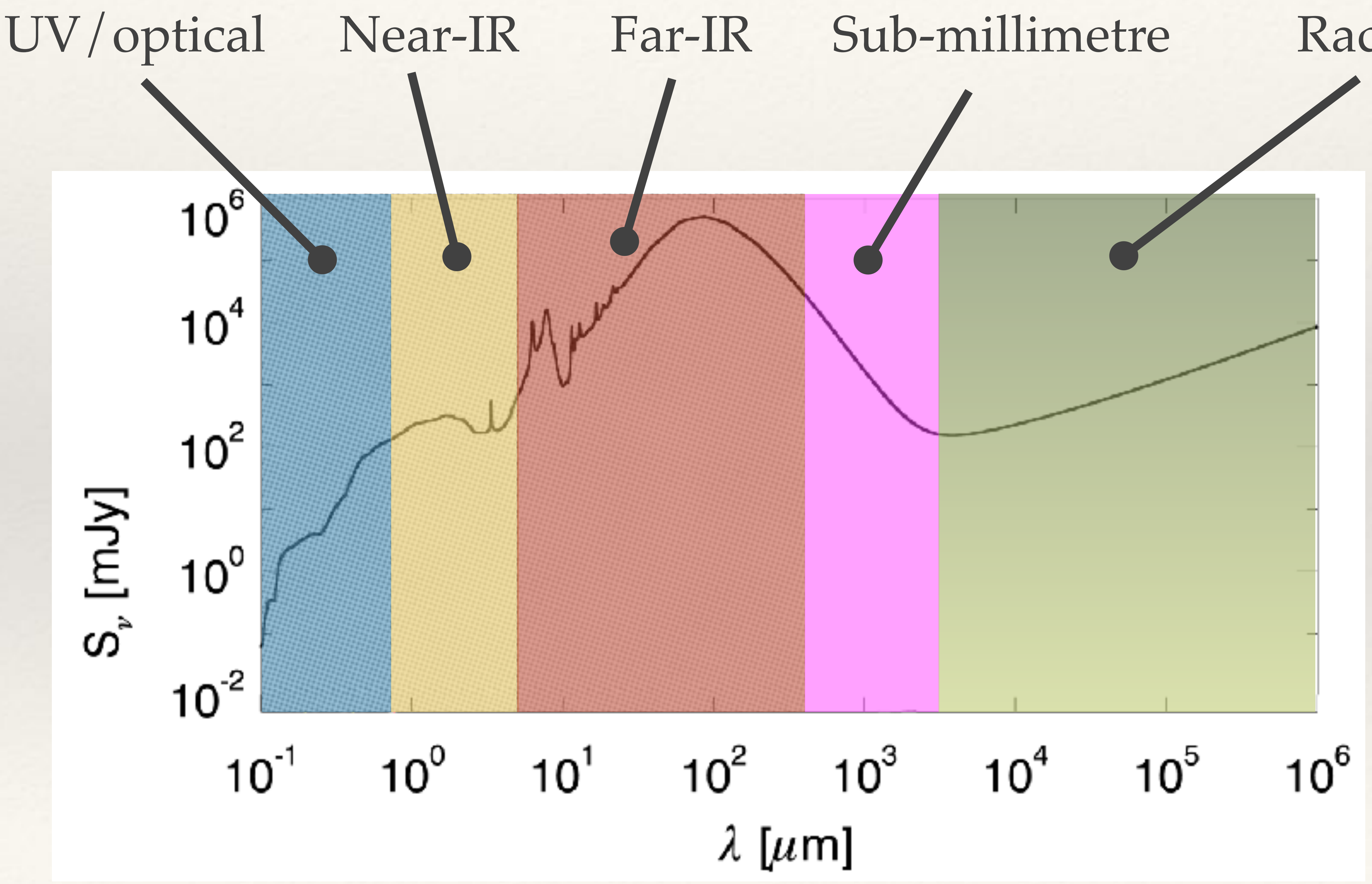
Infra-red astronomy

The cool, dusty, and distant Universe

Matt Bothwell

The infra-red



The infra-red

Wavelength units…

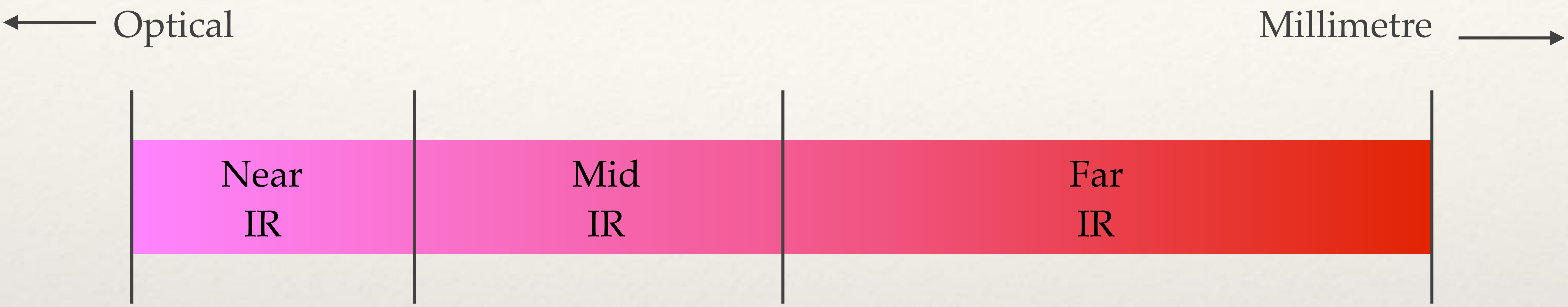
In the radio, units are *frequency (i.e., 300 MHz)*

In the optical, units are *Angstroms* ($= 10^{-10}$ *m*)

In the IR, we use ***Microns*** ($= 10^{-6}$ *m*)

This is the old-fashioned word for micro-metres,
but it's stuck in IR astronomy

The infra-red



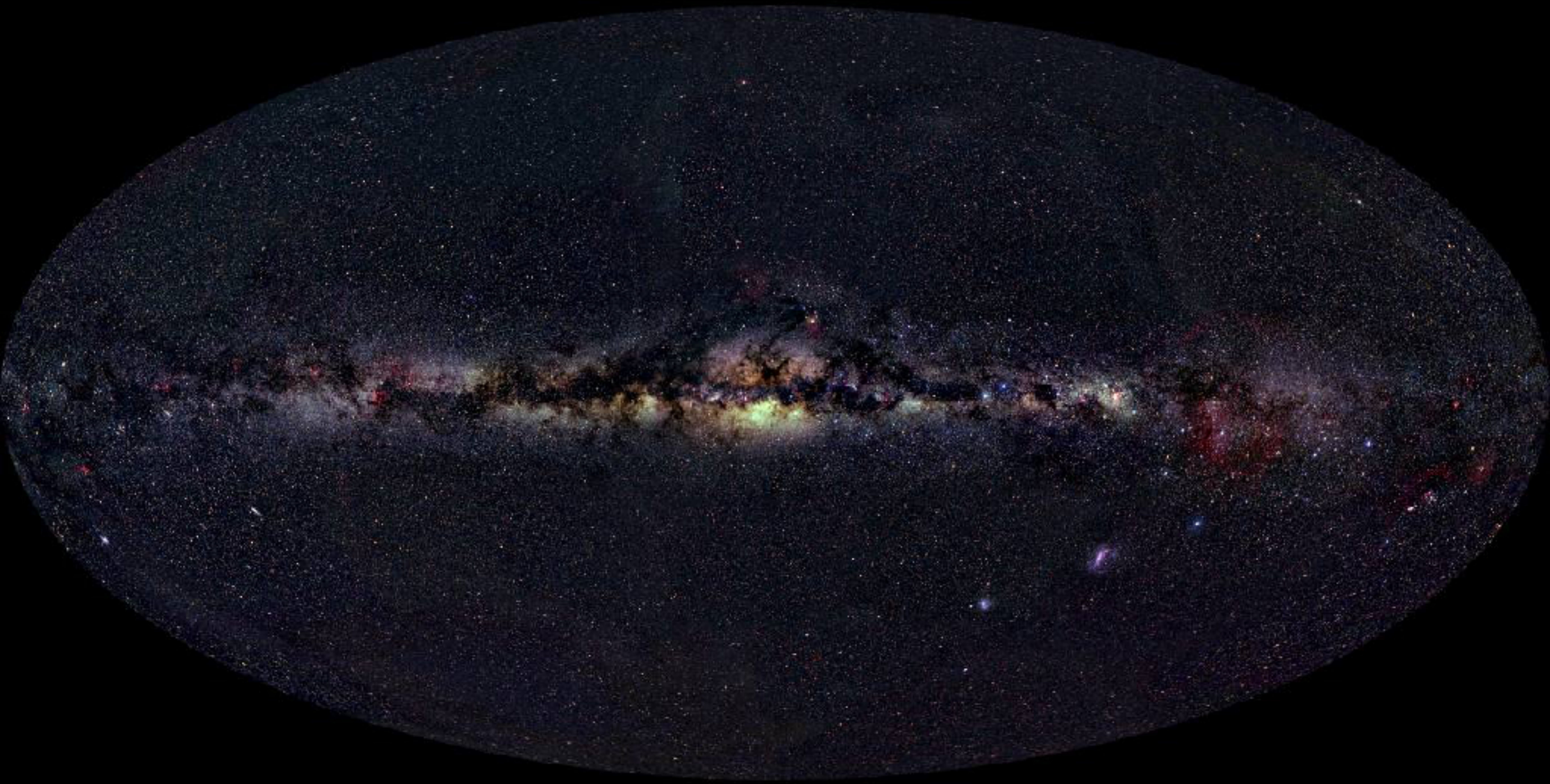
The infra-red

The infra-red

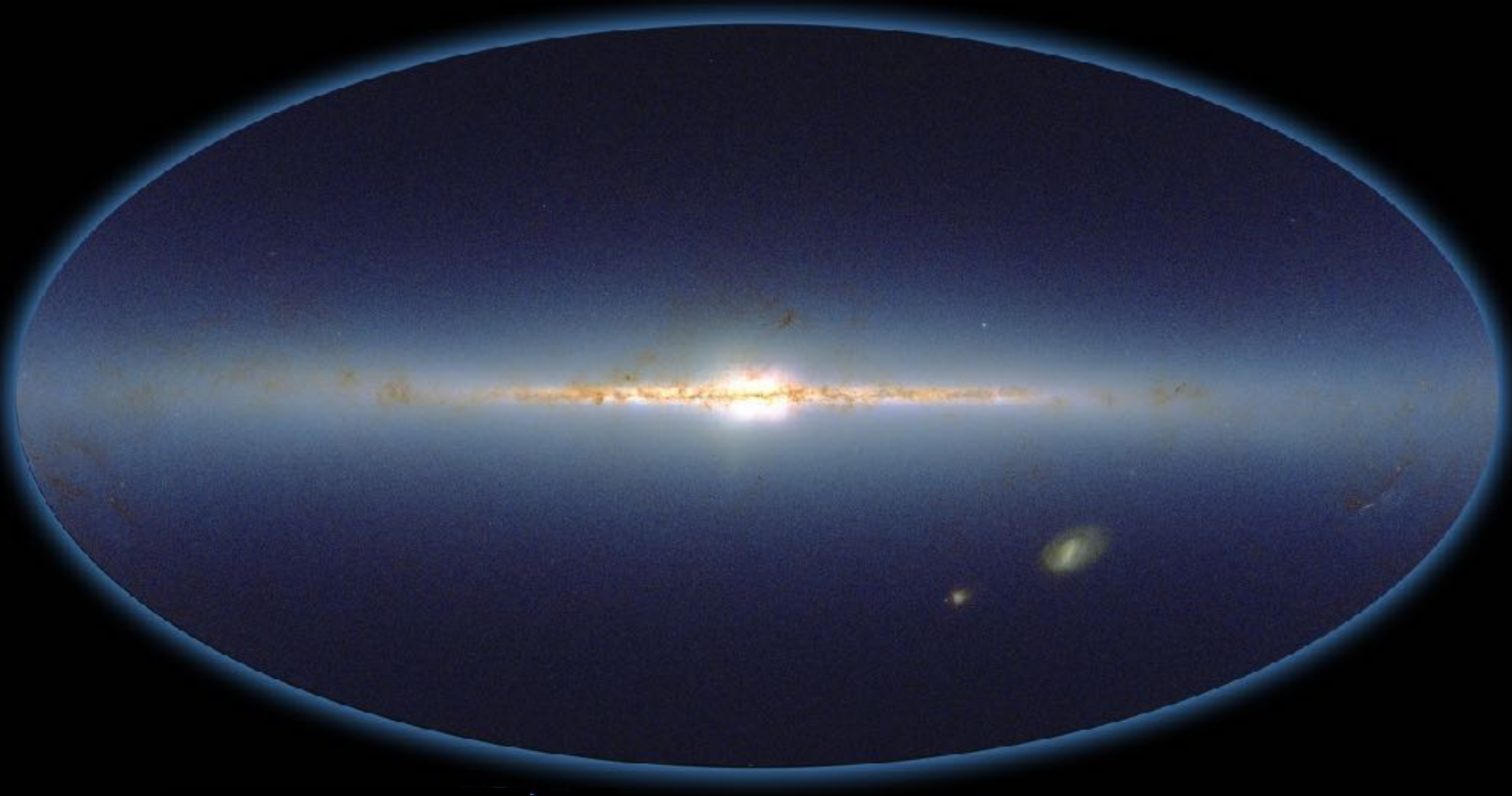
These wavelength boundaries are not agreed upon!

They are rough guidelines only

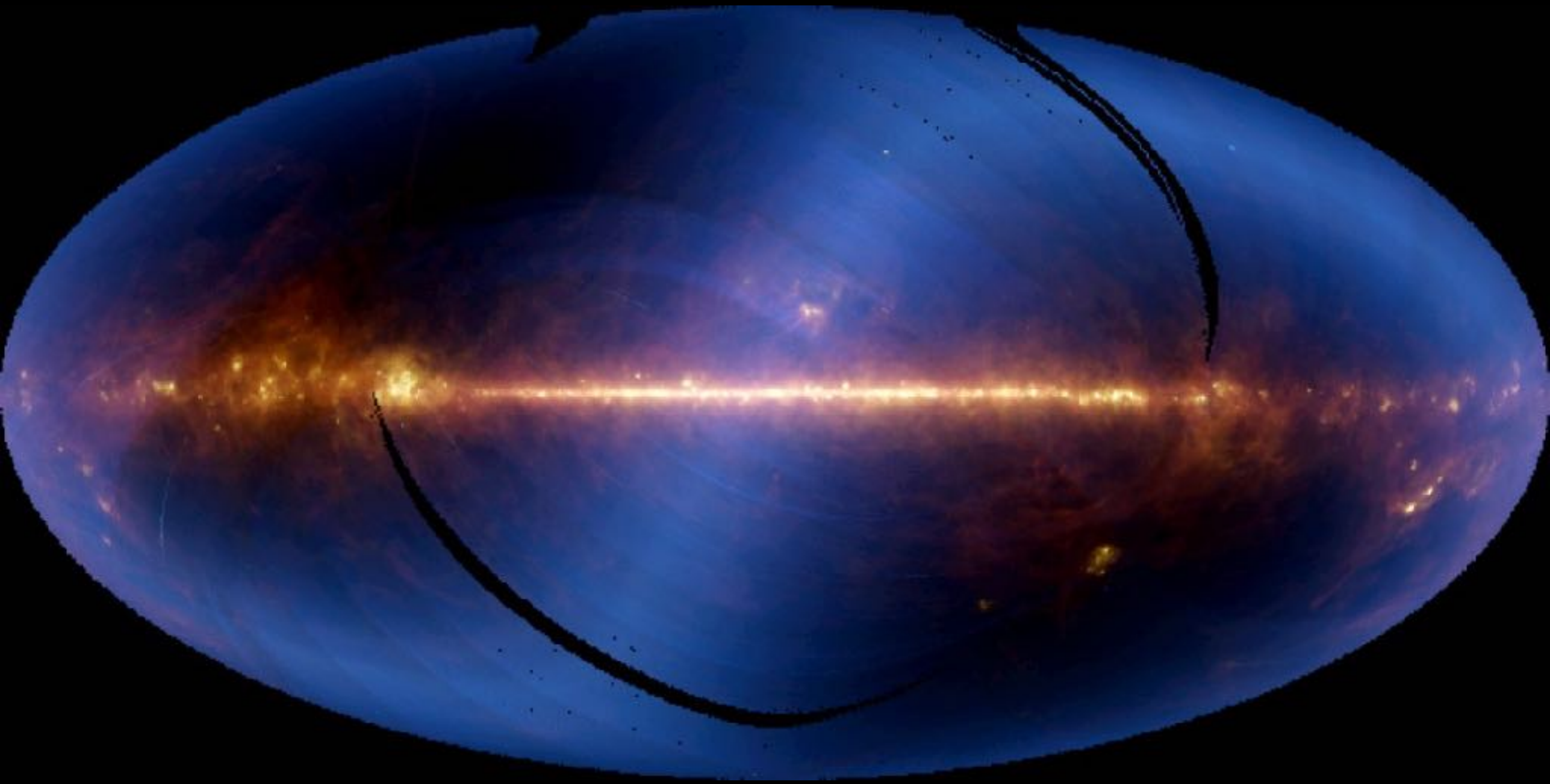
Optical



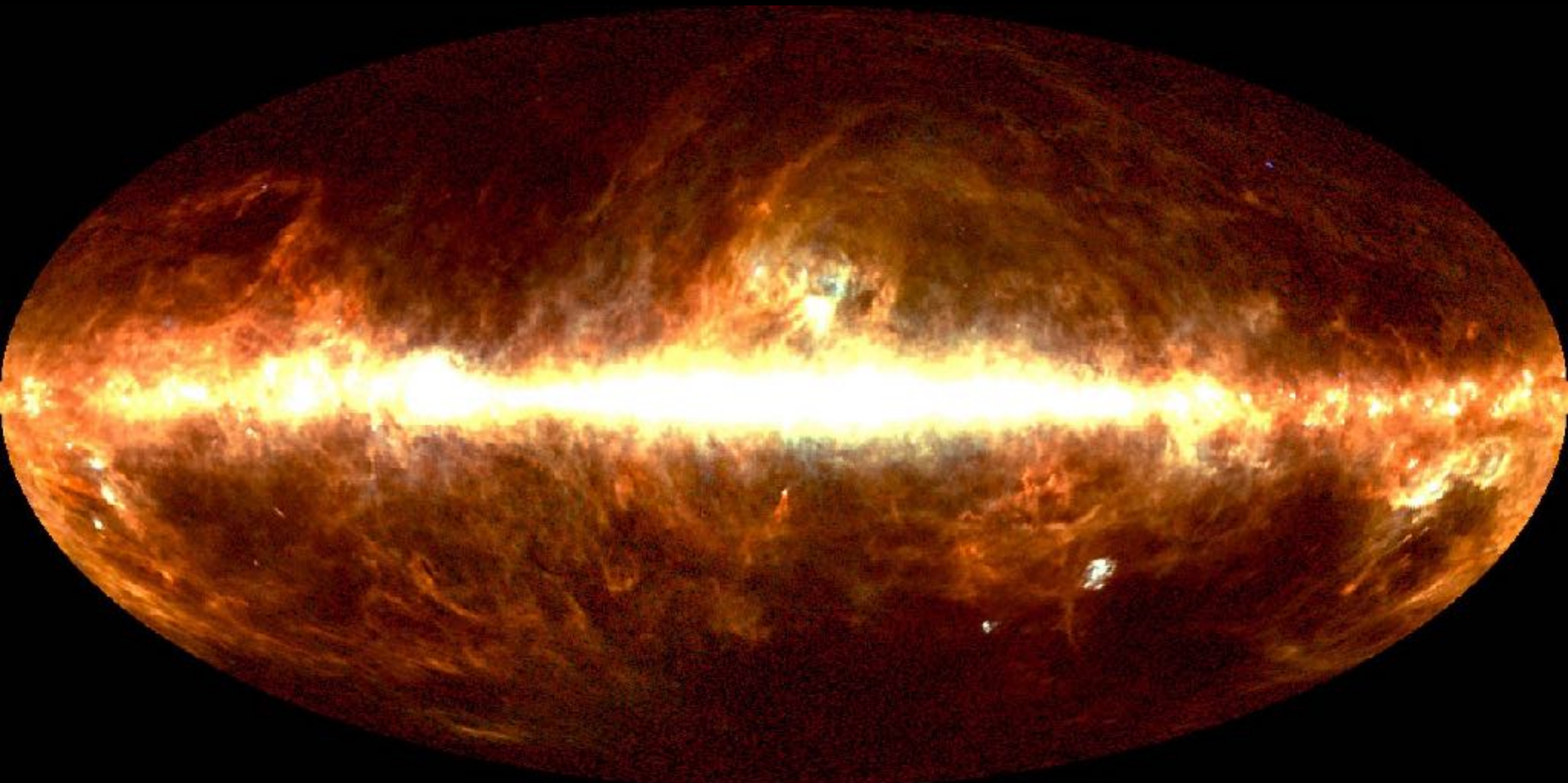
Near IR (2 microns)



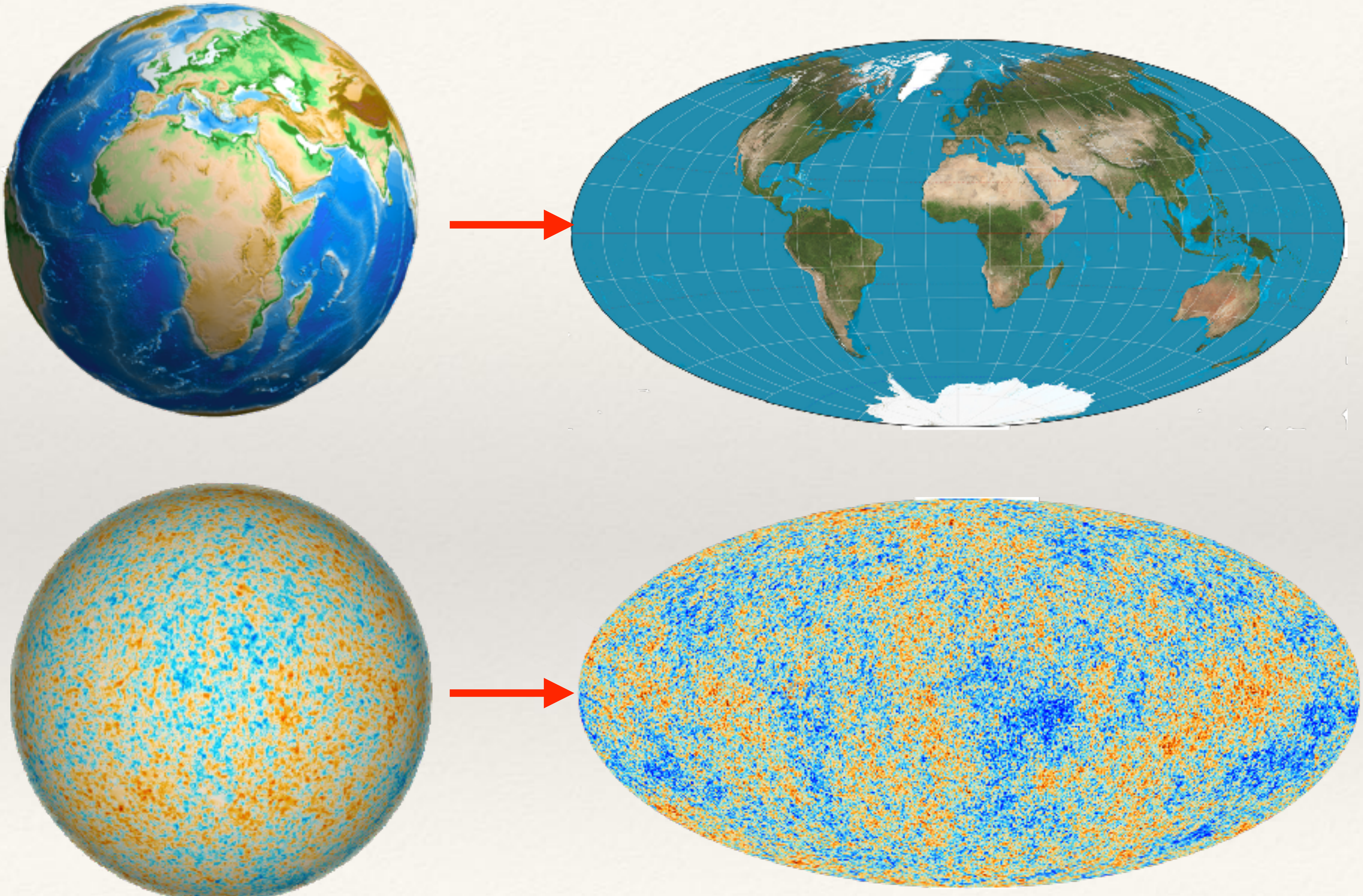
Mid IR (12+25 microns)



Far IR (100 microns)

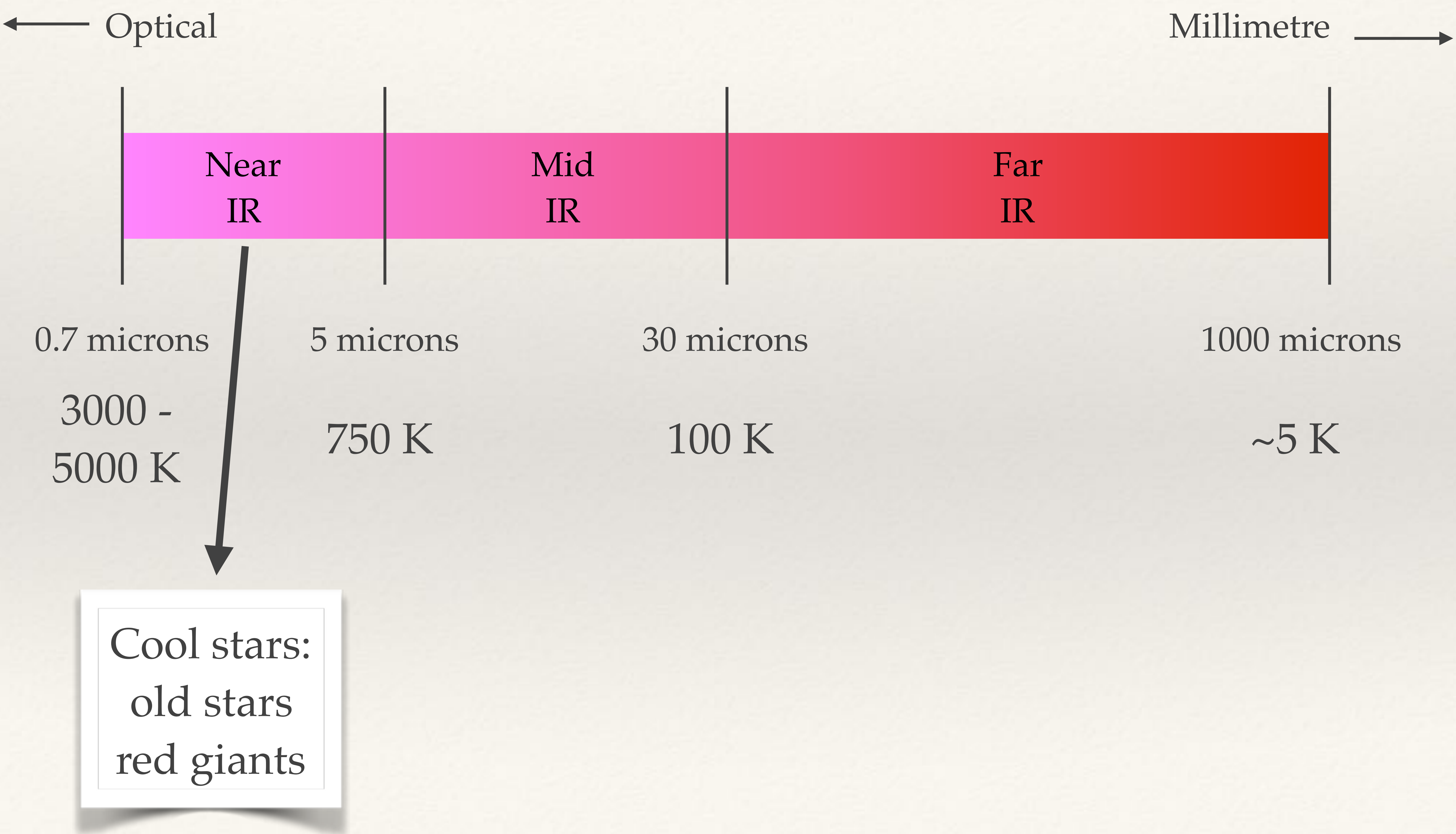


Aitoff projection

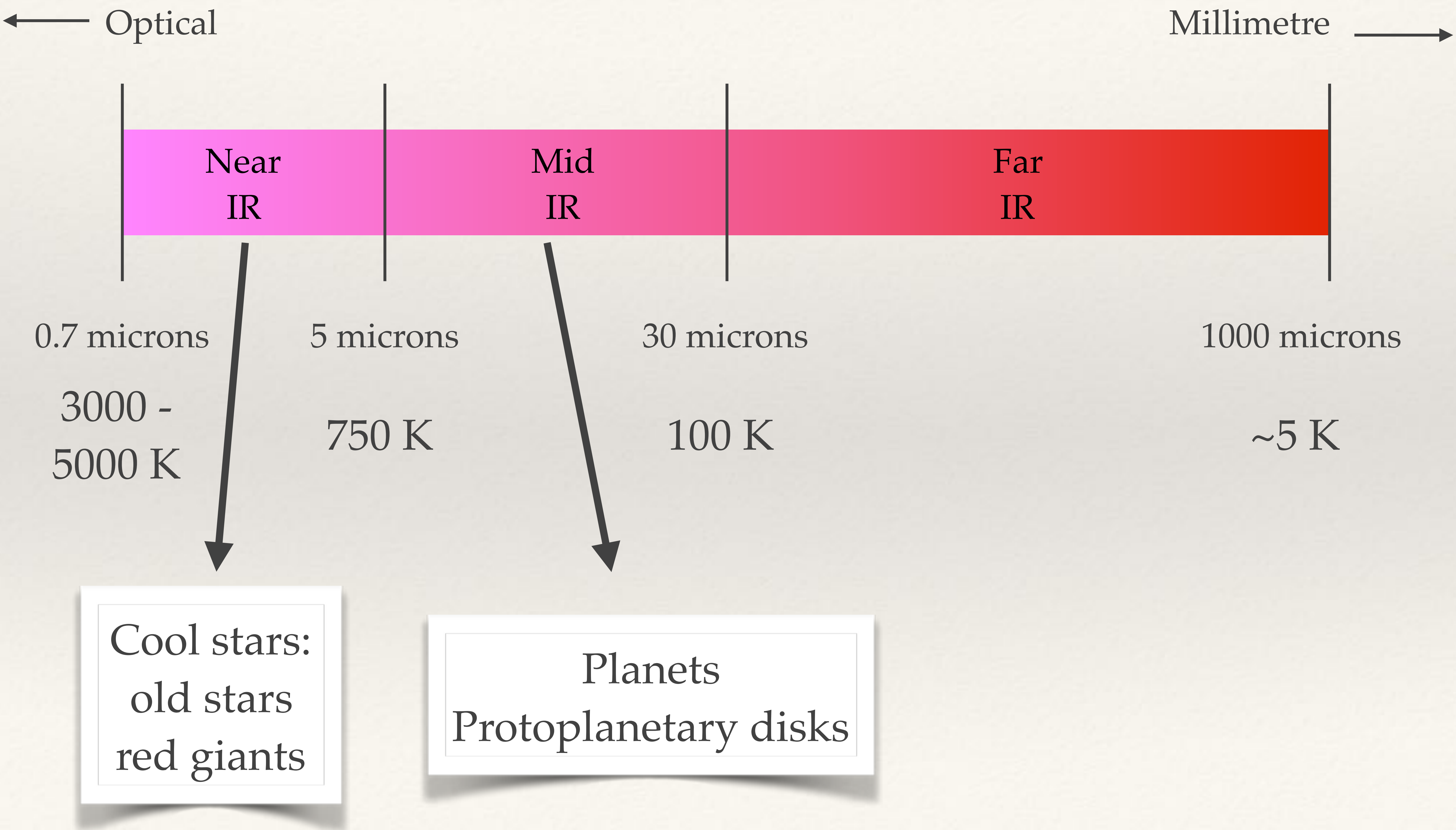


The infra-red

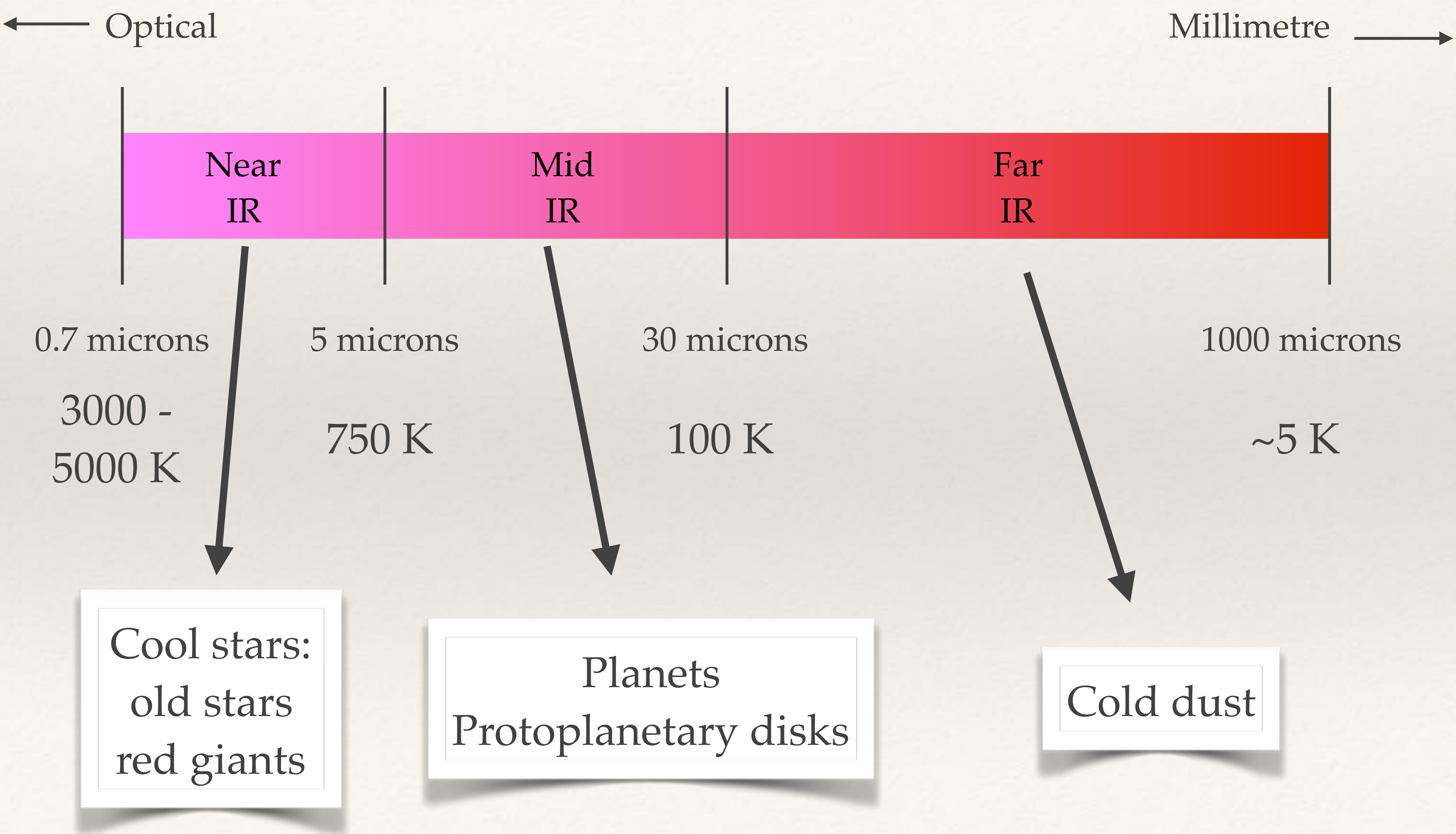
The infra-red



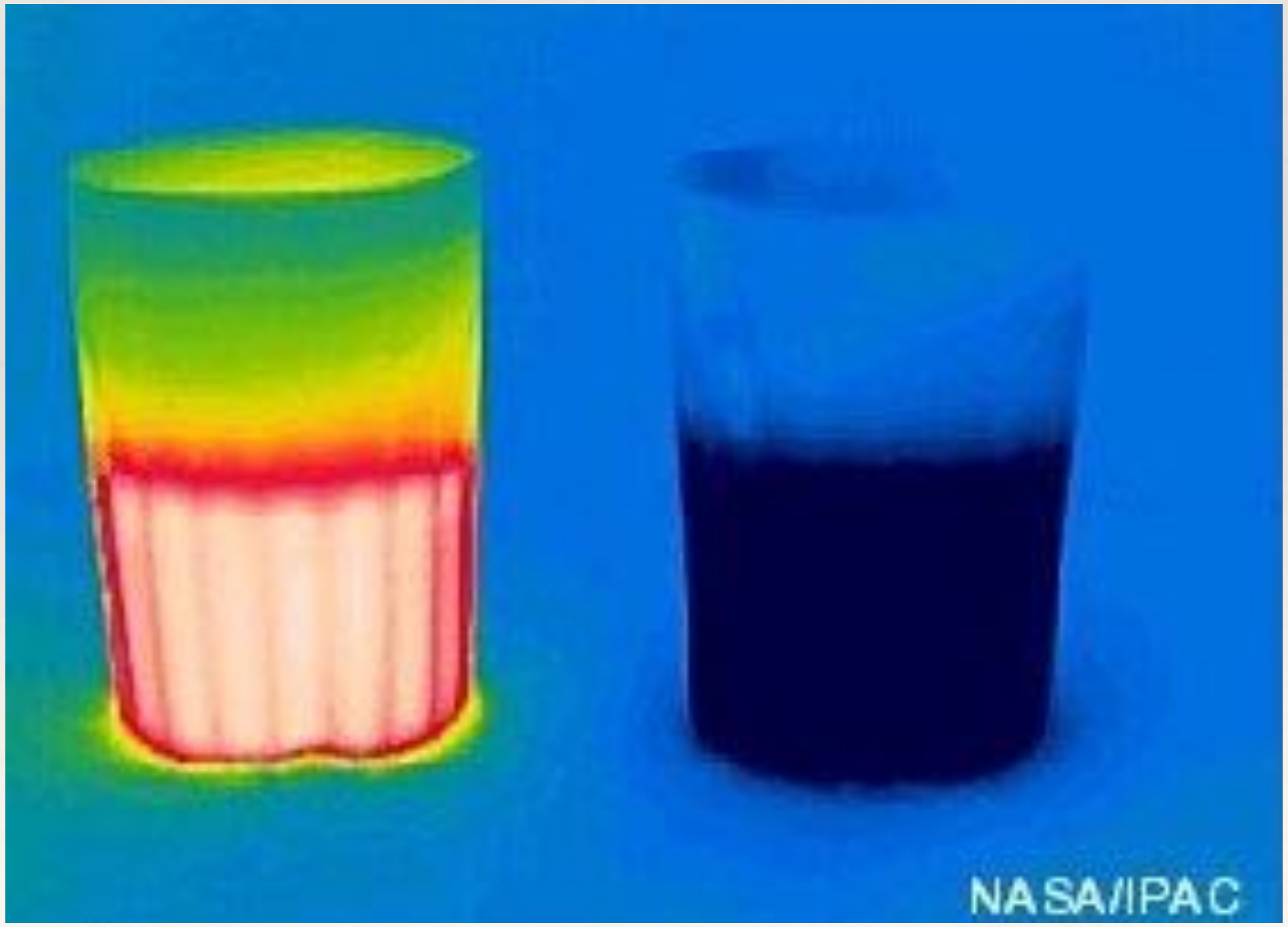
The infra-red



The infra-red

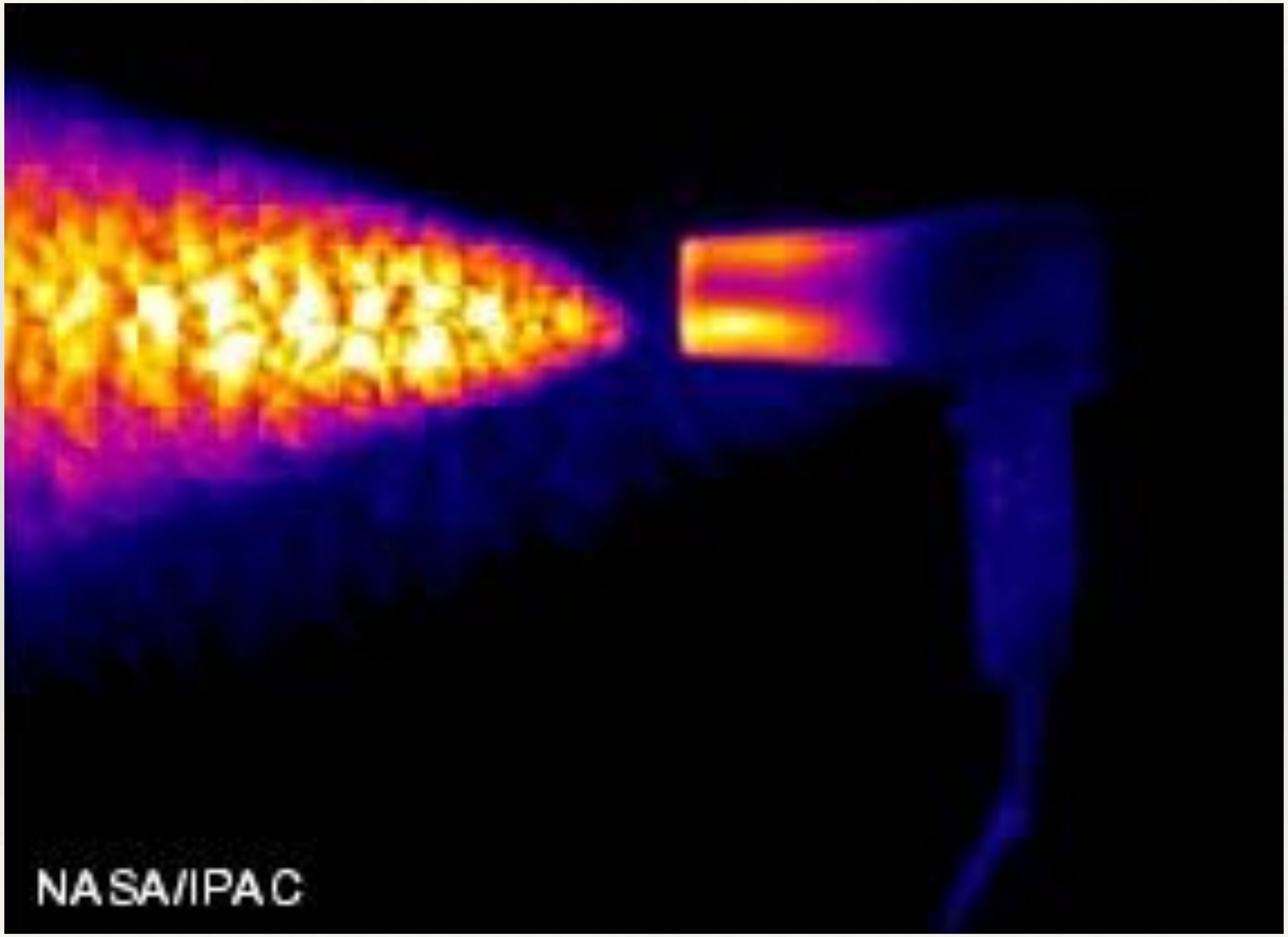


The infra-red



The infra-red

The infra-red



The infra-red

The infra-red

So, IR can be penetrating…
(can see through dust, smoke, plastic bags)

And IR can be blocked…
(can't see through glass)

What about the atmosphere?

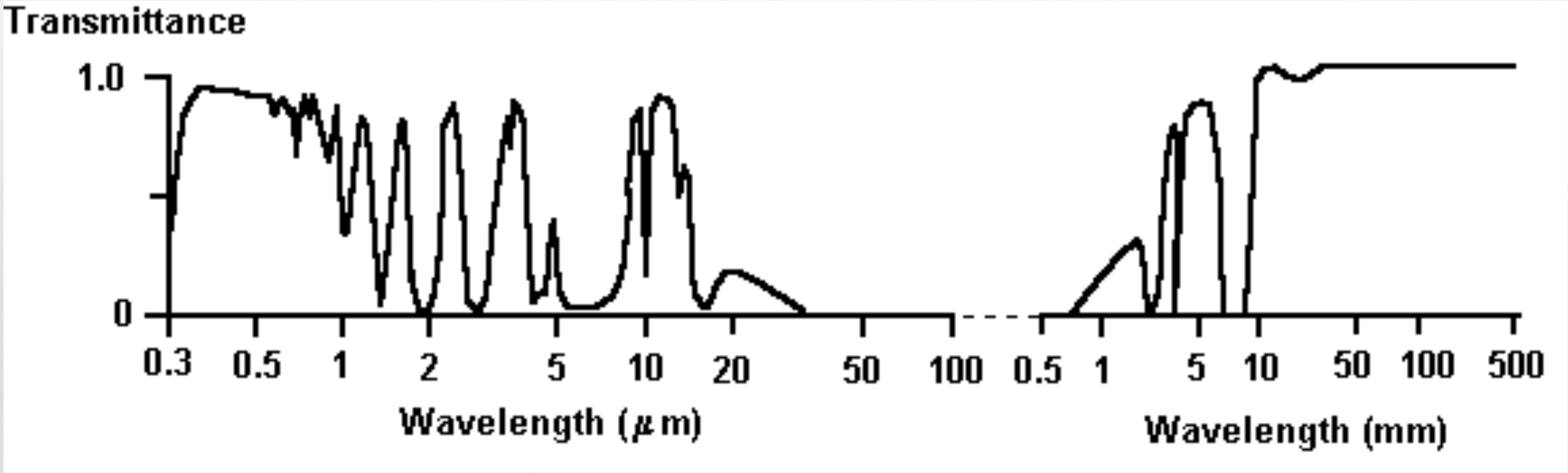
Atmospheric windows

Humans are optical creatures, and think in optical terms: “the atmosphere is transparent"

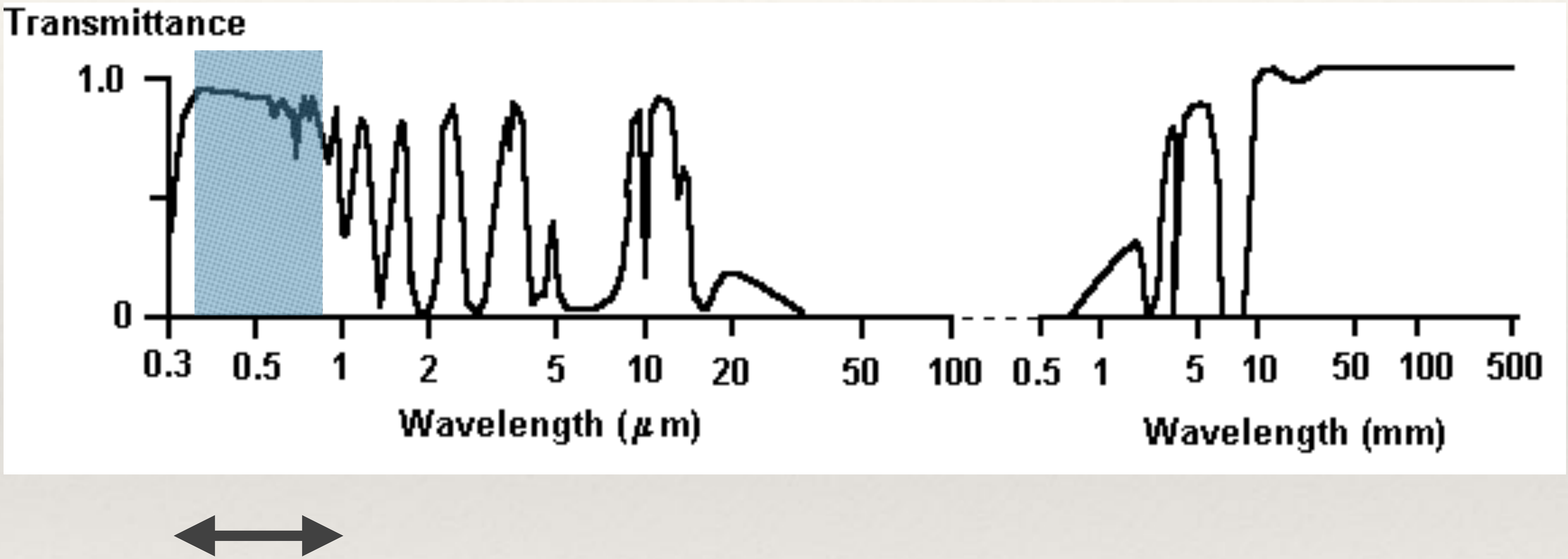
This isn’t true at all wavelengths!

The atmosphere is transparent at wavelengths ~0.5 um, but totally opaque at other wavelengths

Atmospheric windows

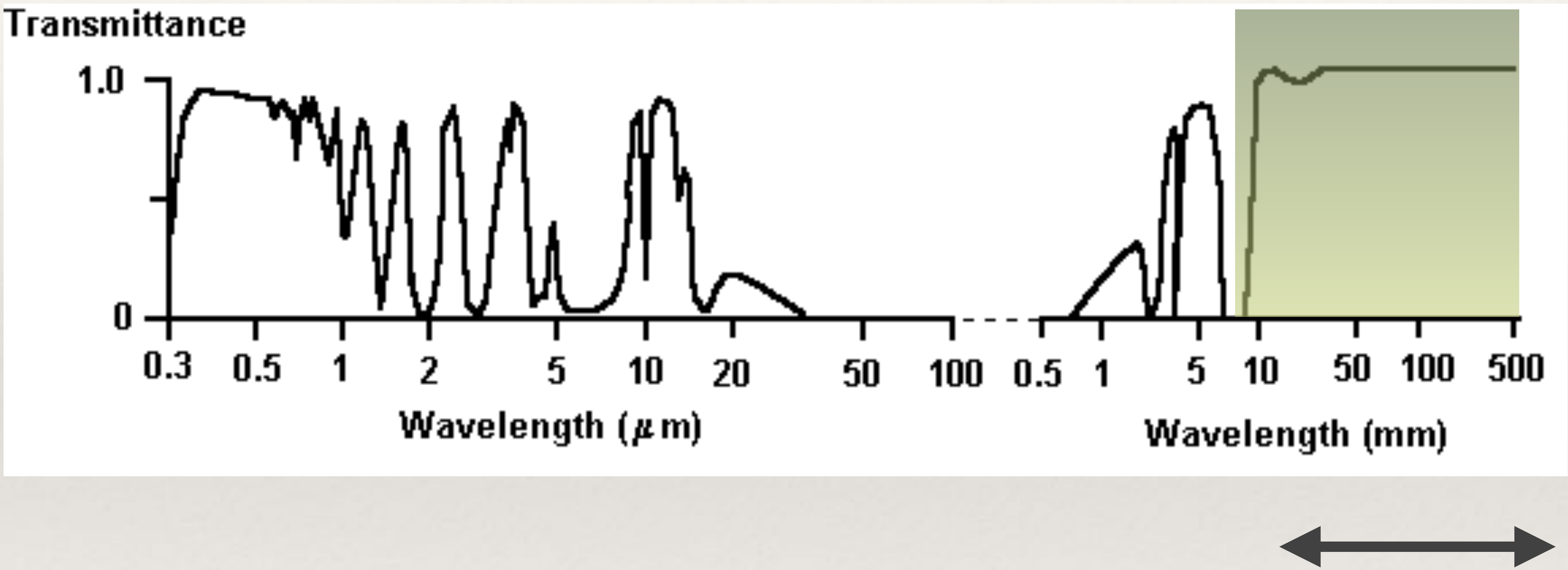


Atmospheric windows



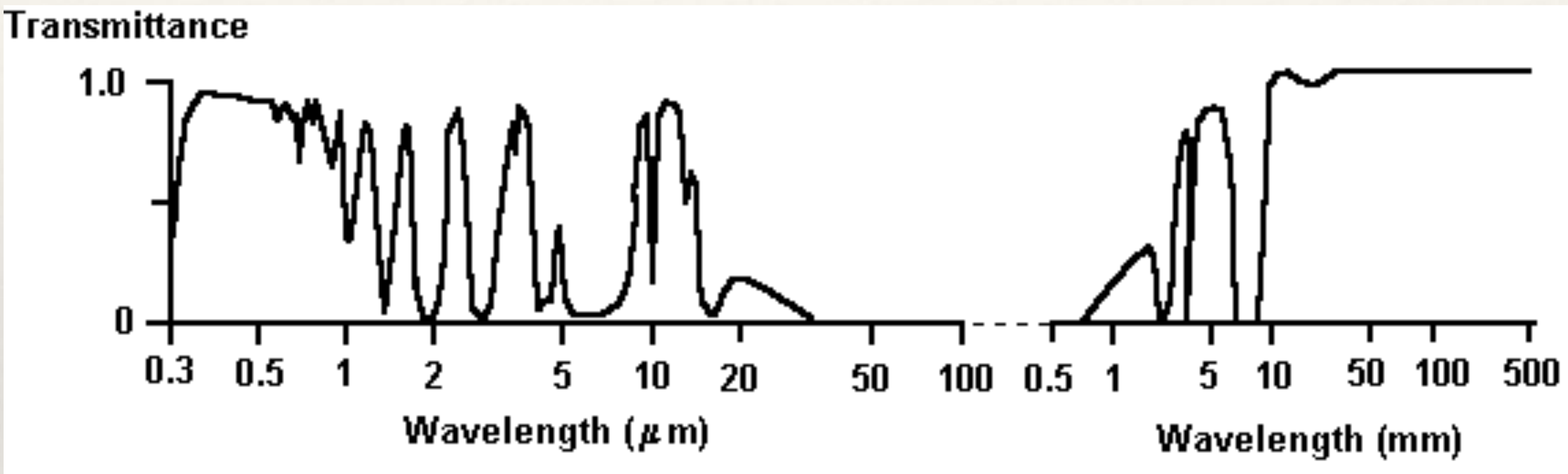
Optical regime:
Atmosphere is transparent

Atmospheric windows



Radio regime:
Atmosphere is transparent

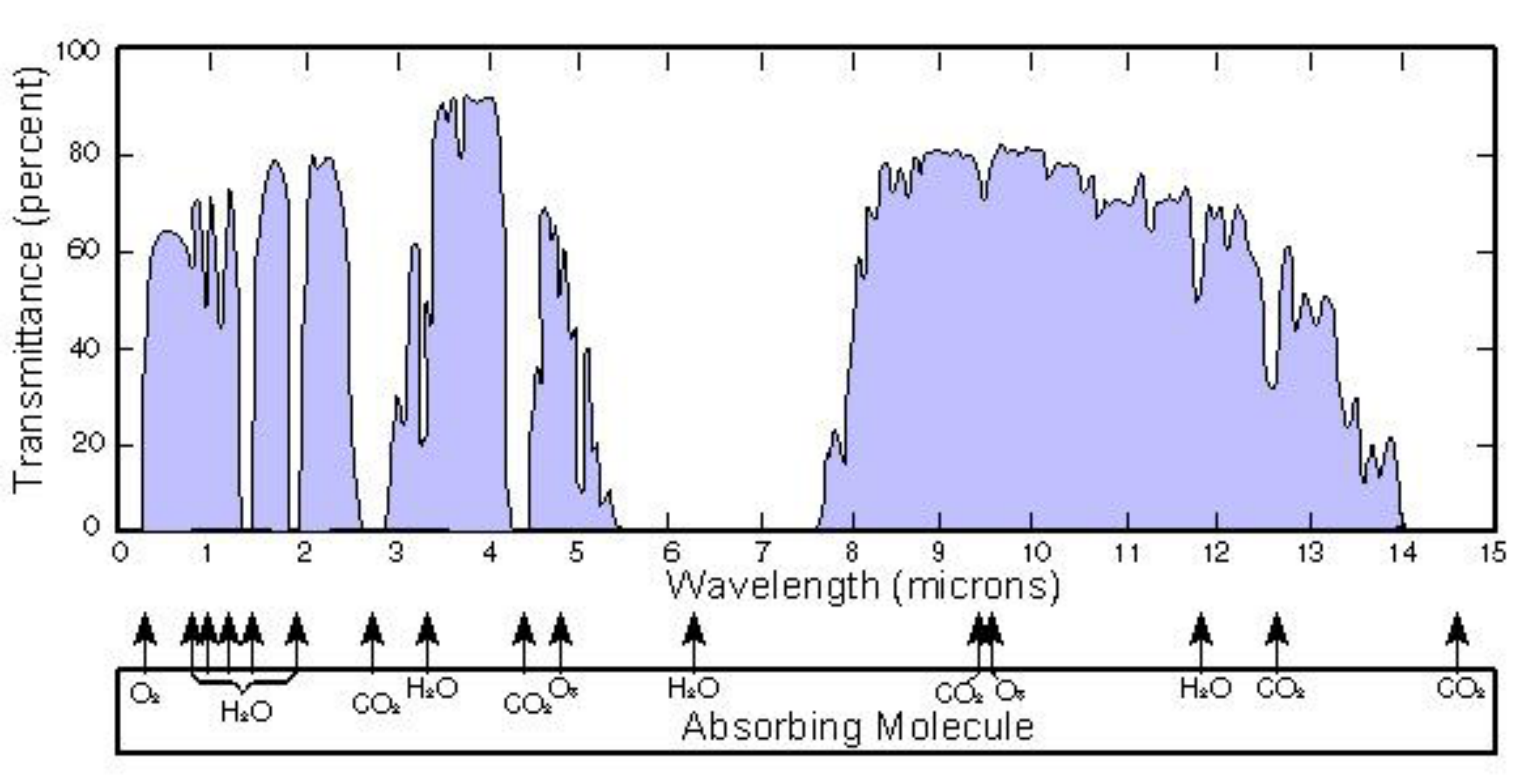
Atmospheric windows



Infrared (and sub-mm!) regimes:
Atmosphere is patchy. Can only observe in 'windows'

(and between 10um and ~0.5mm, almost impossible)

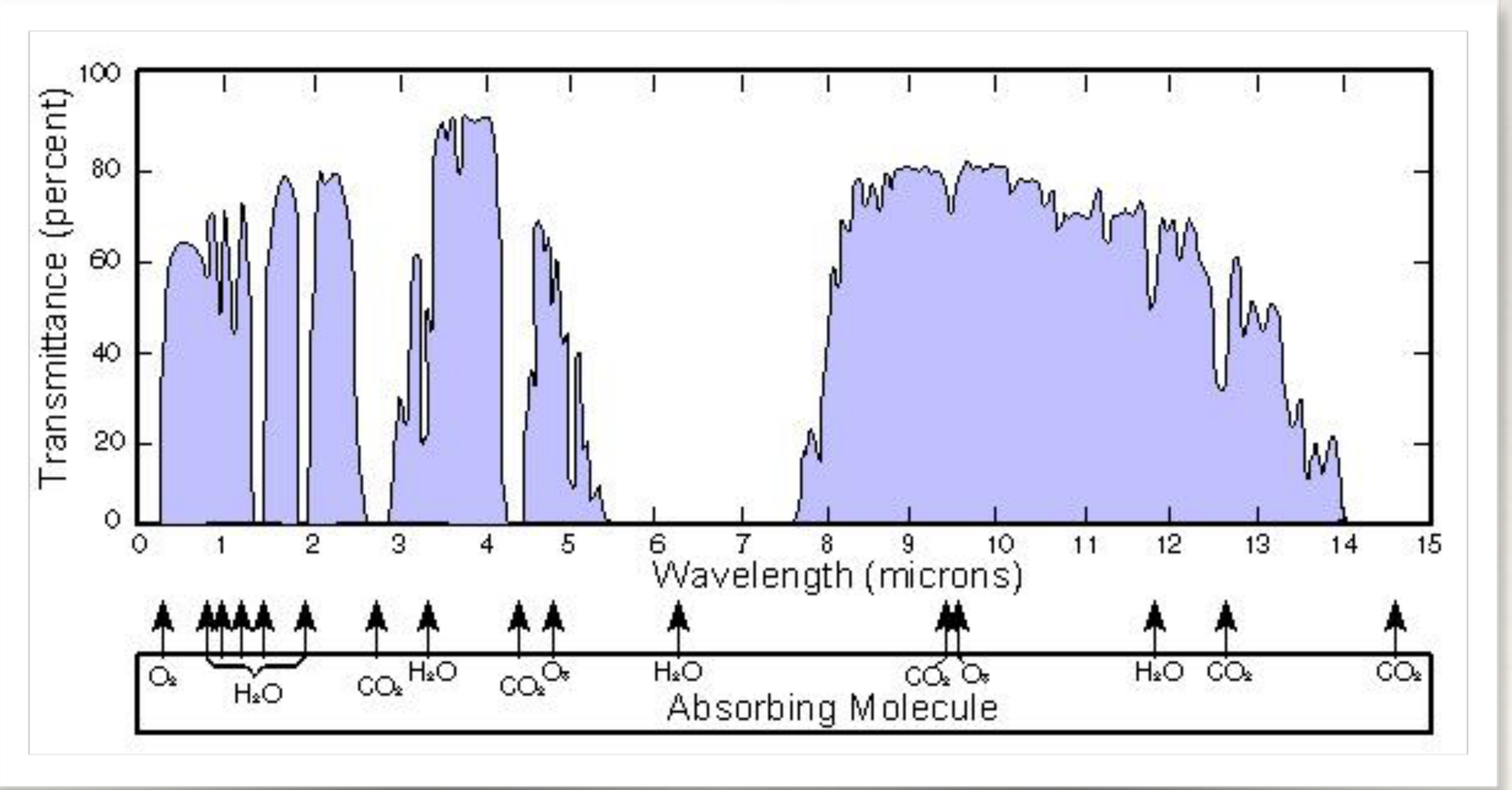
Atmospheric windows



Observing in the IR

So… how do we observe in the IR?

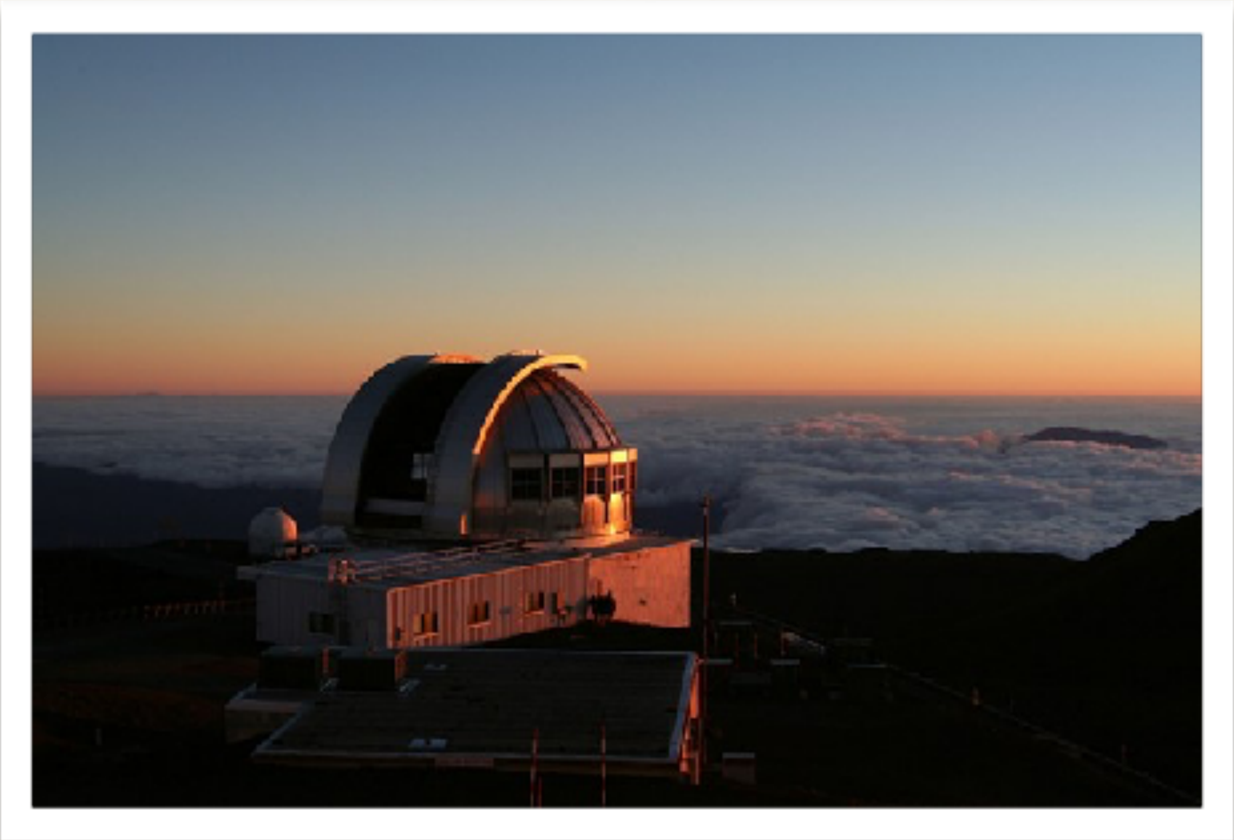
1. Use atmospheric windows



Observing in the IR

So… how do we observe in the IR?

1. Use atmospheric windows
2. Get above as much atmosphere as possible



Observing in the IR

So… how do we observe in the IR?

1. Use atmospheric windows
2. Get above as much atmosphere as possible

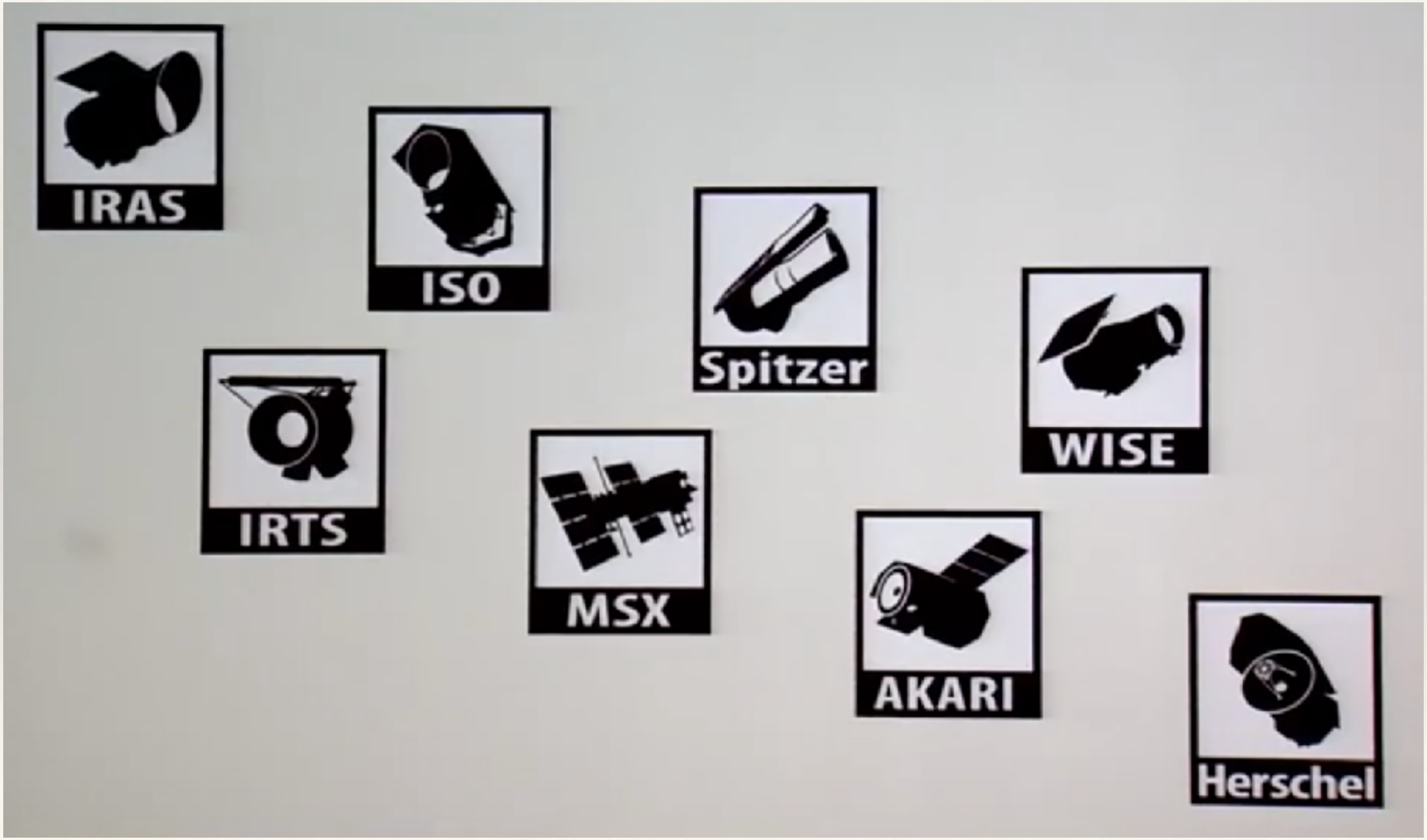

N747N

Observing in the IR

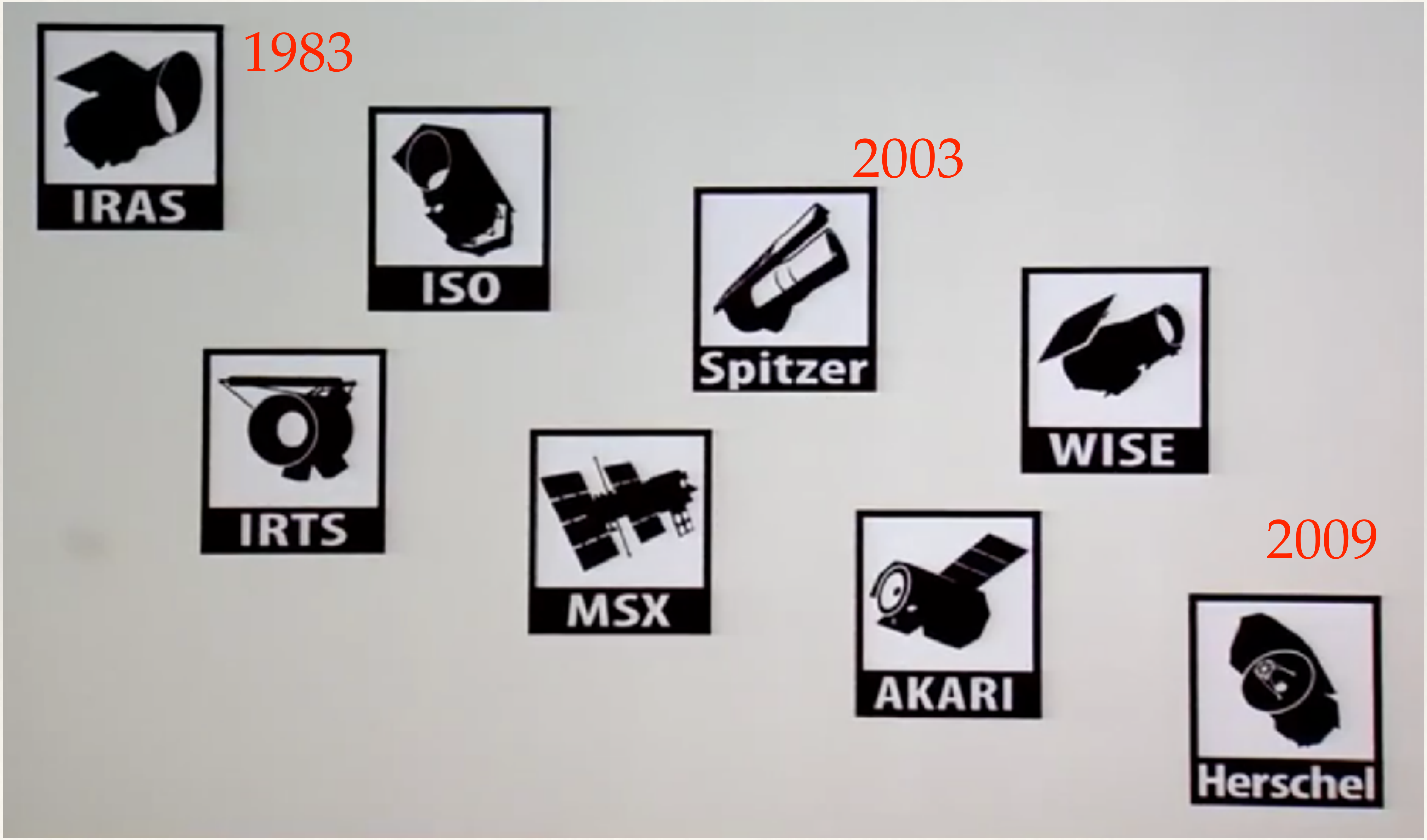
So… how do we observe in the IR?

1. Use atmospheric windows
2. Get above as much atmosphere as possible
3. Get out of the atmosphere altogether…

IR Space Telescopes



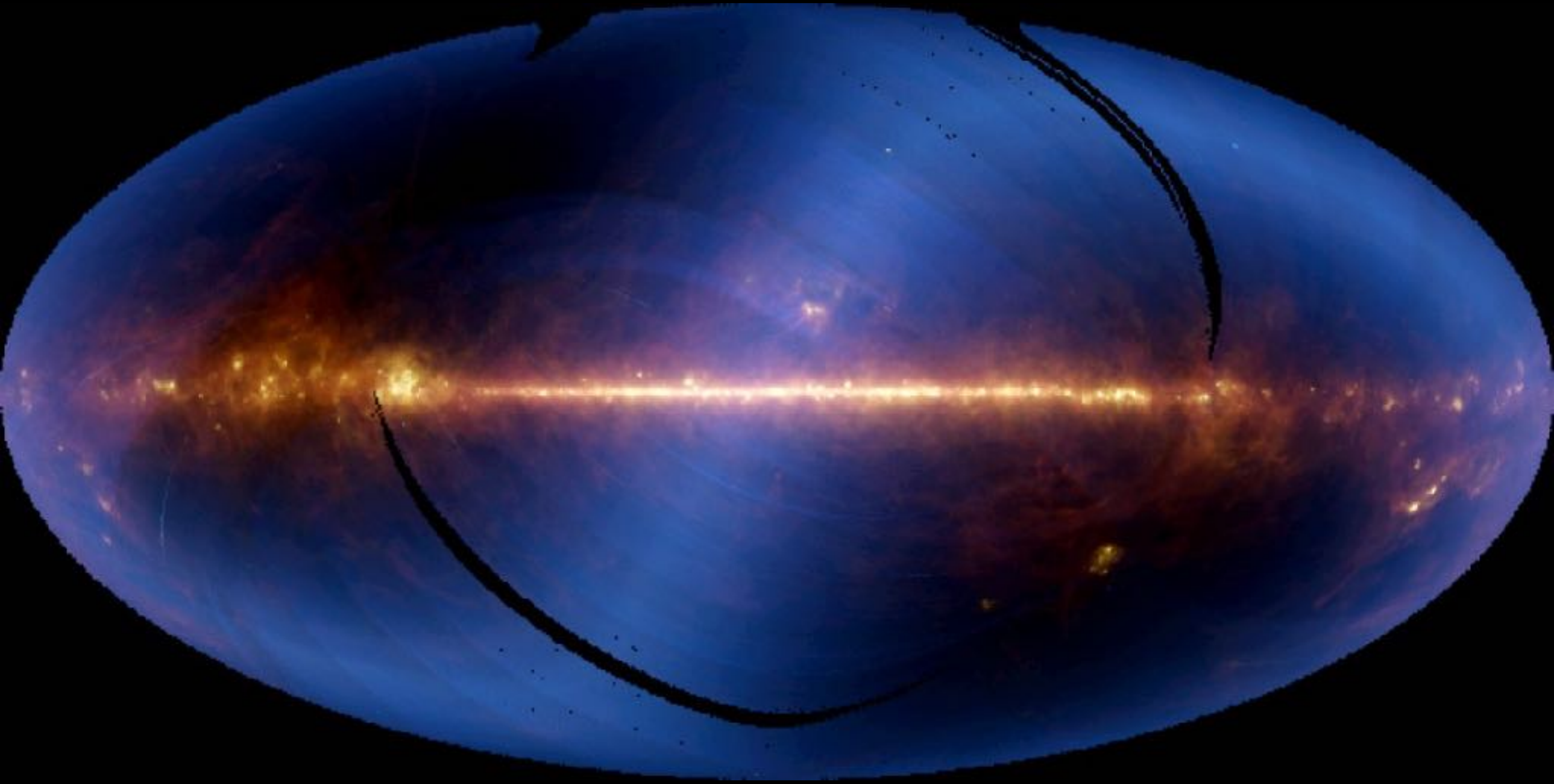
IR Space Telescopes



The Infrared Astronomical Satellite (IRAS)

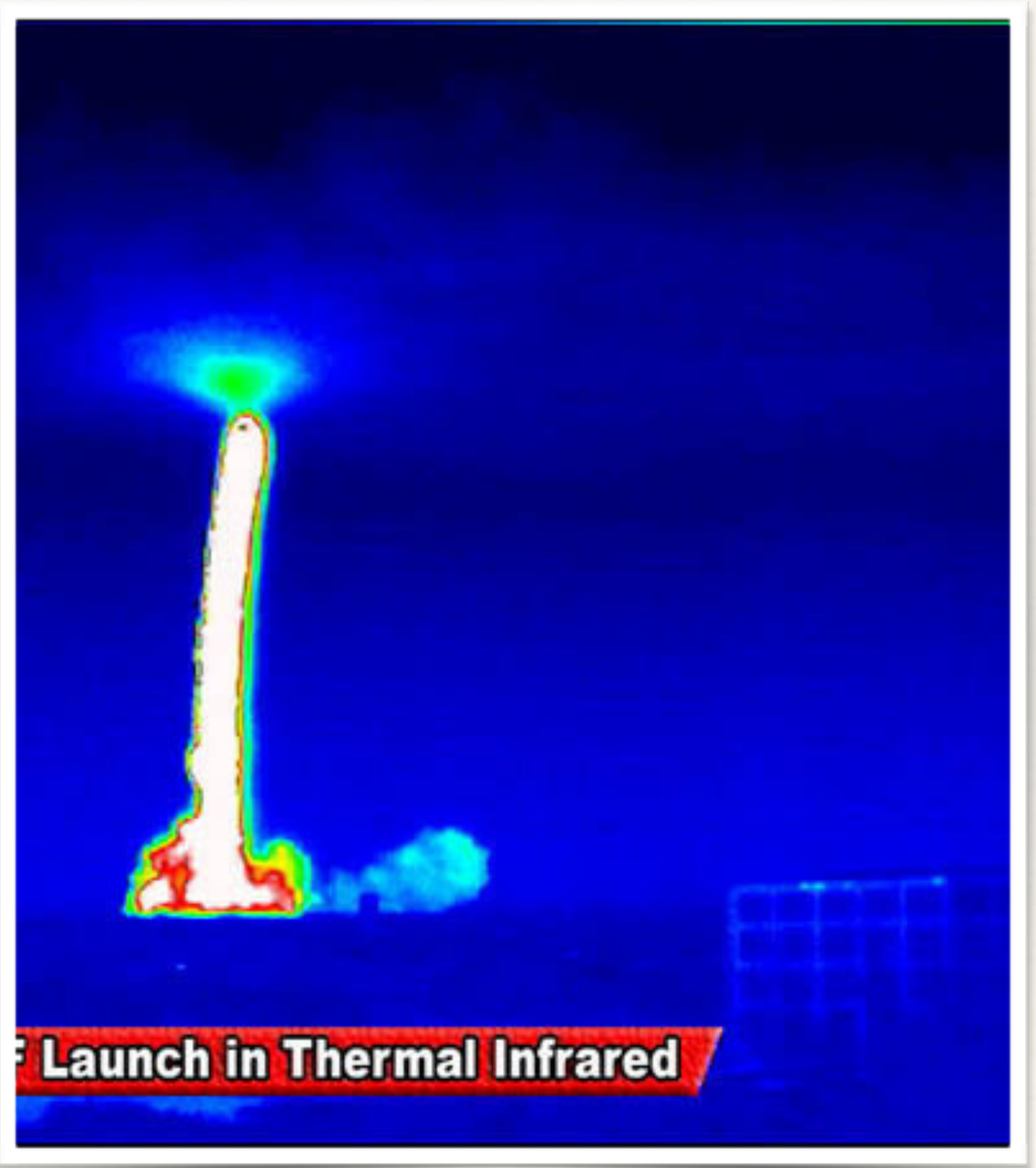
- Launched January 25, 1983
- Really challenging instrument (detectors had to be cold, and nearby electronics had to be warm…)
- Mapped whole sky at 12um, 25um, 60um, and 100um

Mid IR (12+25 microns)



Spitzer Space Telescope

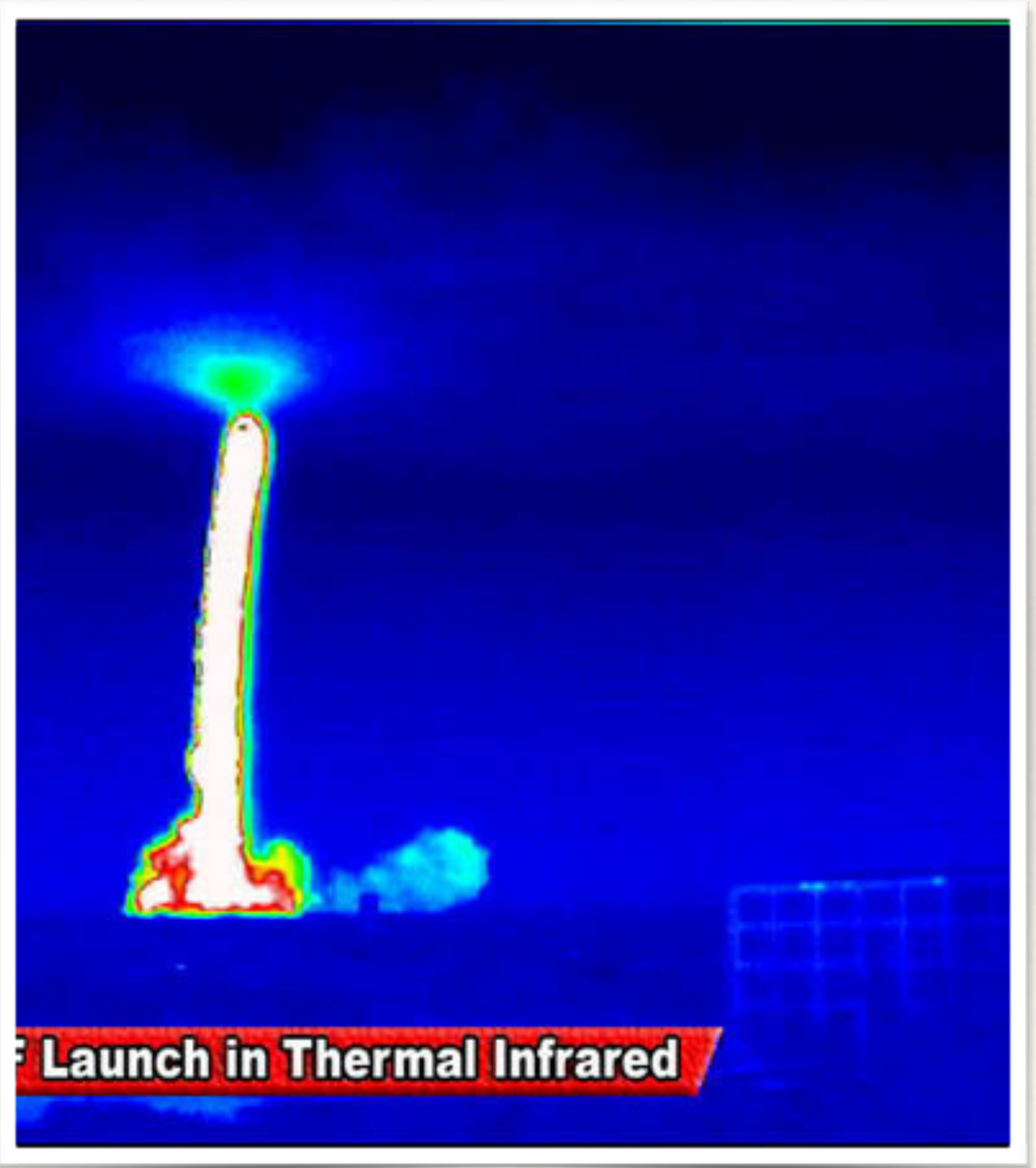
- Launched August 25, 2003
- Followup to IRAS



Spitzer Space Telescope

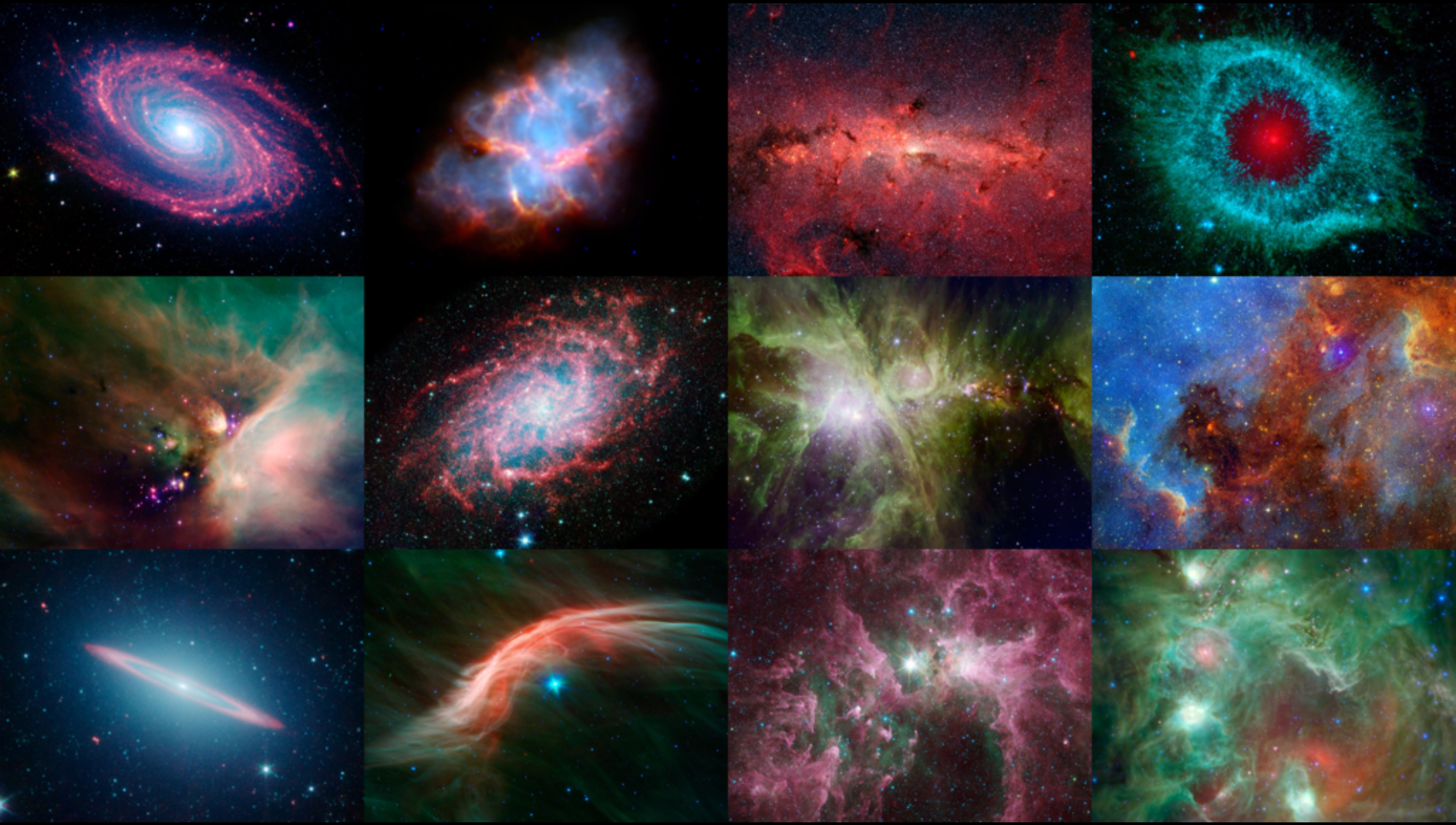
Spitzer Space Telescope

- Launched August 25, 2003
- Followup to IRAS
- 3 instruments, including:
- IRAC (Near-IR camera, operating at 3.6um, 4.5um, 5.8um and 8um)
- MIPS (Far-IR camera, operating at 24um, 70um, and 160um)



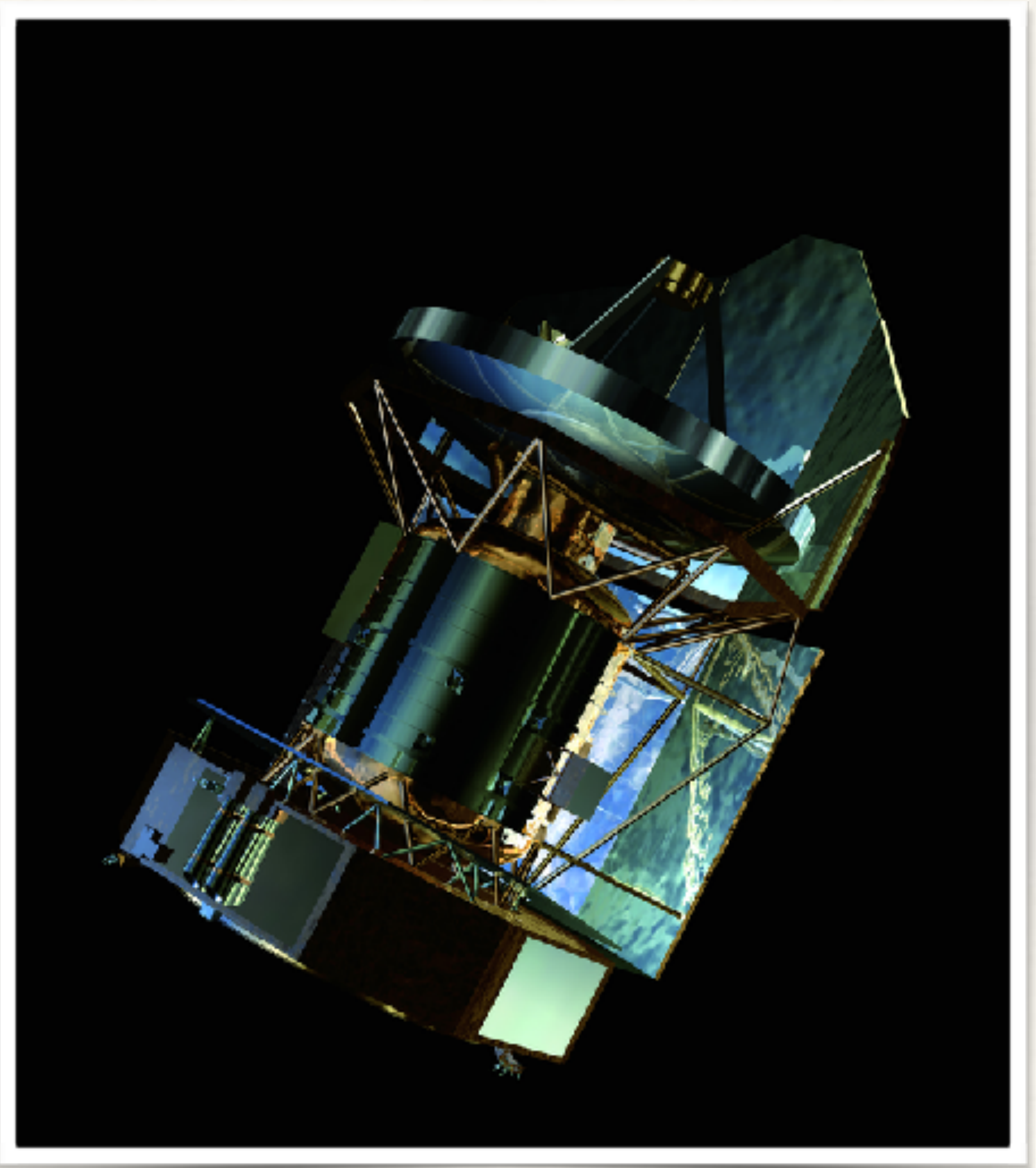
Spitzer Space Telescope

Andromeda at 24um



Herschel Space Observatory

- European mission (not American)
- Launched May 19, 2009 (same payload as Planck!)
- At a *Lagrangian Point*

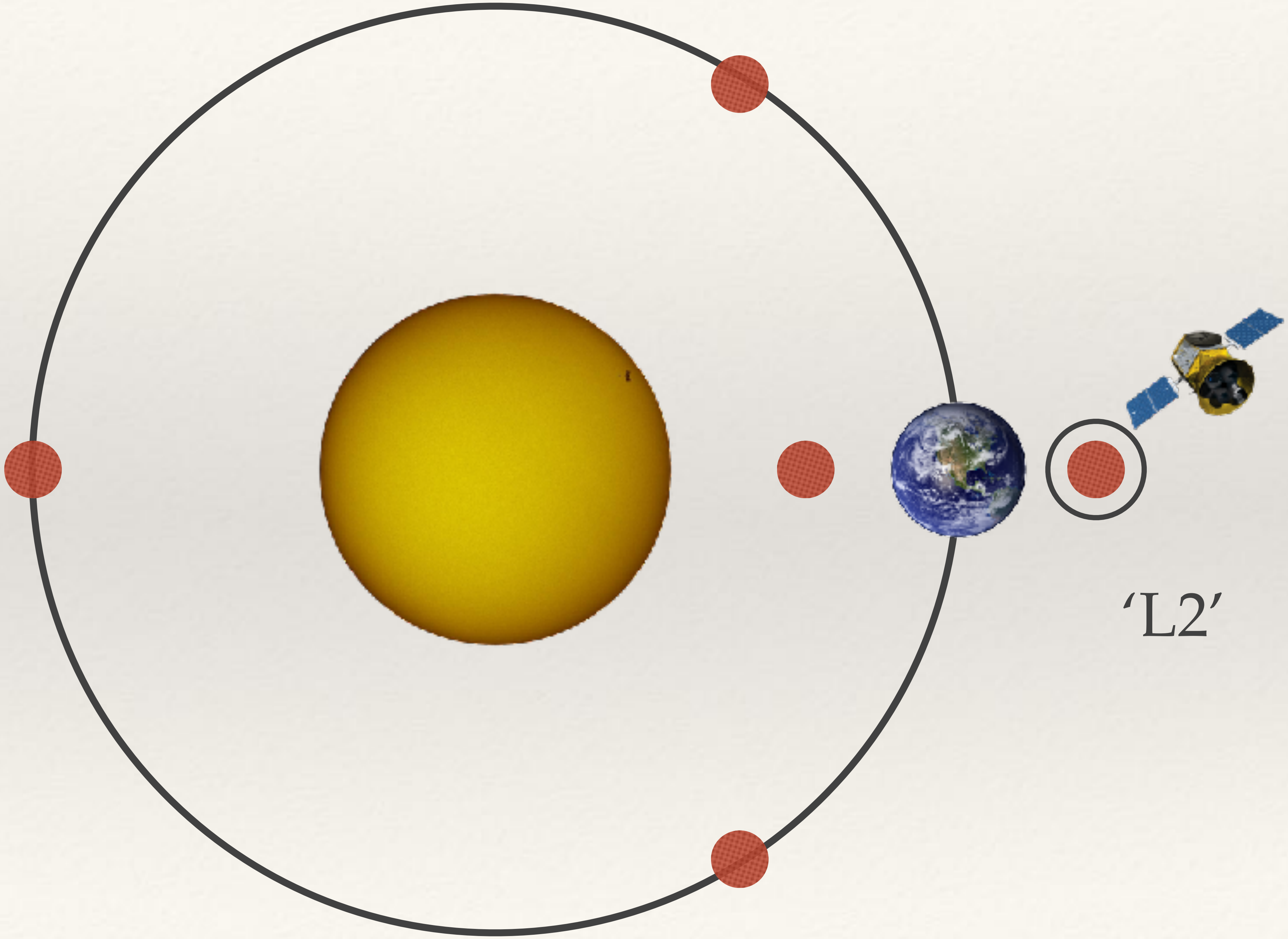


Lagrange Points

Lagrange points are equilibrium points in the Earth-Sun system

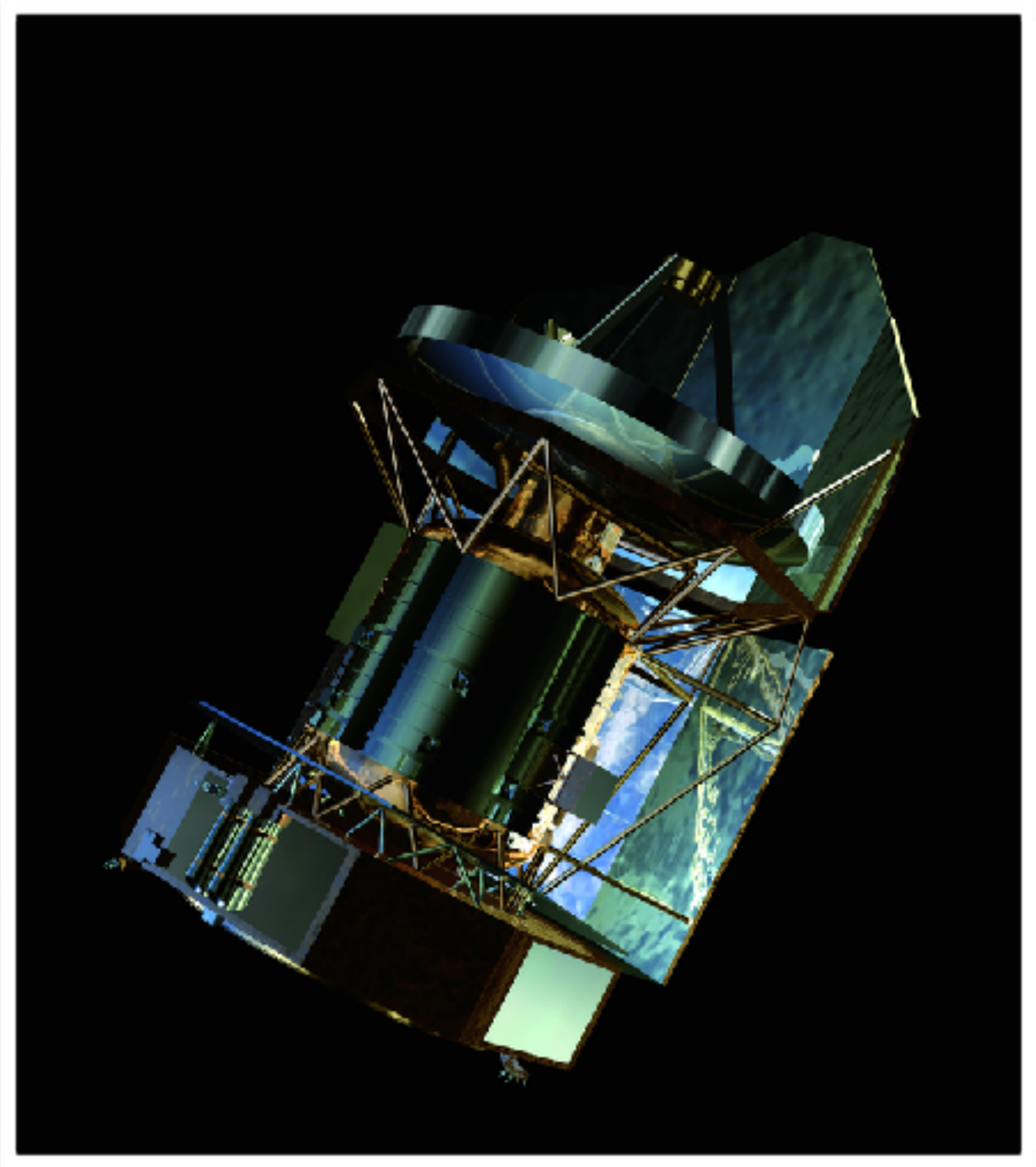
An object placed at a Lagrange point will be stable (good choice for satellites)

Lagrange Points



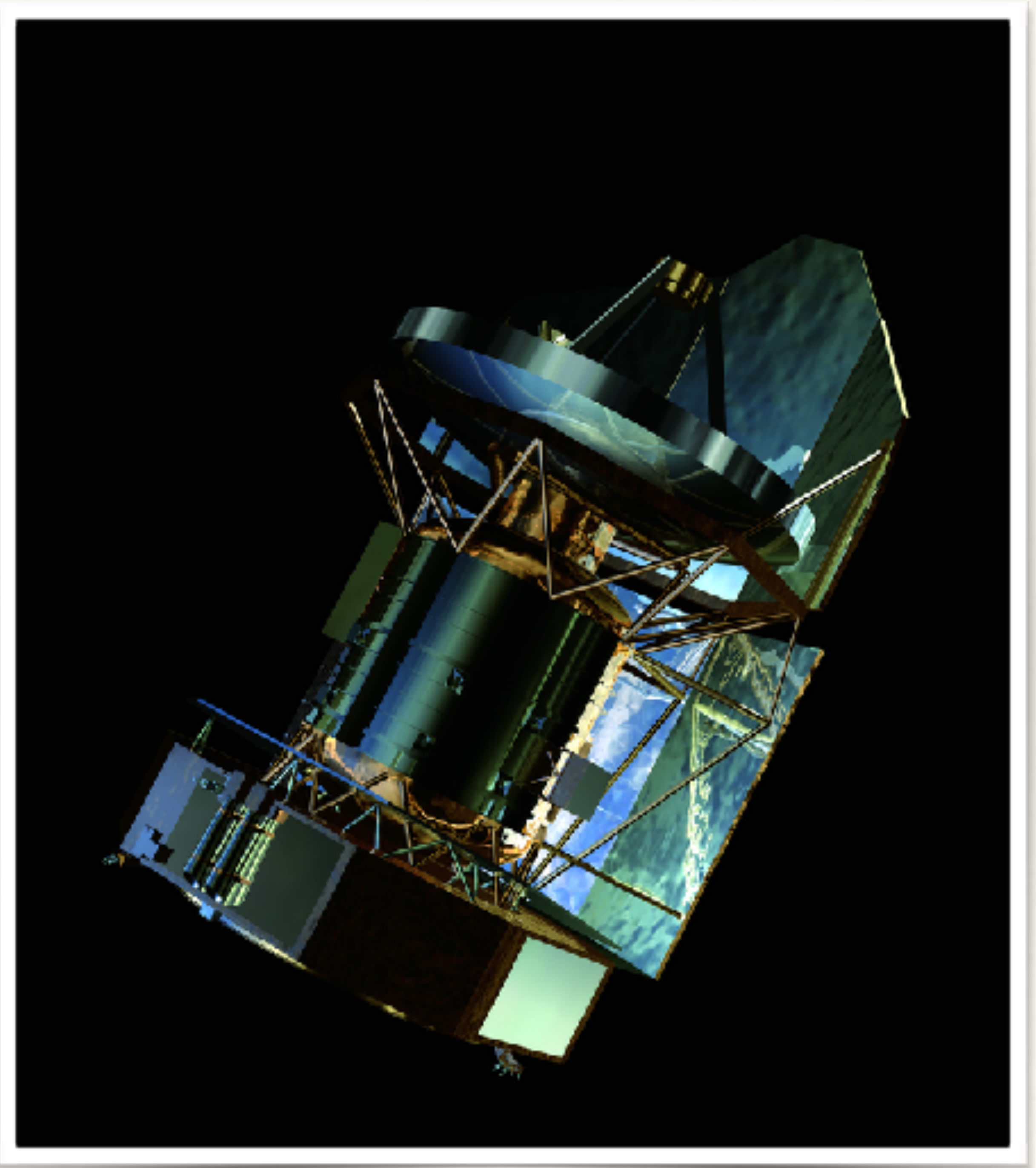
Herschel Space Observatory

- At L2, the Earth+Sun stay in the same position, so shielding and calibration are simple
- Far from the IR radiation from Earth, and doesn't constantly heat+cool due to Earth's shadow (less stress on components)

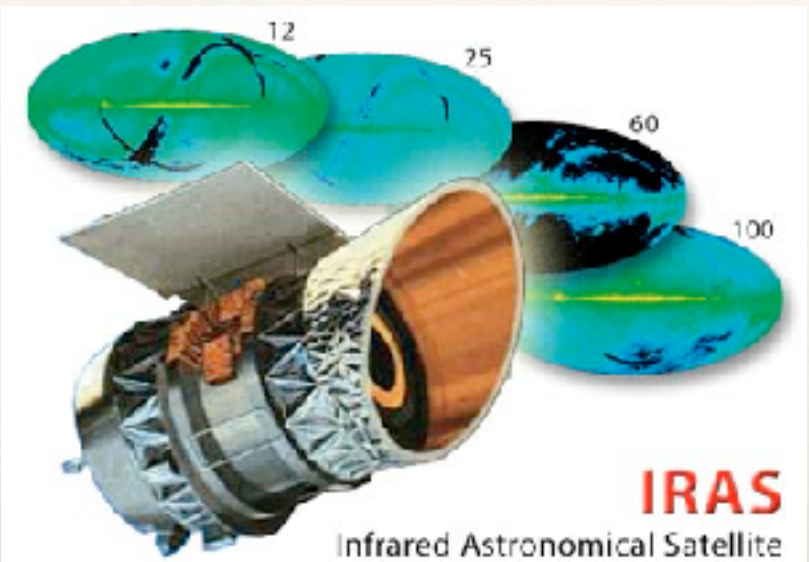


Herschel Space Observatory

- European mission (not American)
- Launched May 19, 2009 (same payload as Planck!)
- Entirely far-IR mission:
- PACS (55-210 um)
- SPIRE (194 - 672 um)
- HIFI (157-212 and 240-625 um)

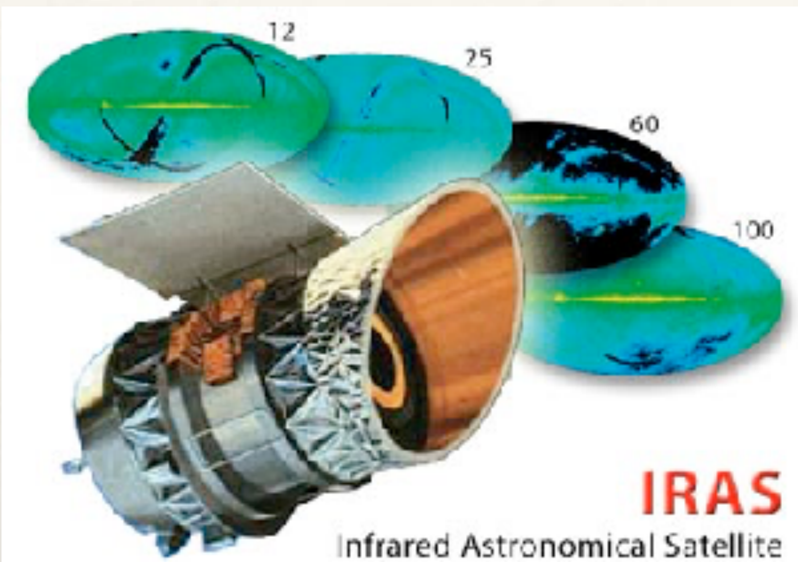


Lifetimes of space-based IR missions



IRAS: January - November 1983
(10 Months)

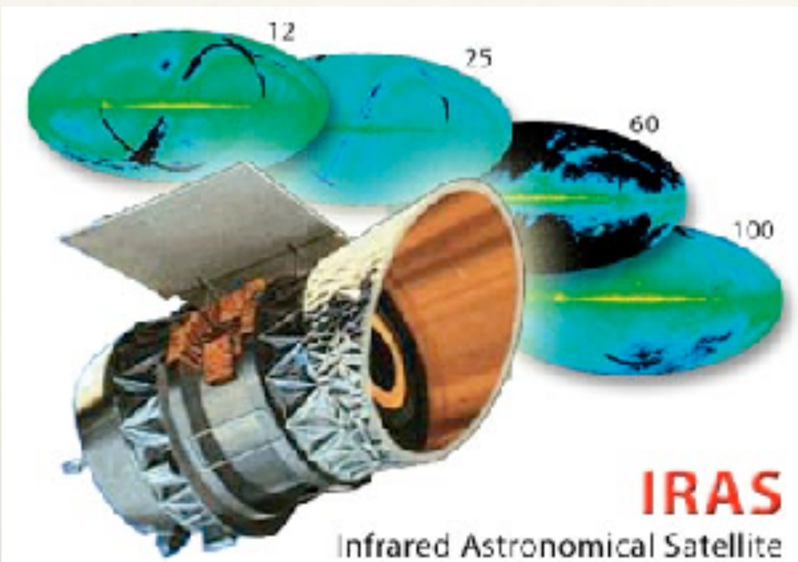
Lifetimes of space-based IR missions



IRAS: January - November 1983
(10 Months)

Spitzer: August 2003 - May 2009
(5.5 yr+… now in warm mode)

Lifetimes of space-based IR missions



Spitzer: August 2003 - May 2009
(5.5 yr+… now in warm mode)

IRAS: January - November 1983
(10 Months)

Herschel: May 2009 - April 2013
(4 years)

What is in the infrared sky?

- Dust
- Protoplanetary disks
- Brown dwarf stars

What is in the infrared sky?

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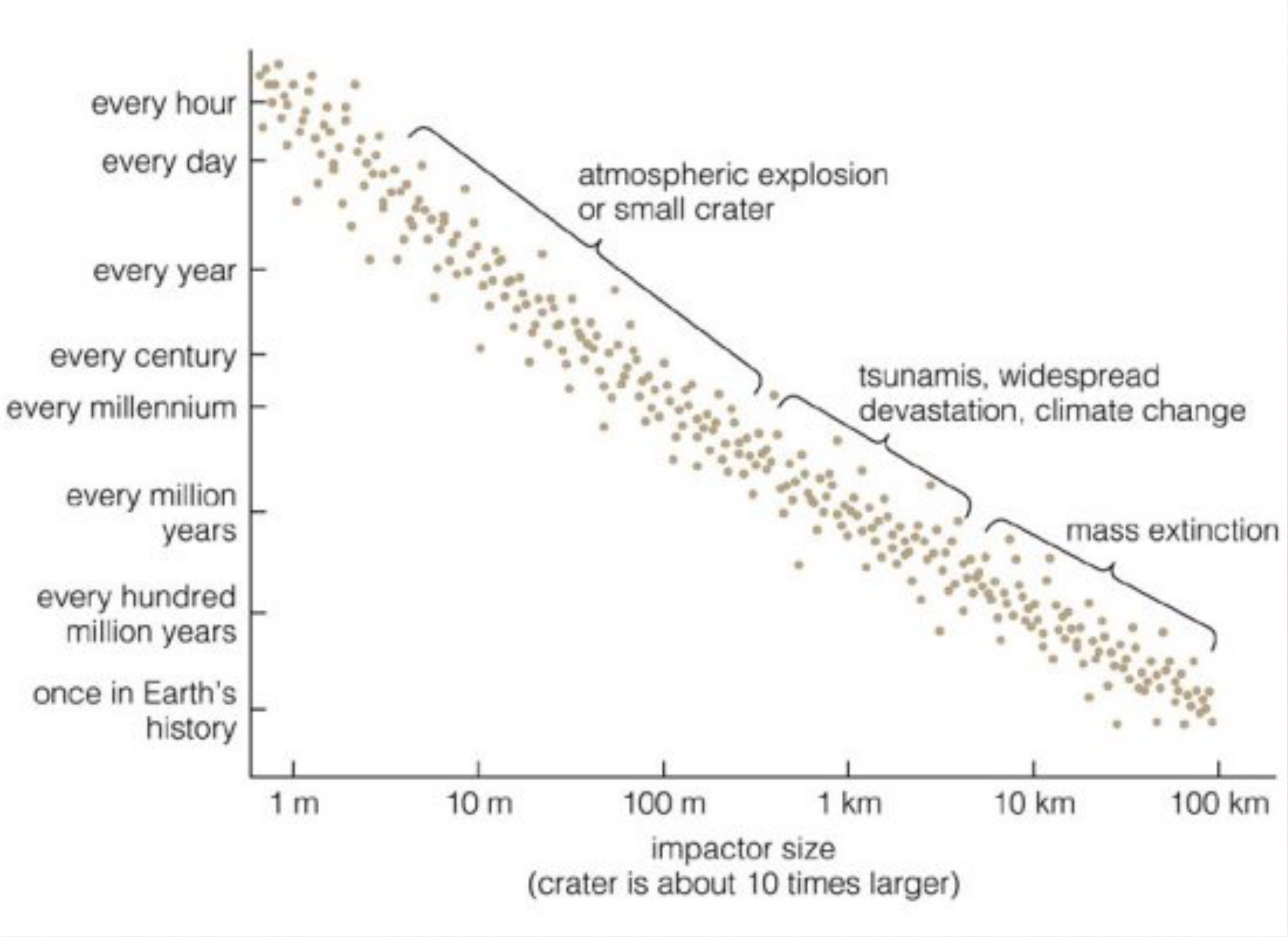
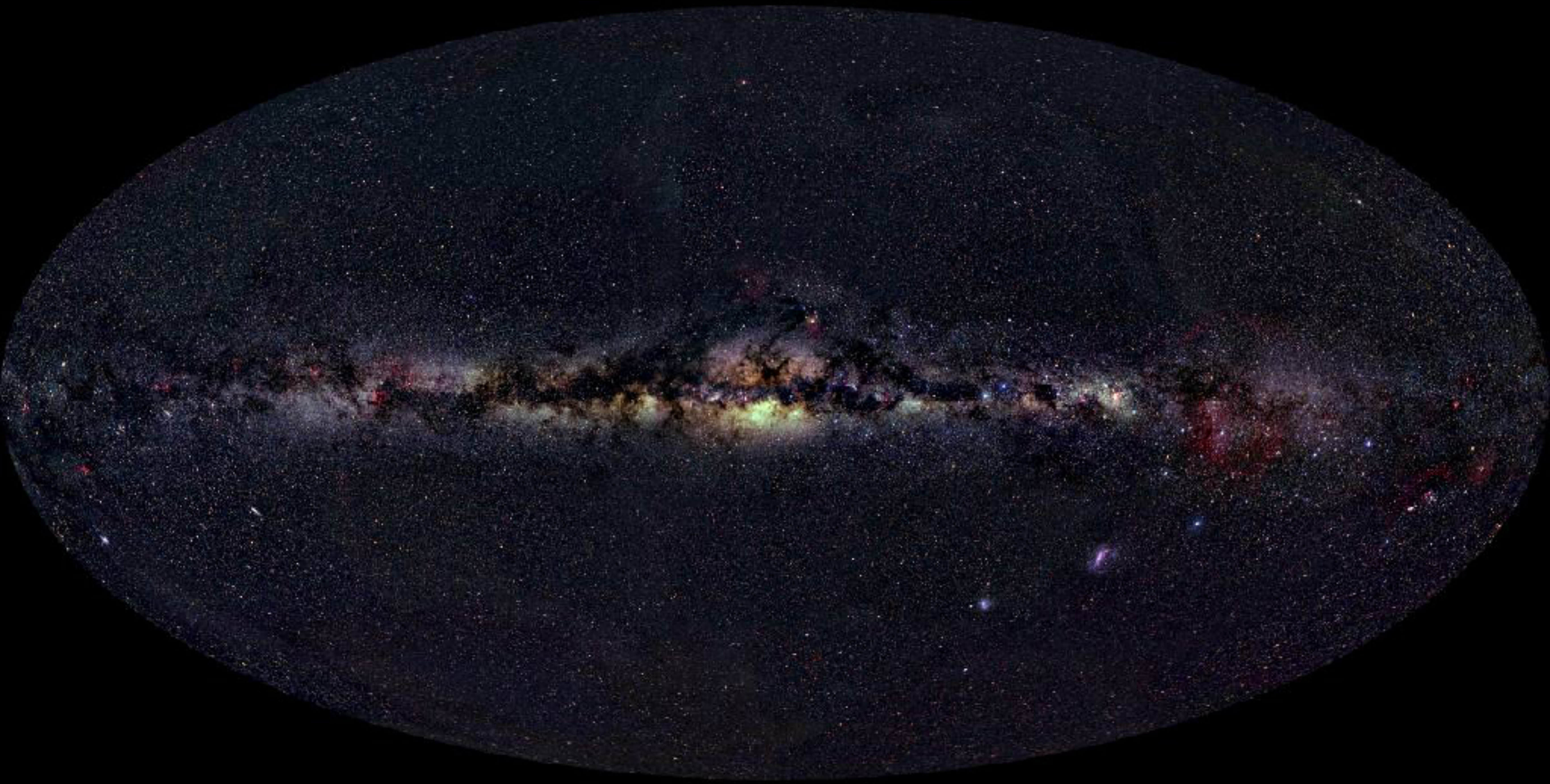
Cosmic dust



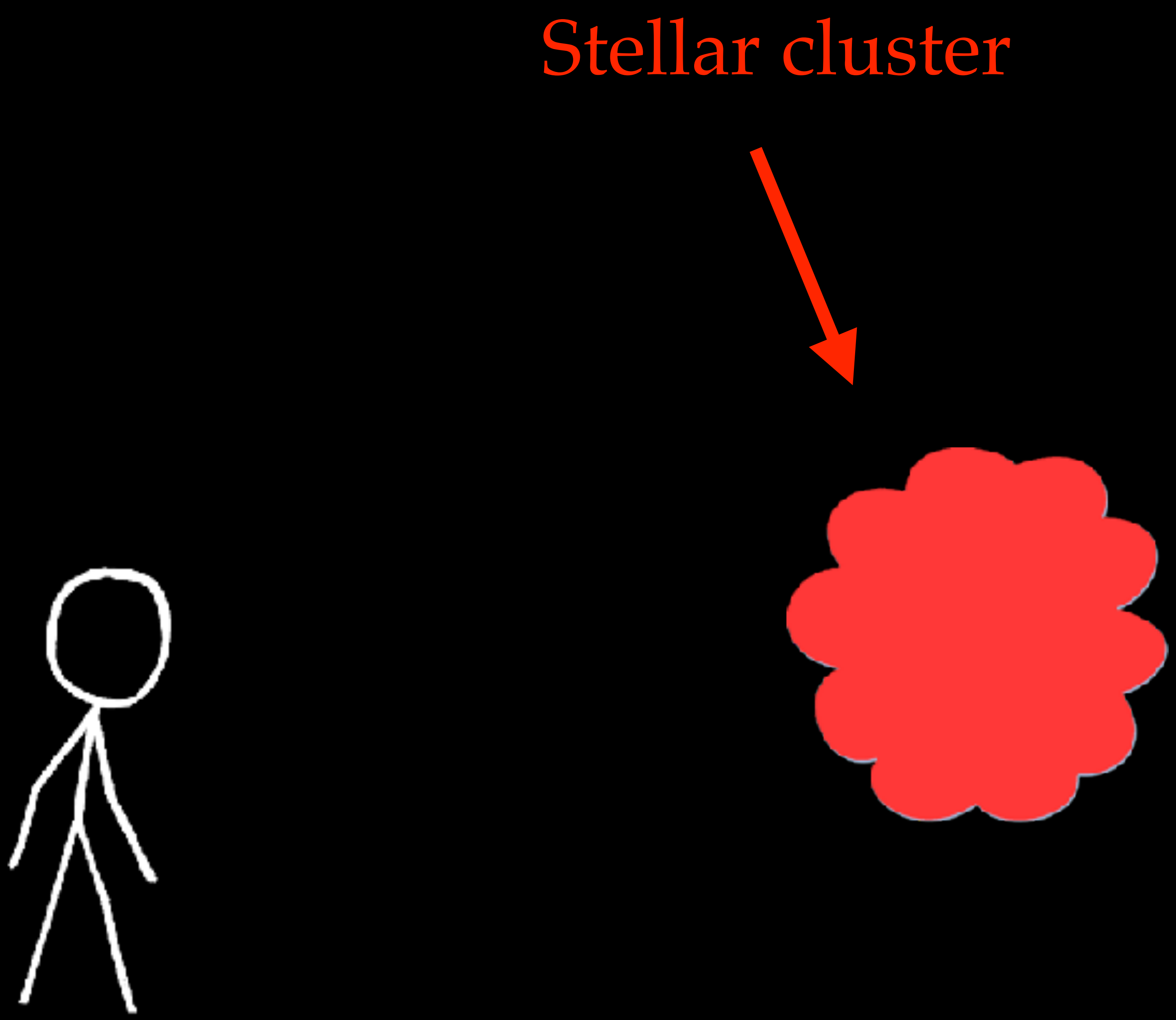
40 tonnes of cosmic dust fall on Earth every day

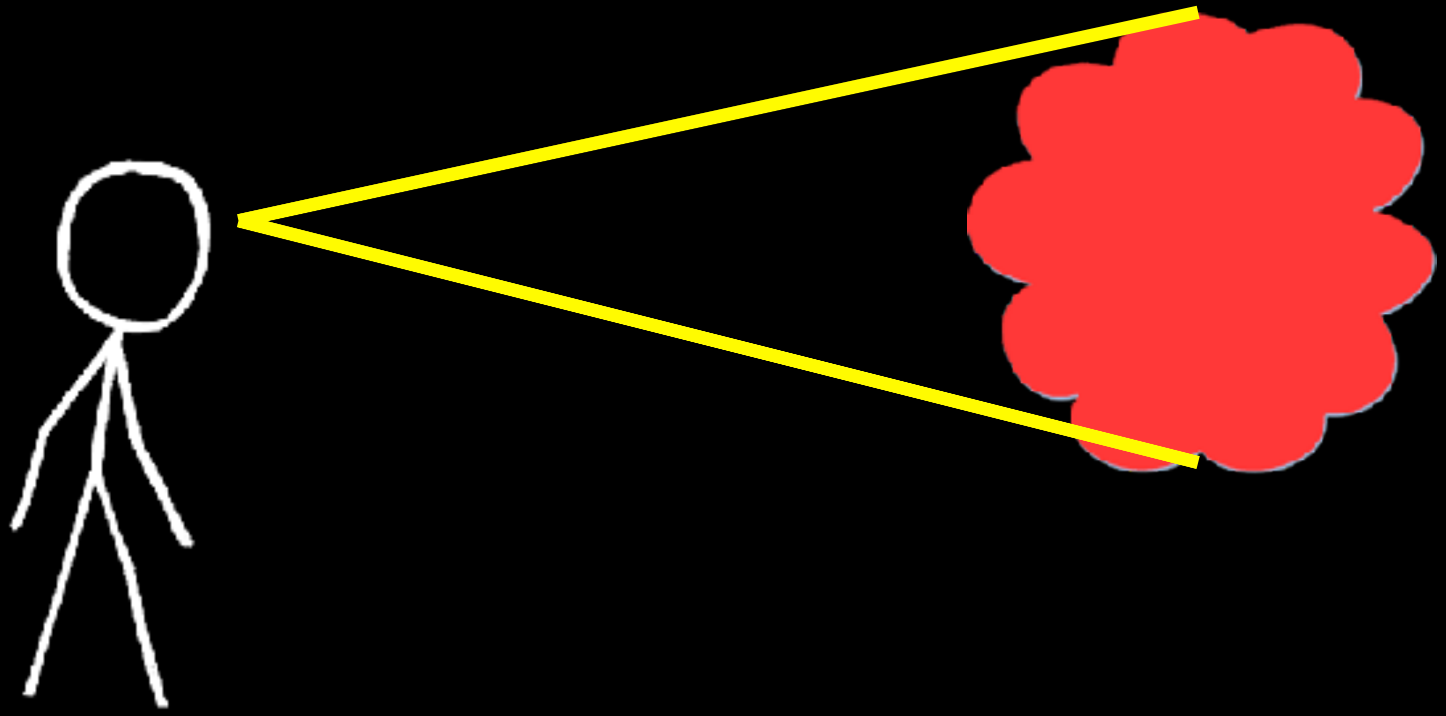
Cosmic dust

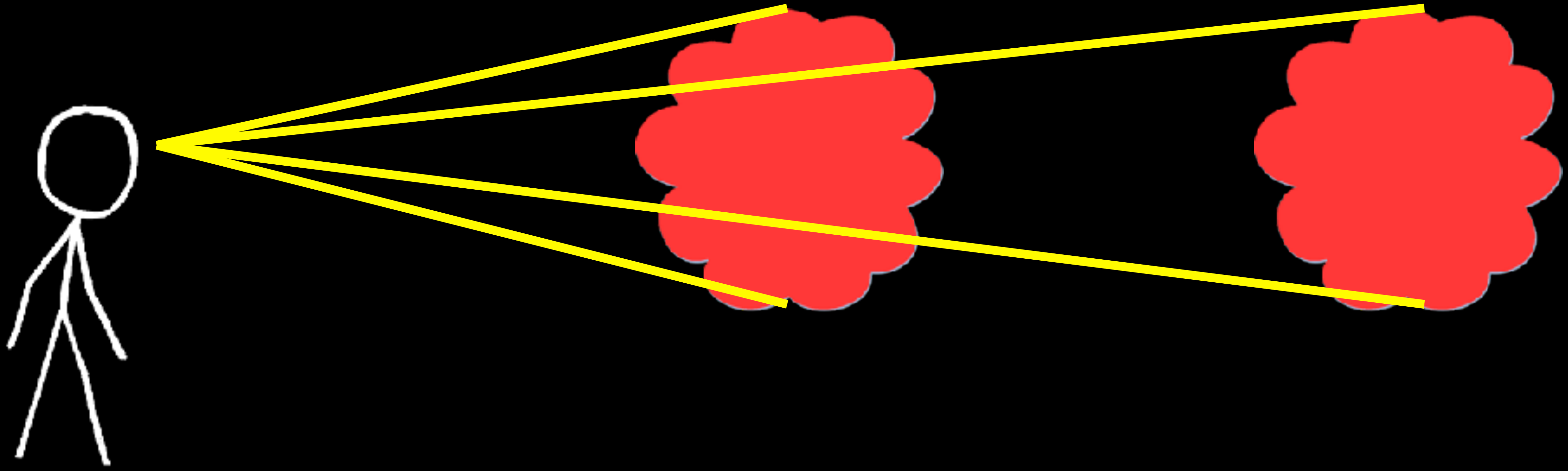


Cosmic Dust

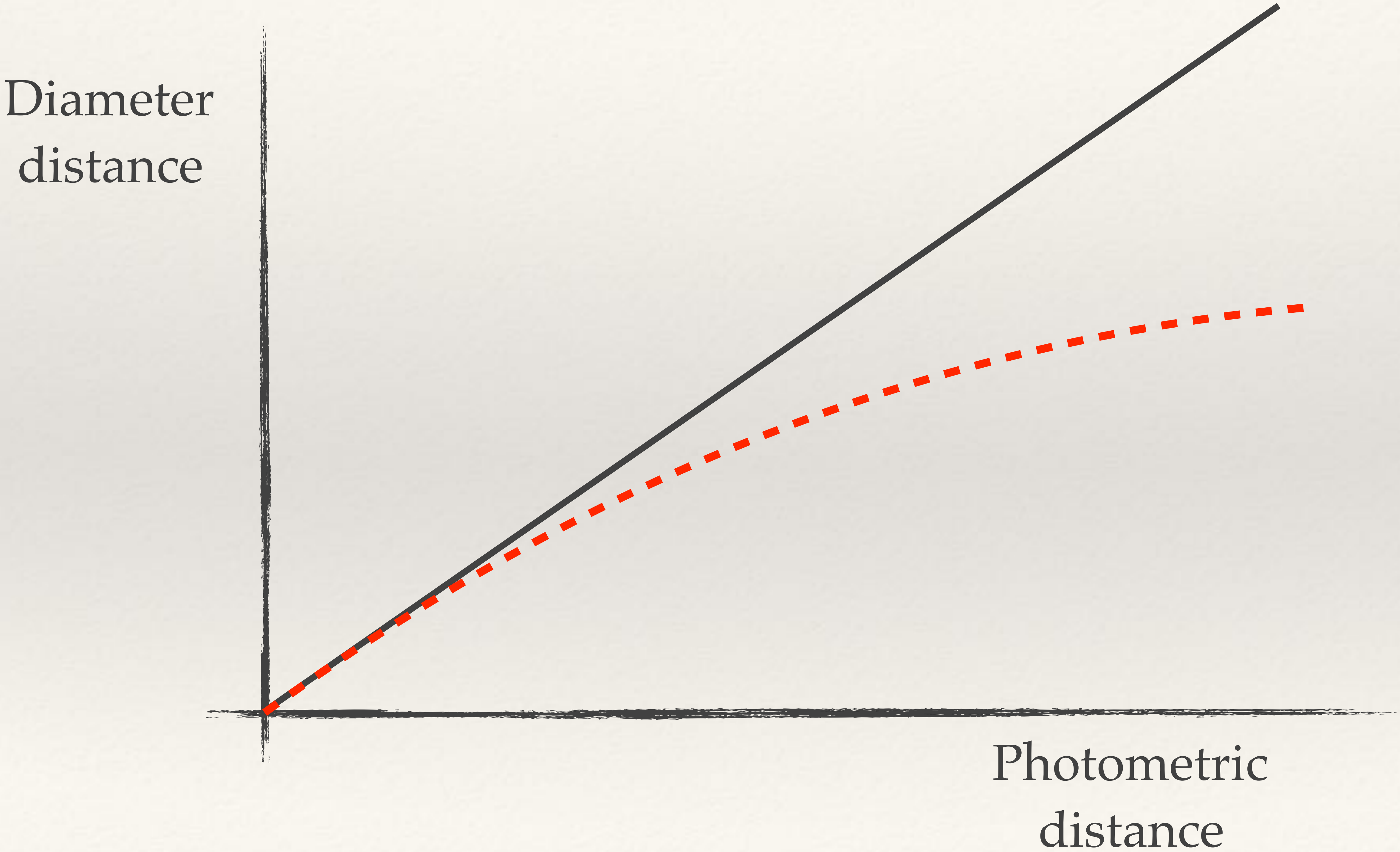
- First evidence found by Robert Trampler (1930's)
- Uncertainties in distances to stellar clusters


Stellar cluster

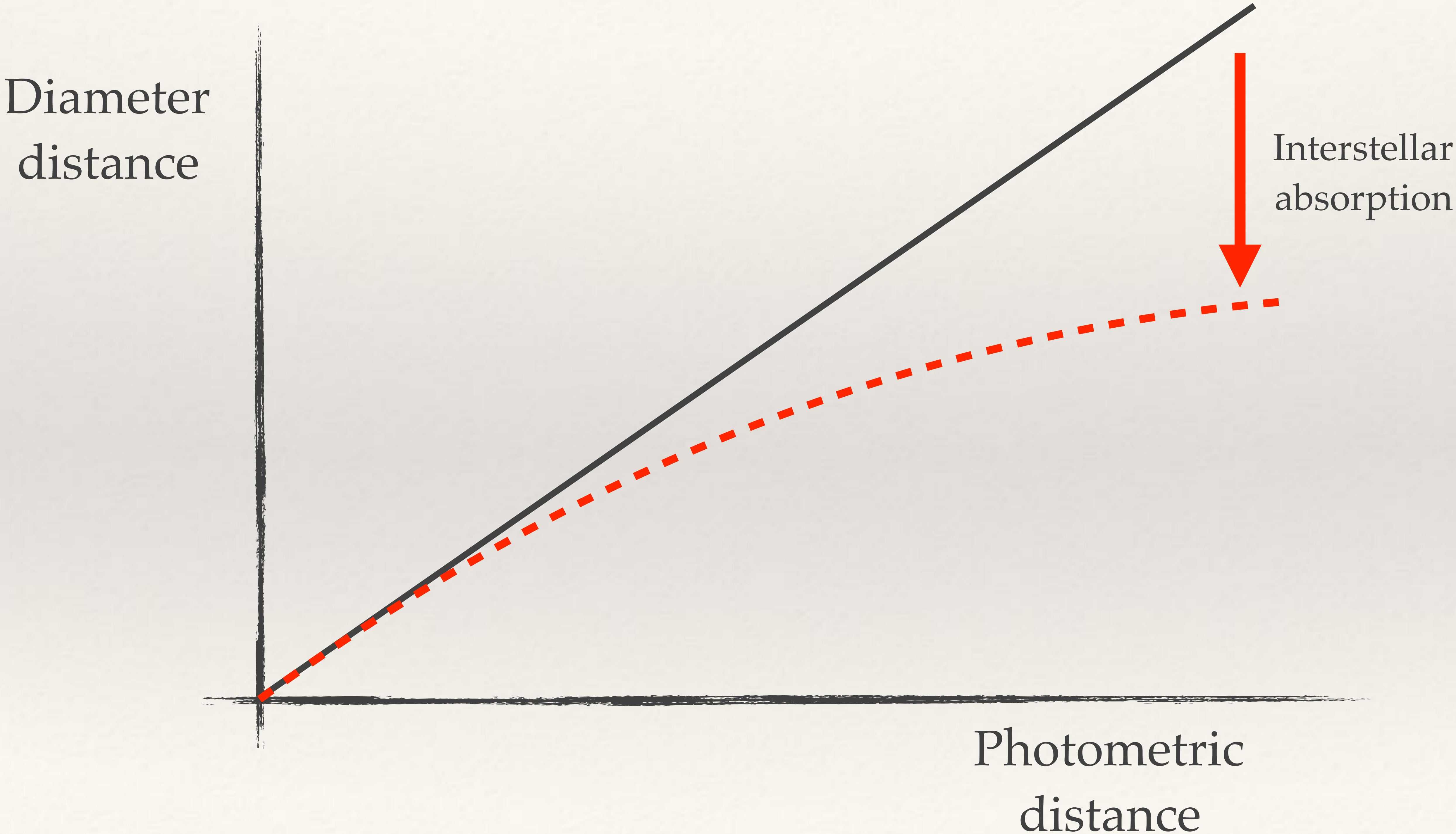




Cosmic Dust



Cosmic Dust



Diameter distance
Interstellar absorption
Photometric distance

Cosmic Dust

- Distant clusters also redder
- Trampler estimated extinction in MW of ~2 mag/kpc
- Attributed to Rayleigh scattering by small grains

Cosmic Dust

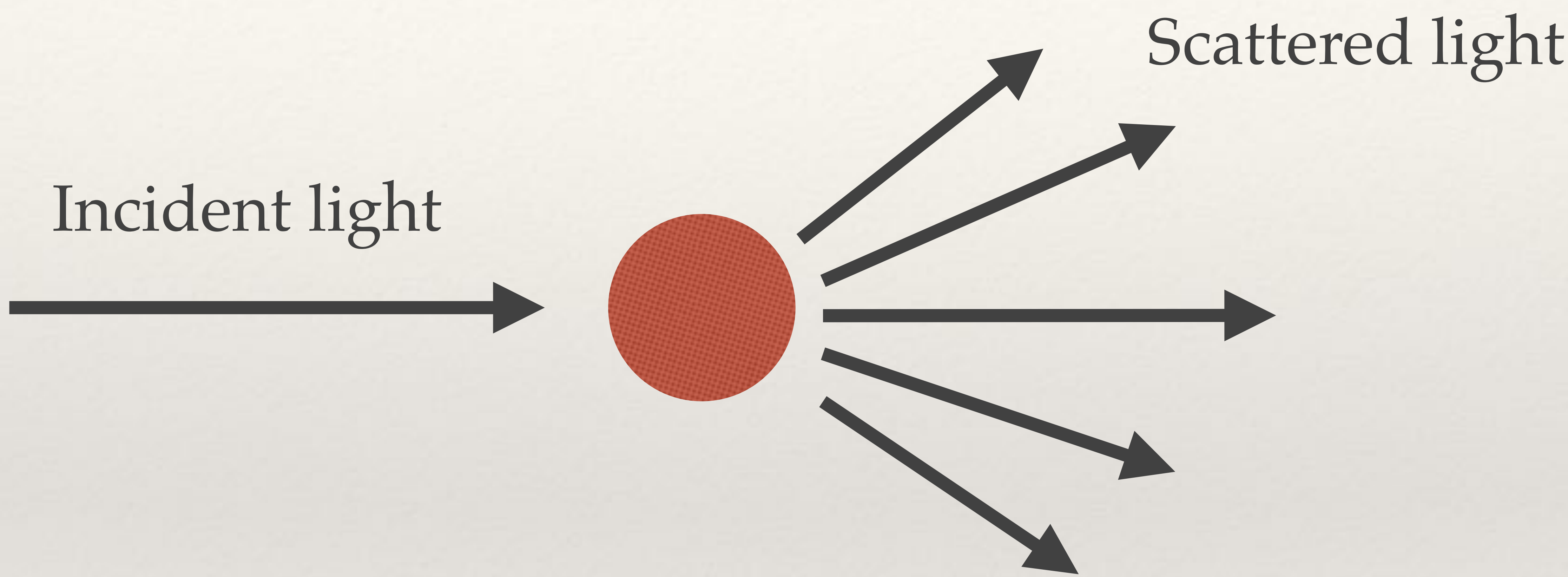
Interstellar dust therefore has two effects:

(1) Dimming

(2) Reddening

These result from scattering by dust grains

Rayleigh Scattering



$$I \propto \frac{1}{\lambda^4}$$

Cosmic Dust

Scattering strength depends on $1/\lambda^4$

Long wavelength light travels unhindered

Short wavelength light gets scattered

Cosmic Dust

Scattering strength depends on $1/\lambda^4$

Long wavelength light travels unhindered

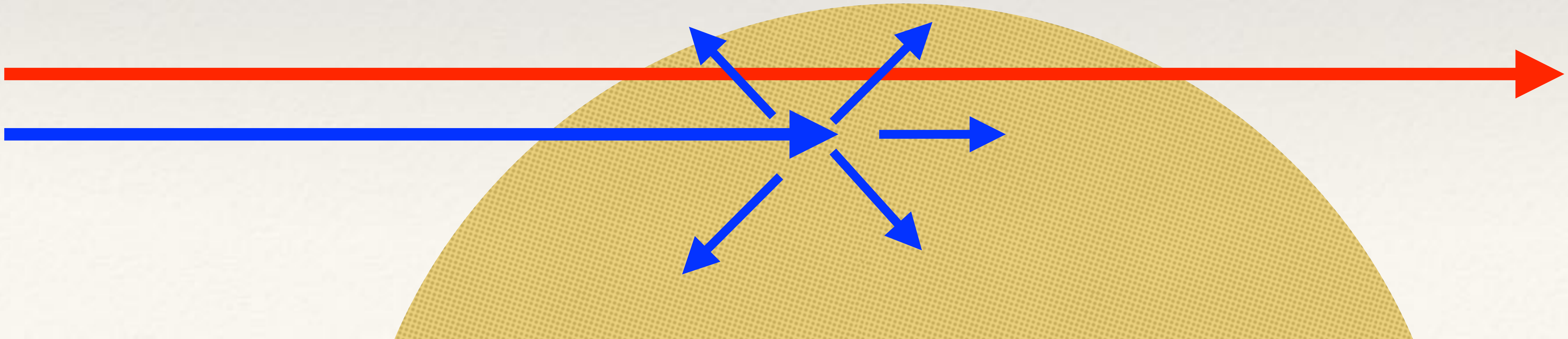
Short wavelength light gets scattered

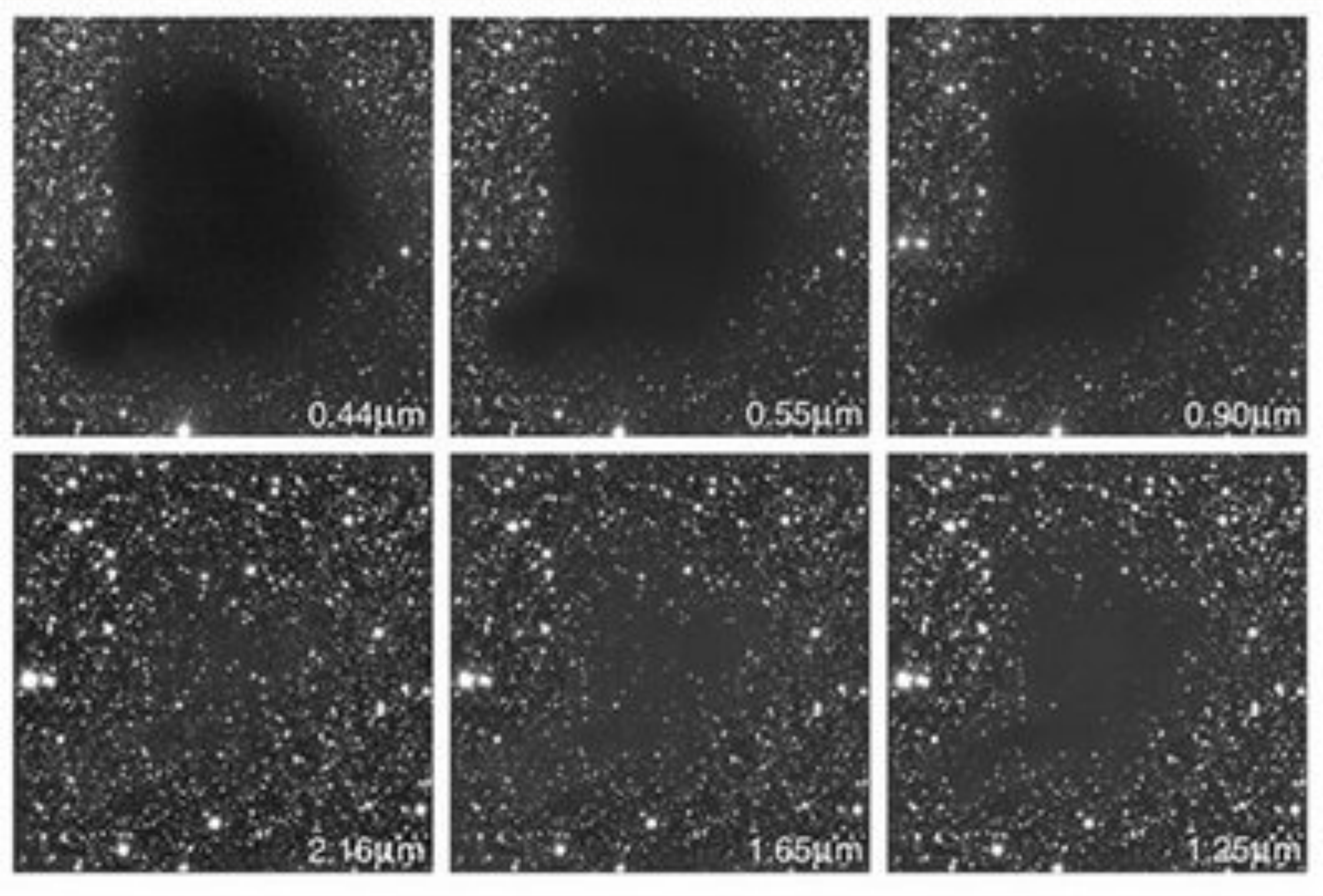
Cosmic Dust

Scattering strength depends on $1/\lambda^4$

Long wavelength light travels unhindered

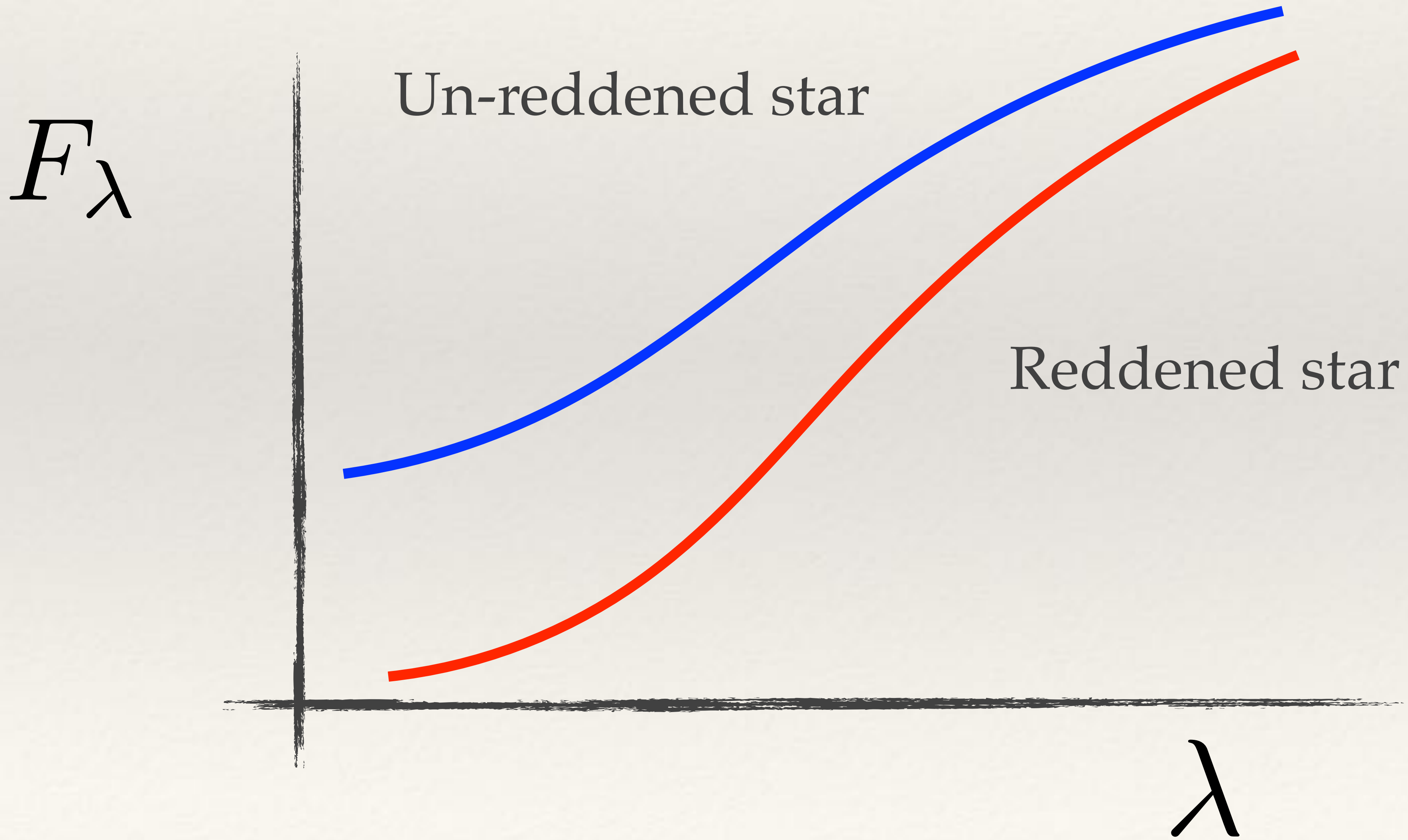
Short wavelength light gets scattered




0.44μm
0.55μm
0.90μm
2.16μm
1.65μm
1.25μm

Cosmic Dust

Correcting for extinction is critical!



Cosmic Dust

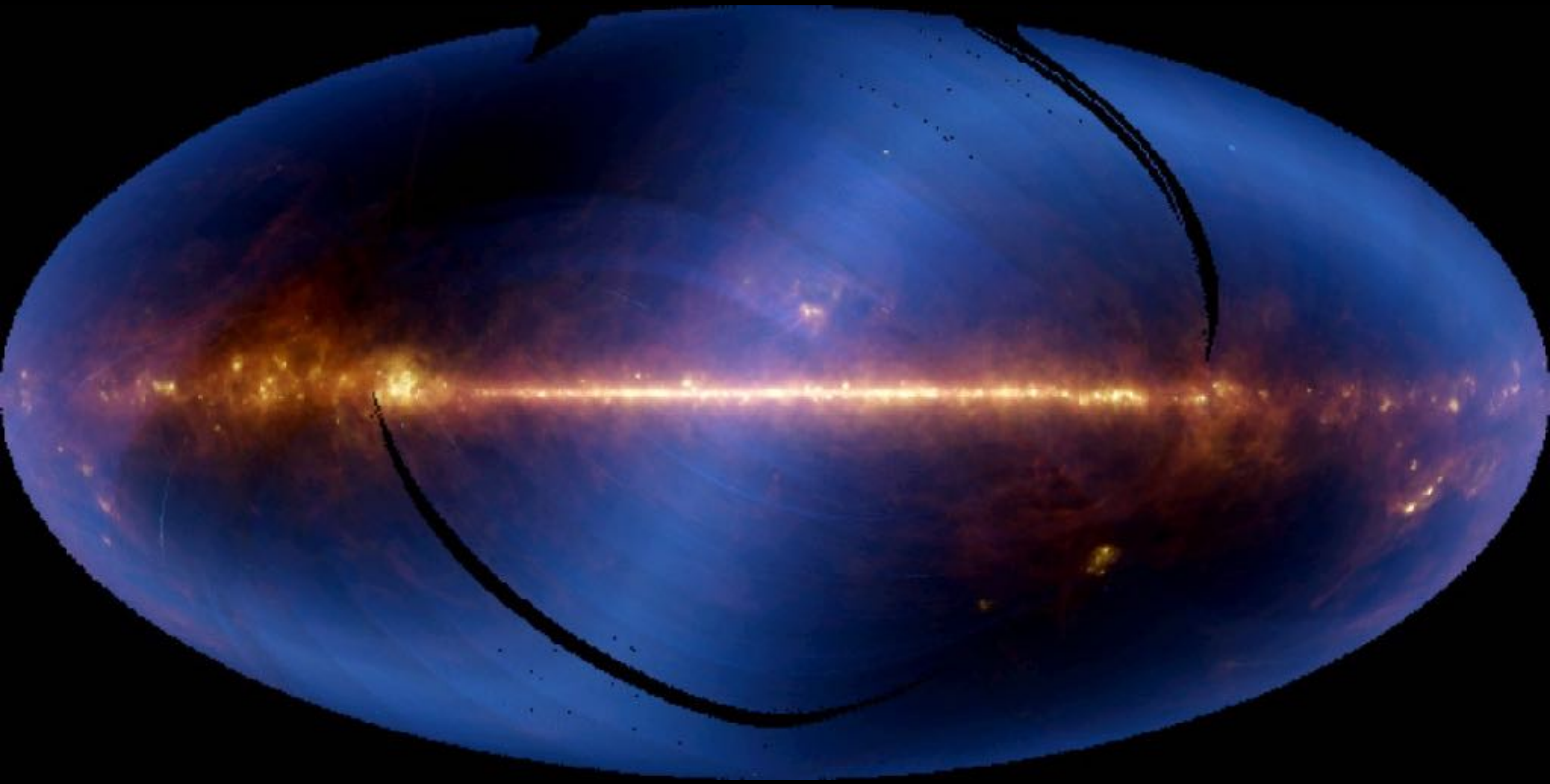
So, dust blocks/scatters optical light

But, dust is generally *cold* (~tens of K), and therefore **emits** in the IR


Visible


Infrared

Mid IR (12+25 microns)



Cosmic Dust

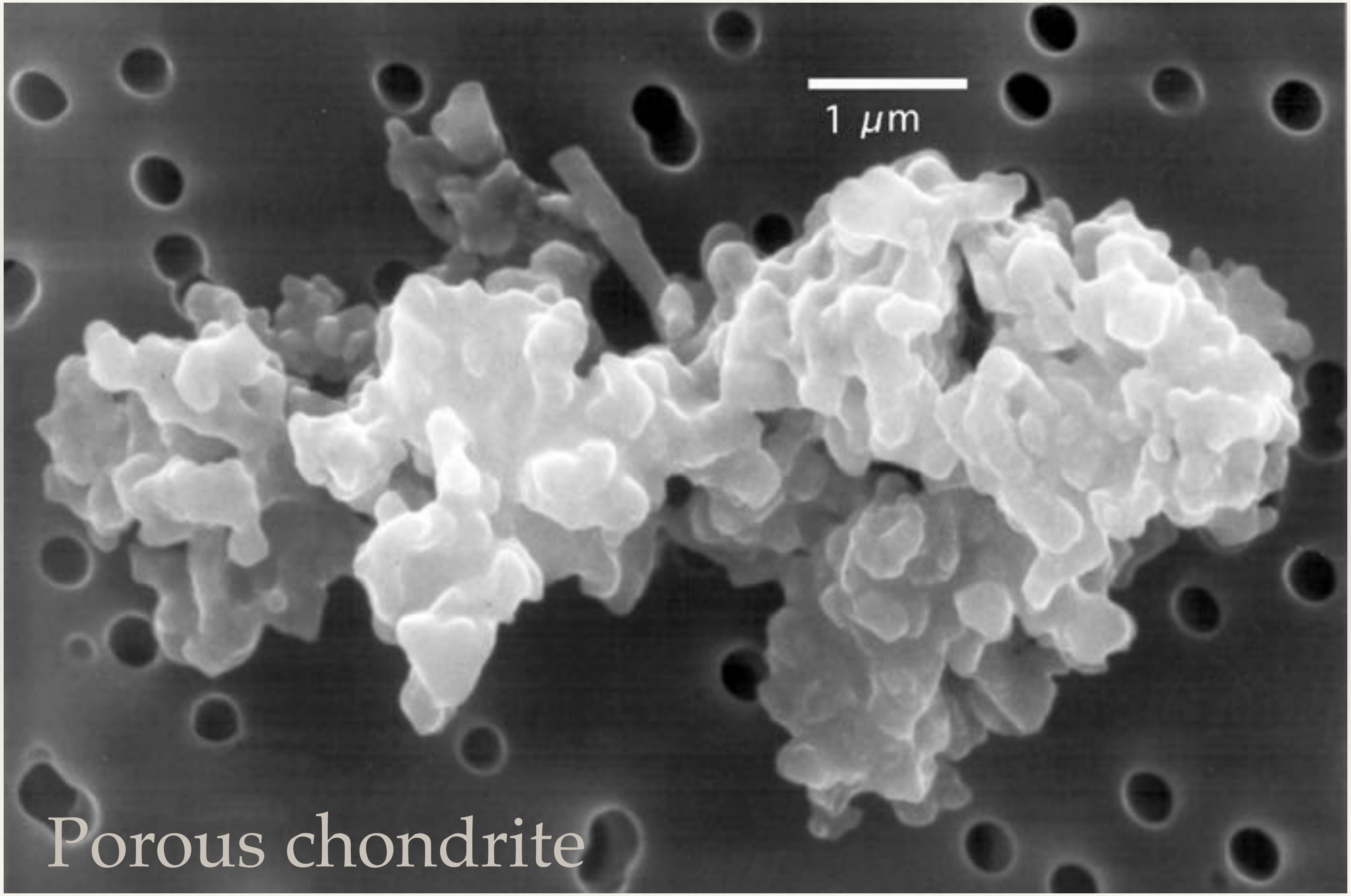
What is cosmic dust?

Large dust grains (generally around stars)

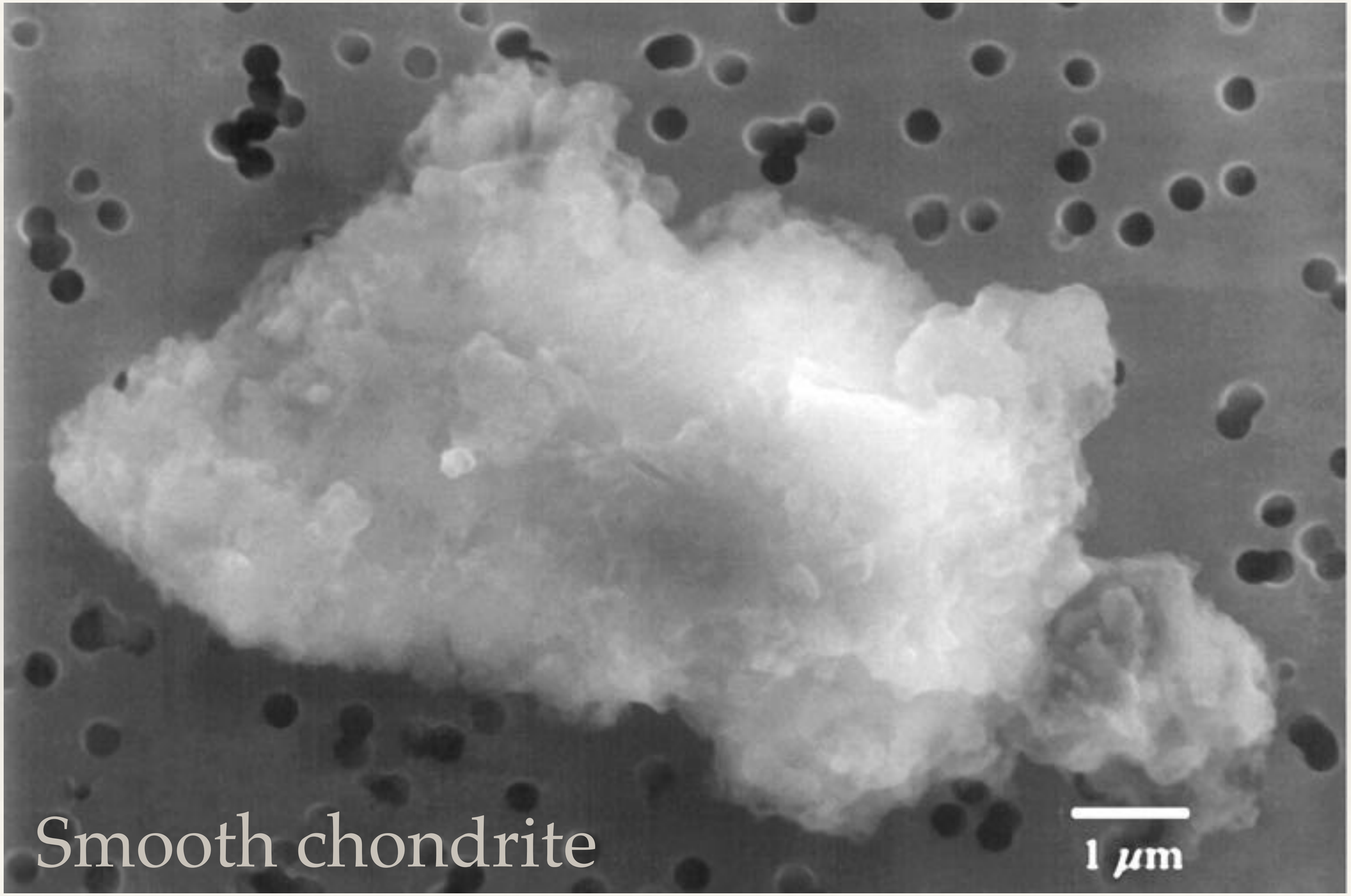
Small dust grains (interstellar)

Tiny dust grains (interstellar)

Cosmic Dust

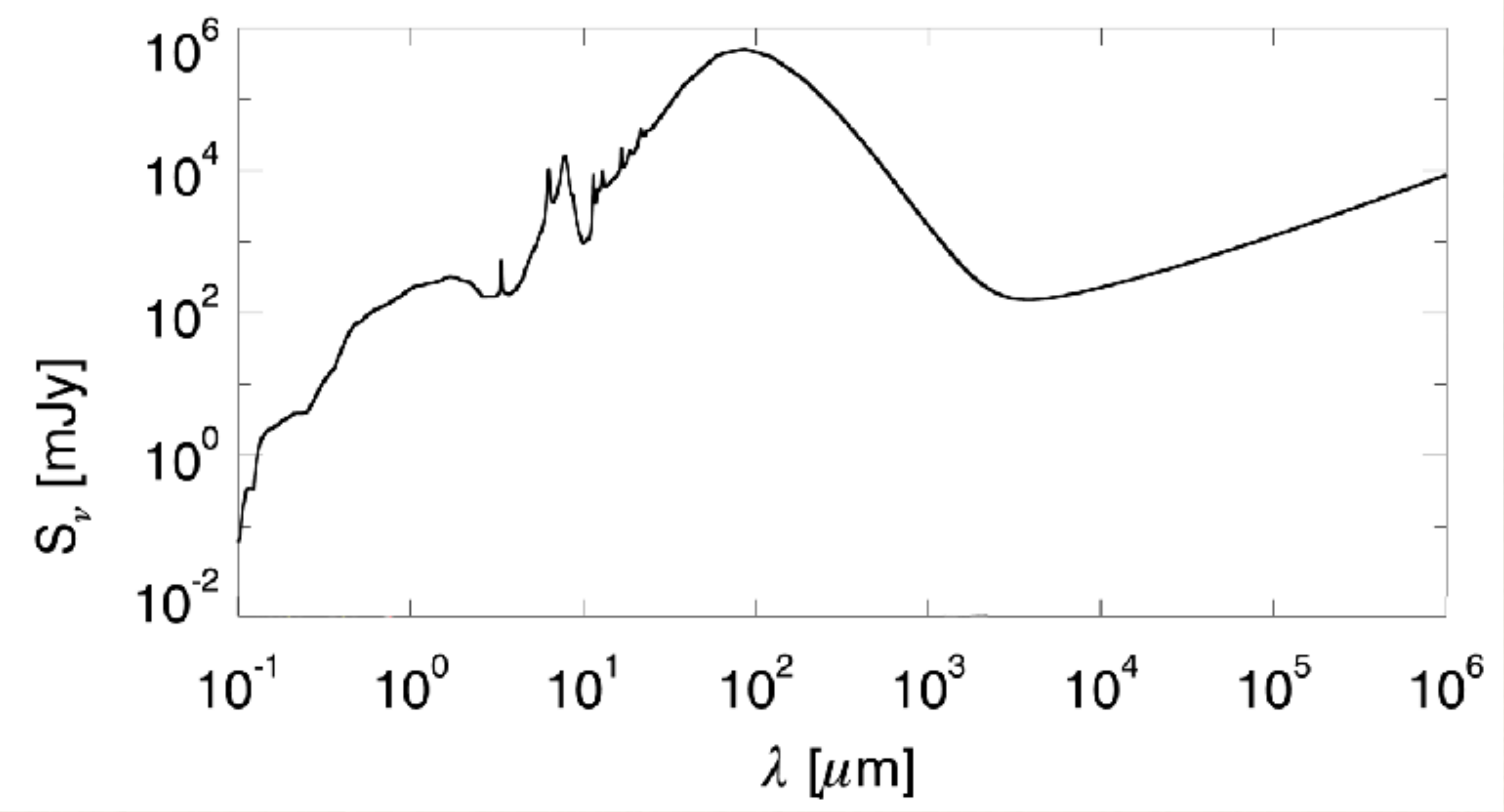


Cosmic Dust



Cosmic Dust

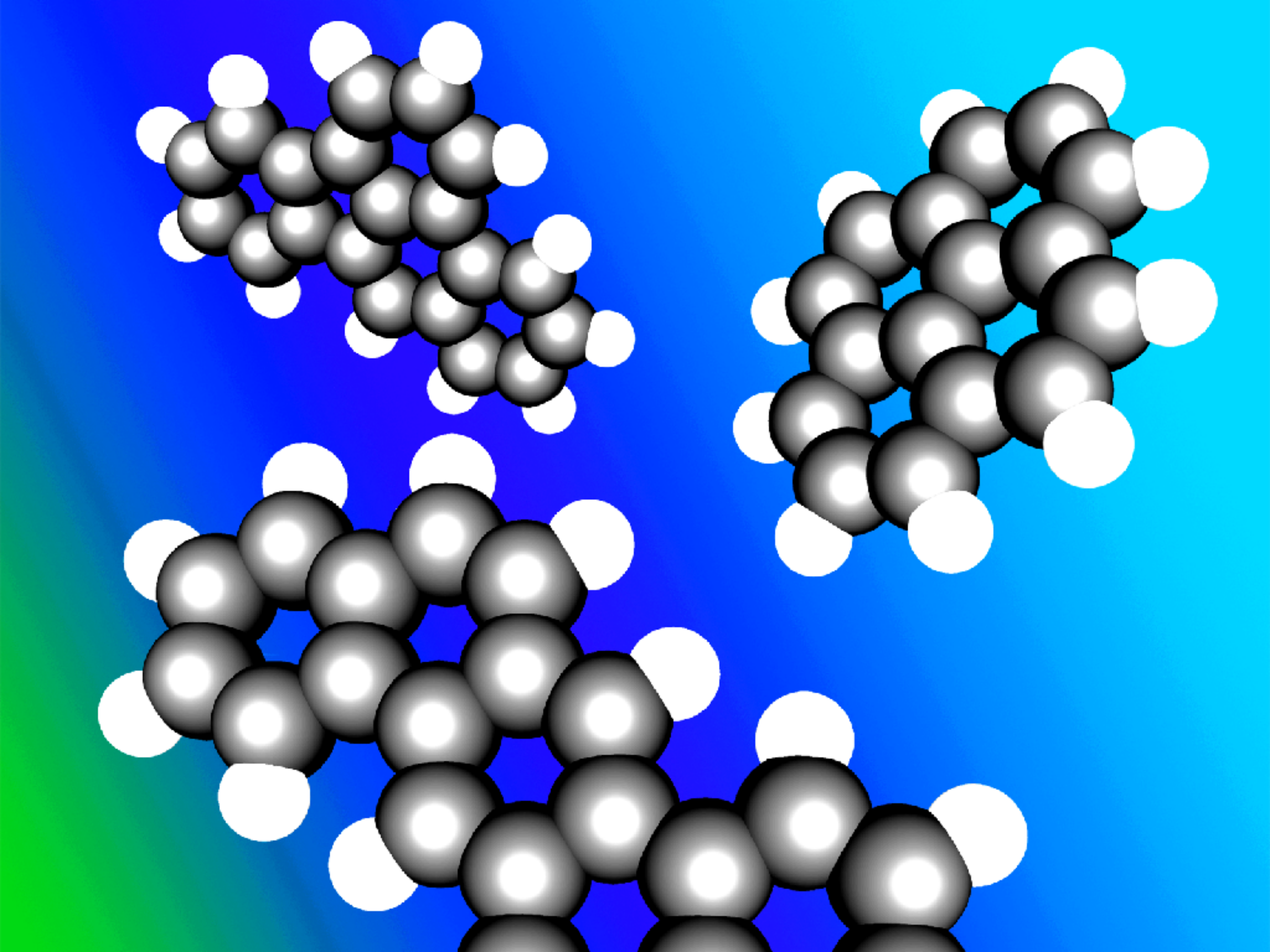
But these small dust grains cannot explain emission features in the mid-IR…



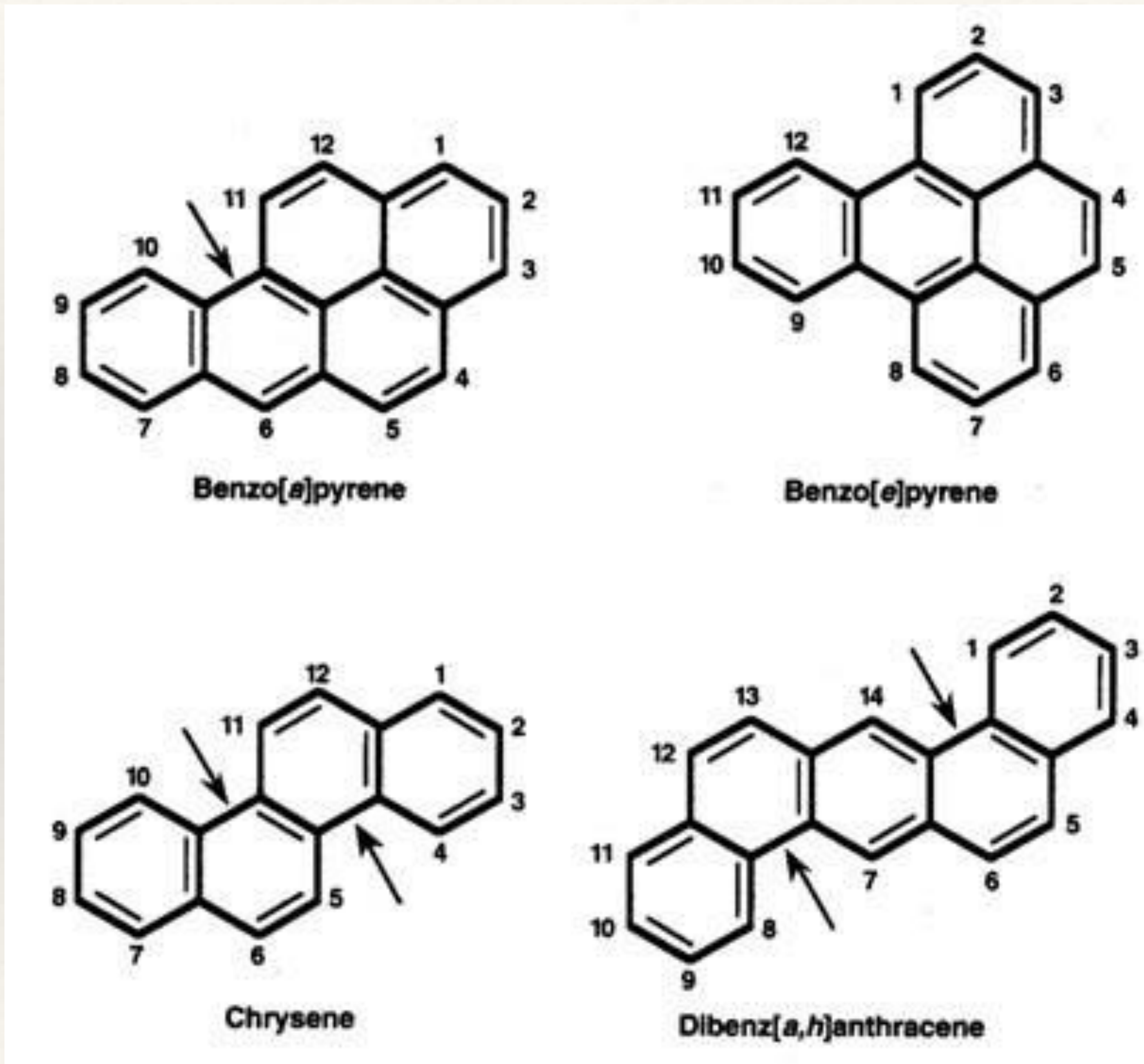
Cosmic Dust

We hypothesise a population of tiny grains, or Polycyclic Aromatic Hydrocarbons (PAHs)

Different to a 'typical' dust grain… a 2D sheet of atoms, rather than a small ball of carbon/silicon

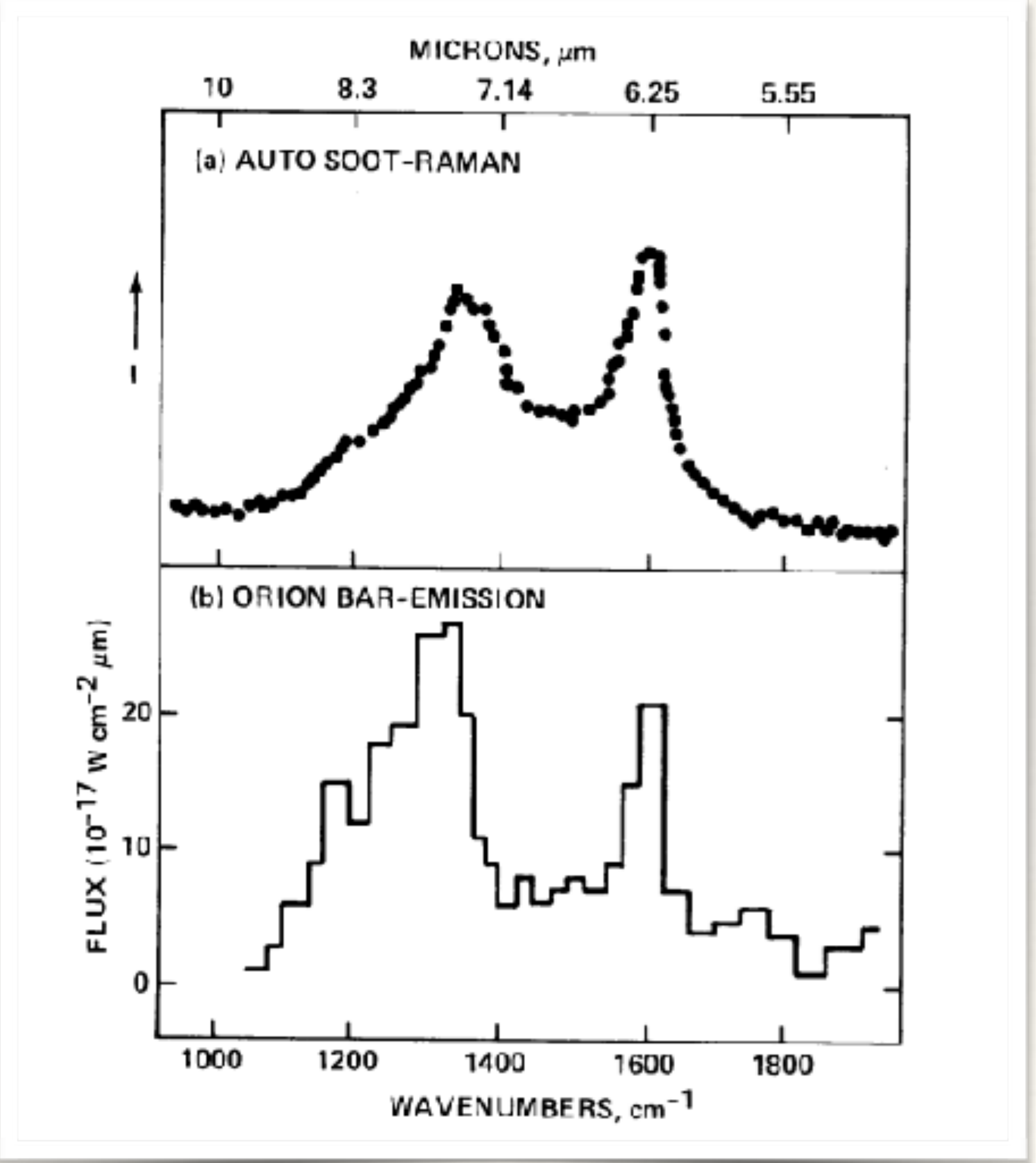


Cosmic Dust


Benzo[a]pyrene
Benzo[e]pyrene
Chrysene
Dibenz[a,h]anthracene

Cosmic Dust

- PAHs are everywhere!
- Galaxies, stars, etc
- Even terrestrially…
- They are powerful tools for examining astrophysical chemistry



What is in the infrared sky?

- Dust
- Protoplanetary disks
- Brown dwarf stars

Protoplanetary disks

Disks of gas and dust exist around pre-Main Sequence stars

Circumstellar disks are a key ingredient to understanding planet formation

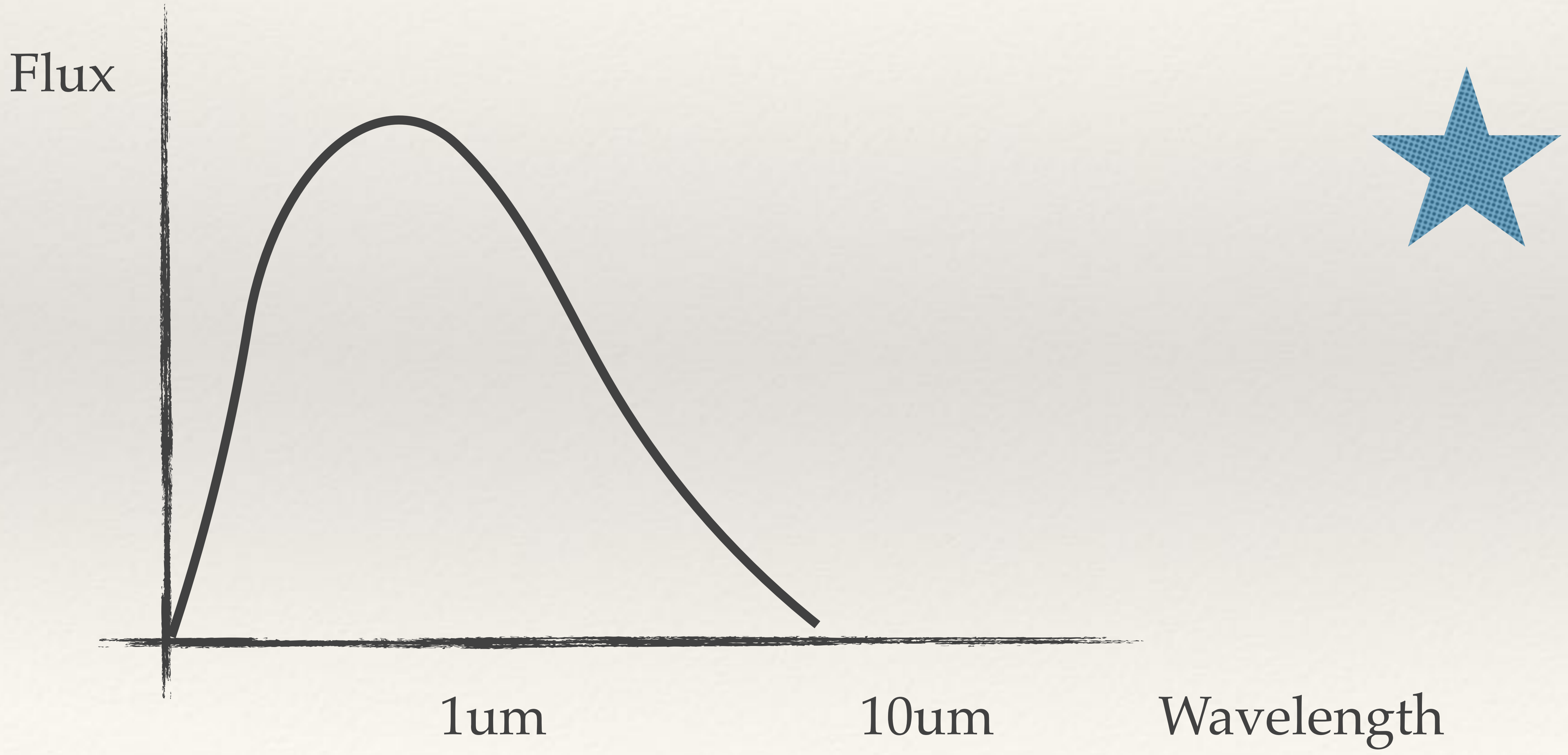
As they are made of gas+dust, the best way to observe them is in the IR!

Protoplanetary disks

First hypothesised based on the 'infra-red excess'

Protoplanetary disks

First hypothesised based on the
'infra-red excess'



Protoplanetary disks

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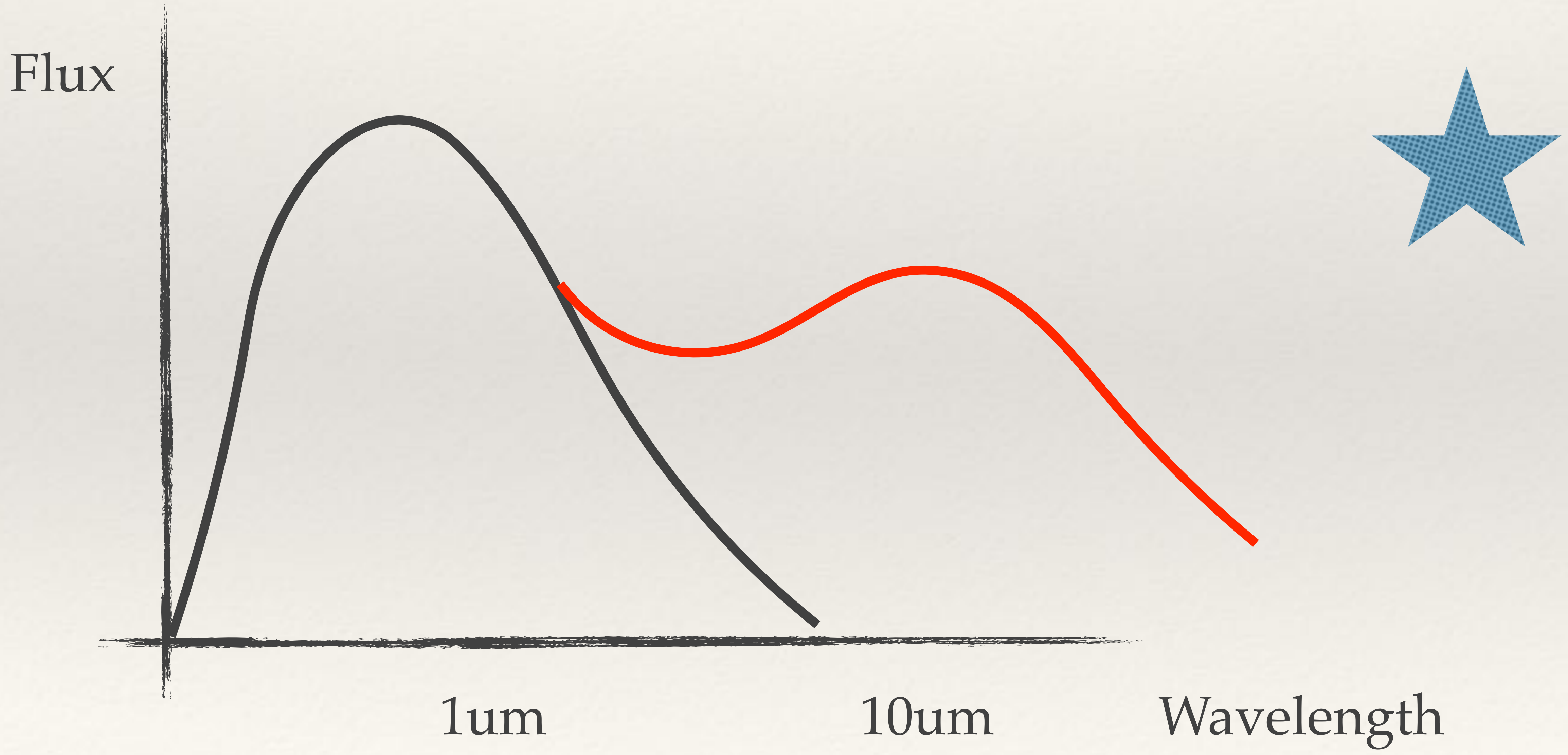
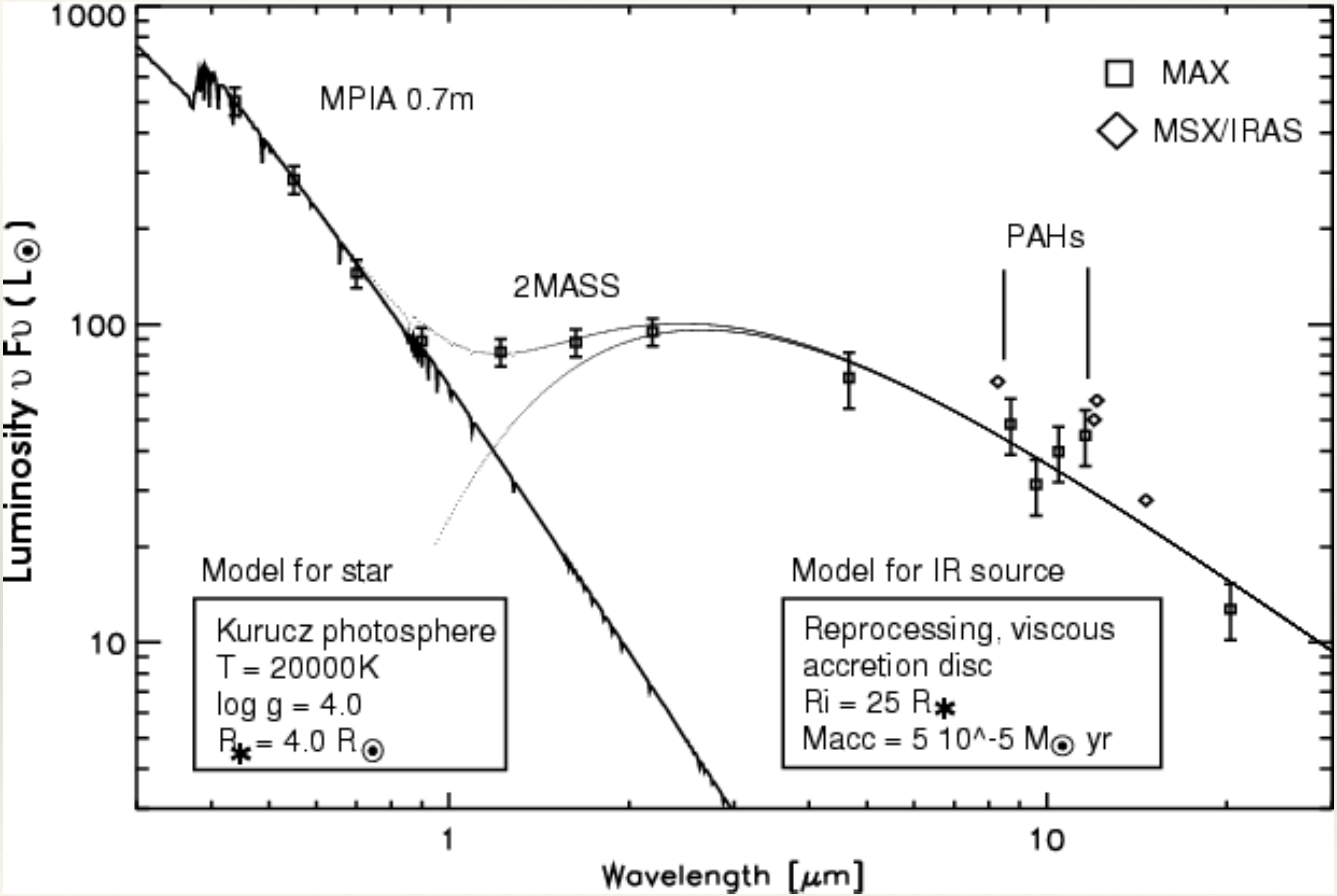
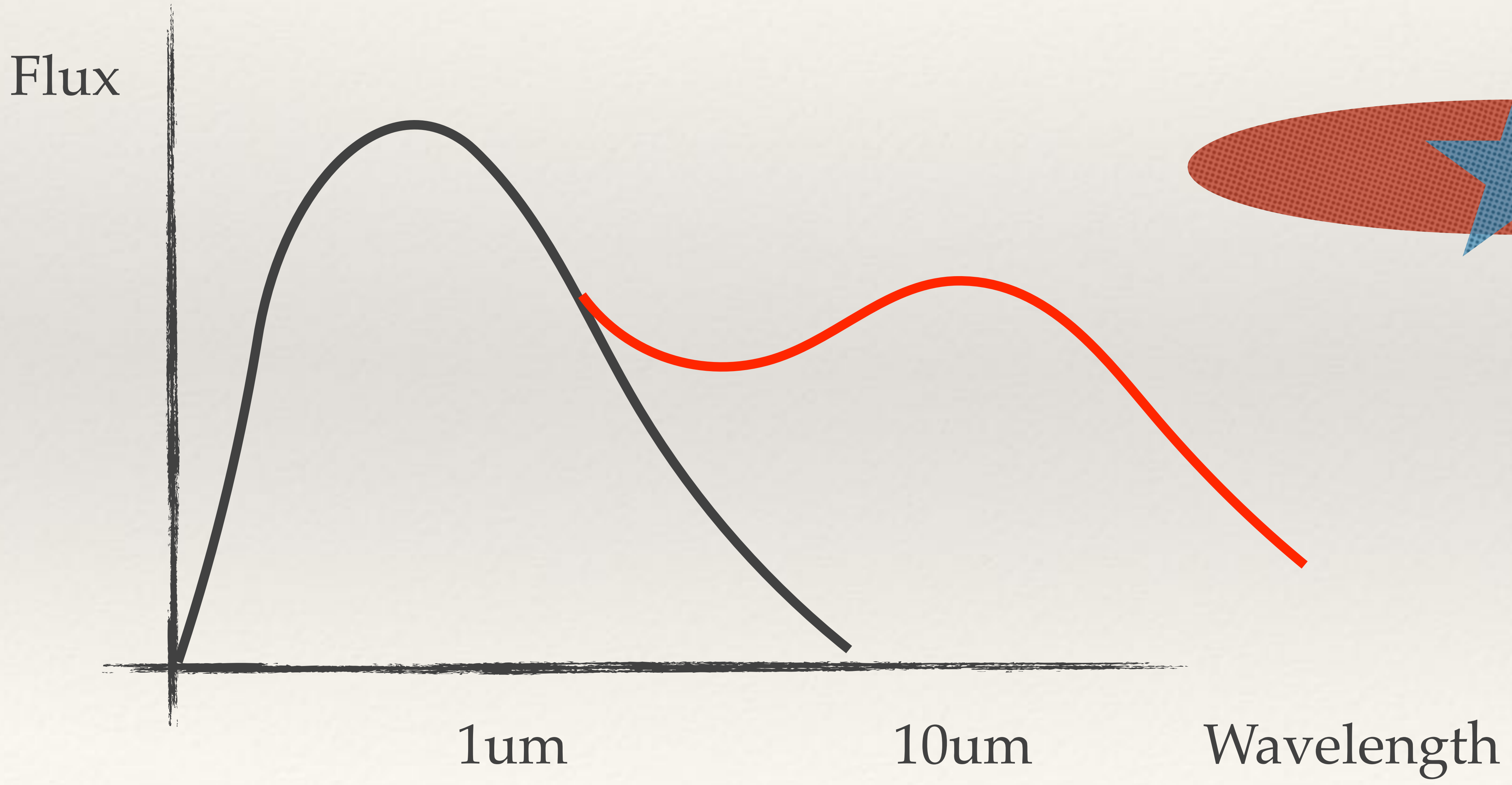


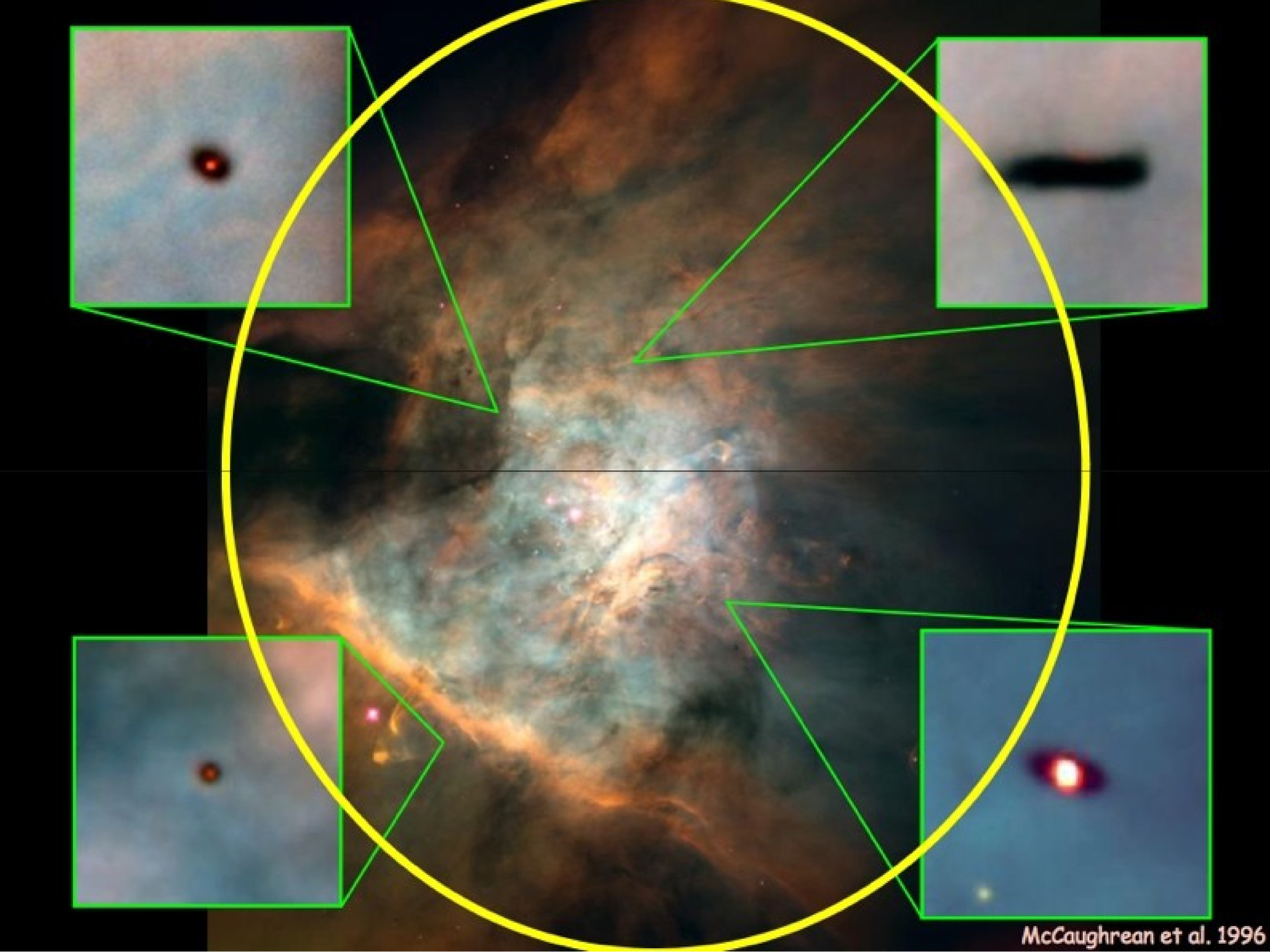


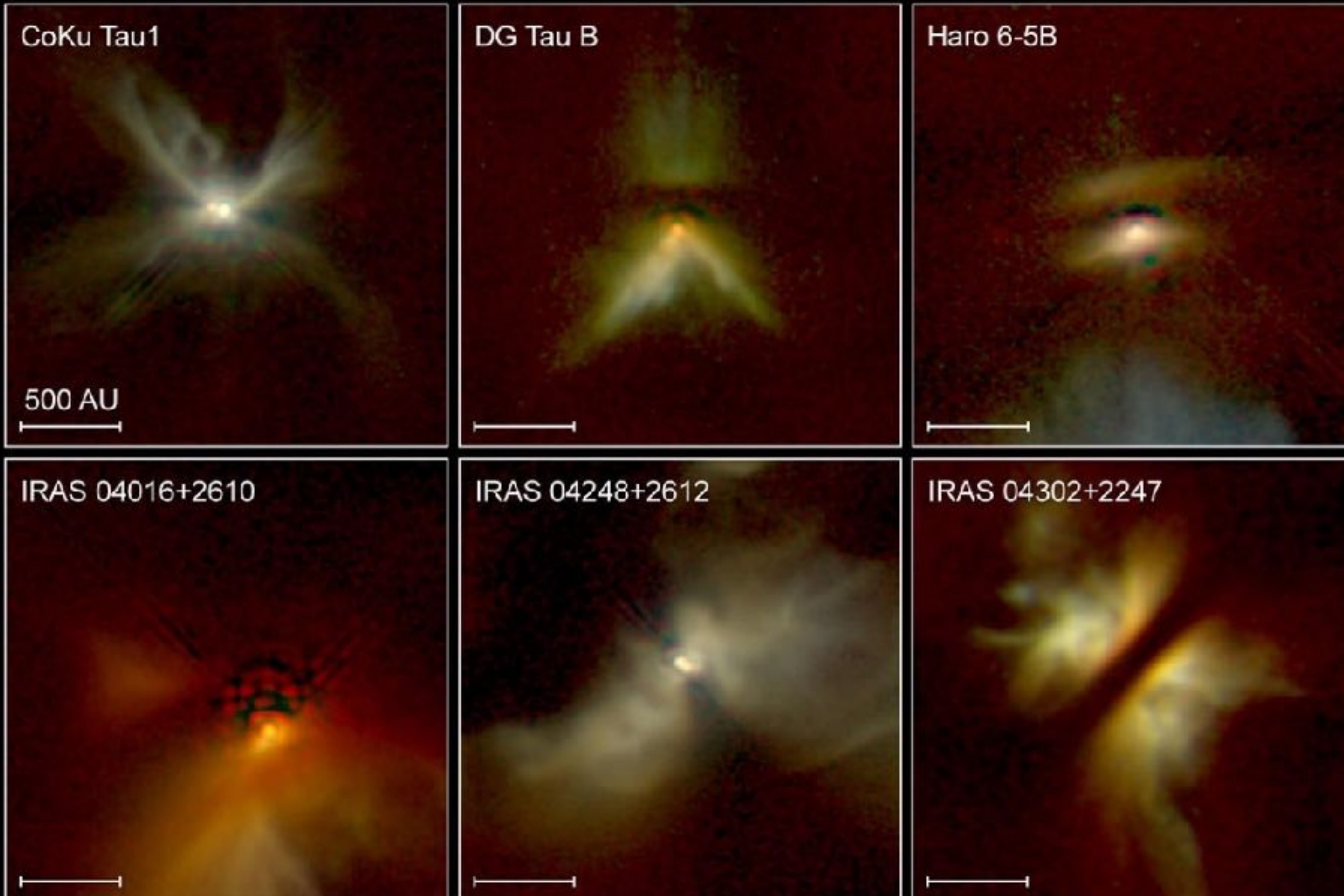
1000
100
10
Luminosity υ Fυ (L⊙)
1
10
Wavelength [μm]
MPIA 0.7m
2MASS
PAHs
MAX
MSX/IRAS
Model for star
Kurucz photosphere
T = 20000K
log g = 4.0
R* = 4.0 R⊙
Model for IR source
Reprocessing, viscous
accretion disc
Ri = 25 R*
Macc = 5 10^-5 M⊙ yr

Protoplanetary disks

First hypothesised based on the
'infra-red excess'




McCaughrean et al. 1996



Young Stellar Disks in Infrared

Hubble Space Telescope • NICMOS

PRC99-05a • STScI OPO • D. Padgett (IPAC/Caltech), W. Brandner (IPAC), K. Stapelfeldt (JPL) and NASA

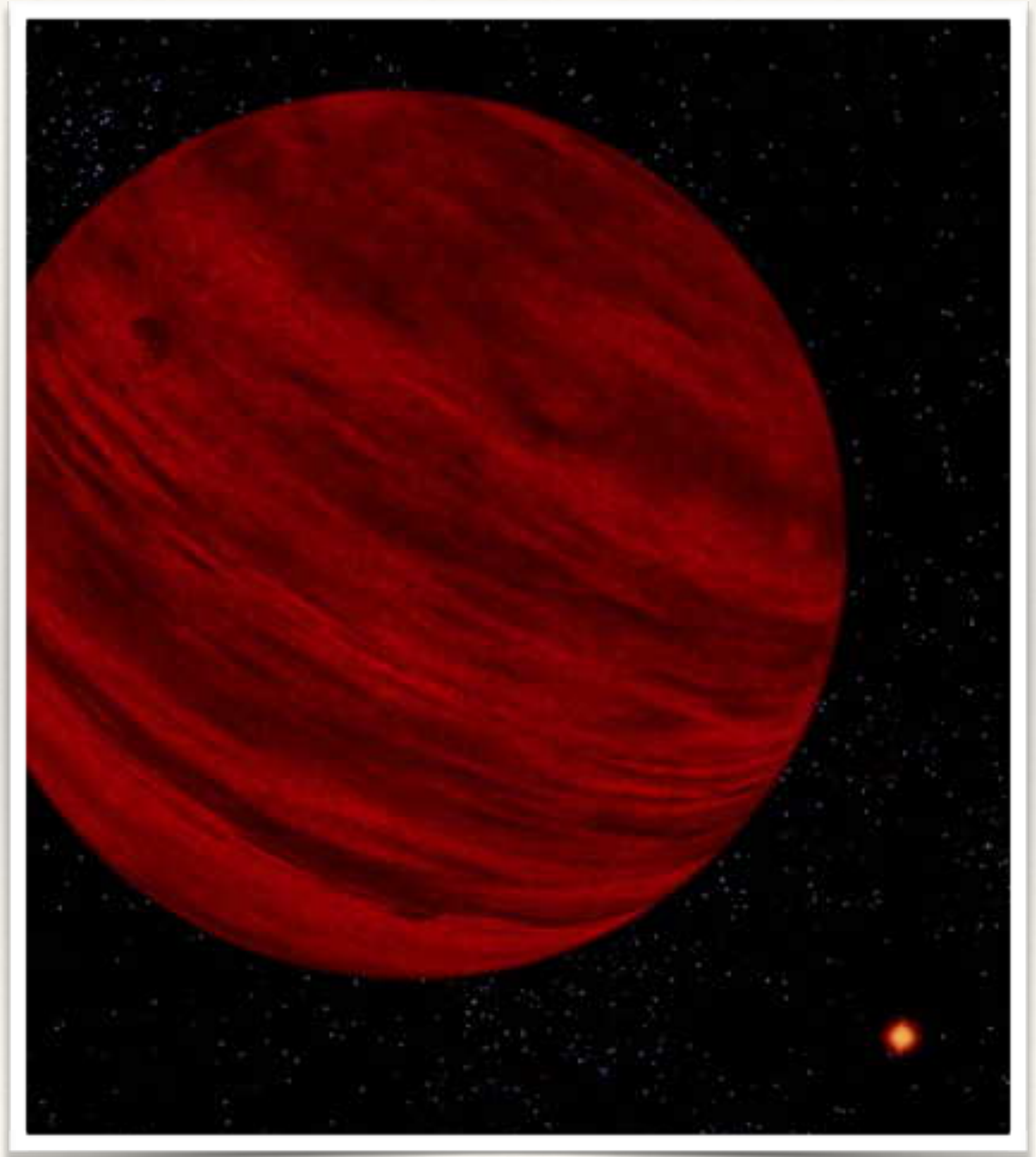
ALMA view of HL Tauri

What is in the infrared sky?

- Dust
- Protoplanetary disks
- Brown dwarf stars

Brown dwarfs

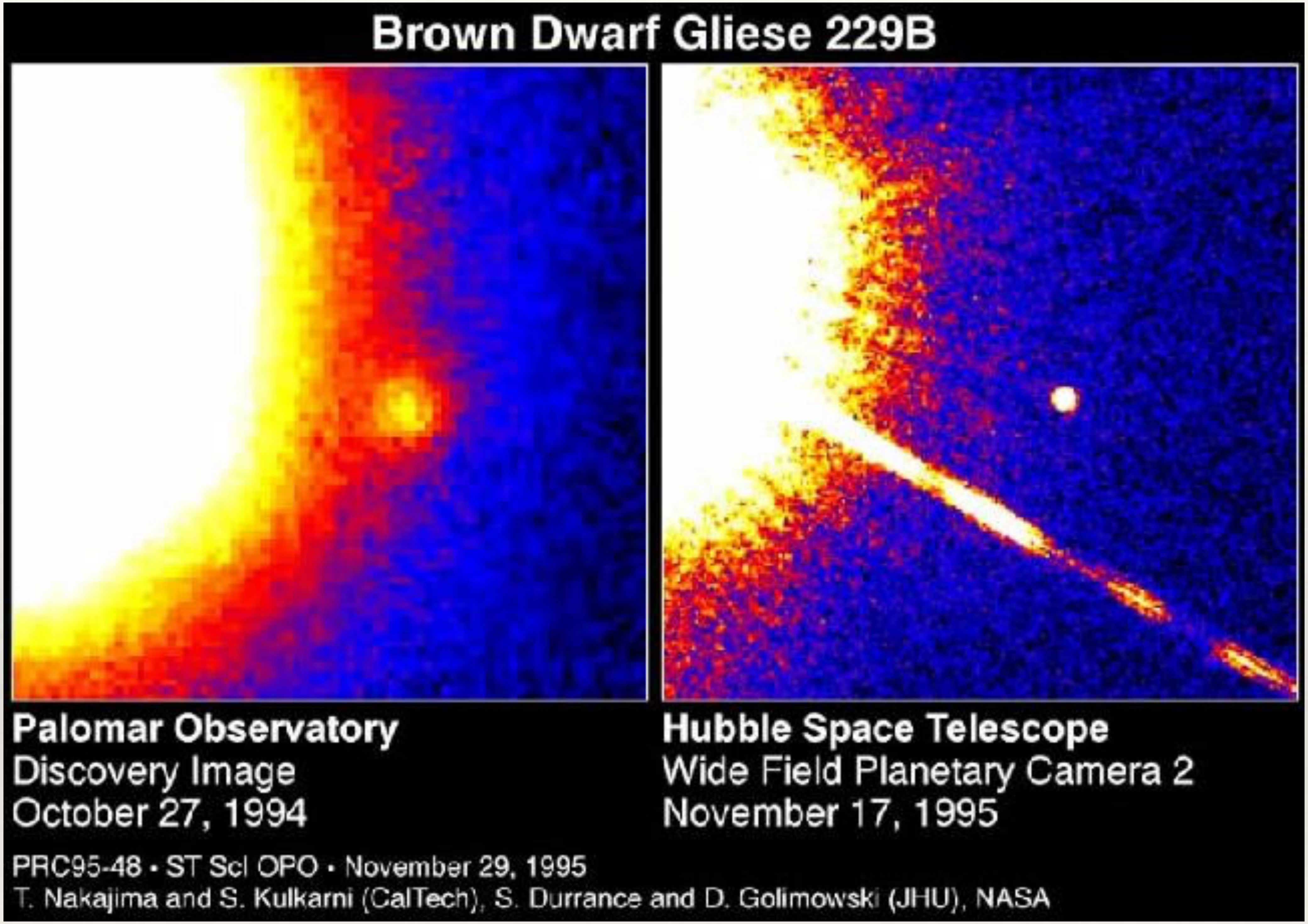
- Hypothesised in 1960s… we knew that stars needed masses of ~75 $M_{Jupiter}$ to start fusion
- Between planets (few times Jupiter mass) and stars (>75x Jupiter mass) there could be a population of 'failed stars'
- Temperatures ~100s of K up to ~1000K (bright in IR).



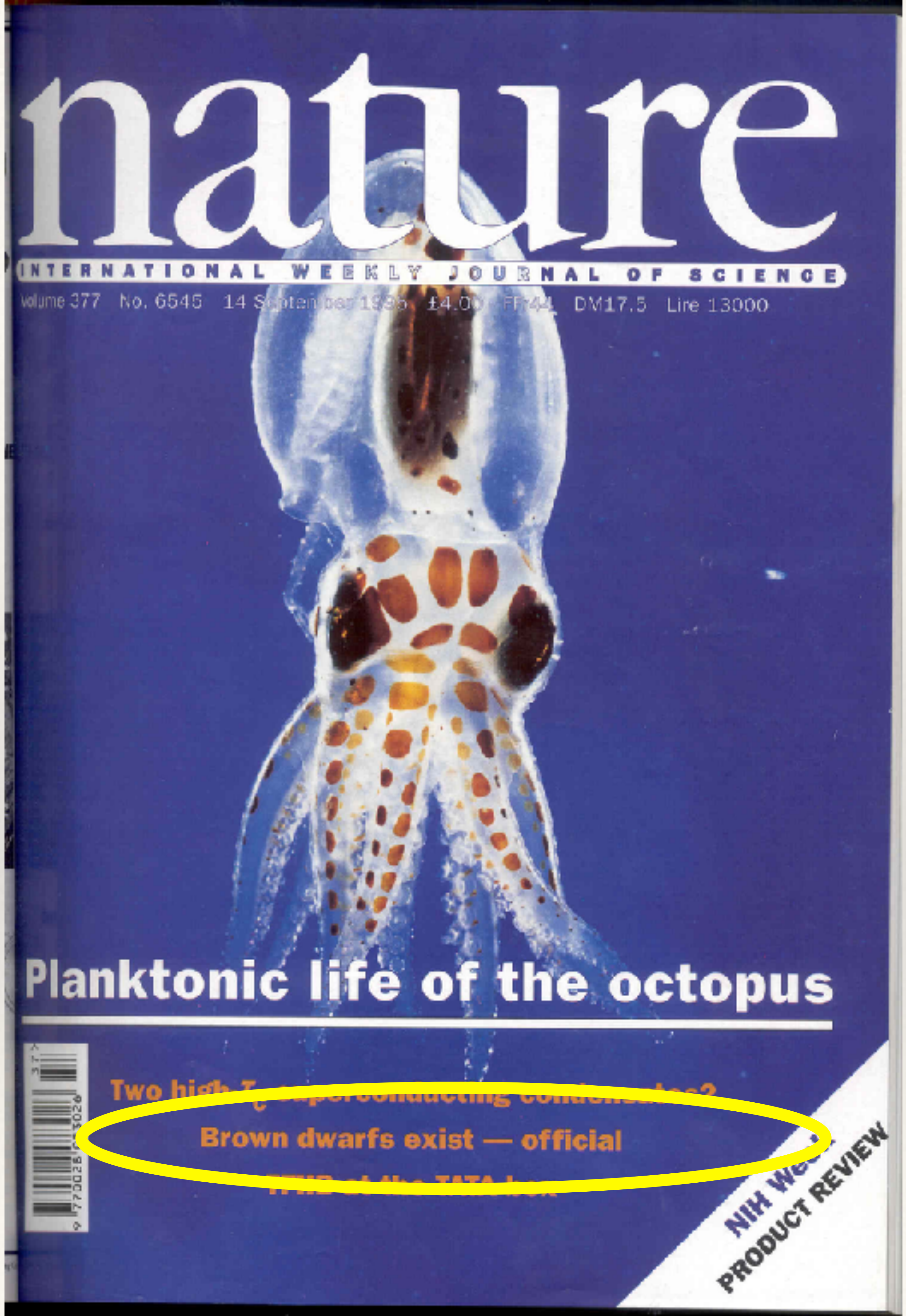
Brown dwarfs

How do we find BDs?

Only detectible in the IR…



First ever discovery of Brown Dwarf!

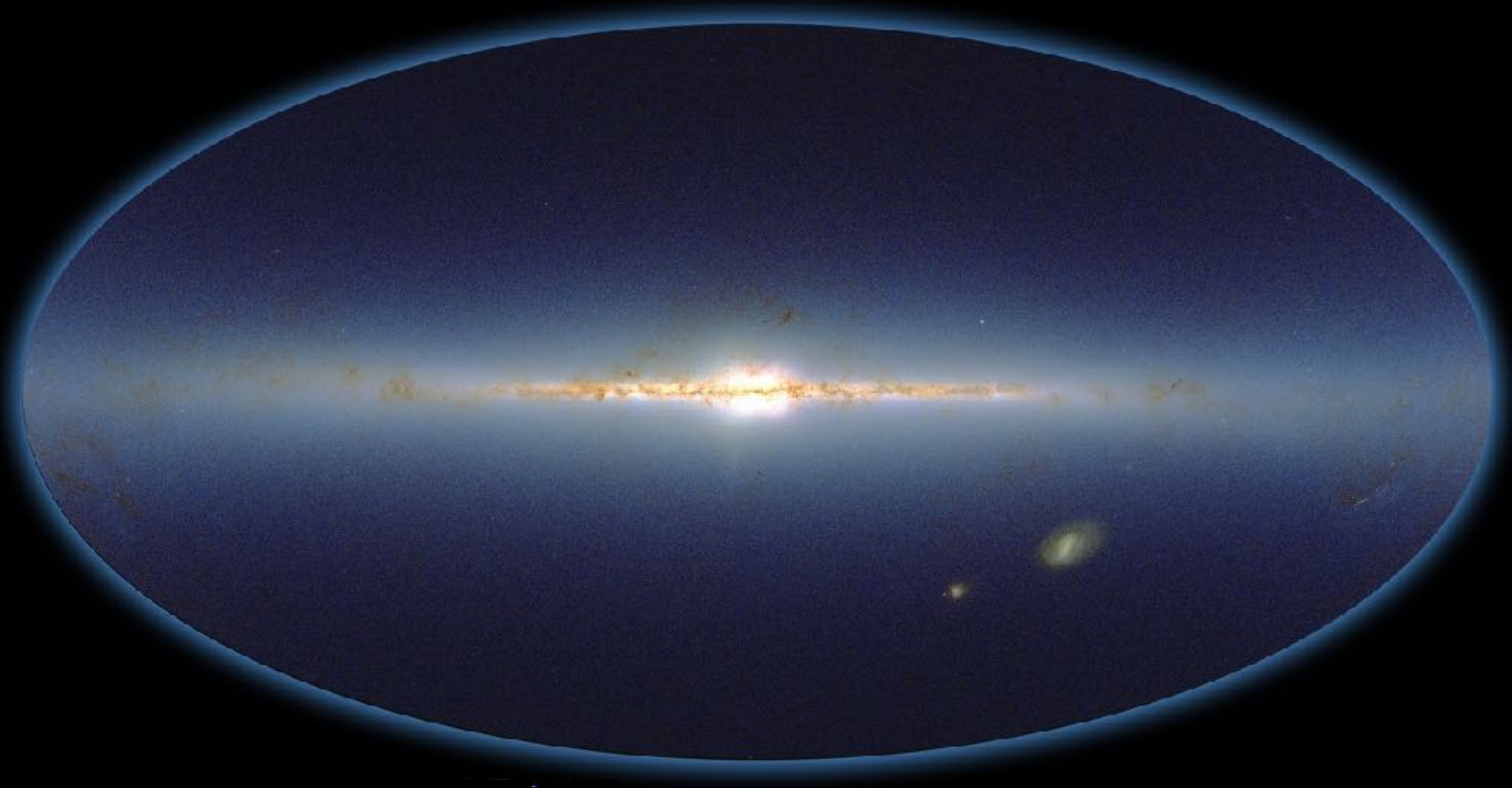

nature
INTERNATIONAL WEEKLY JOURNAL OF SCIENCE
Volume 377 No. 6545 14 September 1995 £4.00 FF44 DM17.5 Lire 13000
Planktonic life of the octopus
Two high
Brown dwarfs exist — official
NIH Week
PRODUCT REVIEW

Trapezium Cluster, optical (left) and IR (right)

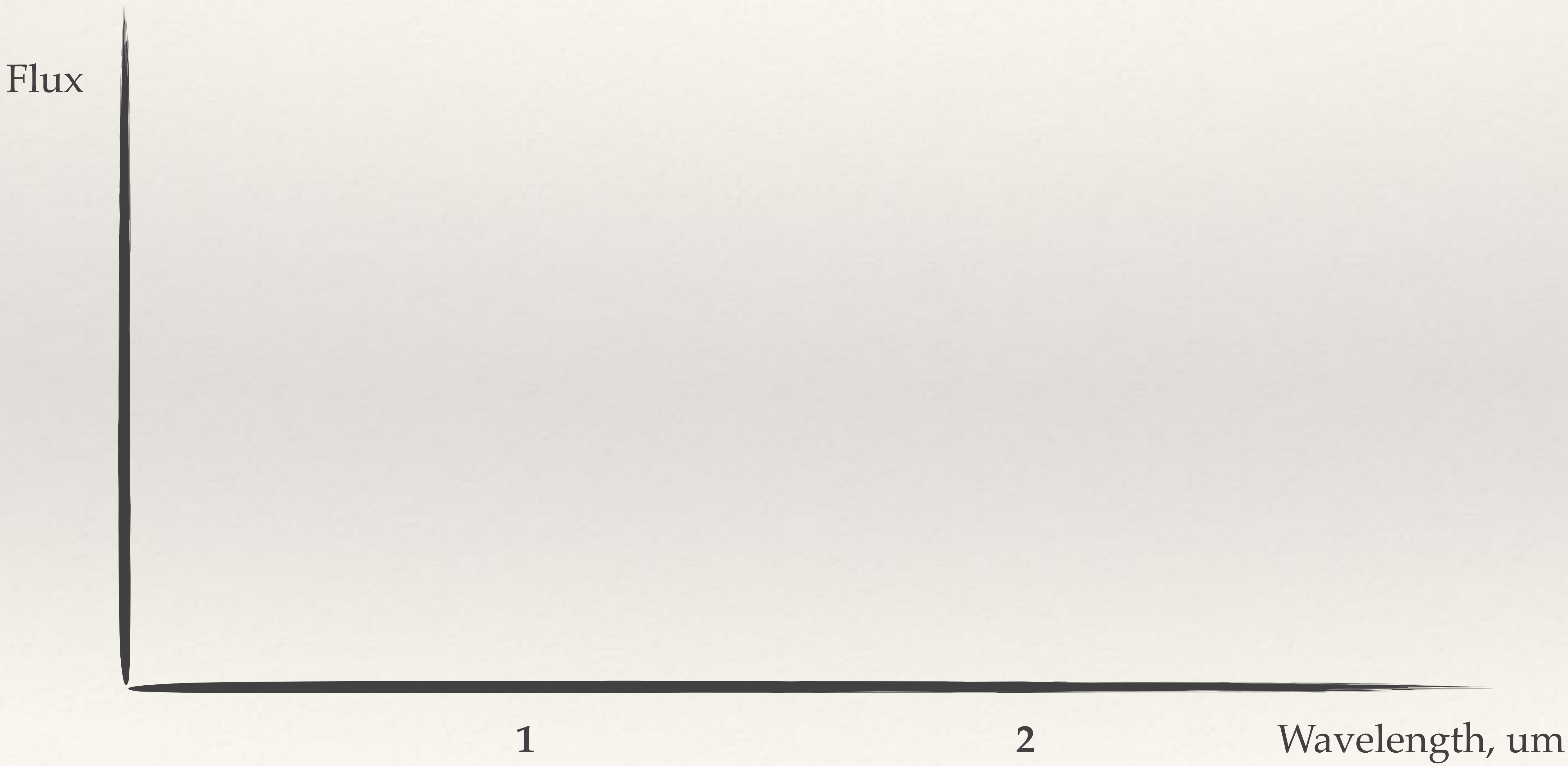
2MASS… ideal for BD hunting

- 2MASS observed > 471,000,000 point sources over the whole sky (40,000 square degrees)
- Observed in 3 NIR bands: J (=1.25um), H (1.6 um), and K (2.1um)

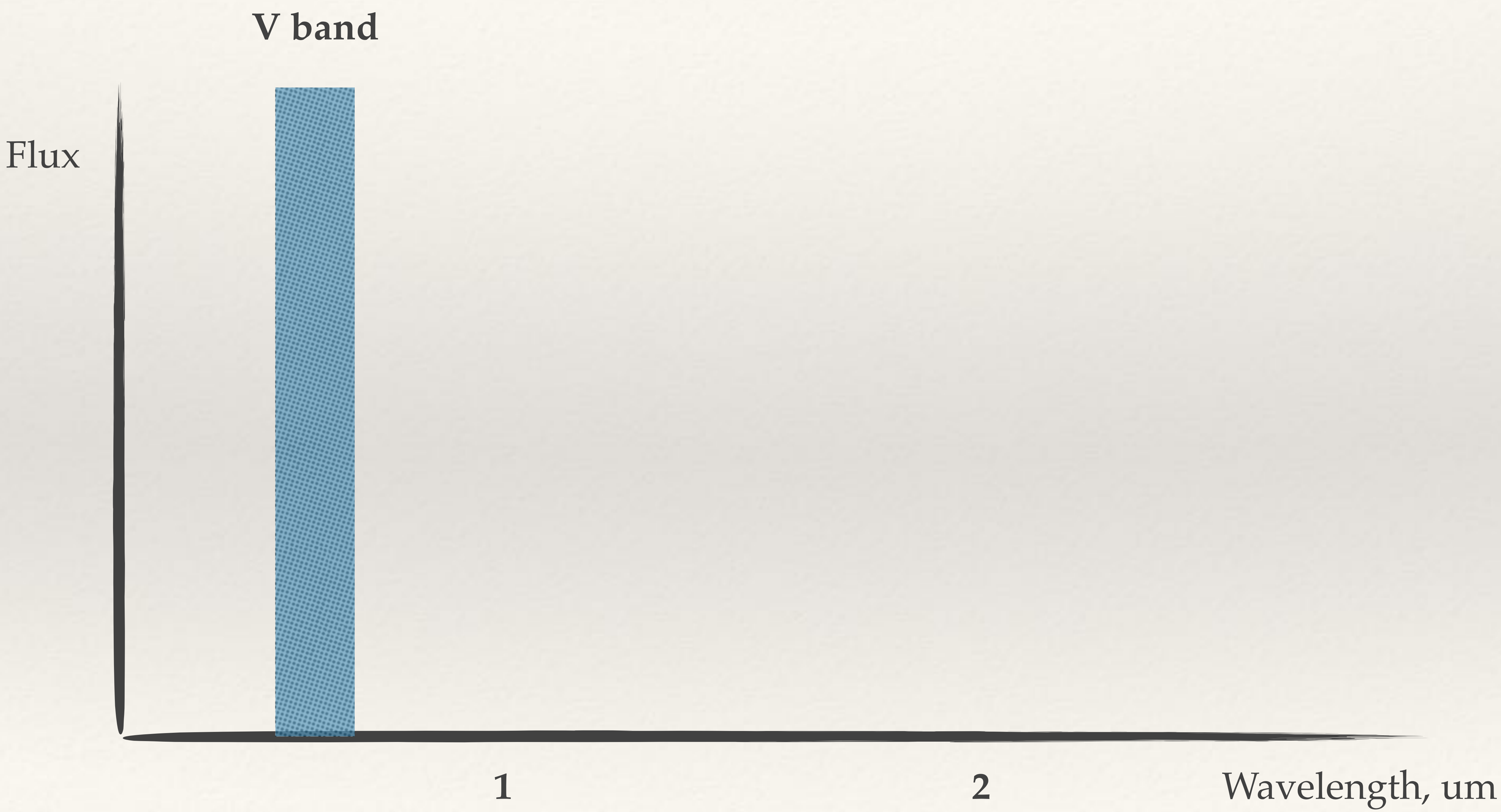
2MASS



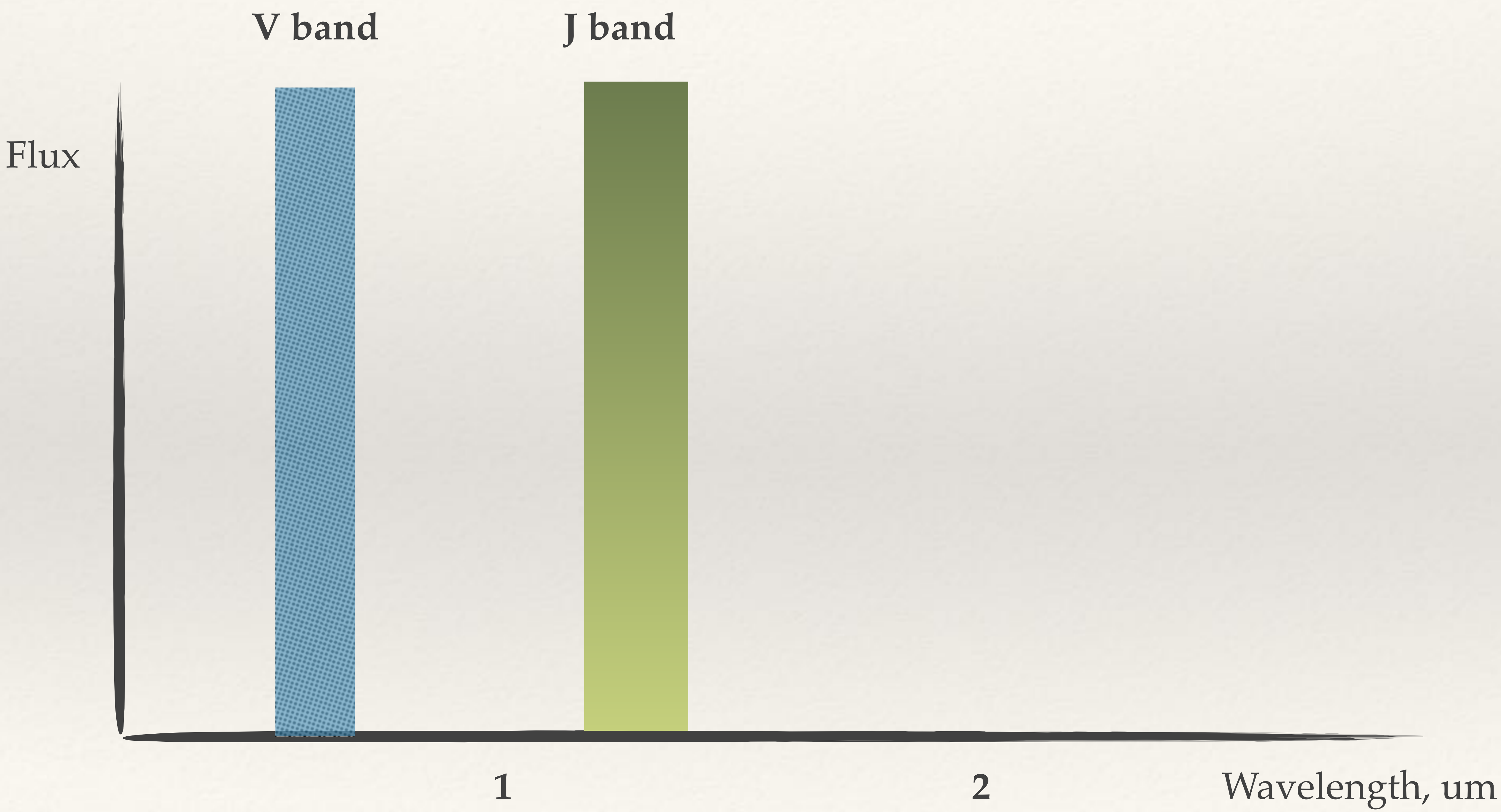
2MASS… ideal for BD hunting



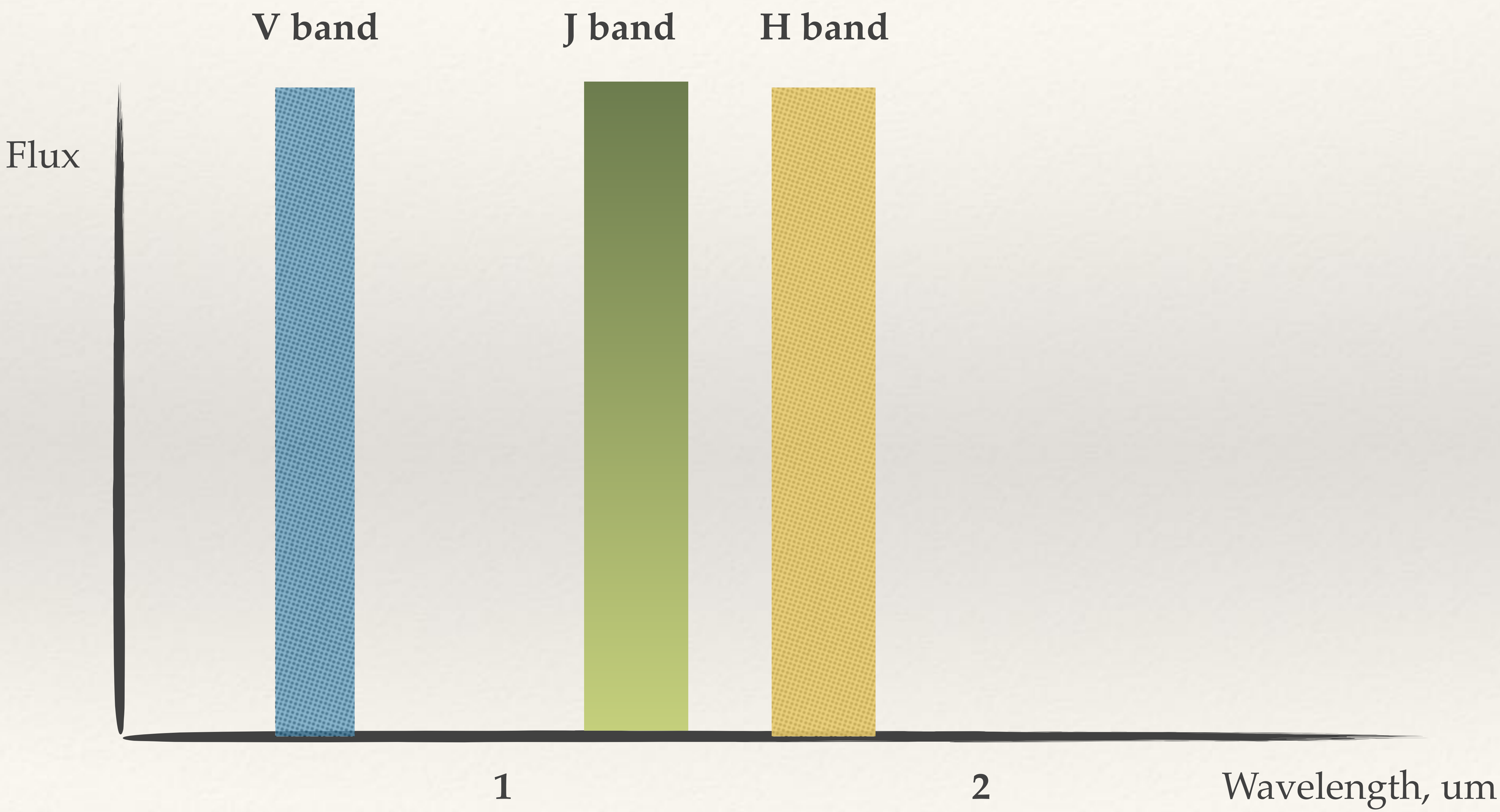
2MASS… ideal for BD hunting



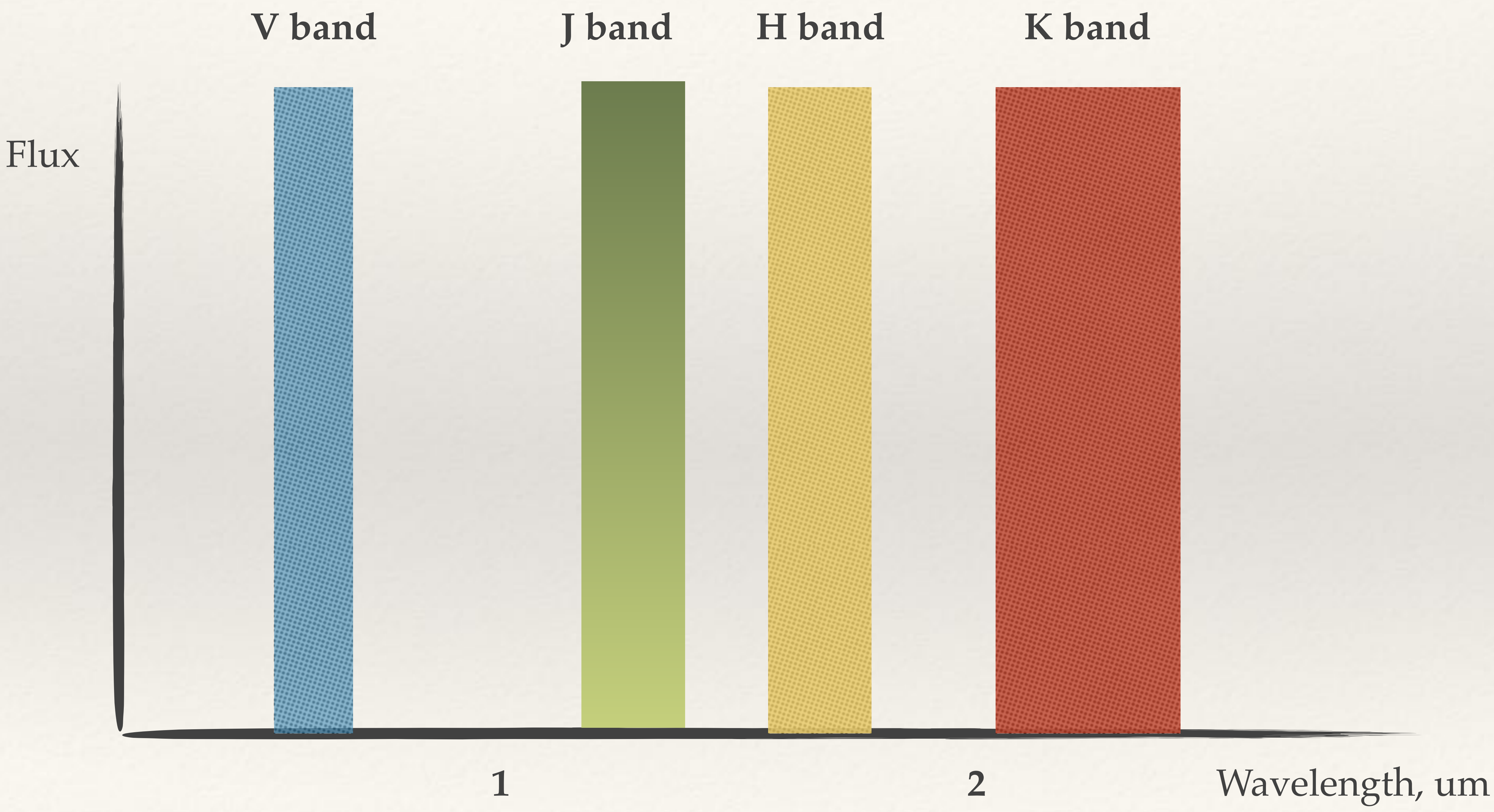
2MASS… ideal for BD hunting



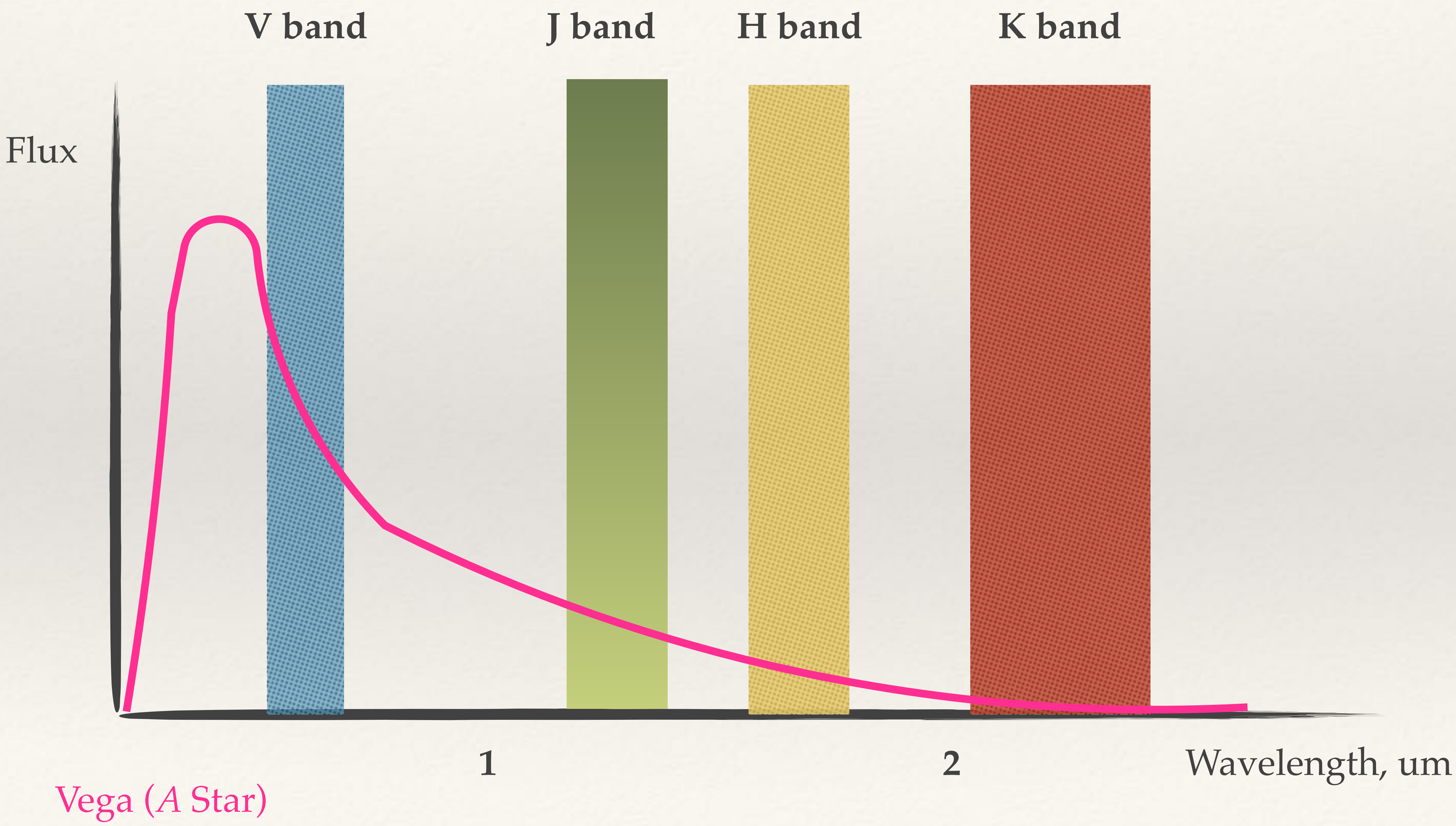
2MASS… ideal for BD hunting



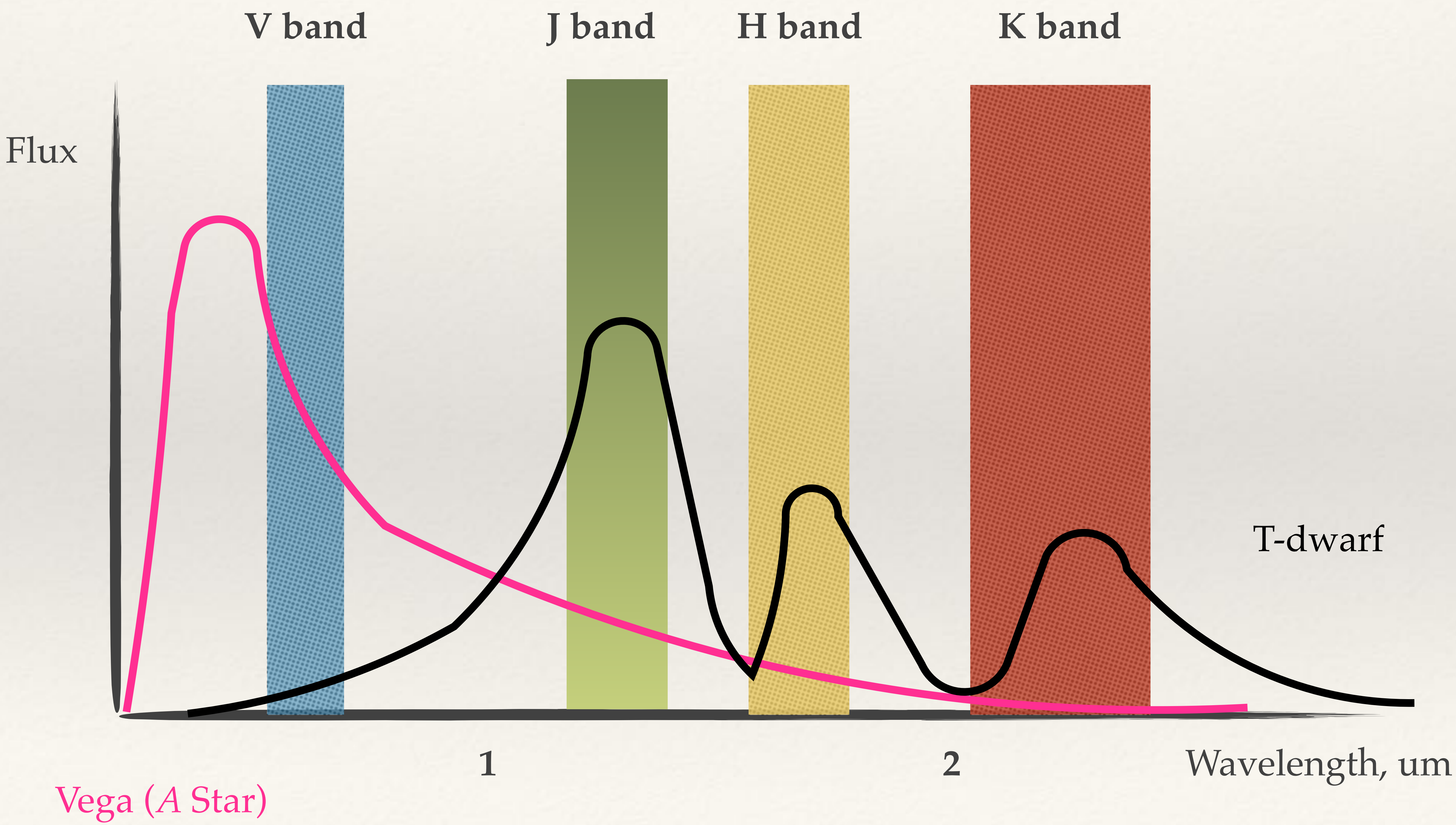
2MASS… ideal for BD hunting



2MASS… ideal for BD hunting



2MASS… ideal for BD hunting

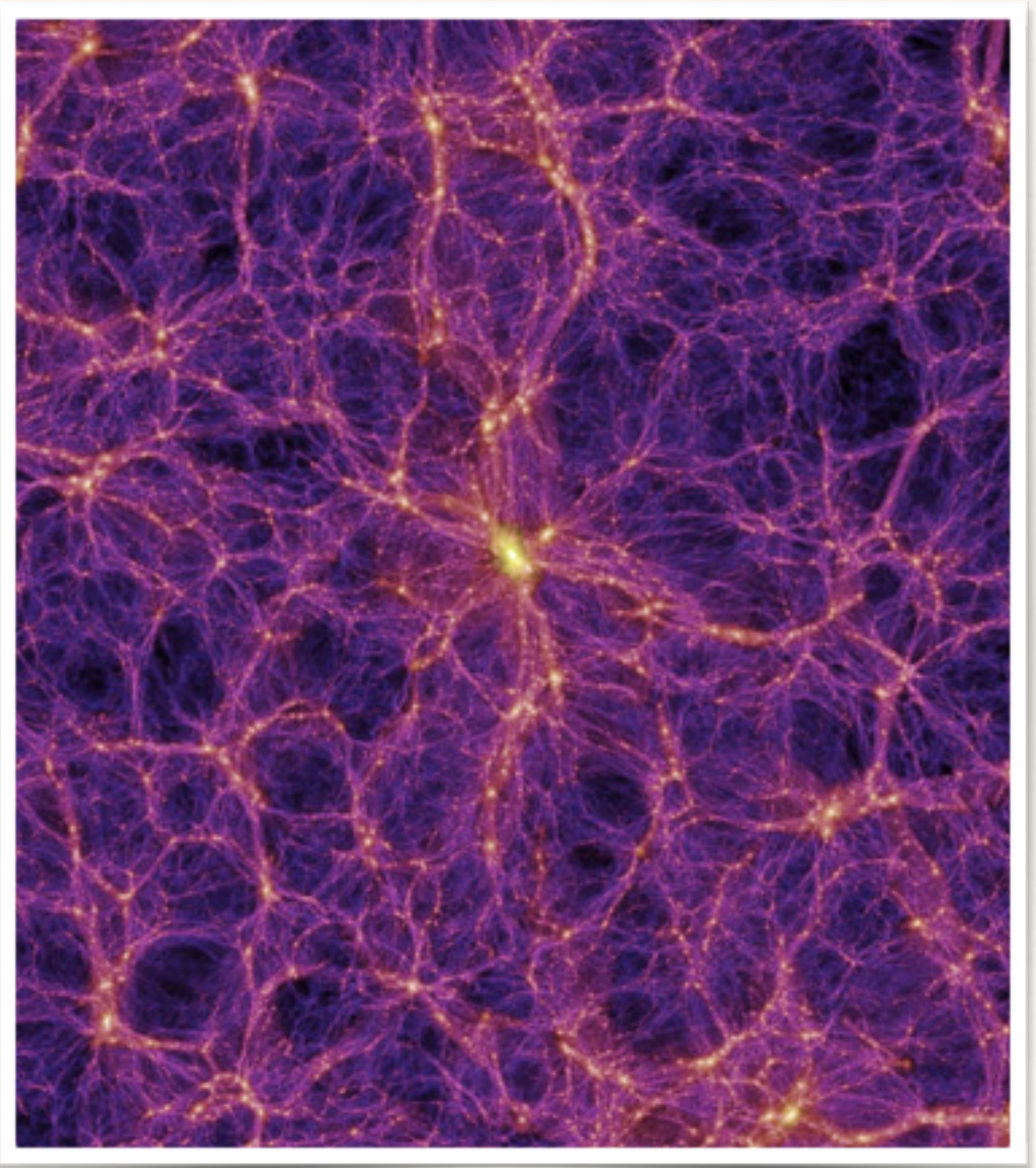


Importance of Brown Dwarfs

- Large contribution to galactic population (as numerous as stars?)
- Probes of galactic process (star formation, metal enrichment, etc)
- Low-temperature environments (chemistry, eco-solar climatology)
- Planet formation theory

Brown Dwarf… Dark Matter?

- Brown dwarfs were once proposed as potential dark matter candidates
- This model of Dark Matter is the 'MACHO' model (MAssively Compact Halo Objects)



Brown Dwarf… Dark Matter? No.

- Brown dwarfs were once
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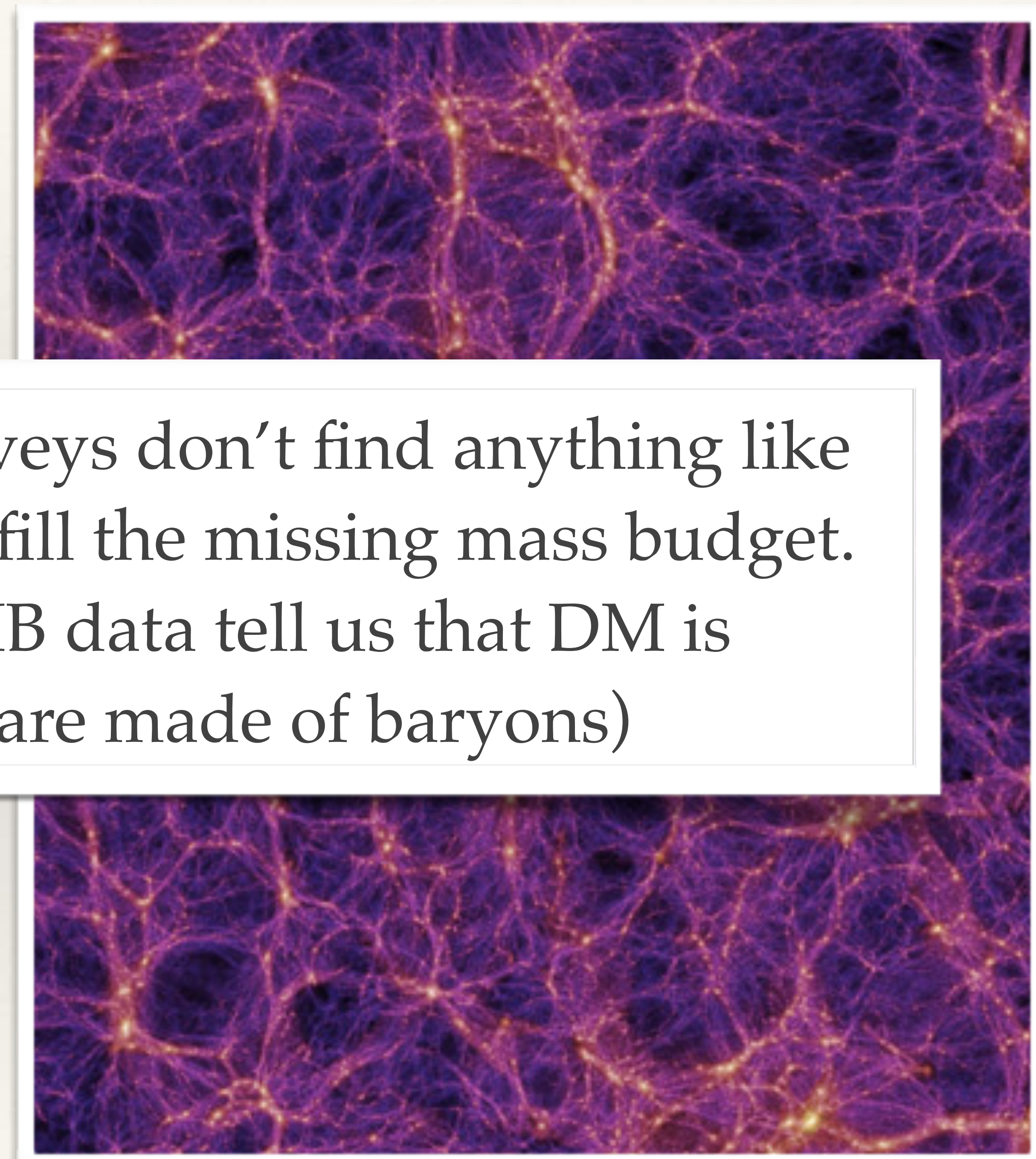
  (MAssively Compact Halo
  Objects).



But, this doesn't work. IR surveys don't find anything like the number of BDs needed to fill the missing mass budget. Plus, constraints from CMB data tell us that DM is *non-baryonic* (and BDs are made of baryons)

Infra-red Astronomy: Summary

- Boundaries between Near-, Mid-, and Far-IR
- Atmospheric windows: high-altitude observations and space-based astronomy (Lagrangian points)
- Cosmic Dust and extinction, PAHs
- Circumstellar disks
- Brown Dwarfs