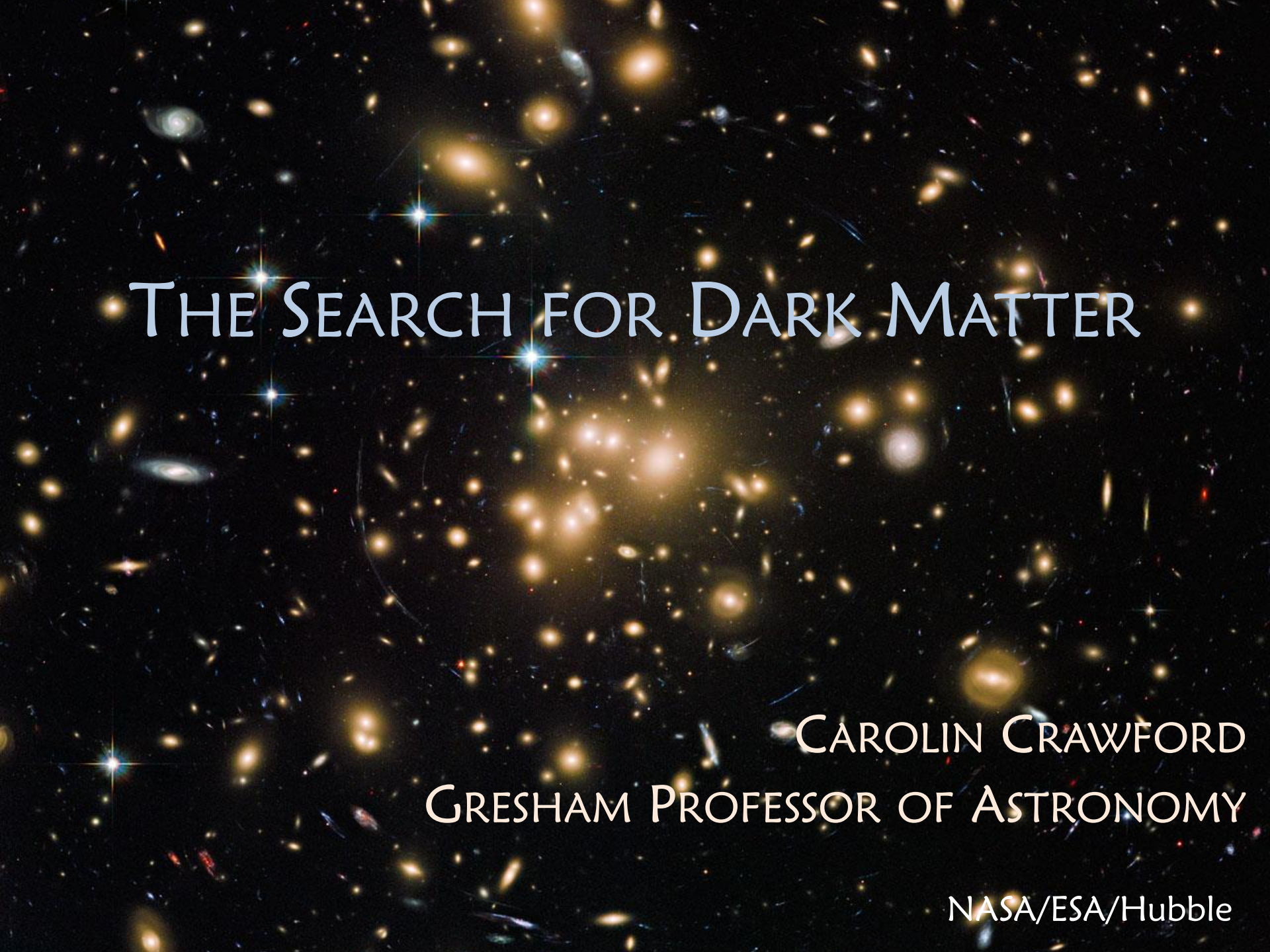
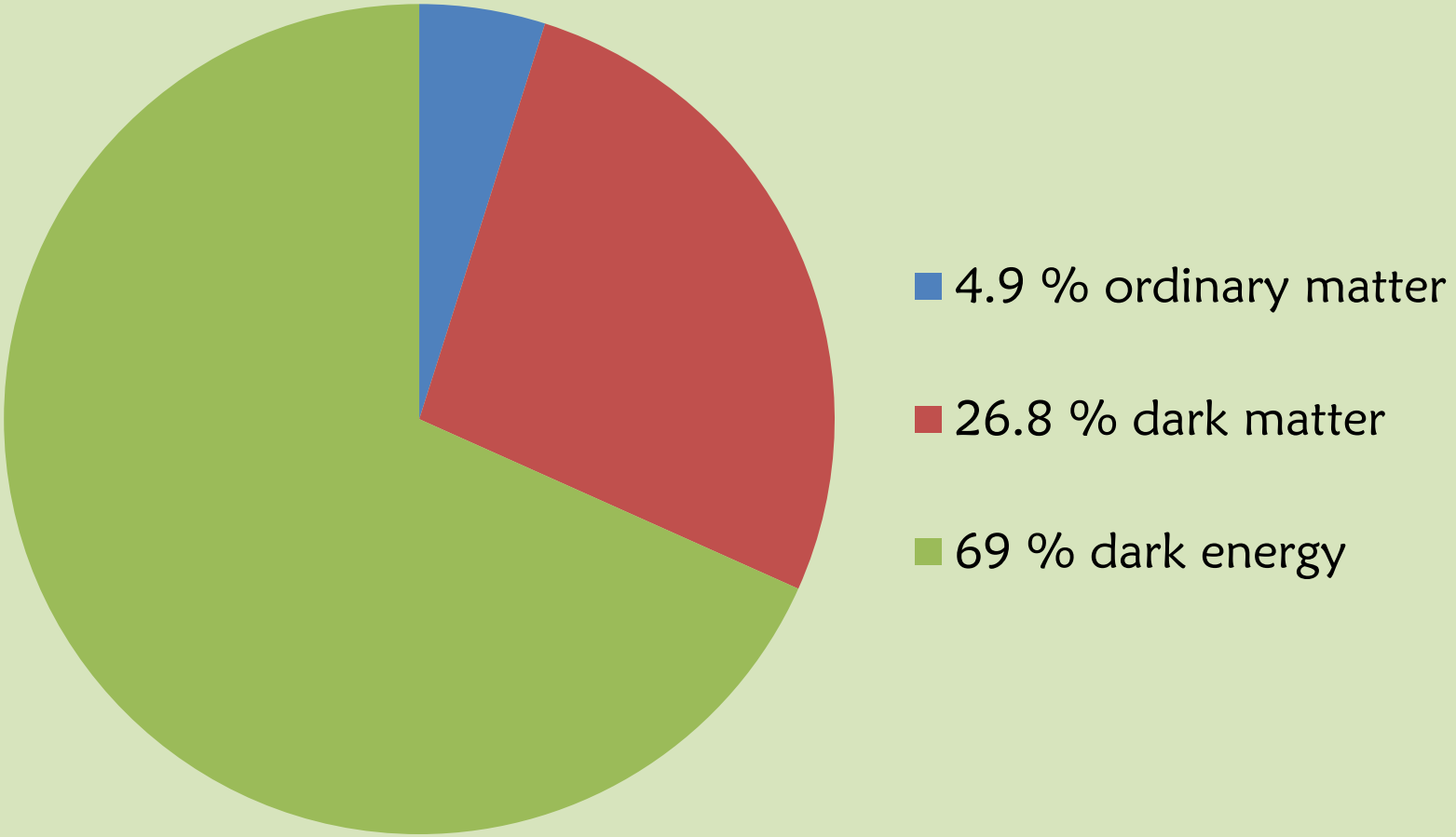


The Search for Dark Matter

Carolin Crawford
Gresham Professor of Astronomy

NASA/ESA/Hubble


HST/NASA

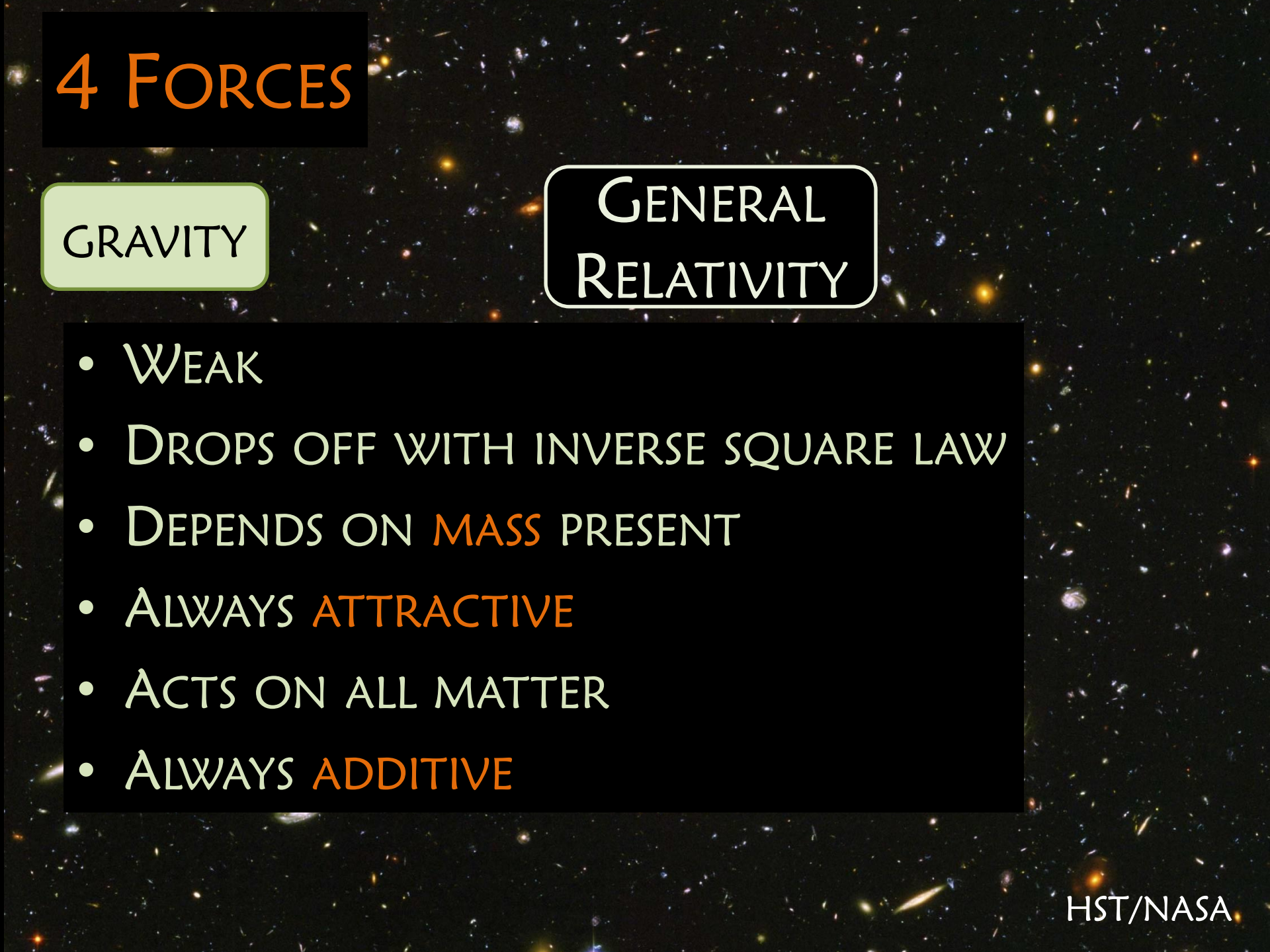

4.9 % ordinary matter
26.8 % dark matter
69 % dark energy

4 Forces

Gravity

General Relativity

- Weak
- Drops off with inverse square law
- Depends on mass present
- Always attractive
- Acts on all matter
- Always additive



HST/NASA

4 Forces

GRAVITY

General Relativity

ELECTROMAGNETISM

- Drops off with inverse square law
- Depends on CHARGE present
- Can be ATTRACTIVE or REPULSIVE
- Does *NOT* influence all matter

HST/NASA

4 Forces

Gravity

Electromagnetism

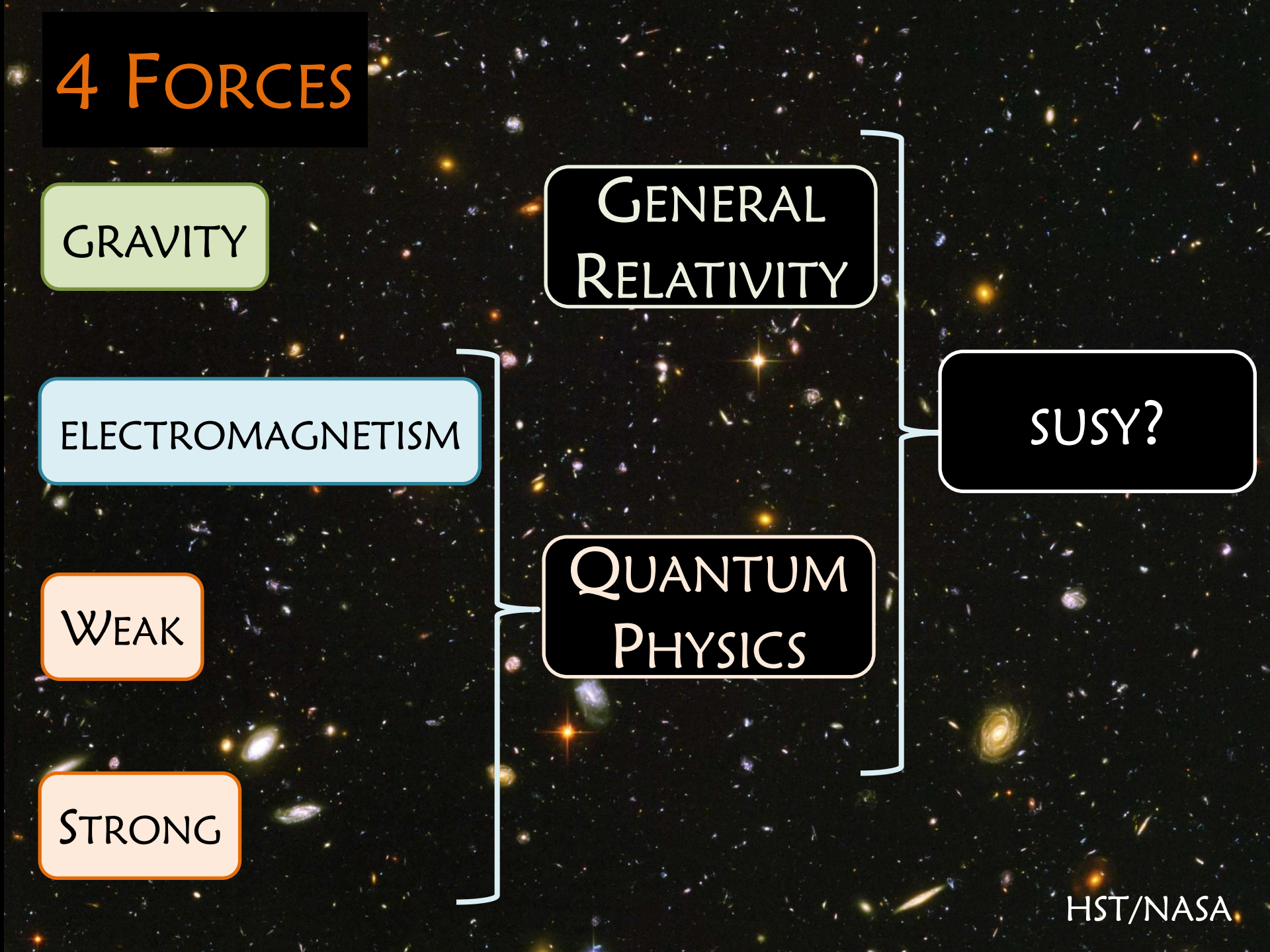
Weak

Strong

General Relativity

Quantum Physics

SUSY?



HST/NASA

4 Forces

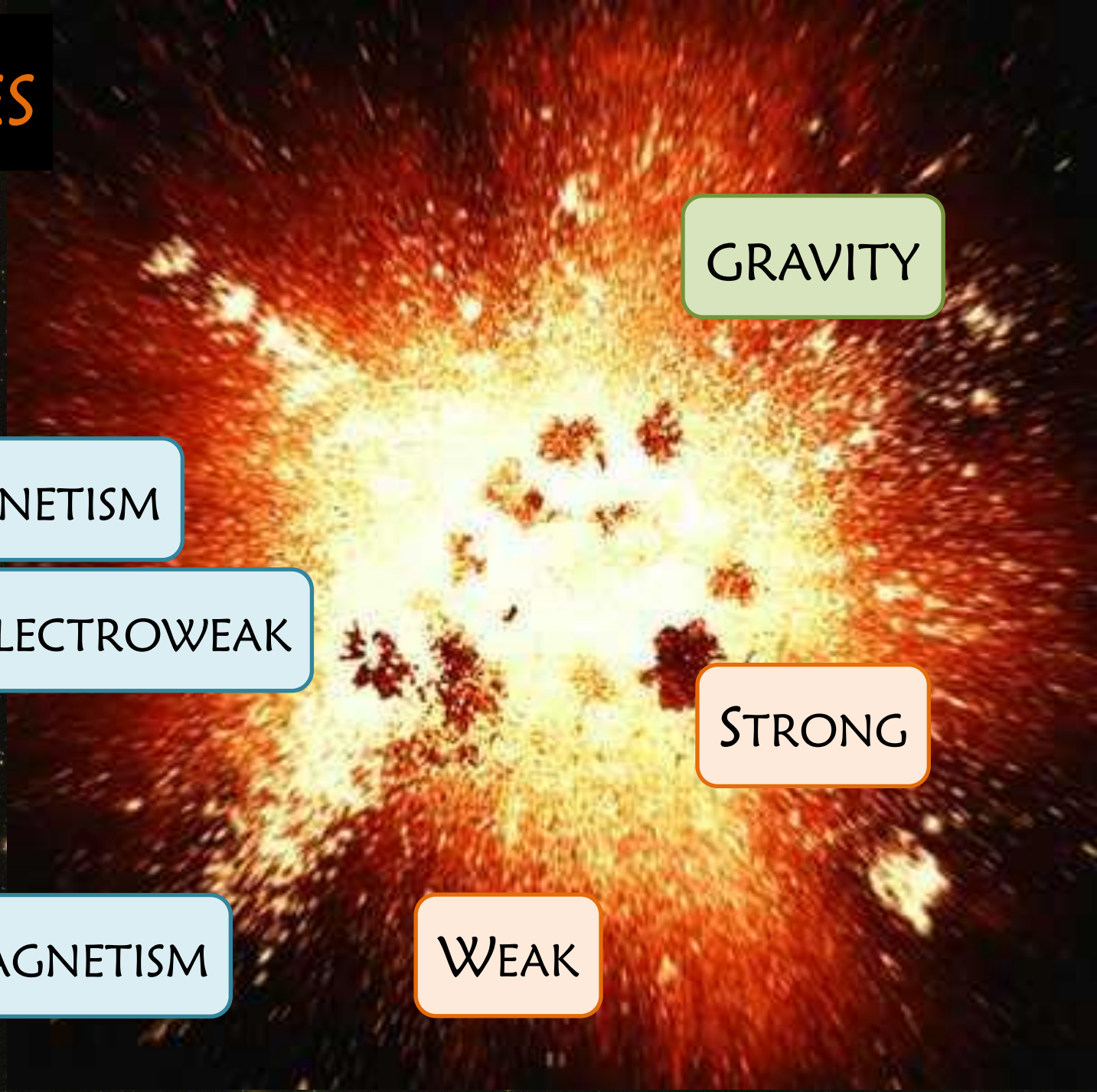
GRAVITY

ELECTROMAGNETISM

ELECTROWEAK

WEAK

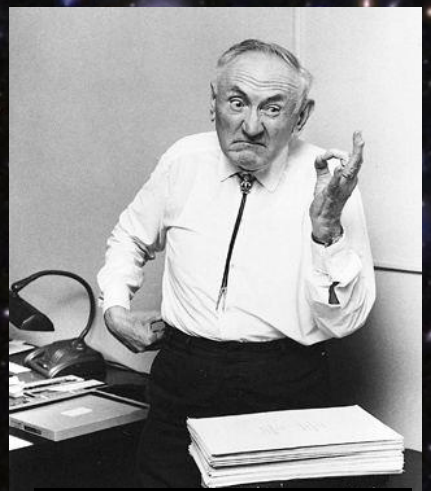
S ELECTROMAGNETISM



GRAVITY

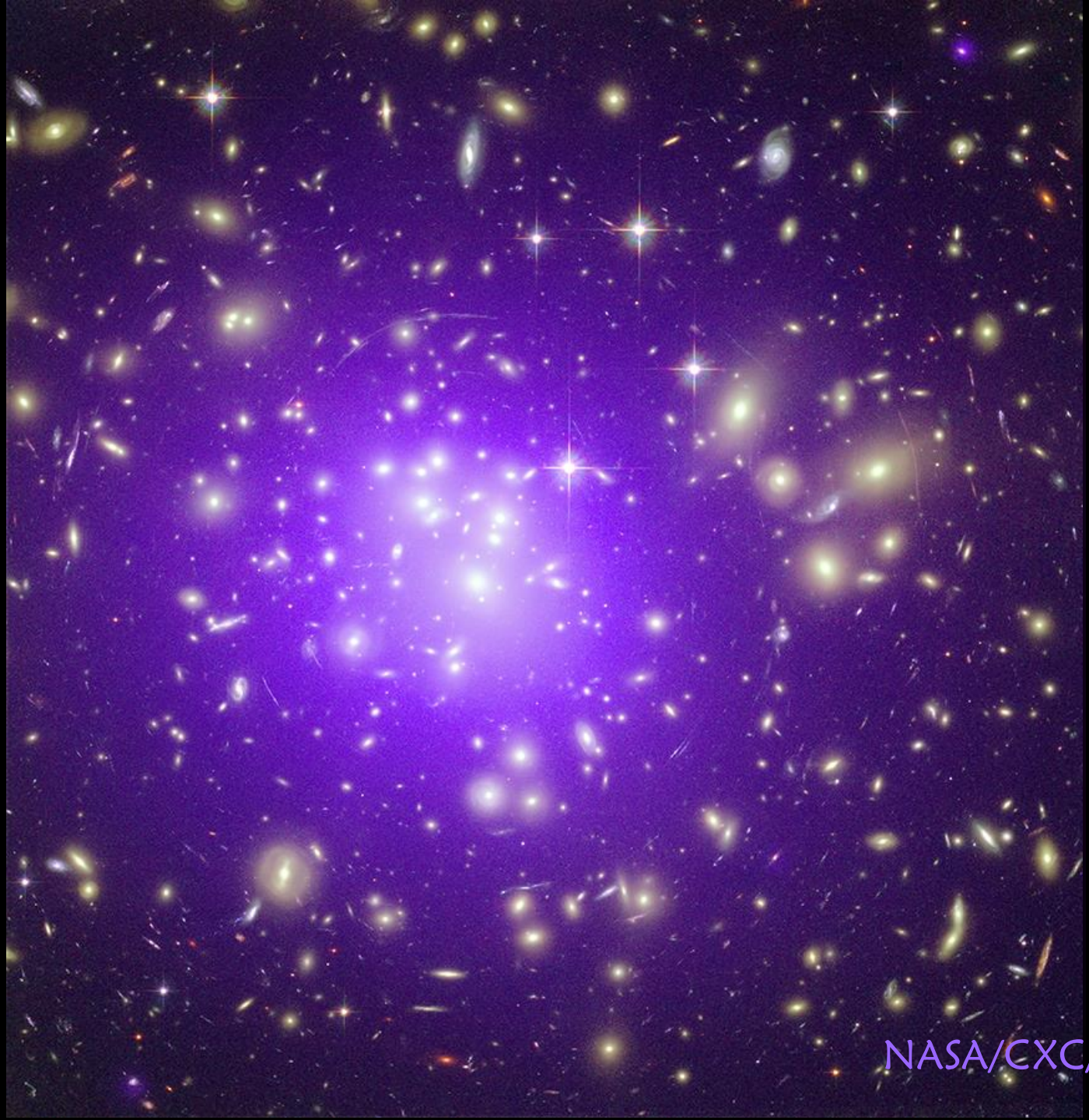
STRONG

WEAK



Fritz Zwicky

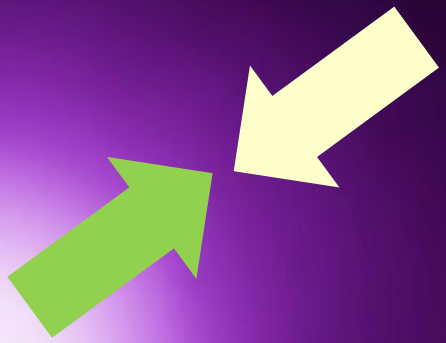
Dean Rowe



optical
X-rays

NASA/STScI
NASA/CXC/MIT/Peng et al

X-RAY CLUSTER MASSES



Balance the

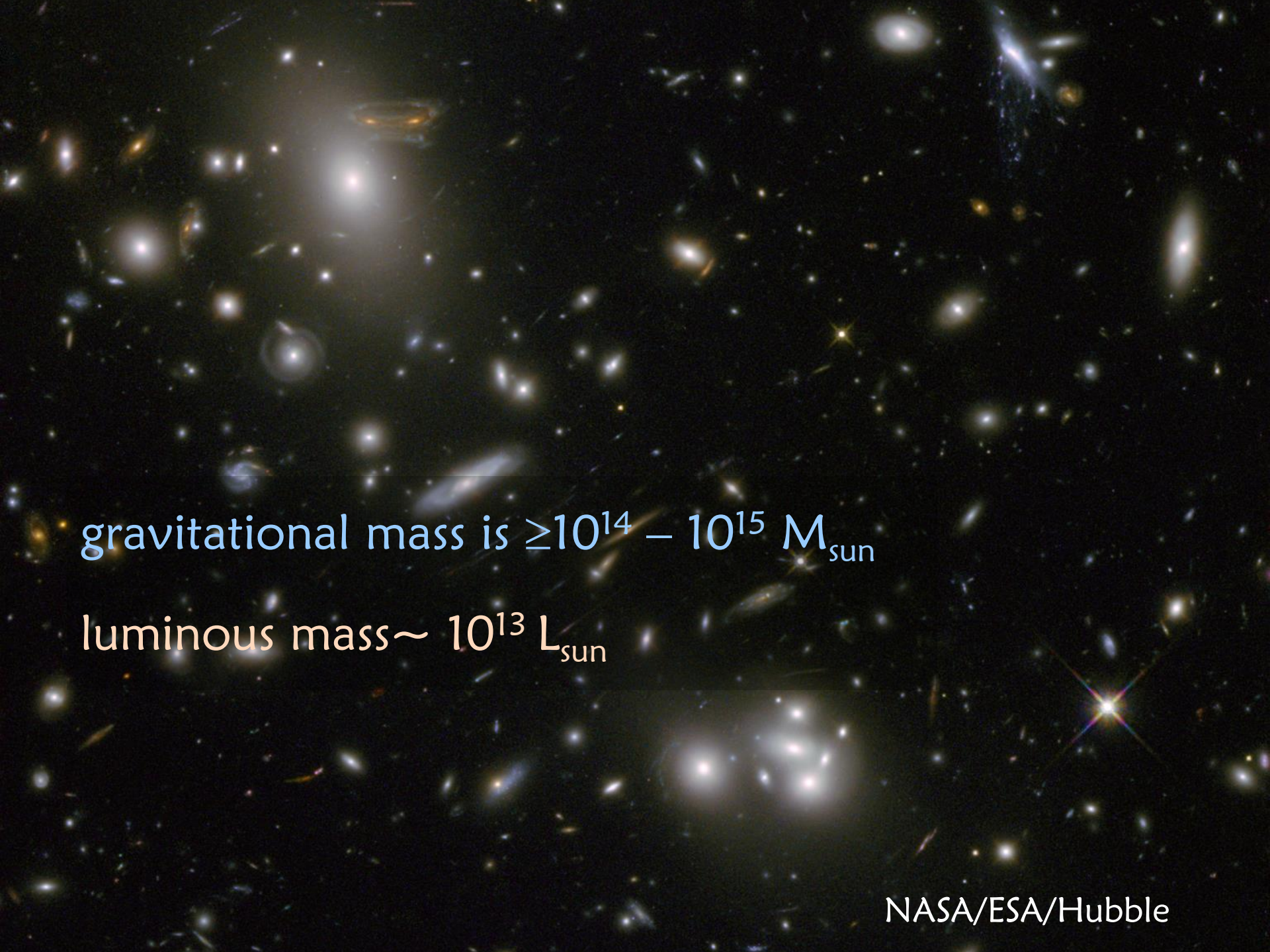
inward force of gravity

(depends on the *total mass* of the cluster)

by the

outward pressure of the hot gas

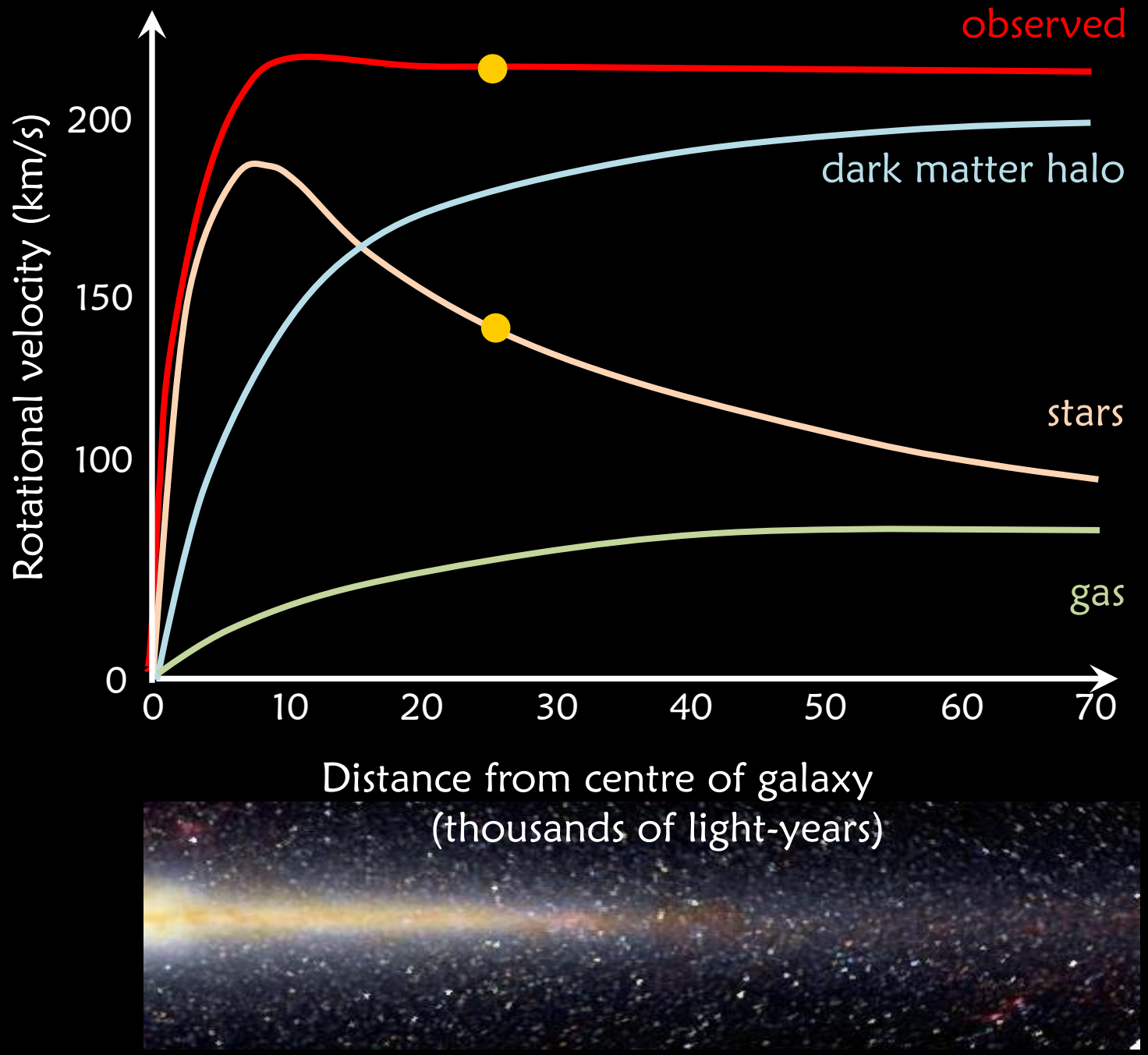
(depends on its *temperature* & *density*)


gravitational mass is $\geq 10^{14} - 10^{15}\ M_{sun}$
luminous mass$\sim 10^{13}\ L_{sun}$
NASA/ESA/Hubble

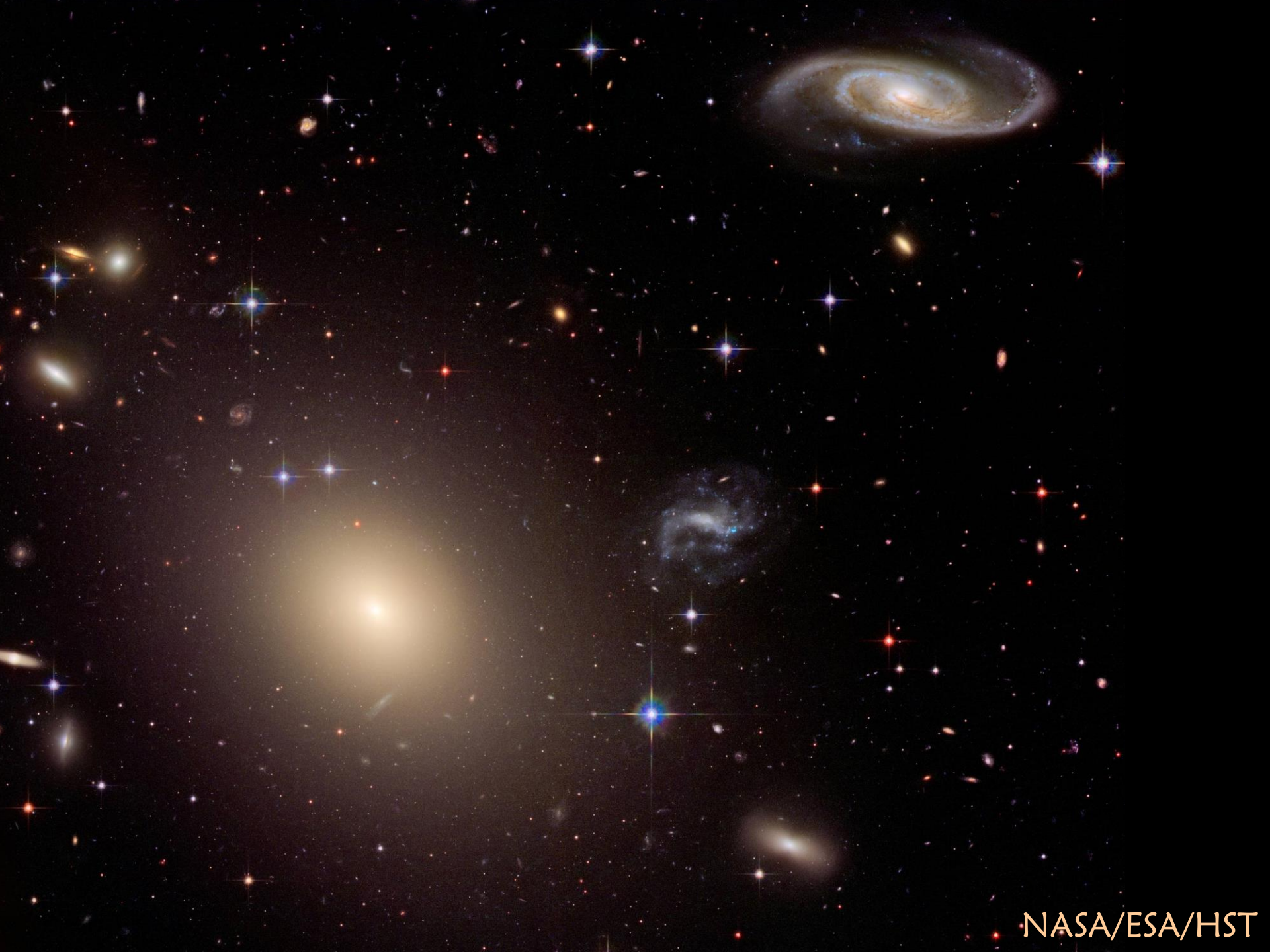

NASA/ESA/Hubble Collaboration


NASA/ESA/Hubble

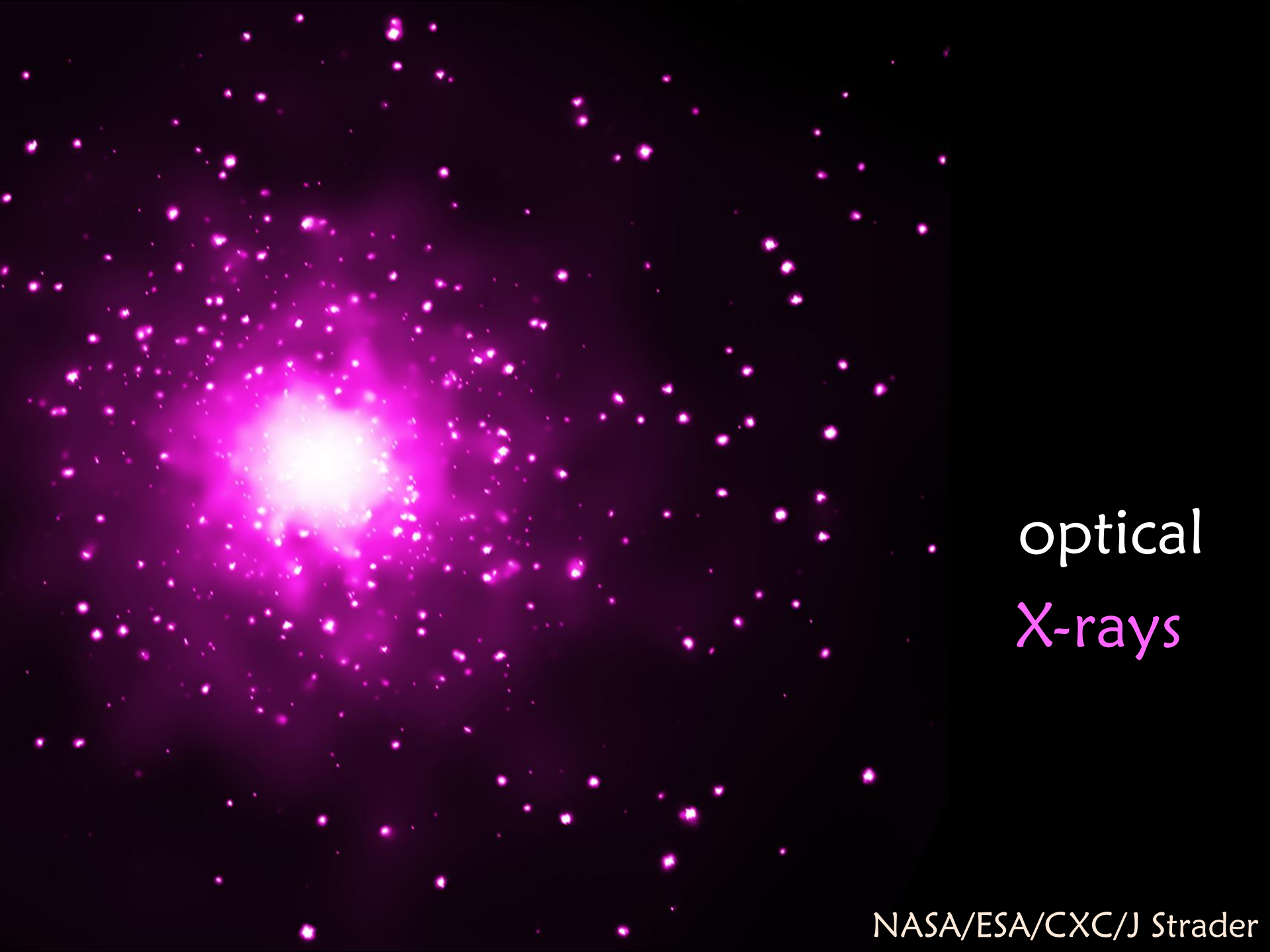

NASA/ESA/Hubble Heritage Team


observed
dark matter halo
stars
gas
Rotational velocity (km/s)
200
150
100
0
0
10
20
30
40
50
60
70
Distance from centre of galaxy
(thousands of light-years)


DARK MATTER
total mass: ~1,200 billion M_{sun}
luminous mass: ~120 billion M_{sun}
NASA/ESA/Hubble

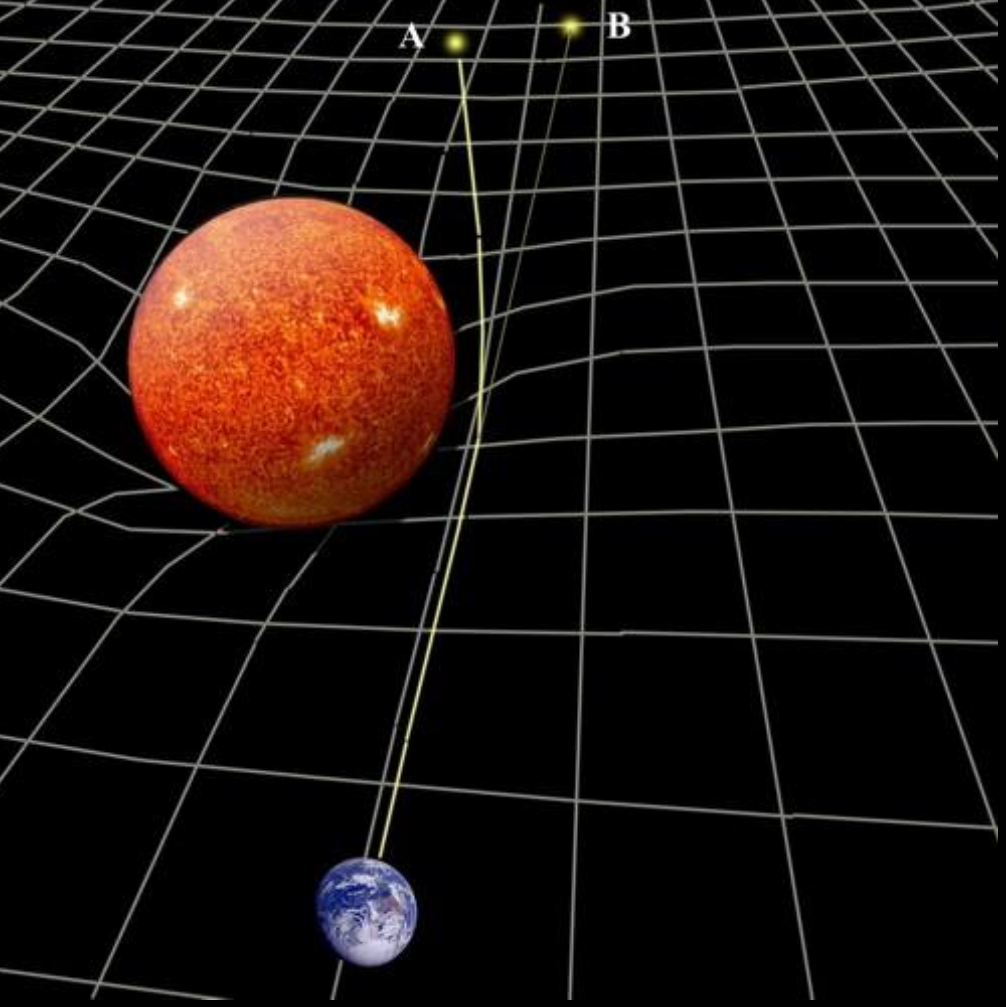

NASA/ESA/HST


NASA/ESA/HST

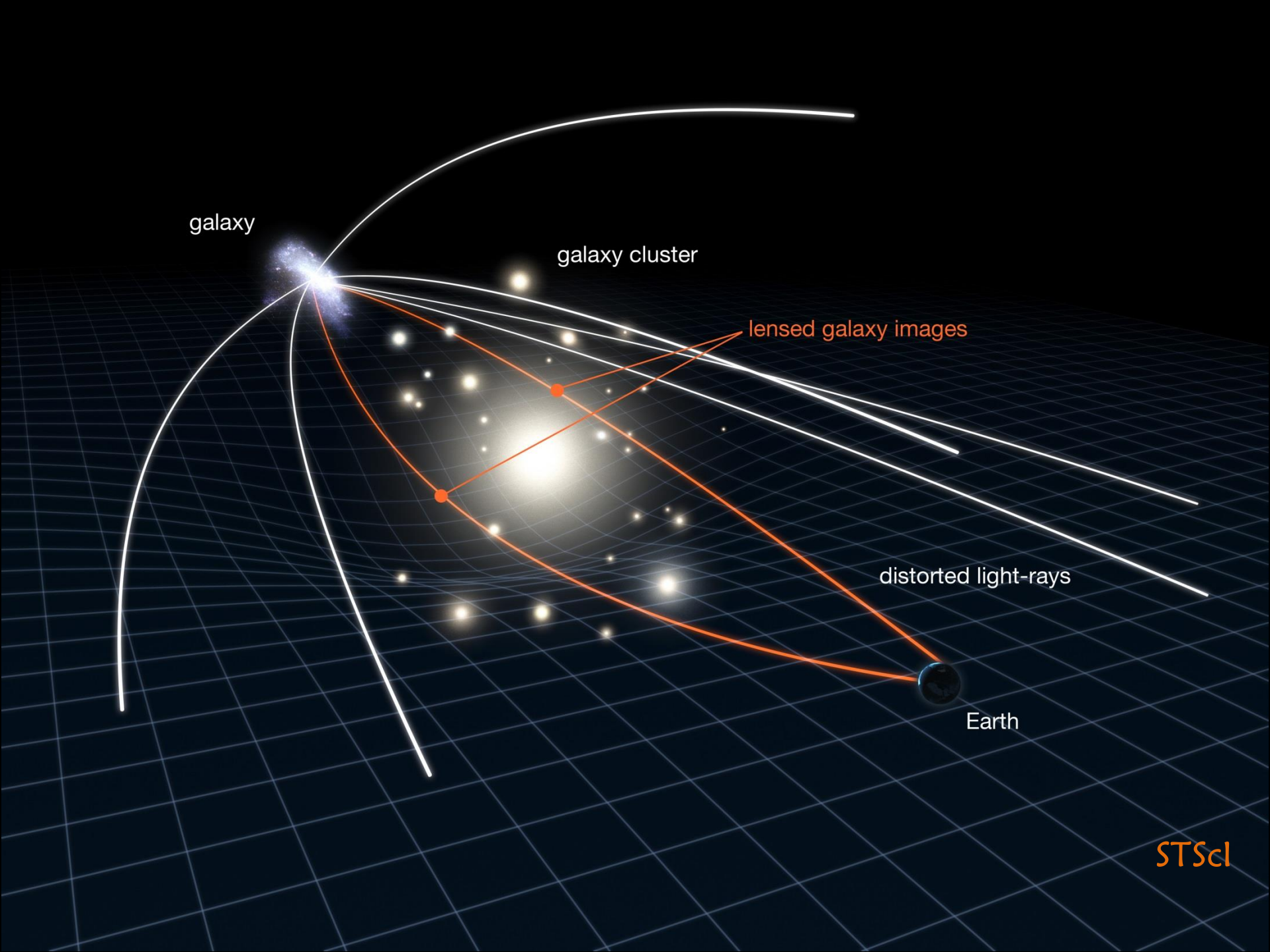

optical
X-rays
NASA/ESA/CXC/J Strader

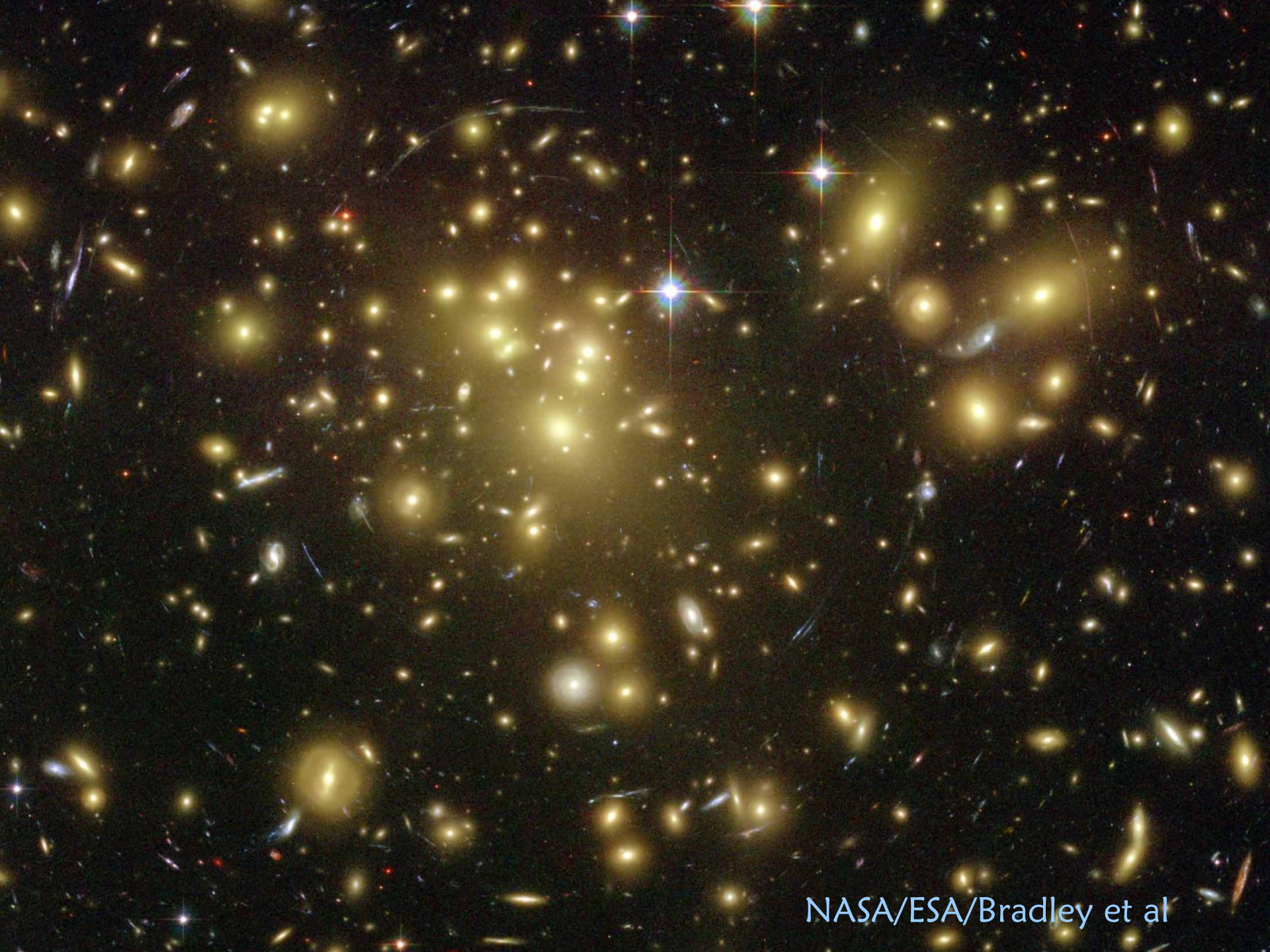
Lensing cluster masses

Fruchter/HST/NASA

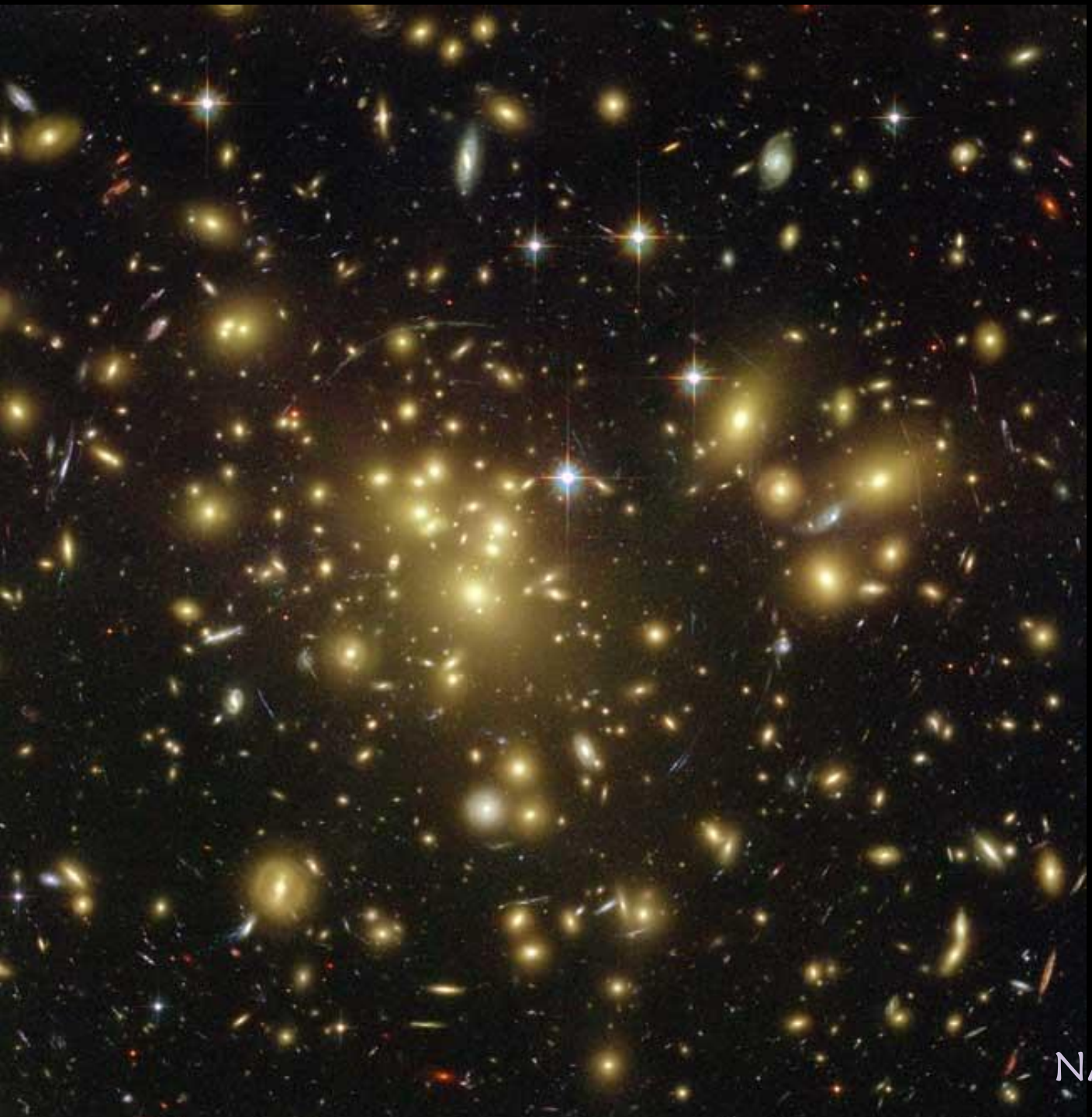


matter in the Universe
influences
the *shape* of space


galaxy
galaxy cluster
lensed galaxy images
distorted light-rays
Earth
STScI


NASA/ESA/Bradley et al

NASA/ESA/Bradley et al



optical

NASA/STSci/D Coe/ESA

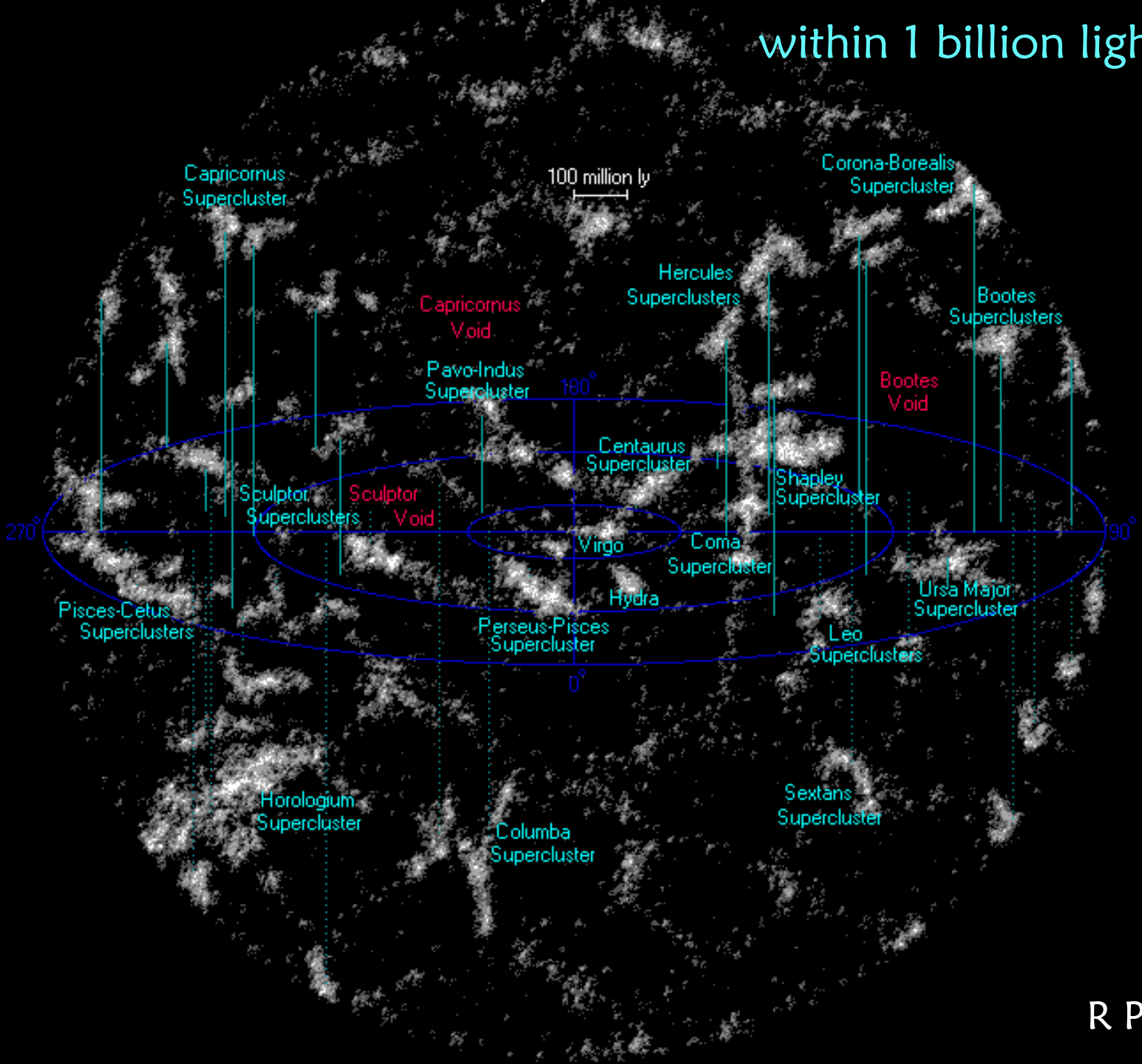
optical
lensing

NASA/STSci/D Coe/ESA

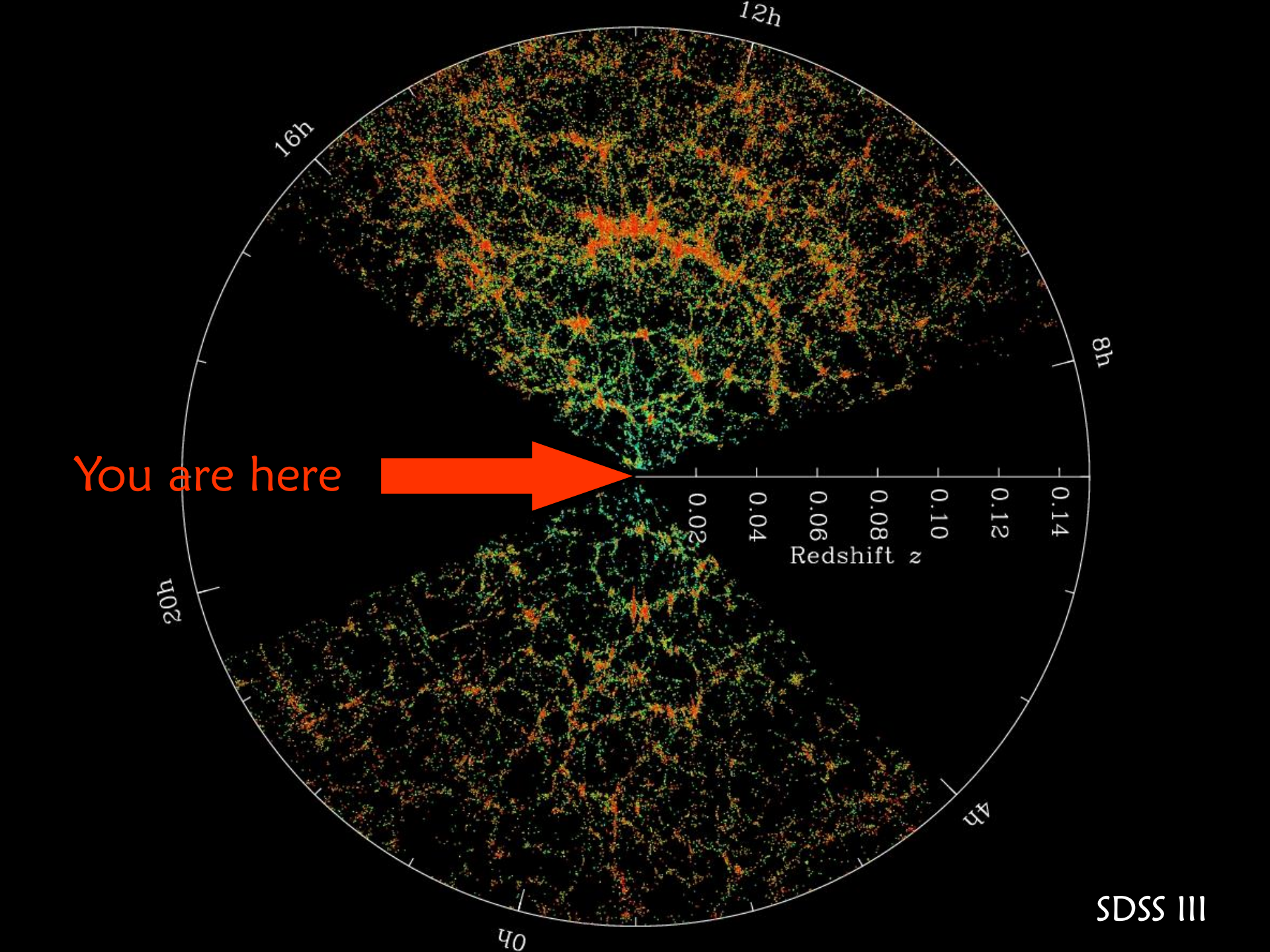

optical
X-ray
lensing
NASA/ESA/HST/Chandra

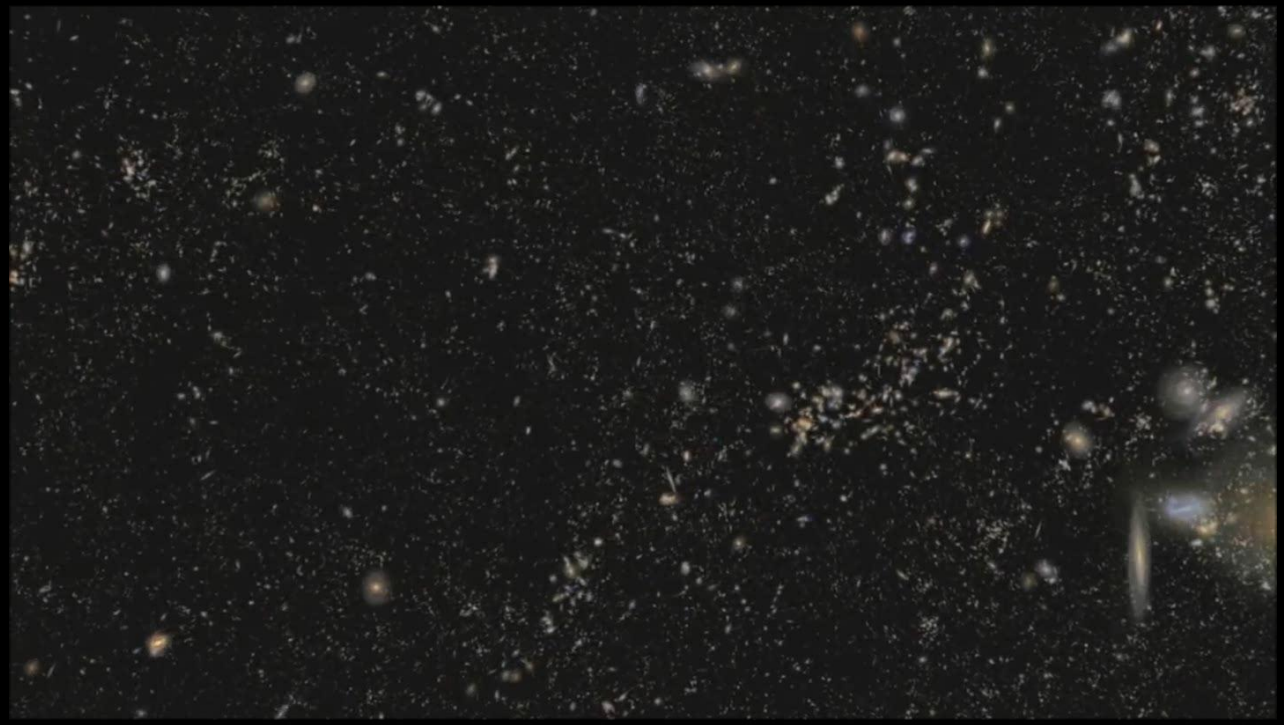
Big bang nucleosynthesis

within 1 billion light-years

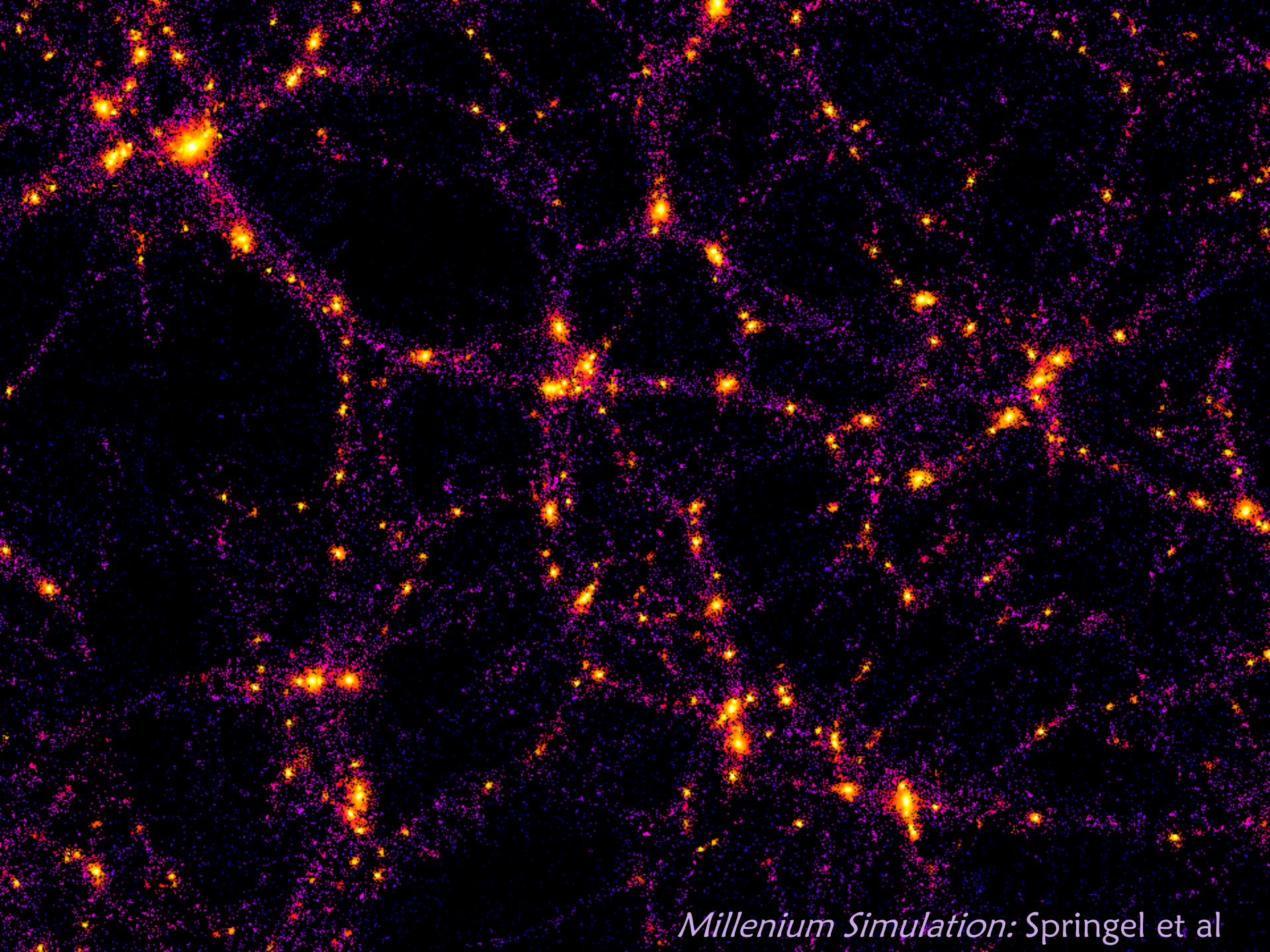


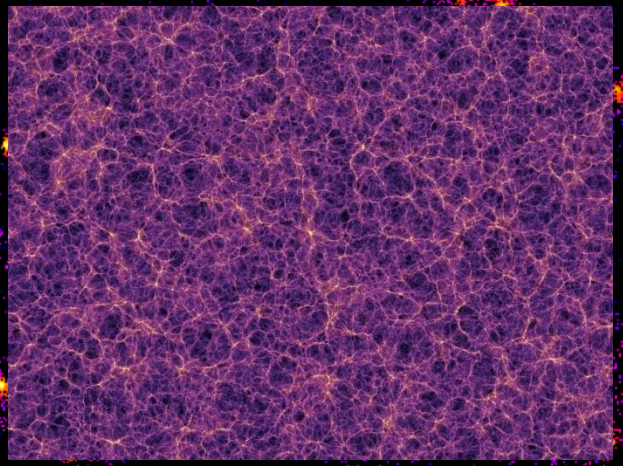
R Powell

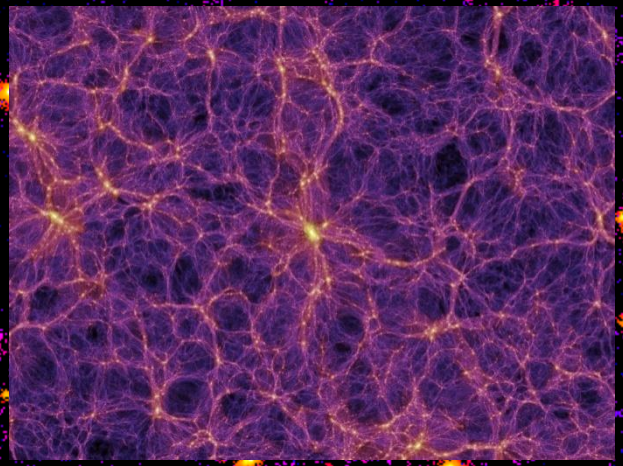

12h
16h
8h
20h
4h
0h
You are here
0.02
0.04
0.06
0.08
0.10
0.12
0.14
Redshift z
SDSS III

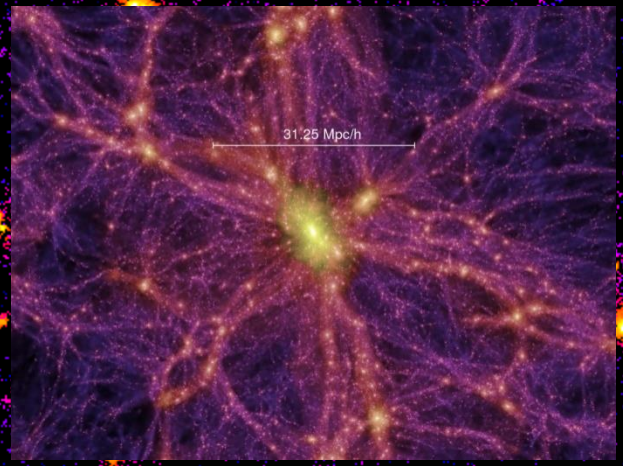


SDSS III/Aragon, SubbaRao & Szalay


Millenium Simulation: Springel et al

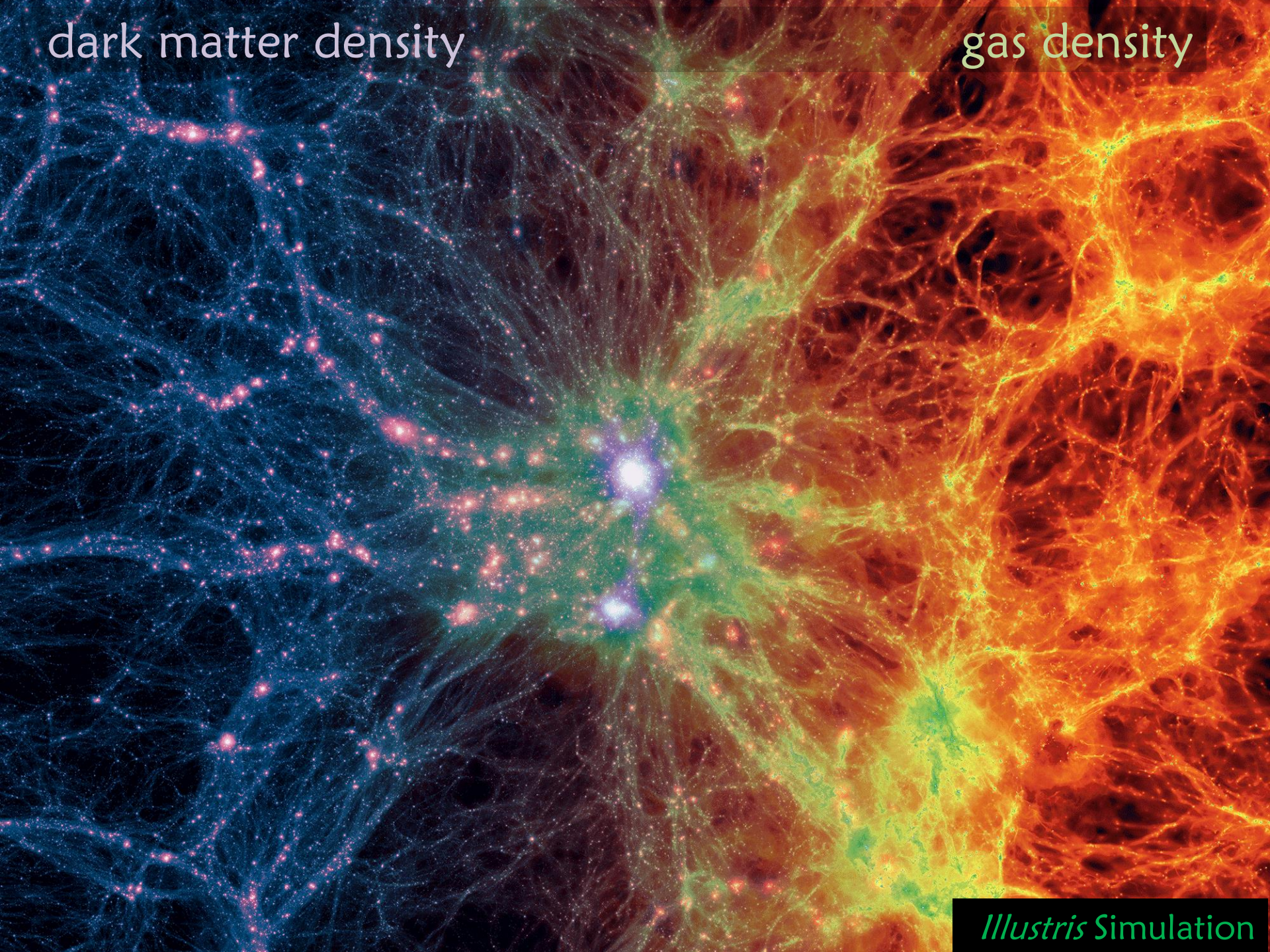






T = 13.6 billion years
T = 4.7 billion years
T = 1 billion years
T = 200 million years

Millenium Simulation: Springel et al

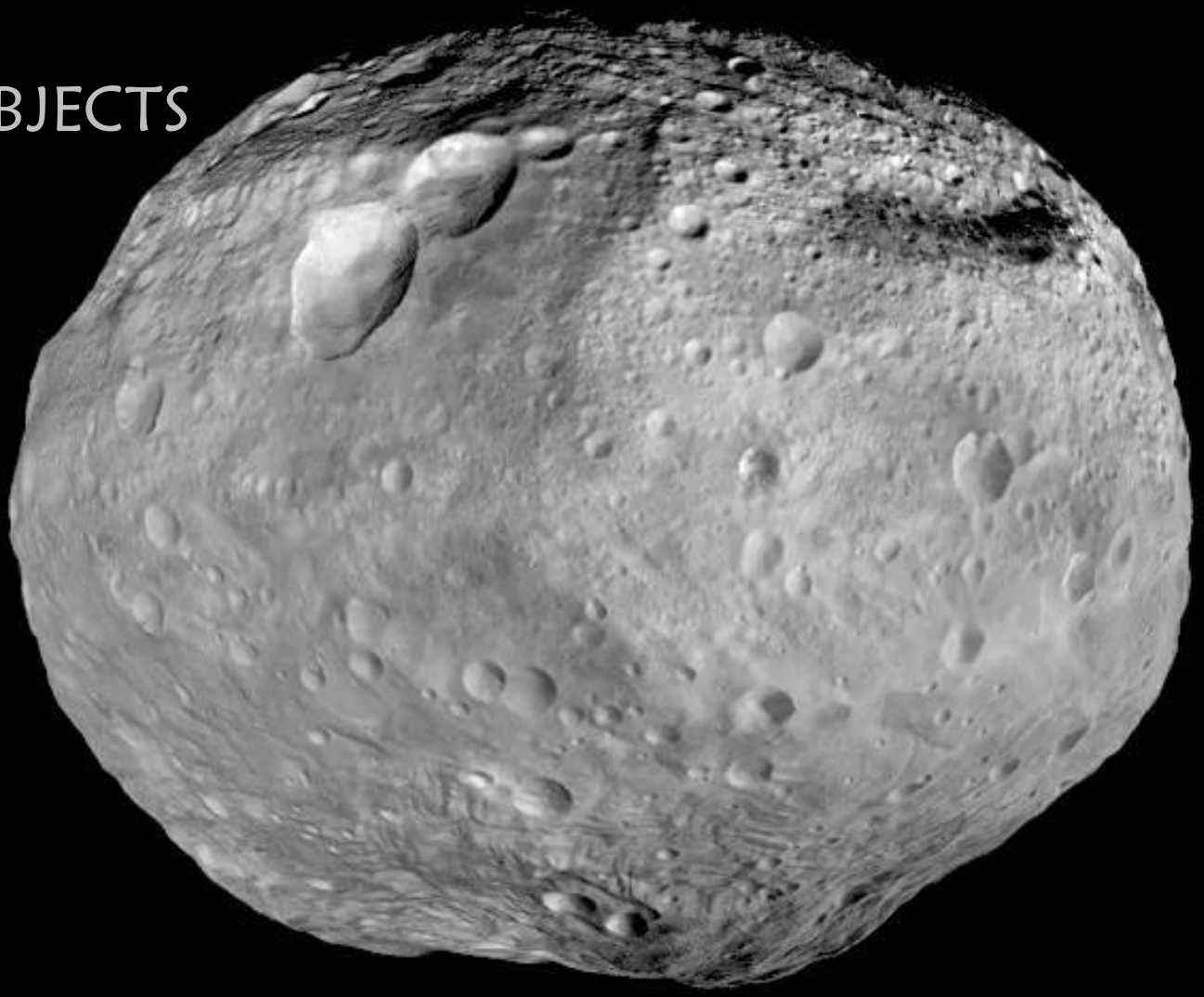

dark matter density
gas density
Illustris Simulation

Illustris Simulation


DARK MATTER CAN BE...
BARYONIC
NOT BARYONIC
Illustris Simulation

Baryonic dark matter

Rocky objects

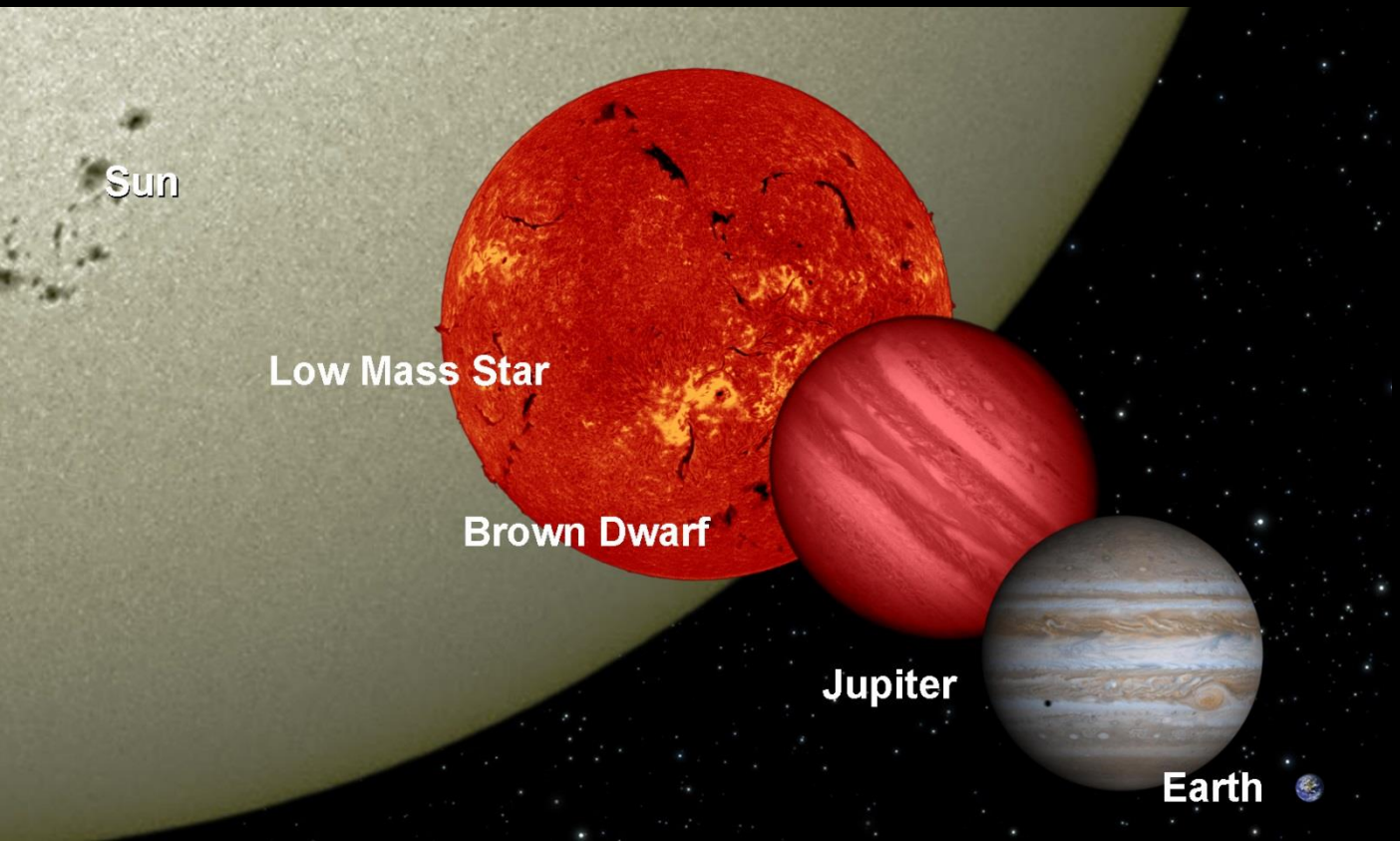


NASA/JPL-Caltech/UCLA

Baryonic dark matter

Rocky objects

Brown dwarfs



NASA/WISE

Baryonic dark matter

- Rocky objects
- Brown dwarfs
- Stellar remnants

ESA/NASA/O'Dell

Baryonic dark matter

Rocky objects

Brown dwarfs

Stellar remnants

NASA/Hubble/A Cool

Baryonic dark matter

~~Rocky objects~~

Brown dwarfs

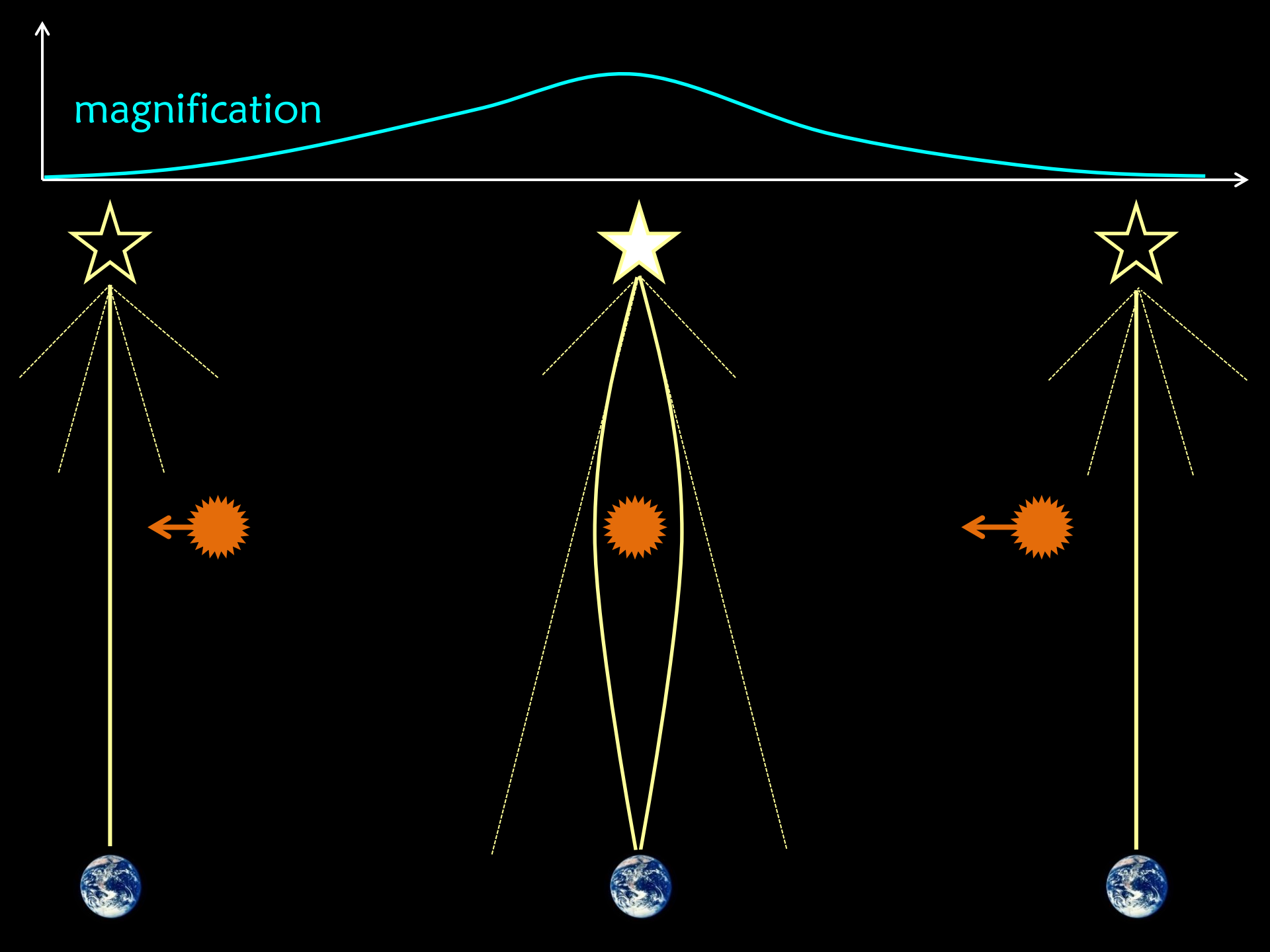
~~Stellar remnants~~

Baryonic dark matter

~~Rocky objects~~

~~Brown dwarfs~~

~~Stellar remnants~~


magnification

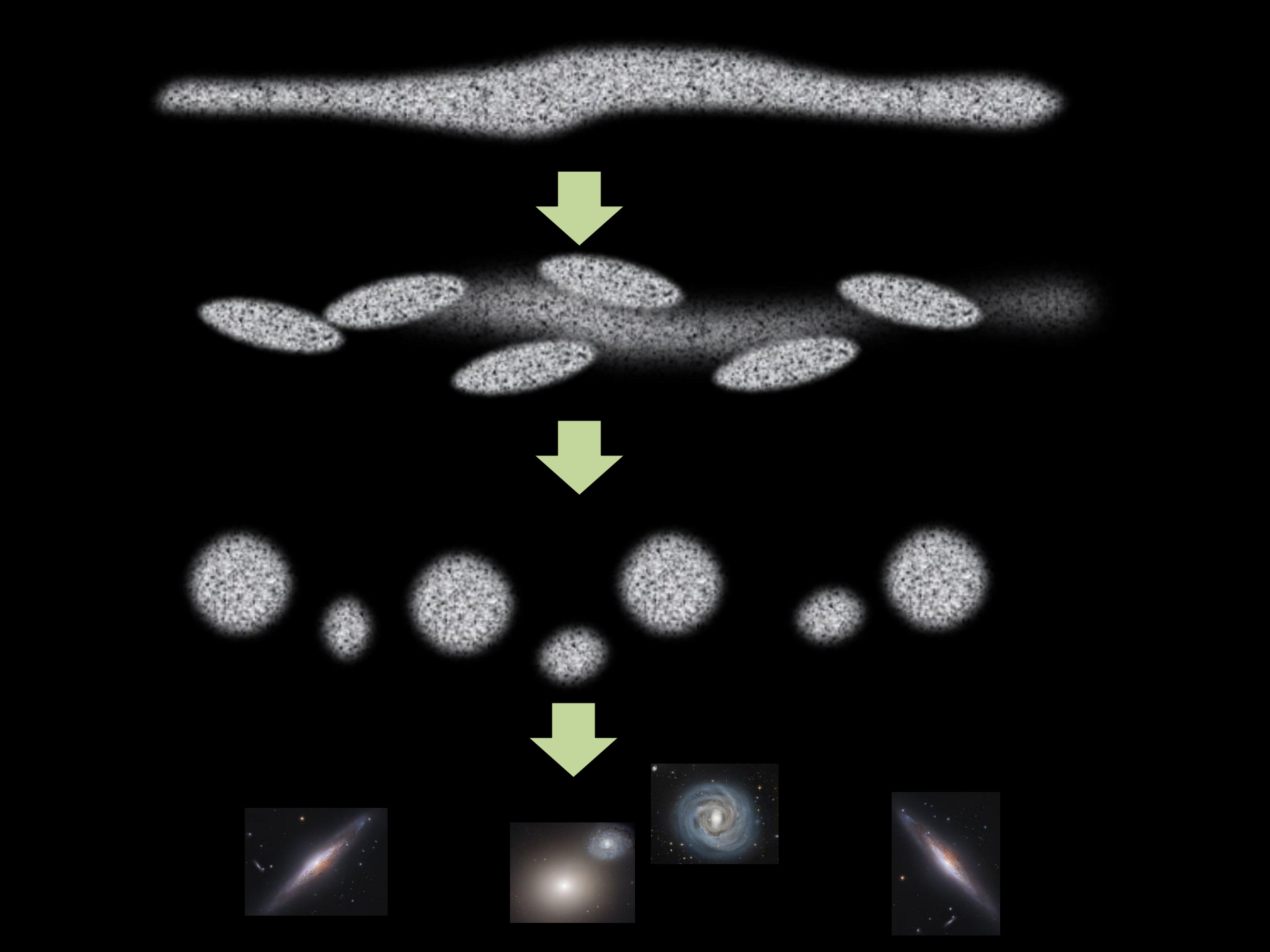
Baryonic dark matter

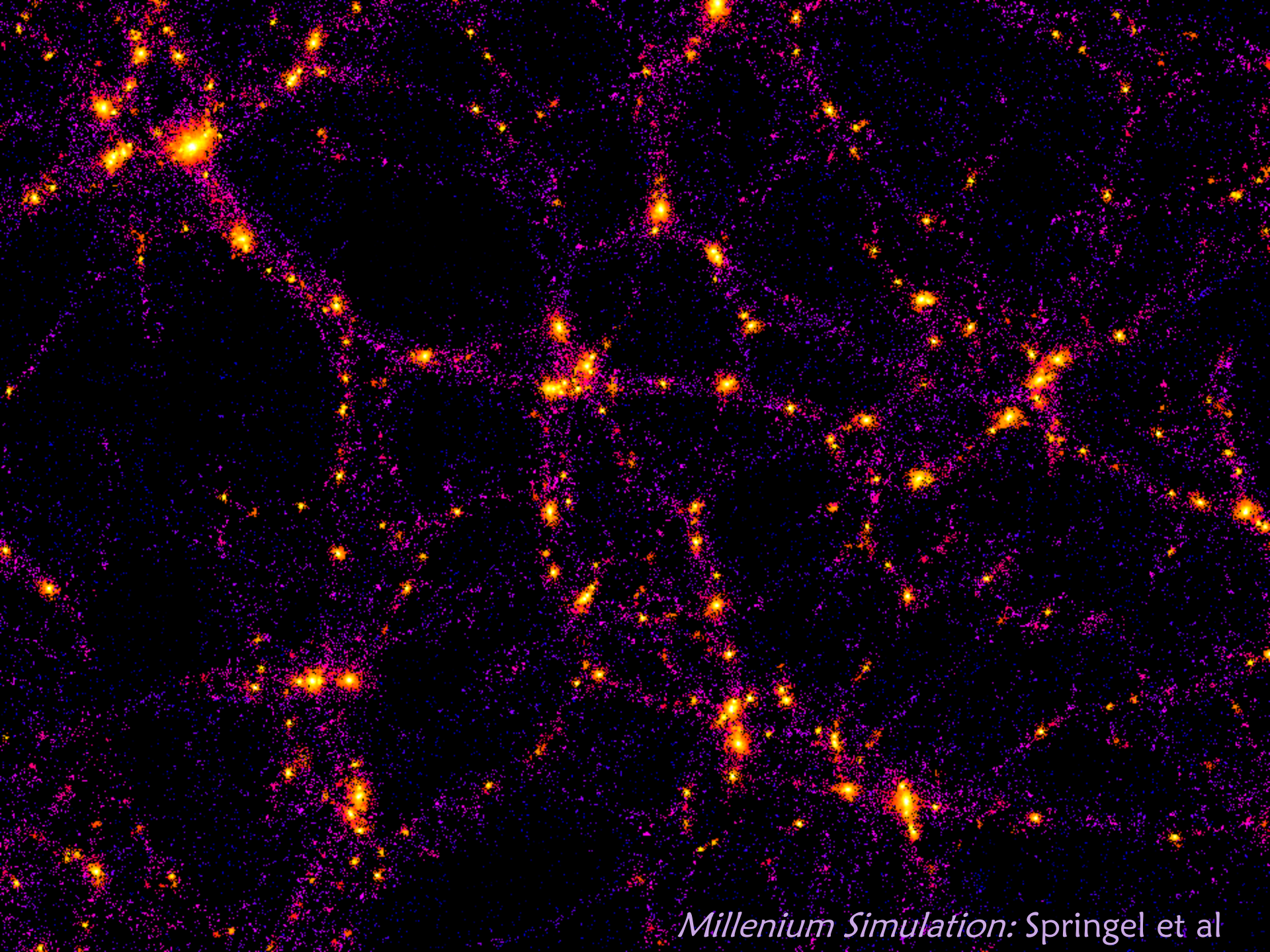
~~Baryonic dark matter~~

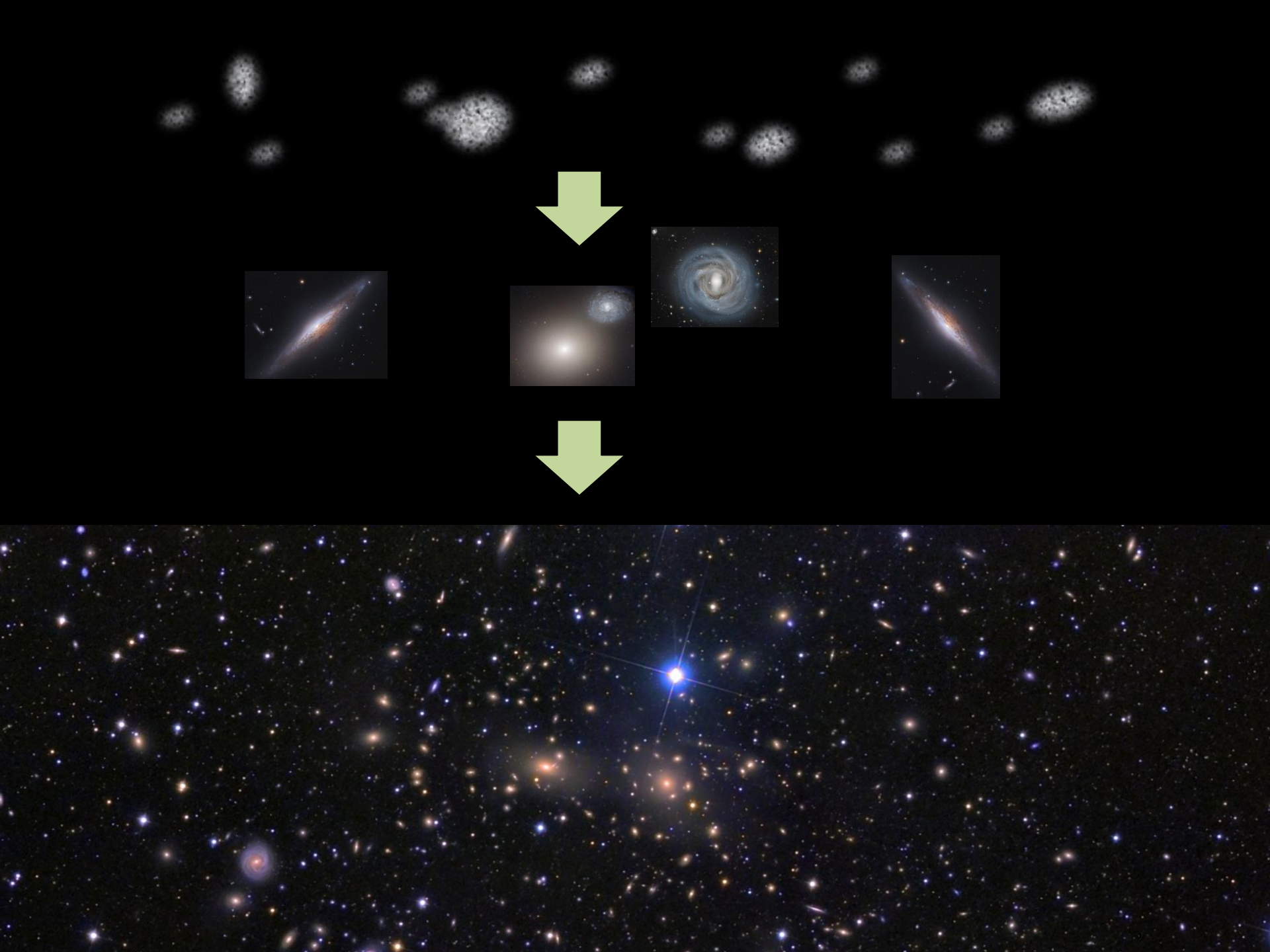
Non-baryonic dark matter

- ✓ Experiences gravity
- ✓ Will react to weak force
- ✓ Does not react to E-M force
- ✓ Does not respond to strong force

- Enough mass?
- Travels too fast!




Millenium Simulation: Springel et al

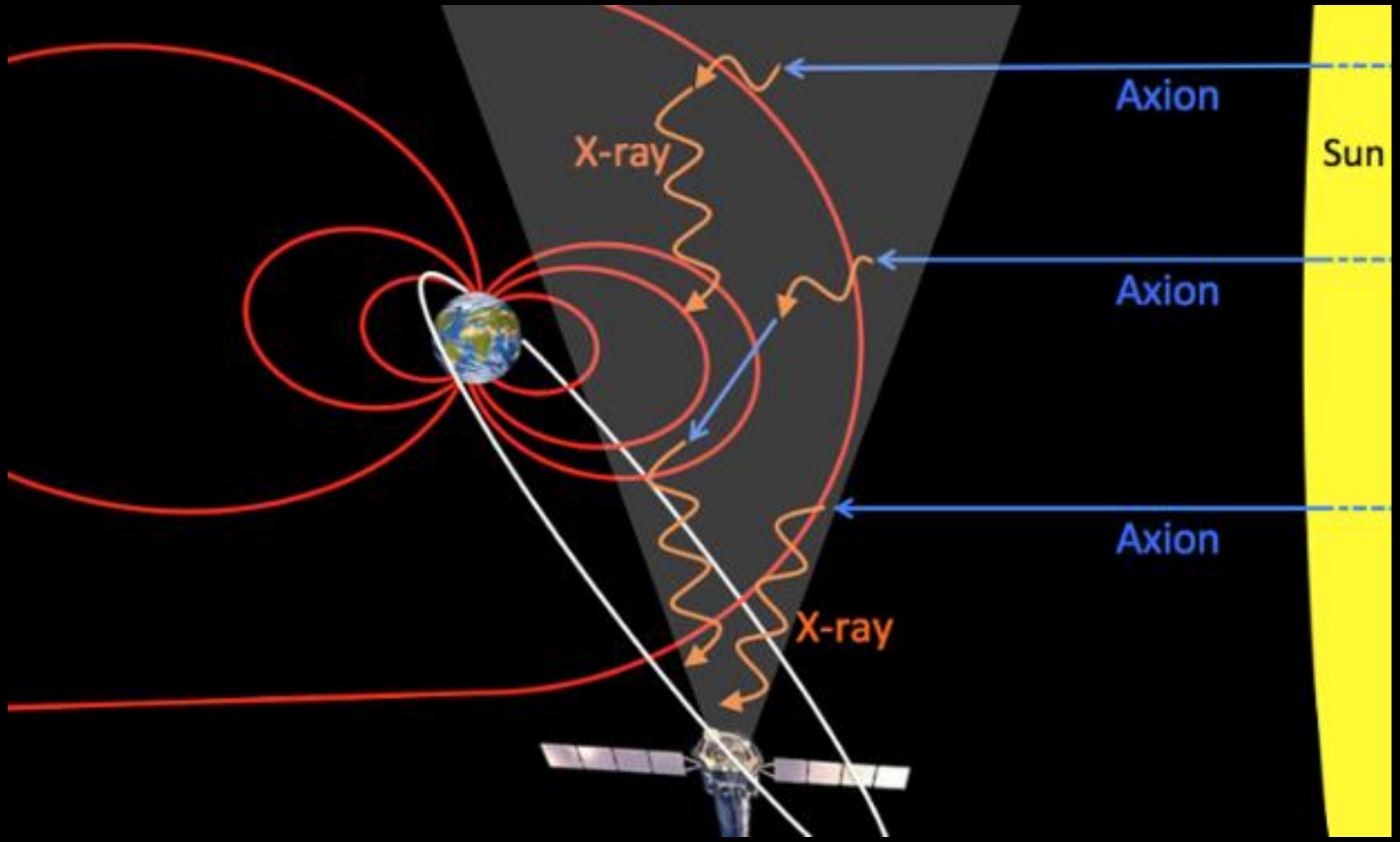


Non-baryonic dark matter

- ✓ experiences gravity
- ✓ Will react to weak force
- ✓ Does not react to E-M force
- ✓ Does not respond to strong force

- Enough mass?
- Travels too fast!

AXIONS

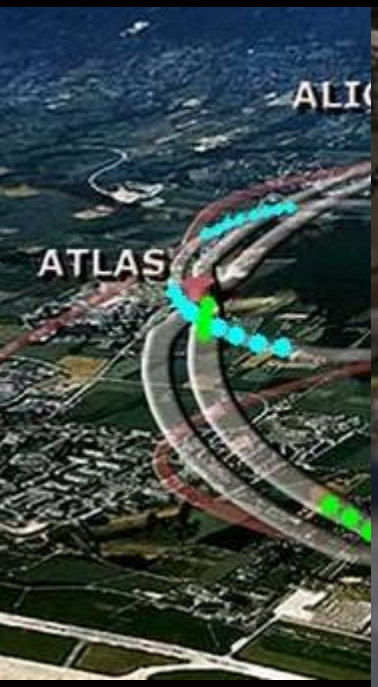


Wimps…

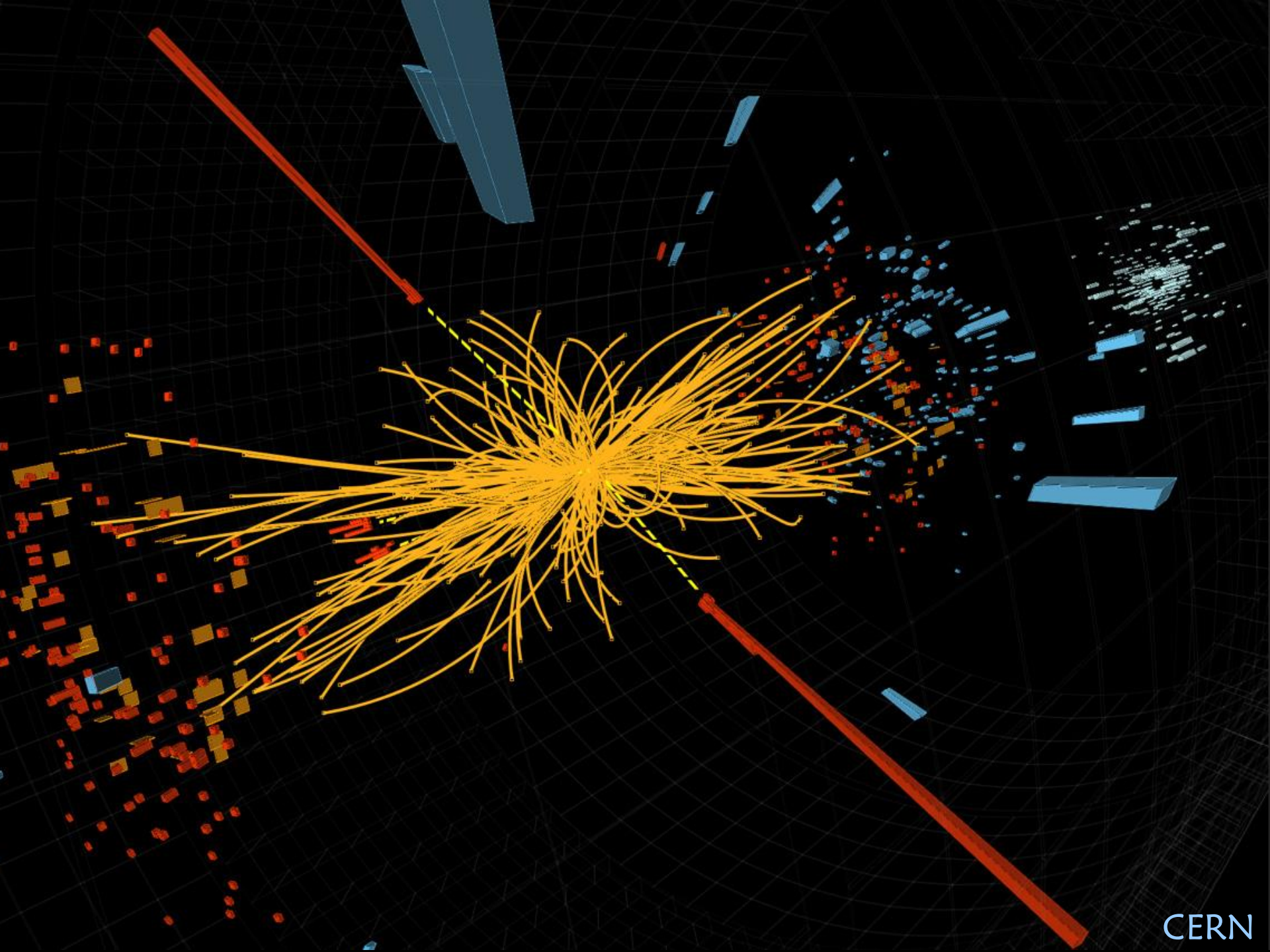
Weakly Interacting Massive Particles

WIMPS…

FROM PARTICLE COLLISIONS

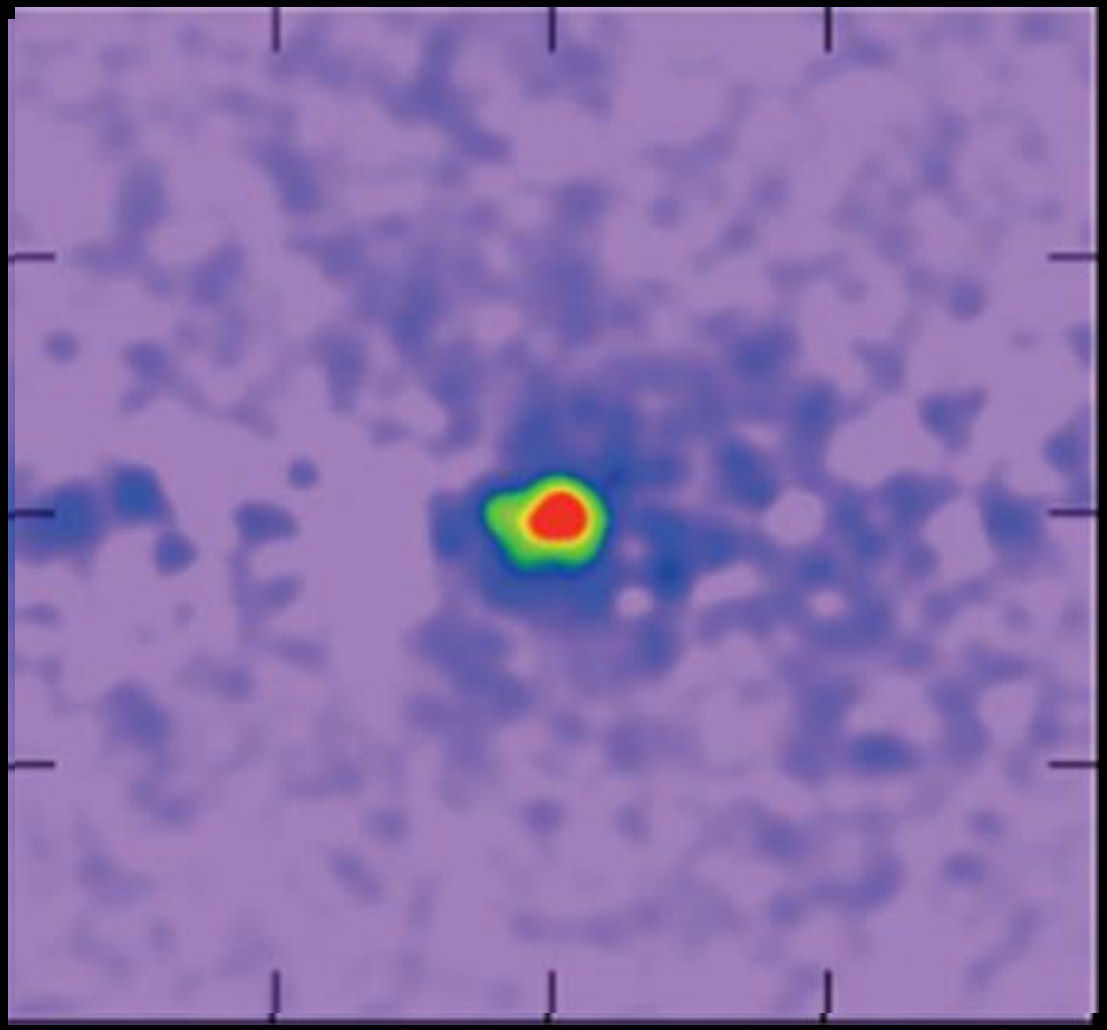


LHC/CERN


CERN

WIMPS…

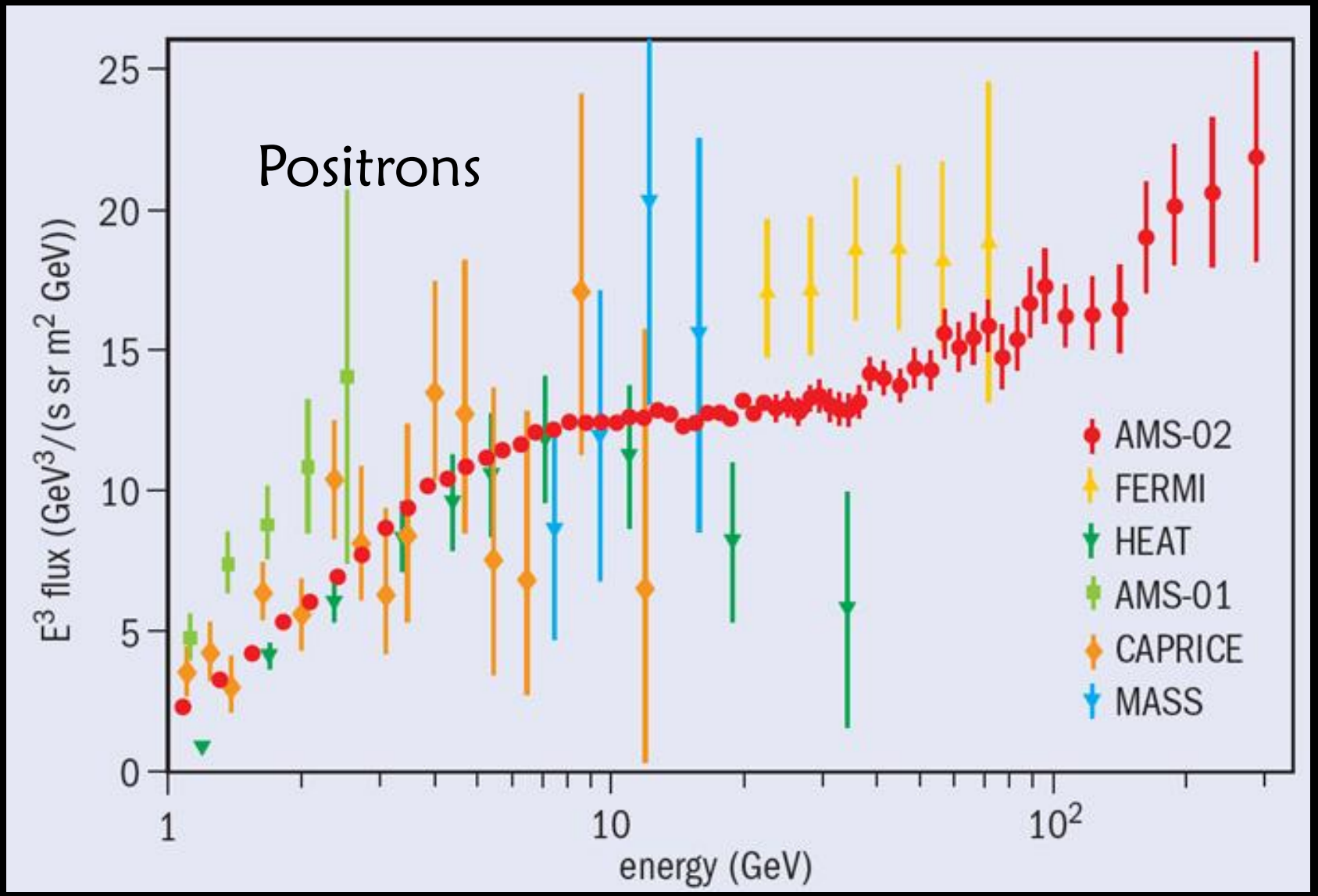
FROM SEARCHES FOR BY-PRODUCTS



γ-rays from the centre of the Galaxy…

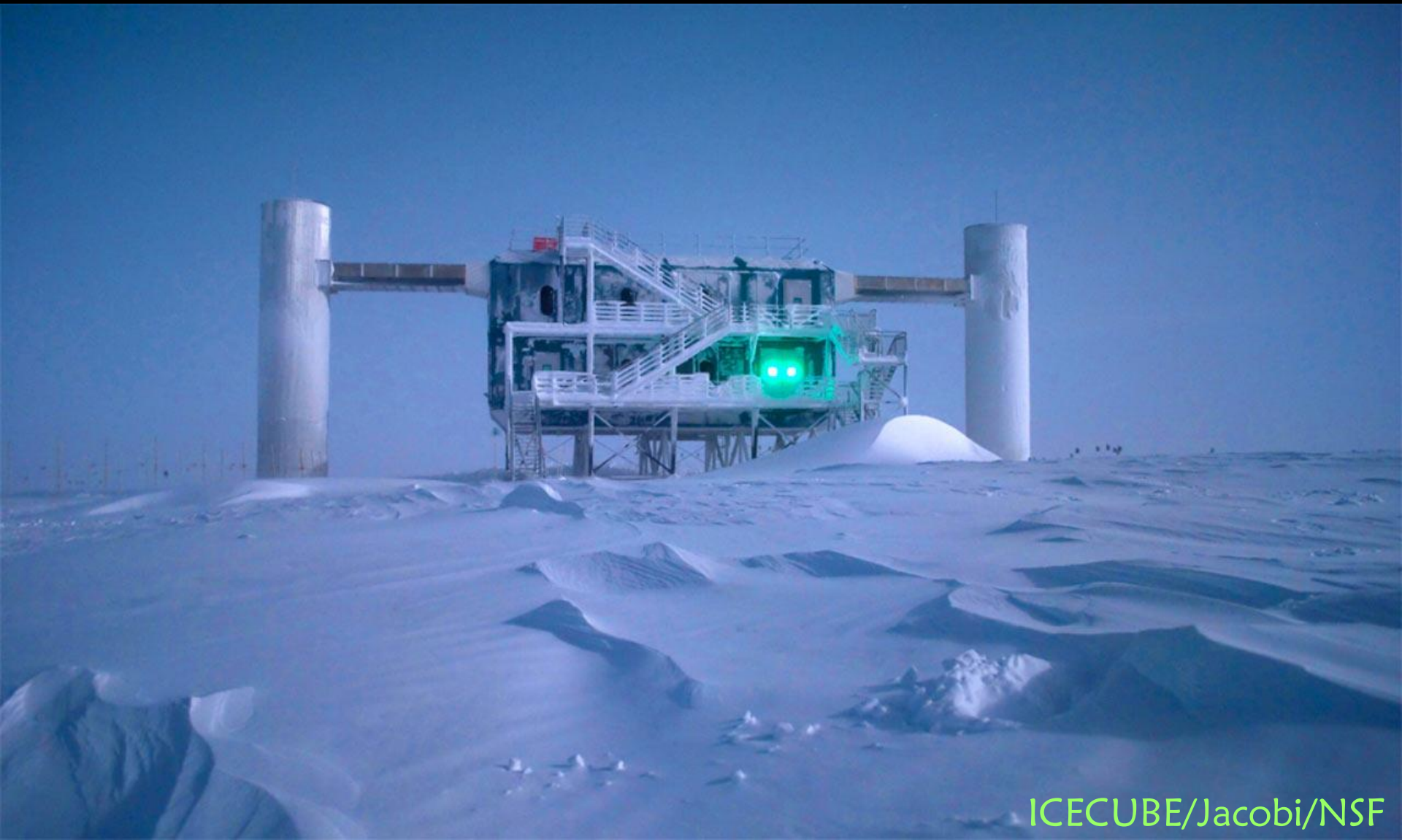
Daylan et al/Fermi


Garan & Expedition 28 crew, NASA
excess of cosmic rays
AMS
AMS



Aguilar, CERN and CIEMAT / AMS collaboration

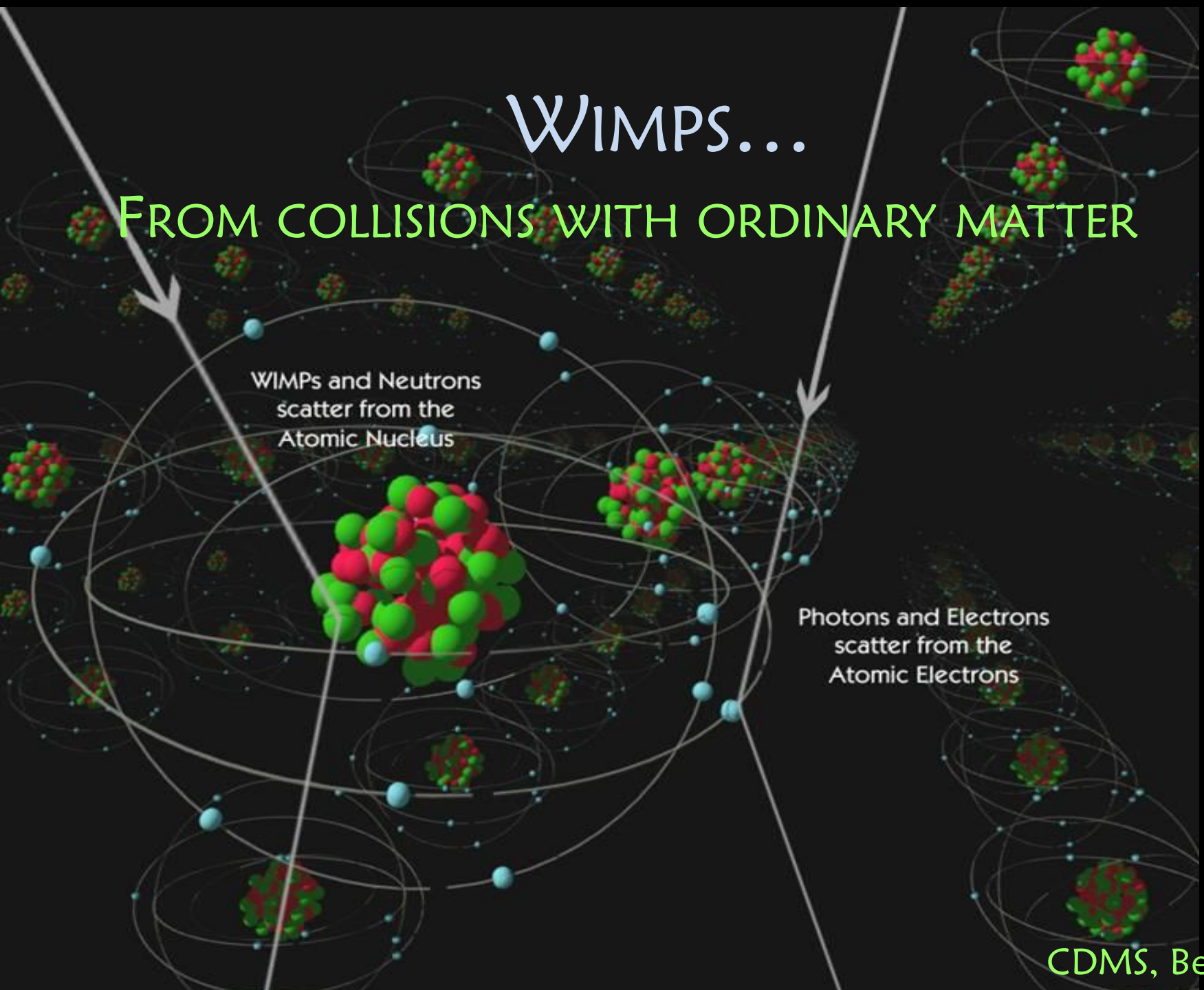
neutrinos



ICECUBE/Jacobi/NSF

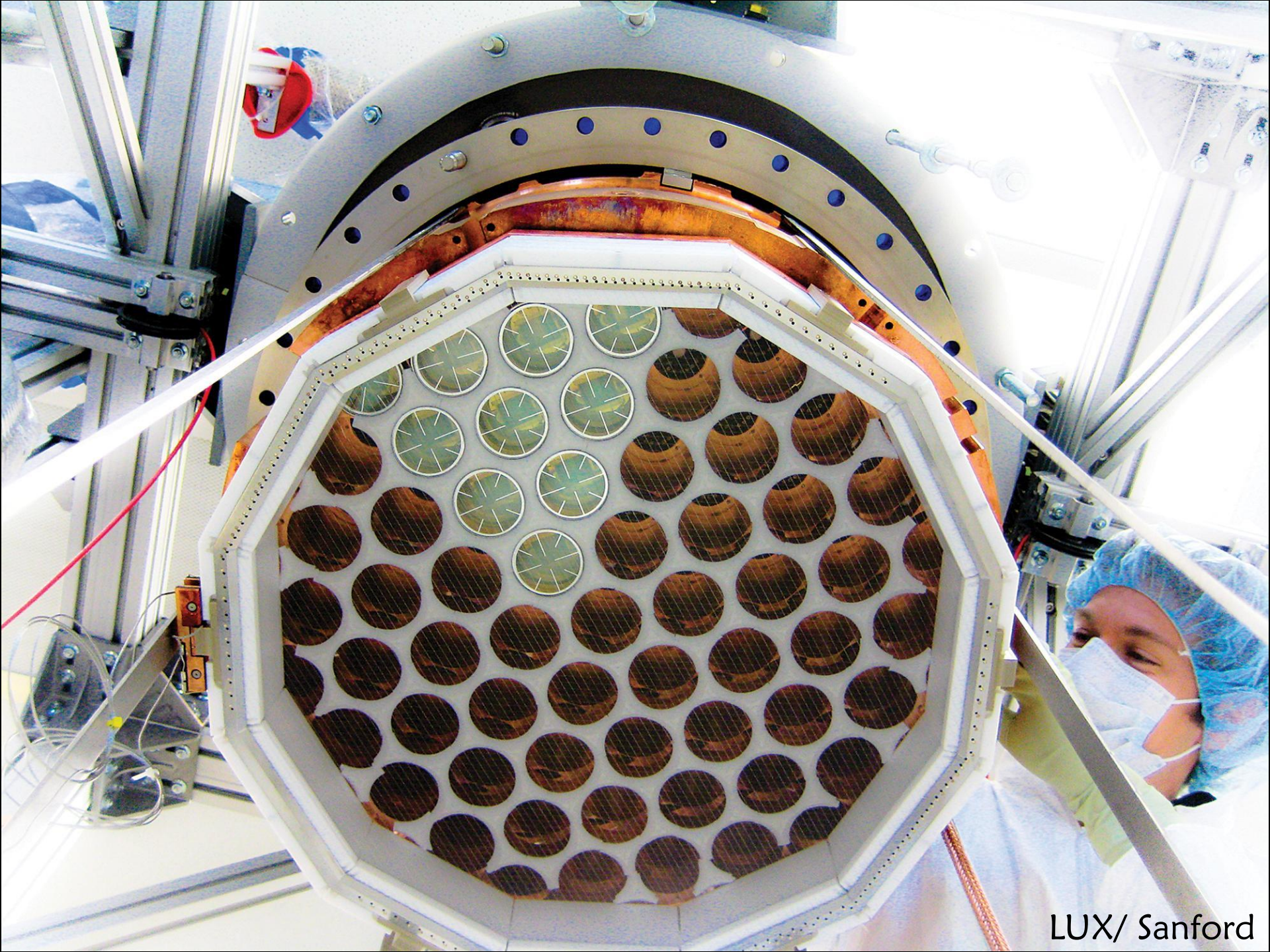
WIMPS…

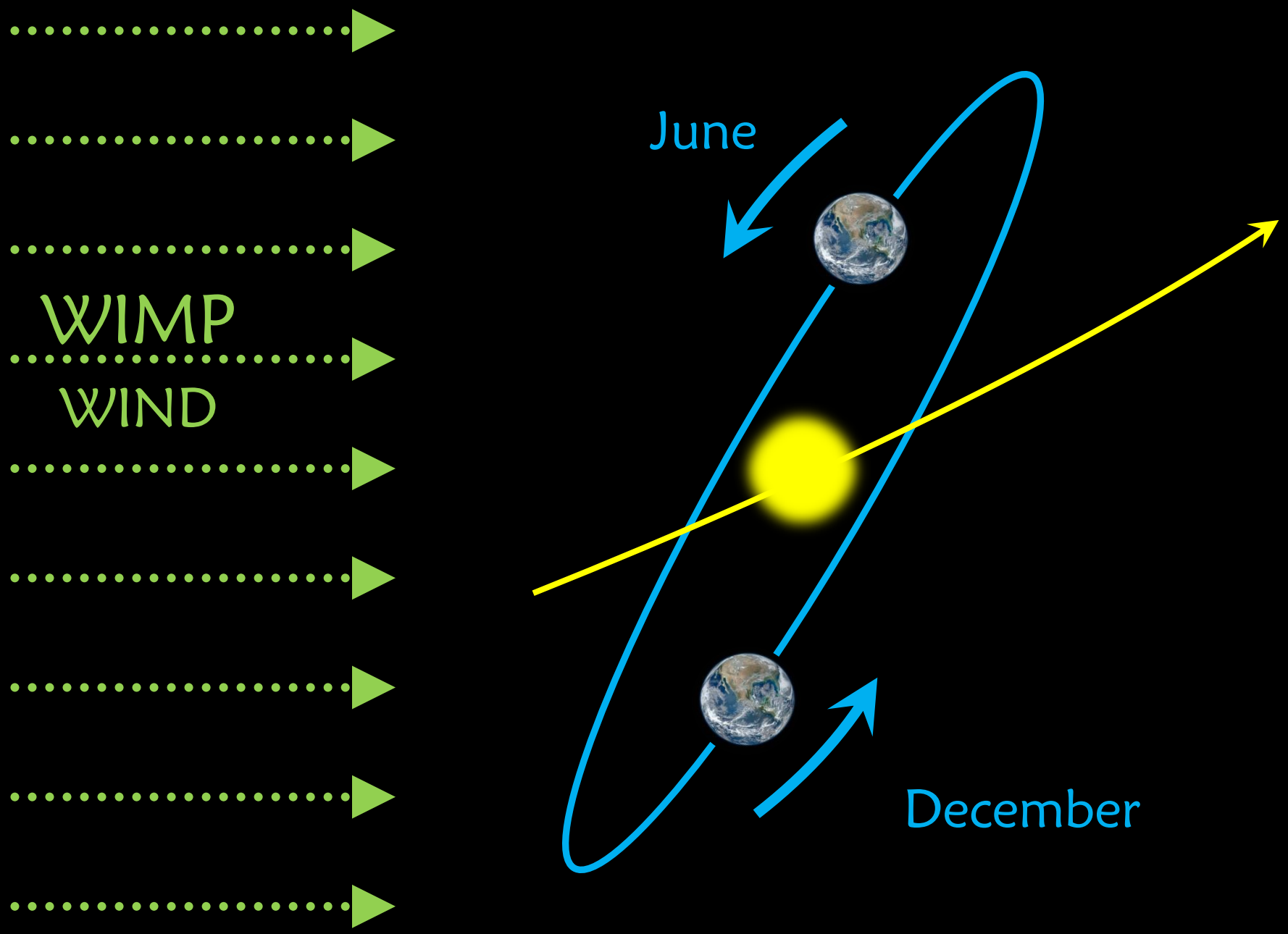
FROM COLLISIONS WITH ORDINARY MATTER

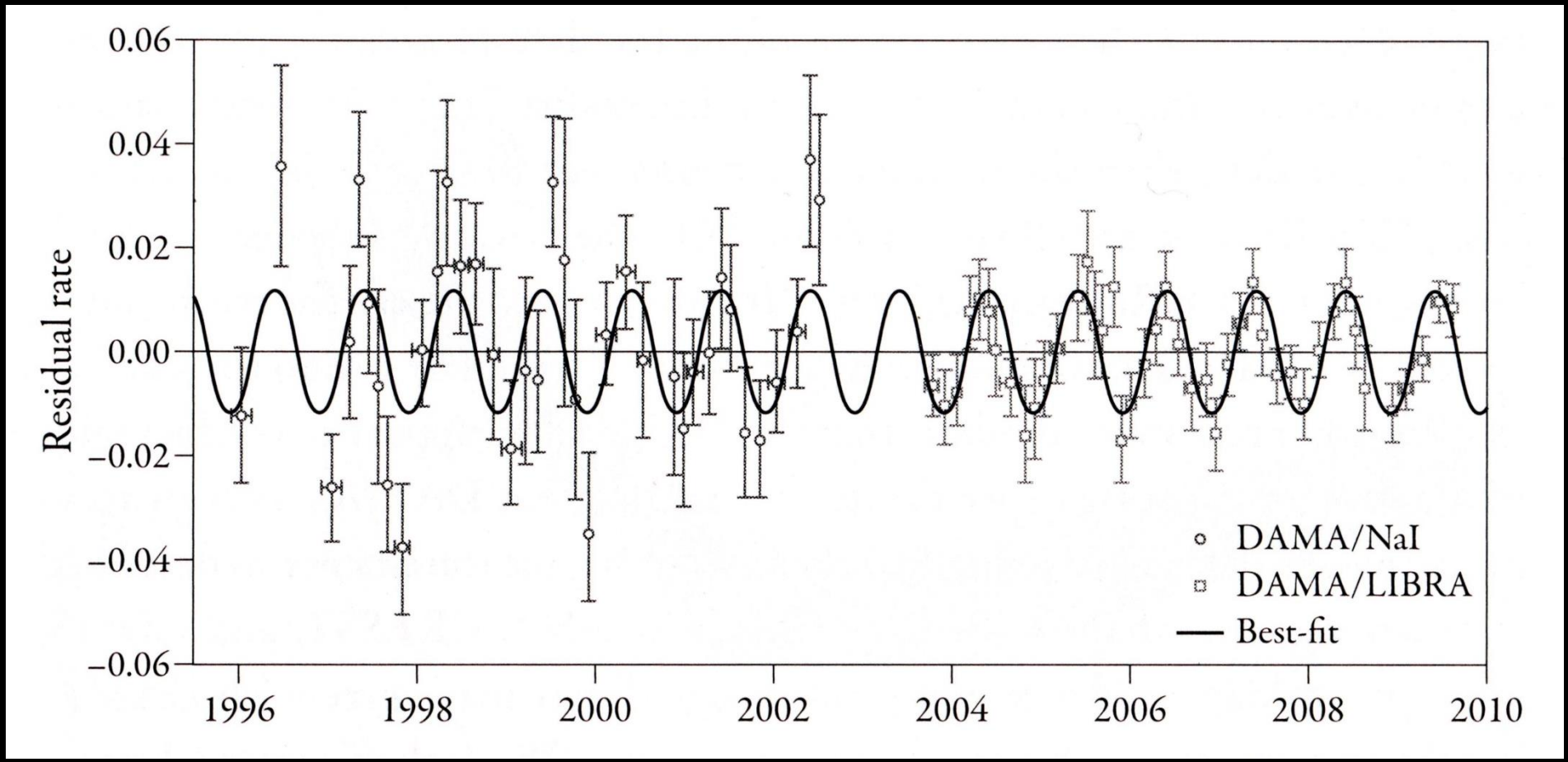


CDMS, Berkeley

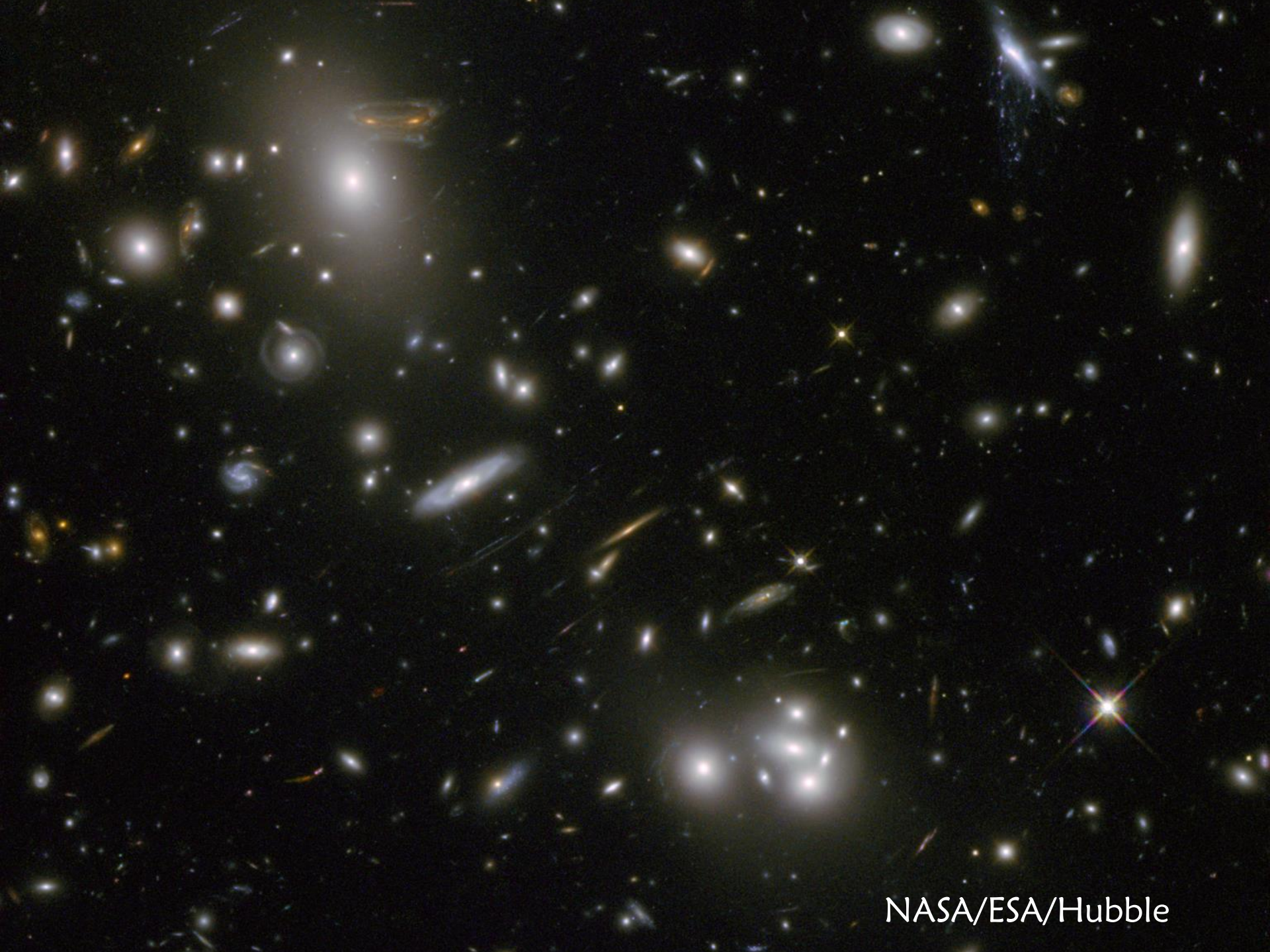

LUX/ Matt Kapust


LUX/ Sanford


WIMP
WIND
June
December

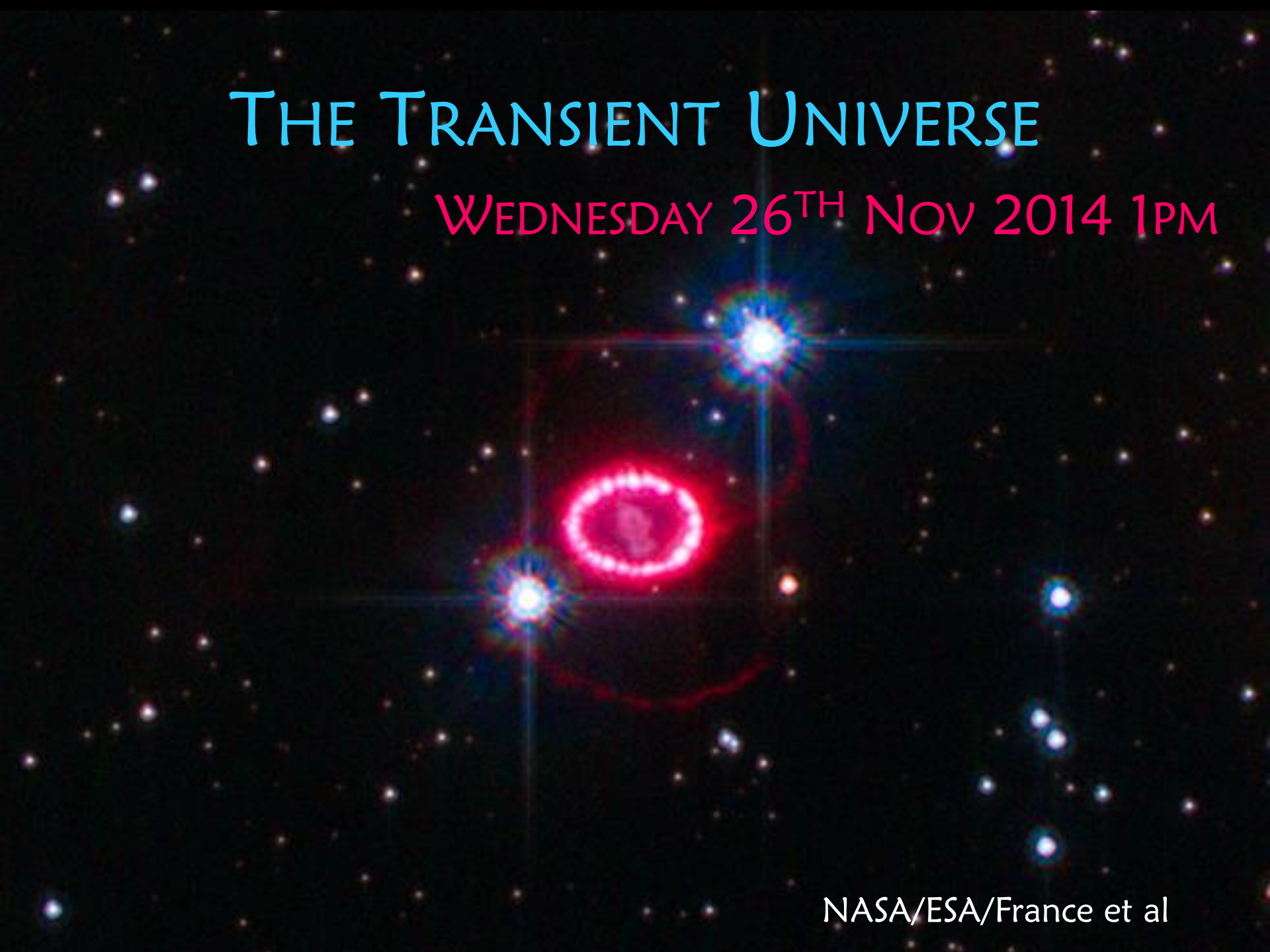


DAMA/Libra/Burnabei et al


NASA/ESA/Hubble

The Transient Universe

Wednesday 26th Nov 2014 1pm



NASA/ESA/France et al