Astronomical Techniques I

Lecture 8

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Assignment 1

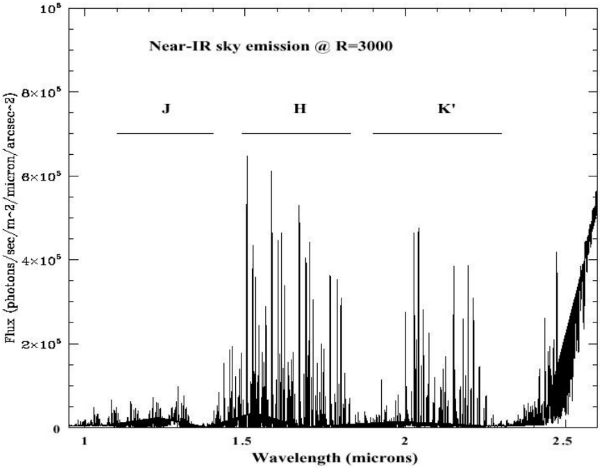
will be posted on the website by tonight or tomorrow morning. Kaustubh Vaghmare (kaustubh@iucaa.ernet.in) is your tutor. If you need any clarifications regarding your assignment, talk to him.

Why IR astronomy is hard from the ground

1. Bright sky and telescope background continuum emission
2. bright atmospheric emission lines
3. strong atmospheric absorption lines (mainly H2O); and
4. high detector dark currents.
5. In the past, the problem was compounded by low sensitivity detectors and the absence of large format 2D detectors.

2,3 above make near IR spectroscopy from the ground extremely difficulty $\Rightarrow$ redshift desert.

The near IR sky



Near-mid Infrared instrumentation

- Use of infrared detector arrays in astronomy began roughly 20 years ago, and our detection capabilities in parts of this spectral range have doubled about every seven months since then if measured by (# of pixels) $\times$ (sensitivity per pixel $)^2$.
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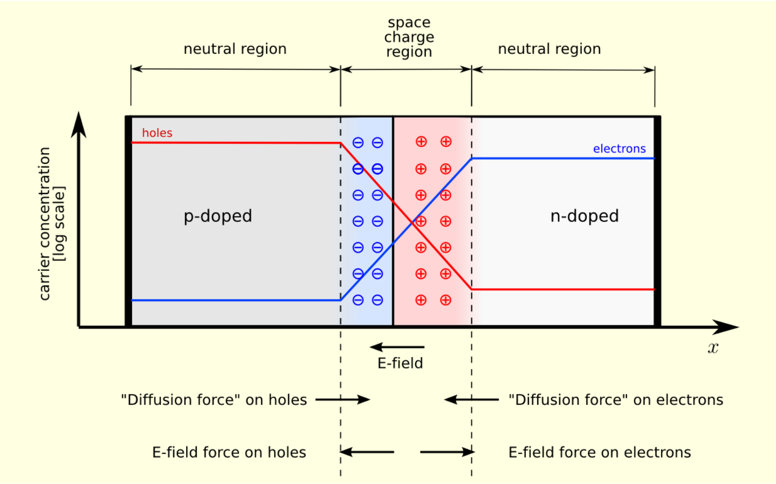
  4. bolometer arrays read out by transistors or superconducting devices in the far-infrared through millimeter-wave spectral range (where heterodyne receivers begin to become more efficient) - future lecture

PN Junction as photodiode



InSb arrays

- band gap at 77 K provides response out to about 5.6 micron, thus nicely matching the JHKLM atmospheric windows.
- material can be grown with good crystallography, high purity, and excellent uniformity, all of which contribute to its high performance in infrared detectors.
- very widely used in near IR arrays until recently

Mercadtel arrays $\mathrm{Hg_{1-x}Cd_xTe}$

- By varying *x* the elemental composition of cadmium (Te is always 50%, the band gap can be changed from 1.55 eV for $x = 1$, corresponding to a cutoff wavelength of 0.8 μm, to a very small band gap energy, or even a metal.

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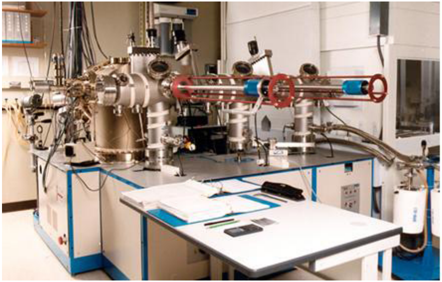
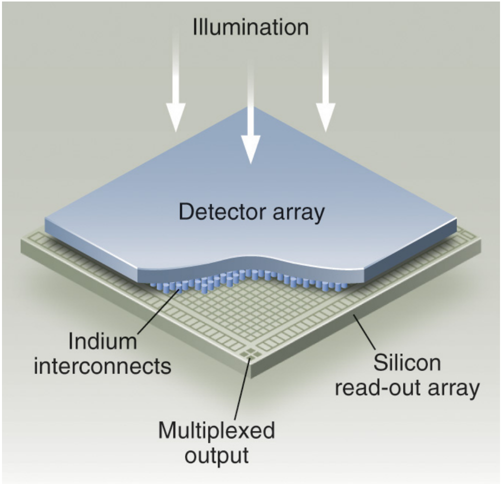
- small band gap $\Rightarrow$ small contact voltage $\Rightarrow$ high dark current, sets long wavelength cutoff at $\sim$ 10 micron.

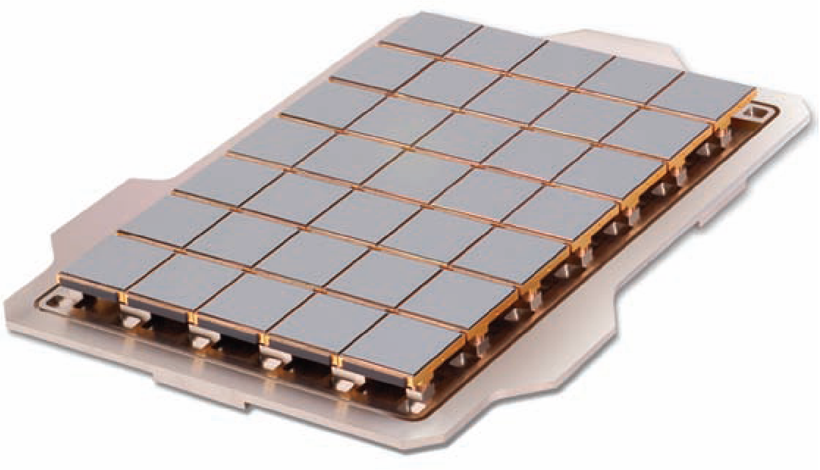
MBE machines at Teledyne imaging sensors



Mercadtel array



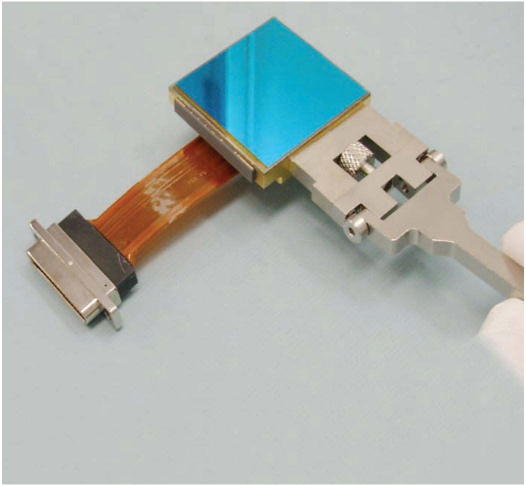
Mercadtel mosaic - 35 2kx2k with 140 million pixels



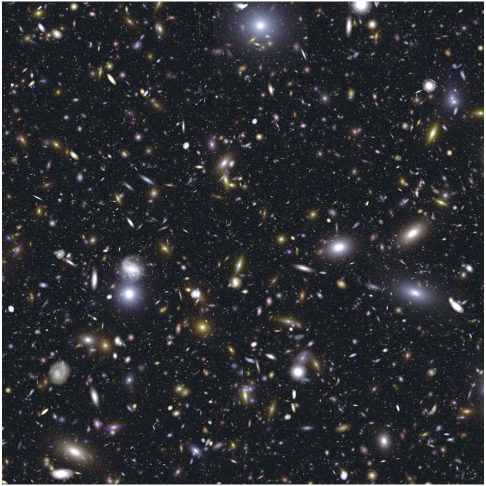
State of the art HgCdTe array - Rockwell H2RG JWST NIRCam

- Wavelength range 0.6-6.3 micron
- Format 2048 $\times$ 2048
- Pixel size 18μm
- Operating tempararature 37 K
- Read noise 6 electrons/pixel (slow readout)
- Dark current : $<$ 0.01 electrons/sec
- Well capacity: 80000 electrons
- Quantum Efficiency: $>$ 80%

NIRCam array on JWST



Simulated JWST image



TIRSPEC - TIFR near IR Spectrograph and imager

Wavelength Range	1 to 2.5 micron
Detector	1k $\times$ 1k Hawaii-1 array
Array Size	1024 x 1024
Pixel Size	18 micron
Pixel Scale	0.3 arcsec/pixel
Field of View	307 $\times$ 307 arcsec^2
Spectral resolution	$\sim$ 1200
Minimum Exposure	0.9 sec

installed at 2m HCT telescope, Hanle, Ladakh

Parent Distributions

Measurement of any physical quantity is always affected by uncontrollable random ('stochastic') processes. These produce a statistical scatter in the values measured. The parent distribution for a given measurement gives the probability of obtaining a particular result from a single measure. It is fully defined and represents the idealized outcome of an infinite number of measures, where the random effects on the measuring process are assumed to be always the same ('stationary').

Systematic versus stochastic

In general, the effects of systematic errors are not manifested as stochastic variations during an experiment. In the lab, for instance, a voltmeter may be improperly calibrated, leading to a bias in all the measurements made. Examples of potential systematic errors in astronomical photometry include a wavelength mismatch in CCD flat field calibrations, large differerential refraction in Earth's atmosphere, or secular changes in thin clouds.

The statistical infrastructure we will discuss in this course here does not permit an assessment of systematic errors. Those must be addressed by other means.

But systematics can be important - high precision, low accuracy

The primary mirror for the Hubble Space Telescope was figured with high precision (i.e. had very small surface features much smaller than a wavelength of light), but it was inaccurate in that its shape was wrong.

The central problem

How to make accurate flux measurements with a precision or SNR appropriate to the scientific goals given the practical constraints?

Non-stochastic effects on number of photons received

per unit time, per unit area, from a unit solid angle of sky per unit wavelength/frequency

- *Interstellar extinction* depends on dust grain column density in direction of source
- *Atmospheric extinction* depends on total atmospheric path length ($\propto \sec Z$, where Z is the angular distance to the zenith)
- *Atmospheric refraction* Prismatic effect of differential refraction for $Z > 0$ causes elongation/chromatic separation of sources
- *Atmospheric turbulence* (seeing) Causes blurring and jitter of images
- Absorption/scattering by optical surfaces Reflecting and refracting surfaces and transmitting media destroy a fraction of photons incident on the telescope aperture.

The discussion today focuses on UVOIR observations made with detectors based on the photoelectric effect.

Major contributors to stochastic noise

1. Photon noise
2. Background noise
3. Measuring process noise
4. Other sources of noise

Contributors to background noise

Diffuse Sky Photon Background

- Earth's atmosphere: scattered city lights, airglow, aurorae, thermal continuum (IR). Atmosphere contributes to both continuum & emission lines. Emission lines (e.g. [O I] and OH) can be highly variable. Atmosphere is not an issue for space observatories at optical/IR wavelengths. However, skyglow emission lines (e.g. O I) from residual atmosphere above 500 km are important in far-UV.

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- Zodiacal light (sunlight scattered by IP grains); strong direction dependence, but not time dependence; has Solar spectrum. Thermal emission in IR.

Contributors to background noise

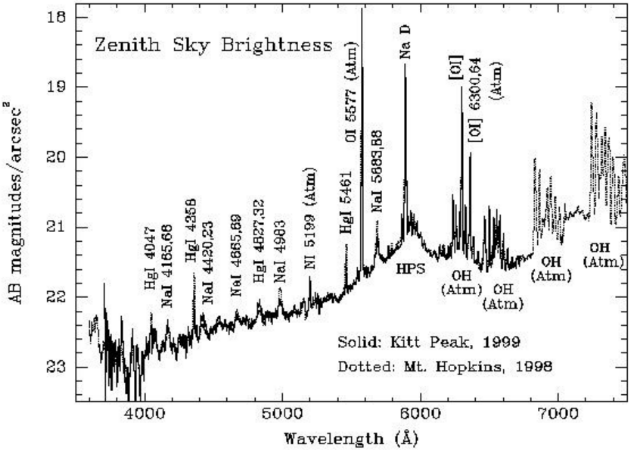
- Galactic background light. In UVOIR, is primarily starlight scattered by IS grains at lower galactic latitudes; has hot-star spectrum but is faint. In the Far-IR ($\lambda > 20\mu$m) emission from warm dust: *IR cirrus*

Background at Mauna Kea - no moon

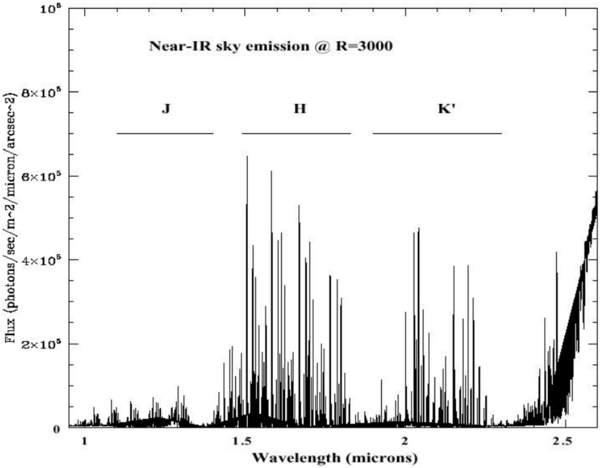
Table 2-1. Broadband sky brightness for Mauna Kea

Band	**Central λ** (μm)	**Brightness** (mag arcsec^{-2})	(AB mag arcsec^{-2})	(μJy arcsec^{-2})	**Flux** (photon cm^{-2}s$^{-1}\mu$m^{-1}arcsec^{-2})
U	0.36	21.6	22.5	3.3	1.74×10^{-2}
B	0.44	22.3	22.2	4.8	1.76×10^{-2}
V	0.55	21.1	21.1	13.2	3.62×10^{-2}
R	0.64	20.3	20.6	20.9	5.50×10^{-2}
I	0.79	19.2	19.7	47.9	1.02×10^{-1}
J	1.23	14.8	15.6	2089.3	2.49
H	1.66	13.4	14.7	4786.3	4.20
K	2.22	13.5	15.4	2511.9	1.74

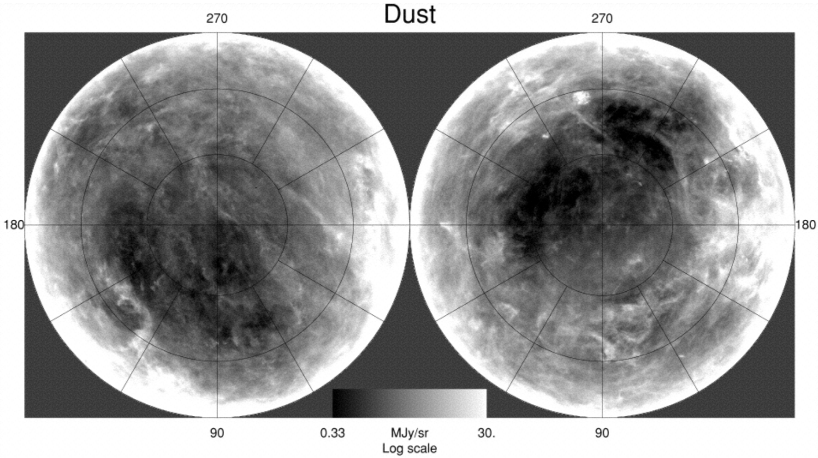
Optical background



Near IR background



Infrared Cirrus



Sources of cirrus

Cirrus emission is produced by warm interstellar dust grains at typical distances of 100-3000 pc within the Galaxy. Far-IR observations can be severely affected by this strongly non-uniform background. Must use Schlegel et al. 1998 maps to account for cirrus.