PTYS544

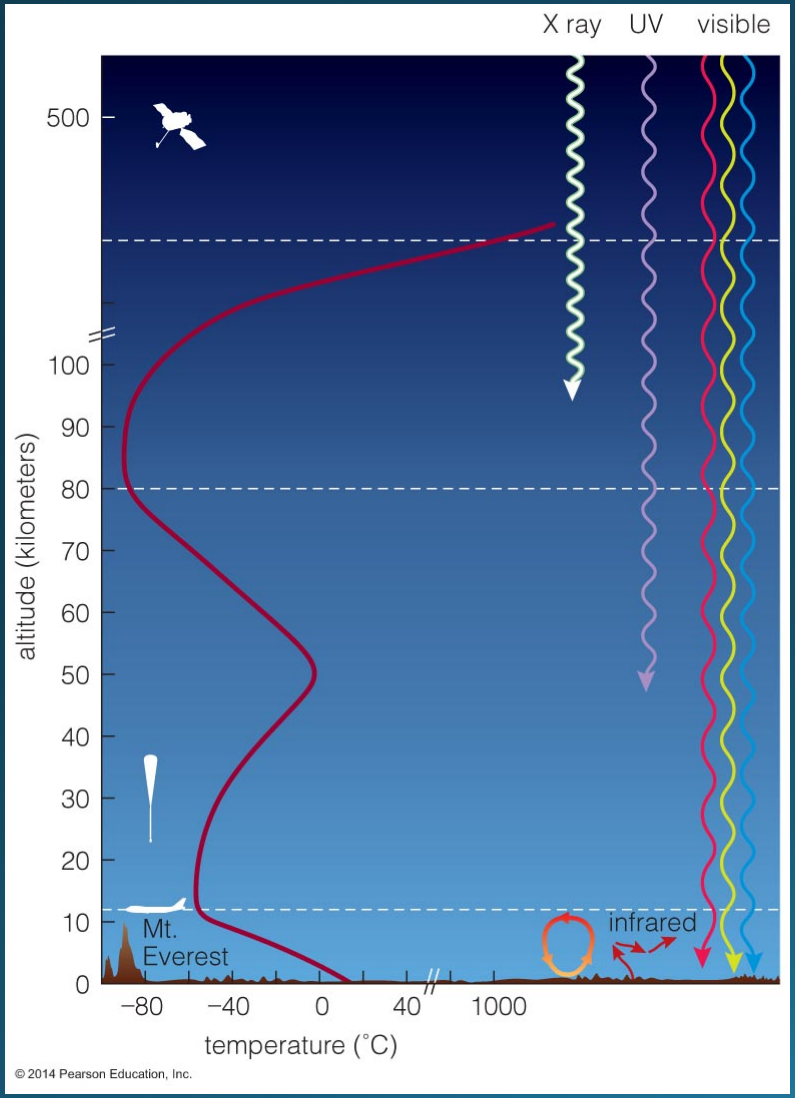
Physics of the High Atmosphere

Basic details

- **Location / Time**
  - Tuesday & Thursday, 12:30 – 13:45
  - Kuiper Space Science (KSS) 301 (except January 17 in 312)
- **Instructor**
  - Tommi Koskinen, KSS 421
  - tommi@lpl.arizona.edu

Right: Kakslauttanen Arctic Resort near Ivalo, Finland, built for viewing the aurora.

Scope: Middle and upper atmosphere (MUA)



Exosphere: Above the atmosphere, even lower density

Thermosphere: High temperature, low density

Mesosphere: Temperature declines, mesopause about -100°C

Stratosphere: Stratopause temperature about -15°C

Troposphere: Temperature declines rapidly with altitude, tropopause about -45°C

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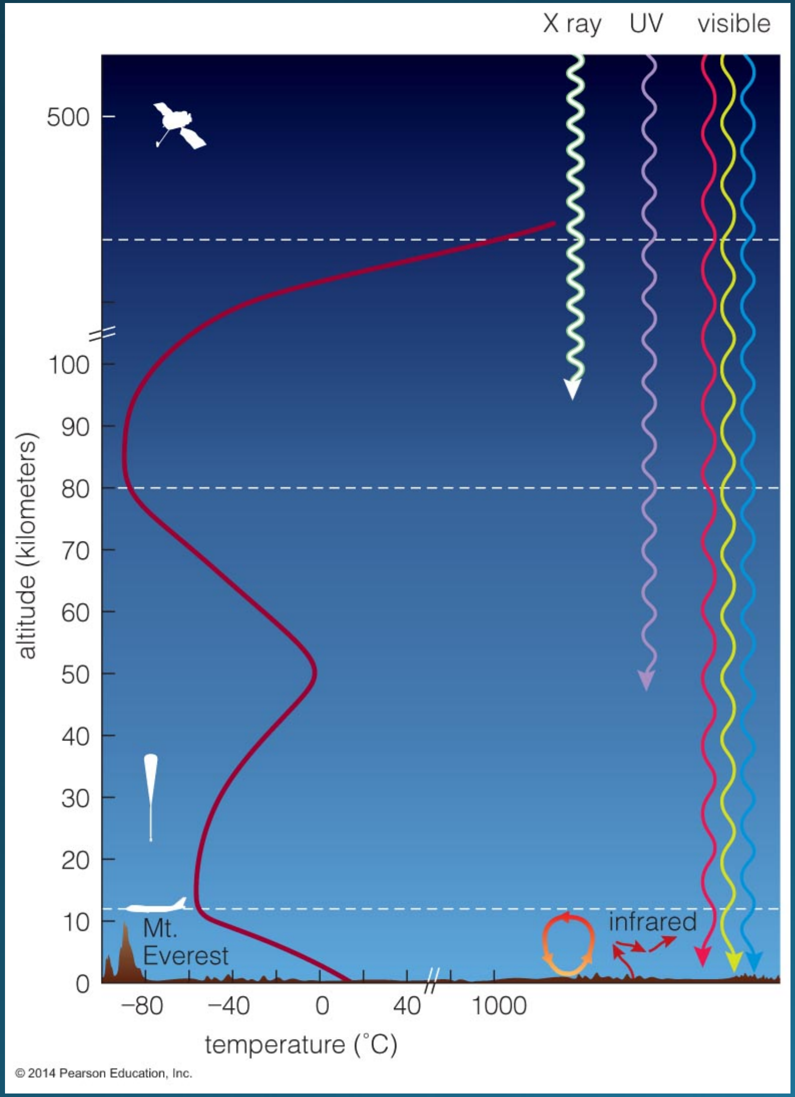

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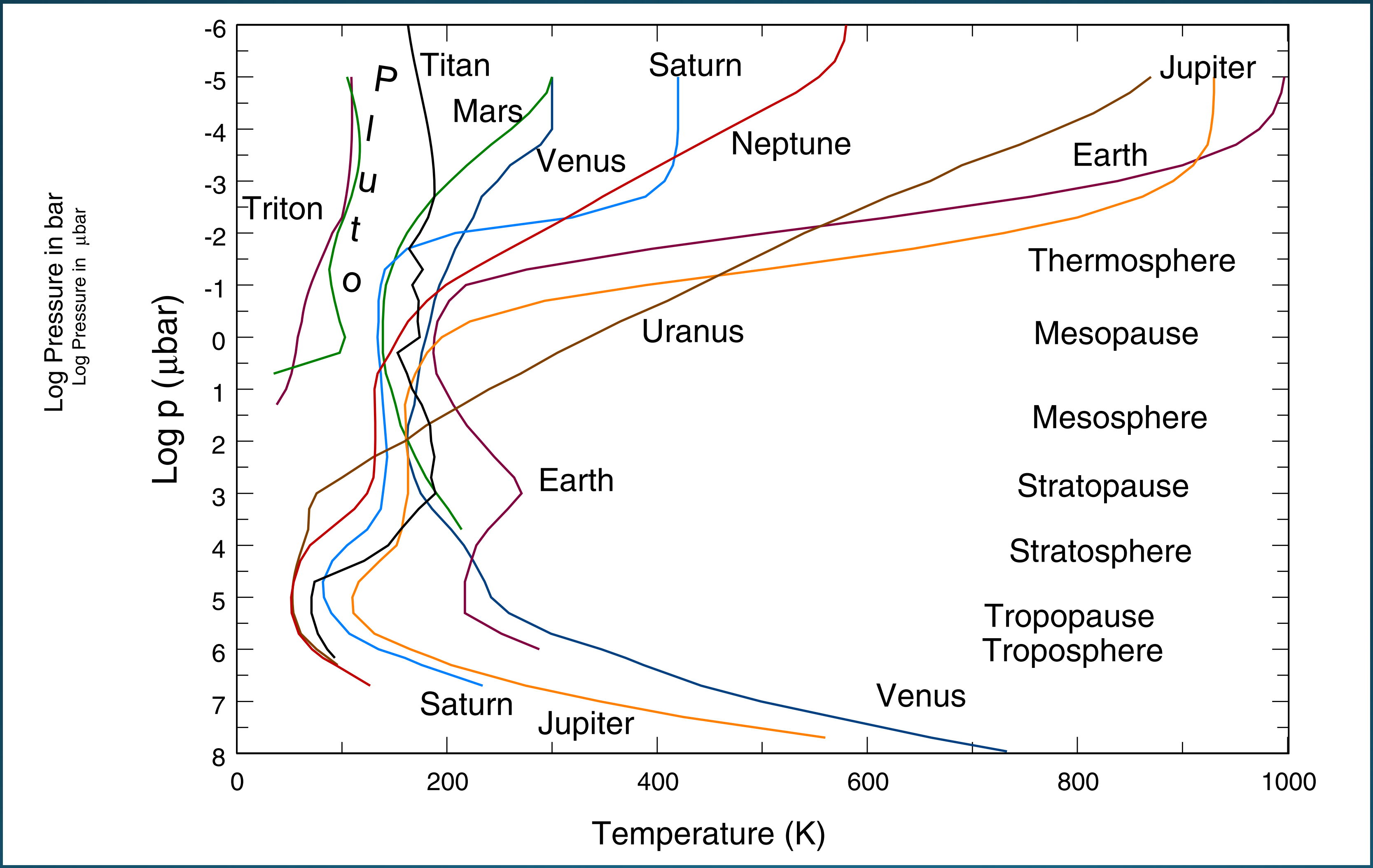
Main objective and motivation

Learn key concepts and physics of the middle and upper atmosphere through an exploration of planetary atmospheres.

We understand the Earth's middle and upper atmosphere relatively well. To what degree is this understanding transferable to other planets: what aspects need revision when we try to understand planetary atmospheres in general?

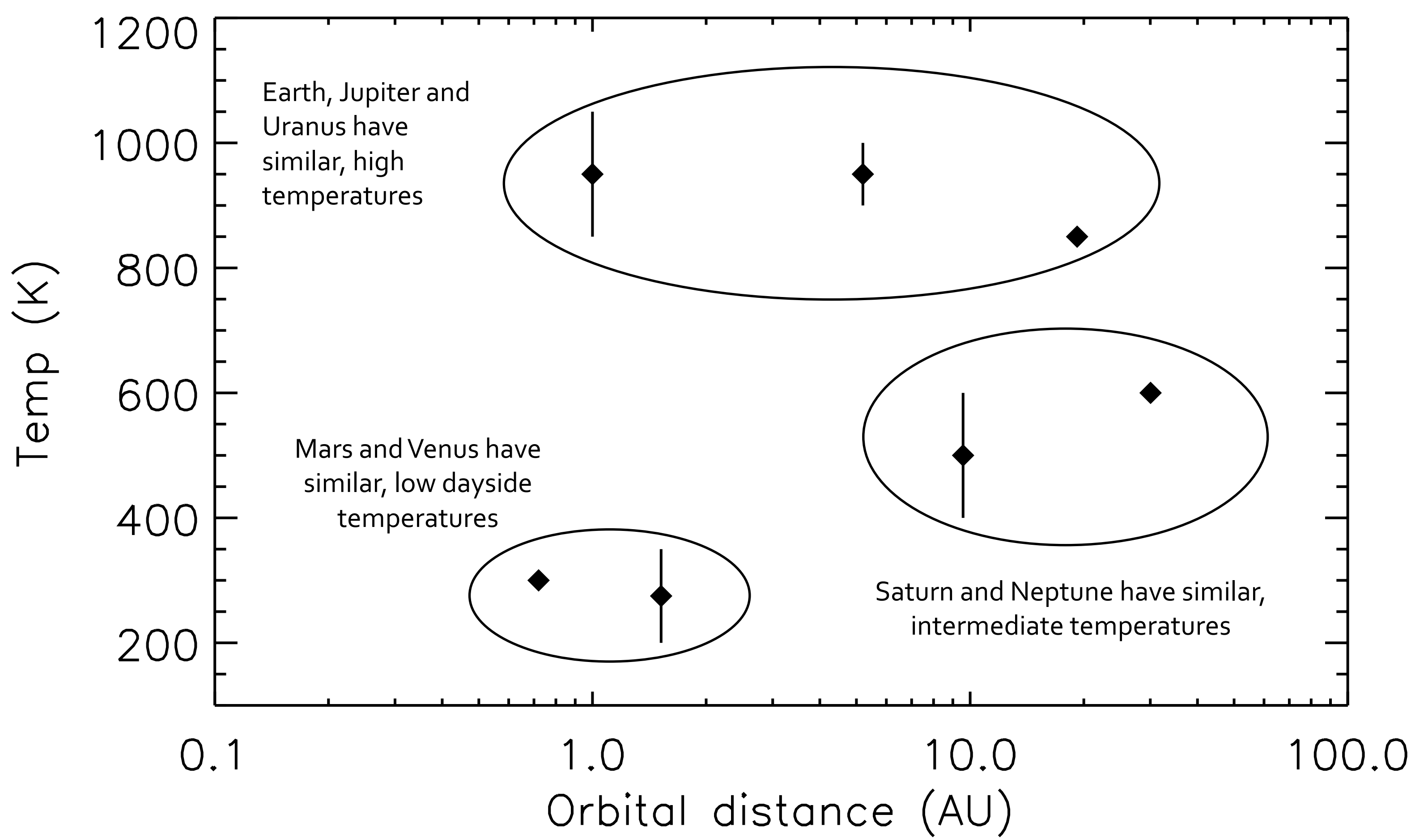
What is the predictive power of the theory of high atmospheres and how can we apply it to understand the atmospheres of extrasolar planets, including Earth-like planets, or to deal with aspects of global change on the Earth that result in changes in the middle and upper atmosphere?

Secondary objective: Developing tools to model MUA temperatures, composition and dynamics.



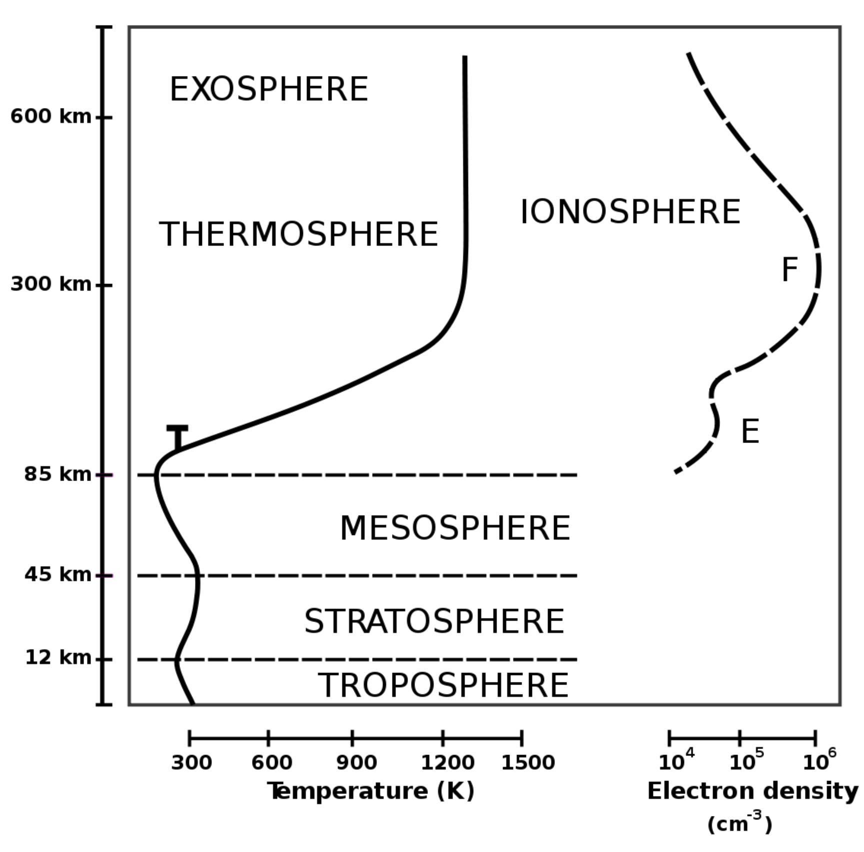
From Müller-Wodarg et al. (2008)

Exospheric temperatures



Basic energy balance: Earth

$$\frac{\partial(\rho c_v T)}{\partial t} + \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \rho c_v T v\right) = \rho\left(Q_{\text{Heat}} + Q_{\text{Cool}}\right) - p\frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 v\right) + \frac{1}{r^2}\frac{\partial}{\partial r}\left(r^2 \kappa \frac{\partial T}{\partial r}\right) + \Phi_\mu$$



Temperatures in the thermosphere correlate with solar activity, ranging from about 700 to 1300 K (global mean). Solar EUV radiation ionizes and heats the thermosphere, mostly balanced by downward conduction.

This works on…well, apparently only on the Earth!

Week 1 reading assignments

- Garcia Munoz, A., Koskinen, T. T., Lavvas, P., 2017. Upper atmospheres and ionospheres of planets and satellites. In *Handbook of Exoplanets*, H. J. Deeg, J. A. Belmonte (eds.), Springer International Publishing, DOI 10.1007/978-3-319-30648-3_52-1
- Muller-Wodarg, I. C. F., et al., 2008. Neutral atmospheres, Space Sci. Rev., 139, 191-234

Theme I: Energy balance

- Heating and ionization by solar X-ray and EUV (XUV) radiation in the thermosphere
- Electron transport and heating efficiency
- Heating by solar UV and near-IR radiation in the middle atmosphere
- Radiative cooling in the middle and upper atmosphere
- Venus and Mars: CO_2 atmospheres
- Giant planets: energy crisis
- Energy-limited escape on close-in extrasolar planets

Theme II: Composition

- Ionospheric regions on the Earth
- Electron transport and secondary ionization
- Comparative planetary ionospheres
- Principles and techniques of neutral photochemistry
- The chemistry of ozone
- Venus and Mars: the stability of CO_2 atmospheres
- Jupiter and Saturn: hydrocarbon chemistry
- Airglow and aurora

Theme III: Global dynamics in the MUA

- Diffusion and mixing
- Heat conduction and viscosity
- Global circulation models
- Electrodynamics
- Atmospheric waves in the MUA
- Atmospheric escape

Schedule outline: Changes likely

- Weeks 1, 2: Middle and upper atmospheres in the solar system
- Week 3: Equations of motion from kinetic theory
- Week 4: Ionosphere formation (non-auroral)
- Week 5: Electron transport, heating and secondary ionization
- Week 6: Energy balance in the thermosphere
- Week 7: Principles of photochemistry
- Week 8: Energy balance in the middle atmosphere
- Week 9: Spring recess

Schedule outline: Changes likely

- Week 10: Numerical methods and models
- Week 11: Airglow and aurora
- Week 12: General circulation models
- Week 13: Comparative aeronomy
- Week 14: Extrasolar planets
- Week 15: Student presentations
- Week 16: Student presentations

Some textbooks

- R. W. Schunk and A. F. Nagy, *Ionospheres: Physics, plasma physics and chemistry*, Cambridge University Press
- M. H. Rees, *Physics and chemistry of the upper atmosphere*, Cambridge University Press
- T. Gombosi, *Gaskinetic theory*, Cambridge University Press
- M. L. Salby, *Fundamentals of atmospheric physics*, Academic Press
- J. W. Chamberlain and D. M. Hunten, *Theory of planetary atmospheres: An introduction to their physics and chemistry*, Academic Press

Grading scheme

- Homework assignments (50%)
- Project presentation (30%)
- In-class participation (20%)
- Scheme: (A) >90%, (B) 80-90%, (C) 65-80%, (D) 50-65%

Project and presentation

- You are expected to choose a topic for intense study that you will present to the class during the final weeks of this class. The selected topic should fall within the scope of the course as confirmed by the instructor. In-class presentations take up one whole session with questions. Treat it as if you were preparing a lecture. The project can consist of an in-depth literature review and/or a research problem. Literature reviews should aim to identify at least a few directions for future original research.

Reading assignments

- In-class participation will consist of class attendance and participation, presenting solutions to homework problems and discussing journal articles. Journal articles will be assigned for reading throughout the course based on a bibliography that I will maintain. You are encouraged to propose papers but this is not a requirement.

Homework before Tuesday

- Think about why you selected this course and pick one topic that you are particularly looking forward to learning and exploring

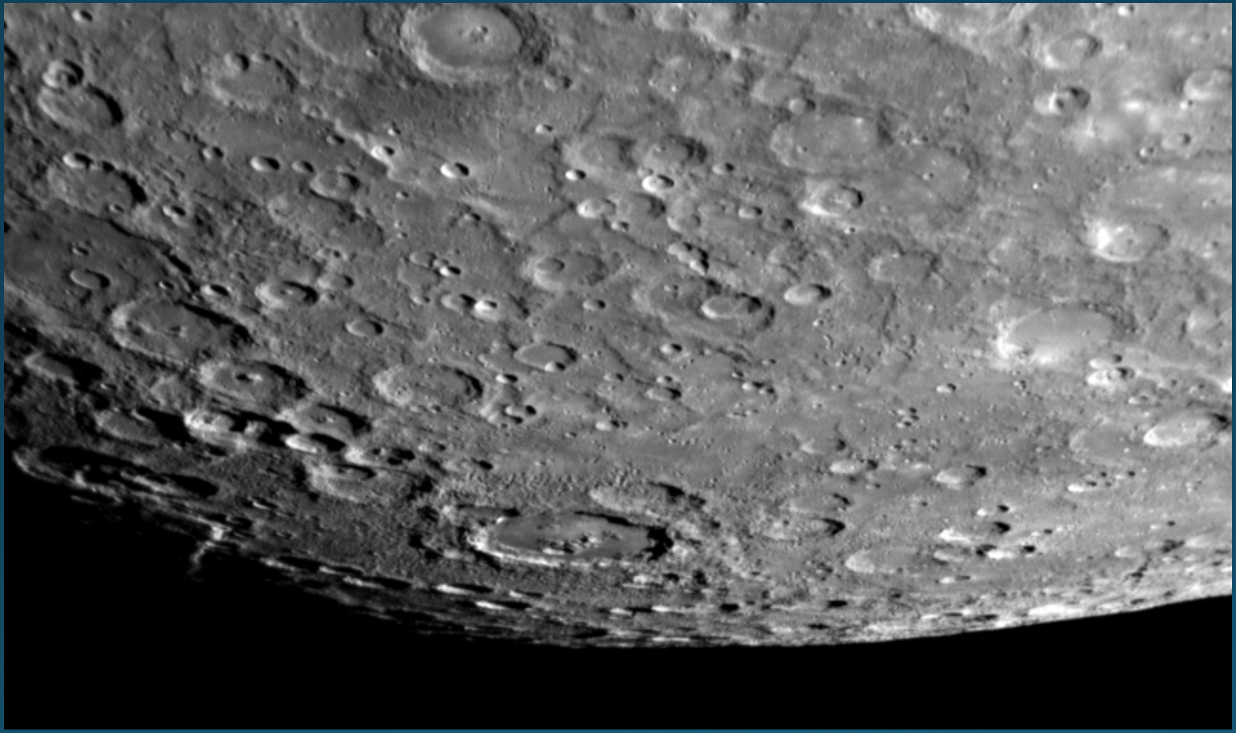
Let’s get started!

Middle and upper atmospheres of the Earth and other planets

Outline

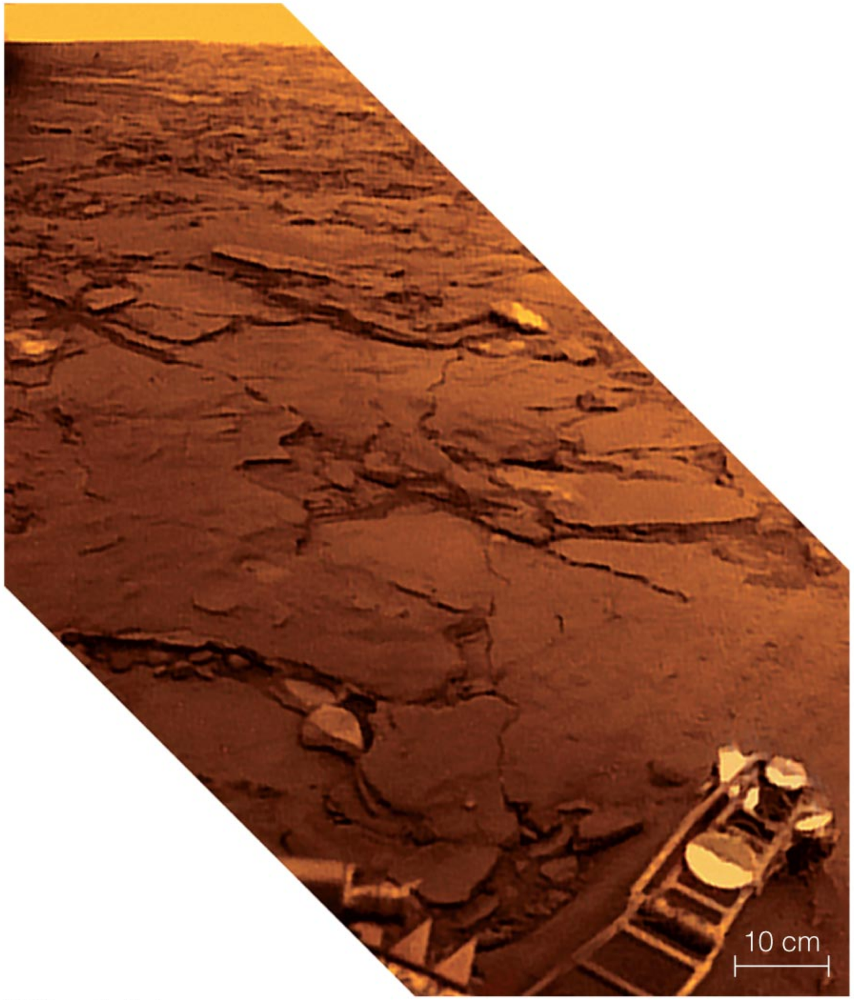
- Solar system atmospheres
- Composition and energy balance of upper atmospheres
- This is a qualitative review that introduces the topics of this course

Mercury



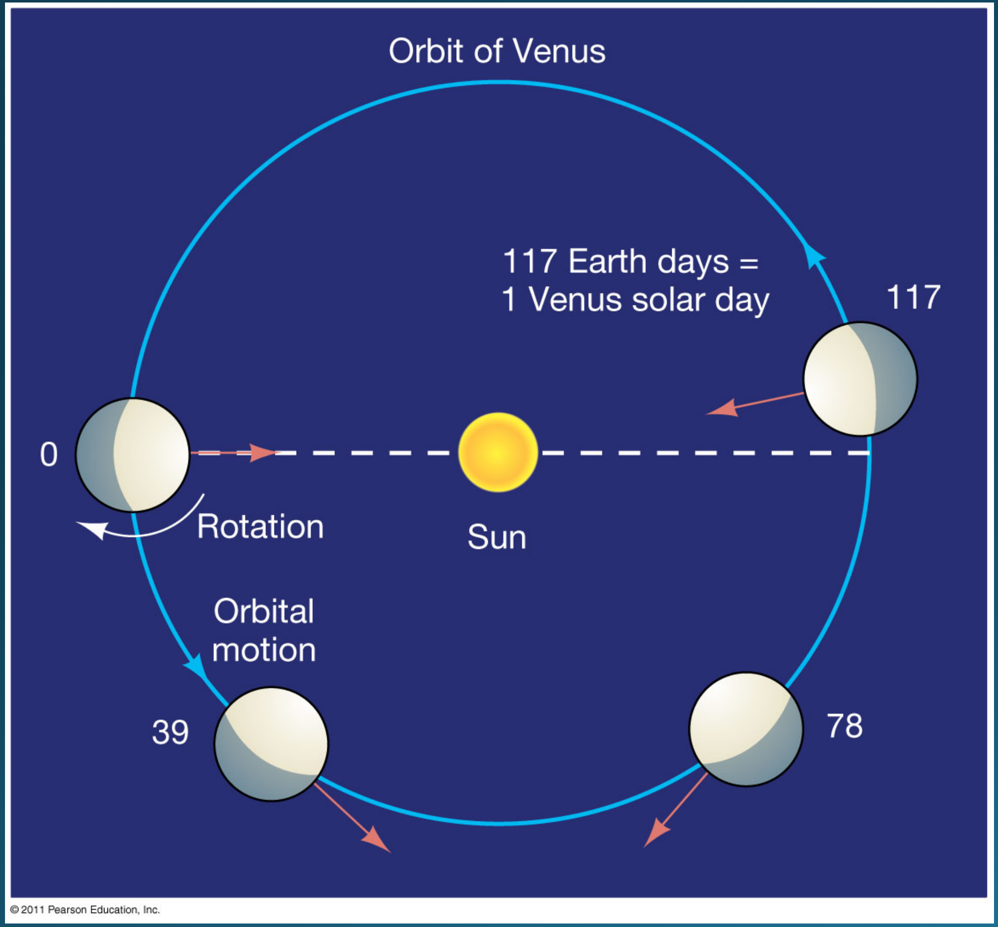
H, He, O, Na, K, Ca and Mg with a surface pressure of less than 10^{-12} bar. This is all exosphere and we will not cover it.

The Venusian atmosphere



Surface temperature:
740 K (day/night)
Surface pressure:
90 bar
Composition:
96% CO_2
3.5% N_2
Conditions:
Slow winds, acid rain, clouds of sulfuric acid

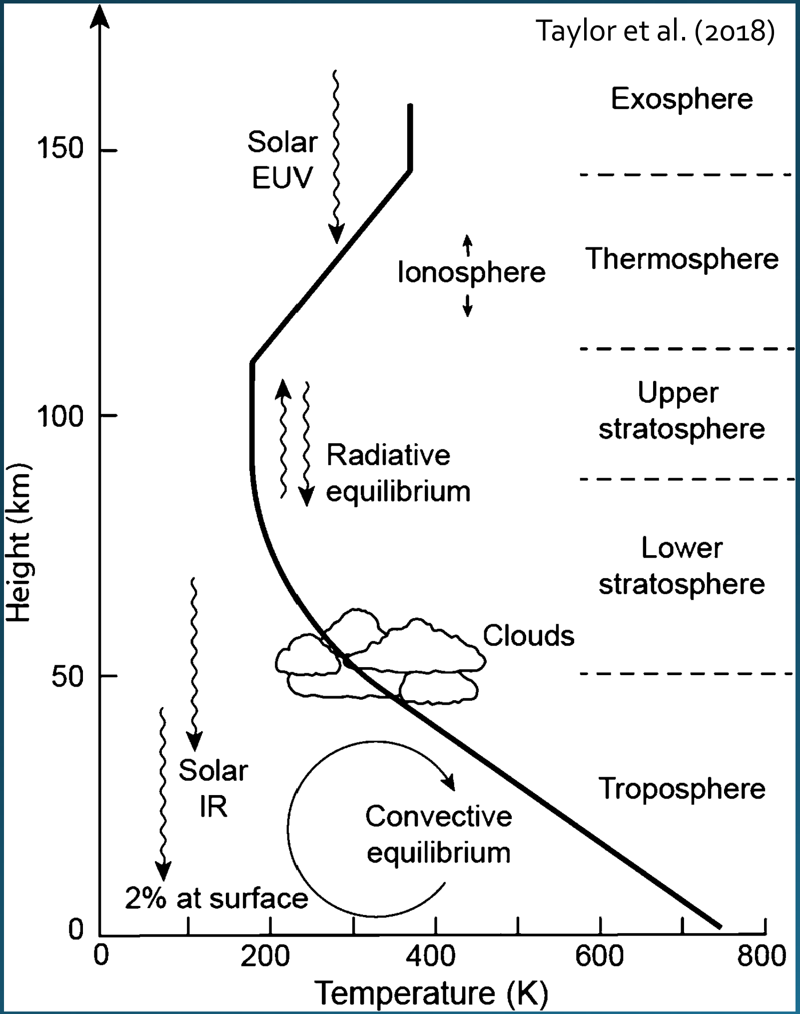
The orbit of Venus



Venus rotates around its axis once every 244 days in the opposite sense to the Earth.

The orbit is nearly circular.

Venus



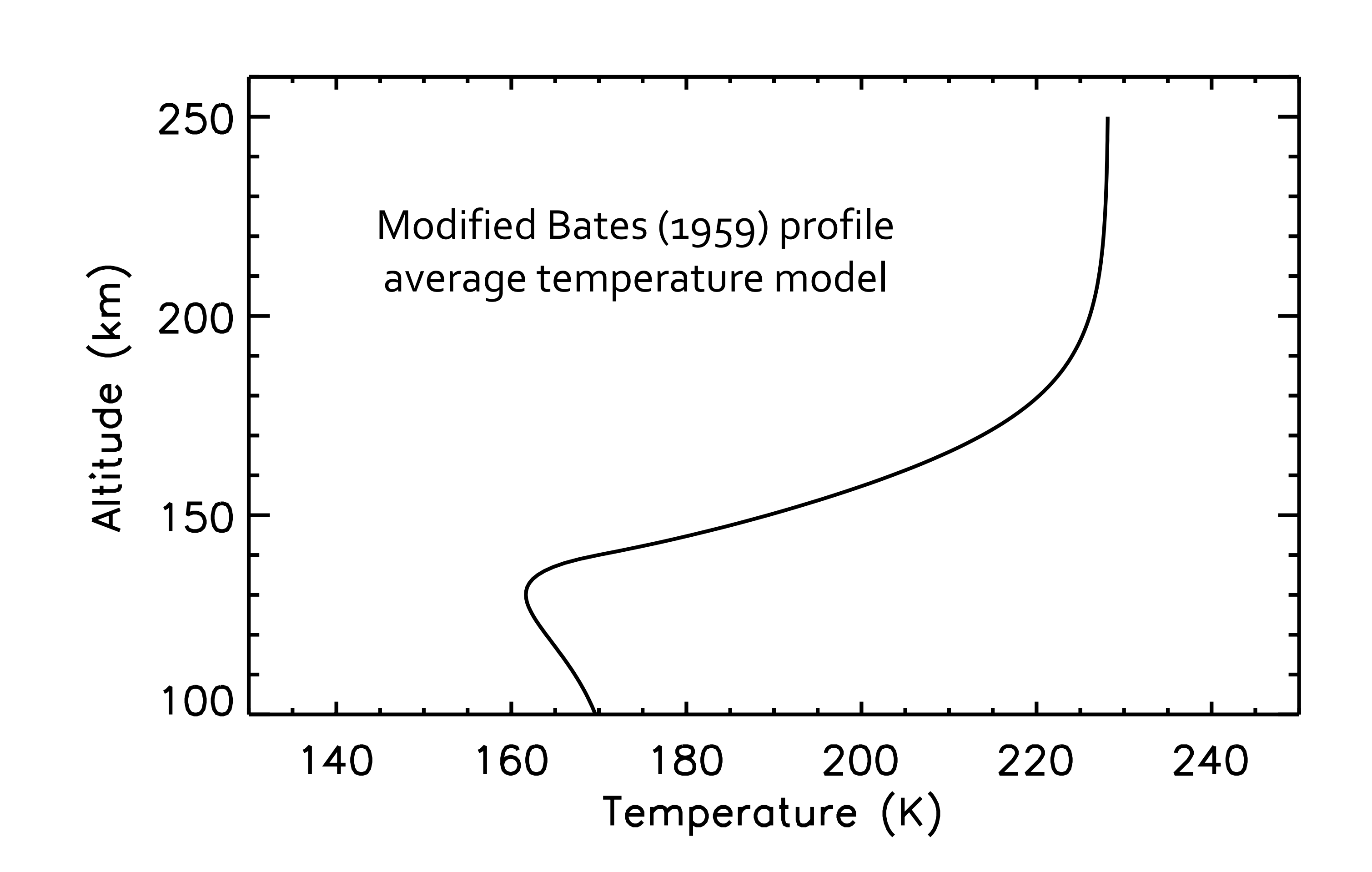
Thermosphere:
EUV and CO_2 near-IR heating balanced by conduction and CO_2 15 μm cooling.

No stratospheric temperature inversion.

Troposphere:
Greenhouse effect due to a thick CO_2 atmosphere, convective equilibrium.

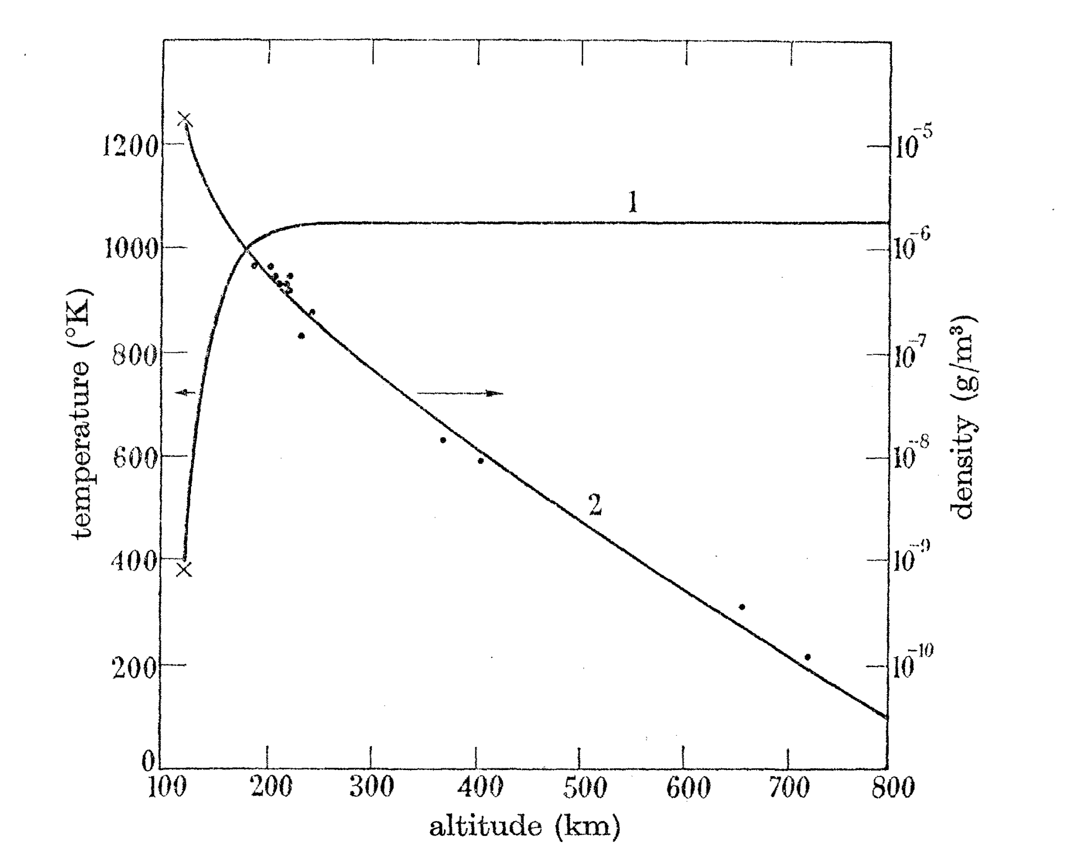
Thermosphere: Hedin+(1983) empirical model

- Pioneer Venus mission: Orbiter and Multiprobe, entered orbit on December 4, 1978, orbiter atmospheric entry on October 8, 1992
- Pioneer Venus Multiprobe: Bus, Large atmospheric entry probe (Sounder) and three small probes to different parts of the atmosphere
- Global variations in the Hedin model mostly from the Orbiter Neutral Mass Spectrometer (ONMS), supporting data from the entry probes
- CO_2, CO, O, N_2, N and He + temperatures



Global empirical model of the Venus thermosphere
(Hedin et al. 1983)

The Bates temperature profile



Bates, D. R., 1959. Some problems concerning the Terrestrial Atmosphere above about the 100 km level. Proc. R. Soc. Lon. A, 253, 451-462.