Hinode/SOT (courtesy of T.J. Okamoto)

# Flare-productive active regions: magnetic properties and evolutions

[ Toriumi et al. 2017, ApJ, 834, 56 ]


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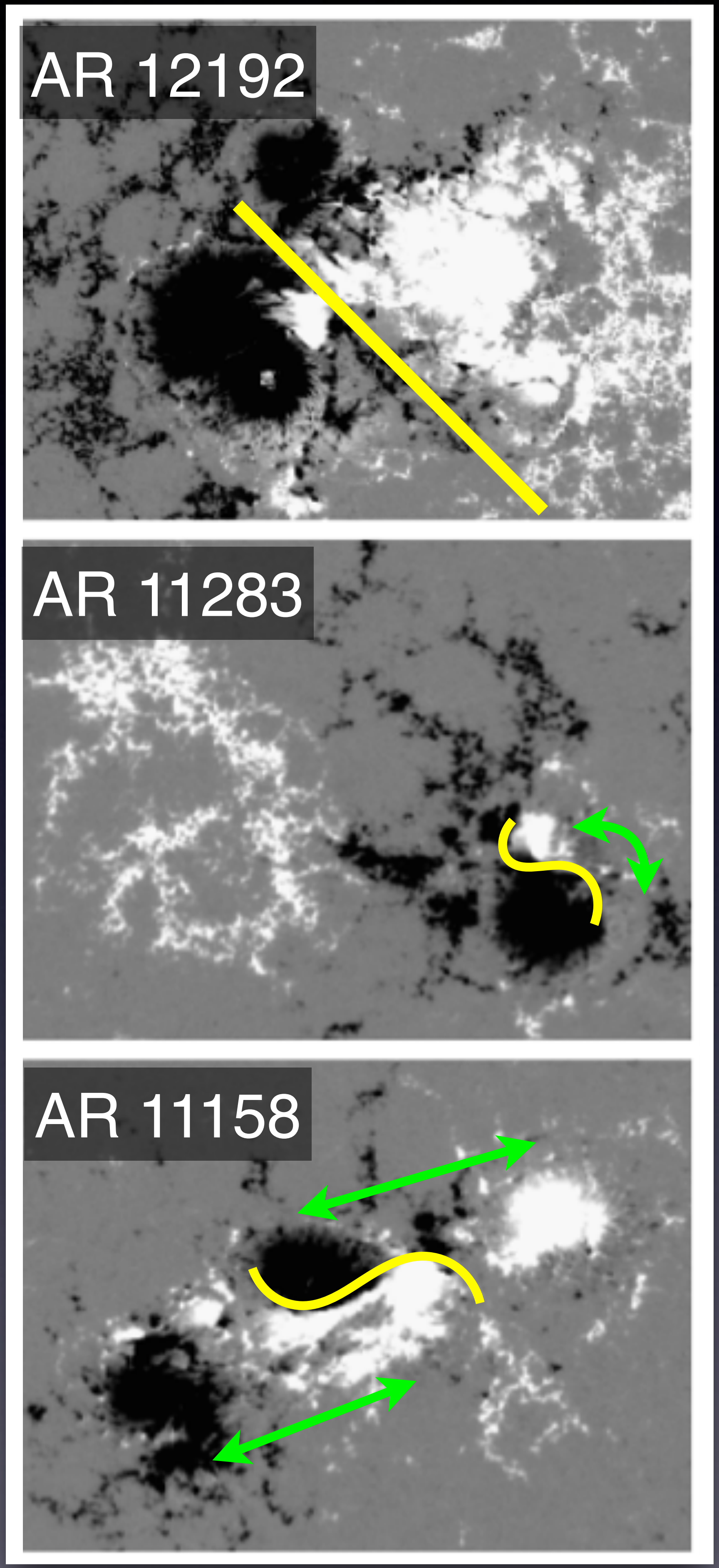
Solarnet IV Meeting (2017 Jan 17)

# 1. Introduction

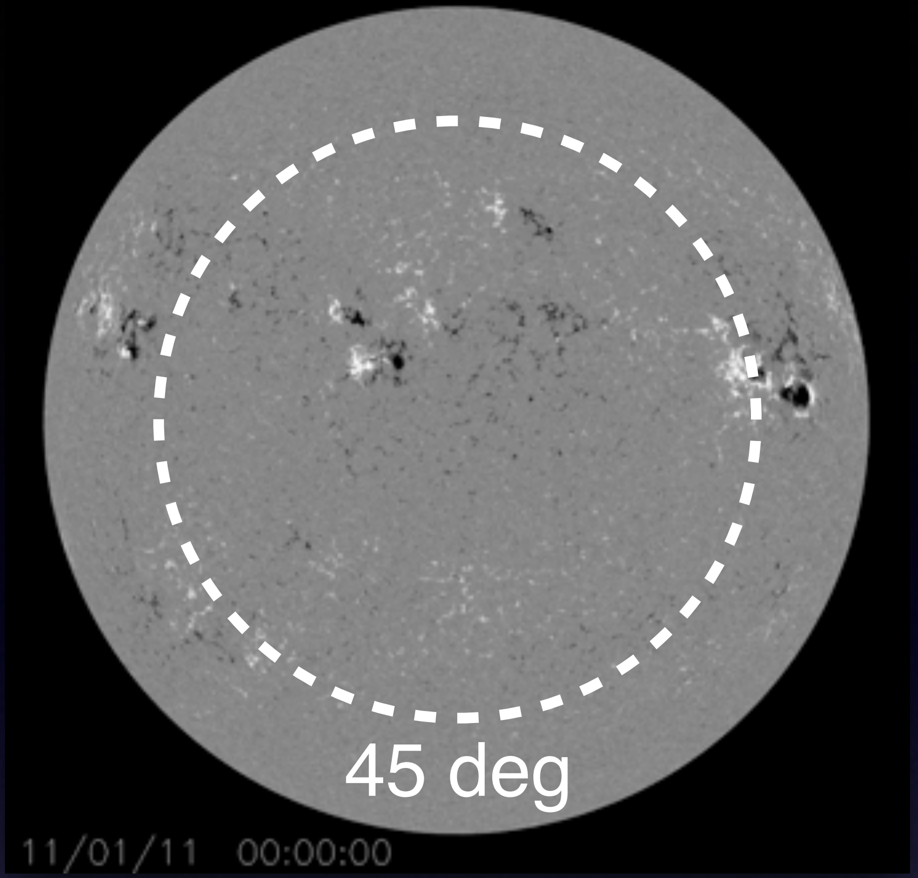
- Observations of Flare ARs
  - Sheared PIL [Zirin & Liggett 1987]
  - Twisted flux tubes [Leka+ 1996]
  - Complex multipolar spots [Zirin & Tanaka 1973]
  - etc…

- Aims of this Study
  - Statistically investigate the trends of flaring ARs with minimum selection bias
    → SDO/HMI and AIA
  - Find parameters that determine the flare duration, magnitude, and CME-eruptive/not
  - Utilize the results as inputs for flux-emergence simulations of flare ARs

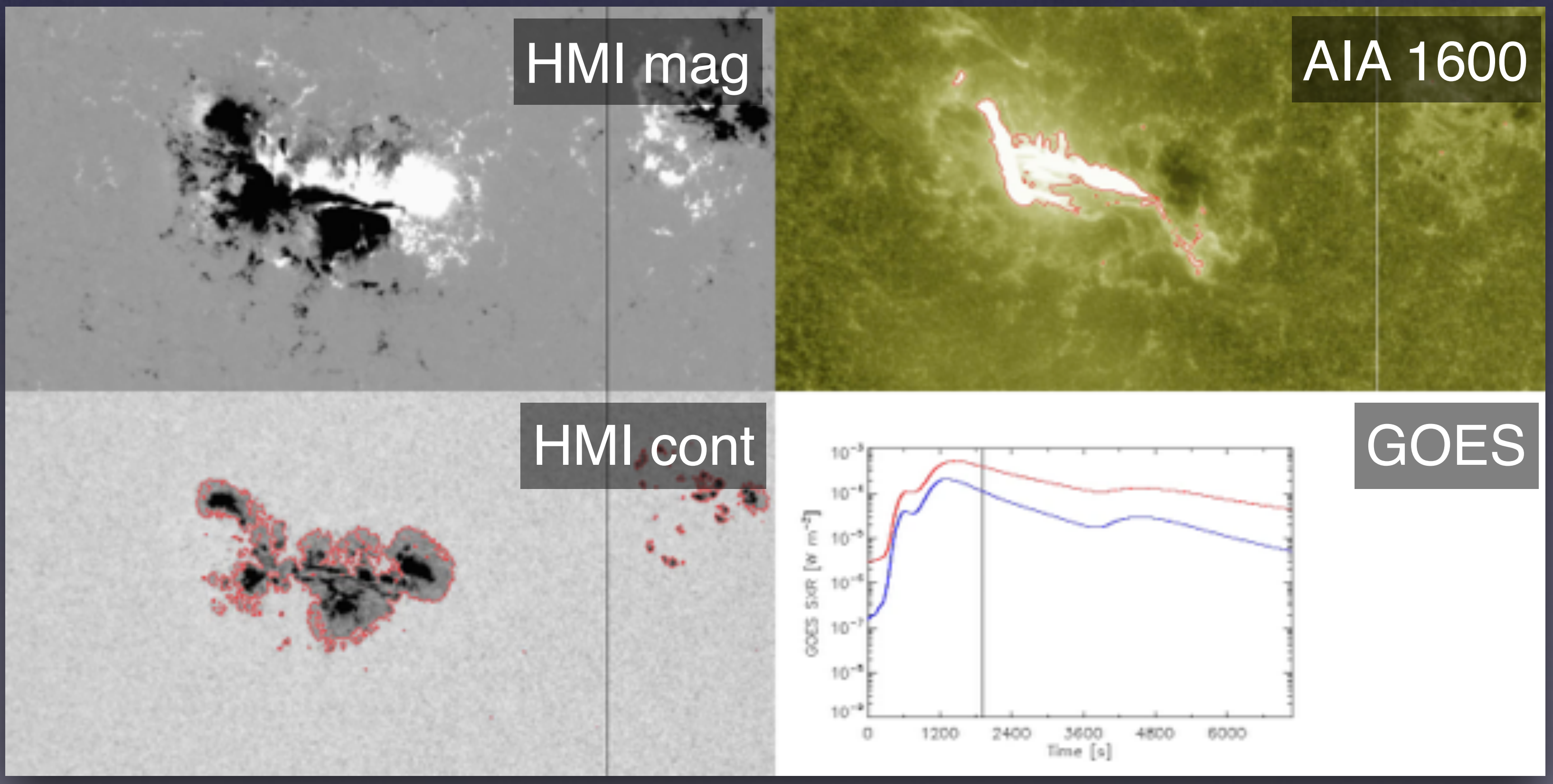


# 1. Introduction

- Flare Events
  - Solar Cycle 24: May 2010 — ~~April 2016~~ Jan 17, 2017
    6.7 (~~6~~ years from beginning to declining phase)
  - All ≥M5.0 flares with heliocentric angle $\theta \le 45$ deg (i.e. $\mu = \cos\theta \ge 0.71$)
  - 51 flares (20 X + 31 M events) from 29 ARs

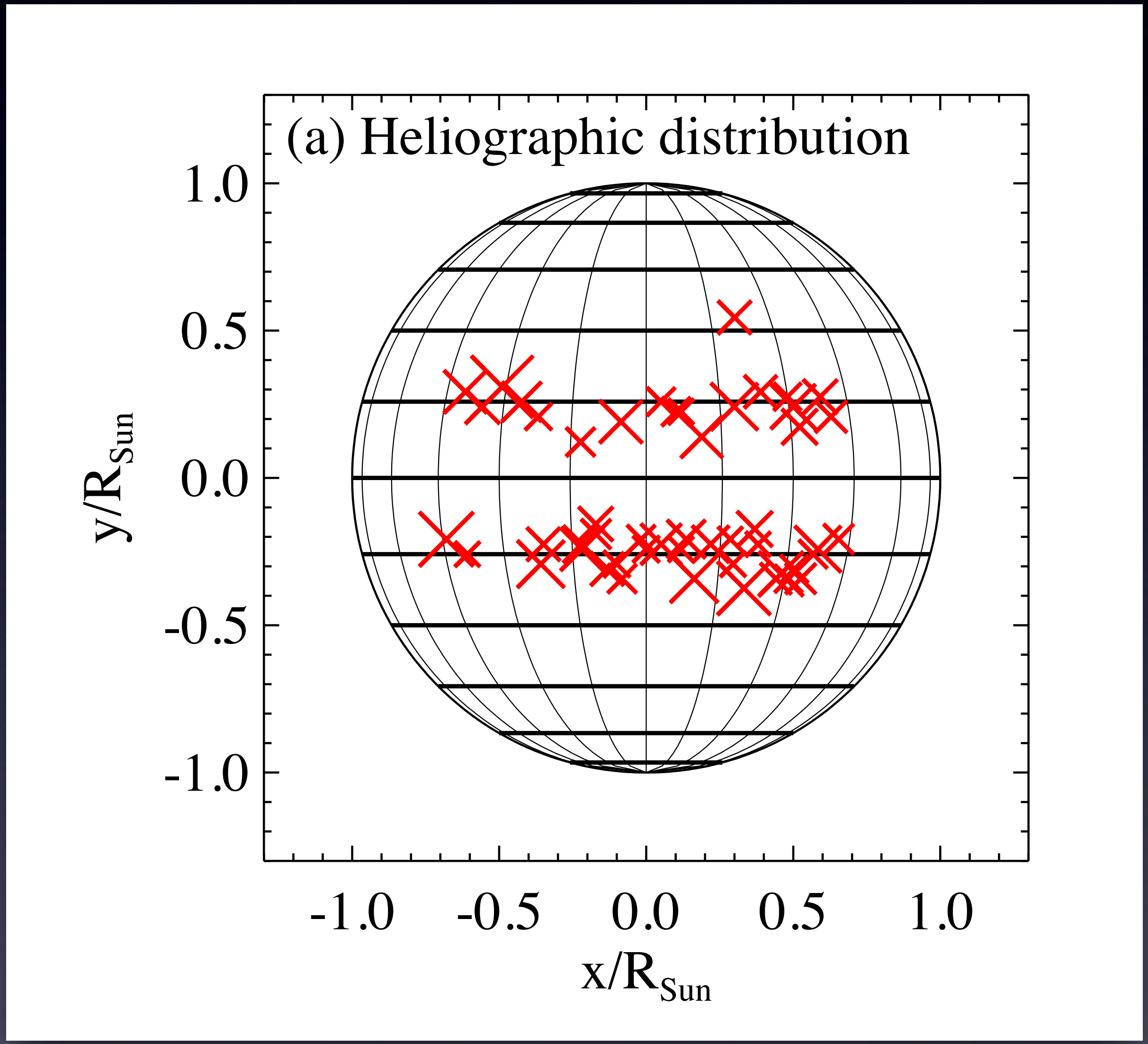



- Data Sets
  - Optical/UV: SDO/HMI and AIA mtrack-ed data
  - SXR: GOES light curves
  - CME: SOHO/LASCO CDAW



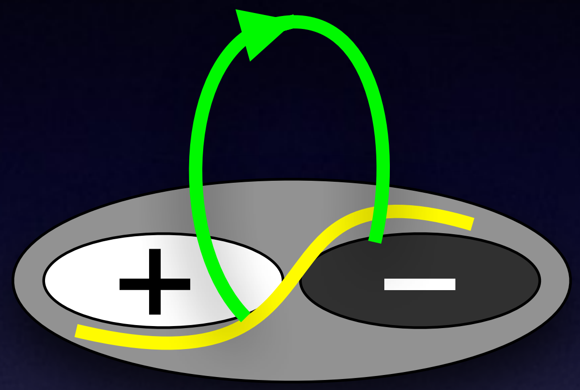
# 2. ARs and Flares

- AR Properties

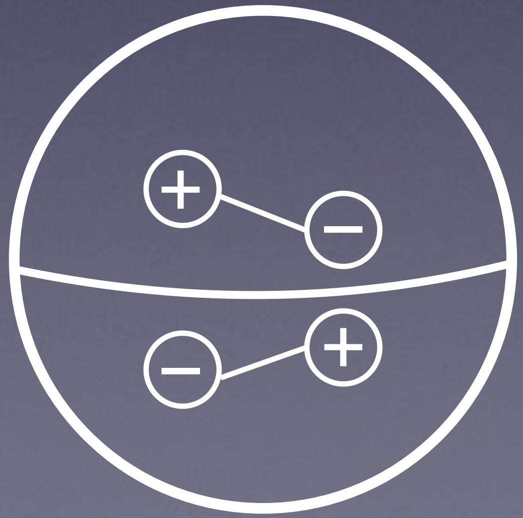



Symbol size varies with the GOES level from M5.0 to X5.4.

- 24 out of 29 ARs (= 83%) showed δ-sunspots for at least one flare occurrence [Künzel 1960, Sammis+ 2000].

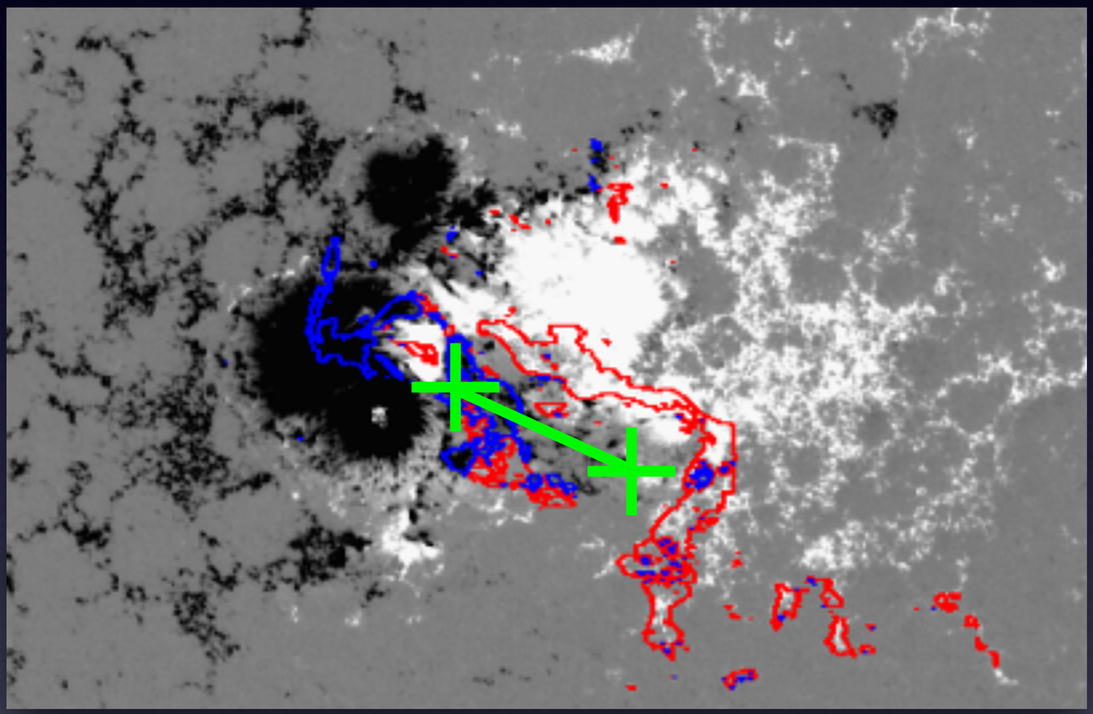


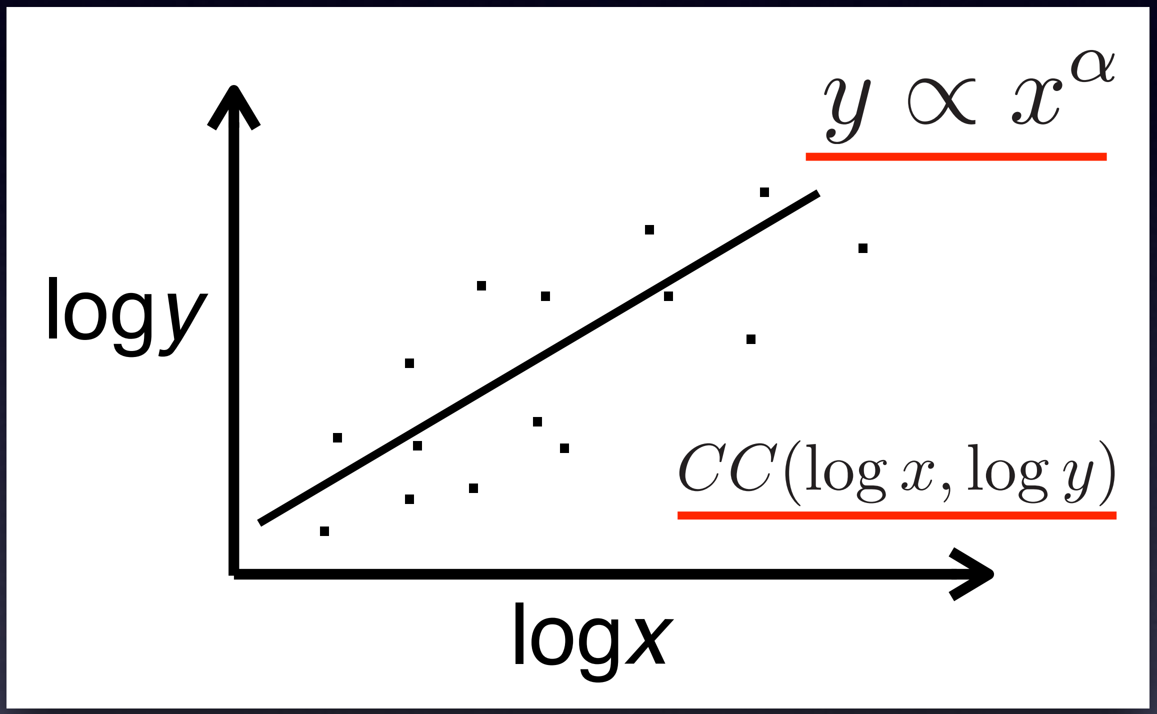
- 4 out of 29 ARs (= 14%) violated Hale's polarity rule for at least one flare occurrence, as opposed to ~4% for all ARs [e.g., Wang & Sheeley 1989, Khlystova & Sokoloff 2009].



# 3. Parameters that Dictate Flares?

- Parameters? → Scatter Plots!

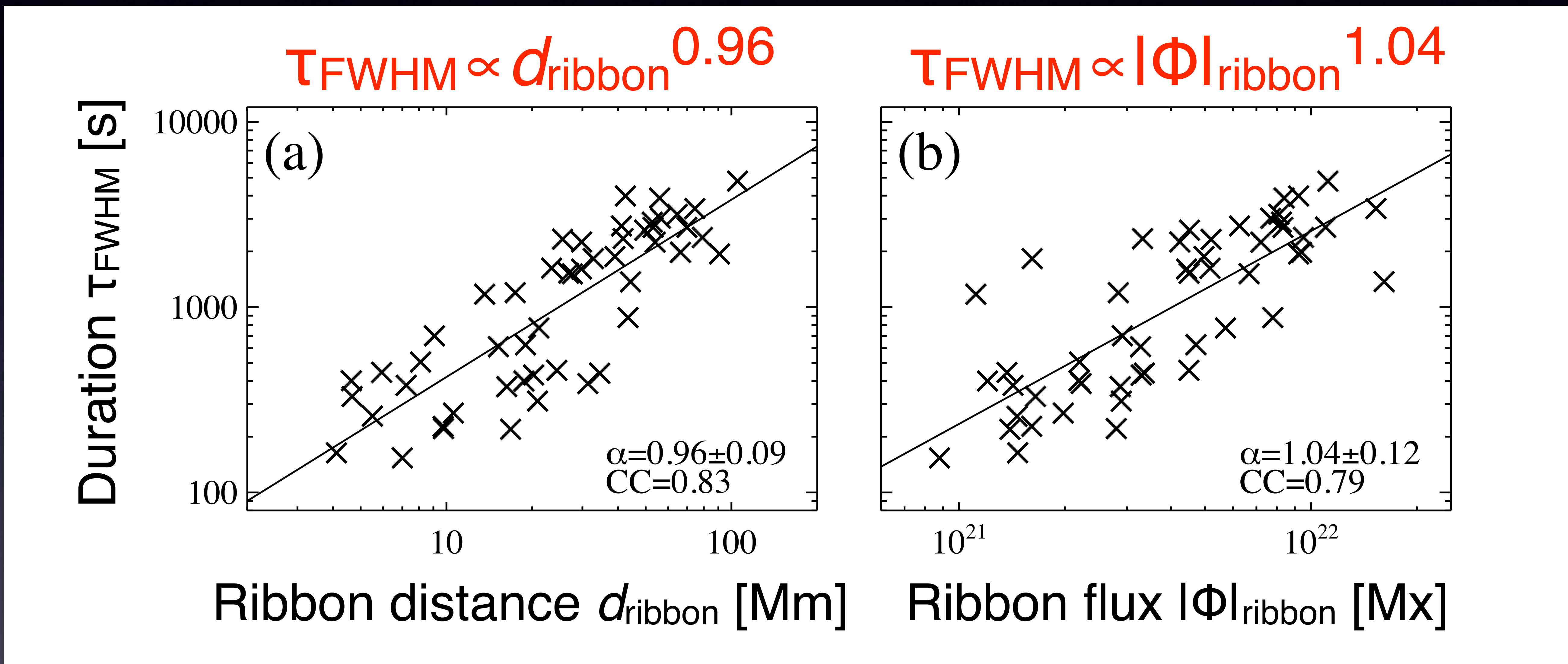





- Extract various parameters for 51 flare events
  - *y* : GOES parameters
    - Flare duration, magnitude
  - *x* : AR parameters and flare parameters
    - Spot area, total mag flux, ribbon area, ribbon distance, etc.

# 3. Parameters that Dictate Flares?

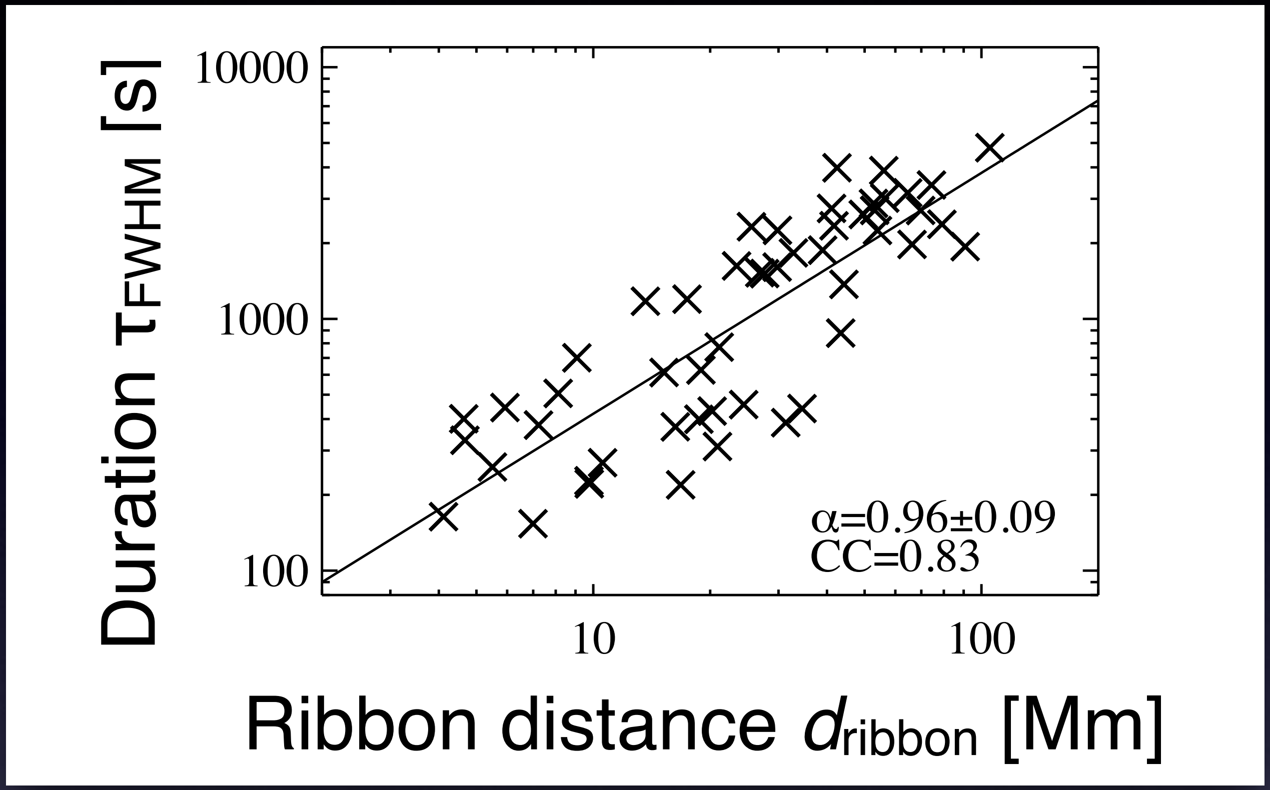
- Two Least-scattered (best-*CC*) Plots

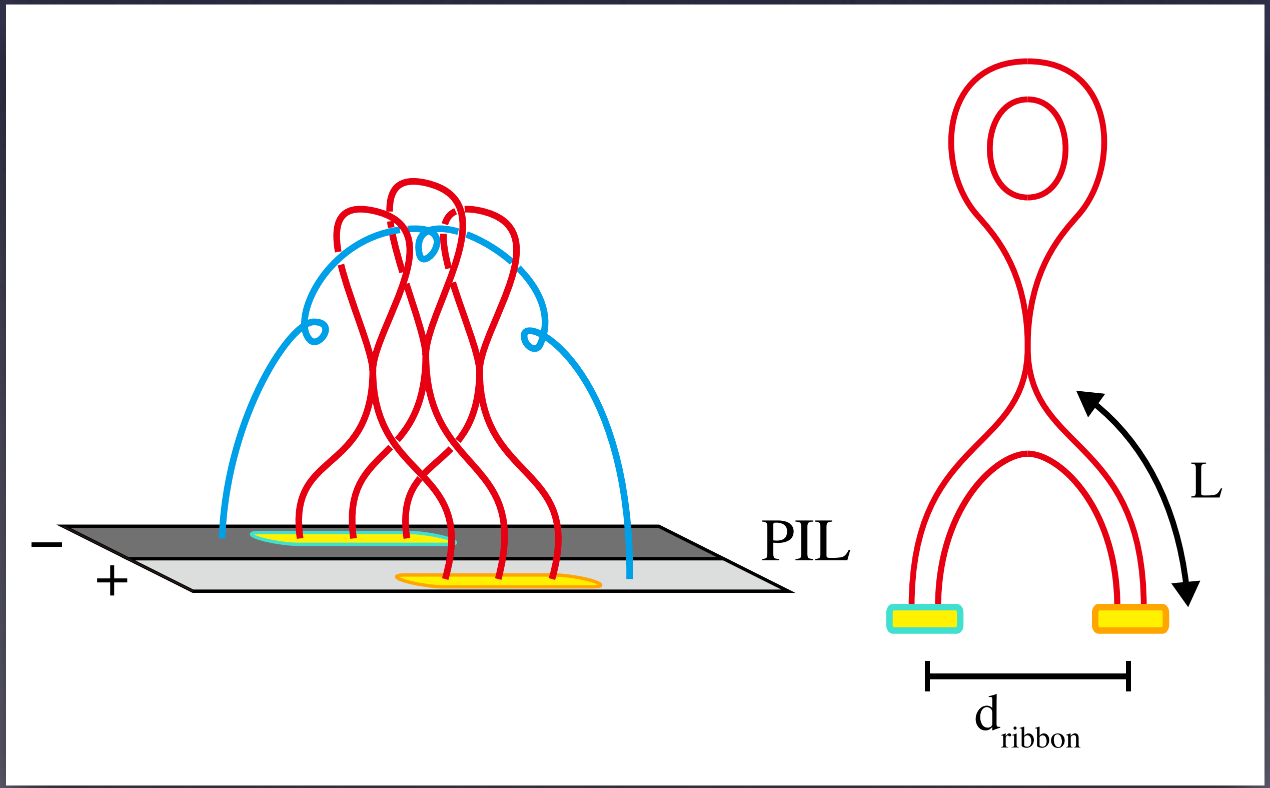



see next slide

As more flux is involved, the reconnection continues longer

# 3. $\tau_{flare} \propto d_{ribbon}$?




- Framework: Standard (CSHKP) flare model [e.g. Shibata & Magara 2011].
- Assumption 1: Ribbon distance $d_{ribbon}$ represents loop length $L$

$$L \sim d_{\rm ribbon}$$

- Assumption 2: Reconnection time determines the flare duration

$$\tau_{\rm flare} \sim \tau_{\rm rec} \sim \tau_{\rm A}/M_{\rm A}$$

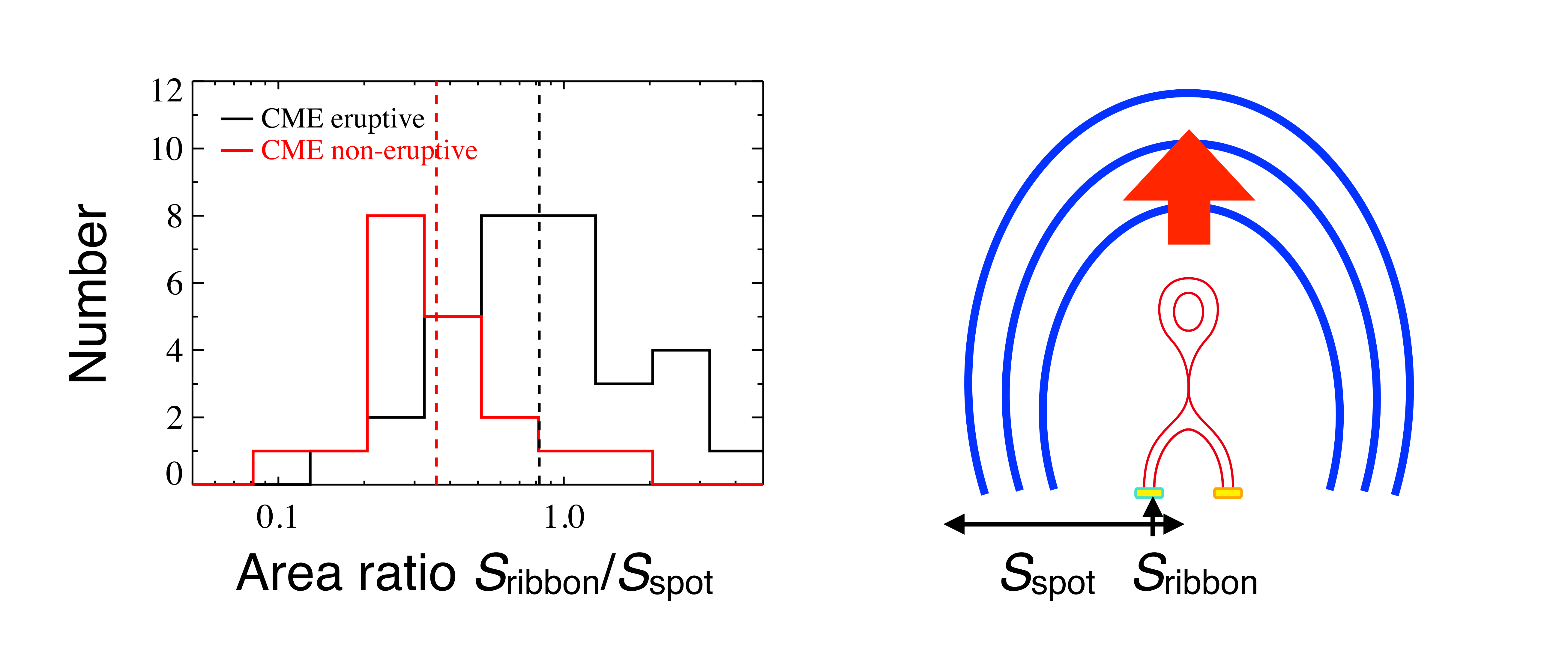
where $\tau_A = L/V_A$ is Alfvén time and $M_A$ is Alfvén Mach number.

- Combining above relations,

$$\tau_{\rm flare} \propto \tau_{\rm A} \propto L \propto d_{\rm ribbon}$$

# 3. Parameters that Dictate Flares?

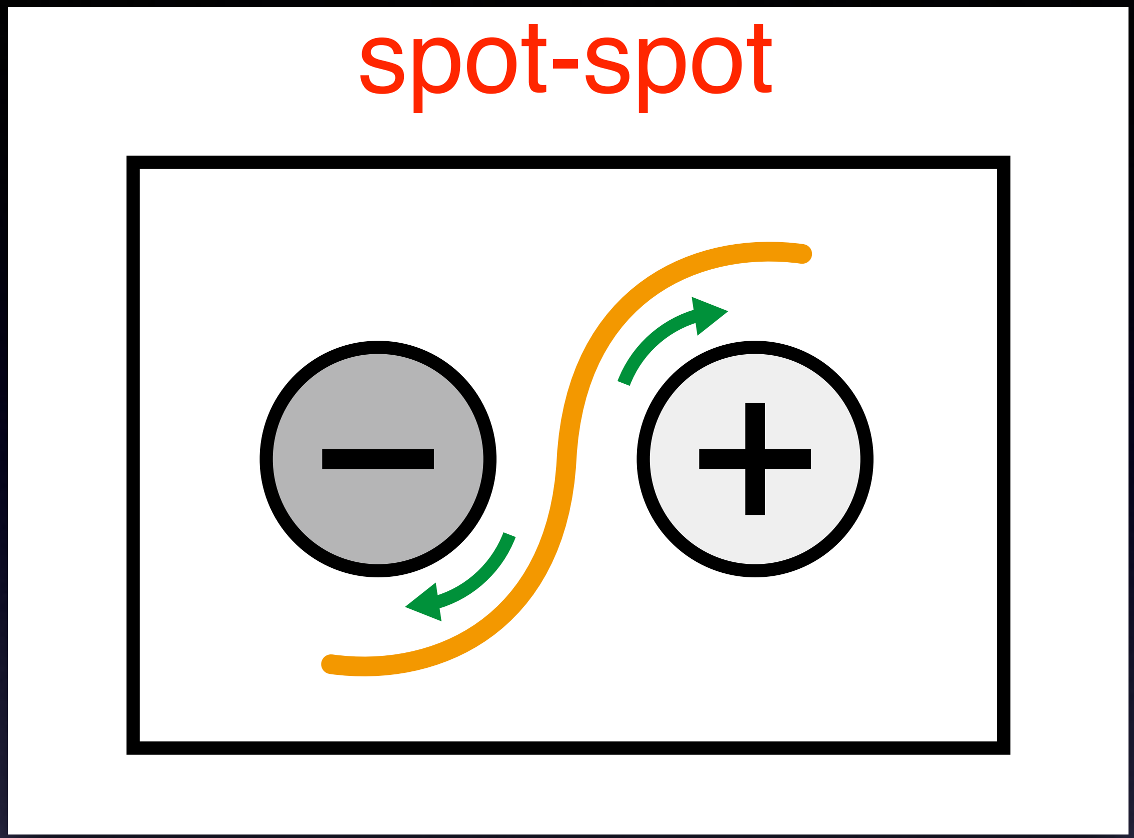
- CME Eruptive or Not?

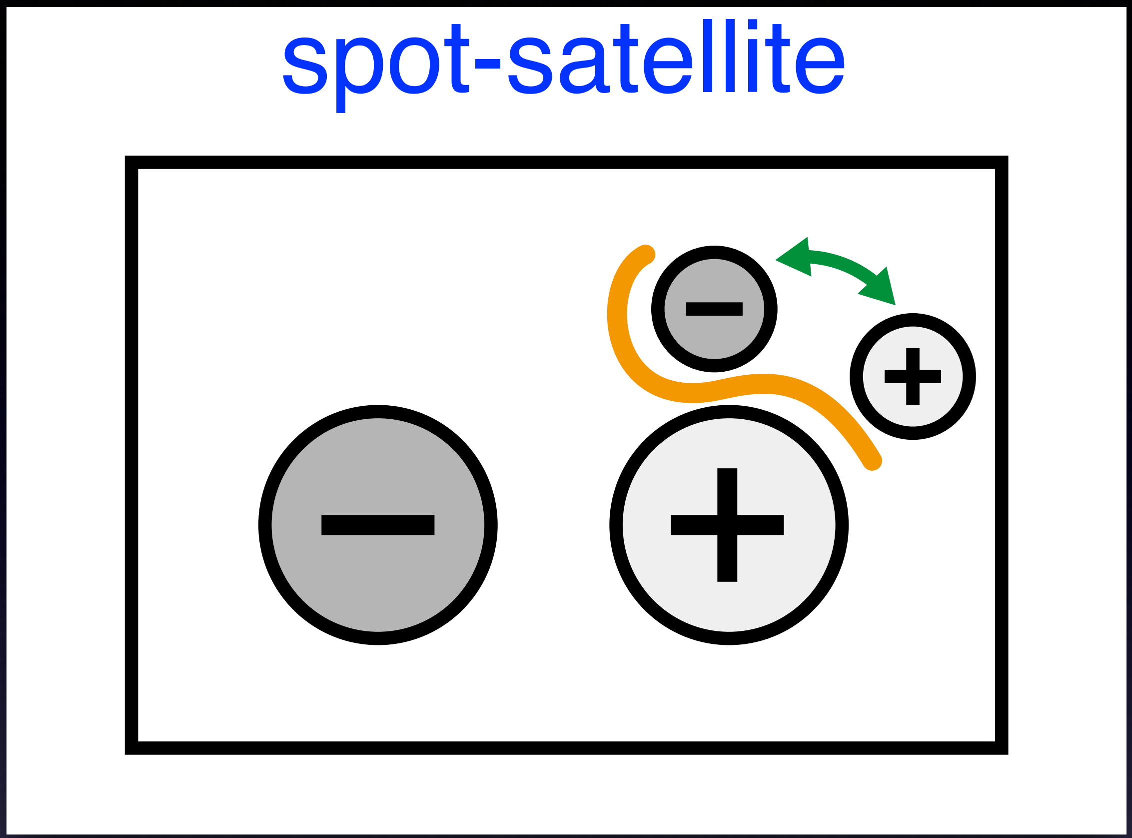


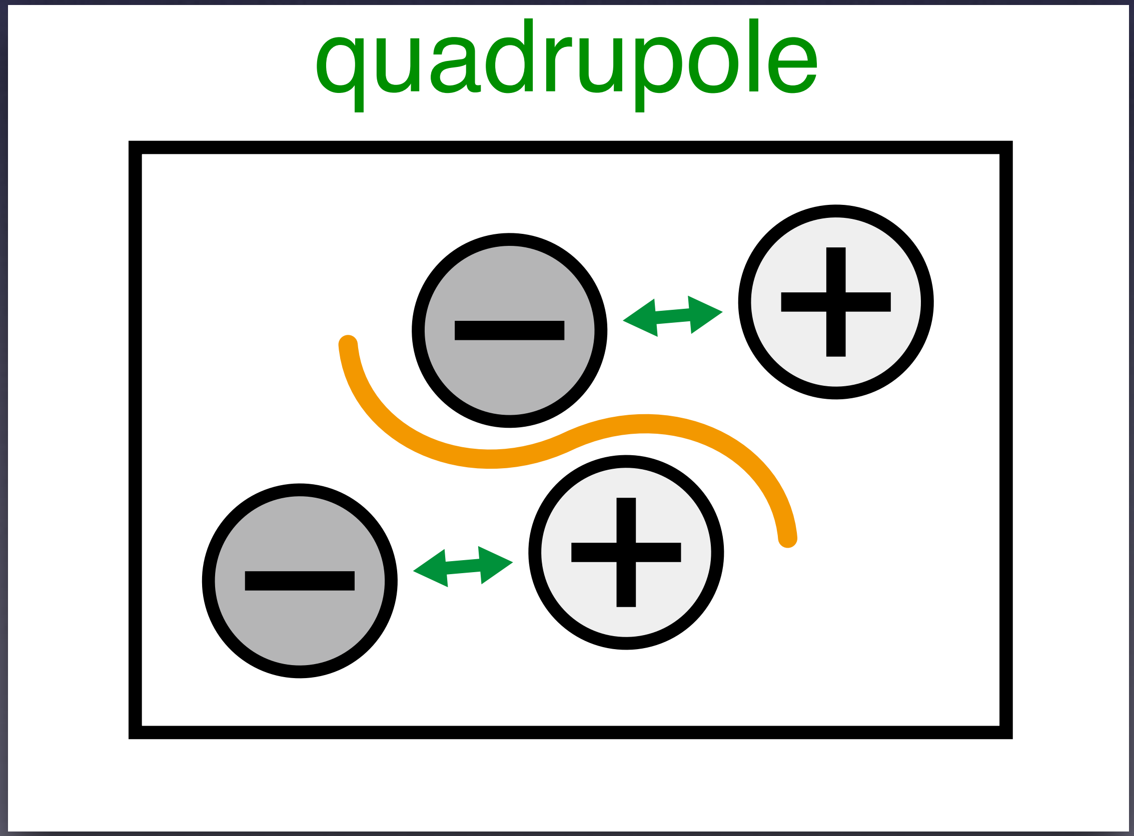

- Area ratio $S_{ribbon}/S_{spot}$ shows a clear difference (79%).
- Stronger overlying fields inhibit the successful filament eruption [e.g., Sun+ 2015 for AR 12192] → structural relation is a key factor

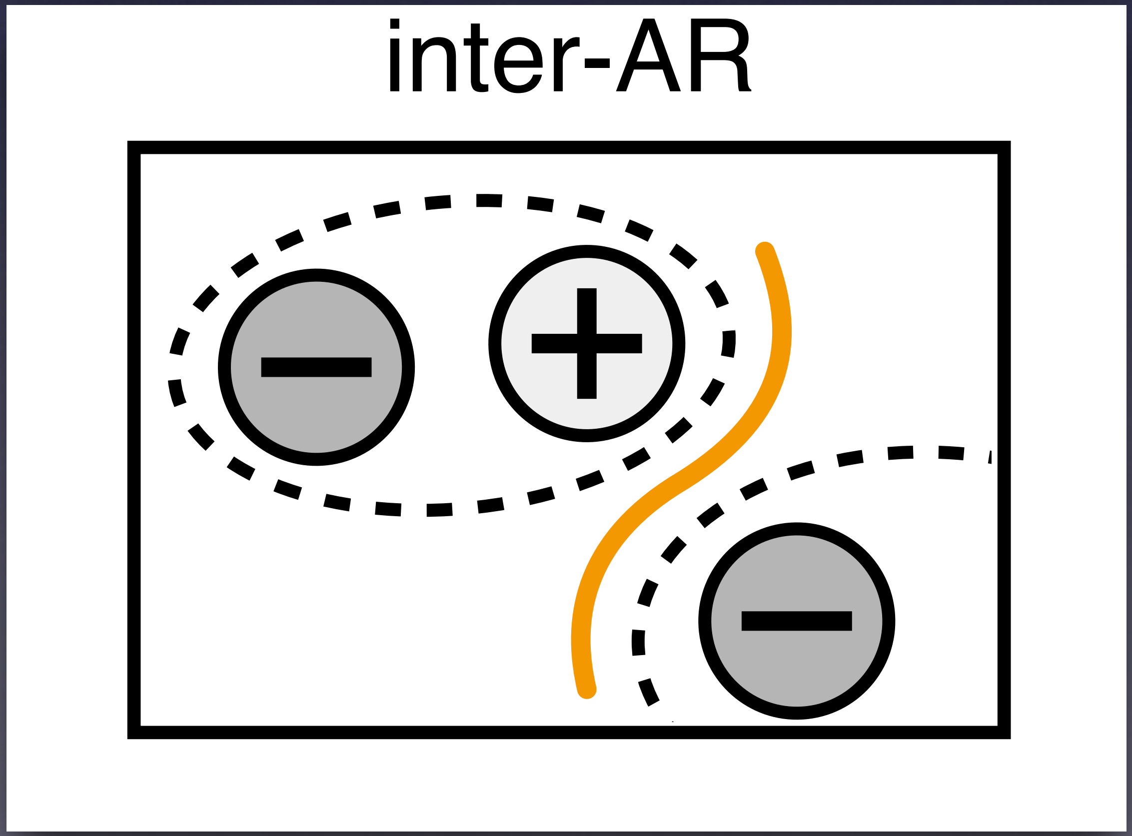
ST & Takasao (in prep)

# 4. Evolution of Flare ARs



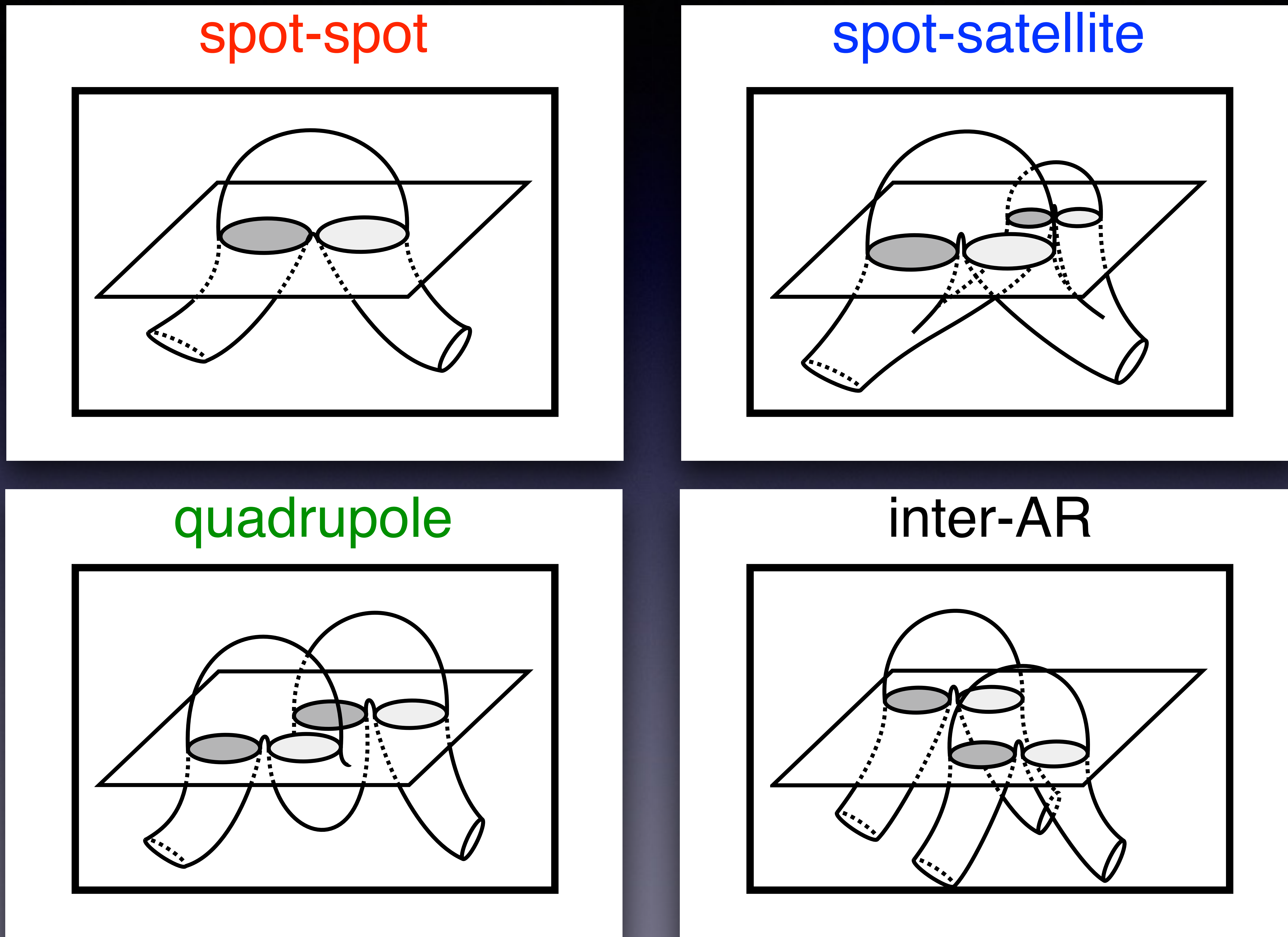



ST & Takasao (in prep)

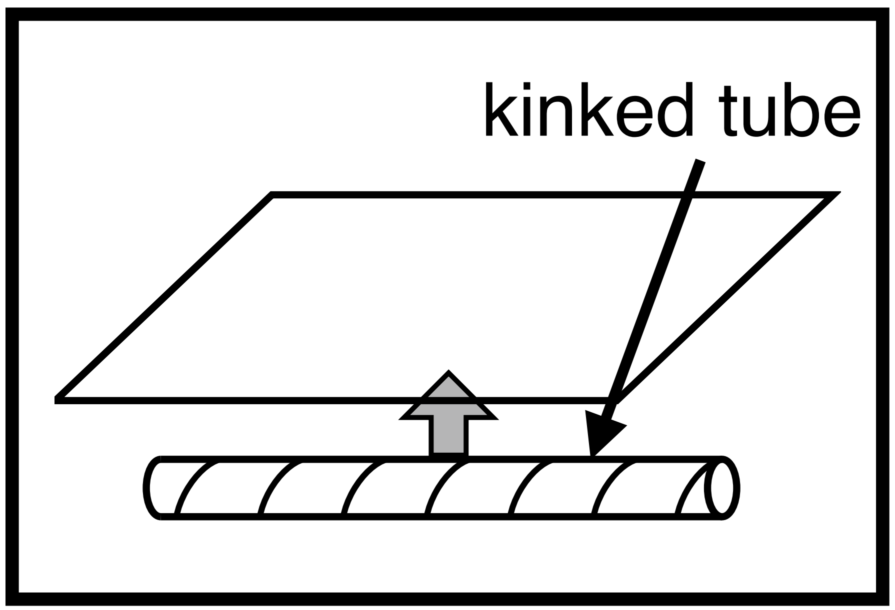
# 4. Evolution of Flare ARs



ST & Takasao (in prep)

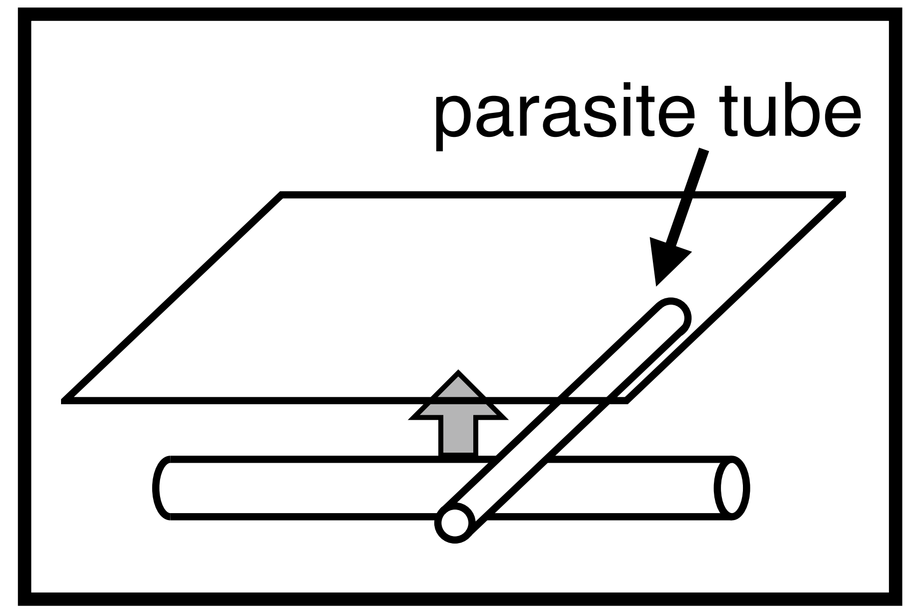
# 4. Evolution of Flare ARs

## spot-spot

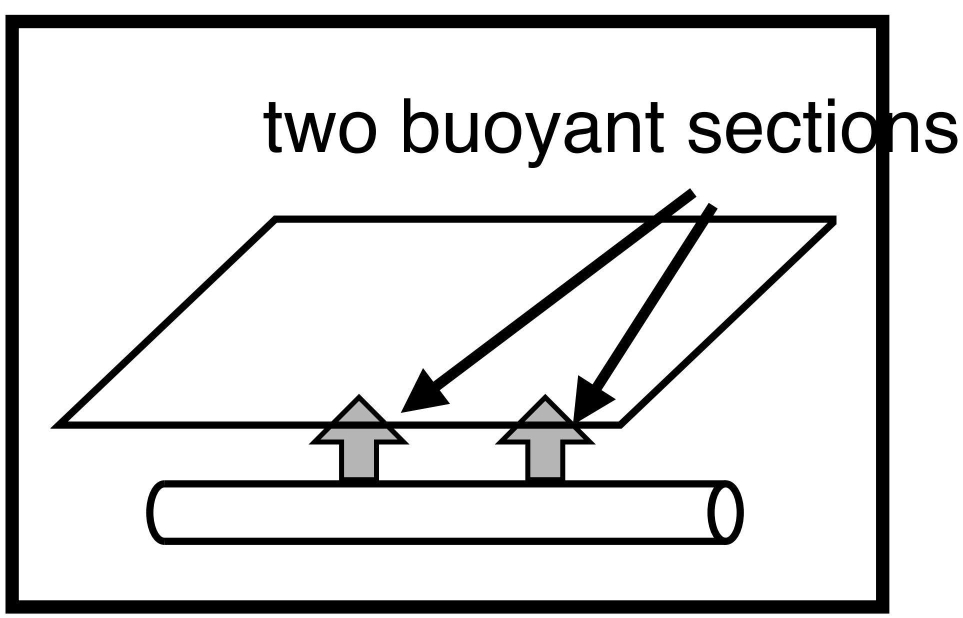



[Fan+ 1999, Takasao+ 2015]

## spot-satellite

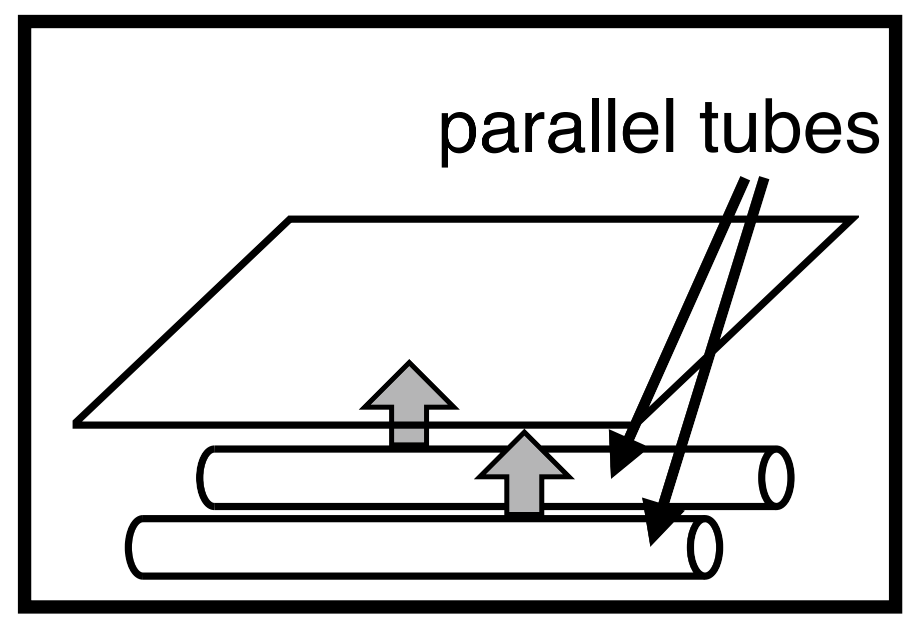



## quadrupole



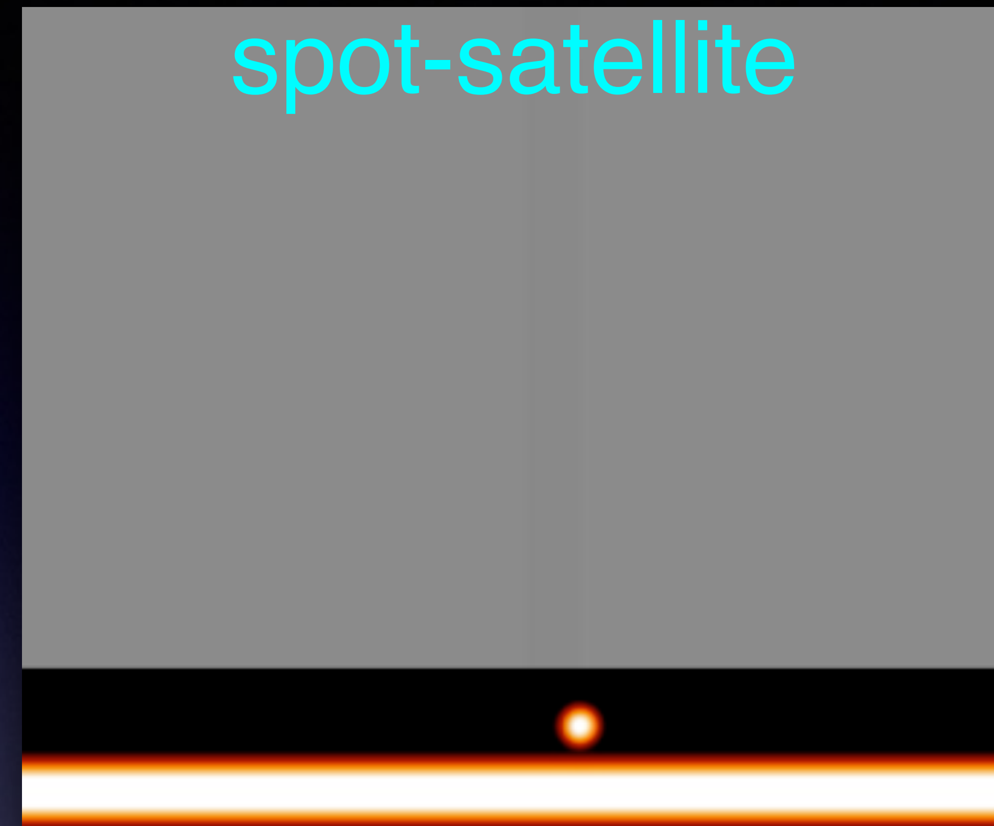

[ST+ 2014, Fang & Fan 2015]

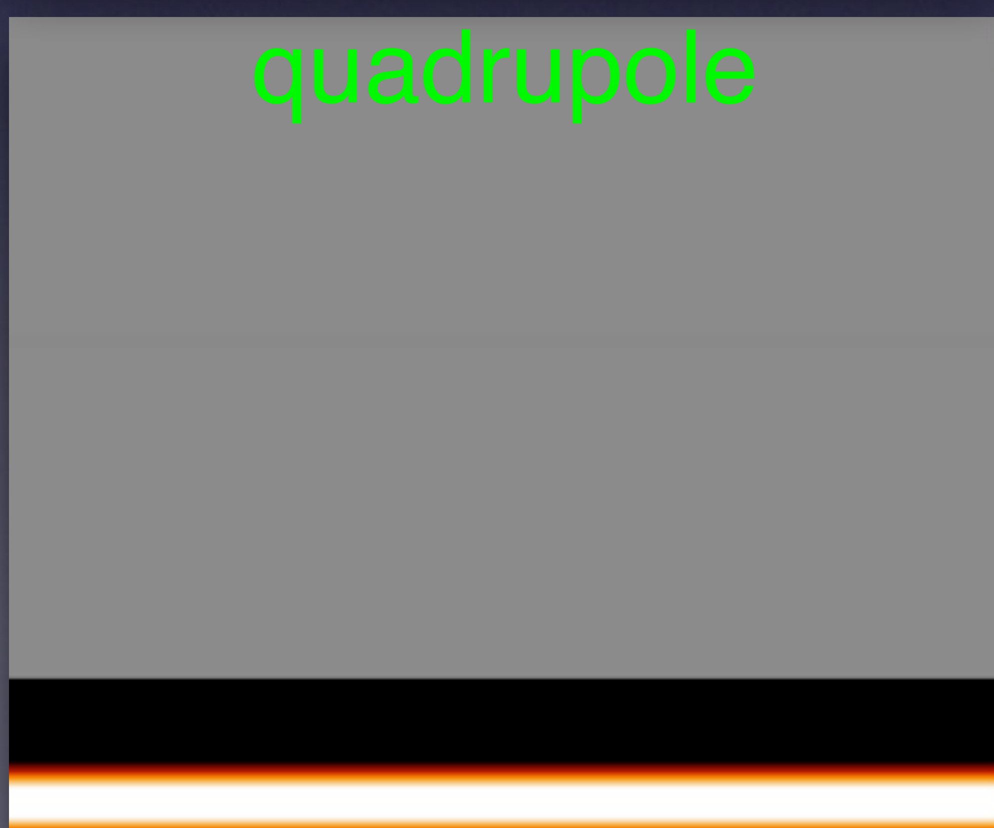
## inter-AR

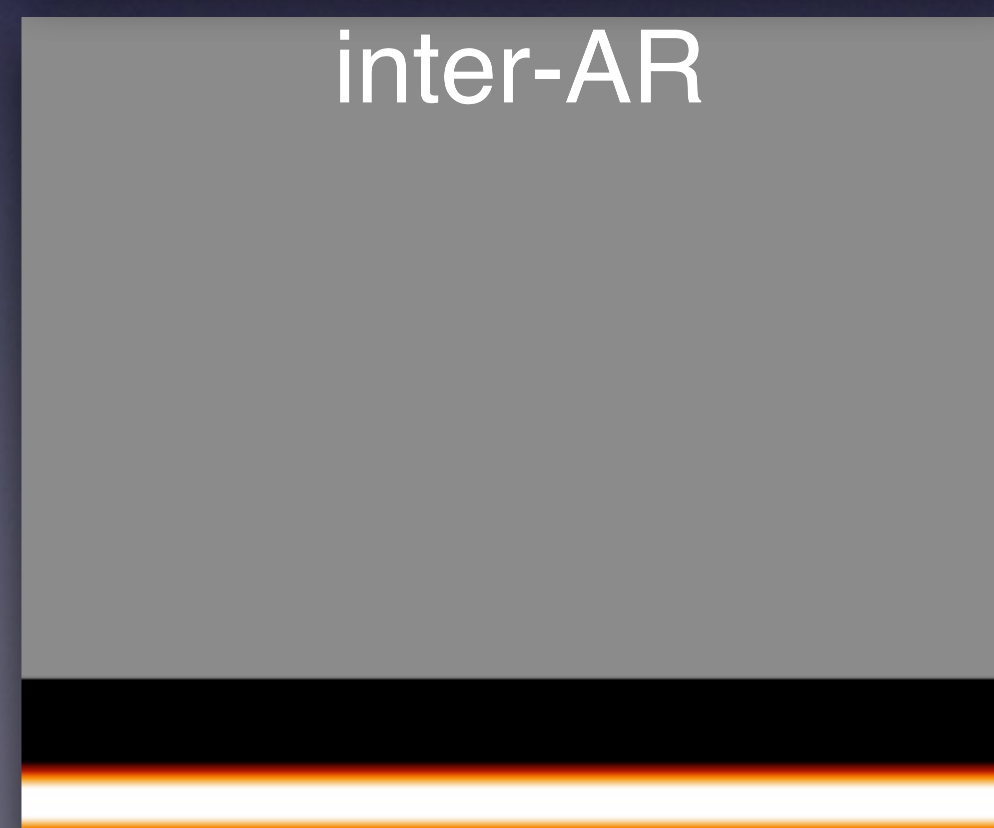


ST & Takasao (in prep)

# 4. Evolution of Flare ARs

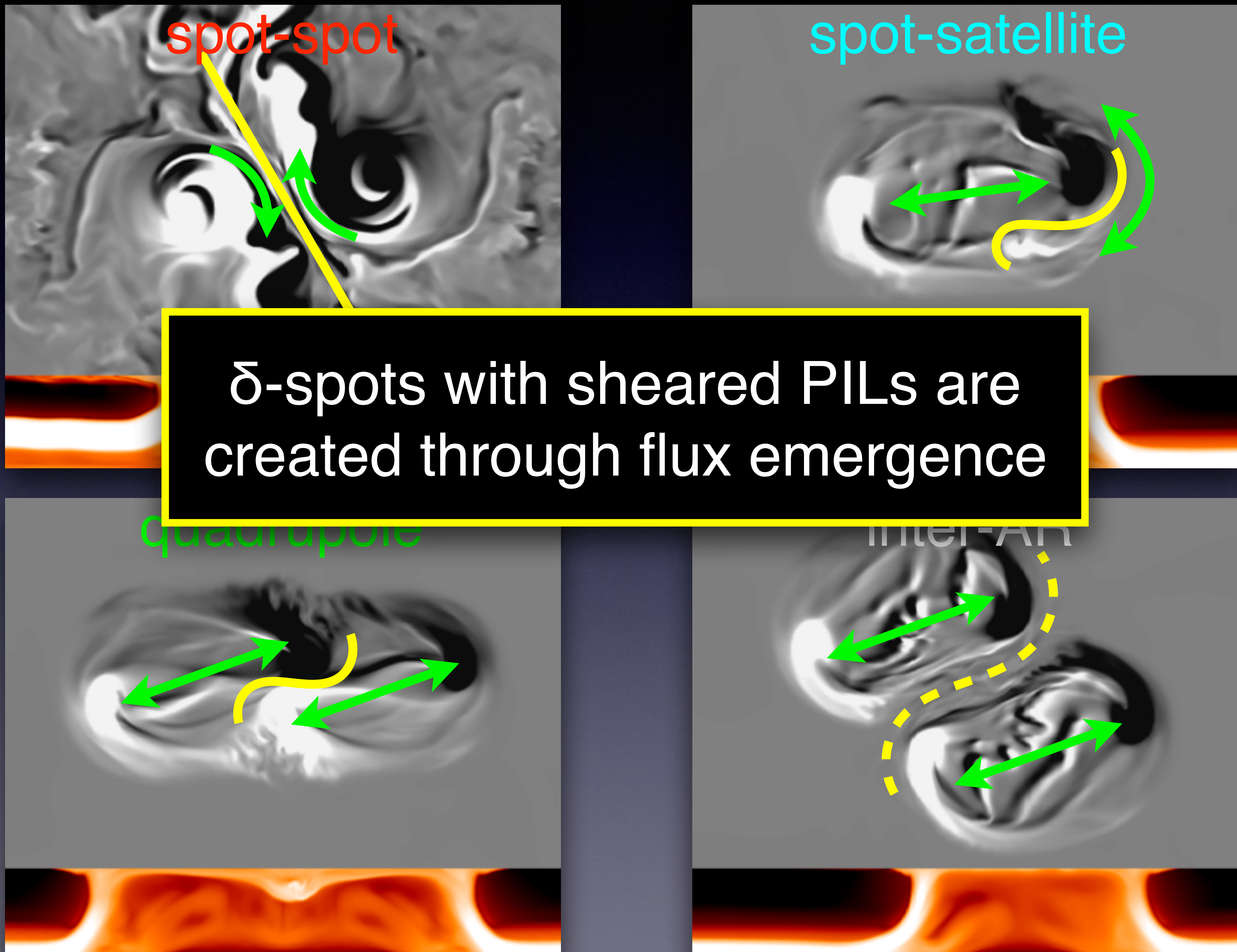



ST & Takasao (in prep)

# 4. Evolution of Flare ARs




δ-spots with sheared PILs are created through flux emergence

Hinode/SOT (courtesy of T.J. Okamoto)

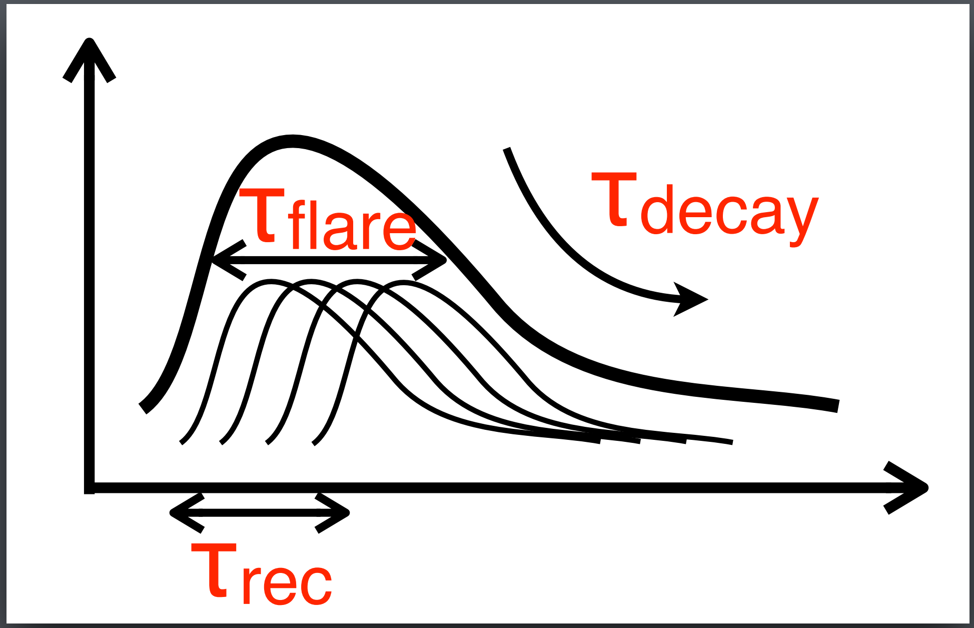
# 5. Summary

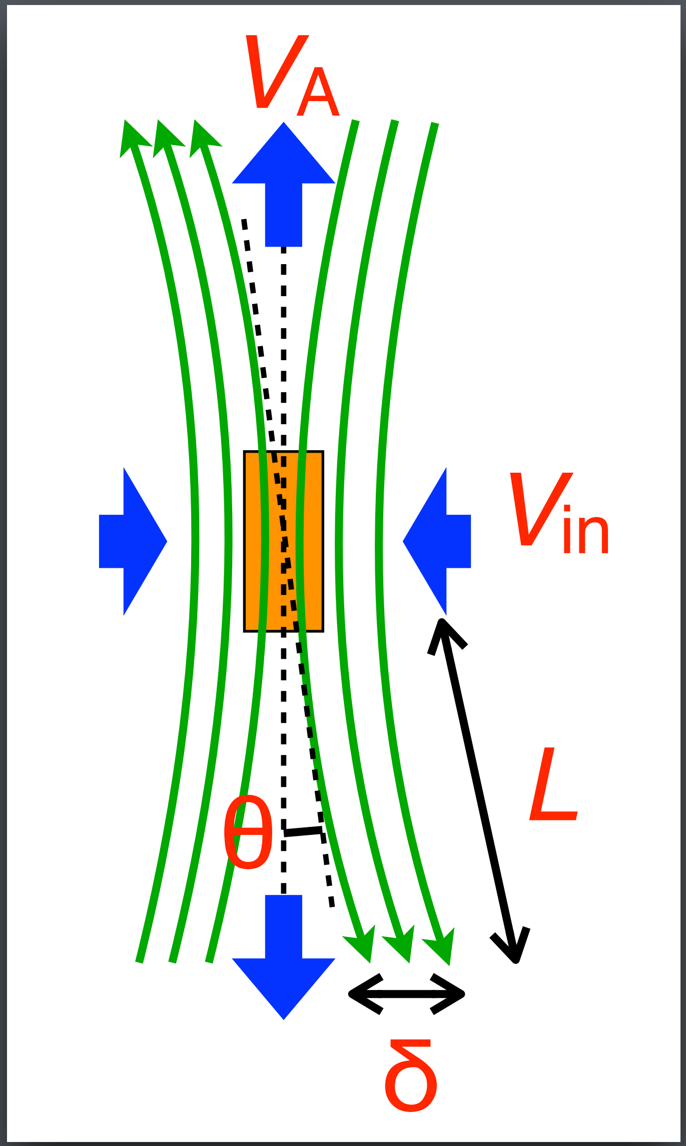
- Analysis
  - All ≥M5 on-disk flares in 6 years
  - 51 flares from 29 ARs
- Results + Discussion
  - >10% of 29 ARs violate Hale's rule, >80% show δ-structure
  - Duration ∝ Ribbon distance → Reconnection time
  - Duration ∝ Ribbon total flux → Flux involved in reconnection
  - CME-less events show smaller $S_{ribbon}/S_{spot}$ → strong overlying loops
- Evolution of Flare ARs
  - Classified into 4 types
  - Evolution determines the properties → Simulations on-going

**see Toriumi+ (2017) for details!**

Thank you for your attention!

# Why $\tau_{\rm flare} \propto d$ ?




- Reconnection continues for $\tau_{\rm rec}=\delta/V_{\rm in}$. For Petscheck type, $\delta=L\sin\theta$ and $\sin\theta \sim V_{\rm in}/V_{\rm A}$. Then, $\tau_{\rm rec} \sim \tau_{\rm A}/M_{\rm A}=L/(V_{\rm A}M_{\rm A})$ [e.g., Yokohama & Shibata (1998)].
- If $\tau_{\rm rec}$ dominates $\tau_{\rm flare}$ and $B$=const., we get $\tau_{\rm flare} \propto L \propto d$.
- However, $\tau_{\rm flare}$ is also determined by $\tau_{\rm cool}$ (radiative and conductive cooling times), which is not (in theory) linearly proportional to $L$ [e.g., Reale (2007)].

$$\tau_{\rm rad} = \frac{2n_{\rm e}\frac{3}{2}k_{\rm B}T}{n_{\rm e}^2\Lambda(T)} \propto \frac{T}{n_{\rm e}\Lambda(T)}$$

$$\tau_{\rm cond} = \frac{2n_{\rm e}\frac{3}{2}k_{\rm B}T}{\kappa_0\frac{T^{7/2}}{L^2}} \propto \frac{n_{\rm e}L^2}{T^{5/2}}$$

- Will study thermal evolution using (M)HD simulation including thermal processes in the loop