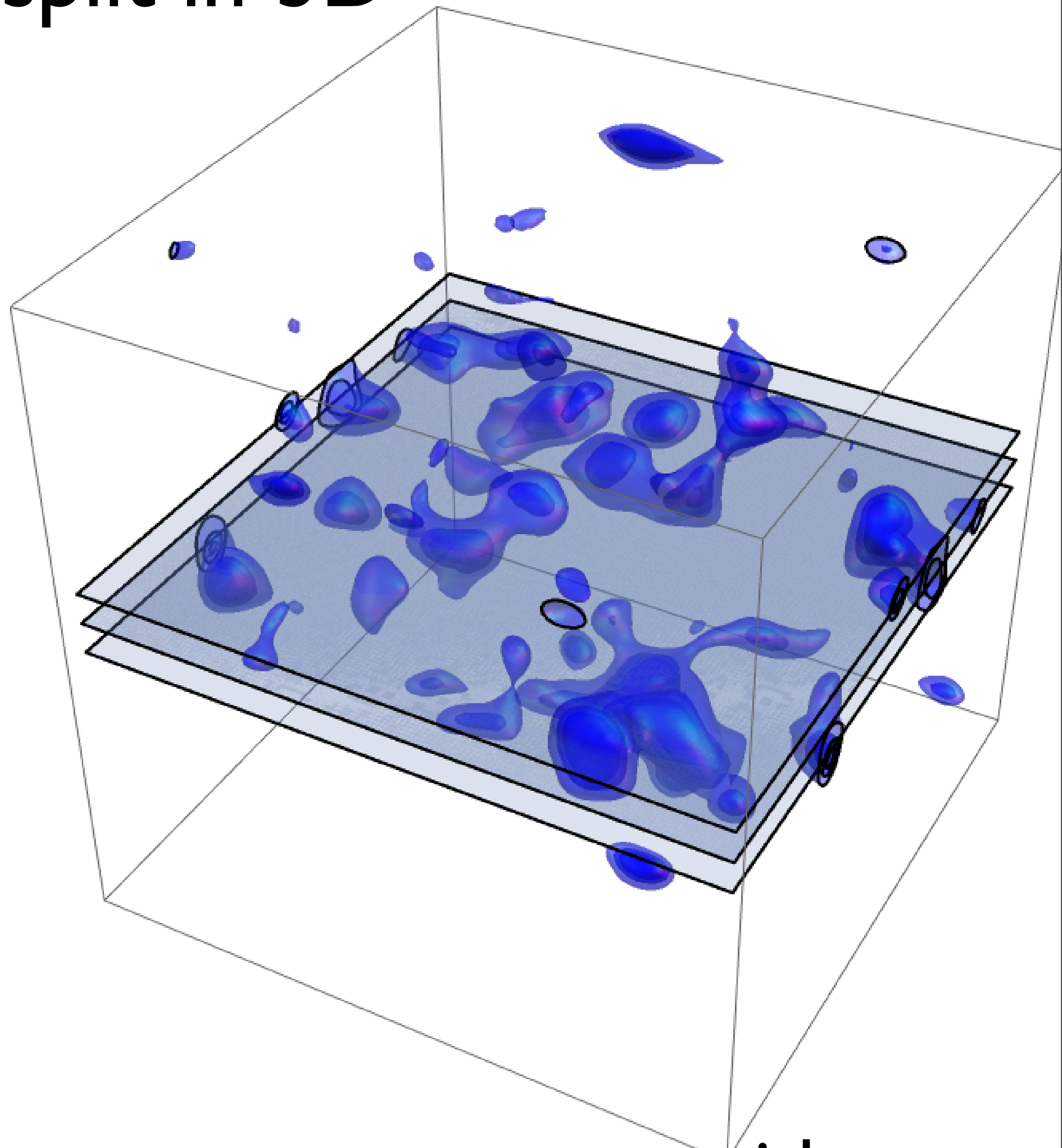


Peak background split

(PBS) in 1D

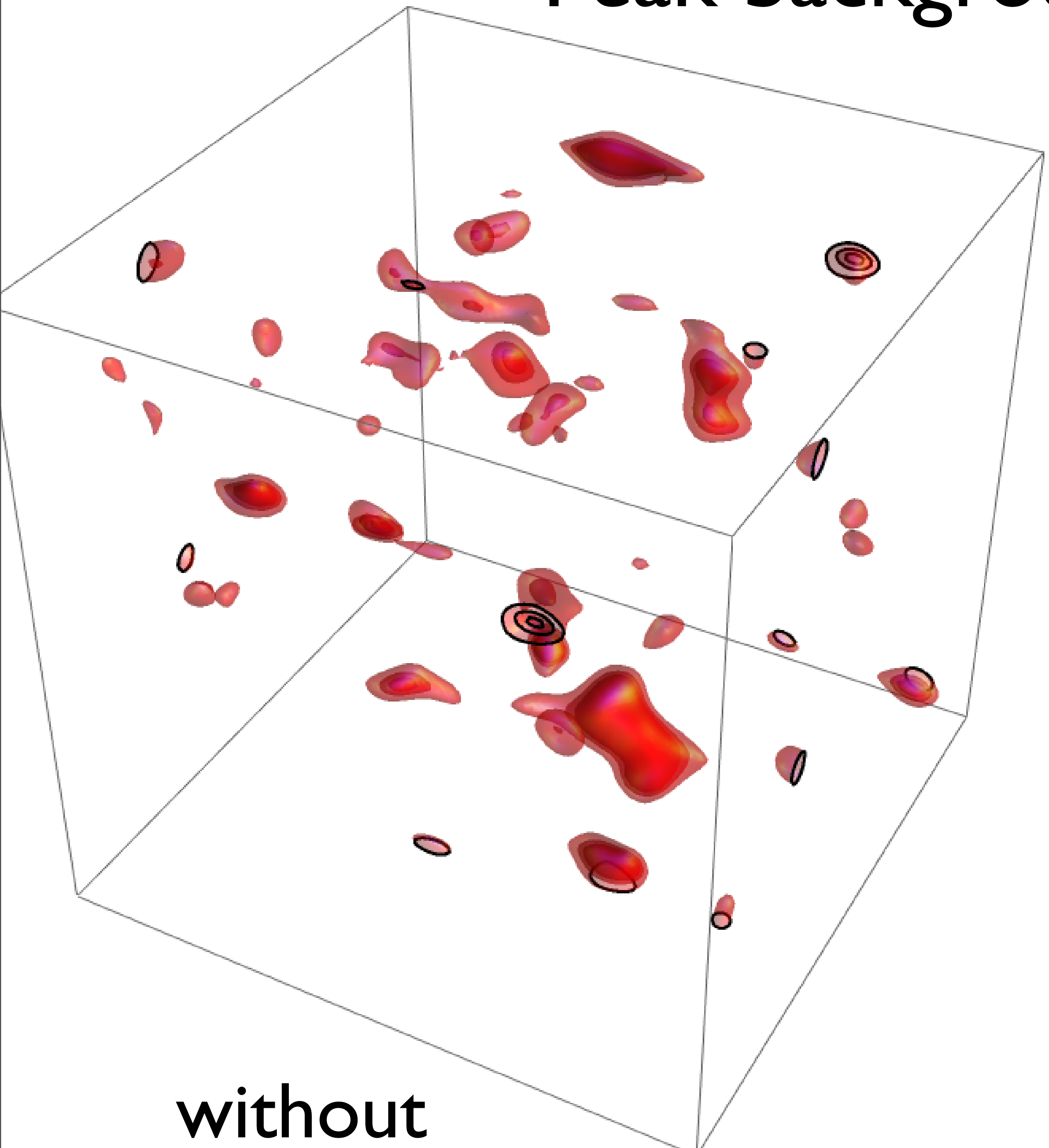
Peak background split in 3D

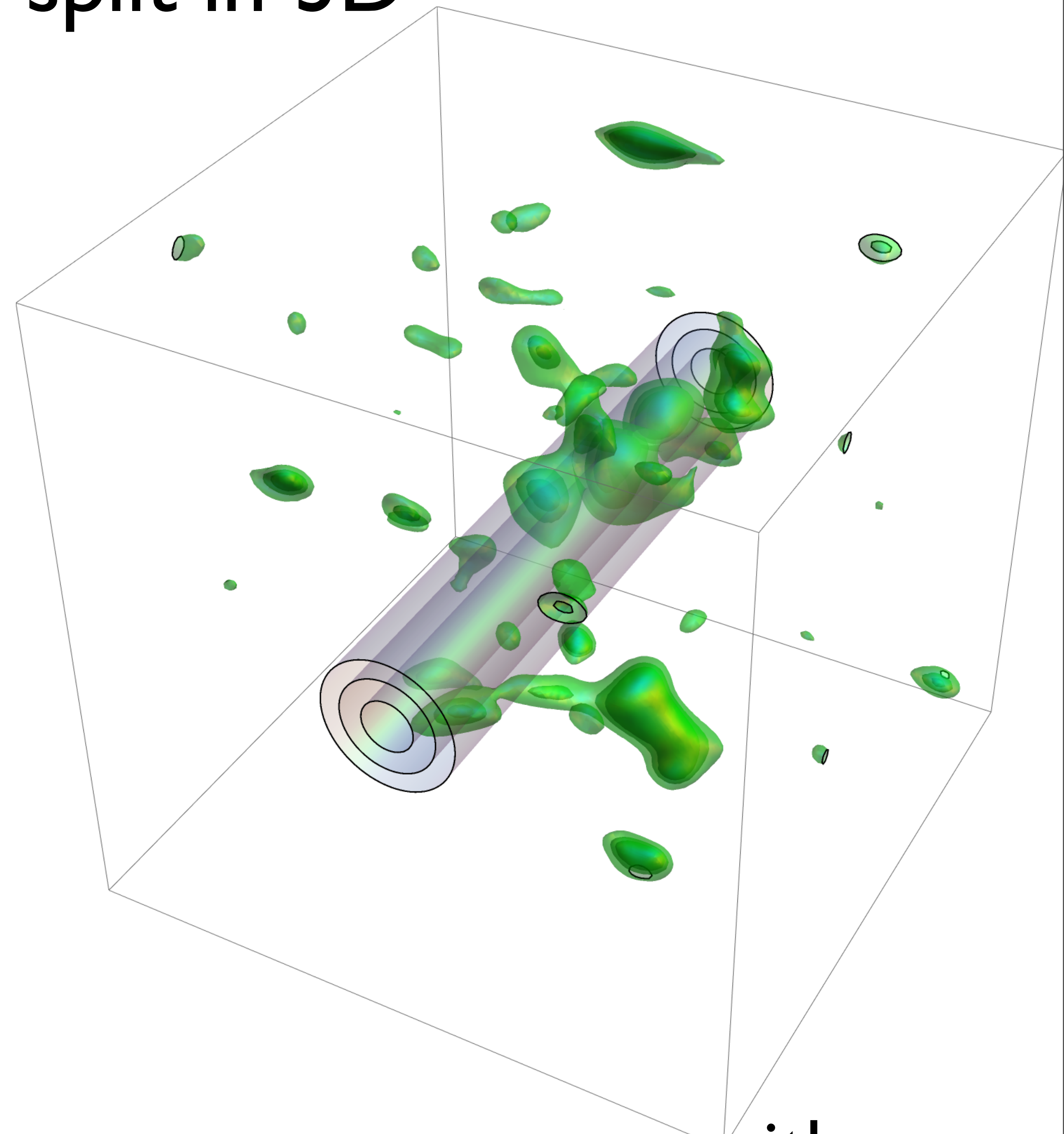




Does this anisotropic biassing have a dynamical signature? *yes! in term of spin!*

Peak background split in 3D





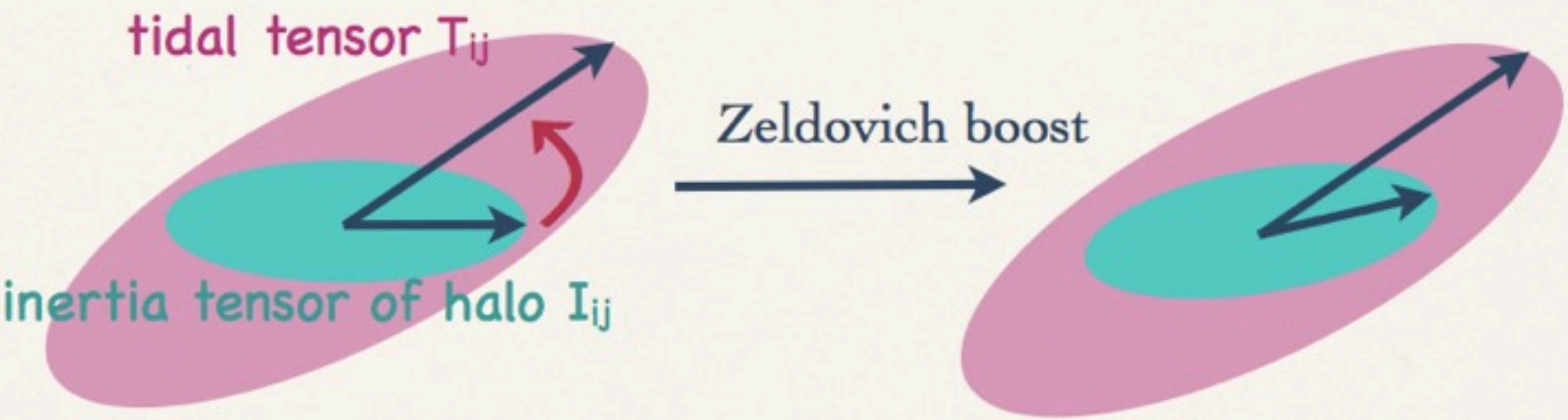
Does this anisotropic biassing have a dynamical signature? *yes! in term of spin!*

Tidal Torque Theory in one cartoon

Can we understand where spin and vorticity alignments come from?

-usual tidal torque theory

$$L_k = \varepsilon_{ijk} I_{li} T_{lj}$$

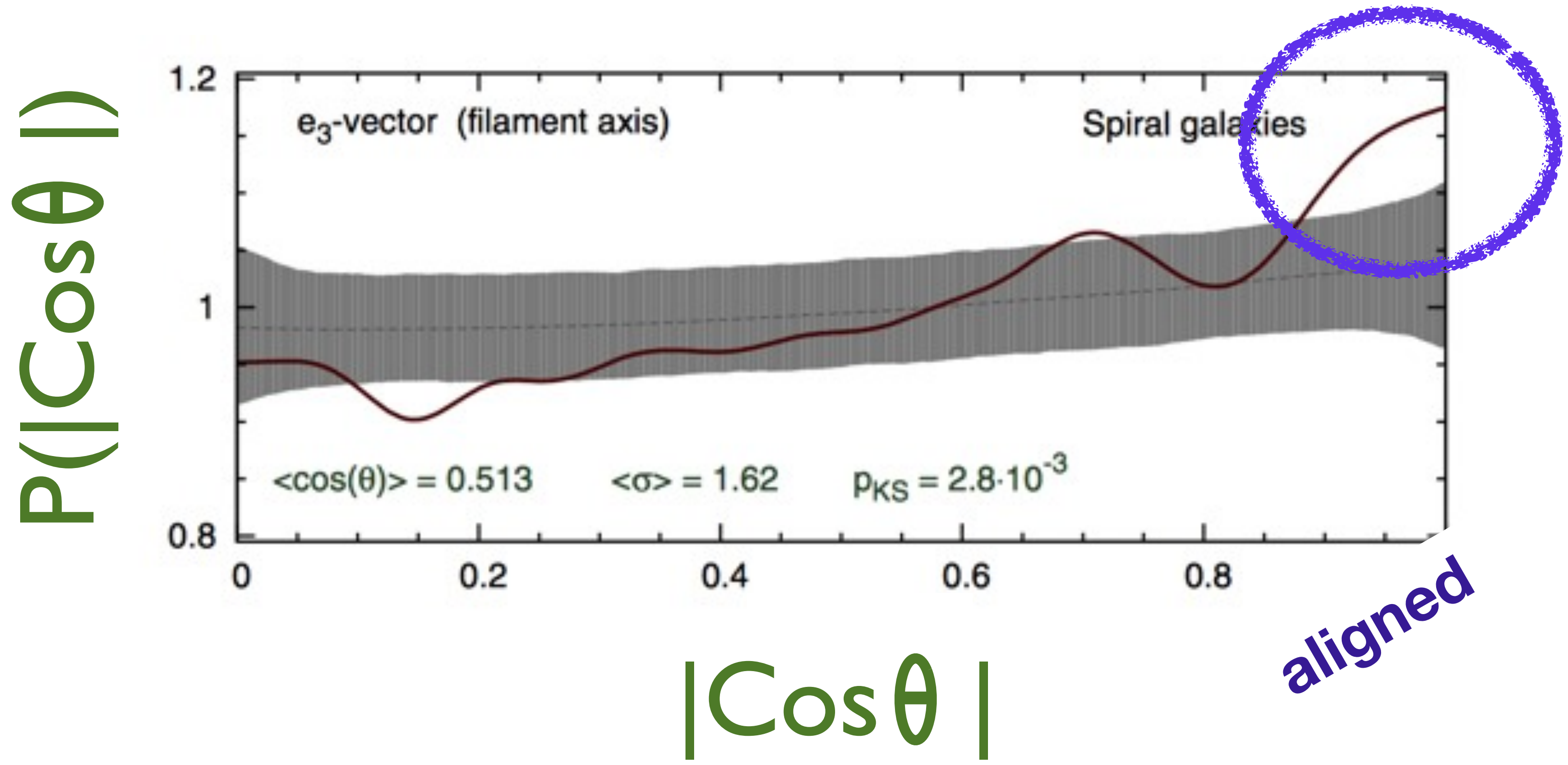


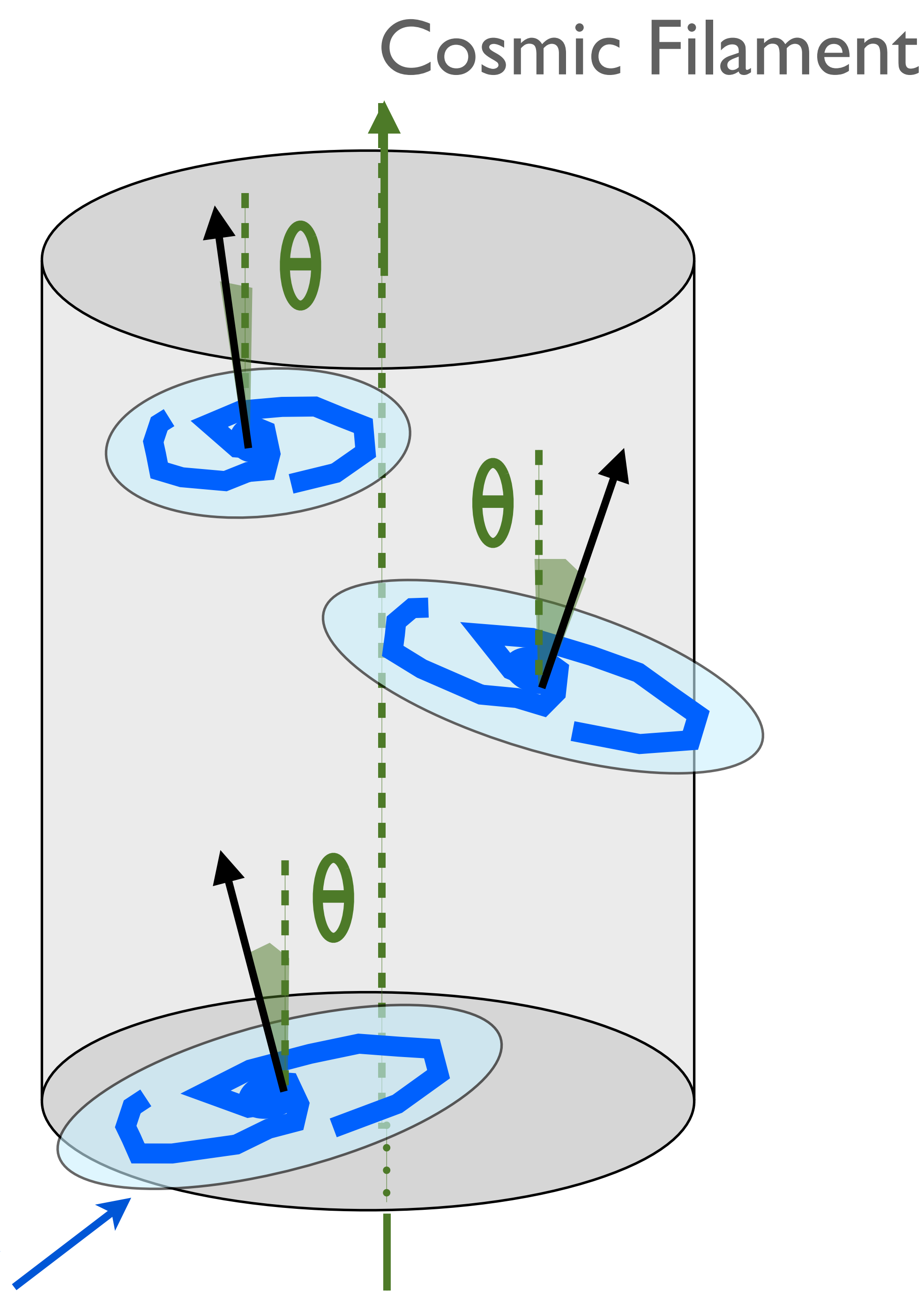
YES! via conditional TTT subject to saddle

Et Voilà !

Evidences of galaxy spin - filament alignment

Tempel+ (2013) in the SDSS

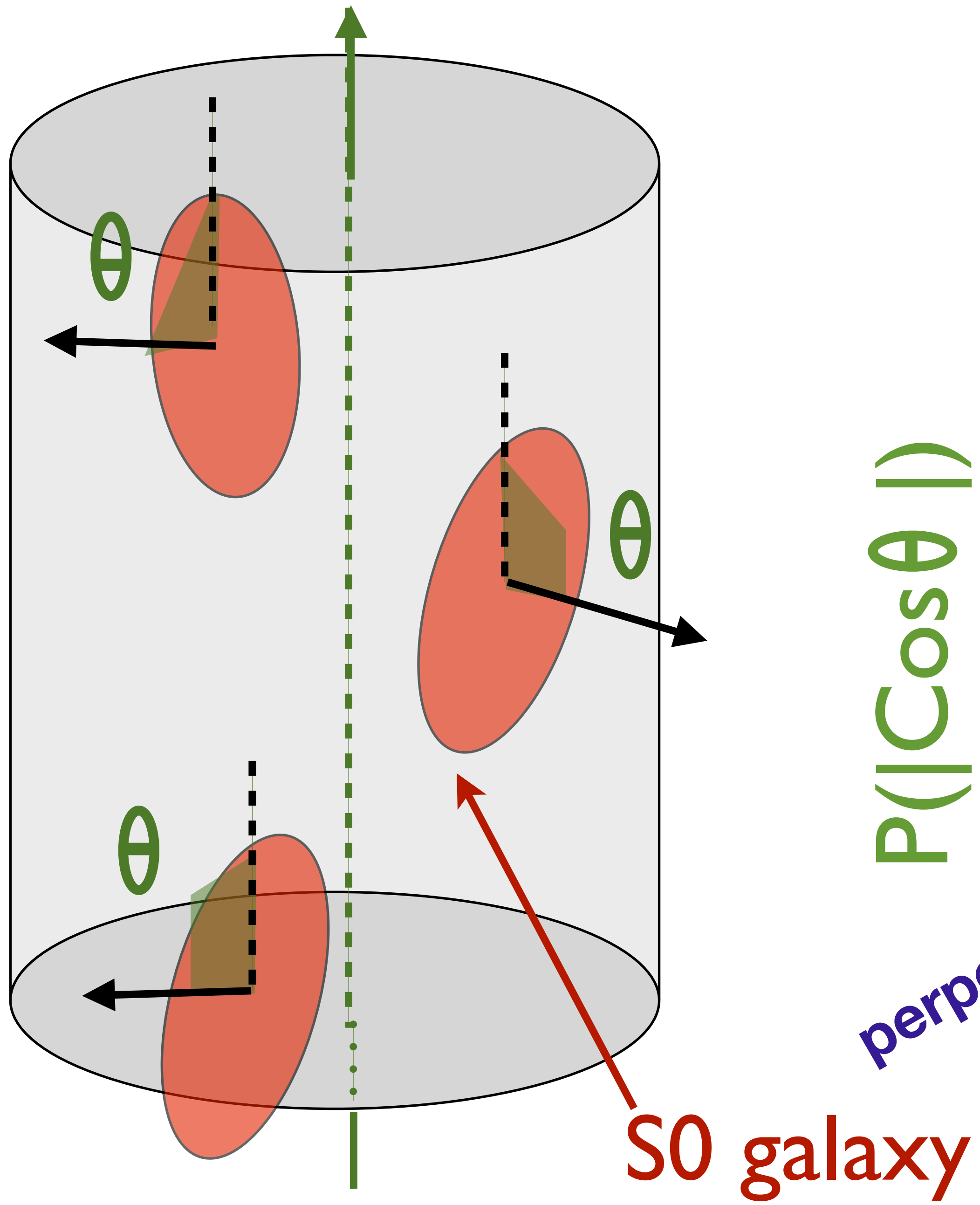




See also:
Aragon-Calvo+ 2007, Hahn+ 2007, Paz+ 2008, Zhang+ 2009, Codis+ 2012, Libeskind+ 2013, Aragon-Calvo 2013, Dubois+ 2014

Evidences of galaxy spin - filament alignment

Cosmic Filament



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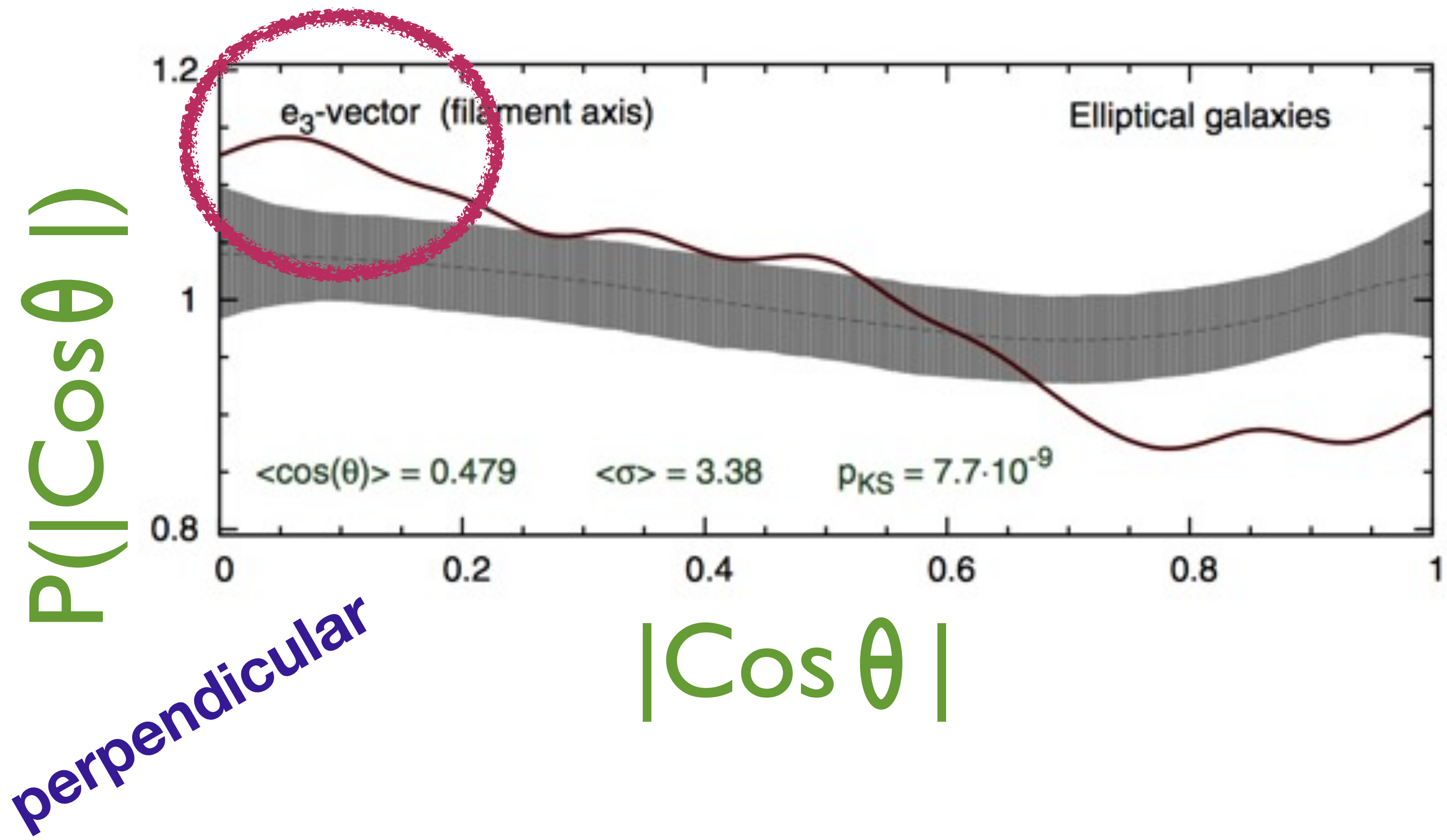

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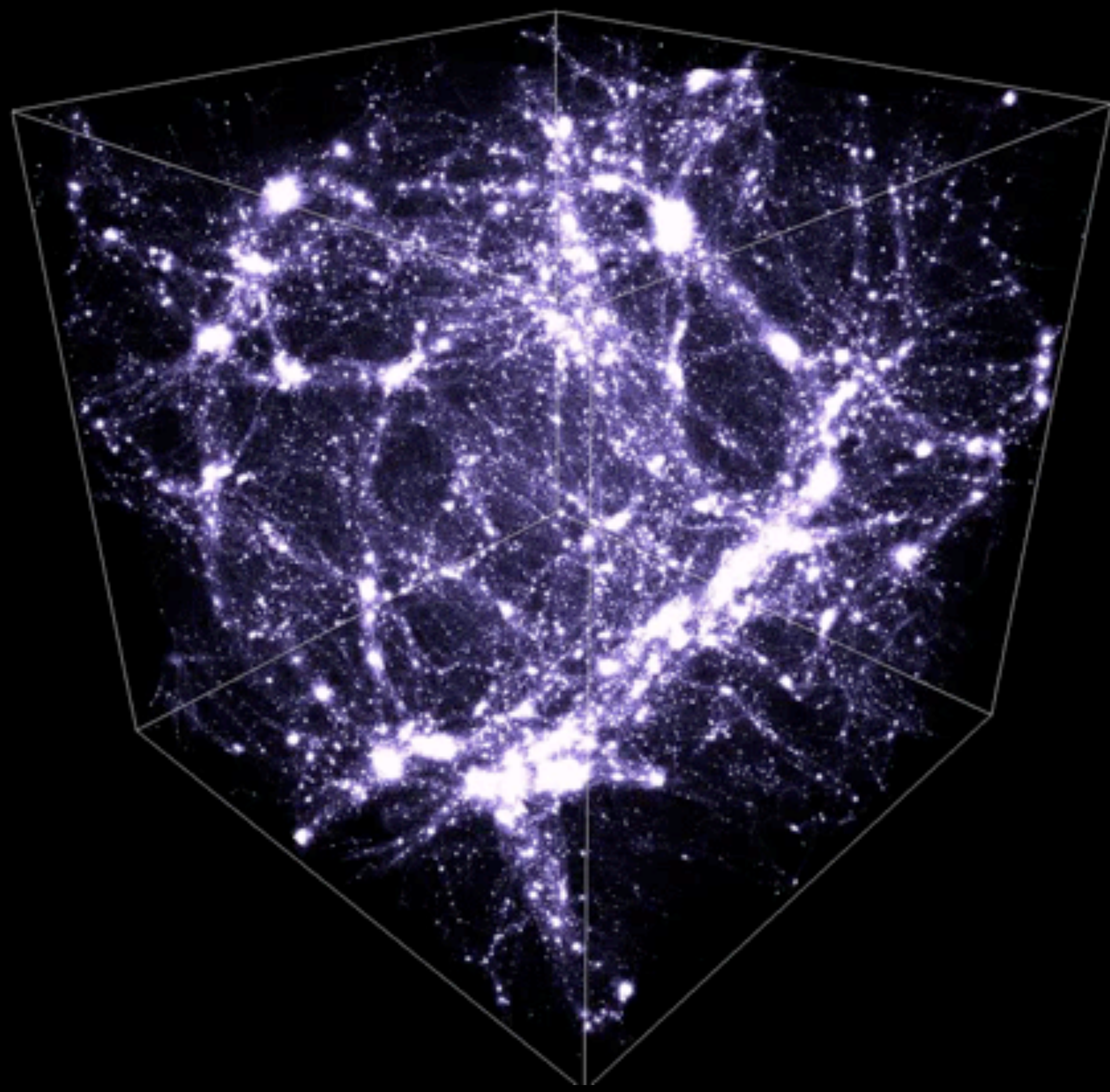
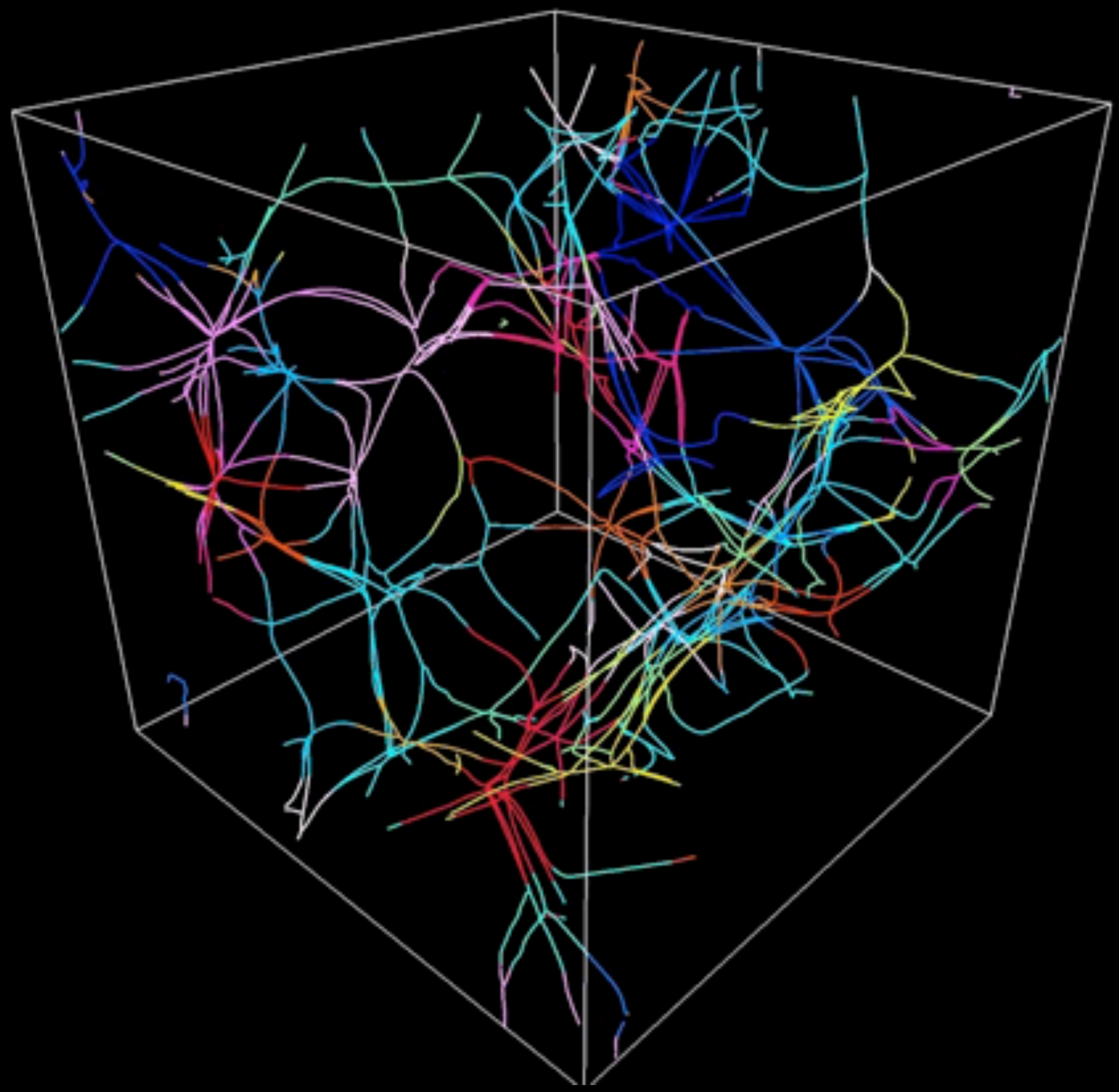
Skeleton of the LSS





traces filaments via crest lines of the density field

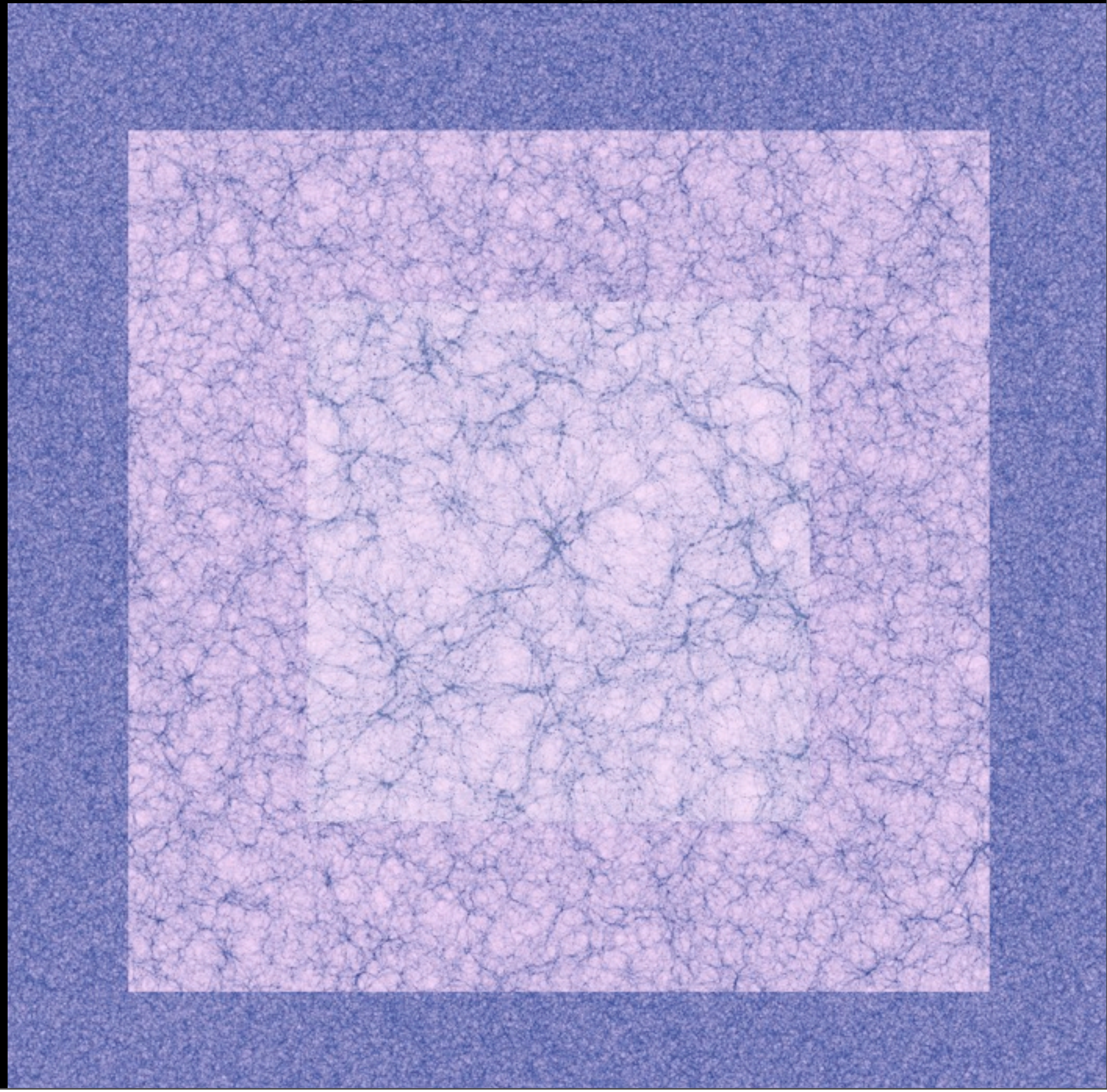
Orientation of the spins w.r.t the filaments

Horizon 4Pi:

DM only
2 Gpc/h periodic box
4096^3 DM part.
43 million dark halos at z=0

(Teyssier et al, 2009)

10 000 000 hrs CPU



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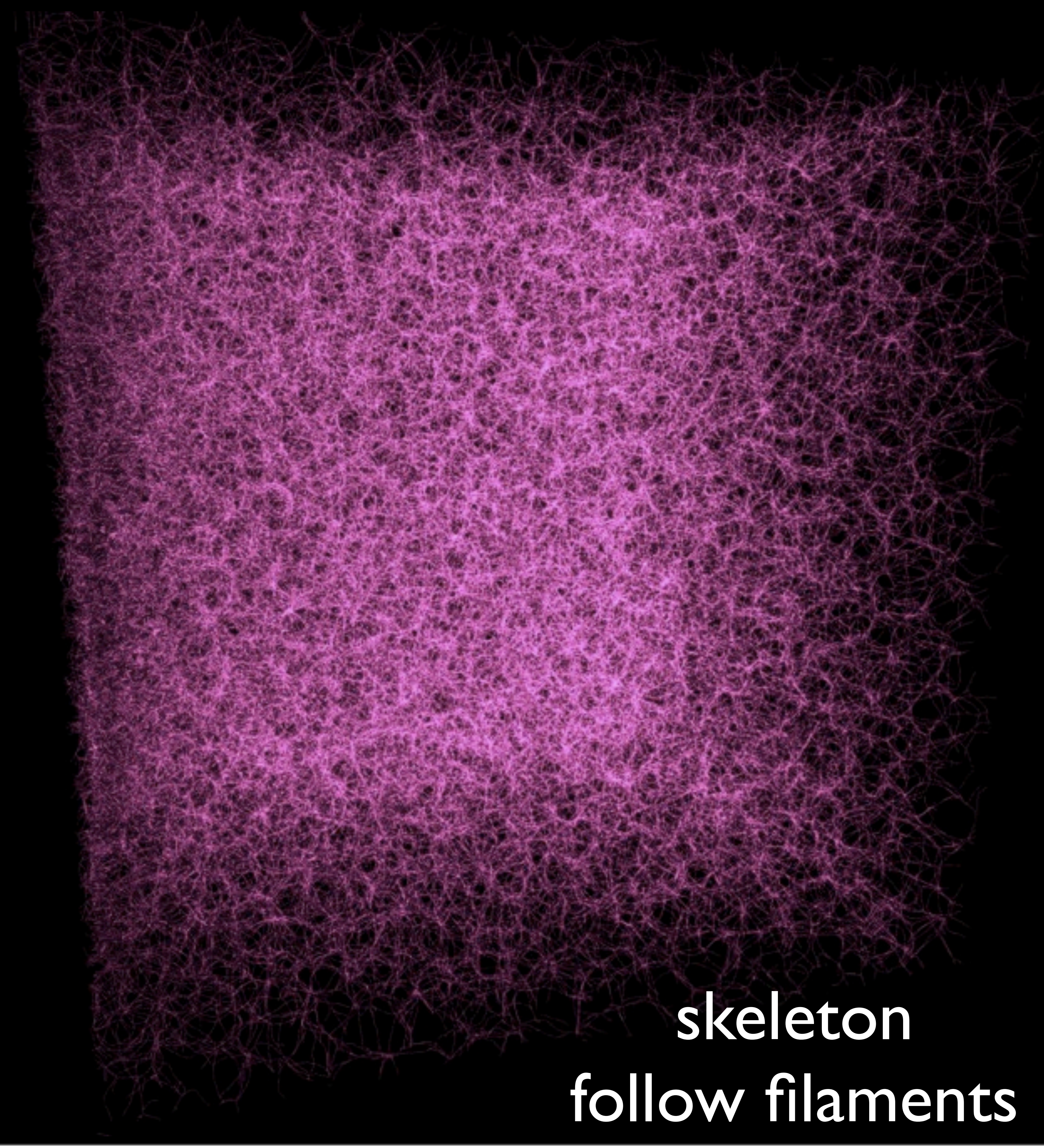


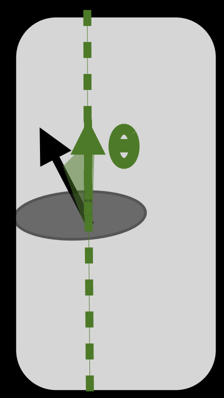
Excess probability of alignment between the spins and their host filament

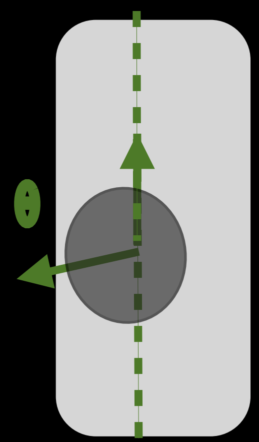
mass transition:

$$M_{\rm crit} = 4 \cdot 10^{12} M_{\odot}$$

$M < M_{\rm crit}$: aligned

$M > M_{\rm crit}$: perpendicular





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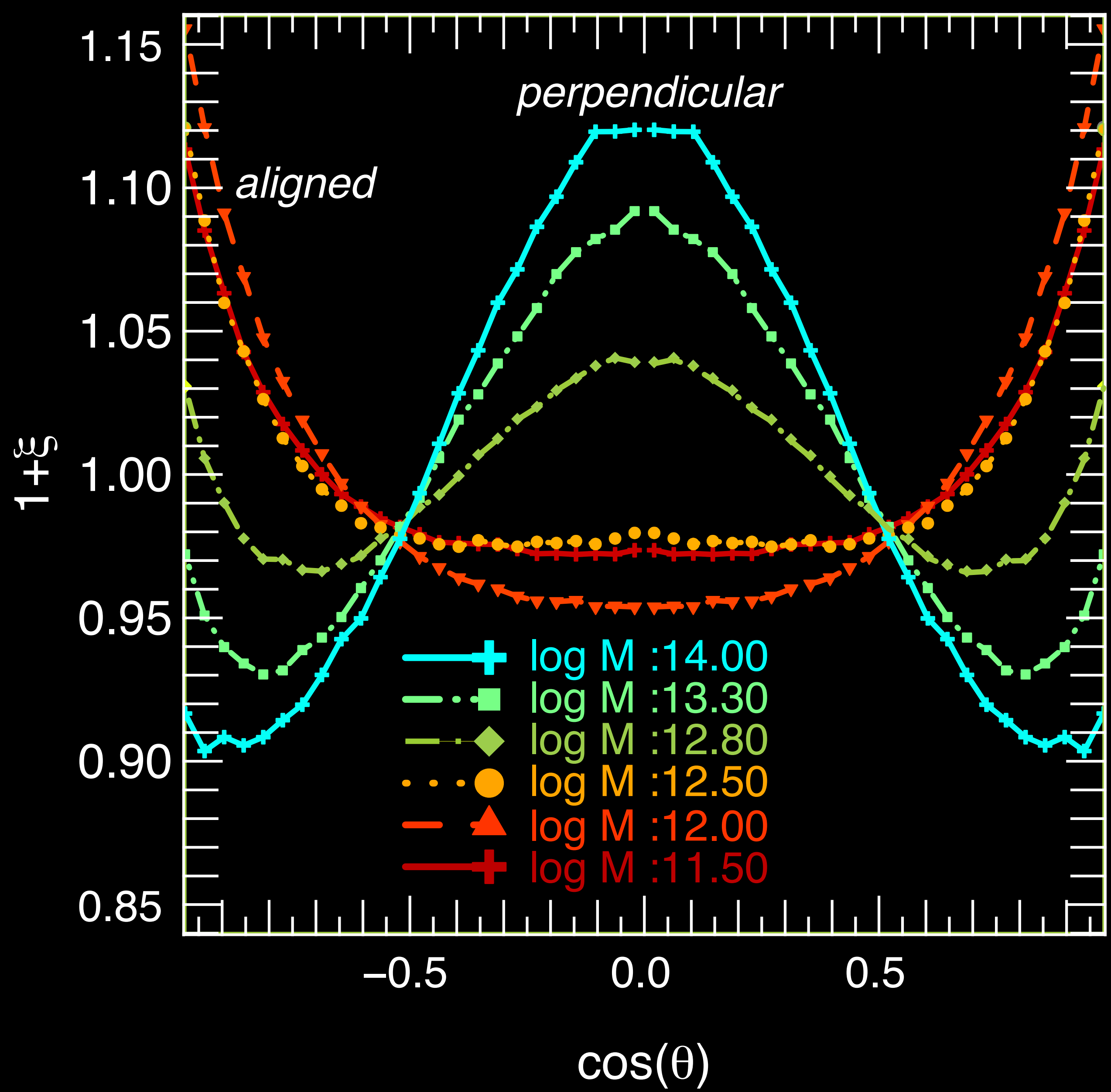

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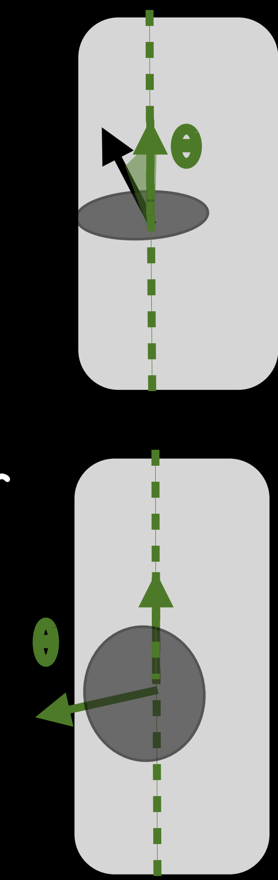
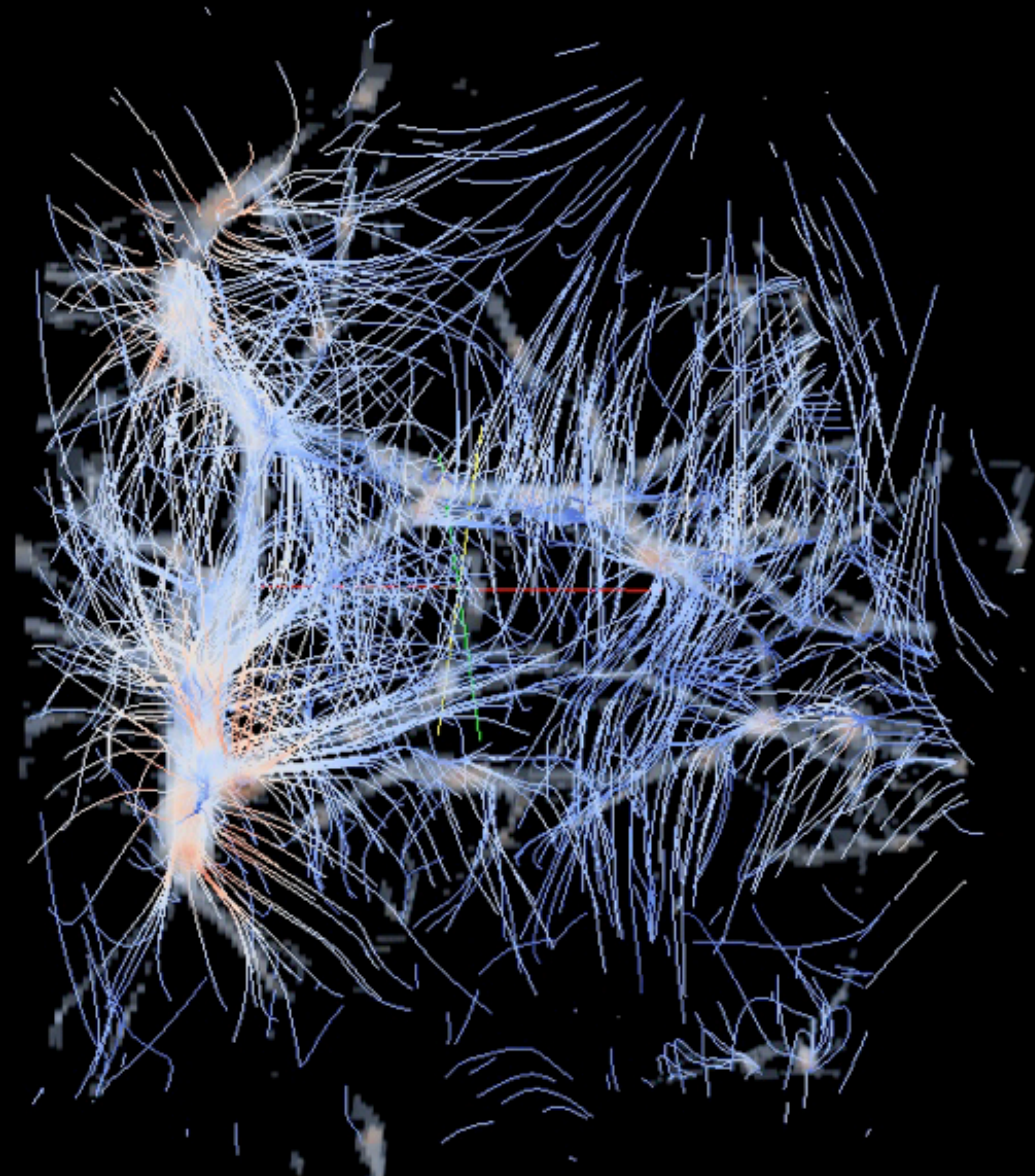


(Codis et al, 2012)

How does the formation of the filaments generate spin parallel to them?

Voids/wall saddle repel...



Vorticity generation in filaments

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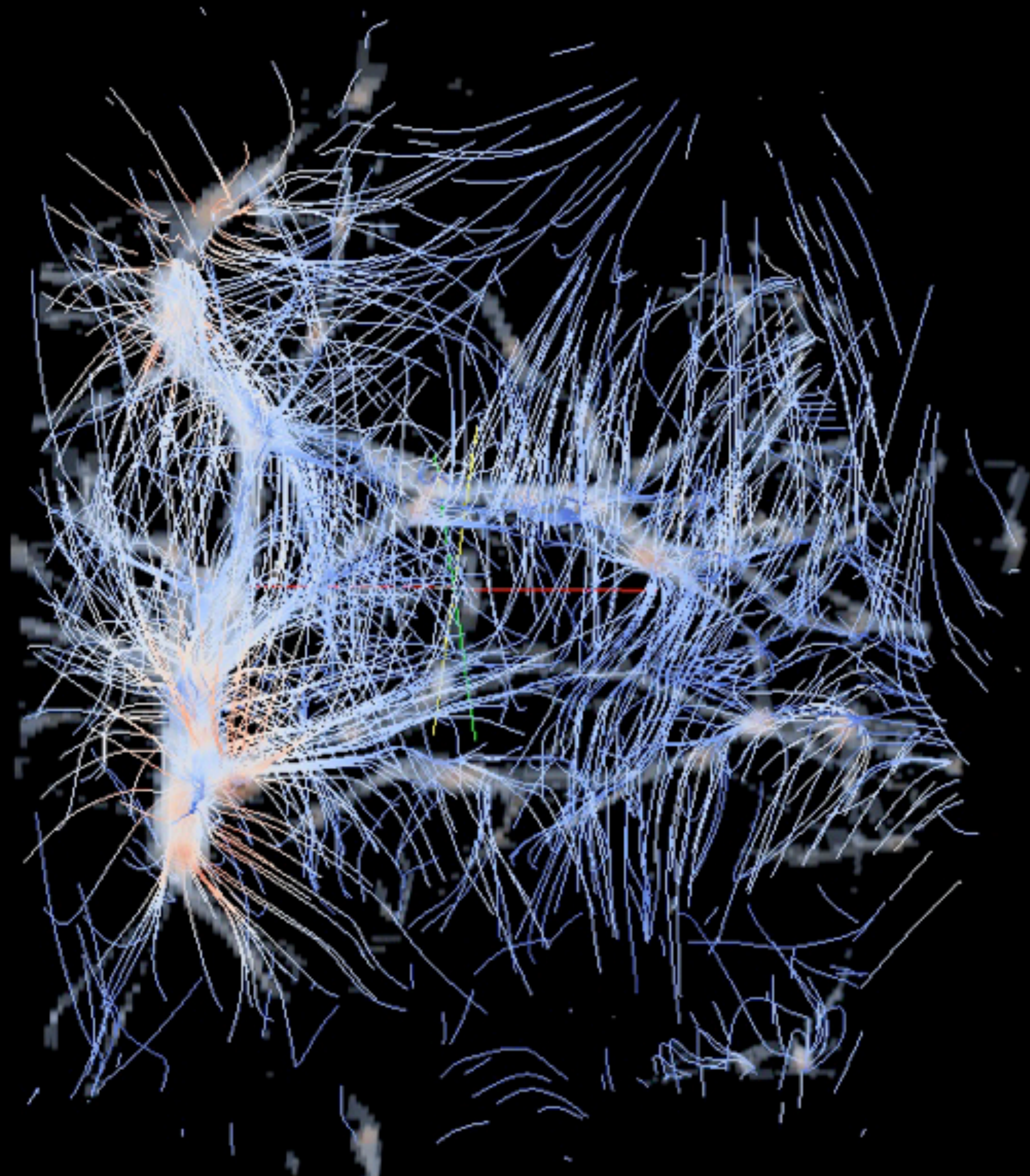
Voids/wall saddle repel...

winding of walls into filaments



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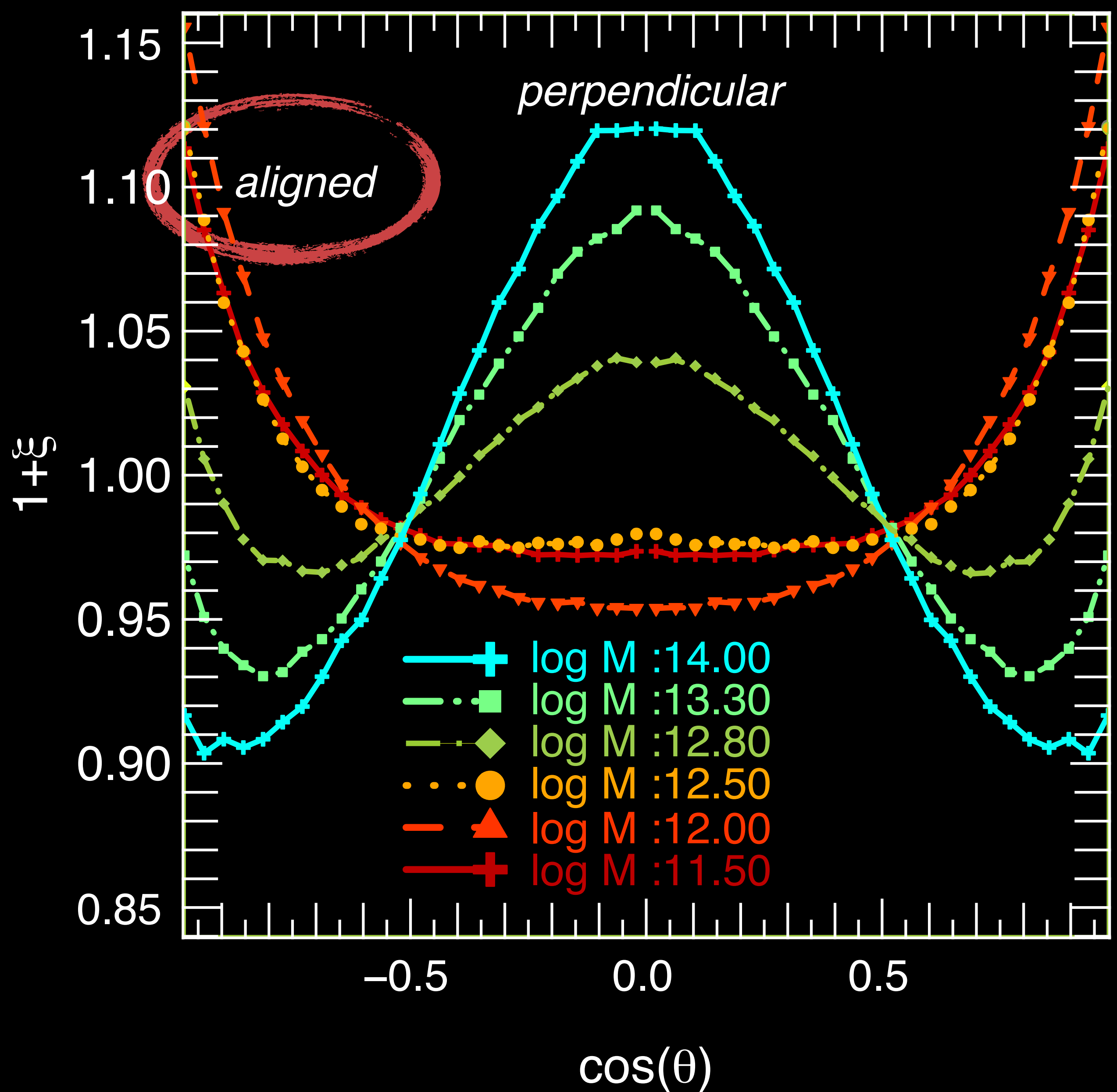
Vorticity generation in filaments

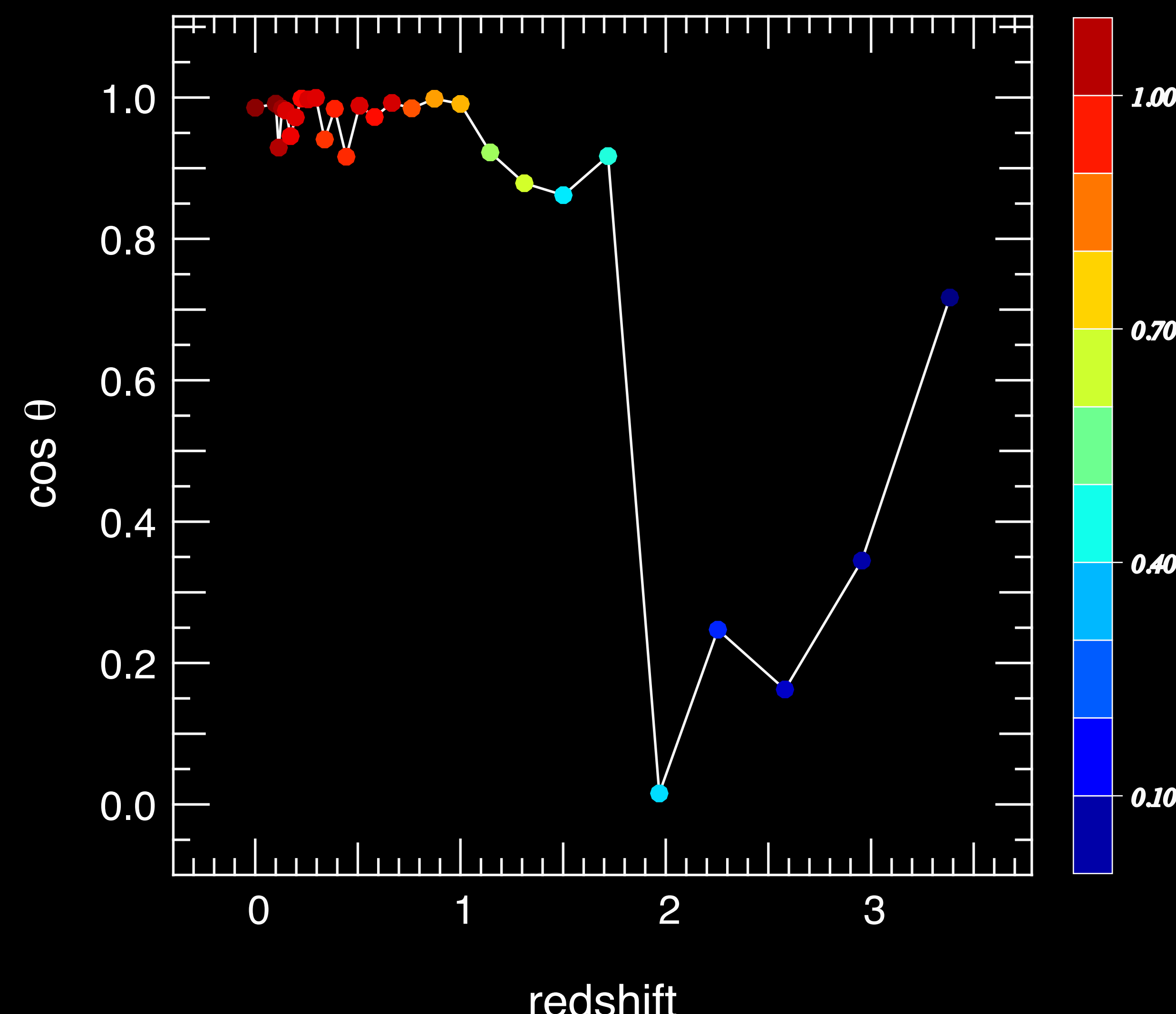
Low-mass haloes: $M < M_{\rm crit}$



$$M_{\rm crit} = 4 \cdot 10^{12} M_{\odot}$$

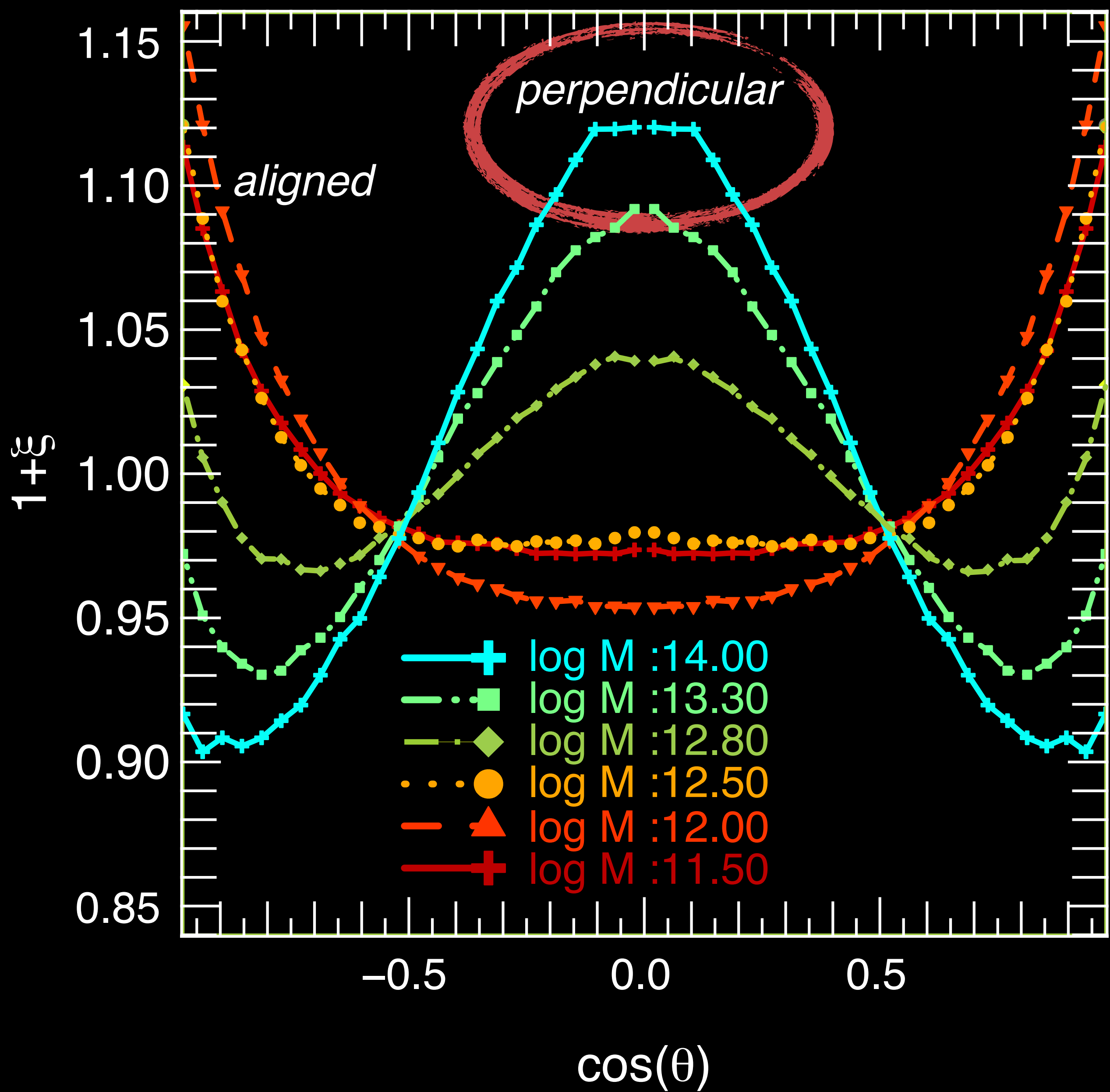
-formed at high z during the formation within filaments

-no major merger but smooth accretion until z=0

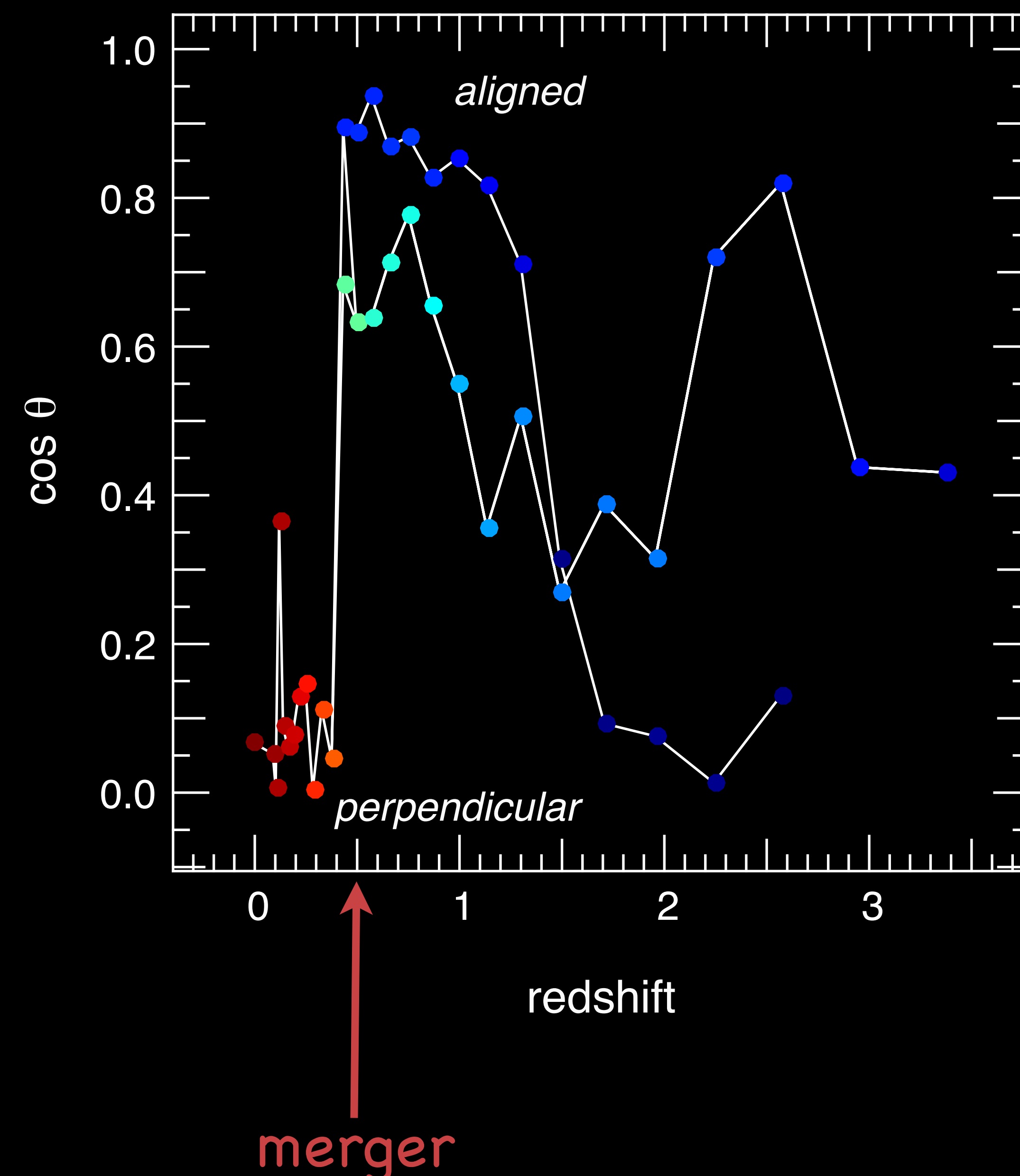


Tuesday, 2February, 16

High-mass haloes: $M > M_{\rm crit}$



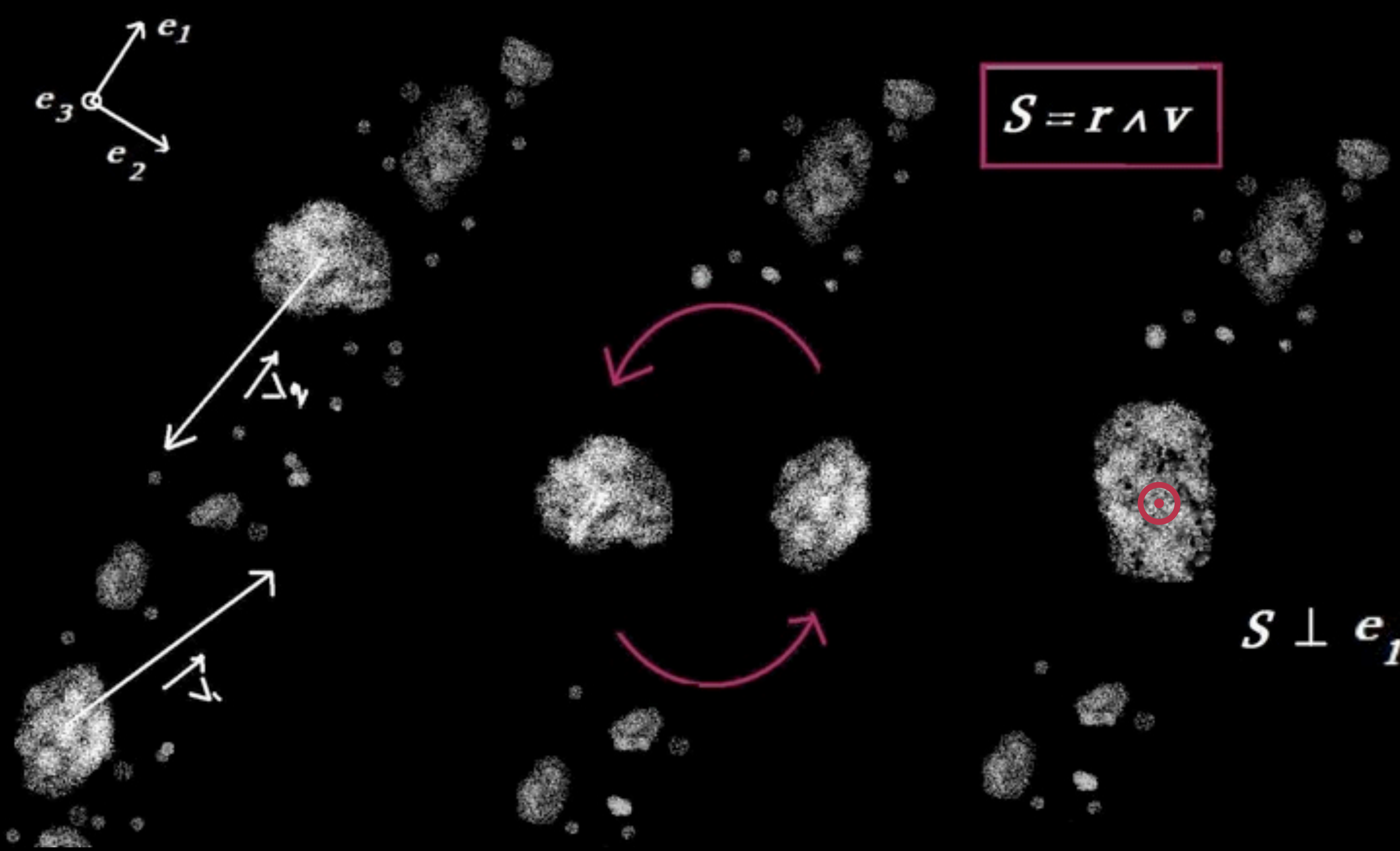
formed at low z by mergers inside the filaments



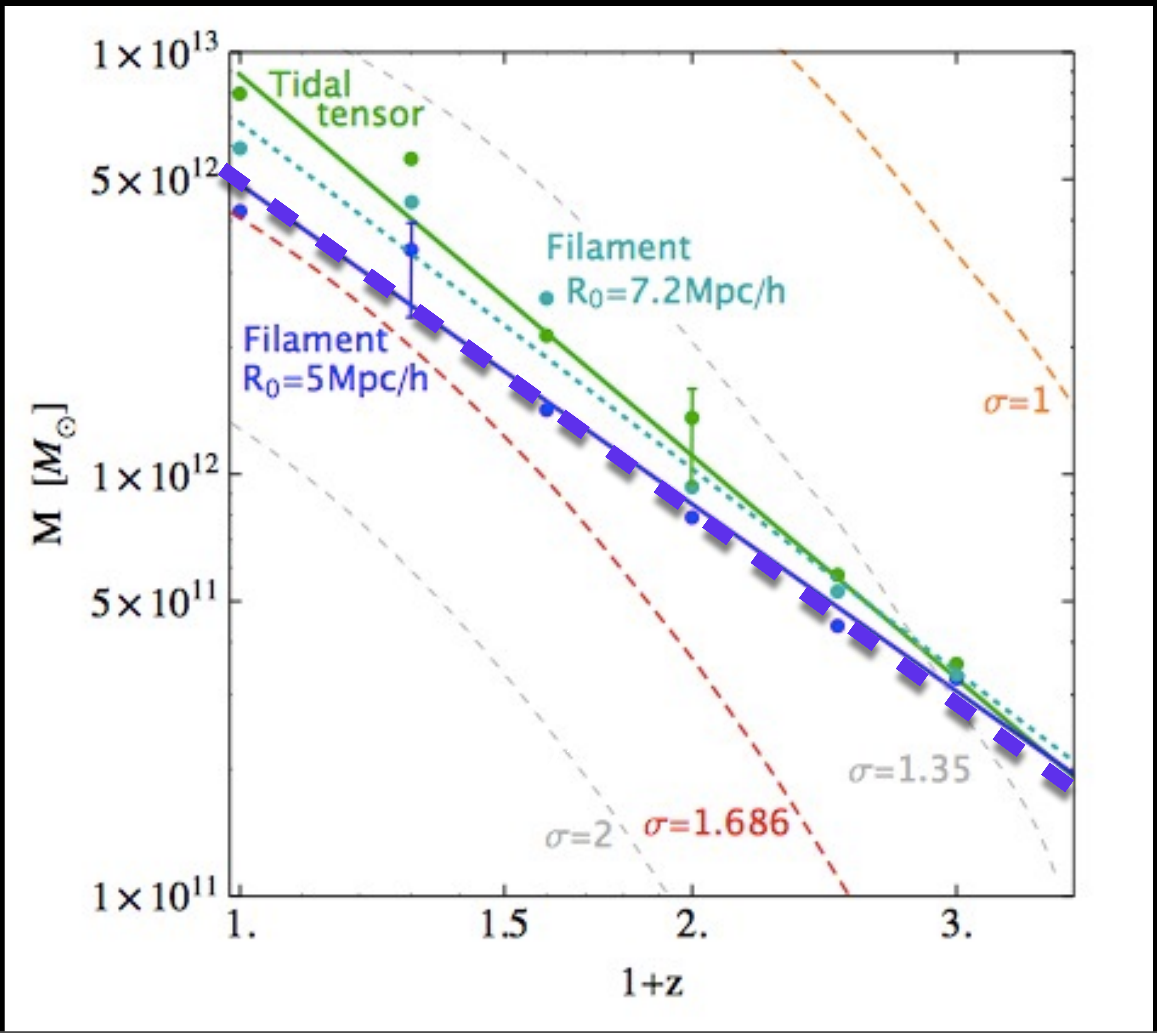
$$M_{\rm crit} = 4 \cdot 10^{12} M_\odot$$

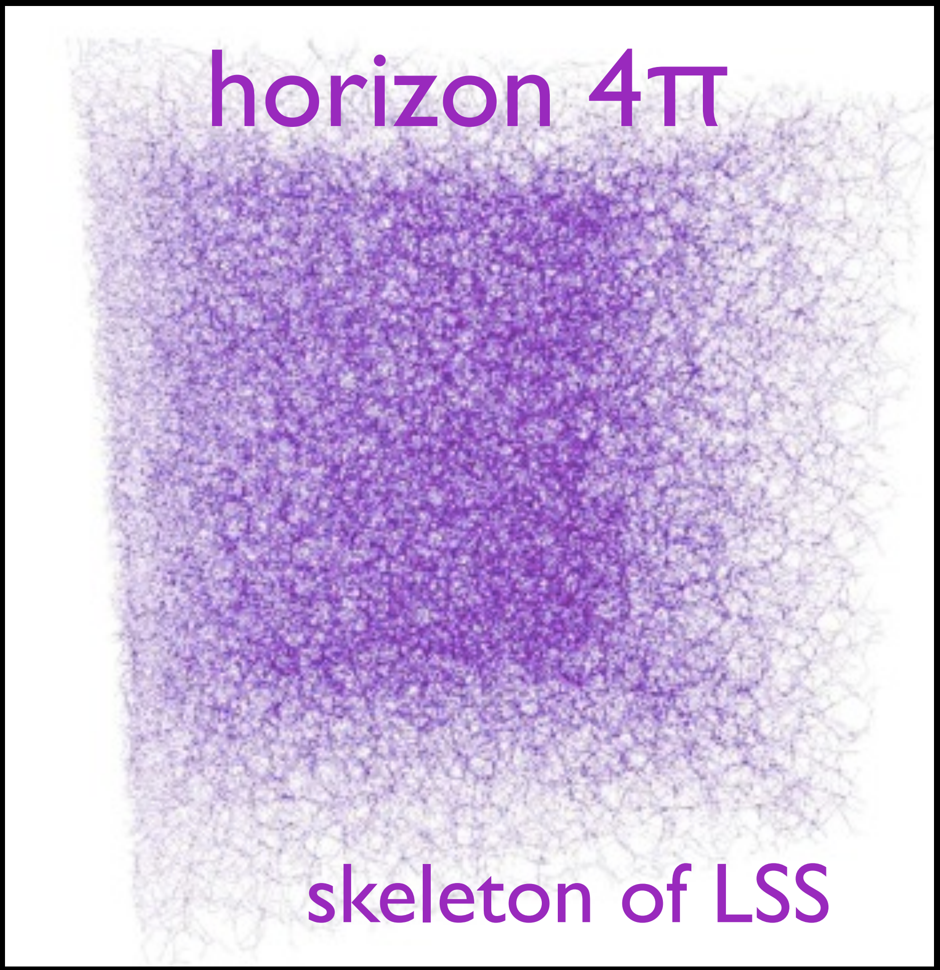
How do mergers along the filaments create spin perpendicular to them?

Halos catch up with each other along the filaments



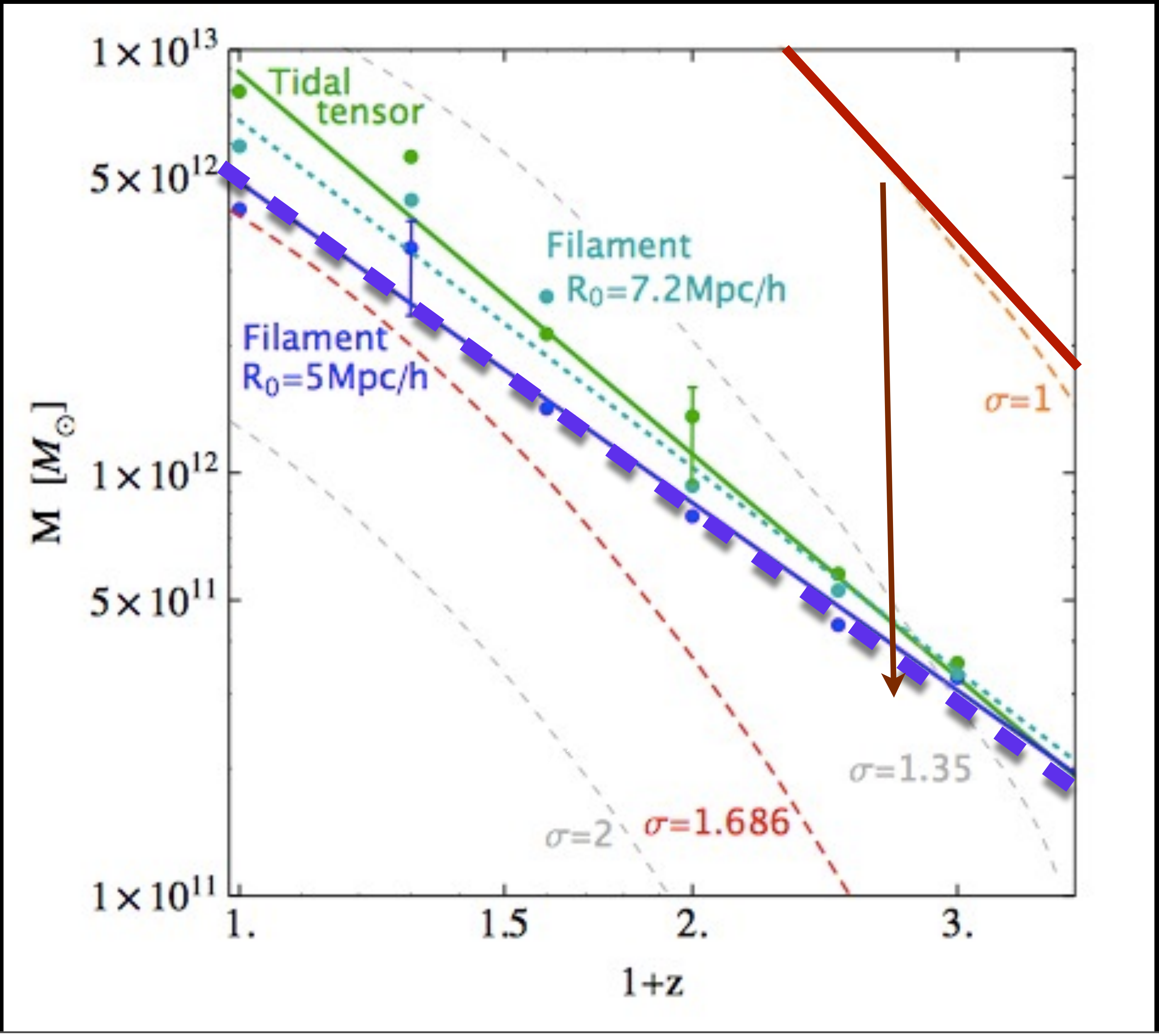
Explain transition mass?

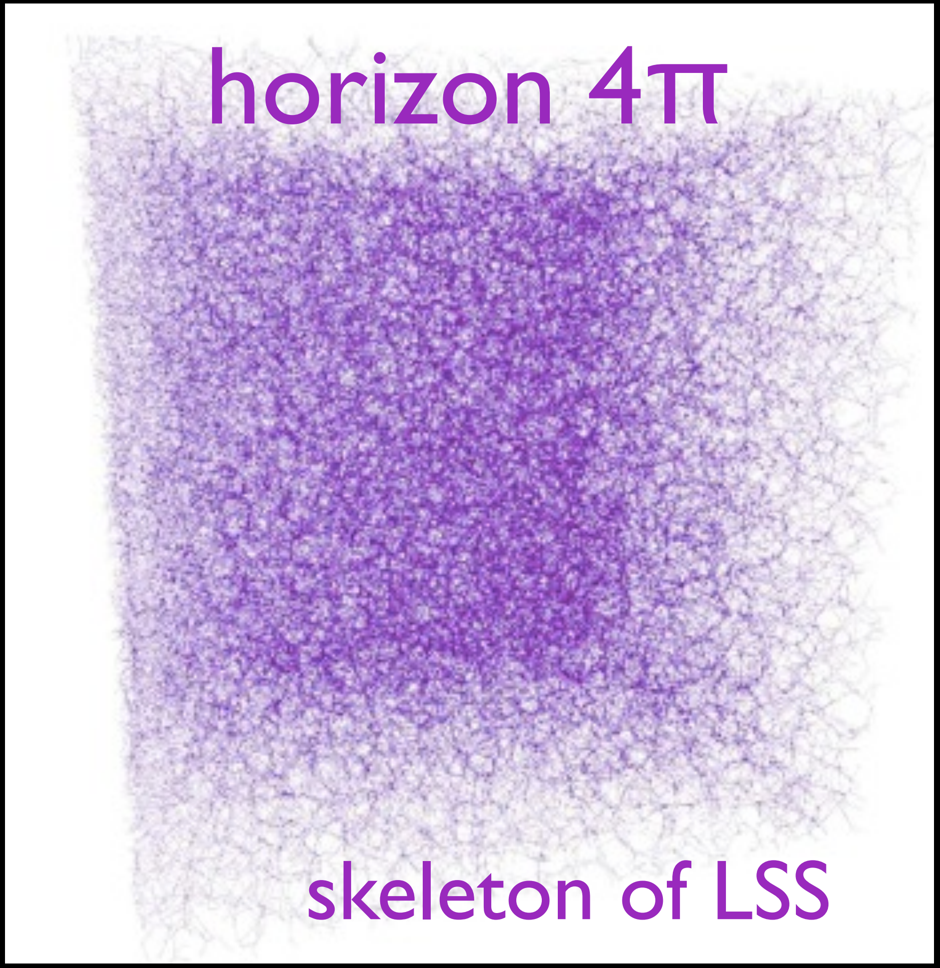




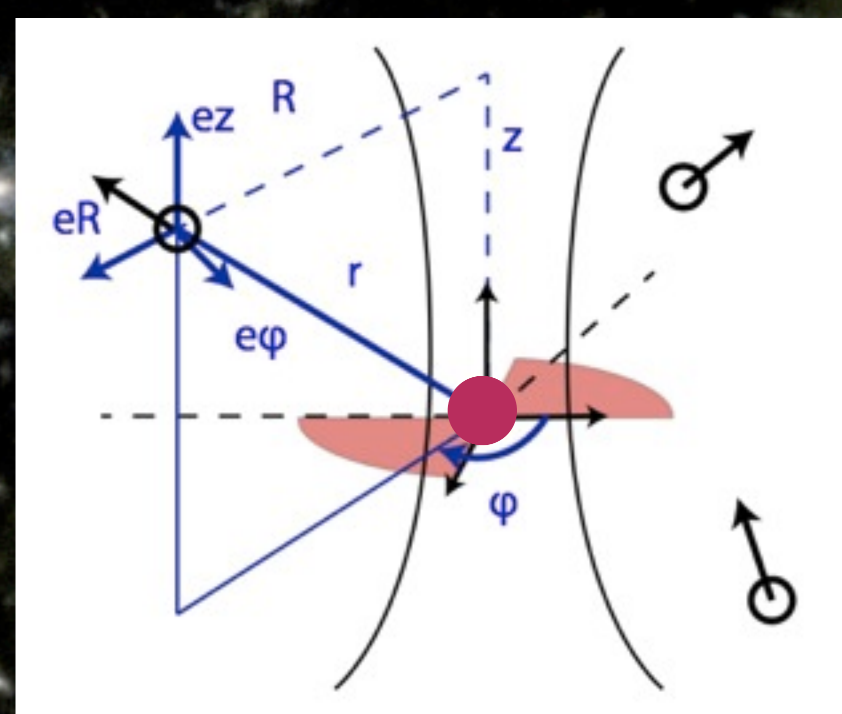
Explain transition mass?

Transition mass versus redshift: **what's wrong???**





Part II
Tidal torque theory with a peak background split near a **saddle**



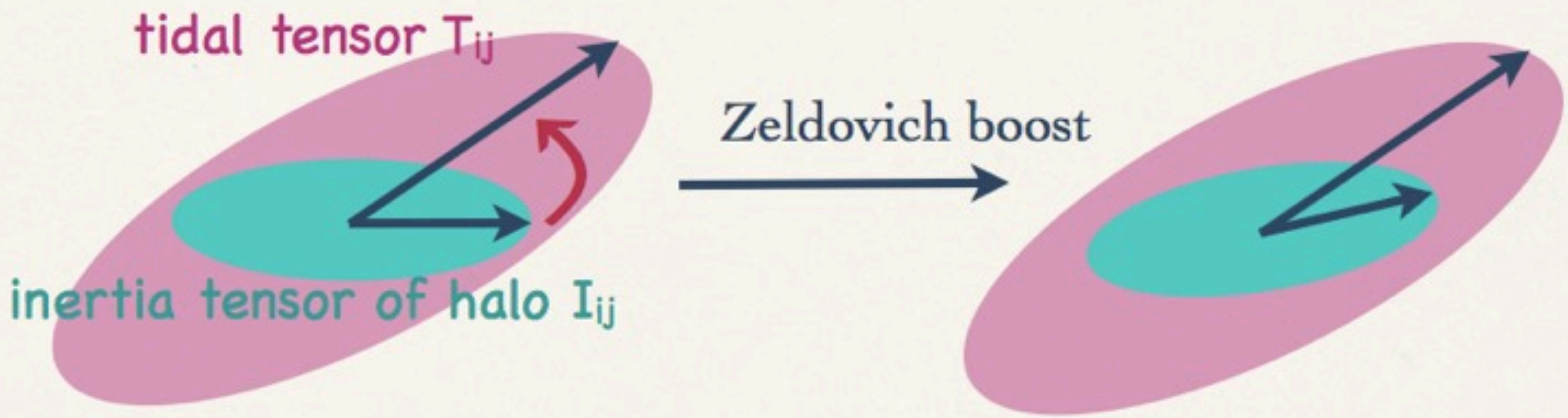
- The Idea
    - walls/filament/peak locally bias differentially tidal and inertia tensor: spin alignment reflect this in TTT
- The picture
    - Geometry of spin near saddle: point reflection symmetric distribution, ~ 1/8 of 'naive size'
- The Maths
    - Very simple **ab initio** prediction for **mass transition**

The Lagrangian view of spin/LSS connection

Can we understand where spin and vorticity alignments come from?

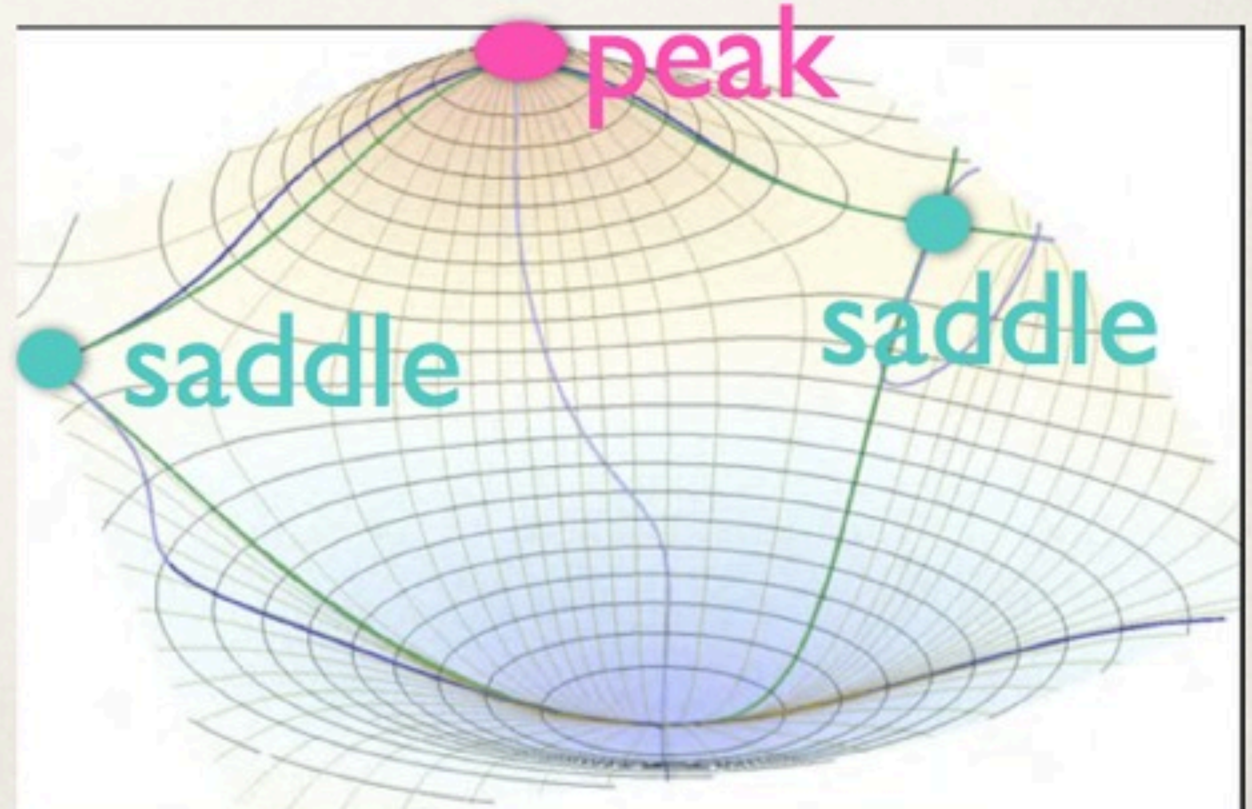
-usual tidal torque theory

$$L_k = \varepsilon_{ijk} I_{li} T_{lj}$$

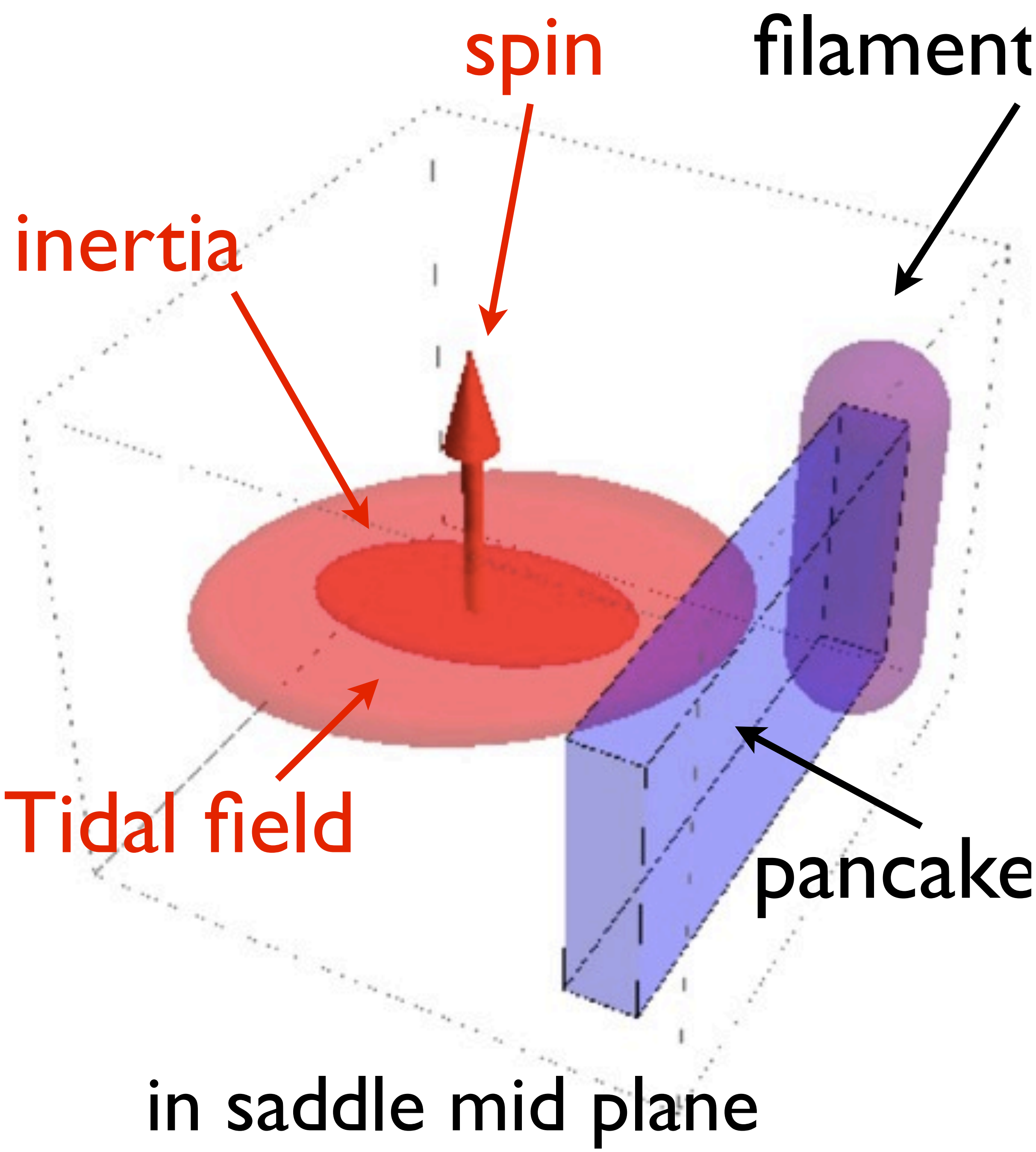


-anisotropy of the cosmic web:

surrounding of a saddle point with typical geometry



Tidal/Inertia mis-alignment



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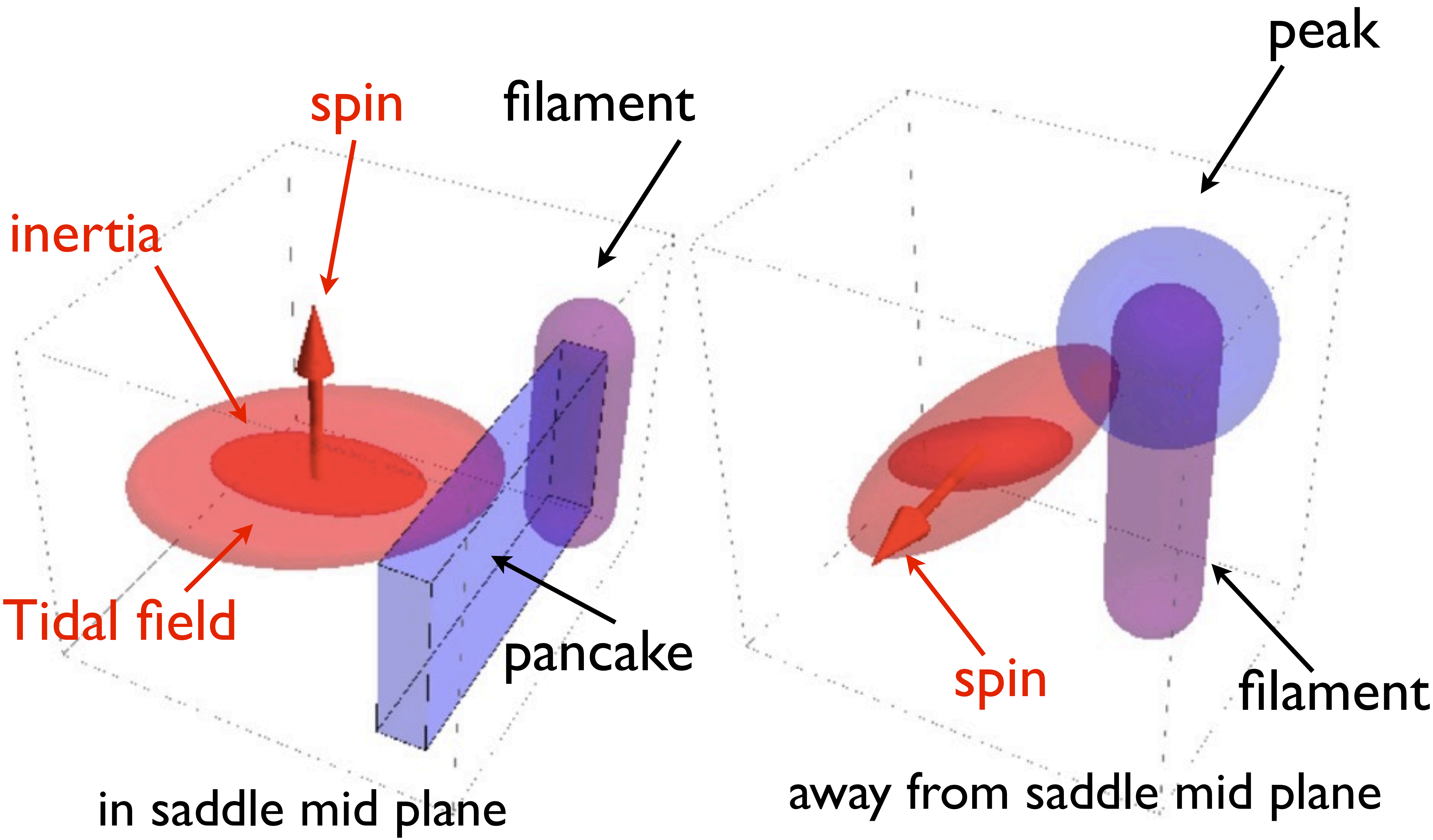
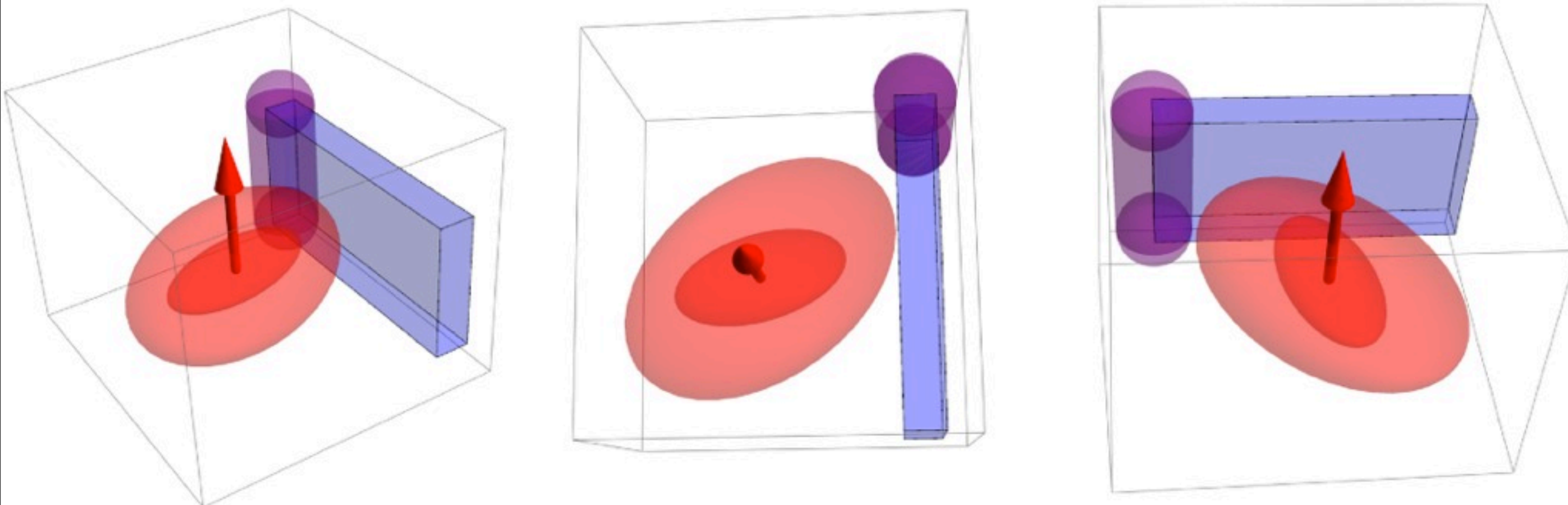
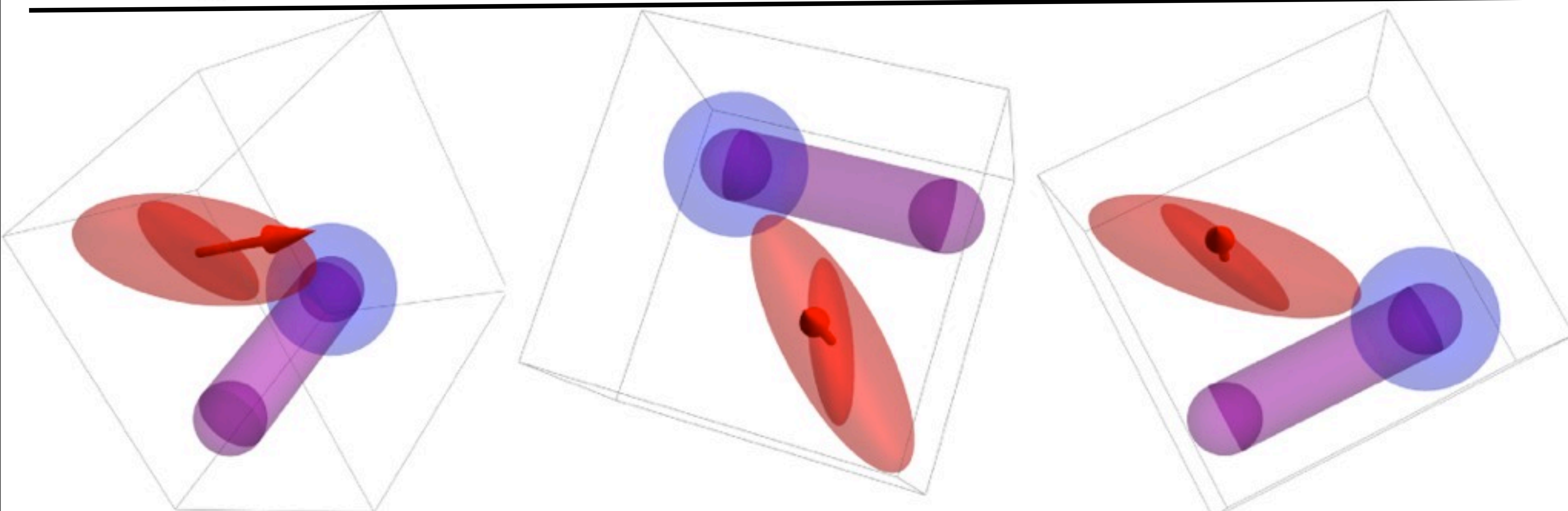


spin wall -filament





spin filament-cluster

animation?

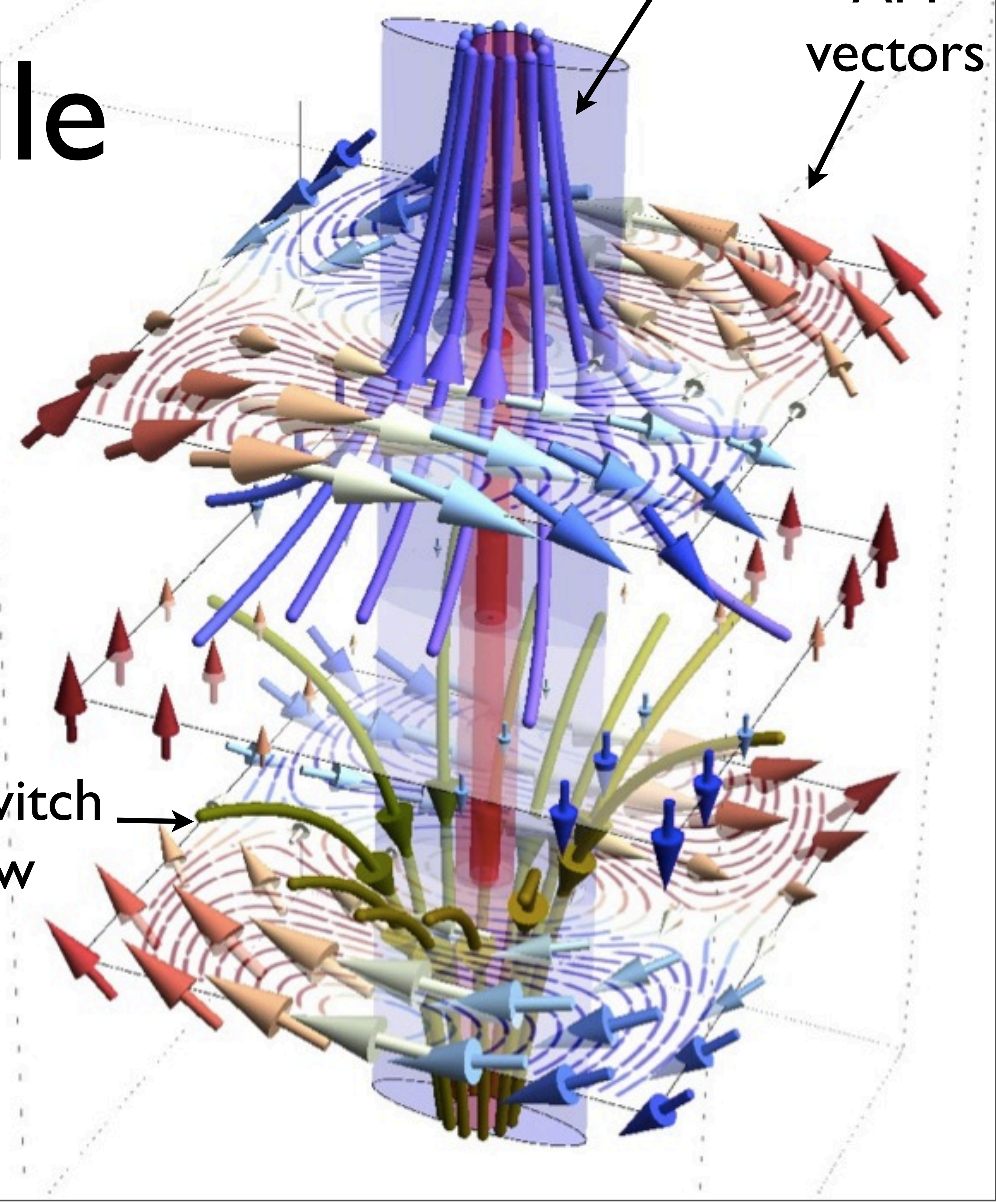
Spin structure near Saddle

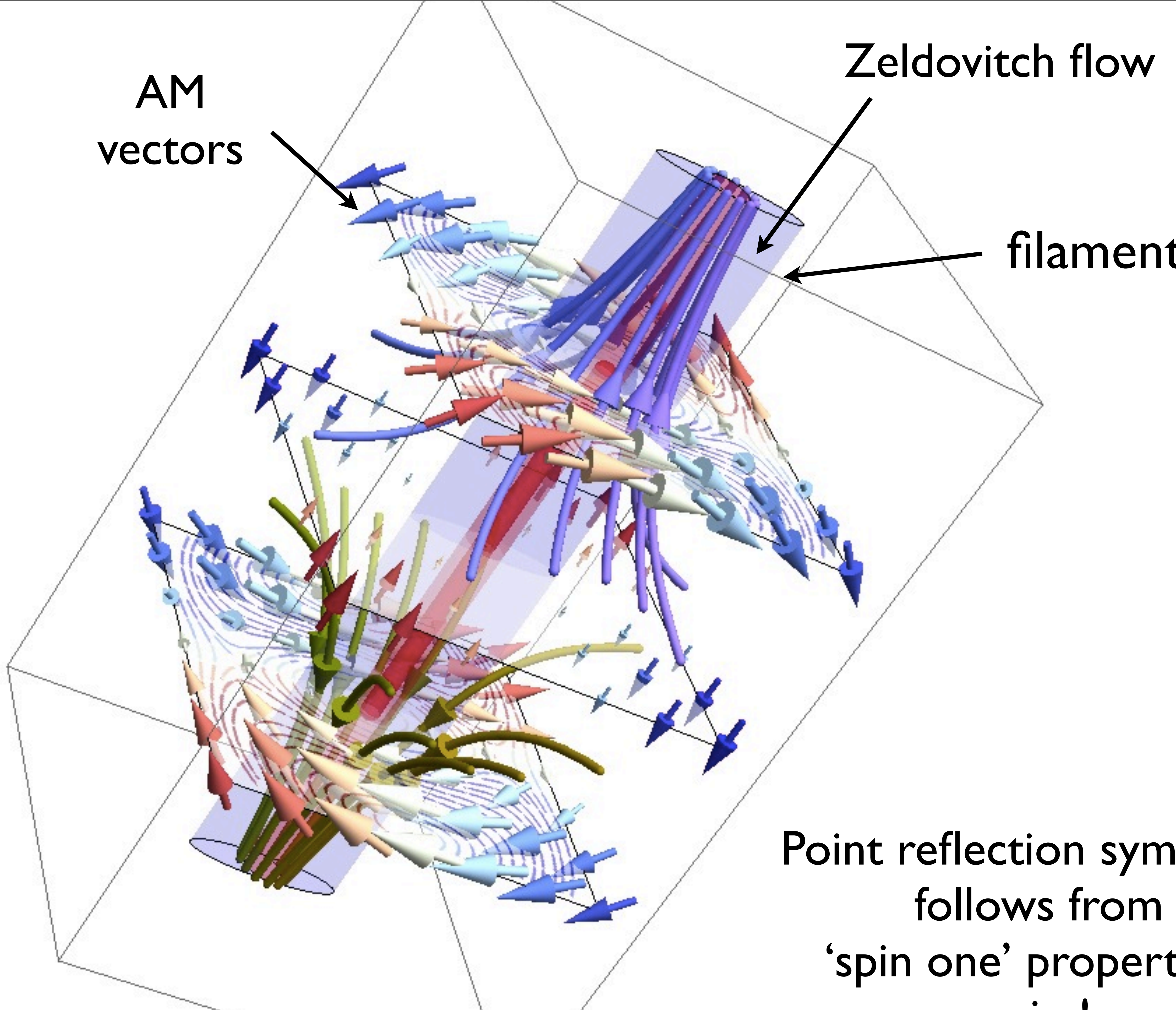
$$L_k = \varepsilon_{ijk}\, I_{li}\, T_{lj}$$

$$\approx \varepsilon_{ijk}\, H_{li}\, T_{lj}$$

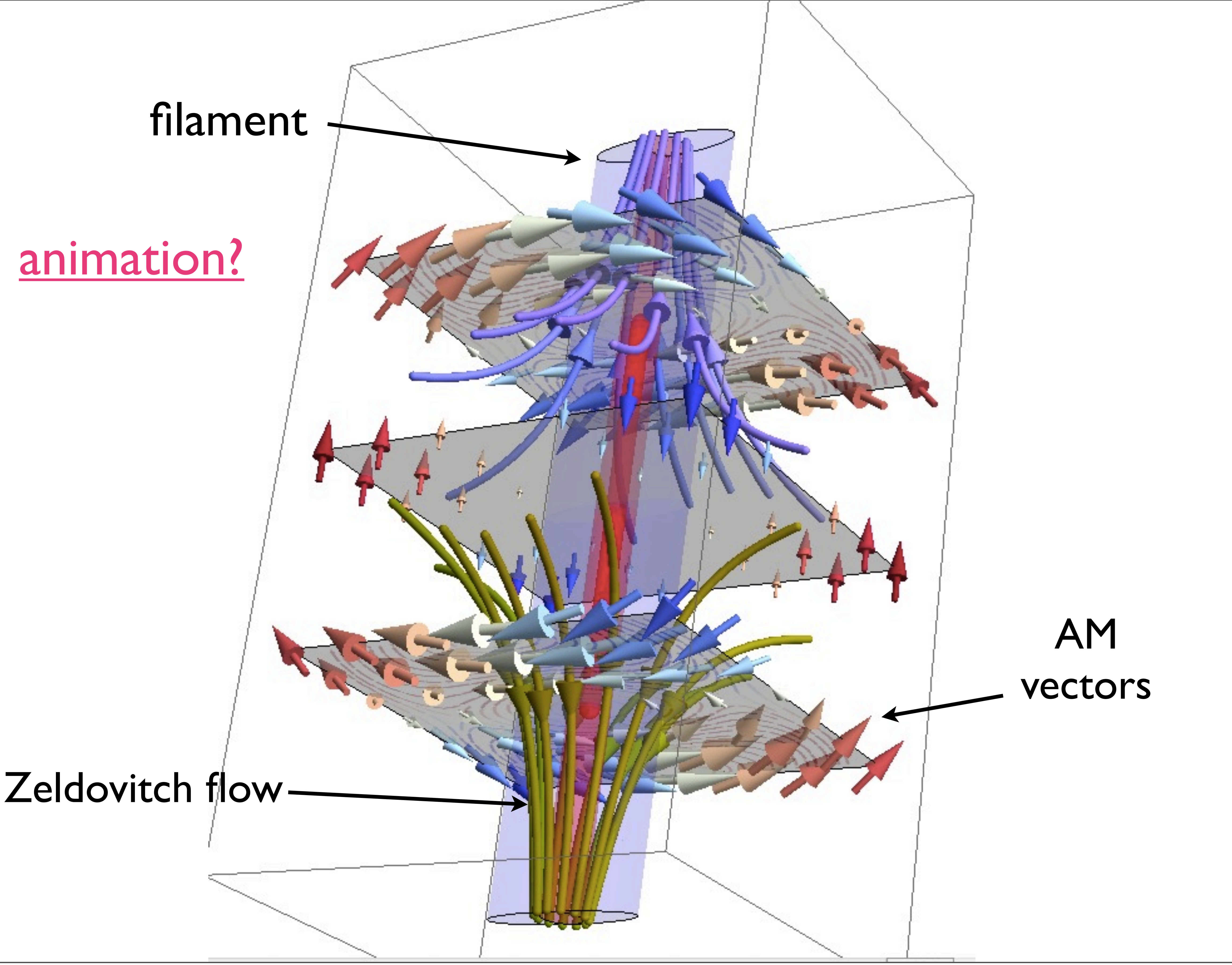
Hessian

Tidal





Point reflection symmetry
follows from
'spin one' property of
spin !


filament
animation?
AM
vectors
Zeldovitch flow

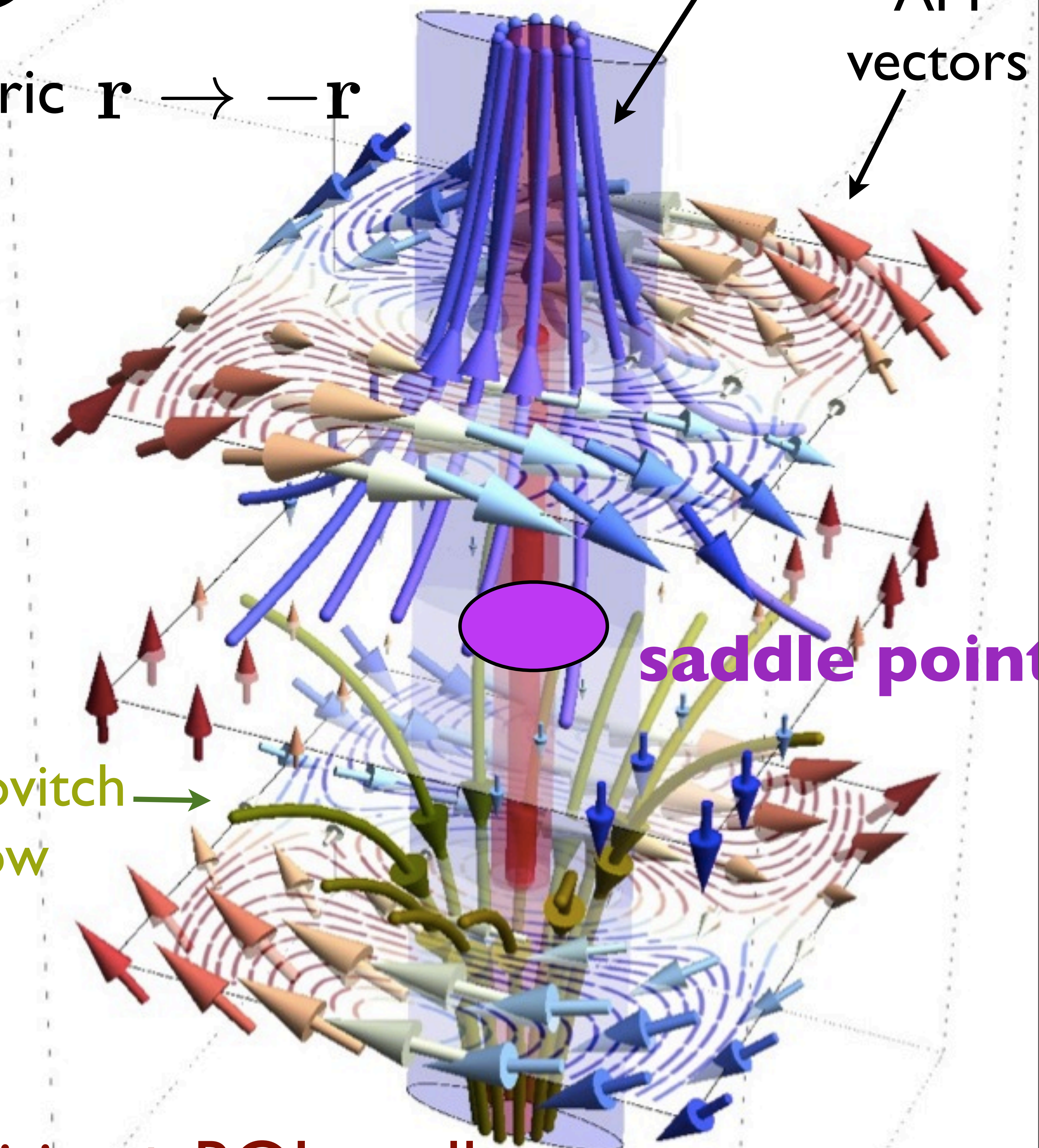
3D TTT@ saddle?

- point reflection symmetric $\mathbf{r} \to -\mathbf{r}$
- vanish if no a-symmetry

perp. along e_φ

spin //
to filament

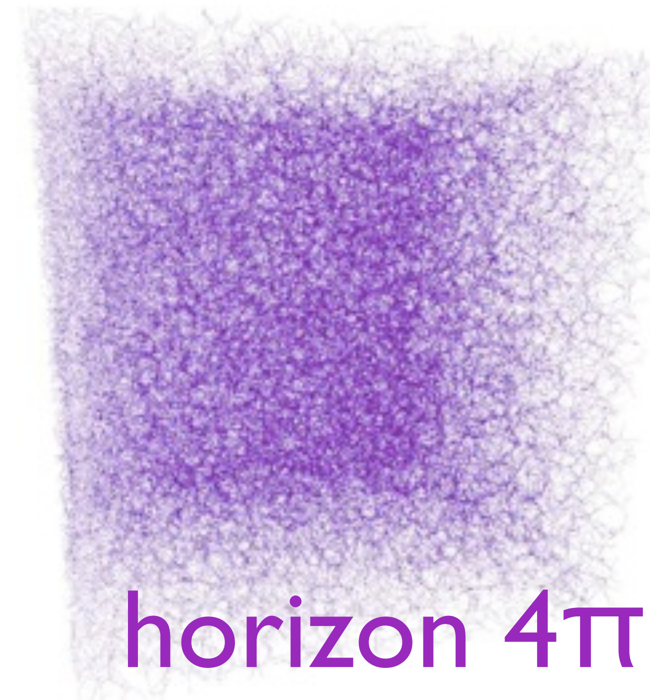
perp =
along e_φ

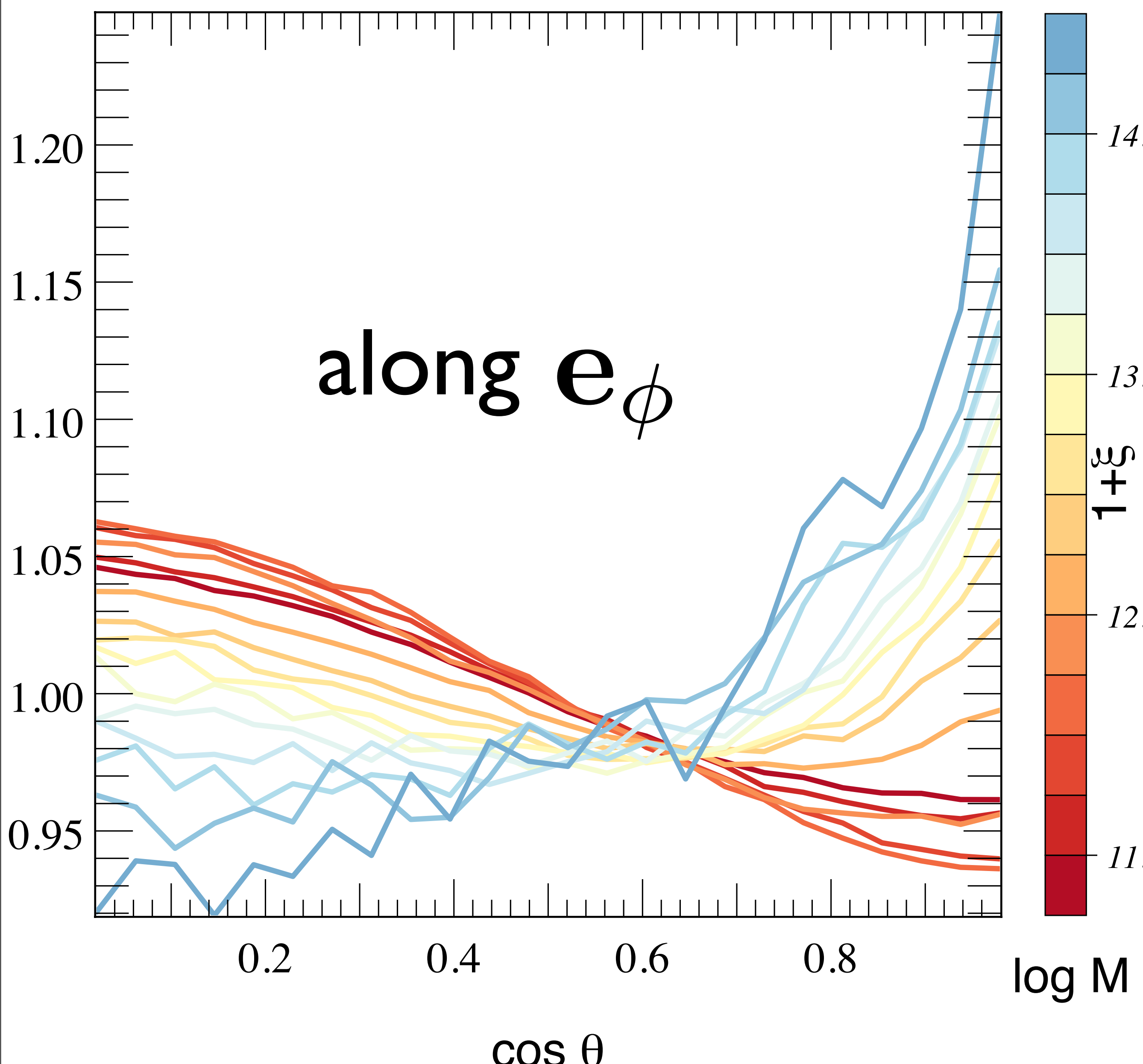


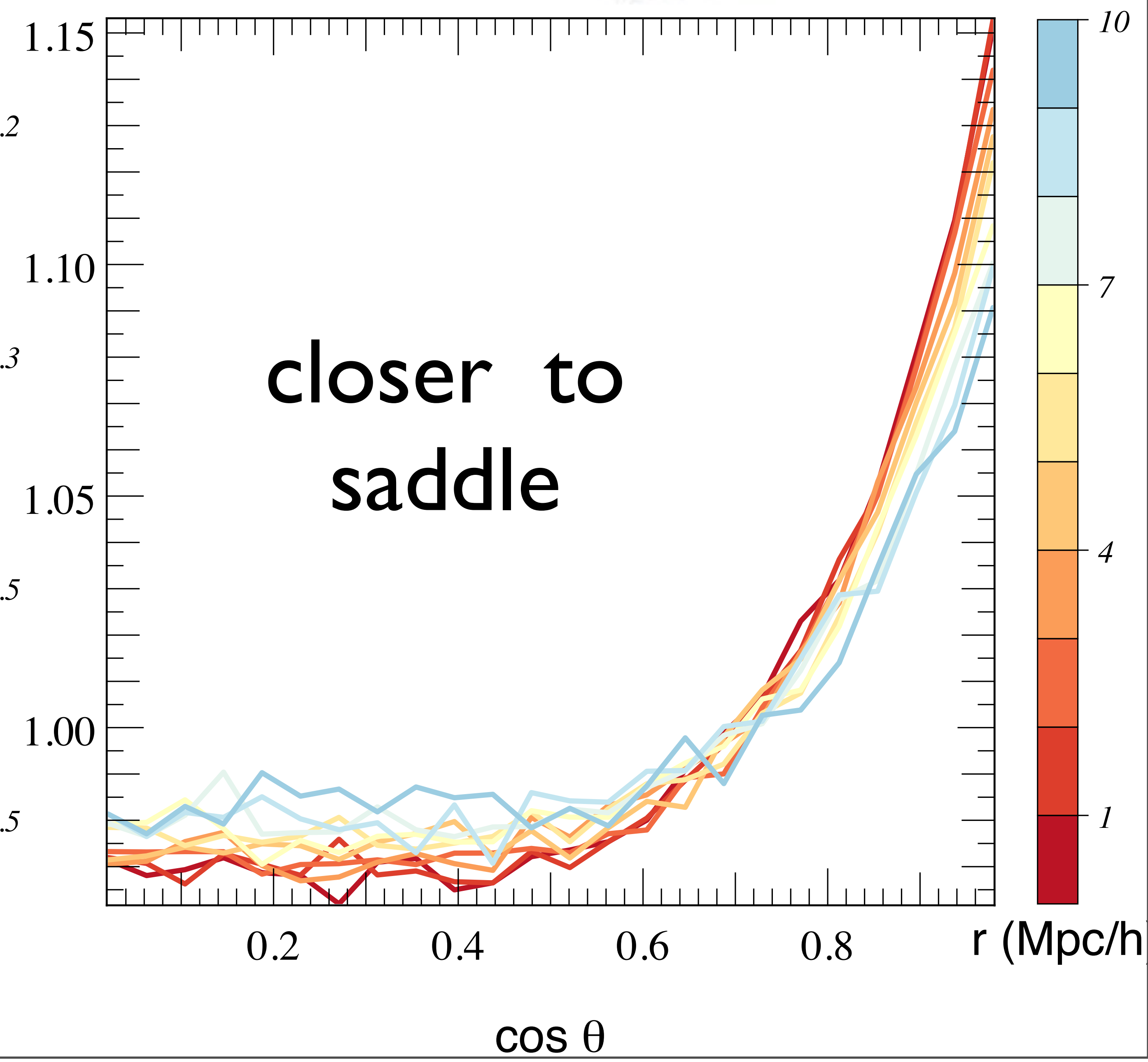
spatial transition+ ROI smaller

Does it work with Dark matter @ z=0?

Clear predictions of aTTT







Codis, Pichon, Pogosyan, 2015

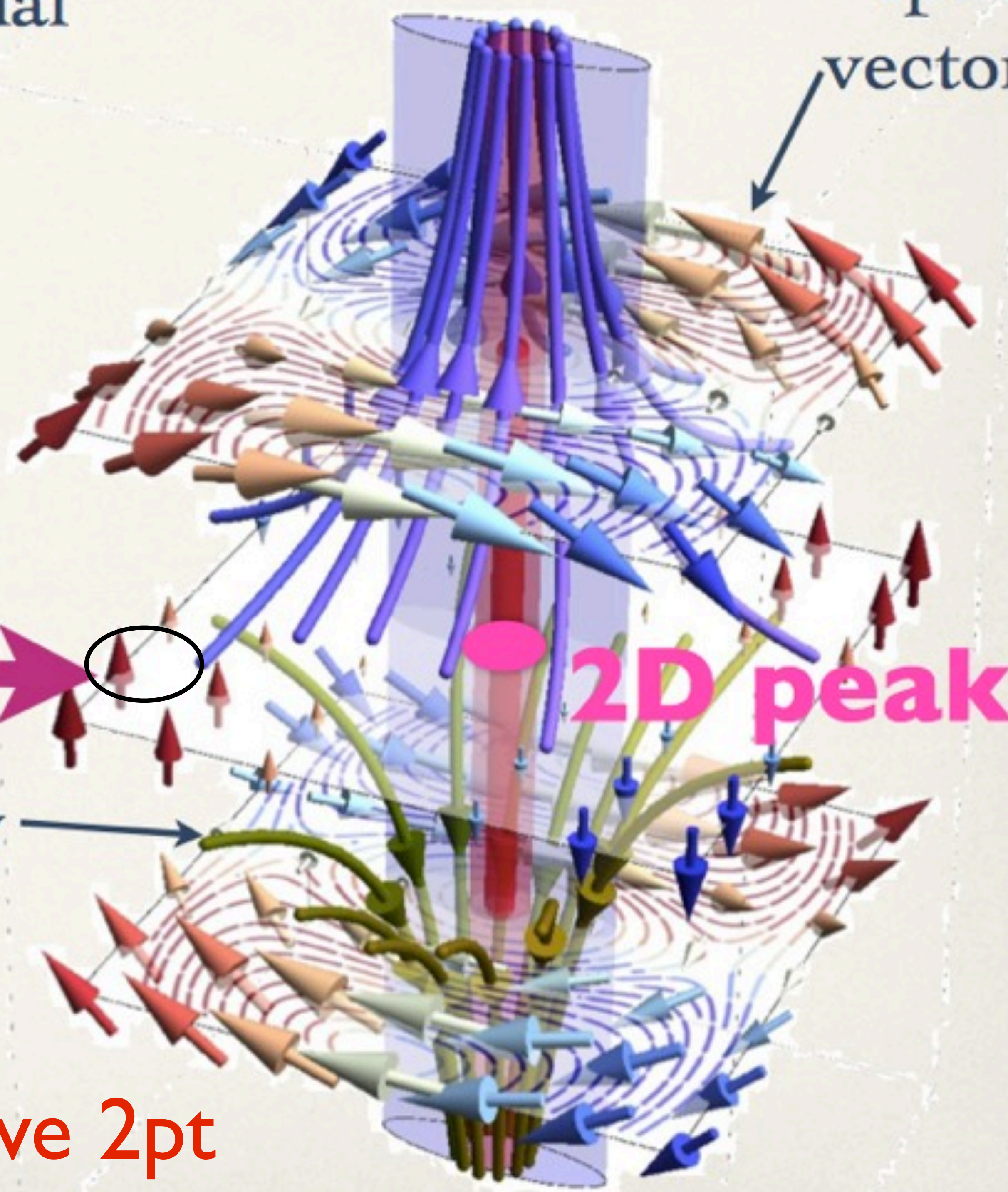
2D Spin acquisition near peaks

$$L_k = \varepsilon_{ijk} I_{li} T_{lj}$$
$$\approx \varepsilon_{ijk} H_{li} T_{lj}$$

Tidal

Hessian

$\langle L|\text{peak}\rangle_{2D}$?



Theory will involve 2pt correlation of field AND 2nd derivatives

TTT@ saddle?

the Gaussain joint PDF of the derivatives of the field, $\mathbf{X} = \{x_{ij}, x_{ijk}, x_{ijkl}\}$ and $\mathbf{Y} = \{y_{ij}, y_{ijk}, y_{ijkl}\}$ in two given locations ($\mathbf{r}_x$ and $\mathbf{r}_y$ separated by a distance $r = |\mathbf{r}_x - \mathbf{r}_y|$) obeys

$$\mathrm{PDF}(\mathbf{X},\mathbf{Y}) = \frac{1}{\det|2\pi\mathbf{C}|^{1/2}} \times$$

$$\exp\left(-\frac{1}{2}\begin{bmatrix}\mathbf{X}\\ \mathbf{Y}\end{bmatrix}^{\mathrm{T}} \cdot \begin{bmatrix}\mathbf{C}_0 & \mathbf{C}_\gamma \\ \mathbf{C}_\gamma^{\mathrm{T}} & \mathbf{C}_0\end{bmatrix}^{-1} \cdot \begin{bmatrix}\mathbf{X}\\ \mathbf{Y}\end{bmatrix}\right), \quad \text{(A2)}$$

subject to the "saddle" constraints (2D)

"height"

$$x_{0,2} + x_{2,0} = \nu,\ \ x_{1,2} + x_{3,0} = 0,\ \ x_{0,3} + x_{2,1} = 0,$$

zero gradient

$$\kappa\cos(2\theta) = \frac{1}{2}\left(x_{4,0} - x_{0,4}\right),\ \ \kappa\sin(2\theta) = -x_{1,3} - x_{3,1}\,.$$

parametrized curvature

Define the spin at point $\mathbf{r}_y$ along the z direction as the anti-symmetric contraction of the de-traced tidal field and hessian:

(2D)

$$L(\mathbf{r}_y) = \varepsilon_{ij}\overline{y}_{il}\overline{y}_{jmml} = (y_{2,0} - y_{0,2})(y_{1,3} + y_{3,1}) + \frac{y_{1,1}}{2}(y_{0,4} - y_{4,0}) - \frac{y_{1,1}}{2}(y_{4,0} - y_{0,4}) \,. \tag{A3}$$

It is then fairly straightforward to compute the corresponding constrained expectation, $\langle L|\mathrm{pk}\rangle$, for L as

$$L_z(r, \theta, \kappa, \nu) = \int L(\mathbf{Y})\mathrm{PDF}(\mathbf{X}, \mathbf{Y}|\mathrm{pk})\mathrm{d}\mathbf{X}\mathrm{d}\mathbf{Y} \,. \tag{A4}$$

e.g. for n=-2

Incredibly simple prediction !

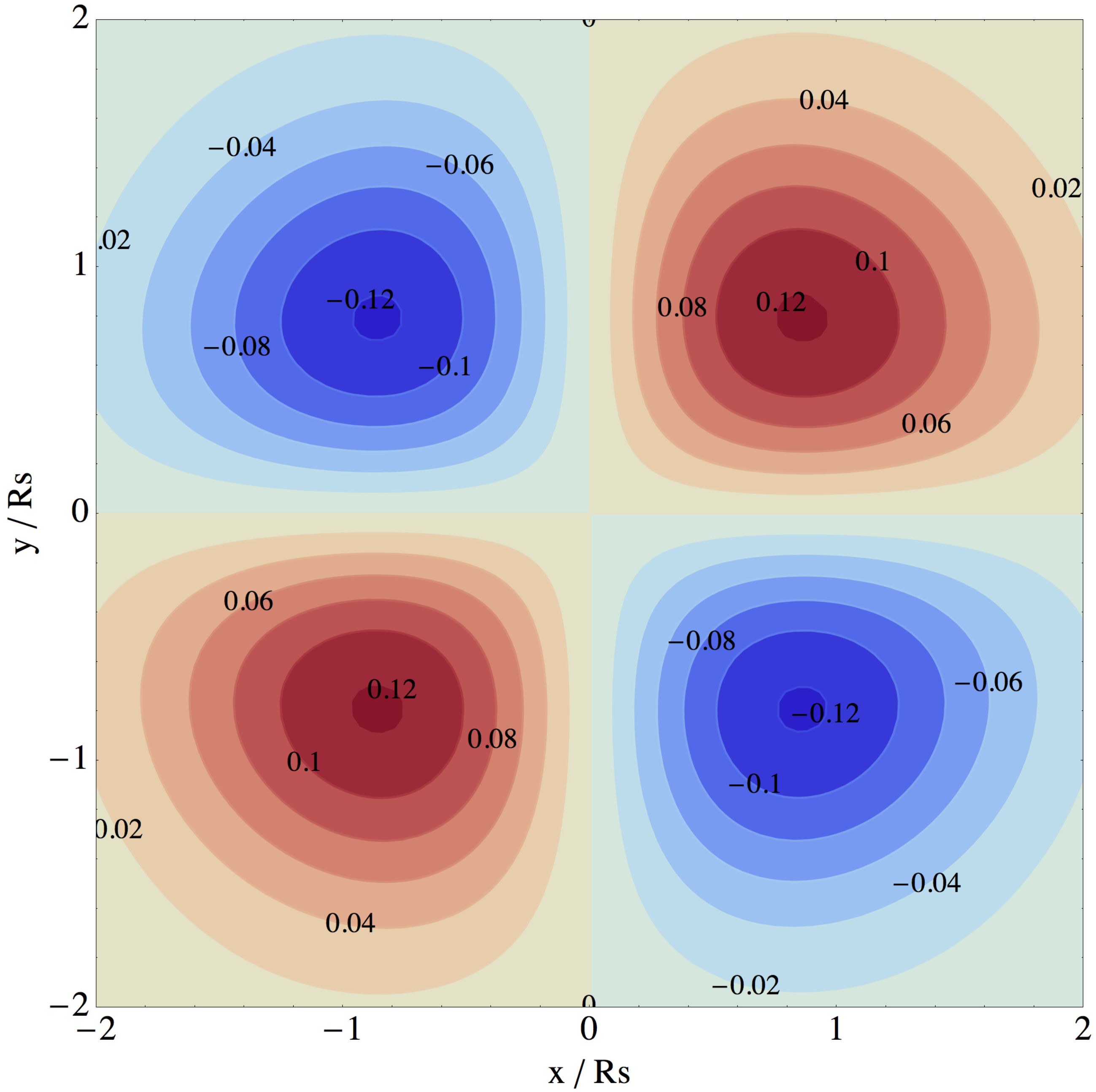
$$L_z = \kappa \frac{r^4 \sin(2\theta)}{144} e^{-\frac{r^2}{2}} \left(\sqrt{6}\kappa\left(r^2 - 4\right)\cos(2\theta) + 6\nu\right) \,.$$

peak height

asymmetry

finite extent

anti-ymmetry



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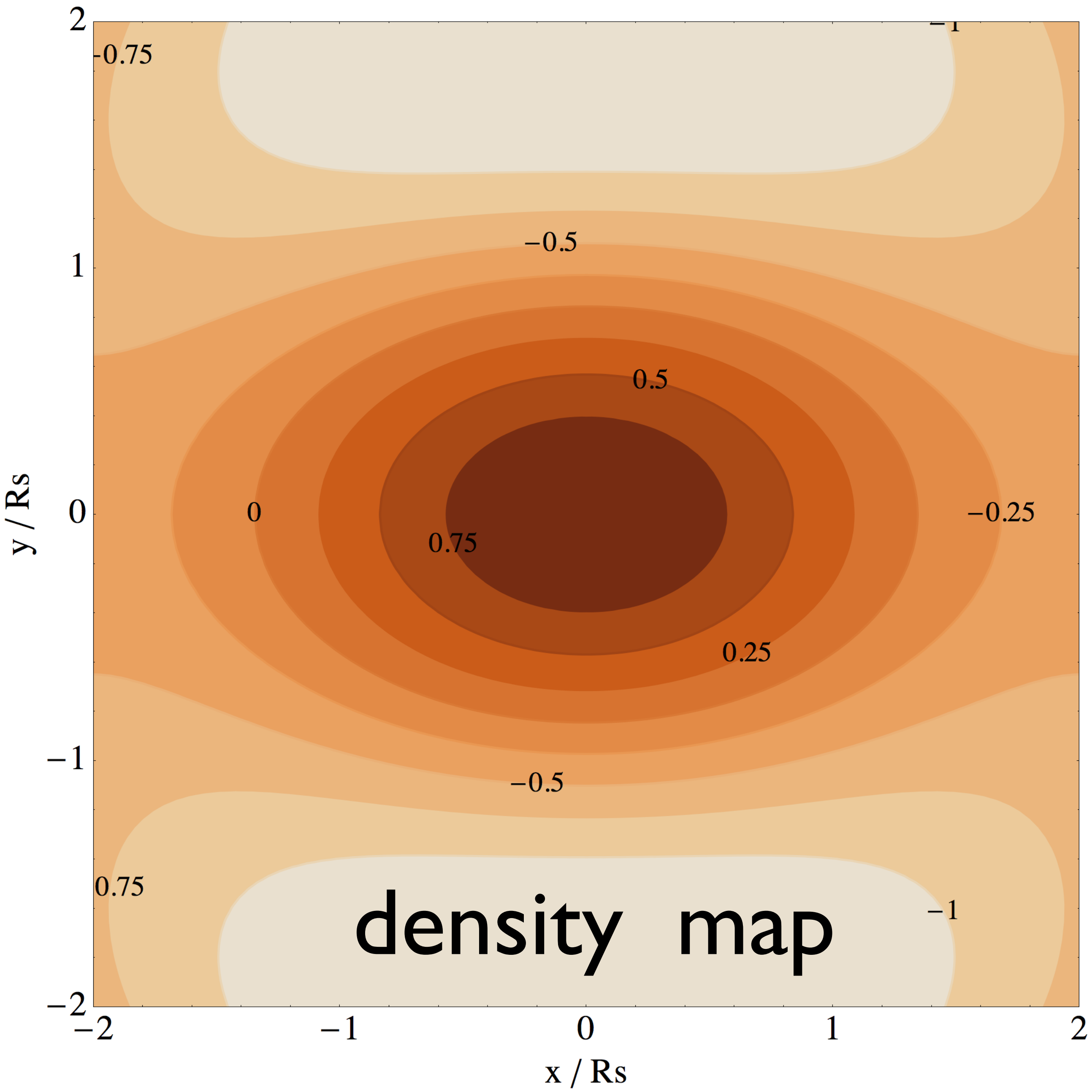
asymmetry · finite extent · anti-ymmetry

2D Theory of Tidal Torque @ saddle?

$$\delta(\mathbf{r},\kappa,I_1,\nu|\mathrm{ext}) = \frac{I_1(\xi_{\phi\delta}^{\Delta\Delta}+\gamma\xi_{\phi\phi}^{\Delta\Delta})+\nu(\xi_{\phi\phi}^{\Delta\Delta}+\gamma\xi_{\phi\delta}^{\Delta\Delta})}{1-\gamma^2} + 4\left(\hat{\mathbf{r}}^{\mathrm{T}}\cdot\overline{\mathbf{H}}\cdot\hat{\mathbf{r}}\right)\xi_{\phi\delta}^{\Delta+},$$

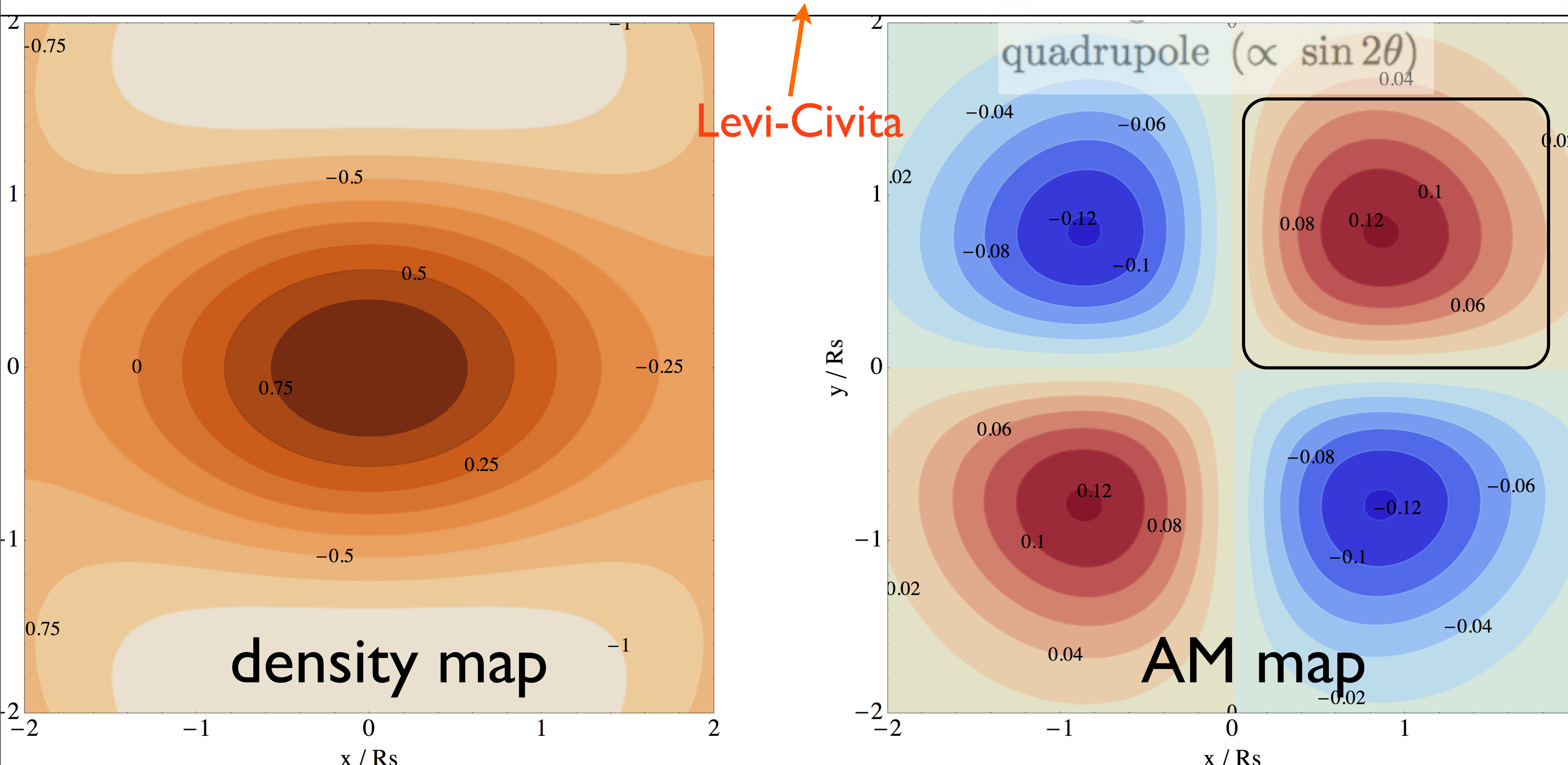
Hessian



$$f^{+} = (f_{11} - f_{22})/2 \text{ and } f^{\times} = f_{12}.$$

2D Theory of Tidal Torque @ saddle?

$$\langle L_z|\mathrm{ext}\rangle = L_z(\mathbf{r},\kappa,I_1,\nu|\mathrm{ext}) = -16(\hat{\mathbf{r}}^{\mathrm{T}}\cdot\epsilon\cdot\overline{\mathbf{H}}\cdot\hat{\mathbf{r}})\left(L_z^{(1)}(r)+2(\hat{\mathbf{r}}^{\mathrm{T}}\cdot\overline{\mathbf{H}}\cdot\hat{\mathbf{r}})L_z^{(2)}(r)\right)$$



$$L_z^{(1)}(r) = \frac{\nu}{1-\gamma^2}\left[(\xi^{\Delta+}_{\phi\phi}+\gamma\xi^{\Delta+}_{\phi\delta})\xi^{\times\times}_{\delta\delta} - (\xi^{\Delta+}_{\phi\delta}+\gamma\xi^{\Delta+}_{\delta\delta})\xi^{\times\times}_{\phi\delta}\right]$$

$$L_z^{(2)}(r) = (\xi^{\Delta\Delta}_{\phi x}\xi^{\times\times}_{\delta\delta} - \xi^{\times\times}_{\phi\delta}\xi^{\Delta\Delta}_{\delta\delta}) + \frac{I_1}{1-\gamma^2}\left[(\xi^{\Delta+}_{\phi\delta}+\gamma\xi^{\Delta+}_{\phi\phi})\xi^{\times\times}_{\delta\delta} - (\xi^{\Delta+}_{\delta\delta}+\gamma\xi^{\Delta+}_{\phi\delta})\xi^{\times\times}_{\phi\delta}\right]$$

In order to compute the spin distribution, the formalism developed in Section 2 is easily extended to 3D. A critical (including saddle condition) point constraint is imposed. The resulting mean density field subject to that constraint becomes (in units of σ_2):

$$\delta(\mathbf{r},\kappa,I_1,\nu|\mathrm{ext}) = \frac{I_1(\xi_{\phi\delta}^{\Delta\Delta}+\gamma\xi_{\phi\phi}^{\Delta\Delta})}{1-\gamma^2} + \frac{\nu(\xi_{\phi\phi}^{\Delta\Delta}+\gamma\xi_{\phi\delta}^{\Delta\Delta})}{1-\gamma^2} + \frac{15}{2}\left(\hat{\mathbf{r}}^{\mathrm{T}}\cdot\overline{\mathbf{H}}\cdot\hat{\mathbf{r}}\right)\xi_{\phi\delta}^{\Delta+}, \quad (3.1)$$

where again $\overline{\mathbf{H}}$ is the *detraced* Hessian of the density and $\hat{\mathbf{r}}=\mathbf{r}/r$ and we define in 3D $\xi_{\phi x}^{\Delta+}$ as $\xi_{\phi\delta}^{\Delta+}=\langle\Delta\delta,\phi^+\rangle$, with $\phi^+=\phi_{11}-(\phi_{22}+\phi_{33})/2$. Note that $\hat{\mathbf{r}}^{\mathrm{T}}\cdot\overline{\mathbf{H}}\cdot\hat{\mathbf{r}}$ is a scalar quantity defined explicitly as $\hat{r}_i\overline{H}_{ij}\hat{r}_j$. As in 2D, the expected spin can also be computed. In 3D, the spin is a vector, which components are given by $L_i=\varepsilon_{ijk}\delta_{kl}\phi_{lj}$, with $\boldsymbol{\epsilon}$ the rank 3 Levi Civita tensor. It is found to be orthogonal to the separation and can be written as the sum of two terms

$$\mathbf{L}(\mathbf{r},\kappa,I_1,\nu|\mathrm{ext}) = -15\Big(\mathbf{L}^{(1)}(r)+\mathbf{L}^{(2)}(\mathbf{r})\Big)\cdot(\hat{\mathbf{r}}^{\mathrm{T}}\cdot\boldsymbol{\epsilon}\cdot\overline{\mathbf{H}}\cdot\hat{\mathbf{r}}), \quad (3.2)$$

where $\mathbf{L}^{(1)}$ depends on height, ν, and on the trace of the Hessian I_1 but not on orientation

$$\mathbf{L}^{(1)}(r) = \Bigg(\frac{\nu}{1-\gamma^2}\left[(\xi_{\phi\phi}^{\Delta+}+\gamma\xi_{\phi\delta}^{\Delta+})\xi_{\delta\delta}^{\times\times}-(\xi_{\phi\delta}^{\Delta+}+\gamma\xi_{\delta\delta}^{\Delta+})\xi_{\phi\delta}^{\times\times}\right] + \frac{I_1}{1-\gamma^2}\left[(\xi_{\phi\delta}^{\Delta+}+\gamma\xi_{\phi\phi}^{\Delta+})\xi_{\delta\delta}^{\times\times}-(\xi_{\delta\delta}^{\Delta+}+\gamma\xi_{\phi\delta}^{\Delta+})\xi_{\phi\delta}^{\times\times}\right]\Bigg)\mathbb{I}_3,$$

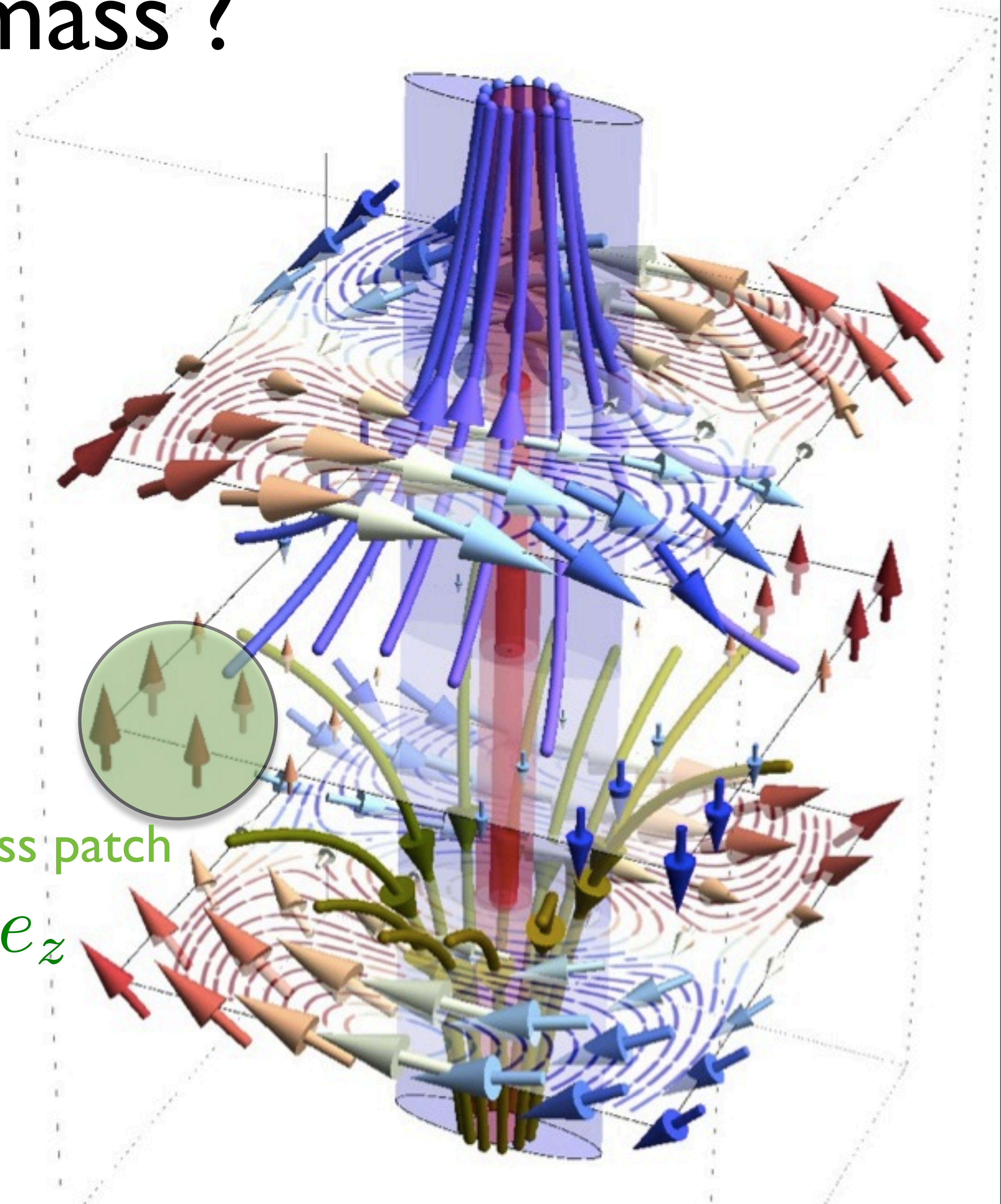
and $\mathrm{L}^{(2)}(\mathbf{r})$ now depends on $\overline{\mathbf{H}}$ and on orientation:

$$\mathbf{L}^{(2)}(\mathbf{r}) = -\frac{5}{8}\Big[2((\xi_{\phi\delta}^{\Delta+}-\xi_{\phi\delta}^{\Delta\Delta})\xi_{\delta\delta}^{\times\times}-(\xi_{\delta\delta}^{\Delta+}-\xi_{\delta\delta}^{\Delta\Delta})\xi_{\phi\delta}^{\times\times})\overline{\mathbf{H}} + ((7\xi_{\delta\delta}^{\Delta\Delta}+5\xi_{\delta\delta}^{\Delta+})\xi_{\phi\delta}^{\times\times}-(7\xi_{\phi\delta}^{\Delta\Delta}+5\xi_{\phi\delta}^{\Delta+})\xi_{\delta\delta}^{\times\times})(\hat{\mathbf{r}}^{\mathrm{T}}\cdot\overline{\mathbf{H}}\cdot\hat{\mathbf{r}})\mathbb{I}_3\Big],$$

3D Transition mass ?

Lagrangian theory
capture spin flip !

Transition mass
associated
with **size**
of quadrant



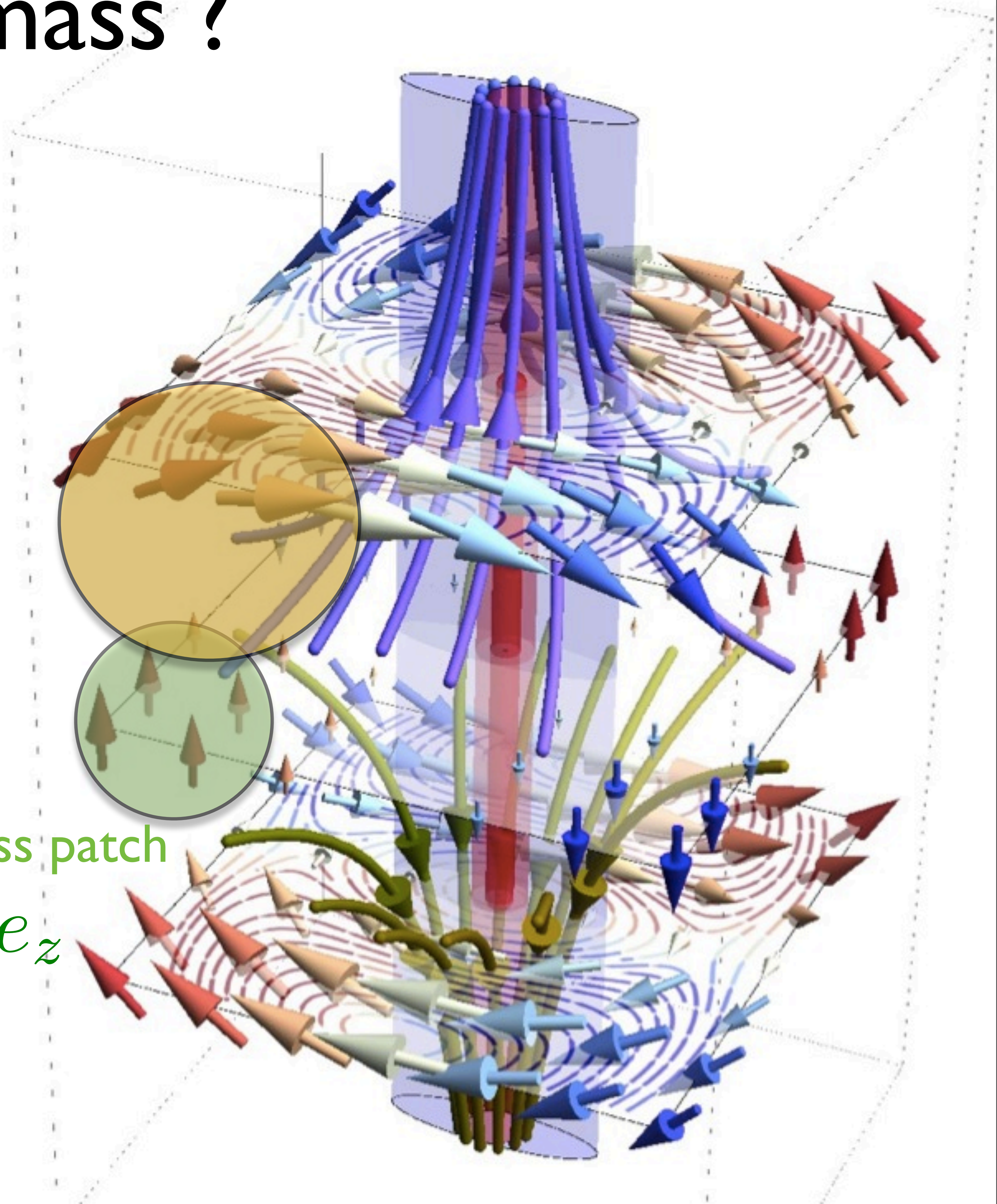
Low mass patch

$L \propto e_z$

3D Transition mass ?

Lagrangian theory capture spin flip !

Transition mass associated with **size** of quadrant



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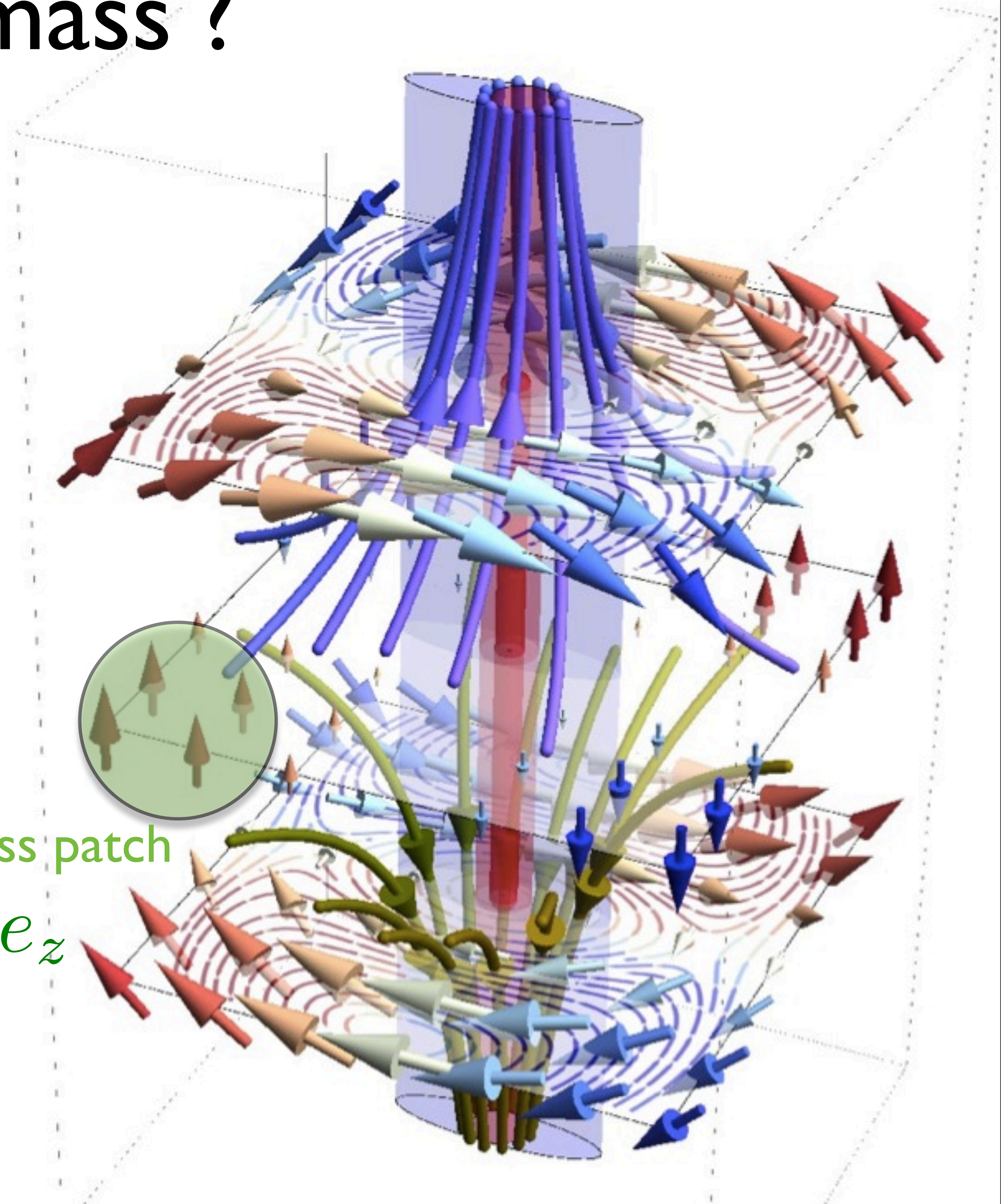

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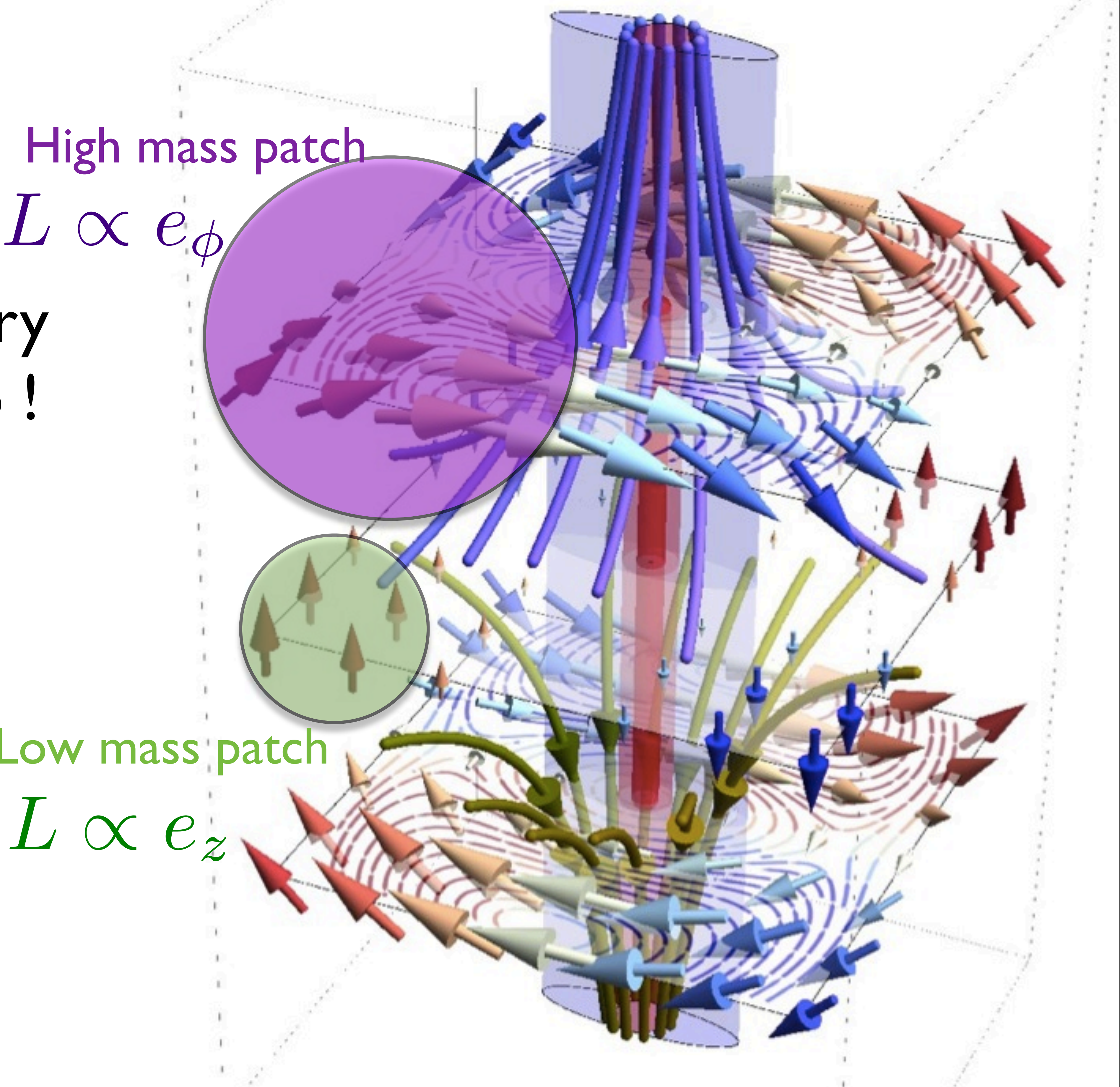


Geometry of the saddle provides **a natural 'metric'** (local frame as defined by Hessian @ saddle) relative to which **dynamical evolution** of DH is predicted.

Cloud in cloud effect

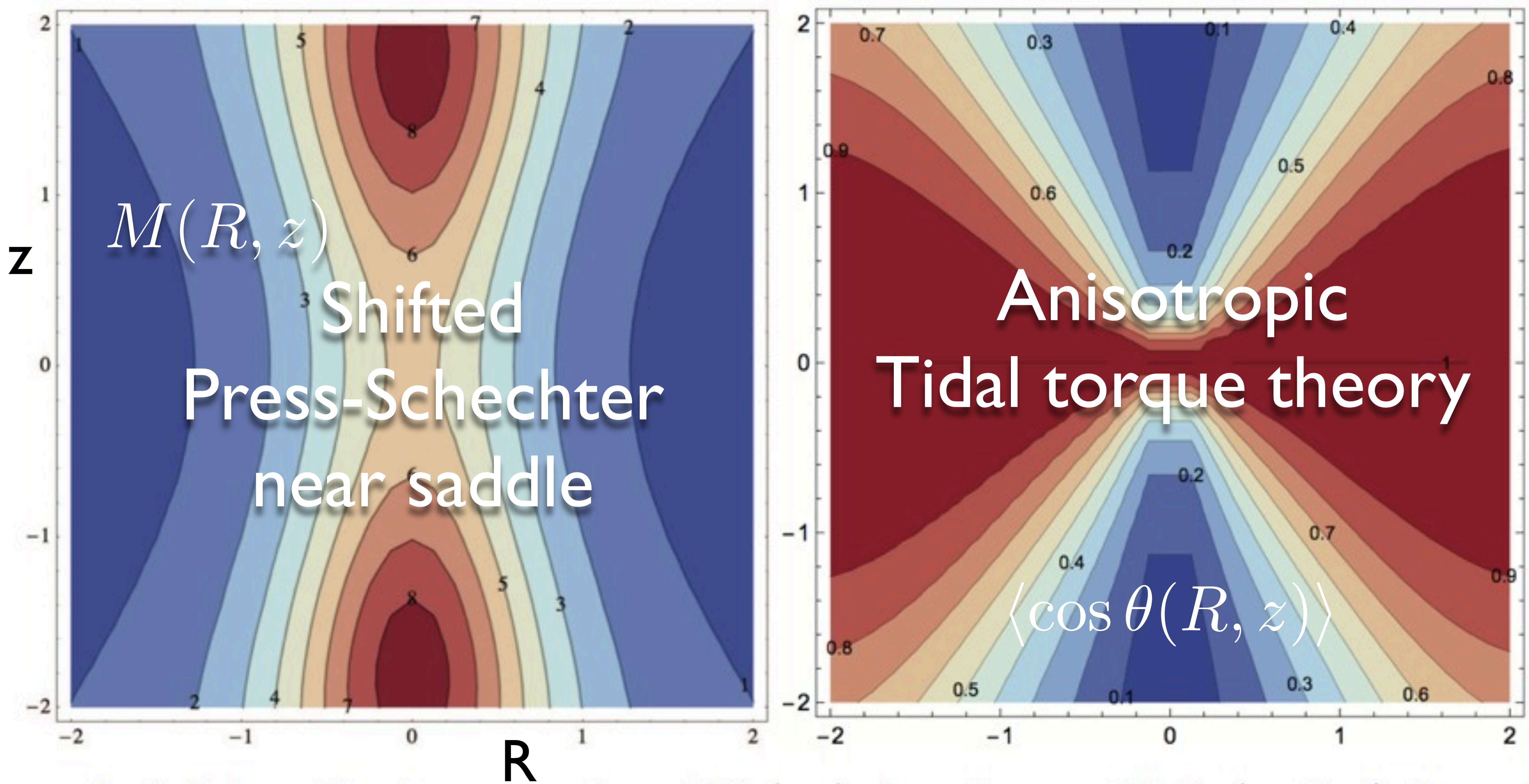


Figure 5. *Left:* logarithmic cross section of $M_p(r, z)$ along the most likely (vertical) filament (in units of $10^{12} M_\odot$). *Right:* corresponding cross section of $\langle \cos\hat{\theta} \rangle(r, z)$. The mass of halos increases towards the nodes, while the spin flips.

geometric split ⟶ mass split

Geometry of the saddle provides **a natural 'metric'** (local frame as defined by Hessian @ saddle) relative to which **dynamical evolution** of DH is predicted.

Cloud in cloud effect

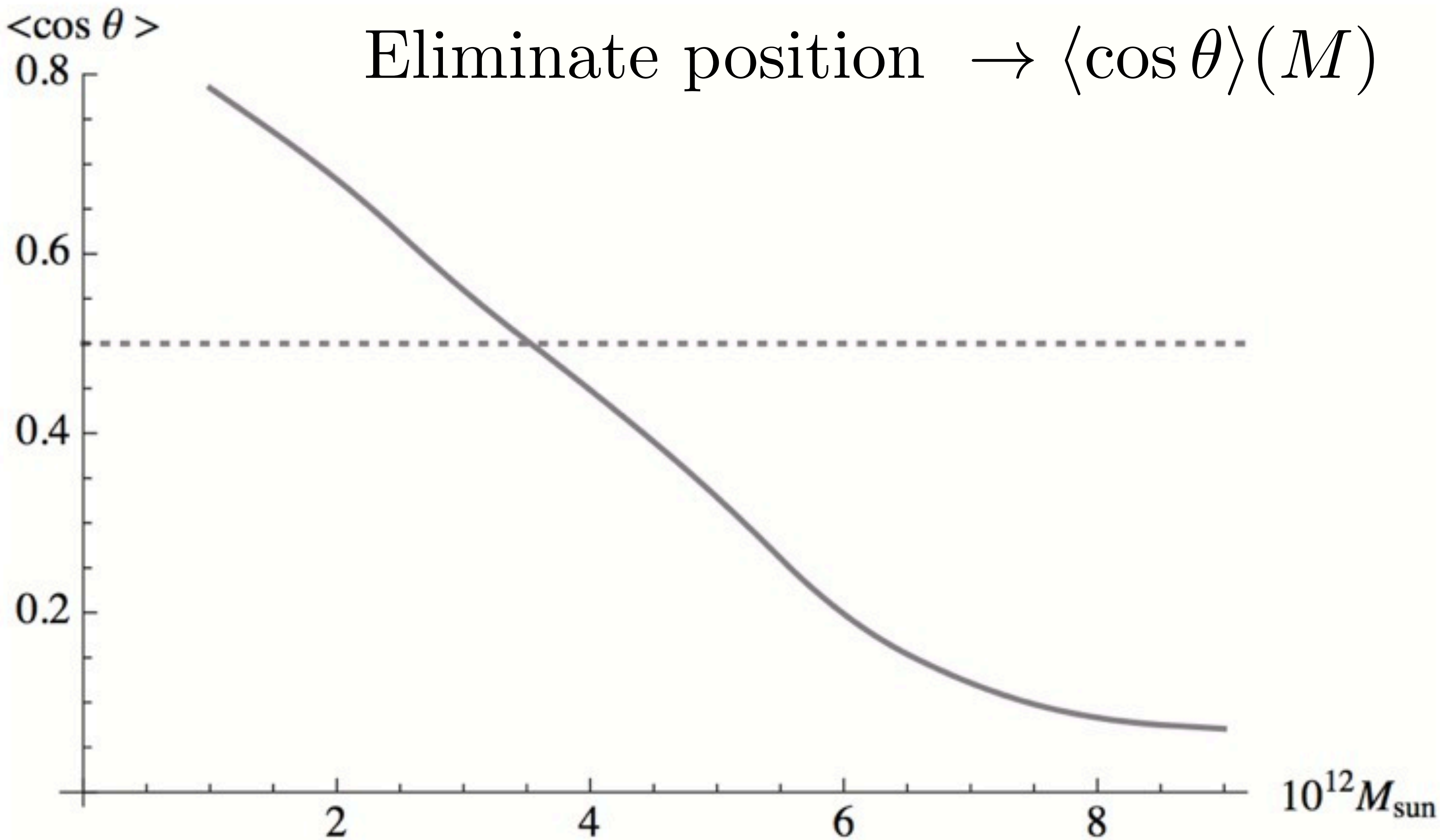
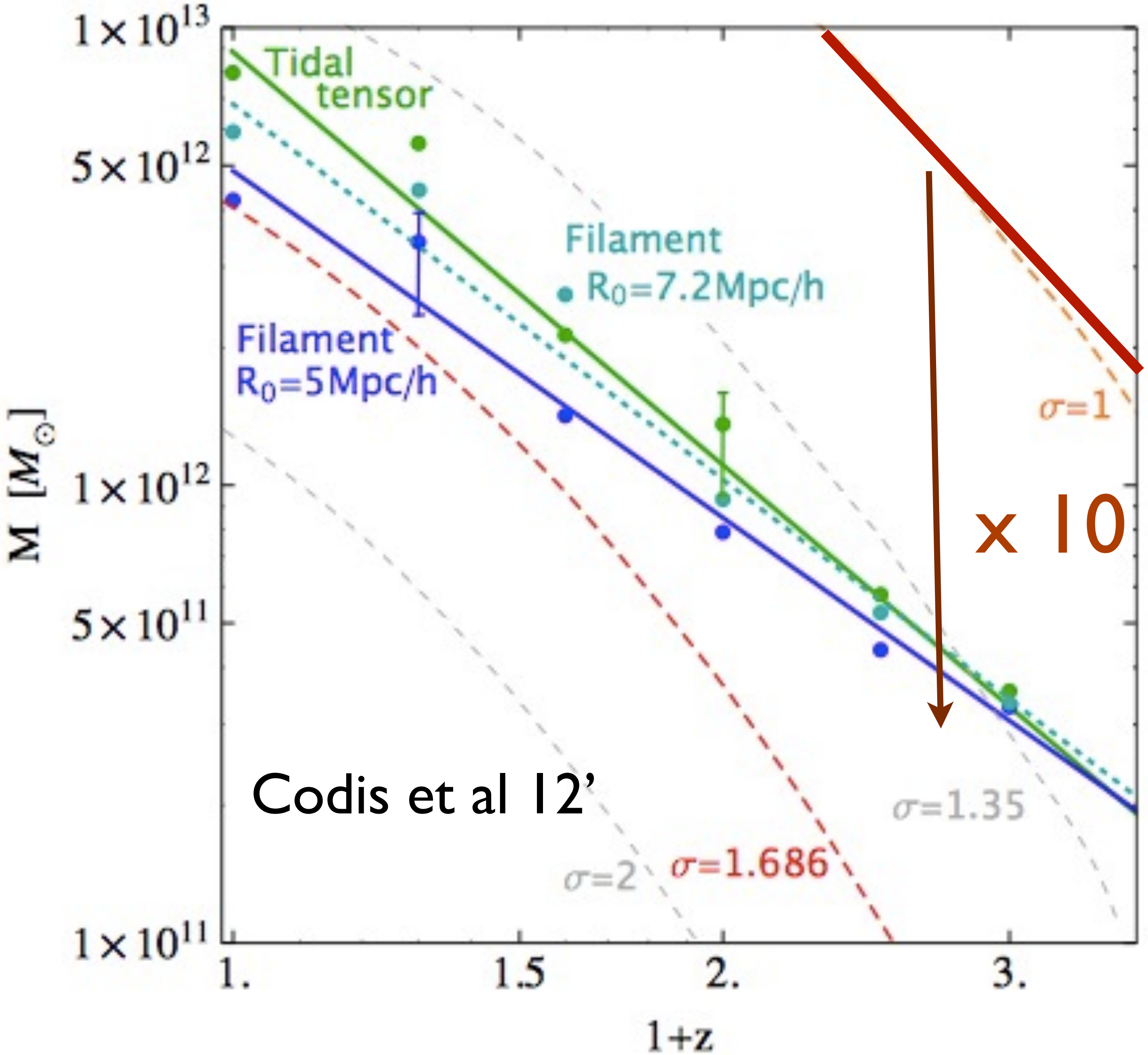


Figure 6. Mean alignment between spin and filament as a function of mass for a filament smoothing scale of 5 Mpc/h. The spin flip transition mass is around $4\,10^{12}\,M_\odot$.

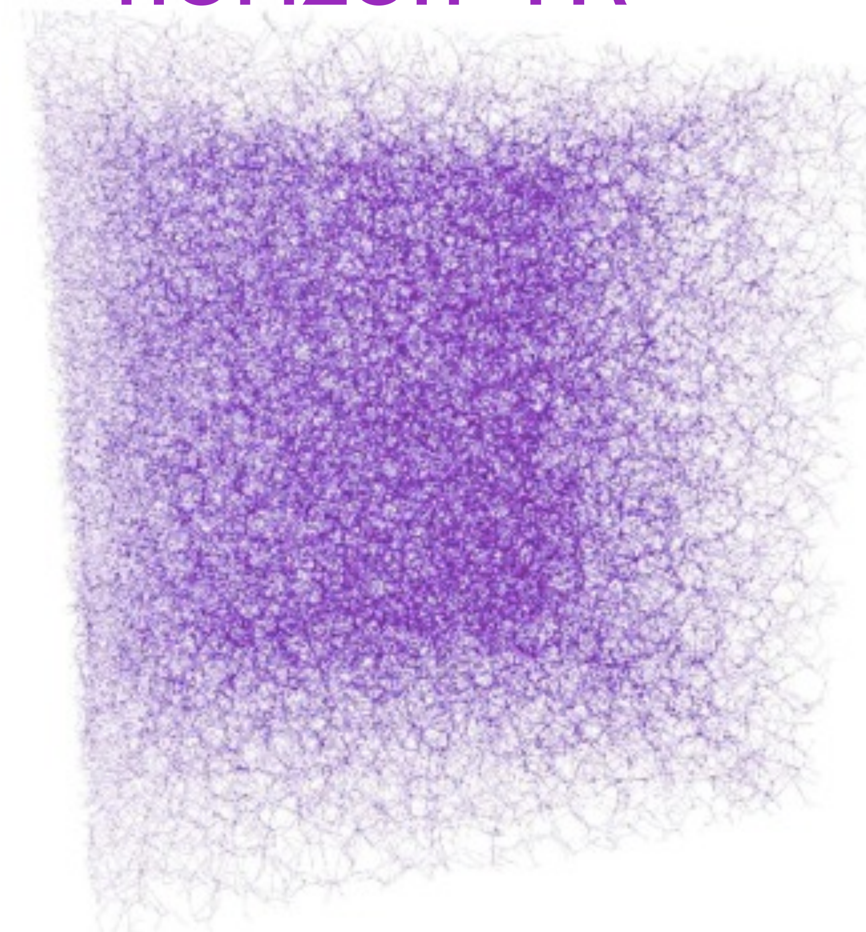
geometric split ⟶ mass split

Explain transition mass? YES!

Transition mass versus redshift



horizon 4π

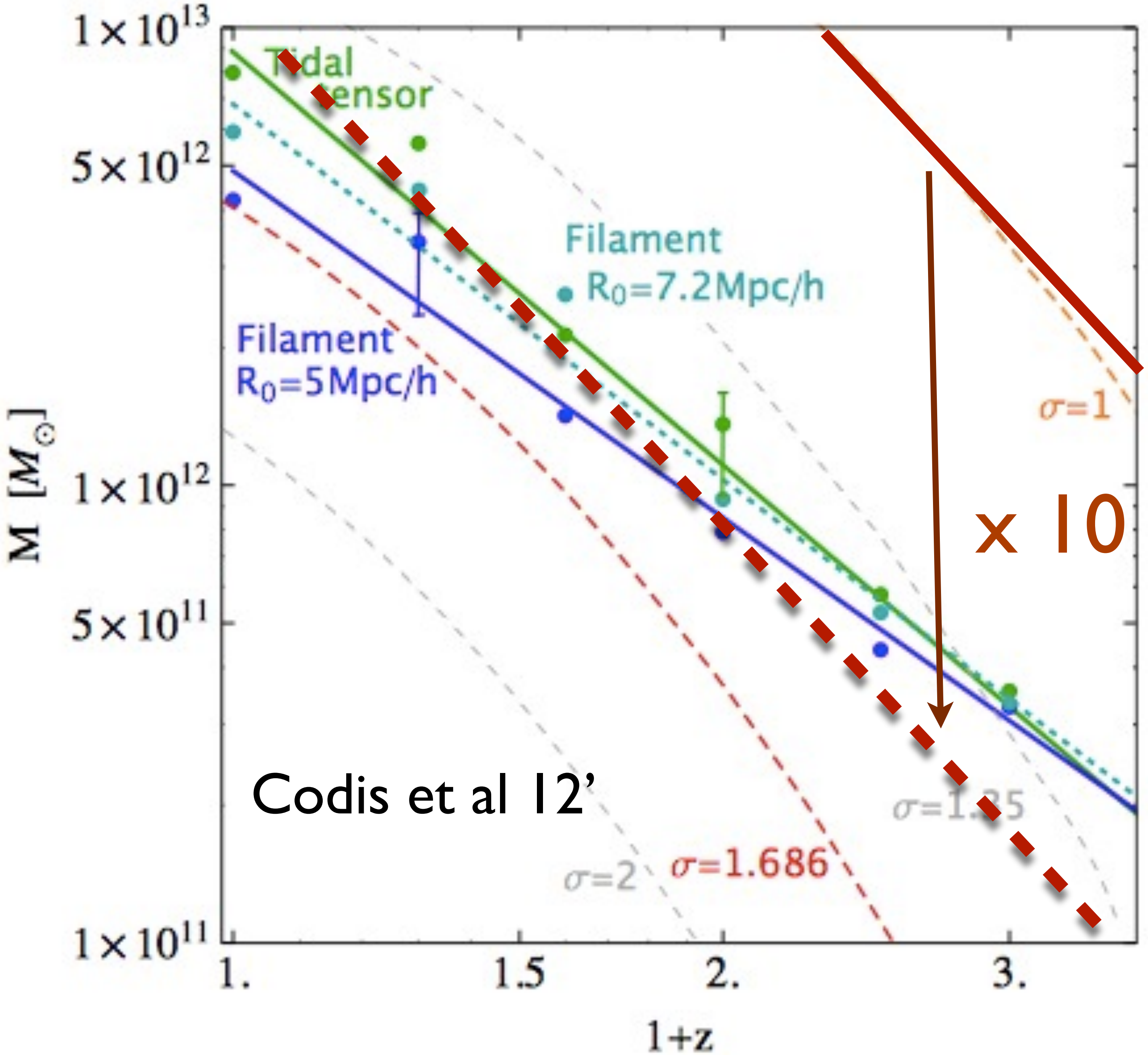


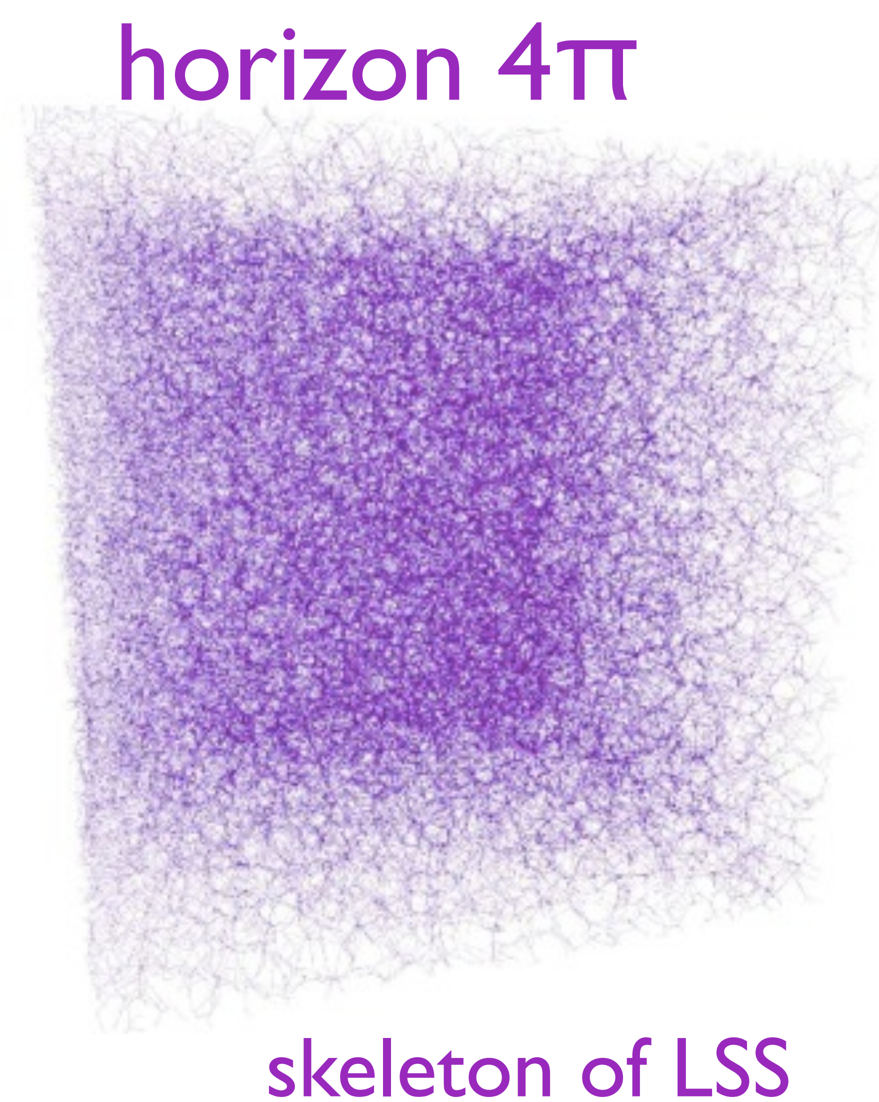
skeleton of LSS

Only 2 ***ingredients***: a) spin is spin one b) filaments flattened

Explain transition mass? YES!

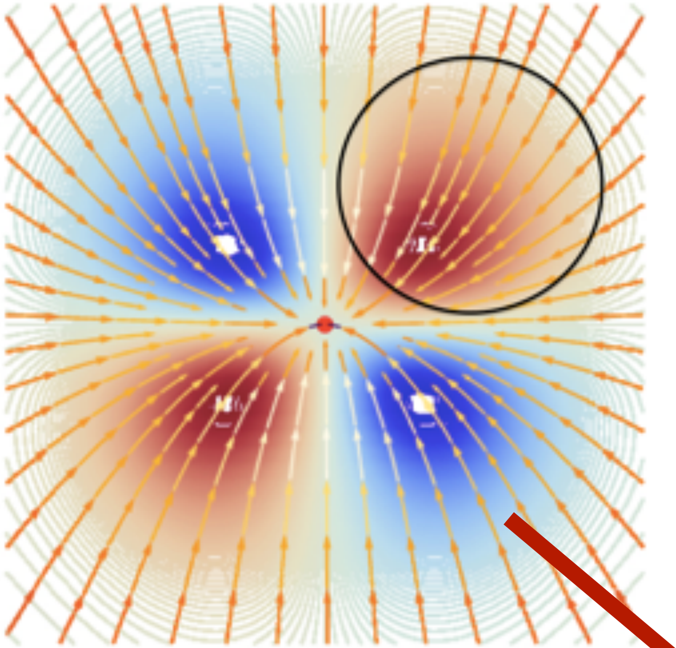
Transition mass versus redshift



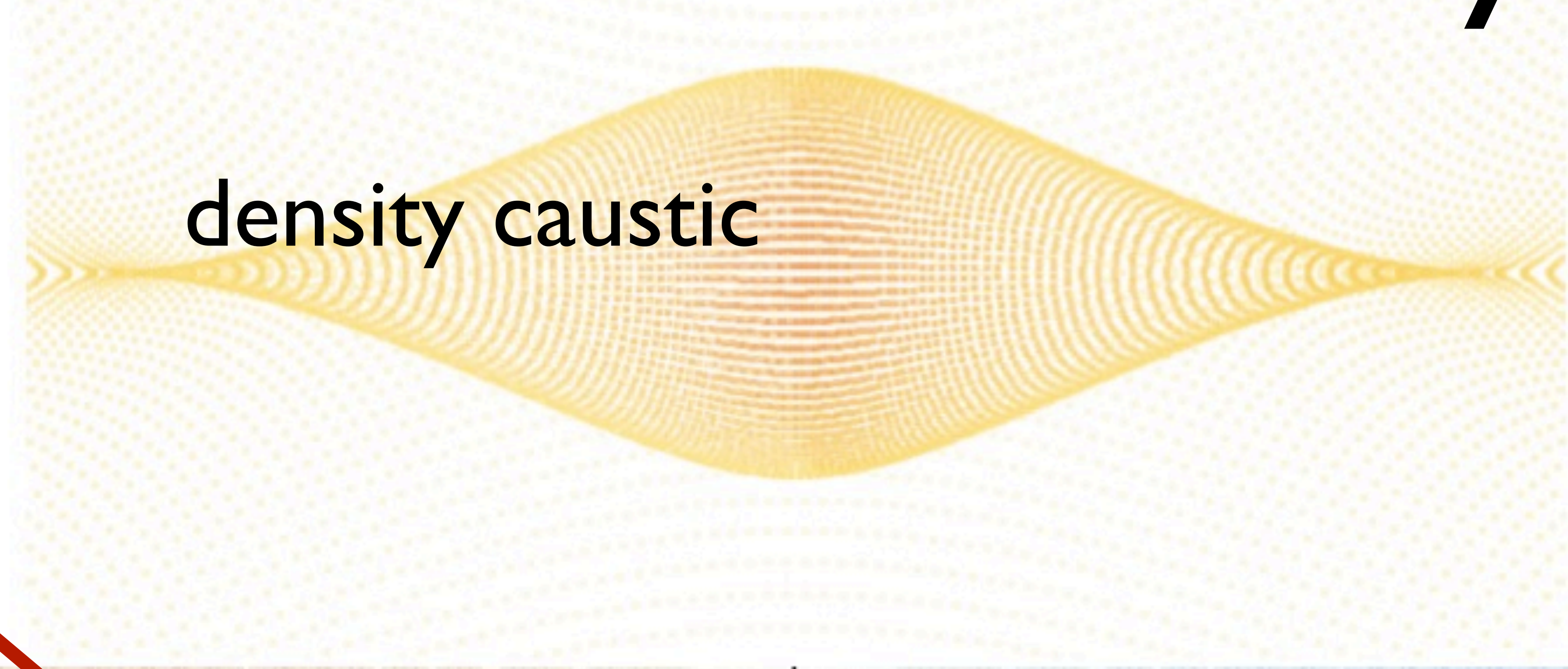


Only 2 ***ingredients***: a) spin is spin one b) filaments flattened

Link with Eulerian vorticity?

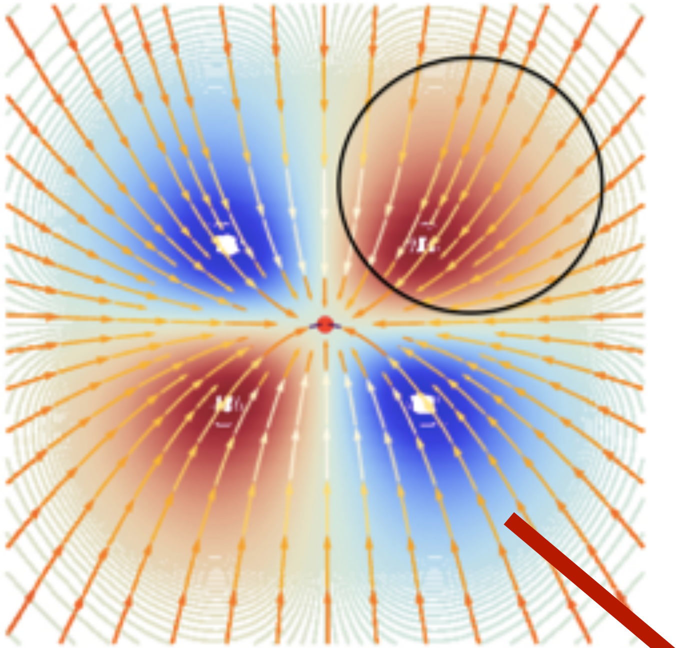


AM Lagragian
map

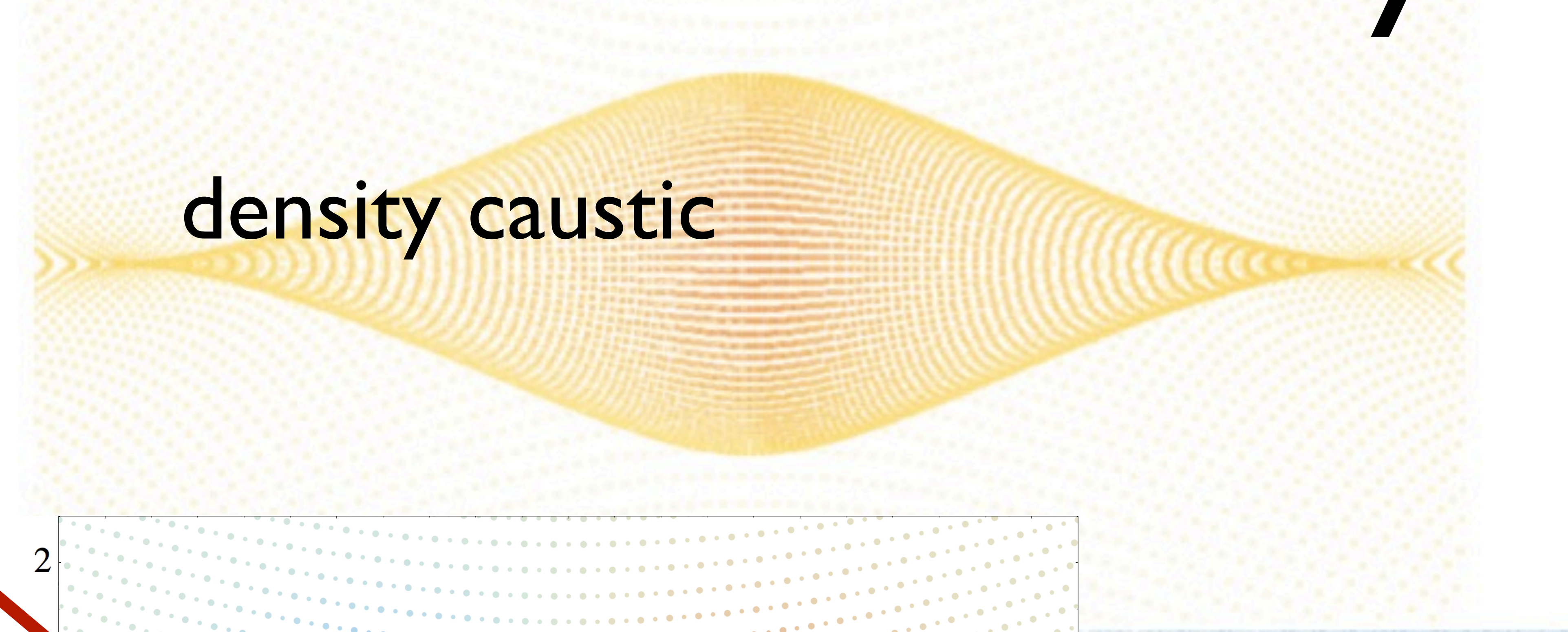


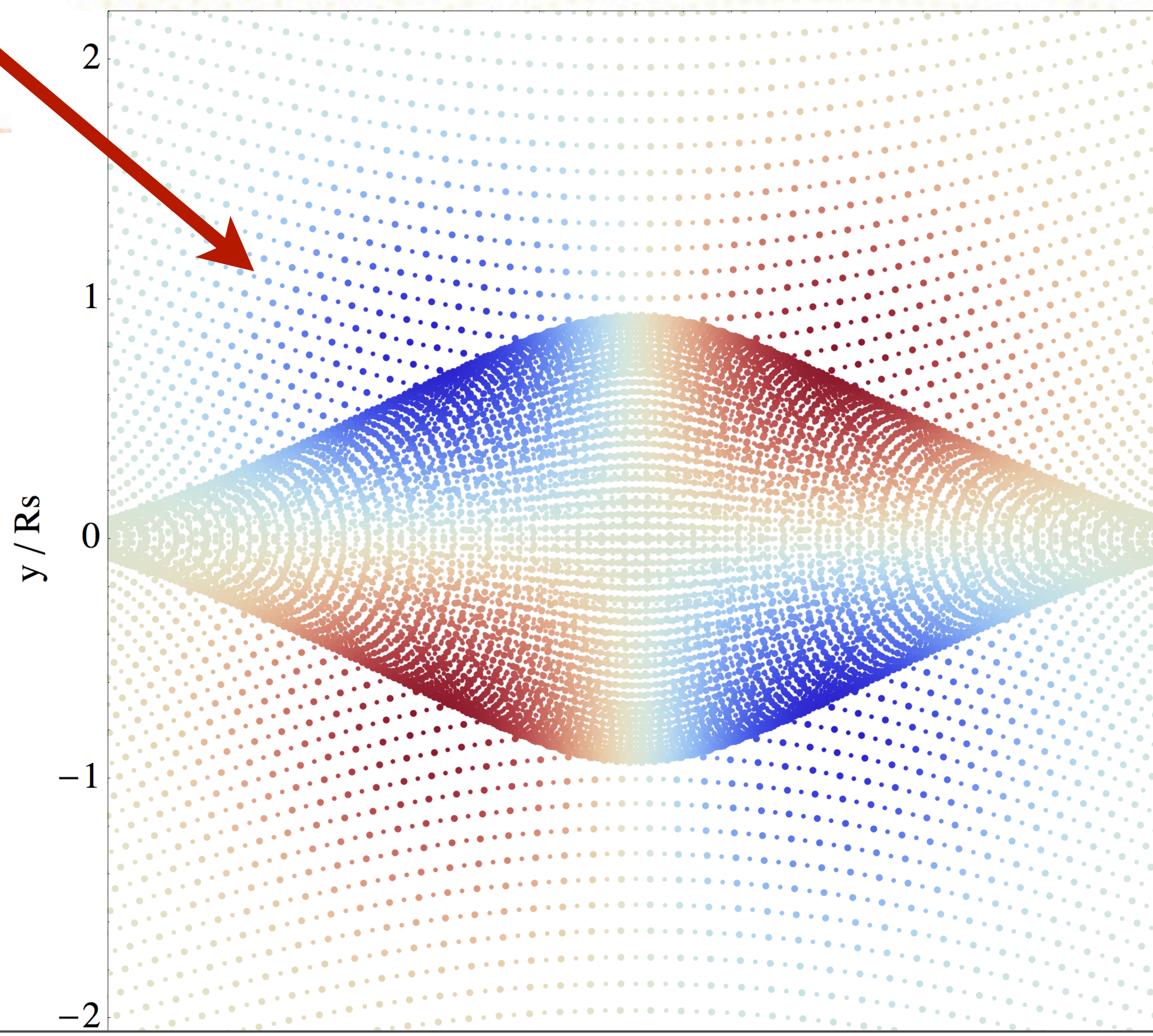
AM
Eulerian map

Link with Eulerian vorticity?



AM Lagragian map



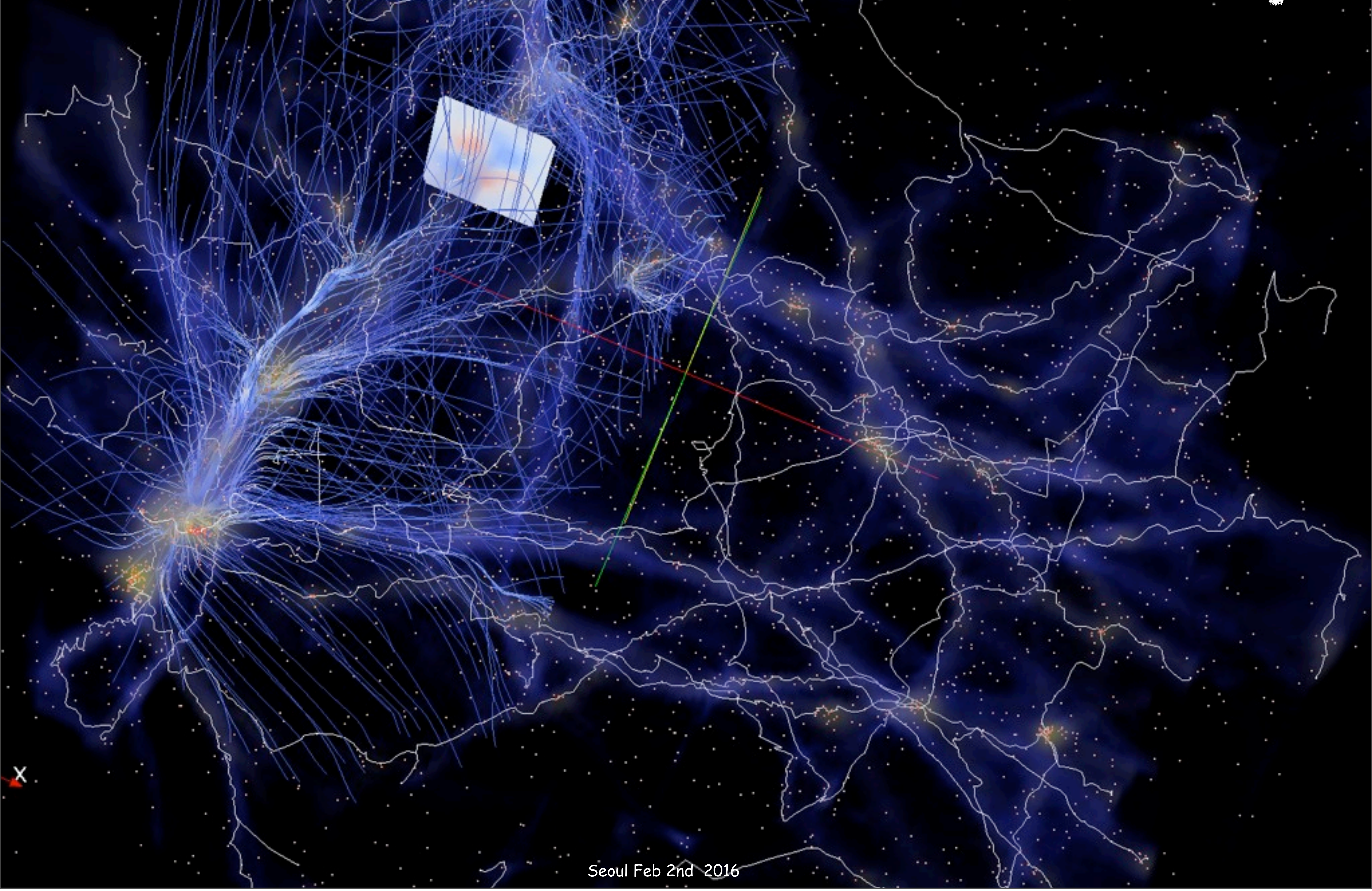


AM Eulerian map

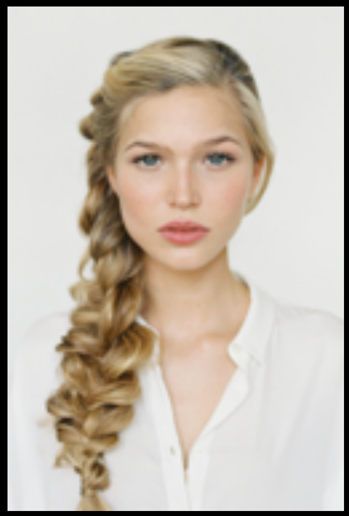
PART III

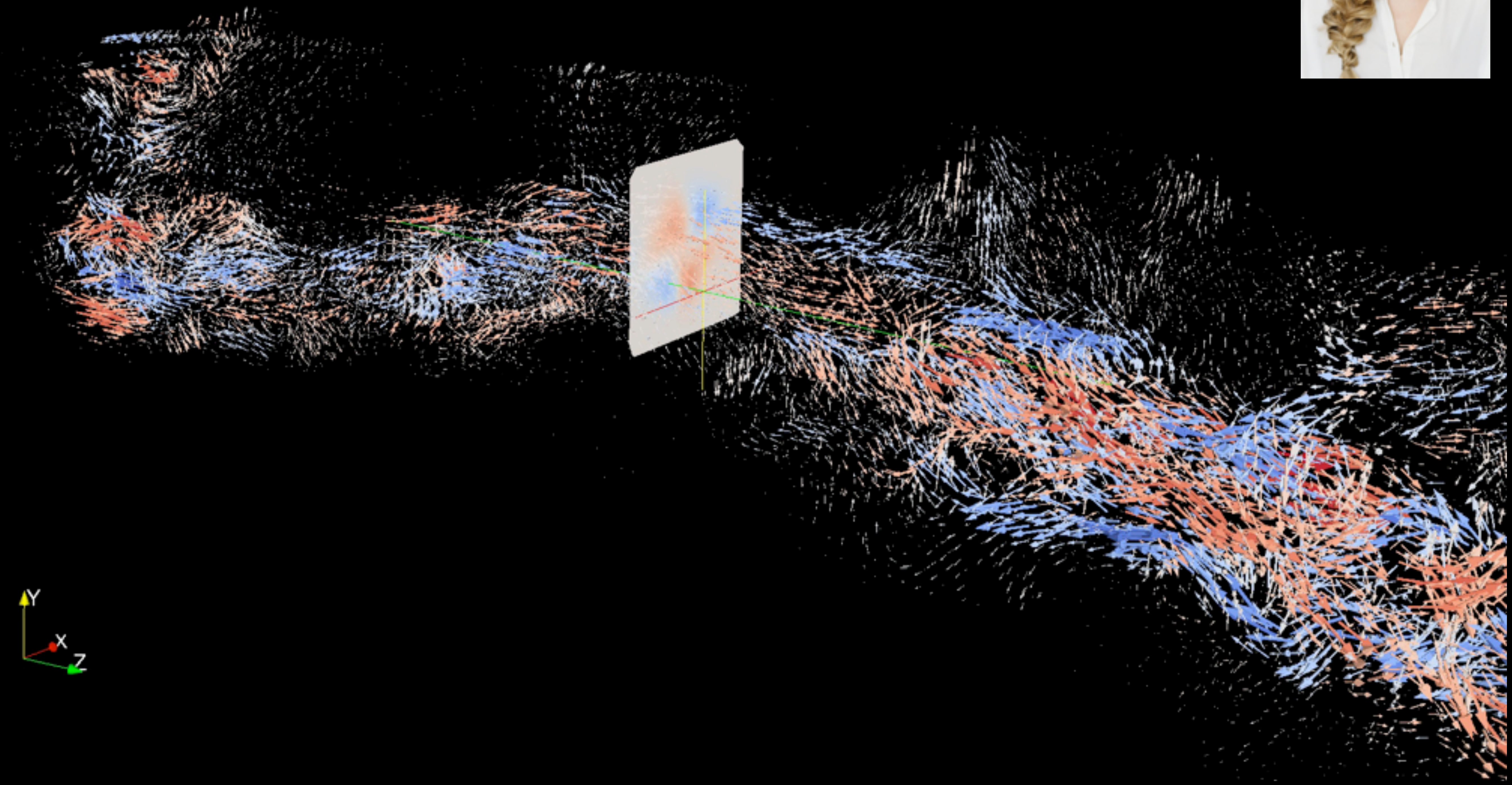
Link with Eulerian vorticity?

Back to wall winding : generation of vorticity



Alignement of vorticity with cosmic web



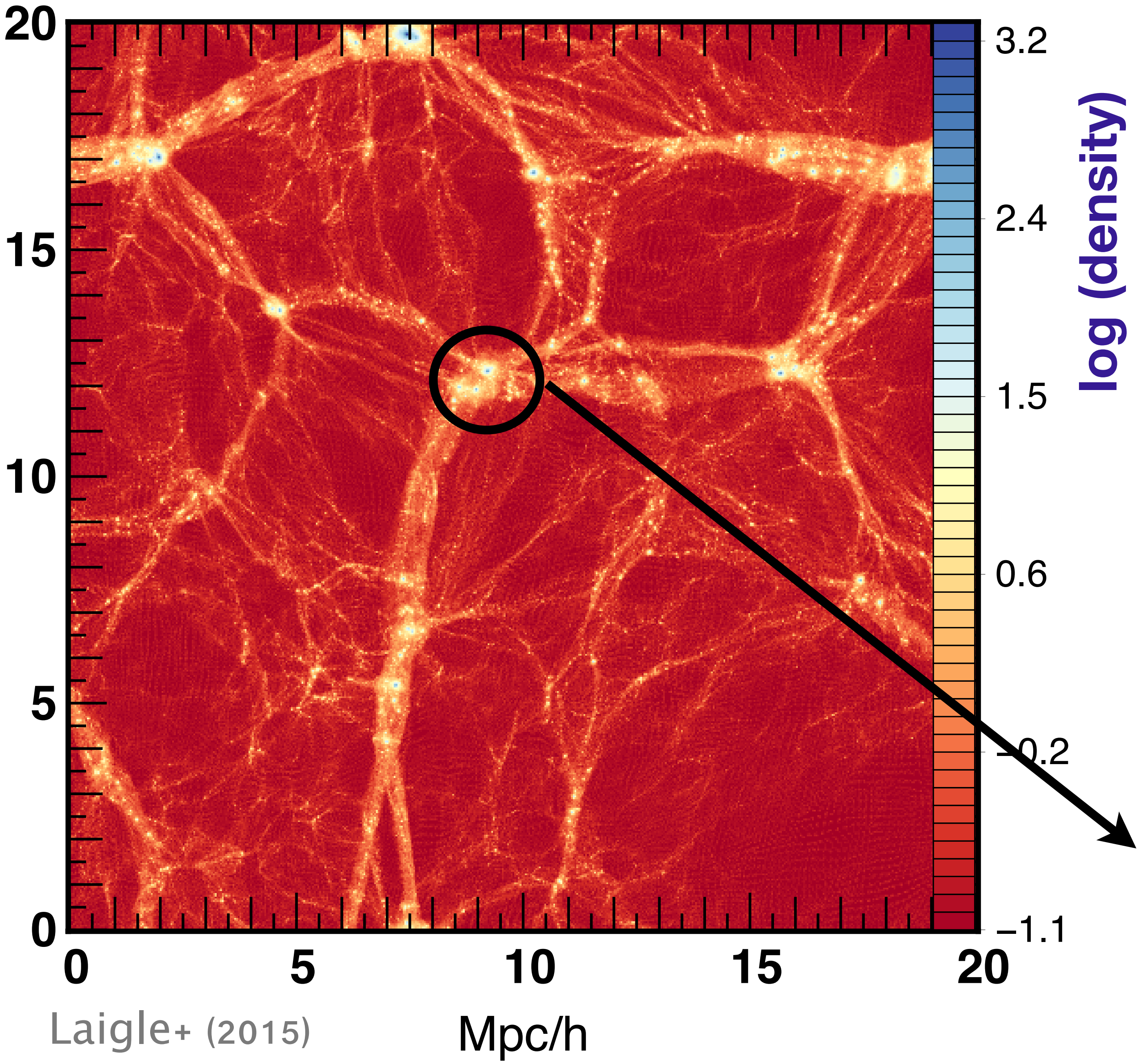


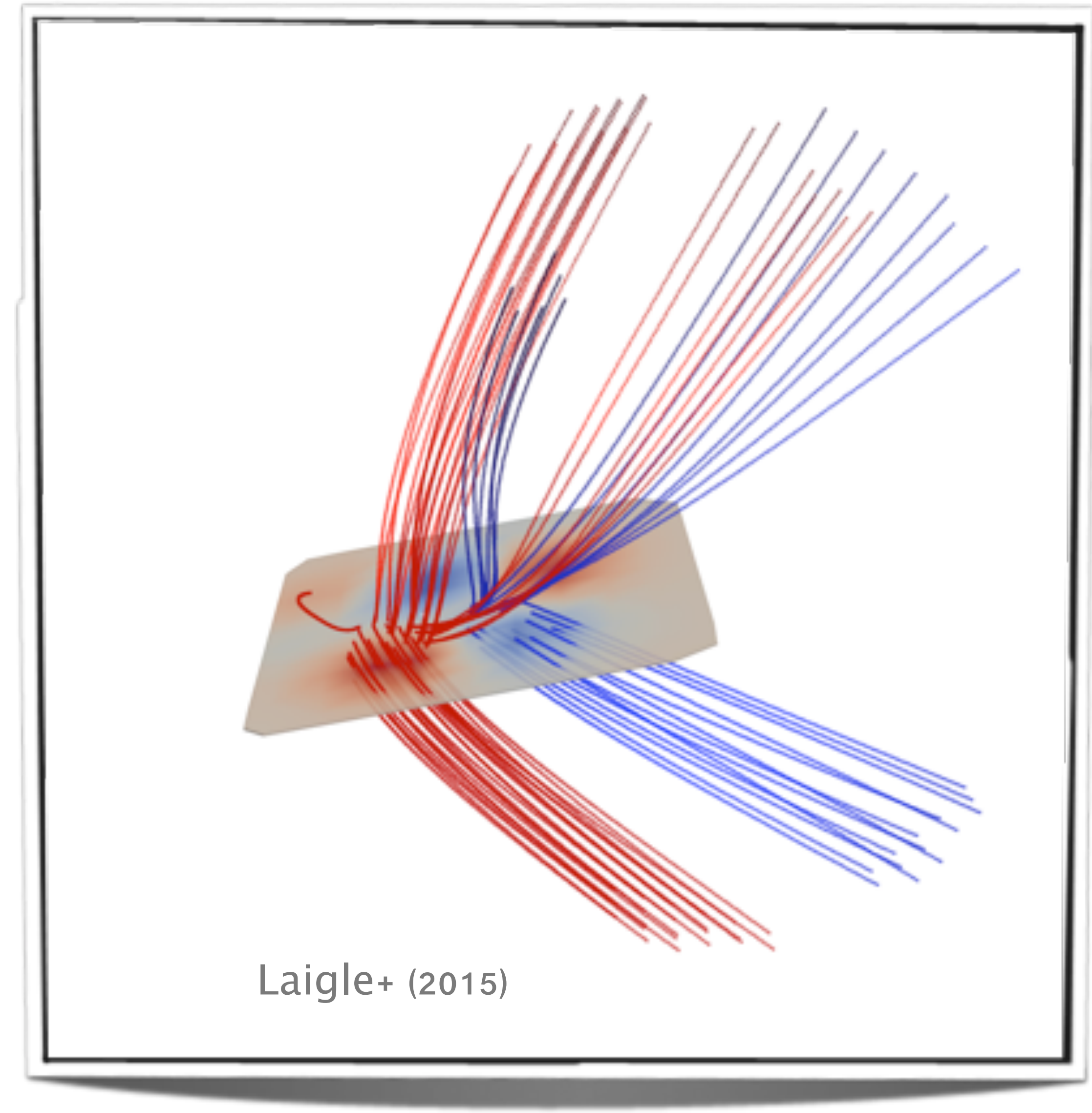
braids structure of vorticity.

Growth of large-scale structure

In the initial phase of structure formation, **flows are laminar and curl-free.**
This is no longer valid **at the shell-crossing.**

Thin slice of a DM simulation at z=0.



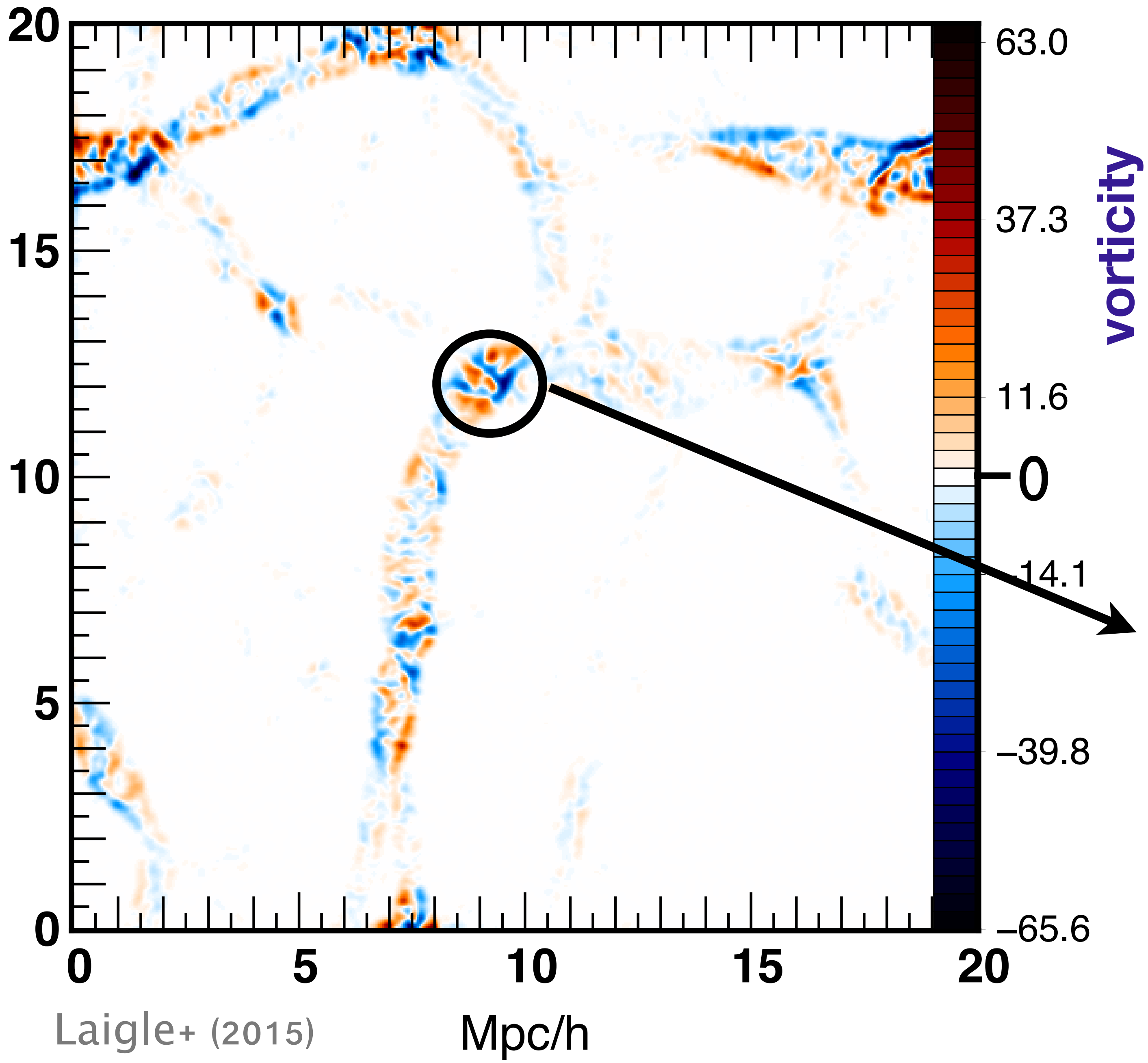


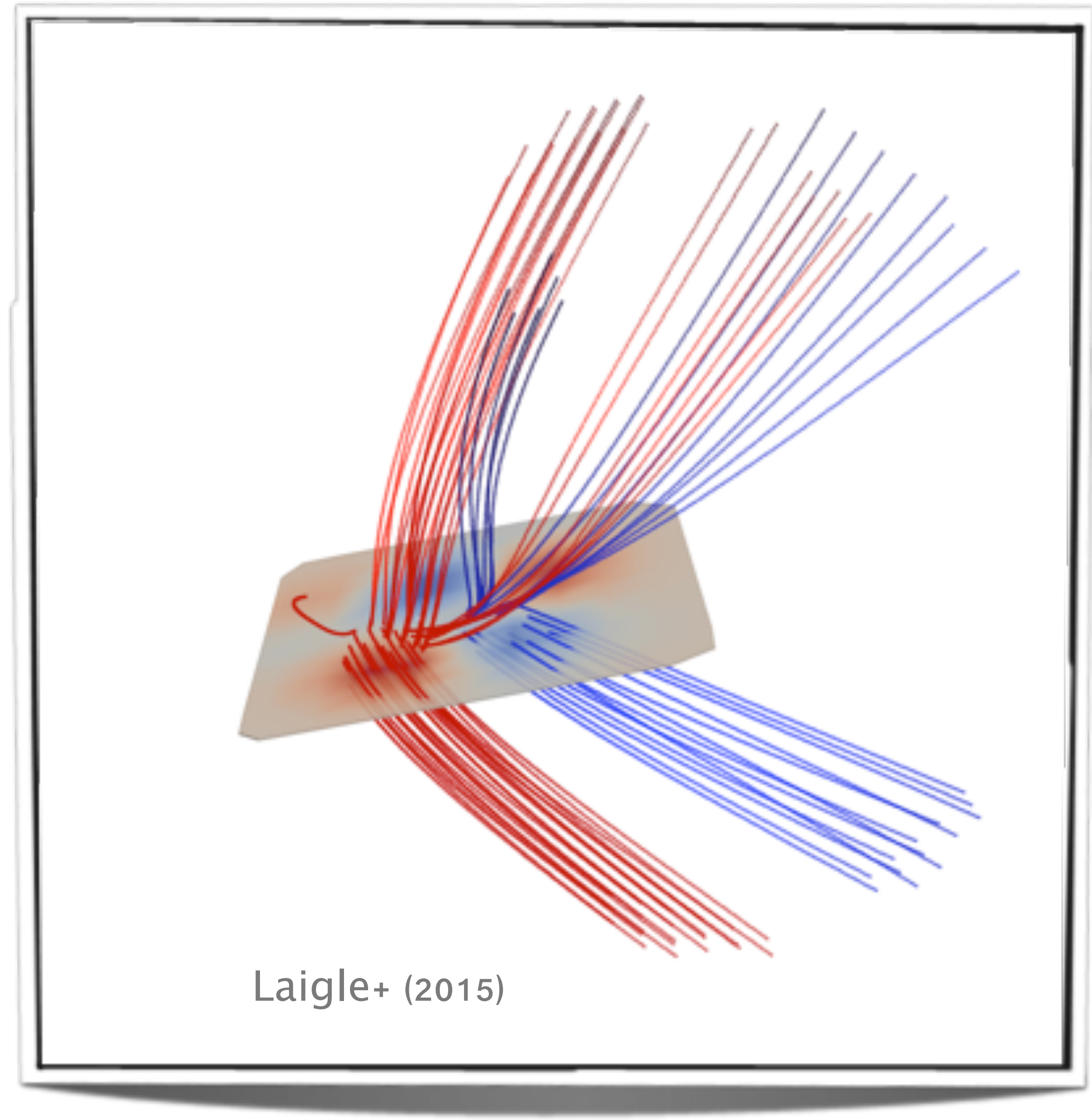
What happens when cosmic flows cross?

Vorticity generation

In the initial phase of structure formation, **flows are laminar and curl-free.**
This is no longer valid **at the shell-crossing.**

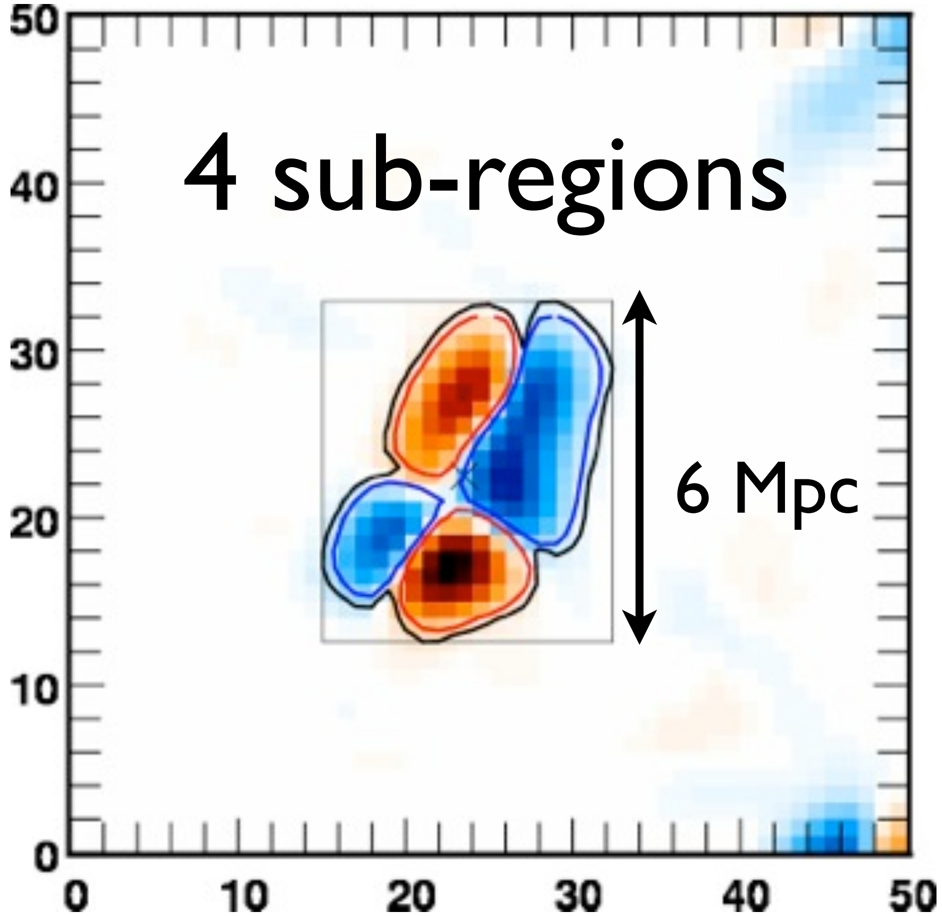
Thin slice of a DM simulation at z=0.

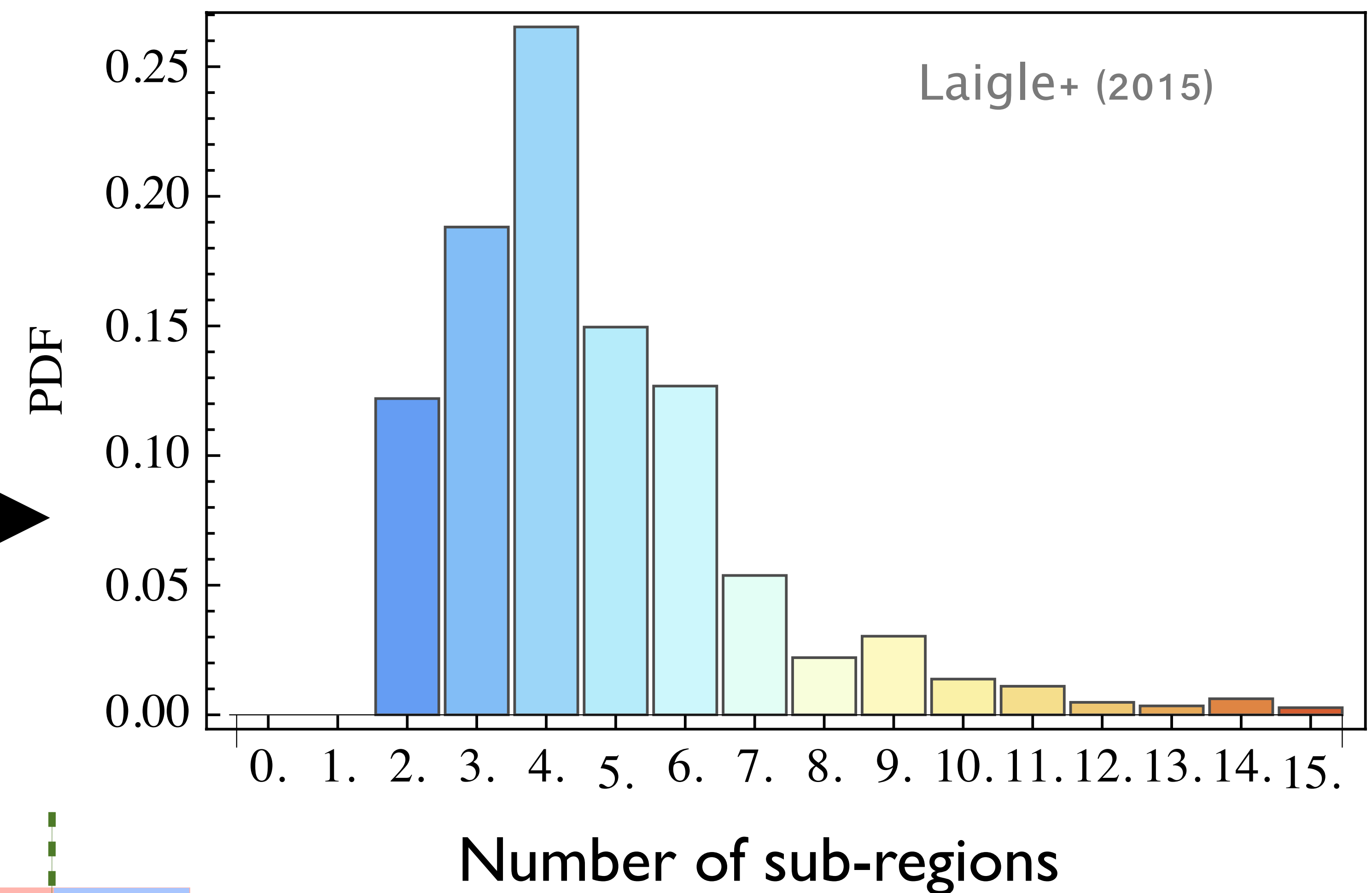


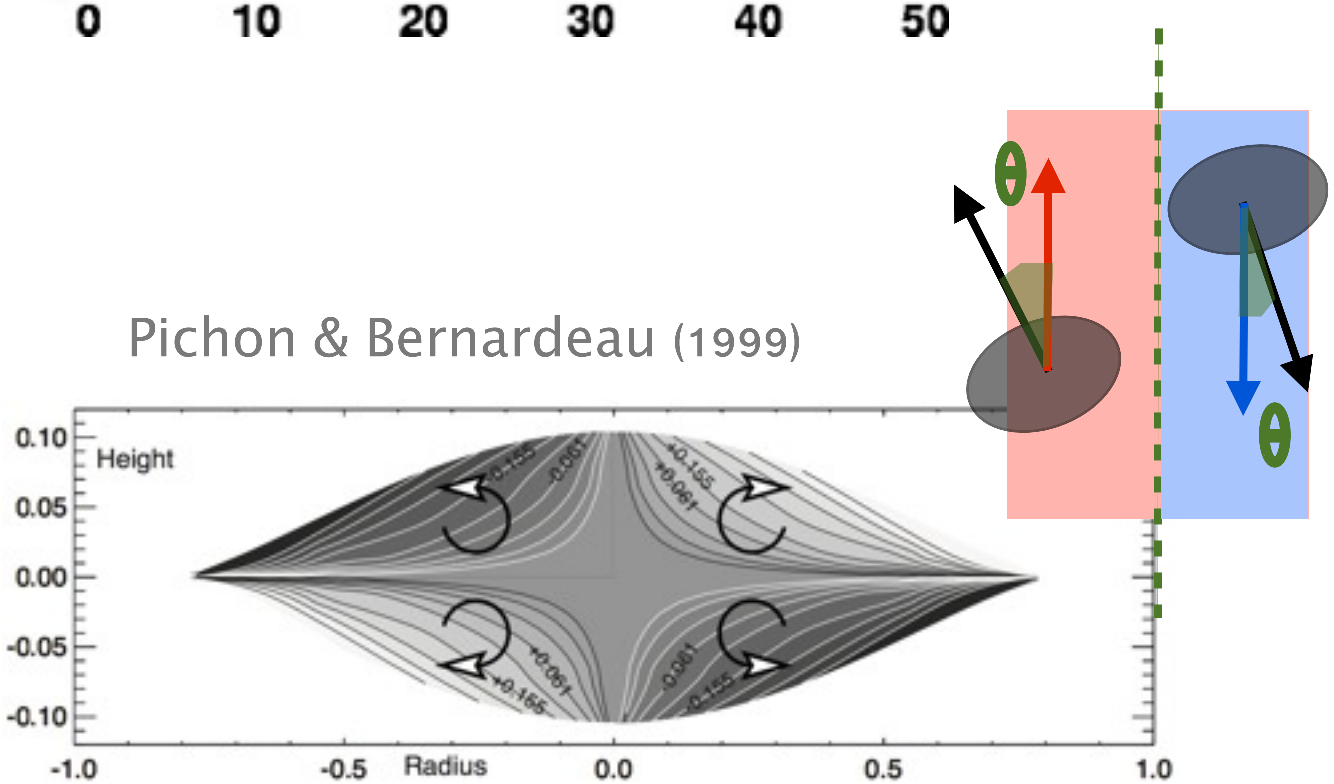


Vorticity is generated and is confined in the filaments.

Geometry of the vorticity cross-section



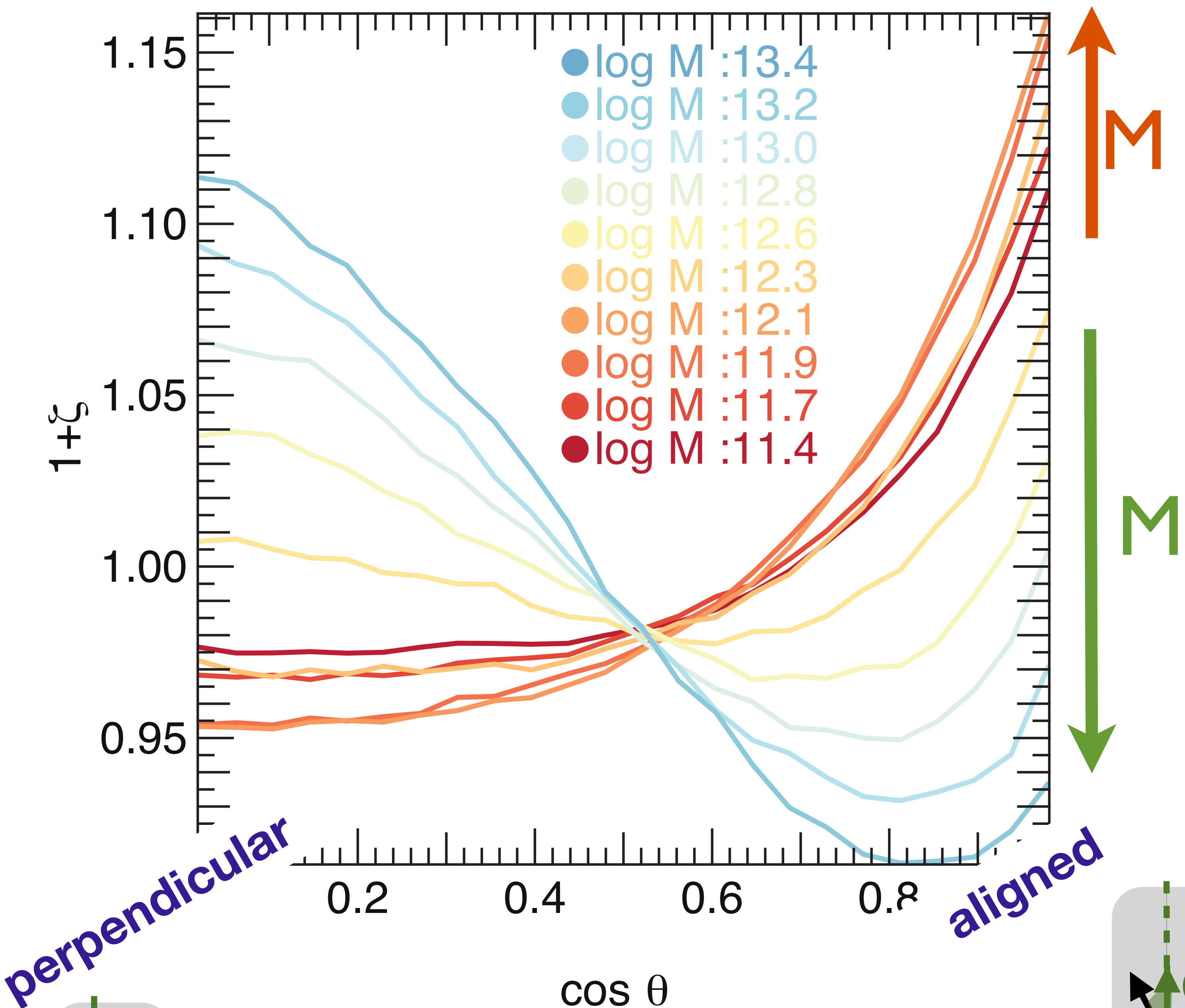




Cross-sections are typically divided in 4 quadrants.

Theoretical prediction from Pichon & Bernardeau 1999

Mass dependent Halo spin - filament alignment



- $M_{halo} < M_{crit}$
  alignment of halo spin with filament increases with mass.

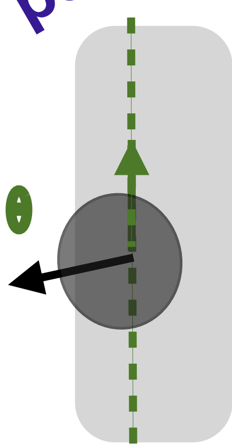
Why?

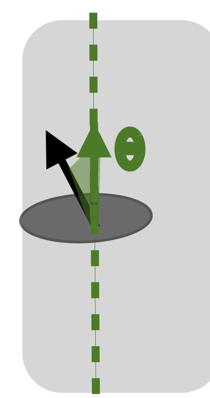
- M_{crit}

When?

- $M_{halo} > M_{crit}$
  halo spin tends to be perpendicular to the filament.

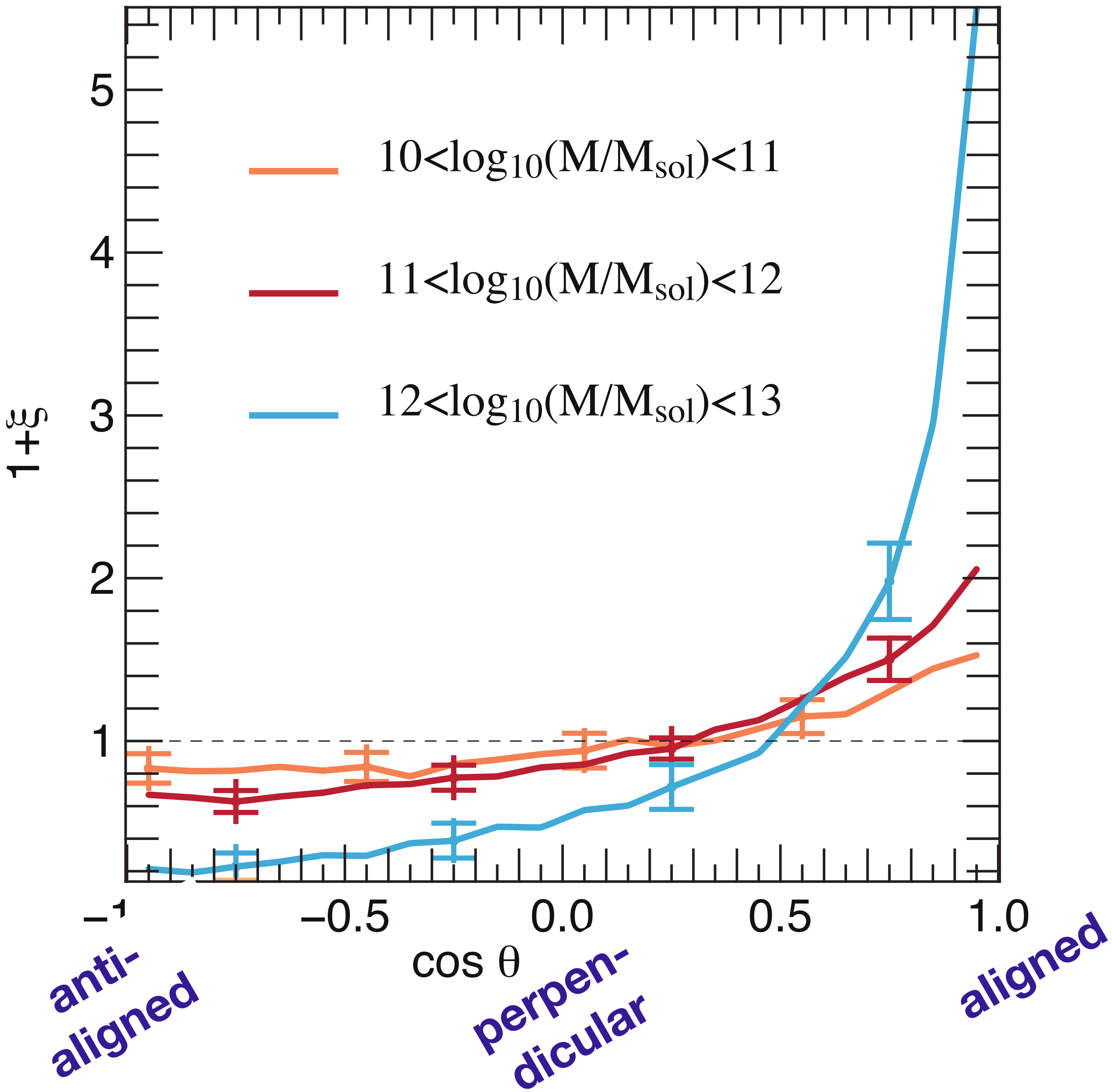
Why?

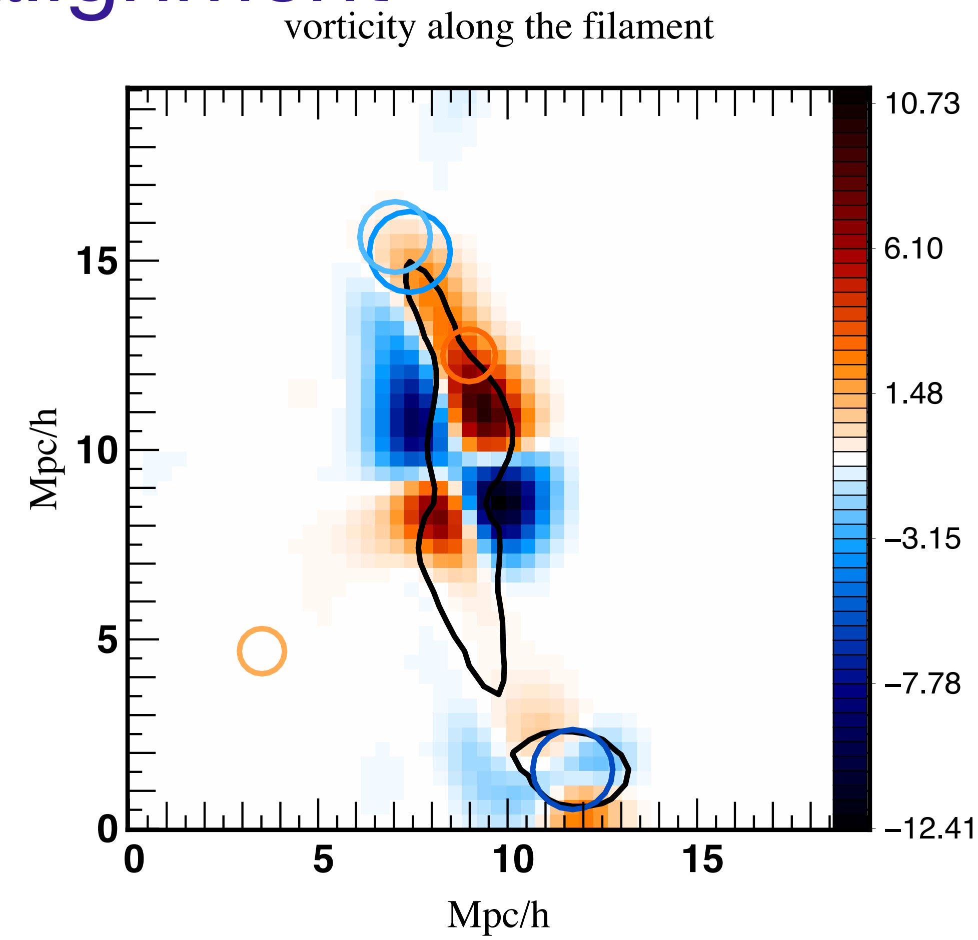


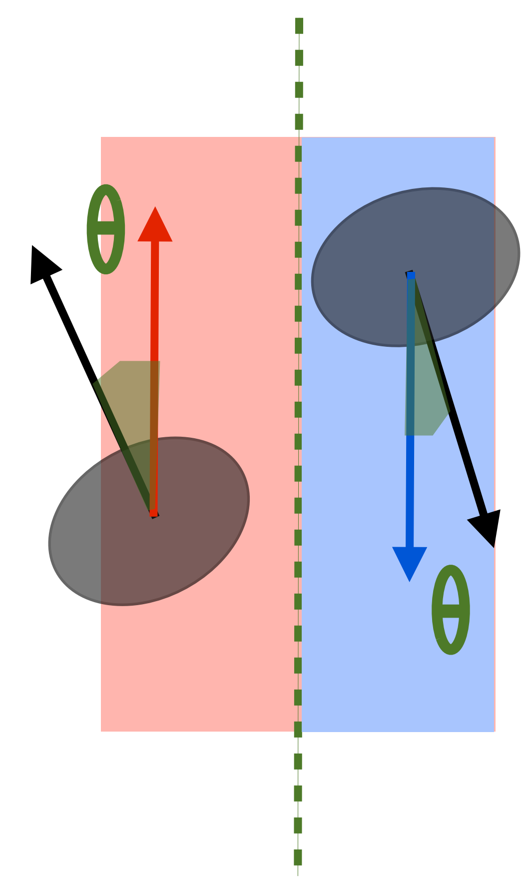


Laigle+ (2015)
in DM simulation (10^5 haloes)

Halo-spin vorticity alignment

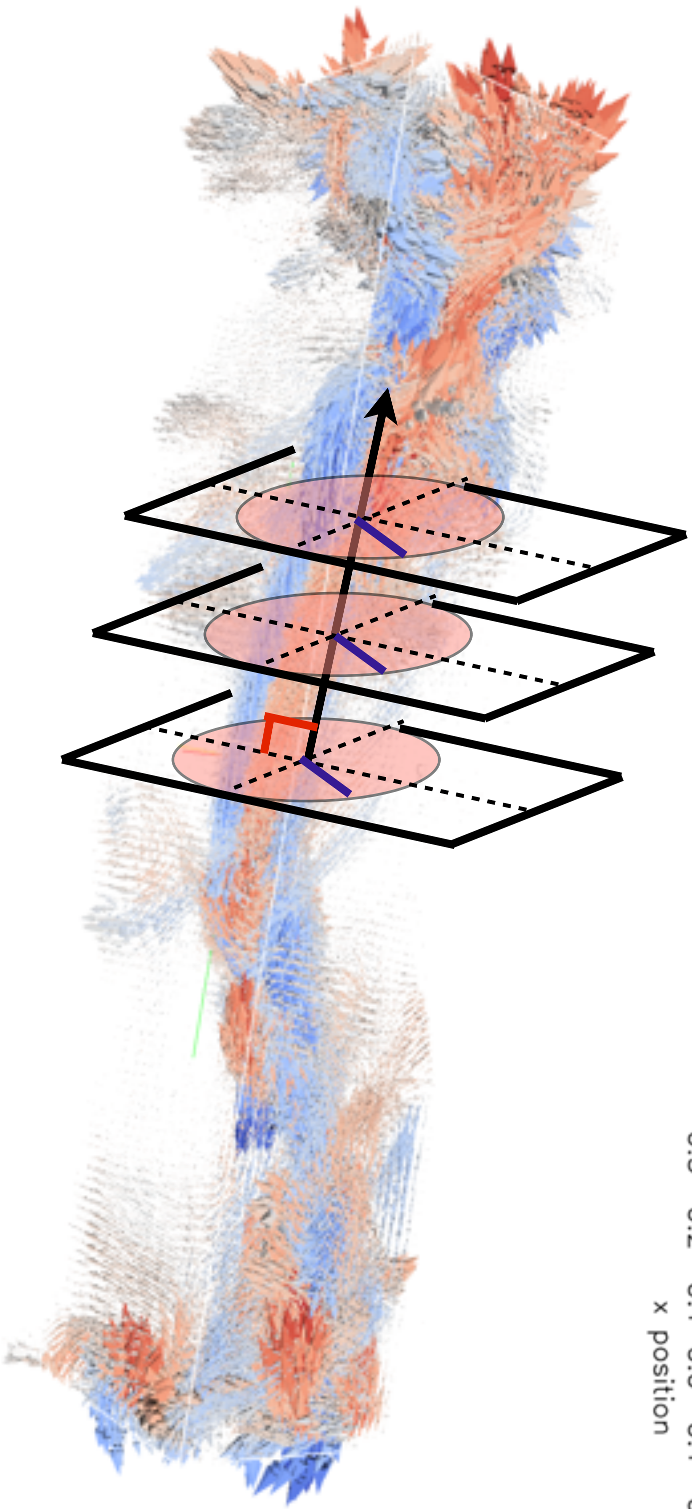




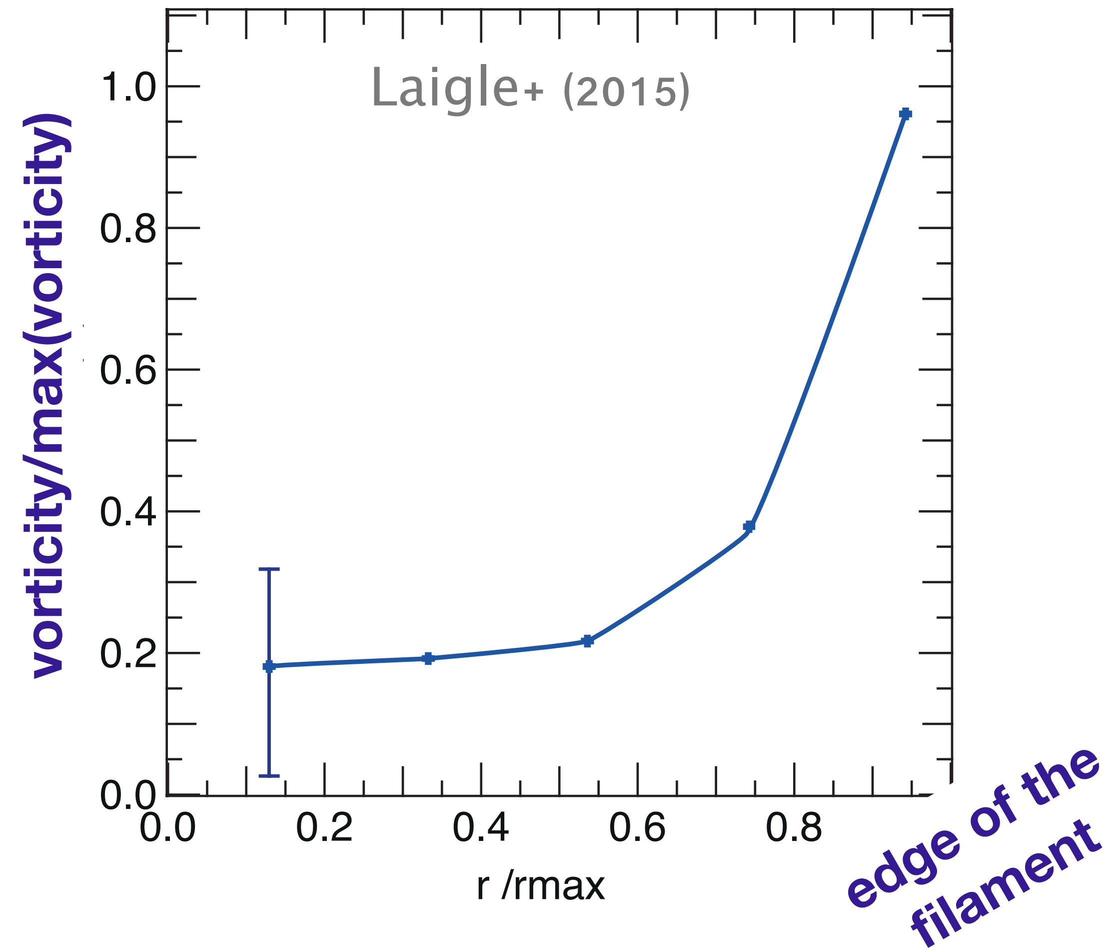


Halo spins are aligned with the vorticity in quadrants.

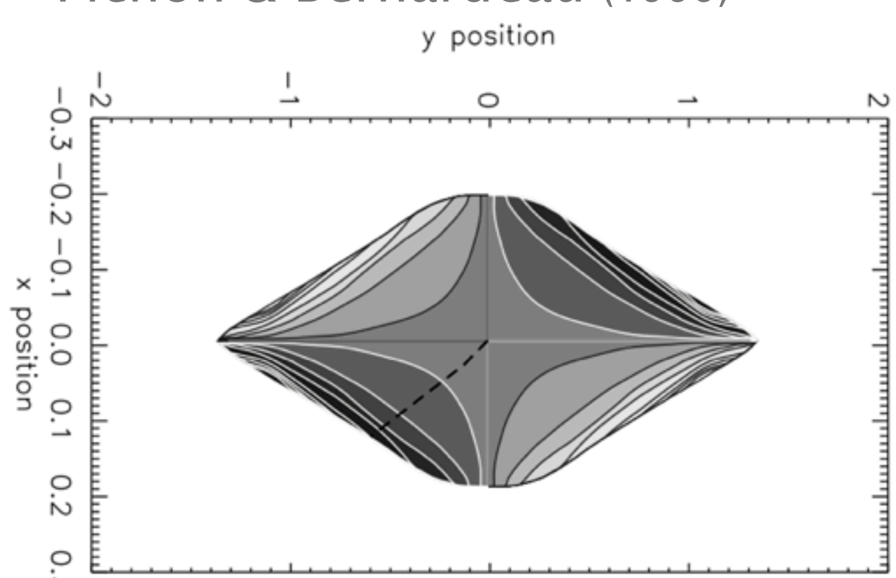
Geometry of the vorticity cross-section

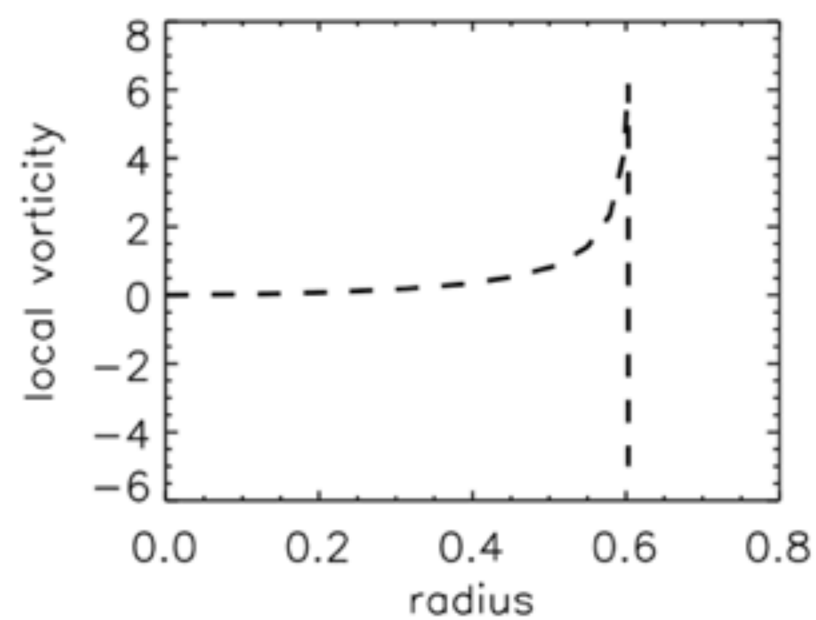


Stacked profile



Pichon & Bernardeau (1999)

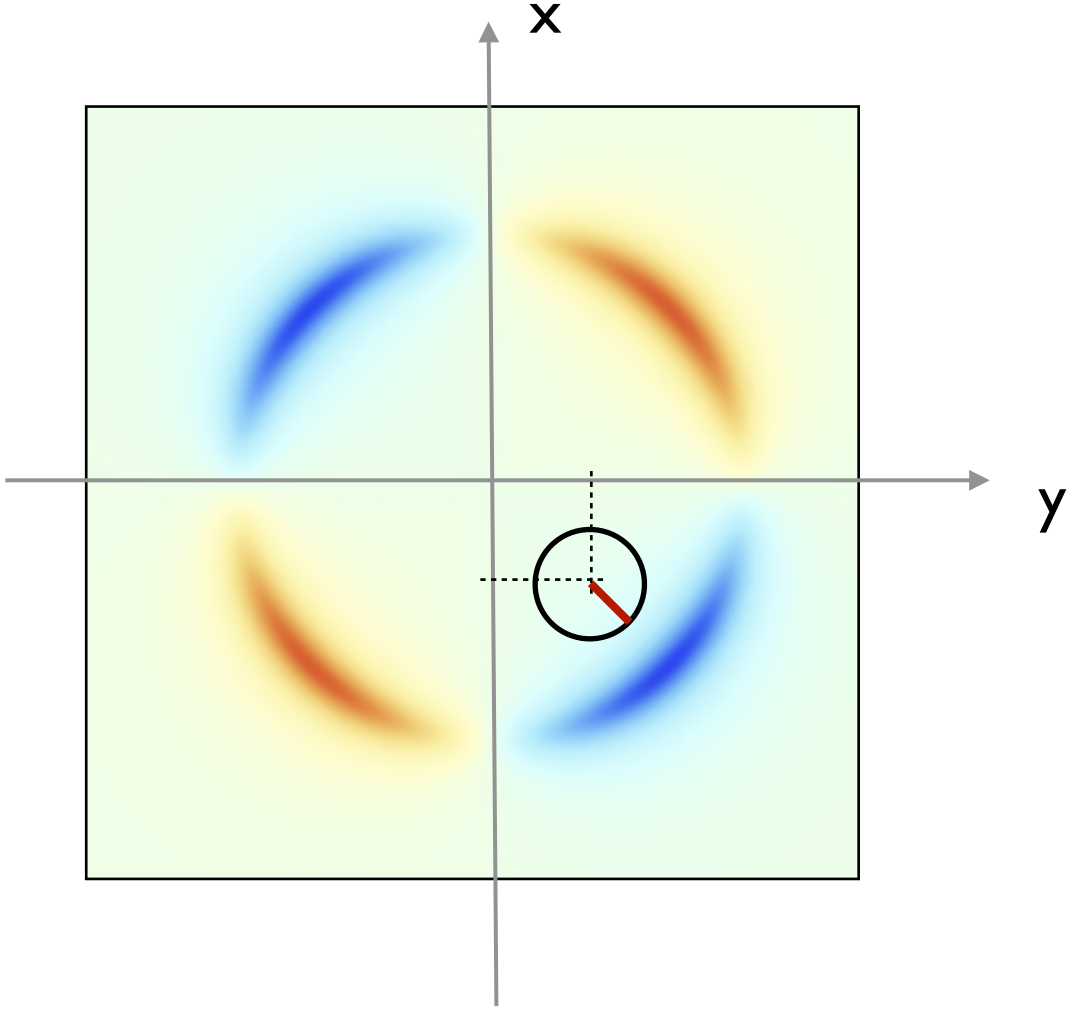


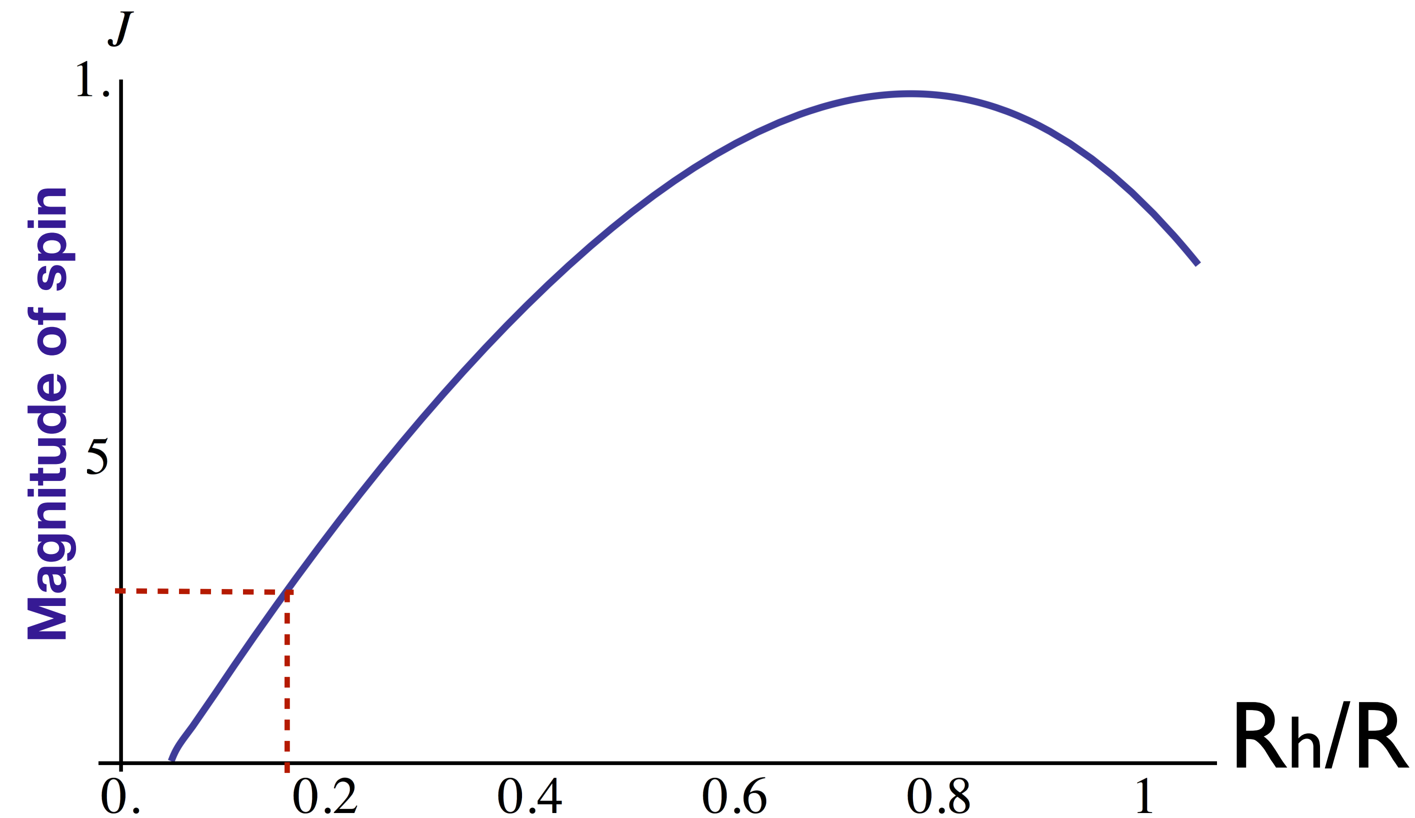


High vorticity regions are located at the edges of the filament.

Mass transition for spin alignment

Idealized **toy model**: The position is fixed and the radius of the halo increases:

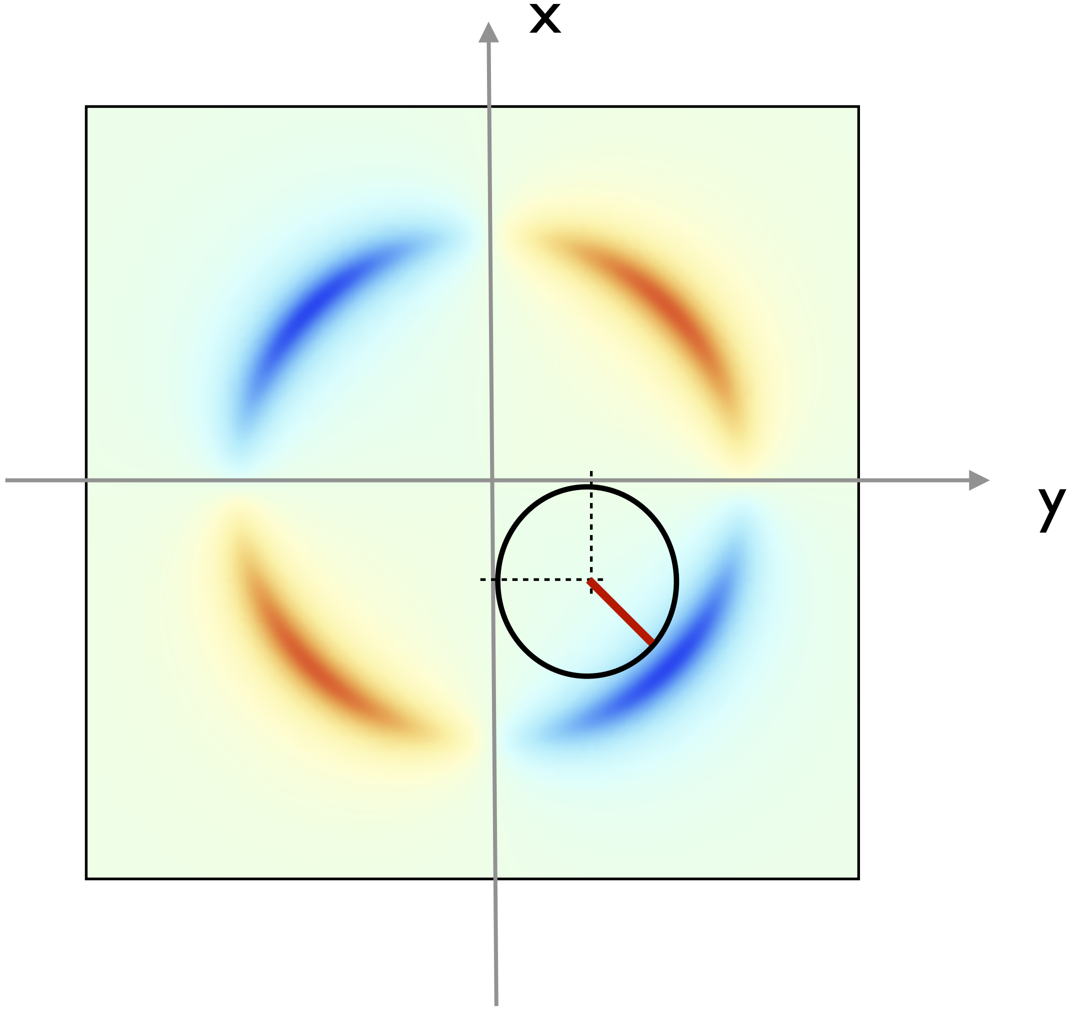


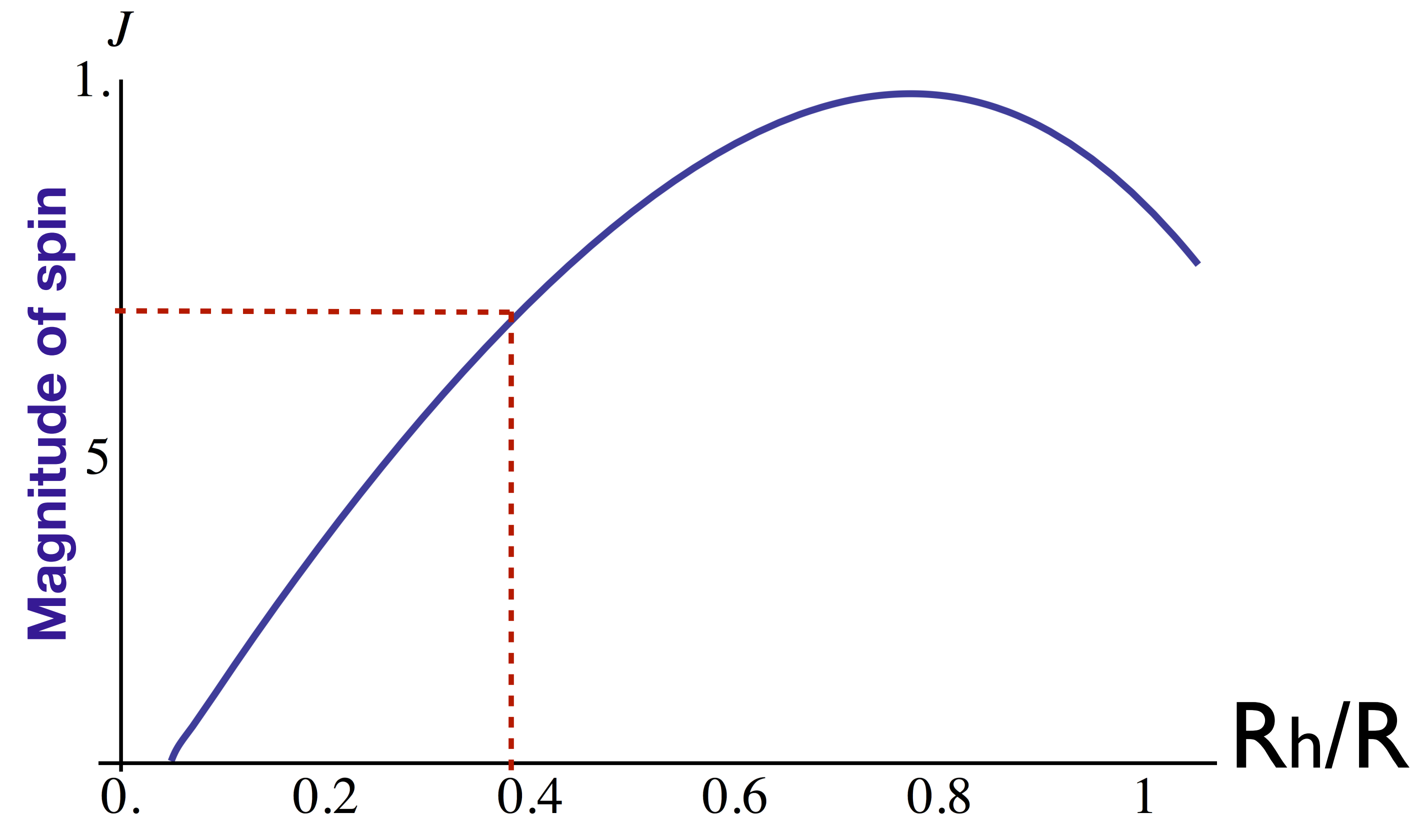


Transition mass is correlated with the size of the quadrants.

Mass transition for spin alignment

Idealized toy model: The position is fixed and the radius of the halo increases:





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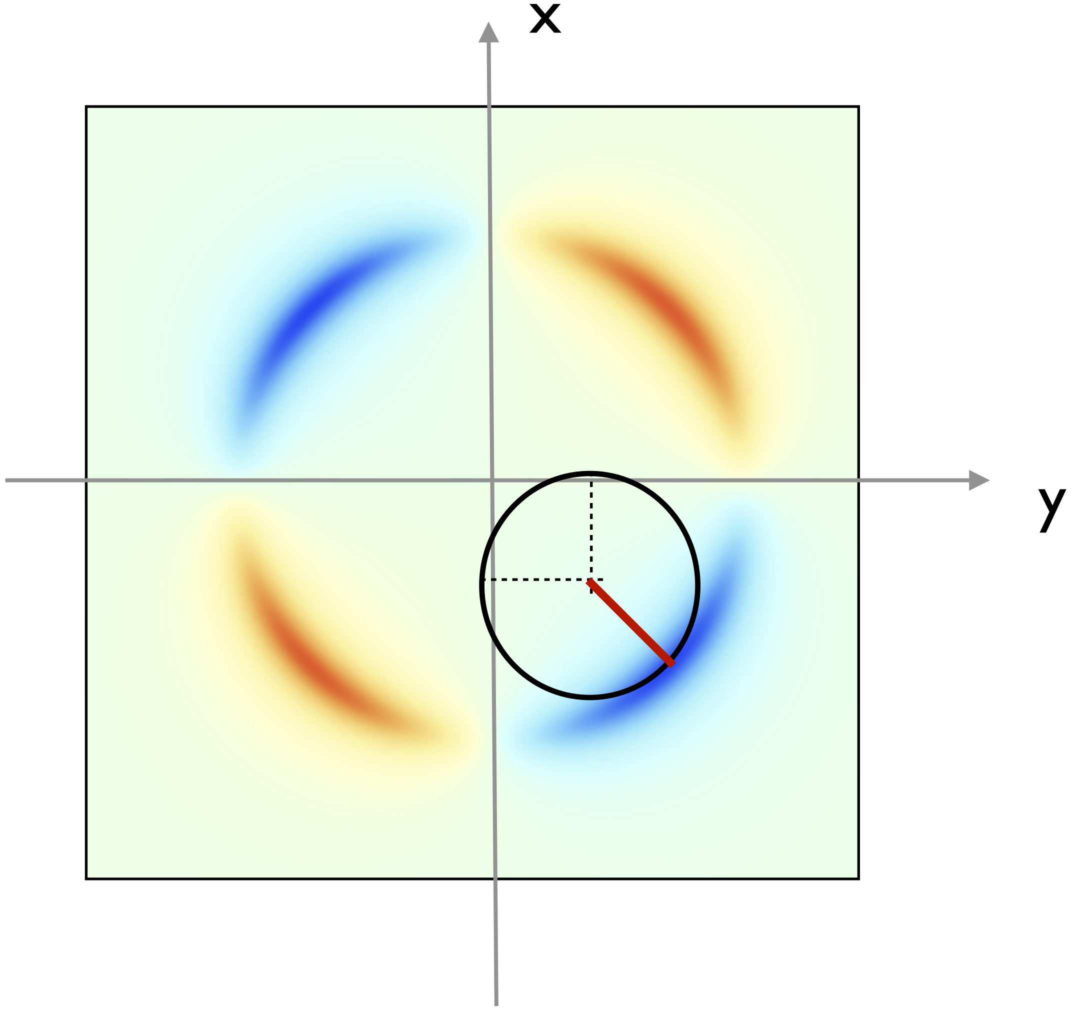

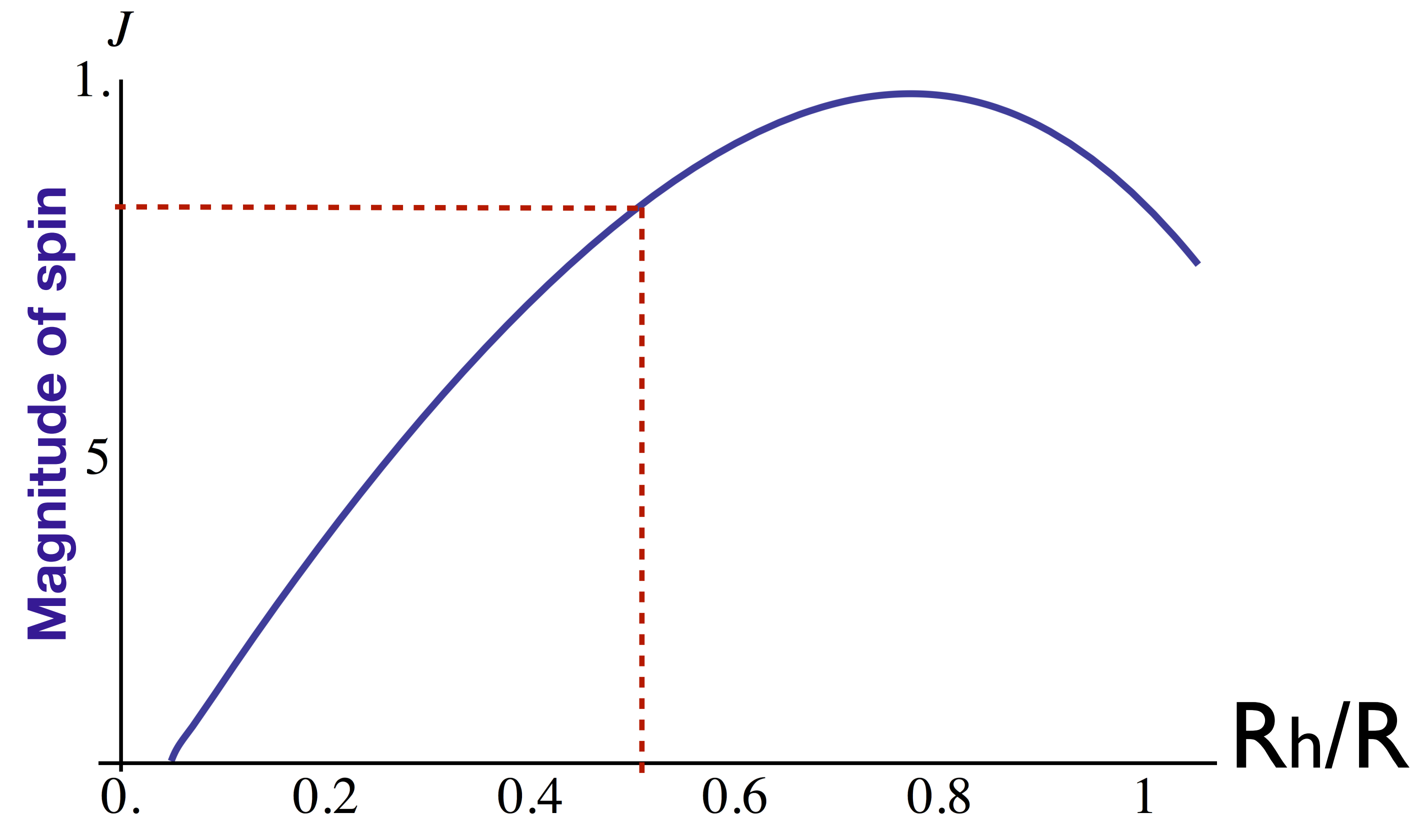

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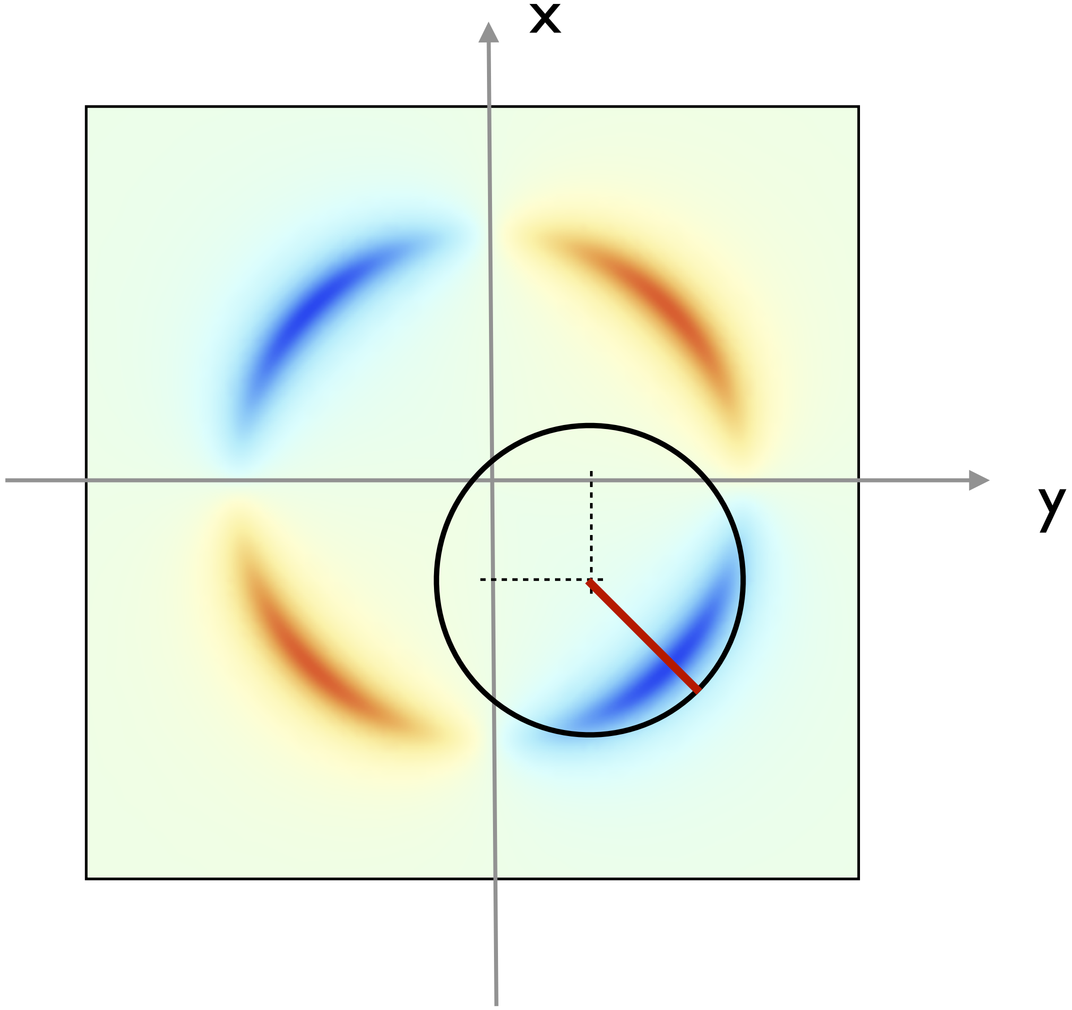

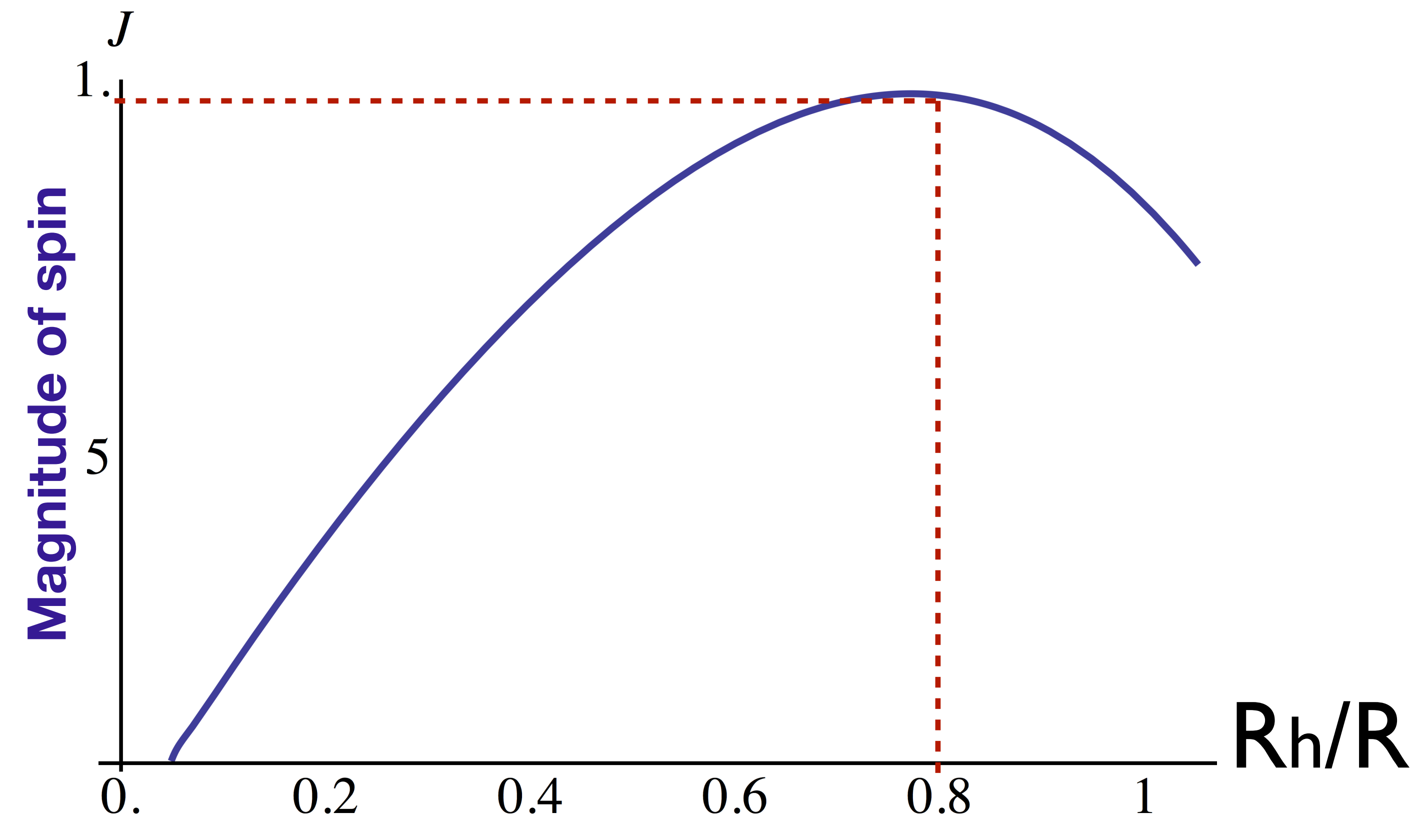

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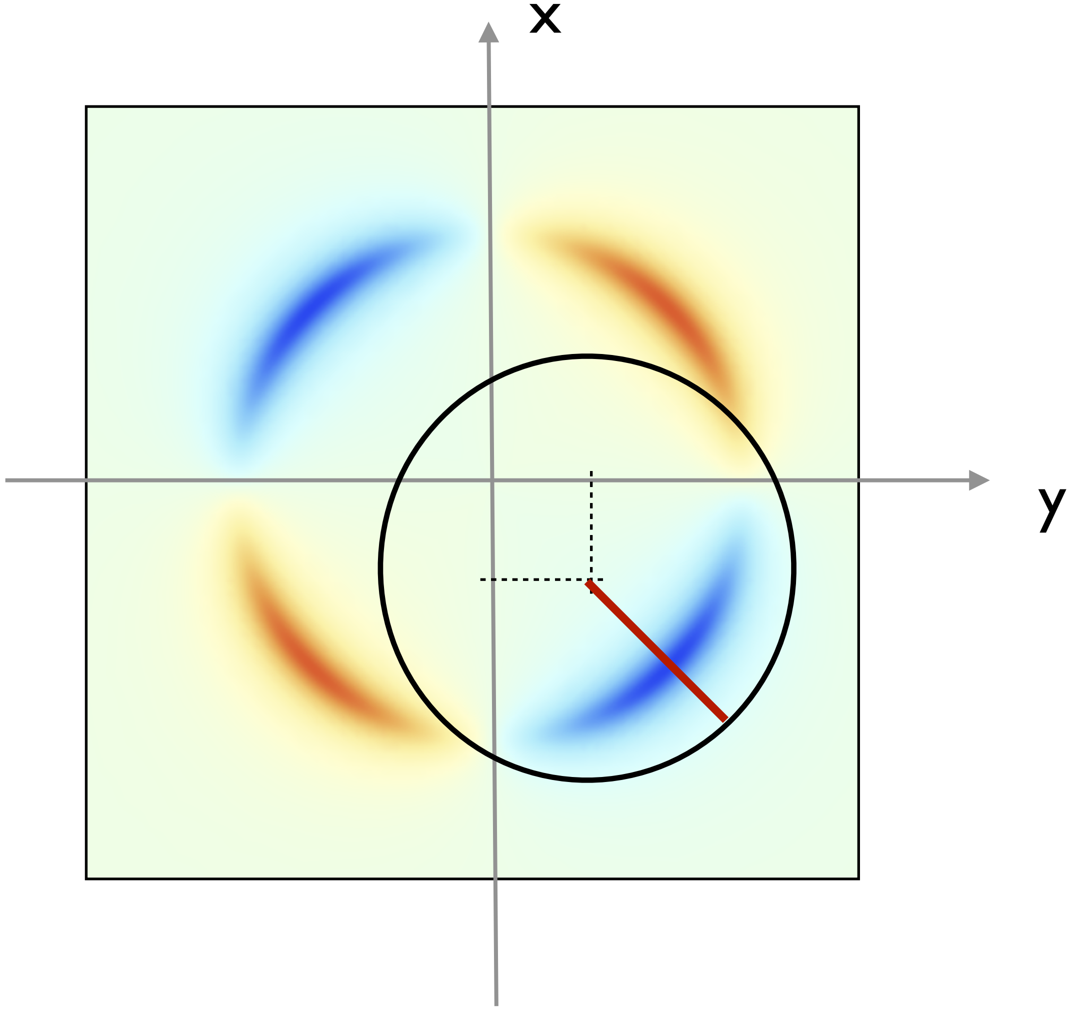
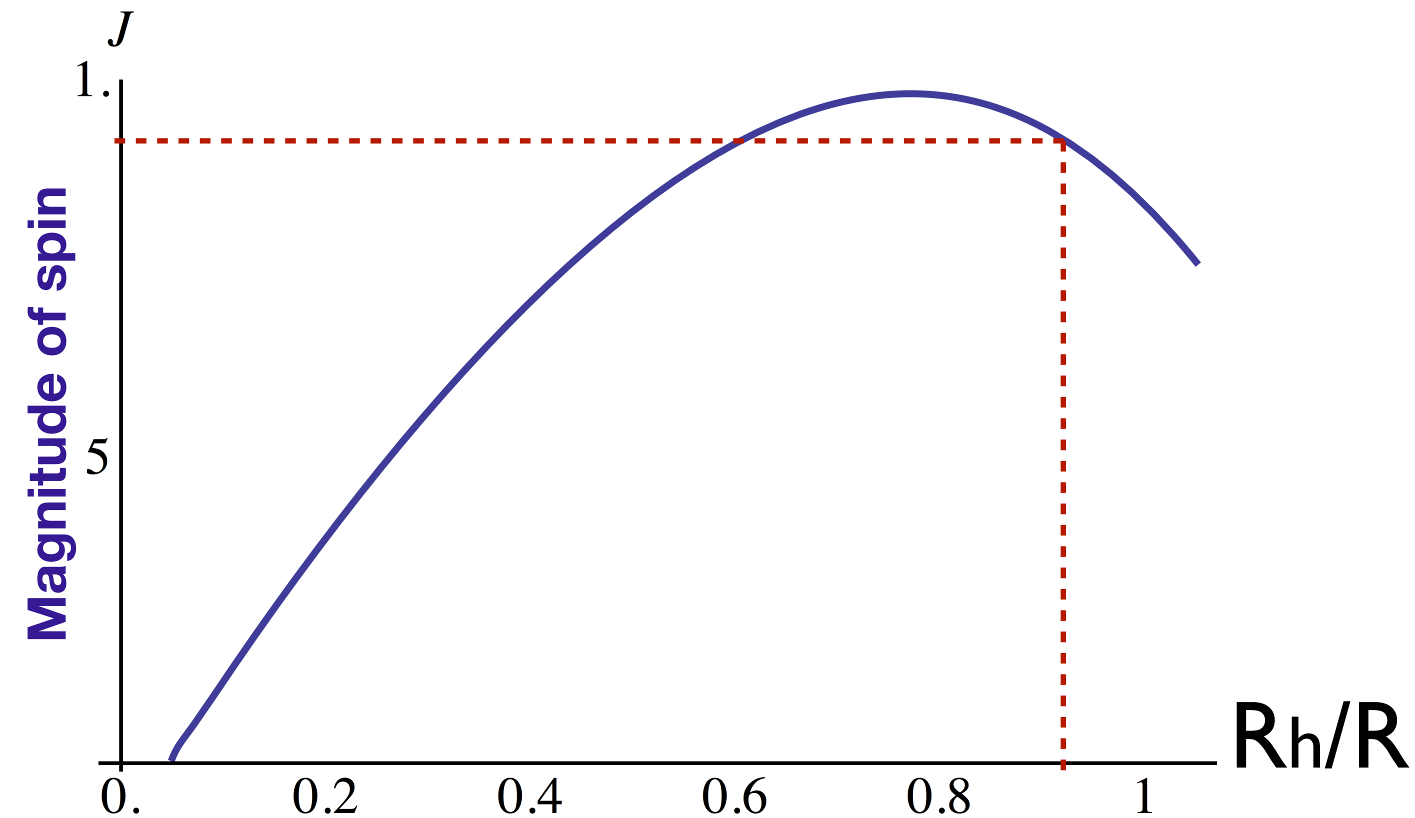
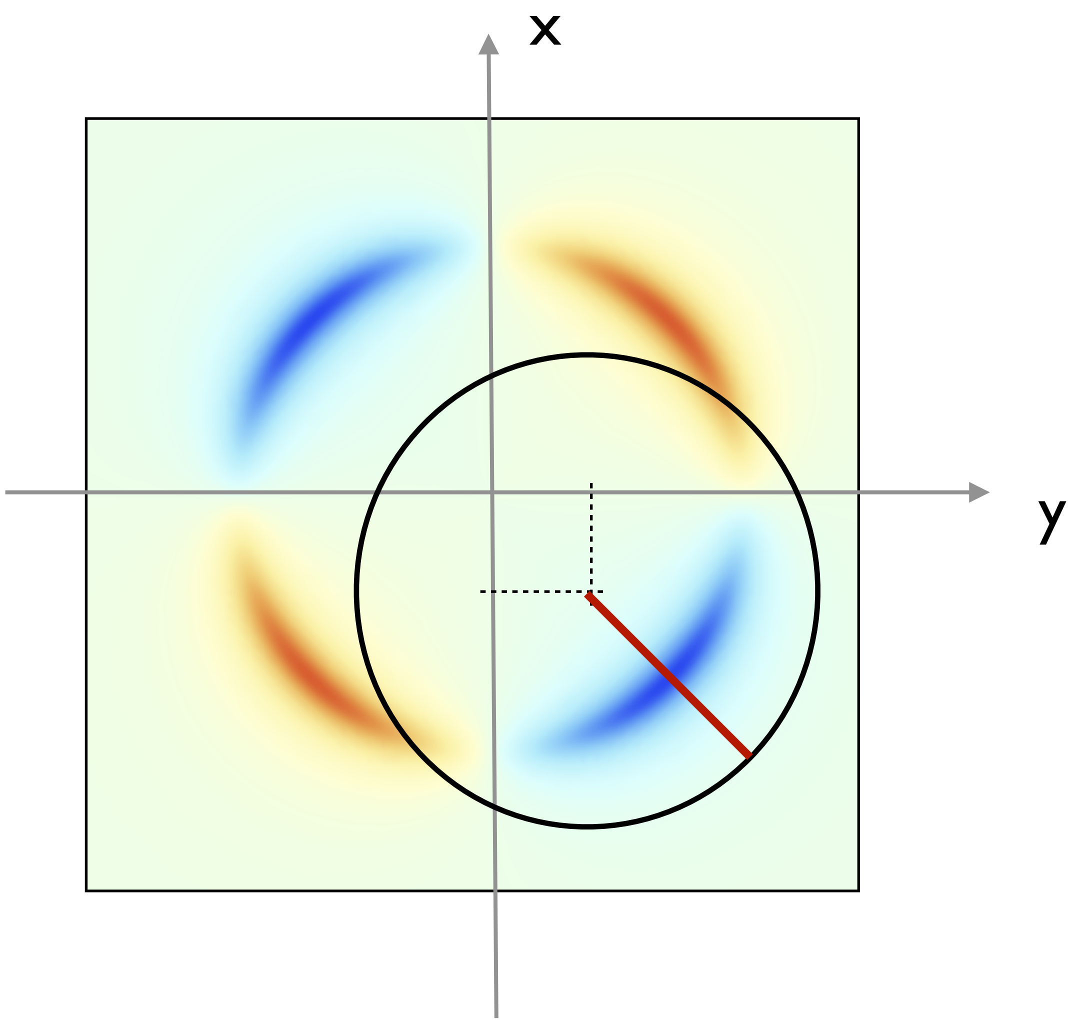


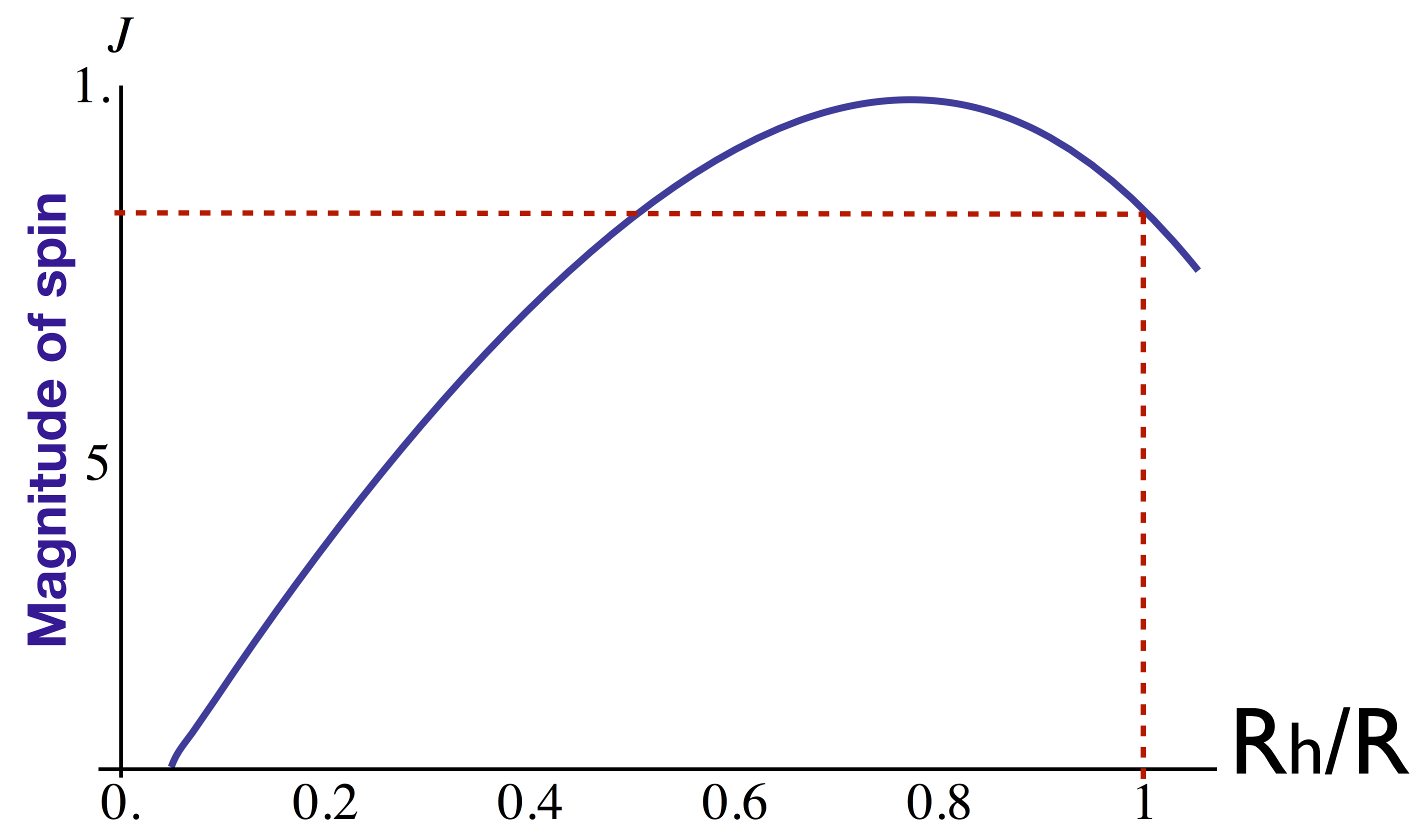


Transition mass is correlated with the size of the quadrants.

Mass transition for spin alignment

Idealized toy model: The position is fixed and the radius of the halo increases:

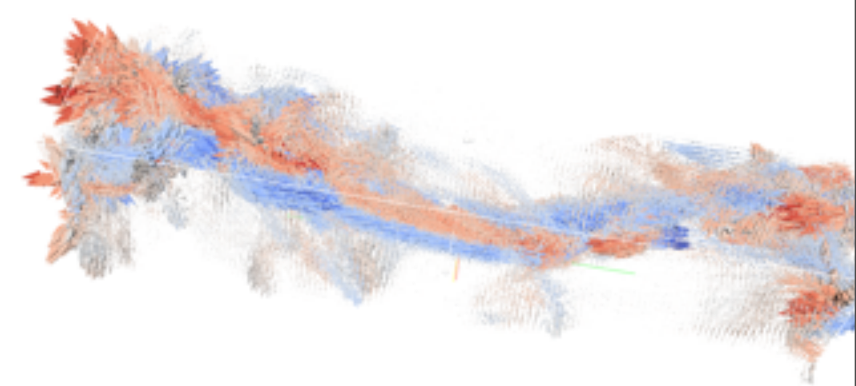


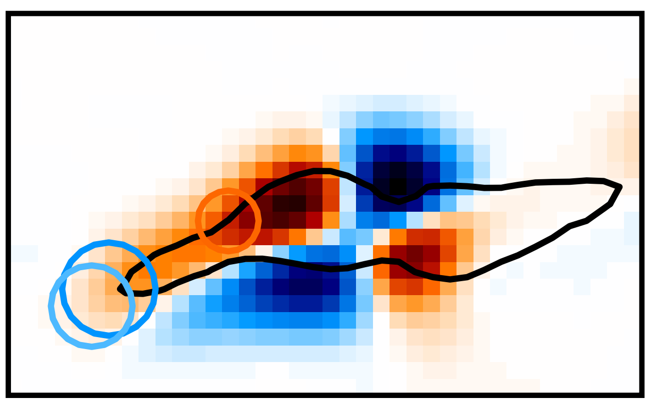


Transition mass is correlated with the size of the quadrants.

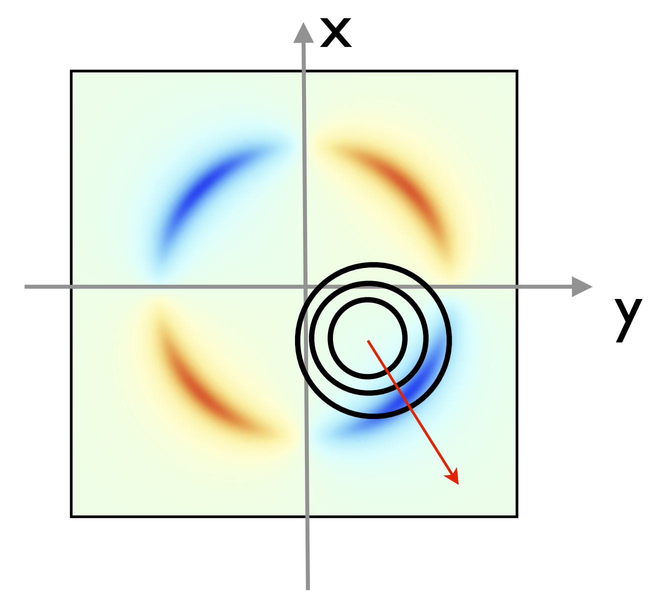
in short...

- Vorticity is confined in the filaments, and aligned with them. The cross-section with a plane perpendicular to the filament is typically quadripolar.





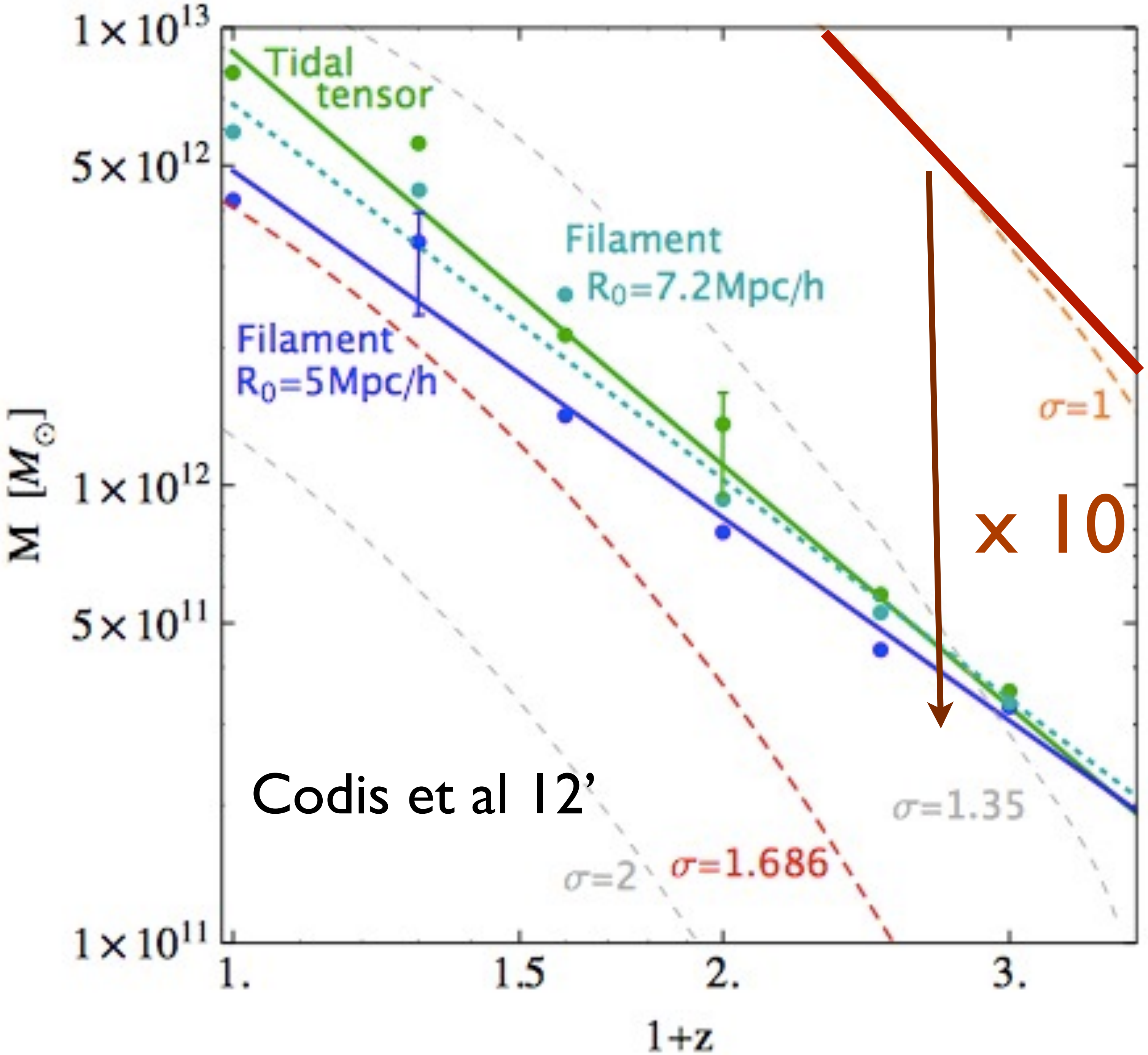
- Halo spins are aligned with the same polarity as vorticity in quadrants.

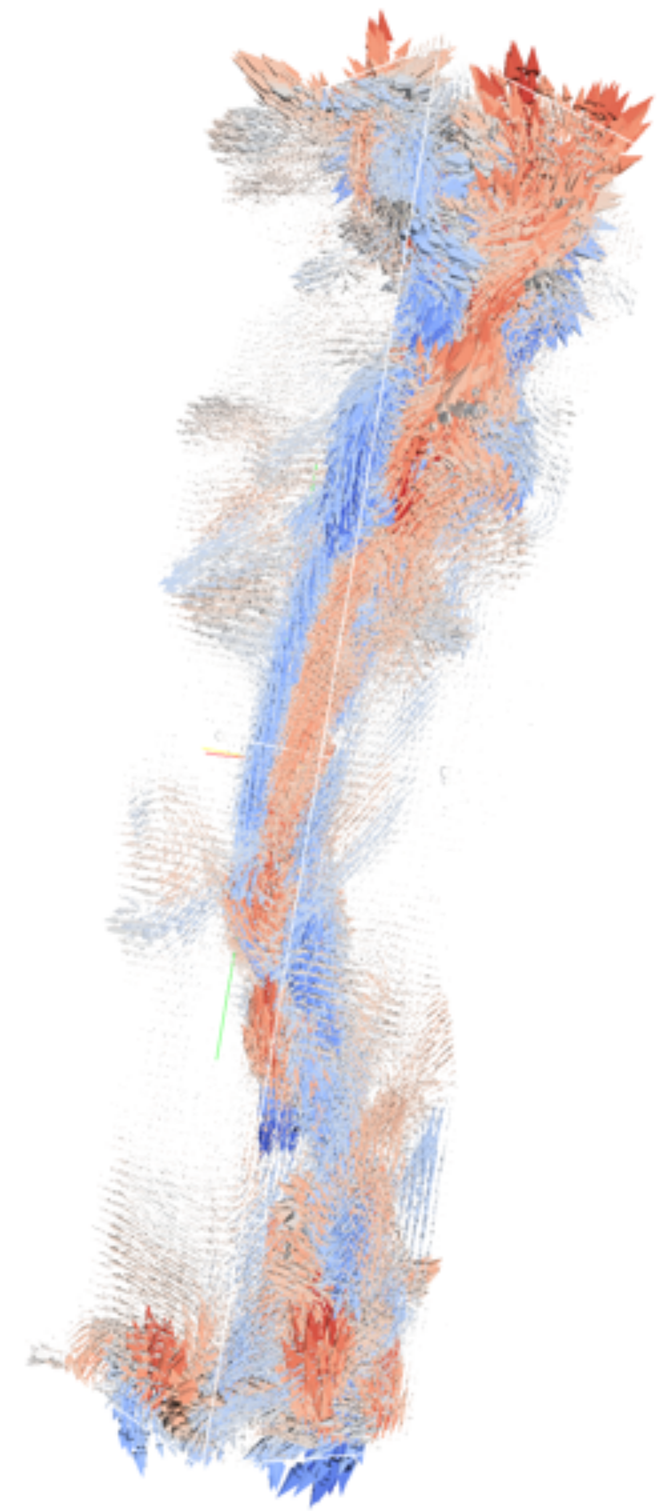


- Qualitatively, the transition mass in the alignment is correlated with the size of the quadrant.

Explain transition mass? YES!

Transition mass versus redshift

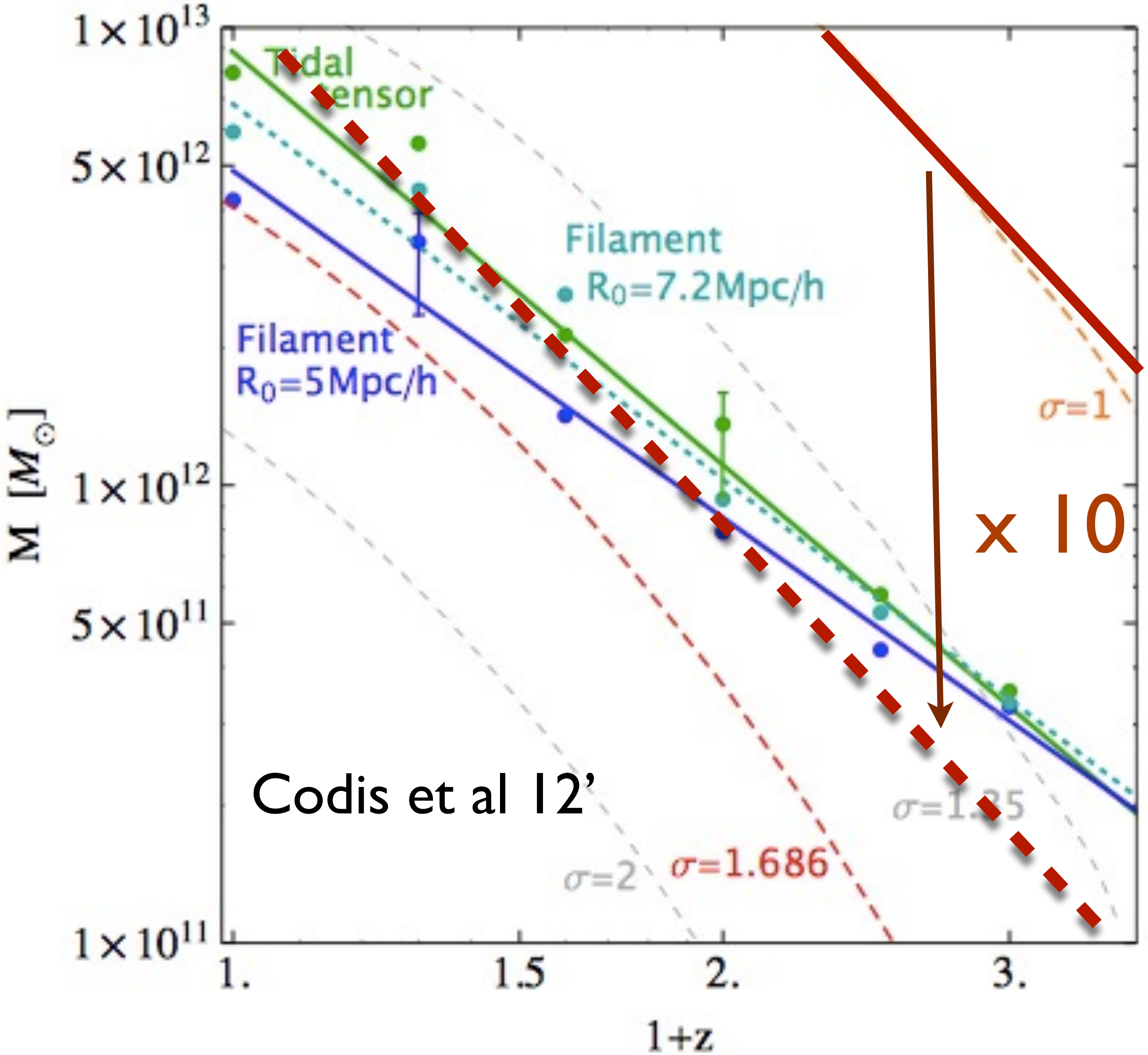


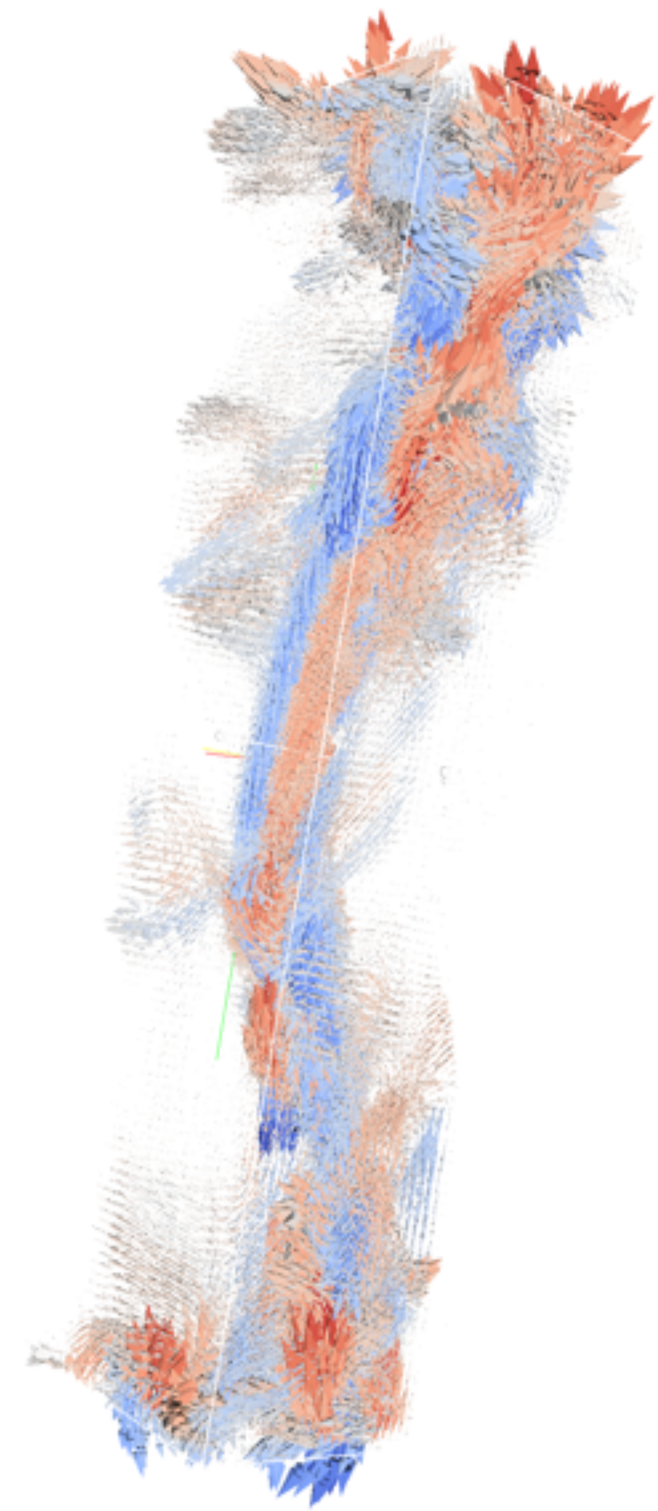


Only 2 ***ingredients***: a) spin is spin one b) filaments flattened

Explain transition mass? YES!

Transition mass versus redshift





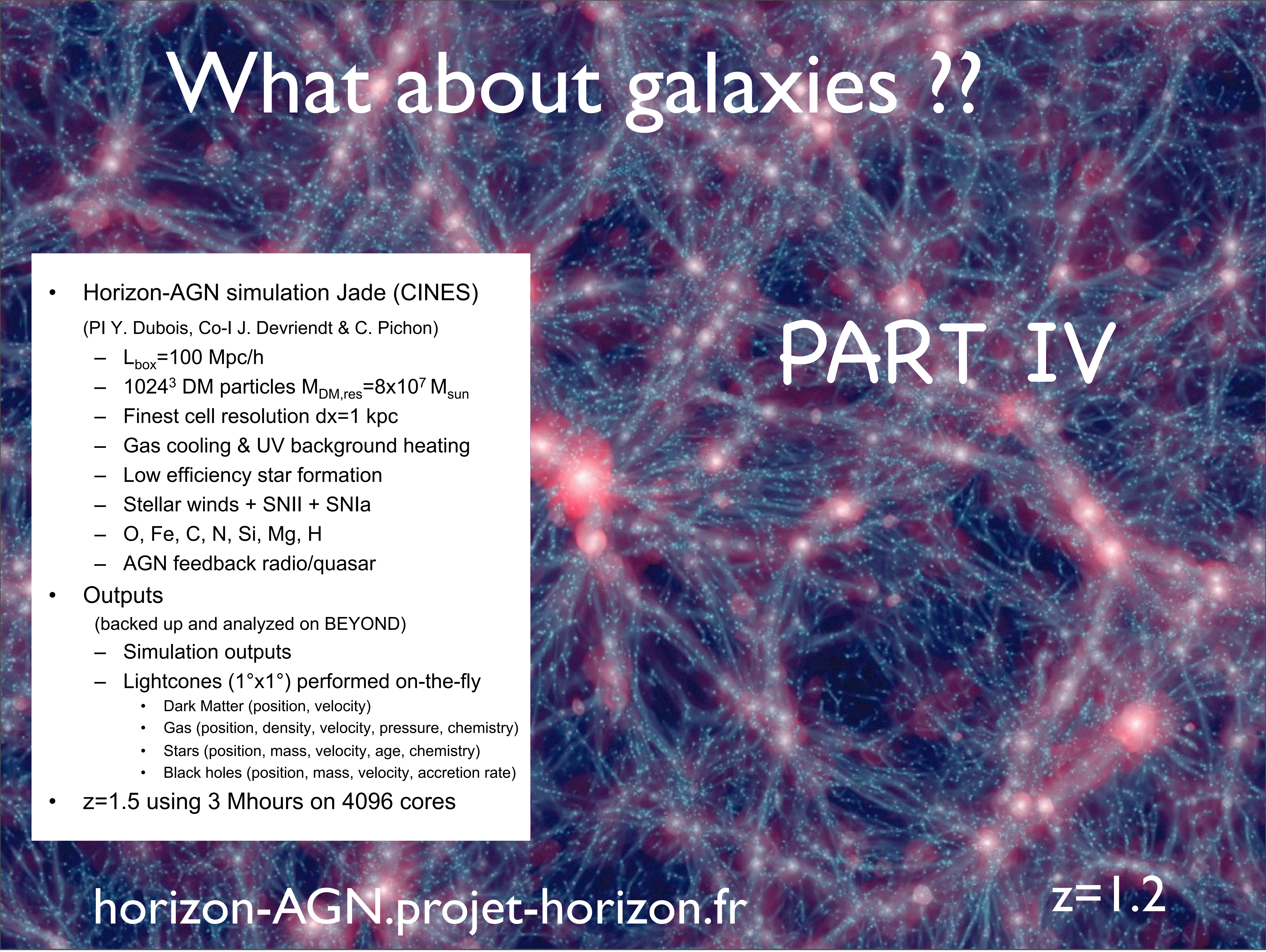
Only 2 ***ingredients***: a) spin is spin one b) filaments flattened

Take home message...

- Morphology (= AM stratification) driven by LSS in cosmic web: can explain Es & Sps where, how & why from **IC**s
- Signature in correlation between *spin* and *internal* kinematic structure of cosmic web on larger scales.
- Process driven by simple PBS/biassed clustering dynamics:

  - requires updating TTT to **saddles**: simple theory :-)
  - can be expressed into an Eulerian theory via vorticity

Where ***galaxies*** ***form does matter, and can be*** *traced* ***back to ICs***
Flattened *filaments* ***generate point-reflection-symmetric*** *AM/vorticity distribution*:
they induce the observed spin *transition mass*



What about galaxies ??

- Horizon-AGN simulation Jade (CINES)
  (PI Y. Dubois, Co-I J. Devriendt & C. Pichon)
  - L_{box}=100 Mpc/h
  - 1024^3 DM particles $M_{DM,res}=8x10^7\ M_{sun}$
  - Finest cell resolution dx=1 kpc
  - Gas cooling & UV background heating
  - Low efficiency star formation
  - Stellar winds + SNII + SNIa
  - O, Fe, C, N, Si, Mg, H
  - AGN feedback radio/quasar
- Outputs
  (backed up and analyzed on BEYOND)
  - Simulation outputs
  - Lightcones (1°x1°) performed on-the-fly
    - Dark Matter (position, velocity)
    - Gas (position, density, velocity, pressure, chemistry)
    - Stars (position, mass, velocity, age, chemistry)
    - Black holes (position, mass, velocity, accretion rate)
- z=1.5 using 3 Mhours on 4096 cores

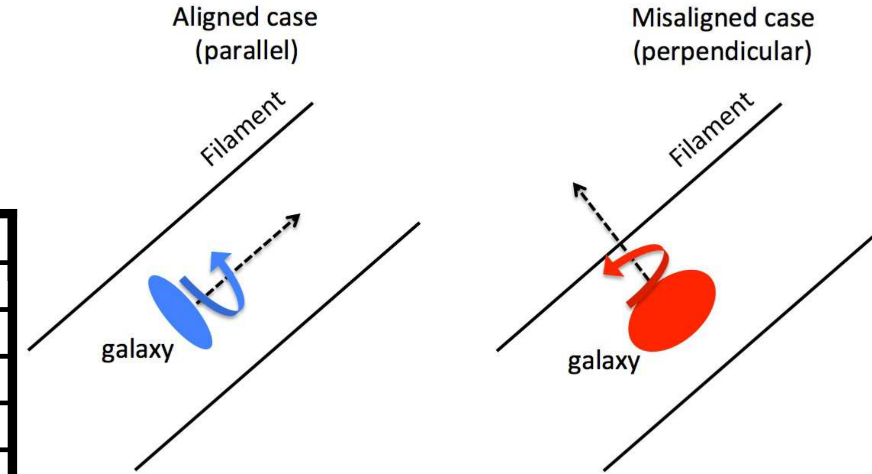
PART IV

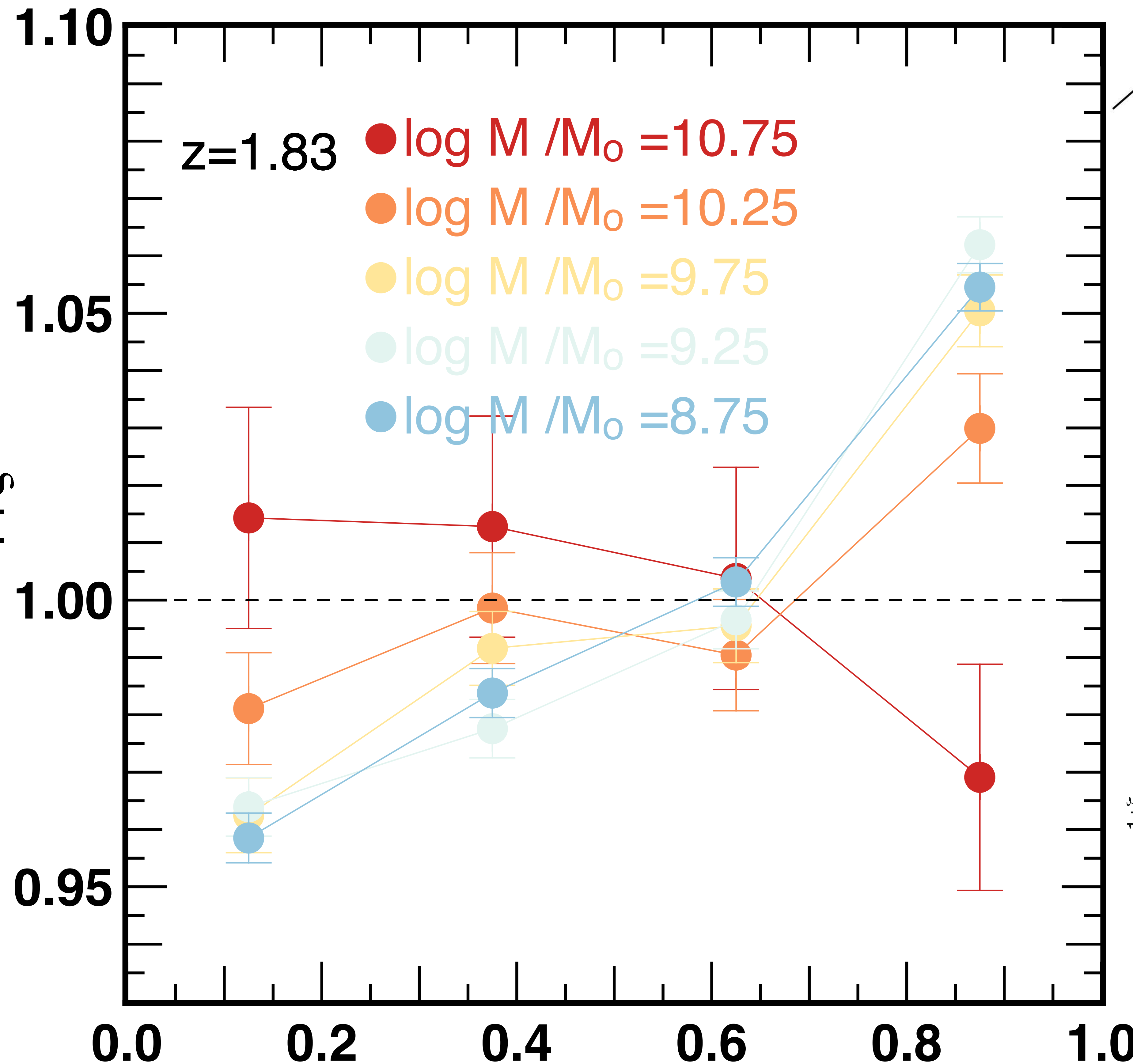
horizon-AGN.projet-horizon.fr

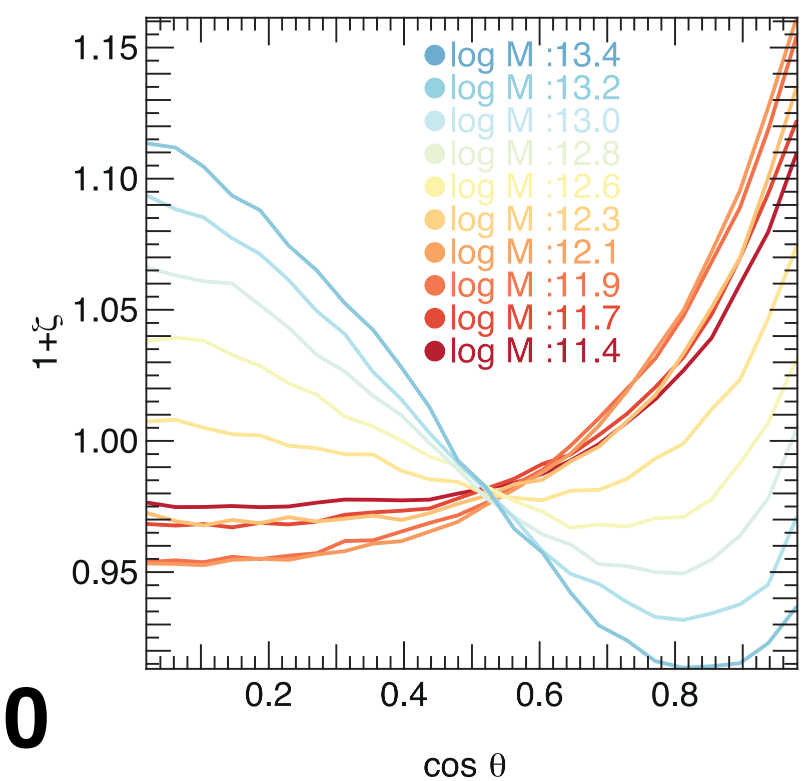
z=1.2

1 Mpc
z=38.305

Filament-galactic spin & mass

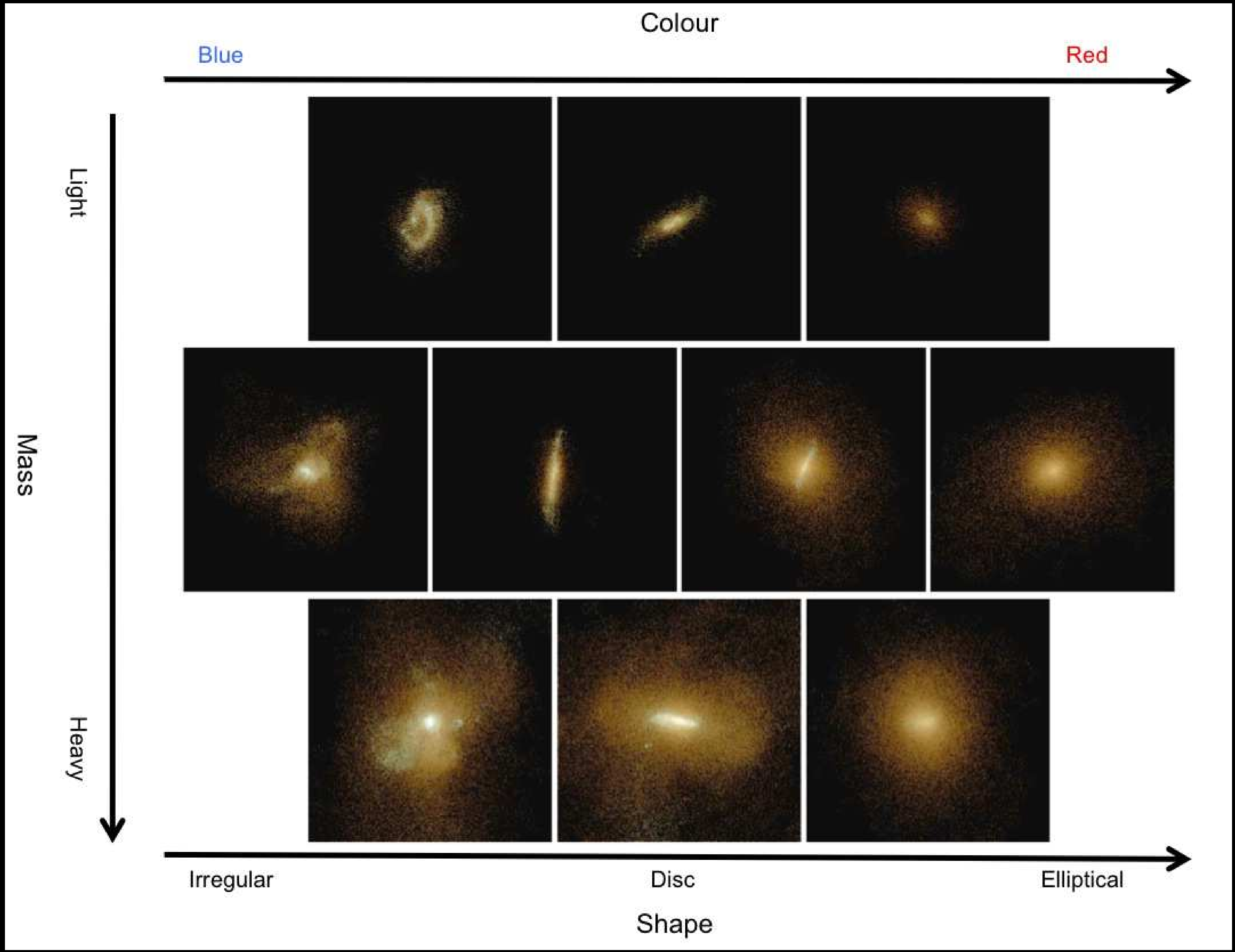




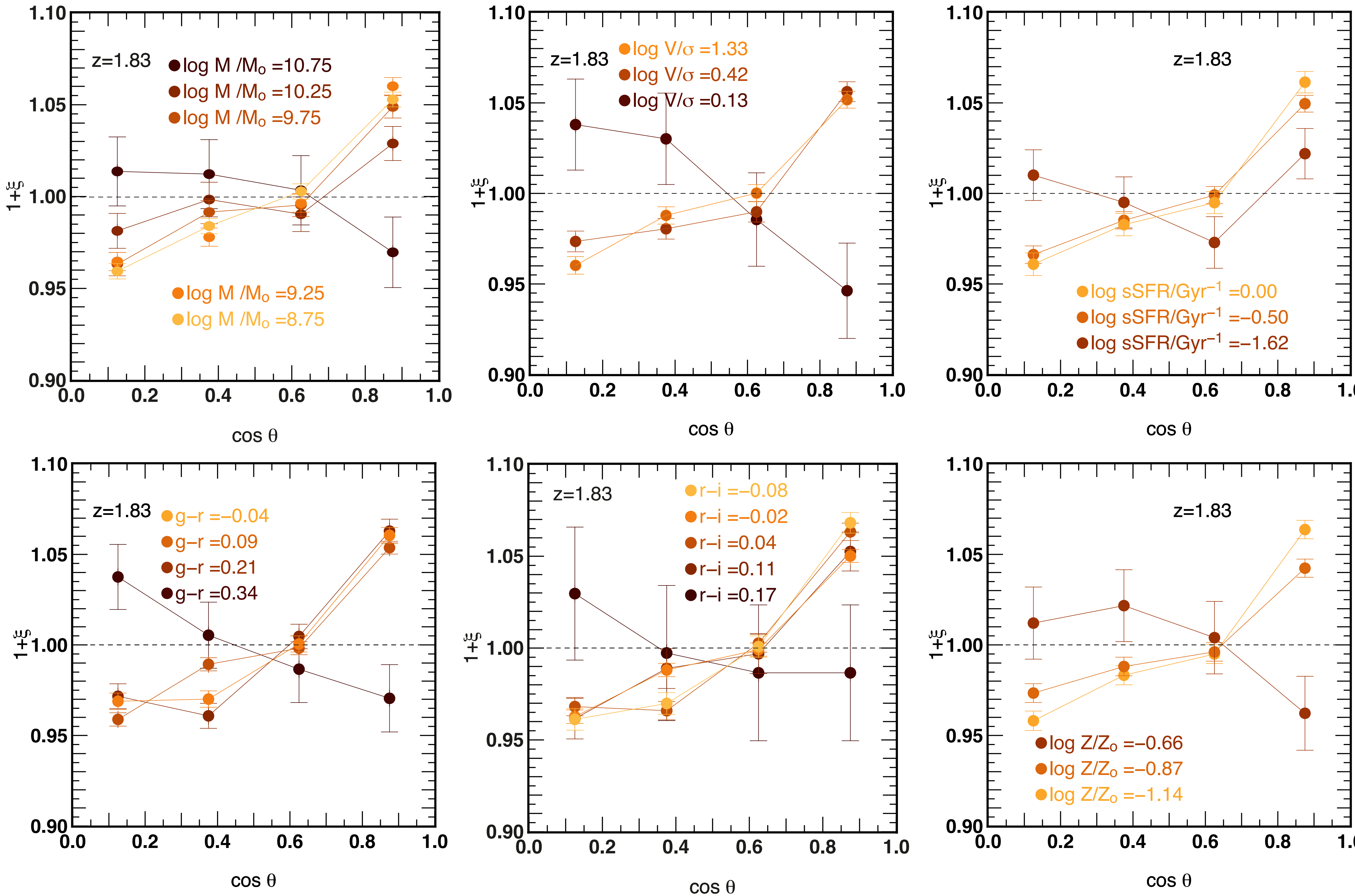


can morphology trace spin flip ?

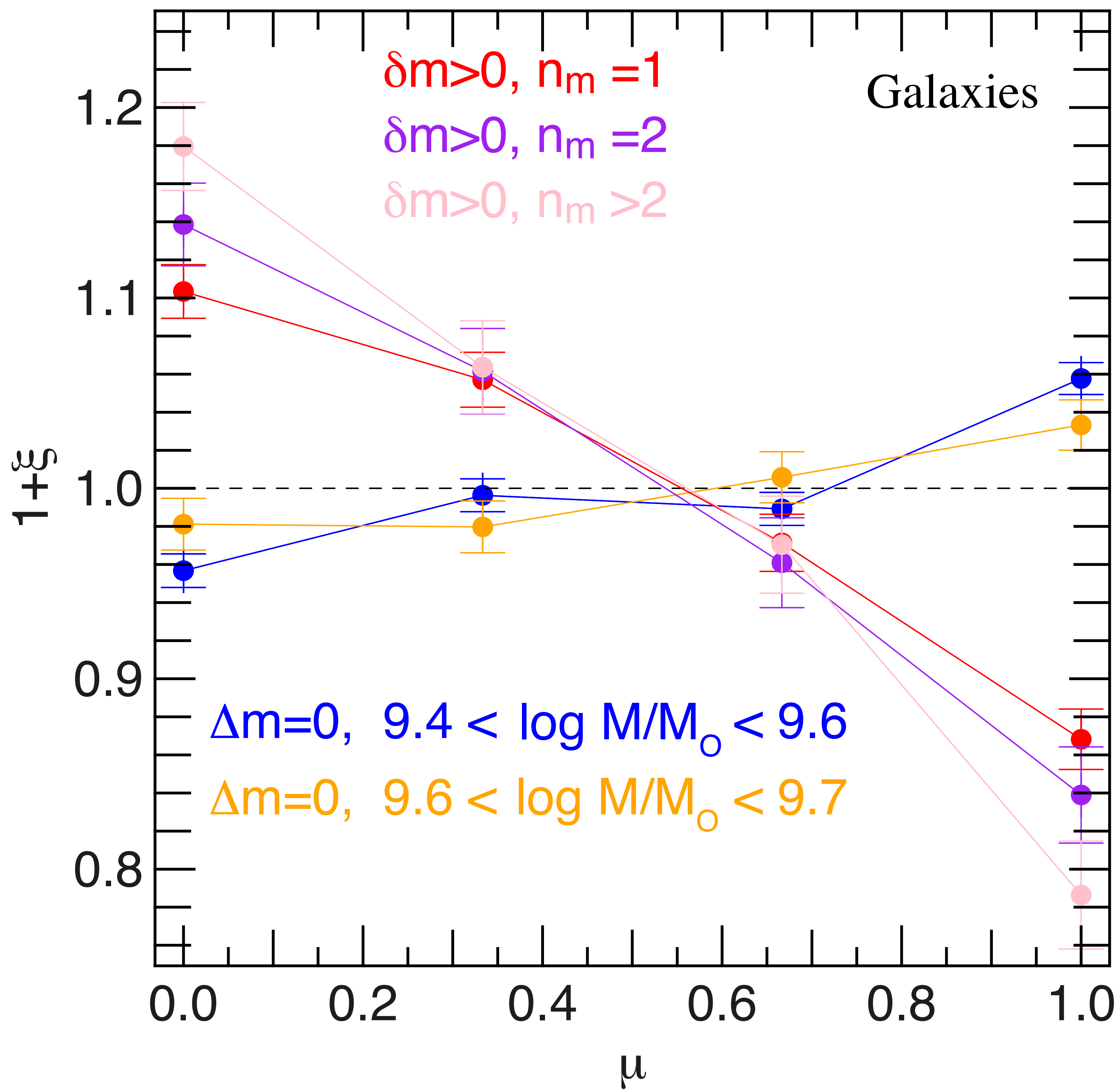
- thanks to AGN feedback we have morphological diversity


Colour
Blue
Red
Mass
Light
Heavy
Irregular
Disc
Elliptical
Shape

Can morphological/physical properties of galaxies trace spin flip?

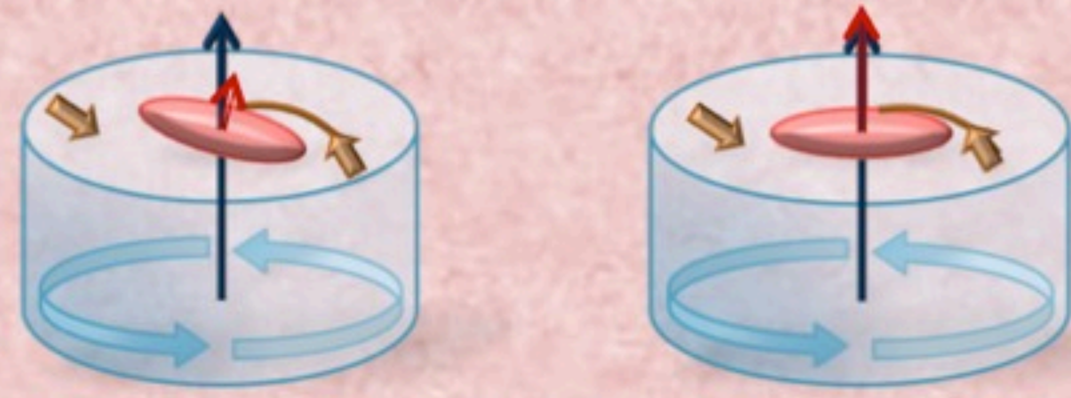


What is the *physical* origin of spin flip? high mass **galaxies** merge!

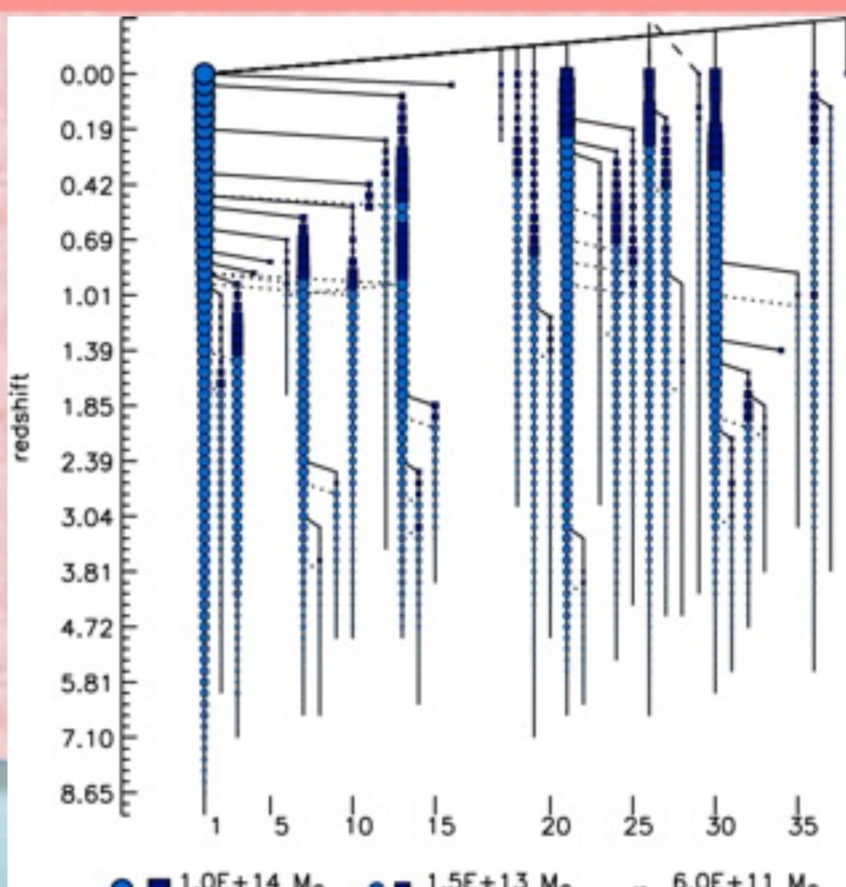


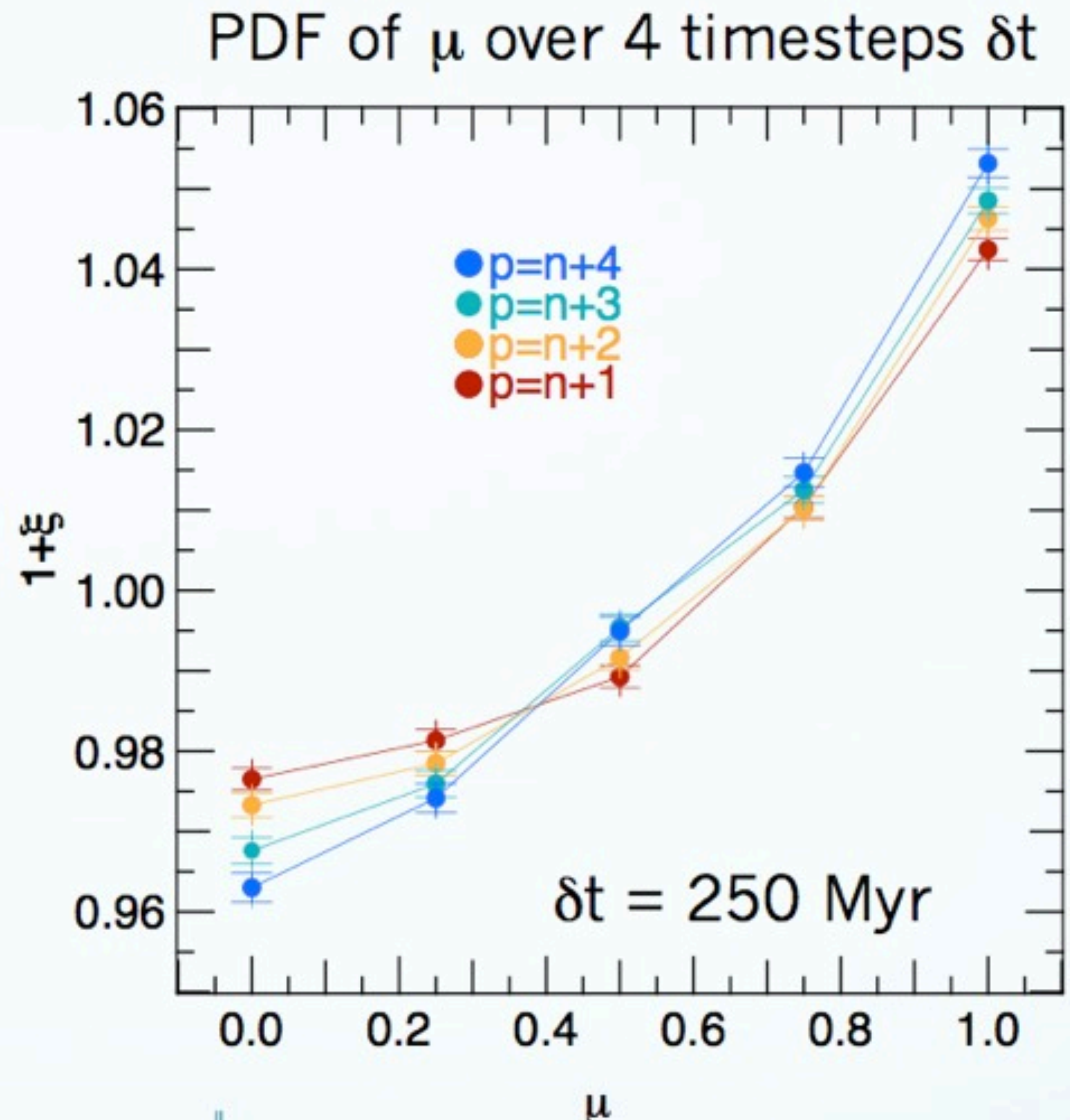
Transition mass versus **merging rate** for galaxies

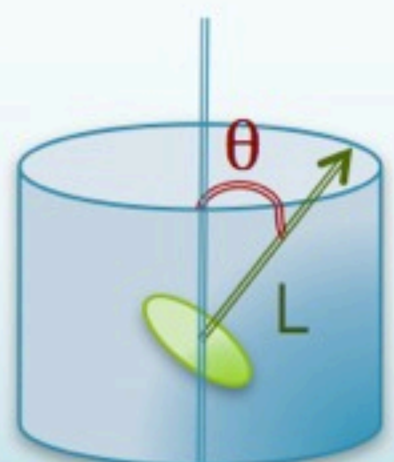
SMOOTH ACCRETION



- Gas inflows (re)-align galaxies with their filament







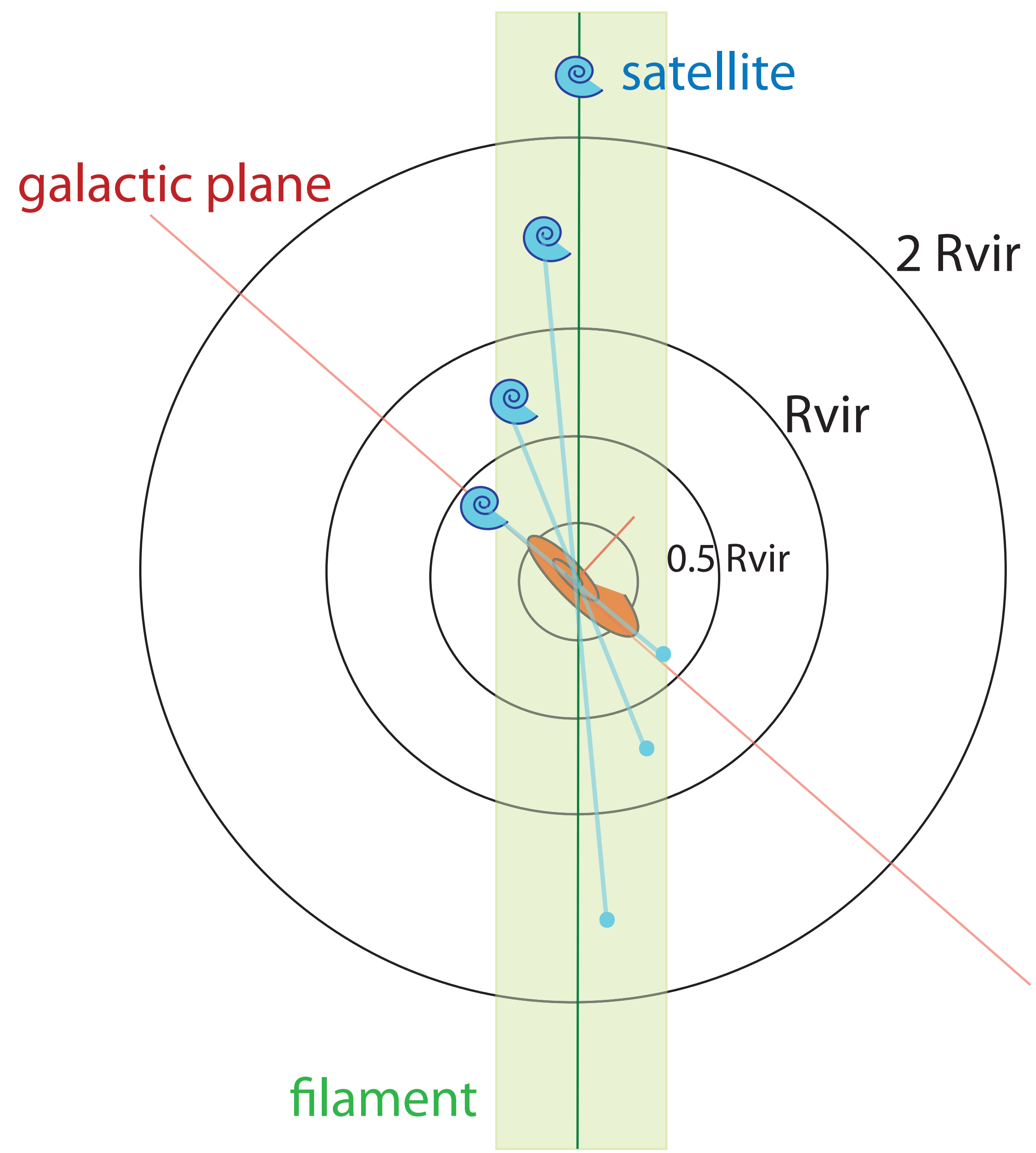
$\mu = |\cos(\theta)|$

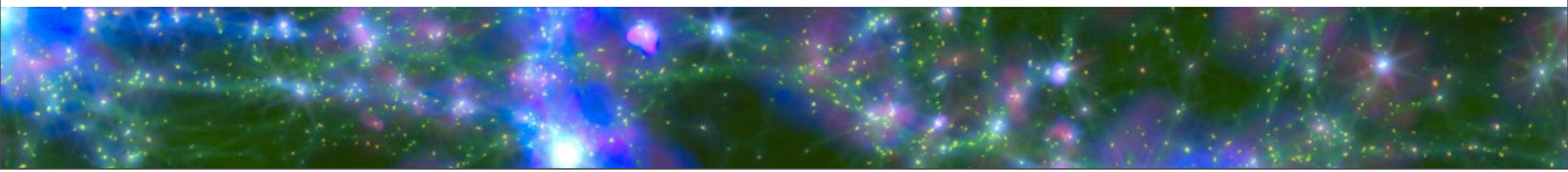
- Spin-filament angle
- ξ : excess probability

no merger : orientation versus look-back time

Caught in the rhythm: satellites in their galactic plane

C. Welker[1*], Y. Dubois[1], C. Pichon[1,2], J. Devriendt[3,4] and N. E. Chisari[3]





Tuesday, 2February, 16