



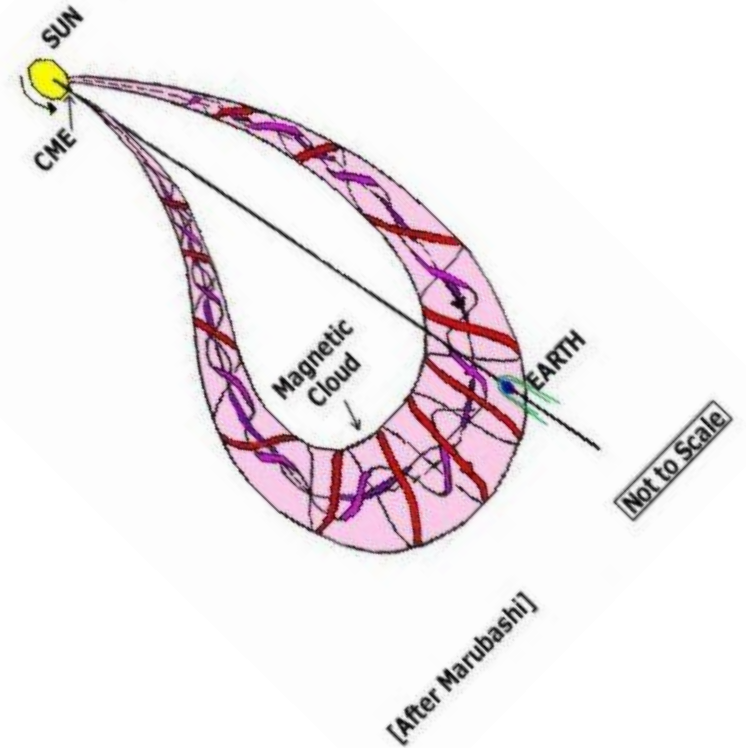
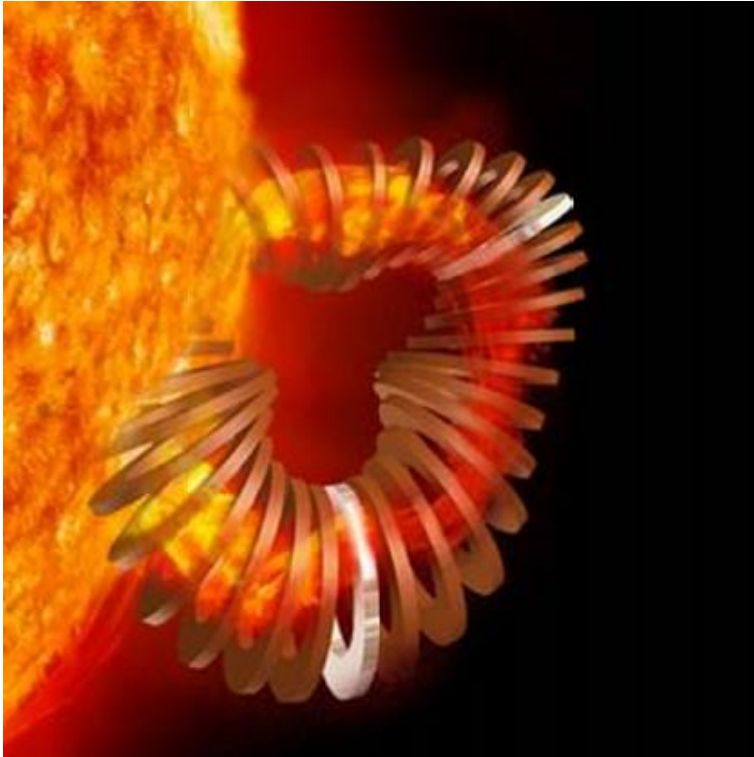
Formation and Properties of the Flux Rope

Reporter : Chen Xing
Advisor : Jiong Qiu
Chunming Zhu

Montana State University
Nanjing University

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Part 1.1 - Introduction



Q1. How does the flux rope form?

Q2. The properties of twist in different parts of a flux rope

Part 1.2 - Q1 : How does the flux rope form?

1. How does a flux rope form?

I. Pre-existing rope

II. In-situ formed rope by reconnection

III. Pre-existing + reconnection

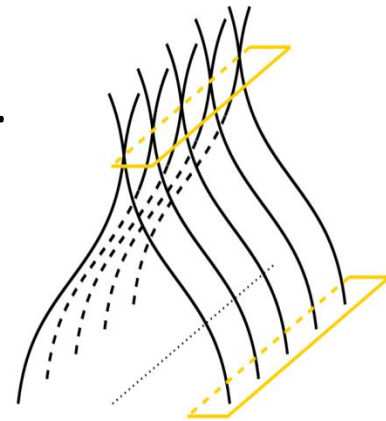
Which one is correct?

- (1) self-reconnection
- (2) zipper-reconnection
- (3) two-line reconnection
- (4) zipper reconnection
+ main-phase reconnection
(two-line reconnection)

2. Flux rope formed by different ways of reconnection, the poloidal flux and toroidal flux in flux ropes have different relationships with reconnection flux injected in flux ropes.

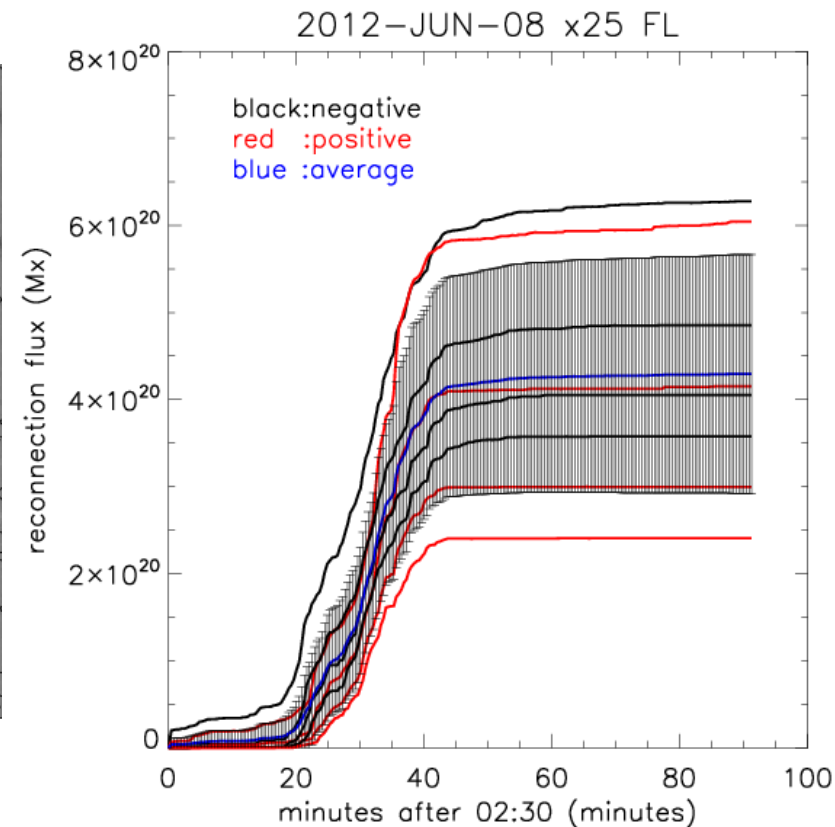
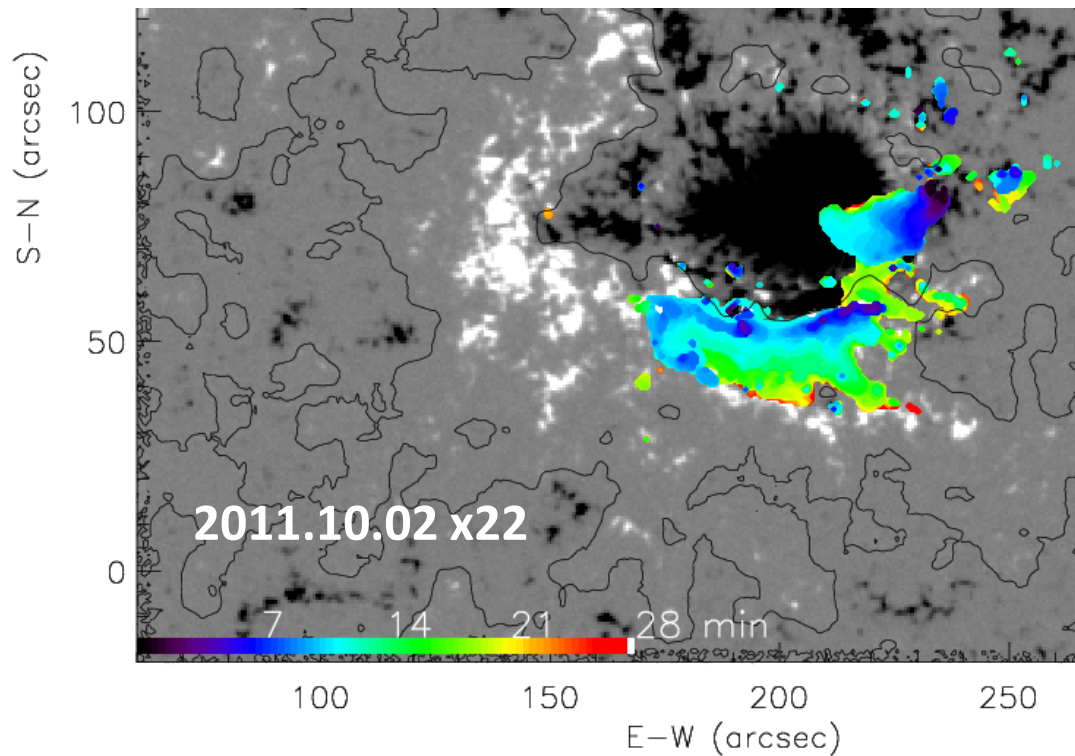
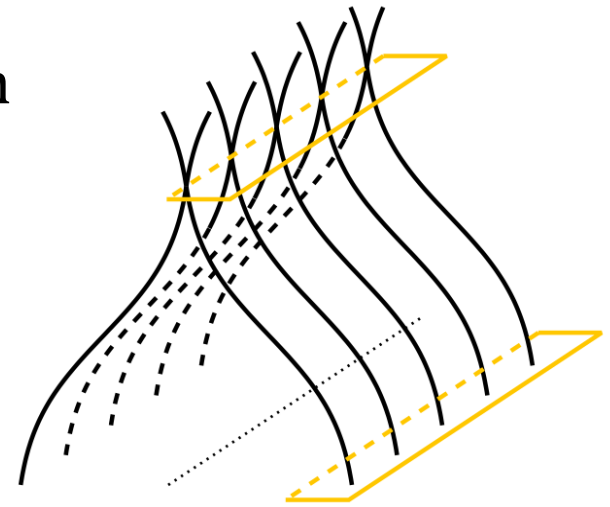
3. How to find these relationships?

Φ_r, Φ_p, Φ_t

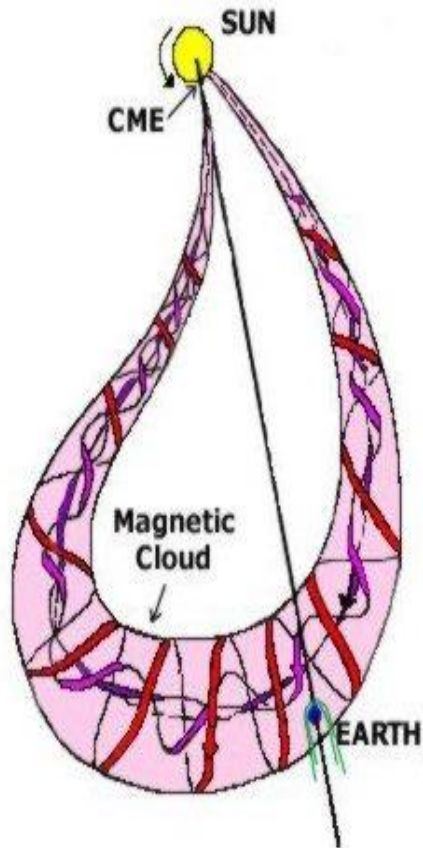


Part 2.1 - Q1 : Measure flux in flare ribbon

$$\Phi_B = \int B_{in} dA_{in} = \int B_R dA_R$$



Part 2.2 - Q1 : Measure flux in magnetic cloud

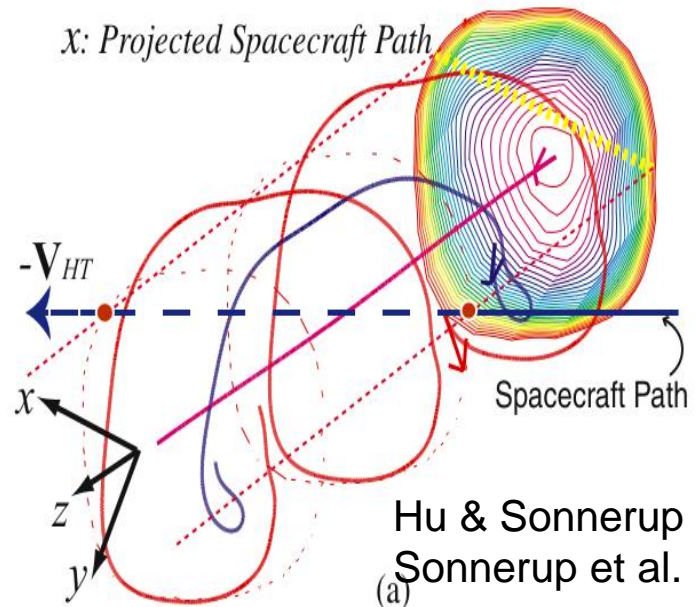


[After Marubashi]

Not to Scale

2D cylindrical structure of the CME flux rope

the Grad-Shafranov solution



Hu & Sonnerup (2002)
Sonnerup et al. (2006)

$$\vec{v}_p = \vec{j} \times \vec{B}$$

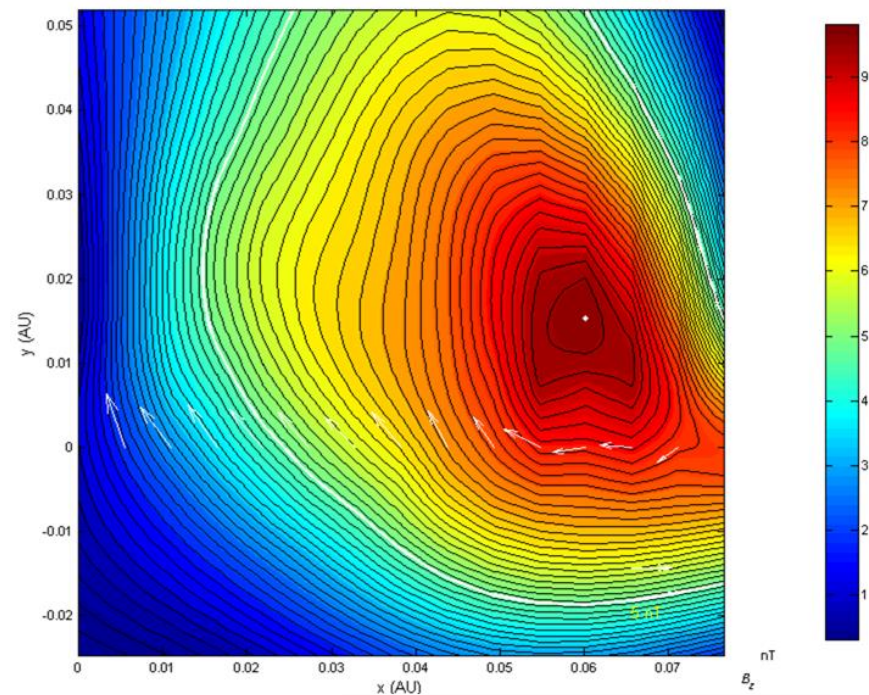
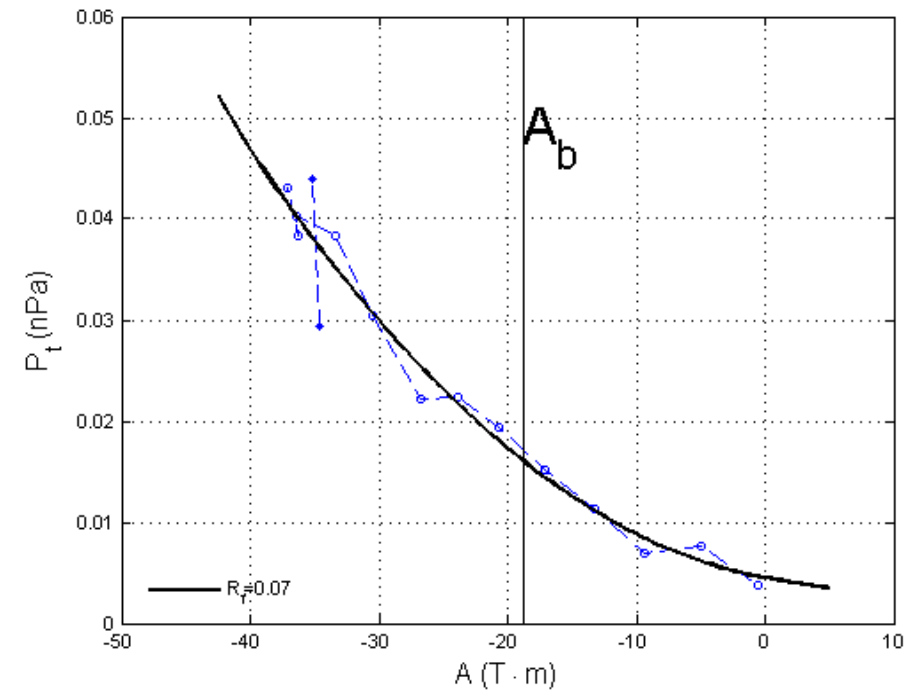
$$\vec{B} = \left(\frac{\partial A}{\partial y}, -\frac{\partial A}{\partial x}, B_z(A) \right)$$

$$P_t(A) = p(A) + B_z^2 / 2\mu_0$$

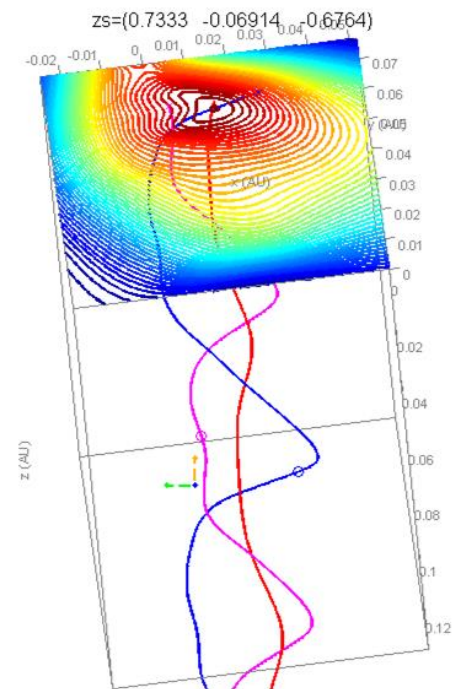
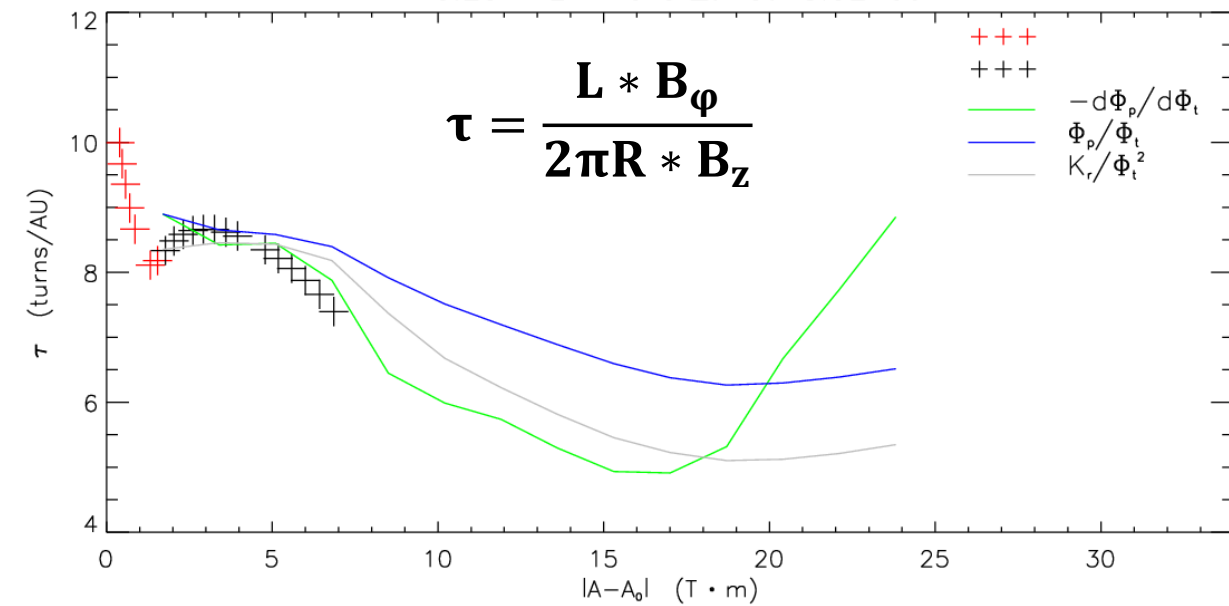
$$\Phi_t = \iint B_z dx dy$$

$$\Phi_p = |A_m - A_b| L$$

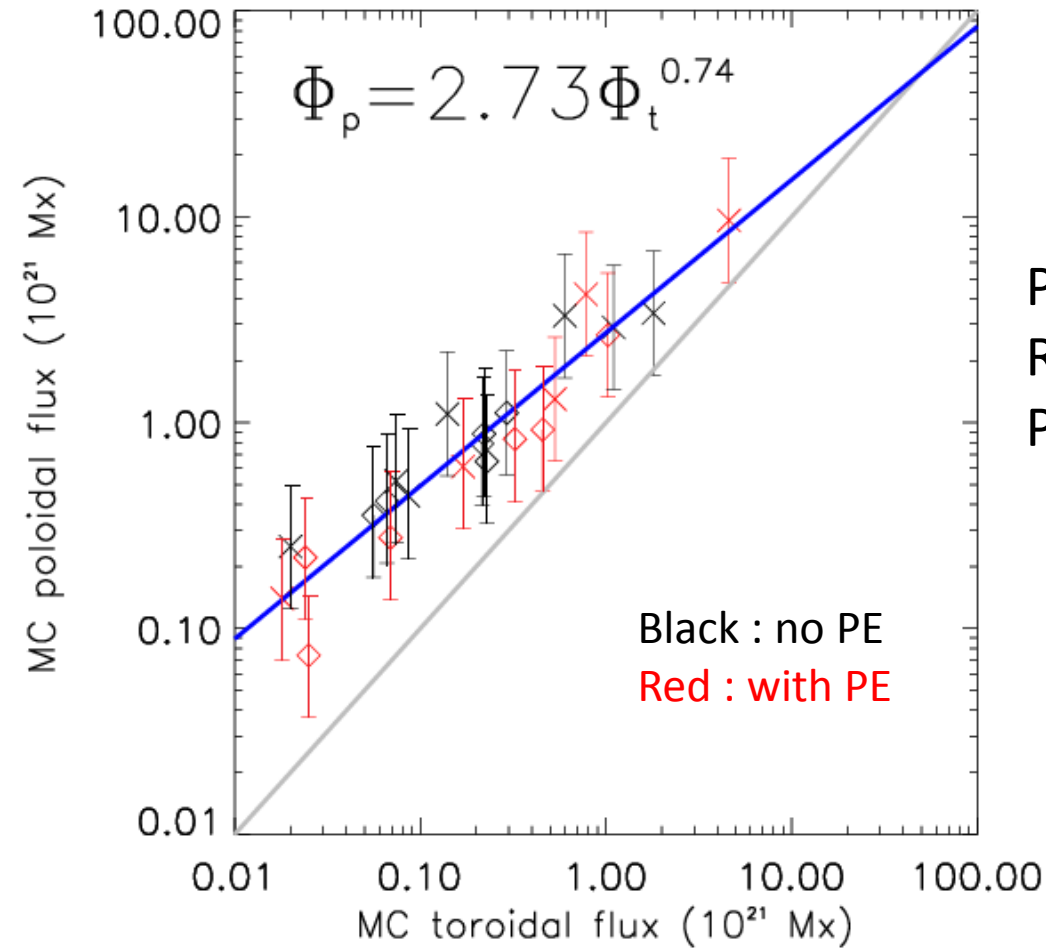
$$\frac{\partial^2 A}{\partial x^2} + \frac{\partial^2 A}{\partial y^2} = -\mu_0 \frac{dP_t}{dA}$$



No.25 FL aver_twist=8.52709



Part 3.1 - Q1 : Poloidal_flux-Toroidal_flux



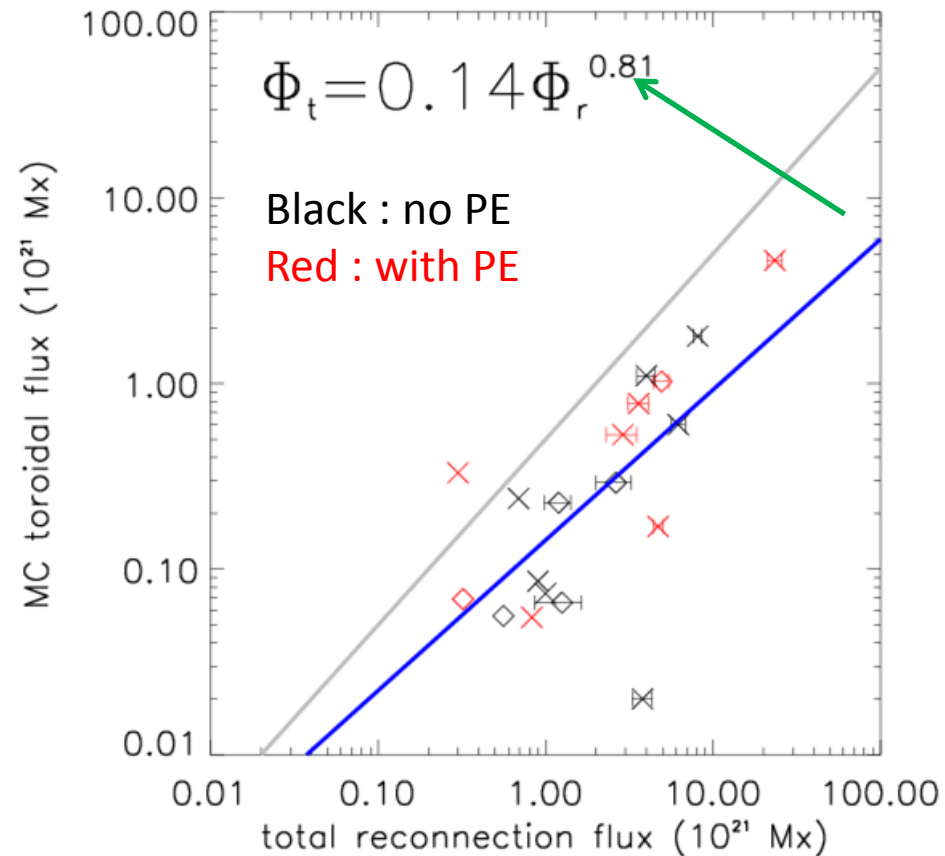
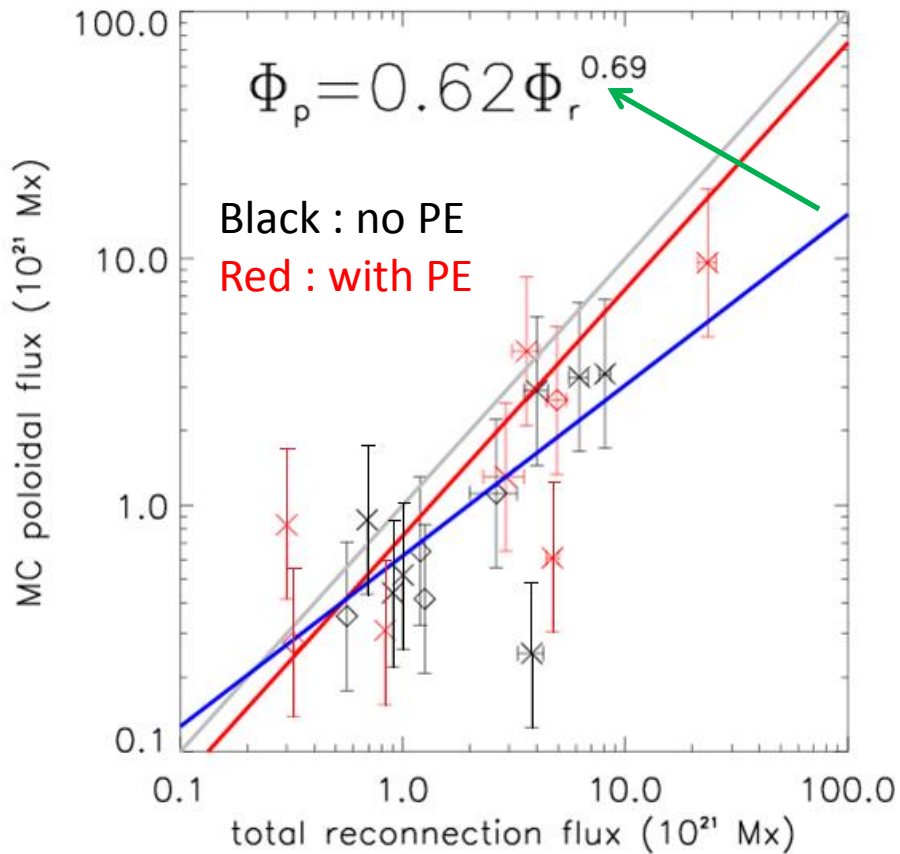
Poloidal_flux : per AU

Rope length : 0.5~2 AU

Poloidal_flux Value range :

0.5~2 * [poloidal_flux (1 AU)]

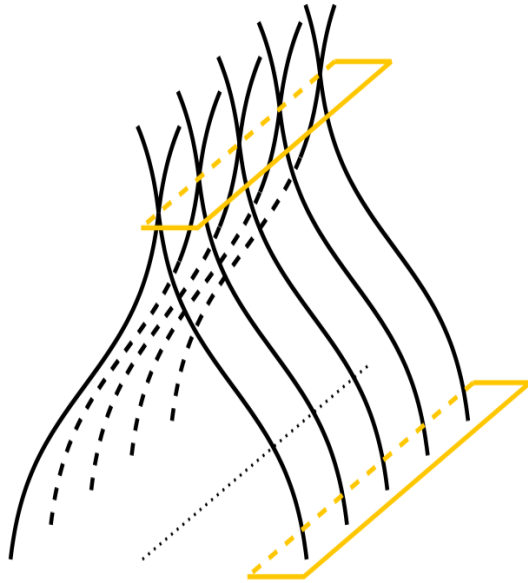
Part 3.2 - Q1 : Poloidal_flux-Reconnect_flux & Toroidal_flux-Reconnect_flux



grey : $po_flux/reco_flux=1$
 red : $po_flux/reco_flux=3/4$
 blue : data fit line

grey : $to_flux/reco_flux=1/2$
 blue : data fit line

Part 3.3 - Q1 : Different ways of reconnection

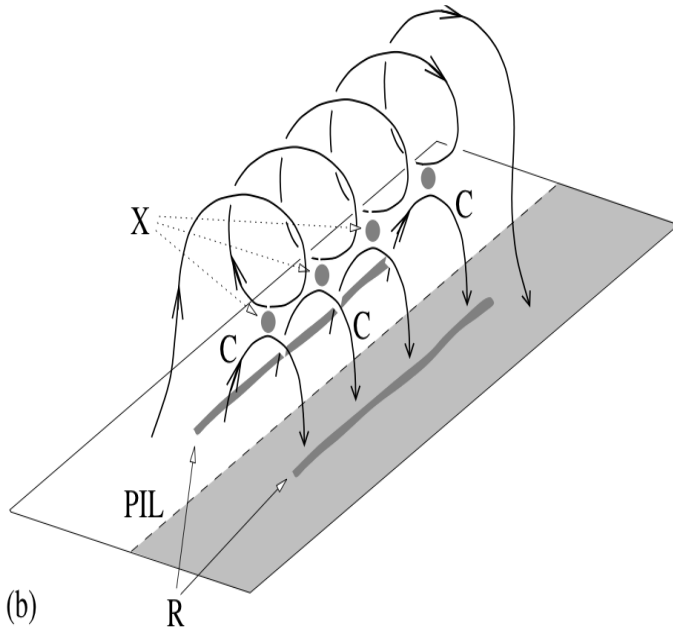


(1) self-reconnection

2D

$$\Phi_p = (\Phi_p)_0 + \Phi_r$$

$$\Phi_t = (\Phi_t)_0$$



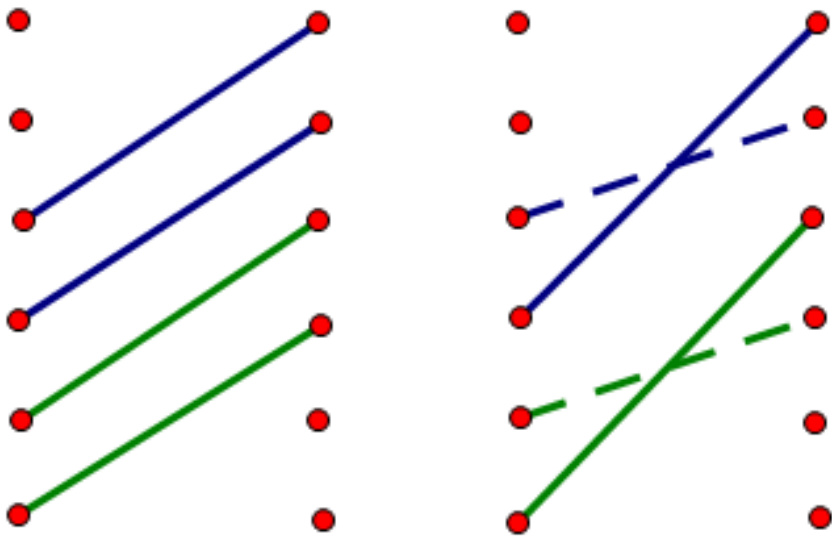
(2) zipper-reconnection

2.5D

If reconnection happen f times along PIL,

$$\Phi_p = (\Phi_p)_0 + \frac{f+0.5}{f+1} \Phi_r$$

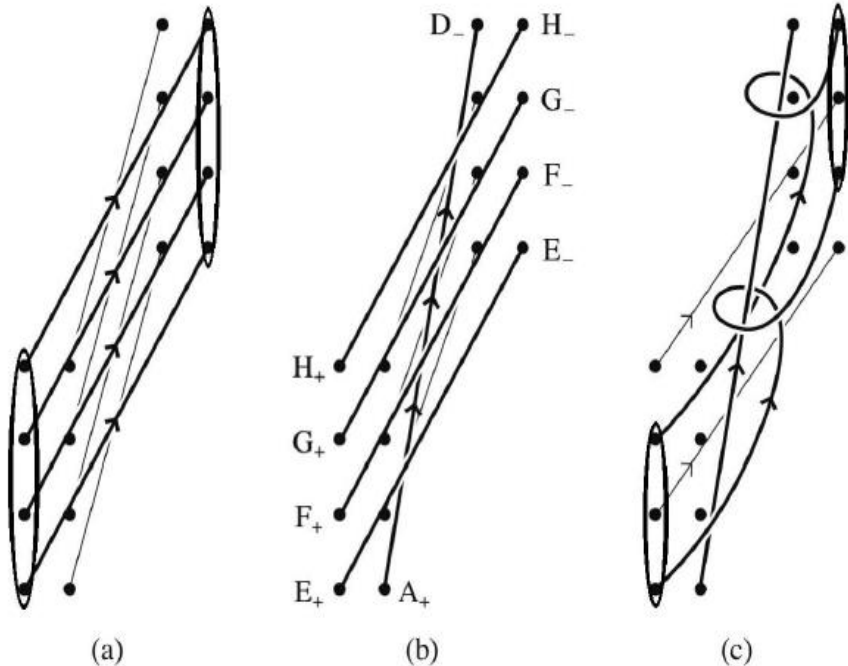
$$\Phi_t = (\Phi_t)_0 + \frac{1}{f+1} \Phi_r$$



(3) two-line reconnection 2.5D

$$\Phi_p = (\Phi_p)_0 + \frac{3}{4} \Phi_r$$

$$\Phi_t = (\Phi_t)_0 + \frac{1}{2} \Phi_r$$



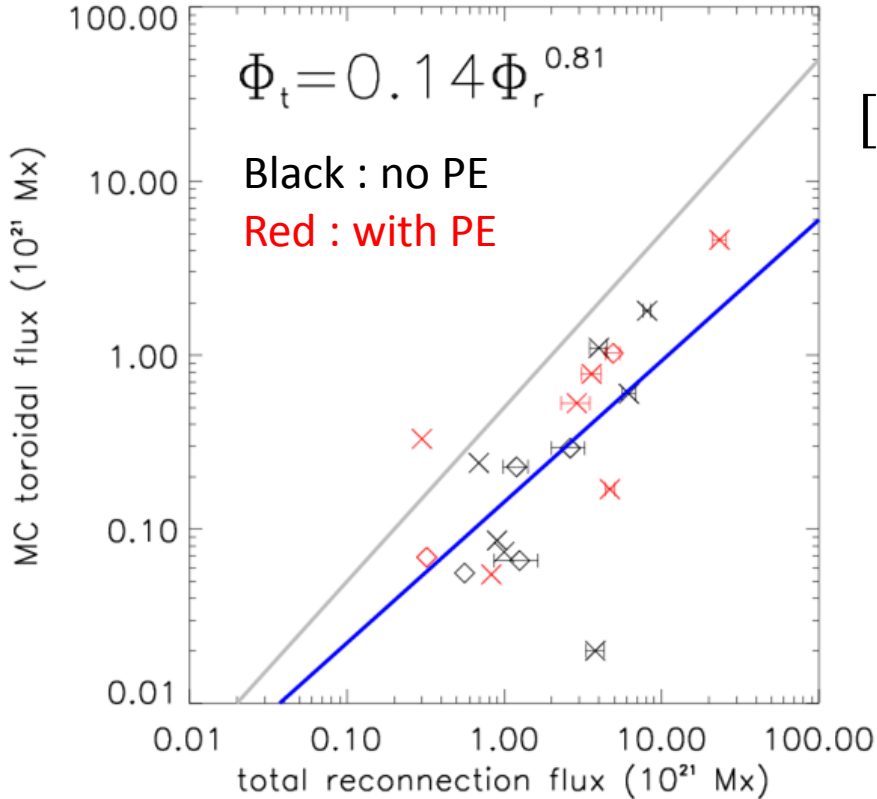
**(4) zipper-reconnection 2.5D
+ main-phase reconnection
(two-line reconnection)**

$$\Phi_r = \Phi_z + \Phi_m$$

$$\Phi_p = (\Phi_p)_0 + \frac{f+0.5}{f+1} \Phi_z + \frac{3}{4} \Phi_m$$

$$\Phi_t = (\Phi_t)_0 + \frac{1}{f+1} \Phi_z + \frac{1}{2} \Phi_m$$

Part 3.4 - Q1 : Analysis



grey : $\text{to_flx}/\text{reco_flx}=1/2$
 blue : data fit line

$$[\Phi_t]/\Phi_r \geq [\Phi_t - (\Phi_t)_0]/\Phi_r = \left\{ \begin{array}{l} V1 \quad (1) \\ V2 \quad (2) \\ V3 \quad (3) \\ V4 \quad (4) \end{array} \right.$$

when $f > 1$

$$\frac{1}{2} = V3 > V4 > V2 > V1 = 0$$

(1) self-reconnection

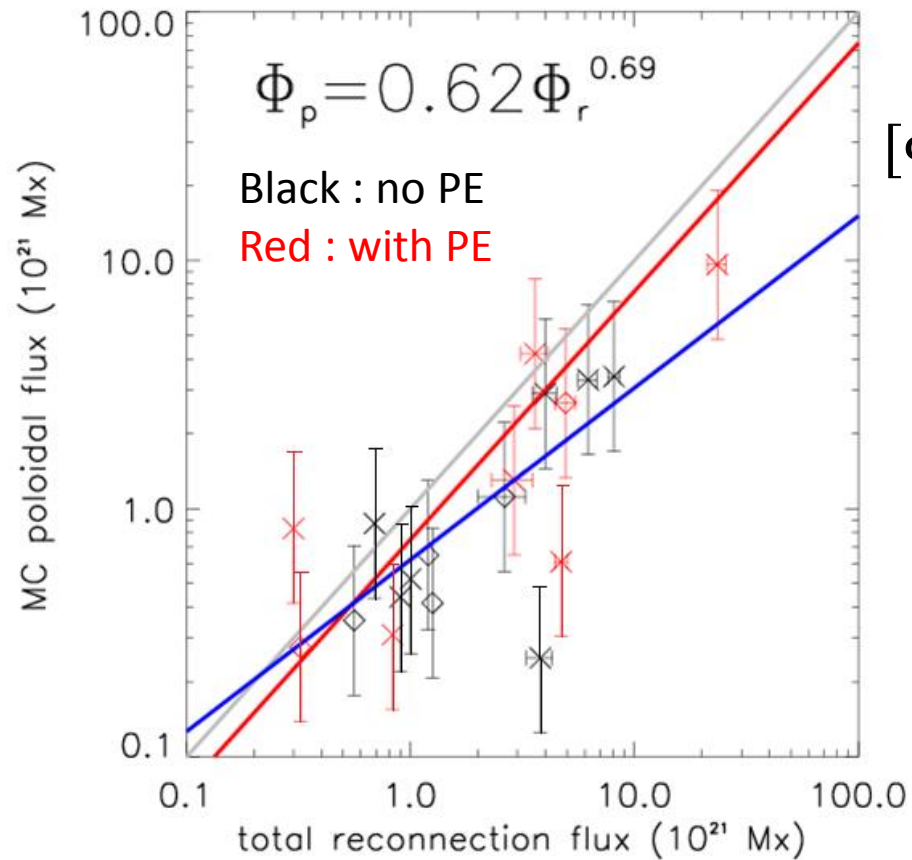
(2) zipper-reconnection

(3) two-line reconnection

(4) zipper-reconnection

+ main-phase reconnection
(two-line reconnection)

$$\frac{1}{f+1}$$



grey : $po_flux/reco_flux=1$
 red : $po_flux/reco_flux=3/4$
 blue : data fit line

$$[\Phi_P]/\Phi_r \geq [\Phi_P - (\Phi_P)_0]/\Phi_r = \left\{ \begin{array}{l} R1 \quad (1) \\ R2 \quad (2) \\ R3 \quad (3) \\ R4 \quad (4) \end{array} \right.$$

when $f > 1$

$$1 = R1 > R2 > R4 > R3 = 3/4$$

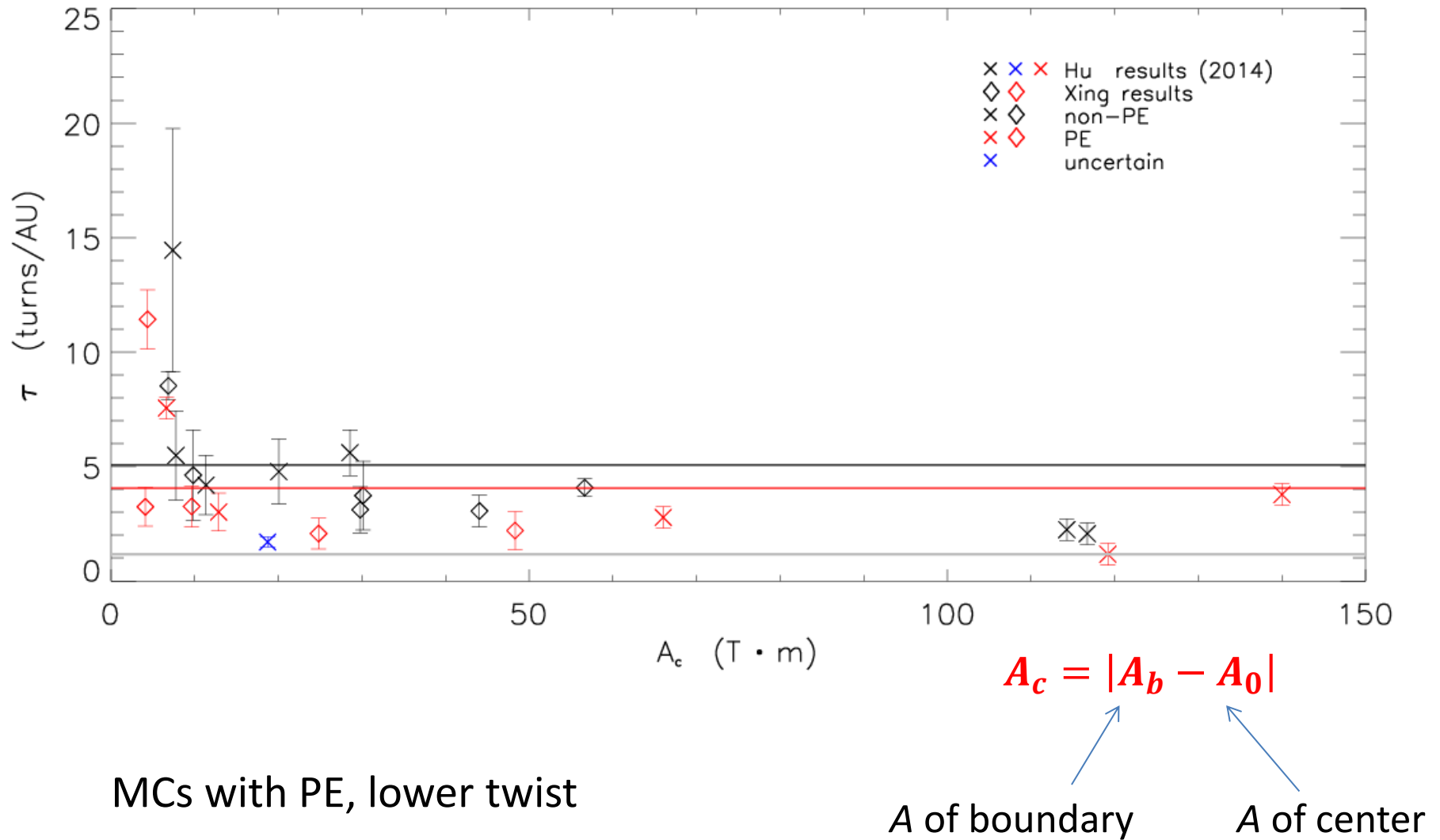
When assume flux rope length is 2 AU,
 How many cases can lie above the ratio line?

- (1) self-reconnection 52%
- (2) zipper-reconnection
- (3) two-line reconnection 79%**
- (4) zipper-reconnection
 + main-phase reconnection
 (two-line reconnection)

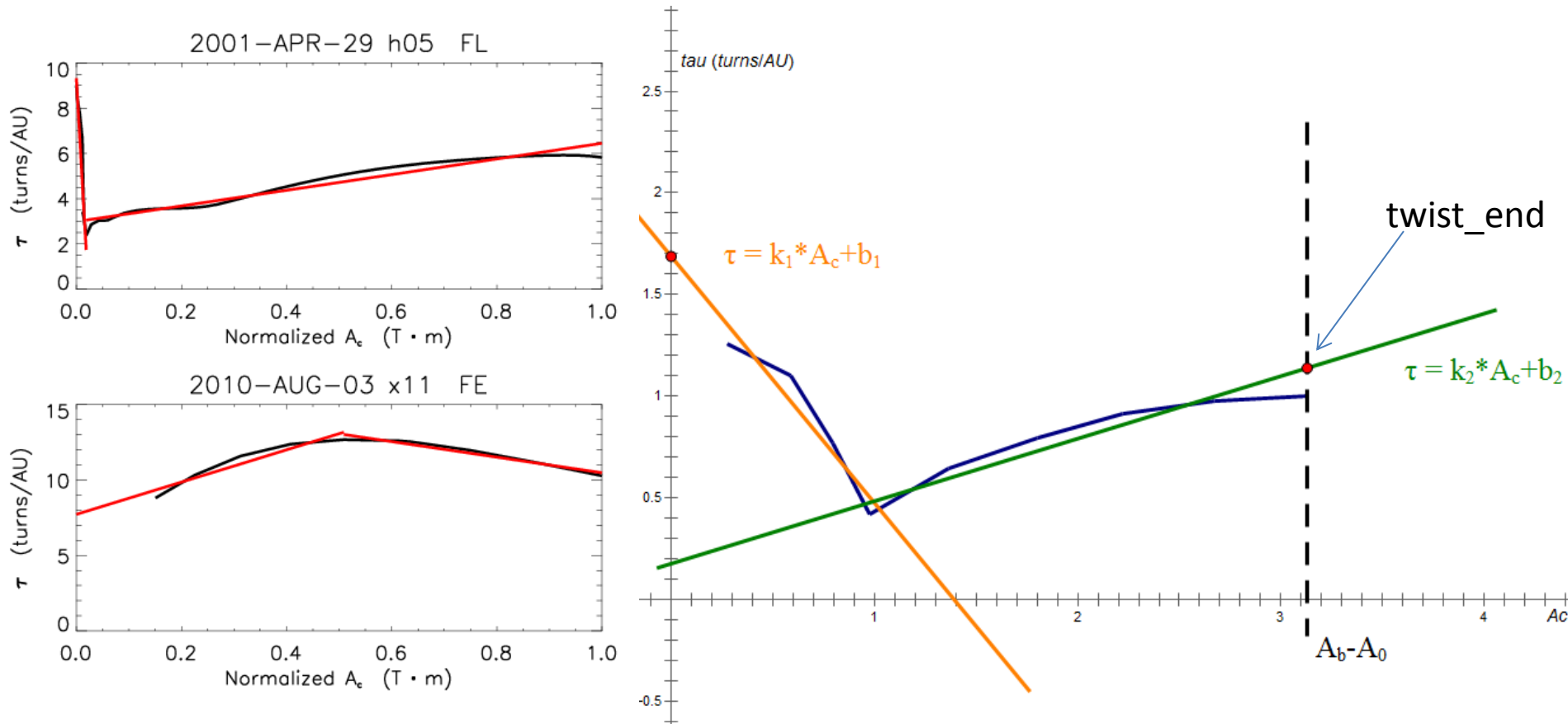
Part 3.5 - Q1 : Conclusions

1. The pre-existing rope doesn't contribute much to flux of the flux rope since cases' poloidal flux don't lie much above the lowest line (3/4 line) even we assume the flux rope length is 2AU.
2. 2D model, self-reconnection (1), its toroidal flux all come from the pre-existing rope, which means that may also exist a high $(\Phi_p)_0$, but this doesn't agree with the real fact. Model 1 may be wrong.
3. From view of toroidal_flux-reconnect_flux, model 2 fits data best. From view of poloidal_flux-reconnect_flux, model 3 fits data best.
4. Actually, zipper-reconnection (2) and two-line reconnection (3) are specialization of model (4) : zipper+main-phase (set phi-m to 0 or phi-z to 0). Model 4 may fit the data.

Part 4.1 - Q2 : Average twist



Part 4.2 - Q2 : Twist distribution curve

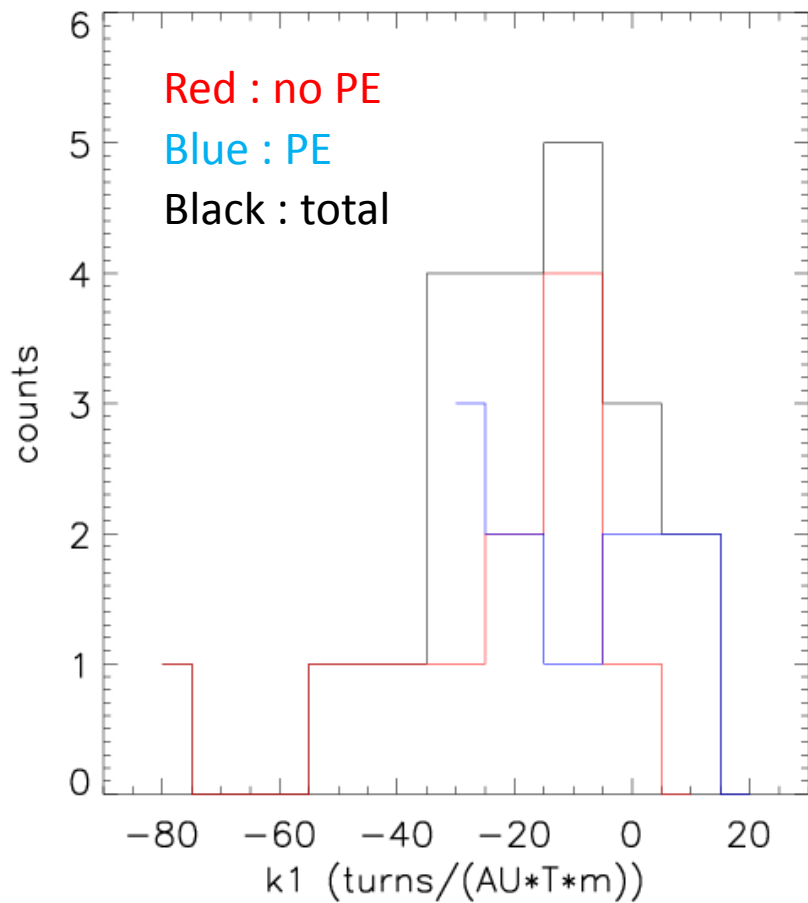


k_1 : it describes how twist distributes in the core of MCs

b_1 : the twist of the core of MCs

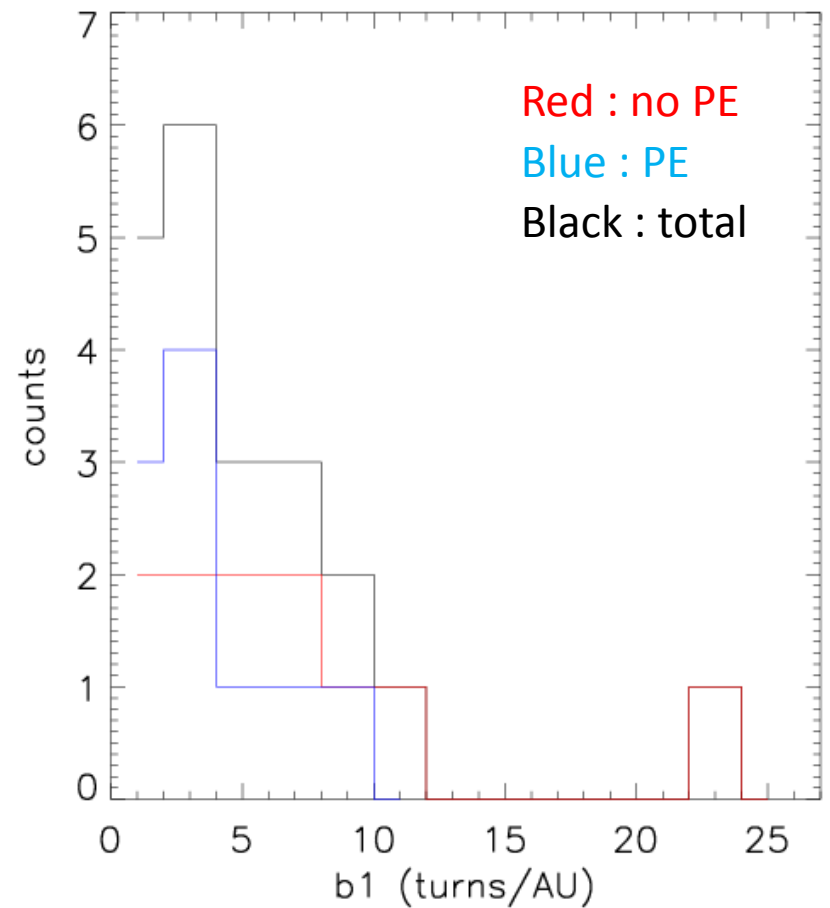
k_2 : it describes how twist distributes in the outer layer of MCs

twist_end: the twist of boundary of MCs



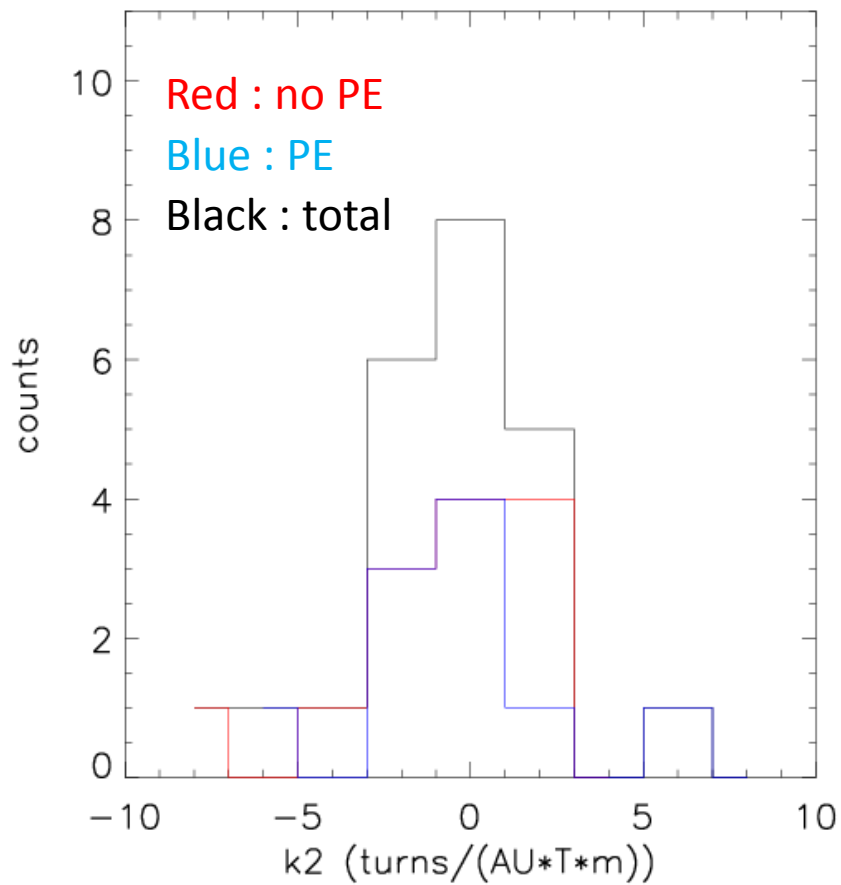
Conclusion 1 :
the core, a decrease distribution

k1 : it describes how
twist distributes in the
core of MCs



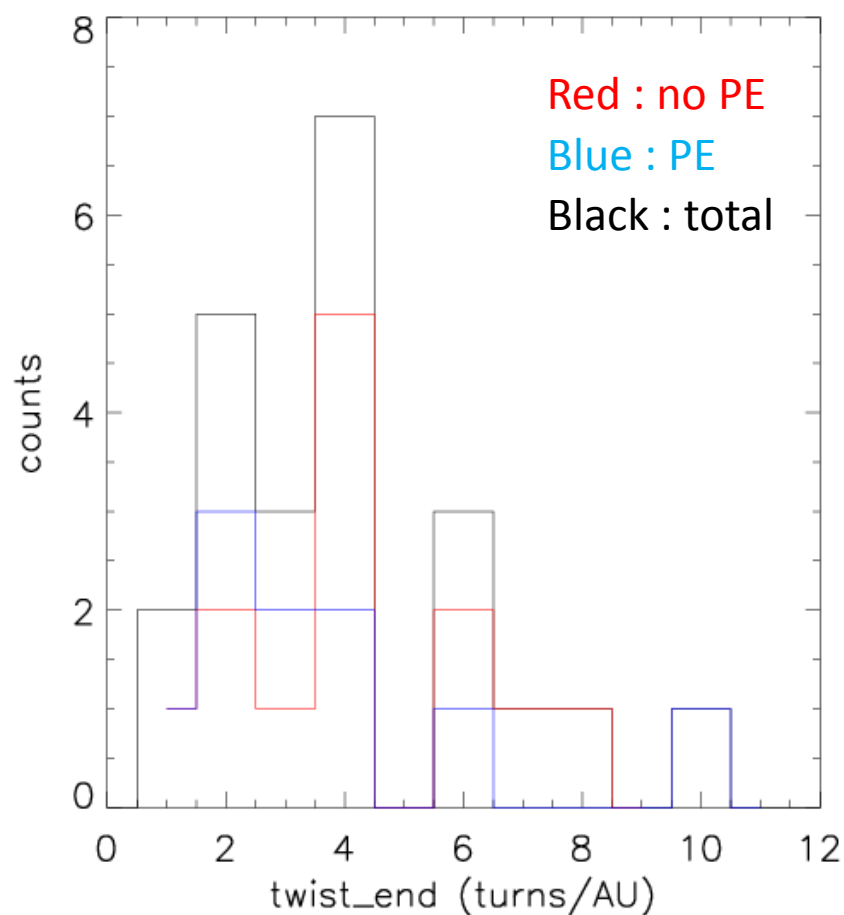
Conclusion 2 :
the twist of the core, 2-8 turns/AU;
MCs with PE, with a lower-twist core

b1 : the twist of
the core of MCs



Conclusion 3 :
the outer layer, a flat distribution,
close to uniform twist

$k2$: it describes how
twist distributes in the
outer layer of MCs



Conclusion 4:
the twist of outer layer, 2-4 turns/AU

twist_end : the
twist of boundary
of MCs

Part 5 - Q2 : Conclusions

- Twist of flux rope with PE is lower than that without PE. For cases with PE, a lower-twist core may contribute to this.
- Most twist distribution curves include a decreasing part and a flat part, infer that there exist a pre-existing rope as core and an uniform-twist outer layer, both for cases with and without PE.
- Twist of flux rope's core is about 2-8 turns per AU. When it is close to flux rope's boundary, the twist is about 2-4 turns per AU. (Compared to Eric Priest's twist model : core-twist is about 4 turns/AU, boundary-twist is about 3.5 turns/AU.)

Thank you for listening!