Astronomy in 2012

Jonathan McDowell

Harvard-Smithsonian Center for Astrophysics

Welcome to the Harvard-Smithsonian Center for Astrophysics (CfA).

We are one of the largest - possibly **the** largest – astronomy research institutions on the planet

(*indeed, as far as we know, in the entire spiral arm*)

The CfA consists of two interwoven institutions, the Harvard College Observatory (HCO) and the Smithsonian Astrophysical Observatory (SAO); its buildings also house the Department of Astronomy of Harvard University.

Here at the CfA we:

- observe the universe, with ground-based telescopes in Arizona, Chile and Hawaii, and instruments in Earth orbit and deep space.
- design, develop and build astronomical instruments, telescopes and space payloads
- carry out theoretical investigations of the planets, Sun, stars, galaxy and universe
- house some of the crucial global services for the astronomy community (ADS, ds9, IAU-MPC, US Simbad-mirror)
- operate NASA's Chandra X-ray Observatory spacecraft for the community

Who we are

Harvard-Smithsonian Center for Astrophysics (CfA)
60 Garden St, Cambridge

Chandra X-ray Center (CXC)

MIT Kavli Institute
1 Hampshire St, Cambridge

Chandra
Operations Control Center (OCC)
1 Hampshire St, Cambridge

Harvard College
Observatory (HCO)

Smithsonian
Astrophysical
Observatory (SAO)

1000 staff at CfA, including 400 PhDs, doing all kinds of research
Here are just a few of them

Charles Alcock (Director)

"MACHO" project discovered microlensing

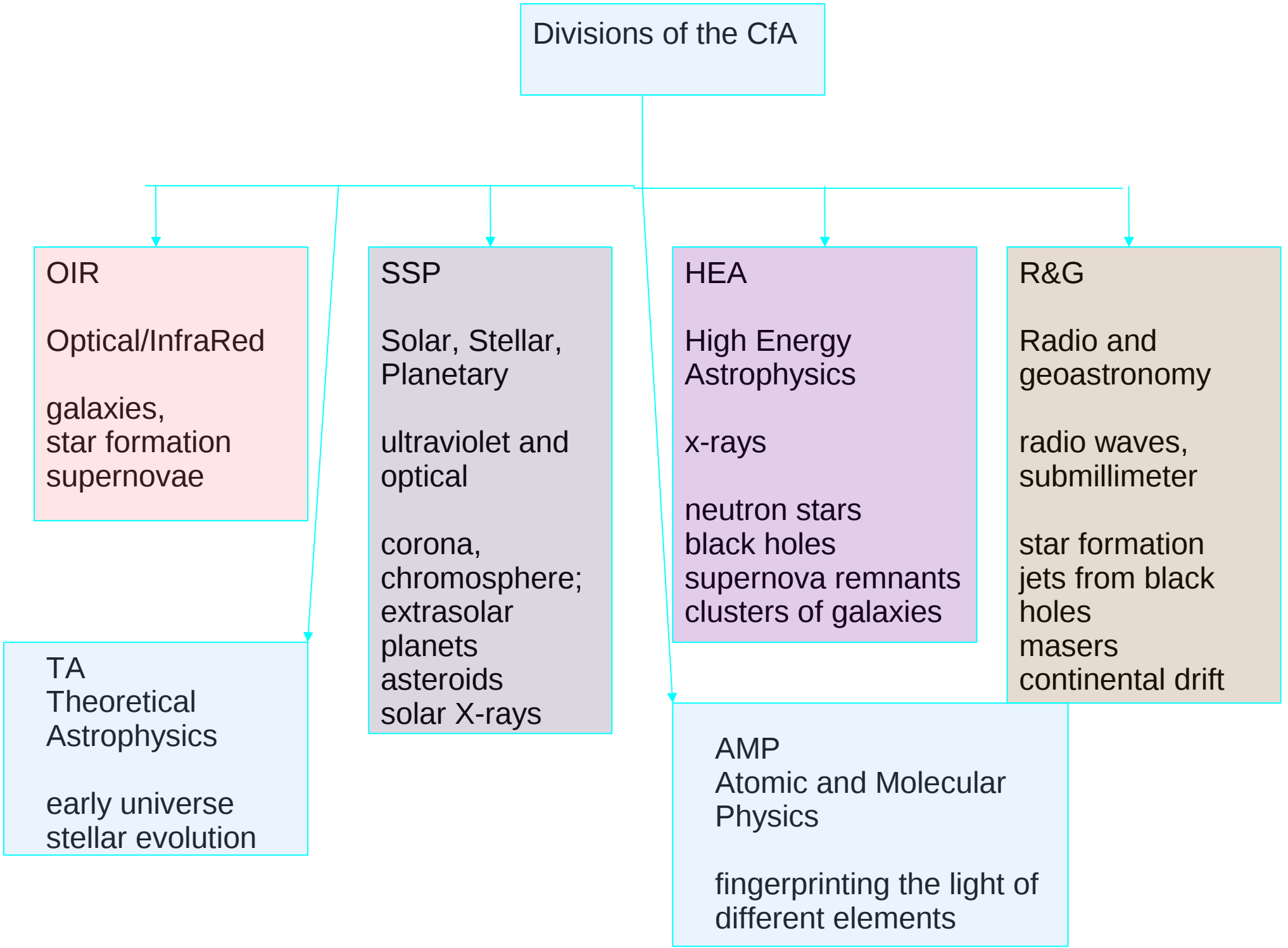
Bob Kirshner – supernova cosmology, discovery of dark energy

Julia Lee – black hole accretion

Dave Charbonneau
Spectrum of an extrasolar planet

Margaret Geller – mapping the universe

Stella Offner – studying how stars form


Divisions of the CfA
OIR
Optical/InfraRed
galaxies,
star formation
supernovae
SSP
Solar, Stellar, Planetary
ultraviolet and optical
corona, chromosphere; extrasolar planets
asteroids
solar X-rays
HEA
High Energy Astrophysics
x-rays
neutron stars
black holes
supernova remnants
clusters of galaxies
R&G
Radio and geoastronomy
radio waves, submillimeter
star formation
jets from black holes
masers
continental drift
TA
Theoretical Astrophysics
early universe
stellar evolution
AMP
Atomic and Molecular Physics
fingerprinting the light of different elements

CfA's Early History

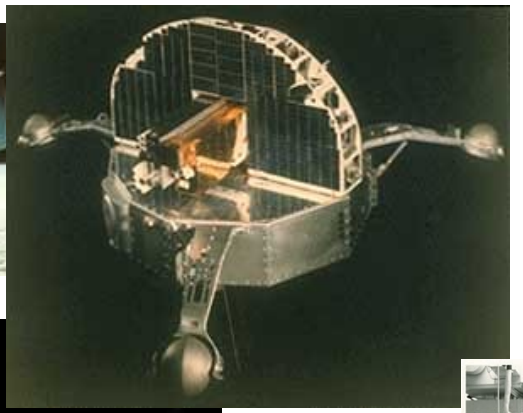
1839 Harvard College Observatory founded

1842 HCO moves to Garden St

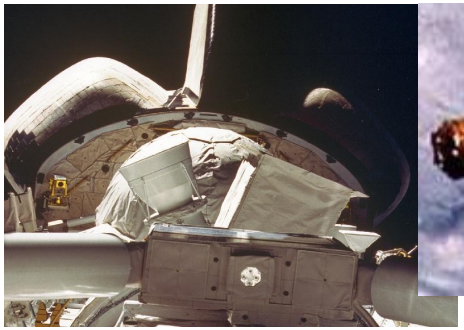
1847 The Great Refractor makes first observations
1847 Early daguerrotypes of the Moon
1848 Bond discovers Saturn VII (Hyperion)
1882 Harvard Photometry list of bright stars
1887 Plate surveys begin
1890 SAO founded in Washington, DC
Studies solar energy output

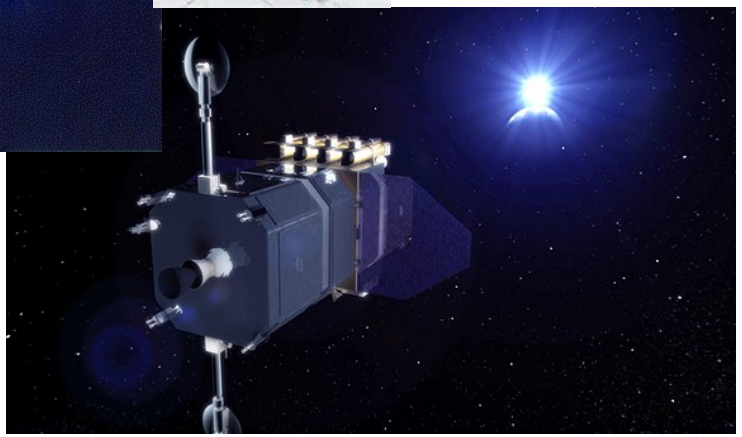
1890 Pickering and Fleming classify star types
1918-1924 Annie Cannon's HD catalog of stellar spectra published
1955 SAO moves to colocate with HCO
1957 Moonwatch project tracks Sputnik and other satellites
1973 SAO and HCO form the CfA
X-ray group joins CfA
1978 Einstein satellite studies X-ray sources
1981 CfA Redshift survey maps the cosmos

The CfA Space Program



Orbiting Solar Observatory – 1962
OAO Celescope – 1968
Gravity Probe A - 1976
Einstein Observatory – 1978
Spacelab 2 IRT - 1985
ROSAT HRI telescope – 1990
SOHO UVCS telescope – 1995
Spartan 201 - 1995
TRACE – 1998
SWAS - 1998
Chandra – 1999
Spitzer IRAC camera - 2003
XRT on Hinode - 2006
Solar Dynamics Observatory - 2010

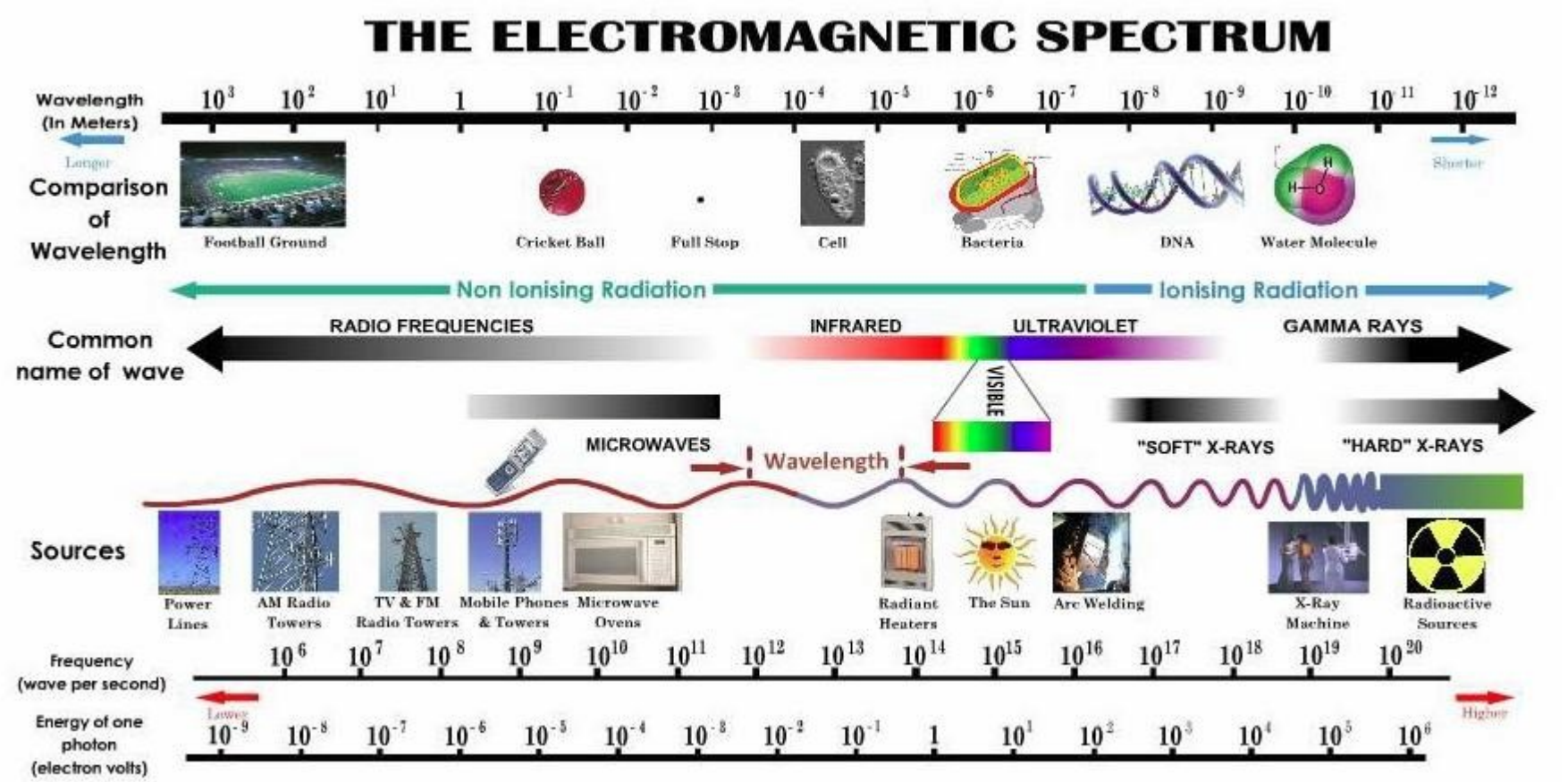




What's happing in the Universe these days?

We often divide up astronomy by the different WAYS WE LOOK AT THE SKY...

- RADIO telescopes
- X-RAY telescopes...



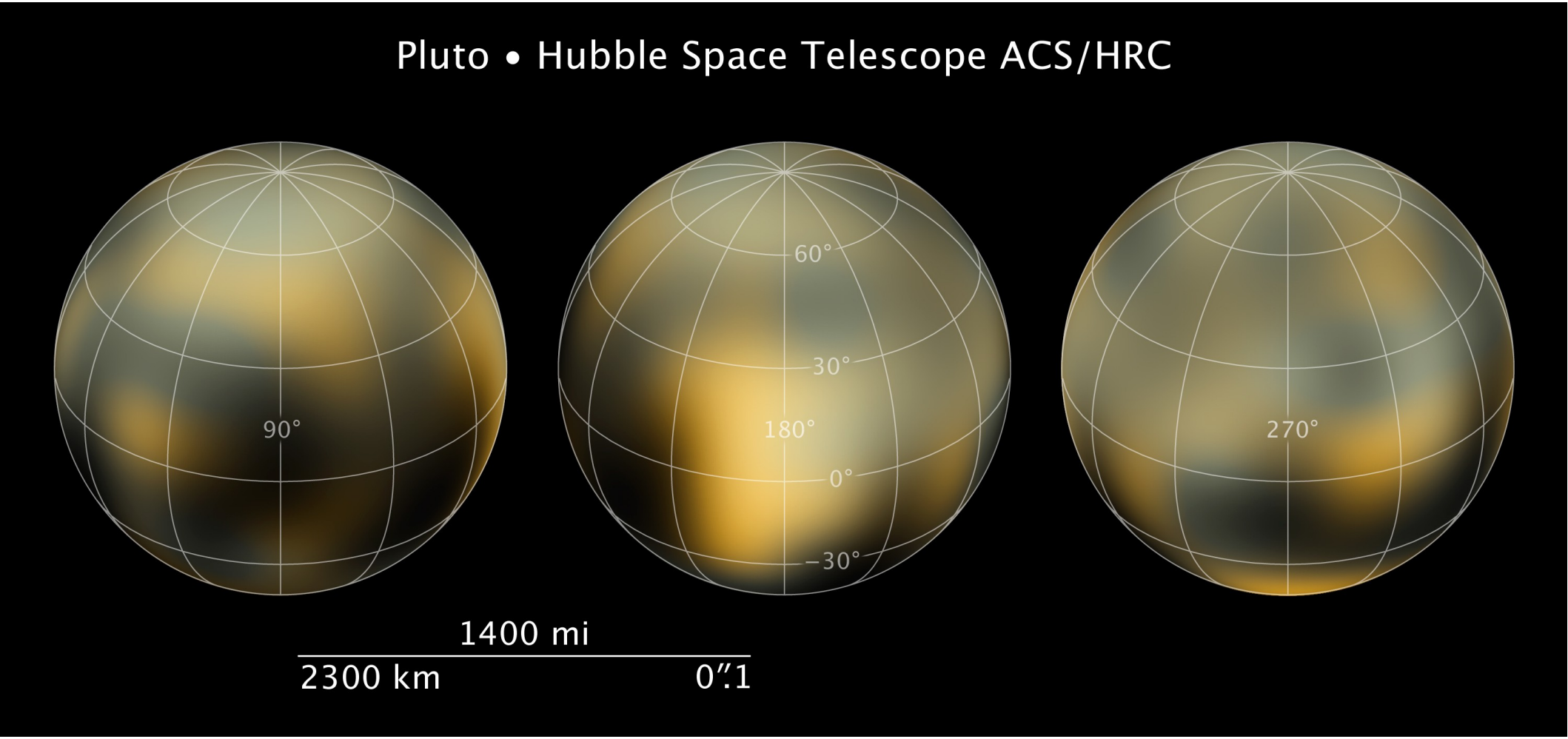
But I'll focus more on .. WHAT ARE WE LOOKING AT?

PLANETS
STARS
NEBULAE
GALAXIES

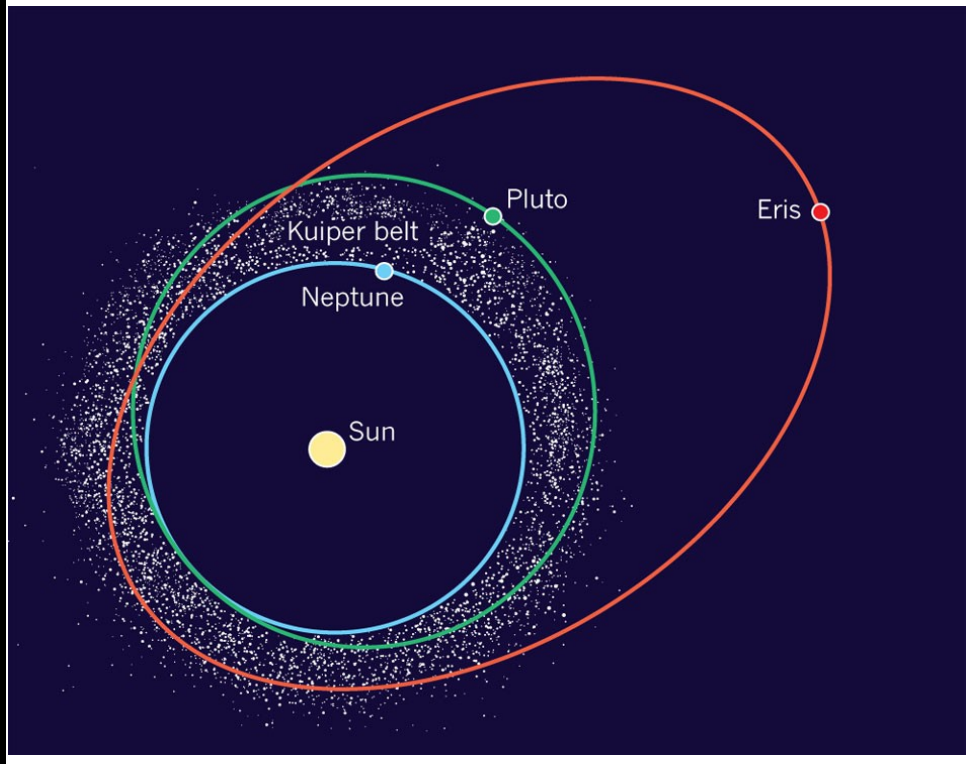
and the universe as a whole!

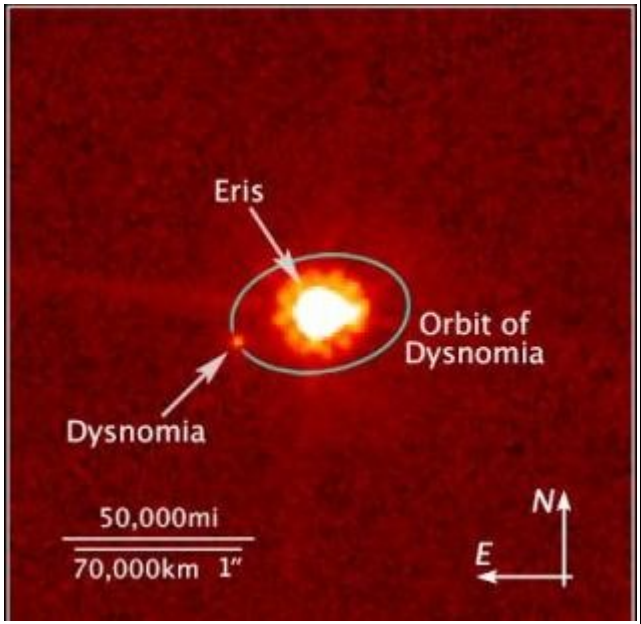
No, it's NOT a planet.

(but the New Horizons probe will visit it in 2015)

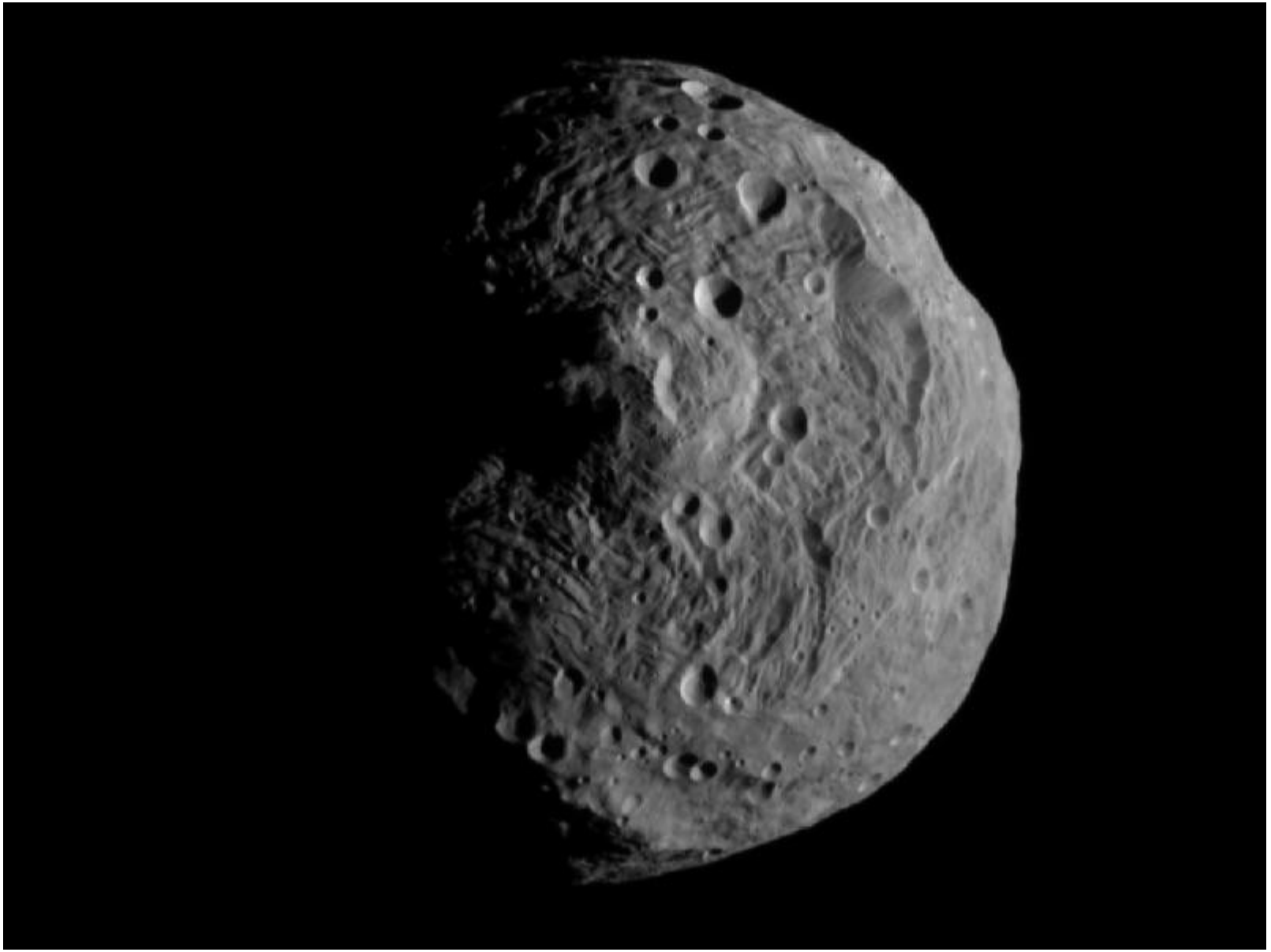



Dysnomia
Charon
Eris
Pluton
Makemake
Haumea
Sedna
Orcus
Quaoar
Varuna


Pluto
Eris
Kuiper belt
Neptune
Sun

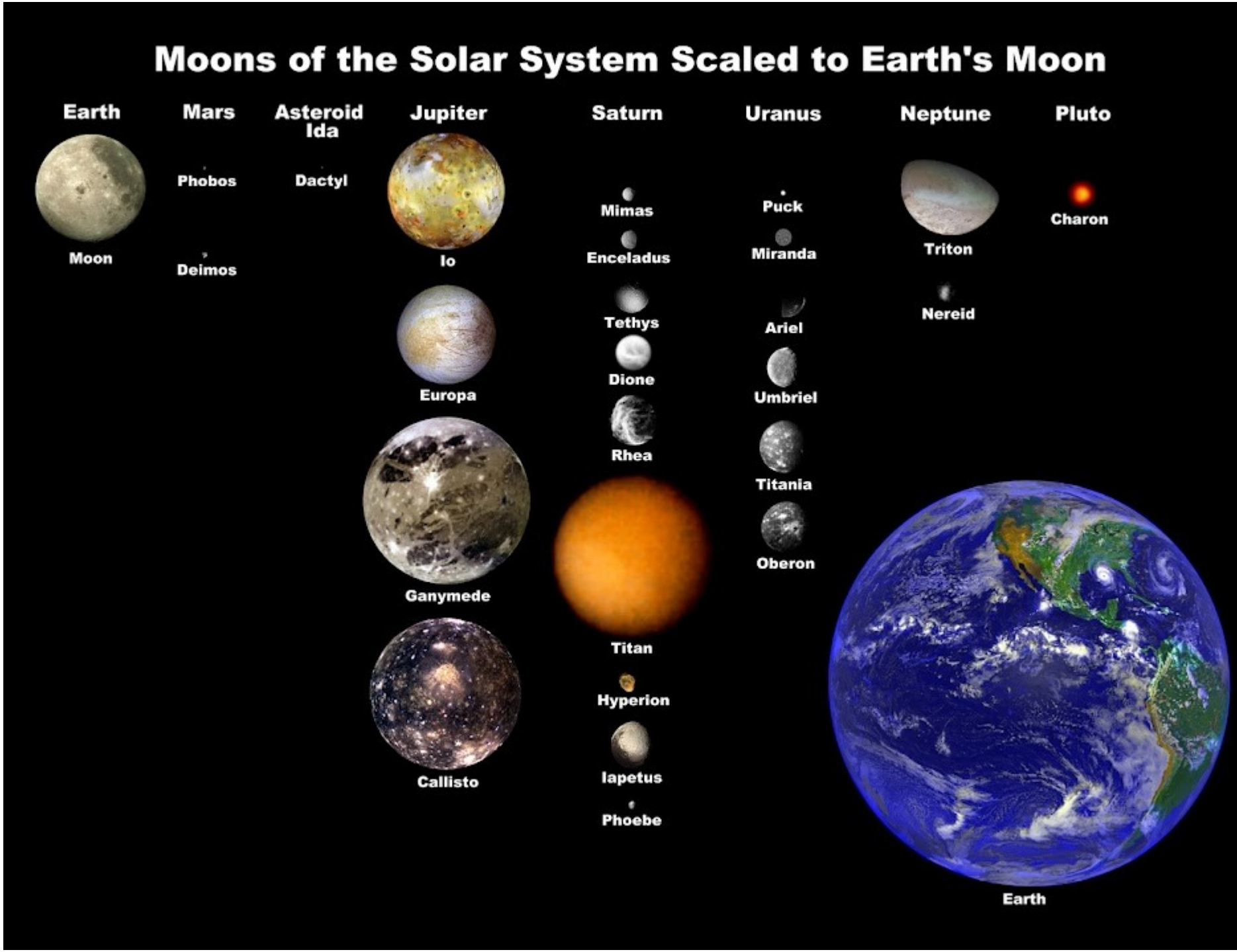

Eris
Orbit of
Dysnomia
Dysnomia
50,000mi
70,000km 1"
N
E

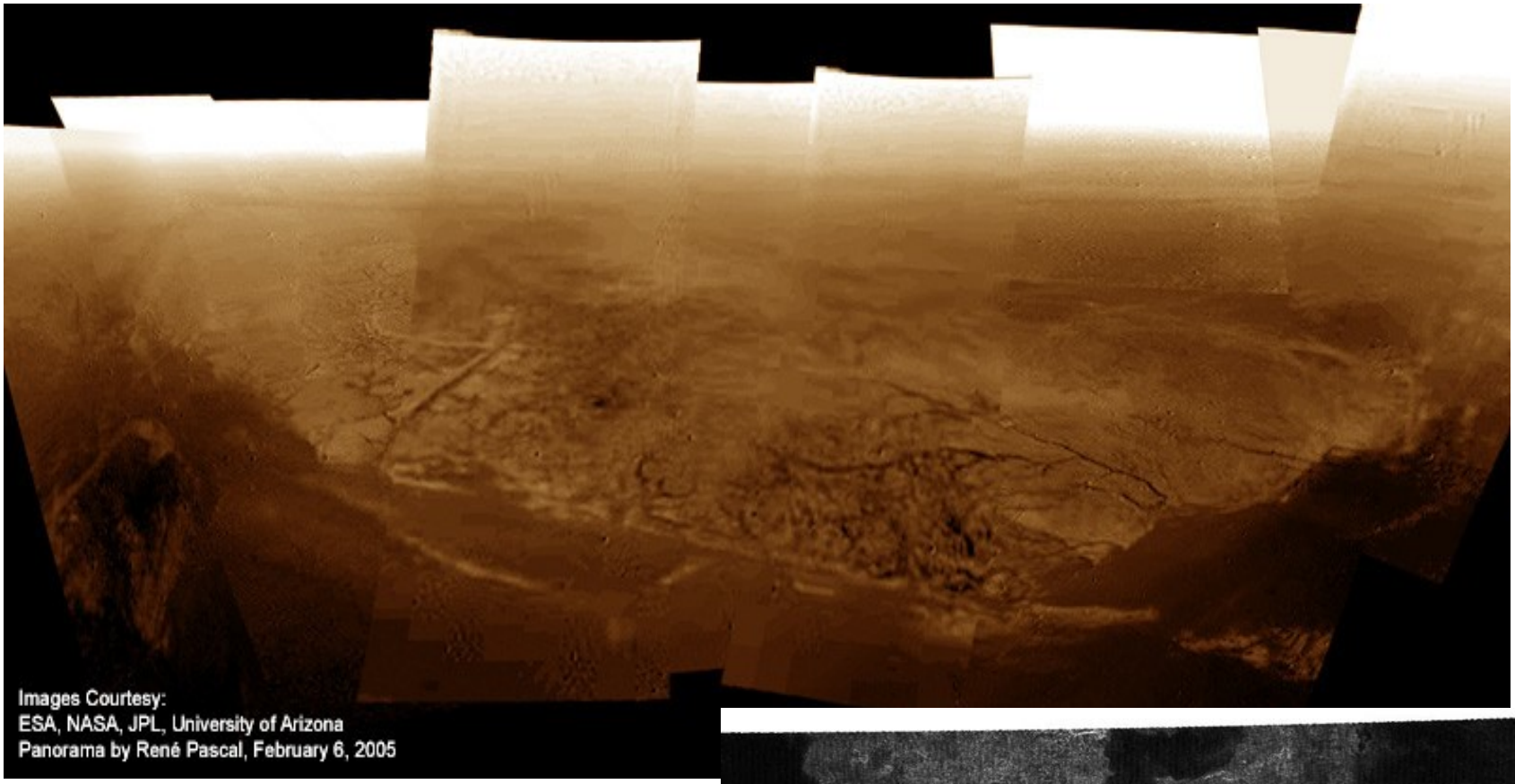

Sedna
Earth
Quaoar
Eris
Pluto
Luna

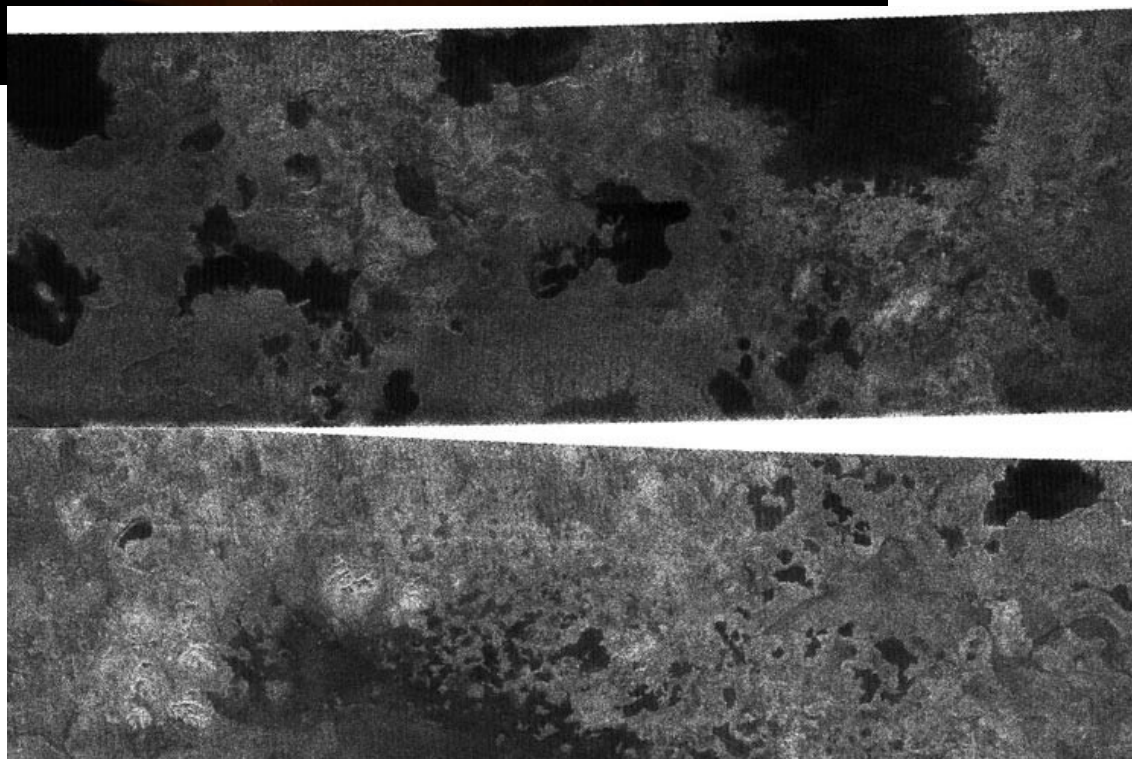


The Dawn space probe is orbiting the planetoid Vesta in the asteroid belt

Moons of the Solar System Scaled to Earth's Moon







The Methane Lakes and Ice Shoreline of Titan

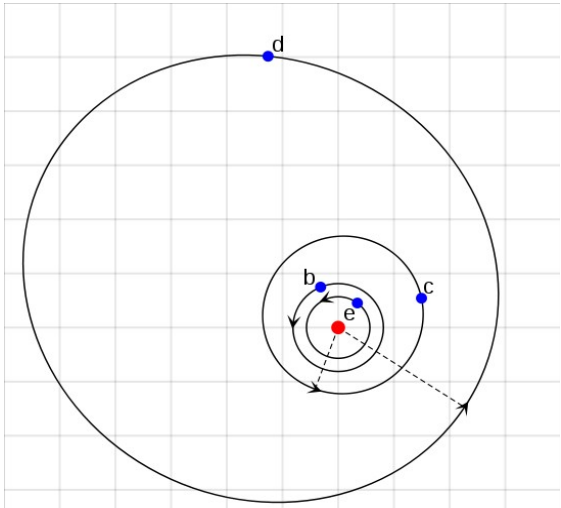
EXOPLANETS

1989: Dave Latham finds object around HD114762 – planet or brown dwarf?

1995: Discovery of 51 Pegasi b (Mayor and Queloz, Geneva)
a “Hot Jupiter”, only 5 million mi (8 million km) from its parent star

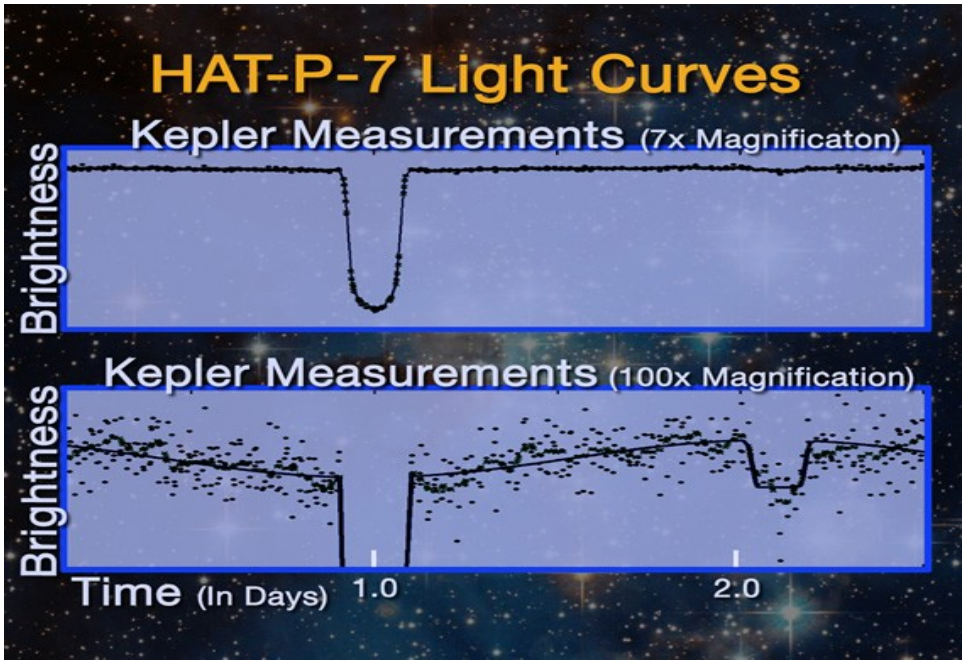
2007-2009: Gliese 581 system
Gliese 581d, mass of 6-10 Earths
A “super-Earth” in the habitable zone

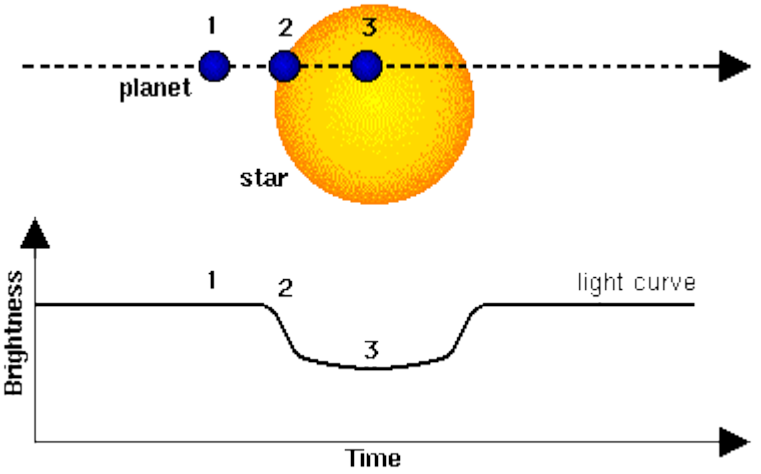
2012: 760 exoplanets now known
Kepler mission finding many new ones, including multiple-planet solar systems and **Earth-sized planets**

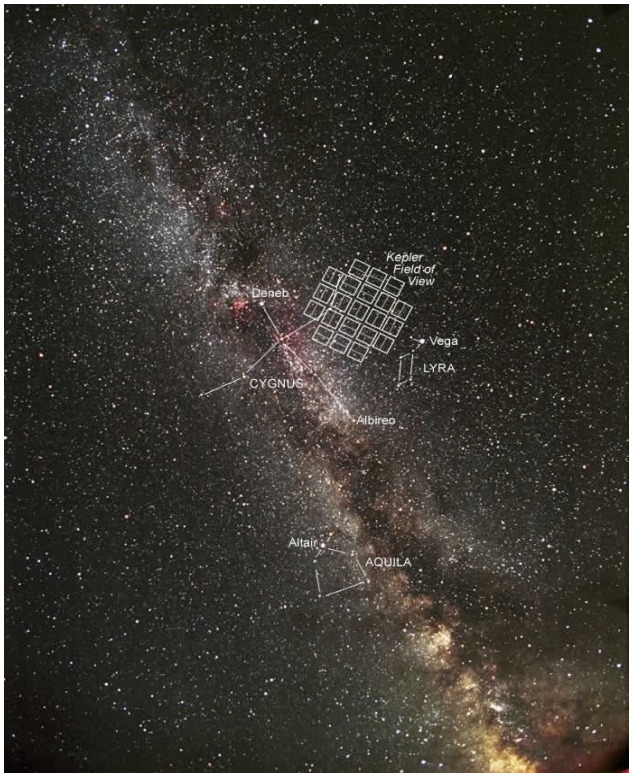


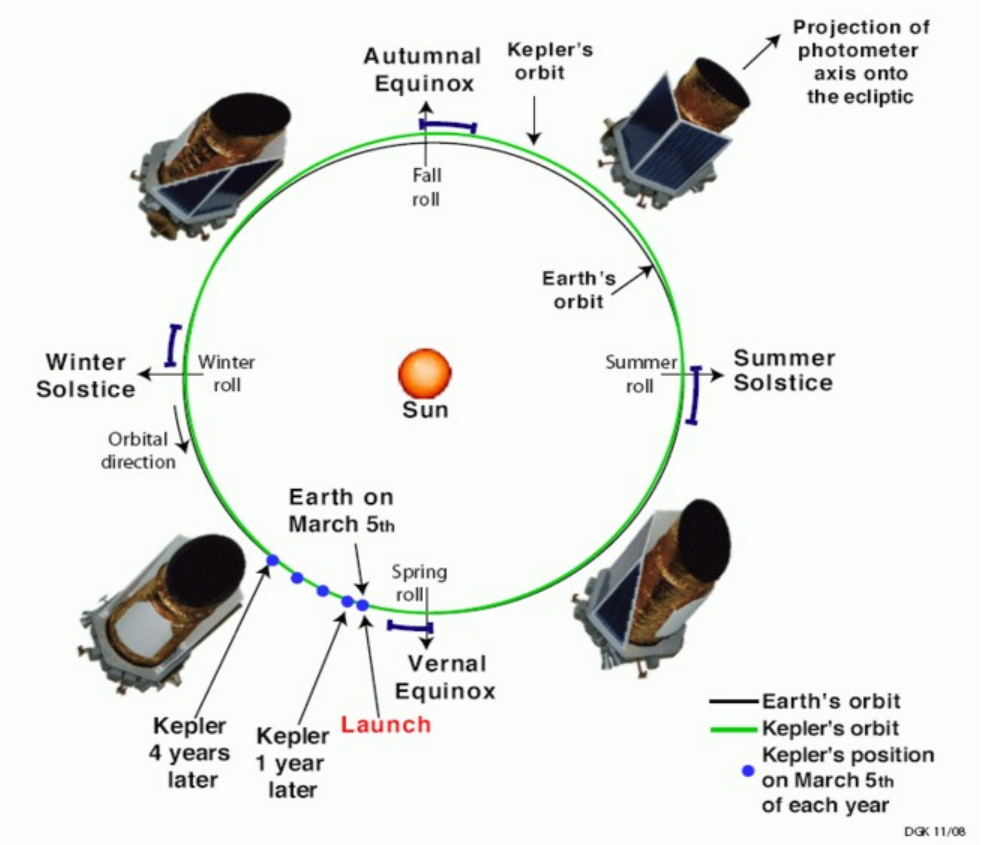
JD 2453152.0 (26 May 2004CE, 12:00:00.0 UT)
Each grid square 0.05 AU × 0.05 AU
Planets and star not to scale

Blue: our solar system. Red: Pre-2012 Kepler planets, Green: new Kepler planets


HAT-P-7 Light Curves
Kepler Measurements (7x Magnificaton)
Brightness
Kepler Measurements (100x Magnification)
Brightness
Time (In Days)
1.0
2.0

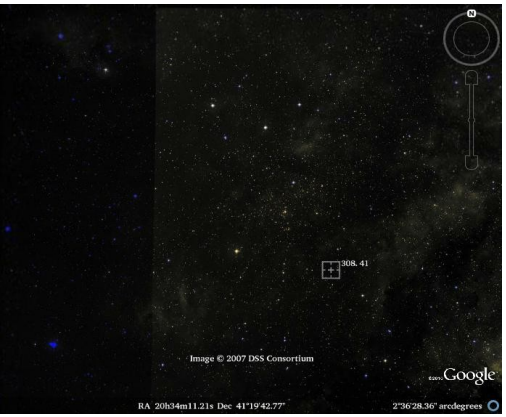

1
2
3
planet
star
Brightness
1
2
3
light curve
Time


Kepler Field of View
Deneb
Vega
LYRA
CYGNUS
Albireo
Altair
AQUILA

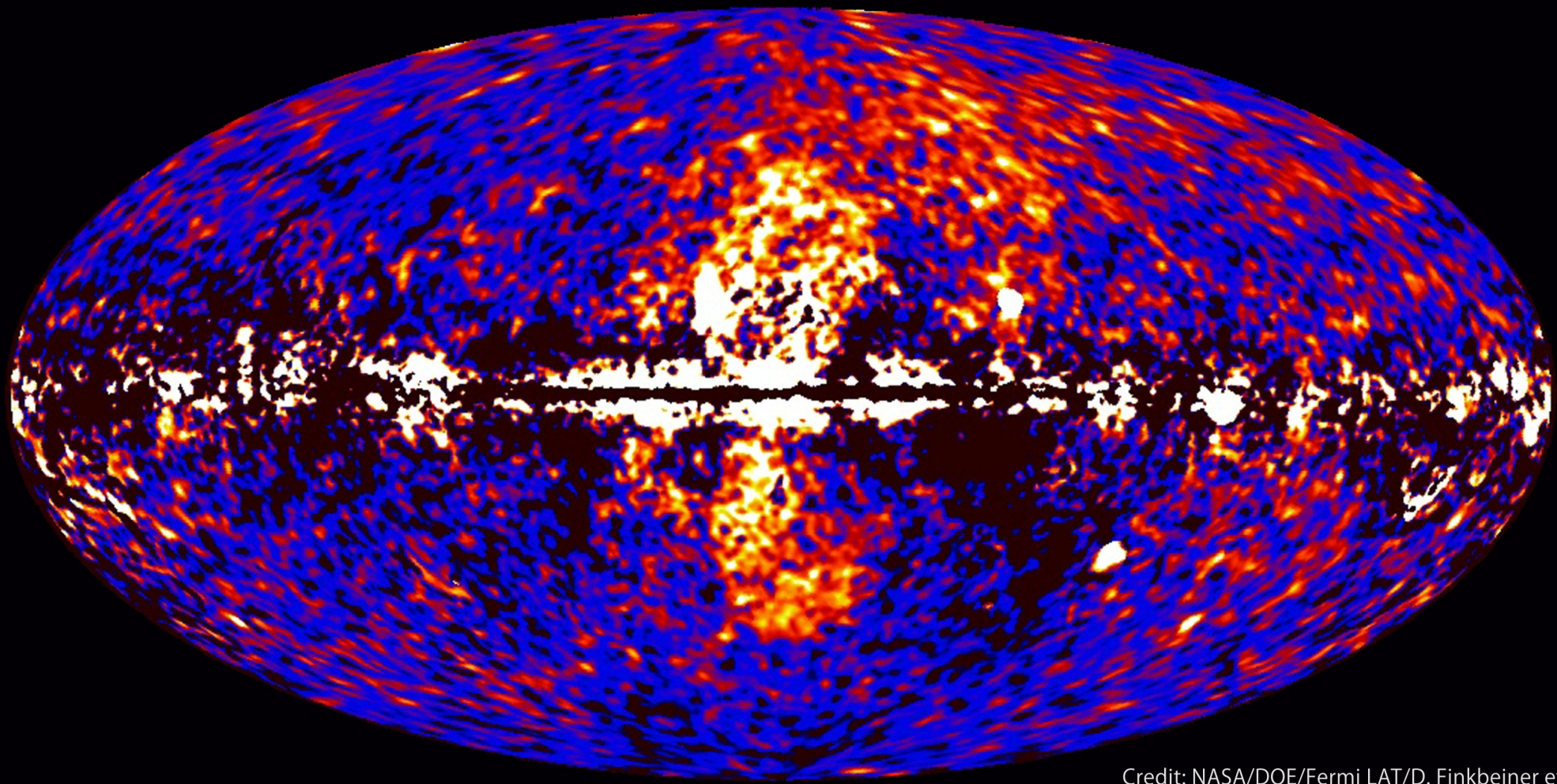

Autumnal Equinox
Kepler's orbit
Projection of photometer axis onto the ecliptic
Fall roll
Earth's orbit
Winter Solstice
Winter roll
Sun
Summer roll
Summer Solstice
Orbital direction
Earth on March 5th
Spring roll
Vernal Equinox
Launch
Kepler 4 years later
Kepler 1 year later
Earth's orbit
Kepler's orbit
Kepler's position on March 5th of each year
DGK 11/08

Infrared image of
Cygnus X
star forming region

The Spitzer telescope lets us peer through regions otherwise opaque and see the young stars shaping the environment around them

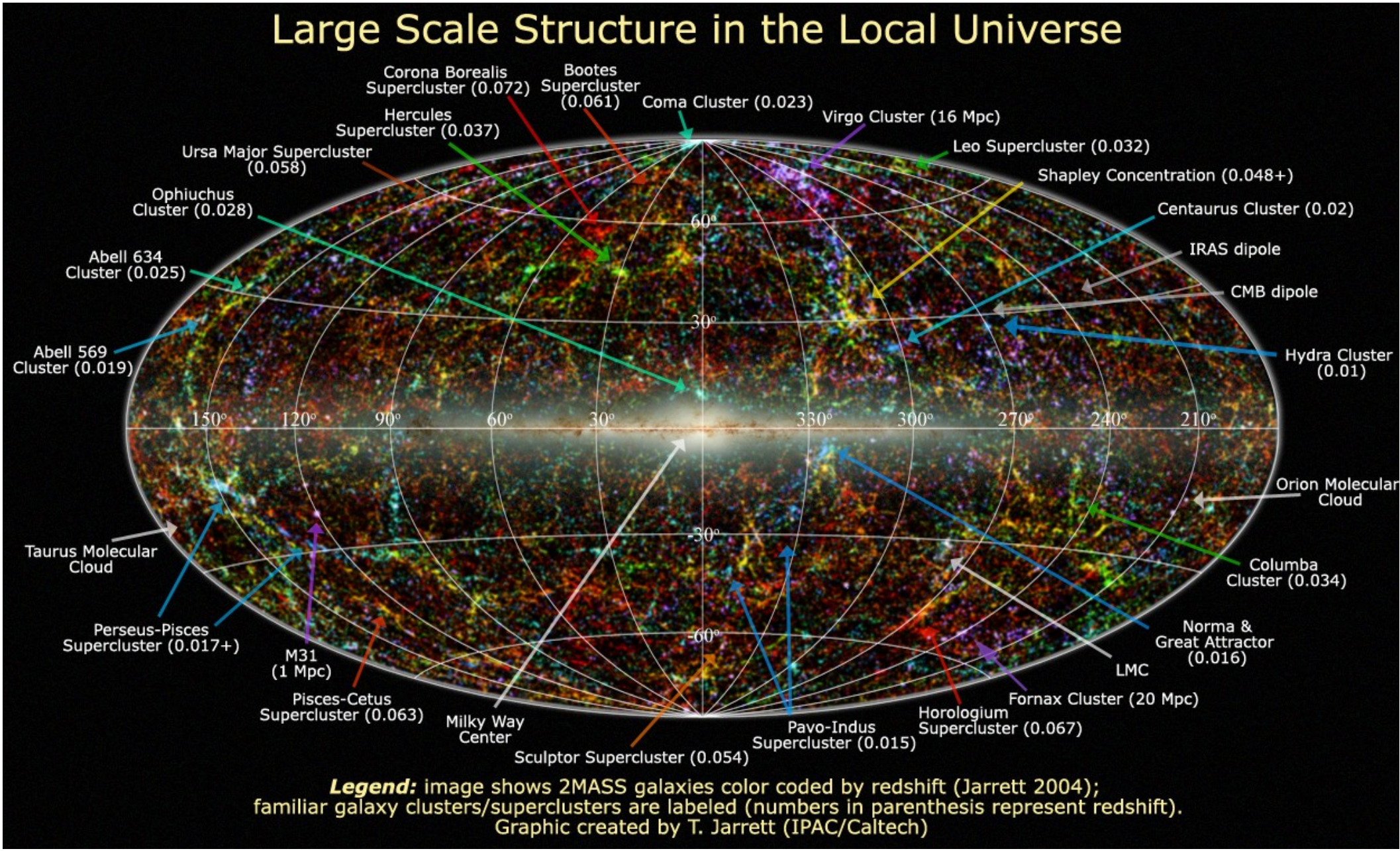


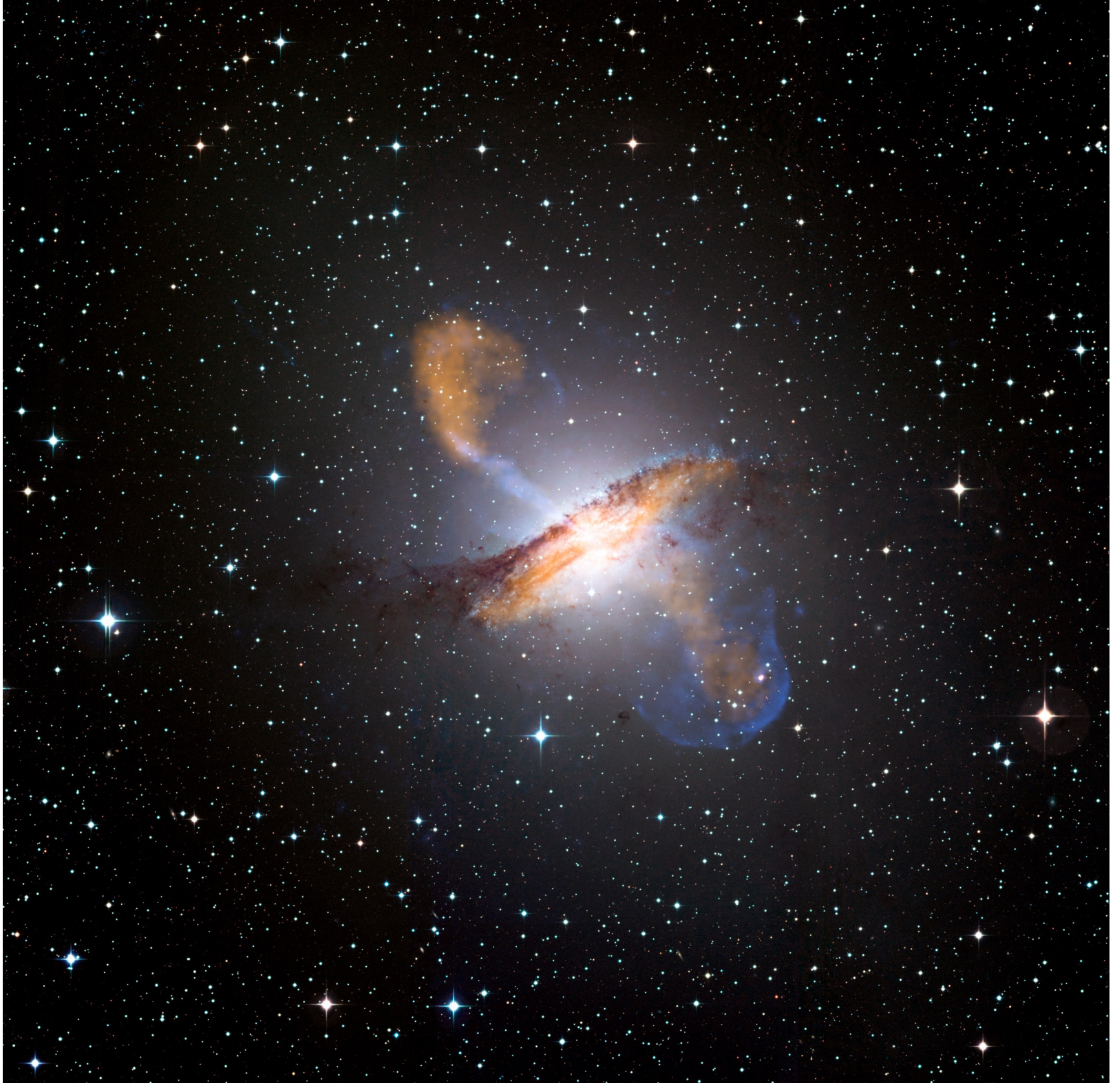
Fermi data reveal giant gamma-ray bubbles

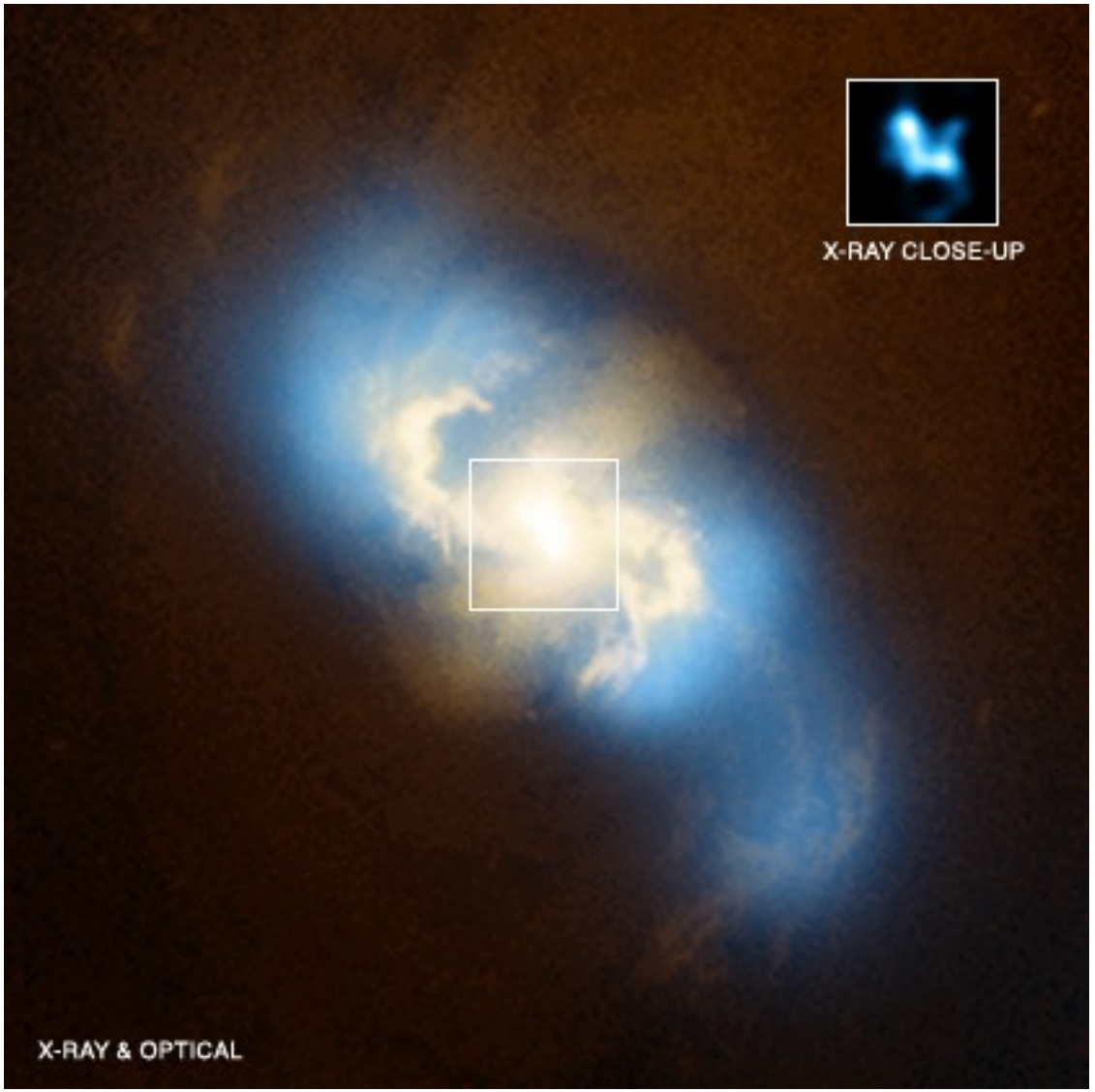


Credit: NASA/DOE/Fermi LAT/D. Finkbeiner et al.

The local neighbourhood
(closest half-billion light years!)

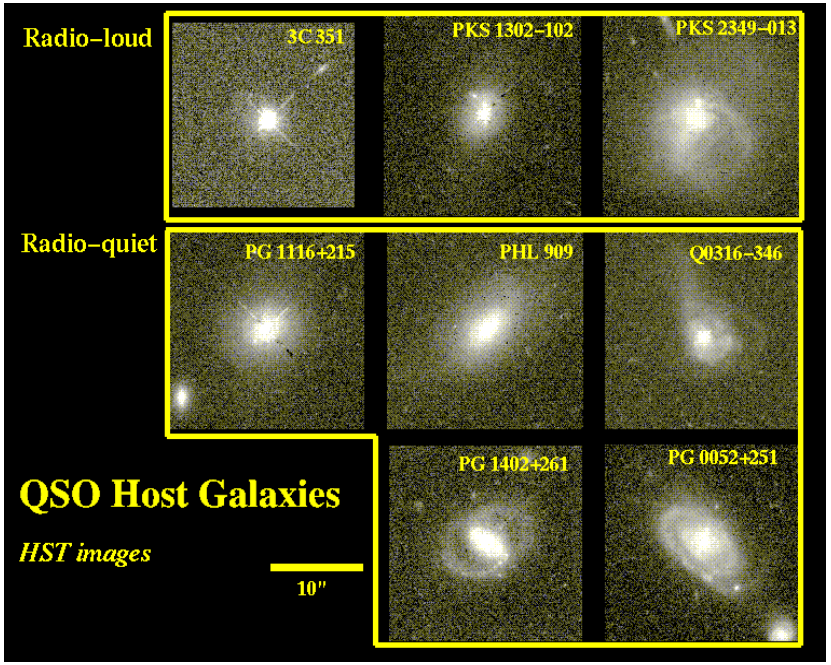




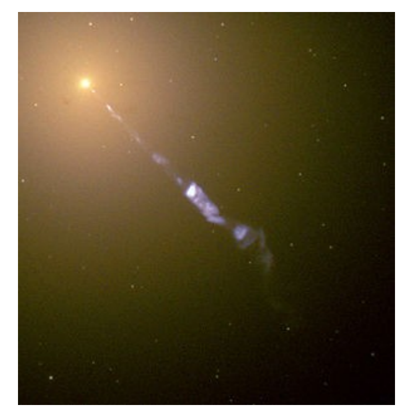


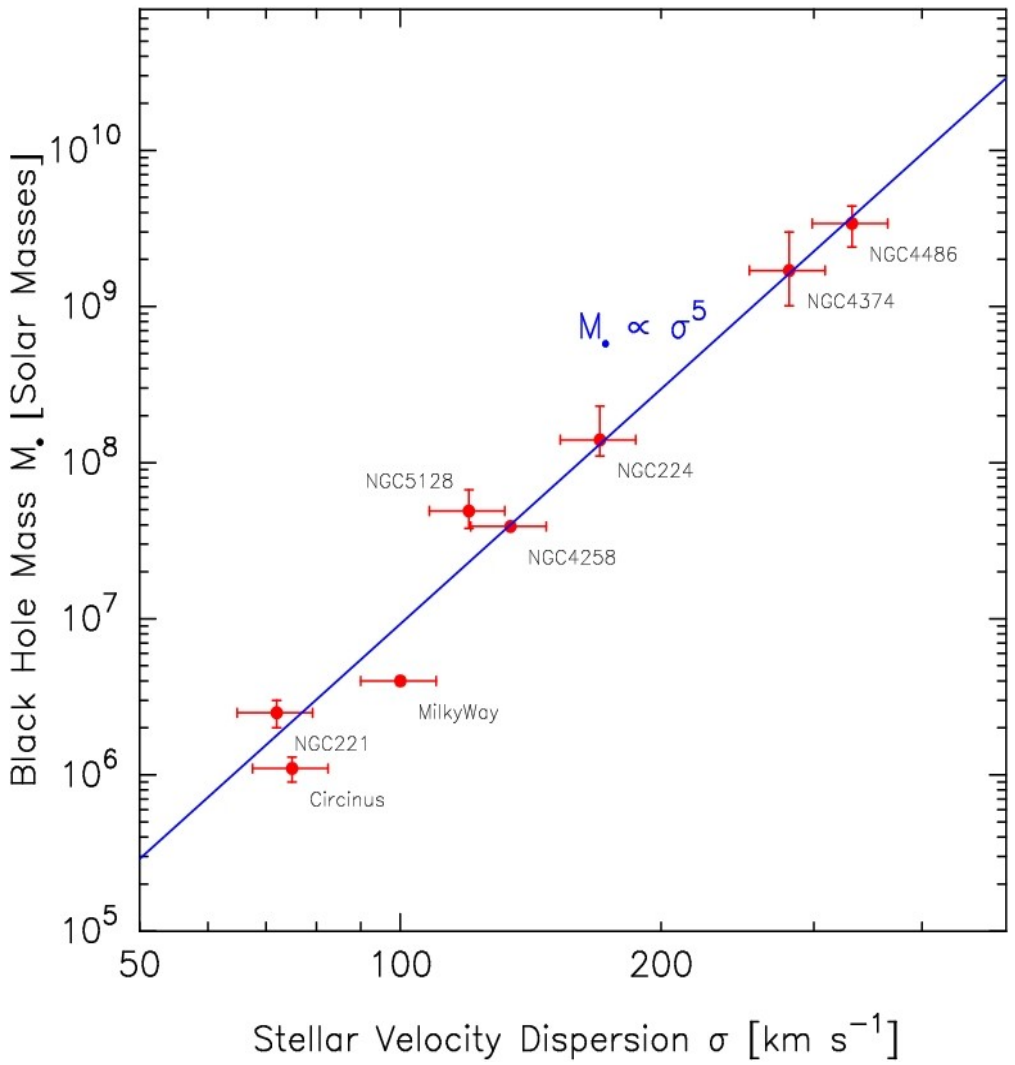
NGC 3393, unusual galaxy with a pair of black holes in the middle

With Hubble we can directly image galaxies with quasars in them (image by Bill Keel)




M87





Galaxies with big central black holes (~ light-hour across) also have massive central bulges (on 1000-lightyear-scale)
What's with that?

“Feedback” - the BH grows as the galaxy grows, and then pumps energy back into the galaxy which switches off star formation

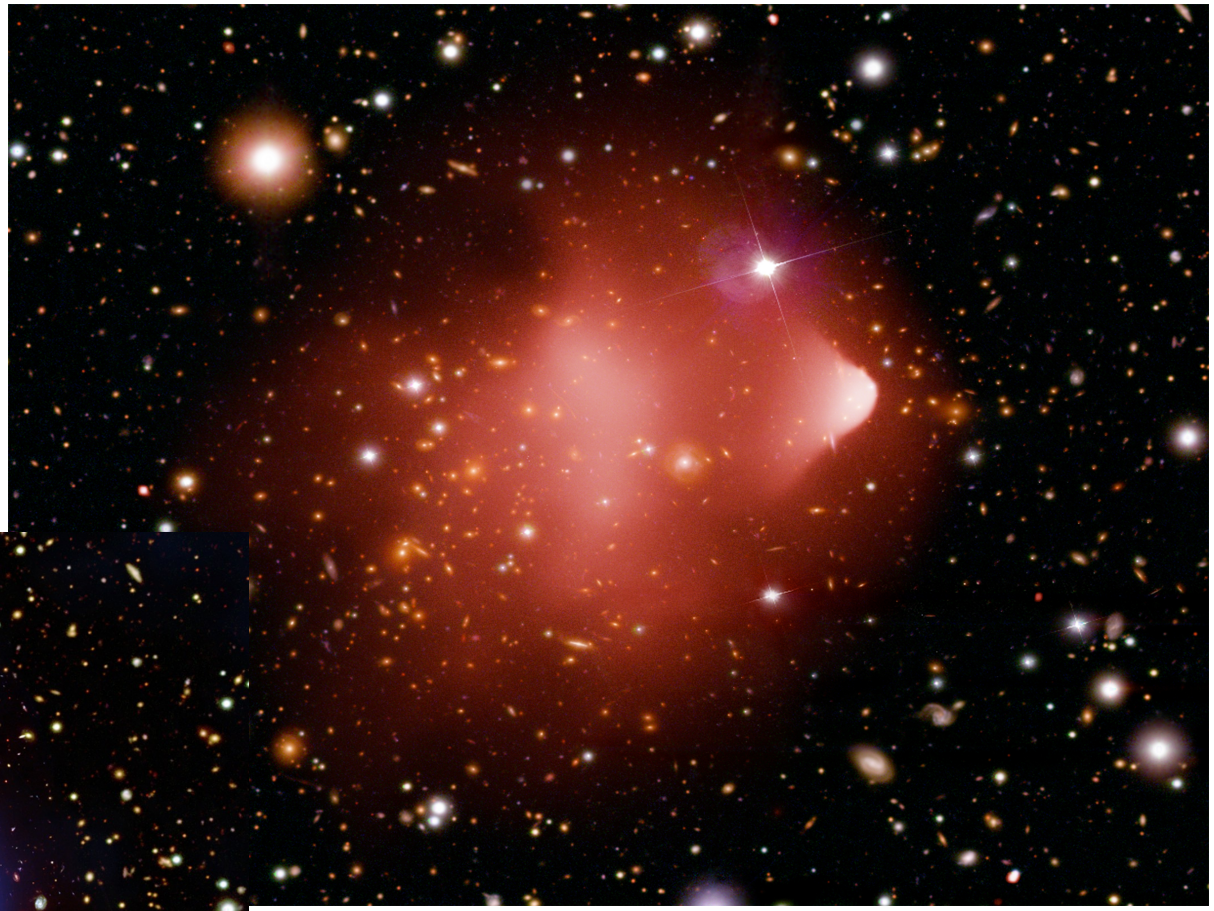
We are just beginning to understand the life cycle of galaxies

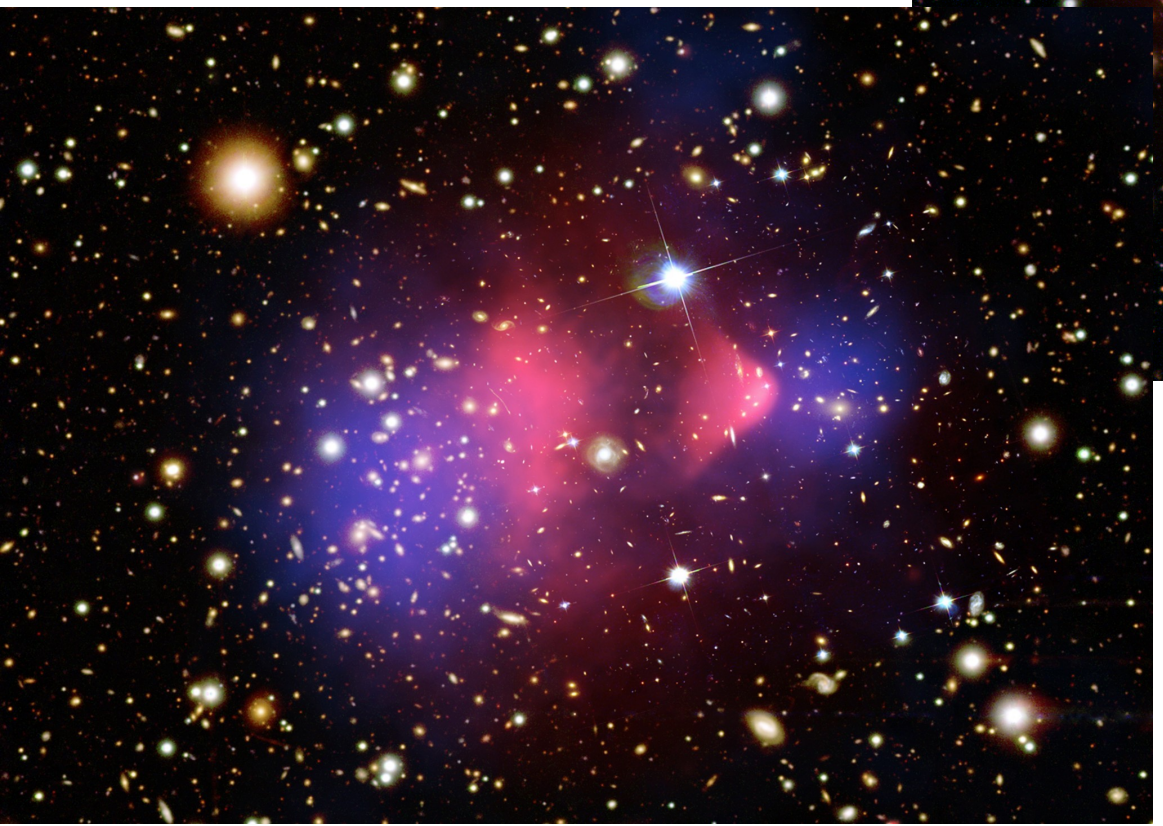
The Bullet Cluster, 1E0657-56

Two clusters in collision: studying this object let us measure the dark matter

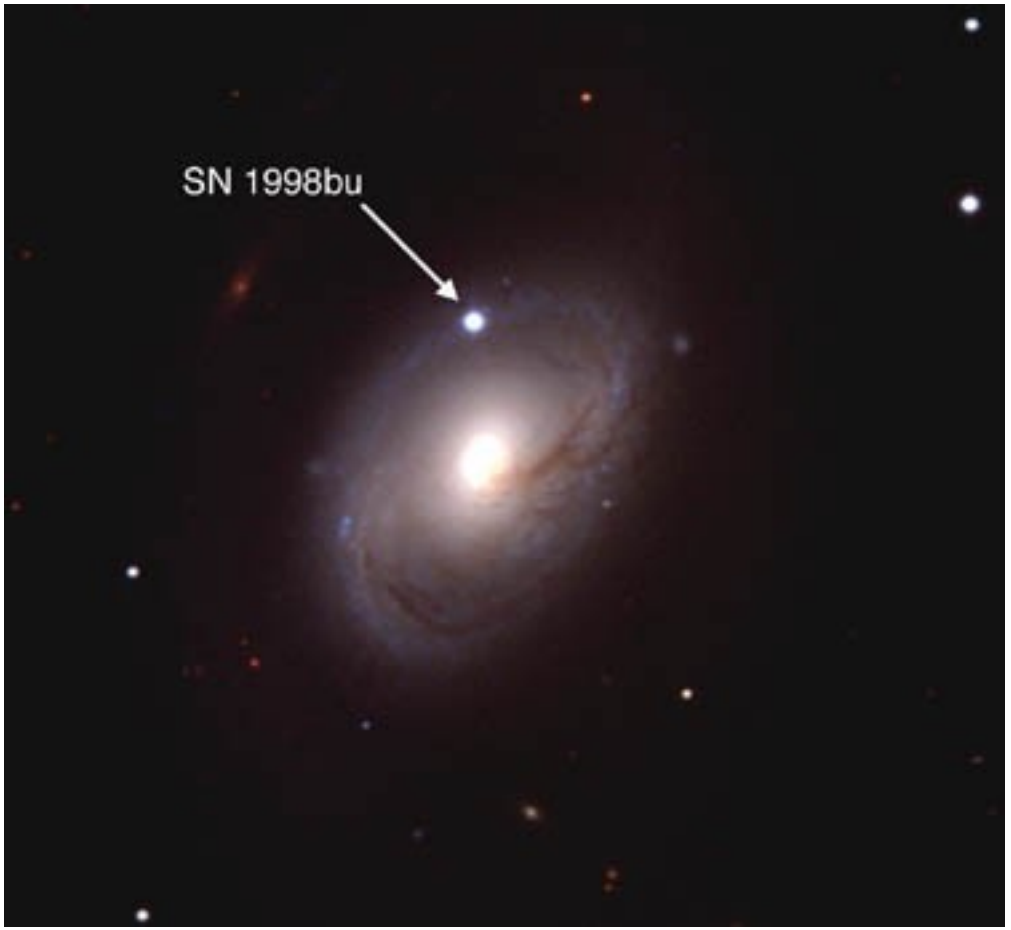
Right: what we see directly in X-rays (red) and optical

Below: blue shows the matter distribution we infer



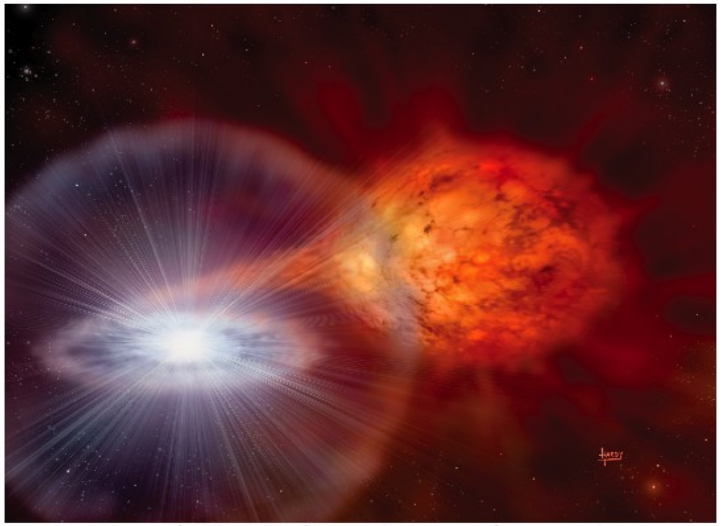


SUPERNOVAE

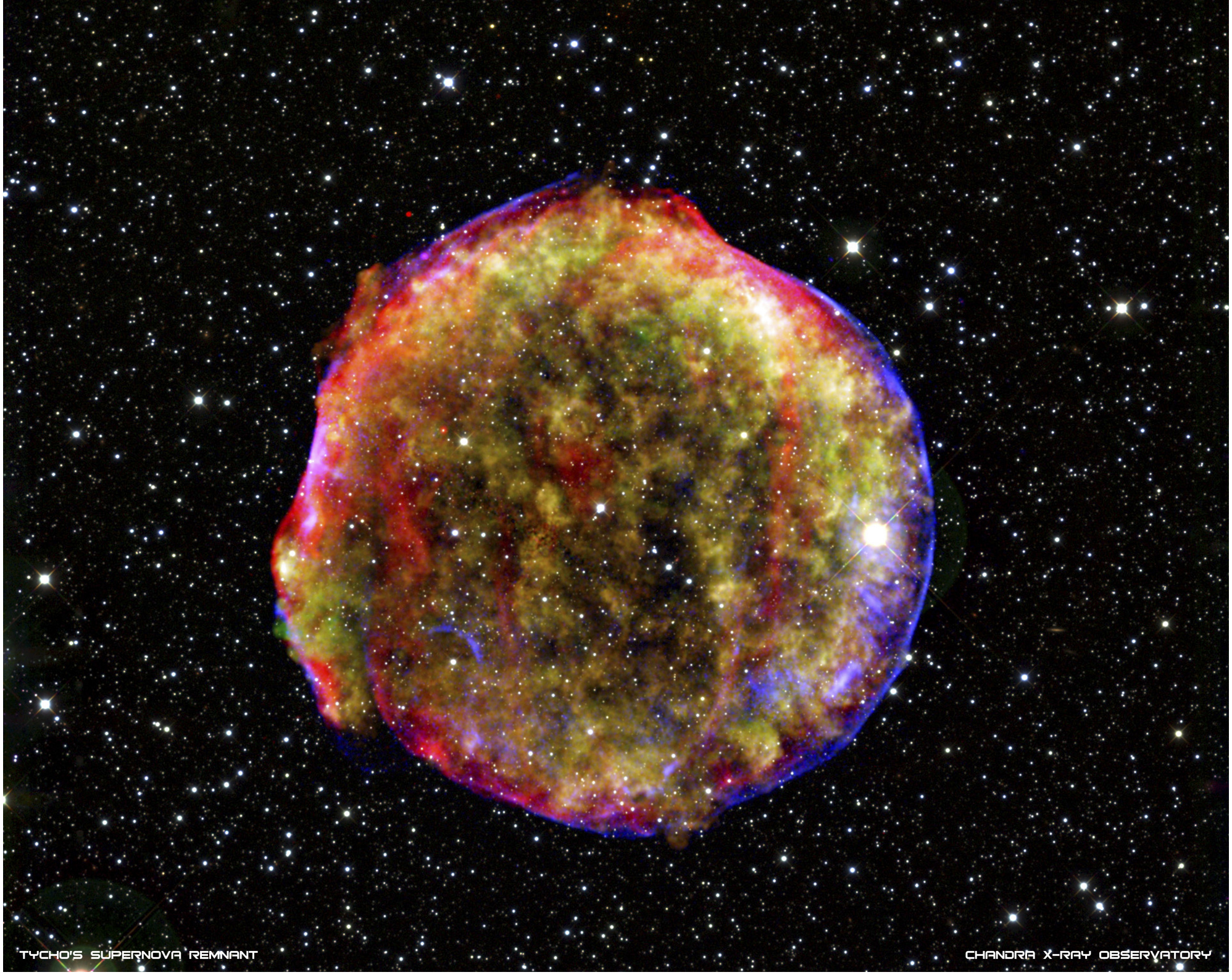


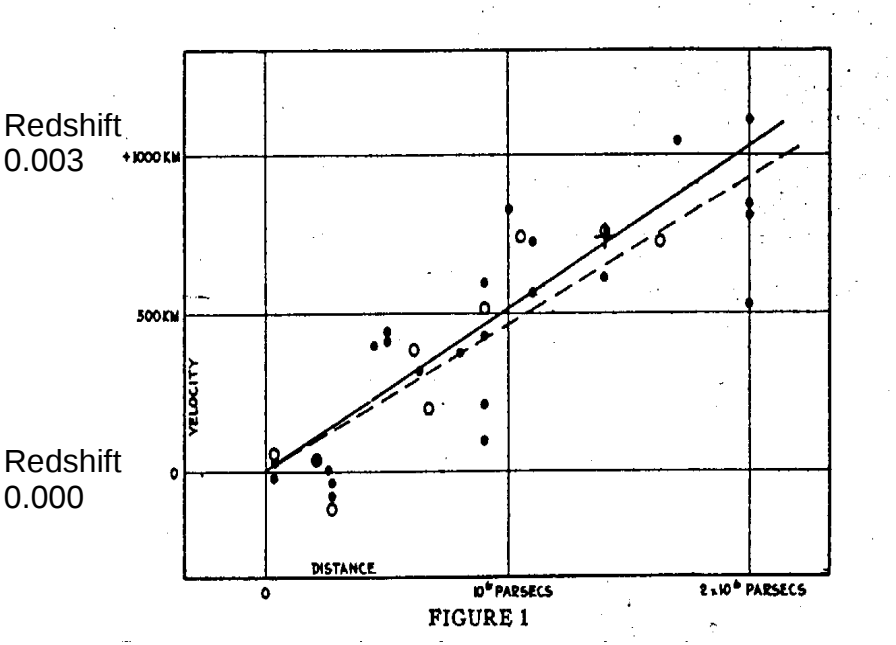
Type 1a SN:

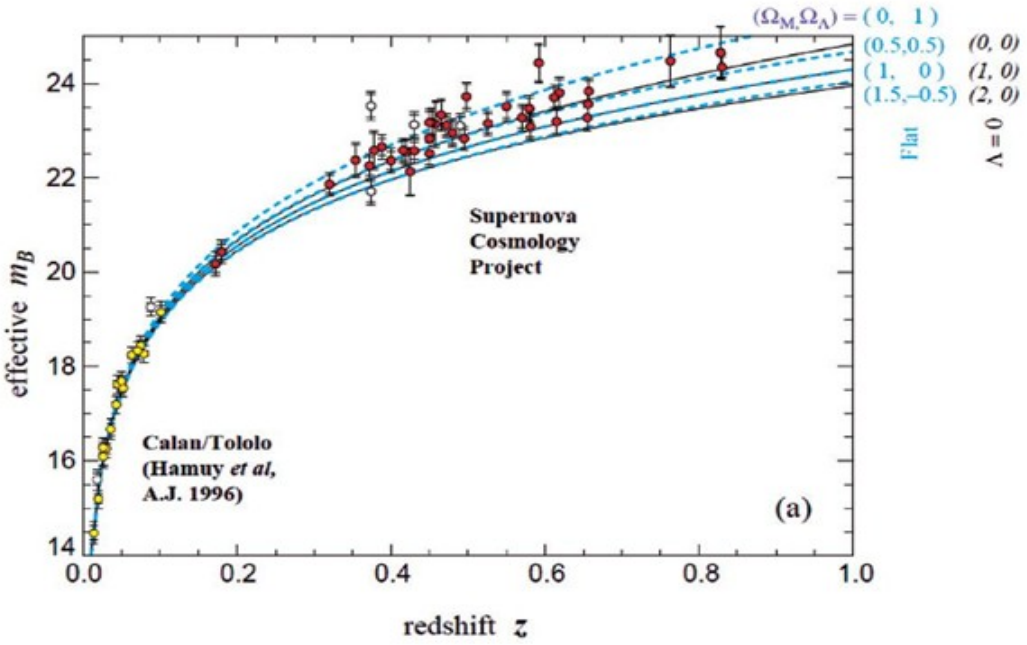
- White dwarf star in binary system
- Steals extra mass from companion
- Reaches critical mass
- Runaway fusion converts part of the star to energy within a few seconds
- Star flies apart
- Radioactive decay of newly made elements releases energy over months
- Can tell how much energy it's putting out from how long it takes to fade, so can tell how far away it is!
- Use them to map out the scale of the universe

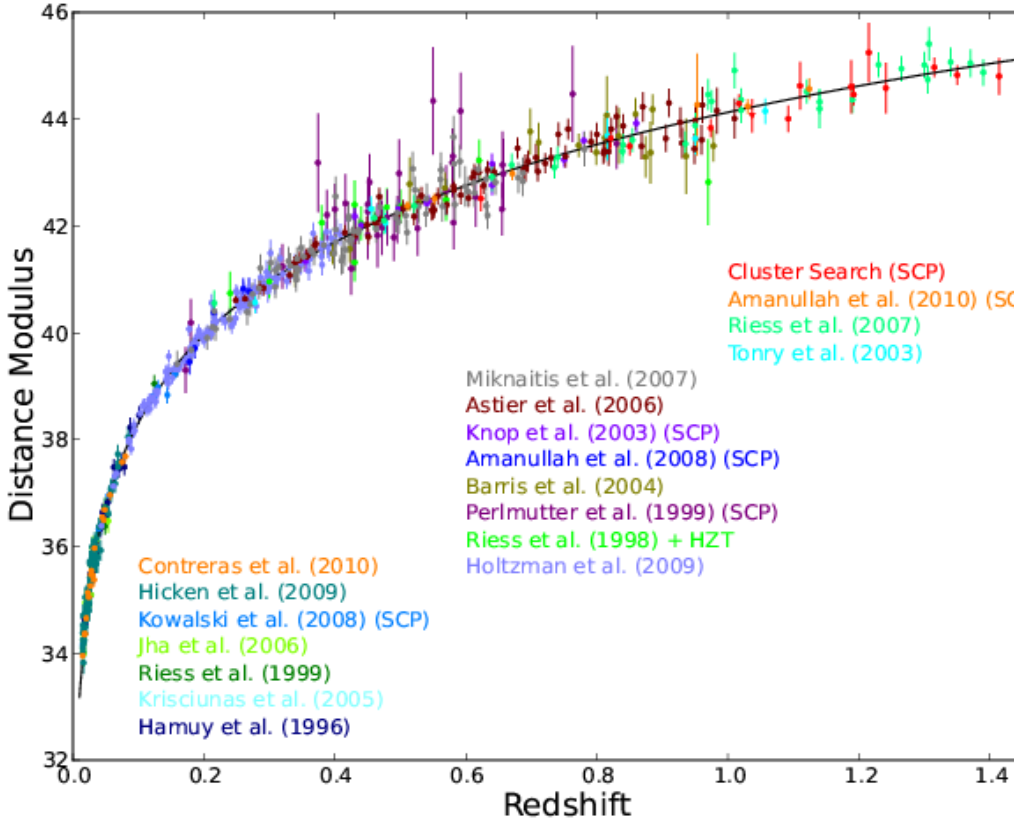


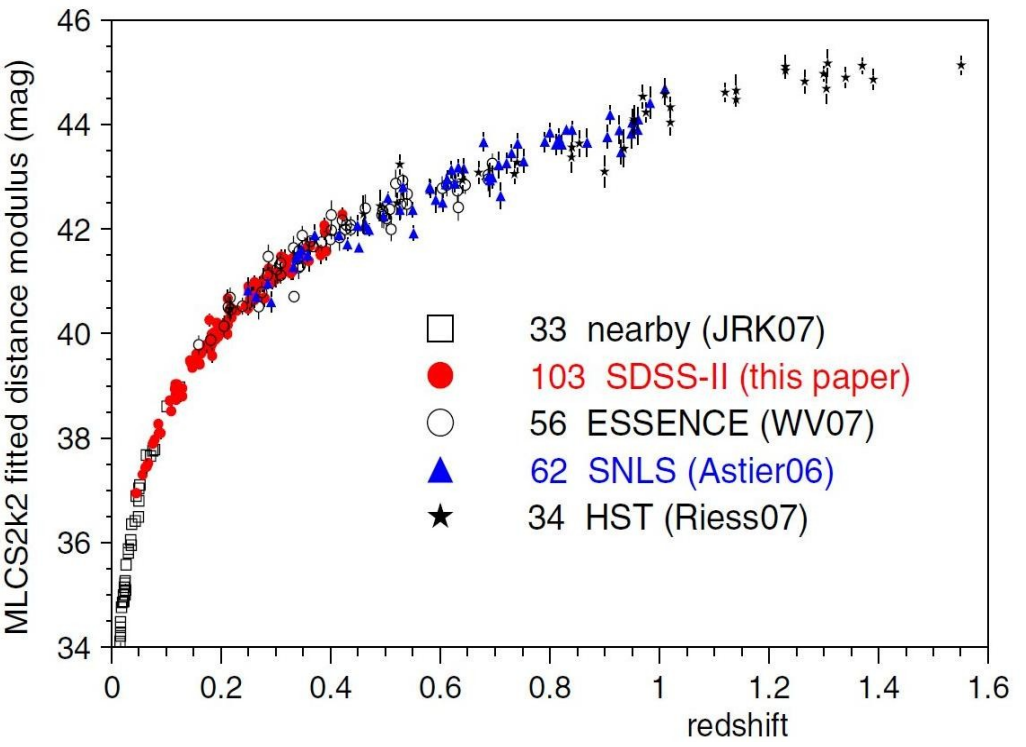
Artist's rendition of a white dwarf accumulating mass from a nearby companion star. This type of progenitor system would be considered singly-degenerate.


TYCHO'S SUPERNOVA REMNANT
CHANDRA X-RAY OBSERVATORY


Redshift
0.003
Redshift
0.000
+1000 KM
500 KM
0
VELOCITY
DISTANCE
0
10^8 PARSECS
2×10^8 PARSECS
FIGURE 1


$(\Omega_M,\Omega_\Lambda) = (0, 1)$
(0.5,0.5) (0, 0)
(1, 0) (1, 0)
(1.5,–0.5) (2, 0)
Flat
$\Lambda = 0$
Supernova
Cosmology
Project
Calan/Tololo
(Hamuy et al,
A.J. 1996)
(a)
effective m_B
redshift z


Distance Modulus
Redshift
Cluster Search (SCP)
Amanullah et al. (2010) (SC
Riess et al. (2007)
Tonry et al. (2003)
Miknaitis et al. (2007)
Astier et al. (2006)
Knop et al. (2003) (SCP)
Amanullah et al. (2008) (SCP)
Barris et al. (2004)
Perlmutter et al. (1999) (SCP)
Riess et al. (1998) + HZT
Holtzman et al. (2009)
Contreras et al. (2010)
Hicken et al. (2009)
Kowalski et al. (2008) (SCP)
Jha et al. (2006)
Riess et al. (1999)
Krisciunas et al. (2005)
Hamuy et al. (1996)


MLCS2k2 fitted distance modulus (mag)
redshift
33 nearby (JRK07)
103 SDSS-II (this paper)
56 ESSENCE (WV07)
62 SNLS (Astier06)
34 HST (Riess07)

WMAP: Imaging the universe as it was 13.7 billion years ago
The specks are the seeds from which galaxy clusters will form
From their size we can work out the age of the universe