Spitzer Space Telescope

(A.K.A. The Space Infrared Telescope Facility)

The Infrared Imaging Chain
The infrared imaging chain

Generally similar to the optical imaging chain...

1) Source (different from optical astronomy sources)
2) Object (usually the same as the source in astronomy)
3) Collector (Spitzer Space Telescope)
4) Sensor (IR detector)
5) Processing
6) Display
7) Analysis
8) Storage

... but steps 3) and 4) are a bit more difficult!
The infrared imaging chain

- Longer wavelength – need a bigger telescope to get the same resolution or put up with lower resolution
Emission of IR radiation

- Warm objects emit lots of thermal infrared as well as reflecting it
  - Including telescopes, people, and the Earth – so collection of IR radiation with a telescope is more complicated than an optical telescope
  - Optical image of Spitzer Space Telescope launch: brighter regions are those which reflect more light
  - IR image of Spitzer launch: brighter regions are those which emit more heat
  - Infrared wavelength depends on temperature of object
Atmospheric absorption

The atmosphere blocks most infrared radiation

Need a telescope in space to view the IR properly
Detection of infrared radiation

- CCDs cannot detect wavelengths > 1 micron
  - IR photons do not have enough energy to knock electrons out of the silicon
  - Different detector technology is required
  - IR detector technology has lagged behind CCD technology
The Spitzer Space Telescope

The last of NASA's four Great Observatories in space

- The latest and greatest in a series of IR space missions (IRAS, MSX, ISO)
- Planning started two decades ago
- Underwent 2 major design revisions to accommodate budget cuts
- Launched August 2003
- Expected lifetime of 5 years (limited by cryogen supply)

Telescope specs:
- 85 cm (33.5 in) primary mirror
- Cooled to 5.5 K
- Wavelength coverage 3 – 160 microns
- Earth-trailing, heliocentric orbit
Telescope orbit

- Innovative orbit – Spitzer trails the Earth as it orbits the Sun
- Telescope orbits the Sun rather than the Earth
- Distance from Earth increasing by 15 million km/year
- Much colder than orbiting Earth itself
- Not servicable

- Less liquid helium cryogen is needed to keep the telescope cool – keeps lifetime long and costs down
Telescope view of the sky

- Where the telescope can point in the sky is limited by *pointing constraints*

- At any time of year:
  - Telescope cannot point too close to the Sun (80°) or it will heat up
  - Telescope cannot point too far away from the Sun (120°) because the solar panels need illumination to power the telescope systems
Telescope design

Important considerations:

- Compact – has to be launched into space
- Lightweight – every kilogram costs
- Thermally stable – so minimally affected by changes in temperature
Telescope design

- **Ritchey-Chretien design**
  - Similar to Cassegrain but hyperboloid shaped mirror
  - Wider field-of-view than Cassegrain
  - Corrected for spherical aberration and coma
Telescope design

- Telescope and mirror made of beryllium
- Very lightweight (telescope < 50 kg)
- All the same material so won't break apart with thermal changes
Telescope Design

- Telescope and instruments cooled to 5.5 K (shown in blue)
- Spacecraft warm (shown in red)

Telescope quite small compared to the whole assembly
- Instruments & electronics
- Solar panels
- Cryostat
- Telecommunications
- System control & power
Instruments

- One of 3 instruments in use at a time
  - Mirrors and beam-splitters send the light to the instrument
- **IRAC** (InfraRed Array Camera)
- **IRS** (InfraRed Spectrograph)
- **MIPS** (Multiband Imaging Photometer for Spitzer)
Instruments

- Instruments are housed in the multi-instrument chamber (MIC) at the focal plane of the telescope
Instruments

- IRAC (InfraRed Array Camera)
  - Images at 3.6, 4.5, 5.8, and 8.0 microns
  - Spatial resolution of 1.8 arcsec in a 5 arcmin x 5 arcmin field
  - Two detectors
    - Each 256 x 256 pixels
    - Two indium + antimony (short wavelengths)
    - Two arsenic-doped silicon (long wavelengths)
  - No moving parts (shutter not used)
Sombrero Galaxy/Messier 104

Visible + Infrared

Spitzer Space Telescope • IRAC

Visible: Hubble Space Telescope/Hubble Heritage Team
Infrared: Spitzer Space Telescope

NASA / JPL-Caltech / R. Kennicutt (University of Arizona), and the SINGS Team

ssc2005-11a
Instruments

- IRS (InfraRed Spectrograph)
  - Low-resolution spectra from 5 – 38 microns
  - High-resolution spectra from 10 – 37 microns
  - Two detectors
    - Each 128 x 128 pixels
    - Arsenic-doped silicon (short wavelength)
    - Antimony-doped silicon (long wavelength)
  - No moving parts
Prebiotic Molecules in Planet Zone of Young Star IRS 46

NASA / JPL-Caltech / F. Lahuis (Leiden Observatory) 

Spitzer Space Telescope • IRS

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Instruments

- MIPS (Multiband Imaging Photometer for Spitzer)
  - Images at 24, 70, and 160 microns
  - Spatial resolutions of 2.5 – 16 arcsec and fields of 5.4 x 5.4 – 5.3 – 0.53 arcmin
  - Very low-resolution spectra from 55 – 100 microns
  - Only moving part is scan mirror
Dust in Andromeda Galaxy (M31)
NASA / JPL-Caltech / K. Gordon (University of Arizona)

Spitzer Space Telescope • MIPS
Visible: NOAO/AURA/NSF
ssc2005-20a
Infrared detectors

Not CCDs (charge coupled devices)
- electrodes across the surface of the array *couple* the pixels together so charge can be transferred across the array and read out
- the use of electrodes in this way works for silicon but not other materials
- pure silicon is not sensitive to wavelengths above 1 micron
Infrared detectors

Hybrid (two-layer) arrays

- upper layer detects the photons – each pixel is a separate detector which stores charge and must be read out separately
- lower layer is a multiplexor which connects each pixel in turn to the readout amplifier

- two layers connected by columns or dots of metal which conducts the charge collected by the pixel to the lower layer
IR detectors vs CCDs

CCDs
- Pros: Cheaper and easier to manufacture, smaller pixels and larger array sizes possible, efficient to read out, low readout noise, linear
- Cons: Don't work in the infrared, saturated pixels bleed into neighboring pixels, all reads are destructive

IR detectors
- Pros: Work in the infrared, saturated pixels don't affect neighbors, non-destructive reads
- Cons: larger pixels and smaller array sizes currently possible, high readout noise, thermal mismatch between layers, non-linear
Spitzer detectors

- **IRAC**
  - Indium antimonide (InSb), 256 x 256 pixels
  - Arsenic-doped silicon (Si:As), 256 x 256 pixels

- **IRS**
  - Si:As, 128 x 128 pixels
  - Antimony-doped silicon (Si:Sb), 128 x 128 pixels

- **MIPS**
  - InSb, 128 x 128 pixels
  - Gallium-doped germanium (Ge:Ga), 32 x 32 pixels
  - Stressed Ge:Ga, 2 x 20 pixels

Longer wavelength, smaller arrays
Fowler Sampling

- Pairs of non-destructive reads
- Measure voltage differences between signal and pedestal reads
- Final voltage is average of 4 voltage differences
- Minimizes read noise
- On-board software calculates the slope of the line and transmits this back to Earth
The rest of the imaging chain

- **Image processing**
  - Get rid of detector artifacts, including dark current, muxbleed, non-linearity correction, flatfielding
  - Co-add multiple frames and combine mosaicked images
  - Flux calibration (converting counts/second to flux density)

- **Display**
  - same as optical, once you have a digital (e.g., FITS) image

- **Analysis**
  - very similar to optical images, on a digital image

- **Storage**
  - Spitzer data takes a lot of space (many Gb)
The infrared universe

If it's all so much more difficult than optical astronomy, why do we bother?

Obviously, we get a different view of the universe in the infrared:

- in optical astronomy we see the hot stuff, while in IR astronomy we see the cool stuff
- in the NIR, we can see through the instellar dust, and in the mid- to far-infrared we can see the dust itself
Seeing through the dust in Orion
Astronomical IR sources

- **Near-infrared (1 – 5 micron)**
  - Temperatures of 740 – 3000 K
  - Cooler red (old) stars, red giant stars, very hot dust in the nuclei of active galaxies (most dust is transparent in NIR)

- **Mid-infrared (5 – 30 micron)**
  - Temperatures 130 – 740 K
  - Planets, comets and asteroids, dust heated by starlight in galaxies, protoplanetary disks

- **Far-infrared (30 – 200 micron)**
  - Cold dust in galaxies, and cold molecular clouds
Some more Spitzer images

Dust in the Center of the Milky Way Galaxy
NASA / JPL-Caltech / S. Stolovy (Spitzer Science Center / Caltech)

Spitzer Space Telescope • IRAC
ssc2006-02b
Henize 206 – star forming region in LMC

visible

8 microns (IRAC)

24 microns (MIPS)

Combined visible/IR
M 82 – starburst galaxy

Combined X-ray (blue), IR (red), hydrogen (orange) and visible (yellow-green)