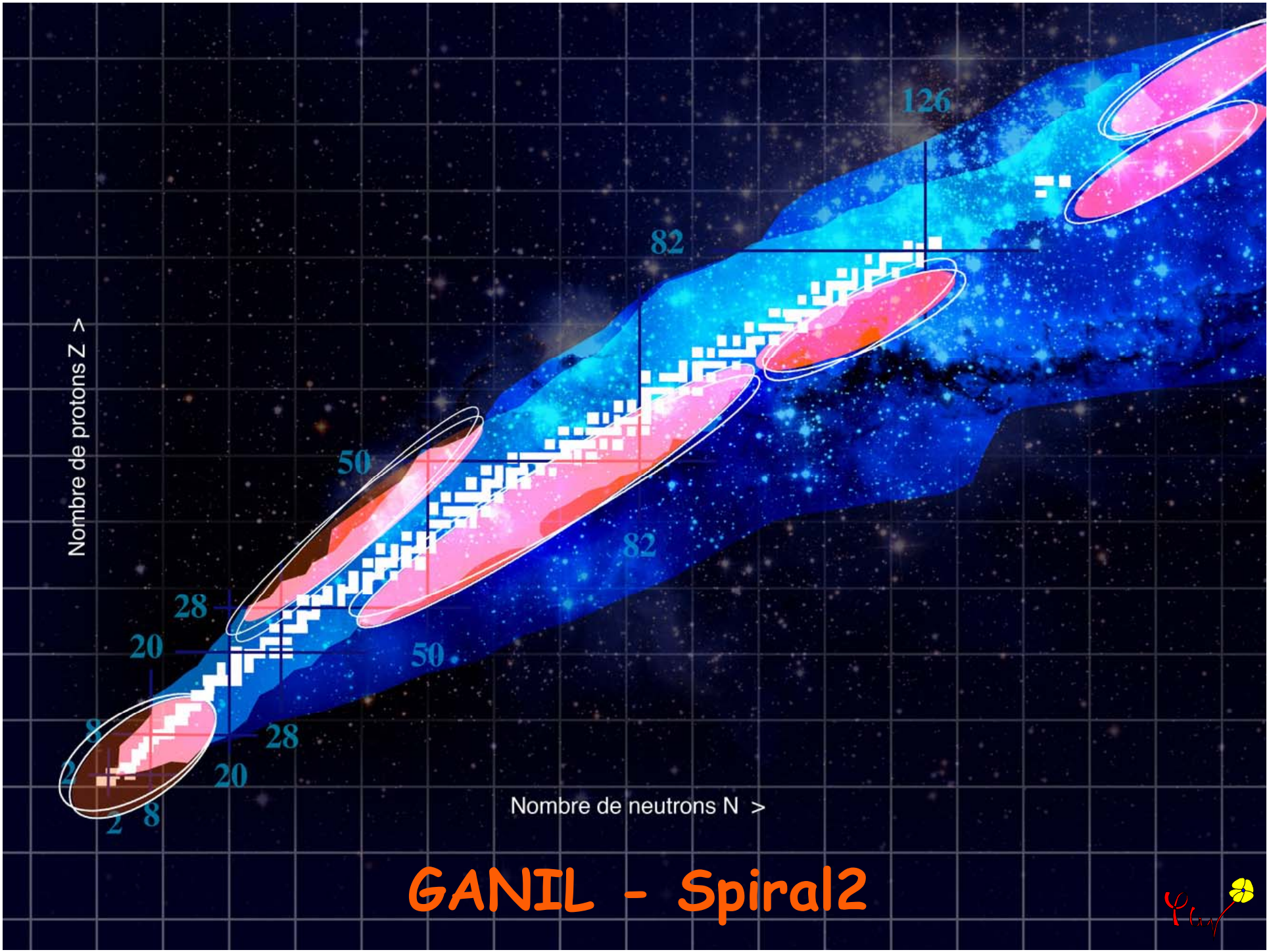
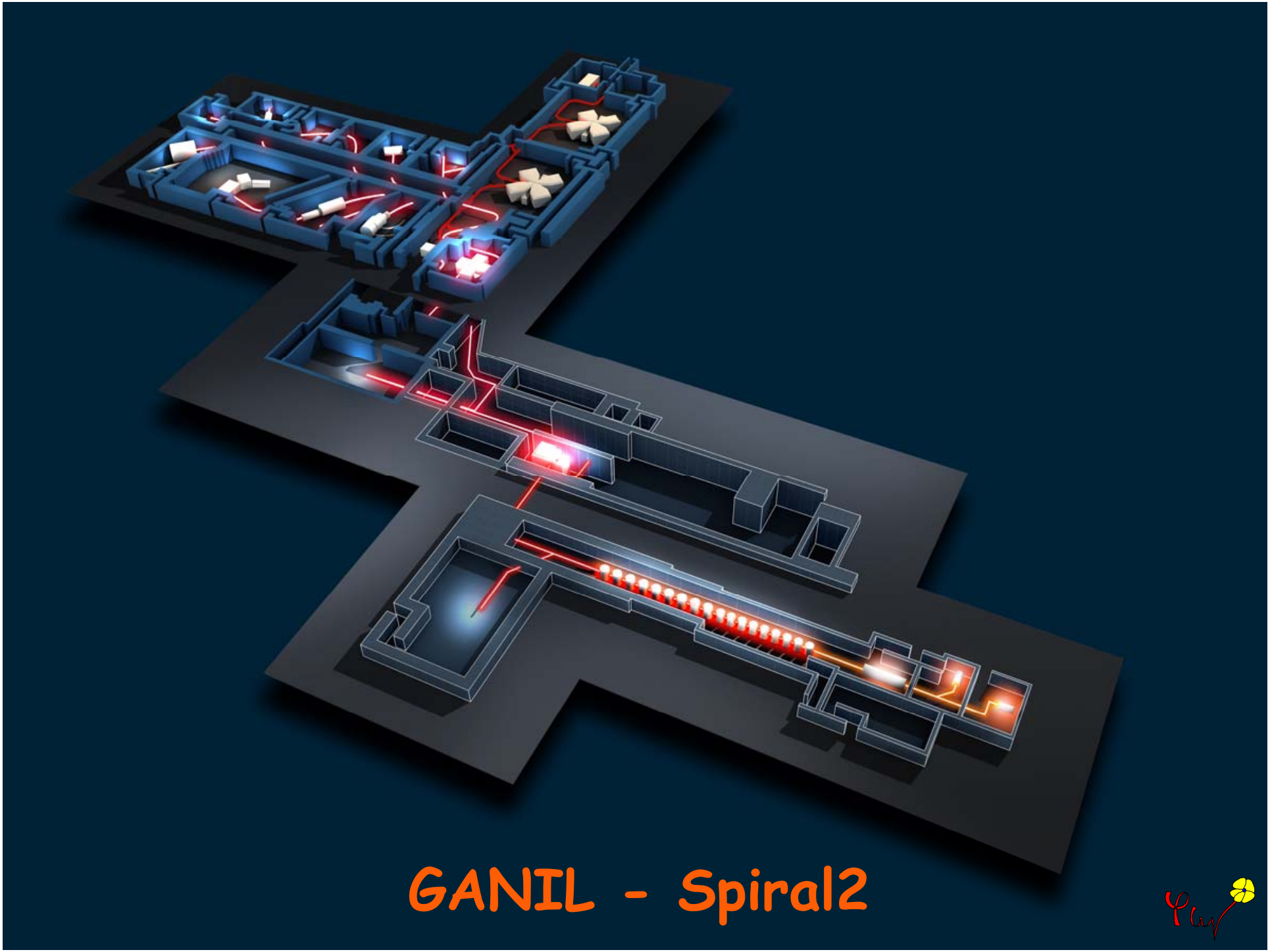
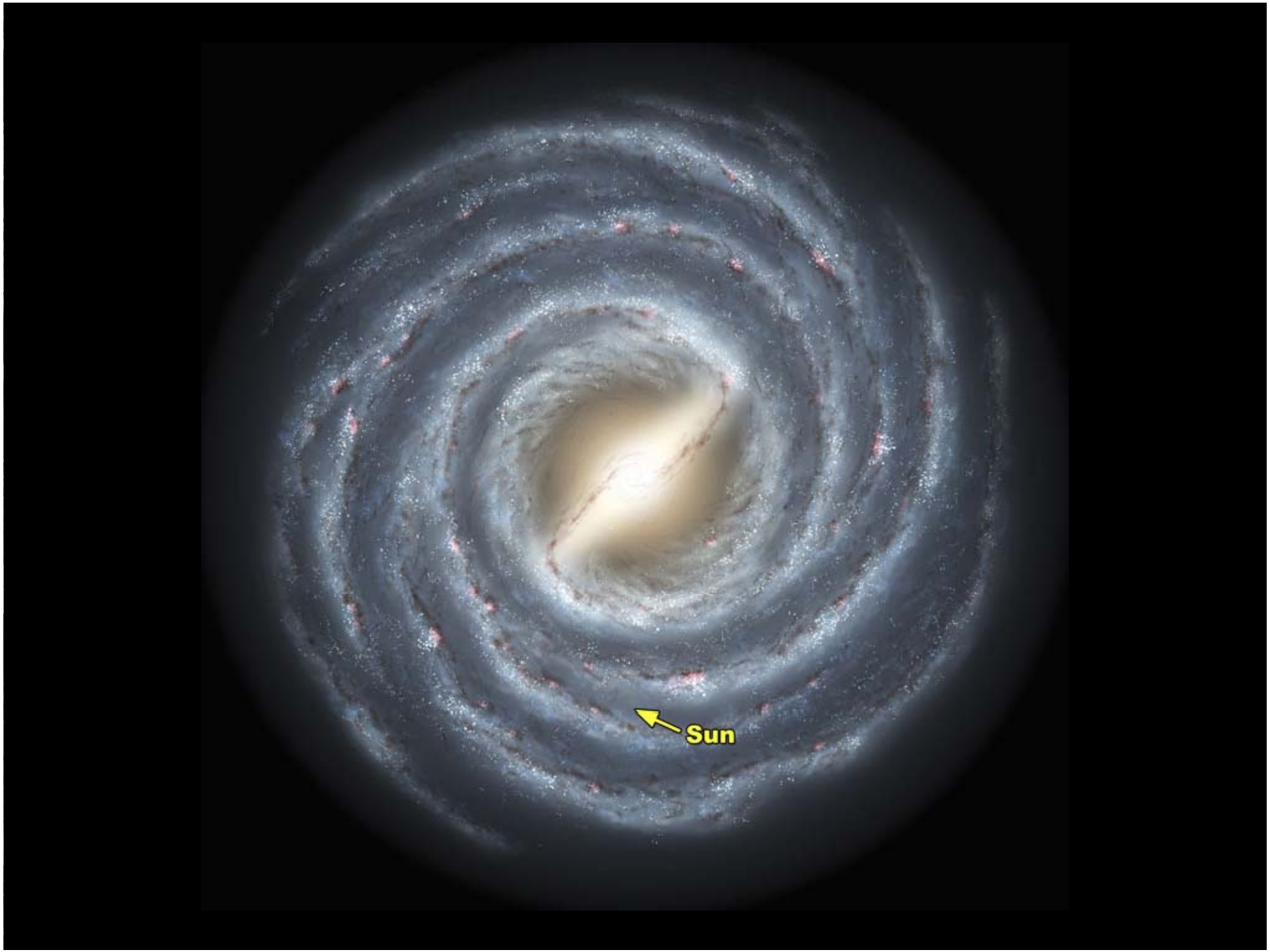
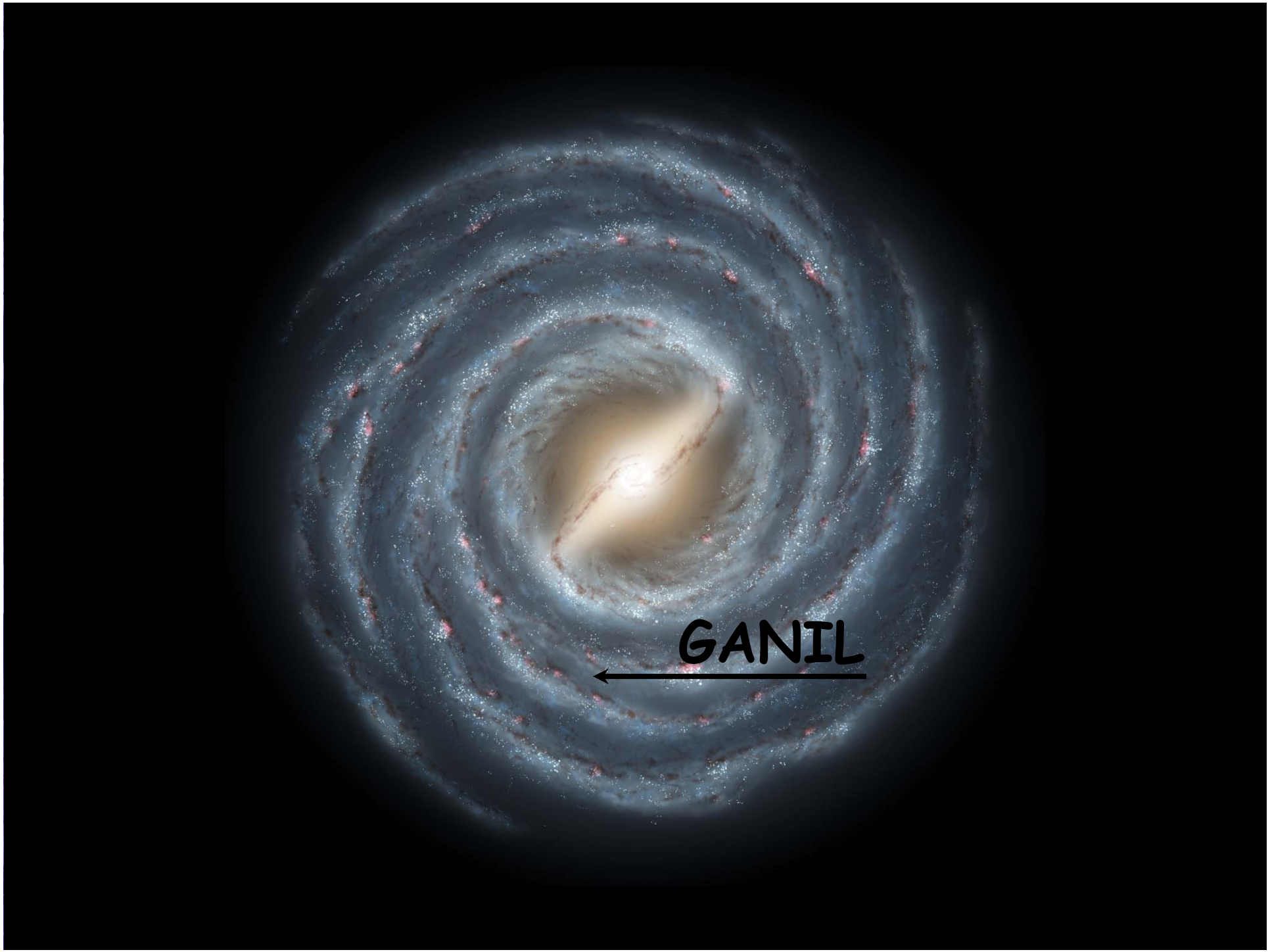


GANIL - Spiral2


GANIL - Spiral2


Sun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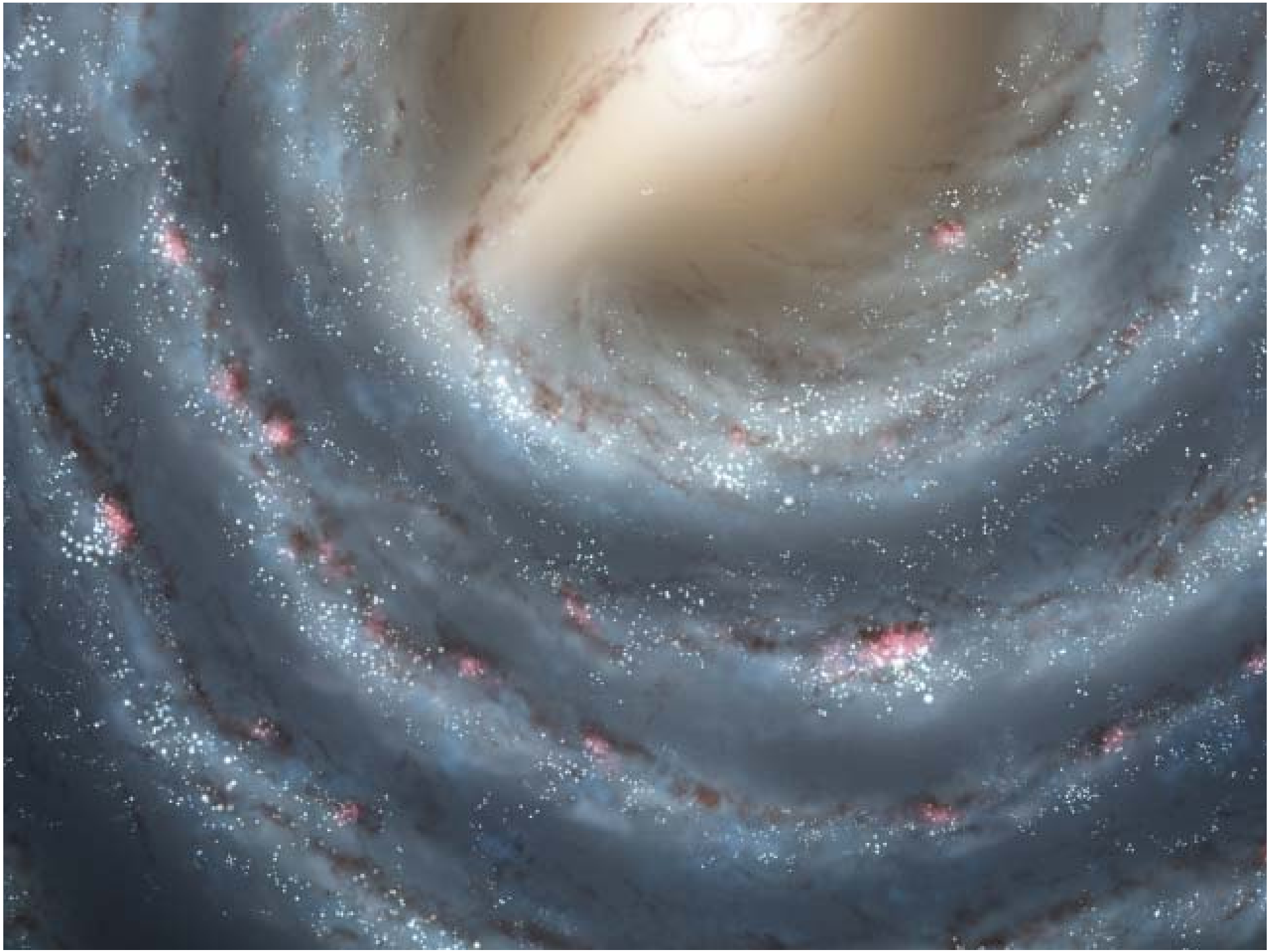
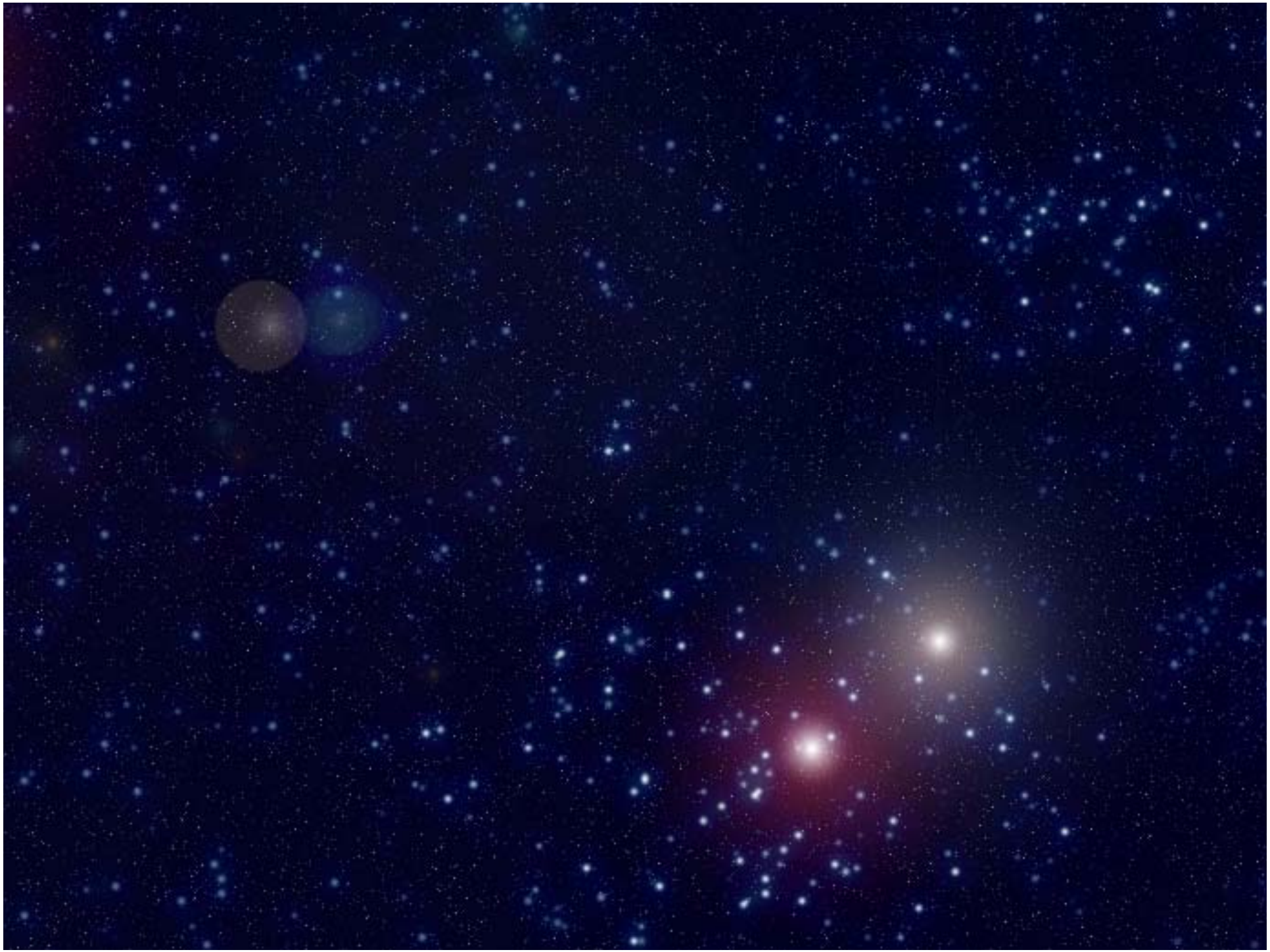
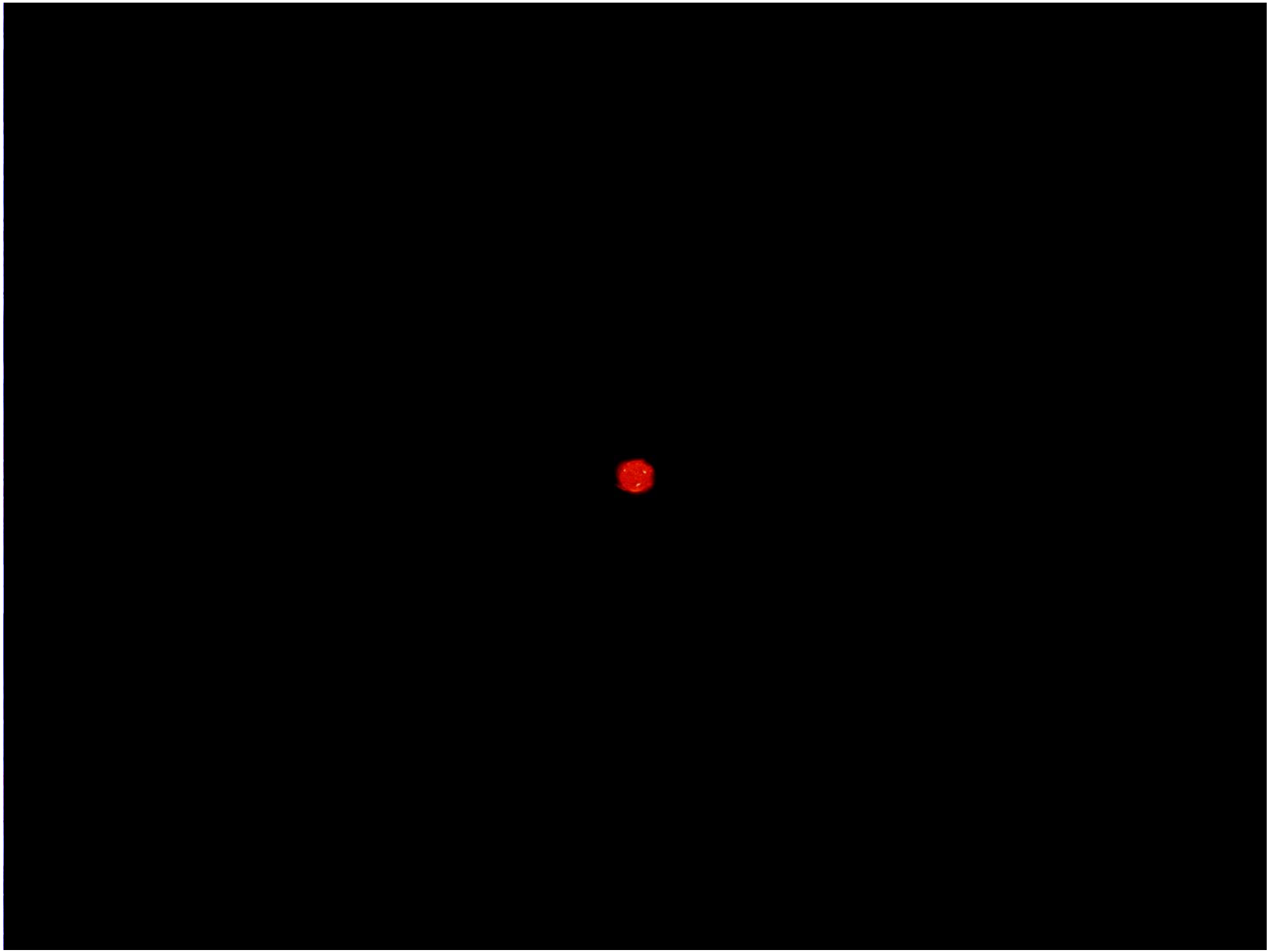
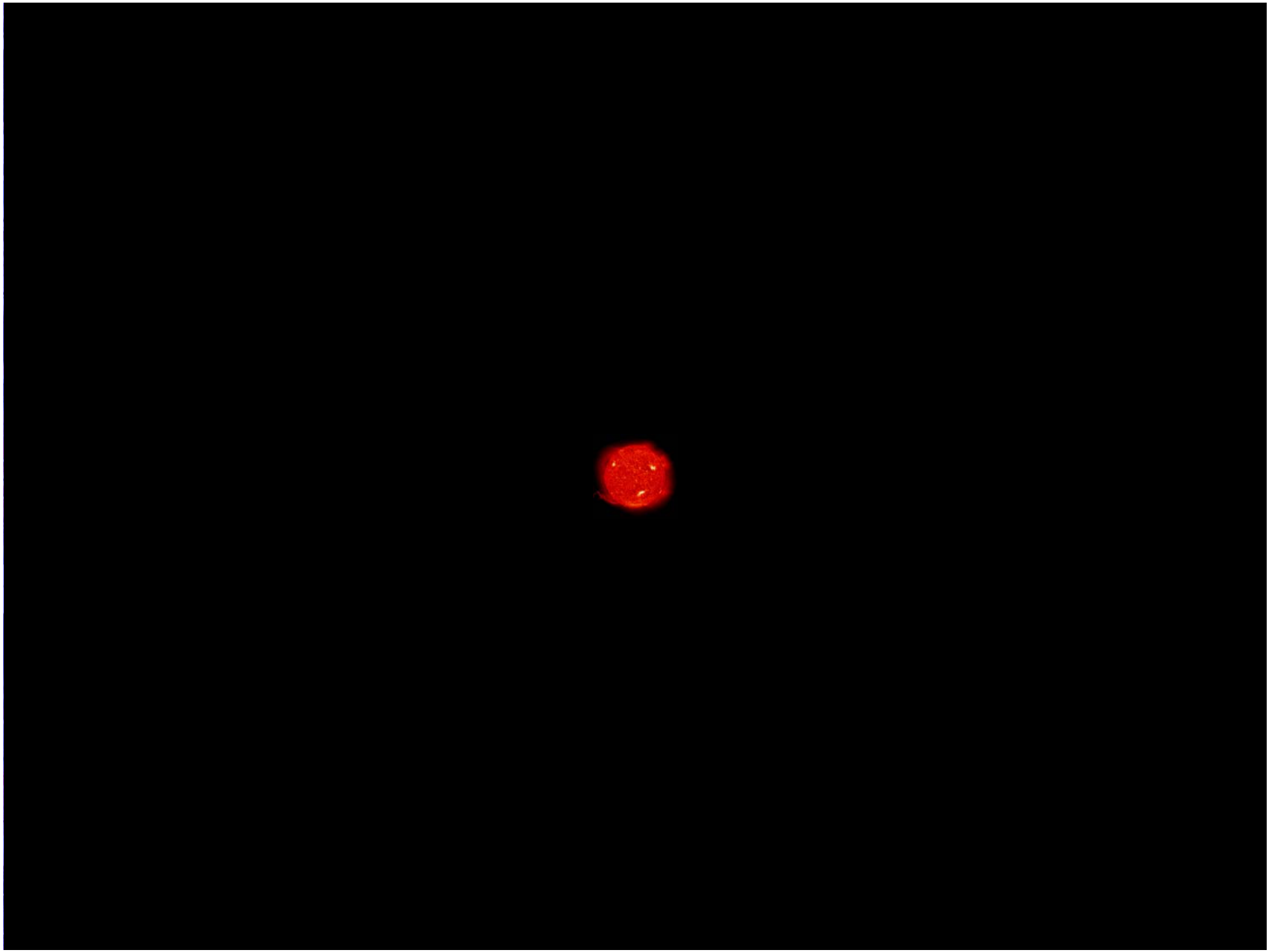
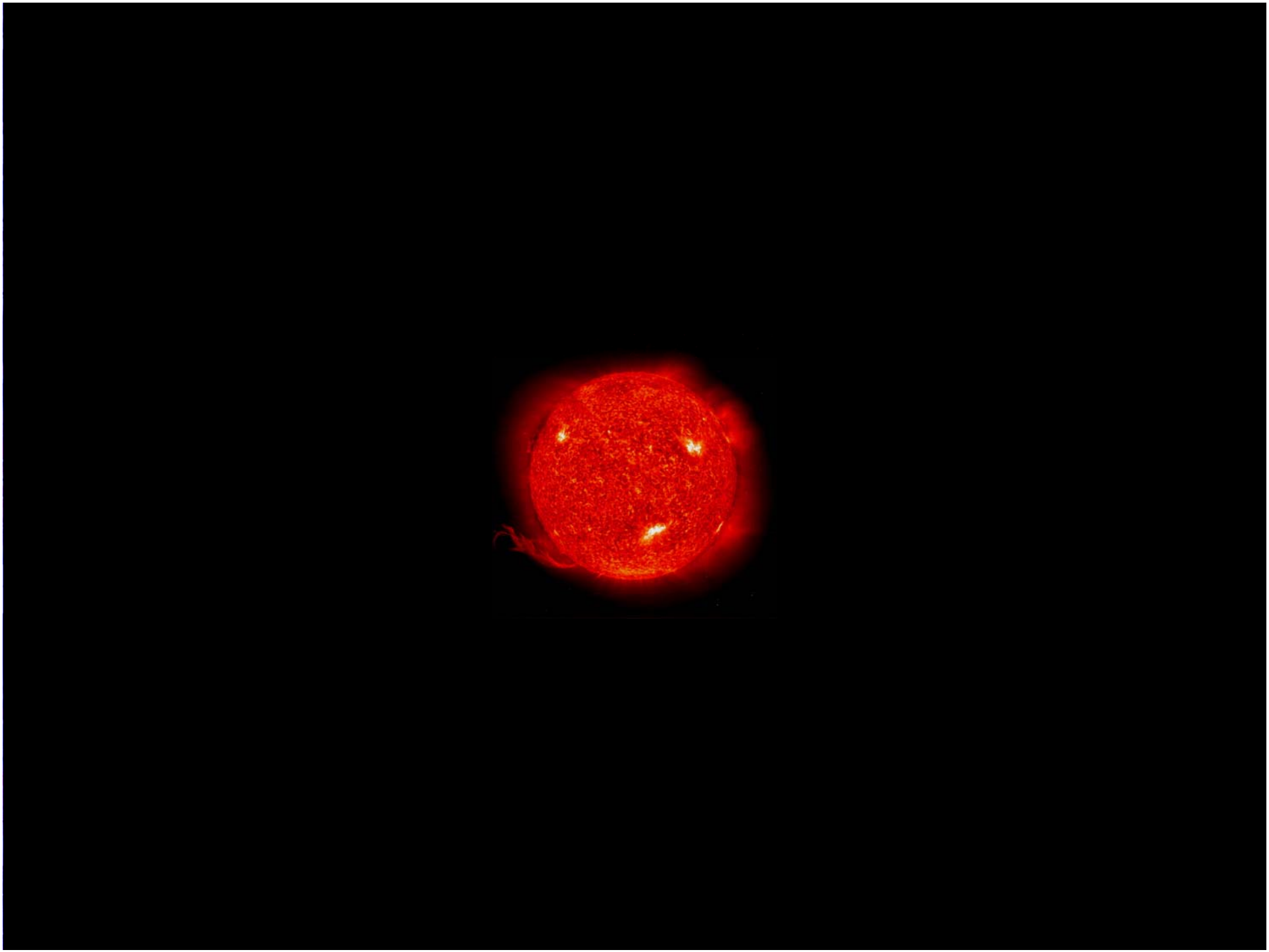
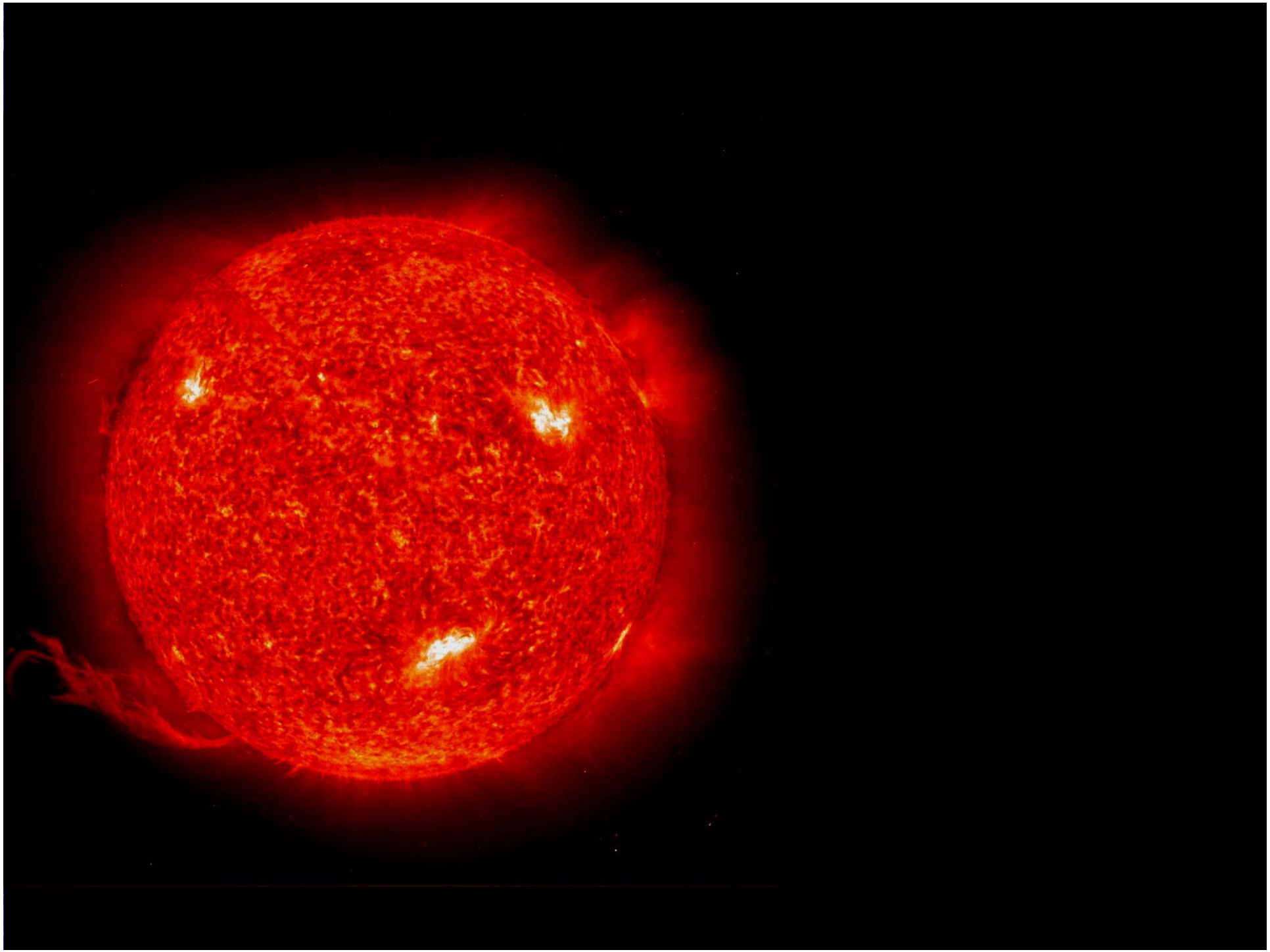


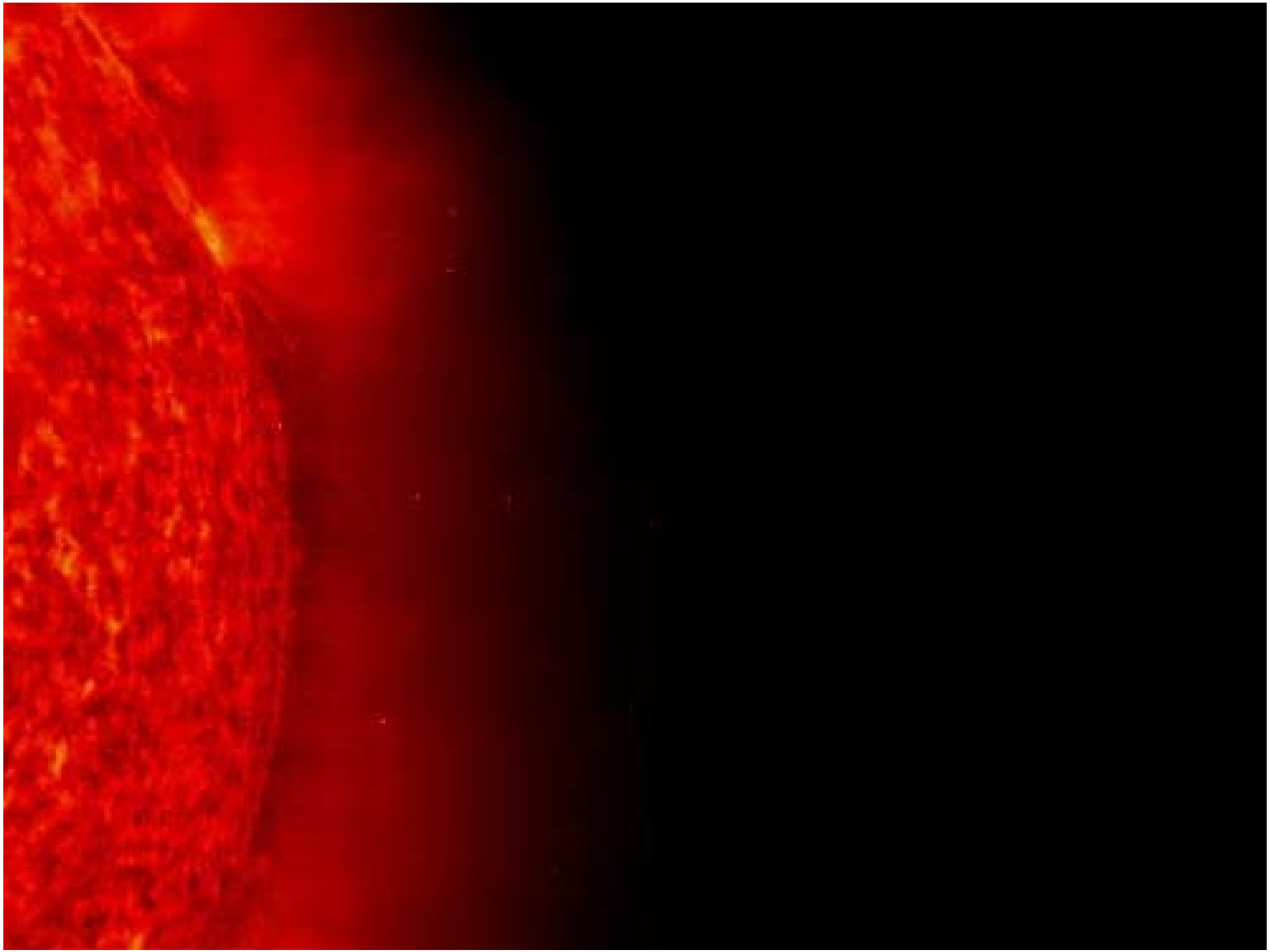


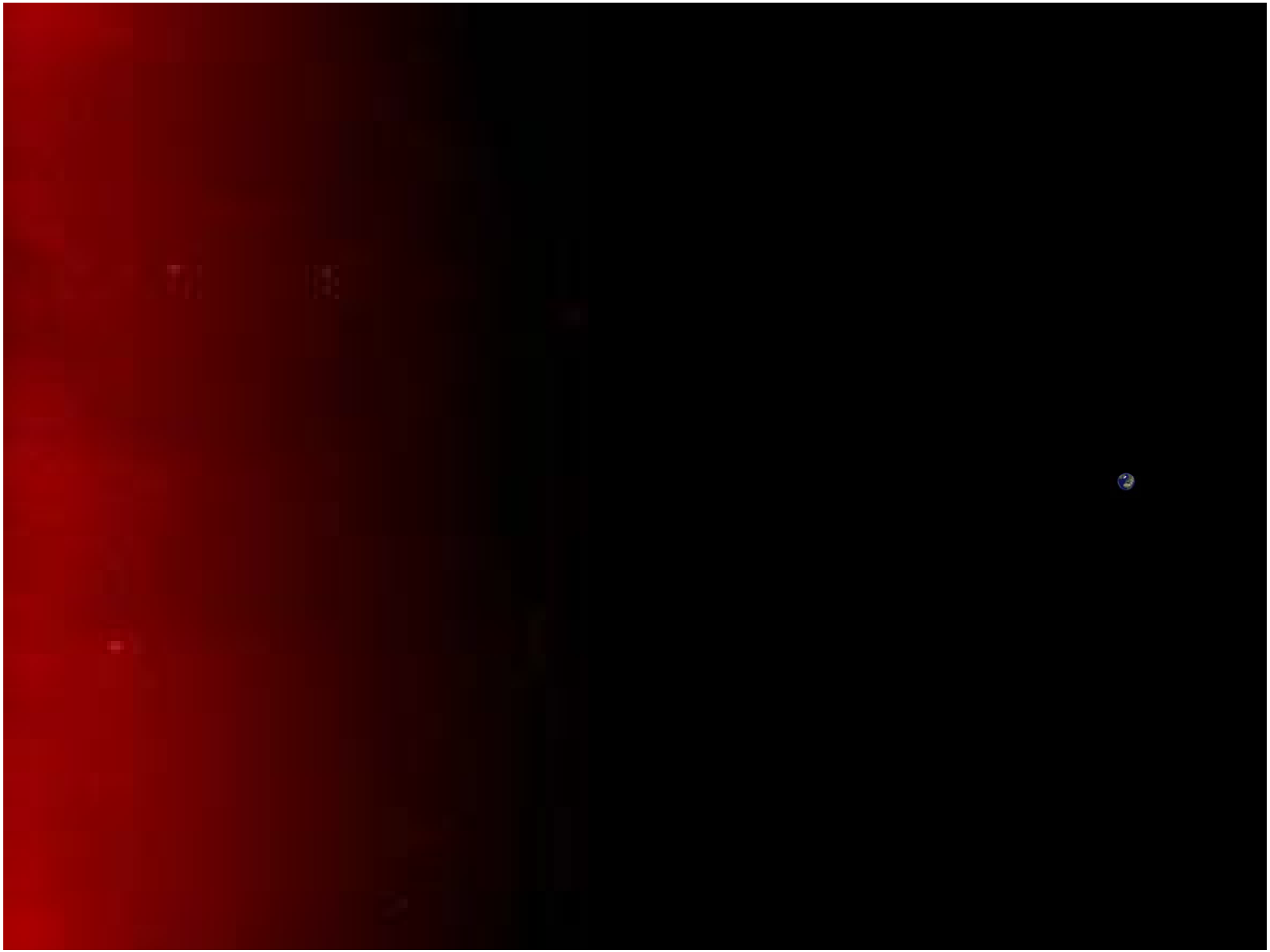


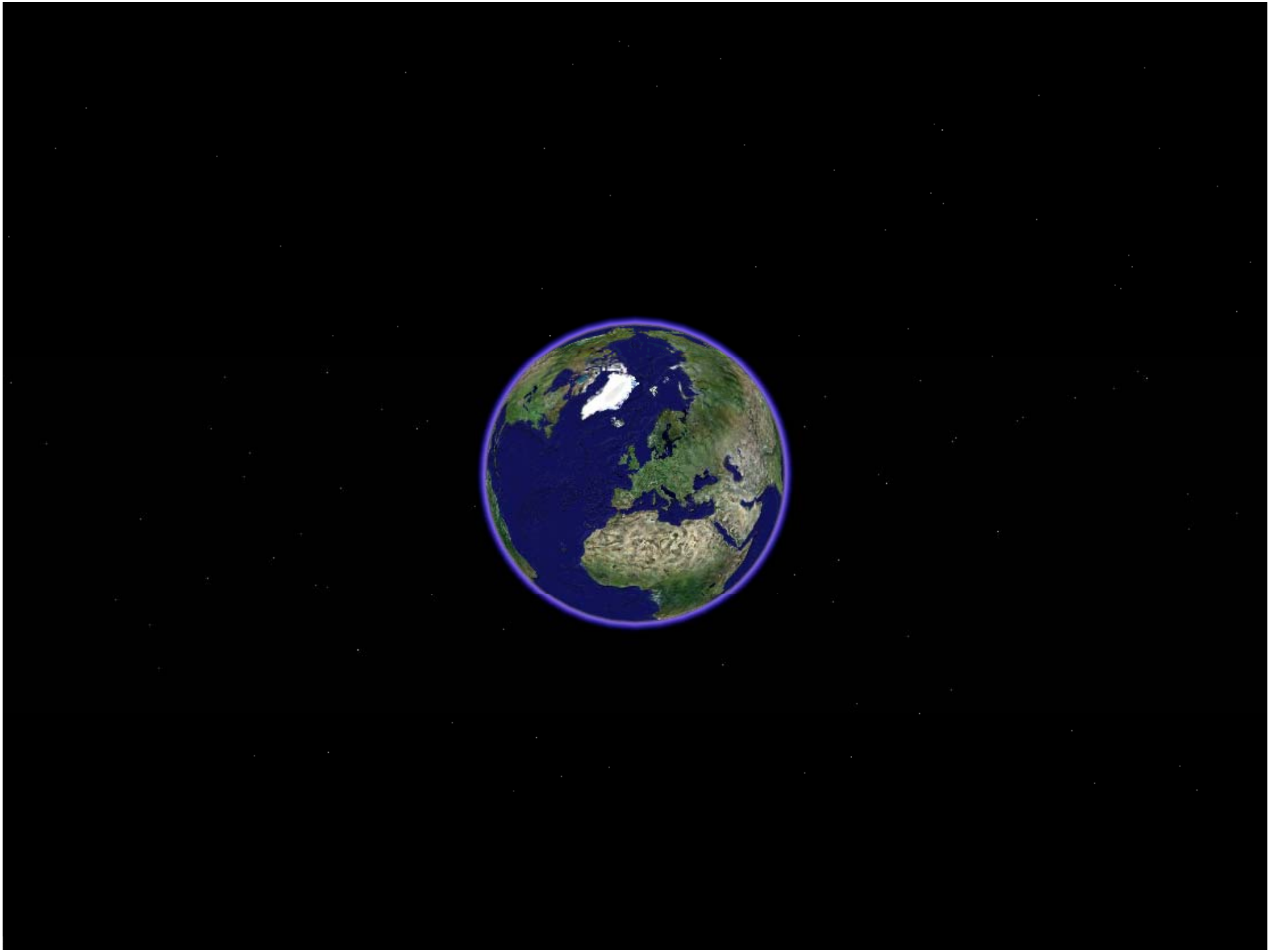












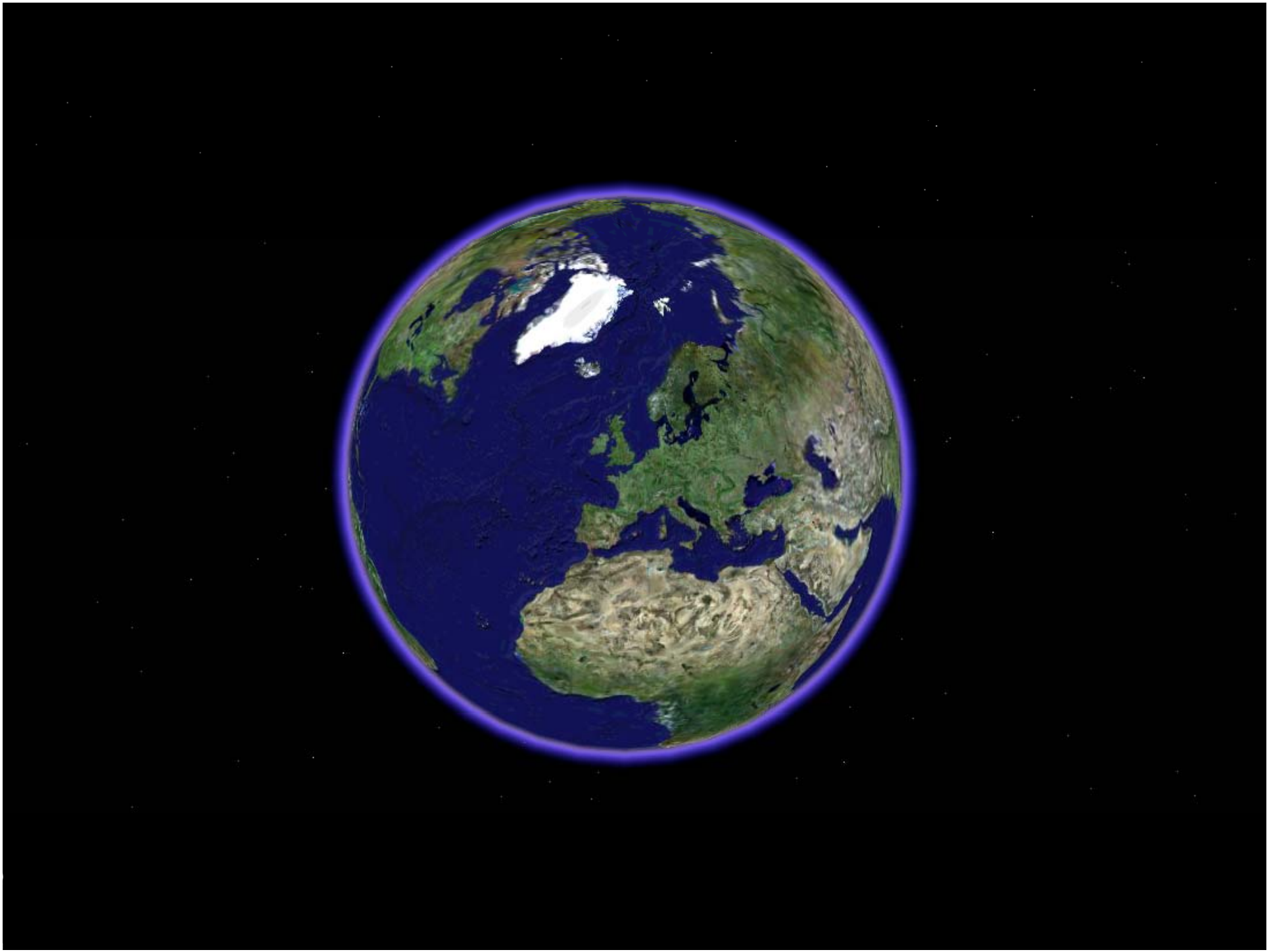
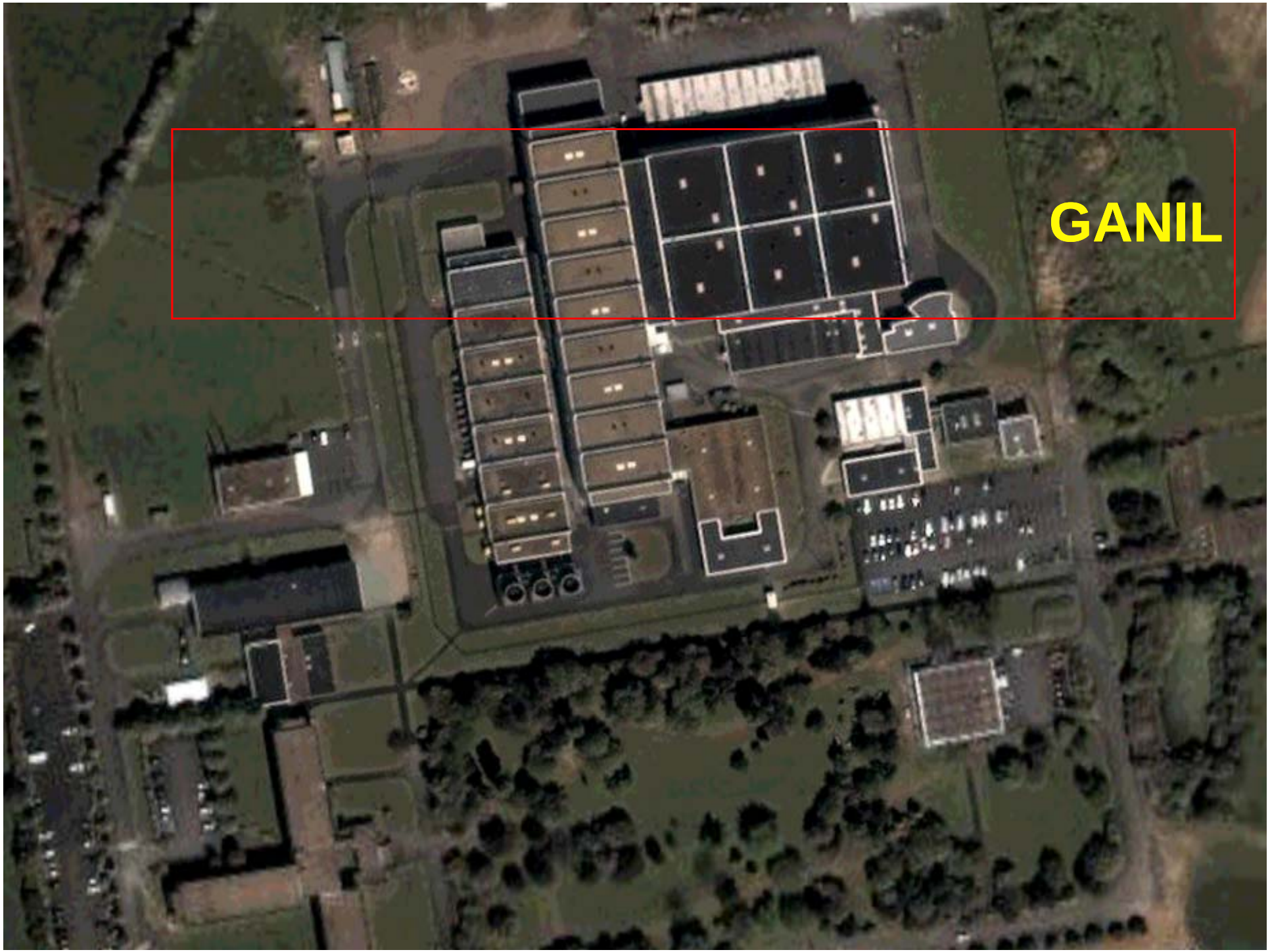
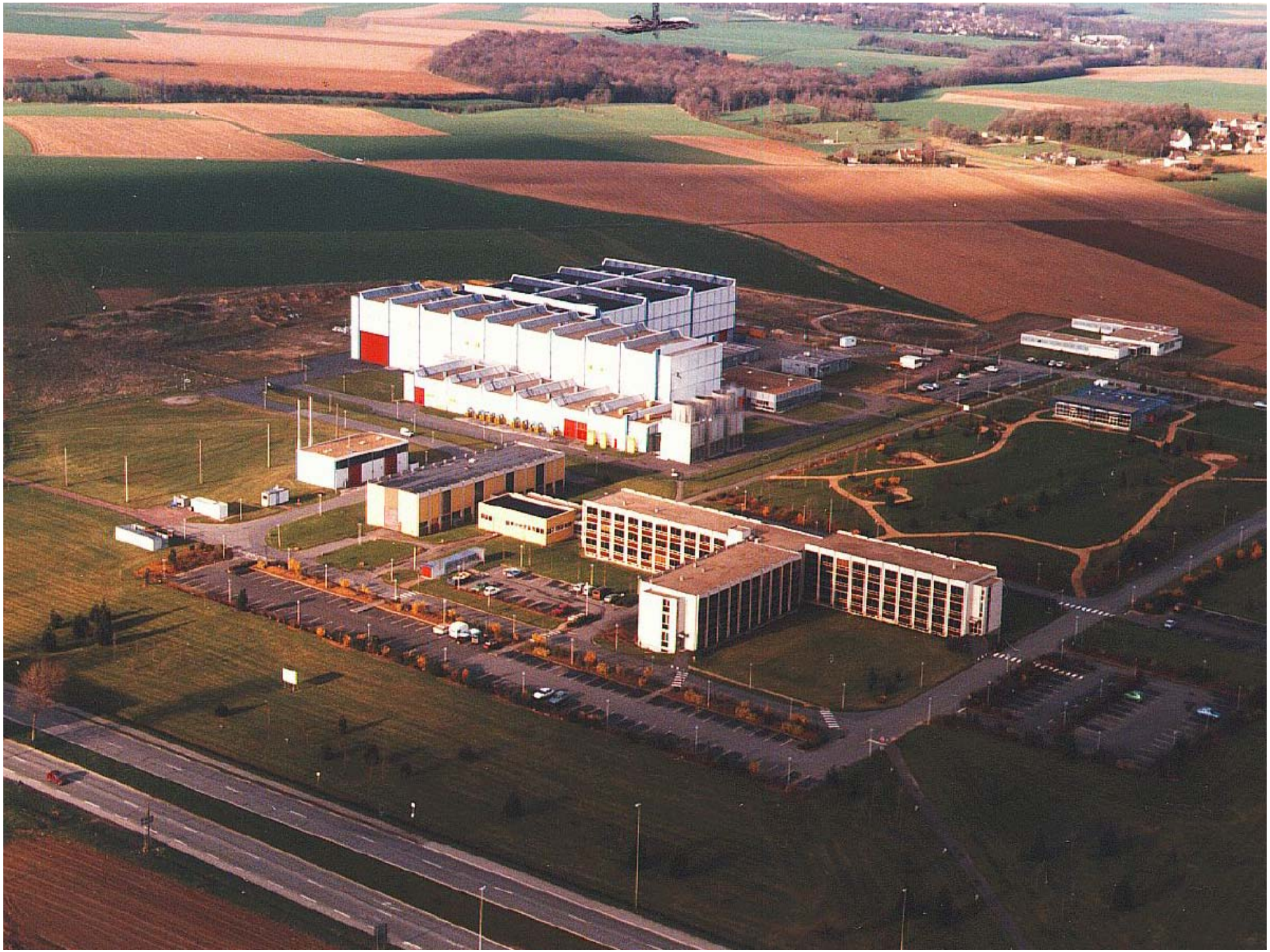
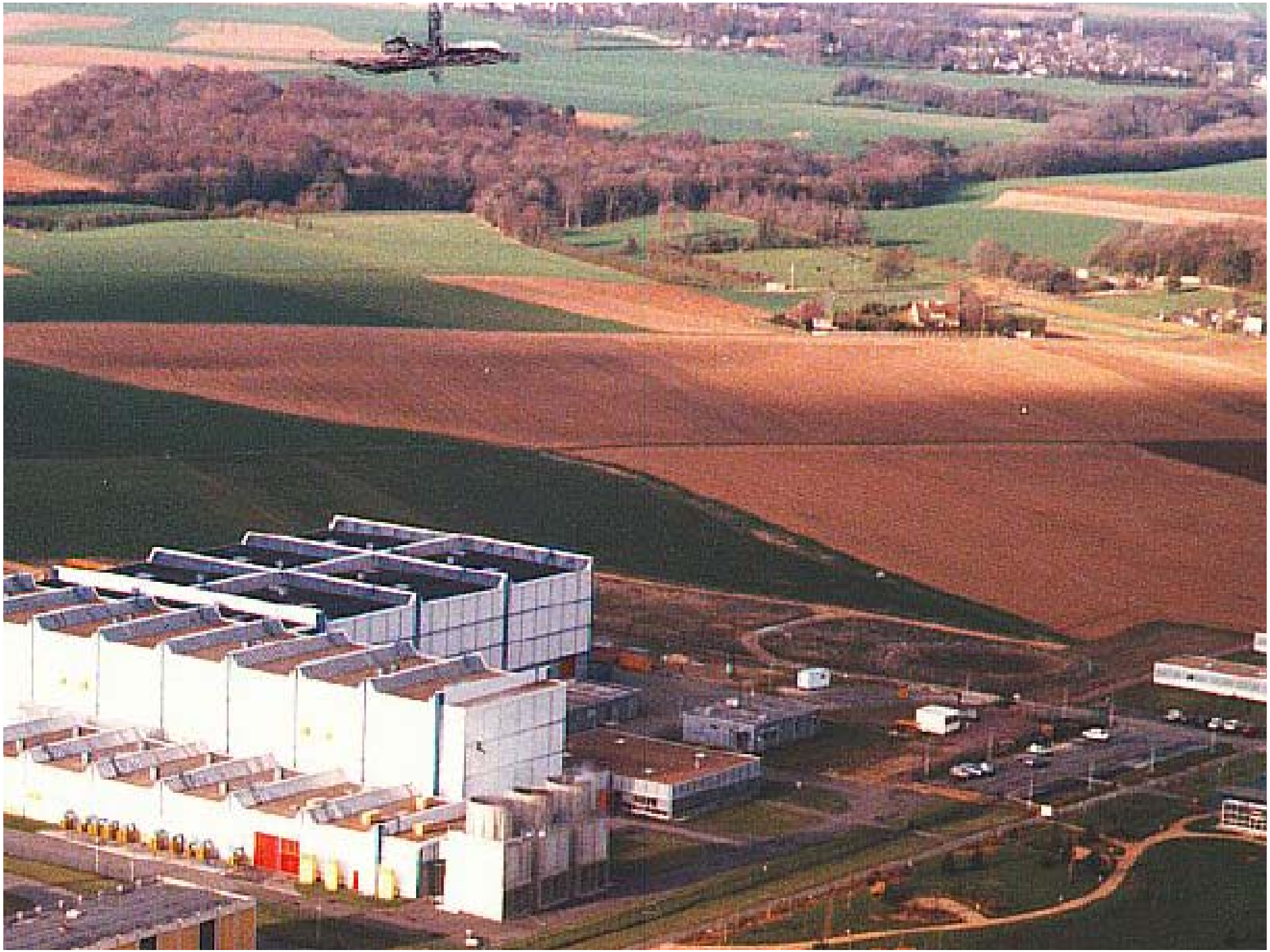
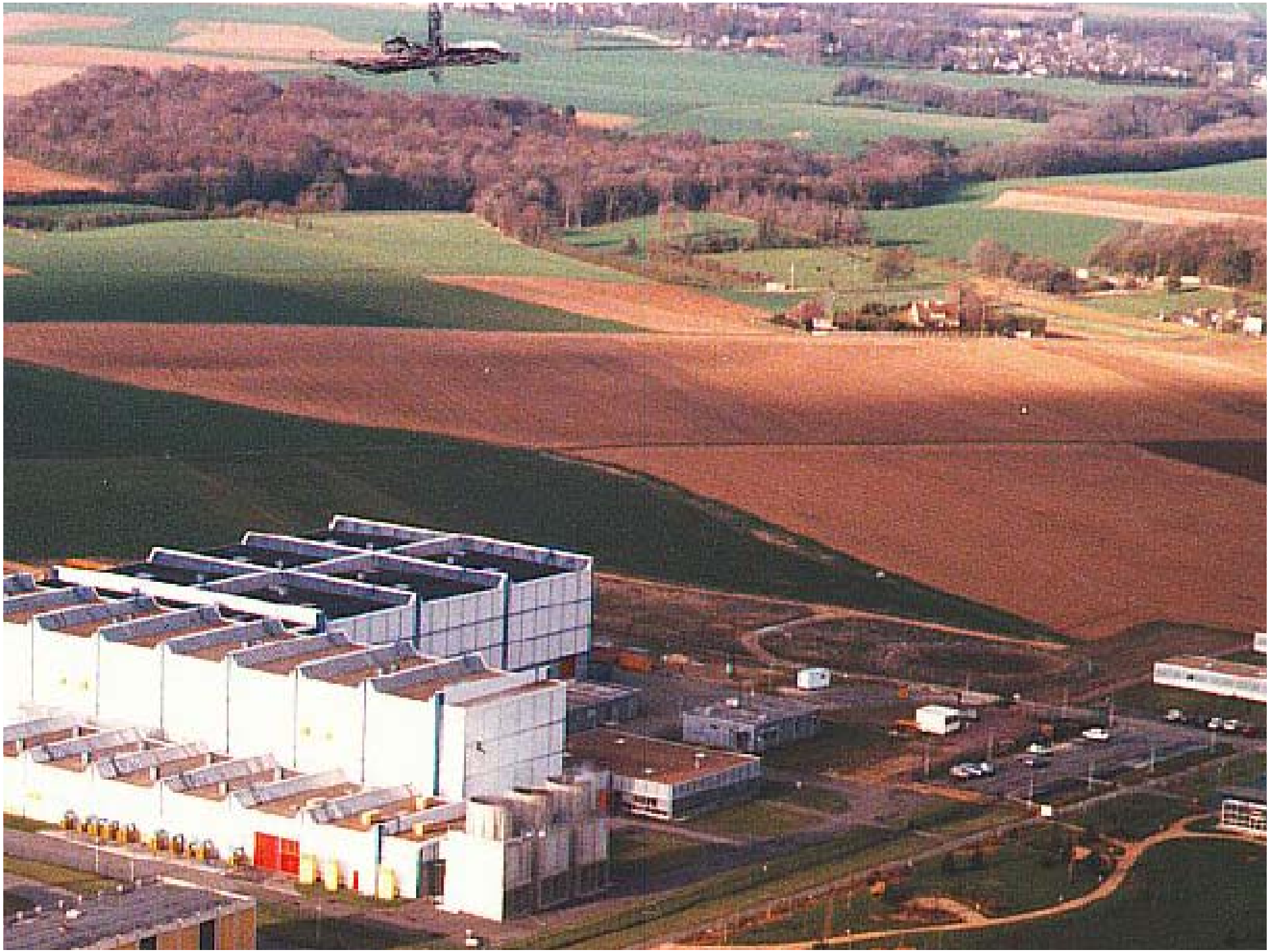


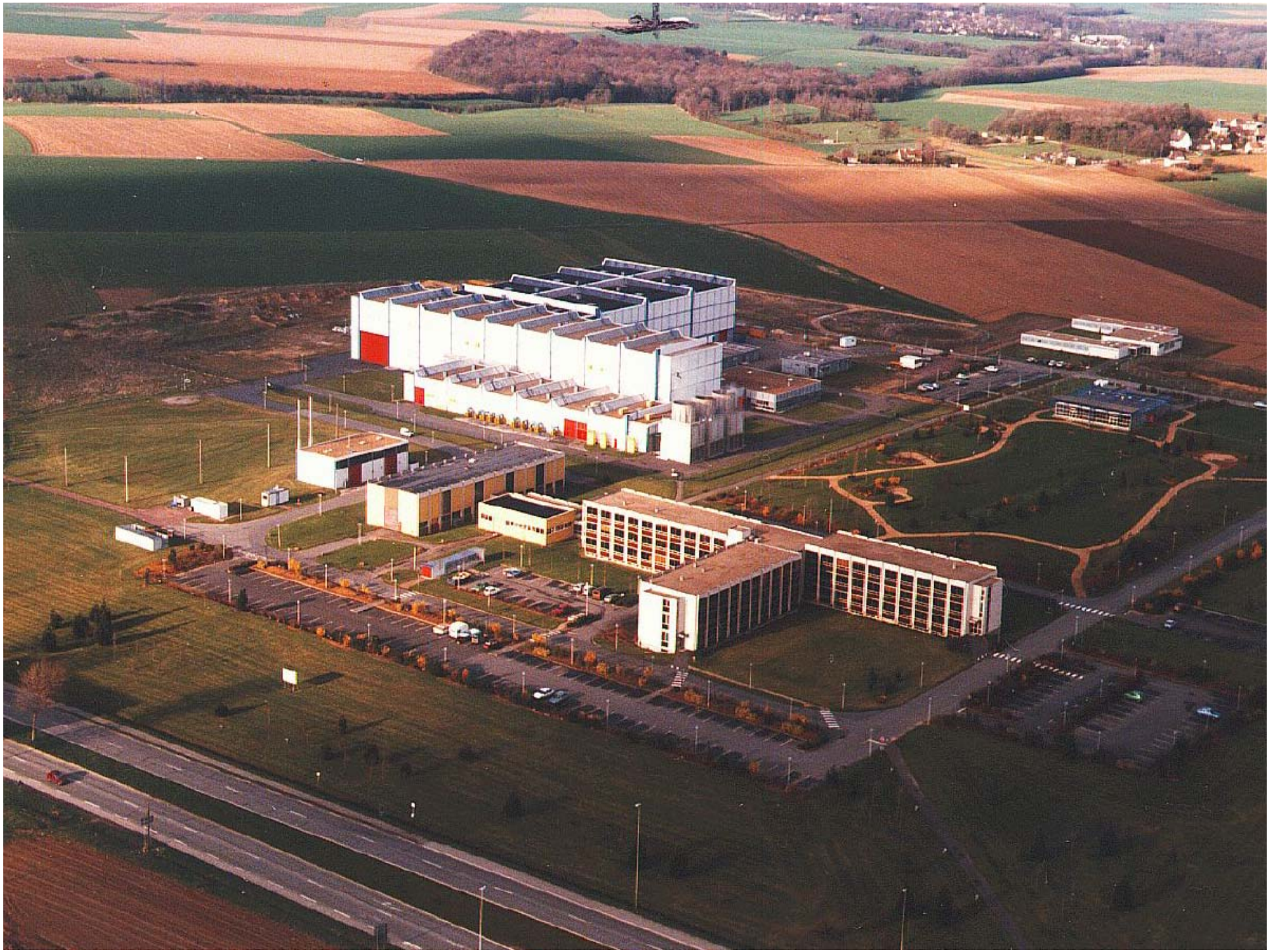

Image © 2005 EarthSat


GANIL









Introduction

The Exotic Nuclei Revolution

Philippe CHOMAZ

GANIL-Caen

La révolution des noyaux exotiques

De GANIL à SPIRAL2

Philippe CHOMAZ

GANIL-Caen

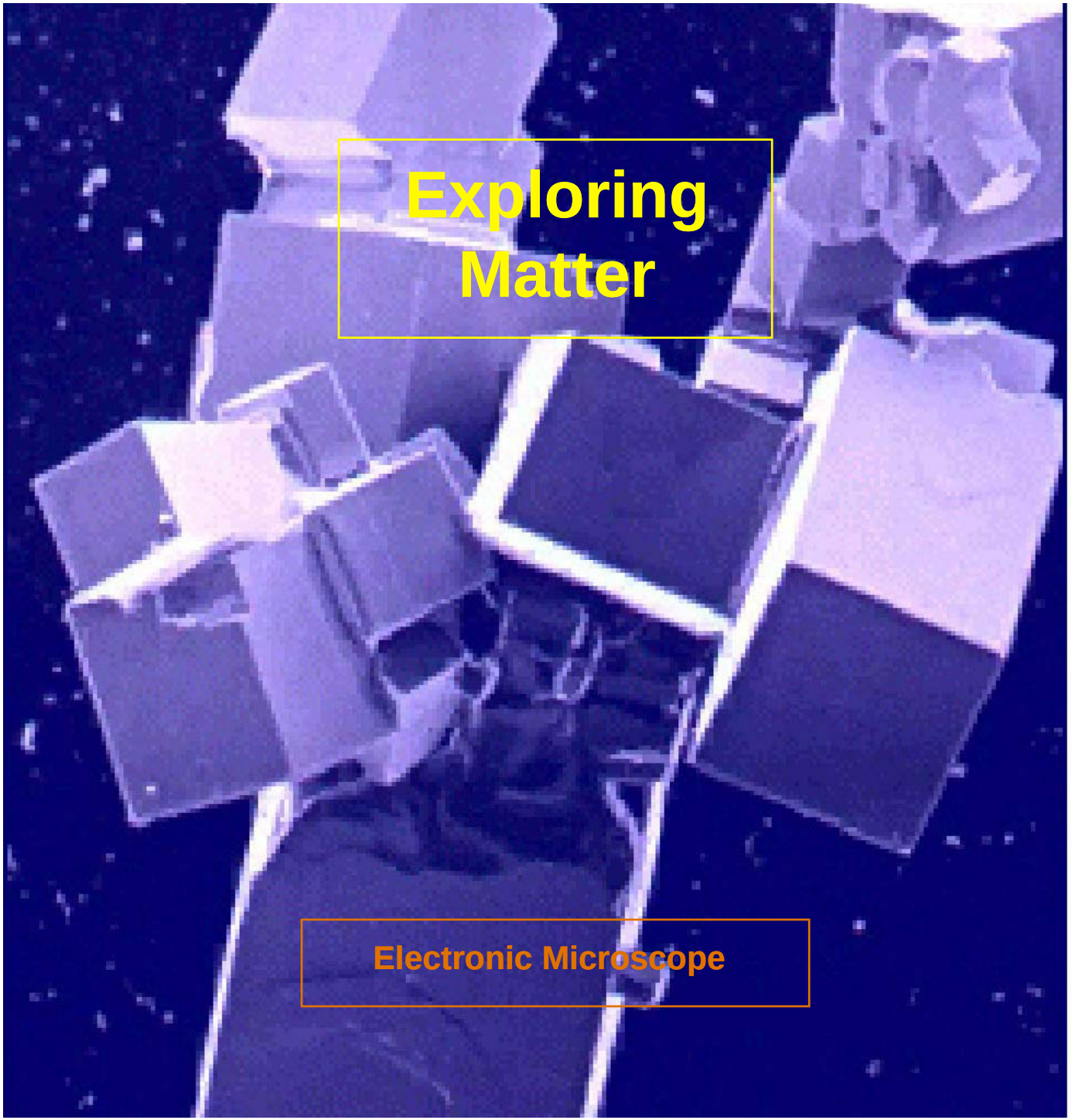
- **Introduction:**
  - The nucleus a quantum complex system
- **Exotic nuclei:**
  - A huge discovery potential
- **Exotic nuclei and matter in the universe**
  - Keys of the nucleo-synthesis
- **Exotic nuclei factories**
  - SPIRAL2 on the ESFRI road map
- **Physics case**
  - Appearance and disappearance of magic numbers
- **Conclusion**

1) Introduction

Nuclear physics

- The nucleus a complex quantum system

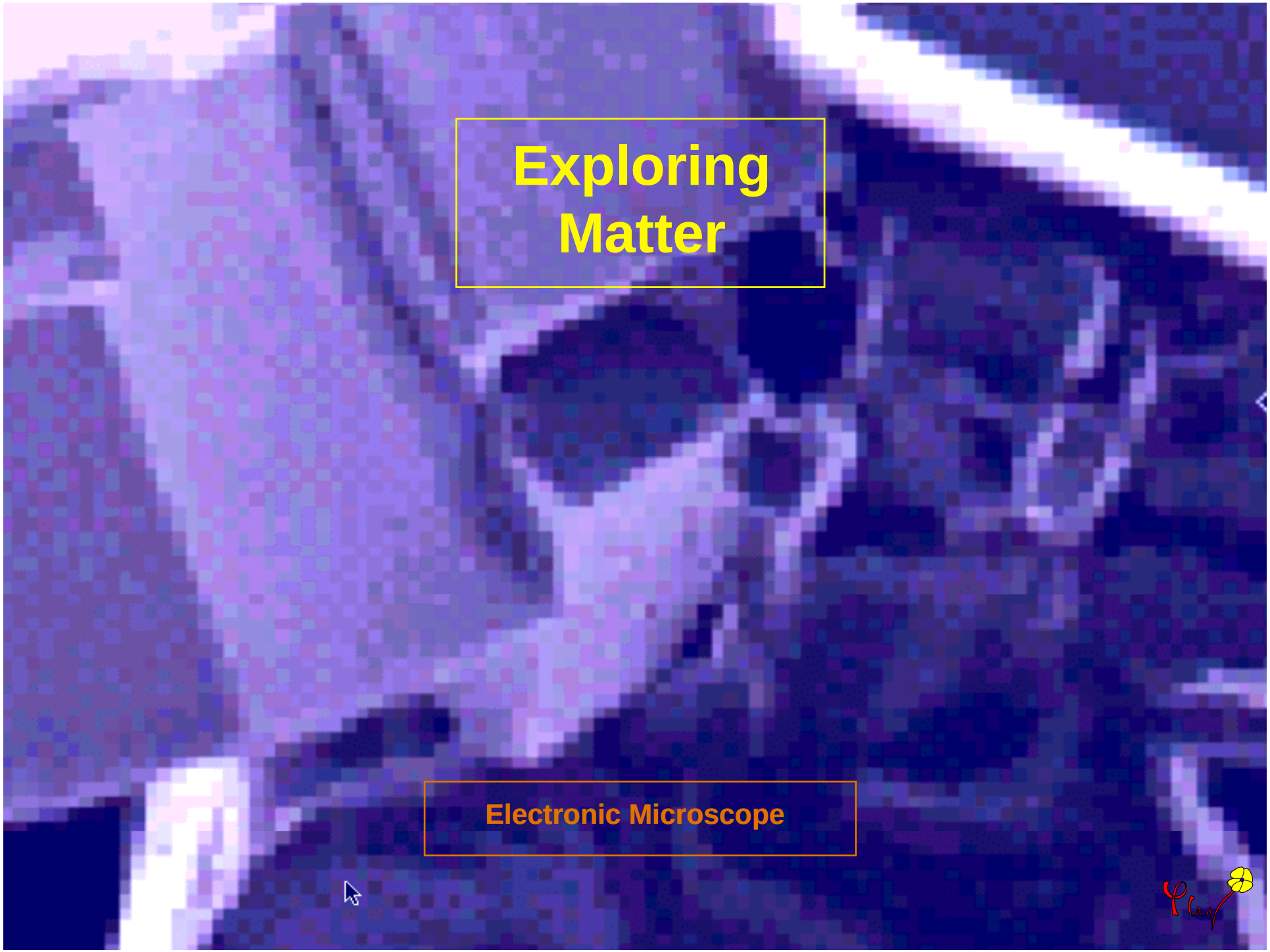
Electronic Microscope



Exploring Matter

Electronic Microscope

CHOMAZ Philippe


Exploring
Matter
Electronic Microscope

Exploring Matter

Matter is made of atoms…

Atomic Force Microscope

Exploring Matter

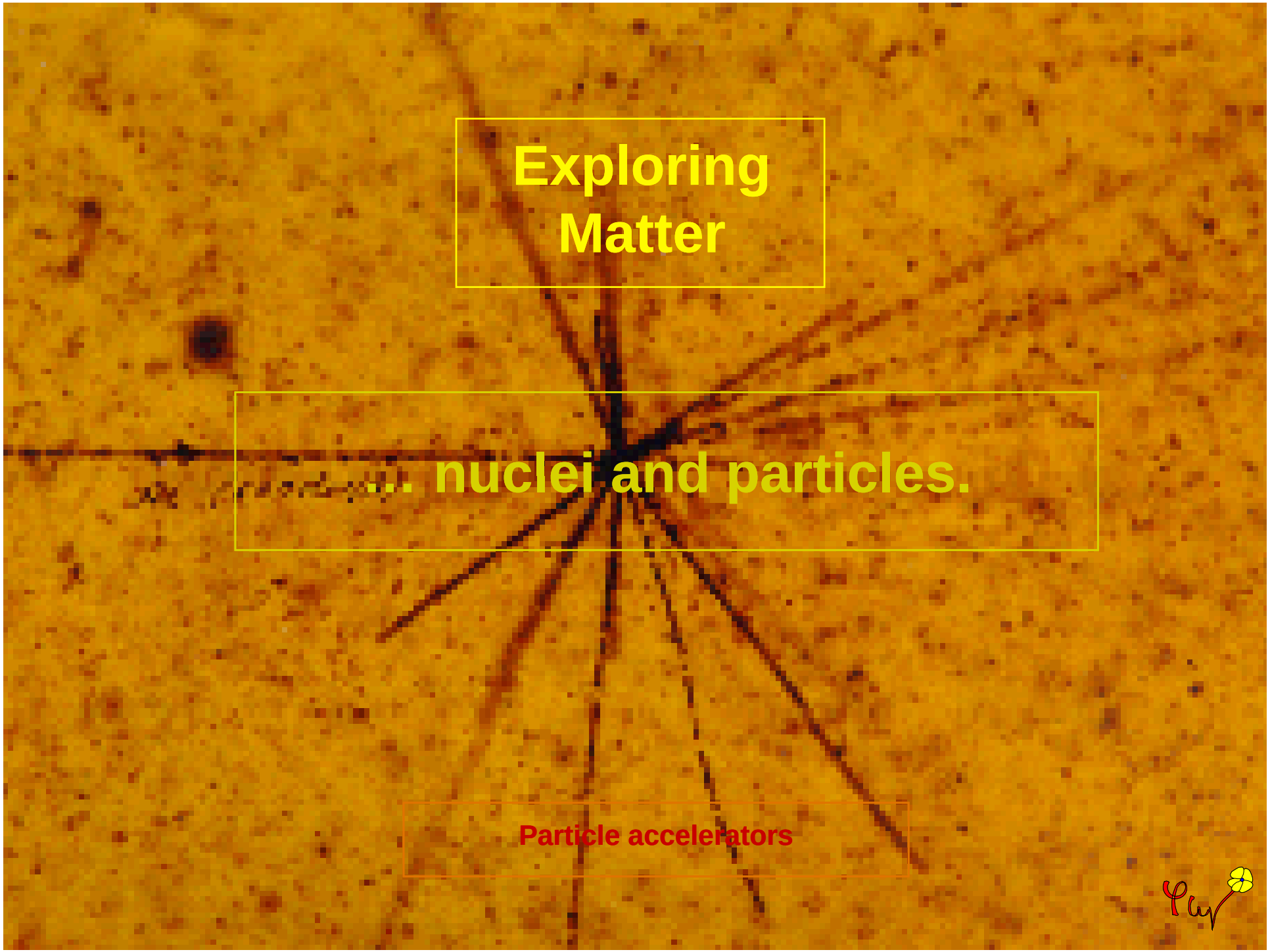
Matter is made of atoms…

Atomic Force Microscope

Exploring Matter

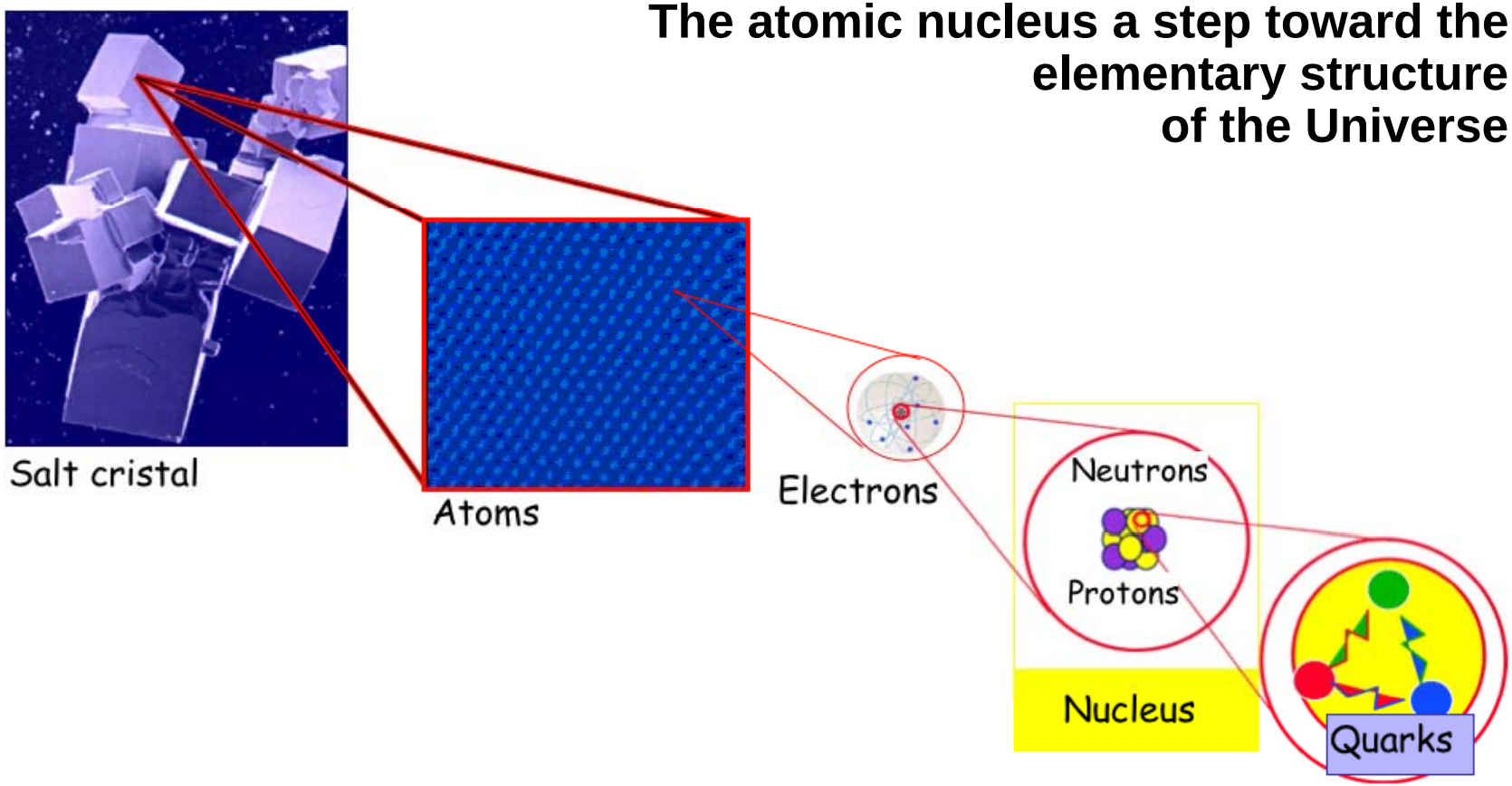
…which contain a whole world…

Particle accelerators


Exploring
Matter
... nuclei and particles.
Particle accelerators

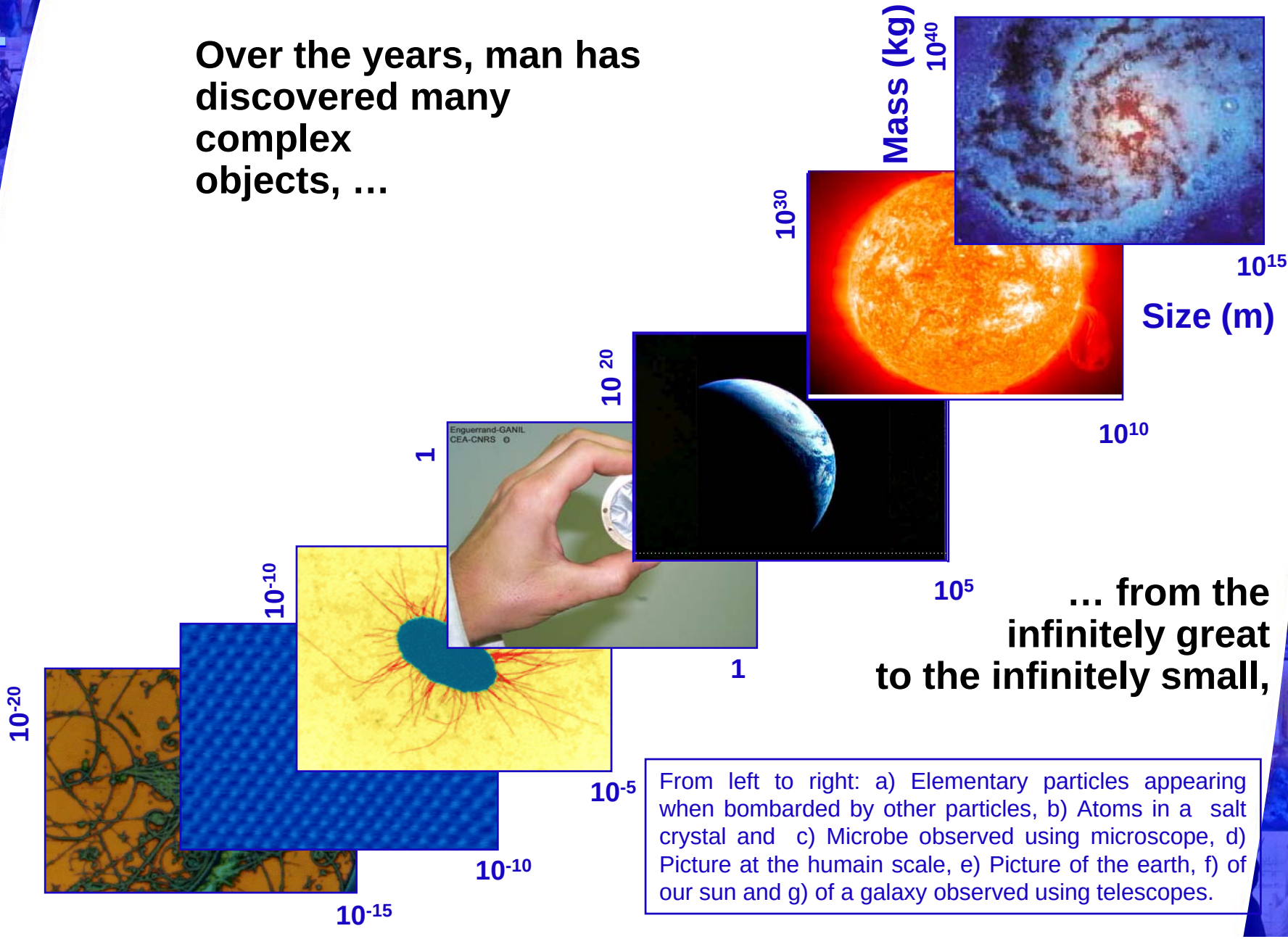
Nuclear Physics

The atomic nucleus a step toward the elementary structure of the Universe



Complex systems hierarchy

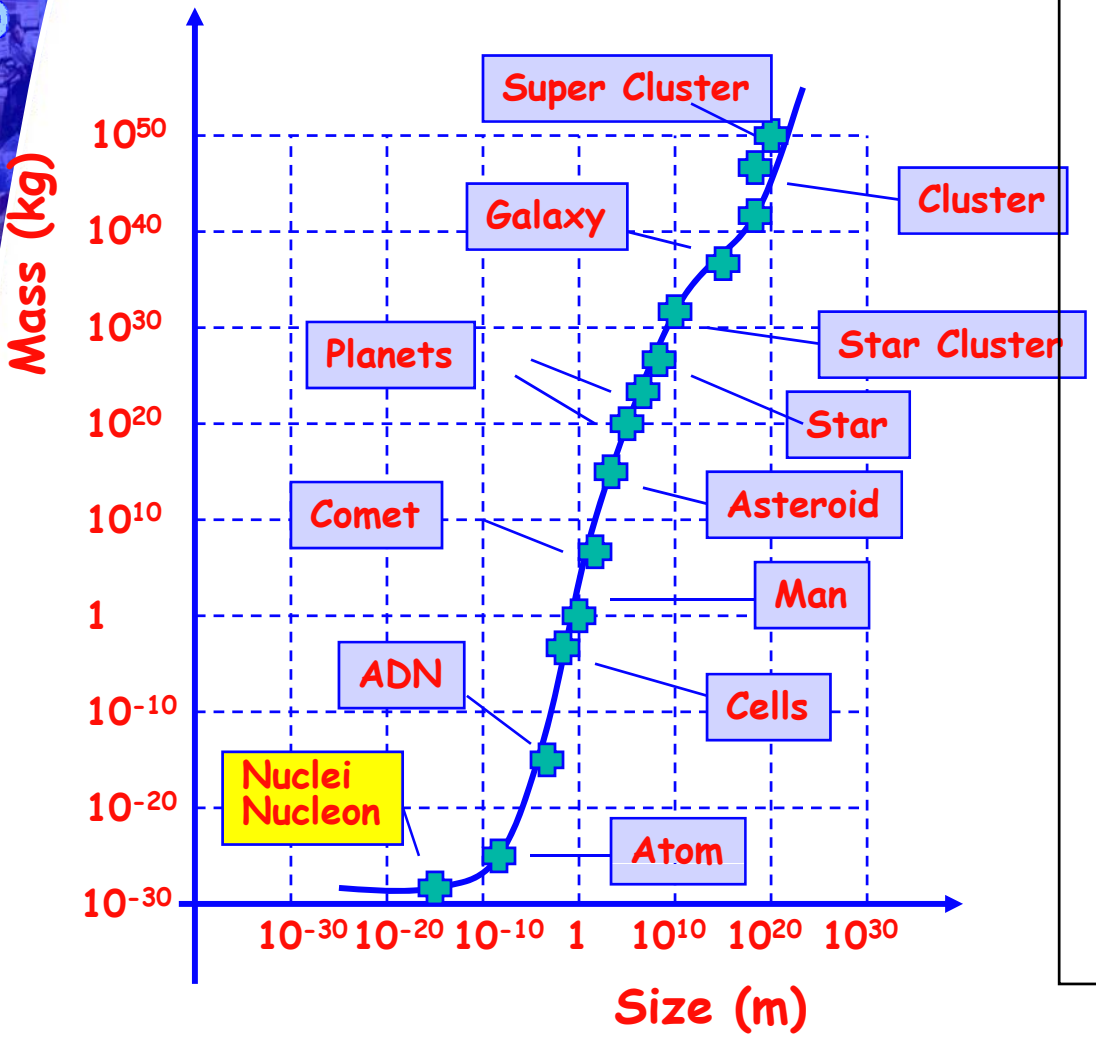
Over the years, man has discovered many complex objects, …



… from the infinitely great to the infinitely small,

From left to right: a) Elementary particles appearing when bombarded by other particles, b) Atoms in a salt crystal and c) Microbe observed using microscope, d) Picture at the humain scale, e) Picture of the earth, f) of our sun and g) of a galaxy observed using telescopes.

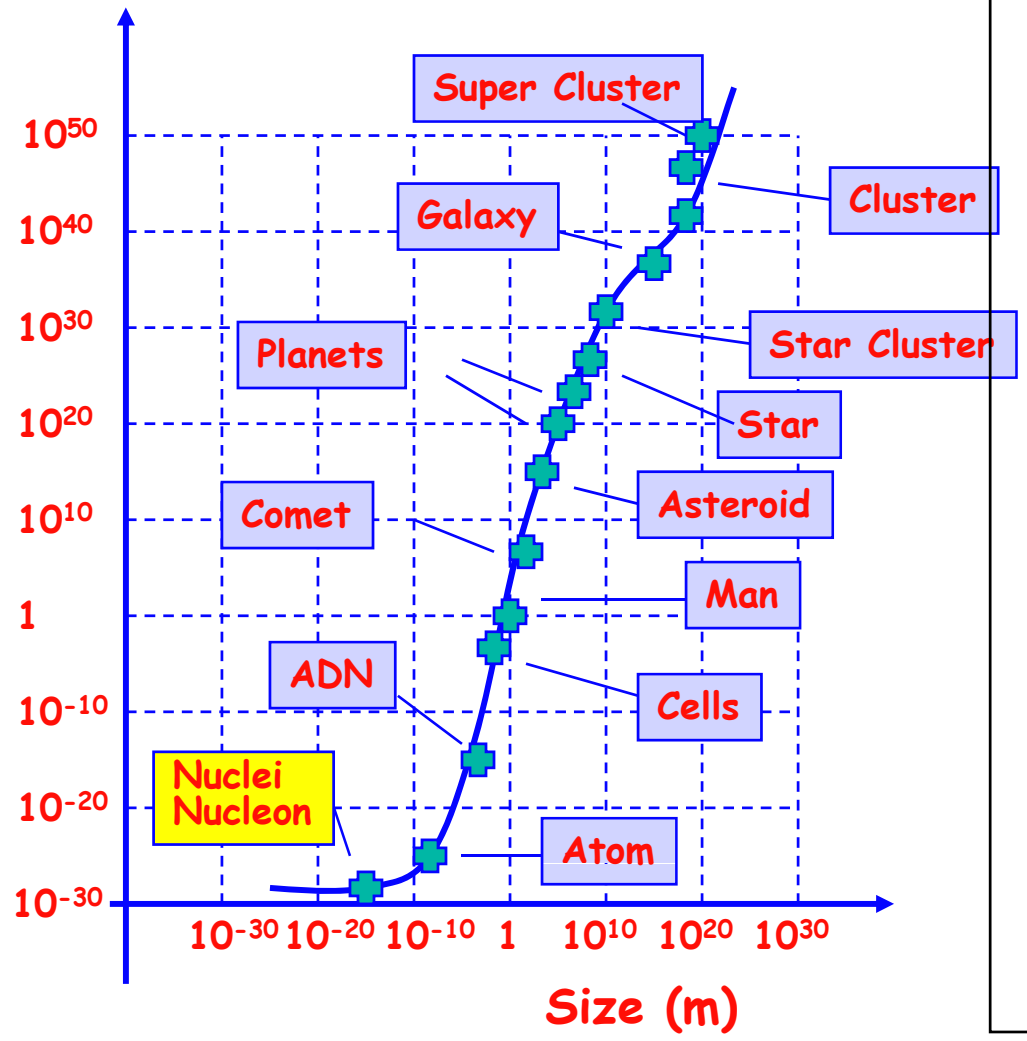
A multi-scale Universe



Olivier LOPEZ (LPC Caen)

Nucleons and nuclei the first steps in the hierarchy of complex systems

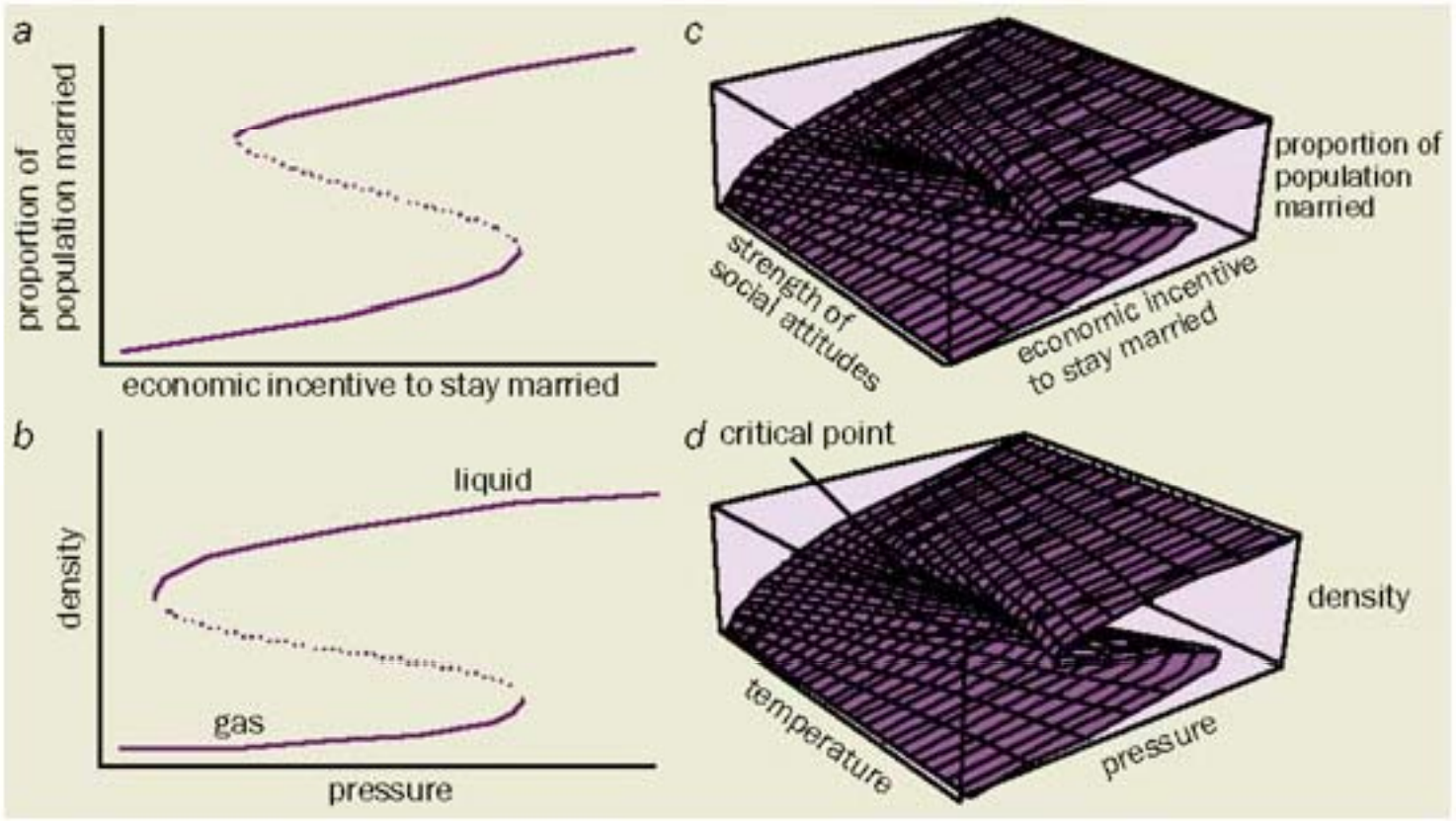
A multi-scale Universe



Olivier LOPEZ (LPC Caen)

Fundamental Questions:

- Relevant degree of freedom
- Effective interaction
- Complex structure
- Connection with elementary level
- Role in the Universe



How marriage depends on social attitudes and economic incentives. *(a)* There may be two stable states that contain different proportions of married people for the same set of conditions (solid lines). In fact, these two branches are linked by a continuous curve (dotted line). However, beyond the turning points of the upper and lower solid curves, the states represented by the dotted curve are unstable. *(b)* This looped curve is exactly what emerges from van der Waals' theory of the liquid-gas phase transition. *(c)* A 3D graph shows the dependence of marriage on both social and economic factors. The loop in the curve appears only if the strength of social attitudes is strong enough. This plot is also familiar from van der Waals' theory, in which the inception of the kink in the surface marks the liquid-gas critical point *(d)*. If "strength of social attitudes" is replaced by temperature, "economic incentives" by pressure, and "proportion of married population" by density, we have the phase space of a fluid.

ndamental
Questions:

degree
m

on

on with
ry level
e Universe

Complex systems hierarchy

… which evolve driven by 4 forces known today.

From left to right: a) the gravity is making the universe evolving at large distance from galaxies to apples falling from threes b) the electromagnetic interaction is responsible for electric and magnetic phenomena, light emission and chemical reactions, c) the weak nuclear interaction is at the origin of many radioactive decays such as the Carbon 14 decay, d) the nuclear energy is powering stars in the Universe.

2) Scientific motivations

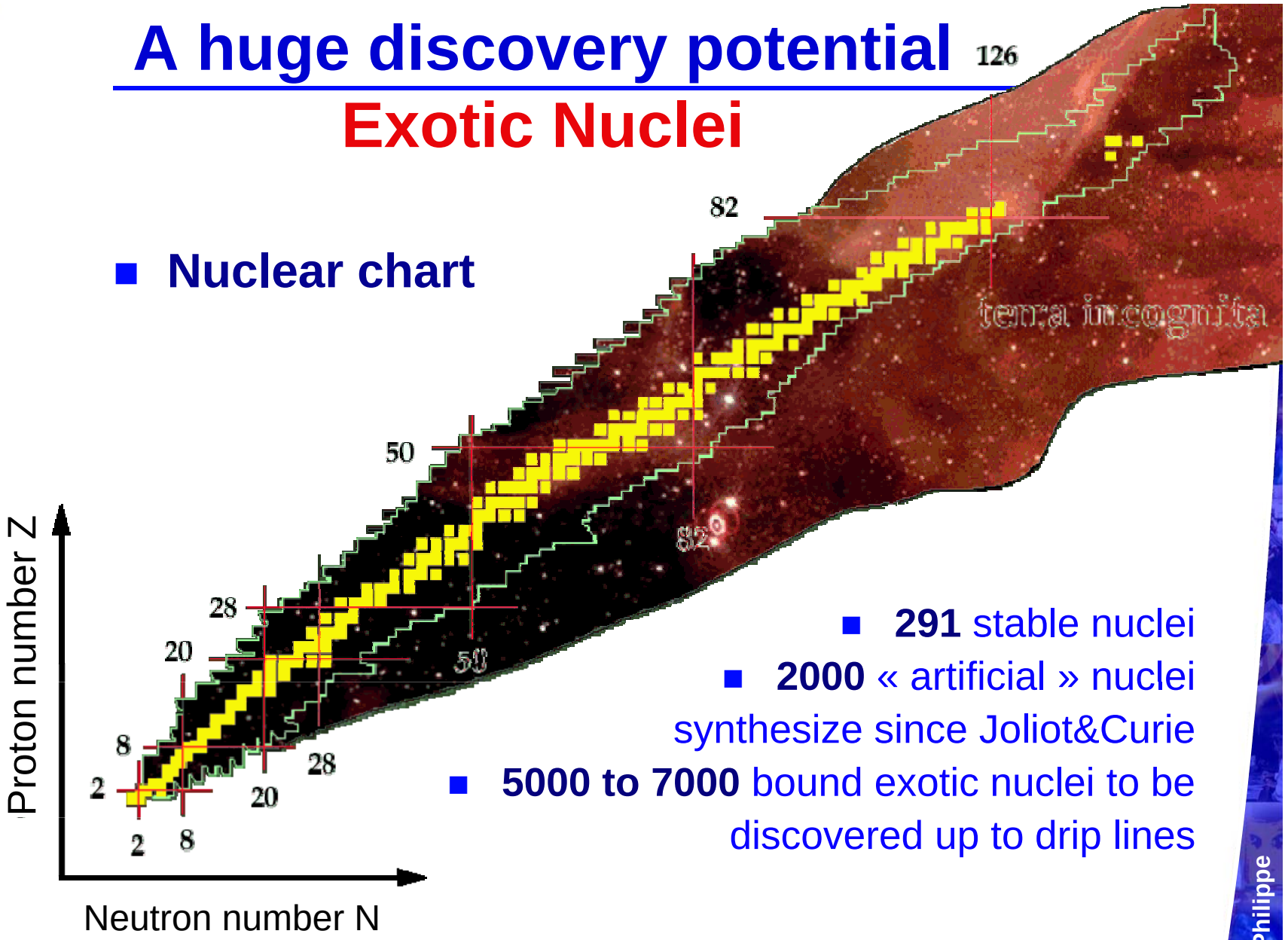
Exotic nuclei research

- **Exotic nuclei Physics case**
  - A huge discovery potential

A huge discovery potential

Exotic Nuclei

- **Nuclear chart**

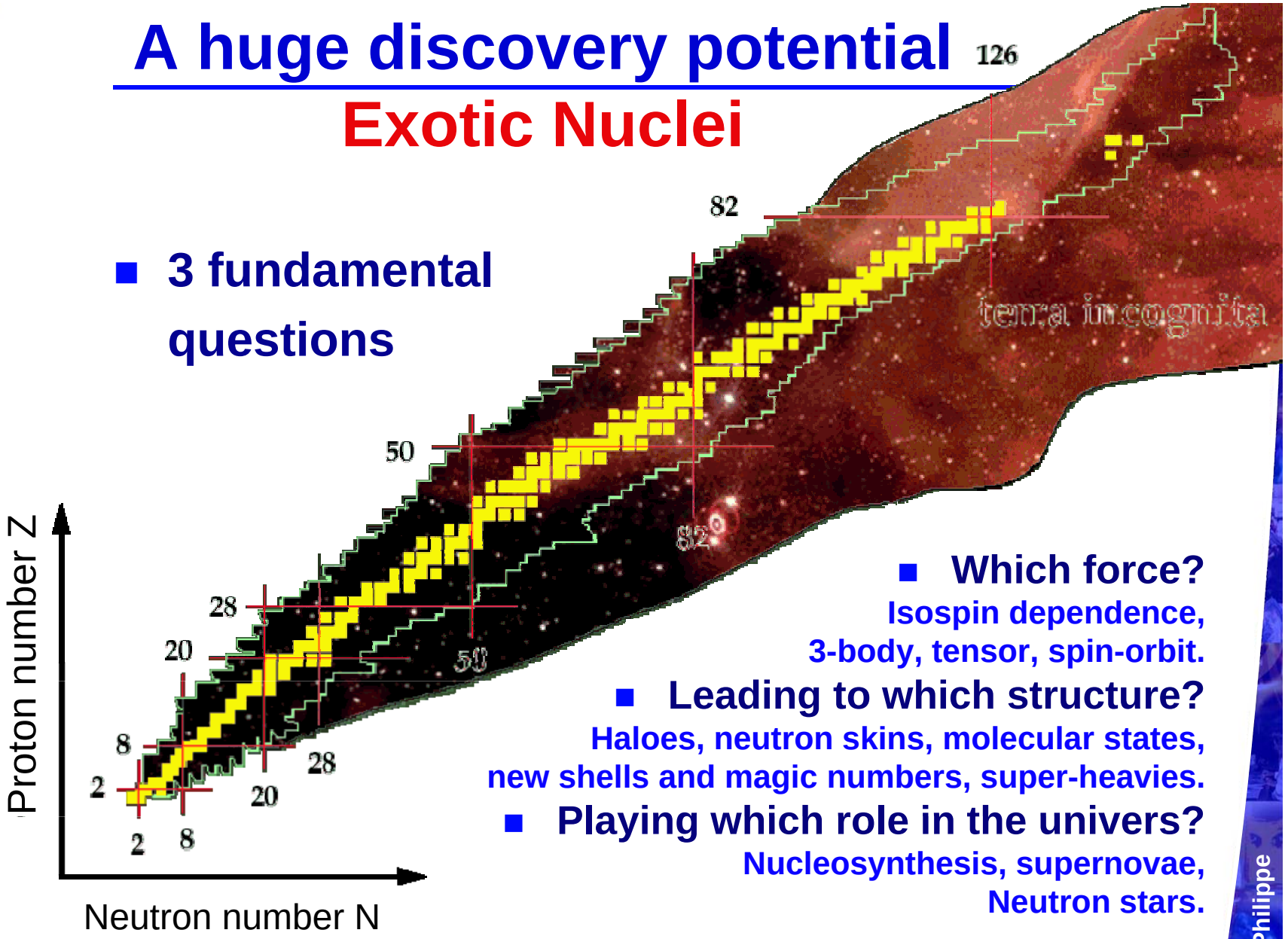


- **291** stable nuclei
- **2000** « artificial » nuclei synthesize since Joliot&Curie
- **5000 to 7000** bound exotic nuclei to be discovered up to drip lines

A huge discovery potential

Exotic Nuclei

- 3 fundamental questions

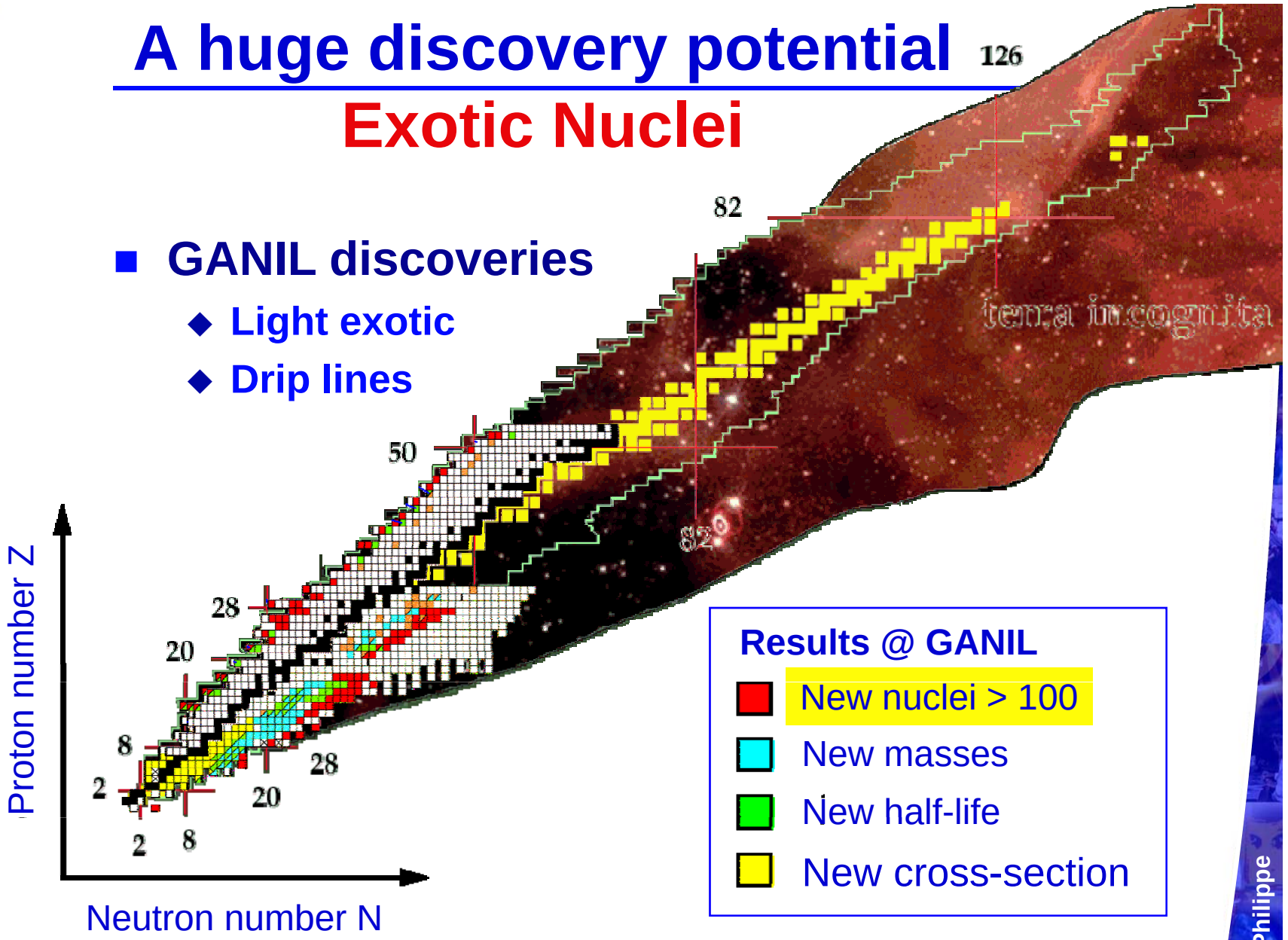


- **Which force?**
  Isospin dependence,
  3-body, tensor, spin-orbit.
- **Leading to which structure?**
  Haloes, neutron skins, molecular states,
  new shells and magic numbers, super-heavies.
- **Playing which role in the univers?**
  Nucleosynthesis, supernovae,
  Neutron stars.

A huge discovery potential

Exotic Nuclei

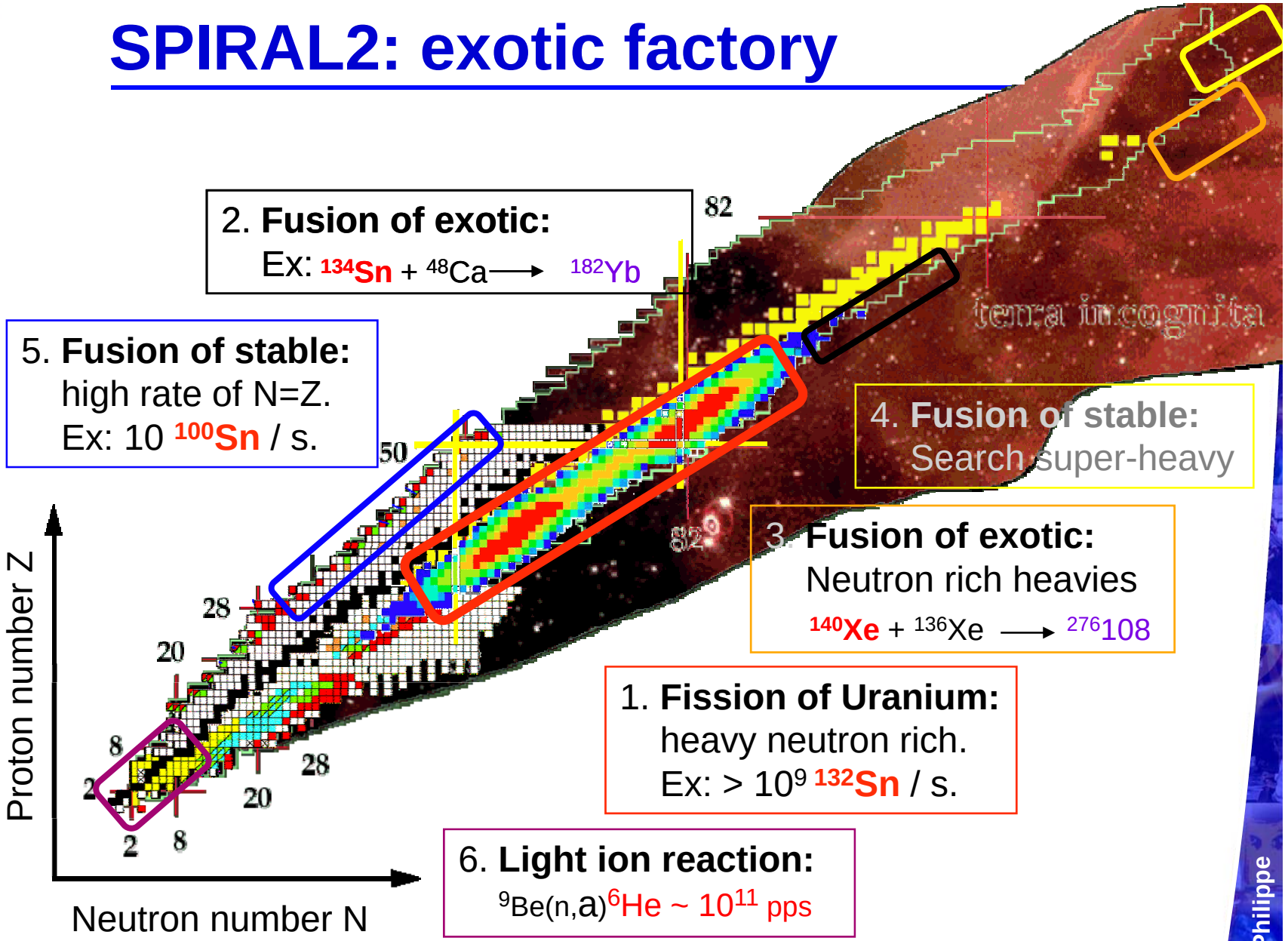
- GANIL discoveries
  - Light exotic
  - Drip lines



Results @ GANIL

- New nuclei > 100
- New masses
- New half-life
- New cross-section

SPIRAL2: exotic factory



2. **Fusion of exotic:**
Ex: $^{134}Sn + ^{48}Ca \longrightarrow ^{182}Yb$

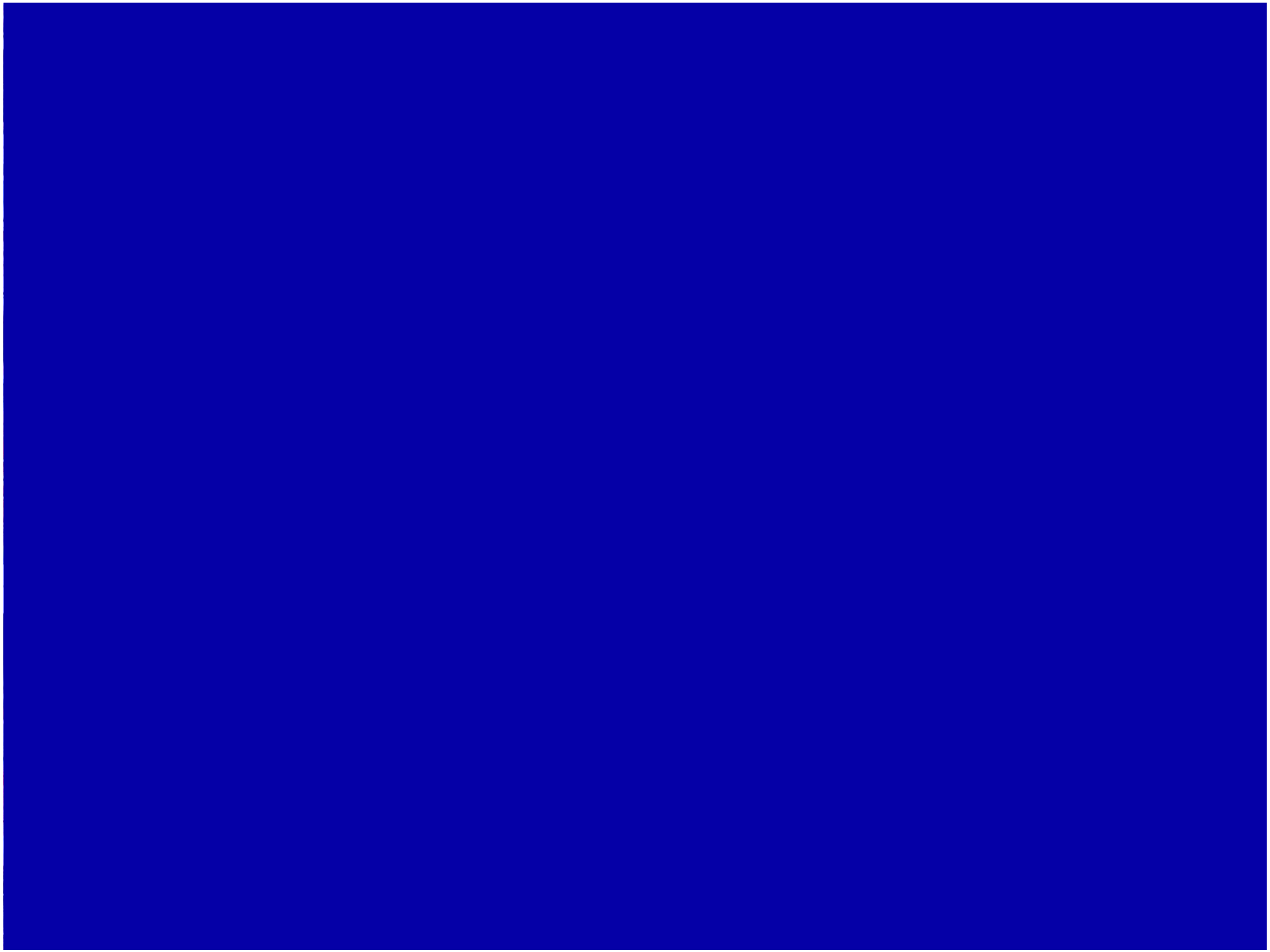
5. **Fusion of stable:**
high rate of N=Z.
Ex: 10 ^{100}Sn / s.

4. **Fusion of stable:**
Search super-heavy

3. **Fusion of exotic:**
Neutron rich heavies
$^{140}Xe + ^{136}Xe \longrightarrow ^{276}108$

1. **Fission of Uranium:**
heavy neutron rich.
Ex: > 10^9 ^{132}Sn / s.

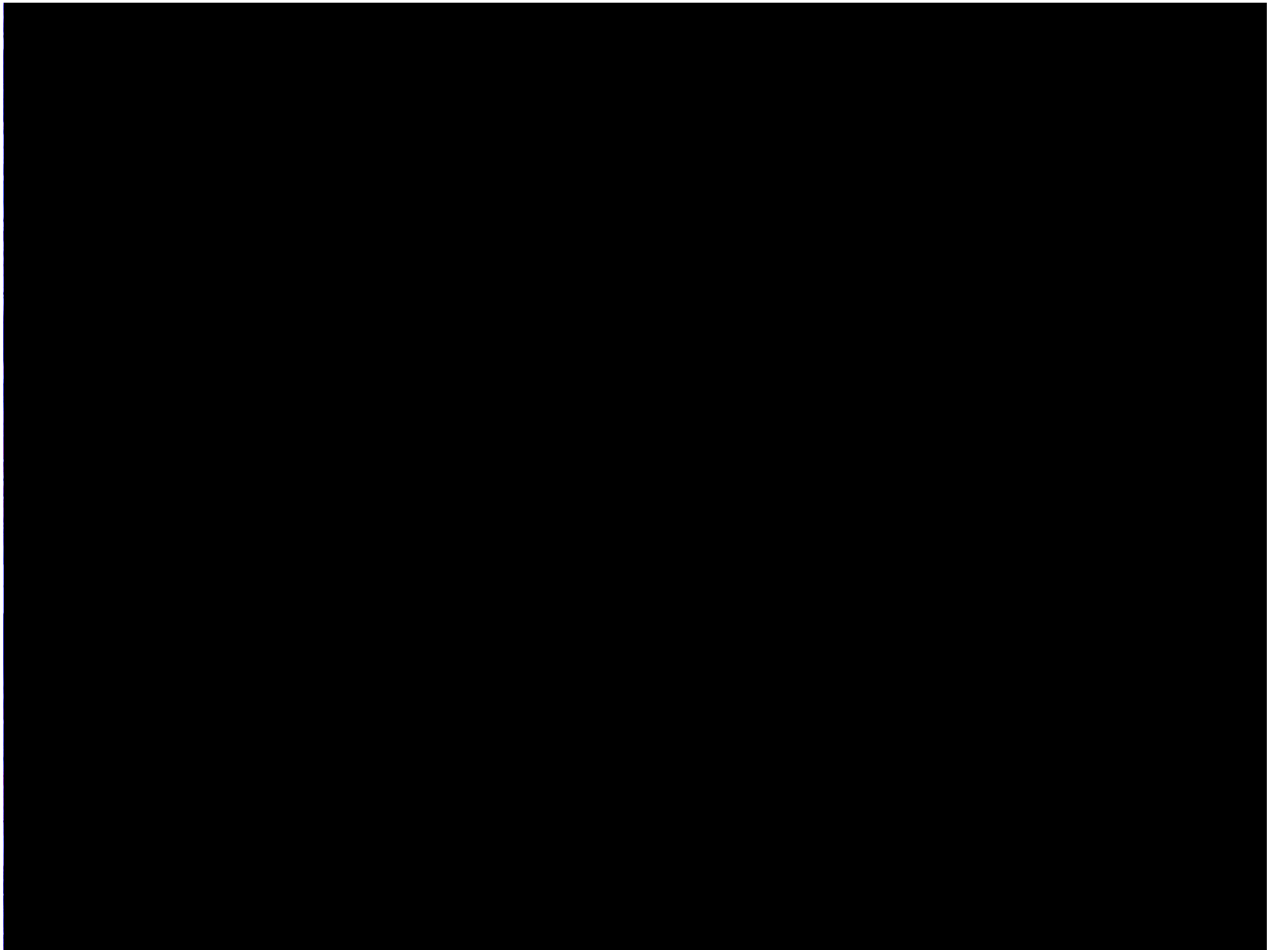
6. **Light ion reaction:**
$^{9}Be(n,\alpha)^{6}He \sim 10^{11}$ pps

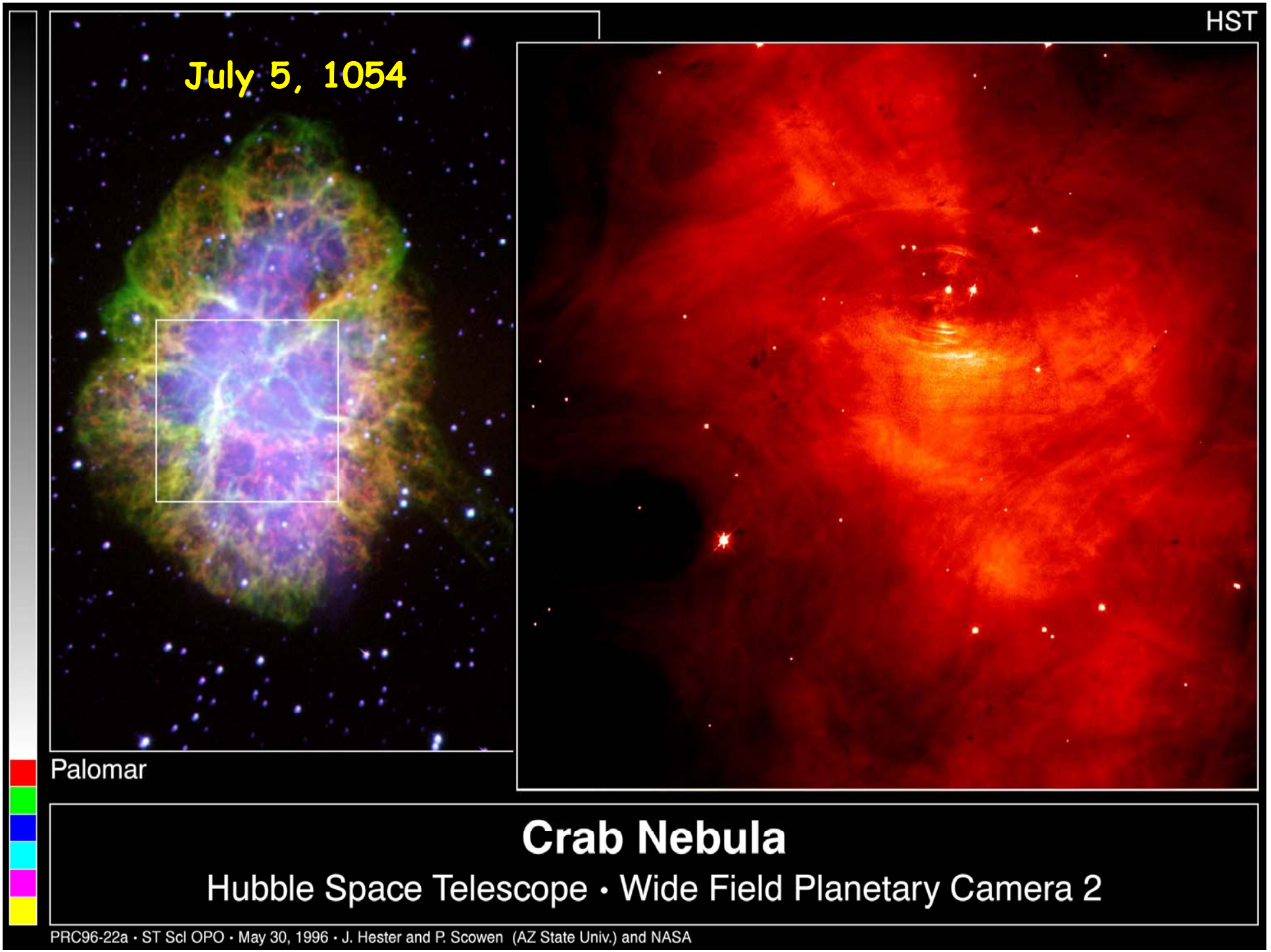


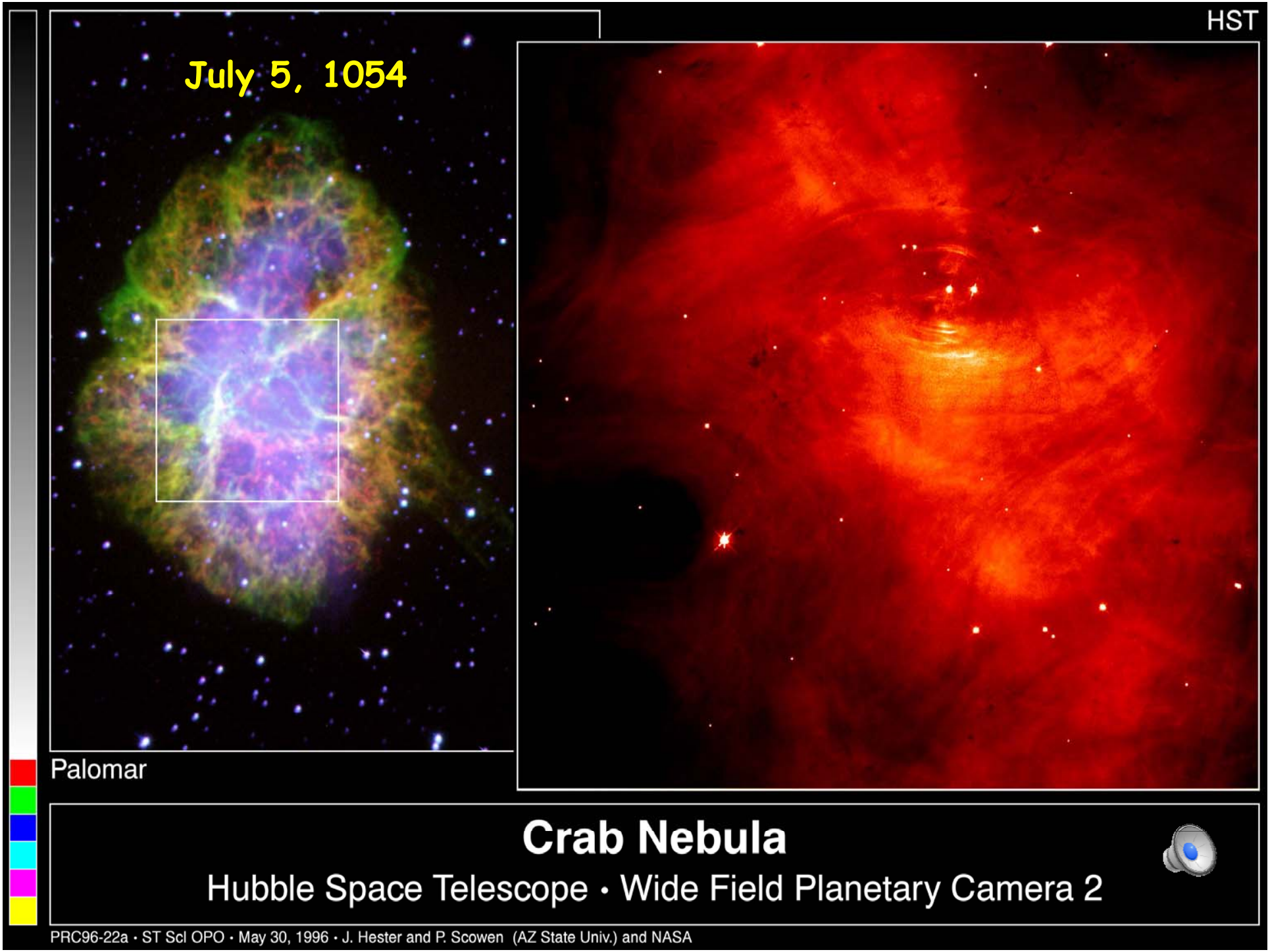
3) Exotic nuclei in the Universe

Nucleosynthesis Paths

- **Exotic nuclei in the Universe**
  - Ex: Rapid neutron capture and Supernovae
  - Ex: Rapid proton capture and X-ray burster
- **Exotic nuclear matter in the Universe**
  - Ex: Supernovae core and neutron stars




July 5, 1054
HST
Palomar
Crab Nebula
Hubble Space Telescope • Wide Field Planetary Camera 2
PRC96-22a • ST ScI OPO • May 30, 1996 • J. Hester and P. Scowen (AZ State Univ.) and NASA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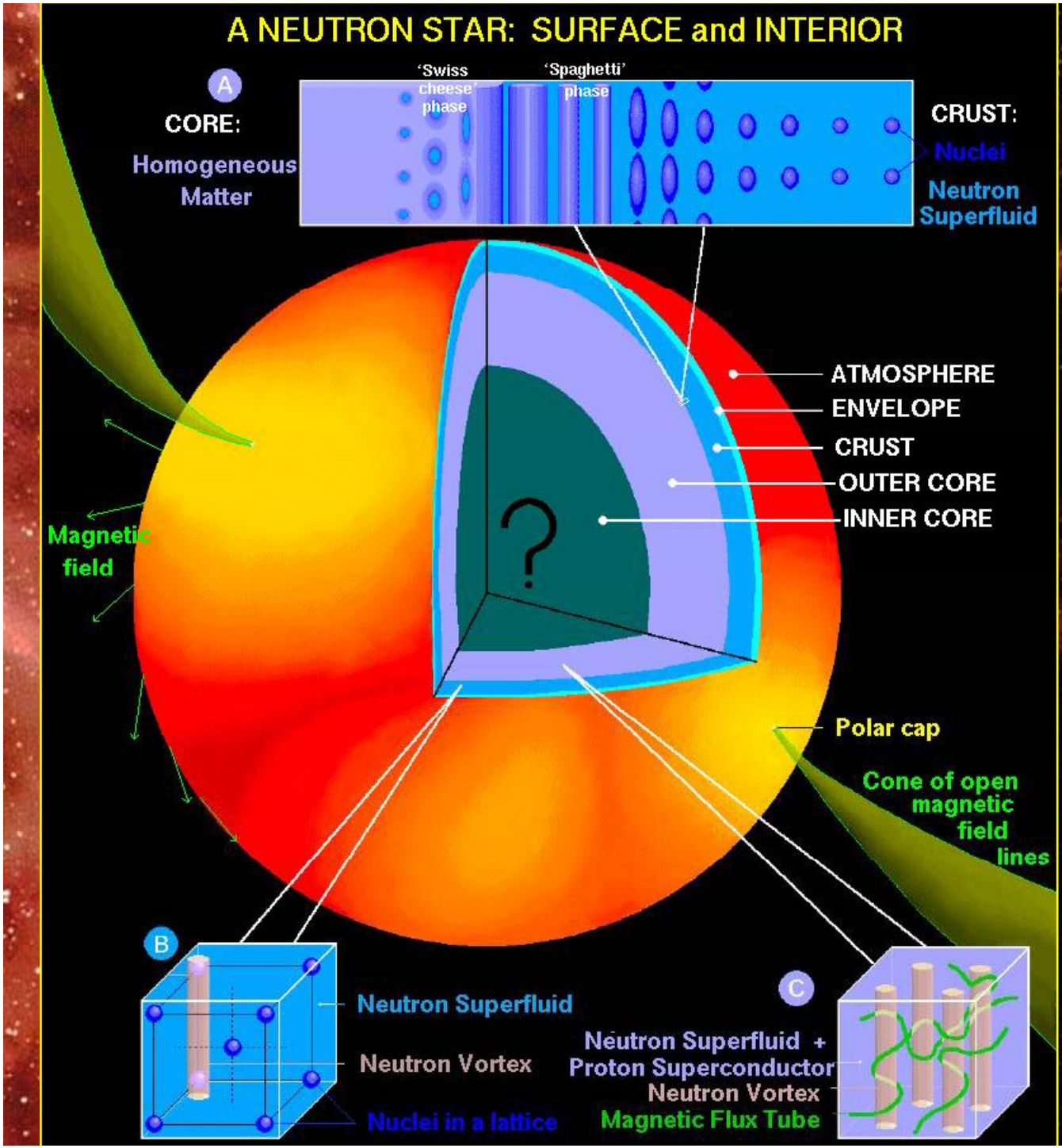
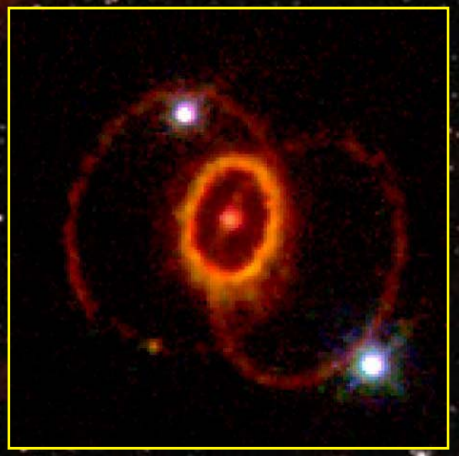
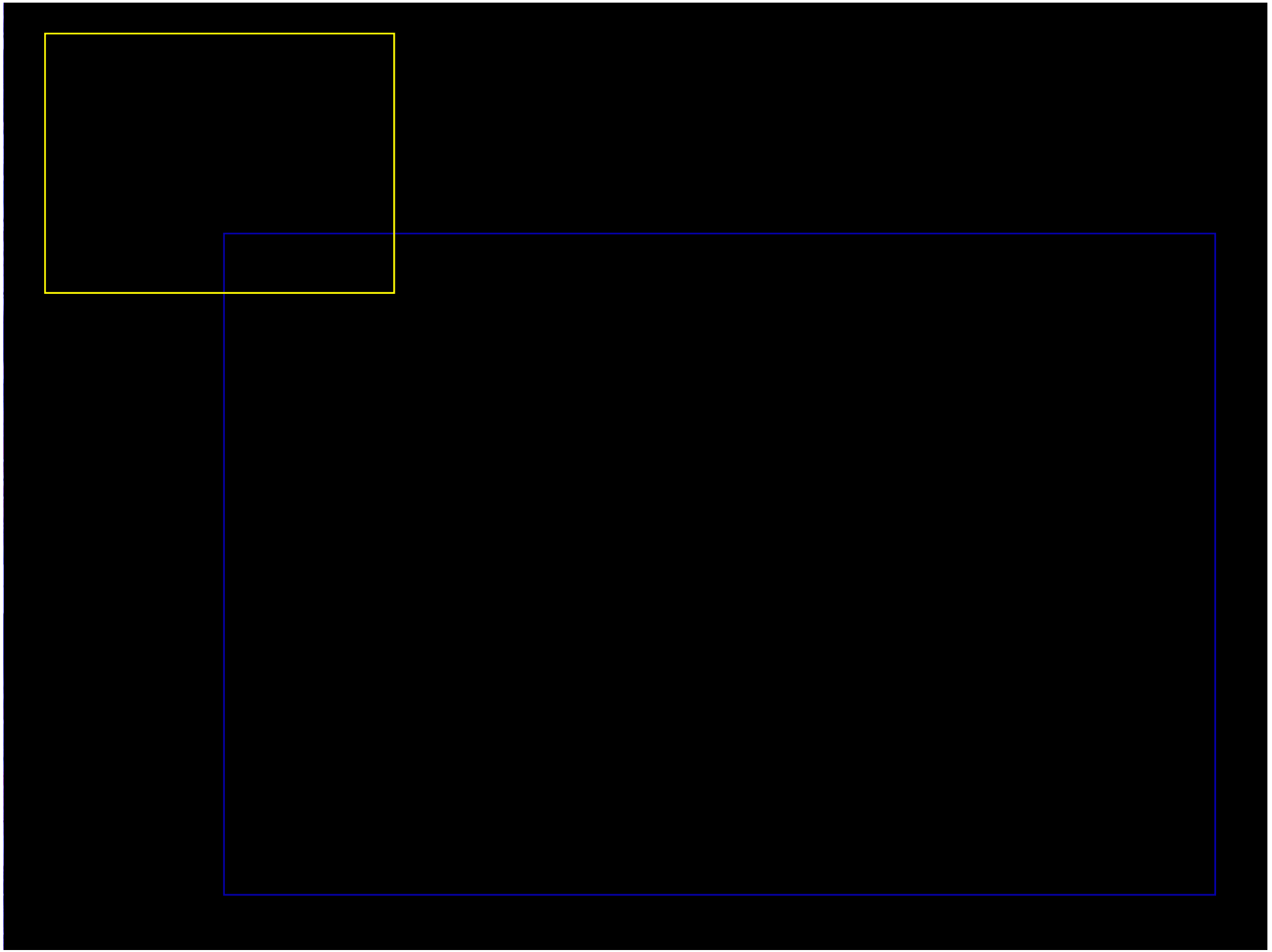


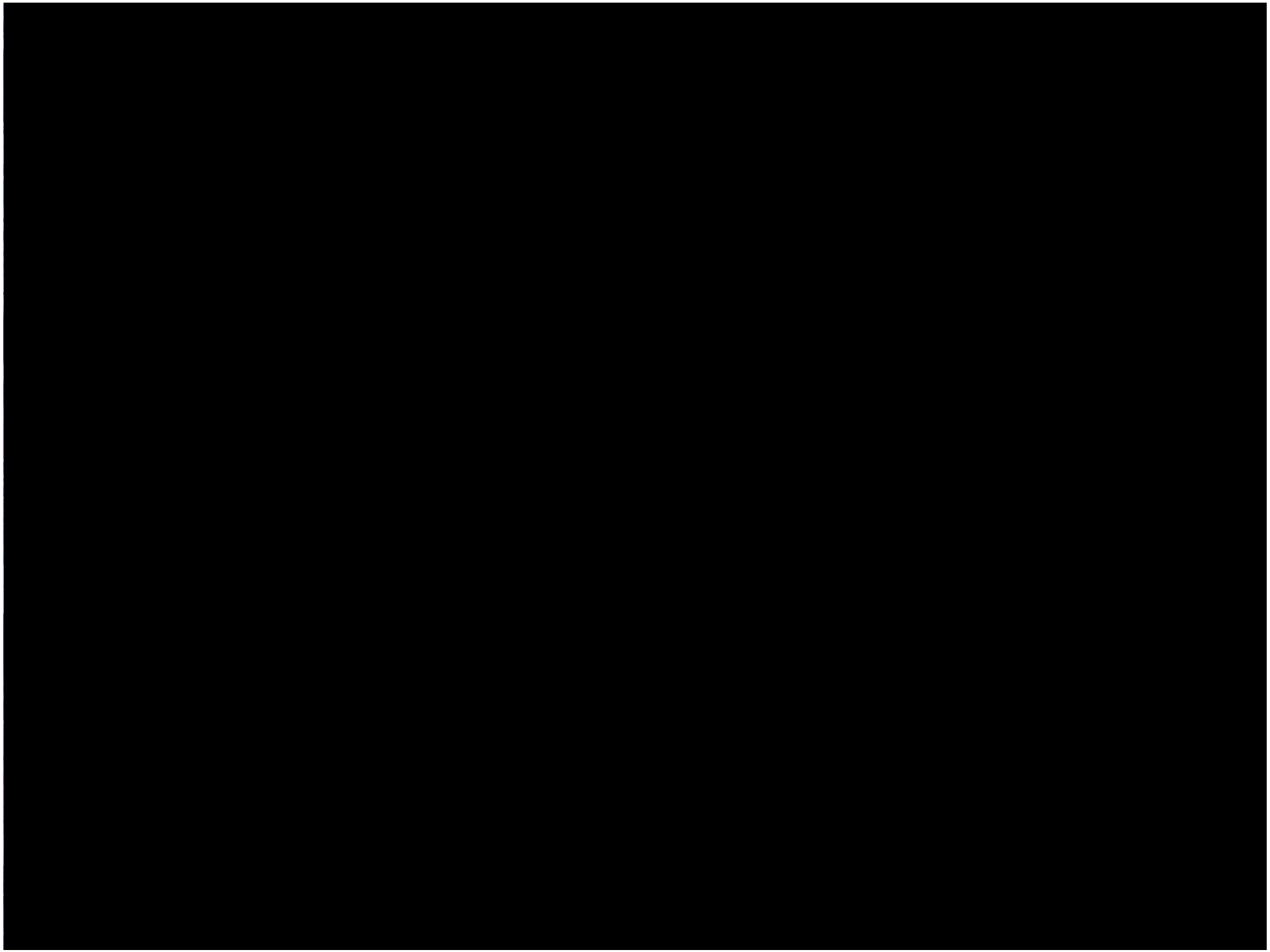
Dense exotic matter in the cosmos

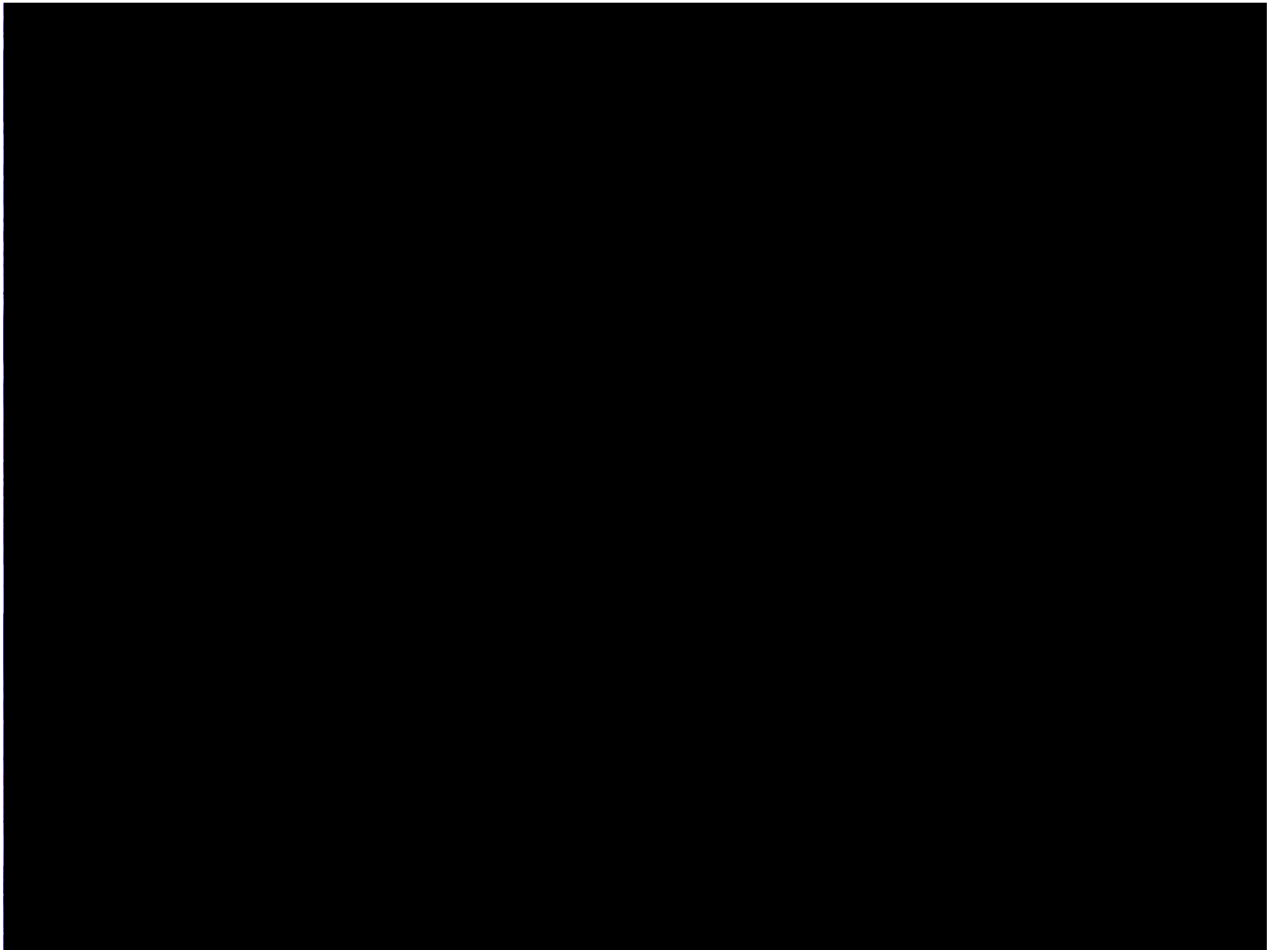
Supernovae and Neutron stars

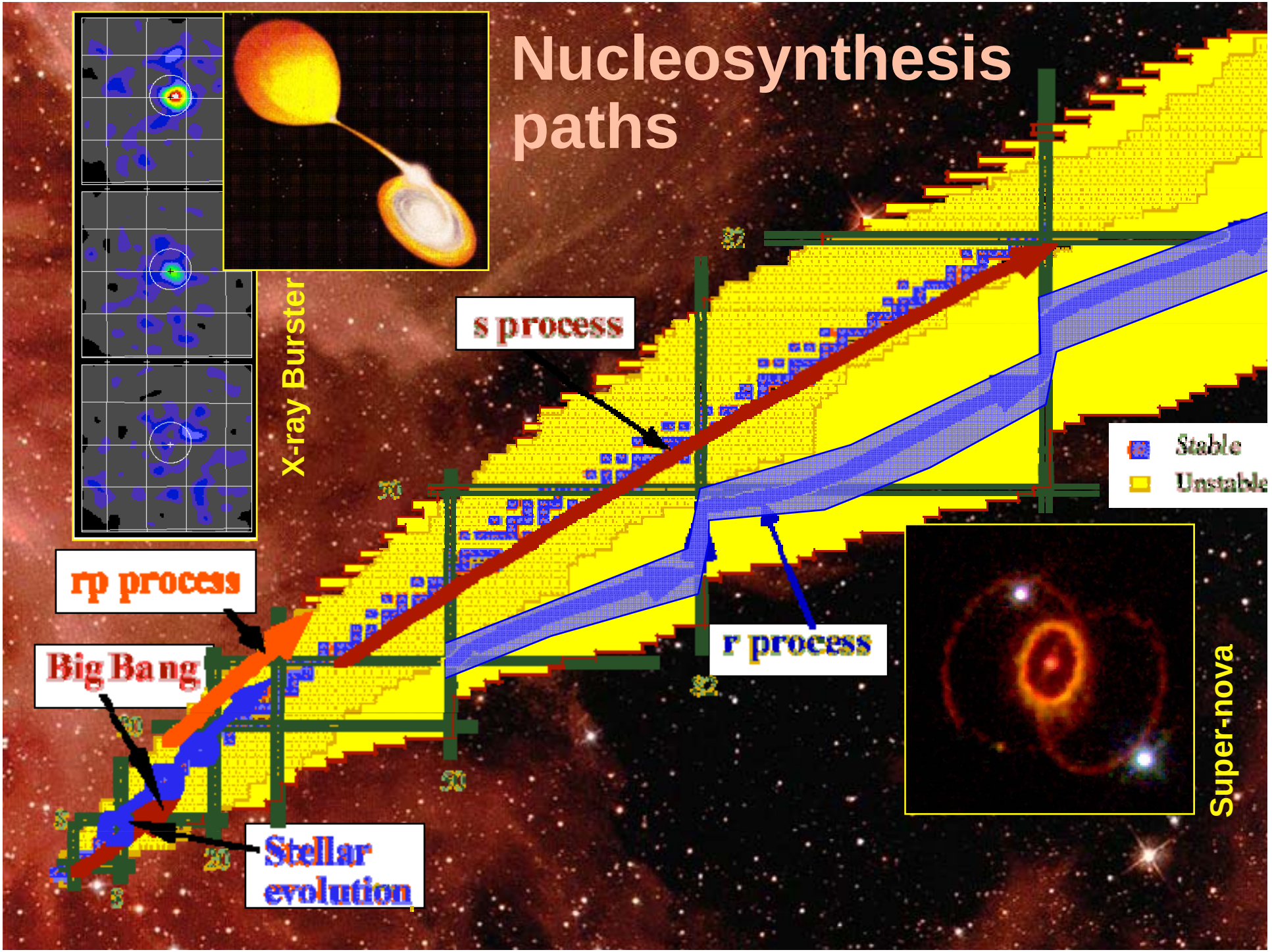


Super-nova

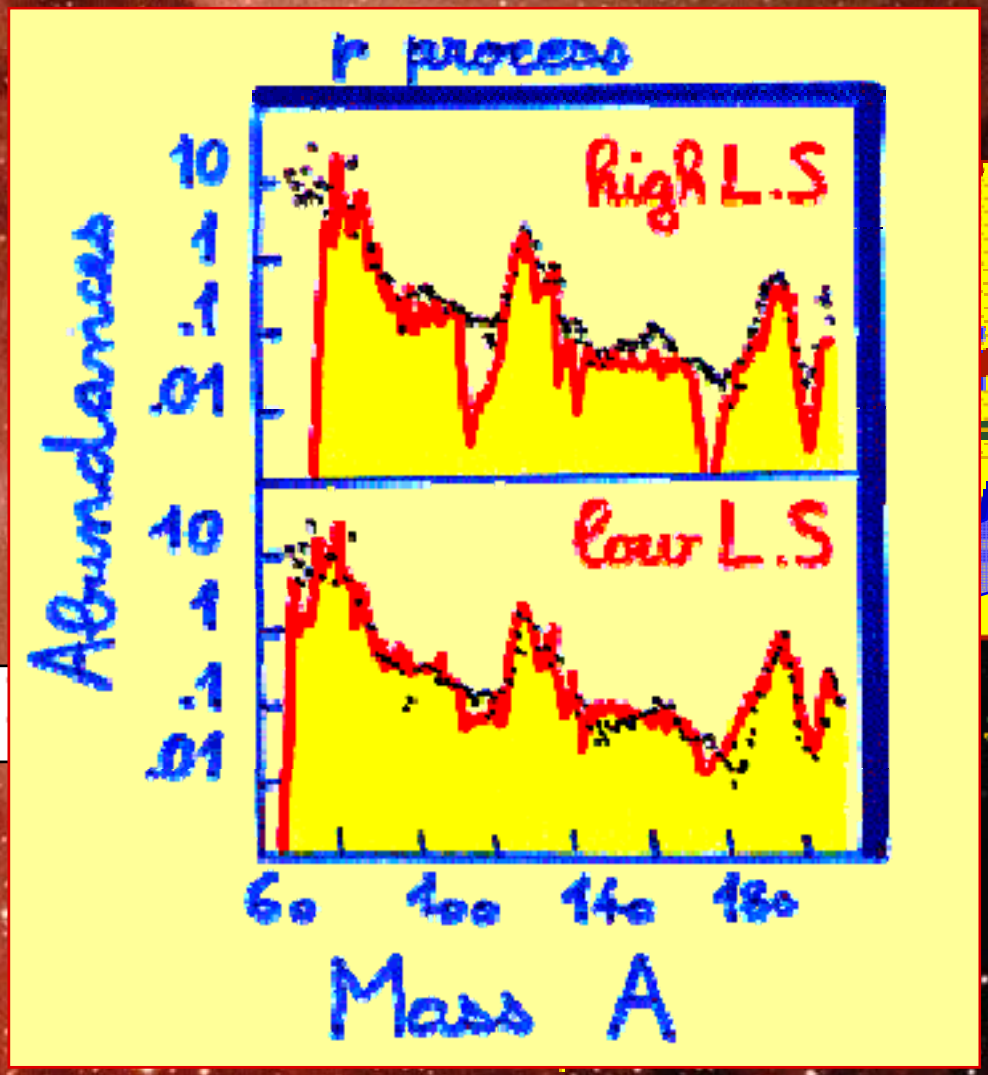


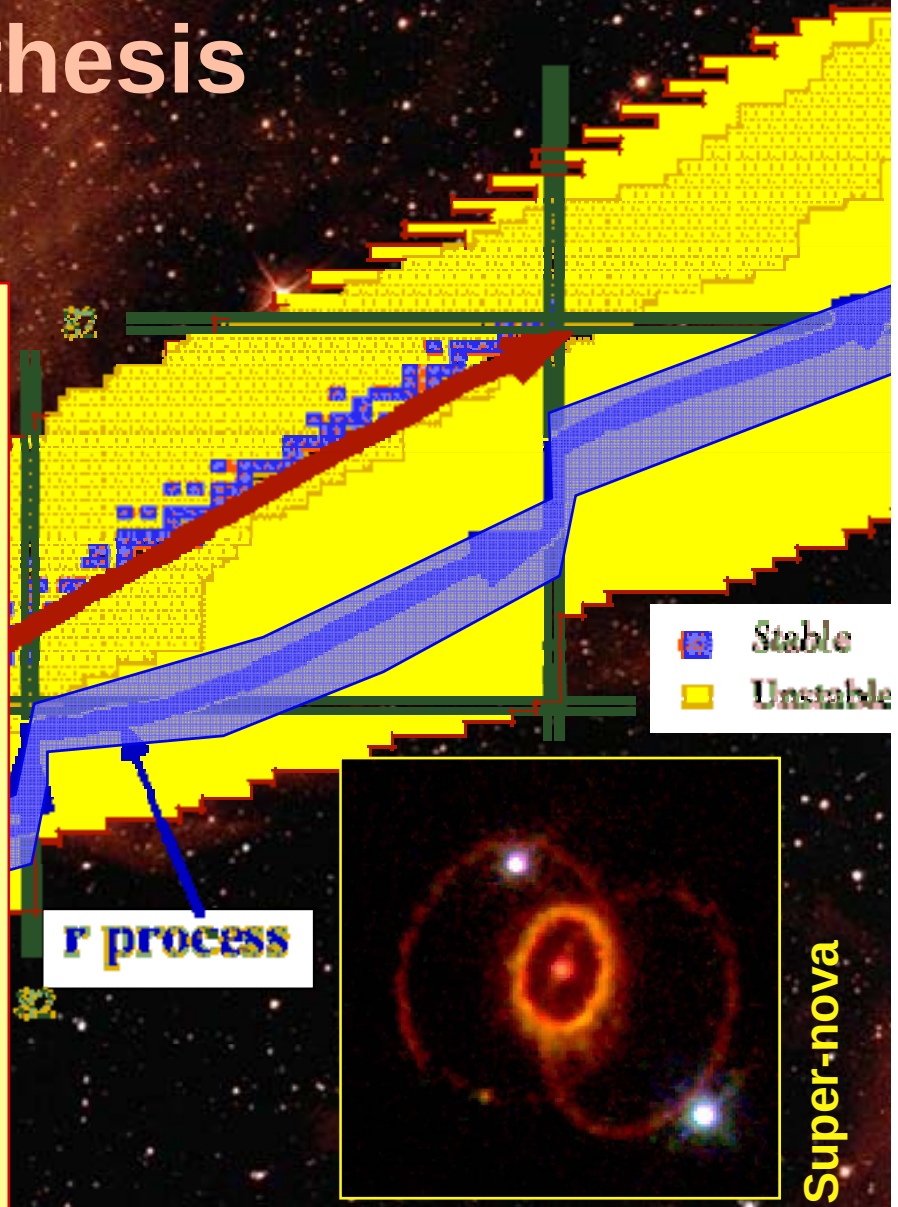





Nucleosynthesis paths
X-ray Burster
s process
rp process
Big Bang
Stellar evolution
r process
Super-nova
Stable
Unstable

Nucleosynthesis paths





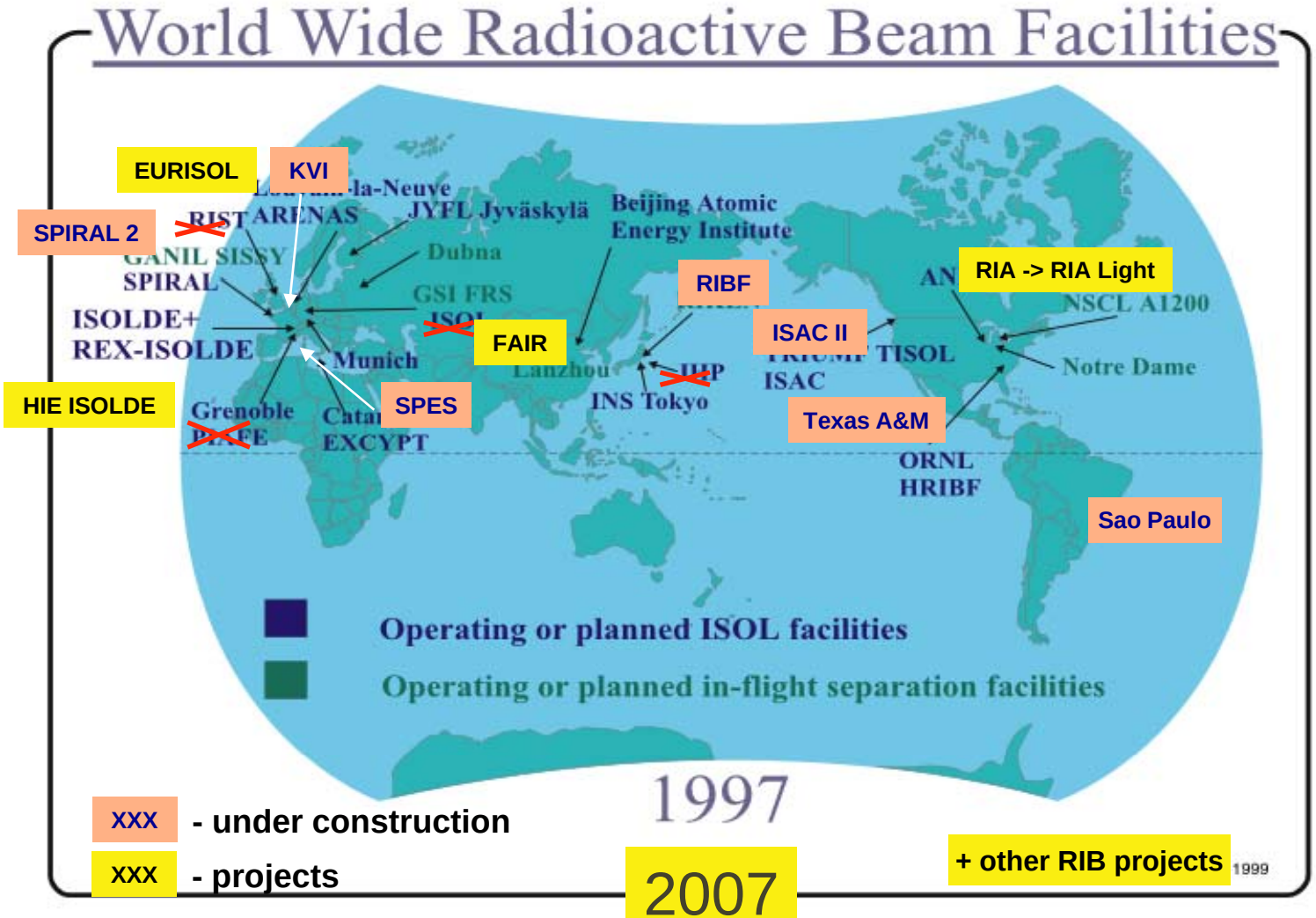
Super-nova

4) Large scale facilities

Exotic nuclei factories

- **Facilities and projects**
  - SPIRAL 2 on the ESFRI road map

A very competitive field



2006 European Strategy

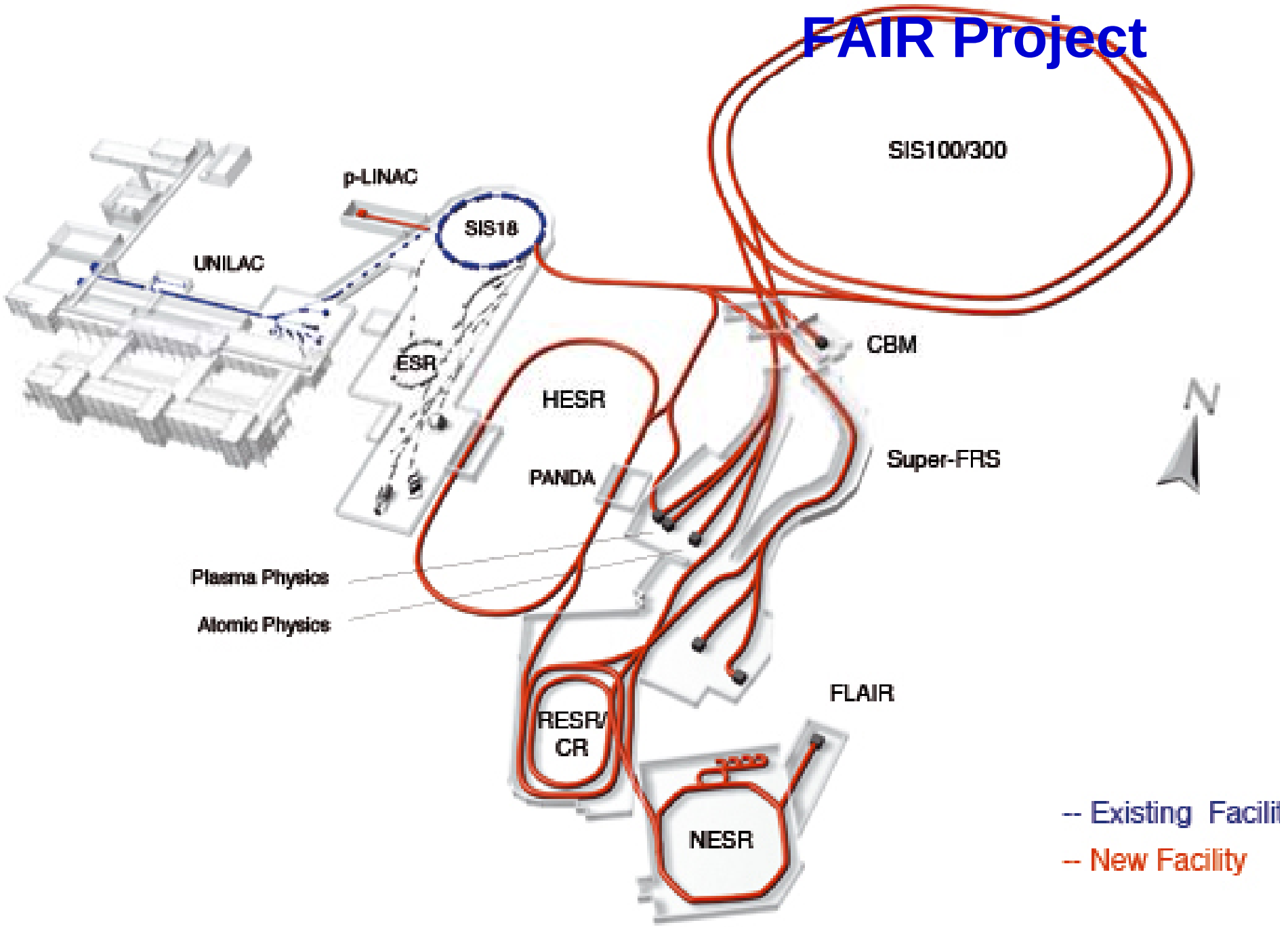
- **ESFRI roadmap (2006) : FAIR et SPIRAL2**

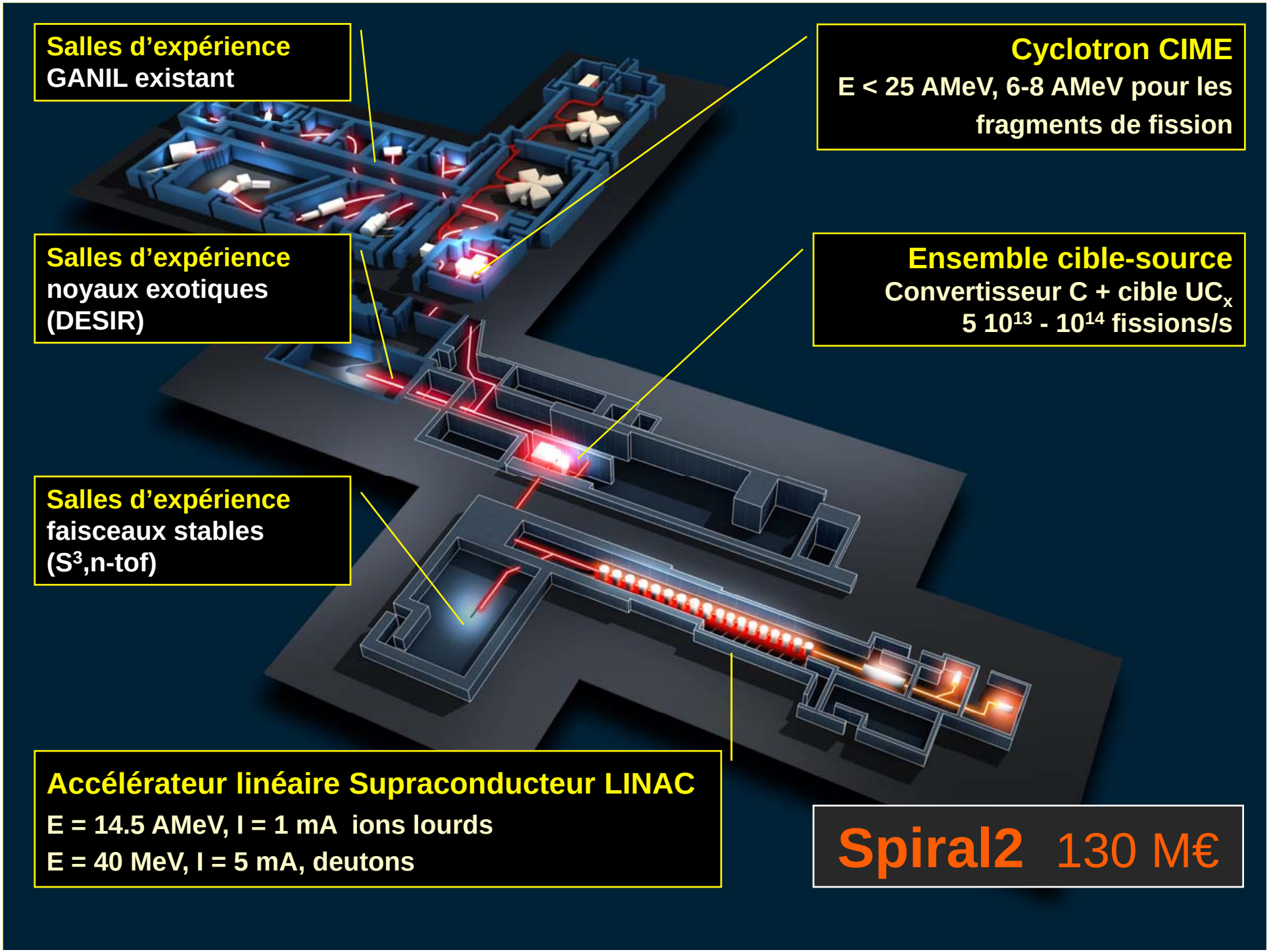
European Strategy Forum
on Research Infrastructures

- **Beams of radioactive nuclei**
  => understand stability limits
  => reduce uncertainties on
  nuclear data

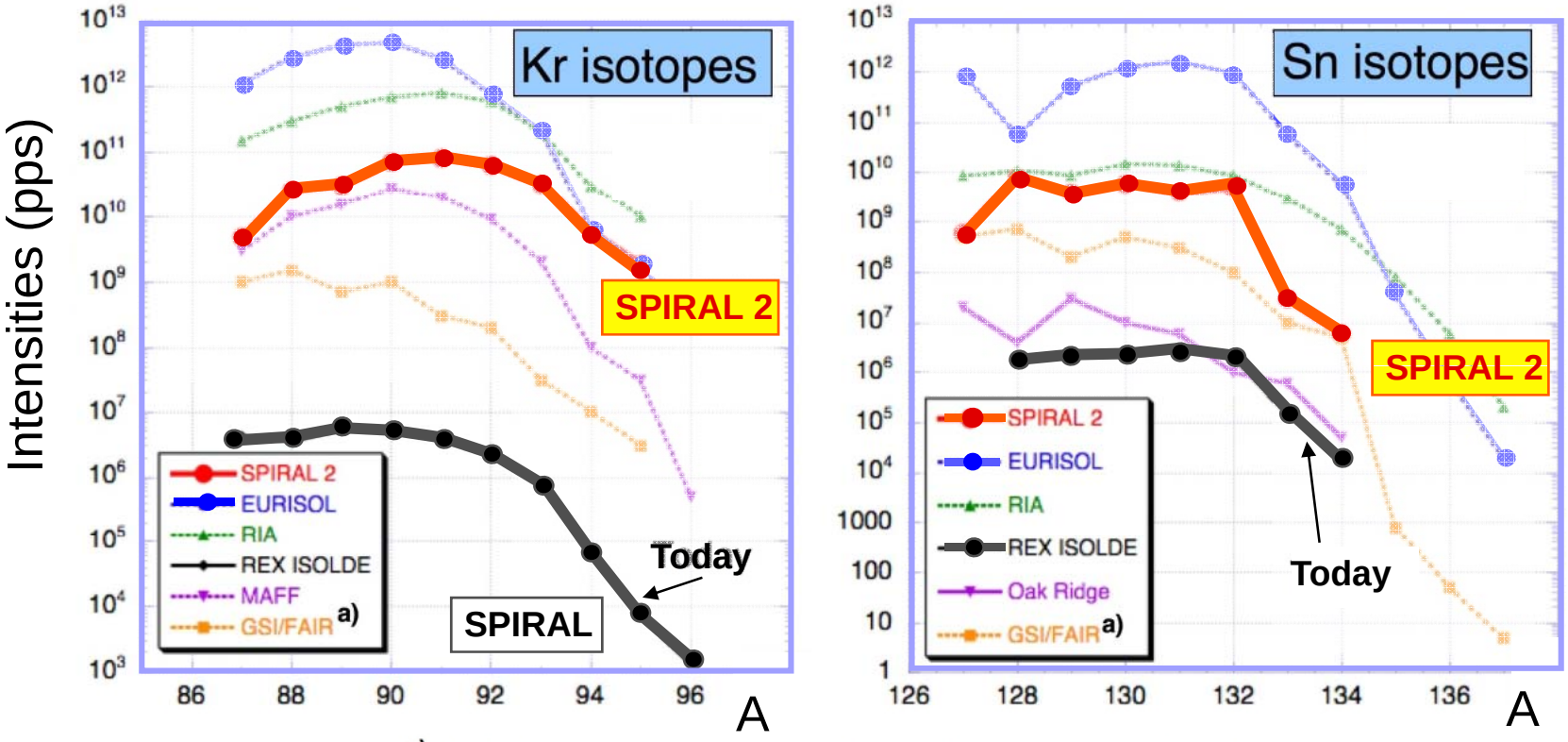
- Two complementary approaches
  => FAIR @ GSI, Darmstadt
  Short lived produced in flight
  at high energy in thin targets
  => SPIRAL2 @ GANIL, Caen
  Intense good quality beams
  produced on line (ISOL) in a
  thick target

FAIR Project

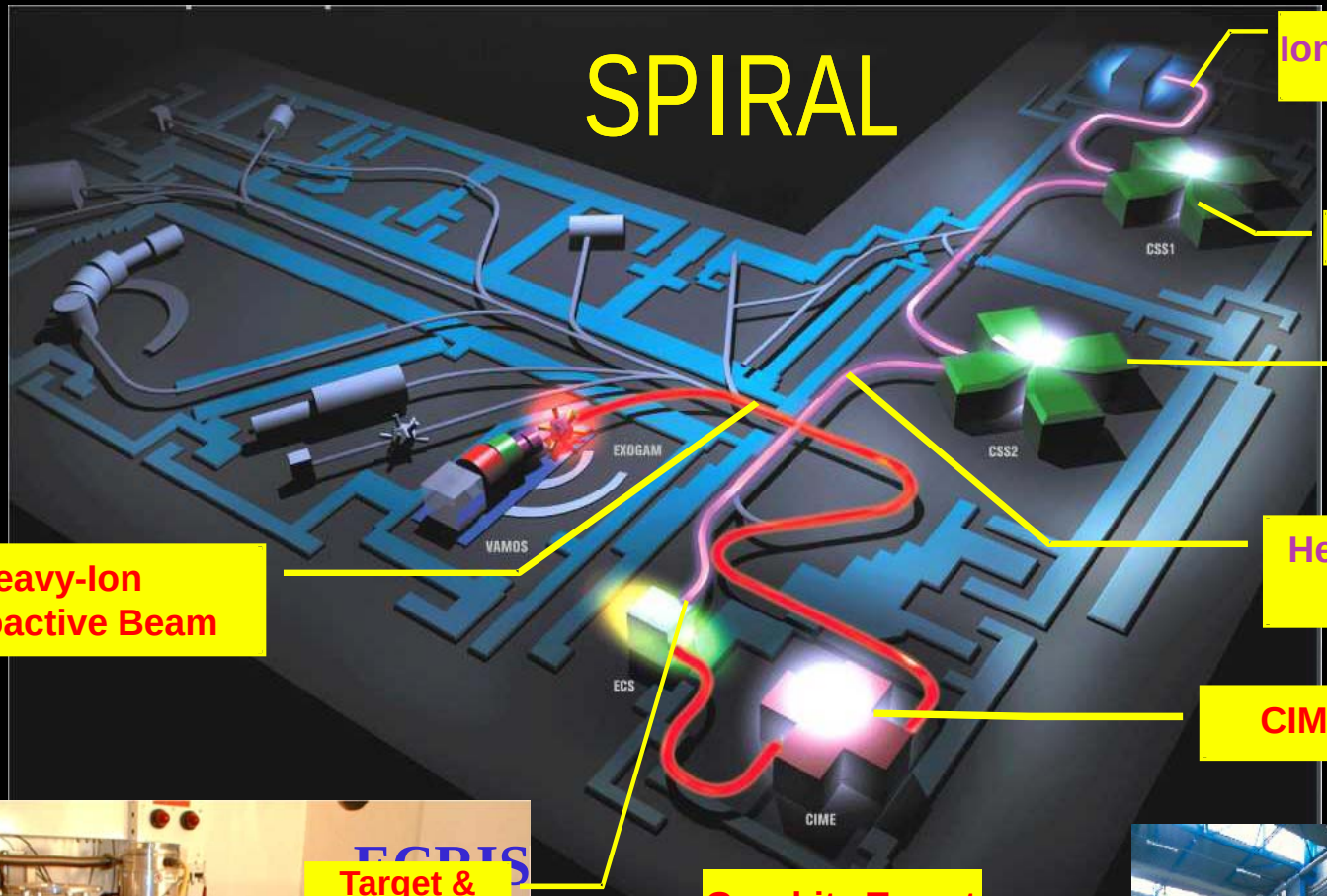


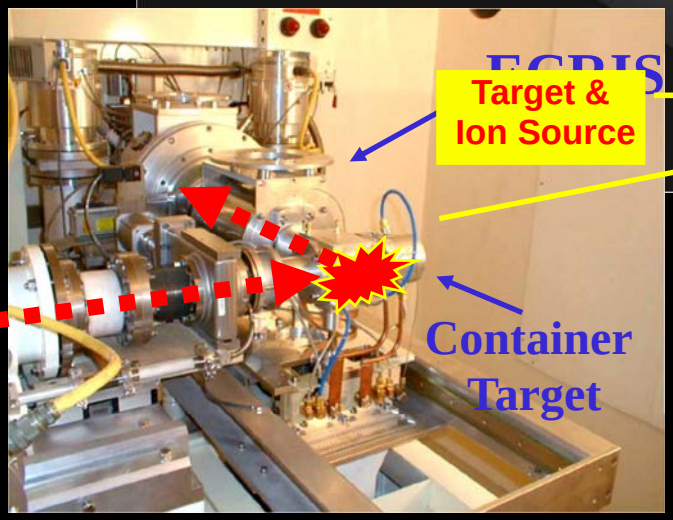

Salles d'expérience
GANIL existant
Salles d'expérience
noyaux exotiques
(DESIR)
Salles d'expérience
faisceaux stables
(S3,n-tof)
Cyclotron CIME
E < 25 AMeV, 6-8 AMeV pour les fragments de fission
Ensemble cible-source
Convertisseur C + cible UCx
5 10^13 - 10^14 fissions/s
Accélérateur linéaire Supraconducteur LINAC
E = 14.5 AMeV, I = 1 mA ions lourds
E = 40 MeV, I = 5 mA, deutons
Spiral2 130 M€

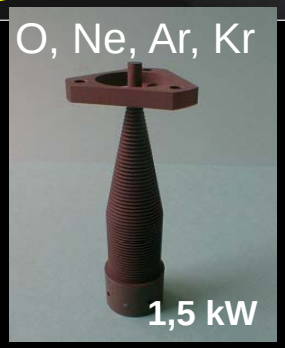
SPIRAL 2: 1000 times more exotic



a) Yields for in-flight production of fission fragments at relativistic energy


SPIRAL
Ion Source
CSS1
CSS2
Heavy-Ion Stable Beam
CIME
Heavy-Ion Radioactive Beam
EXOGAM
VAMOS
ECS
CIME
CSS1
CSS2


Target & Ion Source
Graphite Target
Container Target


O, Ne, Ar, Kr
1,5 kW

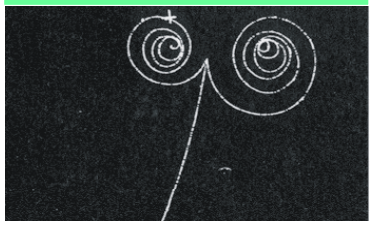

He
3 kW

5) Physics with Exotic Nuclei

Evolution / revolution

Physics with Exotic Nuclei

Fundamental Symmetries and Interactions



Test of the Standard Model CKM-Matrix

rp-Process, Novae and X-ray Bursts

Neutron-proton Pairing

New Decay Modes 2 p and n radioactivity

Neutron & proton Drip lines

Halos, Skins Molecules

New Shell Structure

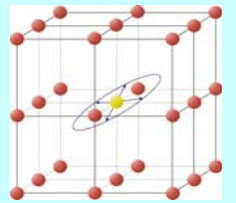
Nuclear Shapes

Structure & Dynamics of Exotic Nuclei

r-Process and Supernovae

Superheavy Elements

Applications



Nuclear Astrophysics

QuickTime™ et un décompresseur codec YUV420 sont requis pour visionner cette image.