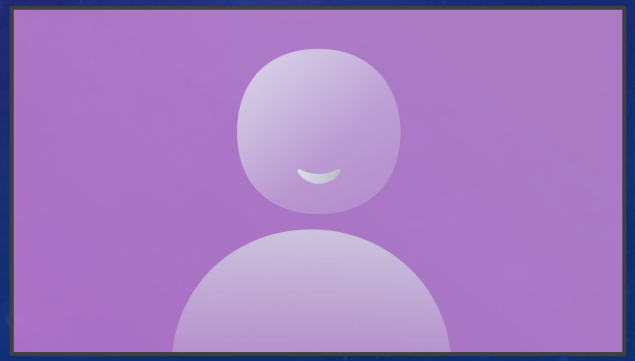
Southwest Research Institute

Enhancing Solar Imagery: Methods, Applications, and Implications for PUNCH Data

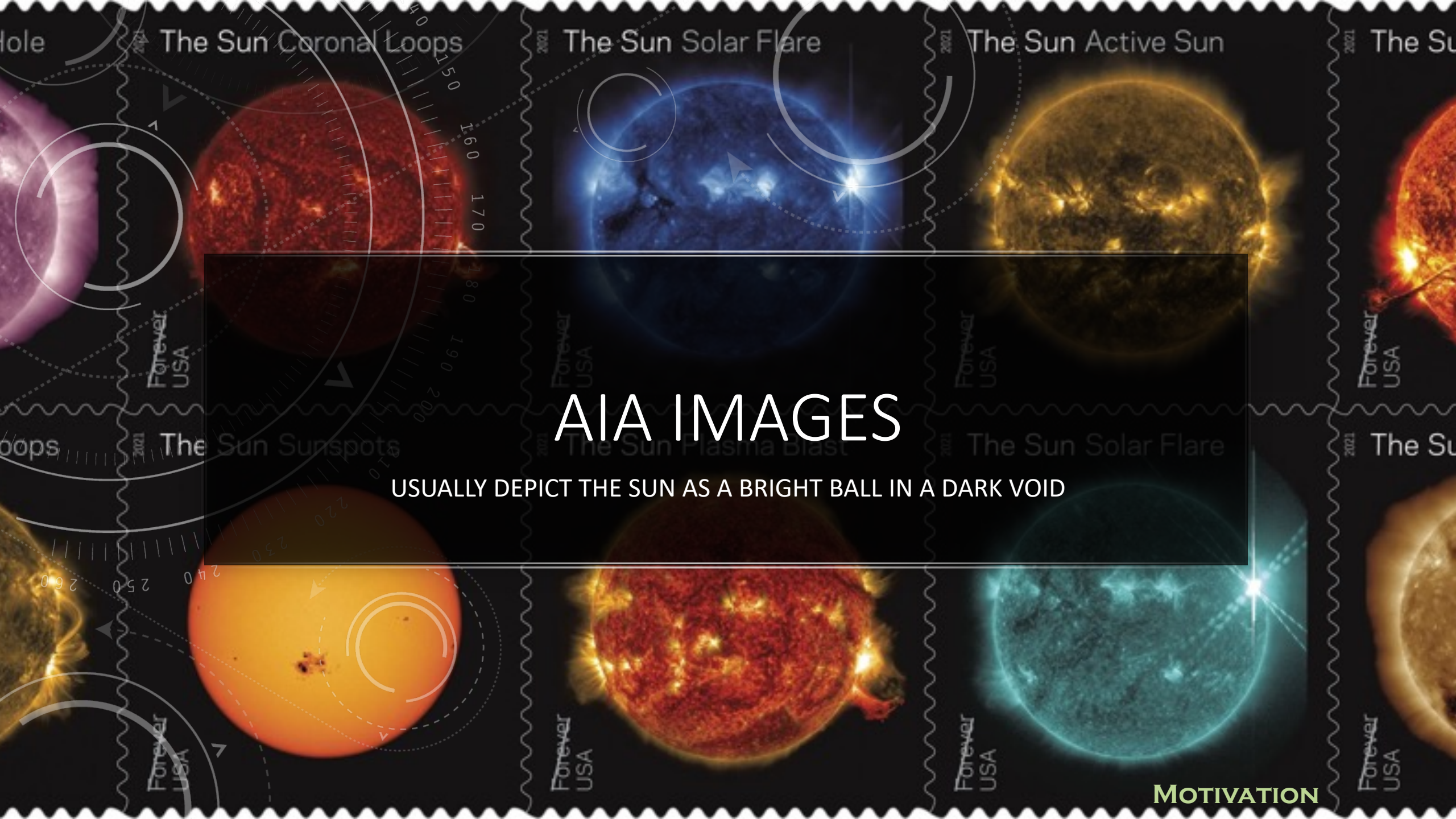
Invited Talk by Dr. Gilly

Postdoctoral Researcher, Southwest Research Institute

Thesis: "*Spectroscopic Analysis and Image Processing of the Optically-Thin Solar Corona*"



PUNCH 6, San Luis Obisco, CA, 2025

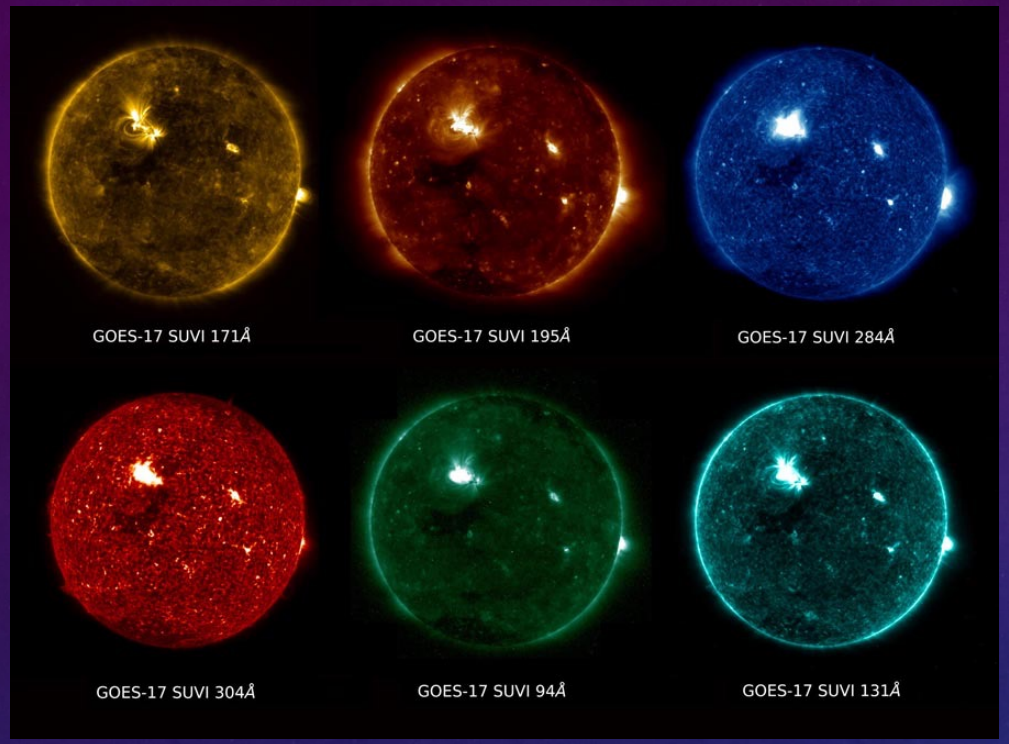


AIA IMAGES

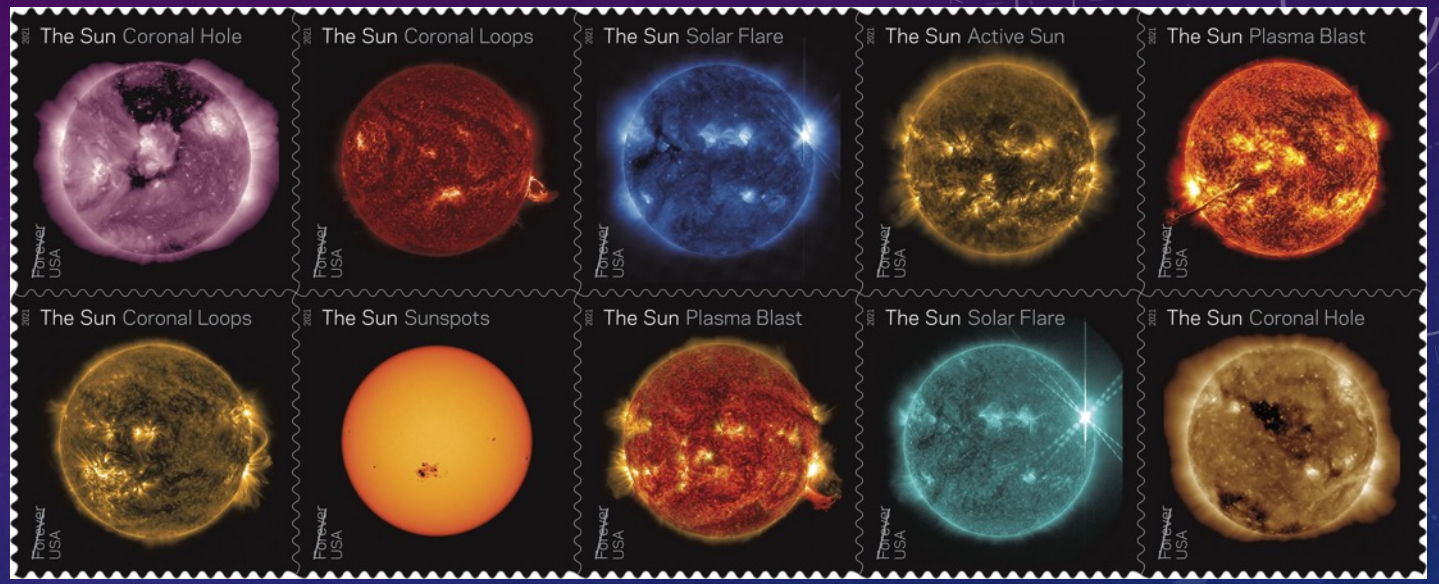
USUALLY DEPICT THE SUN AS A BRIGHT BALL IN A DARK VOID

Full Disk Imagers

GOES/SUVI



SDO/AIA

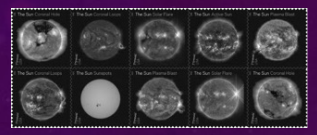


Argument:

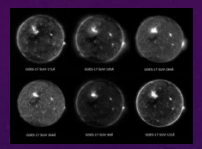
The disk is bright relative to the corona, so we can't see very **far** away from the Sun

Coronagraphs

SDO/AIA

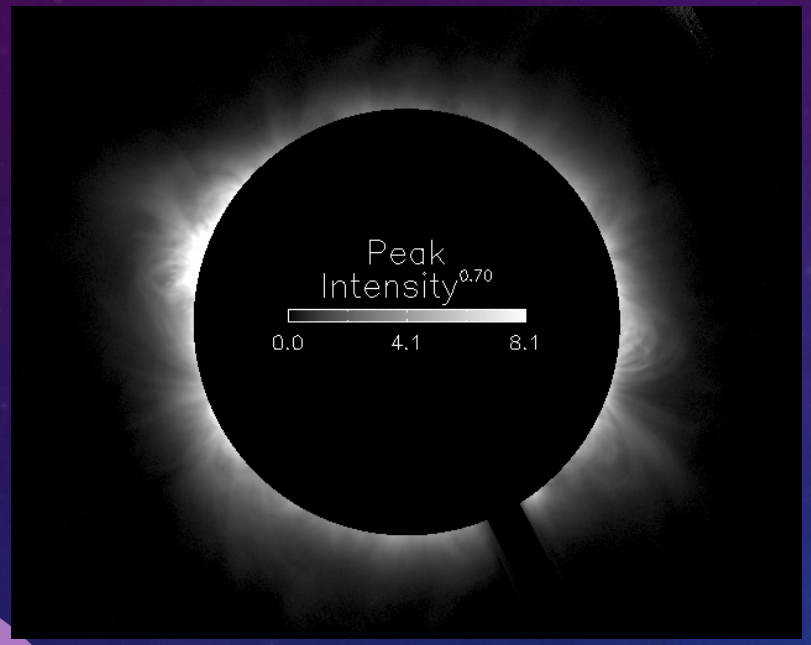


GOES/SUVI

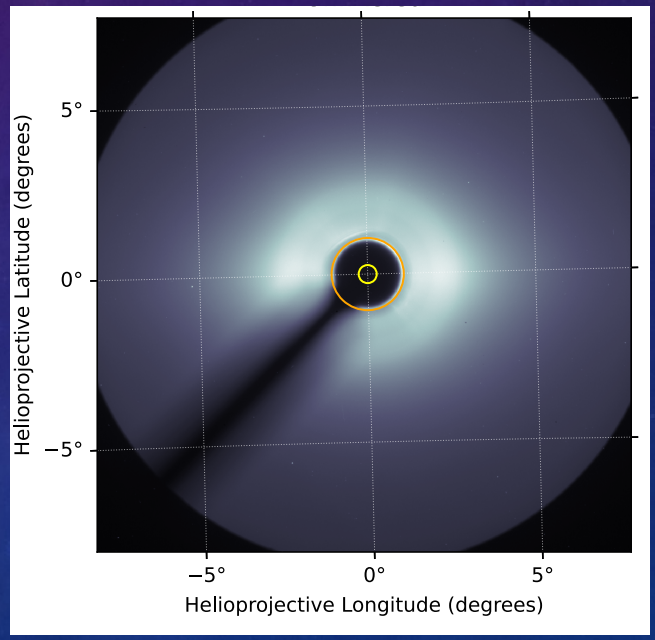


The disk is bright relative to the corona, so we can't see very **near** to the sun, either

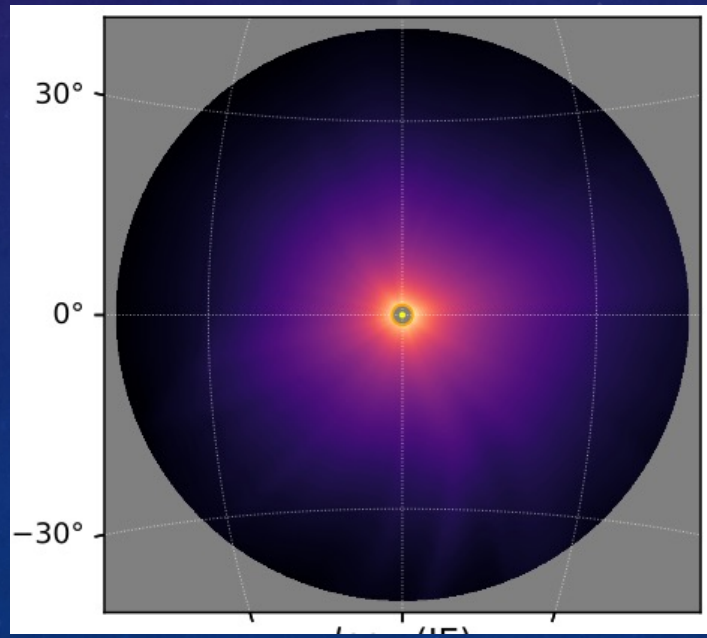
MLSO/UCoMP



SOHO/LASCO

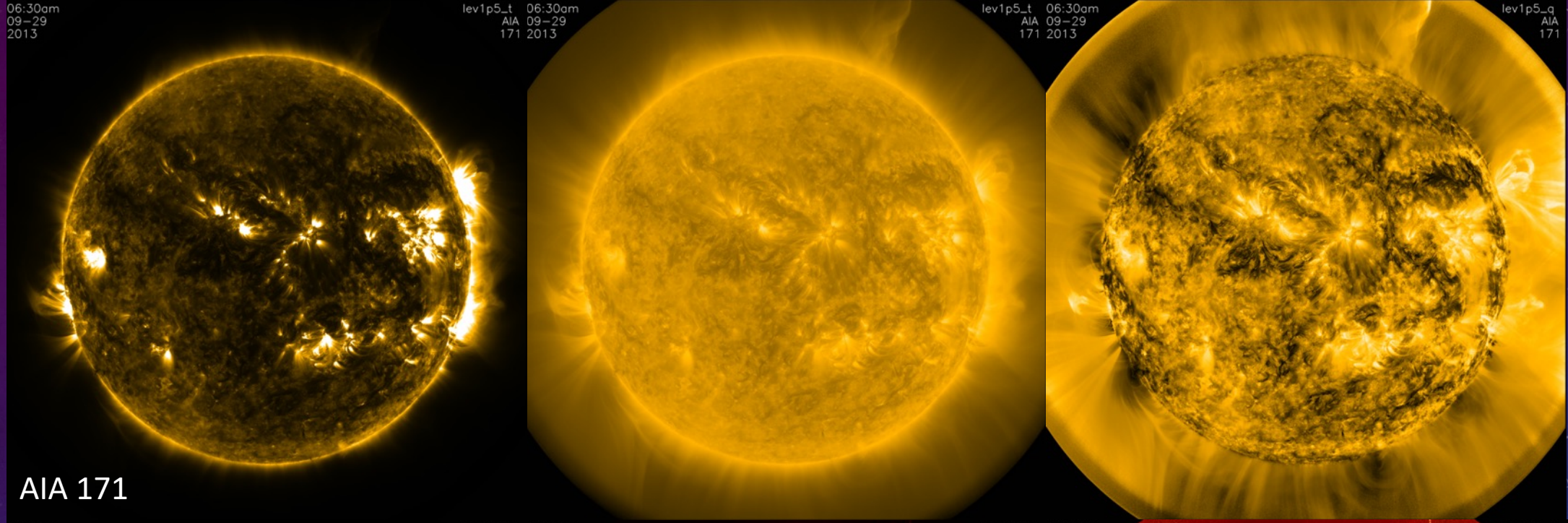


PUNCH (NFI)

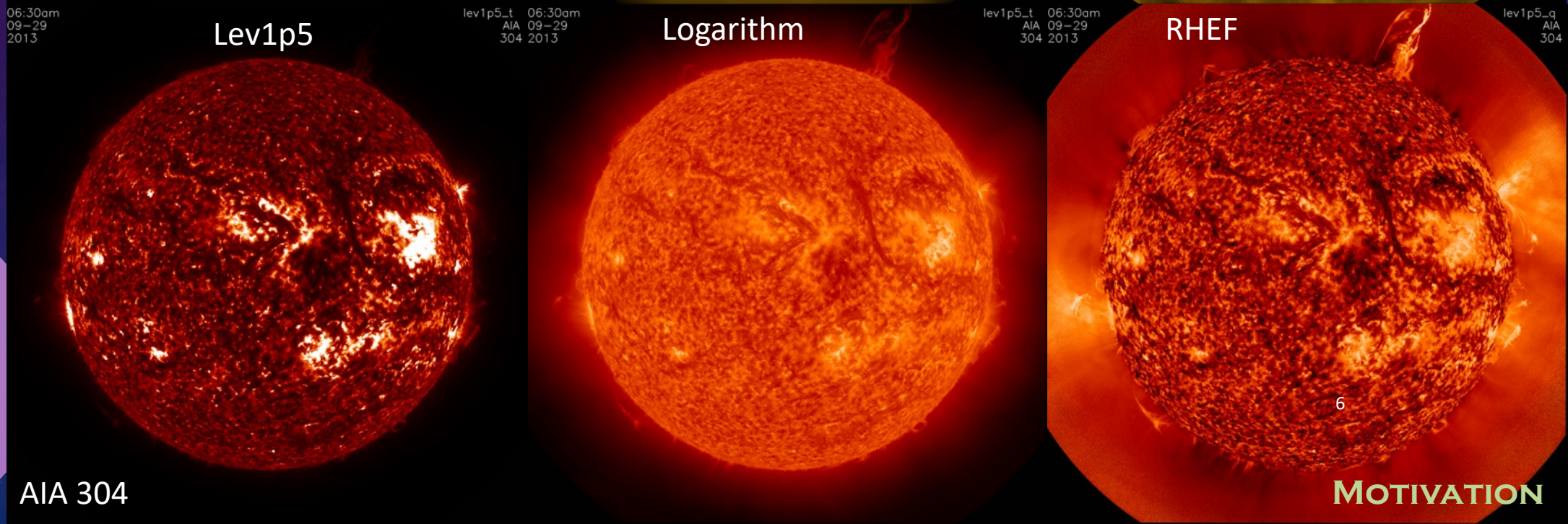


HDR Image Processing

Radial falloff in intensity is extreme



AIA 171



Lev1p5

Logarithm

RHEF

AIA 304

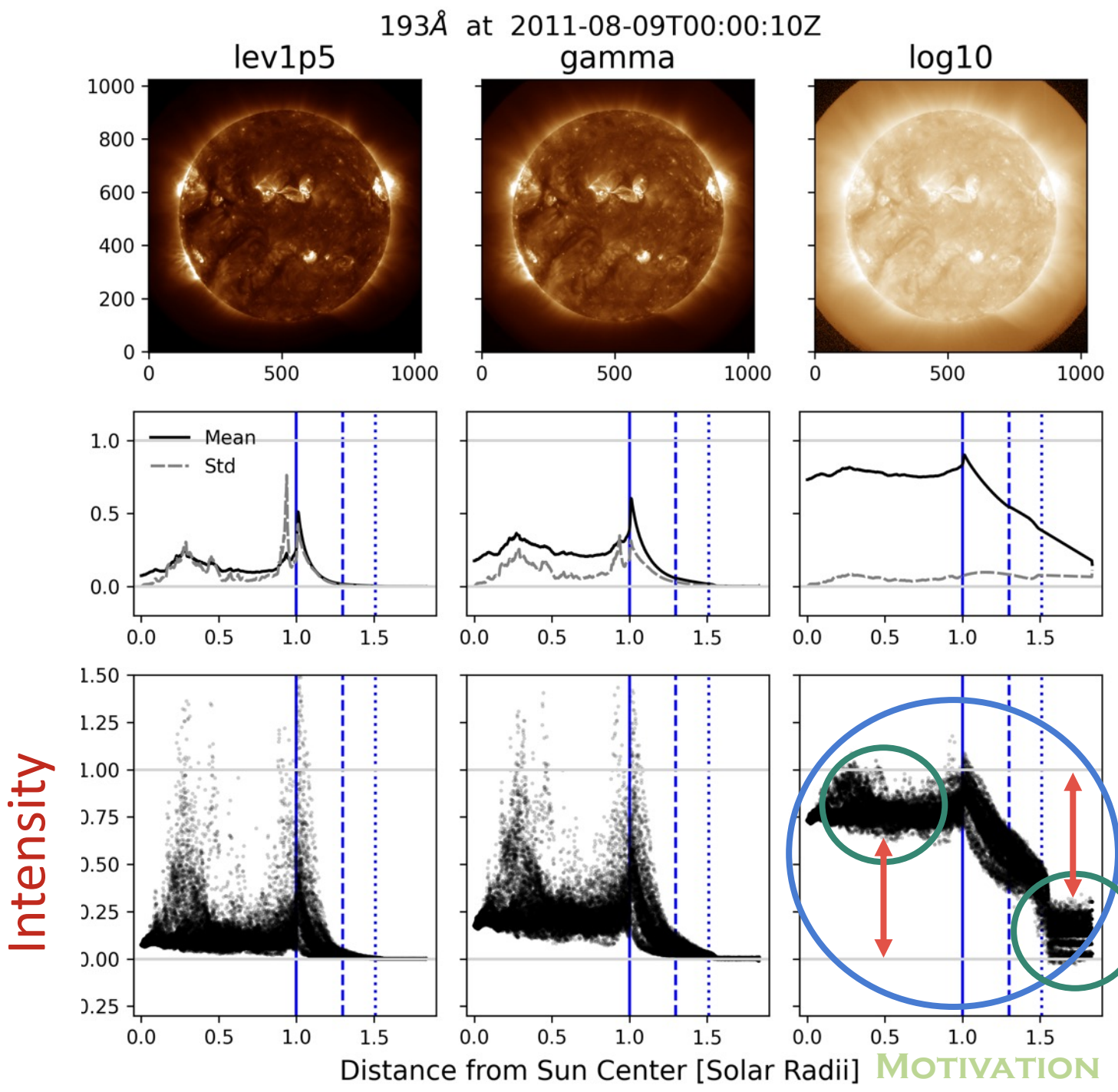
Beware! Filtering destroys photometry

- **After filtering, intensity values are no longer linear-ly related to the measured photon flux.**
  - **Don't try** to find temperatures, densities, ionization states, or **anything else that requires absolute or ratios of intensities**
- Use the images for morphological and feature tracking information information
  - Wave tracking, segmentation, flow speed analysis
  - **Public Outreach**

Looking at HDR Histograms

Challenges:

- Huge difference in total range of values, (4-5 OOM) requiring ***compression***
- Many features in the image have low dynamic range, requiring ***expansion***
- **Nowhere** in the image is the full output range being utilized



High Dynamic Range Image Processing Algorithms

Three Main Families

1. **Radial Graded Filters**

Table 1. A non-exhaustive overview of many of the available filtering methods from each family. Note that some of the filters belong to more than one family. Methods marked with a * are available in the sunpy-affiliated python package `sunkit-image`.

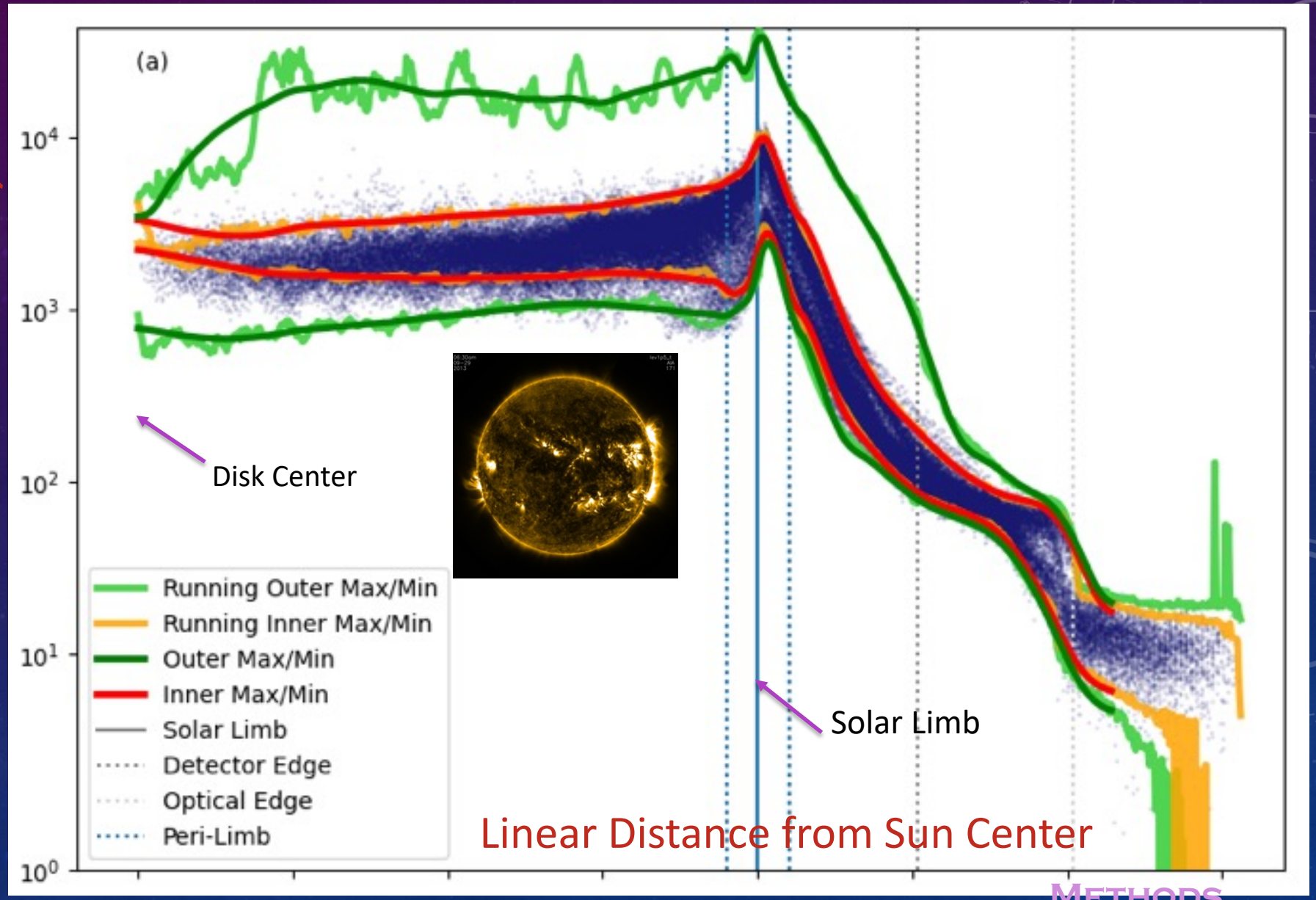
Name	Abbrev	Reference
Radial Graded Filters	RGF	-
Intensity Enhance	*IE	Barnes et al. (2020b)
Normalizing Radial Graded Filter	*NRGF	Morgan, Habbal, and Woo (2006)
Fourier Norm. Radial Graded Filter	*FNRGF	Druckmüllerová, Morgan, and Habbal (2011)
Simple Radial Gradient Filter	SIRGRAF	Patel et al. (2022)
AIA_RFILT	-	Gilly (2022)
AIA_OFFLIMB	-	Gilly (2022)
SWAP Filter	SWAP	Seaton et al. (2023)

Invented by Cranmer, Engel, Morton 2010

Quantile Radial Norm

Gilly 2022

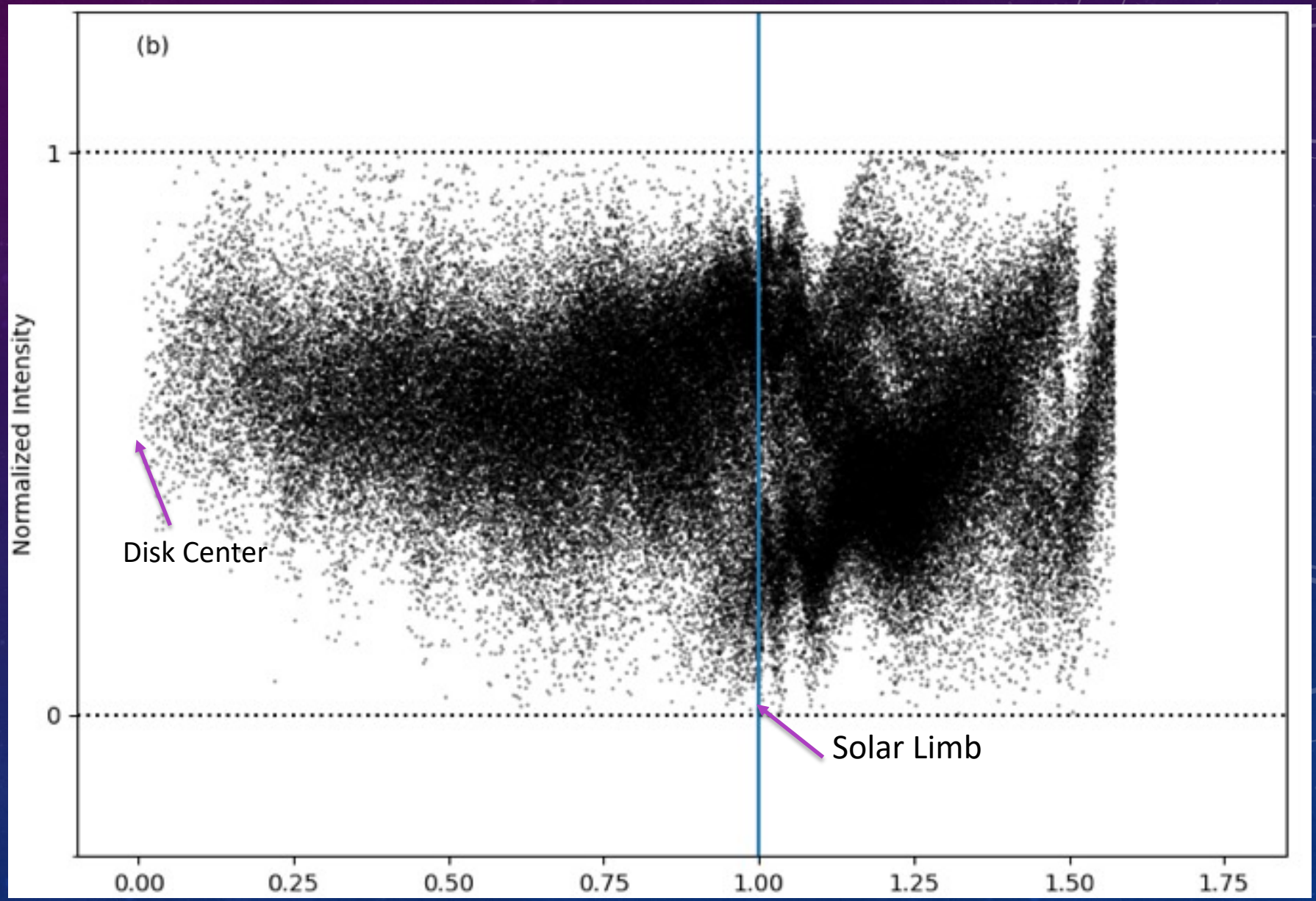
Visualizing High Dynamic Range



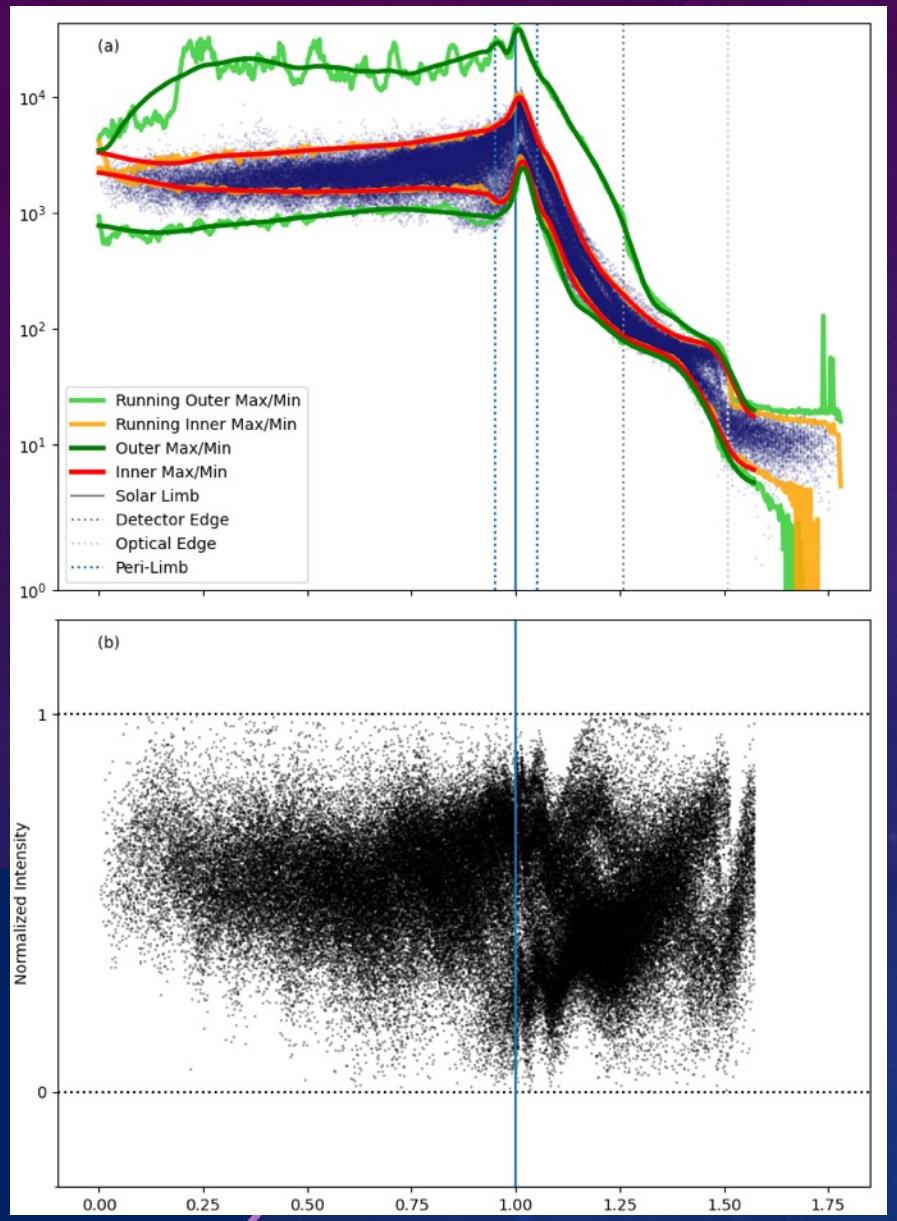
Quantile Radial Norm

Visualizing High Dynamic Range

Intensity (Normed)



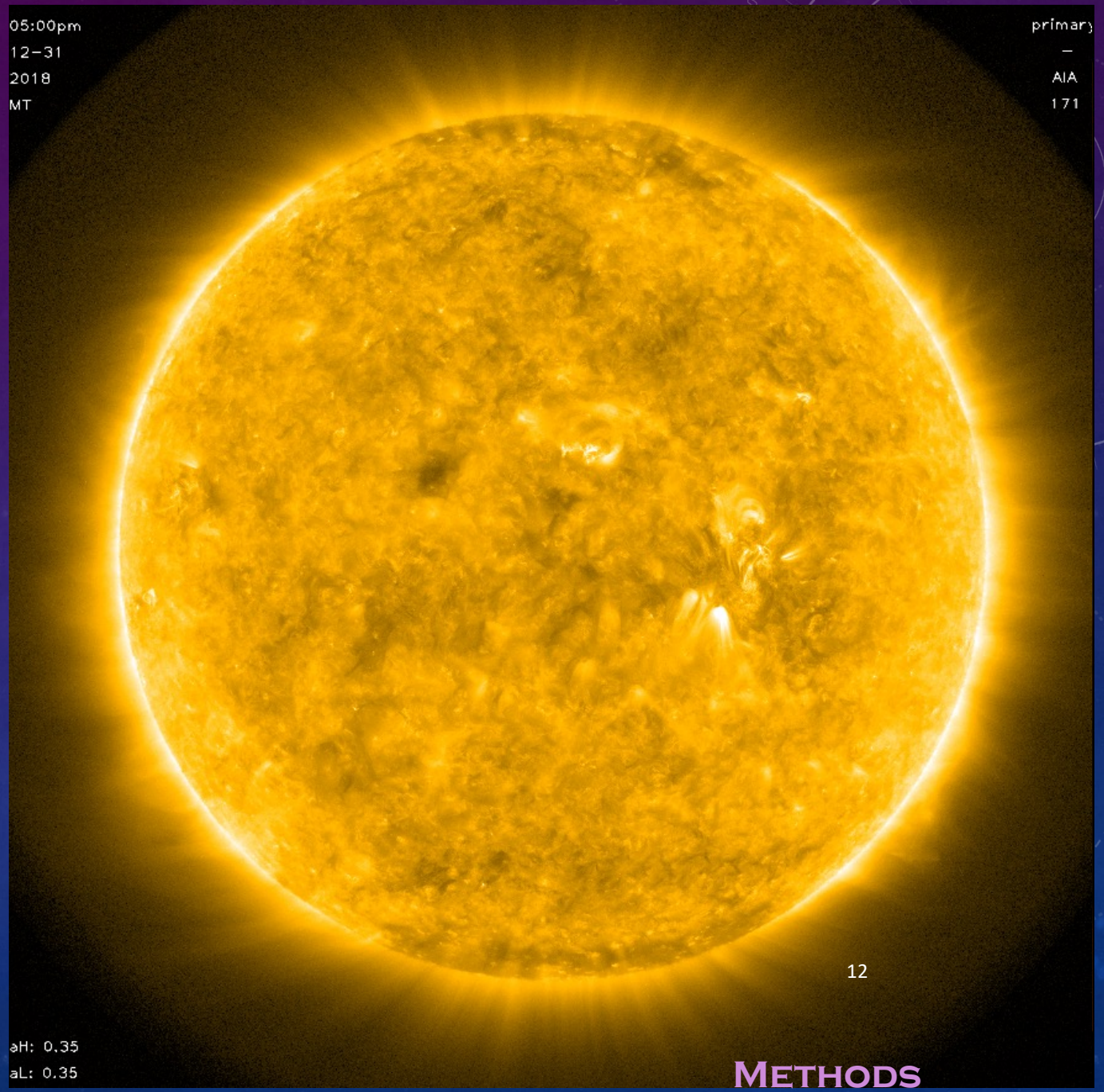
Quantile Radial Norm



Log(Absolute Intensity)

Normalized Intensity

Pixel Distance from Sun Center



Methods

High Dynamic Range Image Processing Algorithms

Three Main Families

1. Radial Graded Filters
2. **Adaptive Histogram Eq.**

Name	Abbrev	Reference
Radial Graded Filters	RGF	-
Intensity Enhance	*IE	Barnes et al. (2020b)
Normalizing Radial Graded Filter	*NRGF	Morgan, Habbal, and Woo (2006)
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AIA_OFFLIMB	-	Gilly (2022)
SWAP Filter	SWAP	Seaton et al. (2023)
Adaptive Histogram Equalization	AHE	Pizer et al. (1987)
Radial Histogram Equalization	*RHEF	**This Paper**
Adaptive Circular HP Filter	ACHF	Druckmüller, Rušin, and Minarovjech (2006)
Noise Adaptive Fuzzy Equalization	NAFE	Druckmüller (2013)
NAFE (Variable Neighborhood)	NAFEVN	Druckmüller, Habbal, and Morgan (2014)
Contrast-Limited Adaptive HE	CLAHE	Zuiderveld (1994); Pisano et al. (1998)

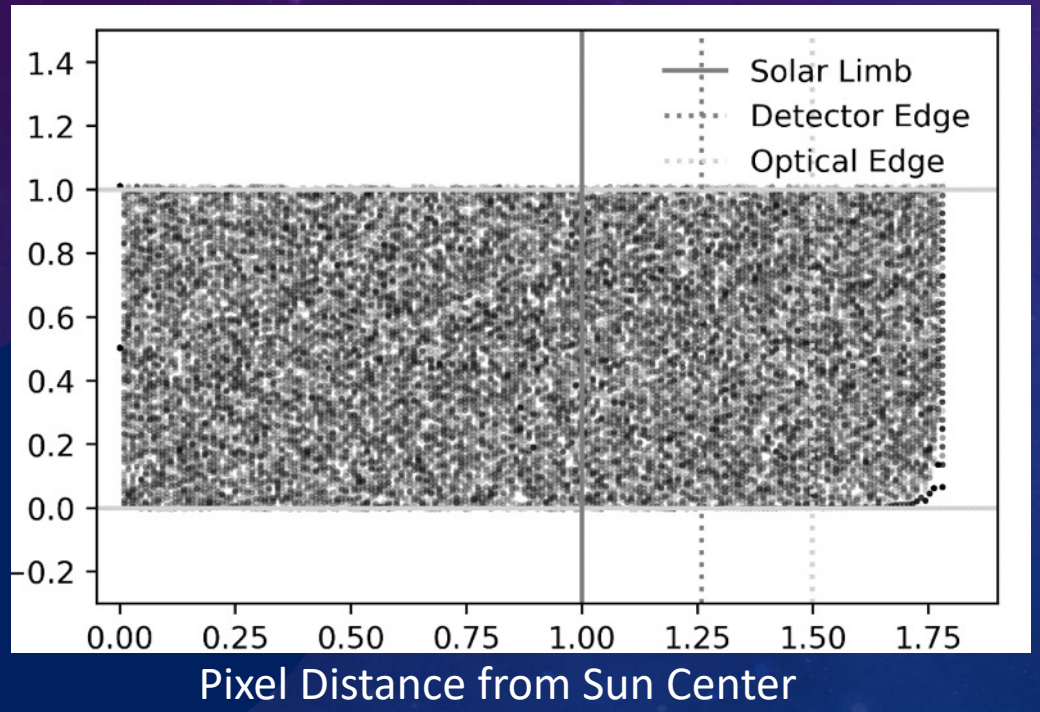
Invented by Cranmer, Engel, Morton 2010

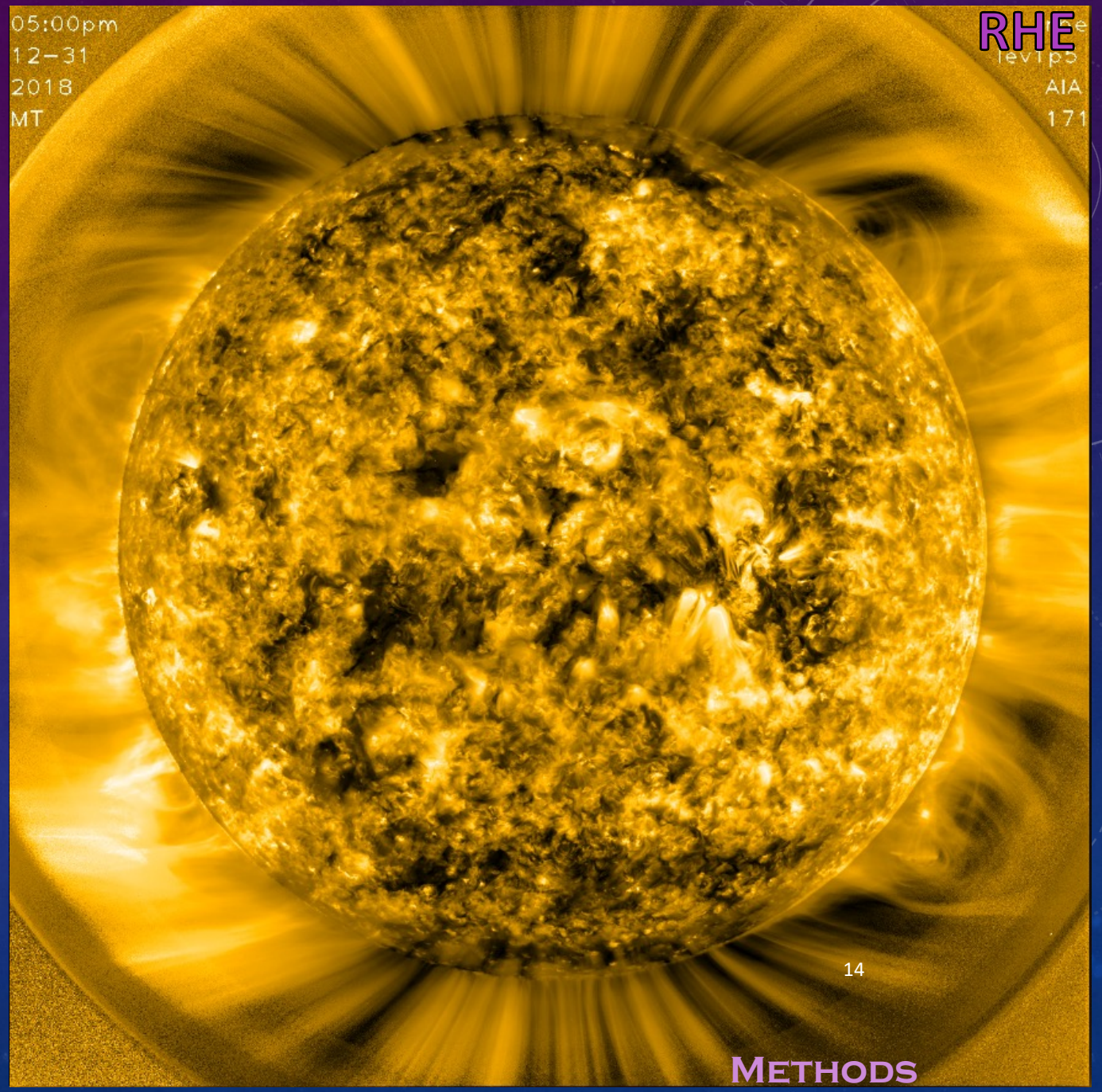
Gilly 2025, in Prep

Radial Histogram Equalization (RHE)

RHE Algorithm

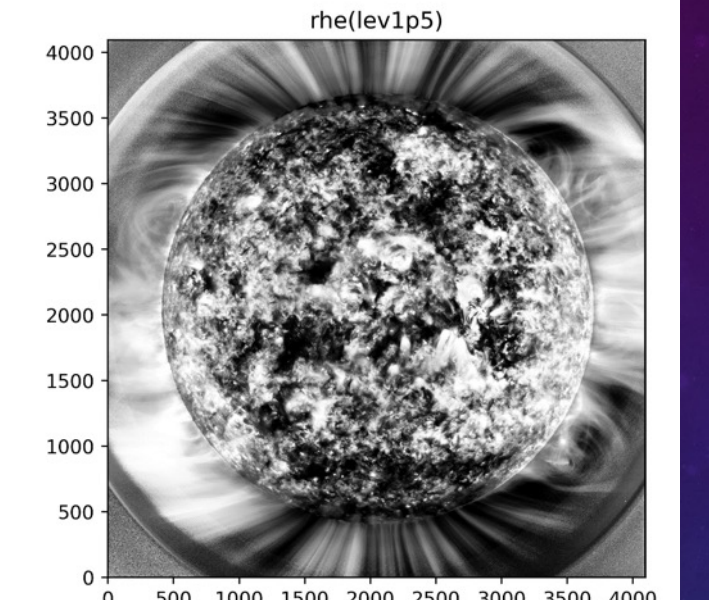
- Sort the pixels by radius
  - Sort the pixels by intensity
  - **Rank them by index**
  - Normalize between 0-1

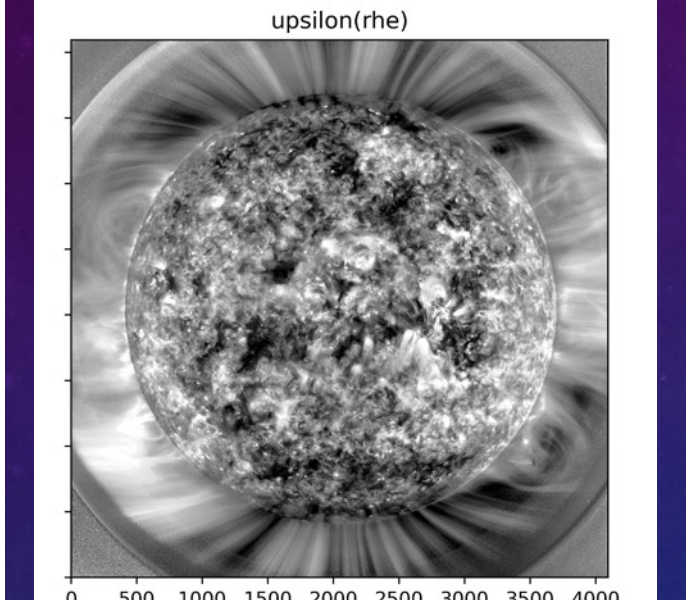


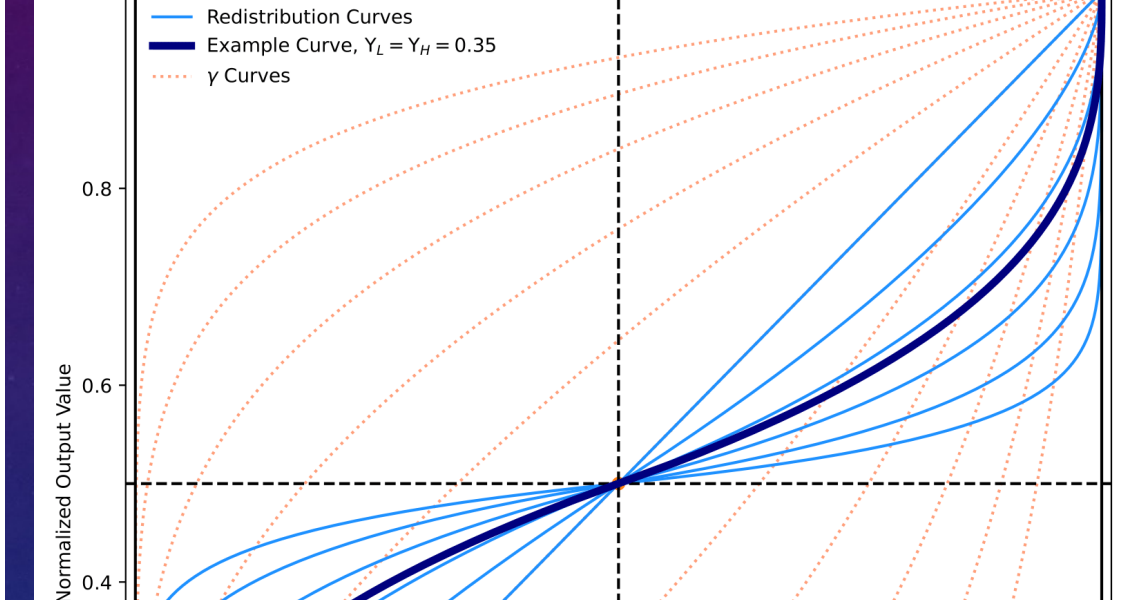


Upsilon Redistribution

Similar to “Curves” or “Levels” in Photoshop
Like ‘Gamma correction’ symmetric about 0.5







High Dynamic Range Image Processing Algorithms

Three Main Families

1. Radial Graded Filters
2. Adaptive Histogram Eq.
3. **Multiscale Methods**

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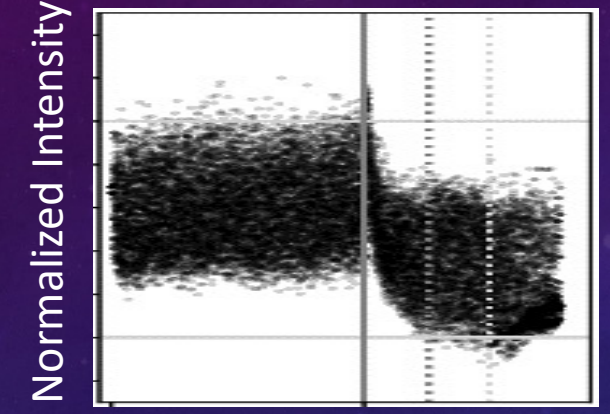
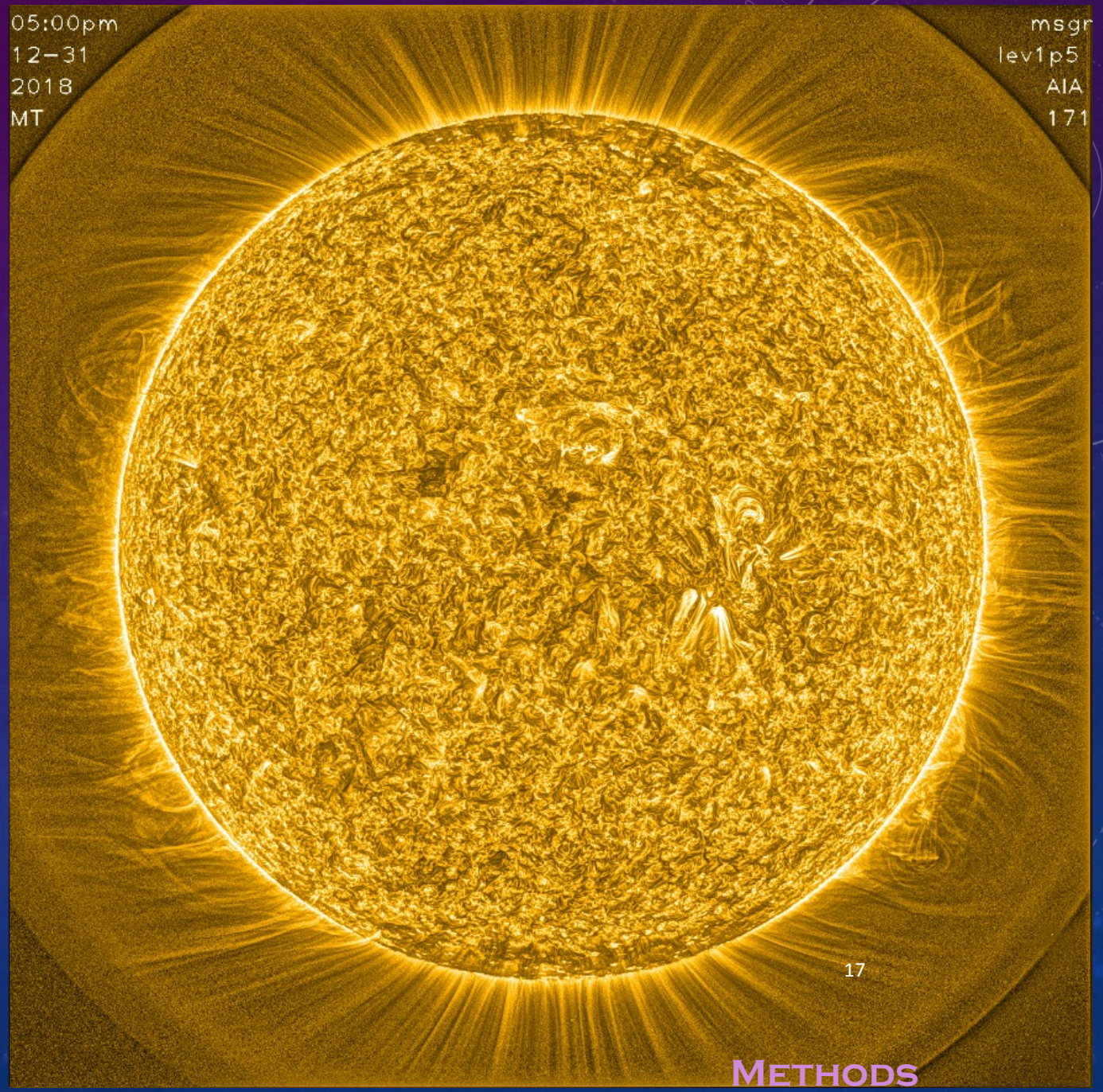
NAFE (Variable Neighborhood)	NAFEVN	Druckmüller, Habbal, and Morgan (2014)
Contrast-Limited Adaptive HE	CLAHE	Zuiderveld (1994); Pisano et al. (1998)
Multiscale Methods	MSM	-
Multi-Scale Gaussian Norm	*MGN	Morgan and Druckmüller (2014)
Radial Local Multiscale Filter	RLMF	Qiang et al. (2020)
Wavelet Transform	WT	(Stenborg and Cobelli (2003) Stenborg, Vourlidas, and Howard (2008))
Wavelet Optimized Whitening	*WOW	Auchère et al. (2023)

Invented by Cranmer, Engel, Morton 2010

Multiscale Gaussian Normalization (MSGN)

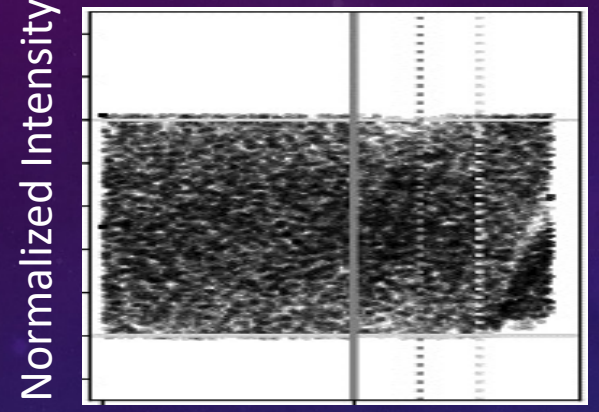


MSGN

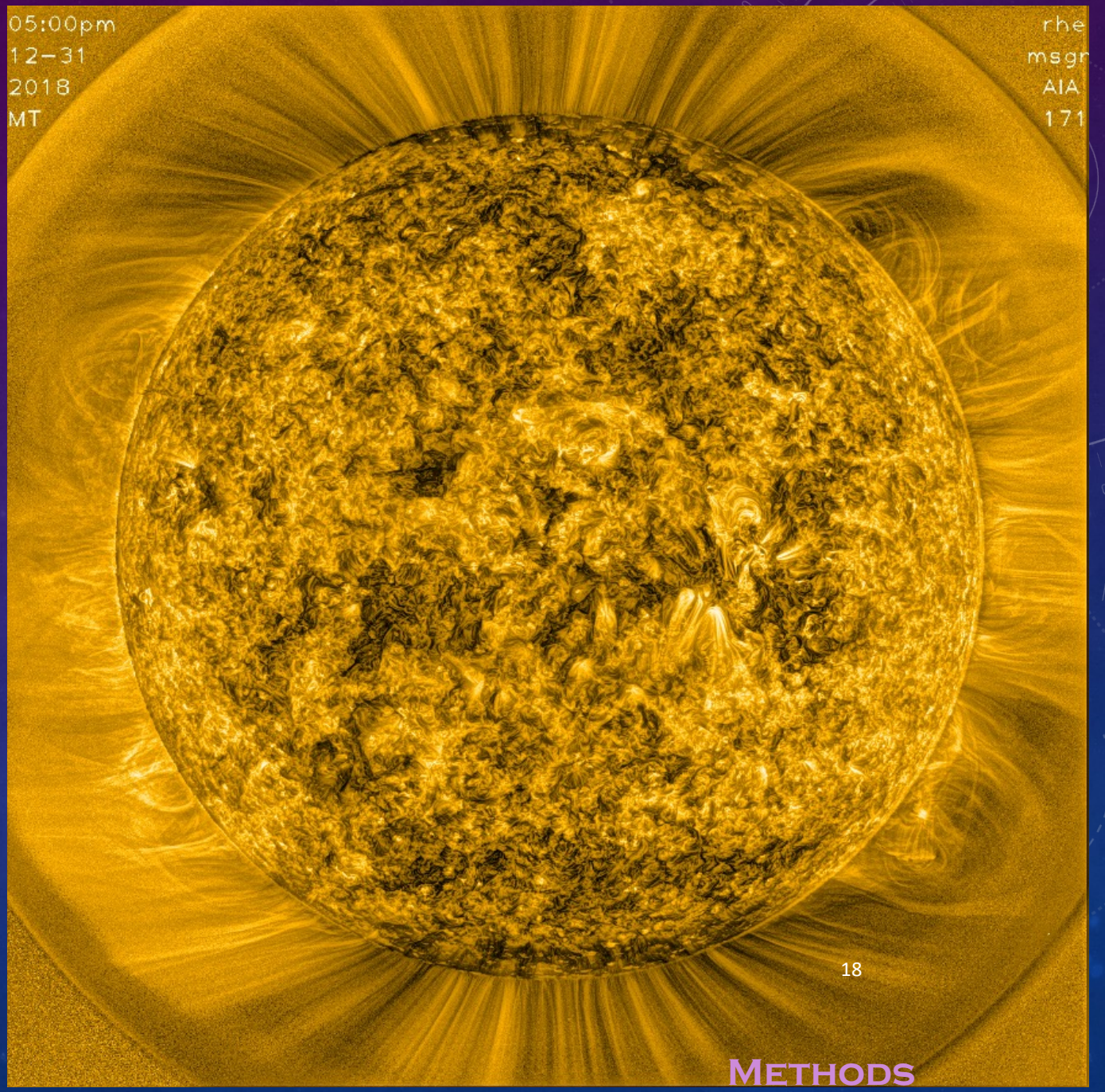


Combining Methods

Average of MSGN & RHE



(RHE(MSGN) + RHE) / 2



Gilly 2025, in Prep

High Dynamic Range Image Processing Algorithms

Three Main Families

1. Radial Graded Filters
2. Adaptive Histogram Eq.
3. Multiscale Methods

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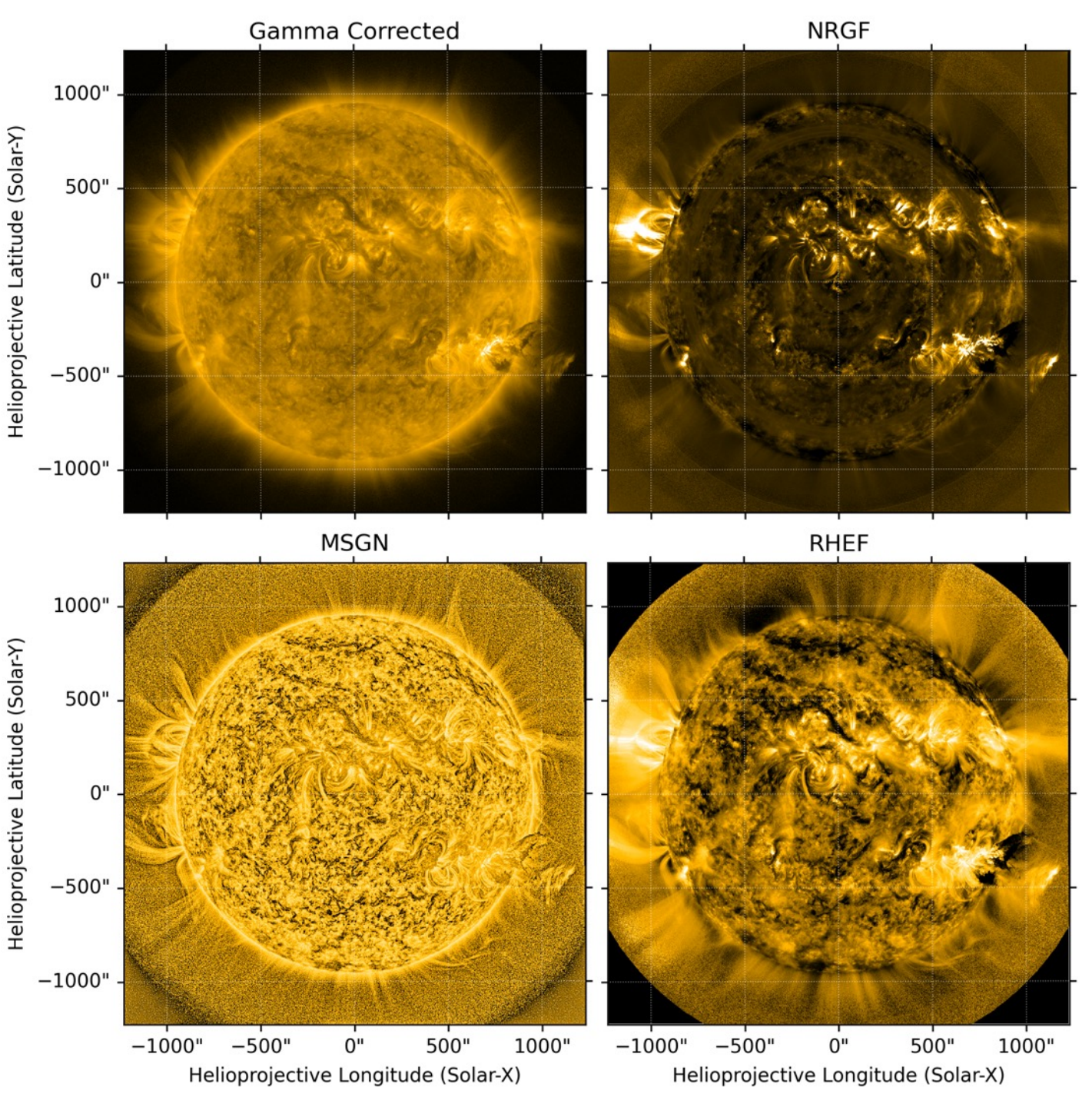
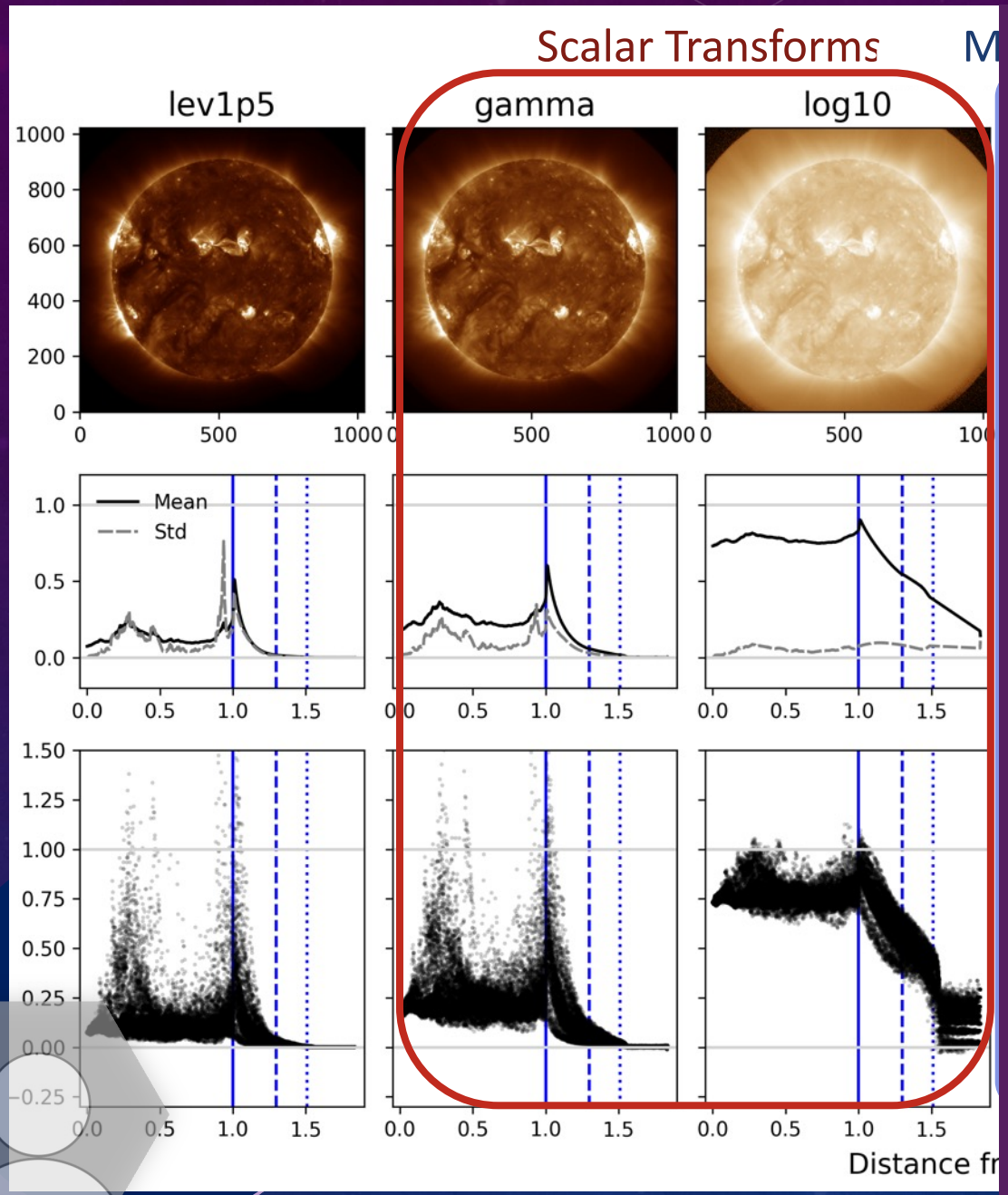
Invented by Cranmer, Engel, Morton 2010


Gamma Corrected
NRGF
MSGN
RHEF
Helioprojective Latitude (Solar-Y)
Helioprojective Longitude (Solar-X)
1000"
500"
0"
−500"
−1000"

Histogram Comparisons

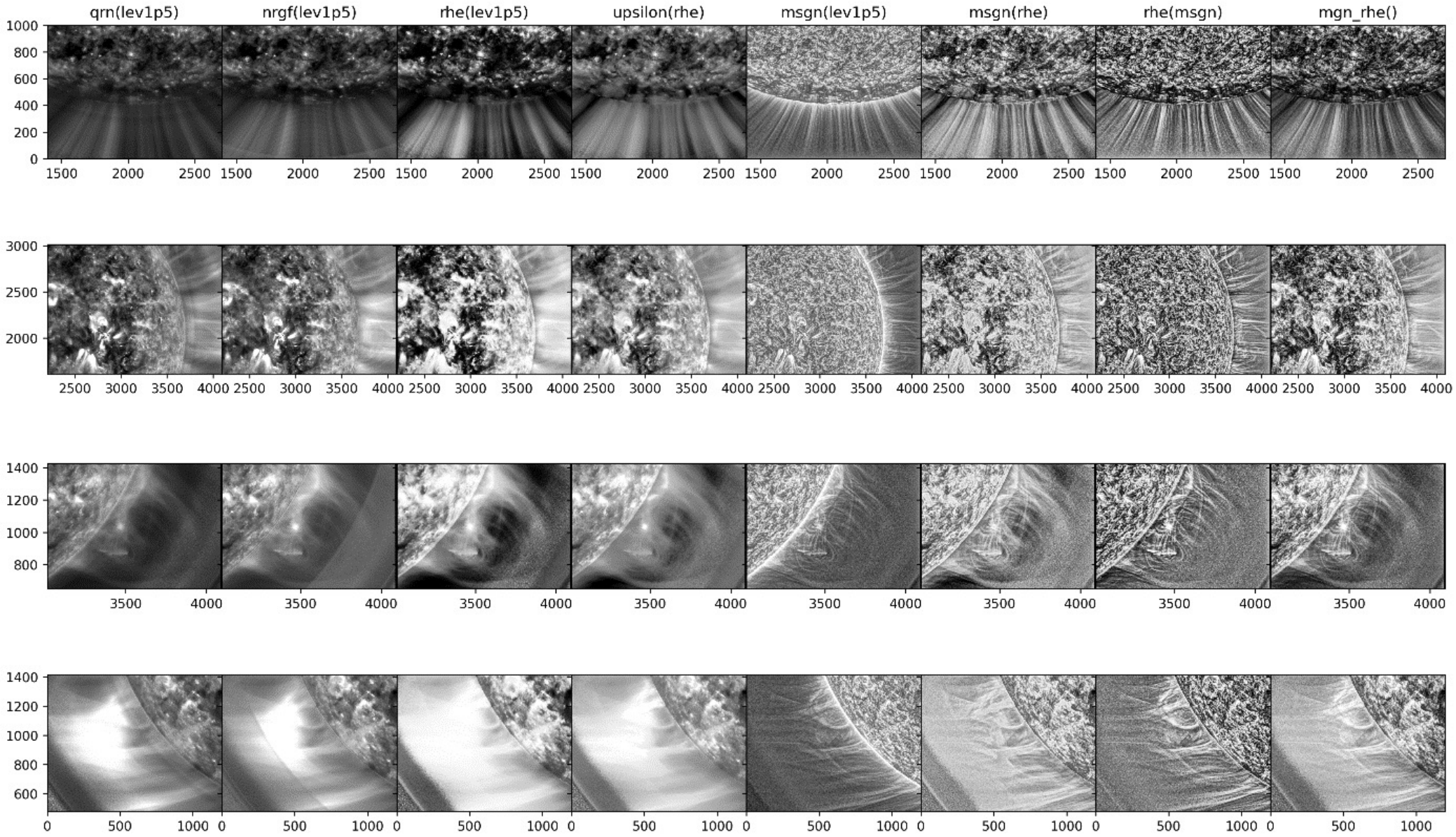


USING THE DATA

Gilly 2022

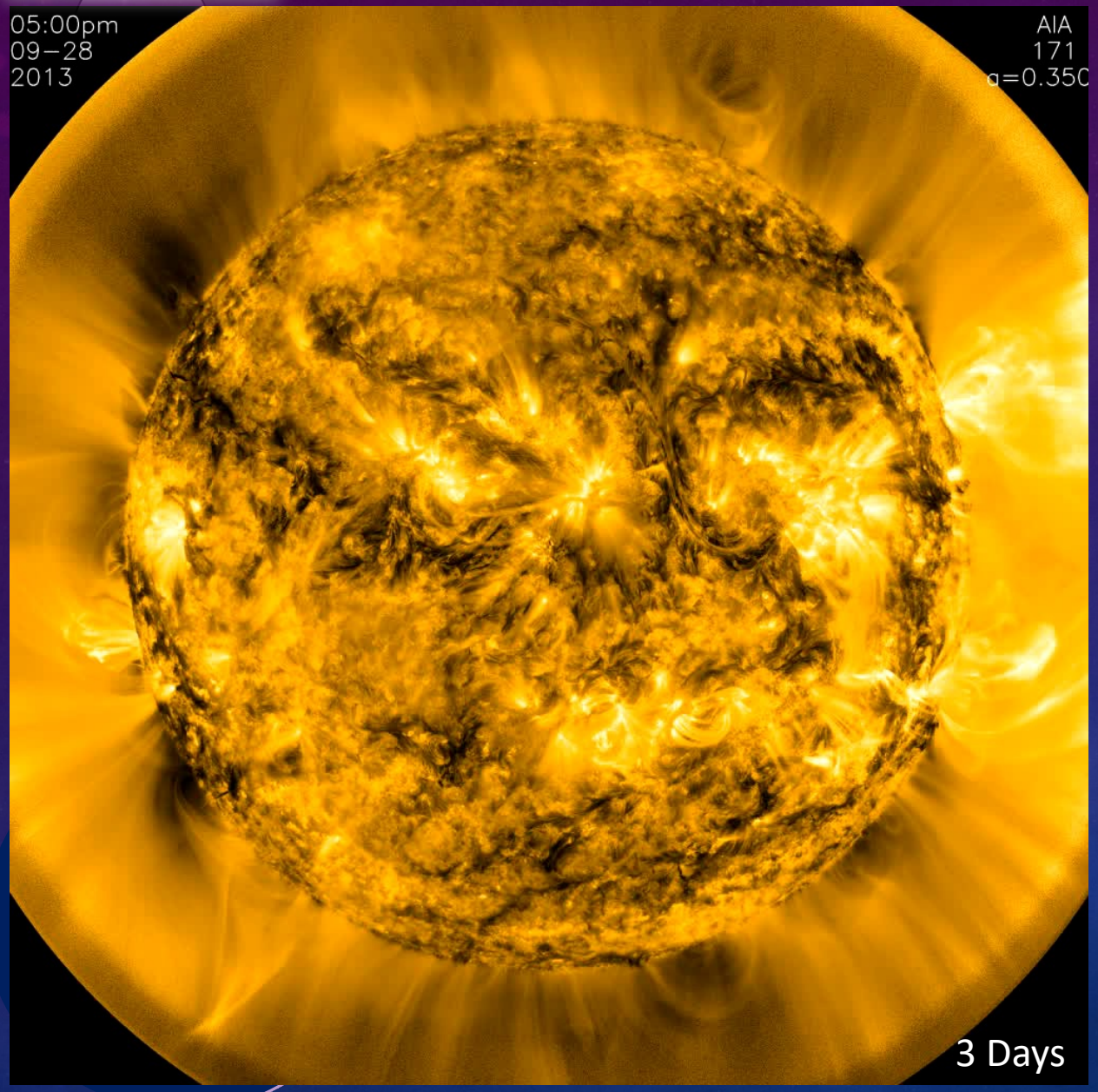
No best method, it just depends what you want to look at.

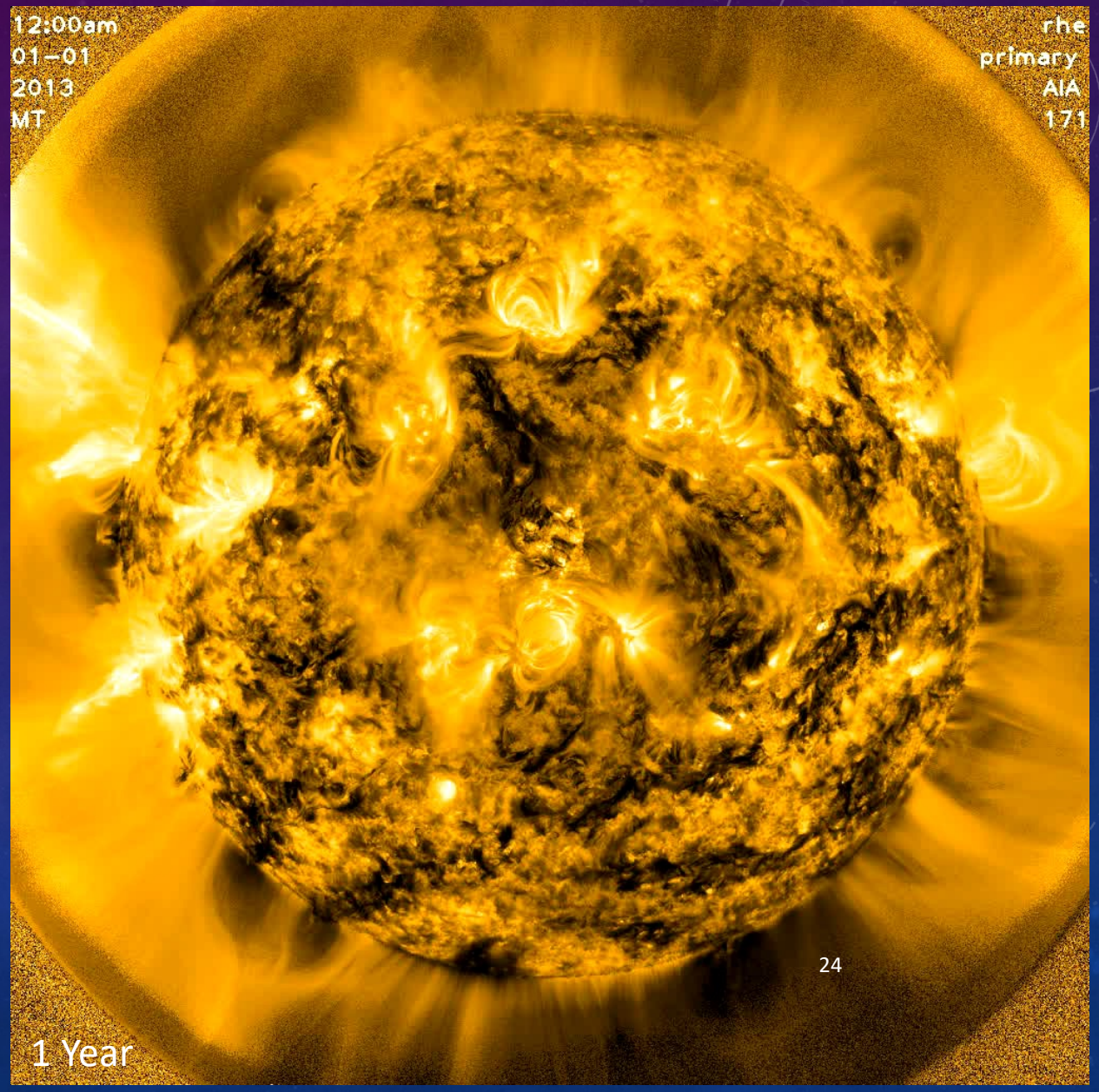
RGFs | Histogram Eq. | Multiscale Methods



Observing the Many Timescales of the Sun

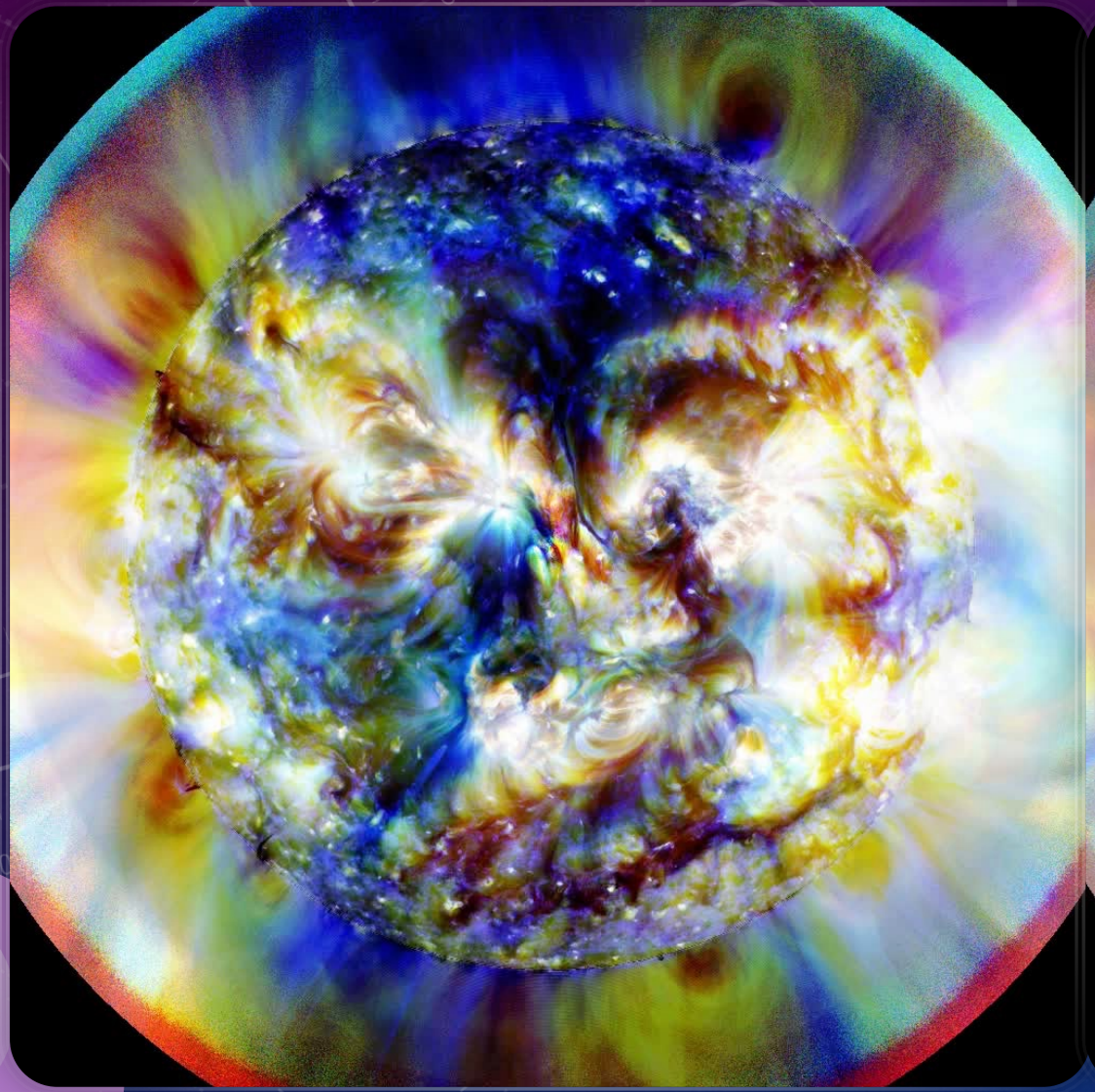
RHEF



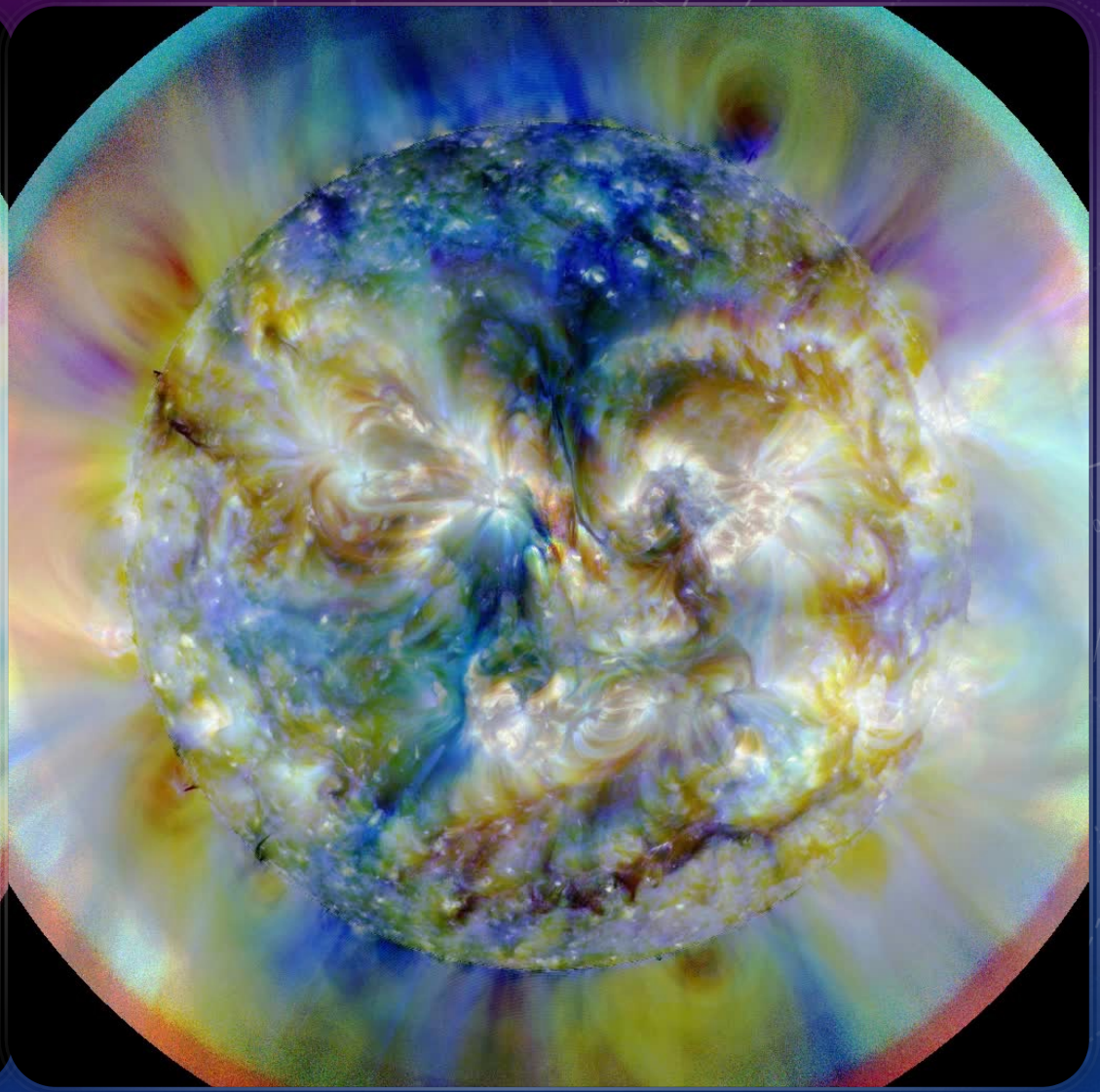


Composite videos processed with RHE

BGR = 0171_0193_0211



without Upsilon



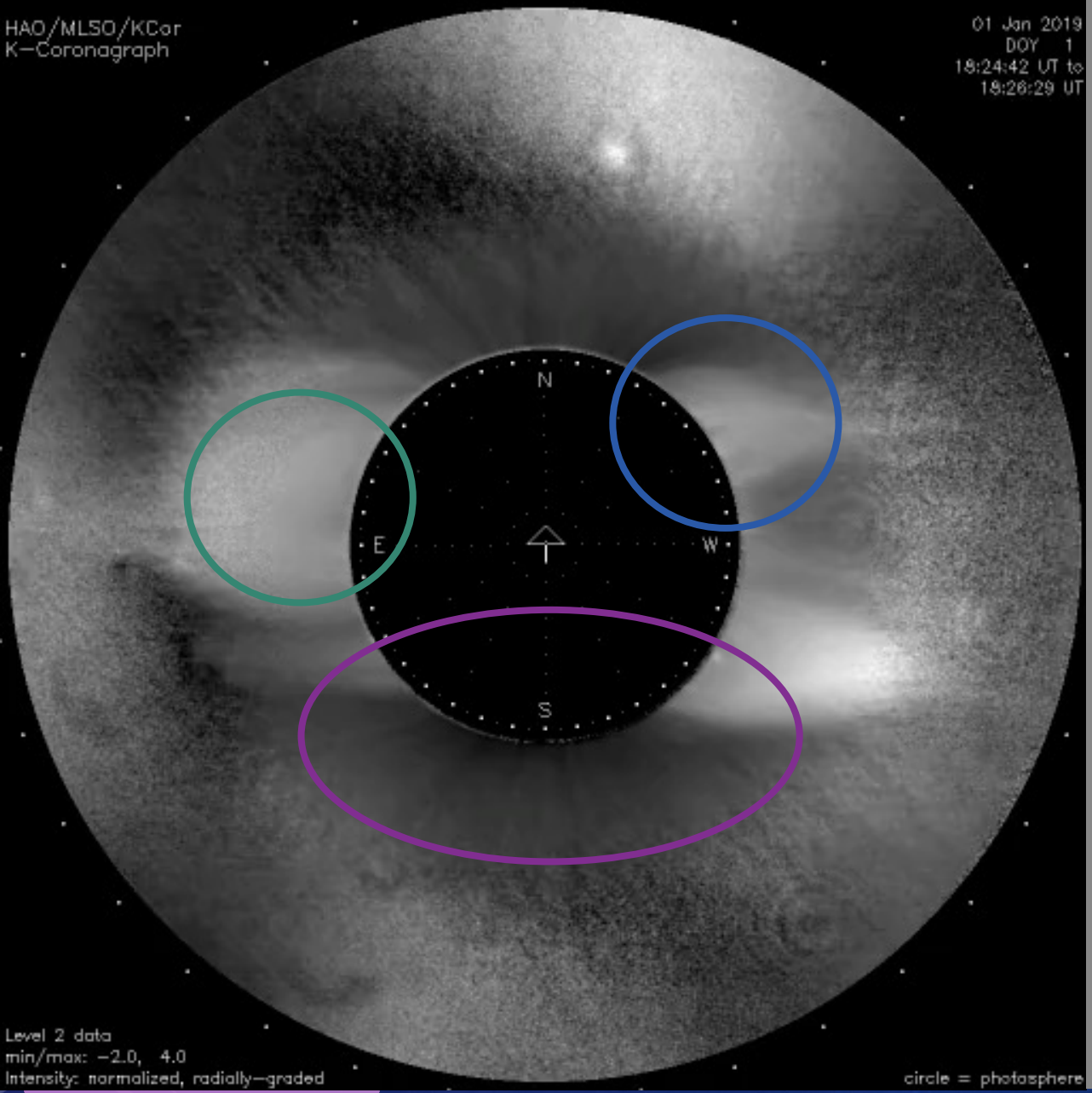
with Upsilon

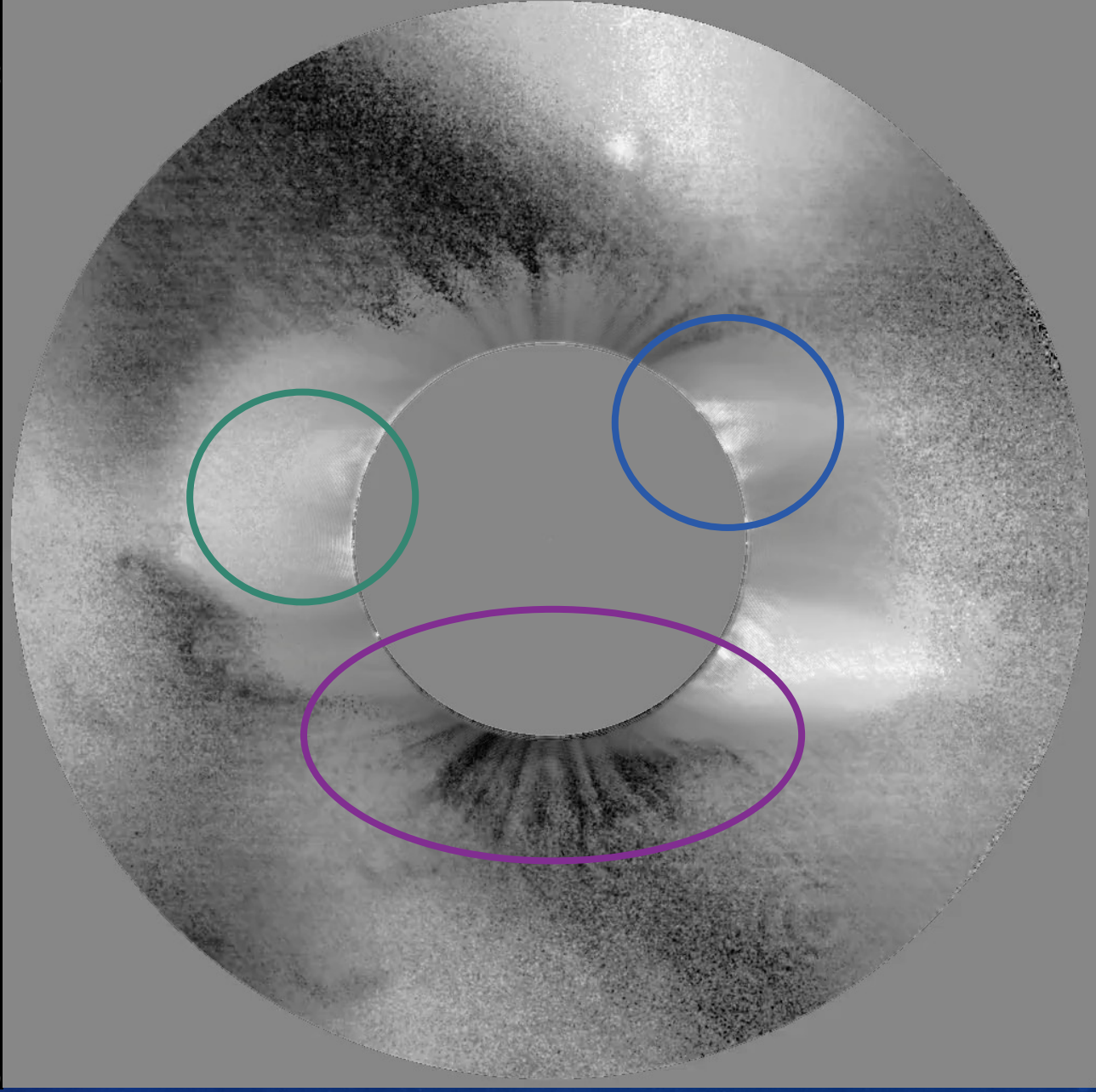
Coronagraphs

NRGF – 10 minute averages

RHEF – 2 minute averages

https://mlso.hao.ucar.edu/mlso_data_summary.php?date=2022-11-25&inst=kcor

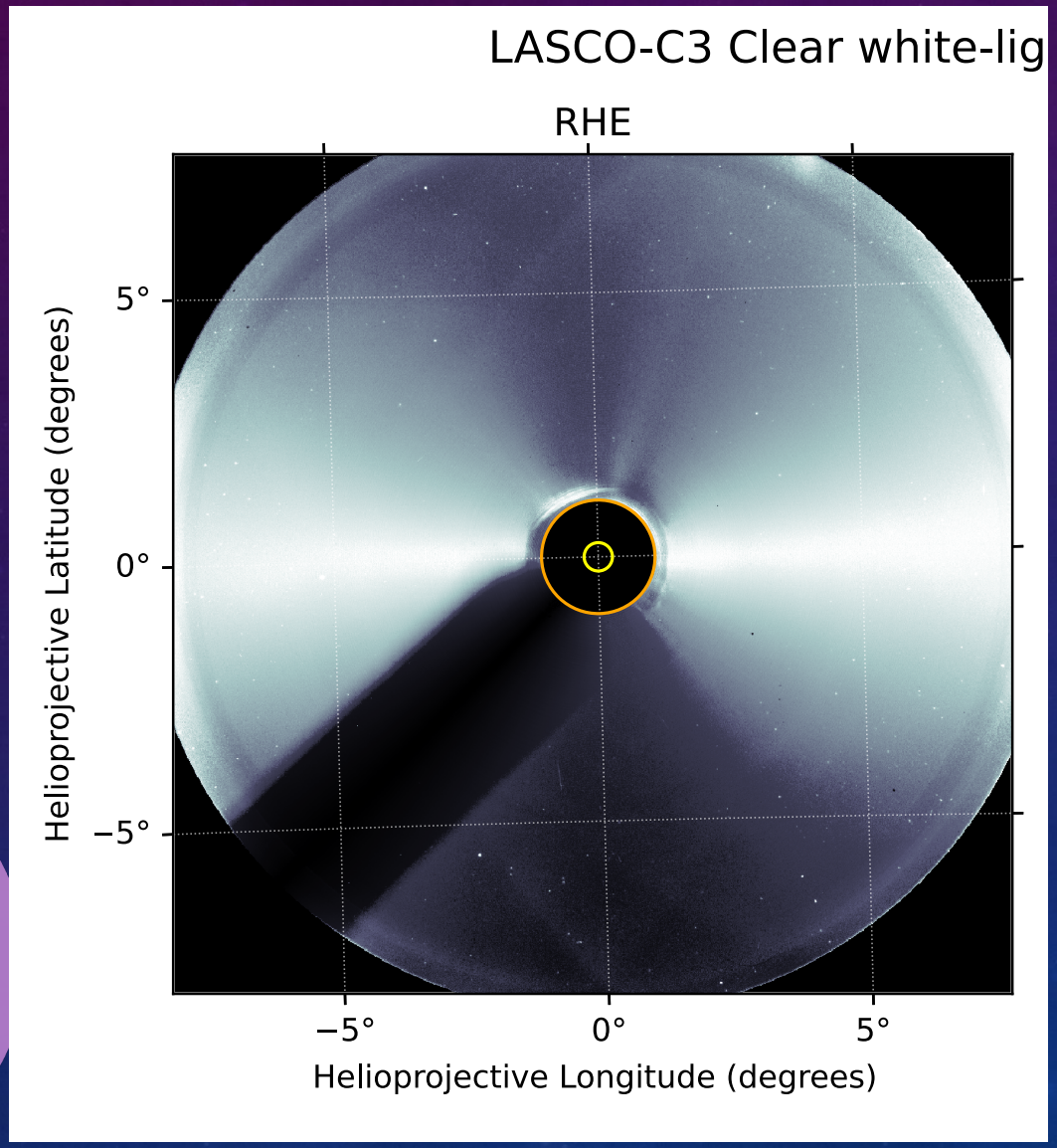


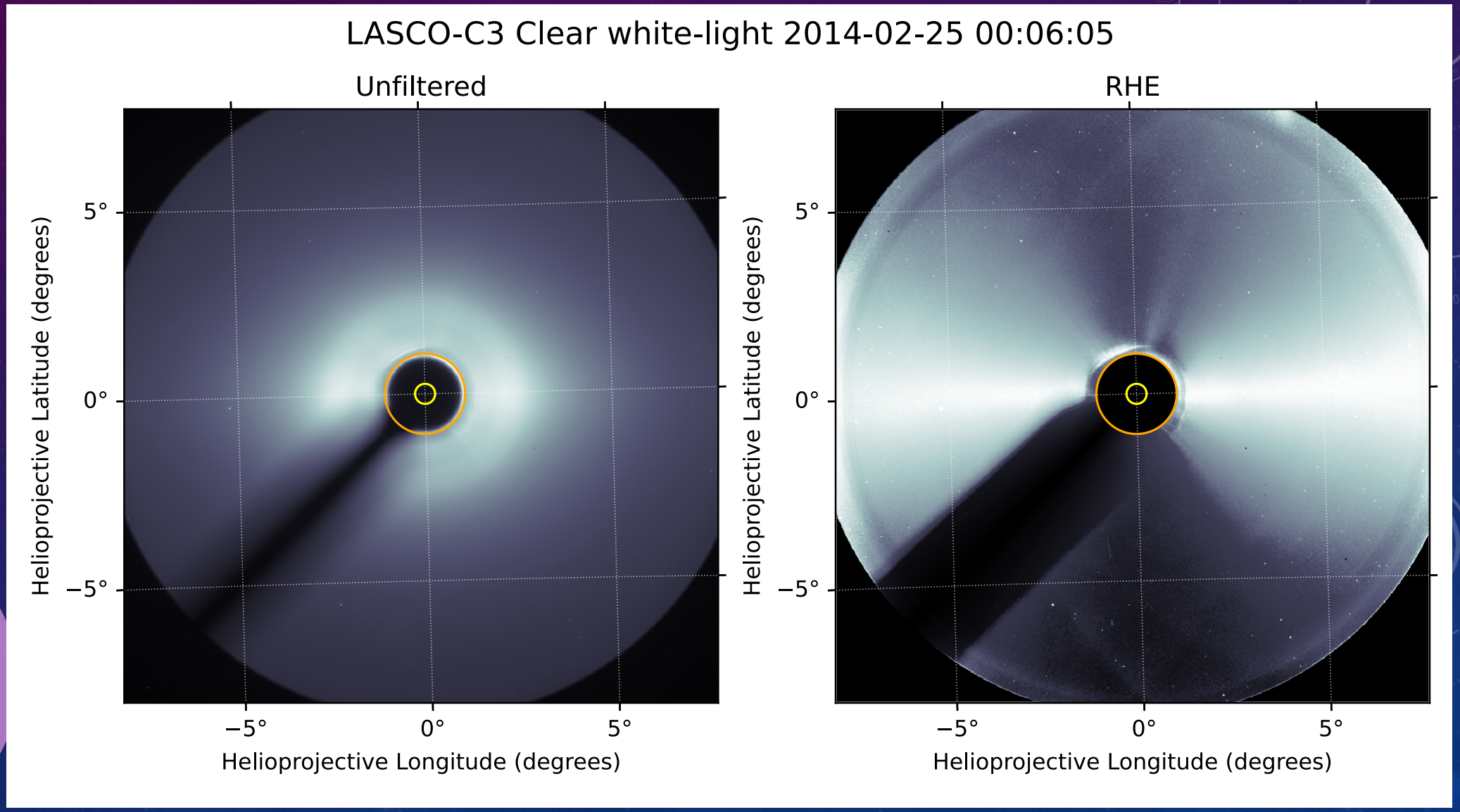


NRGF – 10 minute averages

RHEF – 2 minute averages

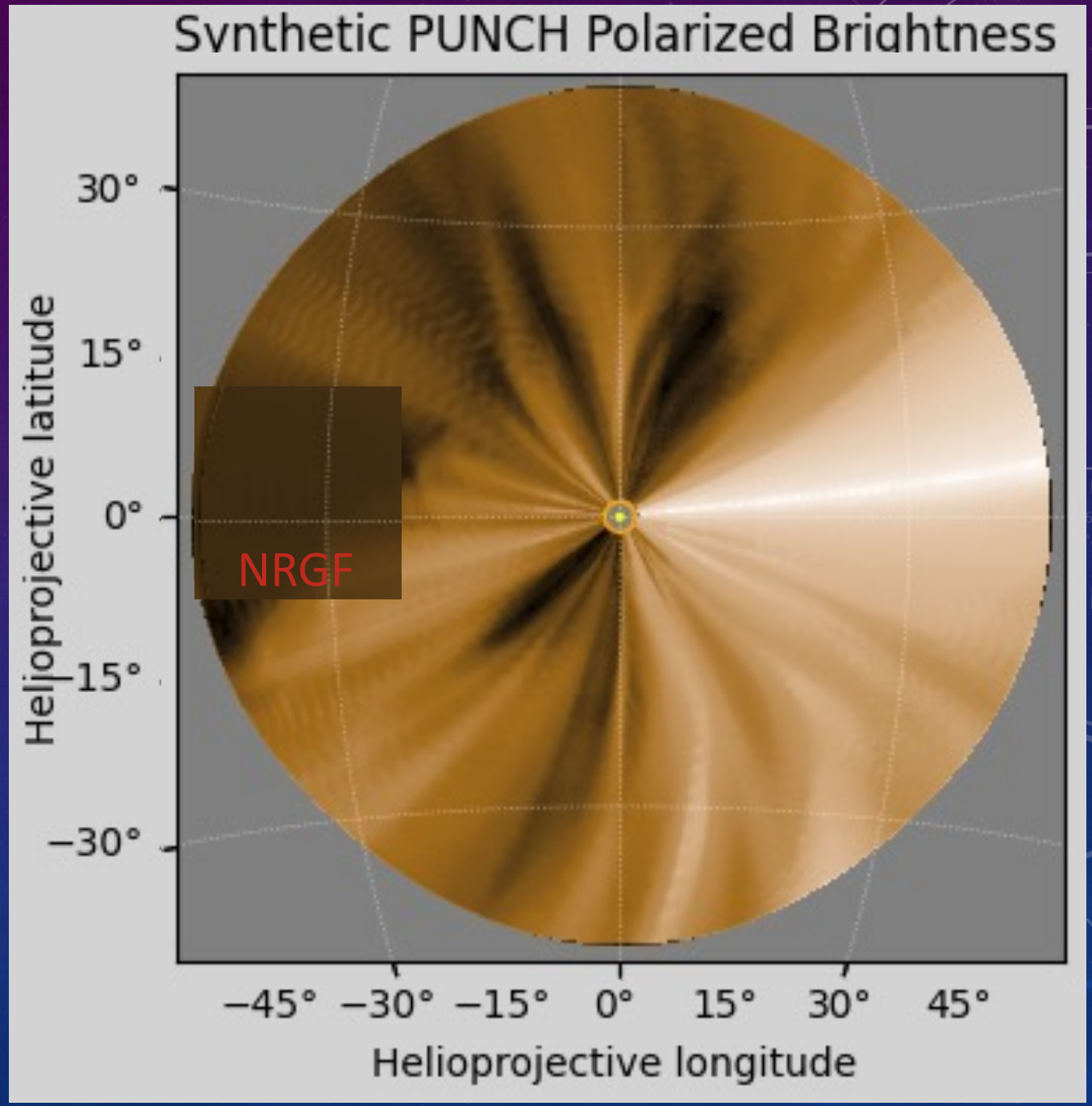
https://mlso.hao.ucar.edu/mlso_data_summary.php?date=2022-11-25&inst=kcor

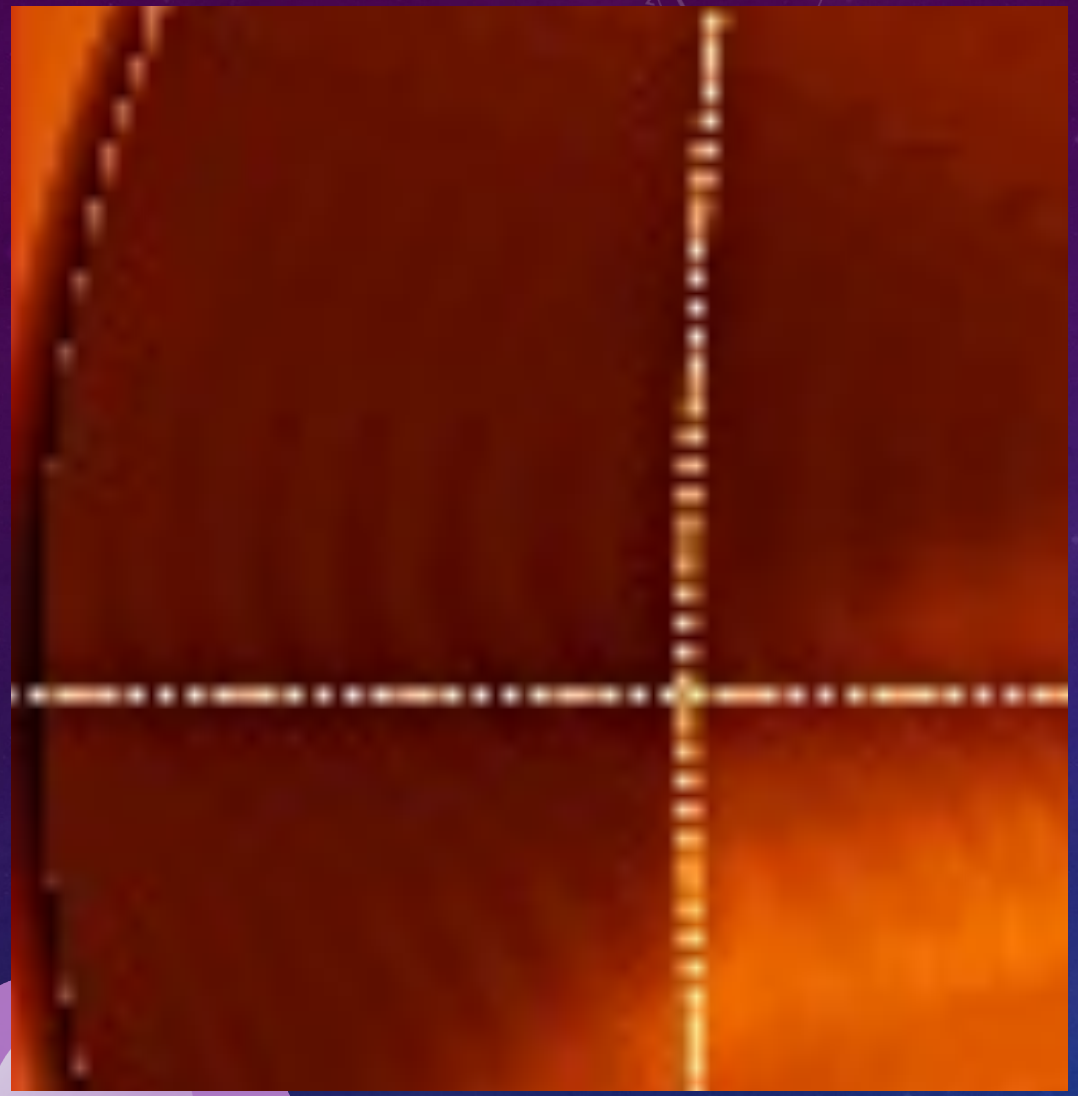

LASCO-C3 Clear white-lig
RHE
5°
0°
−5°
Helioprojective Latitude (degrees)
−5°
0°
5°
Helioprojective Longitude (degrees)


LASCO-C3 Clear white-light 2014-02-25 00:06:05
Unfiltered
RHE
Helioprojective Latitude (degrees)
Helioprojective Longitude (degrees)
5°
0°
−5°

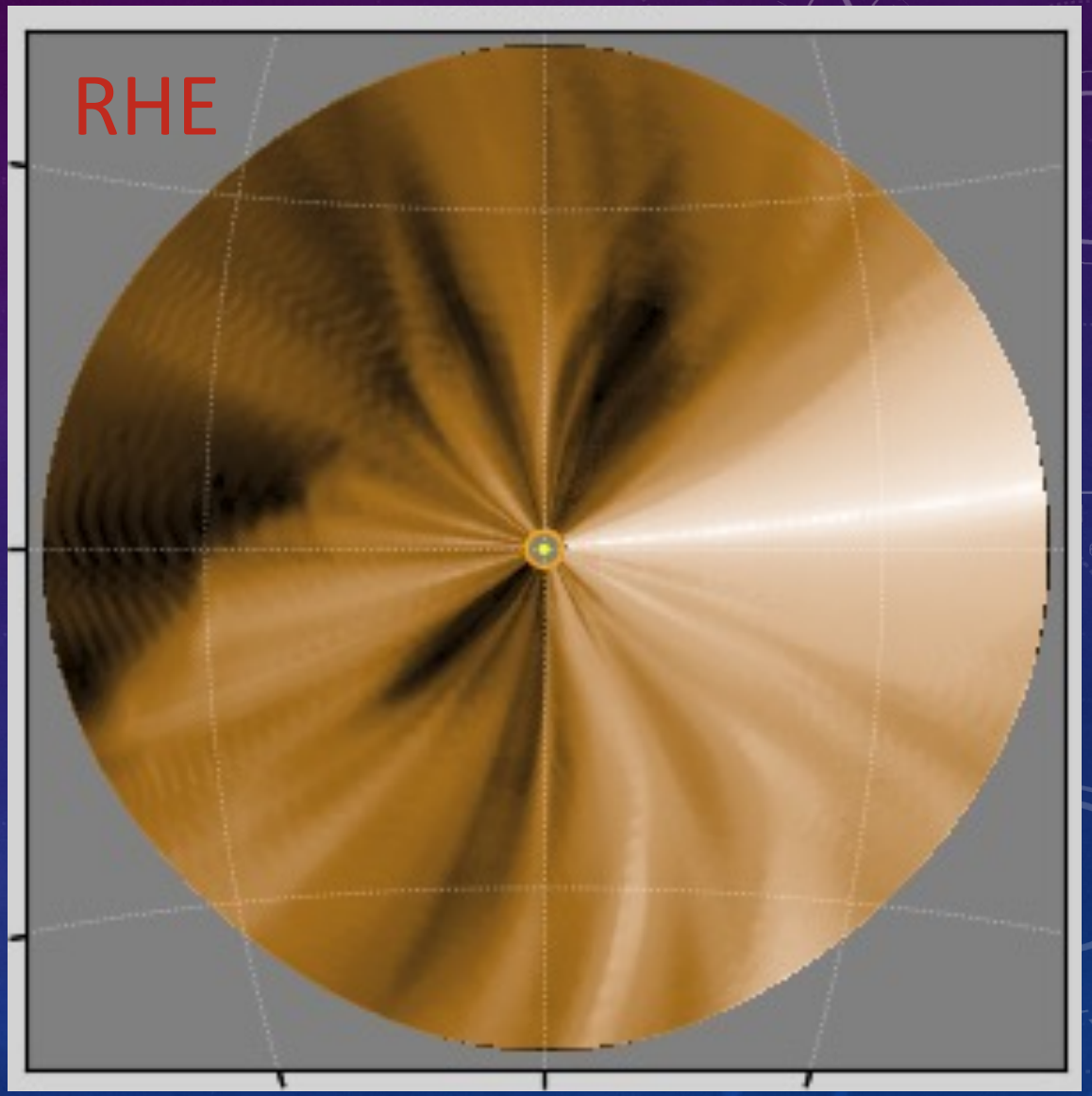
Filtering PUNCH Images

Unfiltered
Log10
NRGF
RHE
Ups(RHE)



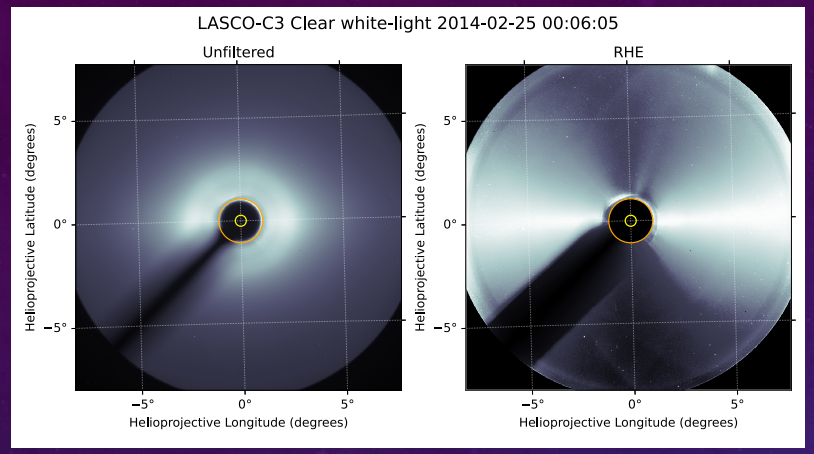


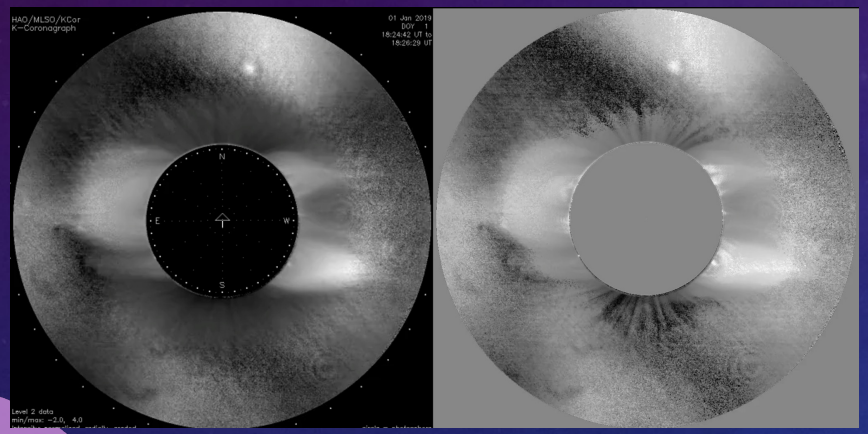
NRGF

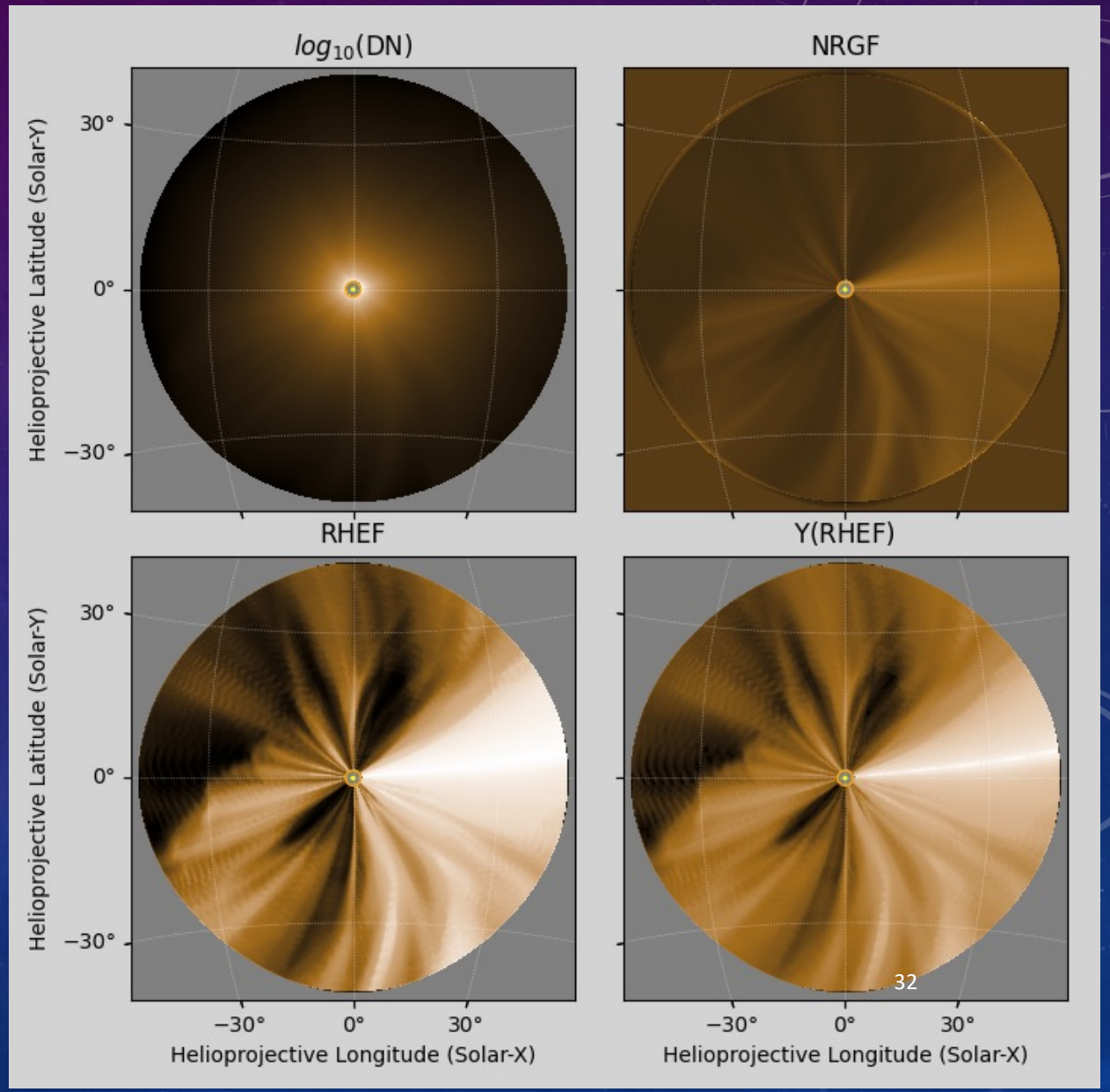


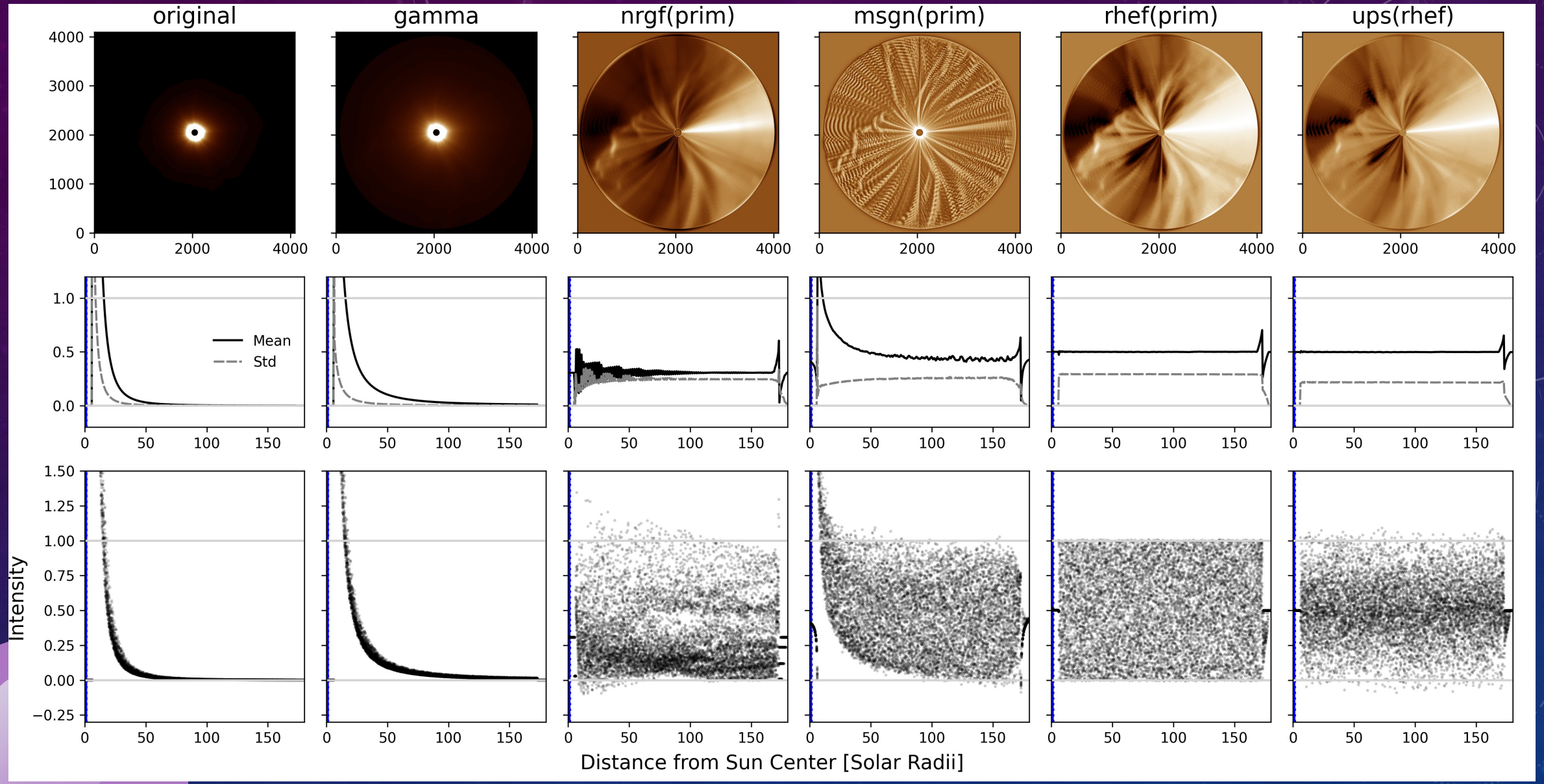
Brightness/Contrast Adjustment in Powerpoint

CORONAGRAPHS








original
gamma
nrgf(prim)
msgn(prim)
rhef(prim)
ups(rhef)
Mean
Std
Intensity
Distance from Sun Center [Solar Radii]

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https://gilly.space/sun.html

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