SPoCA: Software for extraction, characterization, and tracking of Active Regions and Coronal Holes in EUV images

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Outline

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3. Comparing SPoCA to other algorithms
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6. SPoCA AR results SWAP
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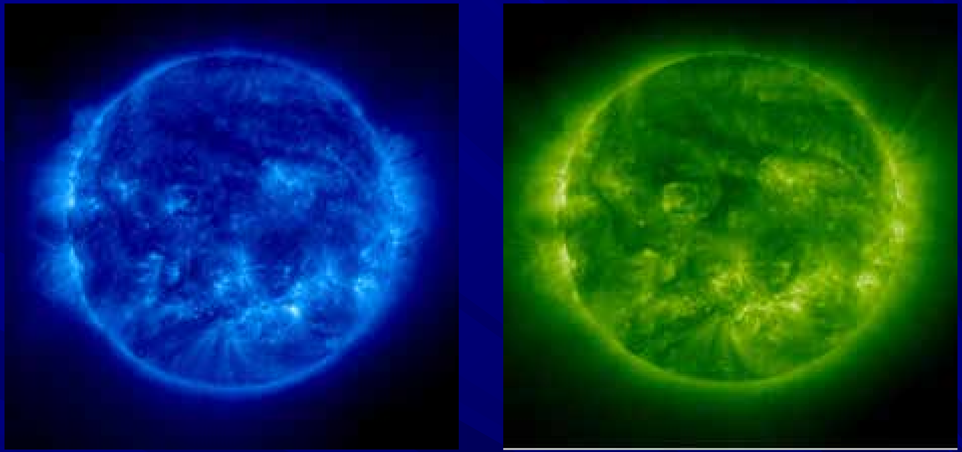
1. Goals and motivation

- SPoCA is intended to enable large scale science studies of AR/QS/CH properties, such as:
  - Ø In-depth study of a particular AR/CH region over its lifetime
  - Ø Statistical study of individual AR/CH regions over solar cycle time scales (e.g., butterfly diagram)
  - Ø Total AR/QS/CH statistics over solar cycle time scales
- Automated detection scheme: needed in view of amount of images to be analyzed
- Fixed algorithm: ensures coherent and reproducible results

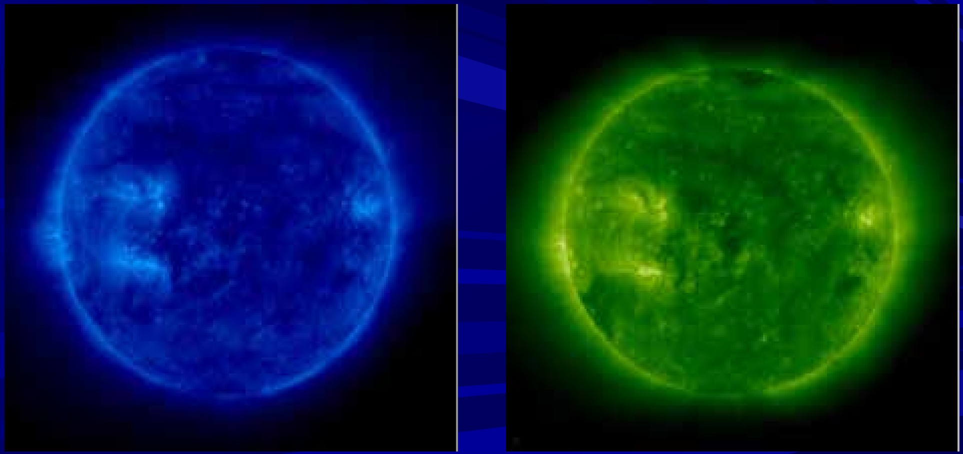
2. Intro to SPoCA: segmentation of coronal EUV images

- For every pixel *j*, we consider the vector (x_j^{171}, x_j^{195}) of pixel values in both channels.
- Using fuzzy clustering techniques, we determine natural clusters (classes) in pixel value vector space and assign membership value u_{ij} of pixel *j* to every class *i*.
- To obtain a segmented image, we need to take a decision: we attribute pixel *j* to class *i* for which membership u_{ij} is largest.

EIT, September 12, 2001



EIT, August 3, 2004



Classical versus fuzzy clustering

Classical clustering

- Attribute pixel *j* to a unique class in {AR, CH, QS}
  - pixel *j* belongs to class AR
- Overlap between classes not possible
- Difficult to introduce expert knowledge
- More often converges to local minimum

Fuzzy clustering

- Attribute membership of pixel *j* to every class in {AR, CH, QS}
  - pixel *j* belongs 80% to AR, 15% to QS, 5% to CH
- Overlap between classes possible: fuzzy boundary AR/QS/CH
- Possible to introduce expert knowledge (for fusion of membership maps)
- More often converges to global minimum

Fuzzy clustering algorithms

C	:	number of classes
$B = (b_1, \ldots, b_C)$	:	vector of centers
x_j	:	descriptor of pixel j
$U[i, j]$	:	membership of pixel j to class i
$d^2(x_j, b_i)$	:	$\|x_j - b_i\|^2$ (euclidean distance, to the square)
N	:	Number of pixels in the data set considered

- **Possibilistic C-Means:** minimize the function

$$J_{PCA}(B,U,X) = \sum_{i=1}^{C} \left(\sum_{j=1}^{N} u_{ij}^m d^2(x_j, b_i) + \eta_i \sum_{j=1}^{N} (1 - u_{ij})^m \right)$$

- Parameter *m* represents the fuzziness of the clustering, typically *m=2*
- First term minimizes fuzzy sum of distances per class
- η_i is a regularization term ➡ better noise behavior

Problem: In case of outliers (cosmic rays, proton storm, flare), AR class can contain just outlier pixels instead of AR pixels

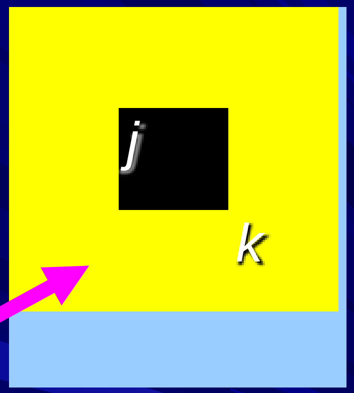
Fuzzy clustering algorithms

- **Spatially Constrained Possibilistic C-Means Algorithm (SPoCA)**

Idea: Add spatial term to impose similar classification for neighboring pixels

➡ reduced sensitivity to outliers

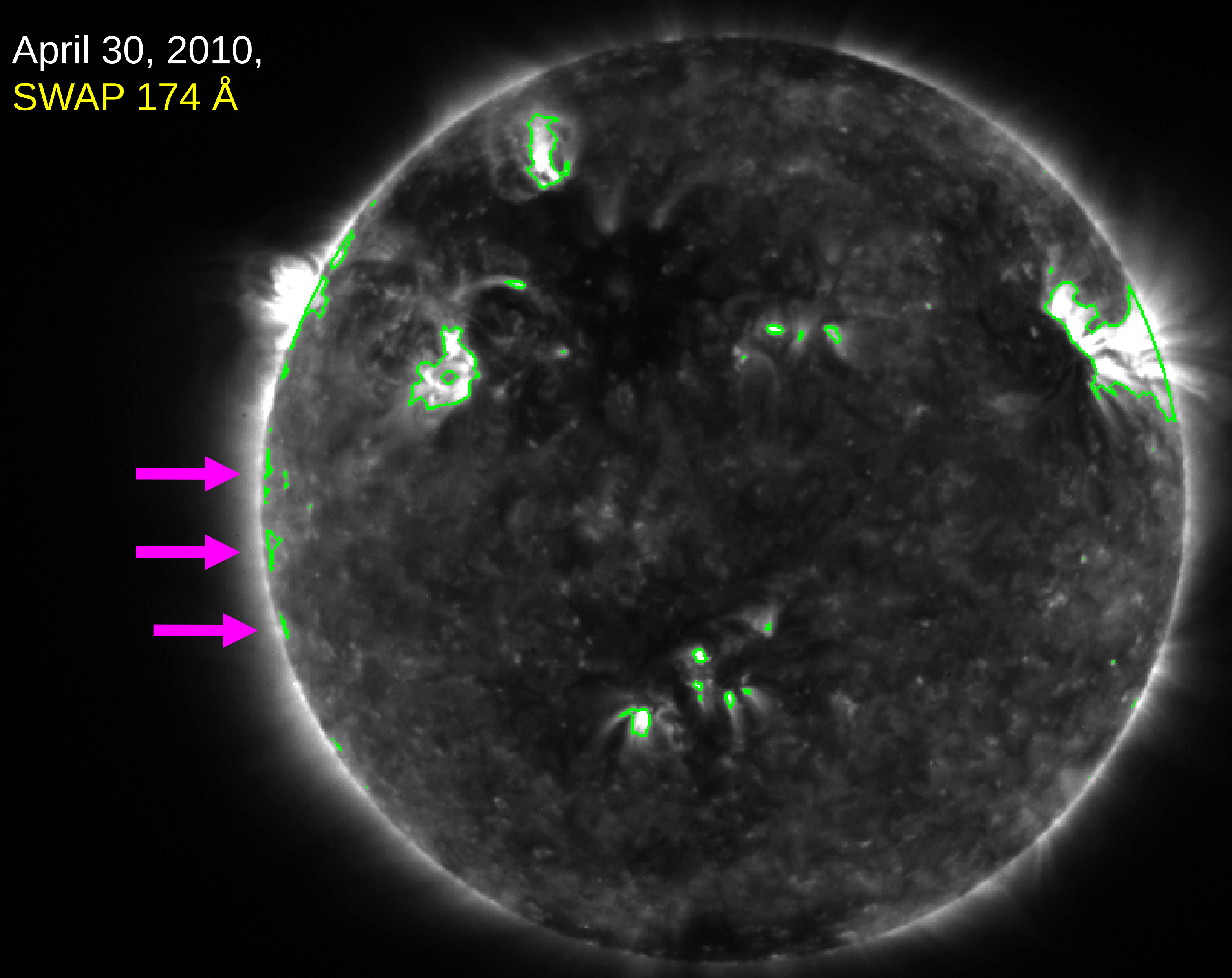
Neighborhood N_j



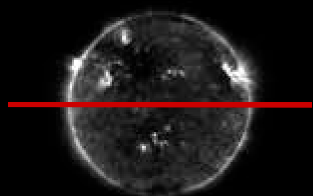
$$\beta_k = \begin{cases} 1 & \text{if} \quad k = j \\ \frac{1}{\mathrm{Card}(N_j)-1} & \text{otherwise} \end{cases}$$

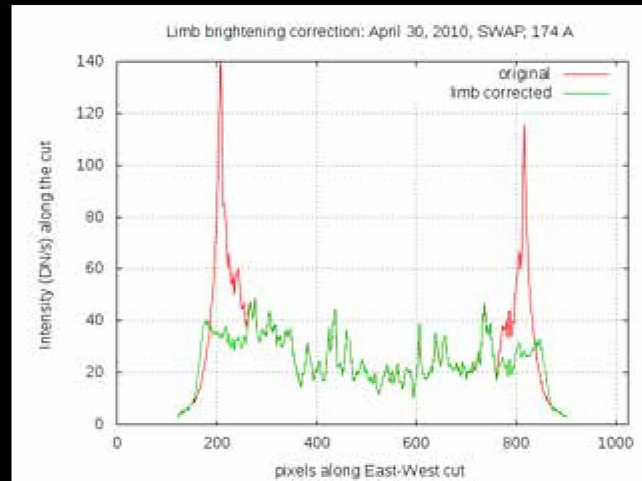
$$J_{\mathrm{SPoCA}}(B,U,X) = \sum_{i=1}^{C} \left(\sum_{j=1}^{N} u_{ij}^{m} \sum_{k \in N_j} \beta_k d^2(x_k, b_i) + \eta_i \sum_{j=1}^{N} (1 - u_{ij})^m \right)$$

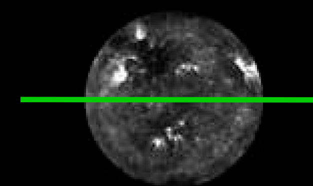
Limb brightening hinders segmentation

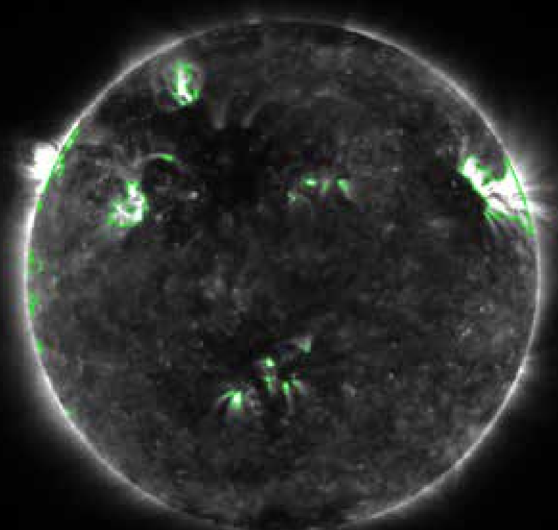


Solution: limb brightening correction

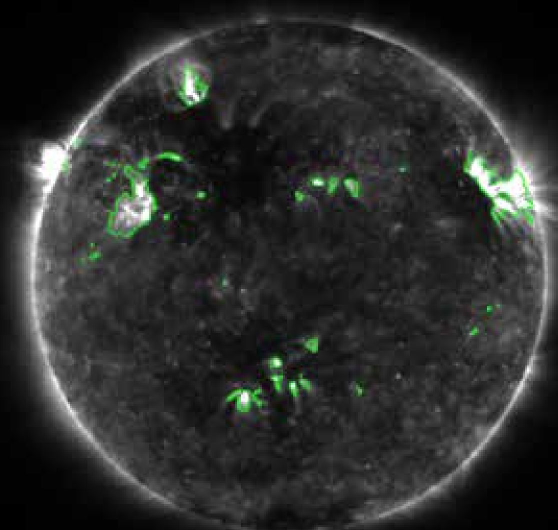






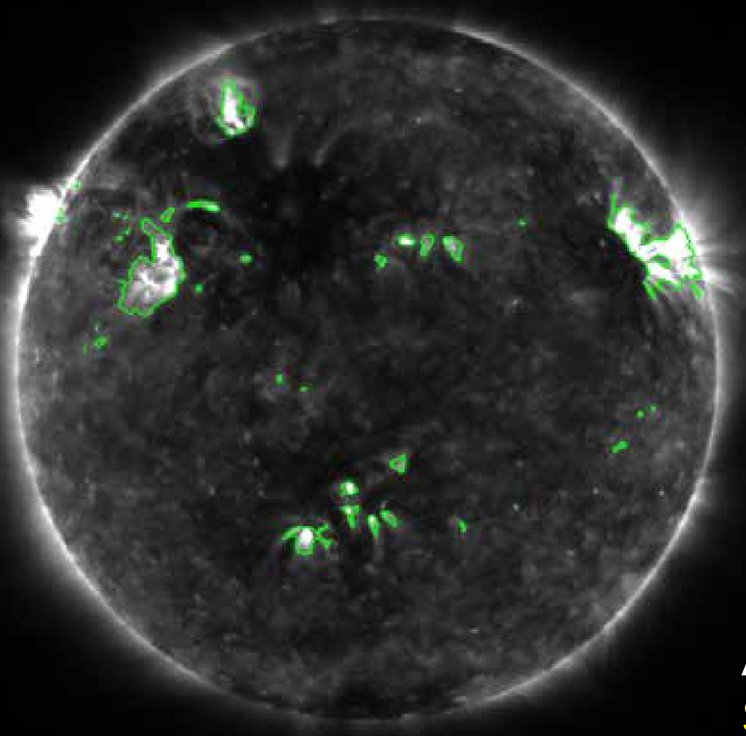


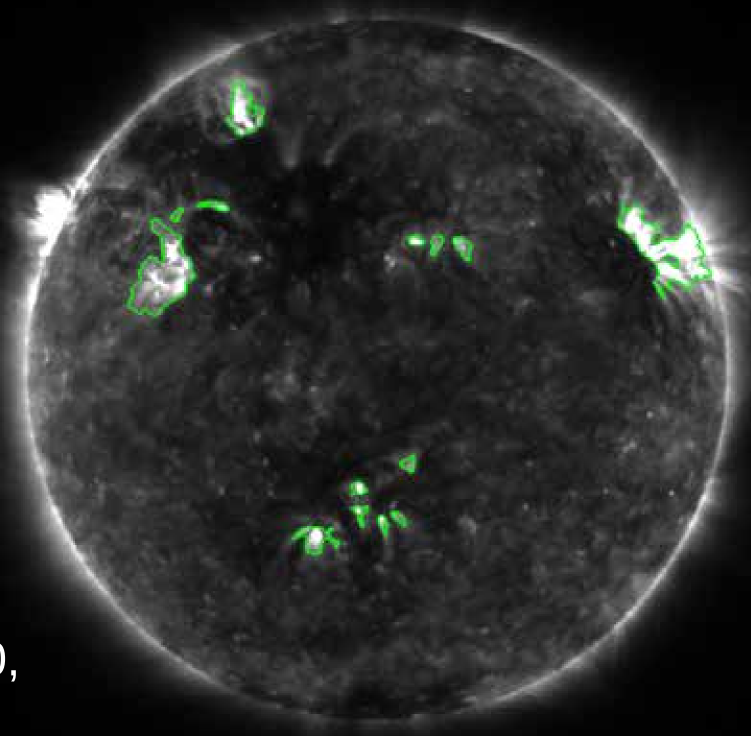
April 30, 2010,
SWAP 174 Å



Detection and tracking of individual AR and CH regions

- Region growing technique to find connected components inside AR segmentation class
- Set lower size limit for AR to distinguish them from Bright Points: 1500 square arcseconds

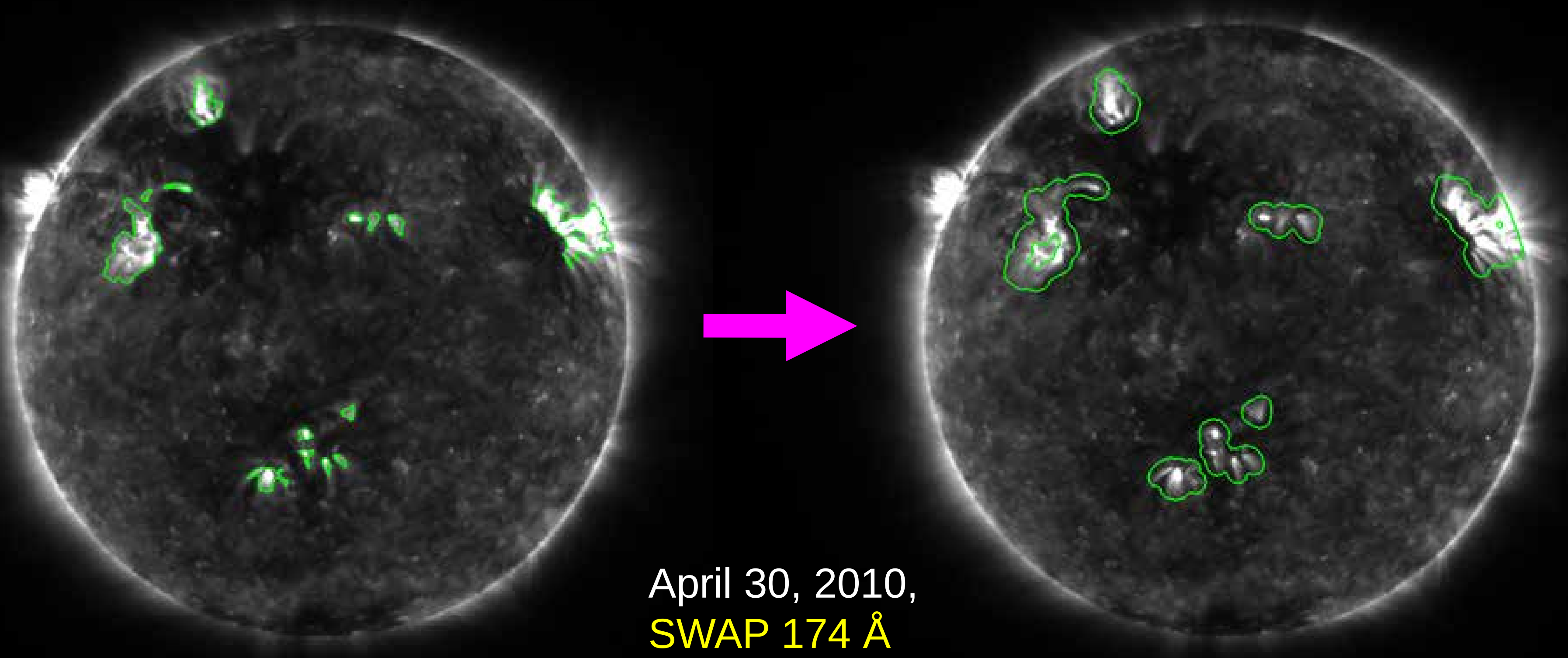




April 30, 2010,
SWAP 174 Å

Collecting bright patches into ARs

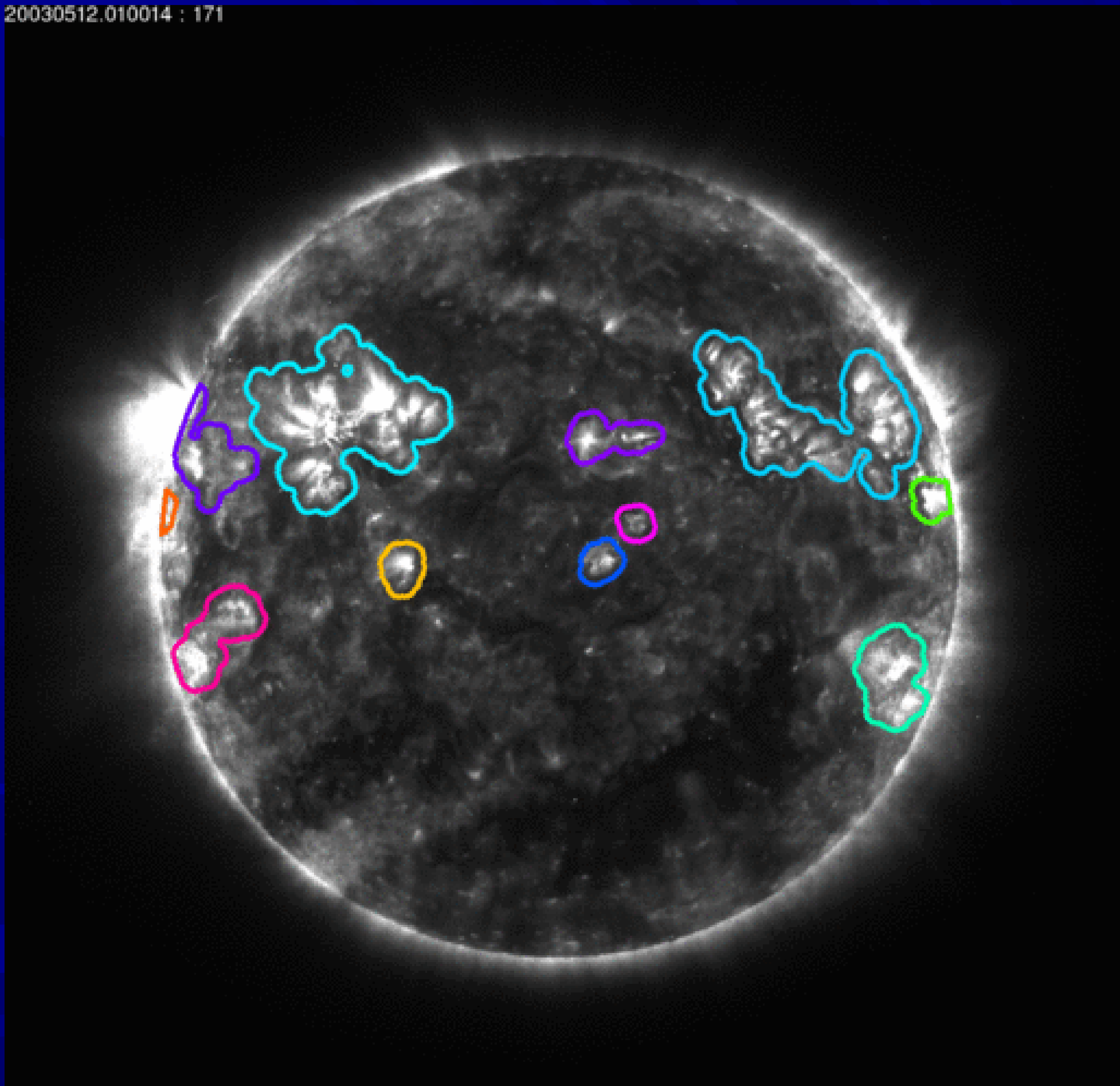
- Segmentation can yield several connected components (bright patches) which correspond to one AR
- Apply circular dilation to AR map
- The resulting connected components are considered to be ARs



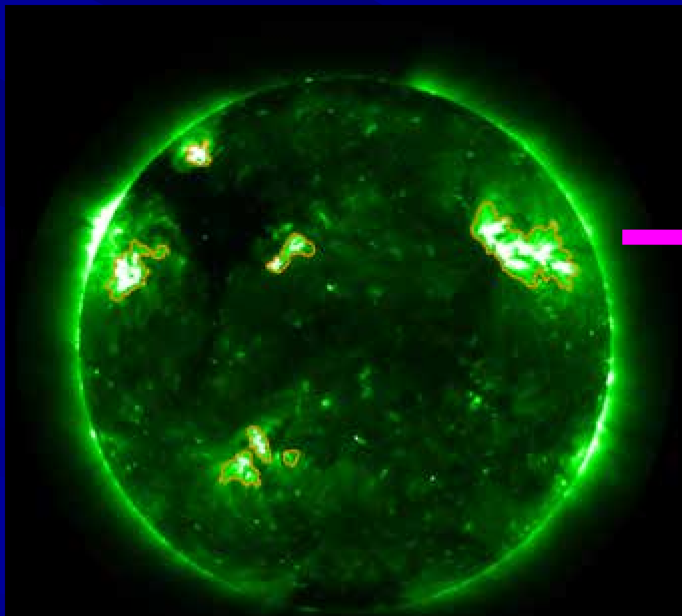
April 30, 2010,
SWAP 174 Å

Tracking of individual Active Regions

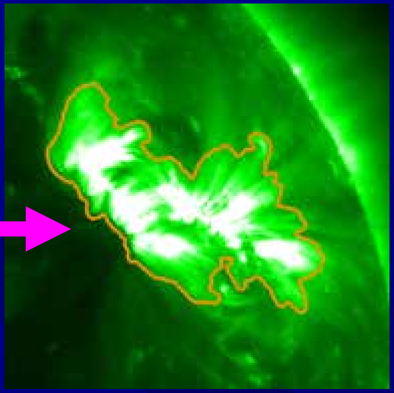
- The ARs detected after dilation are followed over time
- Associate AR1 at time t_1 and AR2 at time t_2 if AR1 and AR2 overlap (every 15 minutes)
- Detect emerging ARs and assign new ID
- Keep track of splitting and merging ARs
- Save tracking results every 4 hours

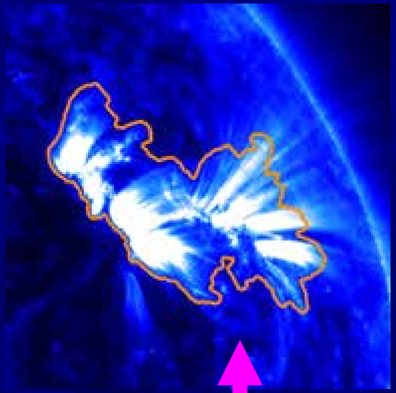


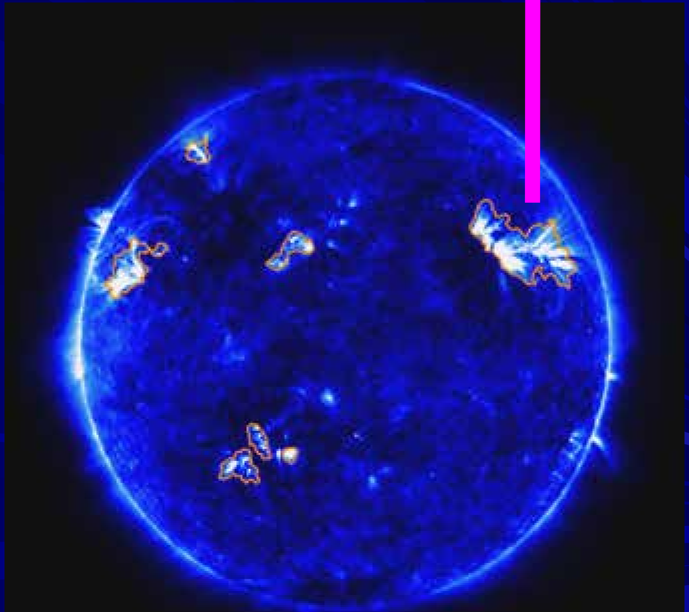
Segmentation of AIA images



April 29, 2010, AIA 193 Å







April 29, 2010, AIA 171 Å

Active Region and Coronal Hole statistics

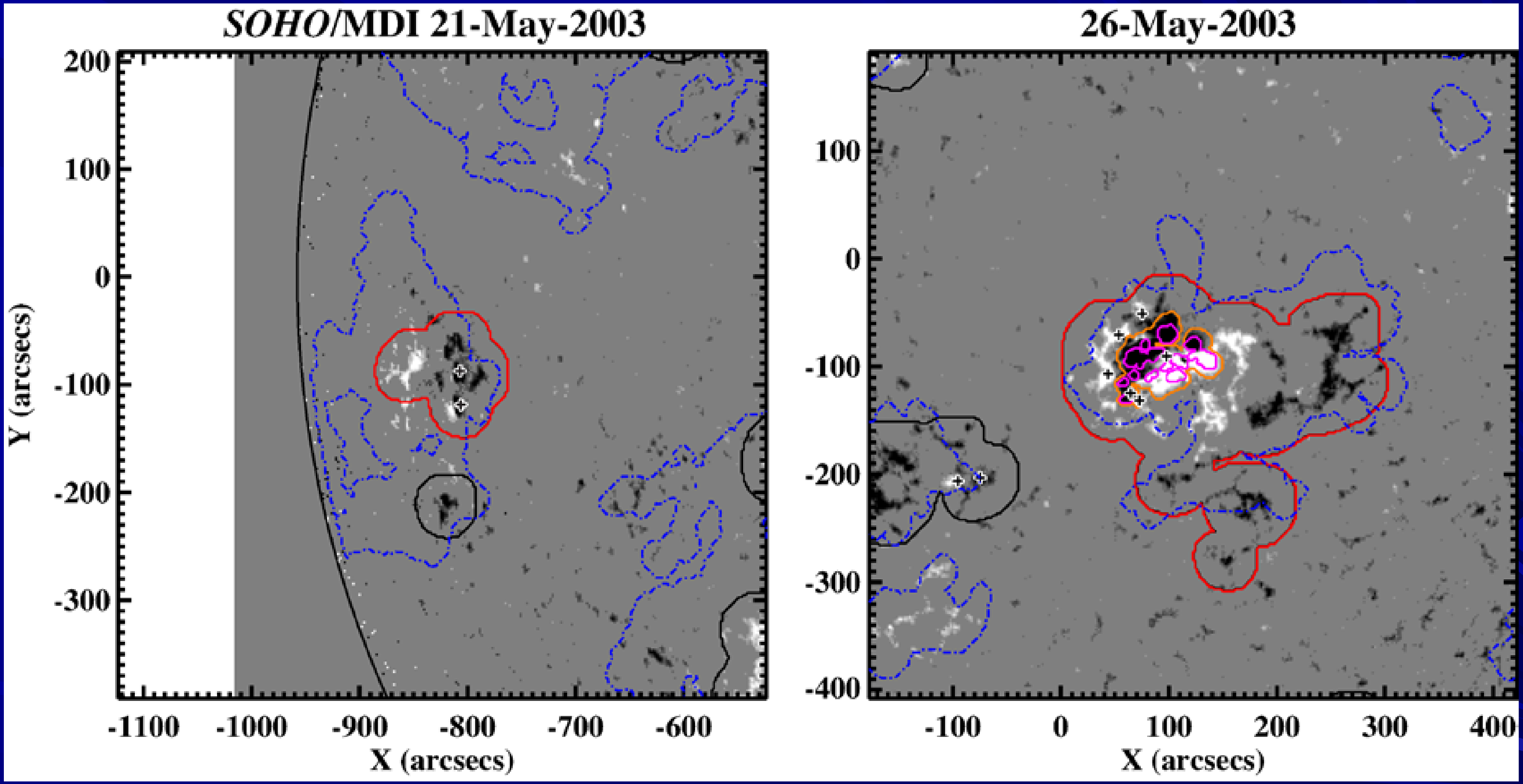
- Several parameters are calculated:
  - Ø for every AR/CH region: position, size, pixel intensity statistics
  - Ø for the entire AR/QS/CH classes: size, pixel intensity statistics
- This allows statistical surveys of AR/QS/CH properties:
  - Ø Throughout the solar cycle
  - Ø Within the lifetime of a specific region of interest

Region Statistics

Barycenter :	(3121,2622)
NumberPixels :	175353
MinIntensity :	322 DN/s
MaxIntensity :	9696 DN/s
Mean :	1834.809 DN/s
Standard Deviation :	1286.050
Skewness :	0.005
Kurtosis :	-3.000
TotalIntensity :	3.217 e+8 DN/s
Area Raw :	33680.616 Mm^2
Area At Disk Center :	55882.873 Mm^2

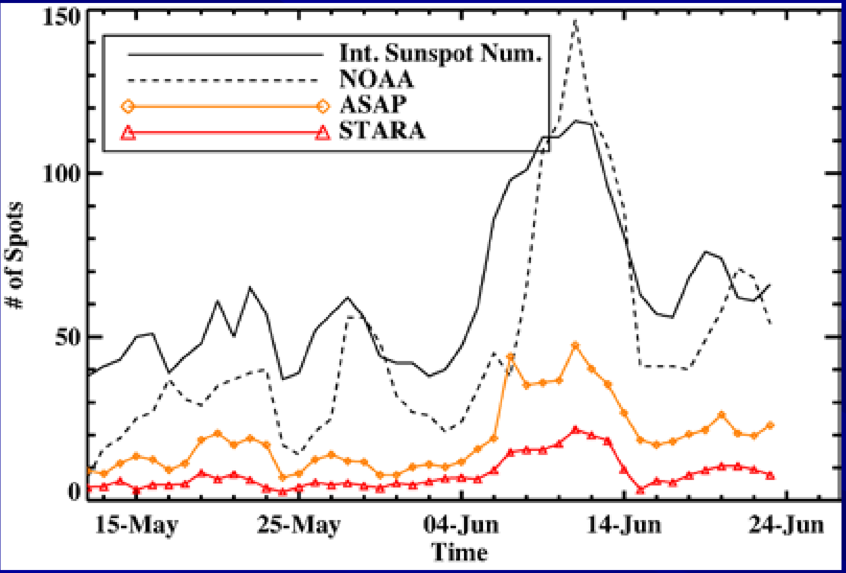
3. Comparing SPoCA to other algorithms

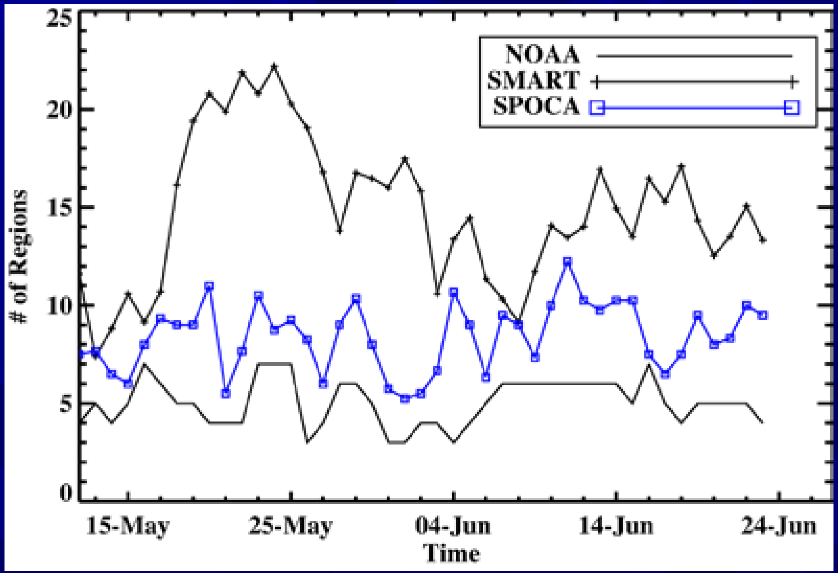
Verbeeck et al., Sol.Phys. 2011

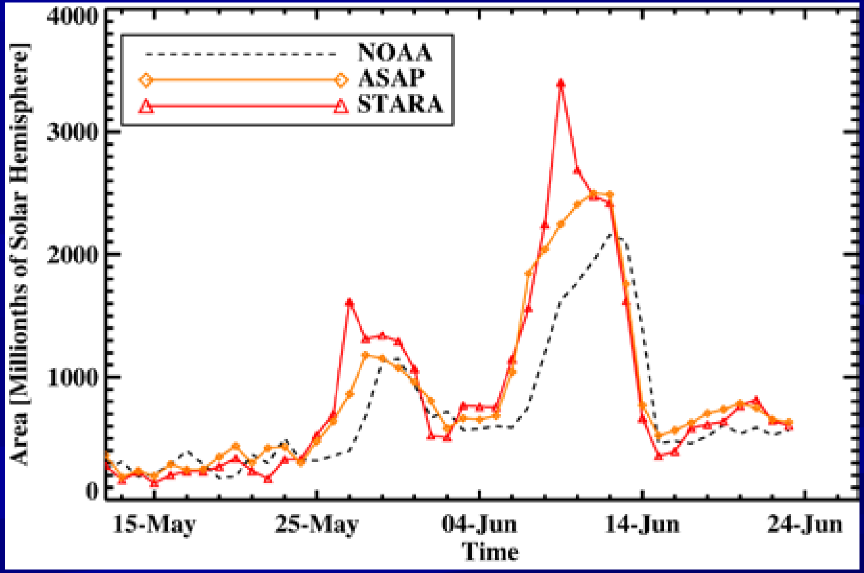


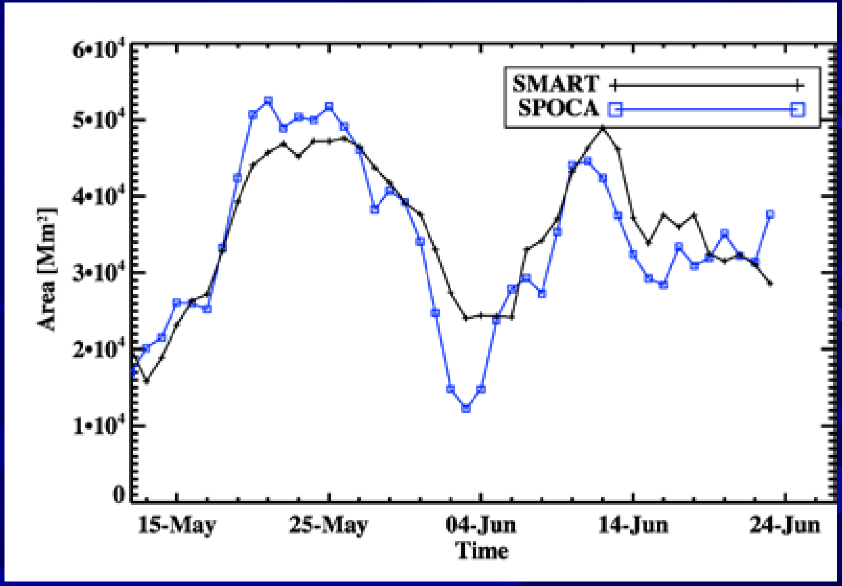
NOAA AR 10365 contours: SMART magnetic AR (in black, 10365 in red), ASAP sunspots (black crosses), STARA sunspots (penumbrae: orange, umbrae: magenta), SPoCA coronal AR (dashed blue).

3. Comparing SPoCA to other algorithms









4. SPoCA analysis of AR/QS/CH EIT 1997-2011

Dataset:

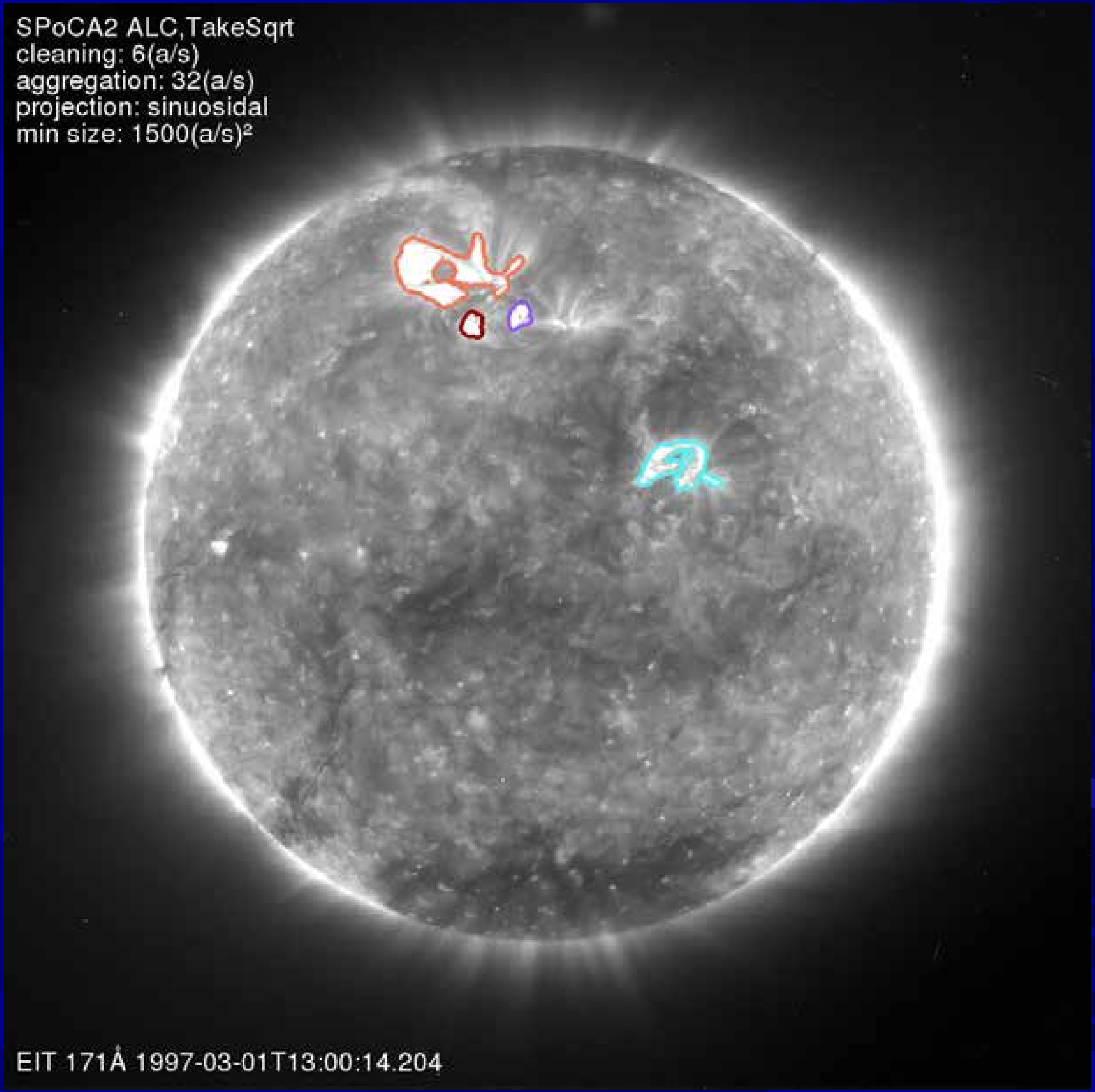
- 1k x 1k EIT image pairs (171 & 195 Å)
- Time range: March 1997-August 2011
- Cadence: 6 hours

Submitted to A&A, 2013

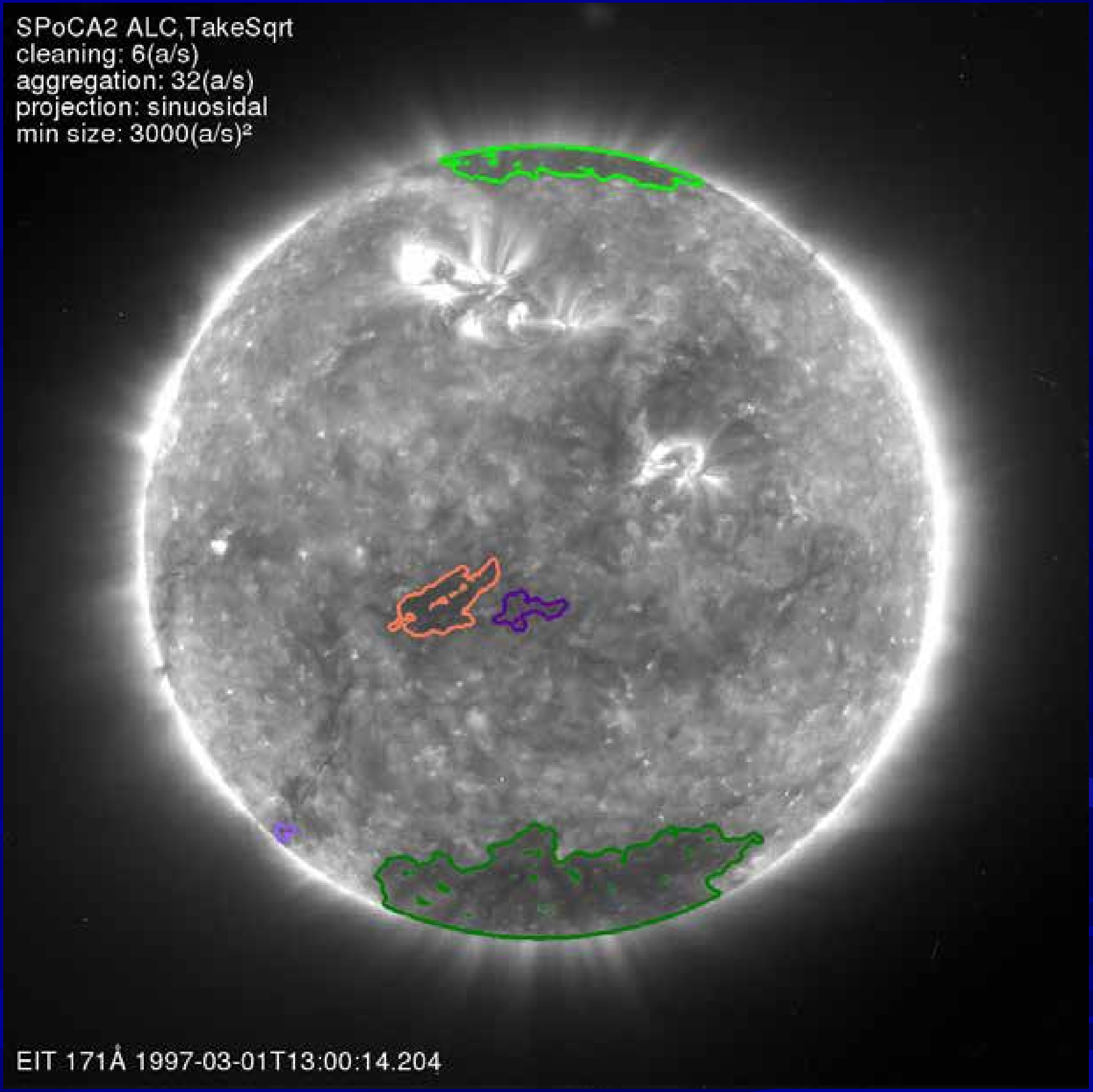
SPoCA AR/QS/CH segmentation:

- Input: square root; 4 classes: CH = {1}, QS={2,3}, AR = {4}
- Initial SPoCA run on subset: 1 image pair per month (112 pairs)
- Problem: AR not well detected during solar min: too little AR pixels
- Solution: Perform fixed attribution on whole dataset using average center and eta values from solar max (42 pairs)
- Results:
  - Ø Segmentations in monthly subset were satisfactory
  - Ø 1997-2011 segmentation criteria are fixed, not image-dependent
  - Ø AR/QS/CH timelines (9 540 points): median I, total I, filling factor

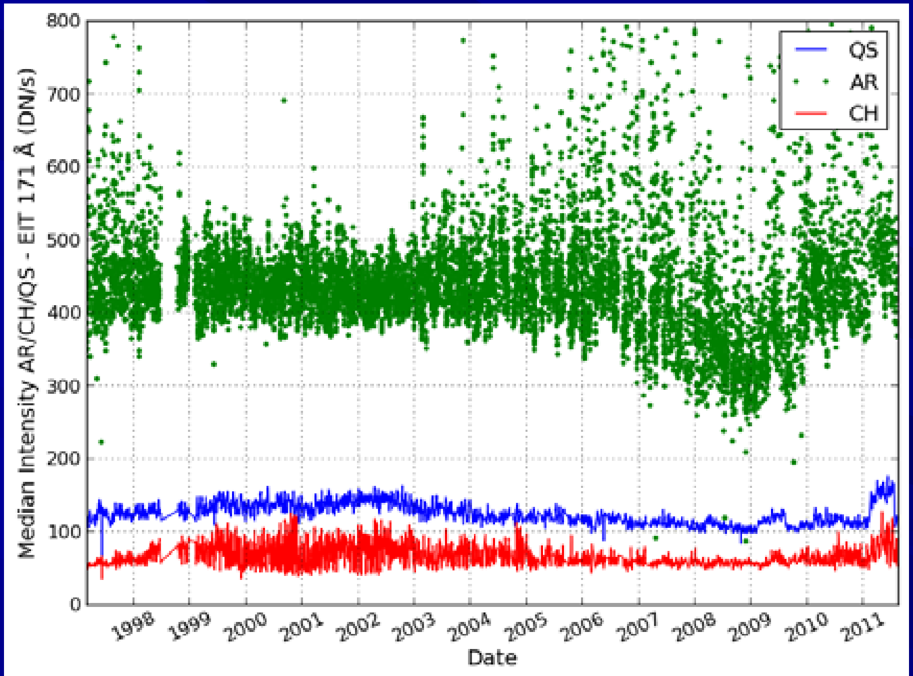
EIT AR movie 1997-2011

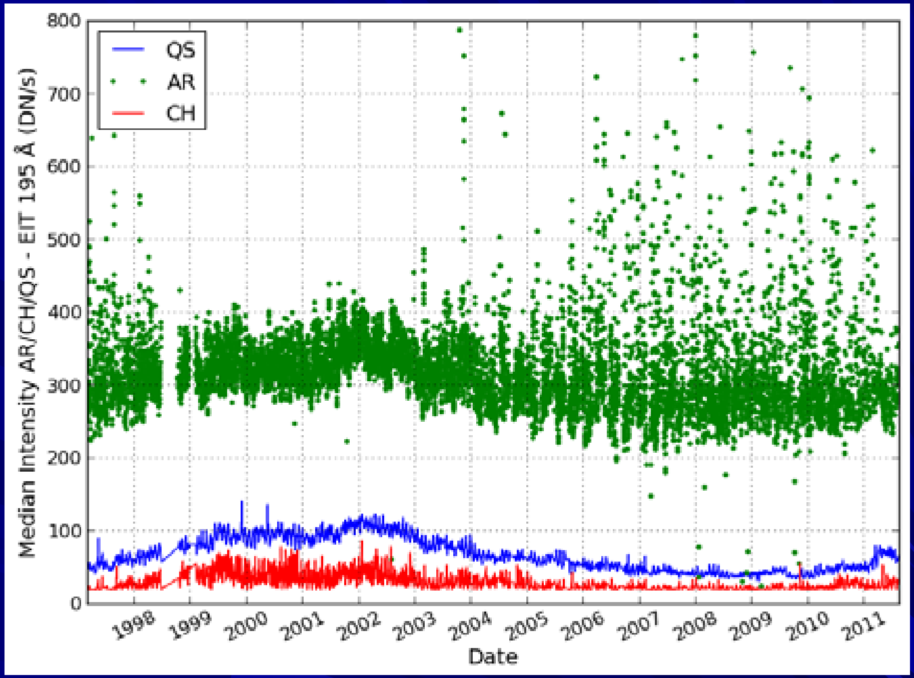


EIT CH movie 1997-2011



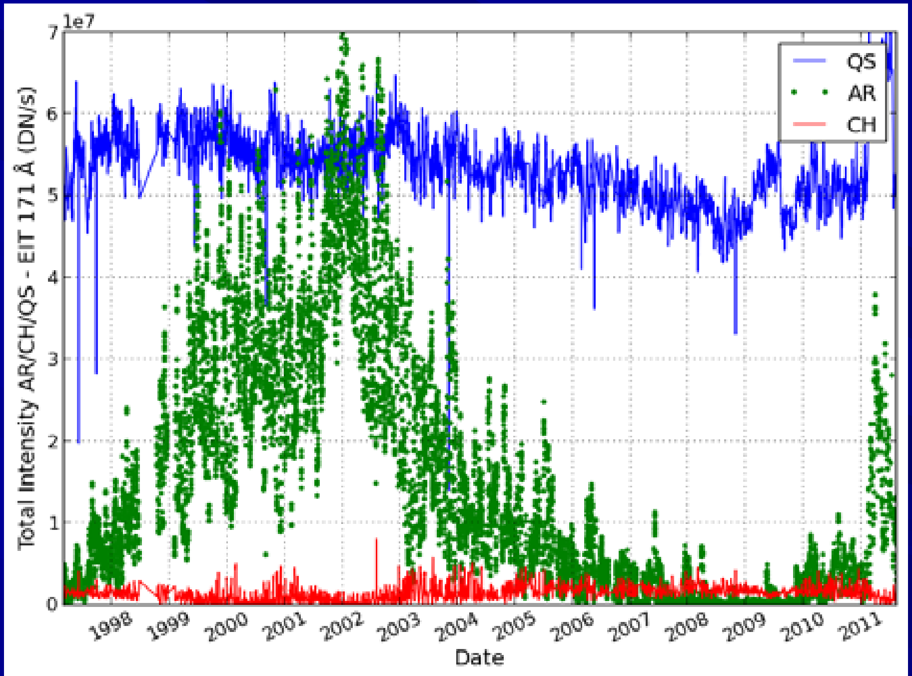
Median intensity EIT 1997-2011

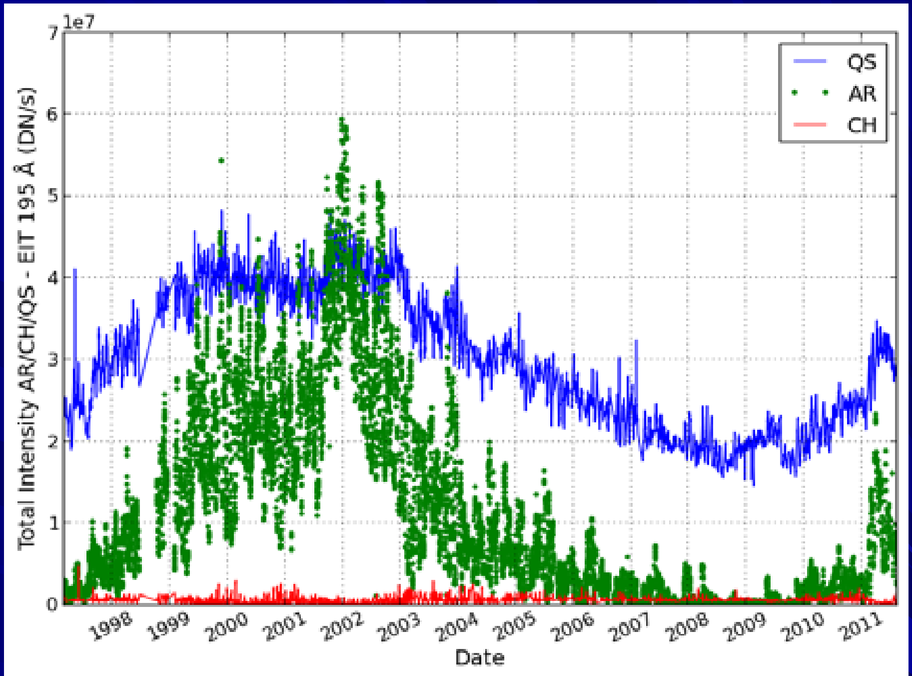




- Slight variation of median intensity AR/QS in sync with solar cycle
  - Ø QS variation is probably due to overlying AR canopies
- Median intensity varies substantially more for AR than for QS & CH

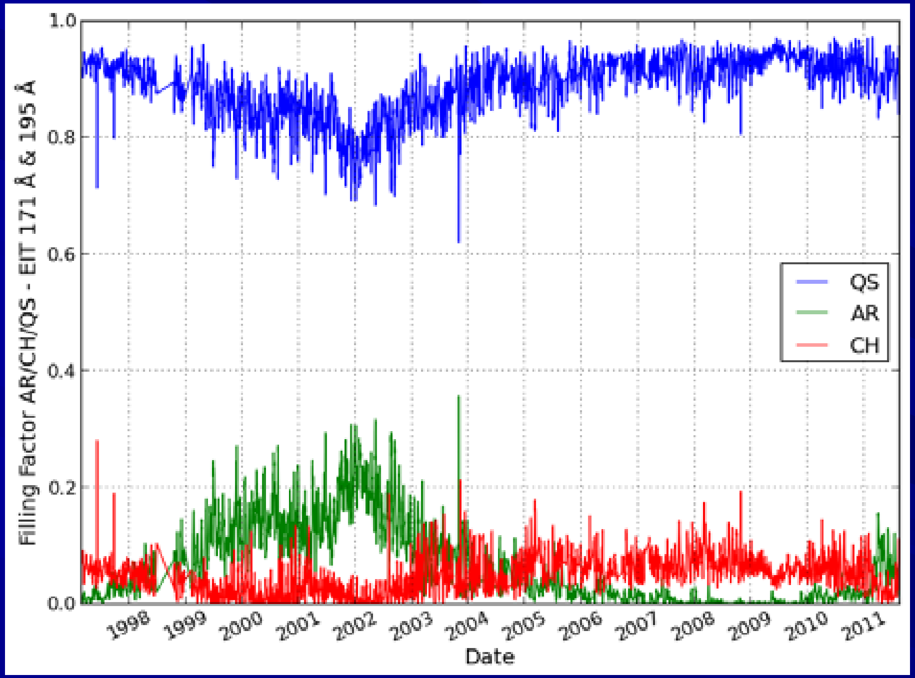
Total intensity EIT 1997-2011

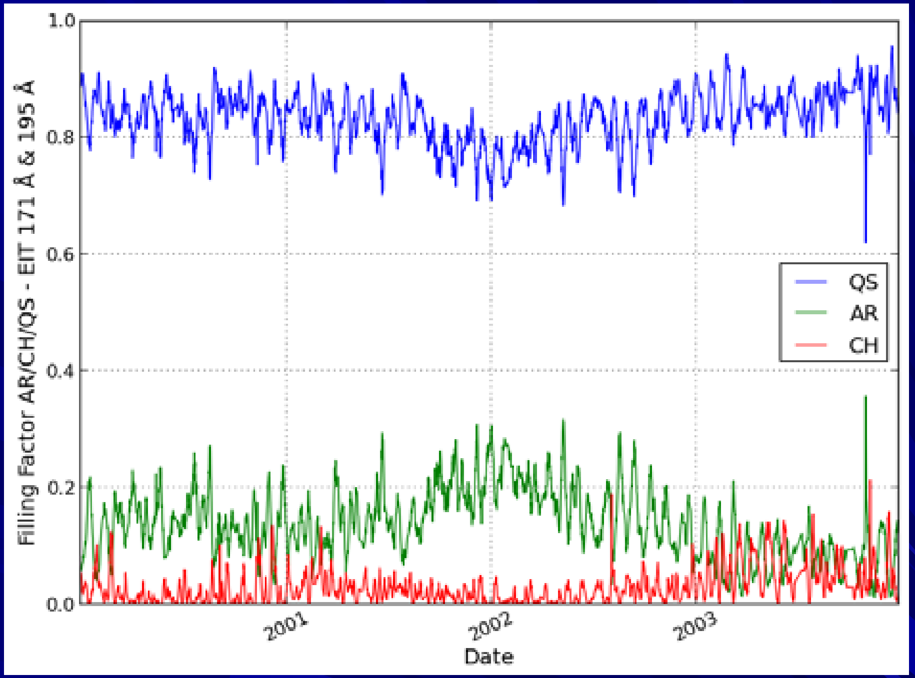




- Total intensity AR in sync with solar cycle, incl. double max 2000 & 2002
- Total intensity QS slightly in sync with solar cycle
- Total intensity CH in anti-phase with solar cycle

Filling factor EIT 1997-2011





- Filling factor (FF) = relative area AR/QS/CH on solar disk
- FF AR in sync with solar cycle, incl. faint double max 2000 & 2002
- FF QS & CH in anti-phase with solar cycle
- Zooming in on FF clearly reveals the 27-day period of solar rotation

5. SPoCA AR/CH results EUVI A & B

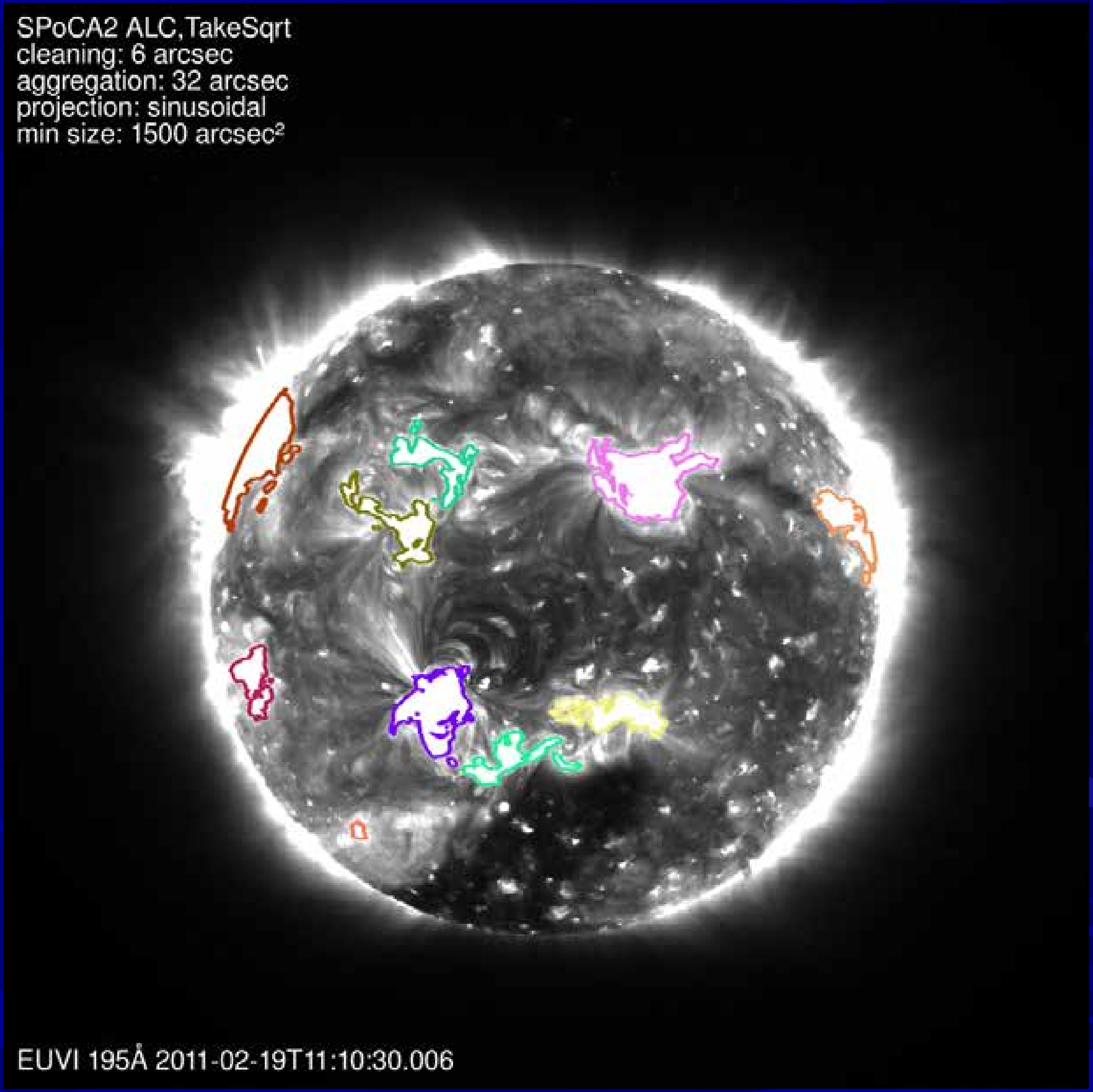
Dataset:

- 1k x 1k EUVI images (195 Å)
- Time range: Jan 11 – March 31, 2011
- Cadence: 1 hour

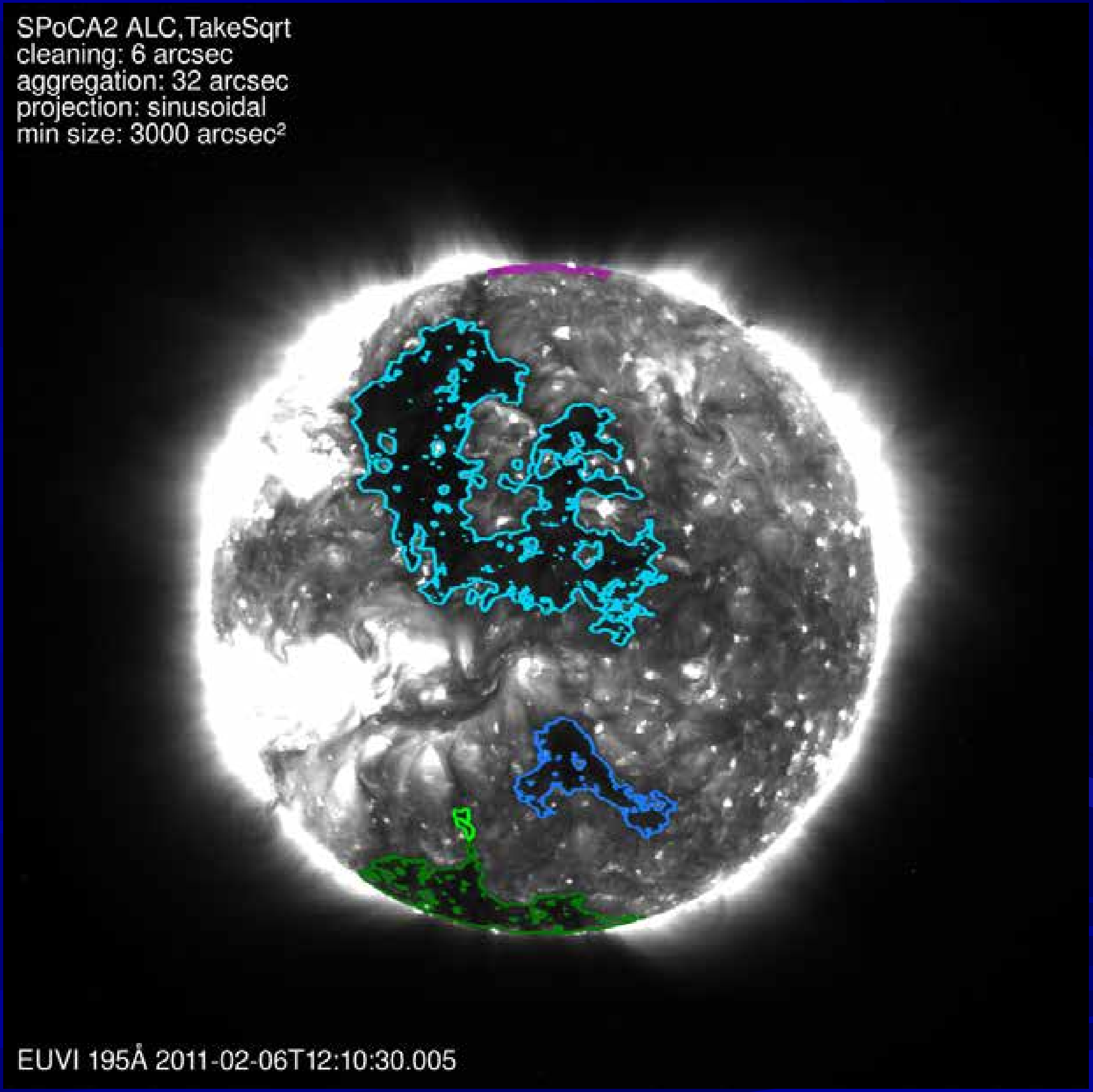
SPoCA AR/QS/CH segmentation:

- Input: square root; 4 classes: CH = {1}, QS={2,3}, AR = {4}
- Initial SPoCA run, followed by final SPoCA attribution run using the median of all center and eta values
- STEREO A & B about 180 degrees apart -> 13.5 day lag expected
- Results:
  - Segmentations were satisfactory
  - Expected 13.5 day lag STEREO A-B in AR/CH time series confirmed

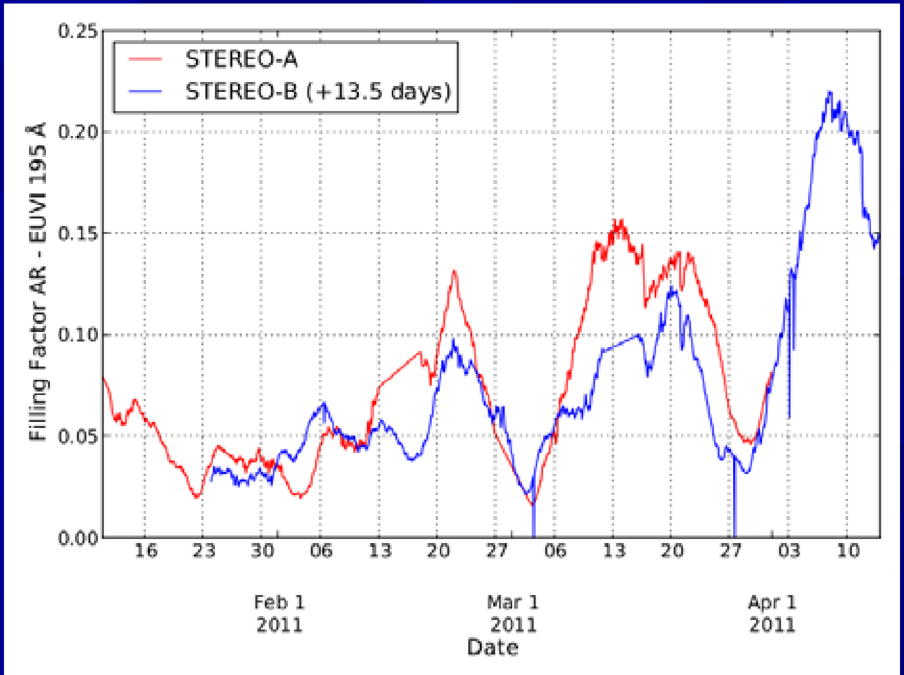
AR detection on EUVI

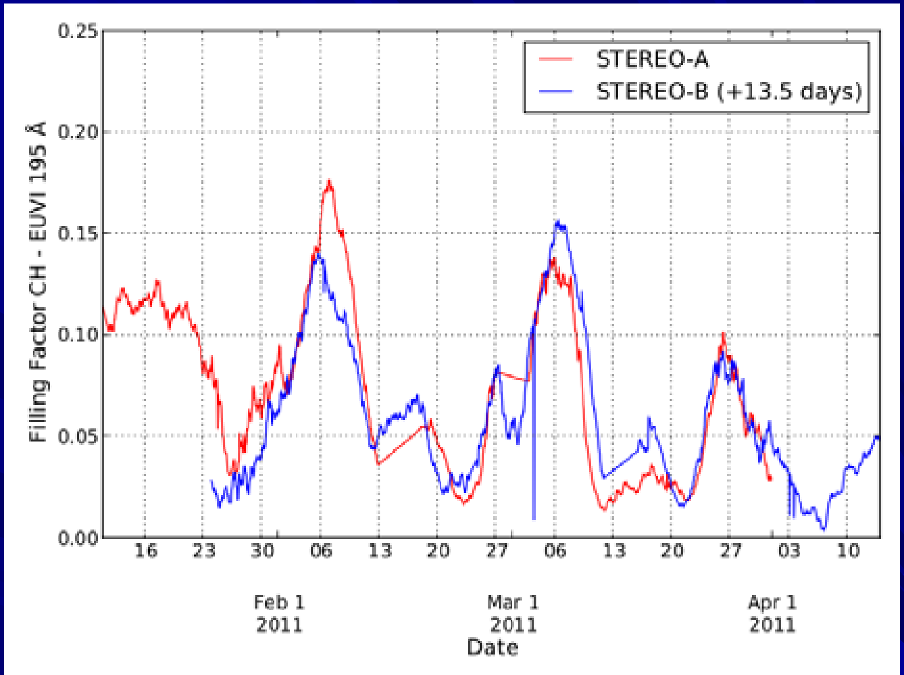


CH detection on EUVI



AR & CH filling factors on EUVI-A & B





- STEREO-B results have been shifted 13.5 days ahead in time
- Filling factors of AR/CH show the expected 13.5 day lag between STEREO-A and B
- One full solar rotation later, we find similar AR/CH filling factors (for both spacecraft)

6. SPoCA AR results SWAP

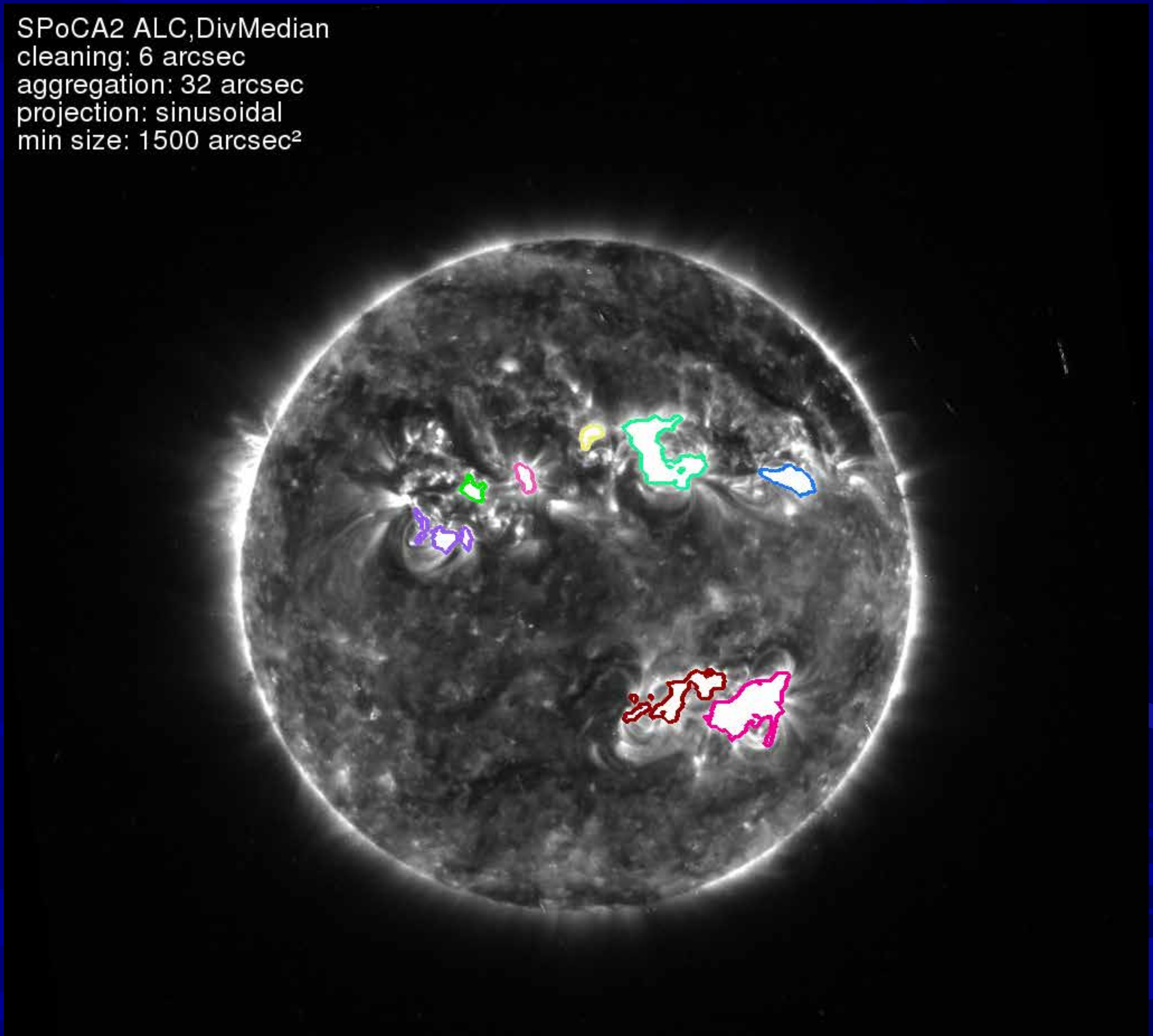
Dataset:

- 1k x 1k SWAP images (174 Å)
- Time range: October 2010-June 2011
- Cadence: 6 hours

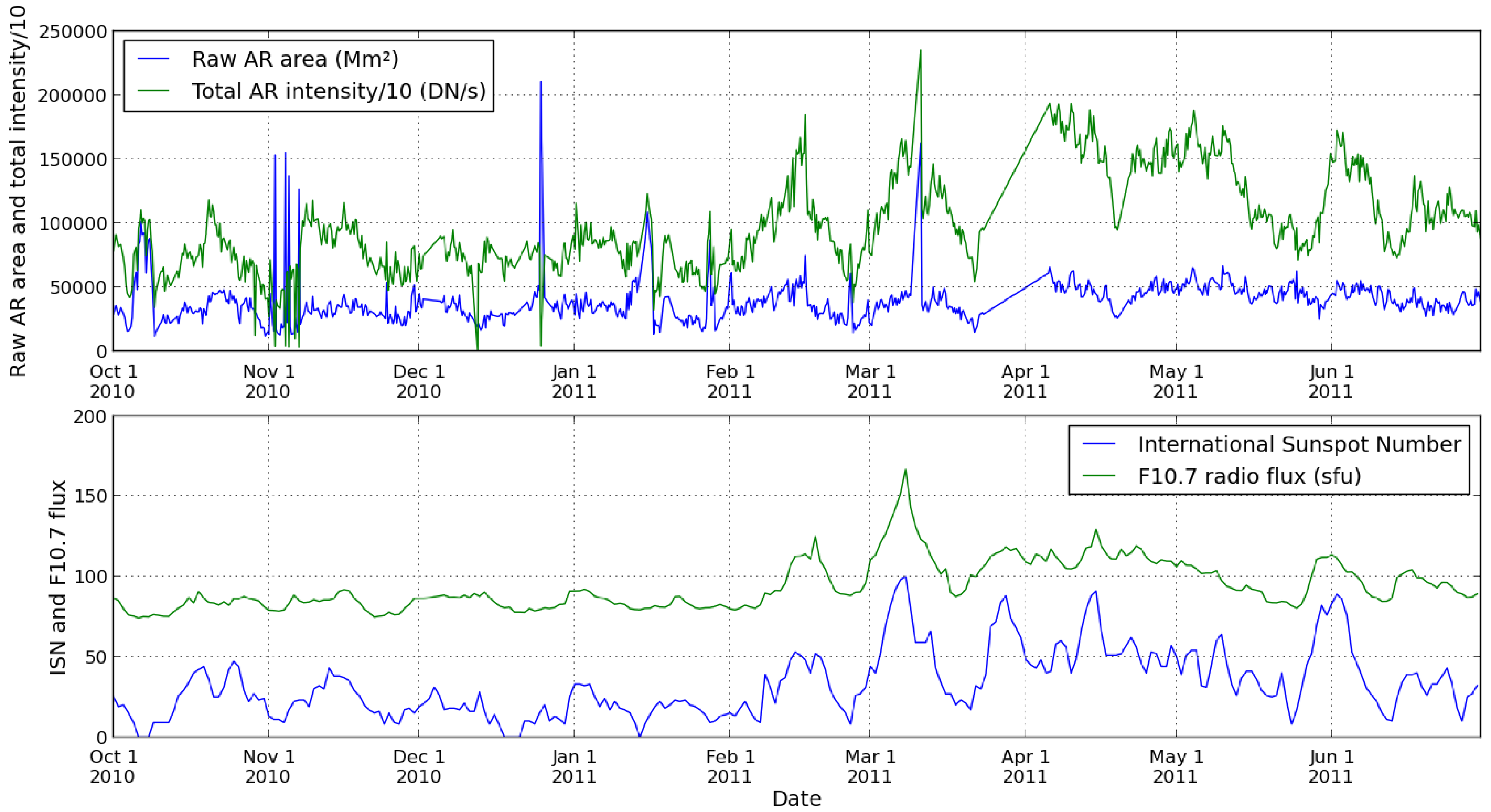
SPoCA AR segmentation:

- Input: linear; 6 classes: CH = {1}, QS = {2,3,4}, AR = {5,6}
- Caution:
  - Ø SPoCA parameters selected by limited ad hoc visual inspection
  - Ø The ARs are a bit smaller than in the EIT 1997-2011 analysis
  - Ø No quality control yet: artifacts due to bad files etc. not removed
  - Ø No CH retained

AR detection on SWAP



Total intensity & FF SWAP 2010-2011



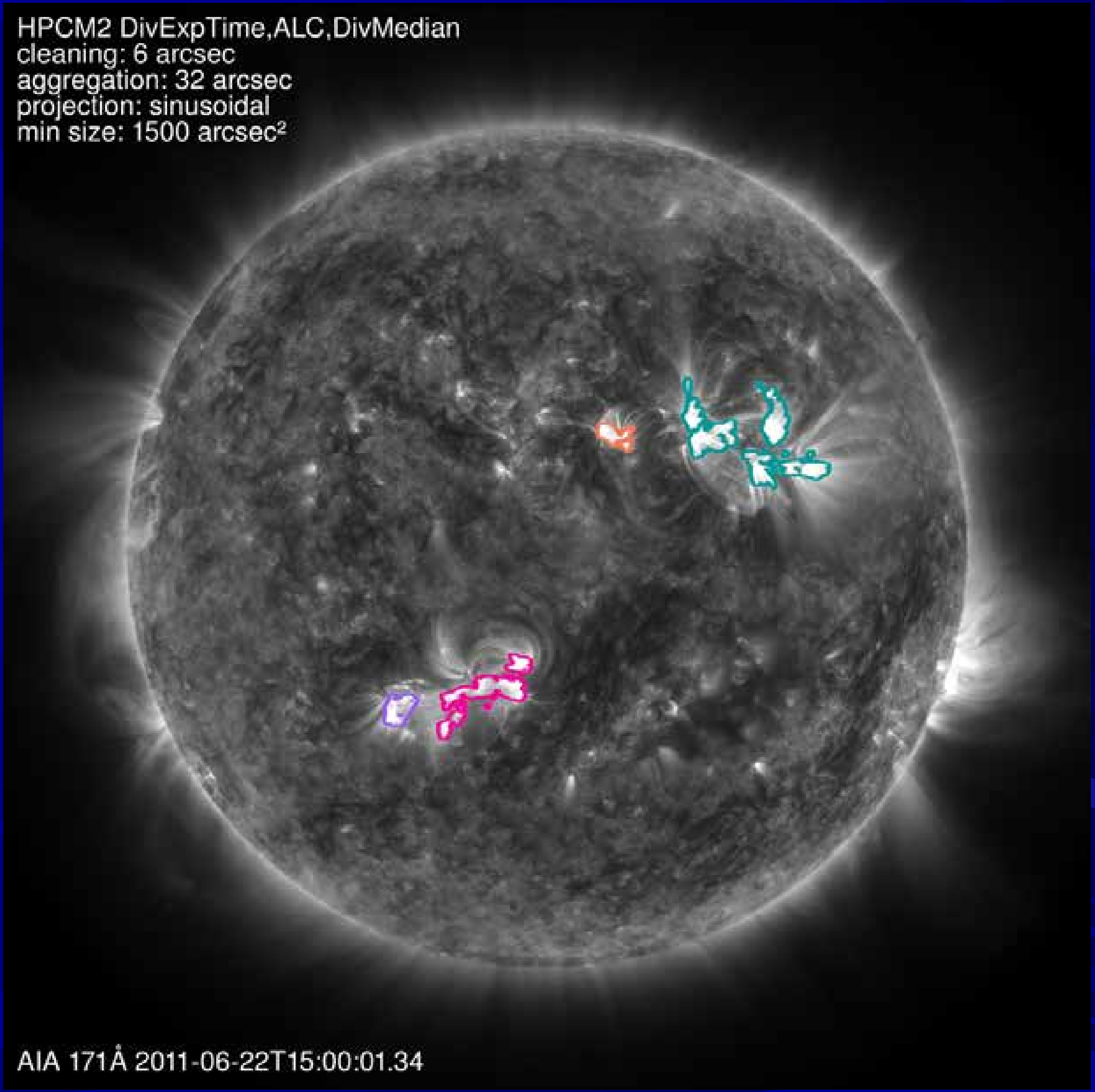
Visually obvious correlation of AR area & especially AR total I with International Sunspot Number & F10.7

7. SPoCA CH results AIA

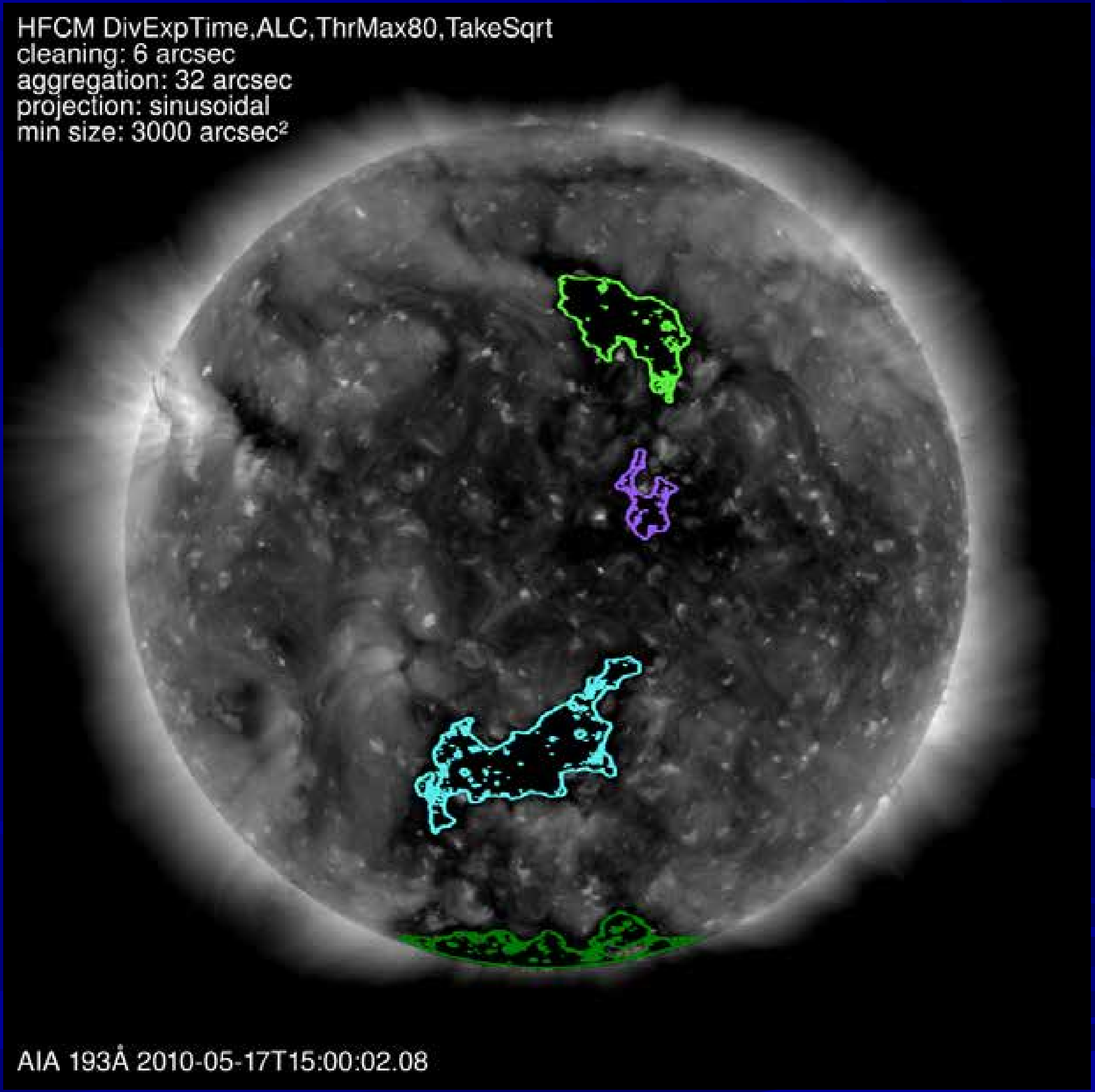
Dataset:
- 4k x 4k AIA images (193 Å)
- Time range: January-April 2011
- Cadence: 1 hour

SPoCA AR/QS/CH segmentation:
- Input: square root; 4 classes: CH = {1}, QS={2,3}, AR = {4}
- Initial HFCM run
- Problem: AR centers sometimes show sudden jumps
- Solution: Perform HFCM attribution using median of last 10 centers
- Results:
  - Ø Segmentations were satisfactory
  - Ø Periods found: solar rotation of ~27 days, period of ~9 days

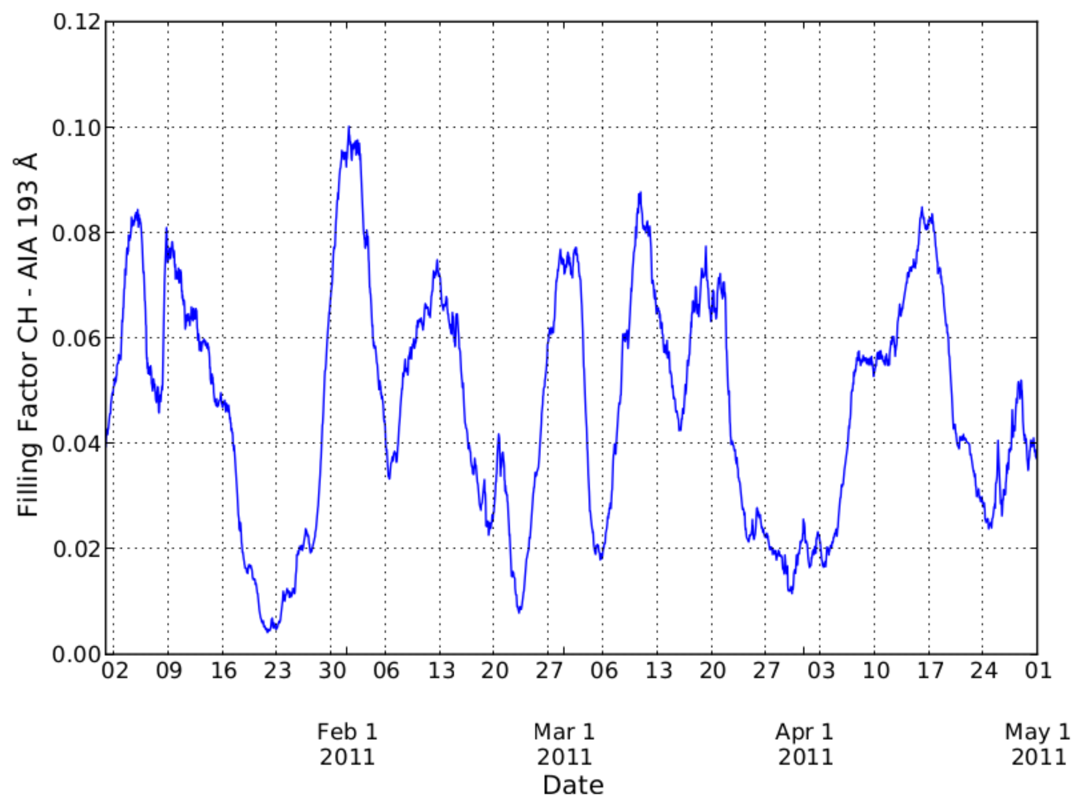
AR detection on AIA



CH detection on AIA



CH filling factors on AIA

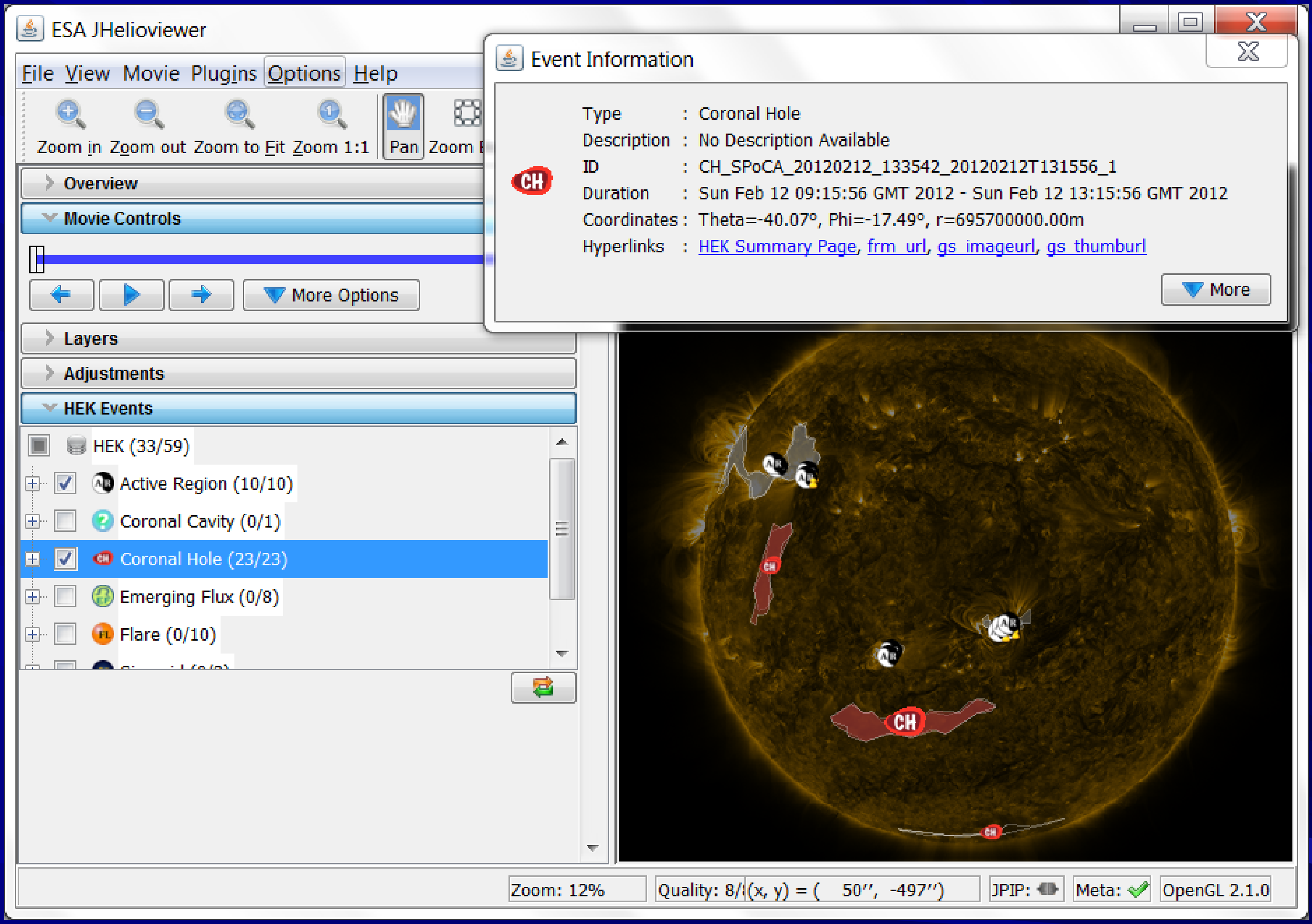


- Periods found in CH filling factors:
  - solar rotation of ~27 days
  - period of ~9 days
- Period of ~9 days was previously found by Temmer et al. (2007) based on GOES-SXI images

8. Applications

- FP7 SOLID project: SPoCA AR/QS/CH filling factors are being included into semi-empirical models of the solar atmosphere, which will be used to model solar EUV irradiance (Haberreiter 2011)
- Construction of AR butterfly diagrams
- Since Sep 2010, SPoCA provides near real time AIA AR & CH results to the HEK (Heliophysics Events Knowledgebase) – also visible in JHelioviewer
- Space weather applications such as near real time localization and extent of CH for estimation of start time and velocity of CH high speed solar wind streams

SPoCA AR & CH in JHelioviewer



AIA 171 Å image Feb 12, 2012 @ 9:15:56 UT together with AR & CH location and chain code info recorded in the HEK.

An Event Information window pops up when clicking on an event or feature.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OR THANKS FOR BEING SLEEPING THE WHOLE PRESENTATION
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