# PLANETARY ATMOSPHERES

Spring 2024

(ASTR 555/ ESS 581 / ATM S 555)

Instructor: David Catling E-mail: dcatling@uw.edu
Office Hours: Appointments via e-mail, please

Classes: JHN 241 (conference room) MW 10.30-11.50AM

**Syllabus**: The schedule below reflects approximate timing only. If we need more time on a particular topic and less on others then we will fall behind or steam ahead as needed.

## 1. Atmospheric Structure: The static structure (Wks 1-5)

1.1 Stability and convection. Lapse rates on different planets and condensables in planetary atmospheres (Earth, Venus; Mars as a case study). Methane on Titan.
1.2 Energy Sources on Planets. Thermal balance. Greenhouse effect. Runaway greenhouse effect (early Venus, future Earth?, exoplanets). Radiative time constant on planets.
1.3 Radiative transfer. Shortwave: Solar/ ultraviolet (Mars as case study). Infrared. Radiative-convective equilibrium.
1.4 Photochemistry on Earth, Mars, Venus.
1.5 The upper atmosphere: Mesosphere, thermosphere, homopause, exosphere.
1.6 Three escape processes: Thermal (Jean's escape, hydrodynamic escape), impact erosion, suprathermal (e.g., sputtering).

## 2. Atmospheric Evolution (Wks 5-7)

2.1 The solar nebula. Planetary formation processes and chemical equilibrium/mixing in the nebula.
2.2 Early steam atmospheres. Ocean-vaporizing impacts on Earth.
2.3 Noble gases and isotopes as indicators of atmospheric evolution. More atmospheric escape.
2.4 Evolution of Earth's atmosphere and climate over geologic history (and life's influence)
2.5 Evolution of Mars' atmosphere and climate
2.6 Evolution of Venus's atmosphere and climate
2.7 Evolution of Titan's atmosphere
2.8 Atmospheric spectroscopy of exoplanets and the search for biosignatures

## 3. Atmospheric Circulations: The moving structure (Wks 7-10)

3.1 Balance concepts: Geostrophic balance on Earth & Mars. Cyclostrophic balance on slow rotators, Venus and Titan, some exoplanets. Thermodynamic balance of ascent, descent.
3.2 Zonal-mean meridional circulation: Hadley cell theory and thermally-forced jet-streams
3.3 Eddy-driven jet-streams. Planetary waves, Buoyancy Waves. Thermal tides.
3.4 Giant Planets: Deep and Shallow models.
3.5 Superrotation. Eddy-driven circulations.
3.6 Observed circulation case studies: Mars, Venus, Titan.

3.7 Triton and Pluto atmospheres. Thin atmospheres, e.g., Io.
3.8 Exoplanet circulation regimes: rocky planets; giant planets.

**Recommended Textbook:**
The textbook is strongly recommended:
**D. C. Catling & J. F. Kasting, Atmospheric Evolution on Inhabited and Lifeless Worlds, Cambridge Univ. Press, 2017.**
It is free online from UW IP addresses or VPN: https://doi.org/10.1017/9781139020558
Also, one copy in UW library.

We follow parts of the above book. It contains too much info for 10 weeks. We skip parts that have a more geochemical focus and concentrate on parts that are concerned with atmospheric physics and chemistry. The book covers everything in the syllabus from structure, chemistry, and dynamics of atmospheres to issues of atmospheric evolution and exoplanets.
The underlying thread throughout the book concerns how an atmosphere can make a planet *habitable* or not -- in our Solar System and beyond.

A diligent student would benefit considerably from reading the following short primer cover-to-cover, either as preparation or as the course goes along:
**Andrew P. Ingersoll (2013) Planetary Climates (Princeton Primers in Climate), Princeton Univ. Press**. Paperback; used copies online ~$15

**Other planetary atmosphere books for reference:**
**1) Sanchez-Lavega, A. An Introduction to Planetary Atmospheres, Taylor & Francis, 2010. 587 pp.**
A very good reference book for planetary atmospheres. It covers a lot more than we have time for in this course, however.

**2) Pierrehumbert. R. T., Principles of Planetary Climate, Cambridge Univ. Press, 2010. 652 pp.**
An excellent resource for planetary atmospheres, which goes through concepts in ways that can be very insightful (and sometimes quirky). The author concentrated his efforts on issues of radiative transfer, which occupy at least half the book.

**3) Taylor, F. W., Planetary Atmospheres, Oxford Univ. Press, 2010. 296 pp.**
This book is shorter and at a lower level (upper undergraduate) than the graduate texts of Sanchez-Lavega or Pierrehumbert. It provides a great intro. The other books are needed for research-level depth.

**4) Heng, K. Exoplanetary Atmospheres, Princeton Univ. Press, 2017. 274 pp.**
The first 1/3-1/2 are on issues of radiative transfer. There’s a brief middle section on atmospheric chemistry, focusing mainly on equilibrium chemistry (appropriate for hot dense, atmospheres). Then the remaining 1/3 is on fluid dynamics with some chapters at the end on atmospheric escape and outstanding problems.

**4) Seager, S. Exoplanet Atmospheres, Princeton Univ. Press, 2010. 243 pp.**
This book is shorter than the books above but has parts on radiation, basic climate, and some dynamics. It has more of an astronomy emphasis on stellar environments than the others. Solar System bodies are covered more comprehensively in the other books.

**5) J. C. G. Walker, Evolution of the Atmosphere, Macmillan, 1977**. This old book is beautifully written and very lucid but 40+ years on is now very out-of-date.

**6) Y. L. Yung and W. B. DeMore, Photochemistry of Planetary Atmospheres, Oxford University Press, 1999.**
Planetary atmospheres with a focus on the photochemistry.

**7) J. W. Chamberlain and D. M. Hunten, Theory of Planetary Atmospheres, 2nd Ed., Academic, 1987**.
Although the title sounds broad, this book focuses on upper atmospheres and aeronomy, where it has very good coverage. Students find it difficult to follow, though.

**8) P. G. Irwin, Giant Planets of Our Solar System (2$^{nd}$ Edition)**, **Springer, 2009, 403 pp.**
Up-to-date and very good graduate-level overview of the physics and chemistry of the giant planets.

**General planetary science books:**

**1) I. de Pater and J. Lissauer, Planetary Sciences, Cambridge University Press, 2010.**
Chapters 1, 3 & 4 cover introductory material, energy transport and planetary atmospheres, respectively.

**2) J. Lissauer and I. de Pater, Fundamental Planetary Science, Cambridge University Press, 2013.**
This is like a shorter version of the Planetary Sciences book.

**3) J. S. Lewis, Physics and Chemistry of the Solar System, Revised Edition, Academic Press, 1997**.
This book covers the whole Solar System and its coverage of atmospheres is biased towards a geochemical viewpoint.
An older book is: **J. S. Lewis and R. G. Prinn, Planets and their Atmospheres: Origin and Evolution, Academic Press, 1984**. This also takes a geochemical viewpoint of planetary atmospheres.

**General atmospheric sciences books:**

Good general intro textbooks that concisely cover the basic principles of atmospheric physics and chemistry to a level used in this course are:

(a) Wallace, J. M. & Hobbs. Atmospheric Science, 2$^{nd}$ Ed, Academic Press, 2006

(b) Andrews, D. G., An Introduction to Atmospheric Physics, CUP, 2010.
(c) Houghton, J., Physics of Atmospheres, 3rd Ed, CUP, 2002.
(d) Petty, G. A., First Course in Atmospheric Radiation, 2nd Ed, Sundog Publ., 2006.

For a more advanced reference on chemistry & aerosols, in particular
(e) Seinfeld, J. H., Pandis, S. N., Atmospheric Chemistry and Physics: From Air Pollution to Climate Change, 3rd Ed, 2016.

**Grade Components**:
1. Homeworks (four problem sets) (70-%).

2. Paper (30%).

Paper on a planetary atmosphere topic of your choice.

The paper is short: up to only **9 pages long**, including figures but **excluding** the references list (which can be as long as you like) or appendices or tables. The paper must be at least 1.5-spaced, 12-point font, with 1 inch top+bottom+side margins. The grade will be reduced if you flout these stipulations because it is an important skill to able to write concisely and accurately.

Details of suggested topics and how the paper will be assessed are in a separate handout.