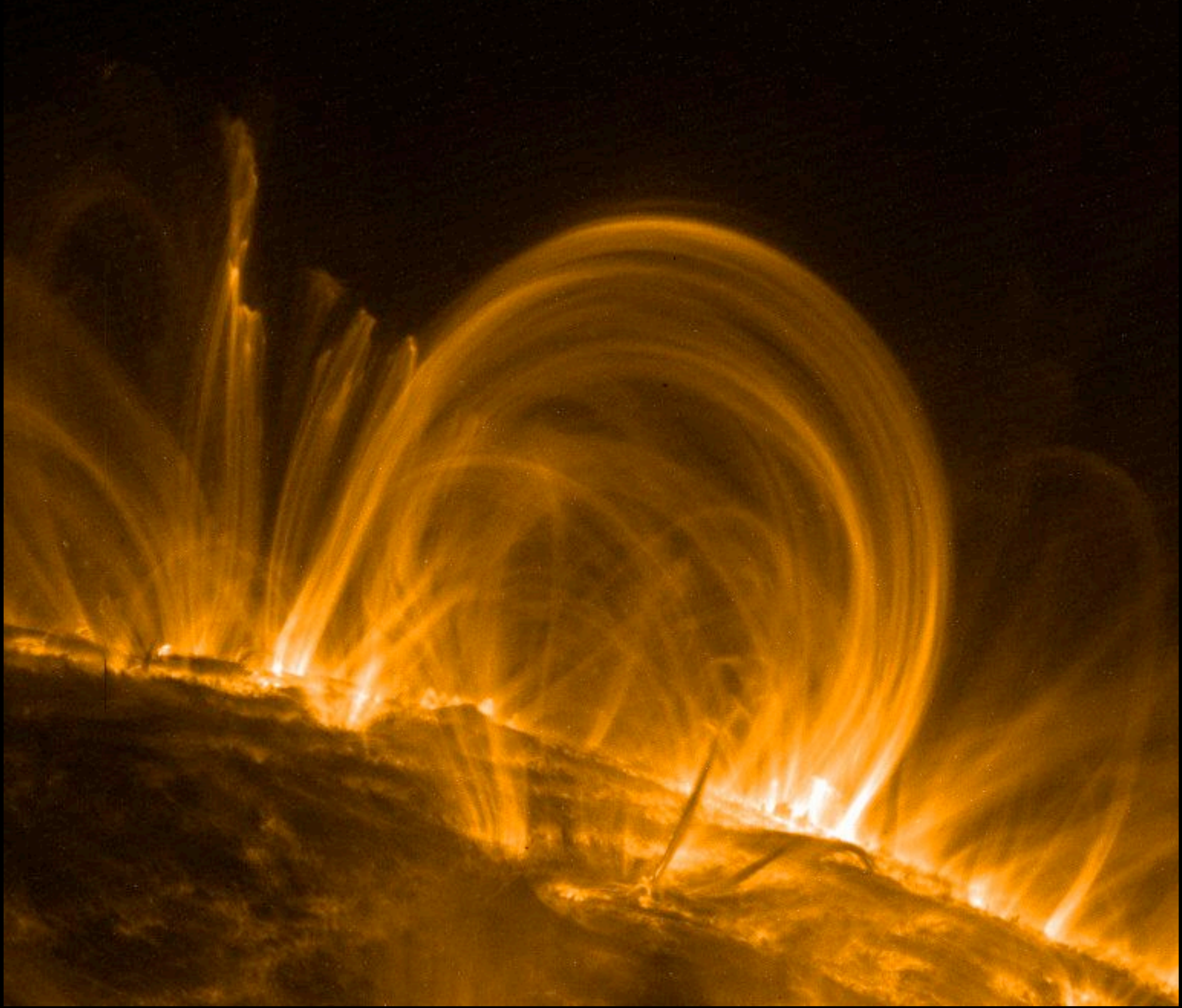
What are active region coronal loops?

Ignacio Ugarte-Urra
Naval Research Laboratory
George Mason University

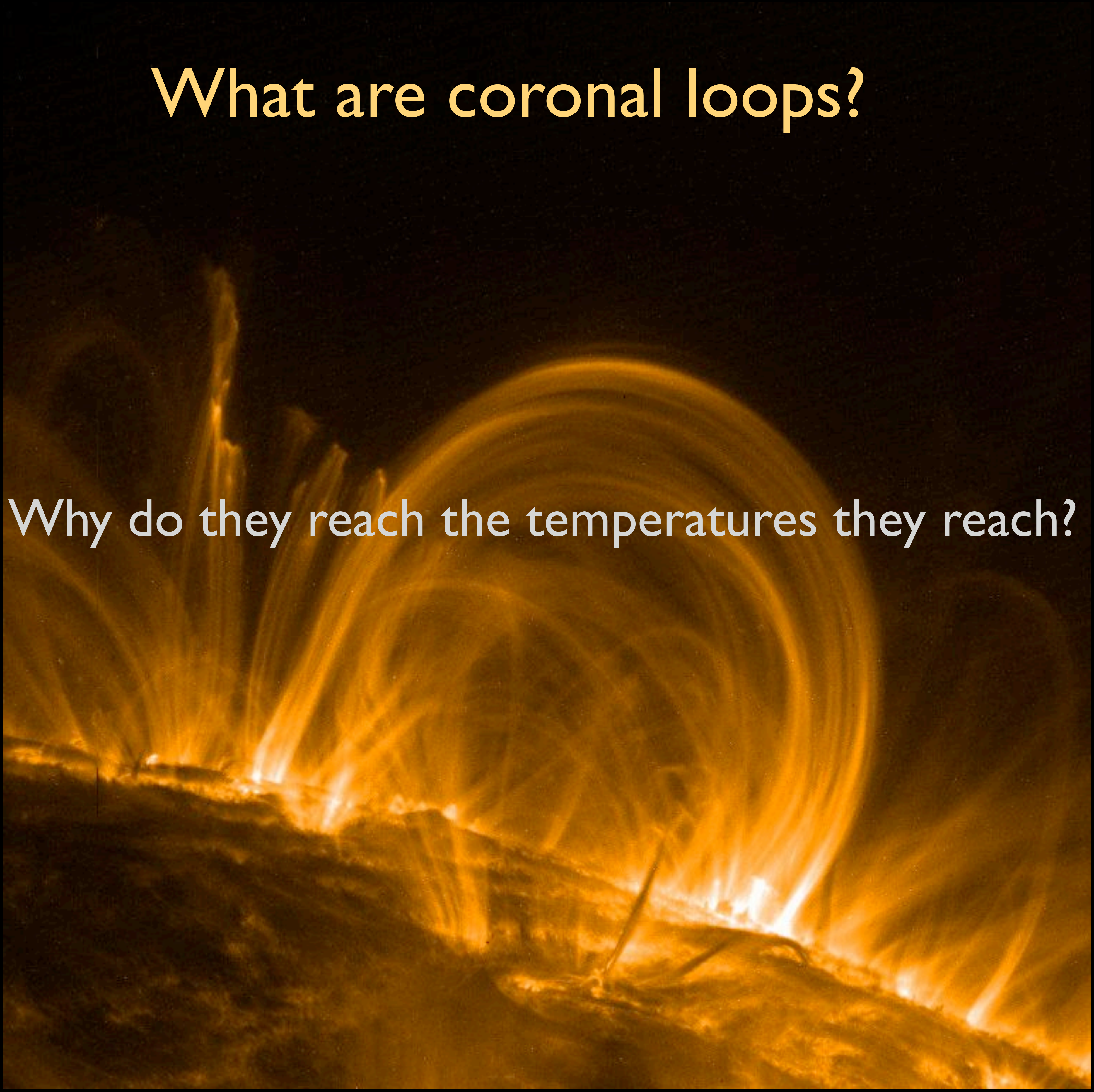
Onset of Solar Cycle 24 Meeting. December 9th 2008. Napa, CA. US.

What are coronal loops?

What are coronal loops?

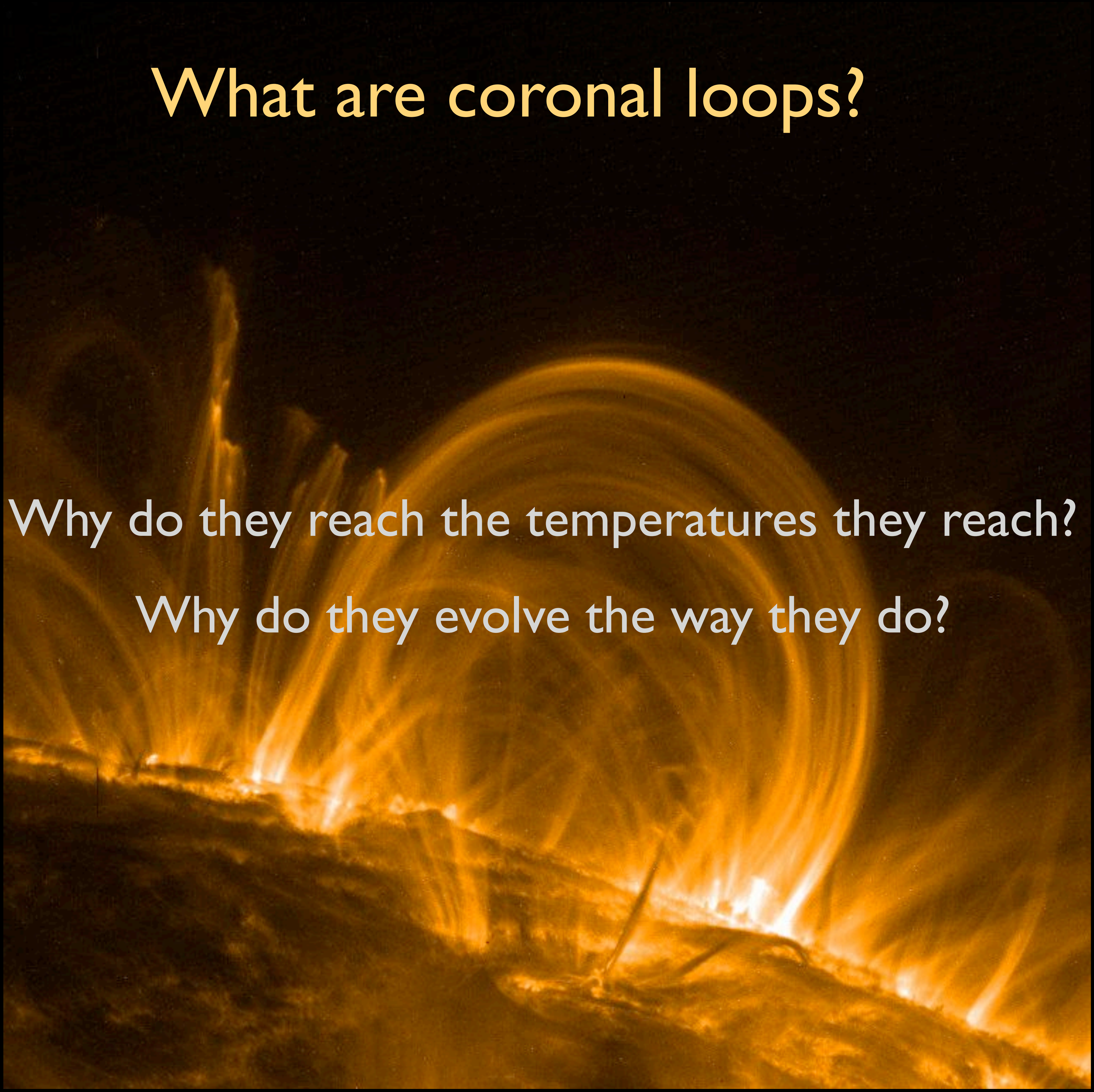


What are coronal loops?



Why do they reach the temperatures they reach?

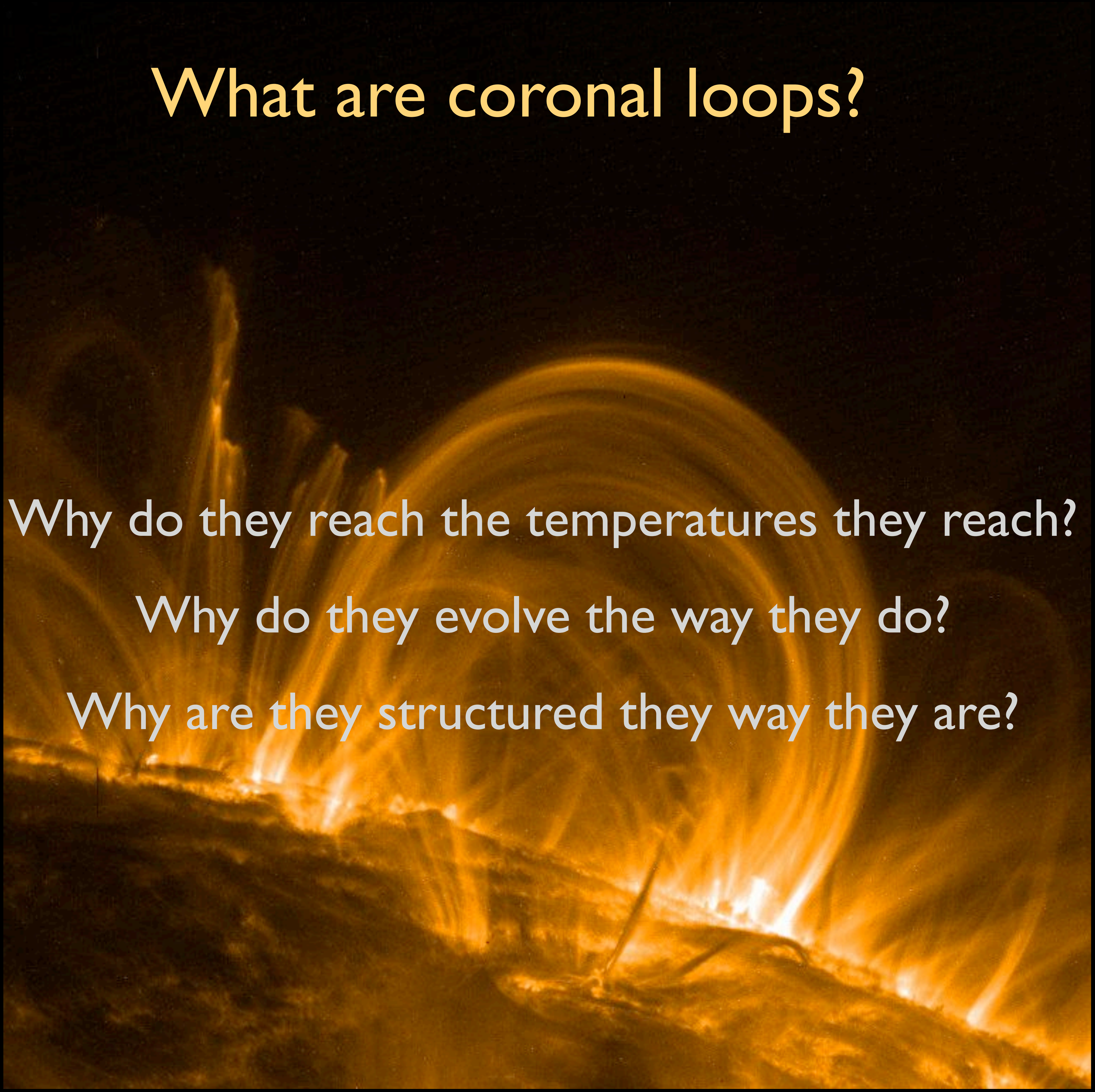
What are coronal loops?



Why do they reach the temperatures they reach?

Why do they evolve the way they do?

What are coronal loops?

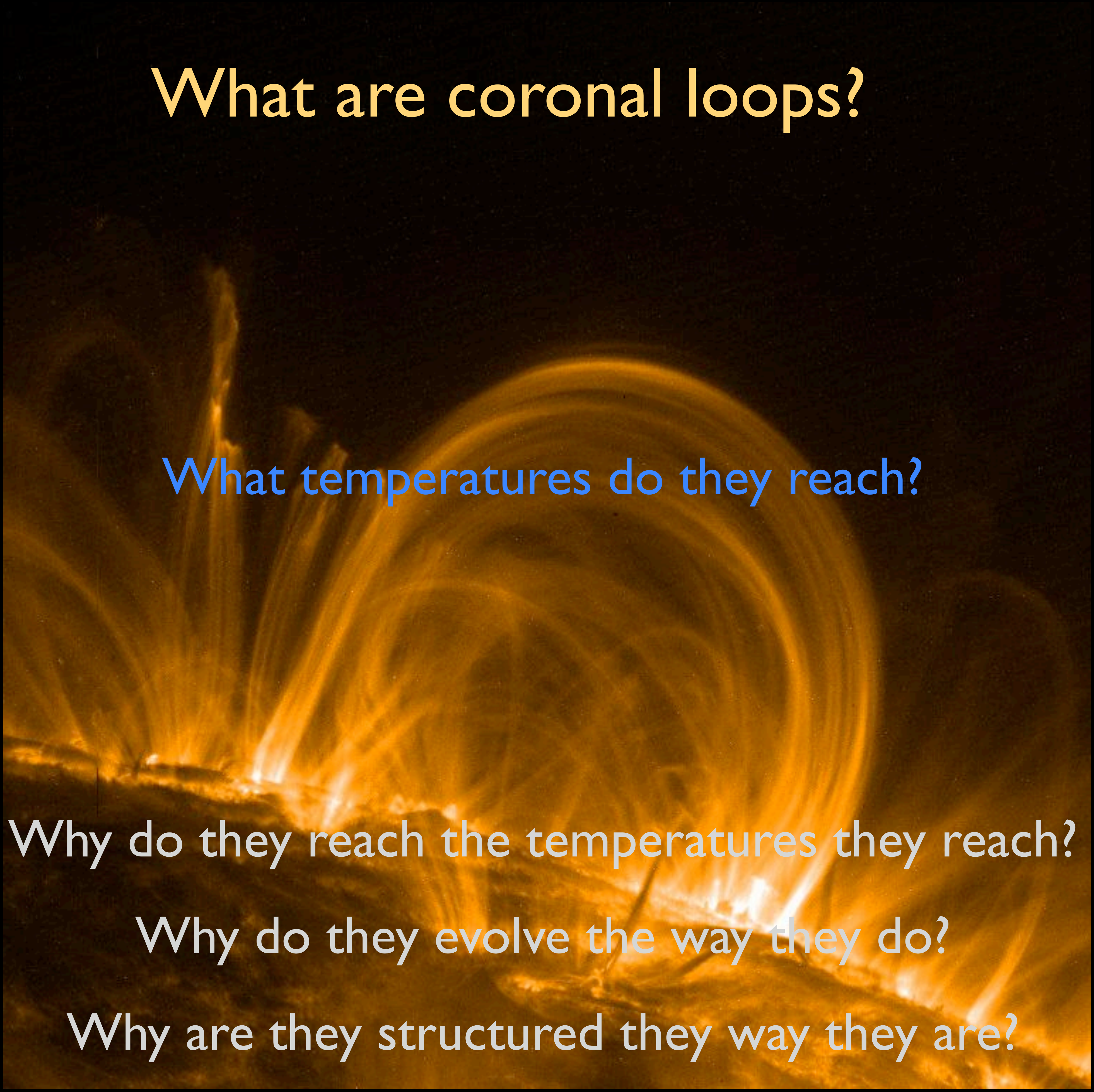


Why do they reach the temperatures they reach?

Why do they evolve the way they do?

Why are they structured they way they are?

What are coronal loops?



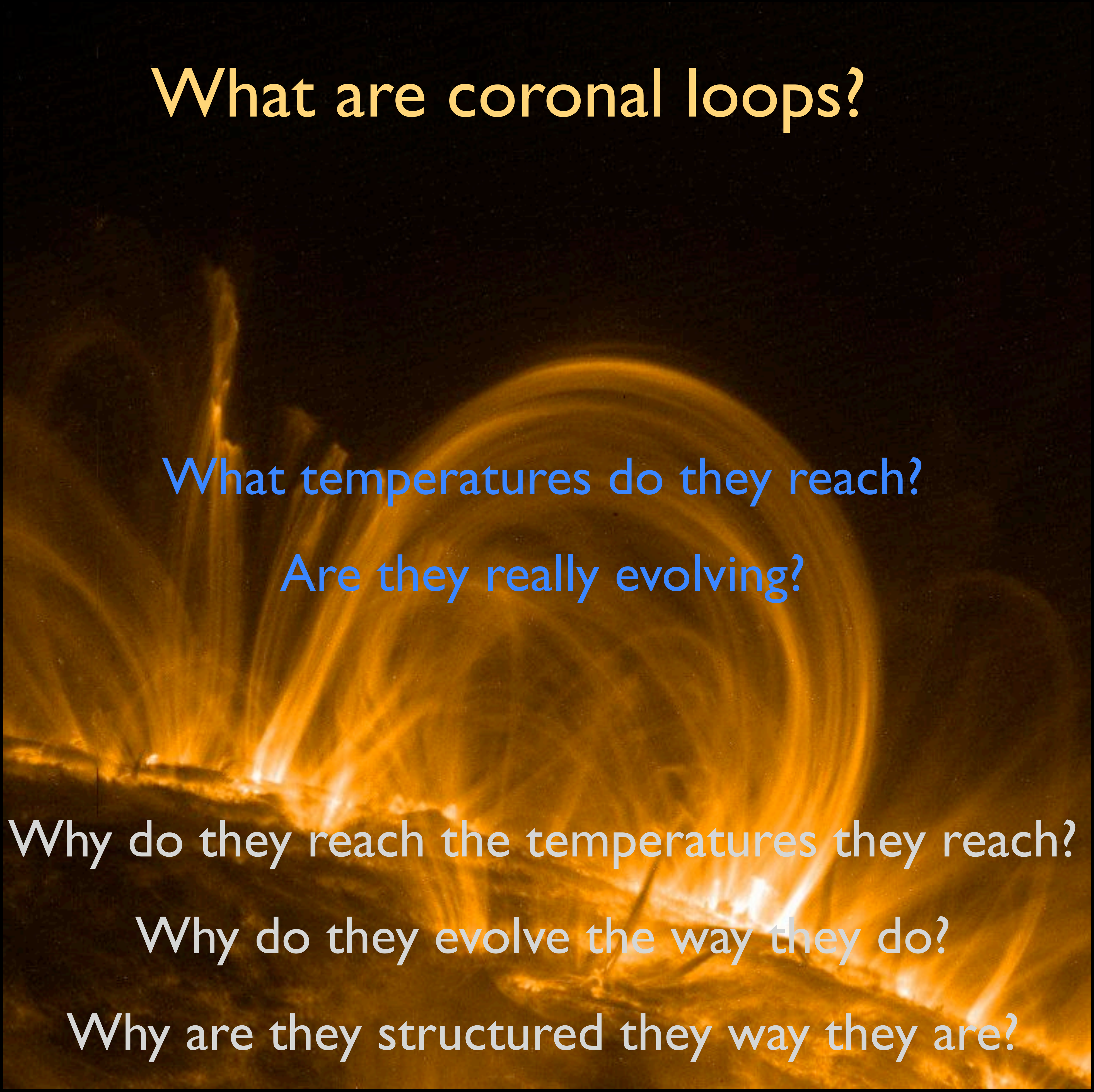
What temperatures do they reach?

Why do they reach the temperatures they reach?

Why do they evolve the way they do?

Why are they structured they way they are?

What are coronal loops?



What temperatures do they reach?

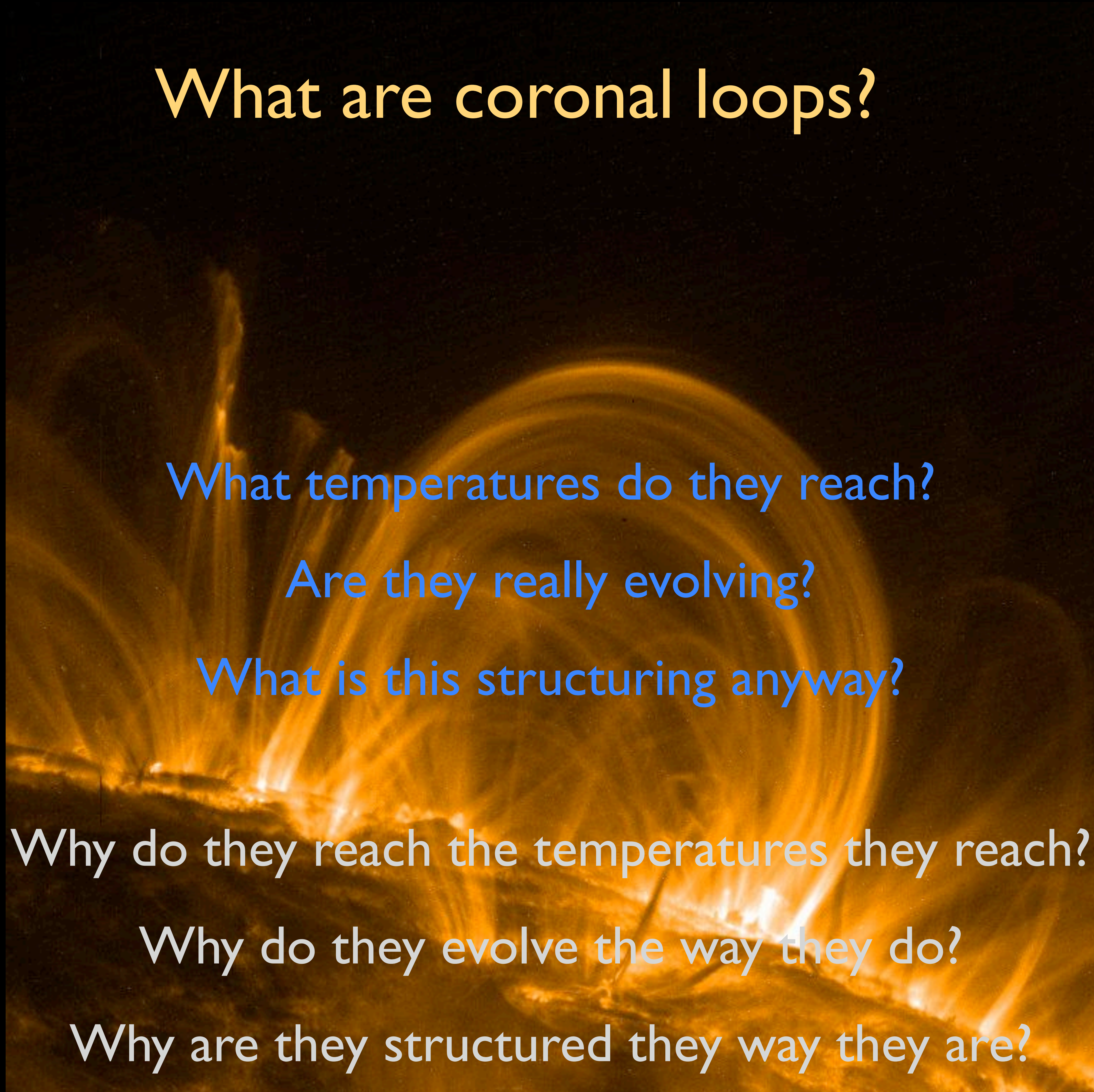
Are they really evolving?

Why do they reach the temperatures they reach?

Why do they evolve the way they do?

Why are they structured they way they are?

What are coronal loops?



What temperatures do they reach?

Are they really evolving?

What is this structuring anyway?

Why do they reach the temperatures they reach?

Why do they evolve the way they do?

Why are they structured they way they are?

What are coronal loops?

What are coronal loops?

Is there such a thing as a typical coronal loop?

What are coronal loops?

Is there such a thing as a typical coronal loop?

Do all loops share common properties?

What are coronal loops?

Is there such a thing as a typical coronal loop?

Do all loops share common properties?

Do we agree on those? and if so...

What are coronal loops?

Is there such a thing as a typical coronal loop?

Do all loops share common properties?

Do we agree on those? and if so...

Are the properties sufficiently well constrained to test the models?

What are coronal loops?

Is there such a thing as a typical coronal loop?

Do all loops share common properties?

Do we agree on those? and if so...

Are the properties sufficiently well constrained to test the models?

What do the models need from observations?

What are coronal loops?

Is there such a thing as a typical coronal loop?

Do all loops share common properties?

Do we agree on those? and if so...

Are the properties sufficiently well constrained to test the models?

What do the models need from observations?

Are we getting that information?

What are coronal loops?

Is there such a thing as a typical coronal loop?

Do all loops share common properties?

Do we agree on those? and if so...

Are the properties sufficiently well constrained to test the models?

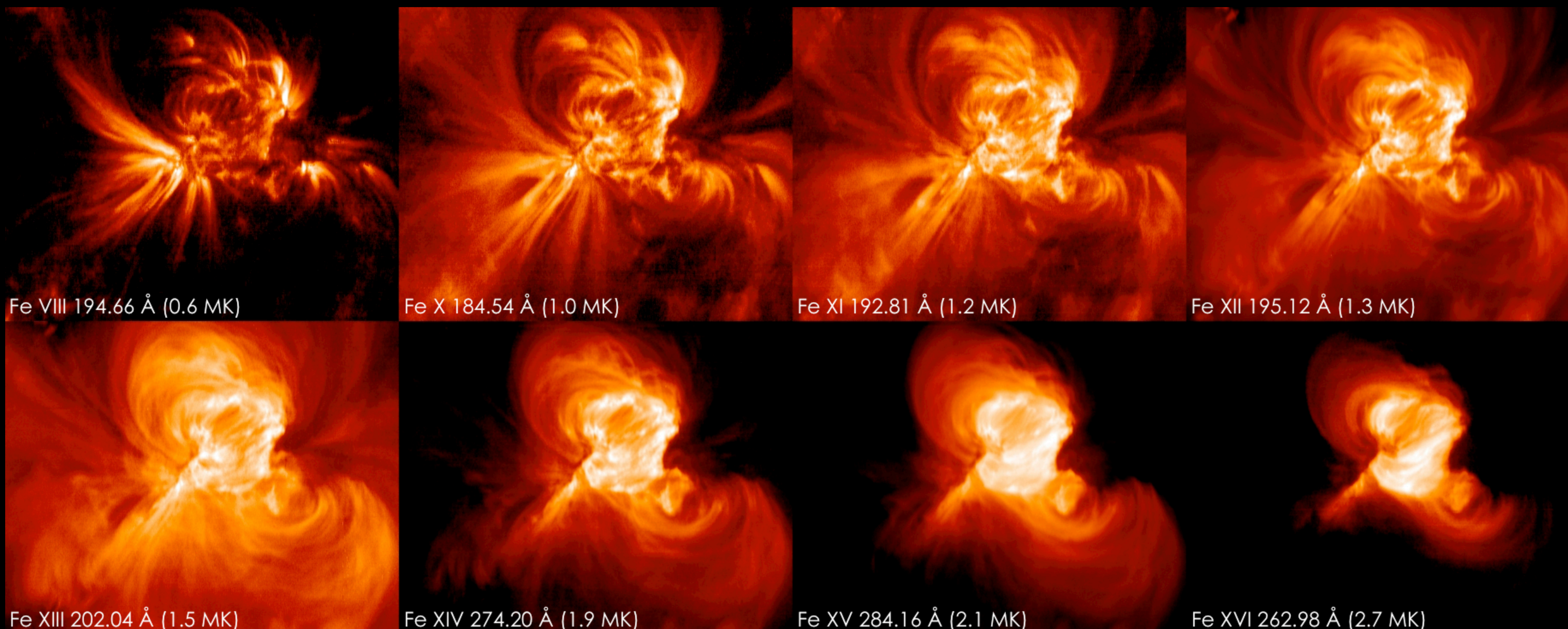
What do the models need from observations?

Are we getting that information?

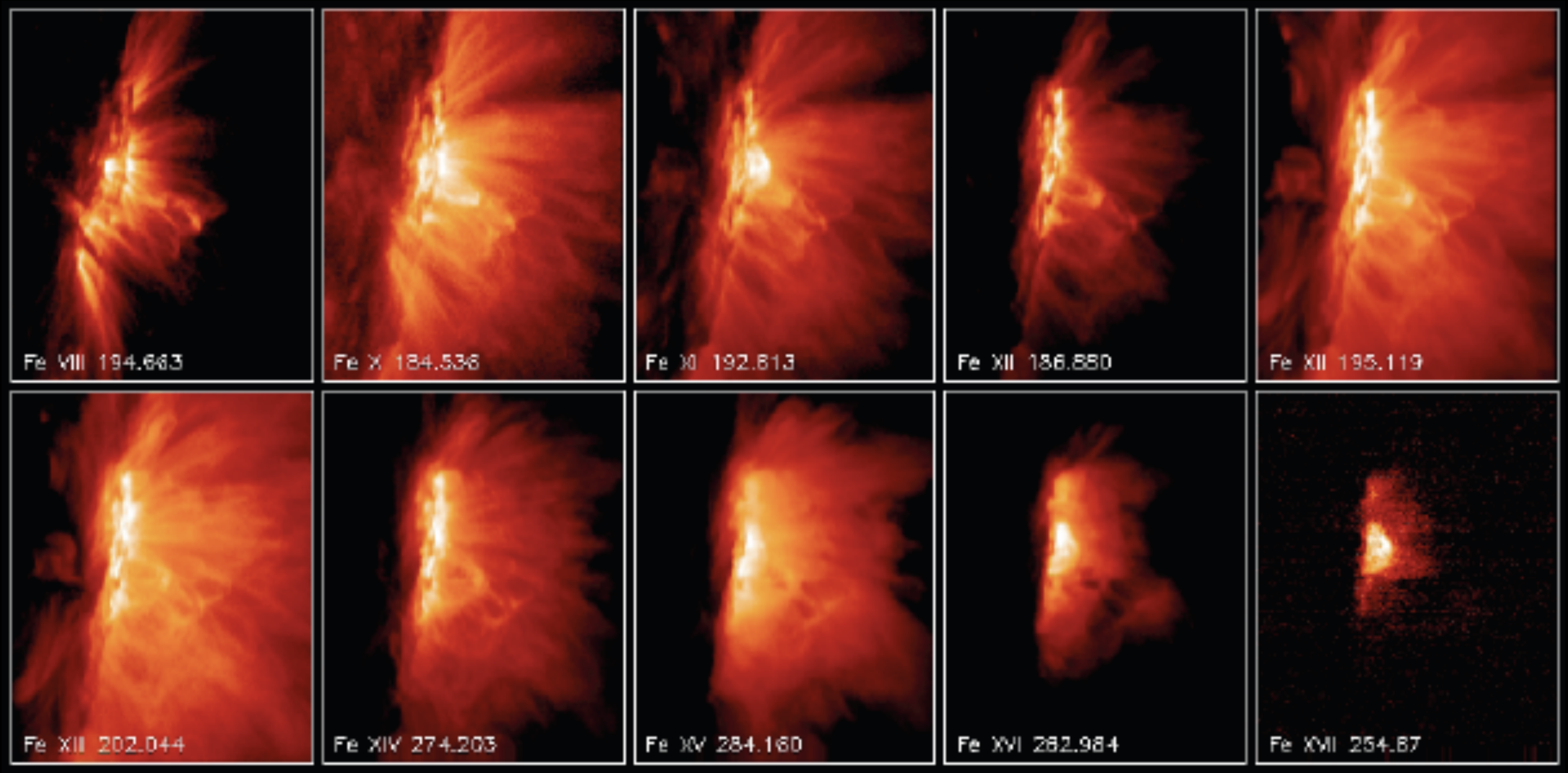
Ultimately, where is the bottleneck?

What temperatures do they reach?

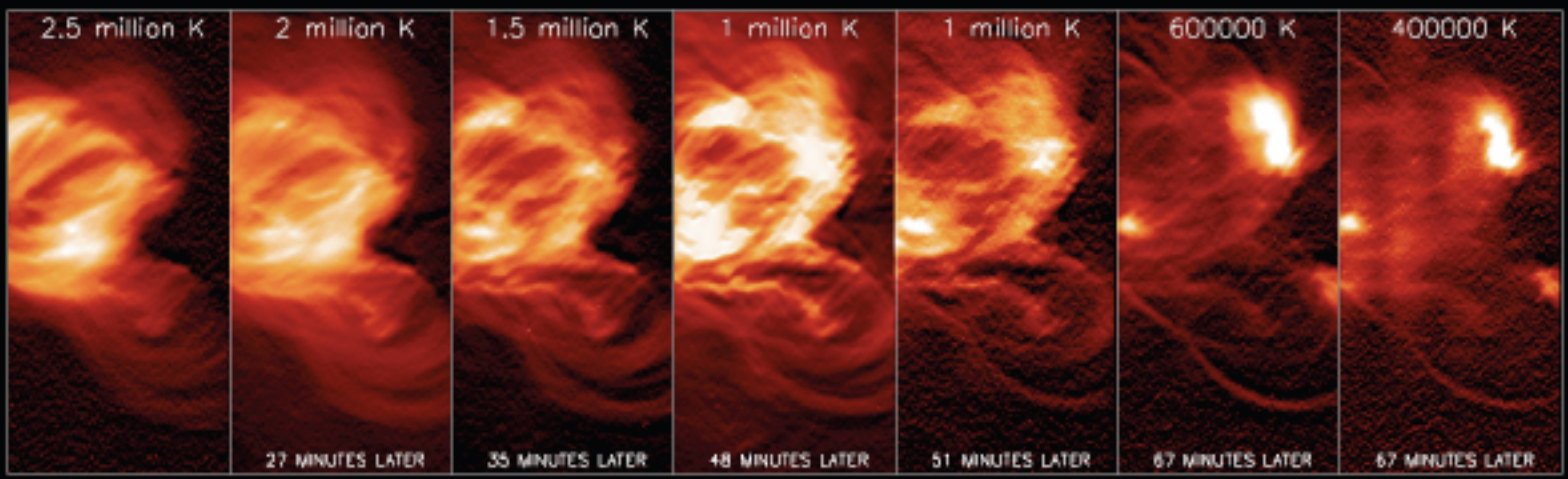
What temperatures do they reach?



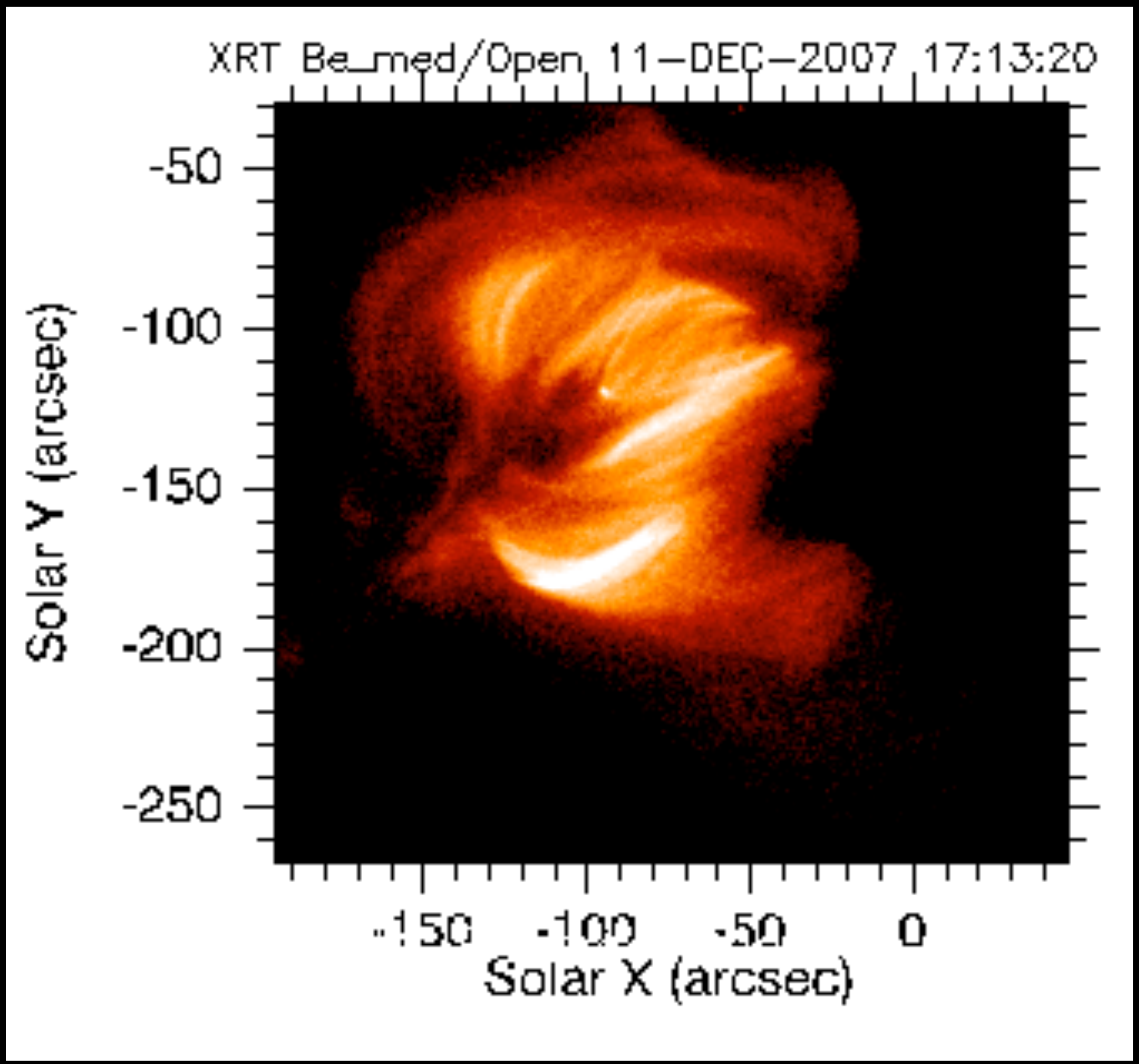
What temperatures do they reach?

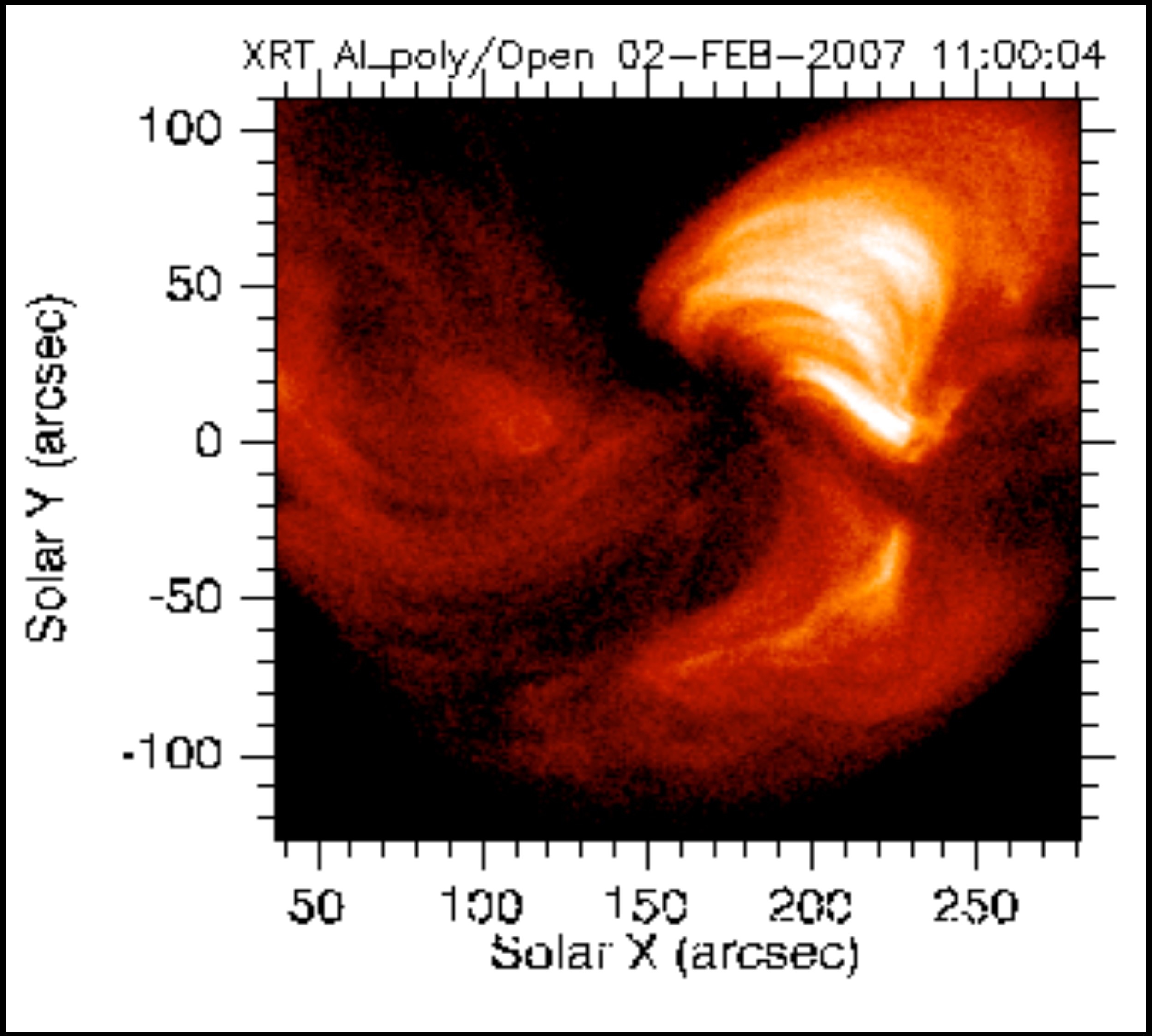


What temperatures do they reach?



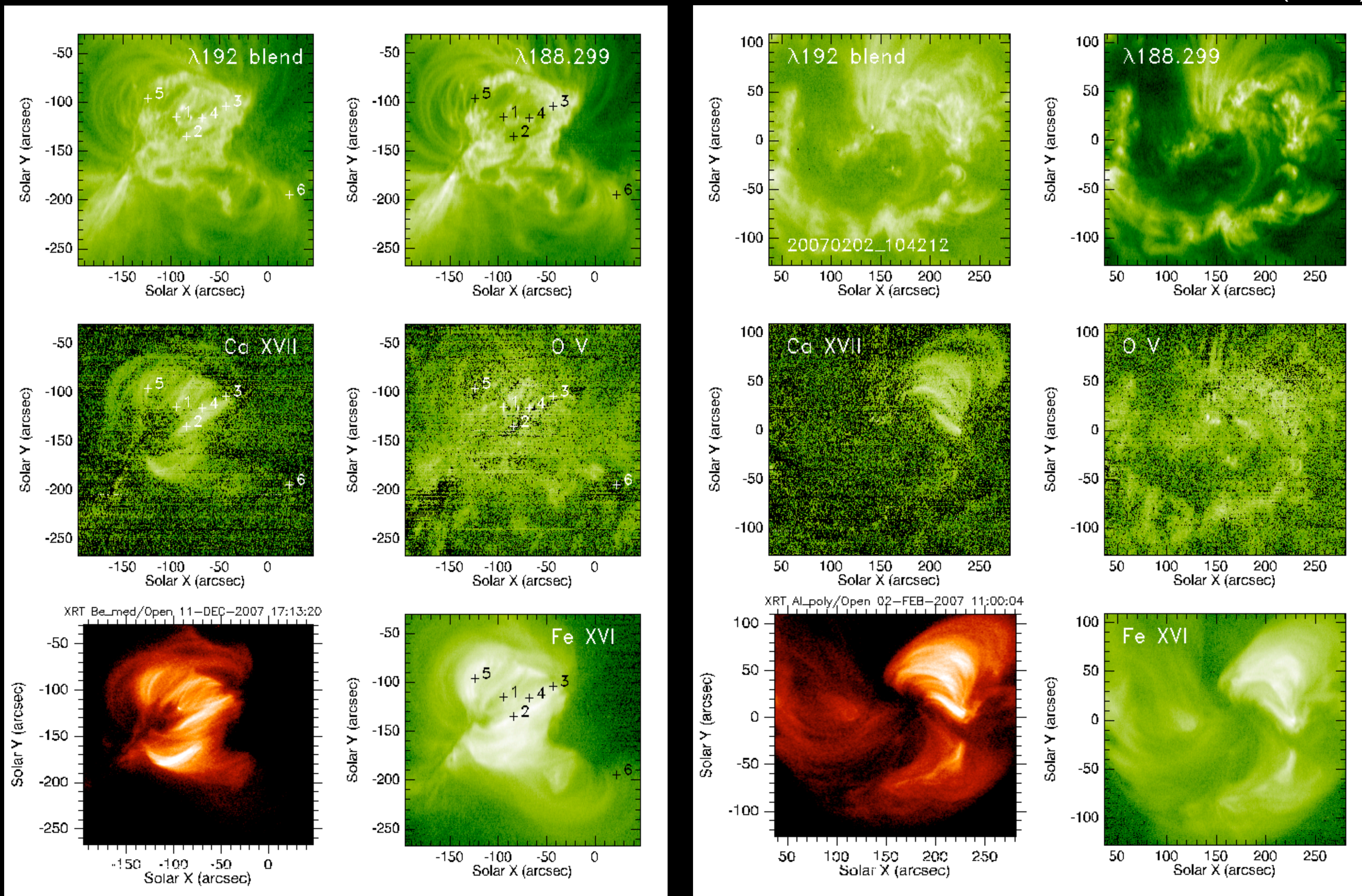
What temperatures do they reach?





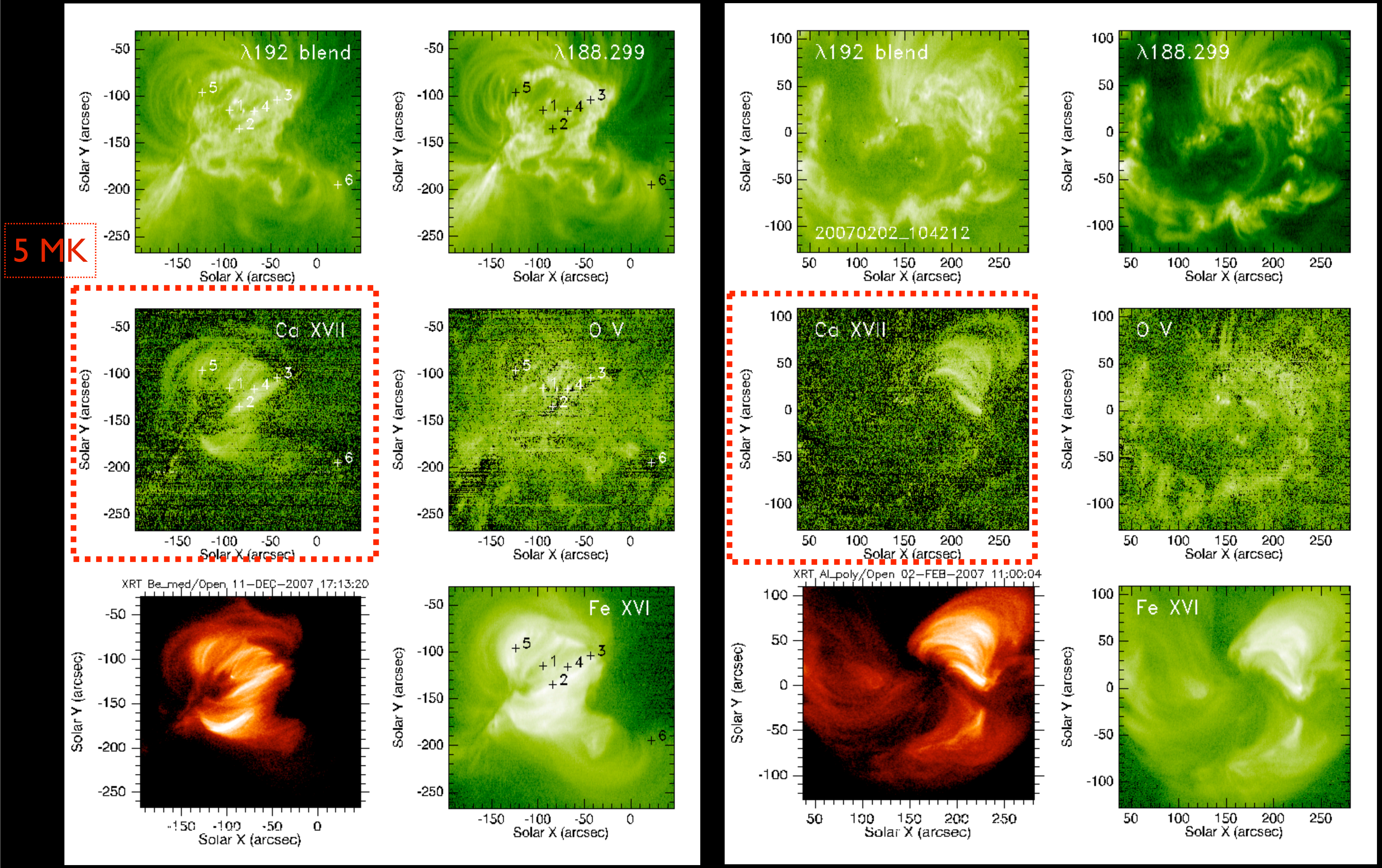
What temperatures do they reach?

Ko et al. (2009)



What temperatures do they reach?

Ko et al. (2009)



Static vs Dynamic

Soft X-ray loops

Pre-SOHO results indicated (Klimchuk 2008):

Static vs Dynamic

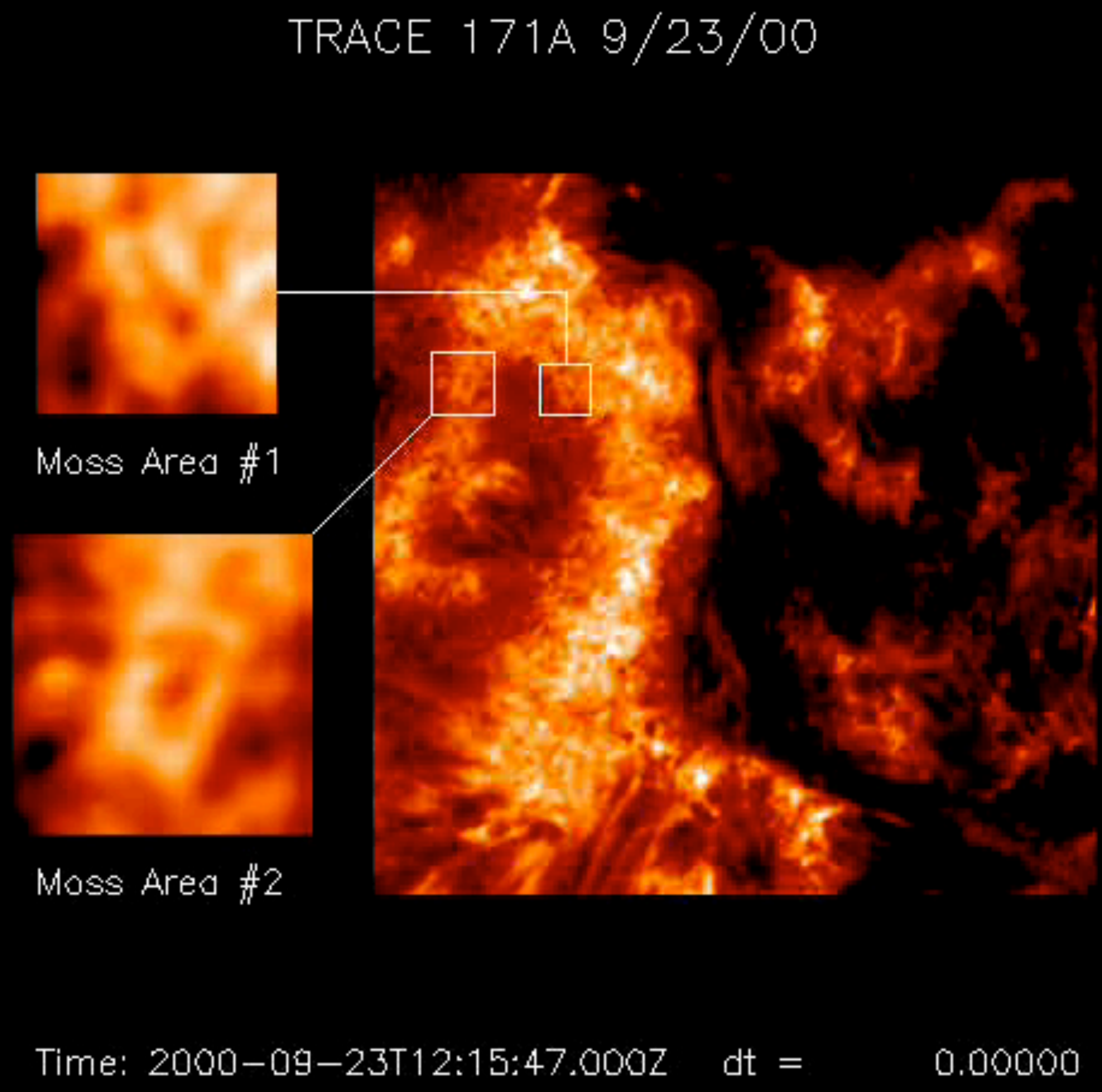
Soft X-ray loops

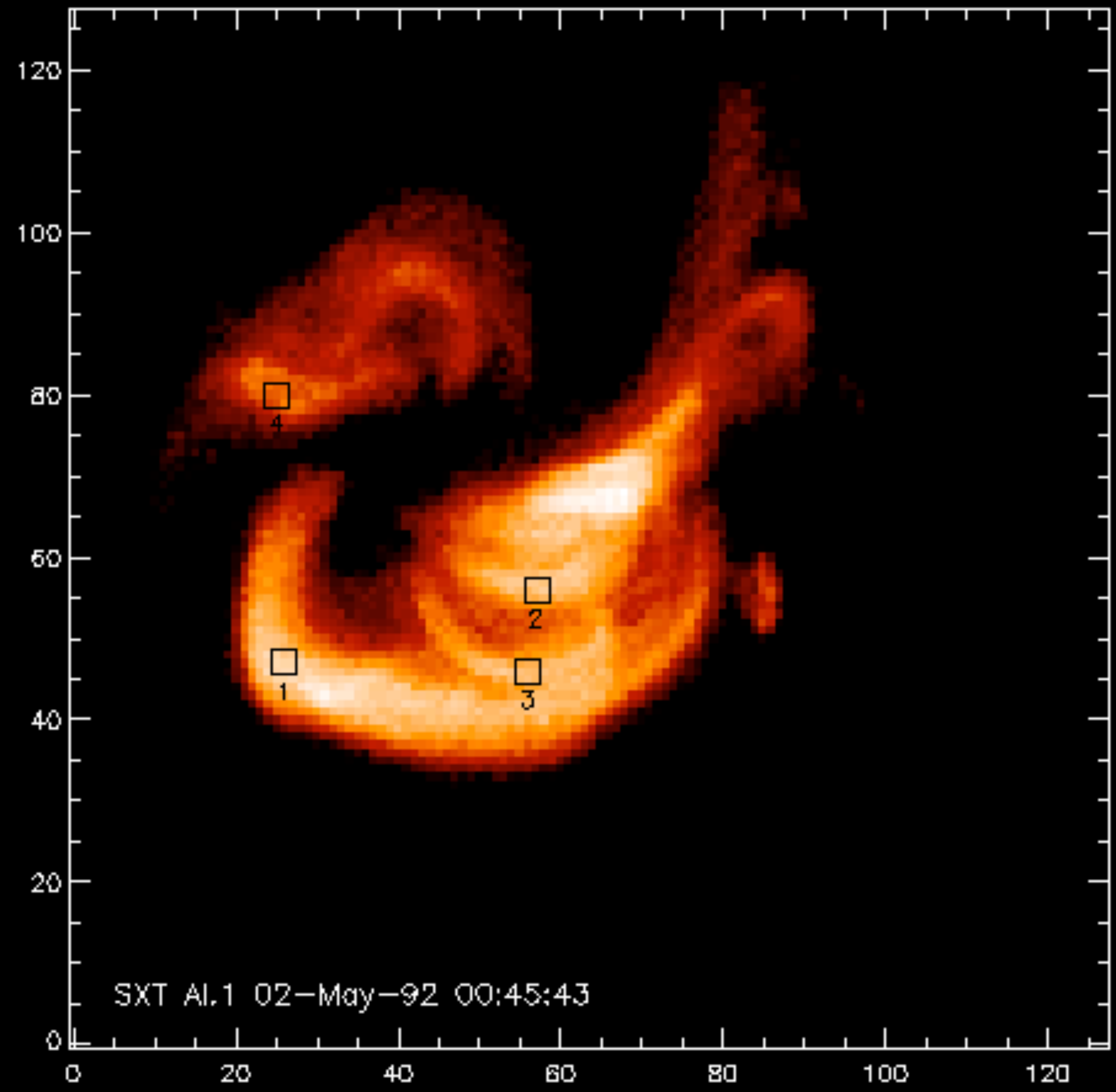
Pre-SOHO results indicated (Klimchuk 2008):

- Hot ($T > 2MK$)

Static vs Dynamic

Soft X-ray loops



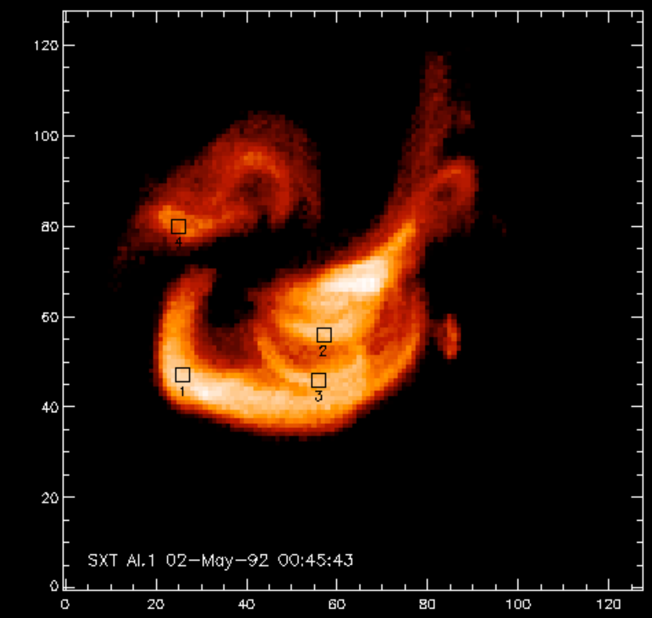


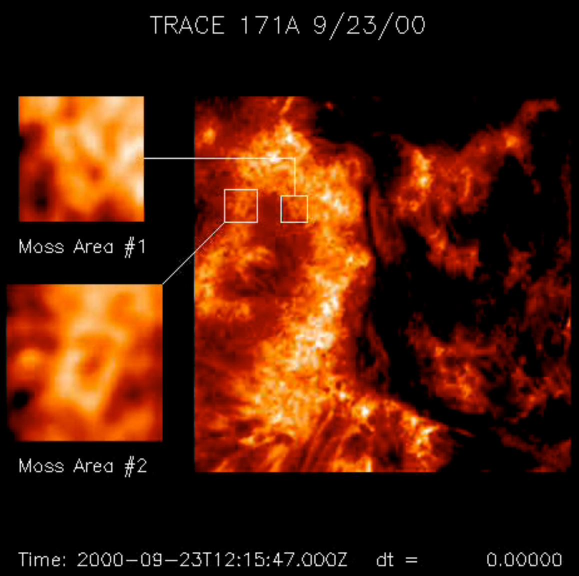
Static vs Dynamic

Soft X-ray loops

Pre-SOHO results indicated (Klimchuk 2008):

- Hot ($T > 2MK$)
- Long lived ($\tau_{life} >> \tau_{cool}$)



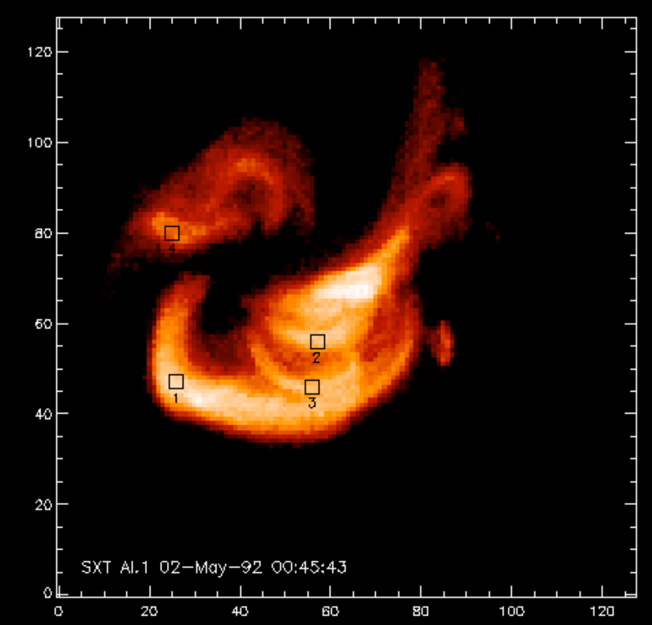


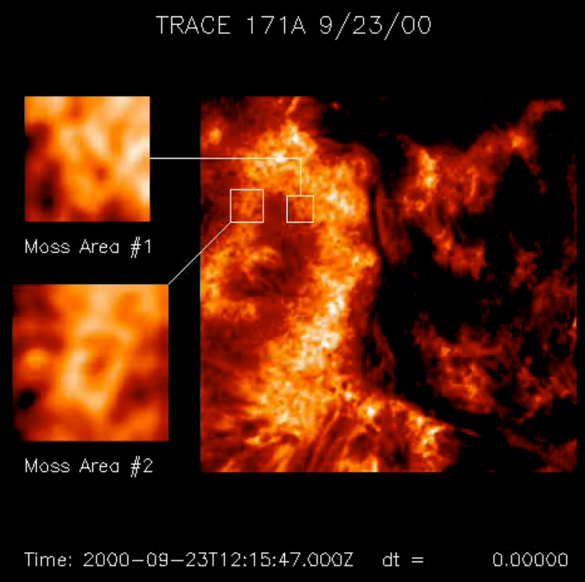
Static vs Dynamic

Soft X-ray loops

Pre-SOHO results indicated (Klimchuk 2008):

- Hot (T > 2MK)
- Long lived ($\tau_{life} >> \tau_{cool}$)
- Obey <u>static equilibrium</u> scaling laws



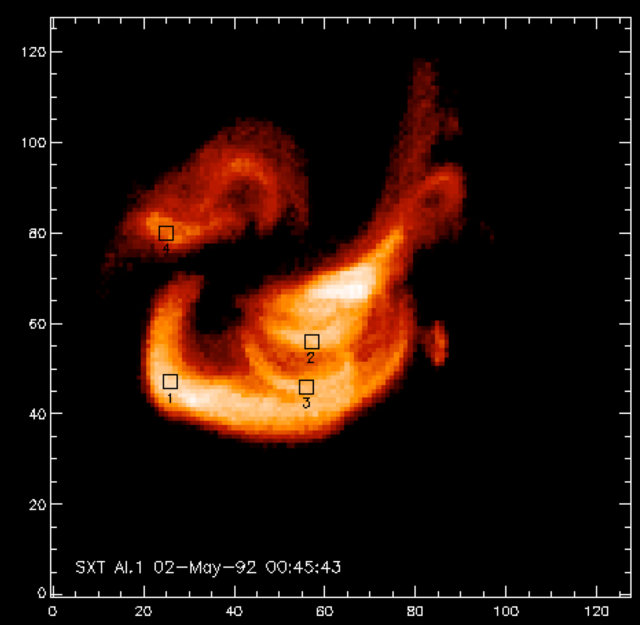


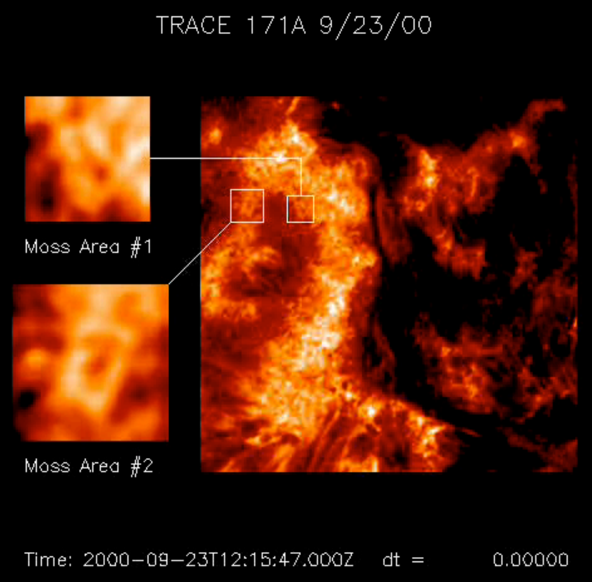
Static vs Dynamic

Soft X-ray loops

Pre-SOHO results indicated (Klimchuk 2008):

- Hot (T > 2MK)
- Long lived ($\tau_{life} >> \tau_{cool}$)
- Obey <u>static equilibrium</u> scaling laws
- Consistent with <u>steady heating</u>



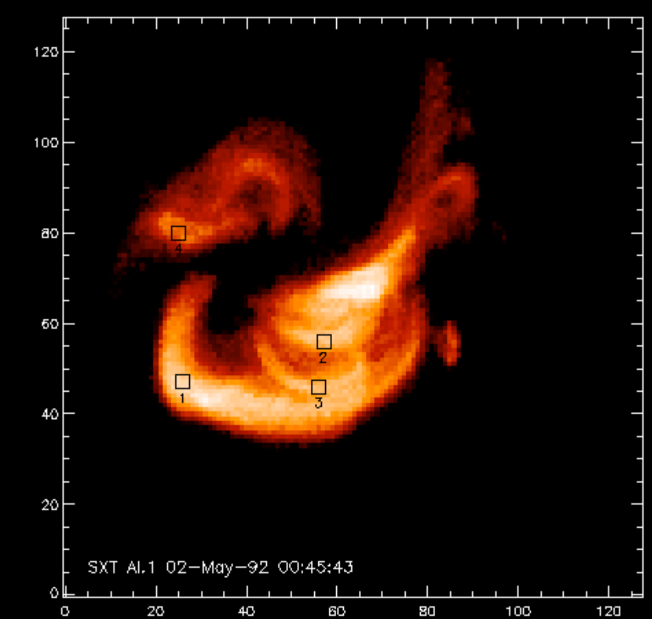


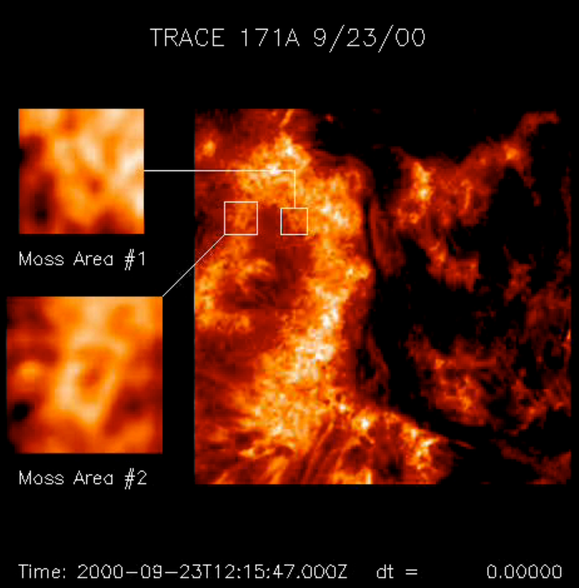
Static vs Dynamic

Soft X-ray loops

Pre-SOHO results indicated (Klimchuk 2008):

- Hot (T > 2MK)
- Long lived ($\tau_{life} >> \tau_{cool}$)
- Obey <u>static equilibrium</u> scaling laws
- Consistent with <u>steady heating</u>

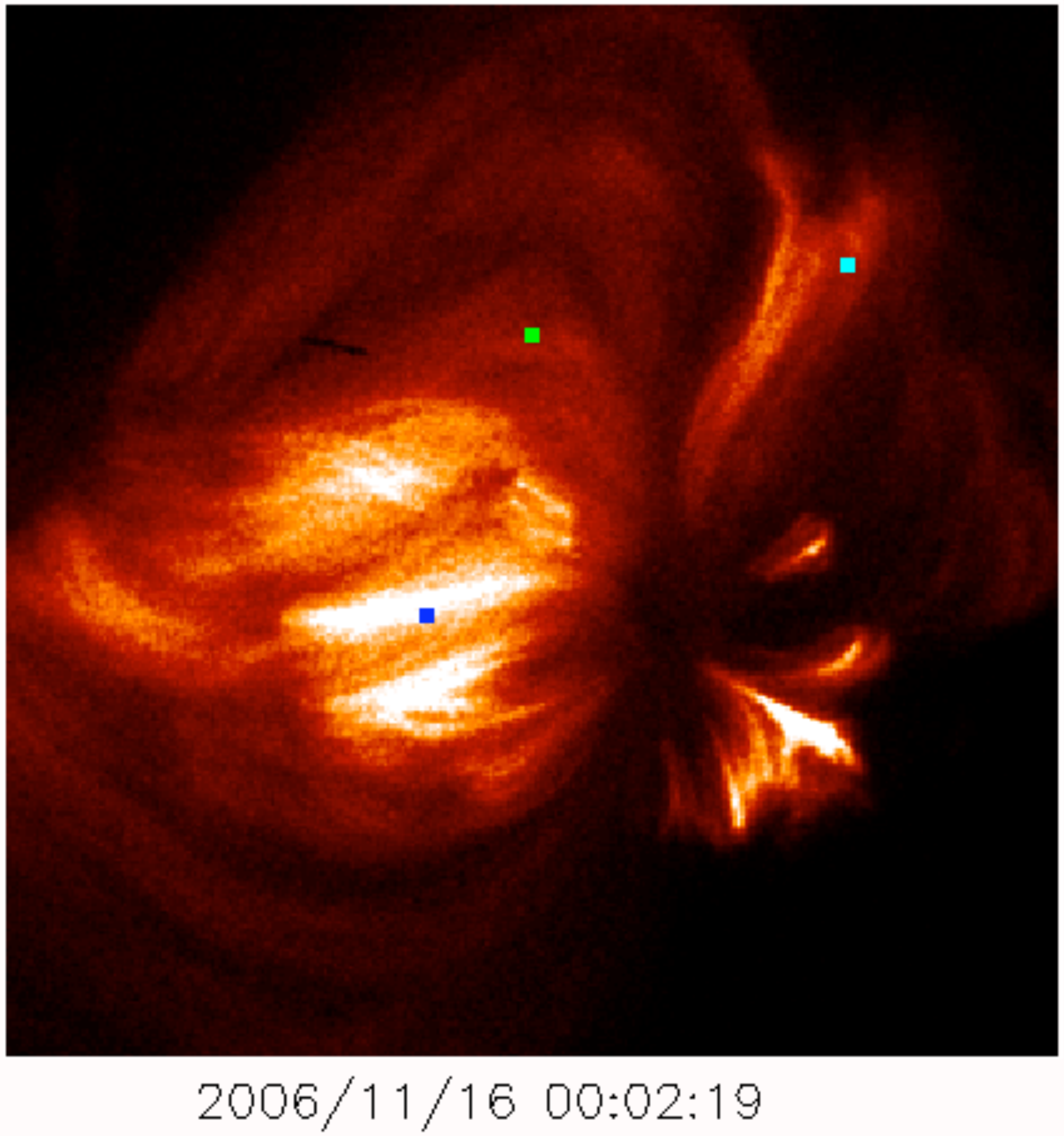


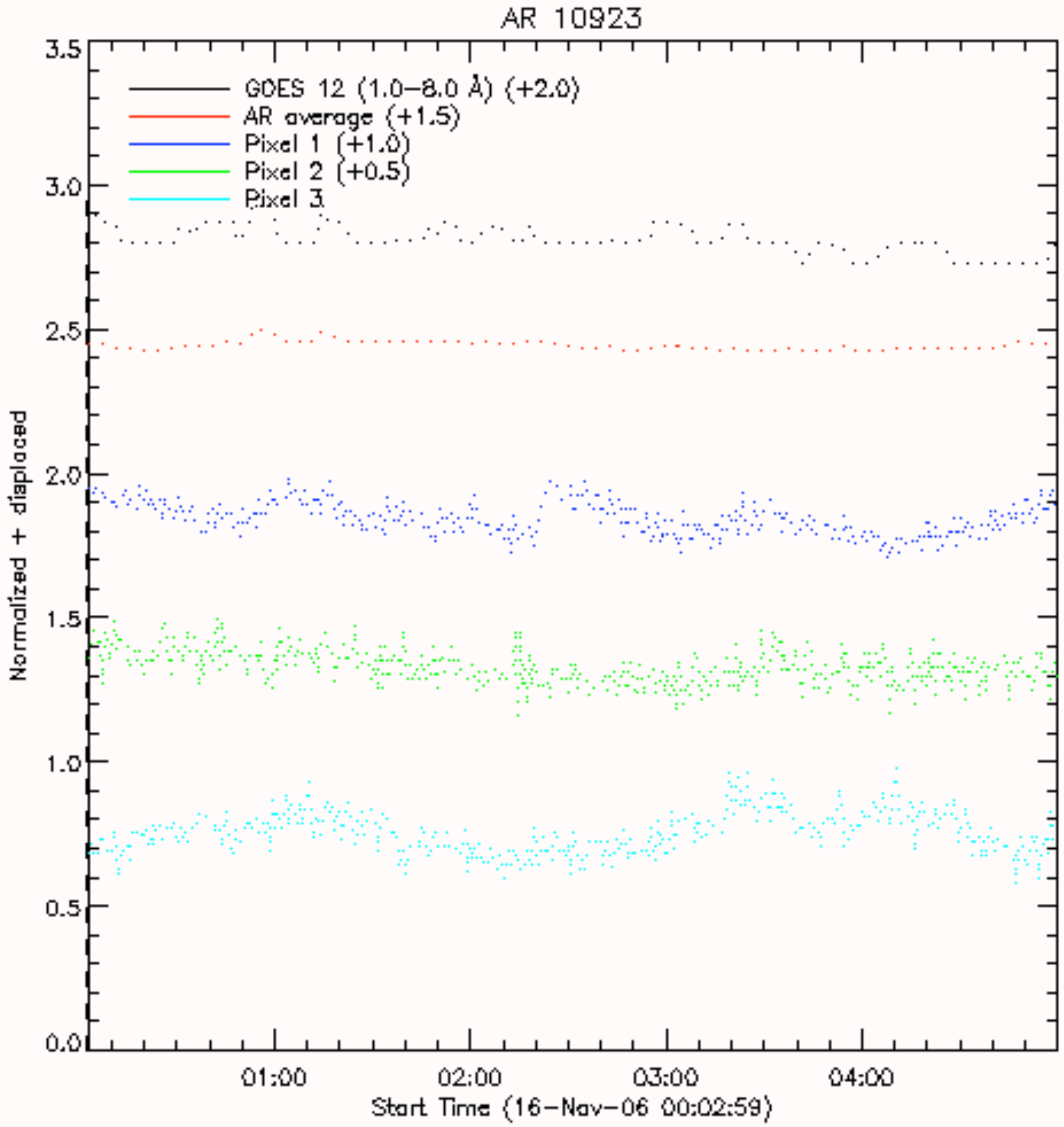


Rosner, Peres, Tsuneta, Antiochos, Golub...

Static vs Dynamic

Soft X-ray loops





Static vs Dynamic

Soft X-ray loops

Static vs Dynamic

Soft X-ray loops

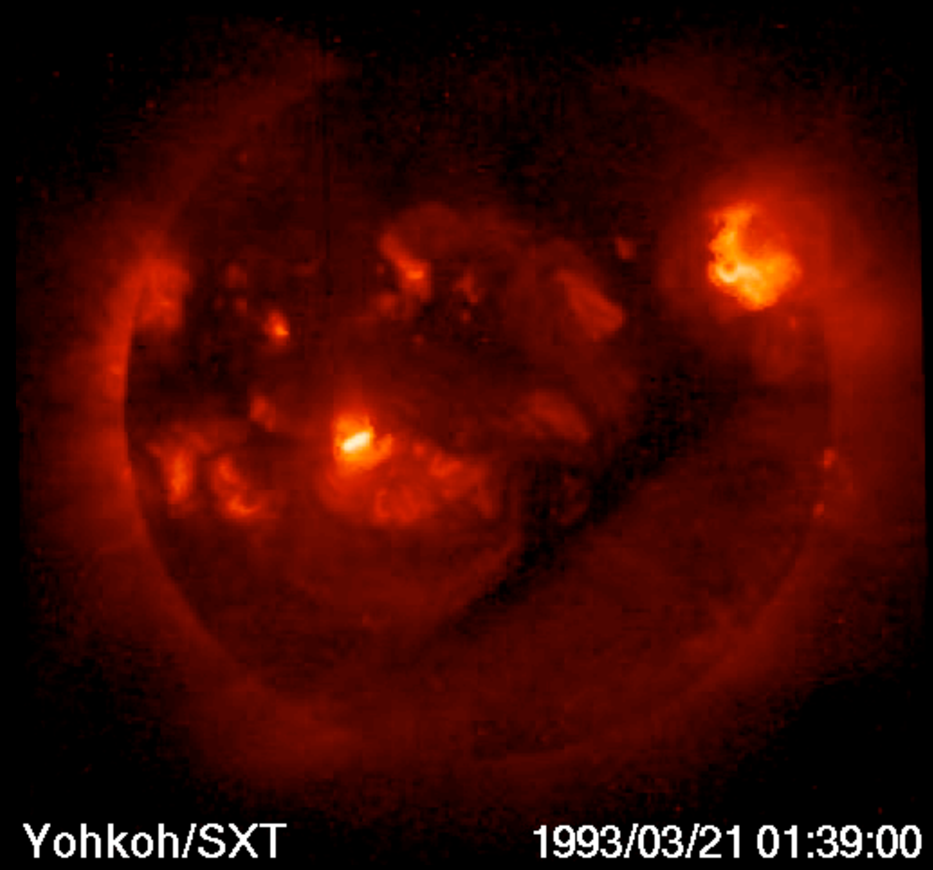
BUT...

Static vs Dynamic

Soft X-ray loops

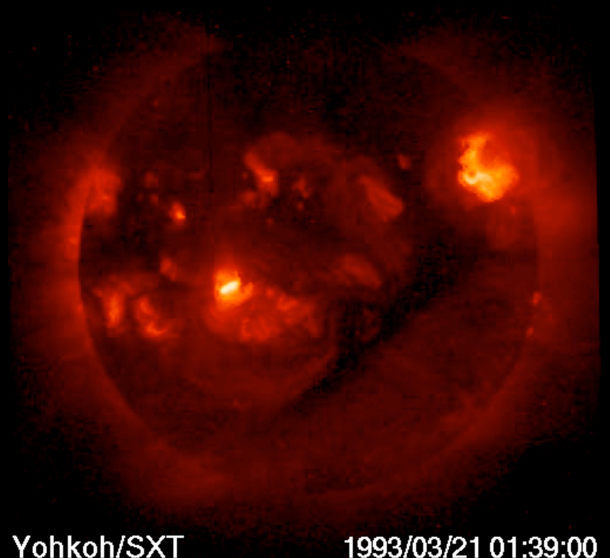
BUT...

- There is a dynamic Soft X-ray component:



Static vs Dynamic

Soft X-ray loops

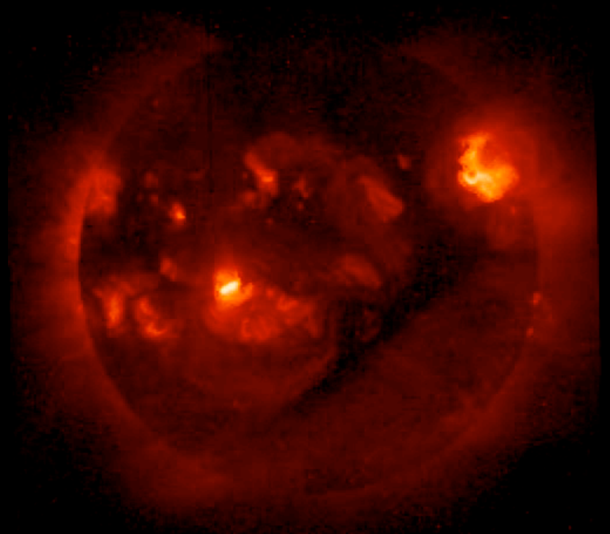


BUT...

- There is a <u>dynamic</u> Soft X-ray component:
  - Active region transient brightenings (Shimizu 1992-1995)

Static vs Dynamic

Soft X-ray loops

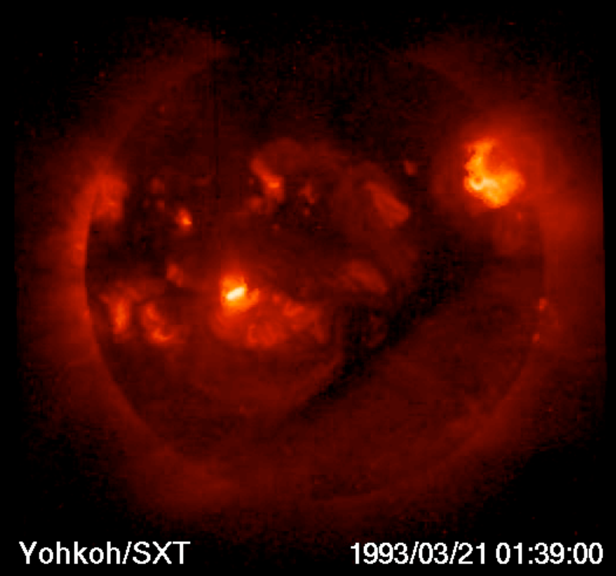


BUT...

- There is a dynamic Soft X-ray component:
  - Active region transient brightenings (Shimizu 1992-1995)
  - It has a EUV counterpart (Berghmans 2001)

Static vs Dynamic

Soft X-ray loops

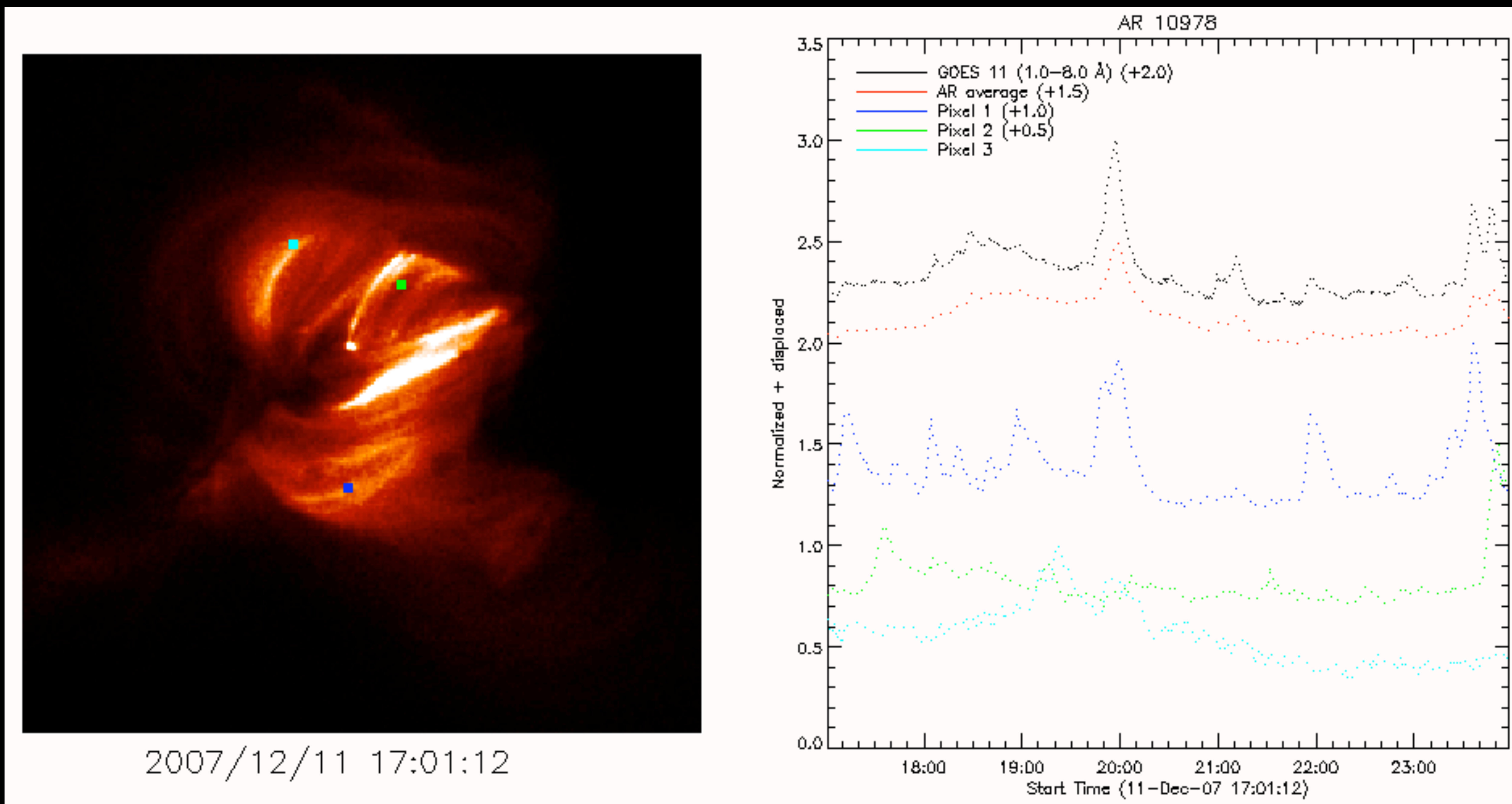


BUT...

- There is a dynamic Soft X-ray component:
  - Active region transient brightenings (Shimizu 1992-1995)
  - It has a EUV counterpart (Berghmans 2001)
  - X-ray loops cool to EUV (Winebarger, Ugarte-Urra, Warren 2005-2008)

Static vs Dynamic

Soft X-ray loops



Static vs Dynamic

Soft X-ray loops

Solar Active Region Evolution: Comparing Models with Observations
ASP Conference Series, Vol. 68, 1994
K. S. Balasubramaniam and George W. Simon (eds.)

Magnetic Reconnection in the Solar Corona

Saku Tsuneta
Institute of Astronomy, The University of Tokyo
Mitaka, Tokyo 181, Japan

law distribution over 5 orders of magnitude. Shimizu (1994) concludes that the microflares observed by *Yohkoh* alone cannot heat the active-region corona, assuming that the same power-law continues to weaker undetectable events.

Do these two observations rule out Parker's nanoflare hypothesis (Parker 1988)? x-ray morphology and fairly flat frequency distribution of microflares appear to be inconsistent with the hypothesis. There is, however, a possibility that we observe only the tip of the iceberg because of the high x-ray background (diffuse loops) of the active regions, and that there is a steep increase of the number of weaker microflares undetectable with *Yohkoh*. We need more sensitivity (higher spatial resolution and relevant temperature range) to give a definite result.

Static vs Dynamic

Soft X-ray loops

Solar Active Region Evolution: Comparing Models with Observations
ASP Conference Series, Vol. 68, 1994
K. S. Balasubramaniam and George W. Simon (eds.)

Magnetic Reconnection in the Solar Corona

Saku Tsuneta
Institute of Astronomy, The University of Tokyo
Mitaka, Tokyo 181, Japan

law distribution over 5 orders of magnitude. Shimizu (1994) concludes that the microflares observed by *Yohkoh* alone cannot heat the active-region corona, assuming that the same power-law continues to weaker undetectable events.

Do these two observations rule out Parker's nanoflare hypothesis (Parker 1988)? x-ray morphology and fairly flat frequency distribution of microflares appear to be inconsistent with the hypothesis. There is, however, a possibility that we observe only the tip of the iceberg because of the high x-ray background (diffuse loops) of the active regions, and that there is a steep increase of the number of weaker microflares undetectable with *Yohkoh*. We need more sensitivity (higher spatial resolution and relevant temperature range) to give a definite result.

Static vs Dynamic

Soft X-ray loops

Solar Active Region Evolution: Comparing Models with Observations
ASP Conference Series, Vol. 68, 1994
K. S. Balasubramaniam and George W. Simon (eds.)

Magnetic Reconnection in the Solar Corona

Saku Tsuneta
Institute of Astronomy, The University of Tokyo
Mitaka, Tokyo 181, Japan

law distribution over 5 orders of magnitude. Shimizu (1994) concludes that the microflares observed by *Yohkoh* alone cannot heat the active-region corona, assuming that the same power-law continues to weaker undetectable events.

Do these two observations rule out Parker's nanoflare hypothesis (Parker 1988)? x-ray morphology and fairly flat frequency distribution of microflares appear to be inconsistent with the hypothesis. There is, however, a possibility that we observe only the tip of the iceberg because of the high x-ray background (diffuse loops) of the active regions, and that there is a steep increase of the number of weaker microflares undetectable with *Yohkoh*. We need more sensitivity (higher spatial resolution and relevant temperature range) to give a definite result.

Static vs Dynamic

Soft X-ray loops

Solar Active Region Evolution: Comparing Models with Observations
ASP Conference Series, Vol. 68, 1994
K. S. Balasubramaniam and George W. Simon (eds.)

Magnetic Reconnection in the Solar Corona

Saku Tsuneta
Institute of Astronomy, The University of Tokyo
Mitaka, Tokyo 181, Japan

law distribution over 5 orders of magnitude. Shimizu (1994) concludes that the microflares observed by *Yohkoh* alone cannot heat the active-region corona, assuming that the same power-law continues to weaker undetectable events.

Do these two observations rule out Parker's nanoflare hypothesis (Parker 1988)? x-ray morphology and fairly flat frequency distribution of microflares appear to be inconsistent with the hypothesis. There is, however, a possibility that we observe only the tip of the iceberg because of the high x-ray background (diffuse loops) of the active regions, and that there is a steep increase of the number of weaker microflares undetectable with *Yohkoh*. We need more sensitivity (higher spatial resolution and relevant temperature range) to give a definite result.

Static vs Dynamic

Soft X-ray loops

Solar Active Region Evolution: Comparing Models with Observations
ASP Conference Series, Vol. 68, 1994
K. S. Balasubramaniam and George W. Simon (eds.)

Magnetic Reconnection in the Solar Corona

Saku Tsuneta , e.g. we need XRT/Hinode.

Institute of Astronomy, The University of Tokyo
Mitaka, Tokyo 181, Japan

law distribution over 5 orders of magnitude. Shimizu (1994) concludes that the microflares observed by *Yohkoh* alone cannot heat the active-region corona, assuming that the same power-law continues to weaker undetectable events.

Do these two observations rule out Parker's nanoflare hypothesis (Parker 1988)? x-ray morphology and fairly flat frequency distribution of microflares appear to be inconsistent with the hypothesis. There is, however, a possibility that we observe only the tip of the iceberg because of the high x-ray background (diffuse loops) of the active regions, and that there is a steep increase of the number of weaker microflares undetectable with *Yohkoh*. We need more sensitivity (higher spatial resolution and relevant temperature range) to give a definite result.

Static vs Dynamic

Soft X-ray loops

Solar Active Region Evolution: Comparing Models with Observations
ASP Conference Series, Vol. 68, 1994
K. S. Balasubramaniam and George W. Simon (eds.)

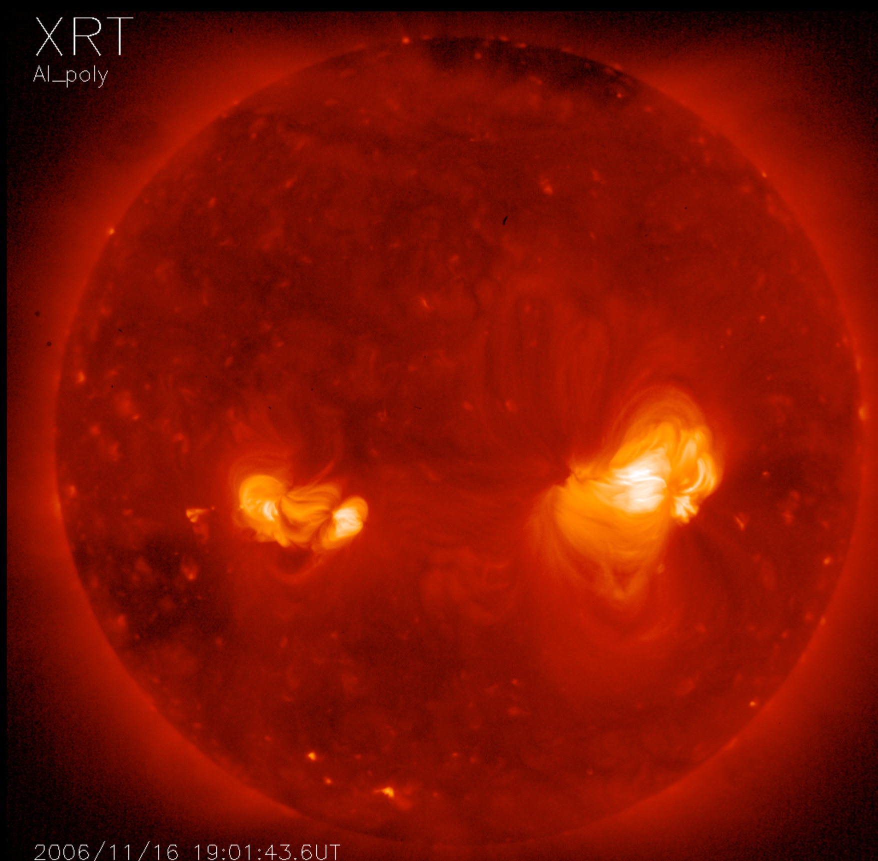
Magnetic Reconnection in the Solar Corona

Saku Tsuneta
Institute of Astronomy, The University of Tokyo
Mitaka, Tokyo 181, Japan

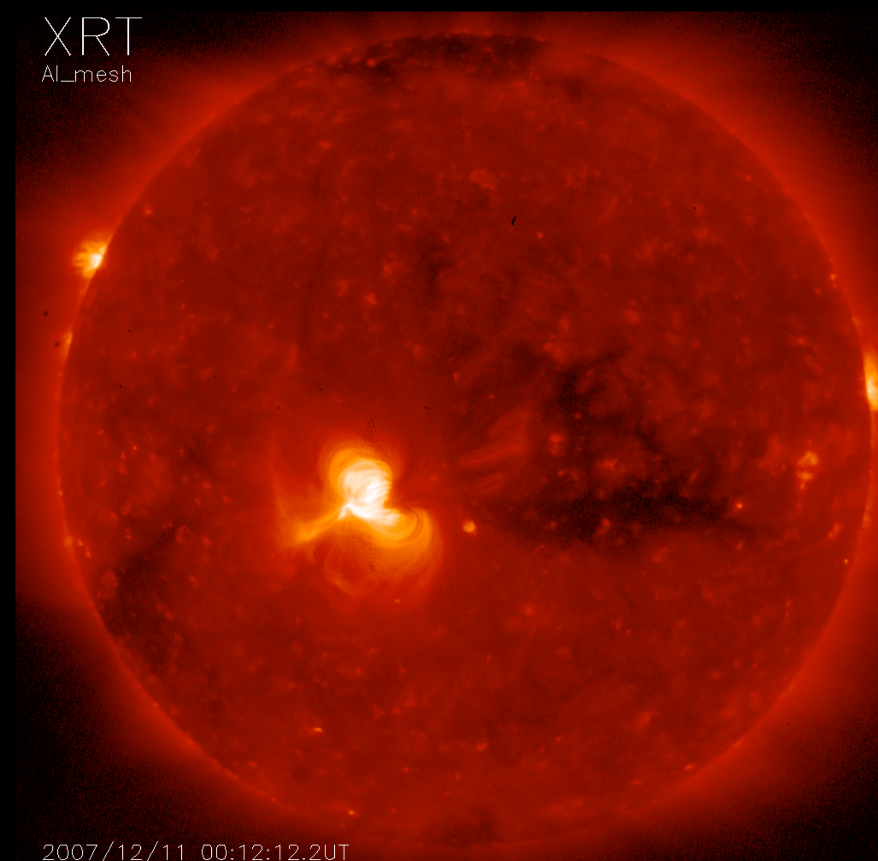
law distribution over 5 orders of magnitude. Shimizu (1994) concludes that the microflares observed by *Yohkoh* alone cannot heat the active-region corona, assuming that the same power-law continues to weaker undetectable events.

Do these two observations rule out Parker's nanoflare hypothesis (Parker 1988)? x-ray morphology and fairly flat frequency distribution of microflares appear to be inconsistent with the hypothesis. There is, however, a possibility that we observe only the tip of the iceberg because of the high x-ray background (diffuse loops) of the active regions, and that there is a steep increase of the number of weaker microflares undetectable with *Yohkoh*. We need more sensitivity (higher spatial resolution and relevant temperature range) to give a definite result. , e.g. we need XRT/Hinode.

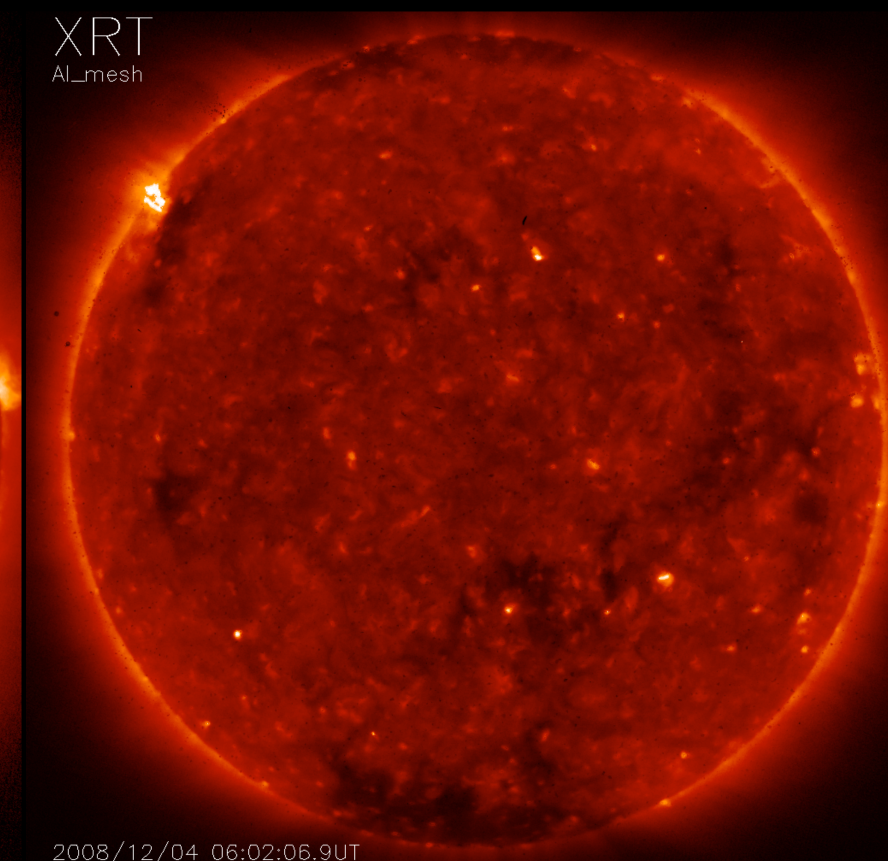
Steady AR



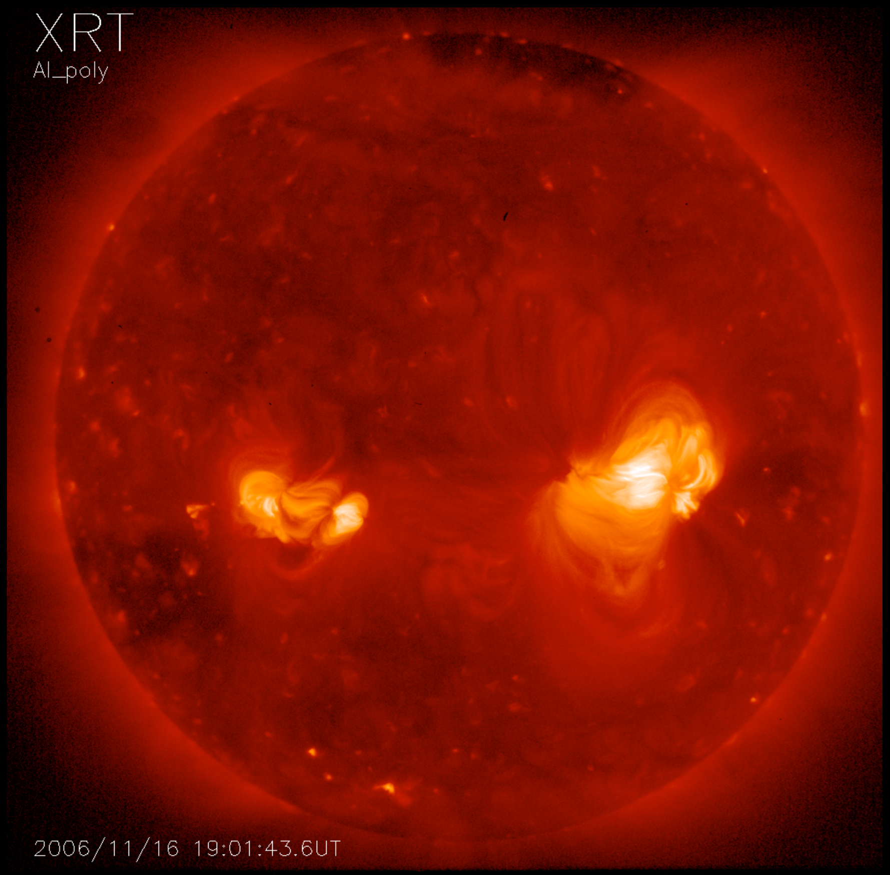
Impulsive AR



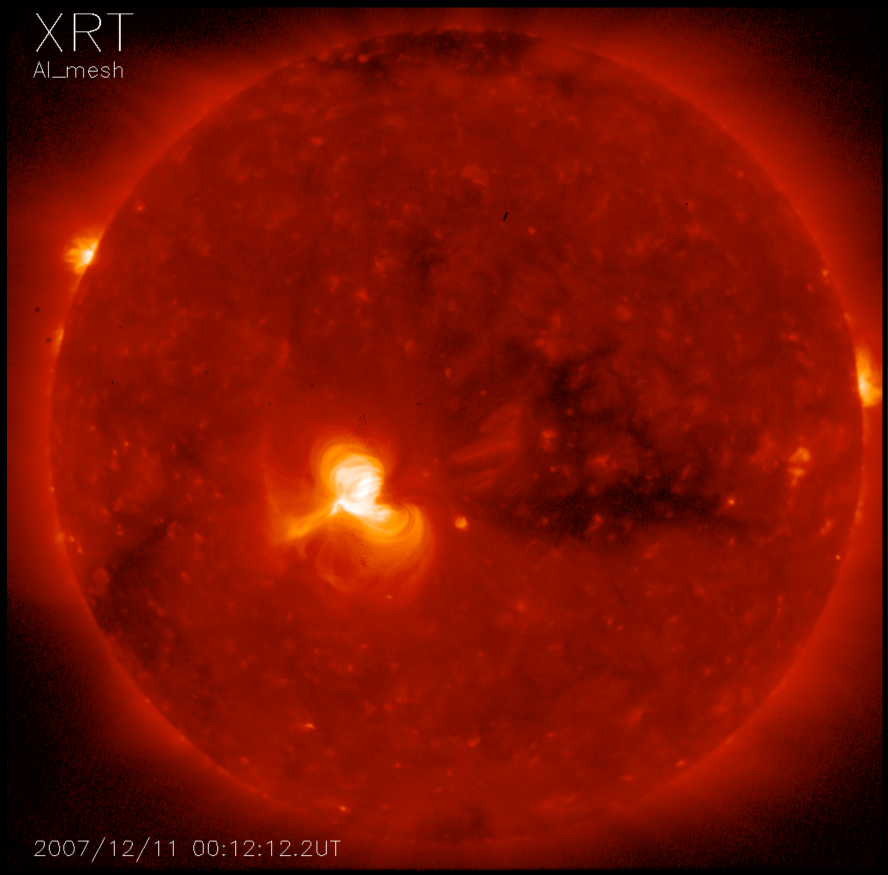
No AR



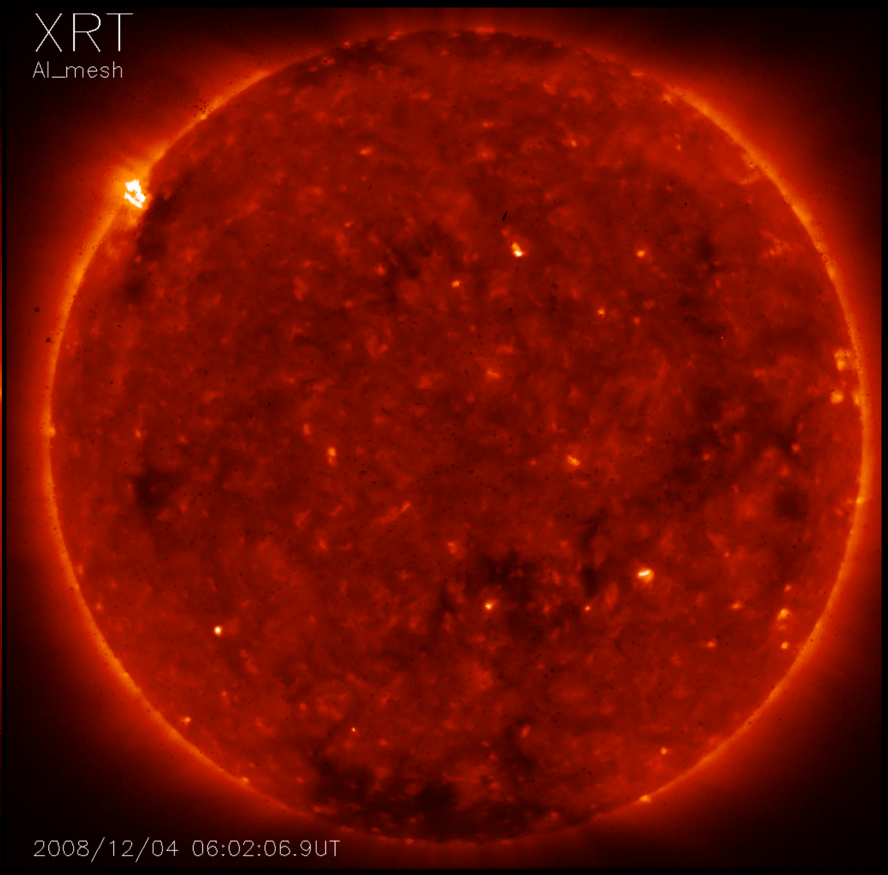
Steady AR



Impulsive AR



No AR



What is the corona we want to explain?

Are they exclusive?

Static vs Dynamic

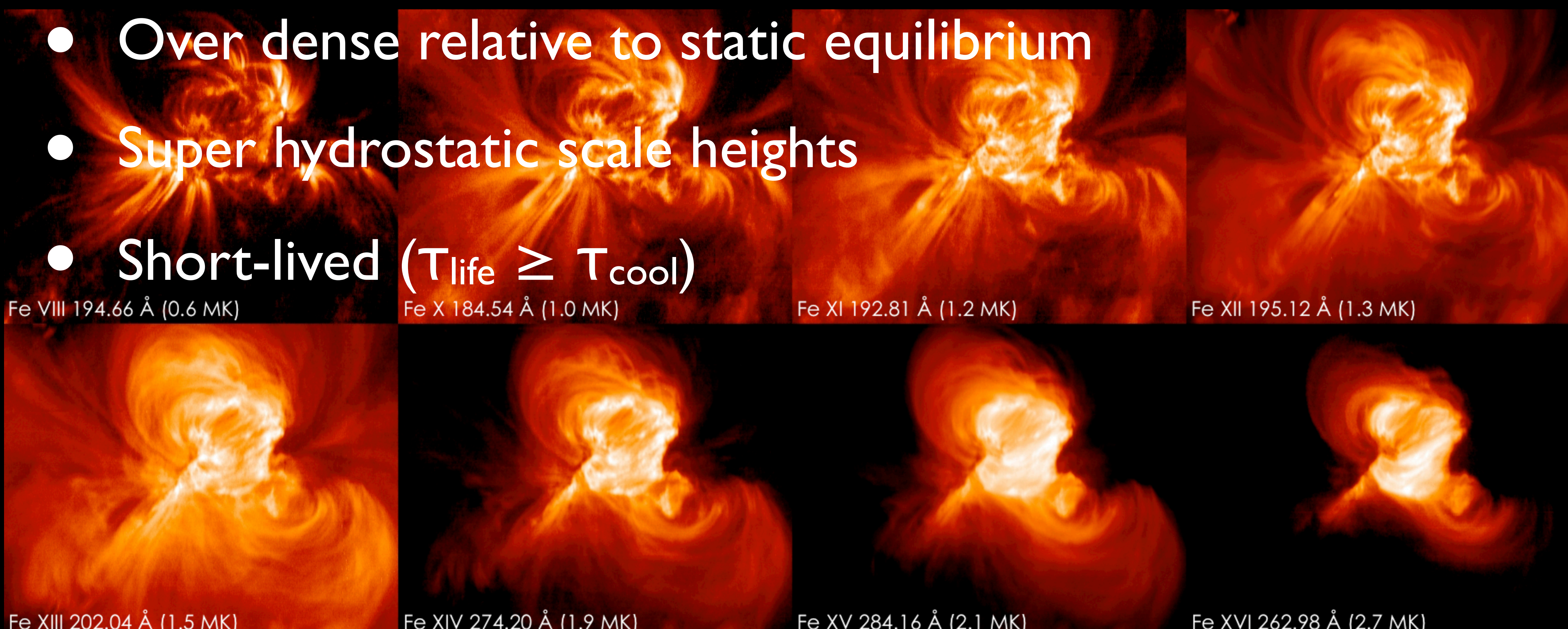
EUV loops

- Warm ($0.5 \leq T \leq$ 1-3 MK)
- Over dense relative to static equilibrium
- Super hydrostatic scale heights
- Short-lived ($\tau_{life} \geq \tau_{cool}$)

Static vs Dynamic

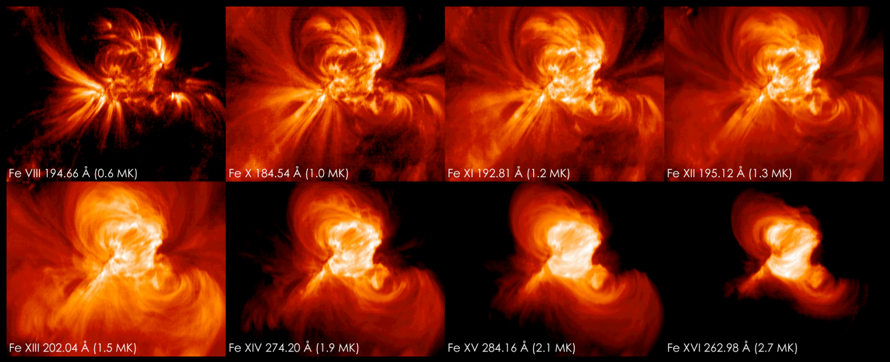
EUV loops

- Warm ($0.5 \leq T \leq 1\text{-}3$ MK)
- Over dense relative to static equilibrium
- Super hydrostatic scale heights
- Short-lived ($\tau_{life} \geq \tau_{cool}$)



Static vs Dynamic

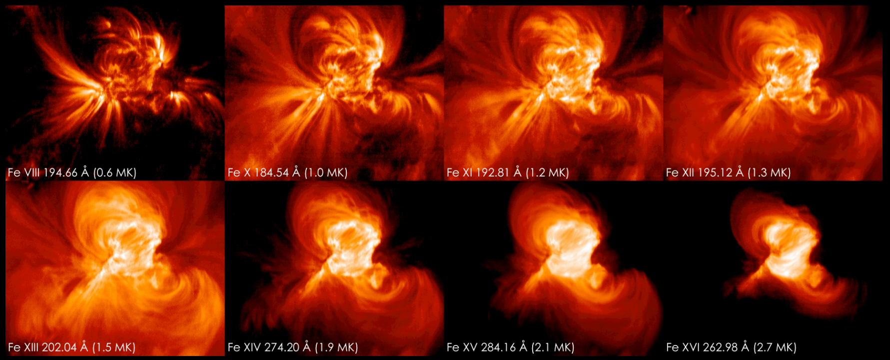
EUV loops



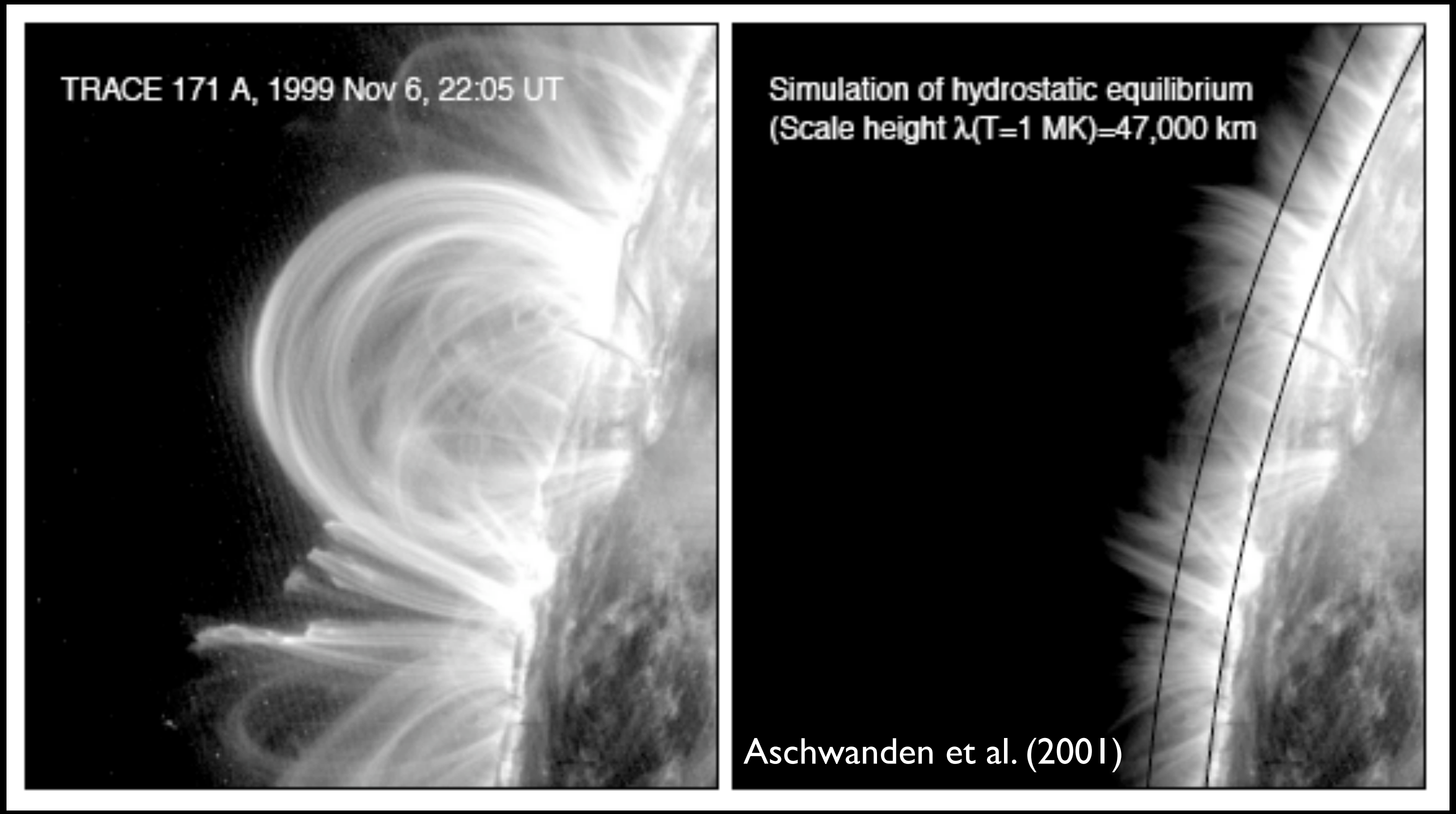
- Warm ($0.5 \leq T \leq$ 1-3 MK)
- Over dense relative to static equilibrium
- Super hydrostatic scale heights

Static vs Dynamic

EUV loops



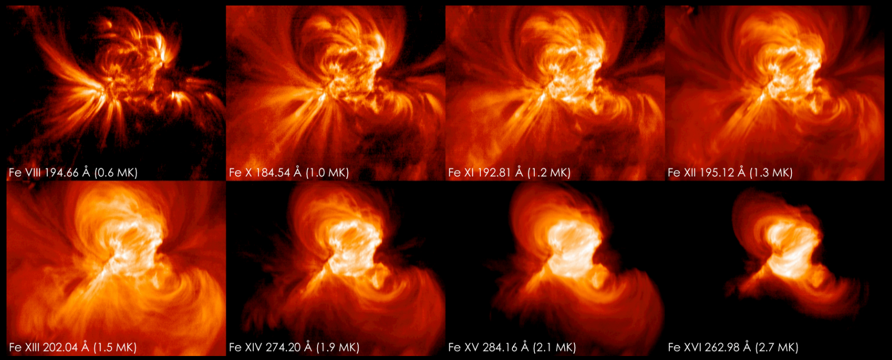
- Warm ($0.5 \leq T \leq$ 1-3 MK)
- Over dense relative to static equilibrium
- Super hydrostatic scale heights



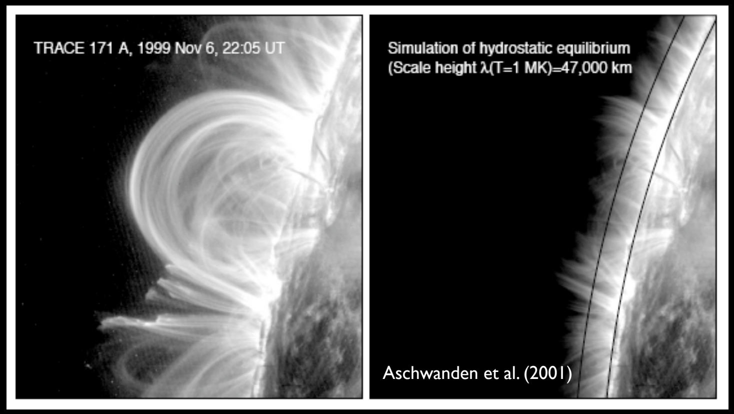
Aschwanden et al. (2001)

Static vs Dynamic

EUV loops

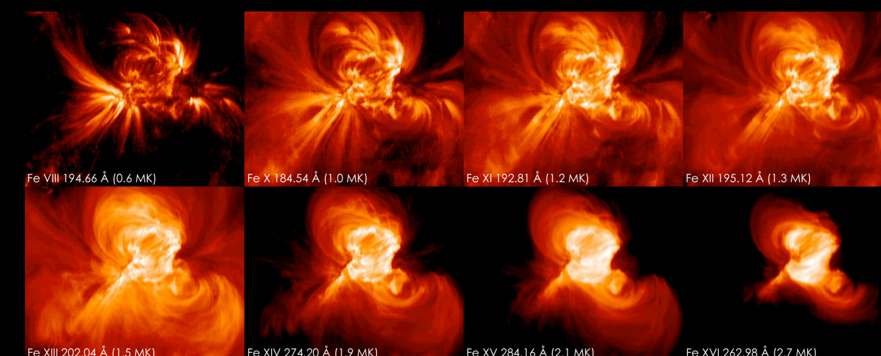


- Warm ($0.5 \leq T \leq$ 1-3 MK)
- Over dense relative to static equilibrium
- Super hydrostatic scale heights

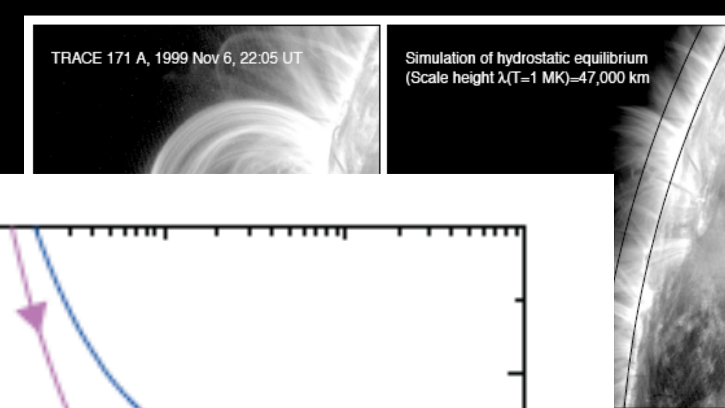


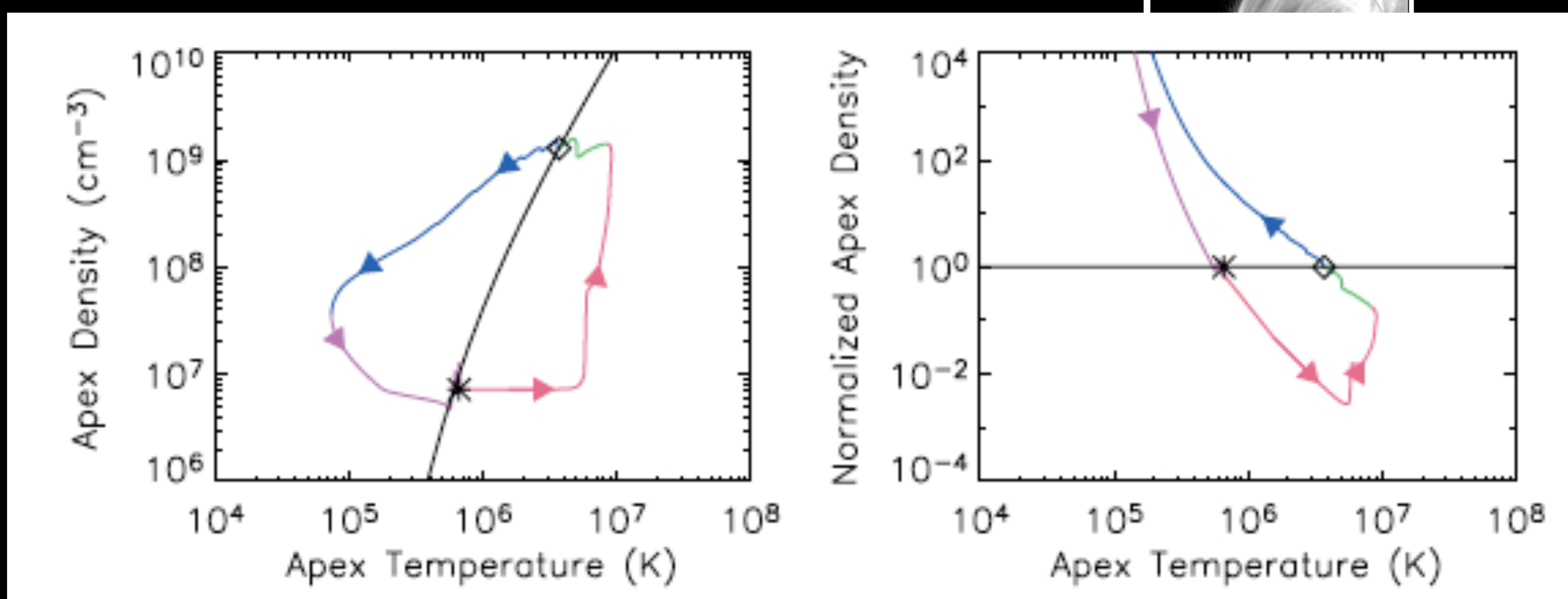
Static vs Dynamic

EUV loops



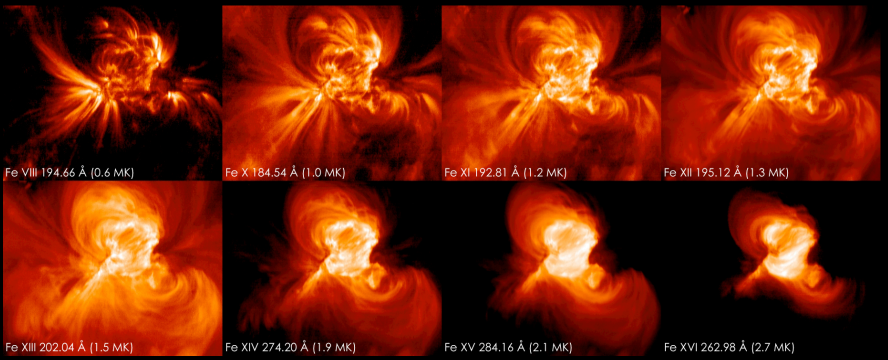
- Warm (0.5 ≤ T ≤ 1-3 MK)
- Over dense relative to static equilibrium
- Super hydrostatic scale heights



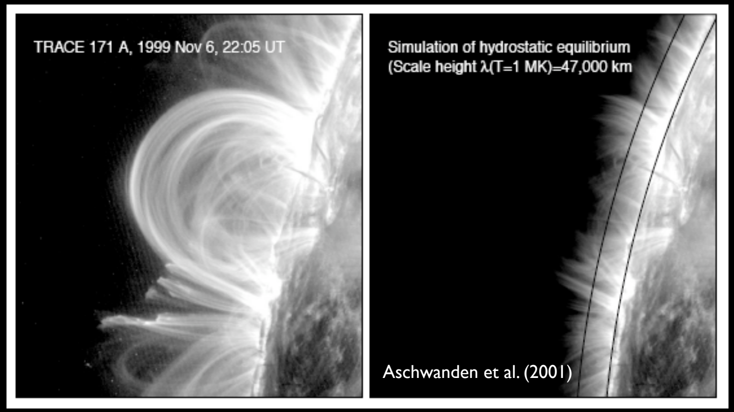


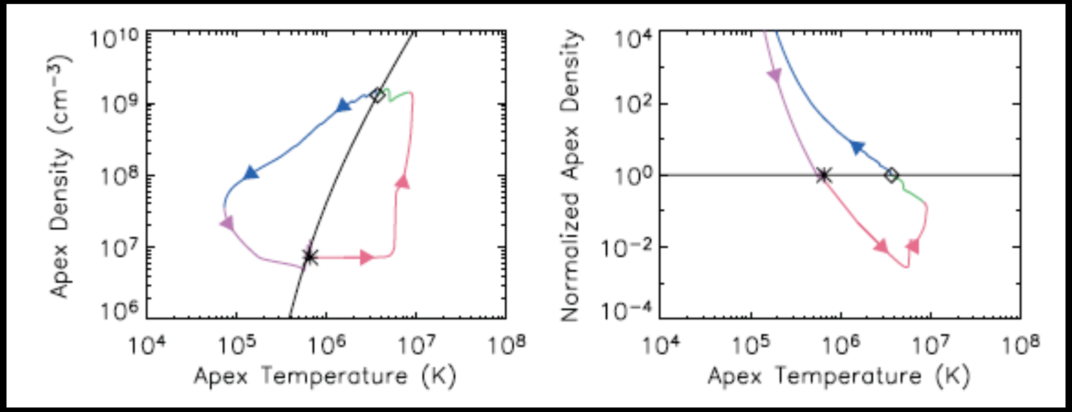
Static vs Dynamic

EUV loops



- Warm ($0.5 \leq T \leq$ 1-3 MK)
- Over dense relative to static equilibrium
- Super hydrostatic scale heights

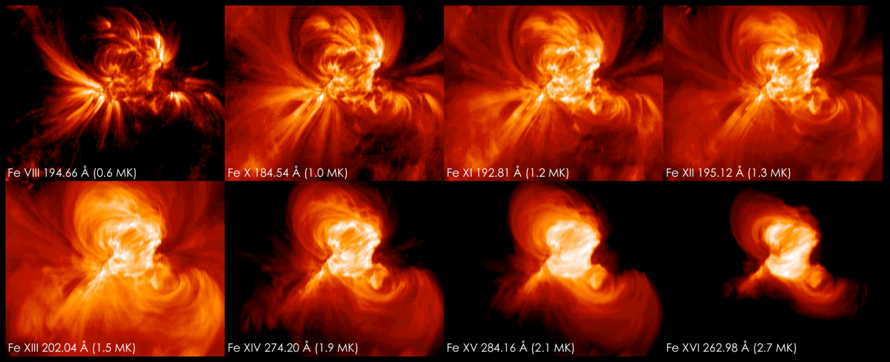




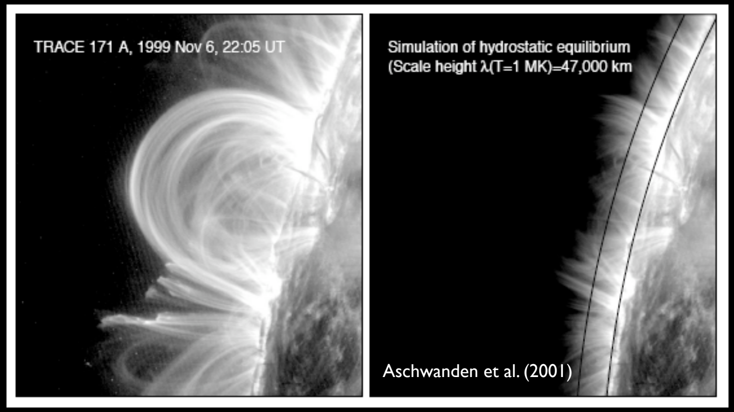
Winebarger et al. (2004)

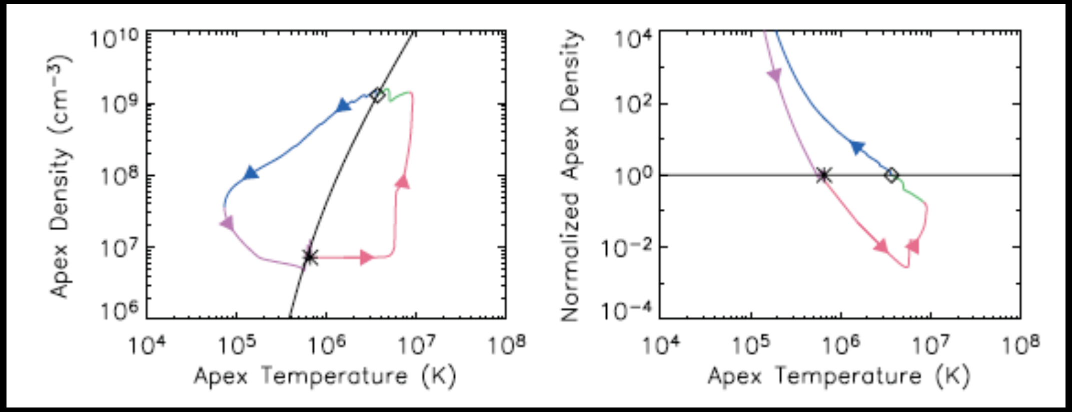
Static vs Dynamic

EUV loops



- Warm ($0.5 \leq T \leq$ 1-3 MK)
- Over dense relative to static equilibrium
- Super hydrostatic scale heights
- Short-lived ($\tau_{life} \geq \tau_{cool}$)





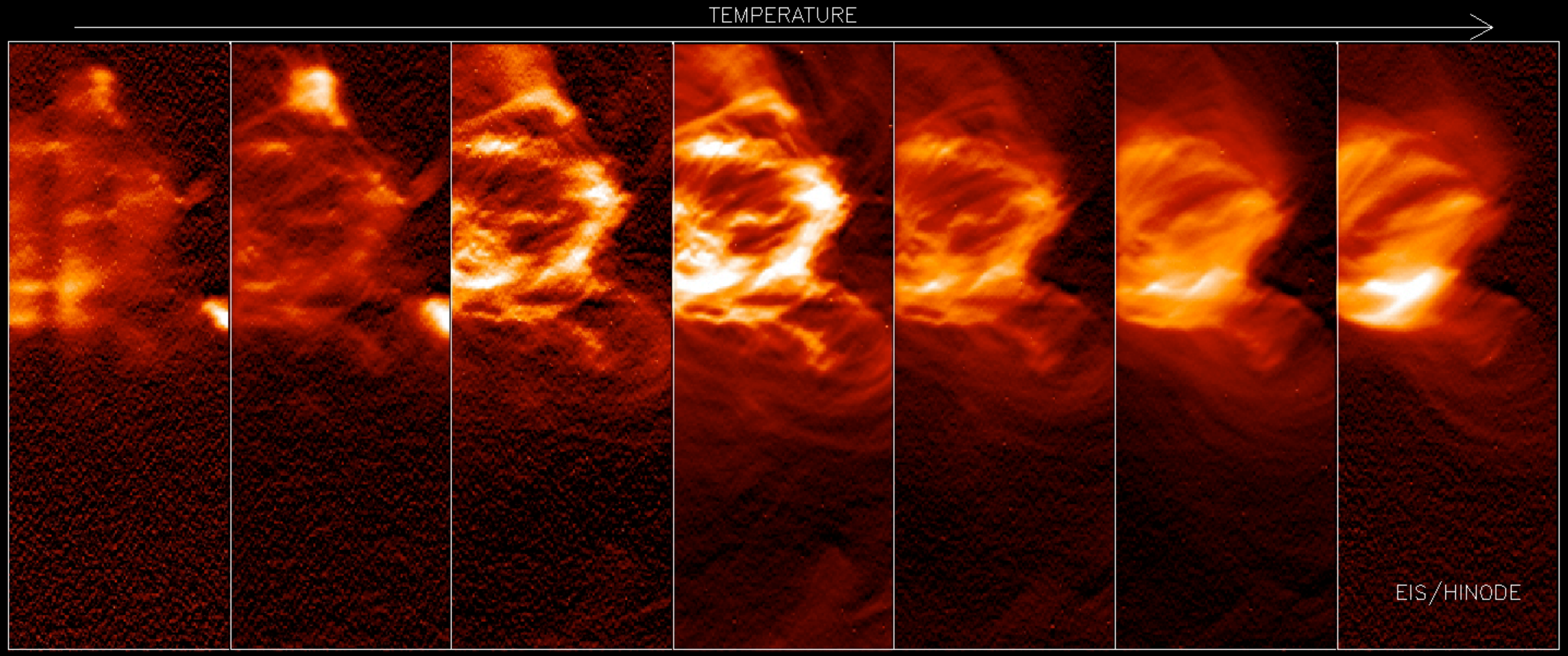
Winebarger et al. (2004)

Static vs Dynamic

EUV loops

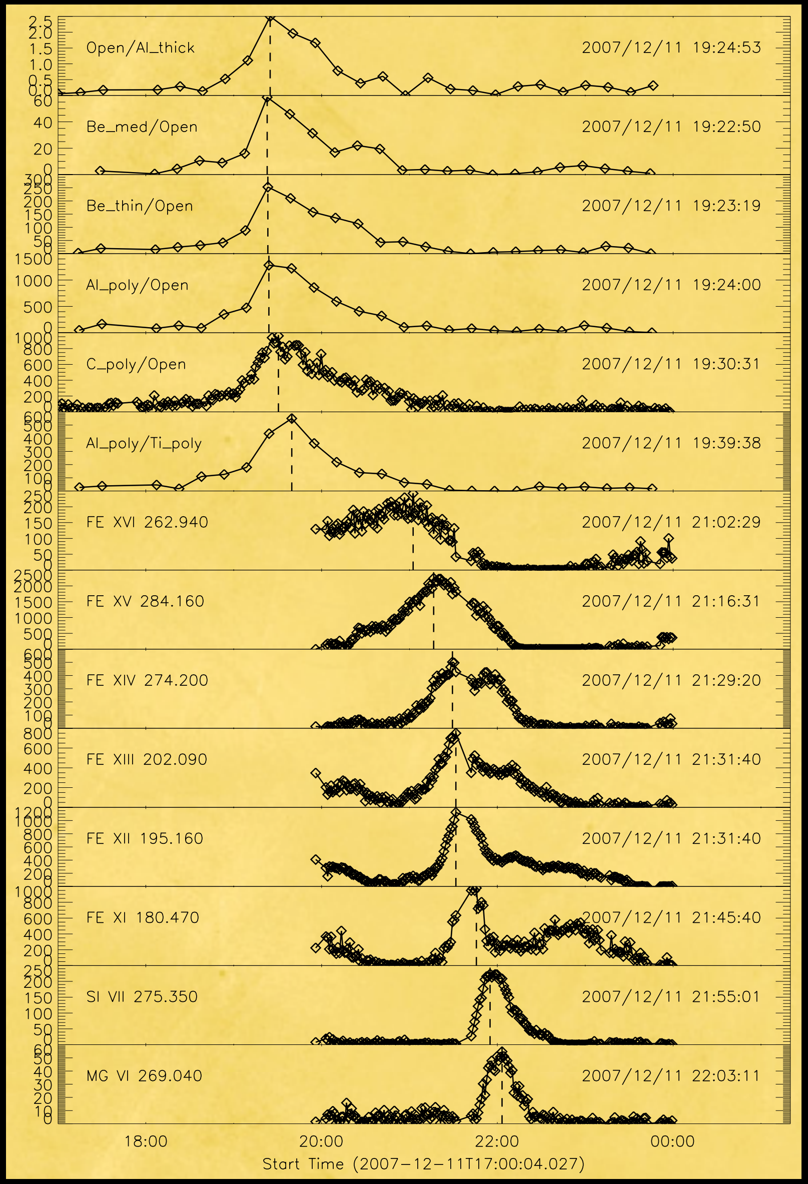
Static vs Dynamic

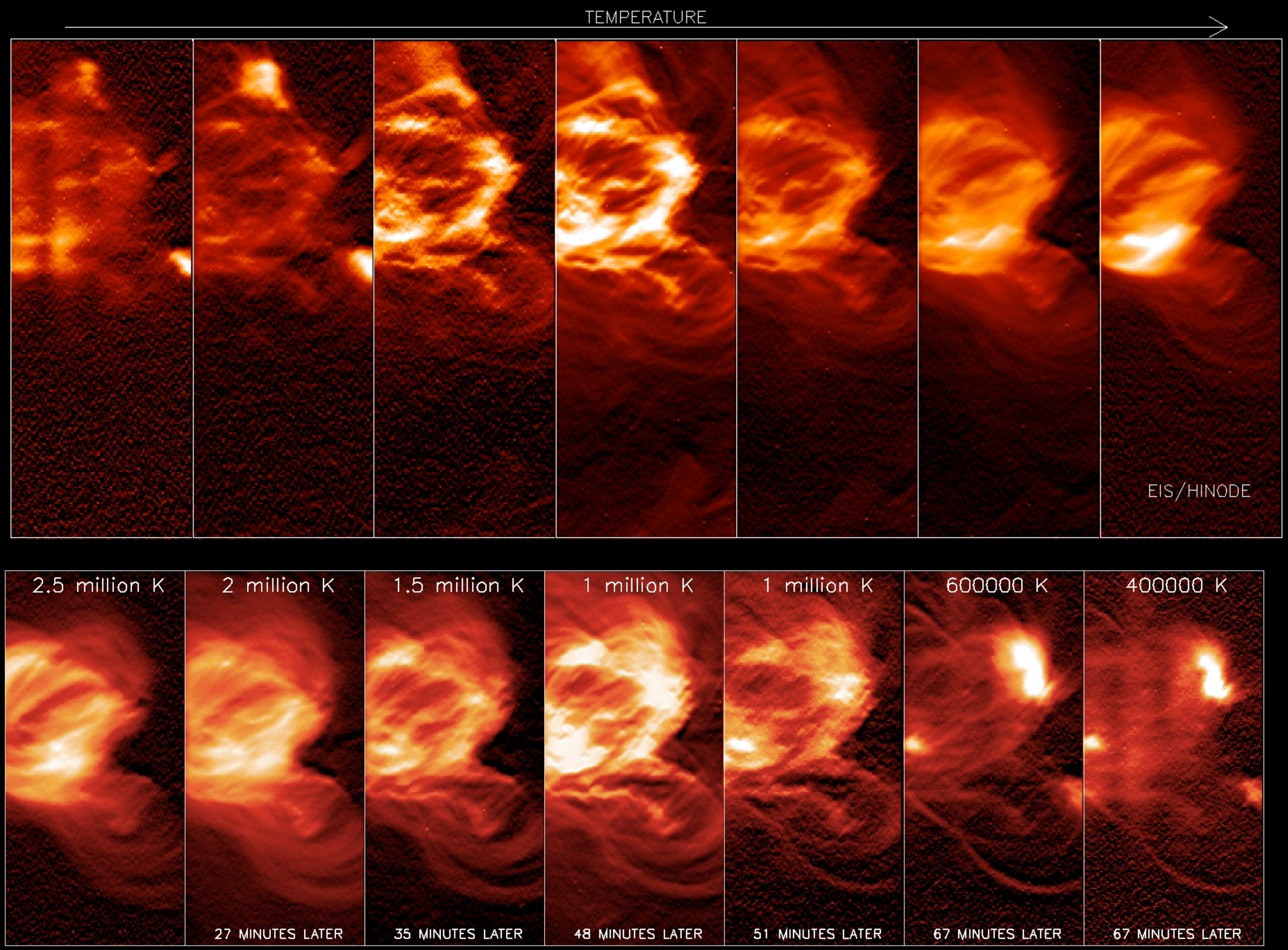
EUV loops



Static vs Dynamic

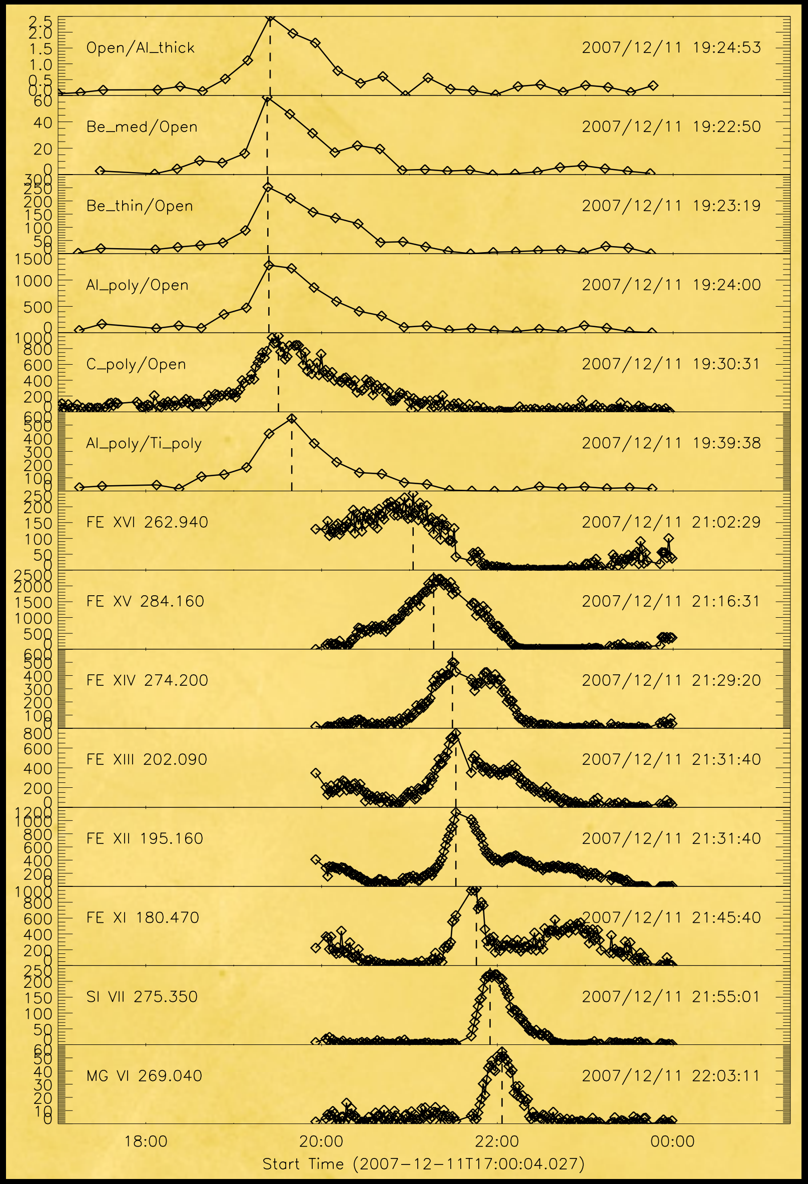
EUV loops

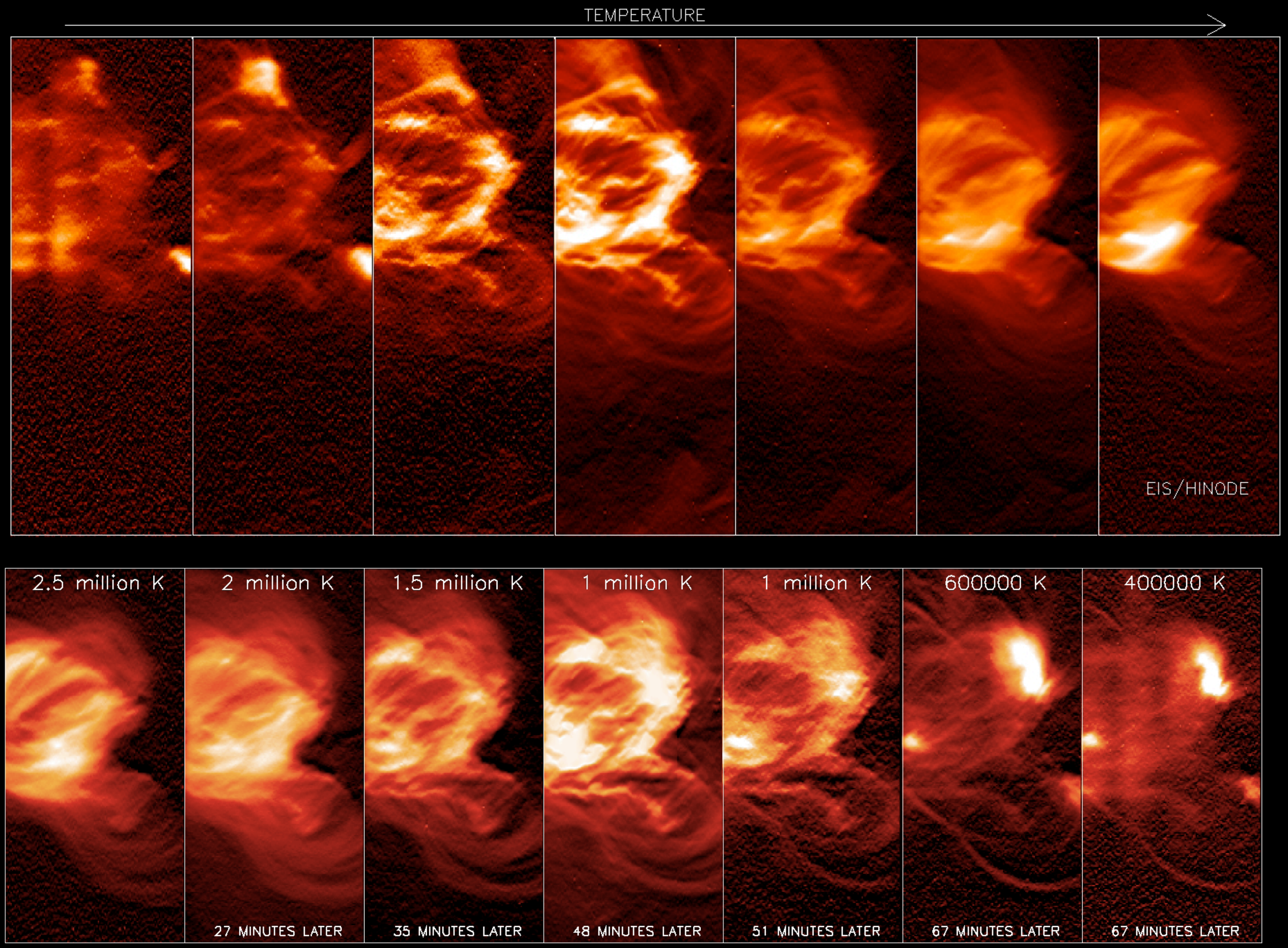




Static vs Dynamic

EUV loops





Ugarte-Urra, Warren & Brooks (2009)

Static vs Dynamic

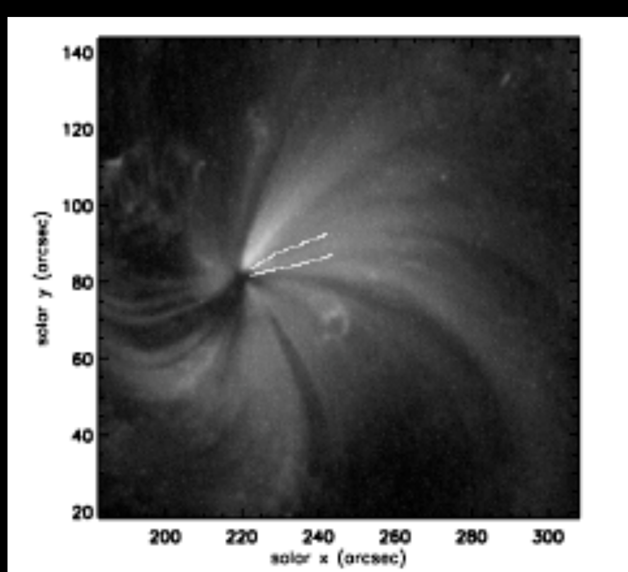
EUV loops

- There is a subset of EUV loops with T ≤ 1 MK

Del Zanna, Del Zanna & Mason (2003), Young et al. (2007), Ugarte-Urra et al. (2009)

- These loops host (slow magnetoaccoustic) waves

De Moortel et al. (2002), Marsh (2006)



0.4 MK 0.6 MK 1.3 MK

Static vs Dynamic

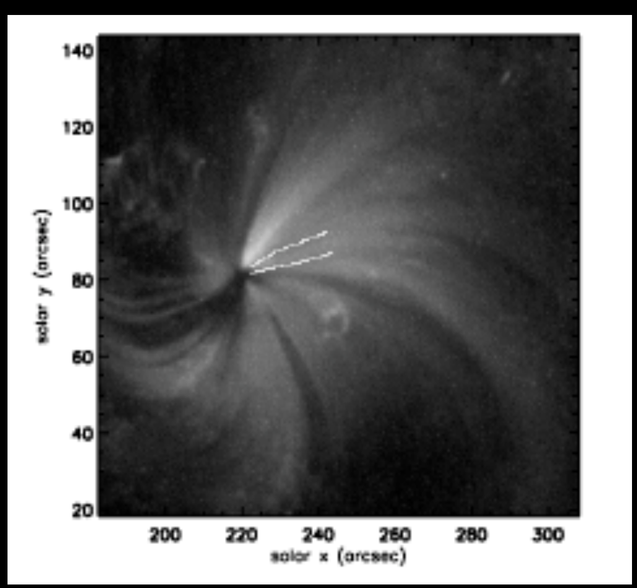
EUV loops

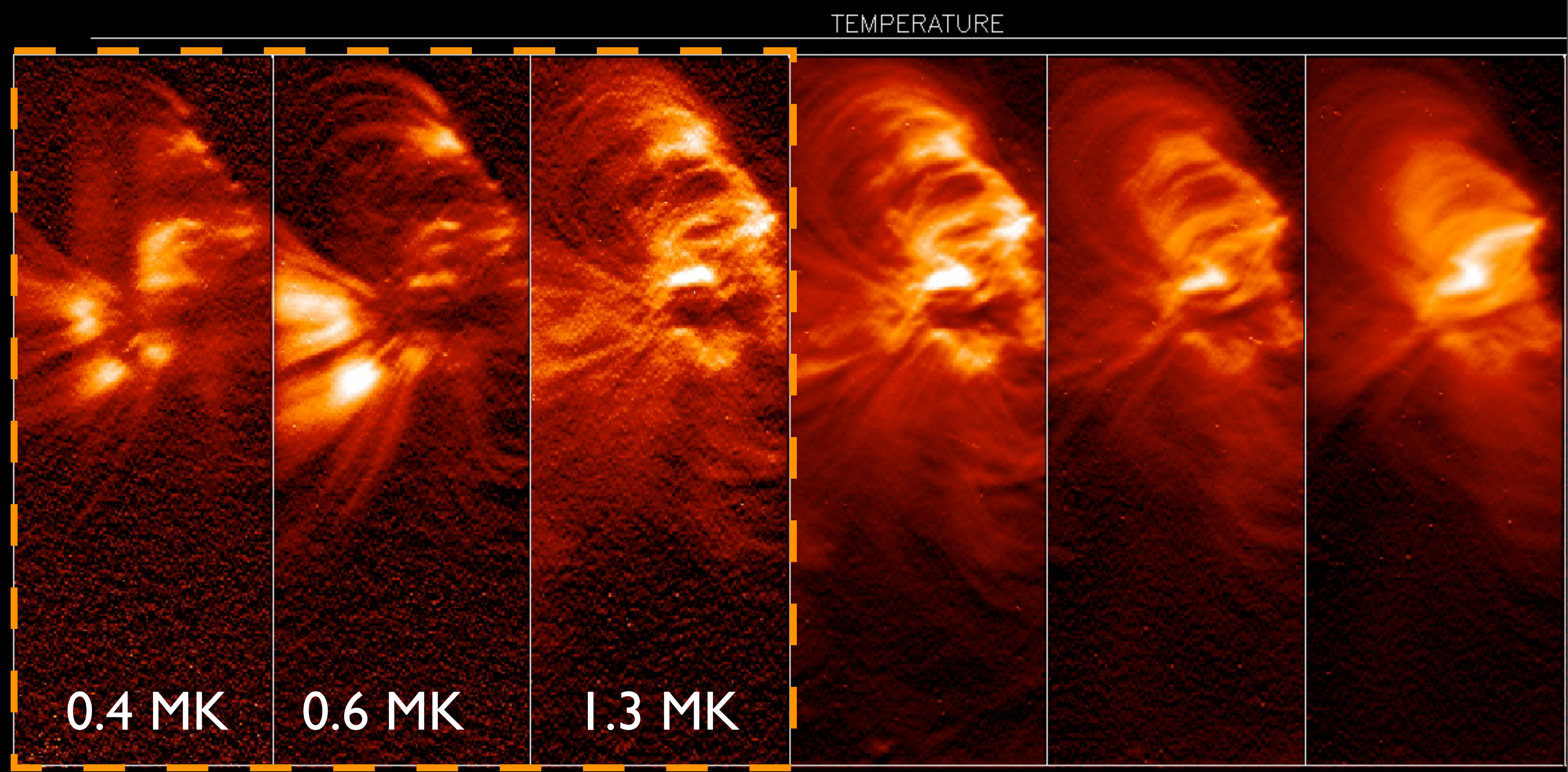
- There is a subset of EUV loops with T ≤ 1 MK

Del Zanna, Del Zanna & Mason (2003), Young et al. (2007), Ugarte-Urra et al. (2009)

- These loops host (slow magnetoaccoustic) waves

De Moortel et al. (2002), Marsh (2006)

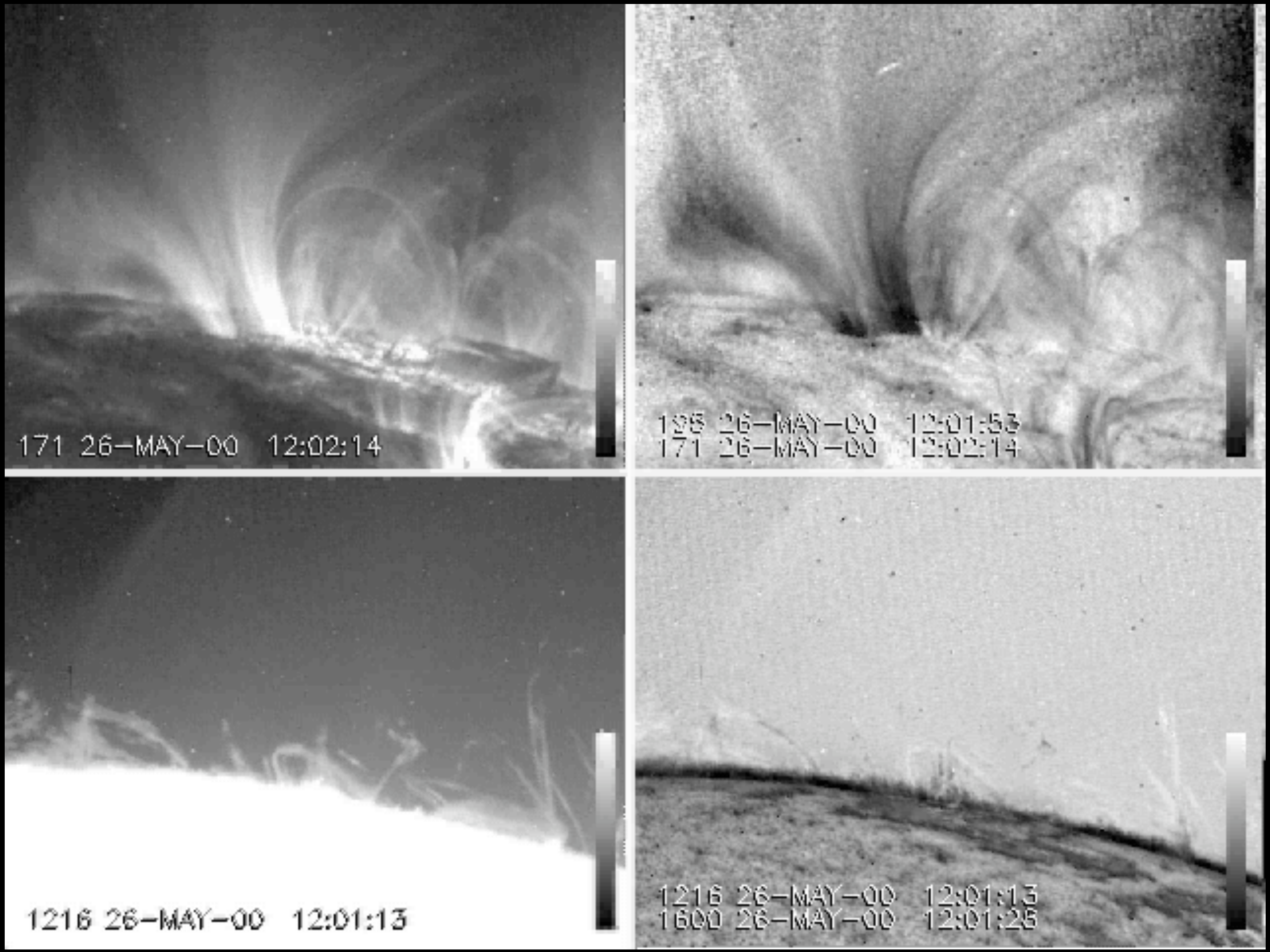




Static vs Dynamic

EUV loops

- Coronal rain



- Thermal non-equilibrium: steady foot-point heating

Mueller, Peter, Hansteen (2003-2005)

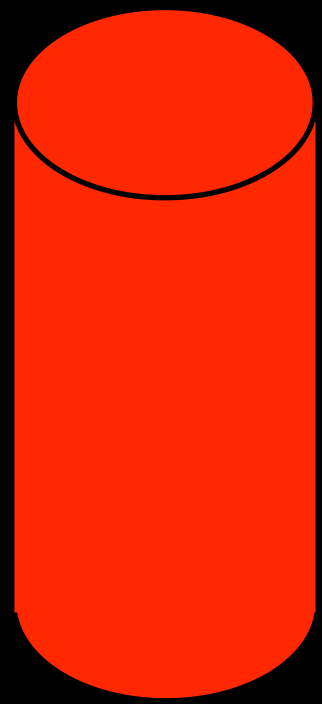
Structuring: are loops monolithic?

Structuring: are loops monolithic?

- Have we seen elementary strands?

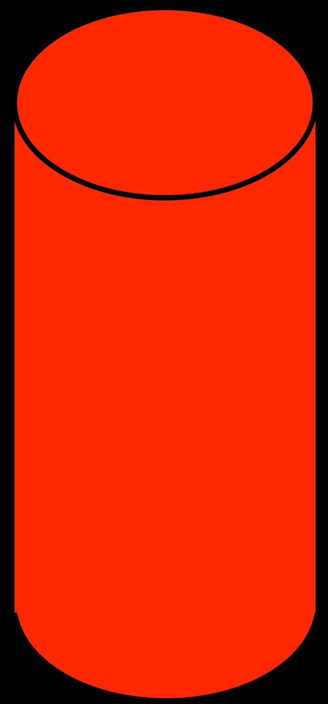
Structuring: are loops monolithic?

- Have we seen elementary strands?
- Fundamental building blocks:



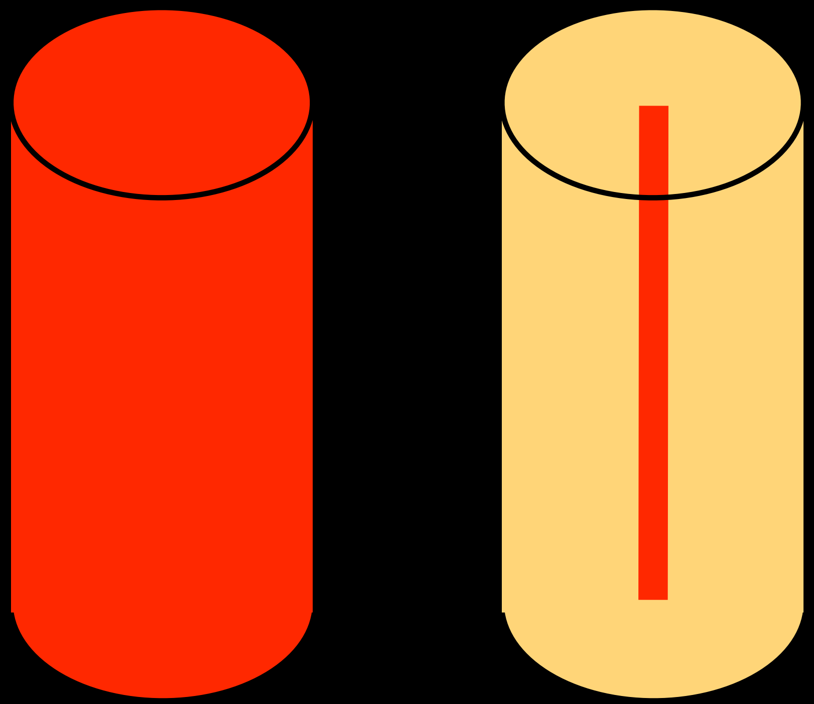
Structuring: are loops monolithic?

- Have we seen elementary strands?
- Fundamental building blocks:
  - homogeneous density and temperature across loop's axis



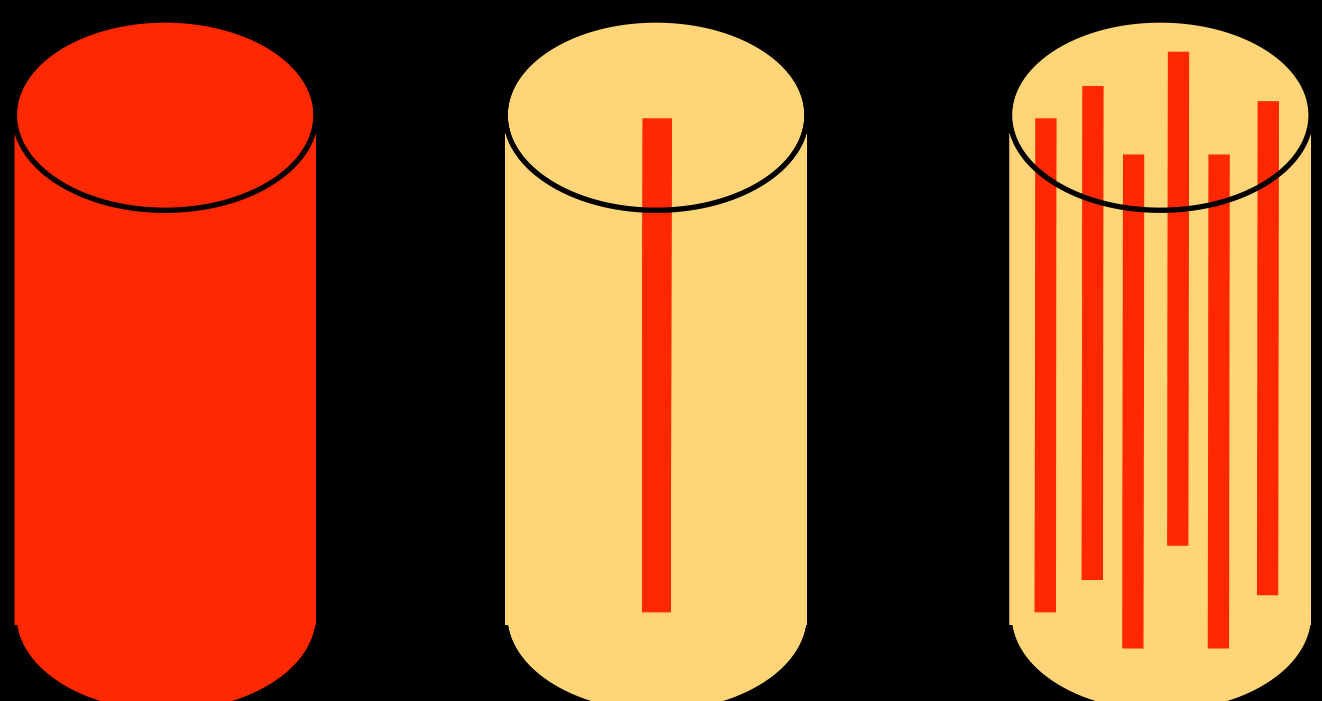
Structuring: are loops monolithic?

- Have we seen elementary strands?
- Fundamental building blocks:
  - homogeneous density and temperature across loop's axis
  - homogeneous density and temperature across strand's axis



Structuring: are loops monolithic?

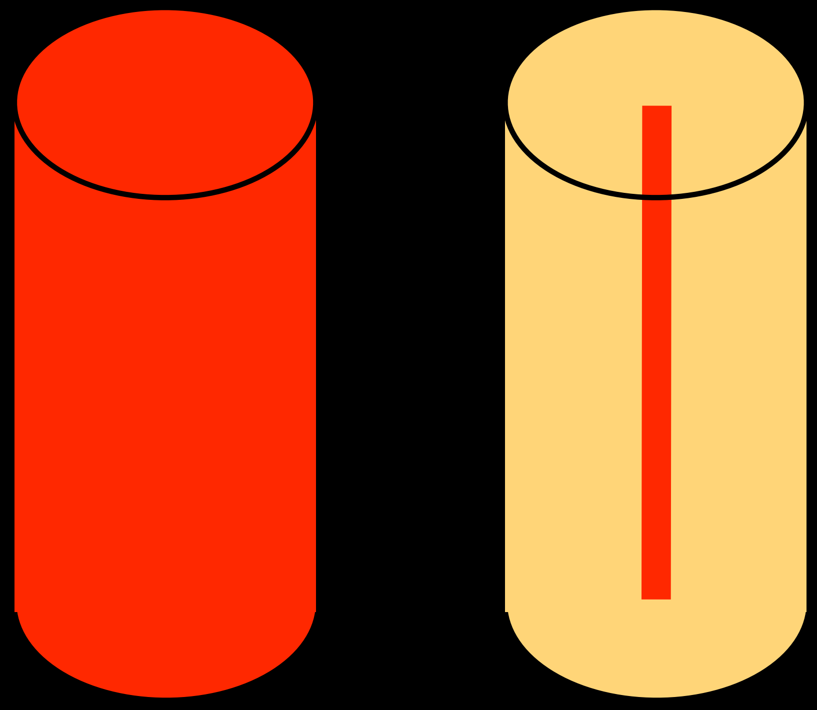
- Have we seen elementary strands?
- Fundamental building blocks:
  - homogeneous density and temperature across loop's axis
  - homogeneous density and temperature across strand's axis



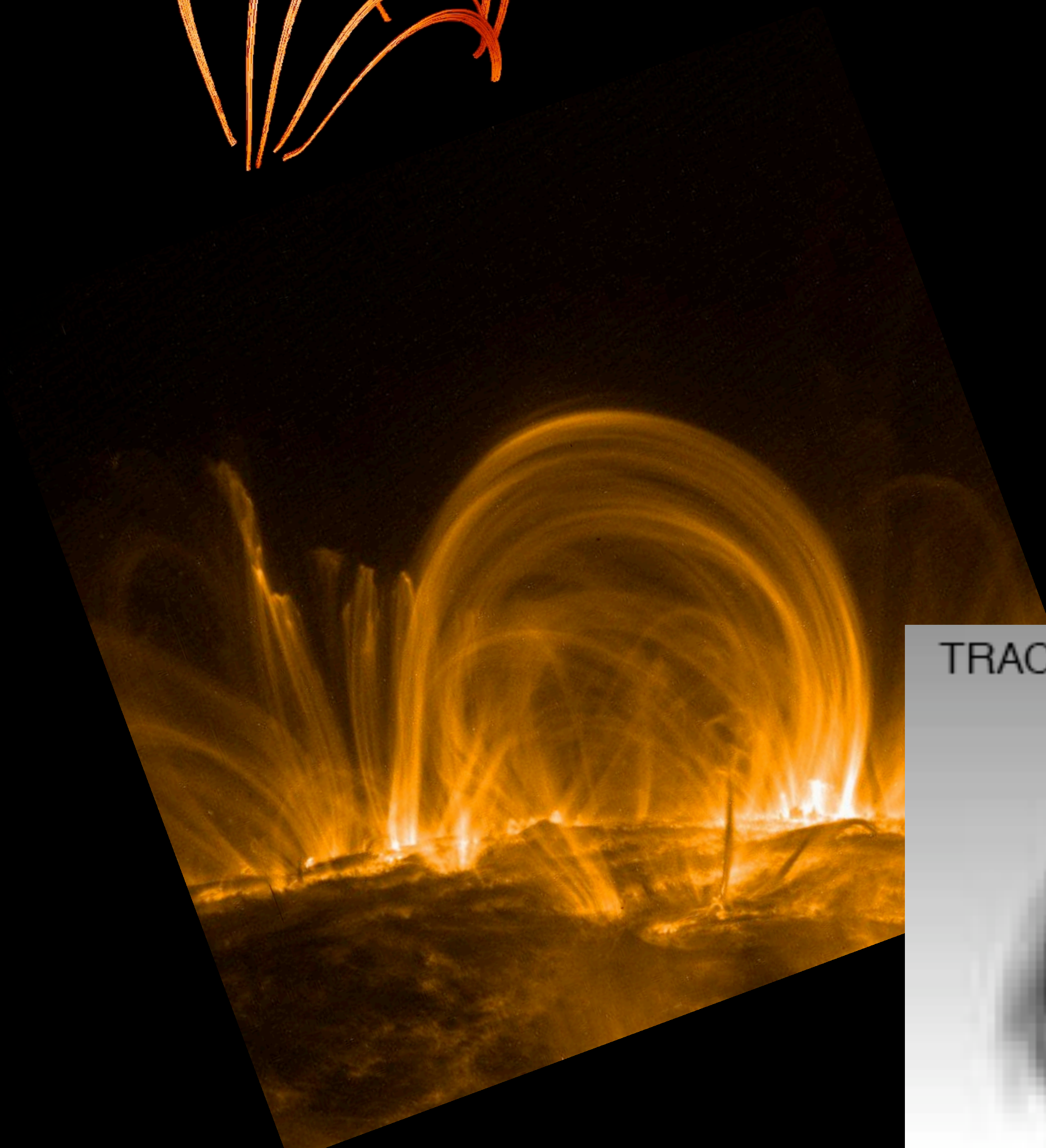
Aschwanden & Nightingale (2005)

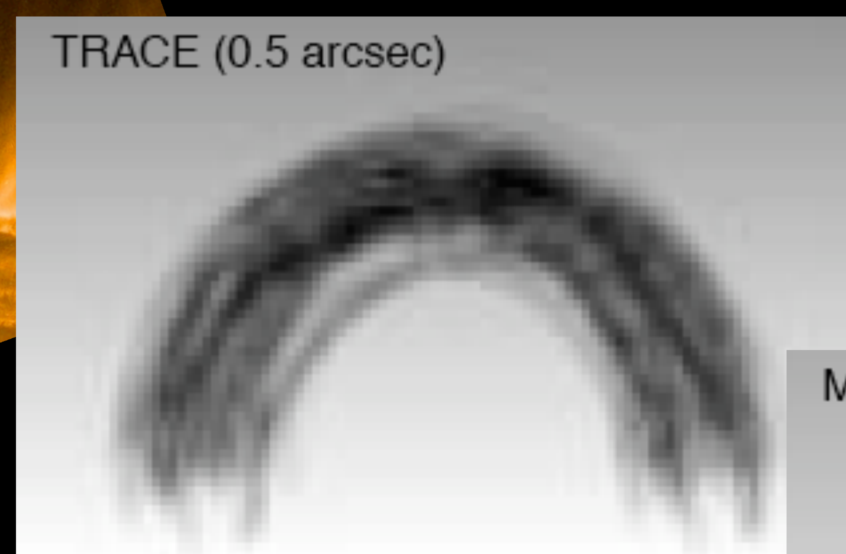
Structuring: are loops monolithic?

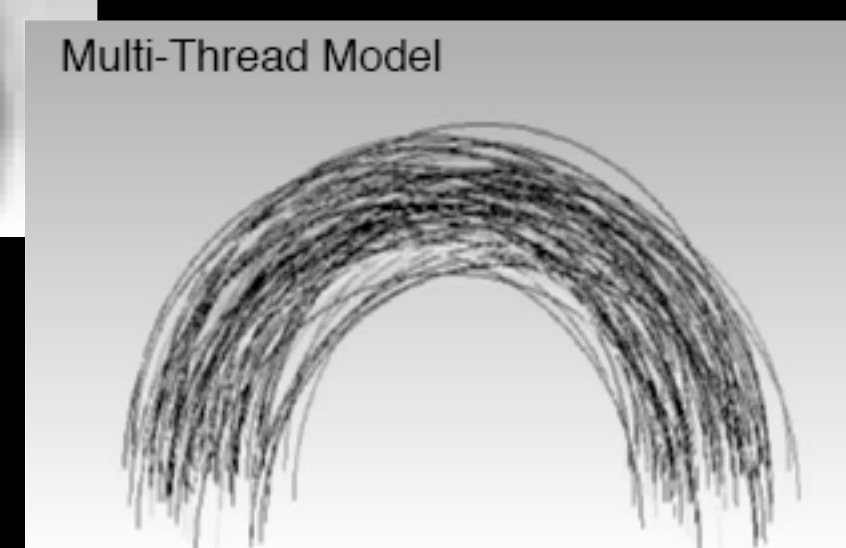
- Have we seen elementary strands?
- Fundamental building blocks:
  - homogeneous density and temperature across loop's axis
  - homogeneous density and temperature across strand's axis



Structuring: are loops multi-stranded?

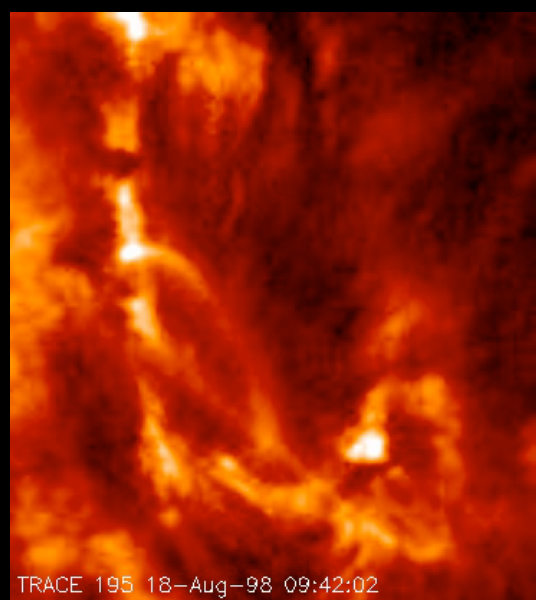


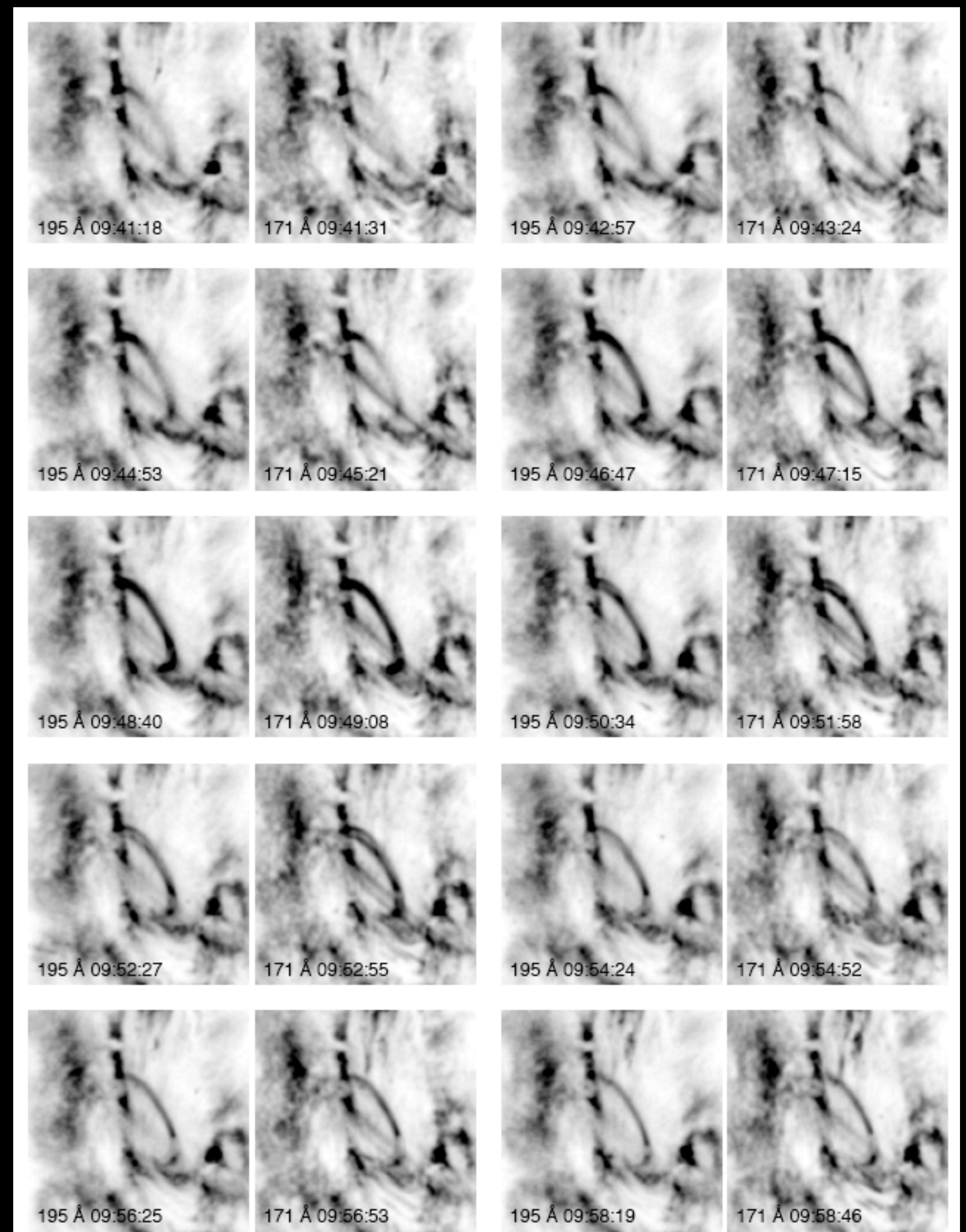




Aschwanden et al. (2000)

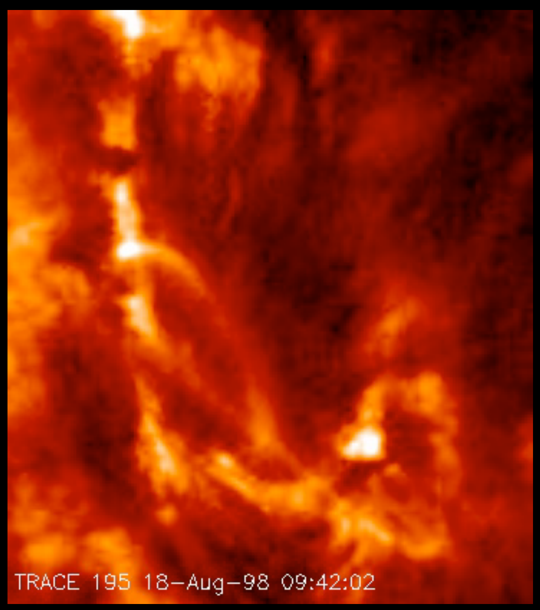
Structuring: are loops multi-stranded?

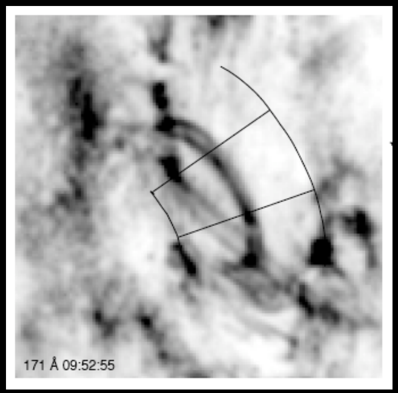


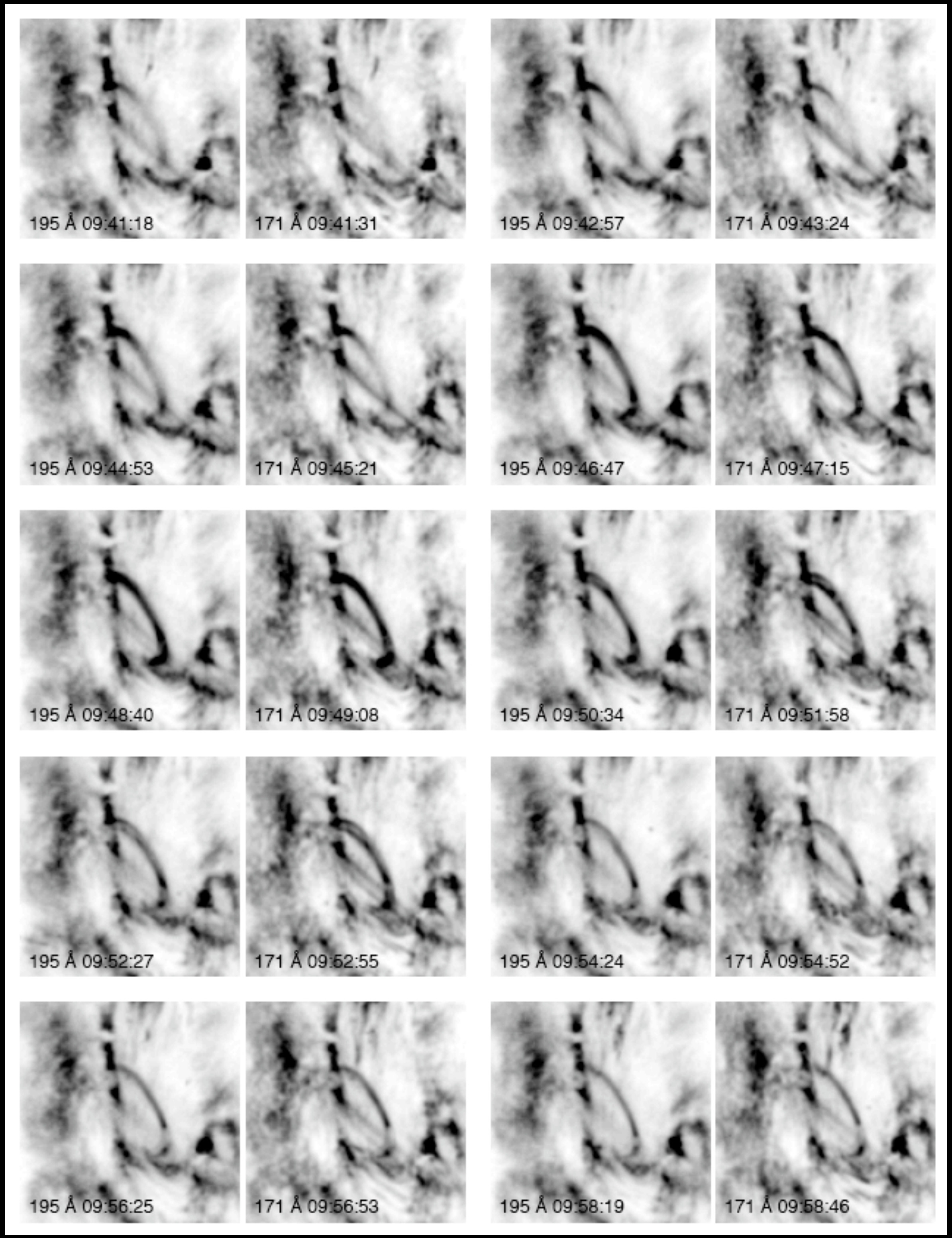


Warren et al. (2003)

Structuring: are loops multi-stranded?

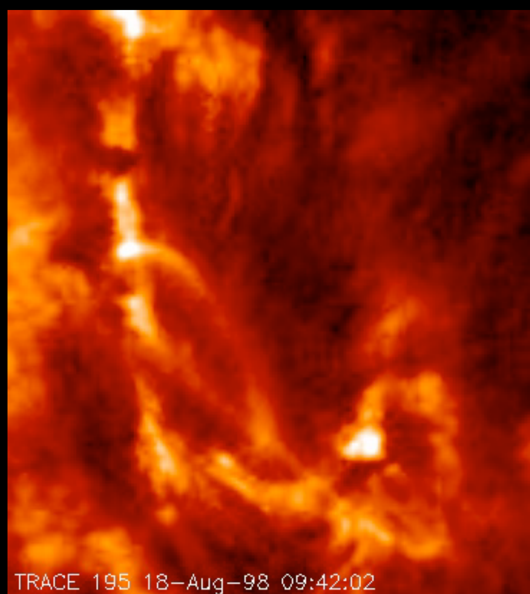


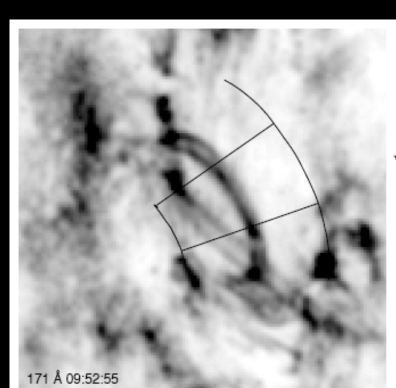


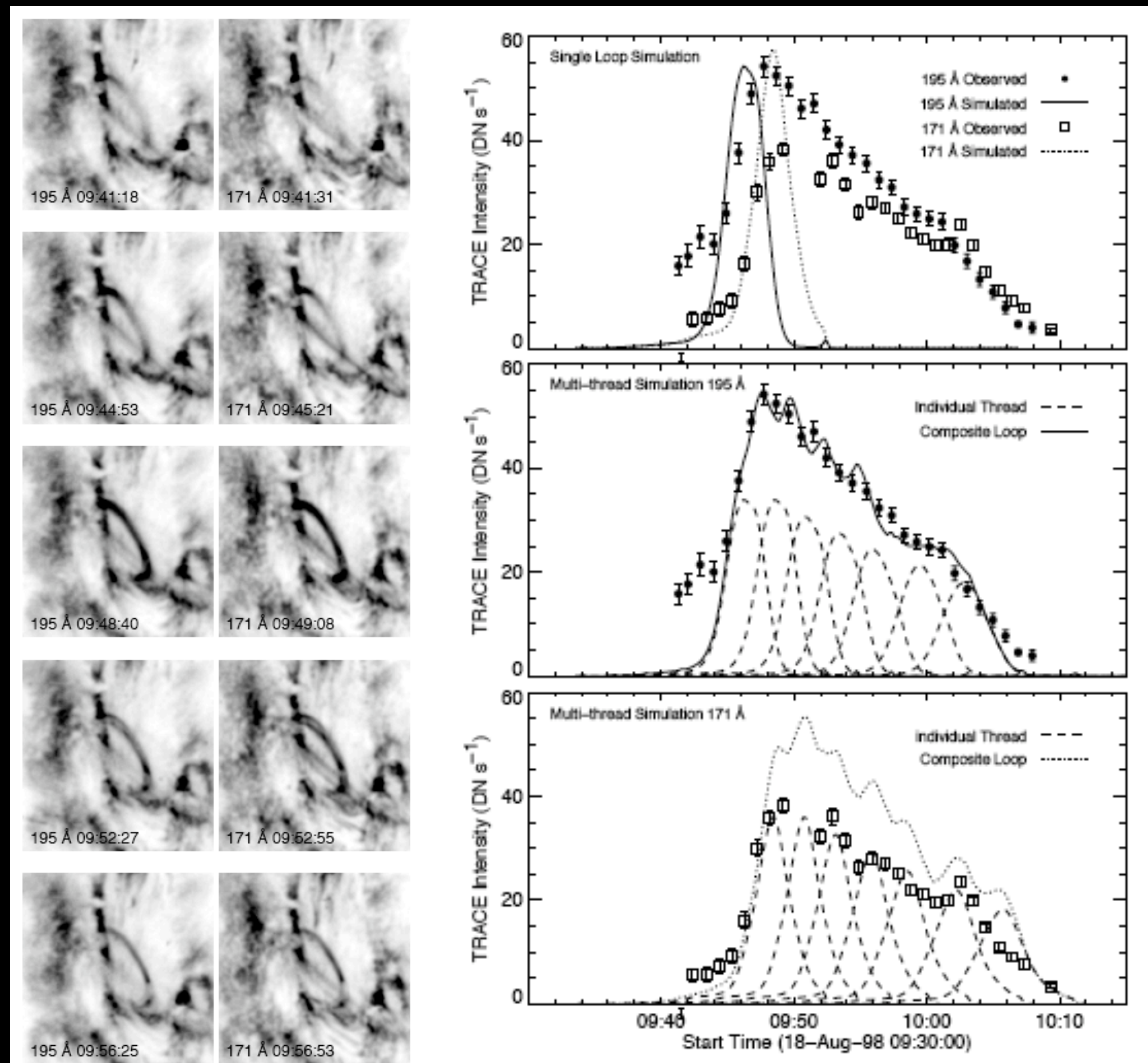


Warren et al. (2003)

Structuring: are loops multi-stranded?

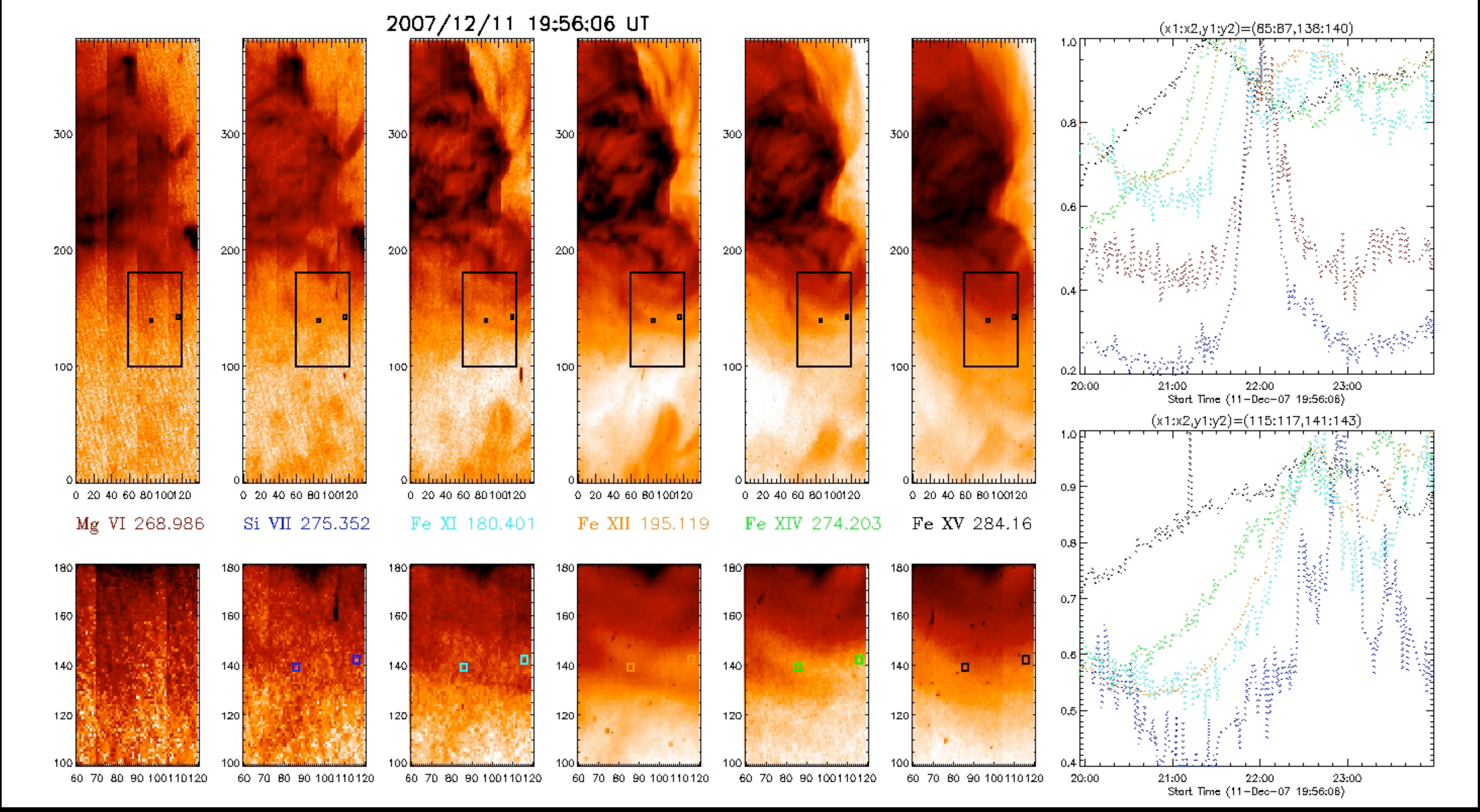




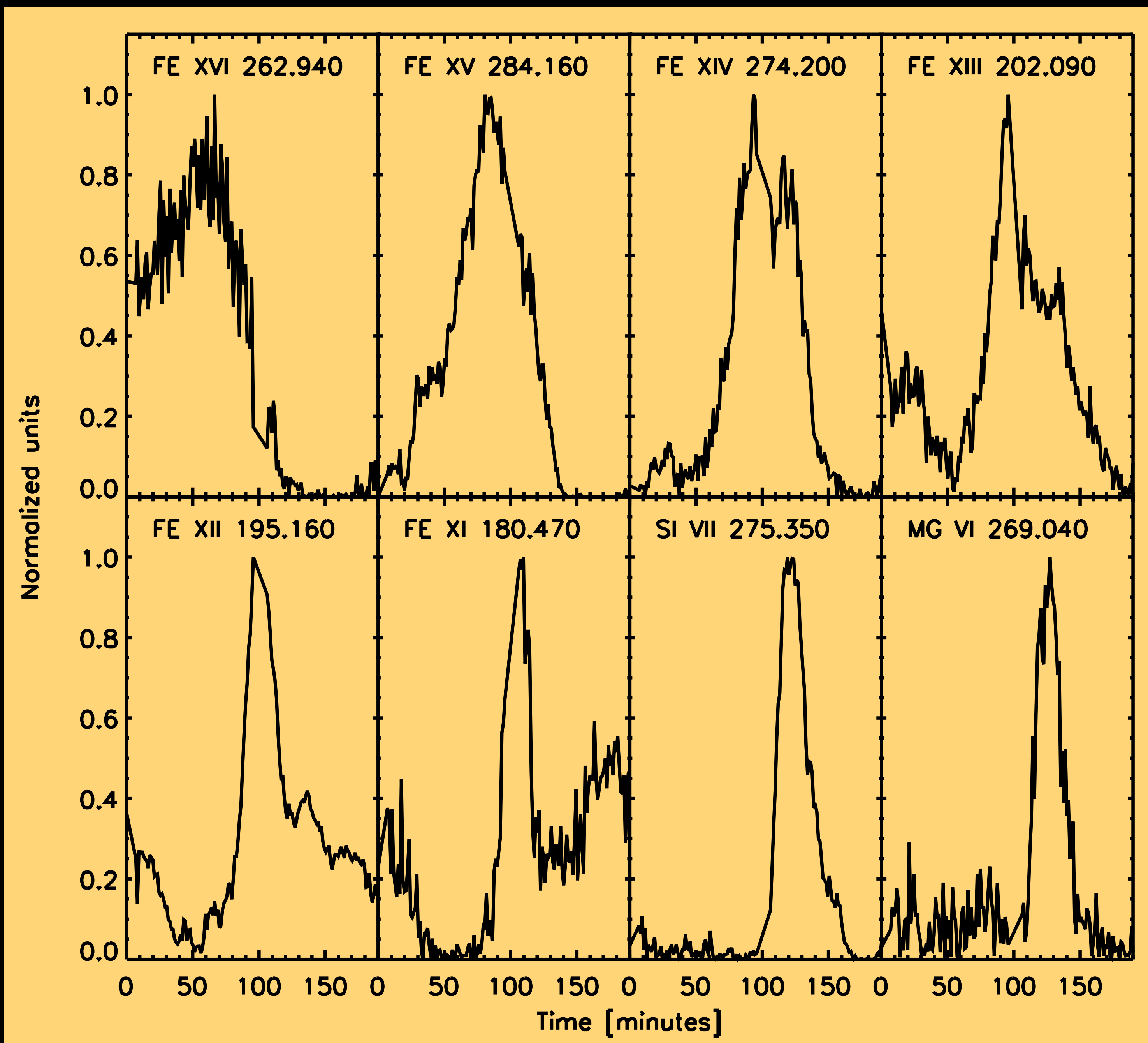


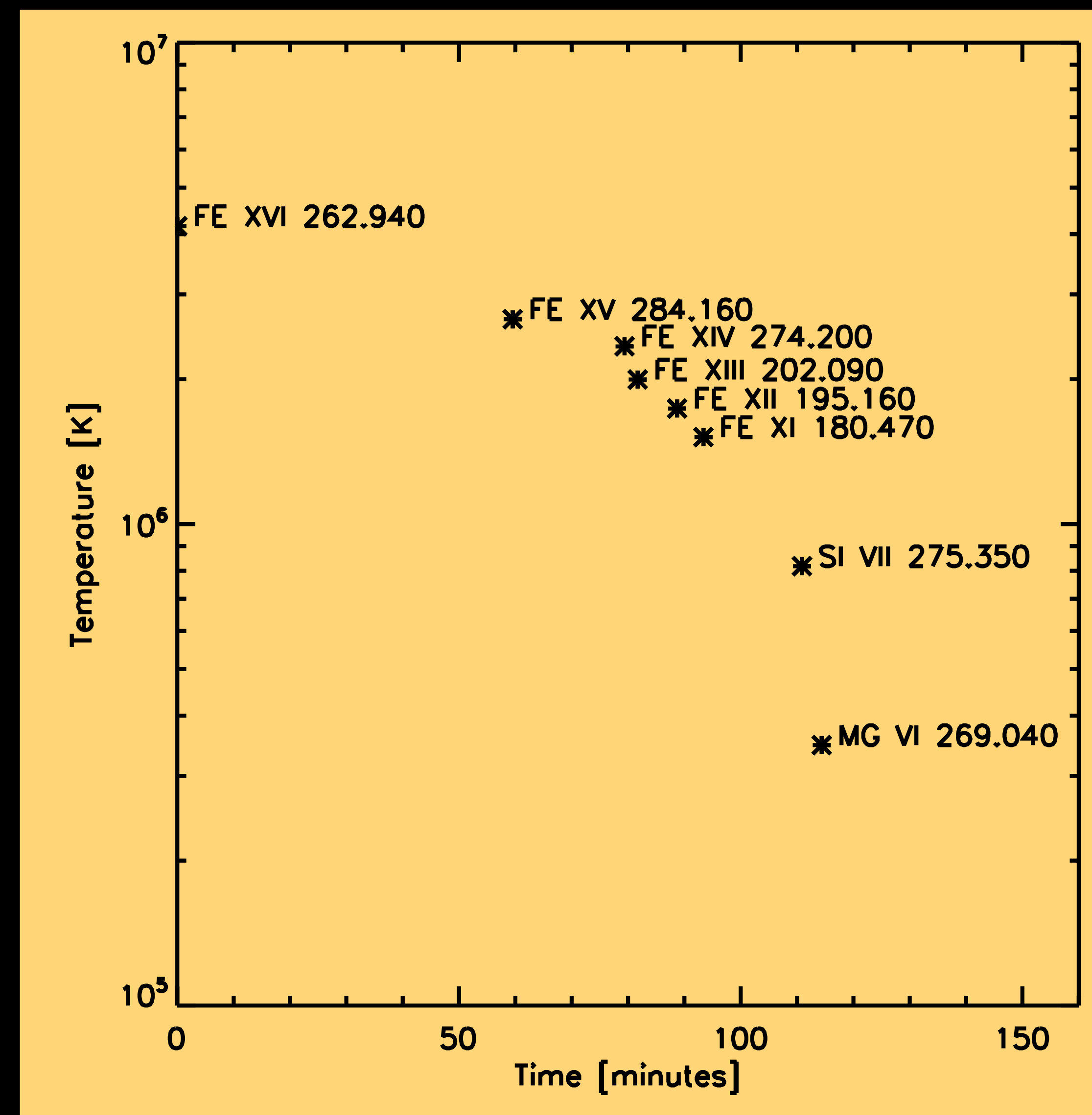
Warren et al. (2003)

Structuring: are loops multi-stranded?



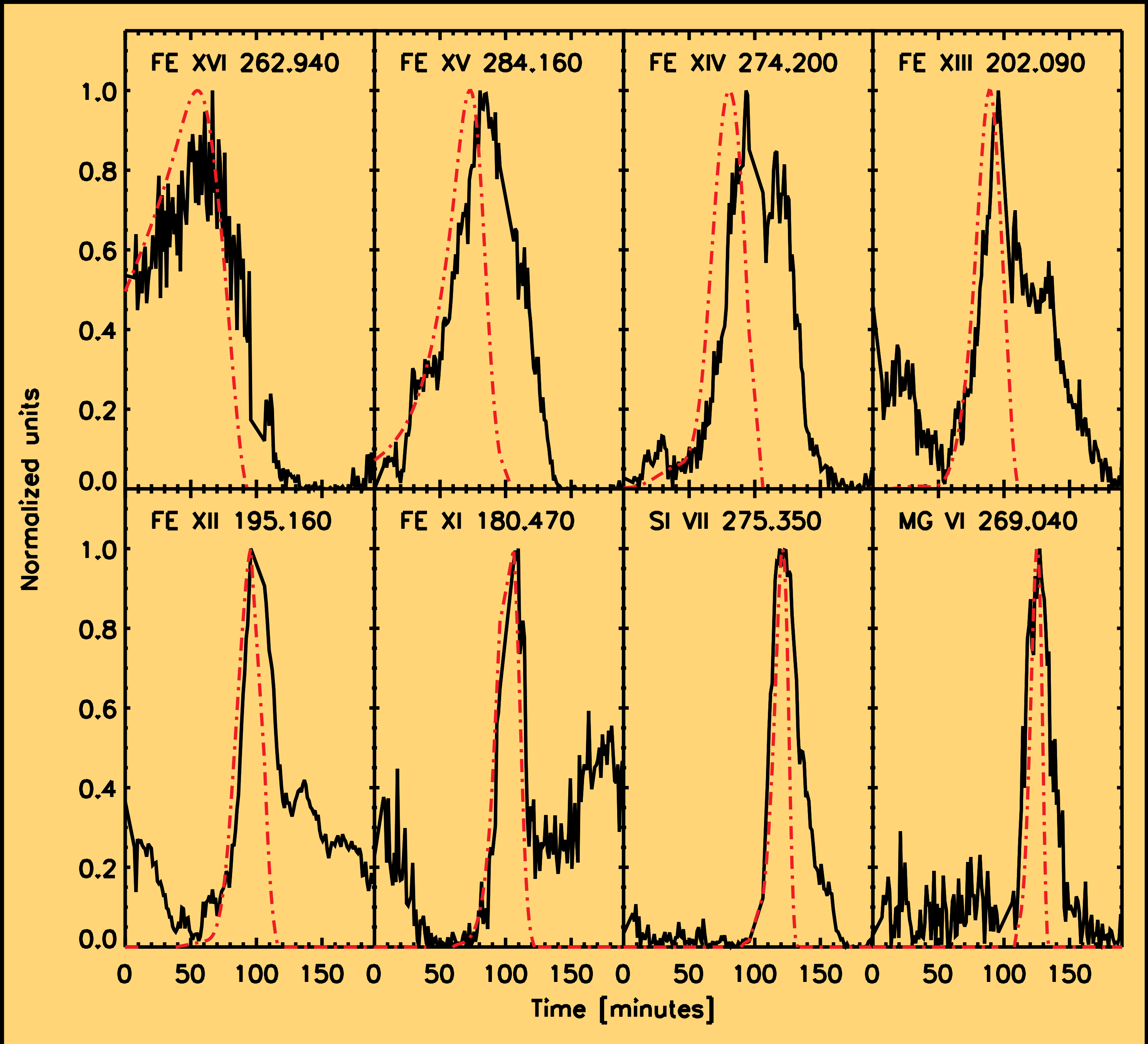
Structuring: are loops multi-stranded?

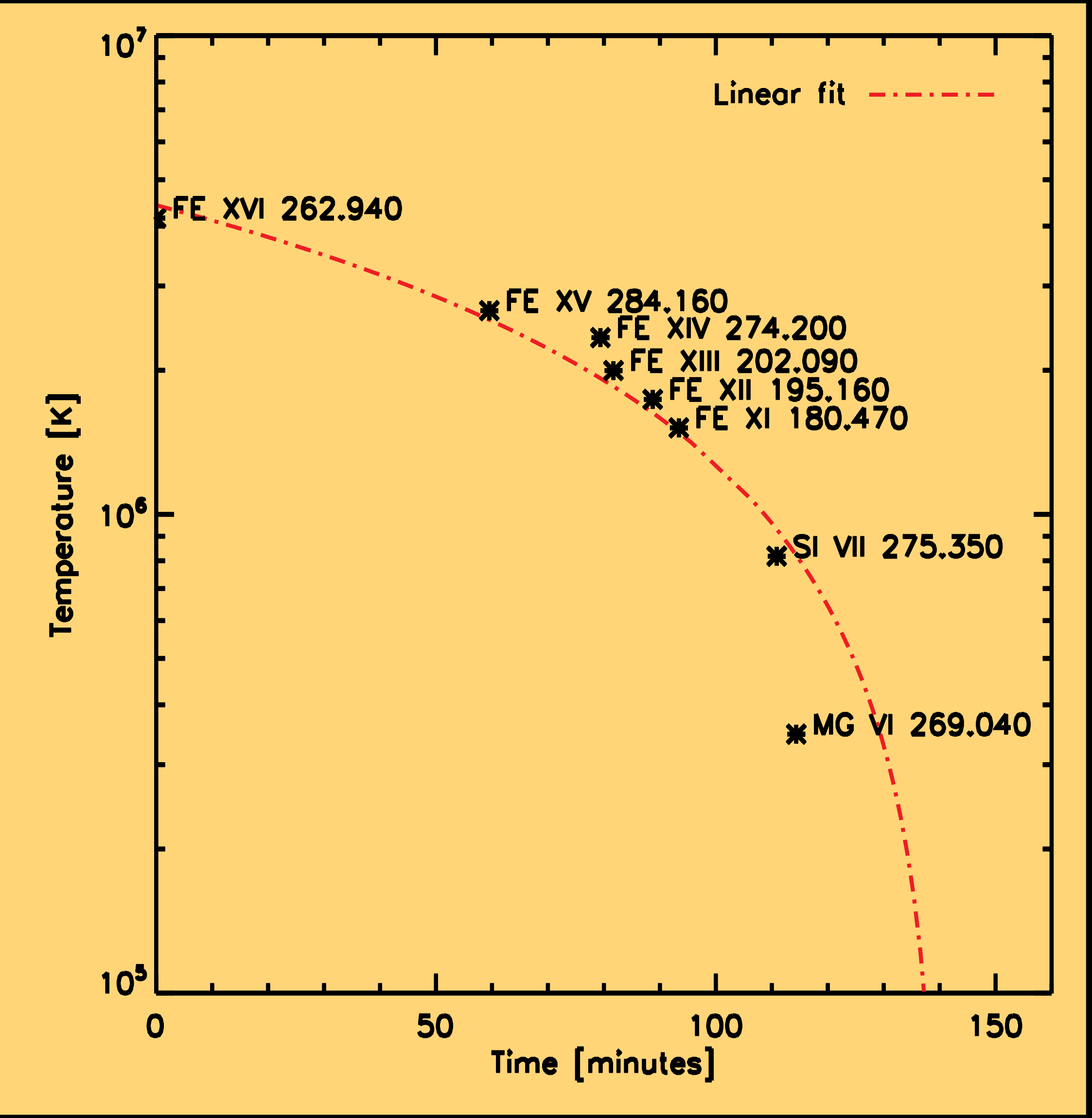




Ugarte-Urra et al. (2009)

Structuring: are loops multi-stranded?





Ugarte-Urra et al. (2009)

Structuring: are loops multi-stranded?

Filling factors

Emission Measure Analysis of Active Region Loops Observed with EIS

					Isothermal			Gaussian						
No.	Date	t_{start}	t_{end}	σ_w	EM_0	n_0	T_0	EM_0	n_0	T_0	σ_T	χ^2_I	χ^2_G	f (%)
1	07 Dec 10	03:36:43	03:37:25	1.18	26.52	9.25	6.16	26.63	9.29	6.19	5.45	1.71	0.79	9.1
2	07 Dec 11	13:11:02	13:11:43	1.42	27.18	9.77	6.11	27.28	9.86	6.15	5.44	2.13	0.88	2.0
3	07 Dec 11	12:57:50	13:01:18	1.35	26.90	9.56	6.13	27.06	9.66	6.16	5.55	2.86	1.44	3.3
4	07 Dec 12	06:31:29	06:36:21	1.36	26.72	9.58	6.06	26.79	9.57	6.07	5.44	2.14	1.49	2.6
5	07 Dec 12	06:29:24	06:30:47	0.97	27.66	9.61	6.07	27.90	9.84	6.01	5.70	5.49	1.52	19.6
6	07 Dec 12	14:52:33	14:53:56	1.17	27.25	9.28	6.07	27.34	9.43	6.08	5.54	4.68	1.49	24.2
7	07 Dec 12	15:01:34	15:07:08	1.54	26.62	9.20	6.08	26.64	9.24	6.08	5.18	1.42	1.31	6.8
8	07 Dec 13	15:35:17	15:36:41	1.19	27.47	9.71	6.20	27.49	9.65	6.20	5.28	1.69	1.58	12.0
9	07 Dec 13	13:45:32	13:46:55	0.97	26.68	9.34	6.16	26.83	9.32	6.12	5.45	3.91	1.65	18.4
10	07 Dec 15	03:40:08	03:41:31	1.03	26.44	9.29	6.12	26.45	9.31	6.12	4.99	0.79	0.85	7.0
11	07 Dec 15	01:44:07	01:44:49	1.20	26.64	9.50	6.13	26.80	9.62	6.20	5.62	3.73	3.59	2.8
12	07 Dec 15	21:17:07	21:23:22	2.30	26.72	9.27	6.17	26.77	9.27	6.16	5.31	2.69	1.48	3.5
13	07 Dec 15	19:50:59	19:52:22	1.69	26.17	9.39	6.16	26.35	9.41	6.16	5.55	1.46	0.85	1.3
14	07 Dec 18	02:15:51	02:17:14	1.07	27.53	10.98	6.19	27.55	10.50	6.18	5.44	2.98	1.52	0.3
15	07 Dec 18	01:11:14	01:14:43	1.57	26.51	9.15	6.19	26.68	9.13	6.16	5.55	3.16	1.66	11.5
16	07 Dec 18	01:39:43	01:44:35	2.73	27.05	9.43	6.15	27.14	9.50	6.17	5.42	1.85	1.12	2.1
17	07 Dec 18	19:51:37	19:55:05	1.16	26.75	9.86	6.20	26.84	9.76	6.17	5.52	1.86	1.34	1.7
18	07 Dec 10	03:27:00	03:32:33	1.28	26.89	9.39	6.22	26.92	9.34	6.21	5.36	1.36	1.18	11.6
19	07 Dec 11	13:13:48	13:15:53	0.90	26.60	9.99	6.19	26.69	10.02	6.20	5.40	1.00	0.42	0.6
20	07 Dec 13	16:08:38	16:10:01	1.04	26.49	9.47	6.10	26.58	9.51	6.09	5.33	2.13	1.20	3.7

Warren et al. (2008)

Structuring: are loops multi-stranded?

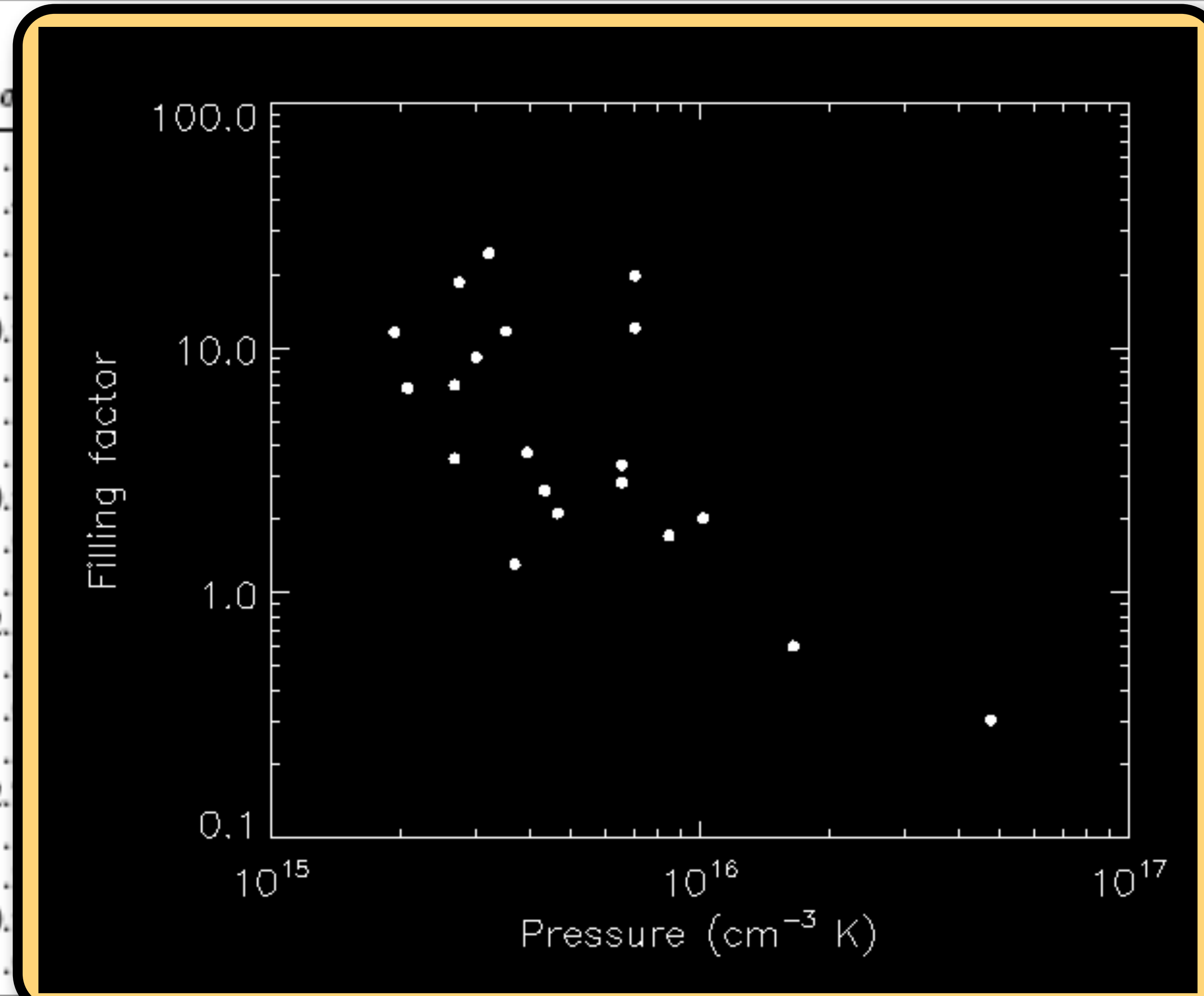
Filling factors

Emission Measure Analysis of Active Region Loops Observed with EIS

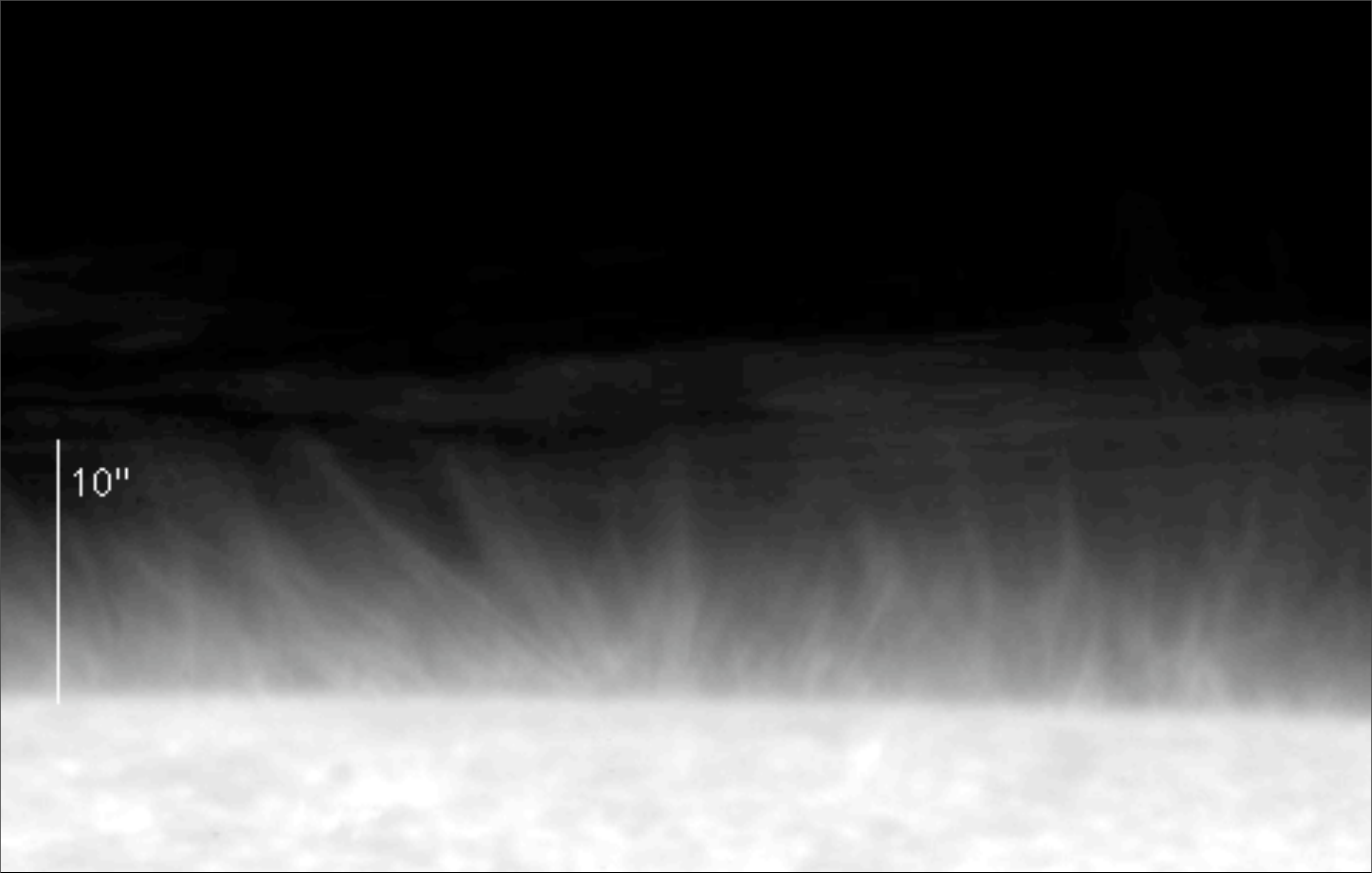
No.	Date	t_{start}	t_{end}	d	f (%)
				1.	9.1
				1.	2.0
				1.	3.3
				1.	2.6
				0.	19.6
				1.	24.2
				1.	6.8
				1.	12.0
				0.	18.4
				1.	7.0
				1.	2.8
				2.	3.5
				1.	1.3
				1.	0.3
				1.	11.5
16	07 Dec 18	01:39:43	01:44:35	2.	2.1
17	07 Dec 18	19:51:37	19:55:05	1.	1.7
18	07 Dec 10	03:27:00	03:32:33	1.	11.6
19	07 Dec 11	13:13:48	13:15:53	0.	0.6
20	07 Dec 13	16:08:38	16:10:01	1.	3.7

$$EM = f n_e^2 V$$

$$f = \frac{EM}{n_e^2 V} \approx 10\%$$



Warren et al. (2008)


10''

Structuring: are loops multi-stranded?

Structuring: are loops multi-stranded?

Let's suppose some of them are!!

Structuring: are loops multi-stranded?

Let's suppose some of them are!!

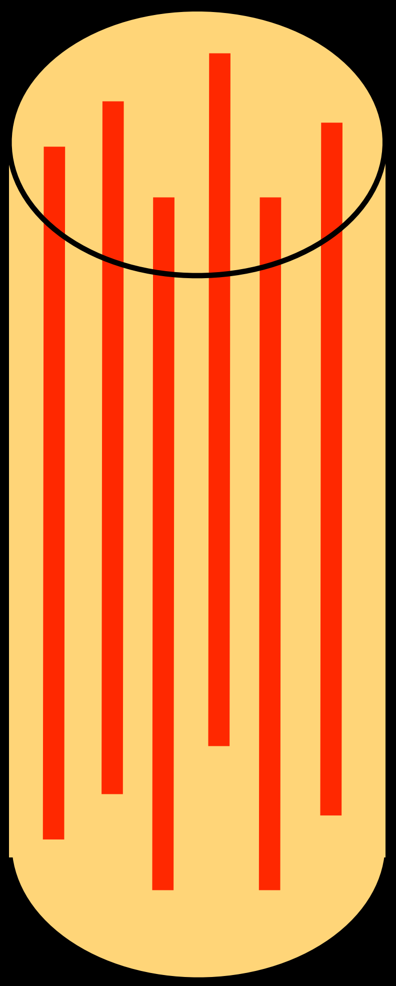
Do the strands evolve coherently or not?

Structuring: are loops multi-stranded?

Let's suppose some of them are!!

Do the strands evolve coherently or not?

Narrow DEM
Homogeneous

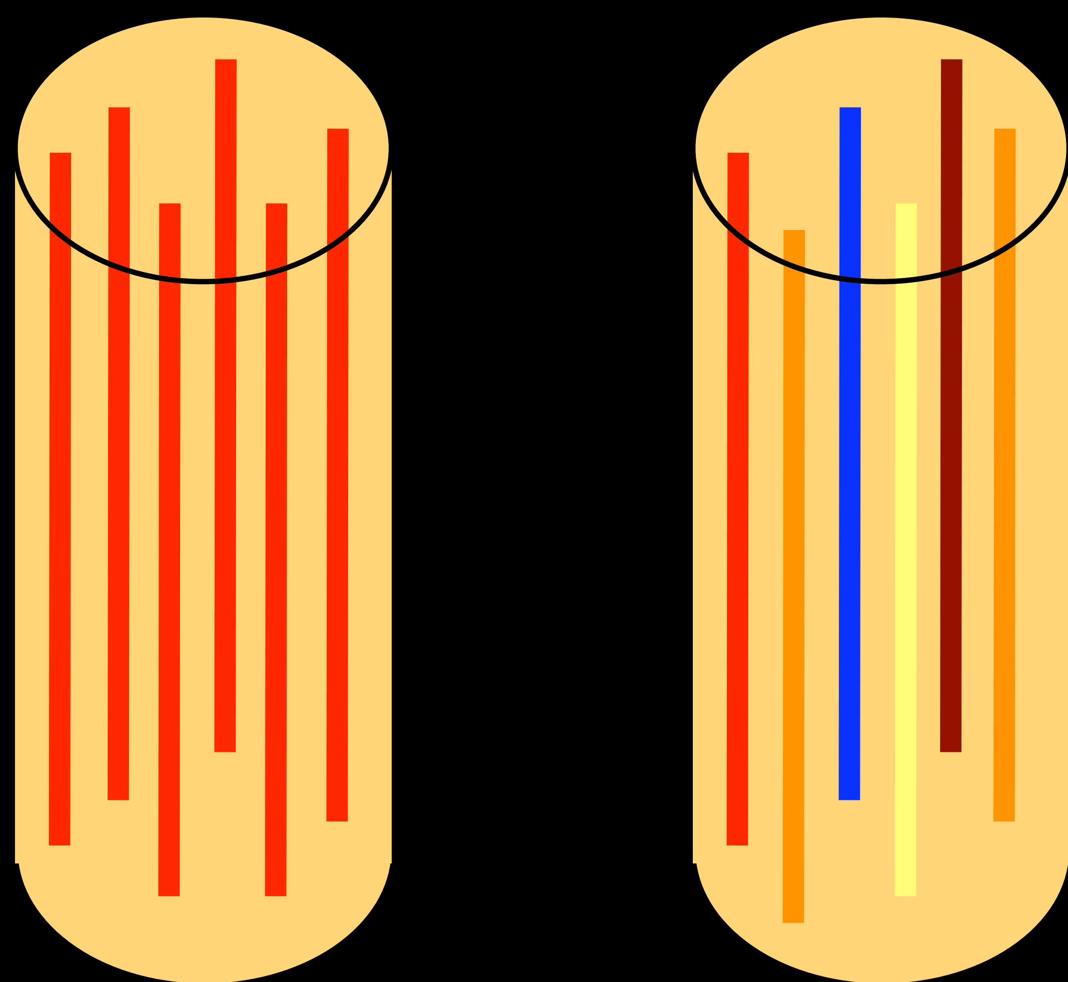


Structuring: are loops multi-stranded?

Let's suppose some of them are!!

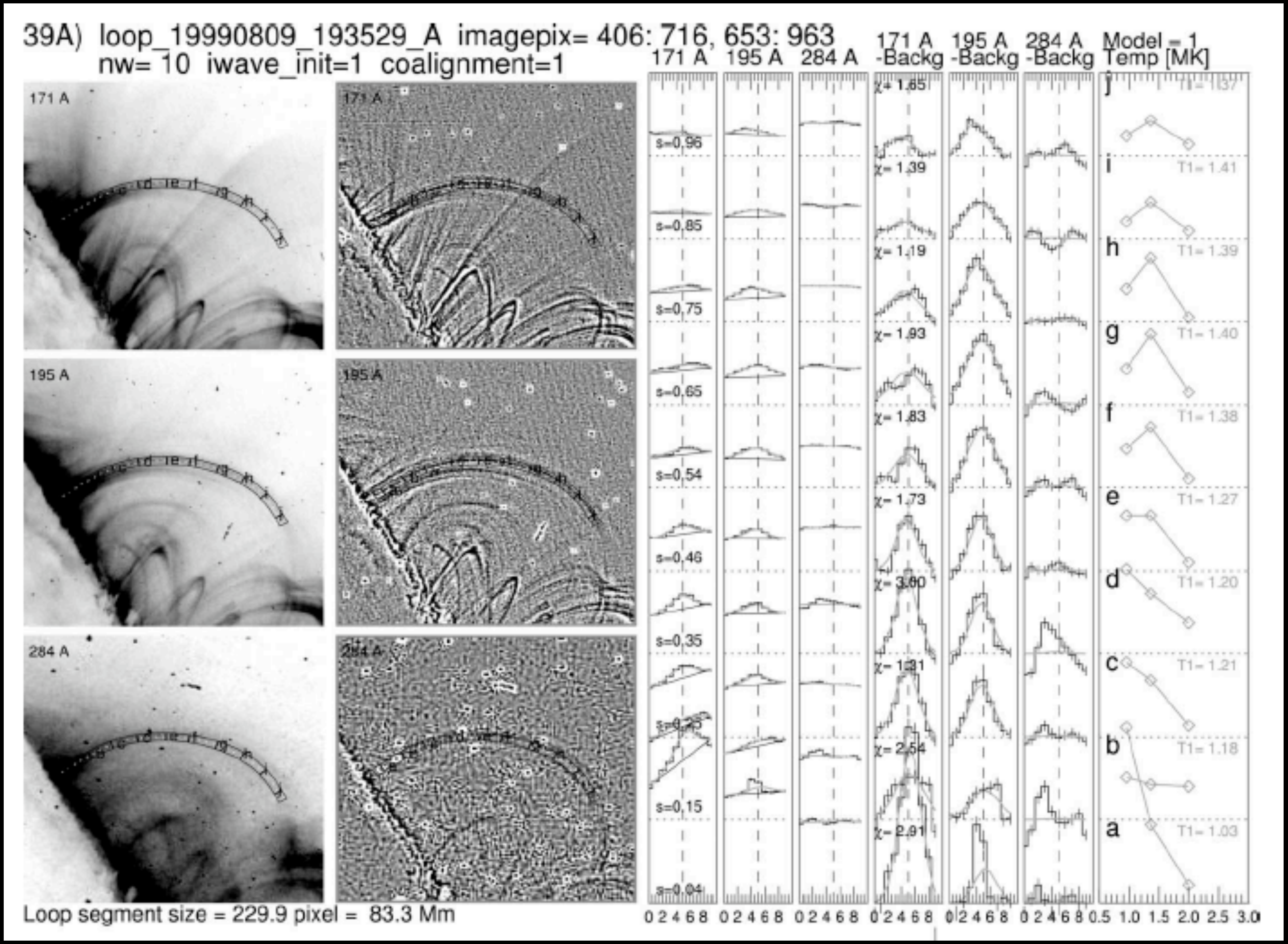
Do the strands evolve coherently or not?

Narrow DEM
Homogeneous

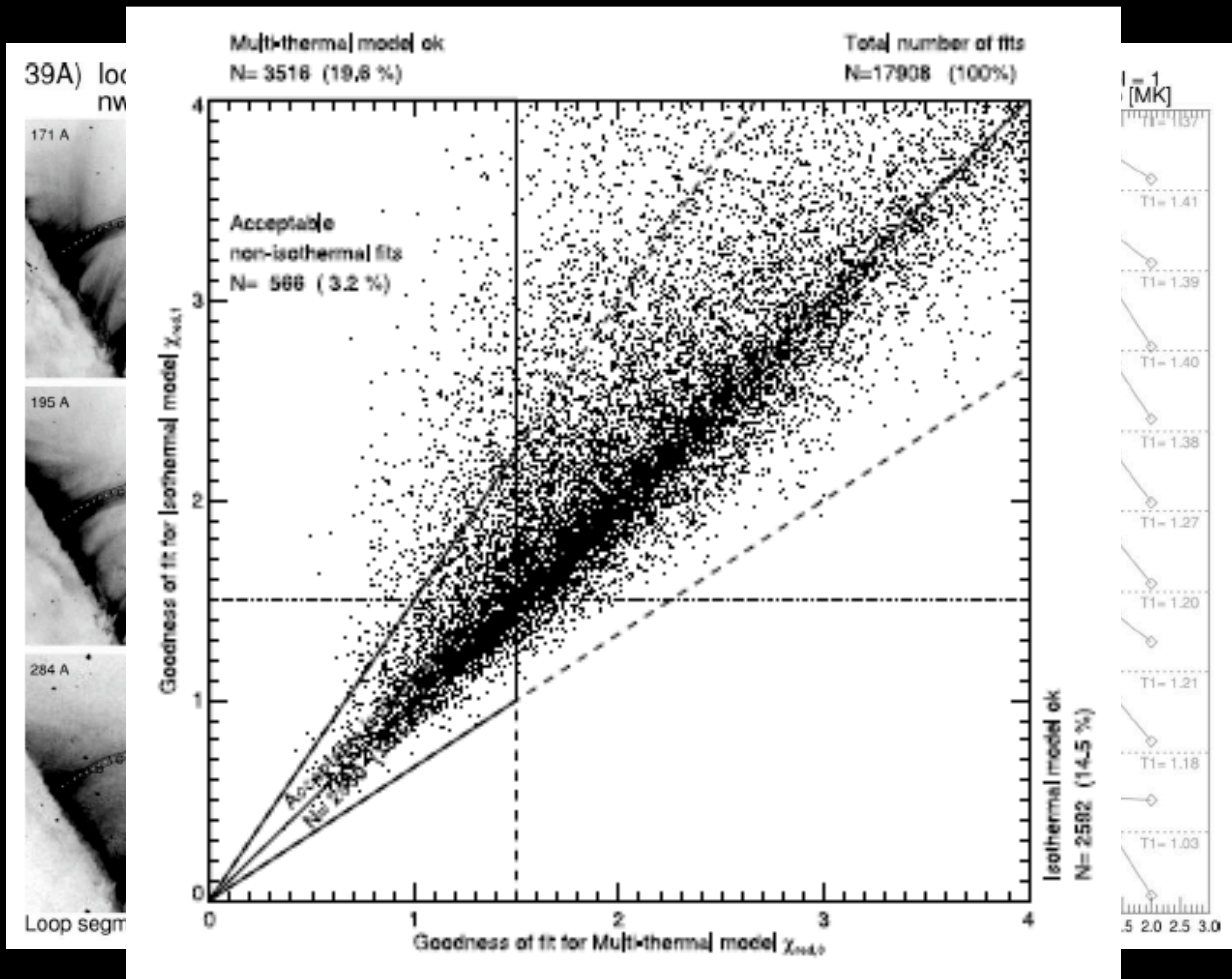


Broad DEM
Inhomogeneous

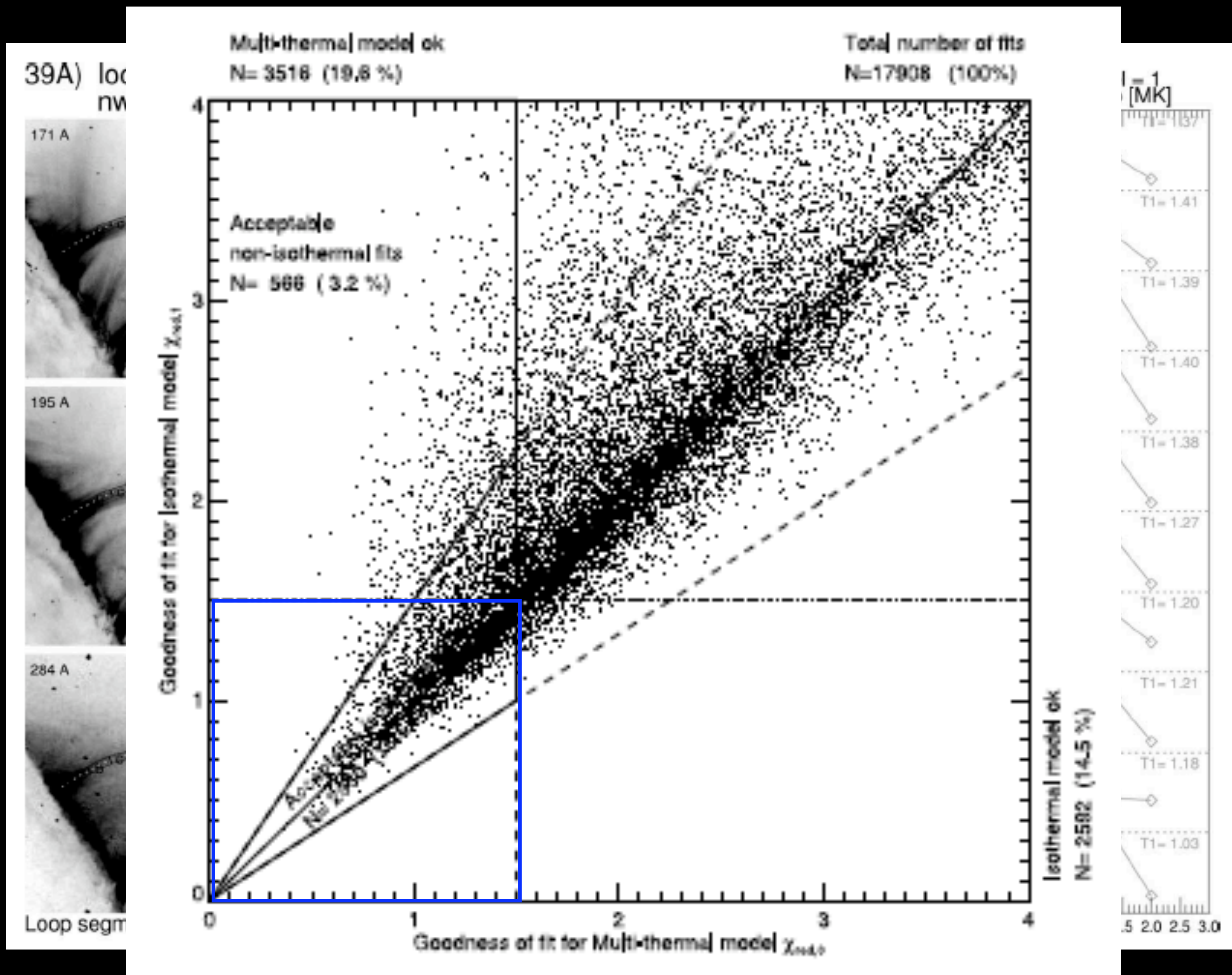
Filter Analysis of 234 Loops (Aschwanden &



Filter Analysis of 234 Loops (Aschwanden &



Filter Analysis of 234 Loops (Aschwanden &



Spectroscopic analysis of 20 Loops (Warren et

#	Date	t_{start}	t_{end}	σ_w	Isothermal EM_0	Isothermal n_0	Isothermal T_0	Gaussian EM_0	Gaussian n_0	Gaussian T_0	Gaussian σ_T	χ_I^2	χ_G^2	$f(\%)$
1	10-Dec-07	03:36:43	03:37:25	1.18	26.52	9.25	6.16	26.63	9.29	6.19	5.45	1.71	0.79	16.8
2	11-Dec-07	13:11:02	13:11:43	1.42	27.18	9.77	6.11	27.28	9.86	6.15	5.44	2.13	0.88	3.7
3	11-Dec-07	12:57:50	13:01:18	1.35	26.90	9.56	6.13	27.06	9.66	6.16	5.55	2.86	1.44	6.1
4	12-Dec-07	06:31:29	06:36:21	1.36	26.72	9.58	6.06	26.79	9.57	6.07	5.44	2.14	1.49	4.8
5	12-Dec-07	06:29:24	06:30:47	0.97	27.66	9.61	6.07	27.90	9.84	6.01	5.70	5.49	1.52	36.2
6	12-Dec-07	14:52:33	14:53:56	1.17	27.25	9.28	6.07	27.34	9.43	6.08	5.54	4.68	1.49	44.7
7	12-Dec-07	15:01:34	15:07:08	1.54	26.62	9.20	6.08	26.64	9.24	6.08	5.18	1.42	1.31	12.5
8	13-Dec-07	15:35:17	15:36:41	1.19	27.47	9.71	6.20	27.49	9.65	6.20	5.28	1.69	1.58	22.0
9	13-Dec-07	13:45:32	13:46:55	0.97	26.68	9.34	6.16	26.83	9.32	6.12	5.45	3.91	1.65	34.0
10	15-Dec-07	03:40:08	03:41:31	1.03	26.44	9.29	6.12	26.45	9.31	6.12	4.99	0.79	0.85	12.9
11	15-Dec-07	01:44:07	01:44:49	1.20	26.64	9.50	6.13	26.80	9.62	6.20	5.62	3.73	3.59	5.1
12	15-Dec-07	21:17:07	21:23:22	2.30	26.72	9.27	6.17	26.77	9.27	6.16	5.31	2.69	1.48	6.5
13	15-Dec-07	19:50:59	19:52:22	1.69	26.17	9.39	6.16	26.35	9.41	6.16	5.55	1.46	0.85	2.4
14	18-Dec-07	02:15:51	02:17:14	1.07	27.53	10.98	6.19	27.55	10.50	6.18	5.44	2.98	1.52	0.6
15	18-Dec-07	01:11:14	01:14:43	1.57	26.51	9.15	6.19	26.68	9.13	6.16	5.55	3.16	1.66	21.3
16	18-Dec-07	01:39:43	01:44:35	2.73	27.05	9.43	6.15	27.14	9.50	6.17	5.42	1.85	1.12	3.8
17	18-Dec-07	19:51:37	19:55:05	1.16	26.75	9.86	6.20	26.84	9.76	6.17	5.52	1.86	1.34	3.1
18	10-Dec-07	03:27:00	03:32:33	1.28	26.89	9.39	6.22	26.92	9.34	6.21	5.36	1.36	1.18	21.4
19	11-Dec-07	13:13:48	13:15:53	0.90	26.60	9.99	6.19	26.69	10.02	6.20	5.40	1.00	0.42	1.1
20	13-Dec-07	16:08:38	16:10:01	1.04	26.49	9.47	6.10	26.58	9.51	6.09	5.33	2.13	1.20	6.8

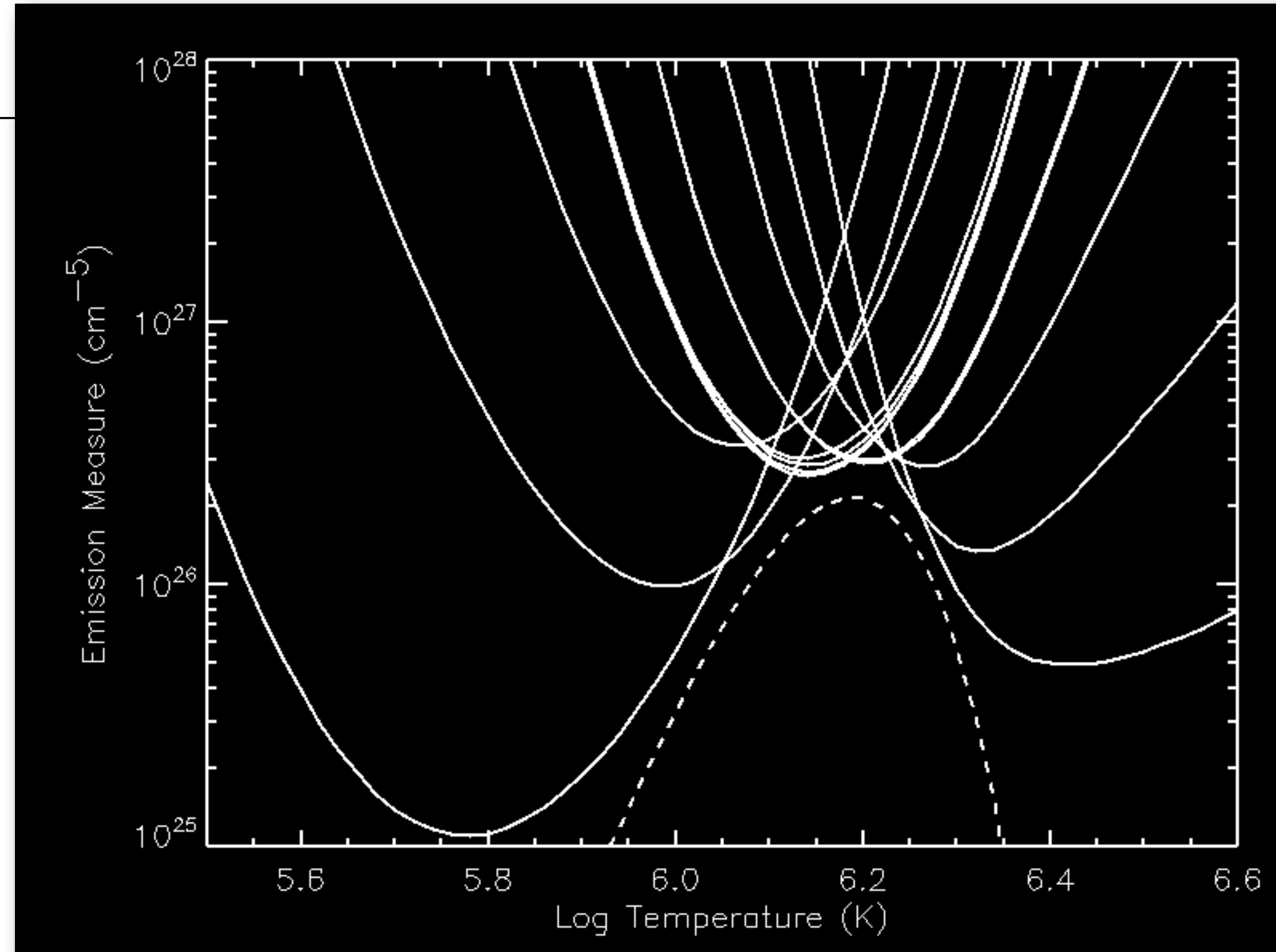
Spectroscopic analysis of 20 Loops (Warren et

$$\langle \sigma_T \rangle = 5.4$$

$$\chi^2_{isothermal} = 2.5$$

$$\chi^2_{Gaussian} = 1.3$$

$$\langle n_0 \rangle = 9.6$$



#	χ^2_G	$f(\%)$
1	0.79	16.8
2	0.88	3.7
3	1.44	6.1
4	1.49	4.8
5	1.52	36.2
6	1.49	44.7
7	1.31	12.5
8	1.58	22.0
9	1.65	34.0
10	0.85	12.9
11	3.59	5.1
12	1.48	6.5
13	0.85	2.4
14	1.52	0.6
15	1.66	21.3
16	1.12	3.8
17	1.34	3.1
18	1.18	21.4
19	0.42	1.1
20	1.20	6.8

Spectroscopic analysis of 20 Loops (Warren et

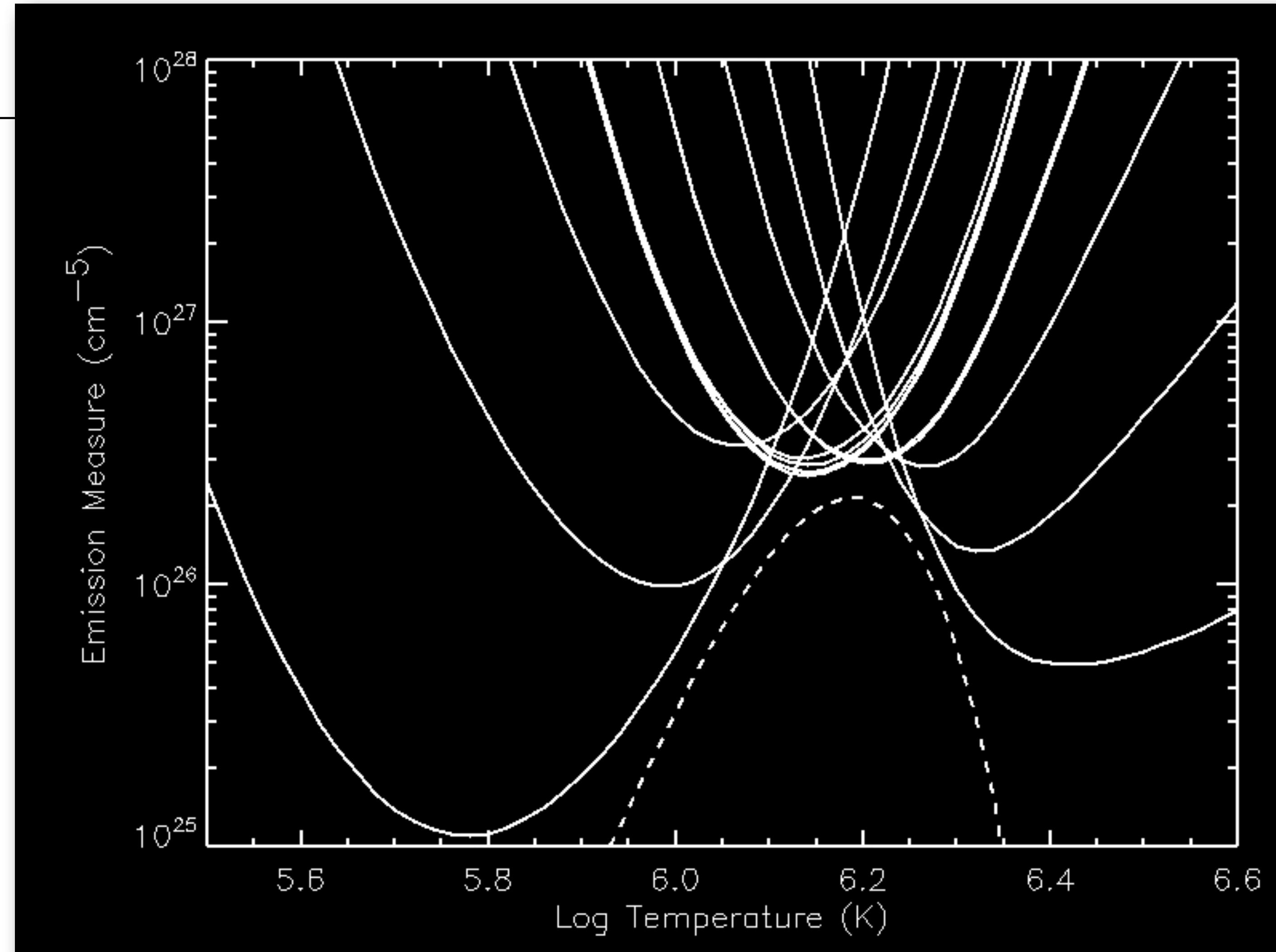
$$\langle \sigma_T \rangle = 5.4$$

$$\chi^2_{isothermal} = 2.5$$

$$\chi^2_{Gaussian} = 1.3$$

$$\langle n_0 \rangle = 9.6$$

#	χ^2_G	$f(\%)$
1	0.79	16.8
2	0.88	3.7
3	1.44	6.1
4	1.49	4.8
5	1.52	36.2
6	1.49	44.7
7	1.31	12.5
8	1.58	22.0
9	1.65	34.0
10	0.85	12.9
11	3.59	5.1
12	1.48	6.5
13	0.85	2.4
14	1.52	0.6
15	1.66	21.3
16	1.12	3.8
17	1.34	3.1
18	1.18	21.4
19	0.42	1.1
20	1.20	6.8



‘Narrow’ DEM (with exceptions)

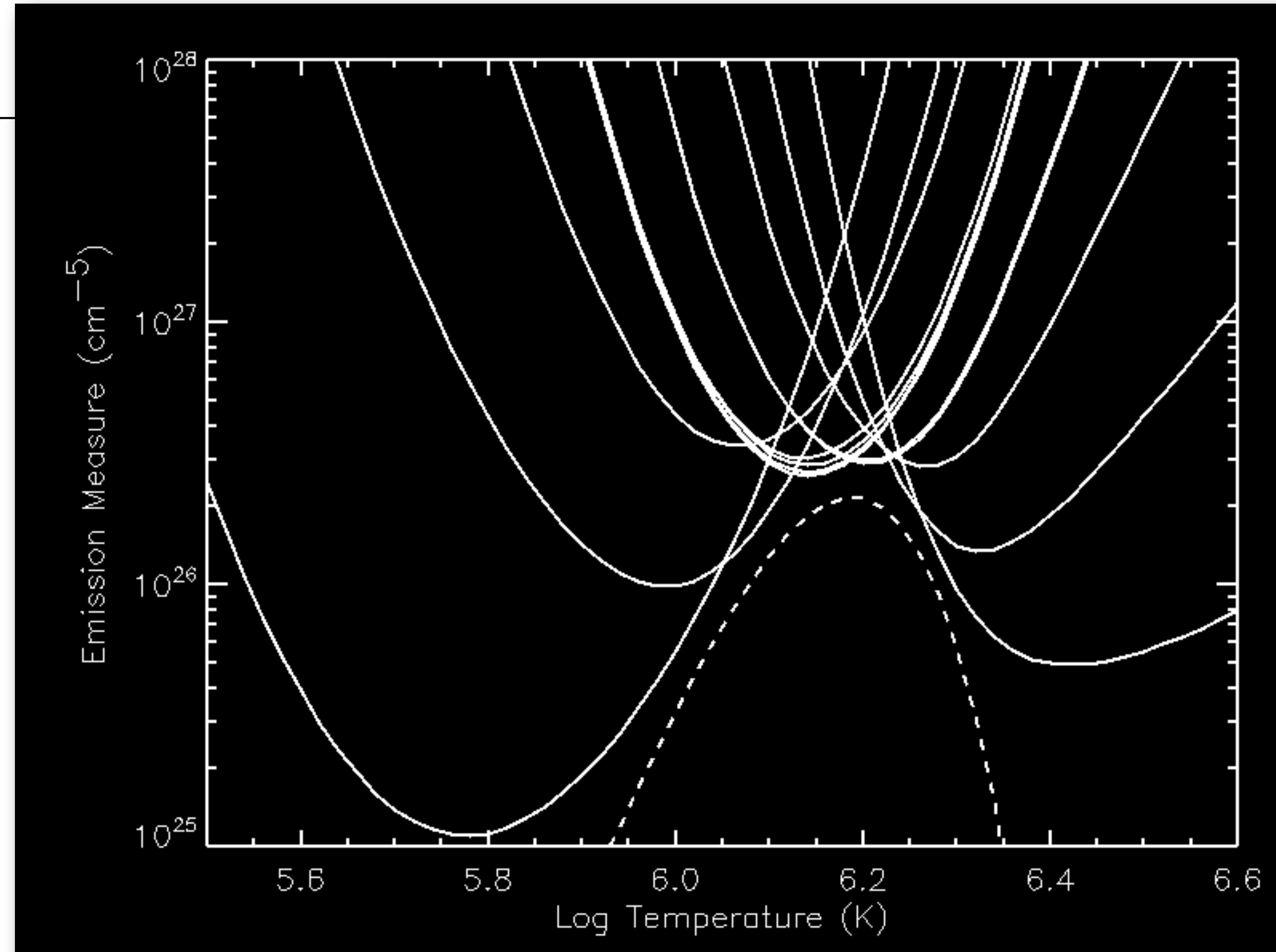
Spectroscopic analysis of 20 Loops (Warren et

$$\langle \sigma_T \rangle = 5.4$$

$$\chi^2_{isothermal} = 2.5$$
$$\chi^2_{Gaussian} = 1.3$$

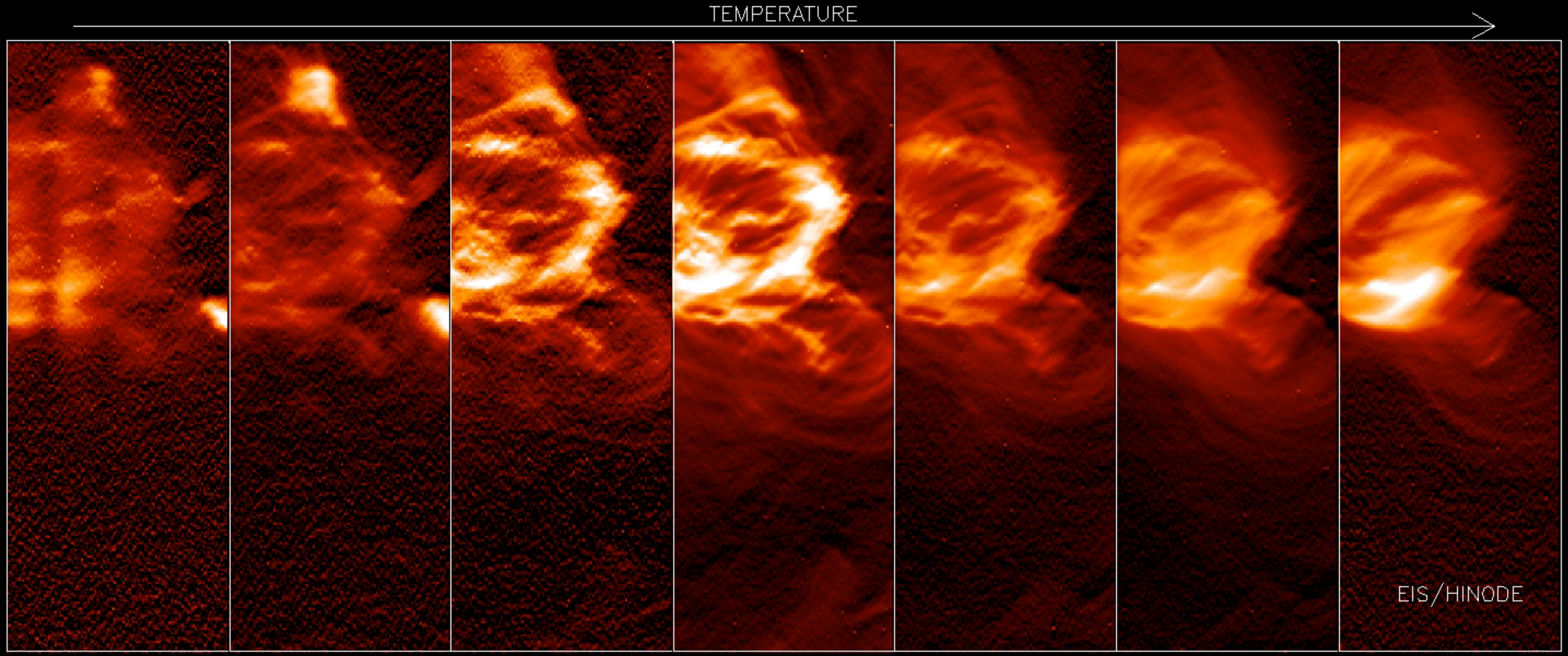
$$\langle n_0 \rangle = 9.6$$

#					χ^2_G	$f(\%)$
1					0.79	16.8
2					0.88	3.7
3					1.44	6.1
4					1.49	4.8
5					1.52	36.2
6					1.49	44.7
7					1.31	12.5
8					1.58	22.0
9					1.65	34.0
10					0.85	12.9
11					3.59	5.1
12					1.48	6.5
13					0.85	2.4
14					1.52	0.6
15					1.66	21.3
16					1.12	3.8
17					1.34	3.1
18					1.18	21.4
19					0.42	1.1
20	13-Dec-07	16:08:38	16:10:01	1.04	1.20	6.8



‘Narrow’ DEM (with exceptions)

Broad DEMs in previous studies (Schmelz & co)


TEMPERATURE
EIS/HINODE

Implications for heating

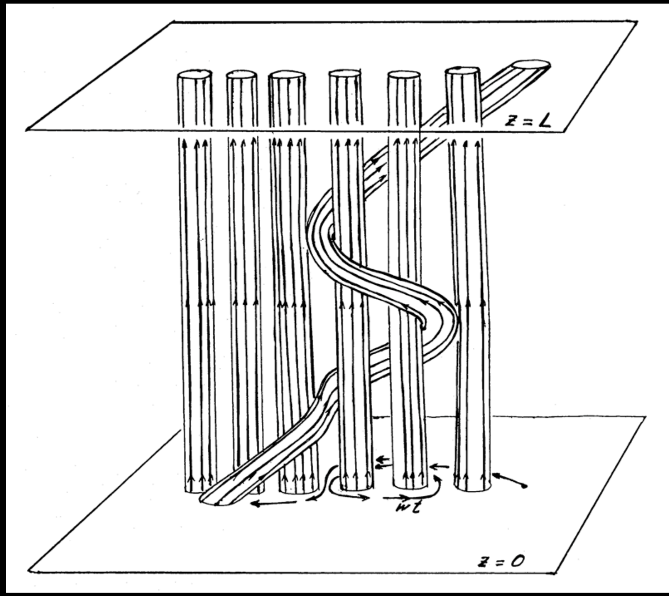
Can we reconcile these observations with coronal heating?

Implications for heating

Implications for heating

Nanoflares

Convection ⇒ Braiding ⇒ Stress ⇒ Reconnection (nanoflare)



Parker (1983)

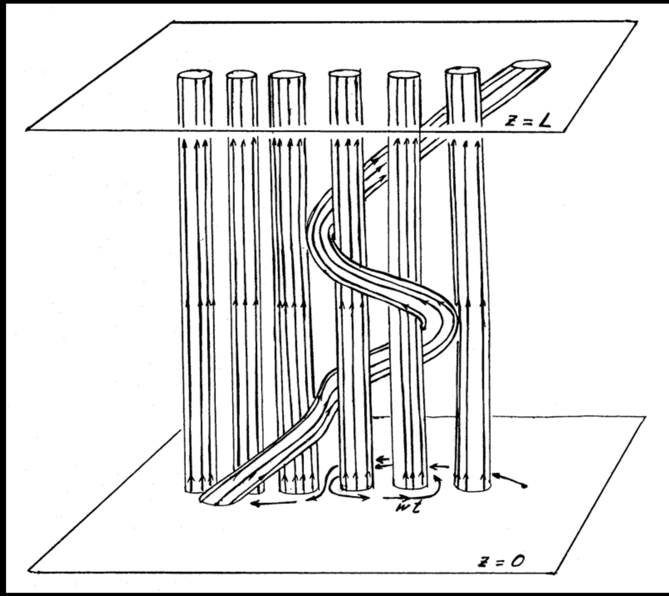
Parker, Cargill, Klimchuk, Patsourakos, Reale, Walsh...

Implications for heating

Nanoflares

Convection ⇒ Braiding ⇒ Stress ⇒ Reconnection (nanoflare)

Pros:



Parker (1983)

Cons:

Parker, Cargill, Klimchuk, Patsourakos, Reale, Walsh...

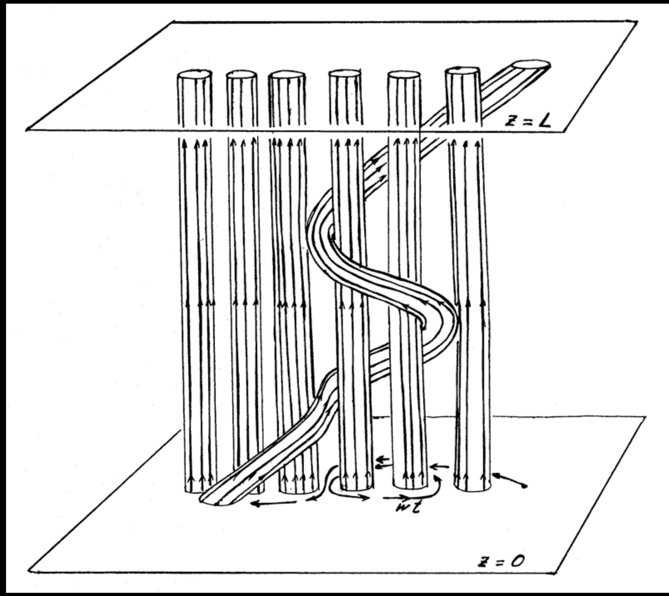
Implications for heating

Nanoflares

Convection ⇒ Braiding ⇒ Stress ⇒ Reconnection (nanoflare)

Pros:

Impulsive nature



Parker (1983)

Cons:

Parker, Cargill, Klimchuk, Patsourakos, Reale, Walsh...

Implications for heating

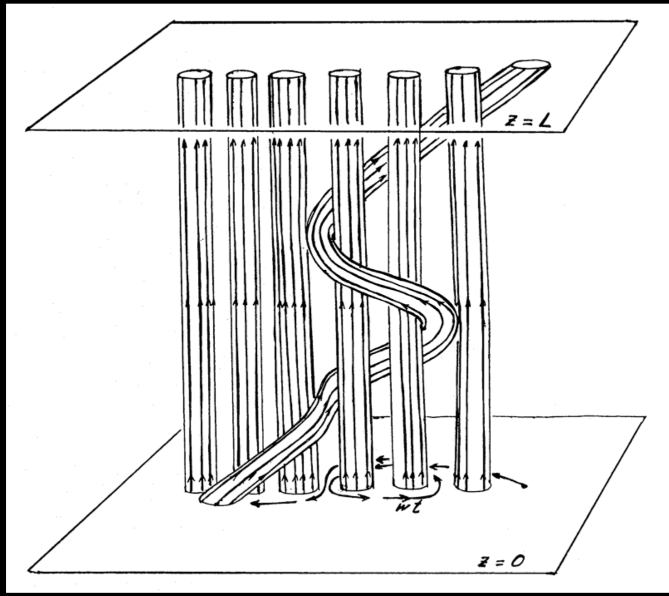
Nanoflares

Convection ⇒ Braiding ⇒ Stress ⇒ Reconnection (nanoflare)

Pros:

Impulsive nature

Can explain overdens.



Parker (1983)

Cons:

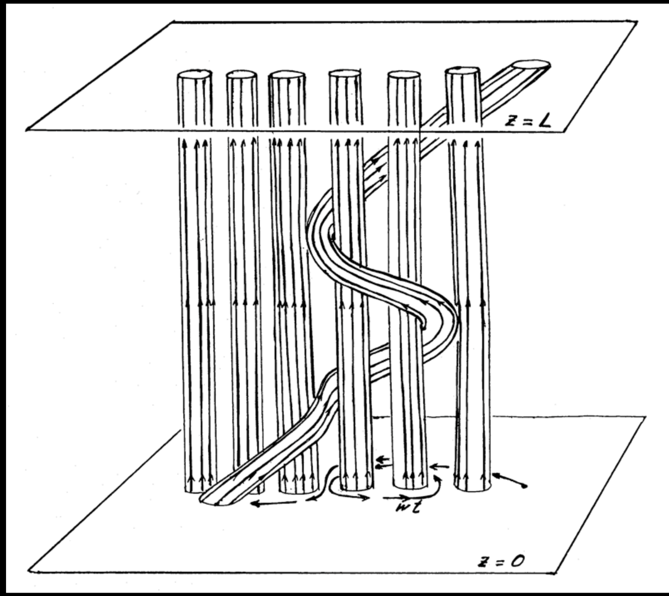
Parker, Cargill, Klimchuk, Patsourakos, Reale, Walsh...

Implications for heating

Nanoflares

Convection ⇒ Braiding ⇒ Stress ⇒ Reconnection (nanoflare)

Pros:
Impulsive nature
Can explain overdens.
Multi-strands



Parker (1983)

Cons:

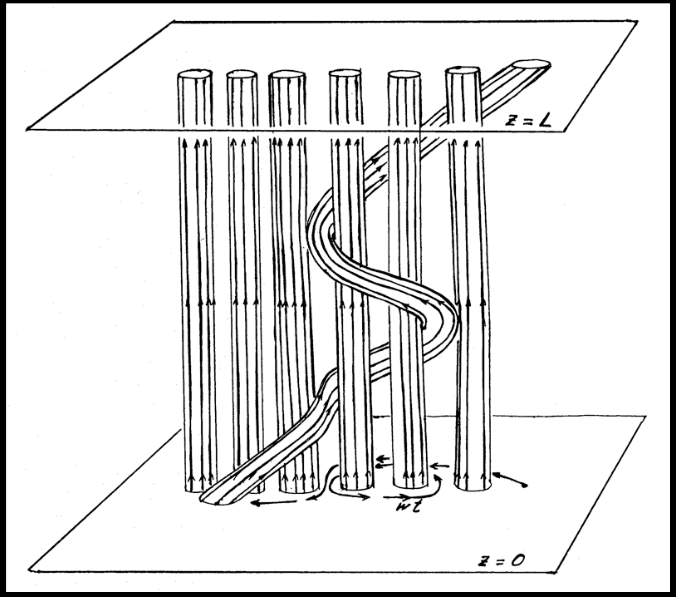
Parker, Cargill, Klimchuk, Patsourakos, Reale, Walsh...

Implications for heating

Nanoflares

Convection ⇒ Braiding ⇒ Stress ⇒ Reconnection (nanoflare)

Pros:
Impulsive nature
Can explain overdens.
Multi-strands
Broad DEMS



Parker (1983)

Cons:

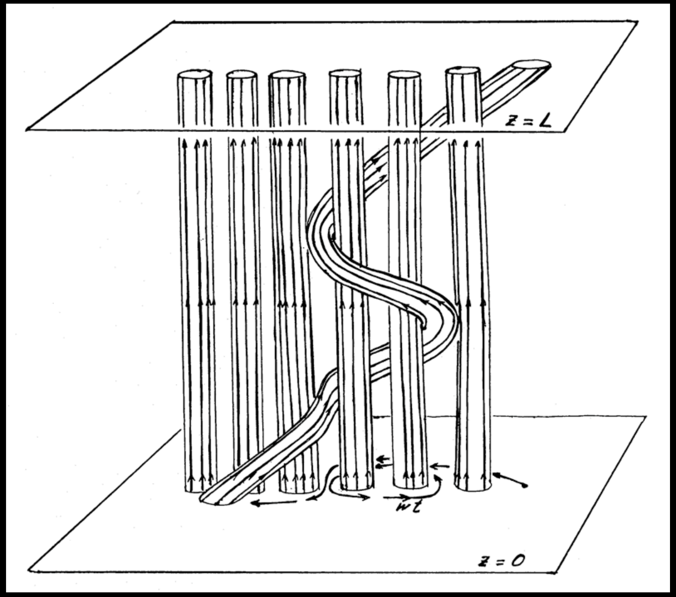
Parker, Cargill, Klimchuk, Patsourakos, Reale, Walsh...

Implications for heating

Nanoflares

Convection ⇒ Braiding ⇒ Stress ⇒ Reconnection (nanoflare)

Pros:
Impulsive nature
Can explain overdens.
Multi-strands
Broad DEMS
No observed braiding



Parker (1983)

Cons:

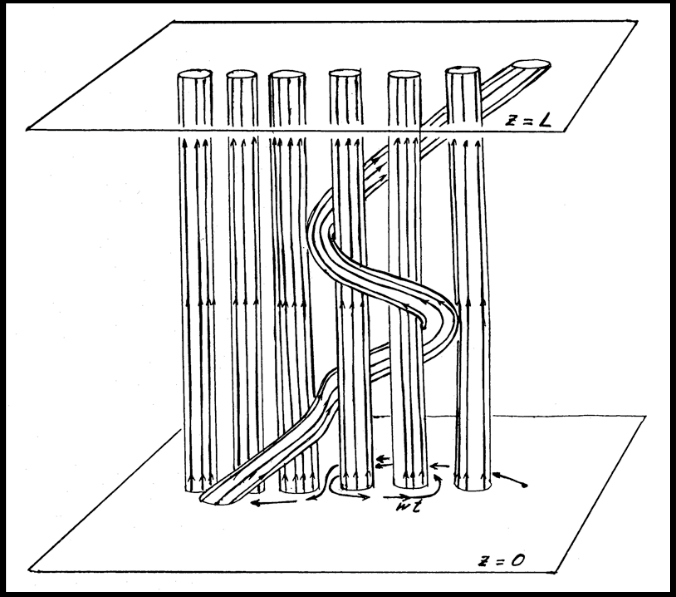
Parker, Cargill, Klimchuk, Patsourakos, Reale, Walsh...

Implications for heating

Nanoflares

Convection ⇒ Braiding ⇒ Stress ⇒ Reconnection (nanoflare)

Pros:
Impulsive nature
Can explain overdens.
Multi-strands
Broad DEMS
No observed braiding



Parker (1983)

Cons:
Not seen (yet at least)

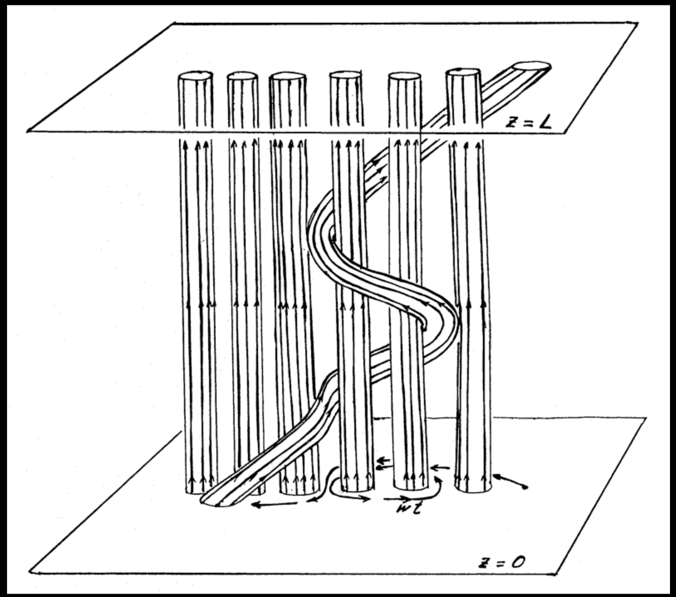
Parker, Cargill, Klimchuk, Patsourakos, Reale, Walsh...

Implications for heating

Nanoflares

Convection ⇒ Braiding ⇒ Stress ⇒ Reconnection (nanoflare)

Pros:
Impulsive nature
Can explain overdens.
Multi-strands
Broad DEMS
No observed braiding



Parker (1983)

Cons:
Not seen (yet at least)
Monolithic loops?

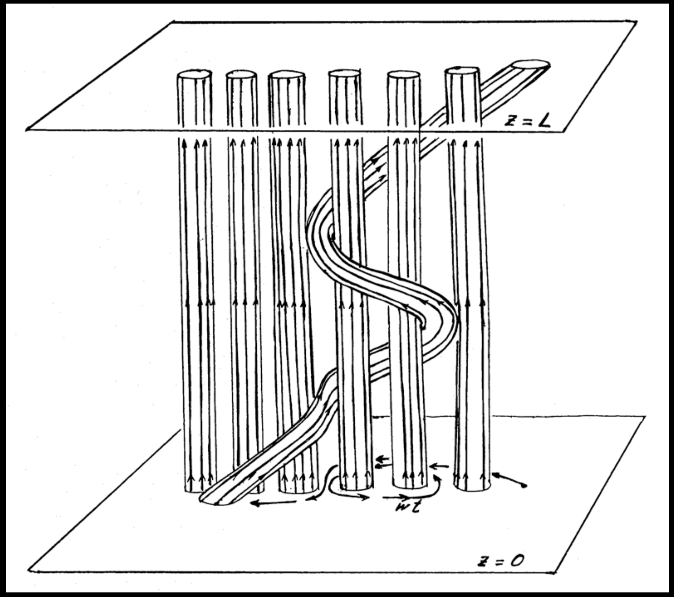
Parker, Cargill, Klimchuk, Patsourakos, Reale, Walsh...

Implications for heating

Nanoflares

Convection ⇒ Braiding ⇒ Stress ⇒ Reconnection (nanoflare)

Pros:
Impulsive nature
Can explain overdens.
Multi-strands
Broad DEMS
No observed braiding



Parker (1983)

Cons:
Not seen (yet at least)
Monolithic loops?
No observed braiding

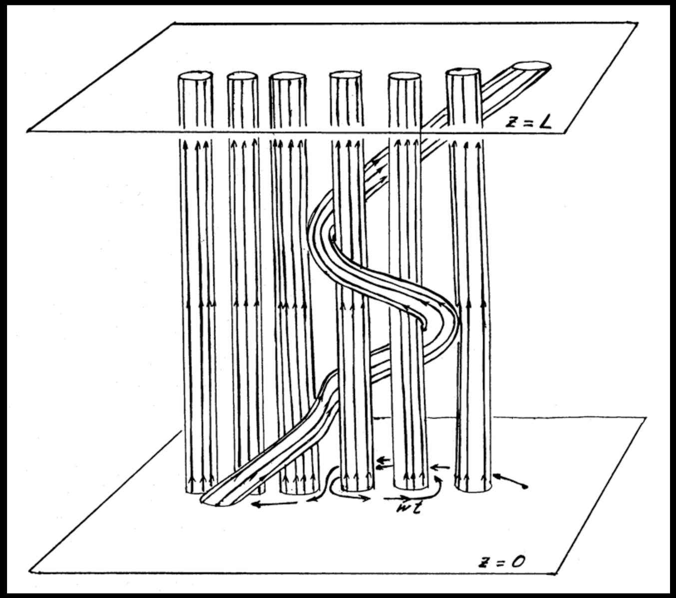
Parker, Cargill, Klimchuk, Patsourakos, Reale, Walsh...

Implications for heating

Nanoflares

Convection ⇒ Braiding ⇒ Stress ⇒ Reconnection (nanoflare)

Pros:
Impulsive nature
Can explain overdens.
Multi-strands
Broad DEMS
No observed braiding



Parker (1983)

Cons:
Not seen (yet at least)
Monolithic loops?
No observed braiding
Narrow DEM?

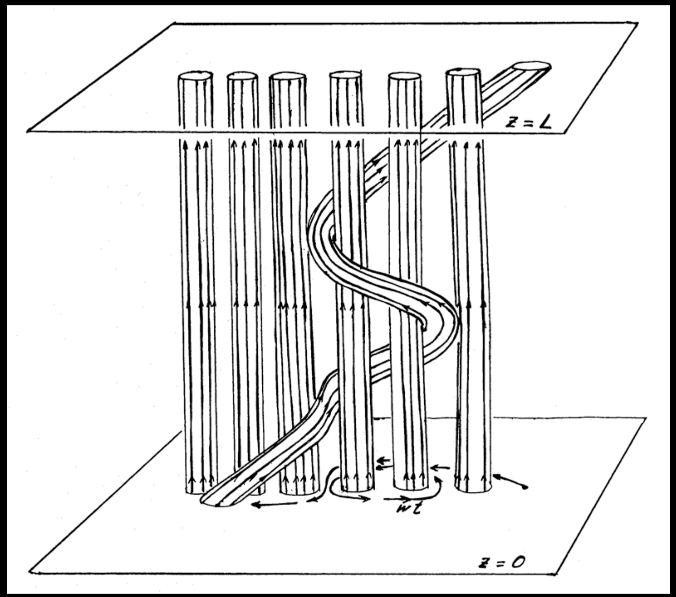
Parker, Cargill, Klimchuk, Patsourakos, Reale, Walsh...

Implications for heating

Nanoflares

Convection ⇒ Braiding ⇒ Stress ⇒ Reconnection (nanoflare)

Pros:
- Impulsive nature
- Can explain overdens.
- Multi-strands
- Broad DEMS
- No observed braiding



Parker (1983)

Cons:
- Not seen (yet at least)
- Monolithic loops?
- No observed braiding
- Narrow DEM?

Nanoflare storms ⇒ narrow DEMs

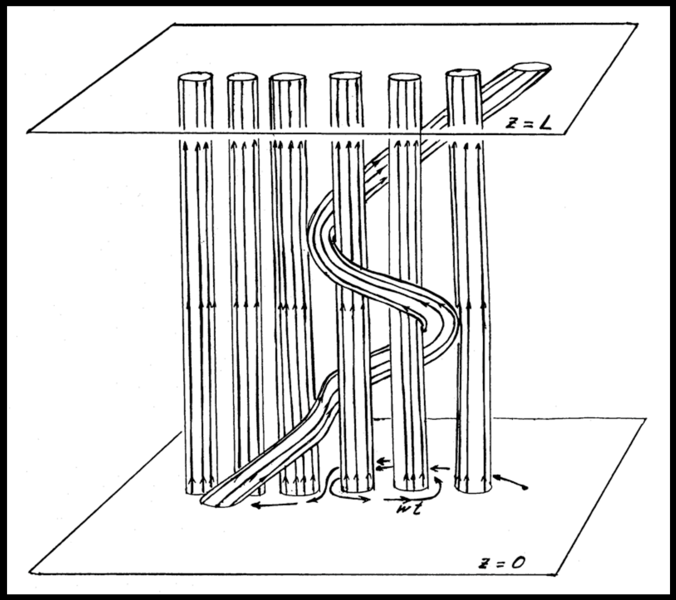
Parker, Cargill, Klimchuk, Patsourakos, Reale, Walsh...

Implications for heating

Nanoflares

Convection ⇒ Braiding ⇒ Stress ⇒ Reconnection (nanoflare)

Pros:
- Impulsive nature
- Can explain overdens.
- Multi-strands
- Broad DEMS
- No observed braiding



Parker (1983)

Cons:
- Not seen (yet at least)
- Monolithic loops?
- No observed braiding
- ~~Narrow DEM?~~

Nanoflare storms ⇒ narrow DEMs

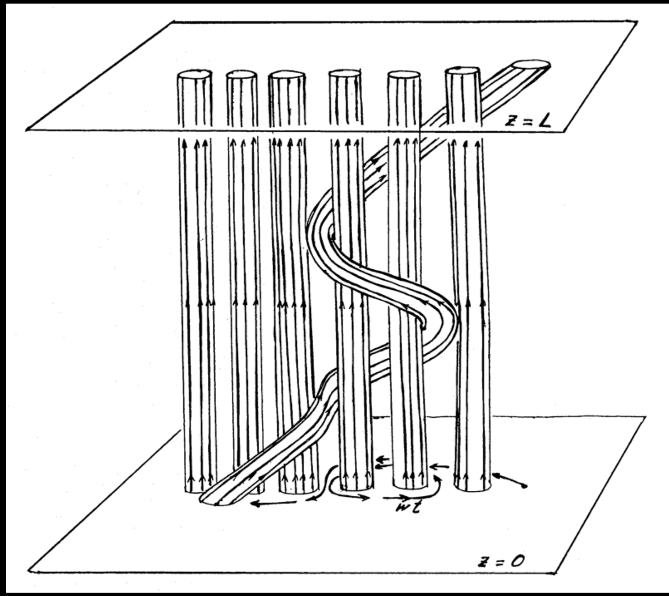
Parker, Cargill, Klimchuk, Patsourakos, Reale, Walsh...

Implications for heating

Nanoflares

Convection ⇒ Braiding ⇒ Stress ⇒ Reconnection (nanoflare)

Pros:
Impulsive nature
Can explain overdens.
Multi-strands
Broad DEMS
No observed braiding



Parker (1983)

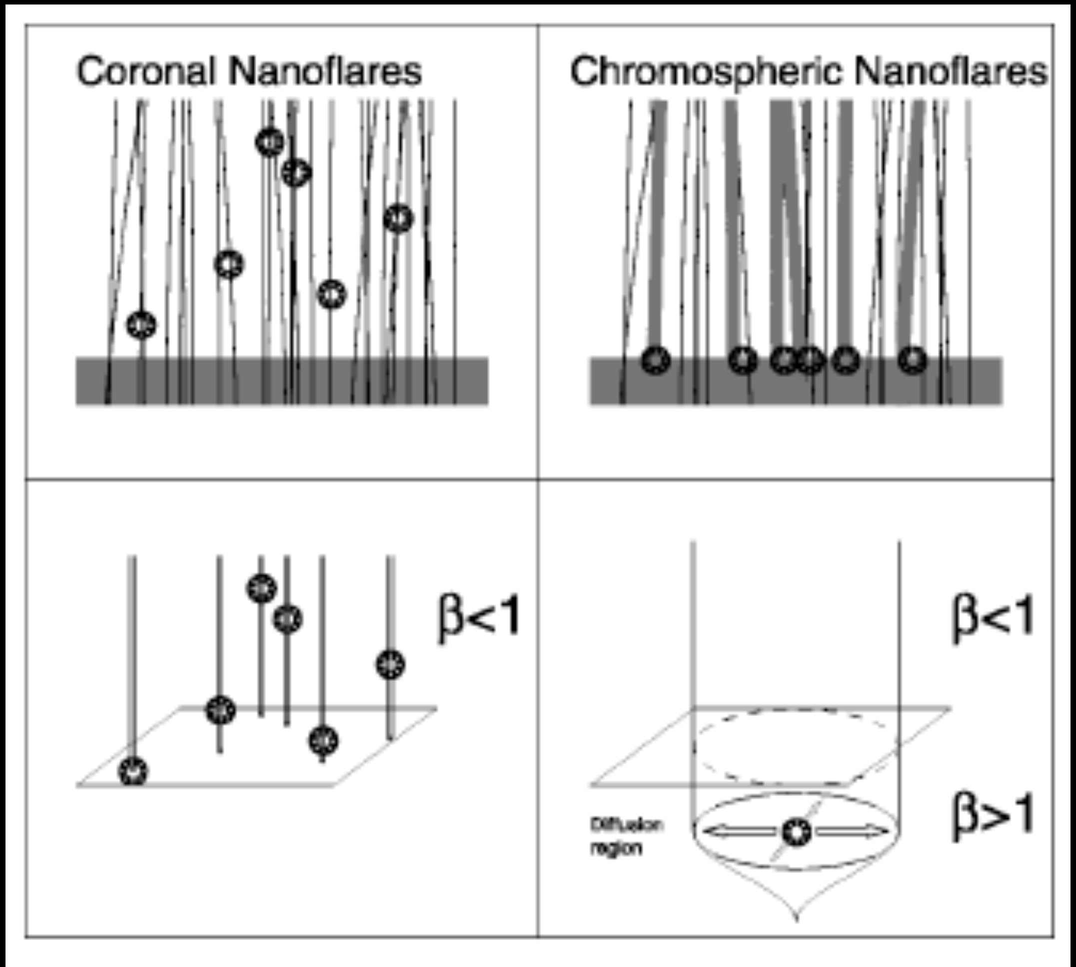
Cons:
Not seen (yet at least)
Monolithic loops?
No observed braiding
~~Narrow DEM?~~
Coherence?

Nanoflare storms ⇒ narrow DEMs

Parker, Cargill, Klimchuk, Patsourakos, Reale, Walsh...

Implications for heating

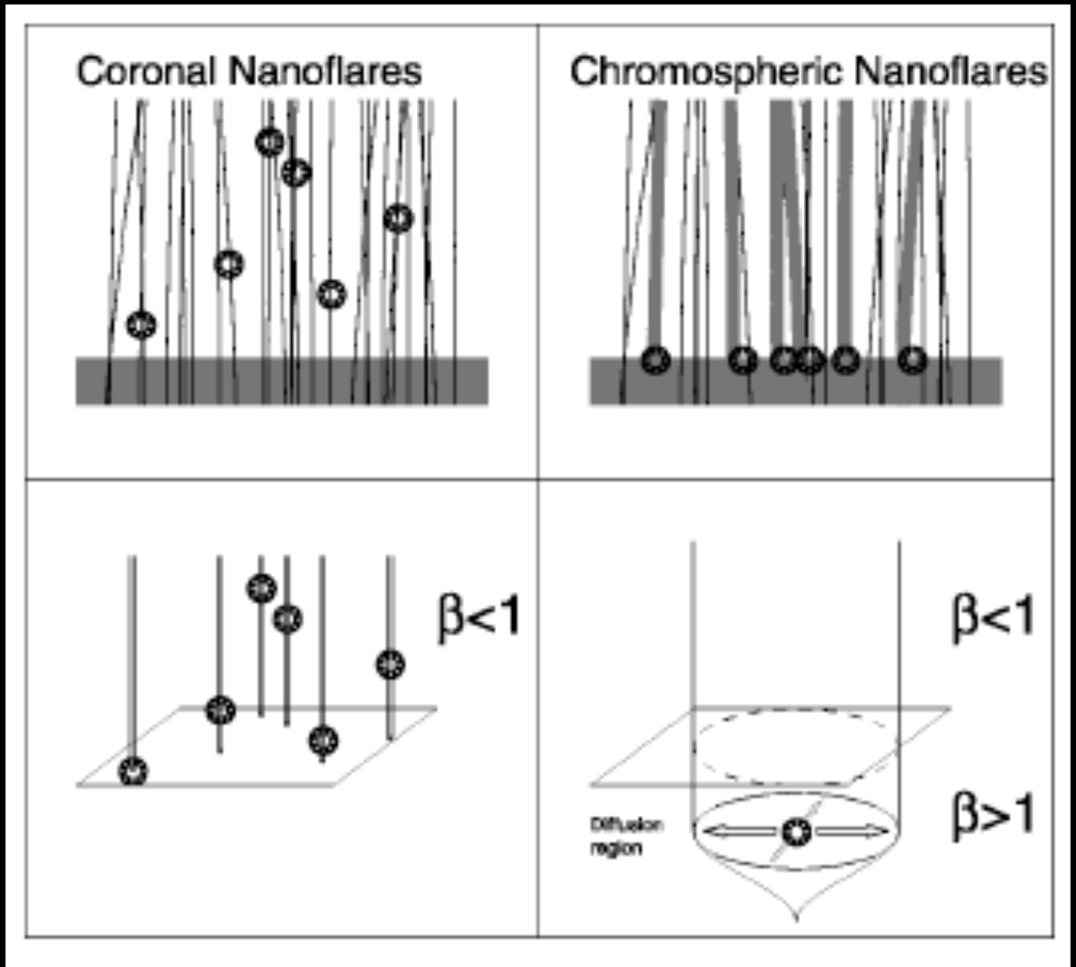
Chromospheric heating



Aschwanden et al. 2005-2008

Implications for heating

Chromospheric heating

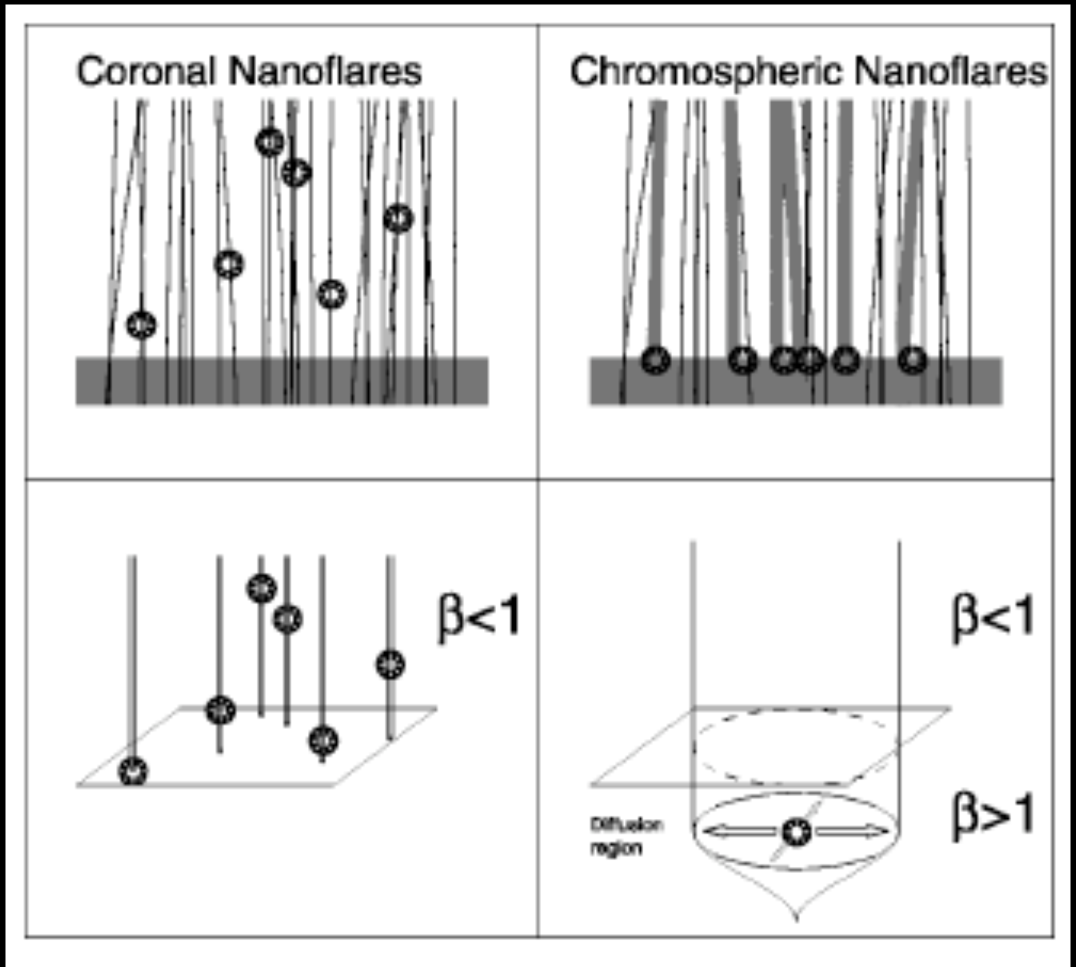


Aschwanden et al. 2005-2008

- Reconnection at chromospheric level

Implications for heating

Chromospheric heating

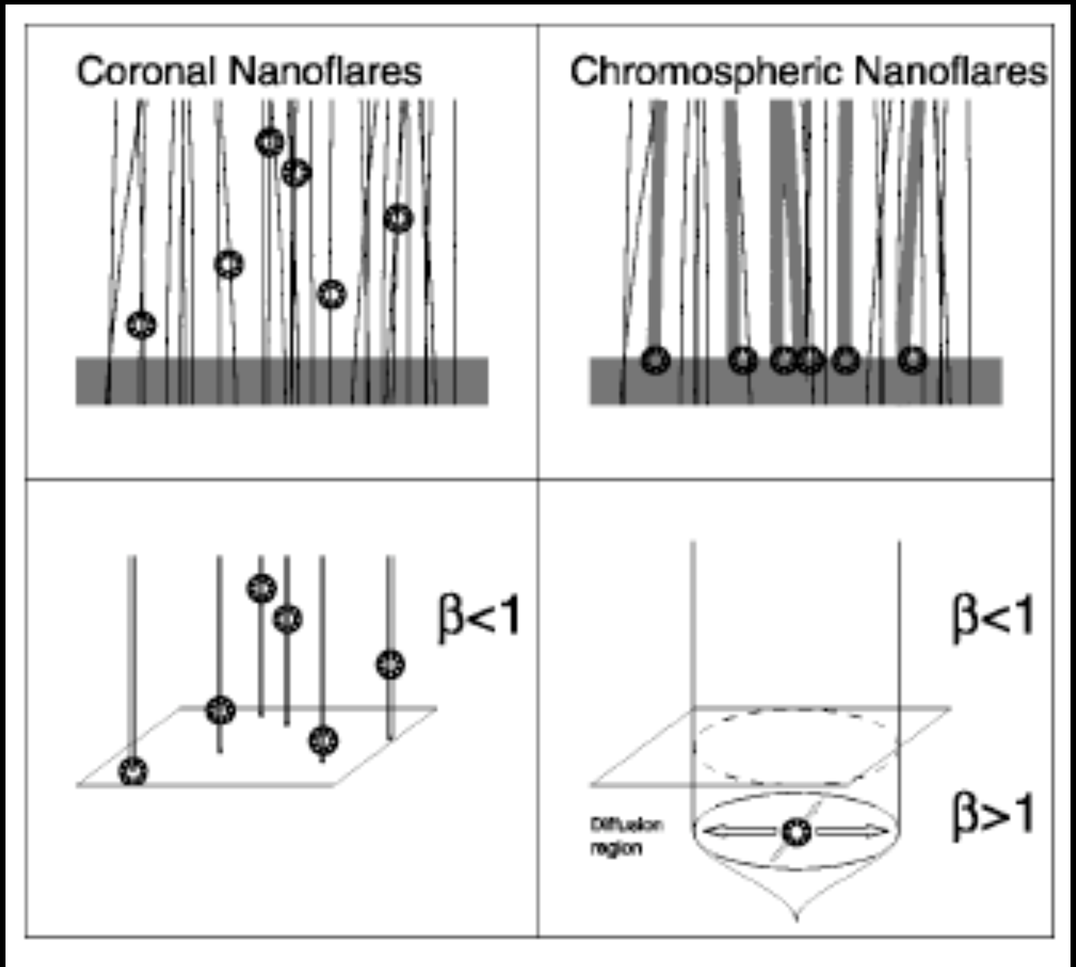


Aschwanden et al. 2005-2008

- Reconnection at chromospheric level
- Cross-field diffusion more efficient

Implications for heating

Chromospheric heating



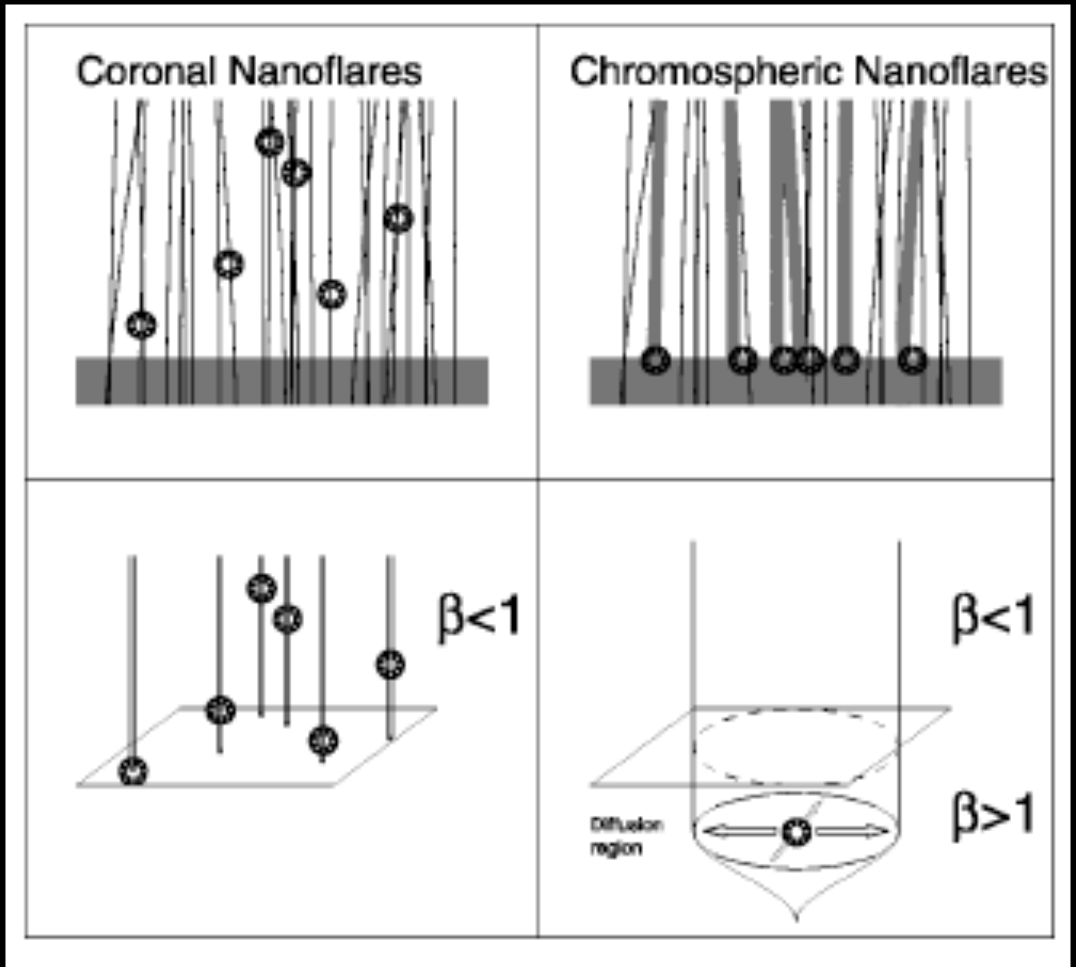
Aschwanden et al. 2005-2008

- Reconnection at chromospheric level
- Cross-field diffusion more efficient

$\Downarrow$

Implications for heating

Chromospheric heating



Aschwanden et al. 2005-2008

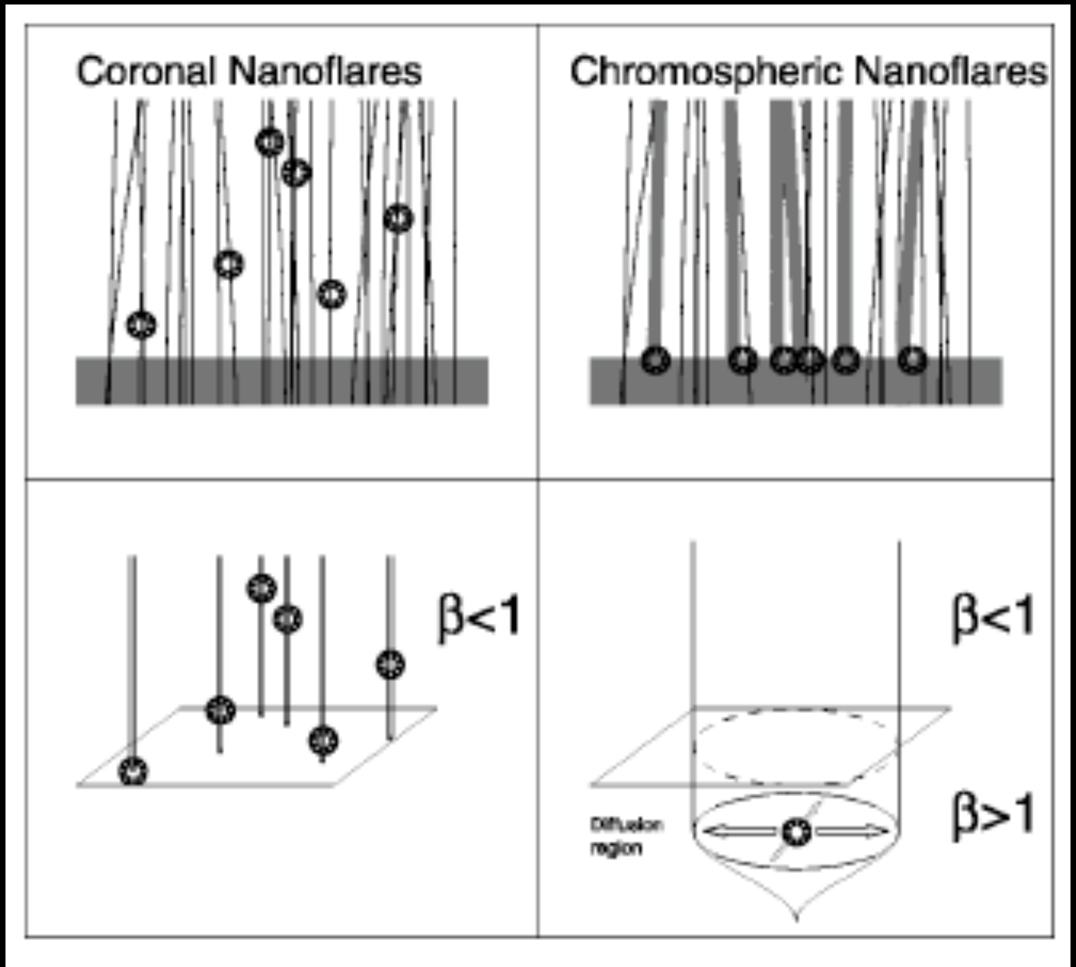
- Reconnection at chromospheric level
- Cross-field diffusion more efficient

$\Downarrow$

coherence

Implications for heating

Chromospheric heating



Aschwanden et al. 2005-2008

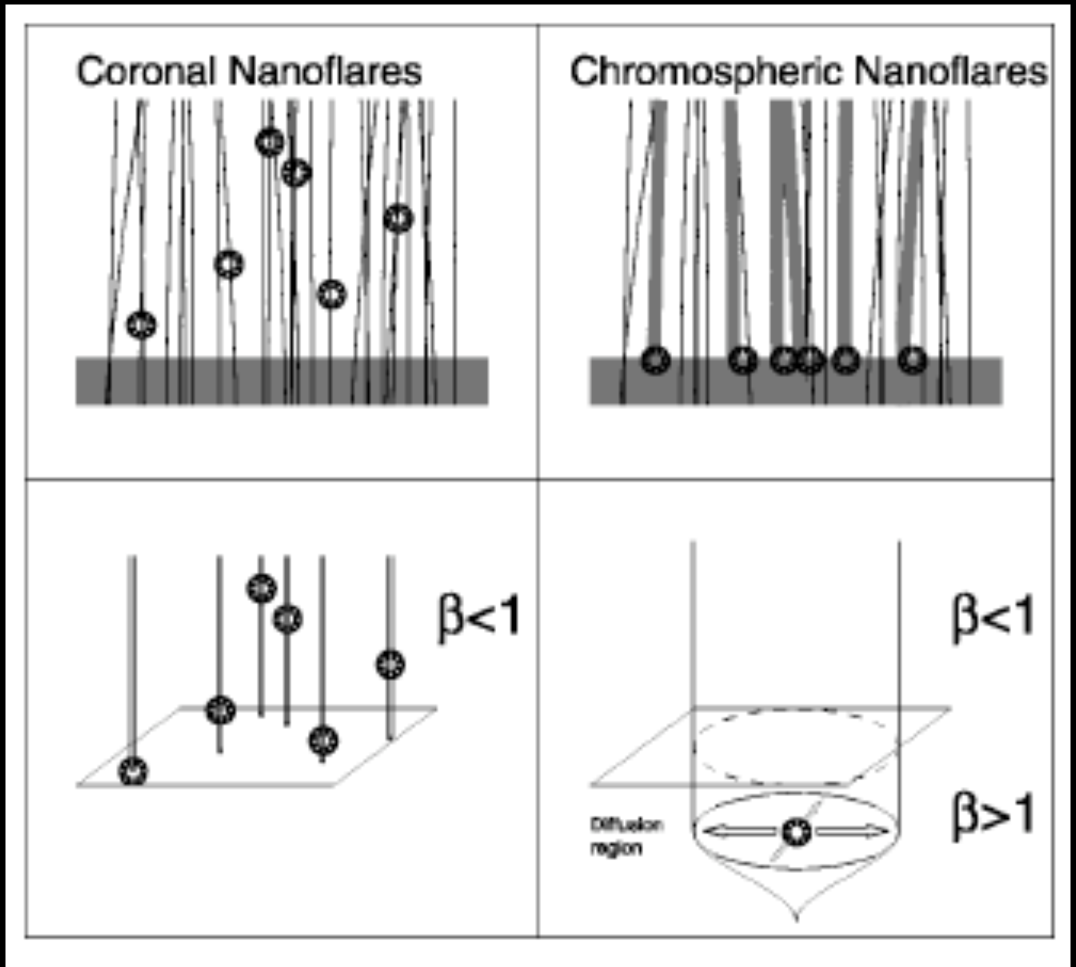
- Reconnection at chromospheric level
- Cross-field diffusion more efficient

  ⇓

  coherence
- Possible explanation for:

Implications for heating

Chromospheric heating

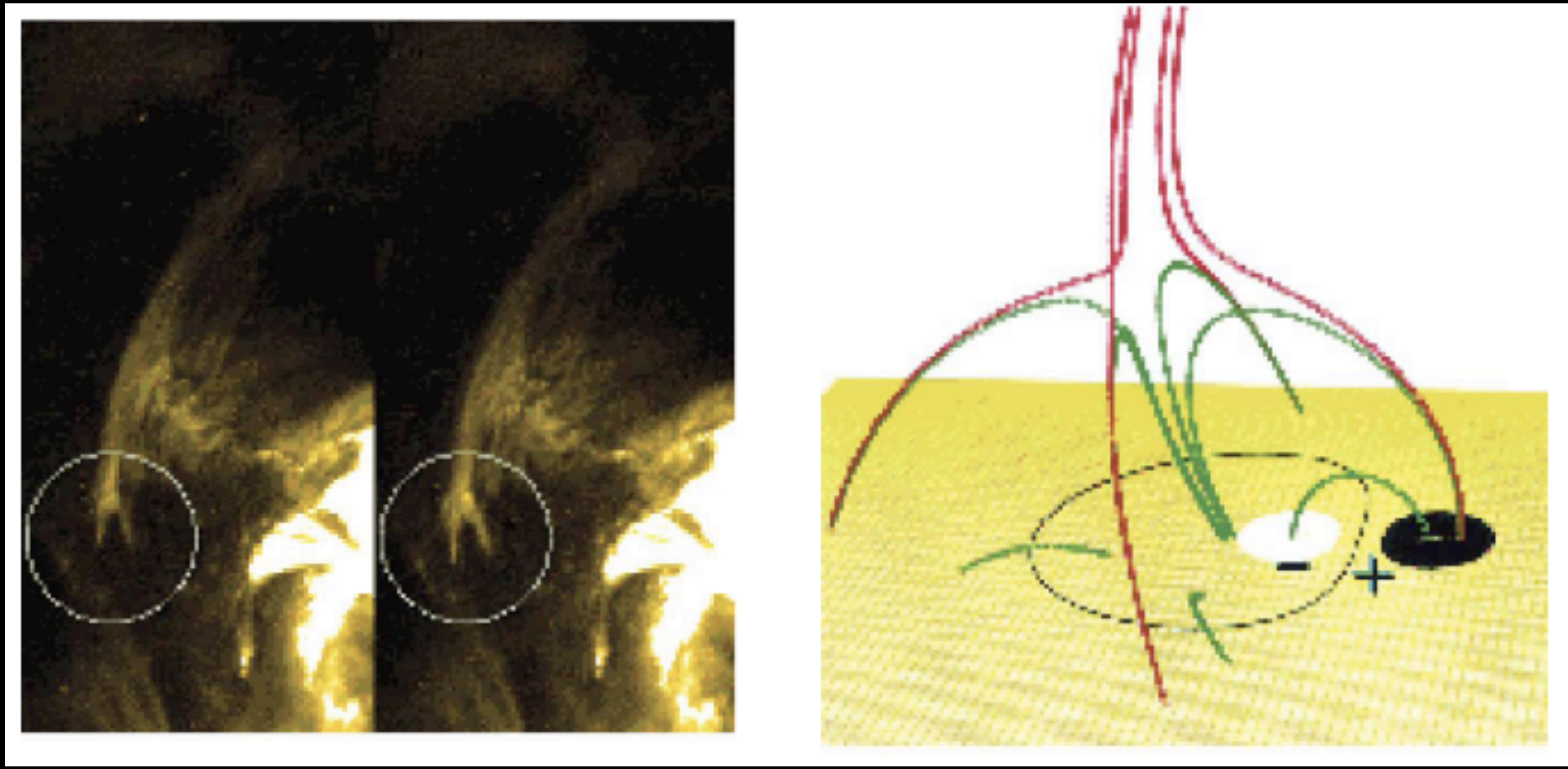


Aschwanden et al. 2005-2008

- Reconnection at chromospheric level
- Cross-field diffusion more efficient
  ⇓
  coherence
- Possible explanation for:
  upflows, waves

Implications for heating

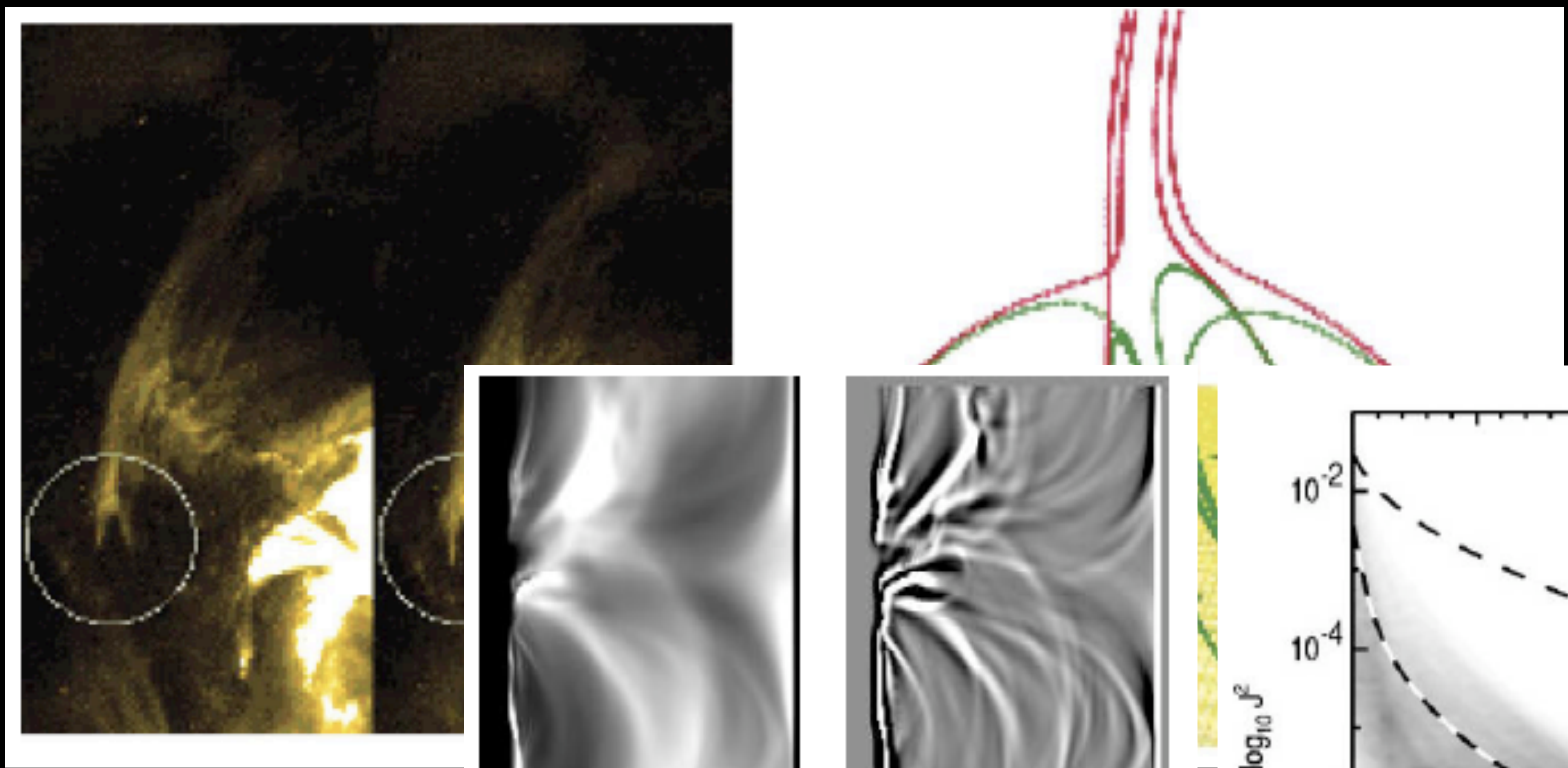
Chromospheric heating



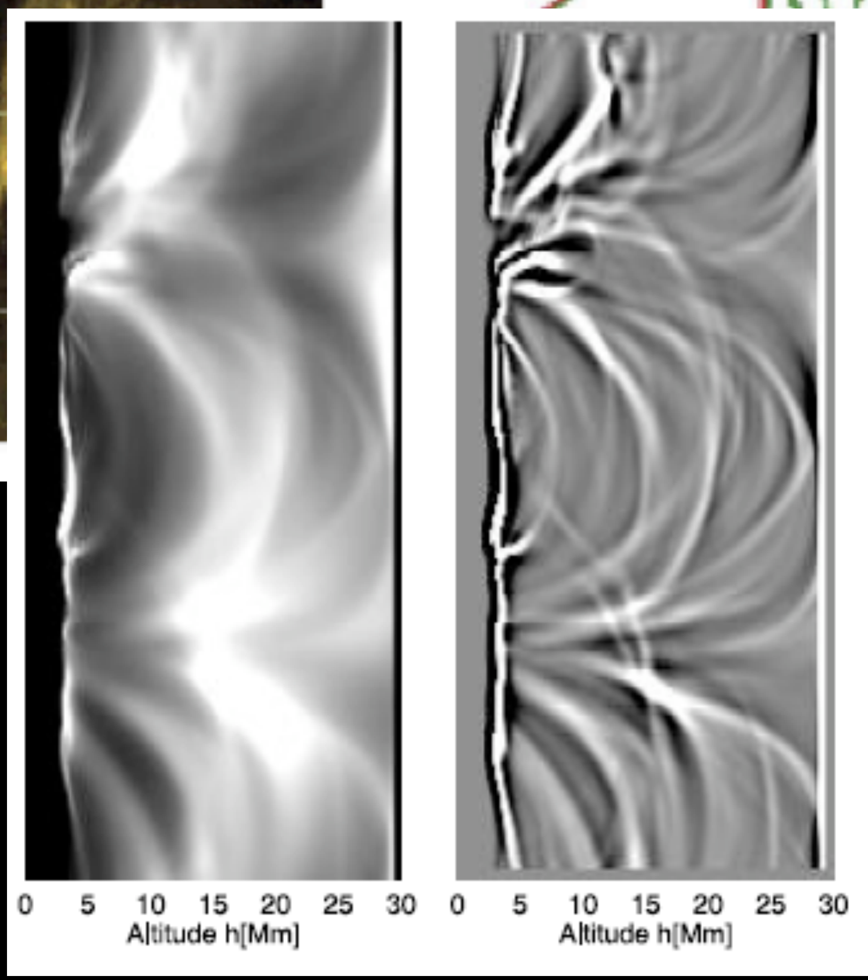
Aschwanden et al. (2007)

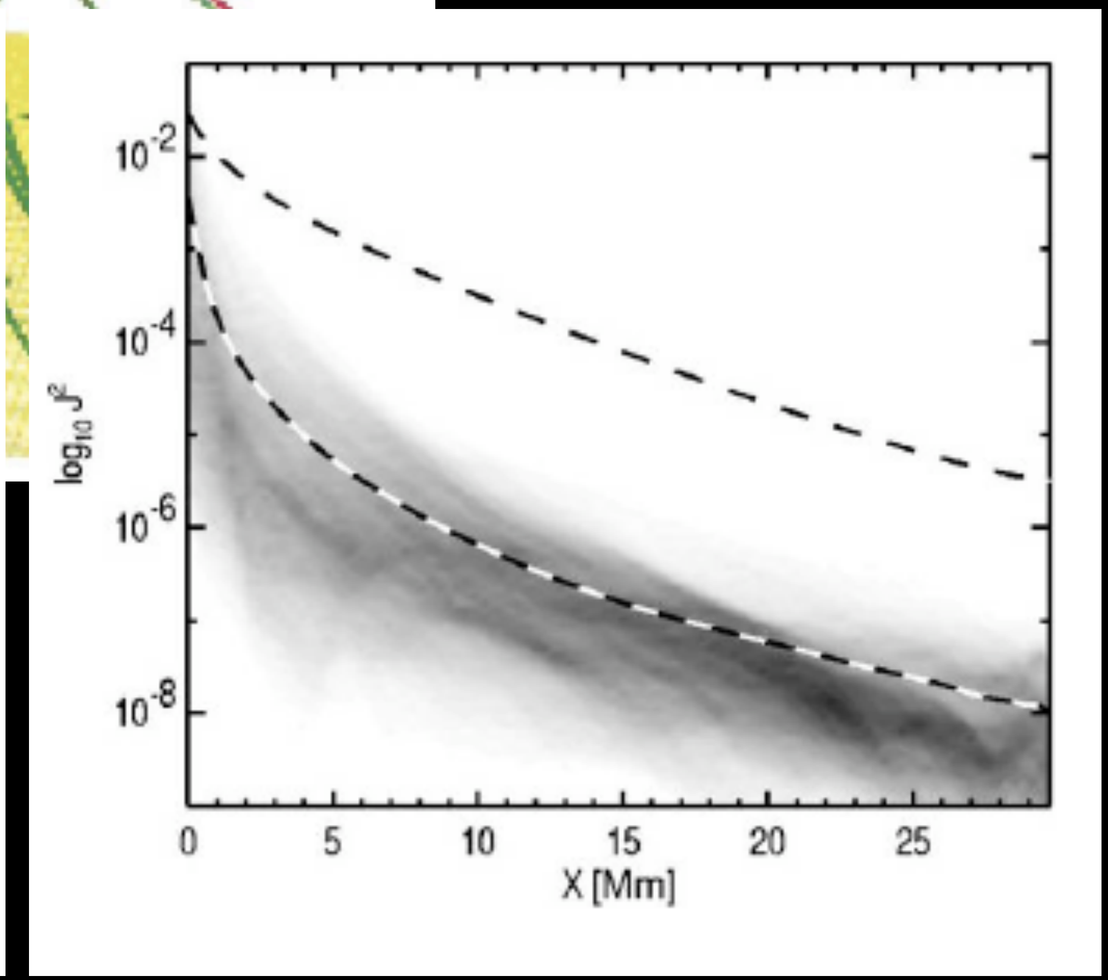
Implications for heating

Chromospheric heating



Aschwanden et al.





Gudiksen & Nordlund (2002)

Implications for heating

Chromospheric heating

Open questions:

- Coronal heating can also explain:
  upflows and chromospheric evaporation
- How much of that dissipation at lower heights goes into heating the corona: explosive events, blinkers, etc.
- Radiative losses?

Implications for heating

Chromospheric heating

Open questions:

- Coronal heating can also explain:
  upflows and chromospheric evaporation
- How much of that dissipation at lower heights goes into heating the corona: explosive events, blinkers, etc.
- Radiative losses?

Cons:

- Hinode: no mixed polarities in plages (Title, 2008)
- Un-tangling of the corona

Implications for heating

Chromospheric heating

Implications for heating

Chromospheric heating

Brooks

Ugarte–Urra & Warren

EIS Fe XVI 40" slot raster

on SOT Magnetograms

START

Summary

Summary

- EUV loops $\Rightarrow$ impulsive heating

Summary

- EUV loops ⇒ impulsive heating
- X-ray loops: static and steady could work, BUT... open questions

Summary

- EUV loops ⇒ impulsive heating
- X-ray loops: static and steady could work, BUT... open questions
- EUV loops can have narrow (also broad) temperature distrib.

Summary

- EUV loops ⇒ impulsive heating
- X-ray loops: static and steady could work, BUT... open questions
- EUV loops can have narrow (also broad) temperature distrib.
- Filamentation: evolution, filling factor, SOT fine structuring

Summary

- EUV loops $\Rightarrow$ impulsive heating
- X-ray loops: static and steady could work, BUT... open questions
- EUV loops can have narrow (also broad) temperature distrib.
- Filamentation: evolution, filling factor, SOT fine structuring

$\Downarrow$

multi-threads

Summary

- EUV loops ⇒ impulsive heating
- X-ray loops: static and steady could work, BUT... open questions
- EUV loops can have narrow (also broad) temperature distrib.
- Filamentation: evolution, filling factor, SOT fine structuring

⇓

multi-threads

- Multi-thread + Narrow T distrib. ⇒ coherence

Summary

- EUV loops ⇒ impulsive heating
- X-ray loops: static and steady could work, BUT... open questions
- EUV loops can have narrow (also broad) temperature distrib.
- Filamentation: evolution, filling factor, SOT fine structuring

⇓

multi-threads

- Multi-thread + Narrow T distrib. ⇒ coherence
- Implications for heating: coronal vs chromospheric

Summary

- EUV loops $\Rightarrow$ impulsive heating
- X-ray loops: static and steady could work, BUT... open questions
- EUV loops can have narrow (also broad) temperature distrib.
- Filamentation: evolution, filling factor, SOT fine structuring

$\Downarrow$

multi-threads

- Multi-thread + Narrow T distrib. $\Rightarrow$ coherence
- Implications for heating: coronal vs chromospheric OPEN

Summary

- EUV loops ⇒ impulsive heating
- X-ray loops: static and steady could work, BUT... open questions
- EUV loops can have narrow (also broad) temperature distrib.
- Filamentation: evolution, filling factor, SOT fine structuring

⇓

multi-threads

- Multi-thread + Narrow T distrib. ⇒ coherence
- Implications for heating: coronal vs chromospheric **OPEN**
- The debate has shifted to heat localization

What are coronal loops?

What are coronal loops?

Is there such a thing as a typical coronal loop?

What are coronal loops?

Is there such a thing as a typical coronal loop? Maybe

What are coronal loops?

Is there such a thing as a typical coronal loop? Maybe

Do all loops share common properties?

What are coronal loops?

Is there such a thing as a typical coronal loop? Maybe

Do all loops share common properties? No? Not sure

What are coronal loops?

Is there such a thing as a typical coronal loop? Maybe

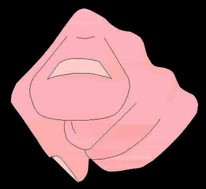
Do all loops share common properties? No? Not sure

Do we agree on those? and if so...

What are coronal loops?

Is there such a thing as a typical coronal loop? Maybe

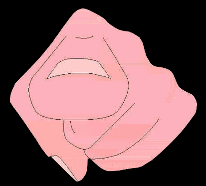
Do all loops share common properties? No? Not sure

Do we agree on those? and if so... 

What are coronal loops?

Is there such a thing as a typical coronal loop? Maybe

Do all loops share common properties? No? Not sure

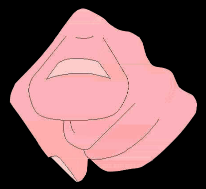
Do we agree on those? and if so... 

Are the properties sufficiently well constrained to test the models?

What are coronal loops?

Is there such a thing as a typical coronal loop? Maybe

Do all loops share common properties? No? Not sure

Do we agree on those? and if so... 

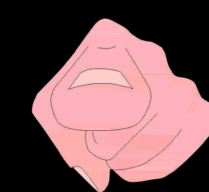
Are the properties sufficiently well constrained to test the models?

What do the models need from observations?

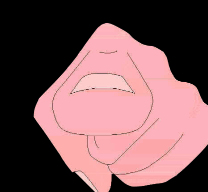
What are coronal loops?

Is there such a thing as a typical coronal loop? Maybe

Do all loops share common properties? No? Not sure

Do we agree on those? and if so... 

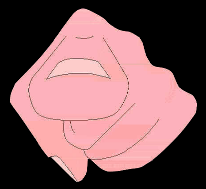
Are the properties sufficiently well constrained to test the models?

What do the models need from observations? 

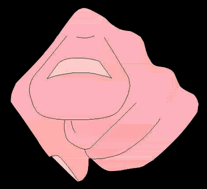
What are coronal loops?

Is there such a thing as a typical coronal loop? Maybe

Do all loops share common properties? No? Not sure

Do we agree on those? and if so... 

Are the properties sufficiently well constrained to test the models?

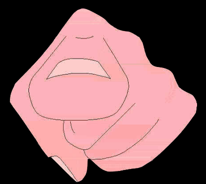
What do the models need from observations? 

Are we getting that information?

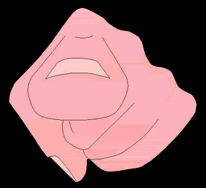
What are coronal loops?

Is there such a thing as a typical coronal loop? Maybe

Do all loops share common properties? No? Not sure

Do we agree on those? and if so... 

Are the properties sufficiently well constrained to test the models?

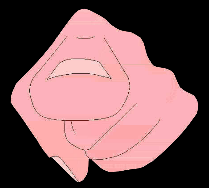
What do the models need from observations? 

Are we getting that information? No? Solar Cycle 24

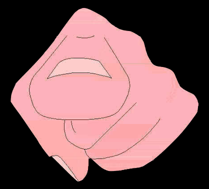
What are coronal loops?

Is there such a thing as a typical coronal loop? Maybe

Do all loops share common properties? No? Not sure

Do we agree on those? and if so... 

Are the properties sufficiently well constrained to test the models?

What do the models need from observations? 

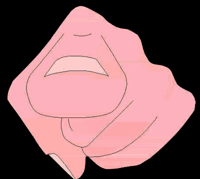
Are we getting that information? No? Solar Cycle 24

Ultimately, where is the bottleneck?

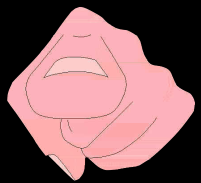
What are coronal loops?

Is there such a thing as a typical coronal loop? Maybe

Do all loops share common properties? No? Not sure

Do we agree on those? and if so... 

Are the properties sufficiently well constrained to test the models?

What do the models need from observations? 

Are we getting that information? No? Solar Cycle 24

Ultimately, where is the bottleneck?

Observations

We need to provide a coherent consensual picture of multi-temperature loop structuring, formation and evolution

To do

To do

- We need to recognize that temporal dimension is important:

To do

- We need to recognize that temporal dimension is important:
  - multi-temperature picture: loops are evolving

To do

- We need to recognize that temporal dimension is important:
  - multi-temperature picture: loops are evolving
  - cooling times ⇒ multiple strands

To do

- We need to recognize that temporal dimension is important:
  - multi-temperature picture: loops are evolving
  - cooling times ⇒ multiple strands
- Diagnostics are crucial: Ne, DEM, Temperature, flows (doppler)

To do

- We need to recognize that temporal dimension is important:
  - multi-temperature picture: loops are evolving
  - cooling times $\Rightarrow$ multiple strands
- Diagnostics are crucial: Ne, DEM, Temperature, flows (doppler)
- Statistically significant datasets.

To do

- We need to recognize that temporal dimension is important:
  - multi-temperature picture: loops are evolving
  - cooling times ⇒ multiple strands
- Diagnostics are crucial: Ne, DEM, Temperature, flows (doppler)
- Statistically significant datasets.

⬇

Spectroscopic + Time dependent properties of
multiple loops / multiple AR's

Magnetic complexity

Dalla et al. (2007)
2880 sunspot regions from NOAA catalog

Subset	number of regions	α (%)	β (%)	$\beta\gamma$ (%)	$\beta\delta$ (%)	$\beta\gamma\delta$ (%)
All	2880	10	73	11	0.8	5.2
NERs	1449	10	82	6	0.3	1.7
companions	468	6	73	13	0.6	7
old regions	1003	8	61	18	1.6	11

Cutoff	All (%)	α (%)	β (%)	$\beta\gamma$ (%)	$\beta\delta$ (%)	$\beta\gamma\delta$ (%)
Flares > C1	38	5	30	90	87	100
Flares > C5	20	0.7	11	63	71	89

Table 1 Mt. Wilson classification rules.

Class	Feature/classification rule
α	A single dominant spot often linked with a plage of opposite magnetic polarity
β	A pair of dominant spots of opposite polarity
γ	Complex groups with irregular distribution of polarities
$\beta\gamma$	Bipolar groups with more than one clear North – South polarity inversion line
δ	Umbrae of opposite polarity together in a single penumbra

Ireland et al. (2008)

Other topics

Full active region modeling

3D forward modeling