UiO : University of Oslo

Long-period intensity pulsations & coronal rain: manifestation of loops heating properties

Clara Froment

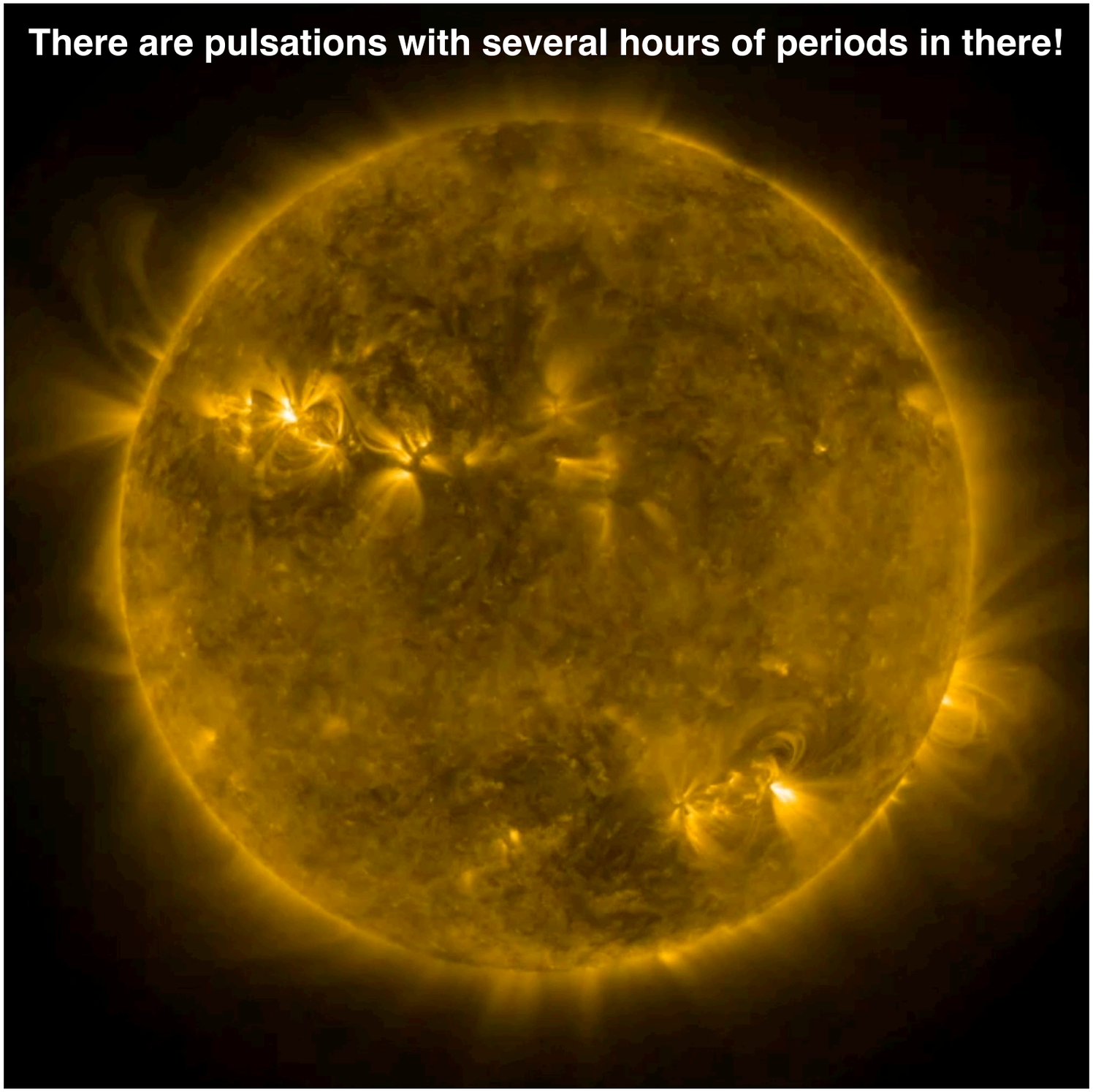
[1]Institute of Theoretical Astrophysics, University of Oslo

F. Auchère[2], G. Aulanier[3], Z. Mikić[4], K. Bocchialini[2], E. Buchlin[2], J. Solomon[2], C. Guennou[3], E. Soubrié[2,5], R. Oliver[5] , P. Antolin[6], G.Pelouze[2], L. Rouppe van der Voort[1]

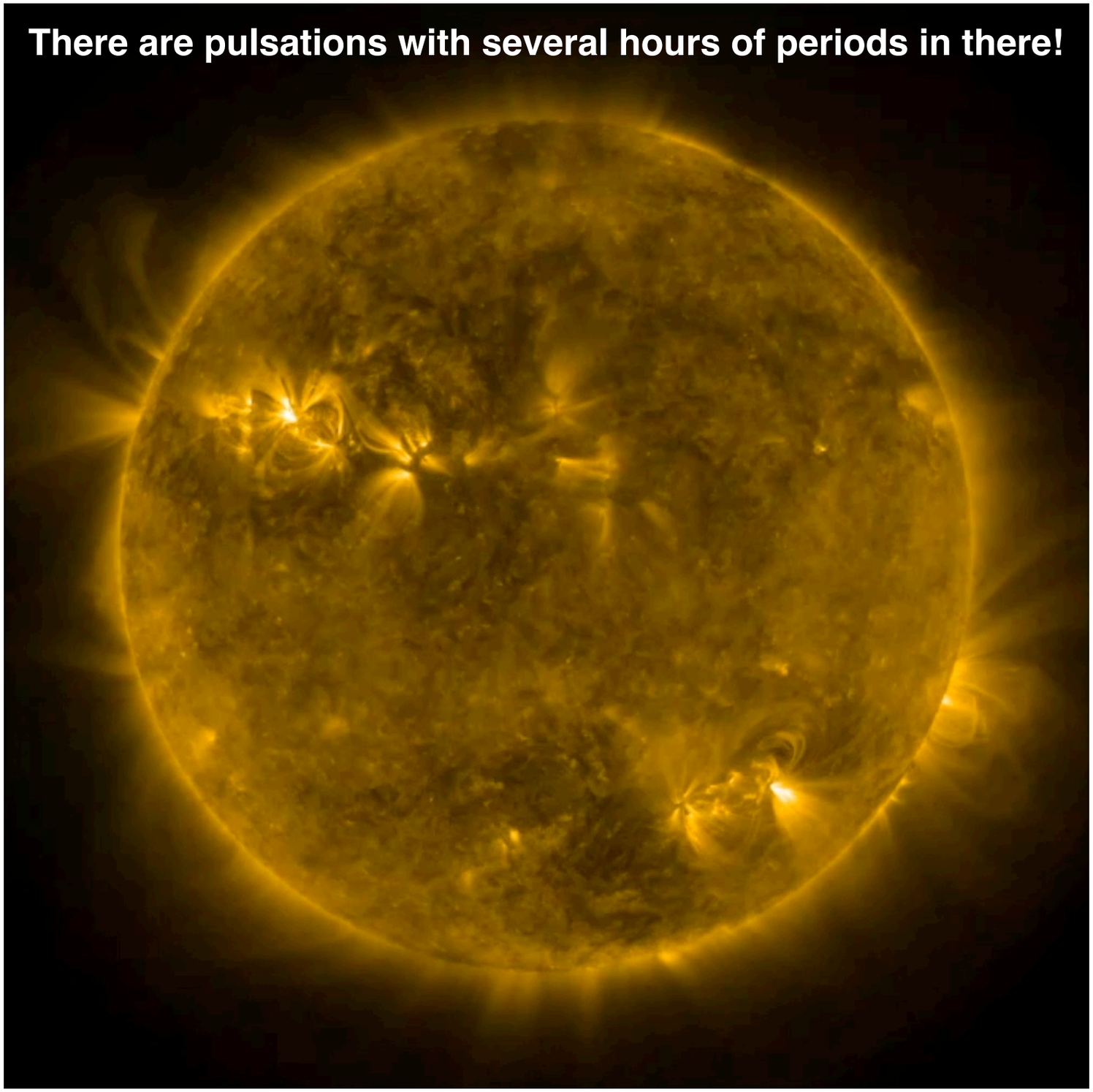
[2]IAS, Orsay, France; [3]LESIA/Observatoire de Paris, Meudon, France; [4]Predictive Science, Inc., San diego, CA, USA; [5]Universitat de les Illes Balears, Spain; [6]University of St. Andrews, UK

8th Coronal Loops Workshop

Long-period intensity pulsations are common in coronal loops

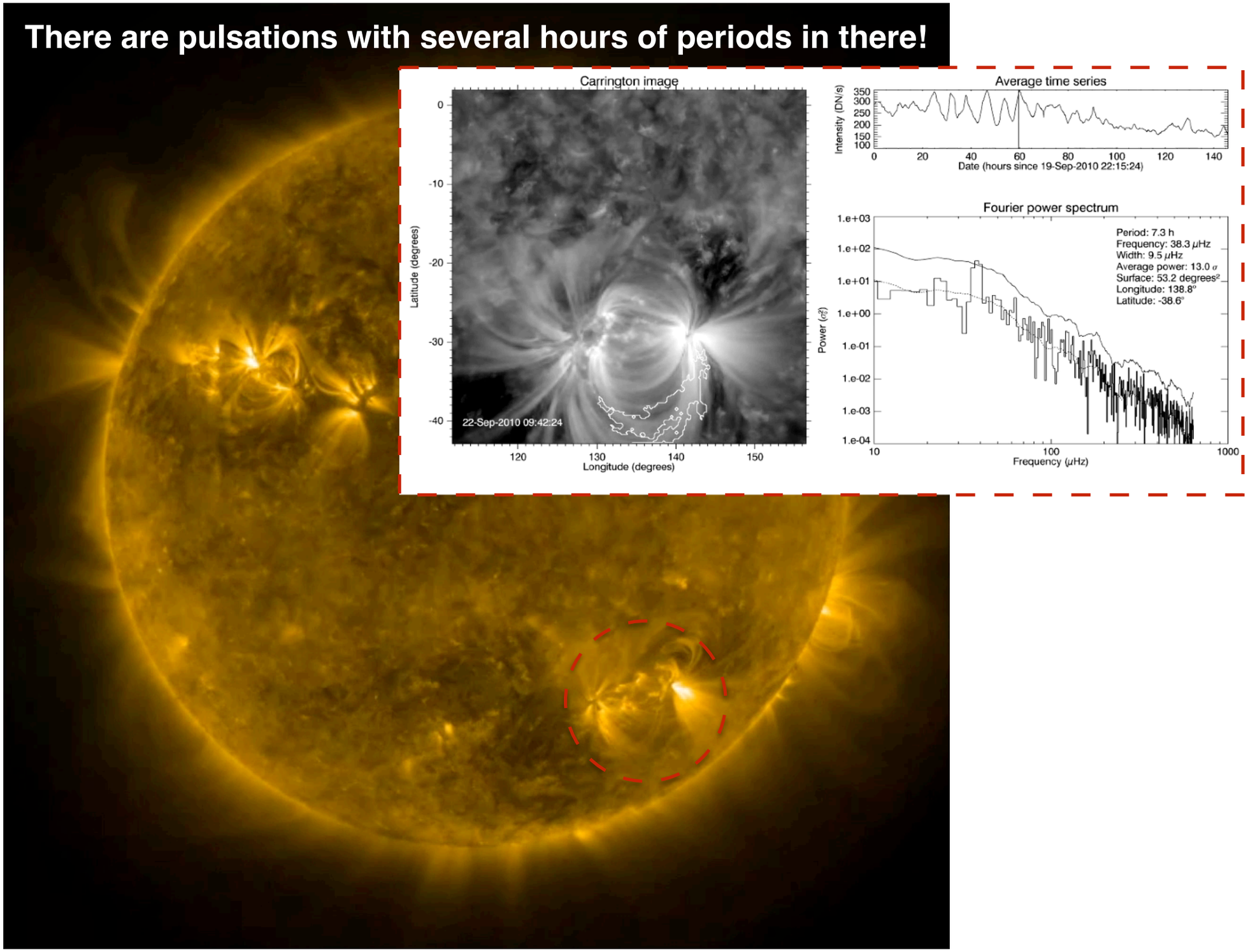


Long-period intensity pulsations are common in coronal loops



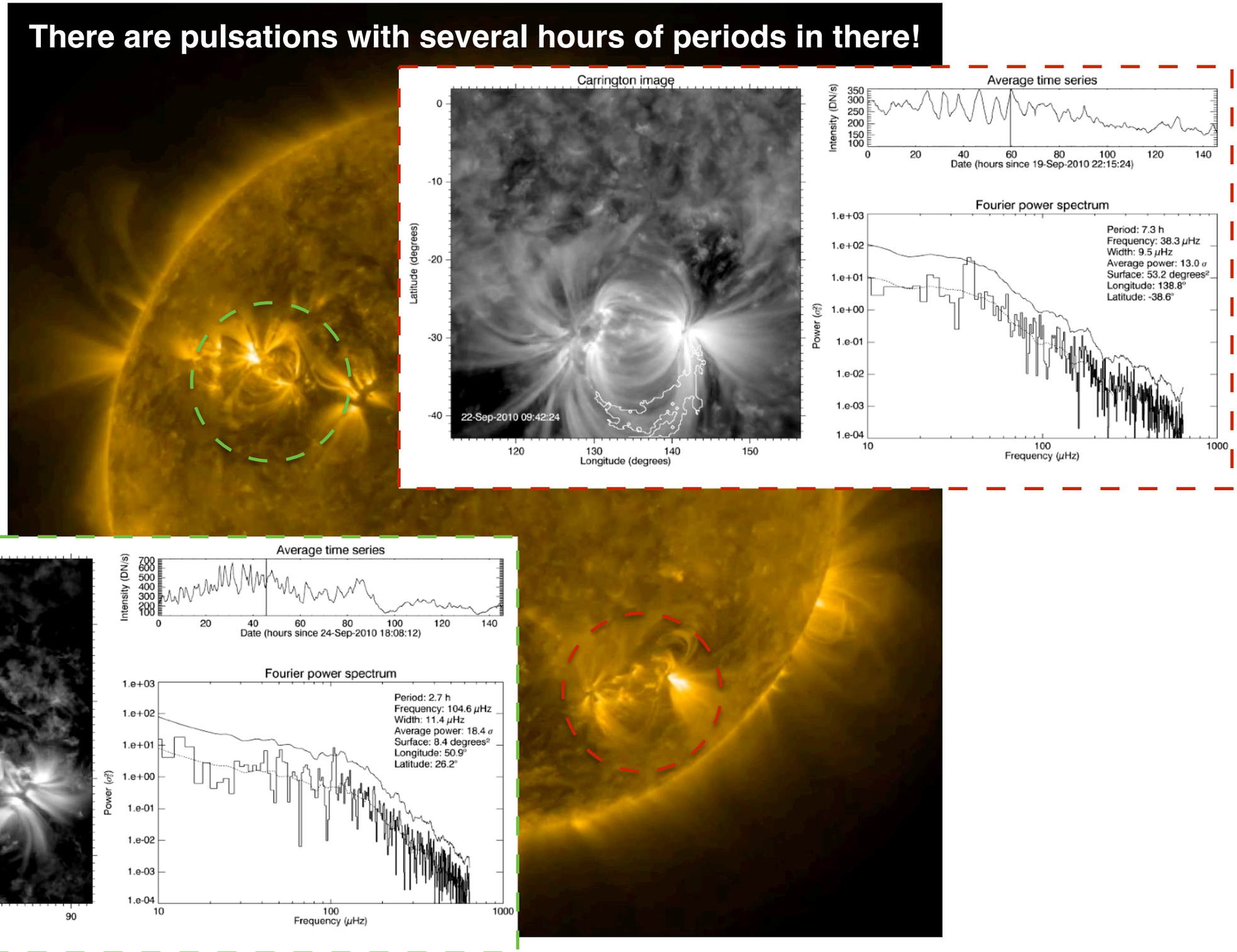
Long-period intensity pulsations are common in coronal loops

There are pulsations with several hours of periods in there!



Long-period intensity pulsations are common in coronal loops

There are pulsations with several hours of periods in there!



Long-period intensity pulsations are common in coronal loops

On-disk detections:

917 events found in 13 yrs of EIT (195)
Auchère et al. 2014, A&A, 563, A8

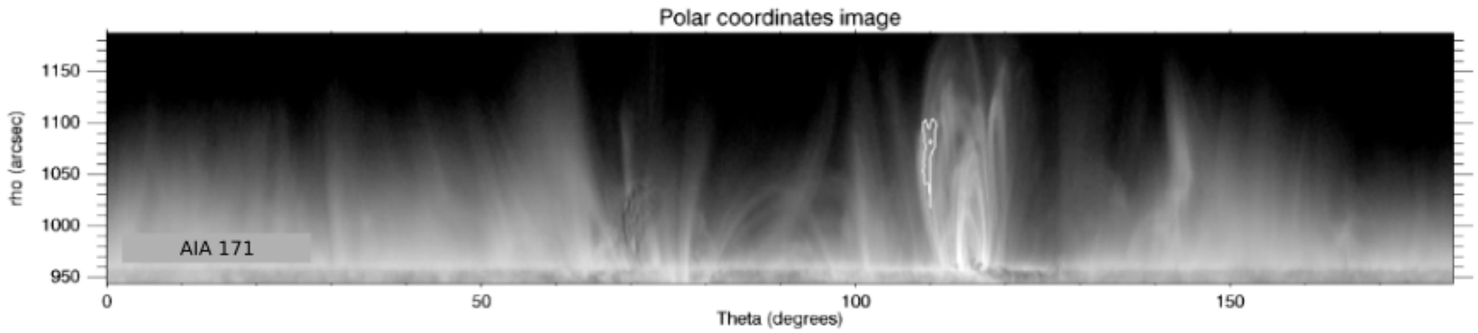
	All events	loop events
QS	45%	5%
AR	54%	95%
Other	1%	0%
Total	917	268

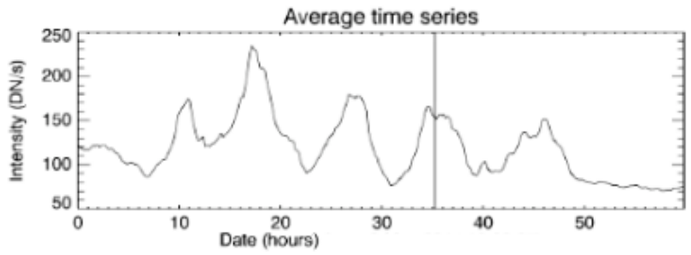
3181 events found in 6 yrs of AIA
Froment 2016, Ph. D. thesis

	193	All bands
QS	44%	33%
AR	56%	67%
Total	1210	3181

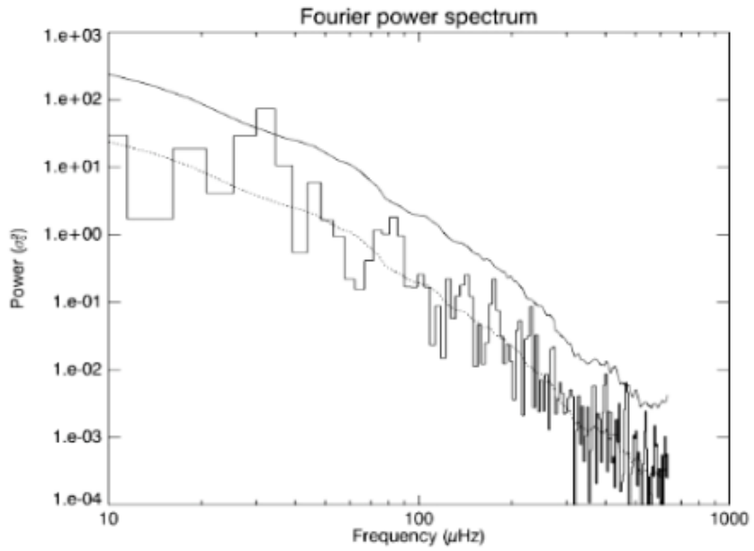
New ! Off-limb detections

+ 4000 events in 7 yrs of AIA, on-going statistics





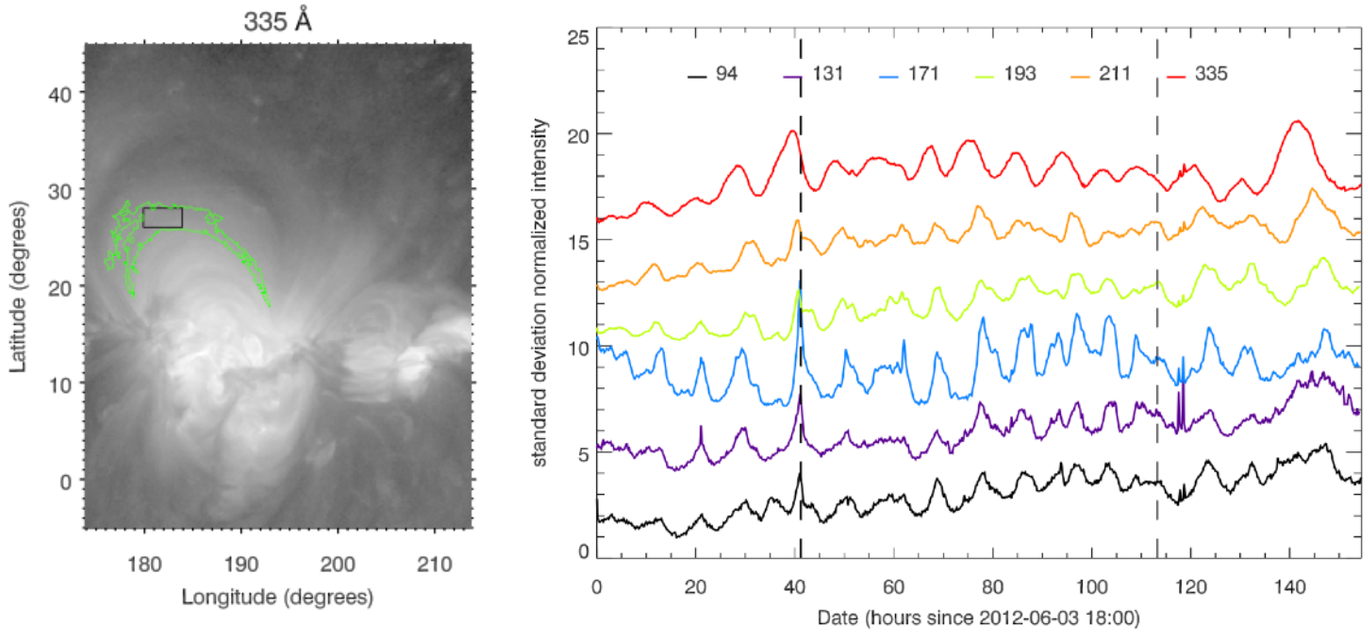
Frequency: 31.3 μHz
Frequency width: 9.2 μHz
Frequency resolution: 4.6 μHz
Period: 8.9 h
Maximum power: 37.6 σ
Average power: 21.7 σ
Average intensity: 118.4
Relative amplitude: 0.196
Threshold: 10.0 σ
Theta: 109.8°
Rho: 1070.5 arsec
Surface: 188.0 pixels

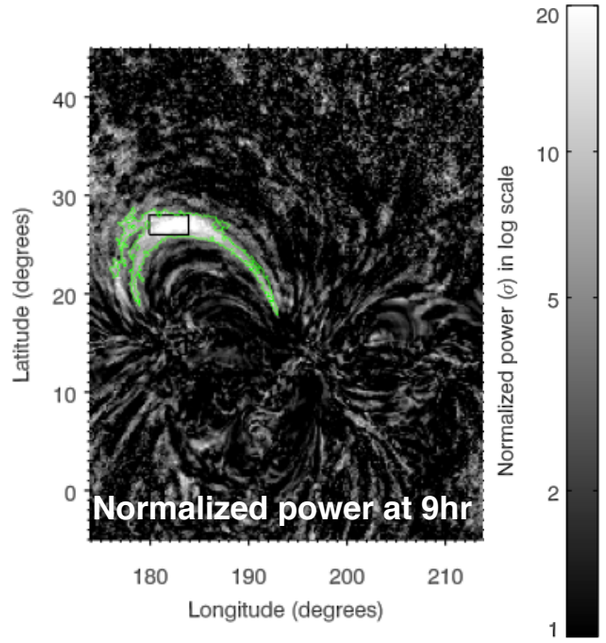


Evaporation/condensation cycles in loops

► **Current explanation for these pulsations: coronal counterpart of thermal non-equilibrium cycles**

- Periodic modification of the thermal structure (DEM analysis, *Guennou et al 2012a,b*)
- Delay between the temperature and the density
- Cooling from time lag maps (Viall *& Klimchuk, 2012 method*)



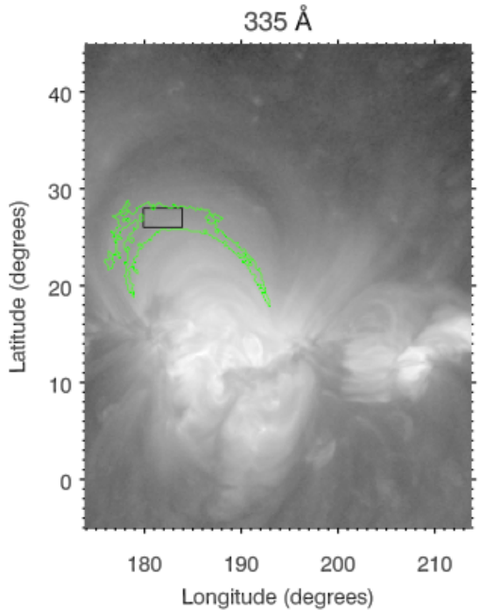


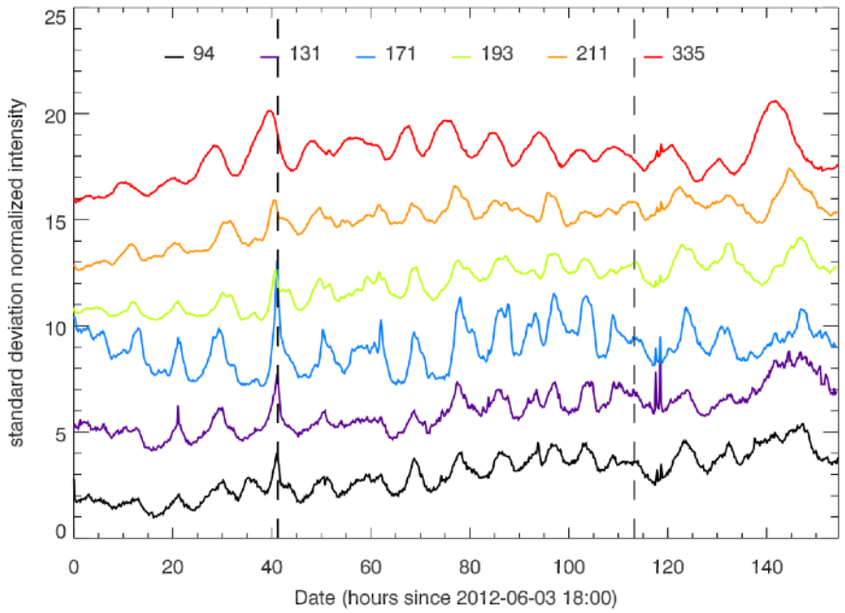
AIA observations from
Froment et al. 2015, ApJ, 807, 158

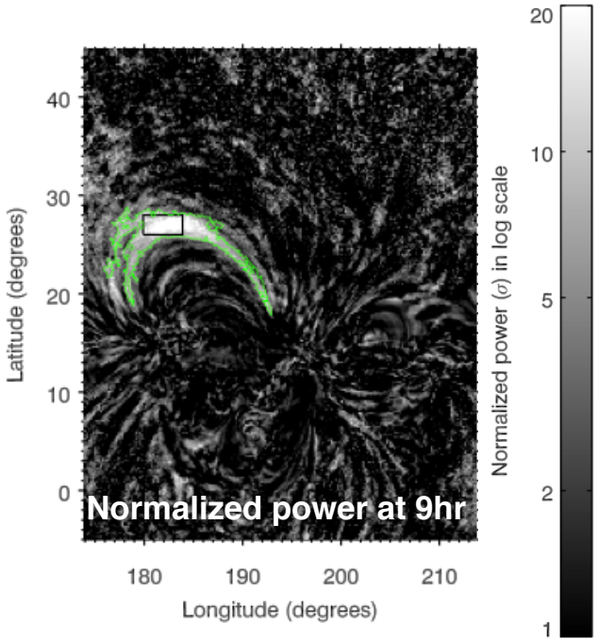
Evaporation/condensation cycles in loops

► **Current explanation for these pulsations: coronal counterpart of thermal non-equilibrium cycles**

- Periodic modification of the thermal structure (DEM analysis, *Guennou et al 2012a,b*)
- Delay between the temperature and the density
- Cooling from time lag maps (Viall *& Klimchuk, 2012 method*)





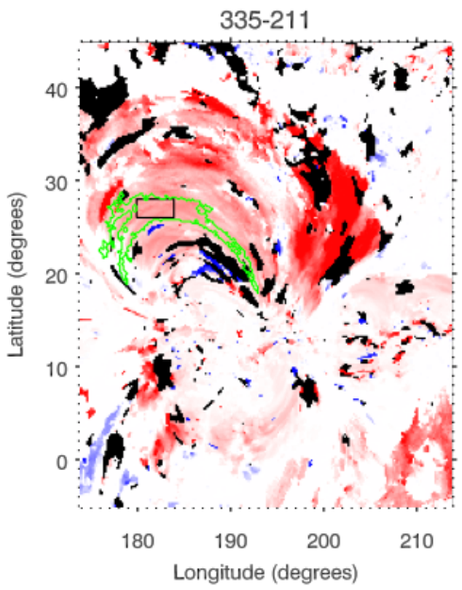


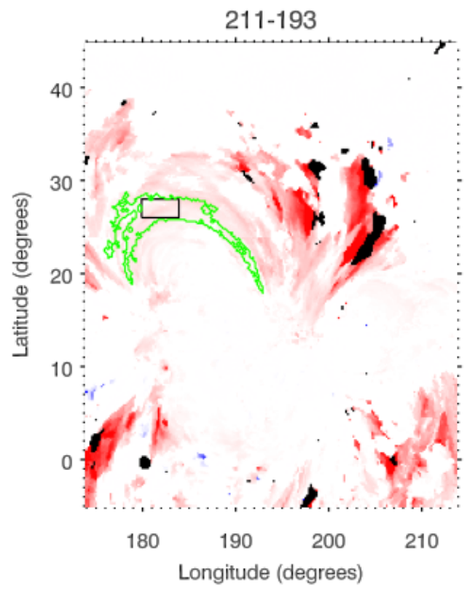
335 → 211 → 193

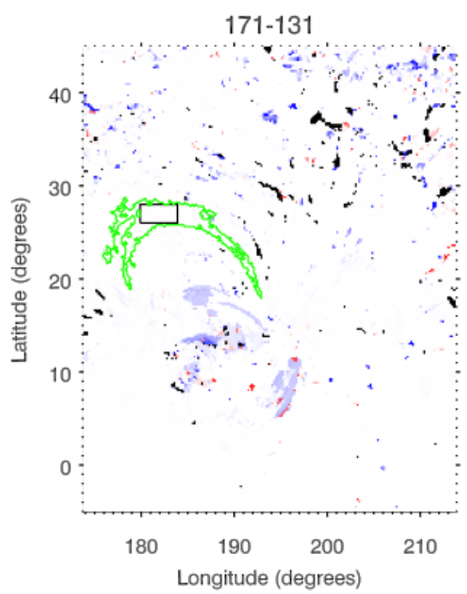
2.5 MK → 2 MK → 1.5 MK

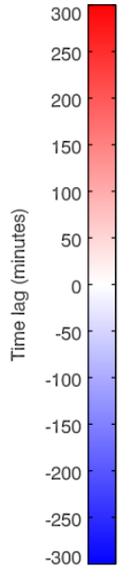
→ 171 / 131

→ 0.8 MK / ~~0.5 MK~~









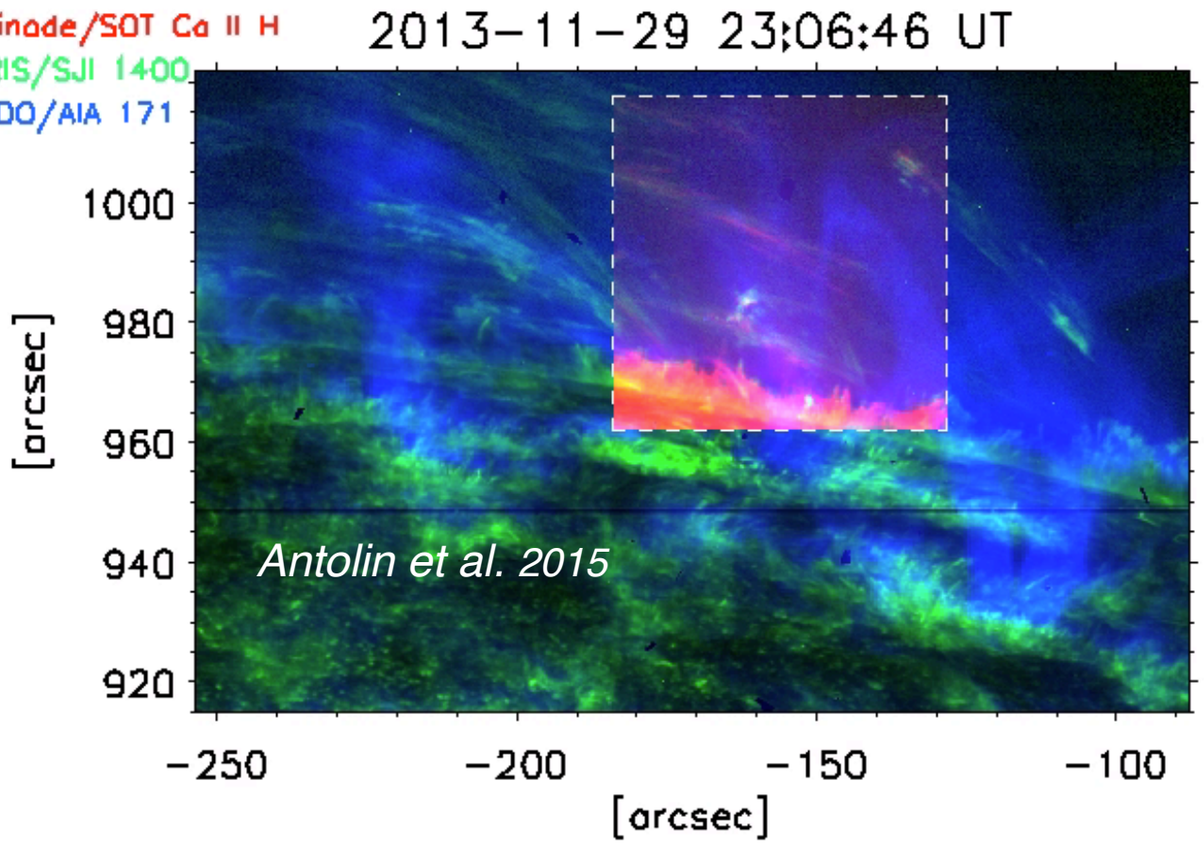
AIA observations from
Froment et al. 2015, ApJ, 807, 158

Evaporation/condensation cycles in loops

► **Current explanation for these pulsations: coronal counterpart of thermal non-equilibrium cycles**

- Periodic modification of the thermal structure (DEM analysis, *Guennou et al 2012a,b*)
- Delay between the temperature and the density
- Cooling from time lag maps (Viall *& Klimchuk, 2012 method*)

► **Coronal rain: condensations seen in transition region and chromospheric lines**
(i.e. *Antolin et al. 2015*, Ignacio Ugarte-Urra's talk)

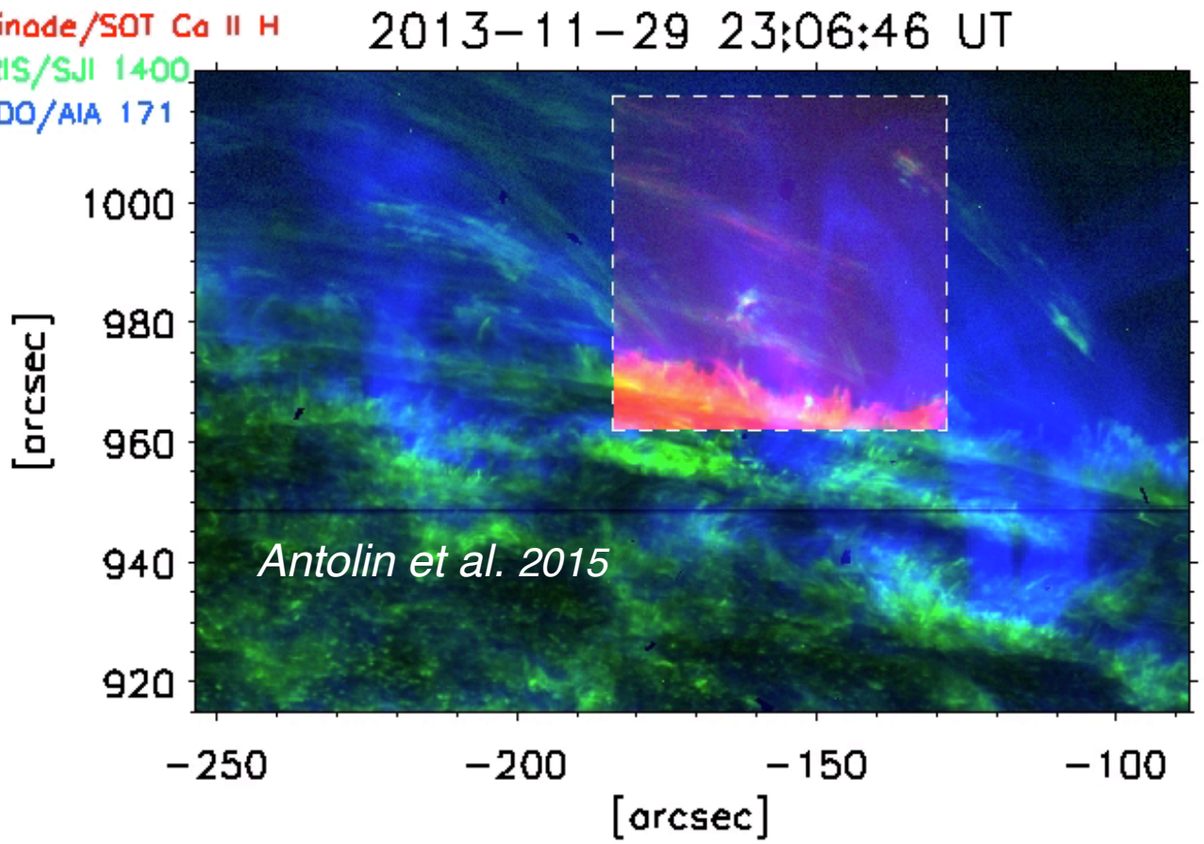


Evaporation/condensation cycles in loops

► **Current explanation for these pulsations: coronal counterpart of thermal non-equilibrium cycles**

- Periodic modification of the thermal structure (DEM analysis, *Guennou et al 2012a,b*)
- Delay between the temperature and the density
- Cooling from time lag maps (Viall *& Klimchuk, 2012 method*)

► **Coronal rain: condensations seen in transition region and chromospheric lines**
(i.e. *Antolin et al. 2015*, Ignacio Ugarte-Urra's talk)



Evaporation/condensation cycles in loops

► **Current explanation for these pulsations: coronal counterpart of thermal non-equilibrium cycles**

- Periodic modification of the thermal structure (DEM analysis, *Guennou et al 2012a,b*)
- Delay between the temperature and the density
- Cooling from time lag maps (Viall *& Klimchuk, 2012 method*)

► **Coronal rain: condensations seen in transition region and chromospheric lines**
(i.e. *Antolin et al. 2015*, Ignacio Ugarte-Urra's talk)

Evaporation/condensation cycles in loops

► **Current explanation for these pulsations: coronal counterpart of thermal non-equilibrium cycles**

- Periodic modification of the thermal structure (DEM analysis, *Guennou et al 2012a,b*)
- Delay between the temperature and the density
- Cooling from time lag maps (Viall *& Klimchuk, 2012 method*)

► **Coronal rain: condensations seen in transition region and chromospheric lines**
(i.e. *Antolin et al. 2015*, Ignacio Ugarte-Urra's talk)

► **AIA obs. of pulsations in loops: consistent with an "incomplete" condensation scenario**

However, with AIA, we have only access to the average loop bundle behavior

Evaporation/condensation cycles in loops

► **Current explanation for these pulsations: coronal counterpart of thermal non-equilibrium cycles**

- Periodic modification of the thermal structure (DEM analysis, *Guennou et al 2012a,b*)
- Delay between the temperature and the density
- Cooling from time lag maps (Viall *& Klimchuk, 2012 method*)

► **Coronal rain: condensations seen in transition region and chromospheric lines**
(i.e. *Antolin et al. 2015*, Ignacio Ugarte-Urra's talk)

► **AIA obs. of pulsations in loops: consistent with an "incomplete" condensation scenario**

However, with AIA, we have only access to the average loop bundle behavior

➡ **How cold are the condensations related to pulsating loops?**

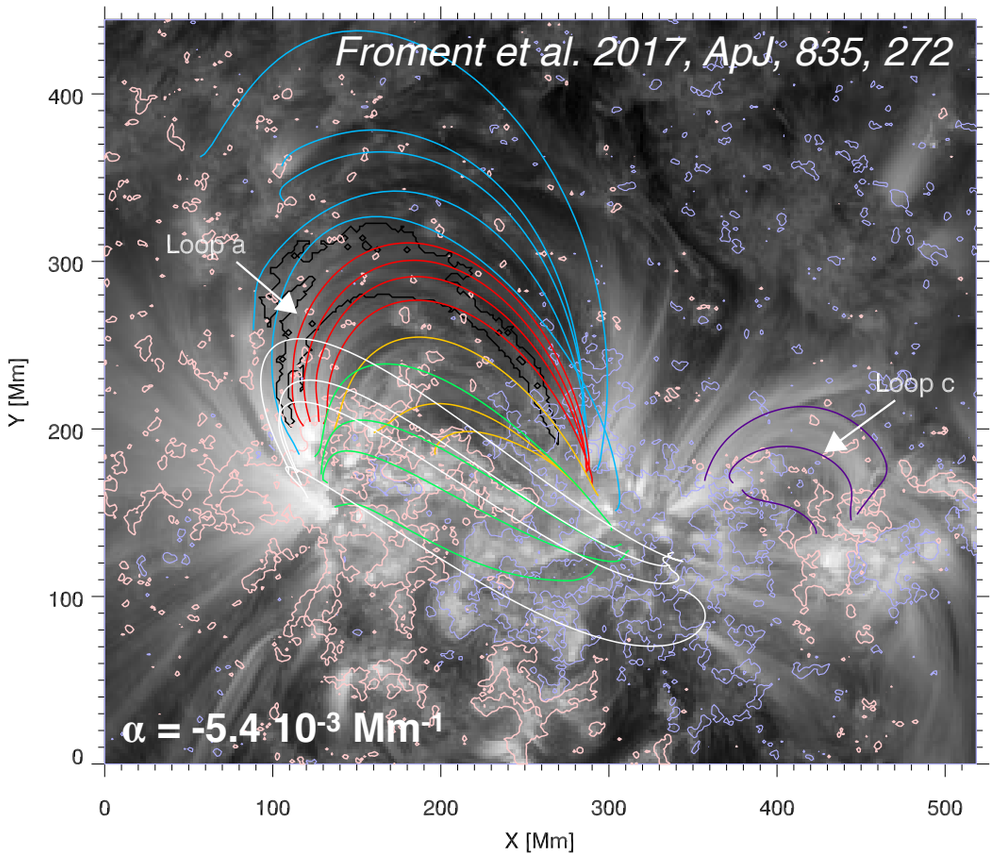
➡ Importance of **loop and heating geometry** in loops modelling (*Mikić et al. 2013*): static loops, TNE **cycles** with « complete » condensations (CC) or « incomplete » condensations (IC)

➡ **Why do these cycles emerge for only some loop bundles?**

1D hydrodynamic simulations

➡ Heating parameters scan with **3 loop geometries :**
pulsating loop, non-pulsating loop and one ad hoc symmetric loop

Loop geometry from LFFF extrapolations

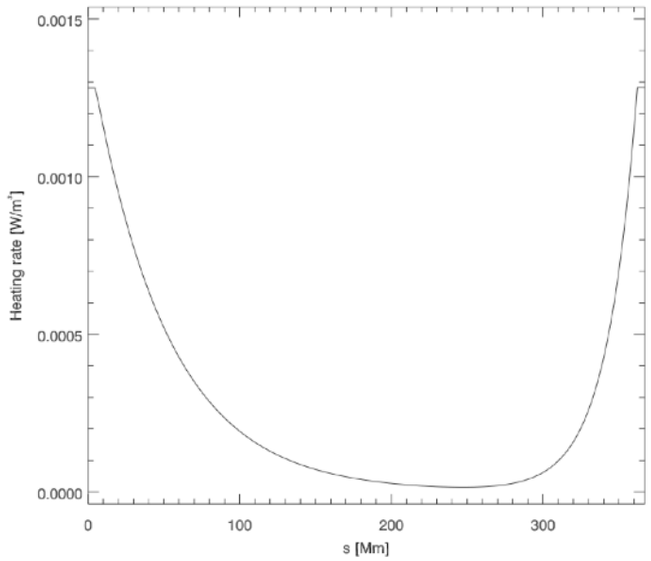


Constant and stratified heating

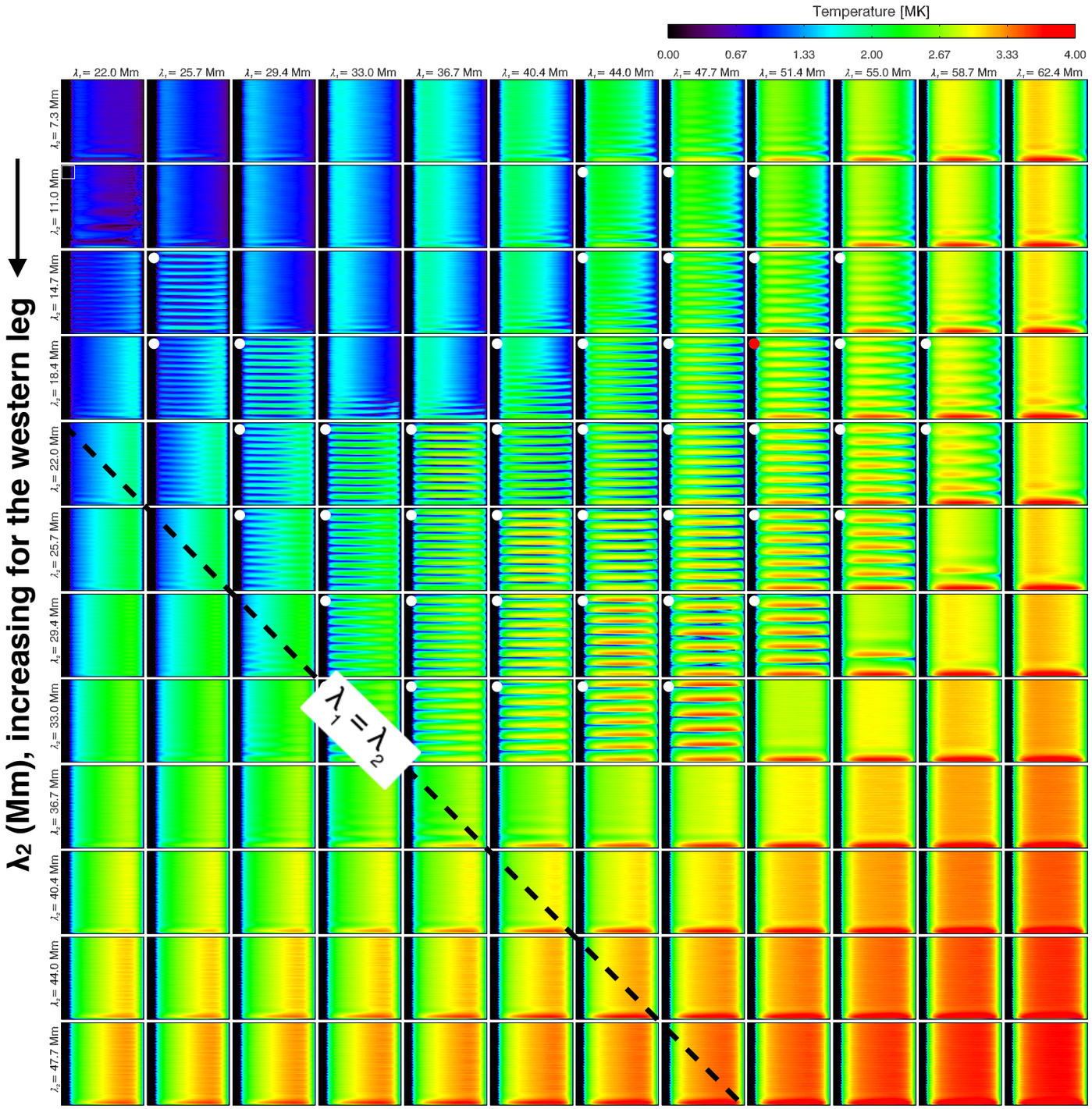
$$H(s) = H_0 + H_1 (e^{-g(s)/\lambda_1} + e^{-g(L-s)/\lambda_2})$$

$$g(s) = \max(s - \Delta, 0) \text{ and } \Delta = 5 \text{ Mm}$$

H_1: volumetric heating rate at the footpoints
λ_1, λ_2: scale height for each leg

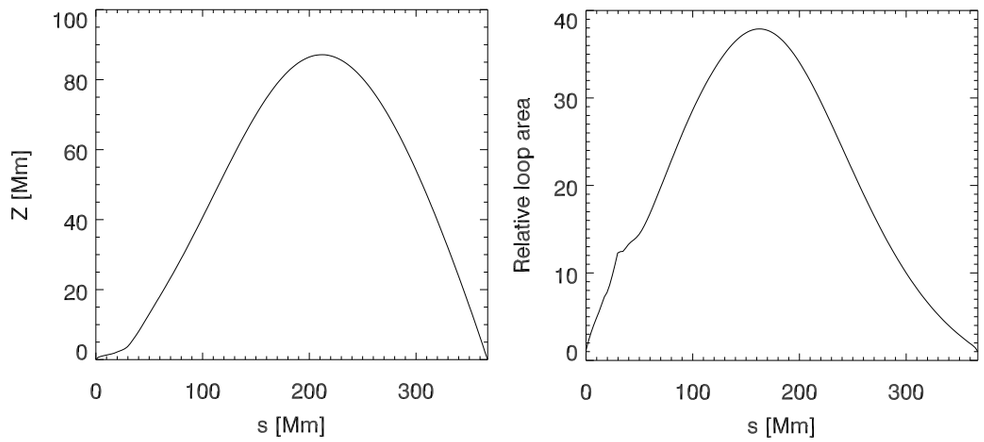


Parameter space study



Froment et al. 2017b, in prep

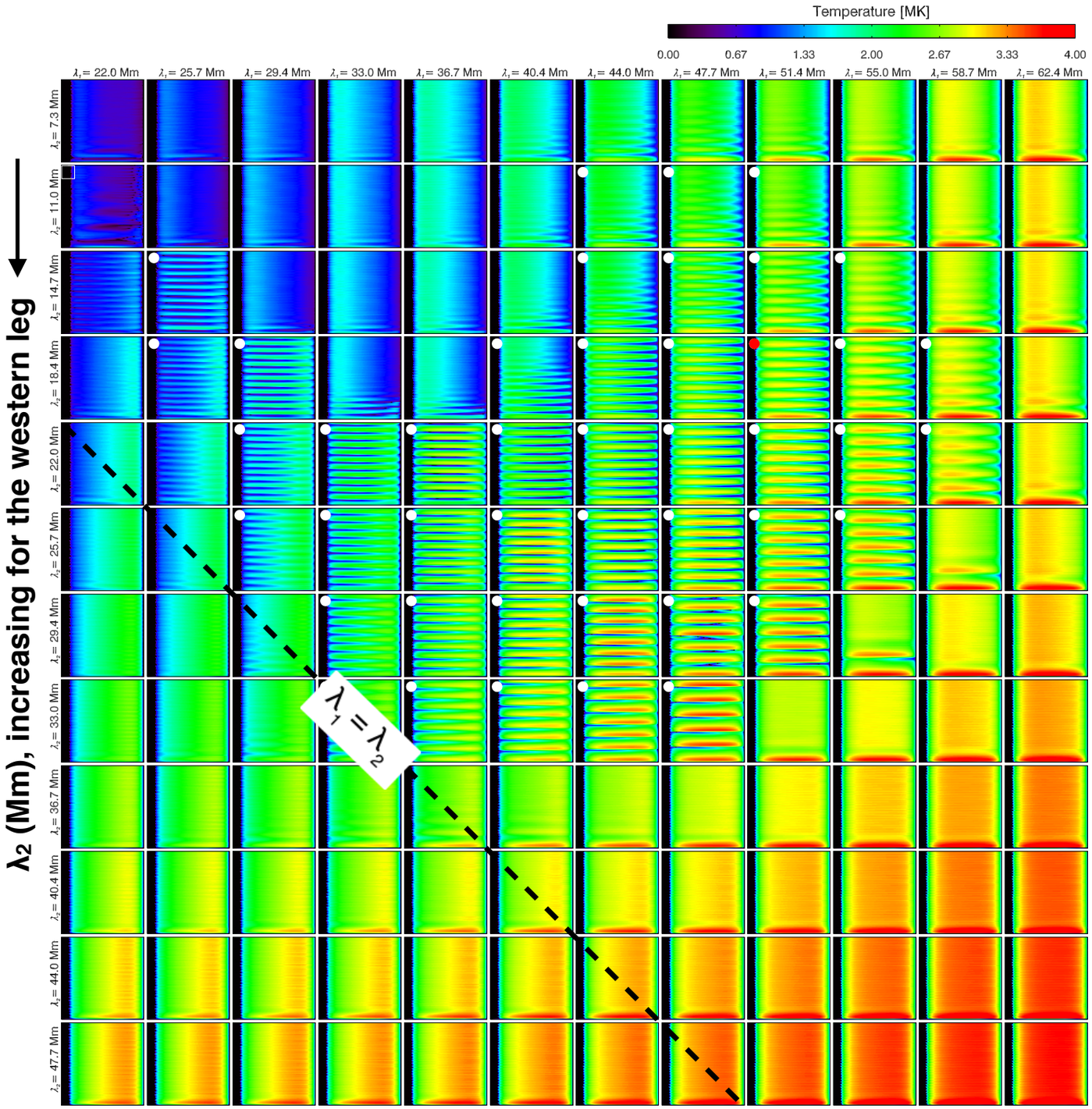
pulsating loop geometry (loop a)



one slice through the scan cube:
one value of heating rate at the footpoints (H_1),
scanning of scale height at each leg

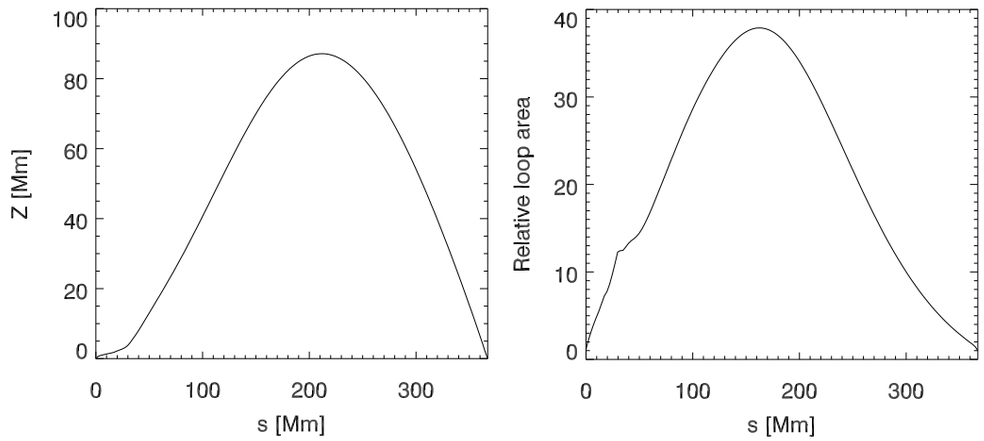
➡ Evaporation/condensation cycles only when $\lambda_1 > \lambda_2$: **asymmetric heating**

Parameter space study



Froment et al. 2017b, in prep

pulsating loop geometry (loop a)



one slice through the scan cube:
one value of heating rate at the footpoints (H_1),
scanning of scale height at each leg

➡ Evaporation/condensation cycles only when $\lambda_1 > \lambda_2$: **asymmetric heating**

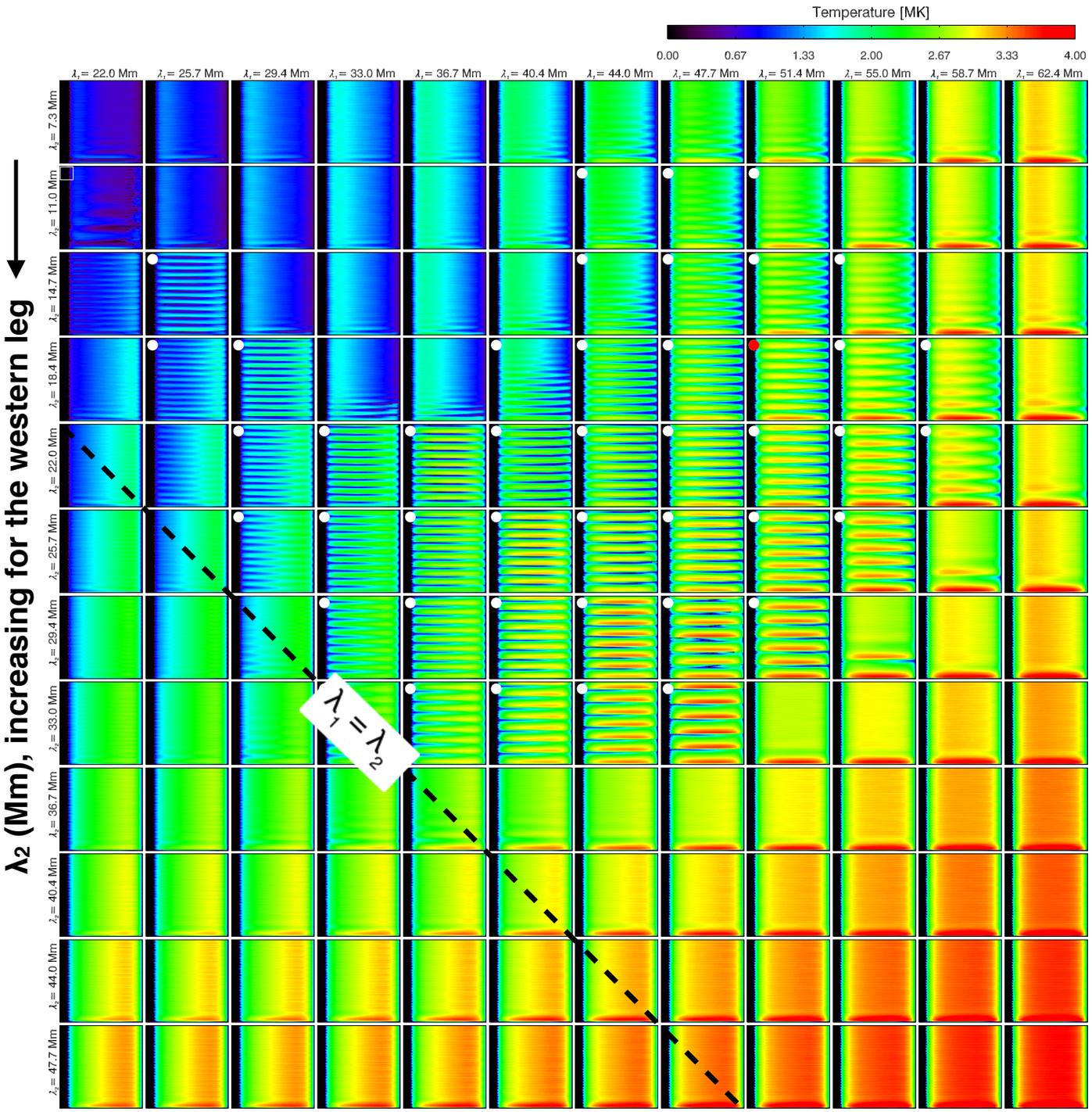
Conclusions with the 3 loop geometries :

➡ We can obtain TNE cycles with any loop geometry

➡ For each loop geometry, the **heating conditions are different**

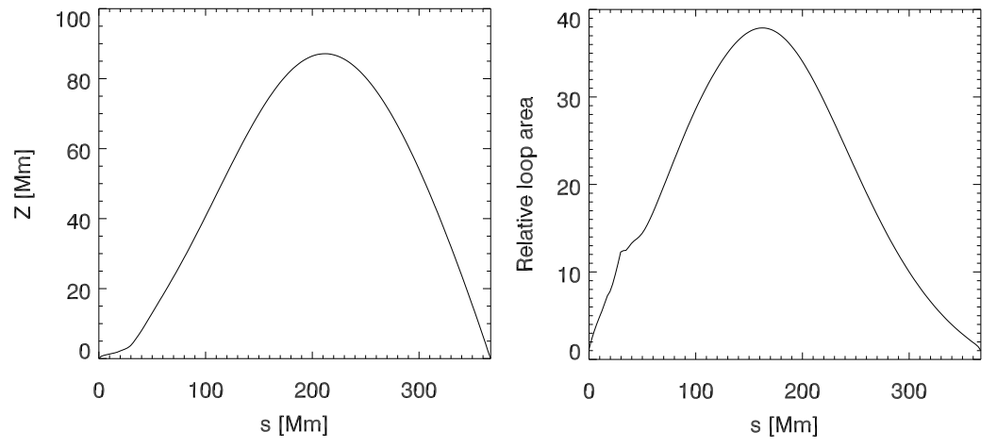
➡ **Production of TNE : very sensitive to a combination of loop geometry and heating parameters**

Parameter space study



Froment et al. 2017b, in prep

pulsating loop geometry (loop a)



one slice through the scan cube:
one value of heating rate at the footpoints (H_1),
scanning of scale height at each leg

➡ Evaporation/condensation cycles only when $\lambda_1 > \lambda_2$: **asymmetric heating**

Can explain why we observe TNE cycles only in some loops bundles and not in all

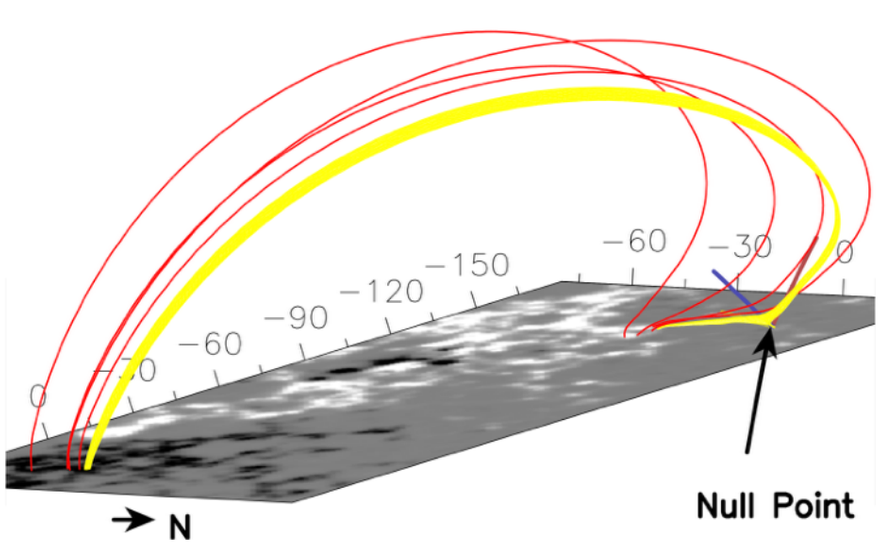
➡ We can obtain TNE cycles with any loop geometry

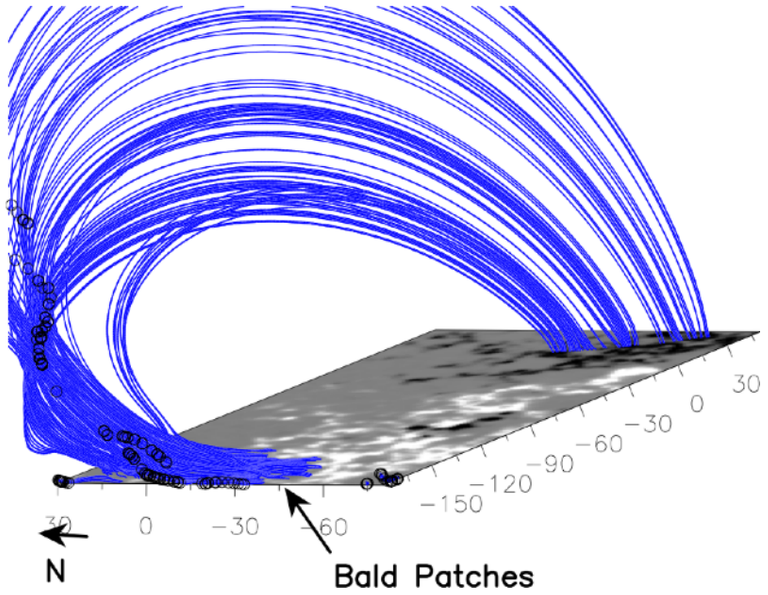
➡ For each loop geometry, the **heating conditions are different**

➡ **Production of TNE : very sensitive to a combination of loop geometry and heating parameters**

Potential evidence of asymmetric heating

Eastern leg of the pulsating loops : a **photospheric null-point** and many ***Bald Patches***

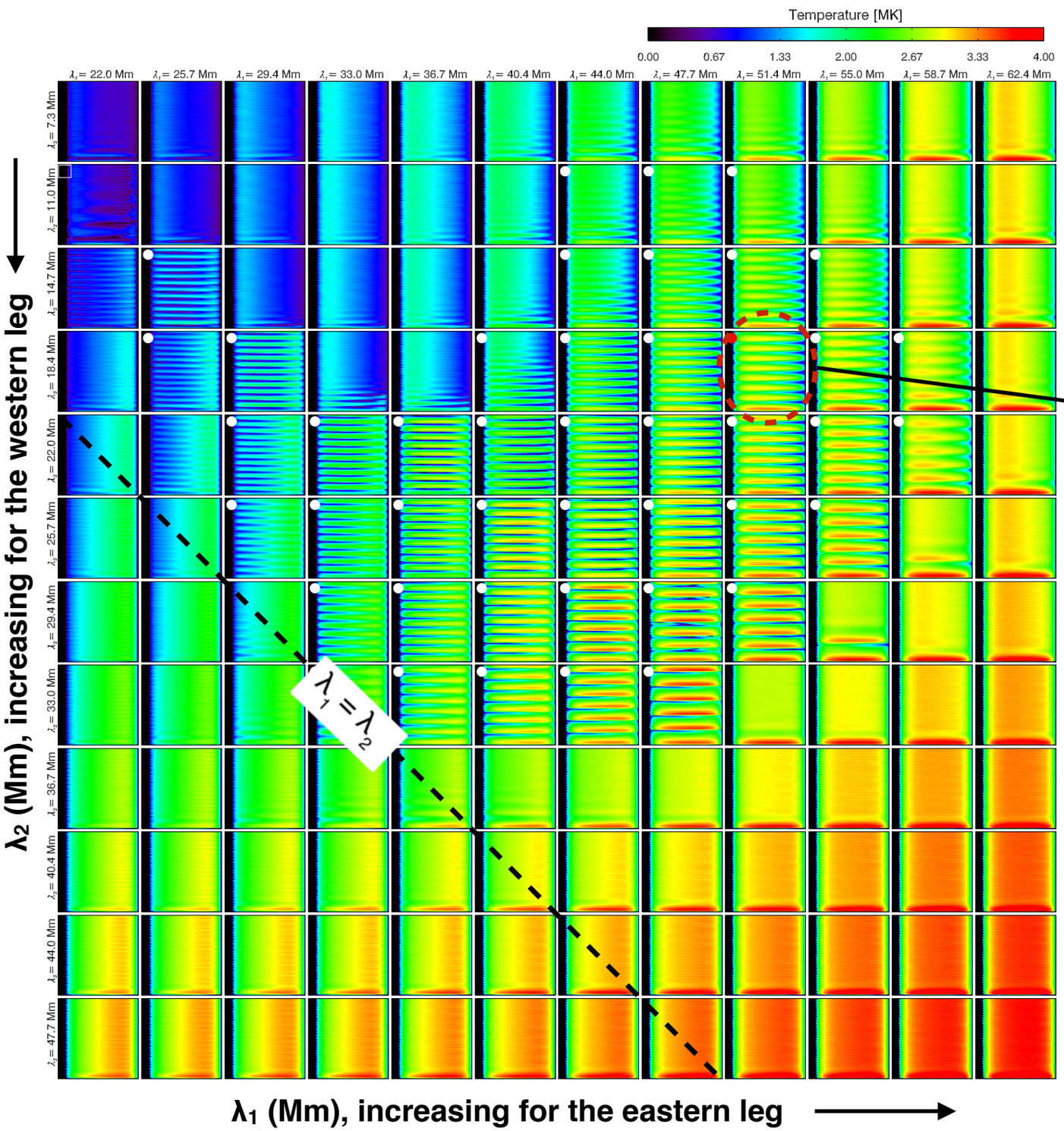


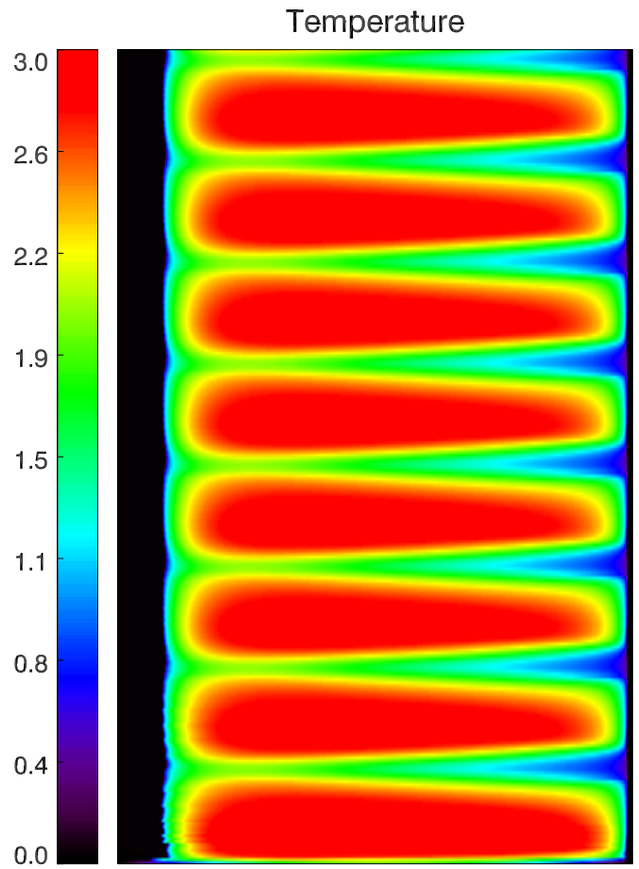


Froment et al. 2017, ApJ, 835, 272

➡ **These particular magnetic topologies could favor reconnection**
➡ **It might be evidence an asymmetric heating for these loops**

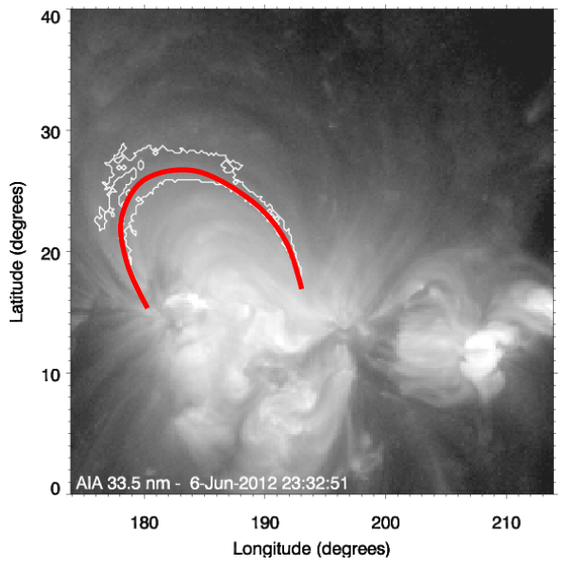
Comparison observation and simulation



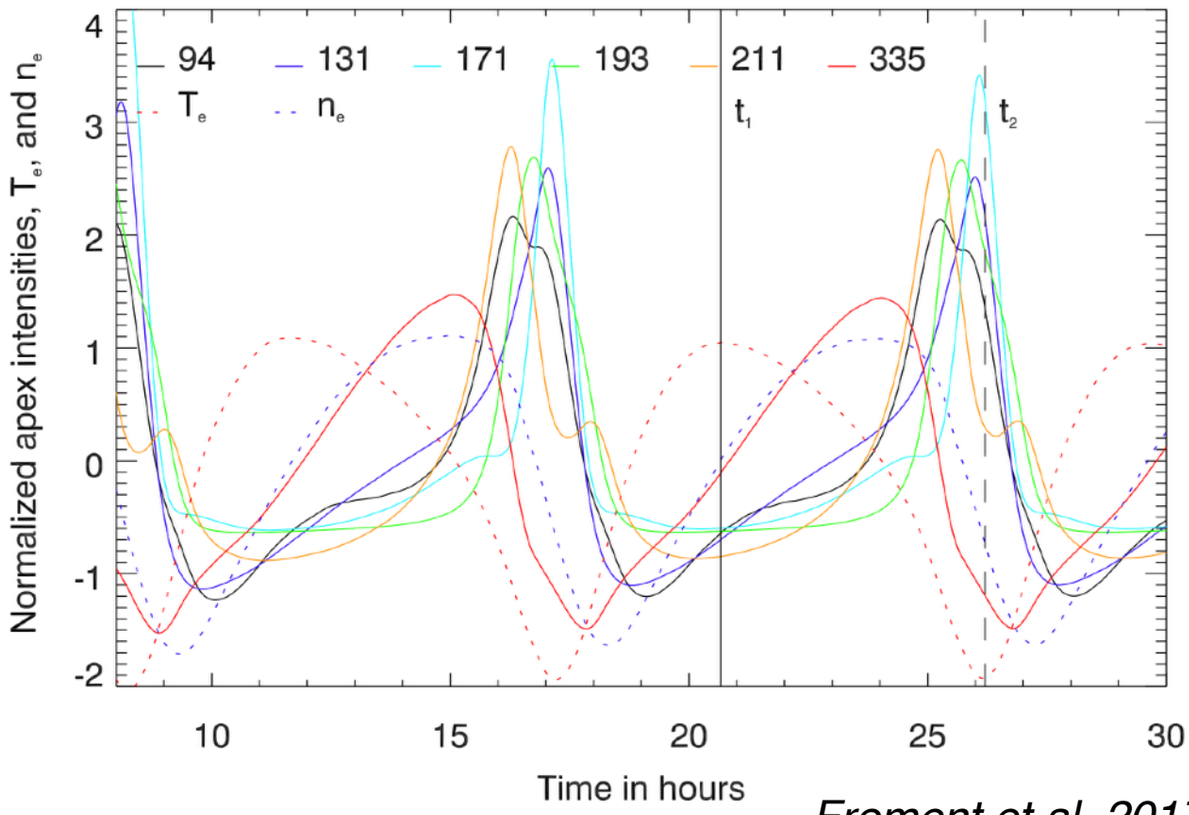


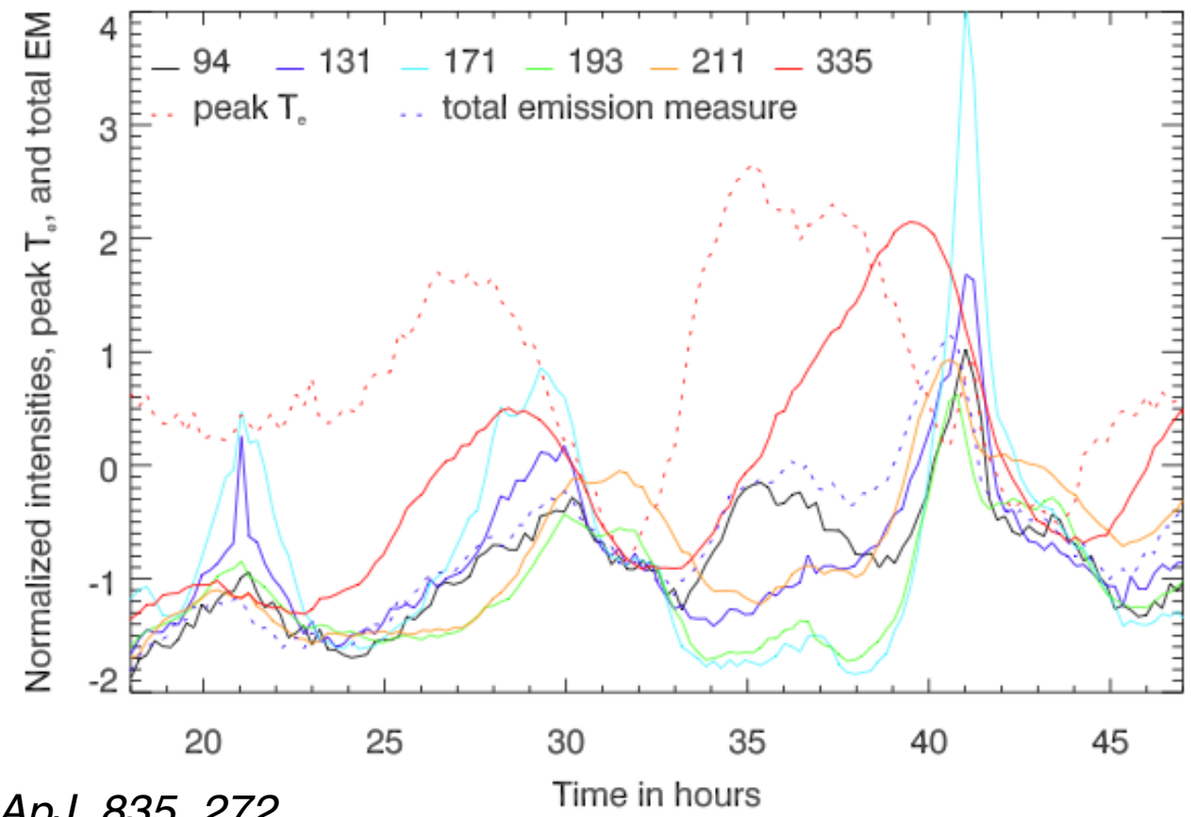
incomplete condensations case

➡ Simulation reproducing the best the average behavior of the loop bundle



Synthetic and observed intensities from an IC case

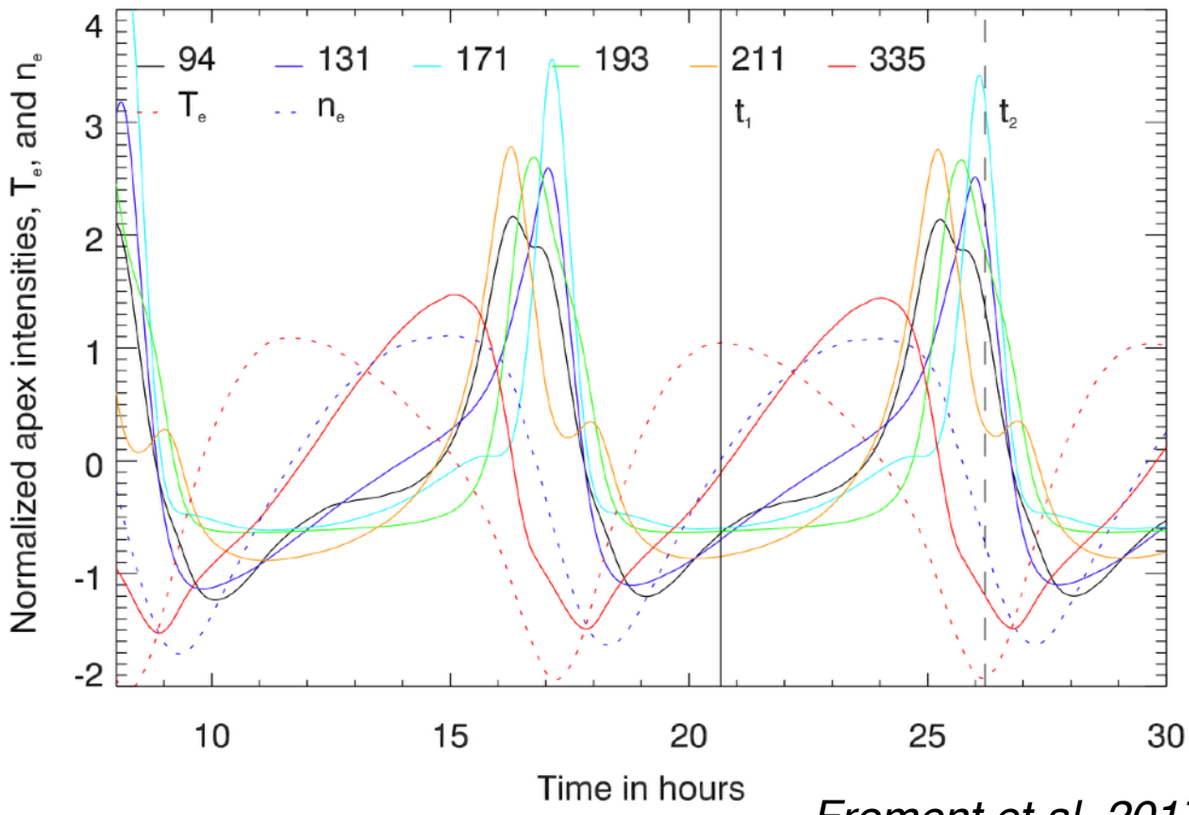


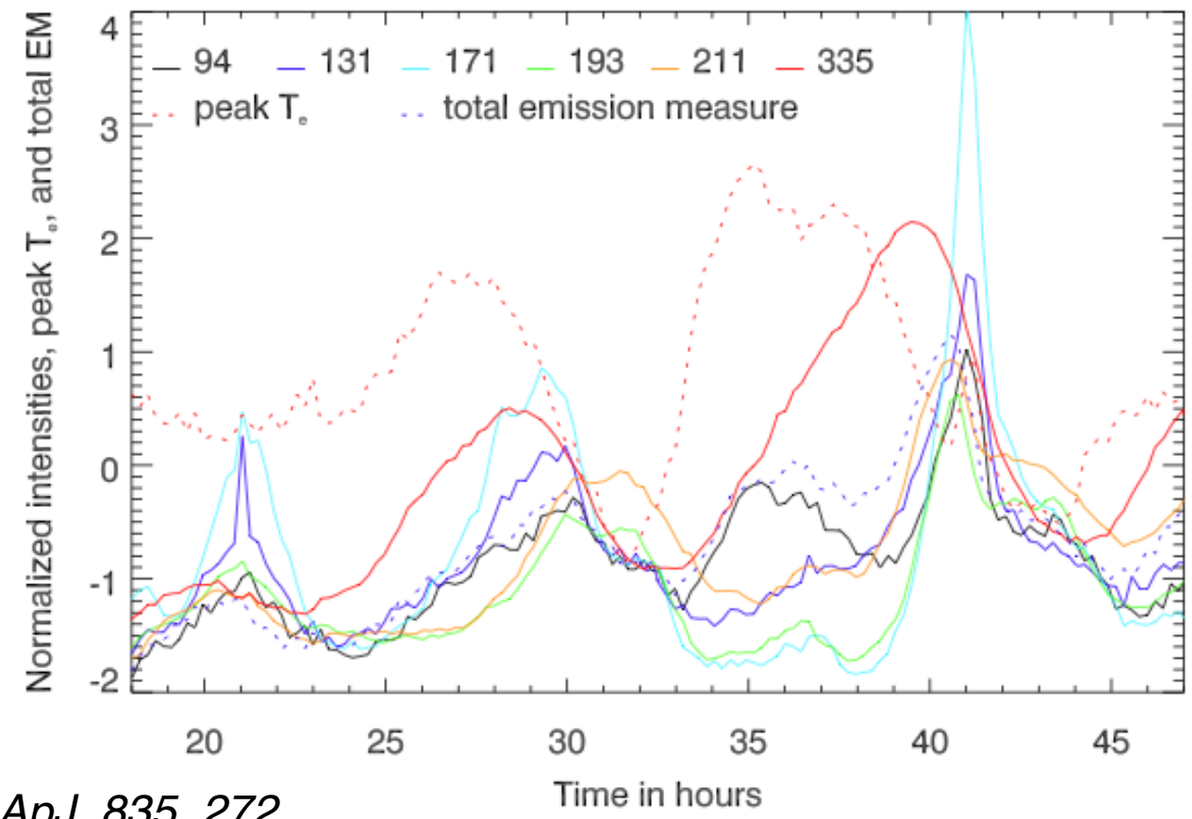


Froment et al. 2017, ApJ, 835, 272

- Mean values around the loop apex
- Synthetic intensities from the AIA response functions (CHIANTI 8.0, *Del Zanna et al. 2015*)
- This model can reproduce the **long-term behavior of the loop**

Synthetic and observed intensities from an IC case





Froment et al. 2017, ApJ, 835, 272

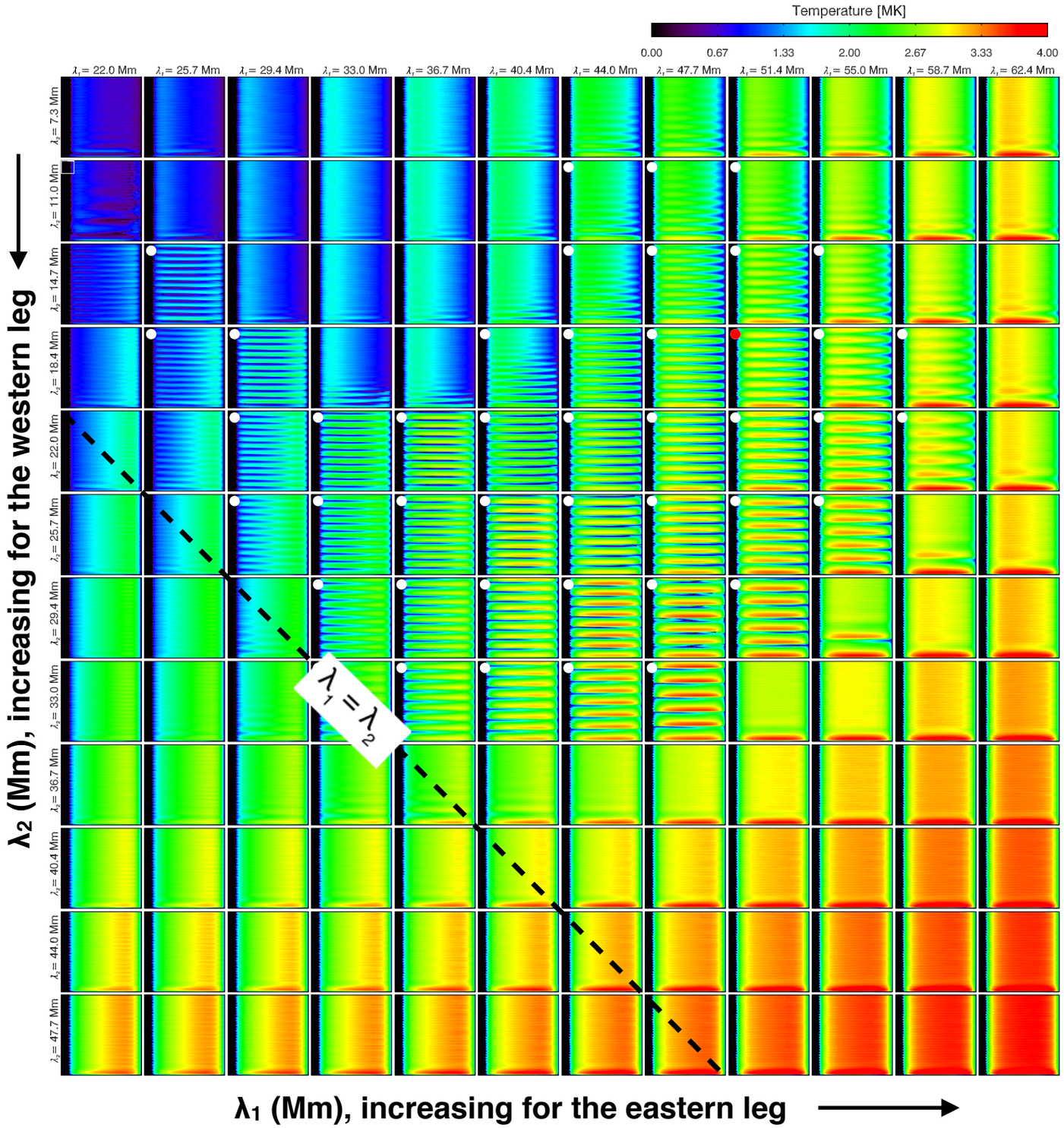
- ➡ Mean values around the loop apex
- ➡ Synthetic intensities from the AIA response functions (CHIANTI 8.0, *Del Zanna et al. 2015*)
- ➡ This model can reproduce the **long-term behavior of the loop**

To bear in mind :

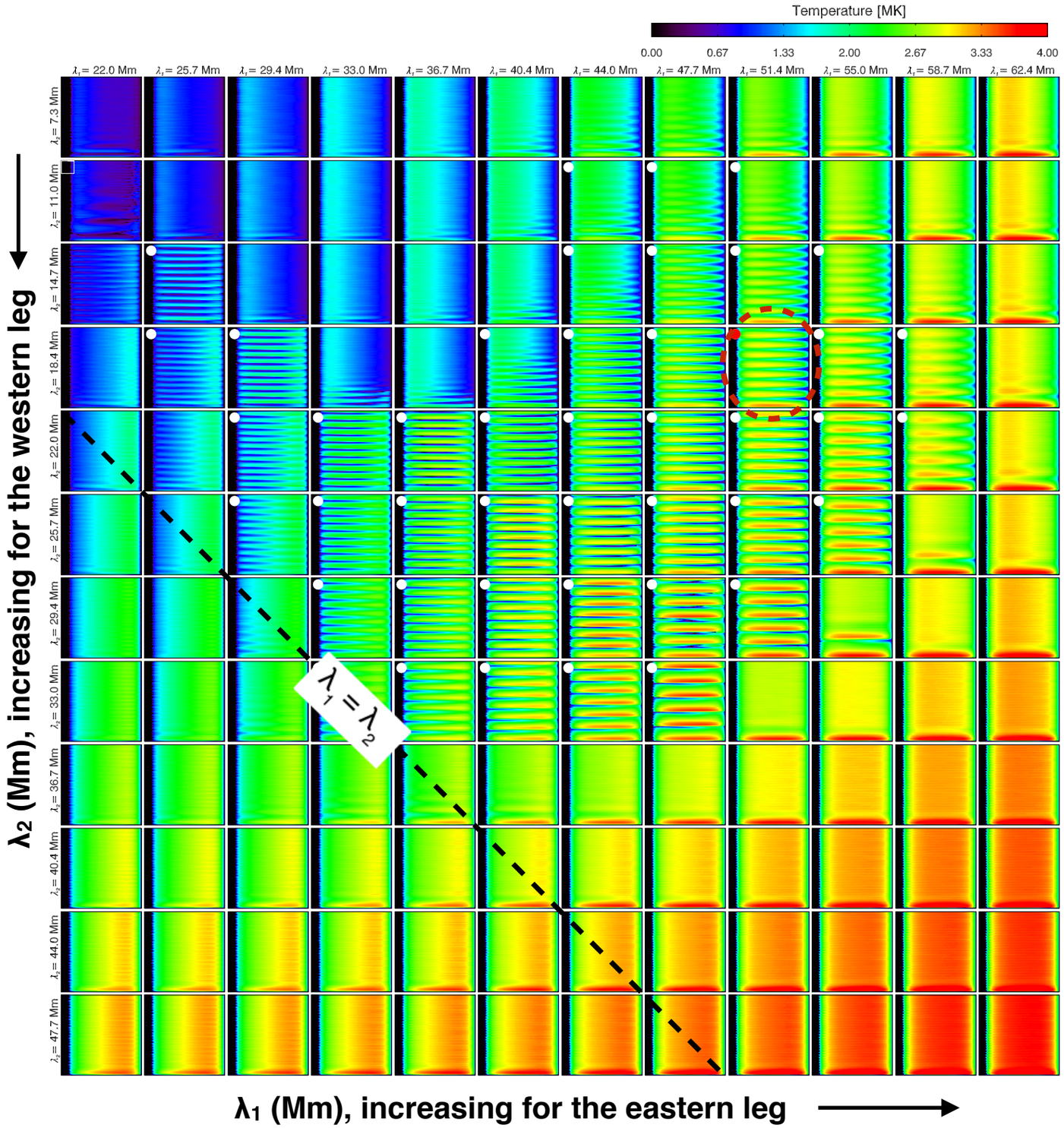
- ➡ 1D simulations: **only one loop**, **no background/foreground emissions**
- ➡ **strictly constant heating**

] we can not reproduce the details = **mean and long-term behavior**

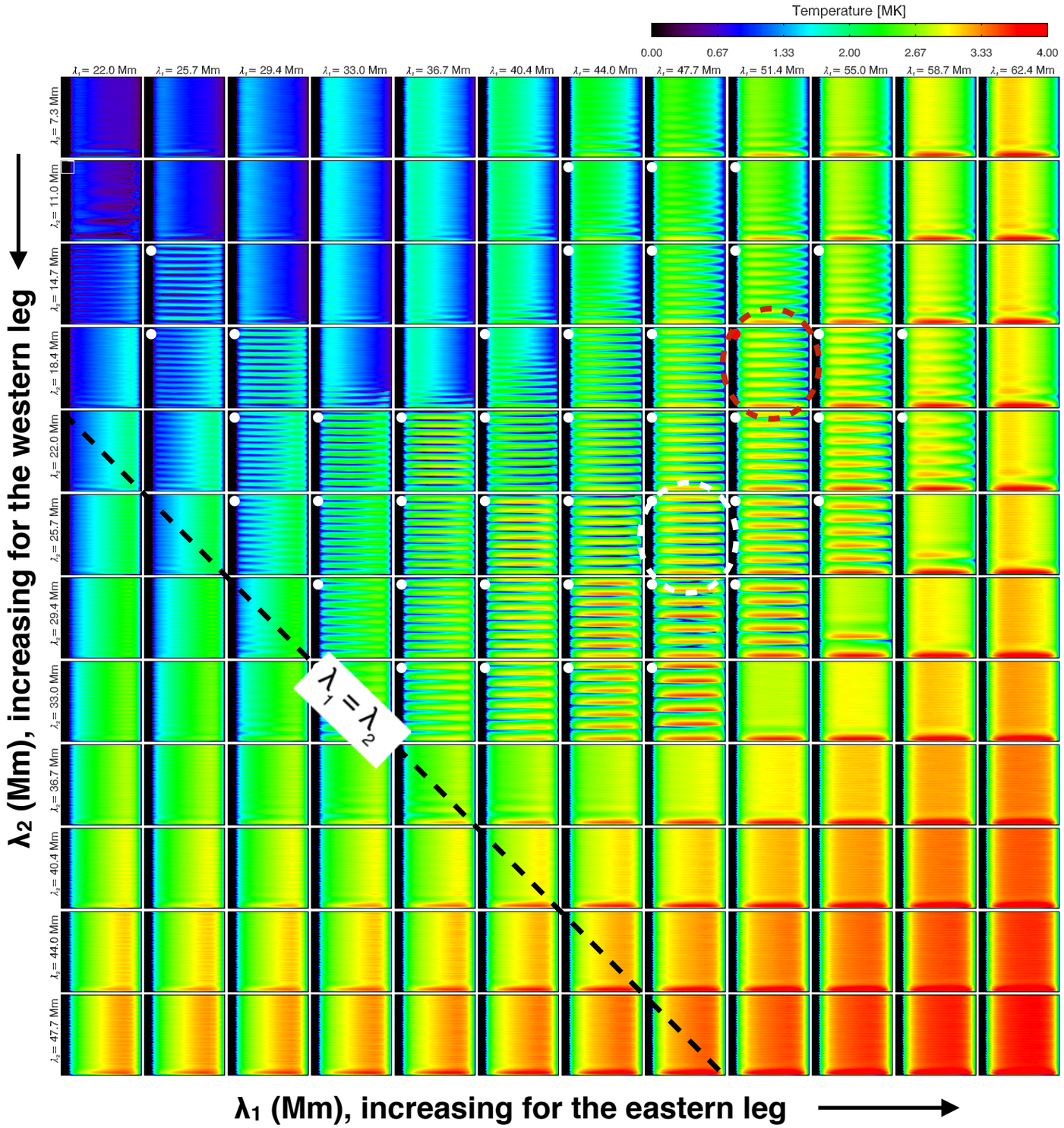
What about an CC case, i.e with coronal rain?



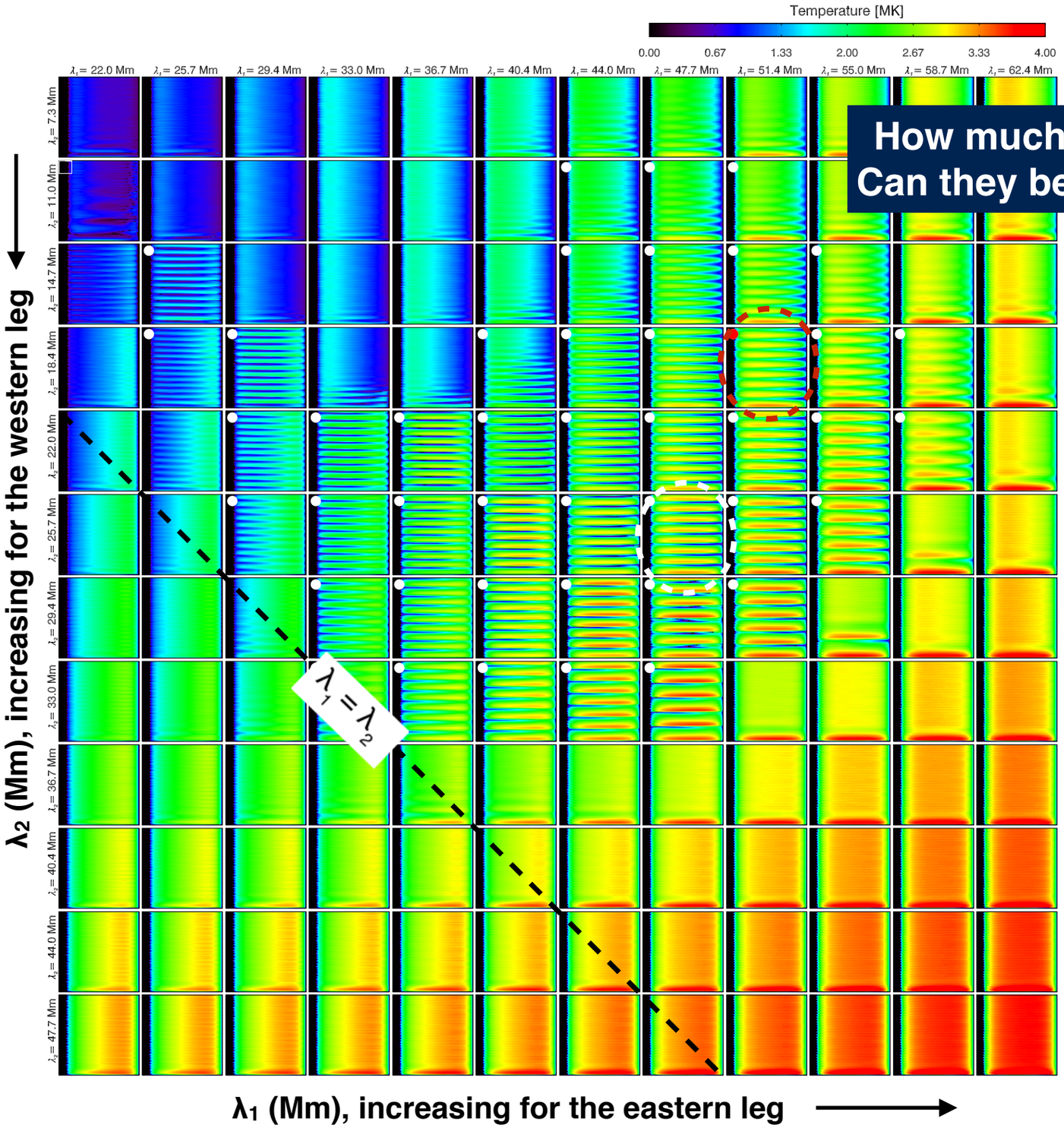
What about an CC case, i.e with coronal rain?



What about an CC case, i.e with coronal rain?



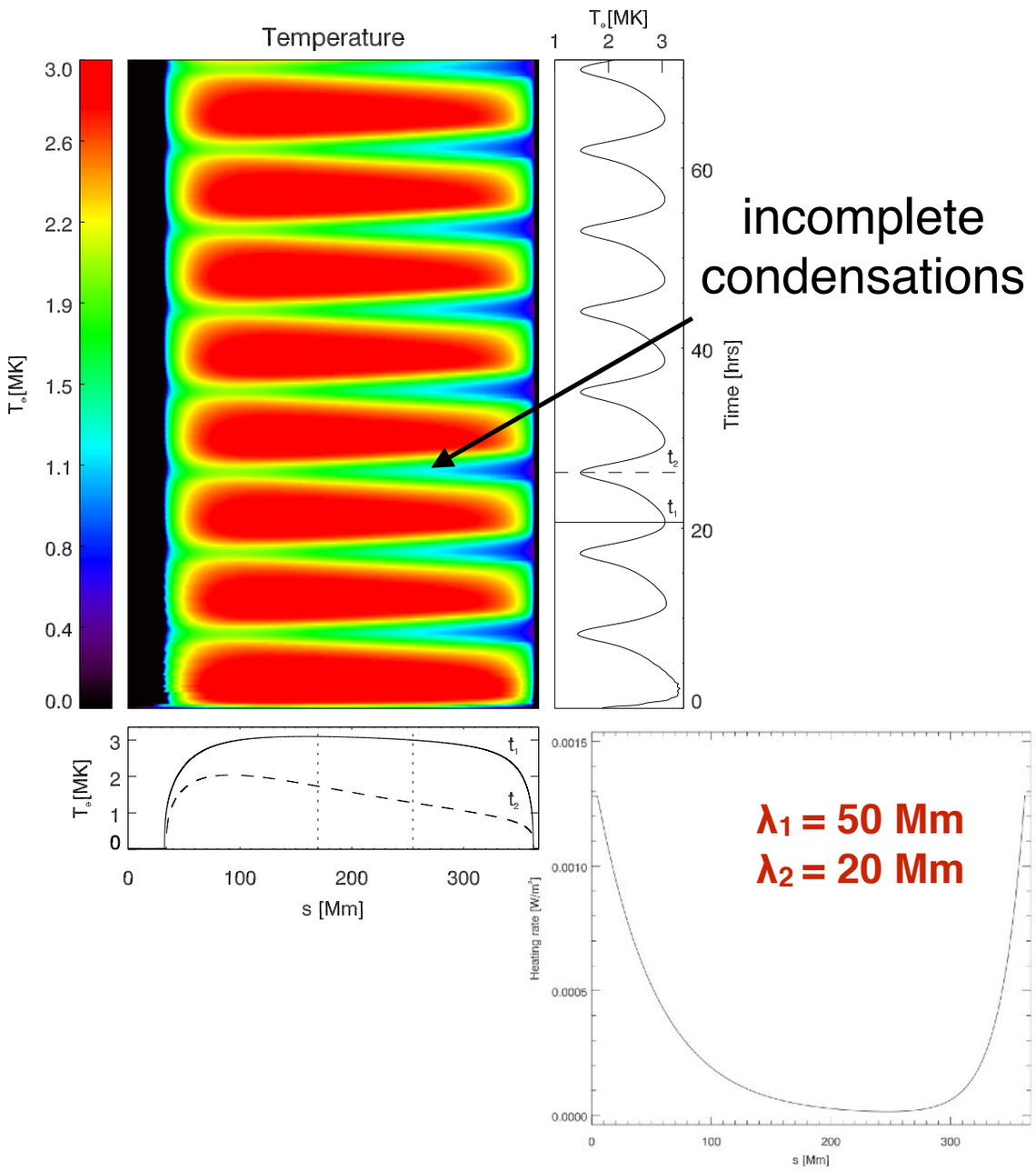
What about an CC case, i.e with coronal rain?



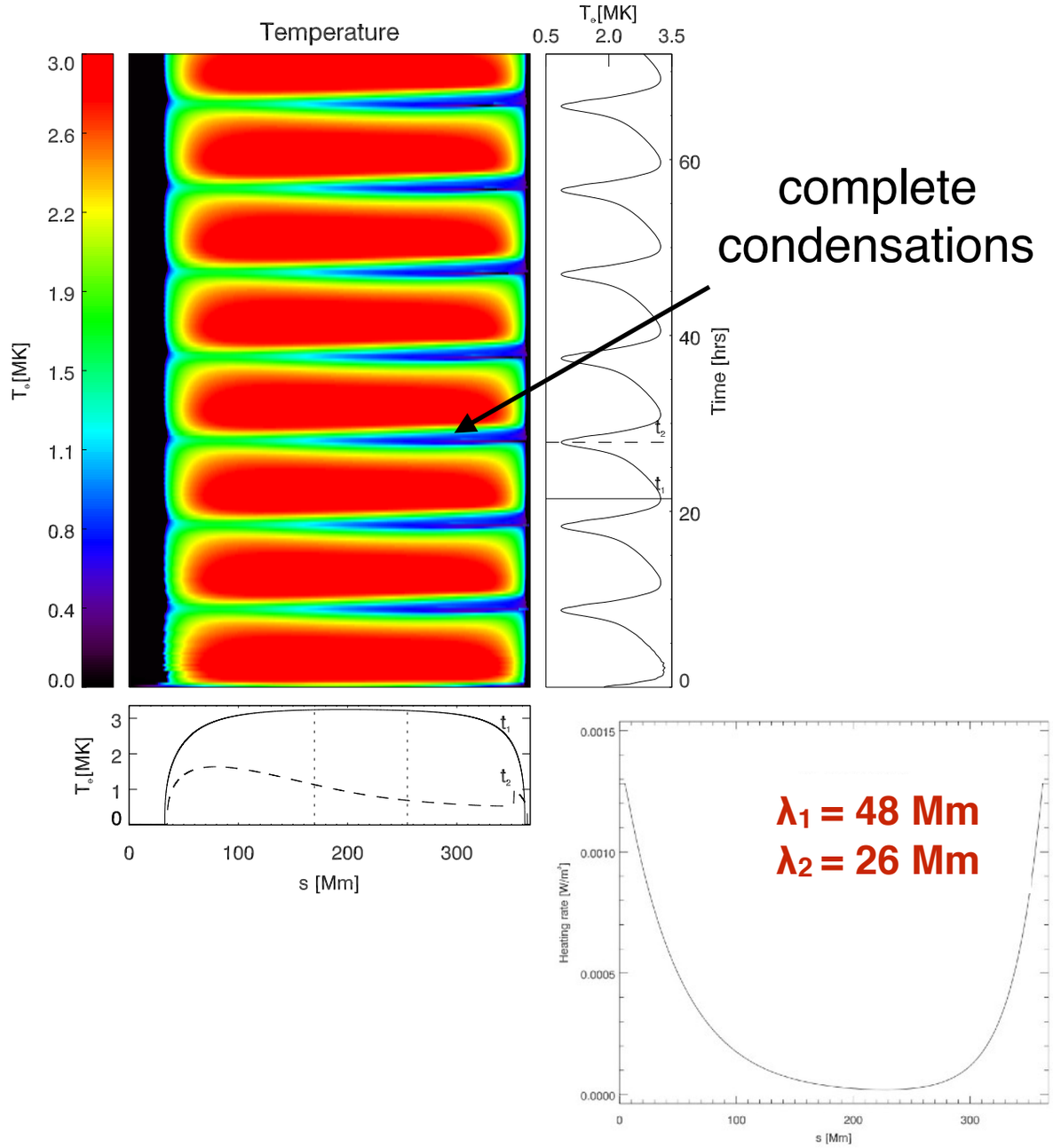
How much an CC case is different from an IC case?
Can they be easily differentiated in the observations?

Different types of behavior produced…

… with similar heating conditions



incomplete condensations

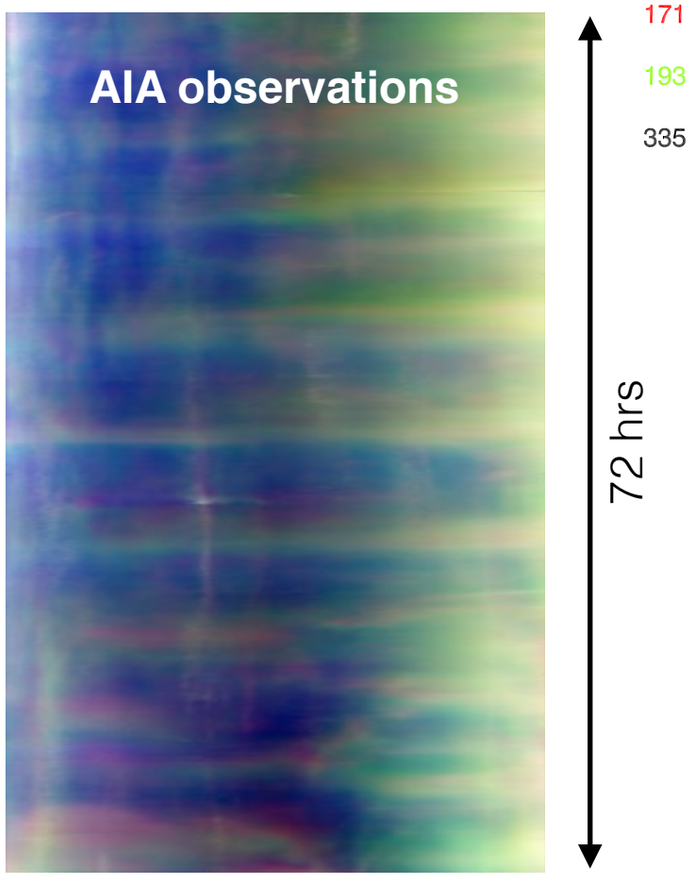


complete condensations

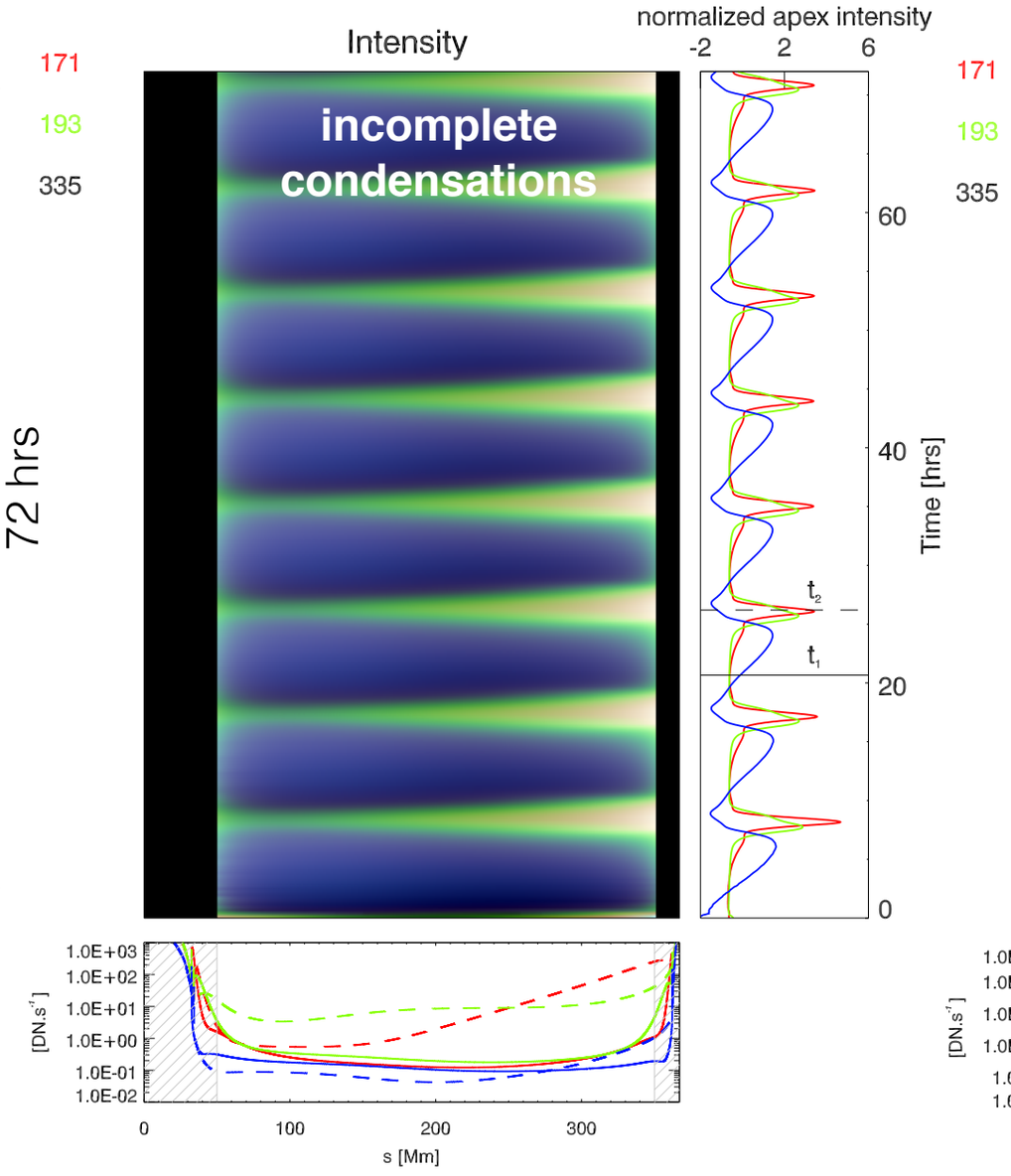
- pulsations in both cases, can be differentiated locally by the temperature drop

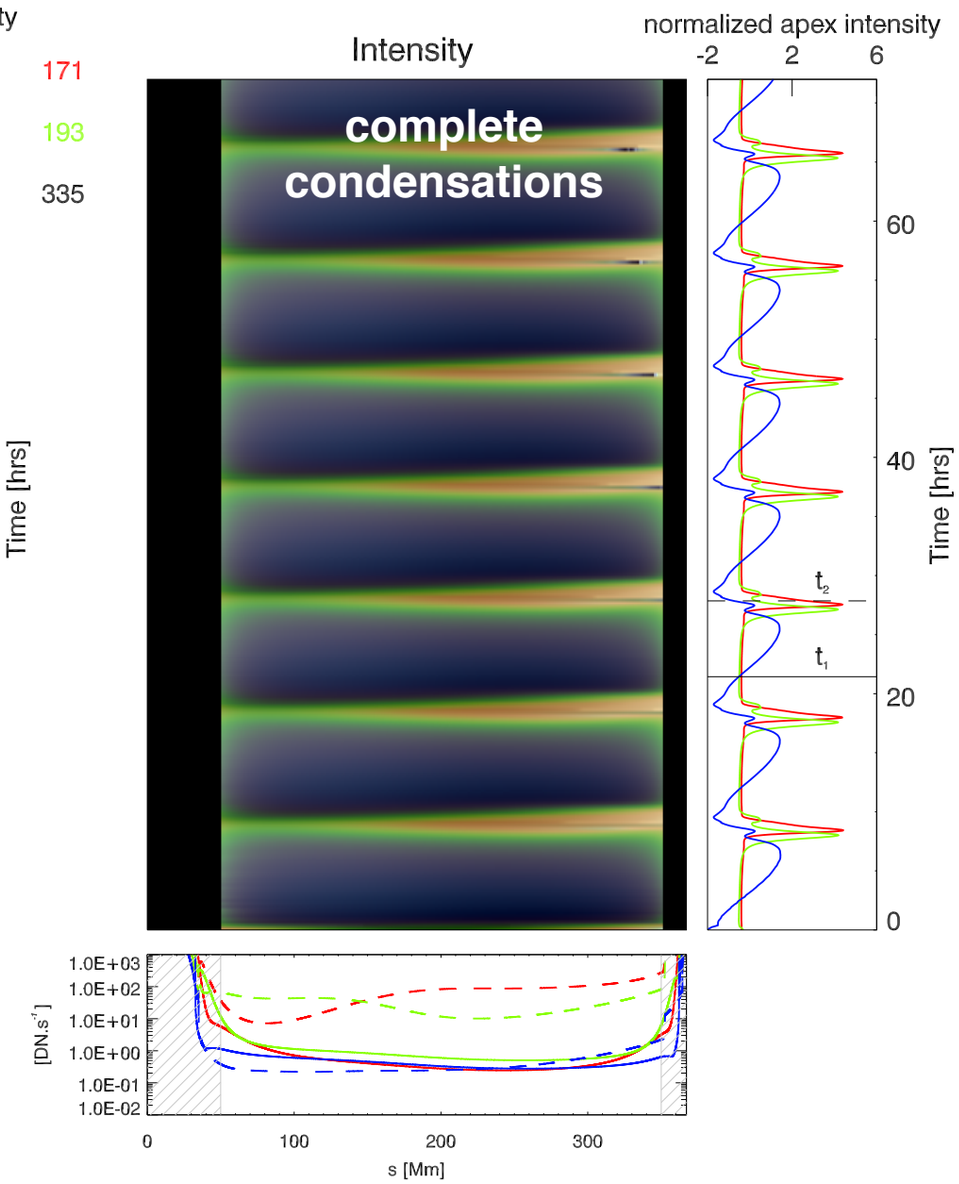
Synthetic and observed intensities (CC, IC & Obs.)

Froment et al. 2015, ApJ, 807, 158



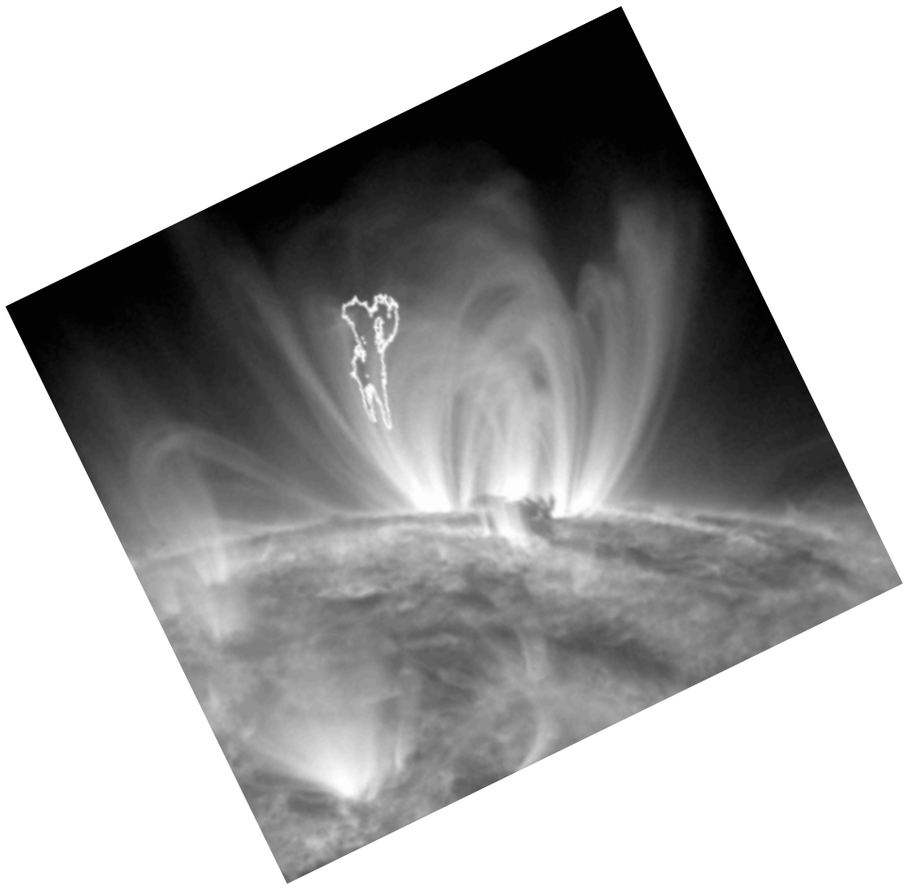
Froment et al. 2017b, in prep

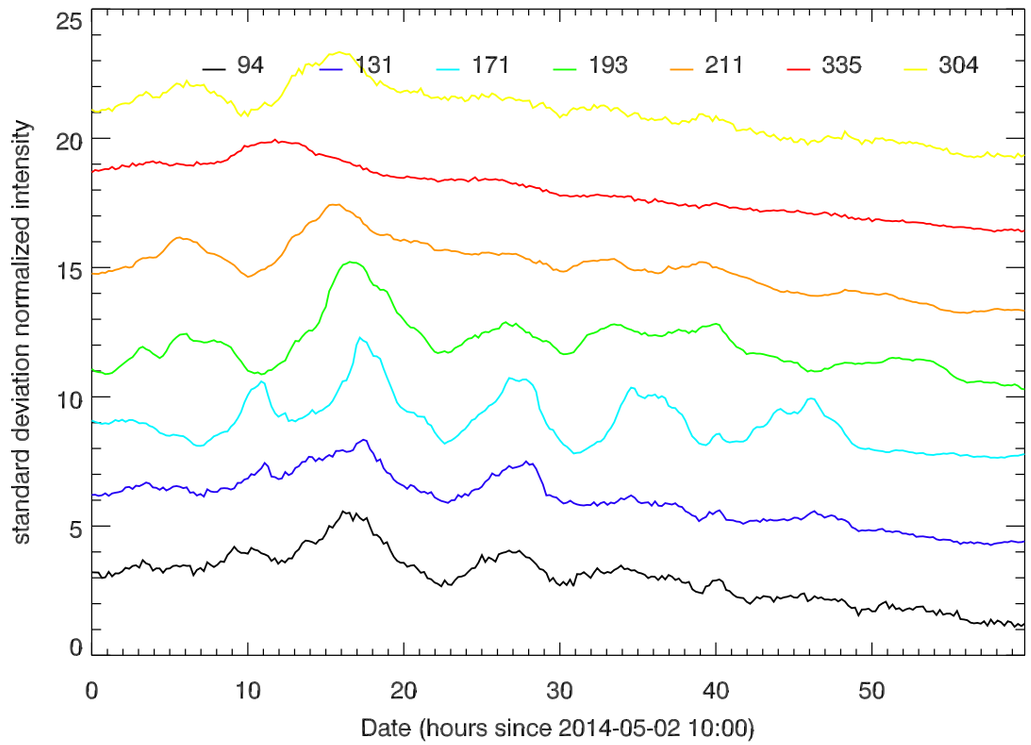




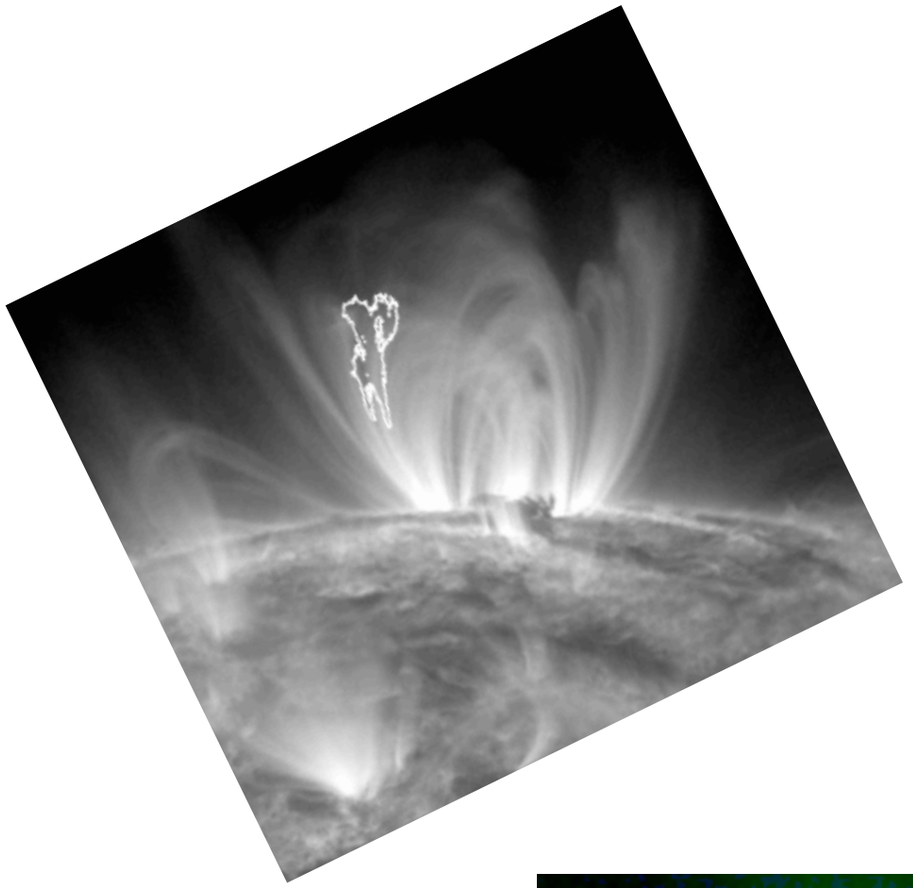
- ➡ Different types of behavior produced, here with similar heating conditions
- ➡ **Both CC and IC cases could be compatible with the observations**

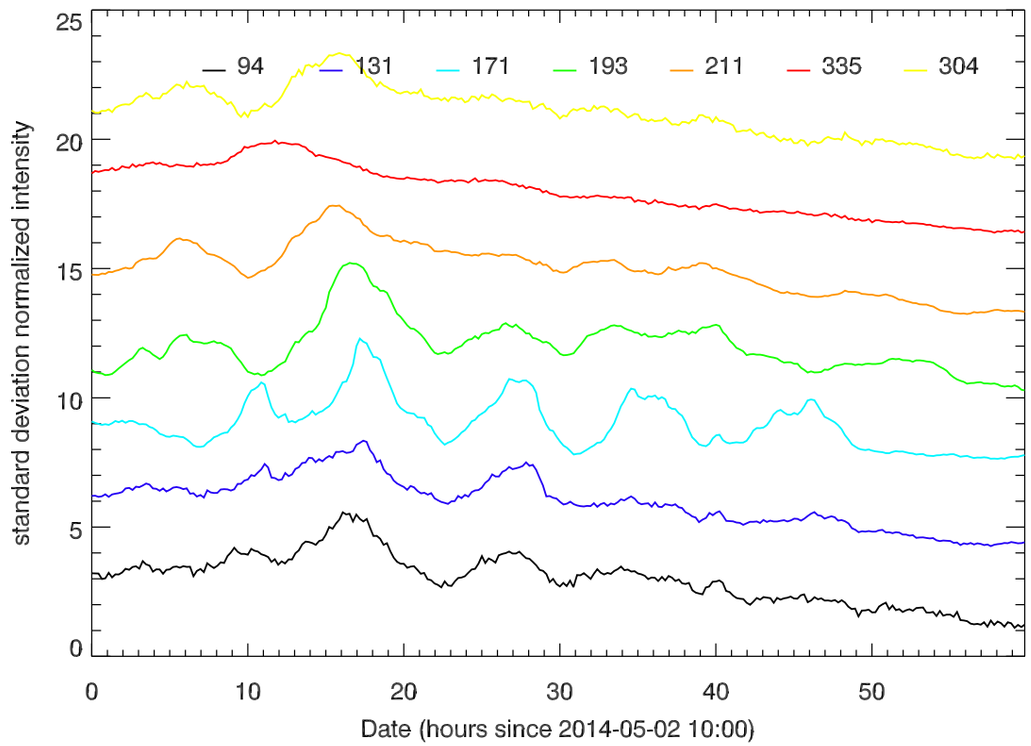
Simultaneous coronal rain and intensity pulsations

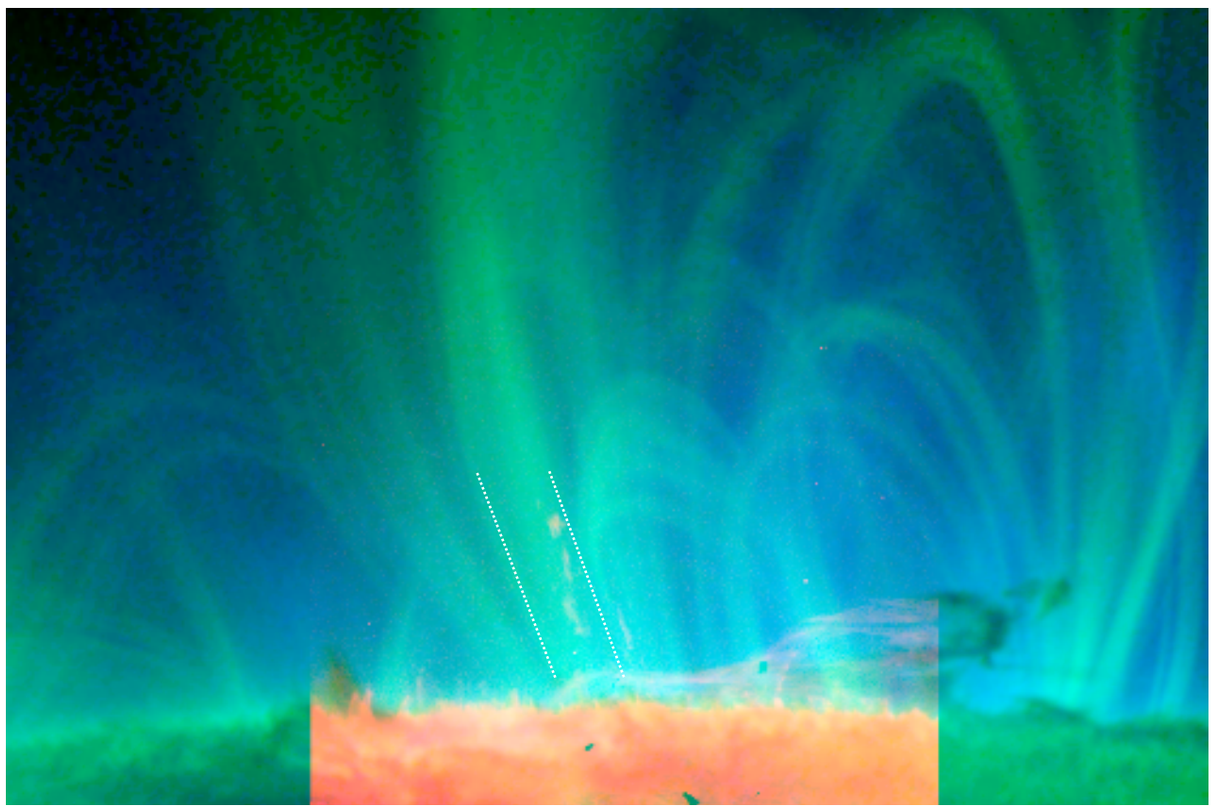




Simultaneous coronal rain and intensity pulsations







SDO/AIA 335
SDO/AIA171
IRIS/SJI 1400

Conclusions

➡ **Long-period intensity pulsations** (several hours) are **very common in coronal loops**

➡ **Thermal diagnostics with AIA**:
- **TNE - cycles of evaporation and condensation**

➡ **Modeling**:
- further strengthens the previous conclusion
- we can reproduce the observed intensities
- and **can explain why only some loops bundle undergo these pulsations**
- quasi-continuous footpoint heating can also lead to “static loops”

➡ **Implications for coronal heating: spatial location and timescale**

Unification of the observed phenomenon with the coronal rain

➡ Observation of the cycle from corona to transition region

… To go further

- Are IC cases related to coronal rain events ?
- What are the mechanisms that produce IC?
- What fraction of the coronal volume experiences TNE?
- Are the non-pulsating loops and diffuse emission produced by a completely different heating deposition in time and space?
- …

Simultaneous observations of long-period intensity pulsations and coronal rain, periodic coronal rain showers

- (see Frédéric Auchère's talk)

Periodic upflows and downflows should be detectable even when no coronal rain is visible

- (see Gabriel Pelouze's talk)

… To go further

- Are IC cases related to coronal rain events ?
- What are the mechanisms that produce IC?
- What fraction of the coronal volume experiences TNE?
- Are the non-pulsating loops and diffuse emission produced by a completely different heating deposition in time and space?
- …

Simultaneous observations of long-period intensity pulsations and coronal rain, periodic coronal rain showers

- (see Frédéric Auchère's talk)

Periodic upflows and downflows should be detectable even when no coronal rain is visible

- (see Gabriel Pelouze's talk)

Thanks for your attention!