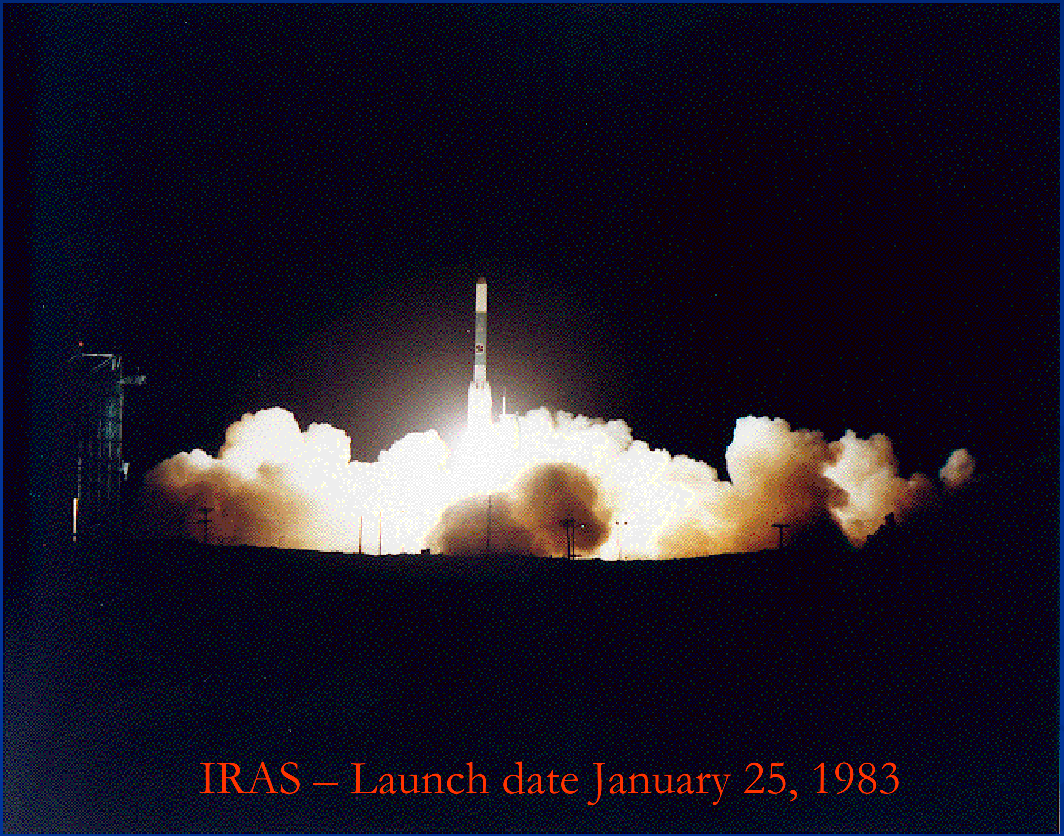
The Evolution of Bright Infrared Galaxies



Halloween, 2003

Stony Brook Open Night

"Normal" massive galaxy types – elliptical & spiral galaxies

Elliptical

- Bulge of old stars
- Large black hole
- Very little gas & dust

Spiral

- Bulge of old stars + large black hole
- Disk of young stars & gas

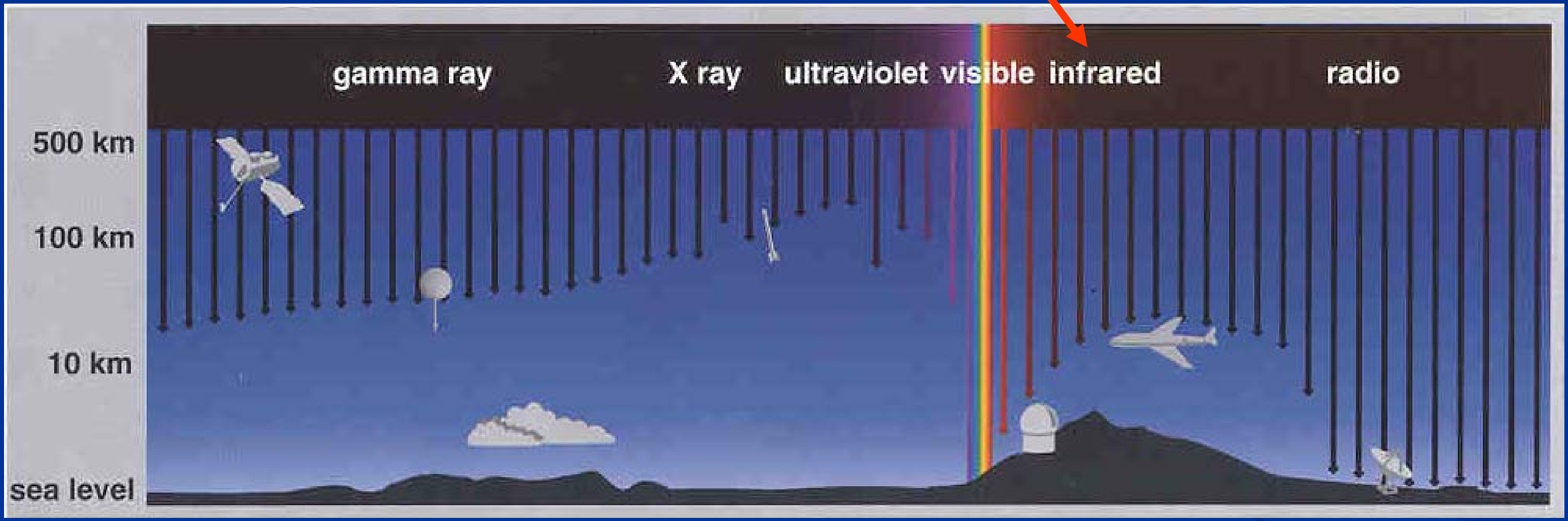
Infrared emission

Visible (0.55 micron) light

10 micron light

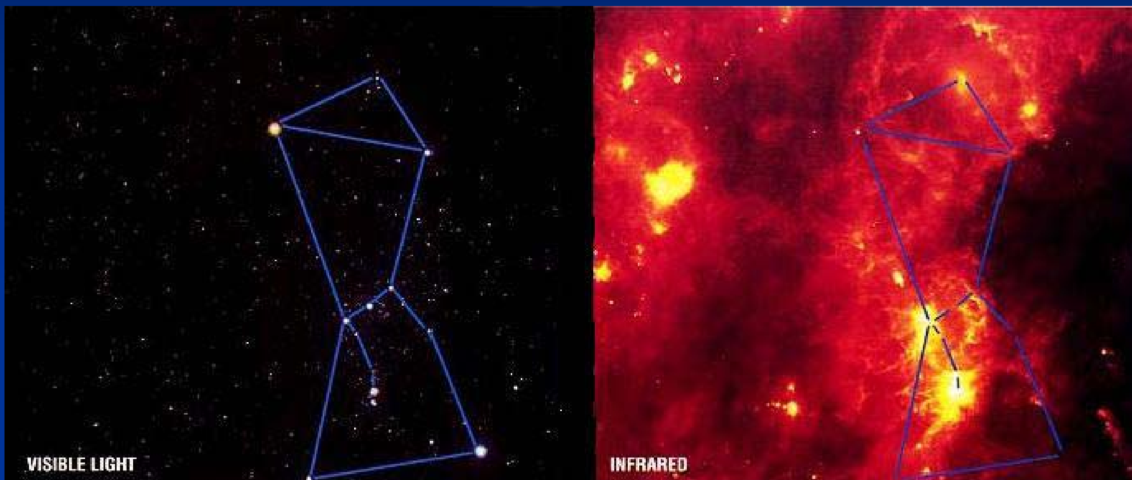
- Stars are very hot & emit the most energy in the visible
- People are warm & emit the most energy at 10 microns
- Dust in galaxies is cool-to-warm & emit the most energy at 2 – 100 microns

Space-based telescopes are needed to detect infrared (10 – 100 μm) radiation



(Exception: 10-25 μm range with 10m-class telescopes built in the 1990s – but it is still tough)

InfraRed Astronomical Satellite (IRAS) – 1983

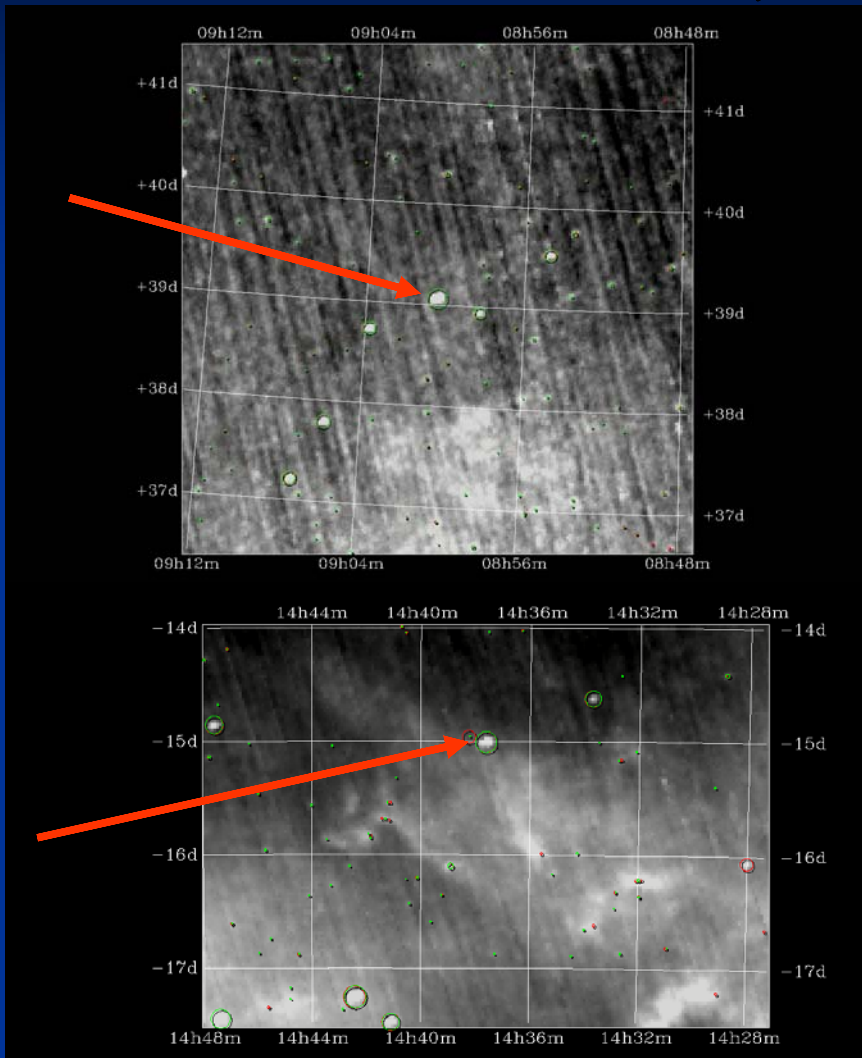


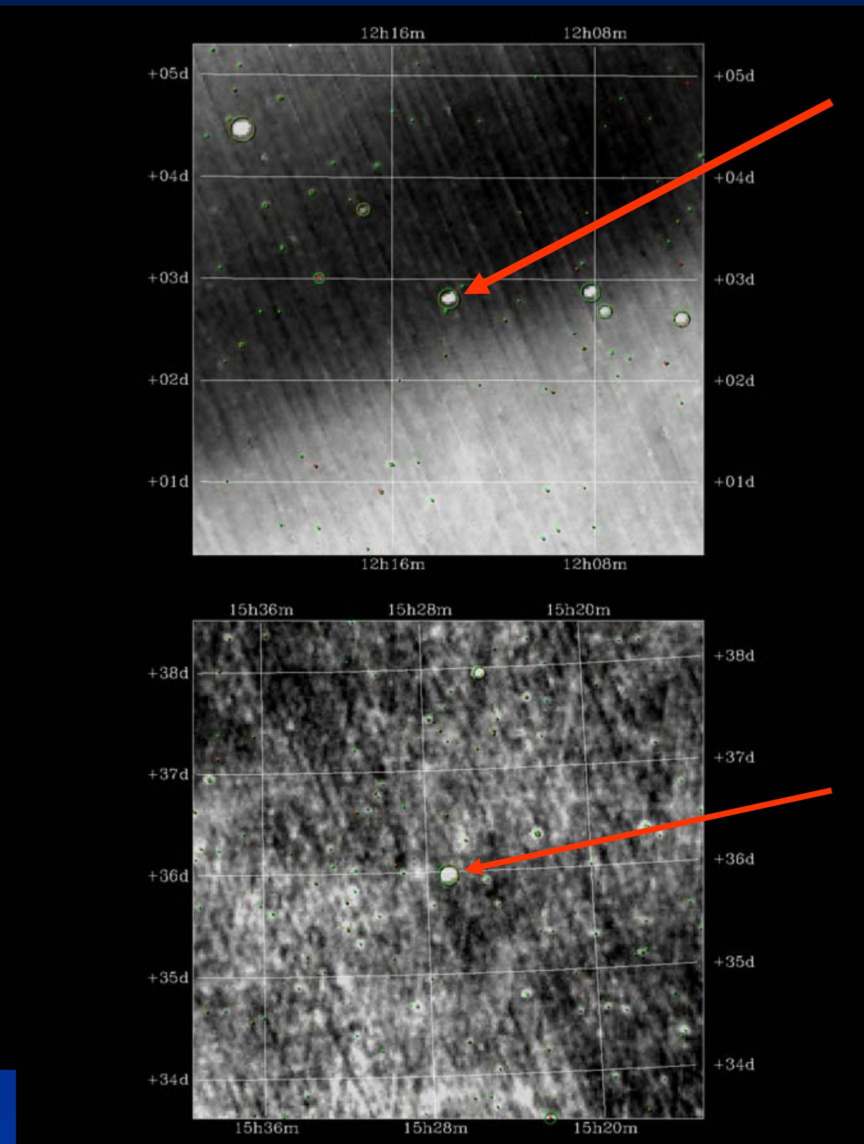
Orion Star Formation Regions

Andromeda Galaxy (M 31)

- Observed the sky at 12, 25, 60, 100 microns
- Emission from dust
- Revealed imbedded star formation
- And…

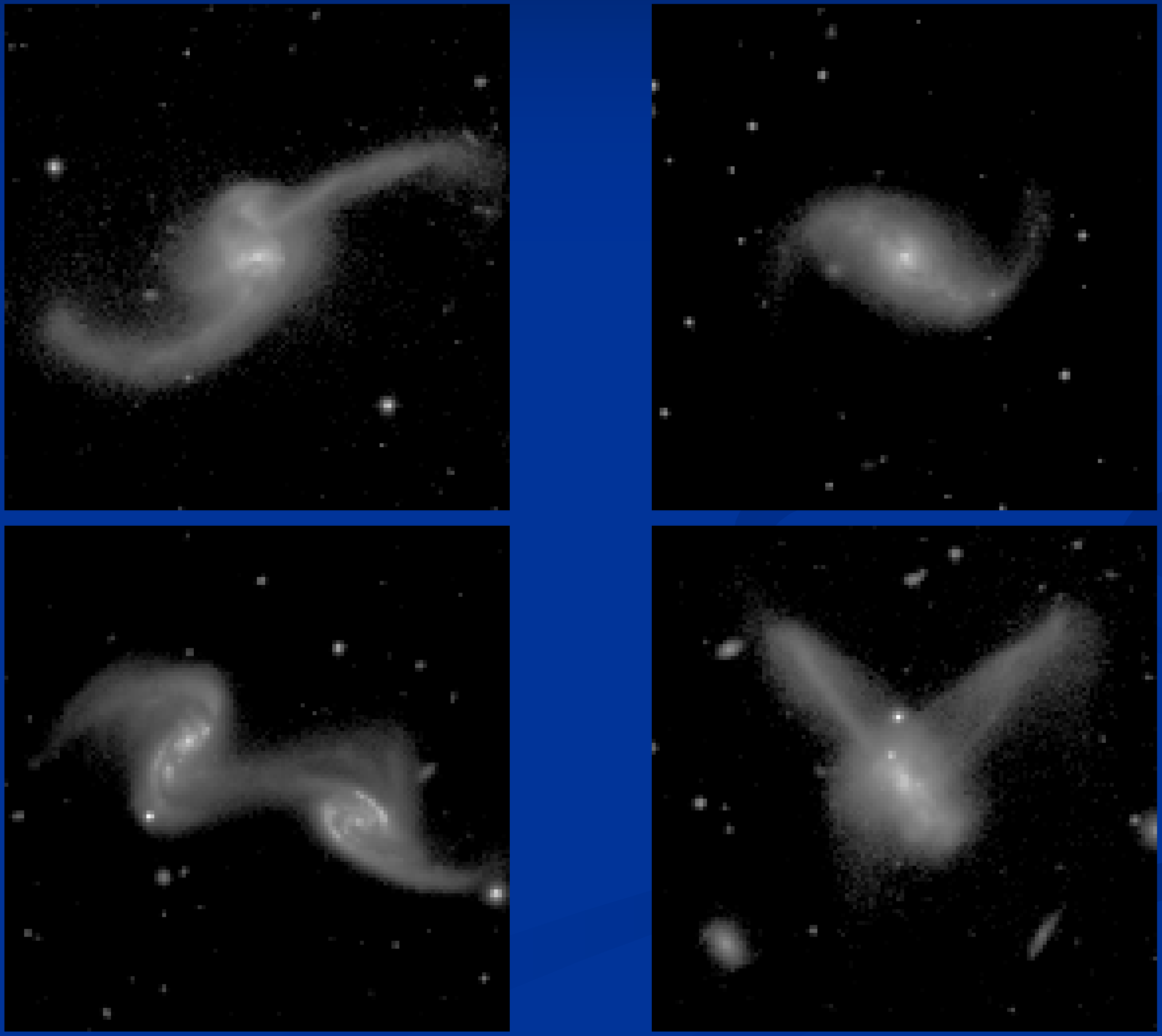
… Some other, unknown sources.



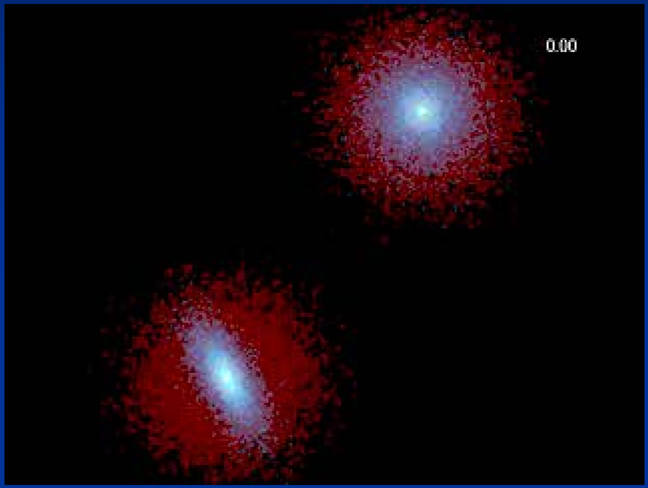


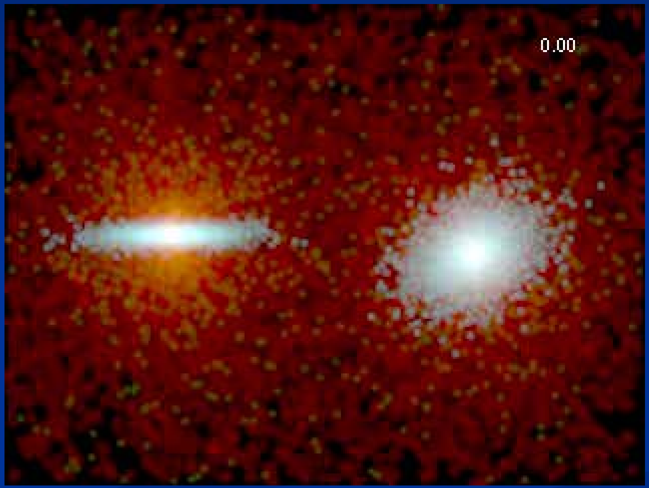
IRAS – 60 micron images

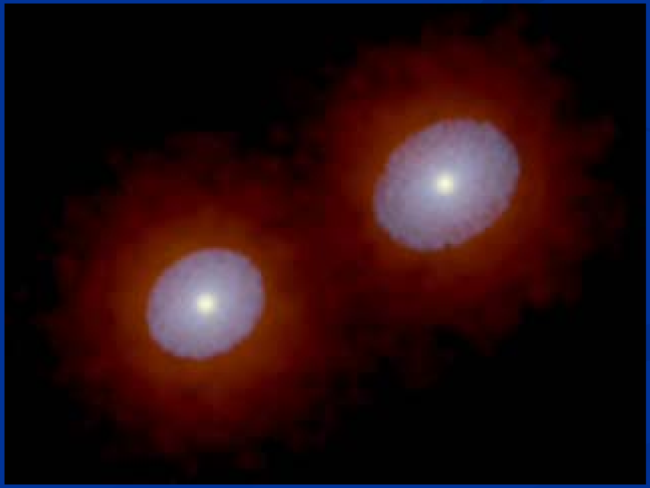
Optical follow-up revealed a population of infrared bright, interacting galaxies



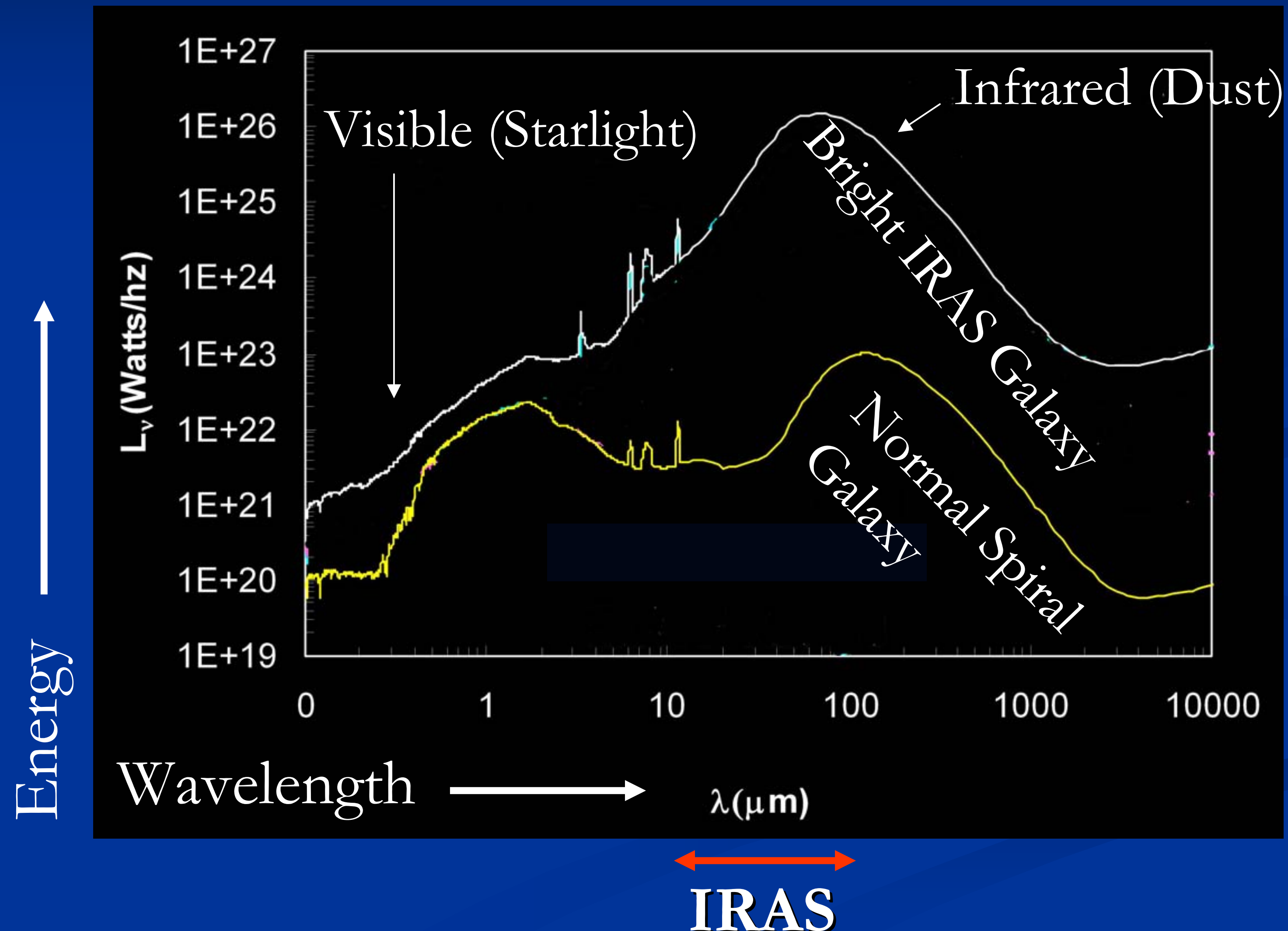
How do we know that they are interacting/merging?





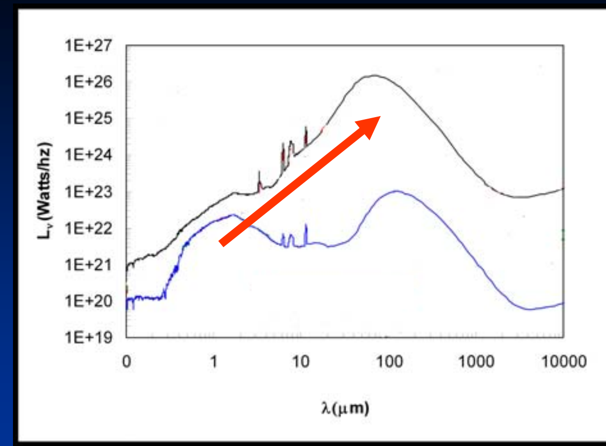


Why were these galaxies easy for IRAS to detect?

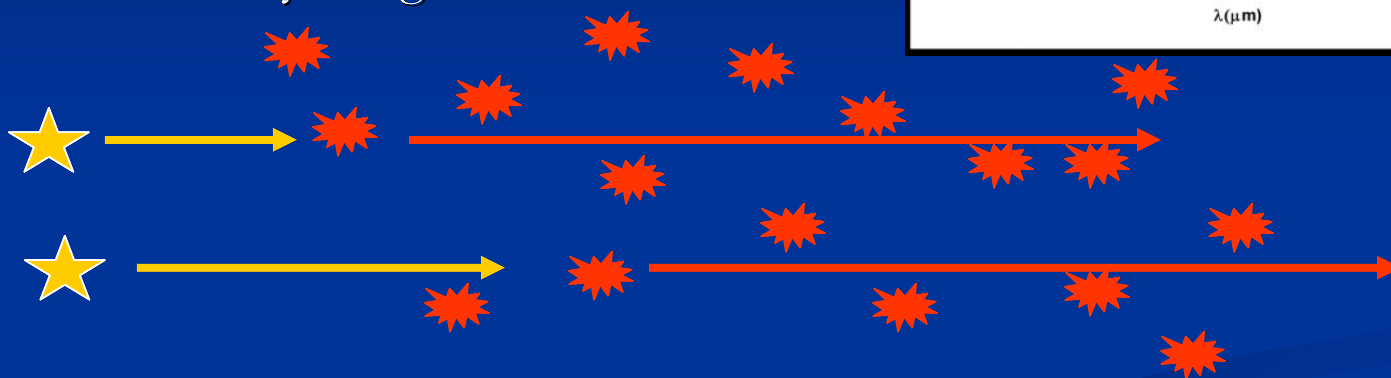


★ Young Stars

✸ Dust



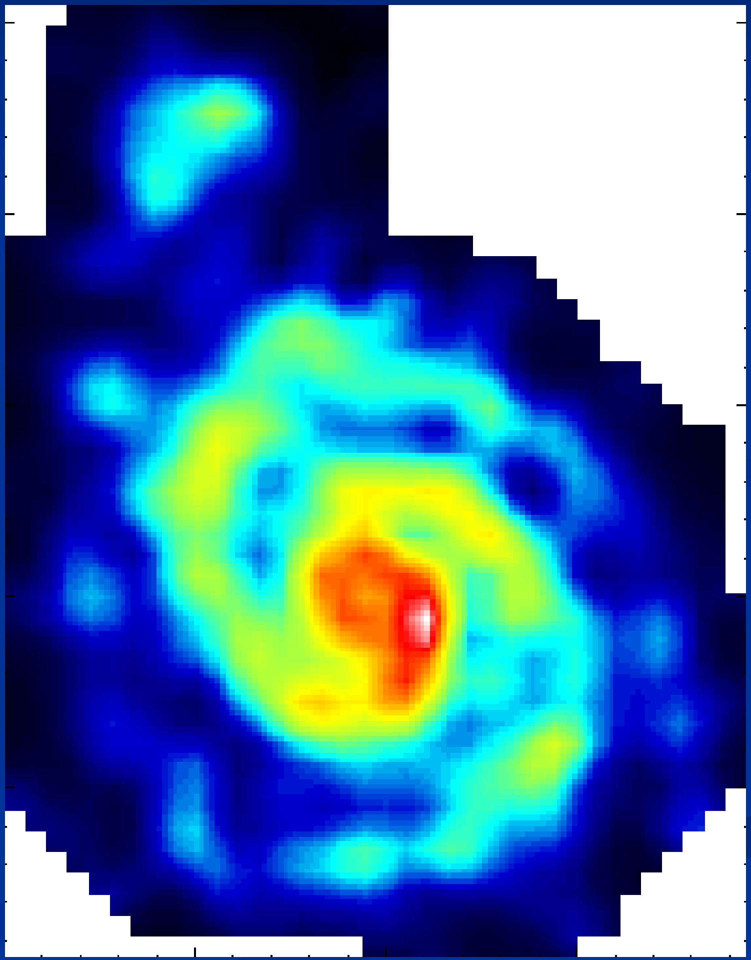
Center of Galaxy Merger



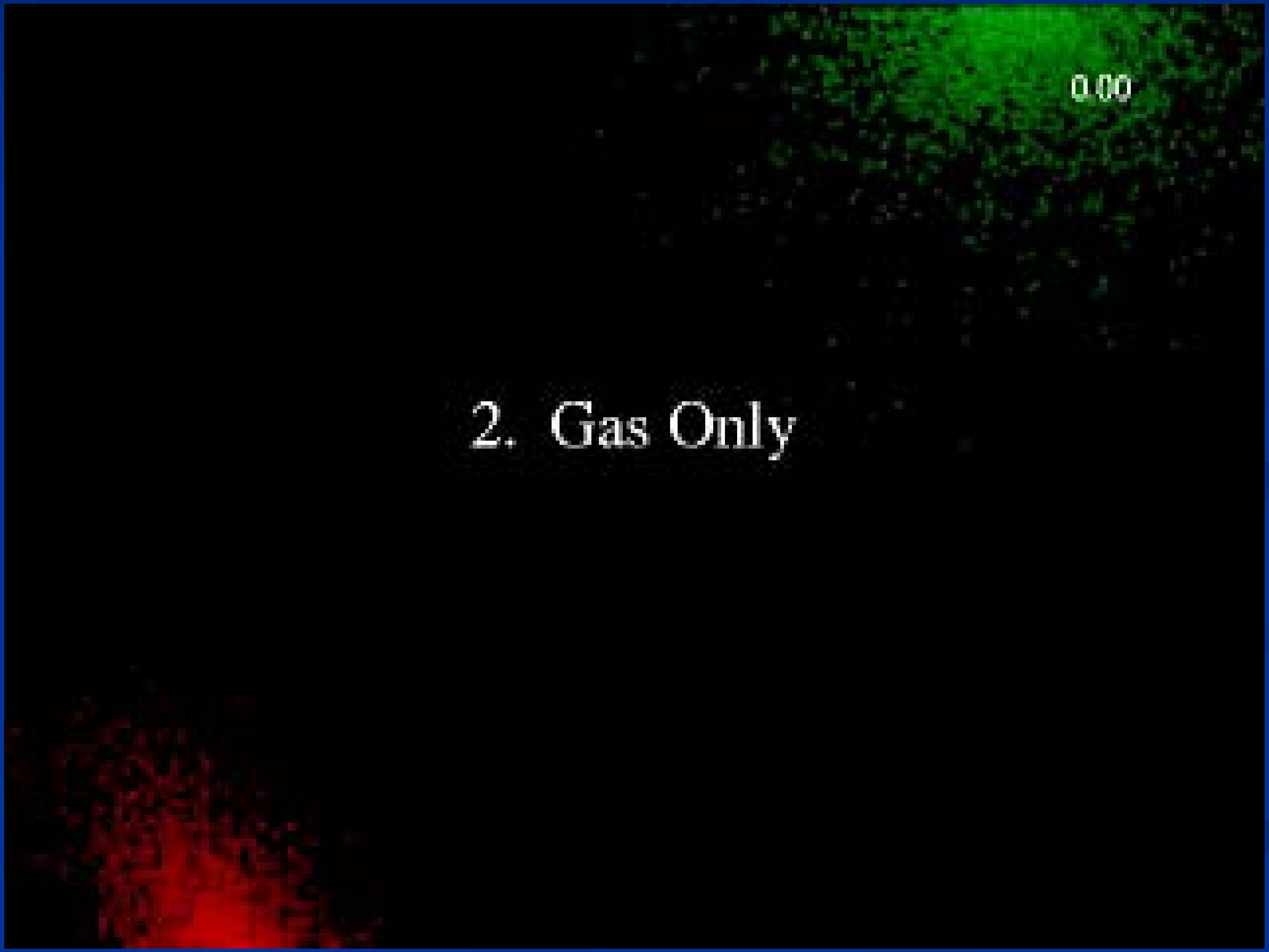
Telescope On Earth

- Dust is Efficient at Absorbing Ultraviolet & Optical Light
- Optical Light from Embedded Stars is Absorbed by Dust and Reradiated as Infrared Light.
- But Infrared Light from this Warm Dust has a much Higher Chance of Escaping.

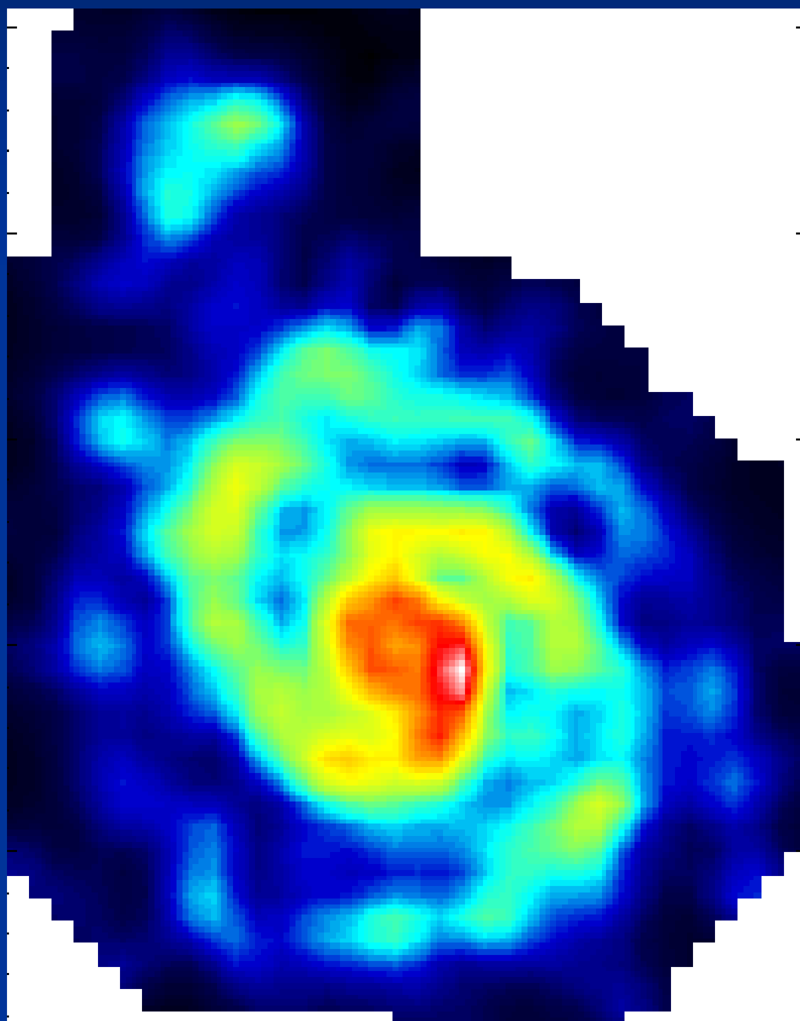
Molecular gas in a nearby spiral galaxy – star formation rate : few solar masses/year

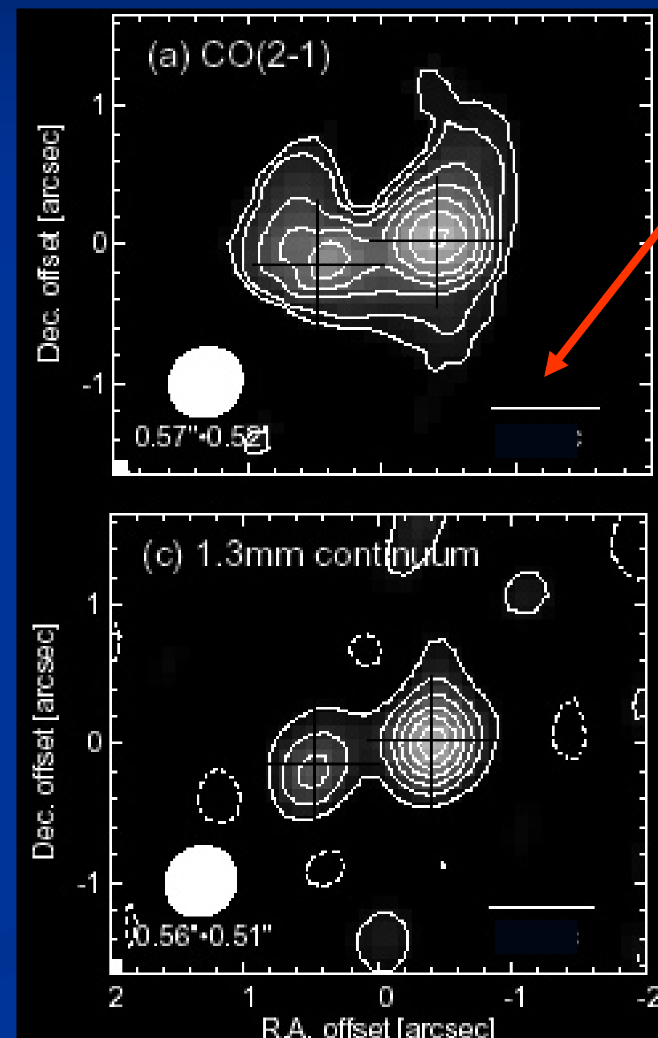


Compression of gas in merger = star formation



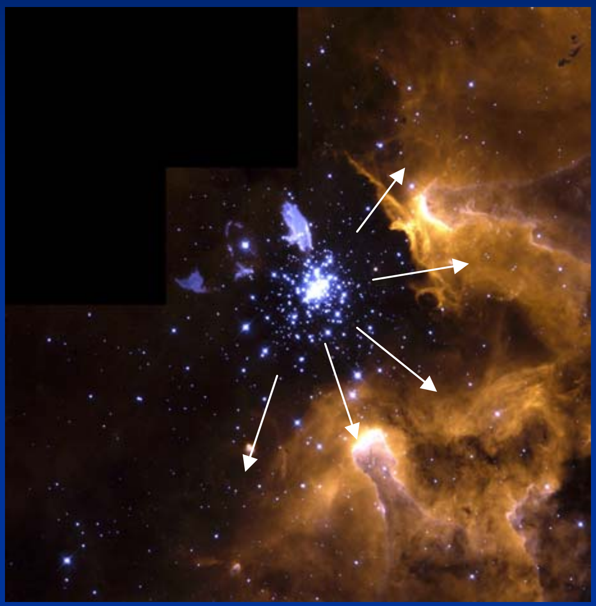
Molecular gas in infrared galaxies. SFR = 100 Solar masses/year



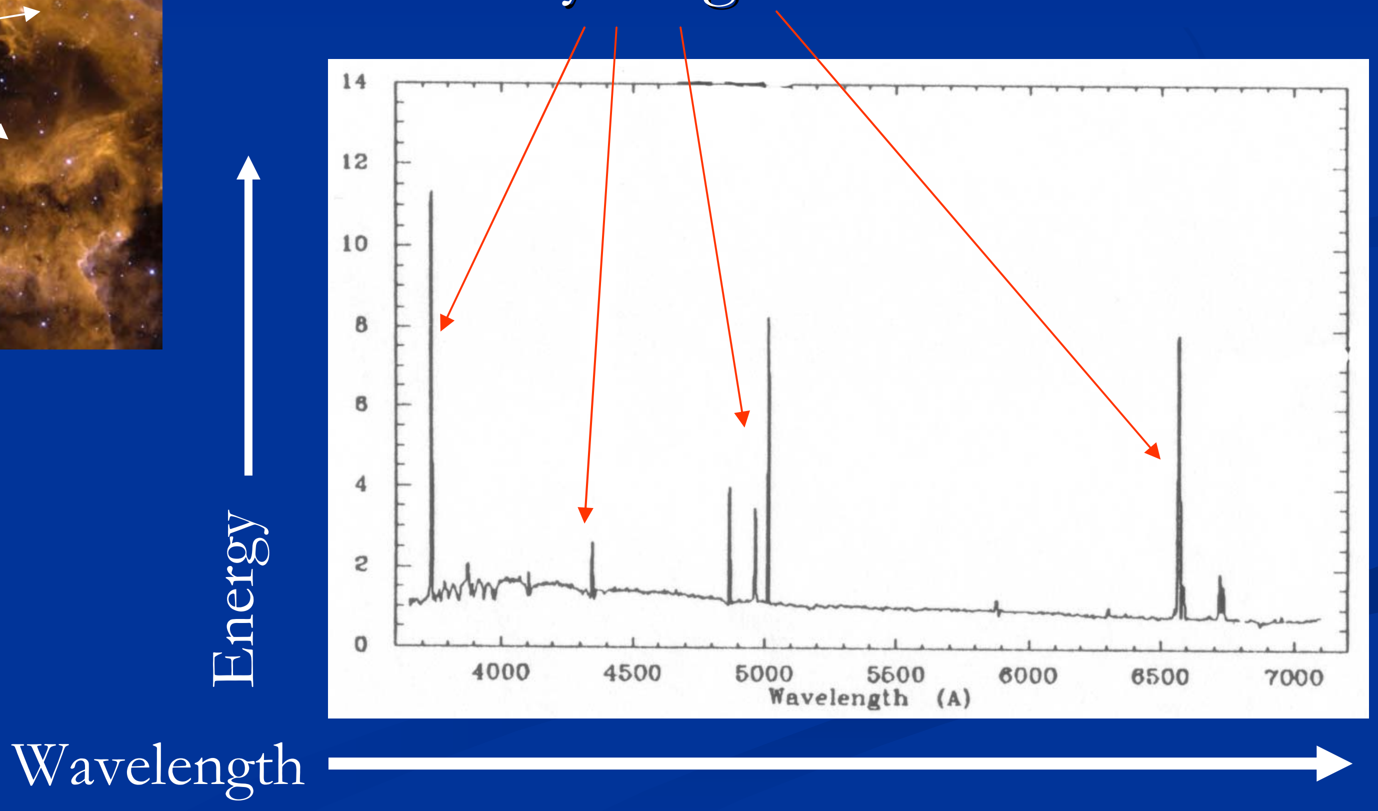


1000
light
years

Star formation signatures also seen in optical spectroscopy



Produced by gas heated by young stars



Late 1980s: … But often, Quasar-like signatures are seen in spectra…

- … And bright, compact Quasar-like nuclei
- … And a few Quasars have distorted host galaxies
- … And many nearby Quasars were detected by IRAS
- … And Quasars are about as common as the intrinsically brightest IRAS galaxies

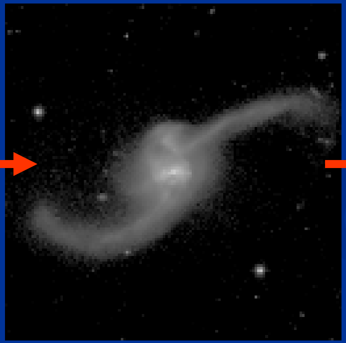
- Maybe the intrinsically brightest IRAS galaxy mergers evolve into quasars

The Model

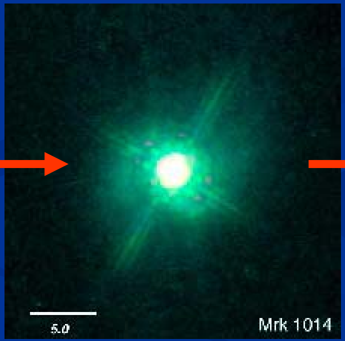
Progenitors

Merger phase

- Gas compression
- Star formation
- Black hole fueling/building



Quasar phase



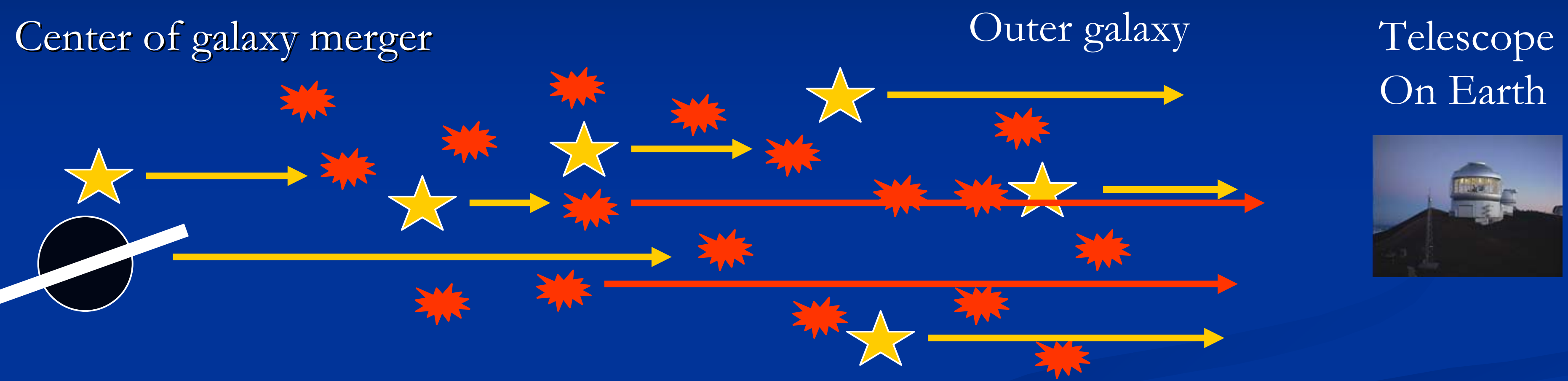
Elliptical

100 million years

1 billion years

Time →

Do stars or Quasars energize bright infrared galaxies? Problem – Dust.



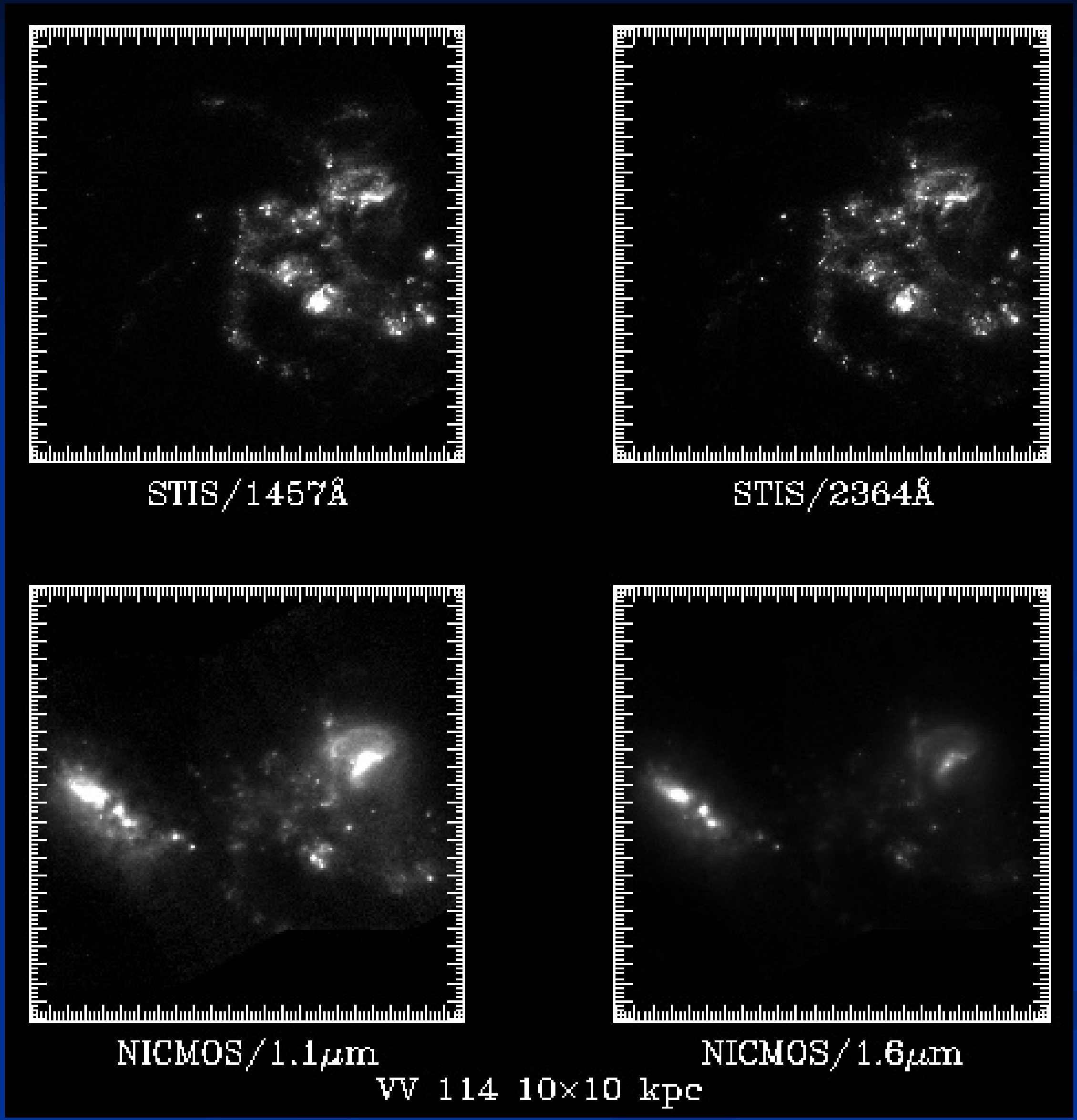
- Optical light from the center of the galaxy does not escape the galaxy, but optical light from stars in the outer galaxy can.

The effects of dust.

Ultraviolet
(0.1-0.2 μm)

Near-Infrared
(1 – 2 μm)

(Note: Optical = 0.55 μm)



Thus, Quasars can hide beneath the dust.

1990s – Probing Infrared Galaxies in the Near-infrared

- Less susceptible to absorption by dust (10,000 times less likely to be absorbed by dust than optical light)
- Accessible from ground and space-based telescopes
- Can get high-resolution (~ wavelength/telescope diameter) images at near-infrared wavelengths

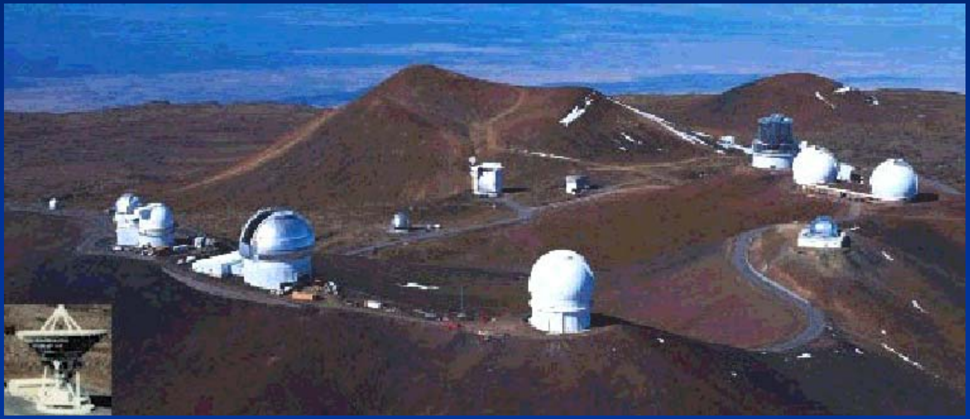
Addressing the Infrared Galaxy – Quasar Connection with Near-Infrared Observations

- **Approach 1** – Near-infrared (1 – 2 μm) imaging of infrared bright galaxies to look for bright, compact nuclei

- **Approach 2** – Near-infrared spectroscopy of infrared-bright galaxies to look for Quasar-like gas heating.

High-Resolution Imaging of galaxies

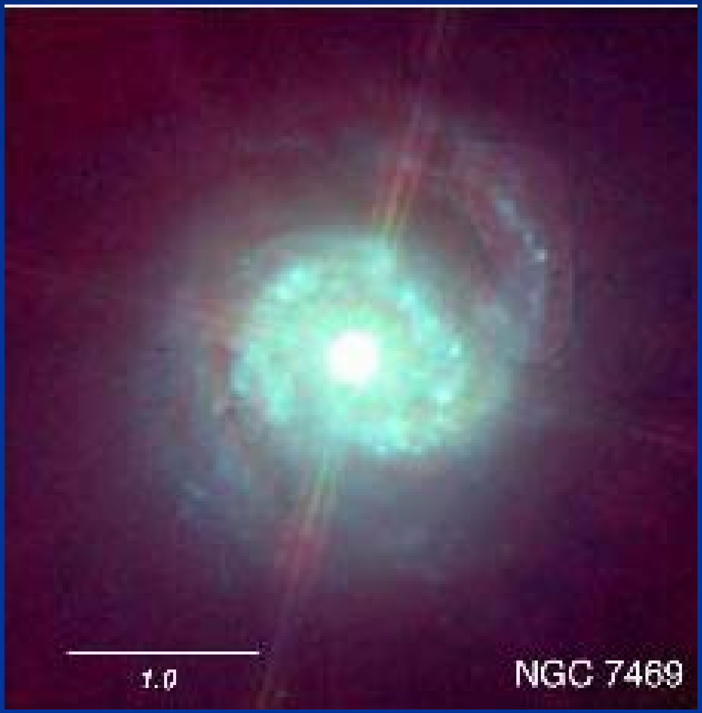
Hubble Space Telescope

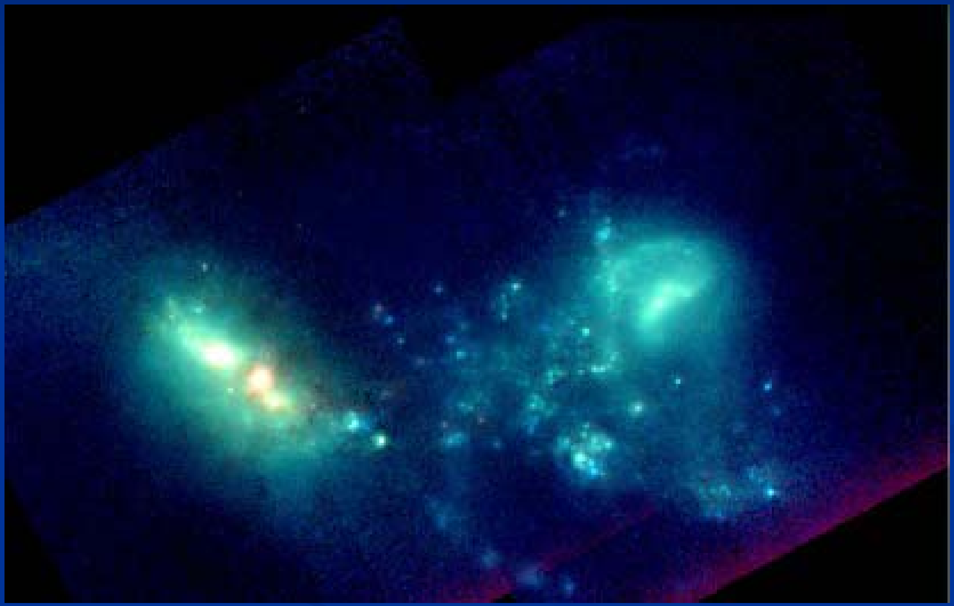


Mauna Kea Observatories, Hawaii
(14,000 ft)

- To get clear images, we go to space, or we go to a high mountaintop.
- Why? To lessen the blurring effects of the dense atmosphere.

A1 – Imaging of Infrared Galaxies using the Hubble Space Telescope Near-Infrared Camera

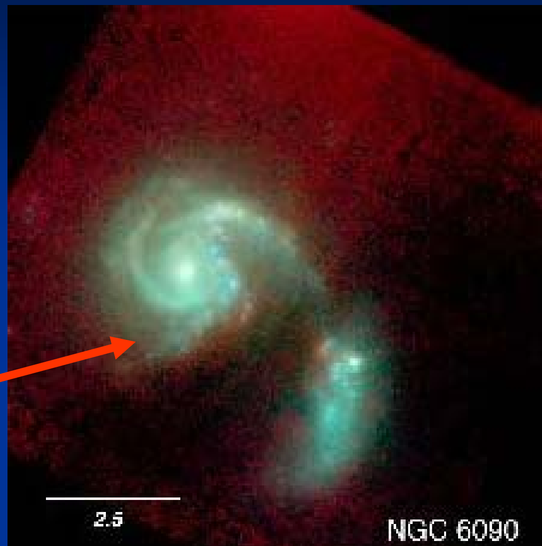


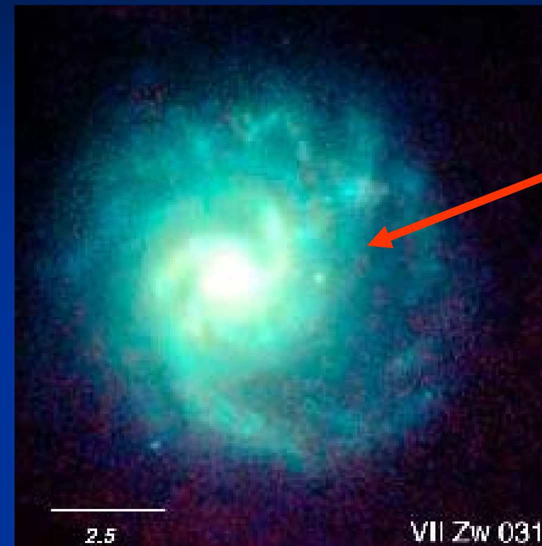


Quasar-Like nucleus

Extended distribution of star clusters

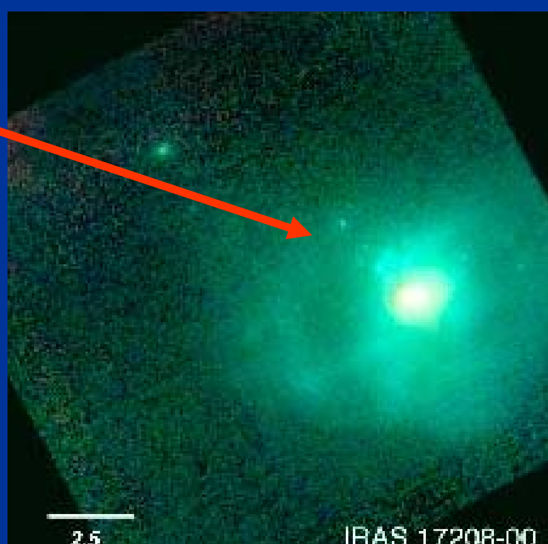
HST Data – Infrared Galaxies

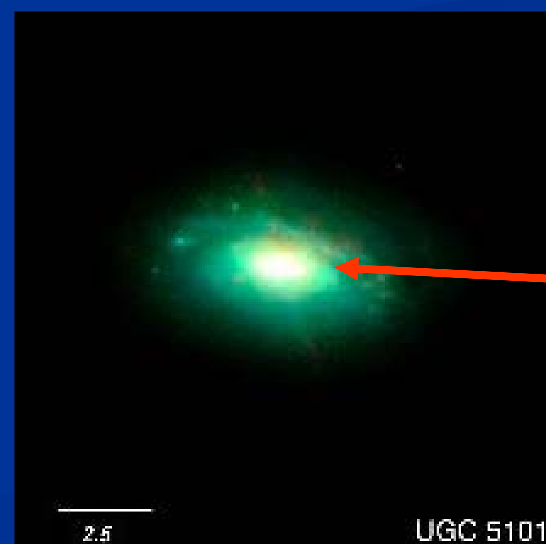




Inner spirals

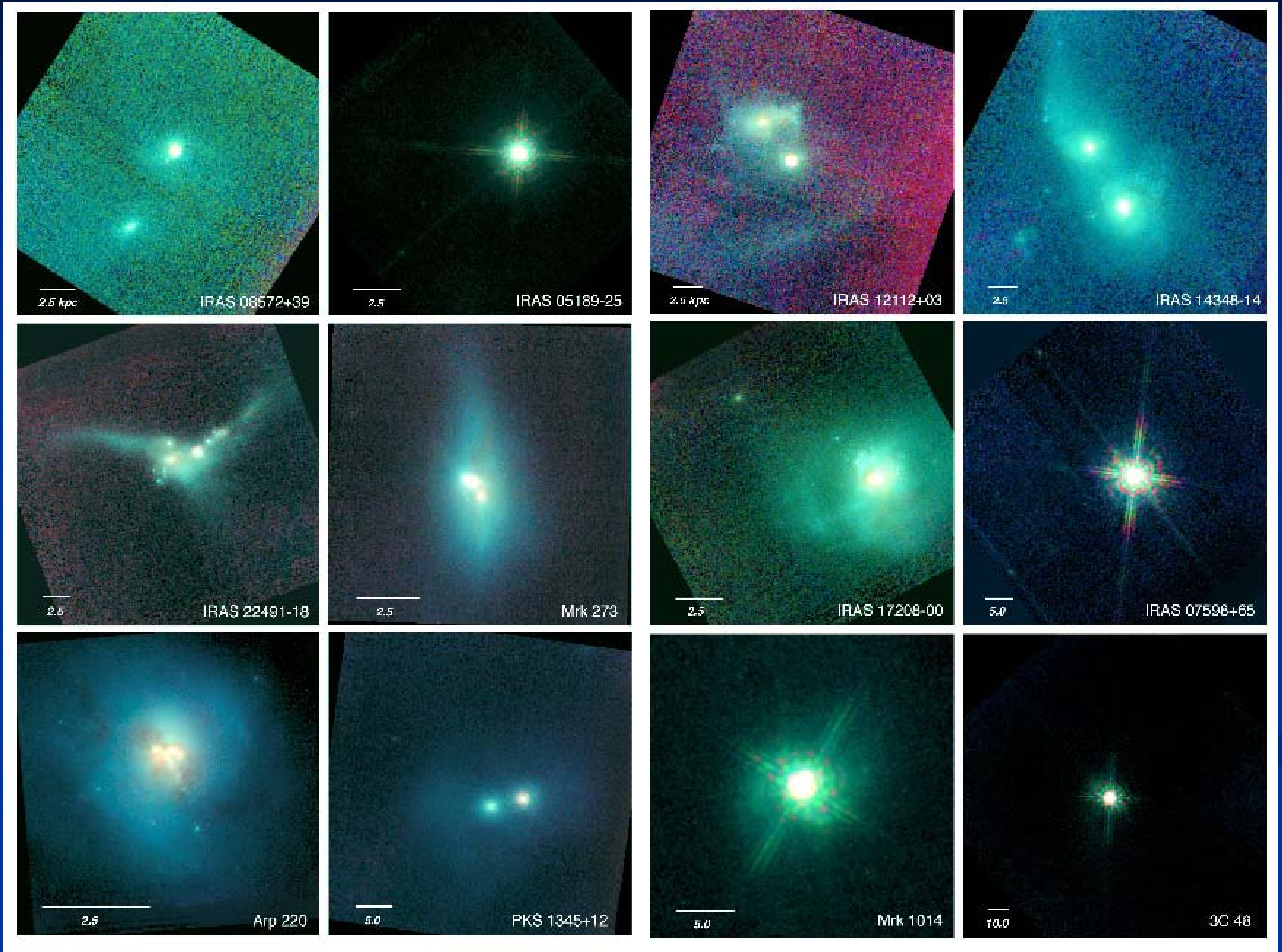
Lots of star clusters



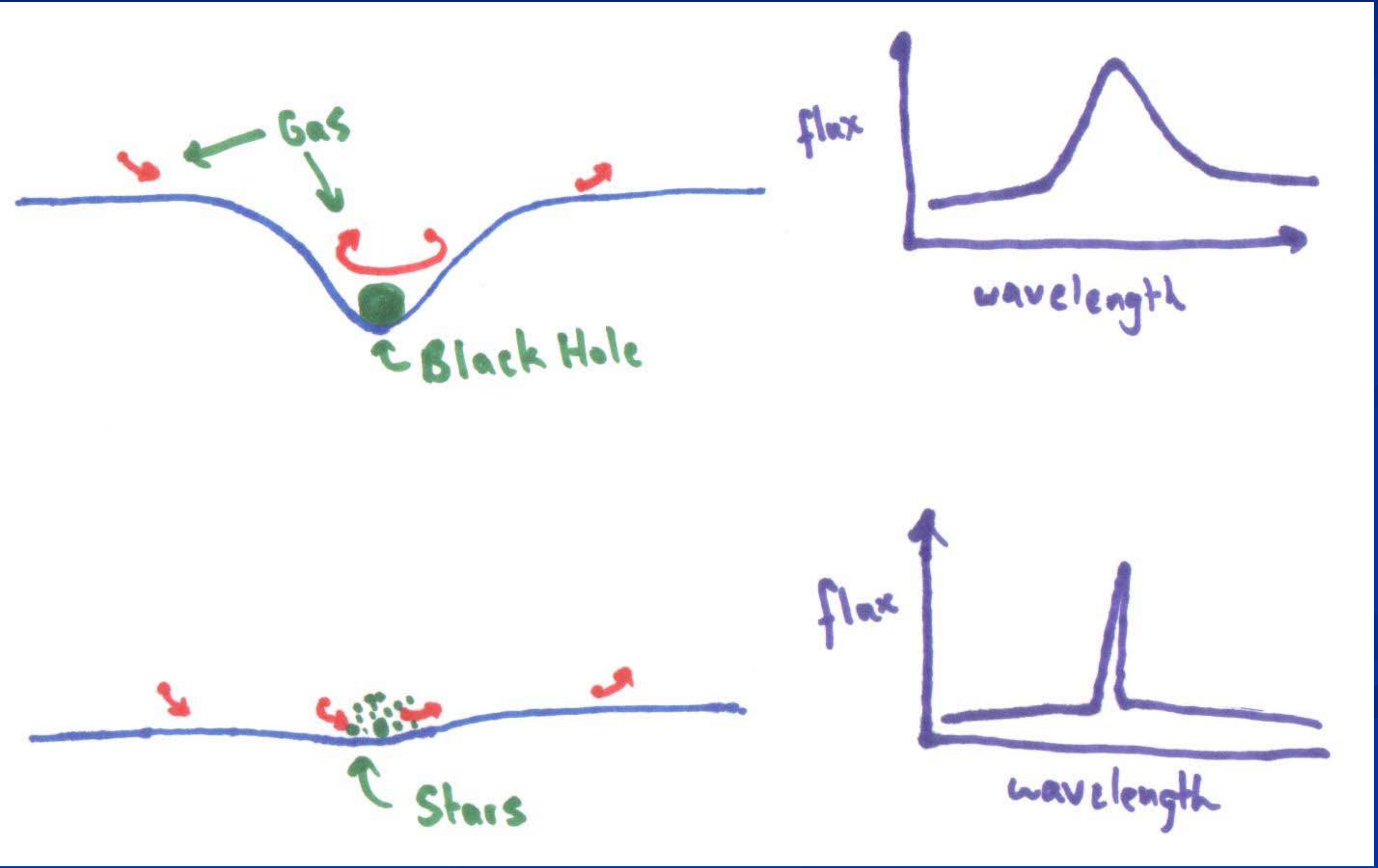


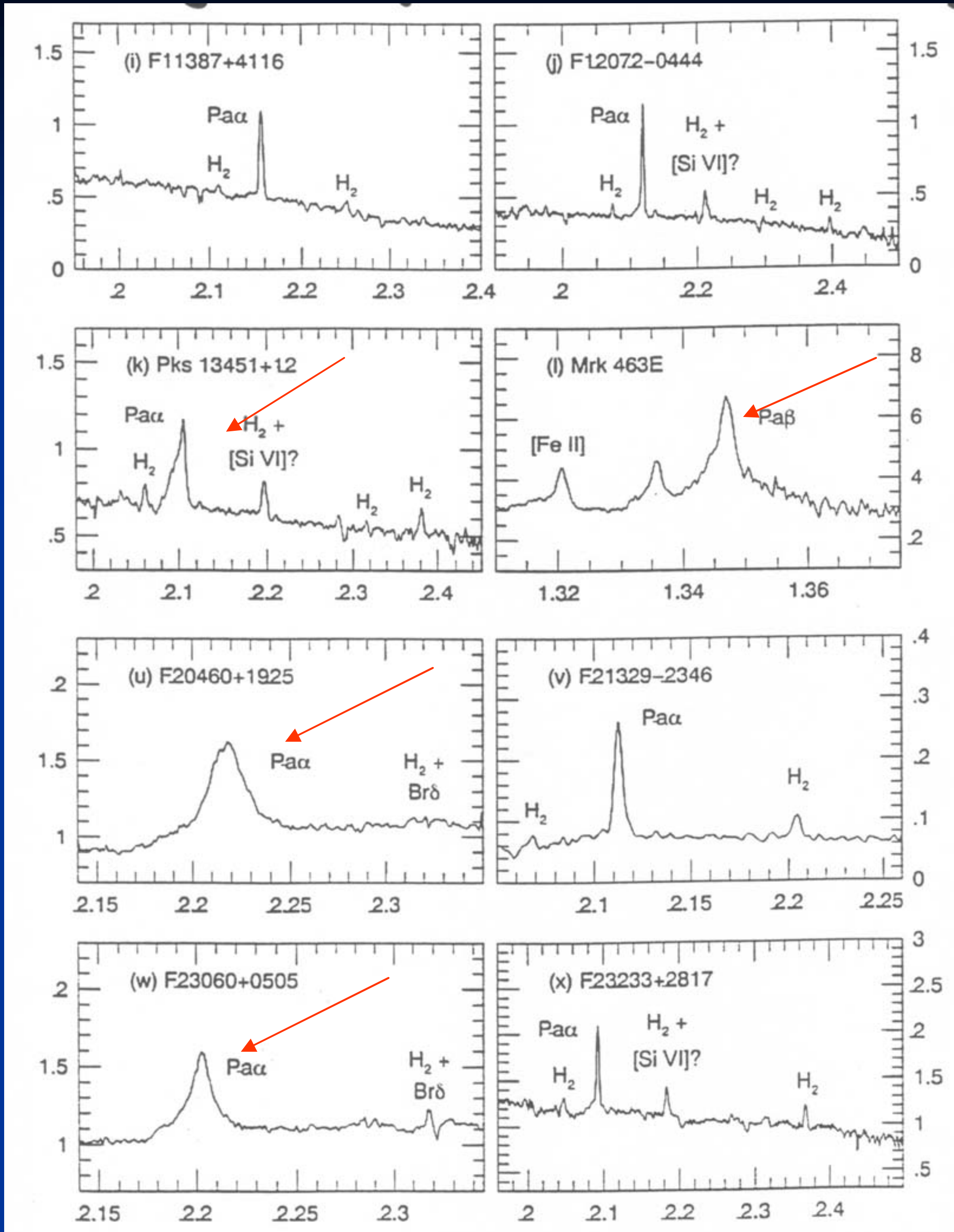
Embedded compact nuclei

But only about 35% have bright, Quasar-like nuclei



A2 – Ground-based Near-infrared Spectroscopy of IRAS Galaxies





Near Infrared Spectroscopy - About 30% show evidence of Quasar-like gas heating

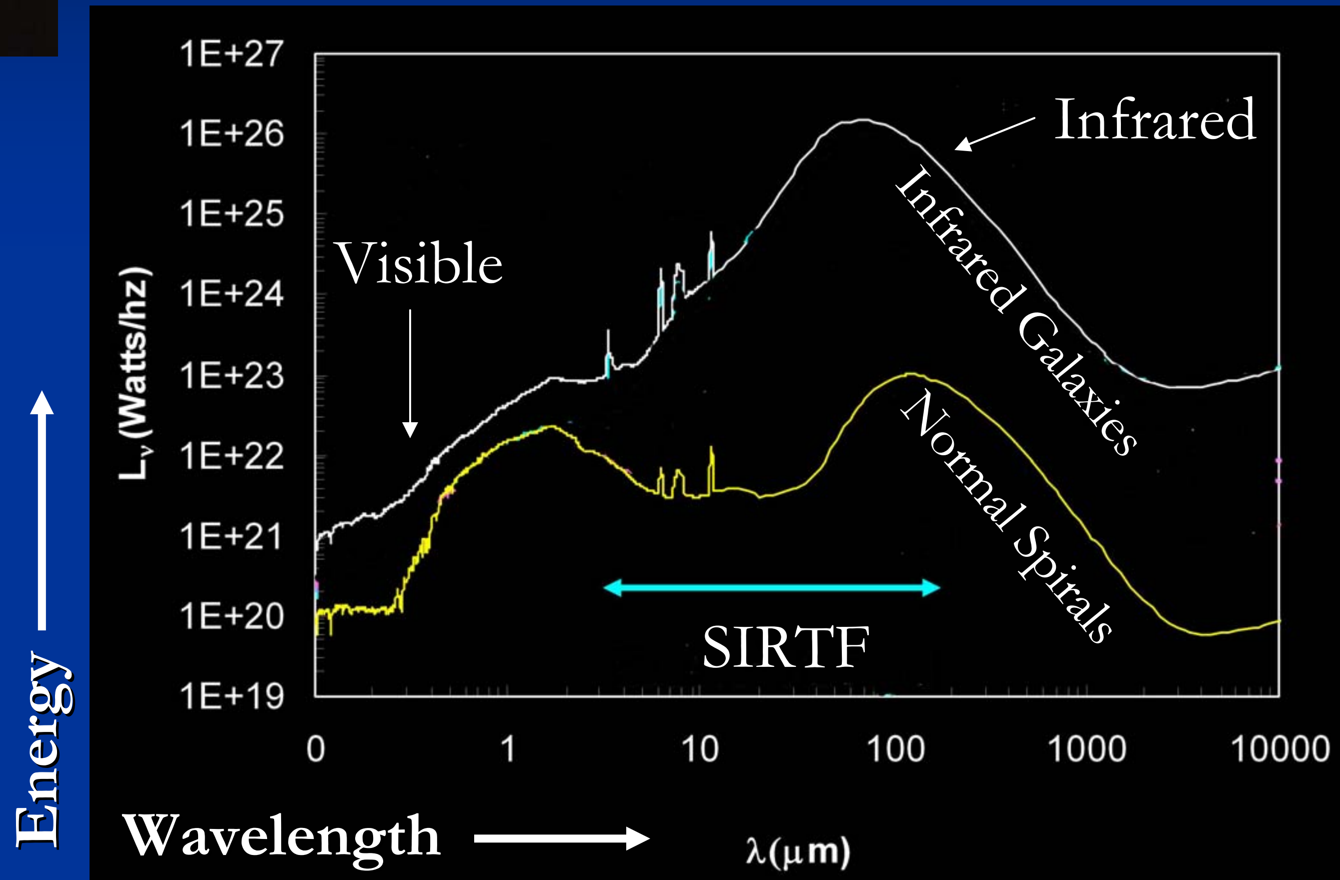
Conclusions – 1990s

- Maybe only some of the brightest infrared galaxies evolve into Quasars
- Maybe the brightest infrared galaxies only spend the last 30-35% of their lives feeding the black hole
- Maybe the Quasars are buried too deep in the dust to be accessible at near-infrared wavelengths

Late 1990s – 2010

- **X-rays** – some observations of Infrared Galaxies with X-ray satellites have already shown evidence of dust covered Quasars in objects that do not look like Quasars even in the near-infrared.

2003 AD – Space Infrared Telescope Facility (SIRTF)



SIRTF will probe deep into the dusty regions of galaxies

Half of the energy emitted since the Big Bang is observed at infrared wavelengths