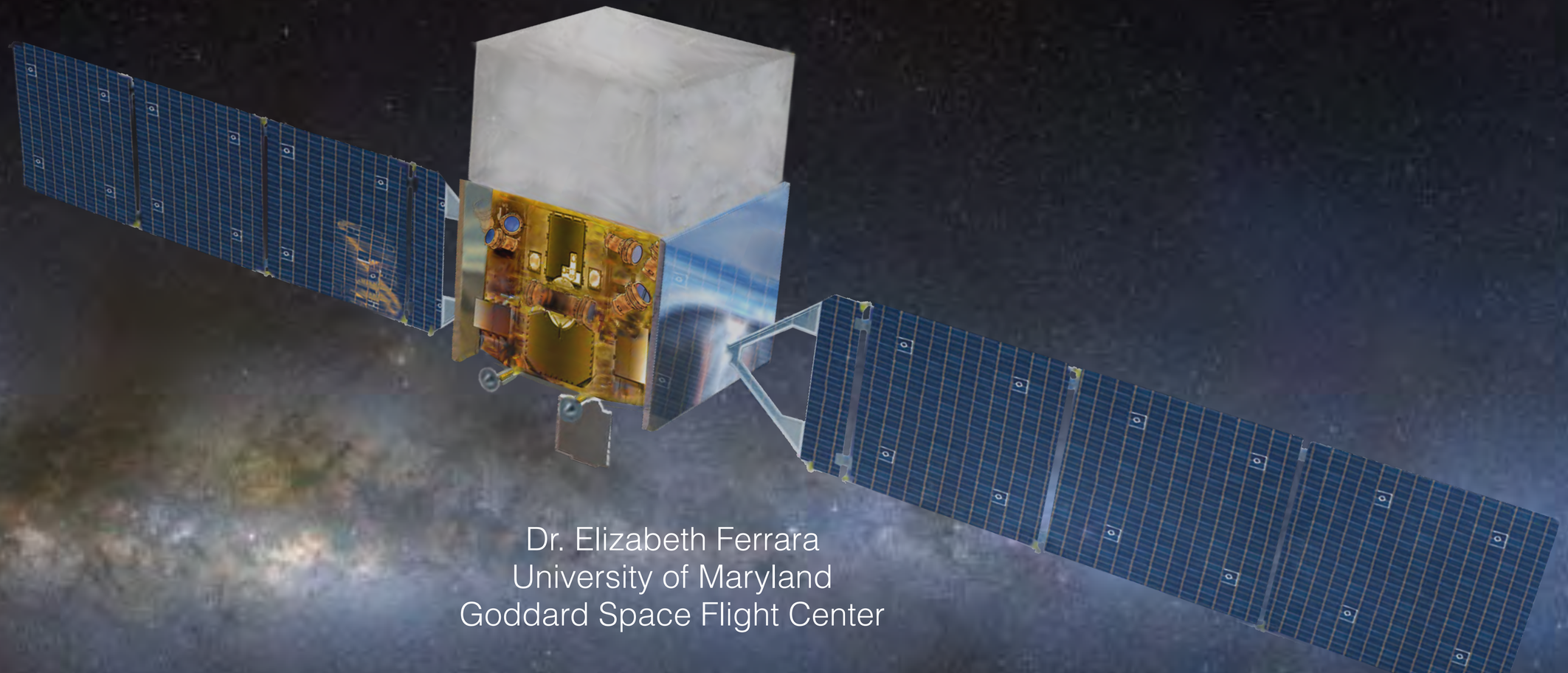
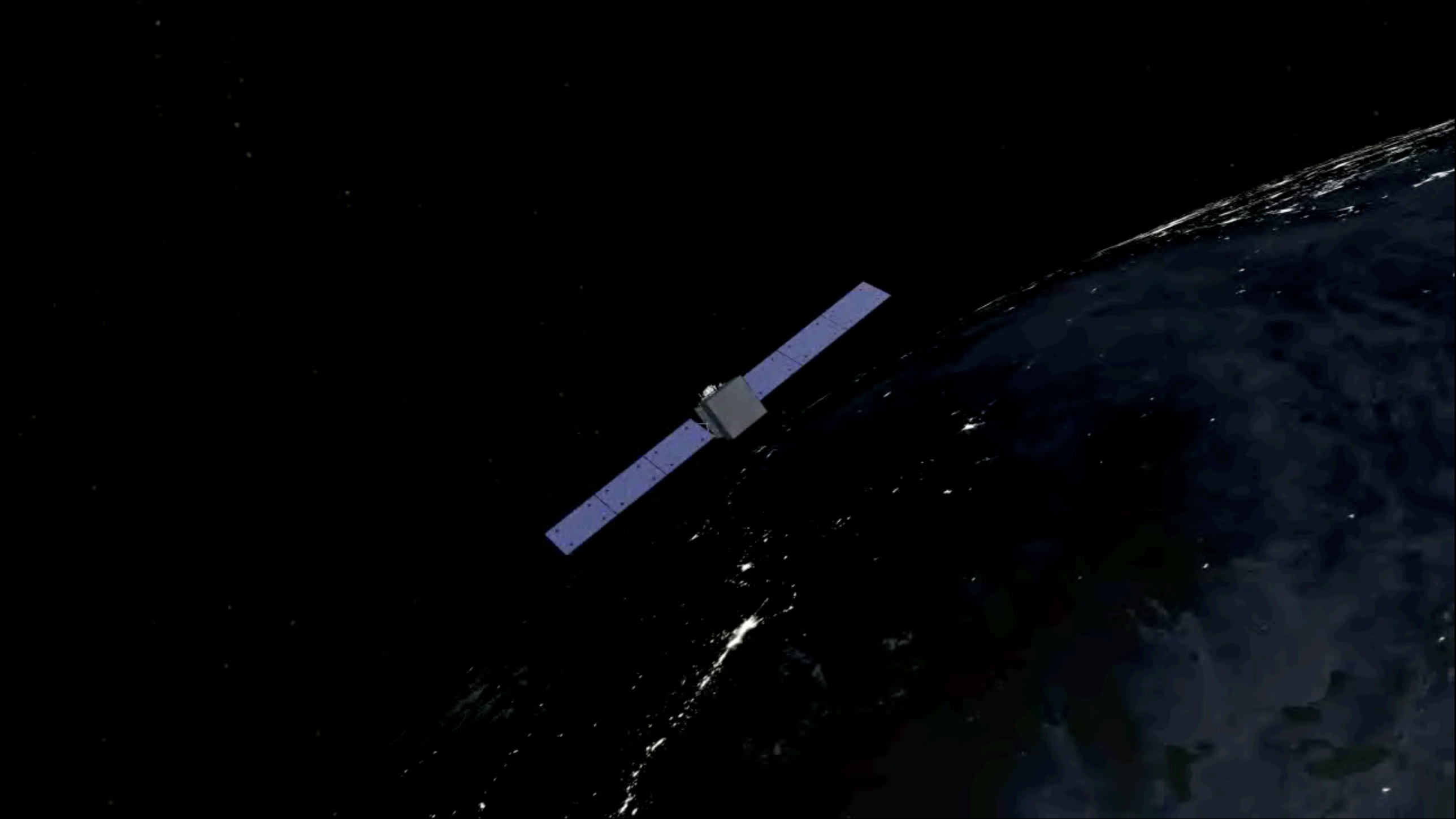
Fermi's Decade of Observing the Extreme Universe



Dr. Elizabeth Ferrara
University of Maryland
Goddard Space Flight Center

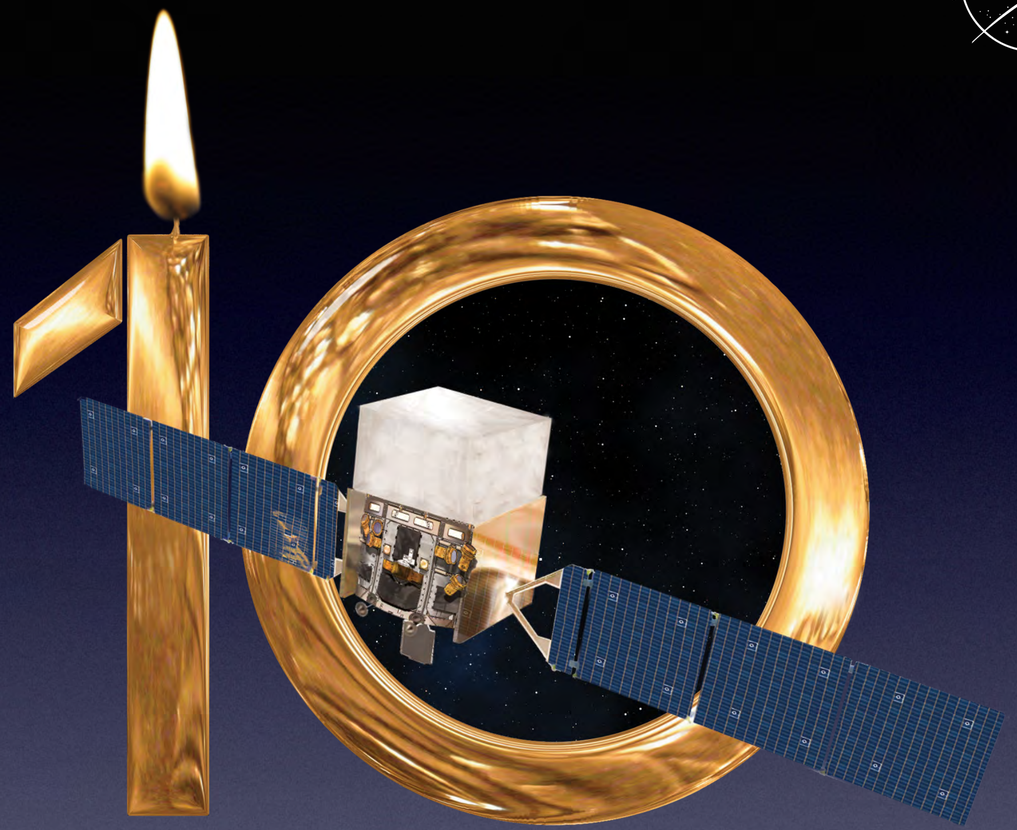



Gamma-ray Large Area Space Telescope
GLAST

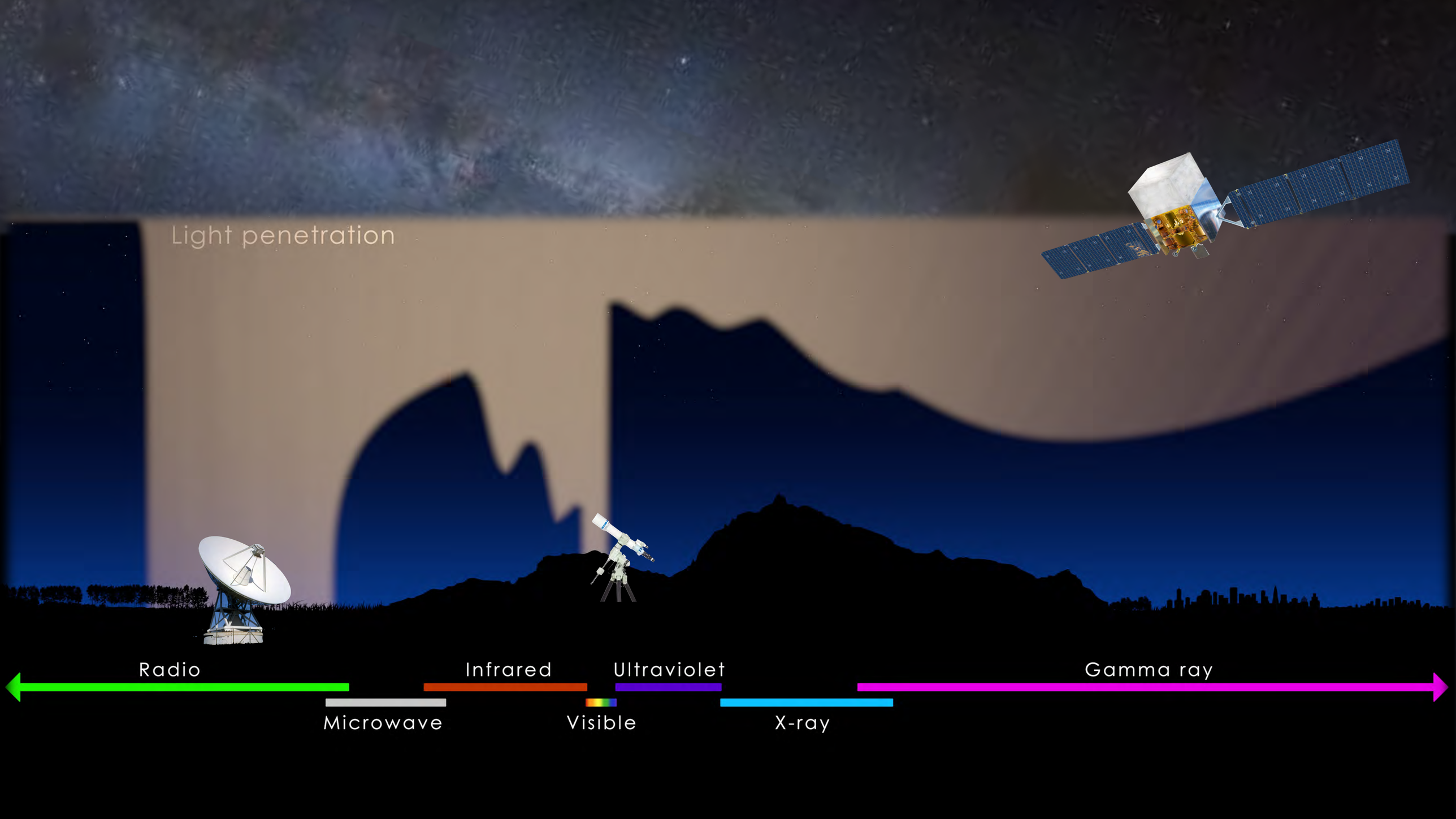
Enrico Fermi
1901-1954

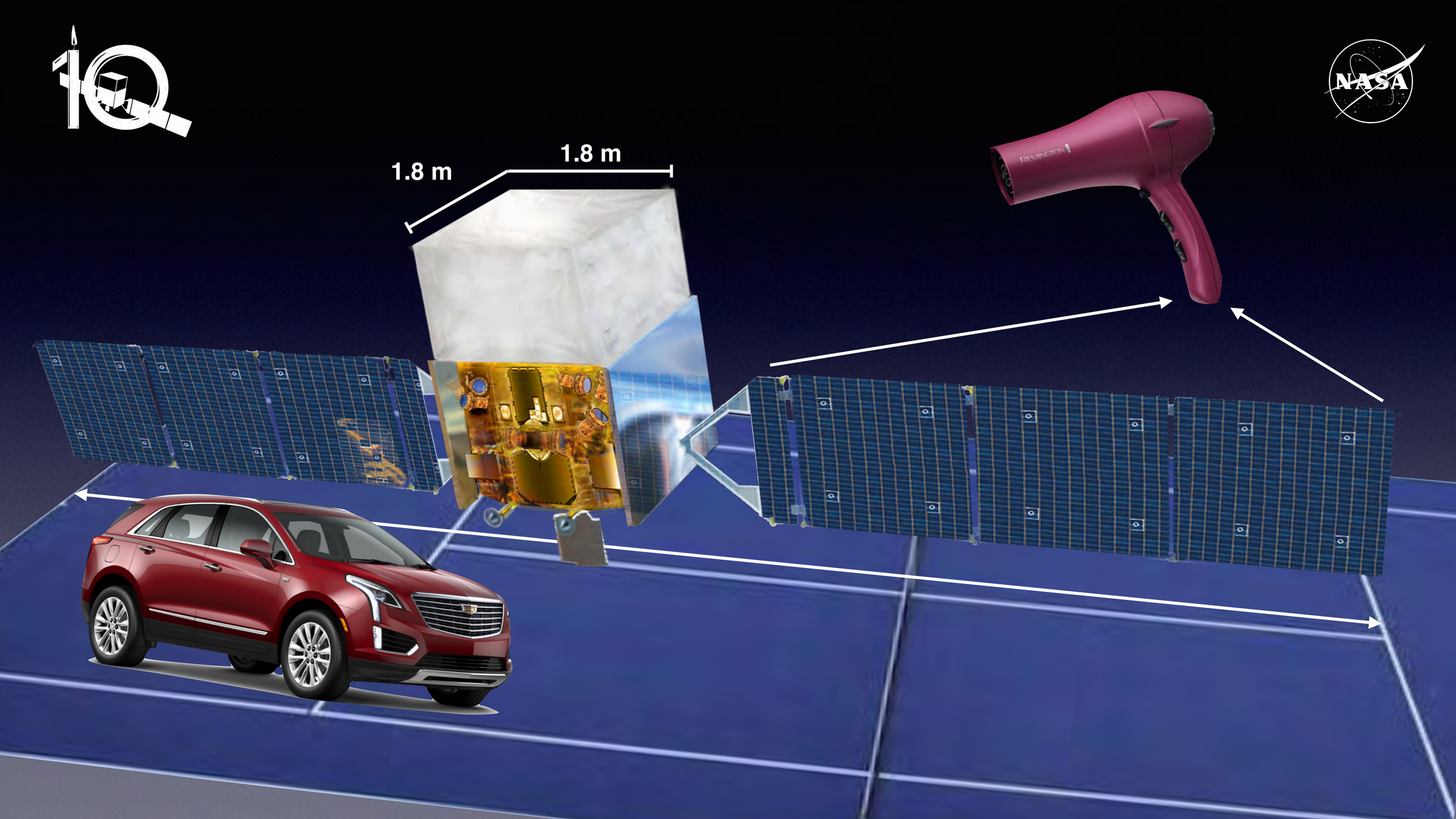
Fermi
Gamma-ray
Space Telescope

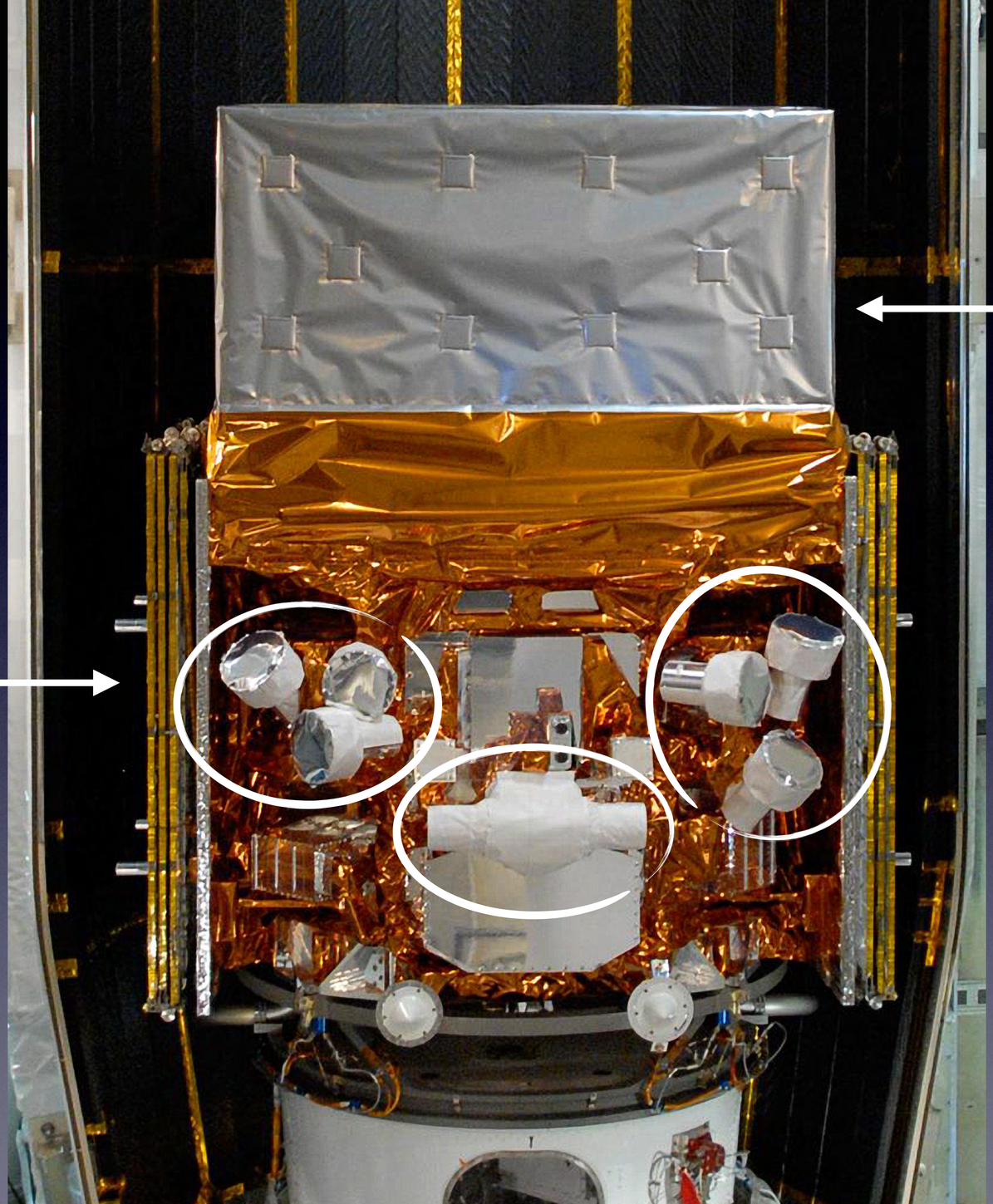
Enrico Fermi
1901-1954



Fermi


Light penetration
Radio
Infrared
Ultraviolet
Gamma ray
Microwave
Visible
X-ray


1.8 m
1.8 m
REMINGTON

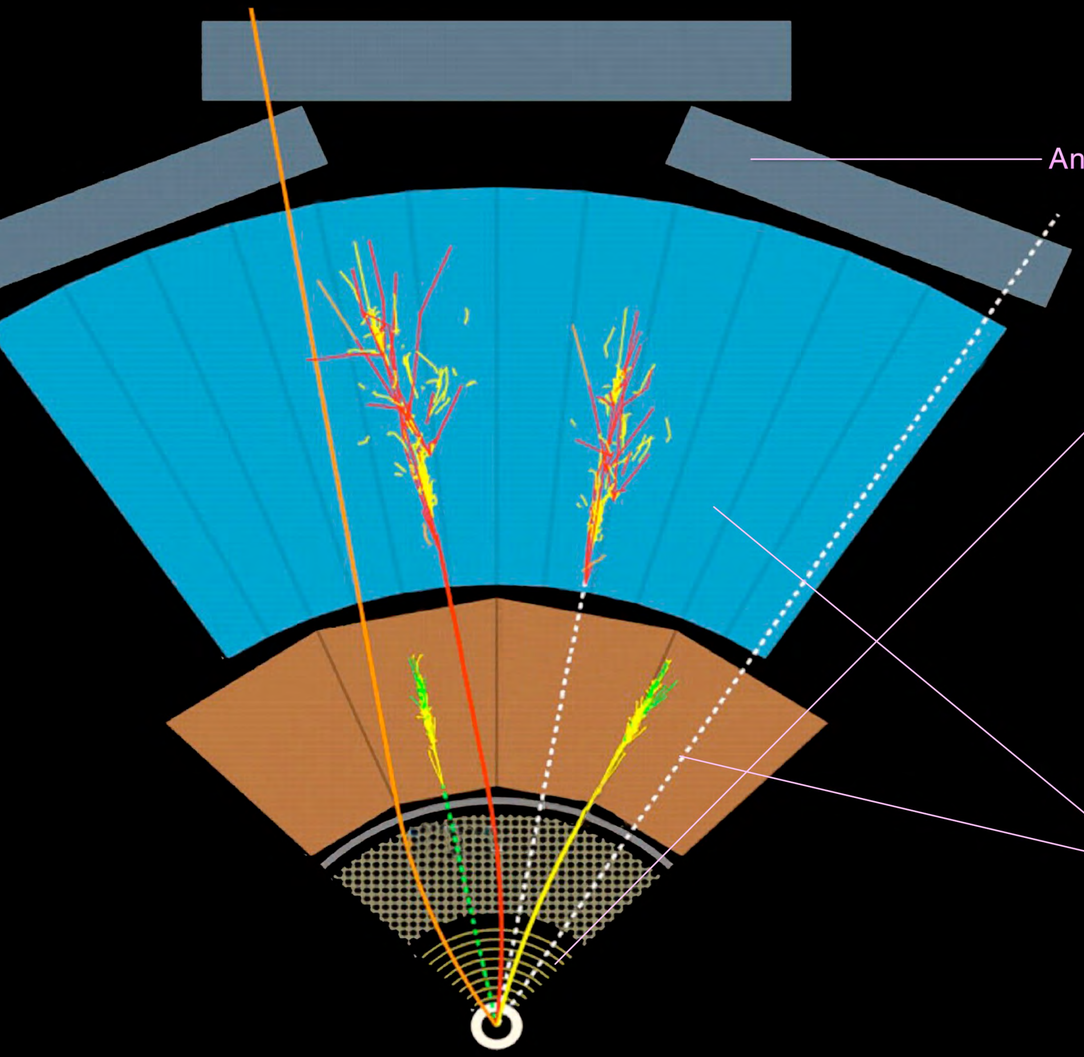


Large Area Telescope (LAT)

$E = MC^2$

Gamma-Ray Burst Monitor (GBM)

Scintillation

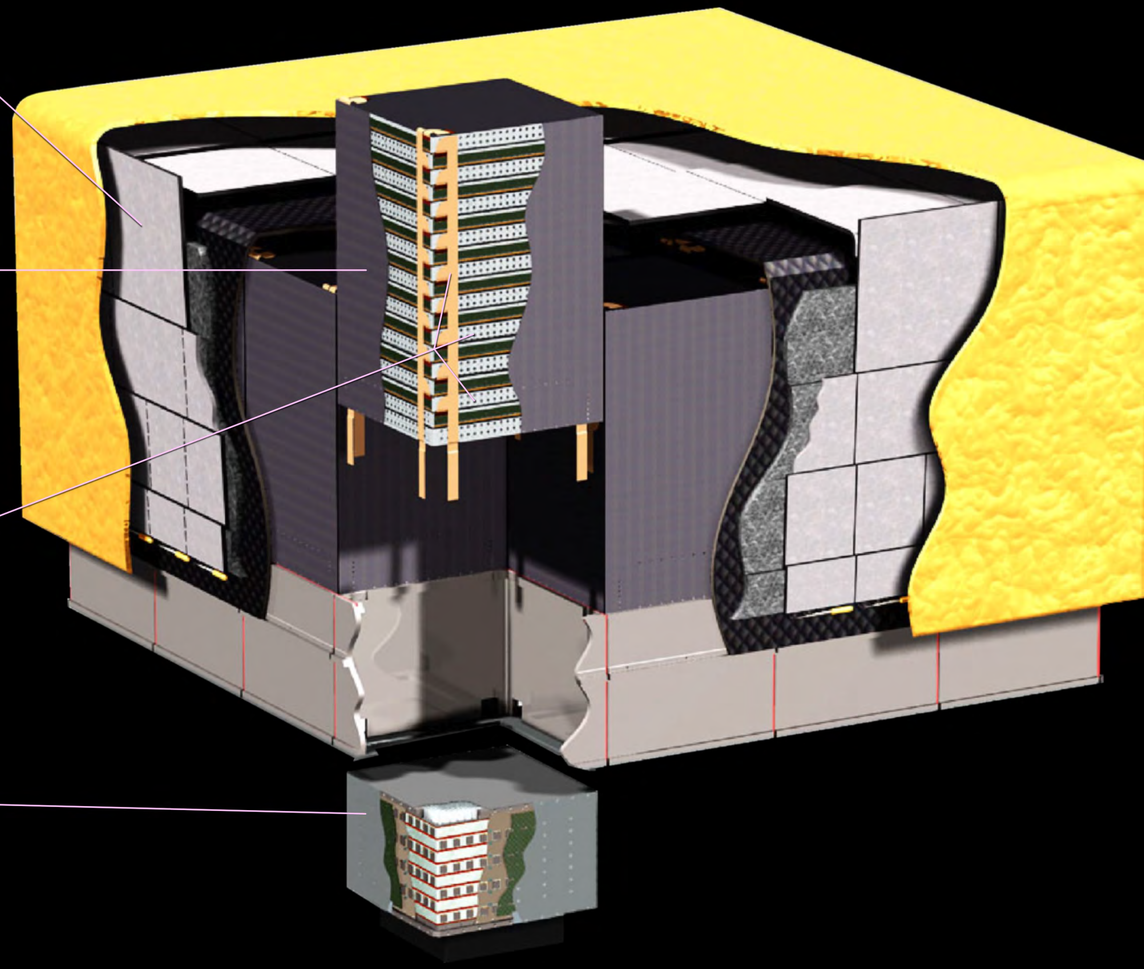


Anti-coincidence detector

Tracker

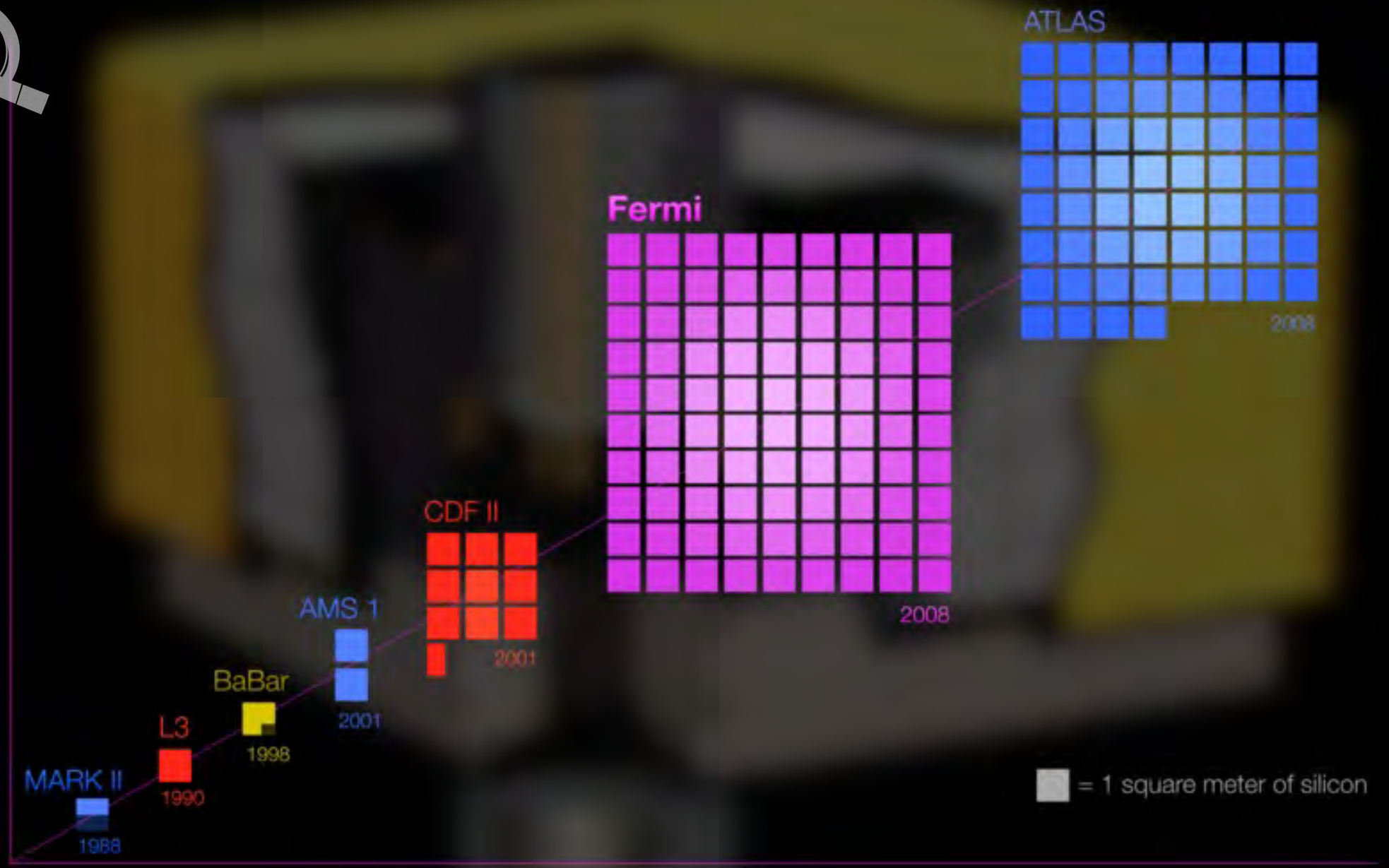
Conversion Layers

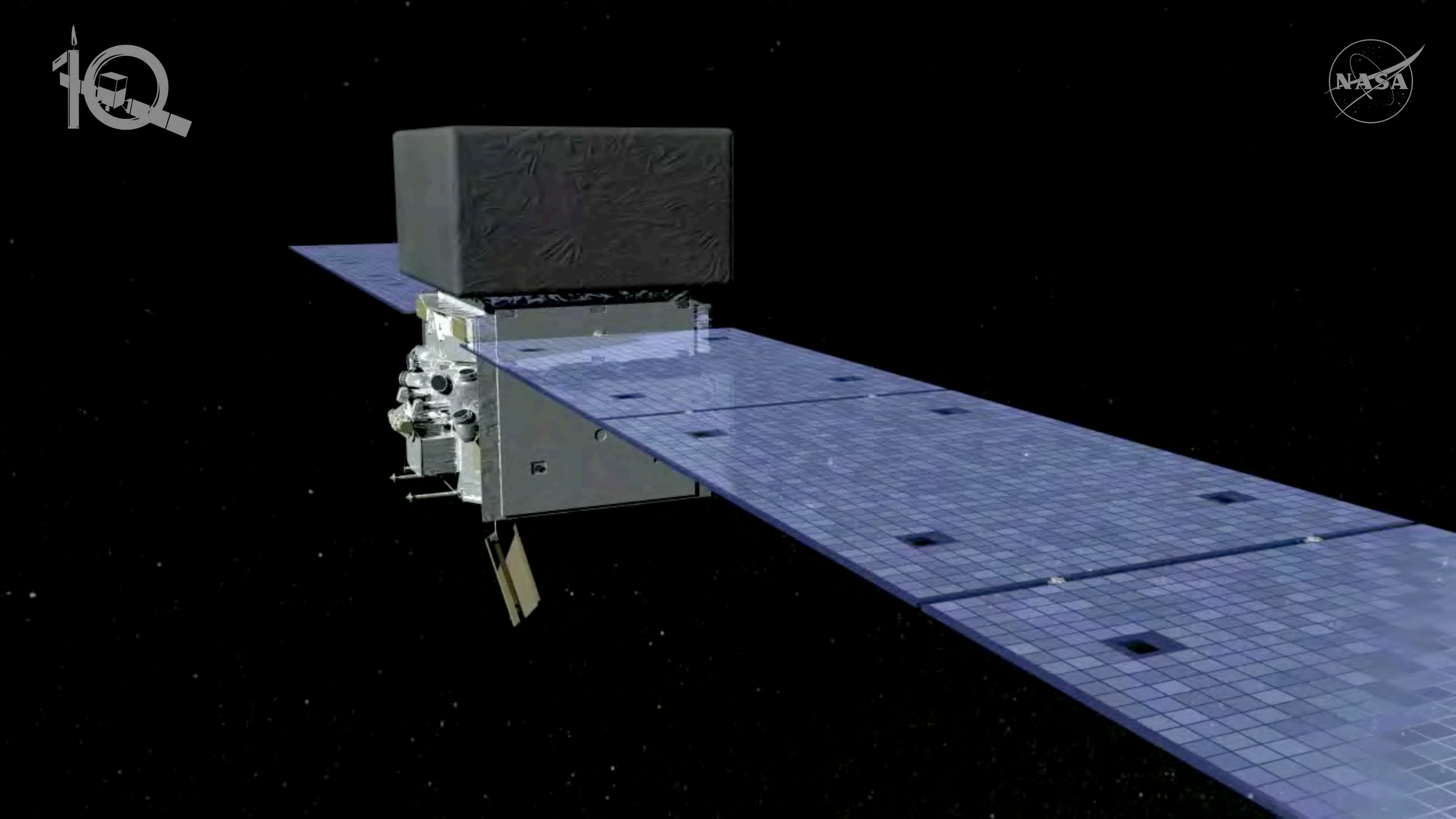
Calorimeter

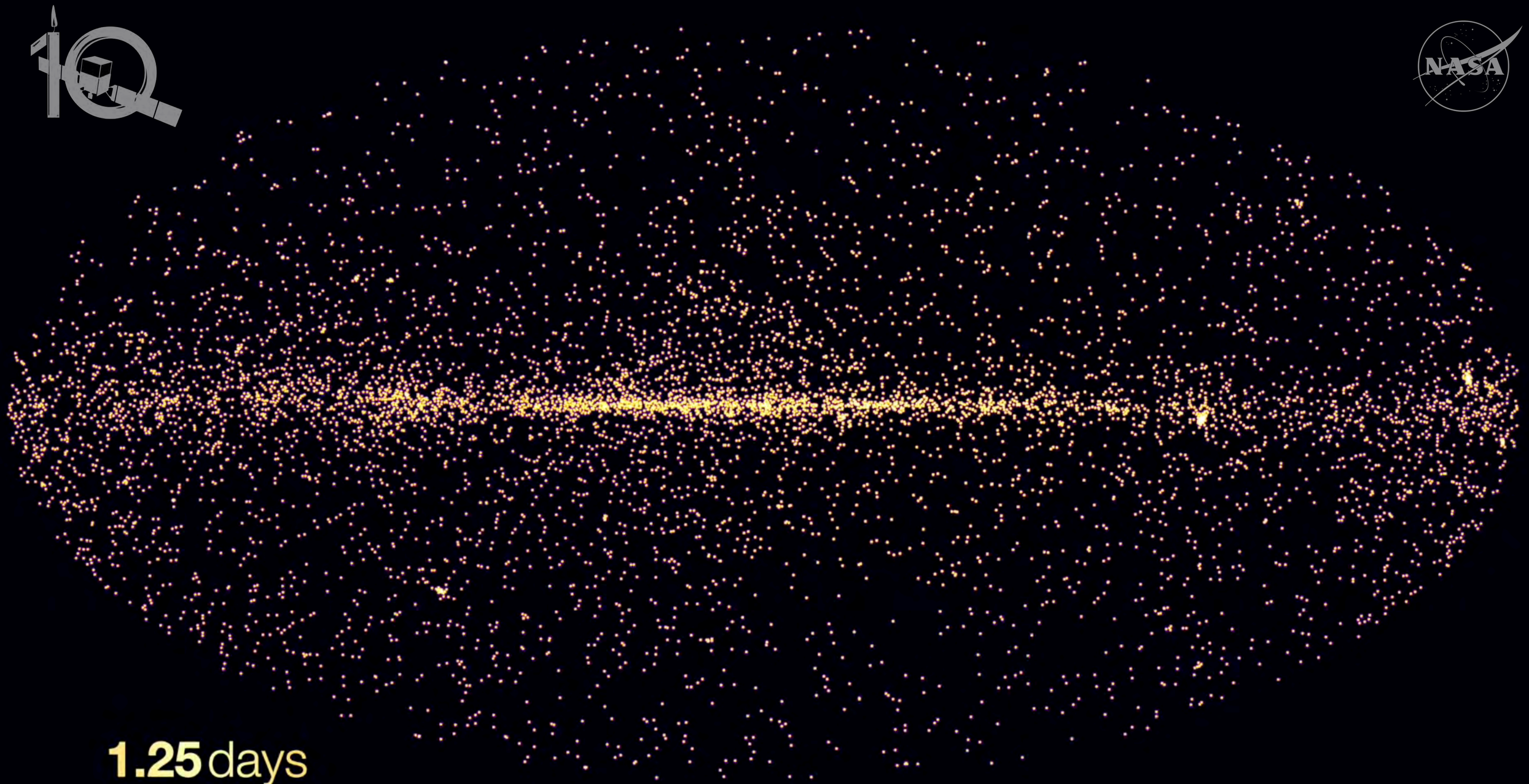


LHC ATLAS Detector

Fermi LAT

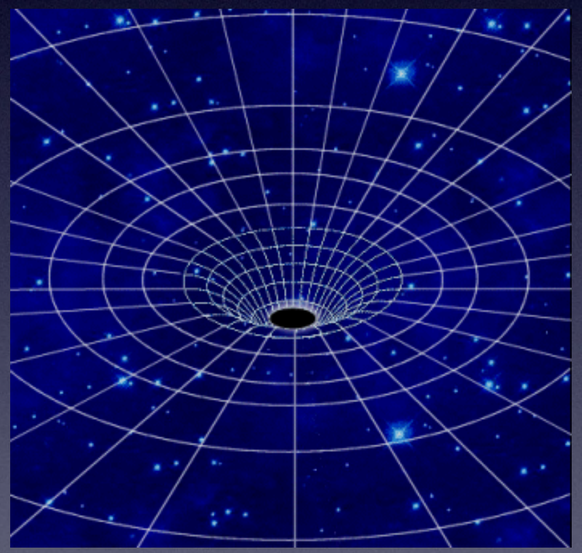

ATLAS
2008
Fermi
2008
CDF II
2001
AMS 1
2001
BaBar
1998
L3
1990
MARK II
1988
= 1 square meter of silicon



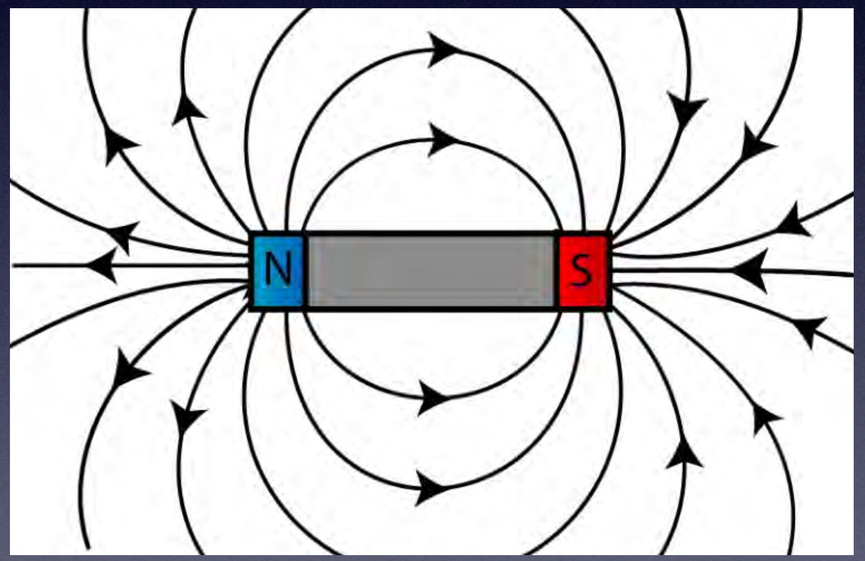

1.25 days

What is the “Extreme Universe?”

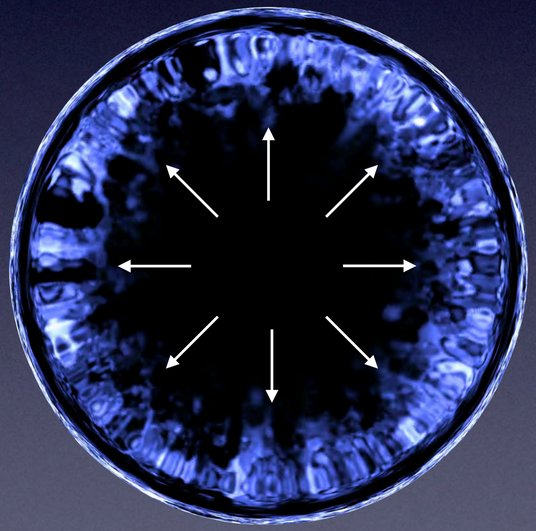
= Where particle acceleration occurs



Strong gravitational fields



Strong magnetic fields



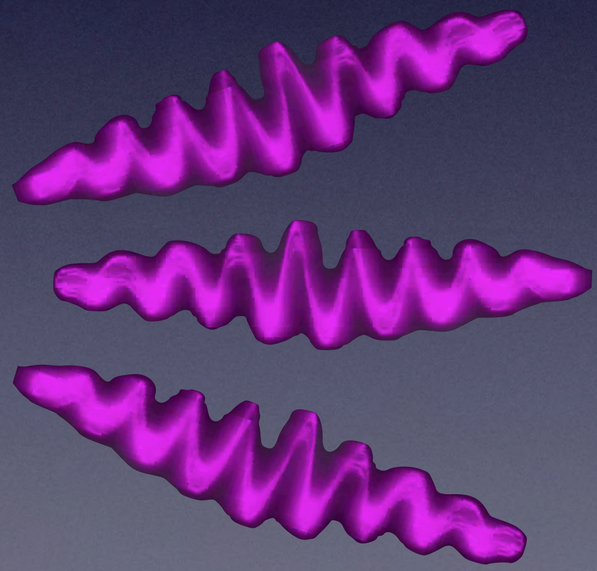
Shocks

What is the “Extreme Universe?”

Accelerated Particles → Interact → Gamma rays

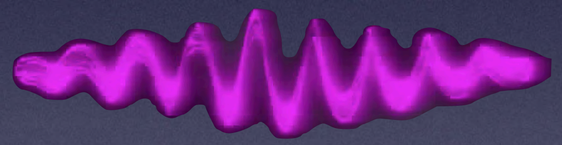
pions
electrons
cosmic rays
protons
etc…

photons
positrons
atomic nuclei
self-decay
etc…



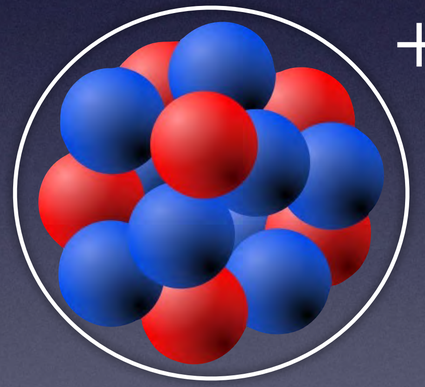
Gamma Rays vs. Cosmic Rays

Gamma rays
are photons

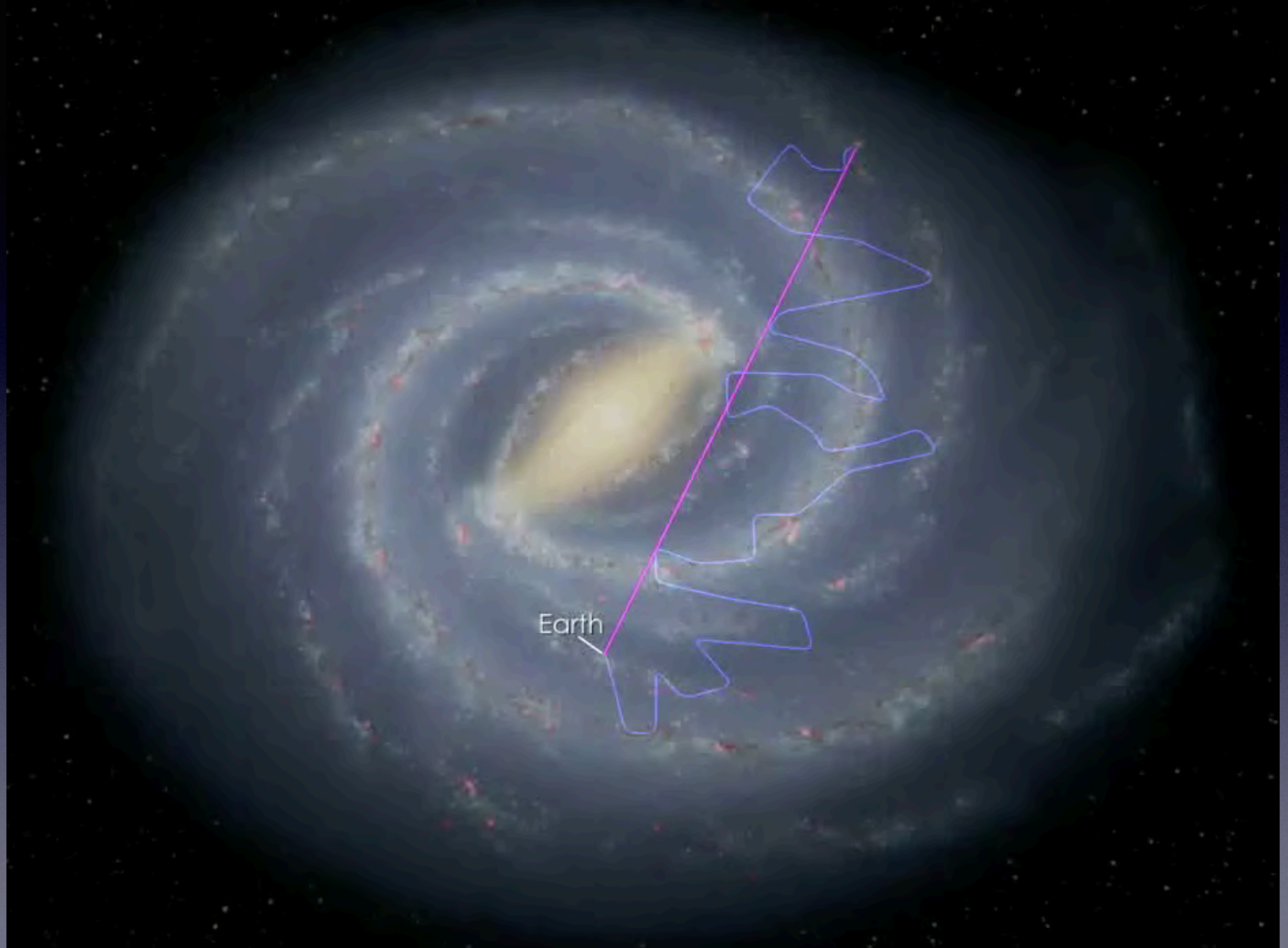


Travel in
STRAIGHT LINES

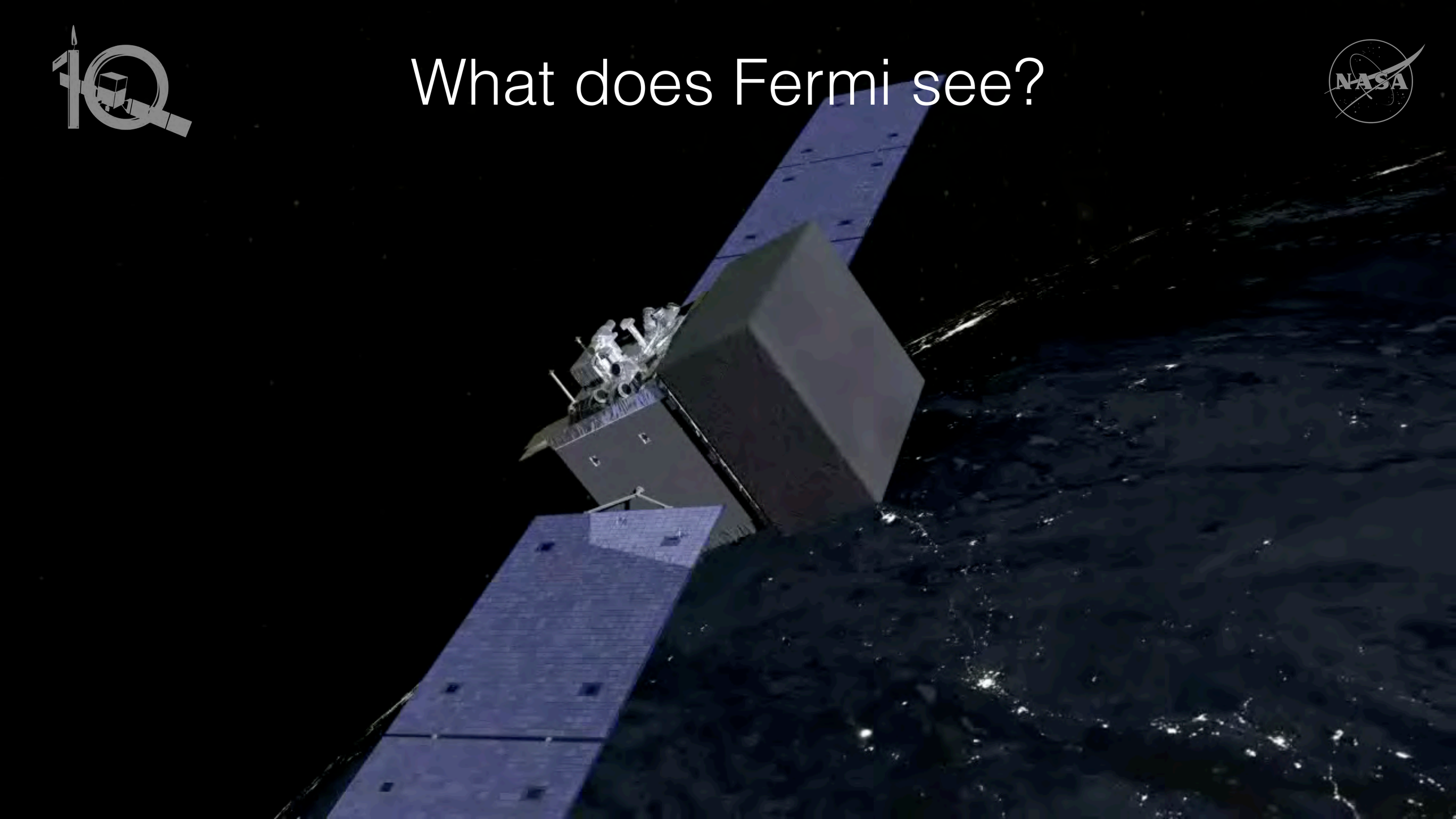
Cosmic rays
are atomic nuclei



Follow
MAGNETIC
FIELD LINES


Earth

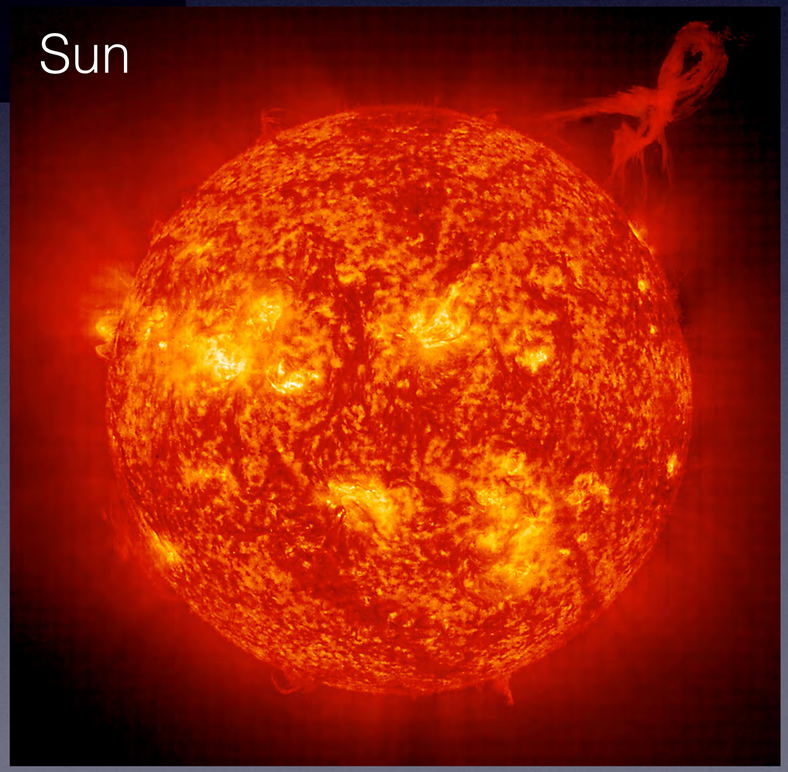
What does Fermi see?

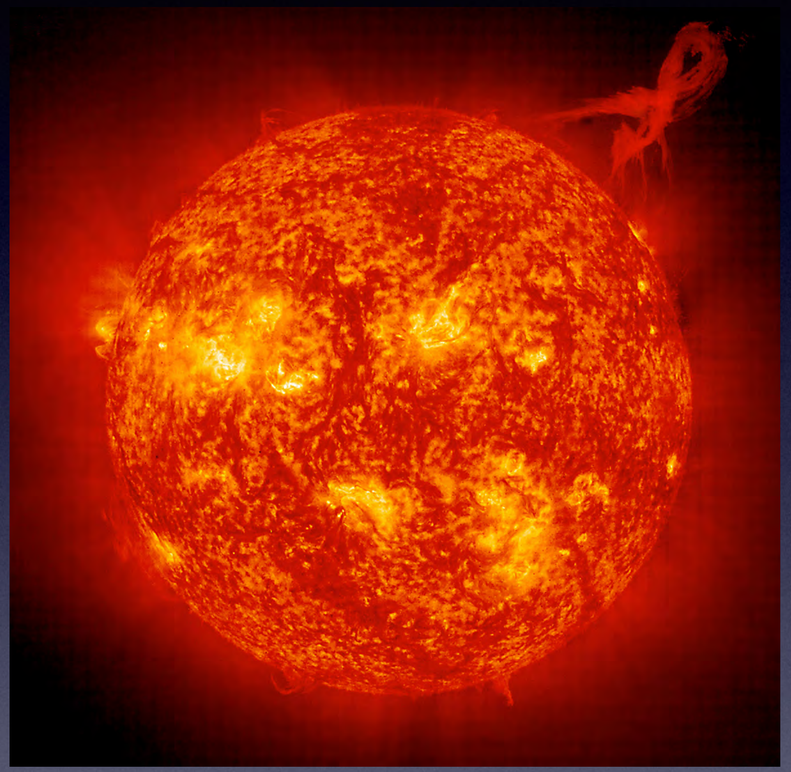


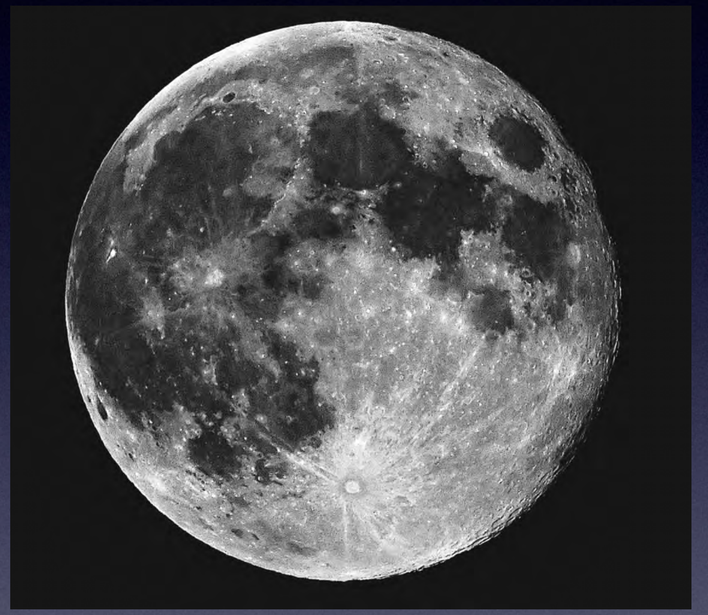
Earth

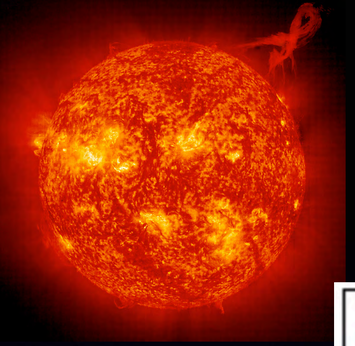
Moon

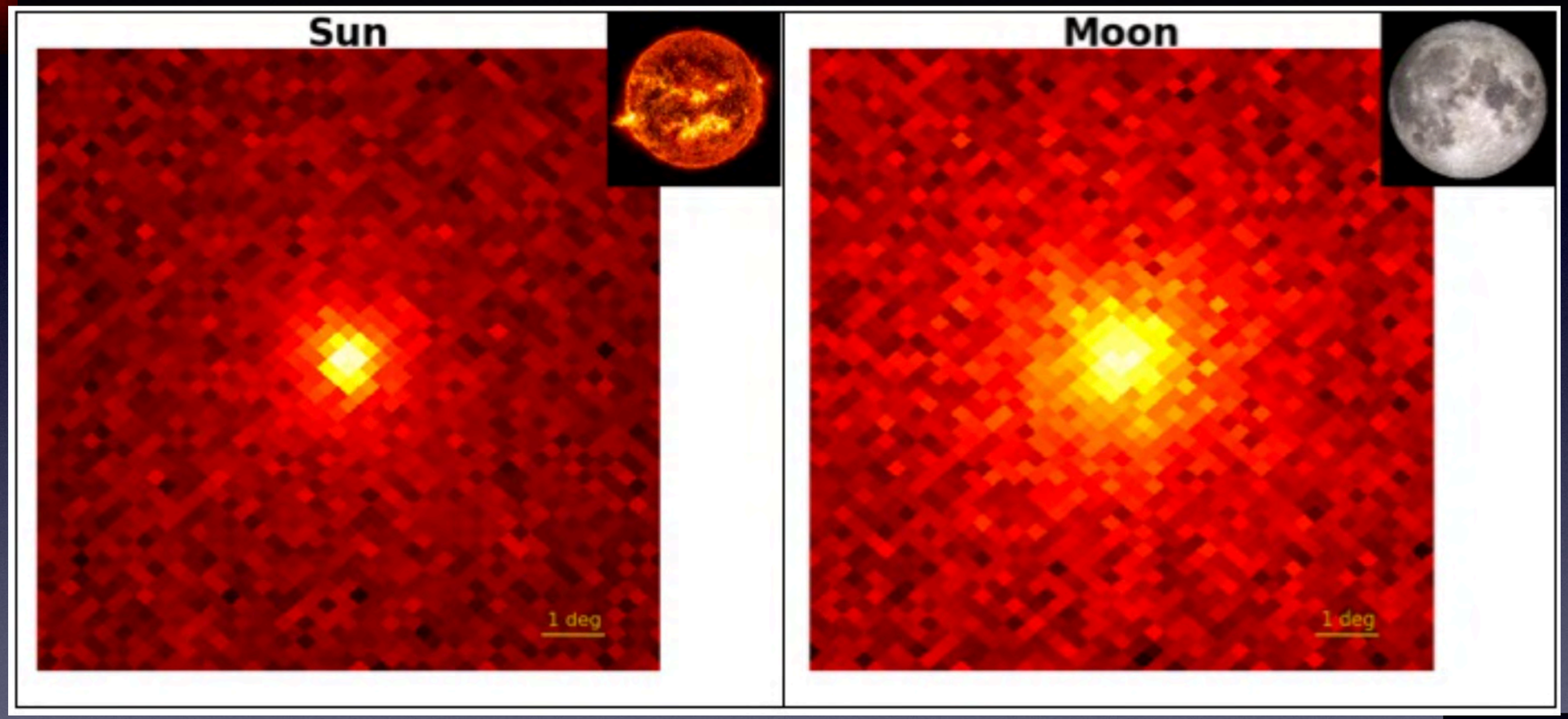
Sun

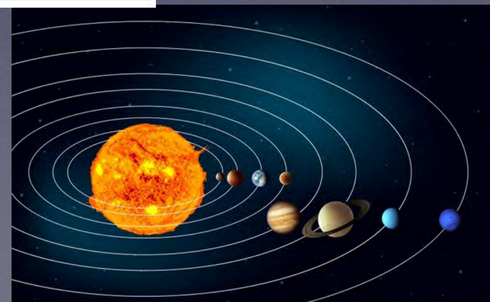


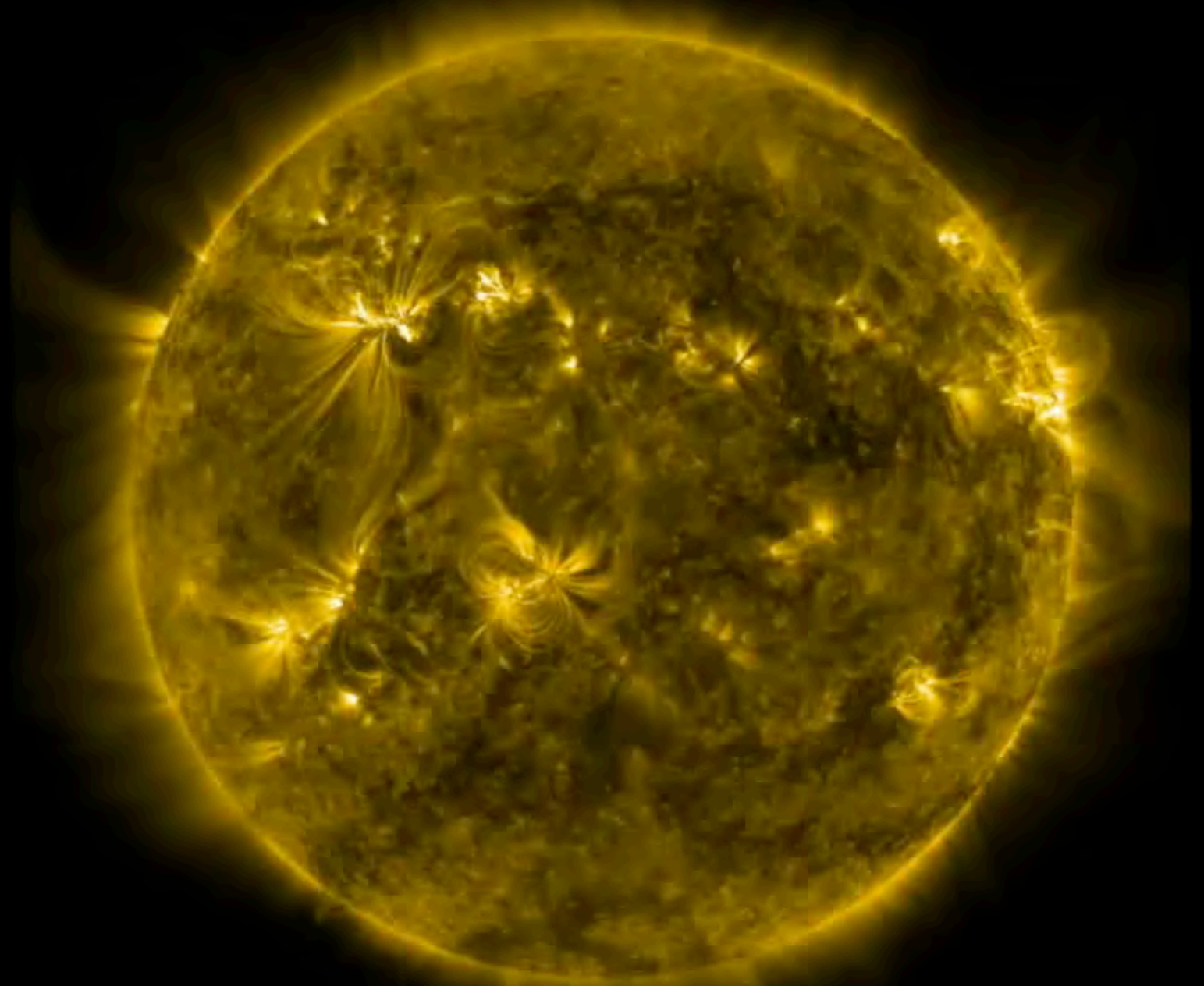


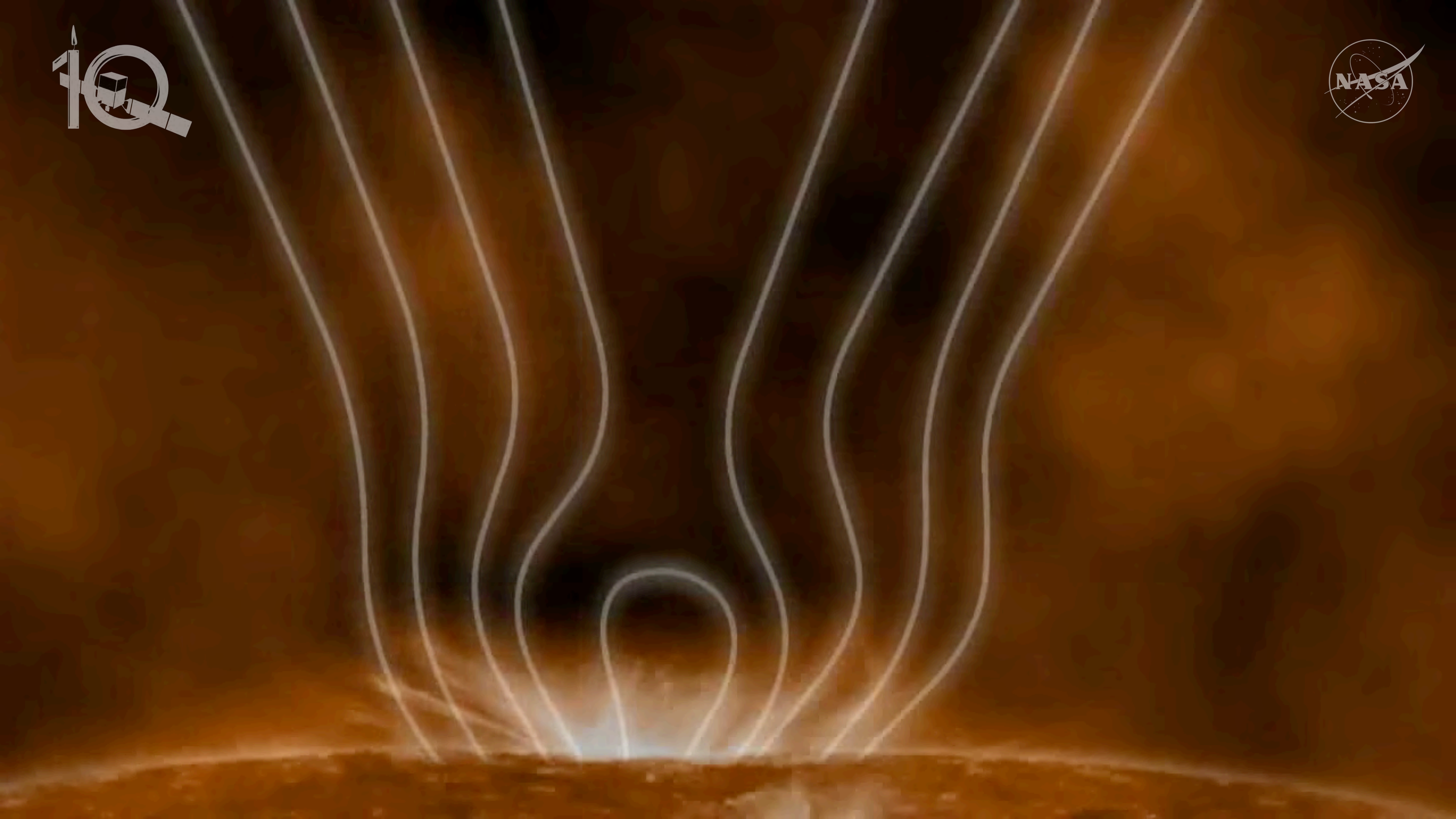


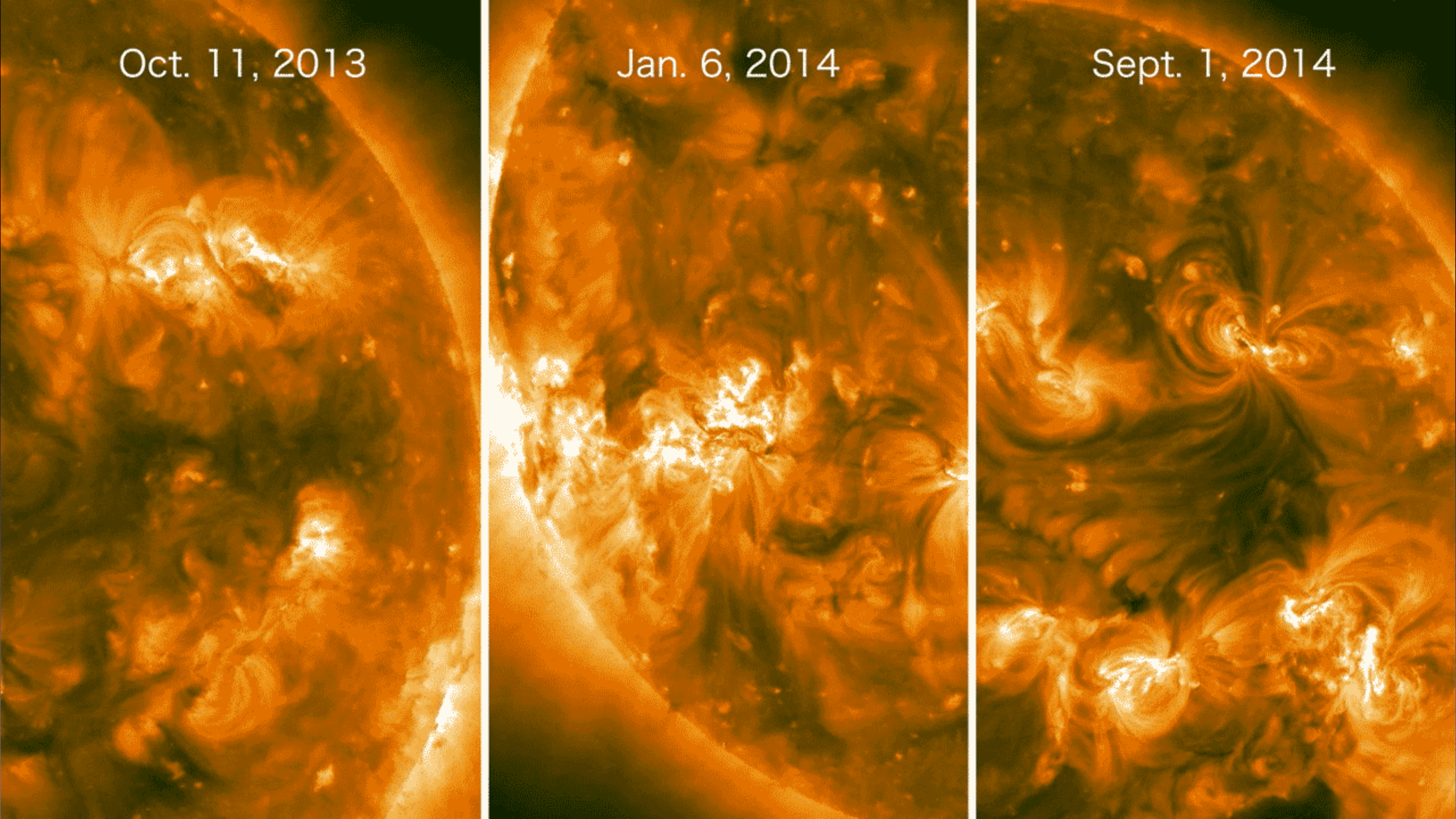



Sun
1 deg
Moon
1 deg





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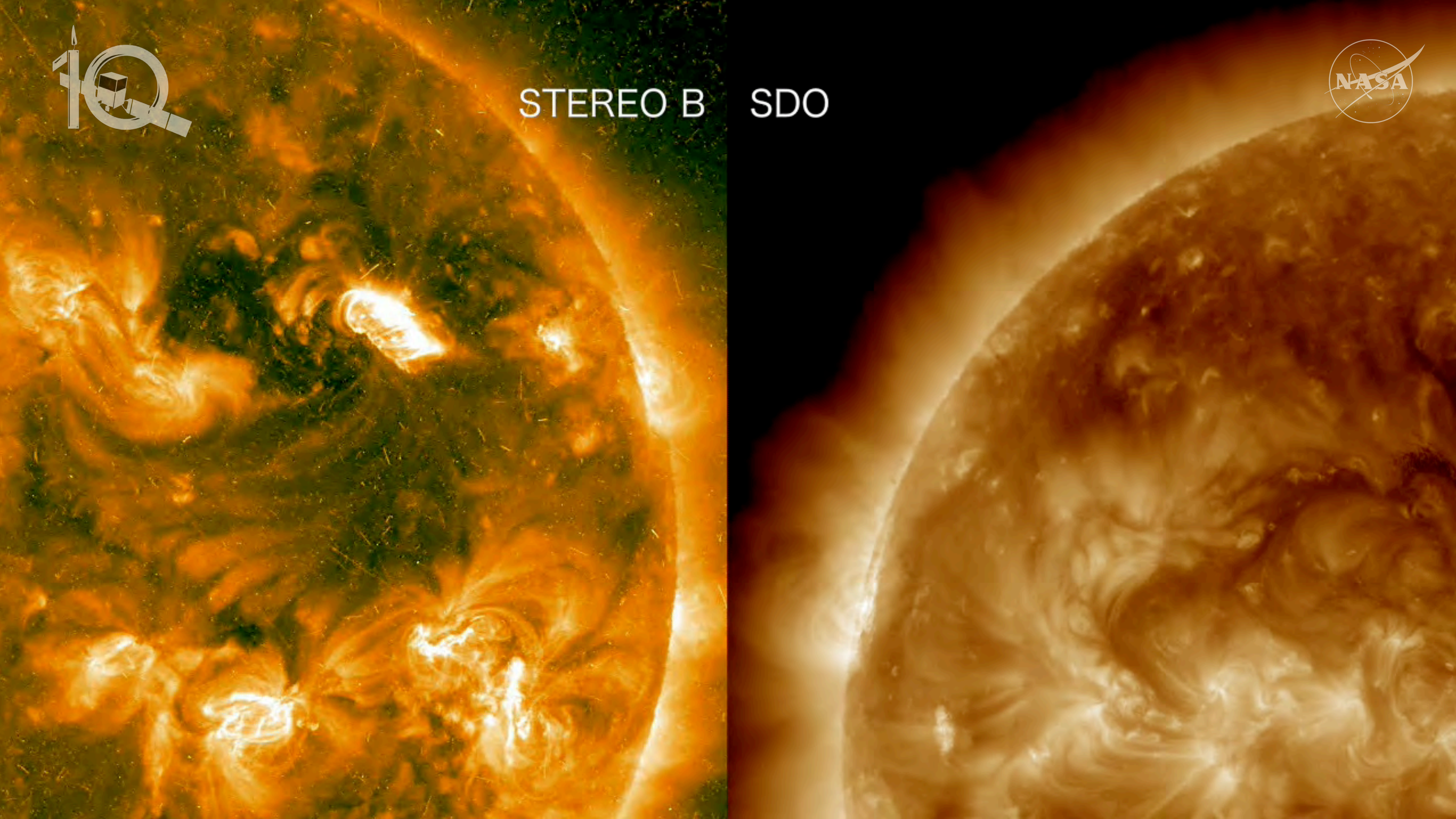
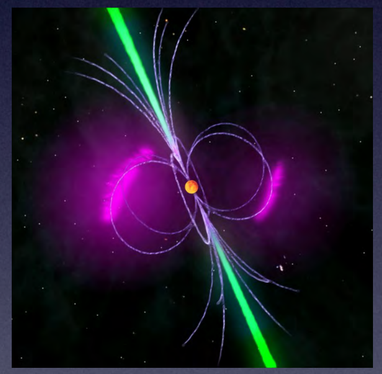
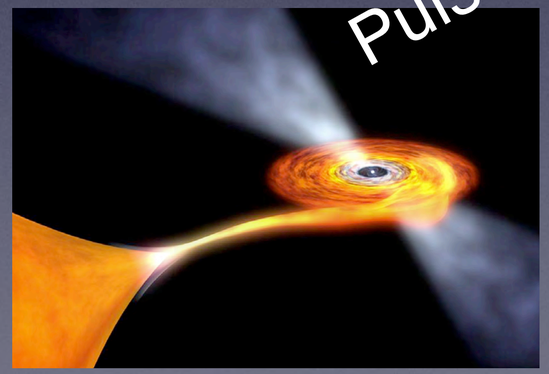
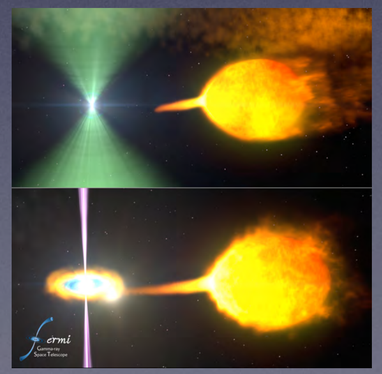
Jan. 6, 2014
Sept. 1, 2014

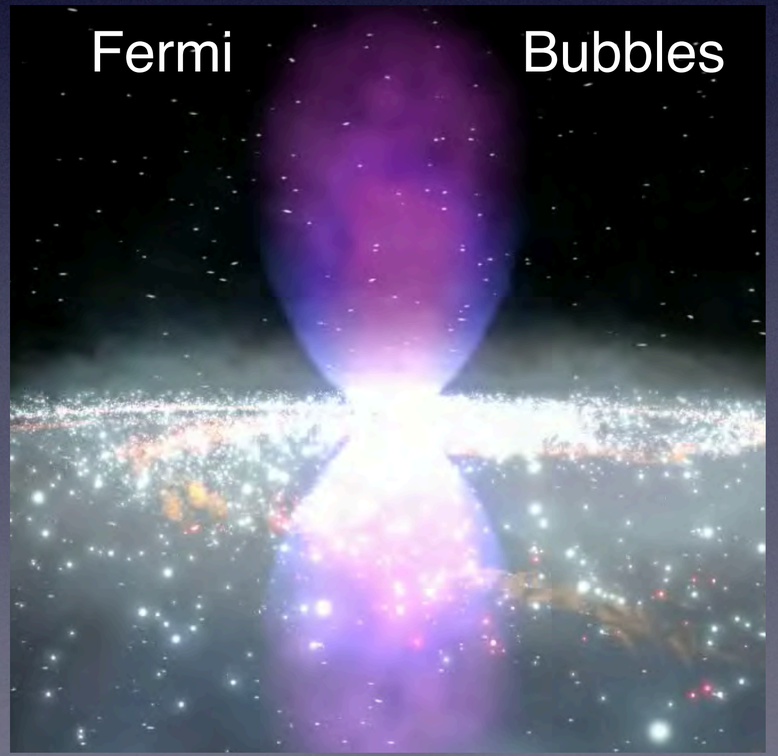

STEREO B
SDO



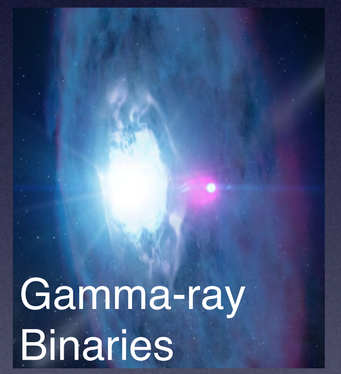
Pulsars





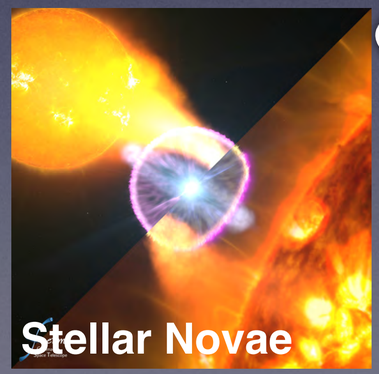


Fermi Bubbles



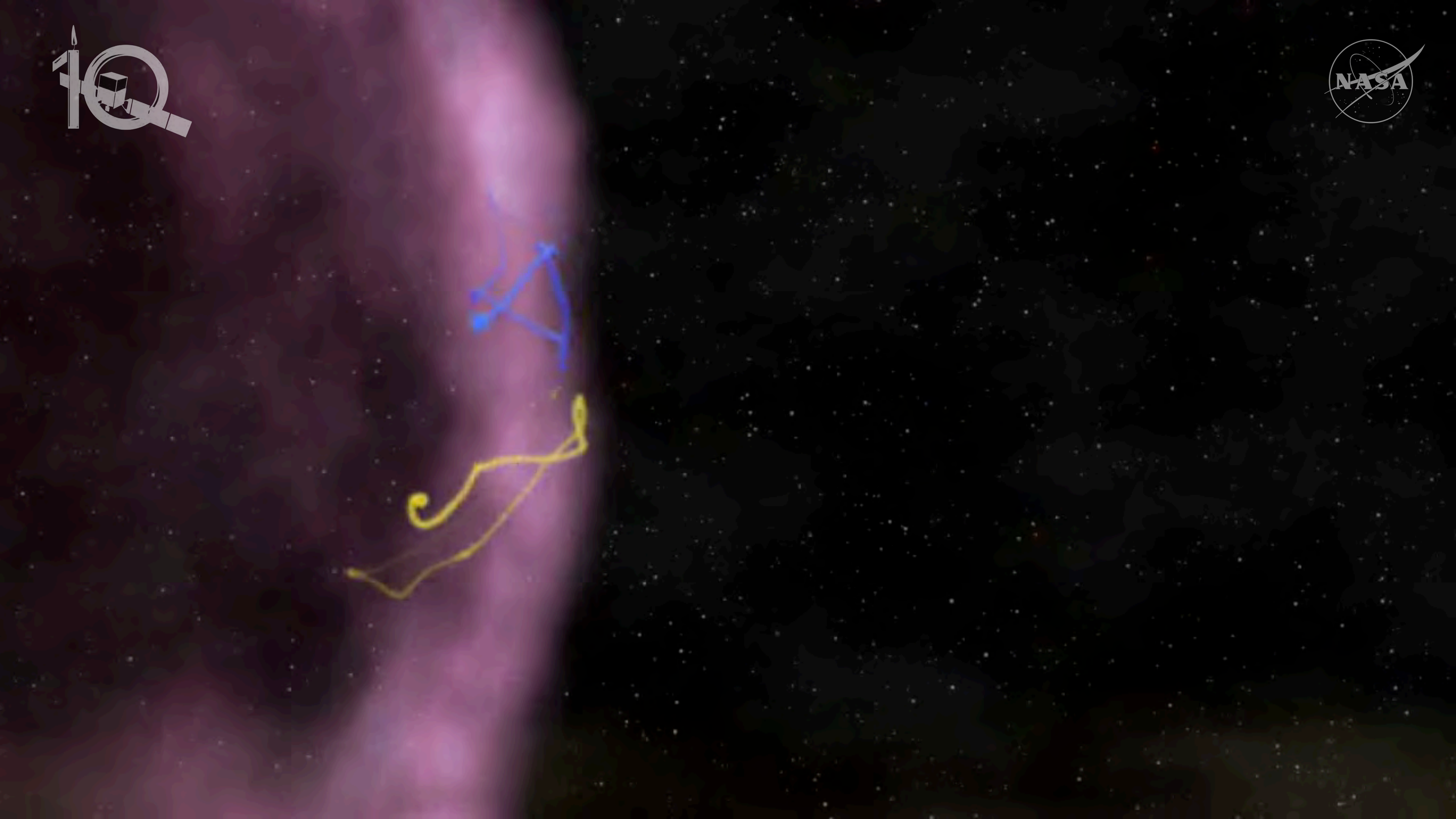
Gamma-ray Binaries

Magnetars

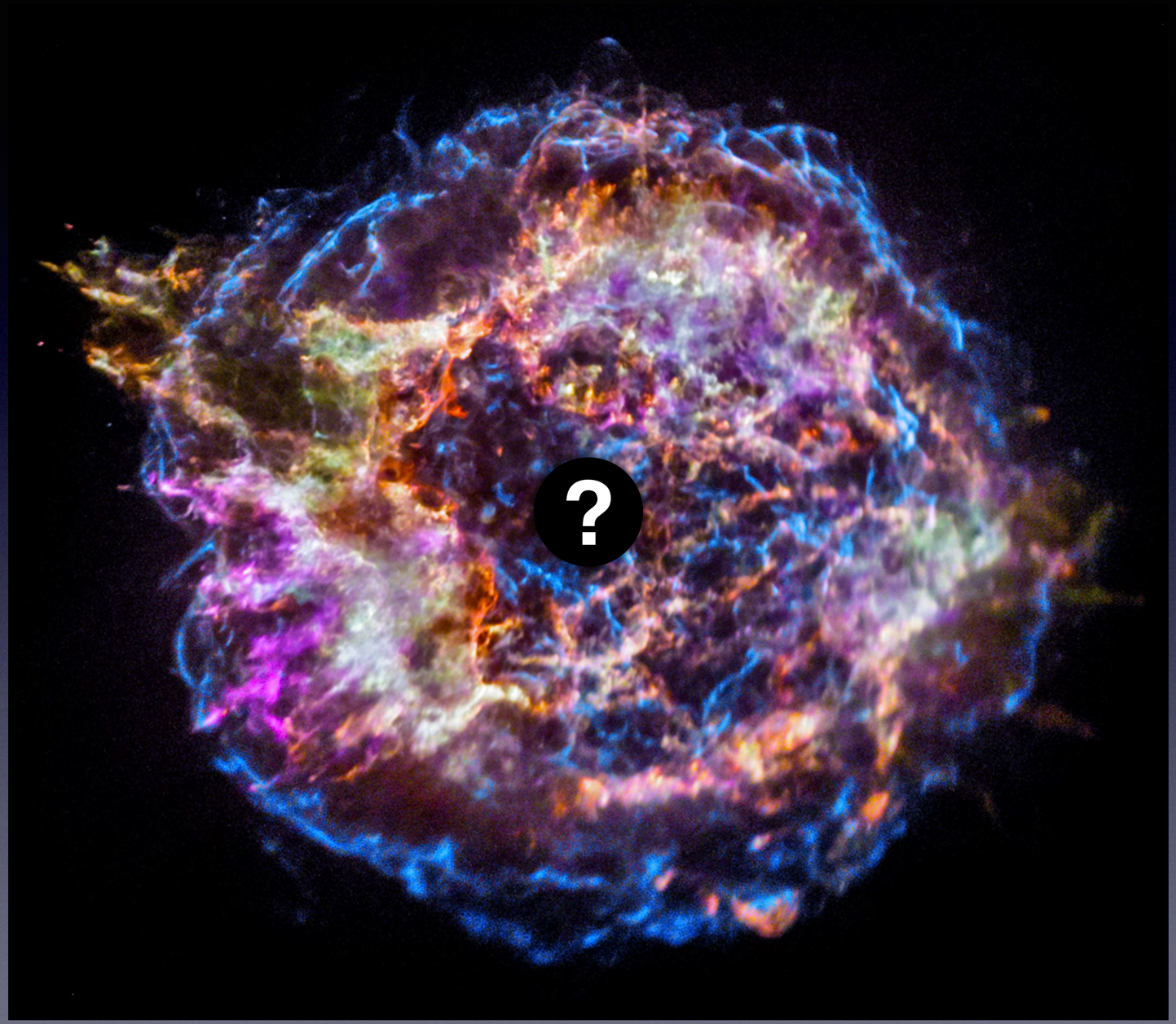


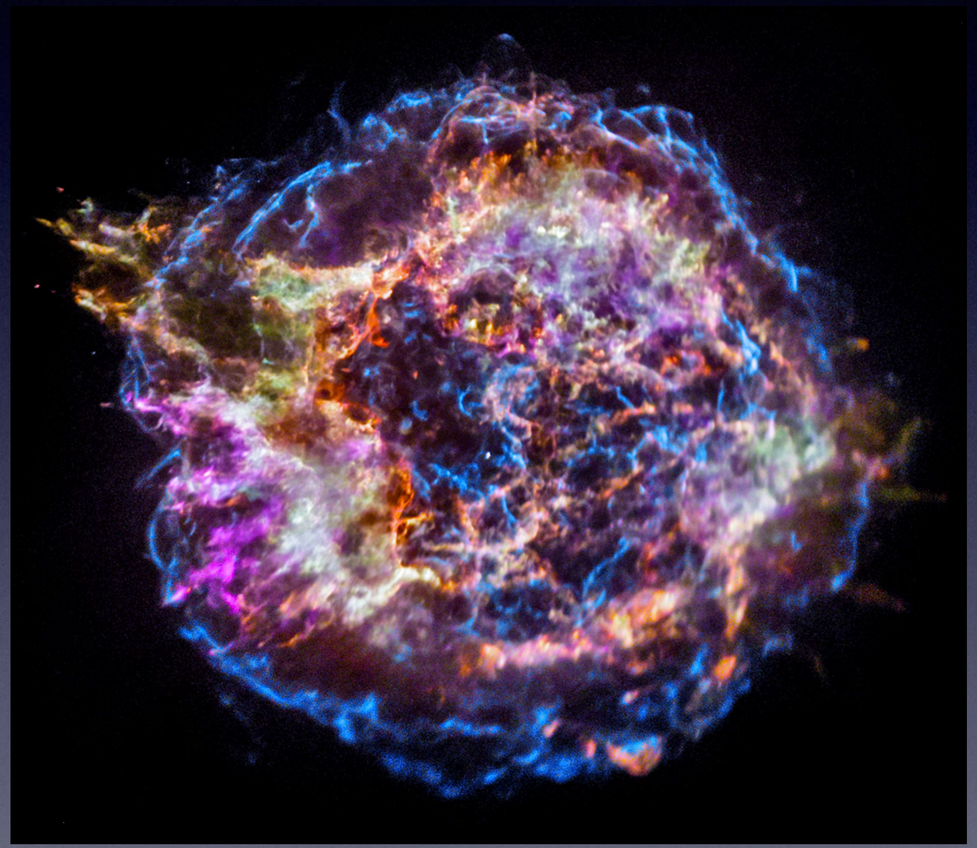
Stellar Novae

Supernova Remnants




IC 443
W 44





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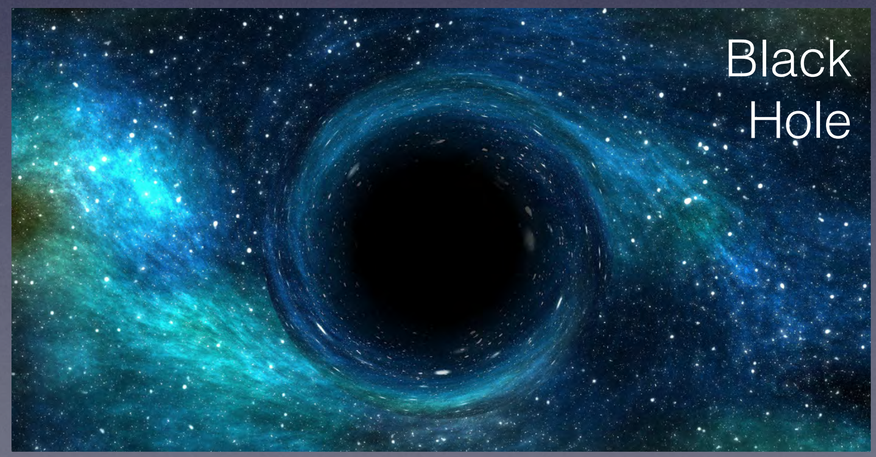
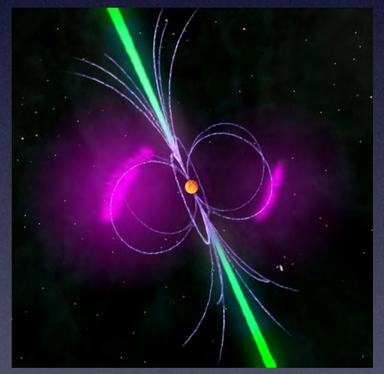


Mass **Size**

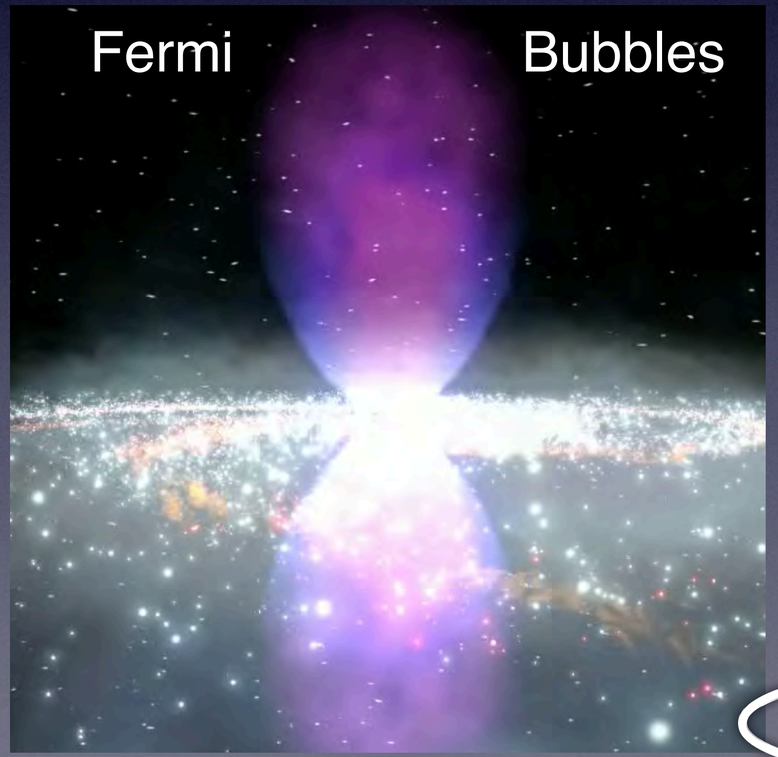
Low Large

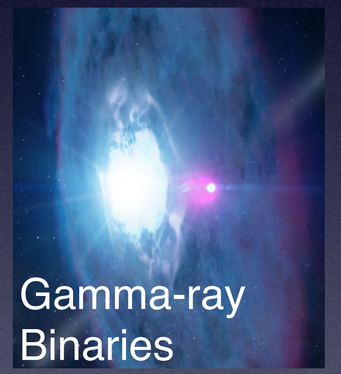
High Small



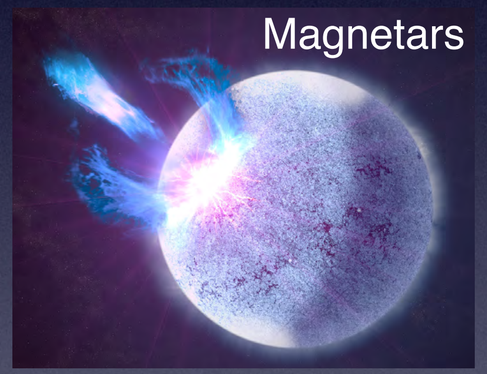
Pulsars

Fermi Bubbles

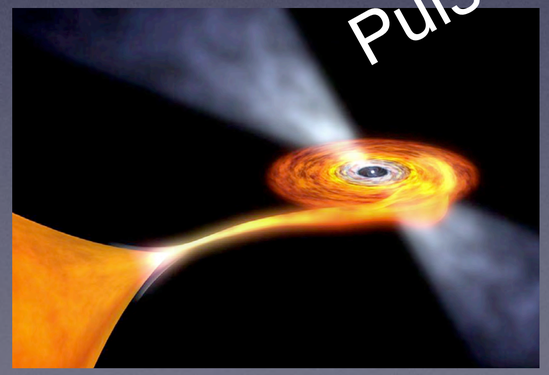


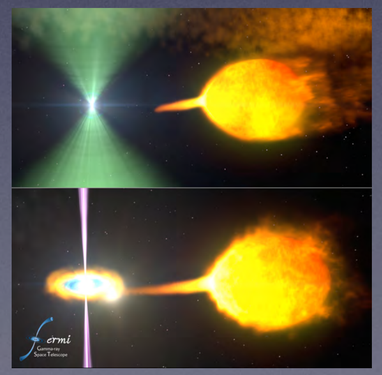


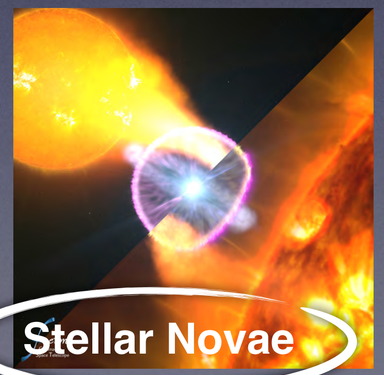
Gamma-ray Binaries



Magnetars

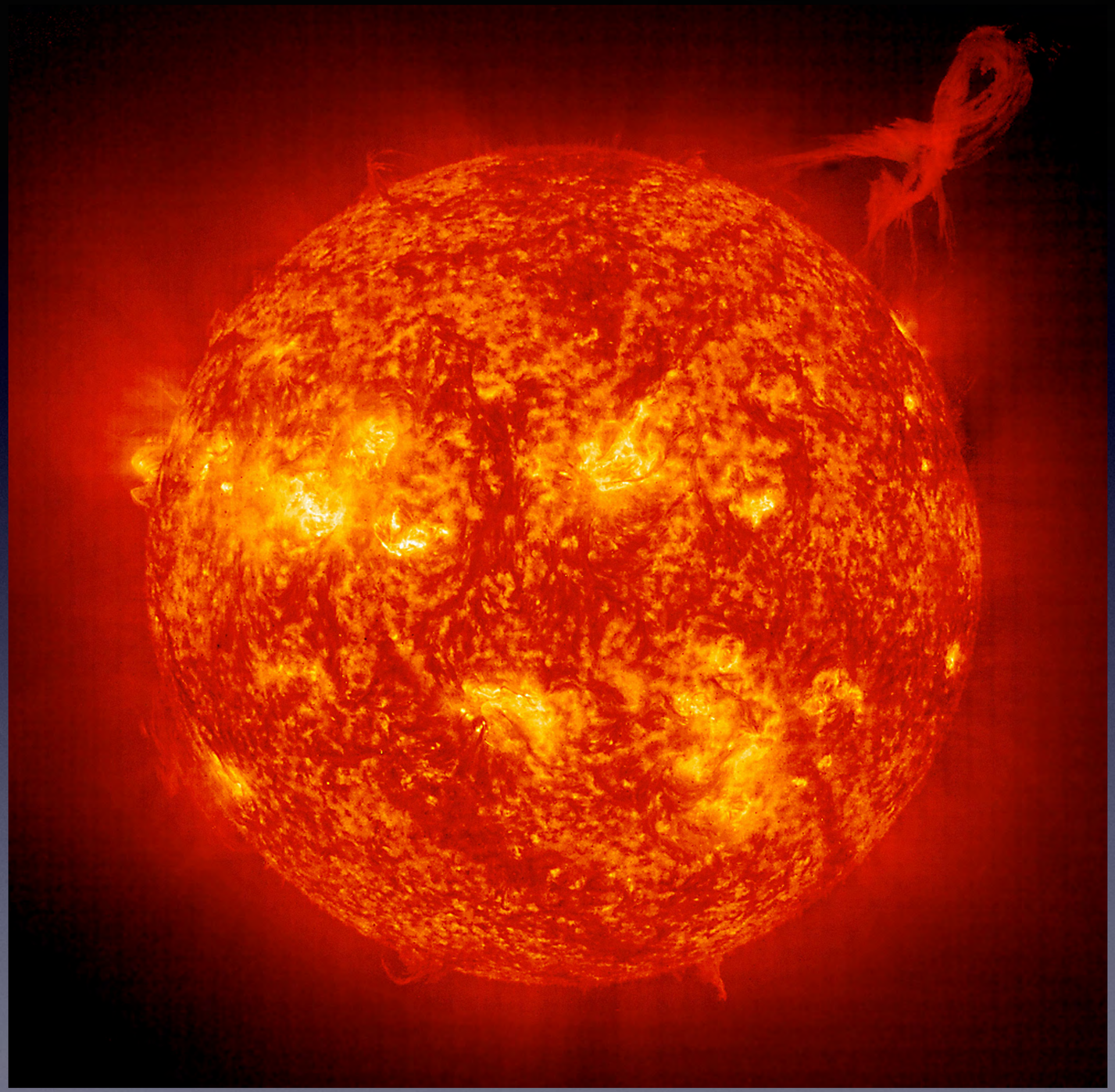


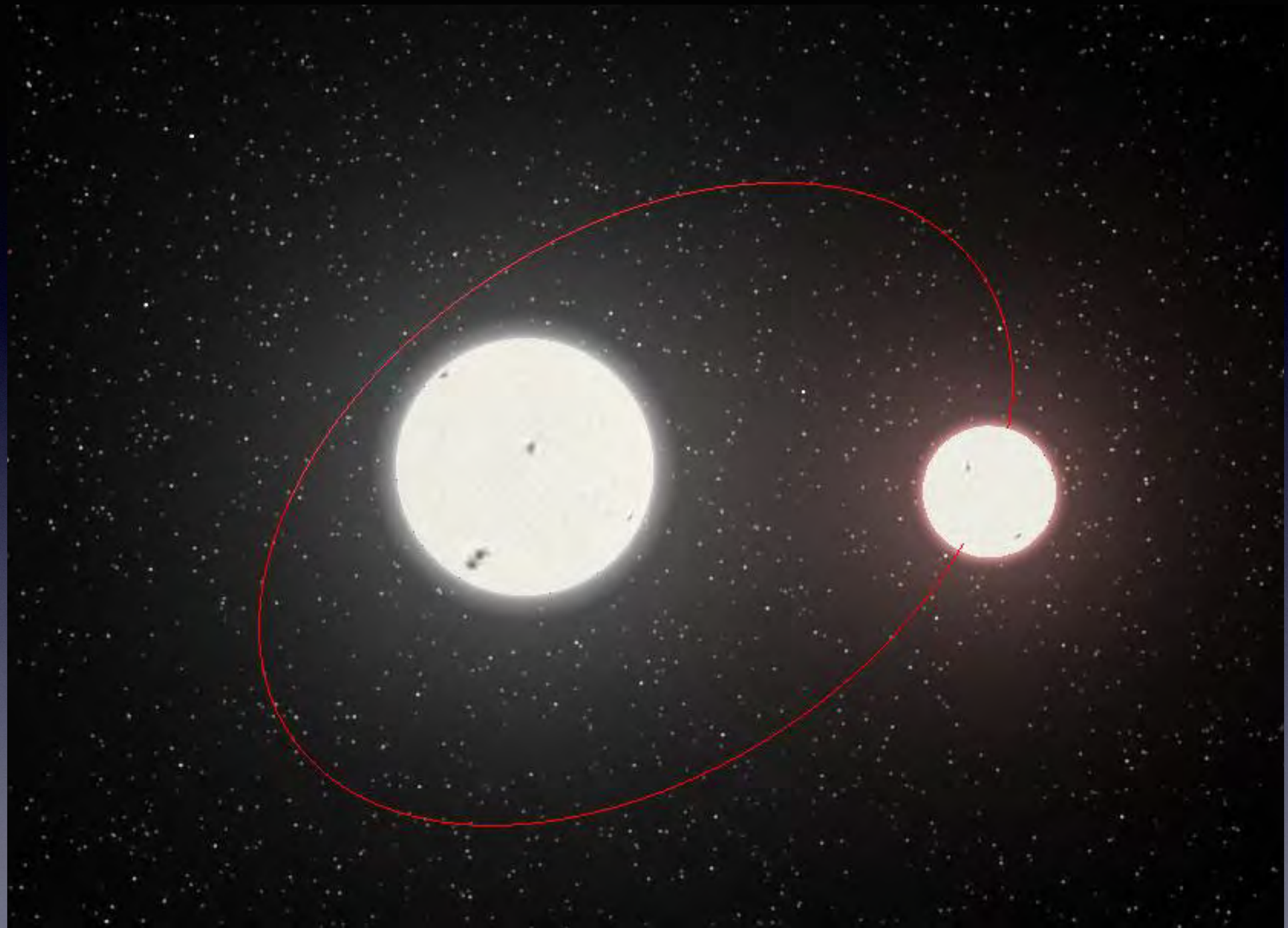


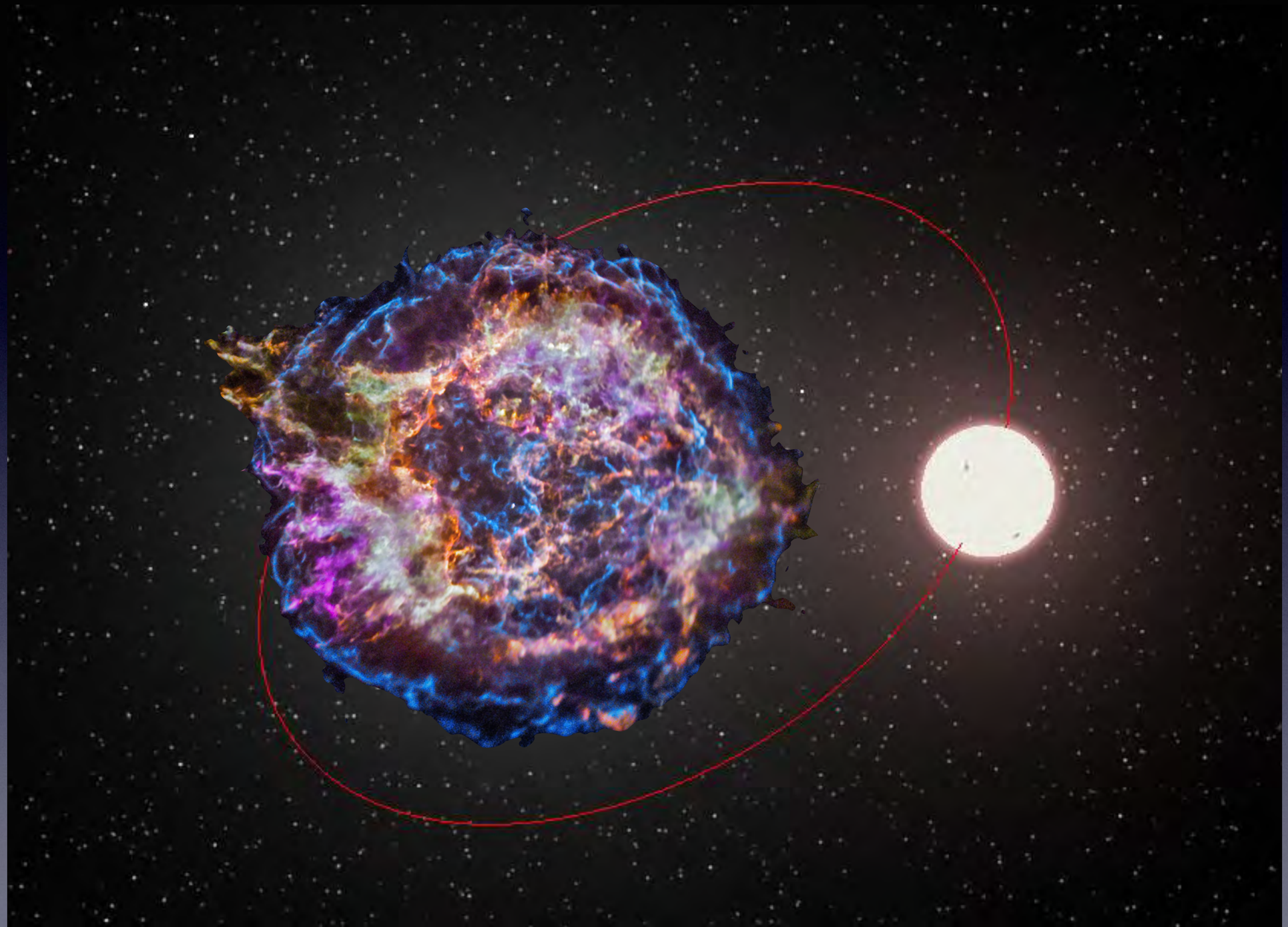


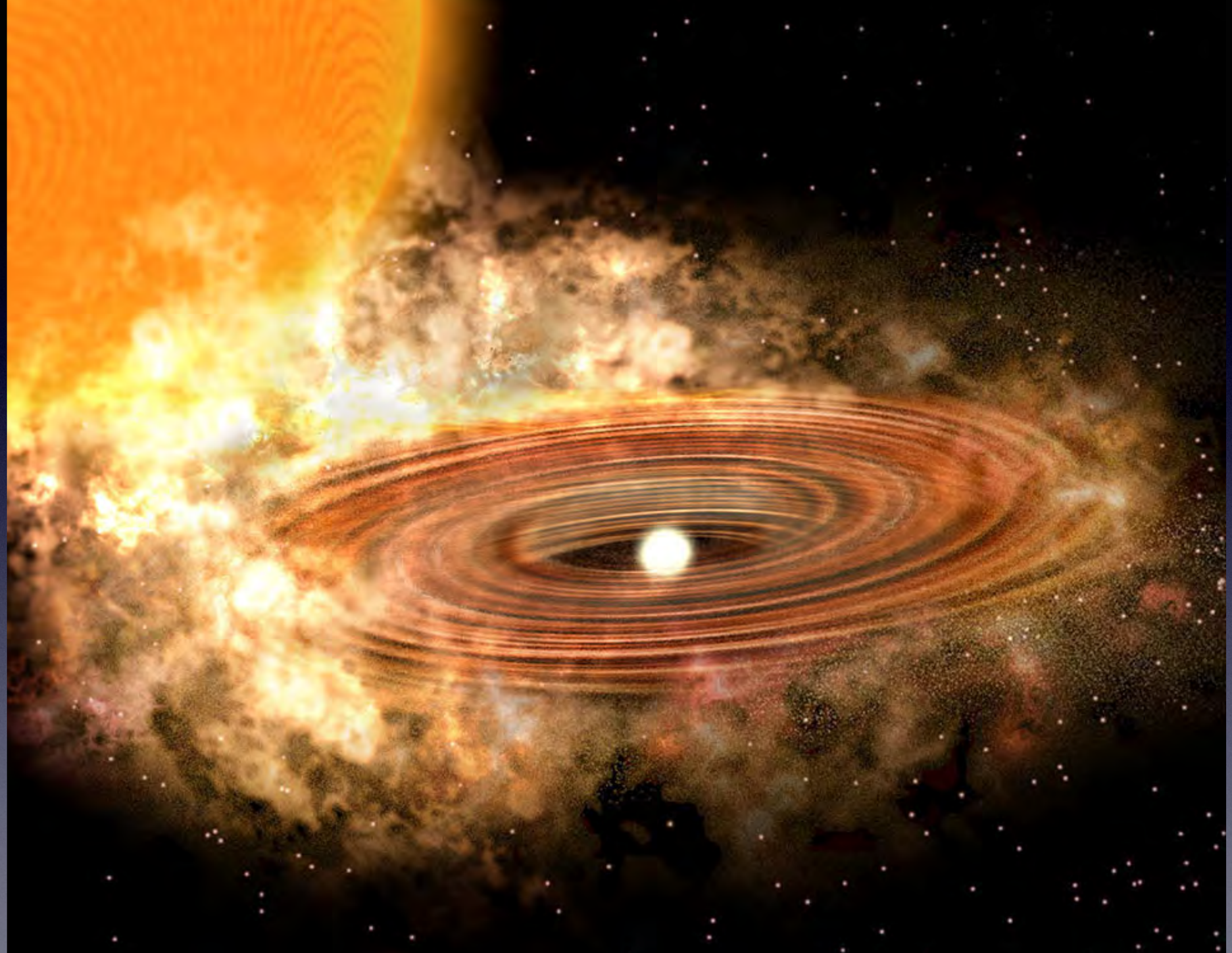
Stellar Novae

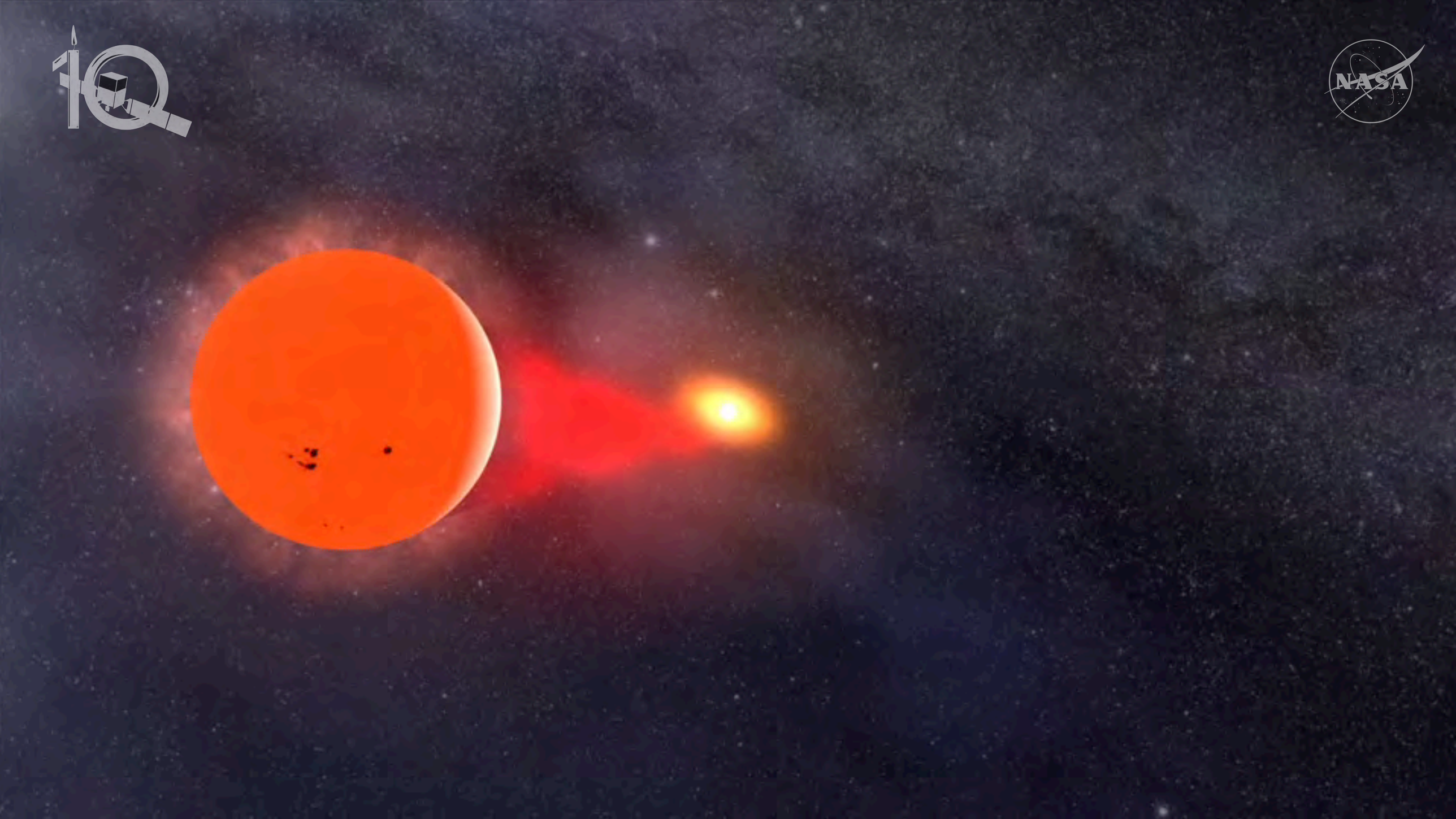
Supernova Remnants

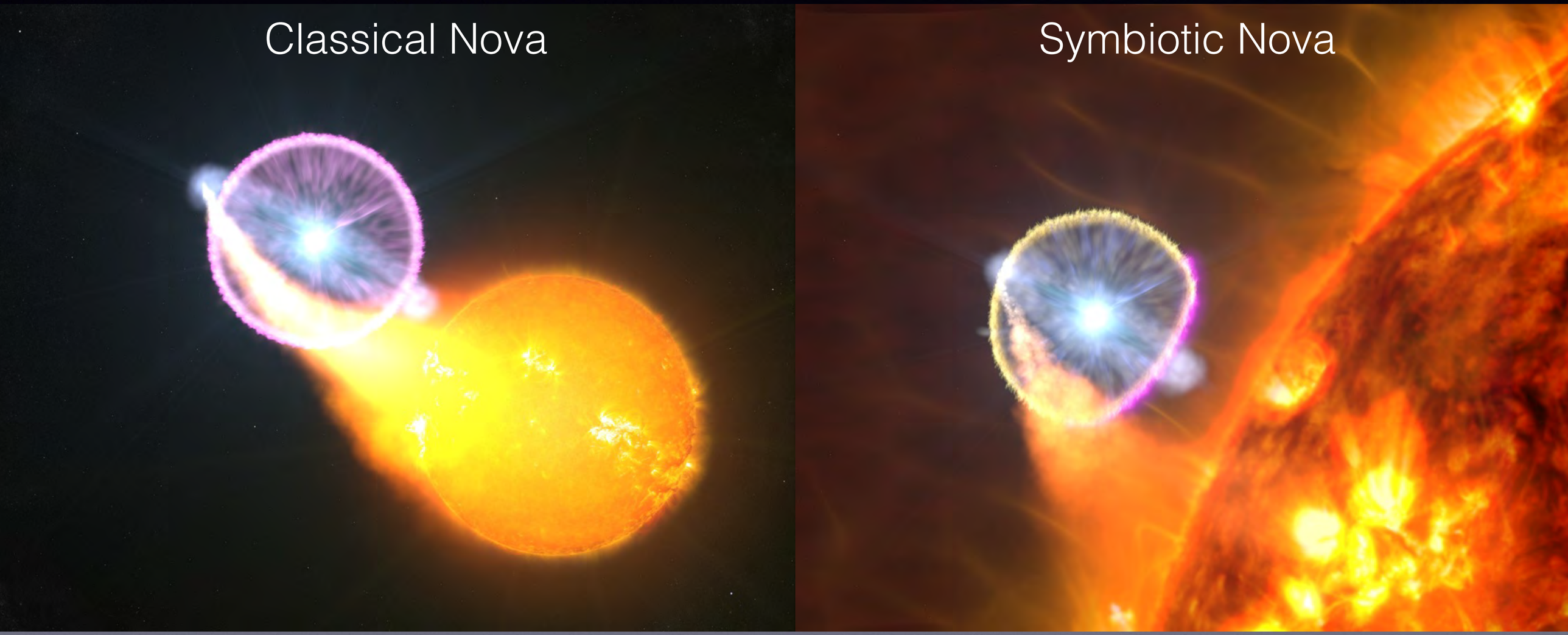


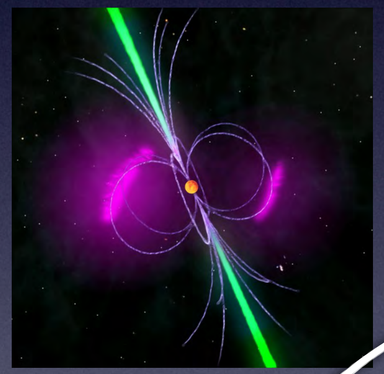




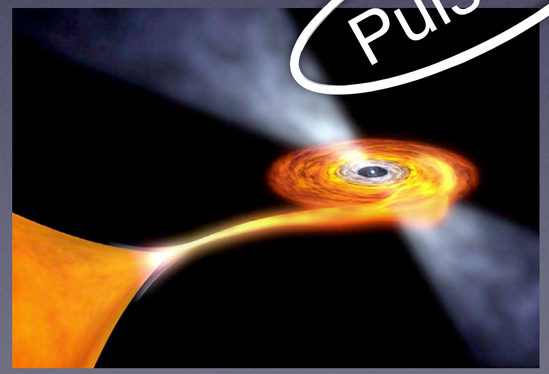


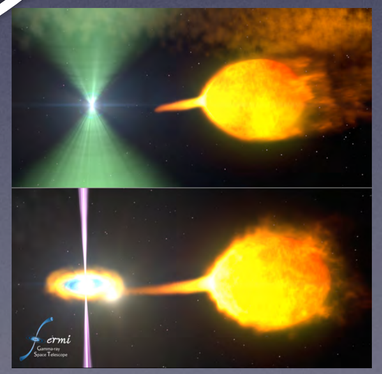


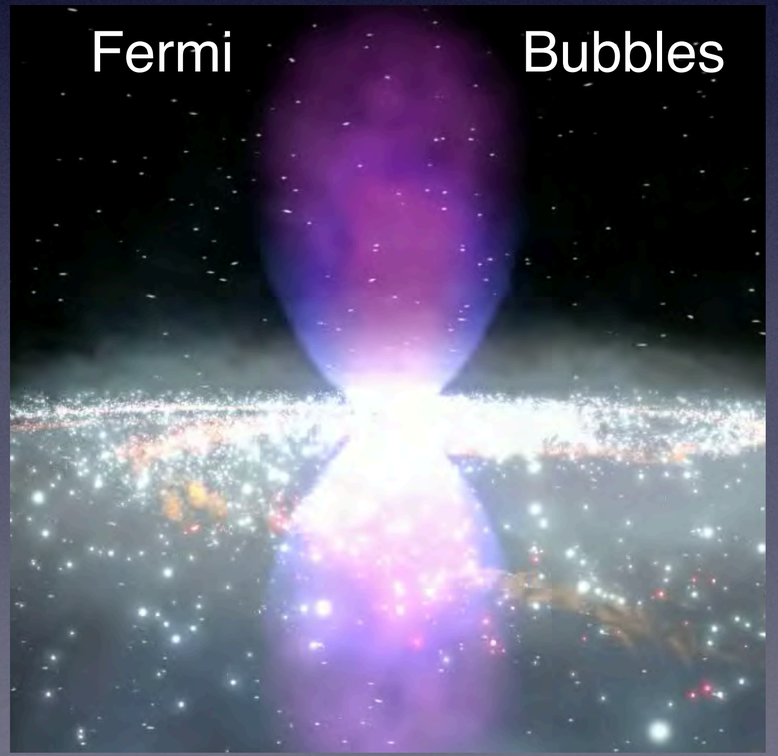

Classical Nova
Symbiotic Nova

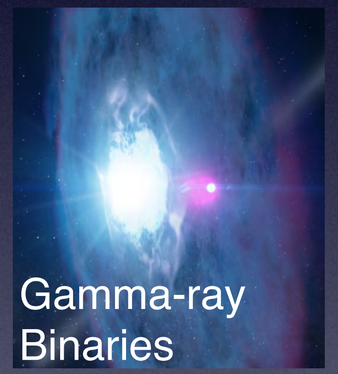


Pulsars

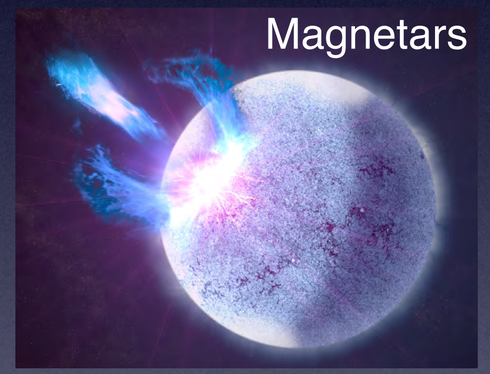




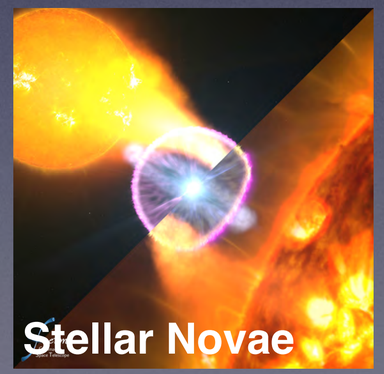




Gamma-ray
Binaries

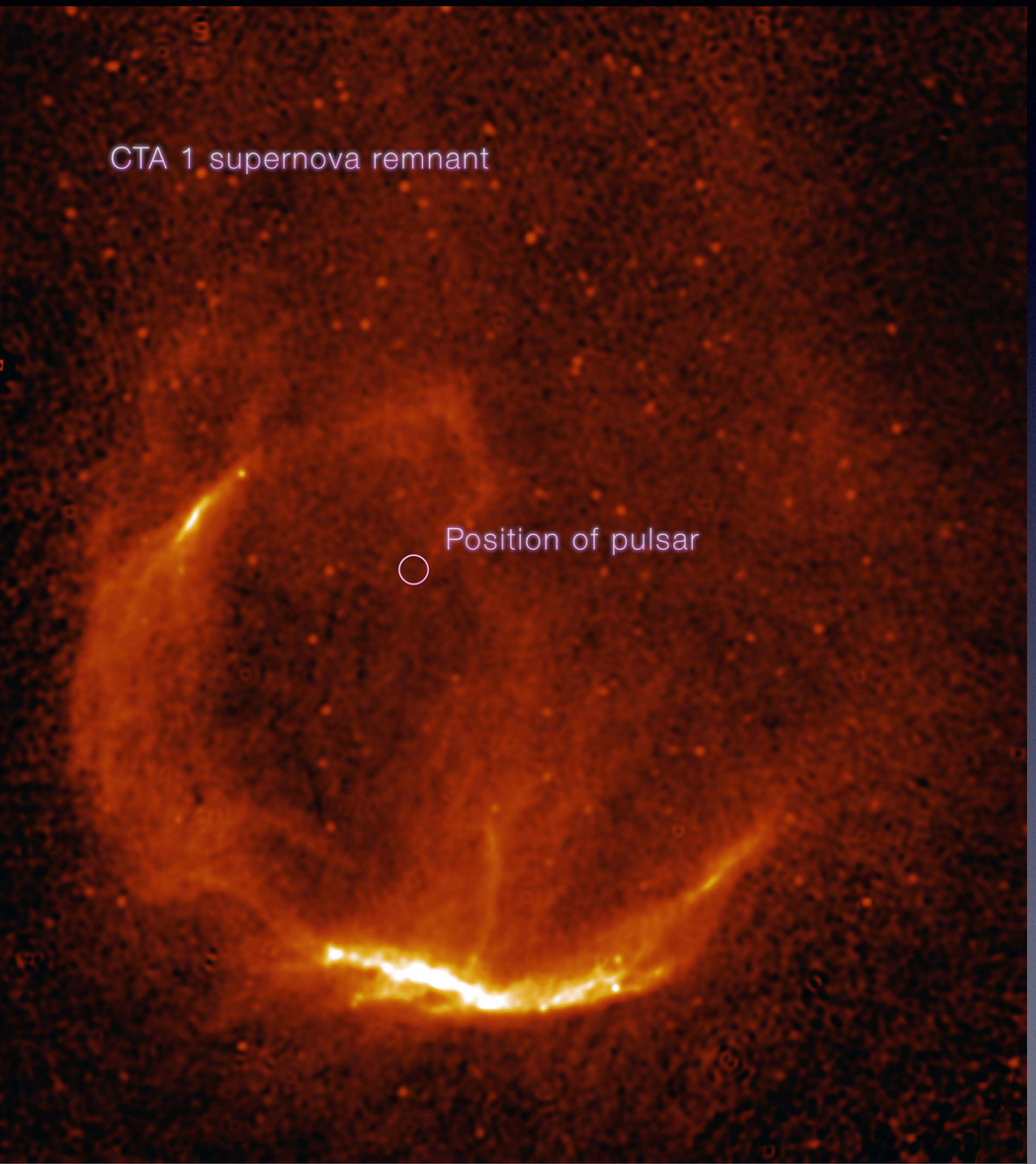


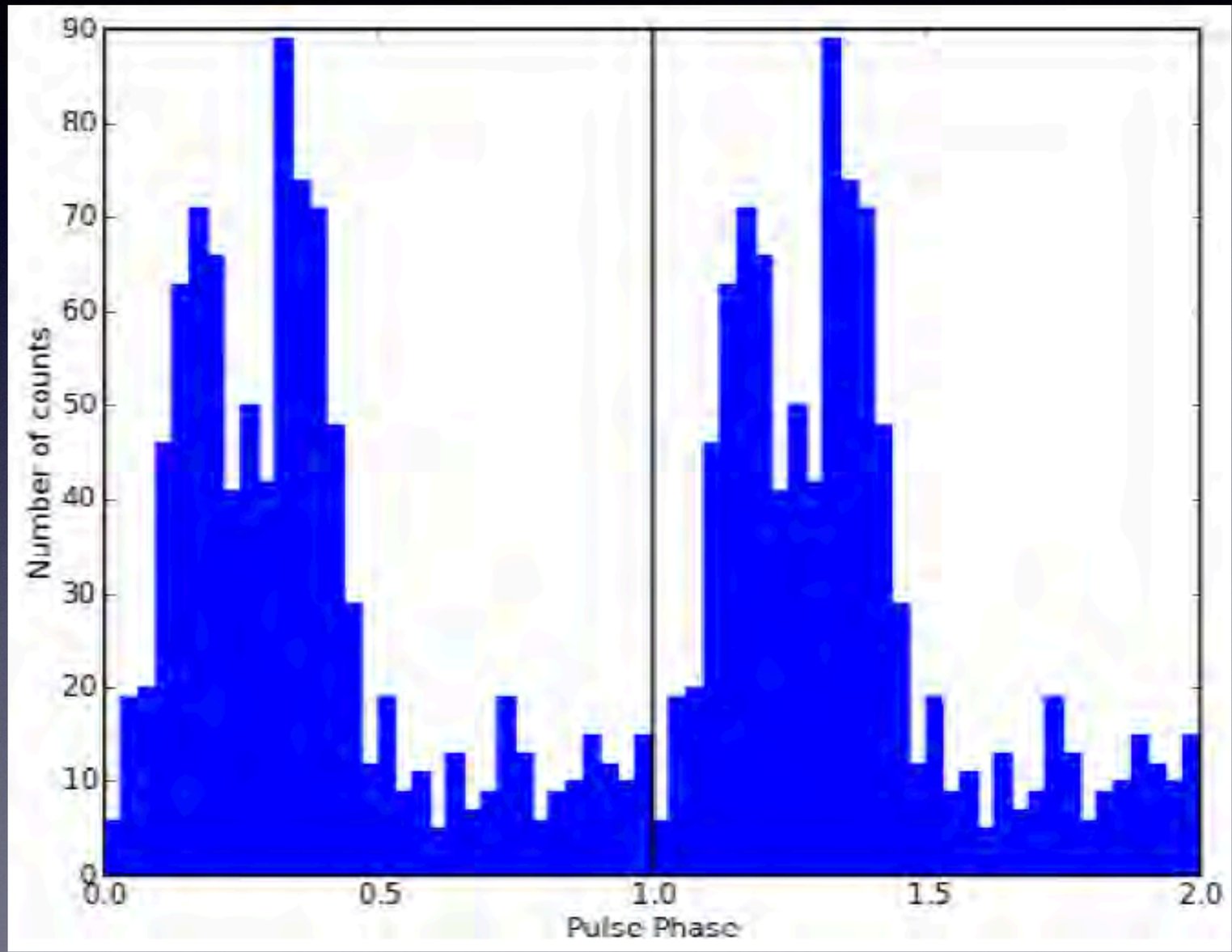
Magnetars

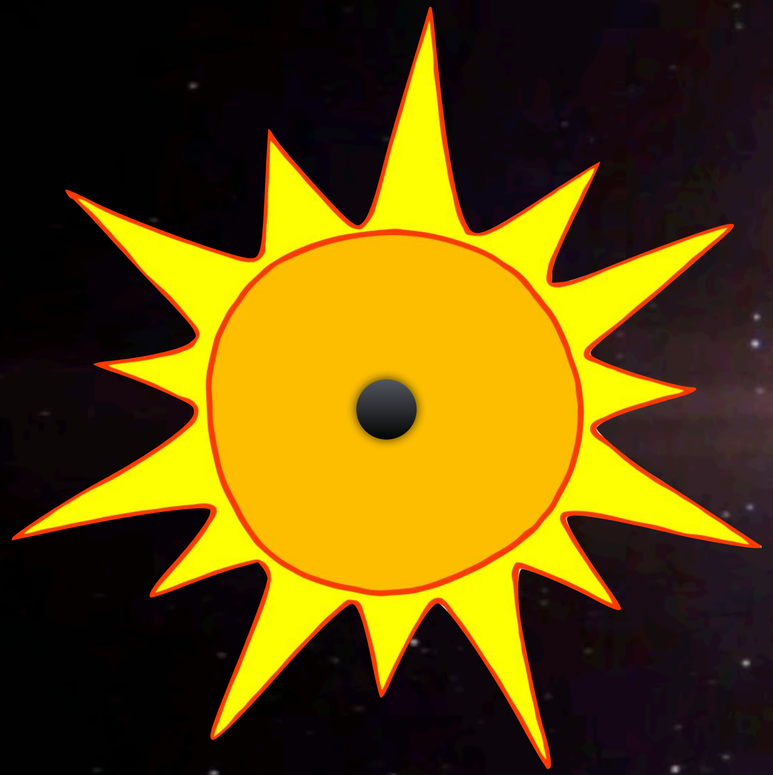


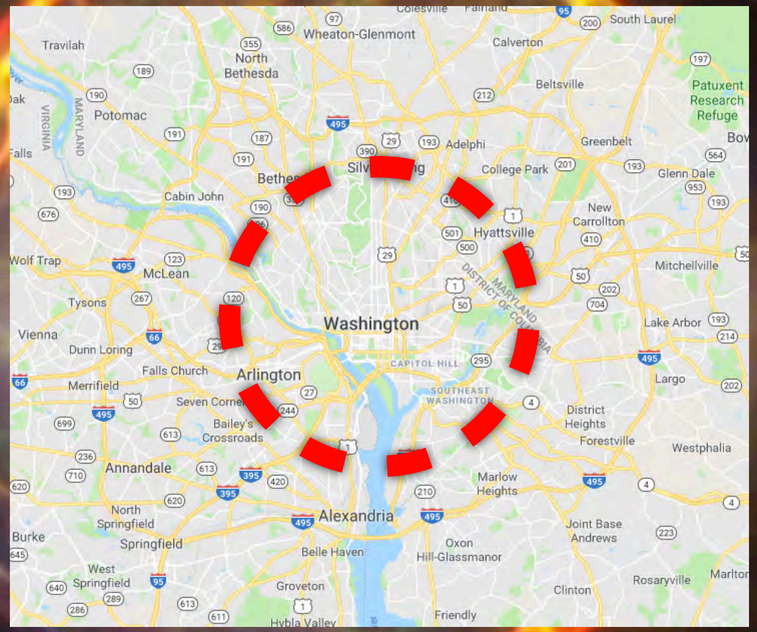
Stellar Novae

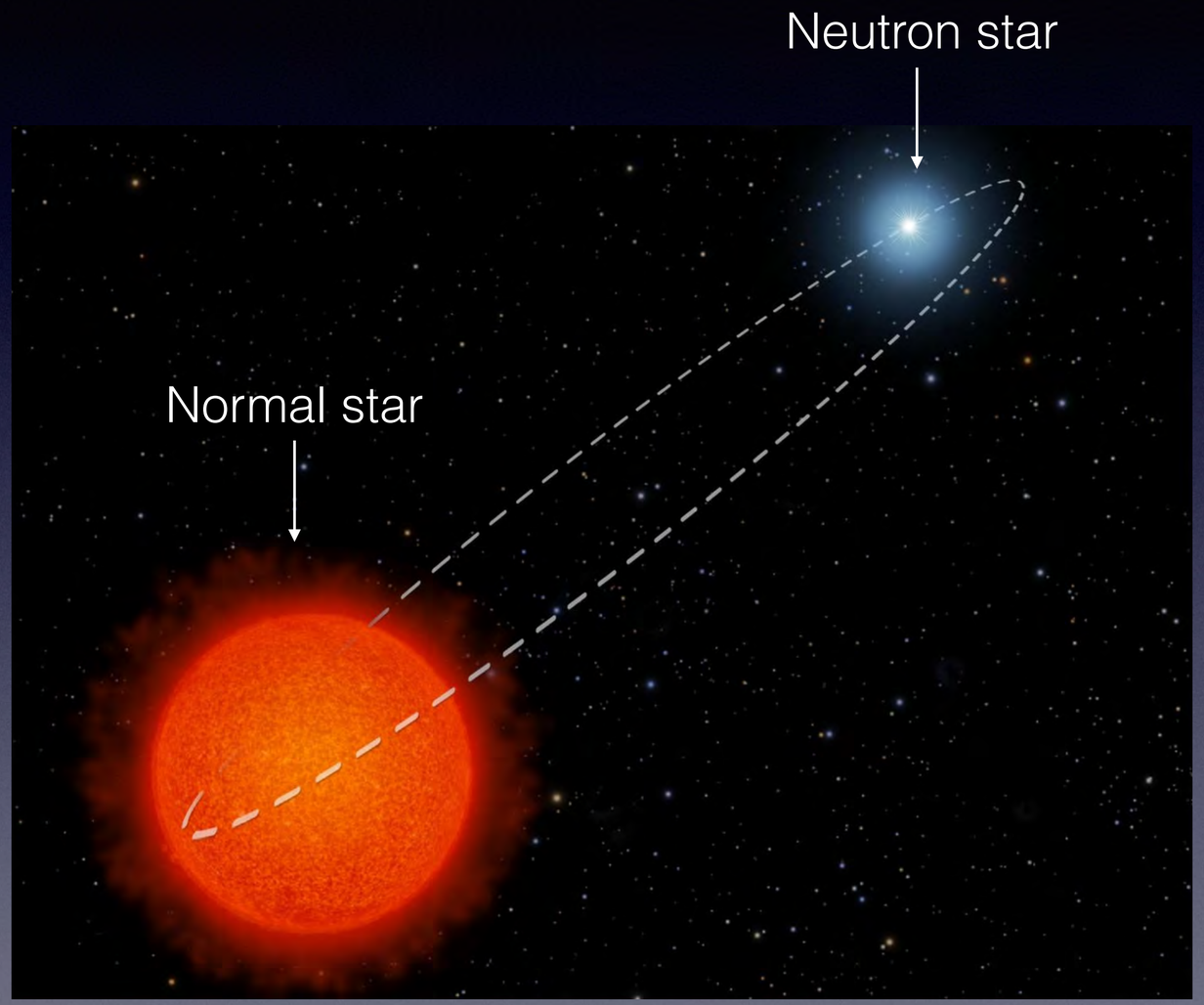
Supernova Remnants

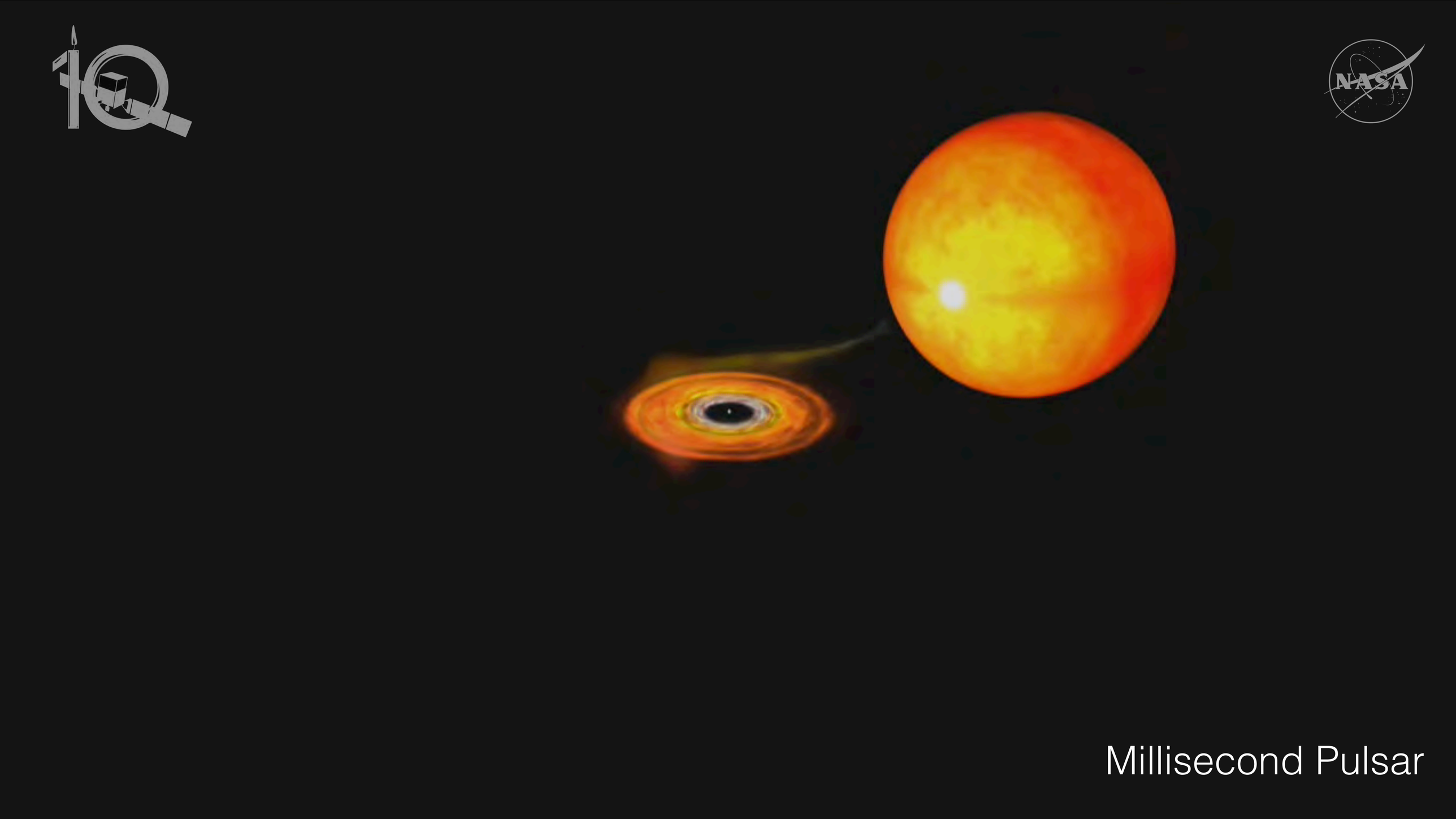

CTA 1 supernova remnant
Position of pulsar


Number of counts
Pulse Phase
0
10
20
30
40
50
60
70
80
90
0.0
0.5
1.0
1.5
2.0

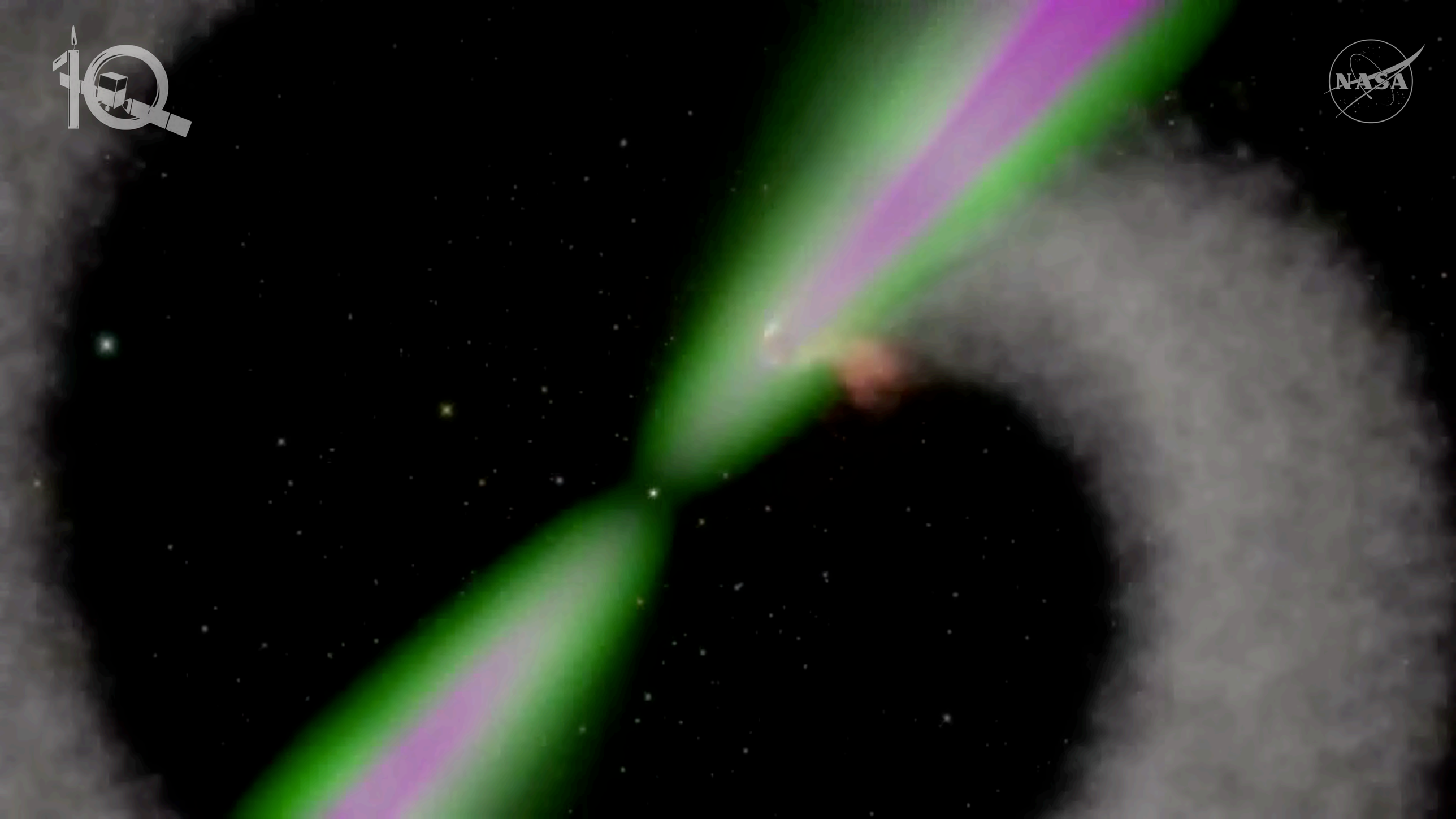



Wheaton-Glenmont
North Bethesda
Potomac
Cabin John
Wolf Trap
McLean
Tysons
Vienna
Dunn Loring
Falls Church
Merrifield
Seven Corners
Bailey's Crossroads
Annandale
North Springfield
Springfield
West Springfield
Burke
Groveton
Hybla Valley
Belle Haven
Alexandria
Arlington
Washington
CAPITOL HILL
SOUTHEAST WASHINGTON
Adelphi
College Park
Hyattsville
Beltsville
Calverton
South Laurel
Greenbelt
Glenn Dale
New Carrollton
Mitchellville
Lake Arbor
Largo
District Heights
Forestville
Westphalia
Marlow Heights
Joint Base Andrews
Oxon Hill-Glassmanor
Clinton
Friendly
Rosaryville
Patuxent Research Refuge
Travilah
VIRGINIA
MARYLAND
DISTRICT OF COLUMBIA

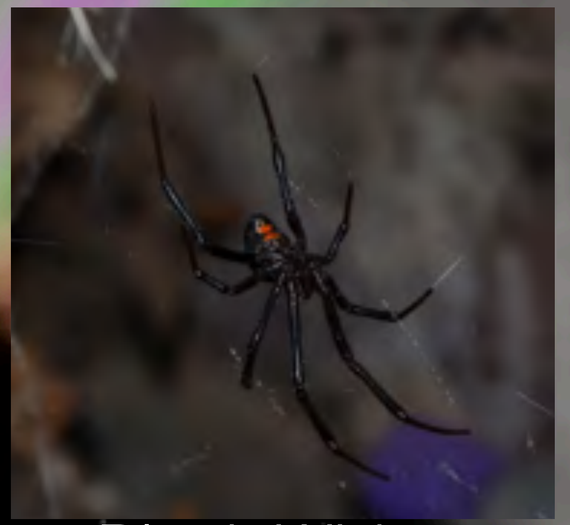

Neutron star
Normal star



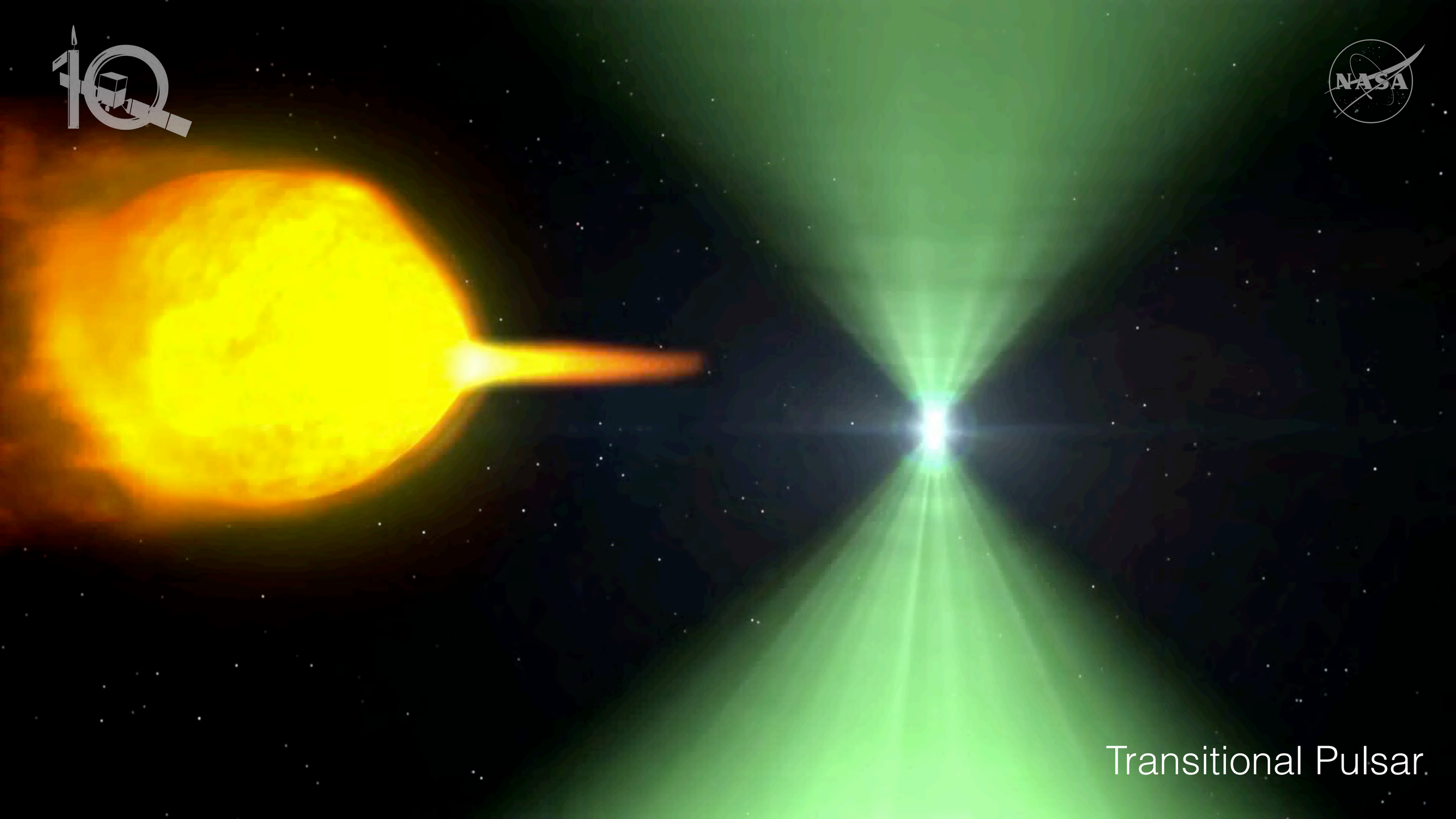
Millisecond Pulsar

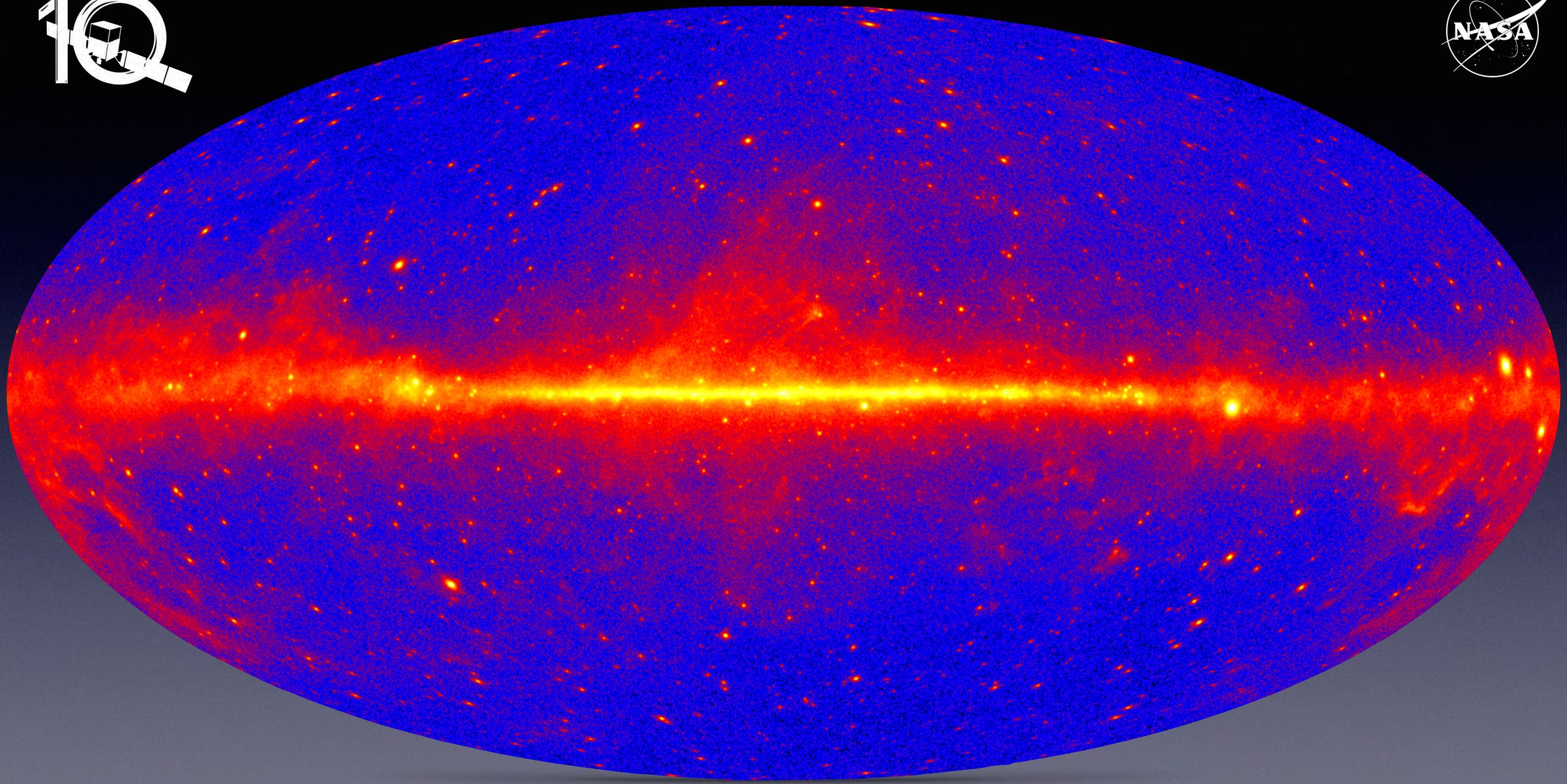


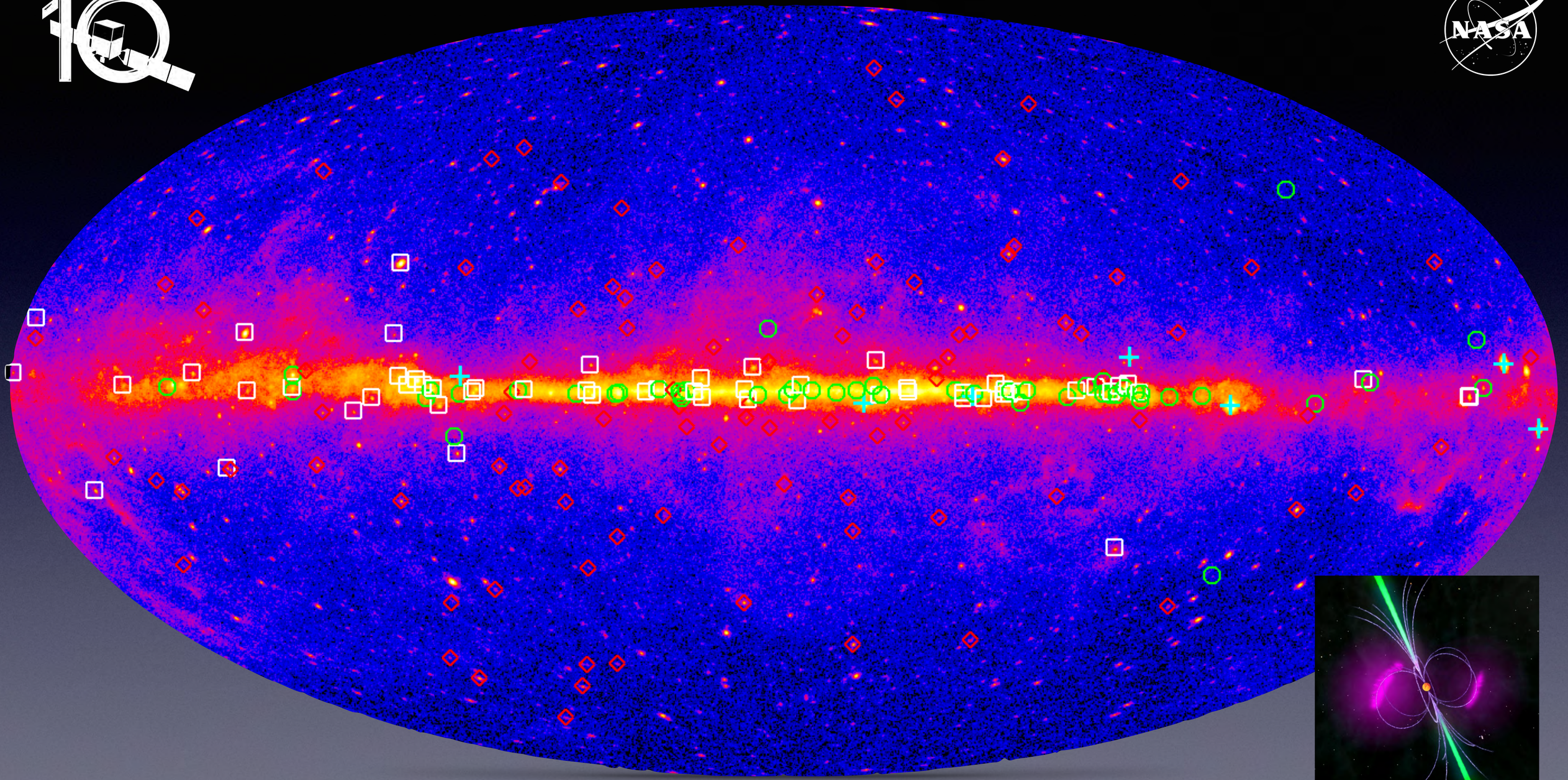
Redback Pulsars

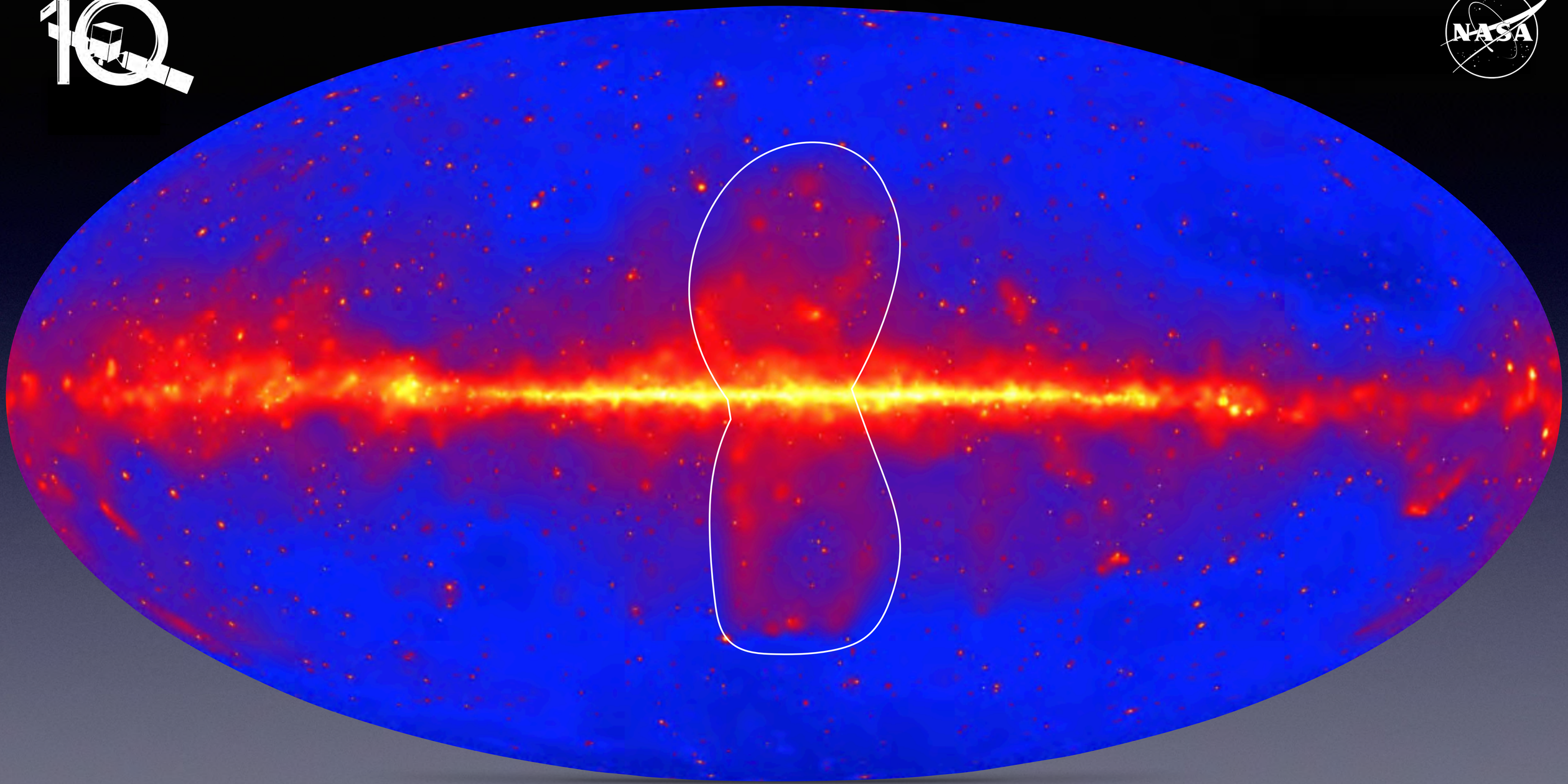


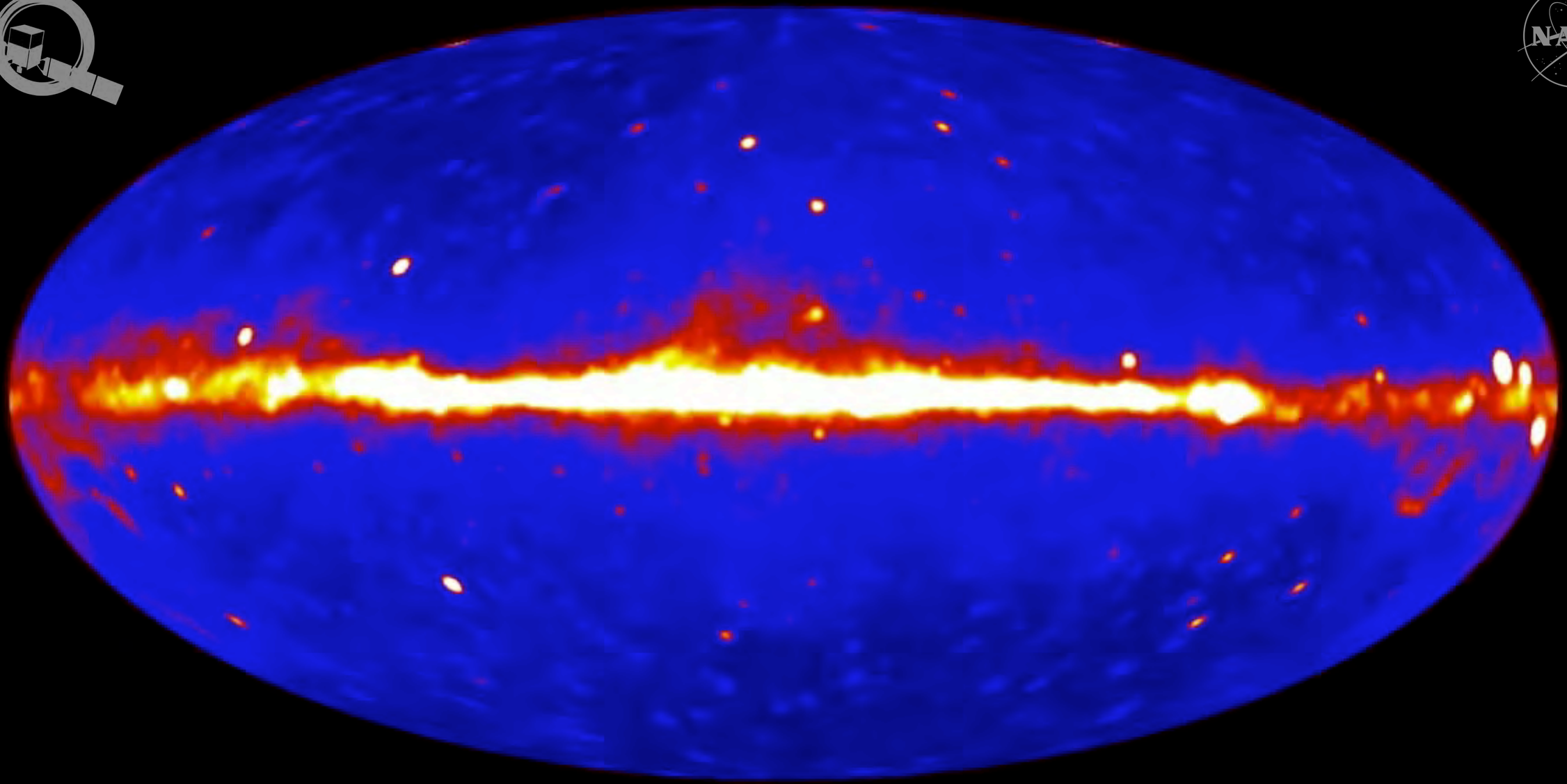
Black Widow Pulsars


Transitional Pulsar

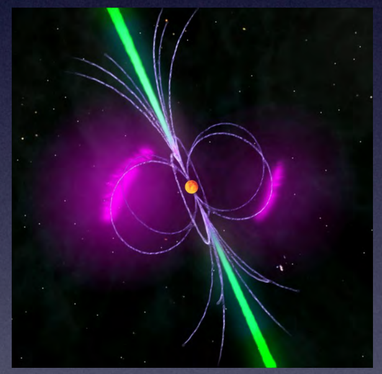




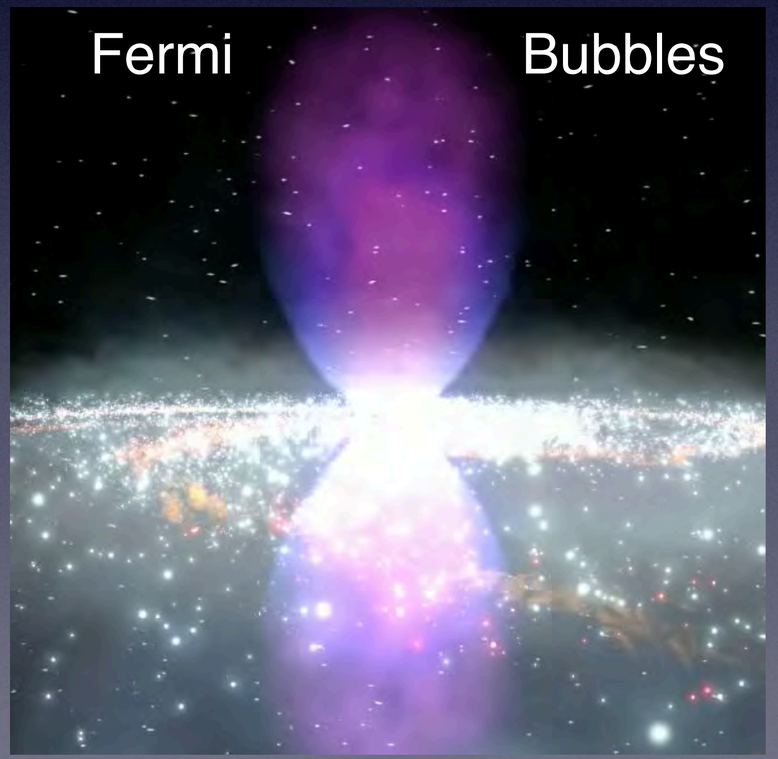




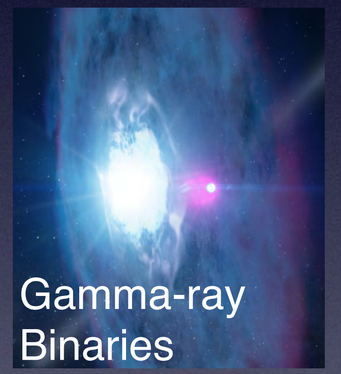
Milky Way Galaxy



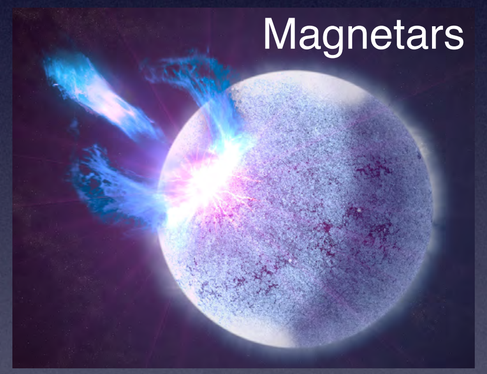
Pulsars



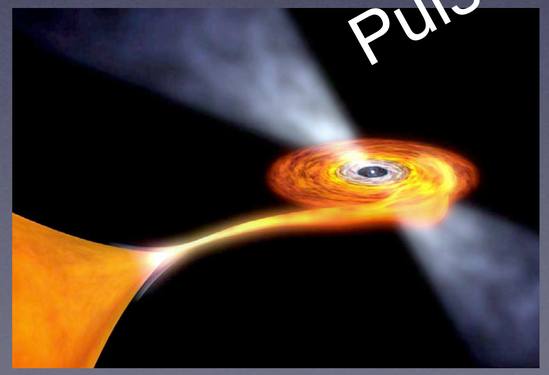
Fermi Bubbles

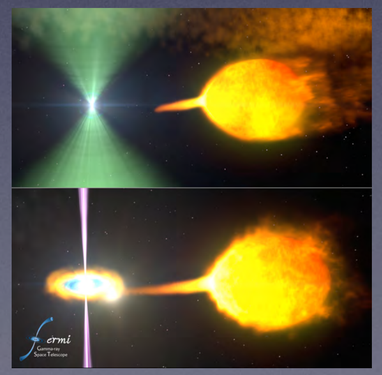


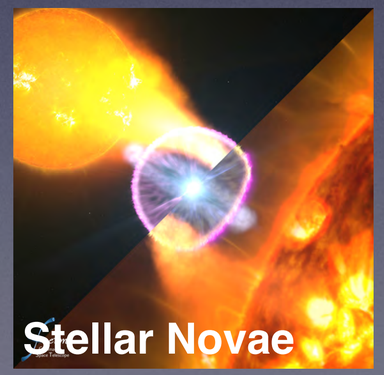
Gamma-ray Binaries



Magnetars

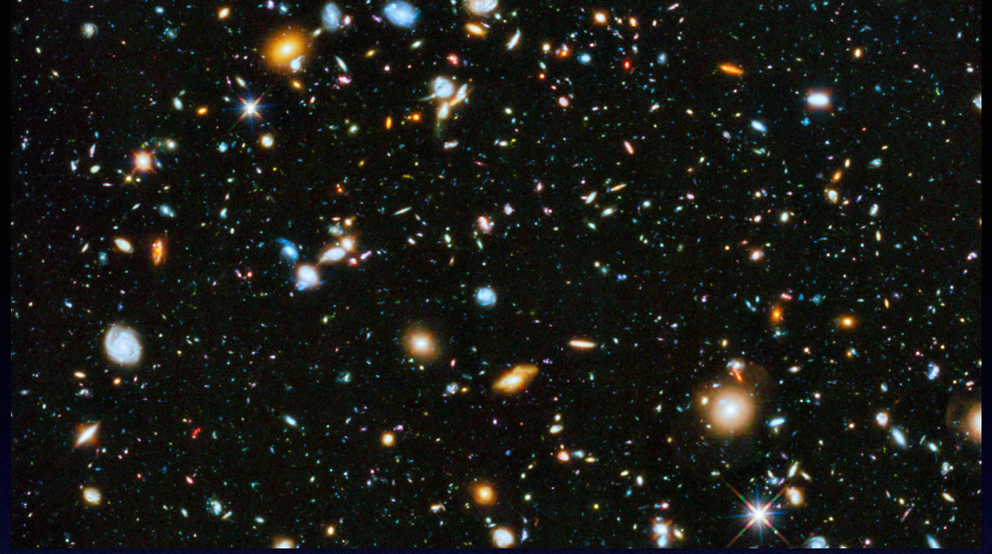




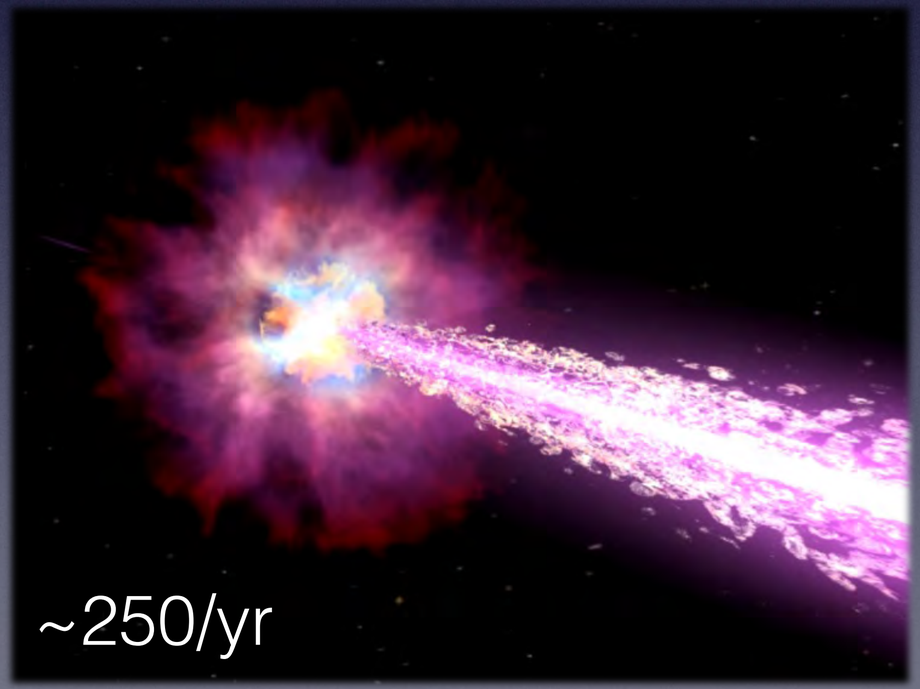


Stellar Novae

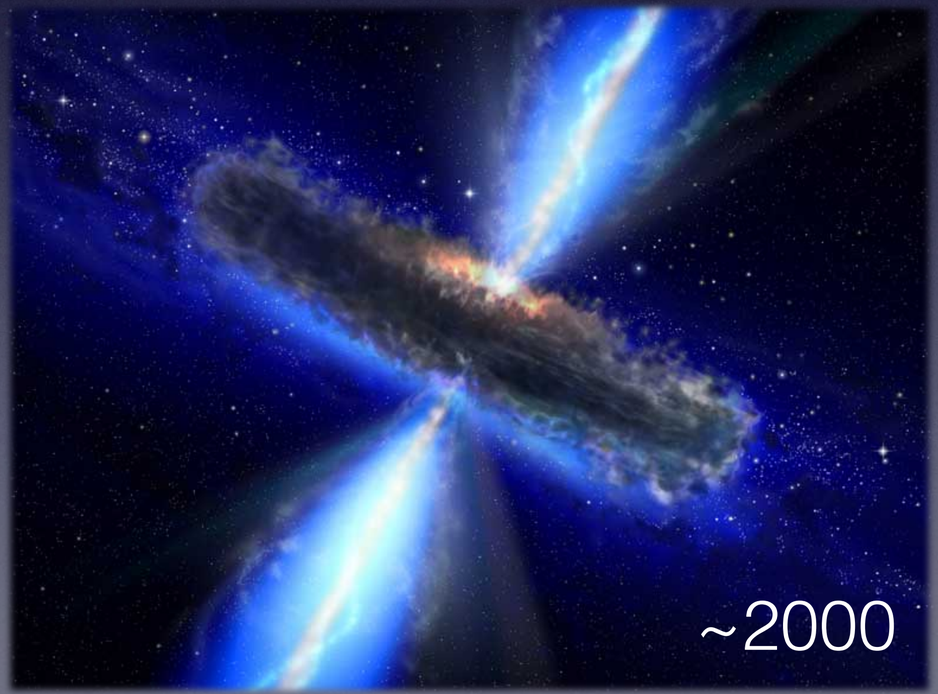
Supernova Remnants

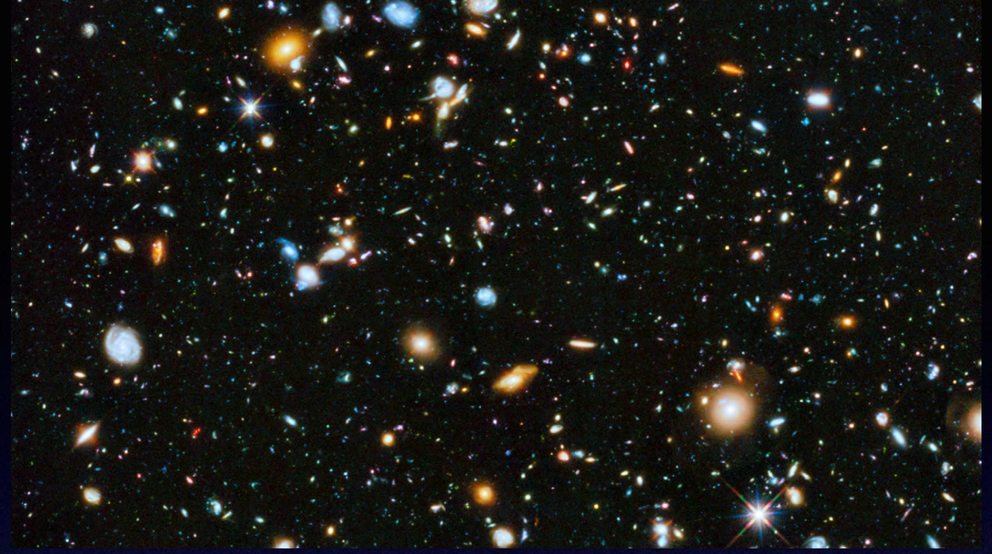


Gamma-ray Bursts

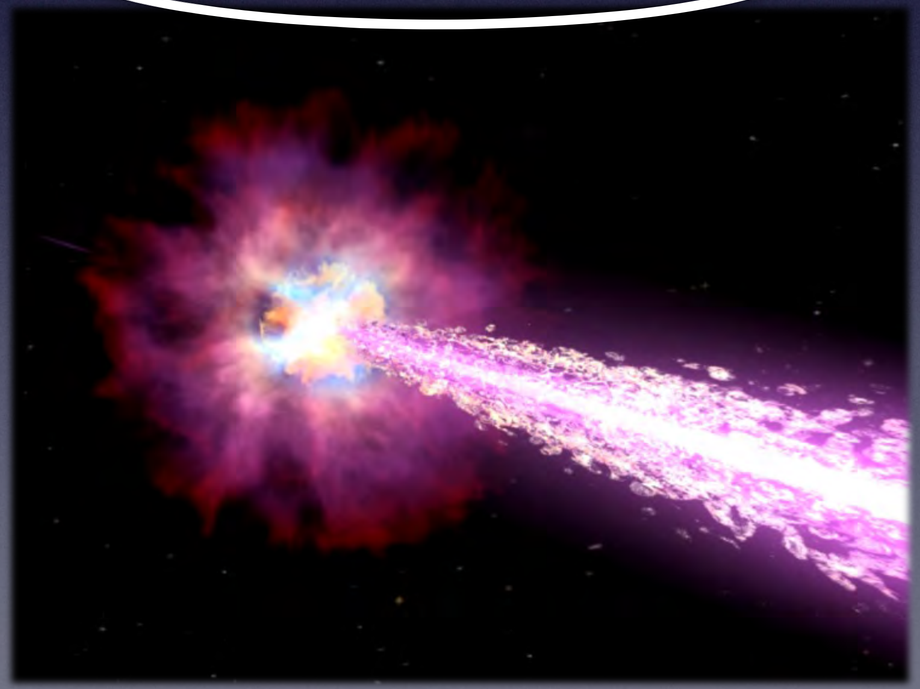


Active Galactic Nuclei

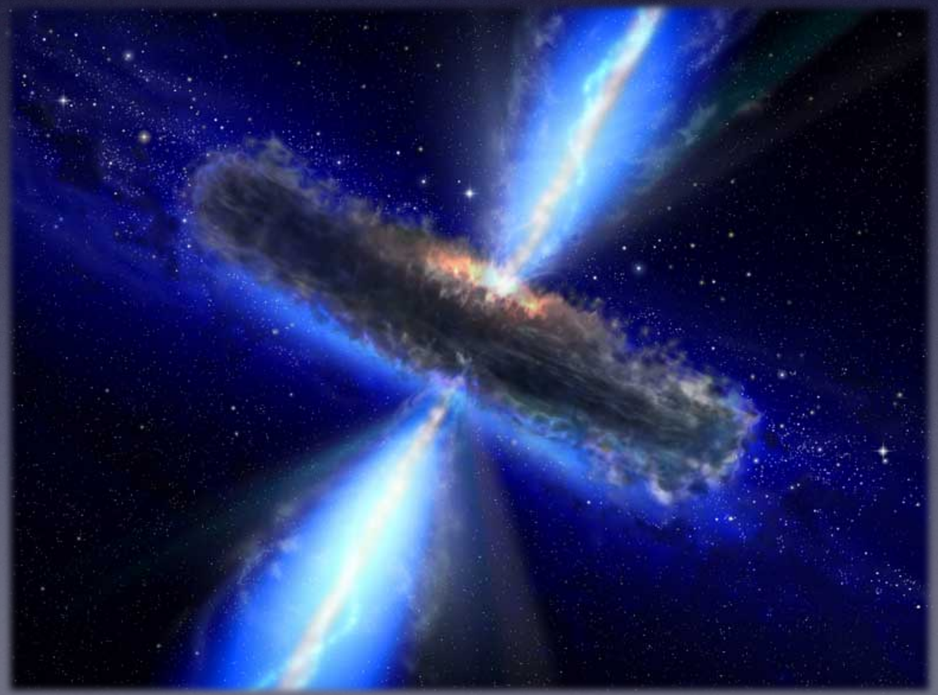




Gamma-ray Bursts

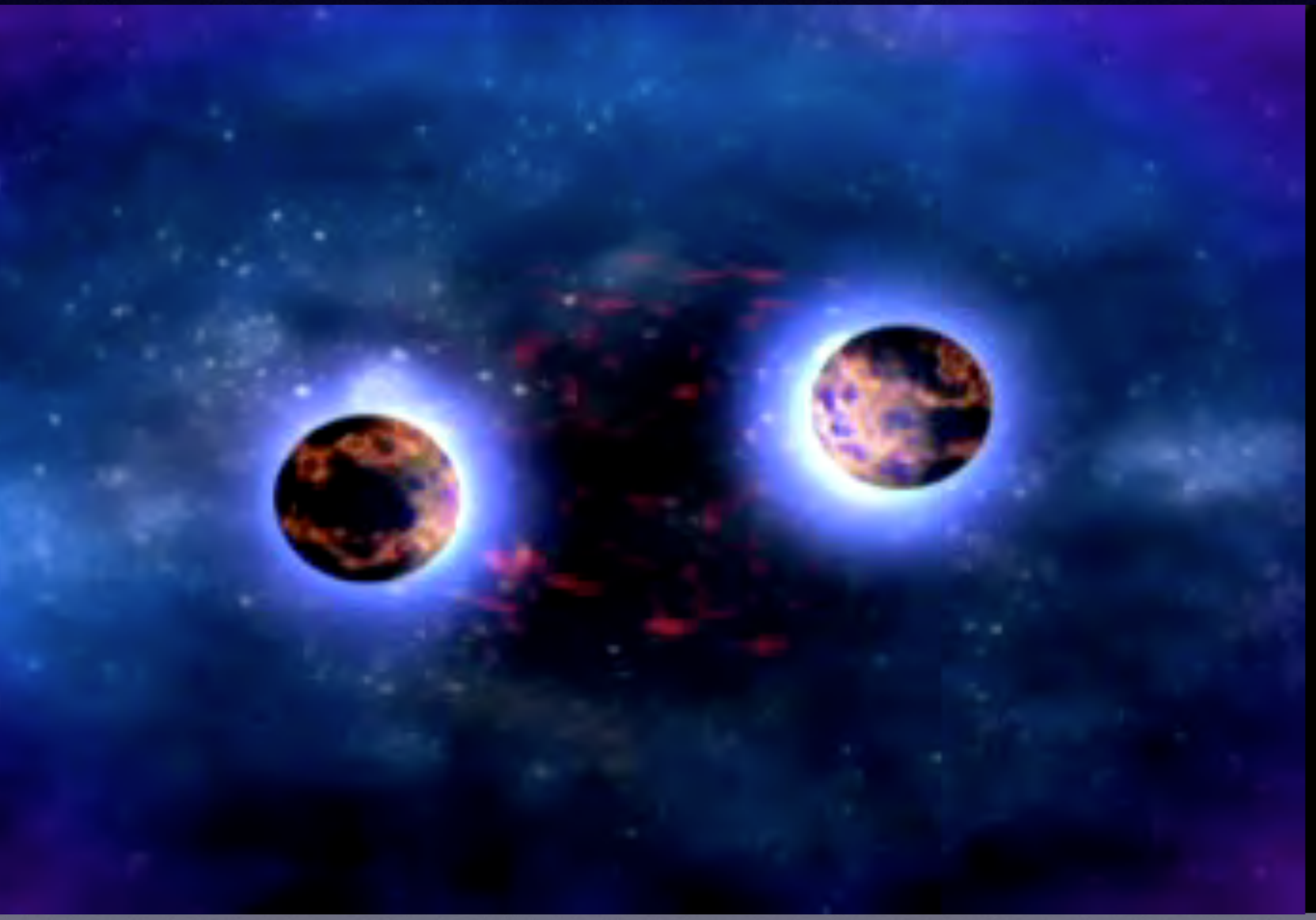


Active Galactic Nuclei

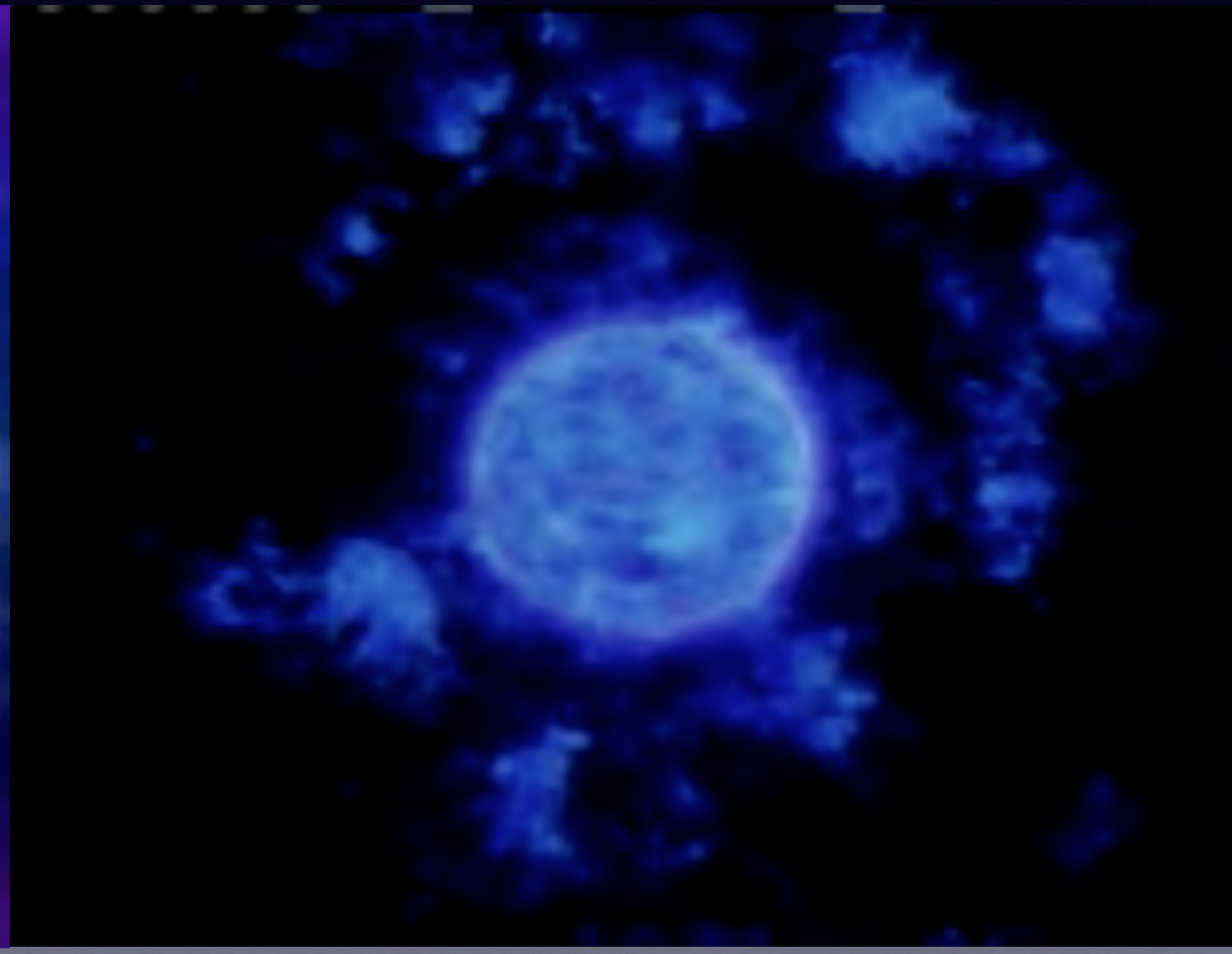


2 “Flavors” of GRBs

“Short” GRBs:
Merging Neutron Stars



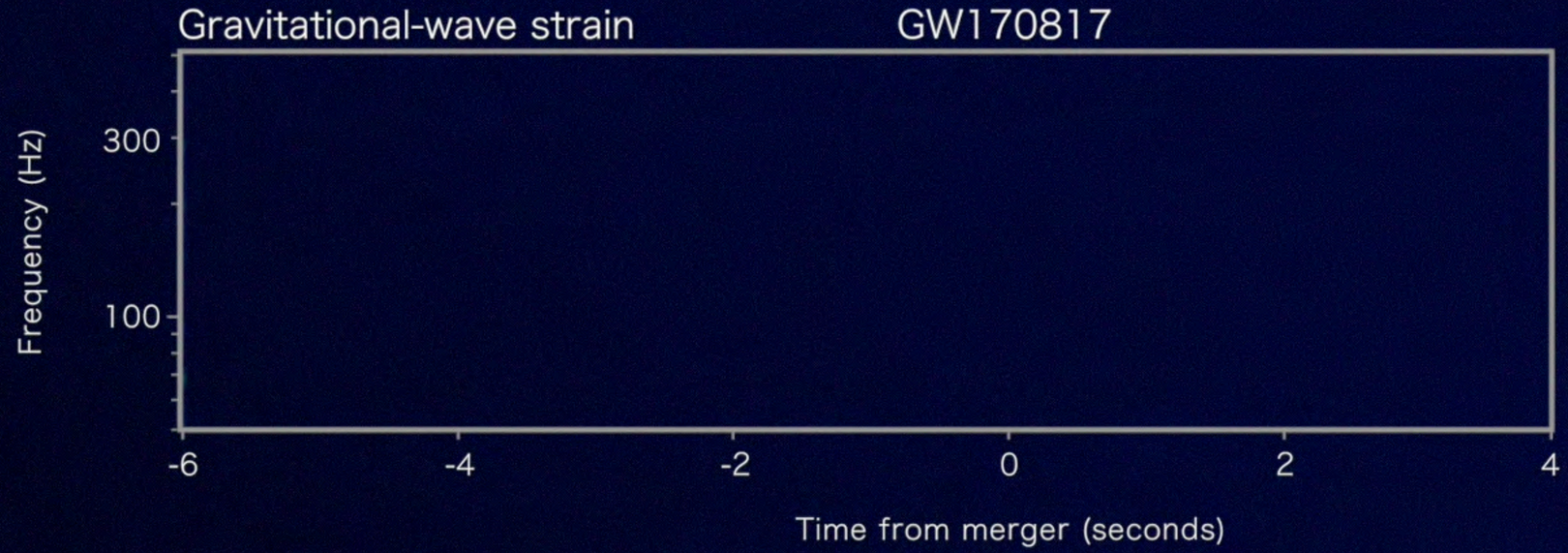
“Long” GRBs:
Collapsing Massive Stars



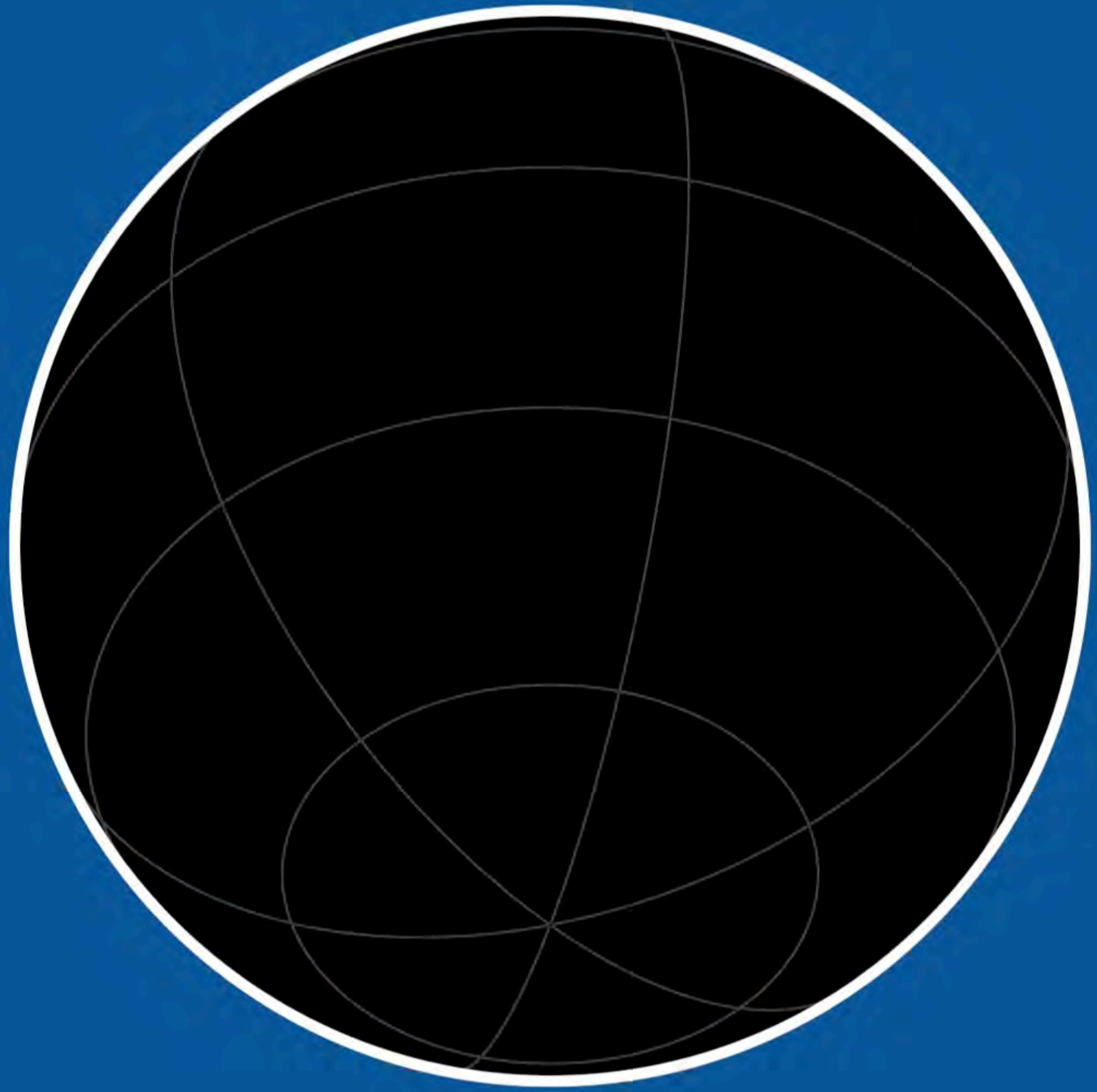
Fermi

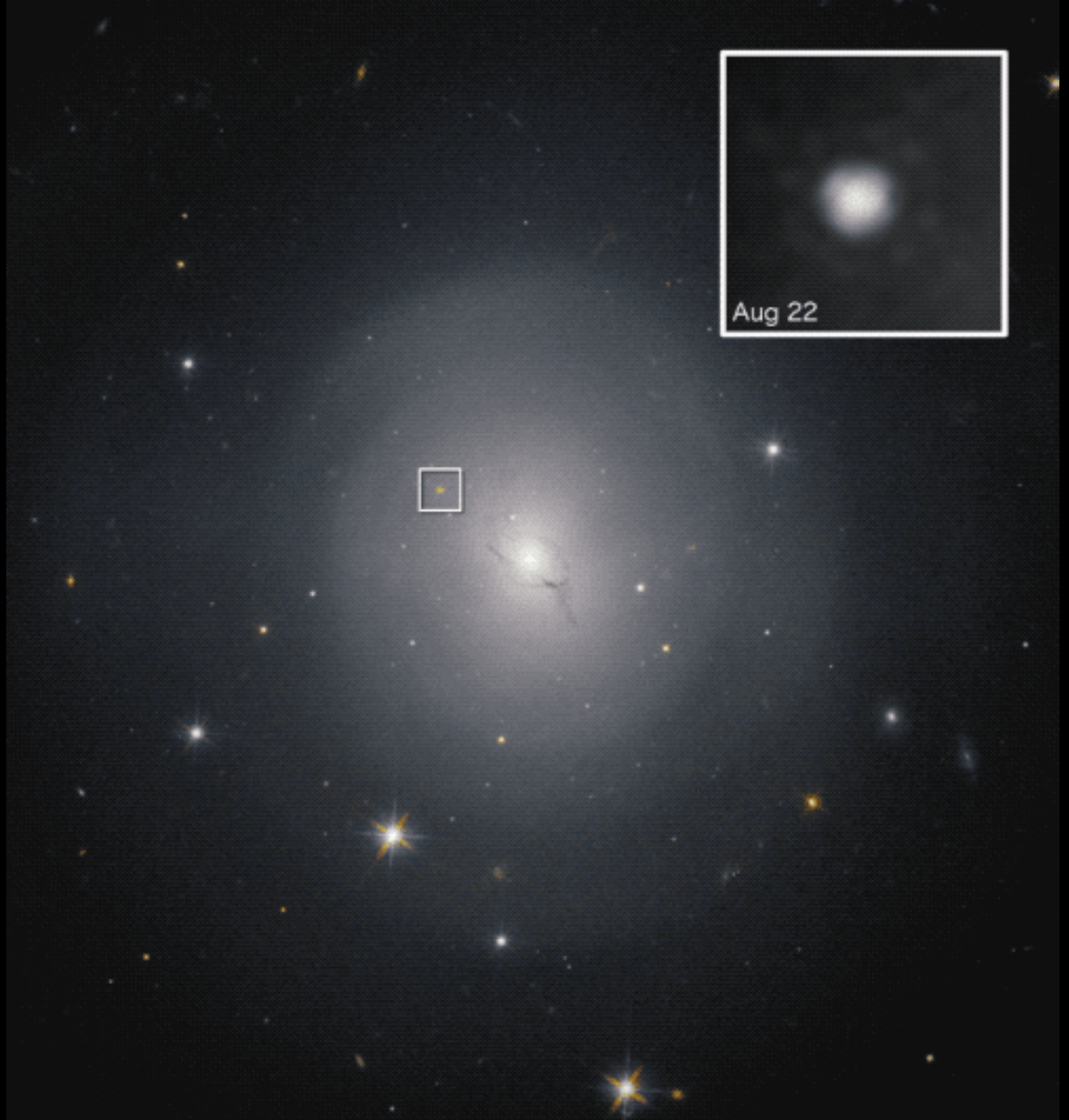

Gamma rays, 50 to 300 keV
GRB 170817A
Counts per second
1,500
1,000
500

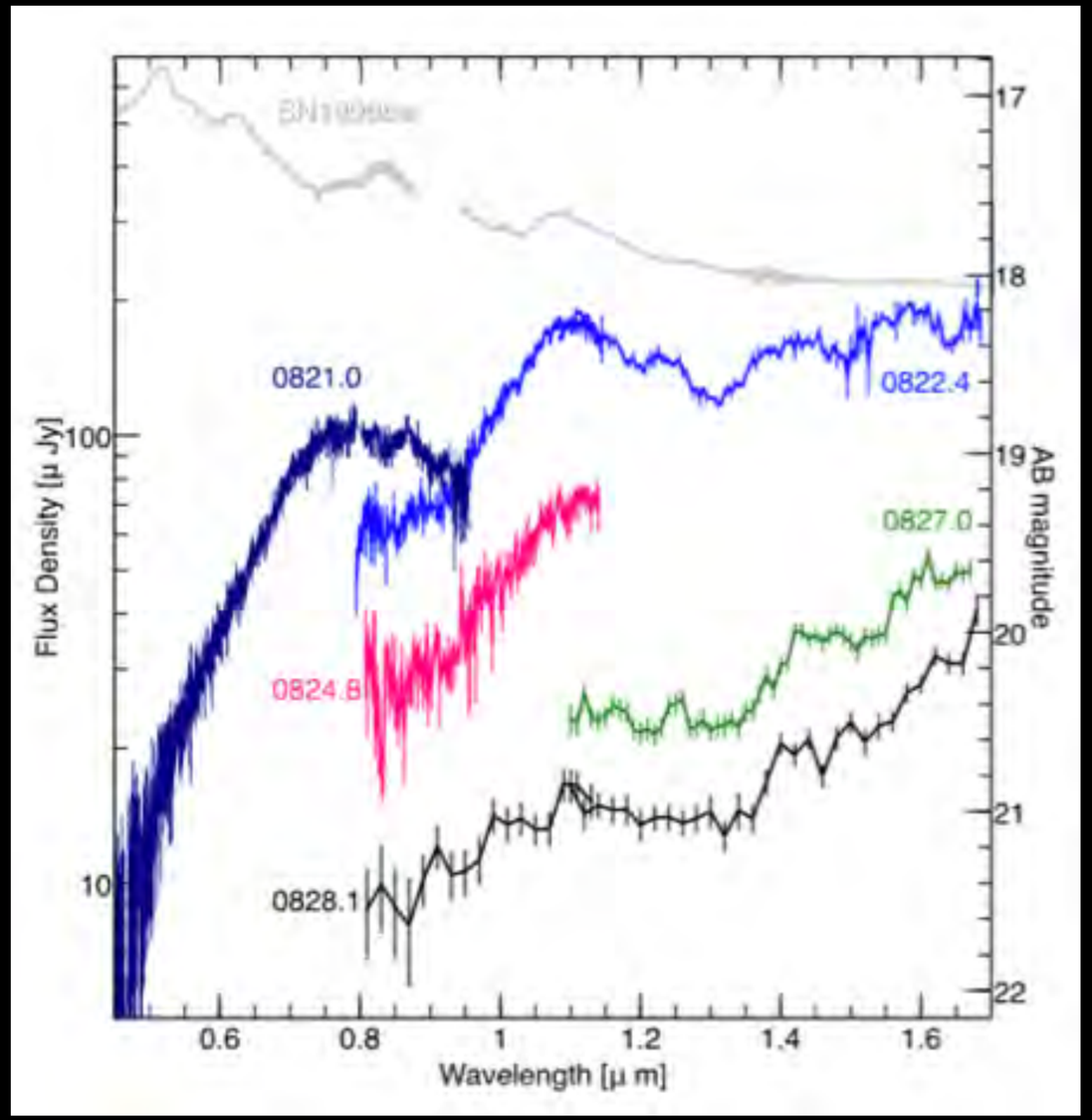
LIGO

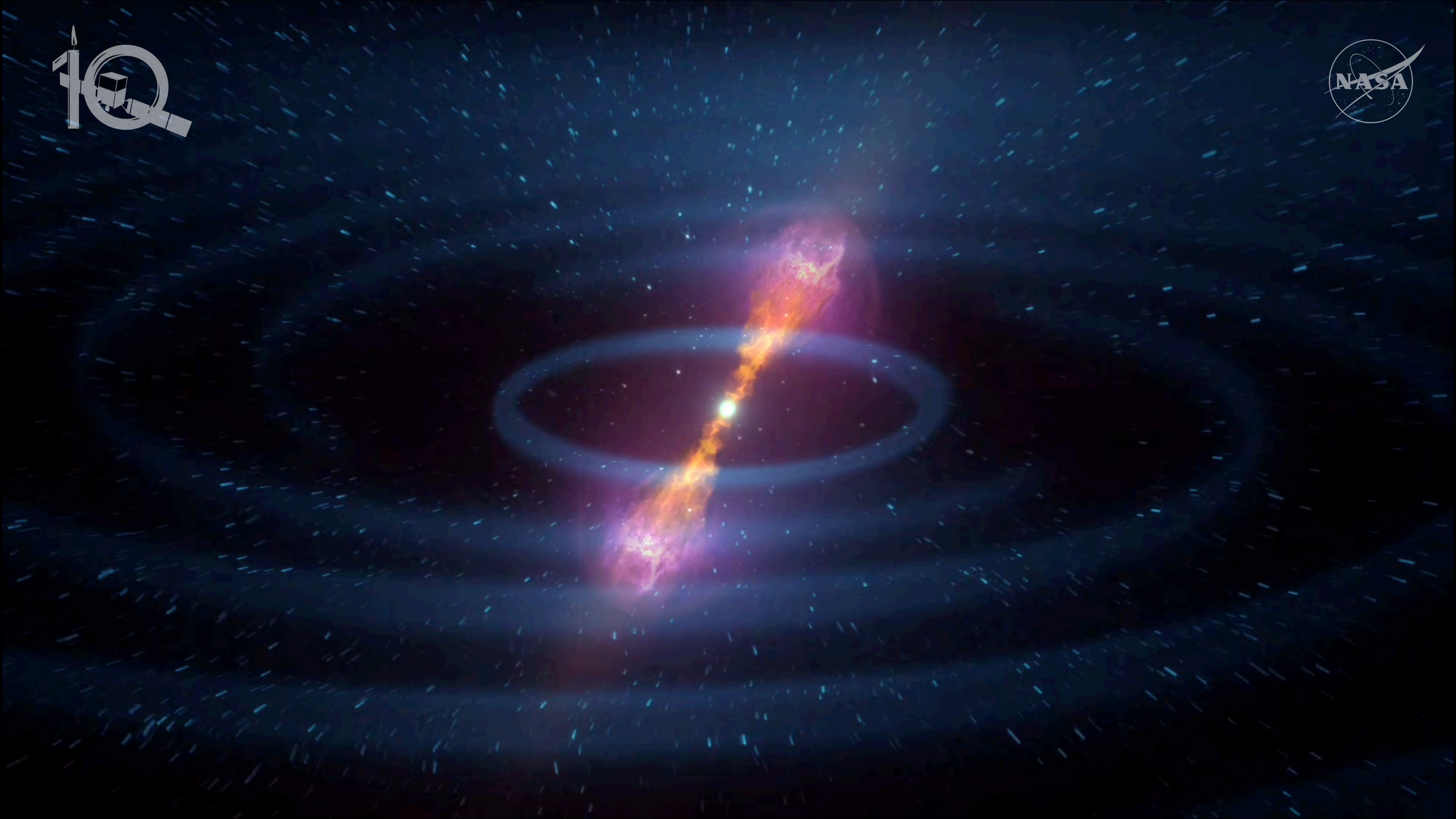

Gravitational-wave strain
GW170817
Frequency (Hz)
300
100
-6
-4
-2
0
2
4
Time from merger (seconds)

Scale of Effect Vastly Exaggerated



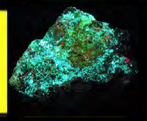

Aug 22


SN1998bw
0821.0
0822.4
0824.8
0827.0
0828.1
Flux Density [μ Jy]
100
10
AB magnitude
17
18
19
20
21
22
0.6
0.8
1
1.2
1.4
1.6
Wavelength [μ m]



Element Origins

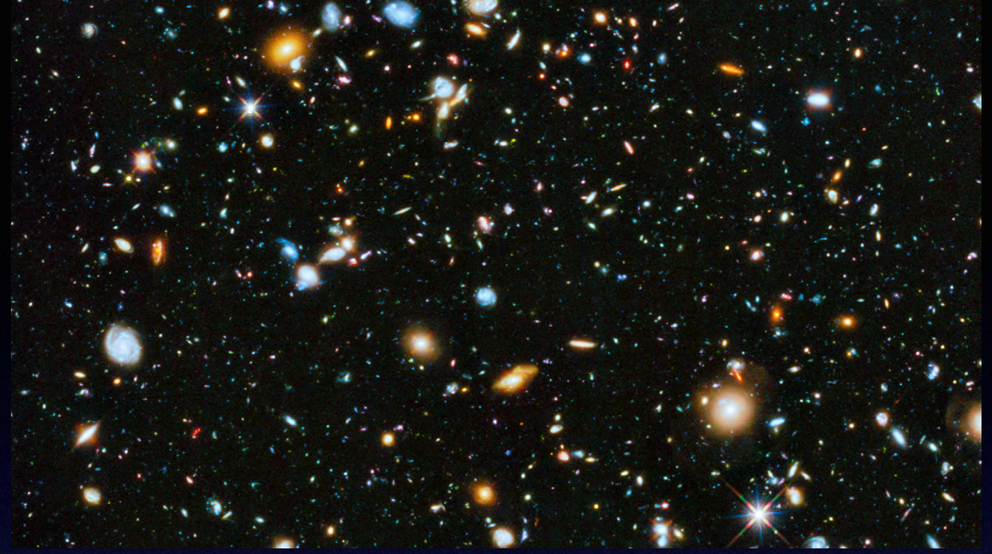
1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba		72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir			80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra																

57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu
89 Ac	90 Th	91 Pa												

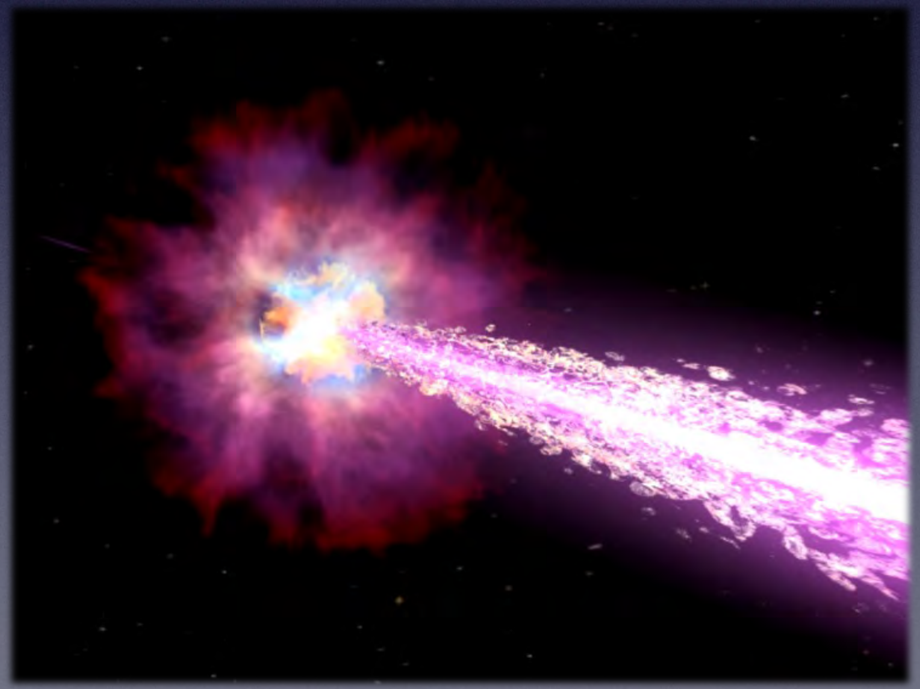
Merging Neutron Stars **Exploding Massive Stars** **Big Bang**

Dying Low Mass Stars **Exploding White Dwarfs** **Cosmic Ray Fission**

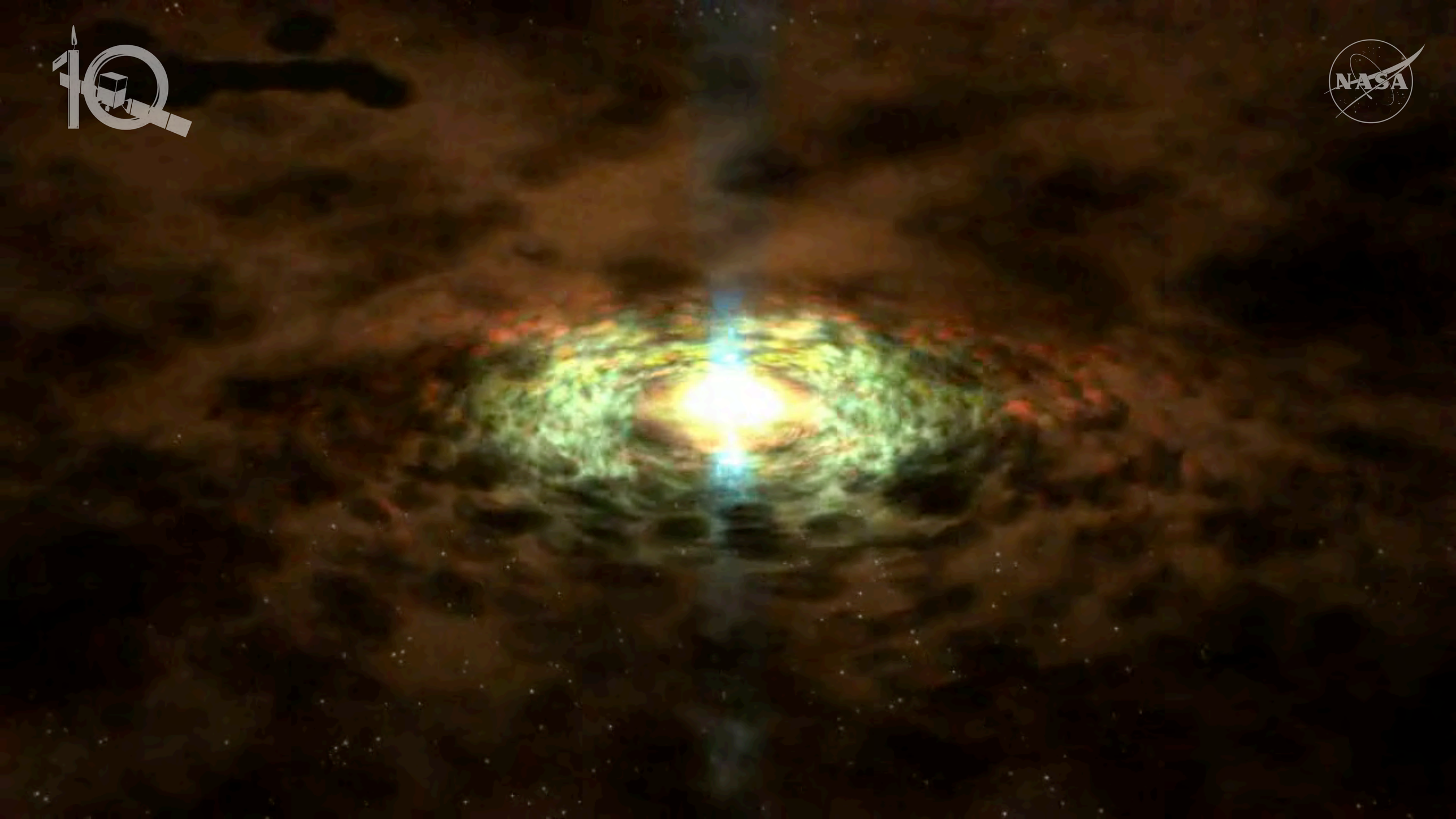
Based on graphic created by Jennifer Johnson

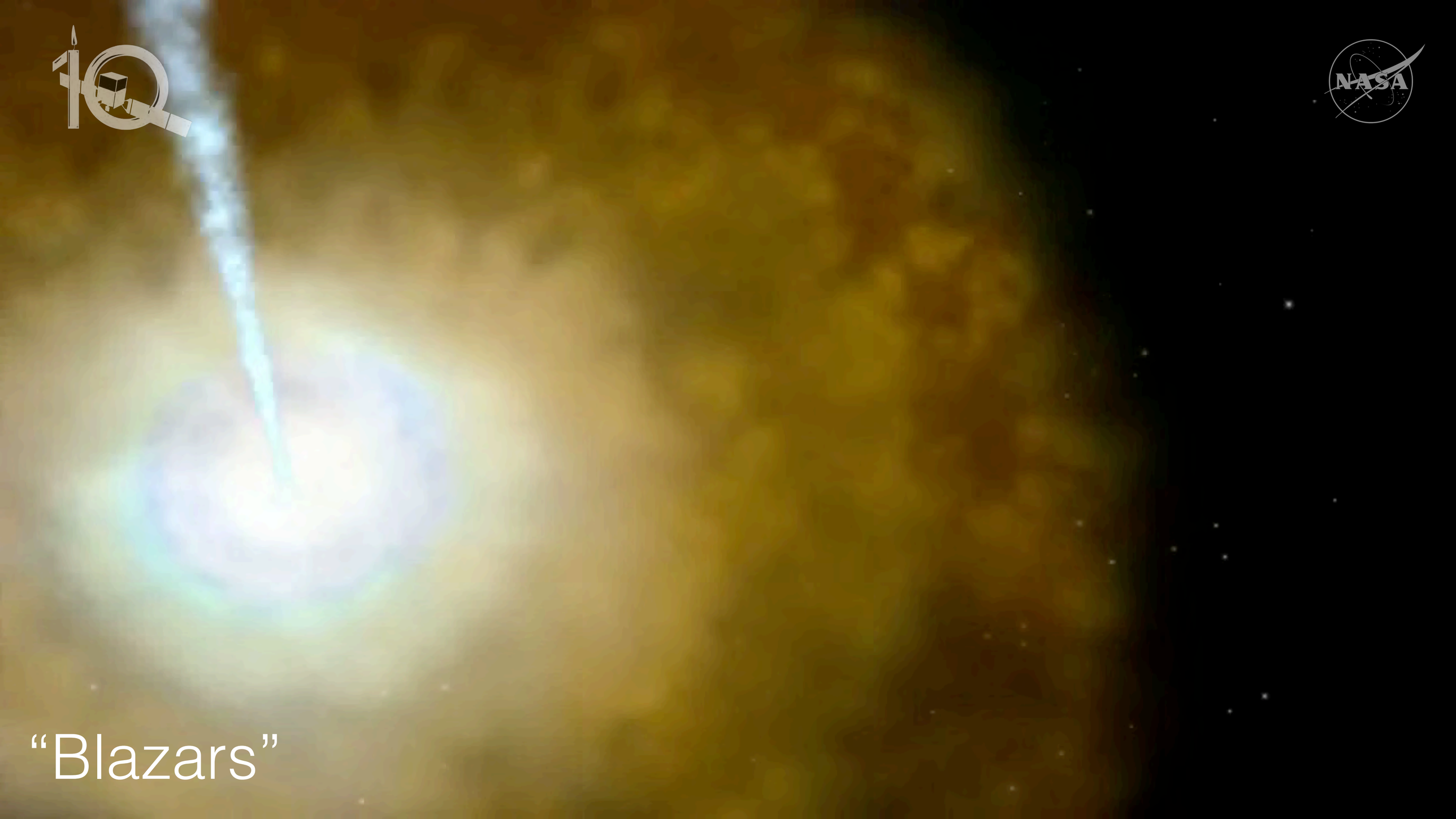


Gamma-ray Bursts



Active Galactic Nuclei





“Blazars”

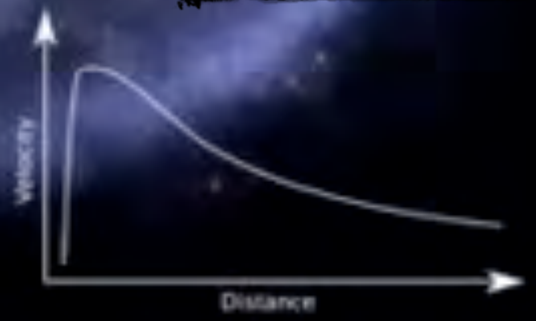
What we expect

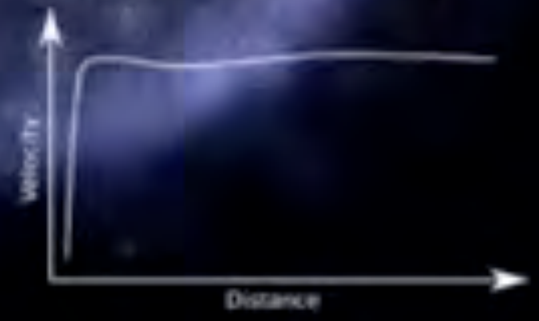
What we see

What we expect

What we see

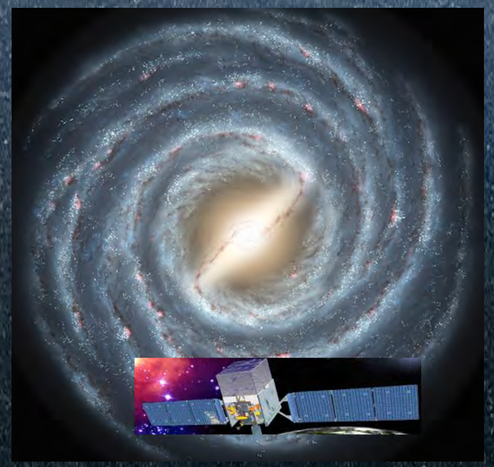
Galaxies rotate faster than expected!



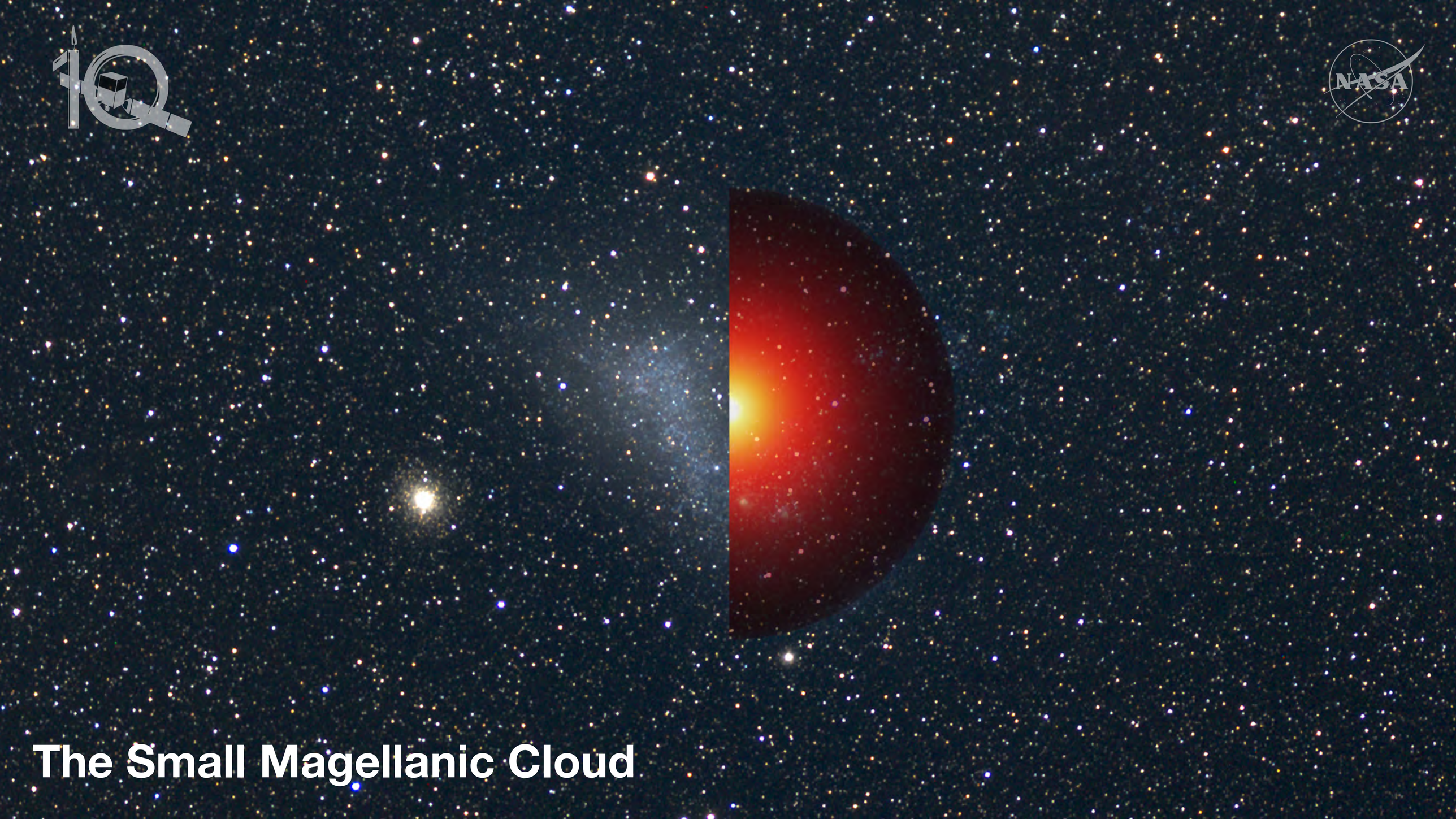



Where should we look?

The Center of the Milky Way

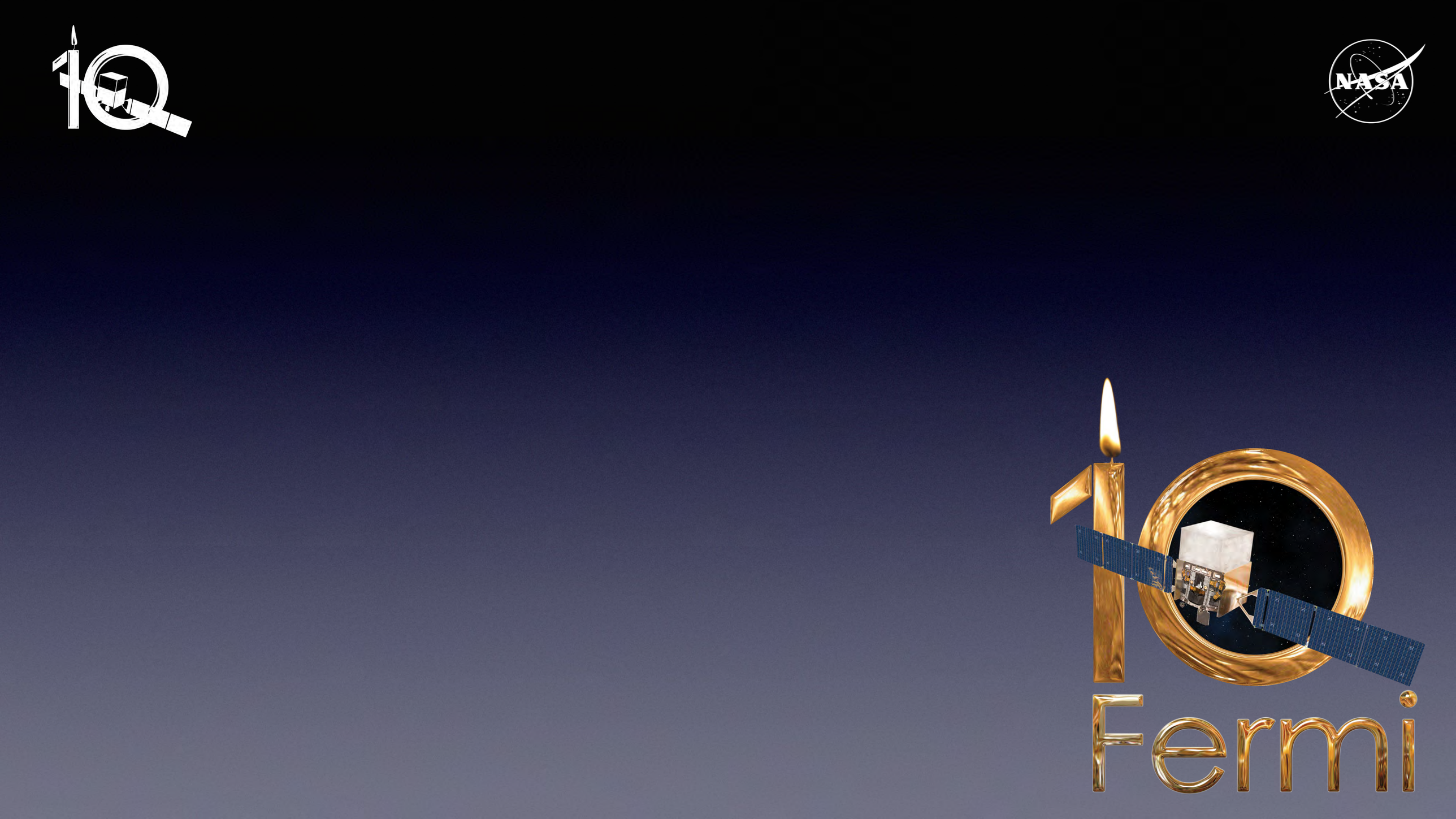


(Not to scale)

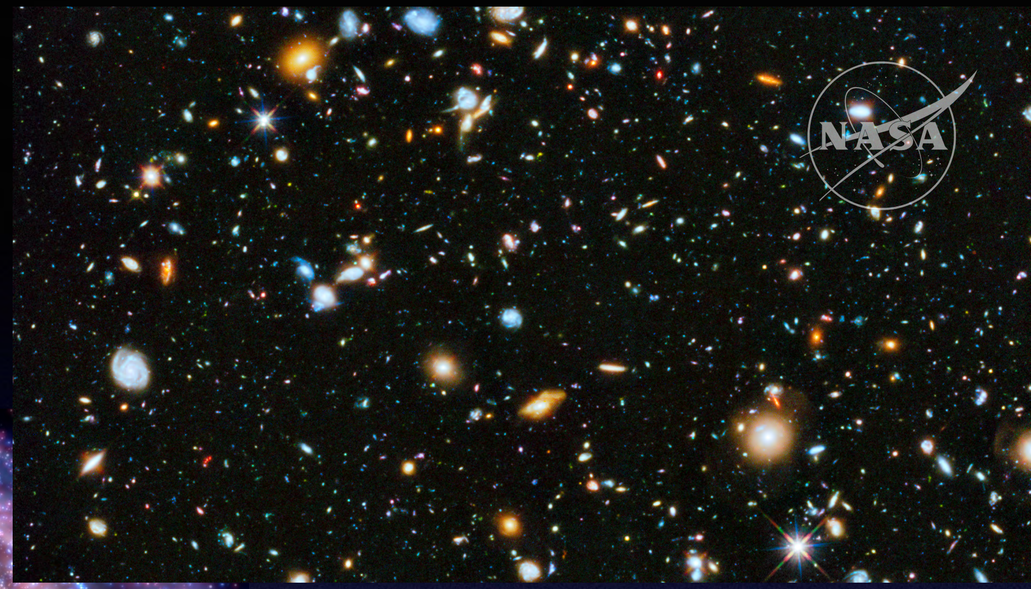

The Small Magellanic Cloud

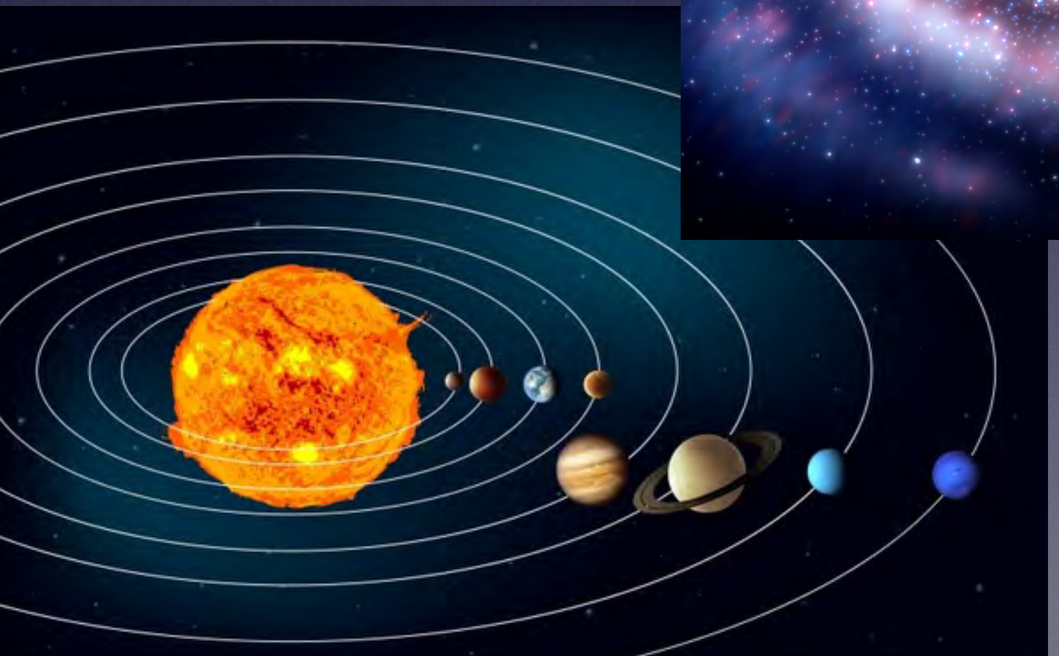
The Small Magellanic Cloud

If not in gamma rays, then how do we detect Dark Matter?


Fermi

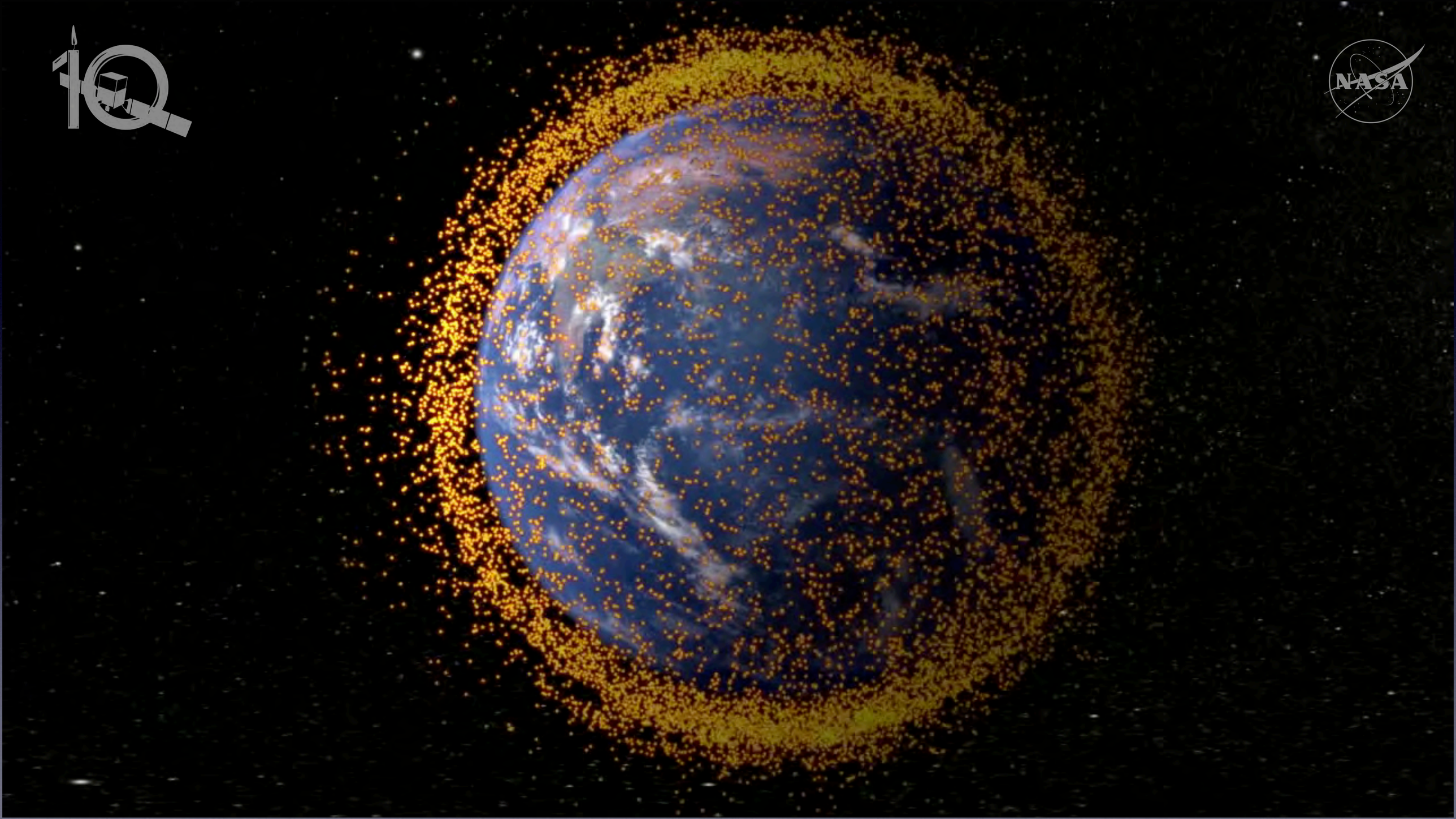
Fermi



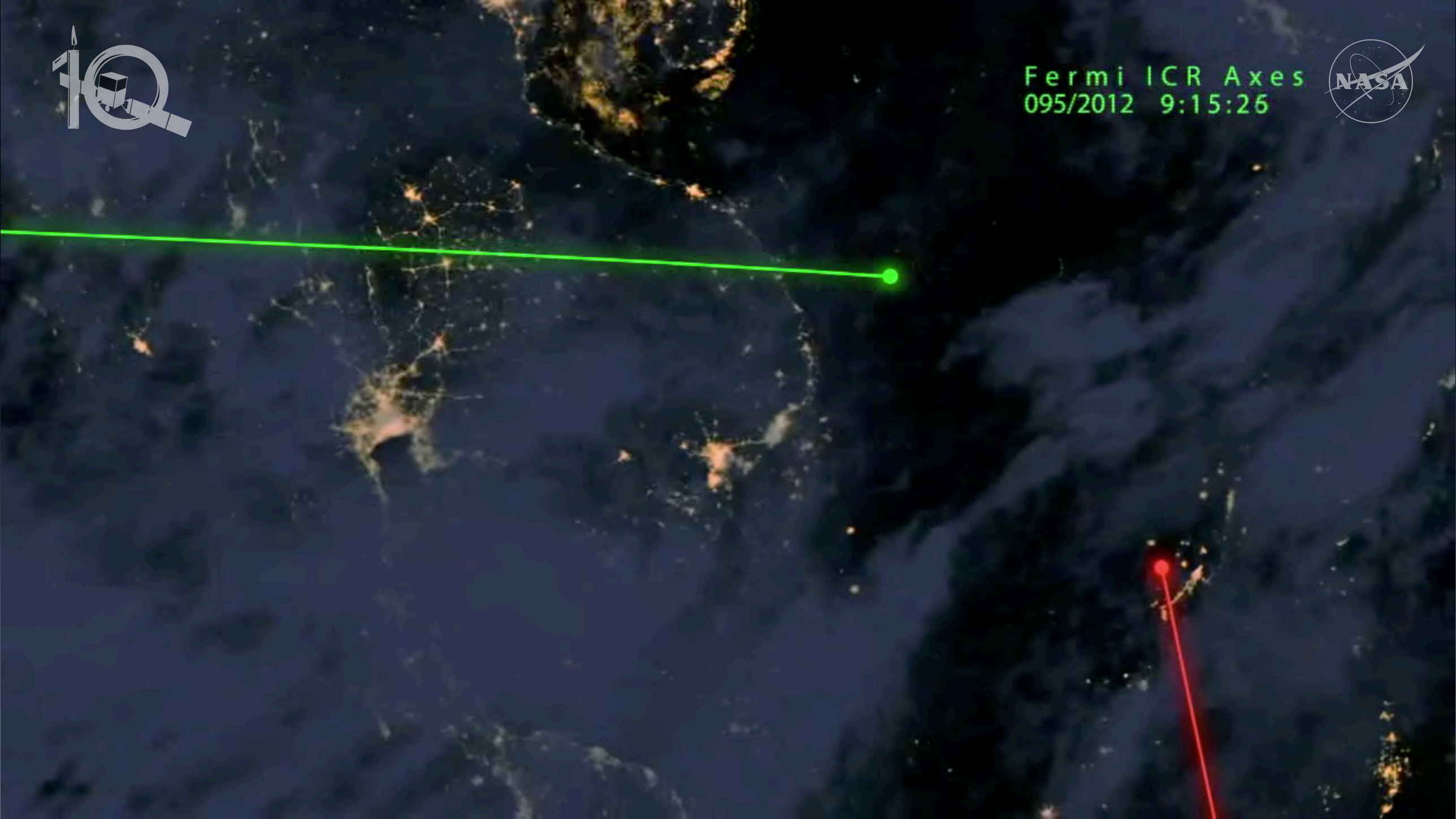


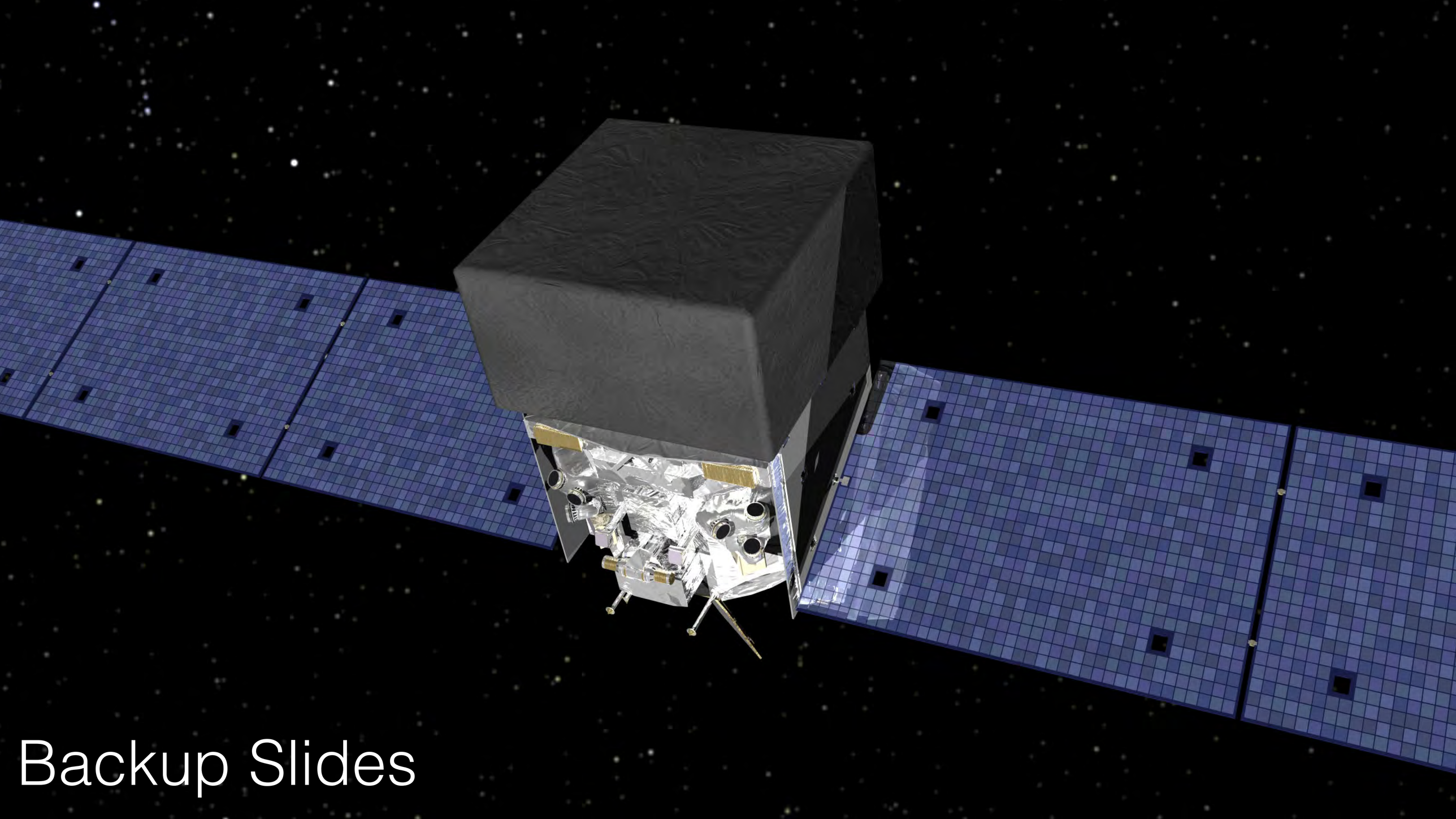
Fermi

Thank you!

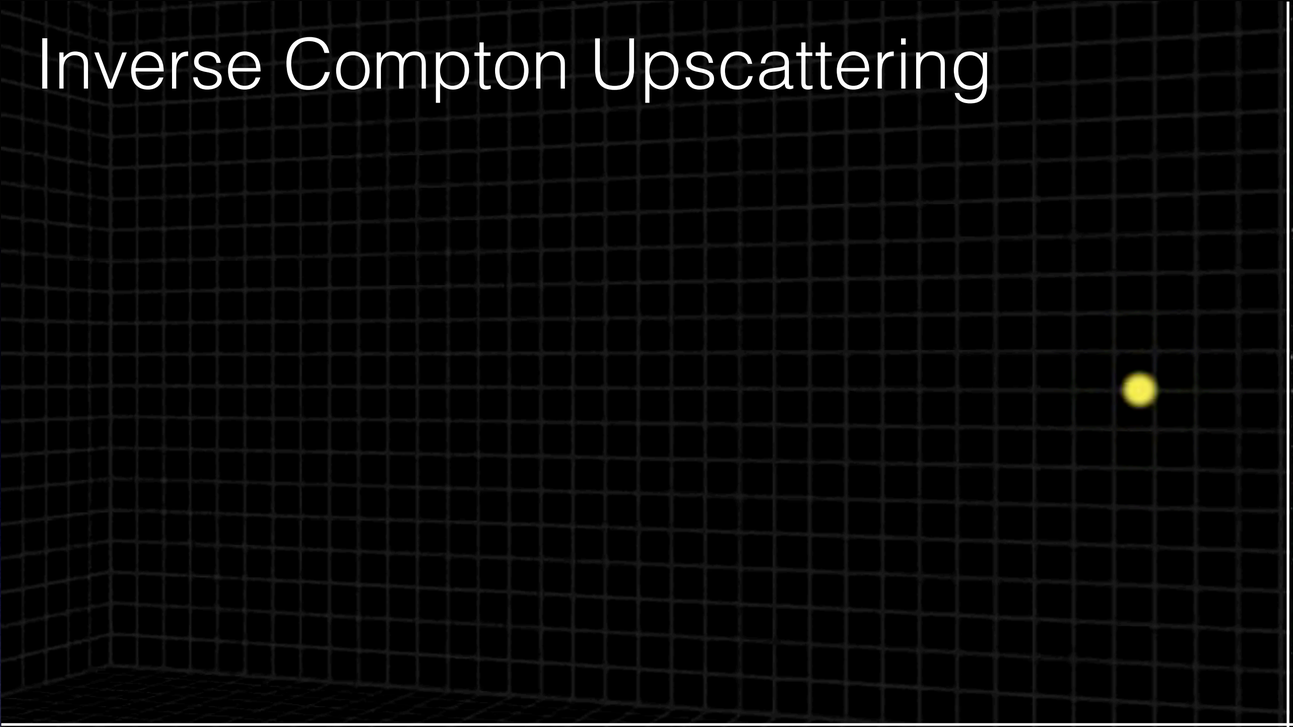



3 April 2012

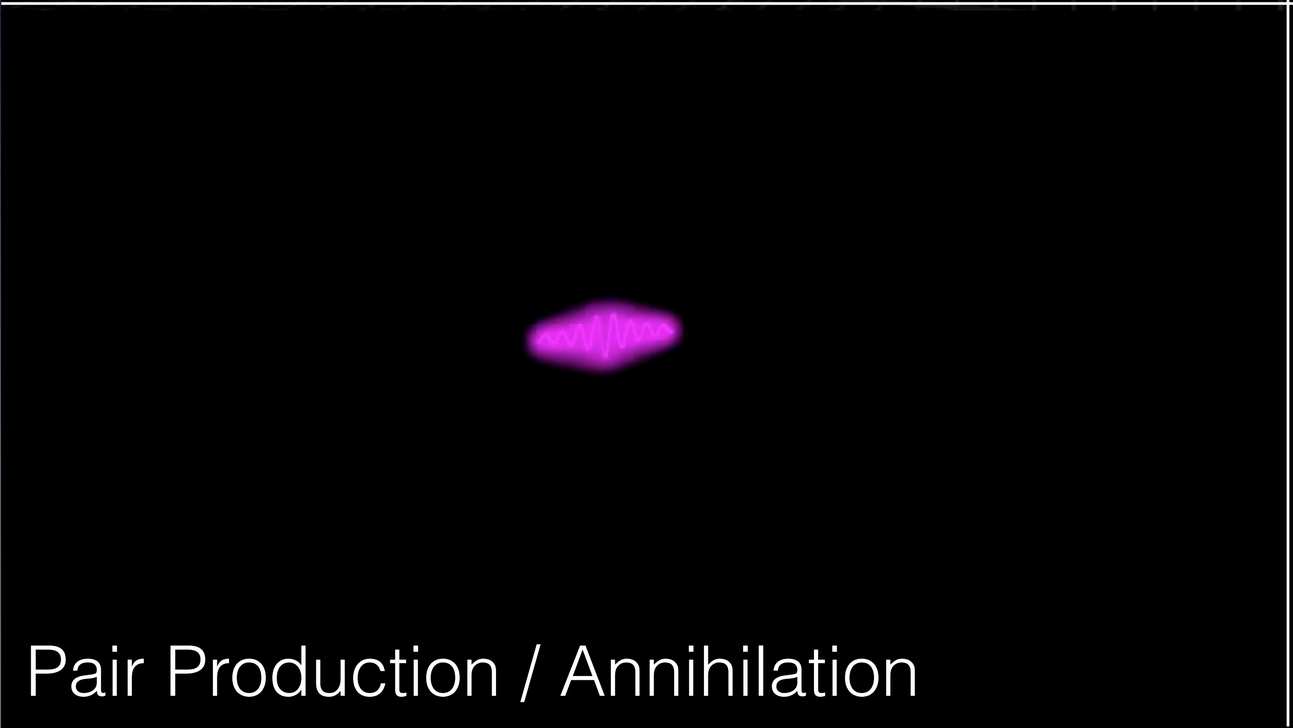

Fermi ICR Axes
095/2012 9:15:26
NASA

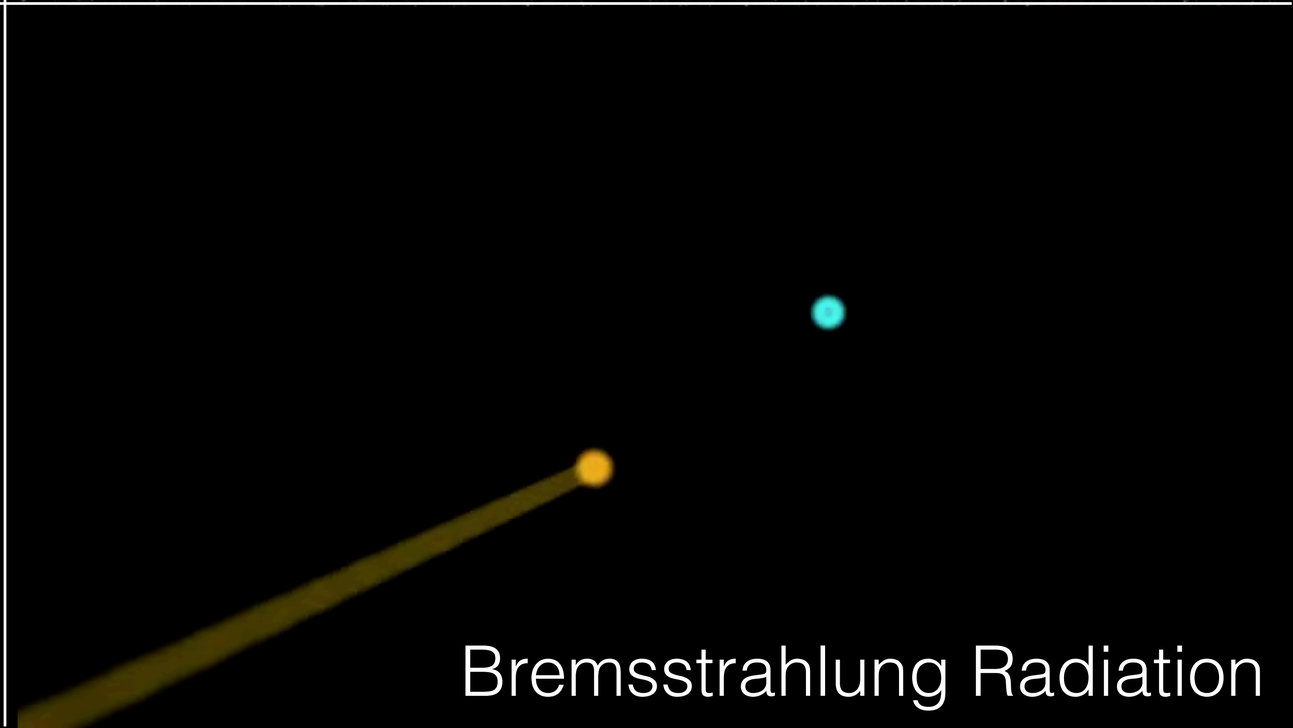


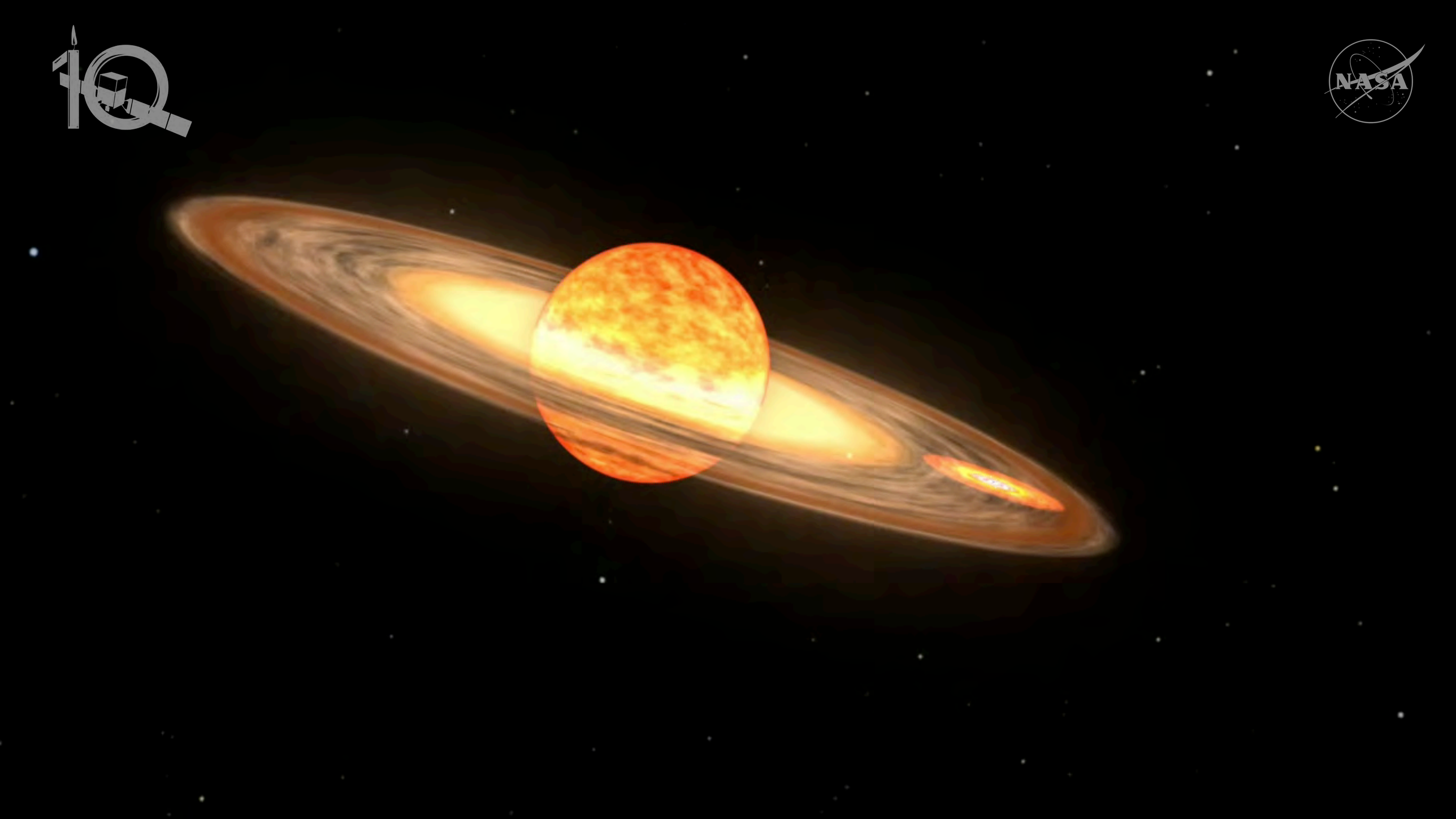
Backup Slides

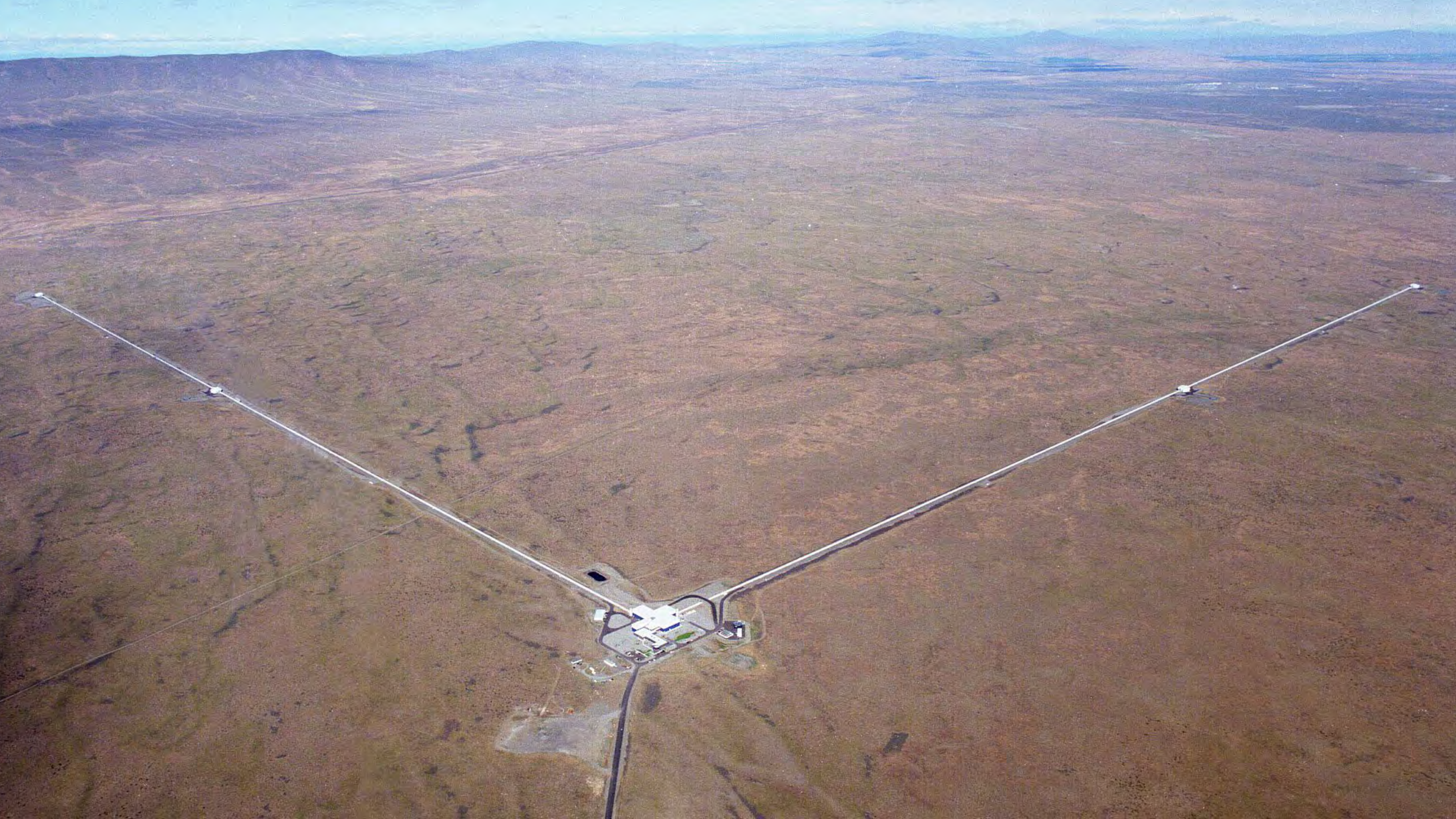

Inverse Compton Upscattering

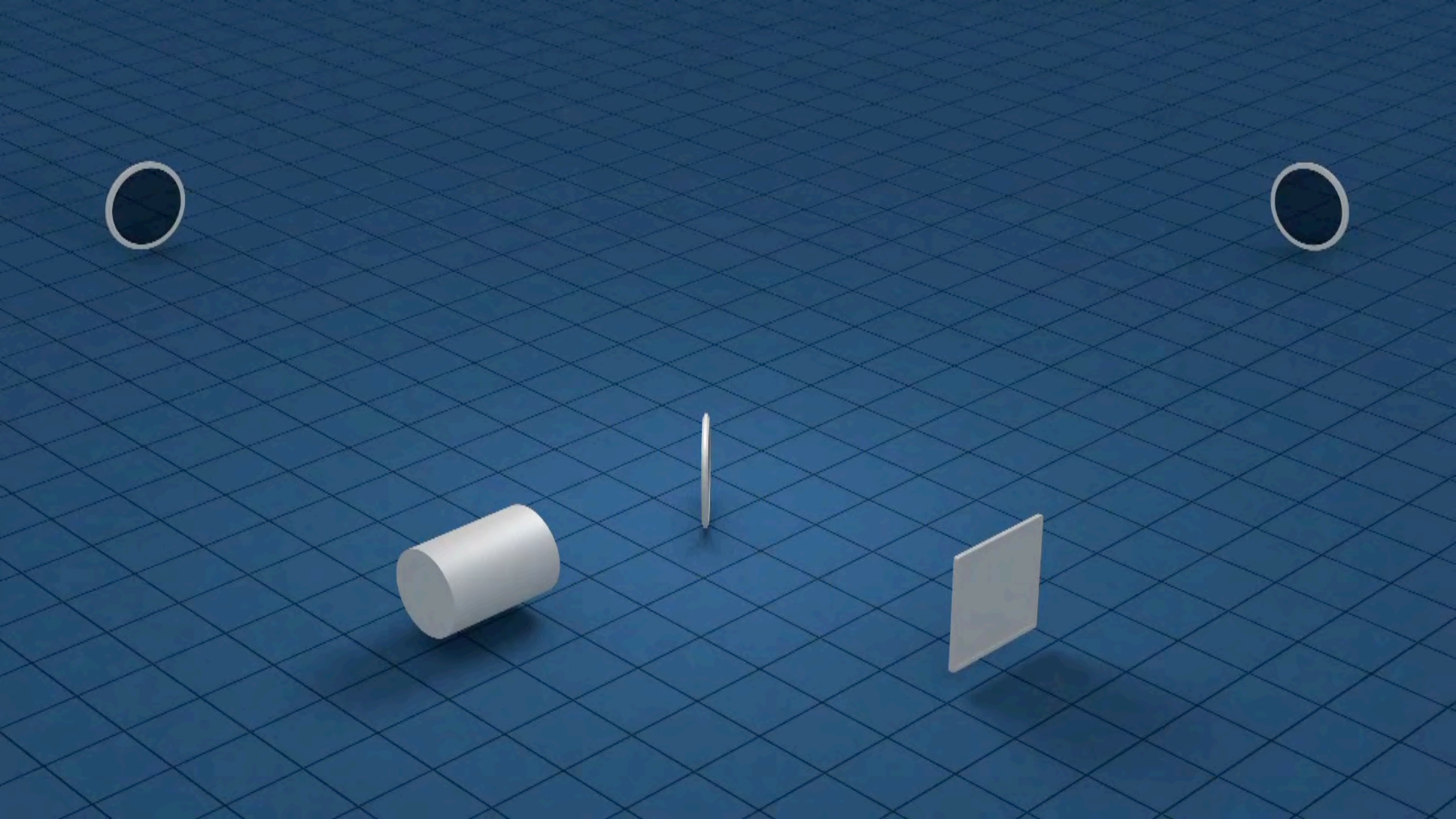

Pion Decay


Pair Production / Annihilation


Bremsstrahlung Radiation







Optical Counterpart & Host Galaxy