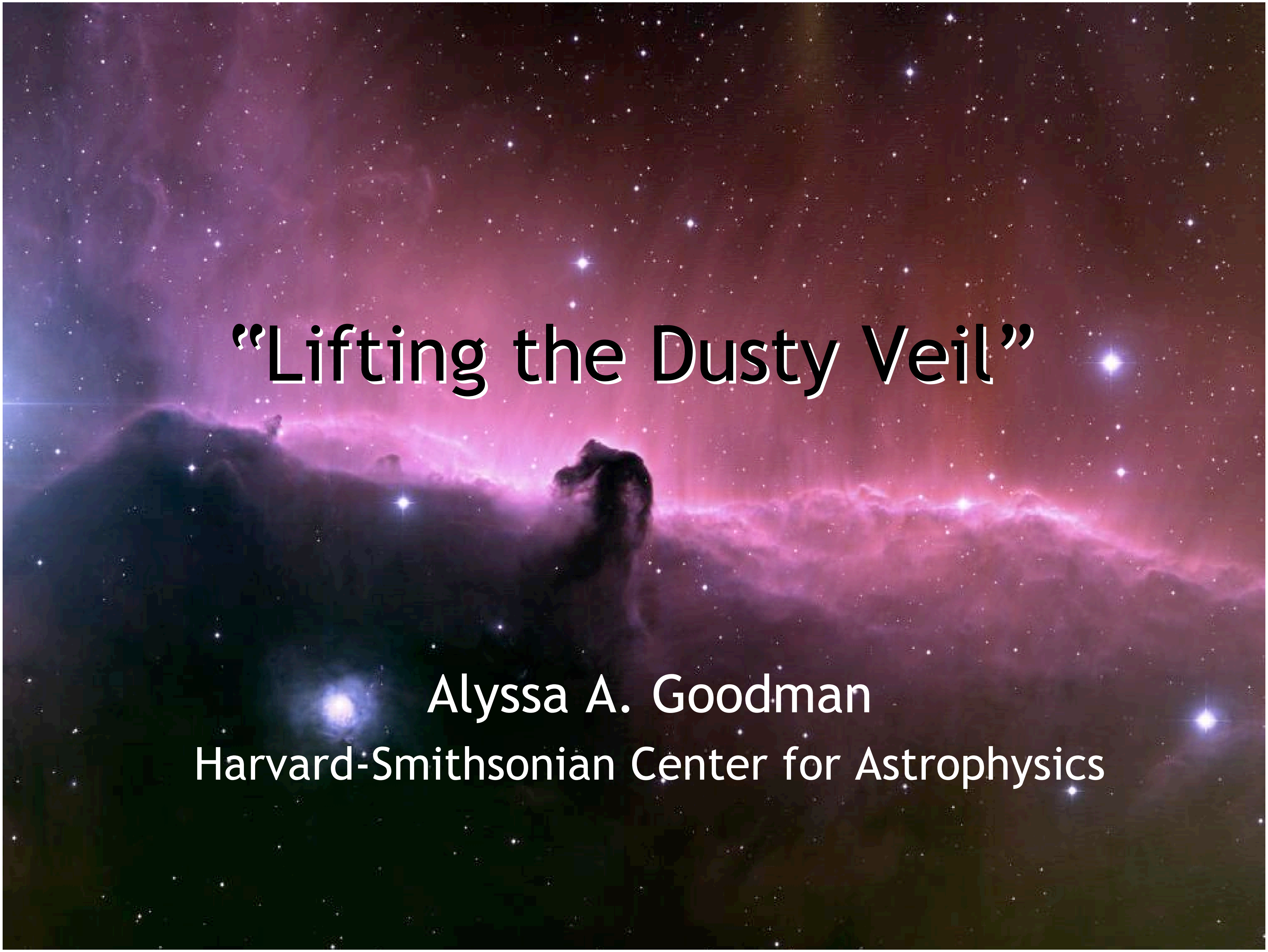
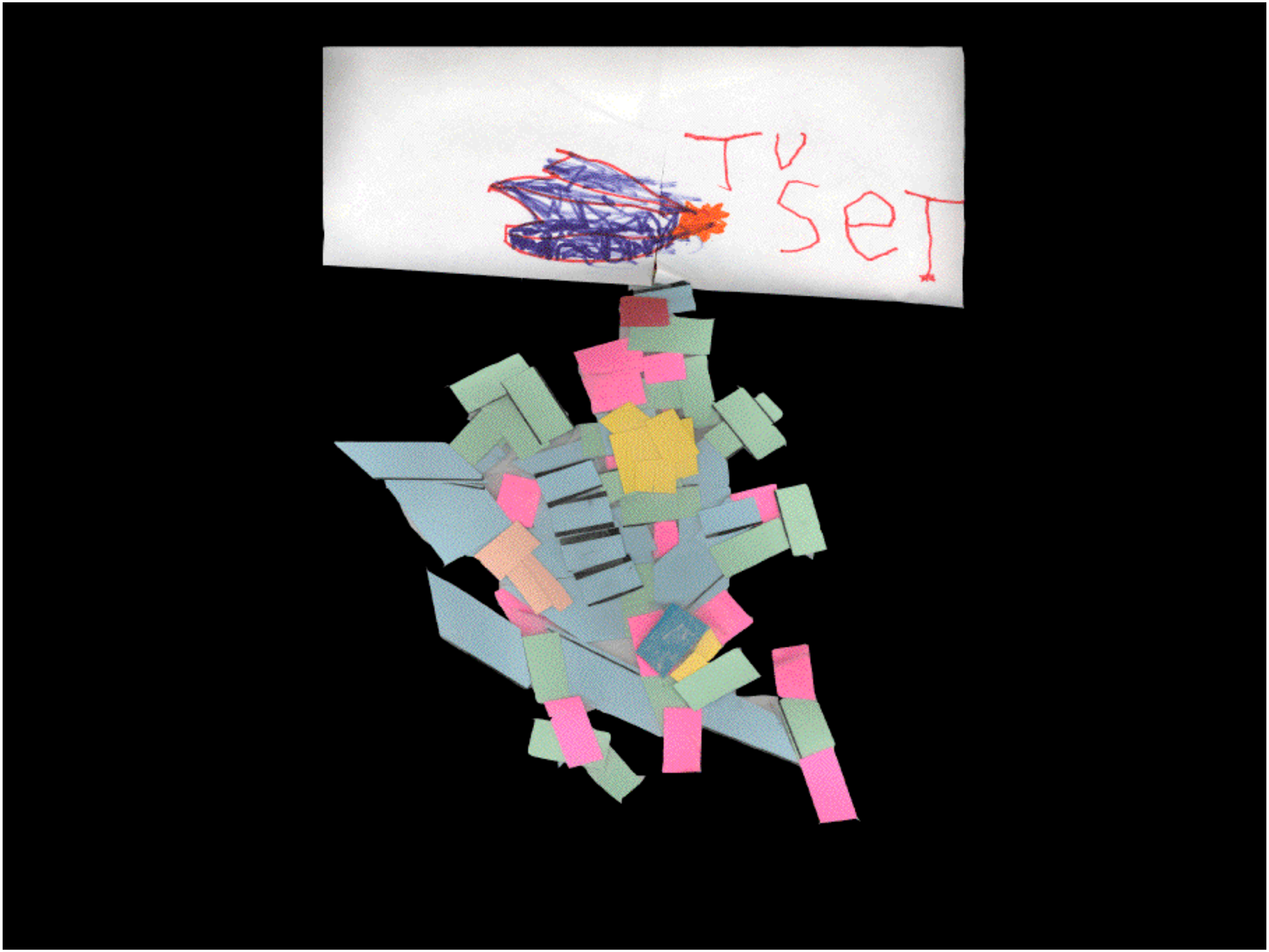

"Lifting the Dusty Veil"
Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics

SAO BATC GSFC U of A SIRTF LMSSC Cornell Caltech NASA JPL

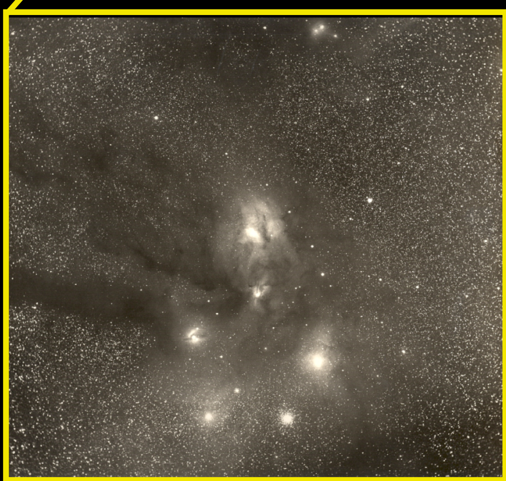
COMPLETE

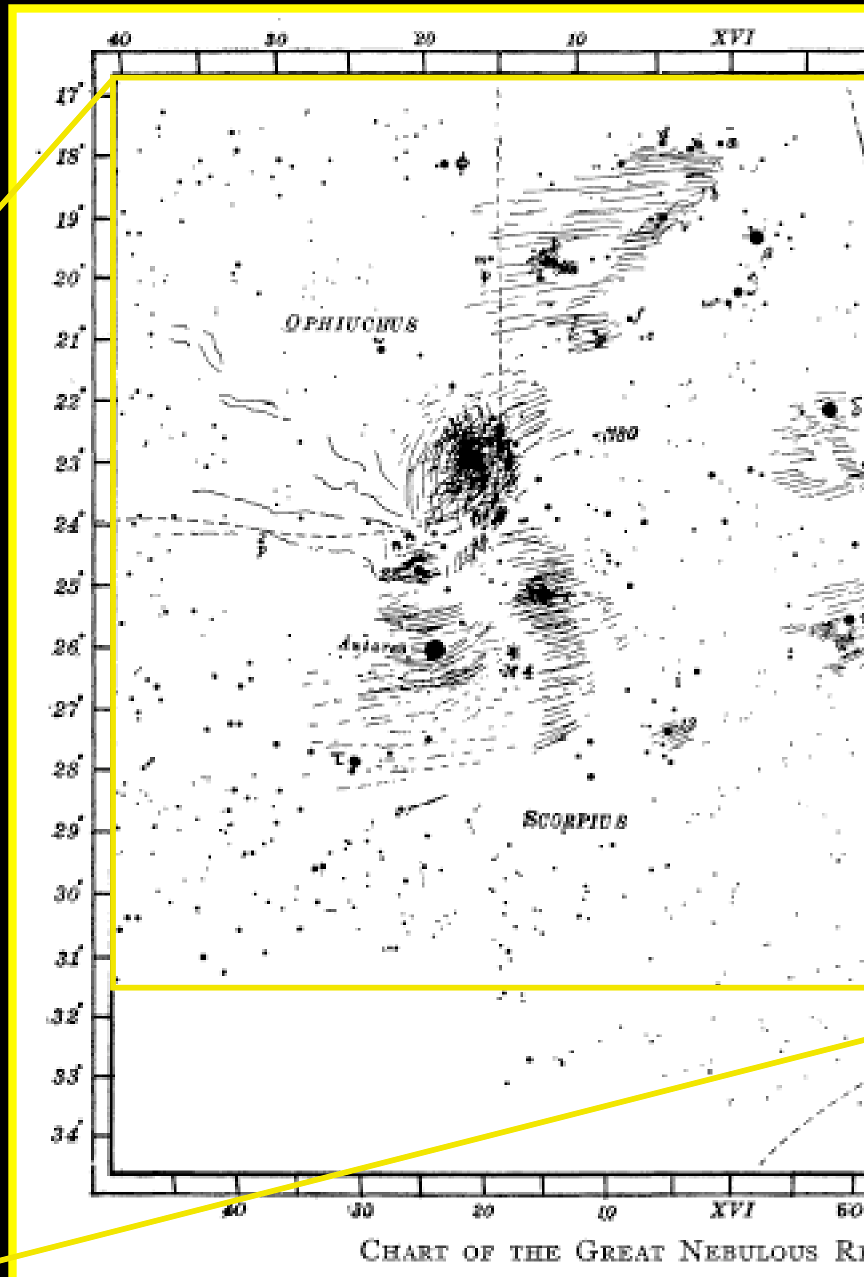

TV SET

Holes in the Heavens?

5.5 hour exposure at Yerkes Observatory, 1907 Jan. 9, E.E. Barnard

Barnard: "*Not* Holes in the Heavens"

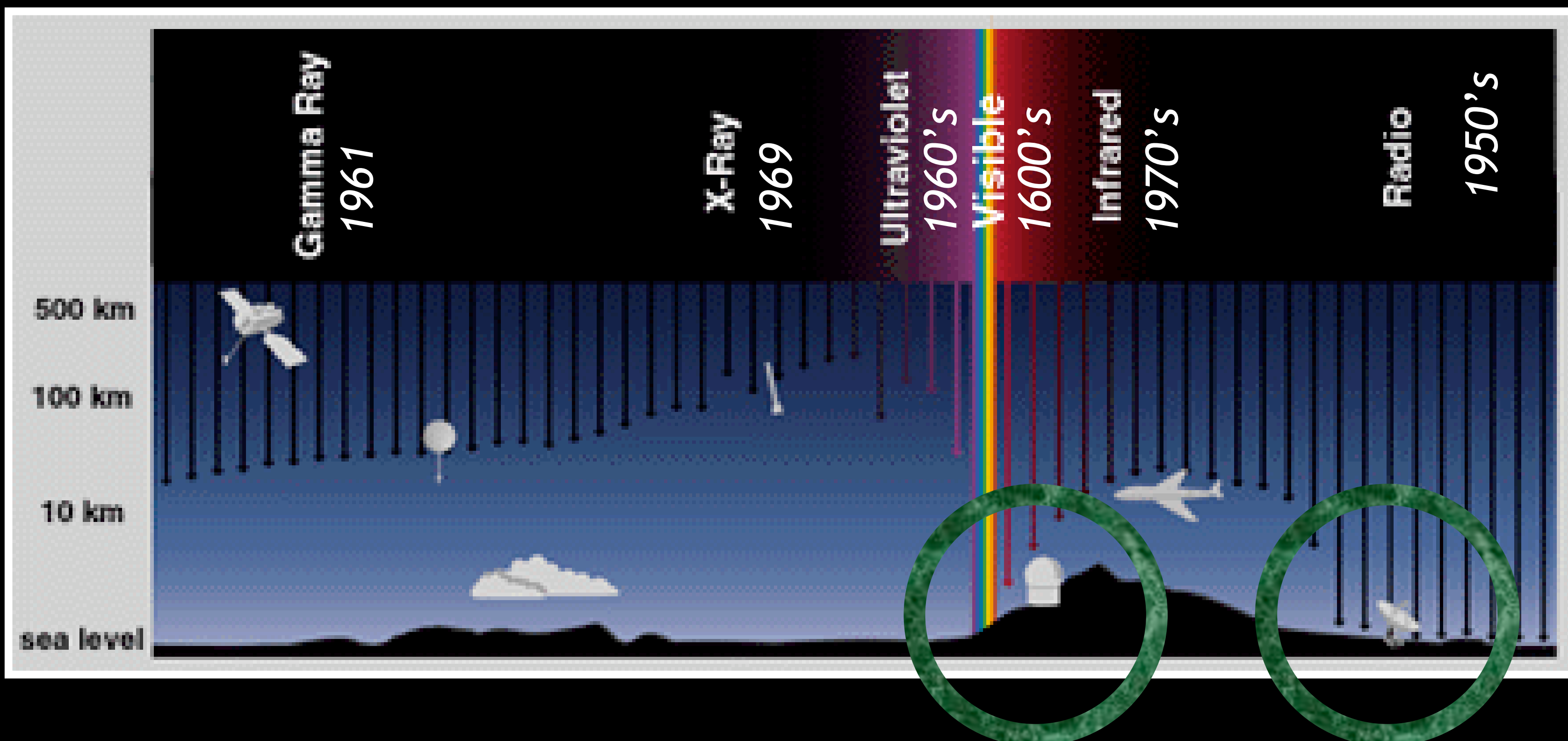




Bright & Dark: Clues to Star Formation

Visualization courtesy American Museum of Natural History, Hayden Planetarium

What's happened since Barnard?



+…moderately realistic computer simulations, c. 1990++

Glossary

for Alyssa Goodman's
Observatory Night Talk, 9/18/03

Extinction--the degree of "blackness" on the sky caused by dust between background objects and an observer

Emission--photons *produced* by some physical process

Absorption--removal of photons by some physical process

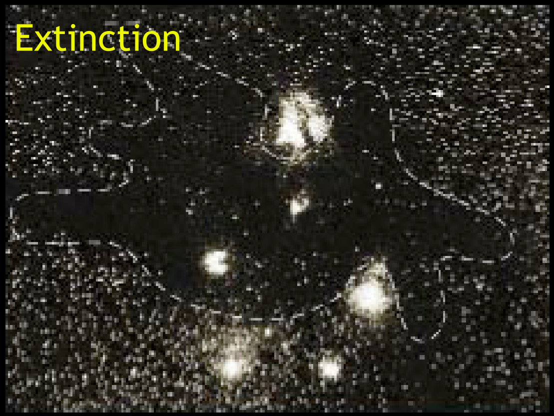
Spectral line--emission or absorption over a very narrow wavelength range, caused by a change in the quantum mechanical state of a particular atom or molecule

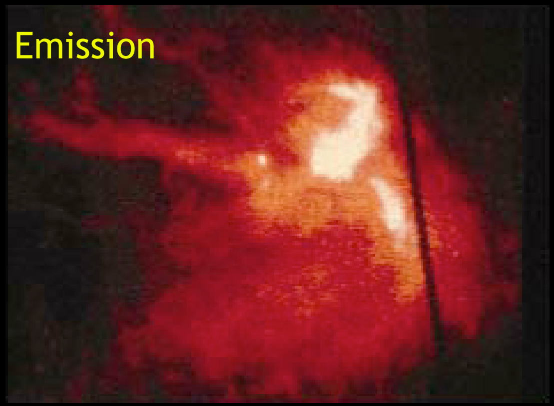
IRAS--Infrared Astronomy Satellite (1983)

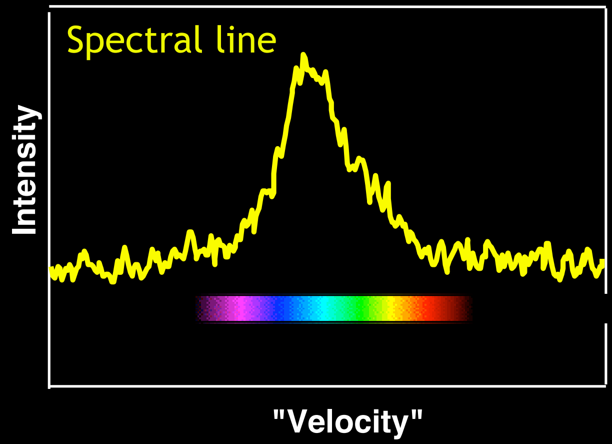
SIRTF--Space Infrared Telescope Facility (launched August 2003)

COMPLETE Survey--COordinated Molecular Probe Line Extinction Thermal Emission Survey

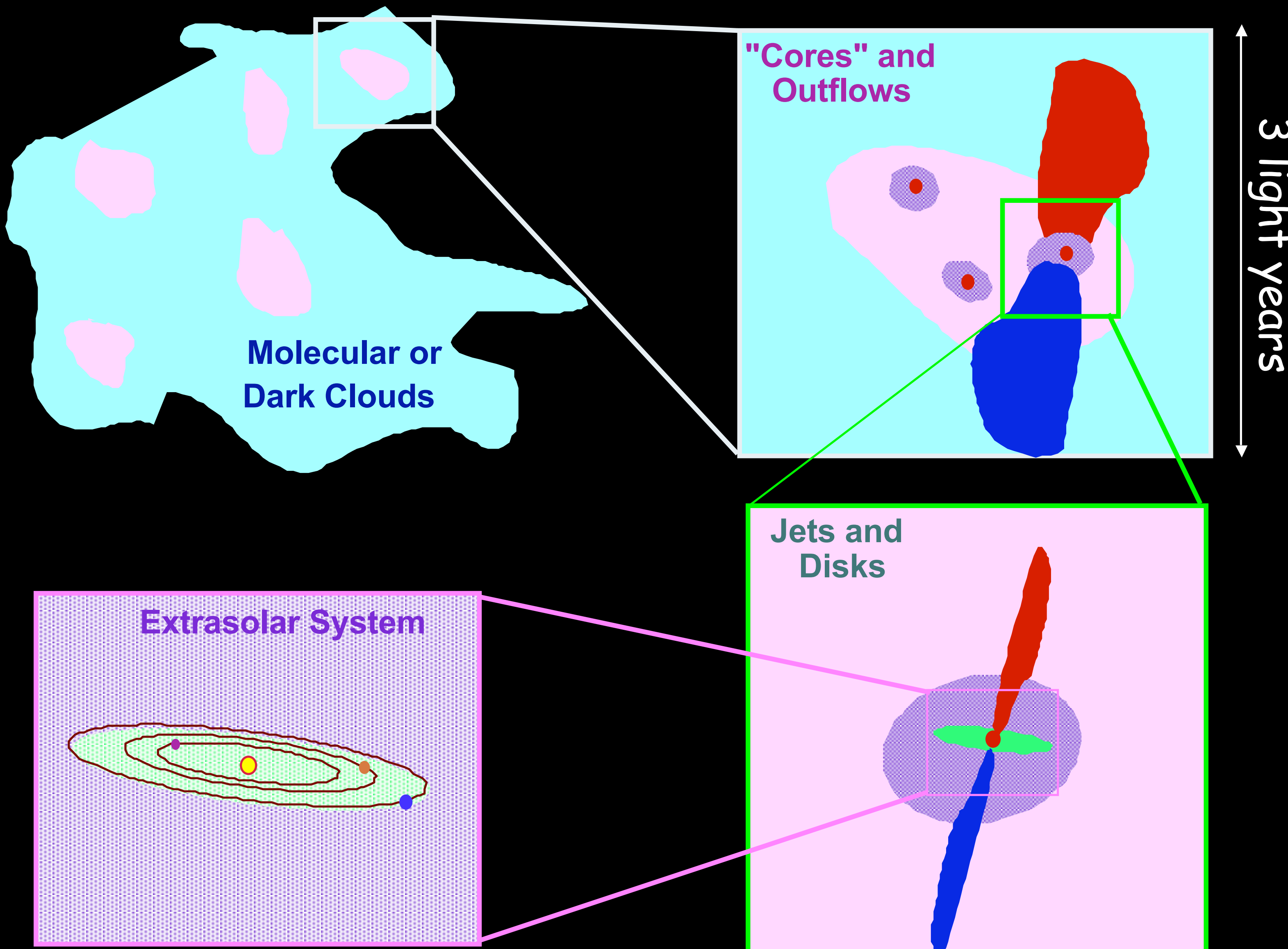
More info:cfa-www.harvard.edu/~agoodman





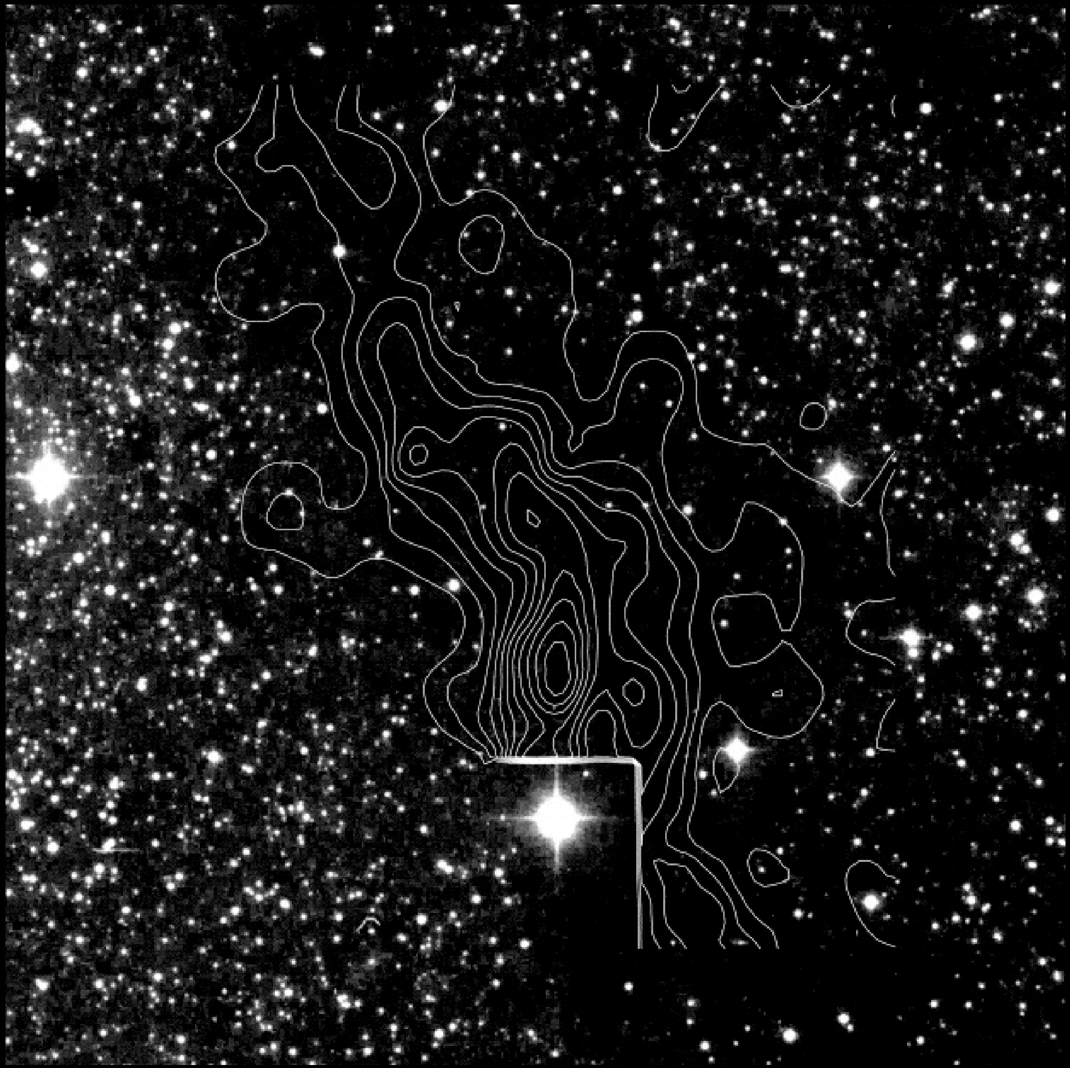


Star Formation Framework



How Dark=How Dense

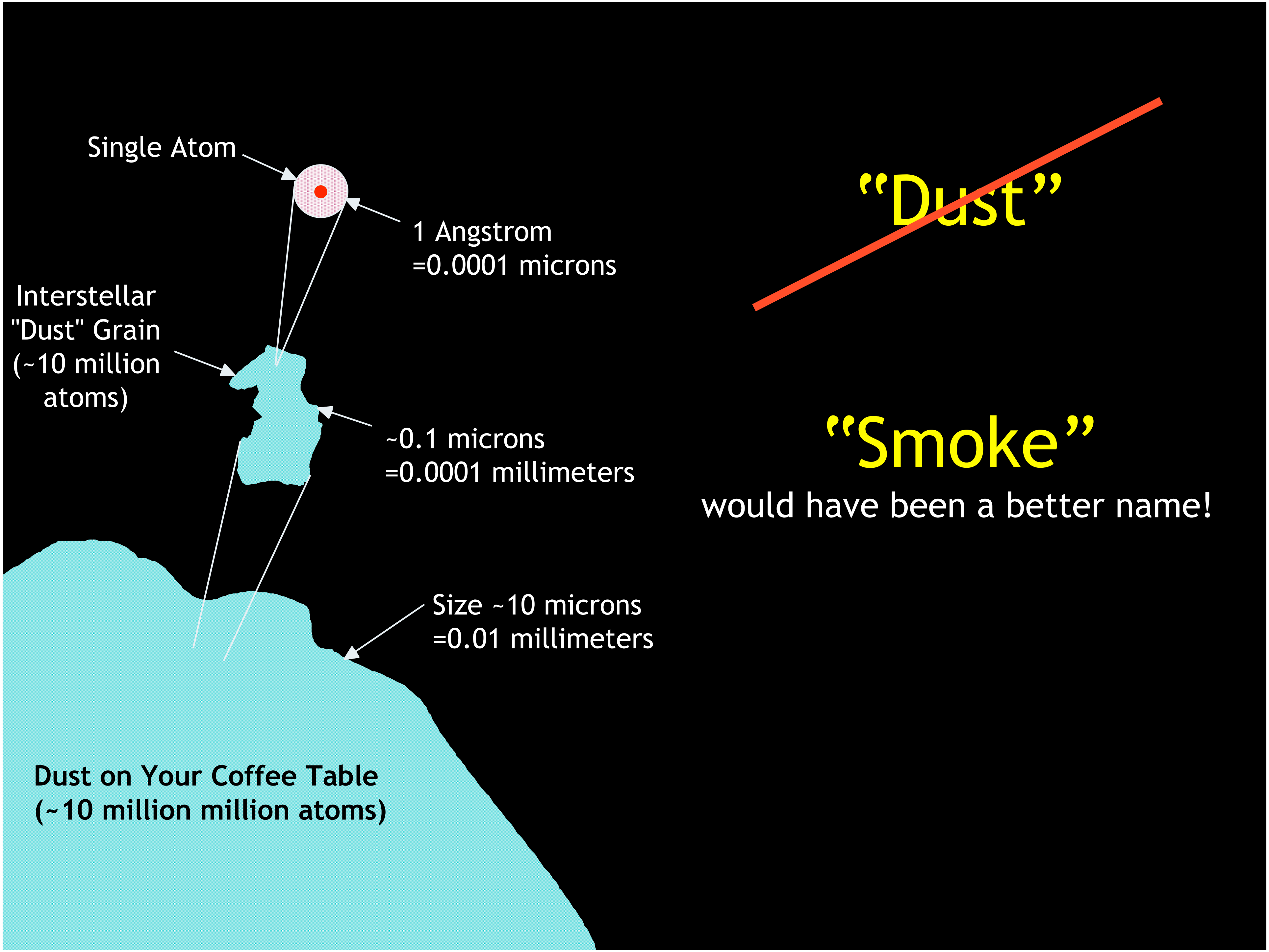
Counts of stars per unit area measure how much material must be producing obscuration, gives "extinction."



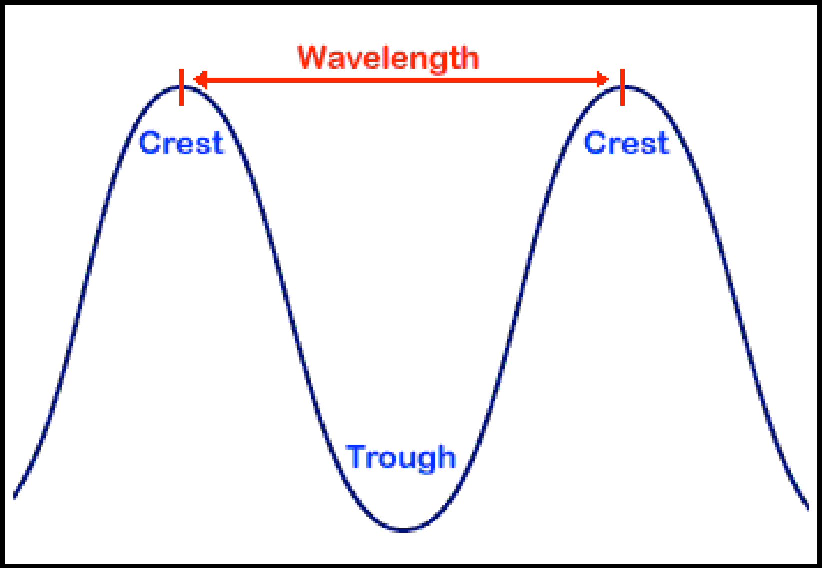
Observations by Alves, Lada & Lada 19

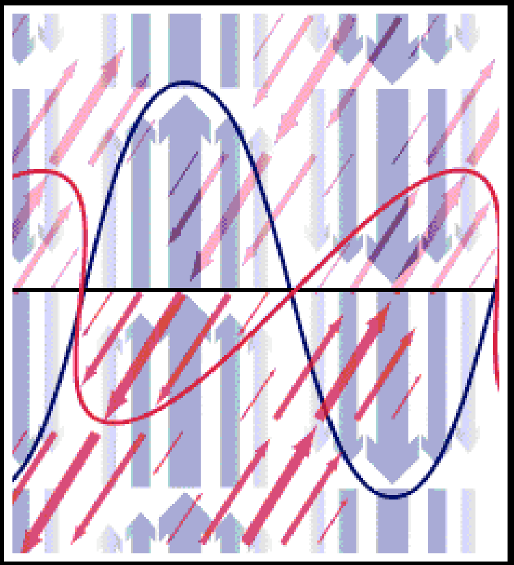
What's hidden in the dark?

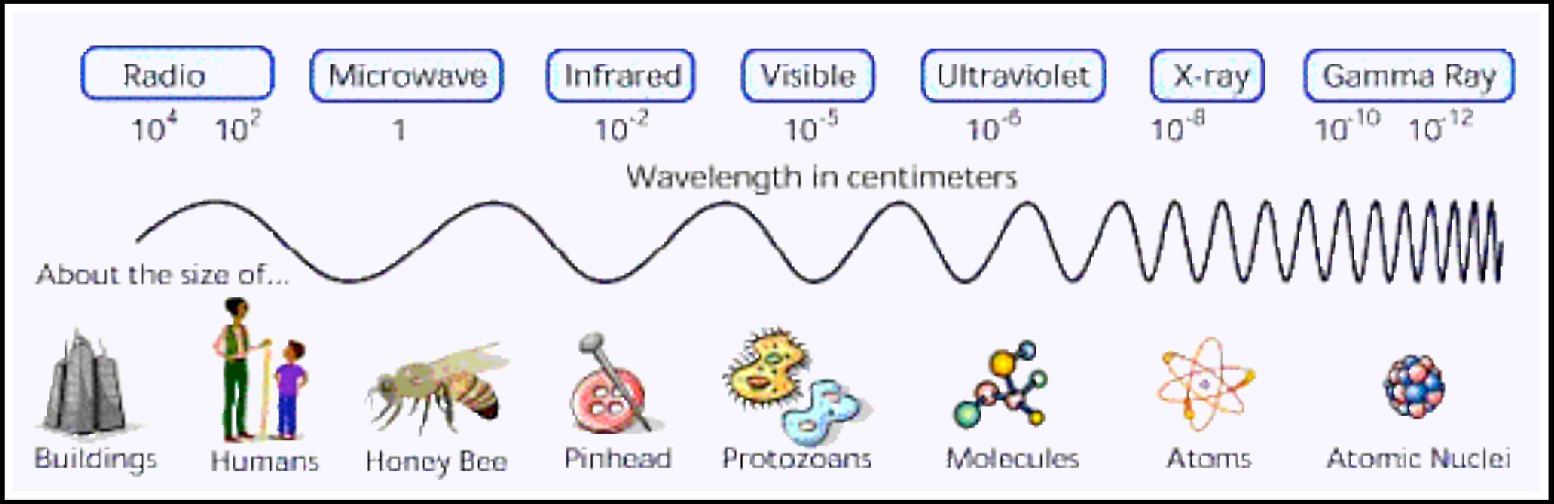
How can we see through the dusty veil?


Single Atom
1 Angstrom
=0.0001 microns
Interstellar
"Dust" Grain
(~10 million
atoms)
~0.1 microns
=0.0001 millimeters
Size ~10 microns
=0.01 millimeters
Dust on Your Coffee Table
(~10 million million atoms)
"Dust"
"Smoke"
would have been a better name!

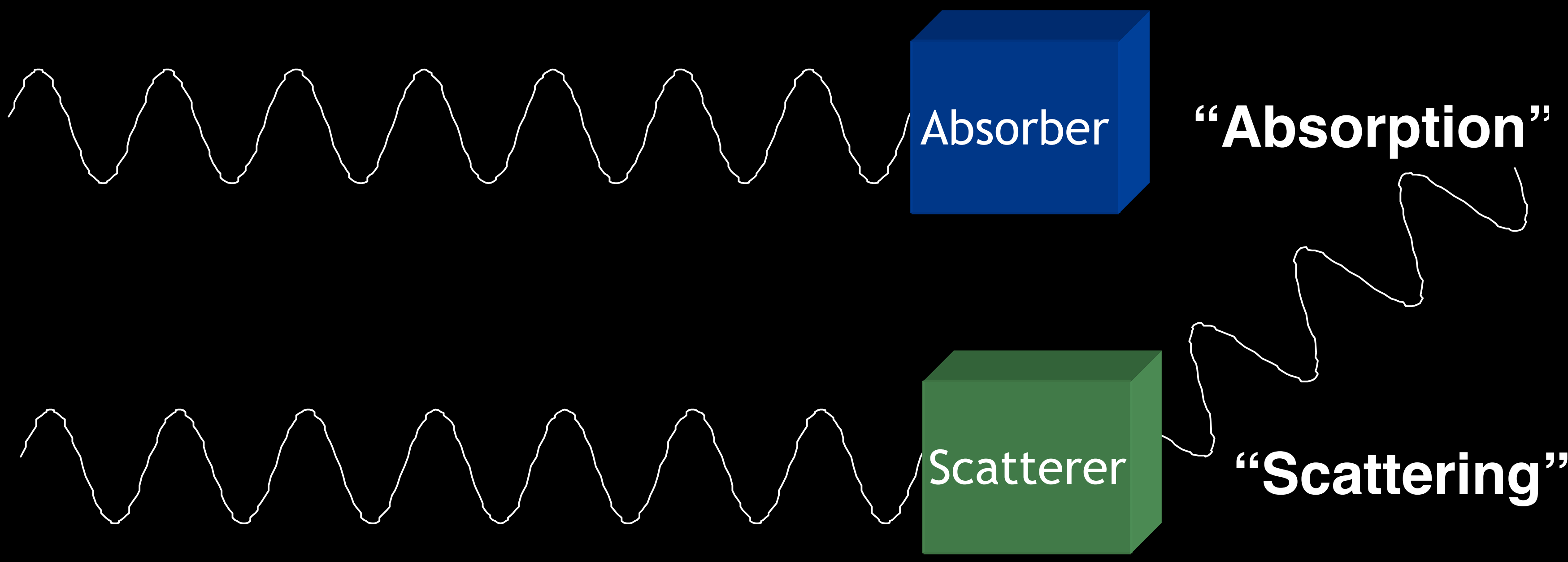
"Wavelength"


Wavelength
Crest
Crest
Trough

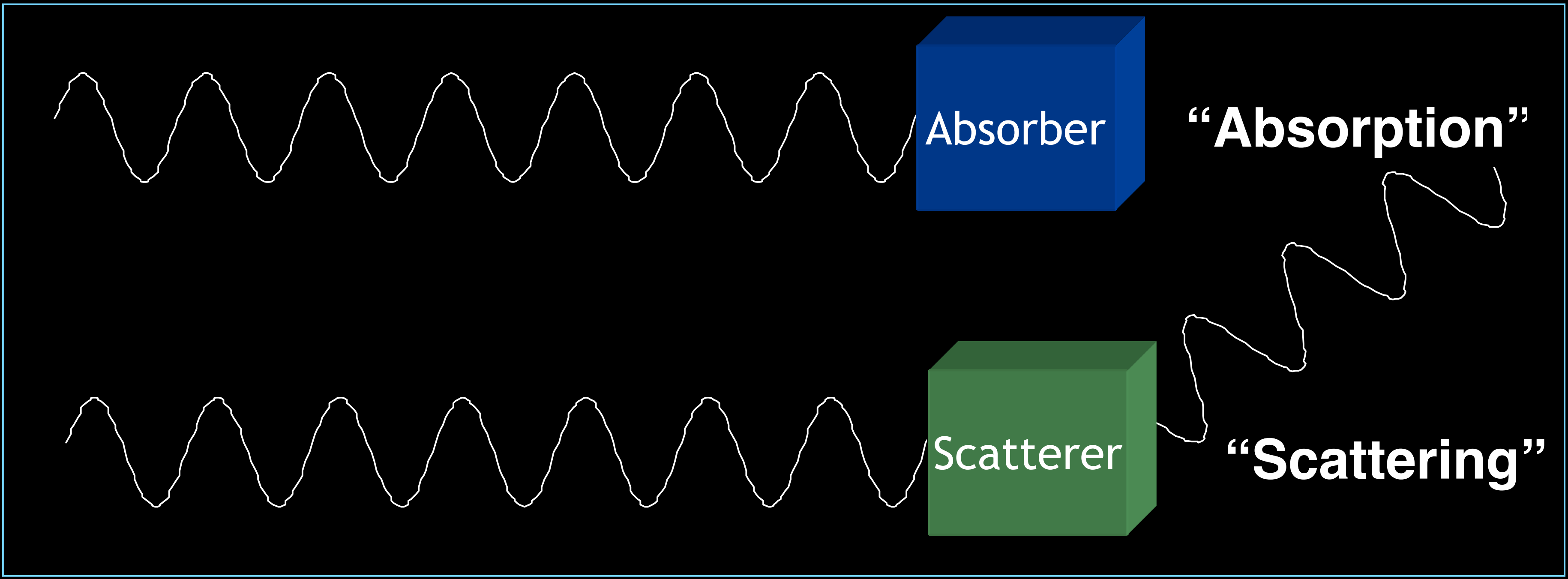



Radio
Microwave
Infrared
Visible
Ultraviolet
X-ray
Gamma Ray
10^4 10^2
1
10^-2
10^-5
10^-6
10^-8
10^-10 10^-12
Wavelength in centimeters
About the size of...
Buildings
Humans
Honey Bee
Pinhead
Protozoans
Molecules
Atoms
Atomic Nuclei

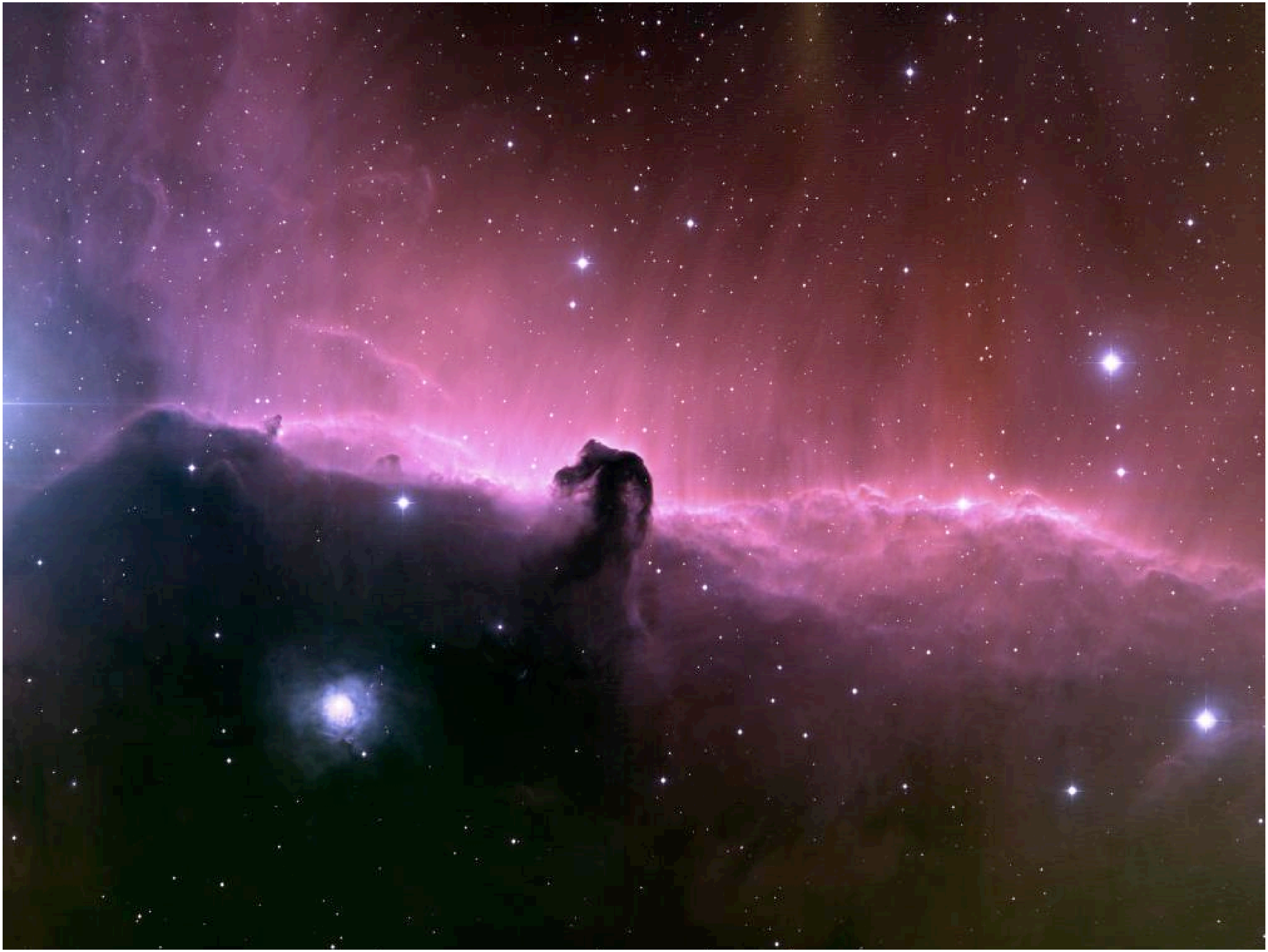
Quick Tutorial:
Absorption, Scattering & Emission



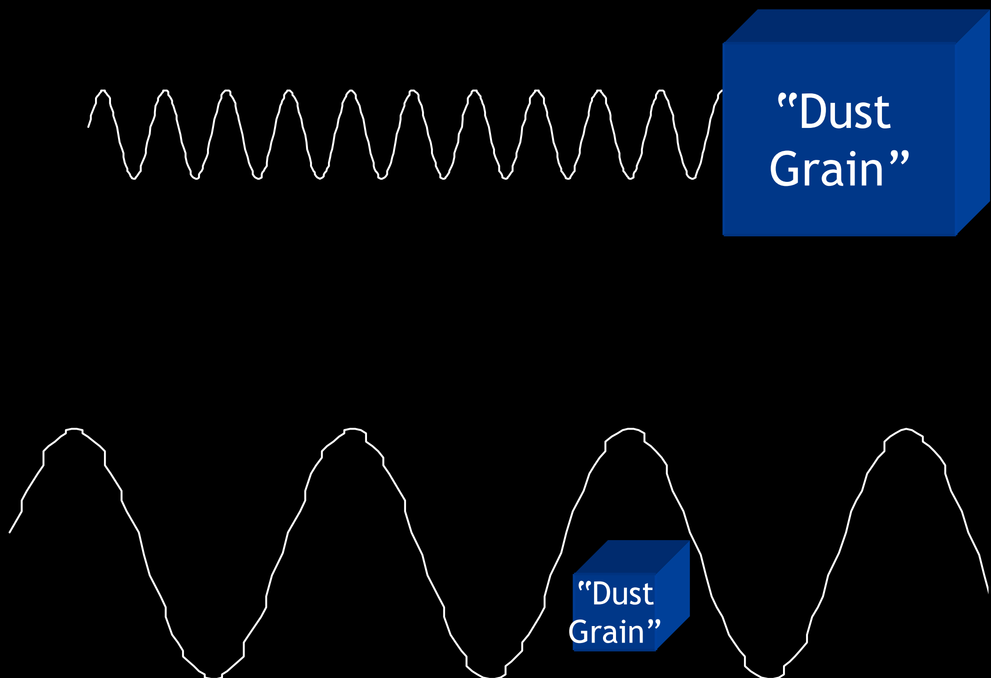
“Extinction” = Absorption + Scattering



Any photon that would have otherwise reached you but doesn’t is “extinguished.”



Advanced (but key) Tutorial:
"Wavelength Dependence of Extinction"
(a.k.a. How we see through the dusty veil.)



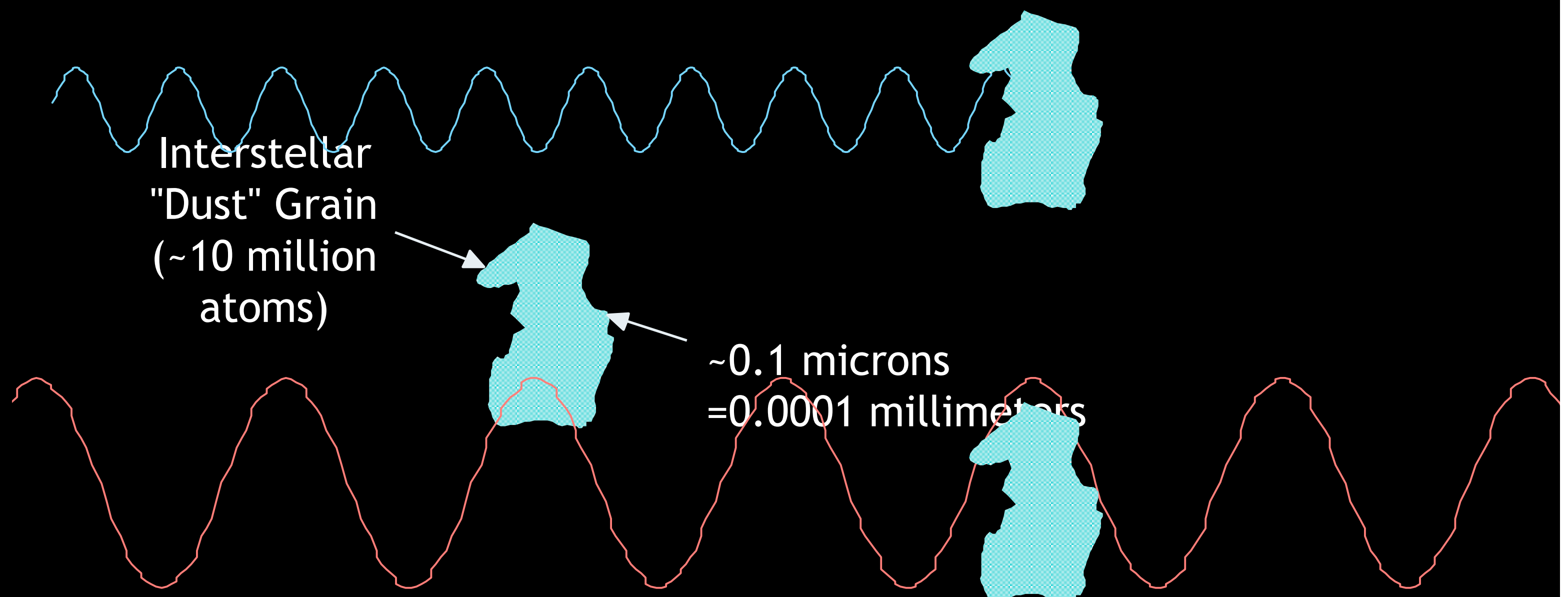
Light is "Extinguished" & Does not Reach Us

Light Goes Right by & Reaches Us

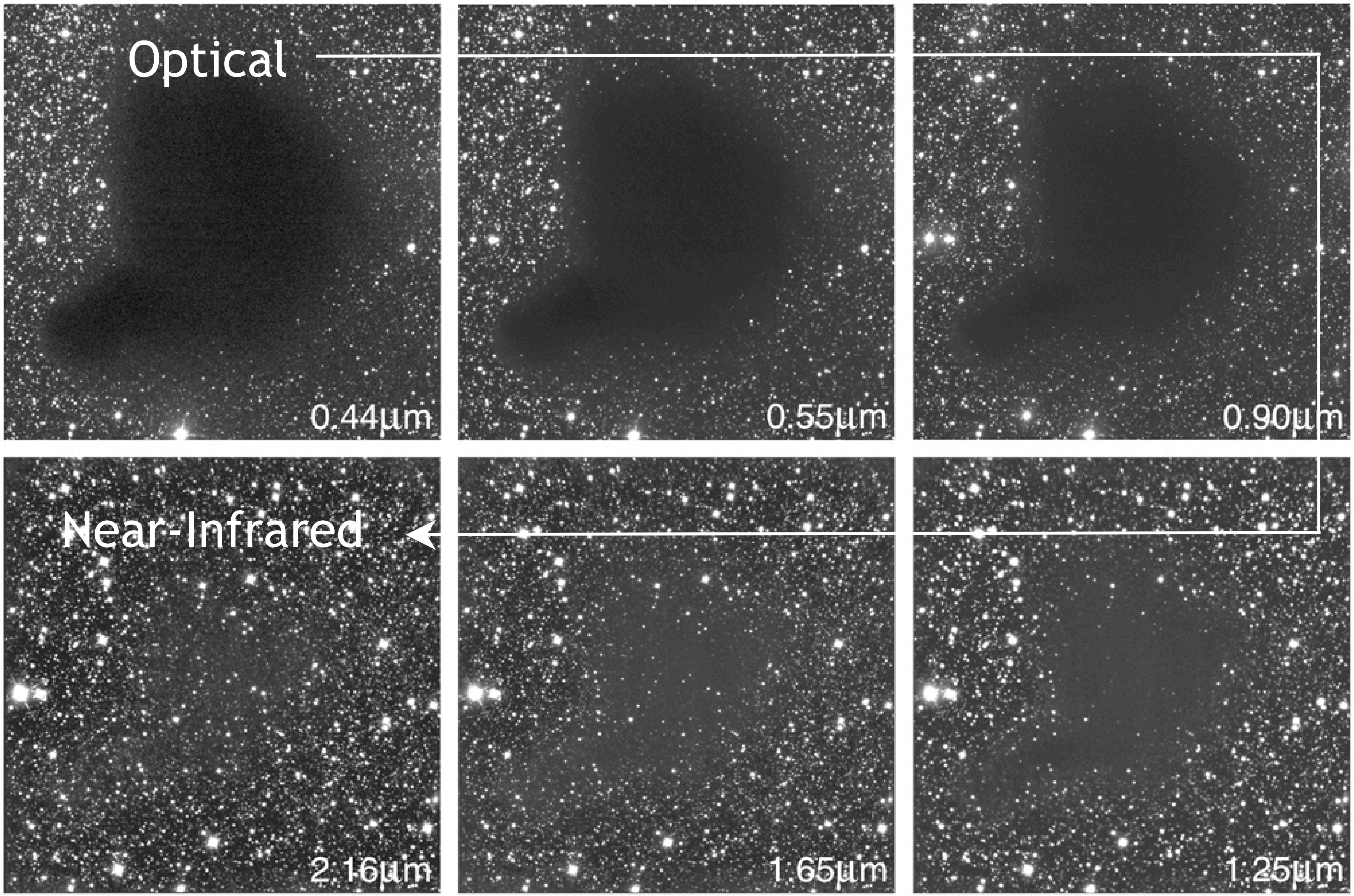
The Secret to "Lifting the Dusty Veil"...

Observe at a Wavelength LARGER than the Typical Dust Grain!

<0.1 μm, a.k.a. "Optical" = BAD



>0.1 mm, a.k.a. "(Near) Infrared" = GOOD



The Dark Cloud B68 at Different Wavelengths (NTT + SOFI)

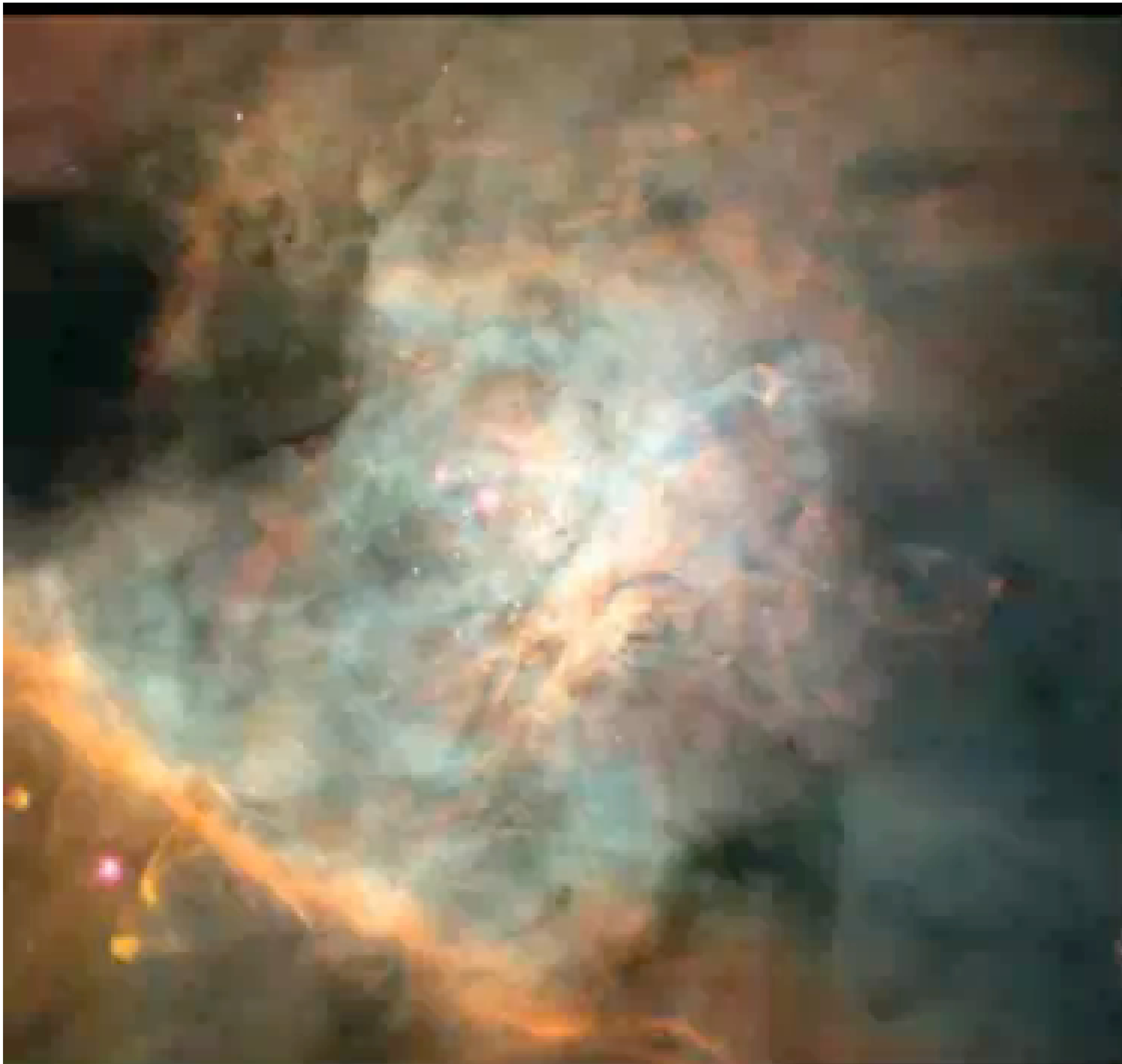
ESO PR Photo 29b/99 (2 July 1999)

"With these images, we are lifting the dusty veil of secrecy from star birth and star death."

--attributed by CNN on 5/12/97, to Rodger Thompson, Chief Scientist for Hubble's Near-Infrared Camera and Multi-Object Spectrometer (NICMOS)

http://www.cnn.com/TECH/9705/12/hubble/

(narrated by Rodger Thompson)



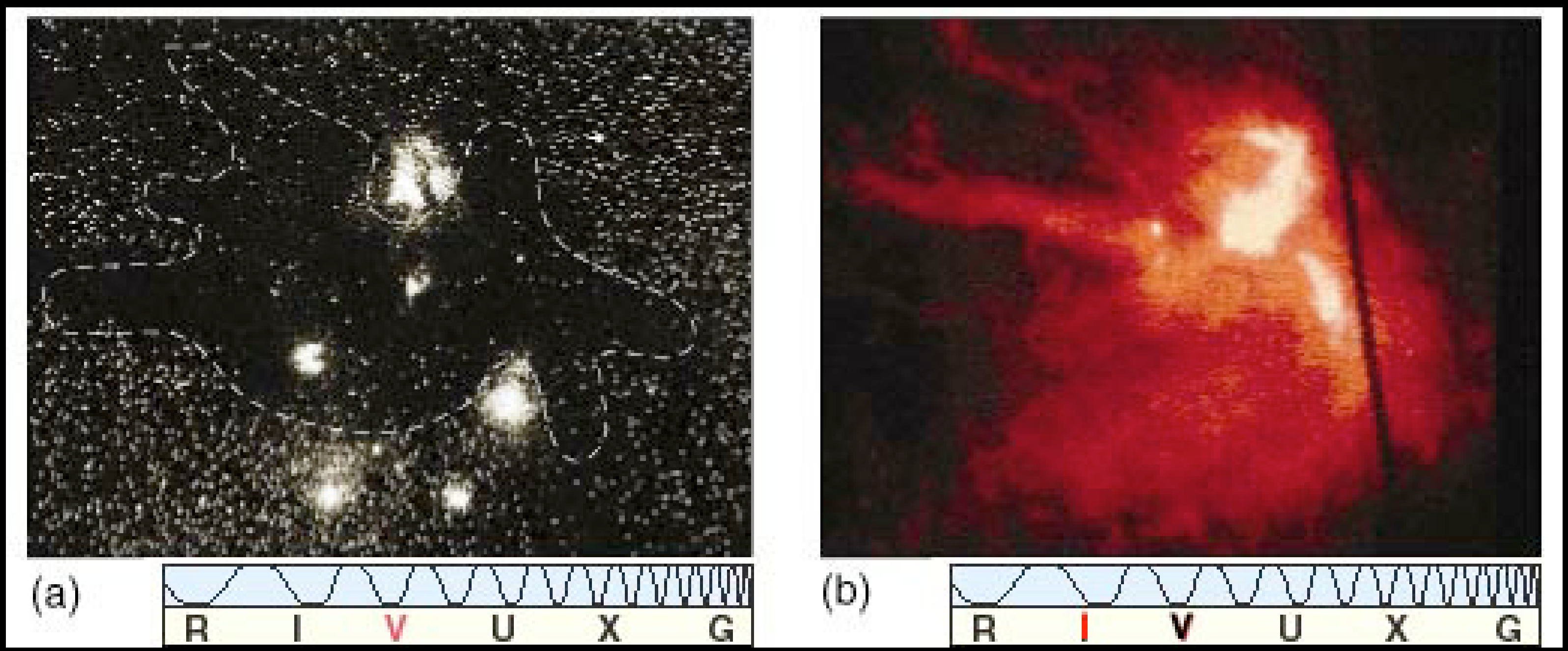
Optical image of Orion Nebula

“Lifting the Veil”

Means using near-IR imaging to see “embedded” sources otherwise shrouded from view.

These embedded sources are nearly all young and forming stars.

"The Veil" Emits, as well as Absorbs, Photons



Barnard's Optical Photograph of Ophiuchus

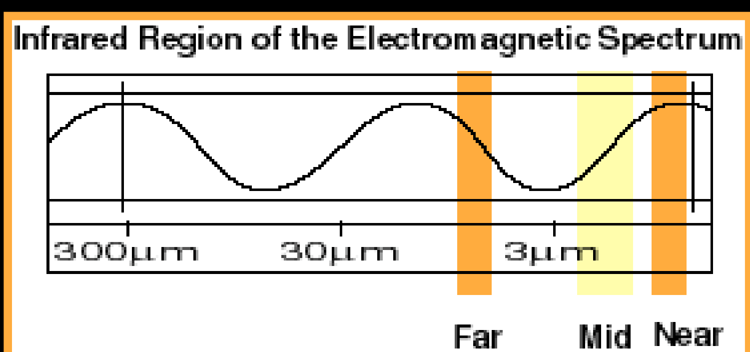
IRAS Satellite Observation, 1983

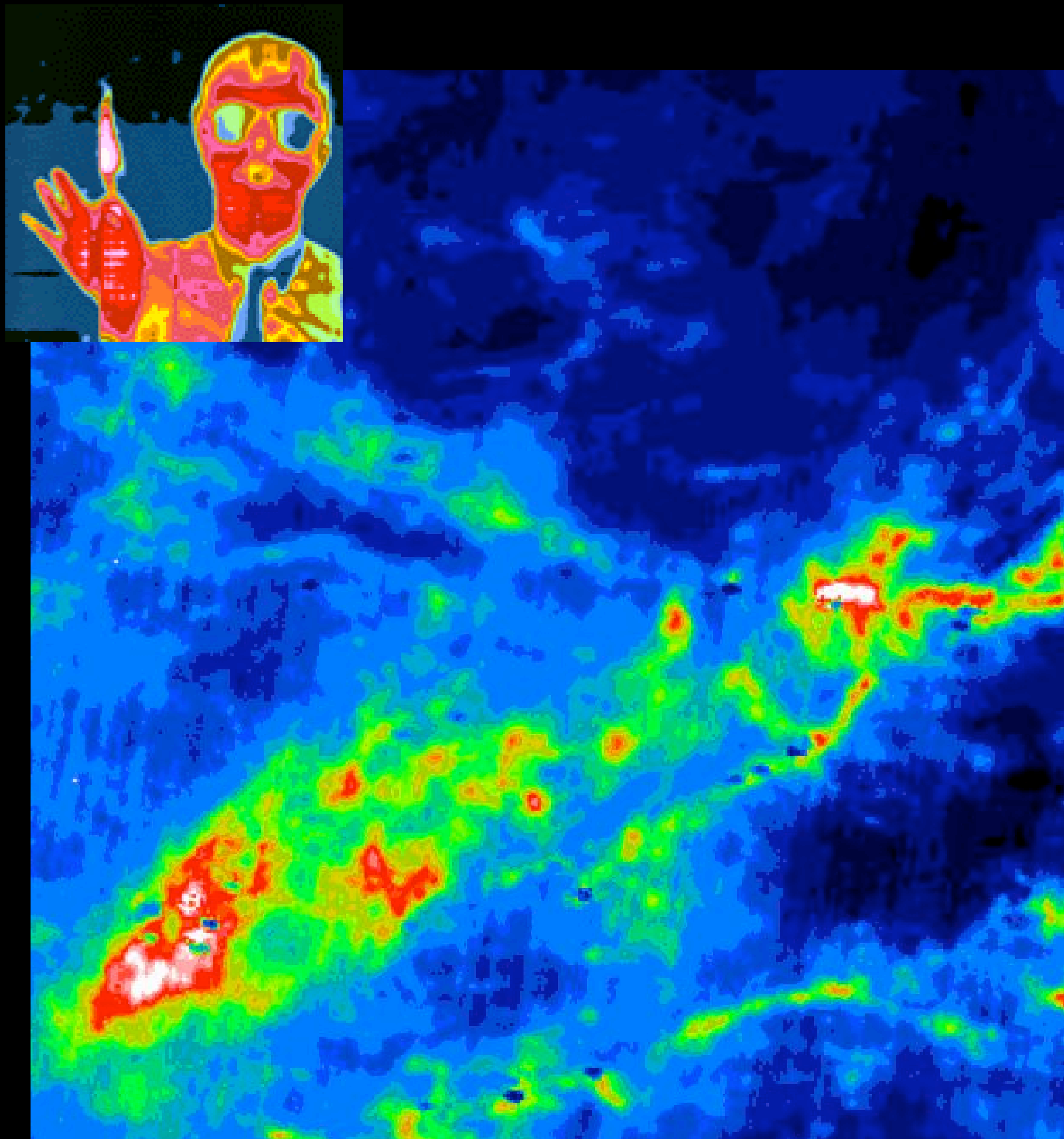
The dust in dark clouds glows most brightly at far-infrared wavelengths.

Optical image of Orion Constellation

Image courtesy Akira Fujii

Infrared Emission



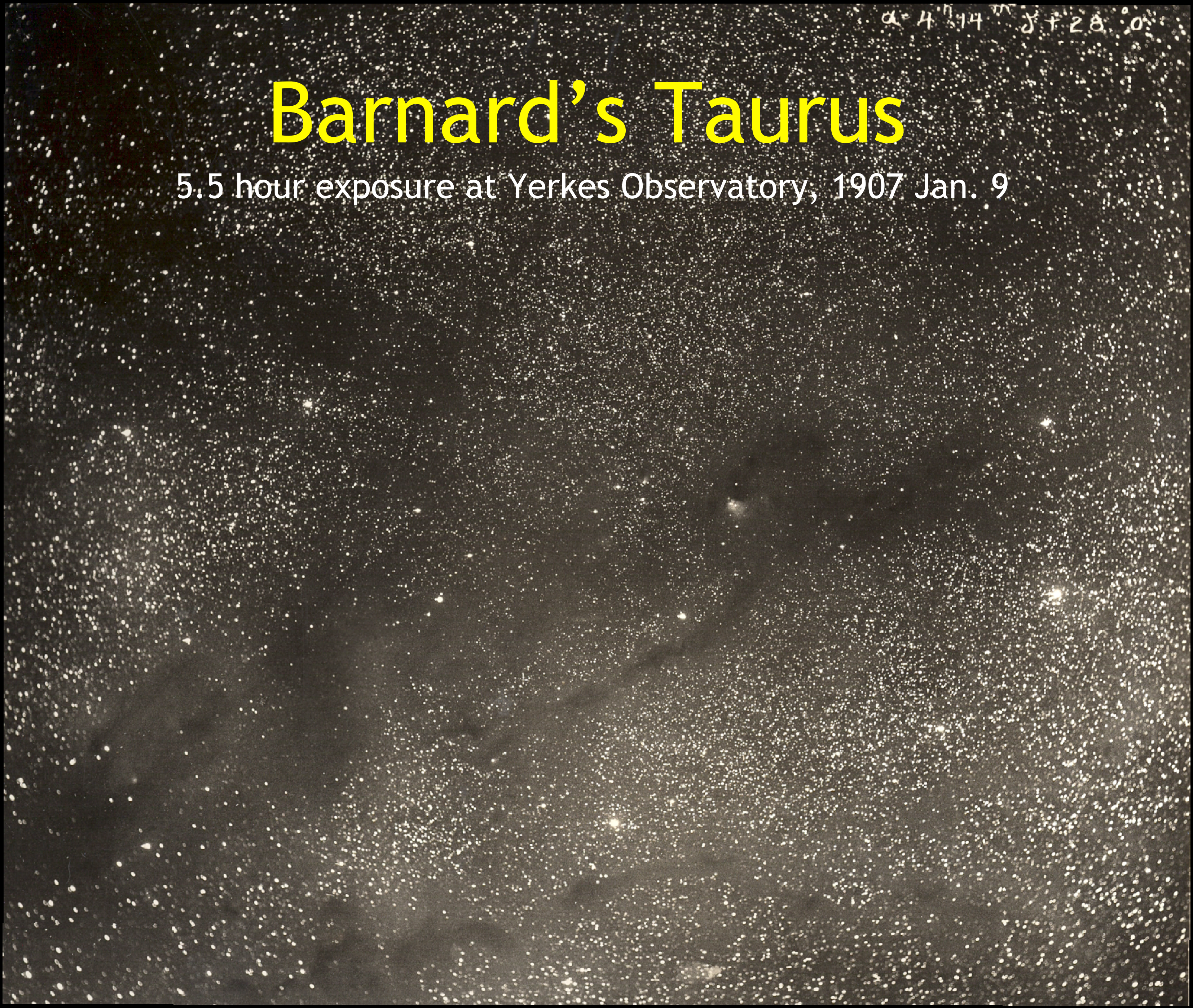


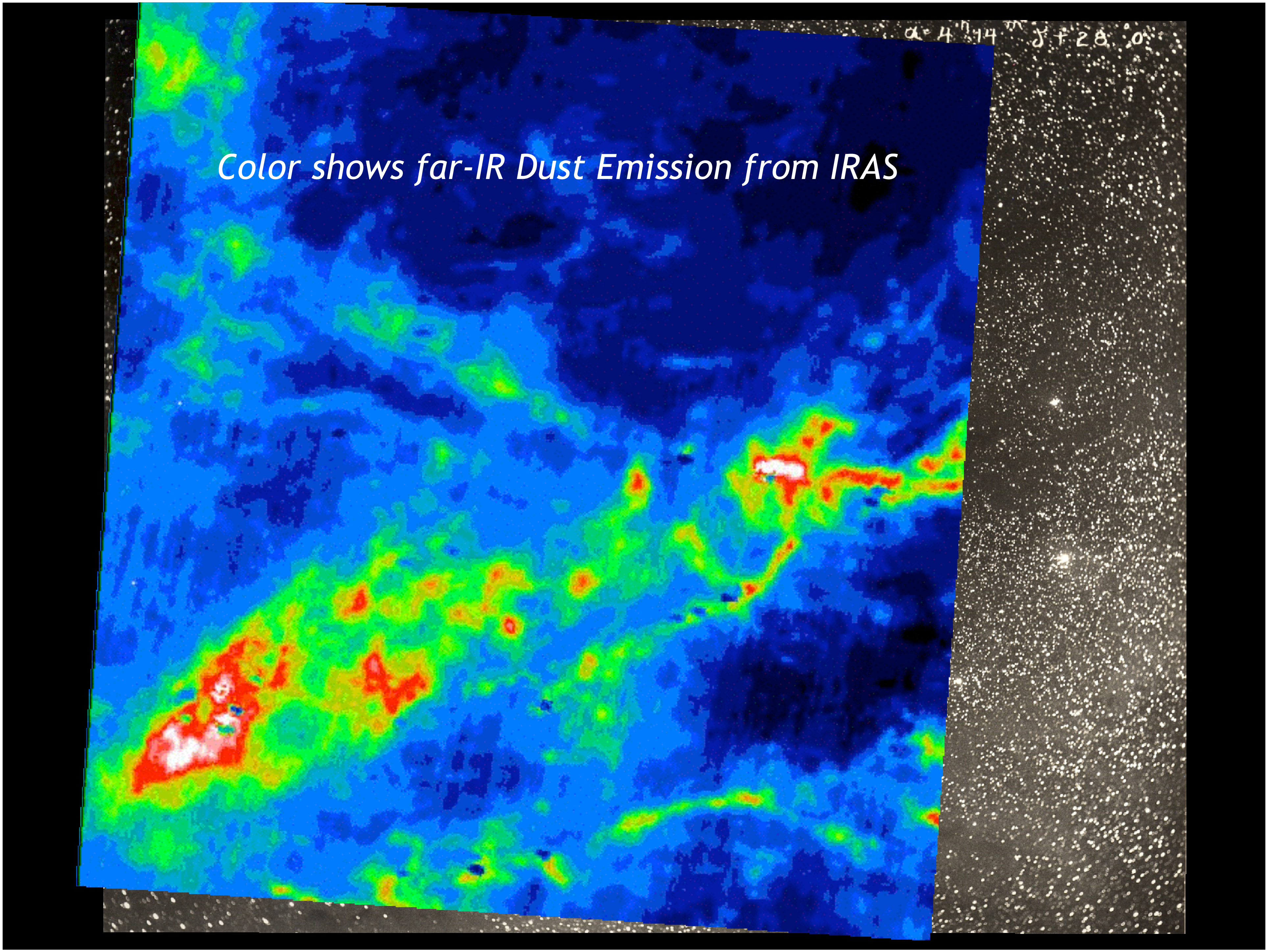
Taurus as seen by IRAS (Arce & Goodman 1999)

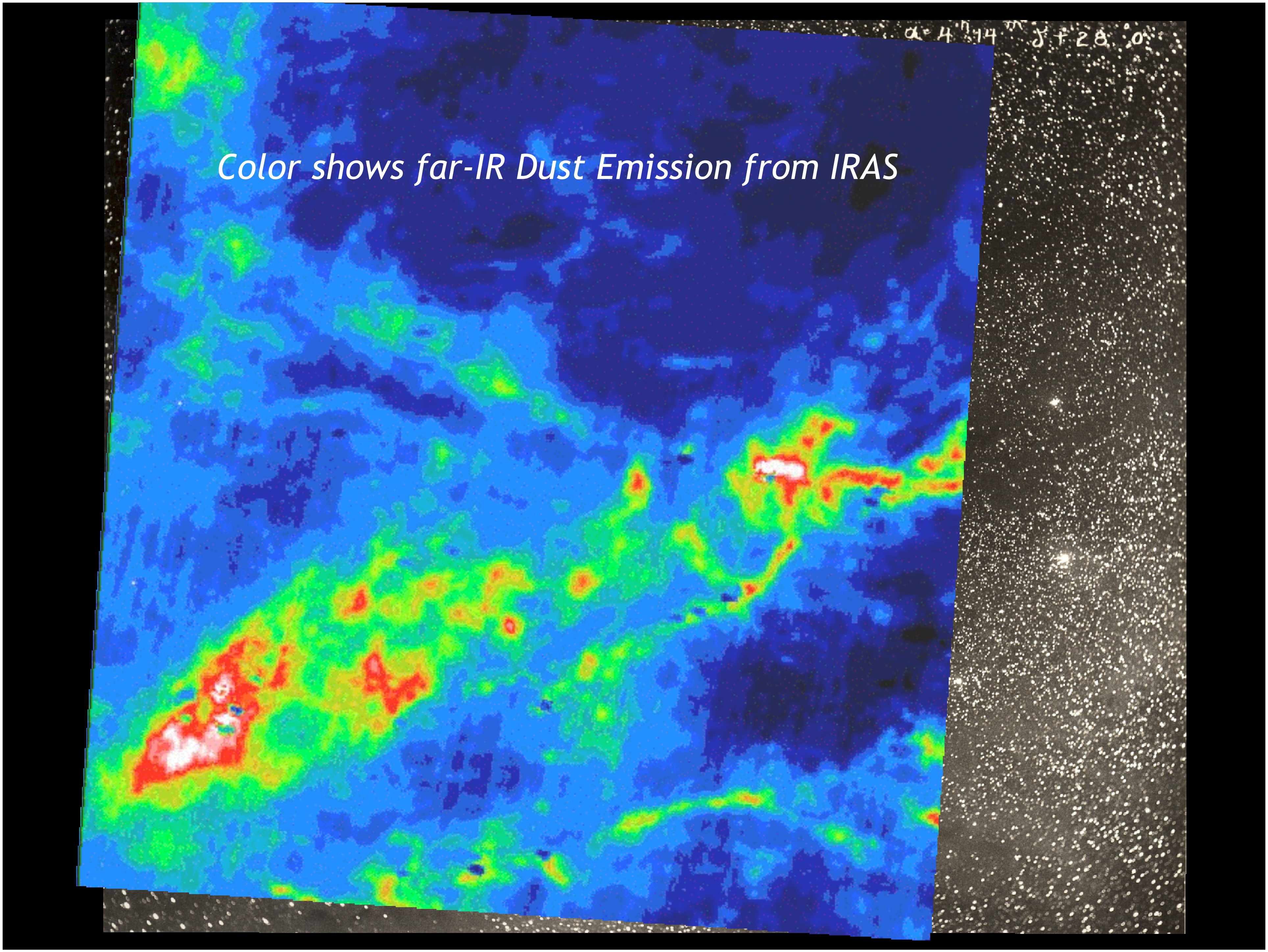
(Far) Infrared Emission from a Dark Cloud Complex

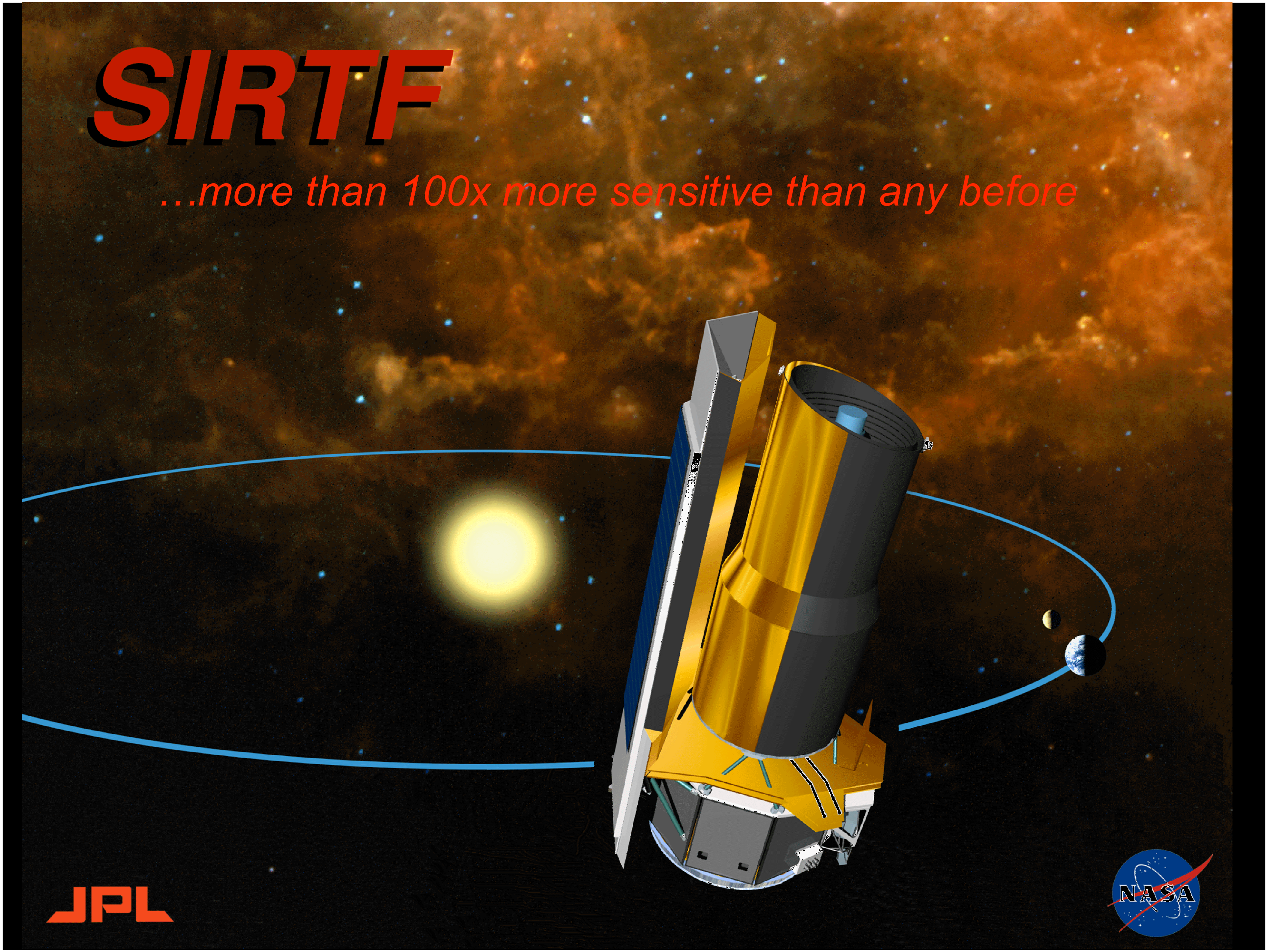
Barnard's Taurus

5.5 hour exposure at Yerkes Observatory, 1907 Jan. 9

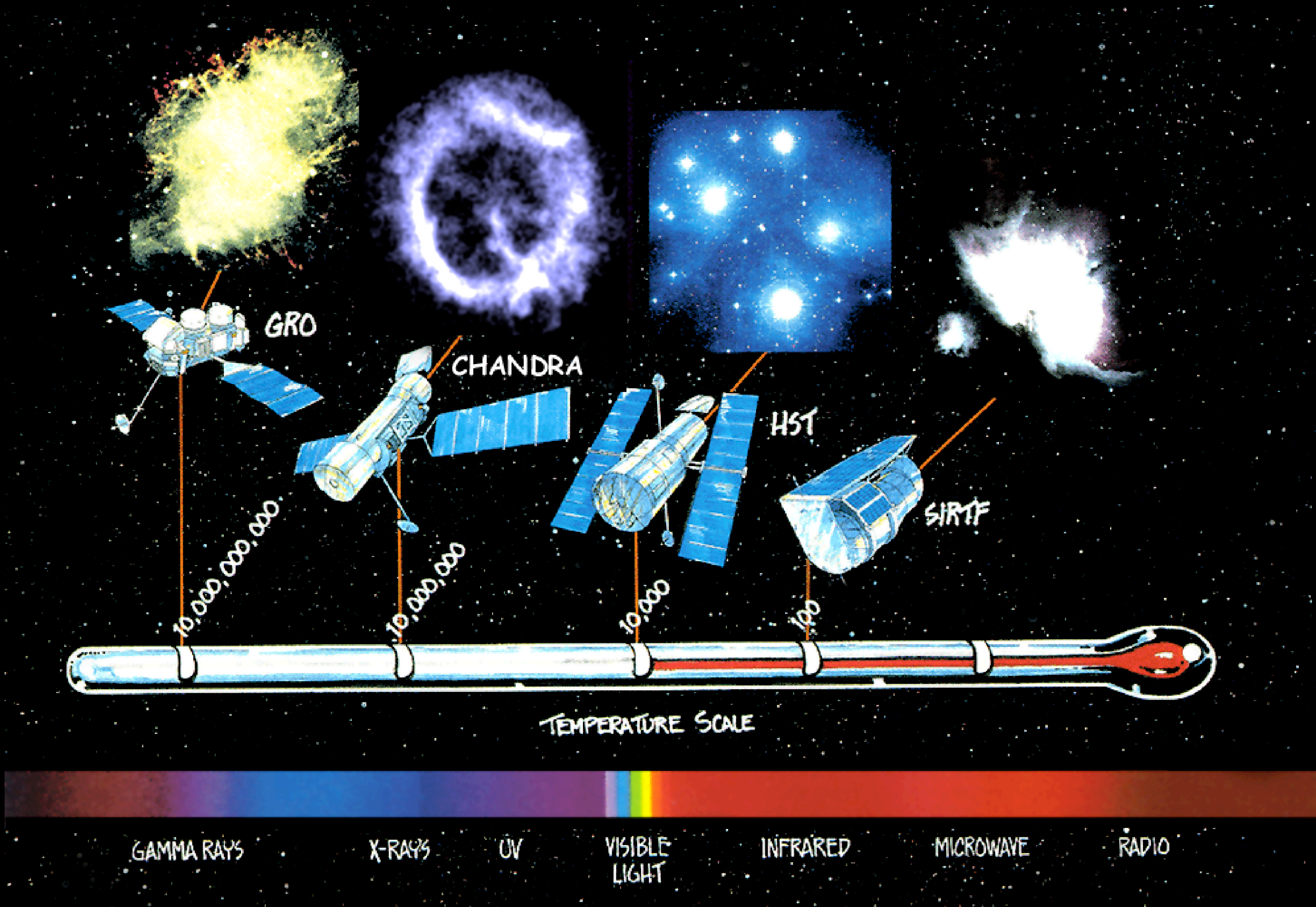



Color shows far-IR Dust Emission from IRAS


Color shows far-IR Dust Emission from IRAS


SIRTF
…more than 100x more sensitive than any before
JPL
NASA

NASA's Great Observatories



Quick Truths About Star Formation Research

We're (pretty) sure that…

Stars form in molecular clouds when pieces of the cloud get dense enough to collapse under their own weight (self-gravity).

We're reasonably confident that…

Most stars form in big clusters, and that star formation in clusters is more complicated than relatively "isolated" star formation.

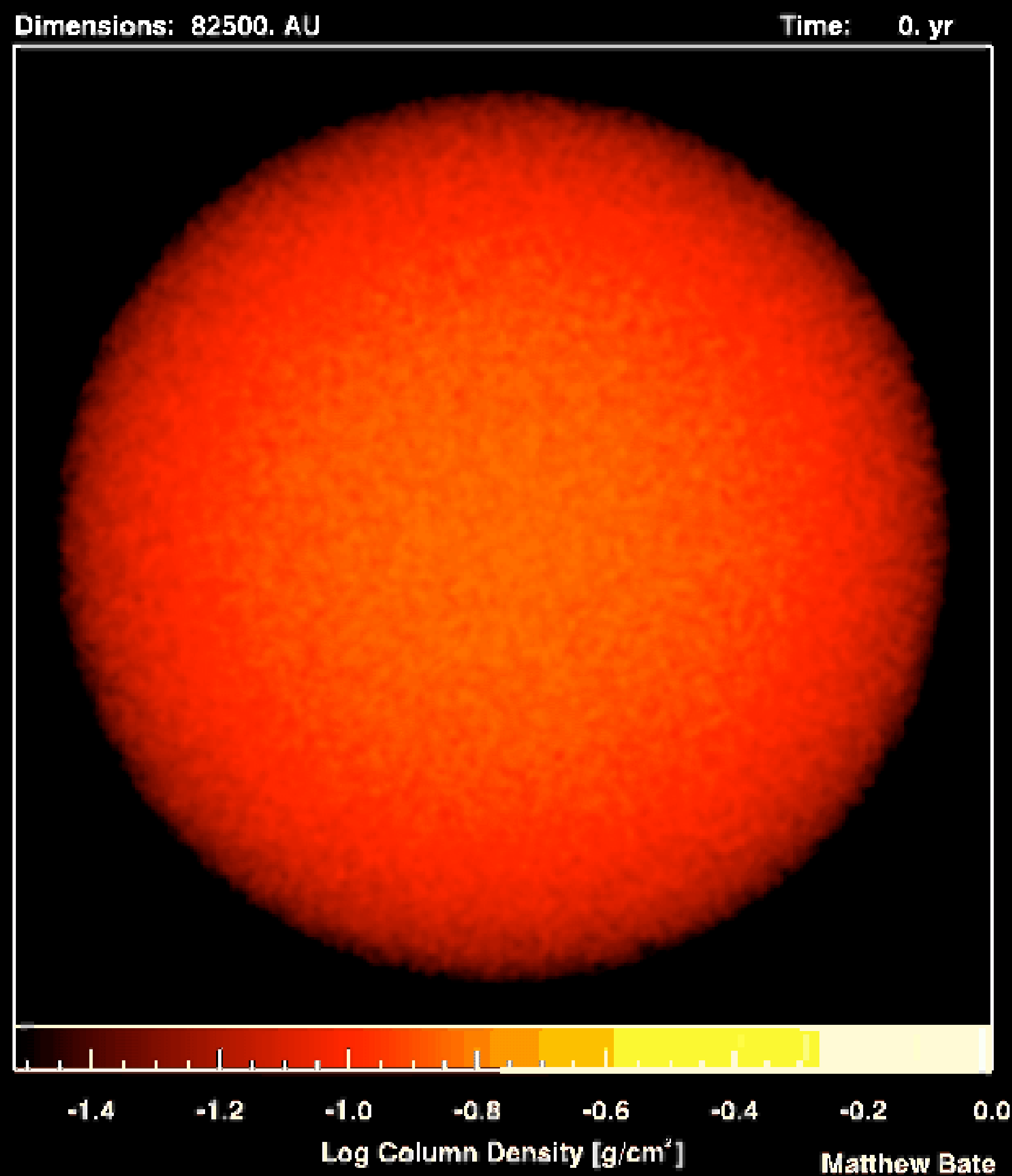
We're nearly clueless as to…

Exactly how star formation gets started & how long it takes under specific conditions.

Star Formation >>101

- MHD turbulence gives "t=0" conditions; Jeans mass=1 M_{sun}
- 50 M_{sun}, **0.38 pc**, $n_{avg}=3 \times 10^5$ ptcls/cc
- forms ~50 objects
- T=10 K
- SPH, no B or [?], [?]
- movie=1.4 free-fall times

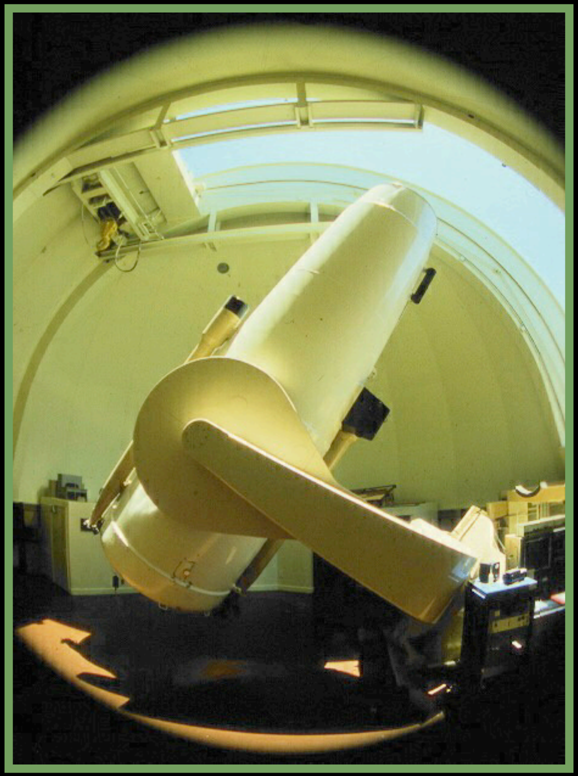
Bate, Bonnell & Bromm 2002



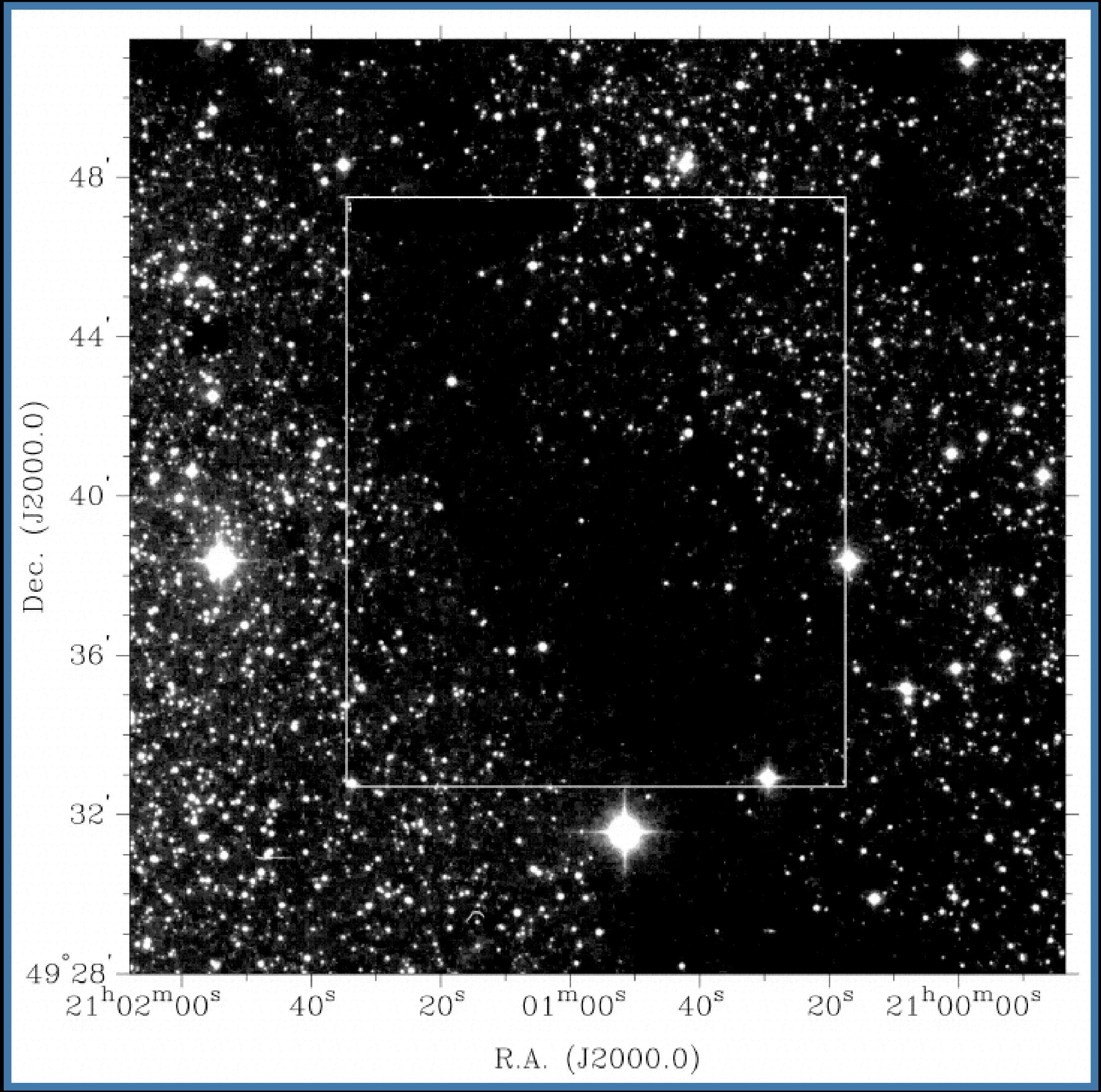
The
COordinated

Extinction
Thermal
Emission
Survey

How do *Molecular Probe Lines* Relate to this Image?

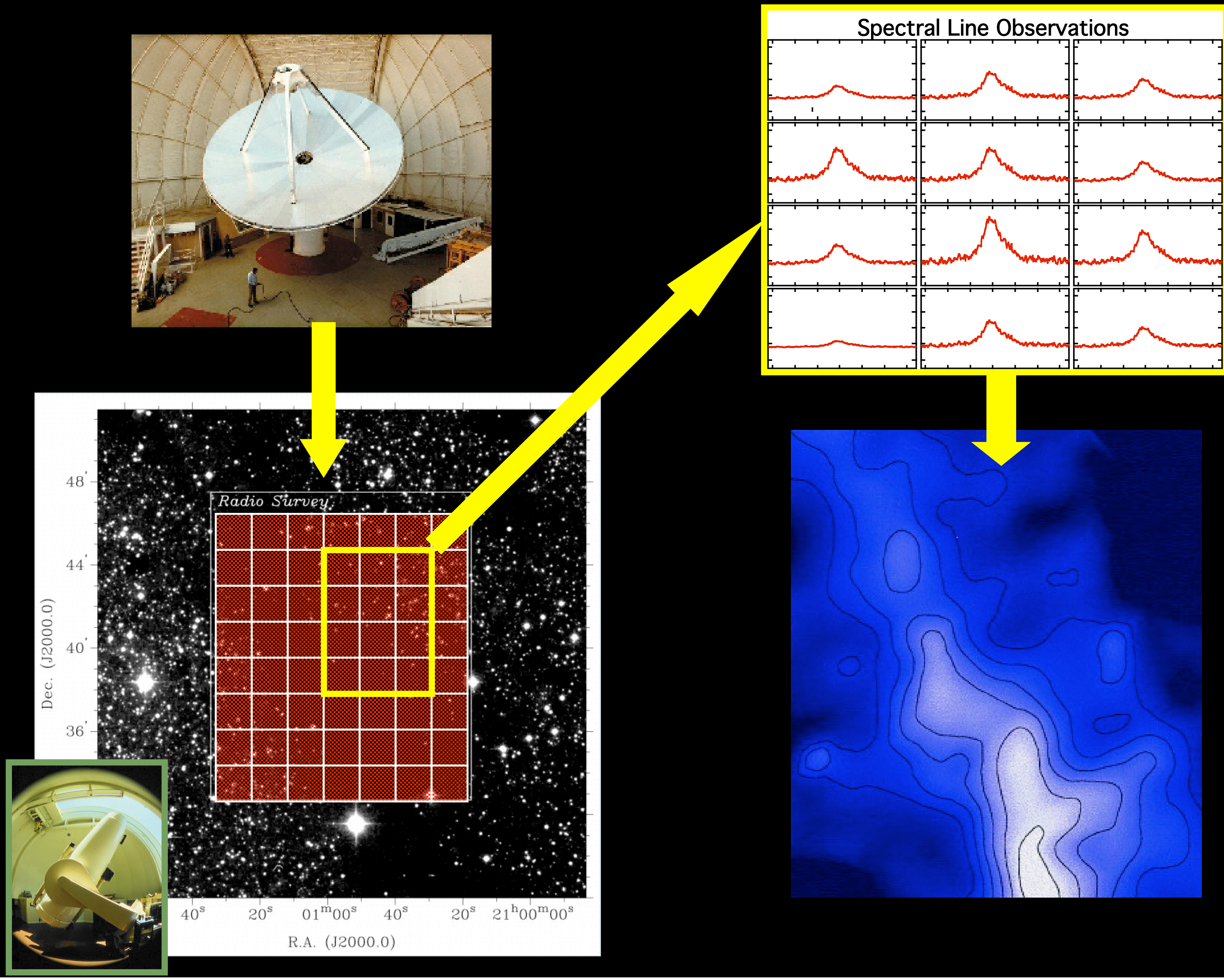


The Oschin telescope, 48-inch aperture wide-field Schmidt camera at Palomar

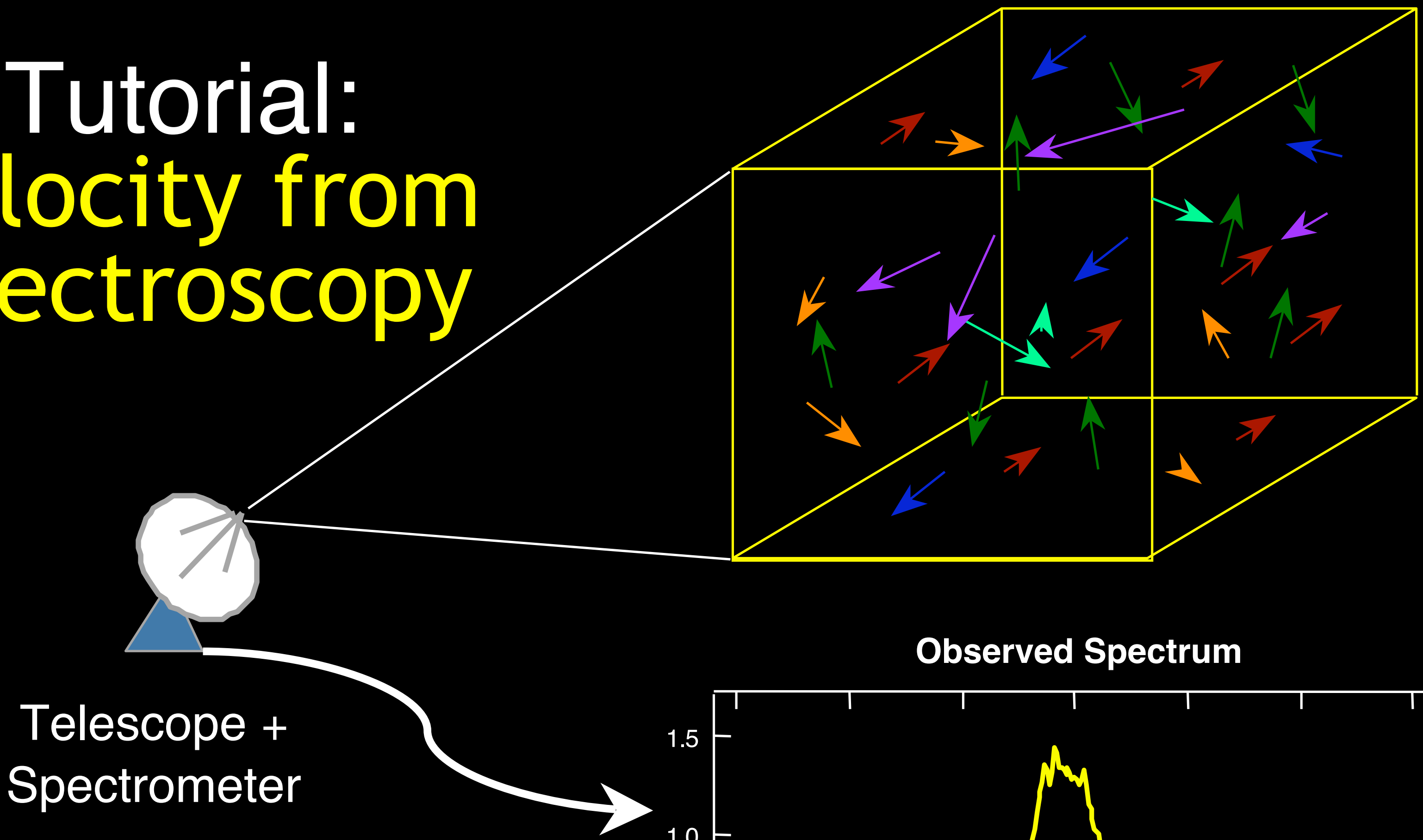


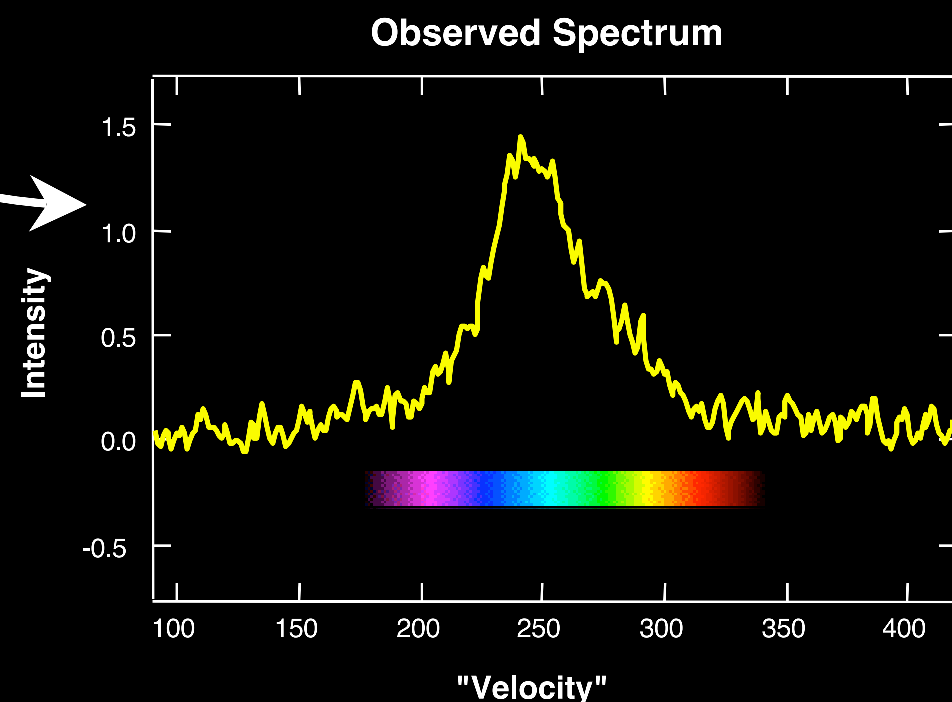
Red Plate, Digitized Palomar Observatory Sky Survey

What's a "Molecular Line Map"?

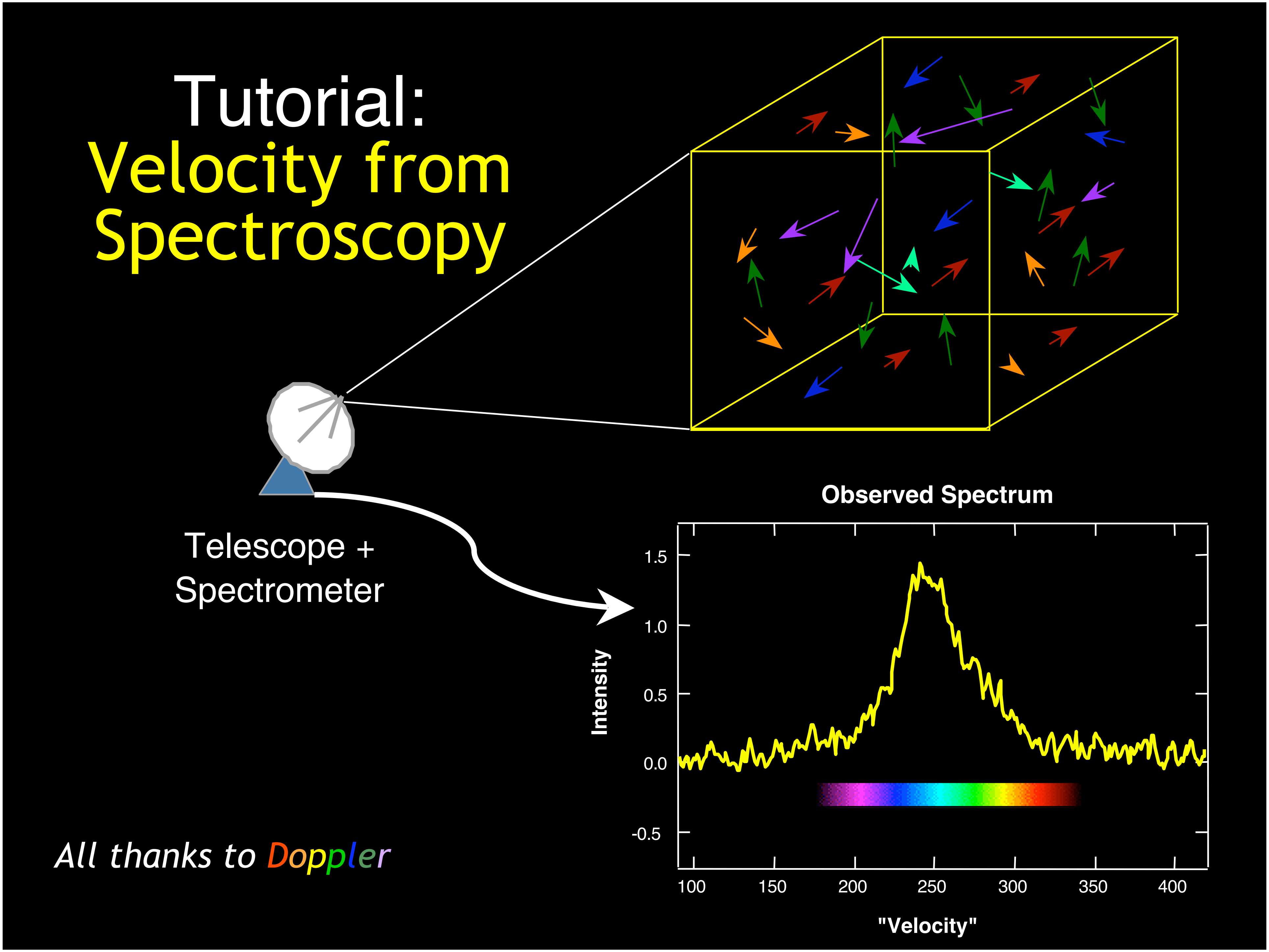


Tutorial:
Velocity from Spectroscopy

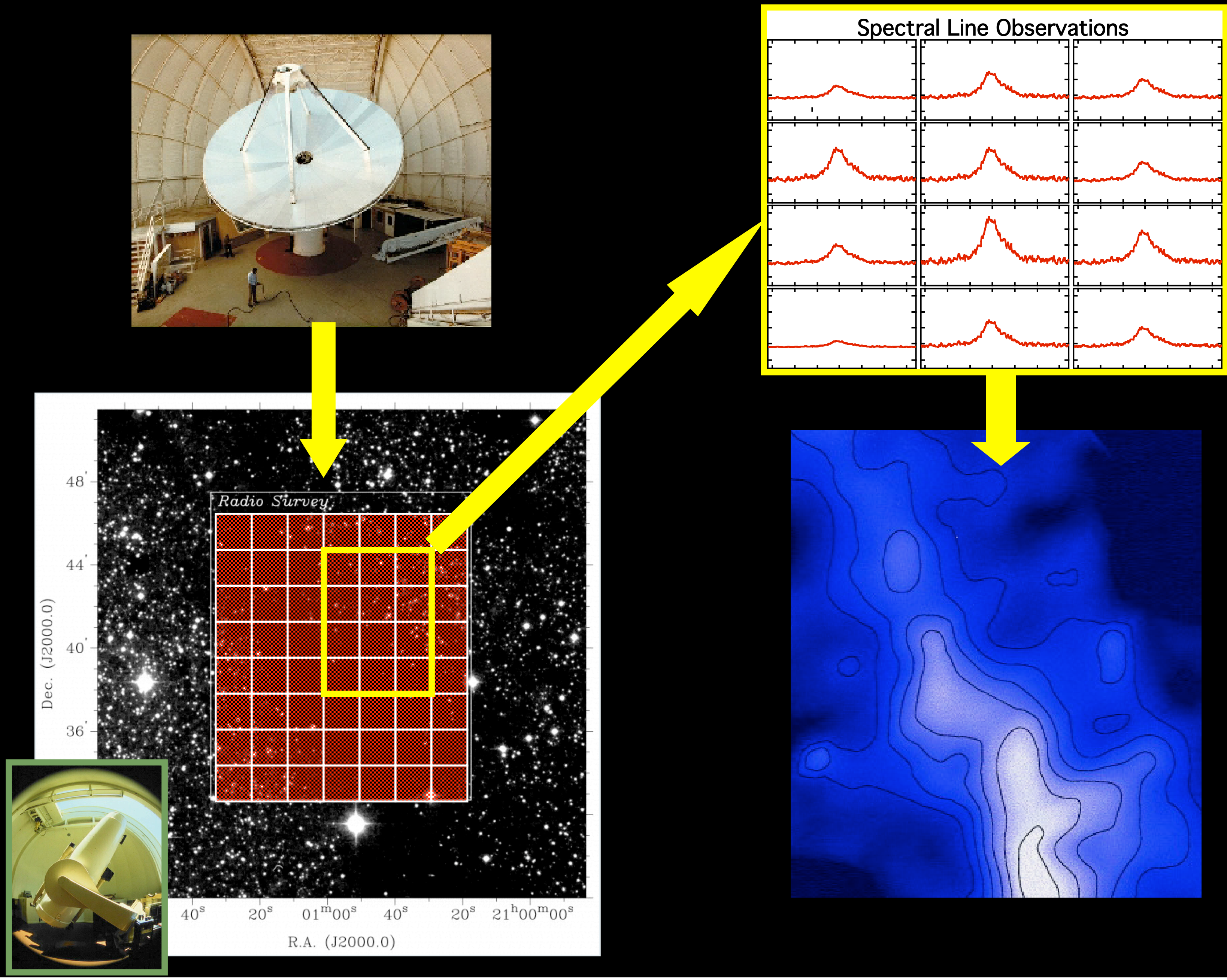




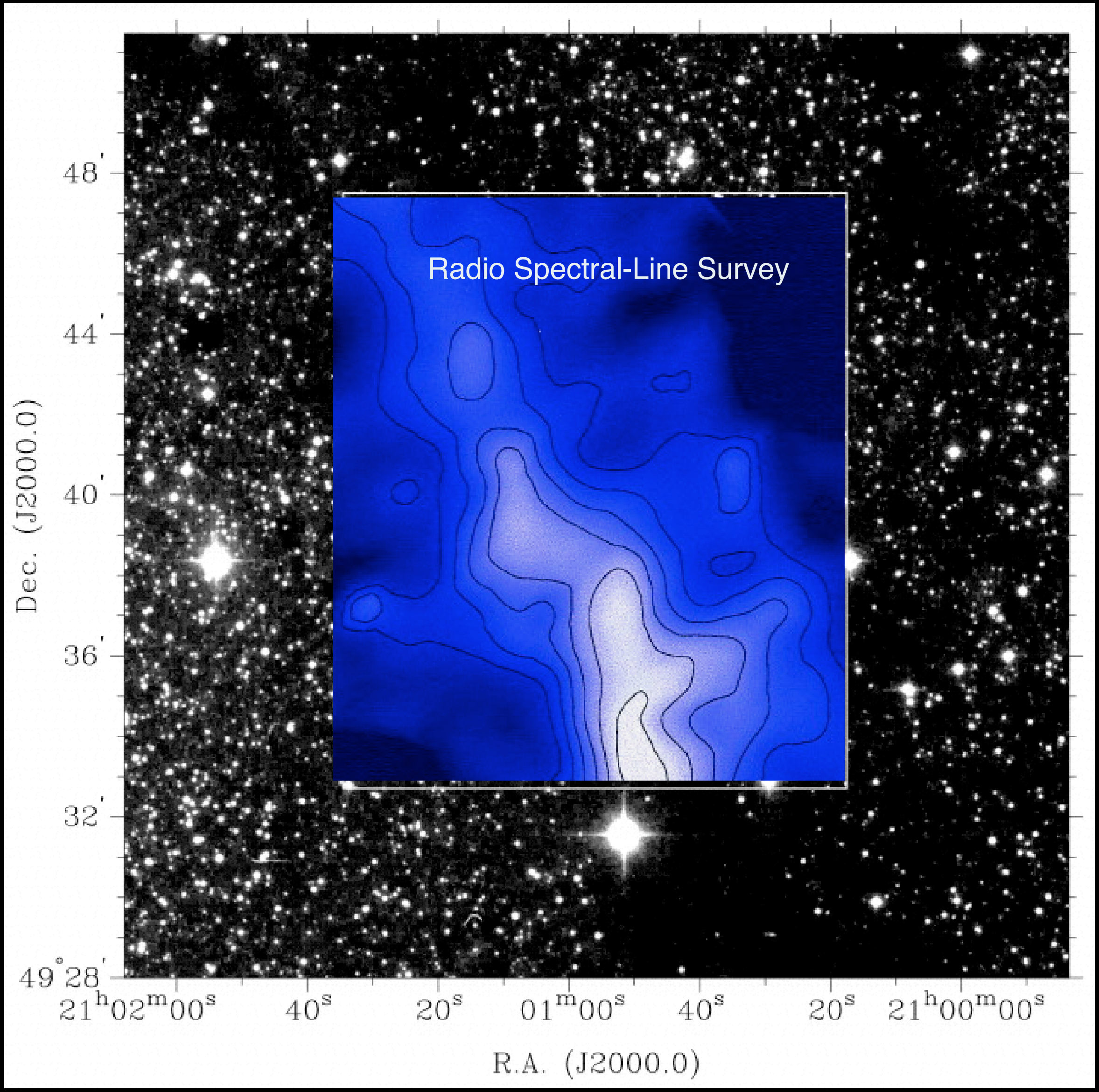
All thanks to Doppler


Tutorial:
Velocity from Spectroscopy
Telescope + Spectrometer
Observed Spectrum
Intensity
1.5
1.0
0.5
0.0
-0.5
100
150
200
250
300
350
400
"Velocity"
All thanks to Doppler

Radio Spectral-line Observations of Interstellar Clouds



Radio Spectral-line Observations of Interstellar Clouds

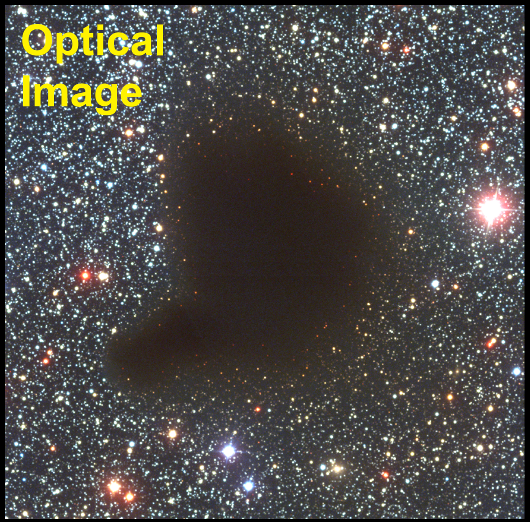


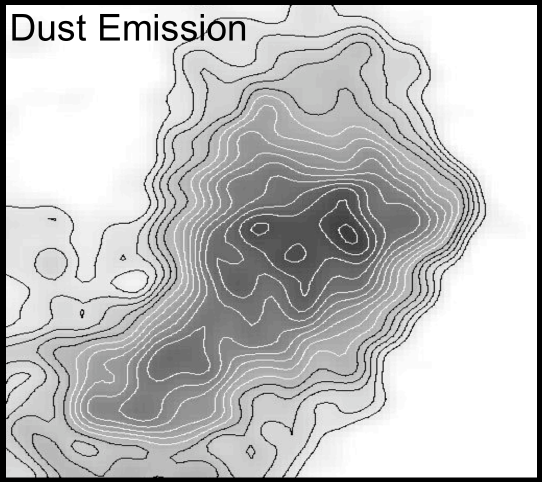
Alves, Lada & Lada 1999

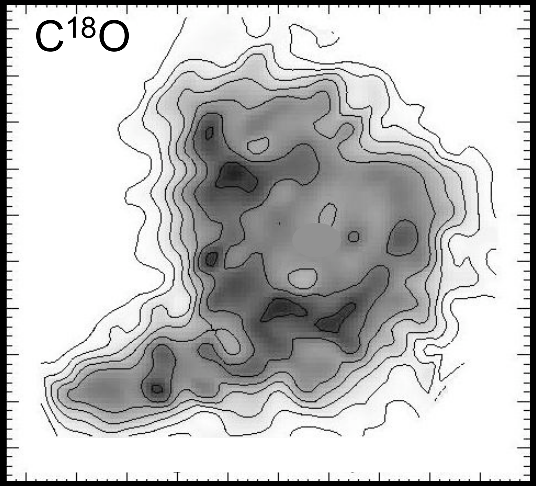
But, spectral lines don't just say where the emission is on the sky…

They give us a velocity.

The Value of “COMPLETE” Observations: B68

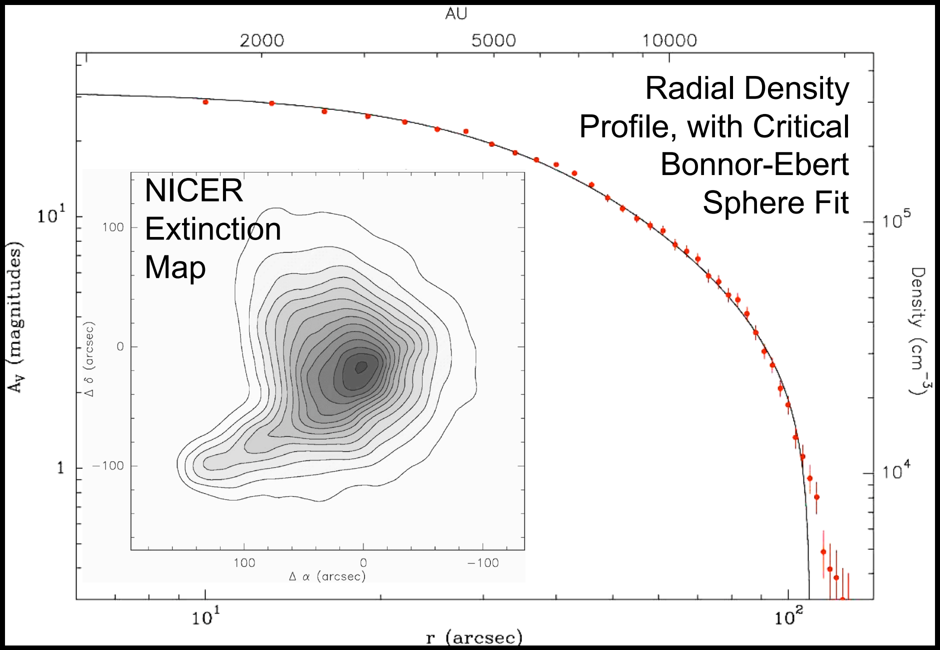




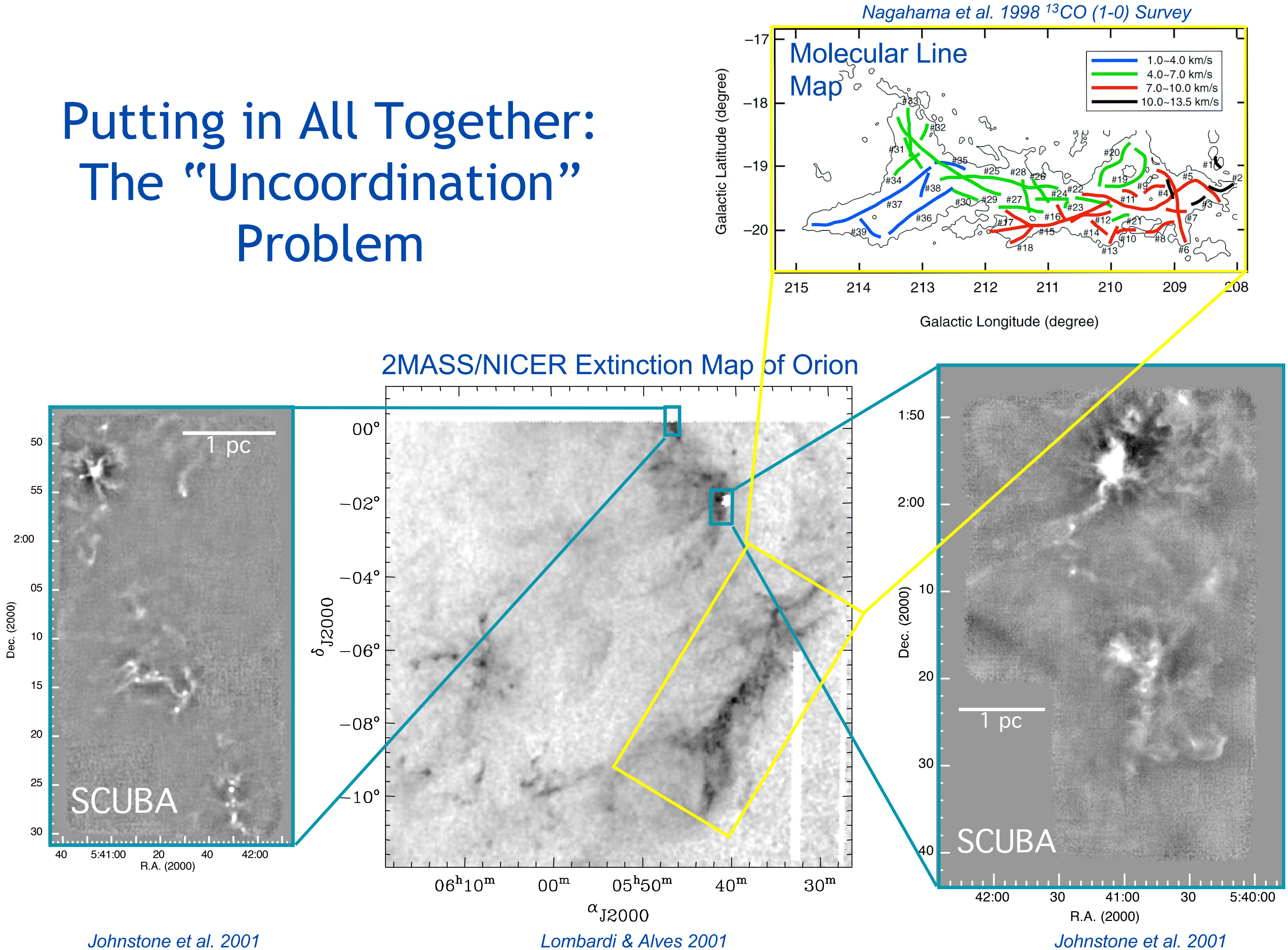


Coordinated Molecular-Probe Line, Extinction & Thermal Emission Observations of Barnard 68

This figure highlights the work of Senior Collaborator **João Alves** and his collaborators. The *top left* panel shows a deep VLT image (Alves, Lada & Lada 2001). The *middle top* panel shows the 850 μm continuum emission (Visser, Richer & Chandler 2001) from the dust causing the extinction seen optically. The *top right* panel highlights the extreme depletion seen at high extinctions in $C^{18}O$ emission (Lada et al. 2001). The inset on the *bottom right* panel shows the extinction map derived from applying the NICER method applied to NTT near-infrared observations of the most extinguished portion of B68. The *graph* in the bottom right panel shows the incredible radial-density profile derived from the NICER extinction map (Alves, Lada & Lada 2001). Notice that the fit to this profile shows the inner portion of B68 to be essentially a perfect critical Bonner-Ebert sphere

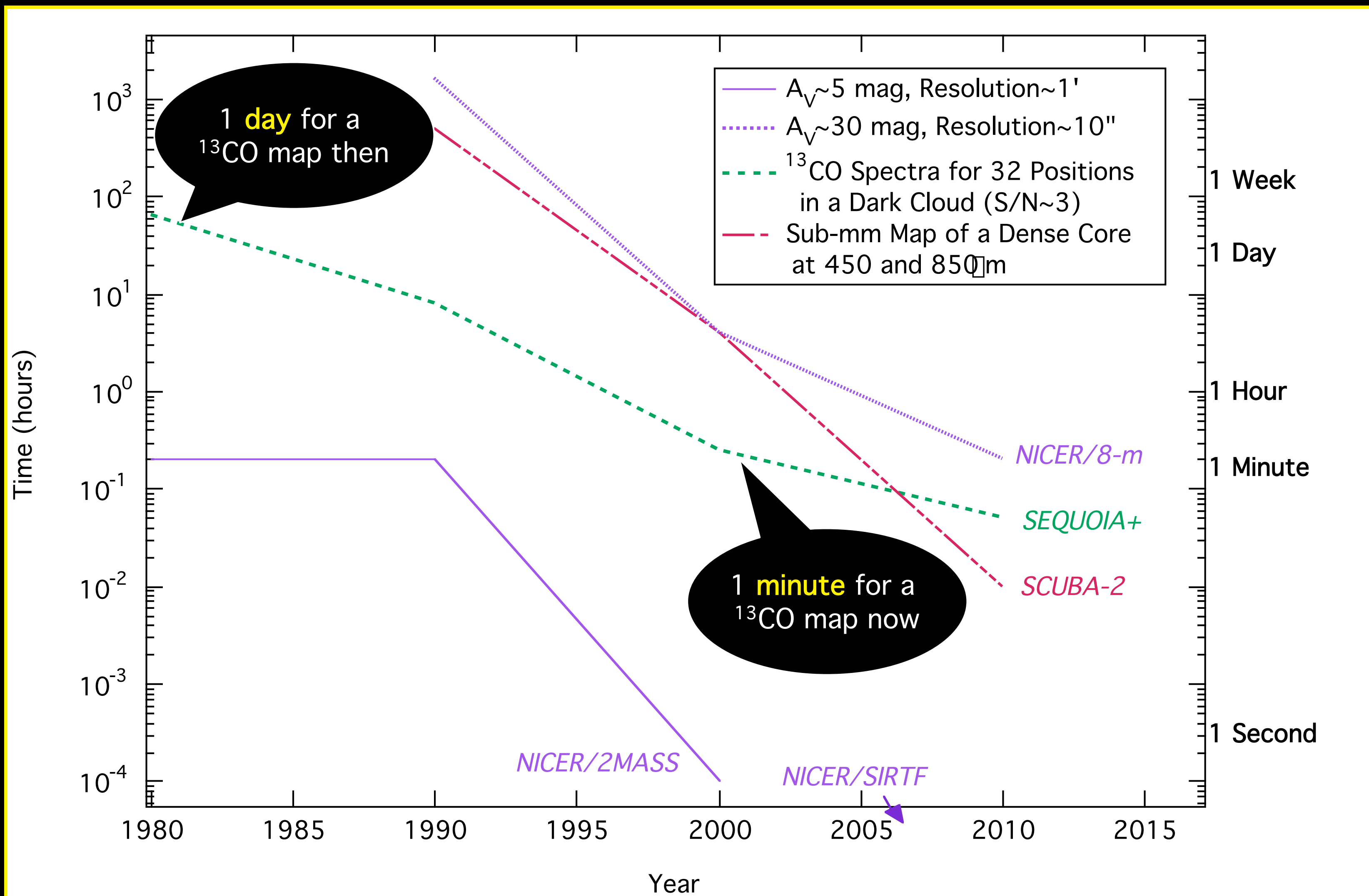


Putting in All Together: The "Uncoordination" Problem



The
COordinated
Molecular
Probe
Line
Extinction
Thermal
Emission
Survey

Is this Really Possible Now?

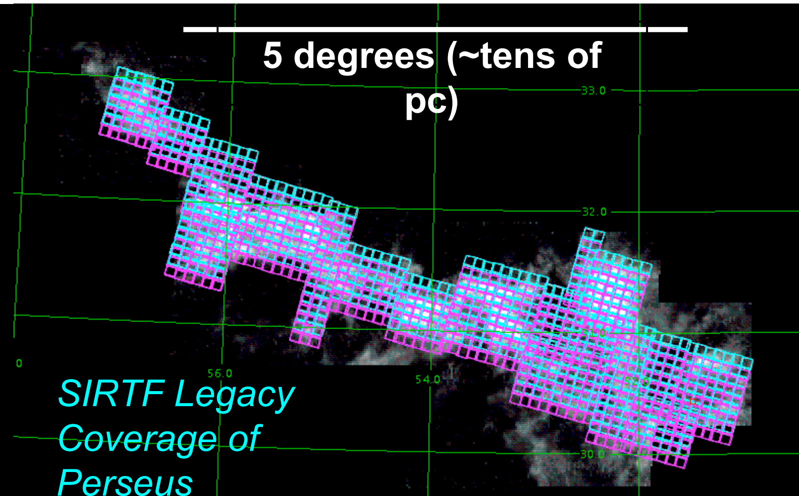


The
COordinated
Molecular
Probe
Line
Extinction
Thermal
Emission
Survey

COMPLETE

Alyssa A. Goodman, Principal Investigator (CfA)
João Alves (ESA, Germany)
Héctor Arce (Caltech)
Paola Caselli (Arcetri, Italy)
James DiFrancesco (HIA, Canada)
Mark Heyer (UMASS/FCRAO)
Di Li (CfA)
Doug Johnstone (HIA, Canada)
Naomi Ridge (CfA)
Scott Schnee (CfA, PhD student)
Mario Tafalla (OAS, Spain)
Tom Wilson (MPIfR)

COMPLETE, Part 1



Observations:

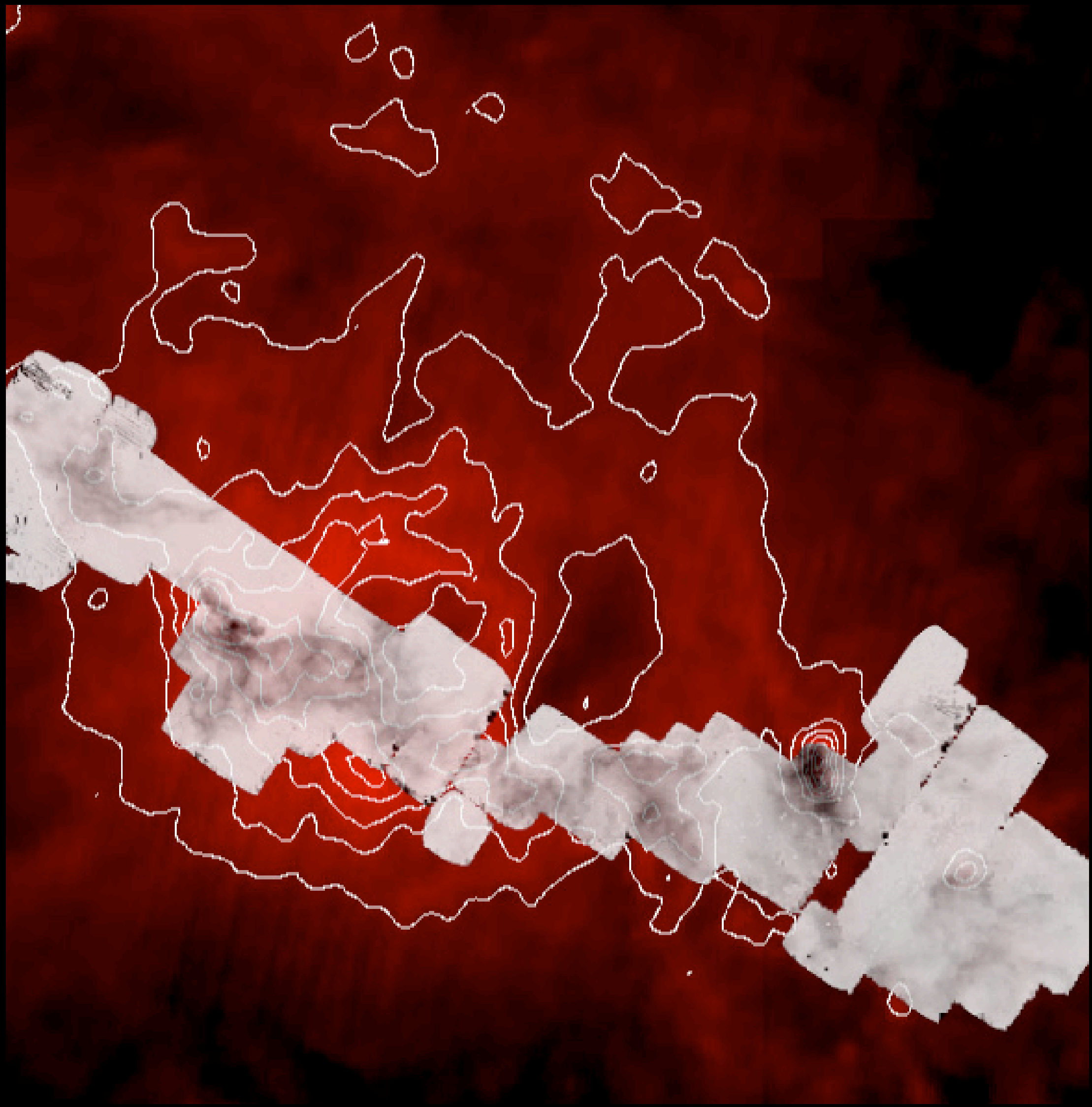
2003-- Mid- and Far-IR SIRTF Legacy Observations: dust temperature and column density

Scien

>10-degree scale Near-IR Extinction, Molecular Line and Dust Emission Surveys of Perseus, Ophiuchus & Serpens

COMPLETE
Perseus

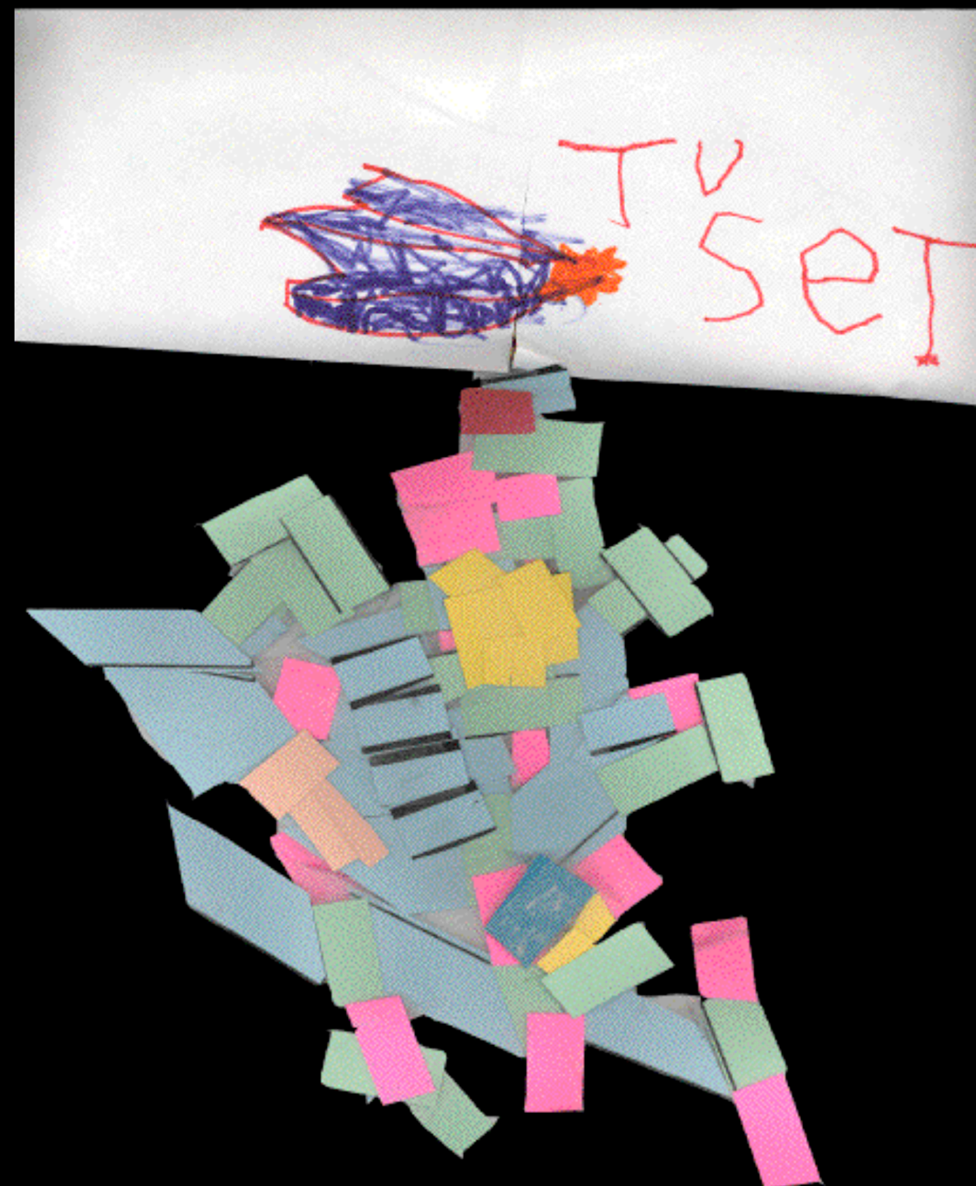
IRAS + FCRAO
(73,000 ^{13}CO Spectra)



What I do for kicks…

Amazing
PV Ceph

a.k.a.
"TV Set"



"Giant" Herbig-Haro Flow from PV Ceph

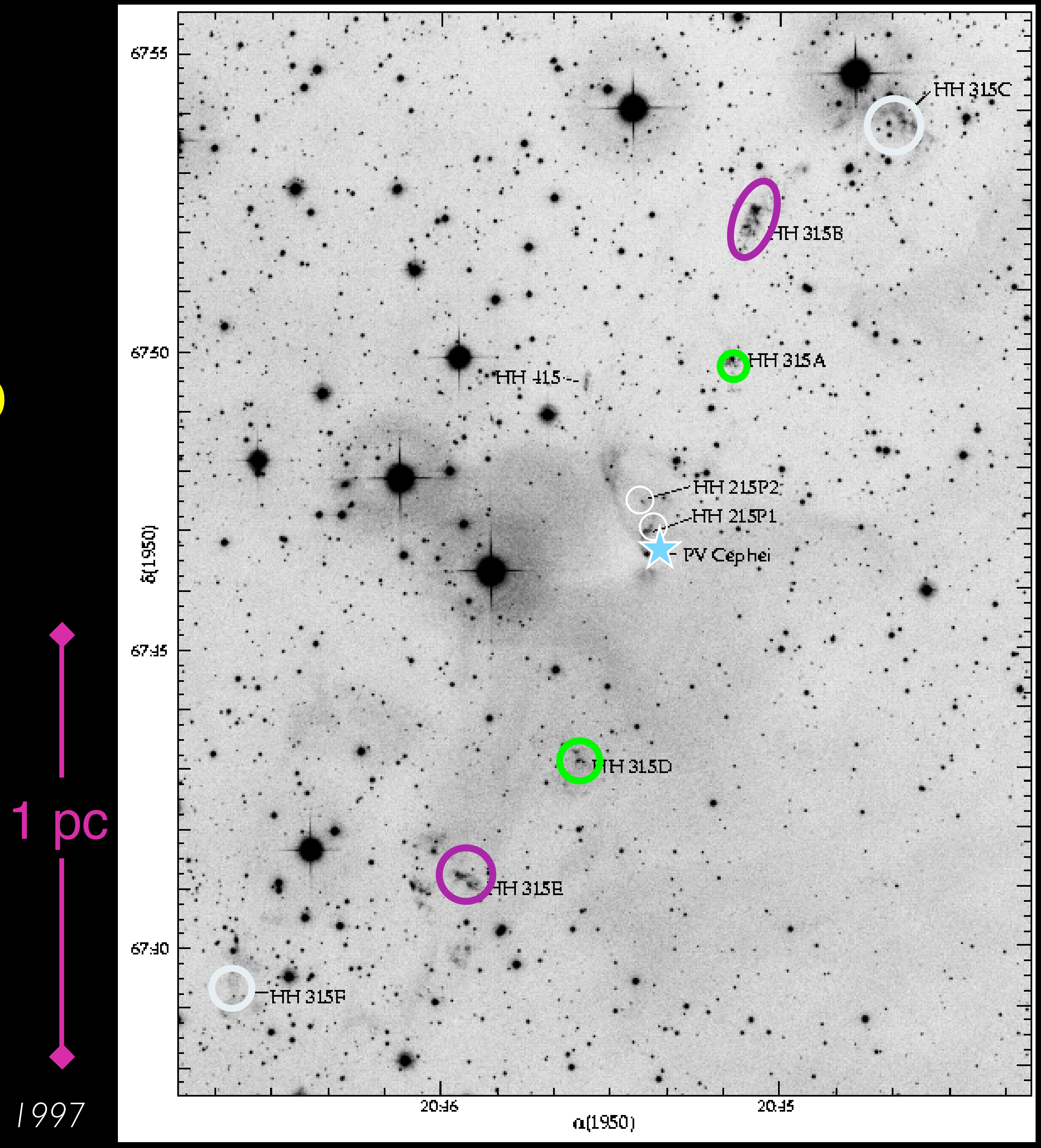
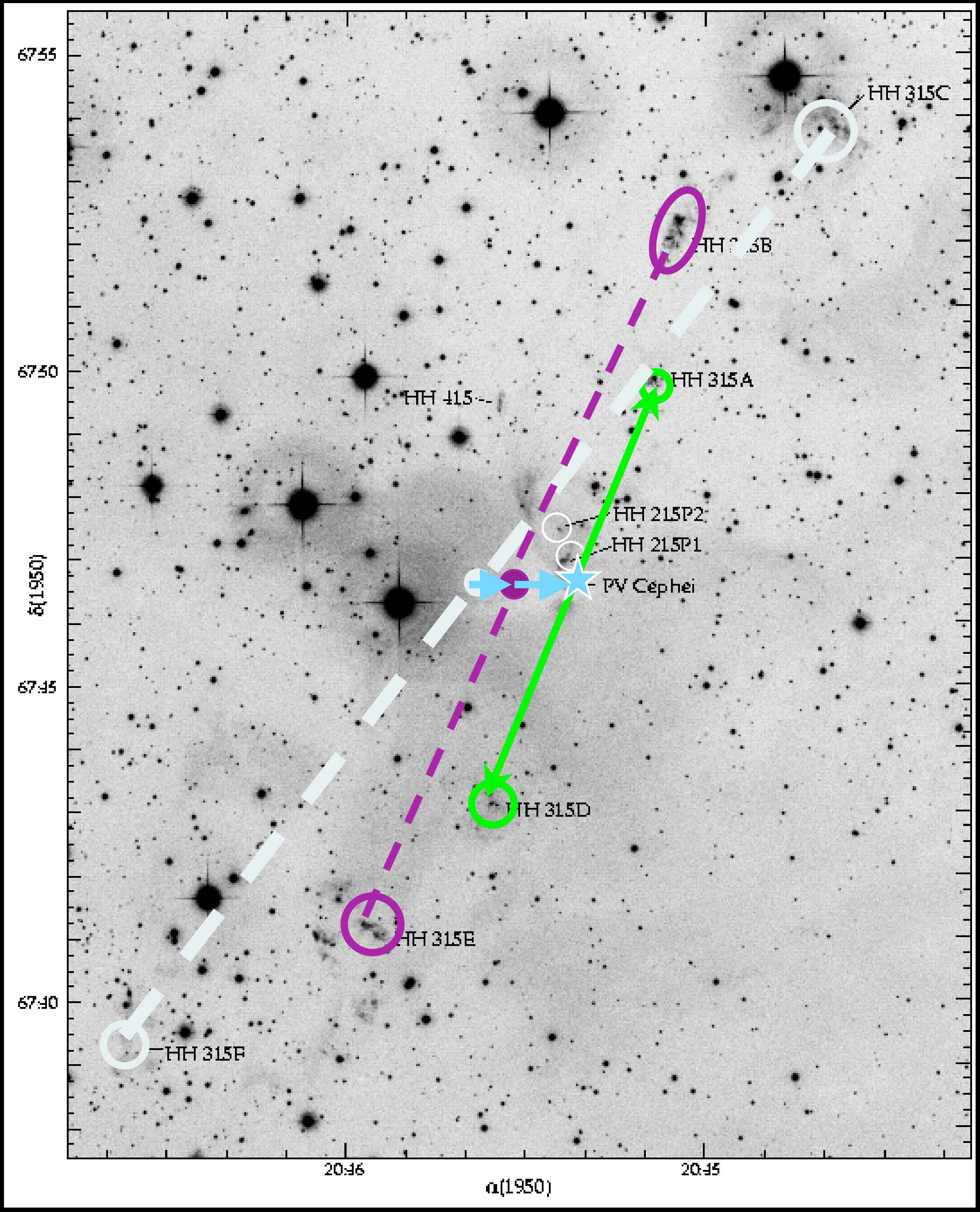


Image from Reipurth, Bally & Devine 1997

PV Ceph

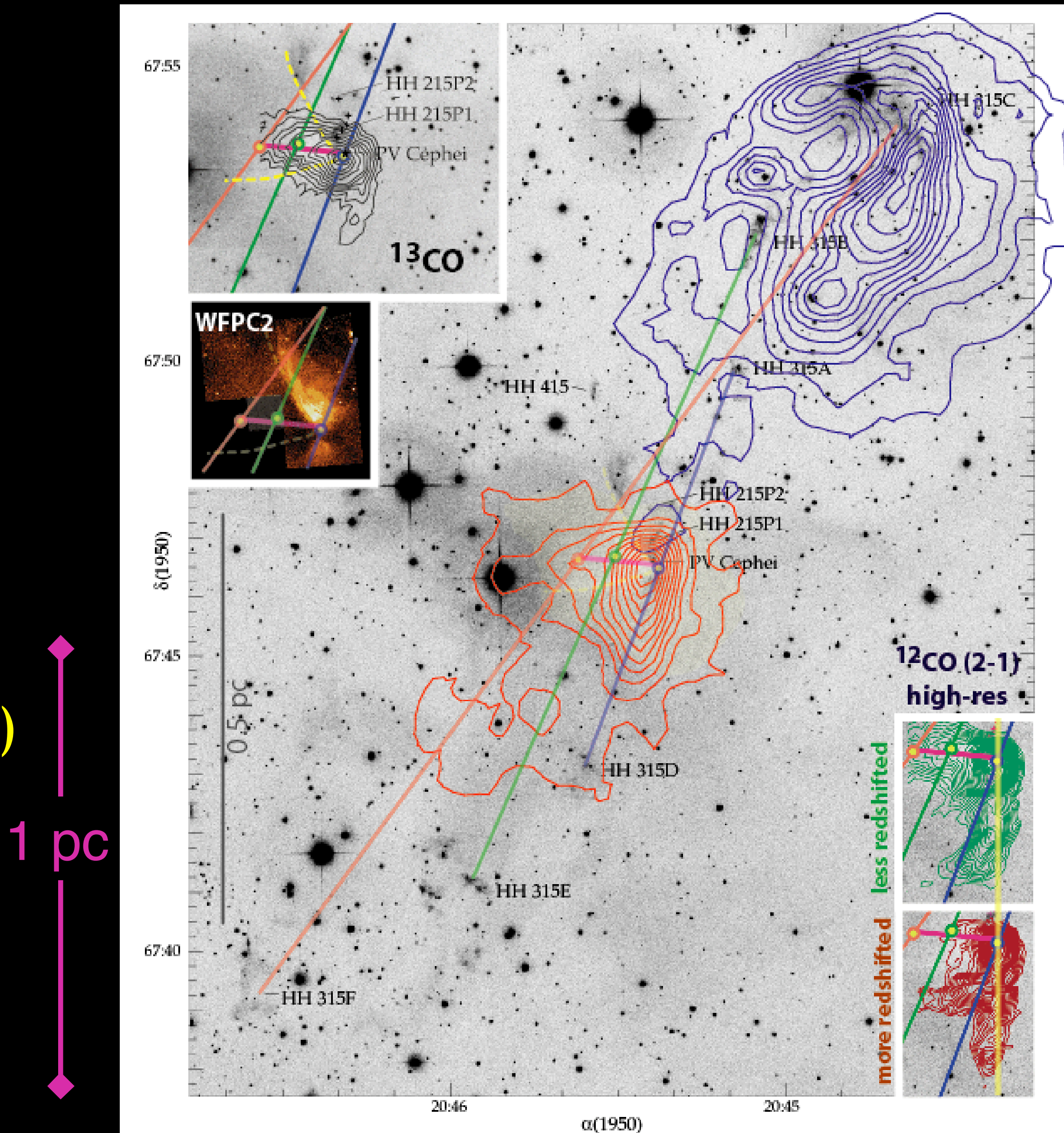
Episodic ejections from a precessing or wobbling moving source



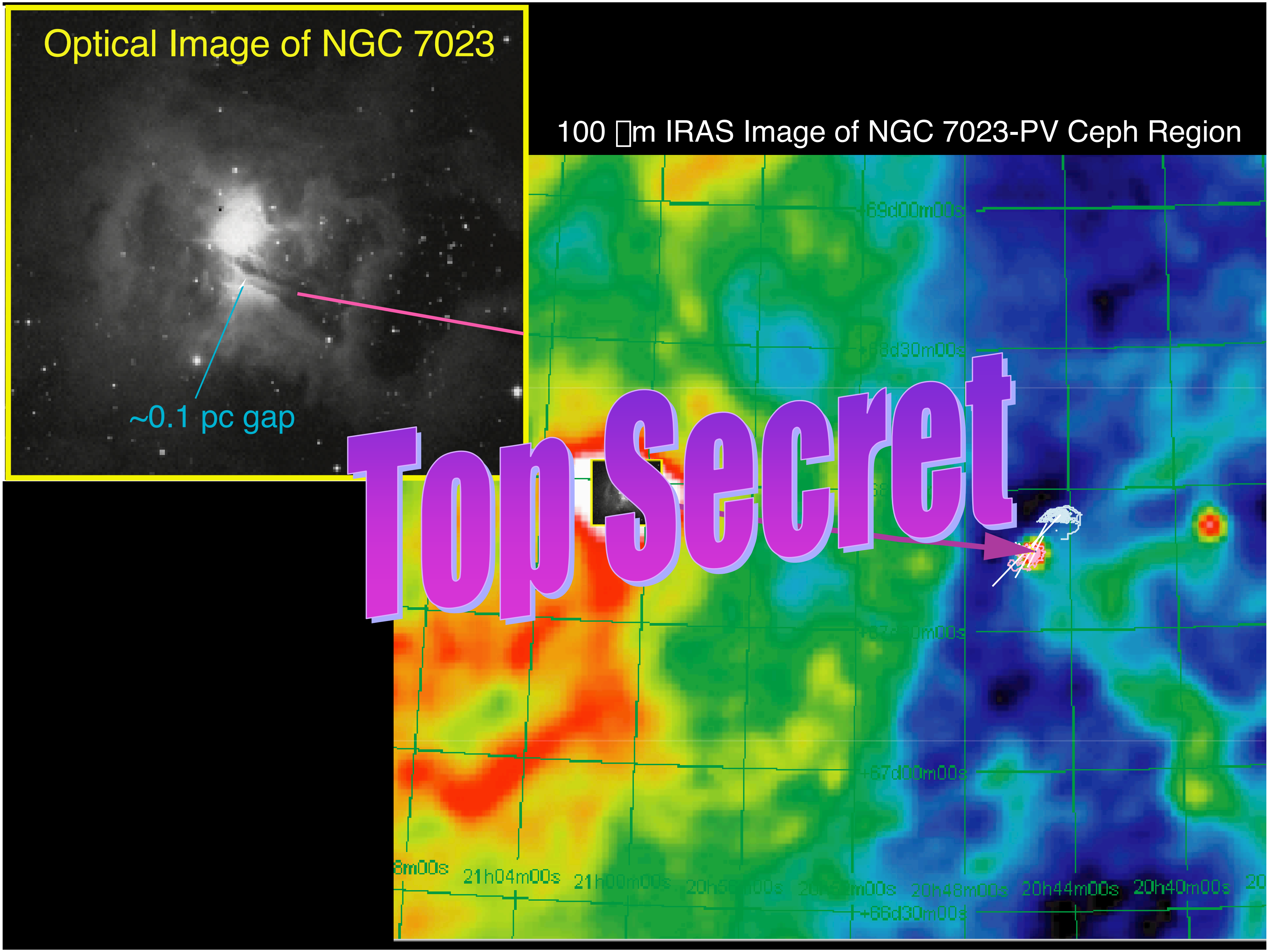
Goodman & Arce 2003

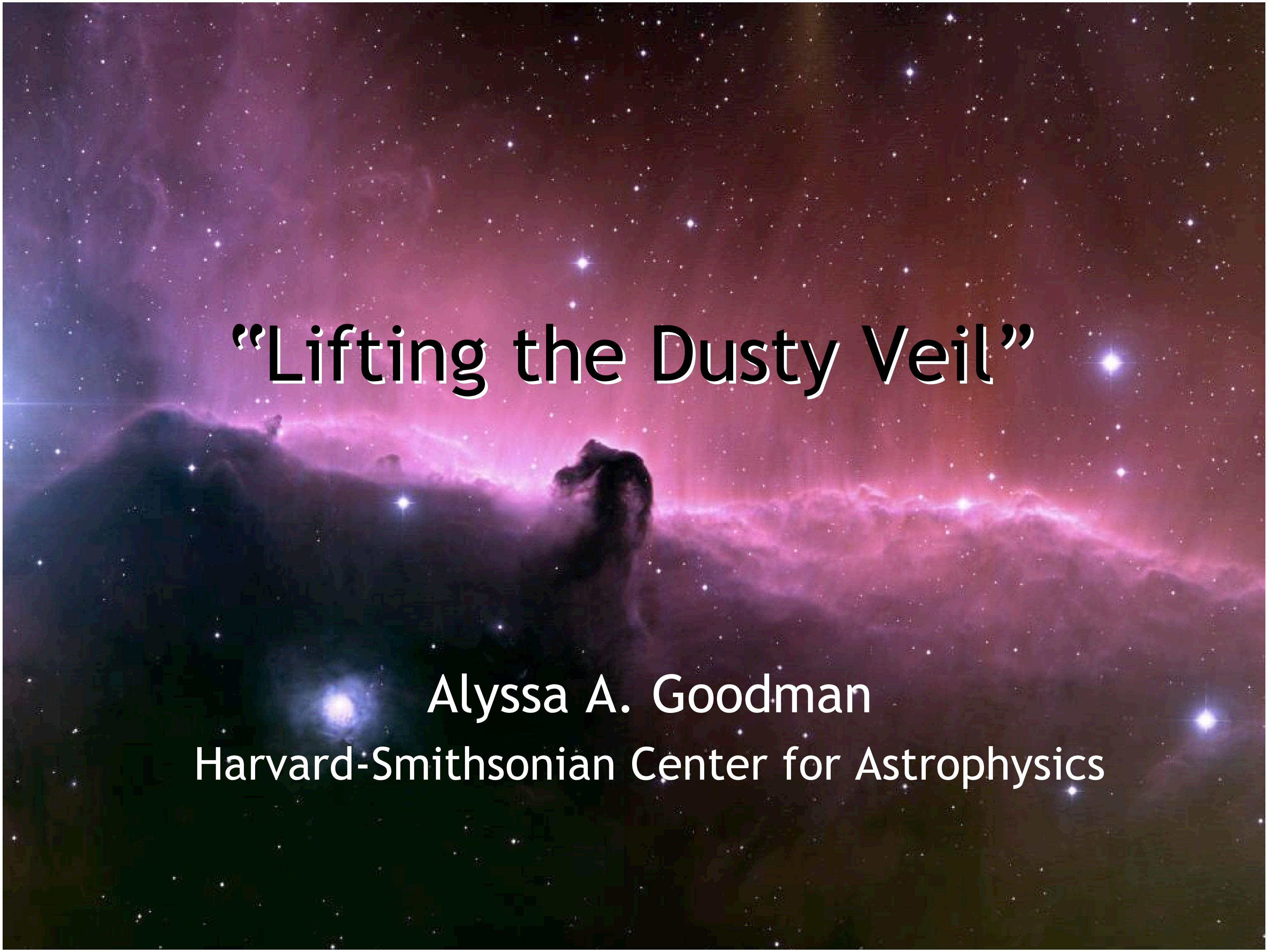
PV Ceph is moving at ~20 km s^{-1}

(from here to Concord in 1 sec)



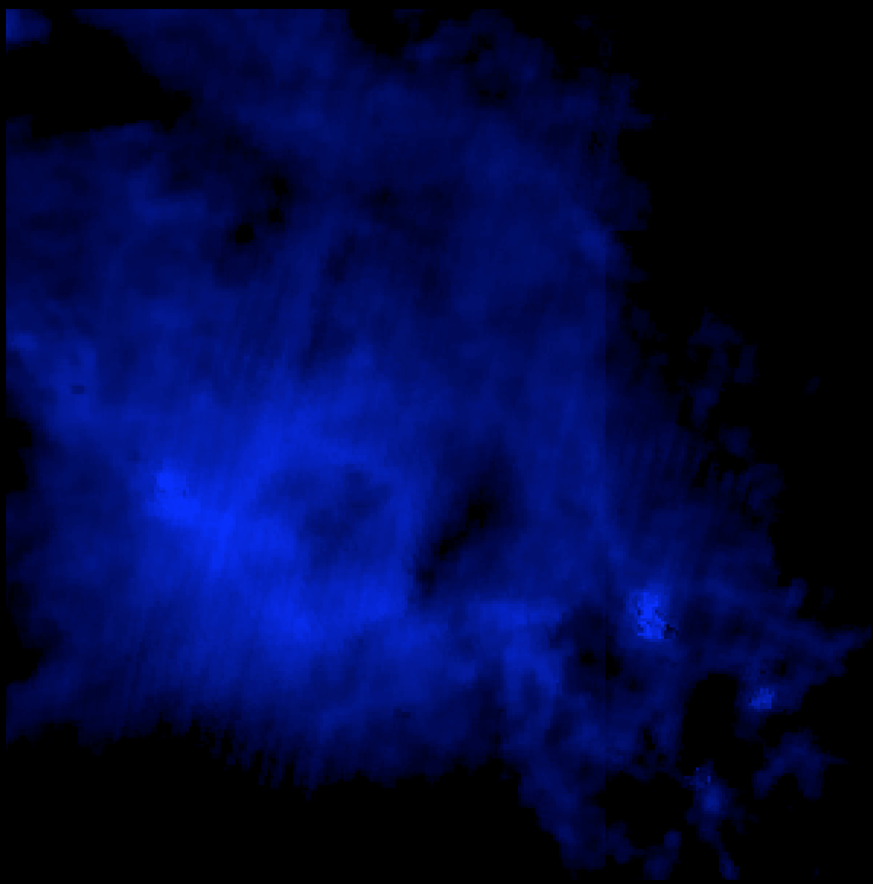
Goodman & Arce 2003


Optical Image of NGC 7023
~0.1 pc gap
100 □m IRAS Image of NGC 7023-PV Ceph Region
Top Secret
69d00m00s
68d30m00s
67d00m00s
+66d30m00s
21h04m00s
20h48m00s
20h44m00s
20h40m00s

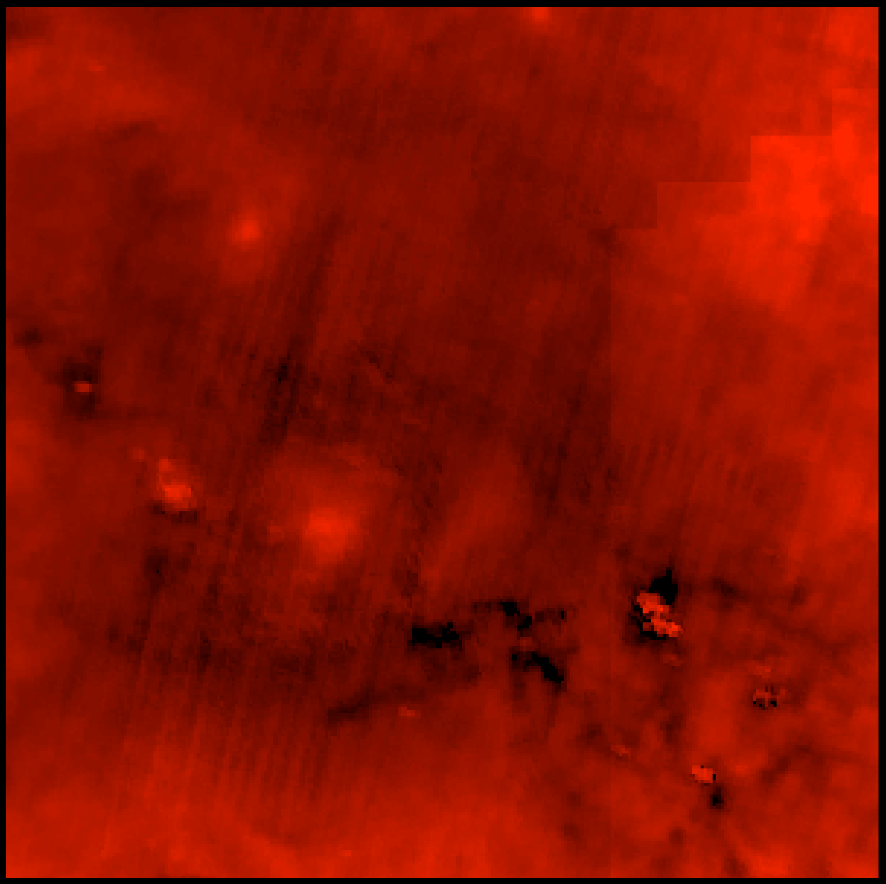

"Lifting the Dusty Veil"
Alyssa A. Goodman
Harvard-Smithsonian Center for Astrophysics

Perseus

Total Dust Column (0 to 15 mag A_V)
(Based on 60/100 microns)

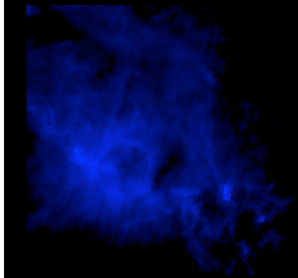


Dust Temperature (25 to 45 K)
(Based on 60/100 microns)



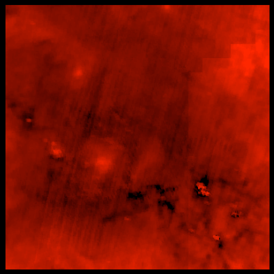
Hot Source in a Warm Shell

Column Density

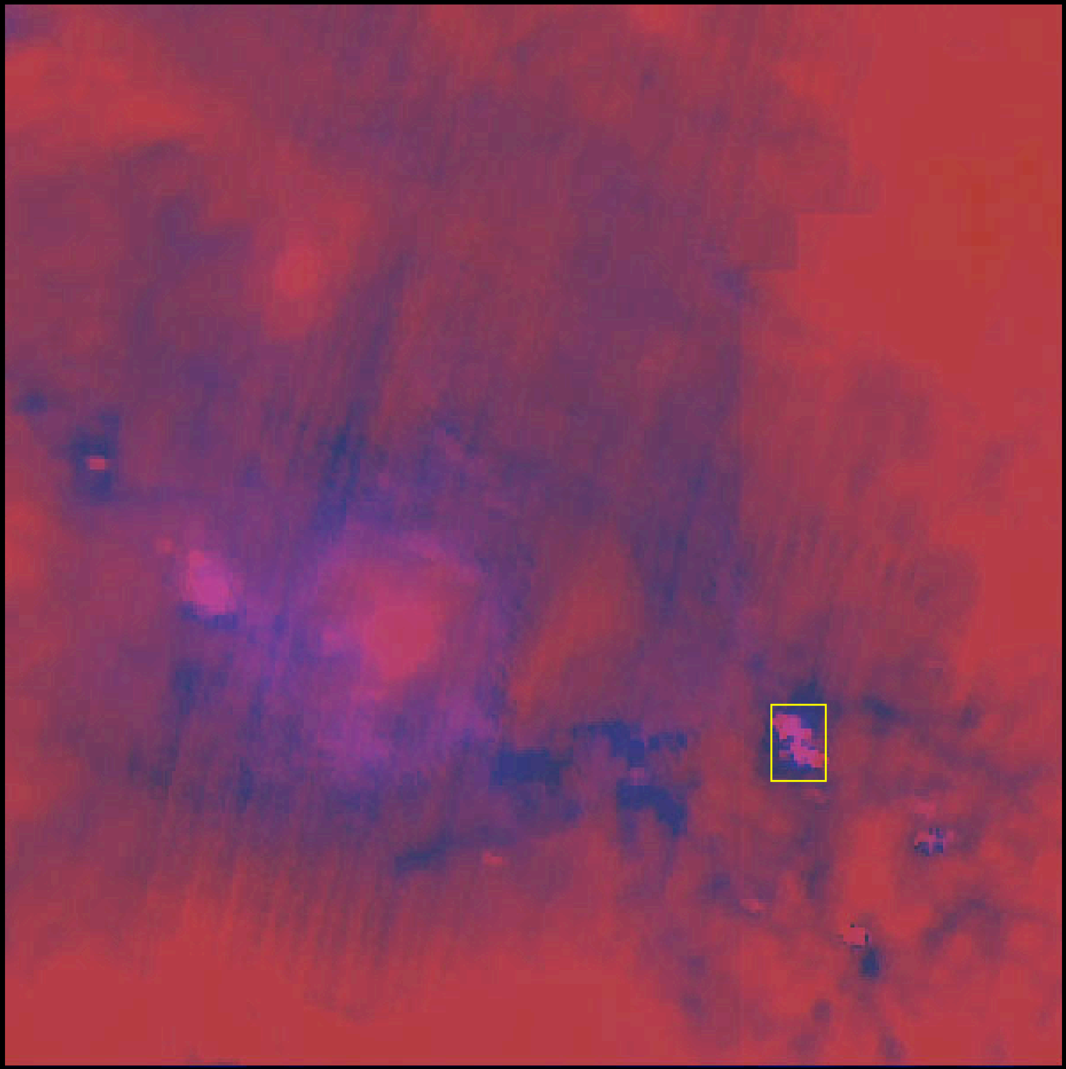


+

Temperature

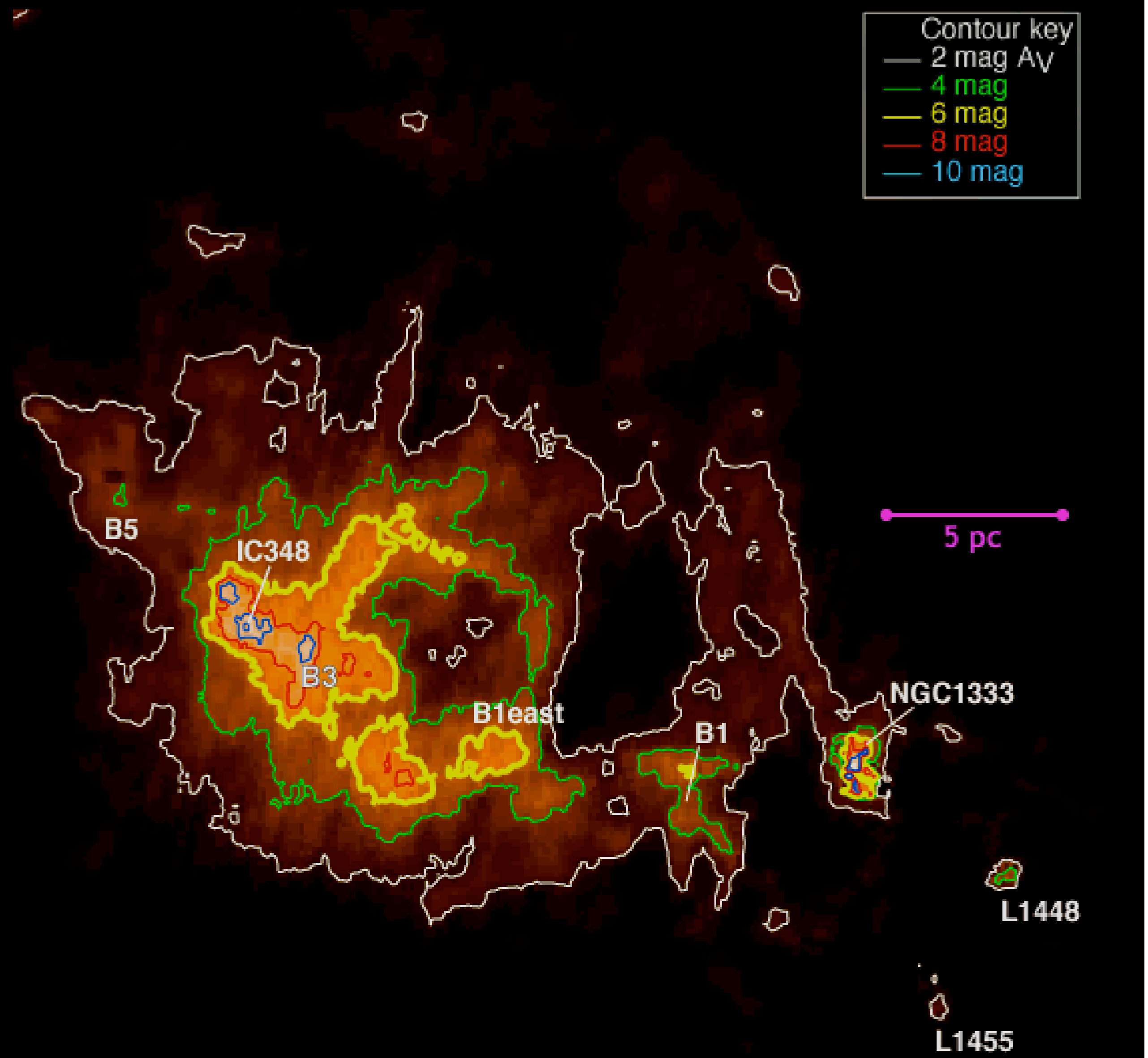


=



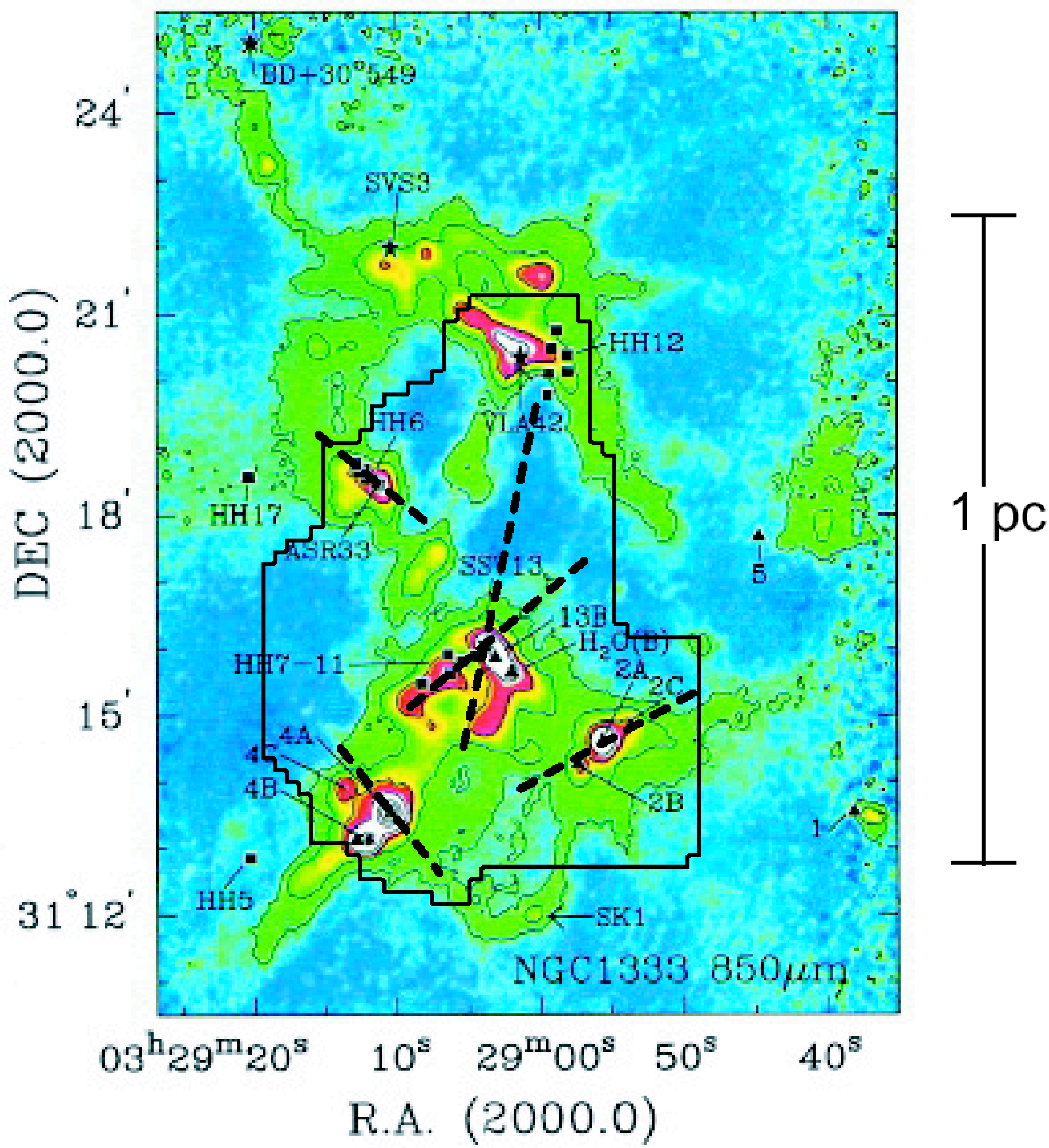
COMPLETE
Warm Dust Emission shows

Great Bubble in Perseus



2×10^{51} erg SN
into 10^4 cm^{-3}
5 pc in 1 Myr
T=30K
v_{exp}=1.5 km s^{-1}

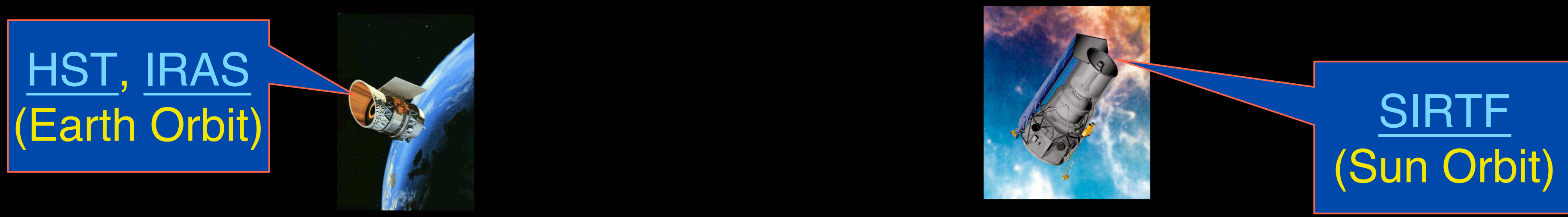
The action of multiple bipolar outflows in NGC 1333?

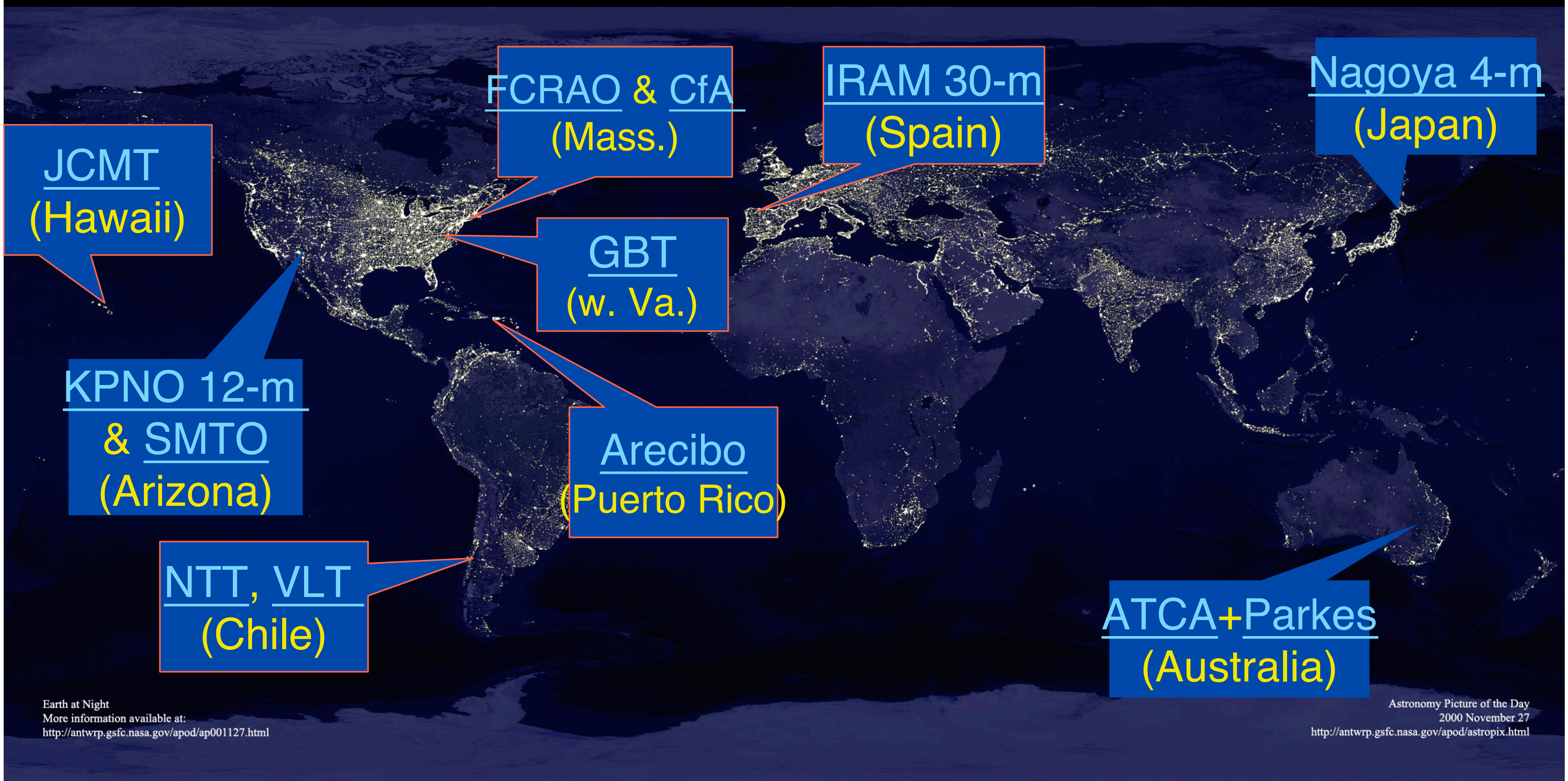


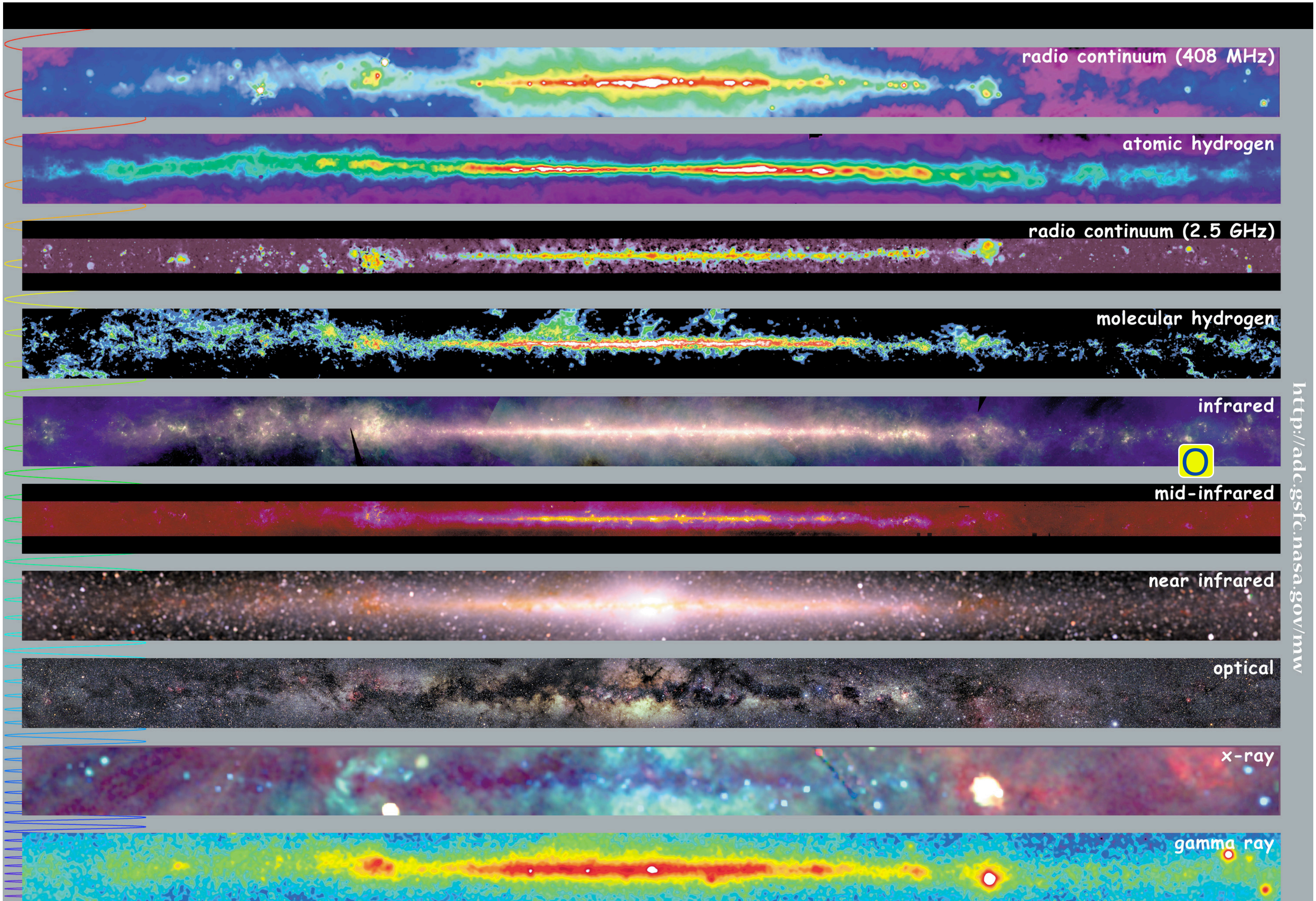
SCUBA 850 mm Image shows N_{dust} (Sandell & Knee 2001)

Dotted lines show CO outflow orientations (Knee & Sandell 2000)

Telescopes Used in Our Mapping of the ISM

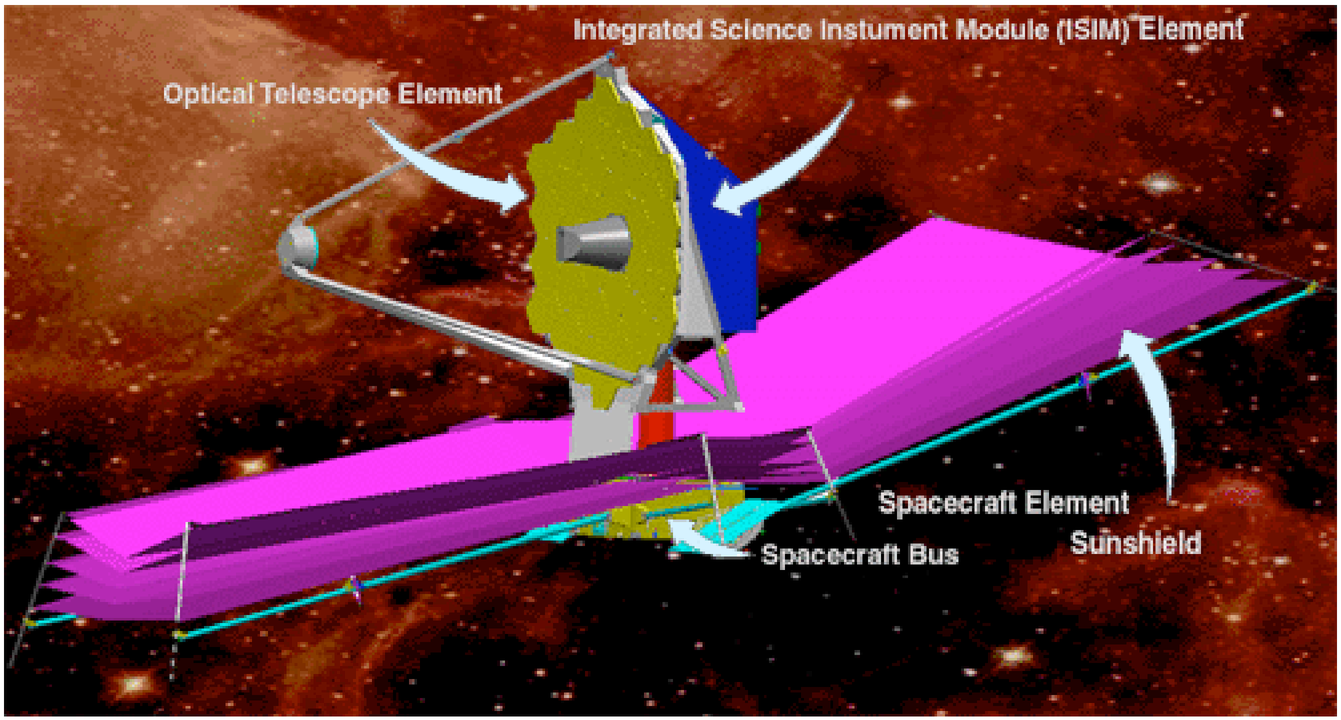






Multiwavelength Milky Way

JAMES WEBB SPACE TELESCOPE
The First Light Machine



2011?

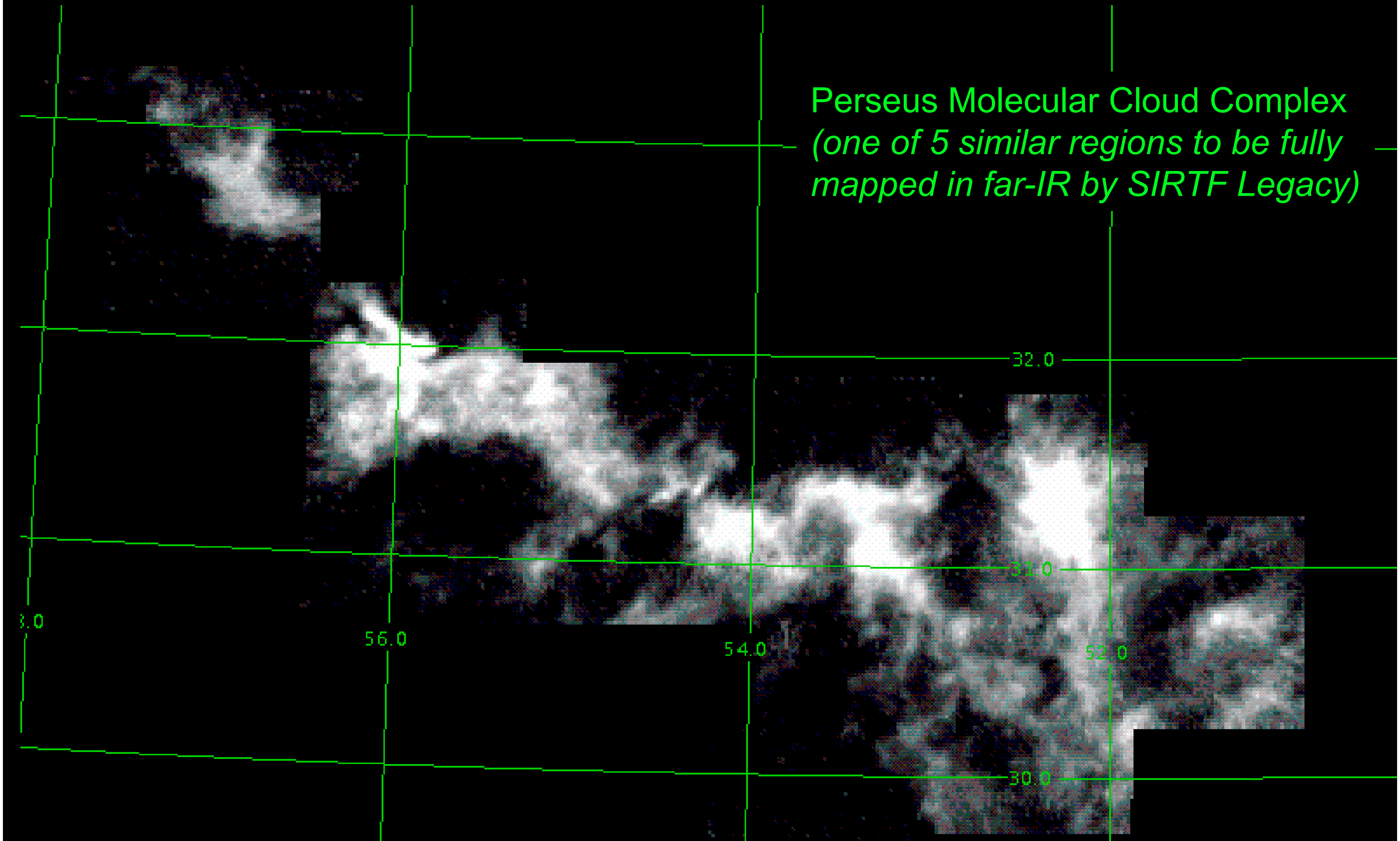
Space Infrared Telescope Facility

Infrared Great Observatory

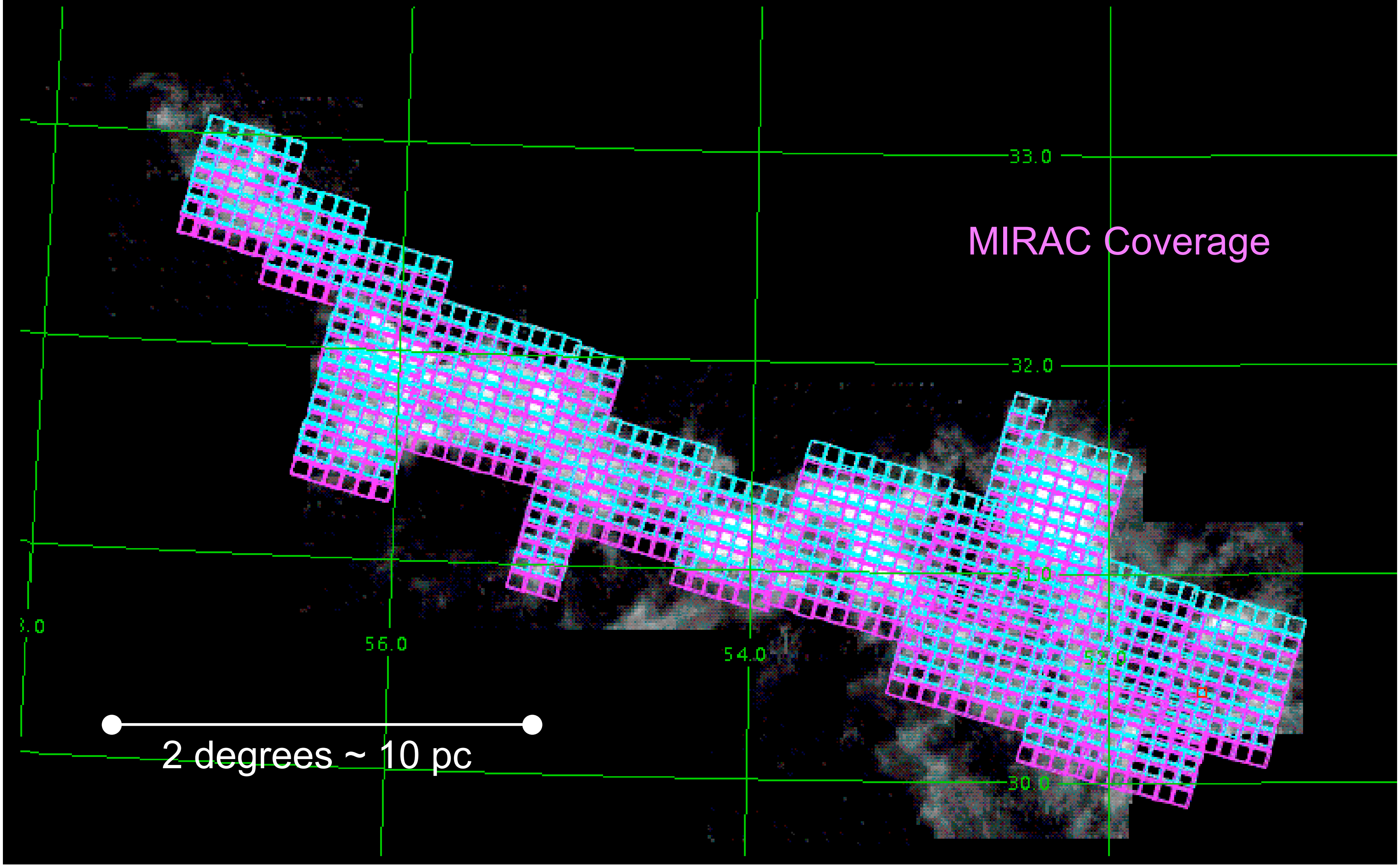
- Background Limited Performance 3 -- 180
- 85 cm f/12 Beryllium Telescope, T < 5.5K
- 6.5μm Diffraction Limit
- New Generation Detector Arrays
- Instrumental Capabilities
  - Imaging/Photometry, 3-180μm
  - Spectroscopy, 5-40um
  - Spectrophotometry, 50-100 μm
- Planetary Tracking, 1 arcsec/sec
- >75% of observing time for the
- General Scientific Community
- 2.5 yr Lifetime/5 yr Goal
- Launched August 2003!! (Delta 7920H)
- Solar Orbit
- $450 M Development Phase Cost Cap

Cornerstone of NASA's Origins Program

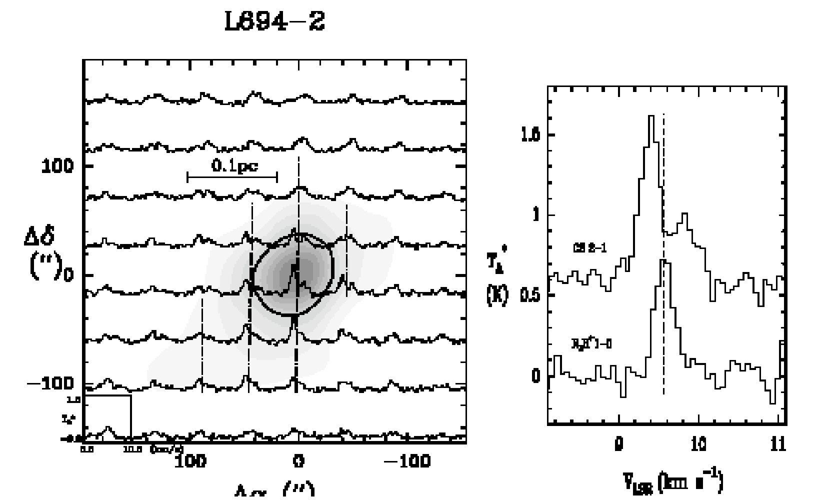
SIRTF Legacy Survey



SIRTF Legacy Survey



COMPLETE, Part 2 (2003-5)



FCRAO N_2H^+ map with CS spectra superimposed.

(Lee, Myers & Tafalla 2001).

- <arcminute-scale core maps to get density & velocity
- structure all the way from >10 pc to 0.01 pc