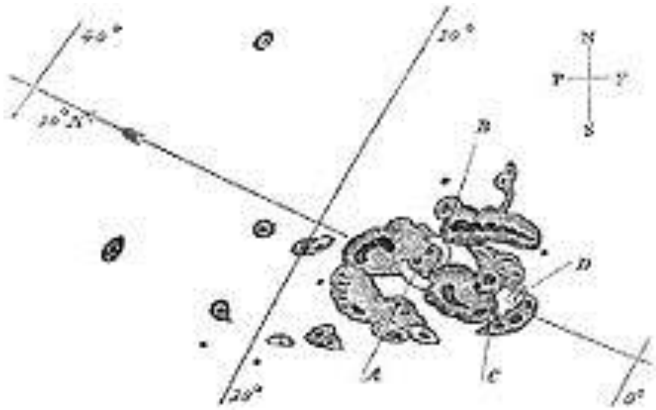
Statistical Properties of Solar White-Light Flares



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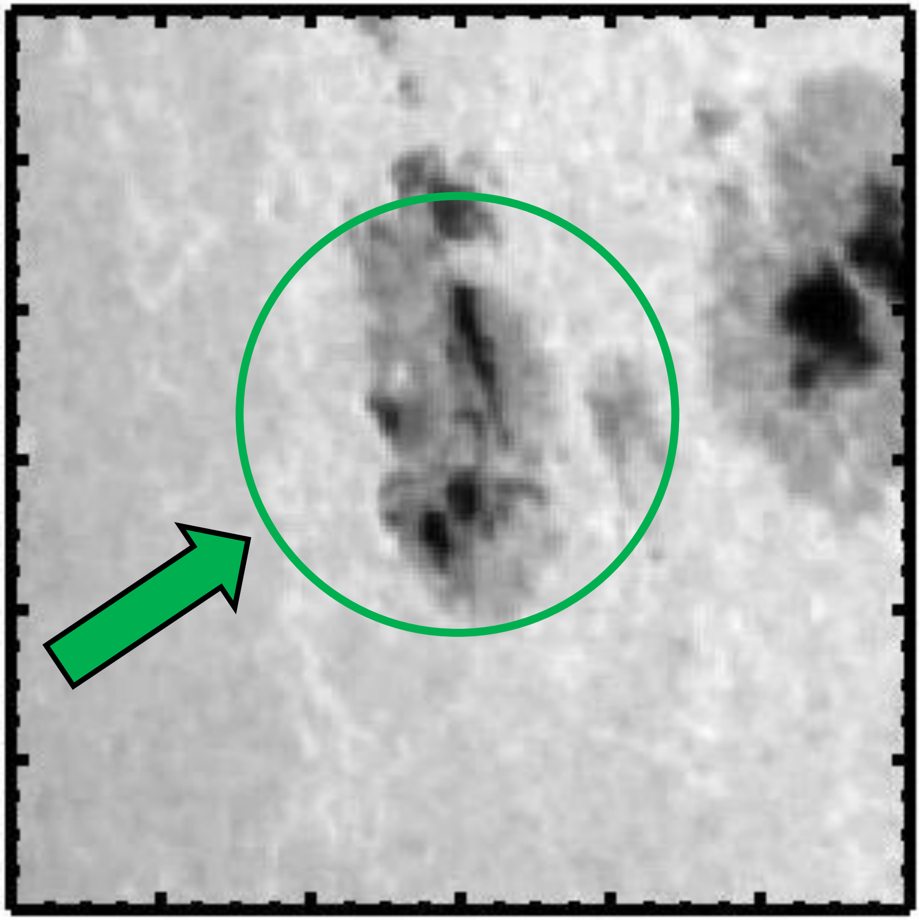
1st-4th, March, 2016
Superflare Workshop
(10min + 5min)

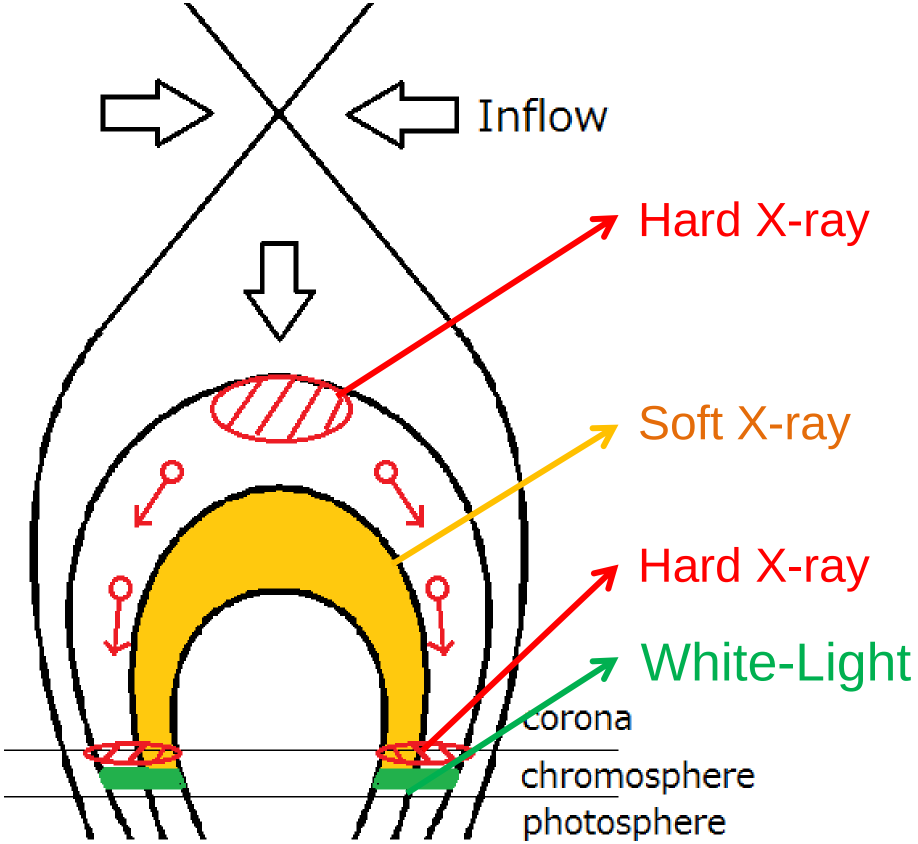
Introduction.　White-Light Flare

White Light Flare (SDO/HMI)

2012/10/23 03:17 + 21.7500min



Mechanism



Introduction. This Study

"Statistical properties of solar white-light flares"

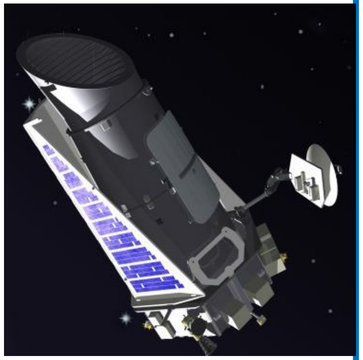
- Solar flares are well studied, because we can spatially resolve the structures of the Sun.

→ Apply the knowledge of solar flares to stellar superflares

→ Only from photometric observations, we want to know more information about stellar flares

(e.g. X-ray flux, magnetic field strength, length scale,…).

- Many stellar superflares are observed as white-light flares by Kepler.



→ Research on the properties of white-light flares is important.

Contents

Statistical analyses about 3 properties of solar white-light flares

1. White-Light and Soft X-ray
   →The correlation of white-light Flux & GOES Soft X-ray Flux

2. Flare Duration
   →The correlation of white-light flare Energy & Duration.

3. Magnetic Field Strength & Length Scale of flare region
   → We use the method of Shibata & Yokoyama (1999,2002)

1.1 Motivation

・We want to estimate GOES X-ray class of superflares from observation with visible bands by Kepler data.

・Shibata et al. (2013) & Maehara et al. (2015) assume (↑Superflare papers)

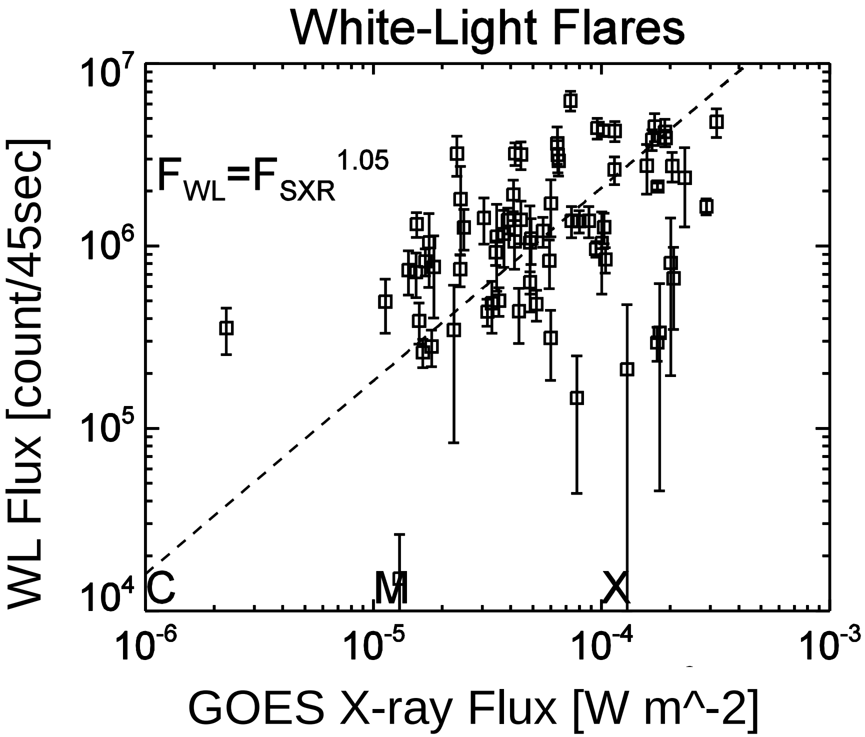
"White-light energy is proportional to GOES X-ray class."

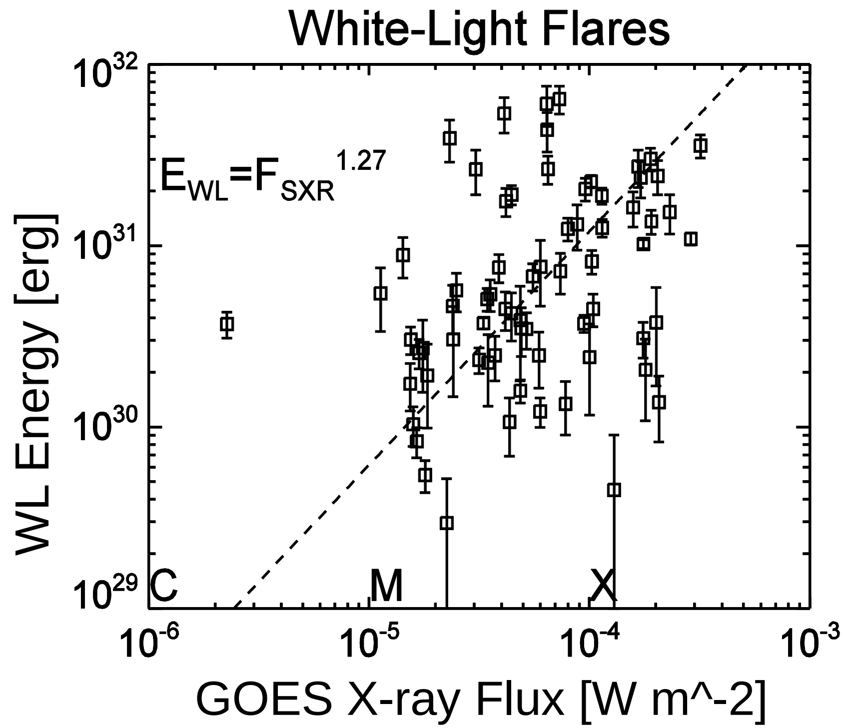
We need to research on the correlation of Soft X-ray flux and White-Light flux

⇩

Statistical research on 71 solar white-light flares

1.2 Results





$$F_{White-light} \propto F_{GOES\ SXR}$$

- Shibata(2013)'s assumption is approximately good.
- GOES class of superflares is thought to be from X100 to X100,000!

There is also a study …

$F_{White-light} \propto F_{GOES\ SXR}{}^{0.6}$

(Kretzshmar 2010)

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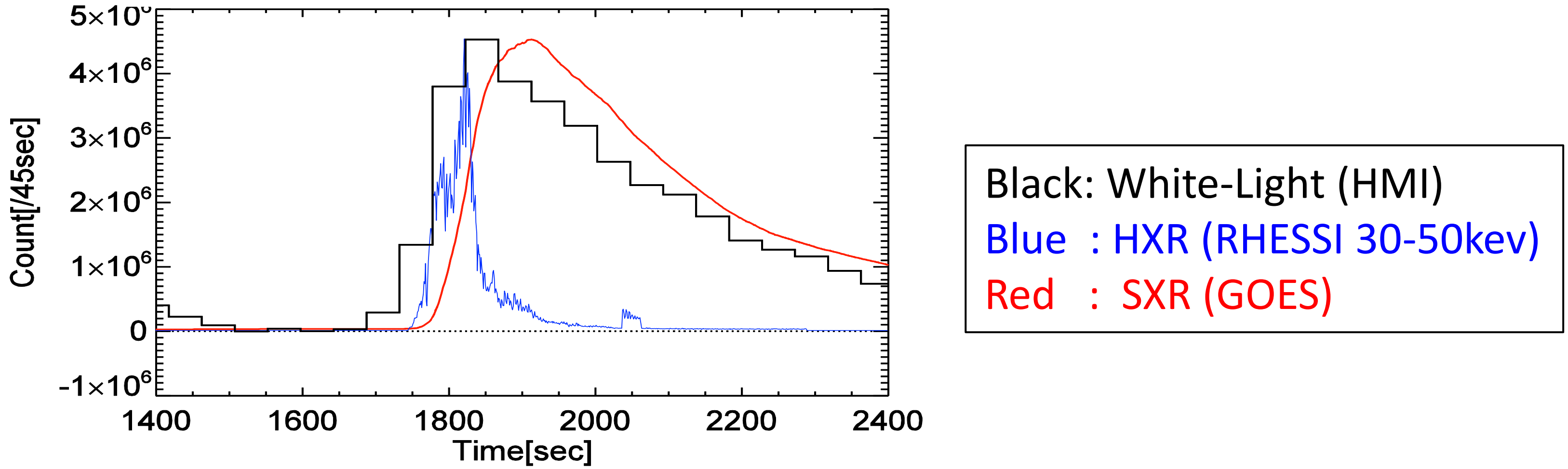
2.1 Motivation

Light curve of solar flare(2012/10/23)



The correlation of Flare **Energy** & **Duration** is studied :

$$\tau_{dur} \propto E^{a}$$

Stellar Superflare WL : $a \sim 0.39 \pm 0.03$ (Maehara et al.2015)

Solar soft X-ray : $a \sim 1/3$ (Veronig et al. 2002)

Solar hard X-ray : $a \sim 0.2$ (Christe et al. 2008)

⇨ Is the correlation can be seen in "solar" white-light flares?

2.1 Results

The correlation of Energy & Duration

$$\tau_{dur} = E^{a}$$

Solar white-light flare : $a = 0.404$ (This study)

Superflare WLF : $a \sim 0.39 \pm 0.03$ (Maehara et al.2015)

Solar soft X-ray : $a \sim 1/3$ (Veronig et al. 2002)

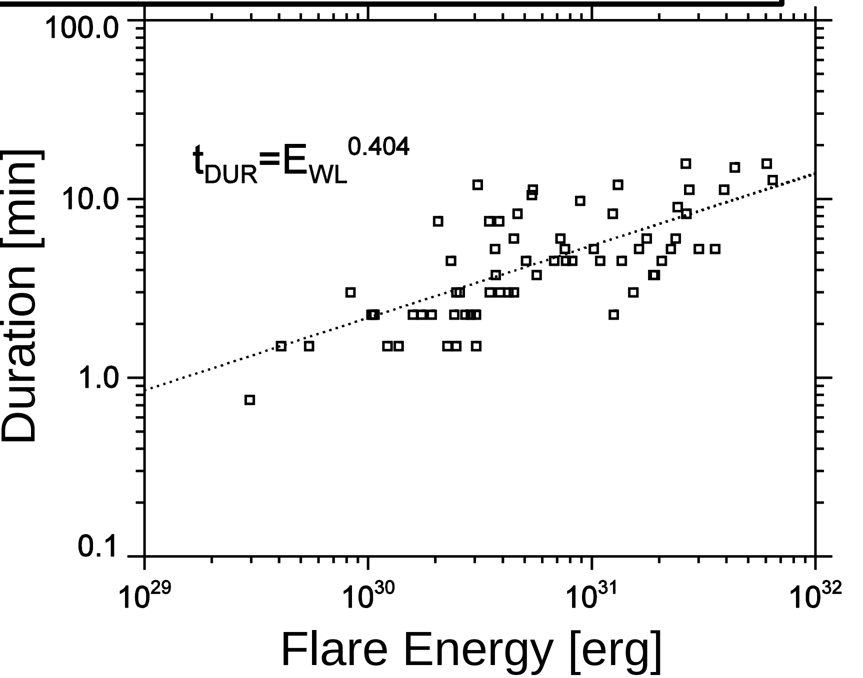
Solar hard X-ray : $a \sim 0.2$ (Christe et al. 2008)

・This correlation is simply understood by the reconnection theory.

$$\tau_{HXR} \sim 10 - 100 t_A \propto \frac{L}{v_A}$$

$$E \propto B^2 L^3$$

$$\tau_{dur} \propto E^{1/3}$$



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   →The correlation of white-light Flux & GOES Soft X-ray Flux

2. Flare Duration
   →The correlation of white-light flare Energy & Duration.

3. Magnetic Field Strength & Length scale of flare region
   → We use the method of Shibata & Yokoyama (1999,2002) in terms of the application to observations of stellar flares.

3.1 What determines Temperature & Emission Measure of flare loop at flare peak?

Shibata & Yokoyama (1999,2002) assumed…

1. Reconnection heating $\frac{B^2 V_A}{4\pi L}$ = conduction cooling $\frac{\kappa T^{7/2}}{2L^2}$

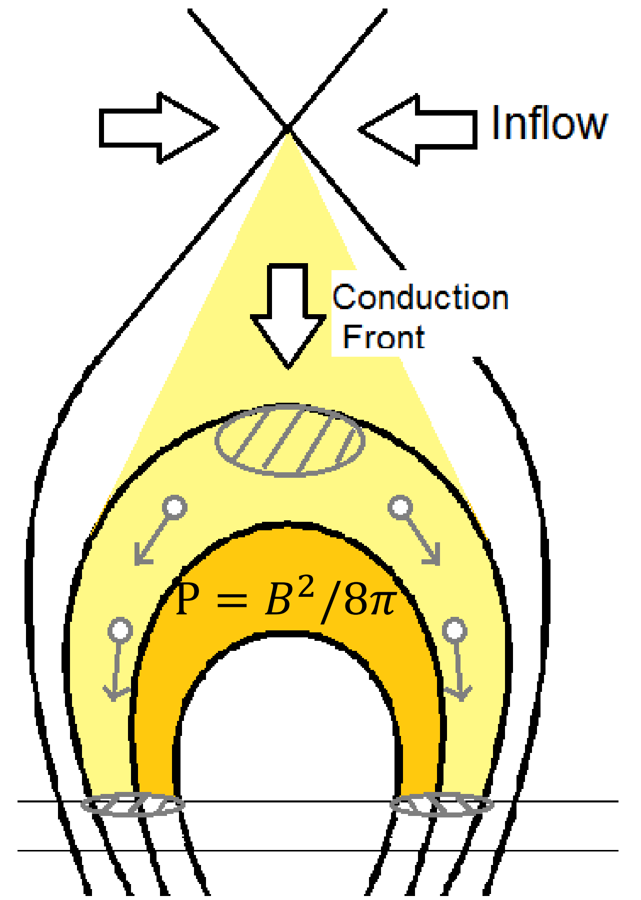
2. Gas pressure p ~ Magnetic pressure $\frac{B^2}{8\pi}$

⬇

$$B = 50\left(\frac{EM[cm^{-3}]}{10^{48}}\right)^{-0.2}\left(\frac{T[K]}{10^7}\right)^{1.7}\ [\mathrm{G}]$$

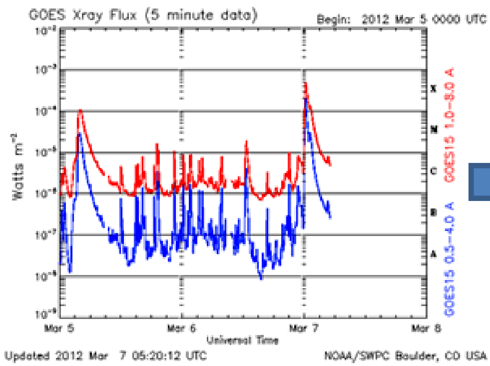
$$\mathrm{L} = 10^9\left(\frac{EM[cm^{-3}]}{10^{48}}\right)^{-0.6}\left(\frac{T[K]}{10^7}\right)^{-1.6}\ [cm]$$

EM=Emission Measure=n^2L^3



3.2 Motivation

- We can get magnetic field strength & scale of flare region only by photometric observation of two X-ray wavebands.(e.g. GOES)



Stellar Photometric Observation → EM & Temperature →

$$B_{est} = 50\left(\frac{EM}{10^{48}}\right)^{-0.2}\left(\frac{T}{10^{7}}\right)^{1.7}\ [\mathrm{G}]$$

$$L_{est} = 10^{9}\left(\frac{EM}{10^{48}}\right)^{-0.6}\left(\frac{T}{10^{7}}\right)^{-1.6}\ [cm]$$

Steller Properties & Structures

↓

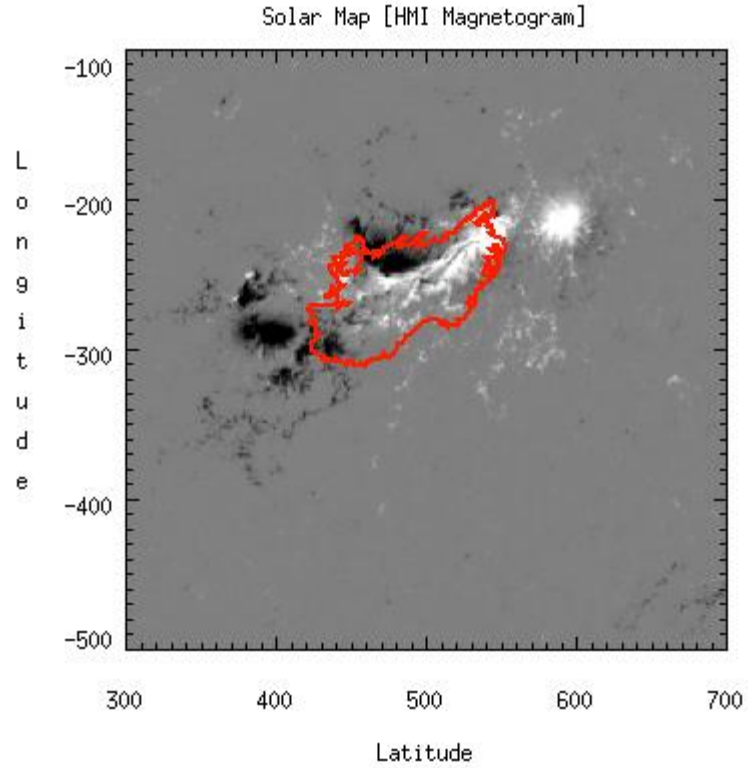
We statistically compare (1) with (2) to test this method

(1) Estimated B_{est} & L_{est} ← GOES X-ray by this method

(2) Observed B_{obs} & L_{obs} ← SDO

3.3 Analysis

We did rough measurements of coronal magnetic field(B_{obs}) with SDO/HMI Magnetgram & AIA 94A.



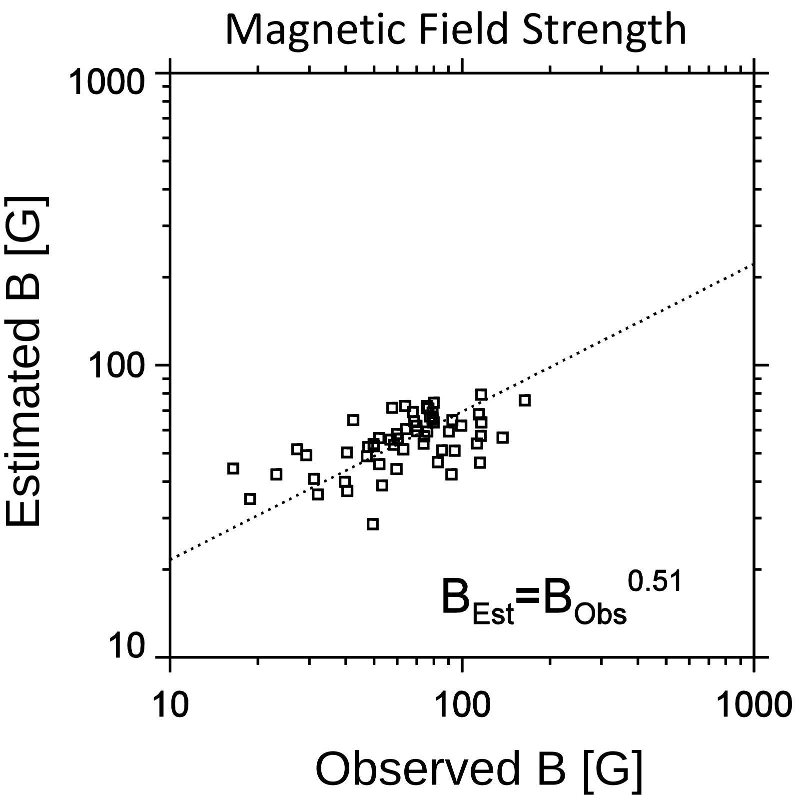
1.Flare Region is defined by AIA 94A(flare region).

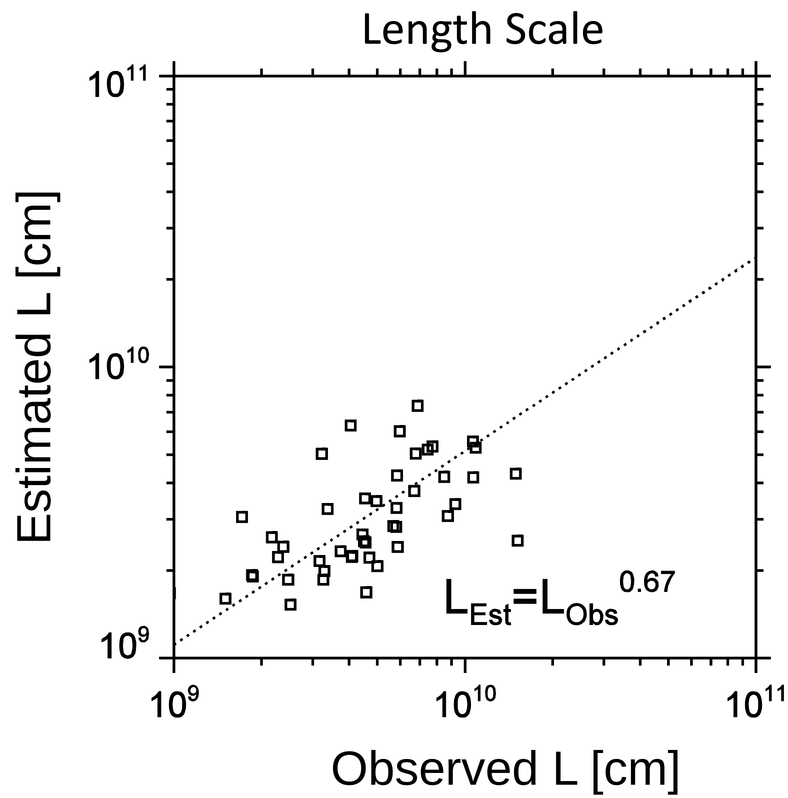
2. Calculate the mean of photospheric magnetic field strength ($\bar{B}$) under the flare region

3. Coronal Magnetic field strength is smaller by factor 3 than $\bar{B}$.(Isobe et al. 2003)

・$B_{obs} = \frac{1}{3}\bar{B}$

3.4 Results

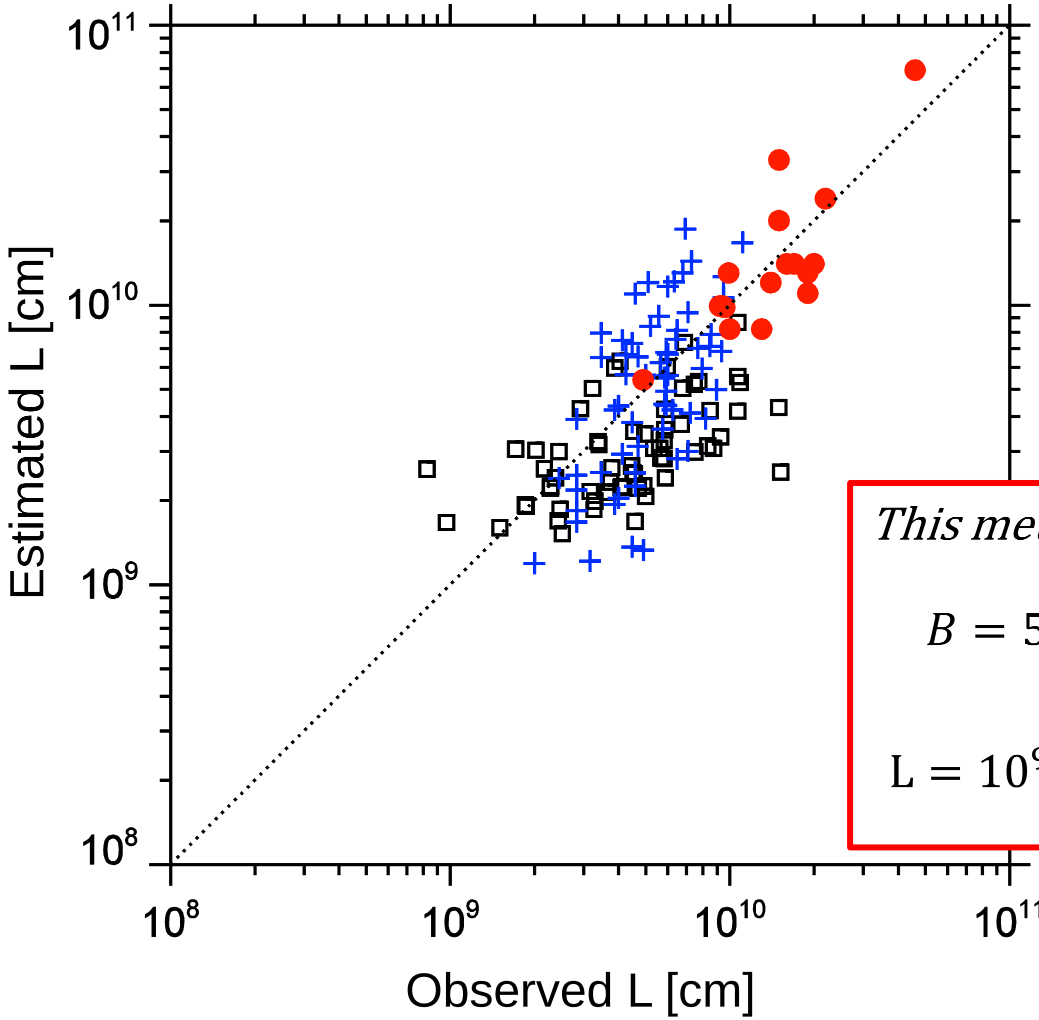




Even by rough measurements,
there is correlation between
estimated & observed values.

3.4 Results

Previous studies also support this method.
(Yamamoto et al. 2002, Akiyama 2001)



This method is useful,

$$B = 50\left(\frac{EM[cm^{-3}]}{10^{48}}\right)^{-0.2}\left(\frac{T[K]}{10^{7}}\right)^{1.7}\ [G]$$

$$L = 10^{9}\left(\frac{EM[cm^{-3}]}{10^{48}}\right)^{-0.6}\left(\frac{T[K]}{10^{7}}\right)^{-1.6}\ [cm]$$

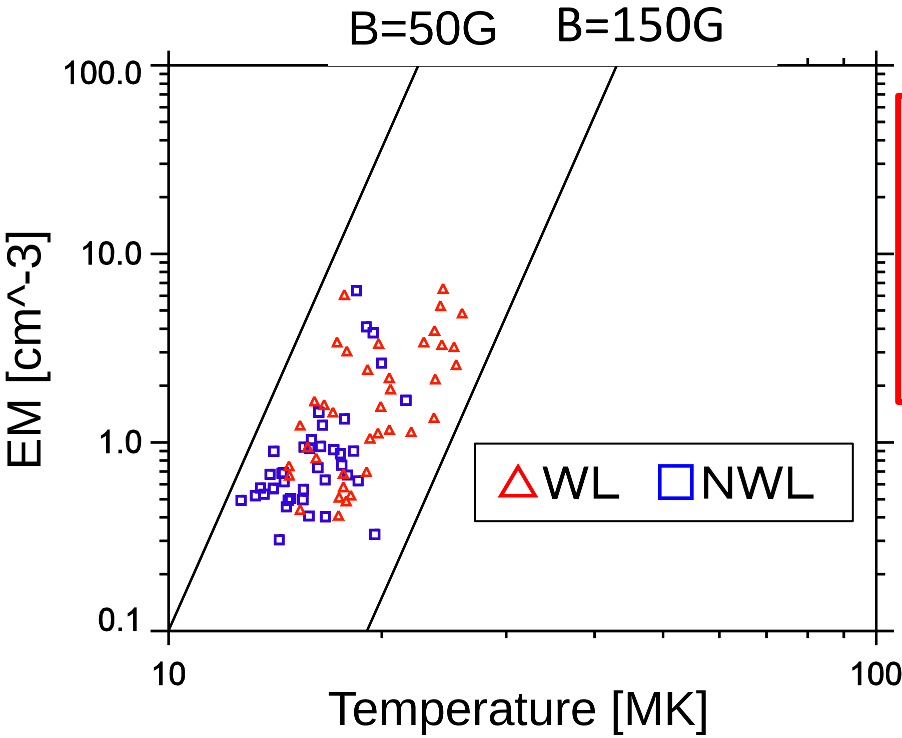
3.5 Discussion

We can apply this method to the discussion of

(1)stellar flares

(2)solar white-light flares

→By this method, Watanabe-san' work (2015) suggests coronal magnetic field strength of white-light flares is strong



$$B = 50\left(\frac{EM[cm^{-3}]}{10^{48}}\right)^{-0.2}\left(\frac{T[K]}{10^{7}}\right)^{1.7}\ [\mathrm{G}]$$

$$\mathrm{L} = 10^{9}\left(\frac{EM[cm^{-3}]}{10^{48}}\right)^{-0.6}\left(\frac{T[K]}{10^{7}}\right)^{-1.6}\ [cm]$$

Summary

- We found interesting correlations of white-light flares.
- We can estimate some properties of stellar superflares, using the knowledge of solar flares.

1. White-Light vs Soft X-ray

   White-light flux is roughly proportional to GOES X-ray flux, so GOES class of superflares may be from X100 to X100,000!

2. Flare Duration

   There is a similar correlation between flare energy and duration

   $$\tau_{dur} \propto E^{1/3}$$

3. Magnetic Field Strength & Length Scale of flare region

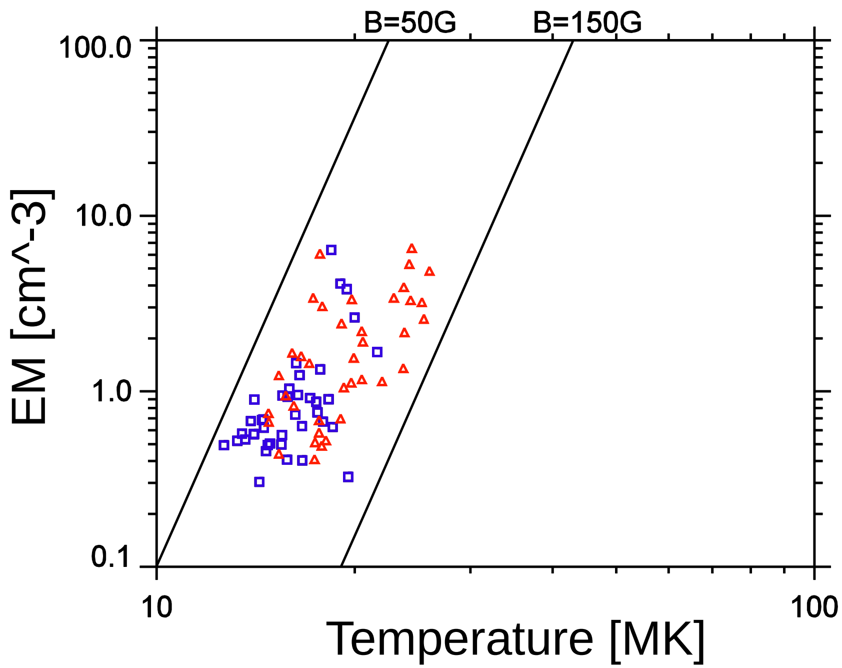
   We can simply estimate stellar properties, e.g.

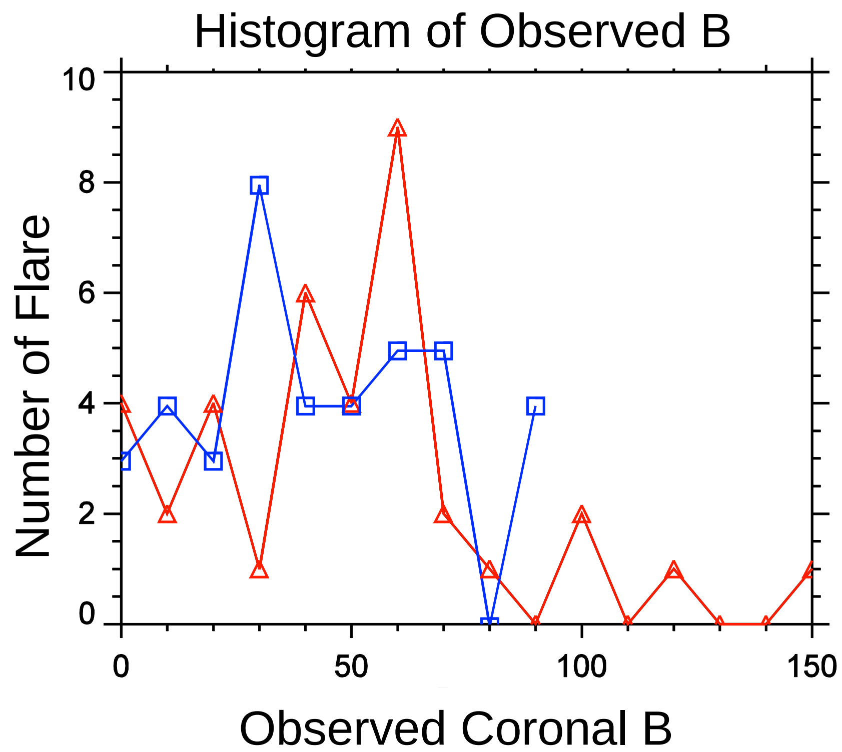
   $$B = 50 \times \left(\frac{EM}{10^{48}}\right)^{-0.2} \left(\frac{T}{10^7}\right)^{1.7} \text{ [Gauss]}$$

Data

3.4 Discussion

Watanabe(2015) plotted 38 white-light & 40 non-white-light flares on EM vs Temperature. △WL □NWL

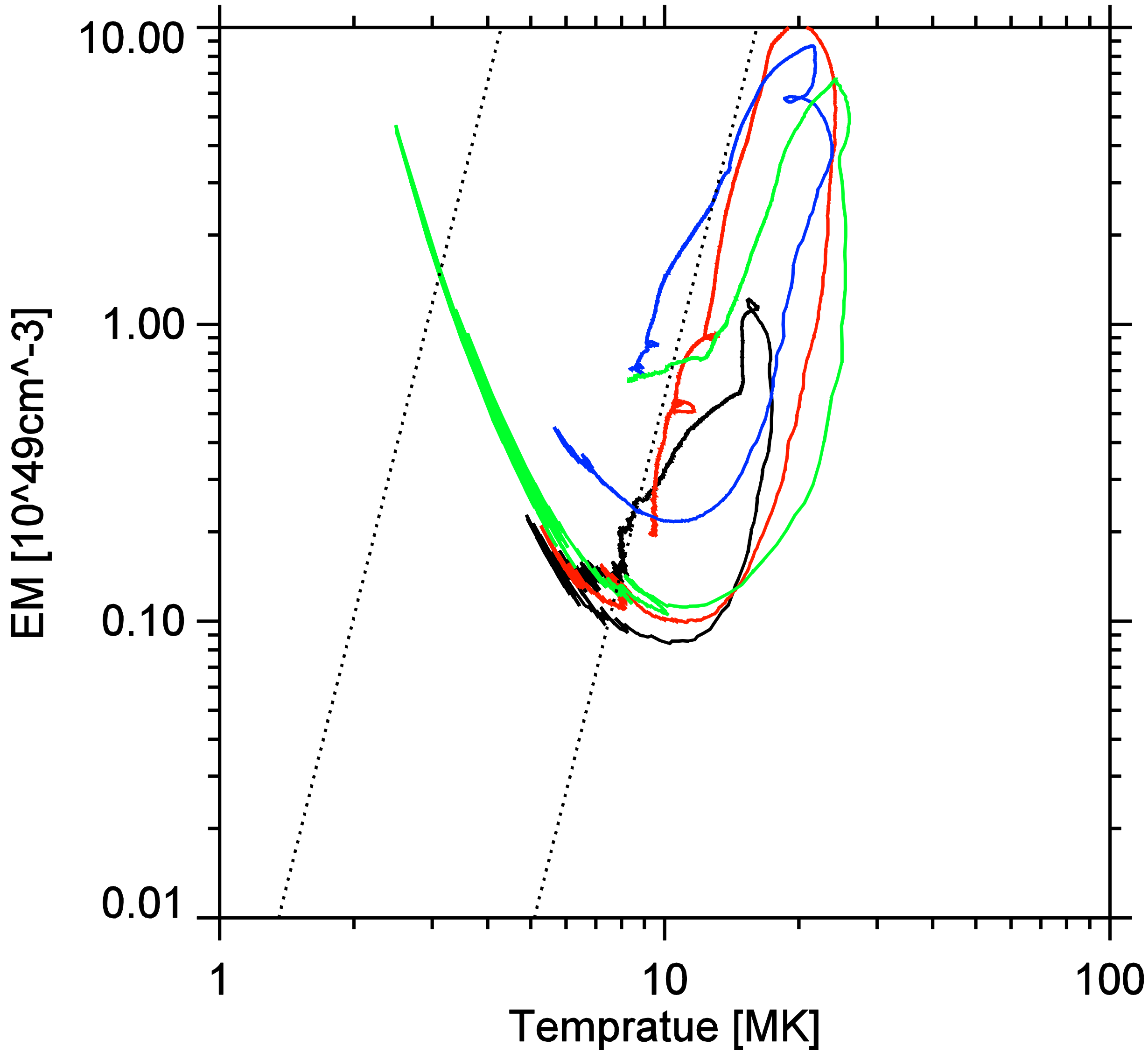




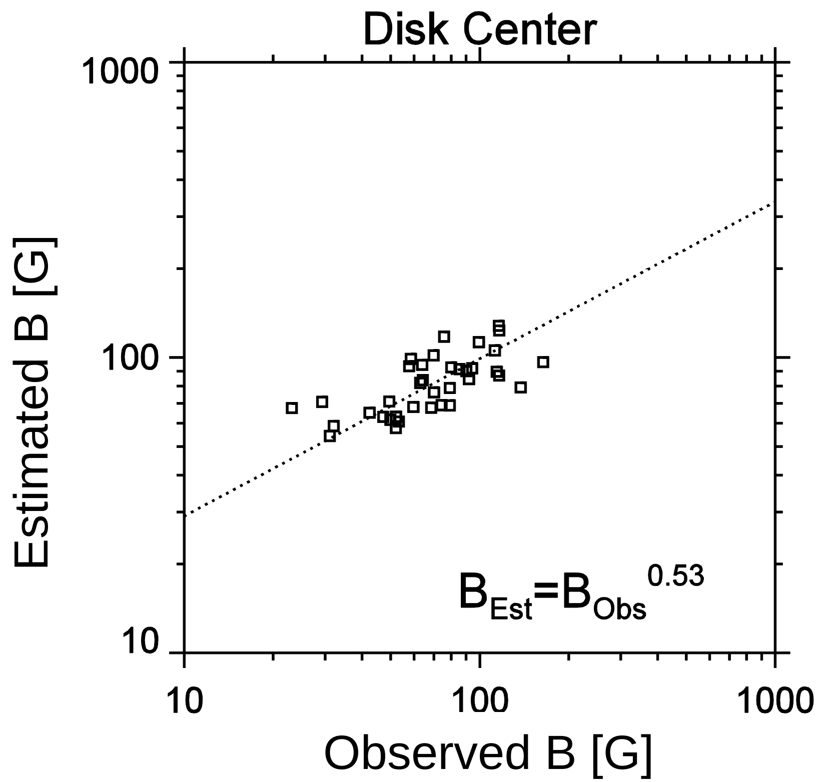
Watanabe(2015) theoretically suggested coronal magnetic field strength of white-light flare is strong

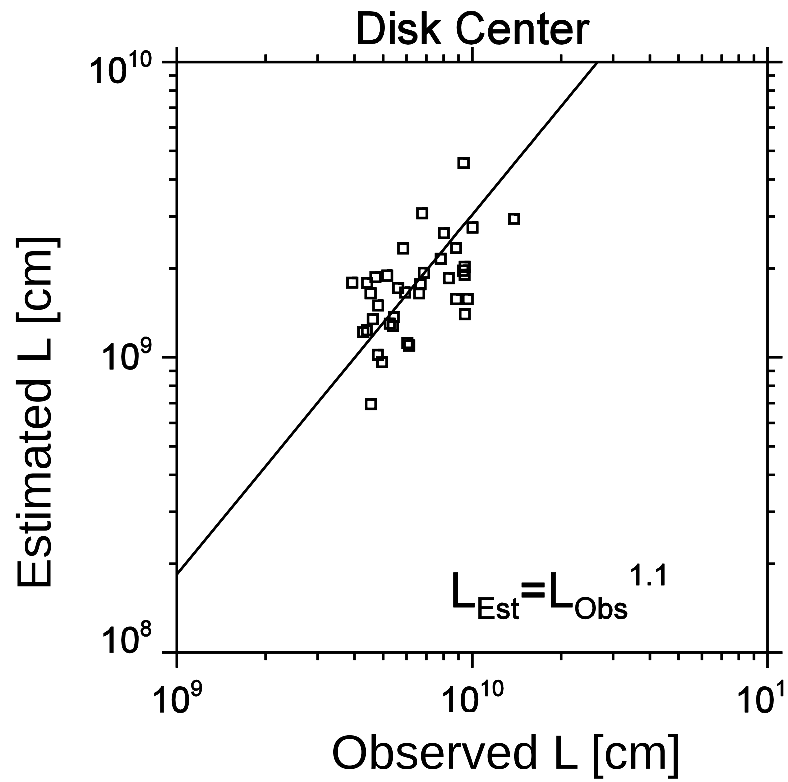
⇨ We confirmed observationally! from SDO/HMI & AIA

Flare Evolution Track



3.4 Results





Even by rough observation, there is correlation.

Other Analysis supports this estimation(Yamamoto2002)

⇨

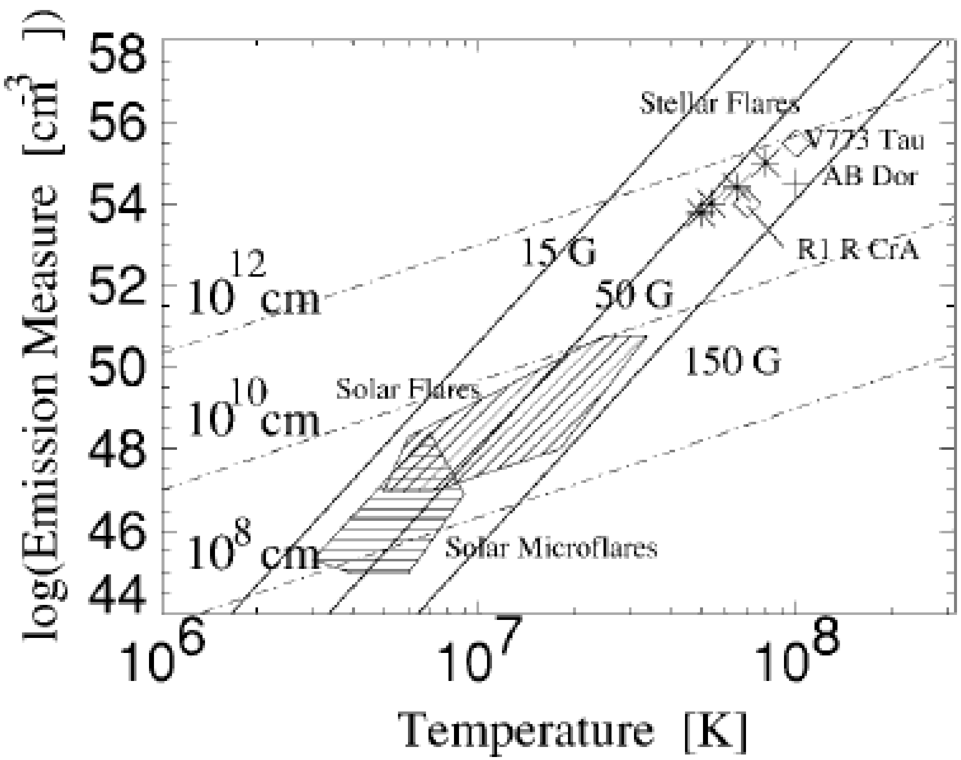
We can use this method,
in consideration of its errors.

$$B = 50\left(\frac{EM[cm^{-3}]}{10^{48}}\right)^{-0.2}\left(\frac{T[K]}{10^{7}}\right)^{1.7}\ [\mathrm{G}]$$

$$\mathrm{L} = 10^{9}\left(\frac{EM[cm^{-3}]}{10^{48}}\right)^{-0.6}\left(\frac{T[K]}{10^{7}}\right)^{-1.6}\ [cm]$$

How to estimate stellar magnetic field strength & scale of flare region?

There is an observational evidence in this relation about solar flares, stellar flares, and protostellar flares.



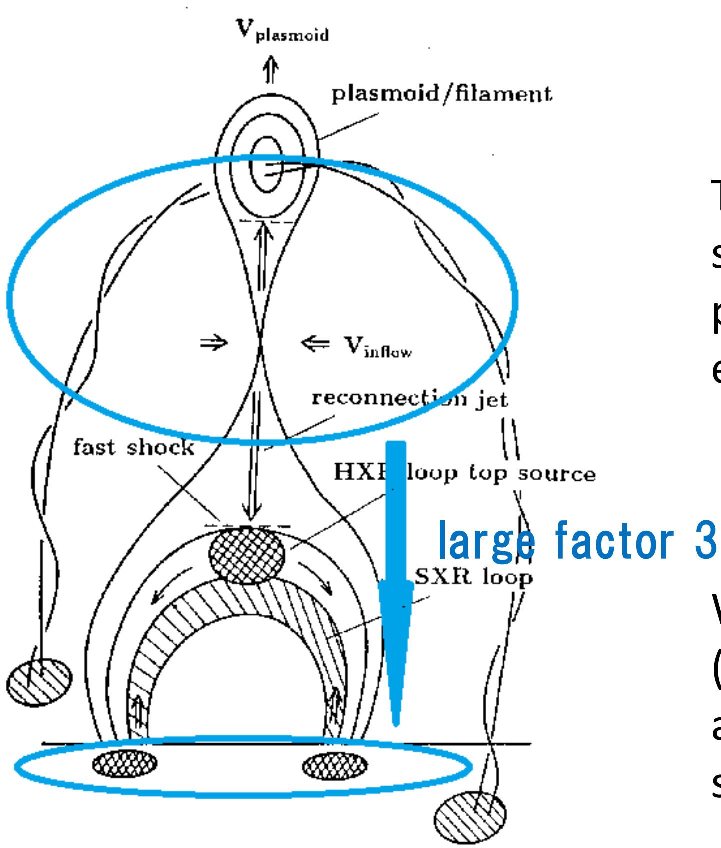
$$EM \propto B^{-5}T^{17/2}$$

EM & Temperature are calculated with two soft X-ray bands, so we can get magnetic field strength as...

$$B = 50\left(\frac{EM}{10^{48}}\right)^{-0.2}\left(\frac{T}{10^{6}}\right)^{1.7}$$

Analysis

We did very rough observation with SDO HMI Magnetgram & AIA 94A on 79 flare catalogue.



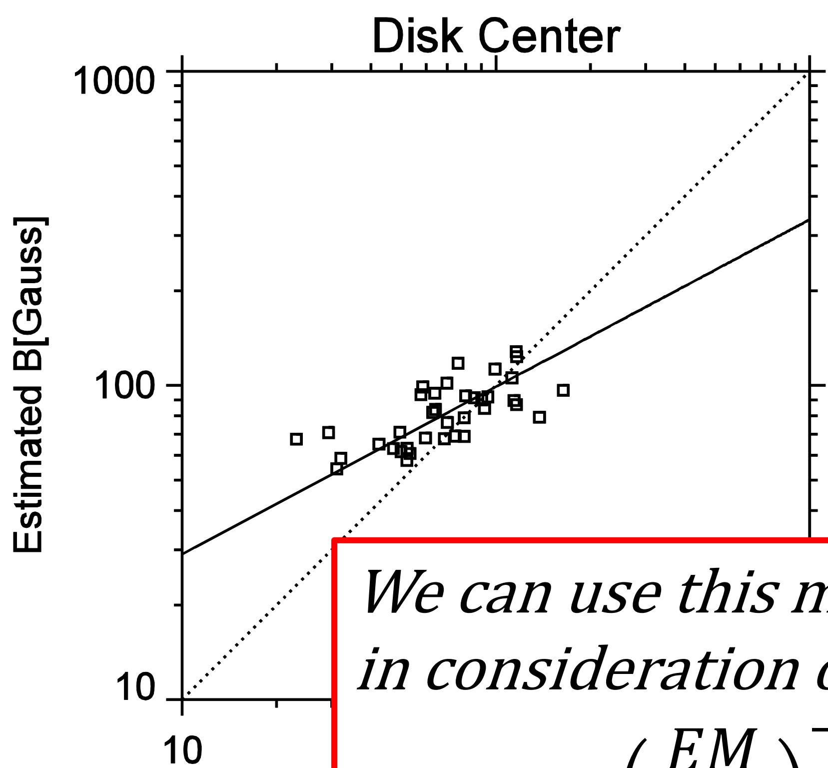
We want to observe magnetic field strength of corona

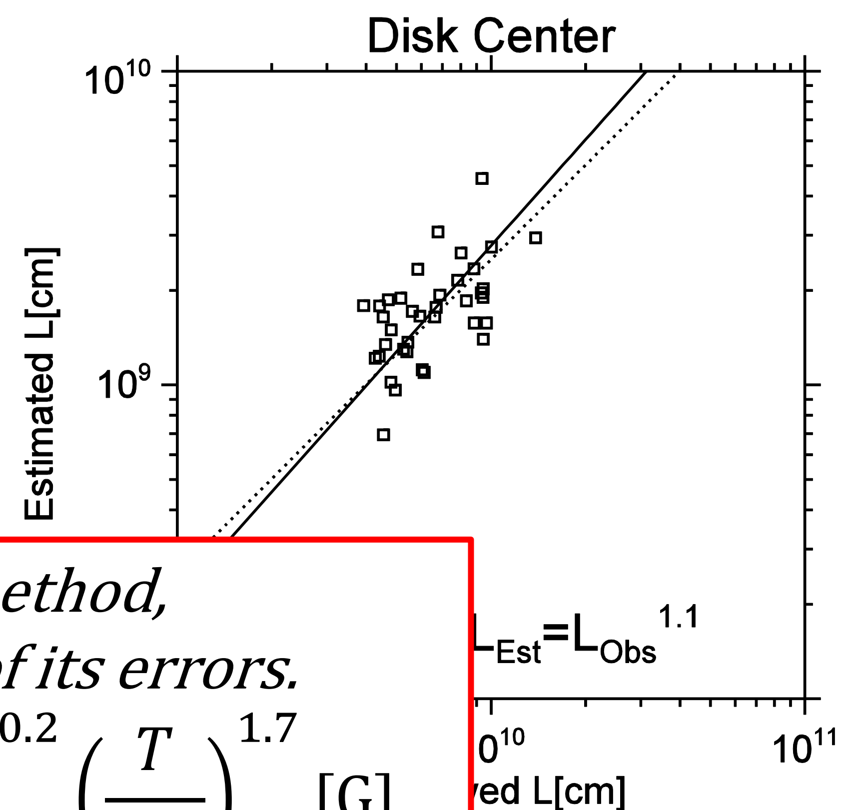
The coronal magnetic field strength is smaller (by a factor 3) than global photospheric magnetic strength. (Isobe et al. 2002)

We observe global HMI Magnetgram (photospheric magnetic field strength) and regard it as coronal magnetic field strength

Results(1)

Even by rough observation, there is correlation.





We can use this method,
in consideration of its errors.

$$B = 50\left(\frac{EM}{10^{48}}\right)^{-0.2}\left(\frac{T}{10^{6}}\right)^{1.7}\ [\mathrm{G}]$$

$$\mathrm{L} = 10^{9}\left(\frac{EM}{10^{48}}\right)^{-0.6}\left(\frac{T}{10^{6}}\right)^{-1.6}\ [cm]$$

※(… ends to be
because we did ver…

Difference of L

- Yamamoto(2002) research Arcade.
- Akiyama(2001's) research flare (C-class to X class).

This method can estimate the length scale by factor 3.

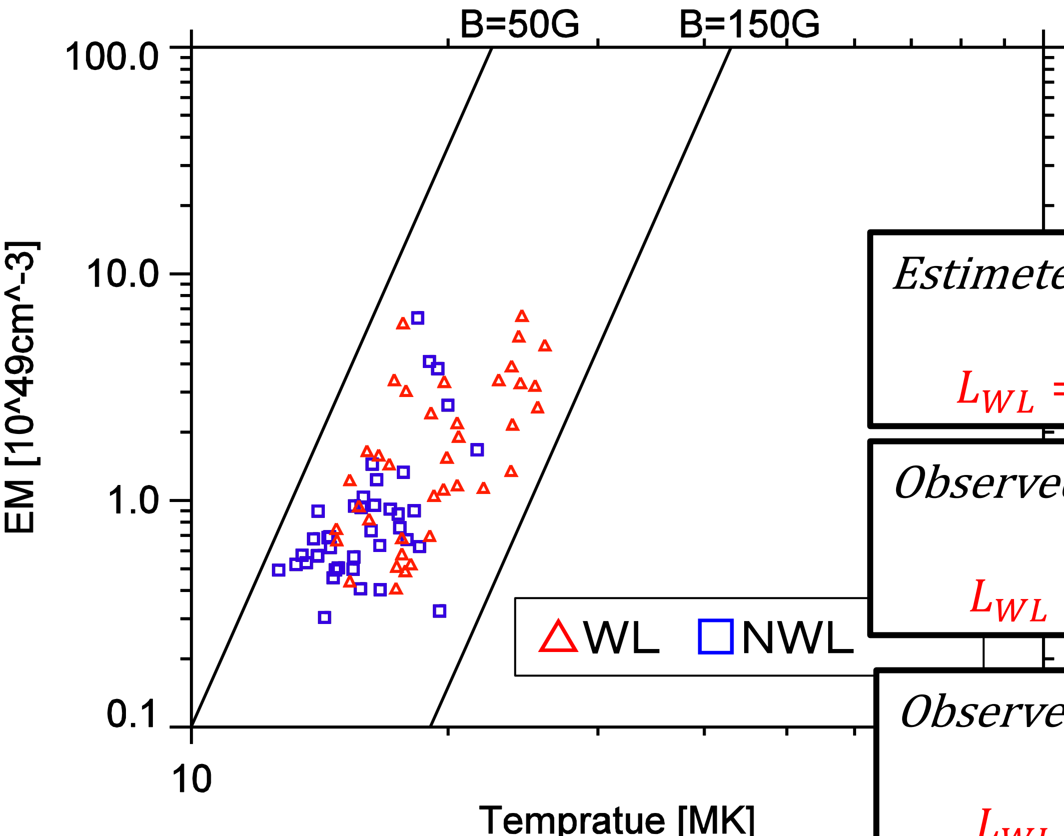
$$B = 50\left(\frac{EM}{10^{48}}\right)^{-0.2}\left(\frac{T}{10^{6}}\right)^{1.7}\ [\mathrm{G}]$$

$$\mathrm{L} = 10^{9}\left(\frac{EM}{10^{48}}\right)^{-0.6}\left(\frac{T}{10^{6}}\right)^{-1.6}\ [cm]$$

Data Discussion(1)

We can use this method to discuss White Light Flare

We plotted 38 white-light & 40 non-white-light flares on EM vs Temperature diagram.



What is the difference of WL and NWL flare?

Estimeted Properties(All Data)

$B_{WL} = 88[G]$ $B_{NWL} = 72[G]$

$L_{WL} = 1.8\ [10^9 cm]$ $L_{NWL} = 1.7\ [10^9 cm]$

ObservedProperties(All Data)

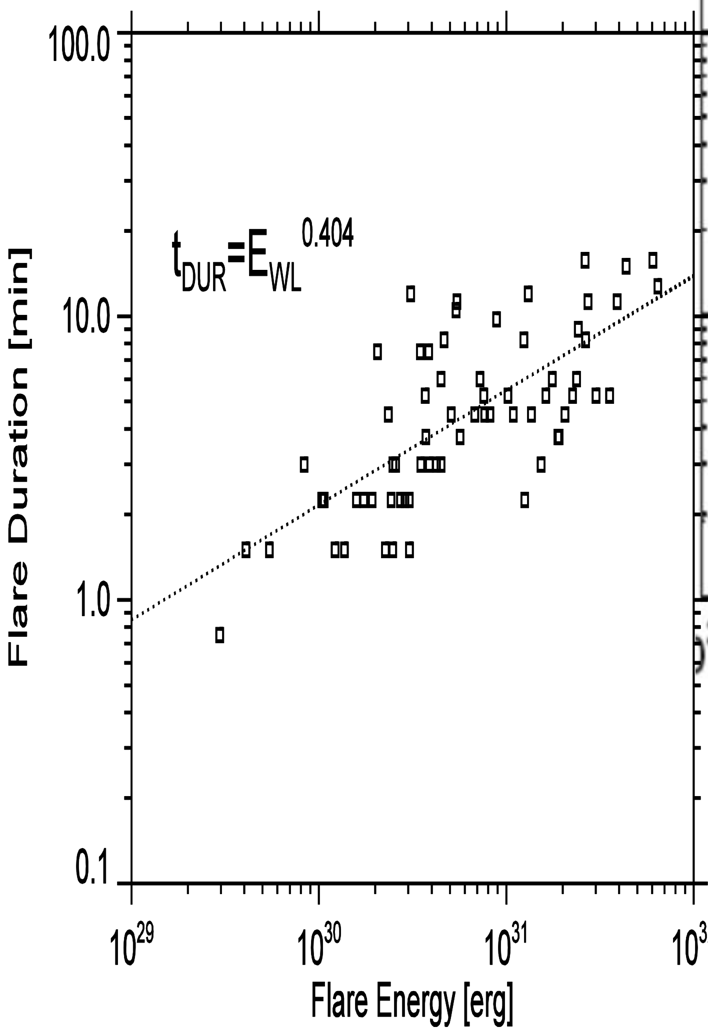
$B_{WL} = 66[G]$ $B_{NWL} = 64[G]$

$L_{WL} = 153\ [pixel]$ $L_{NWL} = 154\ [pixel]$

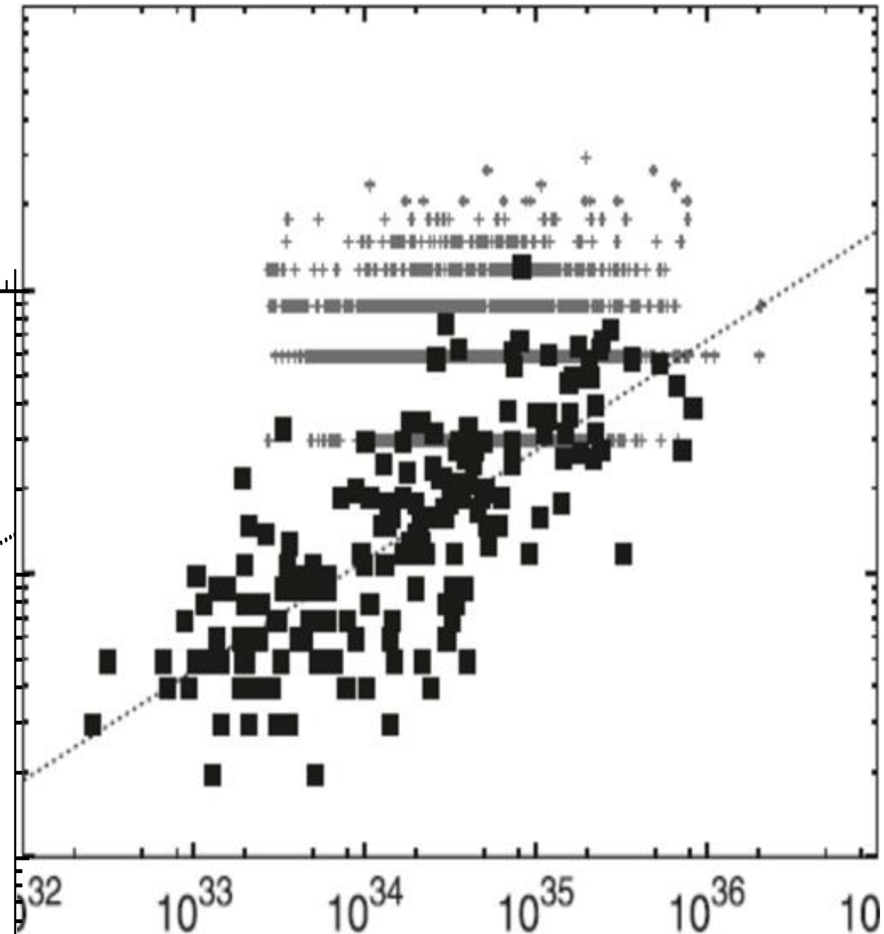
ObservedProperties(Disk Center 37flare)

$B_{WL} = 85[G]$ $B_{NWL} = 66[G]$

$L_{WL} = 169\ [pixel]$ $L_{NWL} = 148\ [pixel]$



WLF(今回の解析)　a=0.4



Maehara et al. (2015)　a=0.39±0.03