Beyond the Visible --

Exploring the Infrared Universe

Prof. T. Jarrett (UCT)

- Infrared Window
- Telescopes
- *ISM -- Galaxies*


The Elegant Universe
Infrared
Sublime
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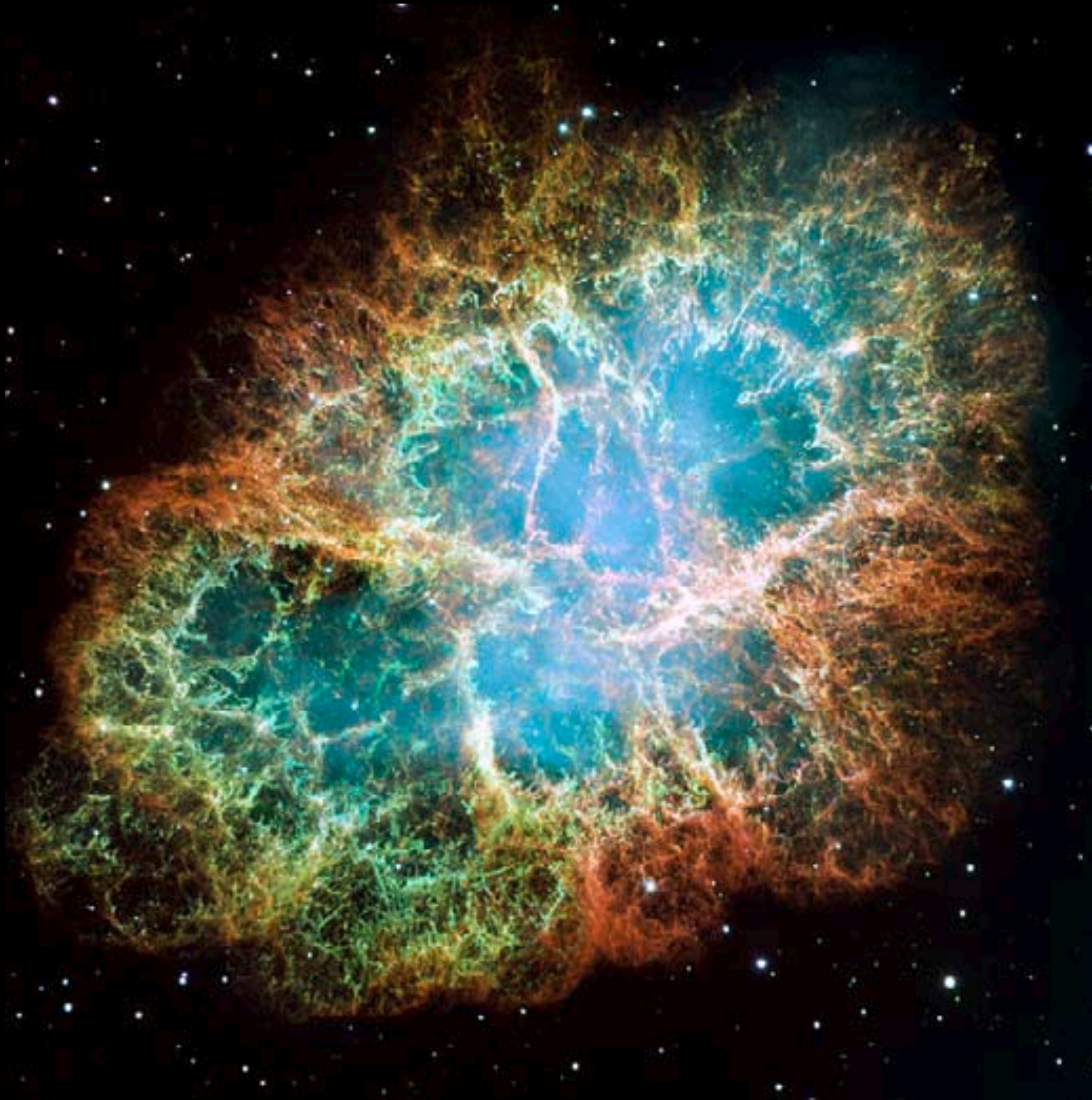
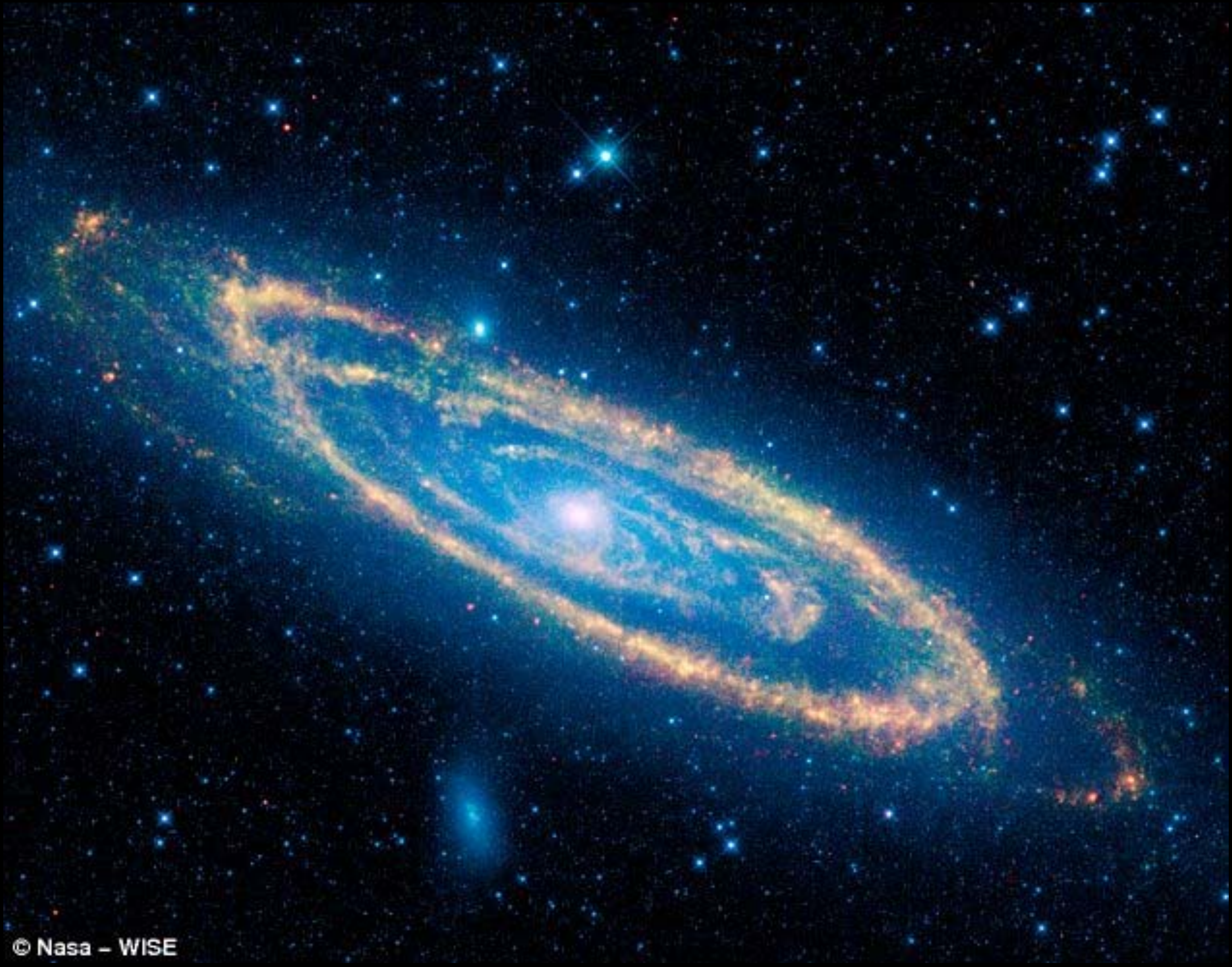
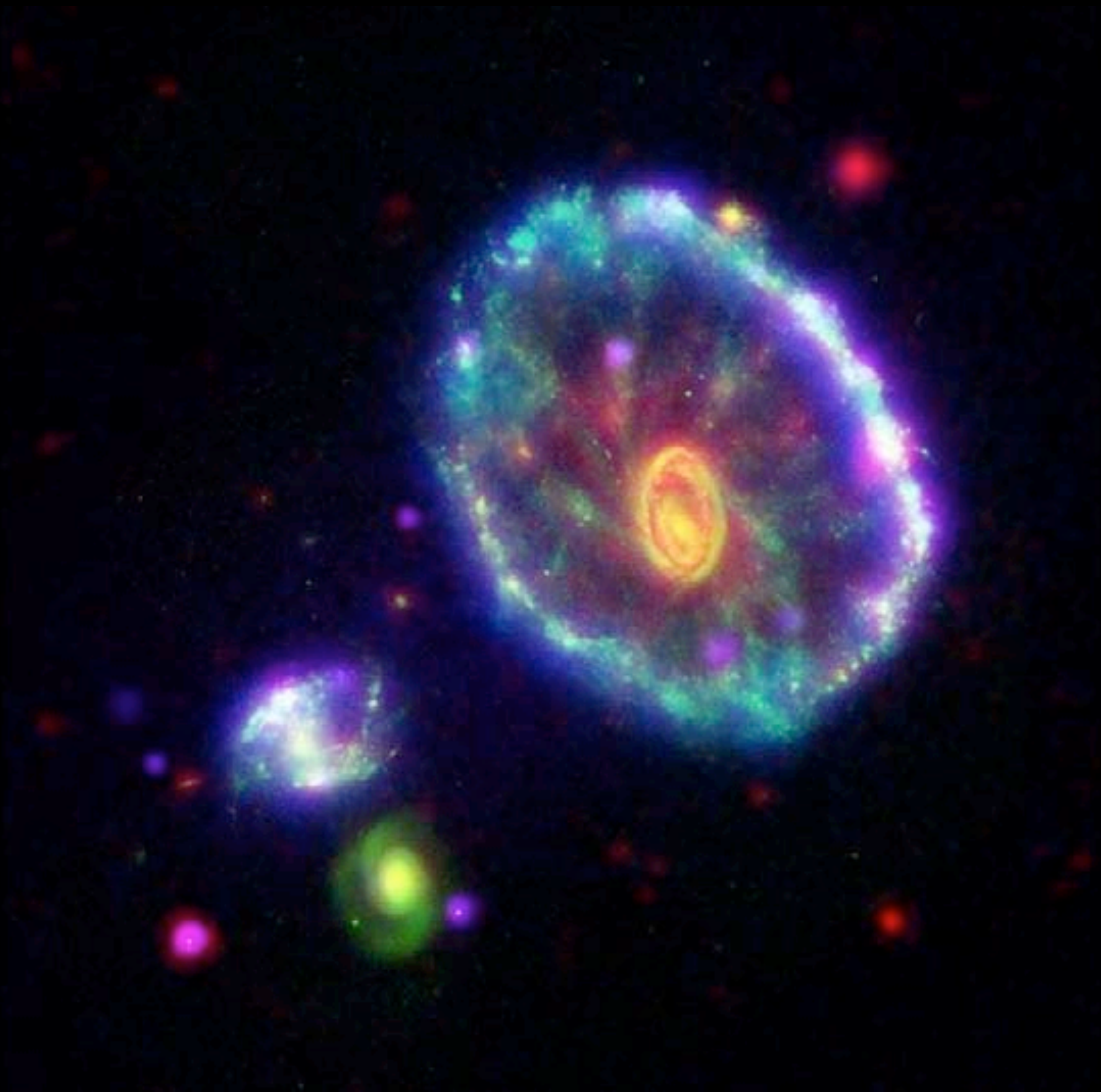
Infrared

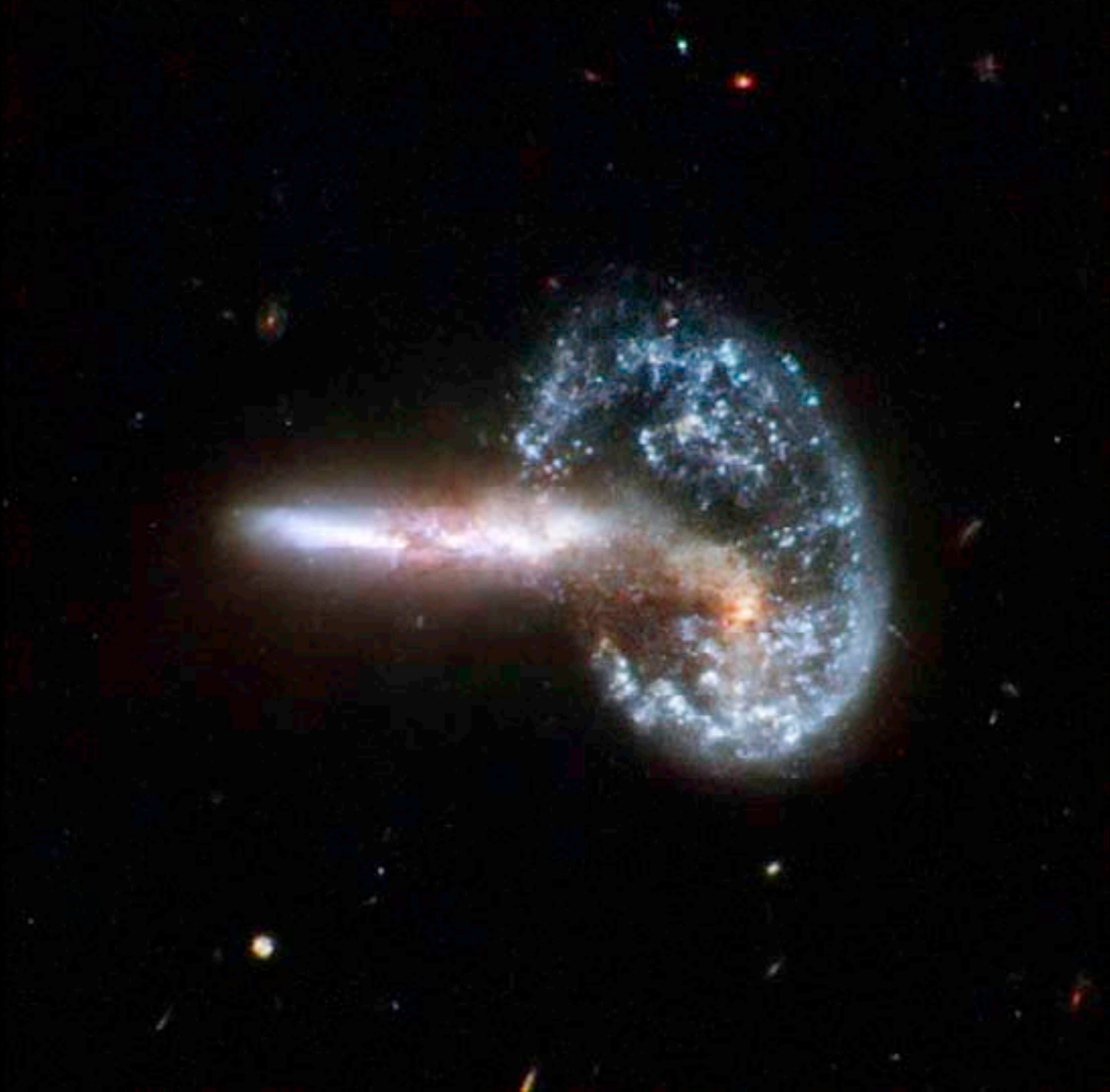


www.jpl.nasa.gov

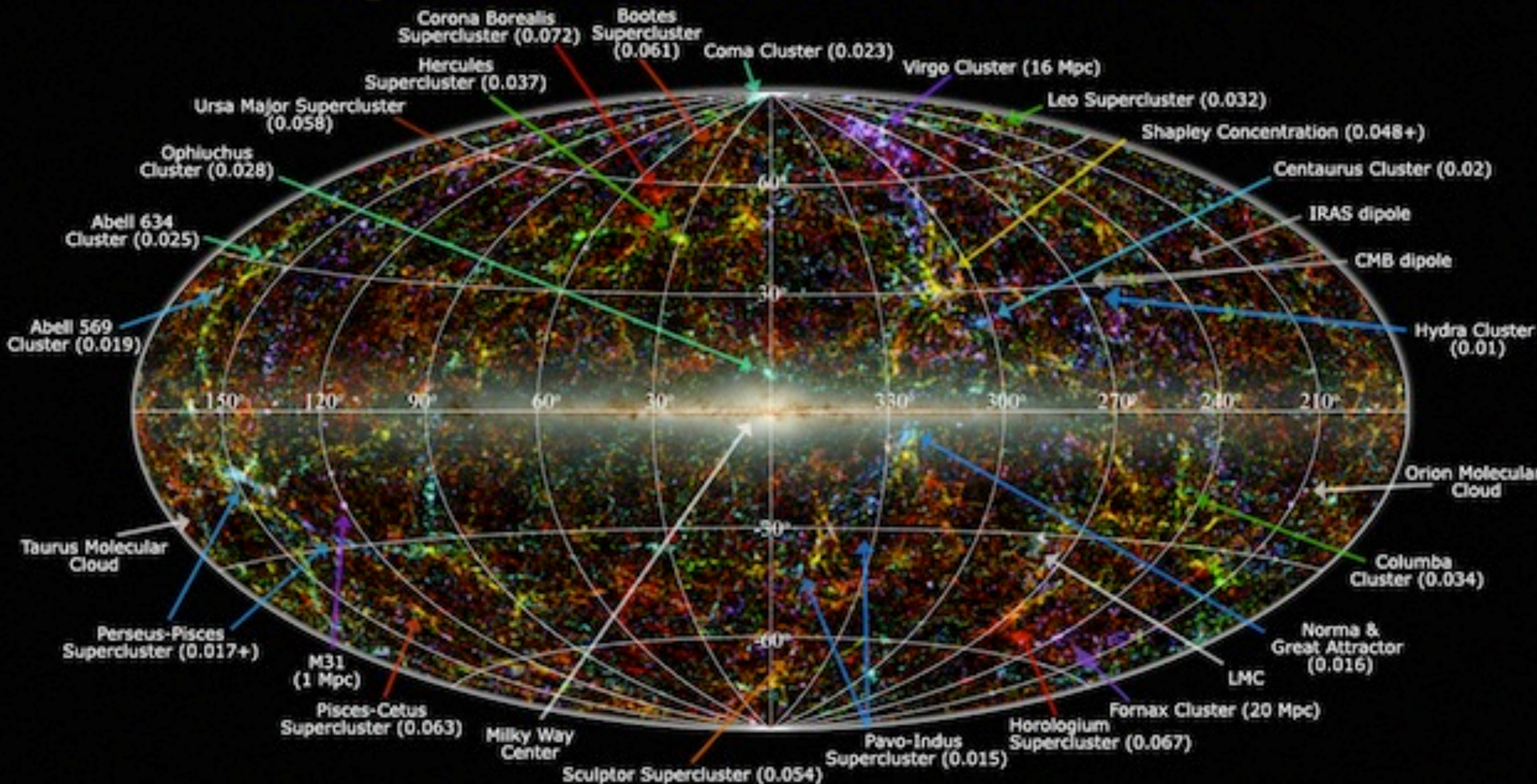

© Nasa – WISE




M 51



Large Scale Structure in the Local Universe



Multi-wavelength Astronomy

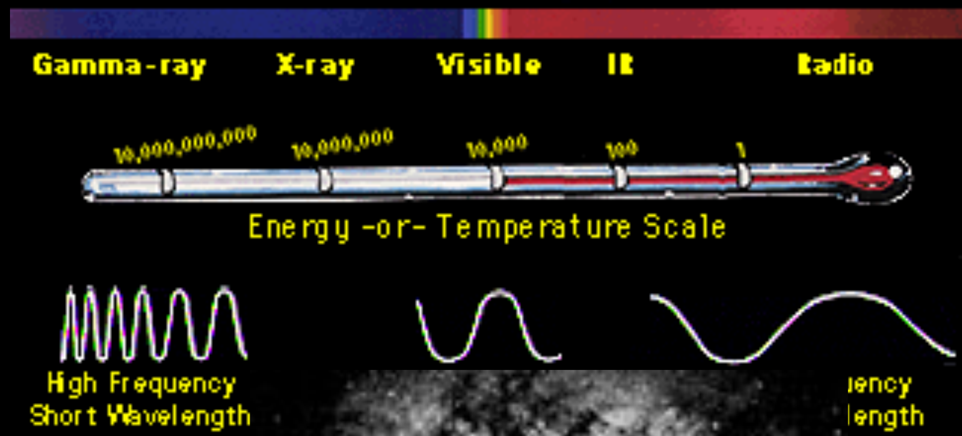
TO UNDERSTAND THE UNIVERSE ASTRONOMERS USE A VAST ARRAY OF TOOLS, INCLUDING MULTI-FREQUENCY DETECTORS AND MODELING/SIMULATIONS

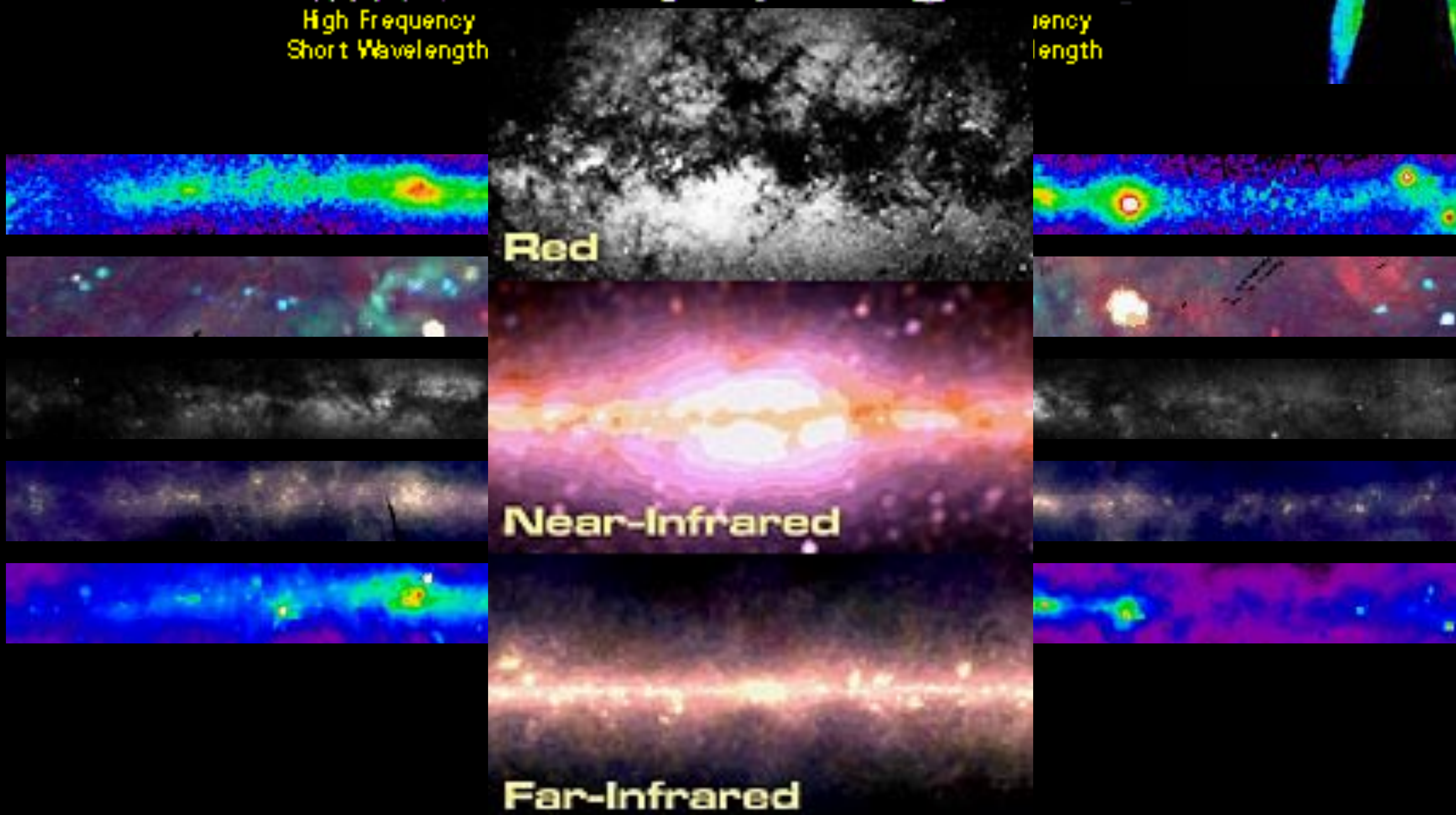
Infrared == Heat

Thermal Emission!!

Infrared Window

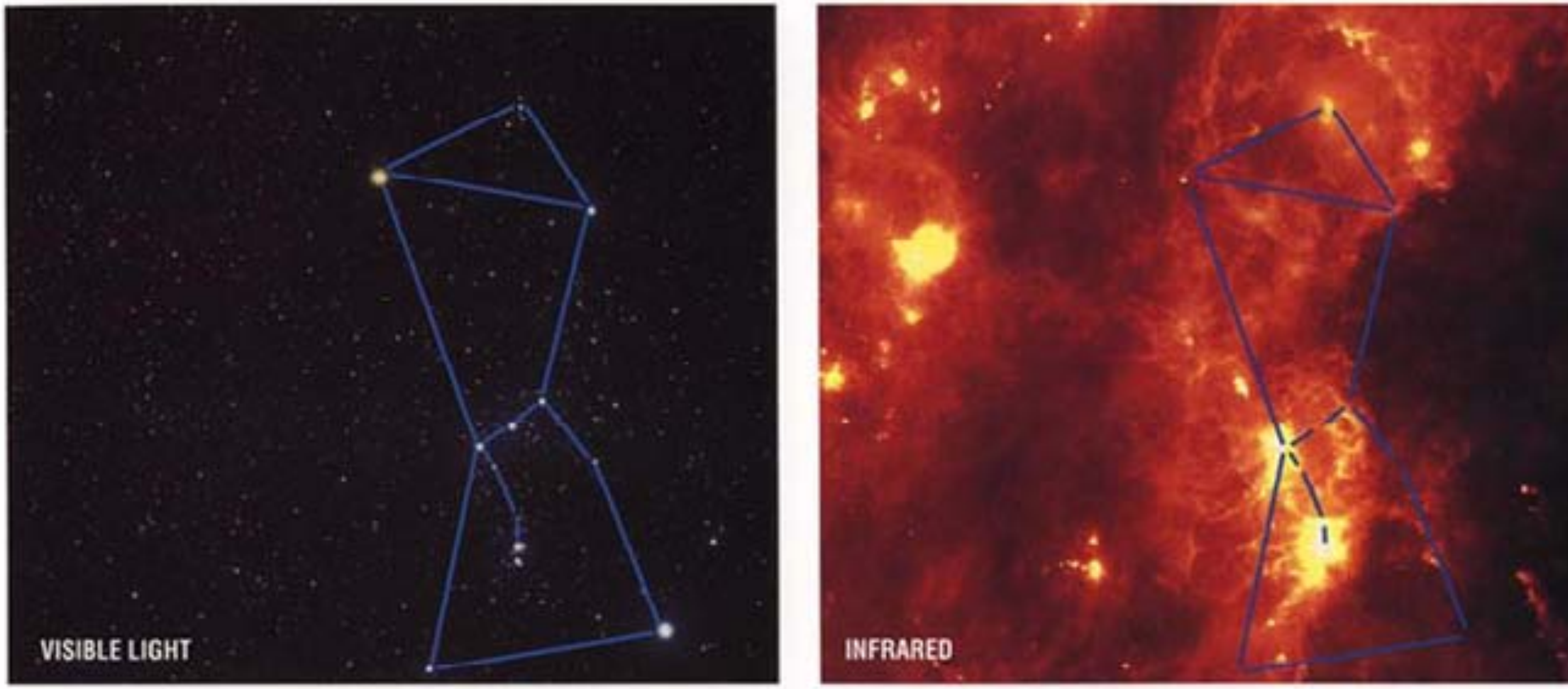
Near-infrared: 1 to 5 μm
Mid-infrared: 5 to 50 μm
Far-Infrared: 50 to 500 μm


Gamma-ray
X-ray
Visible
IR
Radio
10,000,000,000
10,000,000
10,000
100
1
Energy -or- Temperature Scale
High Frequency
Short Wavelength

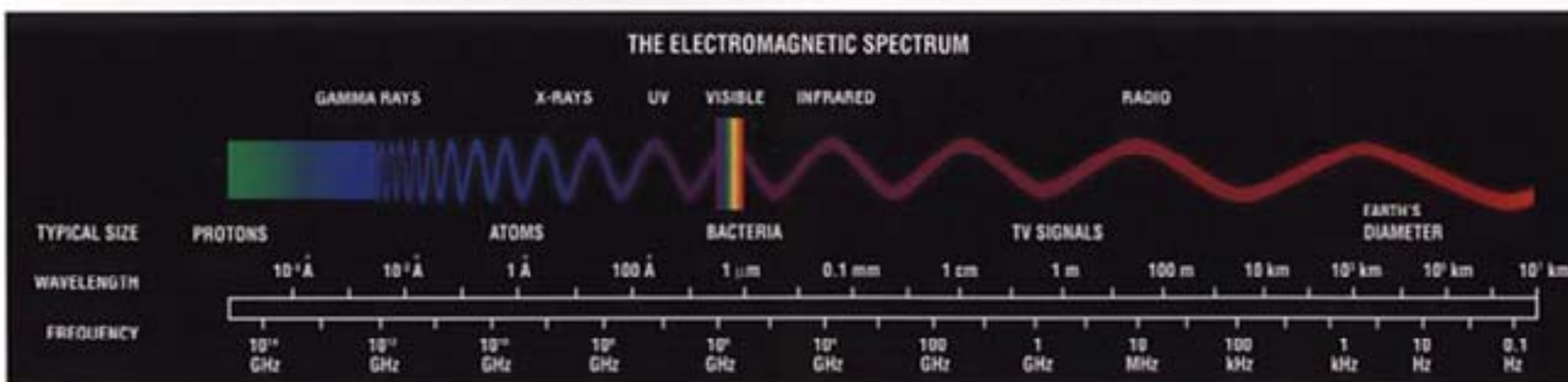

Red
Near-Infrared
Far-Infrared

National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Infrared Astronomy: More than Our Eyes Can See

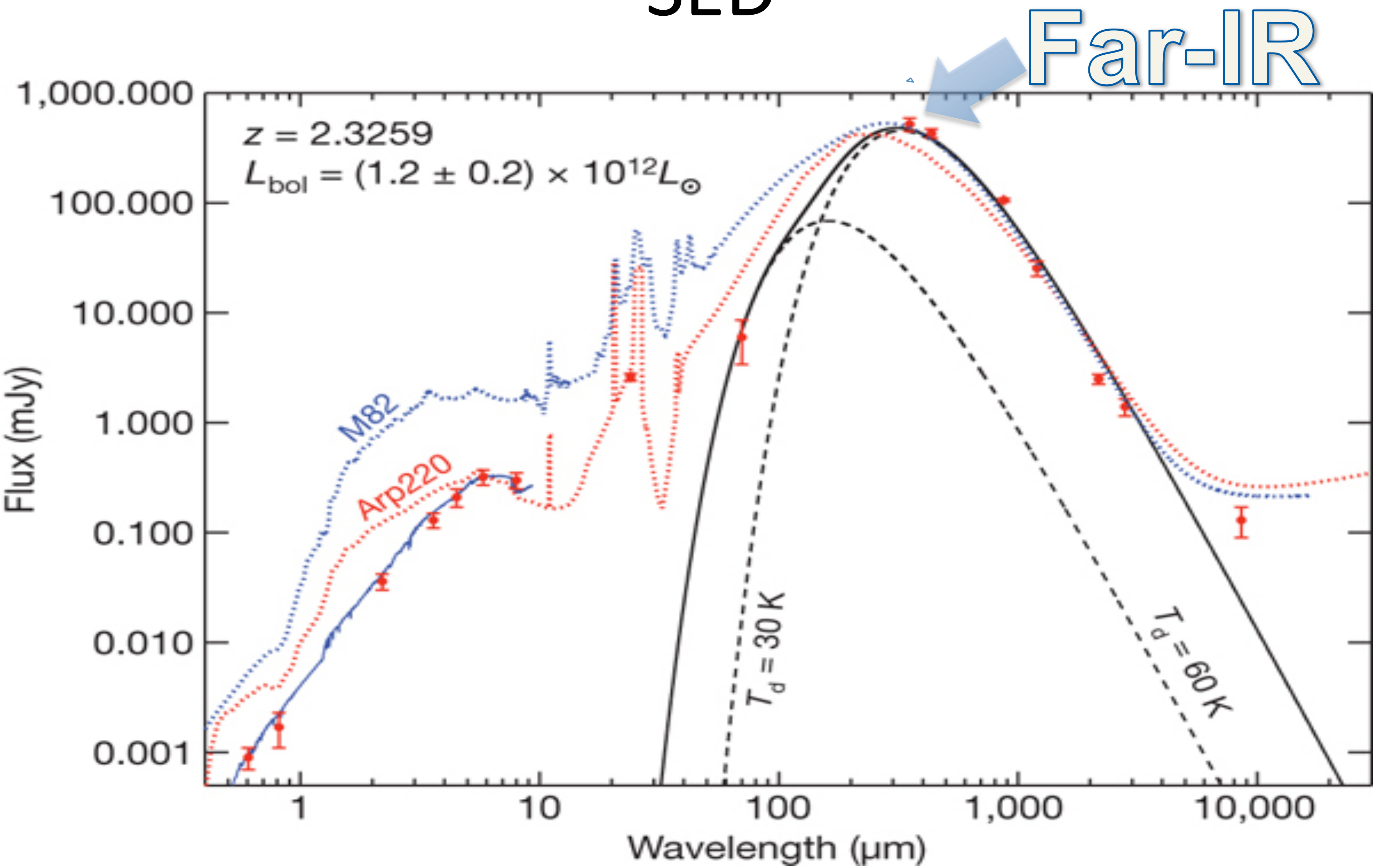


These views of the constellation Orion dramatically illustrate the difference between the familiar, visible-light view and the richness of the universe that is invisible to our eyes, though accessible in other parts of the electromagnetic spectrum.



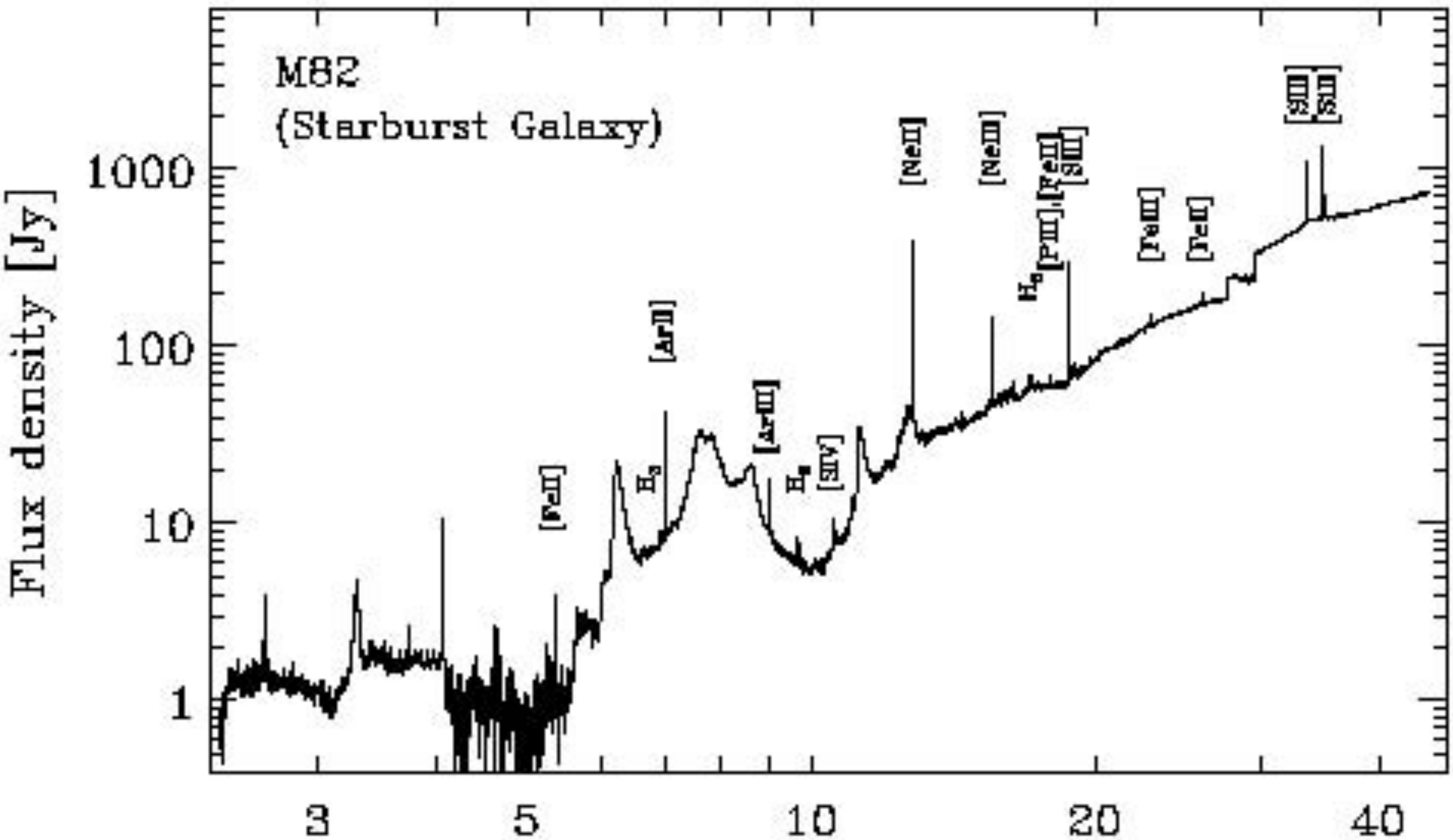
Bolometric Luminosity

SED



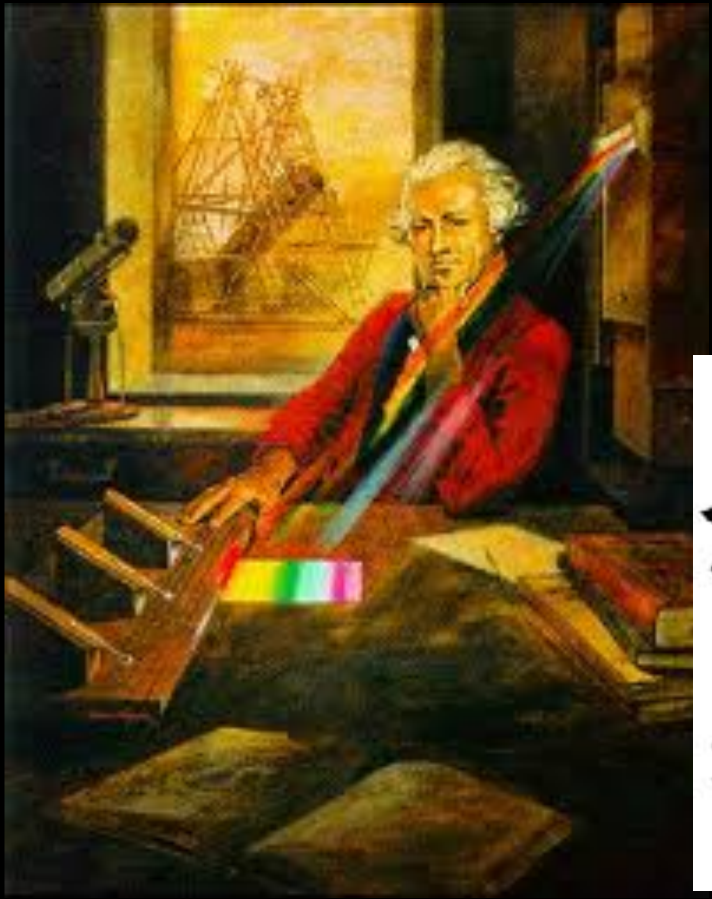
Far-IR
z = 2.3259
L_bol = (1.2 ± 0.2) × 10^12 L_⊙
1,000.000
100.000
10.000
1.000
0.100
0.010
0.001
Flux (mJy)
M82
Arp220
T_d = 30 K
T_d = 60 K
1
10
100
1,000
10,000
Wavelength (μm)

Starburst in the mid-IR Window

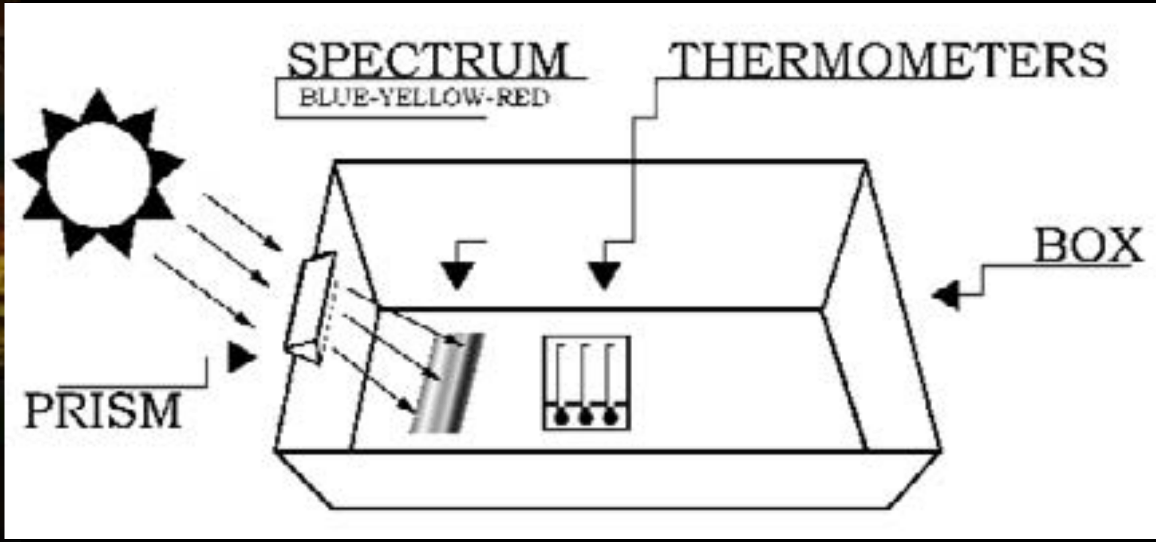


Discovery of the Infrared

Discovery of the Infrared



Gauging the temperature of “color”



William Herschel (1738-1822)

Discovery of the Infrared

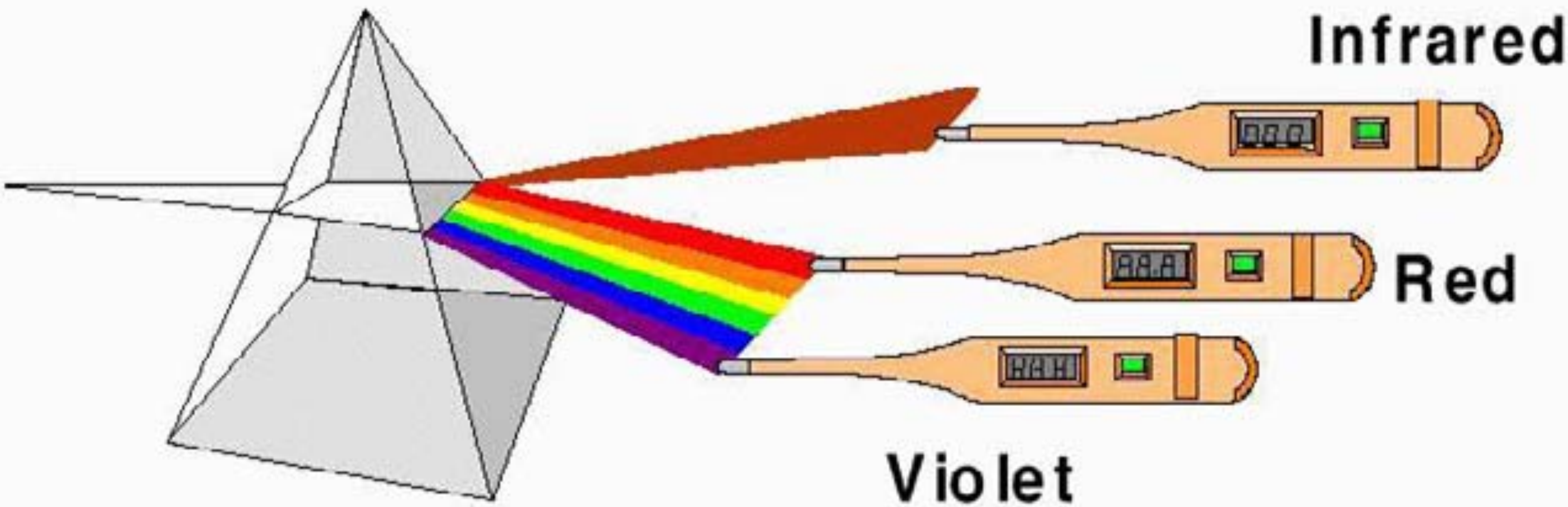
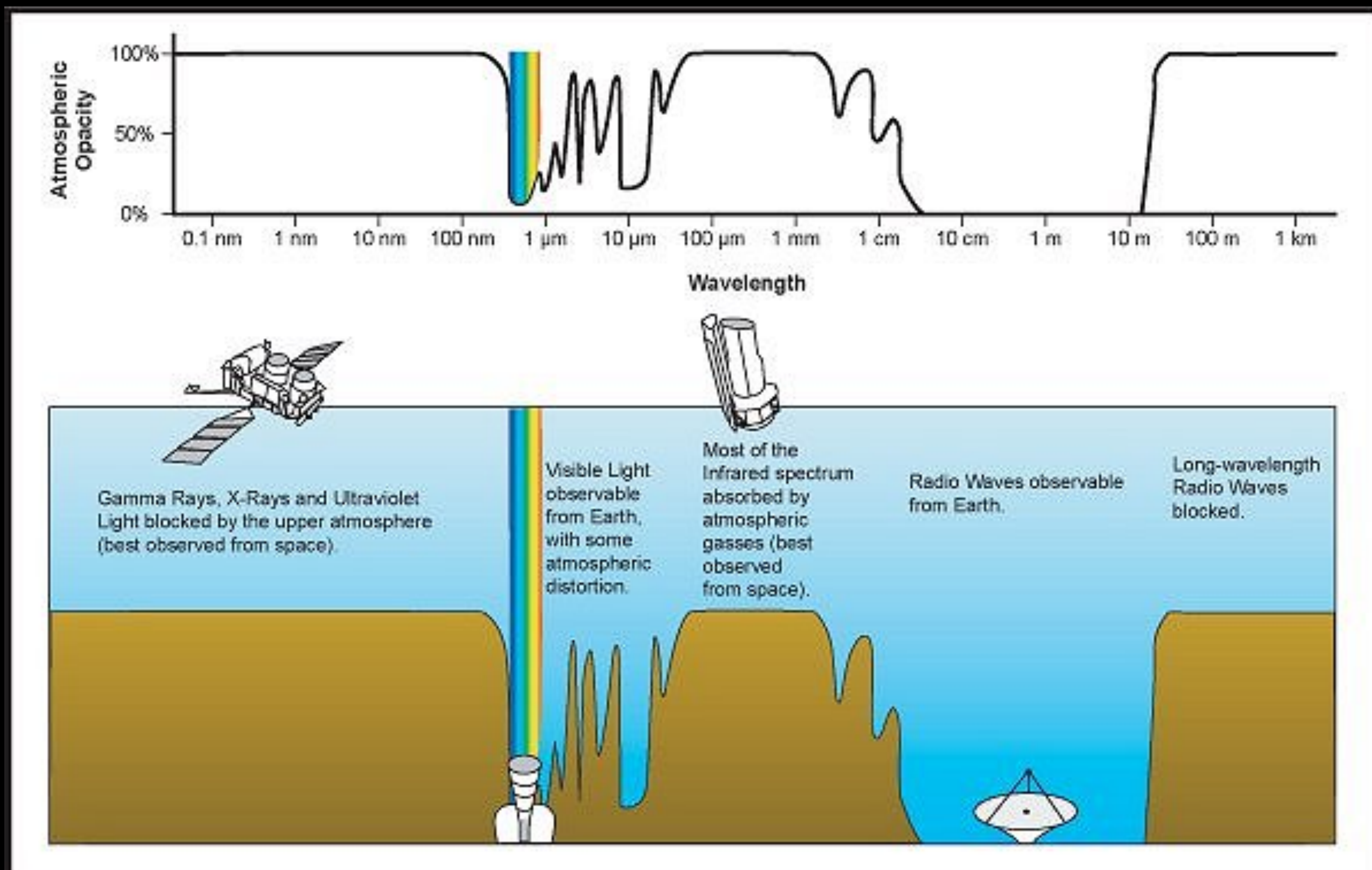


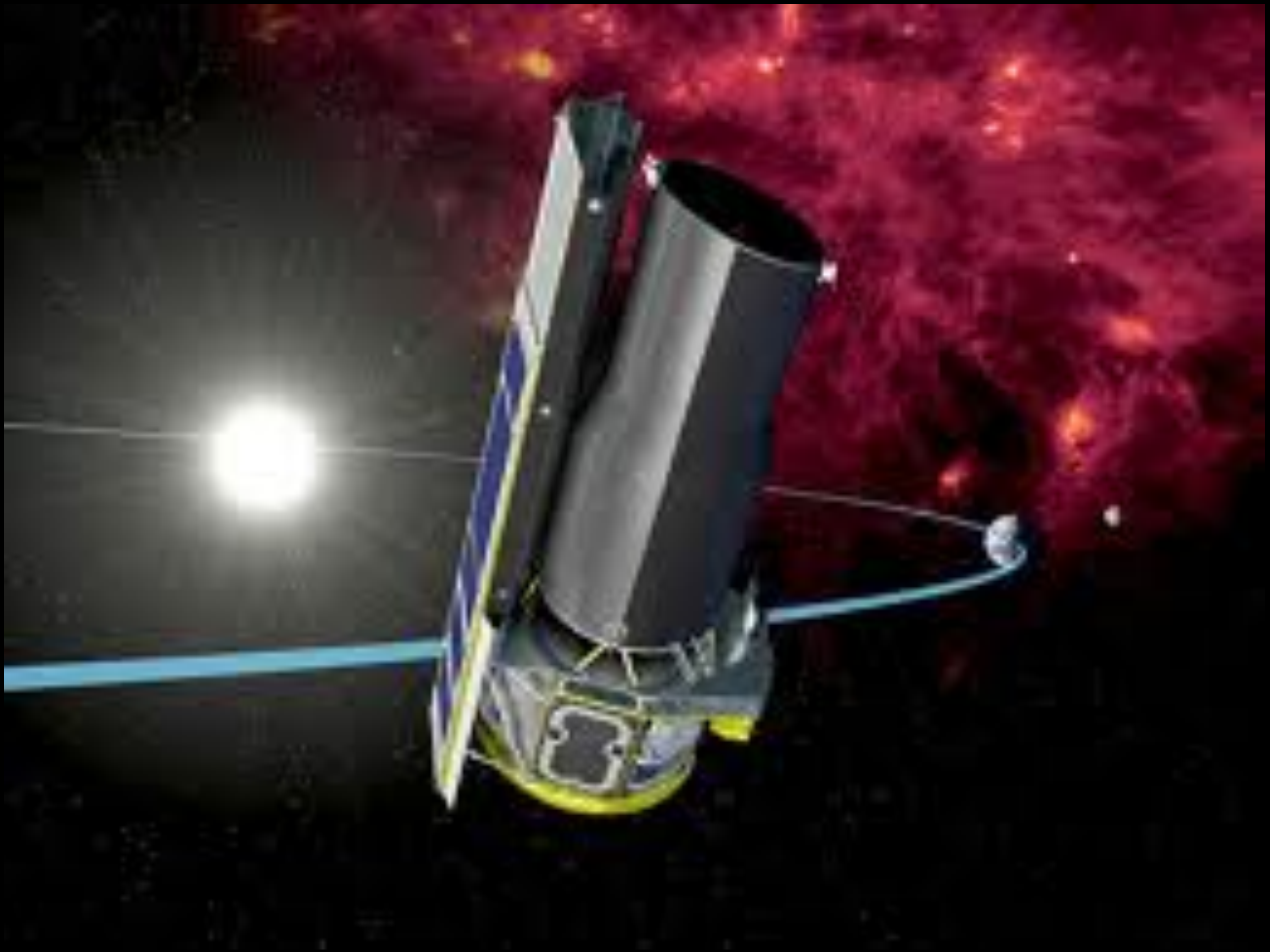
Fig. 1: Herschel used a prism and thermometers in his experiment that eventually led to the discovery of the infrared region of the electromagnetic spectrum.

Infrared Window is accessible through conventional & space telescopes

(with some modification)

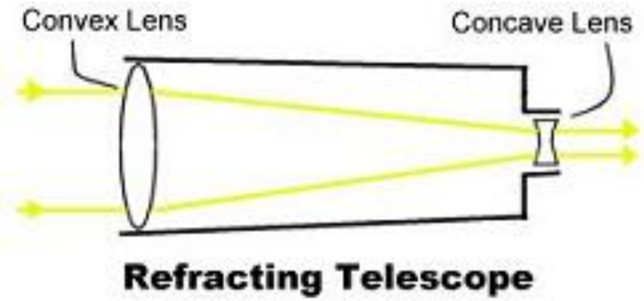


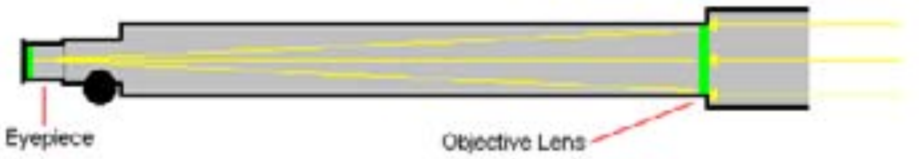
Infrared Space Telescope: Spitzer



Telescopes --
The Astronomer's Time Machine

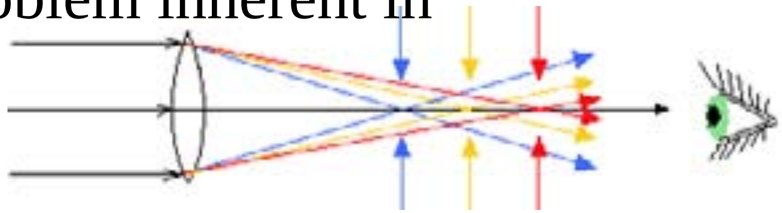
When the first optical telescope appeared in the 1570s, the refracting telescope, the design was simple - one concave and one convex lens fitted inside a tube

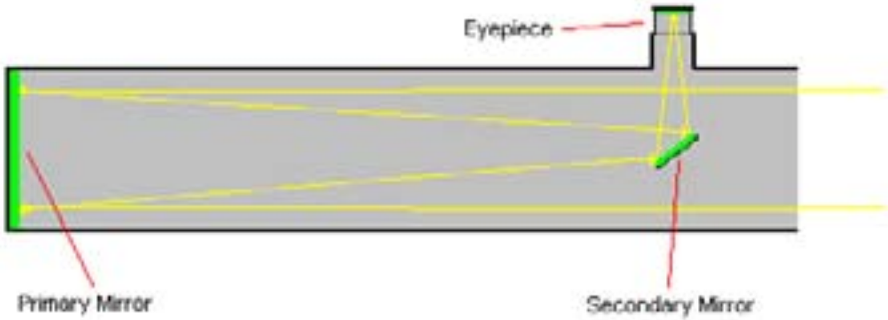


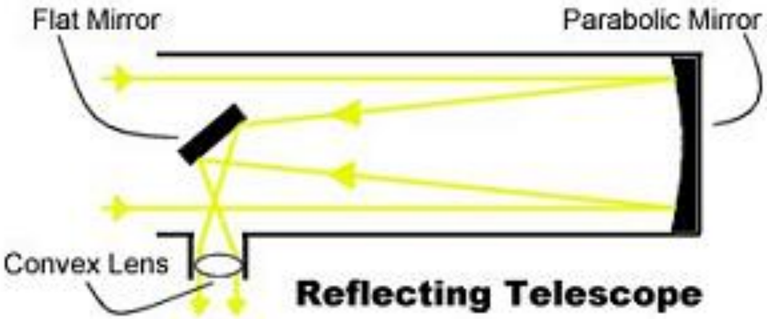


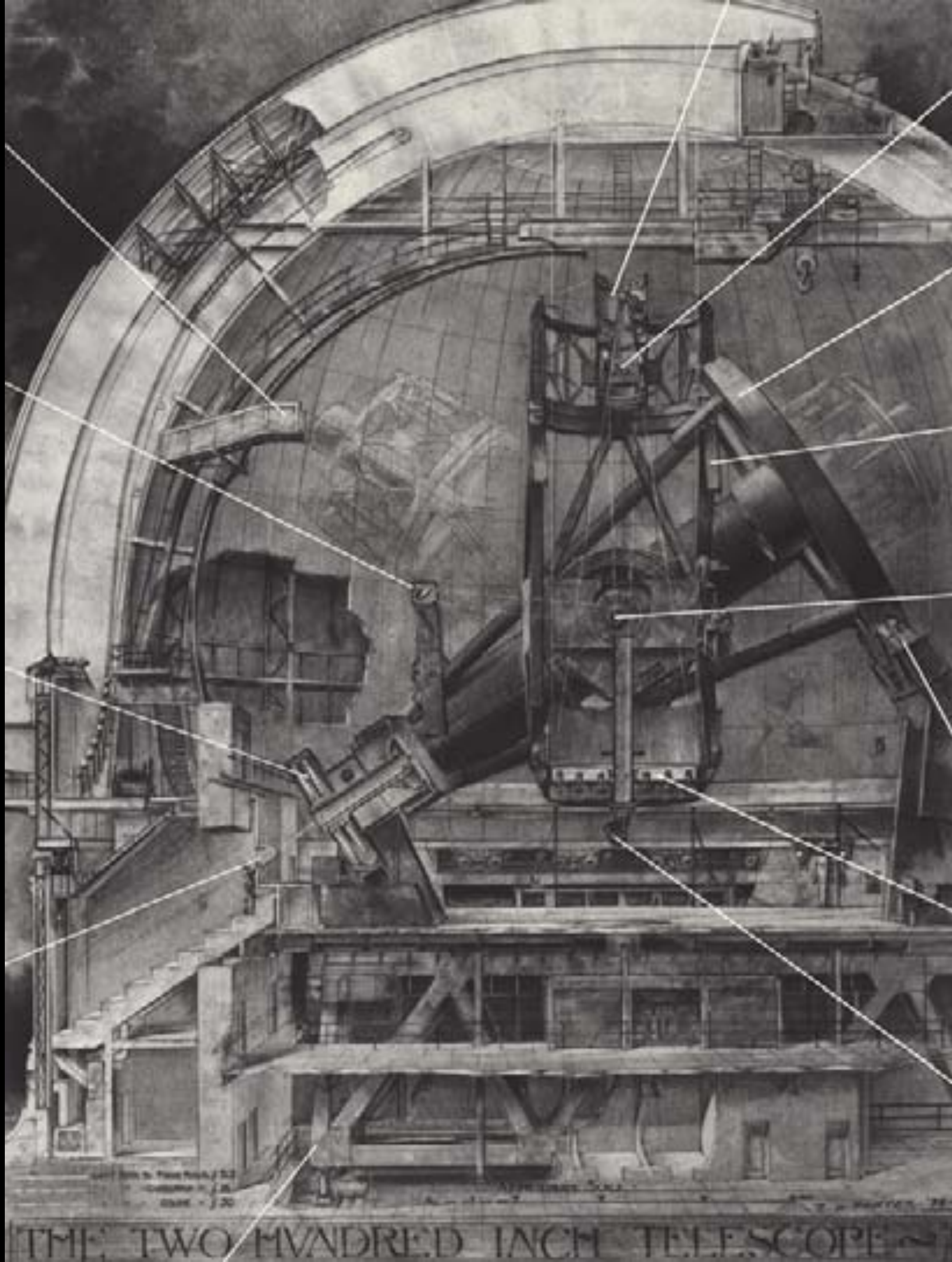
Galileo improved upon the design and by 1609 had developed a 20-power refracting telescope. Galileo made the telescope famous when he discovered the valleys and mountains of the moon and spotted four of Jupiter's satellites.

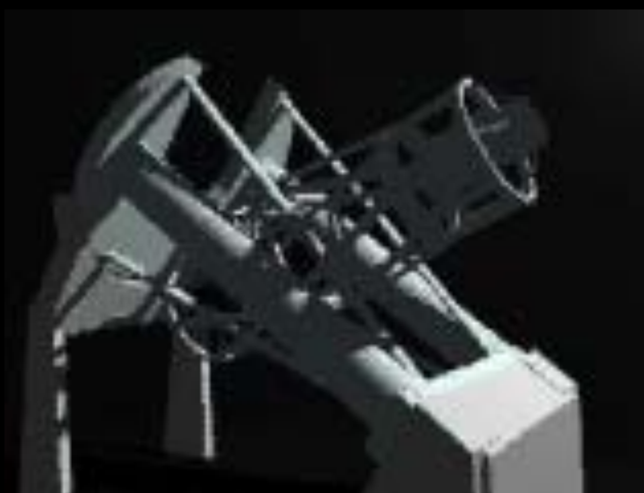
Isaac Newton invented the first reflecting telescope in 1671. By using a curved mirror to reflect and focus the light inside the tube, he was able to reduce the length of the telescope dramatically. The reflecting telescope solved another problem inherent in the refracting telescope: chromatic aberration.

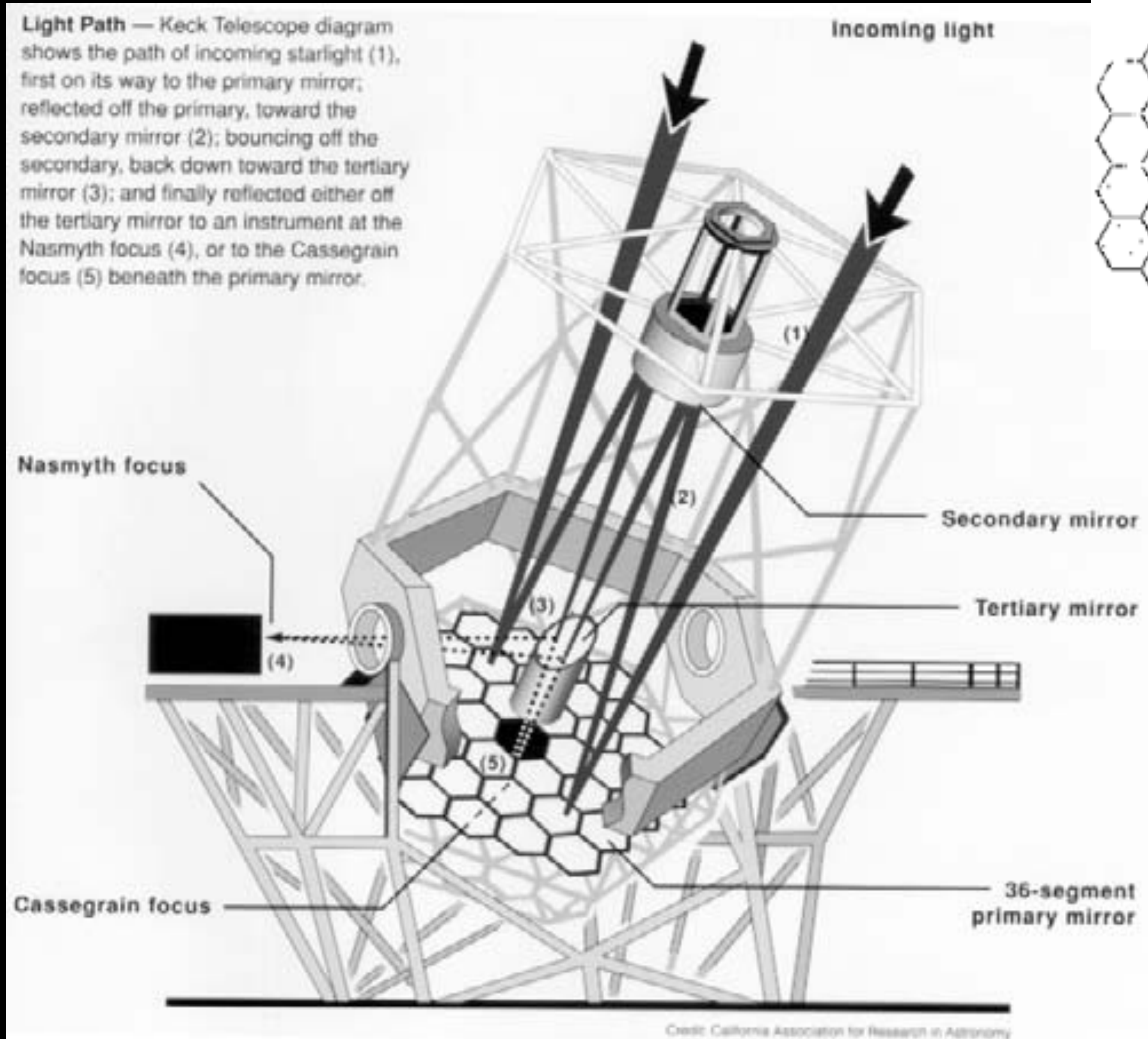




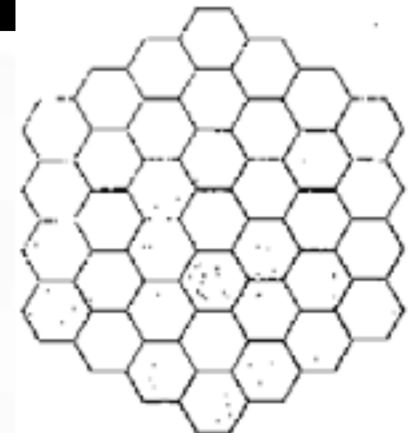


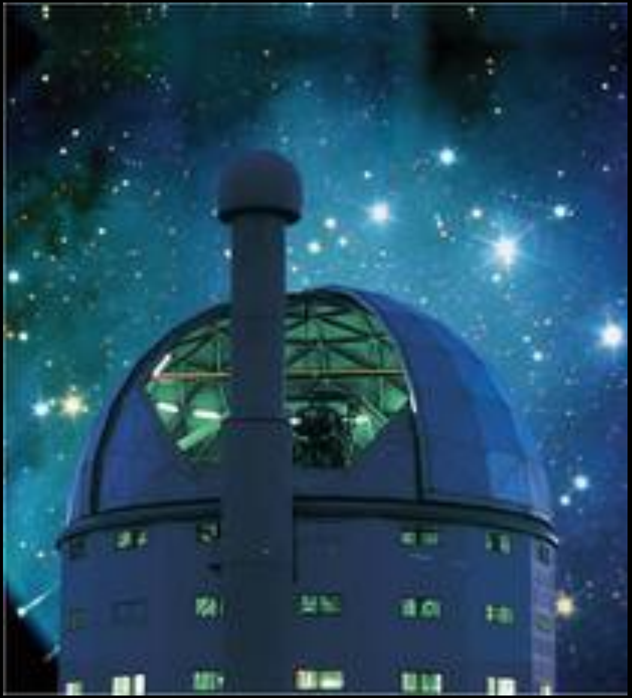

THE TWO HUNDRED INCH TELESCOPE

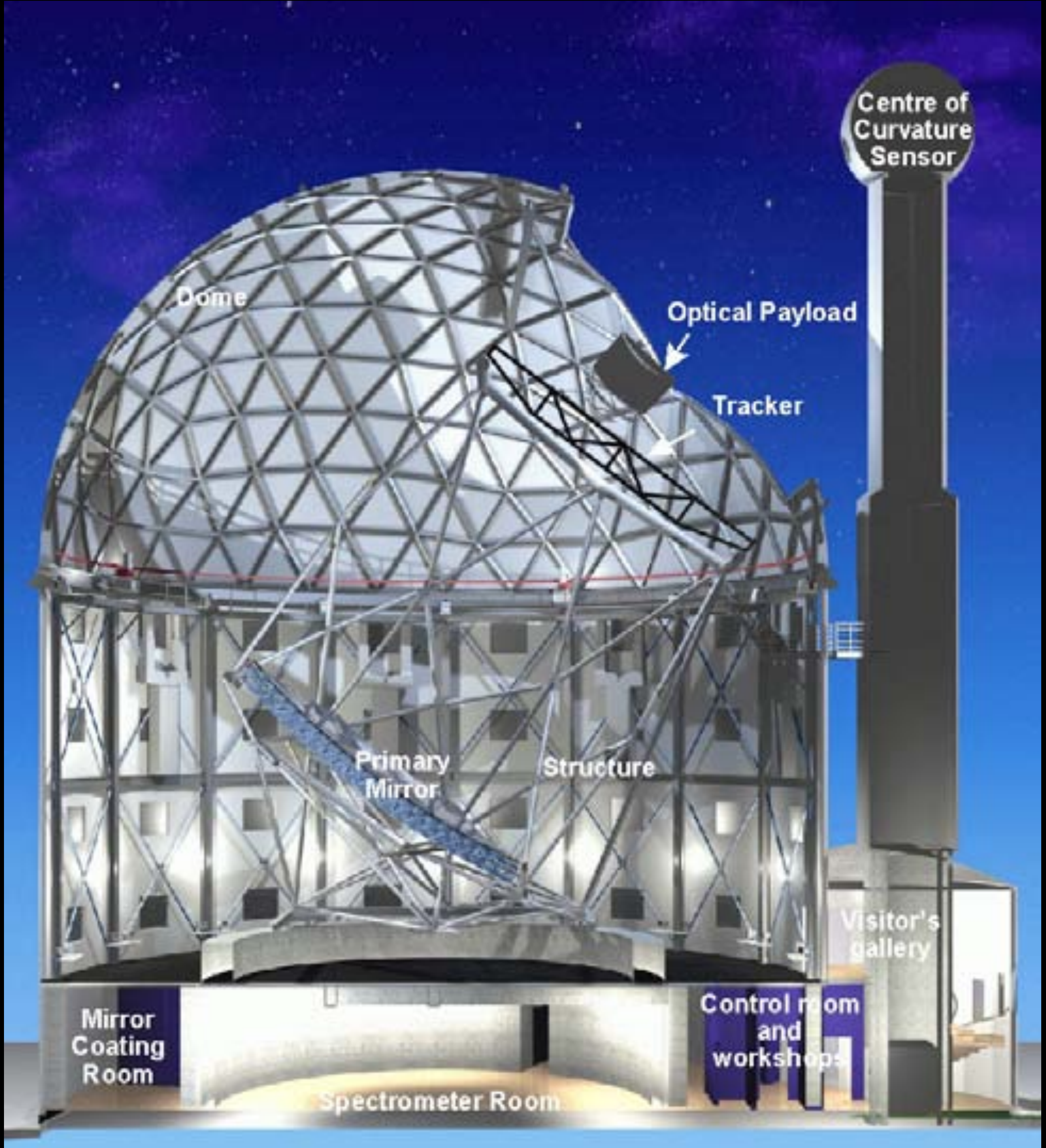




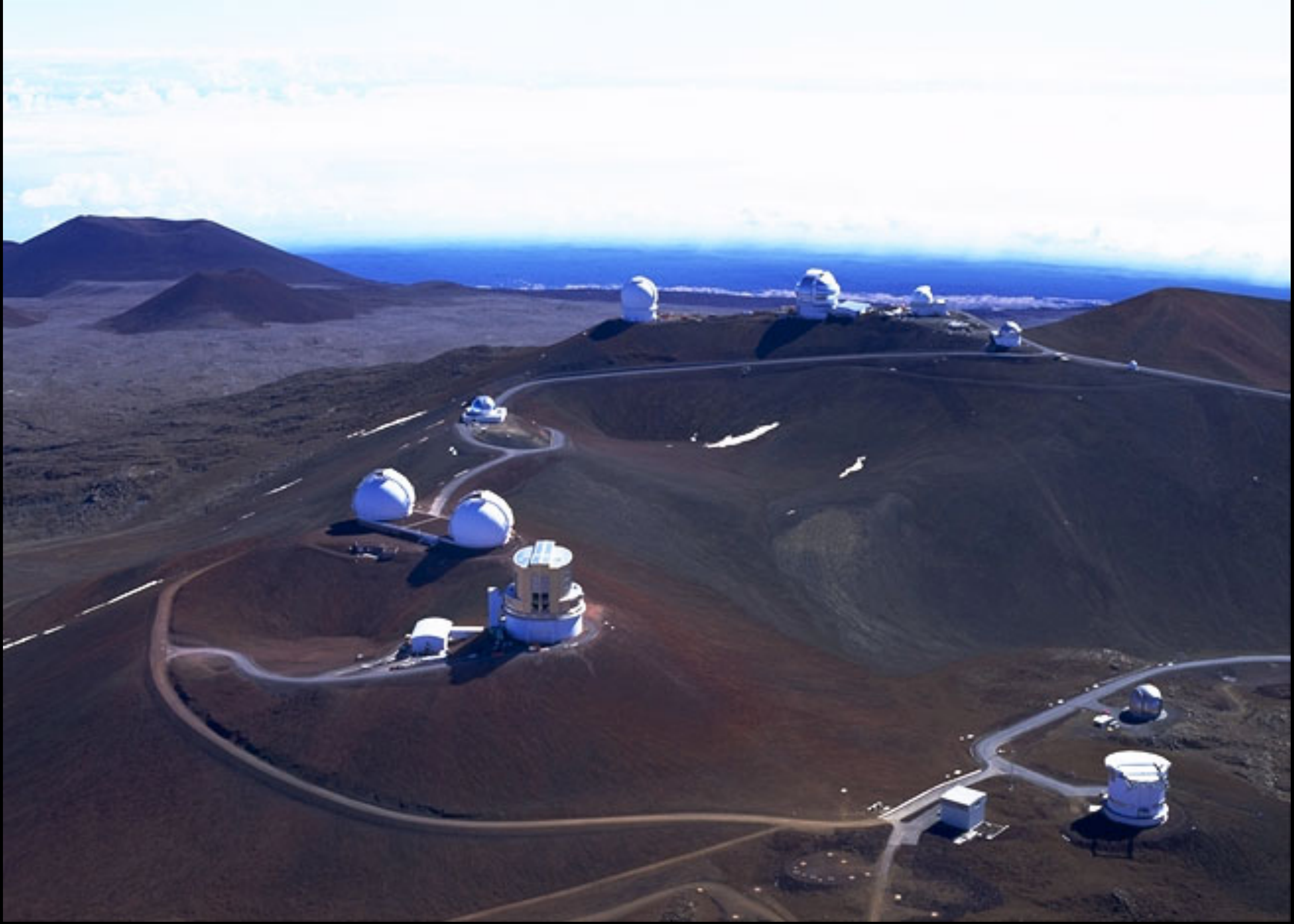
Light Path — Keck Telescope diagram shows the path of incoming starlight (1), first on its way to the primary mirror; reflected off the primary, toward the secondary mirror (2); bouncing off the secondary, back down toward the tertiary mirror (3); and finally reflected either off the tertiary mirror to an instrument at the Nasmyth focus (4), or to the Cassegrain focus (5) beneath the primary mirror.



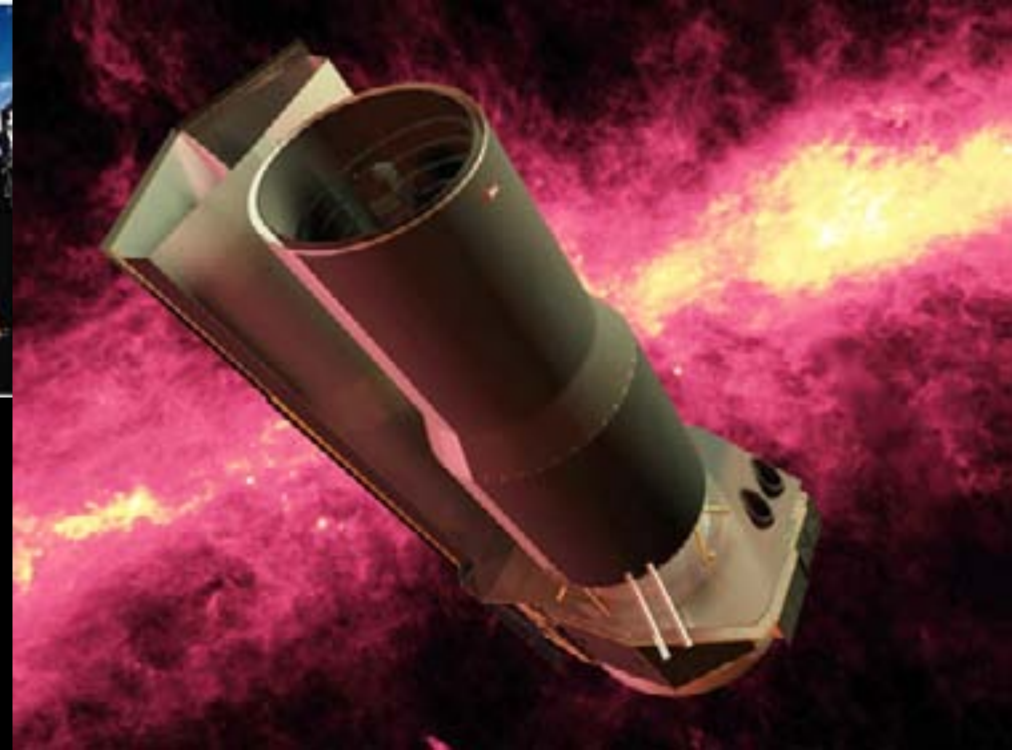



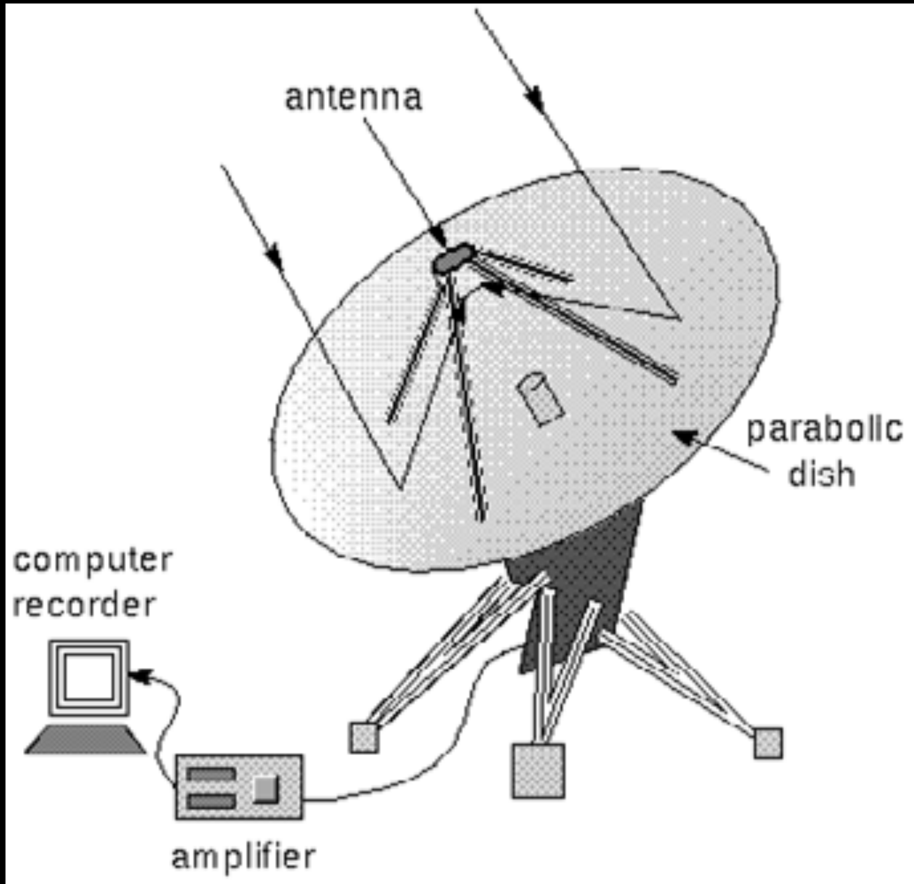

Centre of Curvature Sensor
Dome
Optical Payload
Tracker
Primary Mirror
Structure
Visitor's gallery
Mirror Coating Room
Control room and workshops
Spectrometer Room

AURA/NOAO/NSF

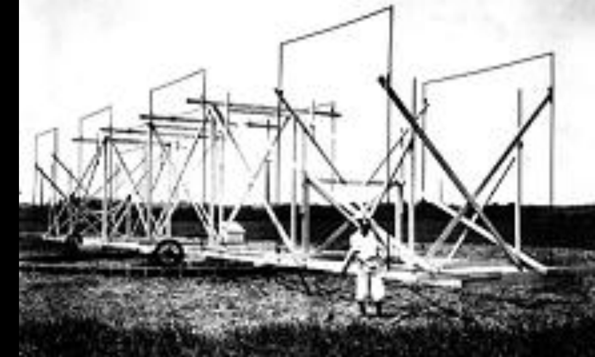






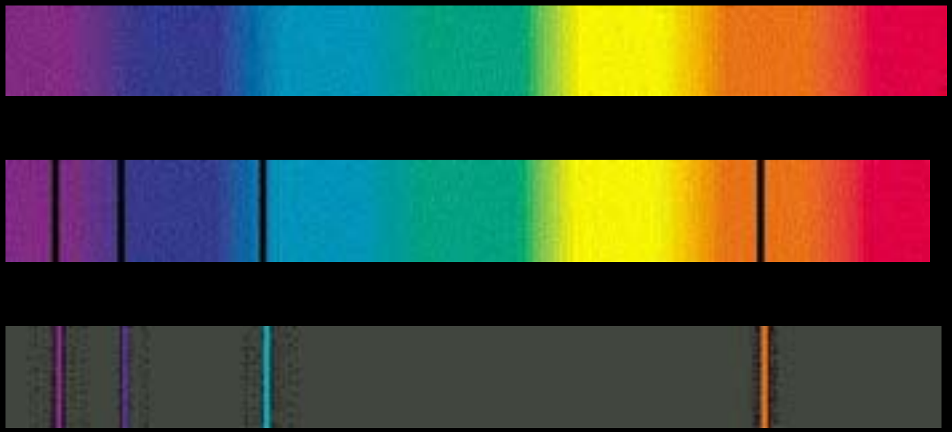


A radio telescope reflects radio waves to a focus at the antenna. Because radio wavelengths are very large, the radio dish must be very large.



SKA-Africa

Spectroscopy

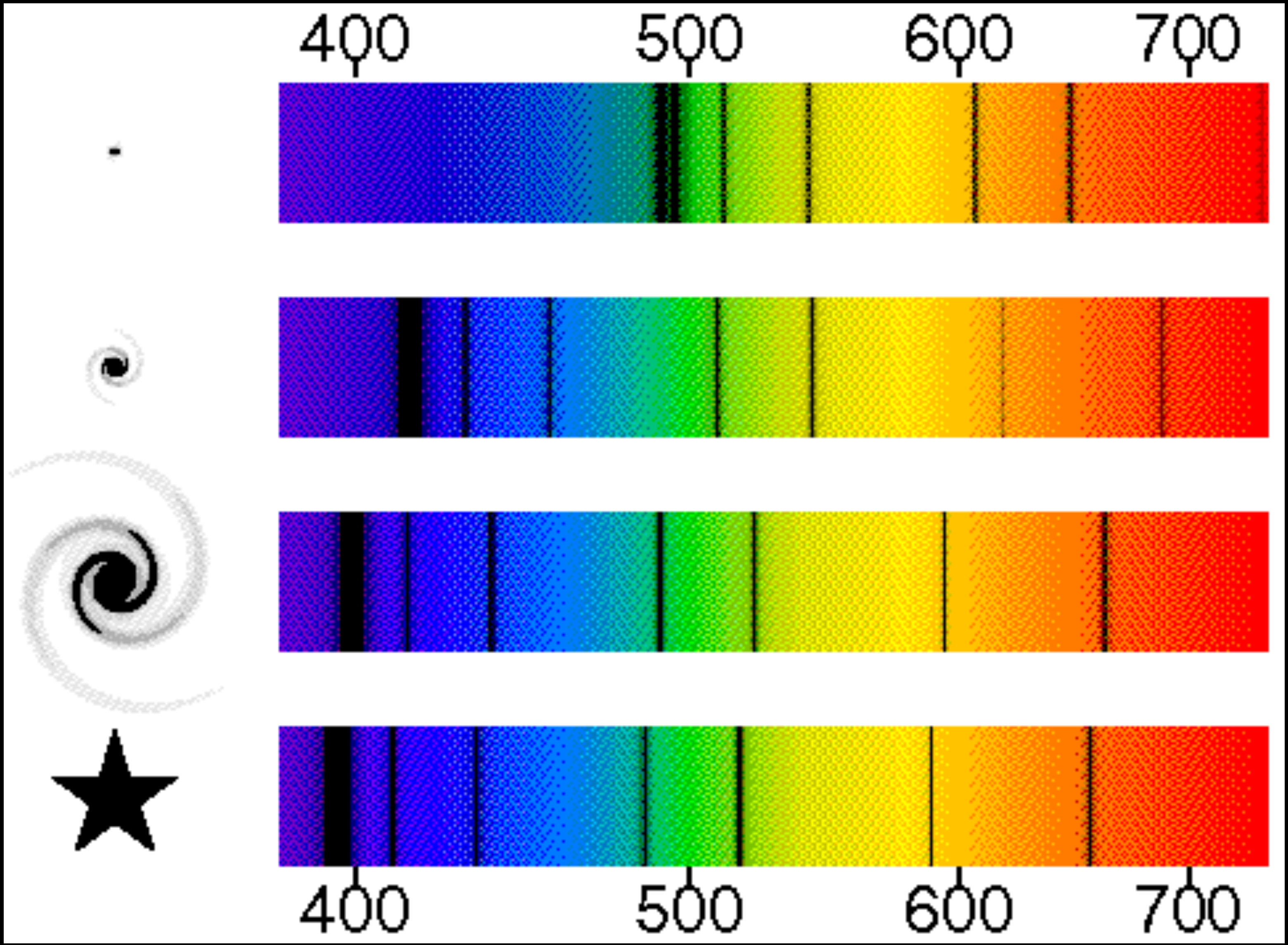


continuum

Hydrogen absorption

emission

Chemical signatures tell us about the composition of the source; emission lines can also be used for “redshift” information …

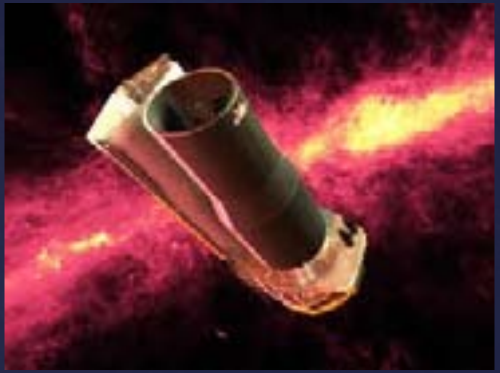


In the star which is at rest with respect to us, or in a laboratory standard, the line wavelengths are 393 & 397 nm from Ca II [ionized calcium]; 410, 434, 486 & 656 nm from H I [atomic hydrogen]; 518 nm from Mg I [neutral magnesium]; and 589 nm from Na I [neutral sodium]. By measuring the amount of the shift to the red, we can determine that the bright galaxy is moving away at 3,000 km/sec, which is 1 percent of the

speed of light, because its lines are shifted in wavelength by 1 percent to the red.


Infrared Astrophysics

Near/Mid-Infrared Emission Sources



- photospheres of evolved stars
- thermal – tracers of ionised gas
- non-thermal (e.g. shocks) – fine structure lines; H_2
- dust grains (small) : continuum > 10µm
- dust grains (large) : absorption features at 9.7µm,18µm
- polycyclic aromatic hydrocarbons (PAHs)
- molecular gas

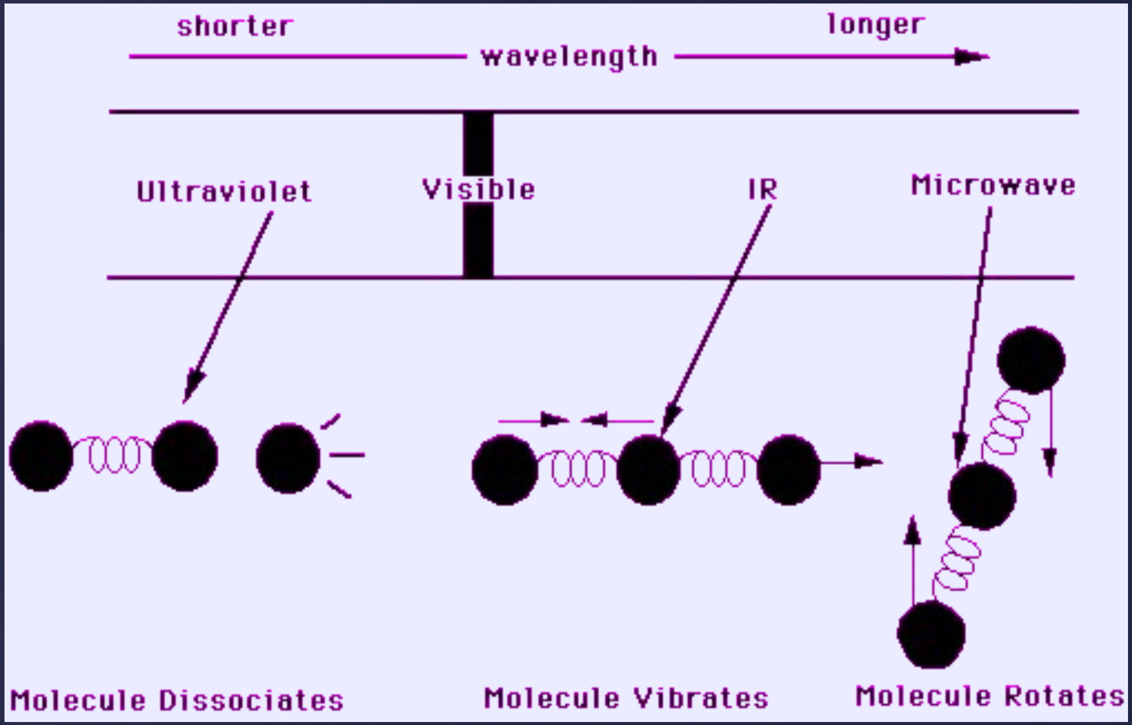
Slide courtesy of M. Cluver

Near-Infrared Emission Lines

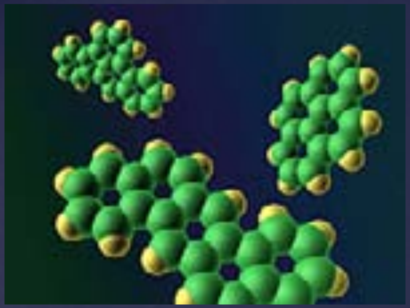
- Paschen-Beta   1.28 µm   >> Recombination
- [FeII] at 1.64 µm >> shock-excited tracer of energic phenom
- H2 at 2.12 µm >> direct measure of molecular hydrogen; shocks
- Br-g at 2.17 µm >> recombination (lower extinction)
- CO bands at >2.2 µm   >> ISM & circumstellar dust

Molecules in the Infrared

- Emission and absorption lines of most molecules and many atoms
- Primary detection method for elements in space



http://www.wag.caltech.edu/home/jang/genchem/infrared.htm



PAH molecules

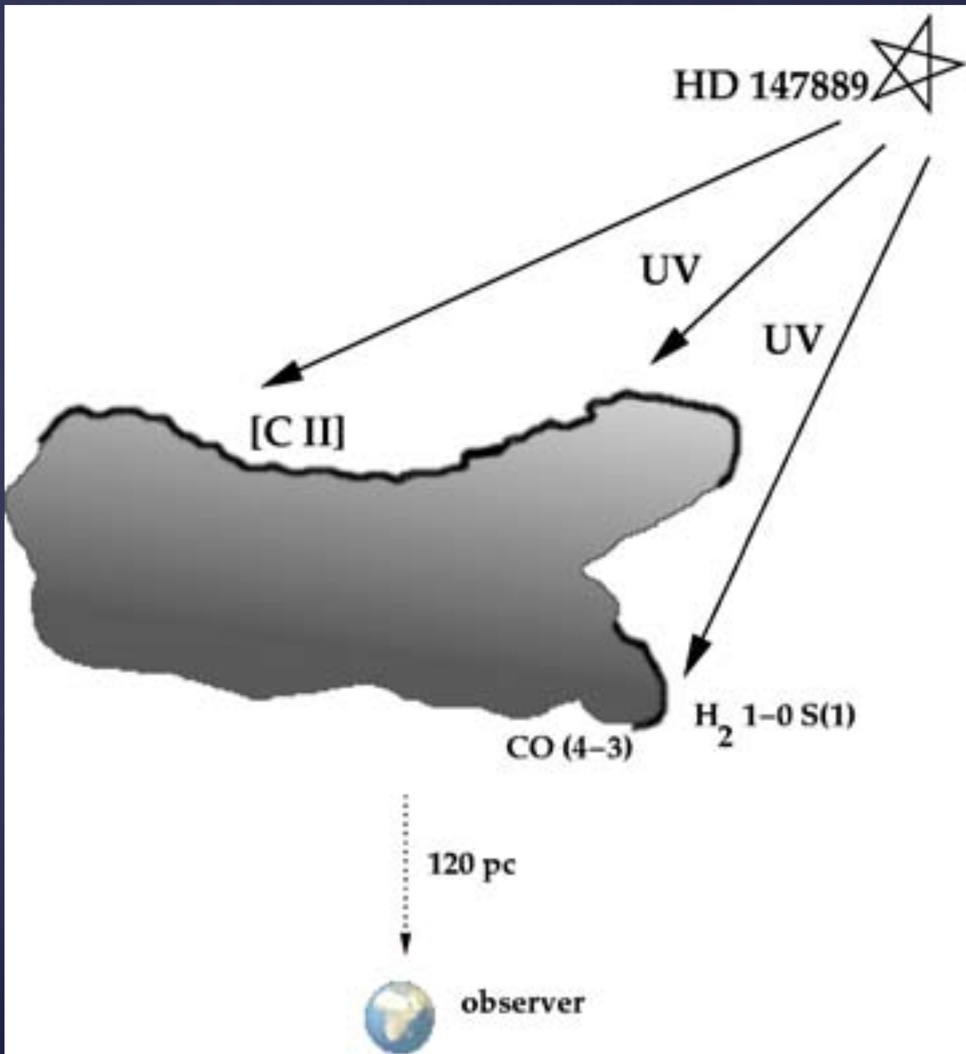
Polycyclic = multiple loops
Aromatic = strong bonds
Hydrocarbons = hydrogen and carbon

- emission bands 3 - 20 microns (** 3.2, 6.2, 7.7, 11.3 μm **)
- thought to originate in star forming regions
- linked to dust formation (precursors?)

PAHs -- Easily destroyed – environment diagnostic (AGN; low metallicity)

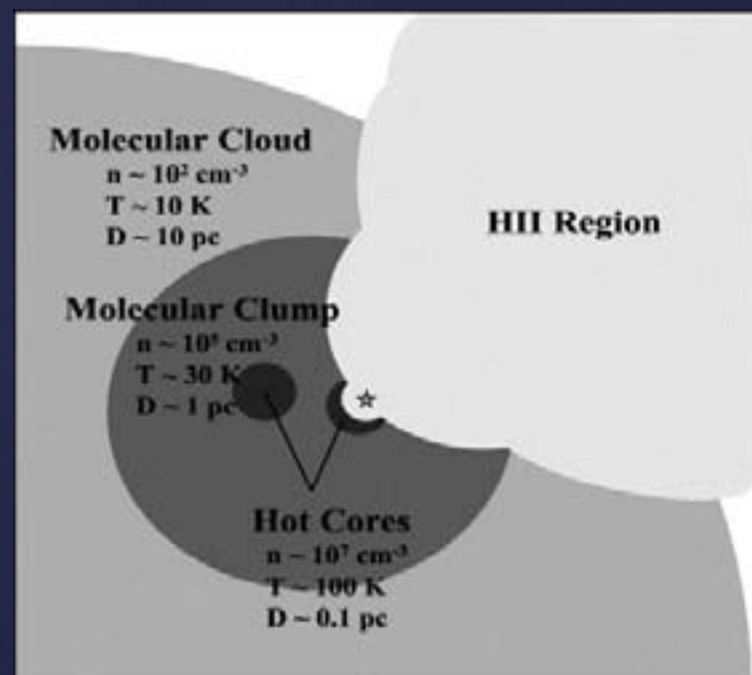
- PAHs suppressed in low metallicity environments
- weak or absent in AGN environment (either destroyed by hard radiation or possibly drowned out by continuum
- associated with PDRs (photodissociation regions) of molecular clouds
- PDR = interface between molecular and ionised regions of the ISM

Photodissociation Regions (PDRs)



Energetic photons create HII regions

- Less energetic photons cause dissociation of H_2 and CO (dominant) at interface with molecular cloud



Galaxies

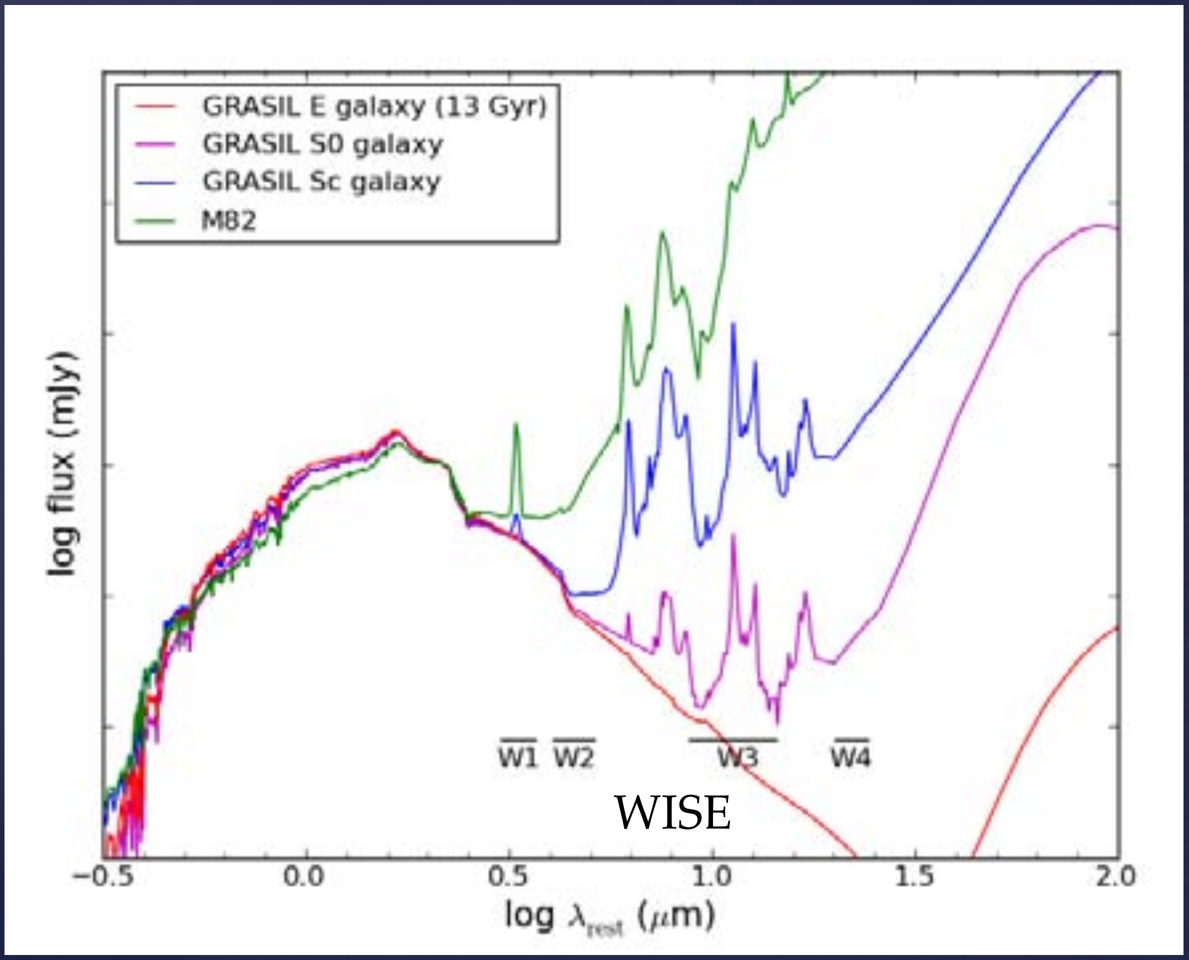
Self-contained “island universe” provide a means to understand the Milky Way and its relationship to the greater universe

Break it down ----

Stellar light traces the galaxy “mass”

“warm dust” and emission from molecules trace the star formation birth cradles

Galaxies Through the OPT-IR Window



- Tracing old stellar population = bulk of stellar mass

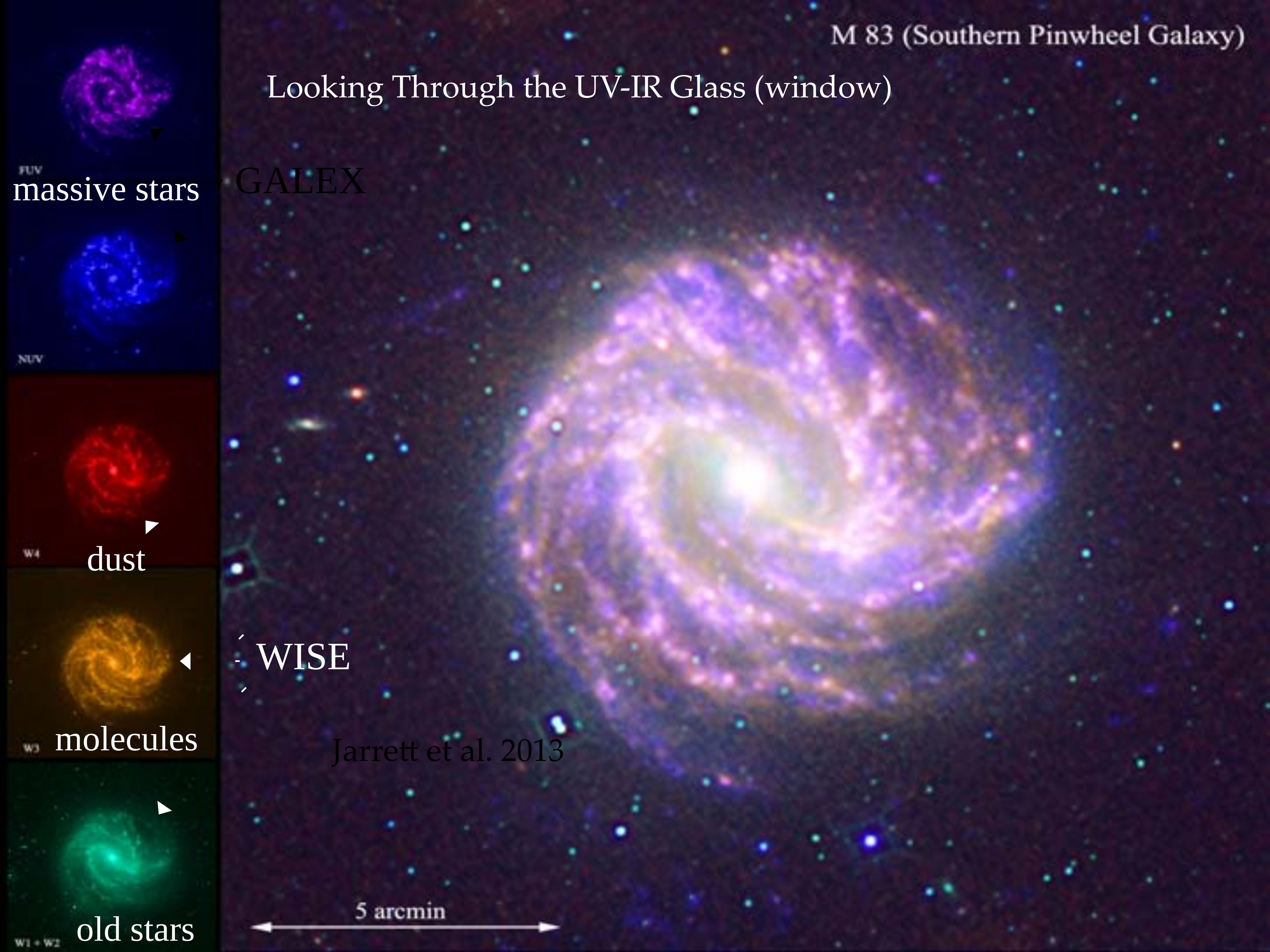
- Interstellar medium = continuum + PAH emission + silicate absorption

→ star formation + AGN activity

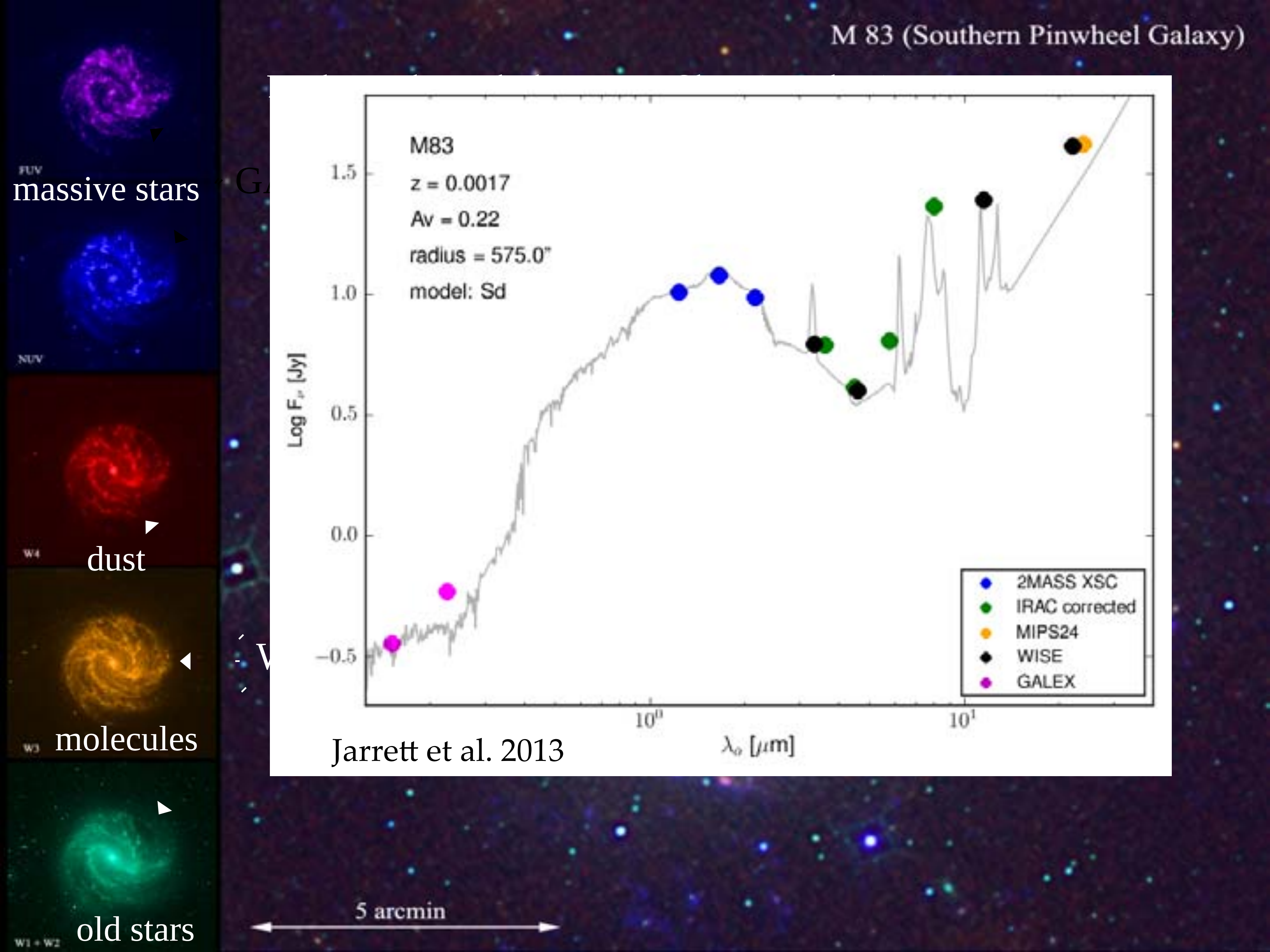
Slide courtesy of M. Cluver

M 83

Southern Pinwheel Galaxy



Looking Through the UV-IR Glass (window)
M 83 (Southern Pinwheel Galaxy)
FUV
massive stars
GALEX
NUV
W4
dust
WISE
W3
molecules
W1 + W2
old stars
Jarrett et al. 2013
5 arcmin



M 83 (Southern Pinwheel Galaxy)
FUV
massive stars
NUV
W4
dust
W3
molecules
W1 + W2
old stars
5 arcmin
M83
z = 0.0017
Av = 0.22
radius = 575.0"
model: Sd
Log F_ν [Jy]
1.5
1.0
0.5
0.0
−0.5
10^0
10^1
λ_o [μm]
2MASS XSC
IRAC corrected
MIPS24
WISE
GALEX
Jarrett et al. 2013

Obscured Star Formation

PAH Young Stars ratio

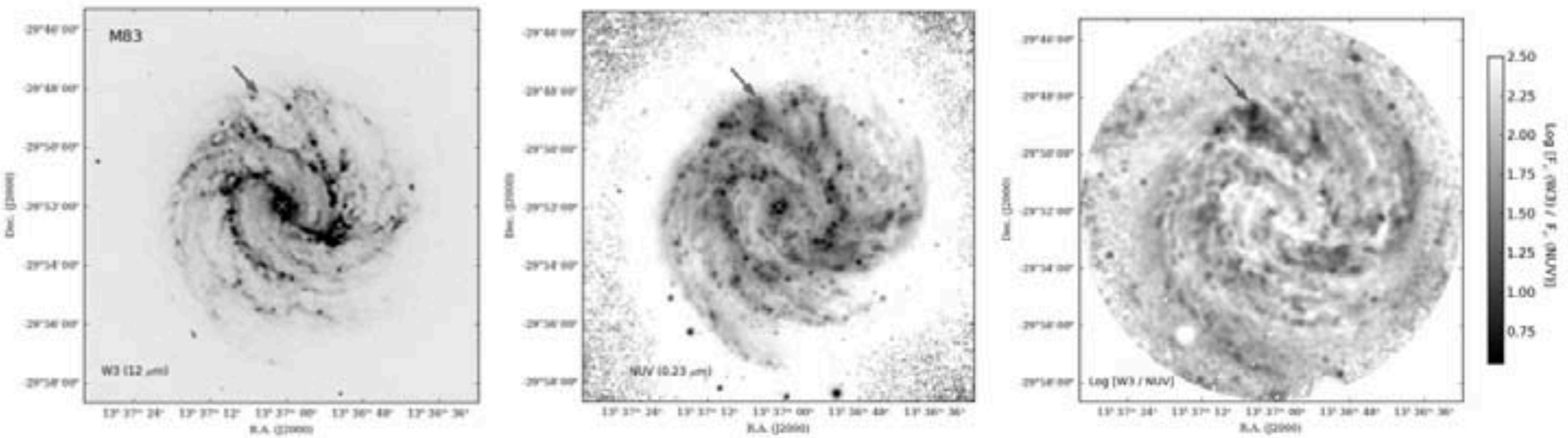
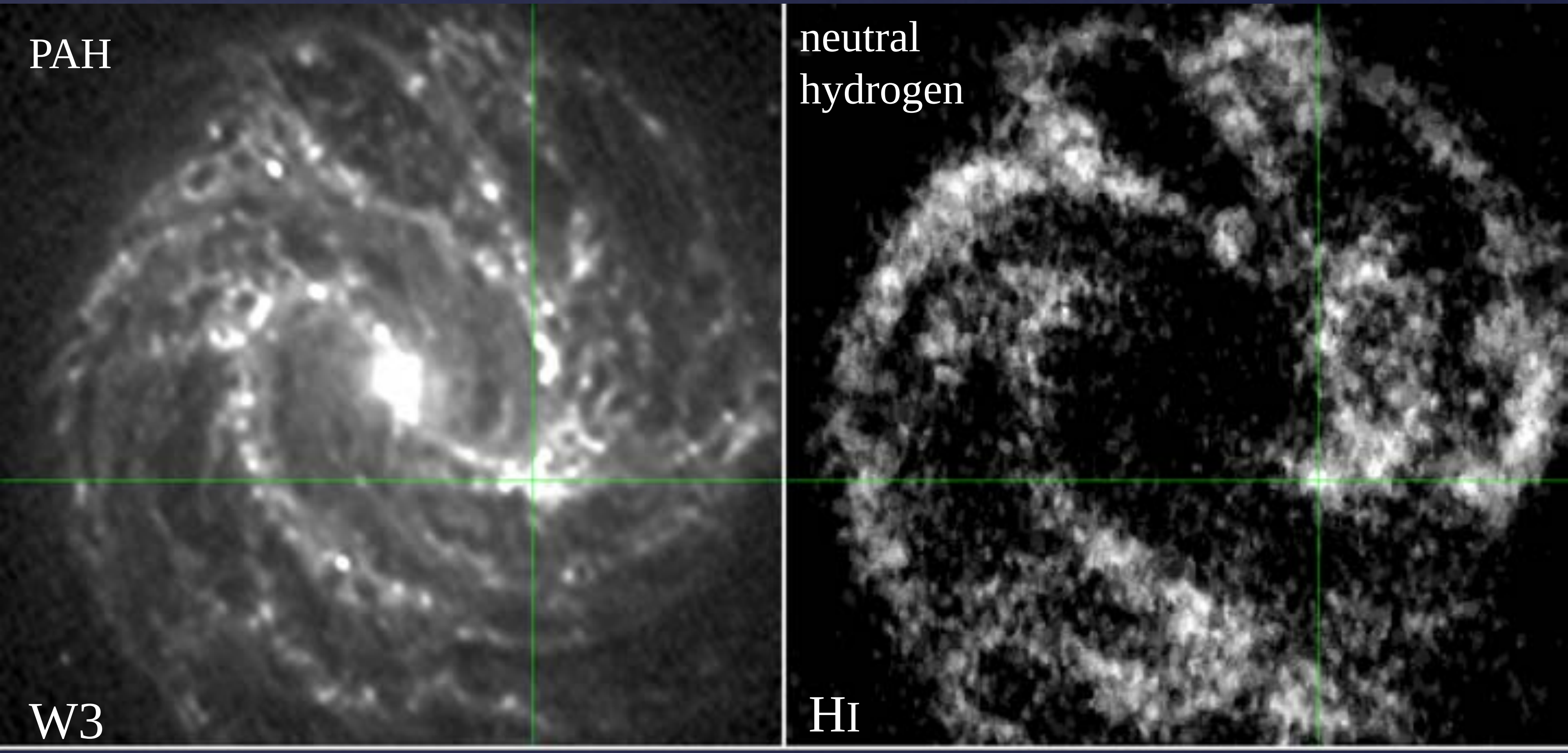
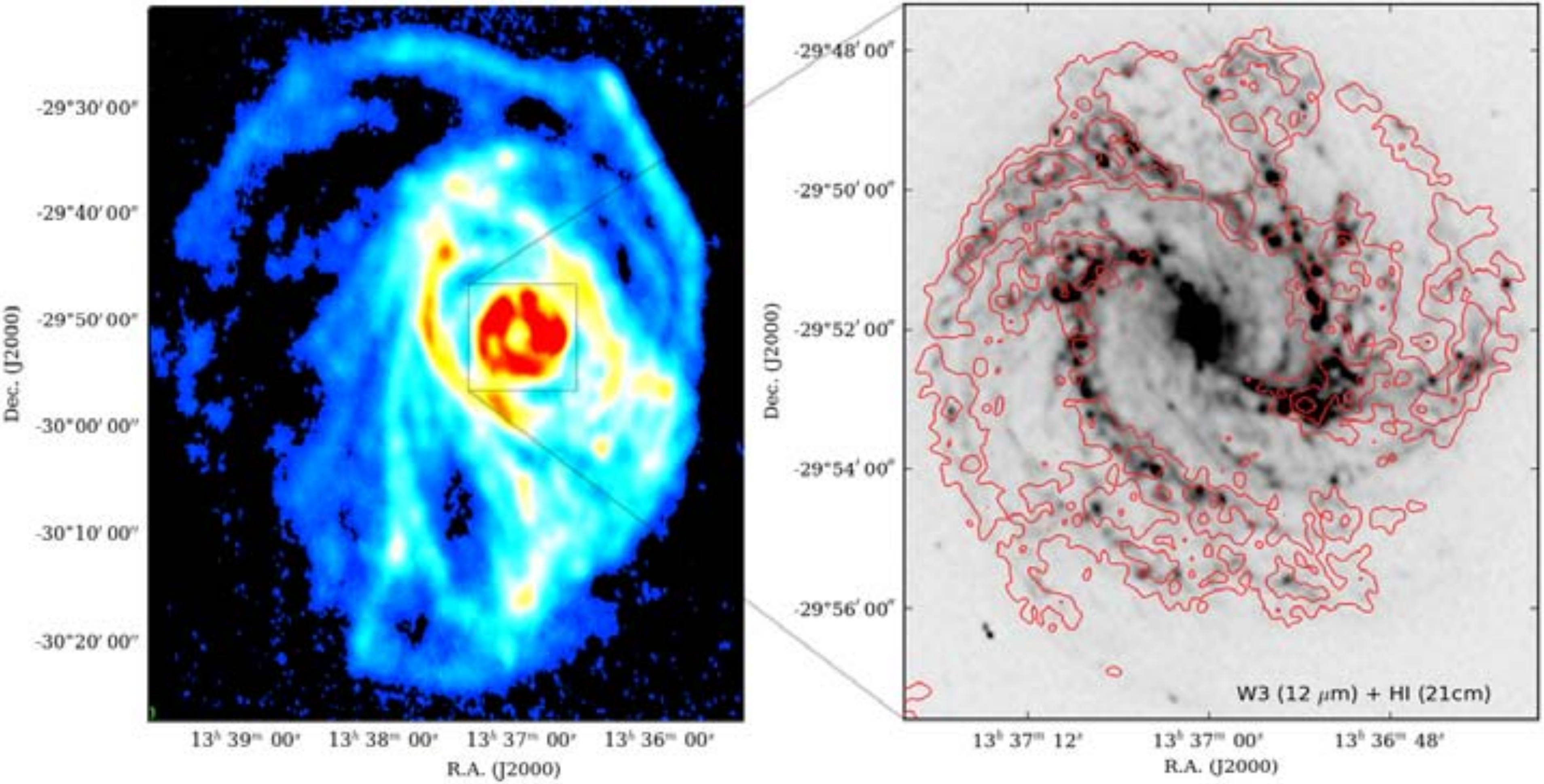


Fig. 17.— (left)WISE W3 comparison with GALEX NUV of M 83 (NGC 5236). The first panel shows a log-stretch of the WISE W3 image, the (middle) panel a log-stretch of the GALEX NUV image, and the (right) panel is the flux ratio between the two bands. Dark grey-scale values indicate strong NUV, while light values indicate relatively strong W3; e.g., the arrow points to high NUV and low W3. The nucleus is denoted with an × symbol.

PAH vs HI Reservoir

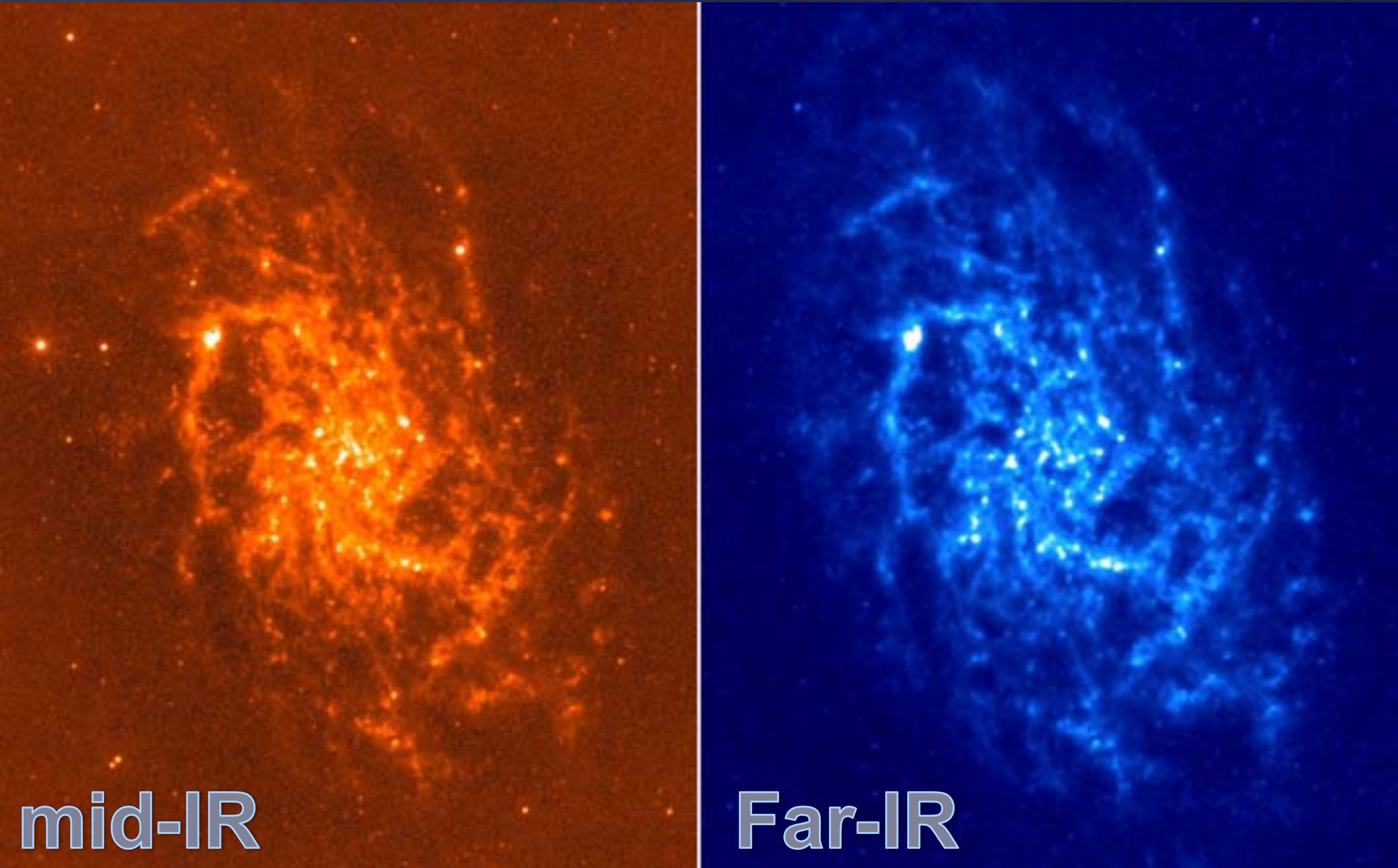


ATCA high-resolution
(Koribalski)



-29°30′00″
-29°40′00″
-29°50′00″
-30°00′00″
-30°10′00″
-30°20′00″
Dec. (J2000)
13ʰ 39ᵐ 00ˢ
13ʰ 38ᵐ 00ˢ
13ʰ 37ᵐ 00ˢ
13ʰ 36ᵐ 00ˢ
R.A. (J2000)
-29°48′00″
-29°50′00″
-29°52′00″
-29°54′00″
-29°56′00″
Dec. (J2000)
W3 (12 μm) + HI (21cm)
13ʰ 37ᵐ 12ˢ
13ʰ 37ᵐ 00ˢ
13ʰ 36ᵐ 48ˢ
R.A. (J2000)

M33: Far-IR vs 12μm



M31 Through the UV-IR Looking Glass

WISE (Jarrett & Masci)

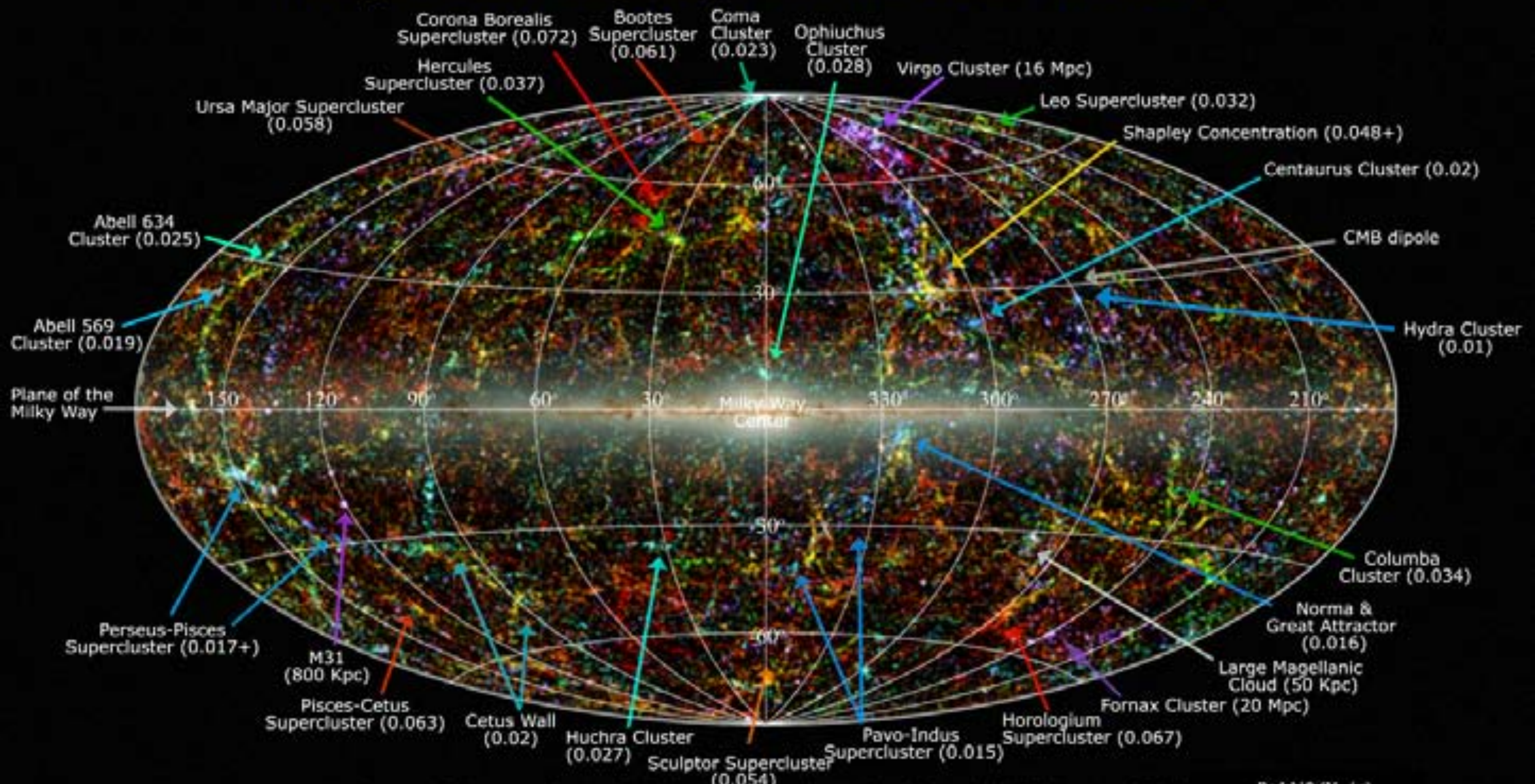
Slide courtesy of M. Cluver

The Big Picture

Local Universe -- the whole enchilada

Panoramic view of the entire near-infrared sky reveals the distribution of galaxies beyond the Milky Way. The image is derived from the 2MASS Extended Source Catalog (XSC)--more than 1.5 million galaxies, and the Point Source Catalog (PSC)--nearly 0.5 billion Milky Way stars. The galaxies are color coded by "redshift" or photometrically deduced from the K band (2.2 um). Blue are the nearest sources ($z < 0.01$); green are at moderate distances ($0.01 < z < 0.04$) and red are the most distant sources that 2MASS resolves ($0.04 < z < 0.1$). (Jarrett 2004)

Large Scale Structure in the Local Universe



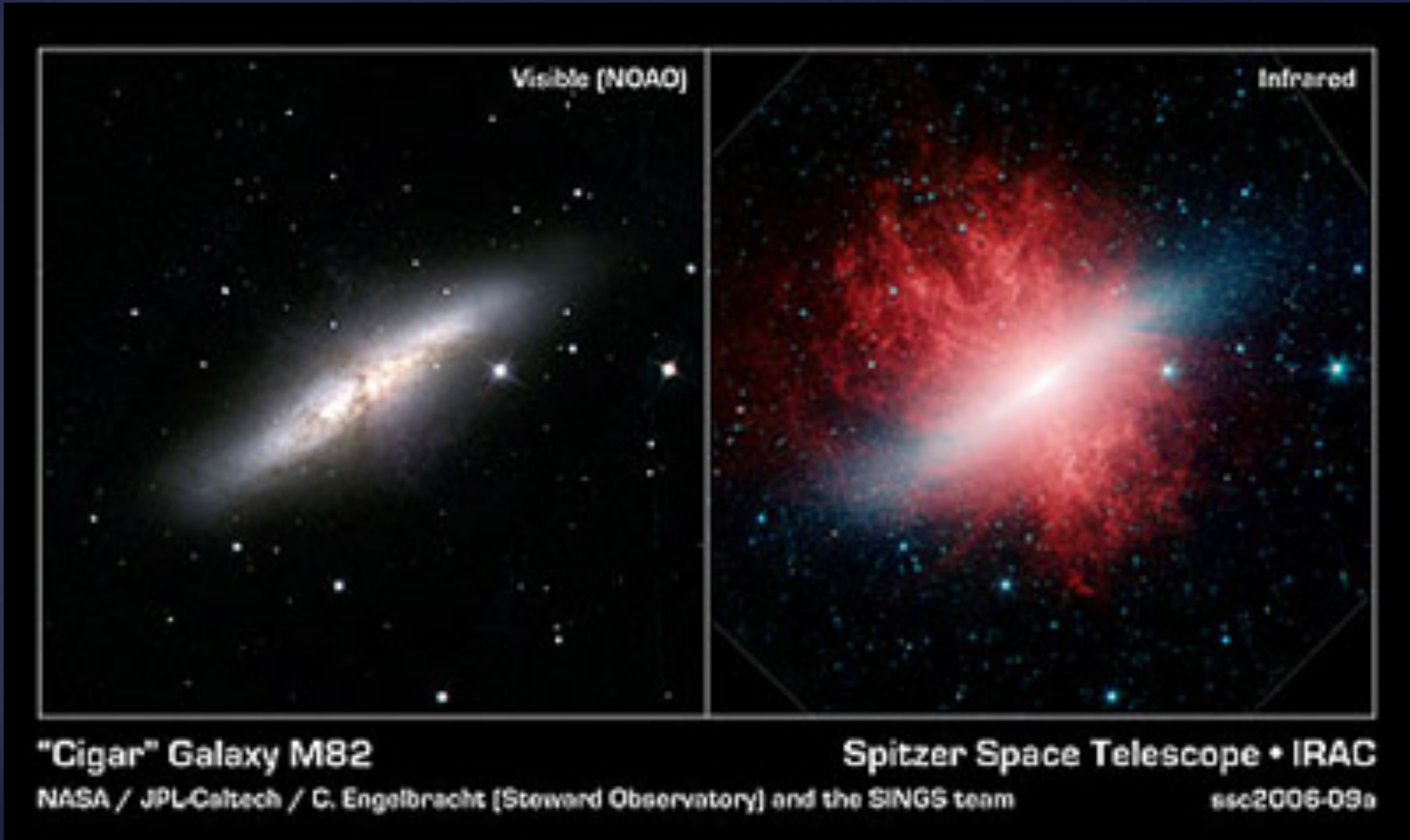
Legend: image shows 2MASS galaxies color coded by redshift (Jarrett 2004) familiar galaxy clusters/superclusters are labeled (numbers in parenthesis represent

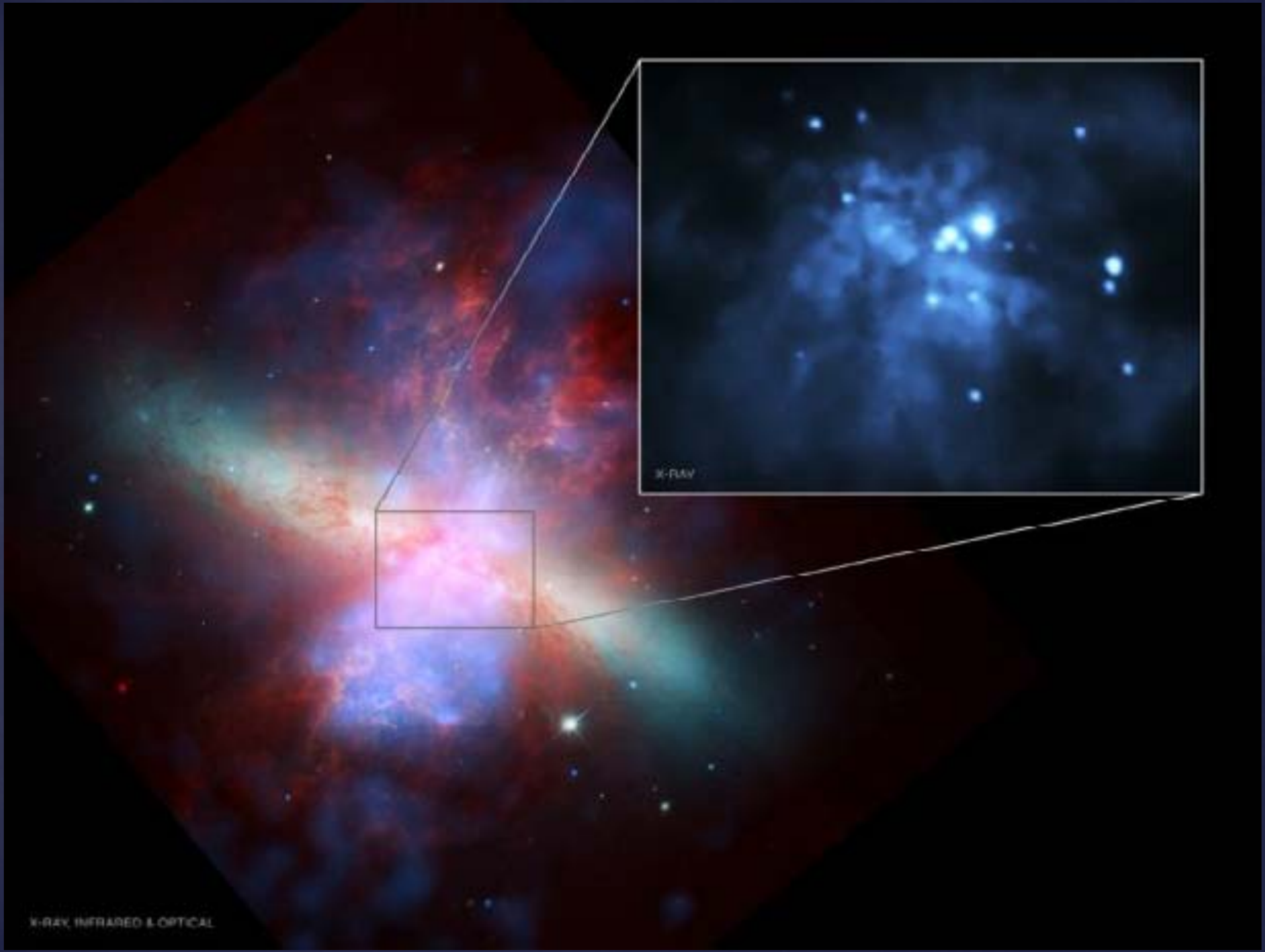
Graphic created by T. Jarrett (IPAC/Caltech)

Final Word:

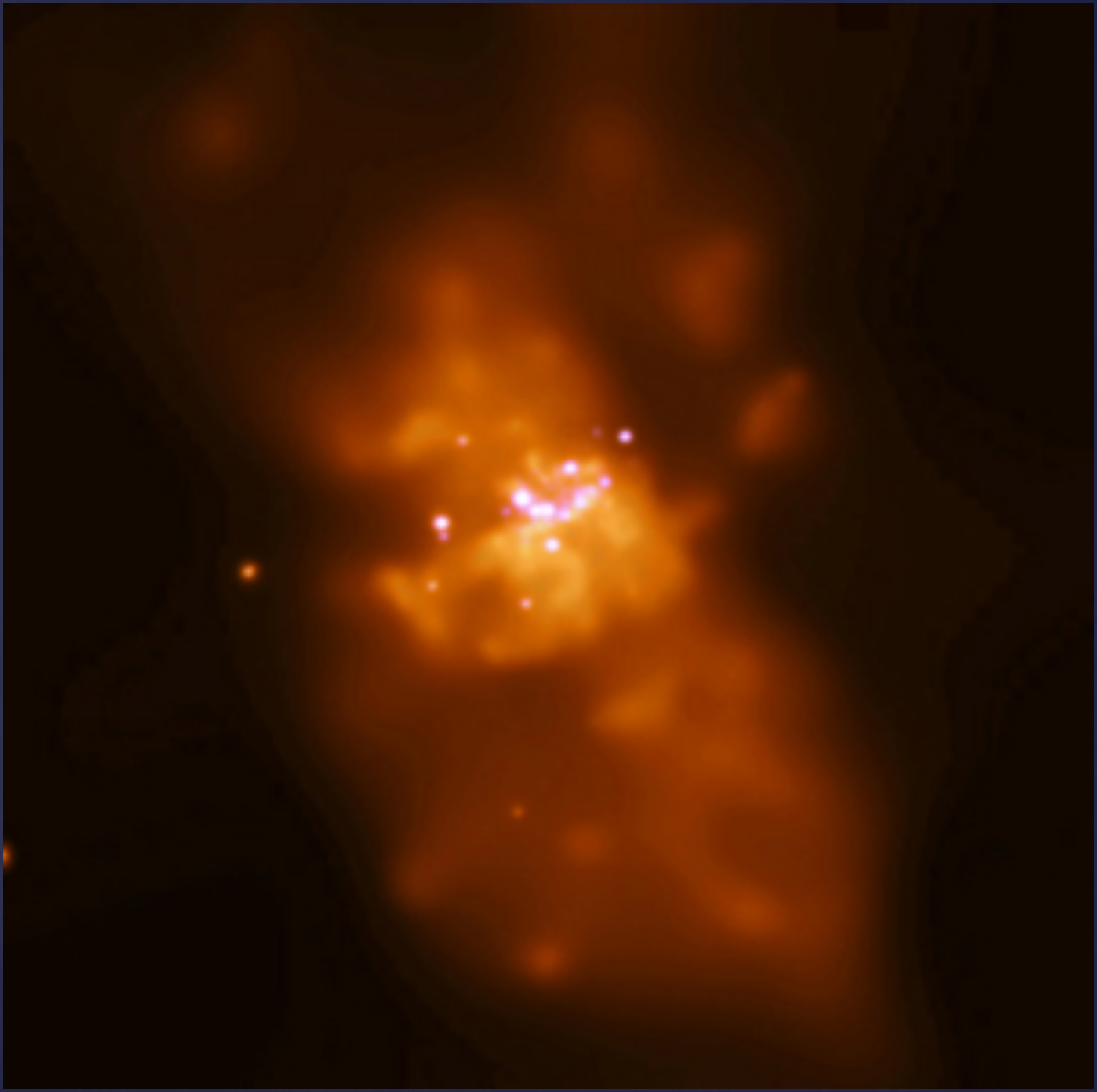
IR astronomy is one component …

Multi-wavelength Astronomy – the future of astrophysics research

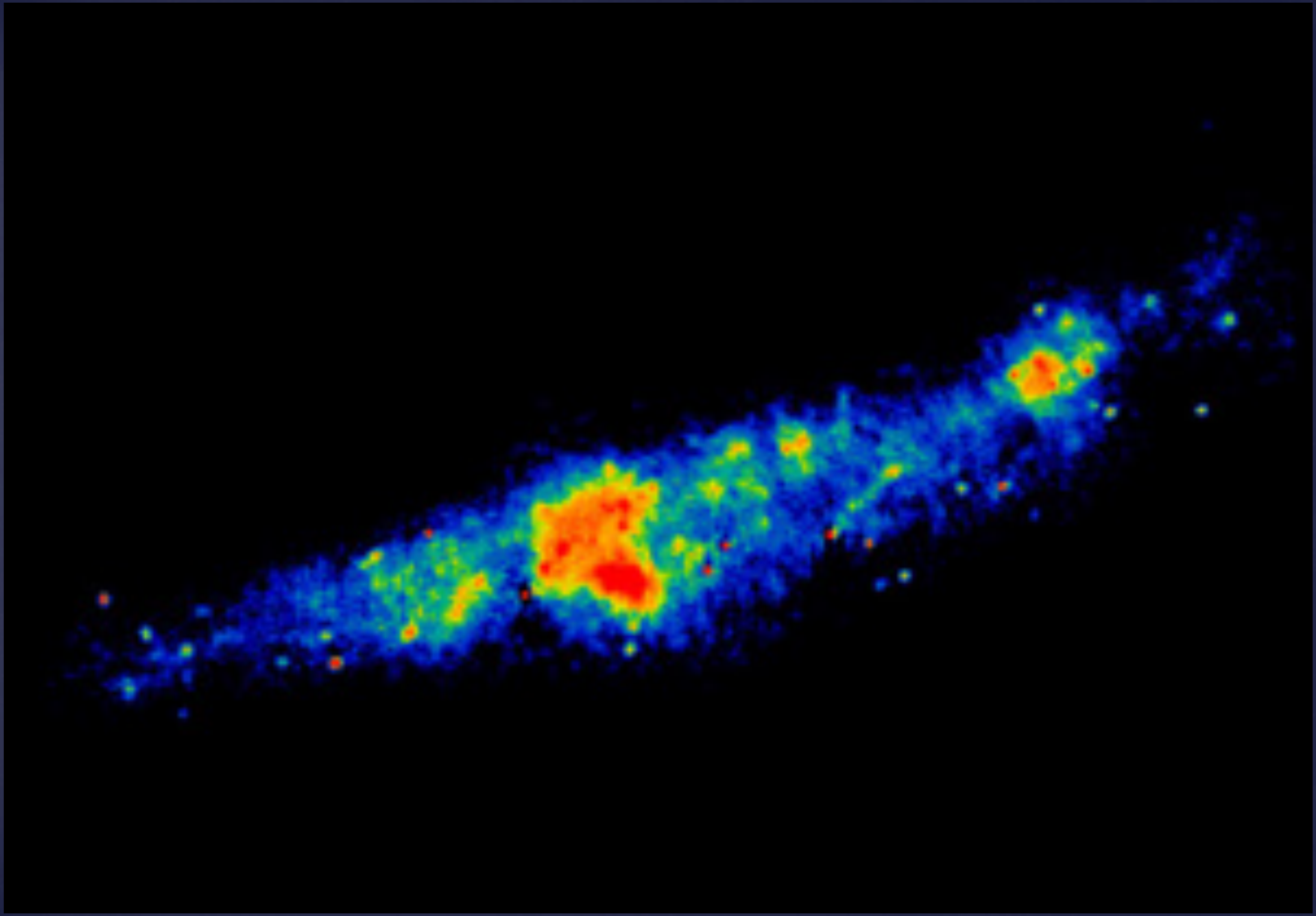

Visible (NOAO)
Infrared
"Cigar" Galaxy M82
Spitzer Space Telescope • IRAC
NASA / JPL-Caltech / C. Engelbracht (Steward Observatory) and the SINGS team
ssc2006-09a



Optical-Infrared-Xray (central xray)



Chandra -- xrays



Radio continuum