Characterizing Exoplanet Atmospheres:

*a new frontier*

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Are we alone?
To answer the question: “Are we alone?”

- Are there planets around other stars? (exoplanets)
- Could they support life?
- What kind of atmosphere?
- Are organic molecules present?
- Are there “biomarkers”?
Primary tools:

• Planet detection
  – Doppler effect
  – Transit detection
• Atmospheric characterization
  – Photometry
  – Spectroscopy
Transit detection:
Photometry:
Spectroscopy:

[Diagram showing the electromagnetic spectrum with increasing energy and wavelength, including categories such as Gamma rays, X-rays, Ultraviolet, Infrared, Radio waves, Radar, TV, FM, AM, and the visible light spectrum from 400 nm to 700 nm.]
Characterizing Exoplanet Atmospheres

- Temperature & composition
- Vertical “structure”
- Heat transport & weather
- Molecules & chemistry
- Photometry & spectroscopy
- Visible light probes atomic species and haze
- Infrared light probes molecules
Why study molecules?

Molecules serve as probes of:

- **Conditions**
- **Composition**
- **Chemistry**
- **History**
Context: Earth’s Atmosphere
Finding the exoplanets
An exoplanet system
around a pulsar

Two planets
PSR1257+12
2.8 & 3.4 $M_\oplus$
89.2 & 66.6 day orbits
Wolszczan & Frail 1992, Nature
51 Peg: a new era

a big surprise

Single planet
Solar type host
1.2 M_J
4.2 day orbit
Mayor & Queloz 1995,
Nature
Popular Interest
Exoplanet detections:  
*A rising tide*

- 303 planets
- Doppler & transit measurements
- Multiplanet systems
- Habitable-zone planets
- 51 transiting planets
Characterizing atmospheres

Water Signatures in Exoplanet HD189733b
Spitzer Space Telescope • IRAC
NASA / JPL-Caltech / G. Tinetti (Institut d'Astrophysique de Paris)
ssc2007-12a
Exoplanet science: *an exceptional period*

- Transition period
- “break through” or “transformational” science
- changing the way we think about exoplanets

2005
Does it exist?
Temperature?
Is it a rock?

2008
Weather forecast
What causes smog
Prebiotic molecules
Transiting planets: something special

- Primary eclipse
  - Blocks starlight
  - Starlight filters through planet atmosphere
- Secondary eclipse
  - Light from planet blocked
- Both detected by measuring intensity as a function of time
The molecule I hope to find in an exoplanet atmosphere...
Density measured
2001: first transit detection

- Diameter & density
- Orbital parameters
- Unseen companions

Brown & Charbonneau
An atmosphere detected
2002: first transmission spectrum

- Light filters through the “limb”
- Some atoms or molecules will absorb specific wavelengths - leaves a “fingerprint”
- Reveals atmospheric composition

Charbonneau et al.
Temperature measured
2005: first emission detected

- Requires working in infrared
- Small signal = difficult!
- \( T = 1500 \text{ K} \)

Deming et al.
Upsilon Andromeda
2006: non-transiting light curve

- Large day/night temperature difference
- A milestone
Emission spectrum 189 & 209
2007

Where is the water?
Not present?
Hidden by T profile?
Hidden by clouds?

Swain et al.
Day and night detected on 189
2007:

- Redistribution of heat
- Day and night temperatures

Knutson et al.
Temperature inversion on 209
Water detected on 189733b
2007
Haze on 189
2007

- Visible transmission spectrum
- Small particles at high altitude
- Would Al Gore care?

50 km out of ~180,000 km!

Pont et al.
Methane detected in an exoplanet atmosphere

Swain, Vasisht, & Tinetti
Nature 2008
The future
Emerging Themes:

• **Molecules**
  - Probe conditions, composition, and chemistry
  - Require spectroscopy

• **Localization**
  - Spatially resolved abundances
  - Dayside vs nightside chemistry
  - Diagnostic of photochemistry & dynamics

• **Variability**
  - Weather
  - Non-transiting planets
I’ll still be looking for ....

caffeine
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Prebiotic molecules: the building blocks of DNA

- Synthesis of amino acids (Miller 1953, Science)
- $\text{CH}_4 + \text{NH}_3 + \text{H}_2\text{O} + \text{H}_2 + \text{electric discharge} \to \text{glycine, } \alpha\text{-alanine, } \beta\text{-alanine}$
Hubble measurement implications:

*enter the molecules*

- Hubble can characterize numerous exoplanets.
- Water, methane, carbon monoxide, carbon dioxide, and ammonia can be measured.
- Small telescopes useful; SNR ~ D.
- Given the appropriate target, we could measure organic molecules on a habitable-zone exoplanet today.
- GJ 436b is “almost there” (Neptune mass, 700 K, hydrogen rich)
The ground joins the show

189 emission dayside

Swain et al. submitted
Variability

Spitzer implications

Swain & Bouwman
Non-transiting planets

*a dramatic increase in possible targets*
Five Myths: exoplanet spectroscopic characterization requirements

- Transits
- Bright targets
- Large telescope
- New instrument technology
- Exceedingly difficult
The Balloon-borne Exoplanet Spectroscopy Telescope (BEST) completing the picture

Deming et al.
Charbonneau et al.
Swain et al. reduction
Knutson et al.
Swain et al.
Grillmair et al.

HST
BEST
Spitzer

relative flux

Wavelength (μm)
Characterizing exoplanet atmospheres

the near future & further future

• nightside spectra
• non-transiting planet’s spectra
• numerous molecules detected
• atmospheric chemistry
• characterization of HZ planet

• atmospheric changes
• surface characterization
• chemistry of organic molecules

A grand adventure!