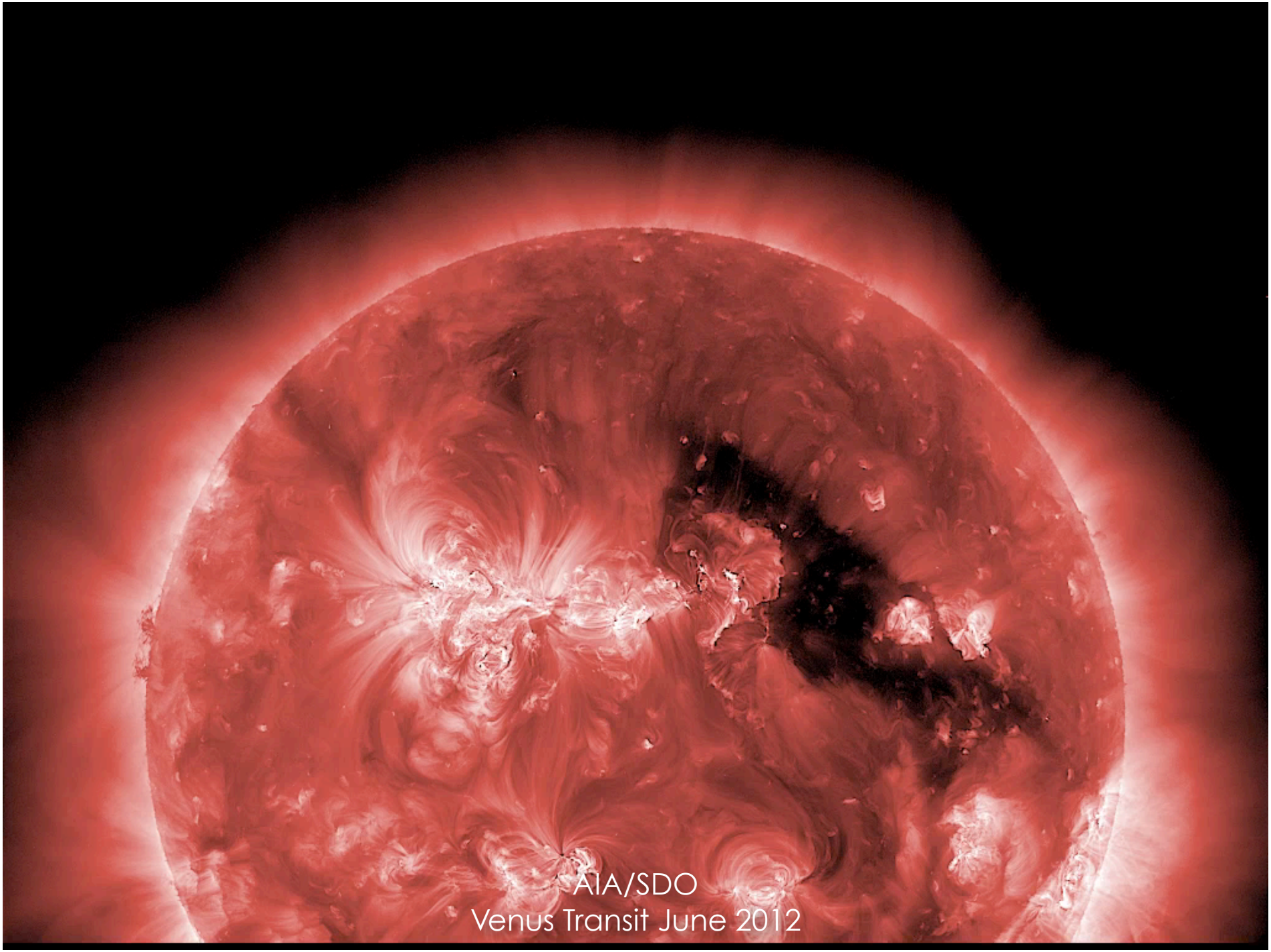
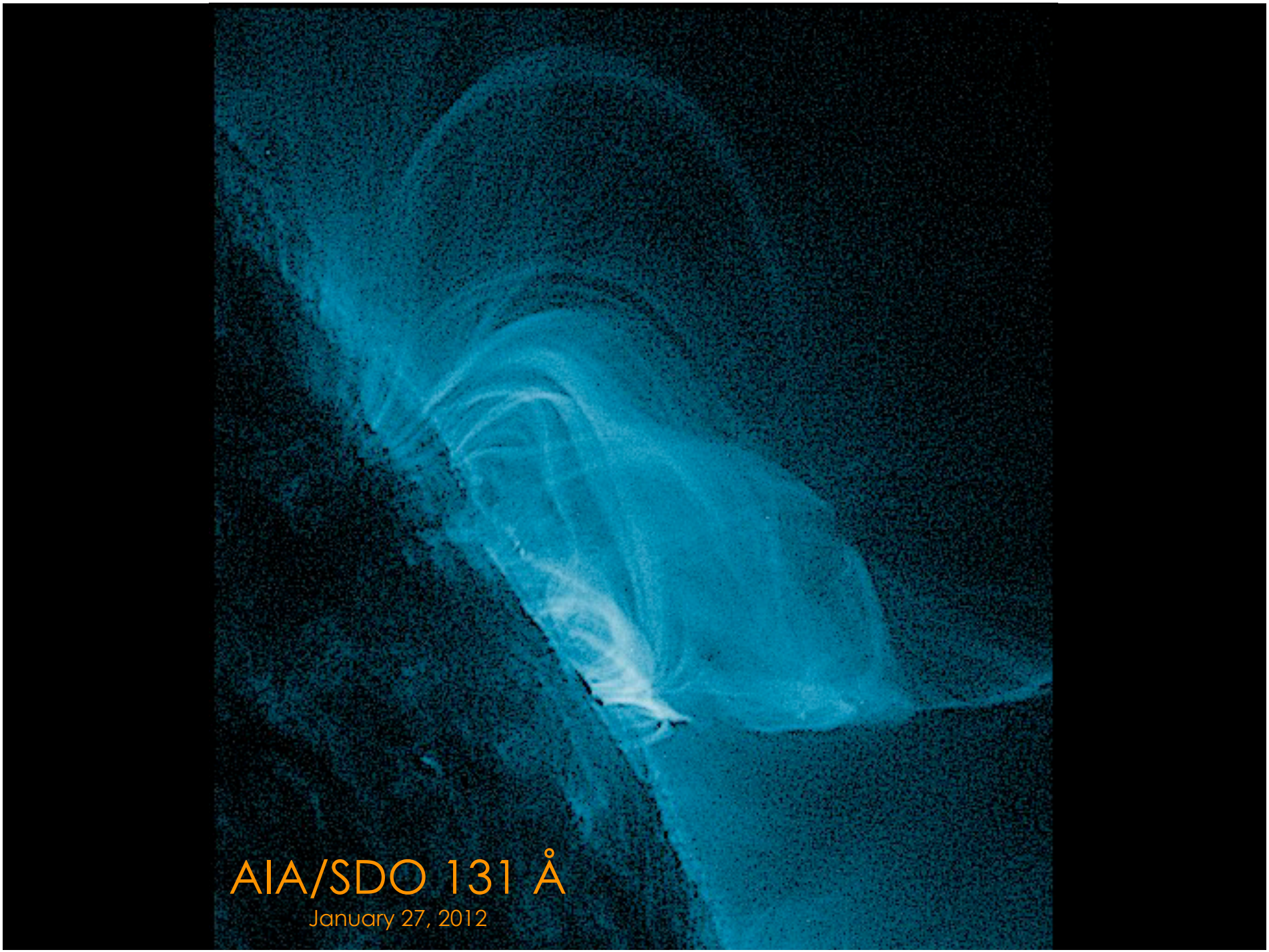
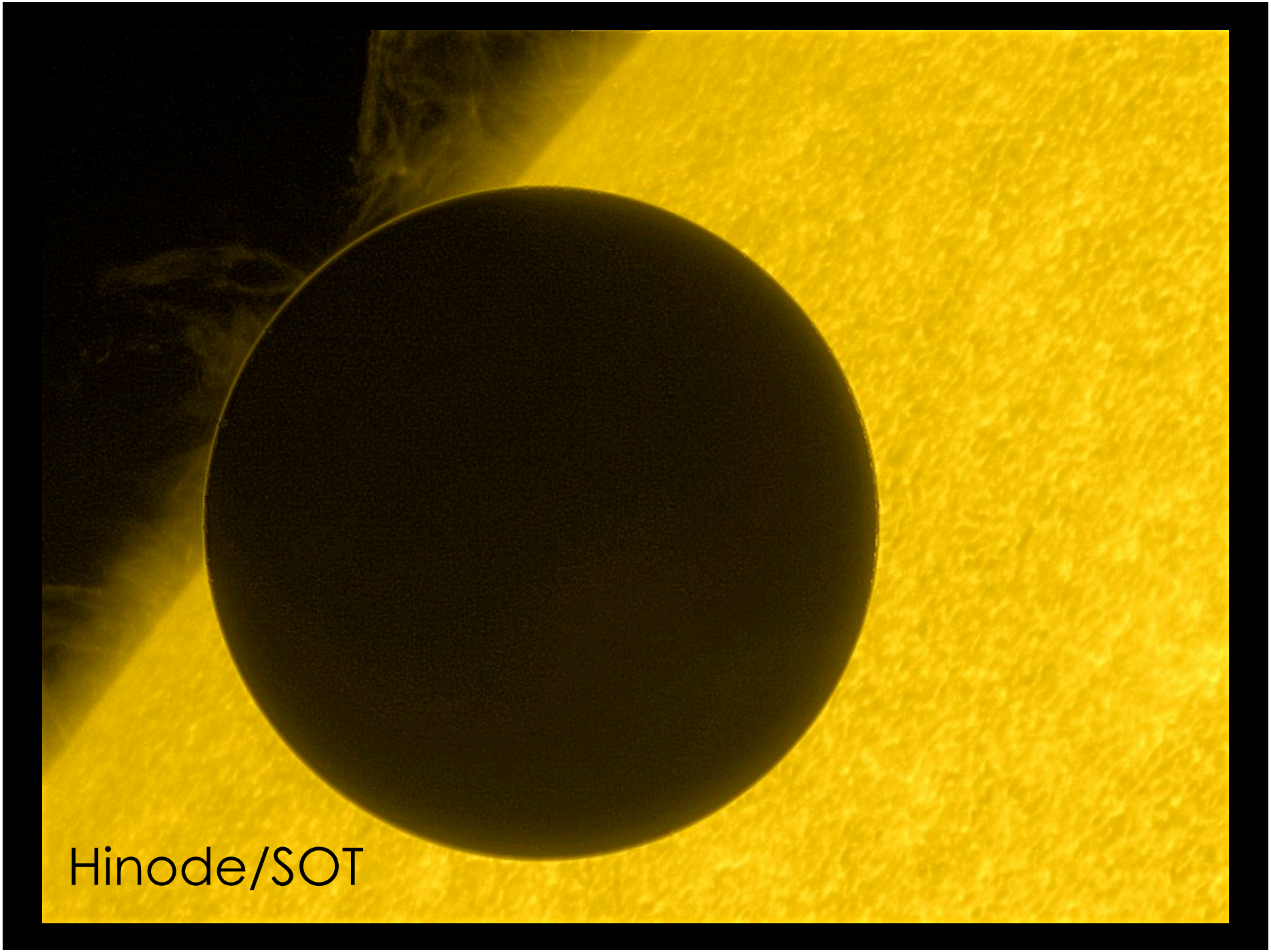
Supra Arcade Downflows and Evidence for Magnetic Reconnection in Solar Flares

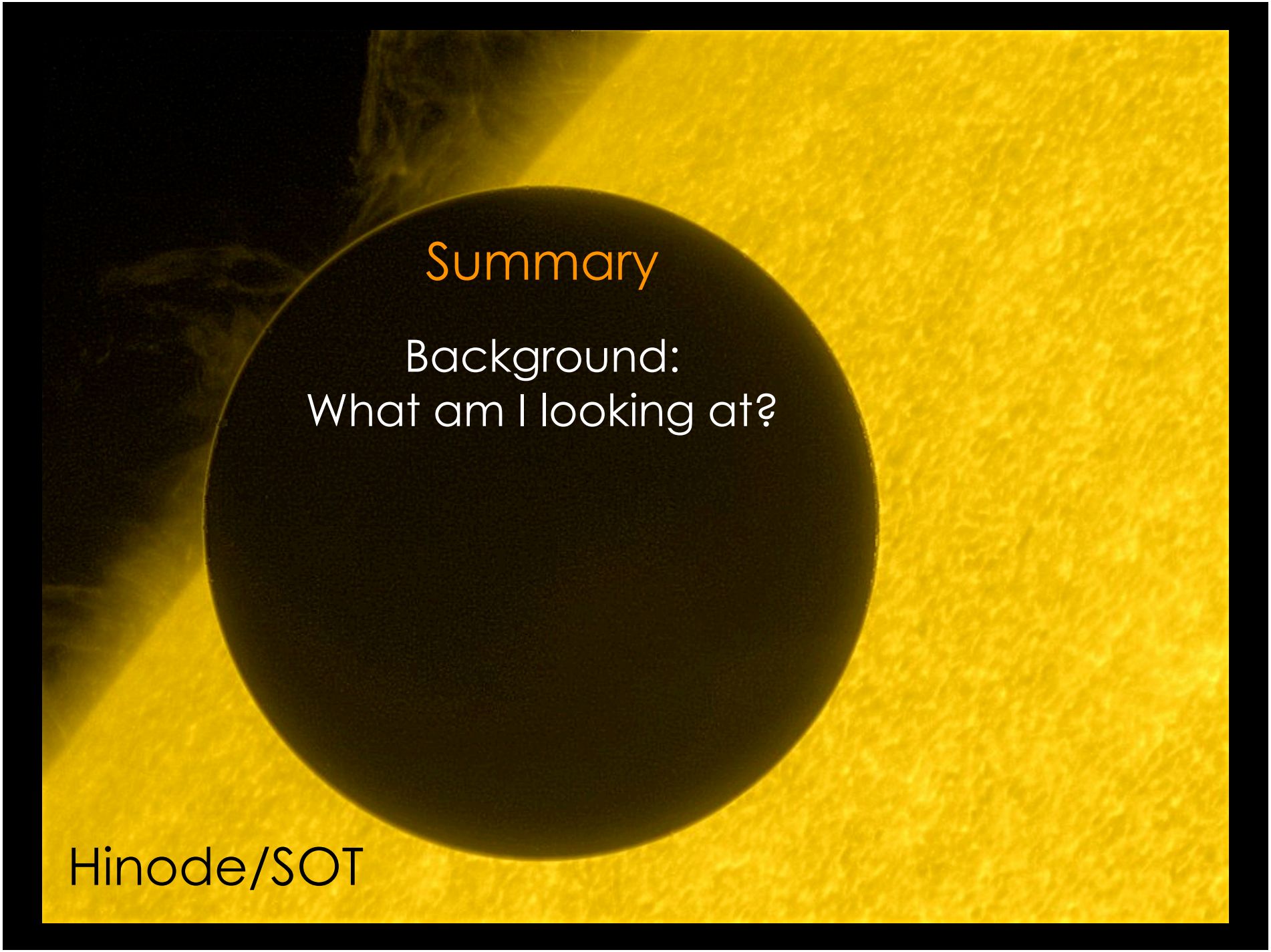
Harry Warren
Naval Research Laboratory

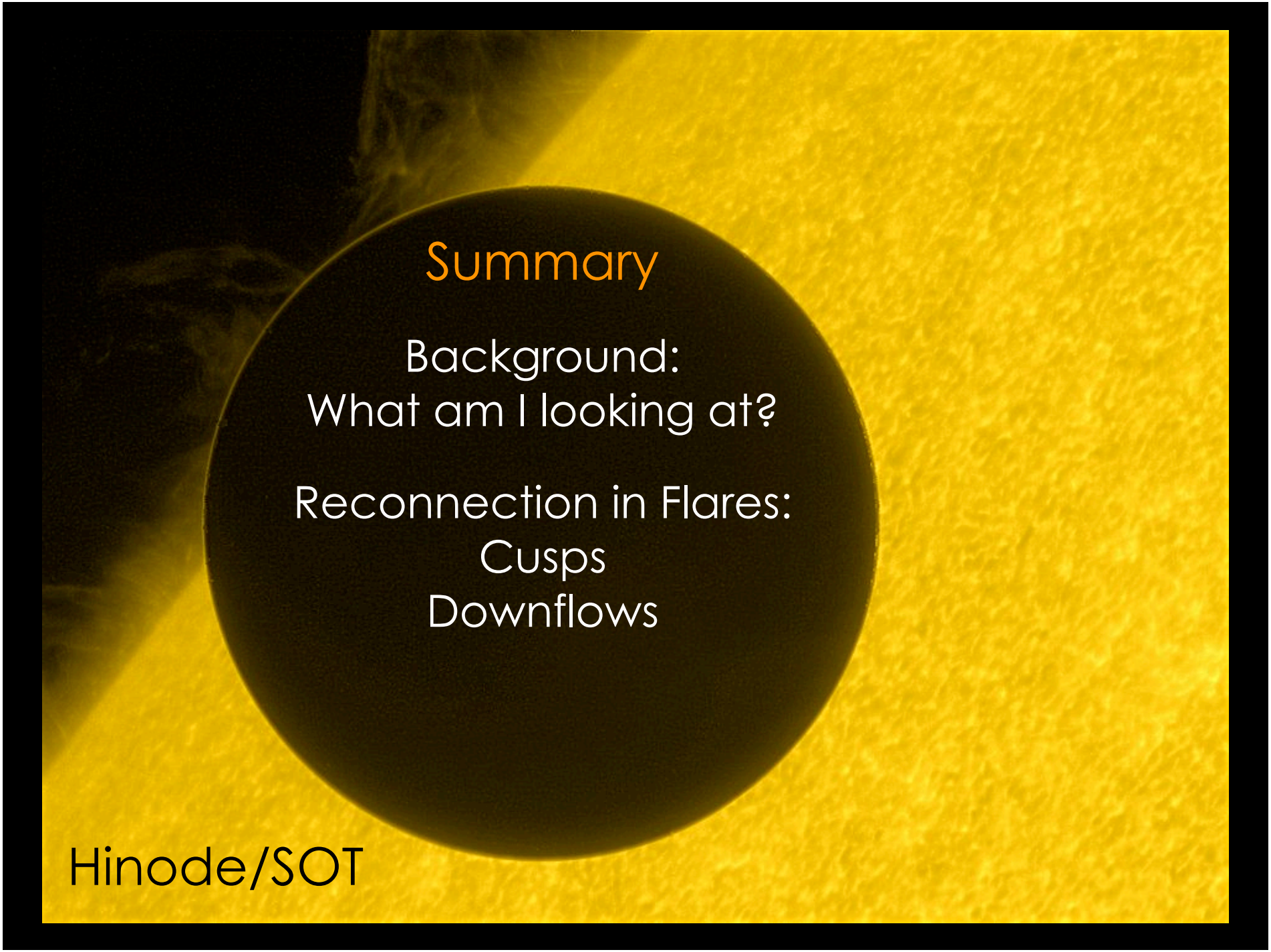
Geospace Environment Modeling 2012 Summer Workshop
June 18, 2012

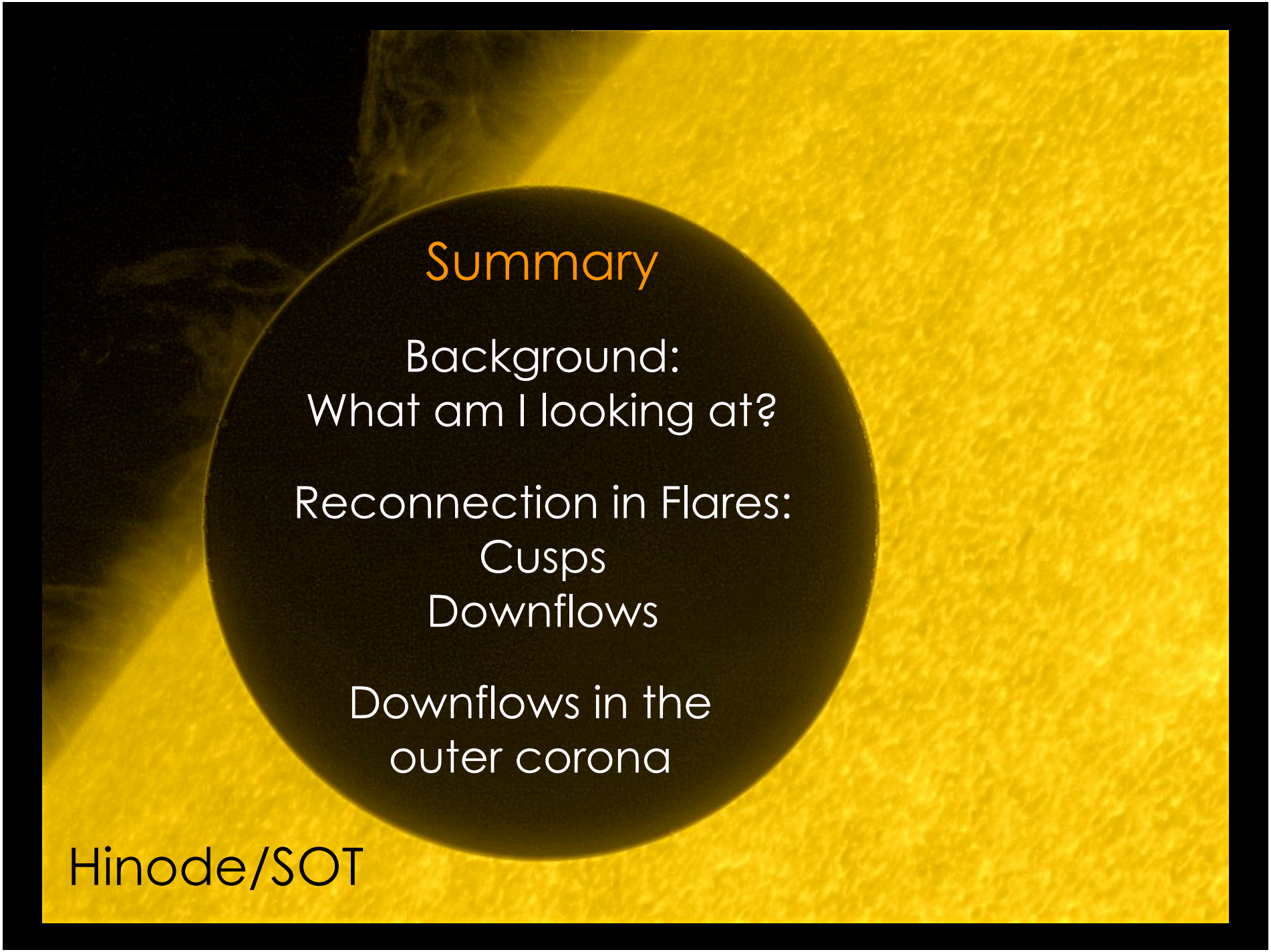

AIA/SDO
Venus Transit June 2012

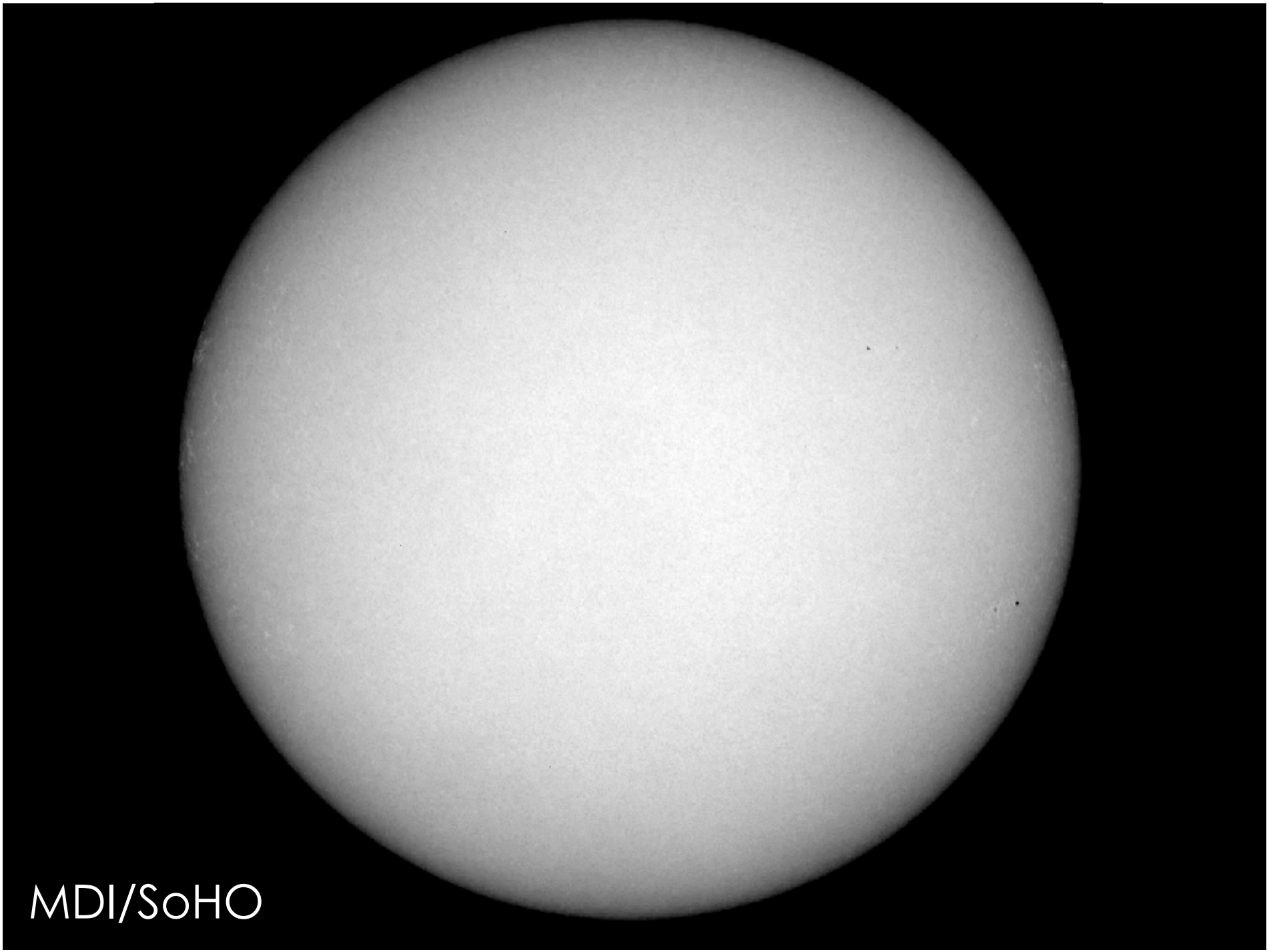

AIA/SDO 131 Å
January 27, 2012

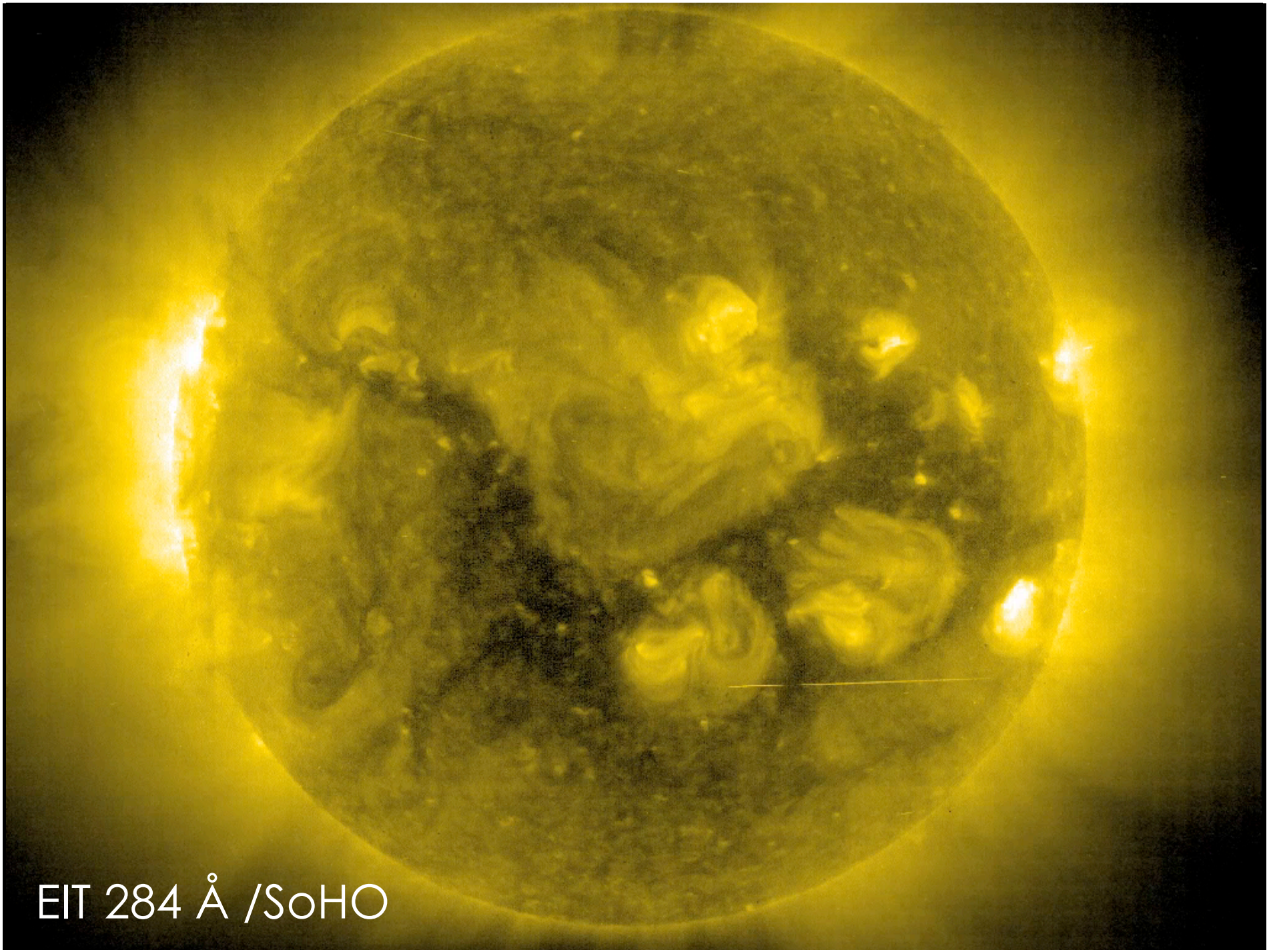

Hinode/SOT

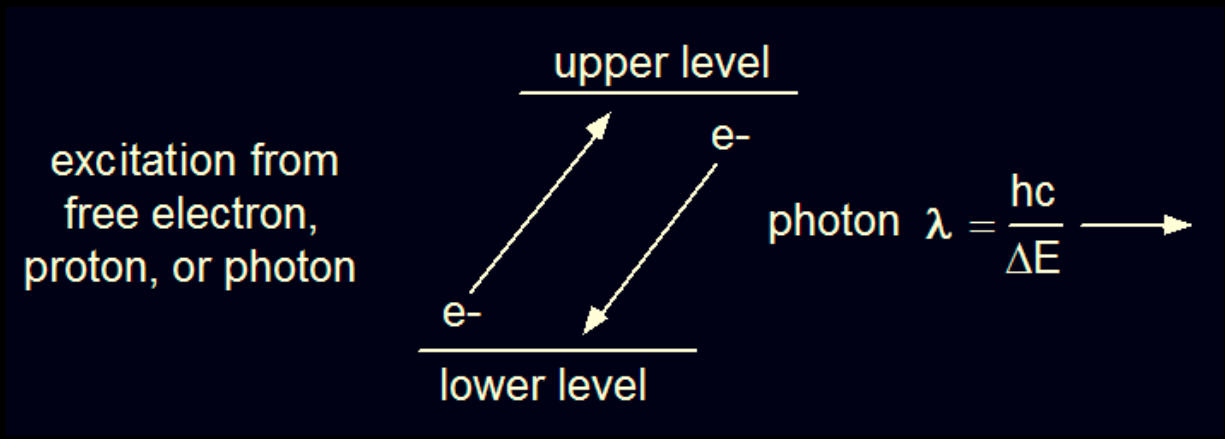

Summary
Background:
What am I looking at?
Hinode/SOT

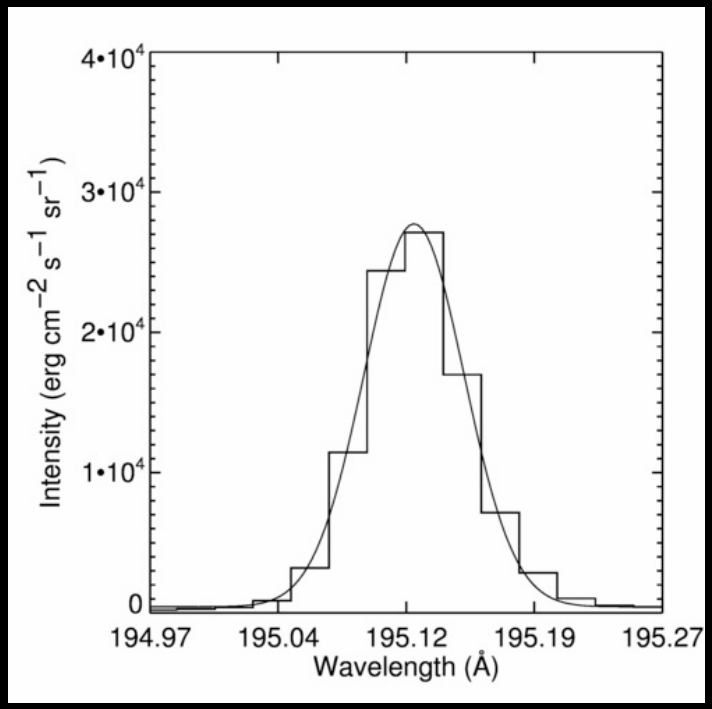

Summary
Background:
What am I looking at?
Reconnection in Flares:
Cusps
Downflows
Hinode/SOT


Summary
Background:
What am I looking at?
Reconnection in Flares:
Cusps
Downflows
Downflows in the
outer corona
Hinode/SOT

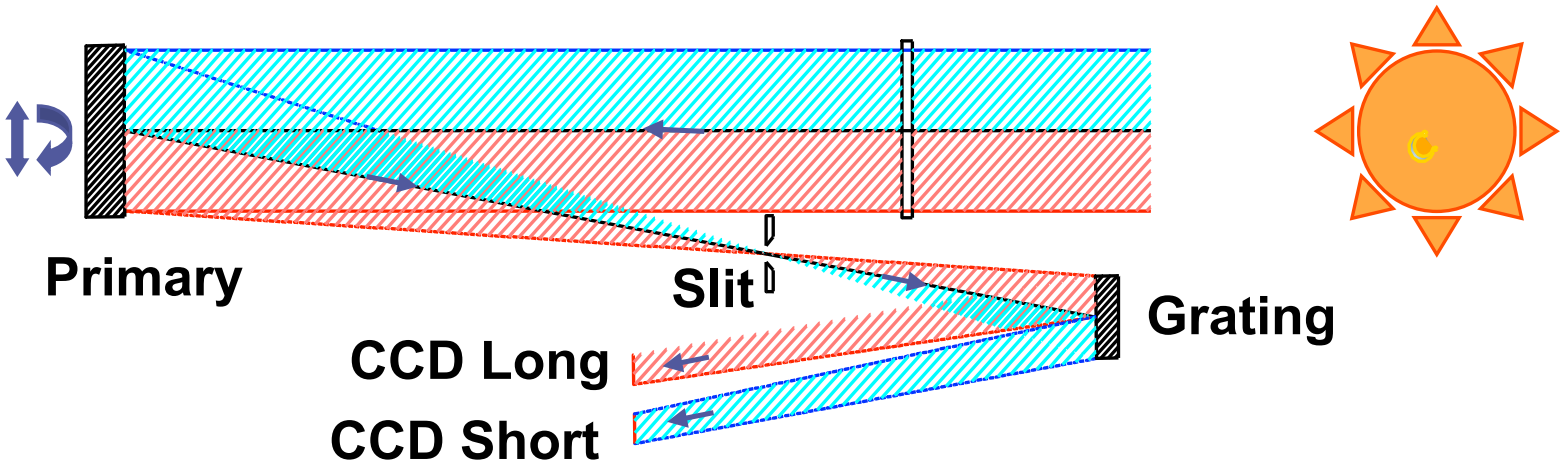

MDI/SoHO

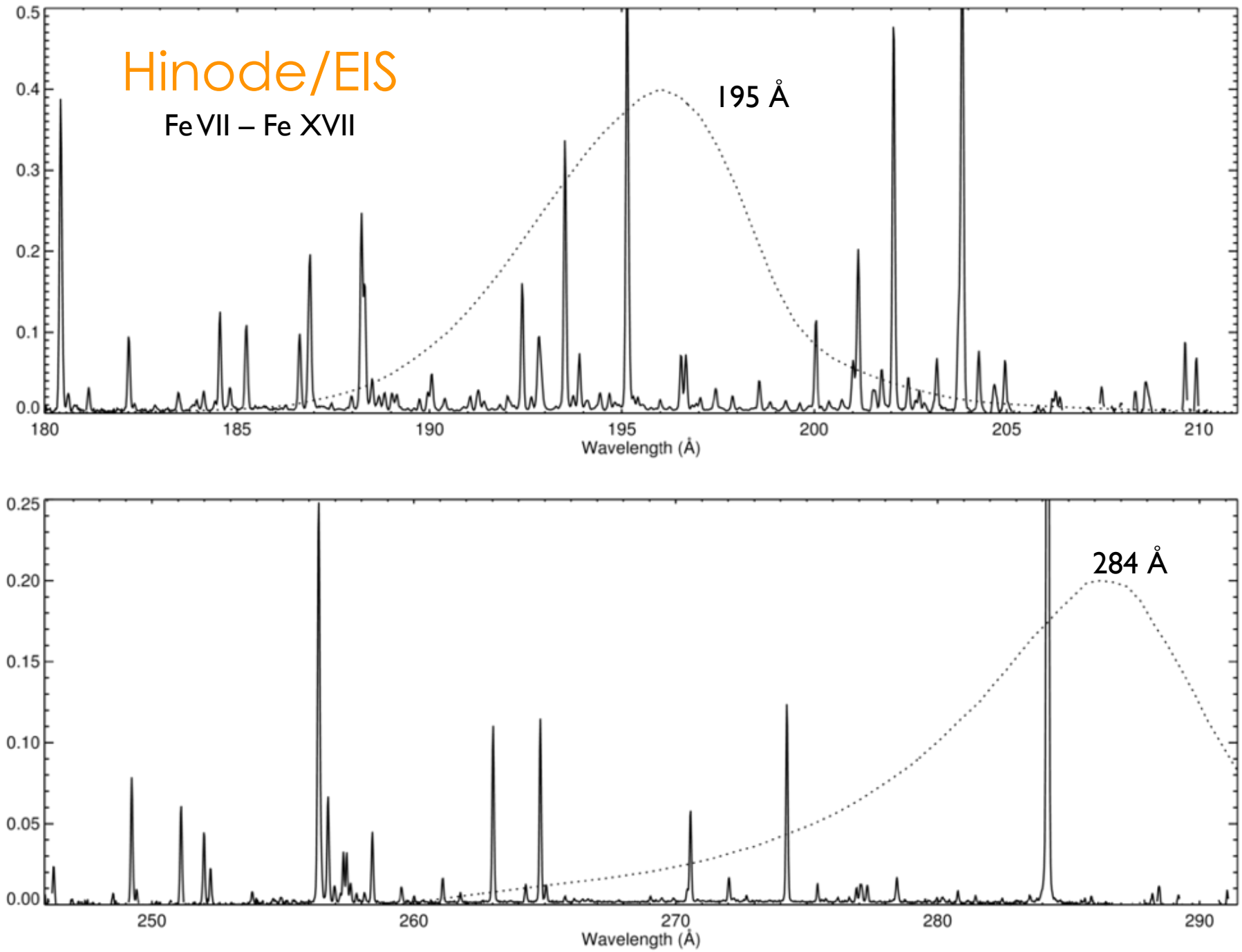

EIT 284 Å /SoHO

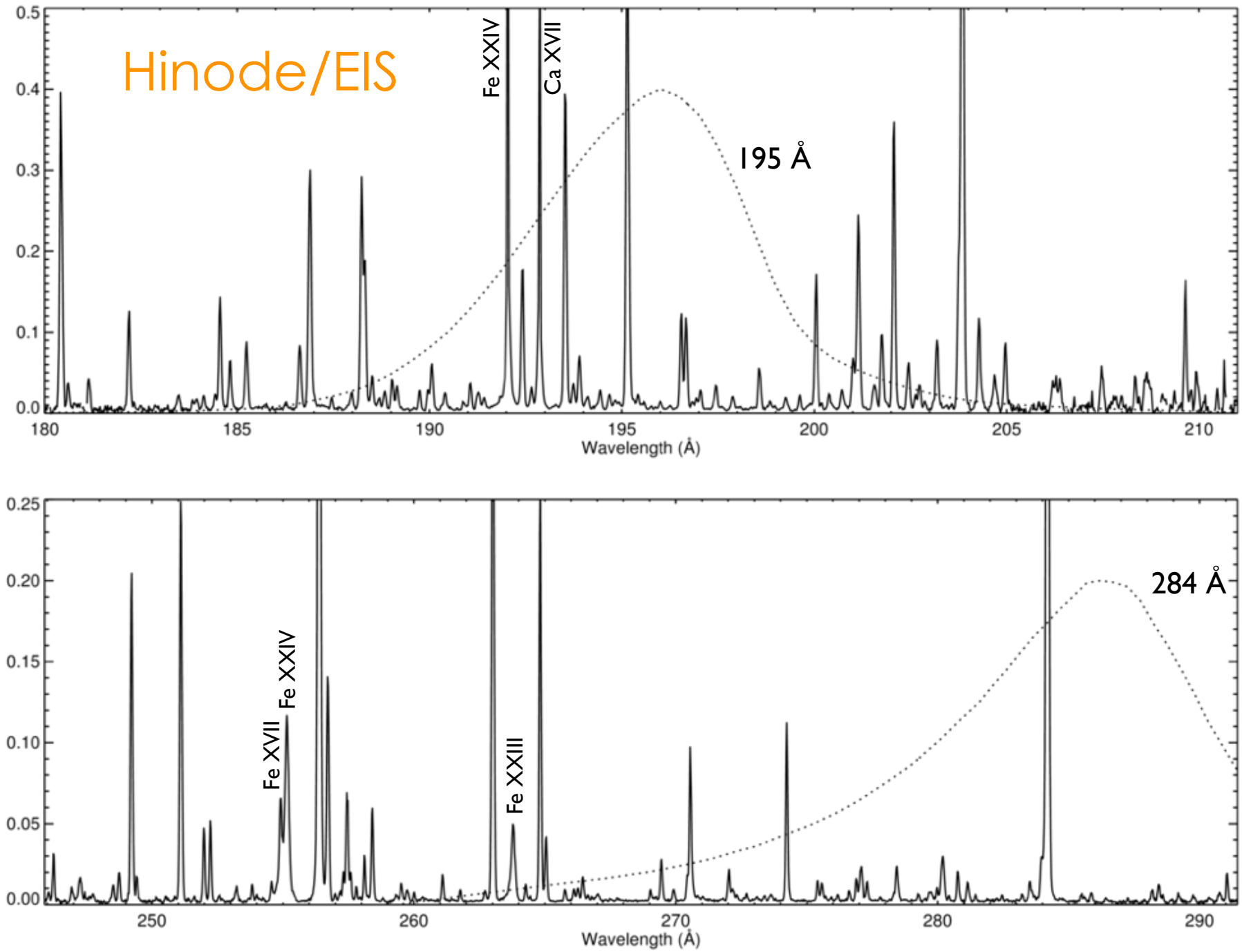


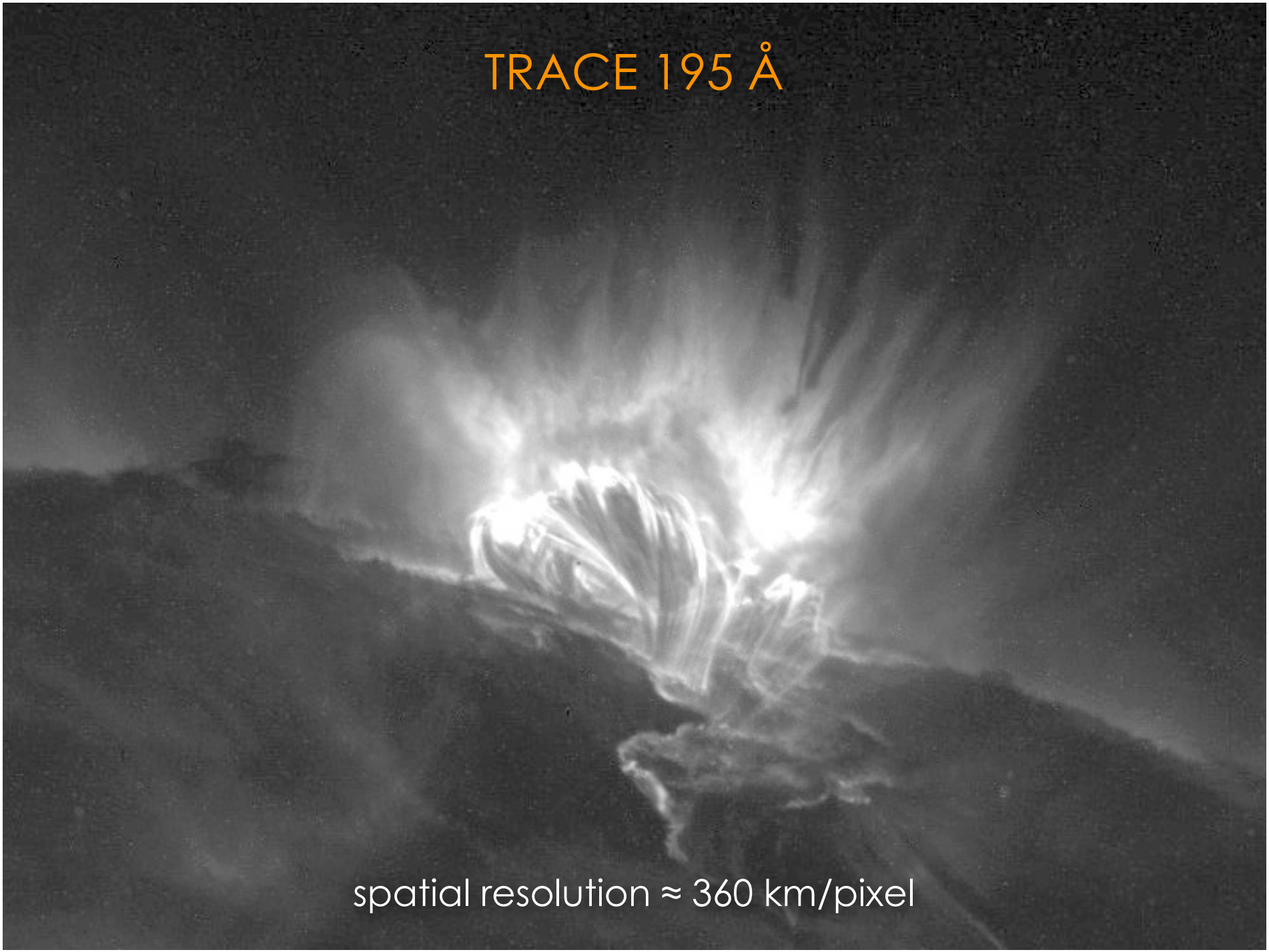


Fe XII 195.119 Å


Primary
Slit
Grating
CCD Long
CCD Short

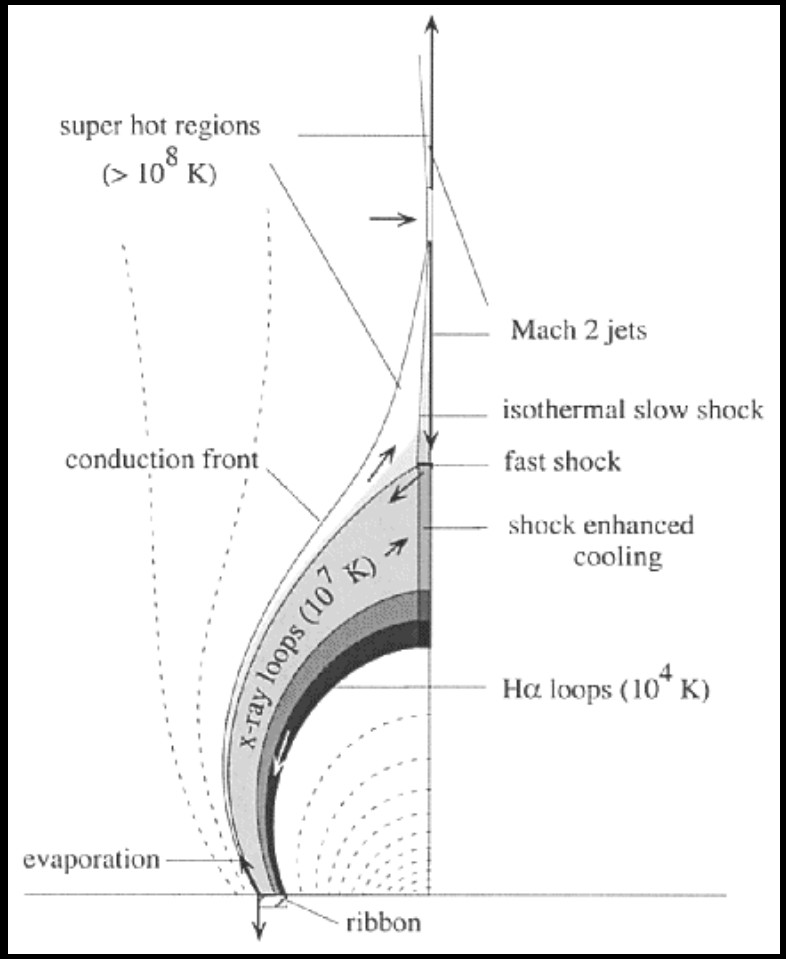

Hinode/EIS
Fe VII – Fe XVII
195 Å
284 Å
Wavelength (Å)
Wavelength (Å)


Hinode/EIS
Fe XXIV
Ca XVII
195 Å
Wavelength (Å)
Fe XVII
Fe XXIV
Fe XXIII
284 Å
Wavelength (Å)


TRACE 195 Å
spatial resolution ≈ 360 km/pixel

The Cusp as "Visual Proof"

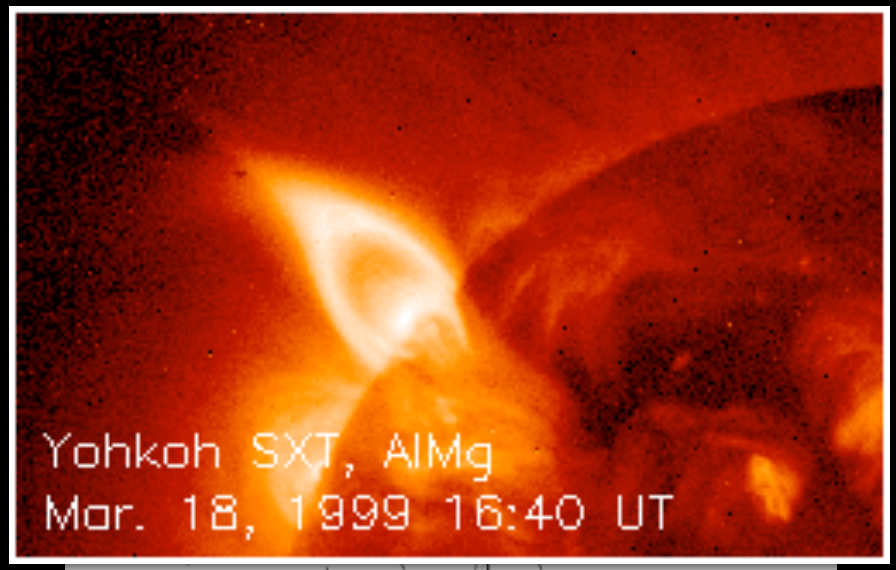
The Cusp as "Visual Proof"

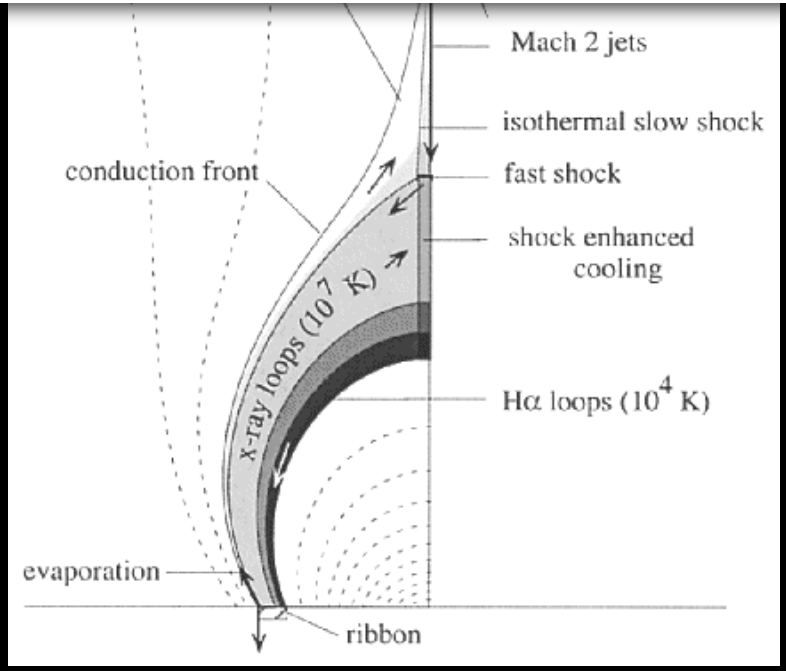


Forbes & Acton, ApJ, 1996

The Cusp as "Visual Proof"

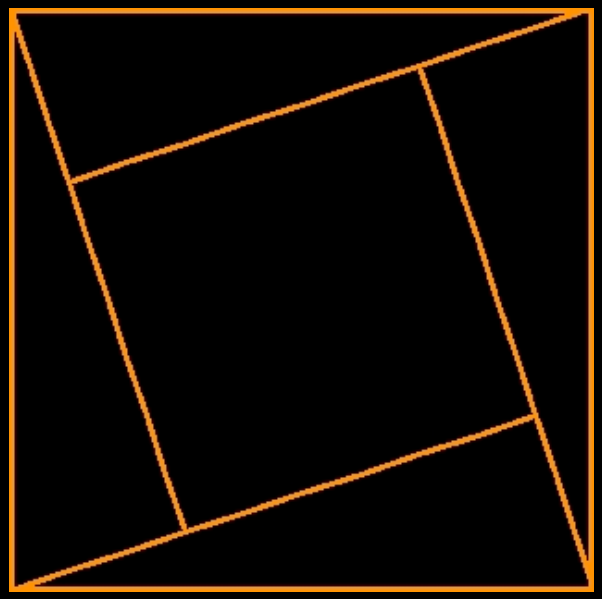
"A Magnificent Cusp"
Hugh Hudson/Yohkoh Science Nugget





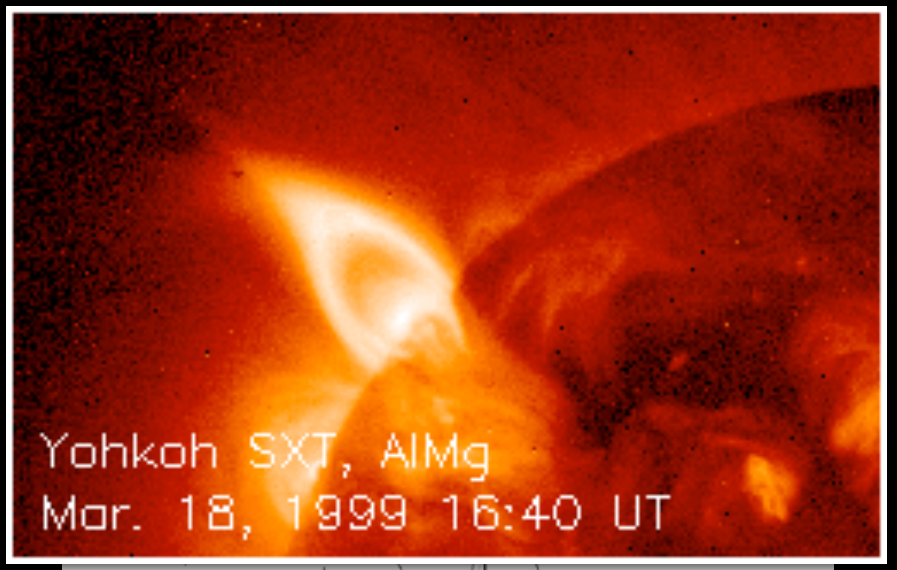
Forbes & Acton, ApJ, 1996

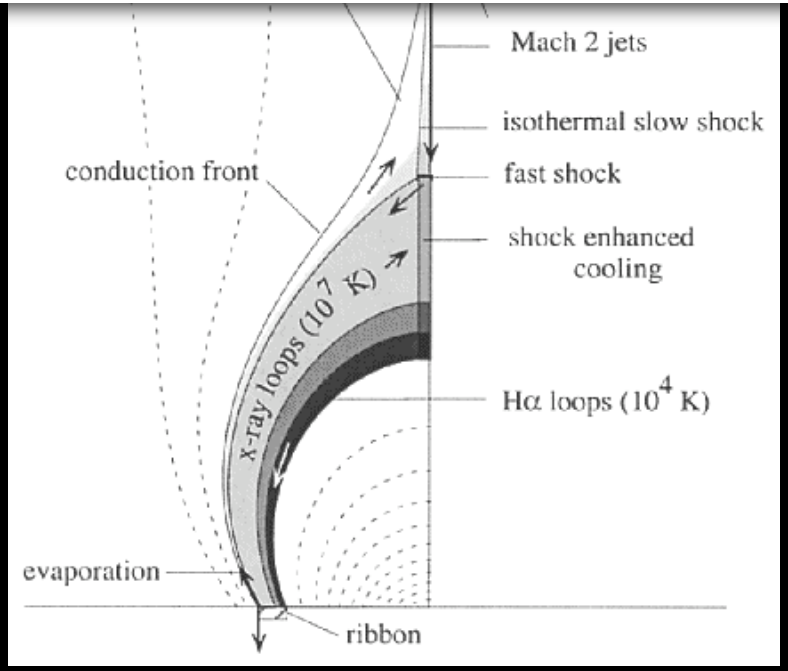
The Cusp as "Visual Proof"



"Behold!"
proof of the Pythagorean Theorem
Bhaskara II (1114-1185)

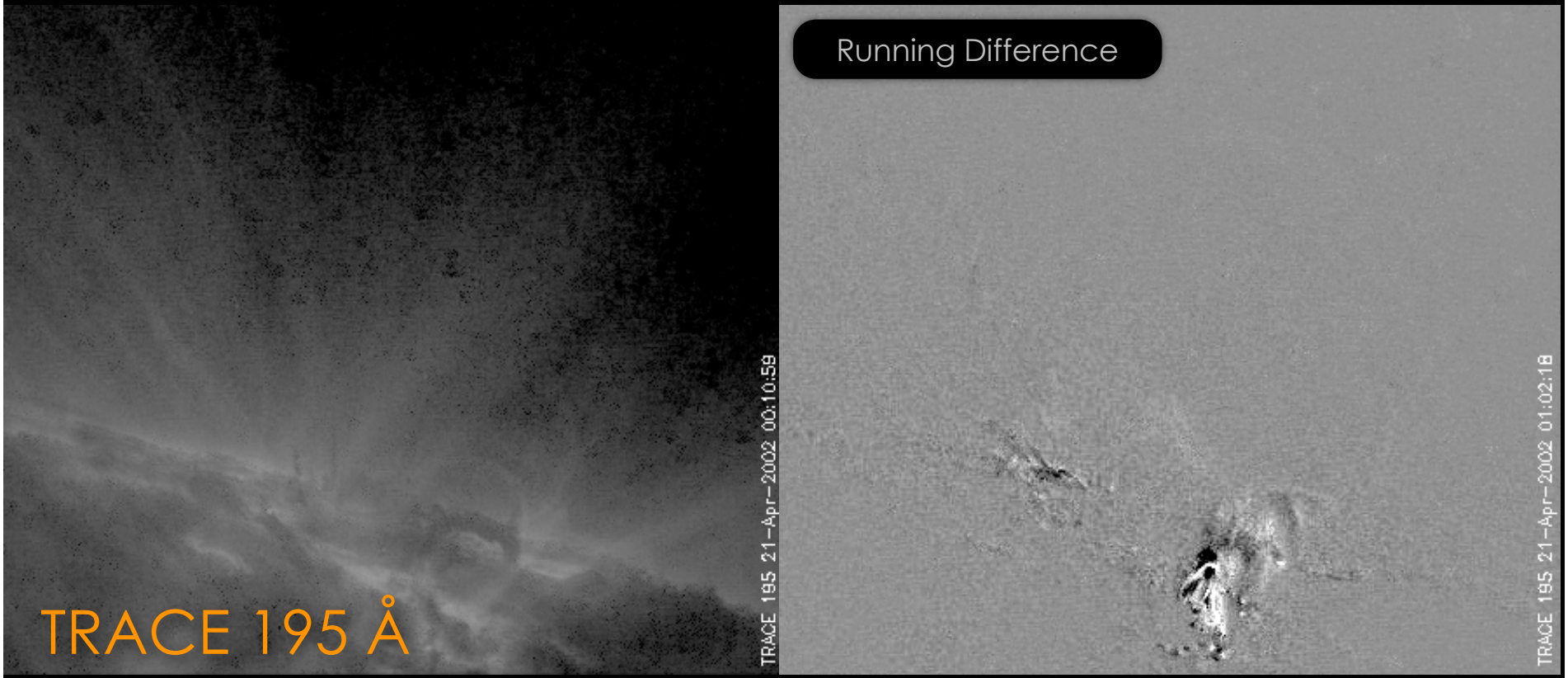
"A Magnificent Cusp"
Hugh Hudson/Yohkoh Science Nugget



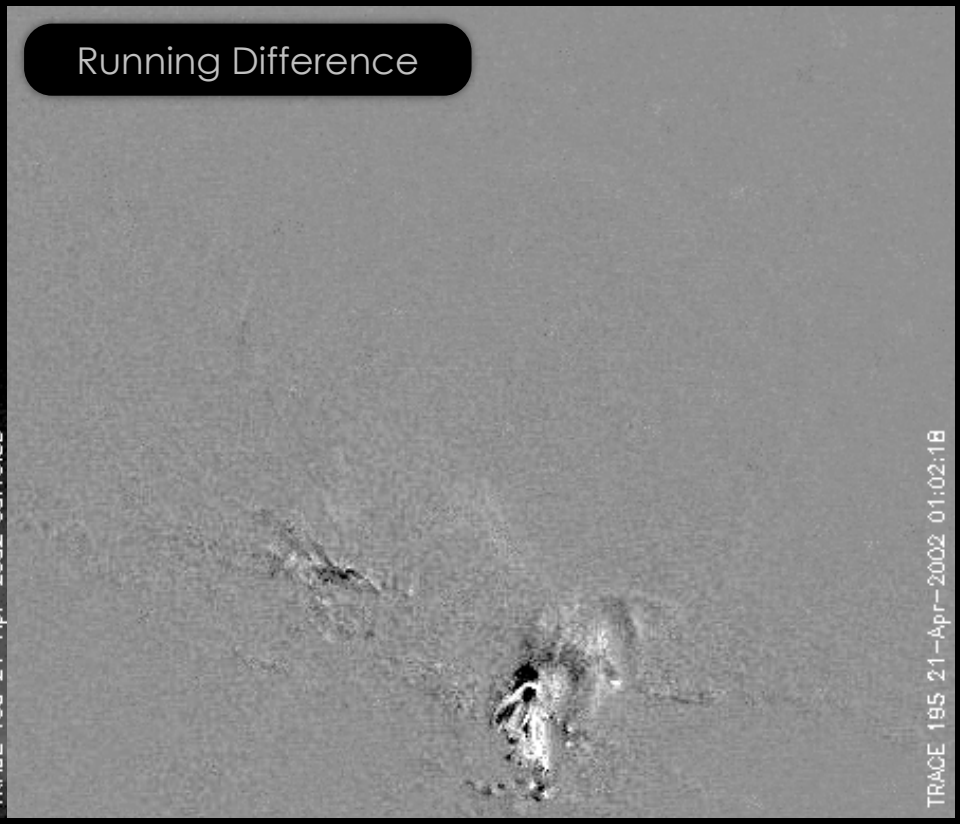


Forbes & Acton, ApJ, 1996

Supra-Arcade Downflows



Supra-Arcade Downflows



- McKenzie & Hudson, ApJ, 1999
- McKenzie, Solar Physics, 2000
- Innes et al., Solar Physics, 2003
- Asai et al., ApJ, 2004
- Sheeley, Warren, & Wang, ApJ, 2004
- Reeves et al., JGRA, 2008
- Warren et al., ApJ, 2011
- Savage & McKenzie, ApJ, 2011
- Takasao et al., ApJ, 2012
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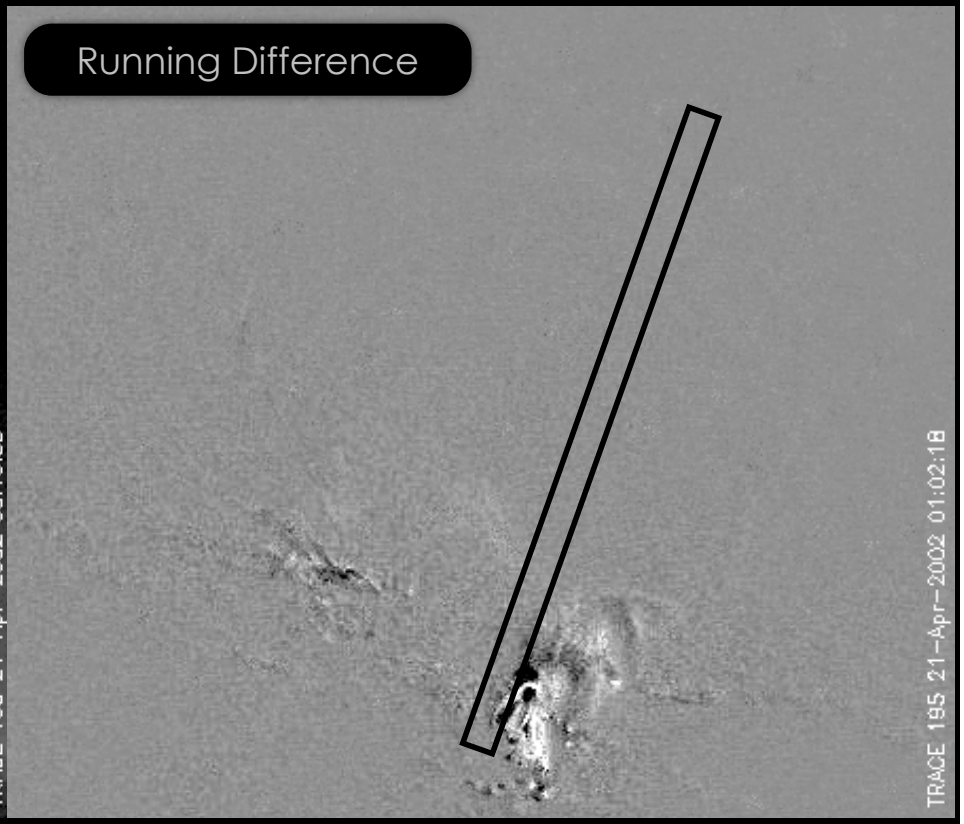
Supra-Arcade Downflows



- McKenzie & Hudson, ApJ, 1999
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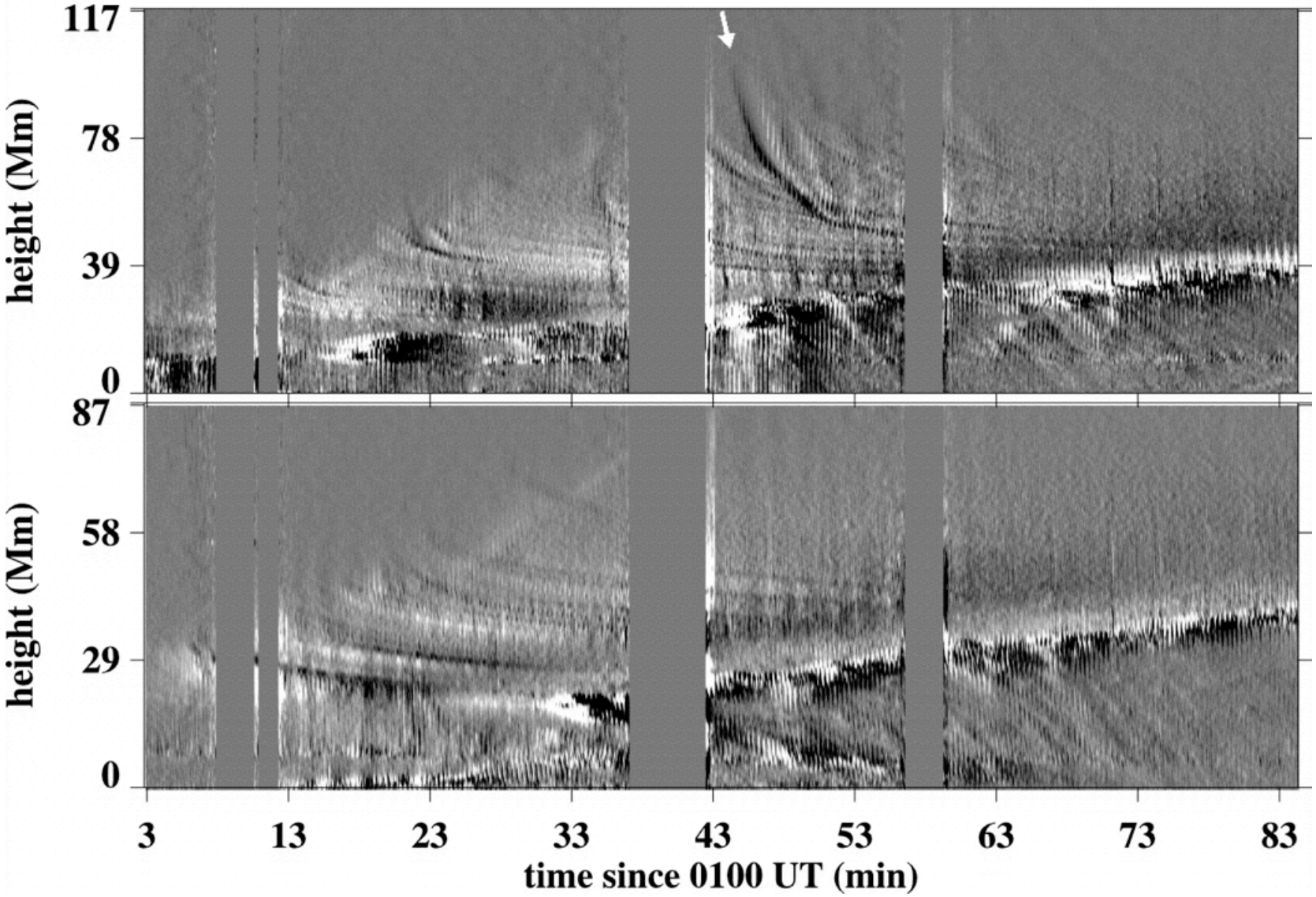
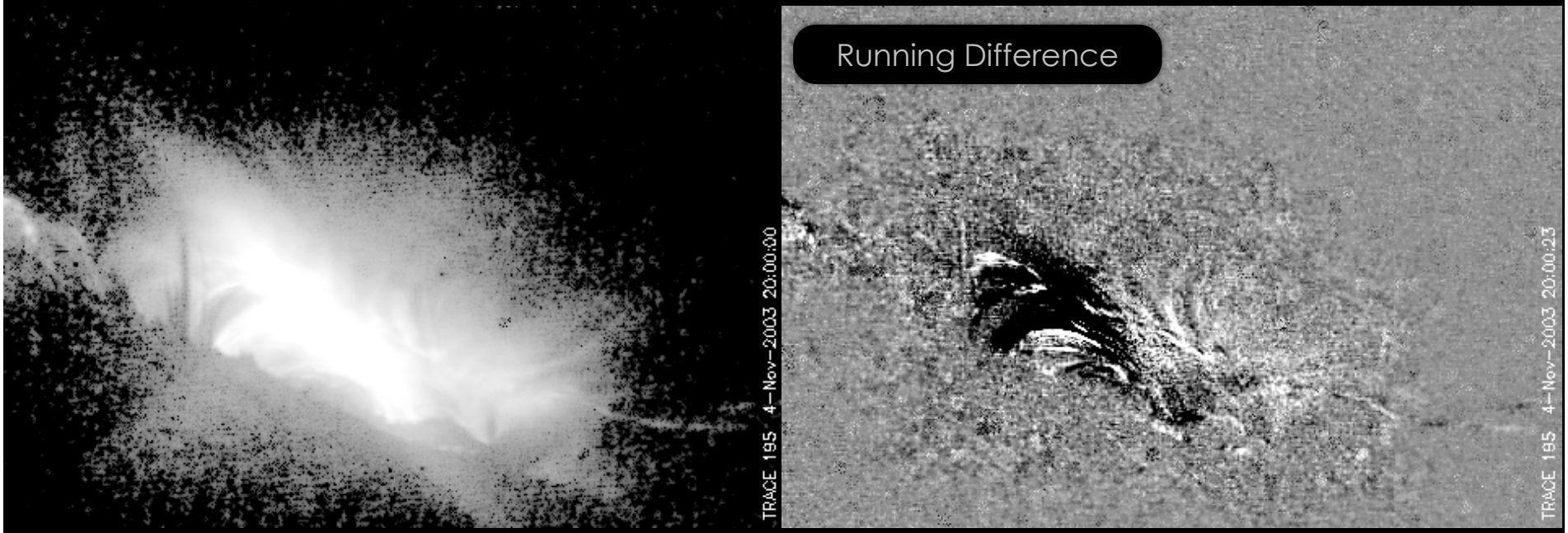
Height-Time Plot for Measuring Kinematics



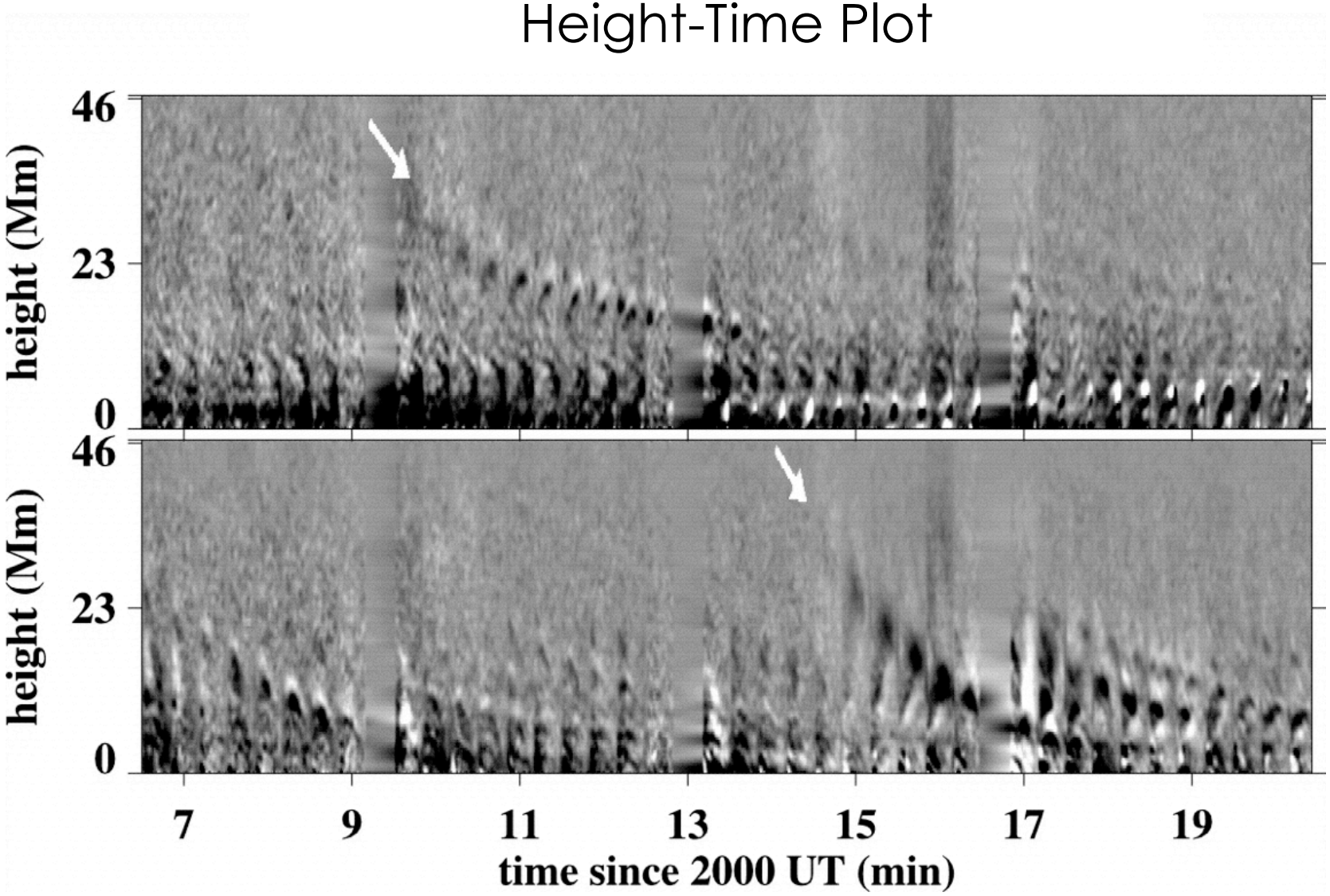
Sheeley, Warren, & Wang, ApJ, 2004

Supra-Arcade Downflows: Another Example

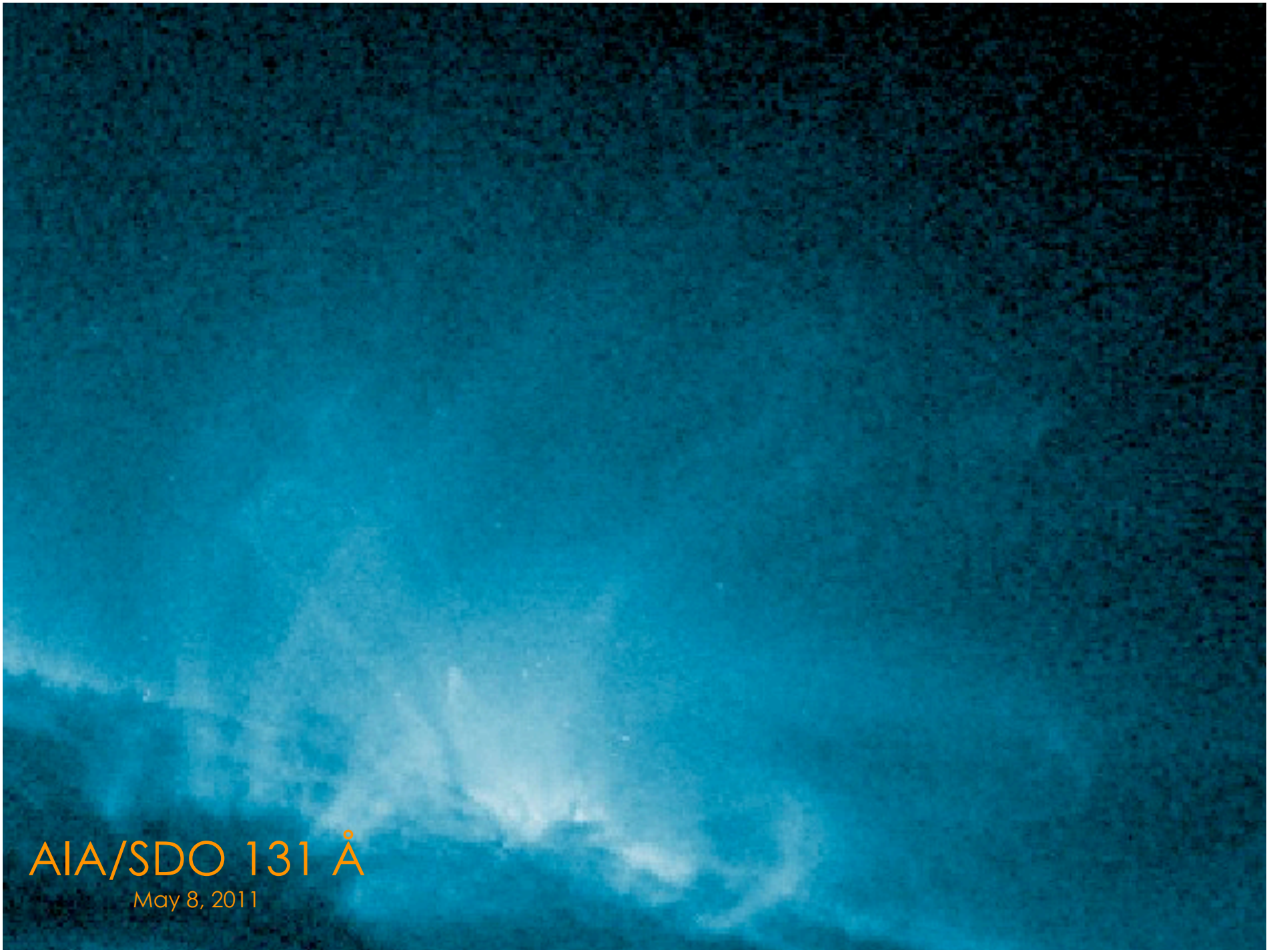


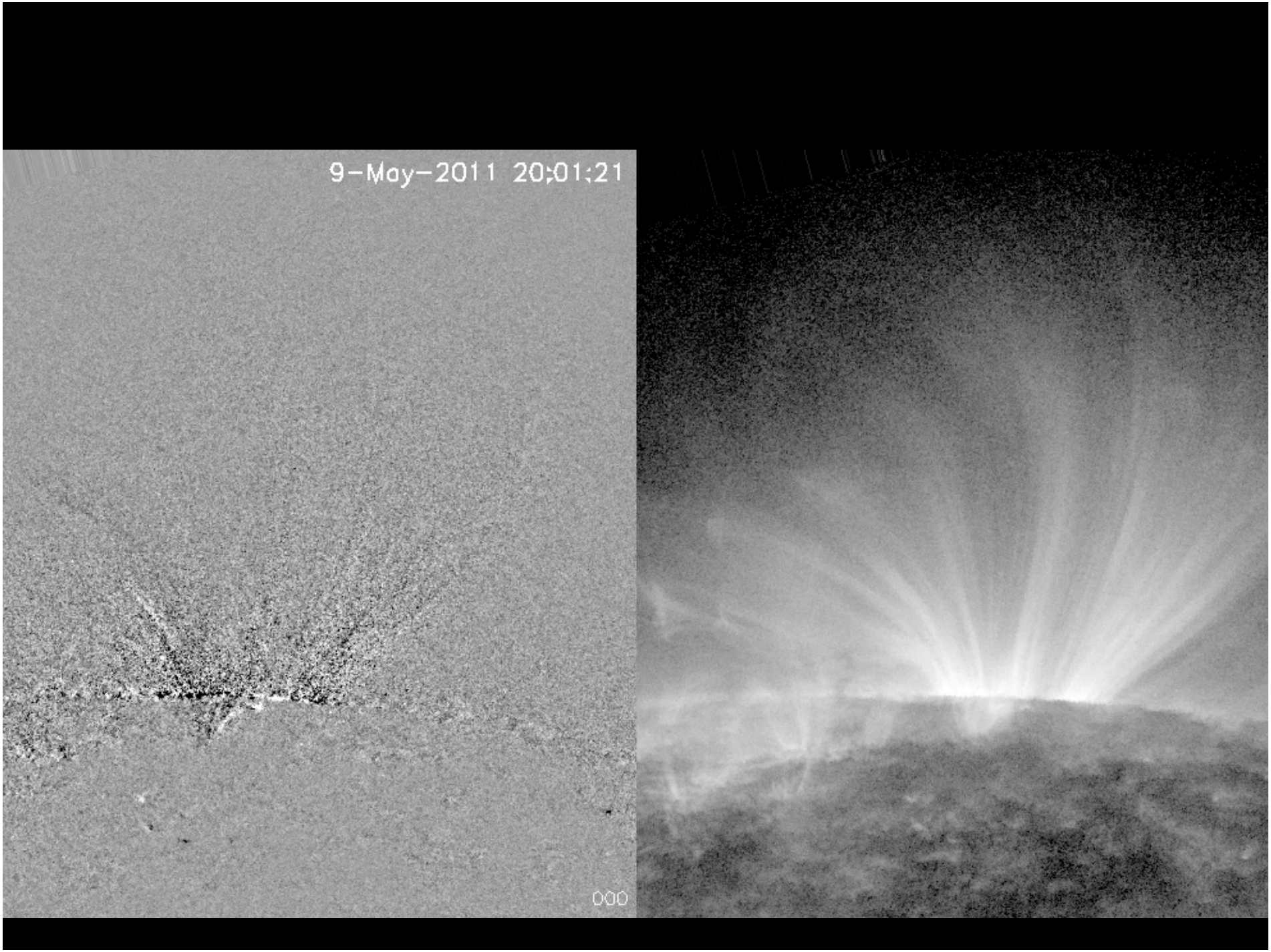
TRACE 195 Å

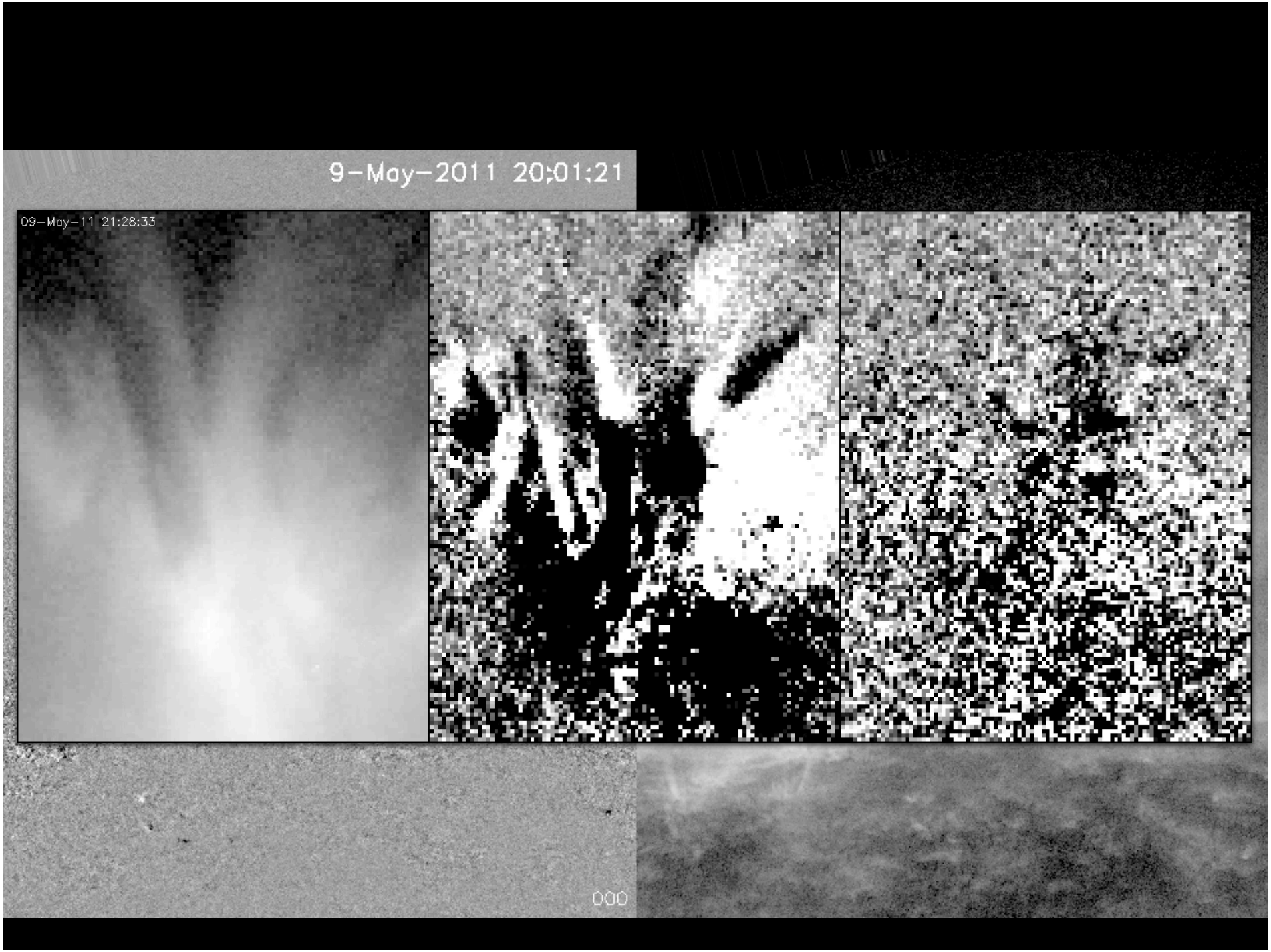
Height-Time Plot



Sheeley, Warren, & Wang, ApJ, 2004


AIA/SDO 131 Å
May 8, 2011


9-May-2011 20;01;21
000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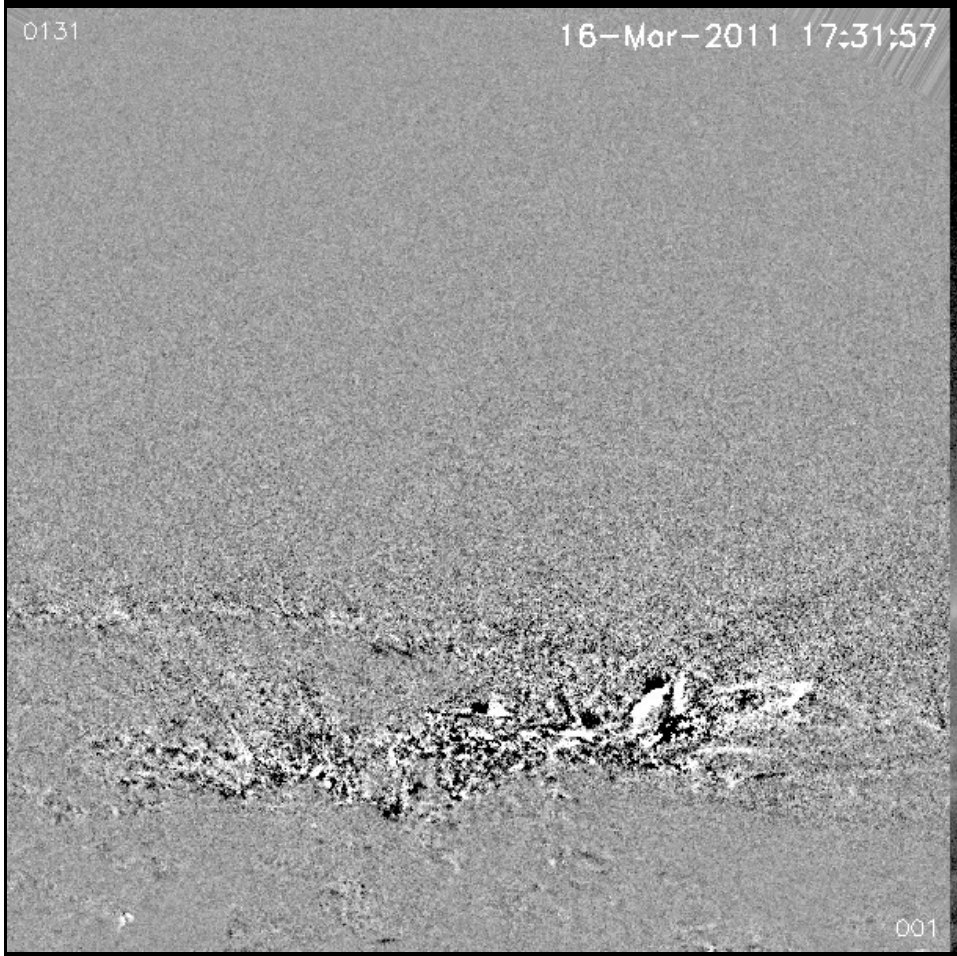
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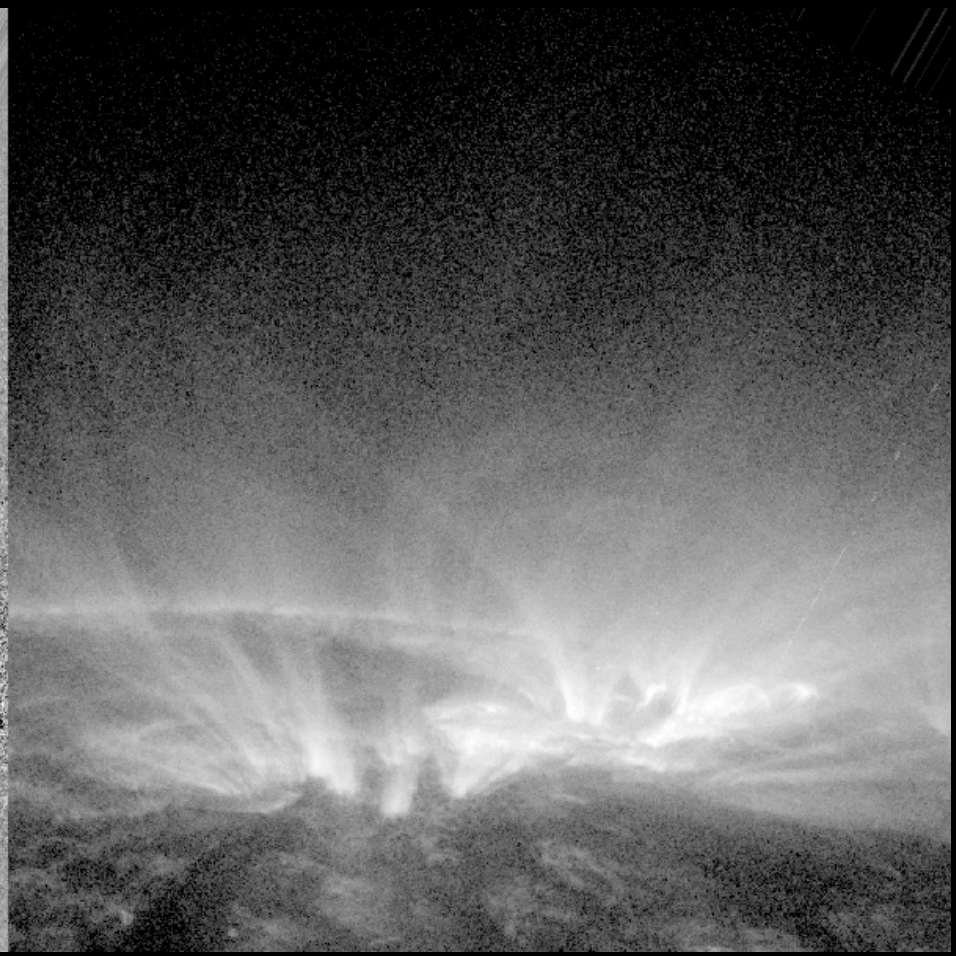
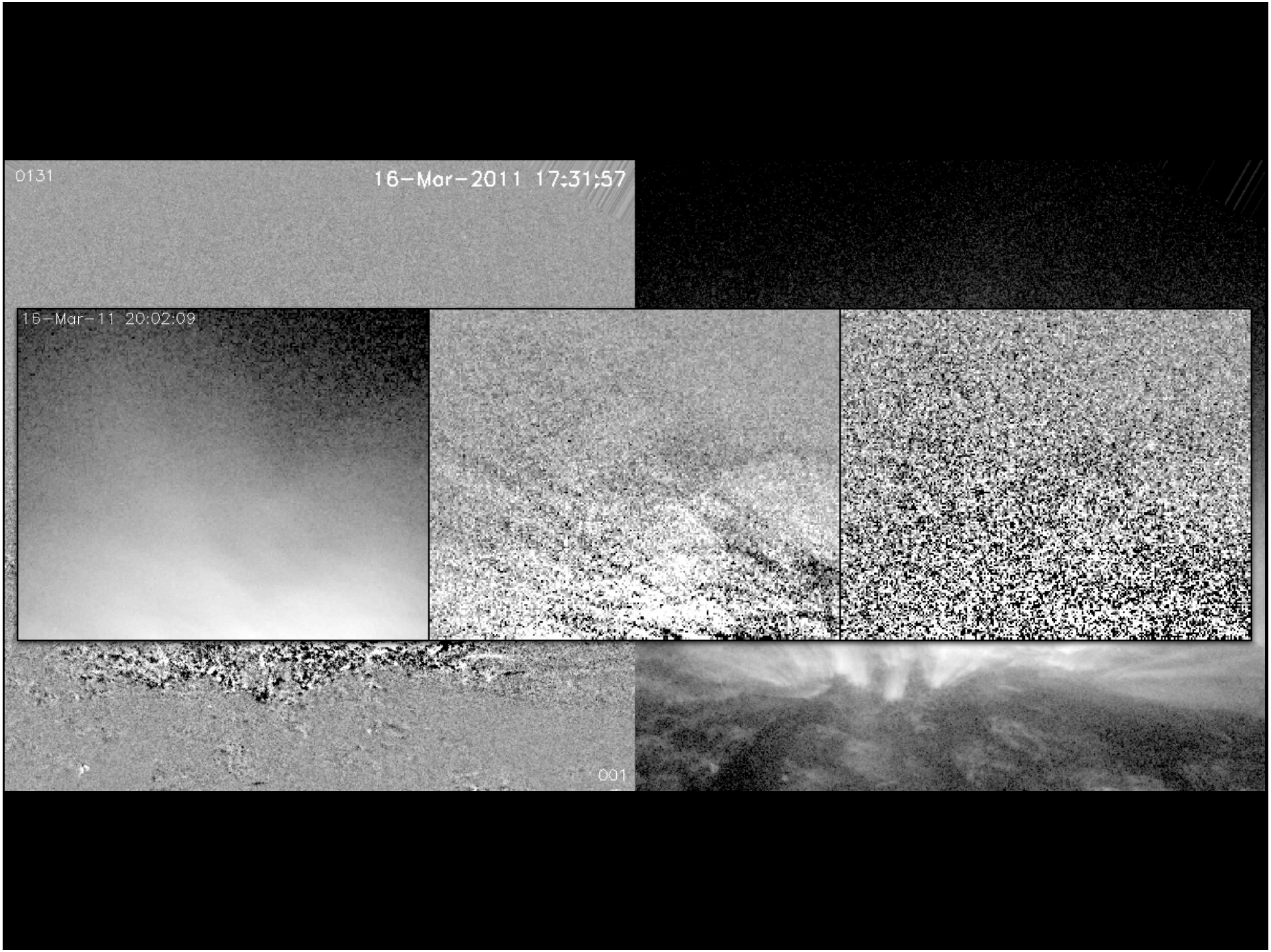
16-Mar-2011 17:31:57
001
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16-Mar-2011 17:31:57
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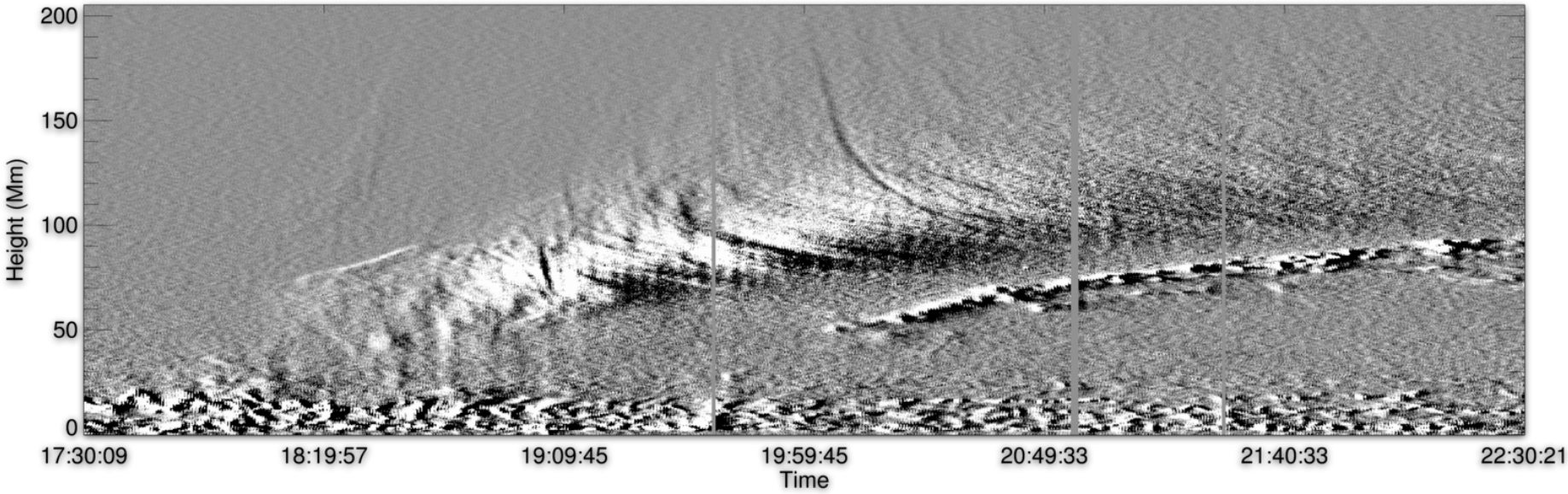
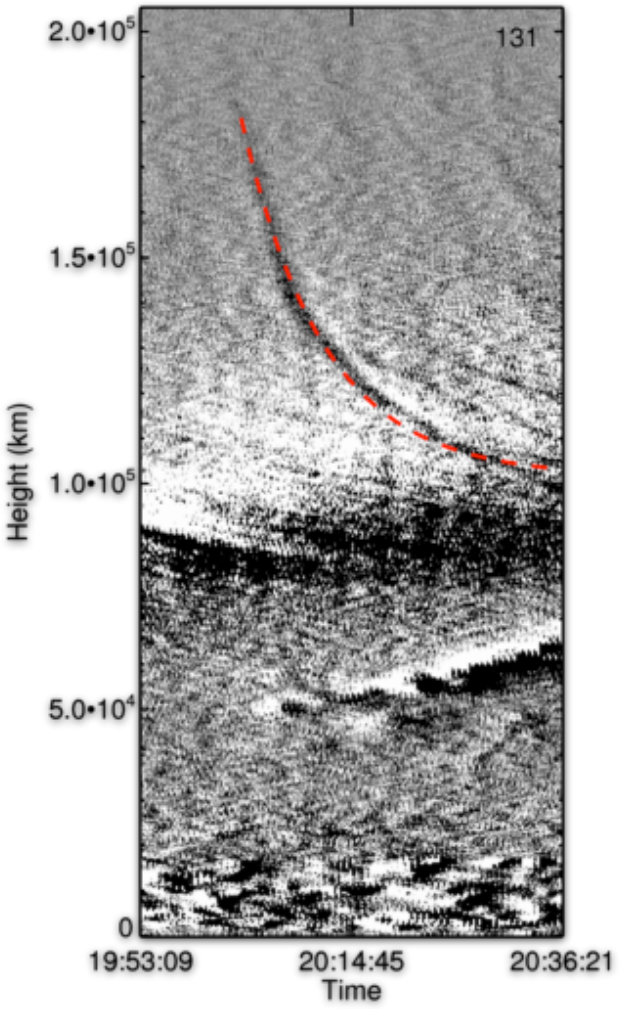
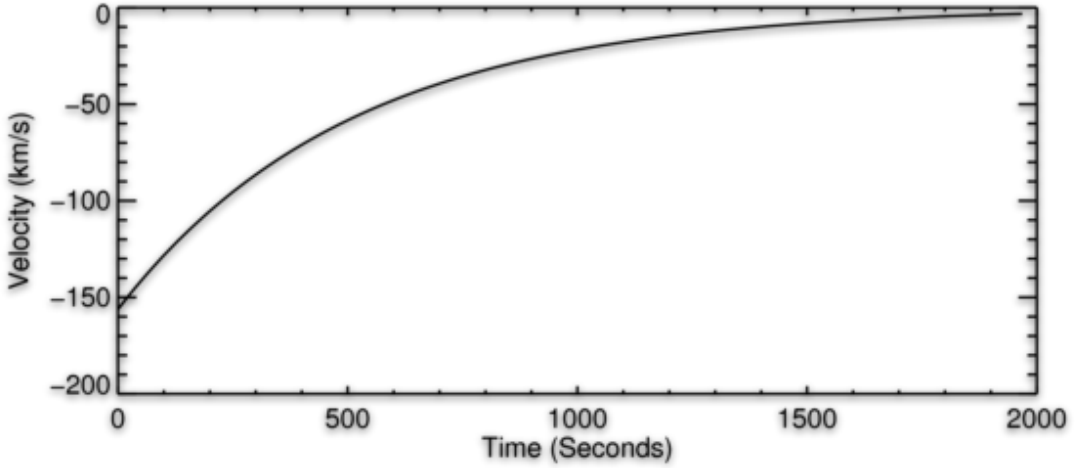
Height-Time Plot: March 16, 2011

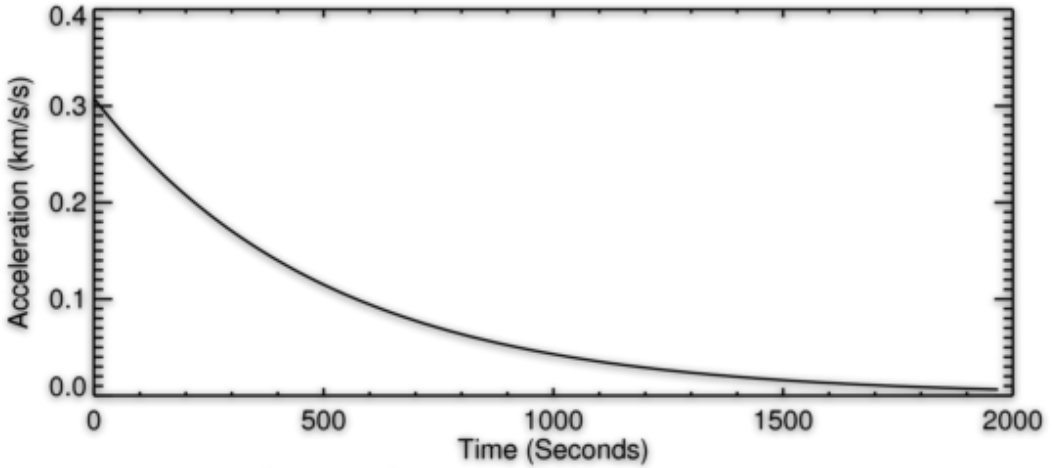
SDO/AIA 131 Å



Example Height Time Track: March 16, 2011







$$h(t) = h_0 + v_T t + a_0 \tau^2 (e^{-t/\tau} - 1)$$

$$v(t) = v_T - a_0 \tau e^{-t/\tau}$$

$$a(t) = a_0 e^{-t/\tau}$$

TABLE 1
INFLOW PROPERTIES

Track	h_0 (Mm)	a_0 (km s^{-2})	τ (s)	v_0 (km s^{-1})	v_T (km s^{-1})
16 March 2011					
00	132.6	0.039	831.7	-32.1	0.0
01	149.0	2.282	119.0	-271.6	0.0
02	178.6	0.274	454.1	-124.5	0.0
03	196.6	0.492	290.6	-143.0	0.0
04	204.3	0.857	226.7	-194.2	0.0
05	136.5	0.619	261.2	-161.7	0.0
06	188.9	0.271	500.6	-135.8	0.0
07	180.9	0.308	507.7	-156.2	0.0
08	225.6	0.089	1031.3	-91.7	0.0
09	250.4	0.044	1938.6	-84.6	0.0
9 May 2011					
00	113.6	2.185	128.1	-279.9	0.0
01	118.9	1.043	212.5	-221.7	0.0
02	131.1	1.506	166.6	-250.9	0.0
03	117.6	0.581	231.3	-134.3	0.0
04	128.2	0.440	345.3	-152.1	0.0
05	110.8	0.161	406.1	-65.3	0.0
06	63.8	0.087	659.1	-57.1	0.0
07	82.0	0.237	363.8	-86.1	0.0
08	80.4	1.050	115.6	-121.3	0.0
09	103.7	0.786	192.2	-151.1	0.0
10	73.8	0.306	245.1	-75.1	0.0
11	90.9	0.375	270.7	-101.7	0.0
18 May 2011					
00	75.2	2.687	102.1	-274.4	0.0
01	84.7	2.726	97.1	-264.8	0.0
02	83.3	0.451	274.1	-123.7	0.0
03	70.5	3.407	77.7	-264.8	0.0
04	61.7	1.190	120.0	-142.8	0.0
05	75.1	0.867	165.8	-143.7	0.0
06	88.3	0.473	316.6	-149.9	0.0
07	70.7	1.059	155.9	-165.0	0.0
08	76.7	0.438	243.4	-106.5	0.0
09	83.1	0.403	440.2	-177.5	0.0

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08	225.6				
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00	113.6				
01	118.9				
02	131.1				
03	117.6				
04	128.2				
05	110.8				
06	63.8				
07	82.0				
08	80.4				
09	103.7				
10	73.8				
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18 May 2011					
00	75.2				
01	84.7				
02	83.3				
03	70.5				
04	61.7				
05	75.1	0.867	165.8	-143.7	0.0
06	88.3	0.473	316.6	-149.9	0.0
07	70.7	1.059	155.9	-165.0	0.0
08	76.7	0.438	243.4	-106.5	0.0
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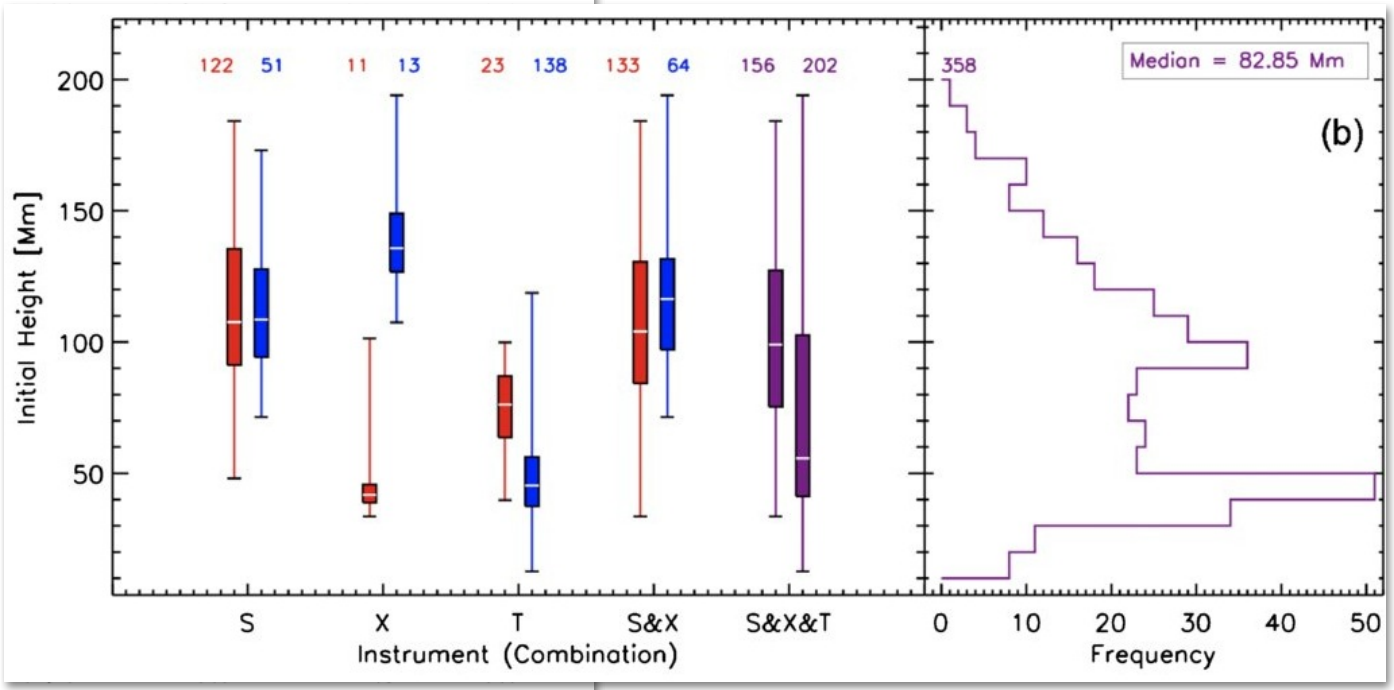
Median Initial Height

AIA: 111 km/s

Savage & McKenzie 2011: 83 km/s



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06	63.8	0.087	659.1	-57.1	0.0
07	82.0	0.237	363.8	-86.1	0.0
08	80.4	1.050	115.6	-121.3	0.0
09	103.7	0.786	192.2	-151.1	0.0
10	73.8	0.306	245.1	-75.1	0.0
11	90.9	0.375	270.7	-101.7	0.0
18 May 2011					
00	75.2	2.687	102.1	-274.4	0.0
01	84.7	2.726	97.1	-264.8	0.0
02	83.3	0.451	274.1	-123.7	0.0
03	70.5	3.407	77.7	-264.8	0.0
04	61.7	1.190	120.0	-142.8	0.0
05	75.1	0.867	165.8	-143.7	0.0
06	88.3	0.473	316.6	-149.9	0.0
07	70.7	1.059	155.9	-165.0	0.0
08	76.7	0.438	243.4	-106.5	0.0
09	83.1	0.403	440.2	-177.5	0.0

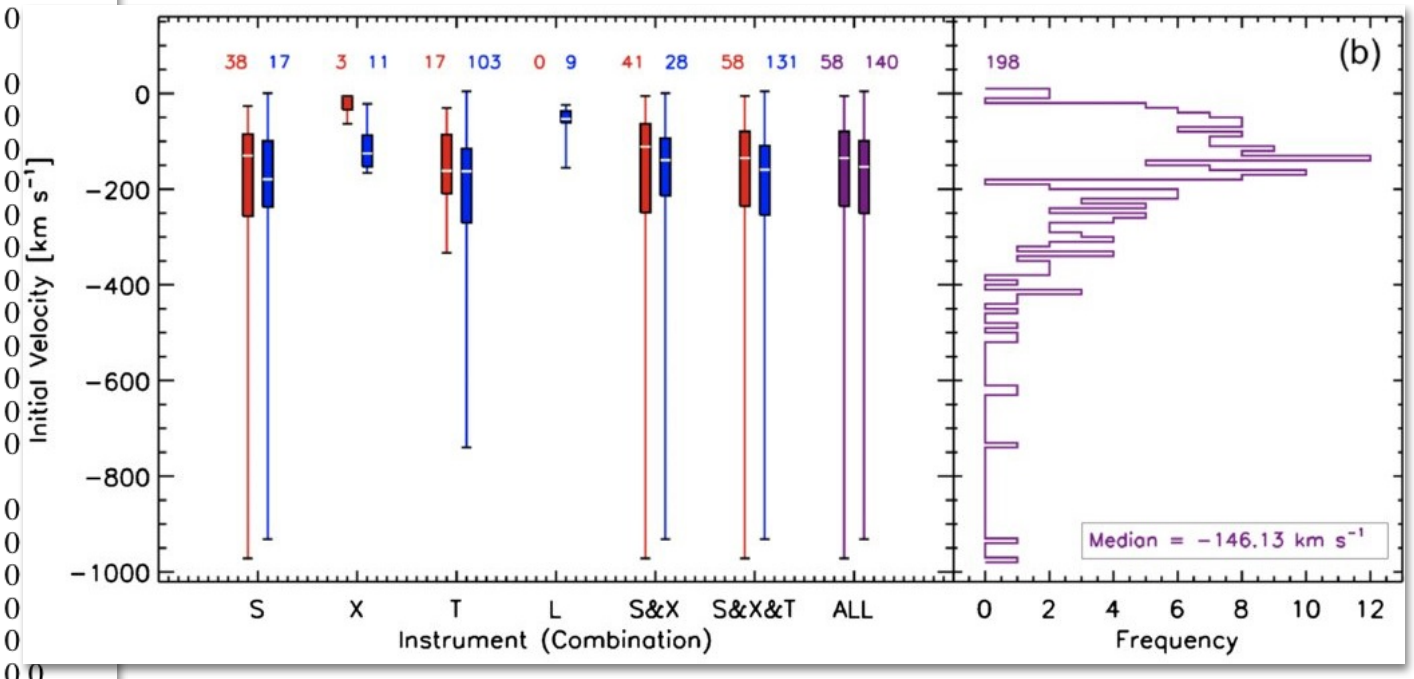
TABLE 1
W PROPERTIES

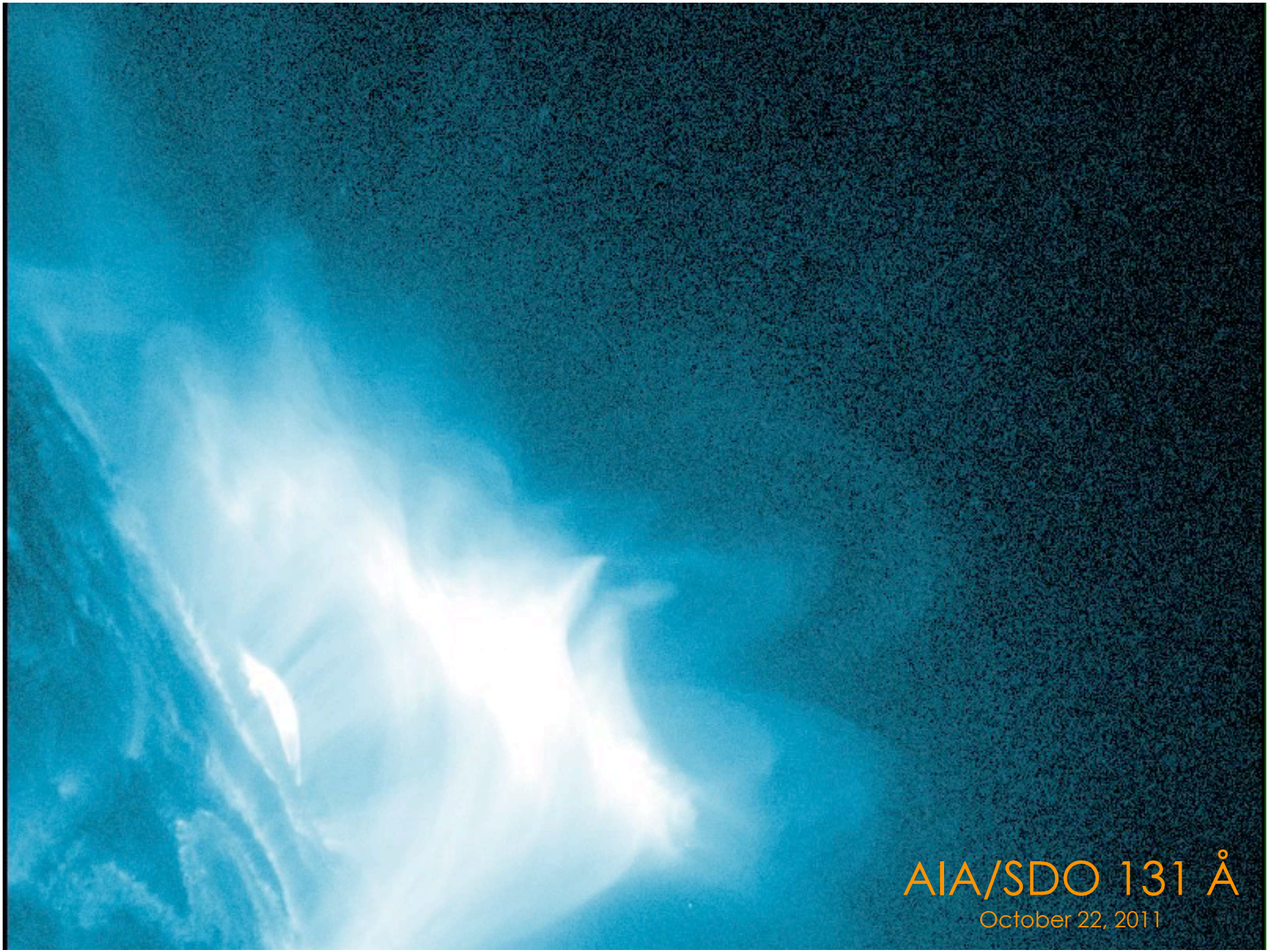
	τ (s)	v_0 (km s^{-1})	v_T (km s^{-1})
	831.7	-32.1	0.0
	119.0	-271.6	0.0
	454.1	-124.5	0.0
	290.6	-143.0	0.0
	226.7	-194.2	0.0
	261.2	-161.7	0.0
	500.6	-135.8	0.0
	507.7	-156.2	0.0
	1031.3	-91.7	0.0
	1938.6	-84.6	0
	128.1	-279.9	0
	212.5	-221.7	0
	166.6	-250.9	0
	231.3	-134.3	0
	345.3	-152.1	0
	406.1	-65.3	0
	659.1	-57.1	0
	363.8	-86.1	0
	115.6	-121.3	0
	192.2	-151.1	0
	245.1	-75.1	0
	270.7	-101.7	0
	102.1	-274.4	0
	97.1	-264.8	0
	274.1	-123.7	0
	77.7	-264.8	0
	120.0	-142.8	0
	165.8	-143.7	0.0
	316.6	-149.9	0.0
	155.9	-165.0	0.0
	243.4	-106.5	0.0
	440.2	-177.5	0.0

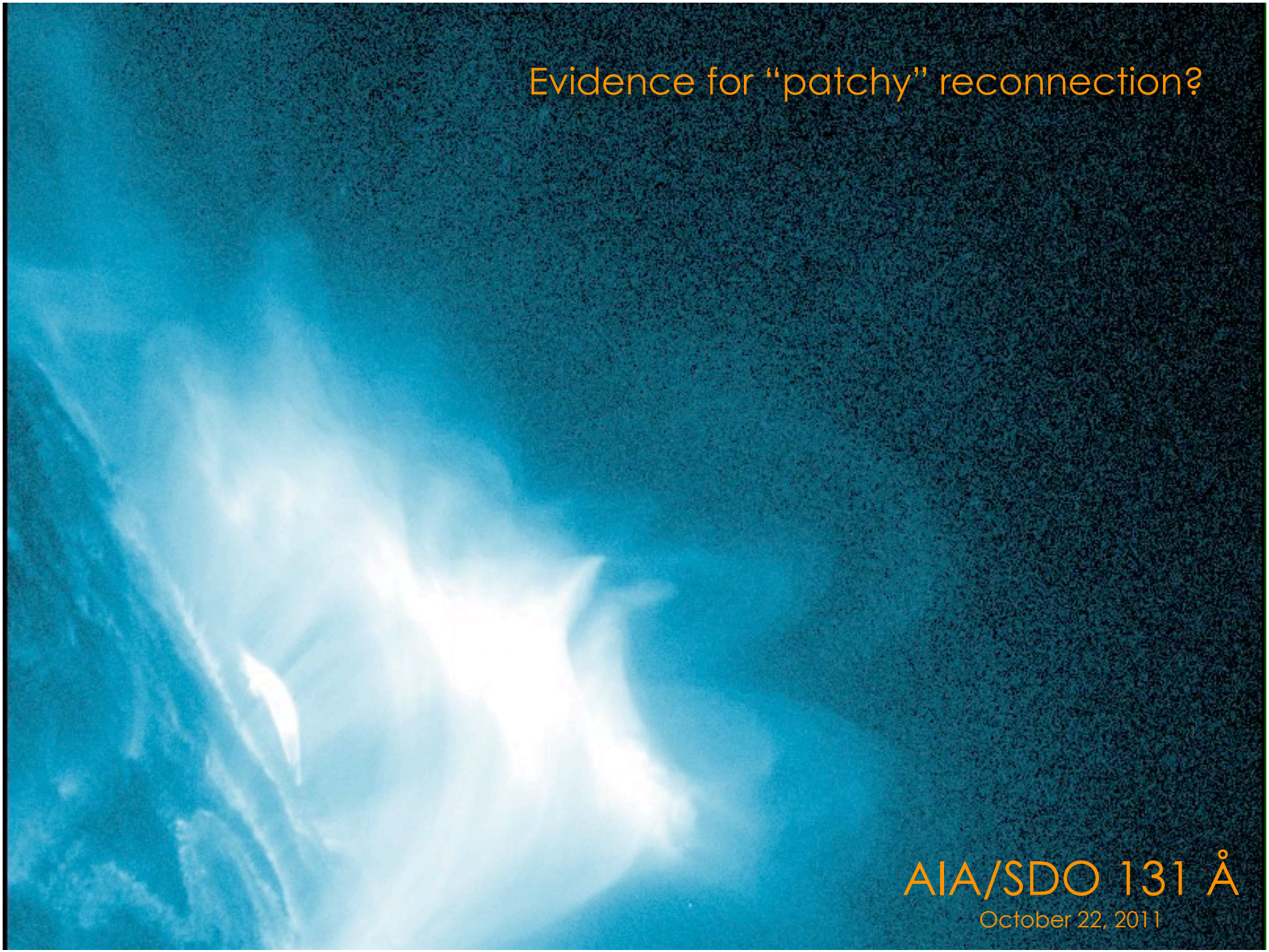
Median Initial Velocity

AIA: -144 km/s

Savage & McKenzie 2011: -146 km/s

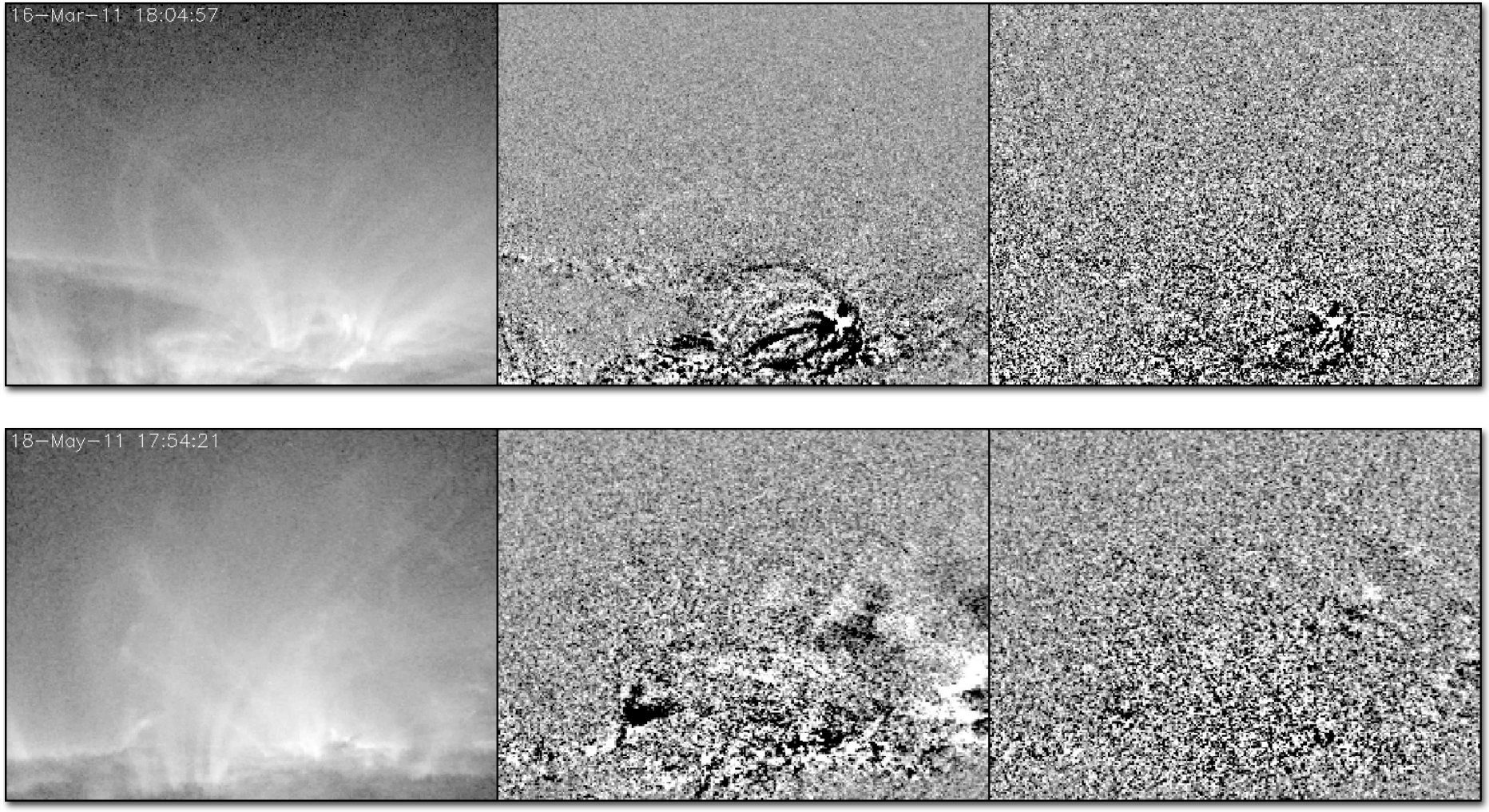



AIA/SDO 131 Å
October 22, 2011


Evidence for "patchy" reconnection?
AIA/SDO 131 Å
October 22, 2011

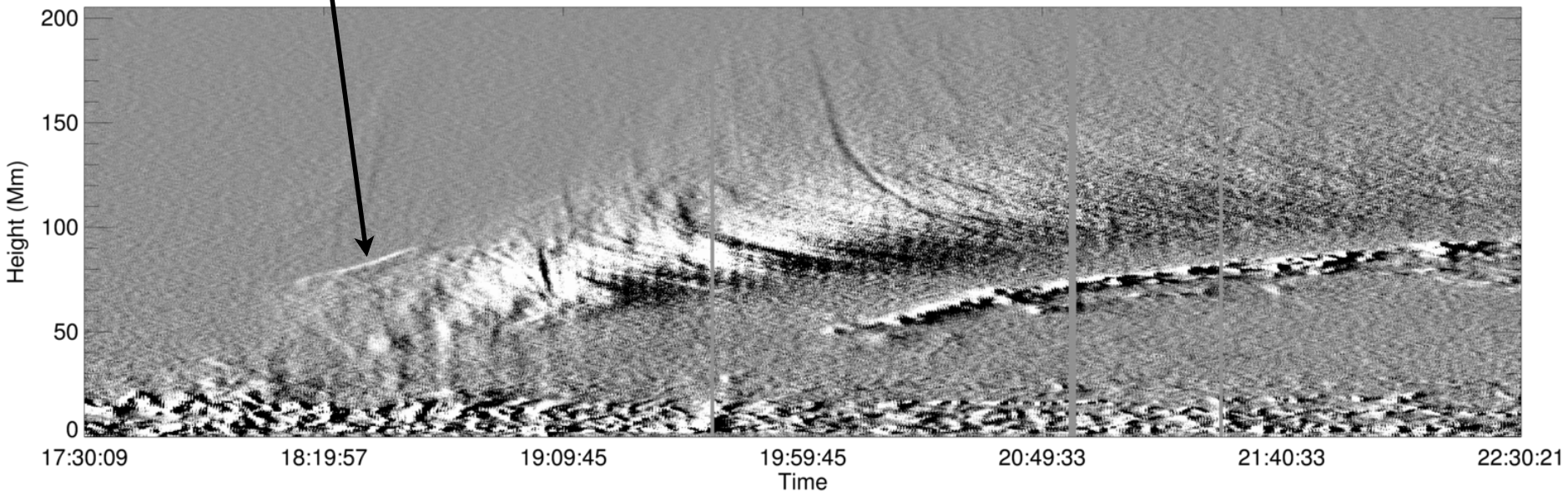
Initial Formation of High Temperature Flare Loops

first hot loops form “in place” - no initial downward motion

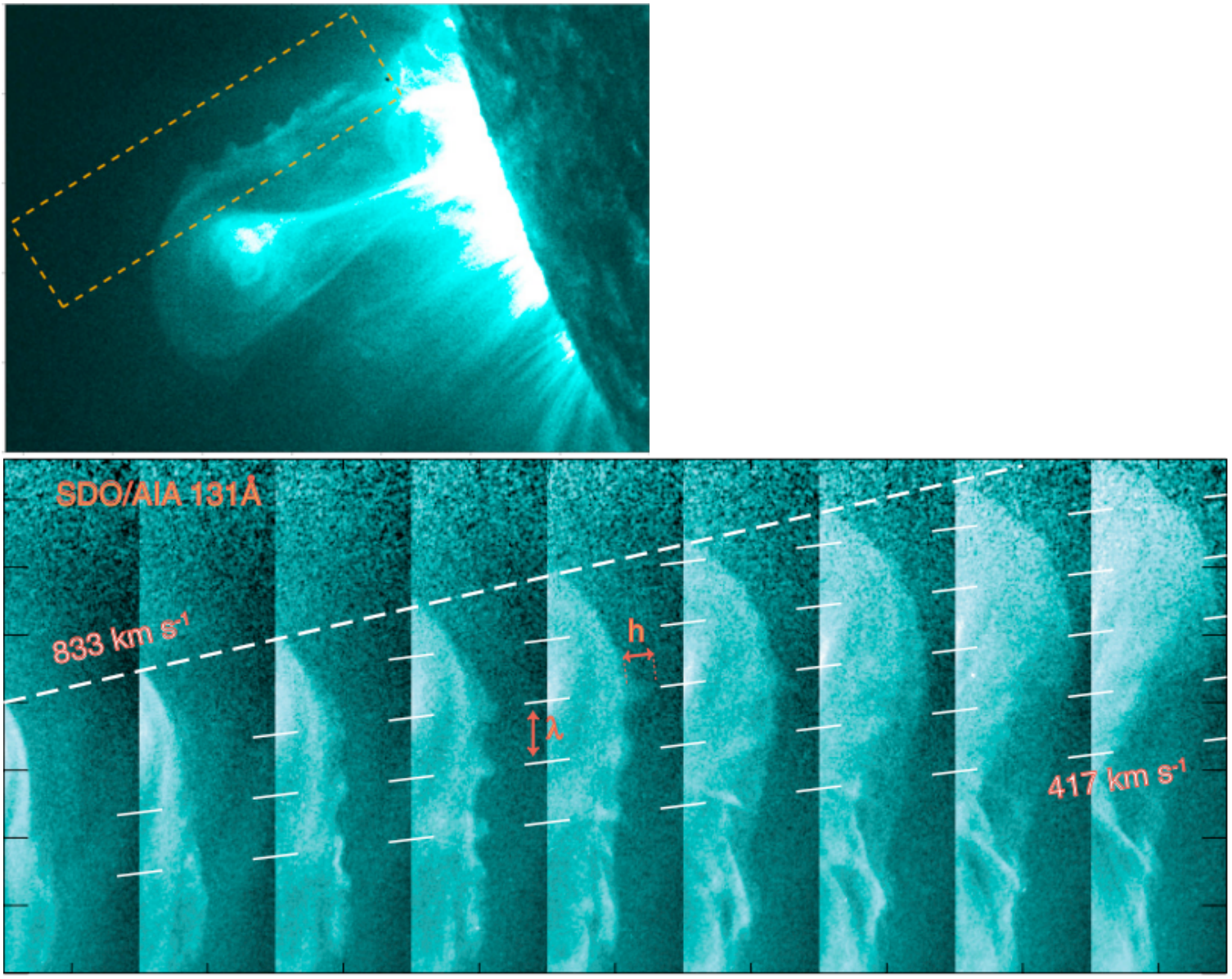


Height-Time Plot: March 16, 2011

first hot loops form "in place" - no initial downward motion

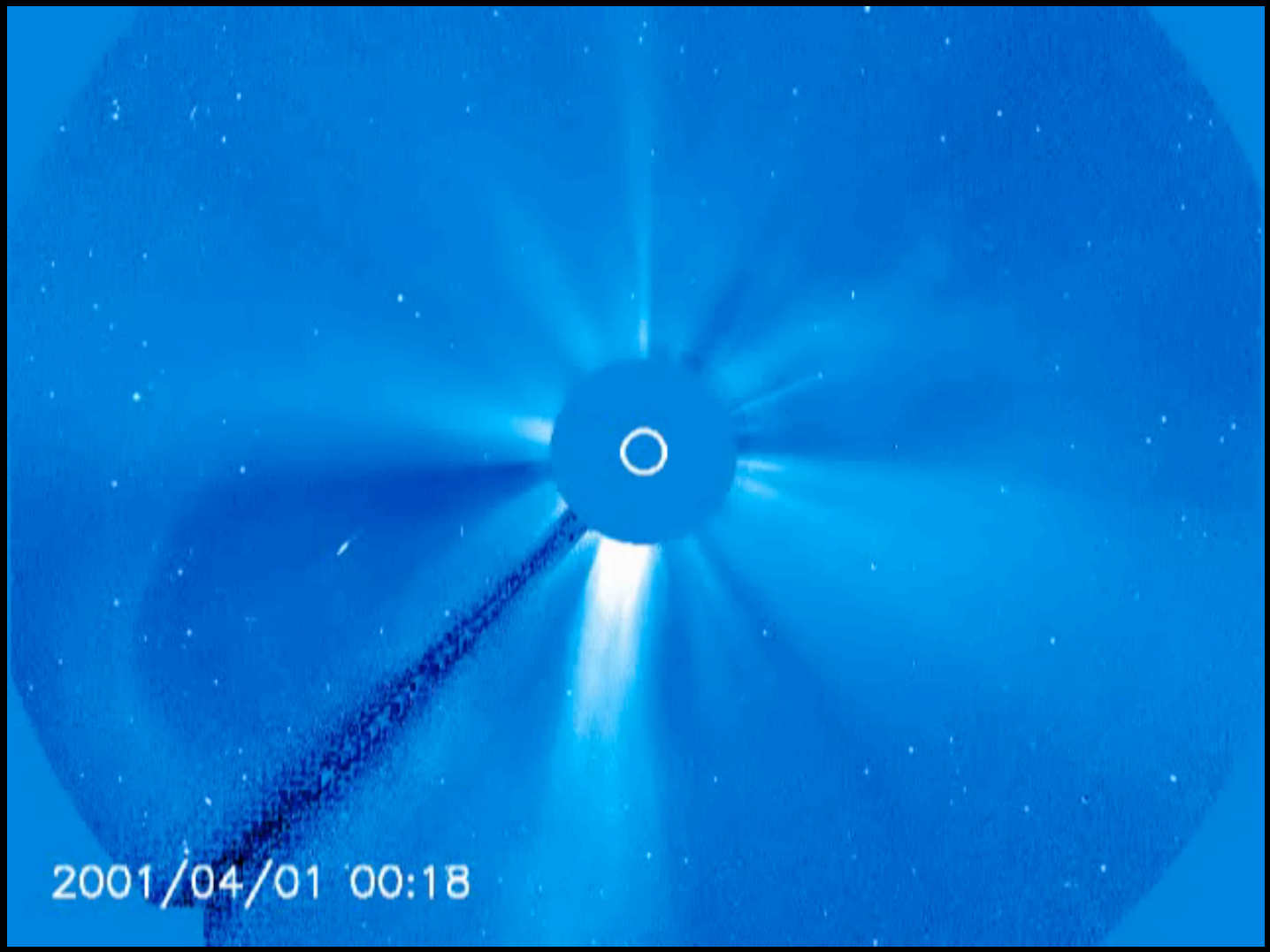


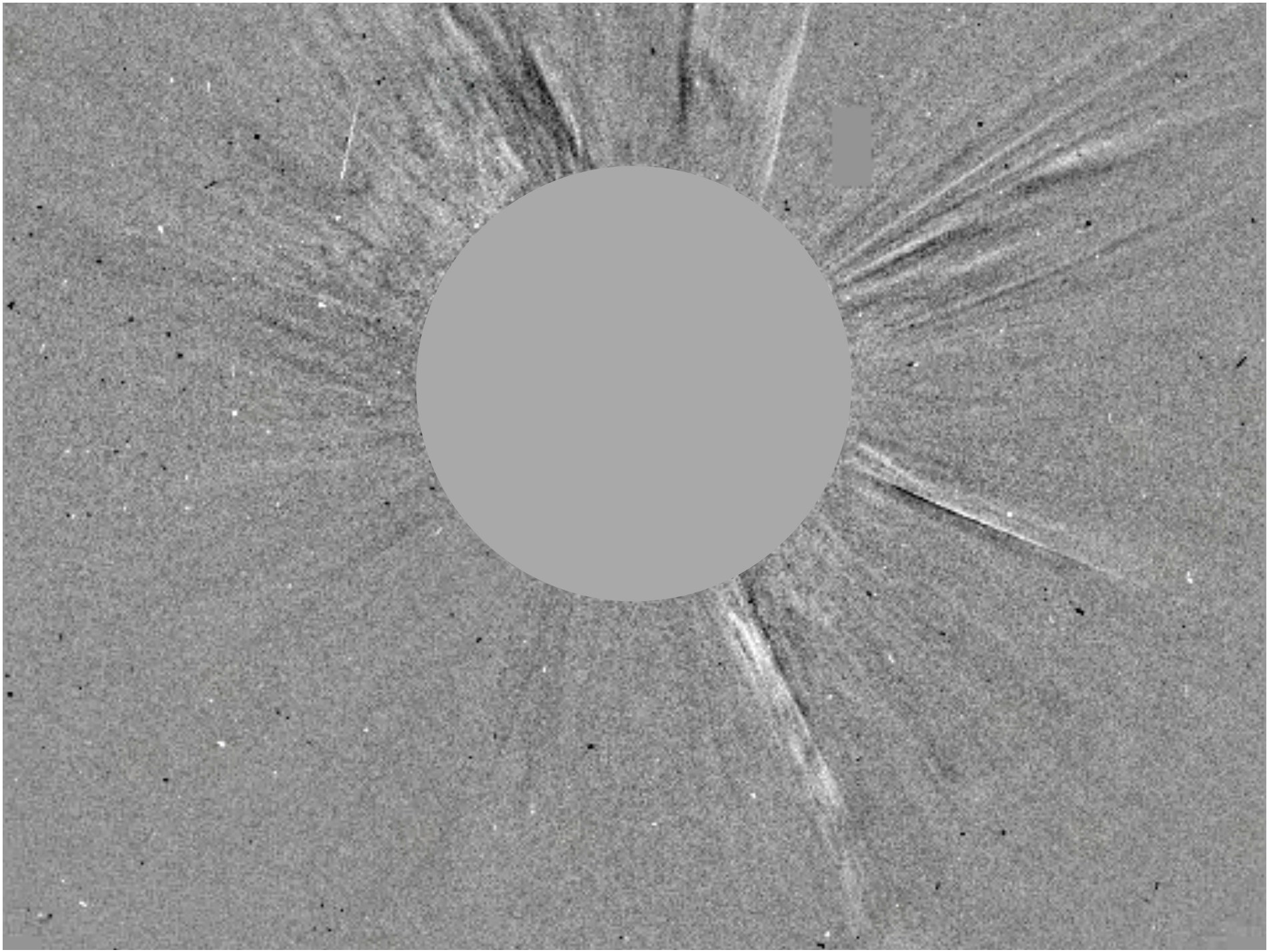
Kelvin-Helmholtz Instability?

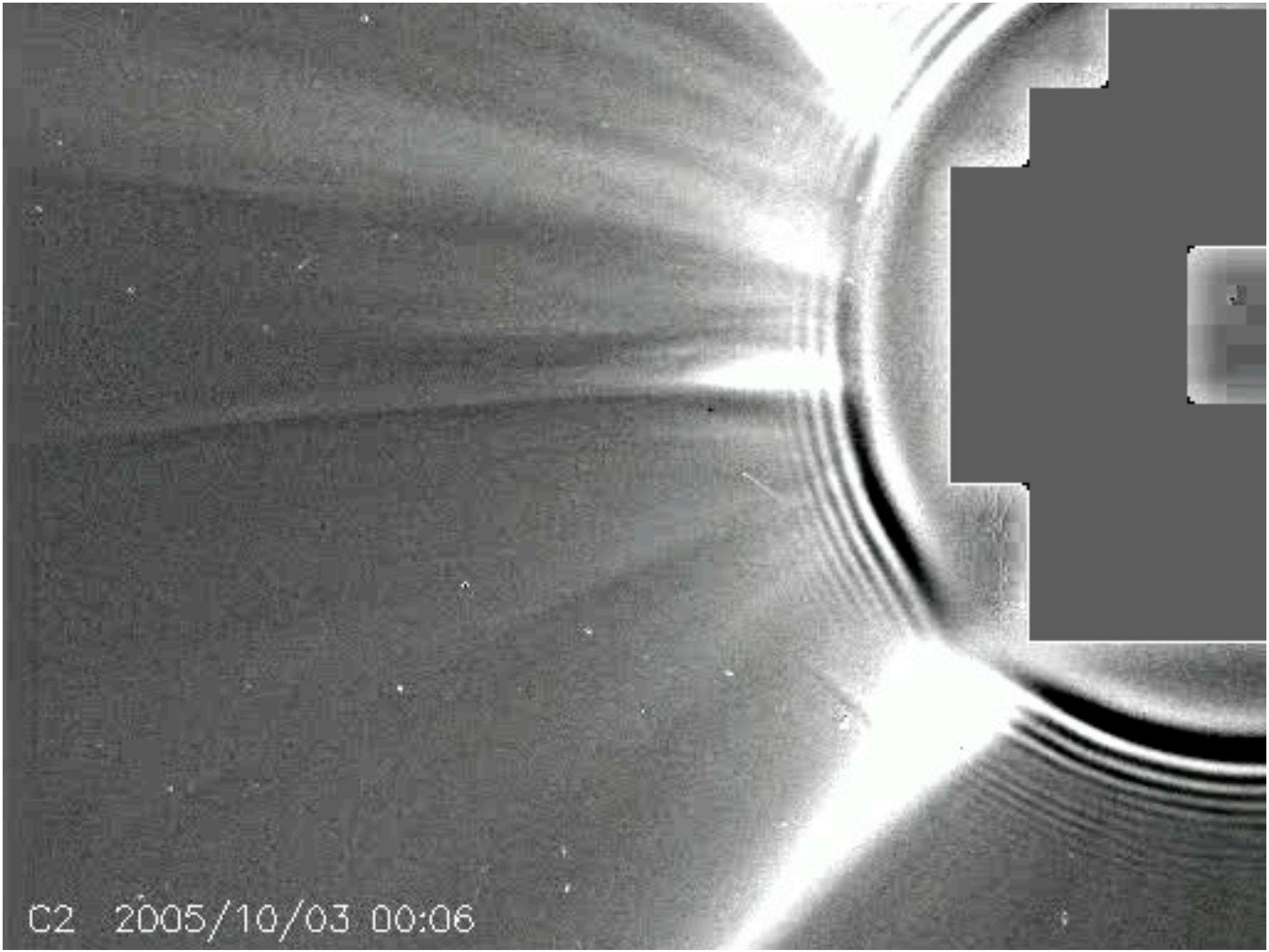


Foullon et al., ApJL, 2011

Inflows in the Outer Corona



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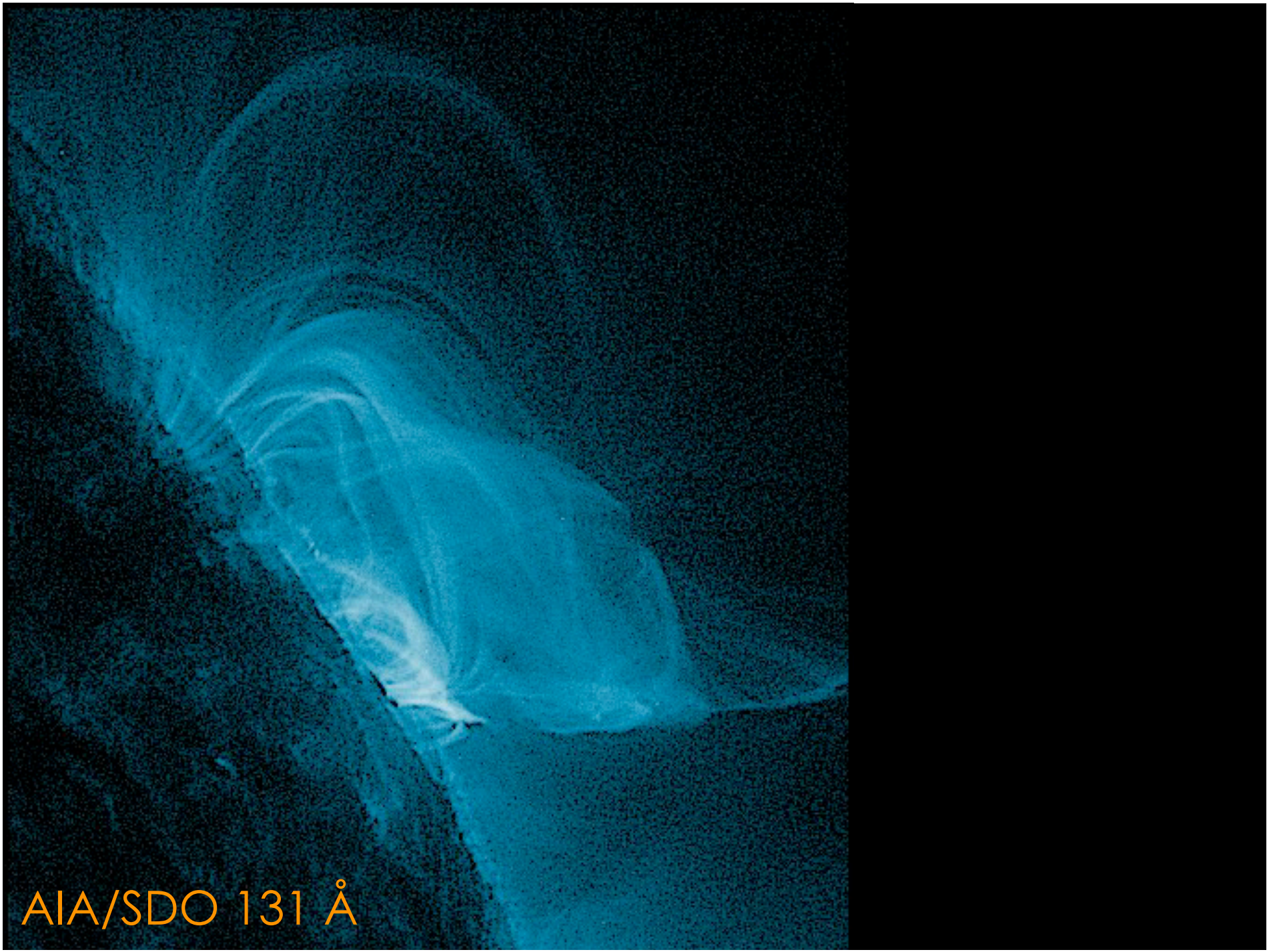
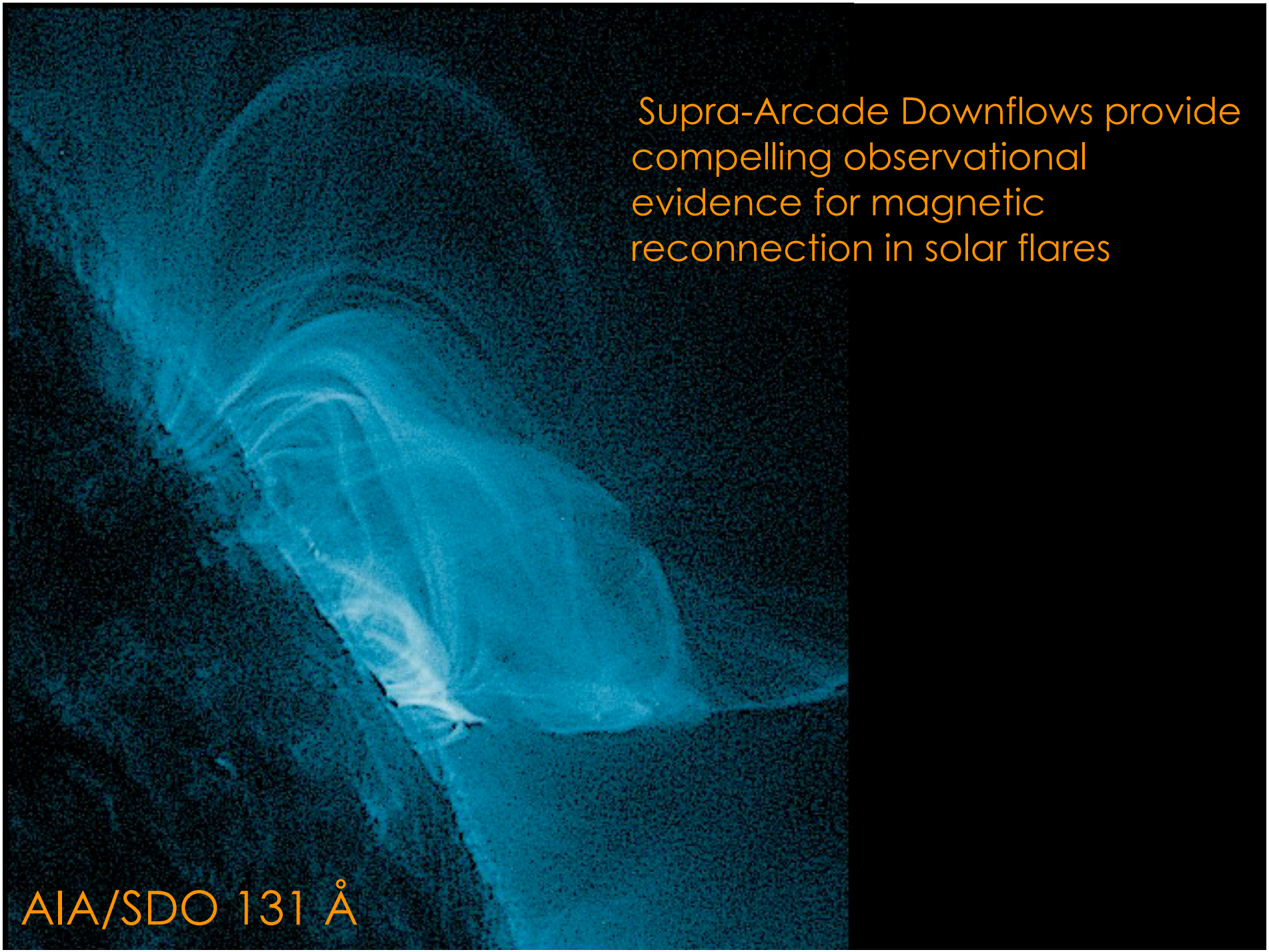

AIA/SDO 131 Å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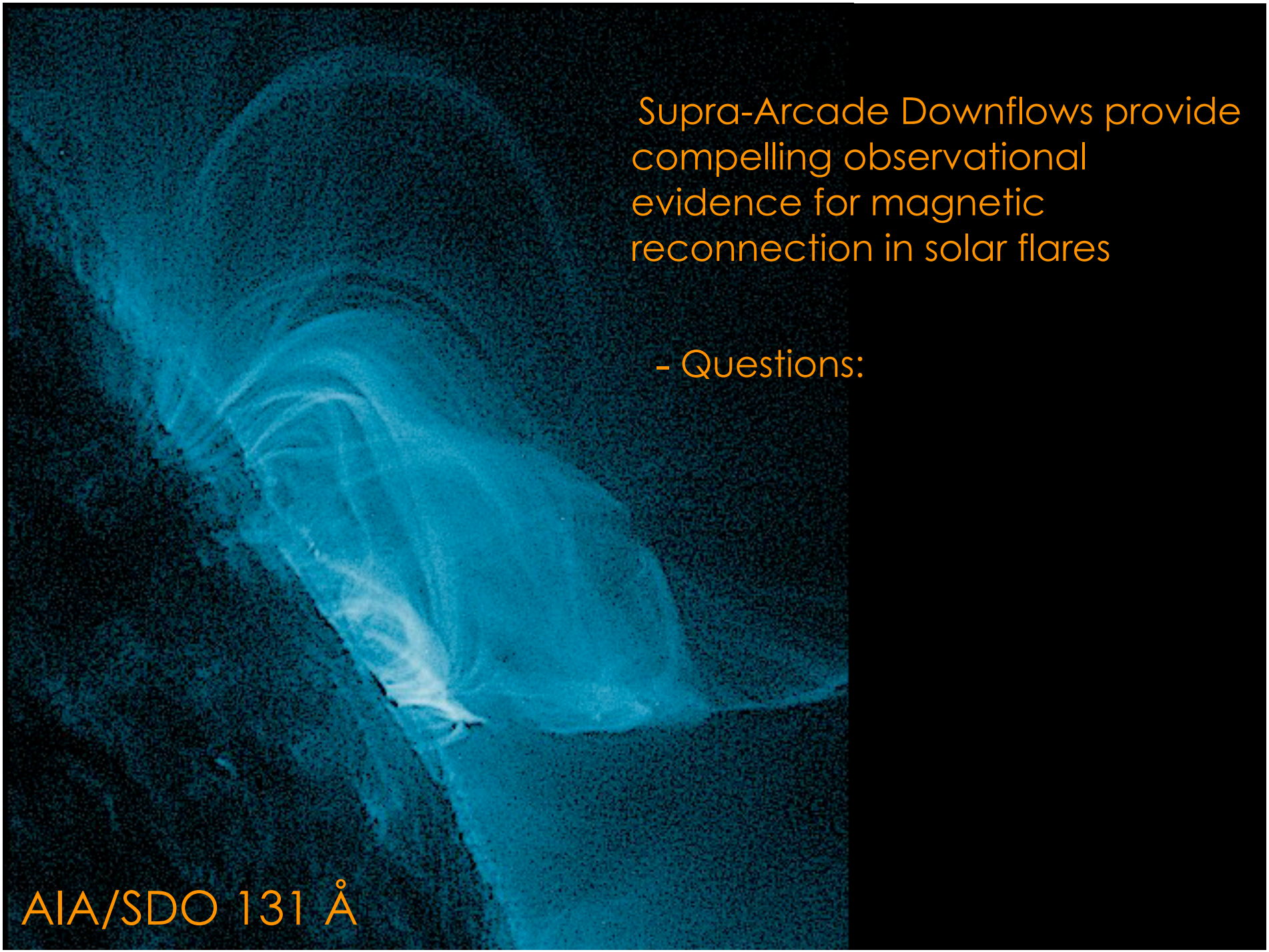
AIA/SDO 131 Å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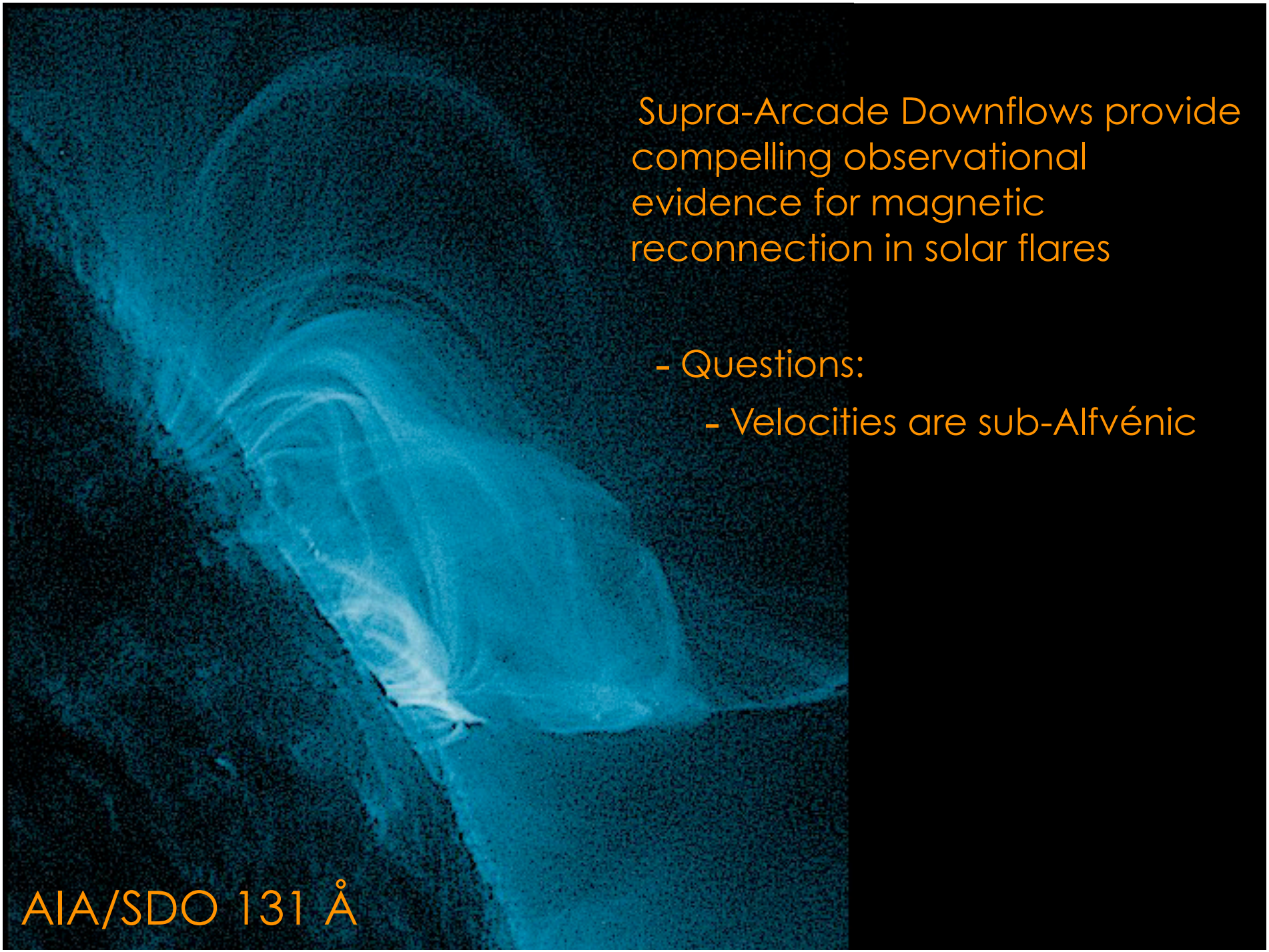
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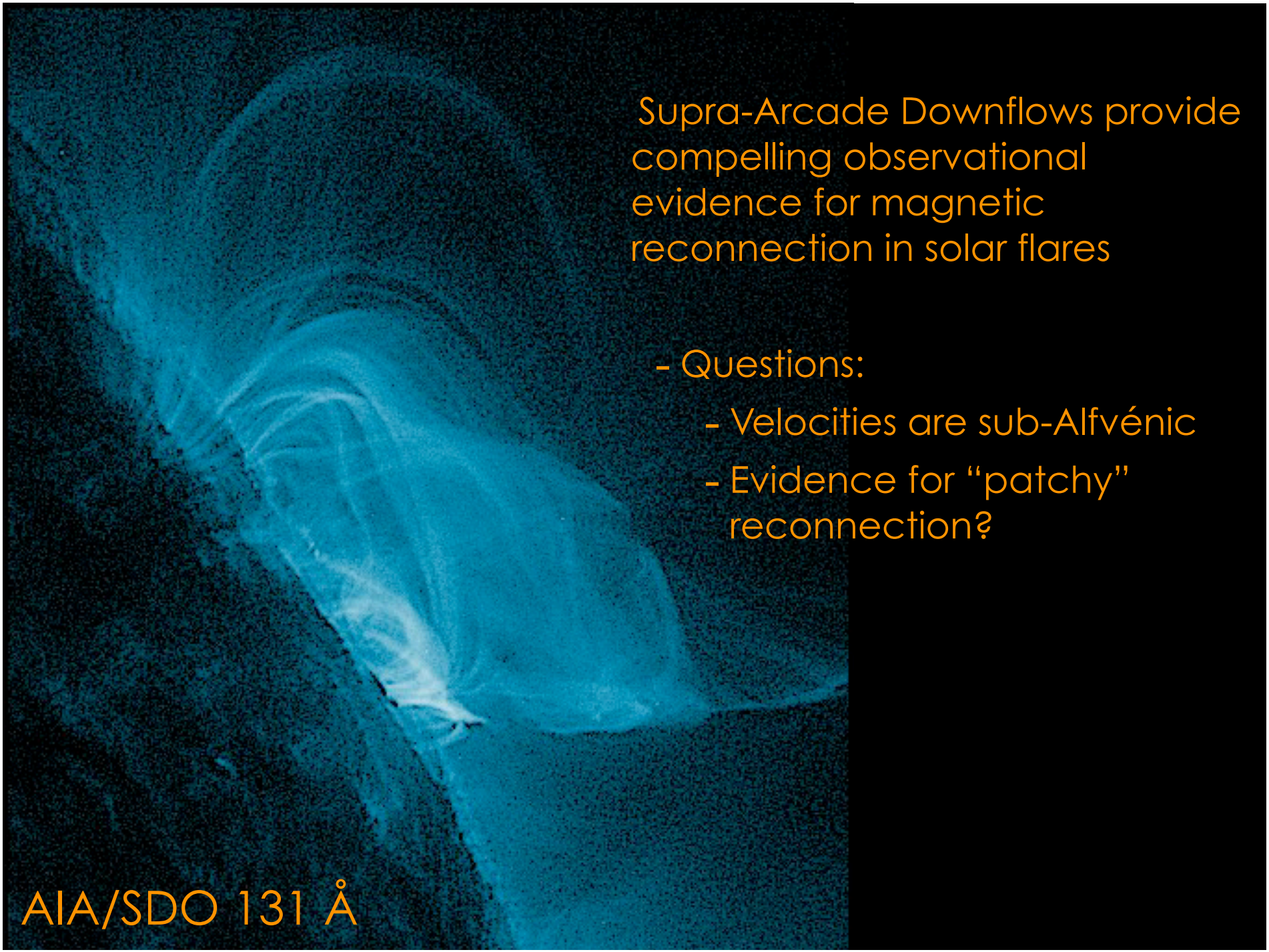
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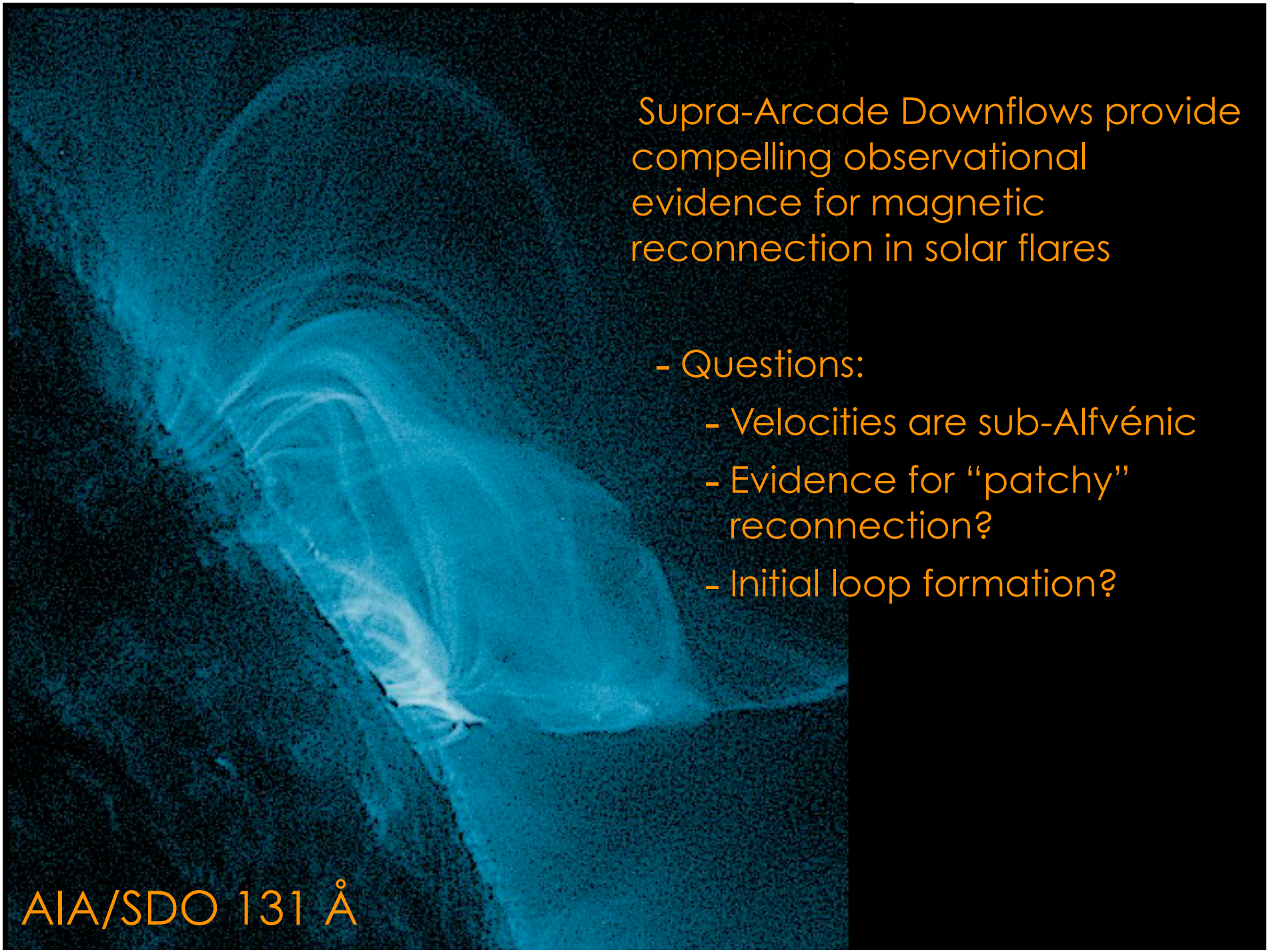
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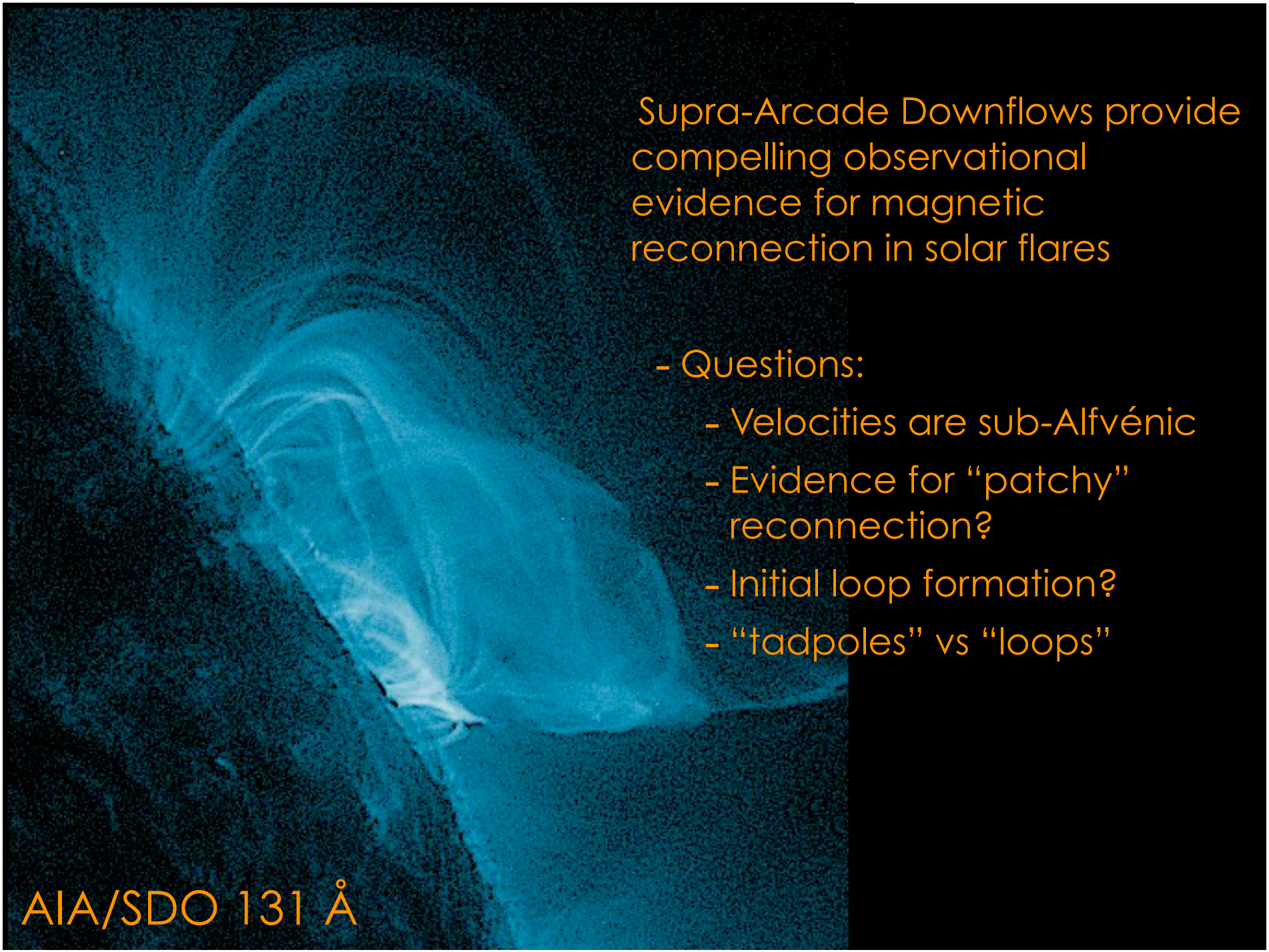
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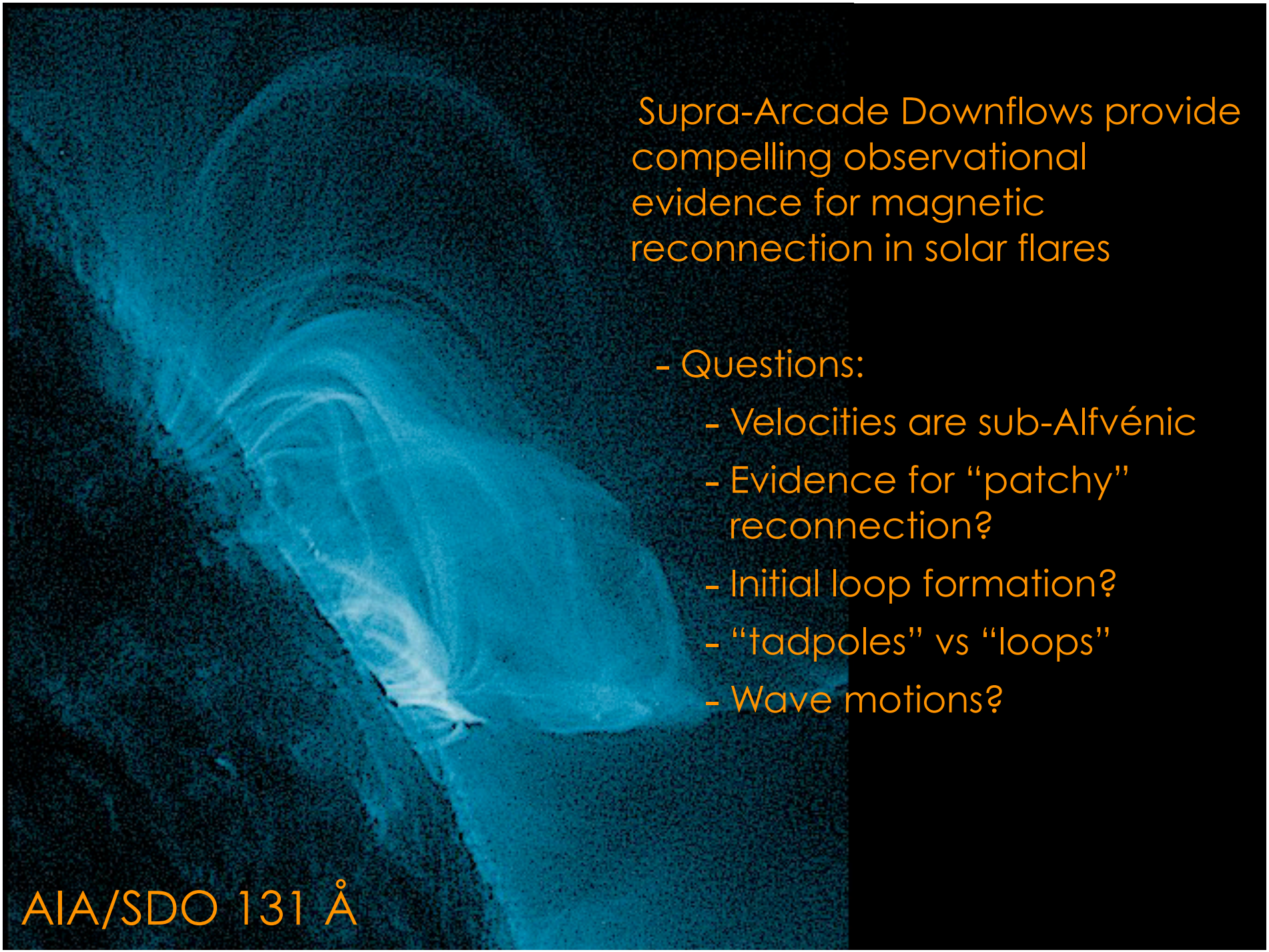
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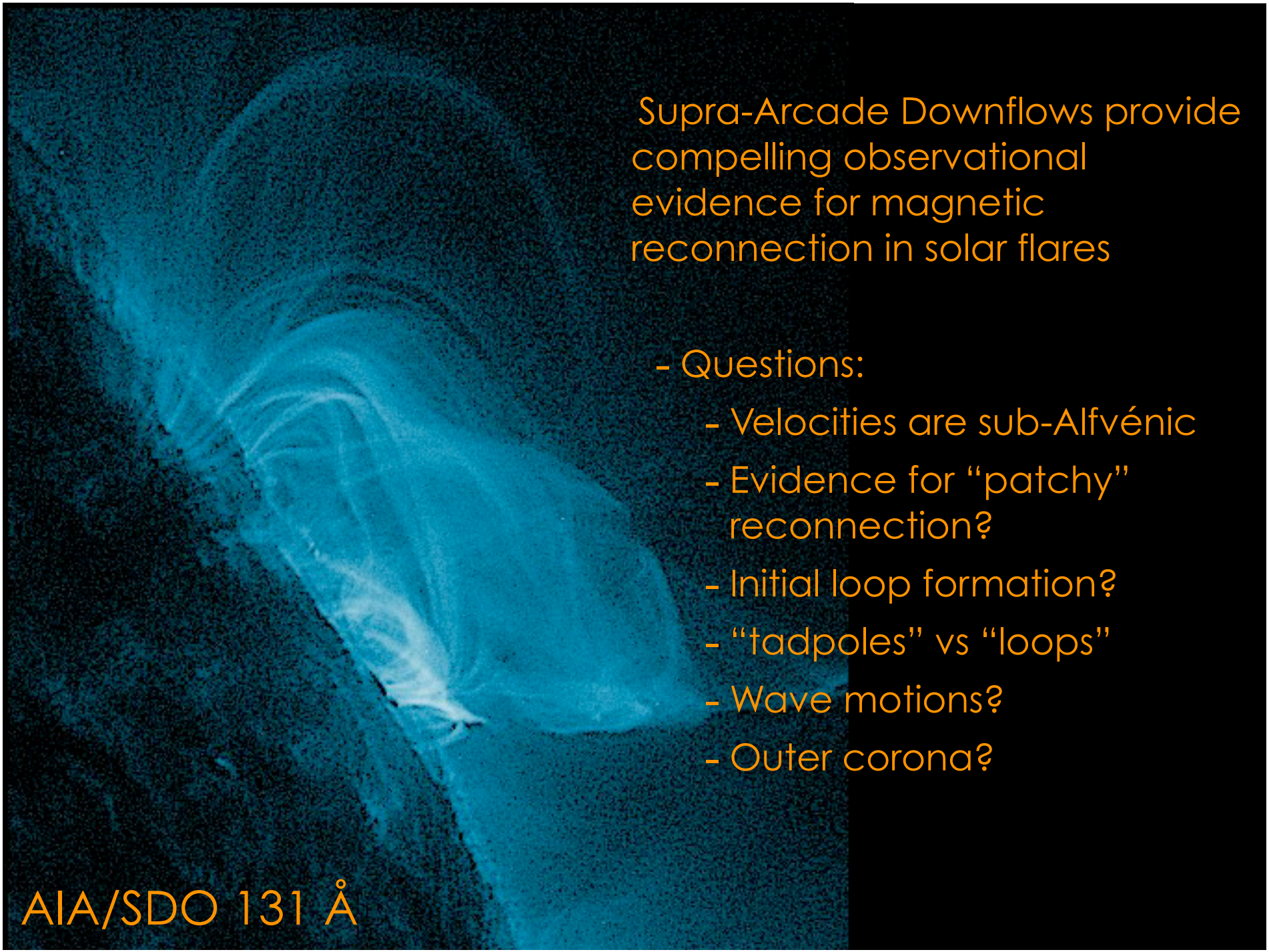
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