

The high energy universe

x-rays

gamma rays

cosmic rays

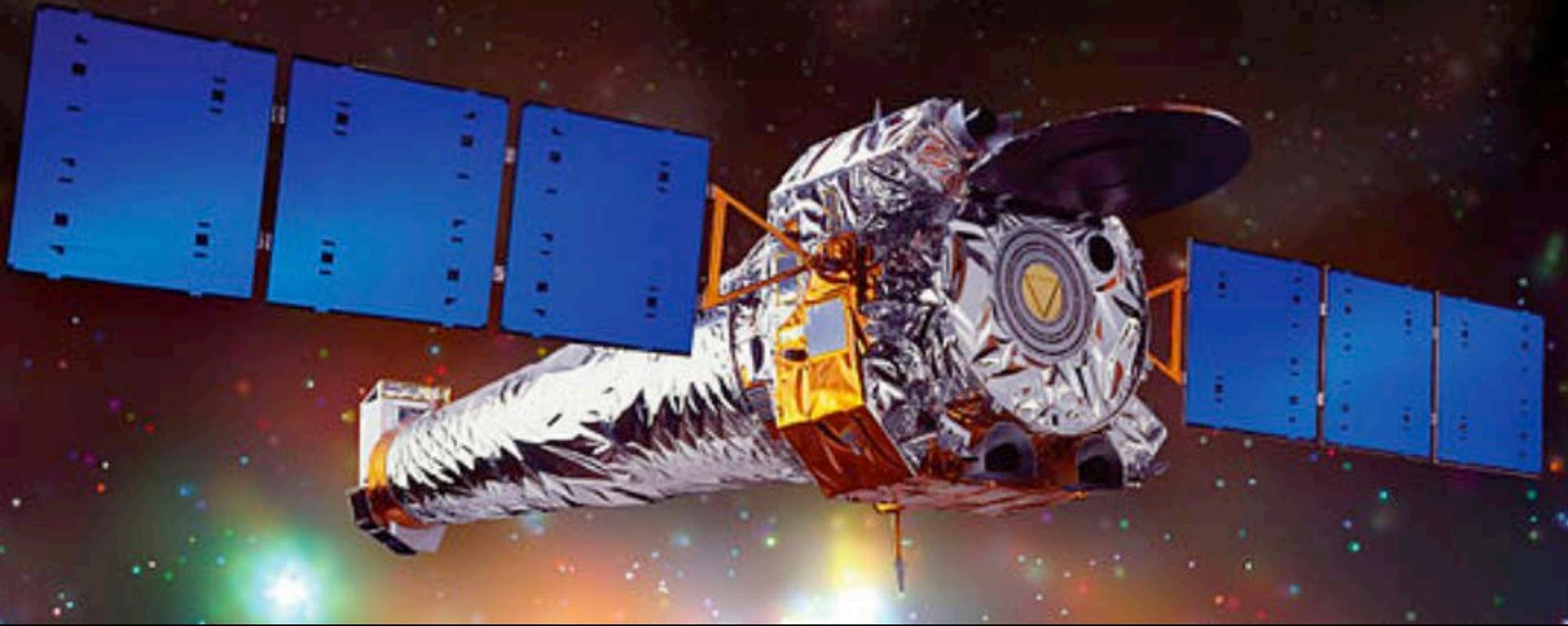
neutrinos

Joseph Silk
Gresham College
31 January 2018

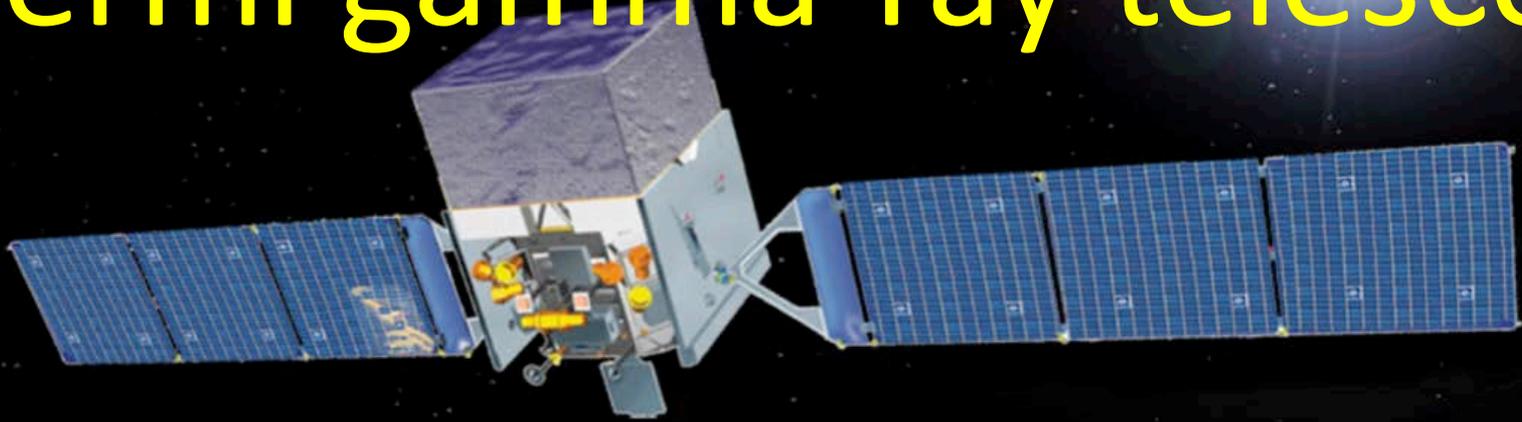
Chandra x-ray telescope

Launched 1999 by Columbia space shuttle

Orbit: 80000 km semi-major axis



Fermi gamma-ray telescope



Launched 2008

Orbit 7000 km semi-major axis



HESS gamma-ray telescope

2012

Namibia, Mt. Gamsberg



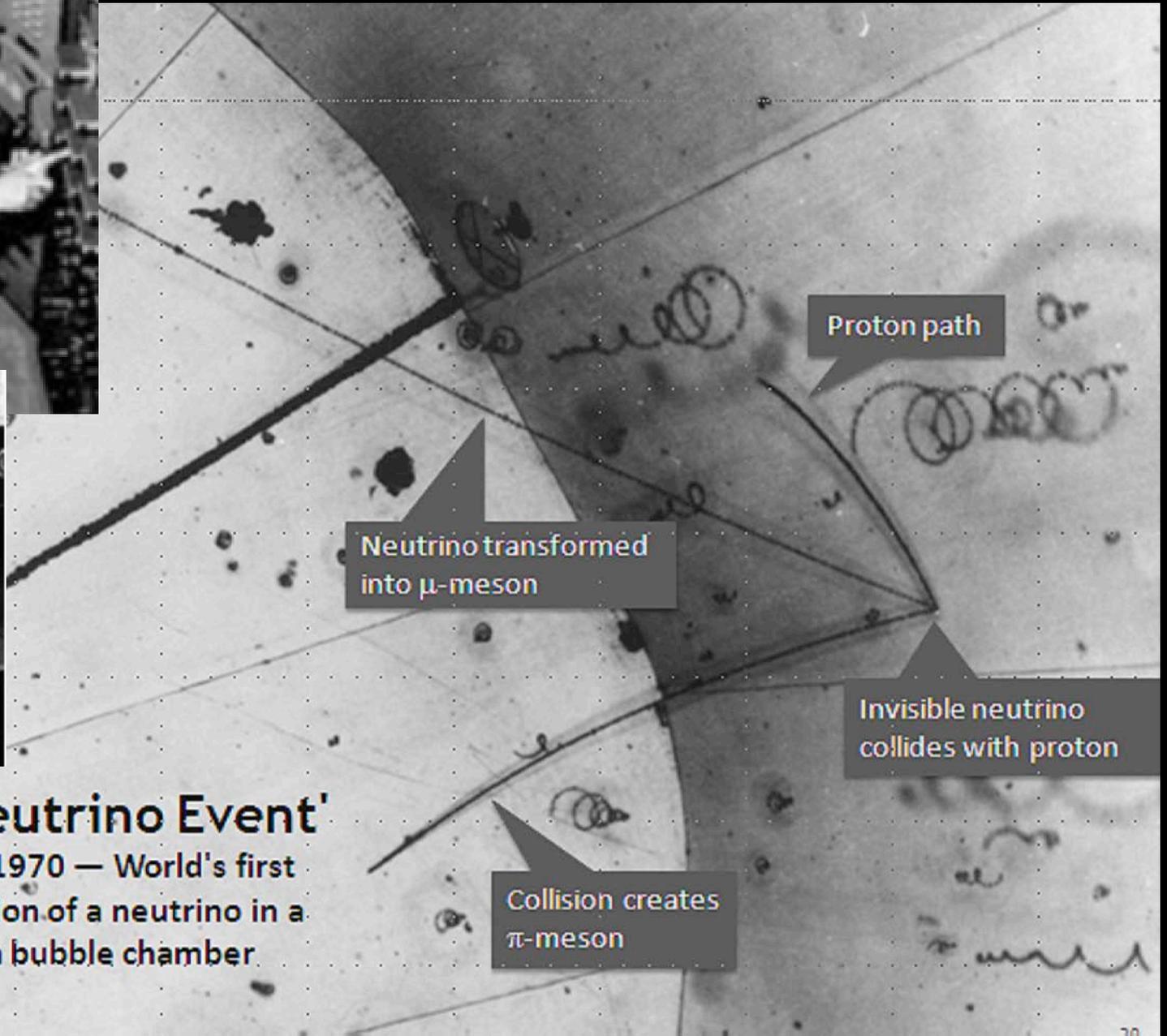
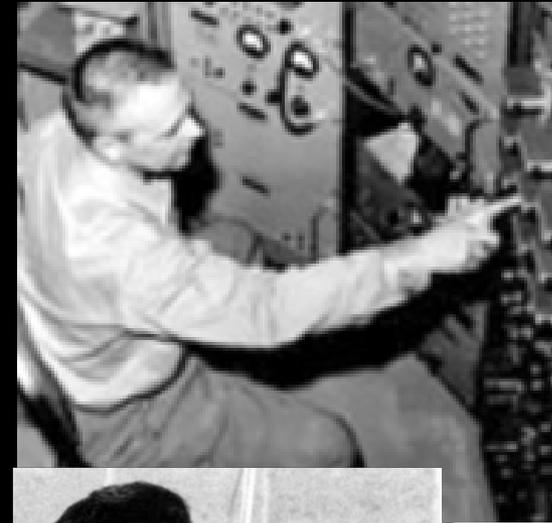
HAWC gamma-ray telescope

2015

Sierra Negra volcano, Puebla, Mexico at 4100m



Discovery of neutrino: 1956



The 'Neutrino Event'

Nov. 13, 1970 — World's first observation of a neutrino in a hydrogen bubble chamber

A neutrino telescope

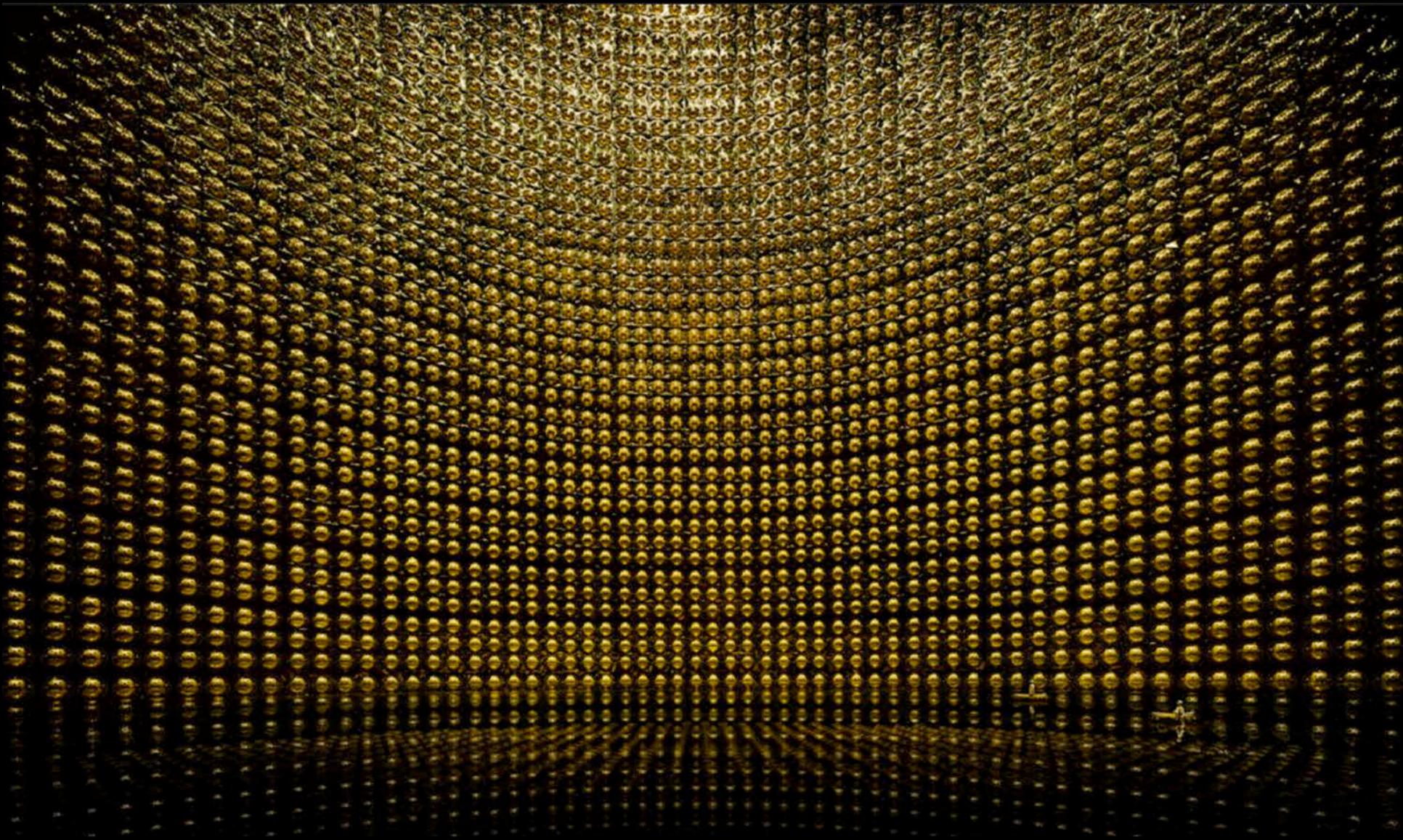
SuperKamiokande Neutrino Detection Experiment

Mt Ikeno, Hida, Japan, 1km underground, Mozumi mine

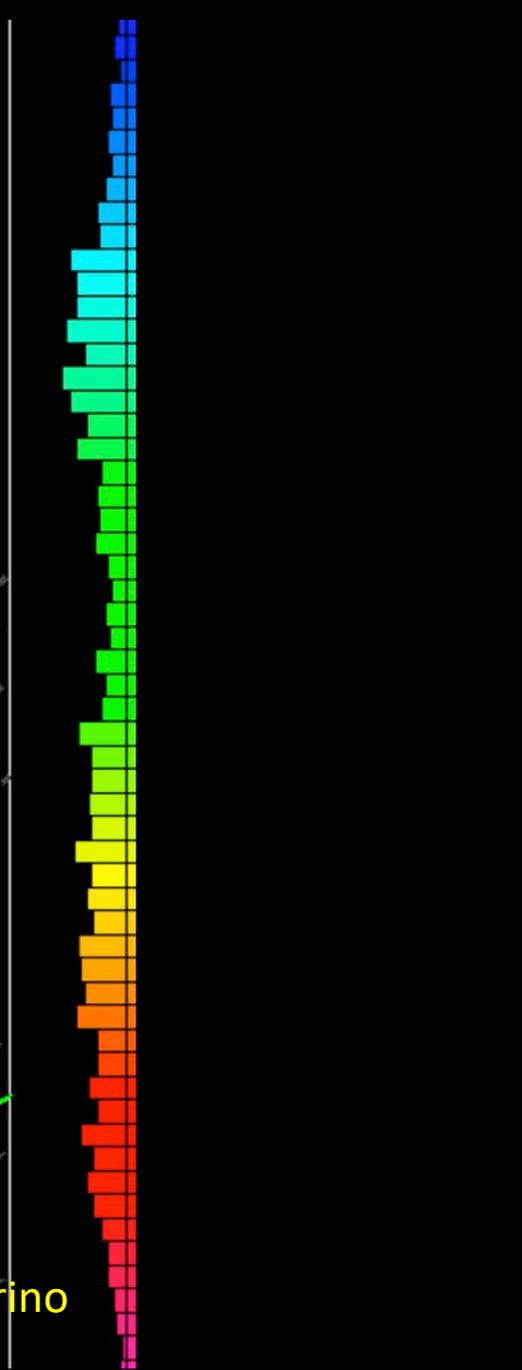
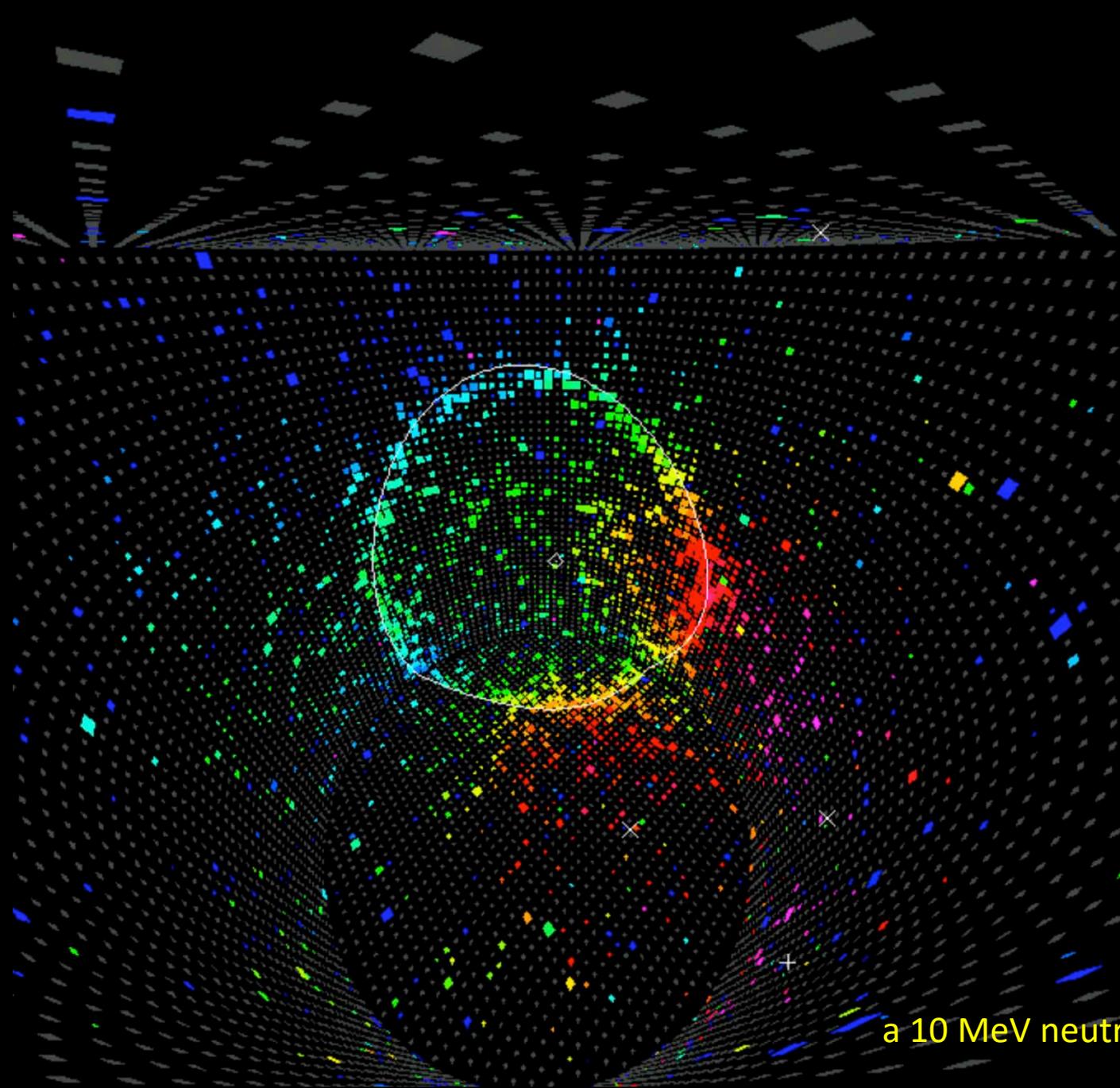
1996: 50000 tons of purified water + 13000 photomultiplier tubes

Searching for neutrinos from the sun





Andreas Gursky 2007

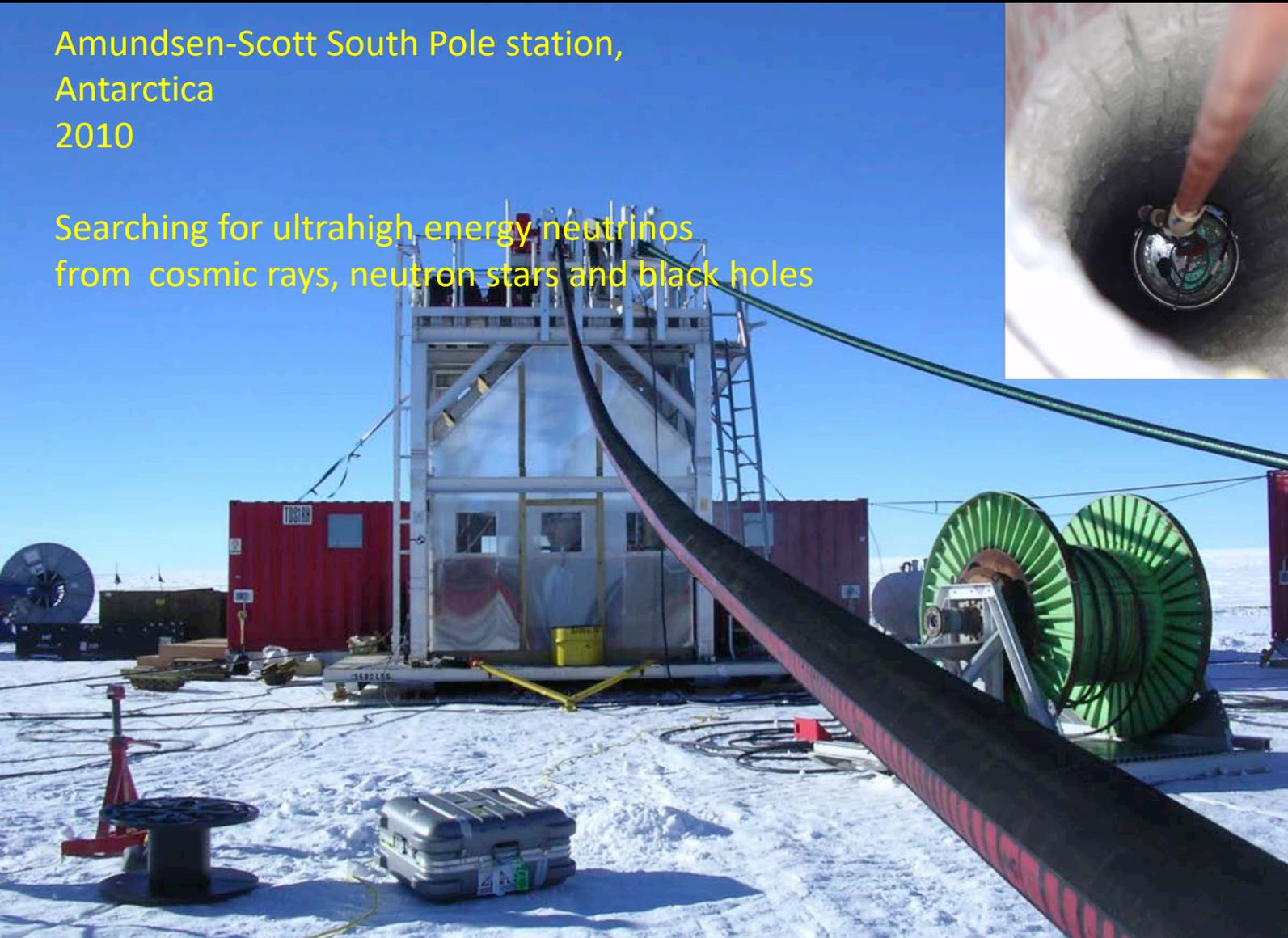


a 10 MeV neutrino

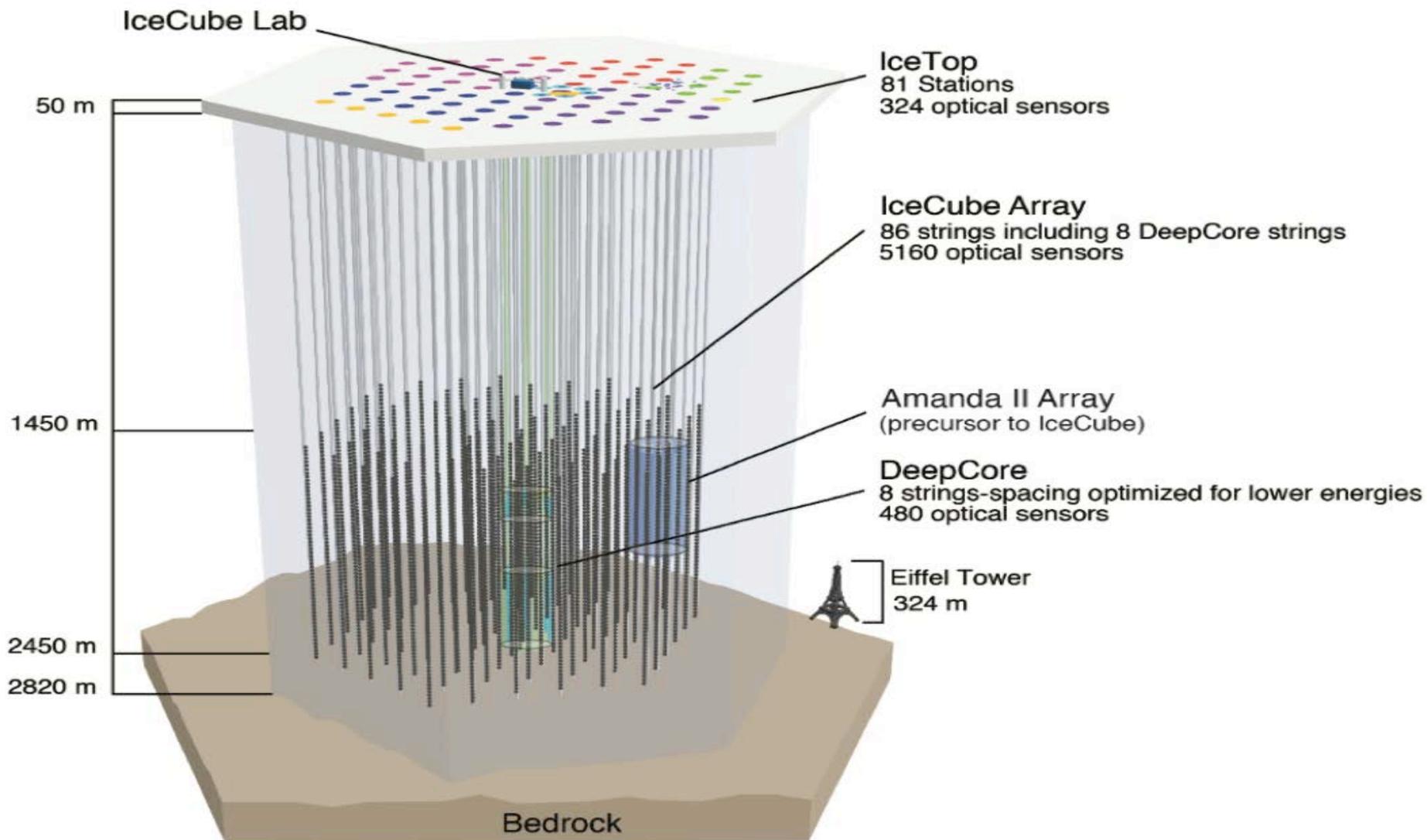
Another neutrino telescope

Amundsen-Scott South Pole station,
Antarctica
2010

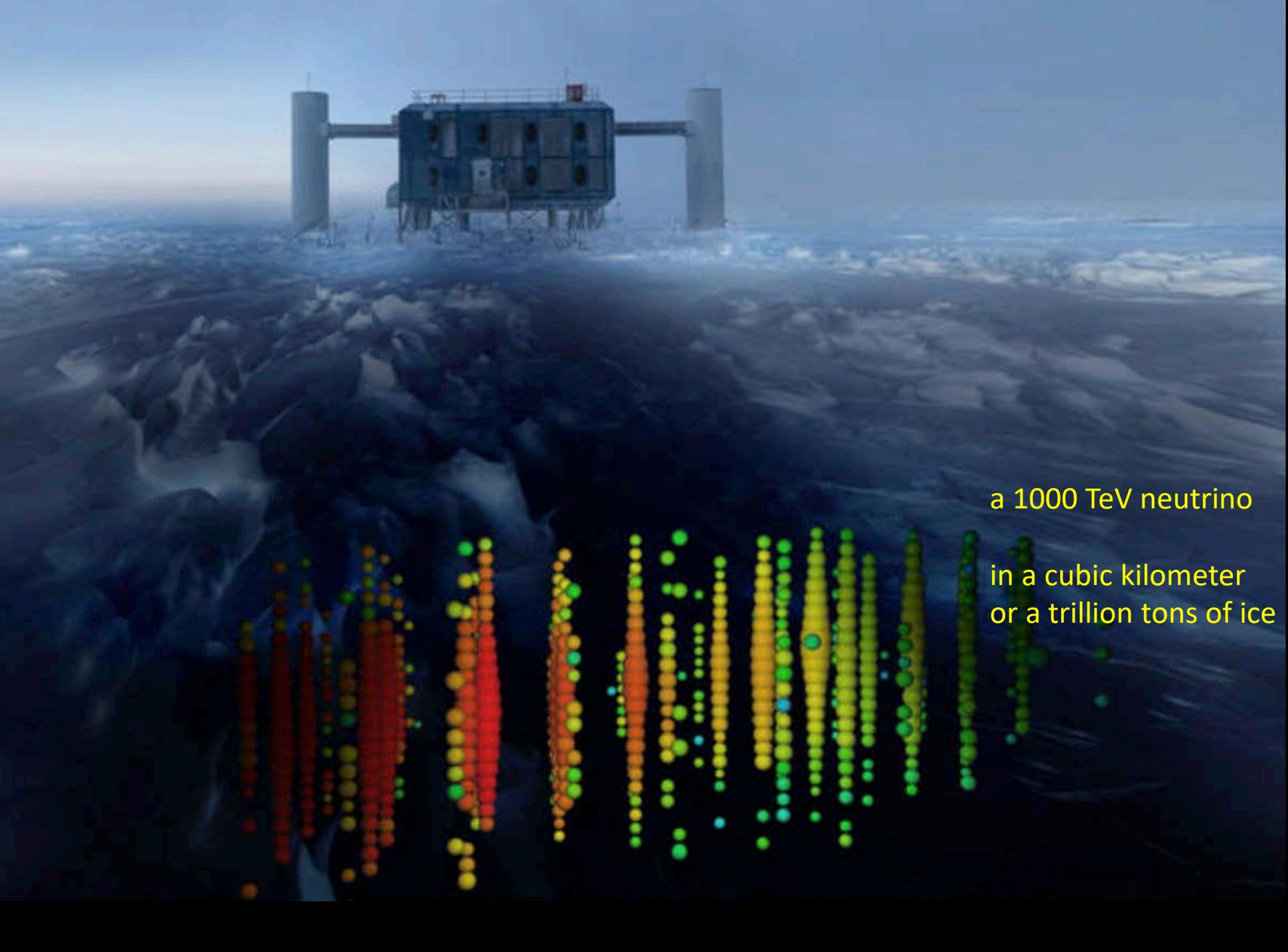
Searching for ultrahigh energy neutrinos
from cosmic rays, neutron stars and black holes



ICECUBE NEUTRINO OBSERVATORY

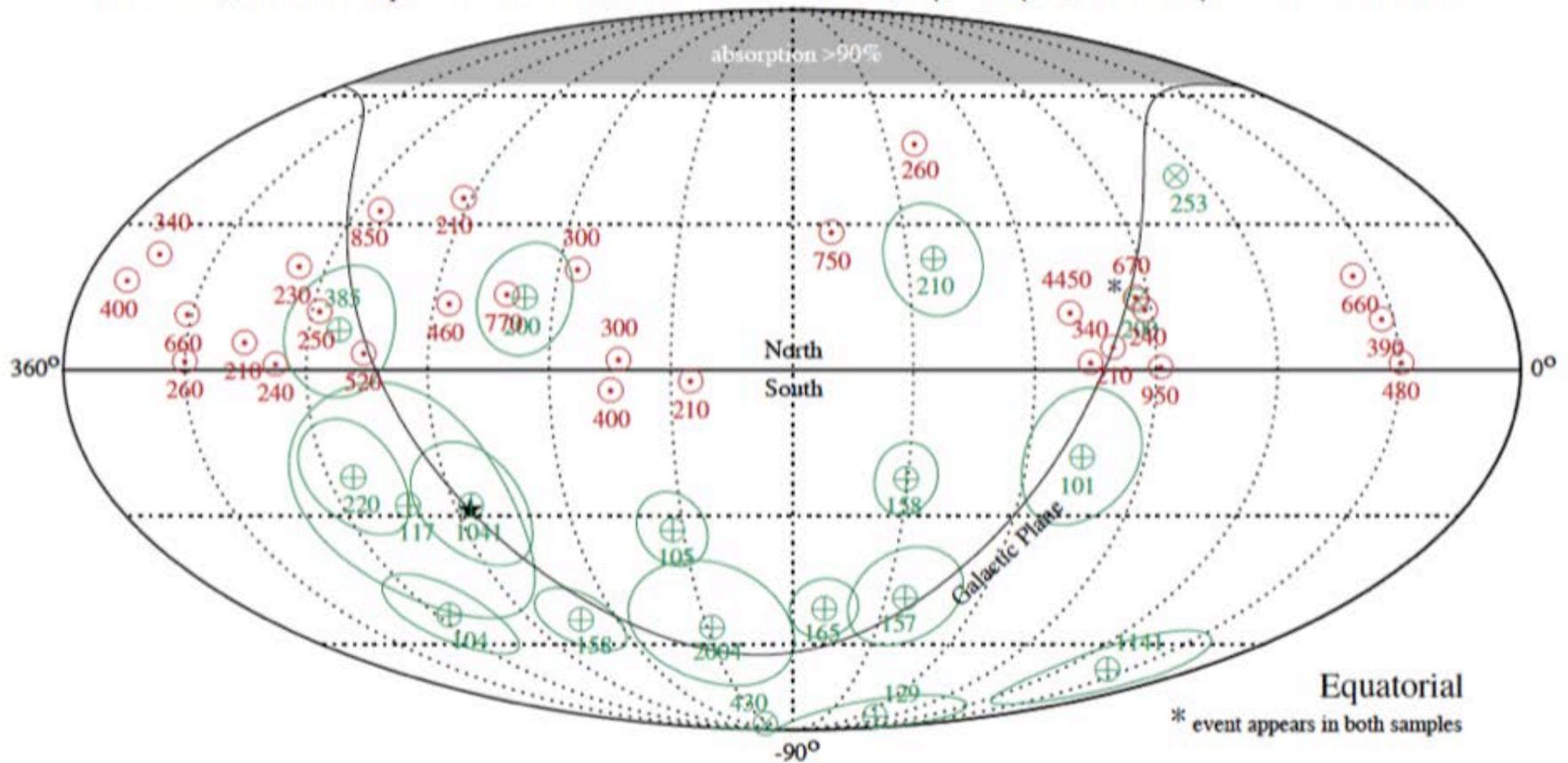






a 1000 TeV neutrino
in a cubic kilometer
or a trillion tons of ice

HESE 4yr with $E_{\text{dep}} > 100$ TeV (green) / Northern sky $\nu_{\mu} + \nu_{\mu}^{-}$ 6yr with $E_{\mu} > 200$ TeV (red)



Discovery of cosmic rays: 1911



A cosmic ray telescope

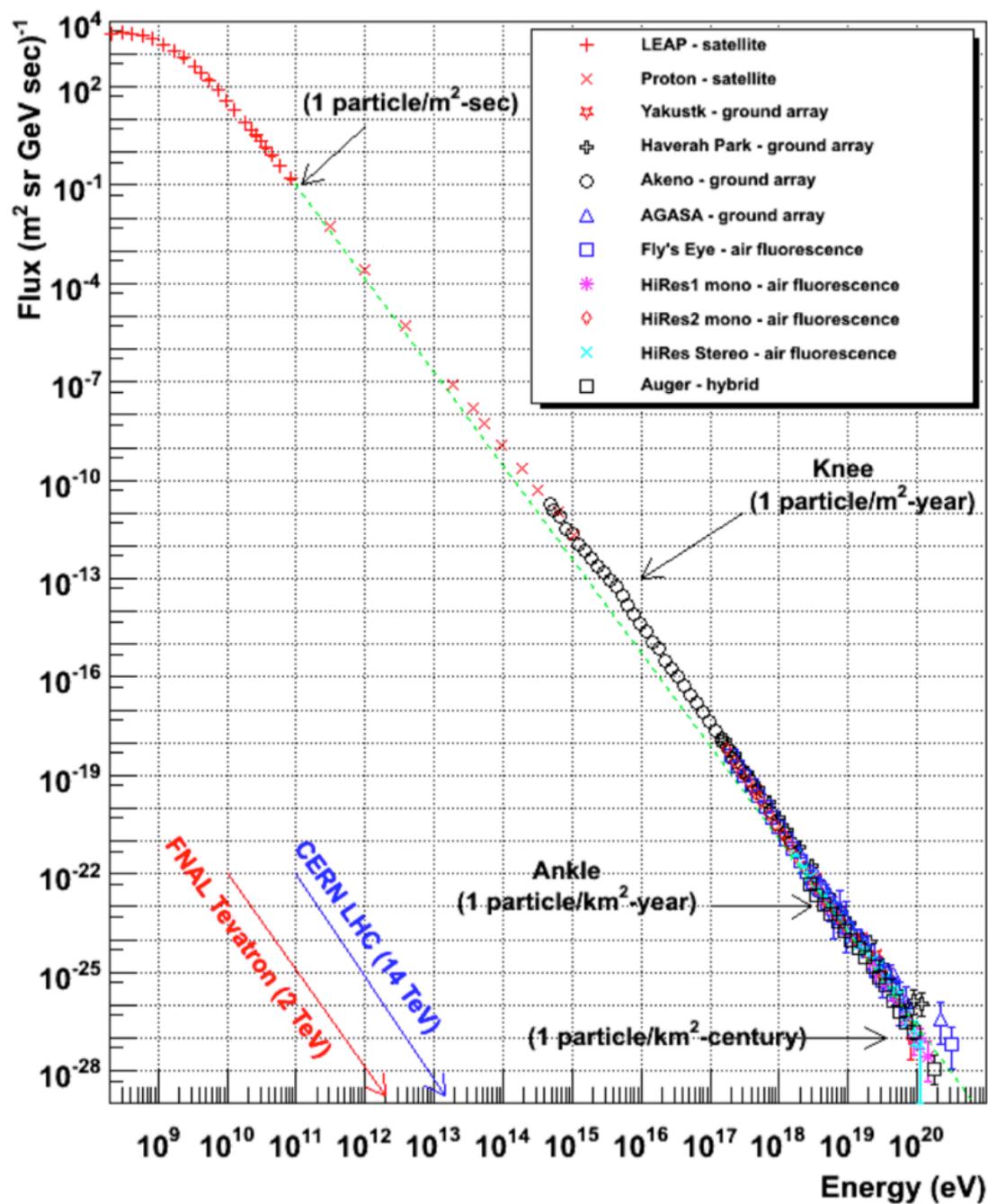
Mendoza, Argentina, 1400m altitude
2008
1600 tanks spread over 3000 sq km



Auger Observatory

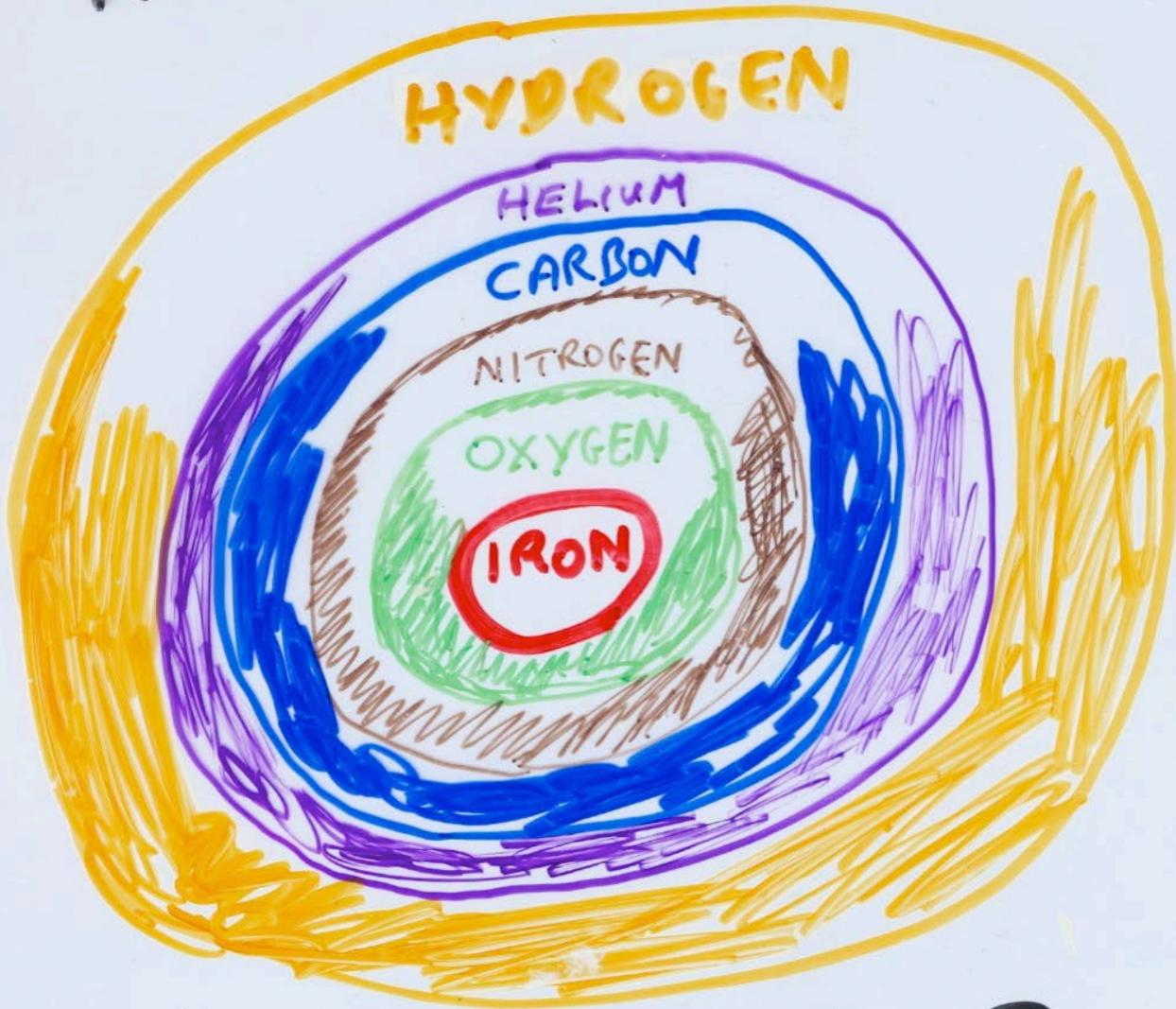
Ultrahigh energy
cosmic ray air showers
1 per sq km per century





Exploding stars

A MASSIVE STAR EVOLVES

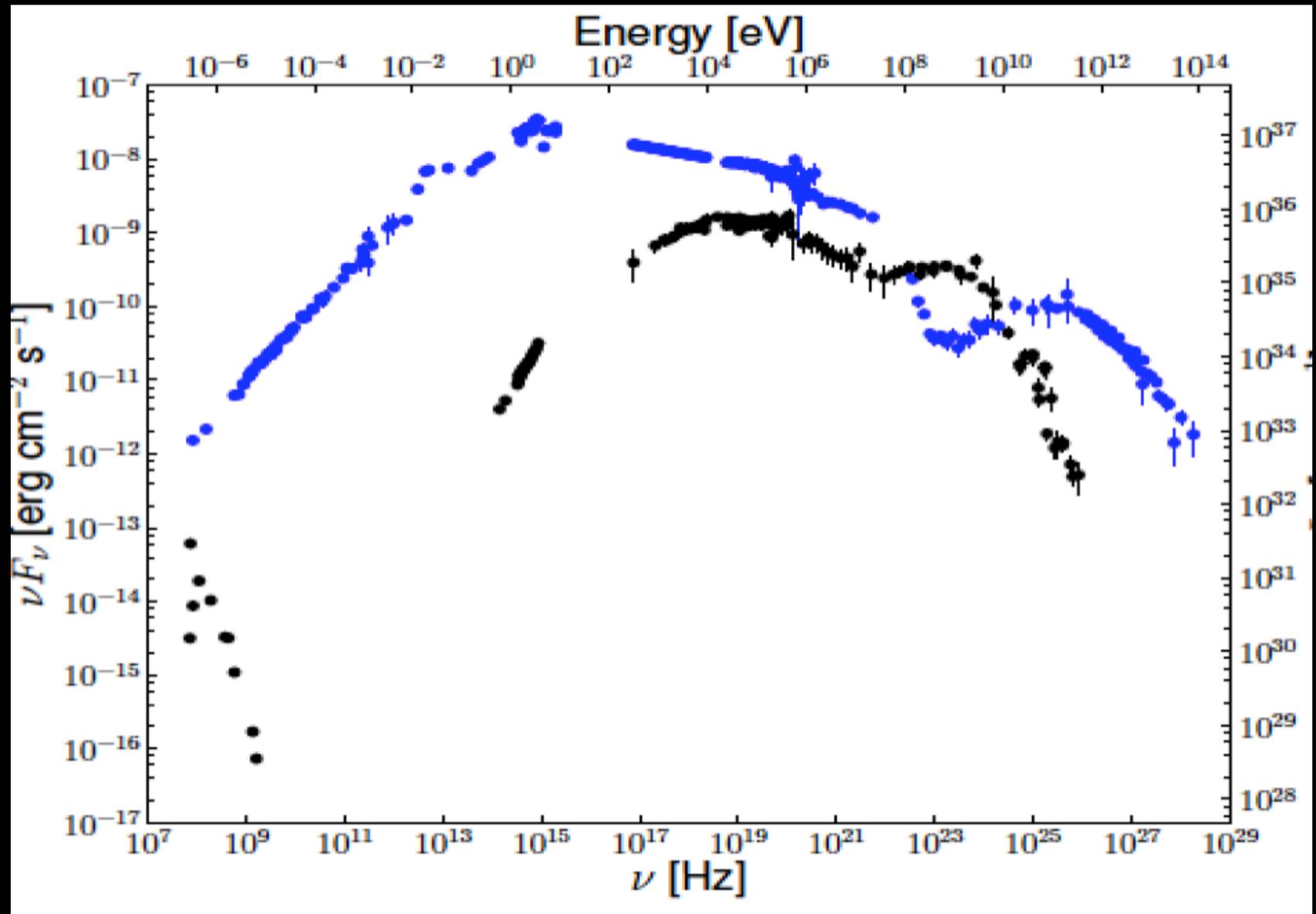


AND EXPLODES

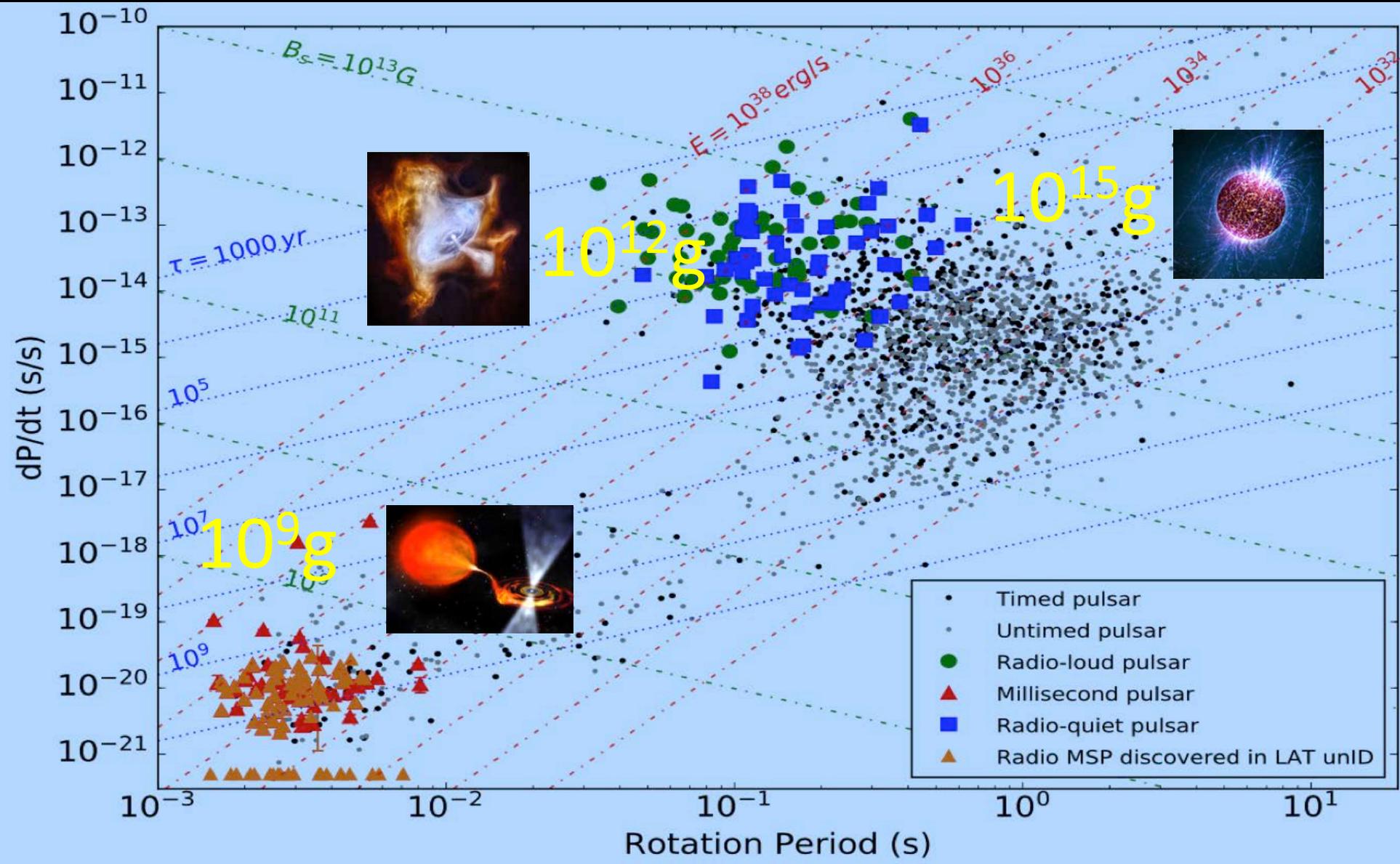
FROM ITS ASHES OUR SOLAR SYSTEM FORMED



CRAB spectral energy

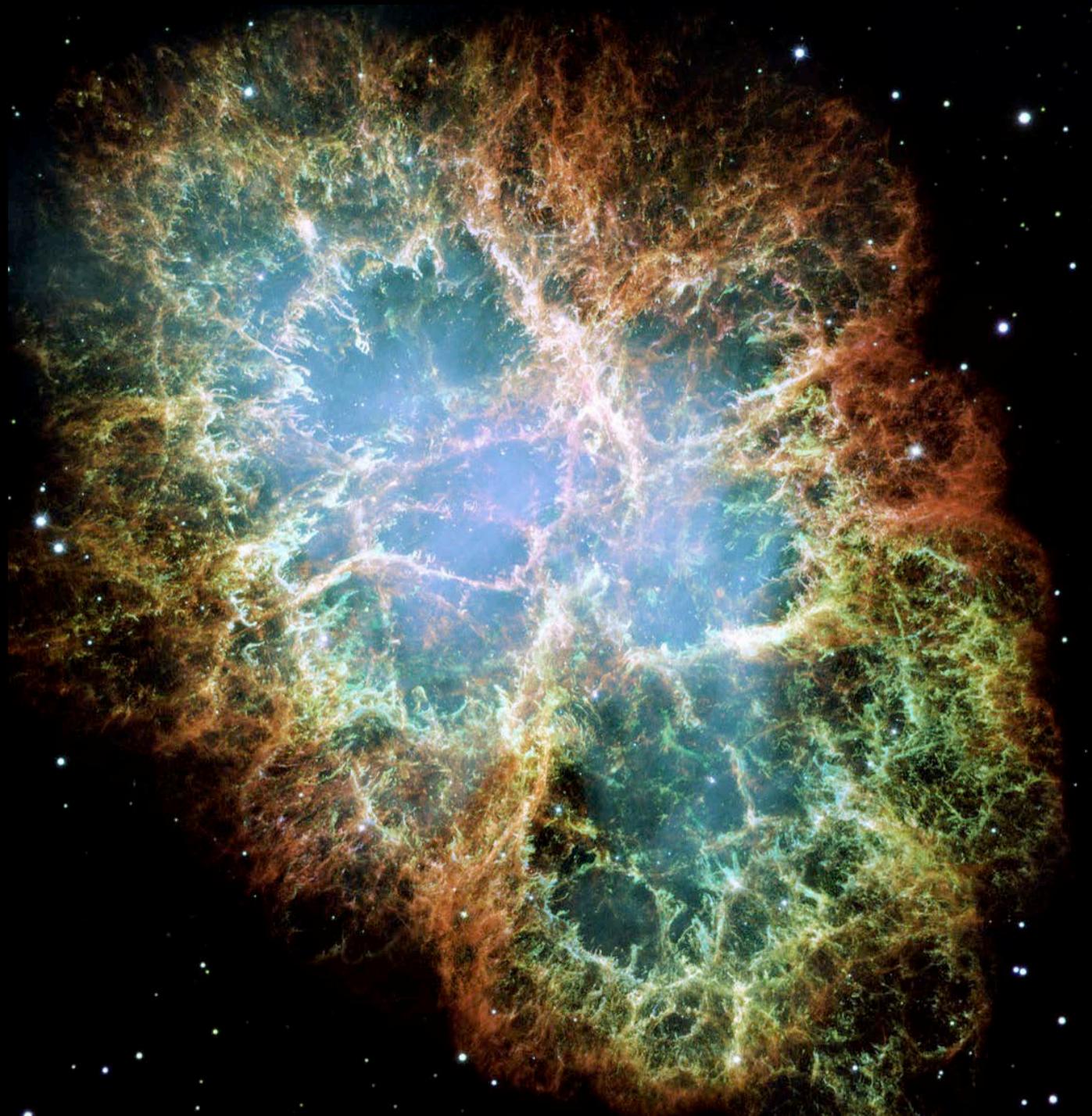


Pulsars

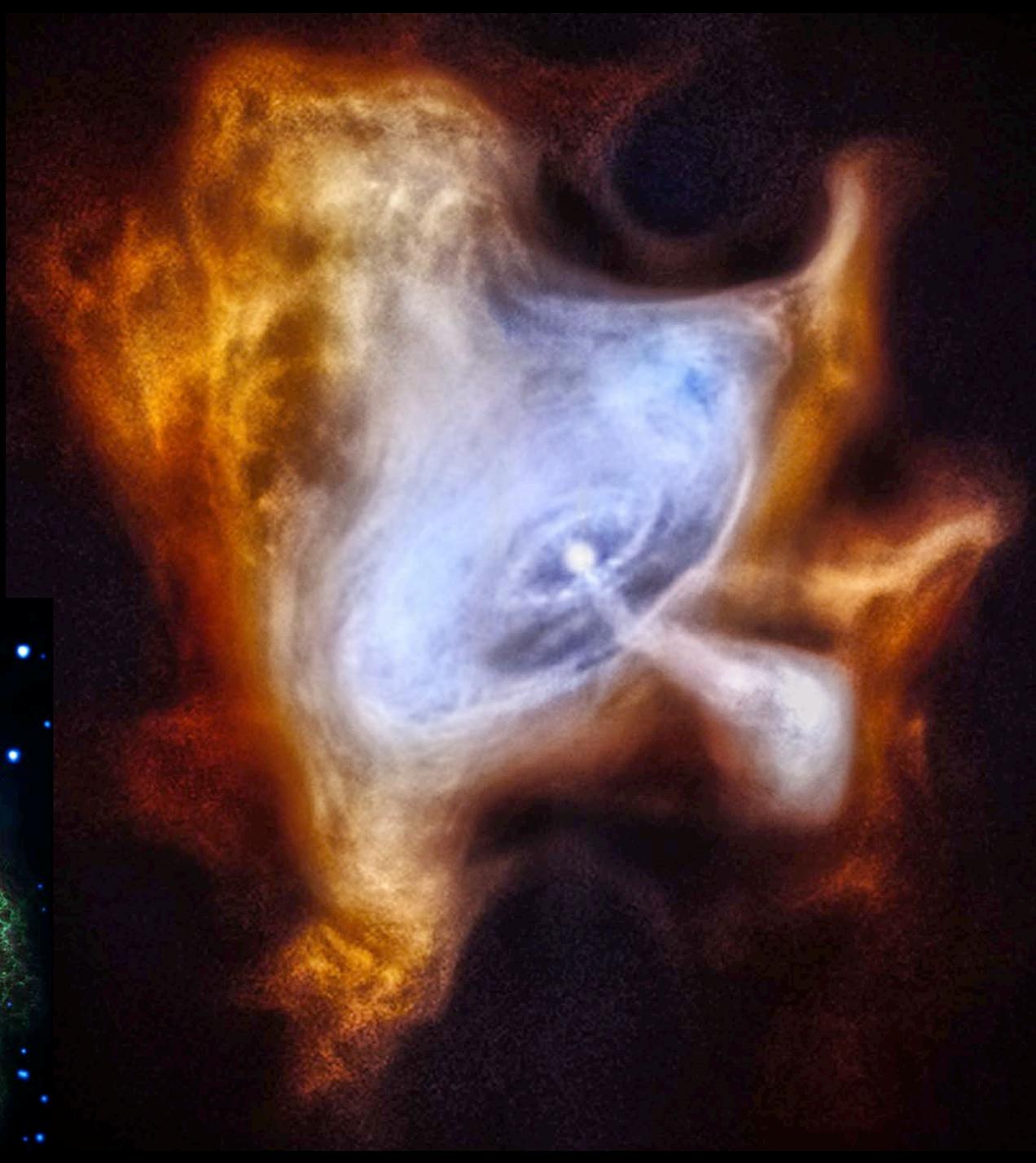


Crab
Supernova
1054 AD

Radio, IR, optical, xr

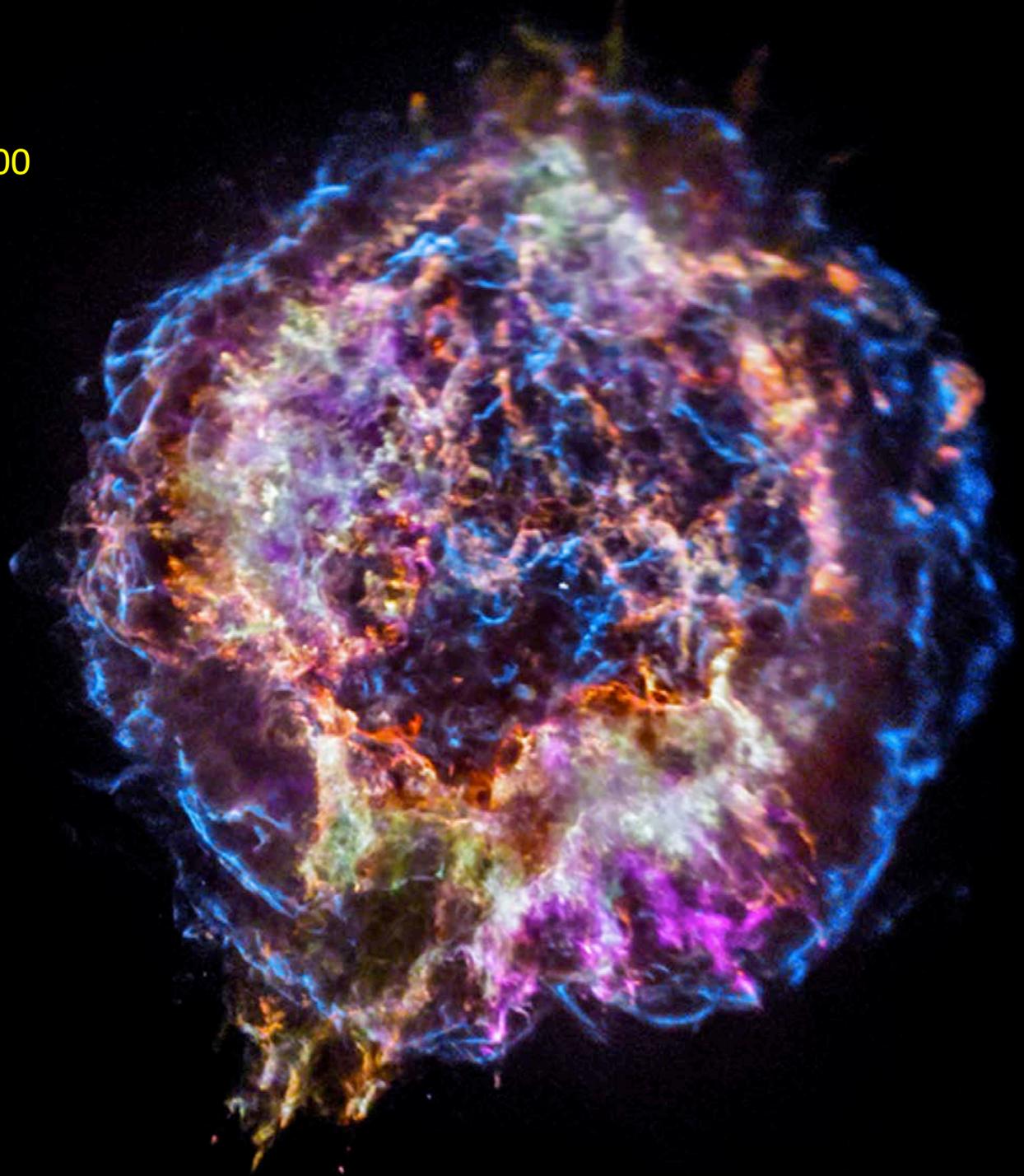


XR image of crab



Cassiopeia A

Supernova remnant c. 1700



Vela supernova remnant
exploded 10000 yrs ago



Cygnus loop: Veil supernova remnant
exploded 8000 yrs ago

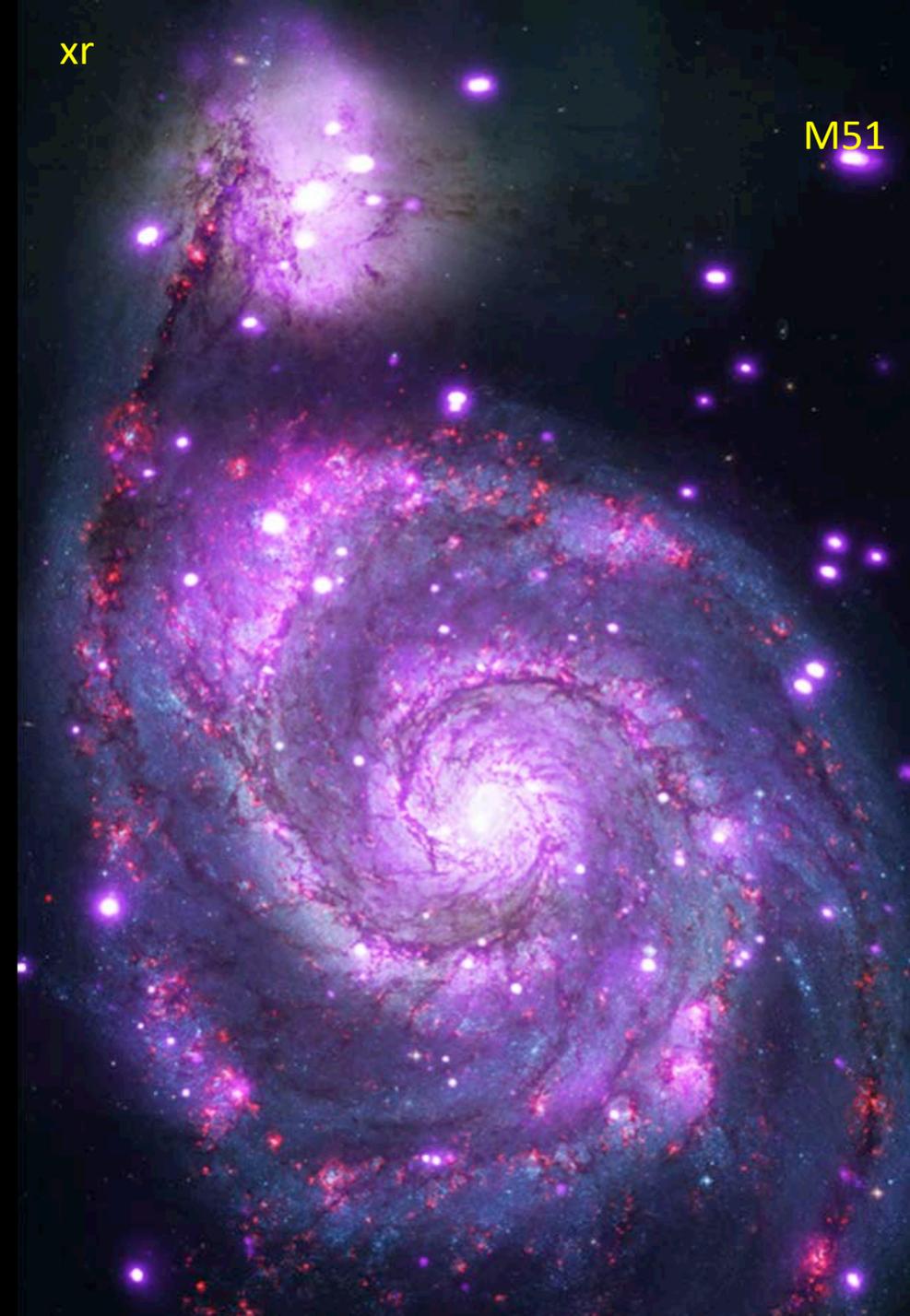
Galaxies



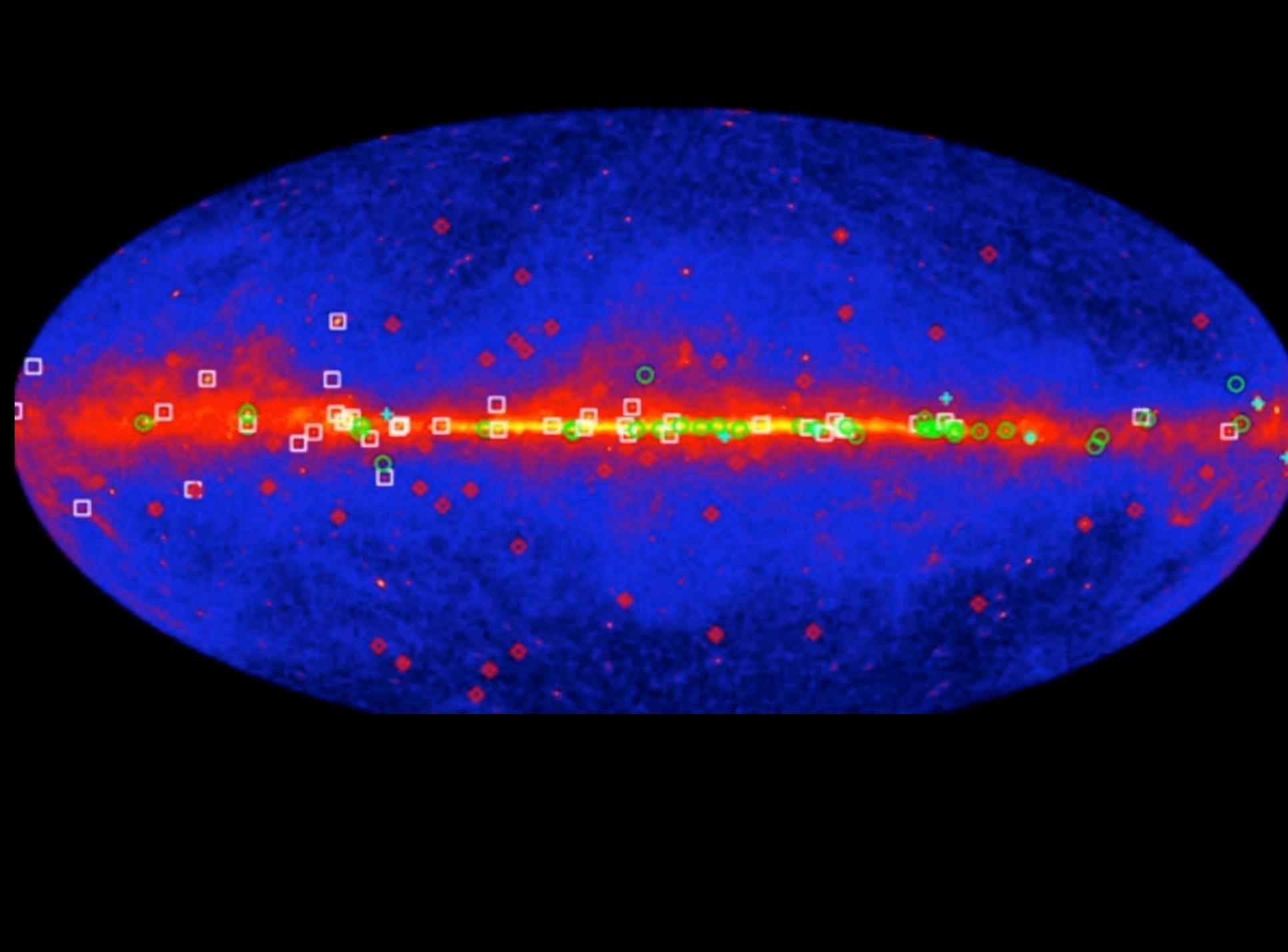
xr

M51

optical

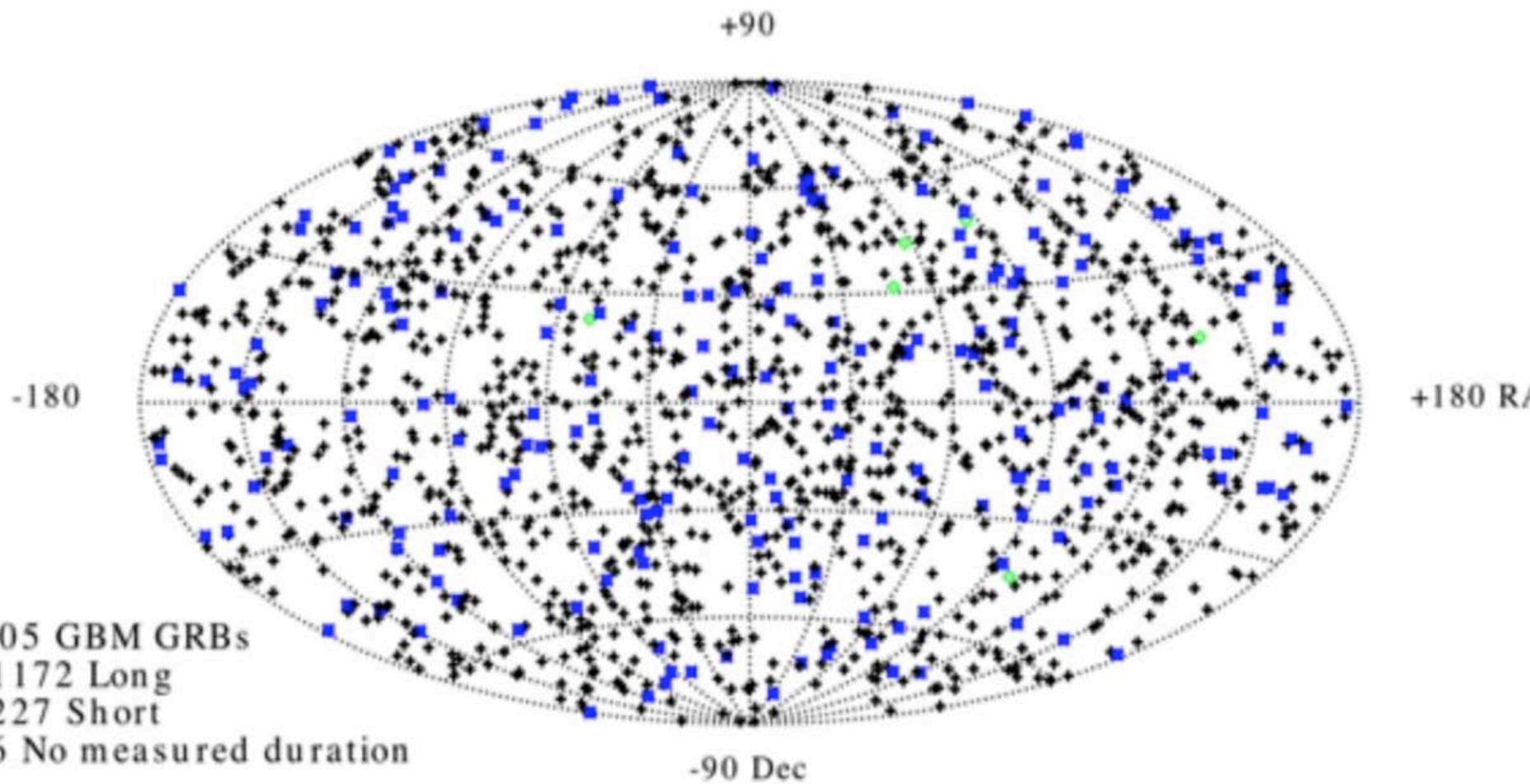


Gamma ray pulsars



Gamma ray bursts

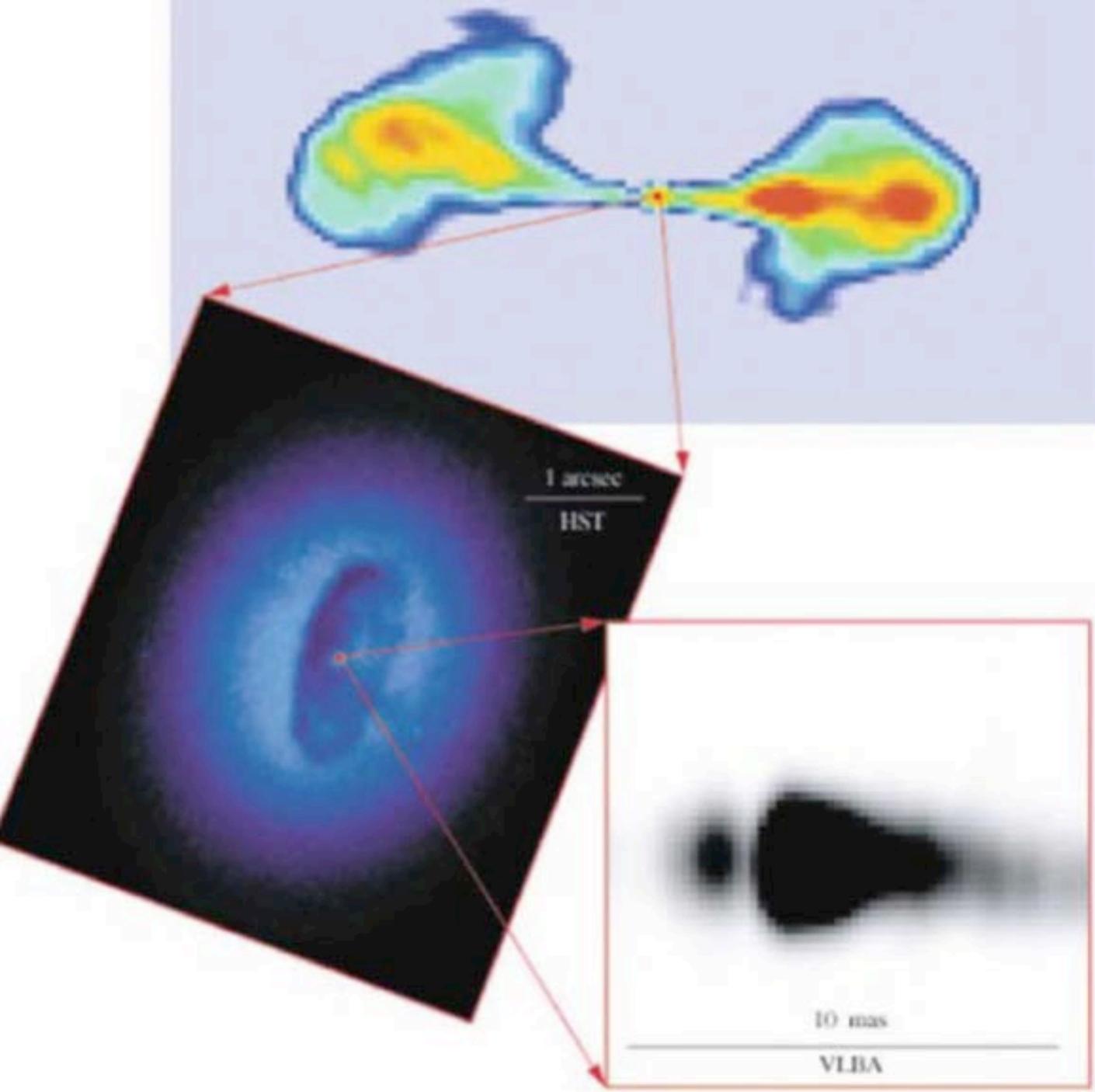
Fermi GBM GRBs in first six years of operation



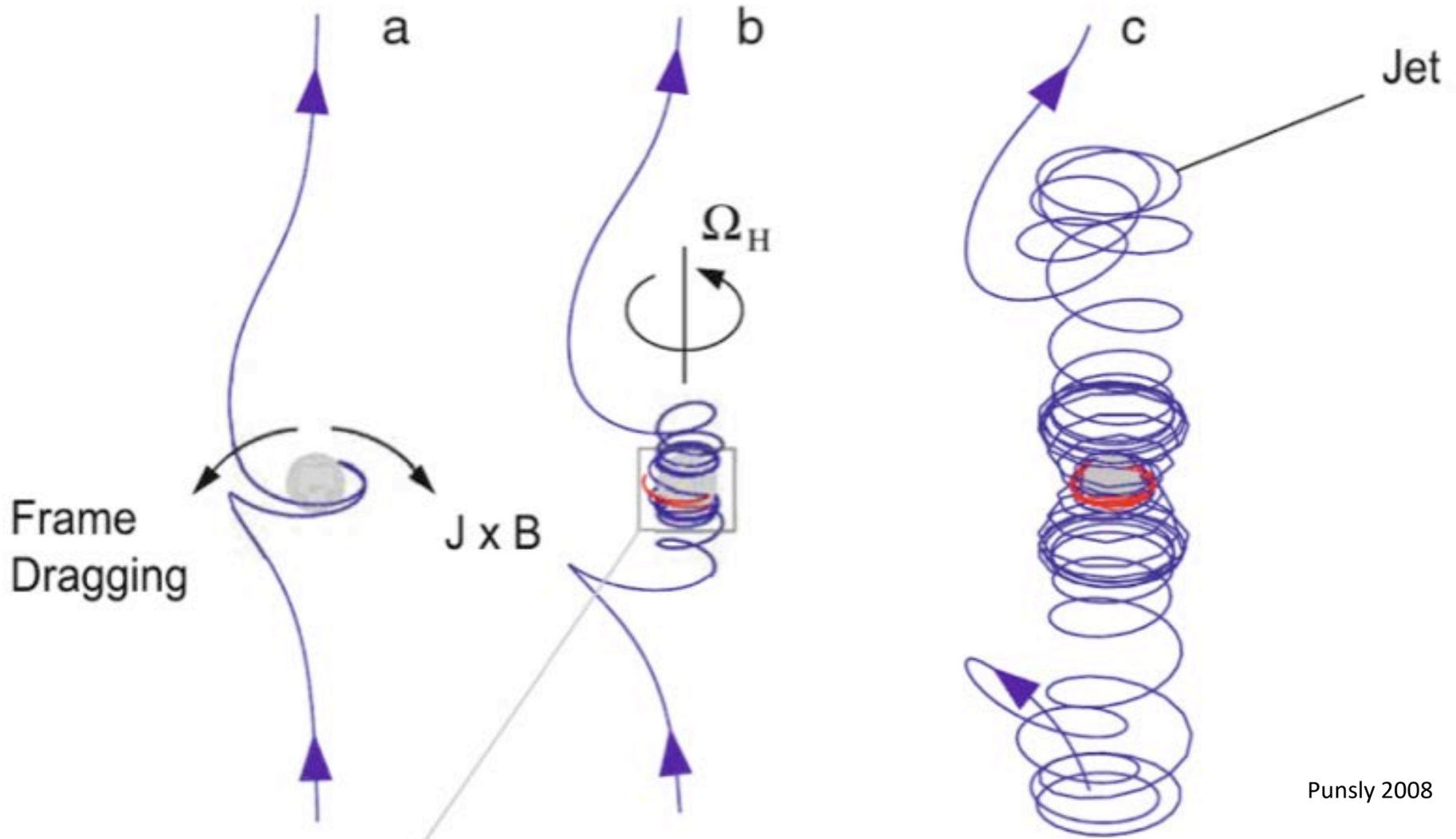
Supermassive Black Holes

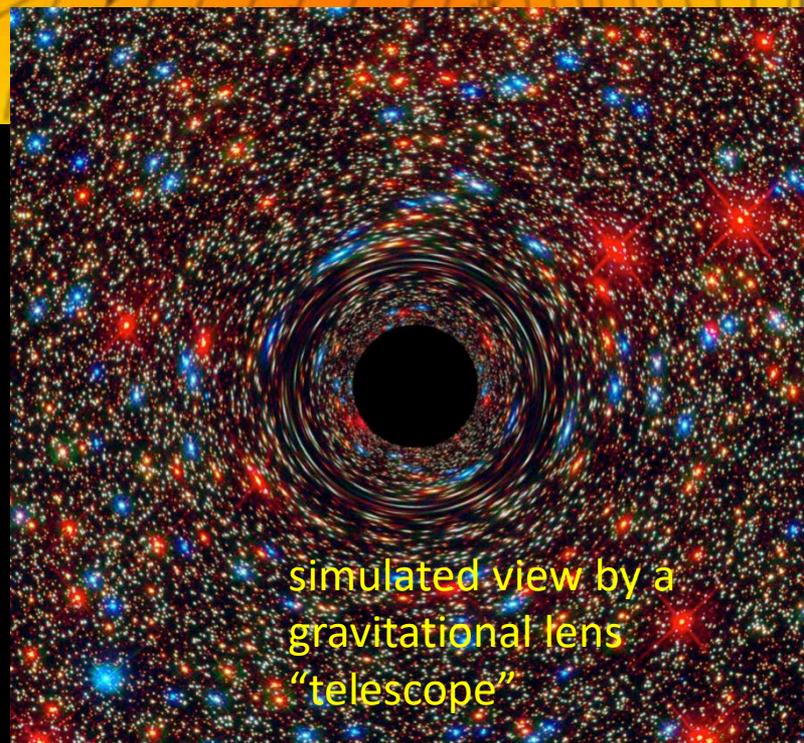
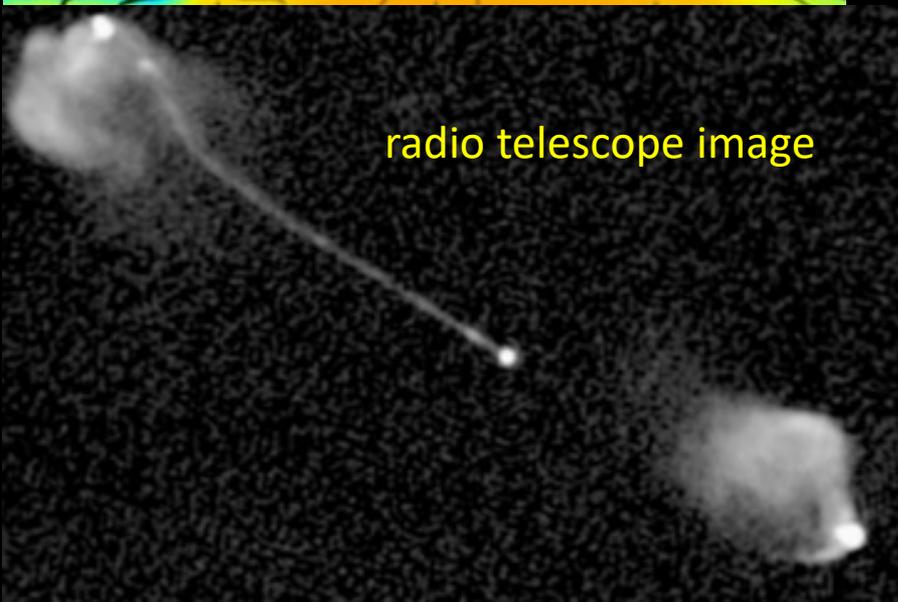
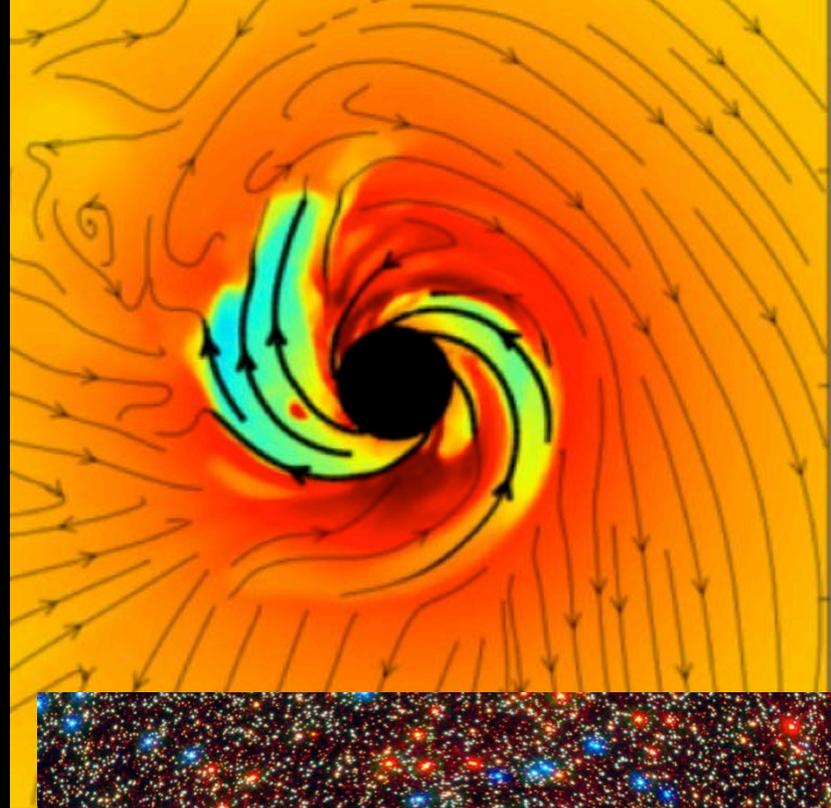
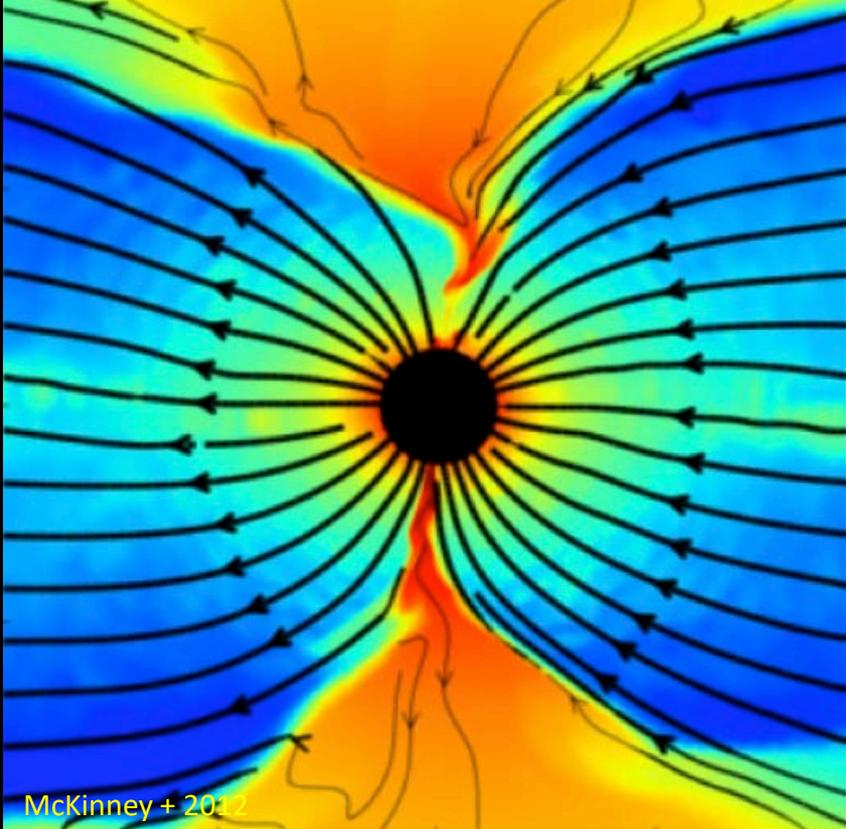
NGC 7052



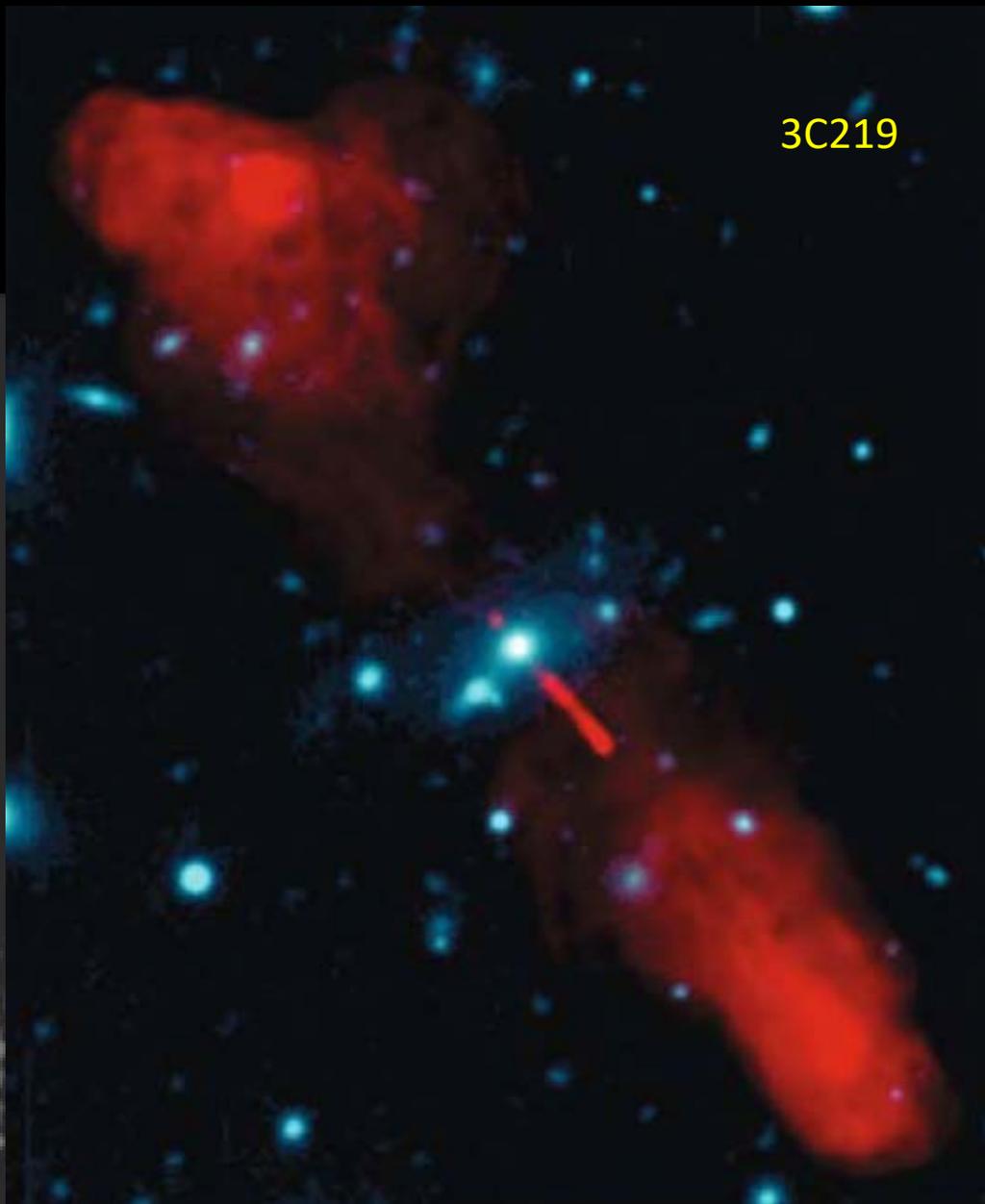
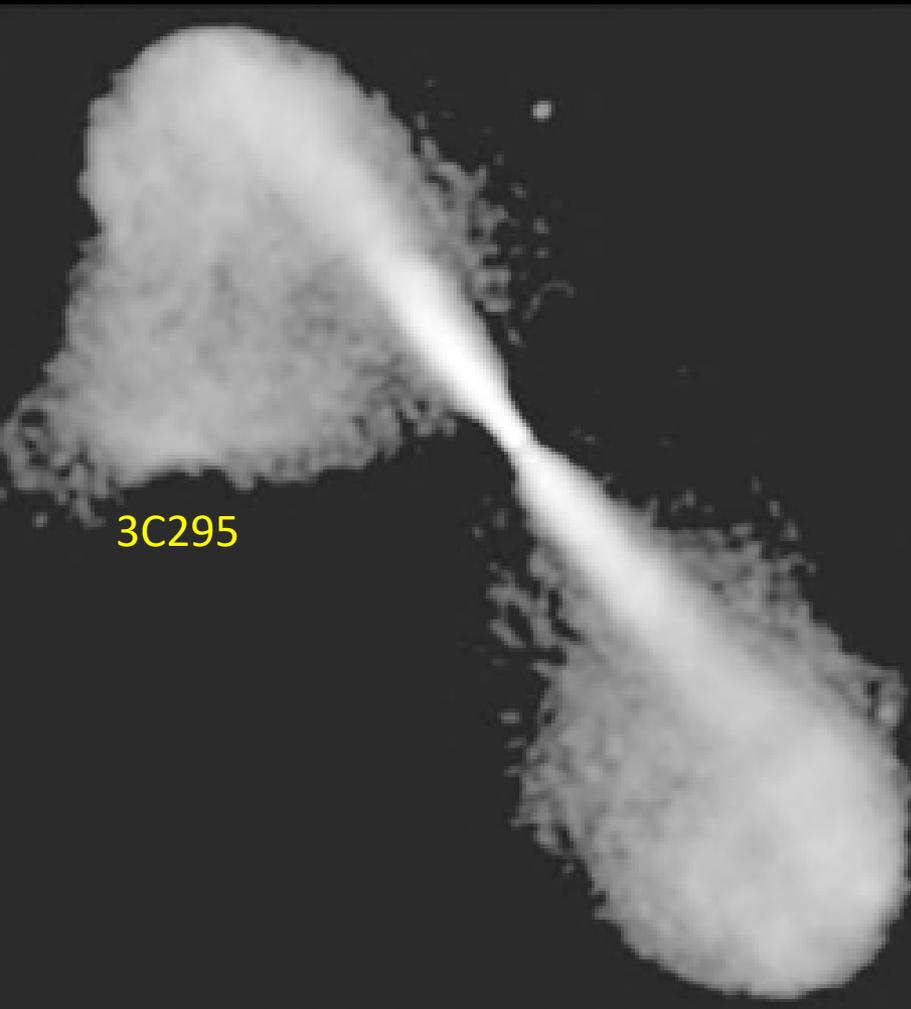


Imagine winding up an elastic band

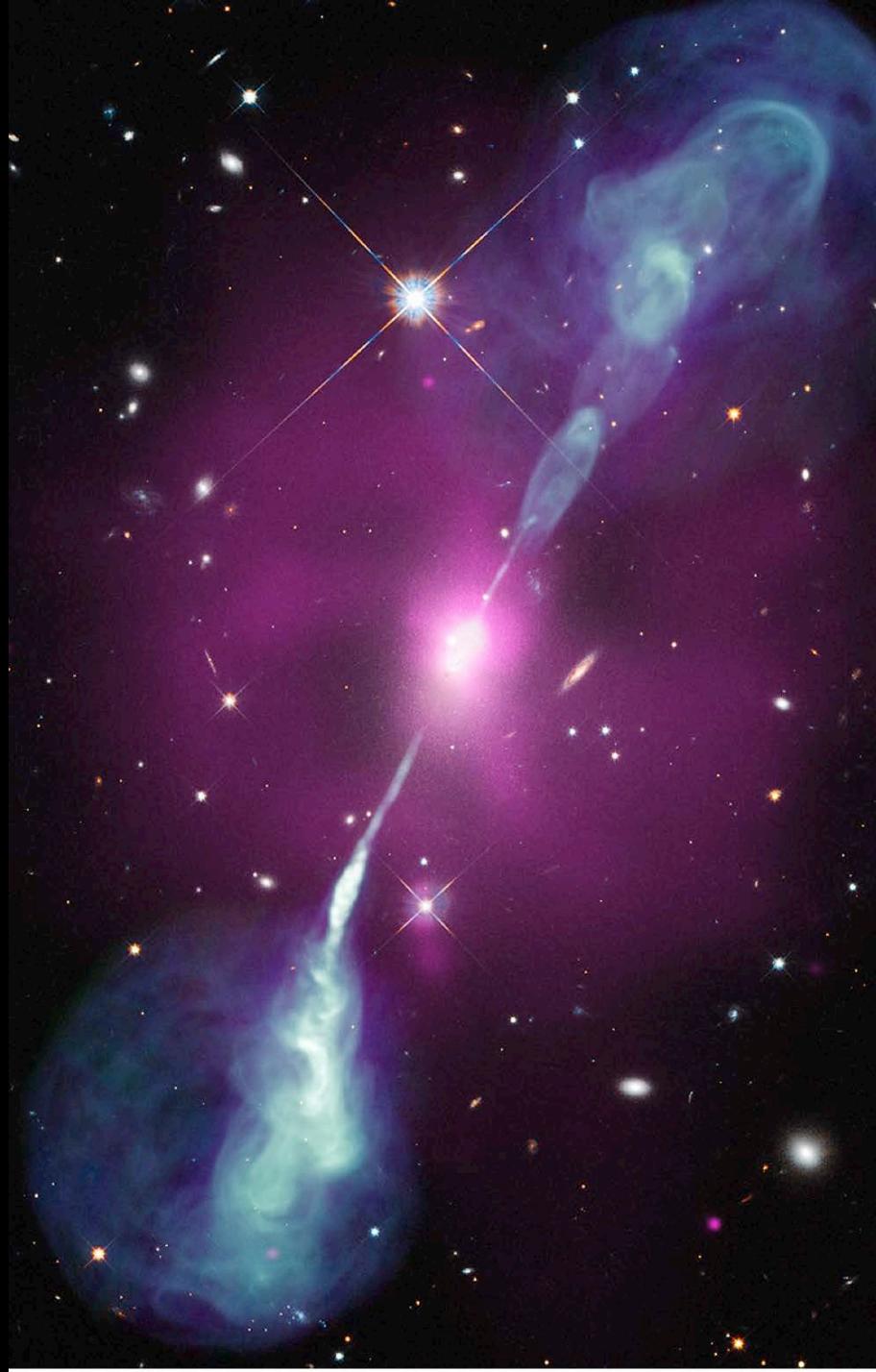




Jets from black holes



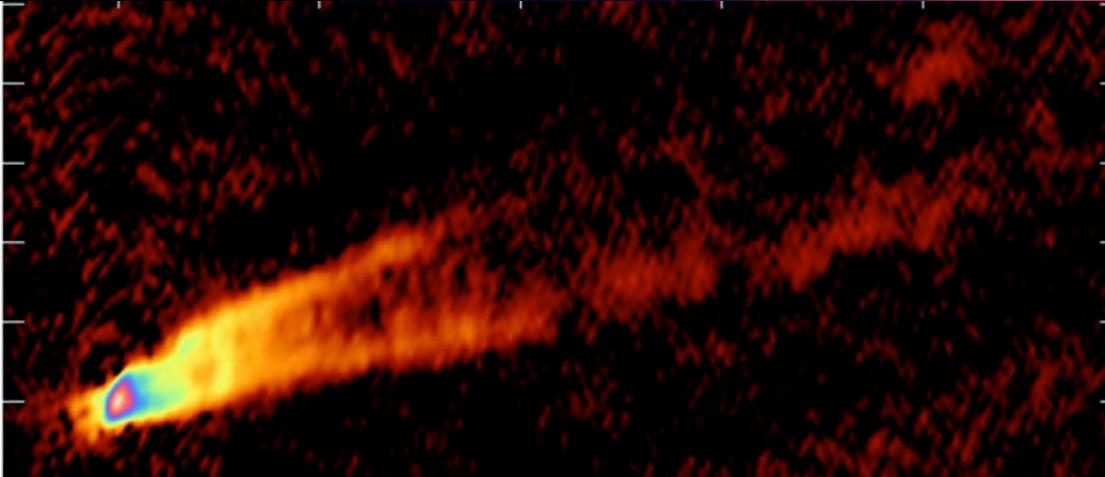
Hercules A



Pictor A



M87



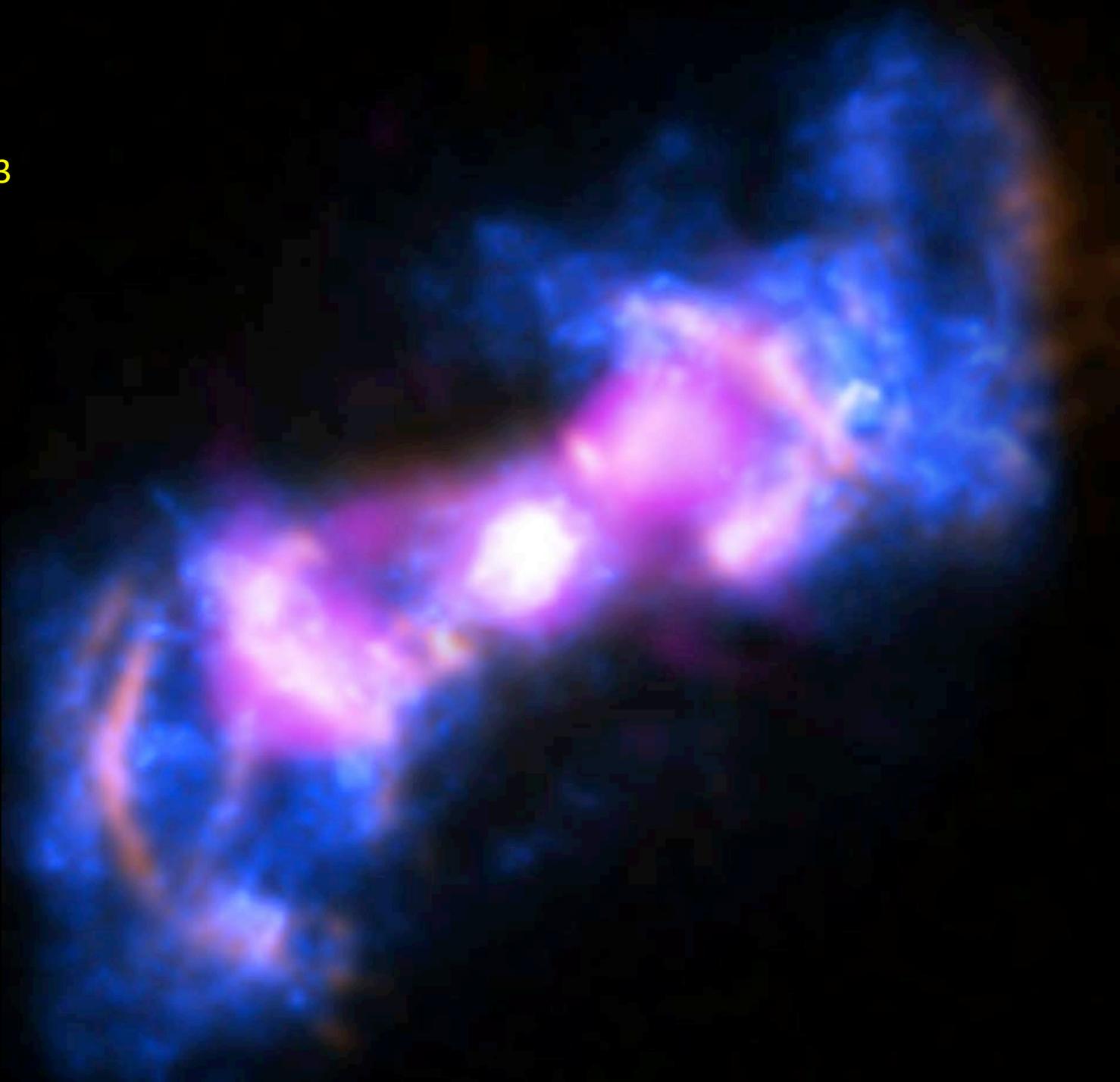
4 arcmin

M87

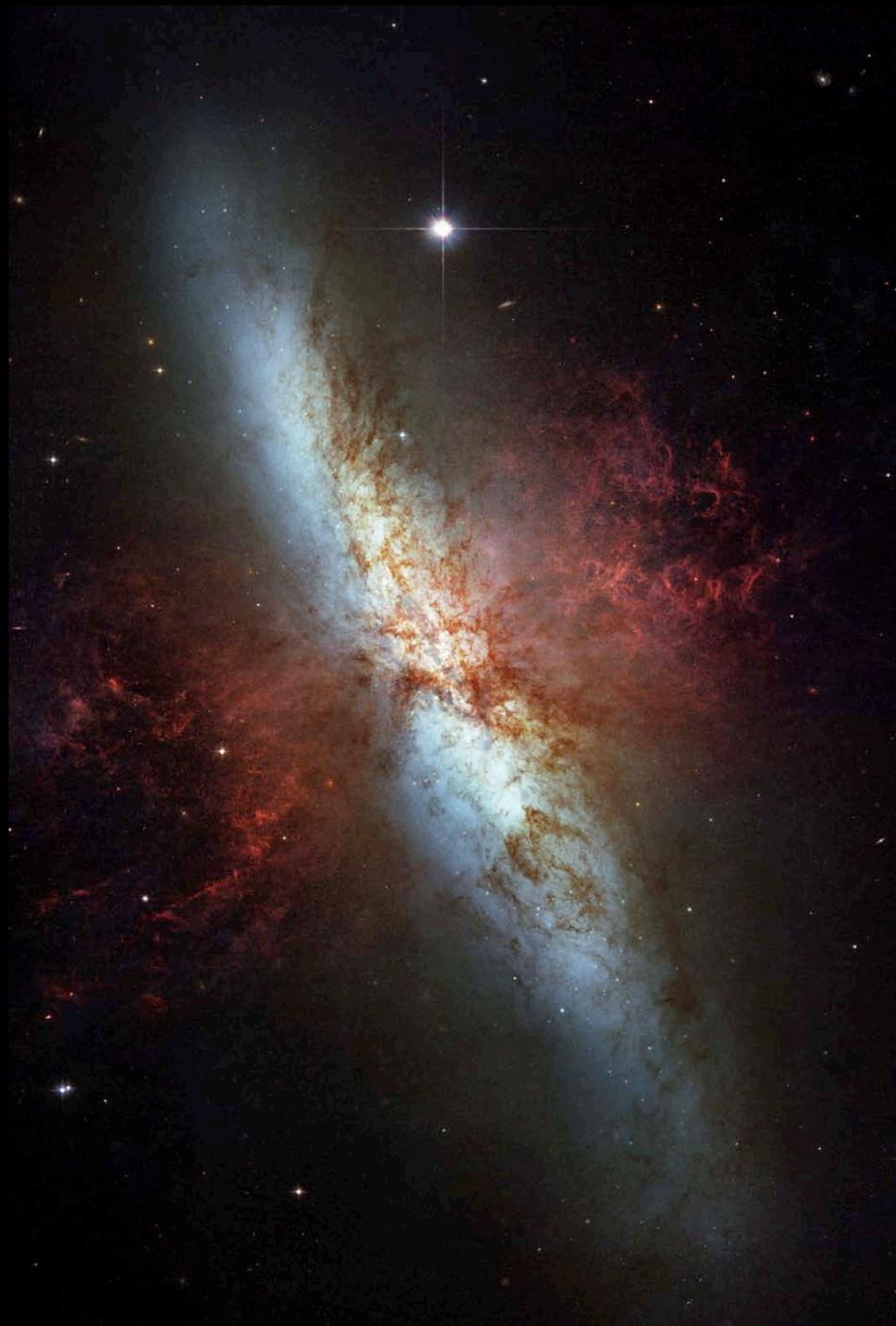


Winds

Markarian 573



M82

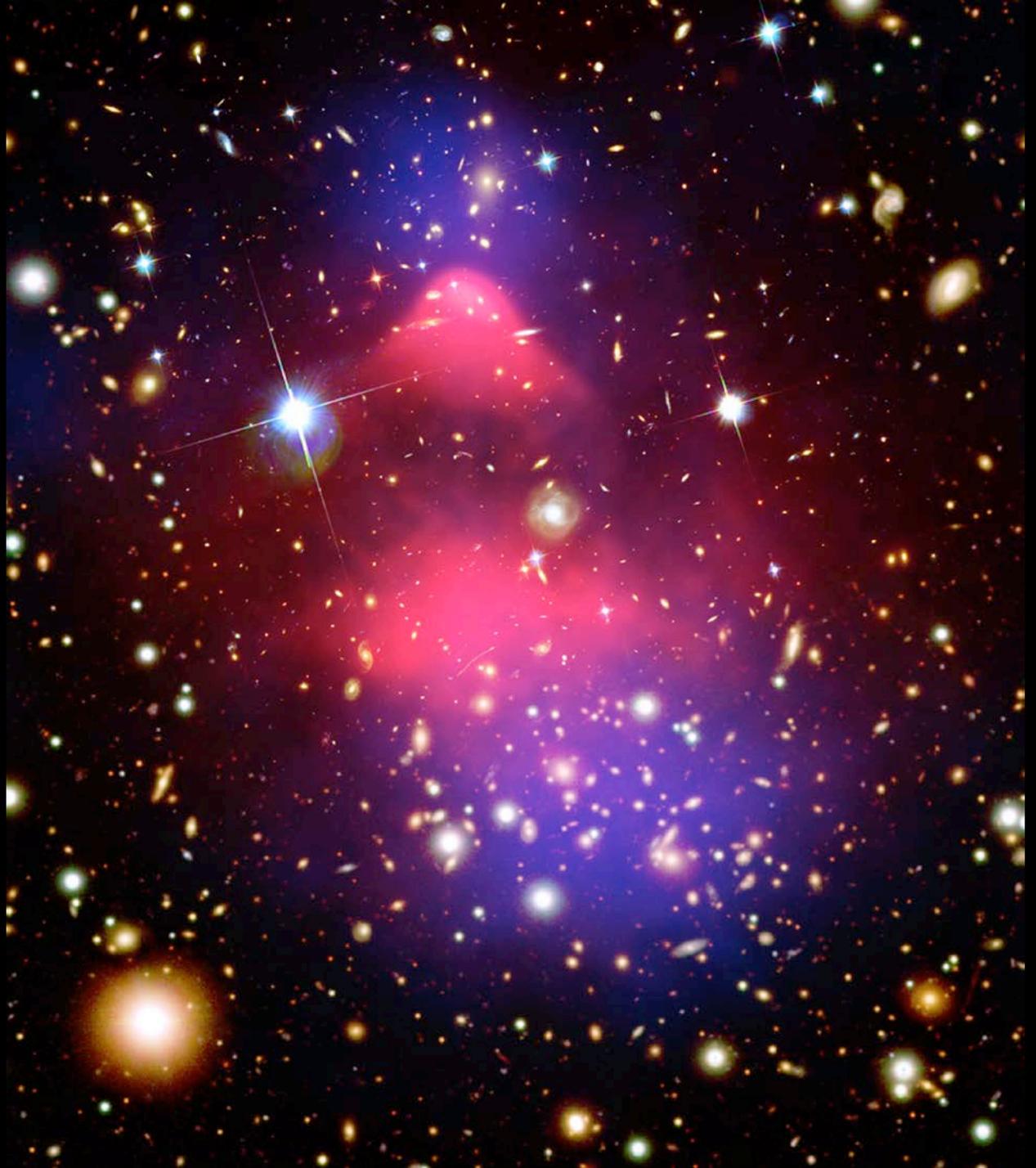


galaxy clusters

Bullet cluster

X-rays from hot gas

Dark matter



Perseus cluster

