Outline

- Introduction to infrared
- A little bit of context for THREE(!) IR missions
- Recent results – a crash course in star formation
- How you can get involved (!)
- Summary
Recall Wien’s Law: \( \lambda_{\text{Max}} (\text{nm}) = \frac{2.9 \times 10^6}{T(\text{K})} \)
EM spectrum

Converted into infrared by dust.

Does anyone still do this?

It's really the very far infrared

Too few photons to matter much

(Where it's at)

Infrared World...

“False color” image

Visible light

Infrared light

Temperature scale!
Hot and Cold Water

Hot things glow in the infrared

Hot water

Cold water

Hairdryer

Infrared can reveal things hidden in visible light
Infrared can see through some things that are opaque in visible light

...And some things transparent in visible light are opaque in infrared

Lots more “infrared world” photos online!
Frozen peas in liquid nitrogen

No peas

Even though these peas were frozen, they glow brightly in the infrared compared with the extremely cold liquid nitrogen. In space, many objects are very cold, but glow very brightly in the infrared compared with the extremely cold background of space.

Lifting the Cosmic Veil

Views of Orion

Spitzer opens the infrared window on the Universe!
Infrared Astronomer Units

Wavelengths in infrared astronomy are commonly expressed in microns = micrometers = \( \mu m \) (or um)

- 5000 Å = 500 nm = 0.5 µm  Visible light
- ~0.9 to 5 µm  Near-infrared  ~smoke particles
- 5 µm to ~30 µm  Mid-infrared  ~hair
- 30 µm to ~350 µm  Far-infrared  ~salt grain

Brightnesses or fluxes are most likely to be given in Janskys (Jy) or mJy (milli Jy) or \( \mu Jy \) (micro Jy).

1 Jansky = \( 10^{-26} \) Watts/m\(^2\)/Hz

Jy can be converted to magnitudes which used to be rarely used in the mid- or far-infrared.

Why do we need to go to space?

1: Space is COLD.
2: Atmosphere absorbs IR light.
3 IR space-based observatories

- Three recent missions have provided tremendous complementary views of the sky:
  - Spitzer Space Telescope
  - WISE = Wide-field Infrared Survey Explorer
  - Herschel Space Telescope

Yes, there WILL be a quiz!

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Spitzer

- NASA-funded mission – Great Observatory
- Covers 3.6 $\mu$m to 160 $\mu$m using 3 instruments (IRAC, IRS, MIPS).
- Launched (from Cape Canaveral) August 2003, ran out of cryogen May 2009 (5.5 yr nominal life); now on ‘extended mission’ for shortest two channels (3.6 and 4.5 $\mu$m).
- Pointed observatory – we have proposal calls; it points in specific places.
- It is in an Earth-trailing orbit; now more than an AU away!
Spitzer being assembled. It is really not that big – 85 cm telescope!

Spitzer Orbits the Sun

Why a Better Choice?

- Better Thermal Environment (allows passive cooling)
- No Need for Earth-Moon Avoidance (Maximizes observing time)
- No Earth Radiation Belt (no damage to detectors or electronics)

Spitzer is now ~1 AU away! (~0.01 AU/month)
Herschel

- ESA-funded mission (similar scope as Great Observatory) – NASA has a piece of it.
- Covers 55 µm to 672 µm using 3 instruments (HIFI, PACS, SPIRE).
- Launched (from French Guiana, with Planck) May 2009, expected to run out of cryogen later 2012 (3.5 yr nominal life); there can’t be an extended mission.
- Pointed observatory – we have proposal calls; it points in specific places.
- It is at a Lagrange point (L2).

Herschel being assembled – mirror is 3.5 m!
Herschel orbits the Sun

- Herschel orbits AROUND the L2 point (gravitationally ~stable)
- Gets away from the Earth-Moon system (cooler, no radiation belts); enables shielding from Sun.

WISE

- NASA-funded mission – Explorer class (=small)
- Covers 3.4 µm to 22 µm using one instrument (4 channels – 3.4, 4.6, 12, 22 µm).
- Launched (from Vandenberg) Dec 2009, ran out of cryogen Oct 2010 (~10 mon!), did a little bit more in 3 bands; turned off Feb 2011, now in ‘hibernation’ and could be reactivated if $.
- Survey mission – it looked at the whole sky.
- It is in a Sun-synchronous polar orbit (at the sunrise/sunset terminator).
WISE being assembled. With a mirror diameter of only 40cm, the telescope (and spacecraft) is very much smaller than Herschel or even Spitzer!

WISE orbits the Earth

The Moon and the radiation belts matter!
A quiz!...

• Which one trails behind the Earth?
• Which one orbits the Earth?
• Which one observed the whole sky?
• Which one had the shortest life?
• Which one observed in the longest wavelengths?
• Which one had cryogen on board?

3 missions

<table>
<thead>
<tr>
<th>Property</th>
<th>Spitzer</th>
<th>Herschel</th>
<th>WISE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Telescope diameter</td>
<td>85cm</td>
<td>3.5m</td>
<td>40cm</td>
</tr>
<tr>
<td>Wavelength coverage</td>
<td>3.6-160 µm</td>
<td>55-672 µm</td>
<td>3.4-22 µm</td>
</tr>
<tr>
<td>Observing strategy</td>
<td>Pointed</td>
<td>Pointed</td>
<td>Survey</td>
</tr>
<tr>
<td>Launch date</td>
<td>2003</td>
<td>2009</td>
<td>2009</td>
</tr>
<tr>
<td>Orbit</td>
<td>Earth-trailing</td>
<td>L2</td>
<td>Sun-synchronous polar orbit</td>
</tr>
<tr>
<td>Cryogen</td>
<td>Not anymore!</td>
<td>Yes, until later 2012</td>
<td>Not anymore!</td>
</tr>
<tr>
<td>Extended mission</td>
<td>Yes, now</td>
<td>Not possible</td>
<td>Brief; hibernation now.</td>
</tr>
</tbody>
</table>

All have public archives, but Spitzer and WISE data are currently easier to use.
Hubble is in low Earth orbit, at an inclination (that used to be) reachable by the Shuttle – goes in and out of daylight, well within radiation belts, and fairly close to the Earth!

**Knowing what you know now, does Hubble do a lot of IR observing?**

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**Two Key Science Questions for IR missions**

- **What did the early universe look like?**
- **How do stars and planetary systems form and evolve?**
In Cepheus, 3000 light years away. Image is ~moon size. (Complex is 10 full moons across!)

All IRAC: 3.6 um (blue), 4.5 um (green), 5.8 um (orange), and 8.0 um (red)

H$_2$ (green) and polycyclic aromatic hydrocarbons (PAHs; brown)

MIPS: 24 um (red); IRAC: 3.6/4.5 um (blue), 5.8/8.0 um (green).
Formation of a [low mass] star

Greene, American Scientist, Jul-Aug 2001
Formation of a [low mass] star

Greene, American Scientist, Jul-Aug 2001

IC 1396

Visible | IRAC | MIPS
M16: “Pillars of Creation”

Image is ~1.2 arcmin square (@2 kpc, smallest pixel is 90 AU!)

Blue=[O III] (5007 A)
Green= Halpha (6560 A)
Red=[S II] (6731 A)

6500 light years away

HST-WFPC2 (optical)
Hester & Scowen (Arizona State/ NASA), Nov 1995

4-color Spitzer image: 4.5, 8, 24, and 70 microns; this field of view is 28 x 32 arcminutes.

Red here means hotter dust heated by a SN 8000-9000 years ago; the blast wave is crumpling the towers!

Image: NASA/ JPL-Caltech/ N. Flagey & MIPSAL team
4-color Herschel image: 70 (blue), 160 (green) and 250 μm (red).

Dust shown is ~10K (red) to ~40K (blue).

Image: ESA/Herschel/PACS/SPIRE/Hill, Motte, HOBYS Key Programme Consortium

2-color WISE image: 14.5 um (red) and 7.7 um (blue). ‘Blurrier’ due to different resolutions; but WISE covers the whole region!
Resolution and Coverage

Spitzer 3.6 microns

http://www.spitzer.caltech.edu/

WISE 3.4 microns

Spitzer has better spatial resolution and sensitivity, but it does not cover the whole sky!

Formation of a [low mass] star

Greene, American Scientist, Jul-Aug 2001
Lynds 1014

“Starless” Core L1014
NASA / JPL-Caltech / N. Evans (Univ. of Texas at Austin)

600 LY away

Spitzer Space Telescope • IRAC • MIPS
Visible / DSS
ssc2004-20n

 NGC 1333

NGC 1333 is 1000 light years away in Perseus

• TONS of stars forming -- complete chaos here!
• Everything green is a jet associated with a young star.
Fomalhaut

Dust disk surrounding the 18th brightest star in the sky. (25 light years away, in Piscis Austrinus.)

@24 um, CO$_2$ freezes; @70 um, N$_2$ freezes.

370 AU across! (5x Sol Sys!)

Asymmetry!

Fomalhaut Circumstellar Disk
NASA / JPL-Caltech / K. Stapelfeldt (JPL)

Debris disks
Systems more like ours

• A lot of stars like our Sun (20-60%) have dusty disks -- does that mean that lots have (rocky) planets? (Meyer et al. 2008)

• Lots of water found in clouds around young stellar objects -- will it ultimately get caught up into planets? (Watson et al. 2007, Carr & Najita 2008, Salyk et al. 2008)

• Our Moon formed from a giant collision between planetesimals. But a lot of stars now at that age do not seem to have lots of dust. Does that mean large moons (and tides that go with them) are rare? (Gorlova et al. 2007, but see also Currie et al. 2008)
Did comets bring Earth’s water?

The thought had been that comets could have brought no more than 10% of Earth’s water (asteroids brought most), based on the ratio of D/H in a few Oort cloud comets. (~2x Earth). **Herschel has upended this;** this KB object has ~Earth D/H → large reservoir of Earth-like water in outer Solar System!

*(Hartogh et al. 2011)*

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Planetary smash-ups
Planets around binaries

Spitzer results: Trilling et al. 2007…
Kepler finding circumbinary planets!
(Doyle et al. 2011; Welsch et al. 2012)
Epsilon Eridani

- Our closest known planetary system, ~10 light-years away.
- A younger, fainter version of our sun, about 800 million years old -- about the same age of our solar system when life first took root on Earth.
- It has two asteroid belts, in addition to previously identified candidate planets and an outer comet ring.

North American Nebula – 2-minute movie of this at the end if time and interest!

Rebull et al., 2011
And an APOD!
• TIME is the new frontier!!
• Lots of time with Warm Spitzer to stare and see what changes!

http://www.spitzer.caltech.edu/
LOTS of data available

- Spitzer, Herschel, WISE (plus many more) all have public archives! (all of WISE out Mar 14!)
- Tons of data online… nearly all in FITS files.
- Spitzer data in a Citizen Science project: http://www.milkywayproject.org/
- Most of the ‘famous’ objects are observed with Spitzer; ~everything seen by WISE!
- WISE and Spitzer have a very similar archive interface.
- Can you handle FITS files? You can go get original FITS files so you can make your own 3-color images (or analysis)… There are tutorials for both WISE and Spitzer online.

NITARP

- NITARP = NASA/IPAC Teacher Archive Research Program
- Real research! …
- Application available Spring, due Sept
- Google NITARP or email me to get more information!
- http://nitarp.ipac.caltech.edu
Quotes from NITARP

• I had an amazing, exhausting time at the AAS.
• I didn’t anticipate meeting engineers and graphic artists.
• I was surprised at the number of young people [...] I am used to seeing older people as astronomers.
• What I am in awe about is that this relatively small community of scientists, engineers, programmers, and educators has developed and built this incredible astronomical research infrastructure.
• (and you can do it too!)

Summary

• Light beyond the visible: the world looks very different in the infrared!
• Spitzer, Herschel, and WISE are three exciting IR missions, with complementary features.
• Spitzer, Herschel, and WISE study star formation, finding dust everywhere!
• LOTS of cool images… with more coming all the time!