IUTAM Symposium:
Helicity, Structures and Singularity in Fluid and Plasma Dynamics
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Magnetic helicity conservation in a solar active event

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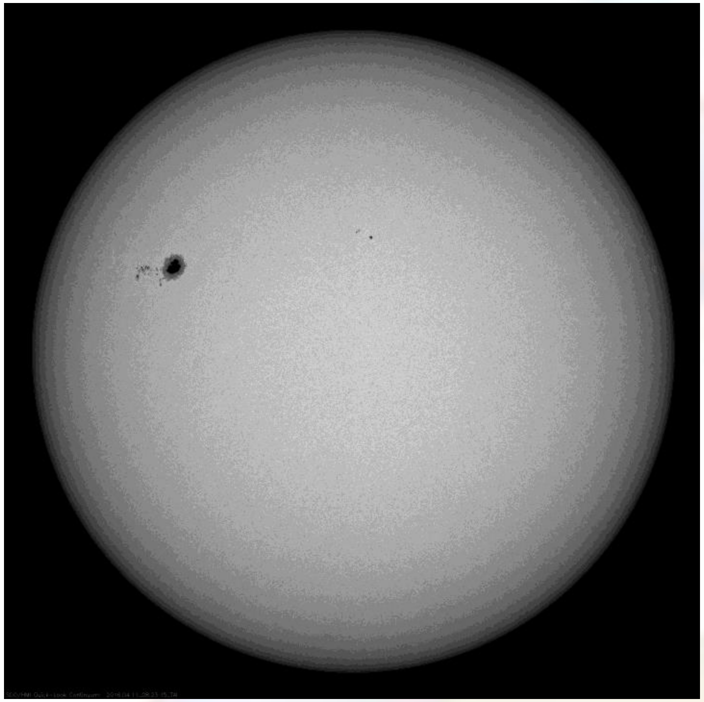
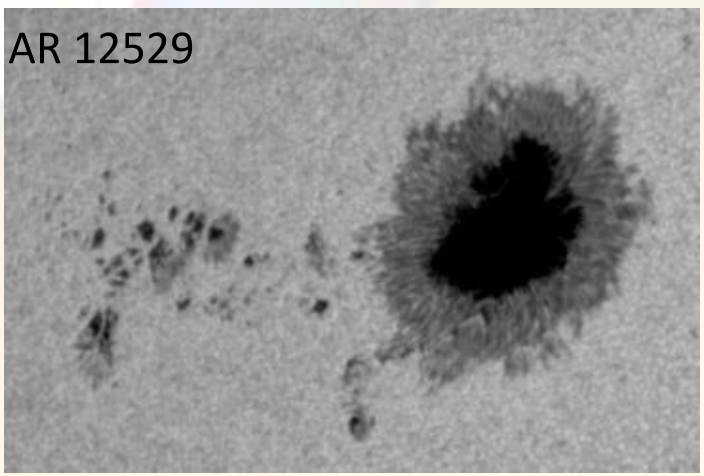
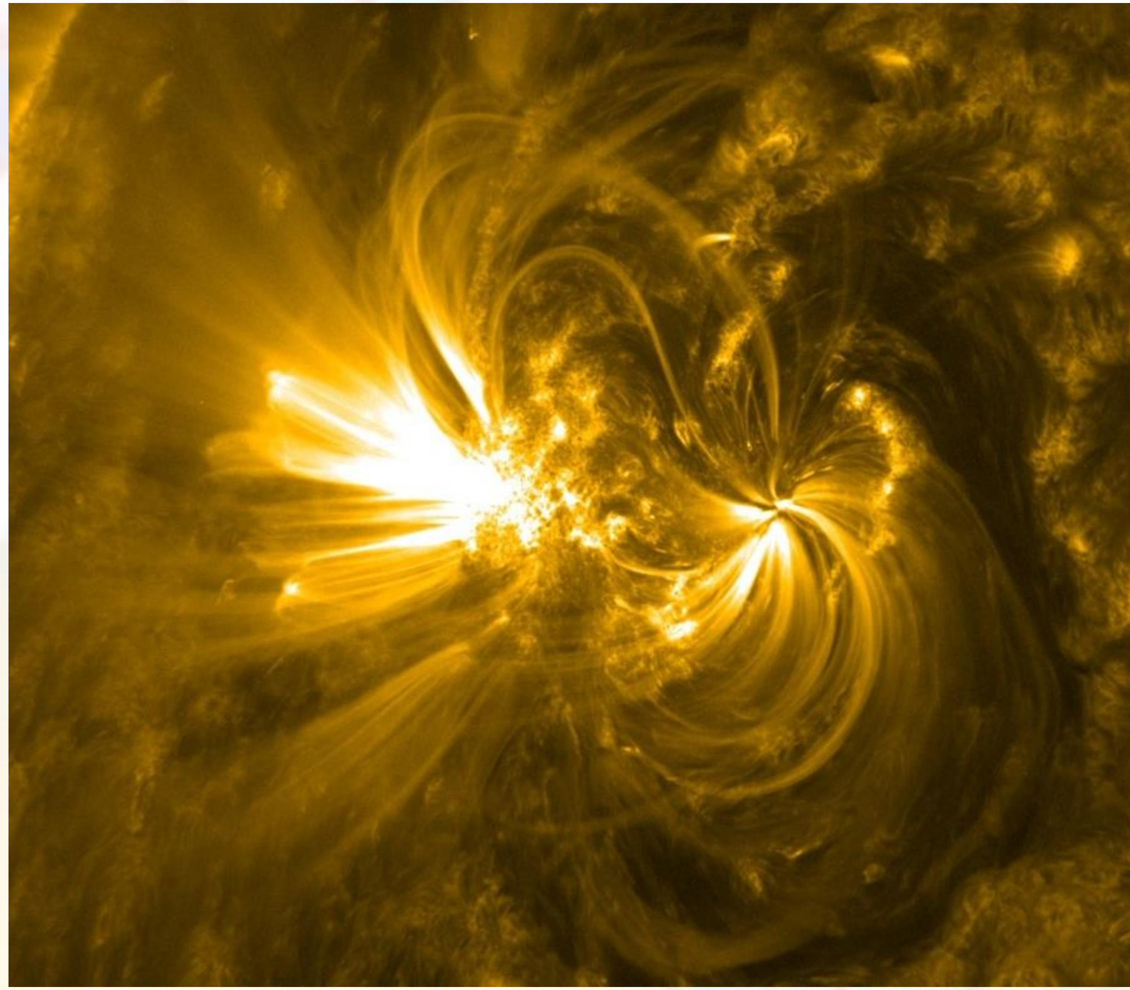
The Sun is celebrating our meeting !



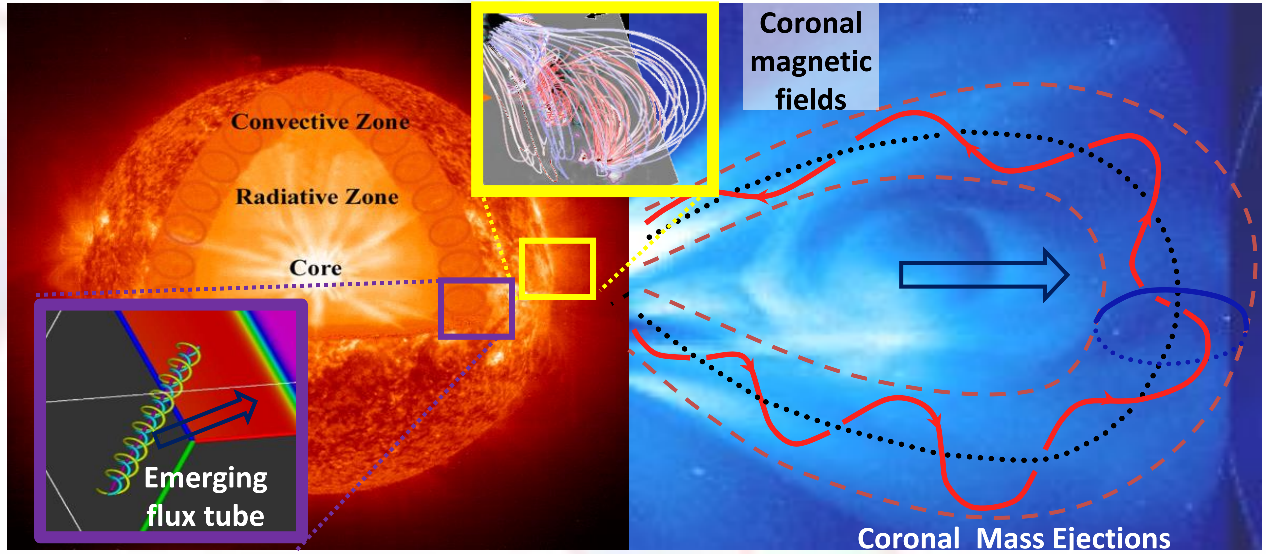


SDO/ AIA & HMI ; 11/04/2016 @ 11H40 UT



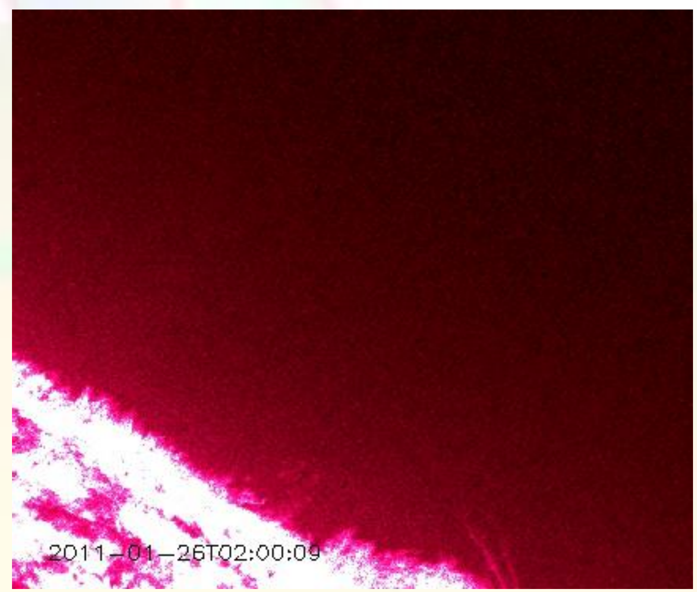
Magnetic Helicity in Solar Physics

- **High interest in solar physics for last 20 yrs**
  - x2 ref. pub. /10 years
  - conserved quantity can be tracked
  - complementary descriptions/ understanding of observed phenomena



- Magnetic helicity conservation is the "raison d'être" of Coronal Mass Ejections (CMEs)
  - Conjecture **(Rust 94, Low 96)** : to limit the buildup of magnetic helicity in the corona, magnetic helicity has to be ejected ➔ CMEs generation

- **Goal of this study: quantify magnetic helicity conservation in numerical simulations of solar active events, and more generally in 3D magnetic field datasets.**



SDO/AIA 304A

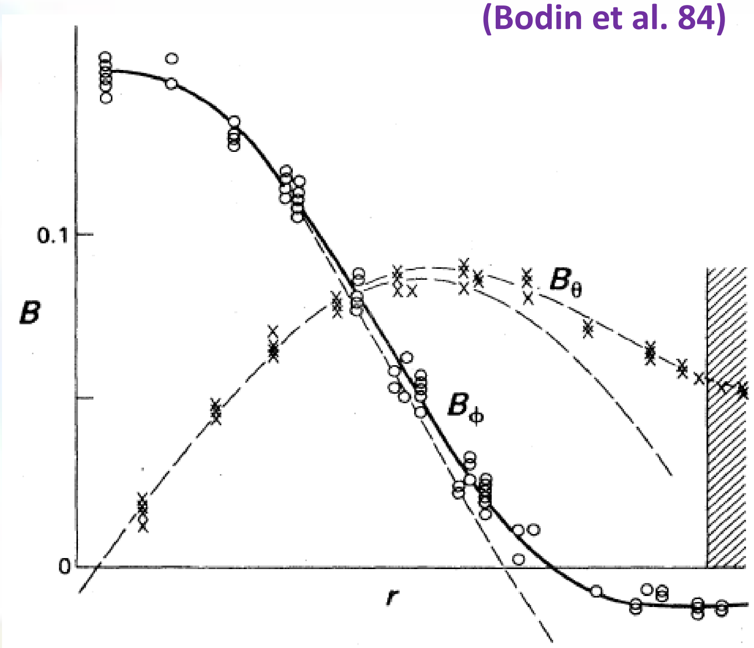
Taylor conjecture

- Magnetic energy invariant in ideal MHD, when field lines cannot reconnect.

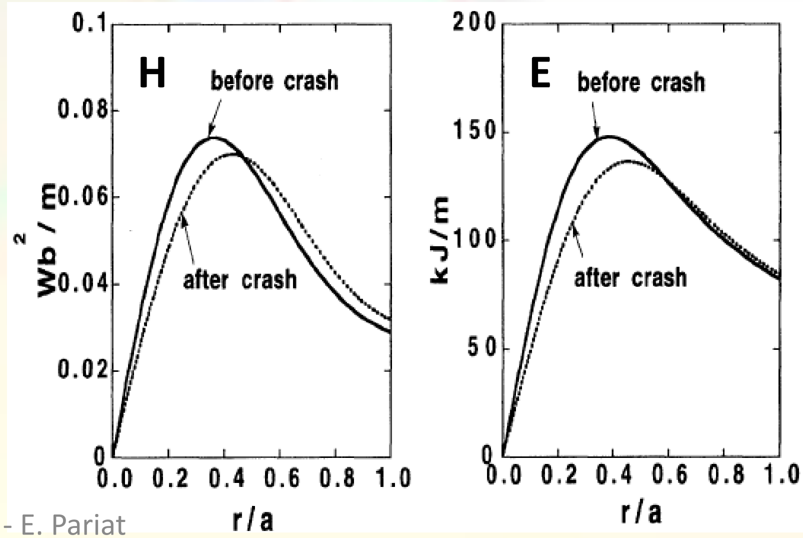
- From laboratory plasma experiment, **Taylor (1974) conjectured: even in non-ideal MHD magnetic helicity should be well conserved.**
  - Magnetic energy cascades to small scales where it is dissipated vs helicity cascades to large scales **(Ji et al. 95, Heidbrink & Dang 00)**.
  - In resistive MHD, helicity dissipation is bounded and slow compared to energy dissipation **(Berger 84, Berger 99)**

- **However non-ideal helicity conservation has yet not been tested in general conditions**, i.e. in 3D, active-like conditions, no periodicity … **(e.g. Kusano et al. 94, Hu et al. 97, Shangbin et al. 13)**

(Bodin et al. 84)

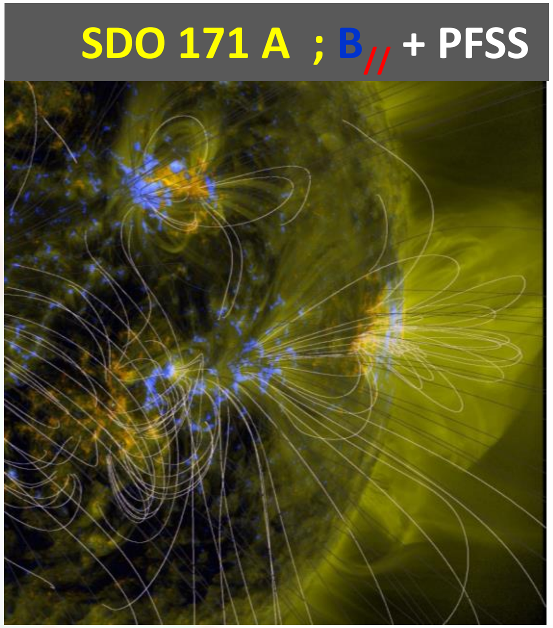


(Ji et al. 95)



Relative magnetic helicity

- Strict definition of magnetic helicity useless for numerous applications to natural plasmas
  - e.g. solar corona boundaries threaded by magnetic fields



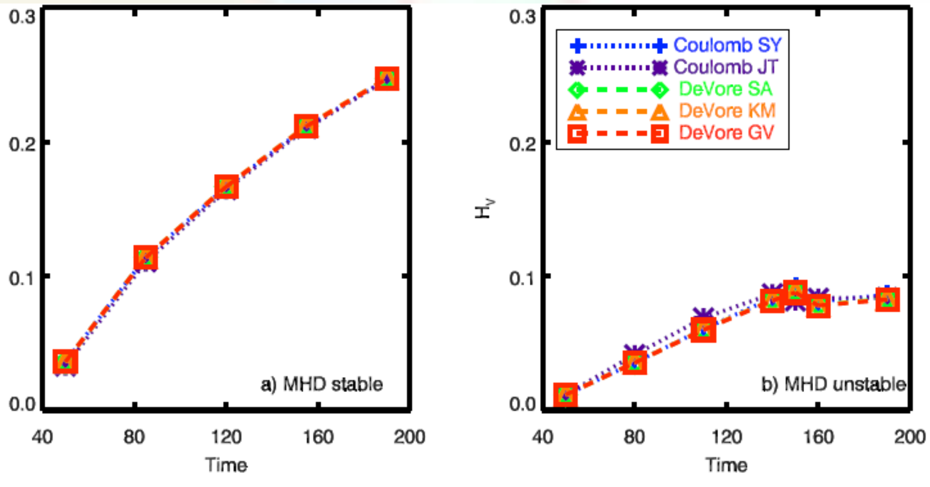
➔Use of relative magnetic helicity
(Berger & Field 1984, Finn & Antonsen 1985)

$$H_{\mathcal{V}} = \int_{\mathcal{V}} (\mathbf{A} + \mathbf{A}_{\mathrm{p}}) \cdot (\mathbf{B} - \mathbf{B}_{\mathrm{p}})\ \mathrm{d}\mathcal{V} \qquad \nabla \times \mathbf{A} = \mathbf{B}$$

with boundary condition :
Reference field with same distribution

$$(\mathbf{B}_{\mathrm{p}} \cdot \mathrm{d}\mathbf{S})|_{\partial\mathcal{V}} = (\mathbf{B} \cdot \mathrm{d}\mathbf{S})|_{\partial\mathcal{V}}$$

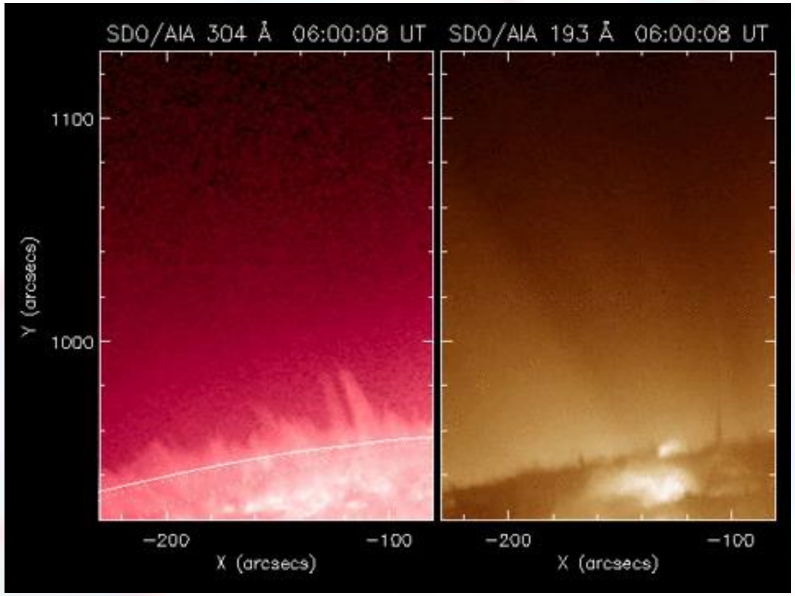
- Recent dev. of methods to compute relative helicity in general 3D datasets:
  - Using Coulomb gauge: **Thalmann et al. 11, Rudenko & Myshyakov 11, Yang et al. 13**
  - Using DeVore gauge (A_z=$A_{p,z}$=0) : **Valori et al. 12, Moraitis et al. 14**
- **➔ Benchmarking performed by ISSI team on "Helicity estimations in models and observations"**

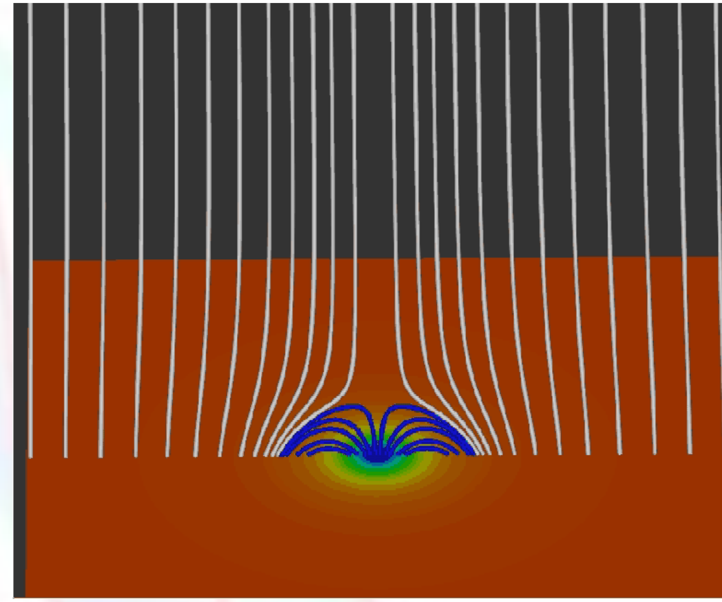


(Valori, Pariat et al. 16)

Test Case: coronal jet simulation

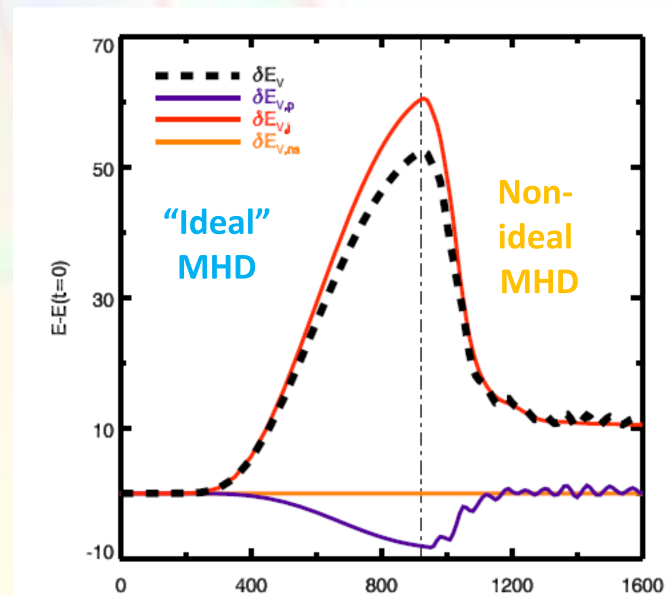
- **3D MHD numerical simulation of a solar coronal jet:** **Pariat et al. 09, 10, 15a, 15b**





- **First phase: quasi-ideal MHD**
  - reconnection is topologically inhibited
  - helicity/energy storage by bottom boundary motions
- **Second phase: non-ideal MHD**
  - impulsive energy release by reconnection
  - ejection of helicity = generation of a solar jet

- 2 distinct phases: test helicity conservation in different conditions



(Pariat et al. 15b)

Method

- In a given system, we compare the volume variation of relative magnetic helicity with its flux at the boundaries of the system
  - Derive the time variation of relative helicity without any assumption on the gauges

Magnetic helicity dissipation

Time variation of relative magnetic helicity

$$\frac{dH}{dt} = -2\int_{\mathcal{V}} \mathbf{B}\cdot\mathbf{E}\, d\mathcal{V} + 2\int_{\mathcal{V}} \frac{\partial\phi}{\partial t}\nabla\cdot\mathbf{A}_\mathrm{p}\, d\mathcal{V}$$
$$+\int_{\partial\mathcal{V}}\left((\mathbf{A}-\mathbf{A}_\mathrm{p})\times\frac{\partial(\mathbf{A}+\mathbf{A}_\mathrm{p})}{\partial t}\right)\cdot d\mathbf{S} - 2\int_{\partial\mathcal{V}}\frac{\partial\phi}{\partial t}\mathbf{A}_\mathrm{p}\cdot d\mathbf{S}$$
$$+2\int_{\partial\mathcal{V}}(\mathbf{B}\cdot\mathbf{A}_\mathrm{p})\mathbf{v}\cdot d\mathbf{S} - 2\int_{\partial\mathcal{V}}(\mathbf{v}\cdot\mathbf{A}_\mathrm{p})\mathbf{B}\cdot d\mathbf{S}$$

Helicity variation and flux of the reference field

(Pariat et al. 15b)

Flux of helicity of the studied field

- Measure the difference between **helicity variations in $\mathcal{V}$** **& helicity flux through the boundary sides $\mathcal{S}$**, **i.e the magnetic helicity dissipation**
  - Dissipation term identical for relative and classical magnetic helicity

- **Helicity-conservation estimation method is completely reconnection-model independent**

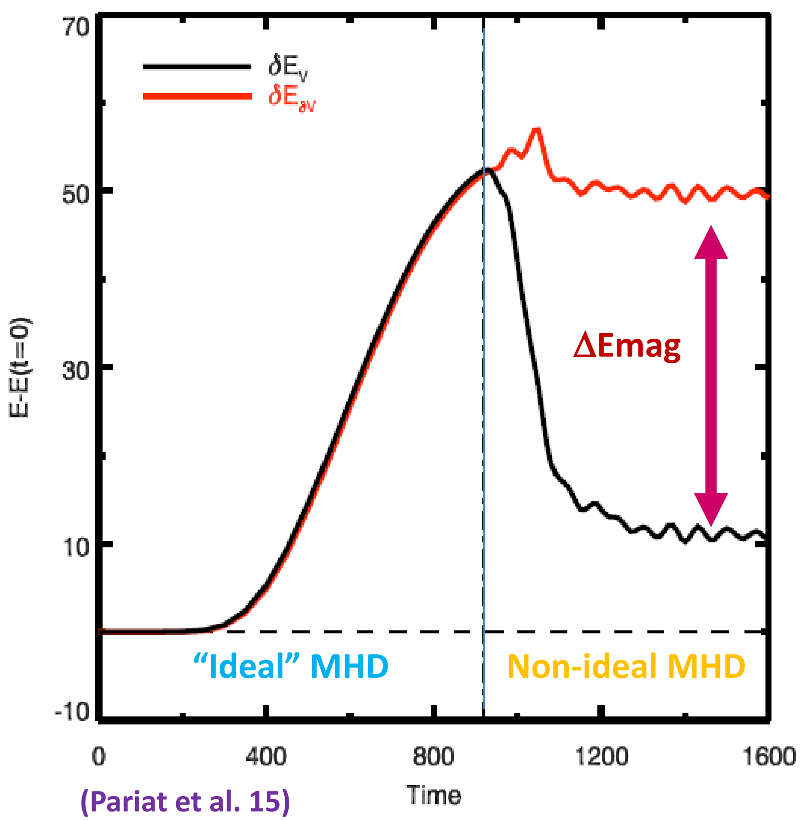
Helicity conservation

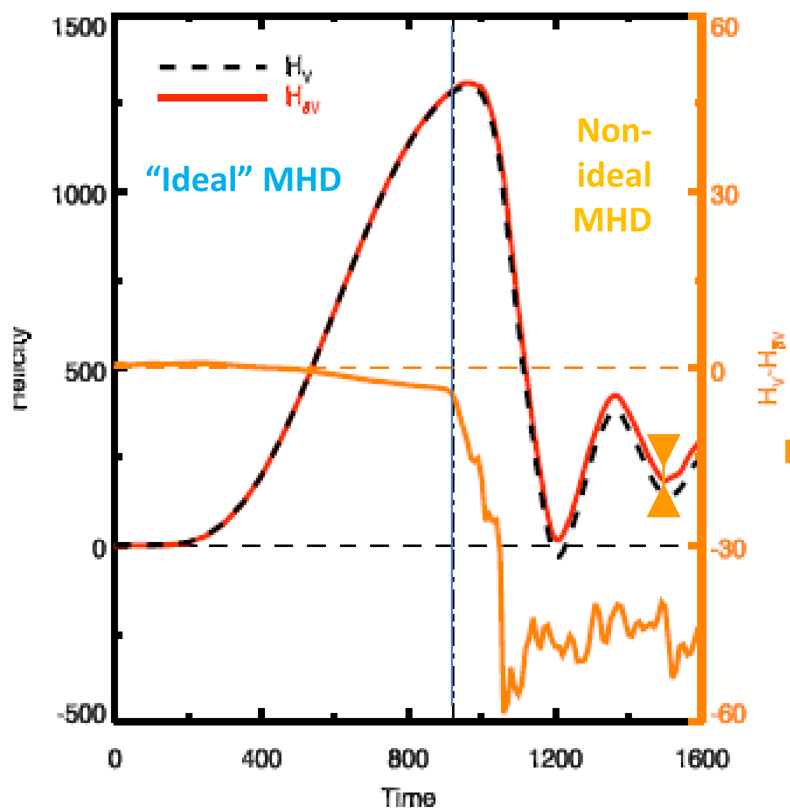
- **Magnetic helicity is very well conserved.**
  - Dissipated helicity is very small compared to the helicity injected in the system.
  - The dissipated helicity is very small compared to the amount of magnetic energy dissipated.

$$\frac{\Delta H_{\mathrm{diss,Ideal}}}{\Delta H_{\mathrm{inj}}} < 3 \times 10^{-3}$$

$$\frac{\Delta H_{\mathrm{diss,\ Non\text{-}ideal}}}{\Delta H_{\mathrm{inj}}} < 0.02$$

$$\frac{\Delta E_{\mathrm{diss,\ Non\text{-}ideal}}}{\Delta E_{\mathrm{inj}}} \sim 0.6$$

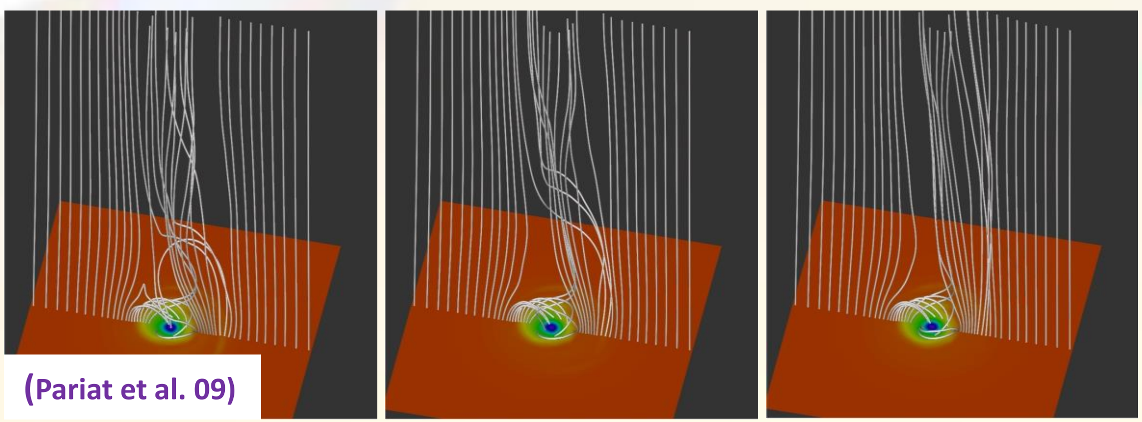




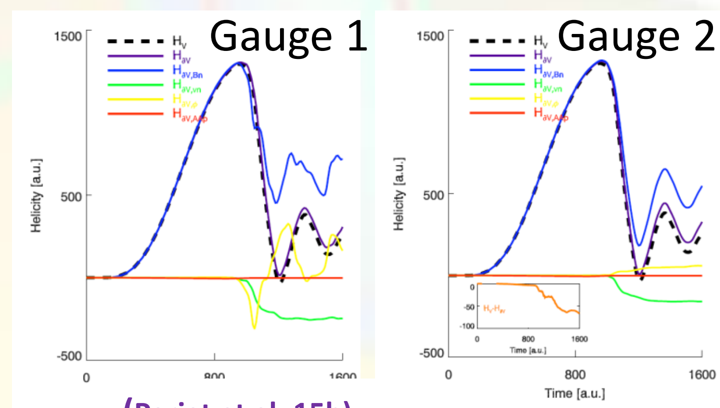
(Pariat et al. 15)

Conclusion

- Recent theoretical & numerical advances now allow the correct estimation of helicity in 3D numerical data sets.
- Estimations of the helicity conservation on an impulsive solar active like events (solar coronal jet).
  - Independent of reconnection models
  - Using several general gauges.
  - **As conjectured, magnetic helicity is very well conserved**
- **Forty years after, the Taylor conjecture can now be numerically tested in general configurations, using typical numerical data sets**
- ➔ Study and characterization of magnetic helicity in solar atmosphere: HELISOL



(Pariat et al. 09)



(Pariat et al. 15b)

Thanks for your attention

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