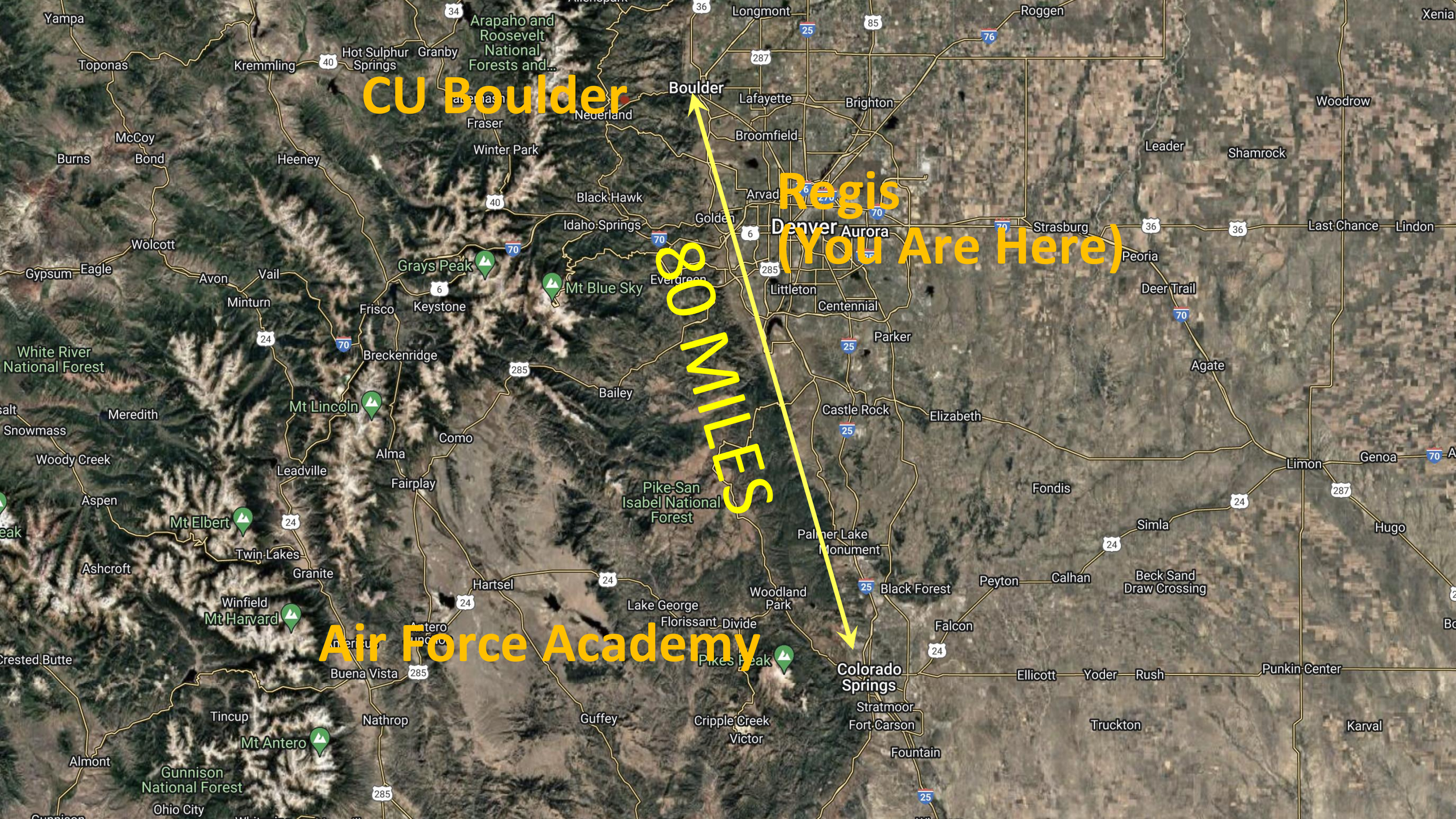
Denver Astronomical Society

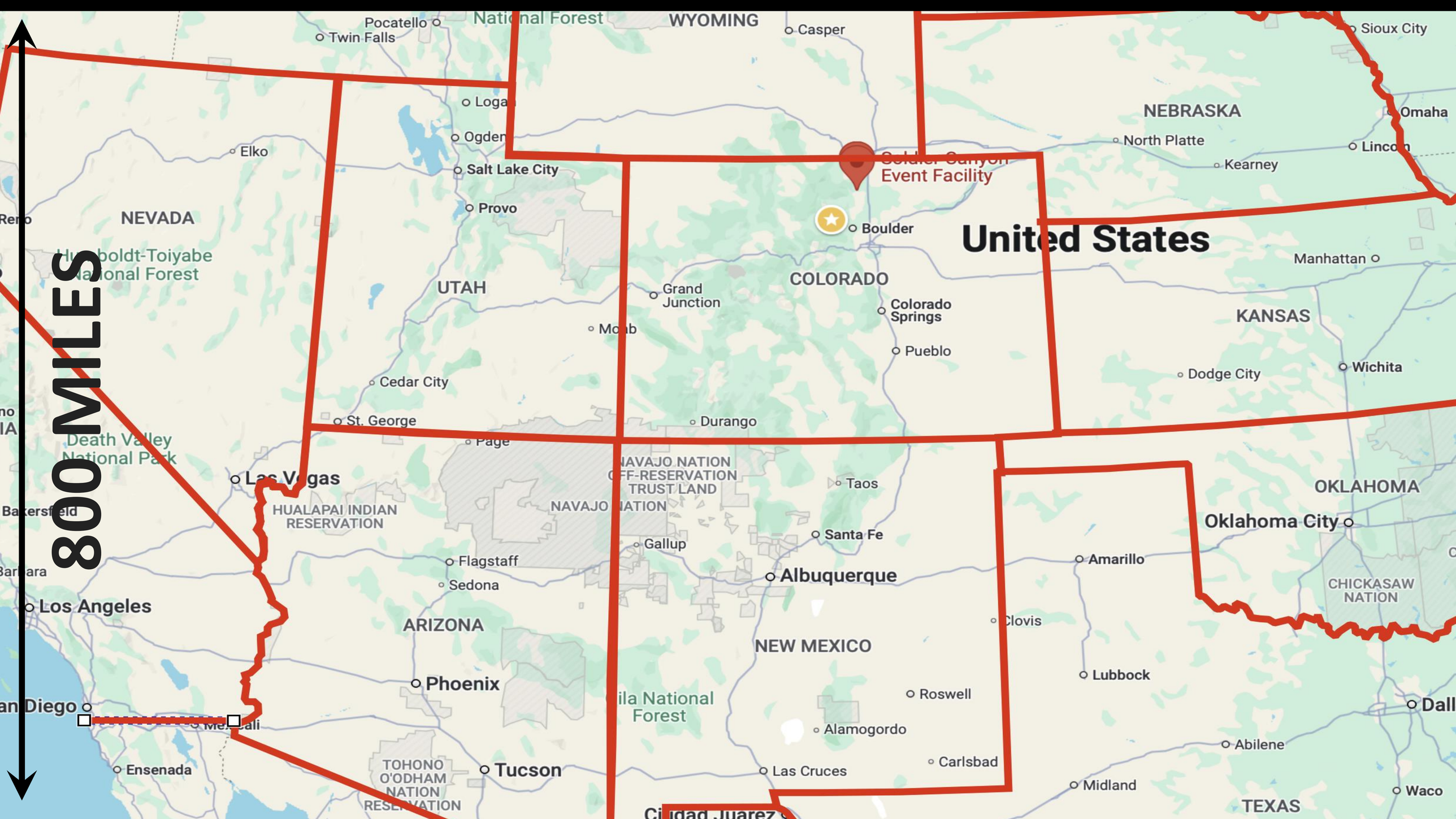
THE SUN TOUCHES HUMANITY: ASTROPHYSICS OF OUR HOME IN SPACE

Dr. Craig DeForest, PUNCH Principal Investigator

SwRI®

You Are Here:
Claver Hall (Regis)
0.8 MILE
Peter Claver Hall
Regis University
Regis University Community Garden
Subie Fix
Baseball Field
Boettcher Commons
David Clarke Hall
Subway
$6.99 Any Footlong Sub
Taco Bell
Crispy Nuggets Taco Bell®
McDonald's
Wendy's
Wendy's Meal Deals
Aria Apartments
Beach Court Elementary School
Zuni Park
Motel 6 Denver, CO – Downtown
McCoy's Restaurant
Rocky Top Tavern
Berkeley Community Church, UCC
24EVCS
Black Oak Builders
Carl Park Community Center
Rocky Mountain RV Service and Trailer...
Ricardo Flores Magón Academy
Clear Creek
Denver's Competitive Ink
Z53
Pecos Place
Romero Funeral Home
Rocky Mountain Lake
Heartland Expy
W 55th Ave
W 54th Ave
W 53rd Ave
W 52nd Ave
W 51st Ave
W 50th Ave
Regis Blvd
W 49th Ave
W 48th Ave
W 48th Ave S Dr
N Federal Blvd
Lowell Blvd
Google


CU Boulder
Regis
(You Are Here)
80 MILES
Air Force Academy
Boulder
Denver
Aurora
Colorado Springs
Longmont
Lafayette
Brighton
Broomfield
Arvada
Golden
Littleton
Centennial
Parker
Castle Rock
Elizabeth
Strasburg
Peoria
Deer Trail
Agate
Limon
Genoa
Fondis
Simla
Hugo
Palmer Lake
Monument
Black Forest
Peyton
Calhan
Beck Sand
Draw Crossing
Falcon
Ellicott
Yoder
Rush
Punkin Center
Truckton
Karval
Stratmoor
Fort Carson
Fountain
Woodrow
Leader
Shamrock
Last Chance
Lindon
Roggen
Xenia
Yampa
Toponas
Kremmling
Hot Sulphur Springs
Granby
Arapaho and Roosevelt National Forests and...
Nederland
Fraser
Winter Park
McCoy
Burns
Bond
Heeney
Black Hawk
Idaho Springs
Evergreen
Wolcott
Gypsum
Eagle
Avon
Vail
Minturn
Grays Peak
Mt Blue Sky
Frisco
Keystone
Breckenridge
White River National Forest
Bailey
Mt Lincoln
Meredith
Snowmass
Woody Creek
Aspen
Como
Alma
Leadville
Fairplay
Pike-San Isabel National Forest
Mt Elbert
Twin Lakes
Ashcroft
Granite
Hartsel
Lake George
Florissant
Divide
Woodland Park
Winfield
Mt Harvard
Antero
Pikes Peak
Crested Butte
Buena Vista
Tincup
Nathrop
Guffey
Cripple Creek
Victor
Mt Antero
Almont
Gunnison National Forest
Ohio City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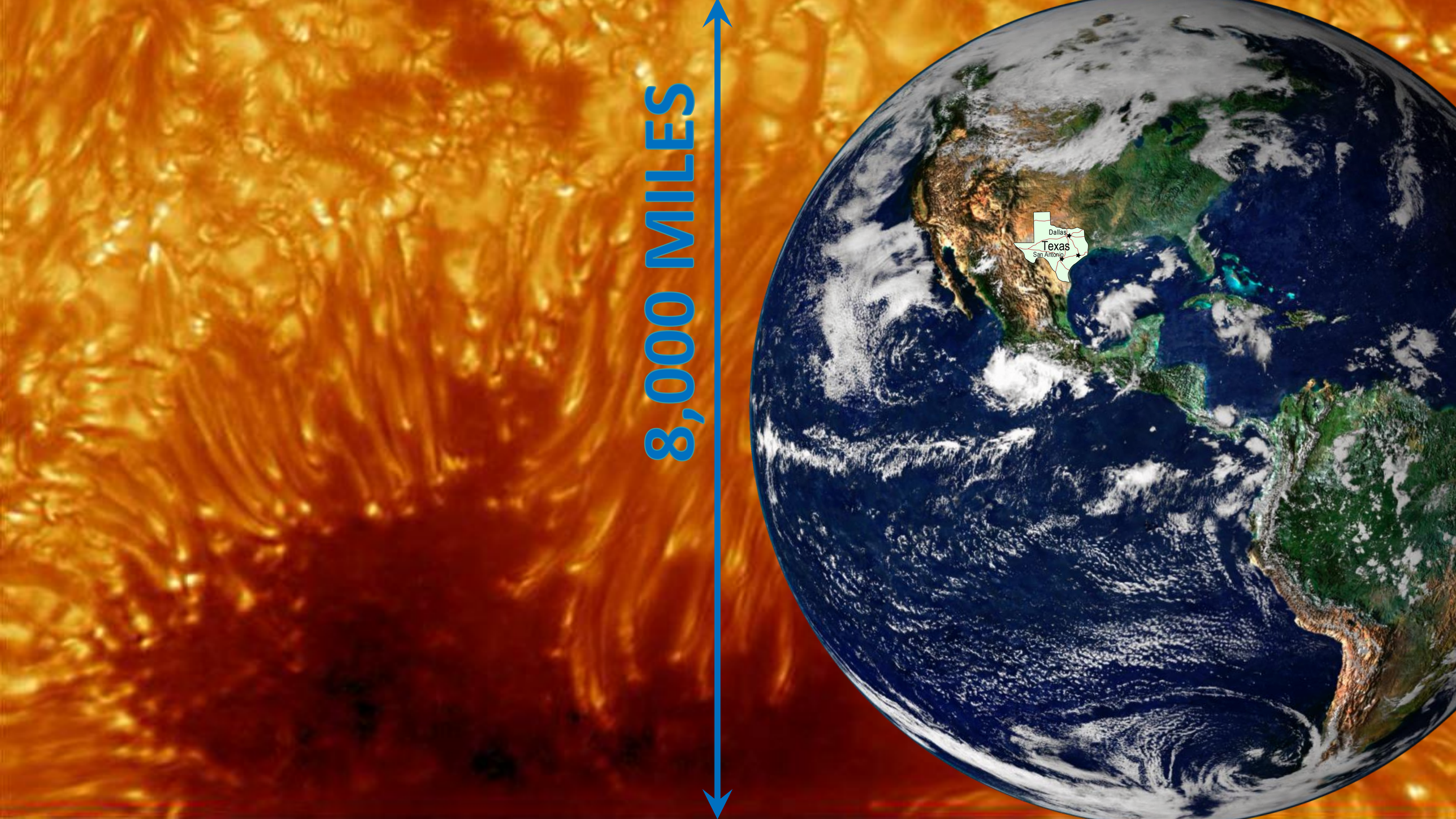
Pocatello
Twin Falls
WYOMING
Casper
Sioux City
Elko
Ogden
Salt Lake City
Provo
NEBRASKA
North Platte
Kearney
Omaha
Event Facility
Boulder
United States
NEVADA
UTAH
COLORADO
Grand Junction
Colorado Springs
Pueblo
Manhattan
KANSAS
Wichita
Dodge City
Cedar City
St. George
Durango
Death Valley National Park
Las Vegas
HUALAPAI INDIAN RESERVATION
NAVAJO NATION OFF-RESERVATION TRUST LAND
NAVAJO NATION
Taos
Santa Fe
Gallup
Flagstaff
Sedona
Albuquerque
OKLAHOMA
Oklahoma City
Amarillo
CHICKASAW NATION
Los Angeles
ARIZONA
NEW MEXICO
Clovis
Lubbock
Phoenix
Roswell
Alamogordo
Carlsbad
Las Cruces
Abilene
Midland
TEXAS
Waco
San Diego
Ensenada
TOHONO O'ODHAM NATION
Tucson
Ciudad Juarez


800 MILES
Texas
NAVAJO NATION OFF-RESERVATION TRUST LAND
NAVAJO NATION
Taos
Gallup
Santa Fe
Albuquerque
Amarillo
Clov
NEW MEXICO
Lubbock
Roswell
Gila National Forest
Alamogordo
Las Cruces
Carlsbad
Hobbs
Abilene
Big Spring
Midland
Ciudad Juárez
CHIHUAHUA
Chihuahua
Delicias
Camargo
Parral
Piedras Negras
COAHUILA
Nuevo Laredo
Monclova
NUEVO LEON
Monterrey
Reynosa
Saltillo
Torreón
Guasave
Mochis
Tulsa
CHEROKEE NATION
OKLAHOMA
Norman
CHOCTAW NATION
CHICKASAW NATION
Fort W
Dallas
Tyler
Waco
Austin
Jonesboro
Memphis
Conway
TENNESSEE
Chattanooga
Huntsville
Birmingham
Tuscaloosa
MISSISSIPPI
ALABAMA
Montgomery
Jackson
Shreveport
Mobile
Pensacola
Biloxi
Gulf Shores
LOUISIANA
New Orleans
Corpus Christi
Gulf of Mexico

800 MILES

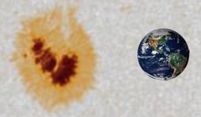
600x REAL TIME (30 min loop)


8,000 MILES
Dallas
Texas
San Antonio

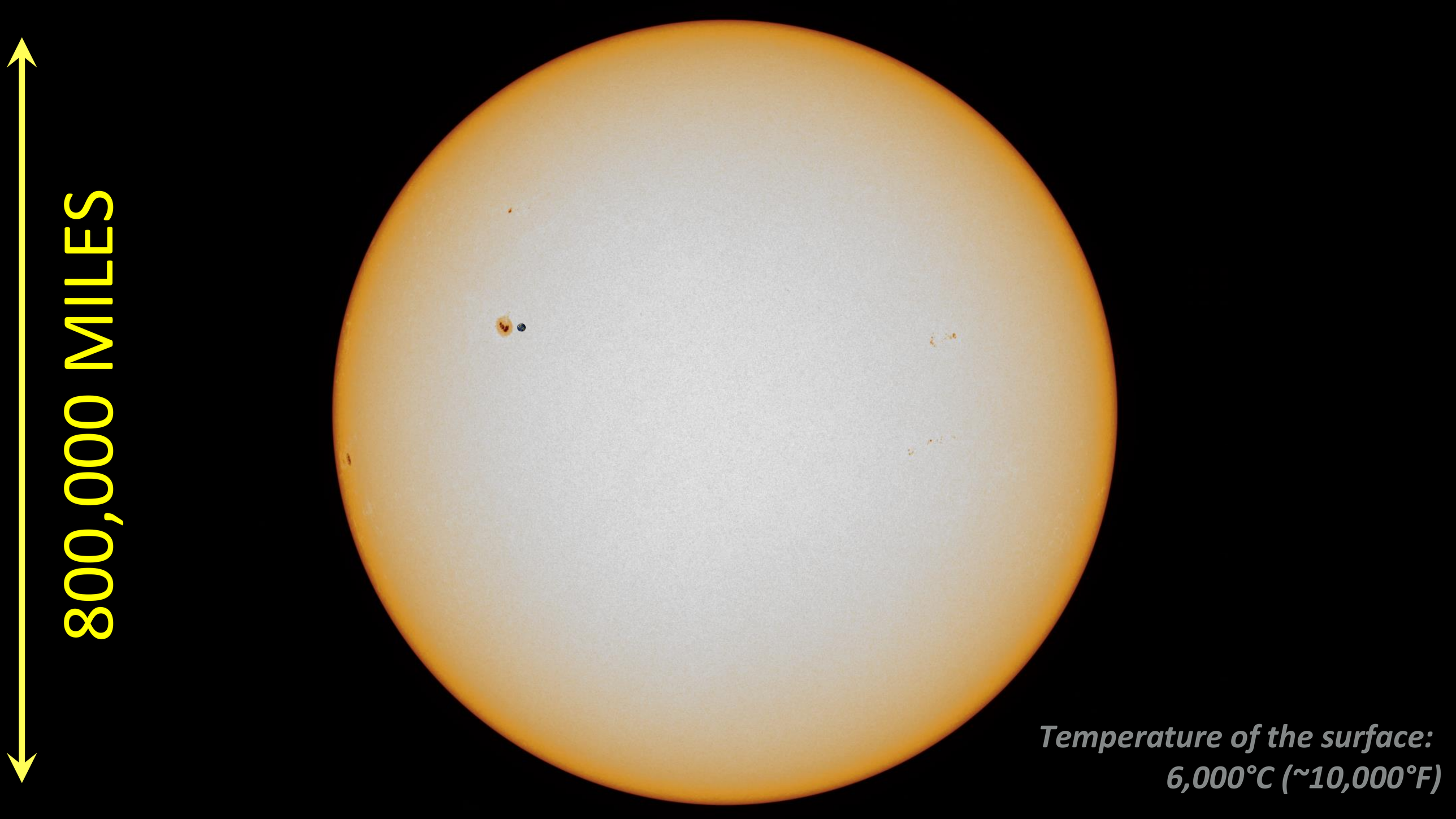
A recent sunspot

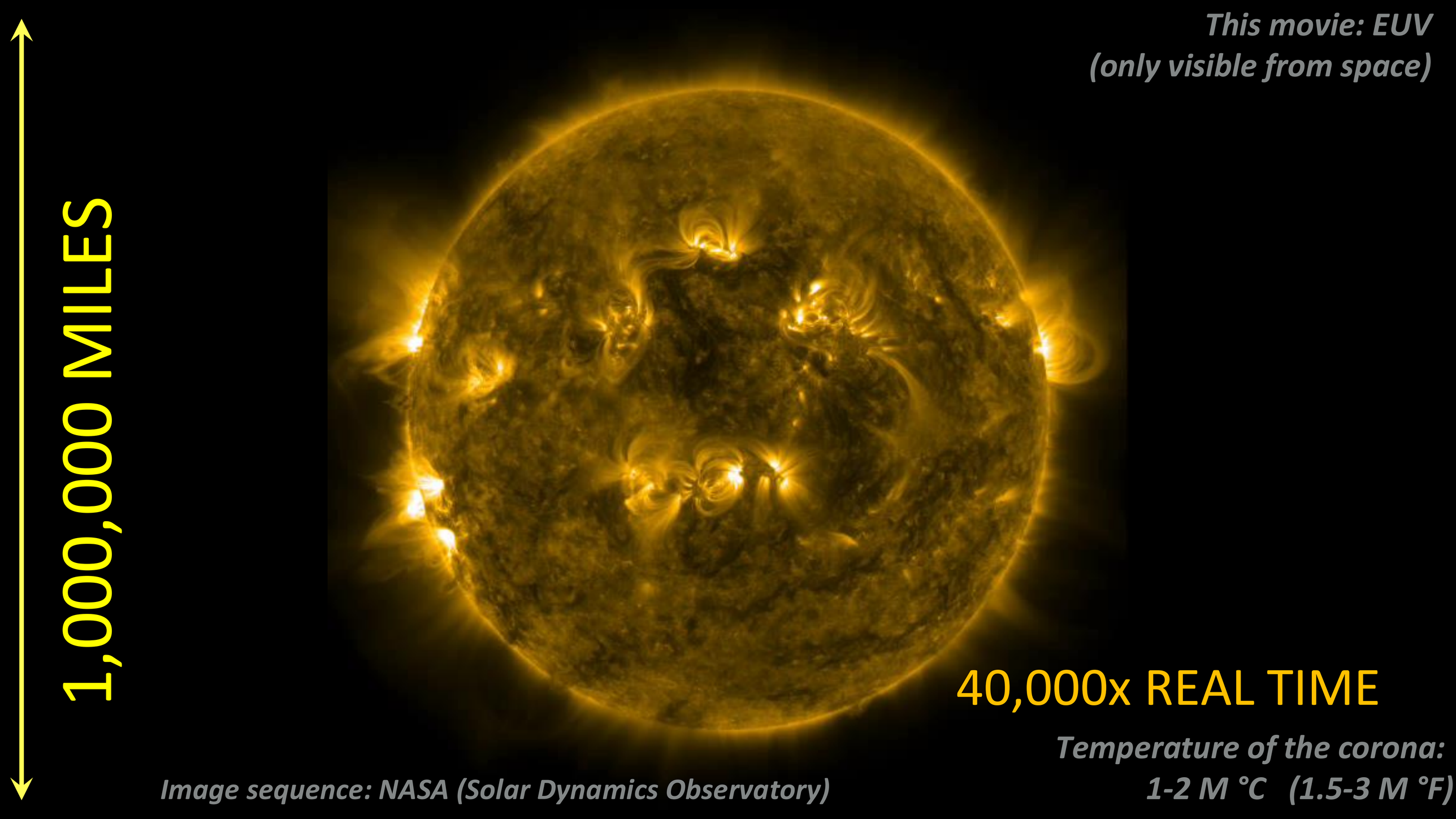
240,000 MILES

EARTH TO SCALE

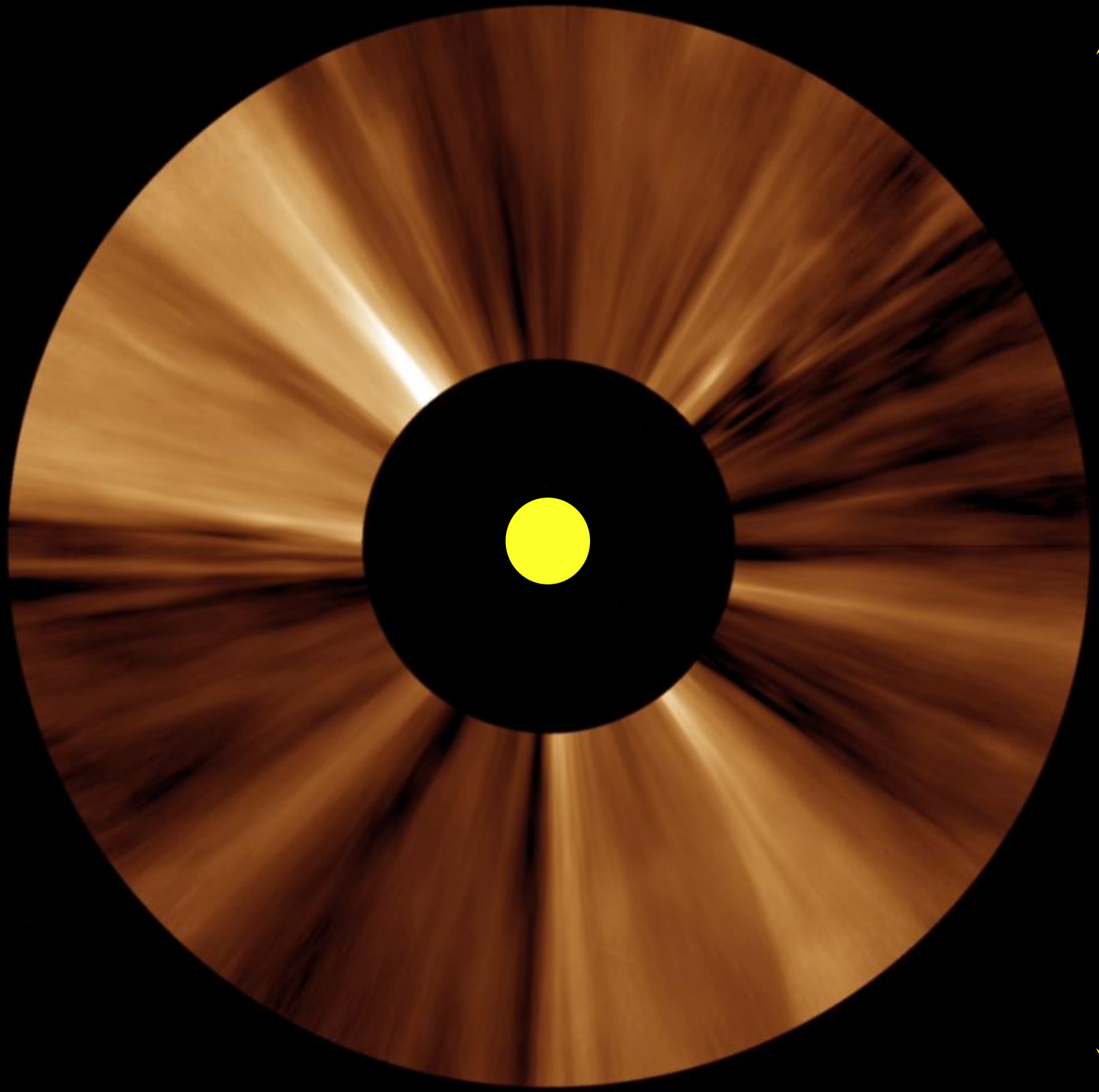


Temperature of the Sun's surface:
6,000°C (~10,000°F)


800,000 MILES
Temperature of the surface:
6,000°C (~10,000°F)


1,000,000 MILES
This movie: EUV
(only visible from space)
40,000x REAL TIME
Temperature of the corona:
1-2 M °C (1.5-3 M °F)
Image sequence: NASA (Solar Dynamics Observatory)

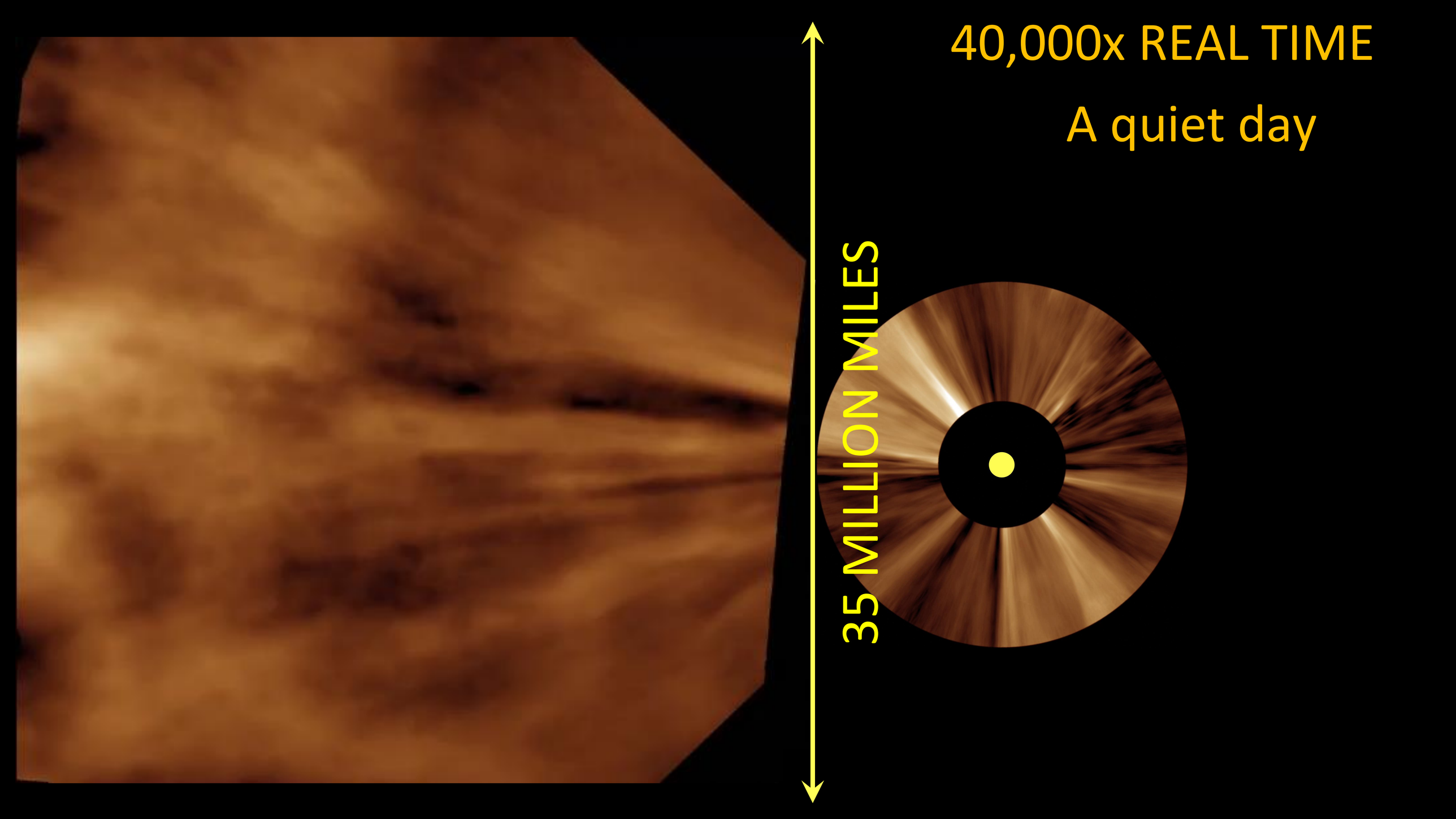

5 MILLION MILES
This image: visible light
Temperature of the corona:
1-2 M °C (1.5-3 M °F)
Composite of 2023 Eclipse: P. Starha, S. Habbal, M. Druckmuller



15 MILLION MILES

This sequence: visible light (processed)

4,000x REAL TIME

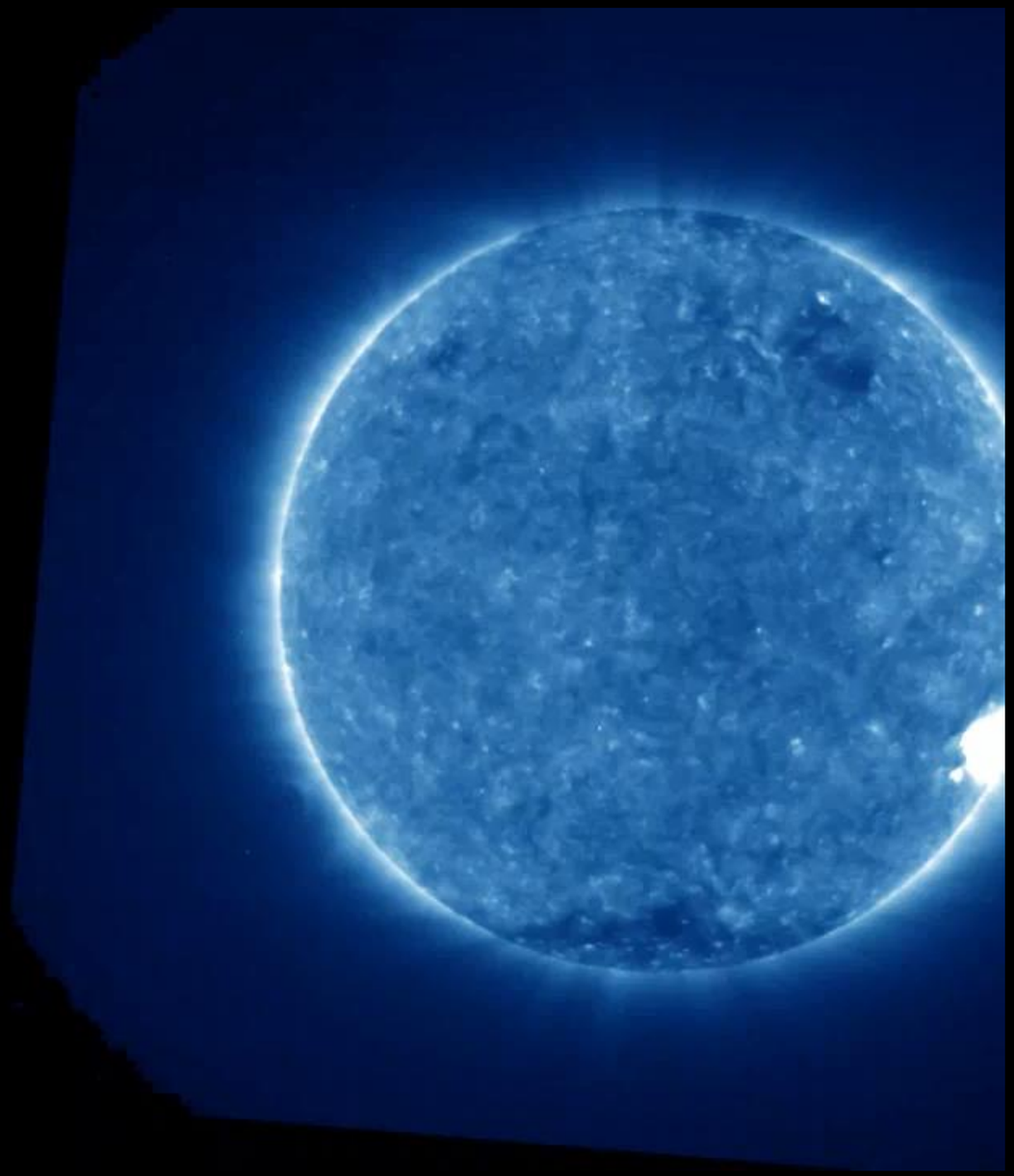

40,000x REAL TIME
A quiet day
35 MILLION MILES

40,000x REAL TIME
A not-so-quiet day

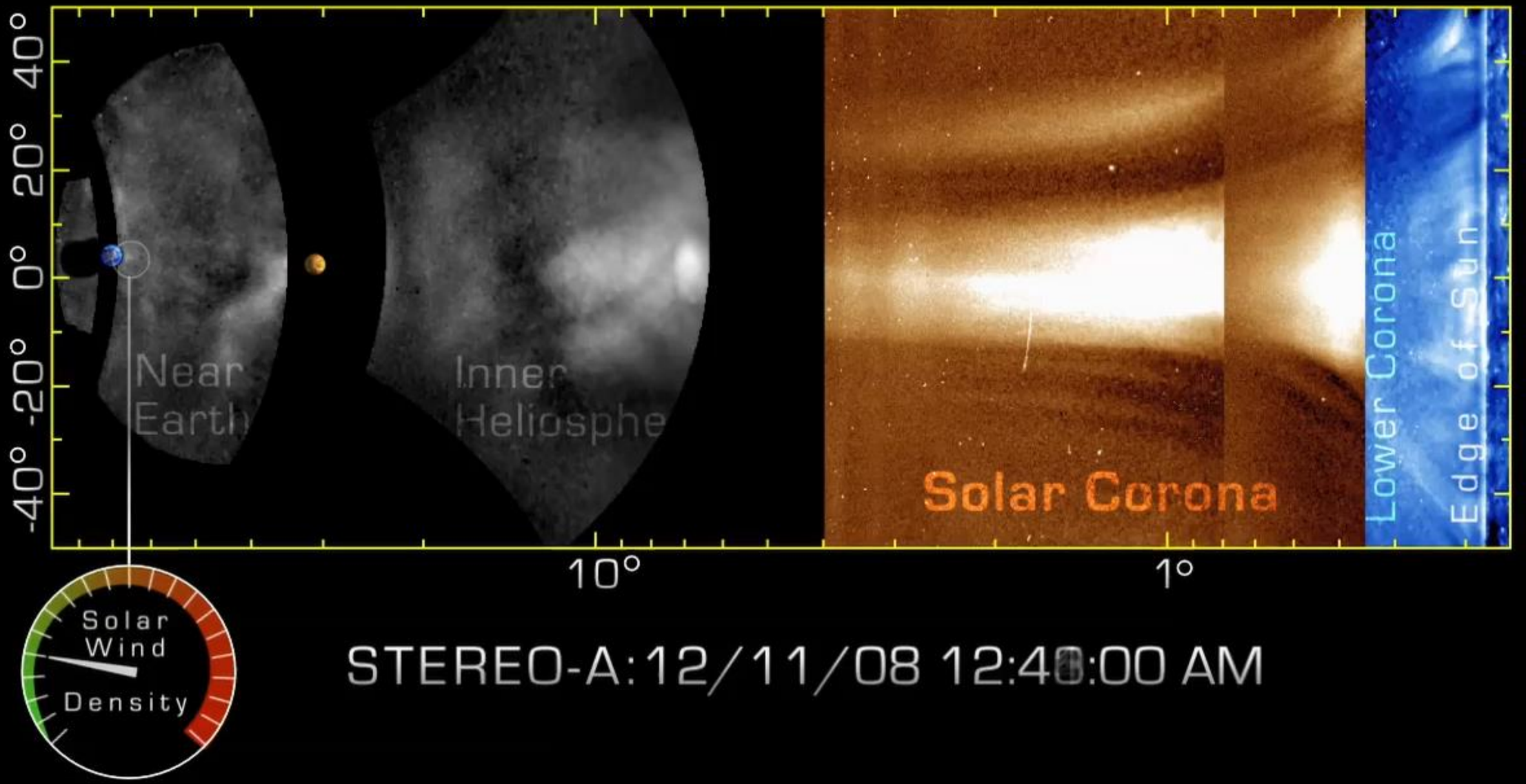
35 MILLION MILES

A Coronal Mass Ejection (CME) leaves the Sun

THE SOLAR CORONA DOESN’T REALLY END…

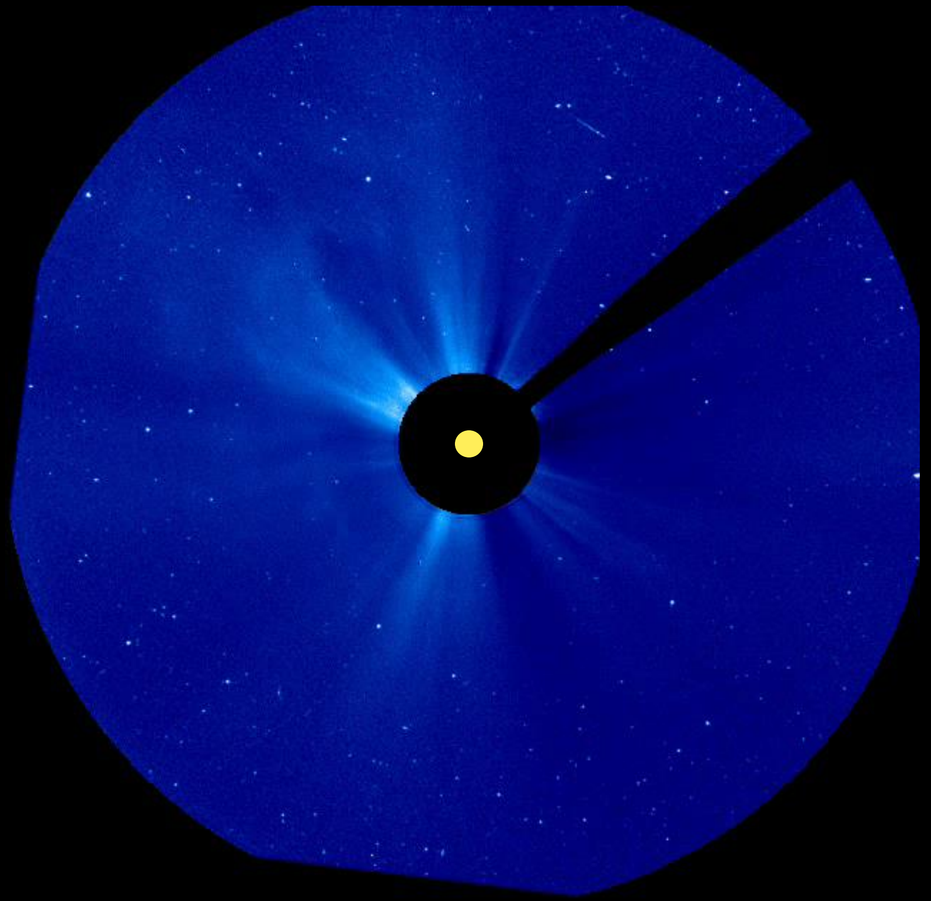


THE SUN AND EARTH ARE CONNECTED!



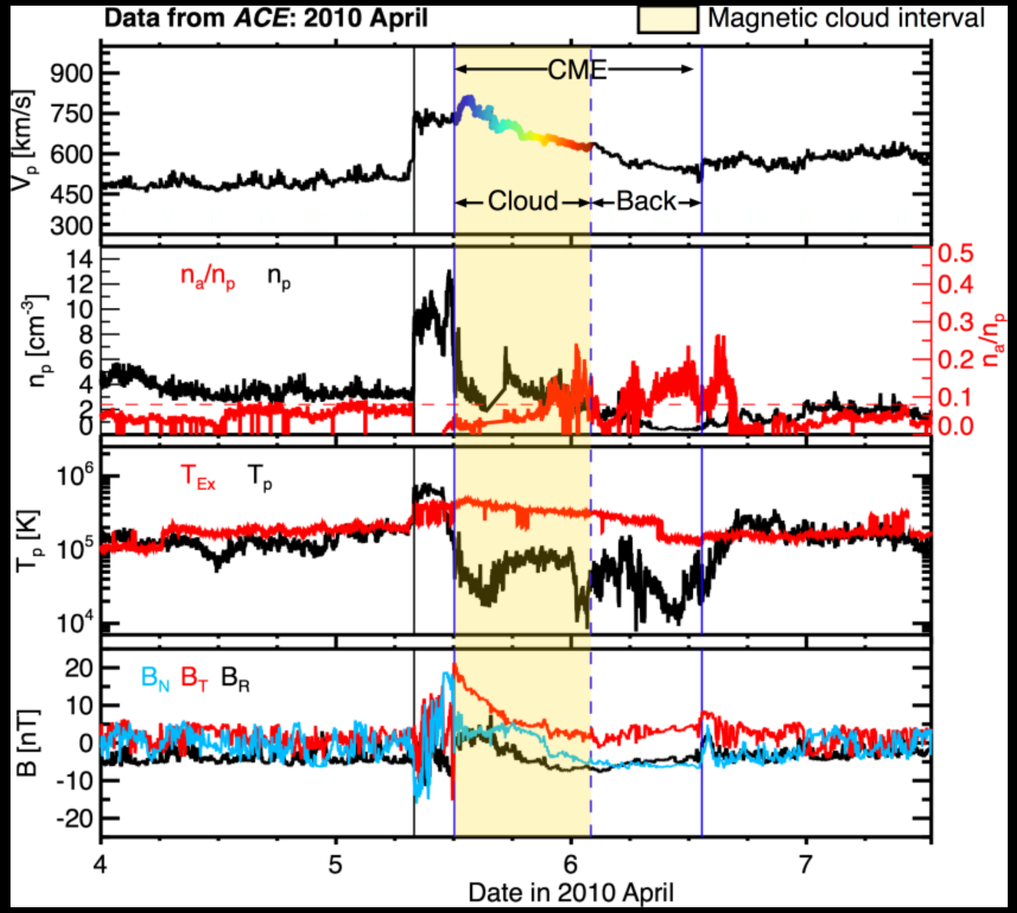
UNIFYING SOLAR PHYSICS & HELIOSPHERIC PHYSICS

Solar physics studies the Sun and corona, mainly through remote sensing and spectral analysis



LASCO timelapse: 90,000x real time

Heliospheric physics studies the solar wind in interplanetary space, mainly through in-situ sampling



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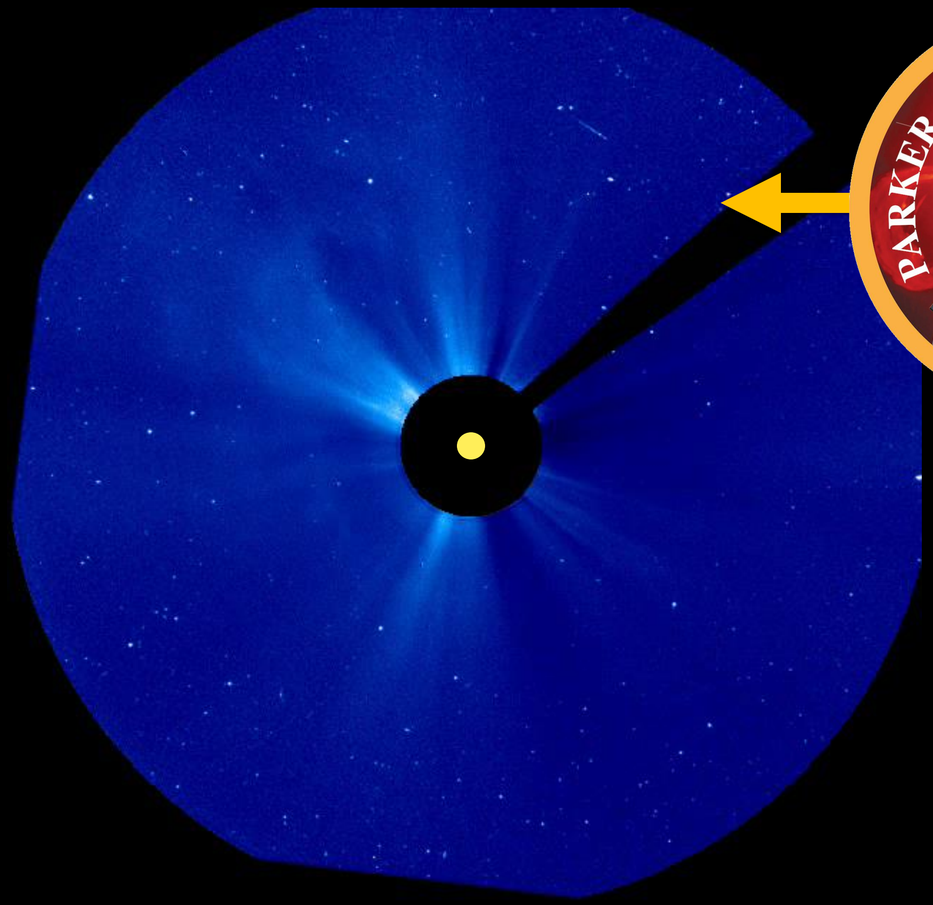
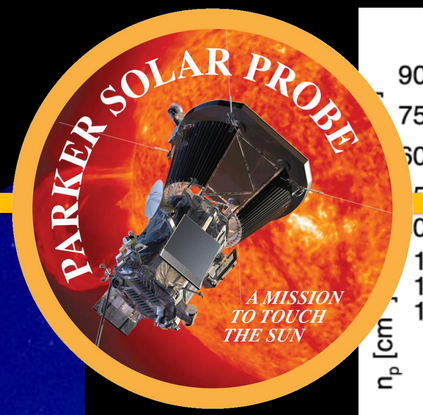
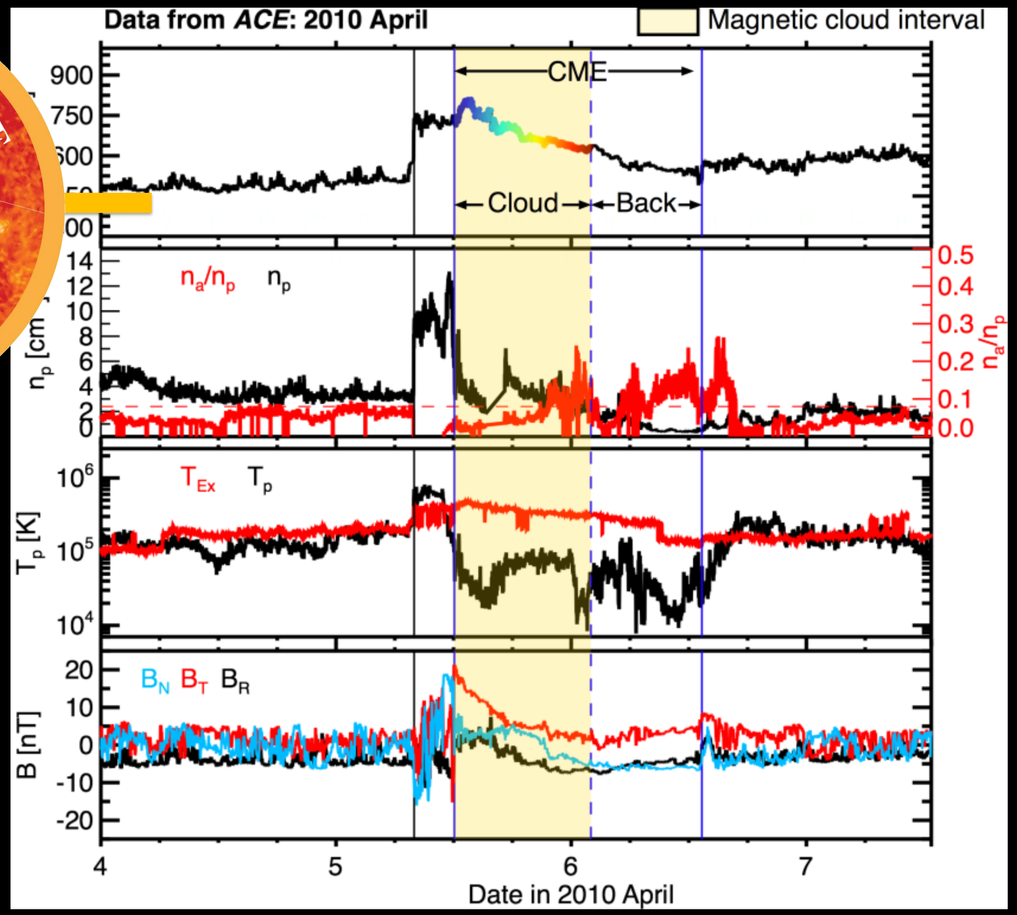


LASCO timelapse: 90,000x real time





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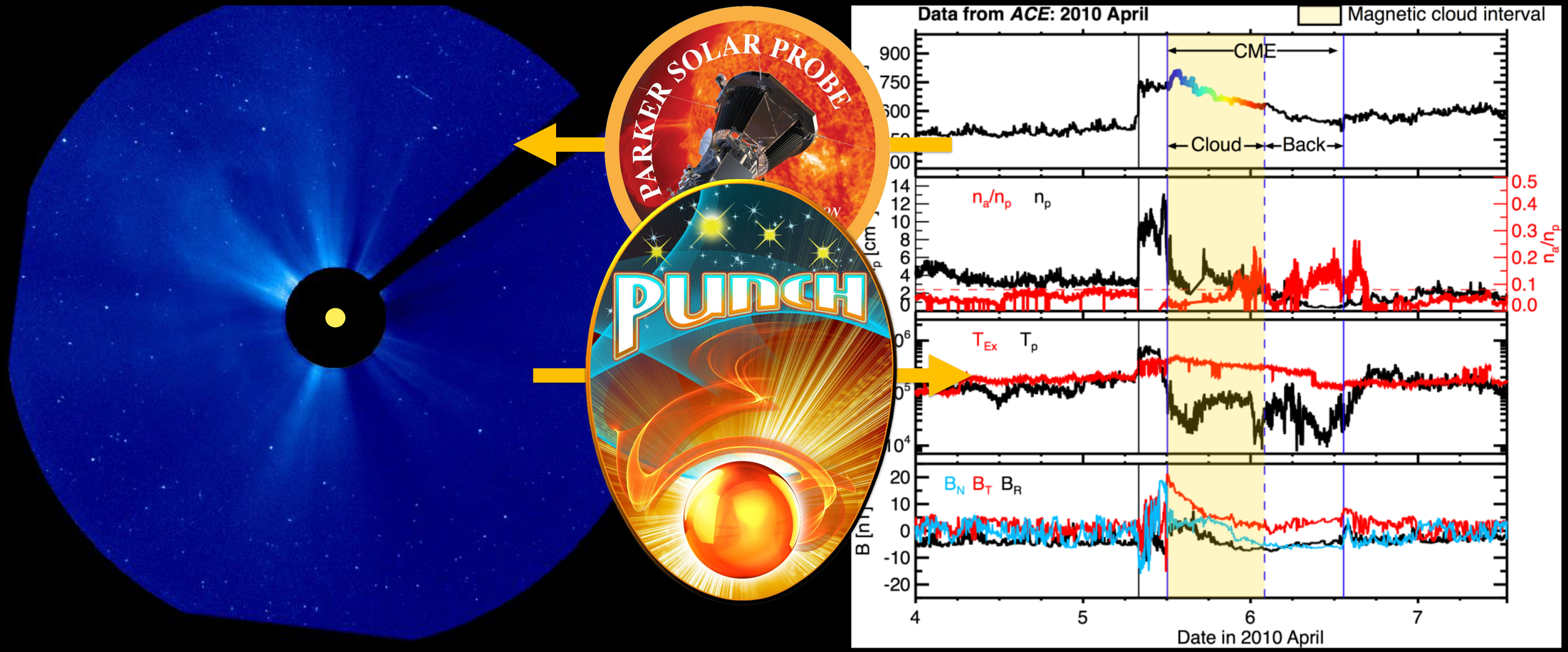
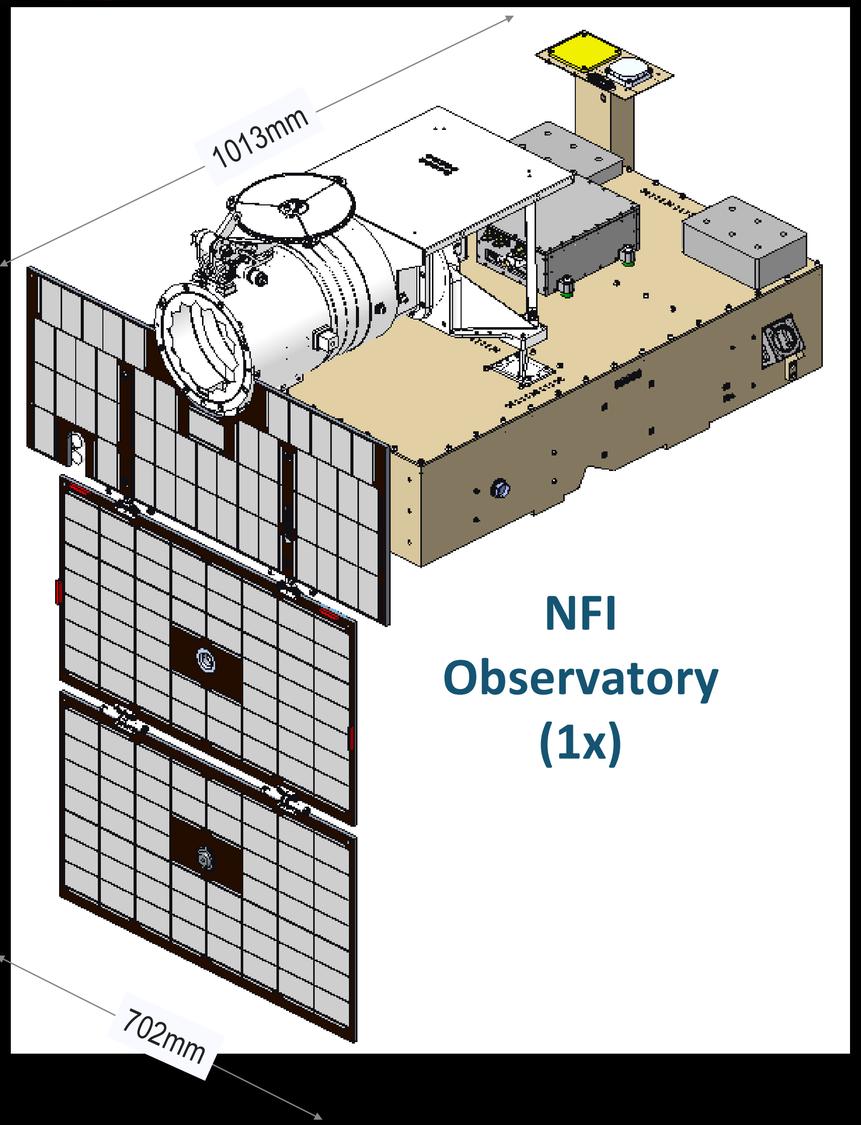


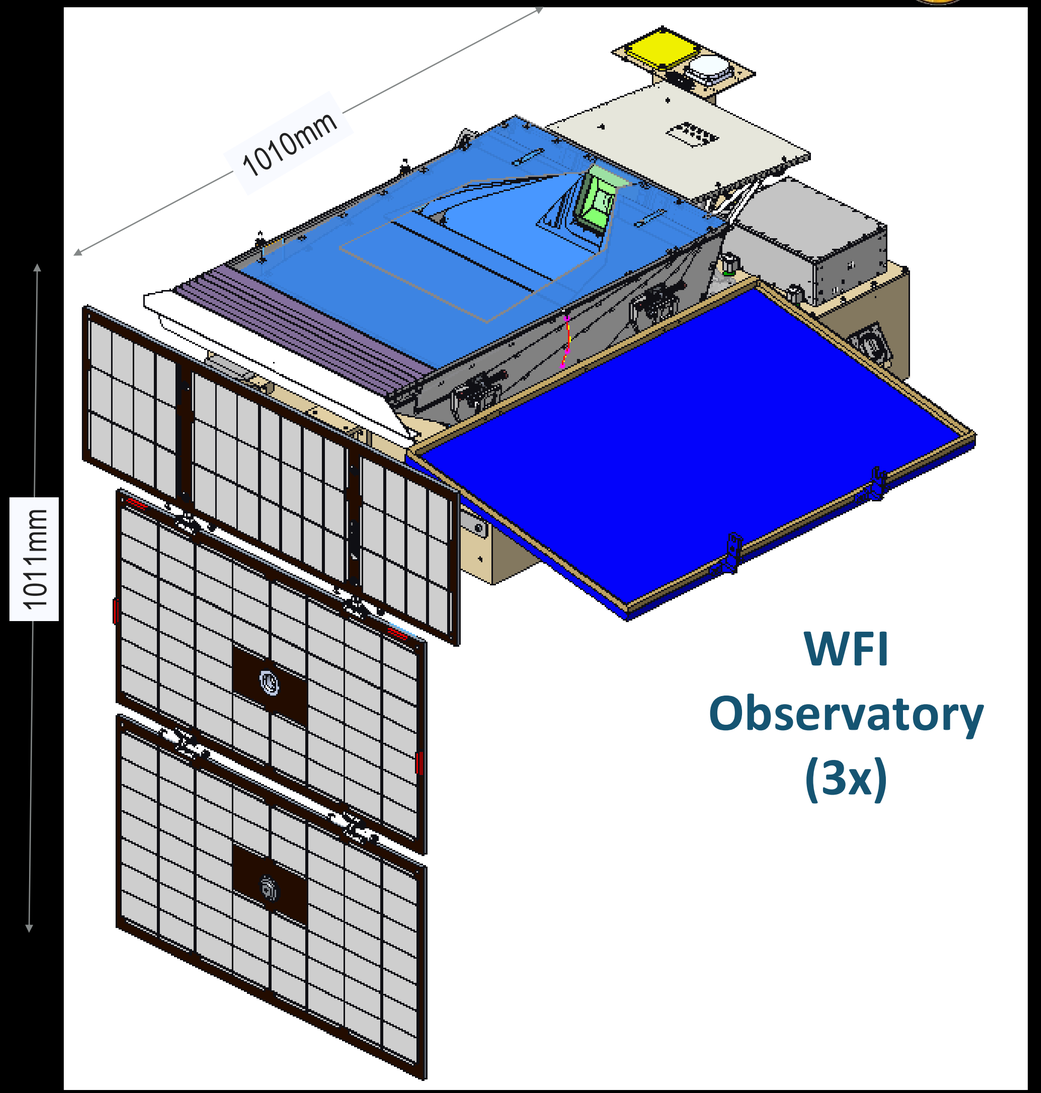
LASCO timelapse: 90,000x real time

PUNCH: FOUR SPACECRAFT WORK TOGETHER

PUNCH Observatories



NFI Observatory (1x)



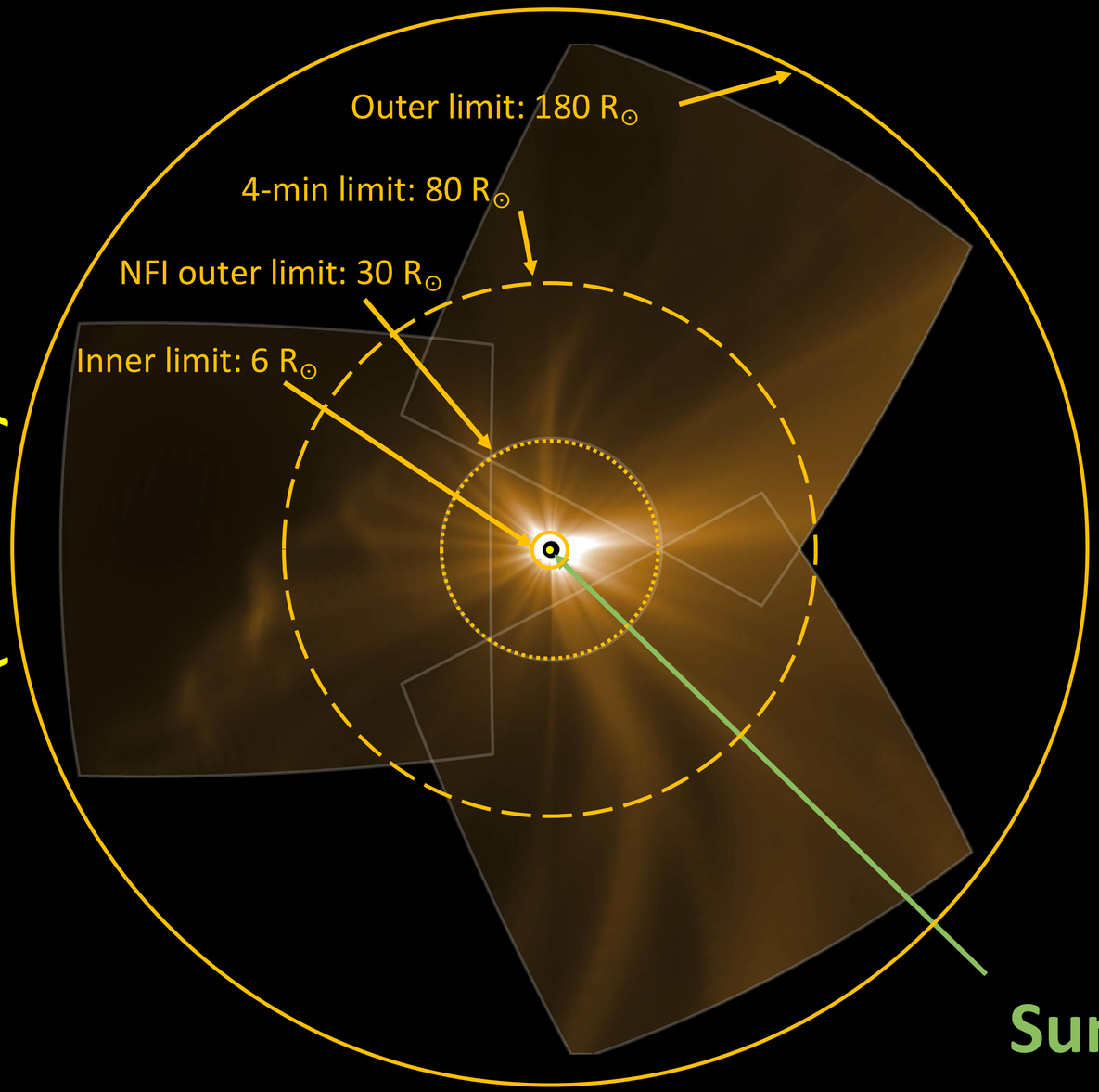
WFI Observatory (3x)

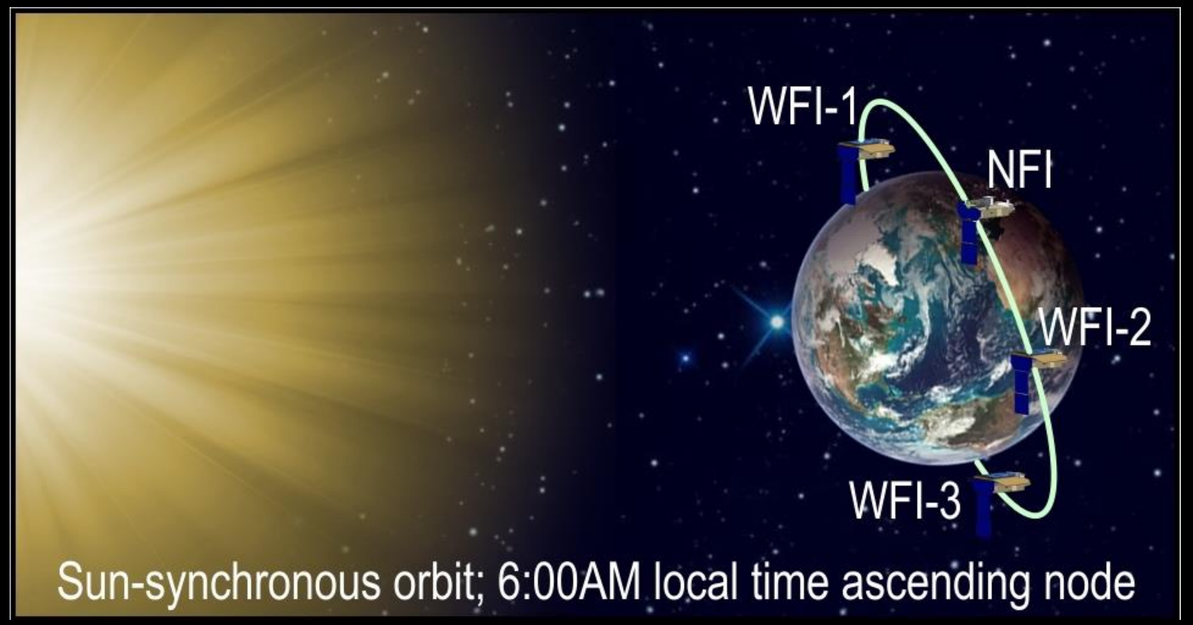
Each PUNCH spacecraft carries one primary instrument; the spacecraft are interchangeable.


PUNCH Rapid Field of View
PUNCH NFI
Field of View
Photo: N. Viall

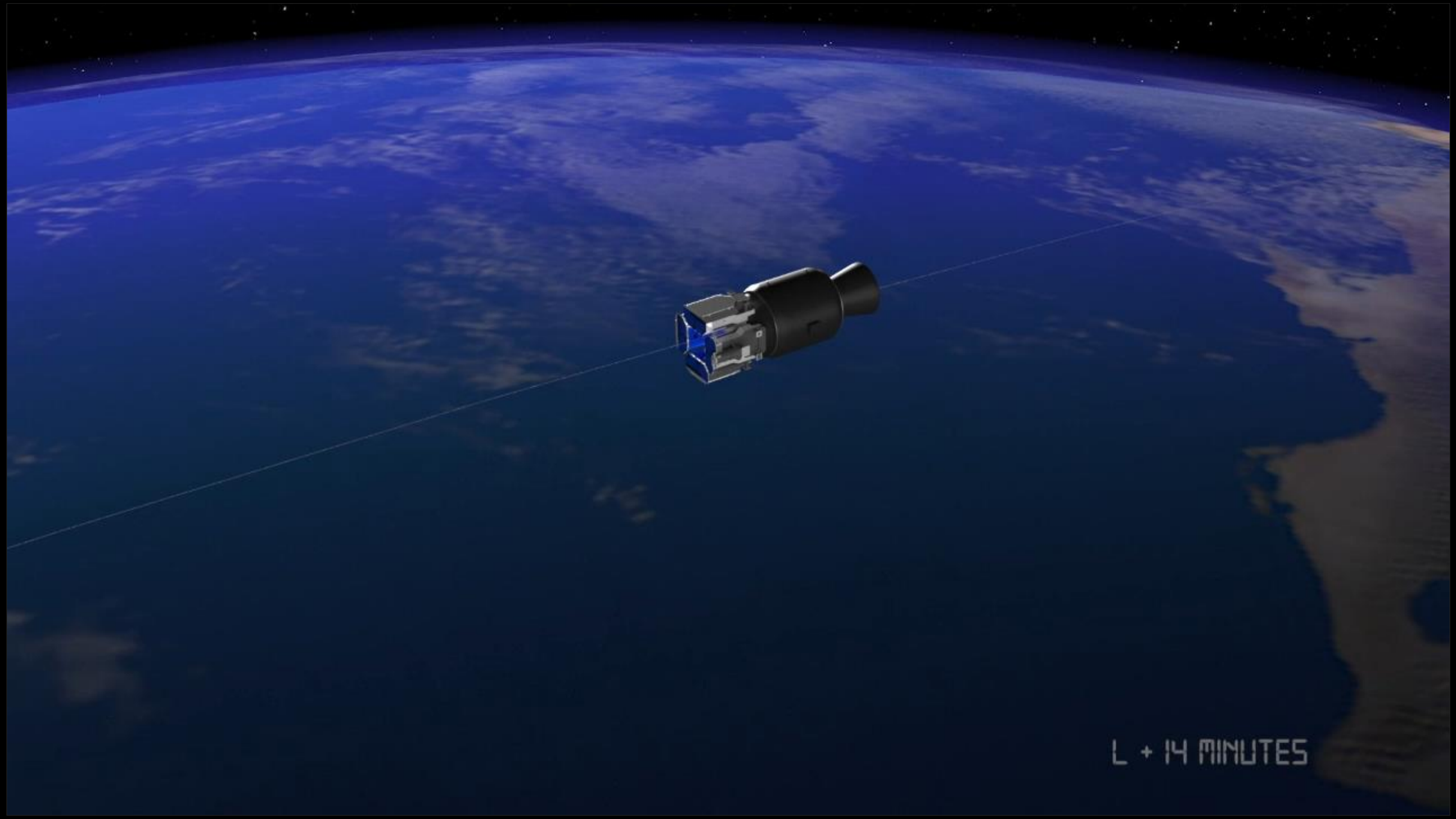
PUNCH WILL MERGE IMAGES INTO ONE BIG PICTURE

200 MILLION MILES
(2 A.U.)



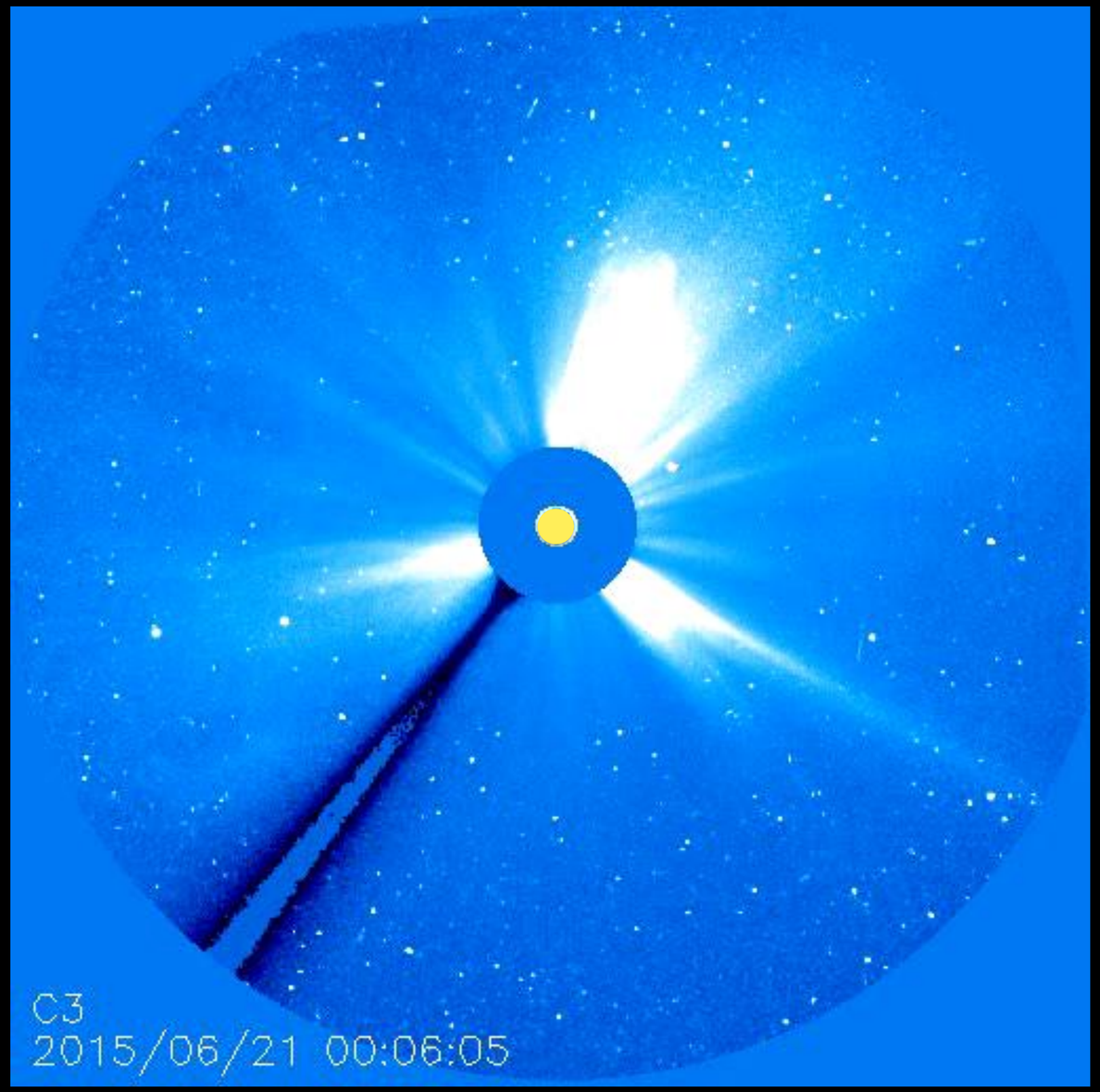


PUNCH MISSION PROFILE

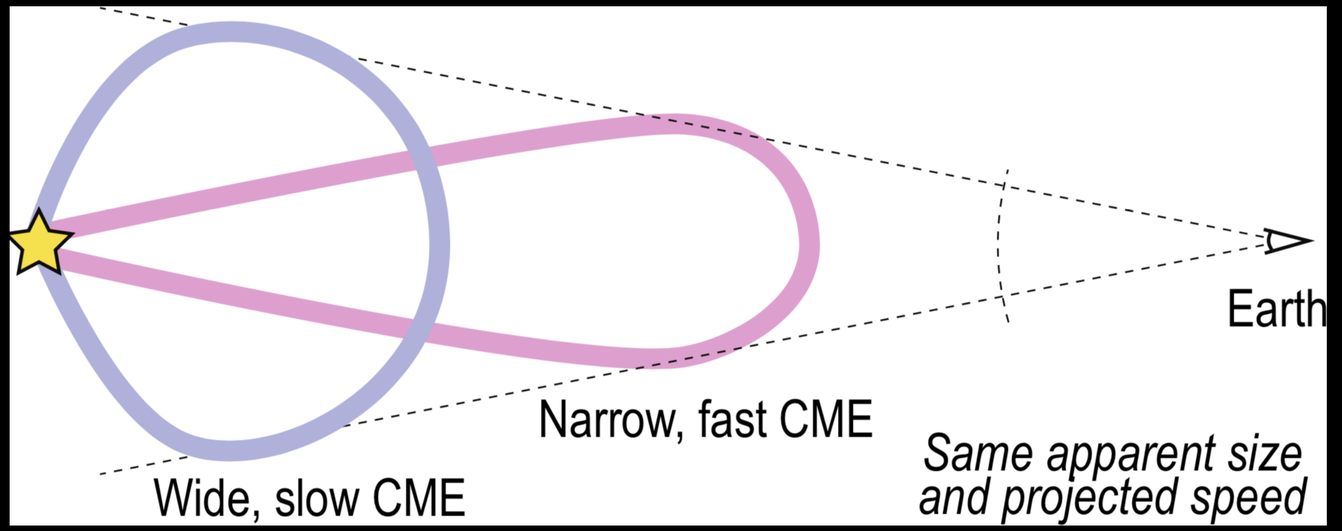


Why polarization? To track solar wind in 3-D

Why polarization? To track solar wind in 3-D

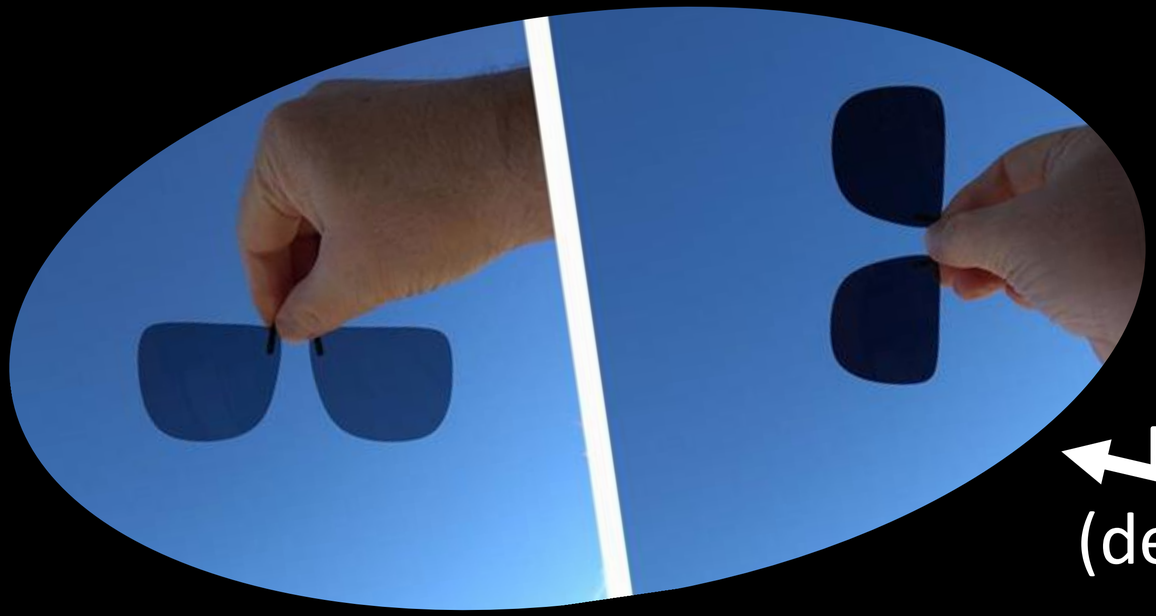


HO/LASCO data: CME coming right at you!

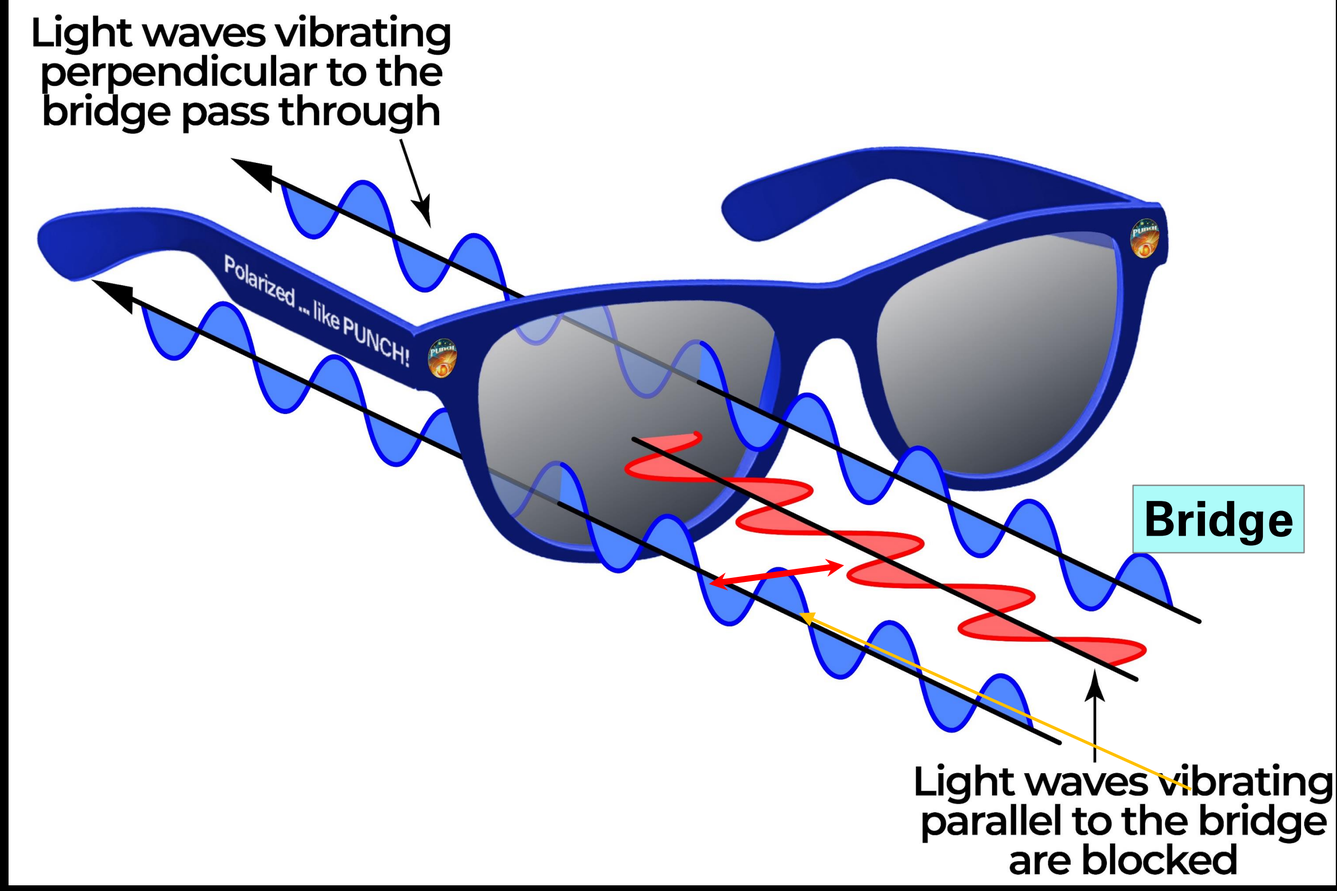


These CMEs look the same from Earth.

Polarization tells us which is which!
(closer is less polarized)

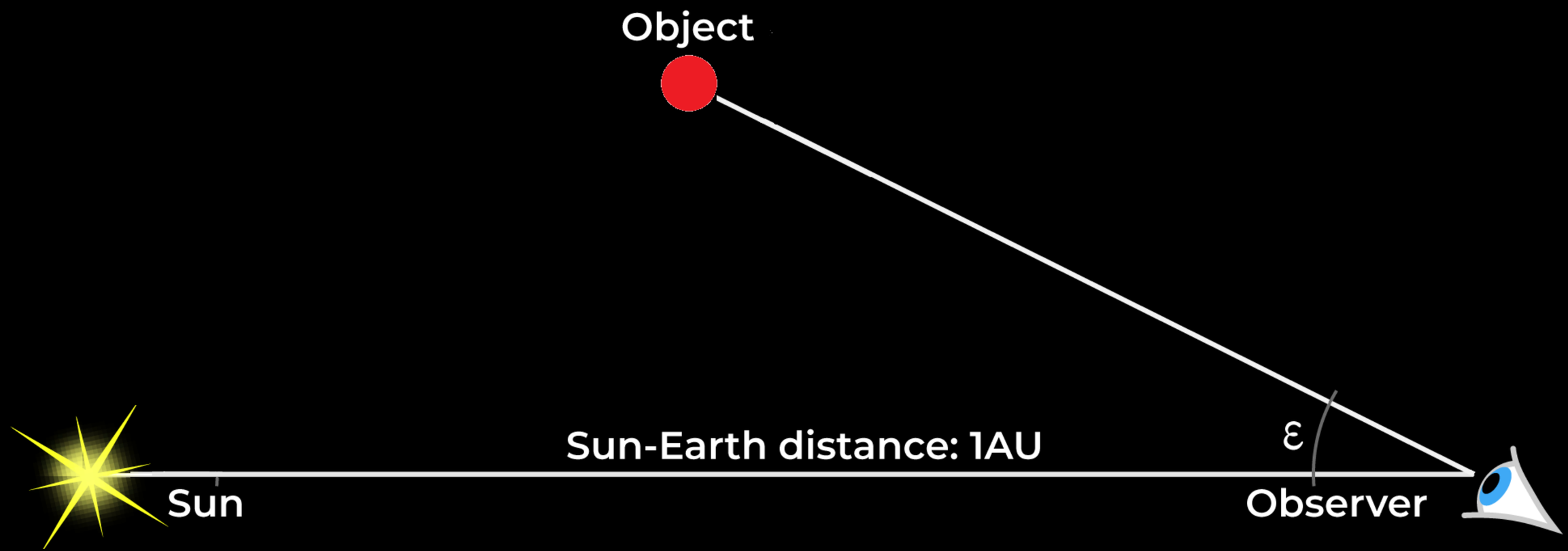


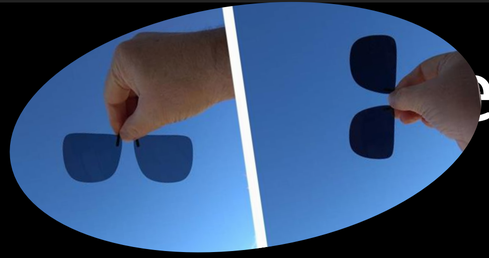
Action of Polarized Sunglasses



PUNCH uses the *difference* in brightness (degree of polarization) to locate stuff in 3D!

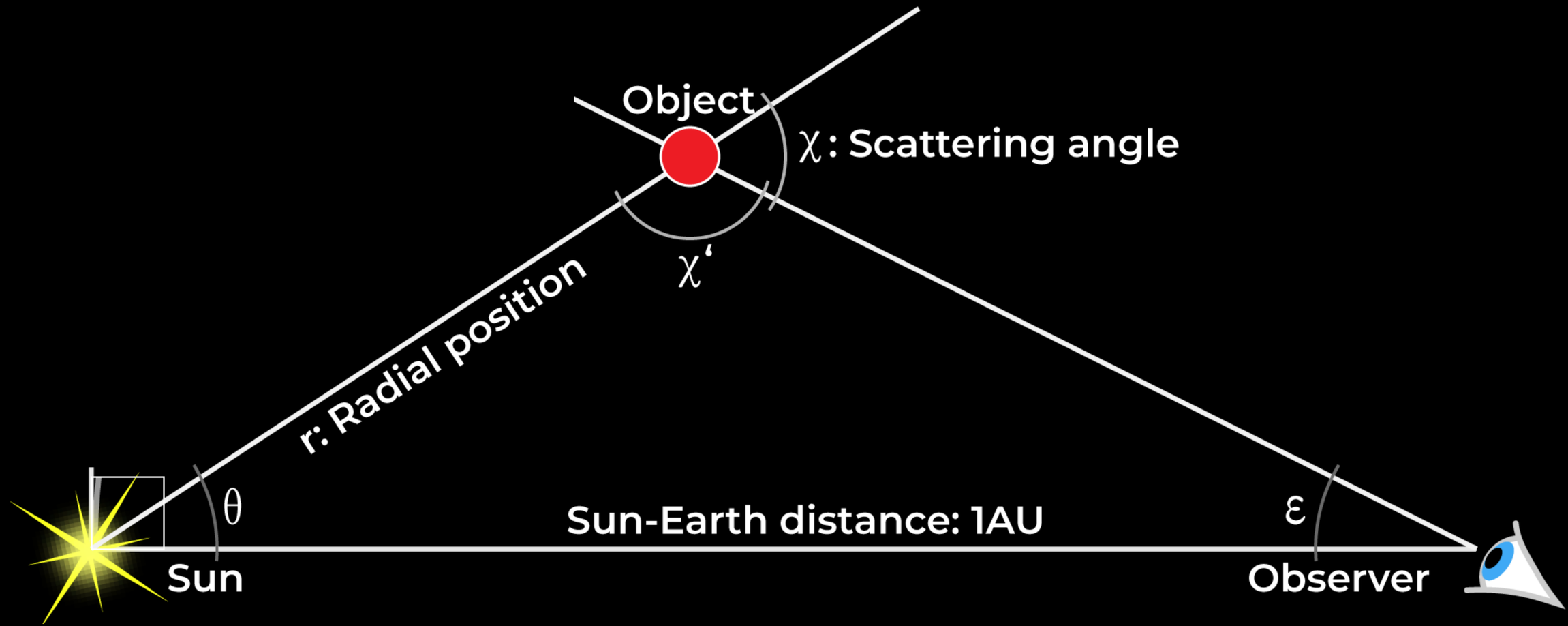
Object


Object
Sun-Earth distance: 1AU
ε
Sun
Observer



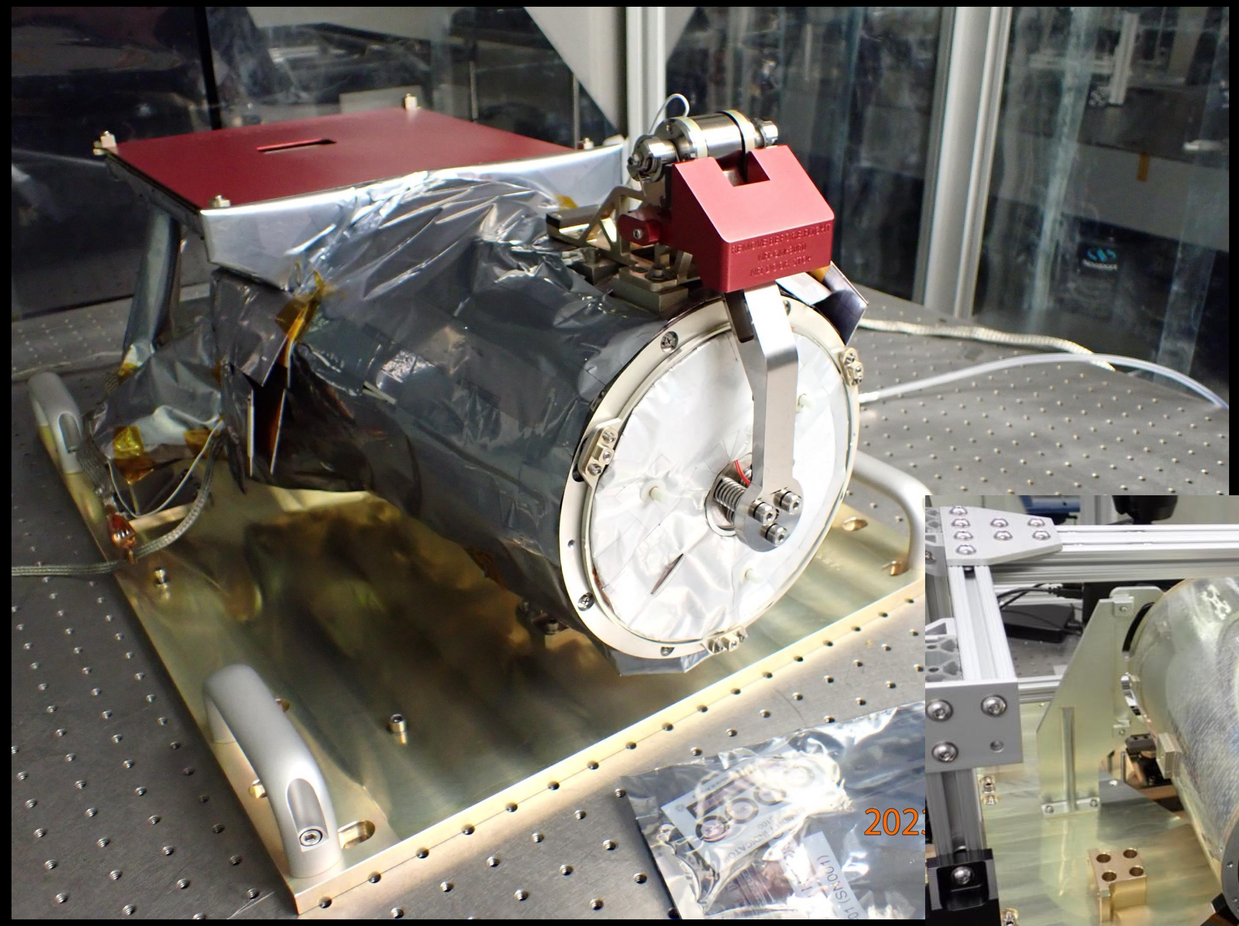
ee of polarization tells us the scattering angle.

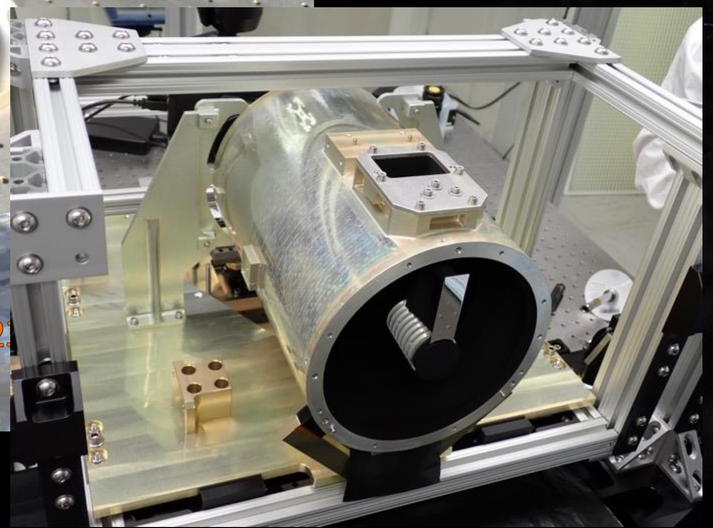
That tells us where the objec



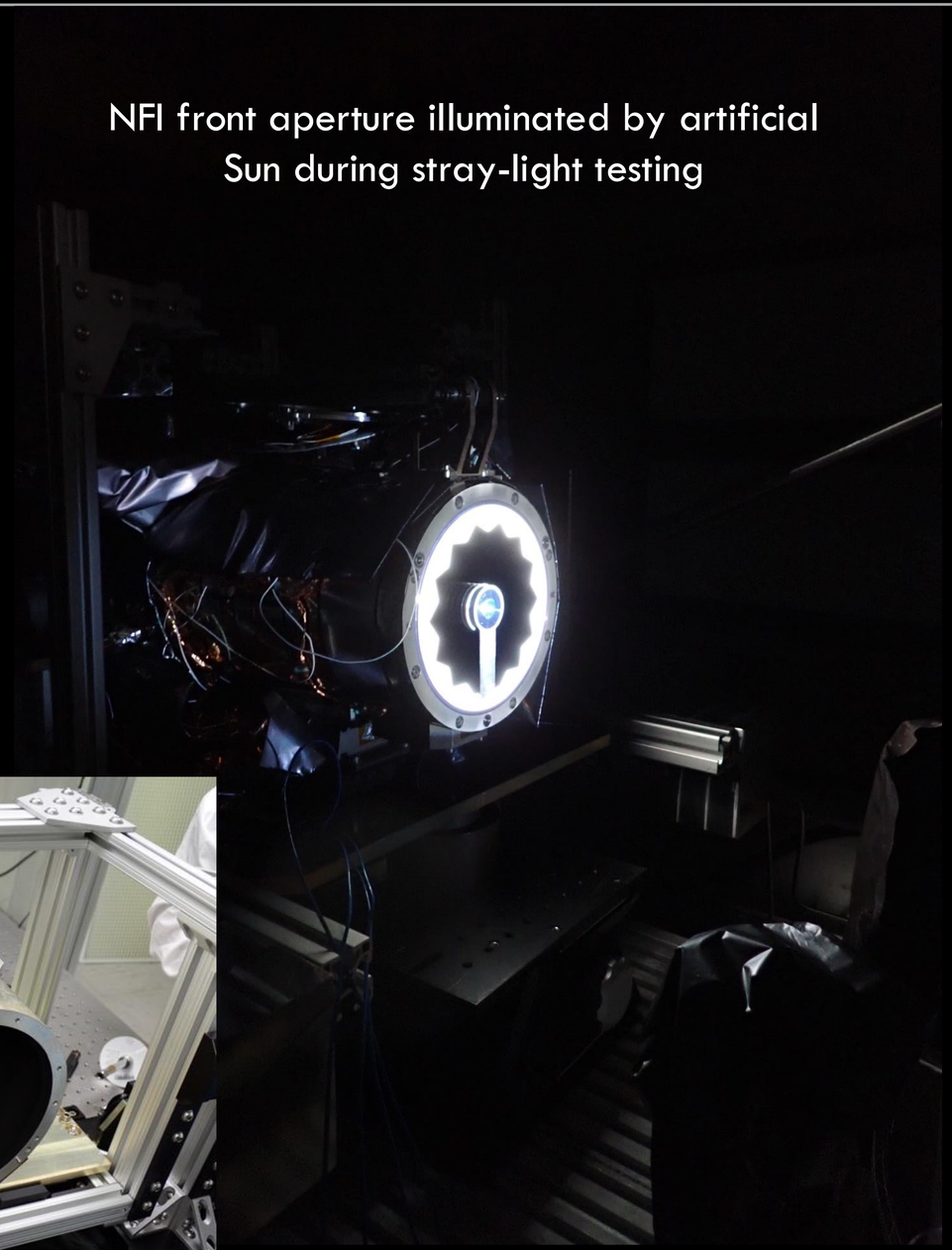
NARROW-FIELD IMAGER: PRE-DELIVERY (FALL 2023)

NFI complete & ready to deliver
(now flying on PUNCH!)

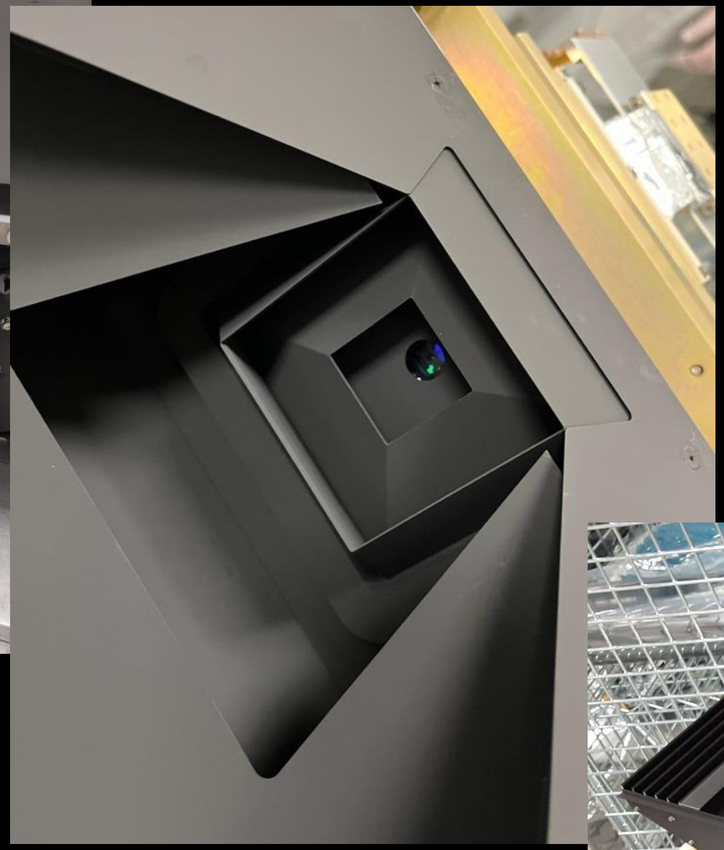


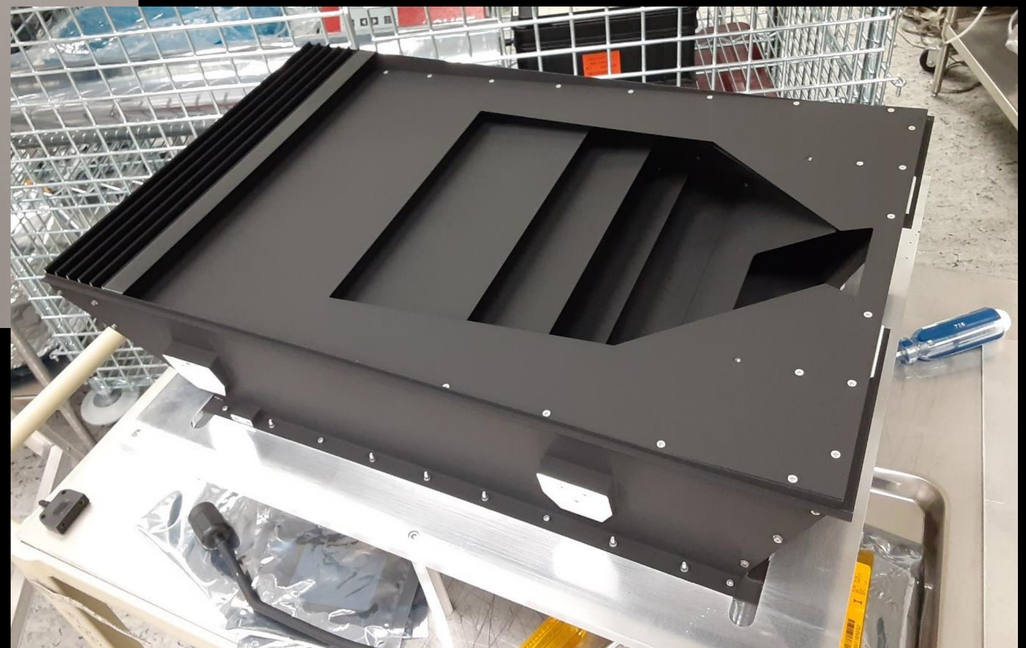


NFI front aperture illuminated by artificial
Sun during stray-light testing



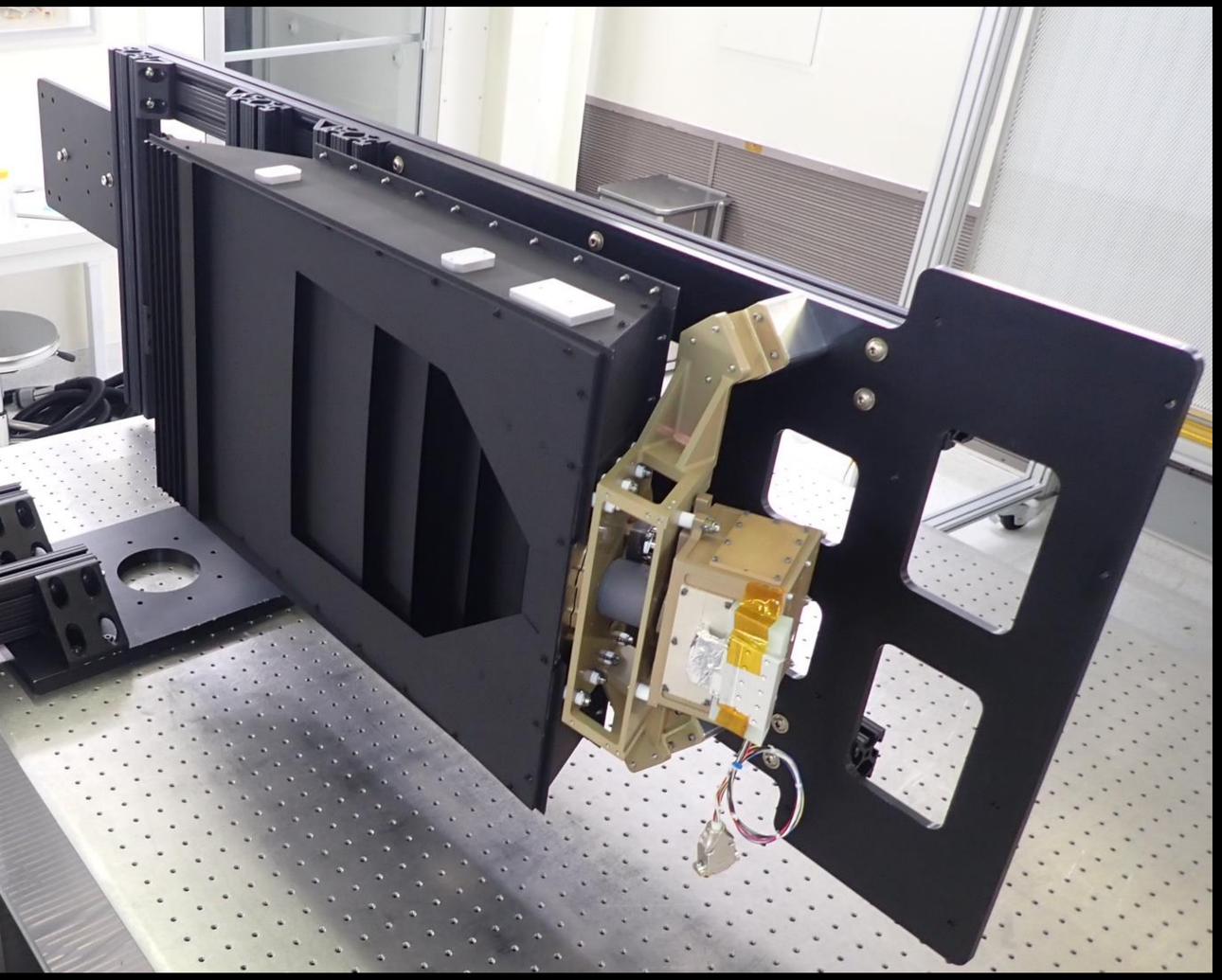
WIDE-FIELD IMAGER: PRE-DELIVERY (FALL 2023)



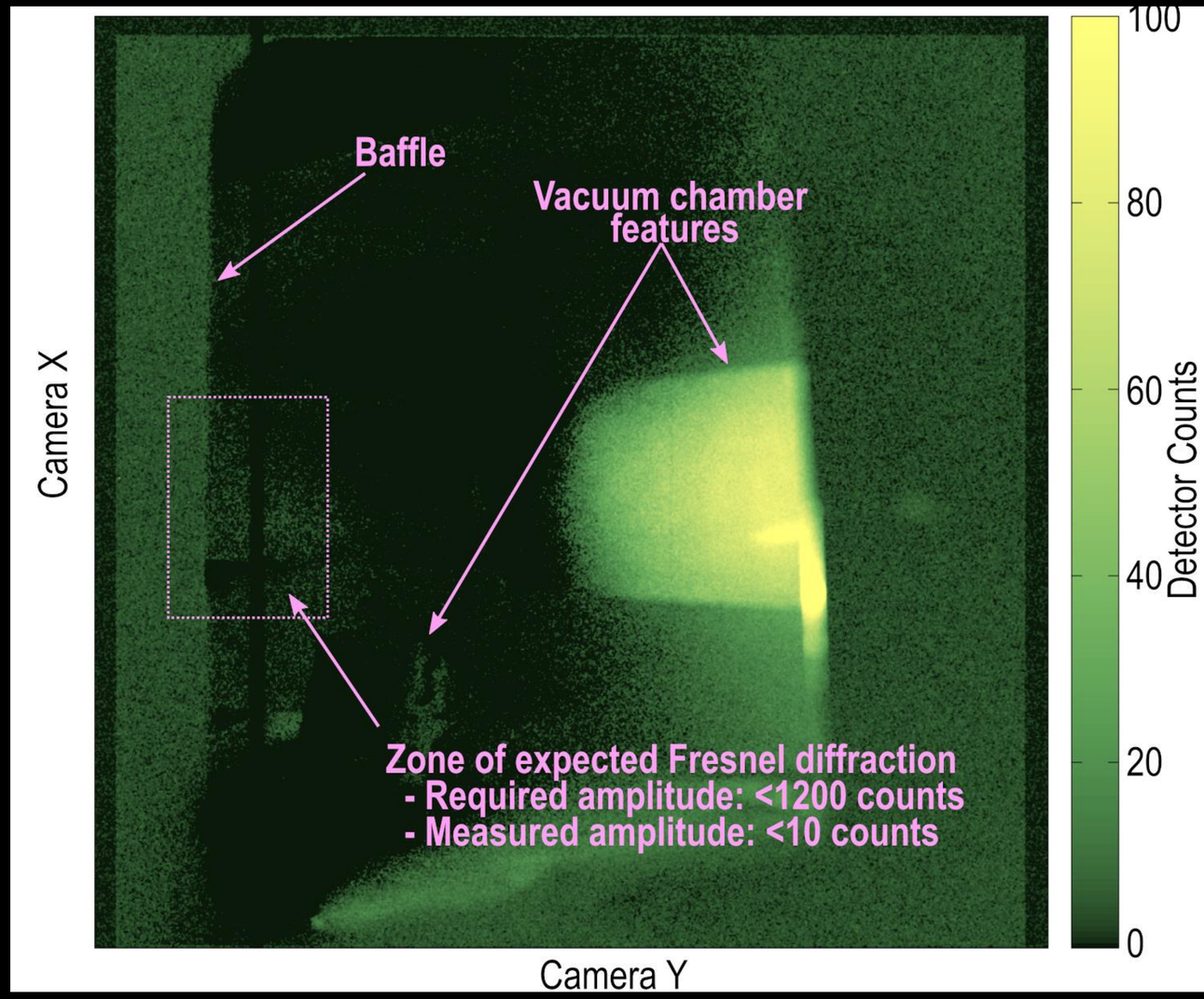


WIDE-FIELD IMAGER DURING VACUUM STRAY LIGHT TESTING

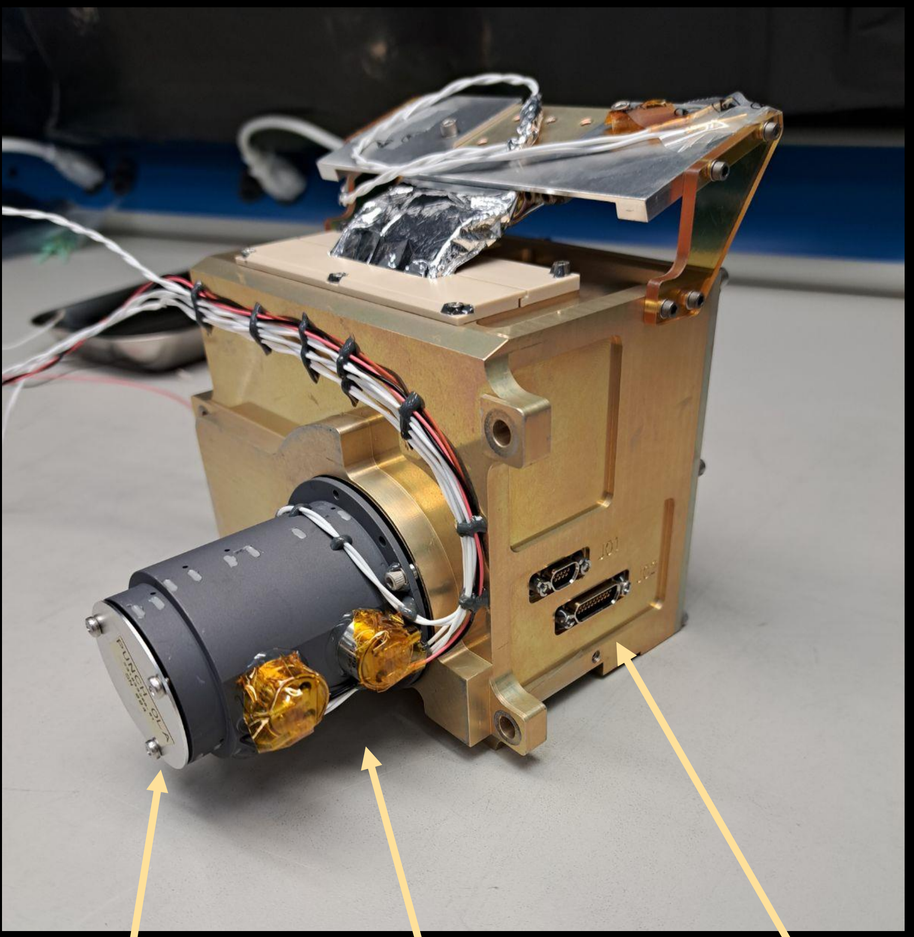
WFI during stray light testing at NRL
(2022)



WFI stray light image demonstrating
10^{-16} stray light performance



WIDE-FIELD IMAGER: OPTICS BY TELE VUE

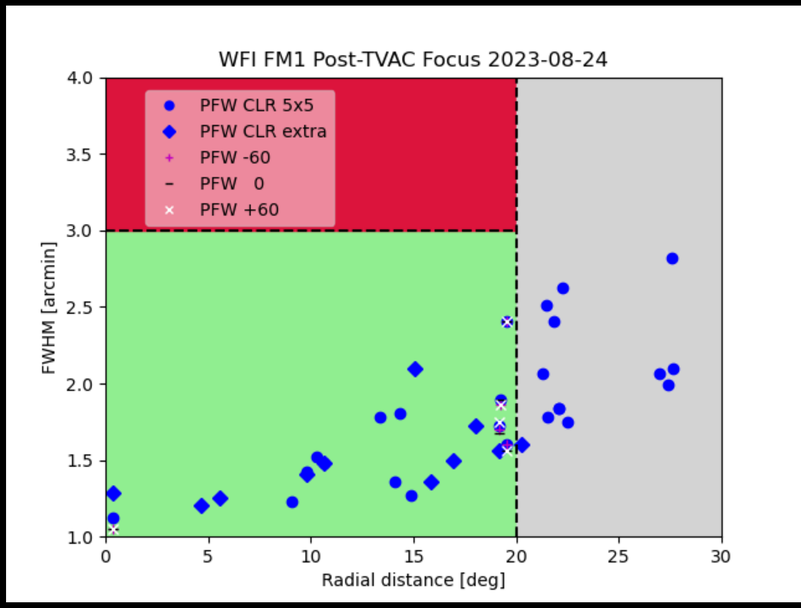


Lens cap

Optics “capsule”

Space-grade CCD camera

- Lens optics designed by Al Nagler (of the Nagler eyepiece)
  - “Eye relief”: external leading pupil
  - Very wide FOV (55° dia.)
  - Achromatic to edge of FOV
  - Excellent in-focus field size



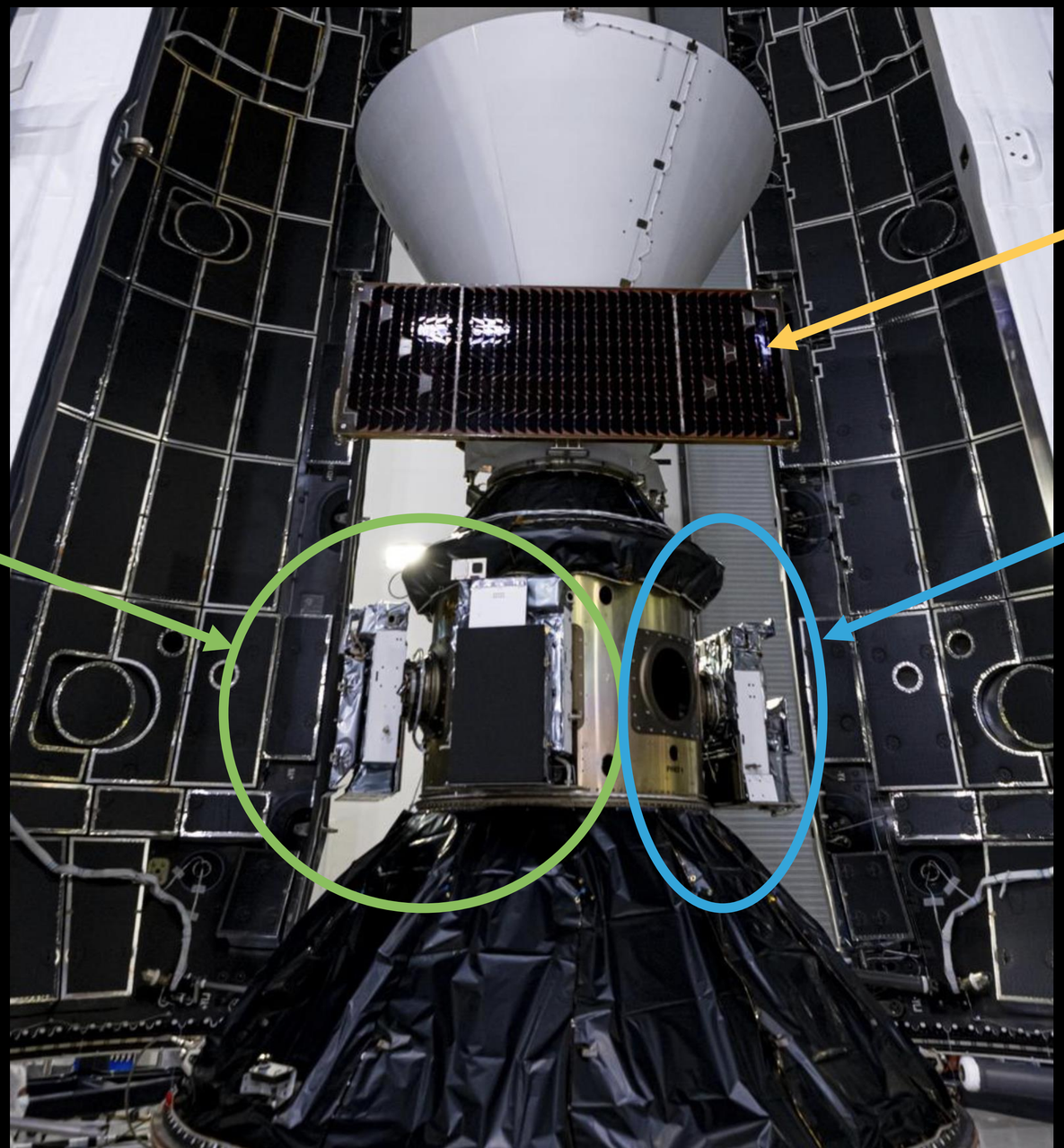
PSF performance: excellent

Al Nagler at the PUNCH Site Visit

WFI-1 INTEGRATION: FIRST LIGHT THROUGH WFI SPACECRAFT

PUNCH Final I&T and launch

PUNCH Observatories at VSFB



Early March 2025

PUNCH Observatories over Africa

March 11, 2025

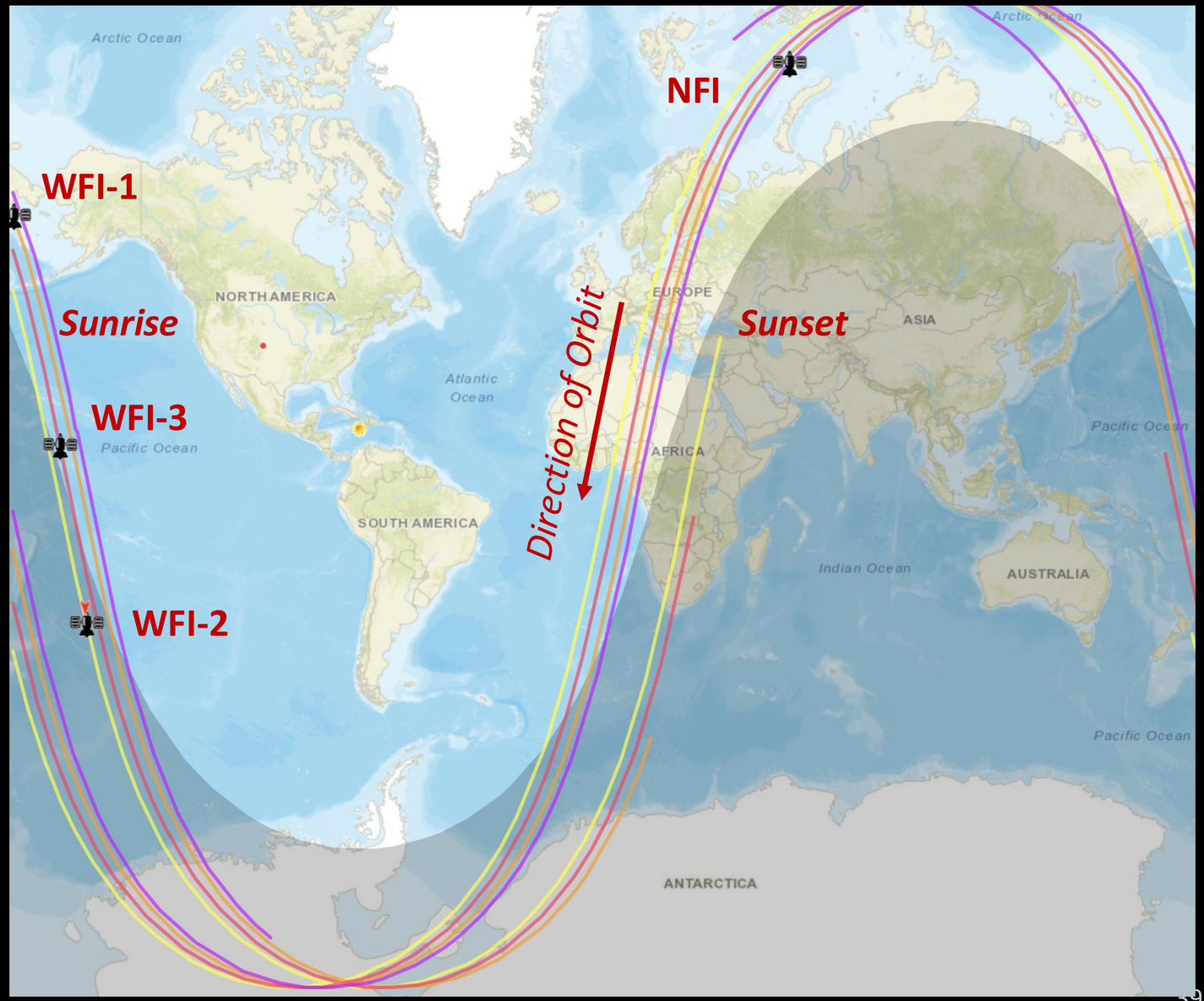
PUNCH Observatories today

- Drift rate: roughly 1° per day
- Today is Day 56 of mission
- Separation is ~50°

Map: n2yo.com

(uses NORAD orbital data)

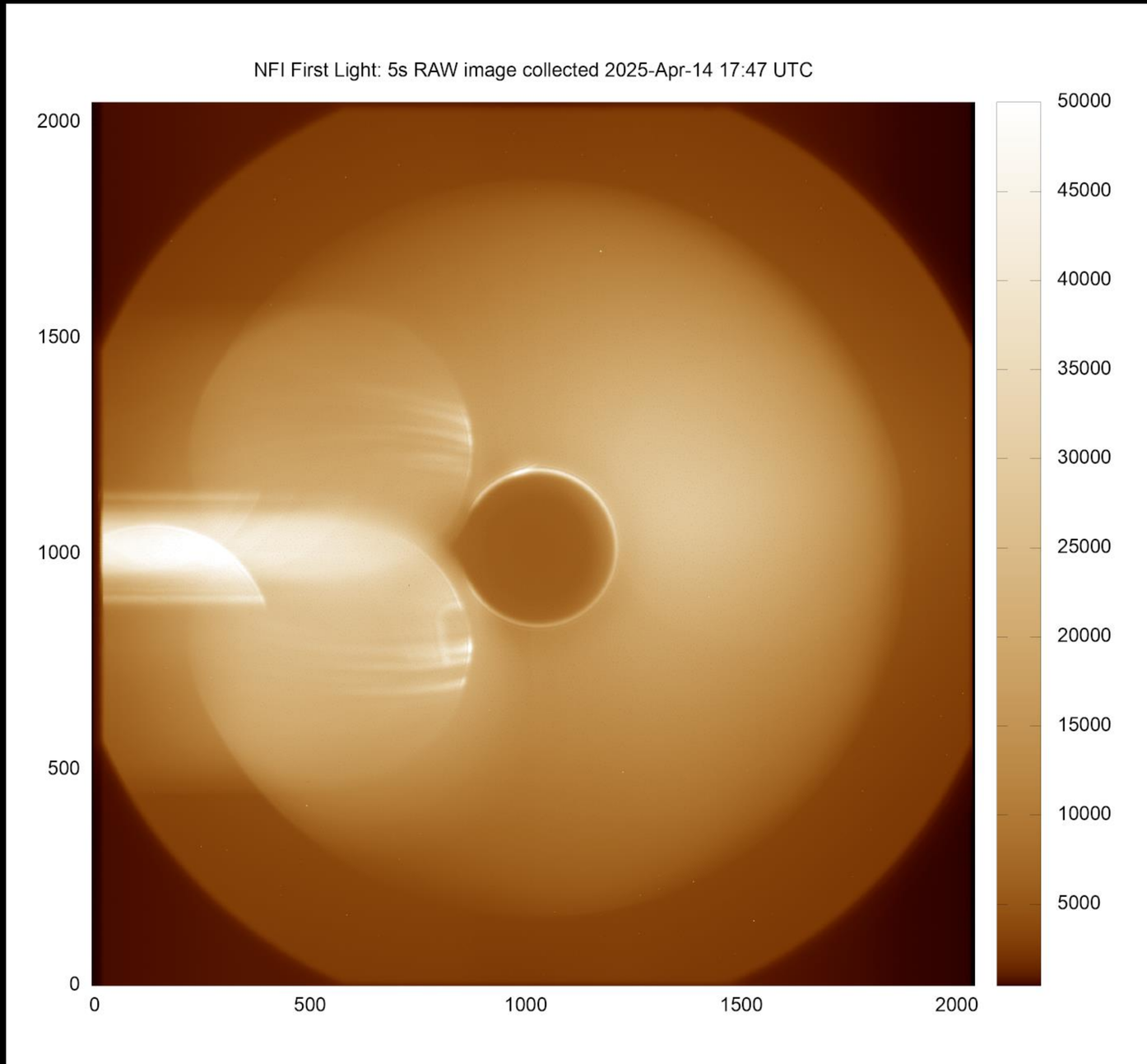
May 5, 2025



NFI FIRST LIGHT

First NFI solar image – direct from camera – 14-April-2025

- Alignment with Sun was good
  (has now been refined)
- Bright features: glint from pylon and occulter
- Stray light pattern: expected from CDR analyses



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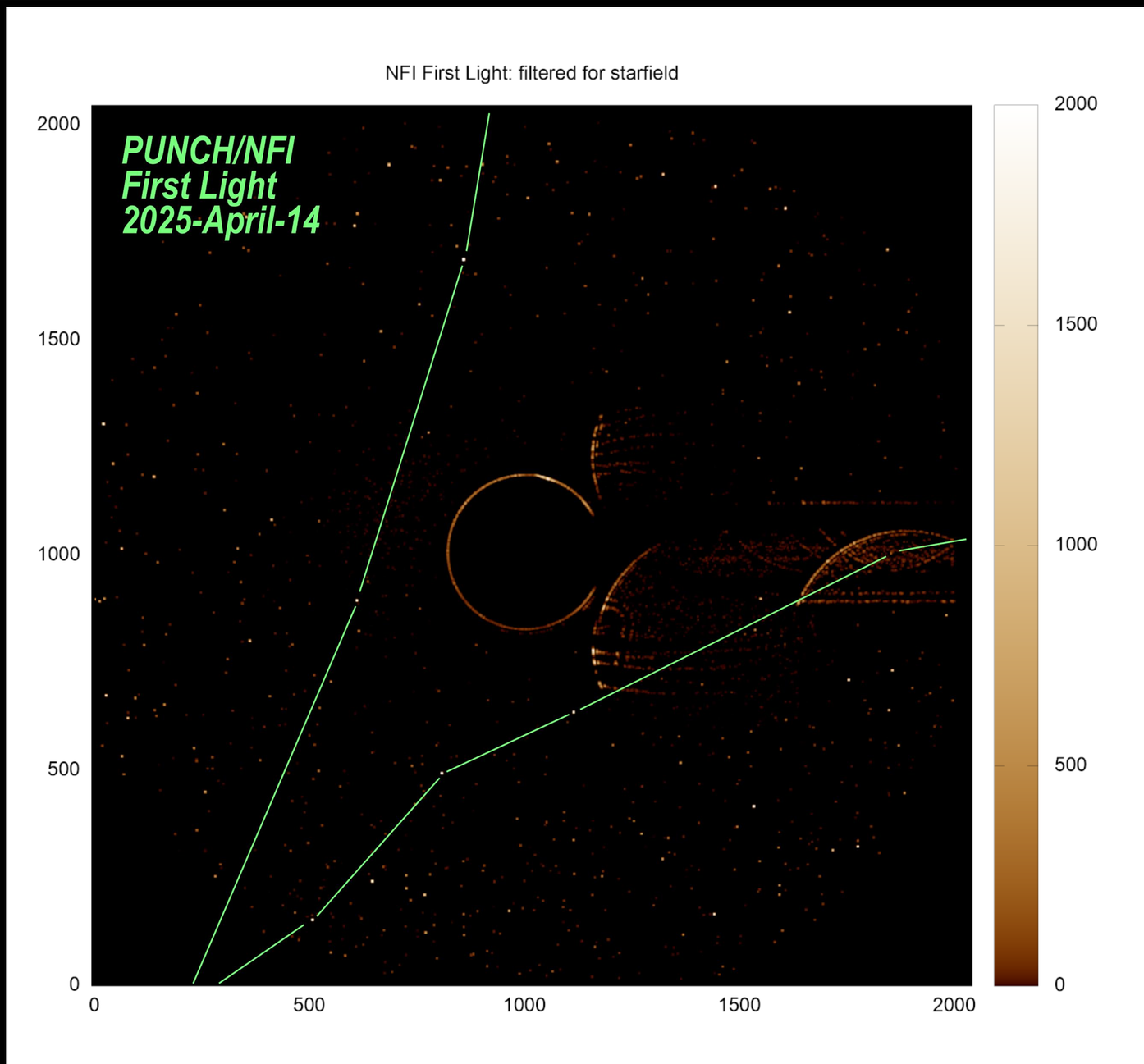
  (has now been refined)
- Bright features: glint from pylon and occulter
- Stray light pattern: expected from CDR analyses

Spatial filtering reveals:

- Excellent focus & detector linearity
- Scientifically useful data (after processing)

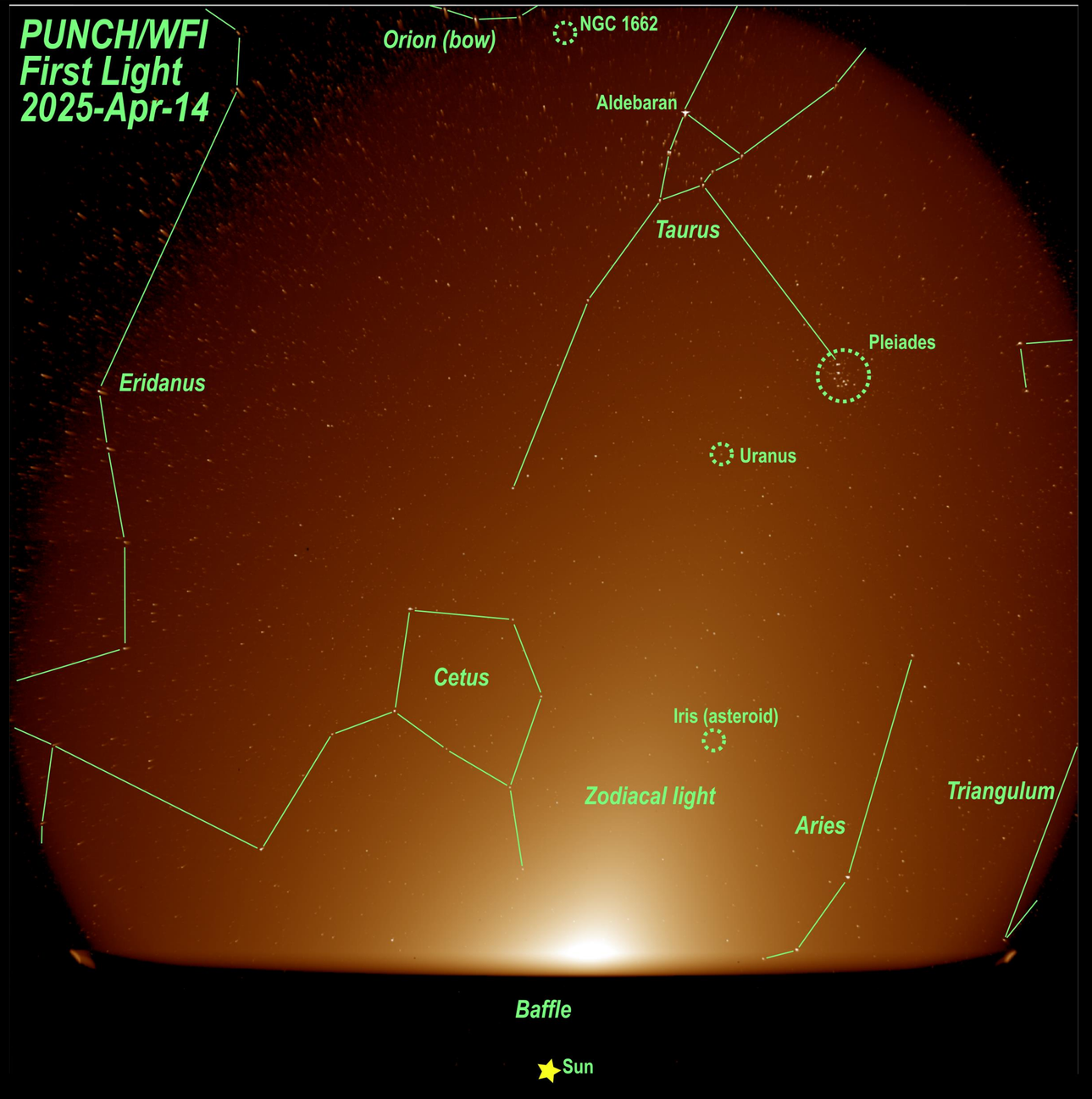


WFI FIRST LIGHT

First WFI image – direct from camera – 14-April-2025

- Focus is ideal
- Stray light is essentially nonexistent
- 9th magnitude objects visible in raw data (Iris)
- This image: WFI-2

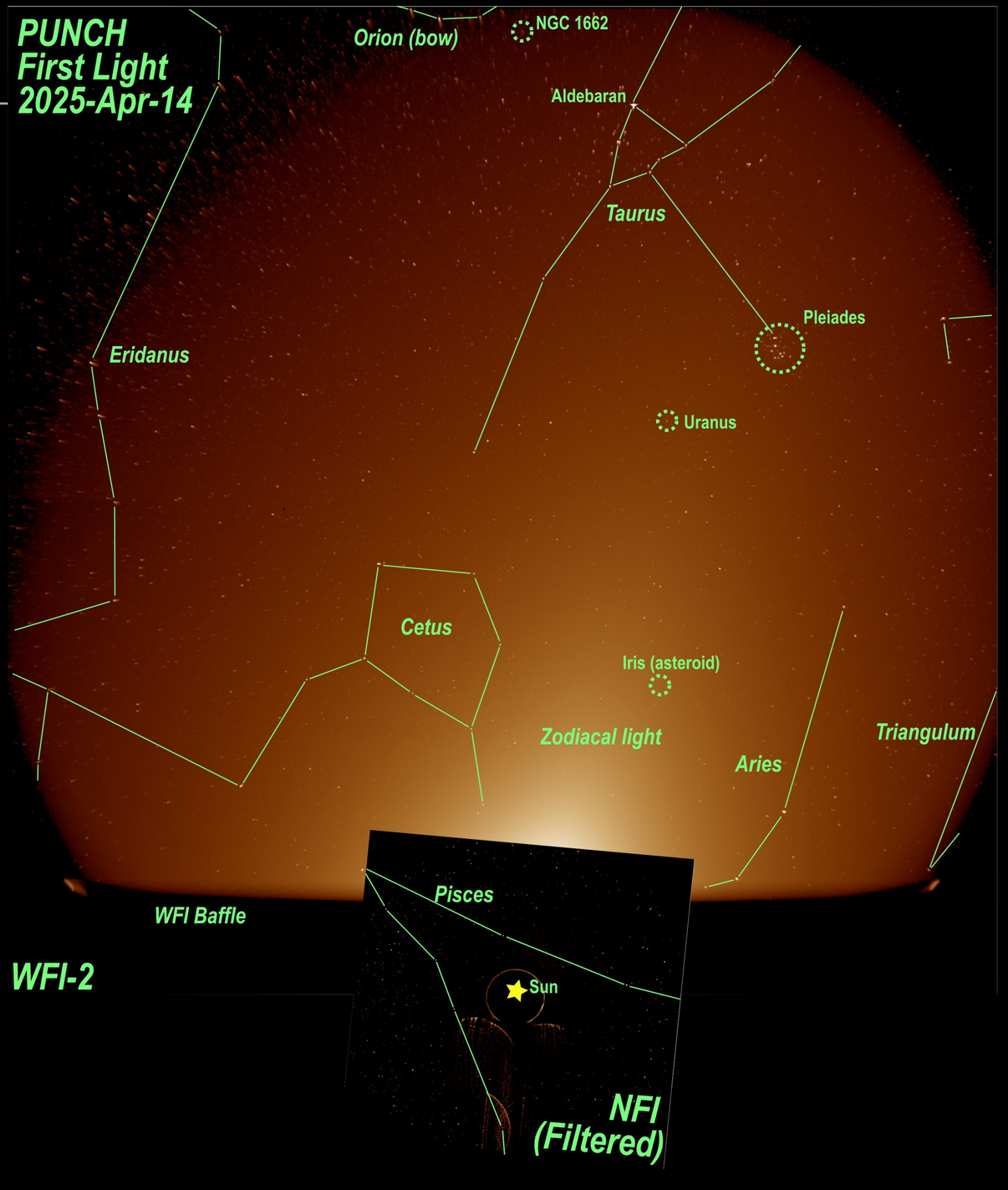
- Some expected coma visible at upper left; will be removed as part of L1 processing



FIRST PARTIAL MOSAIC

Overlay helps visualize fields of view

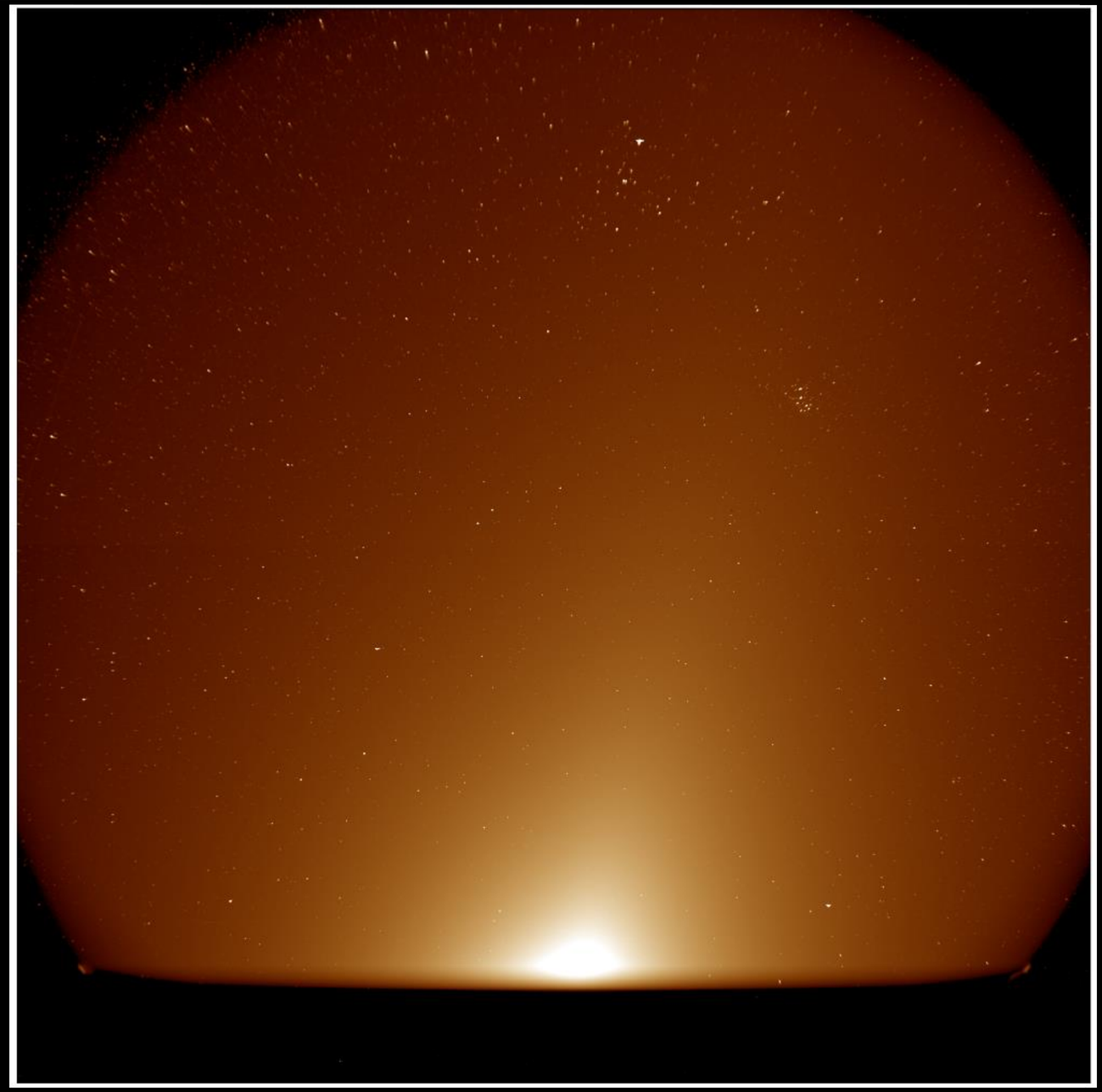
- Manual alignment
- Starfields line up very well (even raw)
- NFI/WFI overlap to calibrate & remove stray light
- WFI “rocking test”: pending



WFI FIRST LIGHT

First WFI-1 image – direct from camera – 16-April-2025

- Essentially identical to WFI-2

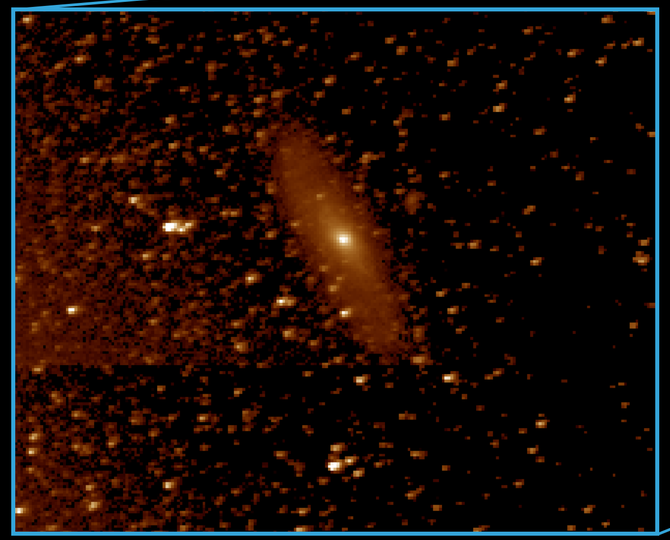


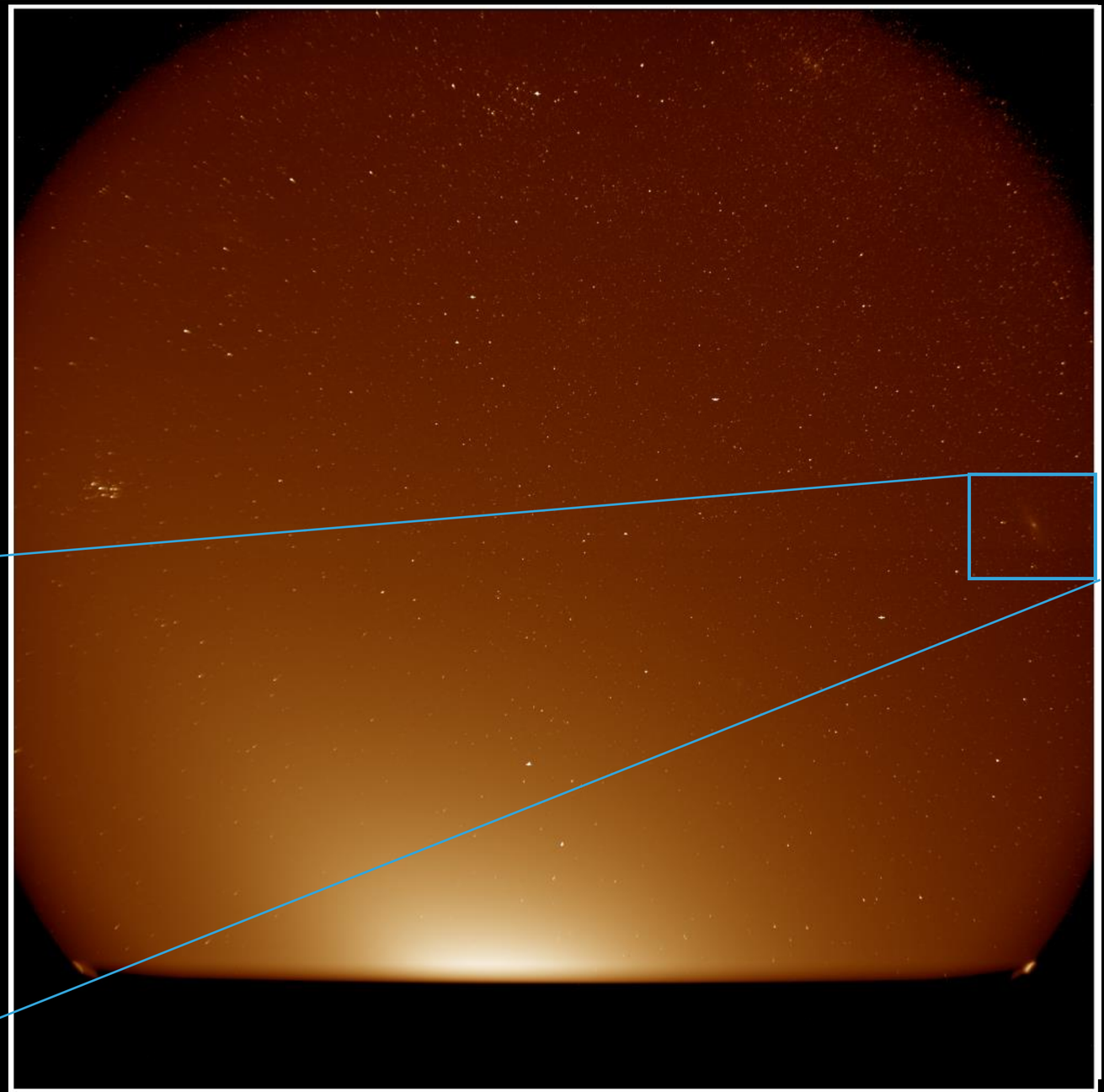
First WFI-3 image – direct from camera – 16-April-2025

- Essentially identical to WFI-2
- Different field

Baby’s First Galaxy!

Andromeda

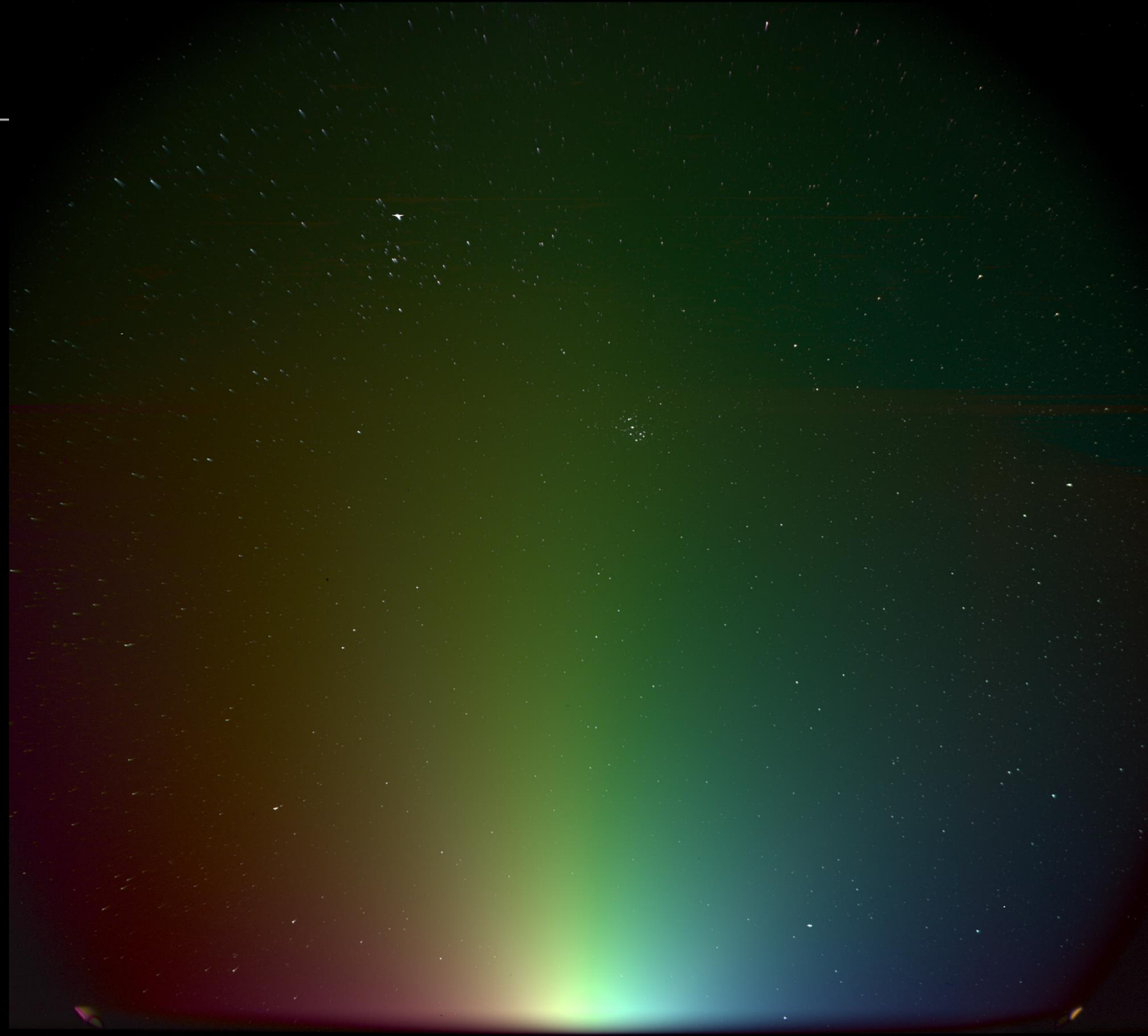




POLARIZATION IS WORKING

First WFI-2 polarized image sequence: 16-April-2025

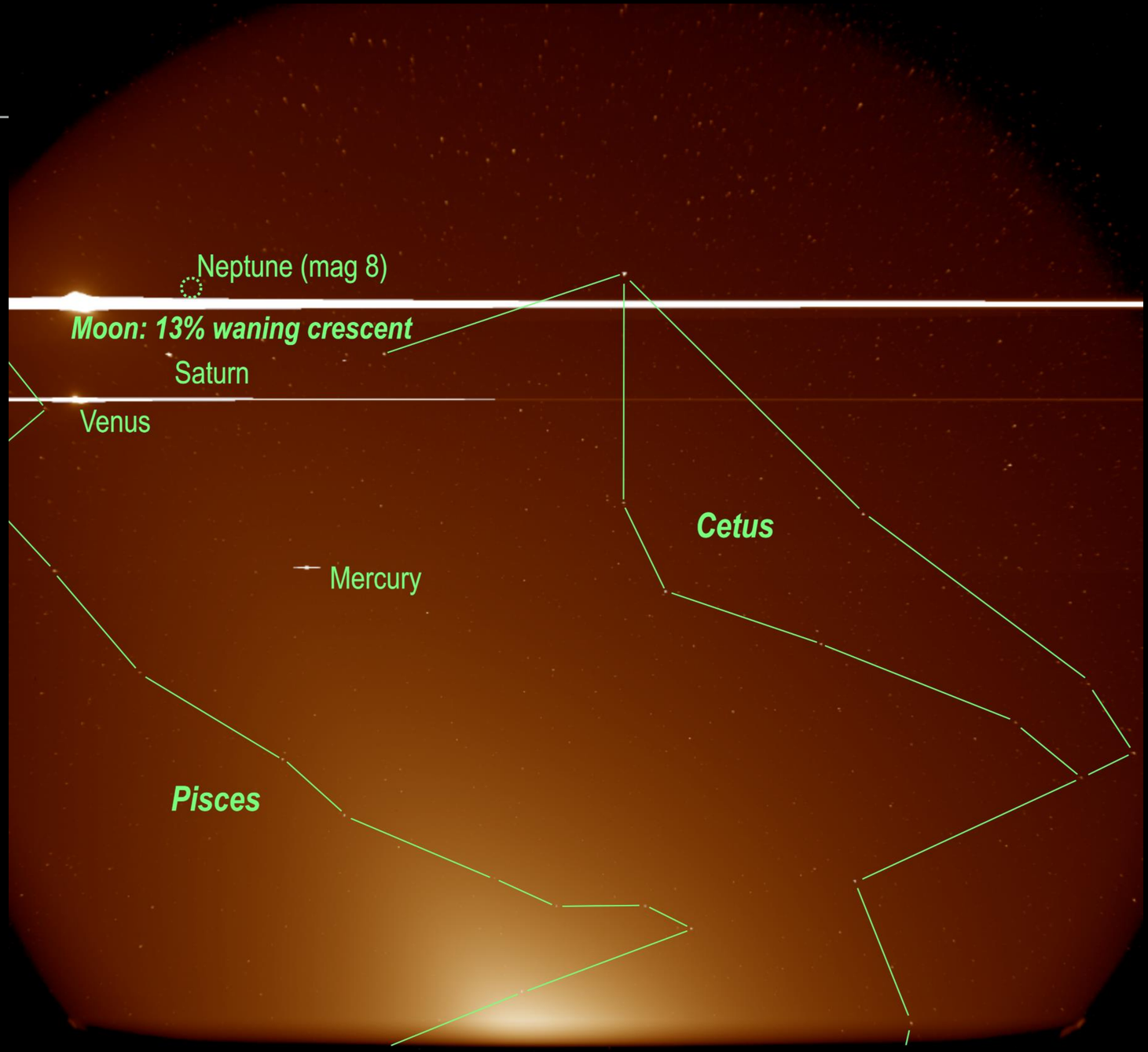
- Uses tri-polarizer method
- Hue encodes polarization
- Matches published strength & direction of F polarization (Leinert et al. 1999)



THE SMILEY CONJUNCTION

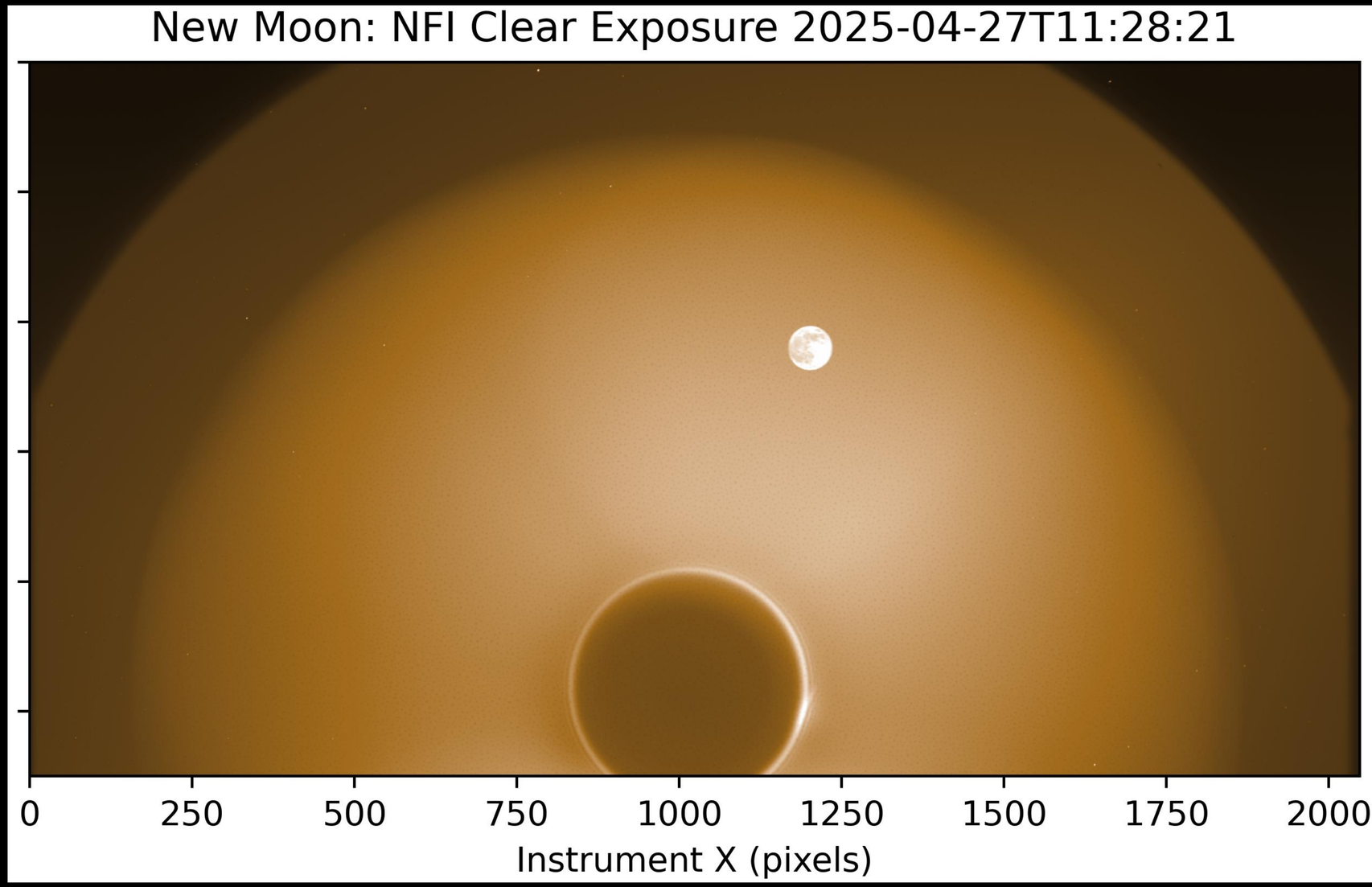
WFI-1 test sequence: 24-April-2025

- Shows effect of Moon on images
- Four planets + Moon: one frame



NFI test image: 27-April-2025

- New moon does not swamp NFI.



PUNCH Data Are Coming!

OPEN DATA POLICY

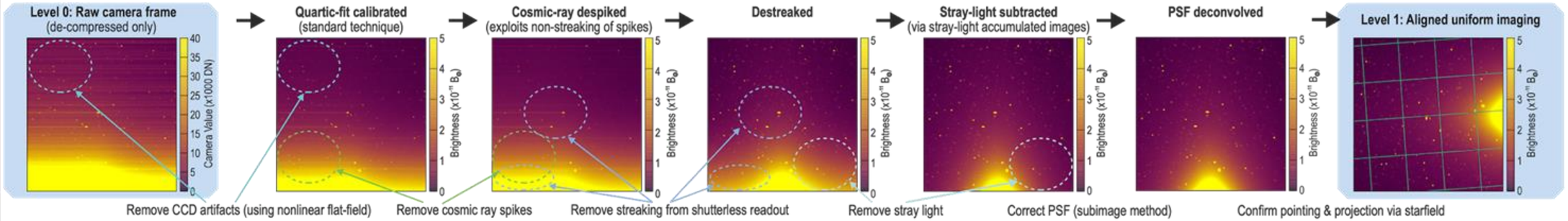
- All PUNCH science data are available to everyone for any purpose.
- Use PUNCH data at your own risk.
- Data distribution starts *this week!*
- *Visit our website: https://punch.space.swri.edu*

PUNCH Science Data Pipeline and Products

For effective data analysis by the PUNCH team and the broader community, PUNCH produces (A-C) and disseminates (D) calibrated, simple-to-use data products and analysis tools.

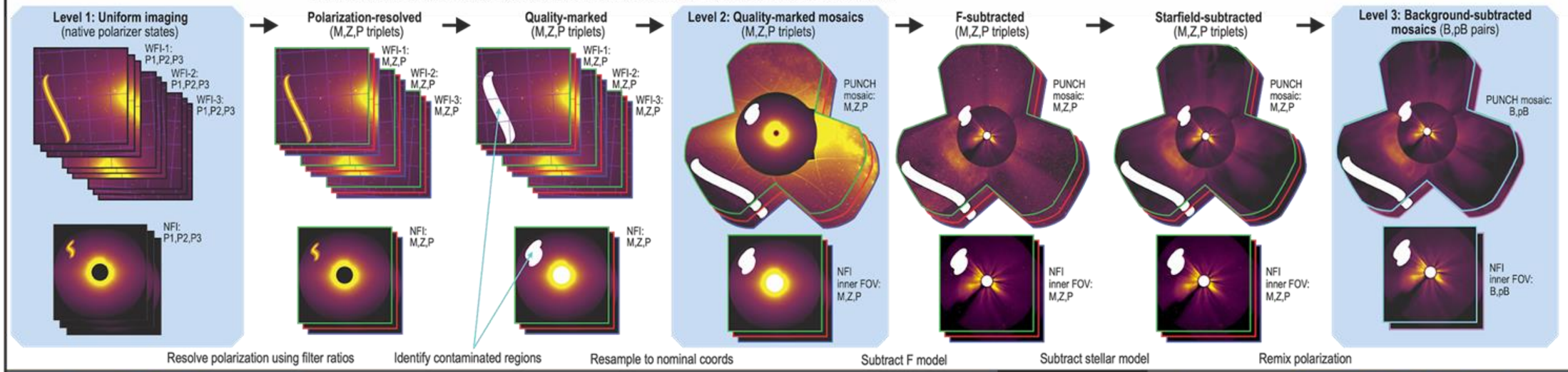
A. Level 0 → Level 1 Pipeline

Level 1 images are photometrically calibrated, precisely aligned images with instrumental artifacts corrected. To demonstrate PUNCH data reduction, we degraded and then processed data from STEREO/HI1 to show the PUNCH L1 processing. For clarity, all visual effects are 10-40x stronger here than in actual PUNCH images. These processing steps are the same for both WFI and NFI.



B. Level 1 → Level 3 Pipeline

The L1 to L2 stage maps polarization to M,Z,P triplet polarizer brightnesses, then generates full PUNCH mosaics. Clear exposures (not shown) skip the (M,Z,P) step. The L2 to L3 stage removes background F corona (fixed in heliospheric coordinates) and starfield (fixed in celestial coordinates), then generates B and pB products. Nearly all frames have no contamination.



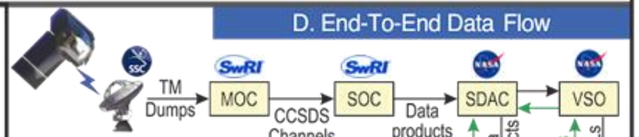
C. Level 3 Data Products

PUNCH Data Products are polarized and clear photometric images suitable for analysis in common existing scientific environments and with PUNCH-specific tools distributed by the project. Primary science products are shown.

Legend

- Data Product
- Polarized Images:
  - M (–60°)
  - Z (0°)
  - P (+60°)
- B
- pB
- Clear

D. End-To-End Data Flow



PUNCH data are downlinked and transferred to the MOC, reduced (Panels A-C) at the SOC, then mirrored to SDAC for archiving & dissemination. SOC software written in Python and publicly accessible via SunPy/Github.

Code/Tool/Doc Repository (main at SwRI; mirror at SDAC)

- PUNCH Science Team
- Science Community
- General Public

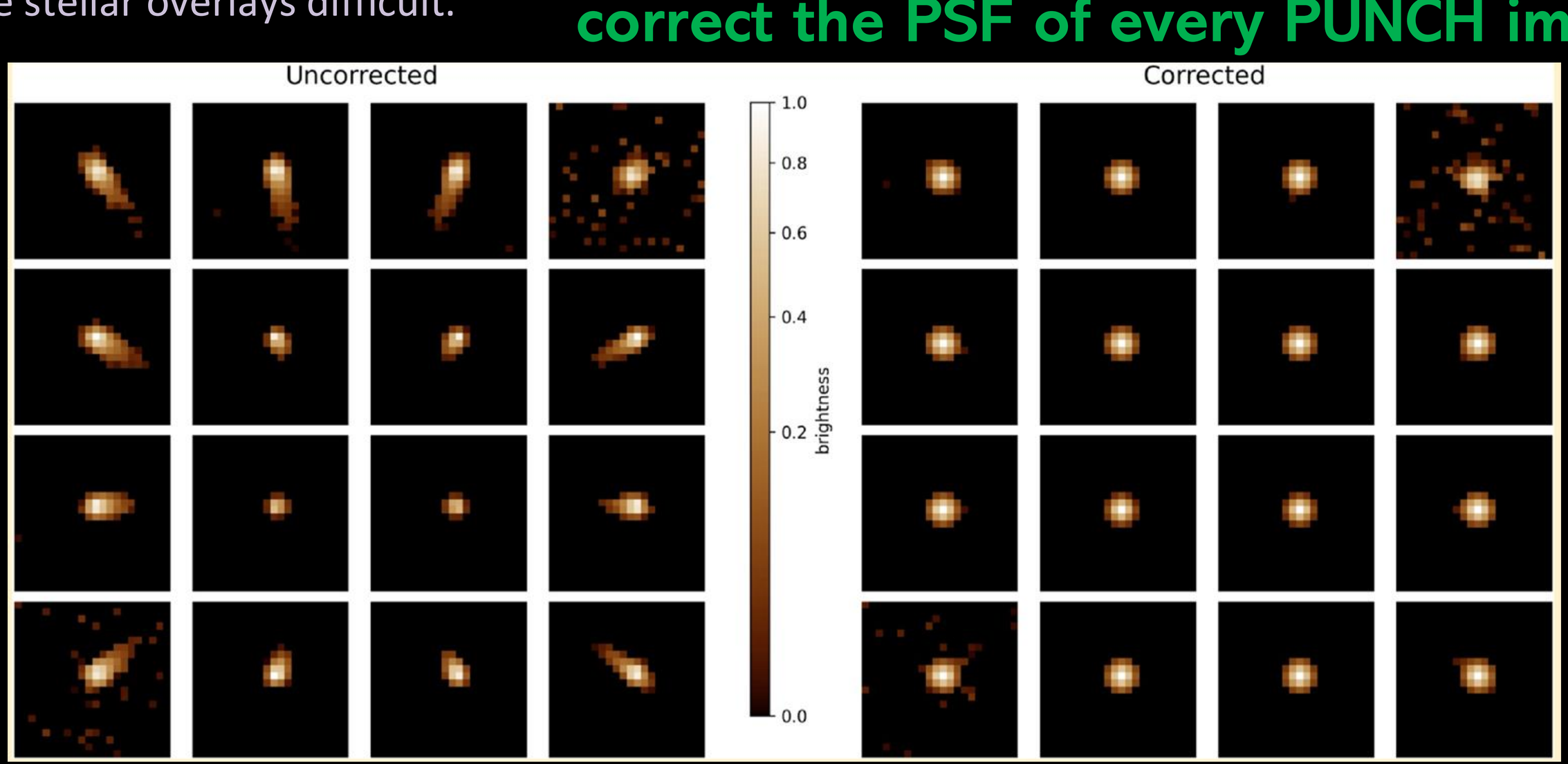
SOC pipeline workflow orchestrated by Prefect. Data & metadata flow managed with NDCube.

PREFECT

CHALLENGE WITH MAKING MOSAICS: VARIABLE DISTORTION IN WIDE-FIELD OPTICS

Problem: coma and other distortion make stellar overlays difficult.

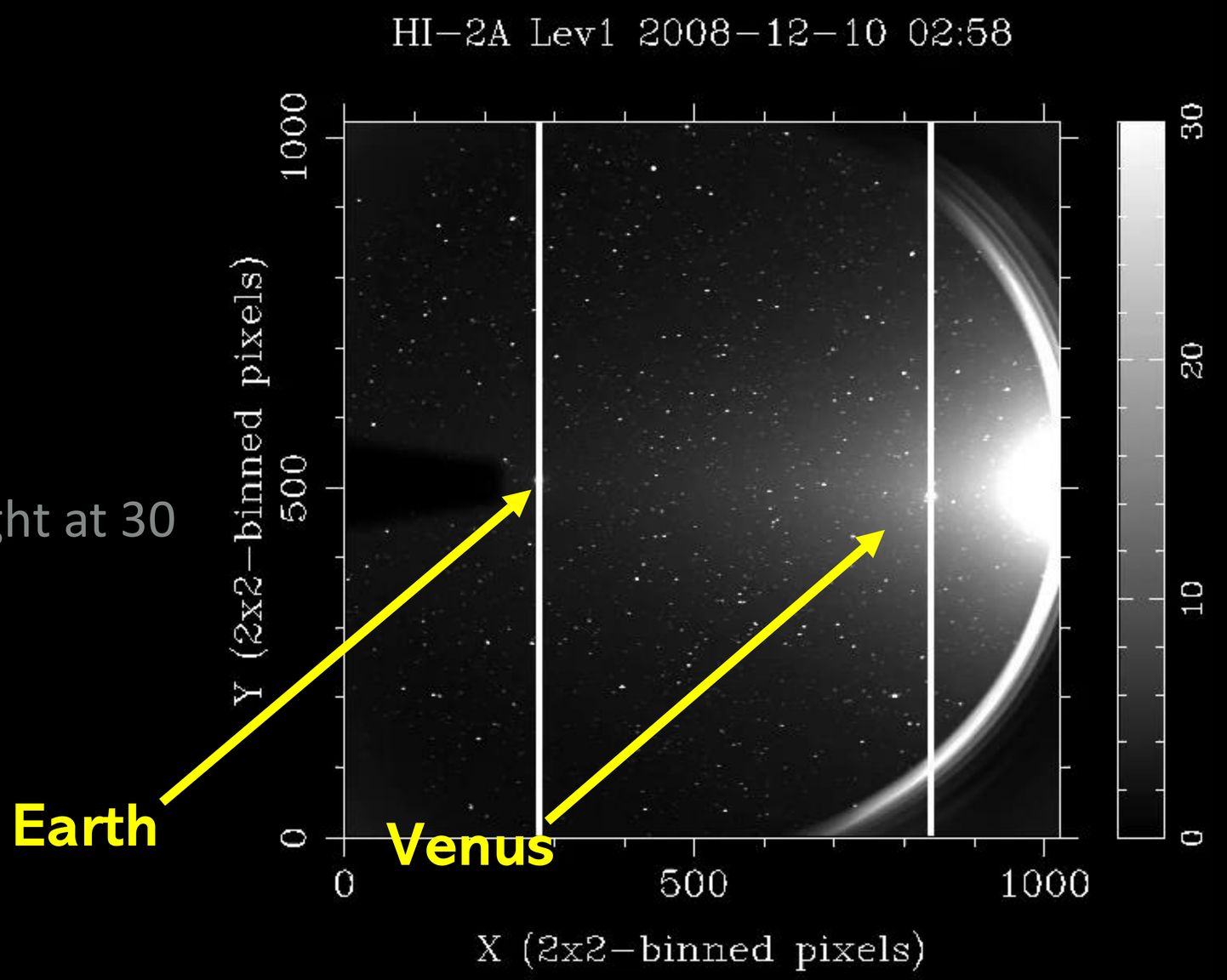
SOLVED: SOC uses Fourier methods to correct the PSF of every PUNCH image



STEP 0:

START WITH PHOTOMETRIC DATA (“L1”)

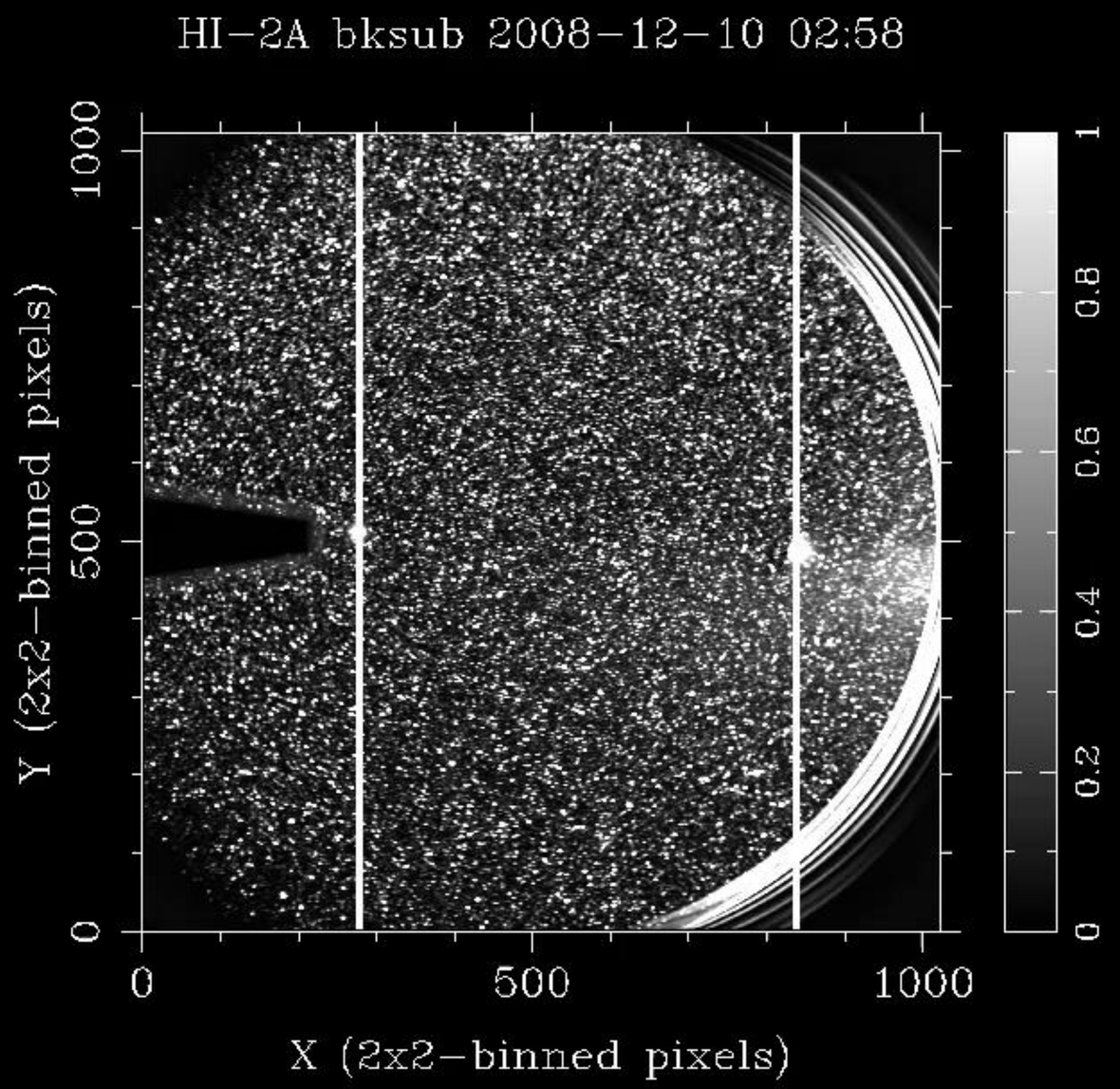
- Main background: Zodiacal light at 30 DN/sec



STEP 1:

REMOVE FIXED PATTERN IN SOLAR COORDS

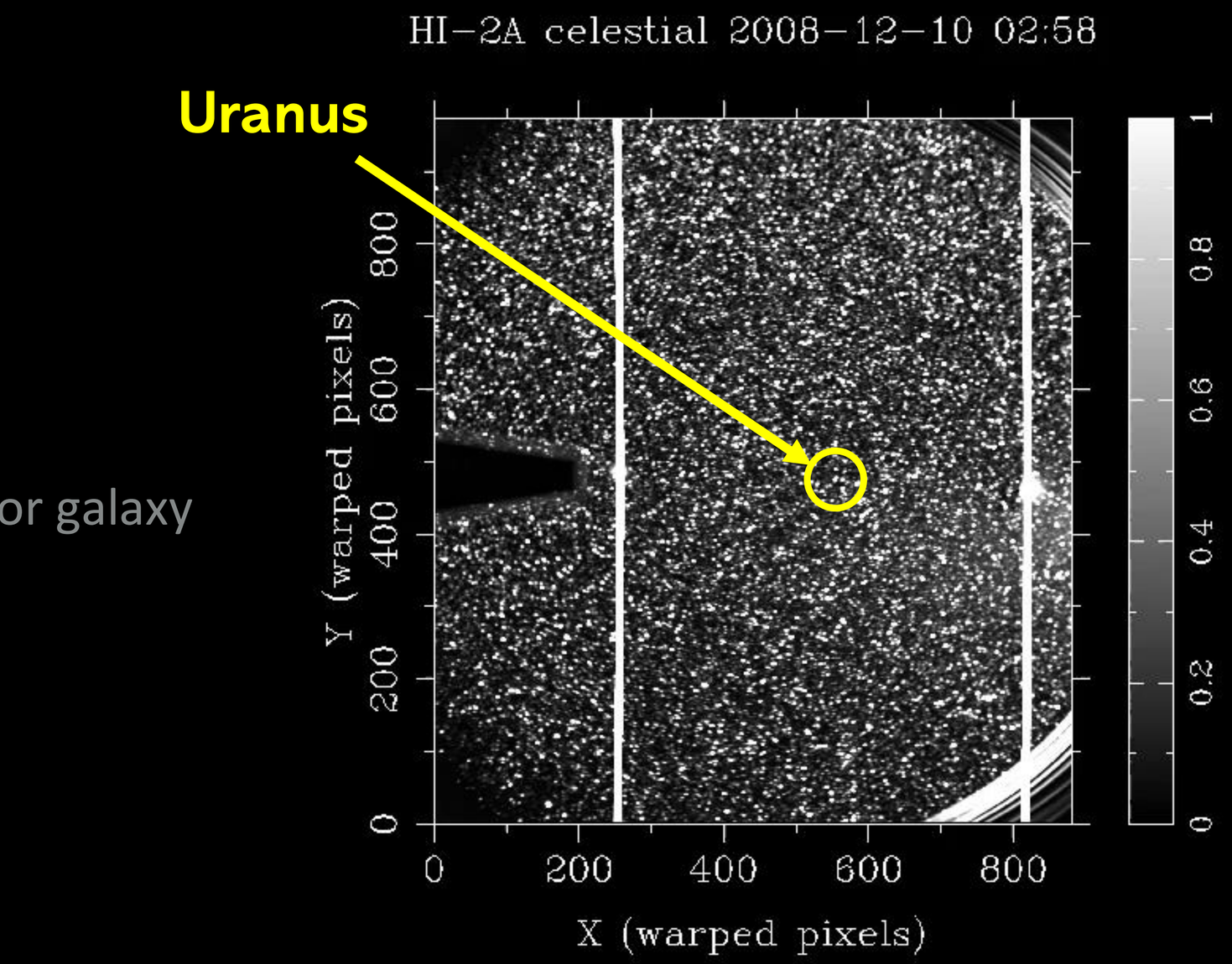
- Main background: starfield or galaxy at 1-50 DN/sec



STEP 2:

CO-ALIGN STARFIELD

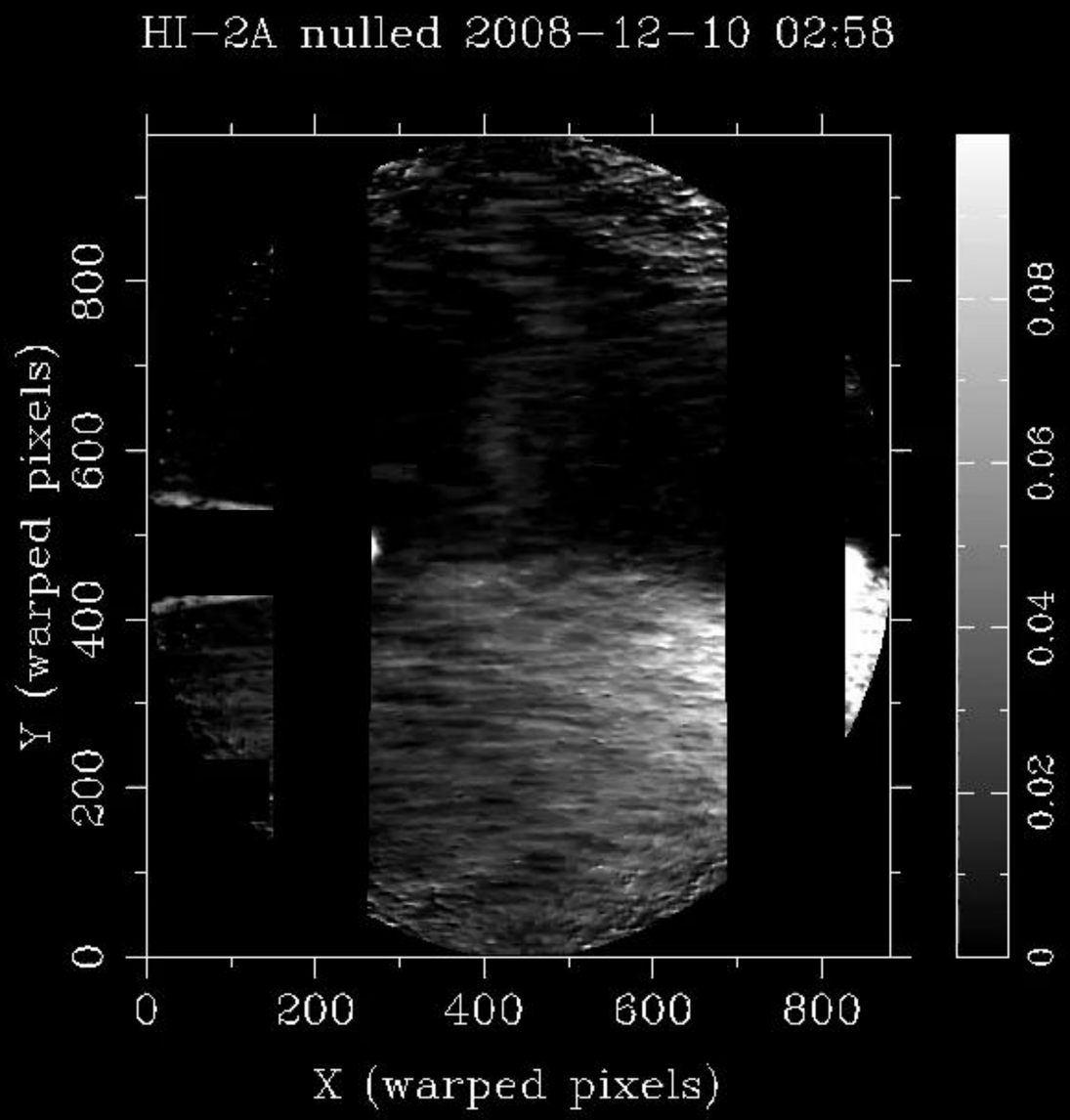
- Main background: starfield or galaxy at 1-50 DN/sec



STEP 3:

REMOVE FIXED PATTERN IN CELESTIAL COORDS

- Main background: residual zodiacal light and 2nd order starfield artifacts at 0.1 DN/sec

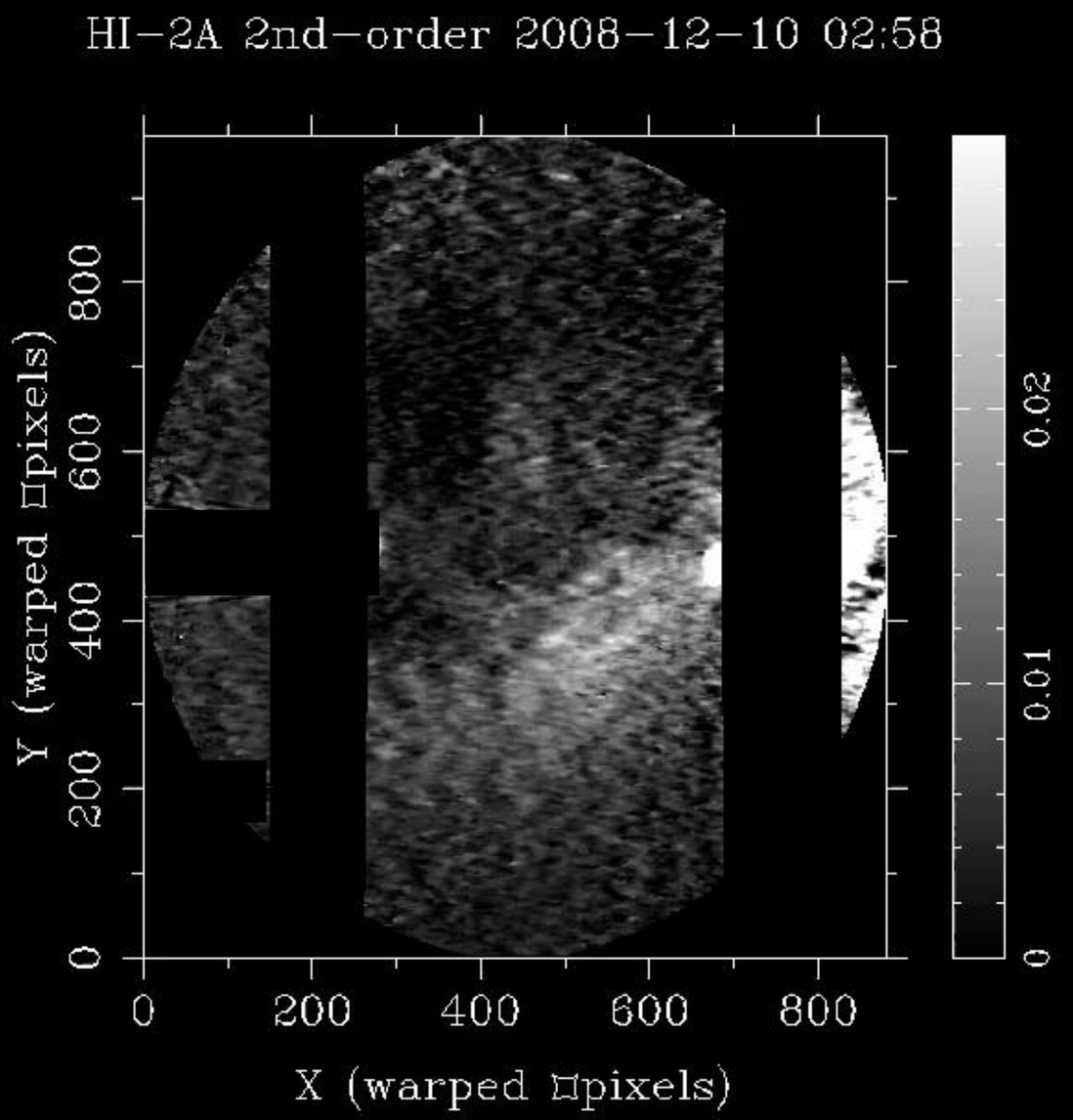


STEP 4:

REMOVE RESIDUAL F CORONA & STELLAR 2ND ORDER ARTIFACTS

(CUBIC TEMPORAL FIT FOR EACH PIXEL)

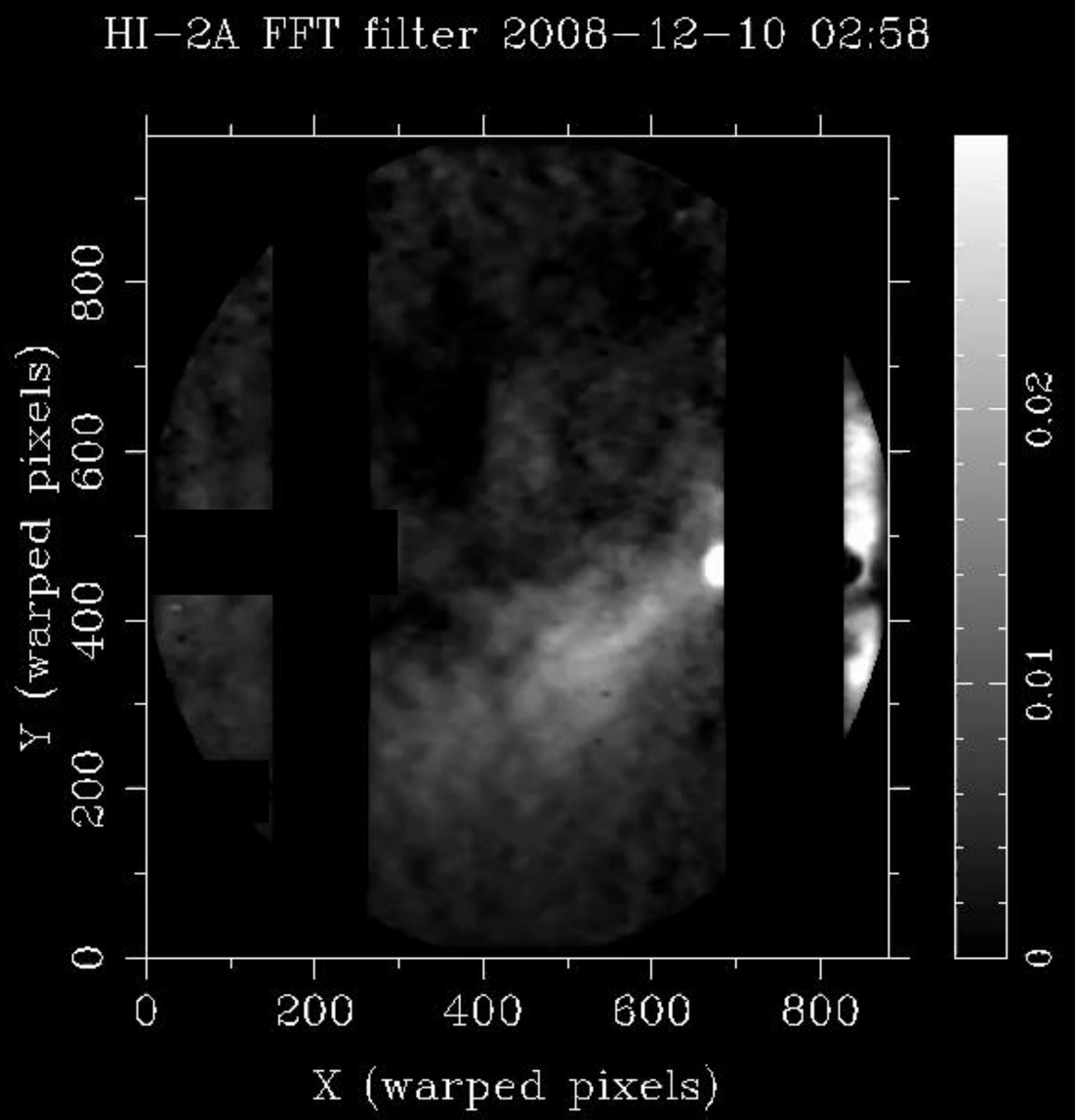
- Main background: nonlinear-photometry starfield artifacts at 0.02 DN/sec



STEP 5:

REMOVE STATIC FEATURES: FOURIER MOTION FILTERING

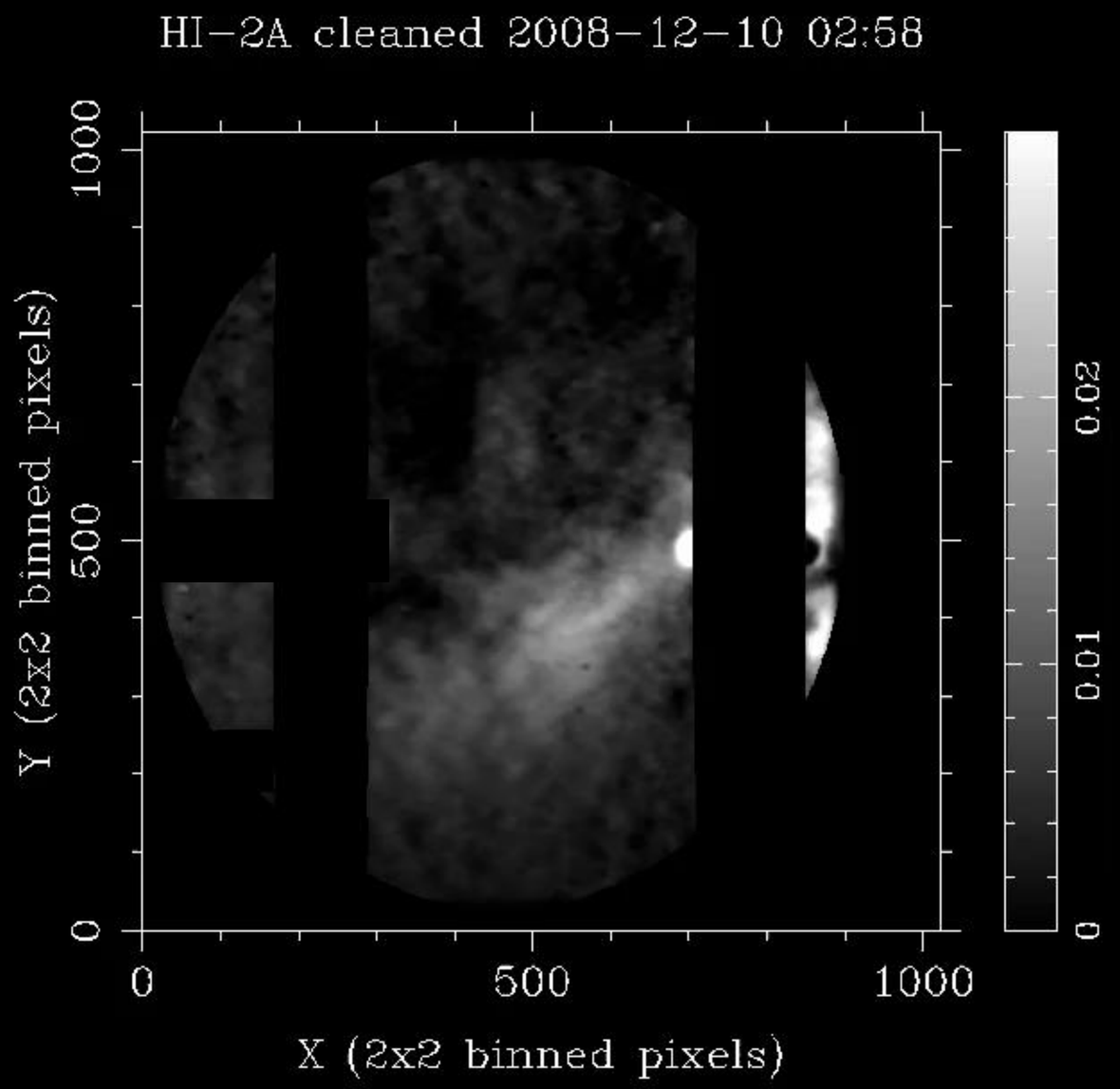
- Main background: stellar residuals and Fourier ringing at 0.002DN/sec



STEP 6:

RESAMPLE TO SOLAR COORDINATES

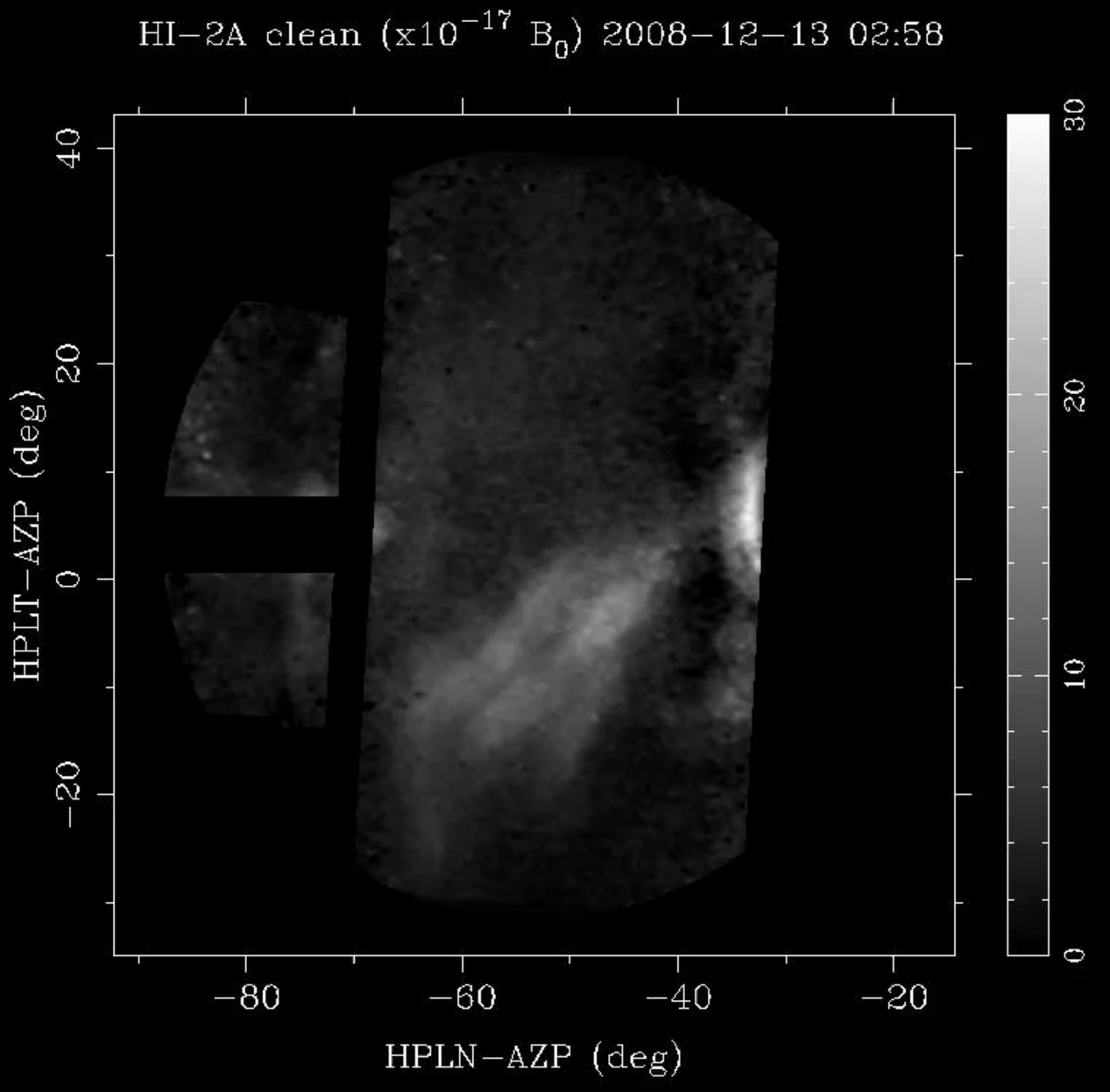
- Main background: stellar residuals and Fourier ringing at 0.002DN/sec



STEP 7:

AVERAGE ACROSS BATCHES

- Main background: stellar residuals at roughly 0.001DN/sec (10^{-17} B_0) in faint starfield regions



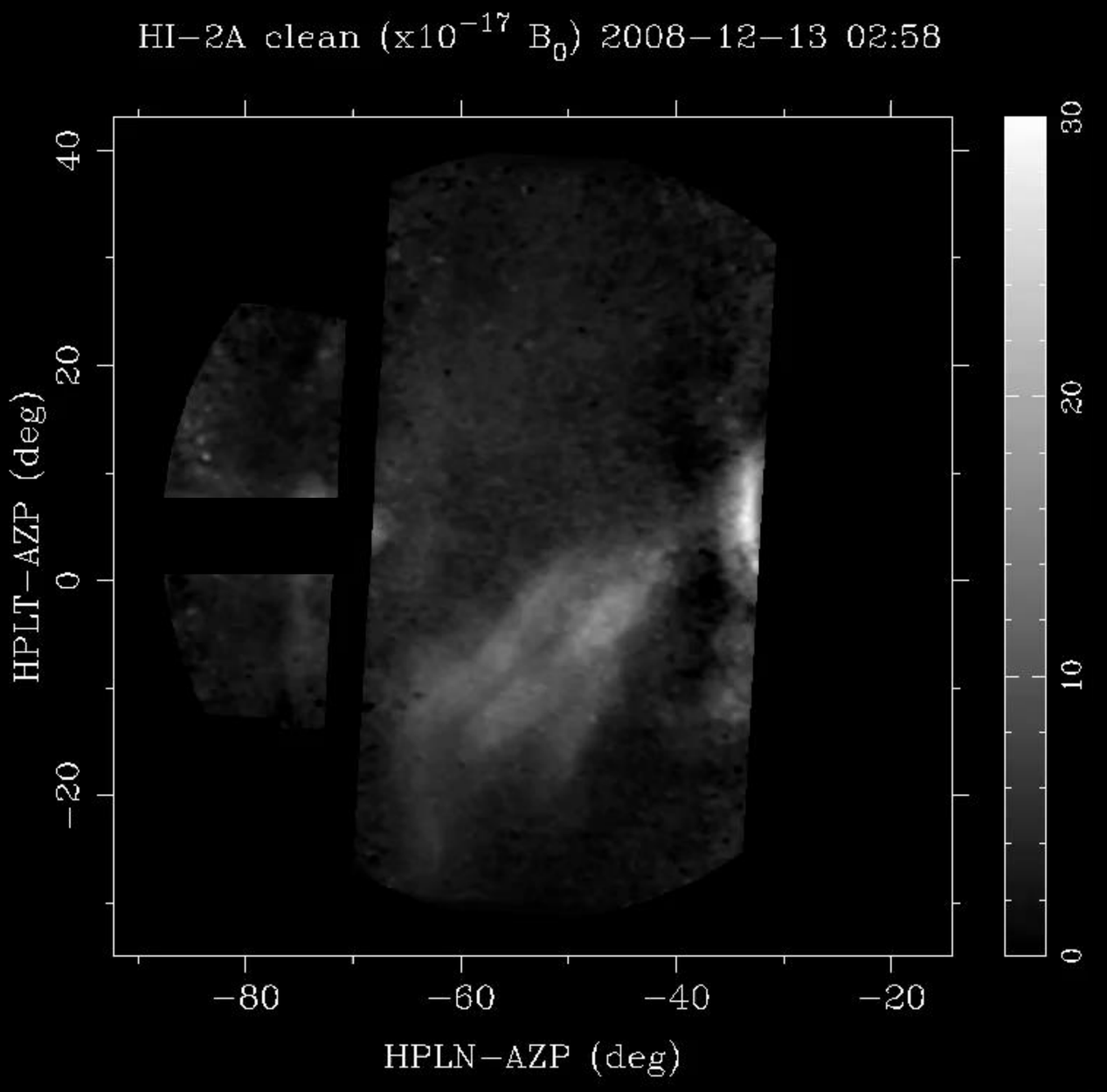
TINY NUANCES OF THE INSTRUMENT ARE CRUCIAL!

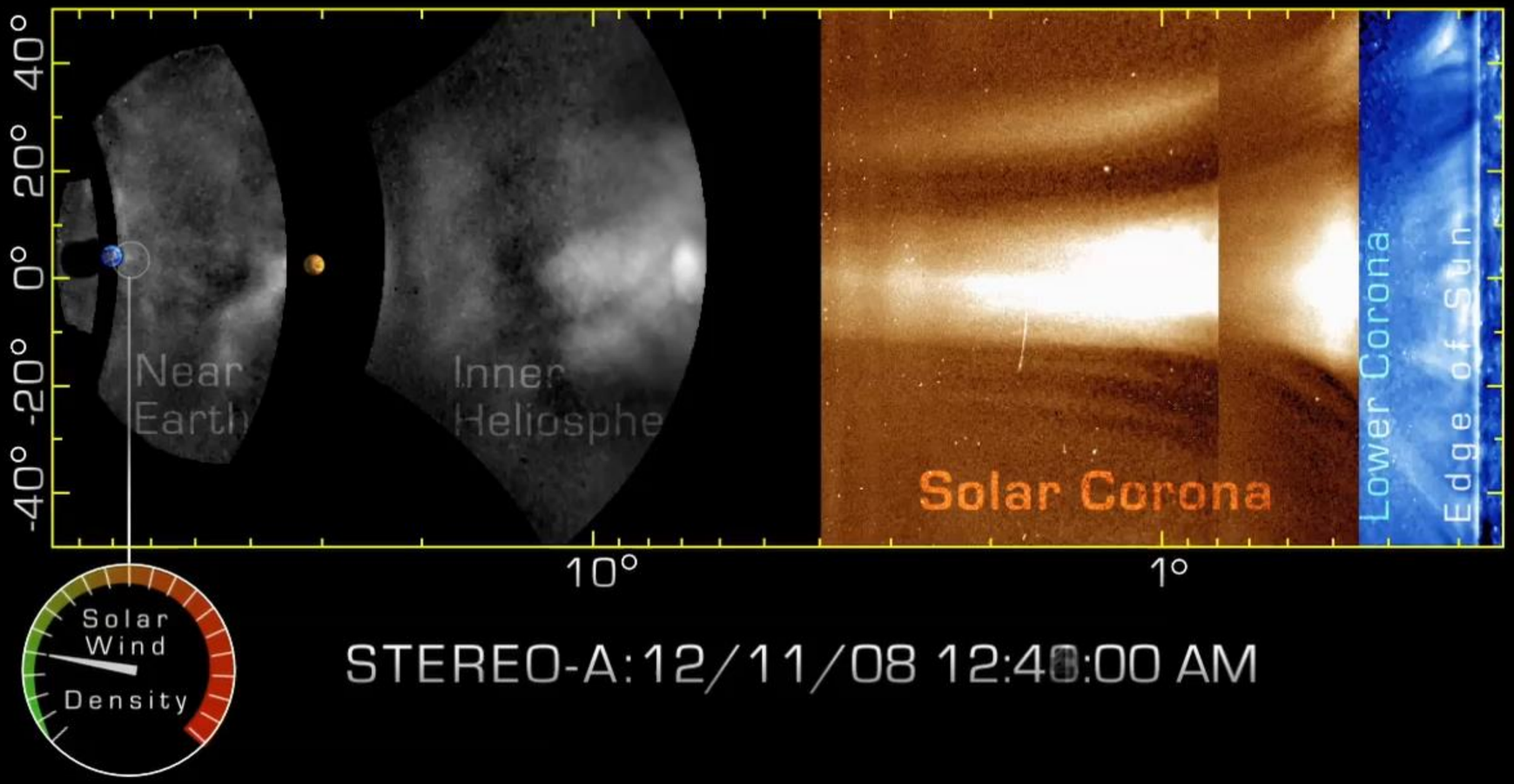
That “Old timey movie” look:

- 0.1% variations in exposure time
- Timing jitter in onboard computer

“Telegraph stars”:

- errors in the camera
  (0.2% nonlinearity)





We live inside a torrent of star-stuff.

PUNCH will help *you* see it, starting this June.

https://punch.space.swri.edu (or google “PUNCH mission”)