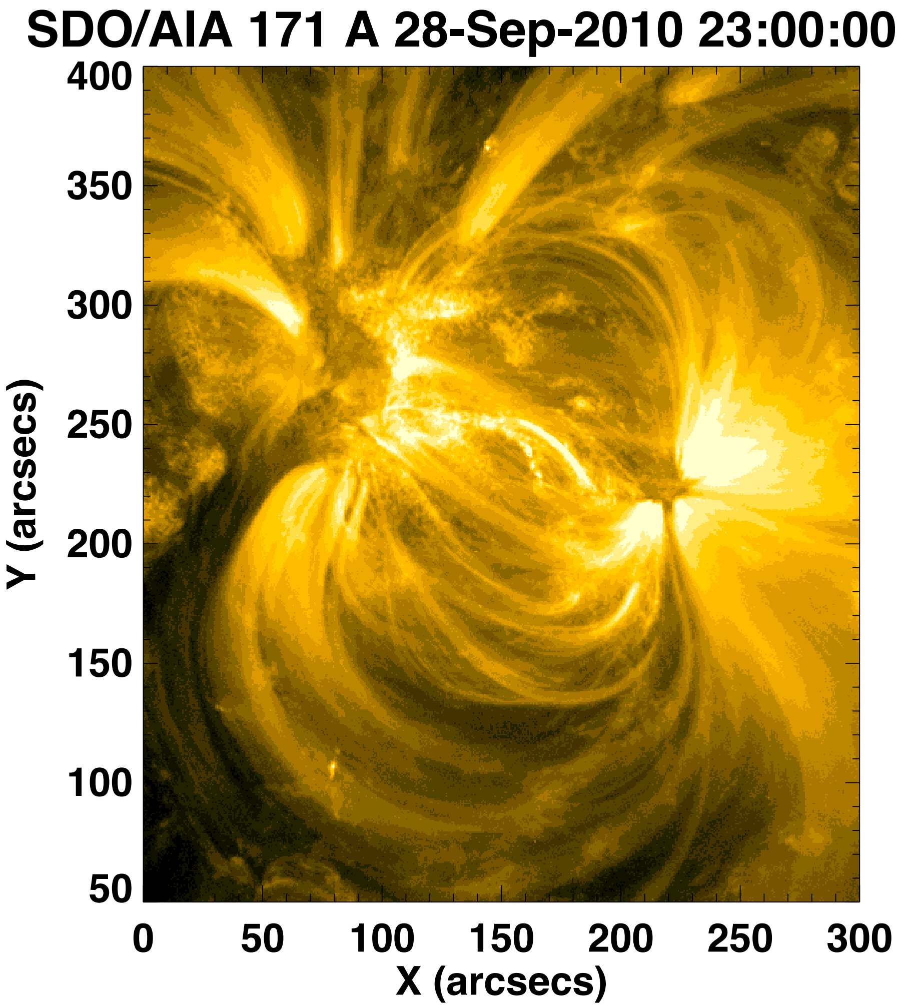
Constraints from Hinode/EIS on the Expansion of Active Region Loops Along the Line of Sight

or

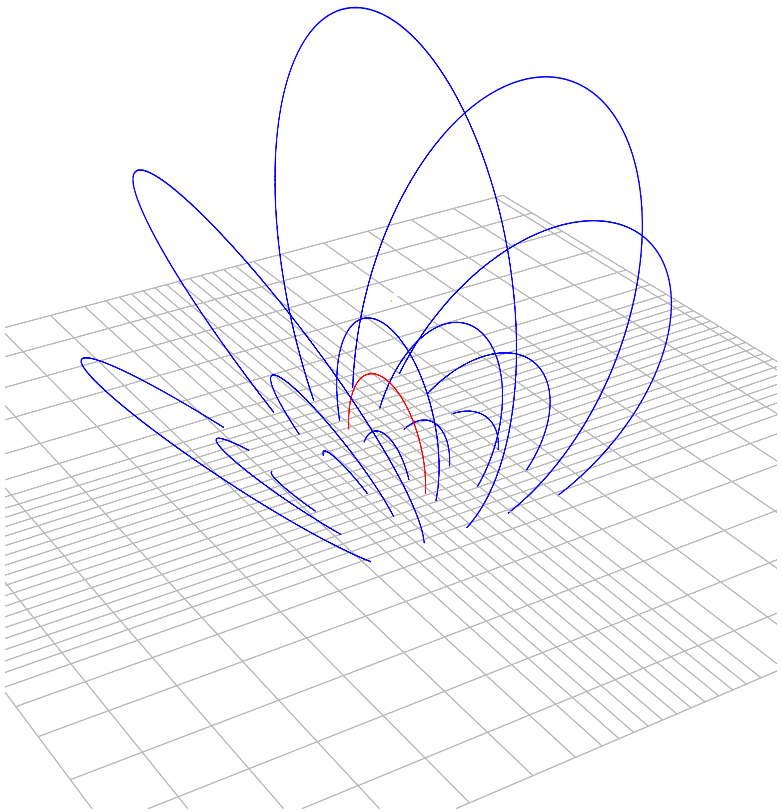
Are Coronal Loops Really Cylindrical? : Spectroscopy Edition

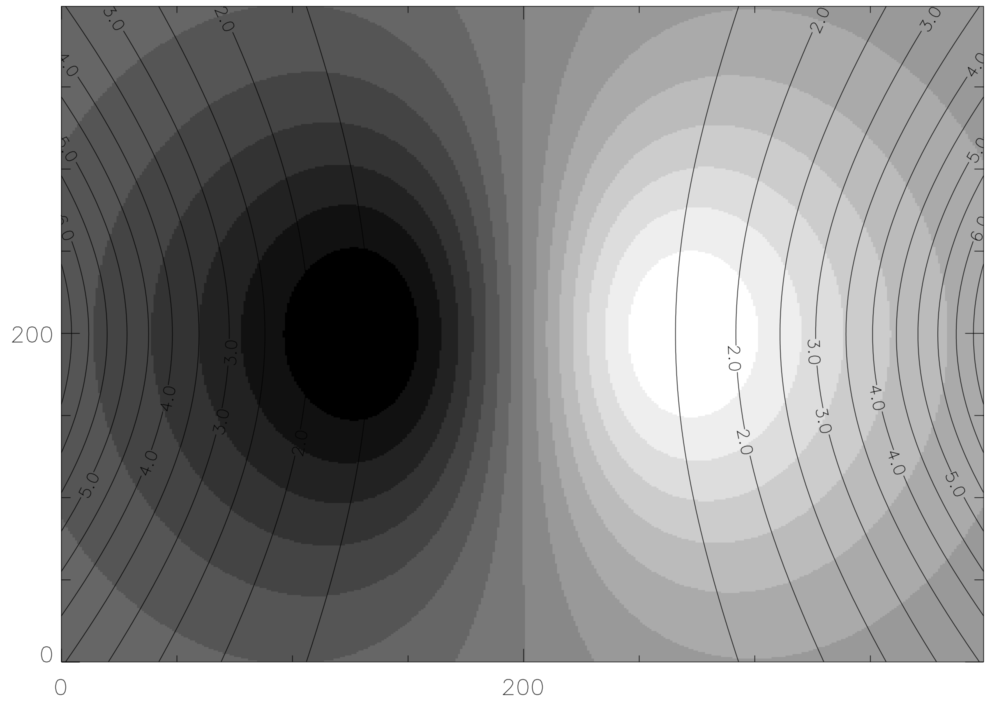
T. Kucera, P. Young, J. Klimchuk & C. Deforest

Loops around 1MK appear to be cylindrical without significant expansion with altitude



We expect the magnetic field and the loops to be expanding





Klimchuk 2000

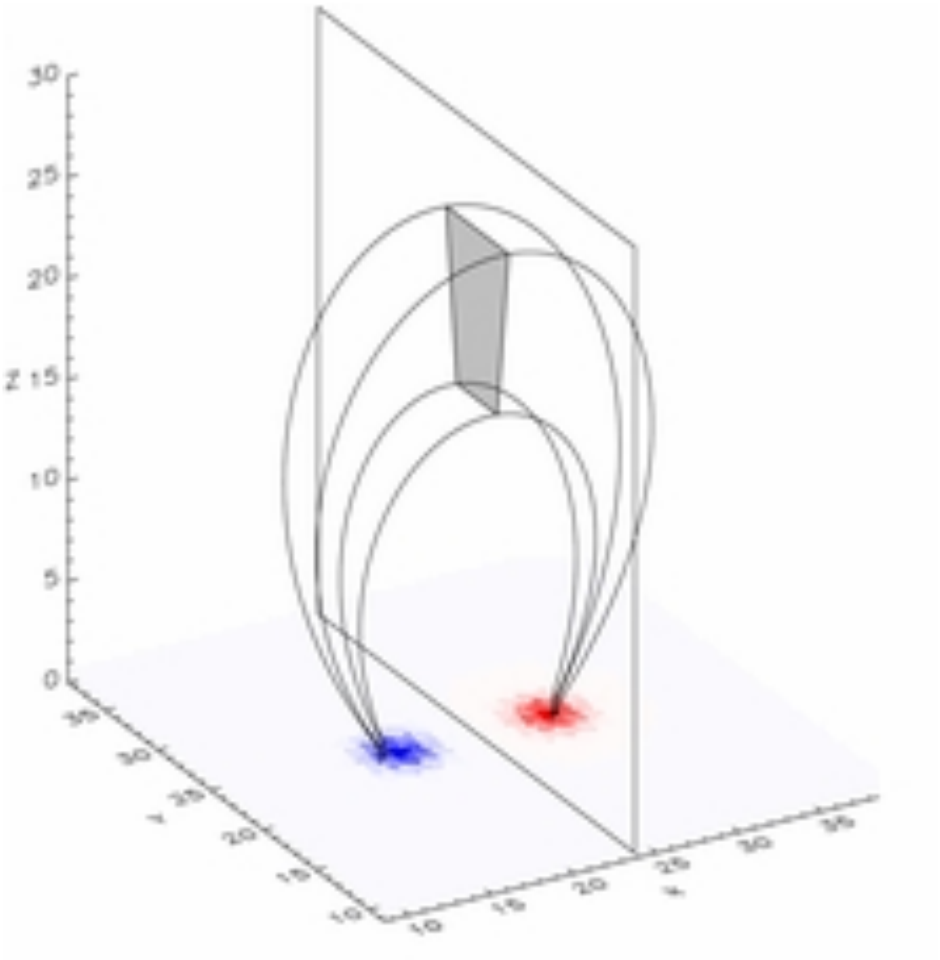
Why might loops be showing less expansion than that expected from the field as a whole?

- Expansion might not be resolved
- Expansion in individual loops could be constrained by currents
- Temperature variation across the loops might affect loop appearance
- Loops may have non-circular cross sections

Why might loops be showing less expansion than that expected from the field as a whole?

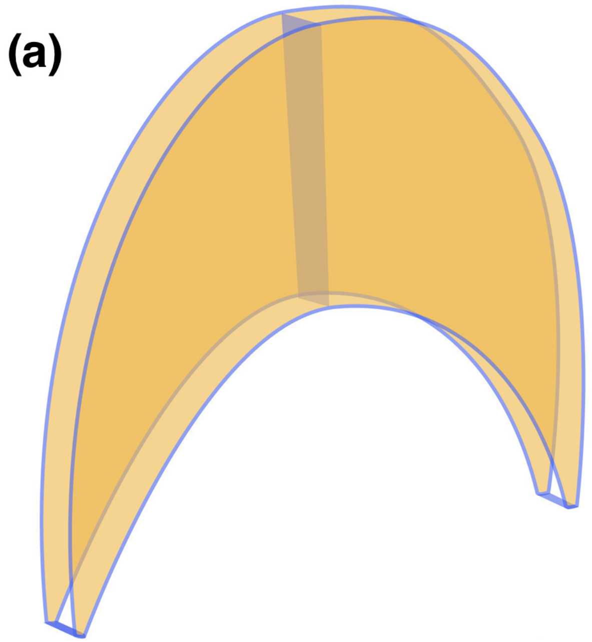
- Expansion might not be resolved
- Expansion in individual loops could be constrained by currents
- Temperature variation across the loops might affect loop appearance
- **Loops may have non-circular cross sections**

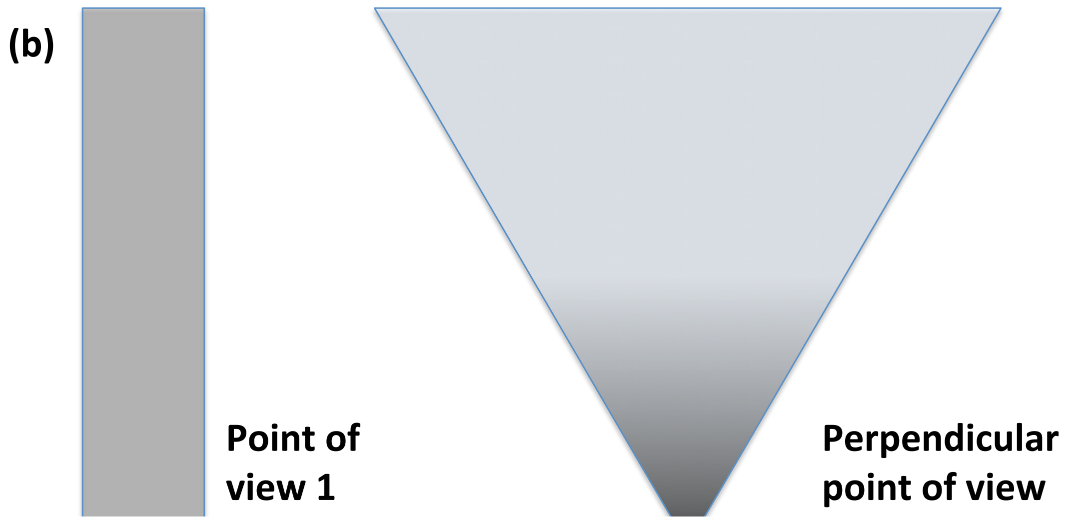
Could Observed Loop Widths be the Result of Non-Circular Loop Cross Sections?



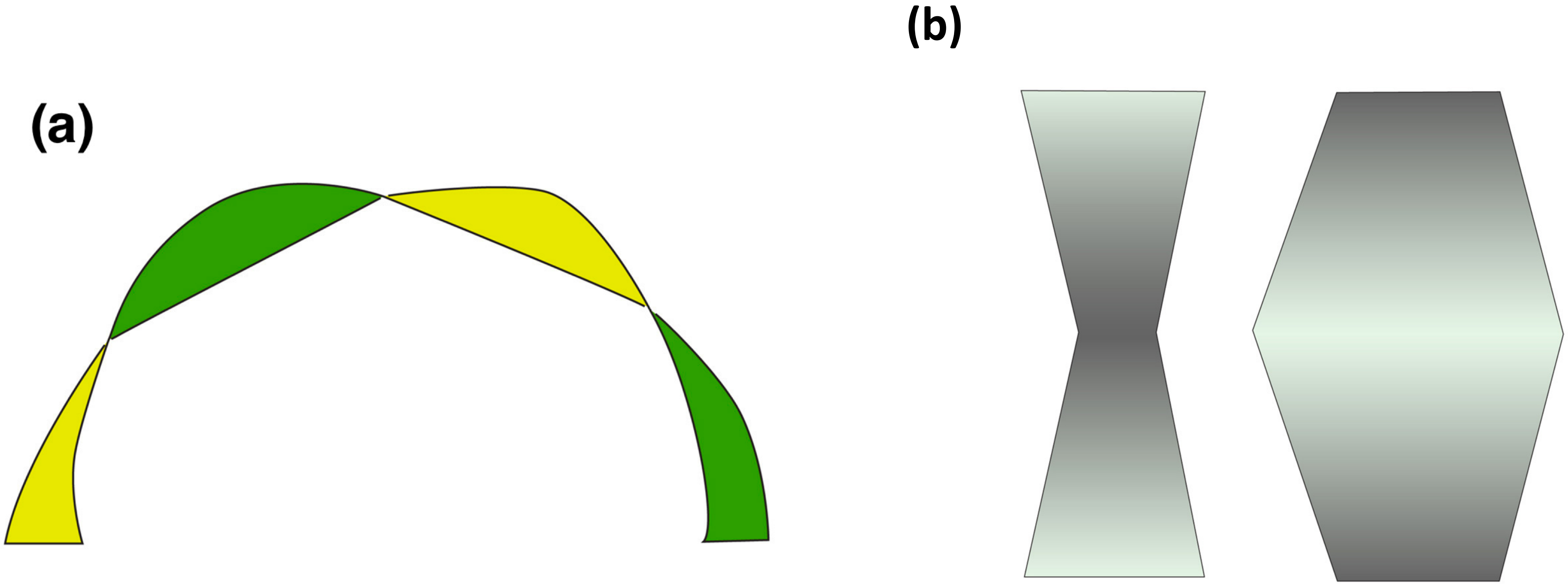
Malanushenko & Schrijver 2013

Simpler concept: Loops with non-circular cross-sections would look different from different points of view





How could we tell if this were the case?

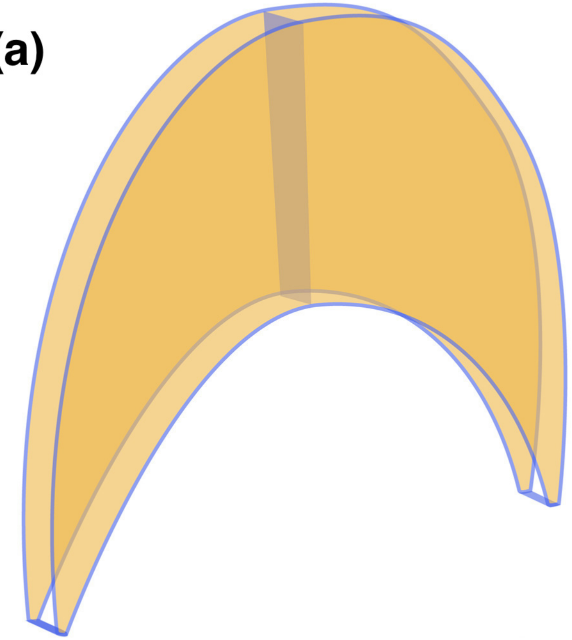


A loop with a non-circular cross section should show variations with intensity if it twists

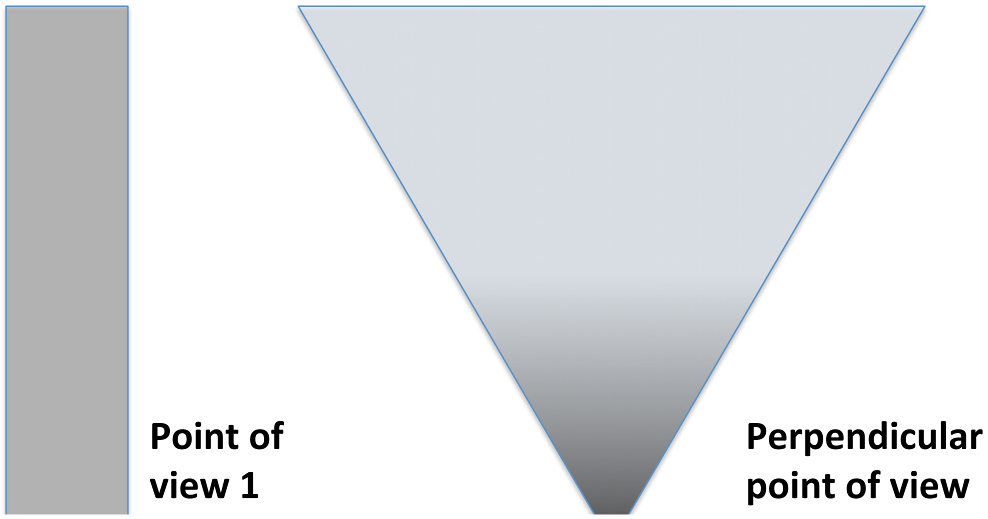
But this is Spectroscopy Club!

With spectroscopy we should be able to constrain the expansion of the loops *into* the plan of the sky.

(a)



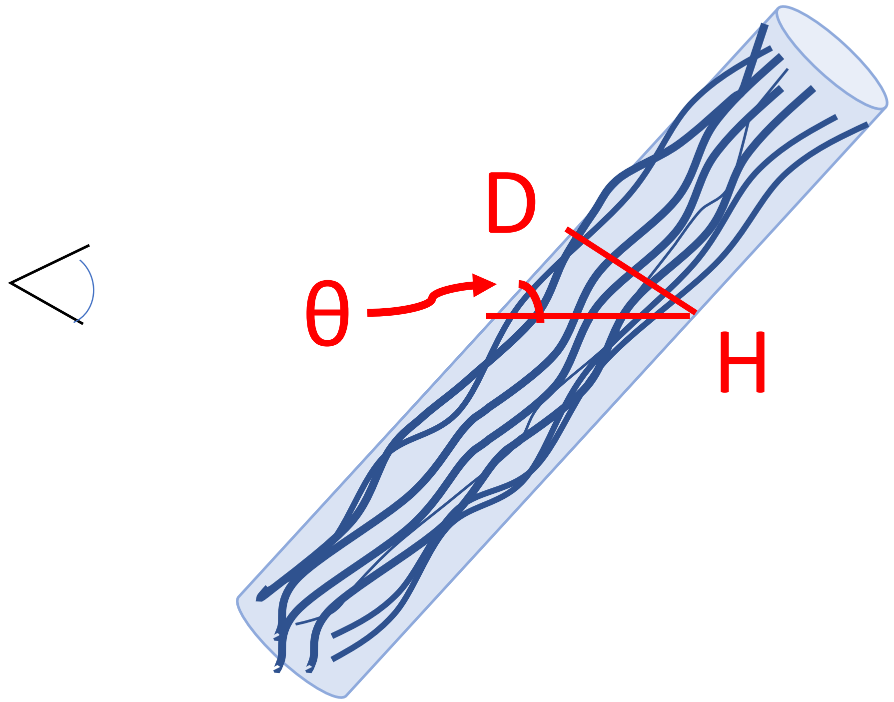
(b)



A digression: How to calculate a filling factor for a loop:

$$EM = n_e^2 H f$$

$$EM = I / (A\, G(n_e, T))$$



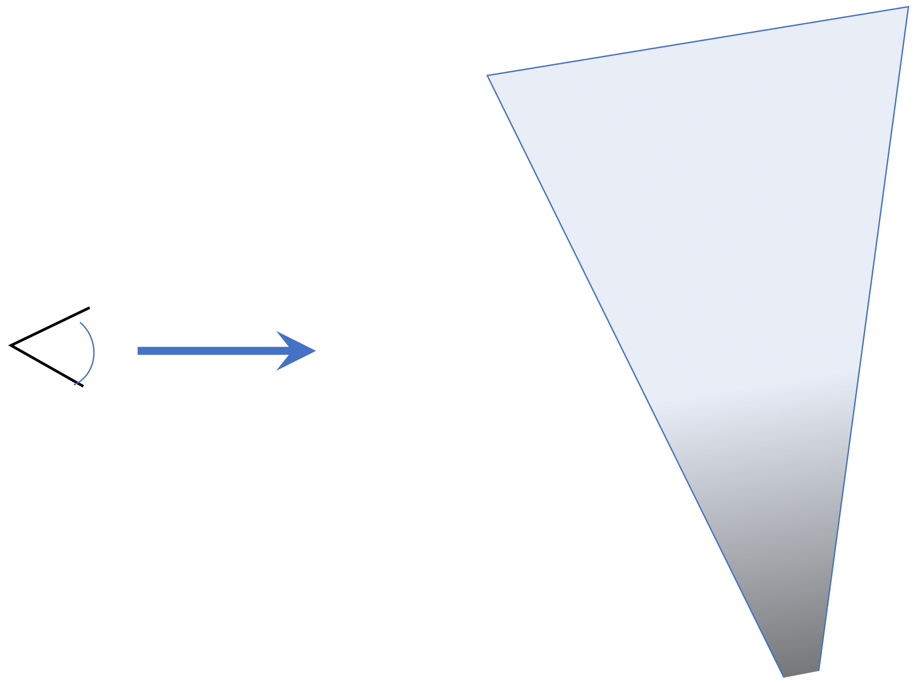
$$f = EM / n_e^2 H$$

Assume $H = D/\sin\theta = W/\sin\theta$

What if $H \neq W$?

$$EM = n_e^2 H f$$

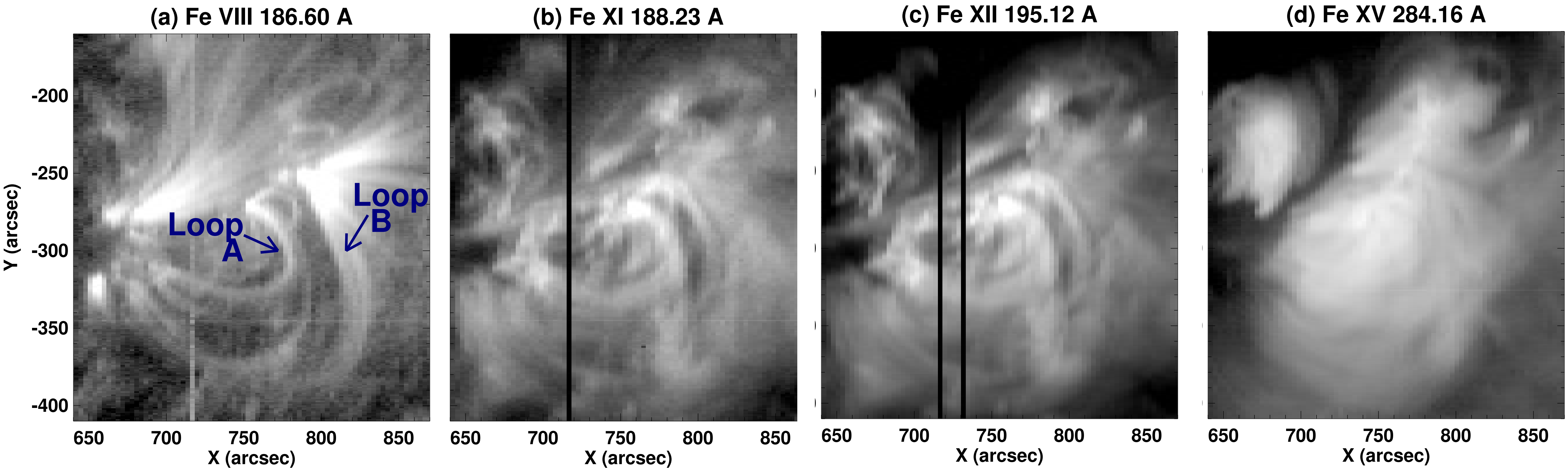
$$EM = I / (A\, G(n_e, T))$$



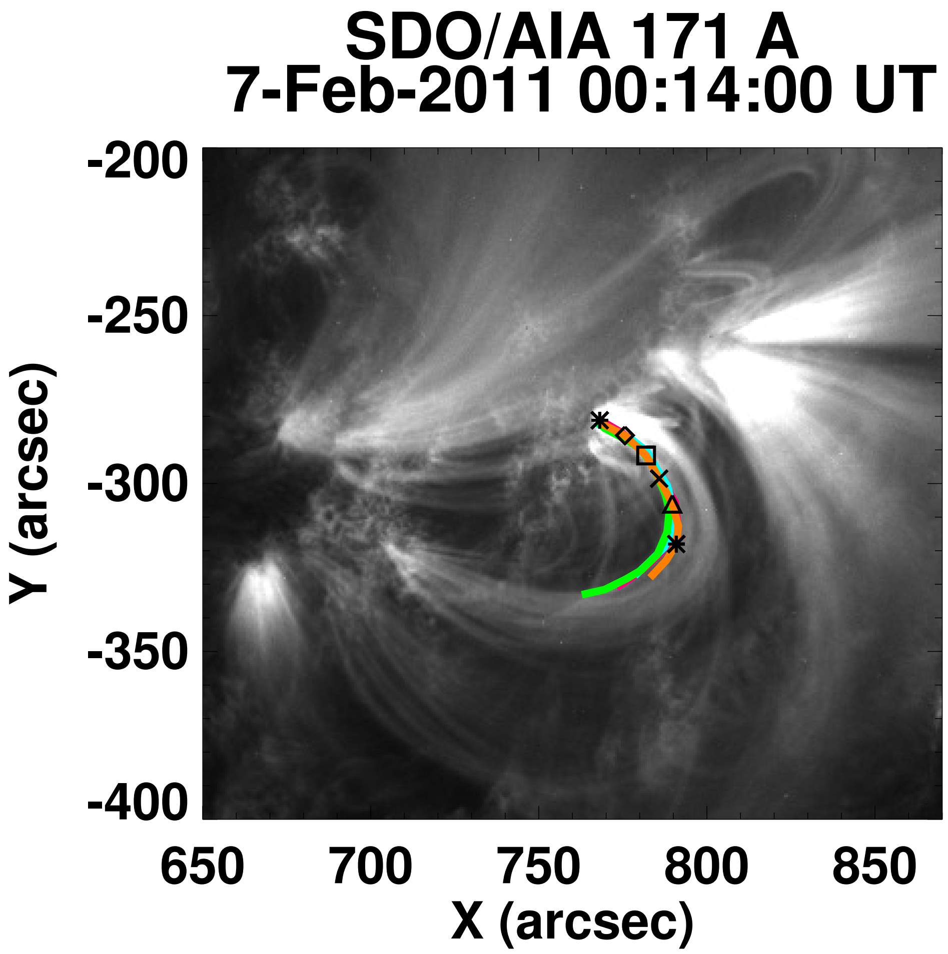
$$H = D/\sin\theta = EM / n_e^2 f$$

Assume f = constant

We analyzed two loops observed by EIS on 6-Feb-2011, AR11150



Loop A in 3D


SDO/AIA 171 A
7-Feb-2011 00:14:00 UT
-200
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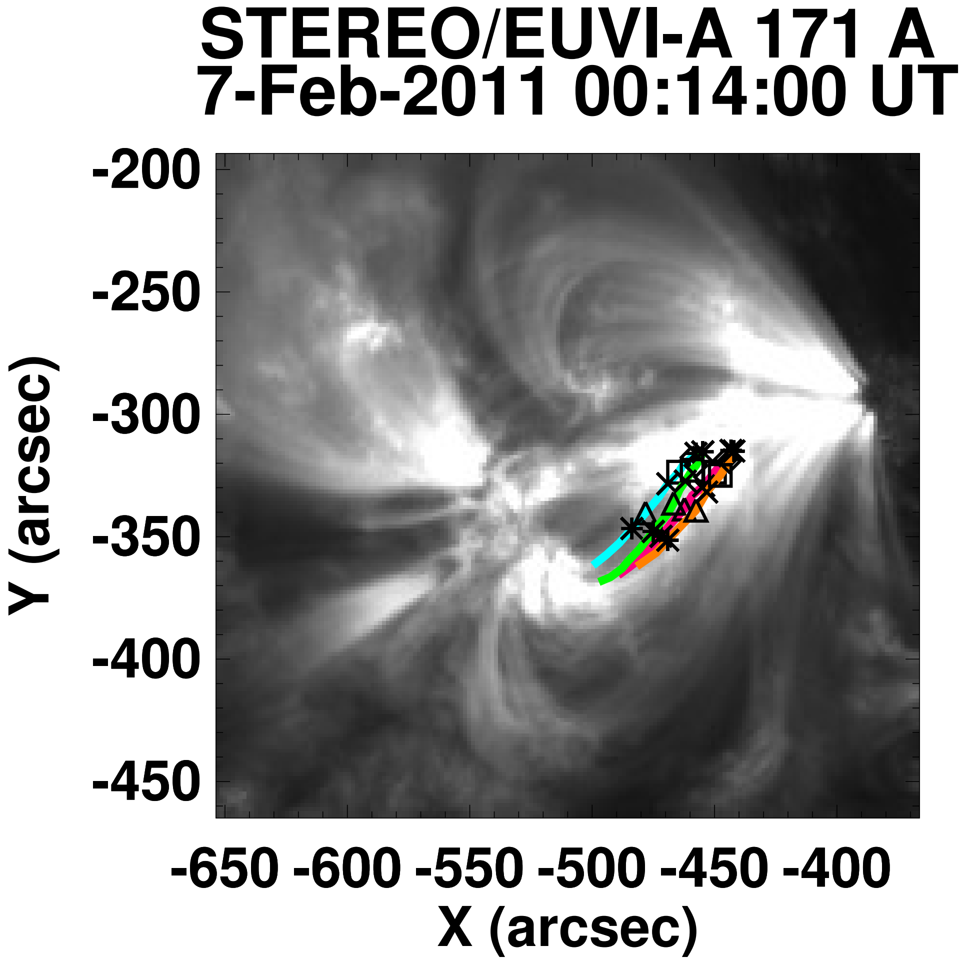
-400
Y (arcsec)
650
700
750
800
850
X (arcsec)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Y (arcsec)
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-500
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-400
X (arcsec)

EIS Observations

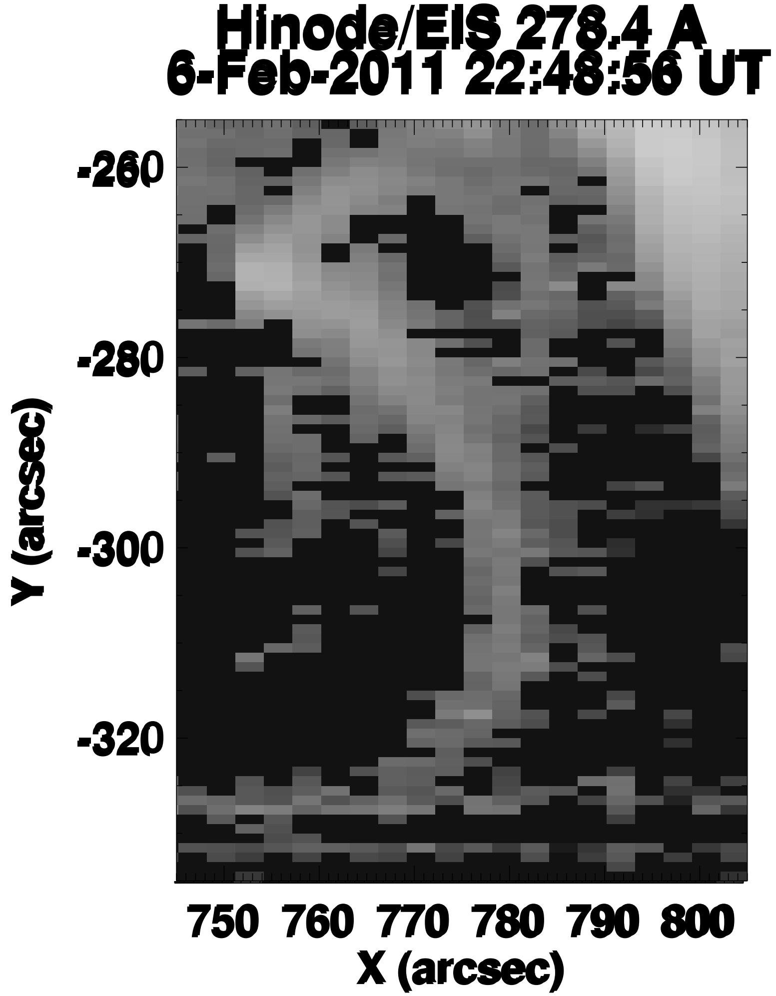
Ion	λ (Å)	Log T (K)	
O V	248.46	5.4	
Mg V	276.58	5.5	
Mg VI	269.00	5.7	
Mg VII	278.40	5.8	n_e diagnostic
Mg VII	280.74	5.8	
Fe VIII	186.60	5.7	
Fe X	184.54	6.0	
Fe XI	188.22	6.1	
Fe XII	195.12	6.2	
Si VII	275.36	5.8	
Si VII	278.45	5.8	
Si VII	275.36	5.8	
Si X	261.06	6.1	

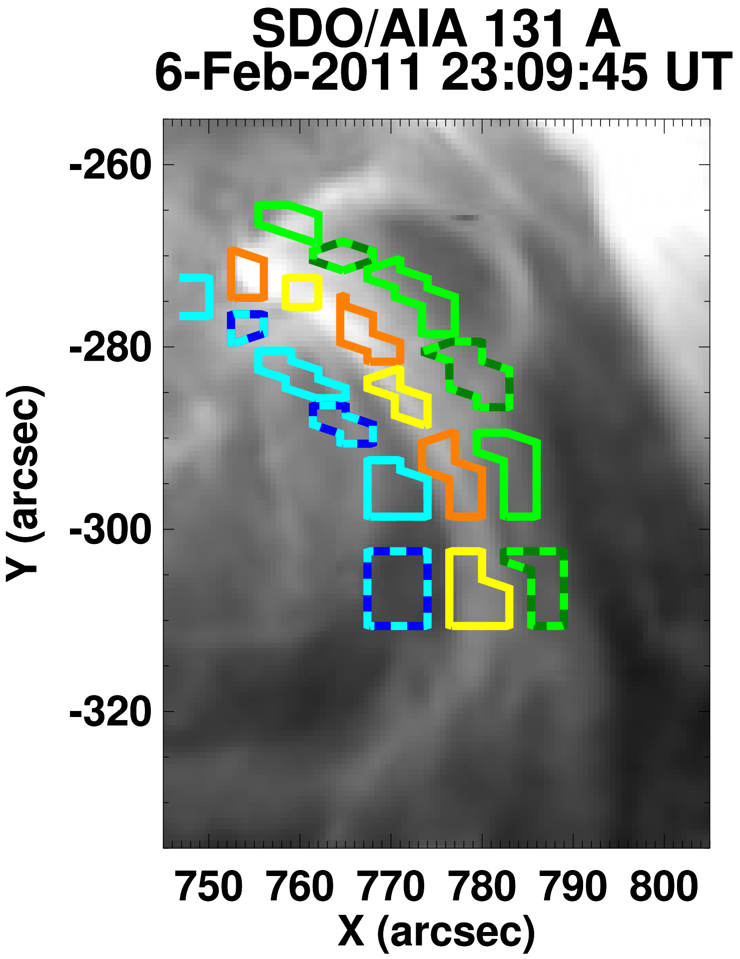
70 min raster

101 steps, 3.9” apart

2” slit

We analyzed the loops at different locations

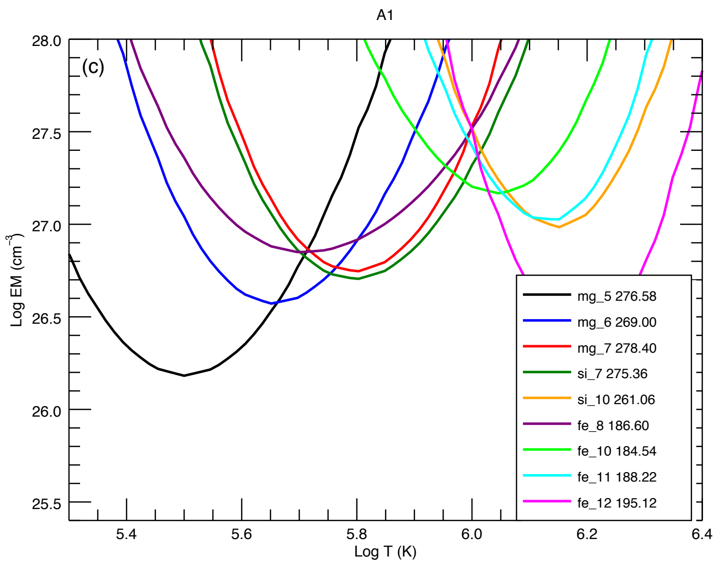


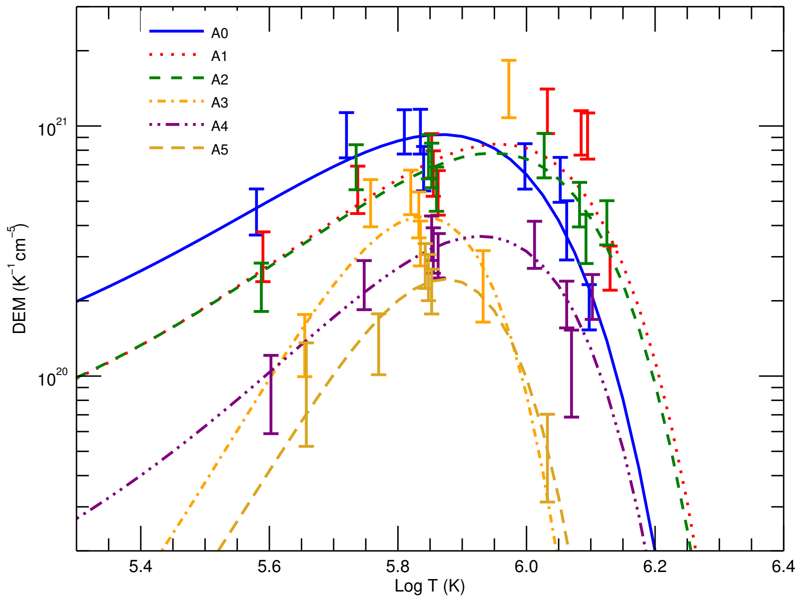


Determining Temperature and EM.

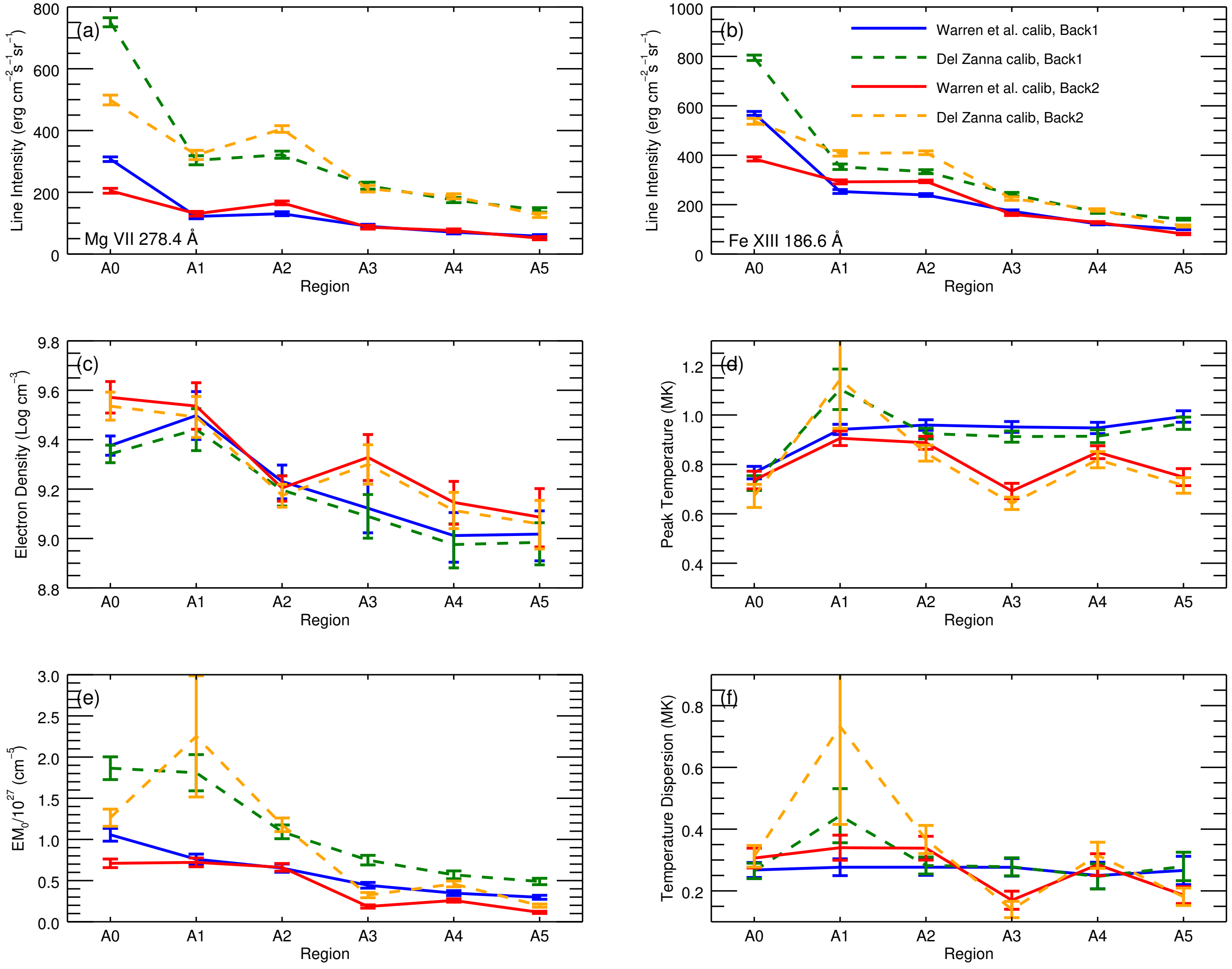
$$\mathrm{DEM} = \frac{EM_0}{\sigma_T\sqrt{2\pi}}\exp\left[\frac{-(T-T_0)^2}{2\sigma_T^2}\right]$$

(Warren et al. 2008)





Loop A Parameters

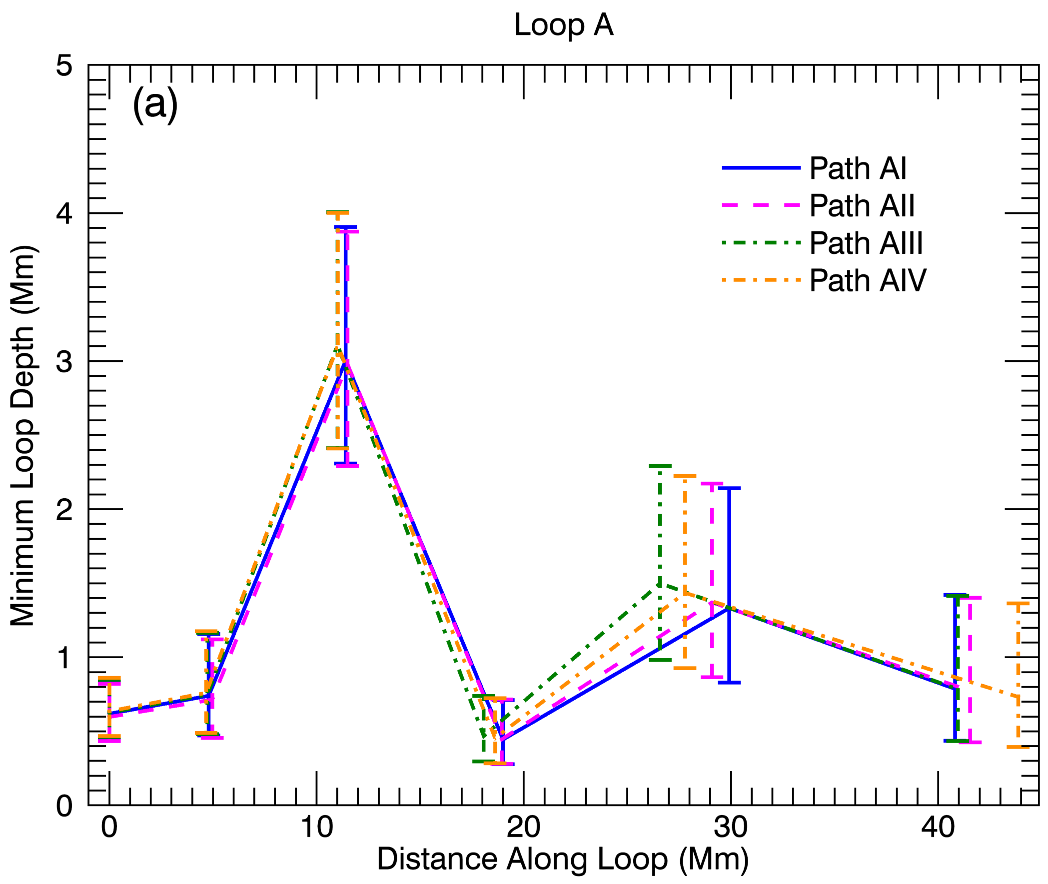


Two EIS Radiomentric Calibrations:

- Warren, Uguarte-Urra & Landi 2013
- Del Zanna 2014

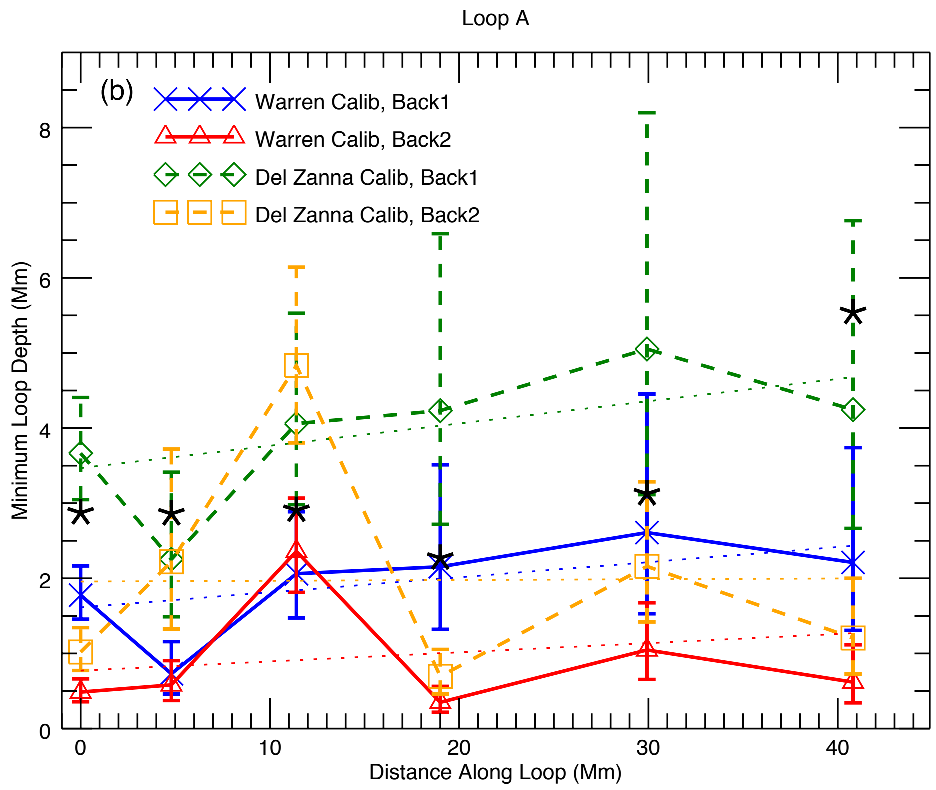
The exact loop angle not too important

$D_{min} = D(f=1)$



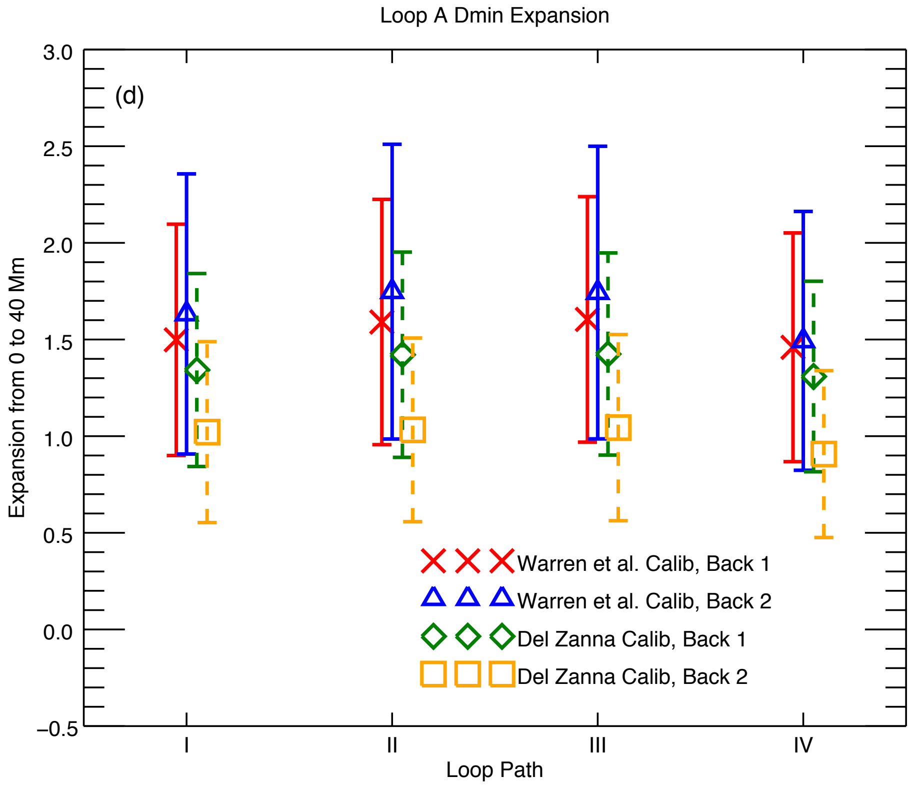
Calibration, background selection and count-based uncertainties all significant for measuring D

$D_{min} = D(f{=}1)$



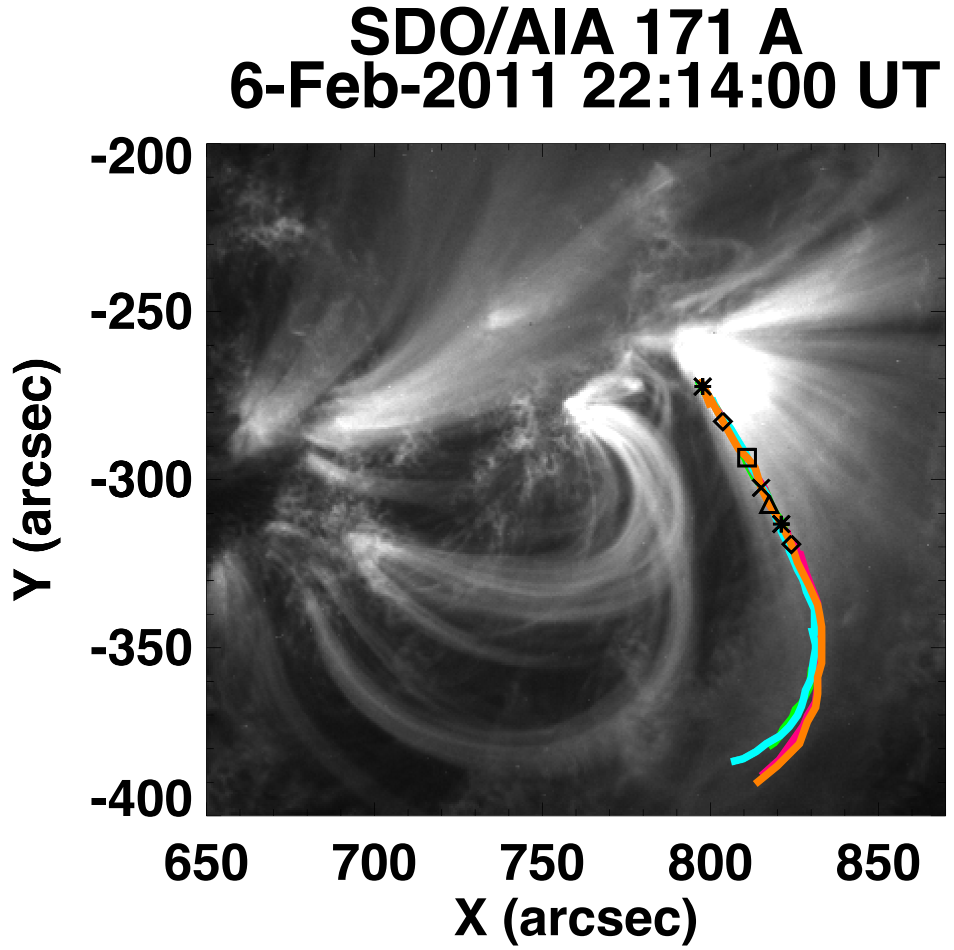
Linear Expansion consistent with no expansion and up to 2.5 expansion over 40 Mm

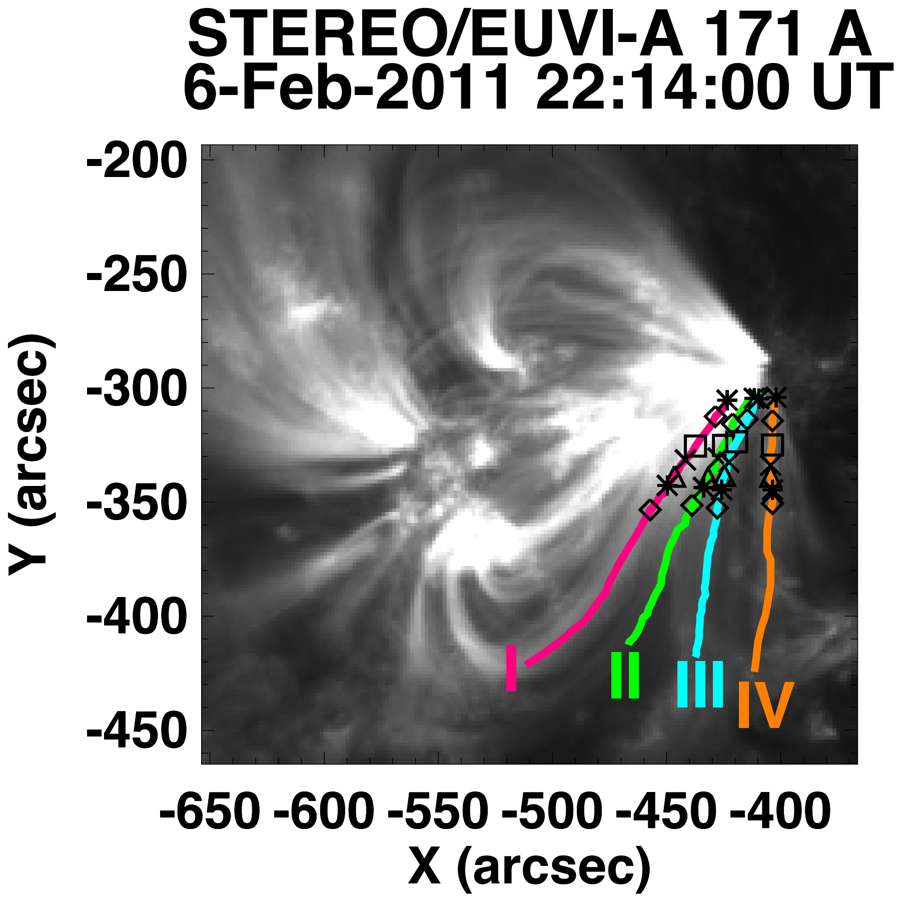
D(40 Mm)/D(0 Mm)

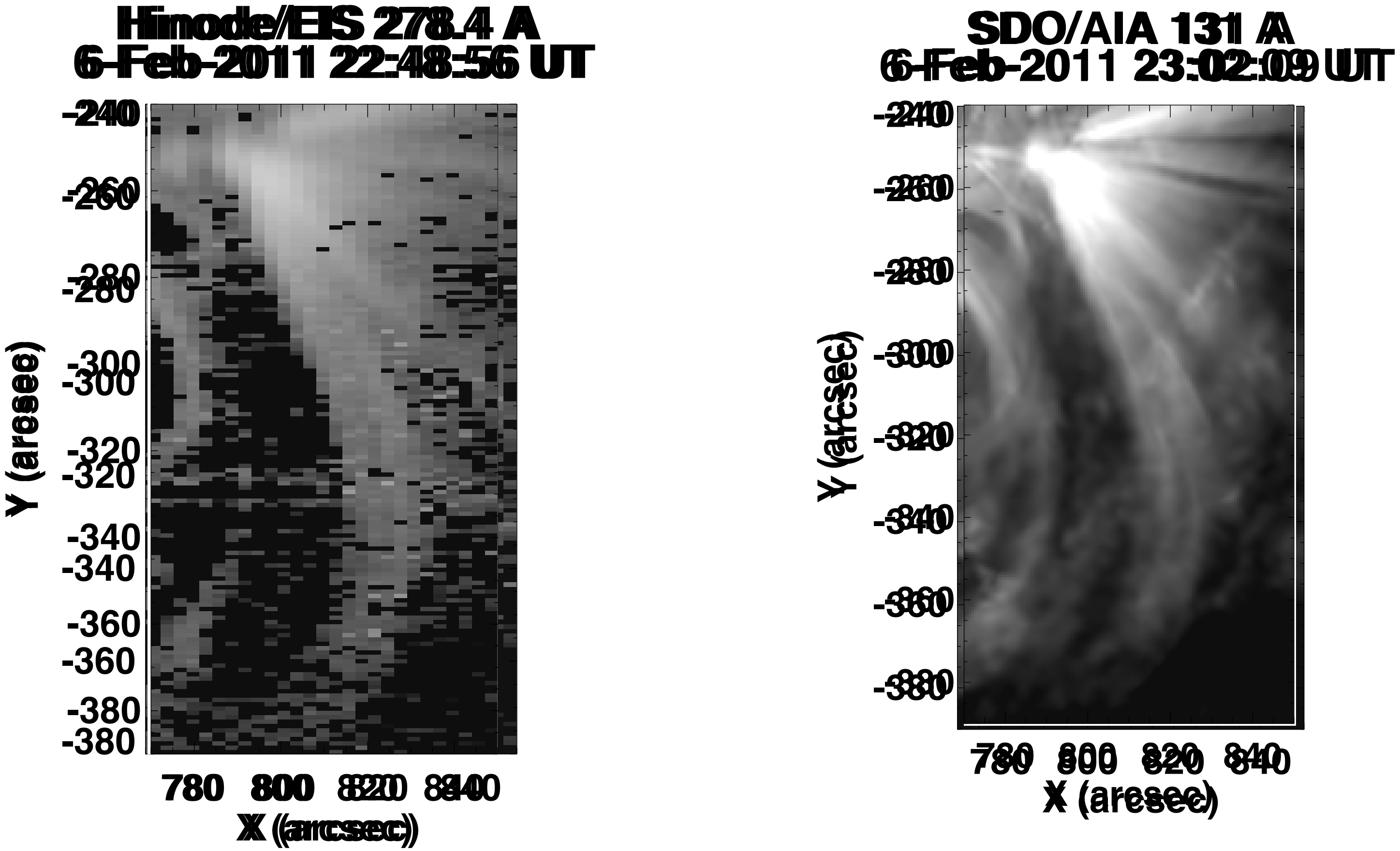


Assumes constant filling factor

Loop B analysis was very similar






Hinode/EIS 278.4 A
6-Feb-2011 22:48:56 UT
-240
-260
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-320
-340
-360
-380
Y (arcsec)
780
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820
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X (arcsec)
SDO/AIA 131 A
6-Feb-2011 23:02:09 UT
-240
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Y (arcsec)
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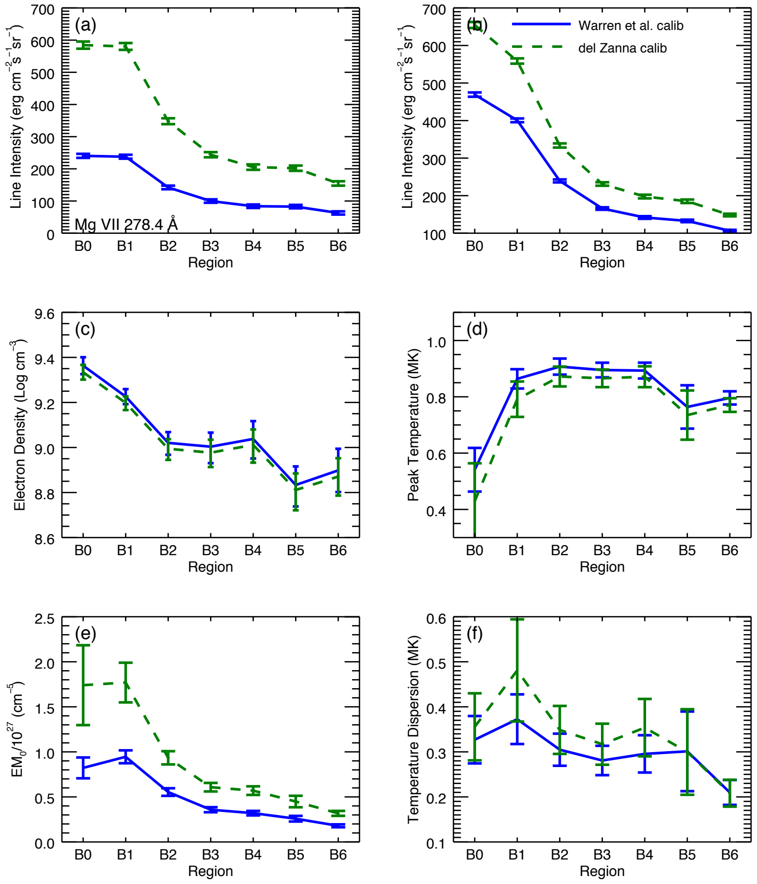
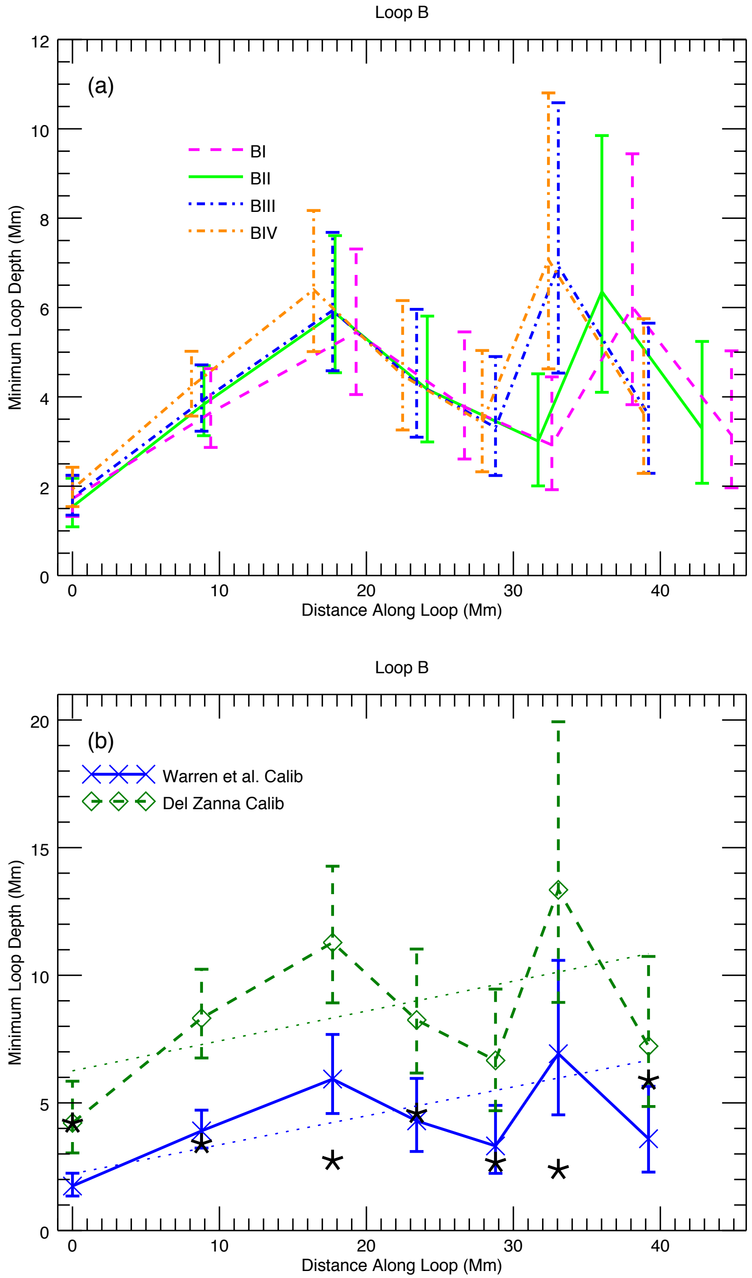
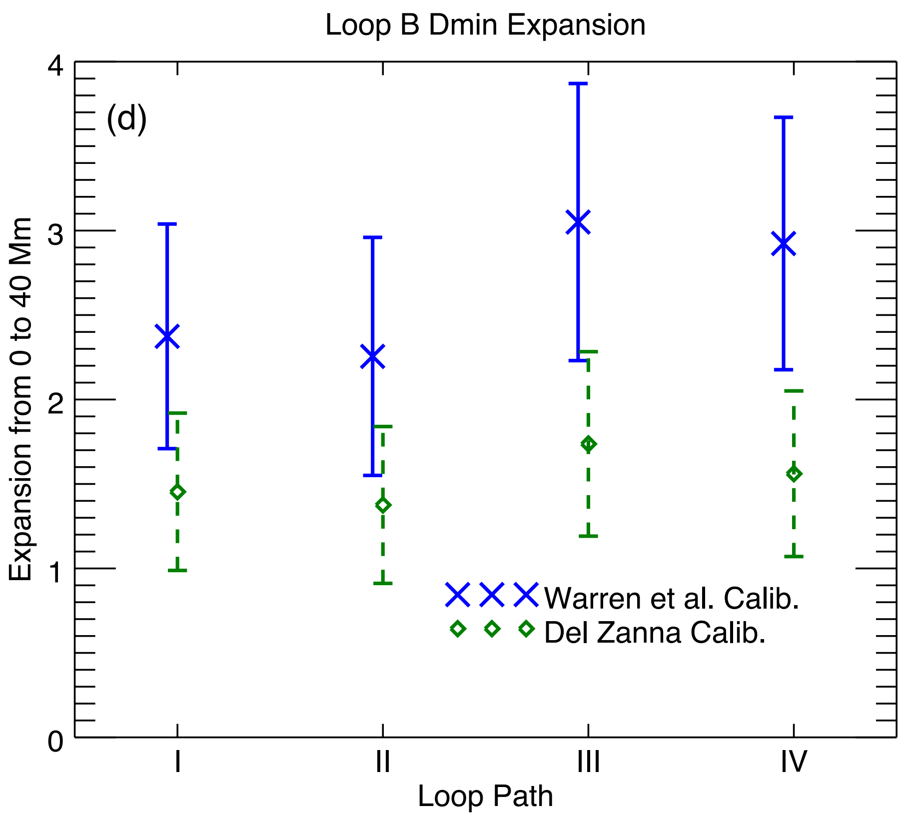
Loop B parameters





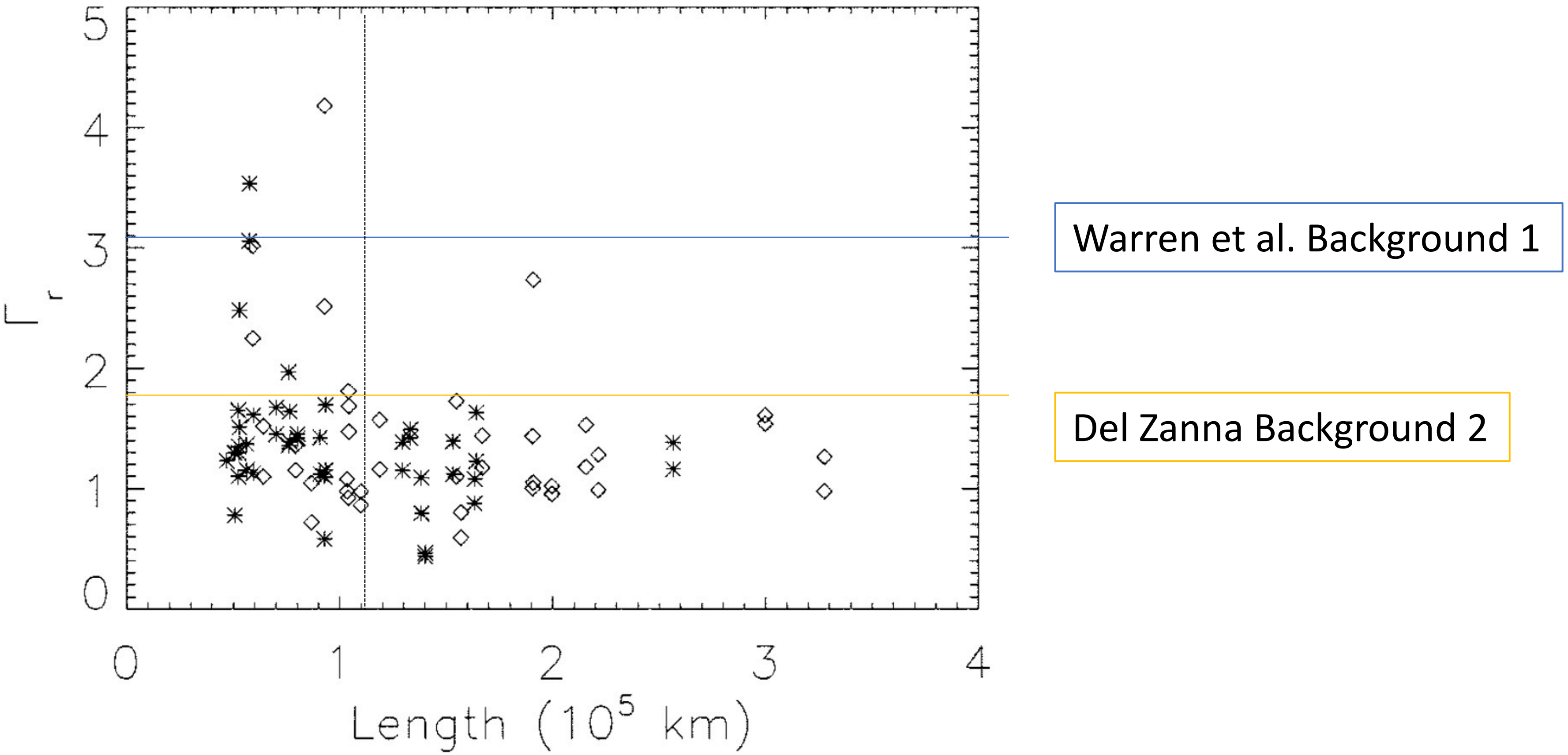
Expansion Factor for B

D(40 Mm)/D(0 Mm)



These constraints are pretty loose

Yohkoh/SXT loop expansion



Horizontal lines are max peak expansion for a 113 Mm loop (LoopA)

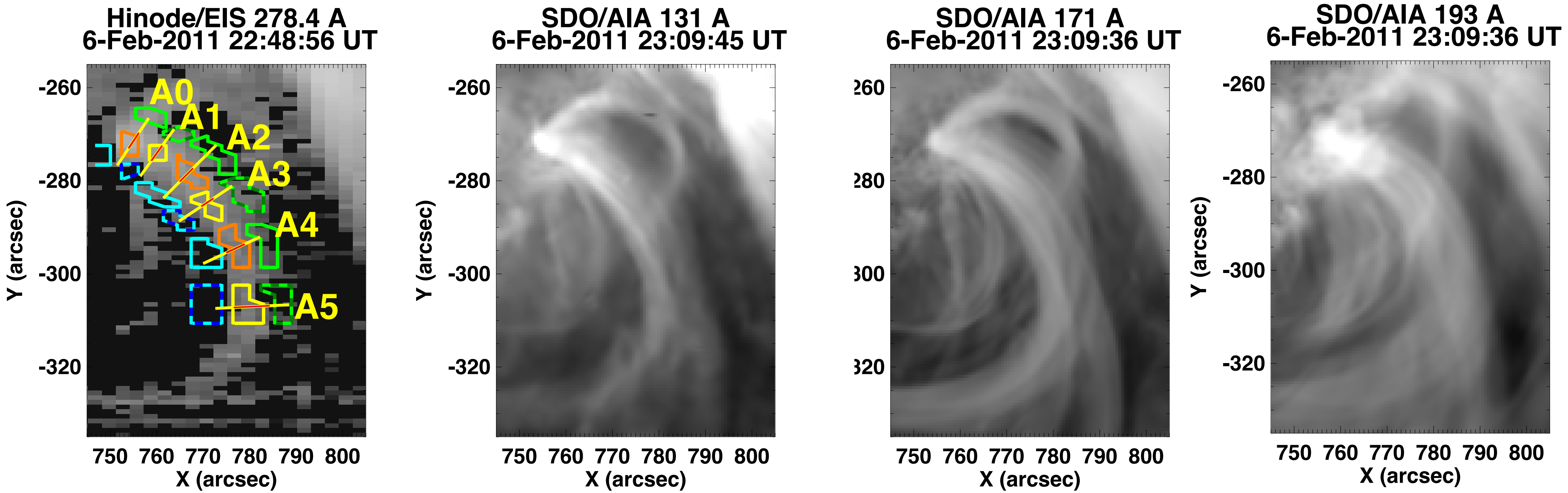
Klimchuk 2000

So, what about the traditional interpretation?

i.e., what filling factor would we calculation with a standard circular-cross section model?

$$f = \frac{EM}{n_e^2 H} = \frac{EM}{n_e^2} \frac{\sin\theta}{W}$$

In order to calculate a filling factor we need to measure a loop width



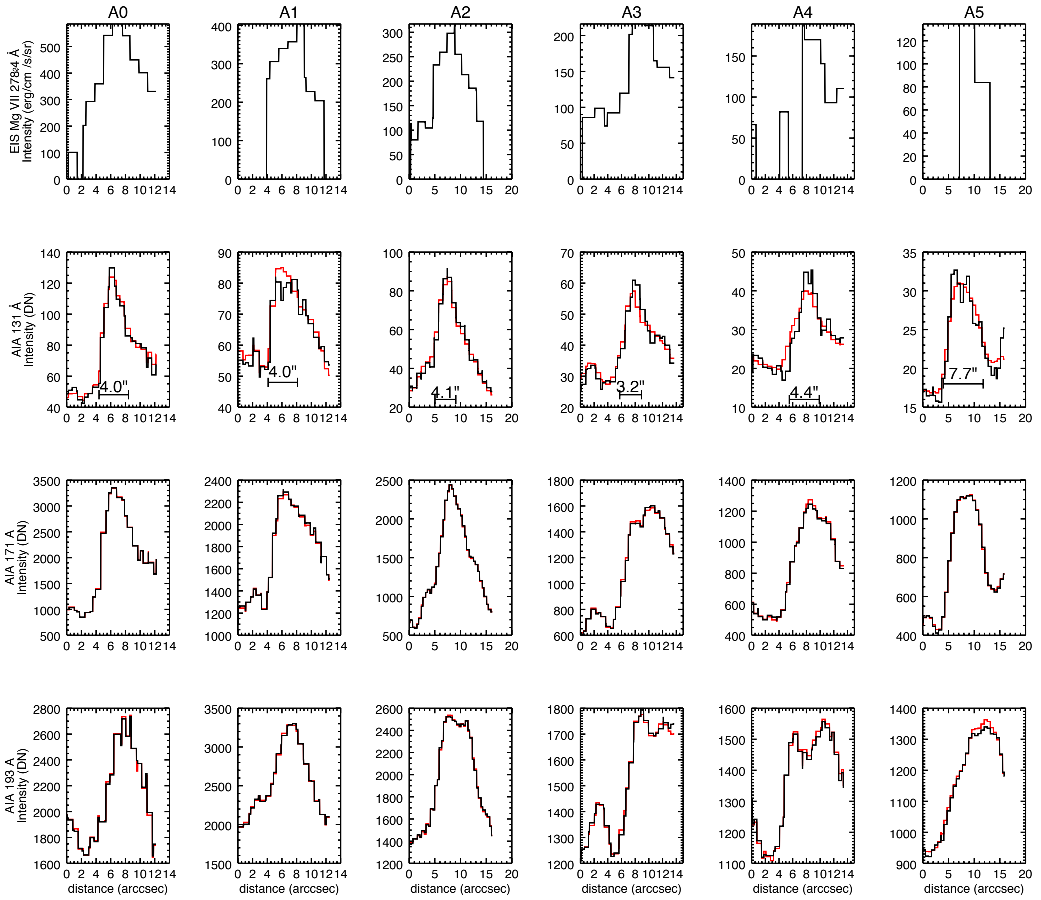
We used AIA data to measure the widths

EIS 278.4 Å

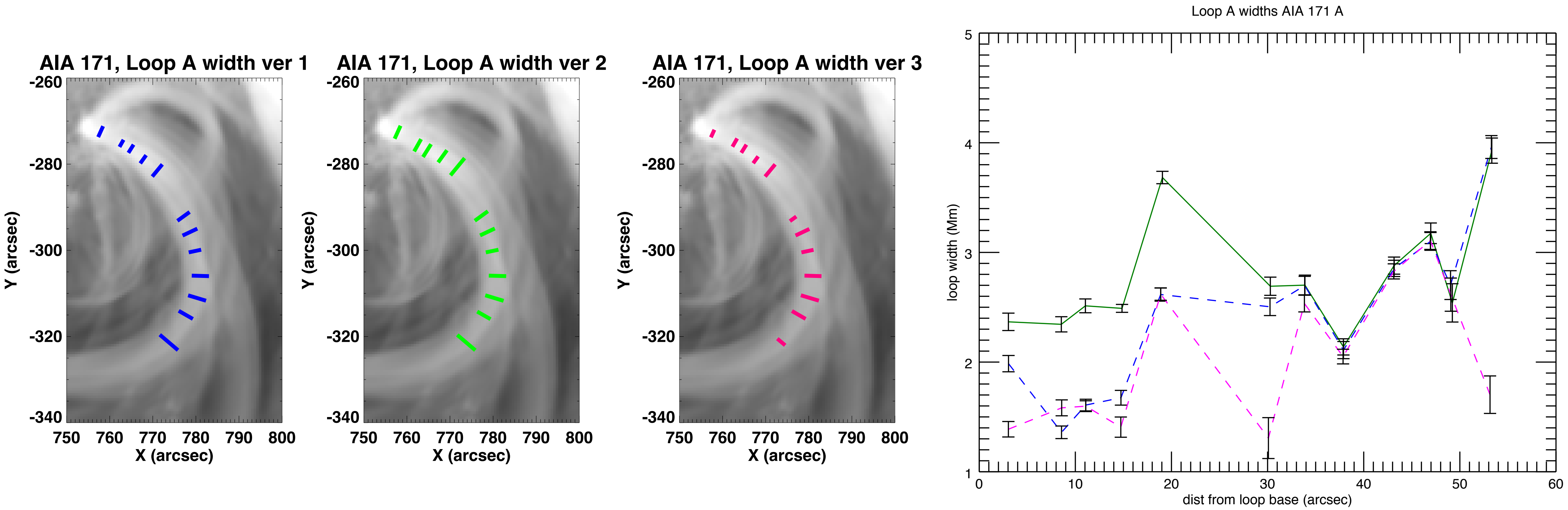
AIA 131 Å

AIA 171 Å

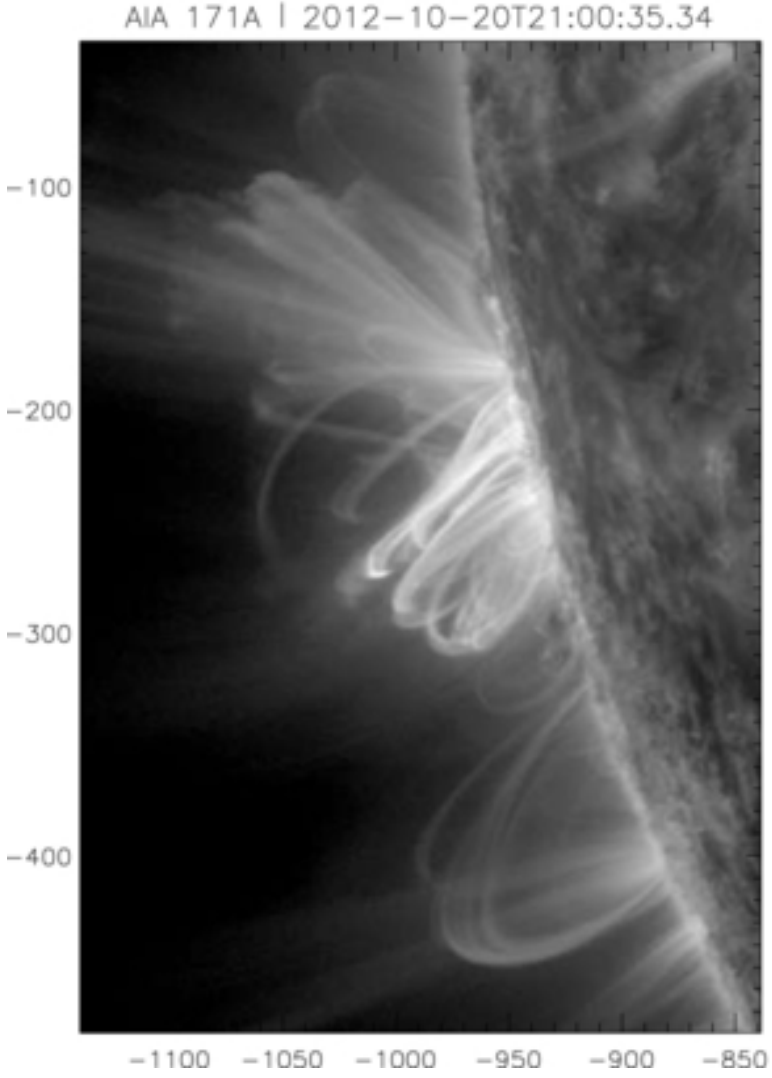
AIA 193 Å

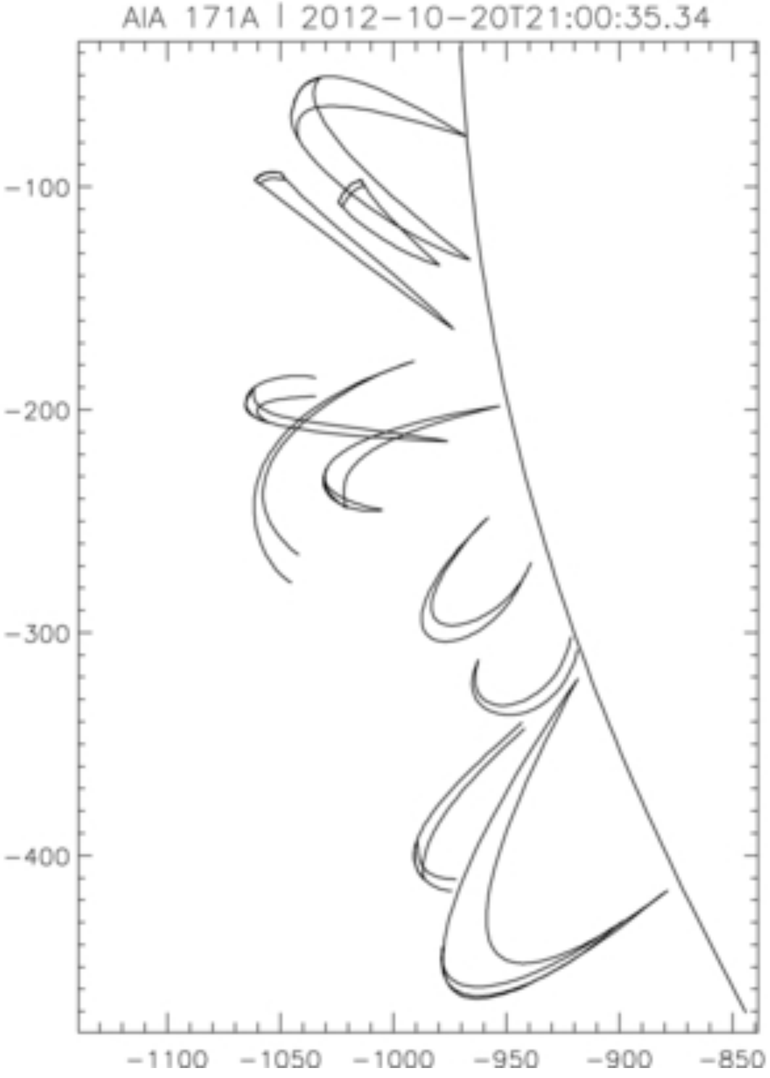


Loop width selection is subjective



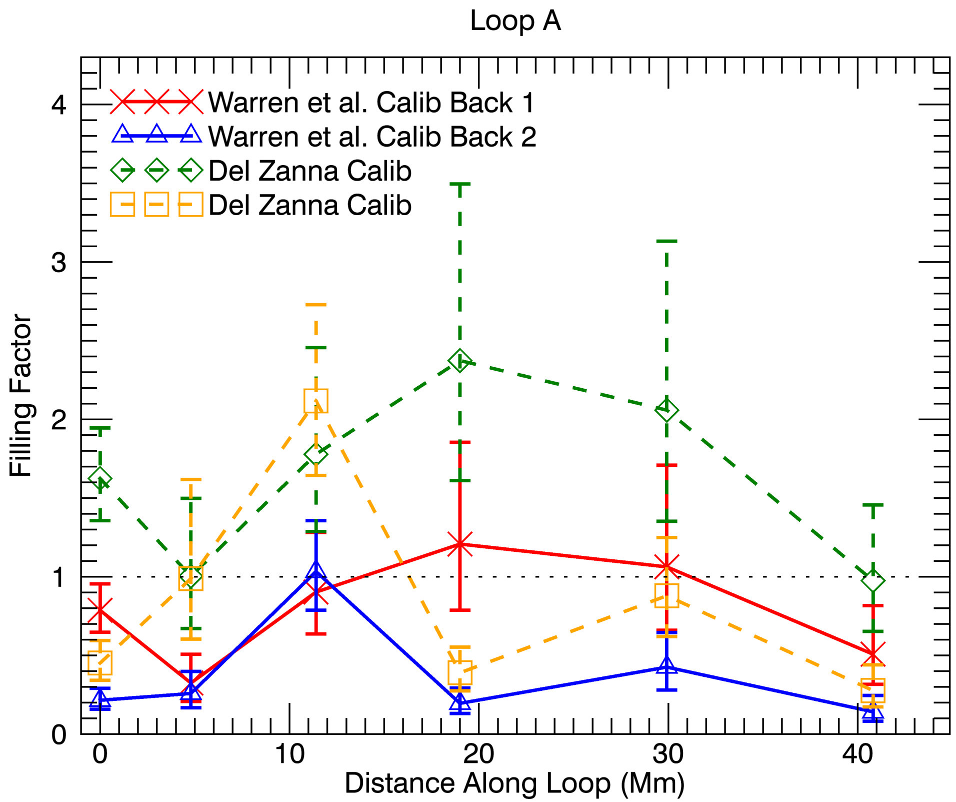
There are different ways to loop substructure



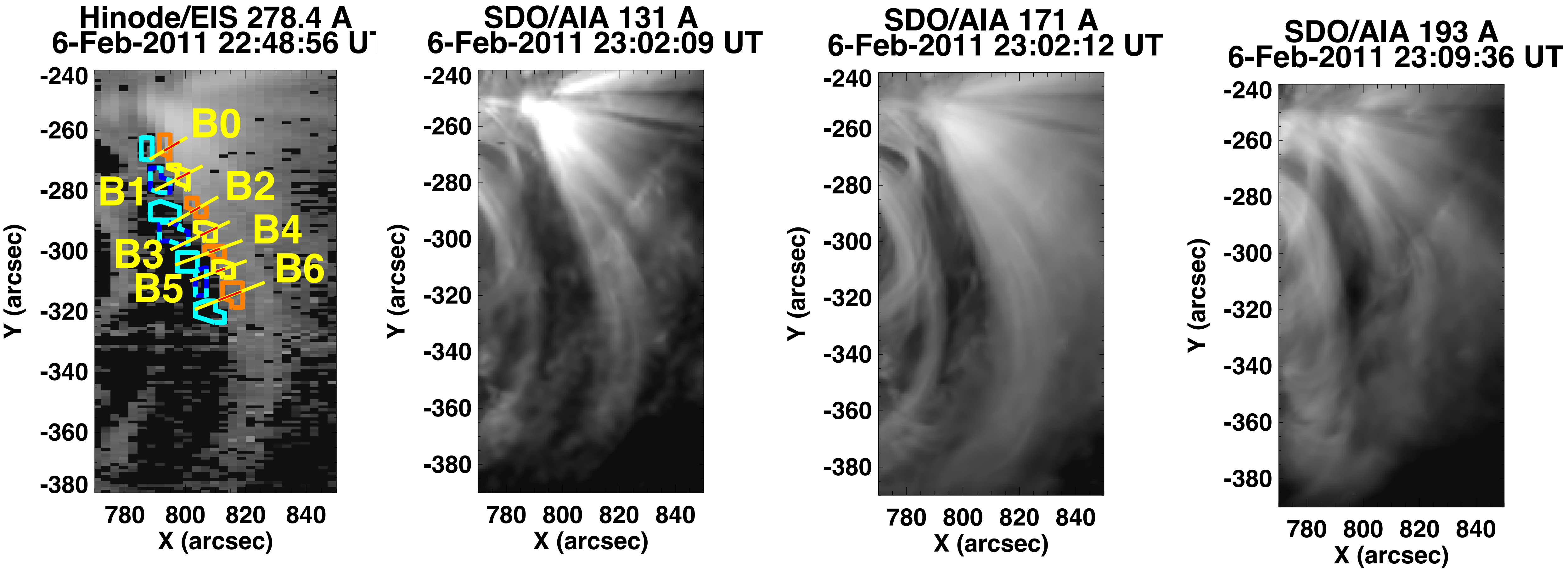


Malanushenko & Schrijver 2013

Filling factors for Loop A



Loop B cross sections



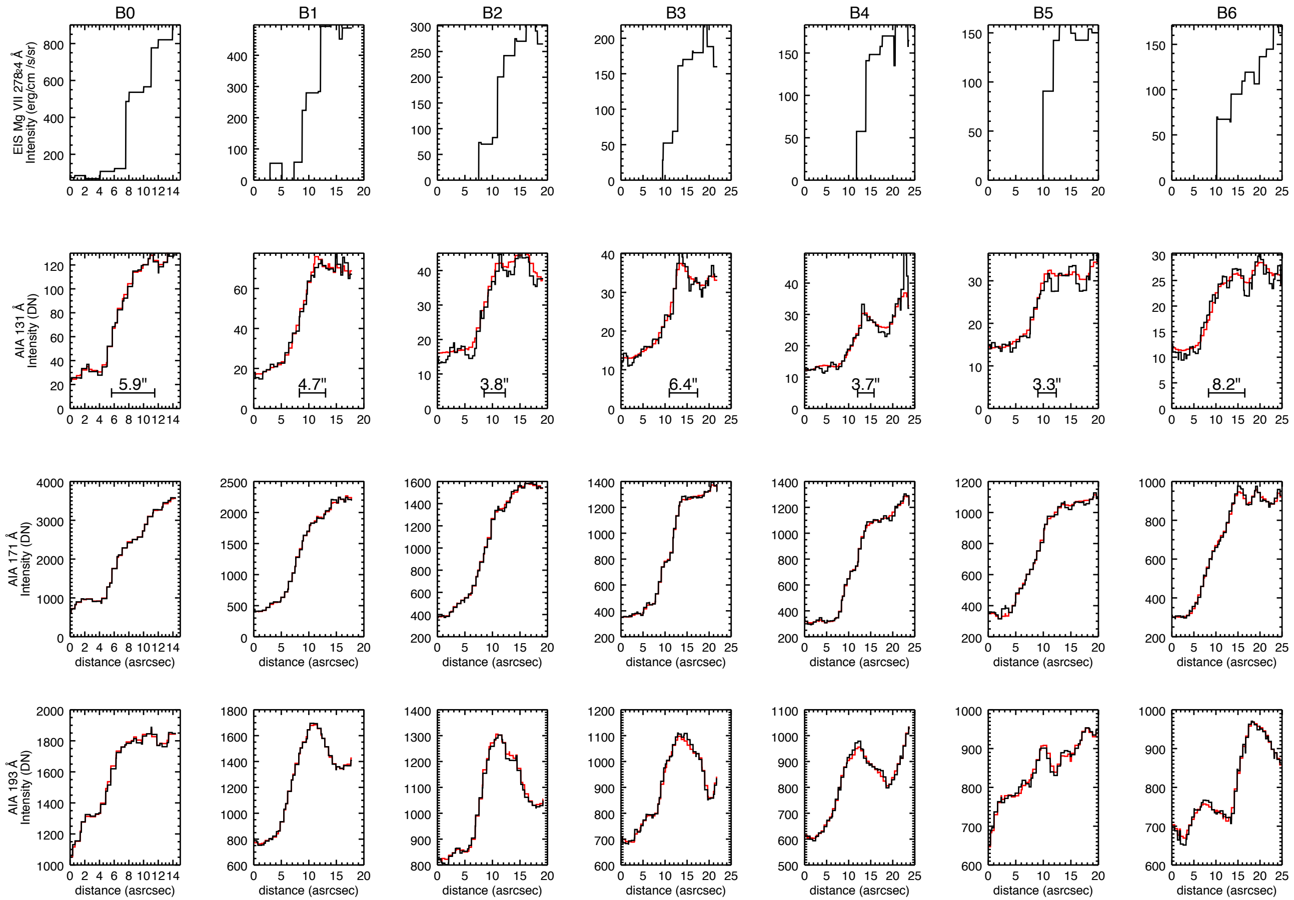
Loop B cross sections

EIS 278.4 Å

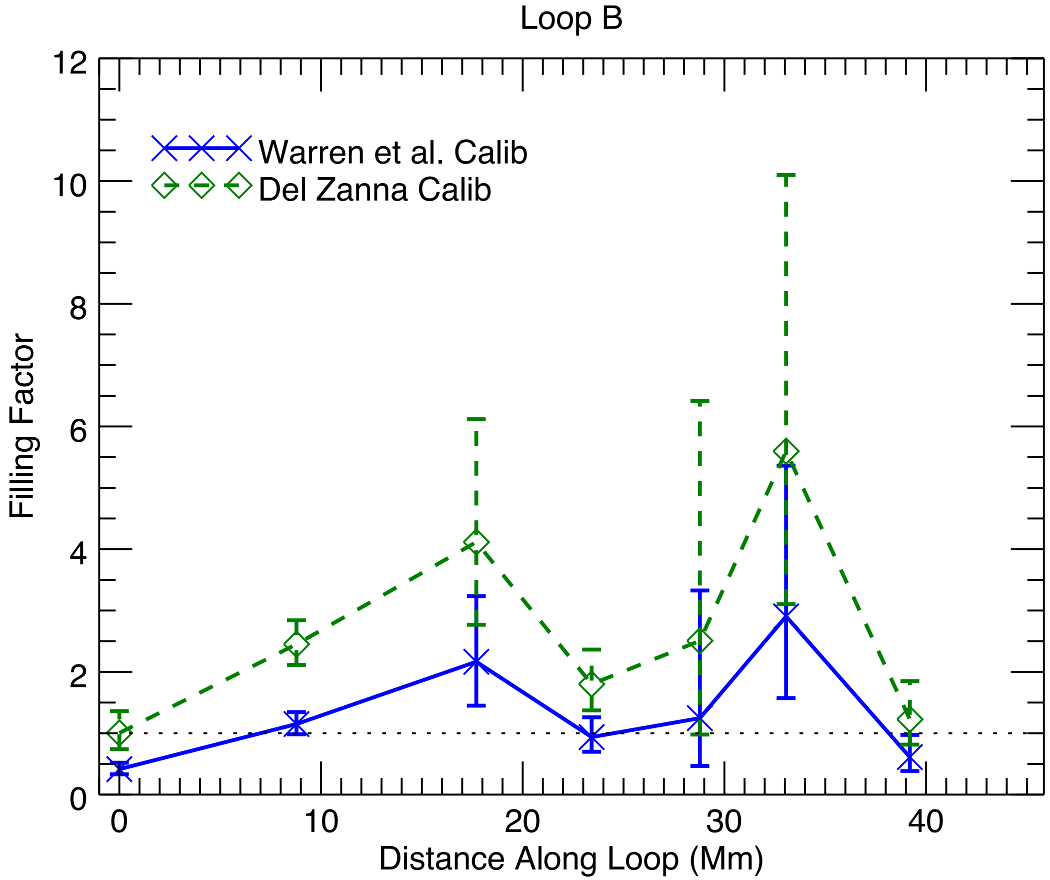
AIA 131 Å

AIA 171 Å

AIA 193 Å



Filling Factor for Loop B



These methods would have lower uncertainties with the following usual suspects:

- Higher signal to noise
- Higher resolution
  - Better to pick out small loop structures
  - Better for background selection (although interpretation of structures is still an issue)
- Better calibration
  - More rocket underflights
  - High quality reference spectra from laboratory sources
- Better atomic data

Conclusions

- The results are generally consistent with circular cross sections and no expansion.
- But also consistent with expansion factors of 3 or higher
- Very tough to determine actual cross section shape
- In theory (mostly with better data from a new instrument) the technique could yield stronger constraints
    - Calibration important – both for D and f estimates.