

GX Simulator Modeling of AR 12760

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June 25, 2025

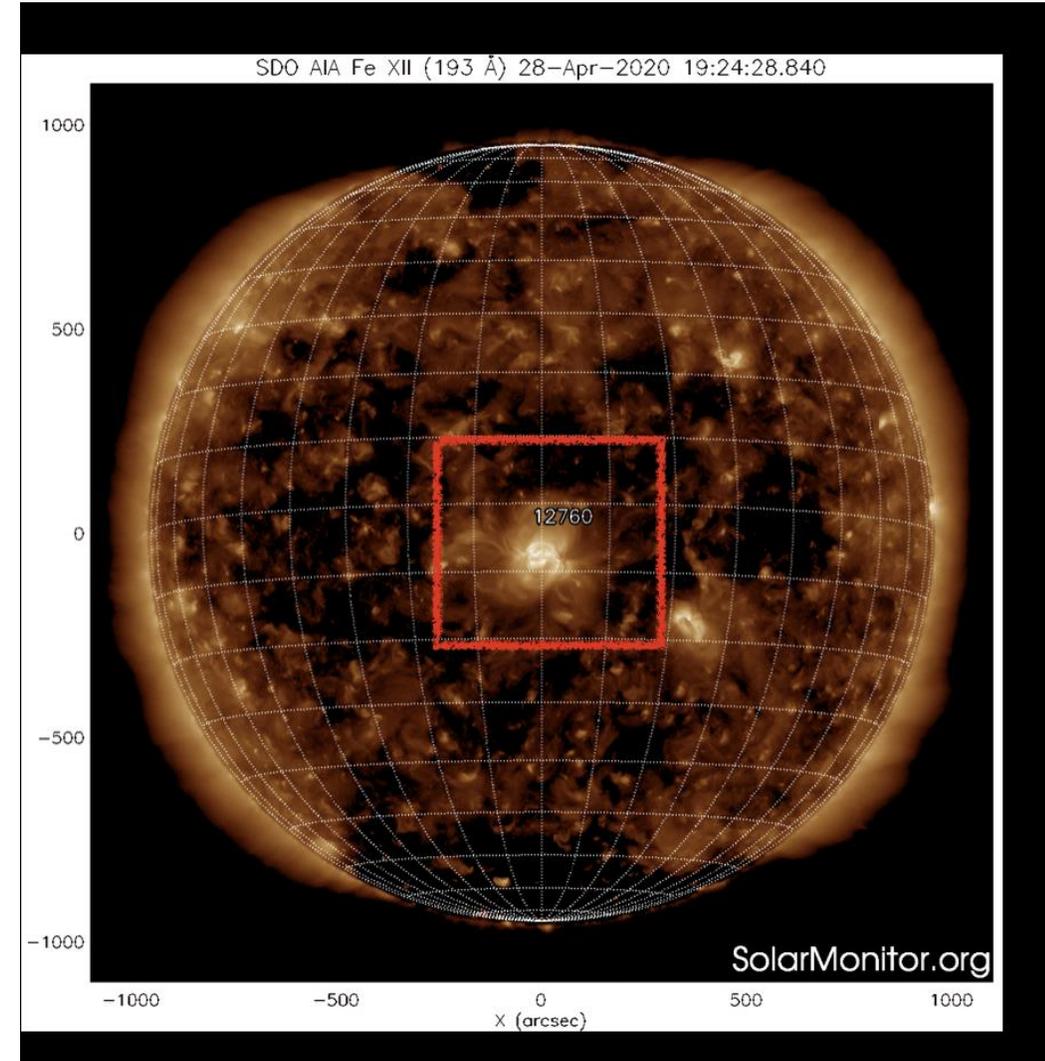


ISWAT region

Ultimate Goal: physics based modeling of active region EUV emission for solar spectral irradiance prediction

AR 12760 on 2020-April-28 selected because

- Magnetically simple and not very active (α/β)
- Little or no sunspots
- Near disk center
- Little other activity on disk
- Data from a range of different instruments

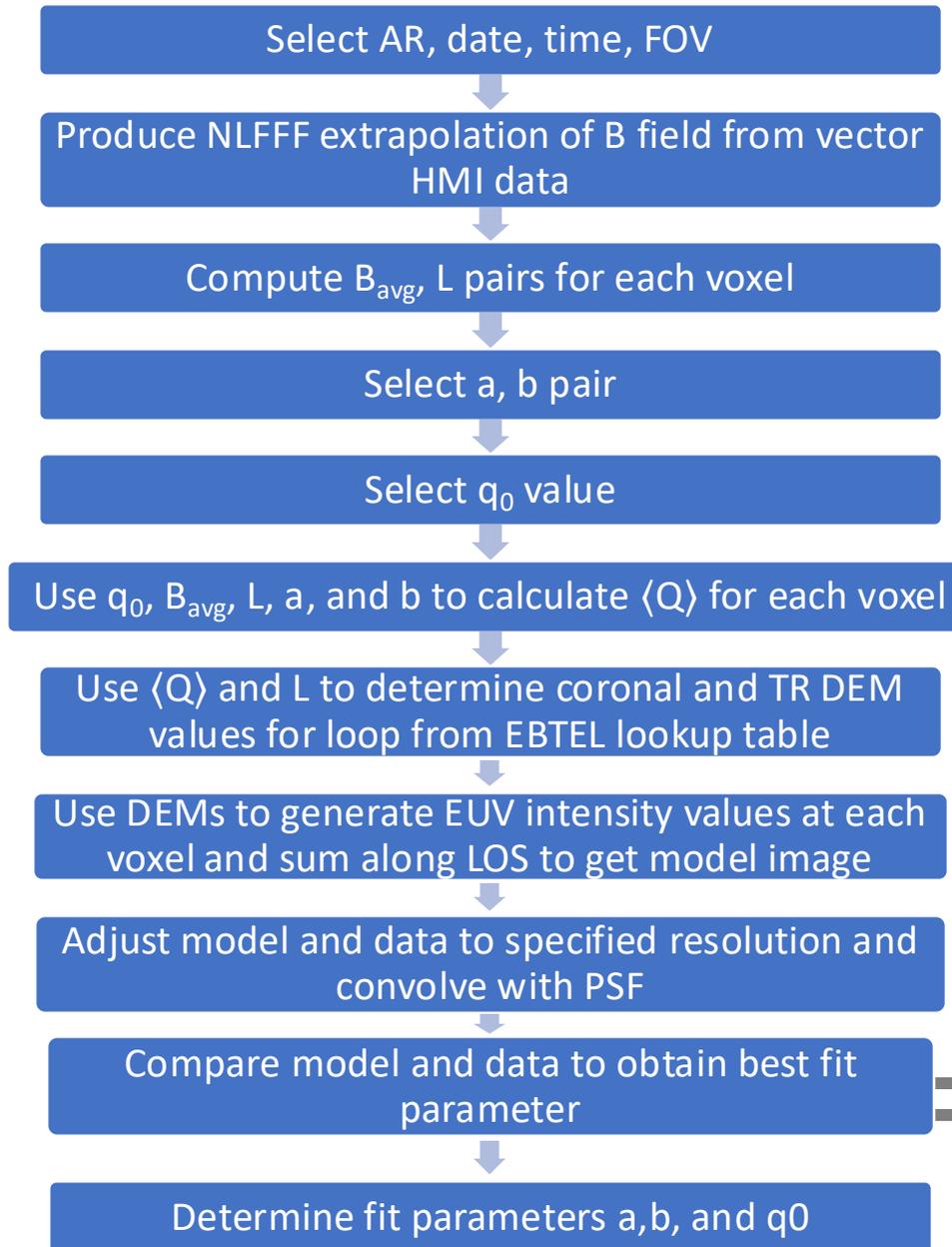


GX Simulator Modeling

Goal: Determine the dependence of heating on magnetic field strength and loop length

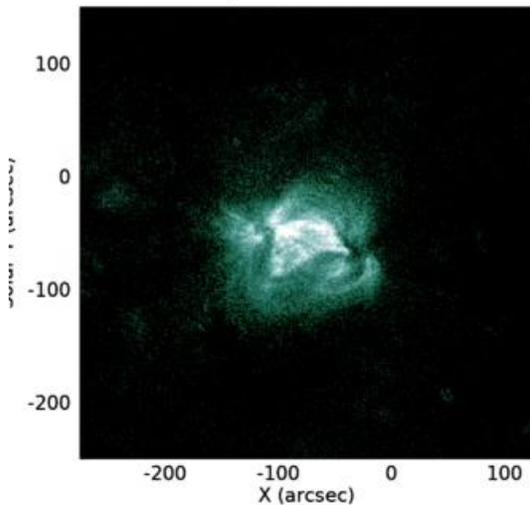
$$\langle Q \rangle = q_0 (B_{\text{avg}}/B_0)^a (L/L_0)^{-b}$$

$\langle Q \rangle$ – time averaged heating rate
 B_{avg} – magnetic field averaged over loop
 L – loop half length

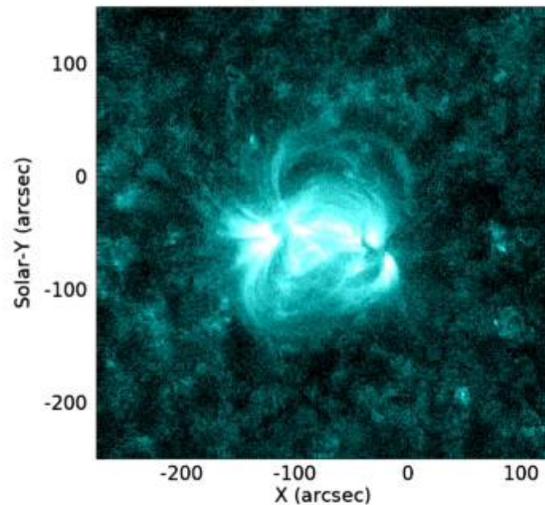


2020 Apr 28 09:15-13:10 UT

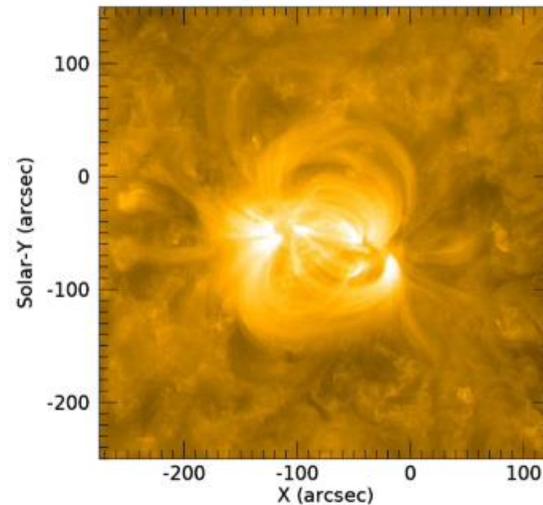
SDO AIA 4 94
28-Apr-20 09:15:12 UT



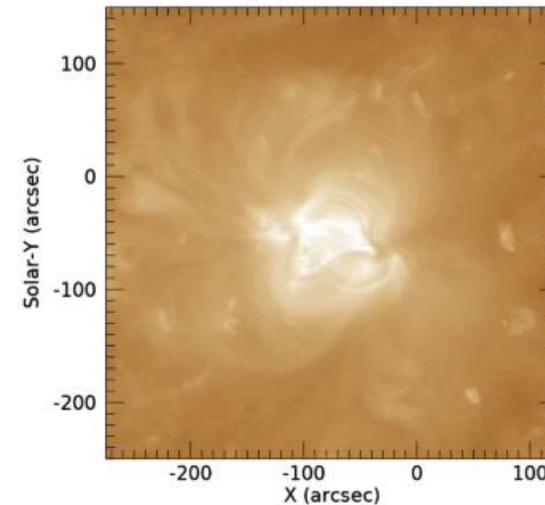
SDO AIA 1 131
28-Apr-20 09:15:08 UT



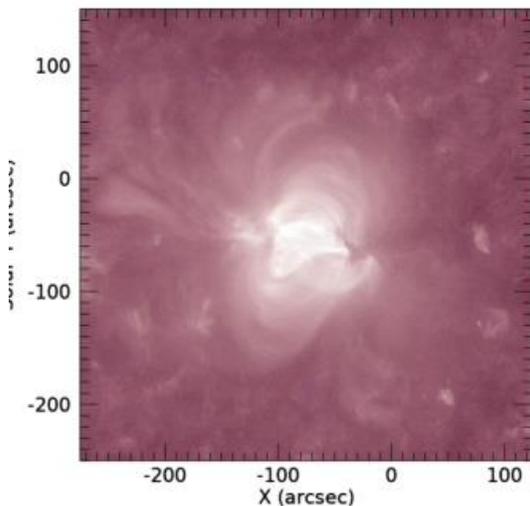
SDO AIA 3 171
28-Apr-20 09:15:10 UT



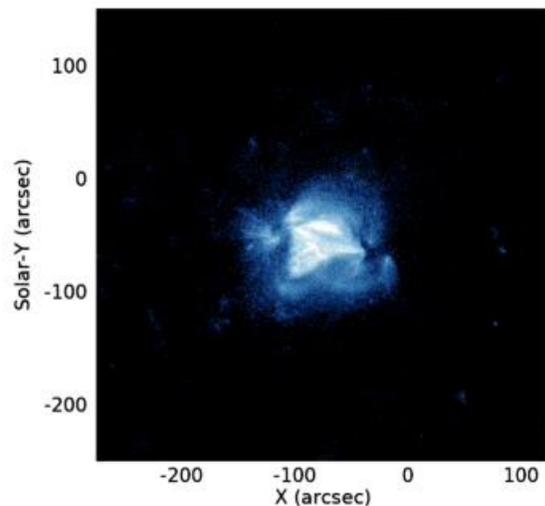
SDO AIA 2 193
28-Apr-20 09:15:05 UT



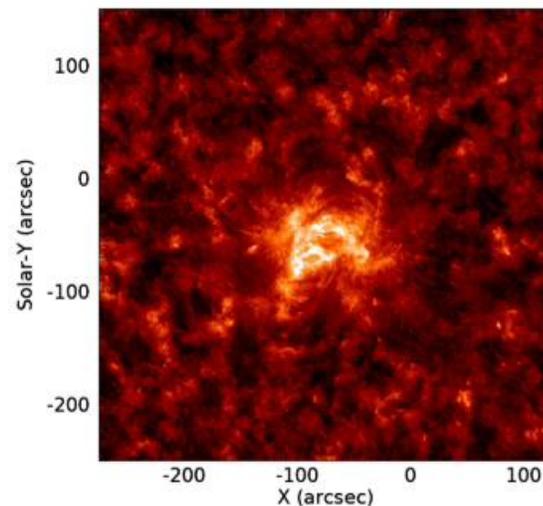
SDO AIA 2 211
28-Apr-20 09:15:11 UT



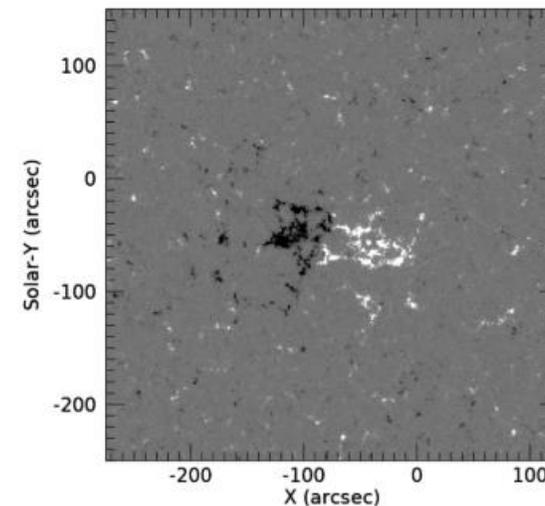
SDO AIA 1 335
28-Apr-20 09:15:02 UT



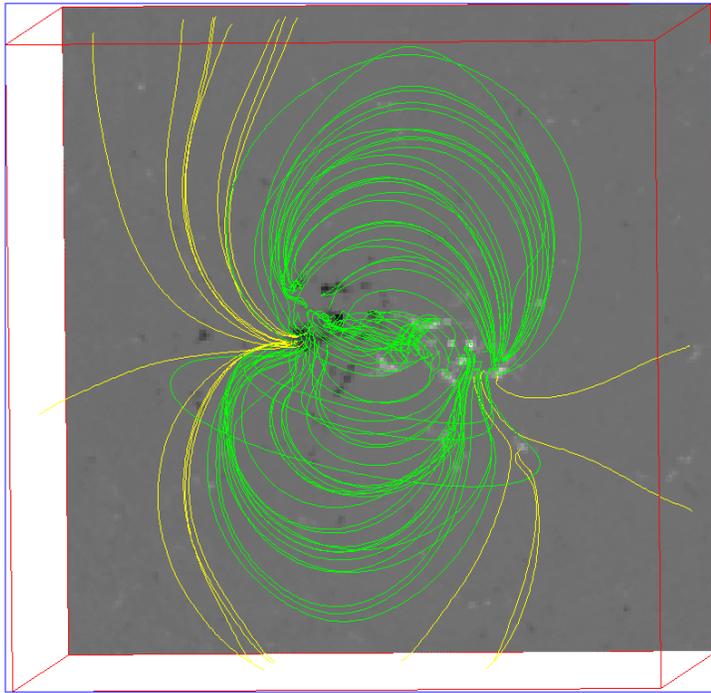
SDO AIA 4 304
28-Apr-20 09:15:06 UT



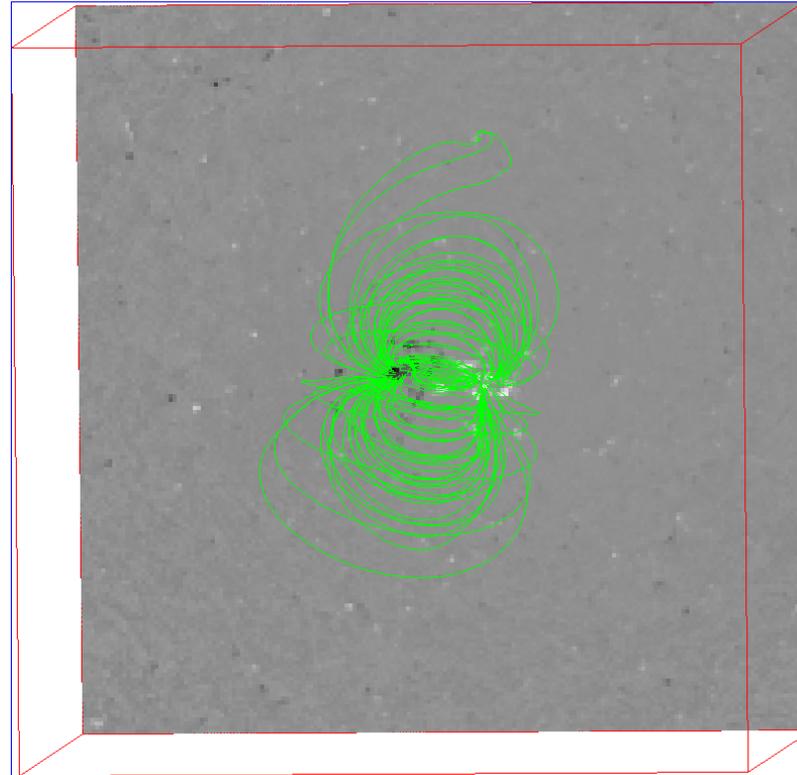
SDO HMI FRONT2 6173
28-Apr-20 09:15:57 UT



Magnetic Field Model



Model 1:
cell size 1400 km
Dimensions 180x180x200



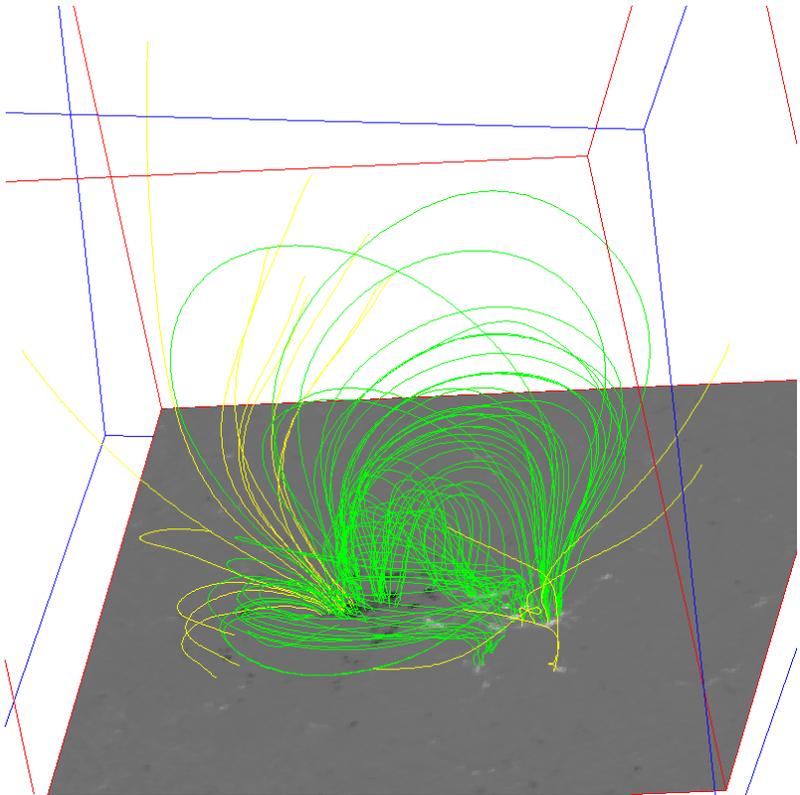
Model 2:
cell size 2800 km
Dimensions 180x180x200

Closed Field
Open Field

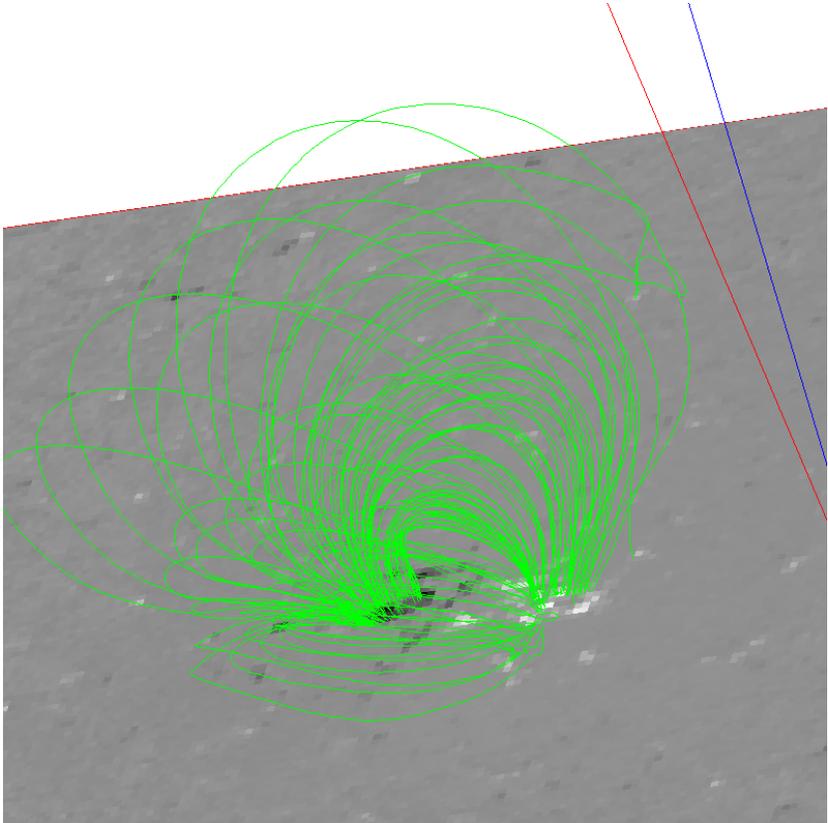
Difficult to model
region with low B field

Magnetic Field Model

Closed Field
Open Field



Model 1:
cell size 1400 km
Dimensions 180x180x200



Model 2:
cell size 2800 km
Dimensions 180x180x200

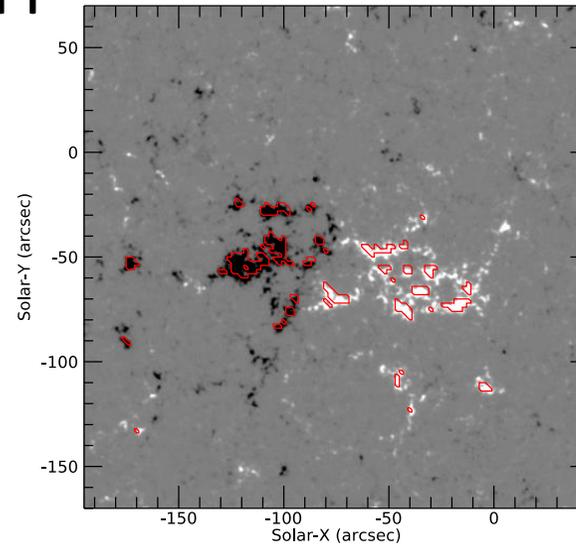
Loop Plasma

- EBTEL calculates a single coronal temperature, density, and pressure for the entire loop. The plasma is distributed over a range of temperatures centered around the average to produce a coronal DEM.
- TR is a full DEM distribution based on energy balanced in the TR.
 - There are questions about how well this replicates 1D models and also how correct the 1D models are.
- We used ebtel file `ebtel_scale=1_alpha=-1.sav`
 - Heating events with power law distribution in delay and intensity ($\alpha = -1$) and average delay = loop cooling time.

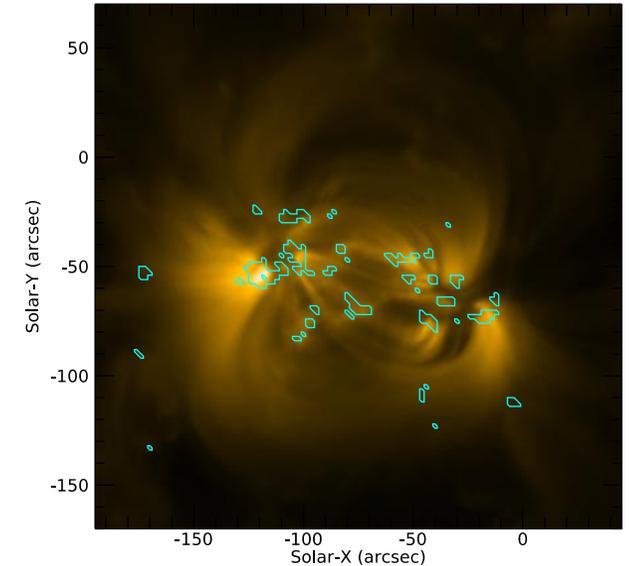
Transition Region Location

- EBTEL assumes all the TR emission comes from the loop footpoint
This will be important later in the talk
- The location of the transition region in our maps is determined with a transition region mask
- We assume there would be TR emission wherever $B_z \geq 200$ Gauss

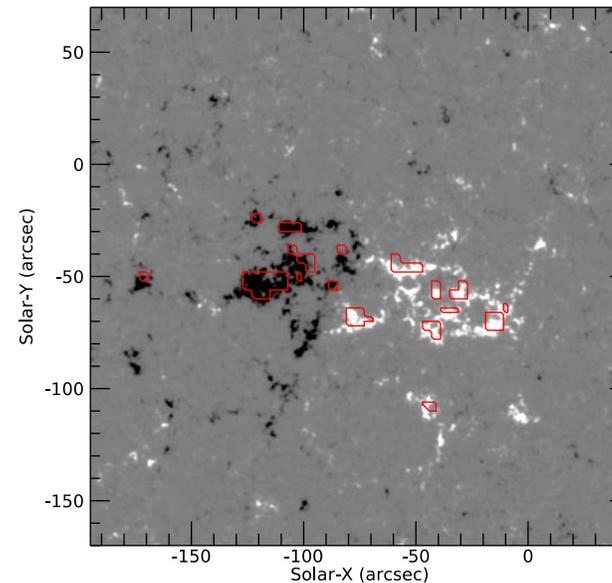
(a) SDO/HMI and Model 1 TR



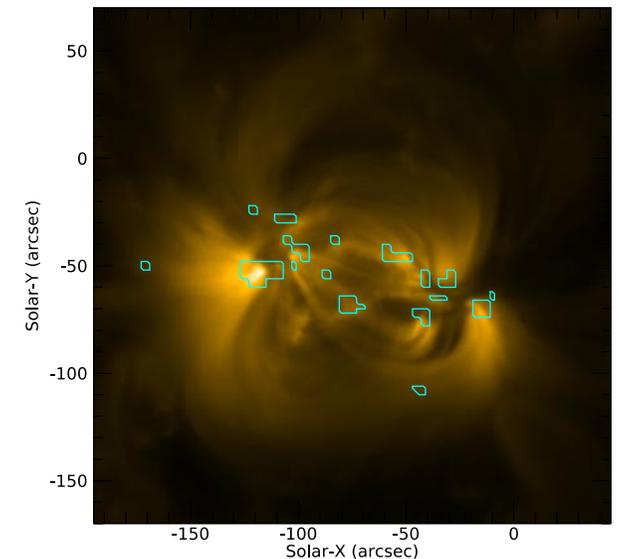
(b) SDO/AIA 171A and Model 1 TR



(c) SDO/HMI and Model 2 TR



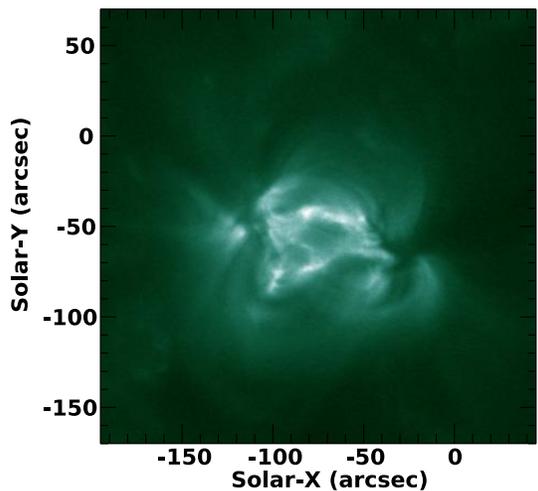
(d) SDO/AIA 171A and Model 2 TR



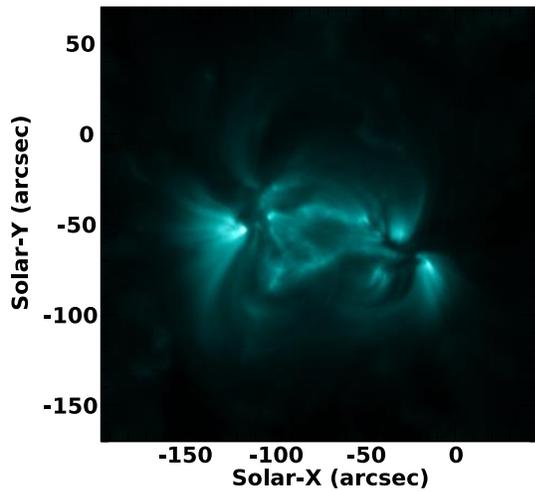
AIA data

- Averaged data from 2020 April 28 09:15-13:10 UT, one image every 5 minutes.
- Used GX Simulator to fit all coronal wavebands (94, 131, 171, 193, 211, and 335 Å).
- Will focus on 211 Å and 171 Å

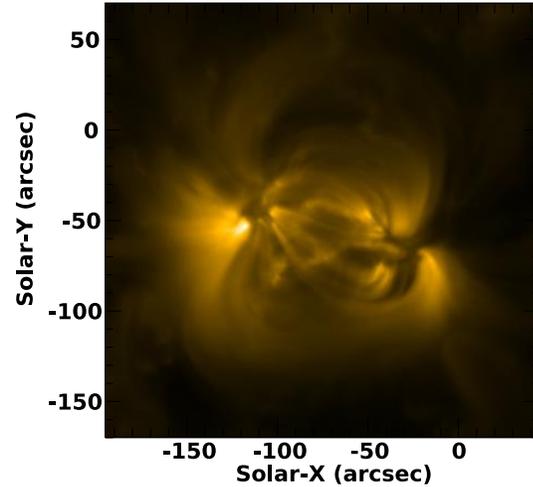
(a) AIA 94 A
Average 28-Apr-2020 09:15-13:15 UT



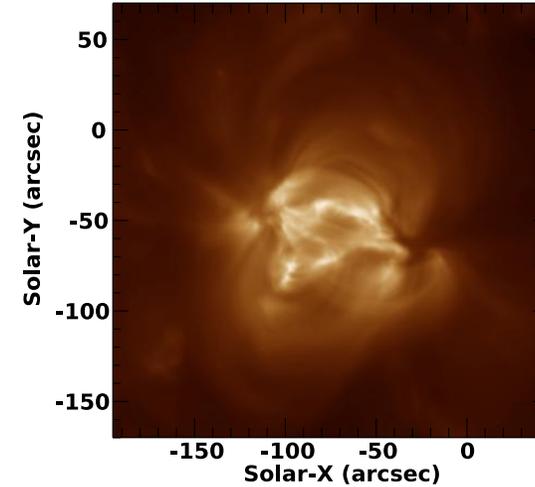
(b) AIA 131 A
Average 28-Apr-2020 09:15-13:15 UT



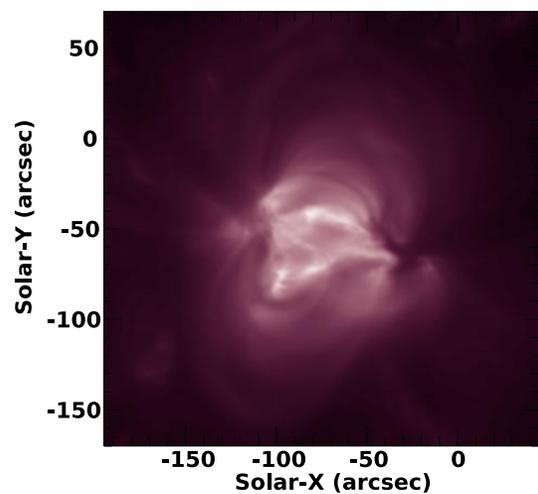
(c) AIA 171 A
Average 28-Apr-2020 09:15-13:15 UT



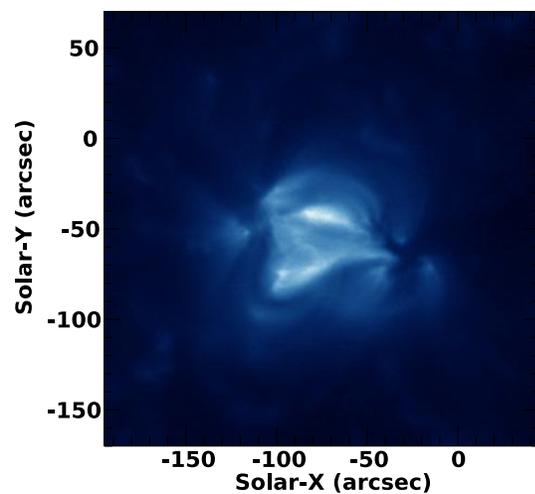
(d) AIA 193 A
Average 28-Apr-2020 09:15-13:15 UT



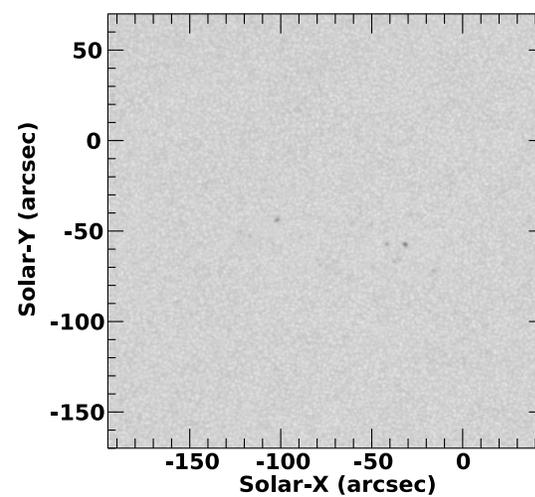
(e) AIA 211 A
Average 28-Apr-2020 09:15-13:15 UT



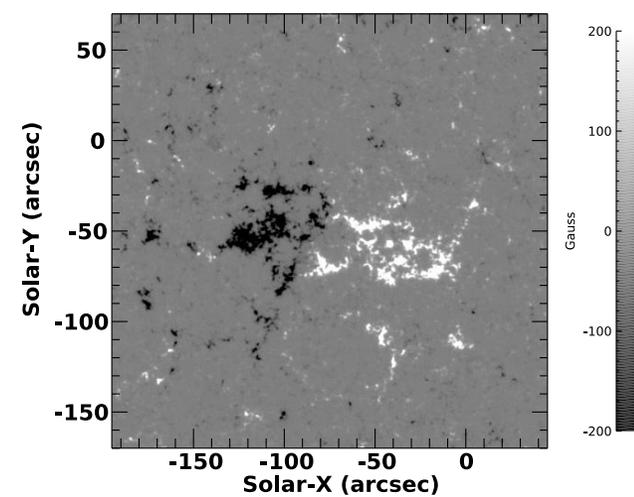
(f) AIA 335 A
Average 28-Apr-2020 09:15-13:15 UT



(g) HMI Continuum
2020-04-28 11:11:27UT



(h) HMI Long B field
2020-04-28 11:11:27UT



Fitting the EUV data

Used a 240x240" region around the active region

For most fits binned AIA data to 2" resolution for comparison

also tried 8" resolution

Use a bet fit metric weighting all pixels equally

$$\sum \delta^2 = \sum (I_{\text{obs}} - I_{\text{model}})^2$$

Gx_simulator steps through a grid of a, b pairs to find the best q_0 value for each pair.

Fitted both Corona + TR and also Corona only

211 Å

a,b grid of best fits

Corona + TR

2" comparison

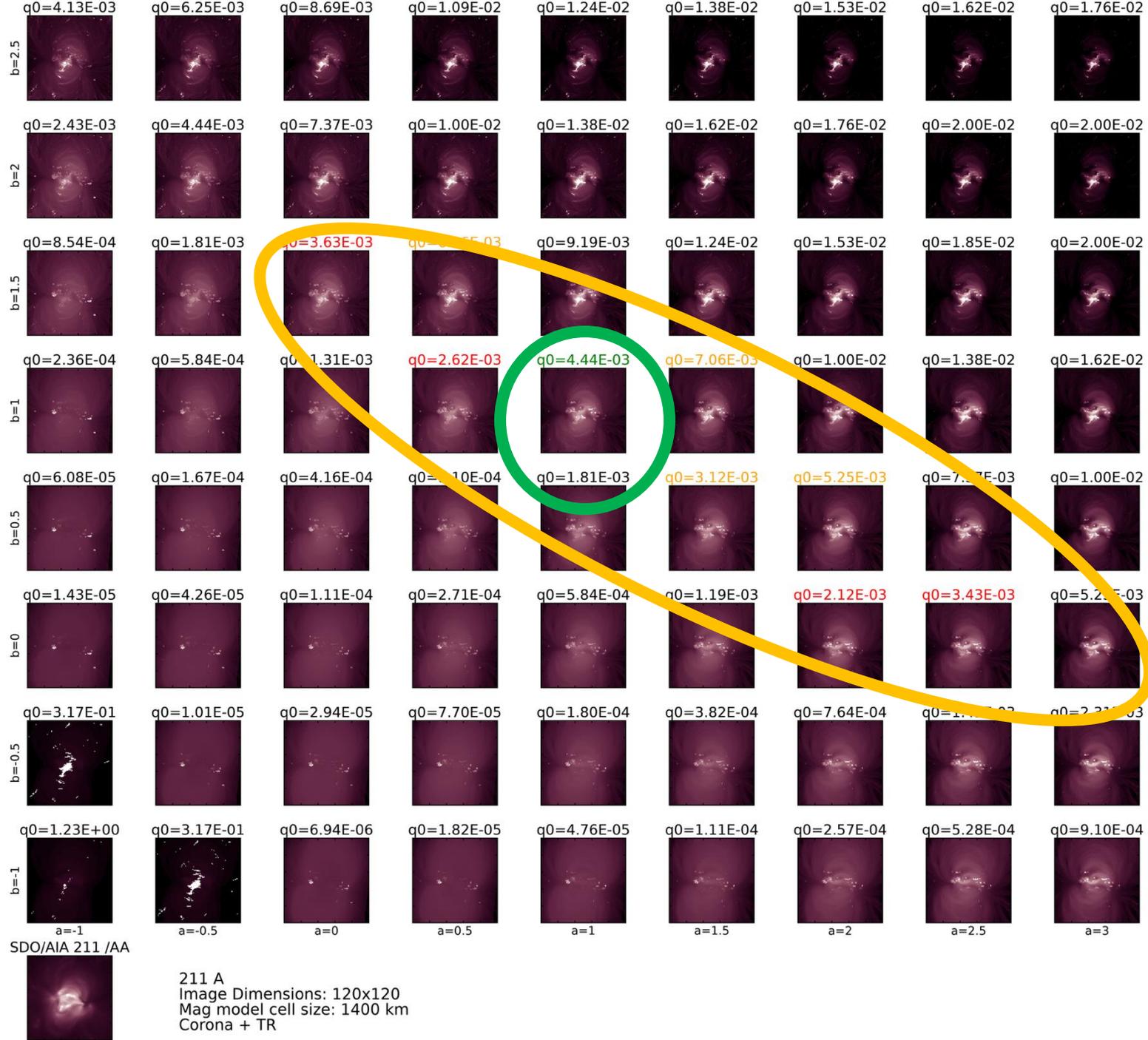
Model 1

best fit

a=1

b=1

$q_0 = 4.44 \times 10^{-3} \text{ erg cm}^{-3} \text{ s}^{-1}$



Best fit for 211 Å

Corona + TR

2" comparison

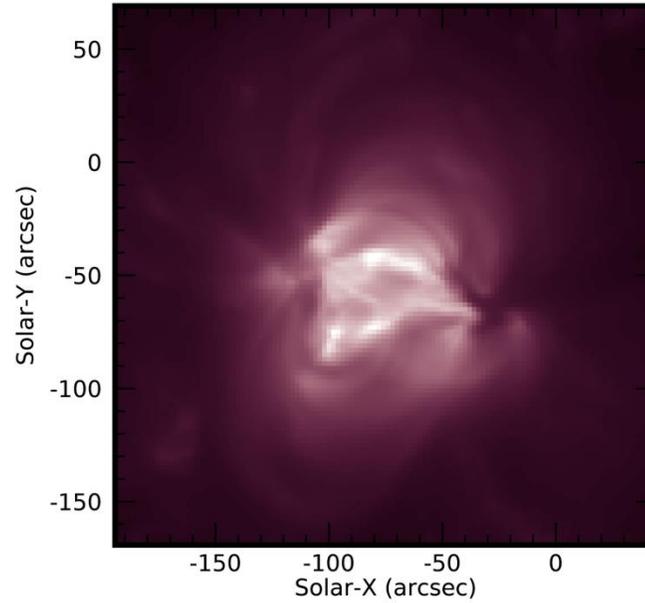
best fit

$a=1.0$

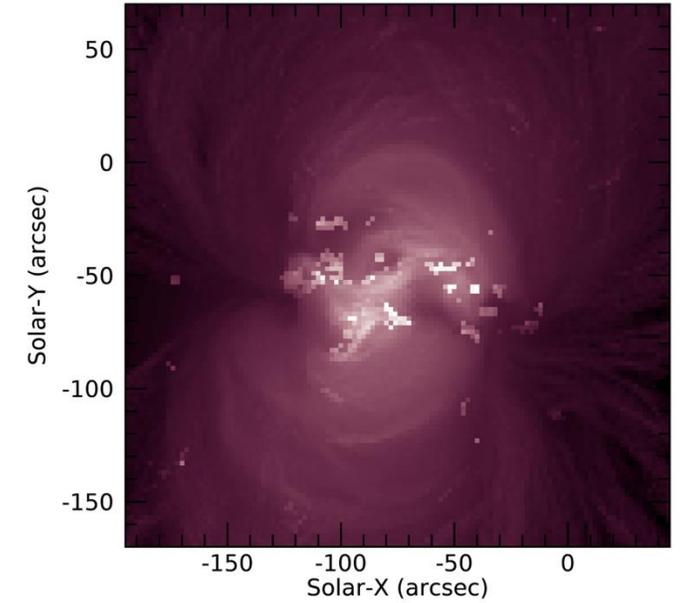
$b=1.0$

$q_0=4.44 \times 10^{-3} \text{ erg cm}^{-3} \text{ s}^{-1}$

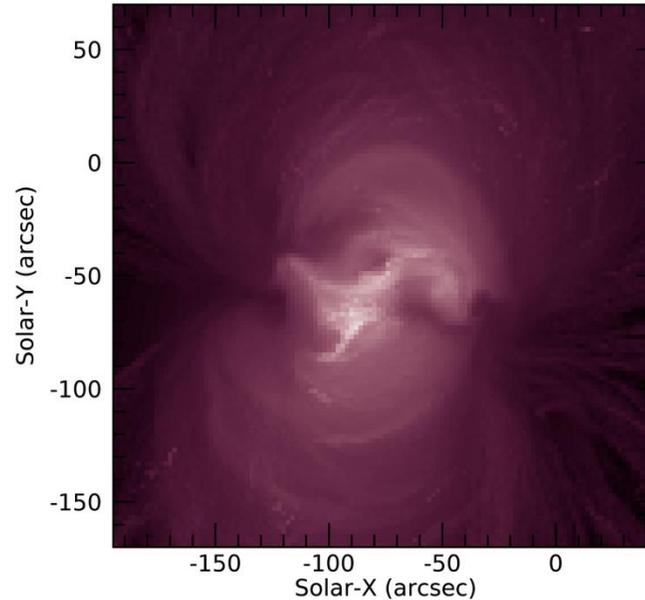
(a) REMAPPED SDO AIA_2 211 Å



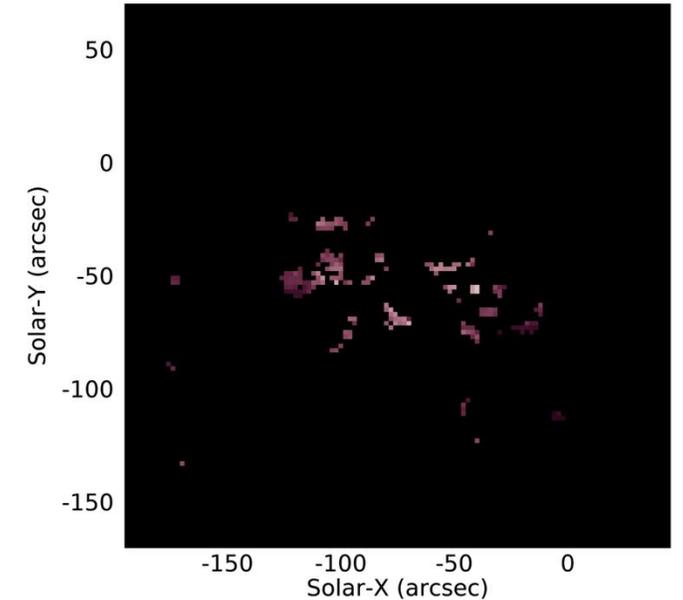
(b) GX I 211 Å $a=1.00$ $b=1.00$ $q_0=4.438e-03$



(c) Corona



(d) Transition Region



Best fit for 211 Å

We are not modeling the individual magnetic features that well, so let's reduce the comparison resolution.

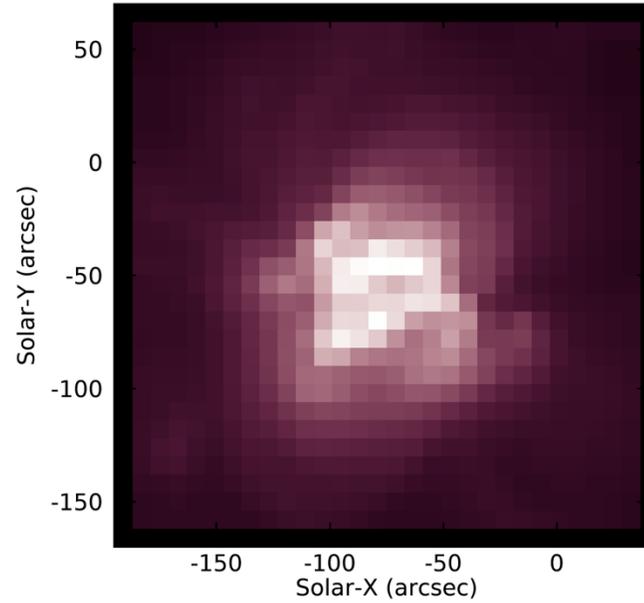
Corona + TR
8" comparison
Model 1
best fit

$$a=1.5$$

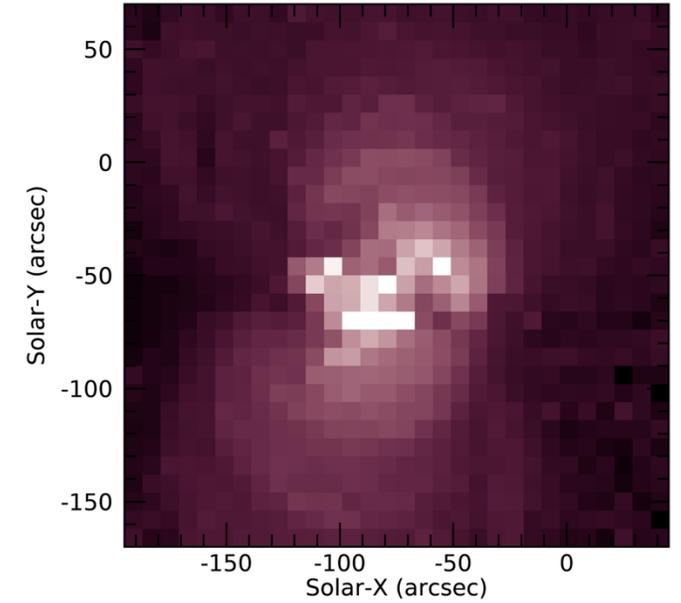
$$b=1.0$$

$$q_0=7.06 \times 10^{-3} \text{ erg cm}^{-3} \text{ s}^{-1}$$

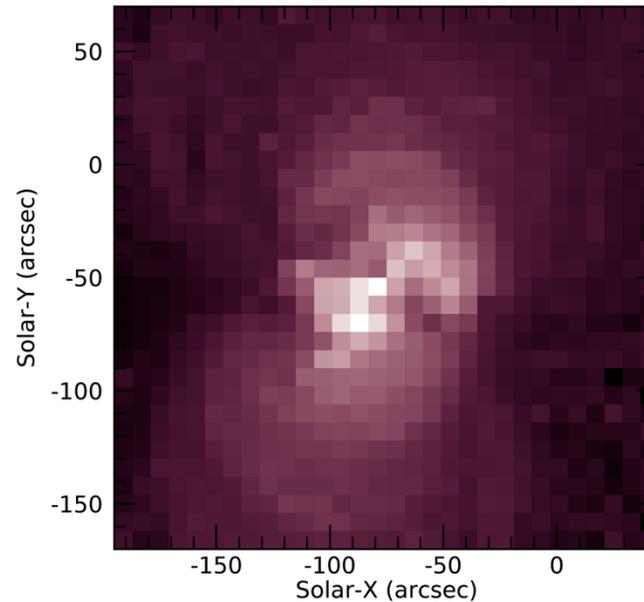
(a) REMAPPED SDO AIA_2 211 Å



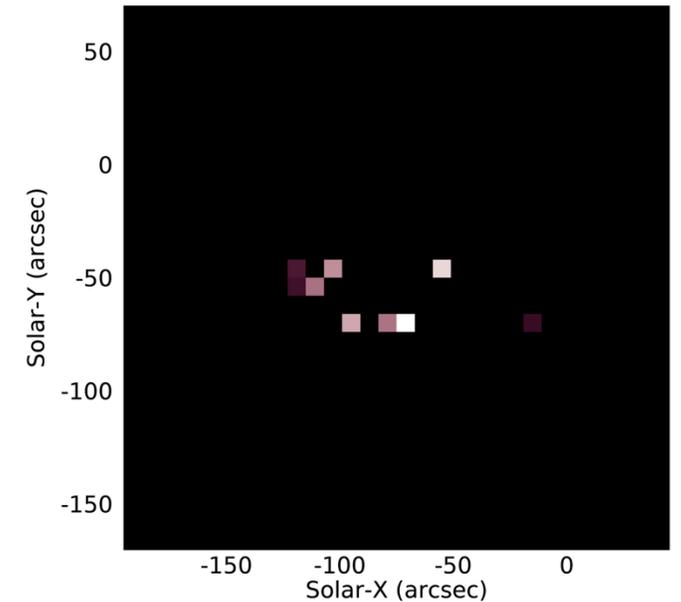
(b) GX I 211 Å $a=1.50$ $b=1.00$ $q_0=7.064 \times 10^{-3}$



(c) Corona



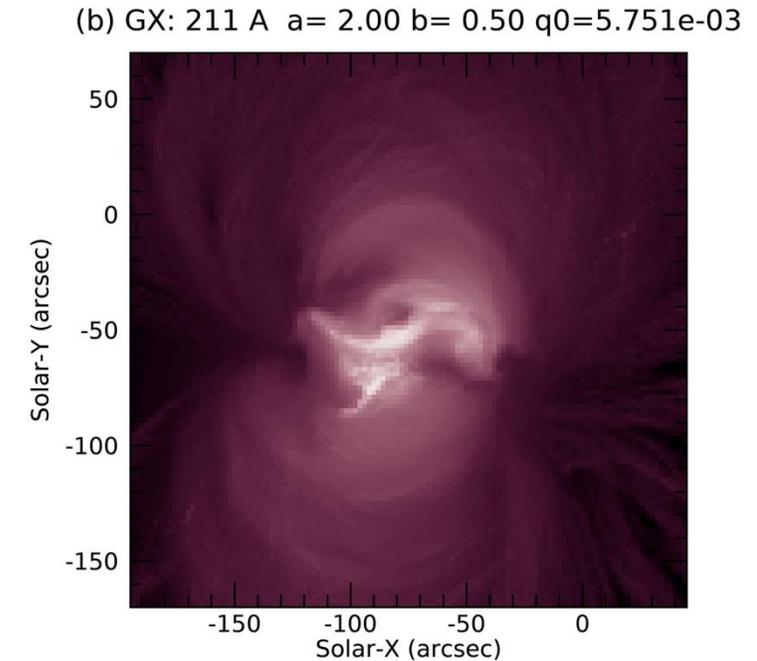
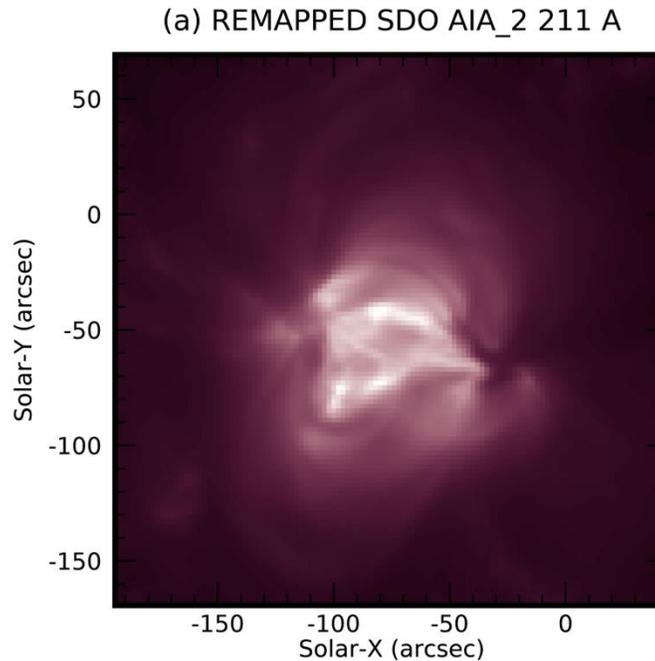
(d) Transition Region



Best fit for 211 Å

Corona only

- No TR included
- TR regions not compared for the fit
- 2" comparison
- Model 1 best fit
 - $a=2.0$
 - $b=0.5$
 - $q_0=5.71 \times 10^{-3} \text{ erg cm}^{-3} \text{ s}^{-1}$



171 Å

a,b grid of best fits

Corona + TR

2" comparison

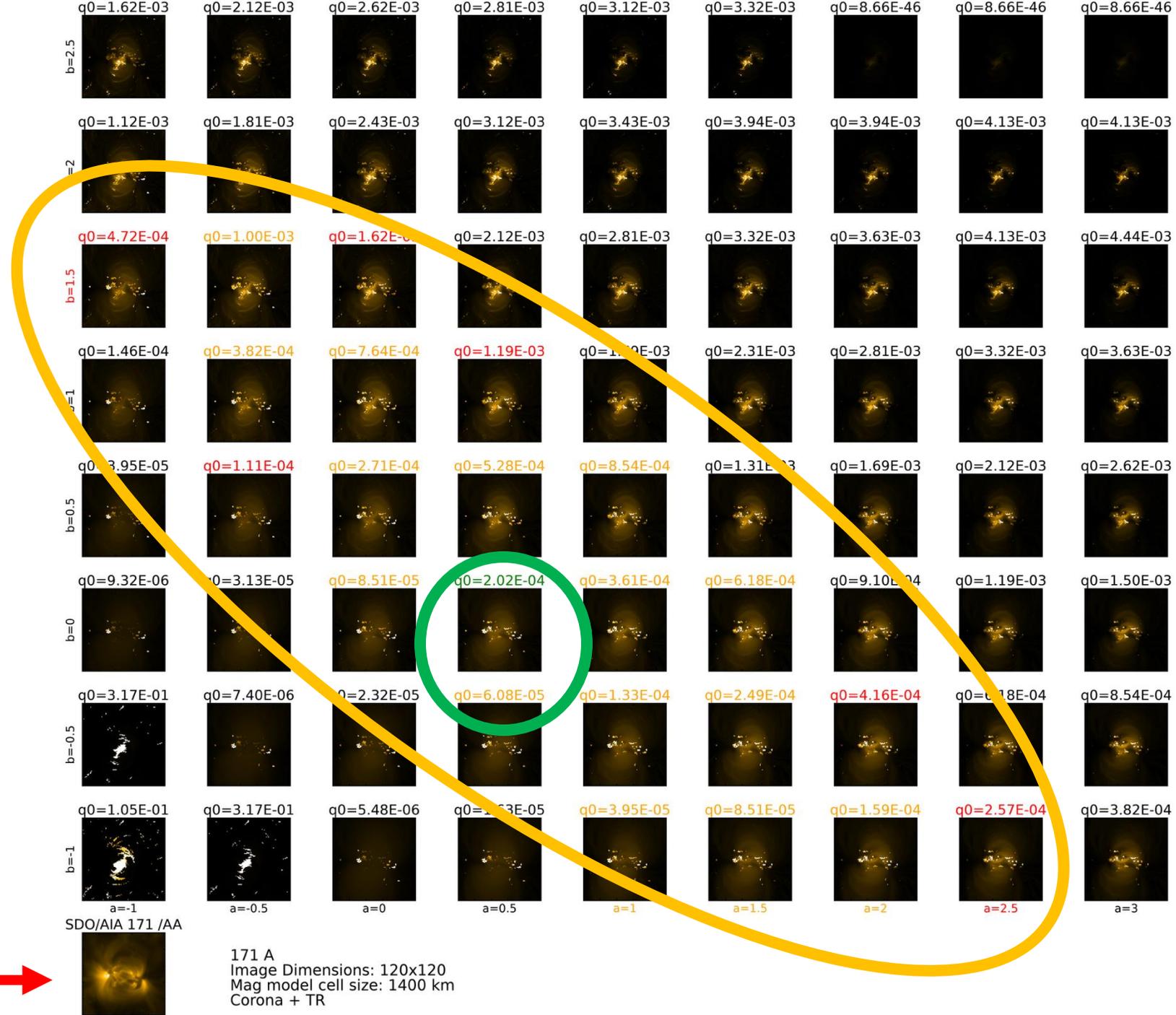
Model 1

best fit

a= 0.5

b= 0.0

$q_0=2.02 \times 10^{-4} \text{ erg cm}^{-3} \text{ s}^{-1}$



Best fit for 171 Å

Corona + TR
2" comparison

Model 1
best fit

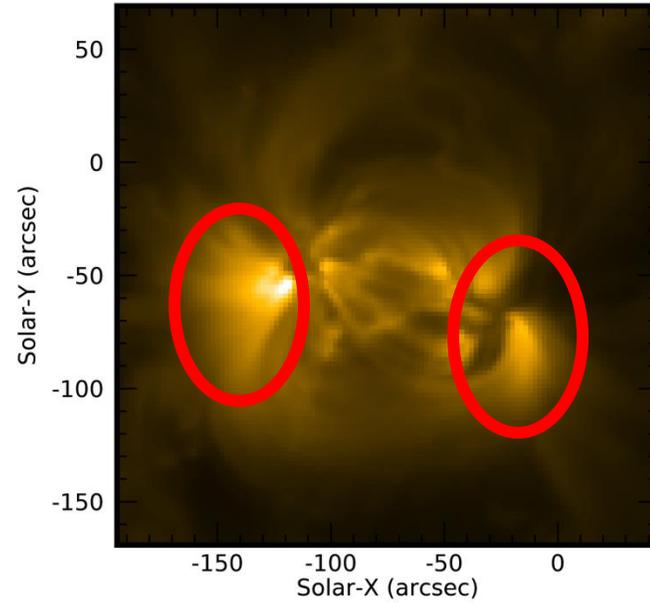
$$a = 0.5$$

$$b = 0.0$$

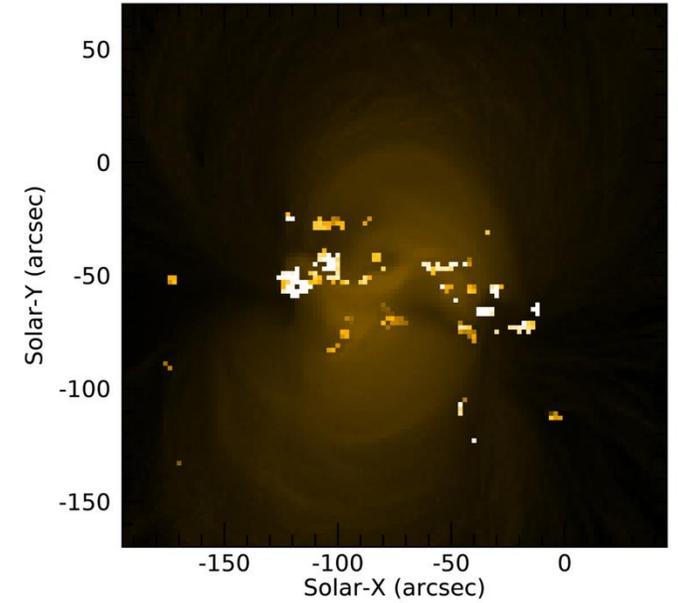
$$q_0 = 2.02 \times 10^{-4} \text{ erg cm}^{-3} \text{ s}^{-1}$$

The main sources of emission seems to be missing entirely.

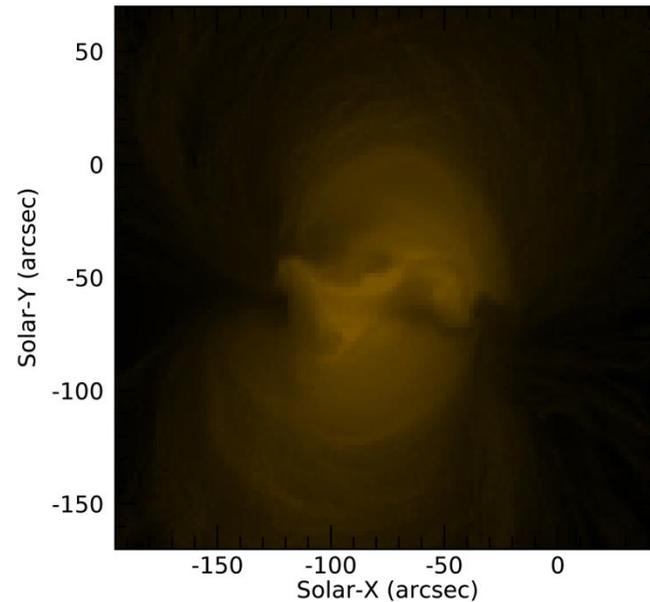
(a) REMAPPED SDO AIA_3 171 Å



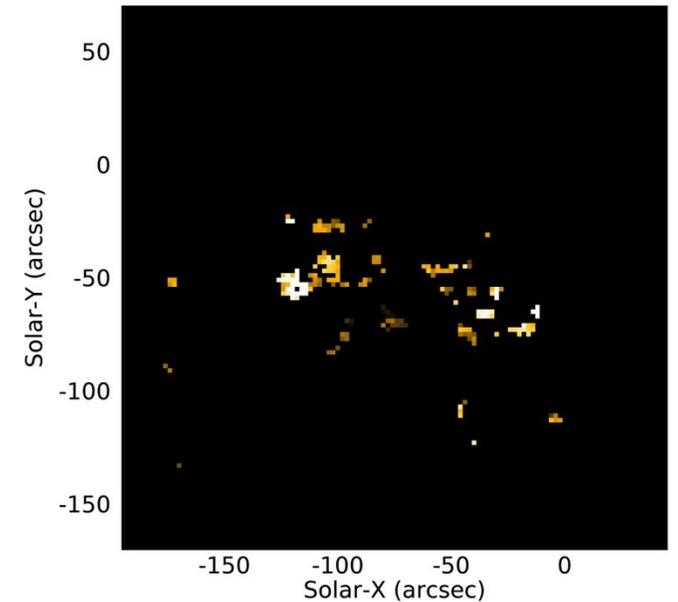
(b) GX I 171 Å a=0.50 b=0.00 q0=2.016e-04



(c) Corona



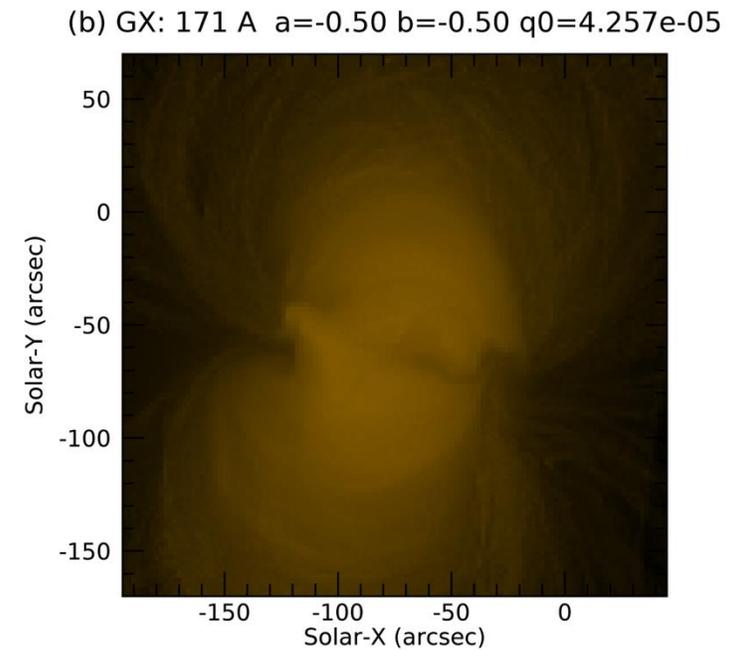
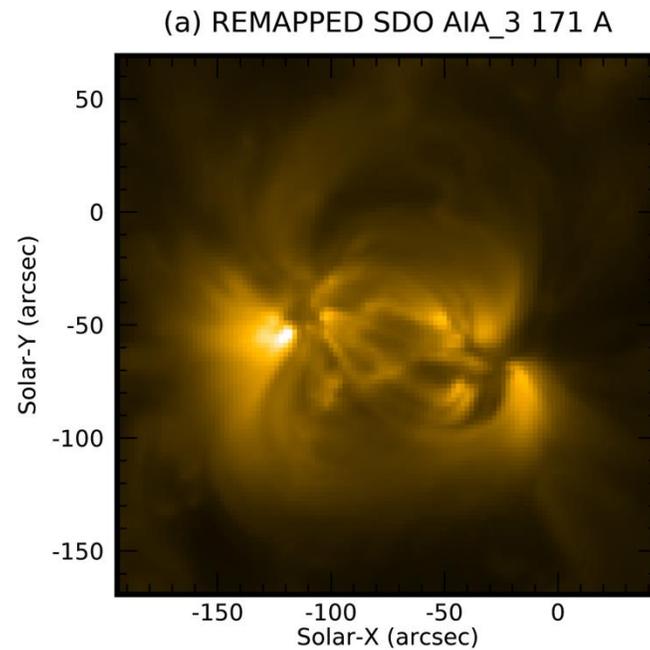
(d) Transition Region



Best fit for 171 Å

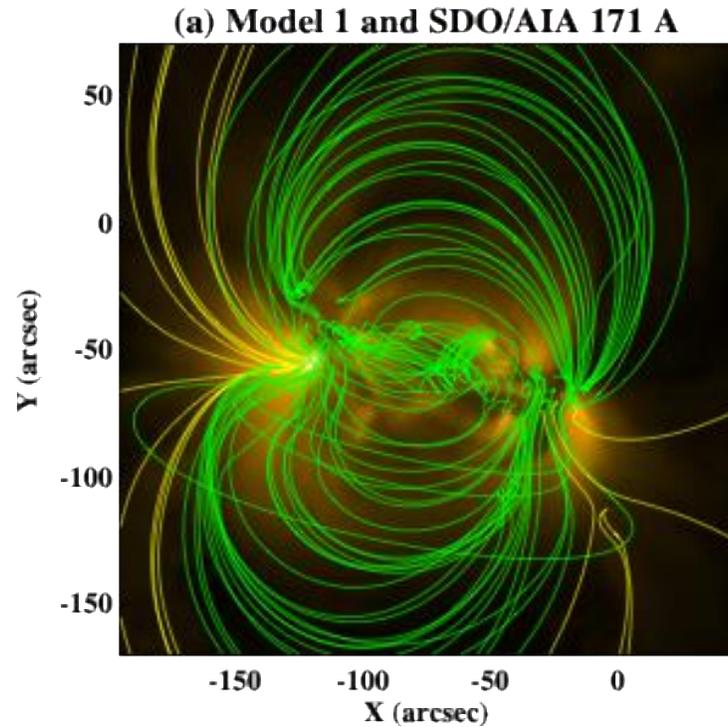
Corona only

- No TR included
- TR regions not compared for the fit
- 2" comparison
- Model 1 best fit
 - $a = -0.50$
 - $b = -0.50$
 - $q_0 = 4.26 \times 10^{-5} \text{ erg cm}^{-3} \text{ s}^{-1}$

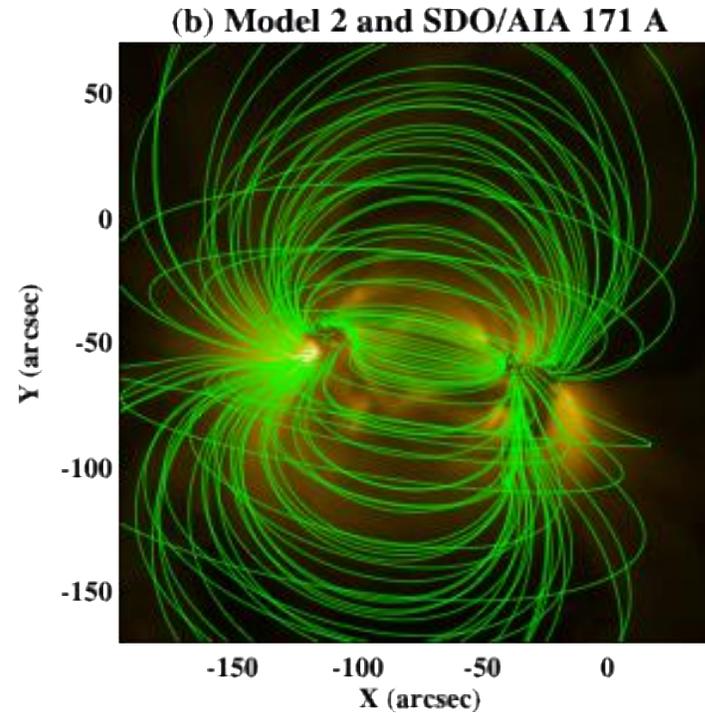


The coronal-only
“best fit” looks even worse

Could it be that the longer field lines at the edge of the Active Region got left out of the model?



Model 1:
cell size 1400 km
Dimensions 180x180x200



Model 2:
cell size 2800 km
Dimensions 180x180x200

Closed Field
Open Field

Best fit for 171 Å

Corona + TR
2" comparison
Model 2
best fit

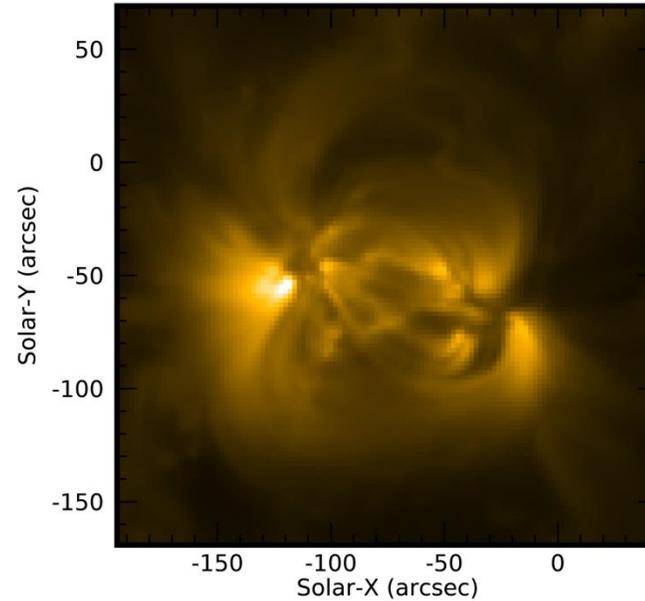
$$a = 1.0$$

$$b = 0.00$$

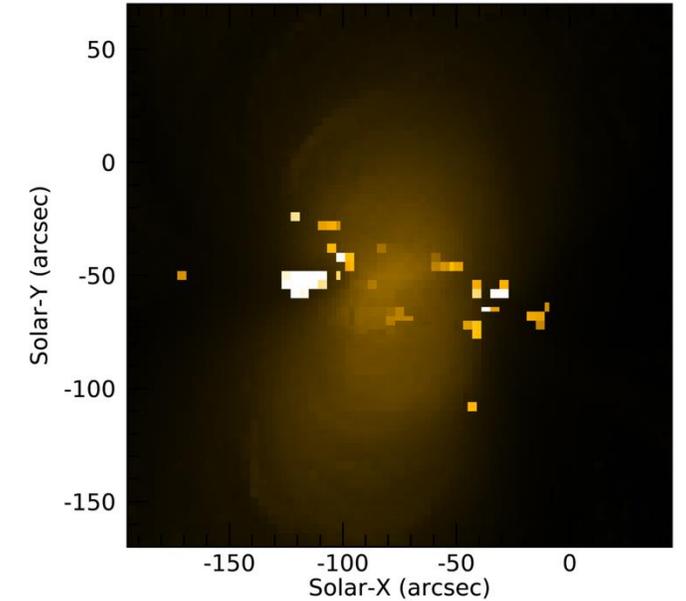
$$q_0 = 4.71 \times 10^{-4} \text{ erg cm}^{-3} \text{ s}^{-1}$$

The loops to the side are still missing – so it does not seem to be a problem with the magnetic field model.

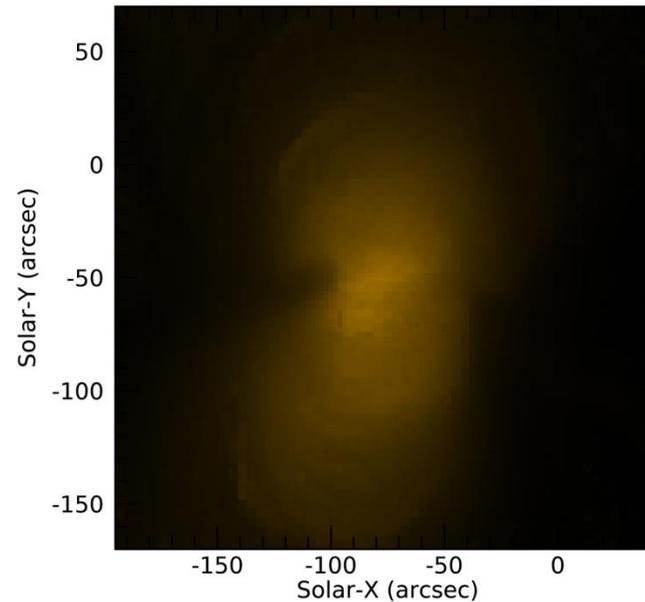
(a) REMAPPED SDO AIA_3 171 Å



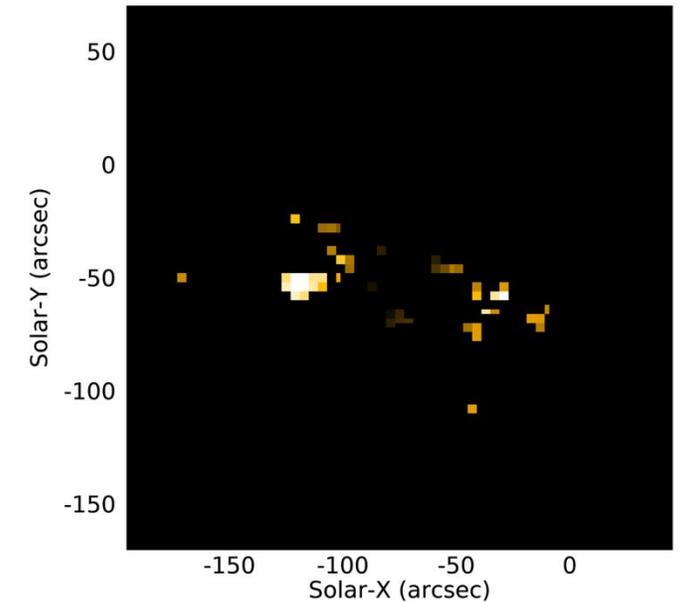
(b) GX I 171 Å $a=1.00$ $b=0.00$ $q_0=4.721e-04$



(c) Corona



(d) Transition Region



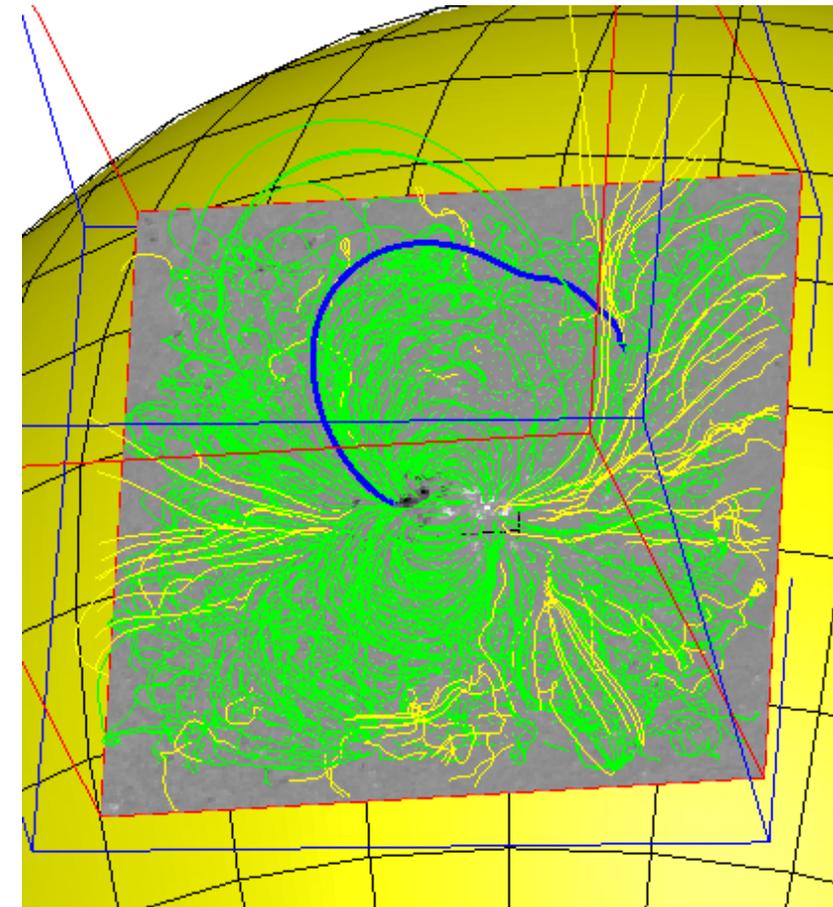
What is going on?

In EBTEL the transition region (defined as the part of the loop where conduction is a heating term) is restricted to the loop foot points.

For long cool loops like the ones at the edges of active regions this may not be the case.

So essentially the “missing” emission is transition region emission extending up into the loops that is not being modeled correctly.

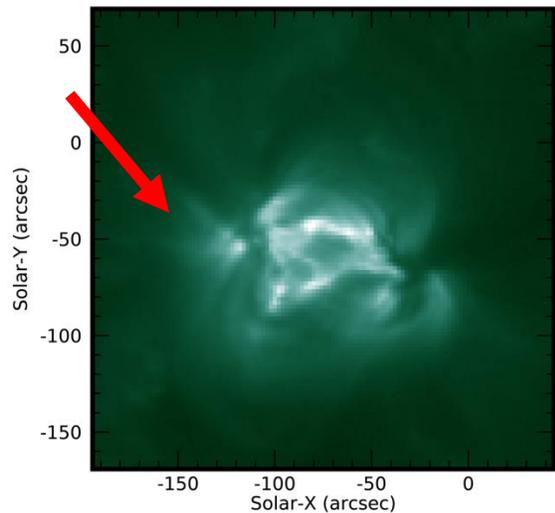
TR for loops that can extend $\approx 0.05L$ from the loop base. For a $L = 2-7 \times 10^{10}$ cm loop that is 10-50”.



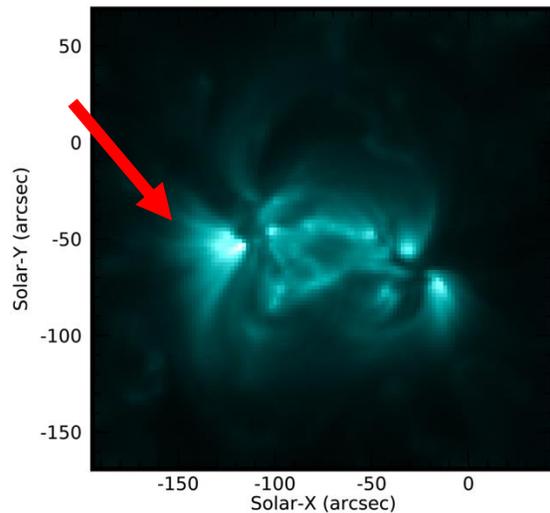
ENW ($s_1 = -0.54L$) - NW ($s_2 = 0.46L$)
 $L = 4.6519e+10$ cm
 $B_{med} = 6.46009$ G
 $B_1[74, 88, 0] = 198.774$ G (ENW)
 $B_0[83, 142, 42] = 0.383648$ G
 $B_2[135, 129, 0] = 54.1228$ G (NW)

Model 2 magnetic field lines

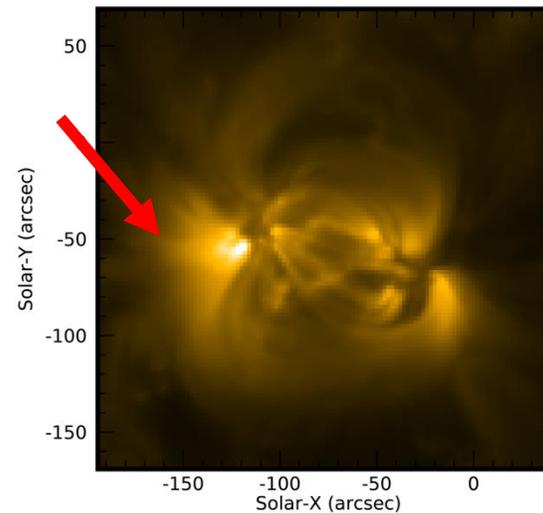
REMAPPED SDO AIA_4 94



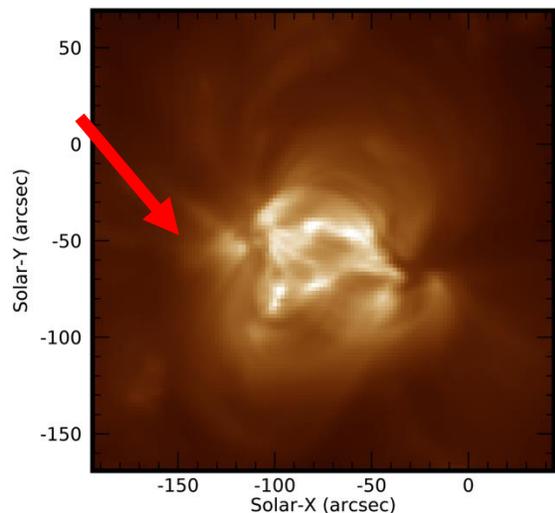
REMAPPED SDO AIA_1 131



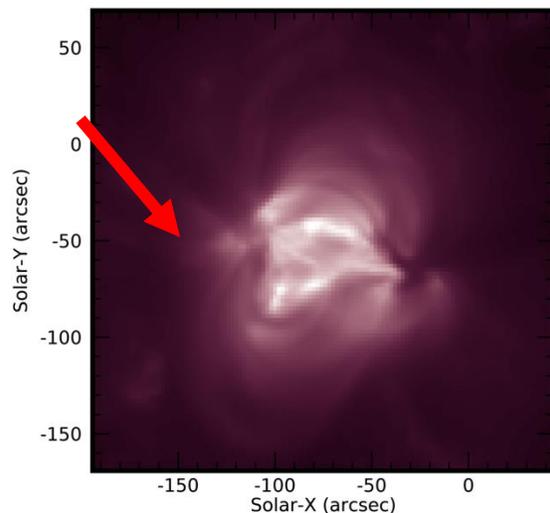
REMAPPED SDO AIA_3 171



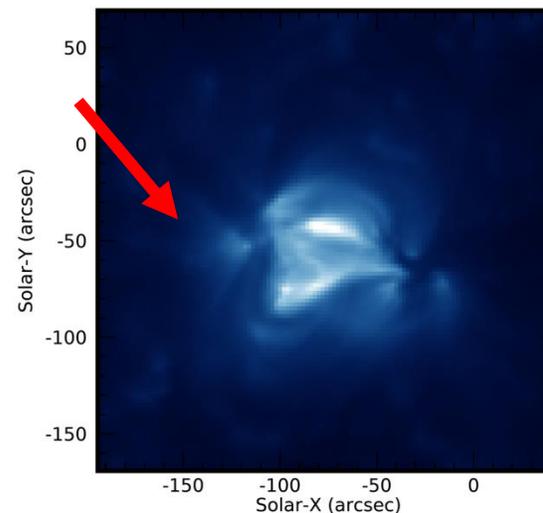
REMAPPED SDO AIA_2 193



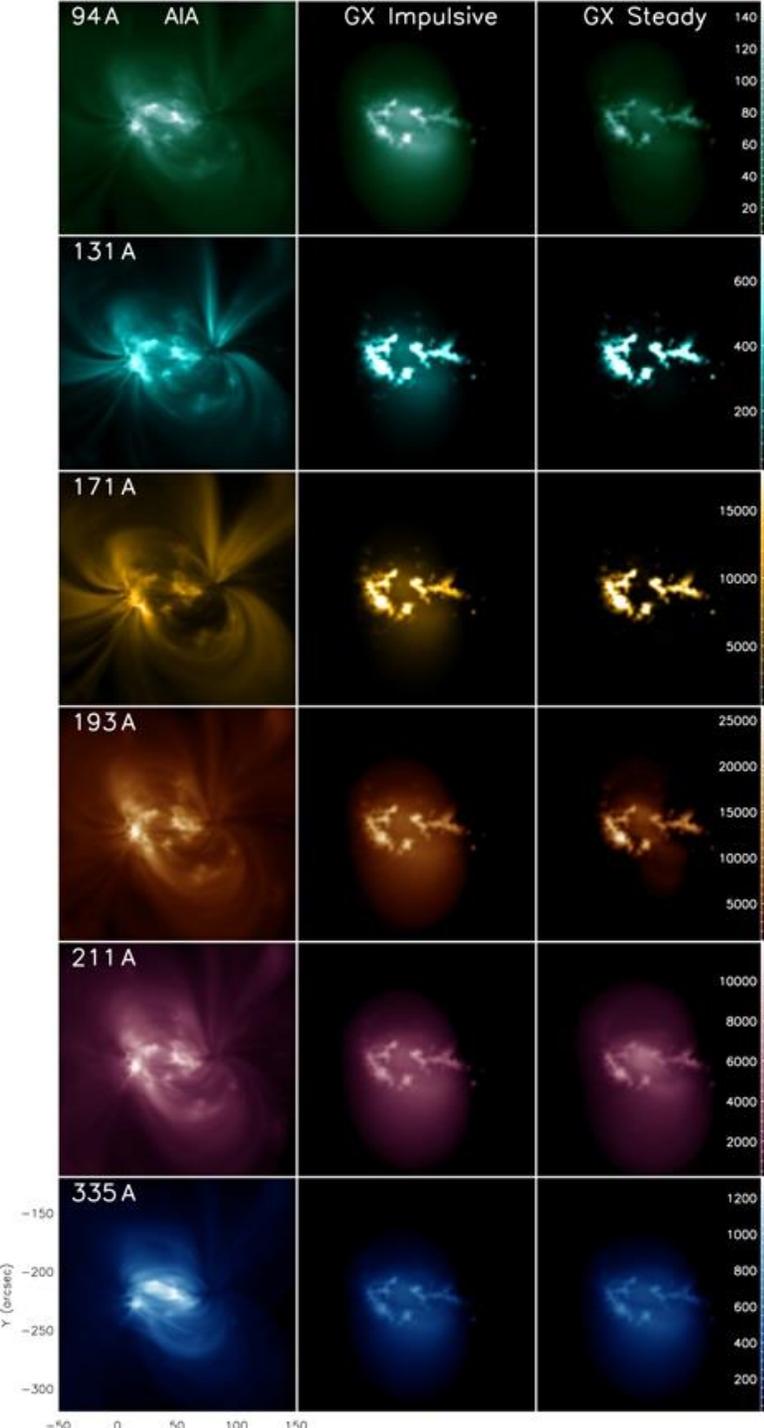
REMAPPED SDO AIA_2 211



REMAPPED SDO AIA_1 335

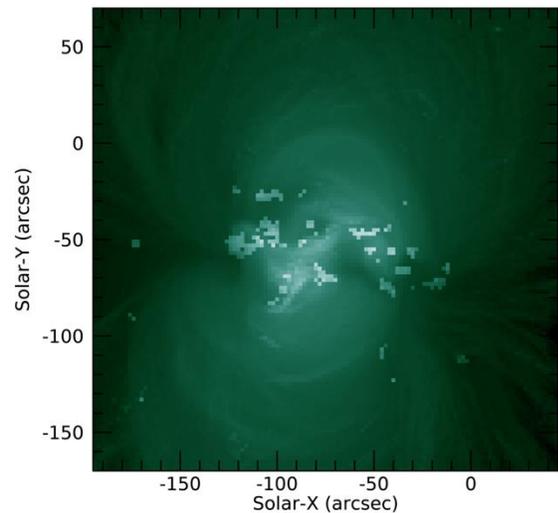


- This missing emission is a problem for modeling many of the AIA bands.
- Worst for ones with substantial cooler contributions (131 Å, 171 Å)
- Least for ones that are mostly hotter (211 Å, 335 Å)

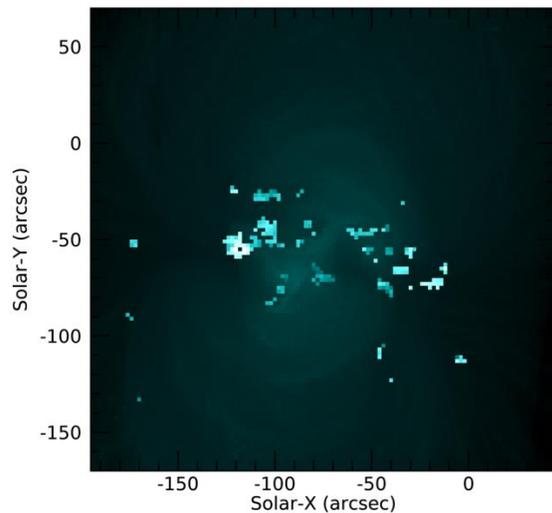


You can see this effect in Nita *et al.* 2018

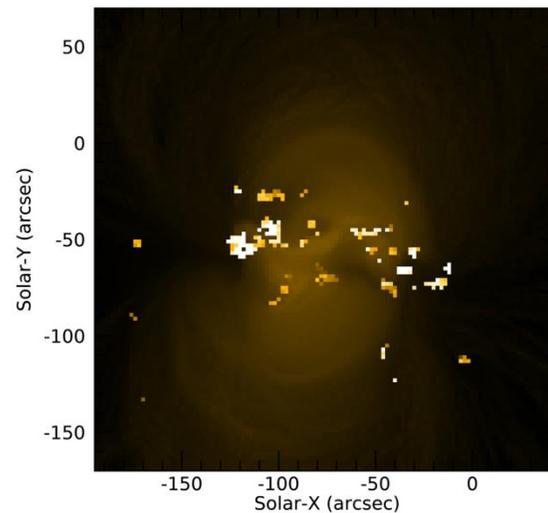
GXSim 94 a=0.5 b=1 q0= 1.073e-03



GXSim 131 a=0 b=0.5 q0= 3.475e-04

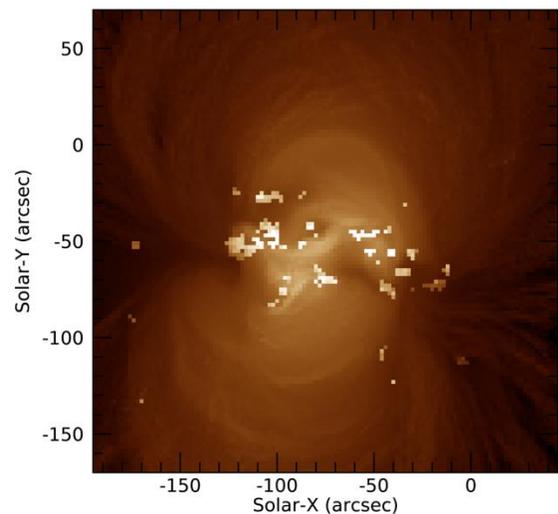


GXSim 171 a=0.5 b=0 q0= 2.016e-04

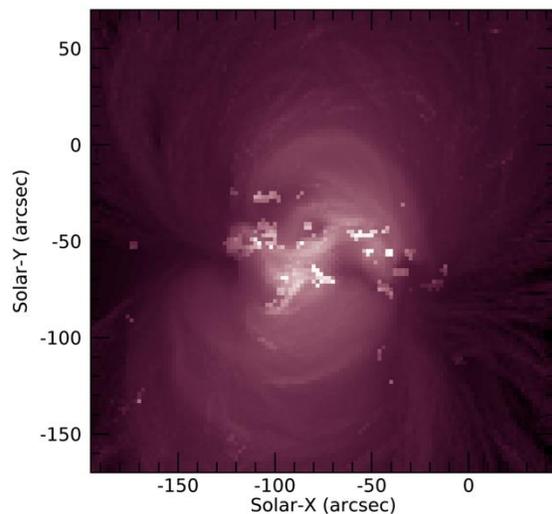


How good the “best fit” models look is a function of how important the cool loops at the edge of the active regions are.

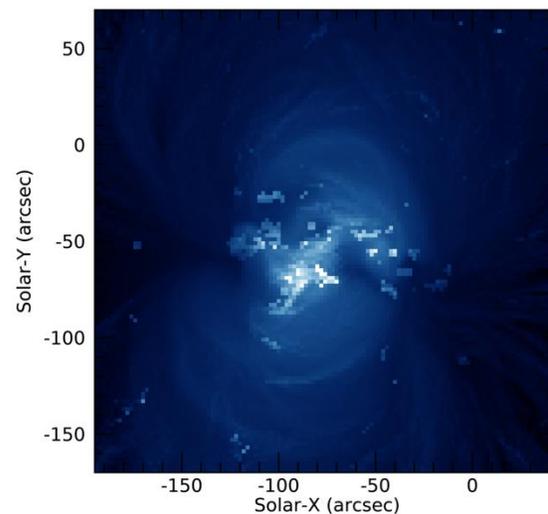
GXSim 193 a=1 b=0.5 q0= 1.693e-03



GXSim 211 a=1 b=1 q0= 4.438e-03

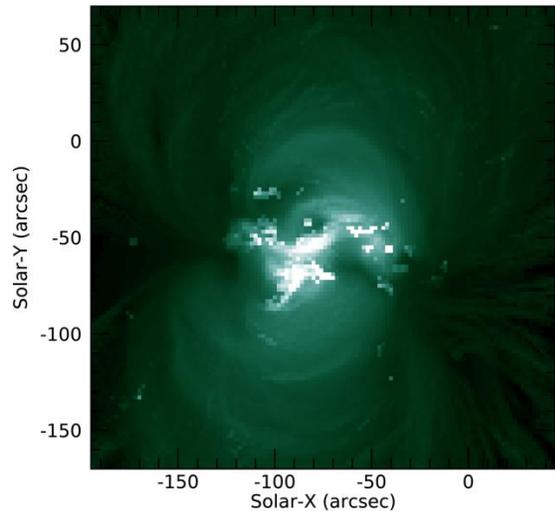


GXSim 335 a=0.5 b=1.5 q0= 3.936e-03

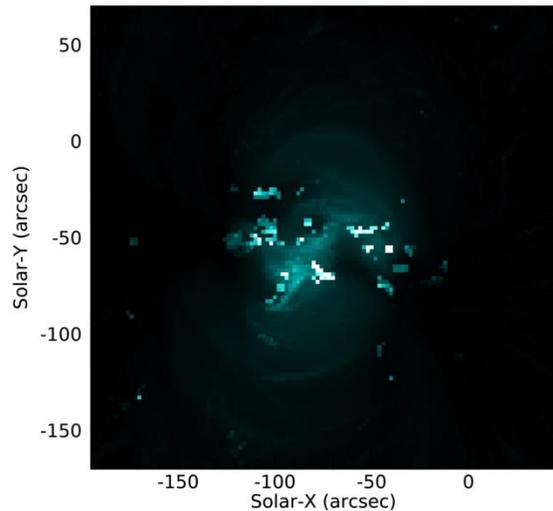


wave (Å)	a	b	q ₀ (erg/cm ³ /s)
94	0.5	1	1.07E-03
131	0	0.5	3.48E-04
171	0.5	0	2.02E-04
193	1	0.5	1.69E-03
211	1	1	4.44E-03
335	0.5	1.5	3.94E-03

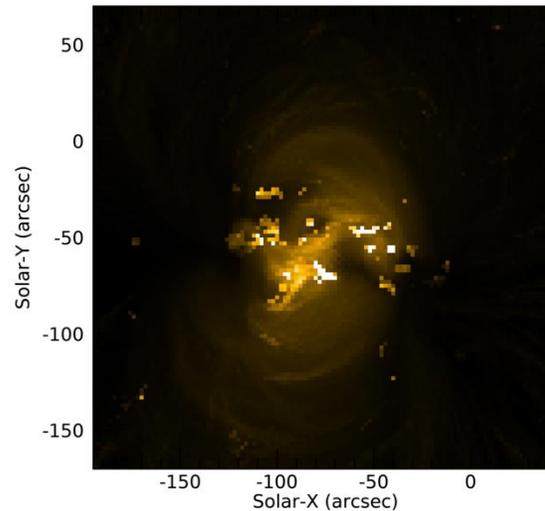
GXSim 94 a=1.5 b=1 q0= 3.125e-03



GXSim 131 a=1.5 b=1 q0= 3.435e-03

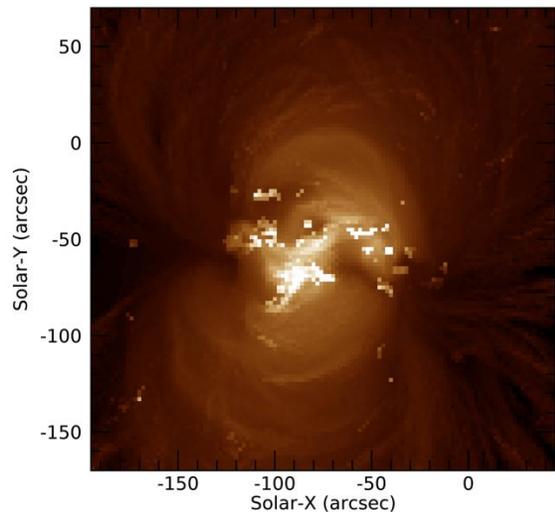


GXSim 171 a=1.5 b=1 q0= 2.313e-03

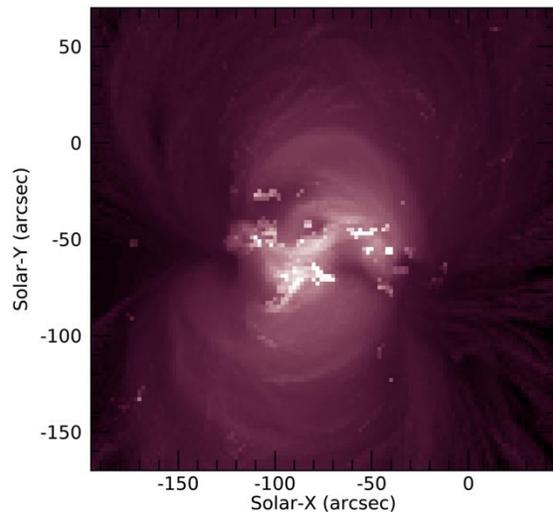


Using the best fit a,b for
211 Å at 8" resolution
Setting a=1.5, b=1 and
using 2" resolution
maps.

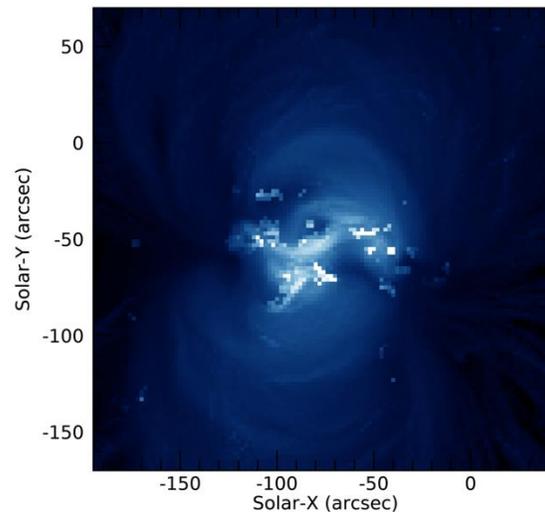
GXSim 193 a=1.5 b=1 q0= 5.751e-03



GXSim 211 a=1.5 b=1 q0= 7.064e-03

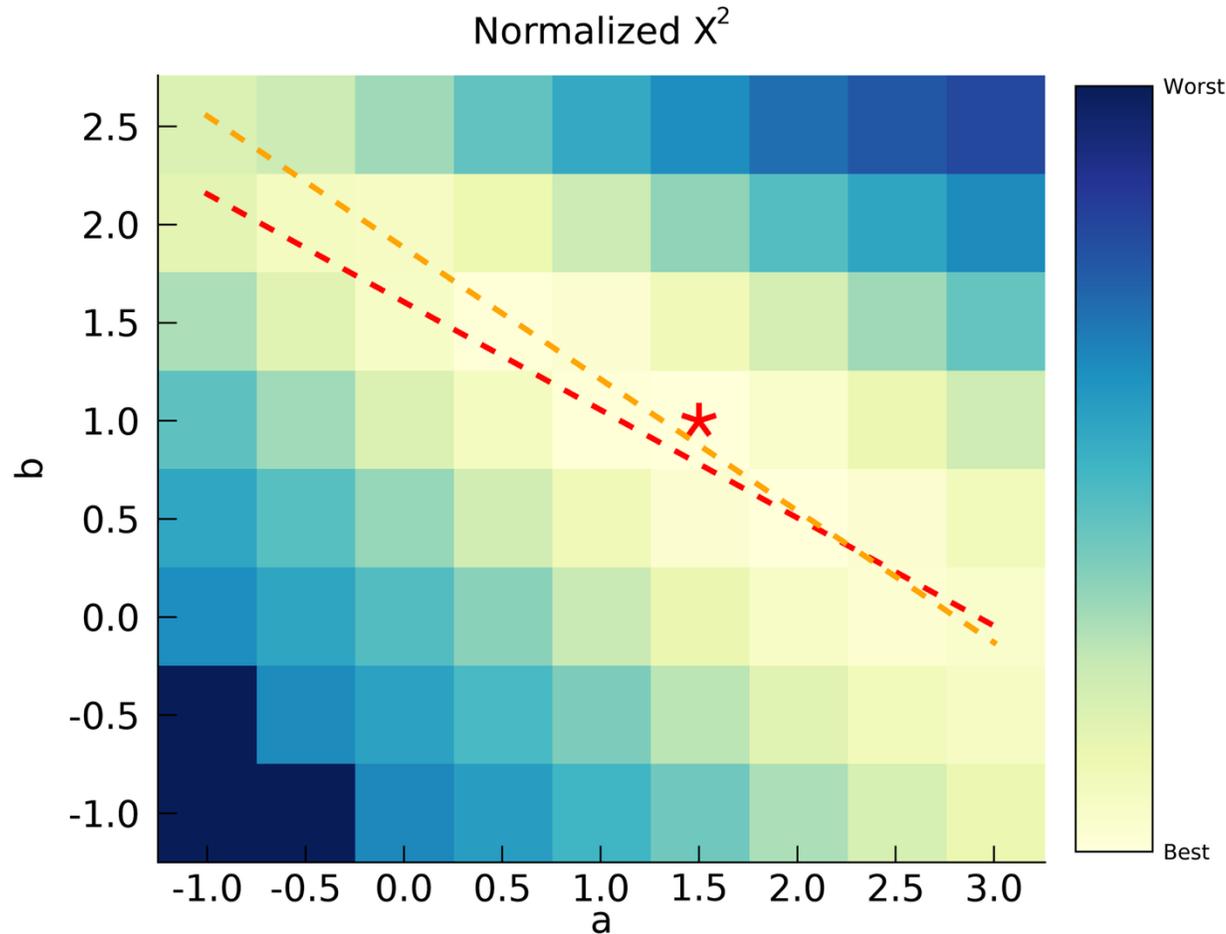


GXSim 335 a=1.5 b=1 q0= 4.748e-03



wave (Å)	a	b	q ₀ (erg/cm ³ /s)
94	1.5	1	4.13E-03
131	1.5	1	4.44E-03
171	1.5	1	2.82E-03
193	1.5	1	7.57E-03
211	1.5	1	9.50E-03
335	1.5	1	6.56E-03

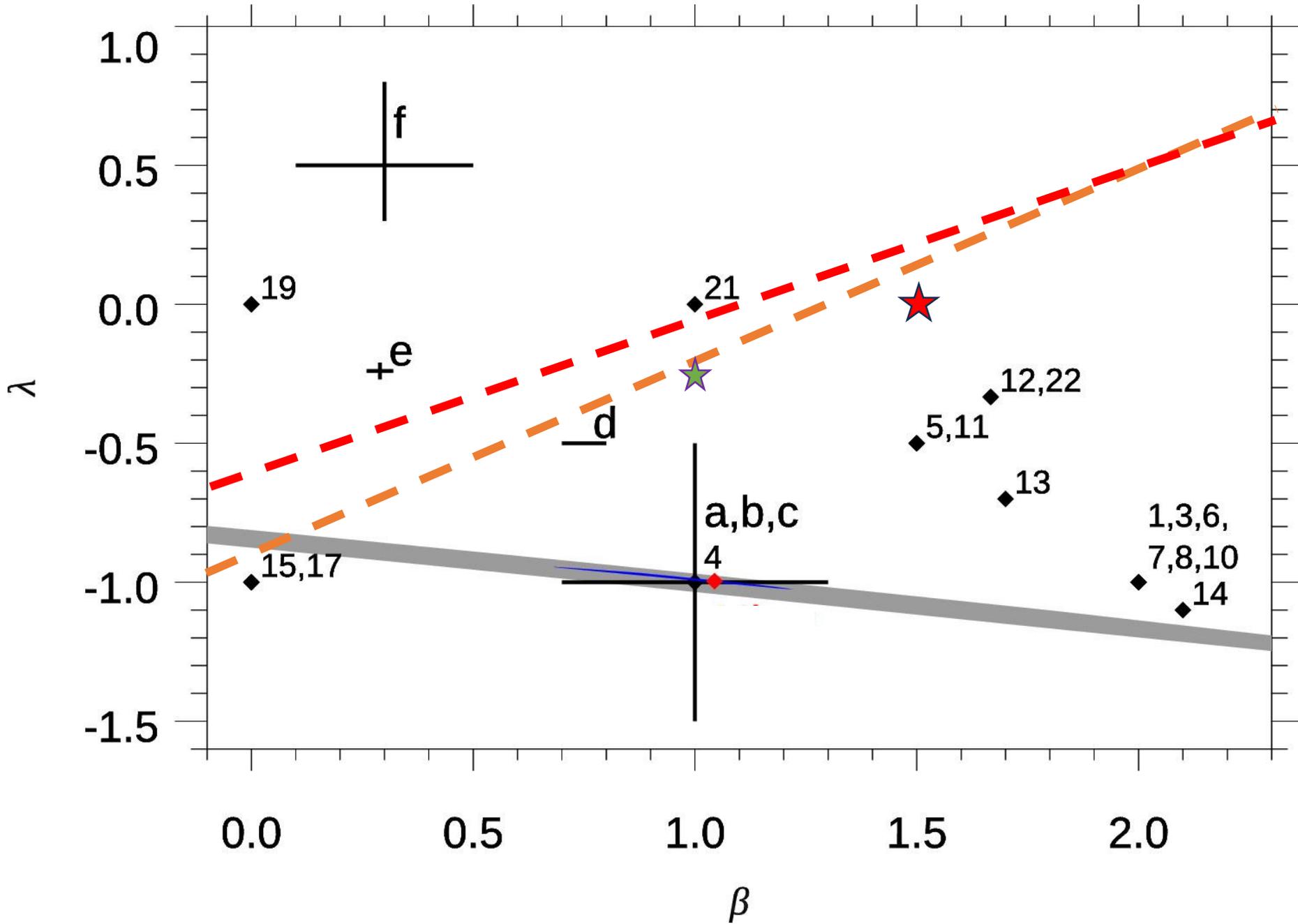
There is a line associated with the best fits in parameter space associated with best fits



$$b \approx 1.61 - 0.55 a$$

$$b \approx 1.88 - 0.67 a$$

Fit to 211 Å using 1400 km grid 8" pixels size



Comparison to other results

Adapted from Ishigami et al. 2024

$$F \propto \langle Q \rangle / L$$

$$\propto B_{\text{base}}^\beta L^{1/2} \lambda$$

$$\beta = a$$

$$\lambda = 1 - b$$

★ 211 Å 8" fit (red lines from the last slide)

★ Fleishman et al 2021

Letters correspond to various observational results

Numbers correspond to models from Mandrini et al. 2000

Conclusions

- The EBTEL assumption that TR emission only comes from low altitude loop footpoints is not sufficient for spatially resolved modeling of EUV emission from many lines observed by AIA. The ones for which this is the least problem are 211 Å and 335 Å.
- AR 12760 was chosen because it is not very active and has a low magnetic field. This makes it hard to model magnetically. This can be remedied somewhat by focusing on a low resolution model images.
- Based on the low resolution 211 Å fits we derive
$$\langle Q \rangle = q_0 (B_{\text{avg}}/B_0)^a (L/L_0)^{-b} = 7 \times 10^{-3} (B_{\text{avg}}/B_0)^{1.5} (L/L_0)^{-1} \text{ erg/cm}^3/\text{s}.$$
- However, there is a larger parameter space that would correspond to a reasonable fit, in particular along a line roughly defined by
$$b = 1.6 - 0.55 a. \text{ and } q_0 \text{ between } 0.003 - 0.011 \text{ erg/cm}^3/\text{s}.$$

Future Steps

- Find a way to extend the TR though more of the loop
 - Our multi-strand modeling will provide DEM (both TR and coronal) as a function of distance along the loop. This should help with the missing TR loop problem.