THE IRCAM REVOLUTION

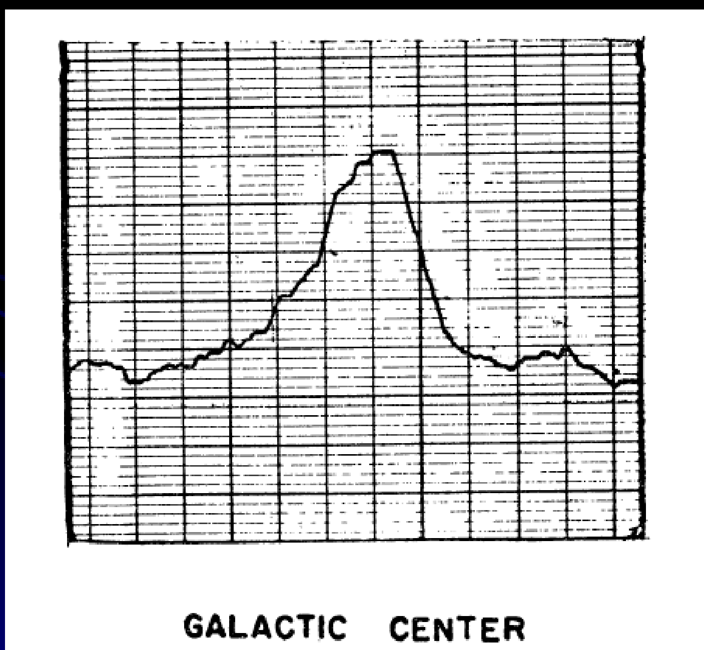
Ian McLean

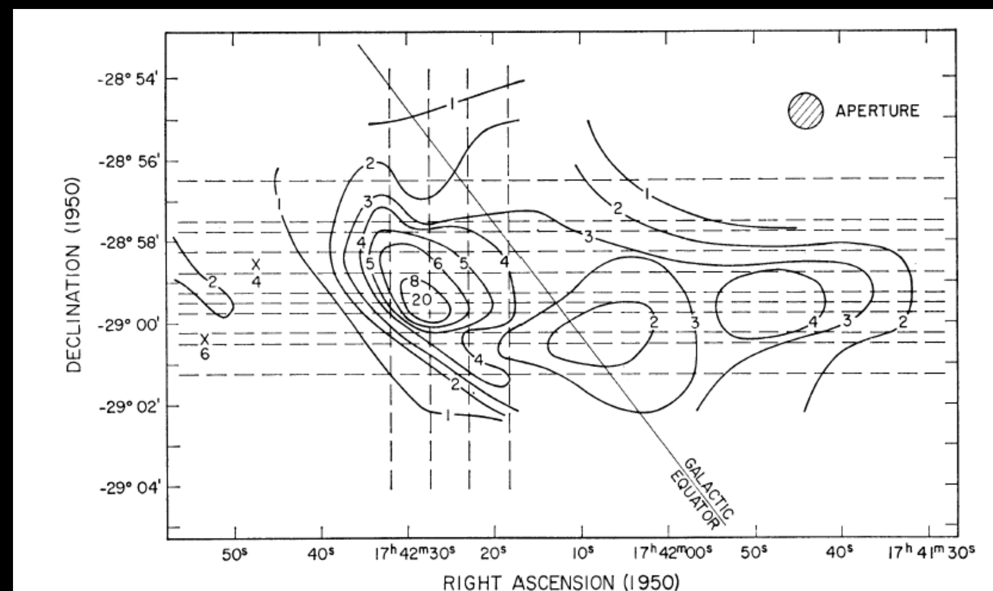
Beginnings of modern infrared astronomy

INFRARED OBSERVATIONS OF THE GALACTIC CENTER*

E. E. BECKLIN AND G. NEUGEBAUER
California Institute of Technology, Pasadena
Received June 13, 1967

Eric and Gerry discover the Galactic Center





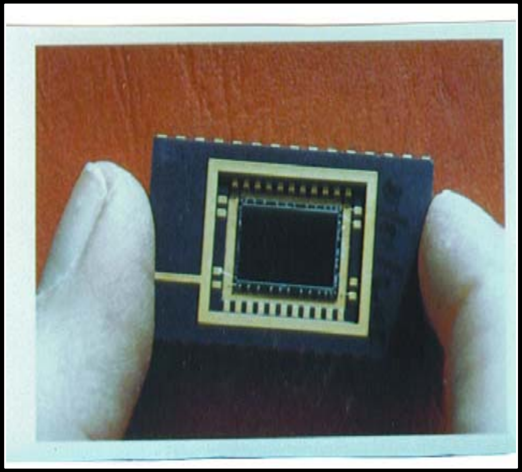
The Two Micron Sky Survey; PbS detectors and Ge bolometers lead the way

Strip charts, raster scans and contour plots …

The advent of Digital Imaging

Visible light astronomy gets the Charge-Coupled Device

“PIXELS”



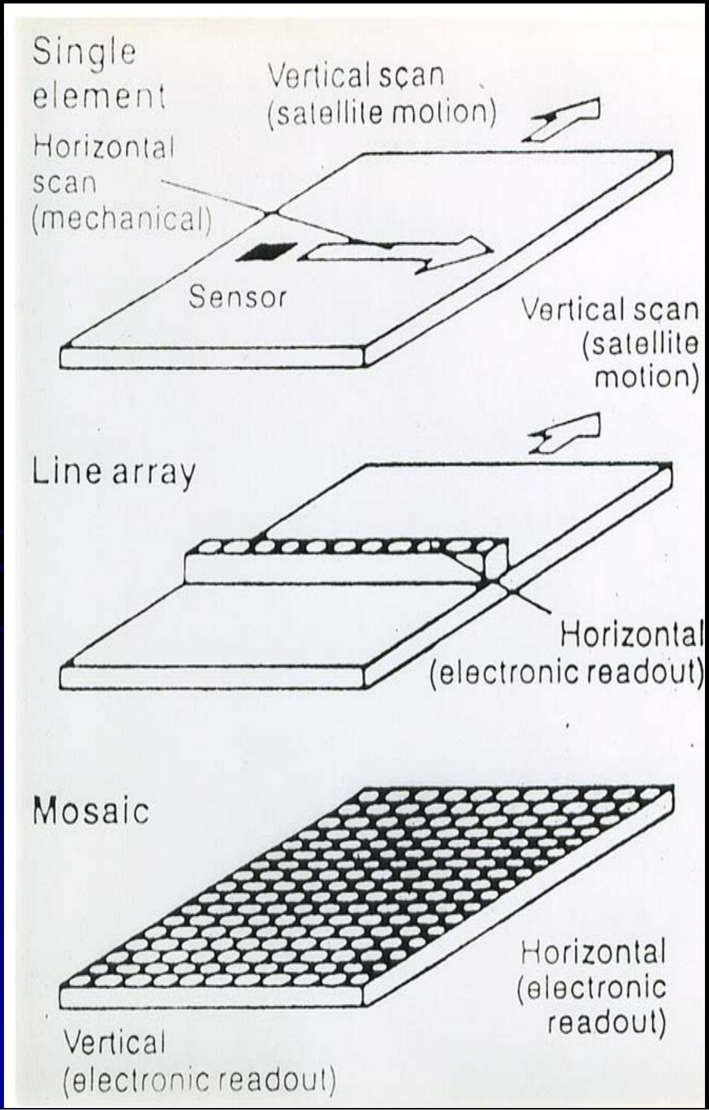
An early CCD

c. 1979

Willard Boyle and George Smith – inventors of the CCD

CCDs change everything! **What about IR?**

Infrared "pictures" made 1 pixel at a time were fuzzy

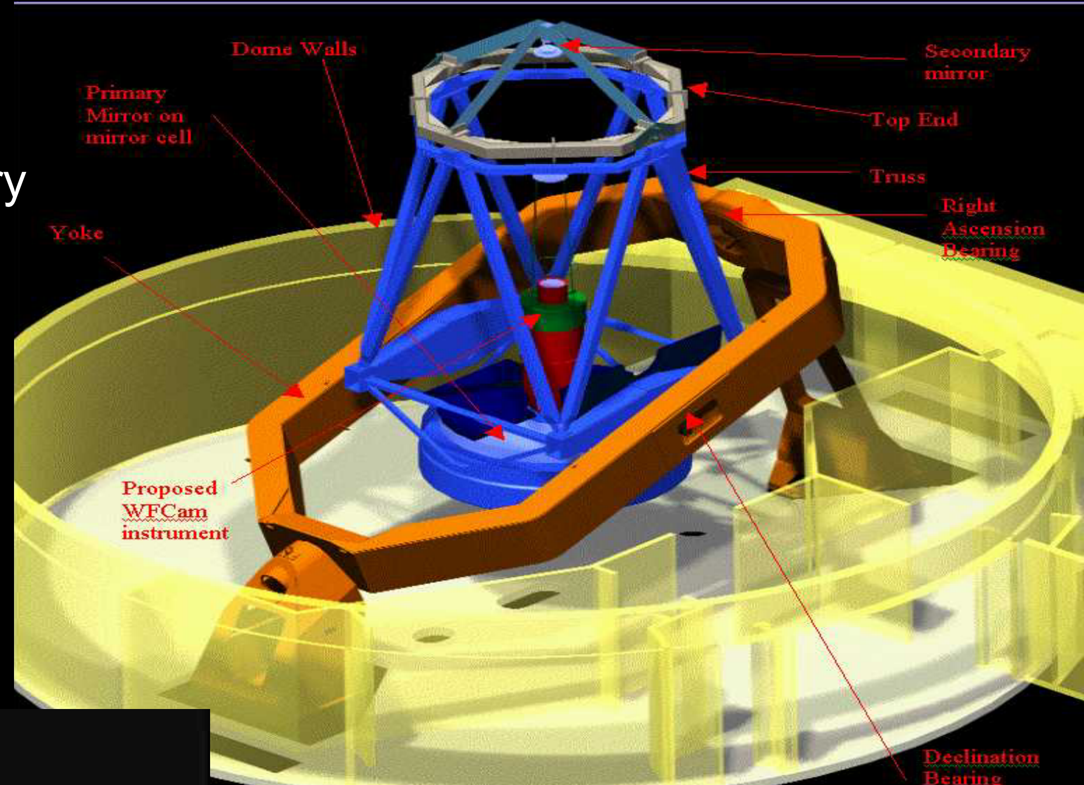


M17: fuzzy pictures obtained by "scanning" a single pixel across the sky

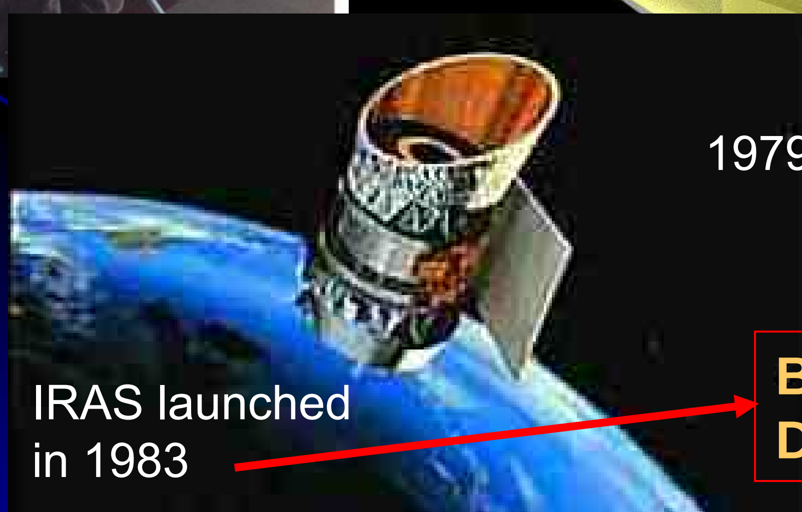
IR astronomy grows

Kuiper Airborne Observatory

1975



1979: Specials IR telescopes on Mauna Kea (UKIRT and IRTF)



IRAS launched in 1983

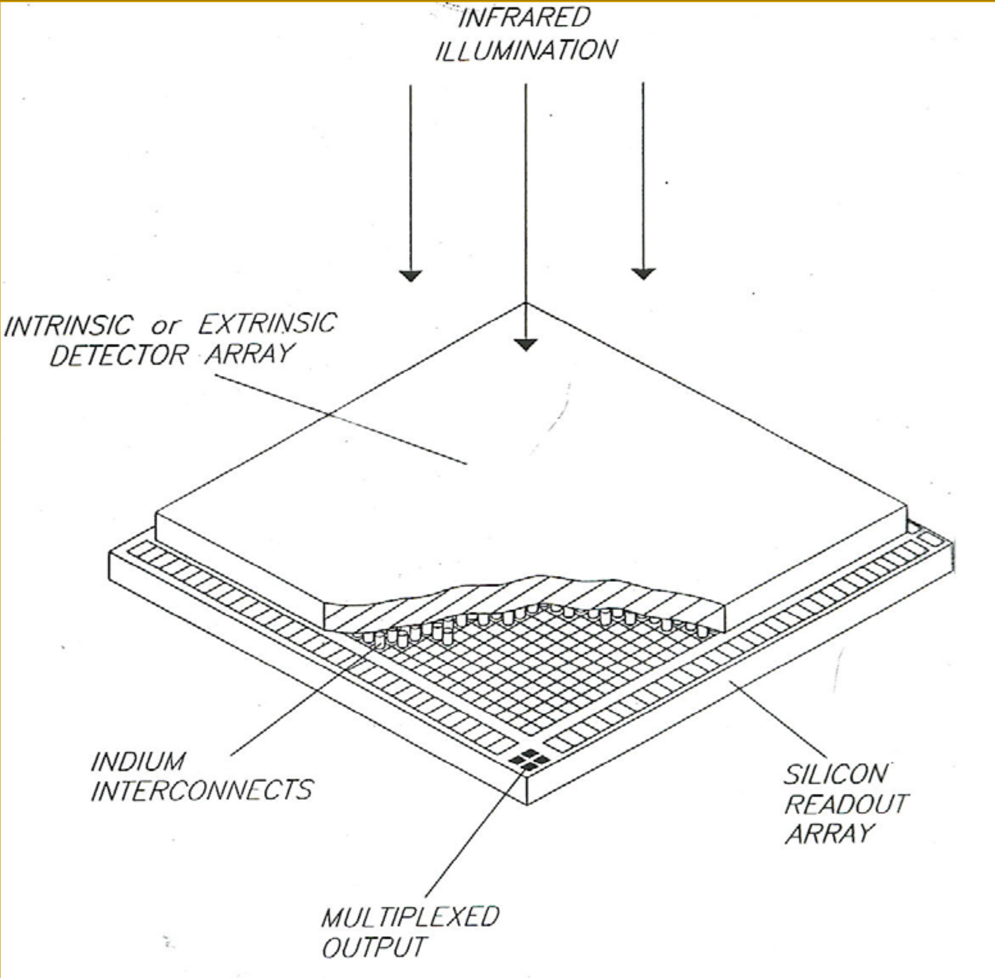
BUT, STILL USING SINGLE PIXEL DETECTORS … NO CAMERAS!

Dawn of the Arrays

- **1981: Royal Observatory Edinburgh wants imaging devices for UKIRT**
- I was building a CCD imaging spectropolarimeter, so … *this becomes my job*
- **1982: My survey reveals best vendors are in USA**
- **But the technology is classified!**
- **Small IR arrays that have "slipped out" to the US astronomical community are designed for high-background, real-time imaging – not what we want**
- **Prospects seem very bleak at first**
- **1983:** An astronomer working for Hughes-SBRC called Alar to think about my visit in October 1982. He convinces his m commercial array development program for astronomy!
- **1984: We *select SBRC (now Raytheon) to develop an InSb array specifically for near-IR astronomy (1-5 μm)***

Infrared Array Detectors

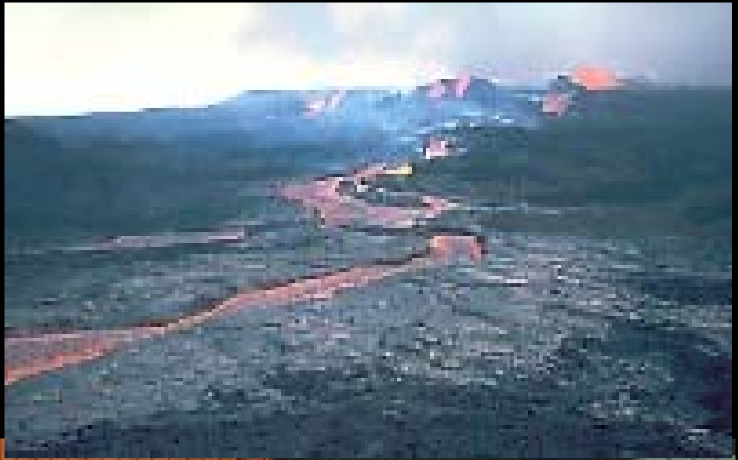
- **Silicon CCDs can't work beyond 1.1 μm**
- **Need lower band-gap semiconductors e.g. Ge, InSb or HgCdTe**
- ***Can't make good CCDs with these materials***
- **HYBRID:** Use the IR-sensitive material to make the detector array and attach this array with *indium* bumps to a silicon readout integrated circuit (ROIC).



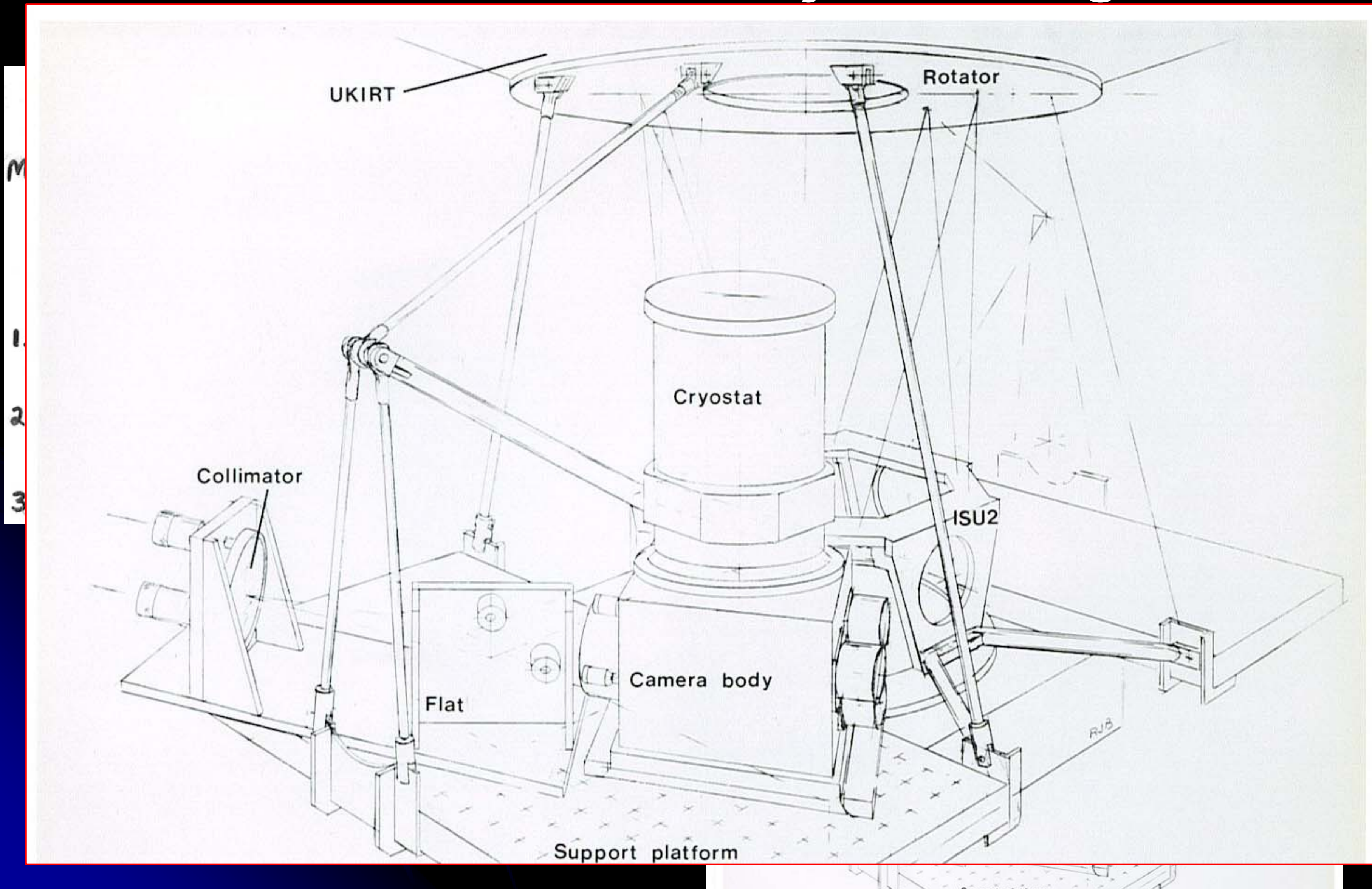
Sensor Chip Assembly or SCA

Negotiating with SBRC

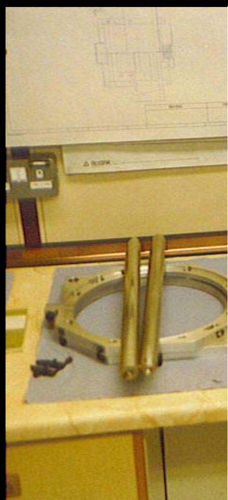
- March 28, 1984
- Mauna Loa is erupting
- SBRC leaders visit UKIRT
- Terry Lee and I take them up
- Spectacular!
- VP says “yes”
- I follow up with visit to Santa Barbara, CA in May with Tim Chuter

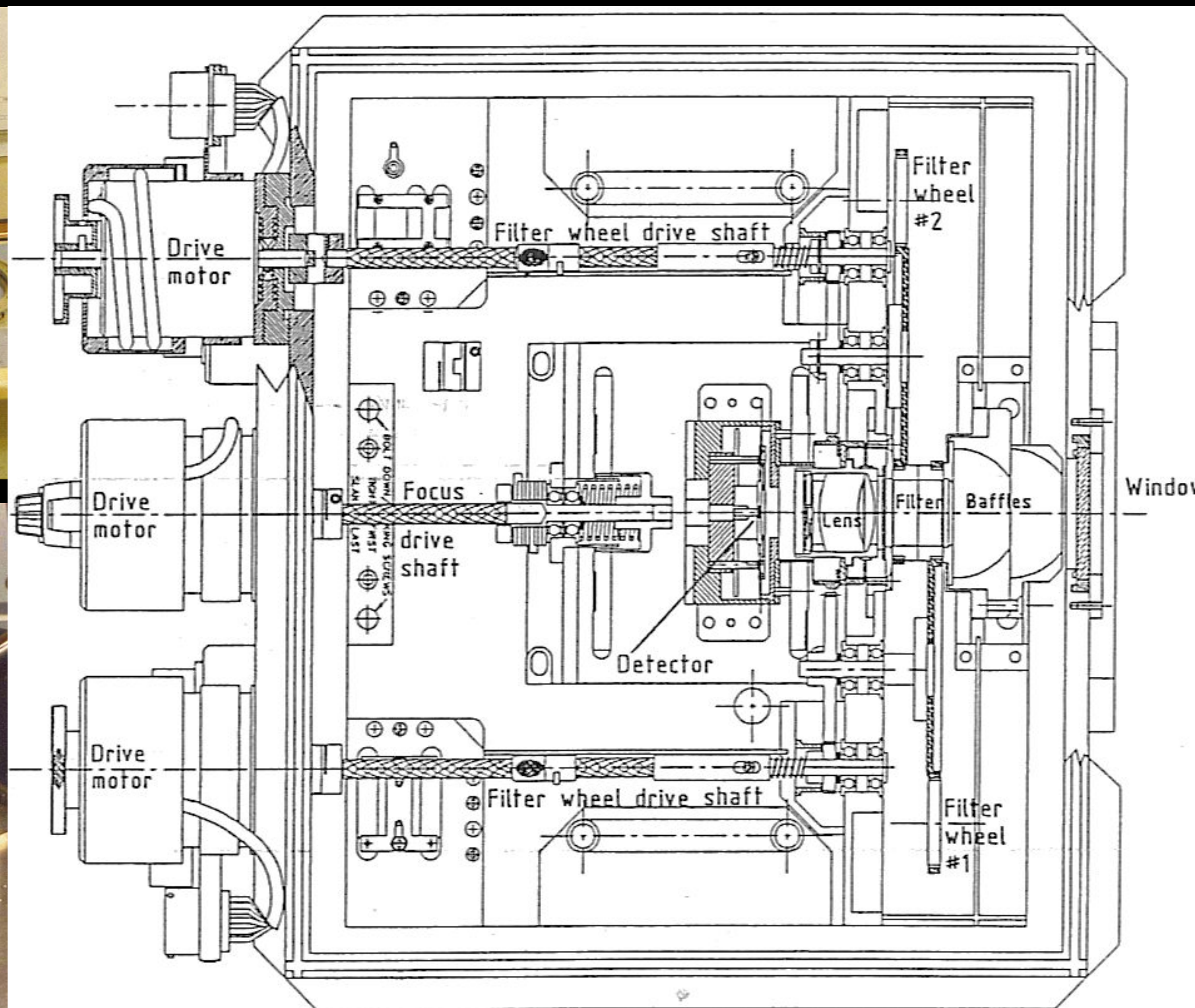


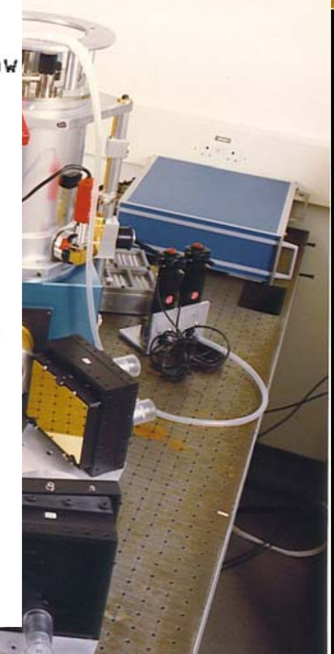
The IRCAM Project Begins



Construction starts

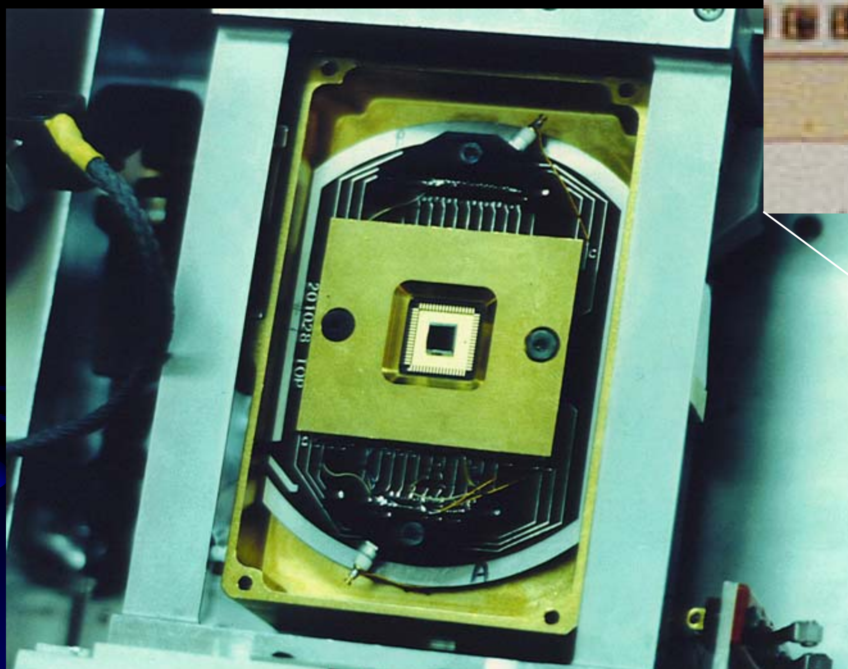


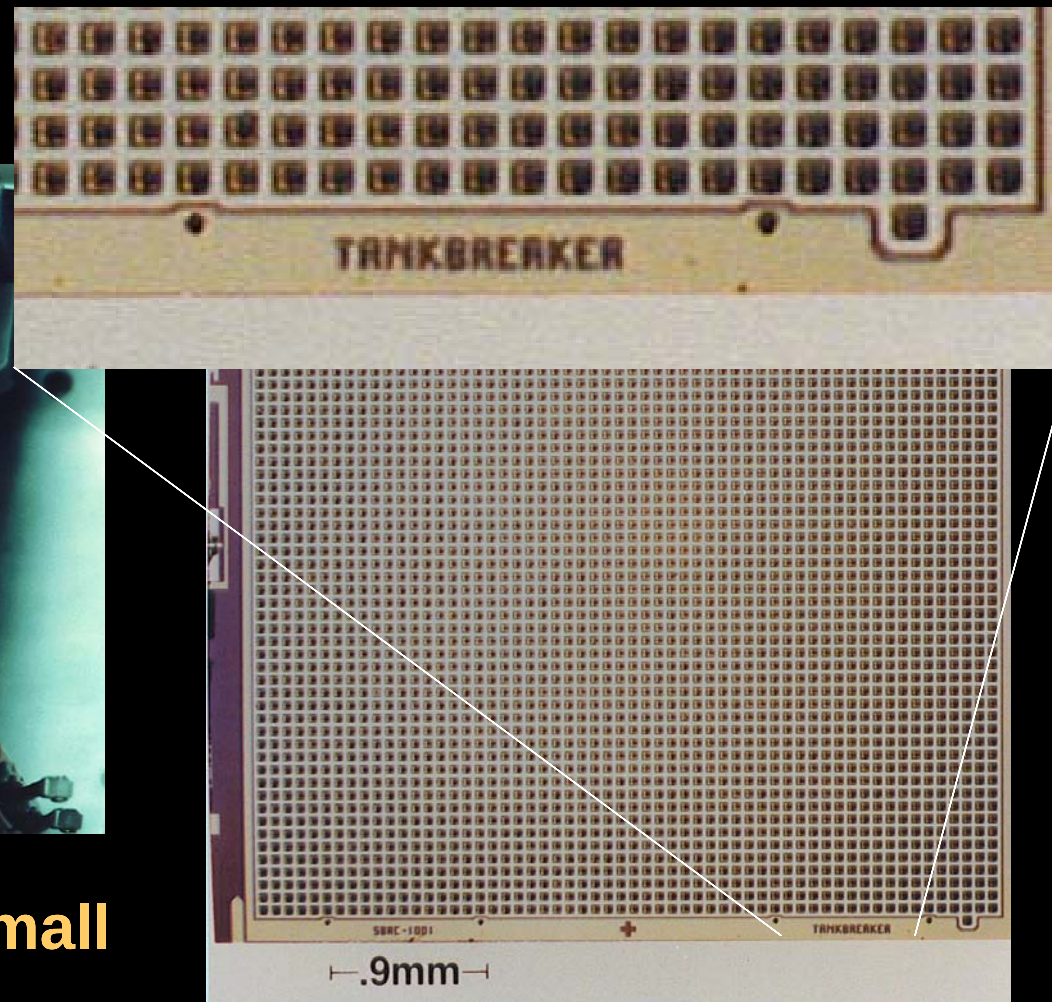




The first IR array for astronomy

Al Fowler at KPNO buys in to this project; we get devices 001 and 002 at same time.

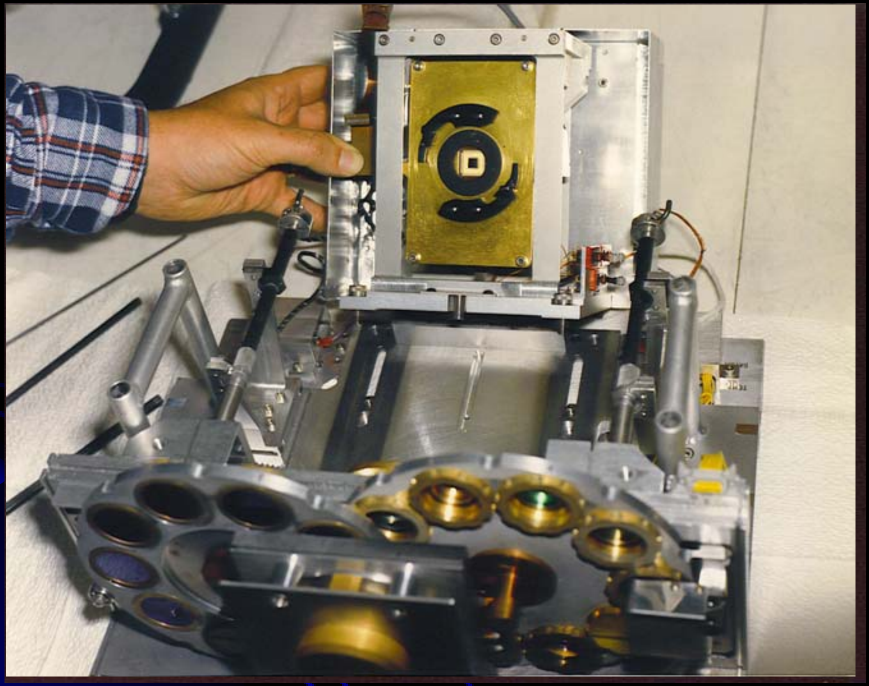




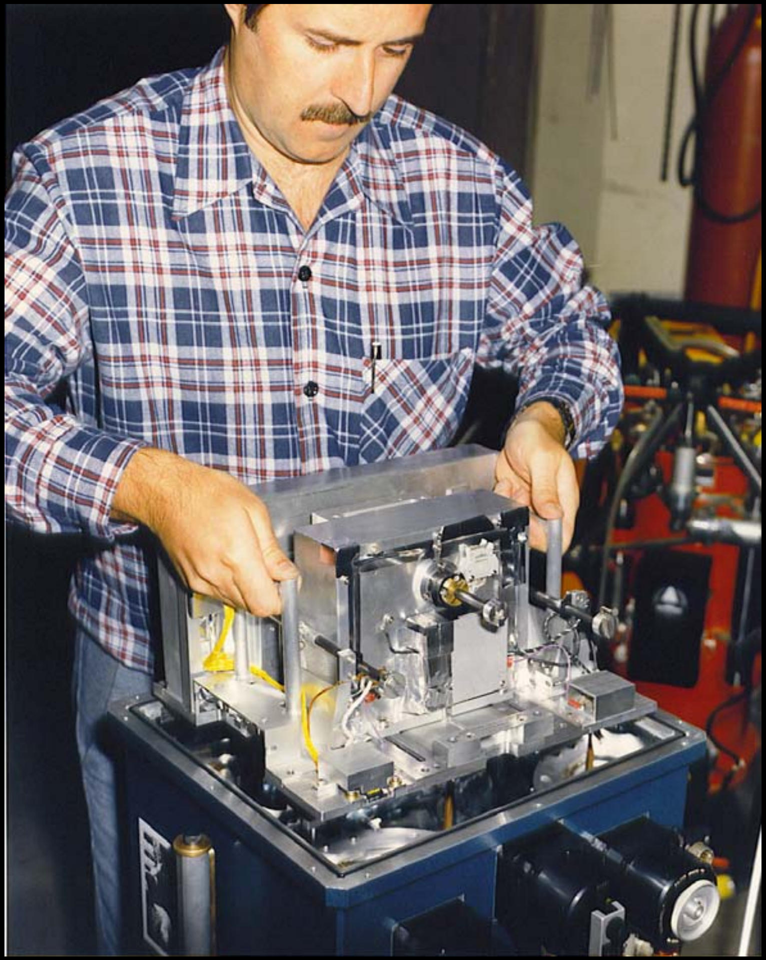
58x62 = 3,596 pixels … small

But 3,595 more than we had before!

IRCAM comes together



Detector and double filter wheel; removable module



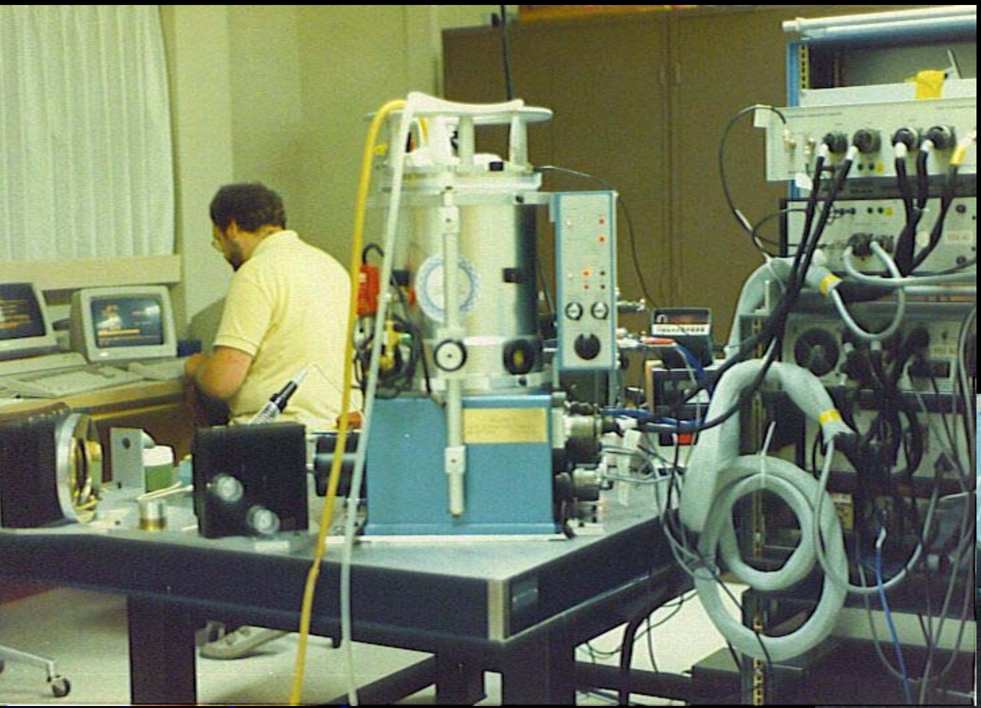
The team celebrates shipping out

September 1986

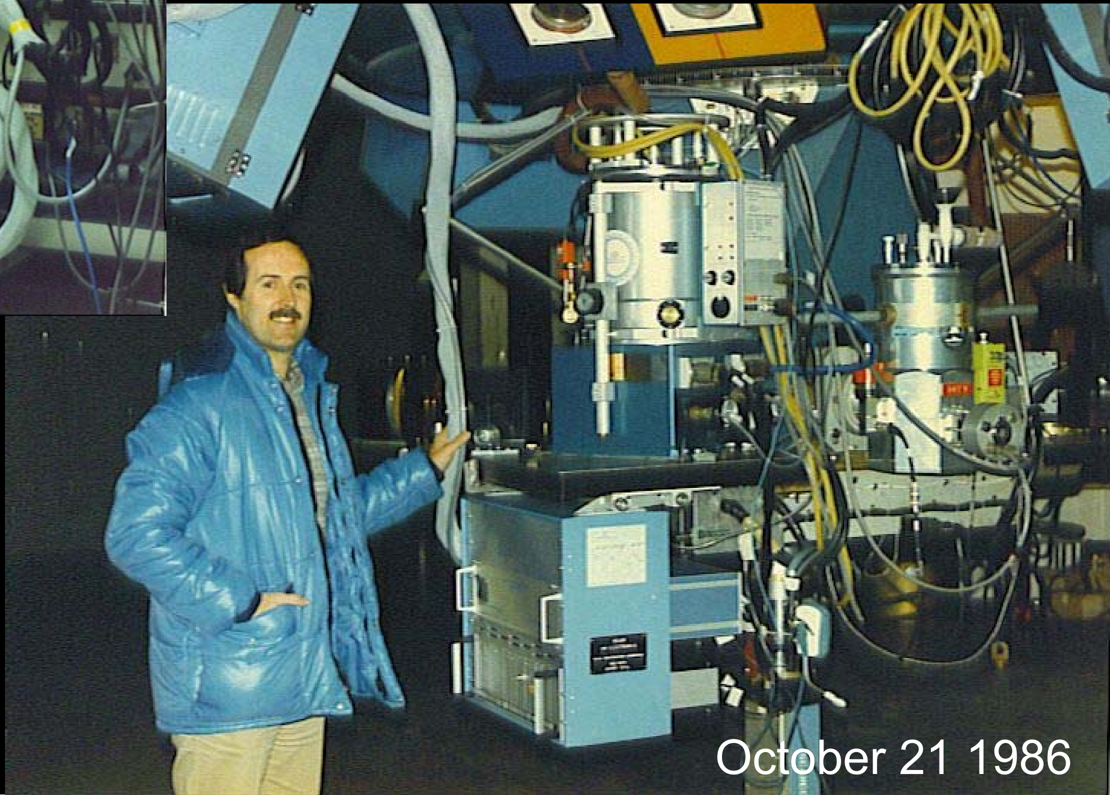
12 crates shipped to Hawaii

In Hawaii

Colin Aspin and I transfer to Hilo. Later we are joined by my two PhD students Mark McCaughrean and John Rayner.



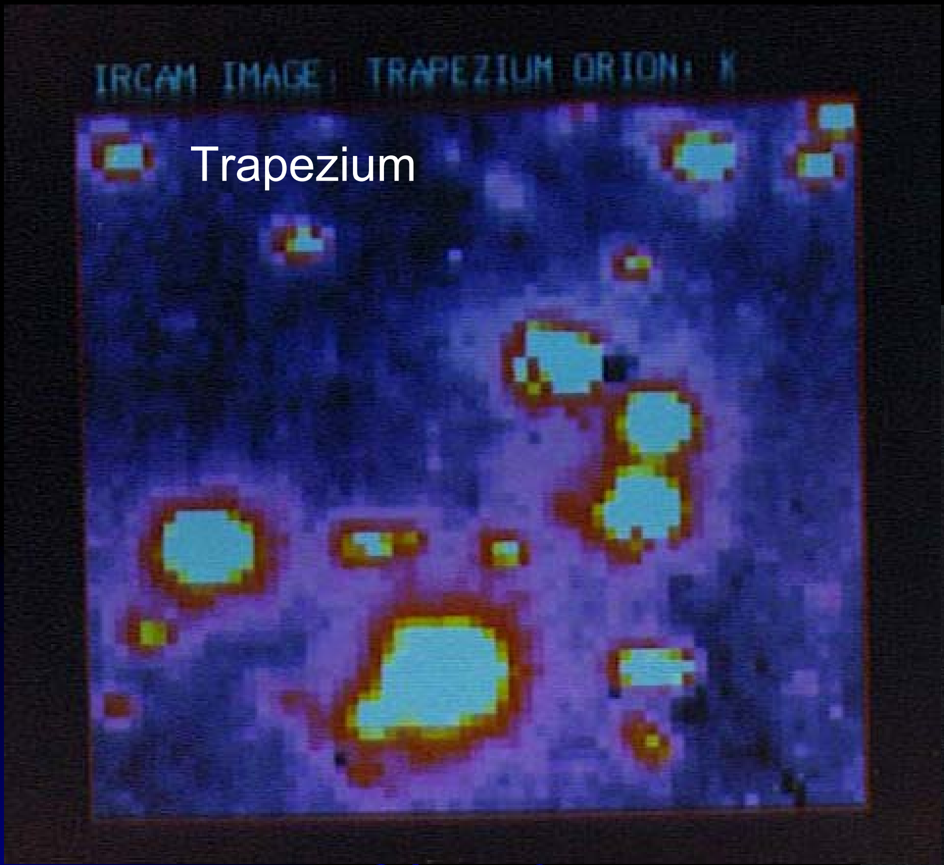
October 10 1986
in JAC Lab



October 21 1986

First Light on the sky

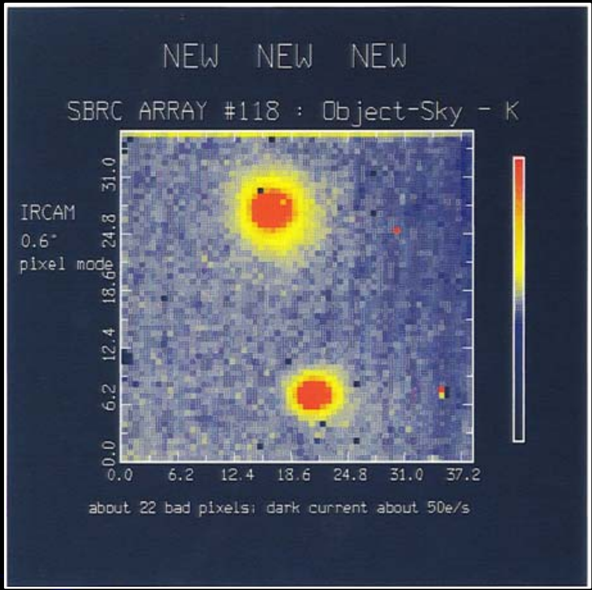
October 23, 1986

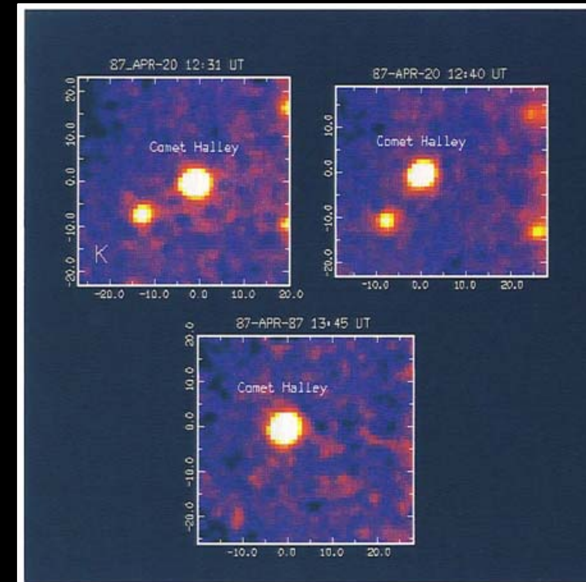


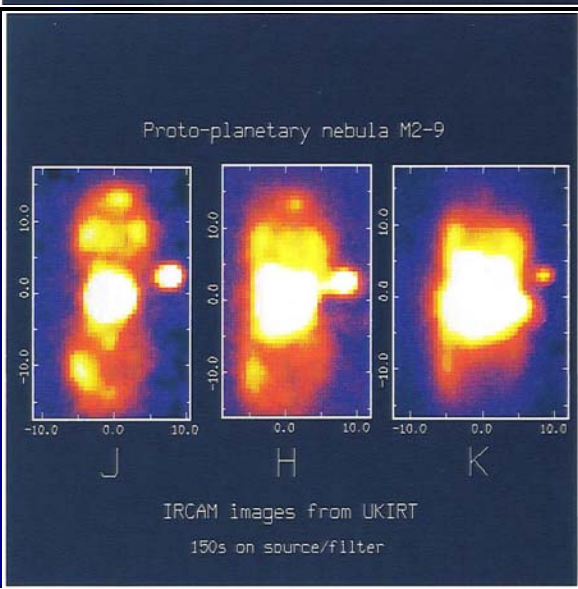
We are given only “morning” observing time after night program ends – confidence in IR arrays was not yet high!

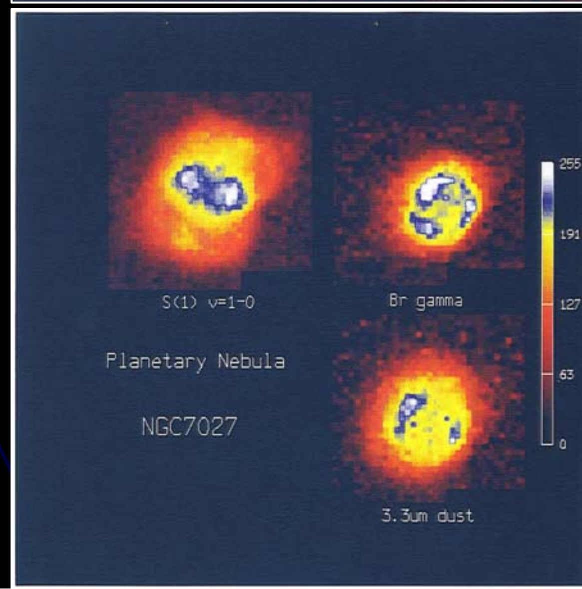
At the telescope was Colin Aspin, Gillian Wright, Dolores Walther and me.

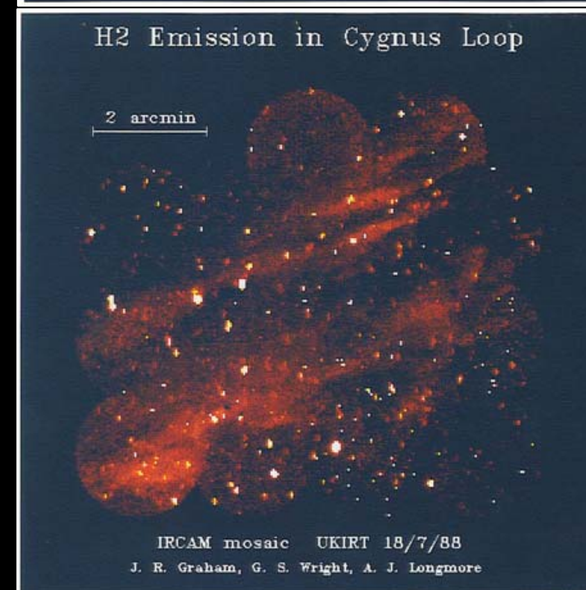
The flood gate opens





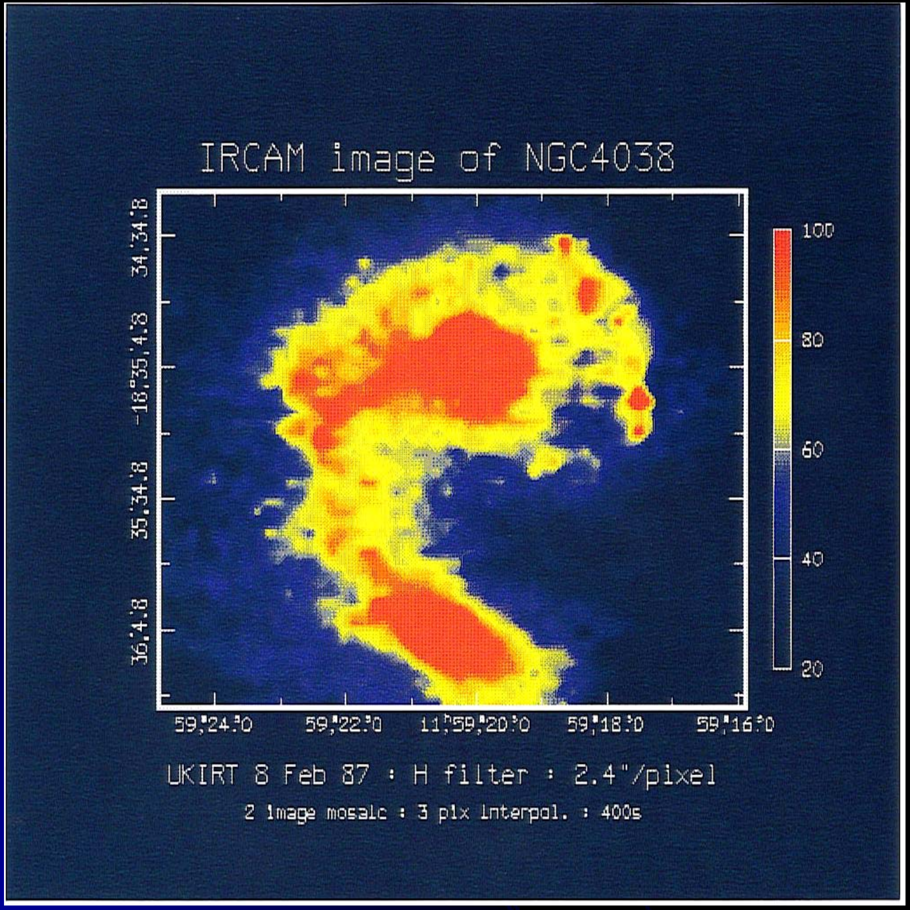


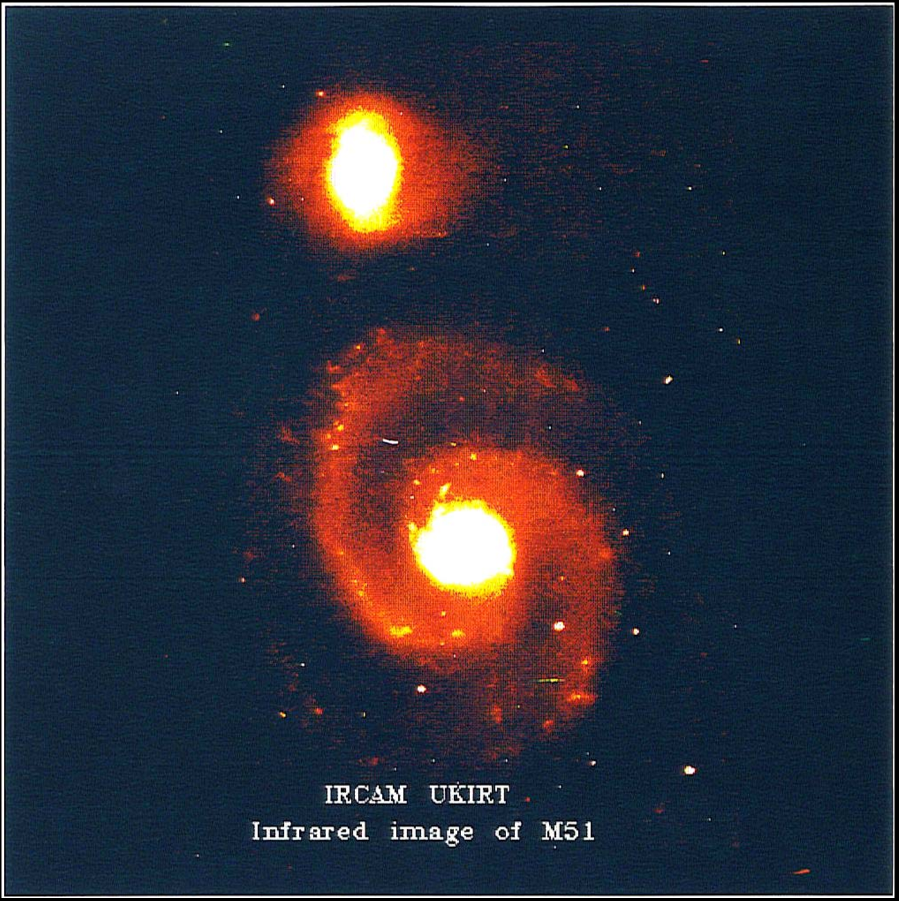




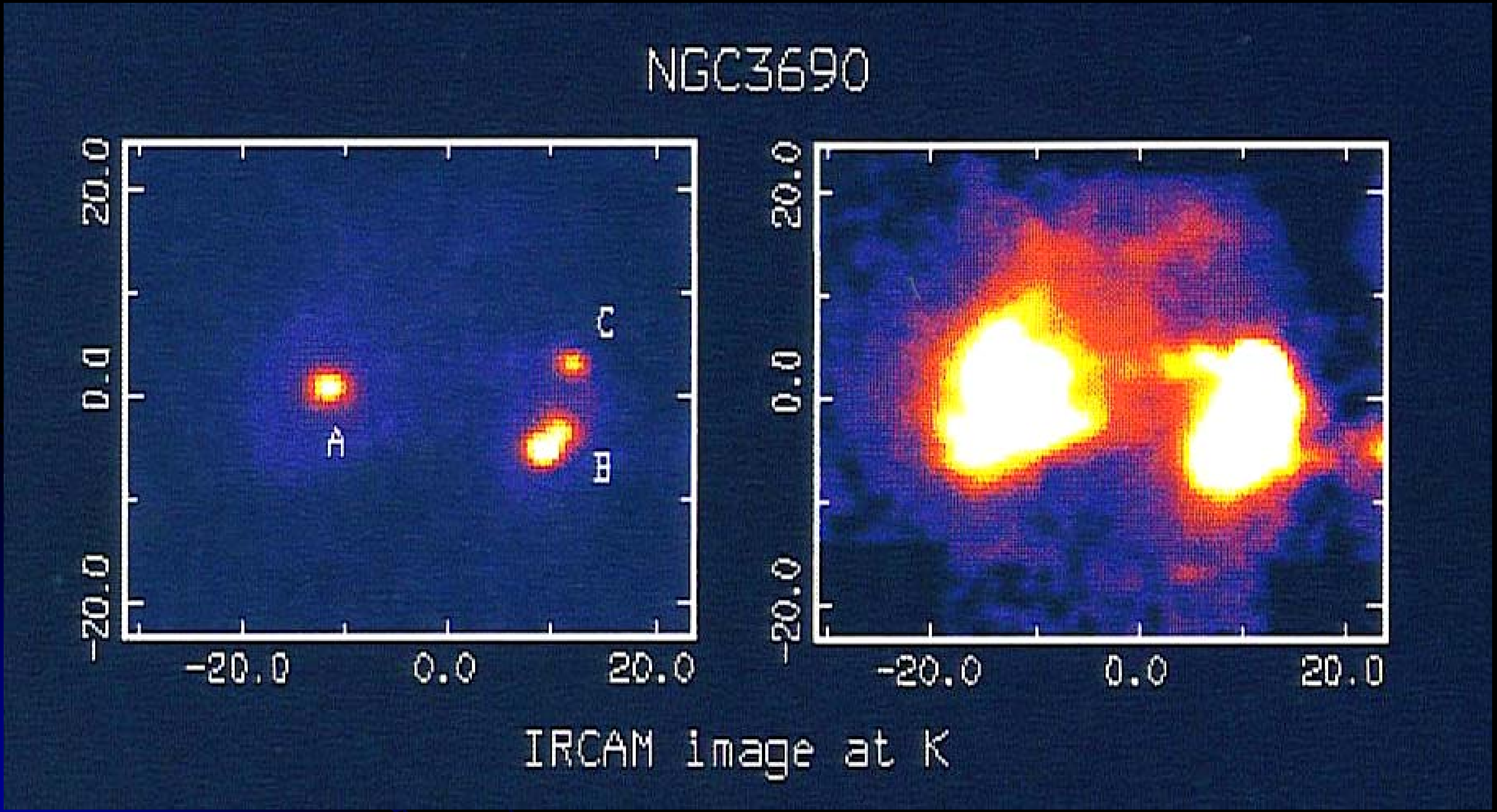
Outside the Galaxy

Yes, we can detect objects outside the galaxy!



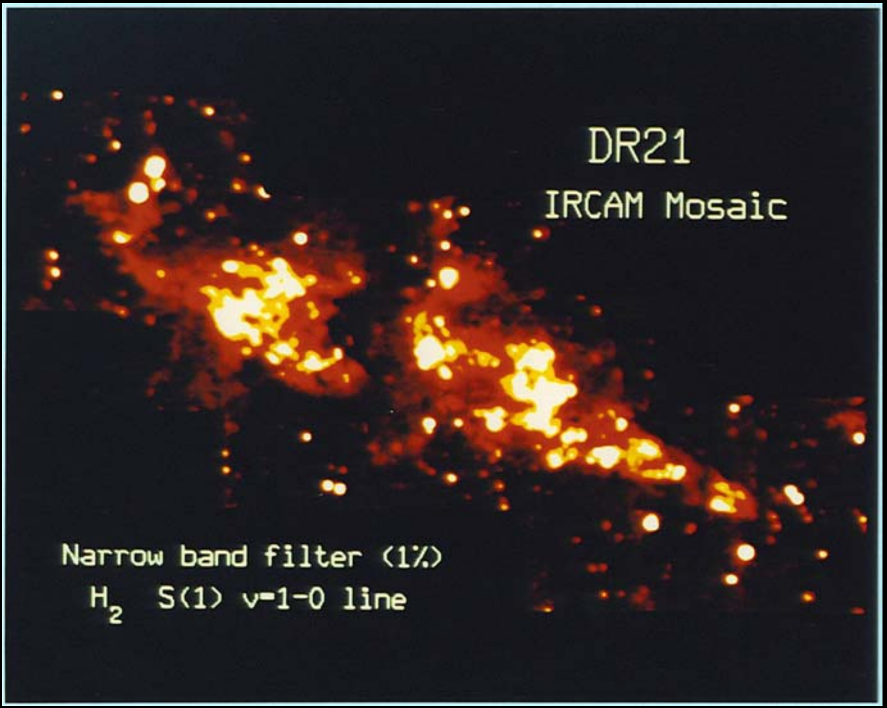


Wow!



Infrared images sharpen up

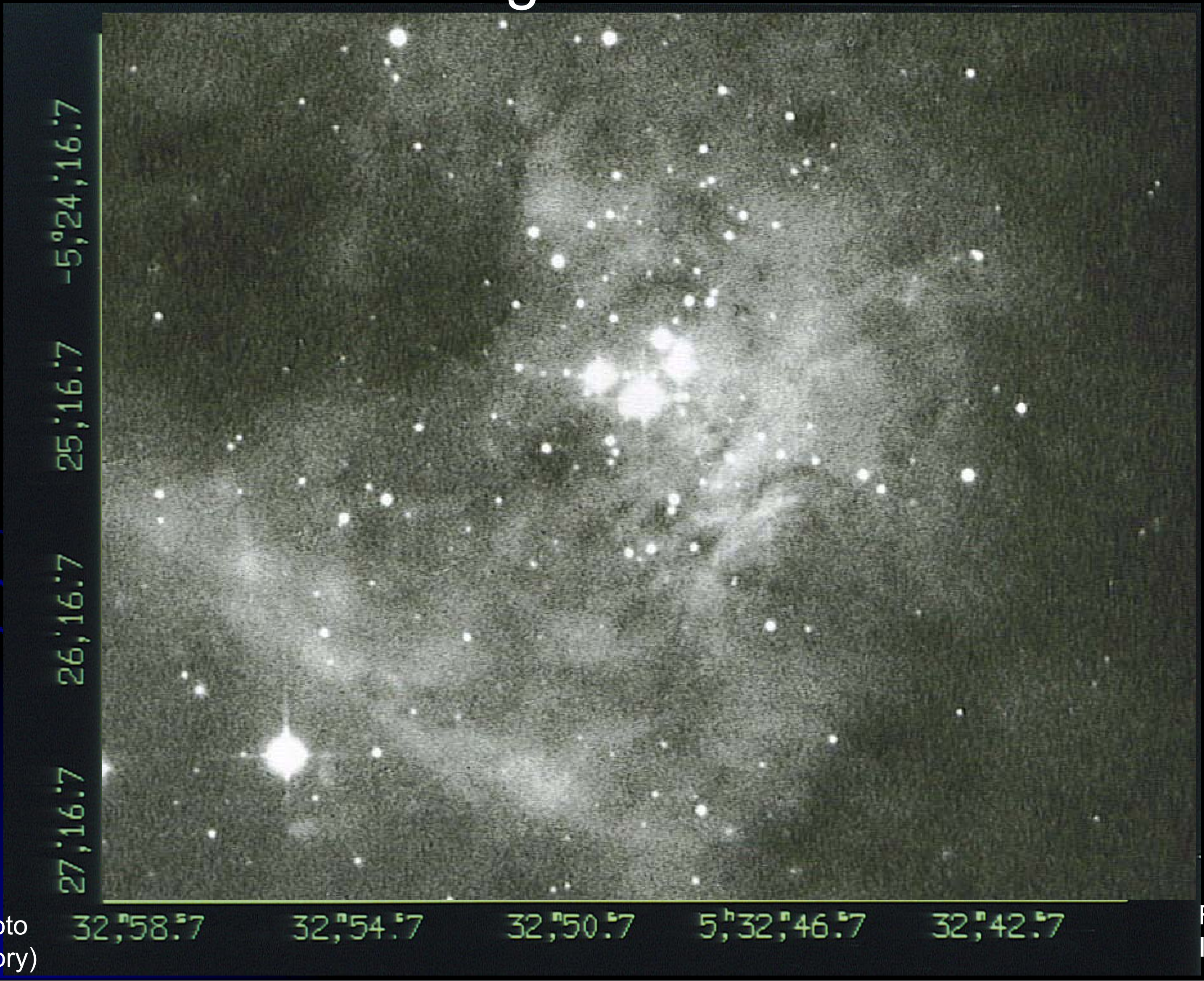
M17



DR21

The Orion Nebula – MOSAIC

Mark McCaughrean's PhD thesis

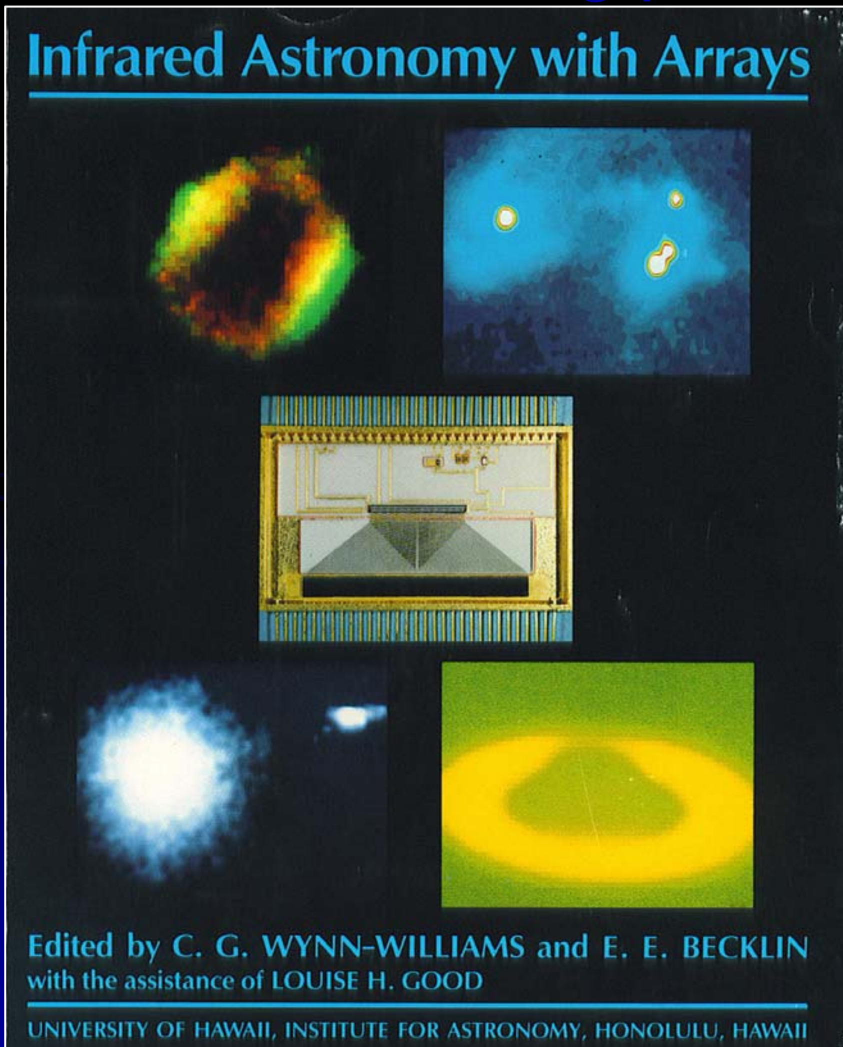


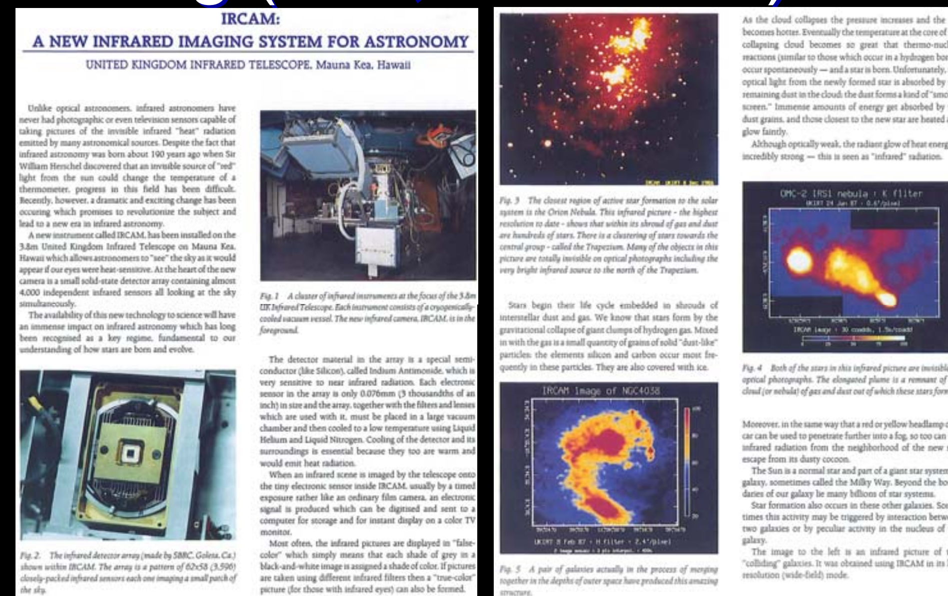
Visible light photo (Lick Observatory)

False-color IRCAM image

Did we know that the world of infrared astronomy had just changed?

1987: "Turning point" meeting (Hilo, Mar 1987)





IRCAM:

A NEW INFRARED IMAGING SYSTEM FOR ASTRONOMY

UNITED KINGDOM INFRARED TELESCOPE, Mauna Kea, Hawaii

Unlike optical astronomers, infrared astronomers have never had photographic or even television sensors capable of taking pictures of the invisible infrared "heat" radiation emitted by many astronomical sources. Despite the fact that infrared astronomy was born about 190 years ago when Sir William Herschel discovered that an invisible source of "red" light from the sun could change the temperature of a thermometer, progress in this field has been difficult. Recently, however, a dramatic and exciting change has been occuring which promises to revolutionize the subject and lead to a new era in infrared astronomy.

A new instrument called IRCAM, has been installed on the 3.8m United Kingdom Infrared Telescope on Mauna Kea, Hawaii which allows astronomers to "see" the sky as it would appear if our eyes were heat-sensitive. At the heart of the new camera is a small solid-state detector array containing almost 4,000 independent infrared sensors all looking at the sky simultaneously.

The availability of this new technology to science will have an immense impact on infrared astronomy which has long been recognised as a key regime, fundamental to our understanding of how stars are born and evolve.

Fig. 1 A cluster of infrared instruments at the focus of the 3.8m UK Infrared Telescope. Each instrument consists of a cryogenically-cooled vacuum vessel. The new infrared camera, IRCAM, is in the foreground.

Fig. 2. The infrared detector array (made by SBRC, Goleta, Ca.) shown within IRCAM. The array is a pattern of 62x58 (3,596) closely-packed infrared sensors each one imaging a small patch of the sky.

The detector material in the array is a special semi-conductor (like Silicon), called Indium Antimonide, which is very sensitive to near infrared radiation. Each electronic sensor in the array is only 0.076mm (3 thousandths of an inch) in size and the array, together with the filters and lenses which are used with it, must be placed in a large vacuum chamber and then cooled to a low temperature using Liquid Helium and Liquid Nitrogen. Cooling of the detector and its surroundings is essential because they too are warm and would emit heat radiation.

When an infrared scene is imaged by the telescope onto the tiny electronic sensor inside IRCAM, usually by a timed exposure rather like an ordinary film camera, an electronic signal is produced which can be digitised and sent to a computer for storage and for instant display on a color TV monitor.

Most often, the infrared pictures are displayed in "false-color" which simply means that each shade of grey in a black-and-white image is assigned a shade of color. If pictures are taken using different infrared filters then a "true-color" picture (for those with infrared eyes) can also be formed.

Fig. 3 The closest region of active star formation to the solar system is the Orion Nebula. This infrared picture - the highest resolution to date - shows that within its shroud of gas and dust are hundreds of stars. There is a clustering of stars towards the central group - called the Trapezium. Many of the objects in this picture are totally invisible on optical photographs including the very bright infrared source to the north of the Trapezium.

Stars begin their life cycle embedded in shrouds of interstellar dust and gas. We know that stars form by the gravitational collapse of giant clumps of hydrogen gas. Mixed in with the gas is a small quantity of grains of solid "dust-like" particles: the elements silicon and carbon occur most frequently in these particles. They are also covered with ice.

IRCAM Image of NGC4038

Fig. 5 A pair of galaxies actually in the process of merging together in the depths of outer space have produced this amazing structure.

As the cloud collapses the pressure increases and the gas becomes hotter. Eventually the temperature at the core of the collapsing cloud becomes so great that thermo-nuclear reactions (similar to those which occur in a hydrogen bomb) occur spontaneously — and a star is born. Unfortunately, the optical light from the newly formed star is absorbed by the remaining dust in the cloud: the dust forms a kind of "smoke-screen." Immense amounts of energy get absorbed by the dust grains, and those closest to the new star are heated and glow faintly.

Although optically weak, the radiant glow of heat energy is incredibly strong — this is seen as "infrared" radiation.

OMC-2 IRS1 nebula : K filter

Fig. 4 Both of the stars in this infrared picture are invisible on optical photographs. The elongated plume is a remnant of the cloud (or nebula) of gas and dust out of which these stars formed.

Moreover, in the same way that a red or yellow headlamp on a car can be used to penetrate further into a fog, so too can the infrared radiation from the neighborhood of the new star escape from its dusty cocoon.

The Sun is a normal star and part of a giant star system or galaxy, sometimes called the Milky Way. Beyond the boundaries of our galaxy lie many billions of star systems.

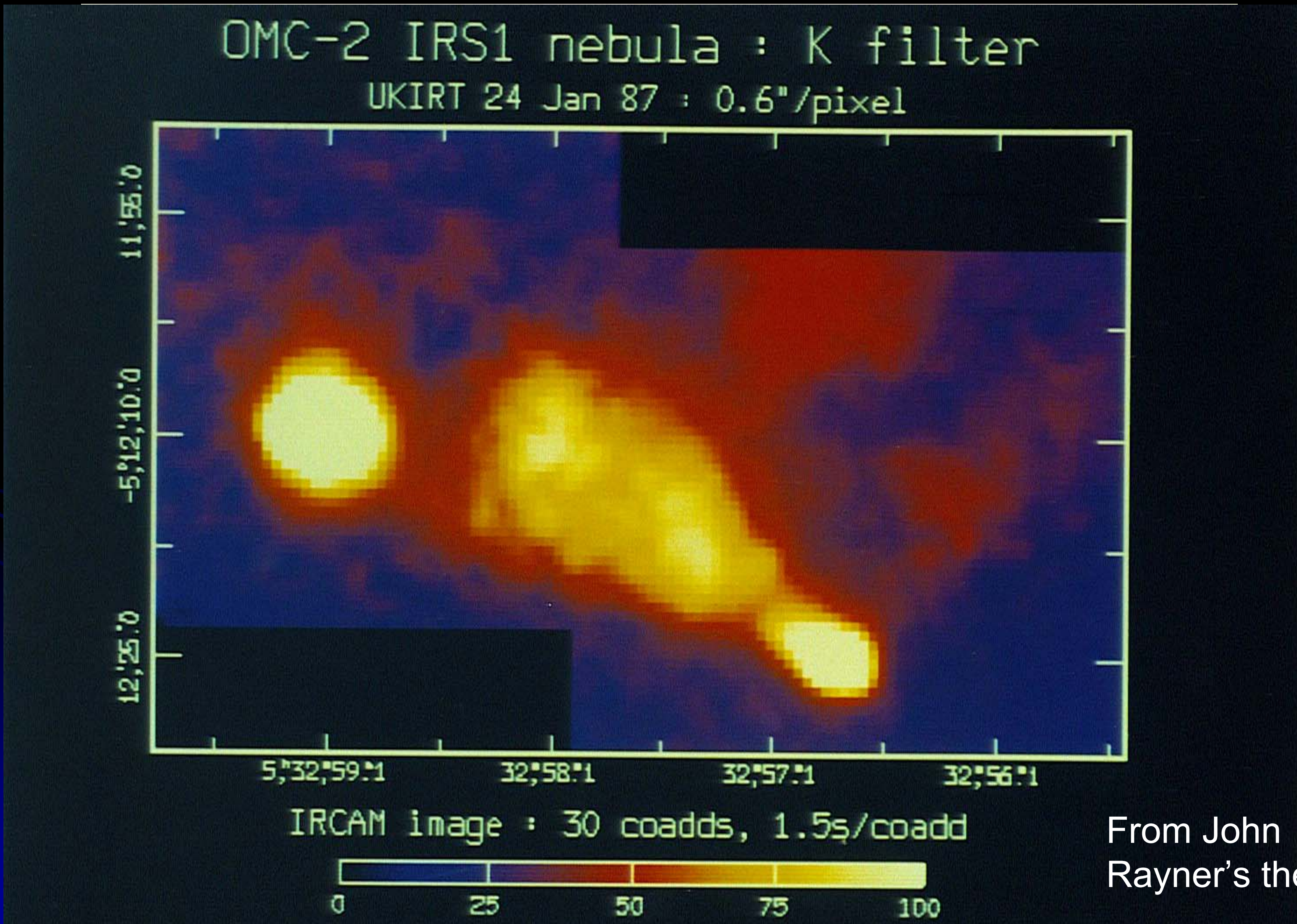
Star formation also occurs in these other galaxies. Sometimes this activity may be triggered by interaction between two galaxies or by peculiar activity in the nucleus of the galaxy.

The image to the left is an infrared picture of two "colliding" galaxies. It was obtained using IRCAM in its low resolution (wide-field) mode.

Wayne van Citters (NSF): "*I don't think there's any doubt that we are on the verge of a promised land in optical and infrared astronomy***."**

Don Hall (UH): *"Things that seemed in the future and beyond my grasp for so long are clearly here."*

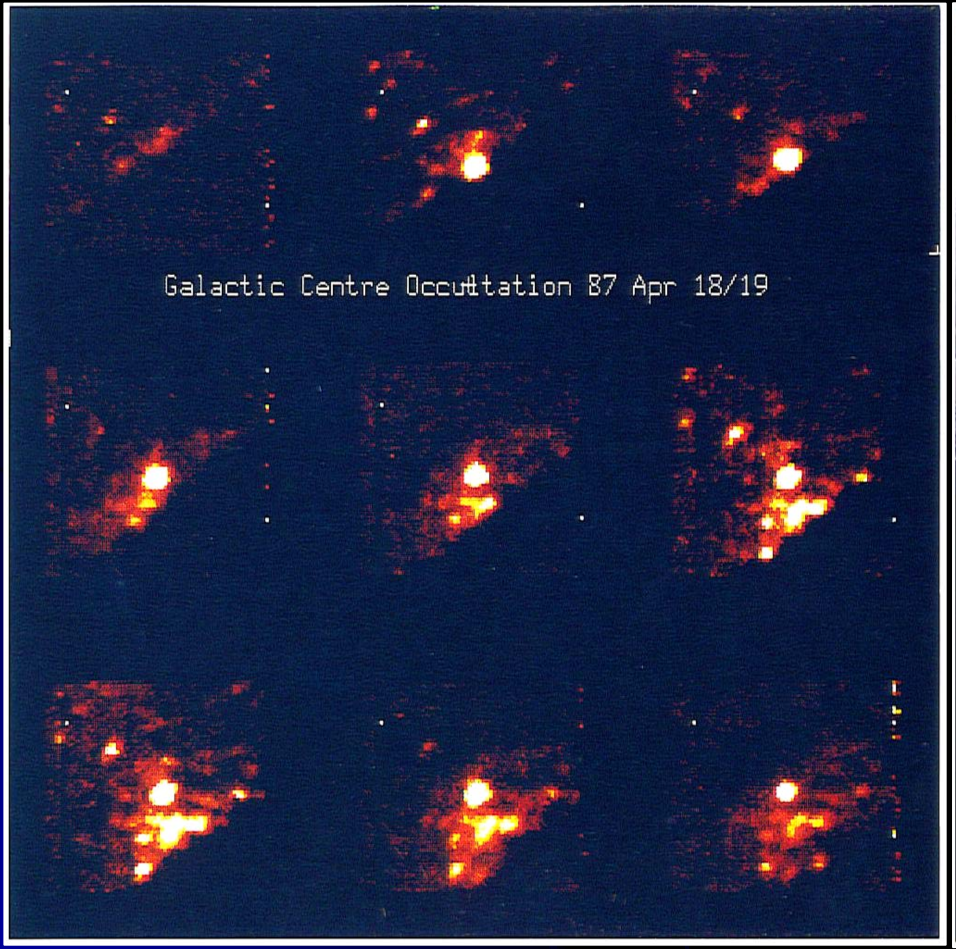
The “I like it” image from the Hilo Meeting



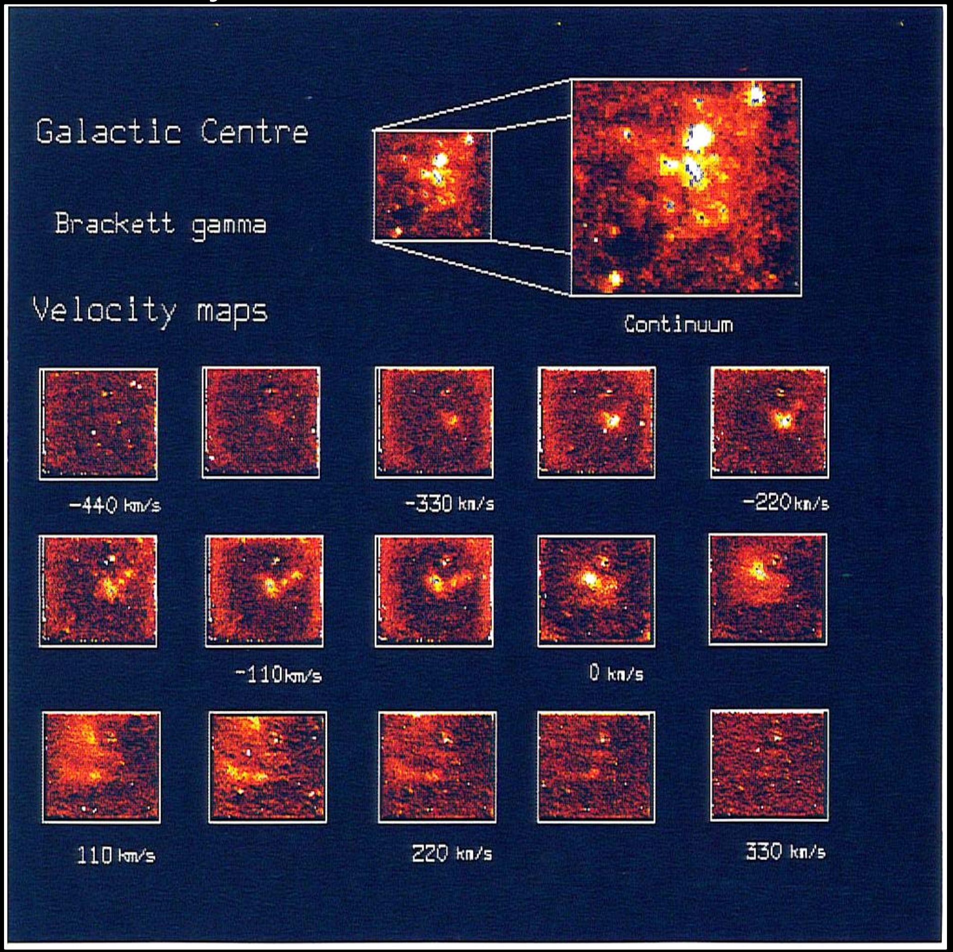
From John Rayner’s thesis

The Galactic Center

IRCAM obtains high-speed snapshots during a lunar occultation in April 1987.

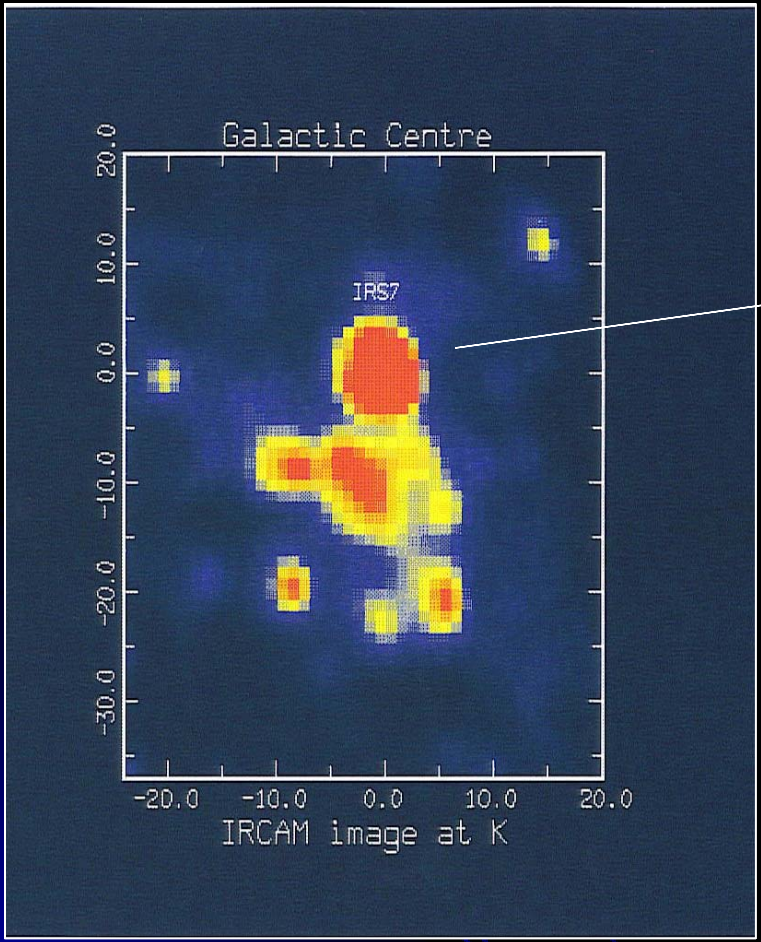


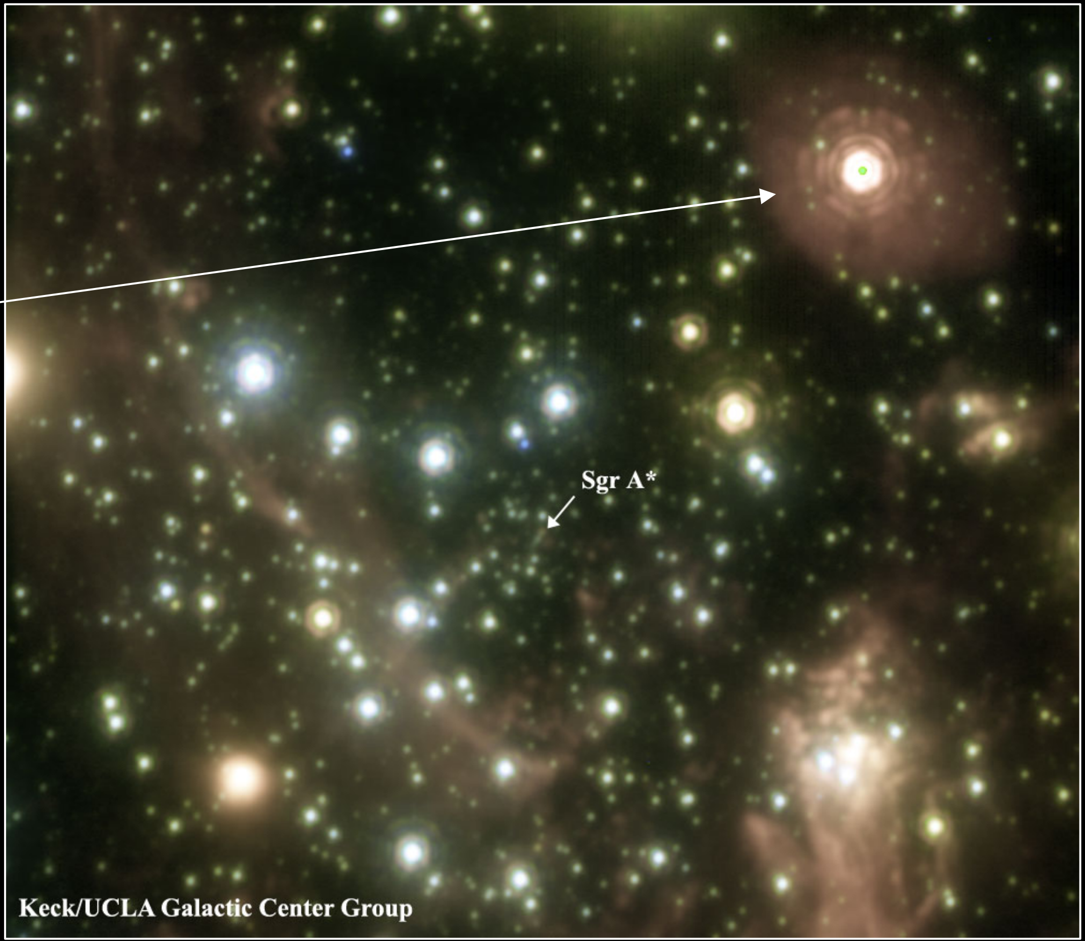
IRCAM creates velocity maps in the Brackett gamma line at 2.17 μm using the Fabry-Perot mode,



The added impact of AO

In the years that follow IR astronomy gets the added bonus of adaptive optics

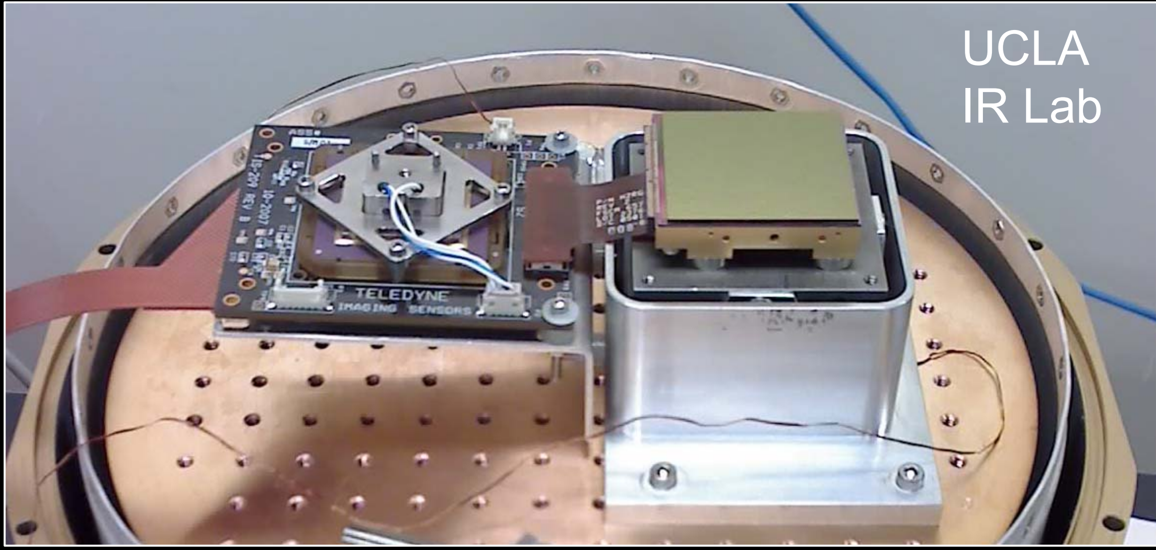




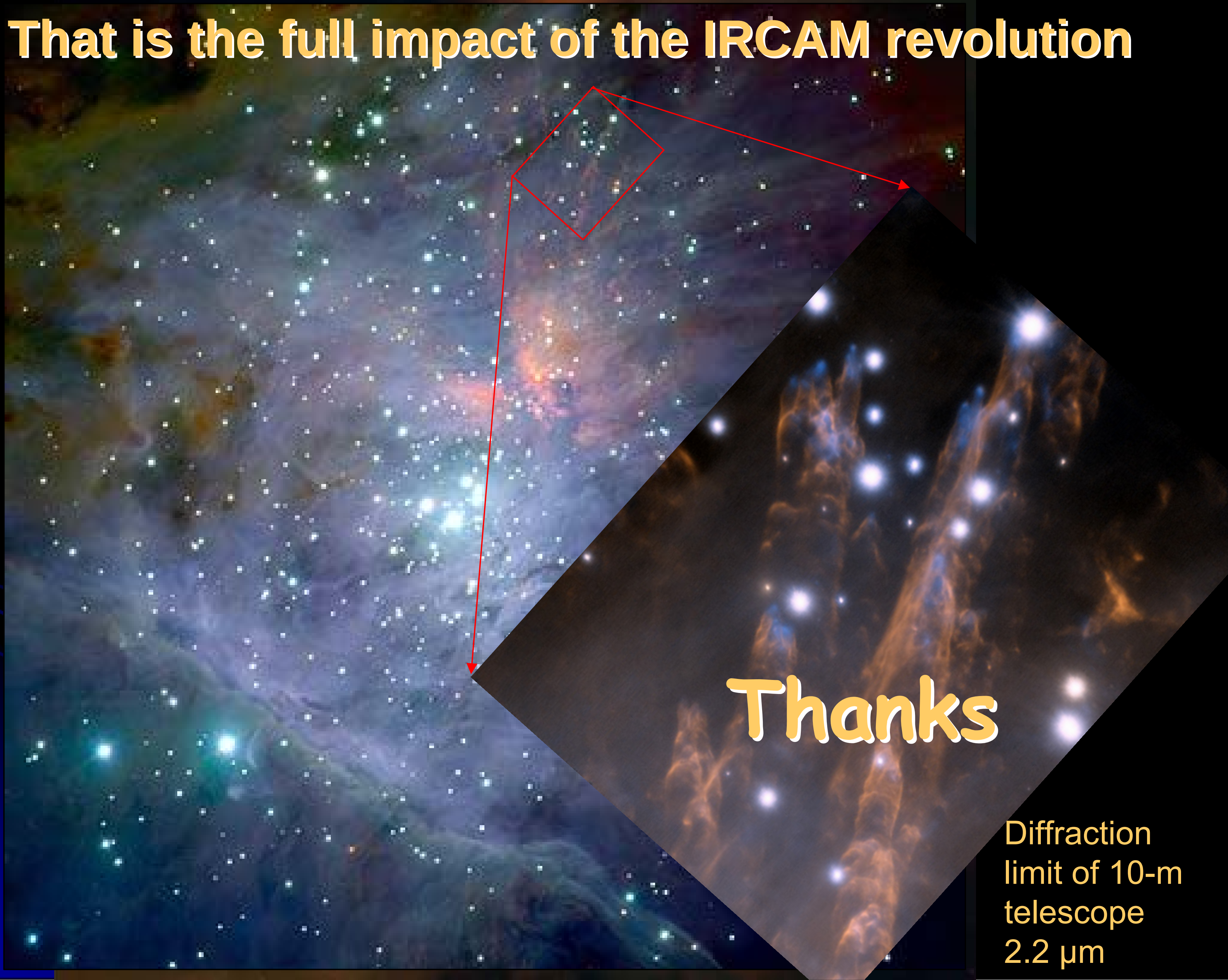
From 1987 to 2007

From 4,000 to 4 million pixels

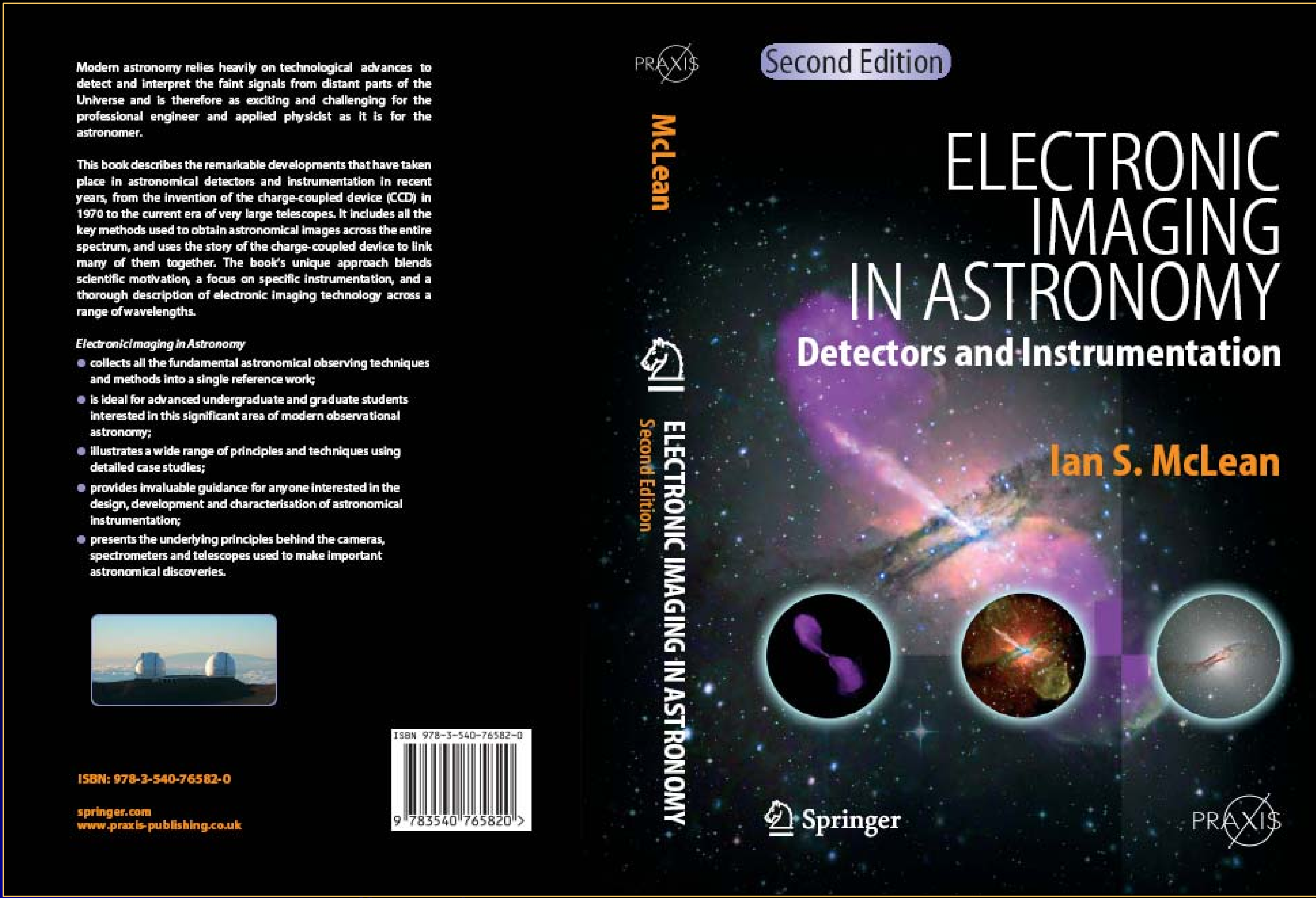
- In 1984 we had 58 x 62 pixels each 60 μm
- Today, 2Kx2K arrays are common
  - e.g. H2-RG HgCdTe 2Kx2K array with 18 μm pixels from Teledyne shown below
- Controlled by a single Application Specific Integrated Circuit (ASIC)
- λ = 0.9-2.5 μm or even 5 μm
- QE >80%
- RN ~5 e- rms
- Dark <0.01 e/s



That is the full impact of the IRCAM revolution



Diffraction limit of 10-m telescope 2.2 μm



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