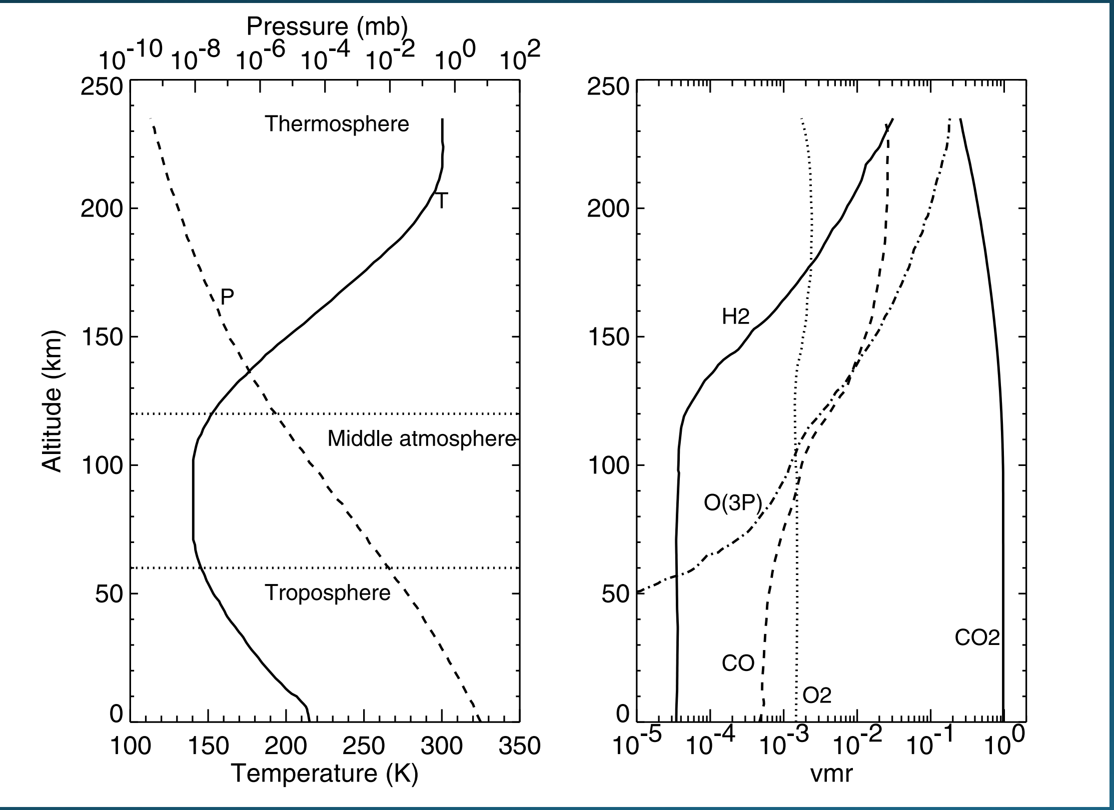
PTYS544

Physics of the High Atmosphere

Basic details

- Location / Time
  - Tuesday & Thursday, 12:30 – 13:45
  - Kuiper Space Science (KSS)
- Instructor
  - Tommi Koskinen, KSS 421
  - tommik@email.arizona.edu

Mars: Basic atmospheric structure



Middle atmosphere energy balance:

- Absorption in the CO_2 near-IR bands
- Absorption and emission in the CO_2 15-μm band
- Absorption and scattering by dust

Plot from Gonzales-Galindo et al. (2005)

Temperatures from MAVEN/NGIMS

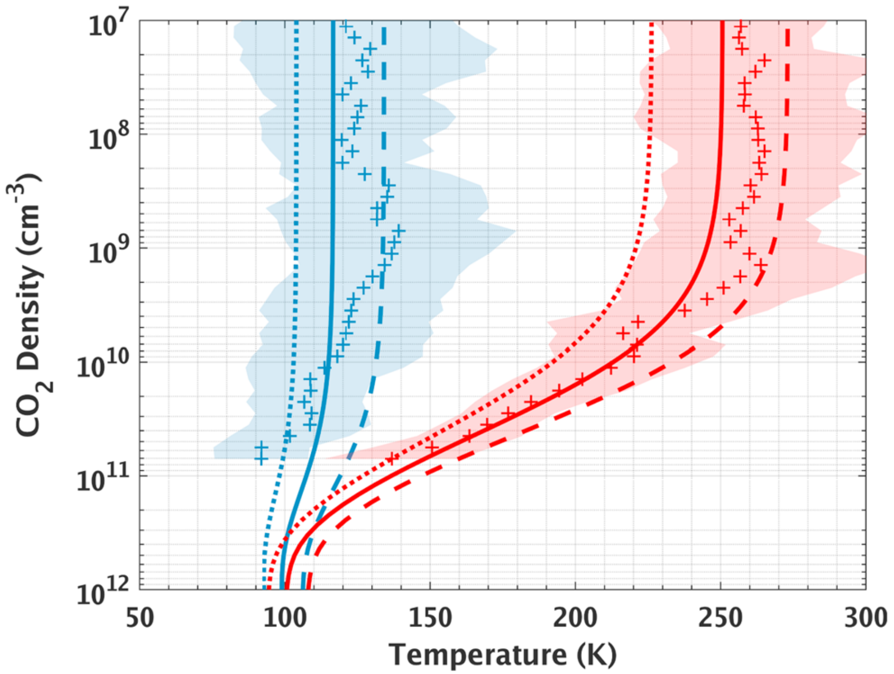


Figure 19. Comparison of modeled temperature profiles with NGIMS data. The model temperature profiles for equatorial latitudes at 12 p.m. (red lines) and 12 a.m. (blue lines) compared to DD2 (red +) and DD6 (blue +) NGIMS temperature profiles. The solid lines are for models calculated with the nominal O-CO_2 collisional deexcitation rate of $k = 3 \times 10^{-12}$ cm^{-3} s^{-1}, the dotted lines for $k = 6 \times 10^{-12}$ cm^{-3} s^{-1}, and the dashed lines for $k = 1.5 \times 10^{-12}$ cm^{-3} s^{-1}. The shaded regions represent 1 σ variabilities of the NGIMS temperatures. NGIMS = Neutral Gas and Ion Mass Spectrometer; DD = Deep Dip.

From Stone et al. (2018)

Note that the expected solar cycle and seasonal variation in dayside exospheric temperature is about 150 K (Bougher et al. 2015a).

Temperature peak and time lag

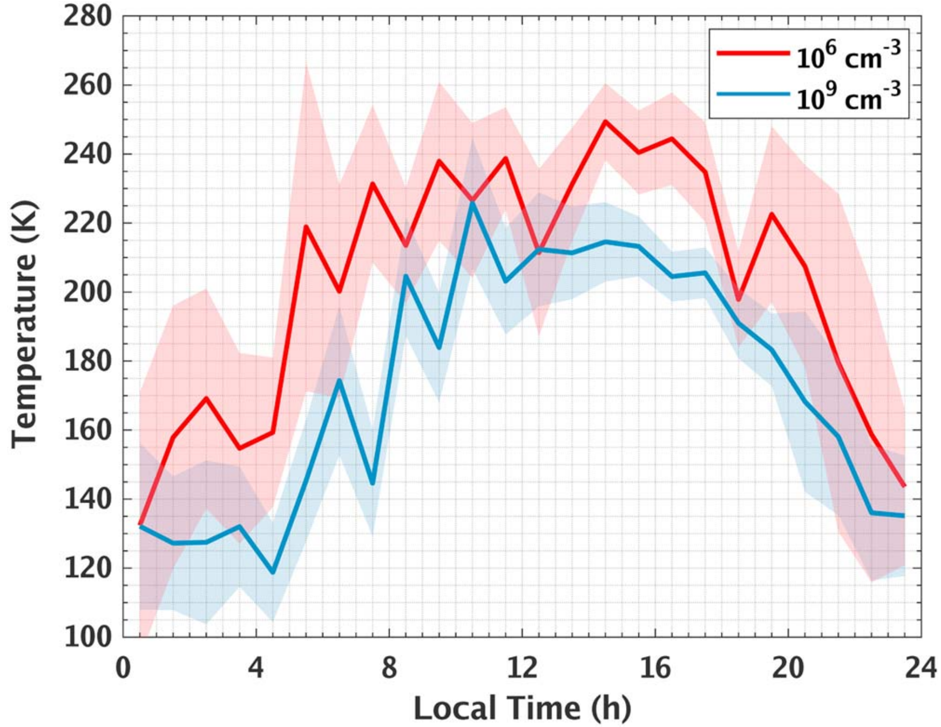
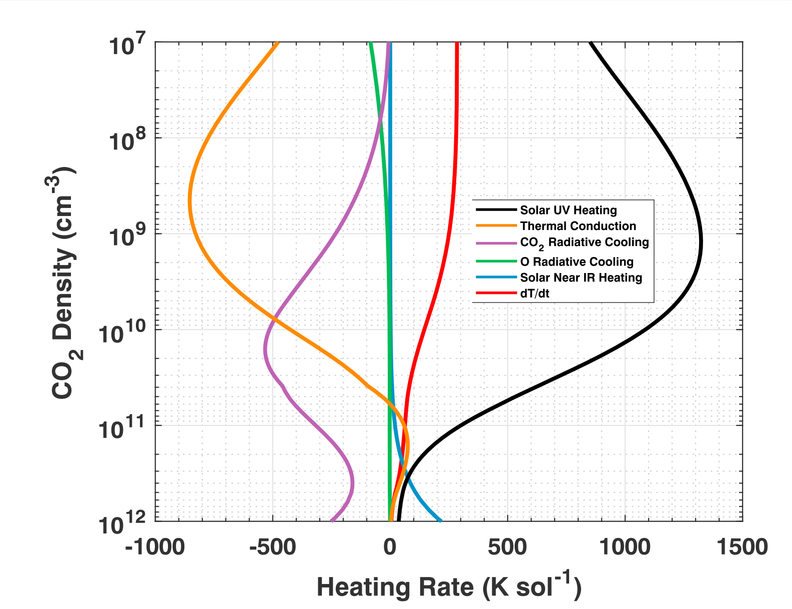
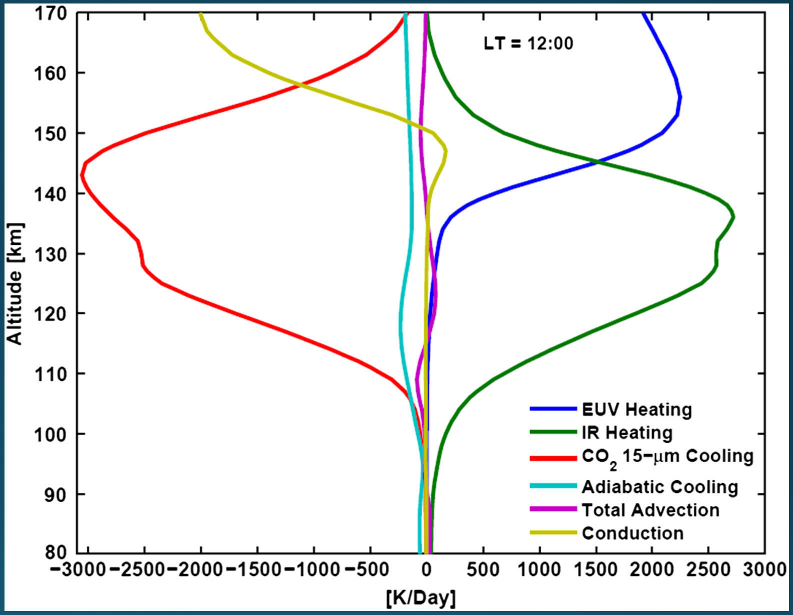


Figure 16. Temperature as a function of Martian local time at two constant CO_2 density levels: 10^6 cm^{-3} (red) and 10^9 cm^{-3} (blue). Measurements are constrained to latitudes between 60°N and 60°S. The shaded regions represent 1 σ variabilities.

From Stone et al. (2018)

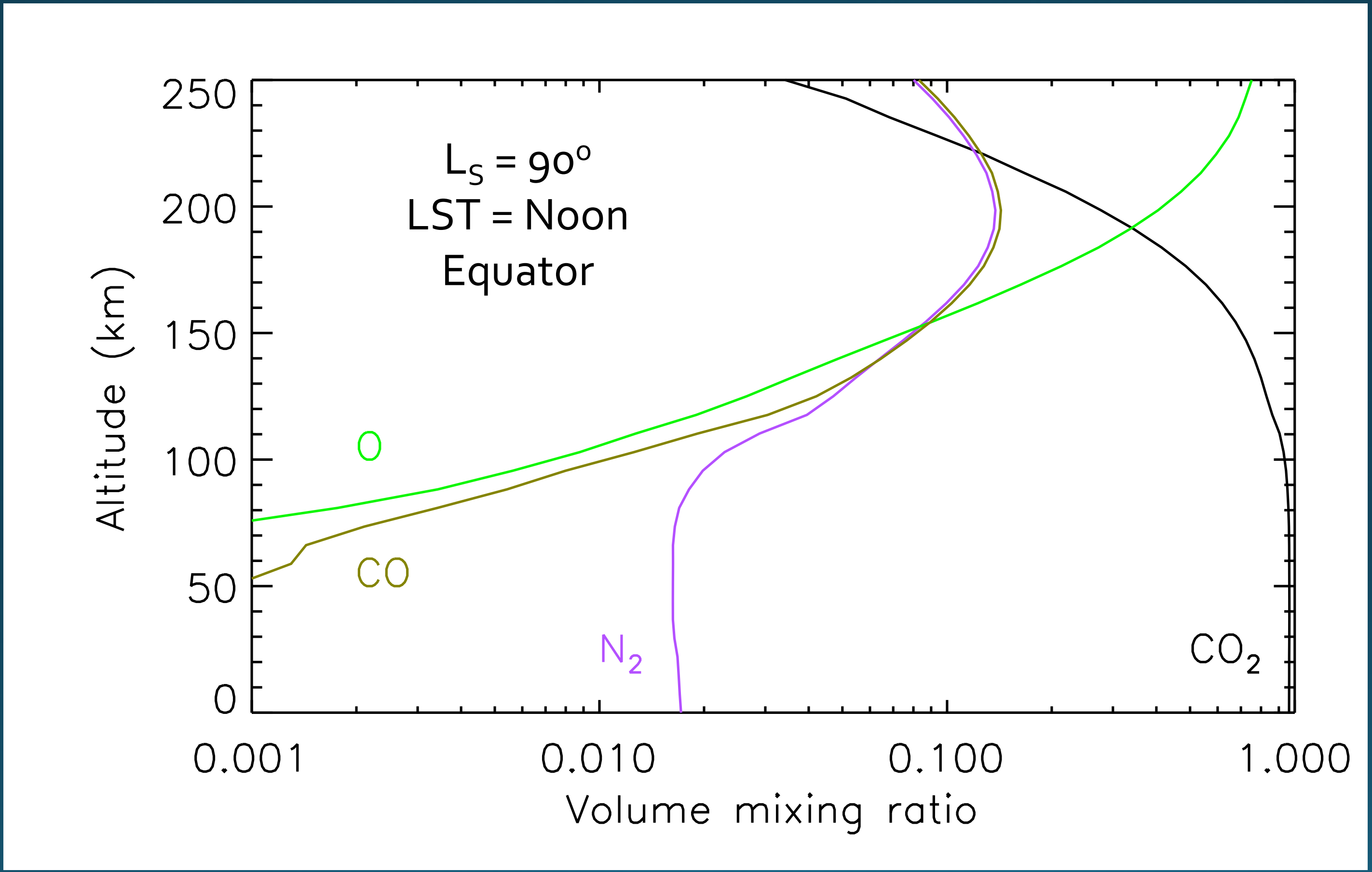
Compare with Venus





The CO_2 thermostat is less efficient on Mars, probably because the Martian O/CO_2 density ratio is smaller (Garcia Munoz et al. 2017).

Neutral composition



Results from the Mars Climate Database (MCD):
http://www-mars.lmd.jussieu.fr/mcd_python/

Neutral photochemistry

Photolysis of CO_2 in the stratosphere (above ~60 km):

$$CO_2 + h\nu \rightarrow CO + O \qquad \lambda < 169 \text{ nm}$$

The reverse reaction is spin-forbidden and thus extremely slow:

$$CO + O + M \rightarrow CO_2 + M$$

Instead, we might expect:

$$O + O + M \rightarrow O_2 + M$$
$$O_2 + h\nu \rightarrow O + O$$

Should end up with CO, O_2 and O with $[CO]/[O_2] = 2$.

$$2(\mathrm{CO} + \mathrm{OH} \rightarrow \mathrm{CO_2} + \mathrm{H})$$
$$2(\mathrm{H} + \mathrm{O_2} \xrightarrow{M} \mathrm{HO_2})$$
$$\mathrm{HO_2} + \mathrm{HO_2} \rightarrow \mathrm{H_2O_2} + \mathrm{O_2}$$
$$\mathrm{H_2O_2} + h\nu \rightarrow 2\mathrm{OH}$$

$$net: \; 2\mathrm{CO} + \mathrm{O_2} \rightarrow 2\mathrm{CO_2} \; (\text{catalytic cycle 1})$$

$$\mathrm{OH} + \mathrm{CO} \rightarrow \mathrm{H} + \mathrm{CO_2}$$
$$\mathrm{H} + \mathrm{O_2} \xrightarrow{M} \mathrm{HO_2}$$
$$\mathrm{HO_2} + \mathrm{O} \rightarrow \mathrm{O_2} + \mathrm{OH}$$

$$net: \; \mathrm{CO} + \mathrm{O} \rightarrow \mathrm{CO_2} \; (\text{catalytic cycle 2})$$

McElroy and Donahue (1972); Parkinson and Hunten (1972)

Neutral photochemistry

$$2(CO + OH \rightarrow CO_2 + H)$$
$$2(H + O_2 \xrightarrow{M} HO_2)$$
$$HO_2 + NO \rightarrow NO_2 + OH$$
$$NO_2 + hv \rightarrow NO + O$$
$$HO_2 + O \rightarrow OH + O_2$$

$$net: \; 2CO + O_2 \rightarrow 2CO_2 \; (\text{catalytic cycle 3})$$

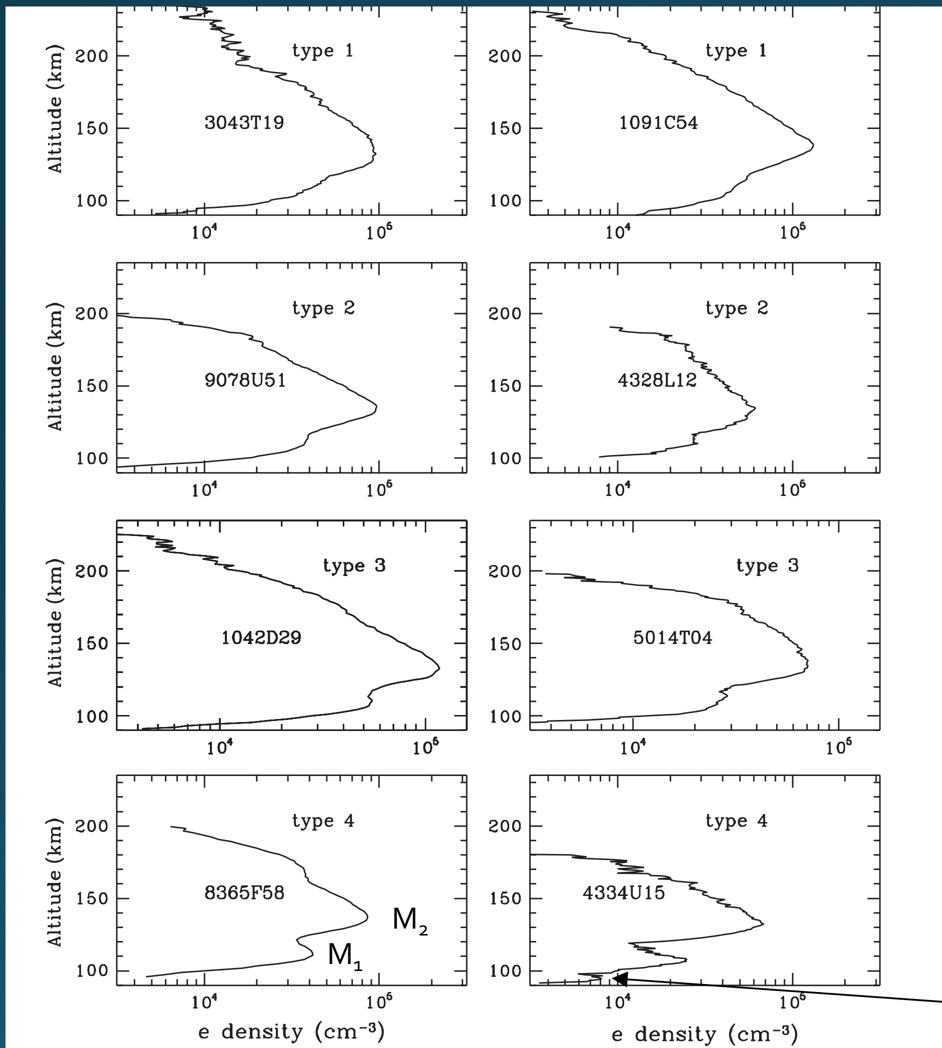
$$OH + CO \rightarrow H + CO_2$$
$$H + O_2 \xrightarrow{M} HO_2$$
$$HO_2 + NO \rightarrow NO_2 + OH$$
$$NO_2 + O \rightarrow O_2 + NO$$

$$net: \; CO + O \rightarrow CO_2 \; (\text{catalytic cycle 4})$$

Nair et al. (1994); Yung and Demore (1999)

See also some new ideas about the possible role of HOCO radicals (Boxe et al. 2014)

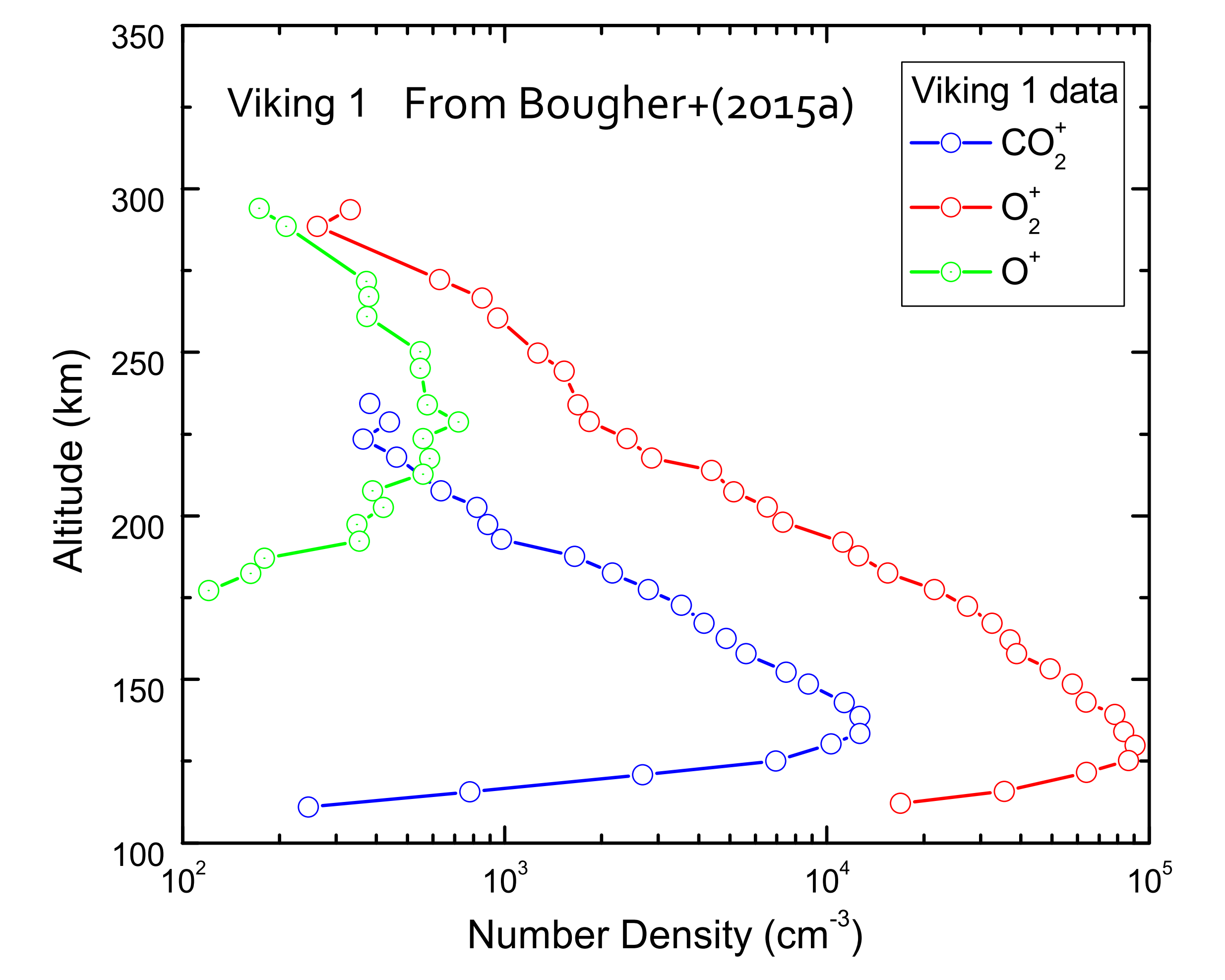
Electron densities



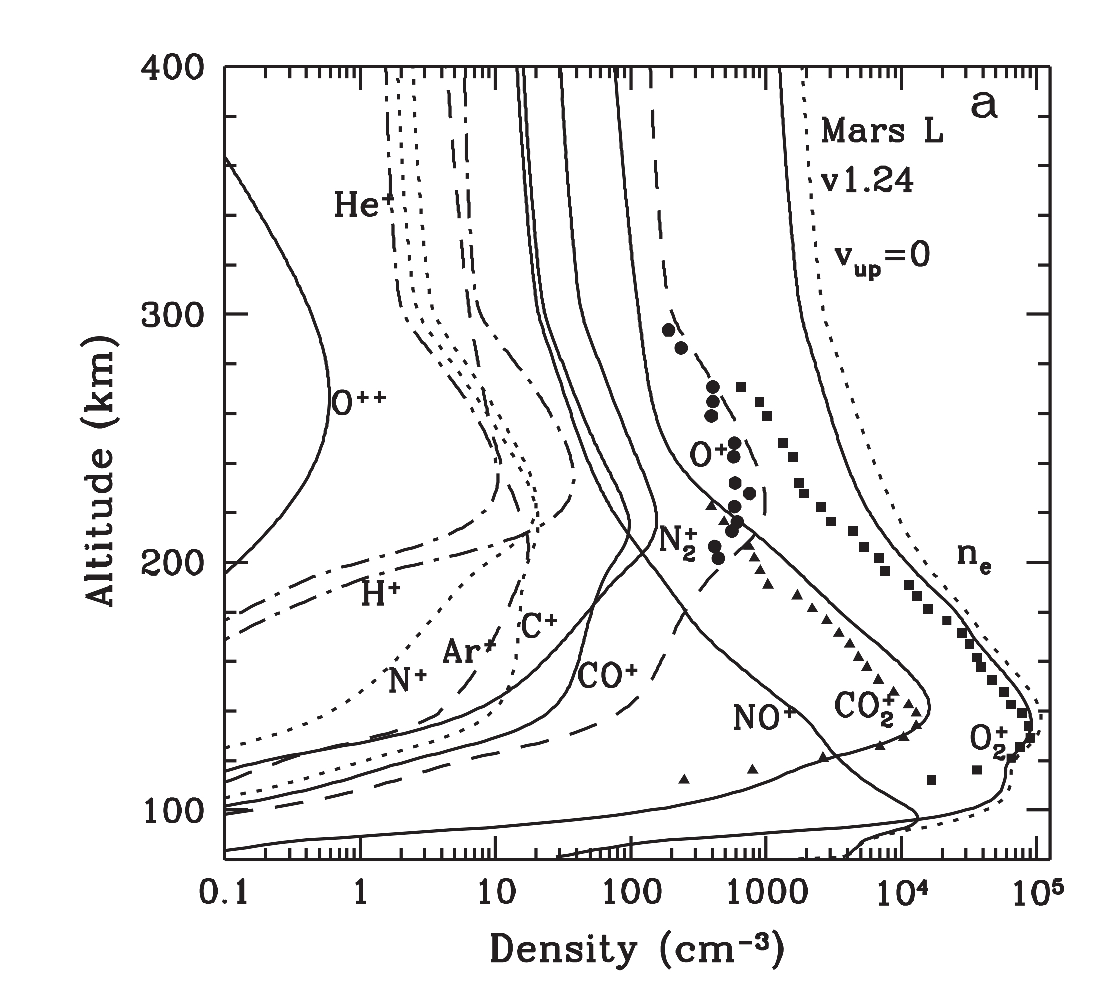
Meteoritic ions

Main peak due to photoionization, lower peak from photoelectron impact ionization, third low altitude peak due to meteoritic ions (Mg^+, Na^+, Fe^+). Plot of Mars Global Surveyor electron density profiles from Fox and Weber (2012).

Ionosphere composition

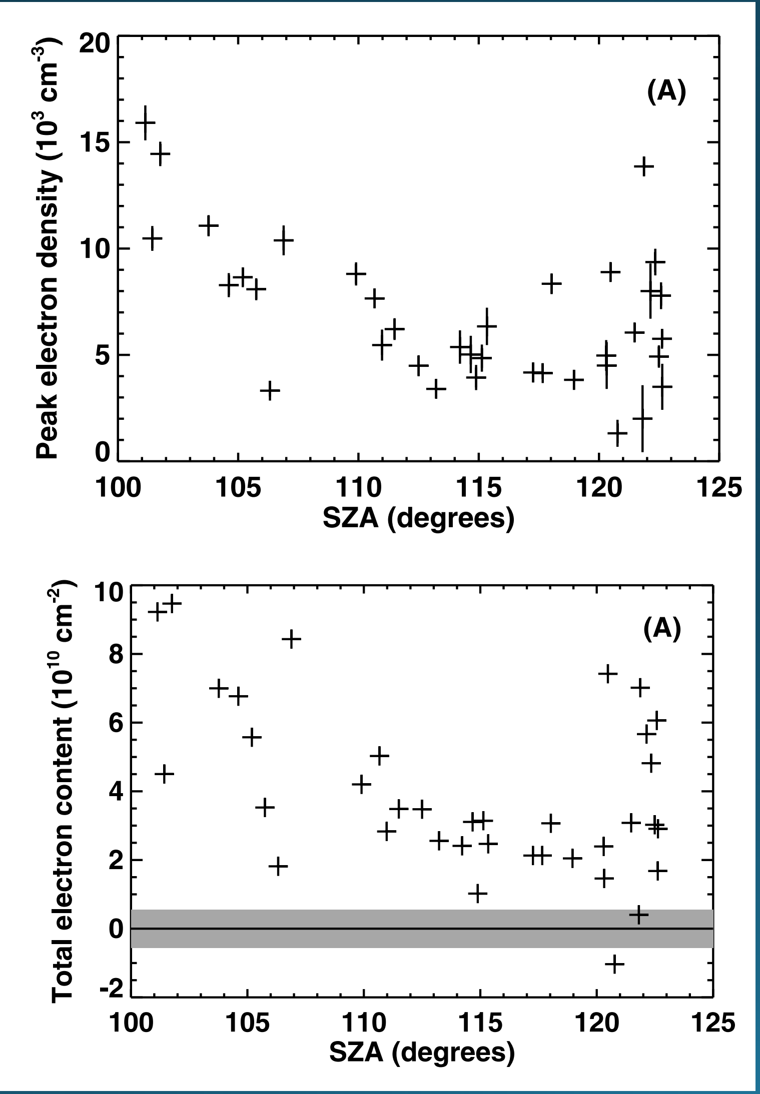


Model ionosphere



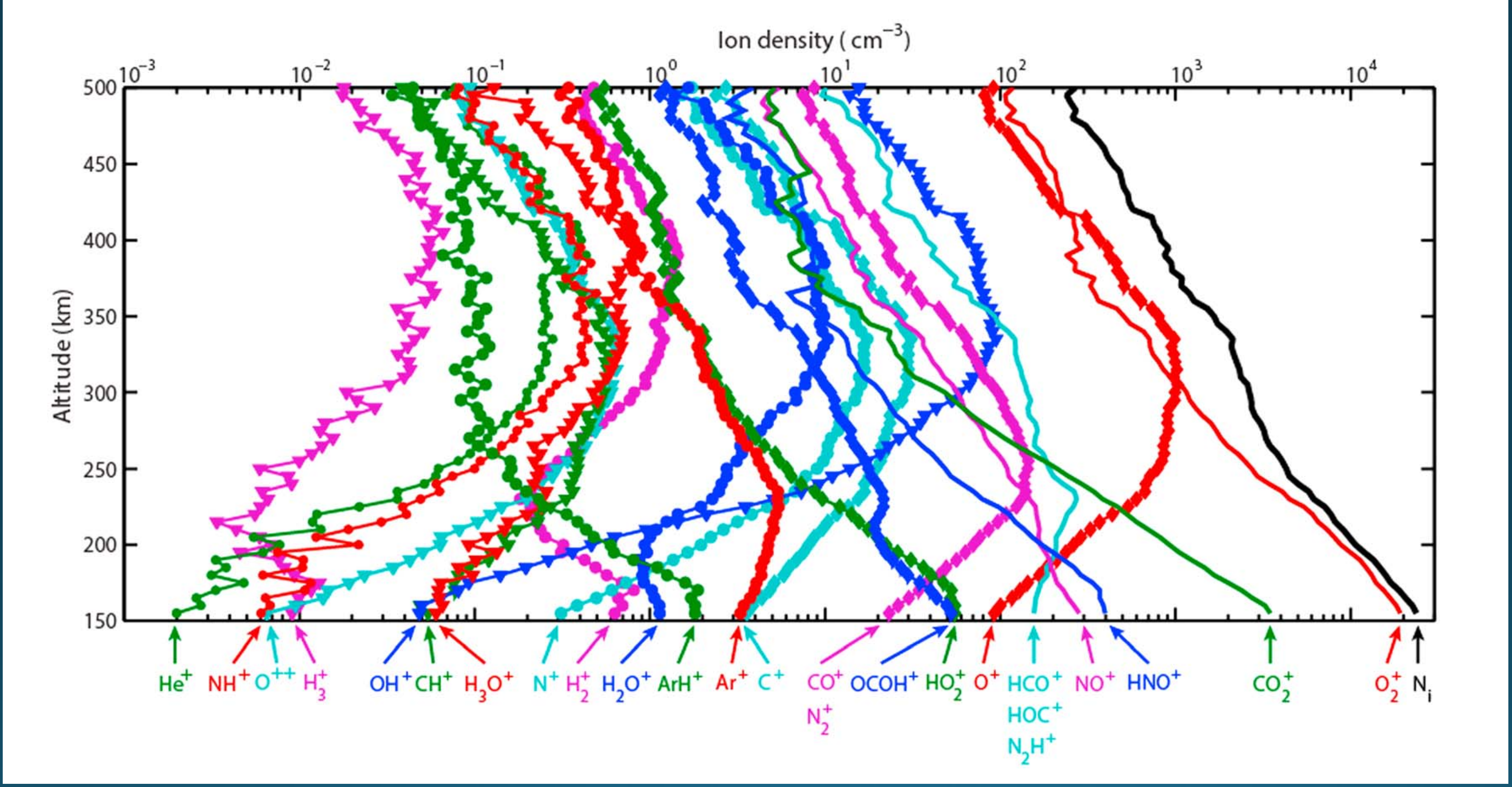
From Fox (2015). Sources and sinks of the main ions similar to Venus.

Day/night differences



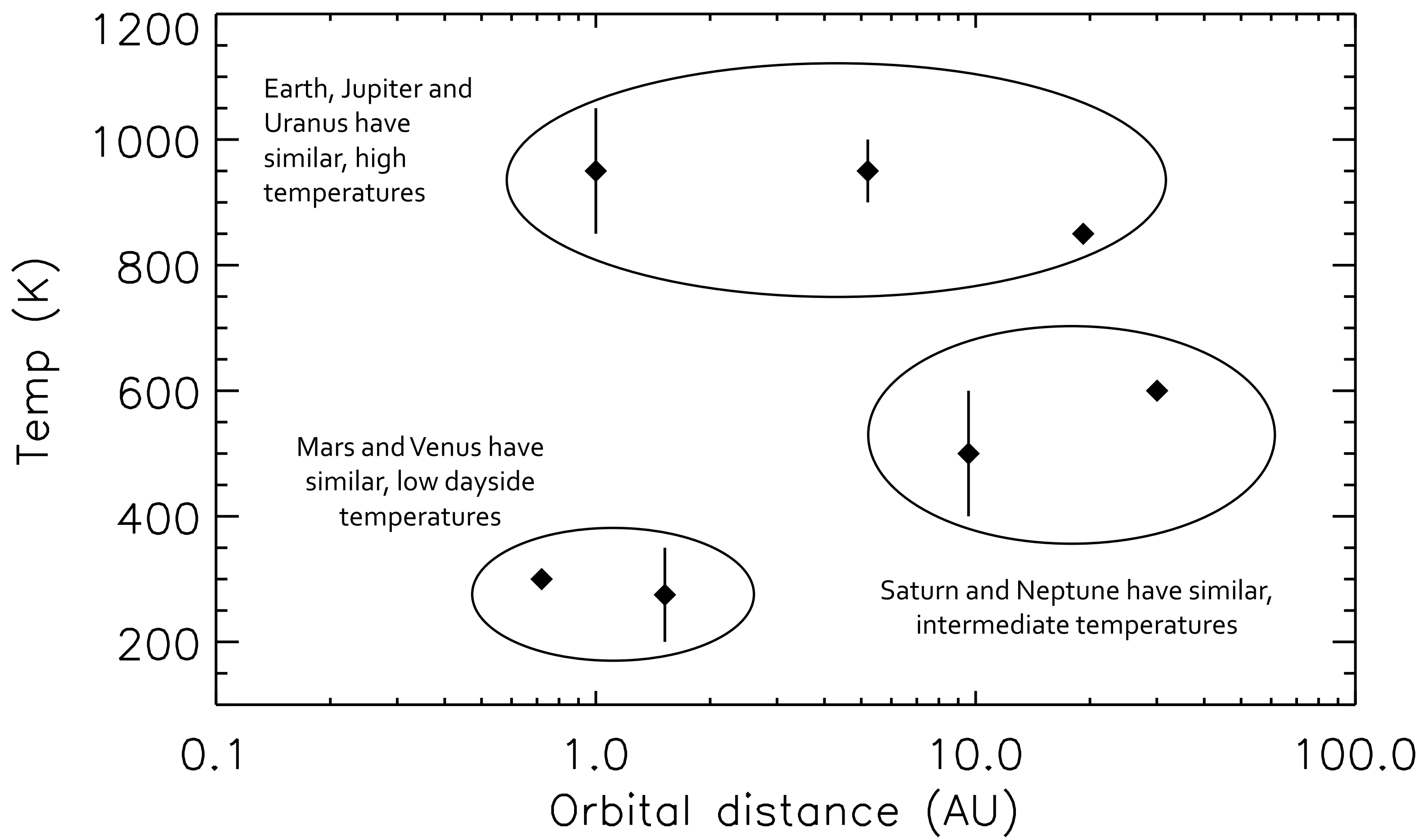
Night side plasma from day to night transport and electron precipitation. See study by Withers et al. (2012) based on Mars Express Radio Science results, and Benna et al. (2015) for SZA variations in ion densities.

Ionosphere from MAVEN/NGIMS



From Benna et al. (2015)

Exospheric temperatures



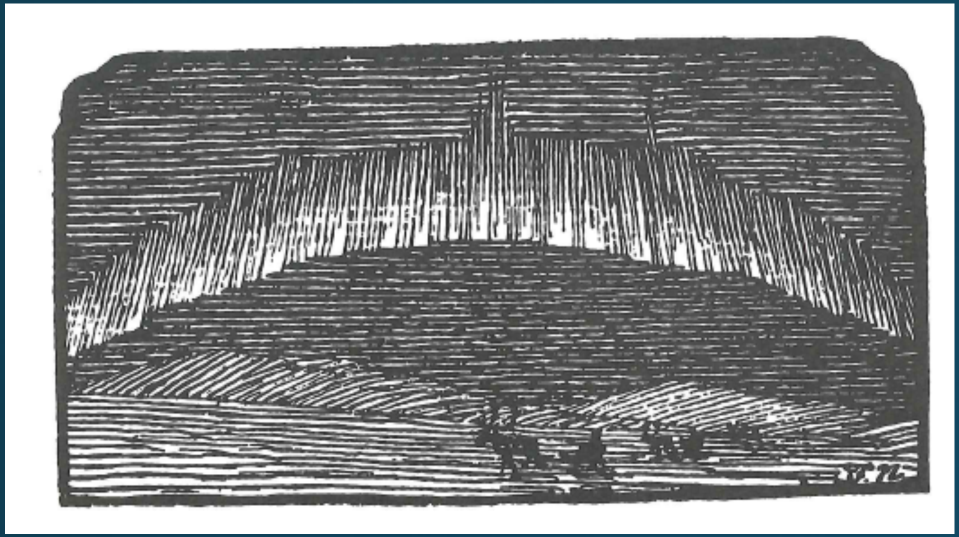
Auroral electrodynamics

Discrete aurora: dance of the spirits

The death dance of the spirits, warriors with their plumes and war clubs, flaring away to the northward, in the frosty nights of winter.

Hiawatha, H. W. Longfellow

The auroral arc



Wood carving of the auroral arc by Fridtjof Nansen (from Kaila 1998).
Below: auroral arc at Utsjoki (www.leuku.fi).

"Pohjola's gates are in sight,
the evil gateways glitter,
the bright covers are
glowing…"

Finnish folk poetry, Sampo

Diffuse red aurora: portents of war and bloodshed

Fierce fiery warriors fought upon the clouds, in ranks and squadrons and right form of war, that drizzled blood upon the Capitol.

W. Shakespeare, JC II, 2, 19

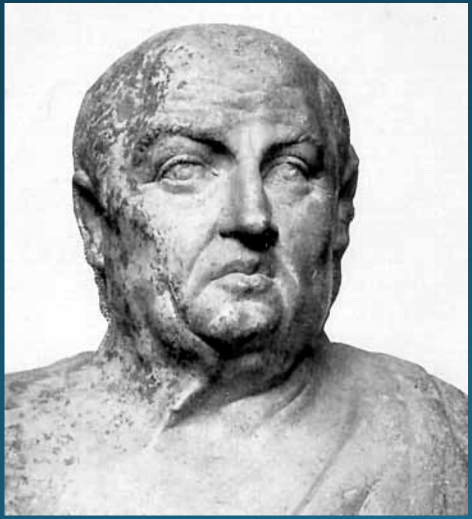
Fires in the sky

“…the cohorts hurried to the succor of the colony of Ostia, believing it to be on fire. During the greater part of the night the heaven appeared to be illuminated by a faint light.”

Seneca, Naturales Questiones I (37 AD)

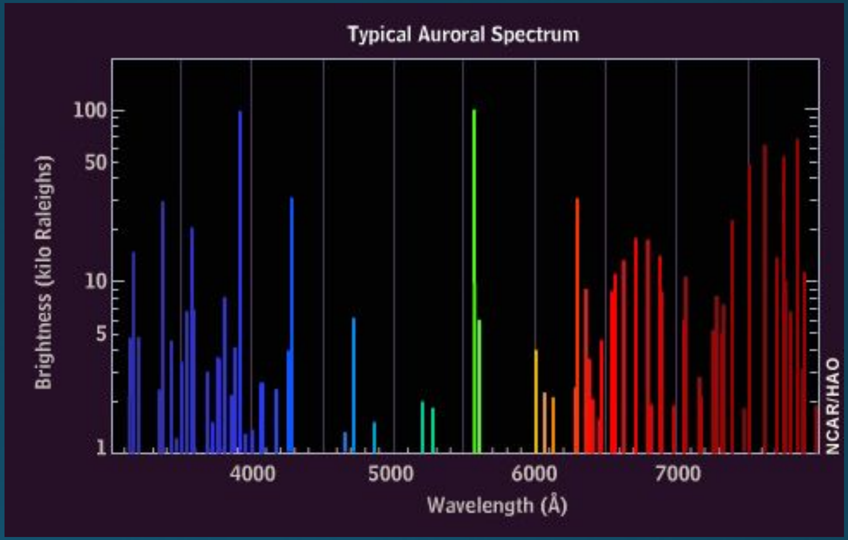
The science of the northern lights

But why does it (the fire) have various colours? Because it makes a difference what element is set ablaze and the quantity and force by which it is set on fire. Falling lights of this sort indicate wind; and, in fact, wind from the region where they started burning. You ask: "The lights which Greeks call sela – how are they produced? In many ways they say. It is possible for the force of the winds to produce them. The high temperature of the upper atmosphere can cause them.



Lucius Annaeus Seneca
Questiones Naturales Book I, Vol. VII

The green line

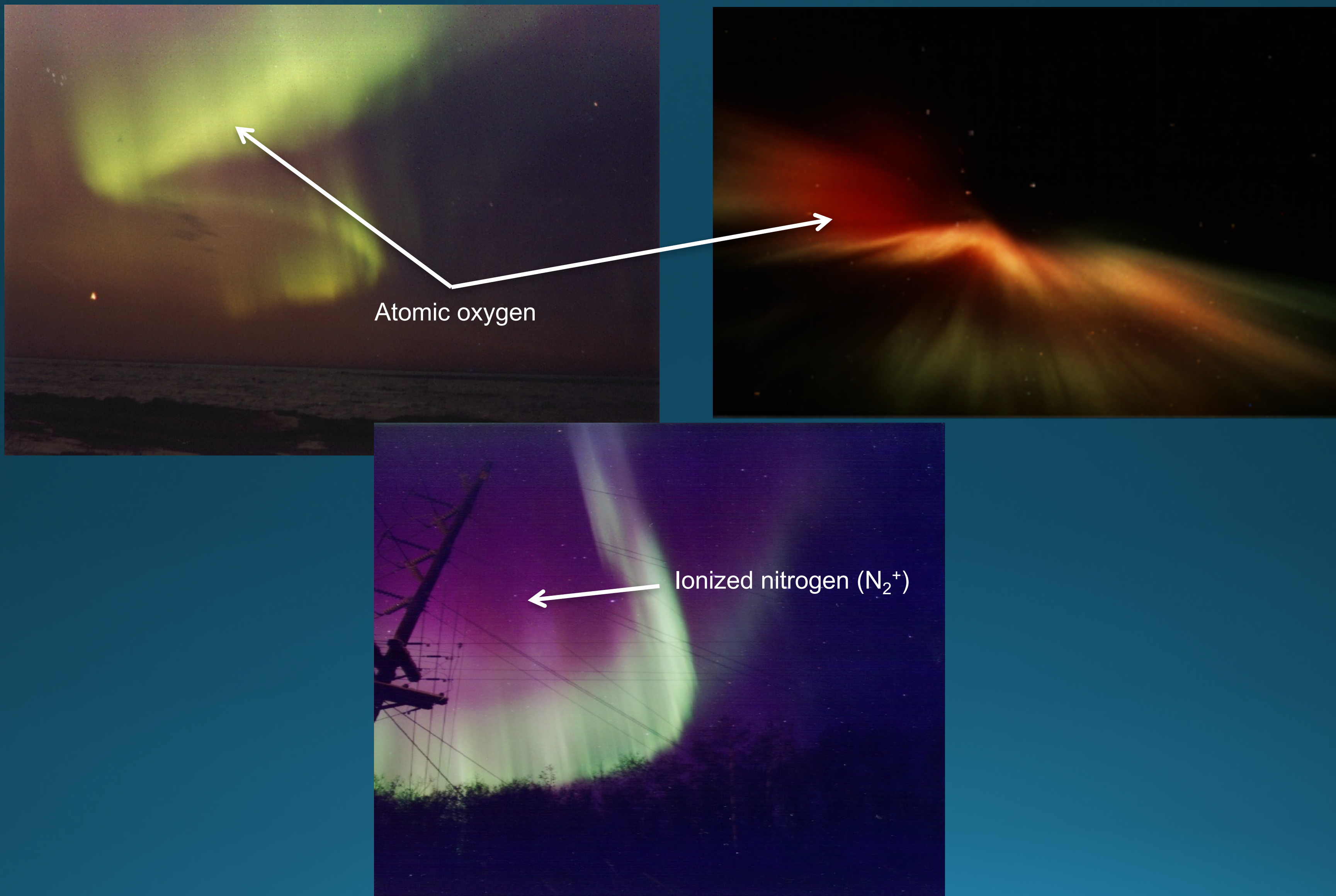


Anders Jonas Ångström (1814–1874) measured the spectrum of the northern lights during 1866 and 1867. In particular he measured the wavelength of 5567 Å for the green line. This was later revised to 5577 Å by Babcock (1923).

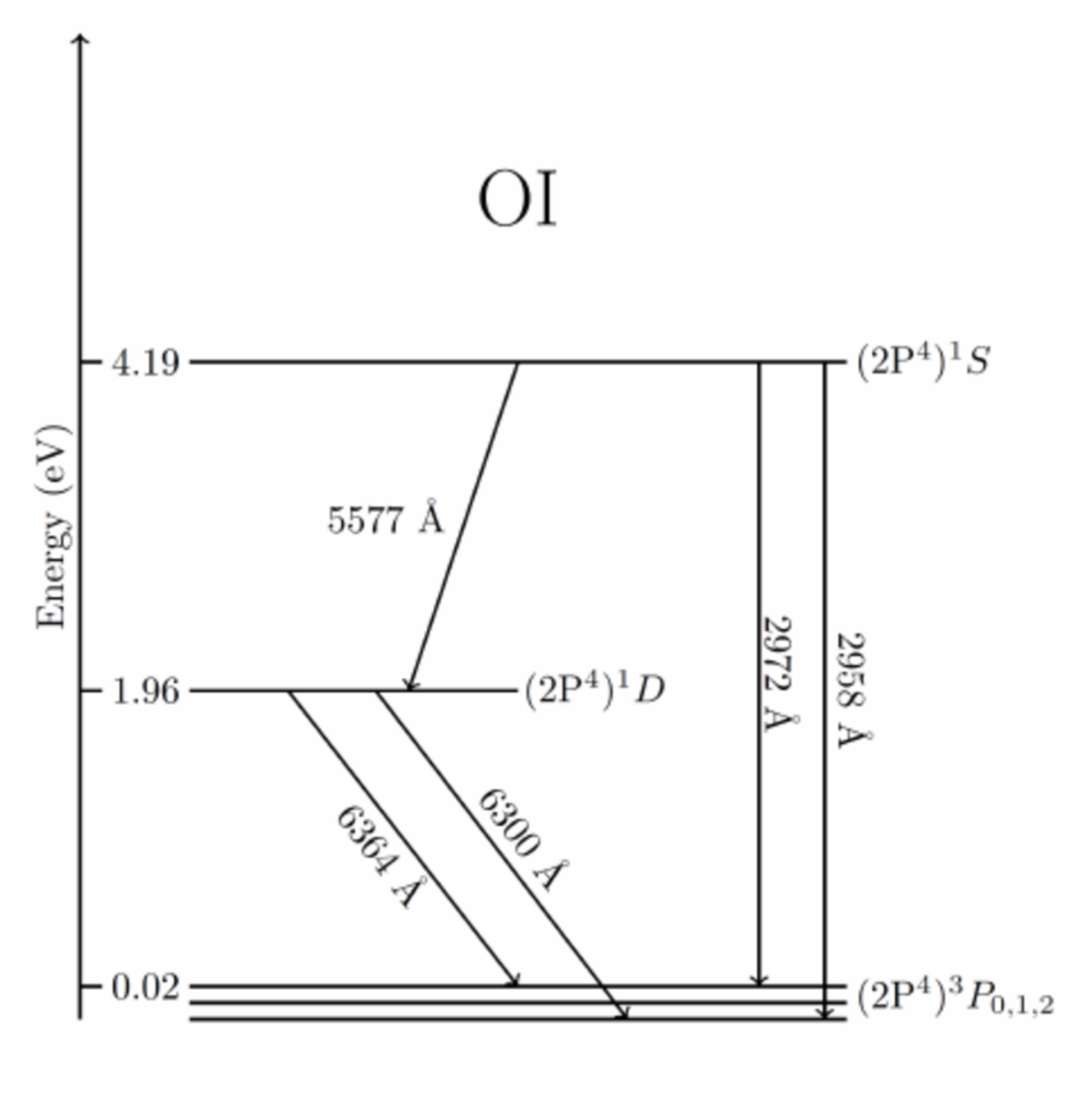
We know nothing at all about the chemical origin of the lines of the polar light – Heinrich Kayser, 1910

- Charles S. Peirce, 1869: unknown species lighter than the hydrogen atom
- Alfred Wegener, 1911: geocoronium
- Niels Bohr, 1913: the Bohr model of atomic hydrogen
- Lars Vegard, 1923: electrified layer of frozen nitrogen (Vegard et al. 1924, *Nature*)
- J. C. McLennan and G. M. Shrum (1924): atomic oxygen
- The samples of Vegard et al. (1924) and McLennan and Shrum (1924) both contaminated by oxygen (Kragh 2009)
- McLennan receives the gold medal from the Royal Society in 1927, his student Shrum is ignored
- Henrikson and Egeland (1988): Theory of the O 5577 Å auroral emissions

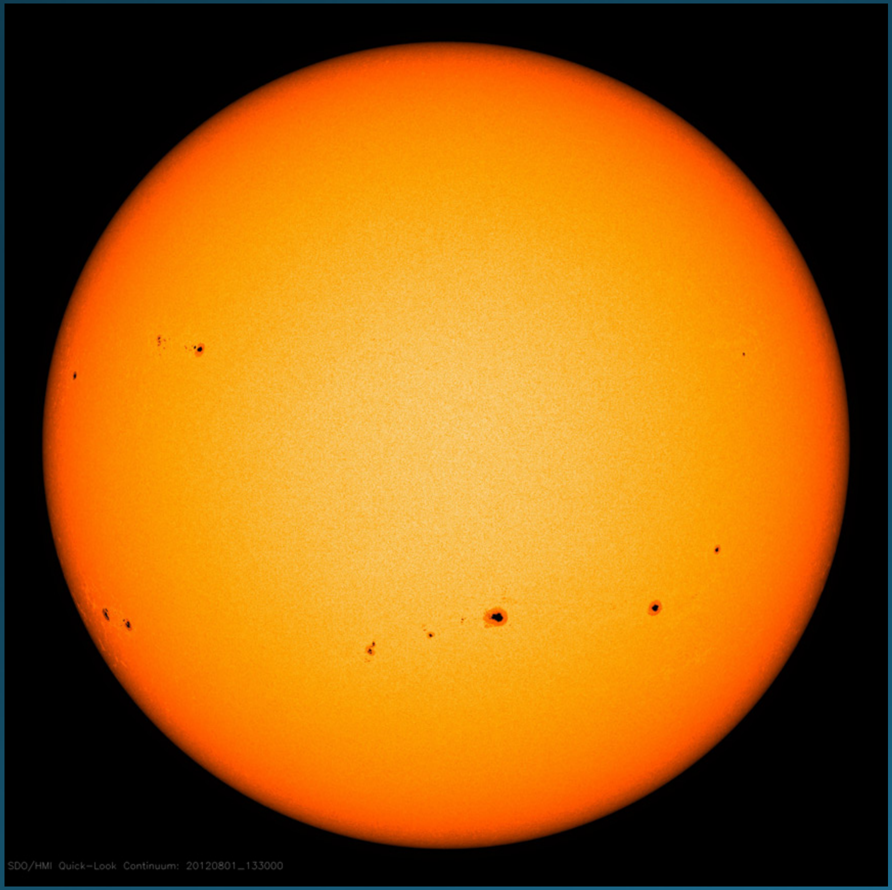
Sources of visible aurora

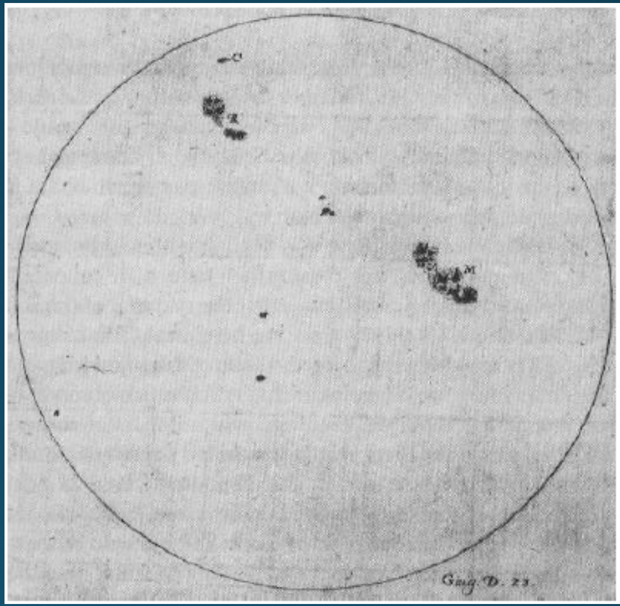


Oxygen energy level diagram



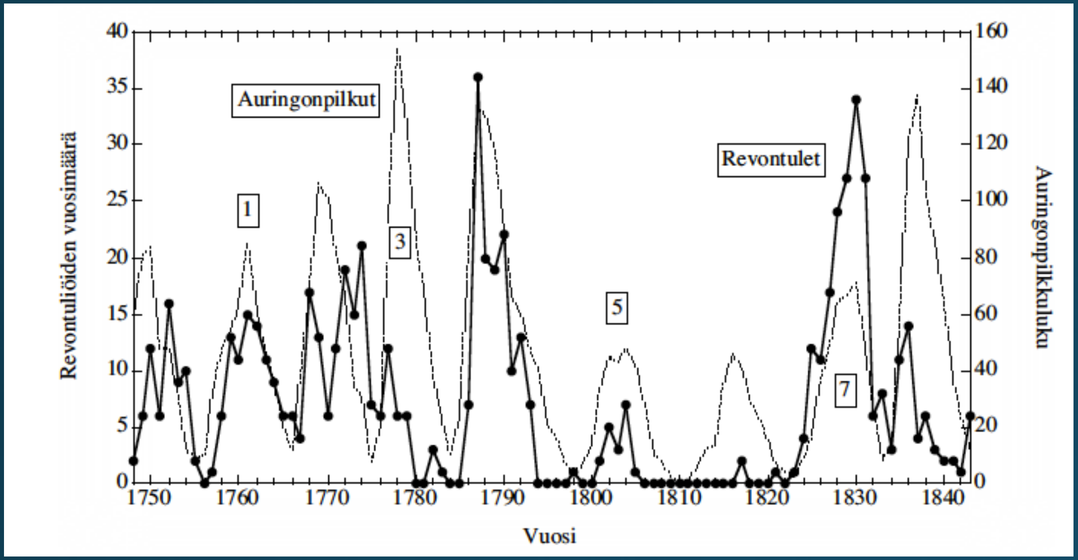
The solar connection

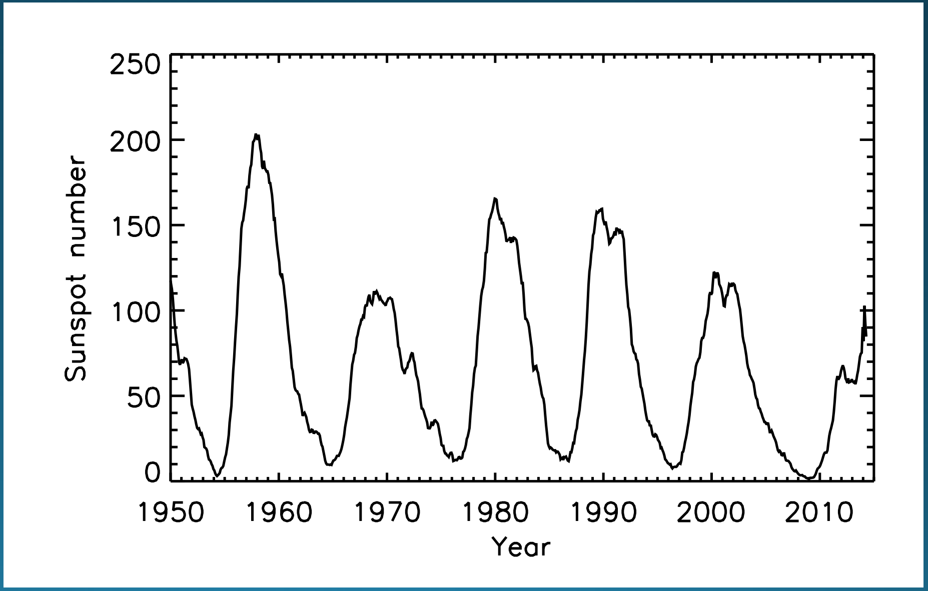




A connection between solar activity and the frequency of the aurora was noted. Above: a sketch of sunspots by Galileo. Left: Image of the sun (July 2012) from NASA's Solar Dynamics Observatory.

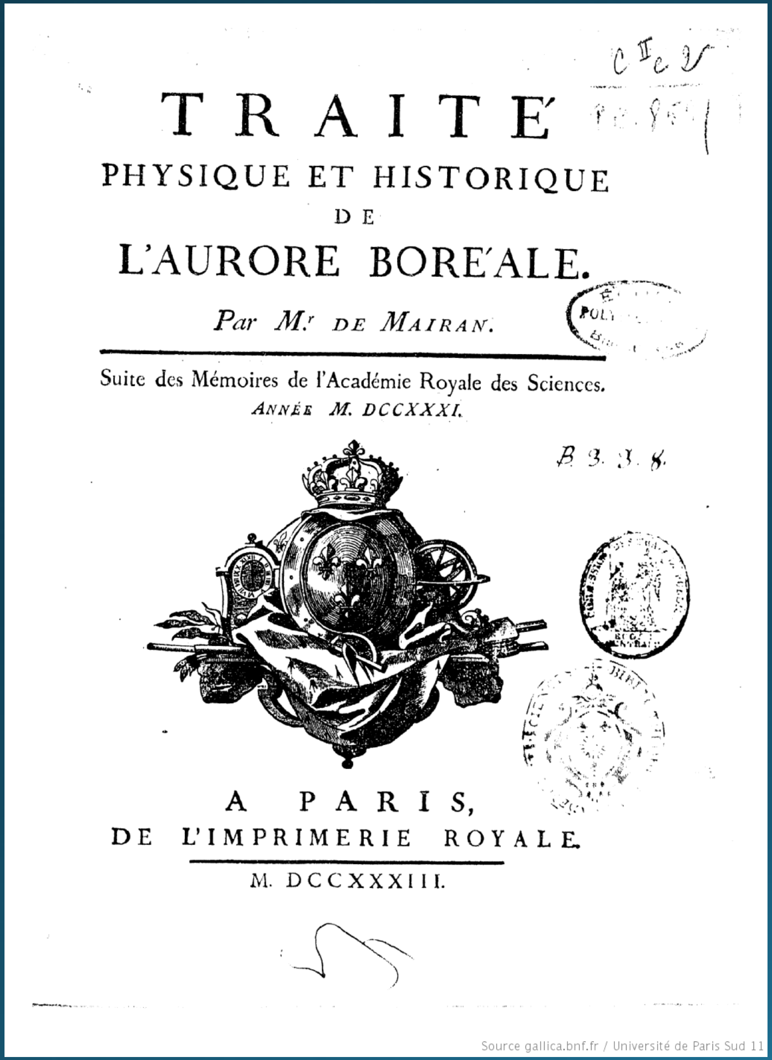
Solar activity and the aurora





Above: Nights with aurora compared with the sunspot number. The observations of the aurora were made by G.G.Hällström in Turku (1748-1828) and Helsinki (1828-1843) (Nevanlinna 2009). Right: The previous sunspot cycle is no. 24.

Falling lights of this sort indicate a wind



TRAITÉ
PHYSIQUE ET HISTORIQUE
DE
L'AURORE BORÉALE.

Par M.r DE *MAIRAN.*

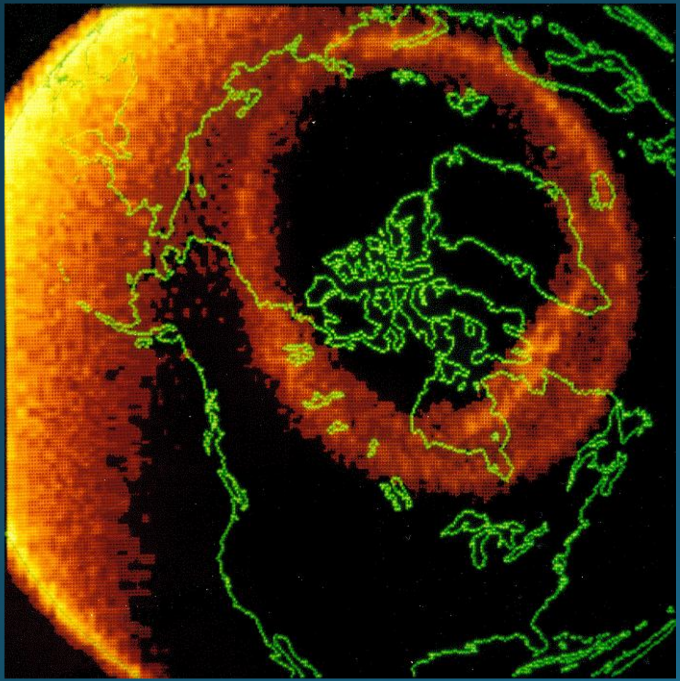
Suite des Mémoires de l'Académie Royale des Sciences.
Année M. DCCXXXI.

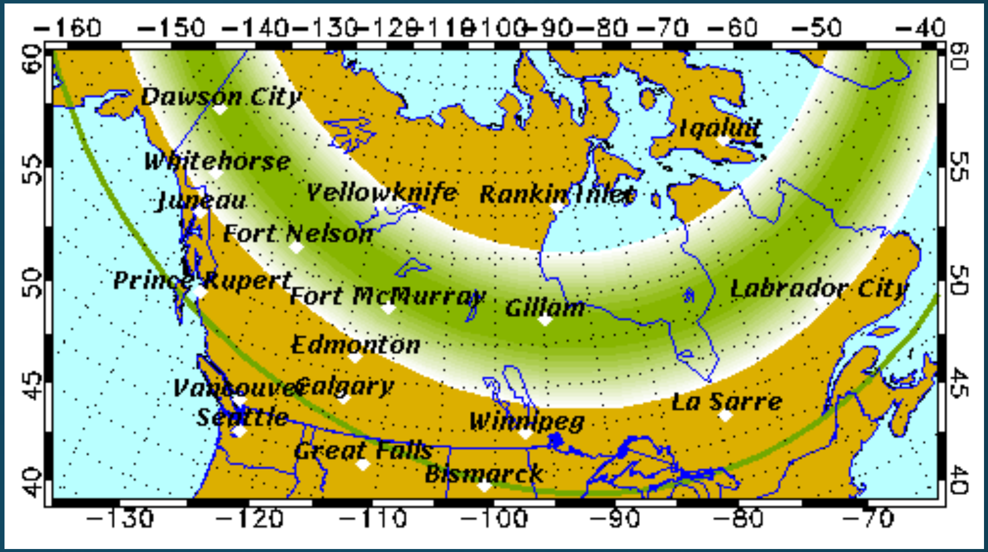
A PARIS,
DE L'IMPRIMERIE ROYALE.
M. DCCXXXIII.

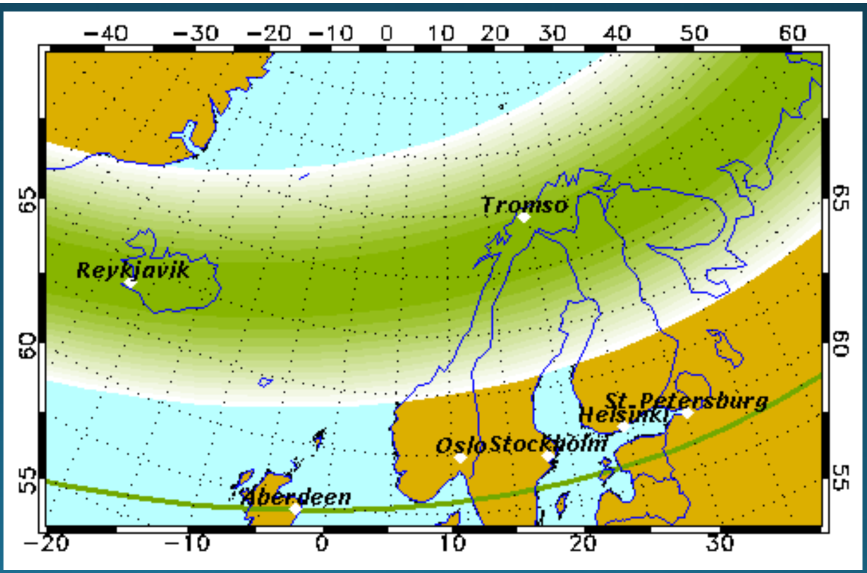
Jean Jacques d'Ortous de Mairan (1678 – 1771) suggested that the interaction of the Earth's atmosphere with the extended atmosphere of the sun produces the aurora borealis.

The auroral oval

In the 19th century to aurorae were mapped to a ring surrounding the pole. This ring is not centered at the north pole but the geomagnetic pole. Image of the UV auroral oval observed by the NASA Dynamics Explorer 1 satellite that was launched in 1981 (below).







The Birkeland – Störmer theory

Kristian Olaf Birkeland (1867 – 1917) argues that the northern lights are caused by electrons as they move along the Earth's magnetic field lines. He also proposes that these electrons stream out from sunspots.