I can show you the worlds
The Science of Planetary Exploration

Anjali Tripathi
Kirit Karkare
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Outline

• Anjali: Robotically Exploring the Solar System

• Kirit: Detecting Extrasolar Planets

• Sukrit: The Search for Life Beyond Earth
I can show you the worlds

How can we learn about the planets?

Anjali Tripathi
Kirit Karkare
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Telescopes
Telescopes
Spacecraft!
Unmanned, or robotic missions
Allow us to get a closer view

Get measurements in place

SENSES in space
Voyager I & II

Flying by the Gas Giants

Science Instruments

Radio/Plasma Wave Antenna
Magnetometers
Golden Record
Imaging (WA/NA)
Spectrometers (UV/IR)
Cosmic Ray
Plasma
Flying by the Gas Giants

Visited Jupiter, Saturn, Uranus & Neptune
discoveries:

- Jupiter has **rings**
- More **moons**
- **Storms** on Neptune

3 - Jupiter
3 - Saturn
10 - Uranus
6 - Neptune
February 14, 1990

4,000,000,000 miles away
Not fare well,
But fare forward, Voyagers.
— T. S. Eliot, The Dry Salvages

Today - Still going!
10,000,000,000 miles away
Cassini-Huygens
Orbiting Saturn, Landing on Titan
Cassini-Huygens
Orbiting Saturn, Landing on Titan
Cassini

Orbiting Saturn

[Diagram of Cassini spacecraft with labeled components]

[Image of Cassini spacecraft during assembly]

NASA/JPL
discoveries about Saturn’s moons:

Prometheus perturbs Saturn’s rings

Enceladus has icy jets

NASA/JPL/Space Science Institute
Phoebe

Voyager II
Sept. 4, 1981

1.3 million miles away

Cassini
June 11, 2004
1200 miles away

NASA/ESA/ASI
a view from the ultraviolet

Ultraviolet (UV) image displays brightness variations. UV spectra confirm presence of water frost on surface.

water frost
Phoebe
Saturn's Moon
NASA/ESA/ASI

made of loose dust and ice particles

a view from the infrared - temperature

day-night variation

Time

0.0
0.46 hours
0.91 hours
2.75 hours
3.16 hours

Temperature, K

70
80
90
95
100
105
110
115
a view from the infrared - mineral distribution

originated in the Kuiper belt
Cassini-Huygens
Landing on Titan

- Imager
- Measure winds using radio
- Analyze the atmosphere
- Measure Titan’s surface
descent unto Titan

Titan’s wind - the furthest sounds in the Solar System
Titan has rain & flows of liquid methane

drainage channels

hills

lakes

pebbles
Gas giants
Mars Exploration Rovers
Roving a Rocky World

Remote Sensing Package
Pancam
Mini-TES

In-Situ Package
Microscopic Imager
Alpha Particle X-Ray Spectrometer
Mössbauer Spectrometer
Rock Abrasion Tool

Magnetic properties experiment

NASA/JPL
RAT hole

water?

Mössbauer Spectrum of Clovis (200 - 220K)

Hematite
Silicate
Goethite
Nanophase-oxide (Goethite?)

Intensity

Velocity

Spirit
NASA/JPL/Cornell/USGS/U. Mainz
water?

blueberries

need water to form

sulphates and standing water

different, rippled layers

Opportunity
NASA/JPL/Cornell/MPI/U. Mainz
coming soon...
sample return
Spacecraft help us sense worlds like our own and wildly different worlds.
I can show you the worlds
Detecting Extrasolar Planets

Anjali Tripathi
Kirit Karkare
Sukrit Ranjan
Outline

• Why is exoplanet detection hard?
• How do we detect exoplanets?
• What have we found?
I want to see an Exoplanet ...

Can I just point a telescope at a nearby star?
Jupiter and its Moons
Seeing Exoplanets is HARD!

- Other stars are far away
- Planets are faint compared to stars
How can we see a planet?

Look for two effects on starlight:

Transit

Stellar wobble

John Johnson (Caltech)

Wikimedia
Effect 1: Transits

A planet crossing a star dims the total light

Just like the transit of Venus
Transits
Transit Light Curve

Charbonneau et al. 2010
Transit Light Curve
Here at Harvard: MEarth
The Kepler Mission
Effect 2: Stellar Wobble

John Johnson (Caltech)
The Doppler Effect

As the star moves back and forth, the colors of light change
The Nature of Light

• Starlight is a mixture of colors

• Separate the colors with a prism
How a Telescope Separates Colors

Steve Vogt (UCSC)
Spectral Line

John Johnson (Caltech)
Stellar Wobble Curve

- Mass
- Orbital period
Stellar Wobble Curve
Keck Telescopes
Direct Imaging

- Block out the starlight with a **coronagraph**
- Just like the sun
- Very recent advance
HR 8799, Beta Pictoris

Wikimedia, ESO/A.-M. Lagrange et al.
What Have We Found?

• 700+ planets!
• Strange properties
I can show you the worlds

Astrobiology: The Search for Extraterrestrial Life

Anjali Tripathi
Kirit Karkare
Sukrit Ranjan
Overview

• What is life? What are we looking for?

• Looking for life in our solar system

• Looking for life beyond our solar system (extrasolar planets)
Overview

• What is life? What are we looking for?

• Looking for life in our solar system

• Looking for life beyond our solar system (extrasolar planets)
What Do We Mean By Life?

• Metabolism
  – Consumes nutrients, releases wastes

• Earthlike life
  – Fewer assumptions
What is Earthlike Life?

- Liquid water
- Carbon-based
Overview

• What is life? What are we looking for?

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• Looking for life beyond our solar system (extrasolar planets)
Life in Our Solar System? Mars
Life in Our Solar System? Mars
Selected Moons of the Solar System Scaled to Earth's Moon

- Earth: Moon
- Mars: Phobos, Deimos
- Asteroid: Ida
- Jupiter: Io, Enceladus, Tethys, Dione, Rhea, Ganymede, Callisto
- Saturn: Mimas, Enceladus, Tethys, Dione, Rhea
- Uranus: Puck, Miranda, Ariel, Umbriel, Titania, Oberon
- Neptune: Proteus, Charon, Dysnomia, S/2005 (136108) 1, S/2005 (79360) 1
- Pluto: Charon
- Others: Earth

Scale: 1 pixel = 25 km
Life in Our Solar System? Europa
Life in Our Solar System? Europa

[Diagram showing Europa's core, ice cover, rocky interior, and liquid water layer]
Life in Our Solar System?
Ganymede
Overview

• What is life? What are we looking for?

• Looking for life in our solar system

• Looking for life beyond our solar system (extrasolar planets)
Life in Other Solar Systems

Our Planet Hunting Neighborhood

Most of the planets found to date lie within about 300 light-years from our Sun.
The Habitable Zone

• Habitable zone: distance from star where liquid water can exist
  – too close: water boils
  – too far: water freezes
The Habitable Zone

• “Goldilocks Zone”
• Depends on brightness of star
  – Brighter stars: further out
  – Dimmer stars: closer in
How Do We Look For Life Lightyears Away?

• Life modifies its environment
  – “Biosignatures”
• Carl Sagan: Galileo Experiment
Biosignatures

- Most detectable feature in Earth’s atmosphere: methane
- Methane in the presence of oxygen is unstable
Spectroscopy: Identifying Chemicals From Afar

- White light is made up of light of many different wavelengths (colors)
Spectroscopy: Identifying Chemicals From Afar

- Substances imprint “fingerprints” on light
Spectroscopy: Identifying Chemicals From Afar

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Spectroscopy: Identifying Chemicals From Afar

- Substances imprint “fingerprints” on light

[Diagram showing absorption and emission spectra for hot and cold gases]
Spectroscopy: Identifying Chemicals From Afar

Wikimedia
Spectroscopy: Identifying Chemicals From Afar
Spectroscopy: Identifying Chemicals From Afar

H

He

Fe

Wikimedia
Transmission Spectroscopy

Starlight filters through the planet’s sodium rich atmosphere.

absorption line spectrum
Transmission Spectroscopy

- Many substances detected for big planets
  - Water, methane, sodium...
- Race on to find and study small planets

NASA, ESA, and G. Bacon (STSci)
Towards Earthlike Worlds: The MEarth Project

GJ1214B - steam planet
I can show you the worlds
Thank you!

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