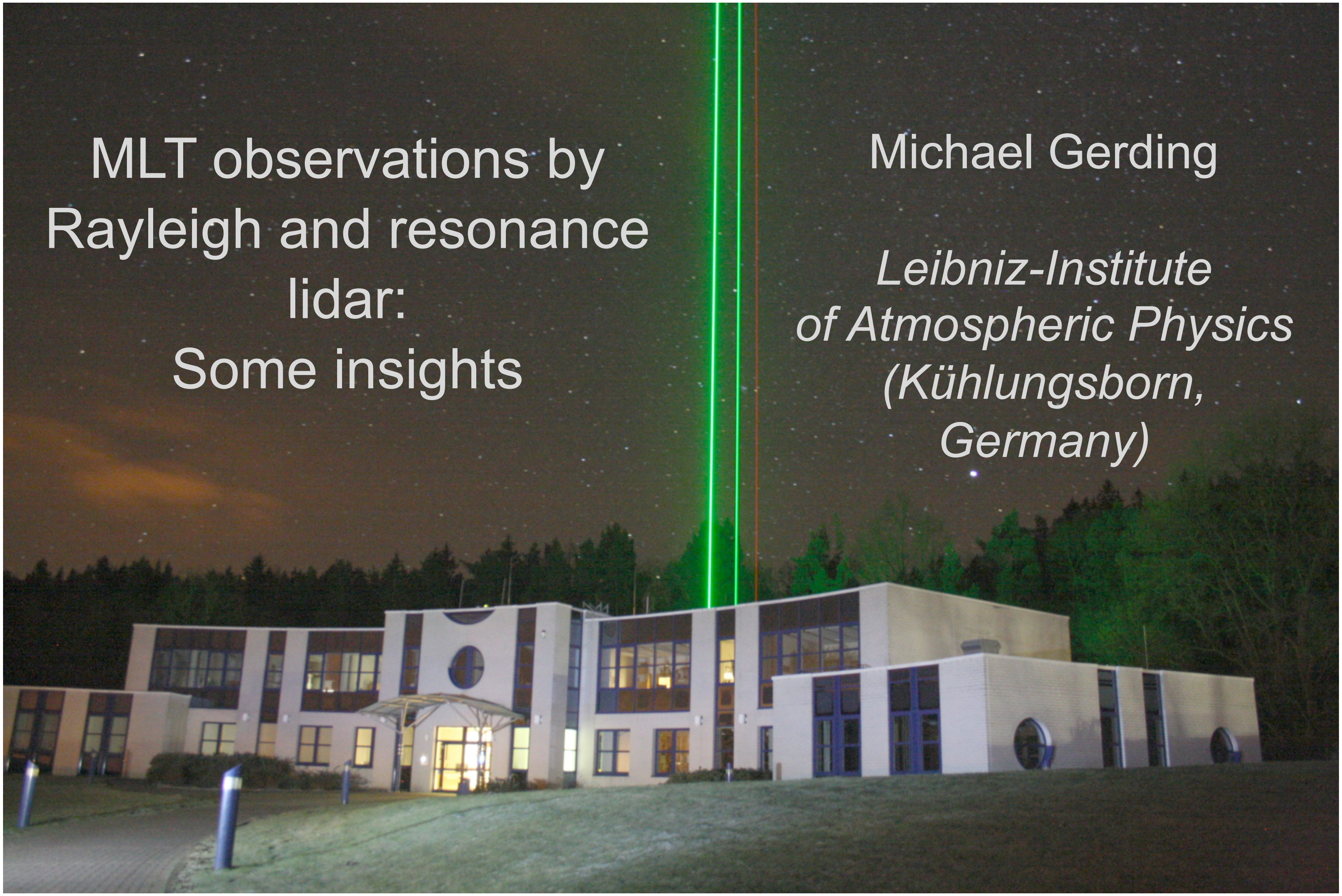


# MLT observations by Rayleigh and resonance lidar: Some insights

Michael Gerding

*Leibniz-Institute of Atmospheric Physics (Kühlungsborn, Germany)*

# Modern Science with Lidars: Fong et al., 2014

AGU PUBLICATIONS

http://publications.agu.org/journals/

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2013JD020784

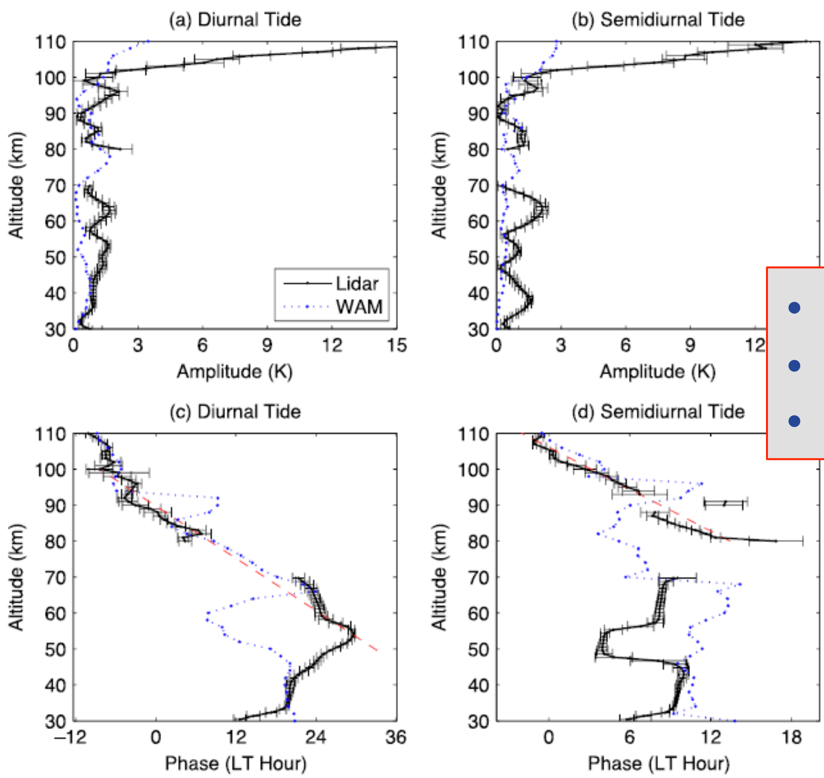
**Key Points:**

- Temperature tides from 30 to 110 km are characterized with lidar and WAM at McMurdo
- A new finding is the fast growth of 24

## Winter temperature tides from 30 to 110 km at McMurdo (77.8°S, 166.7°E), Antarctica: Lidar observations and comparisons with WAM

**Weichun Fong[1,2], Xian Lu[1], Xinzhao Chu[1,2], Tim J. Fuller-Rowell[1,3], Zhibin Yu[1,2], Brendan R. Roberts[1,2], Cao Chen[1,2], Chester S. Gardner[4], and Adrian J. McDonald[5]**

for Research in Environmental Sciences, University of Colorado Boulder, Boulder, Colorado, USA, pace Engineering Sciences, University of Colorado Boulder, Boulder, Colorado, USA, [3]Space Weather A, Boulder, Colorado, USA, [4]Department of Electrical and Computer Engineering, University of Illinois , Urbana, Illinois, USA, [5]Department of Physics and Astronomy, University of Canterbury, land




- First tidal data from 78°S
- Amplitudes grow unexpectedly above 100 km
- Not reproduced by WAM

# Modern Science with Lidars: Yuan et al., 2014

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Atmospheres

RESEARCH ARTICLE

10.1002/2013JD020338

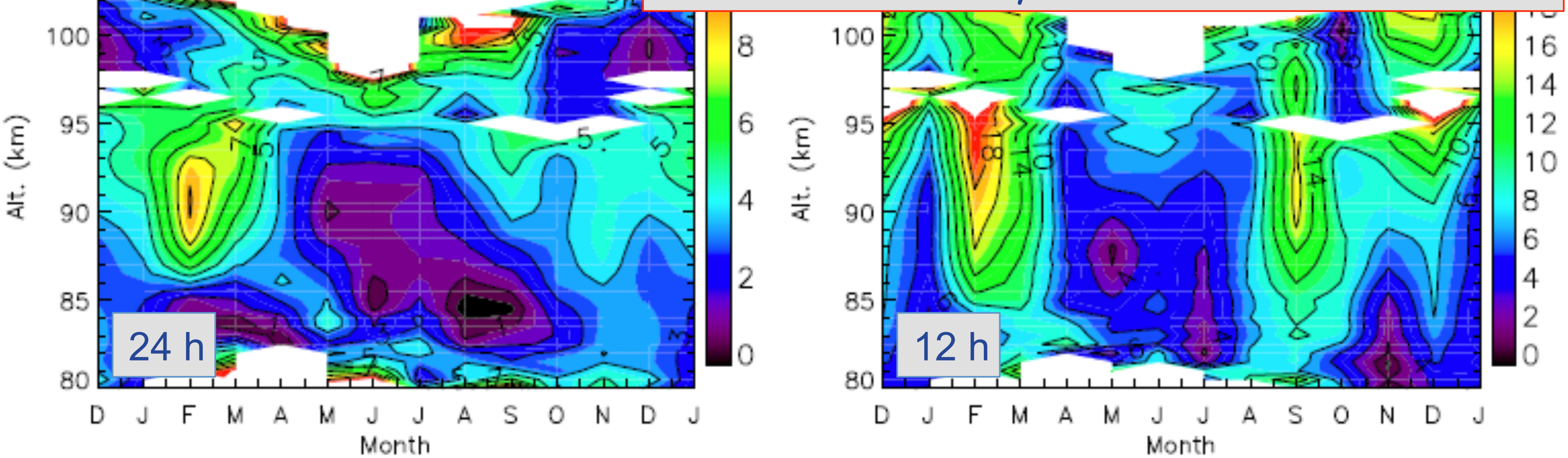
**Key Points:**
- Deduce vertical wind tide from Na density and MLT temperature
- Establish vertical wind tidal climatology
- Observed seasonal variations are in agreement with tidal model

## Vertical tidal wind climatology from full-diurnal-cycle temperature and Na density lidar observations at Ft. Collins, CO (41°N, 105°W)

**Tao Yuan[1], C. Y. She[1,2], J. Oberheide[3], and David A. Krueger[2]**

[1]Center of Atmospheric a
University, Fort Collins, U

- Vertical winds typically too small to be observable (~ cm/s)
- Wind calculated indirectly from temperature and metal density



# Modern Science with Lidars: Yi et al., 2013

Journal of Atmospheric and Solar-Terrestrial Physics 102 (2013) 172–184

ELSEVIER

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

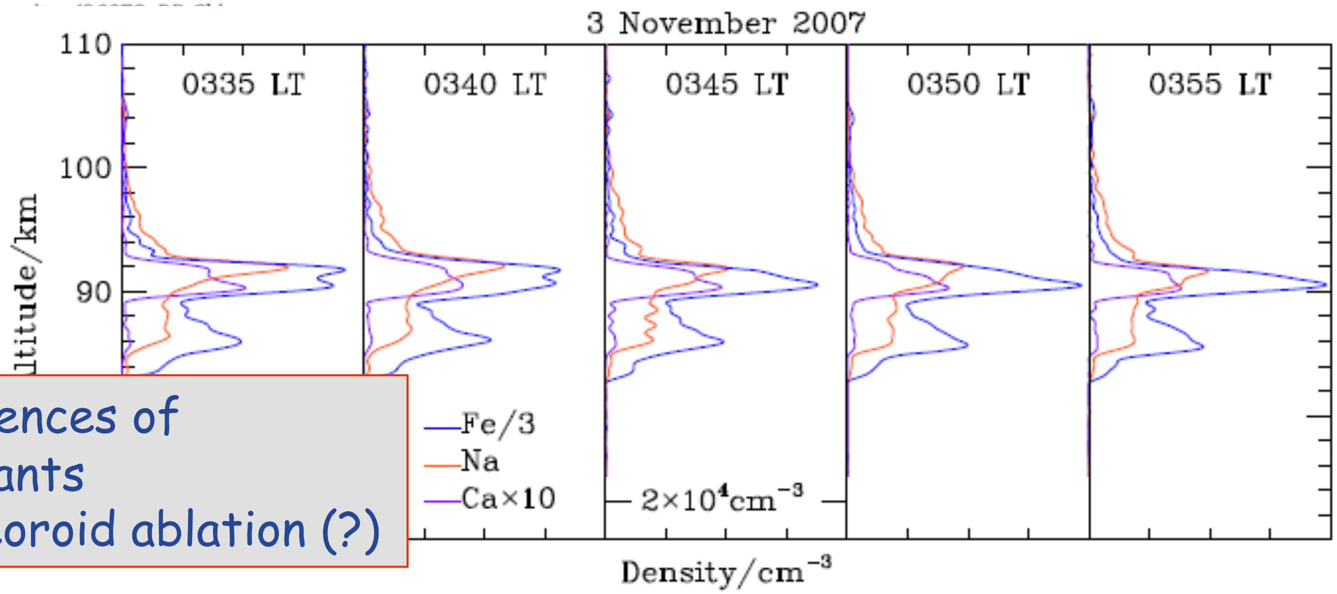
journal homepage: www.elsevier.com/locate/jastp

Simultaneous and common-volume three-lidar observations of sporadic metal layers in the mesopause region

CrossMark

Fan Yi [a,b,c,*], Shaodong Zhang [a,b,c], Changming Yu [a,b,c], Yunpeng Zhang [a,b,c], Yujin He [a,b,c], Fuchao Liu [a,b,c], Kaiming Huang [a,b,c], Chunming Huang [a,b,c], Ying Tan [a,b,c]

[a] School of Electronic Information, Wuhan Uni
[b] Key Laboratory of Geospace Environment an
[c] State Observatory for Atmospheric Remote S




- Insights into differences of chemical rate constants
- Differences in meteoroid ablation (?)

# Modern Science with Lidars: Friedman et al., 2013

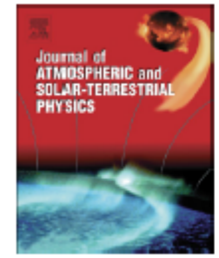
Journal of Atmospheric and Solar-Terrestrial Physics 104 (2013) 253–259

ELSEVIER

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp



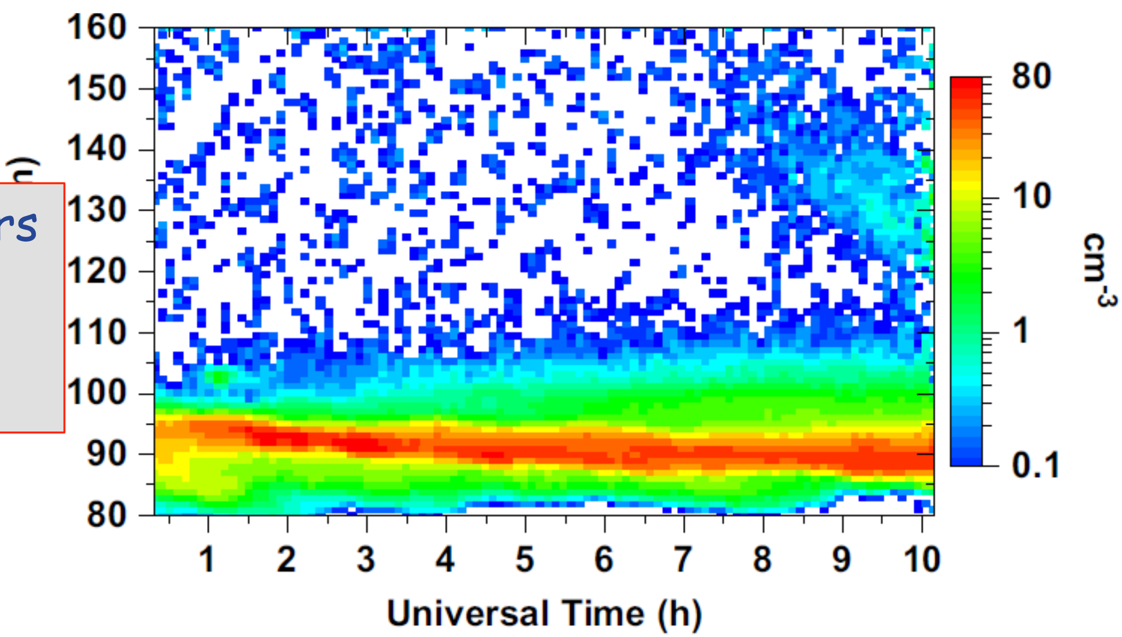

## Observation of a thermospheric descending layer of neutral K over Arecibo

CrossMark

Jonathan S. Friedman [a,c,*], Xinzhao Chu [b], Christiano Garnett Marques Brum [a], Xian Lu [b]

[a] Arecibo Observatory, SRI International, HC-3 Box 53995, Arecibo,
[b] Cooperative Institute for Research in Environmental Sciences & D
216 UCB, Boulder, CO 80309, USA
[c] Puerto Rico Photonics Institute, Universidad Metropolitana, San Ju

- Origin of thermospheric layers
- Global distribution?
- Use for temperature data at >110 km

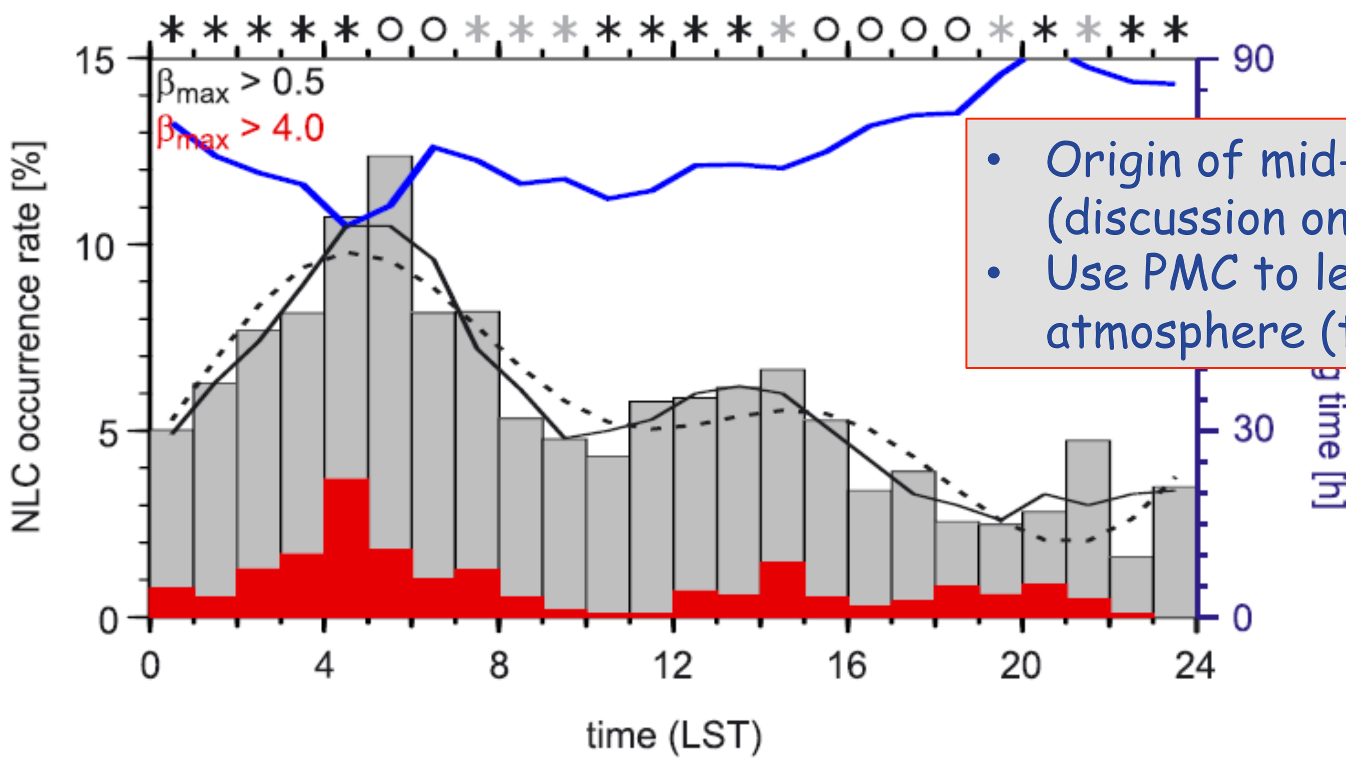


# Modern Science with Lidars: Gerding et al., 2013

GEOPHYSICAL RESEARCH LETTERS, VOL. 40, 6390–6394, doi:10.1002/2013GL057955, 2013

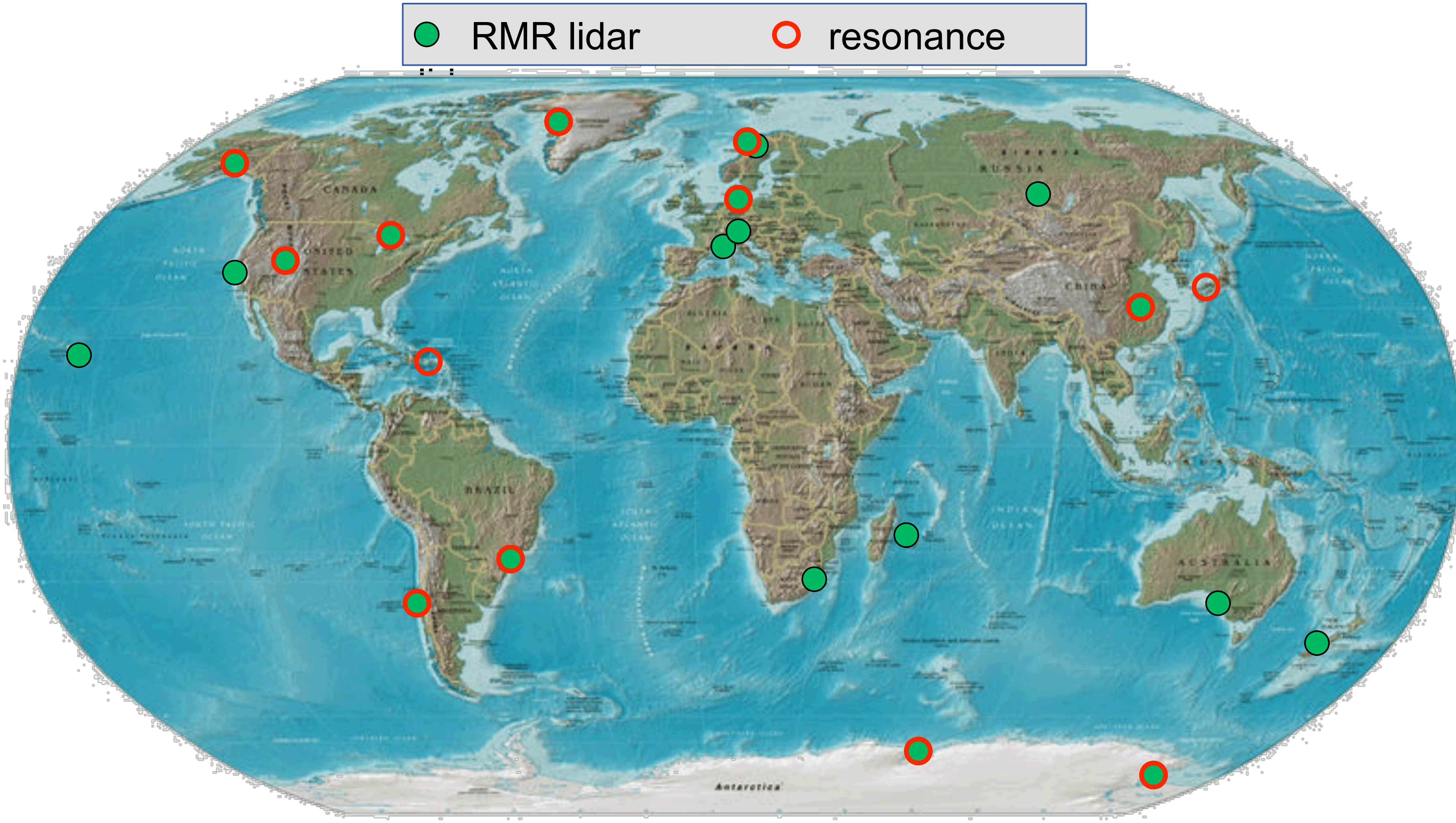
**Diurnal variations of midlatitude NLC parameters observed by daylight-capable lidar and their relation to ambient parameters**

M. Gerding,[1] M. Kopp,[1] P. Hoffmann,[1] J. Höffner,[1] and F.-J. Lübken[1]




- Origin of mid-latitude PMC (discussion on global change)
- Use PMC to learn about background atmosphere (tides)

# MLT lidars

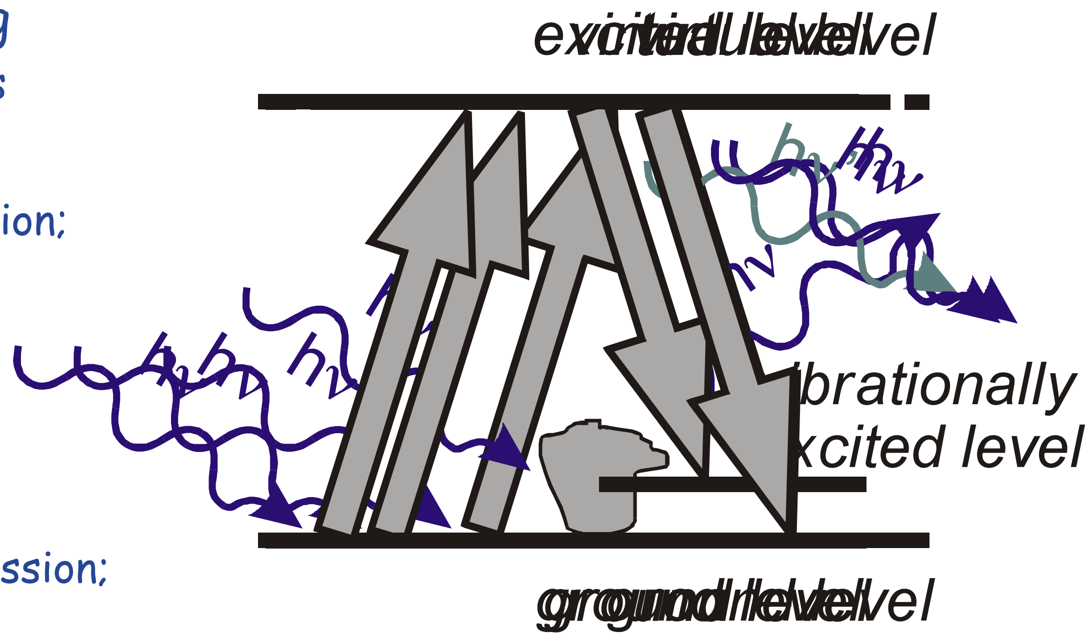


# Overview

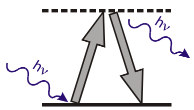
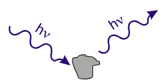
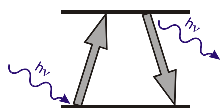
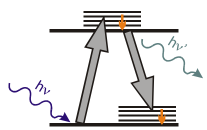
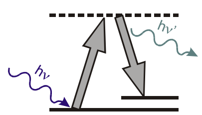
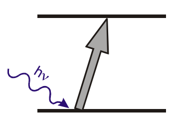
- Modern Science with Lidars
- Lidar Basics
- Data Reduction Methods
  - Temperatures in the Metal Layer
  - Temperatures from Density Soundings
- Tradeoffs ("Is there an optimal RMR lidar?")
- Summary and Outlook

# Light Interaction with the Atmosphere

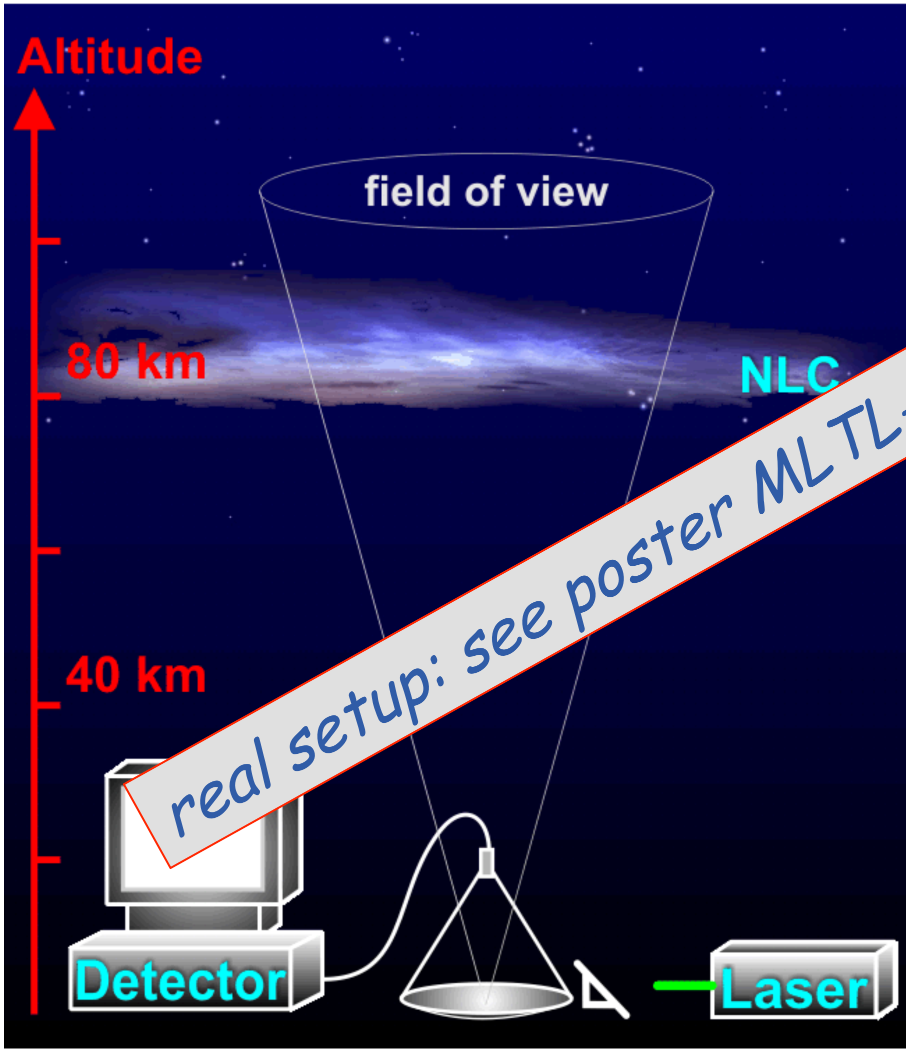
- Rayleigh scattering
  elastic; atoms or molecules
- Mie (particle) scattering
  elastic; aerosol particles
- Resonance fluorescence
  elastic at atomic transition;
  large cross section
- Raman scattering
  inelastic, molecules
- Fluorescence
  inelastic, broadband emission;
  atoms or molecules
- Absorption
  attenuation in bands;
  molecules or particles



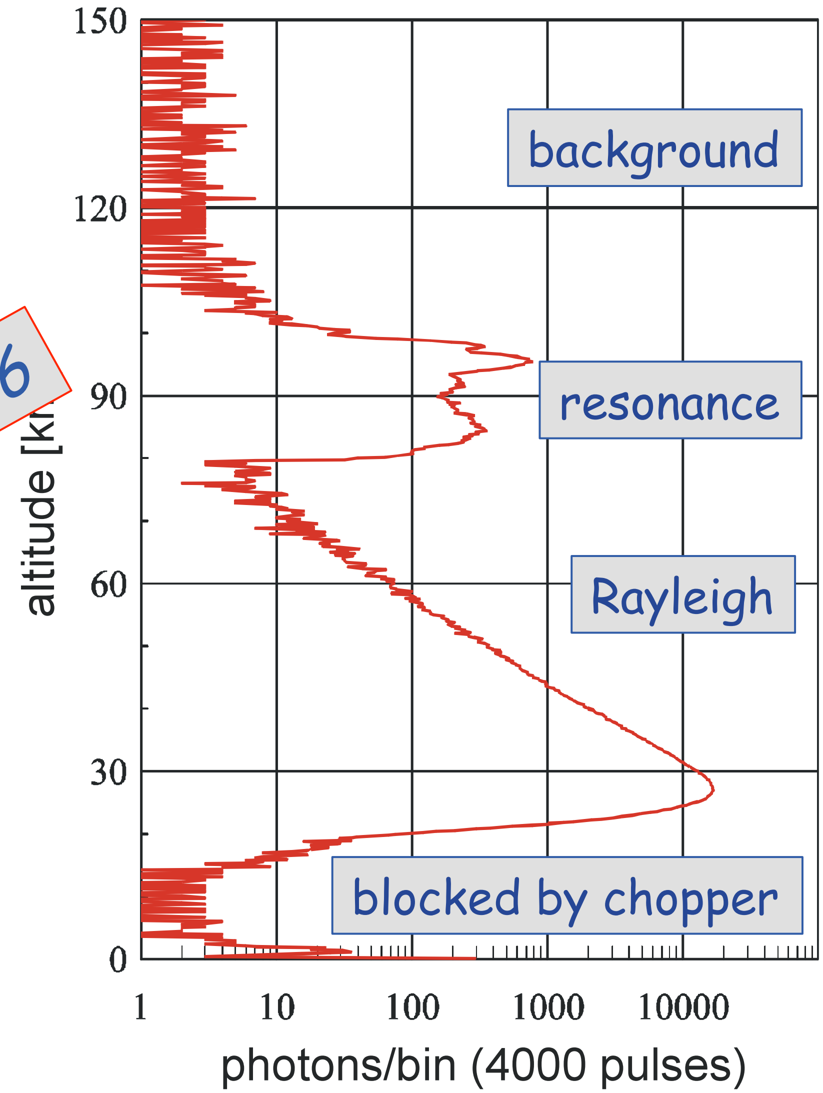
# Light Interactions with the Atmosphere

| process | scheme | species | backscatter cross section σ<br>rel. factor | density | λ dependence |
|---|---|---|---|---|---|
| Rayleigh scattering |  | atoms, molecules | $5 \cdot 10^{-28}$ cm²/sr<br>1 | 0 km: $2.5 \cdot 10^{19}$ cm$^{-3}$<br>25 km: $8 \cdot 10^{17}$ cm$^{-3}$<br>90 km: $6 \cdot 10^{13}$ cm$^{-3}$ | $\lambda^{-4}$ |
| Mie scattering |  | aerosols | $0.2 - 10^{18}$ | 20 km: < 100 cm$^{-3}$<br>PMC: 50-500 cm$^{-3}$ | depends on size |
| resonance fluorescence |  | atoms (ions, molecules) | $10^{14} - 10^{16}$ | 5 – 25000 cm$^{-3}$ | spectrum |
| Raman scattering |  | molecules | 1/1000 | | spectrum |
| fluorescence |  | atoms, molecules | $10^{8}$ | | spectrum |
| absorption |  | molecules, aerosols | | | spectrum |

# Lidar schematic




real setup: see poster MLTL-06



# Basic Lidar Equation

$$I(\lambda, z_i) = I_0(\lambda) \cdot \frac{A}{4\pi z_i^2} \cdot T^2(\lambda, z_i) \cdot \rho(z_i) \cdot \beta(\lambda, z_i) \cdot \eta(\lambda) \cdot \Delta z + B$$

background

bin width

detector sensitivity

total backscatter coefficient ($ß_{Ray}+ß_{Mie}+ß_{Res}$)

geometric overlap between laser and telescope FOV

transmission between ground and scattering altitude $z_i$

solid angle of visible telescope aperture

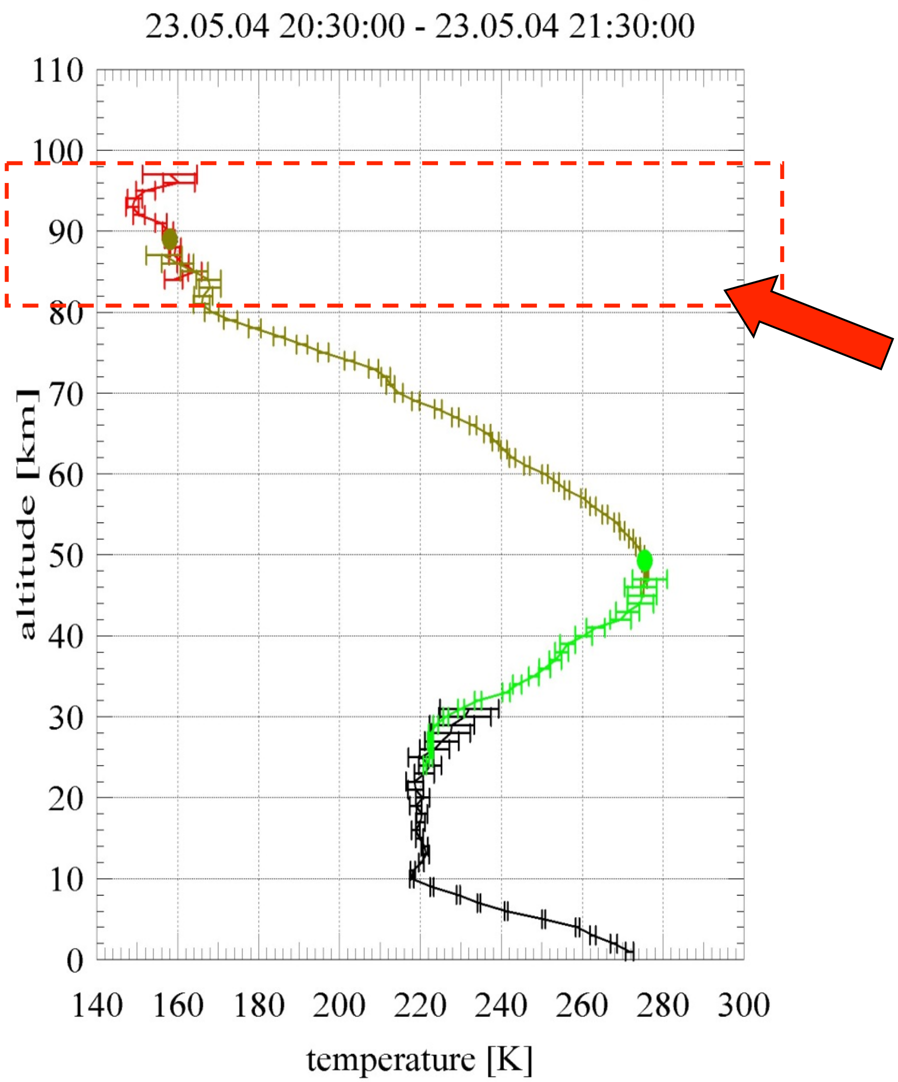
emitted intensity at the wavelength $\lambda$

intensity at the emitted wavelength $\lambda$ received from altitude $z_i$ ($z=c \cdot t/2$)

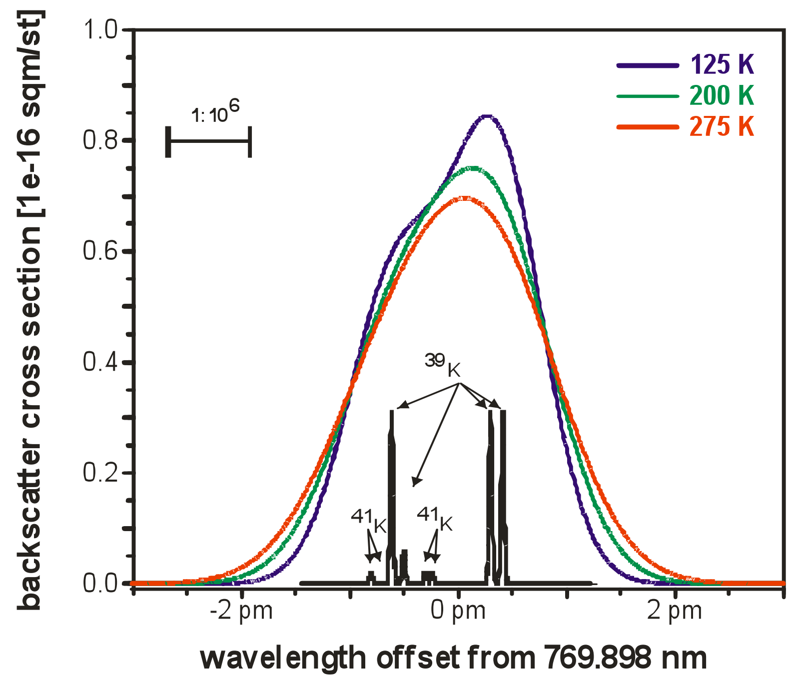
# Overview

- Modern Science with Lidars
- Lidar Basics
- Data Reduction Methods
  - Temperatures in the Metal Layer
  - Temperatures from Density Soundings
- Tradeoffs (“Is there an optimal RMR lidar?“)
- Summary and Outlook

# above 80 km: K resonance lidar

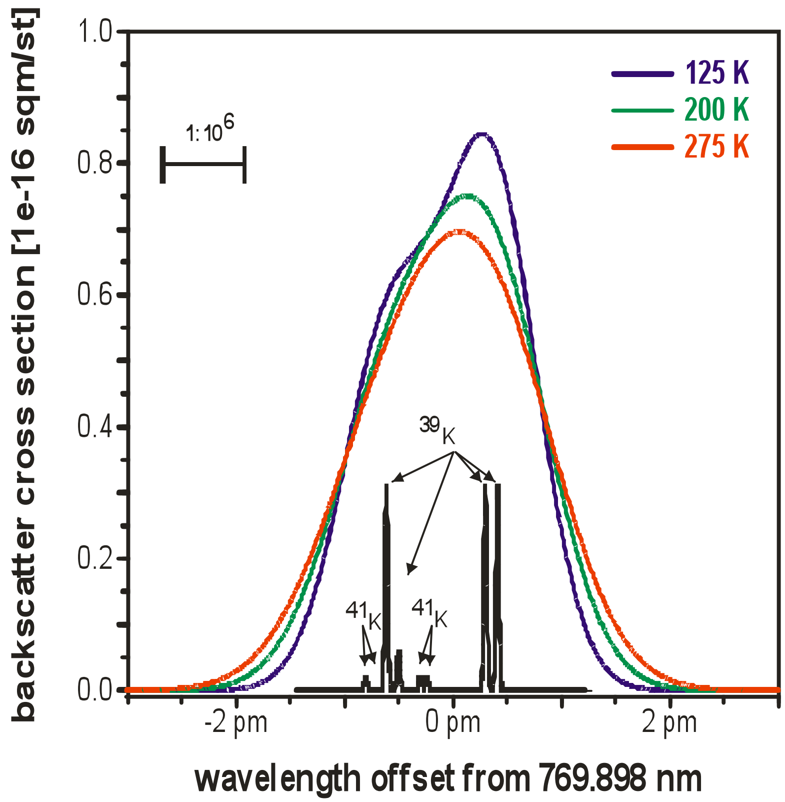



**Hyperfinestructure and Doppler broadening of a K resonance line**

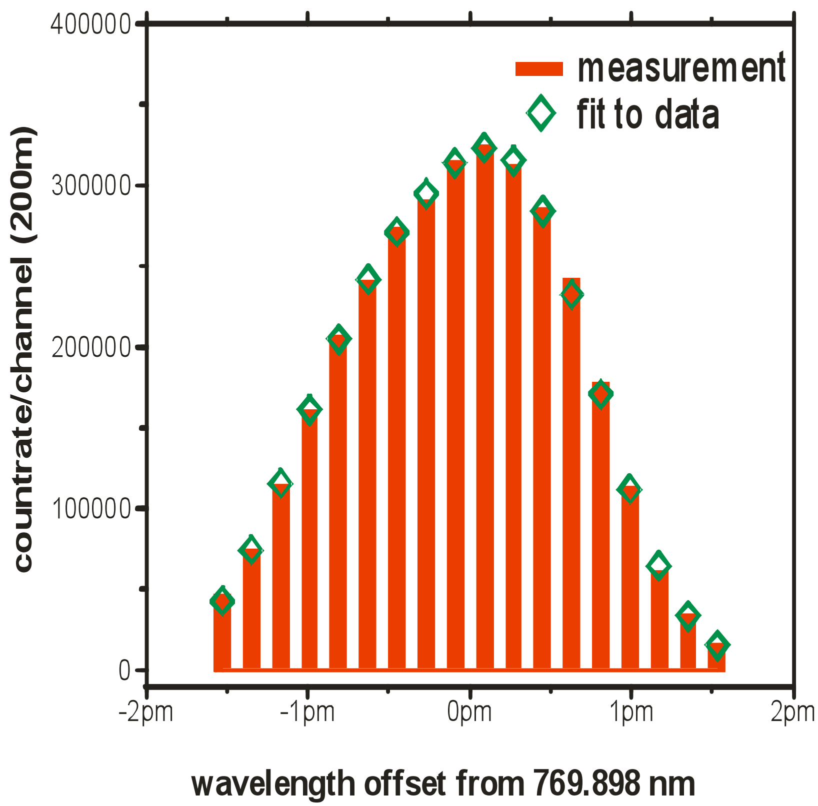


# 80-105 km: K resonance lidar

## Hyperfinestructure and Doppler broadening of a K resonance line




## Measured and fitted shape of the resonance line



# 2-frequency temperature retrieval

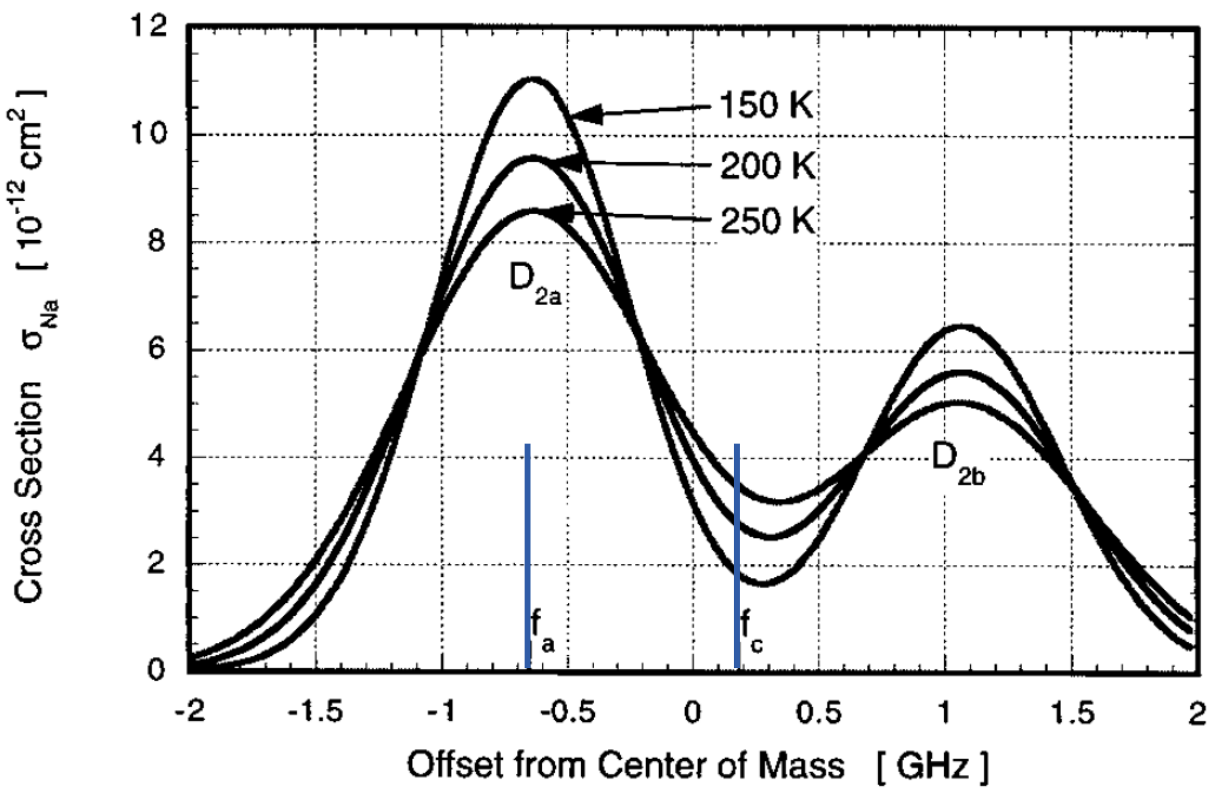



Fig. 1. Resonance fluorescence
$D_2$ transition as a function of fr
A temperature increase causes t
The Na $D_2$ center wavelength is

- ☺ smaller statistical uncertainty than scan method
- ☹ larger (unknown) systematic error if laser is not perfect (broadband, sidemodes)

Papen and Treyer, Appl. Opt., 1998

# Fe-Boltzmann temperature retrieval

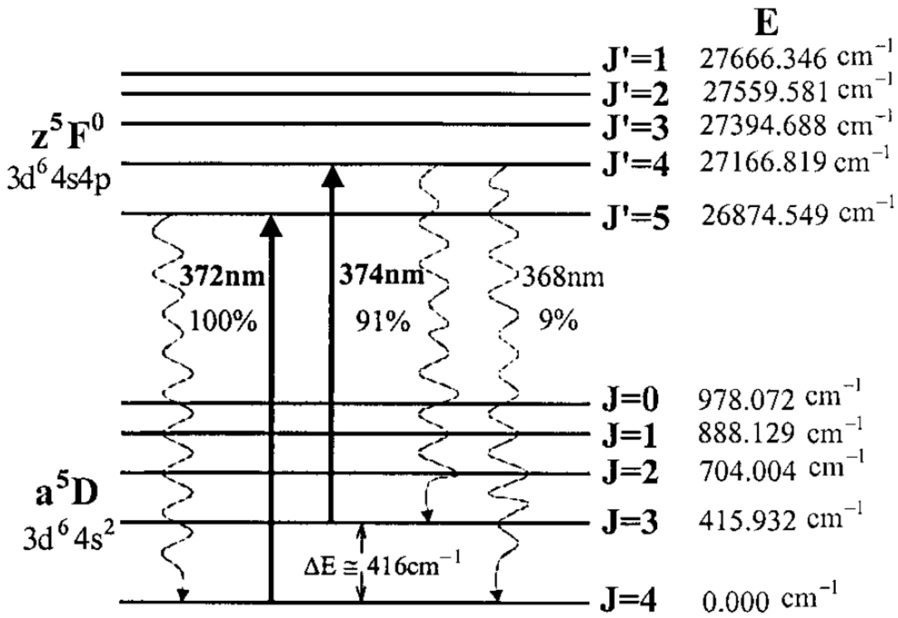
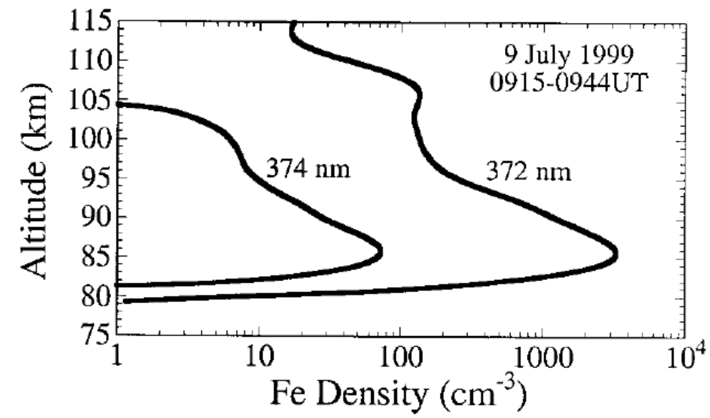
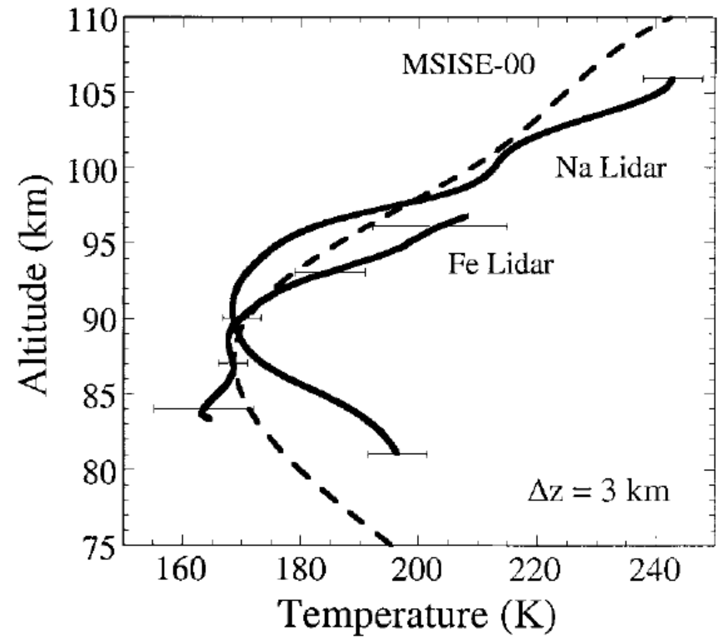



Fig. 1. Energy-level diagram of atomic Fe used for the Boltzmann technique.



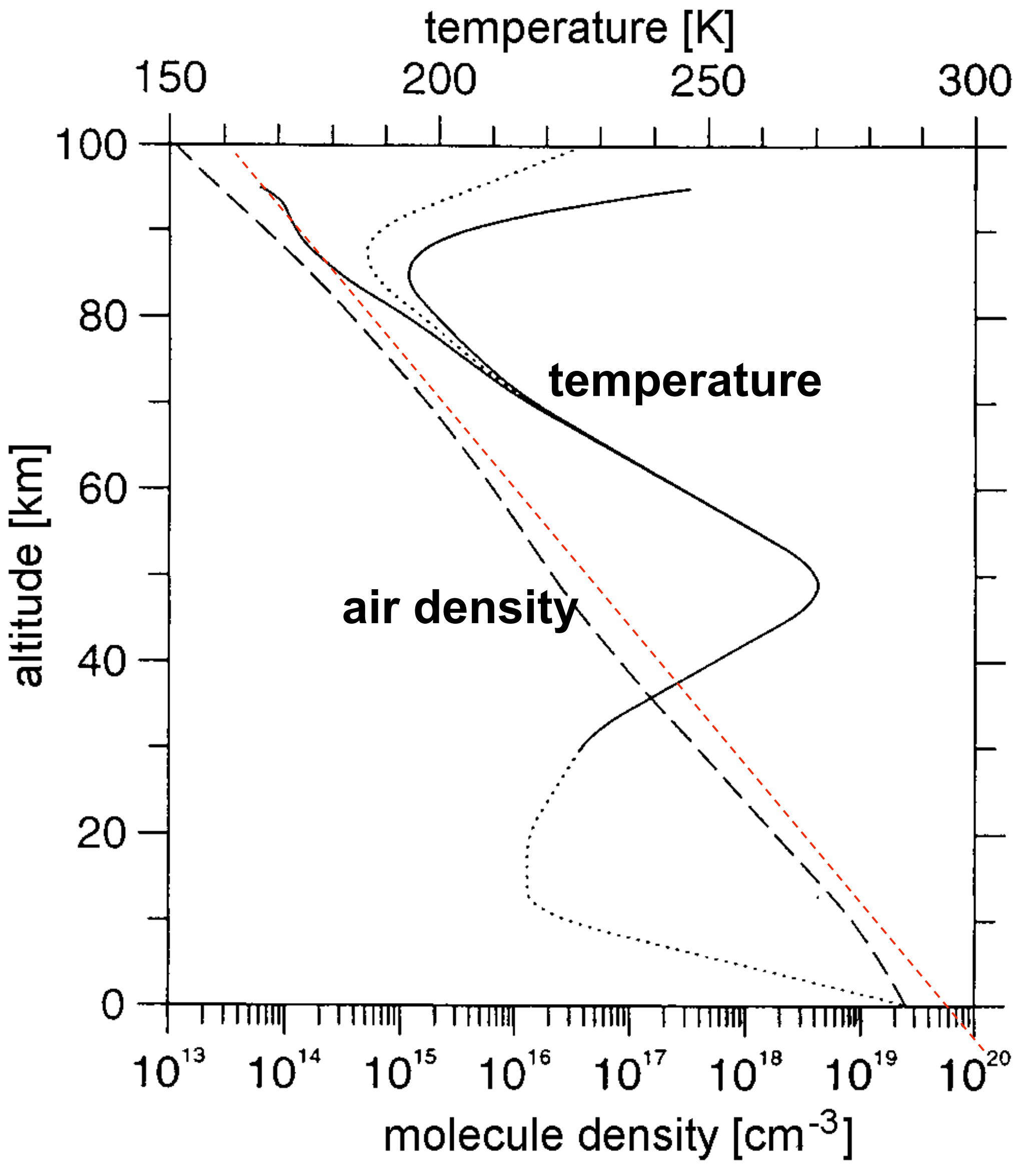

- ☺ requires only broadband laser
- ☹ statistical uncertainty larger at low temperatures (polar summer mesopause)

Chu et al., Appl. Opt., 2002

# Overview

- Modern Science with Lidars
- Lidar Basics
- Data Reduction Methods
  - Temperatures in the Metal Layer
  - Temperatures from Density Soundings
- Tradeoffs ("Is there an optimal RMR lidar?")
- Summary and Outlook

# Temperature profile from air density profile



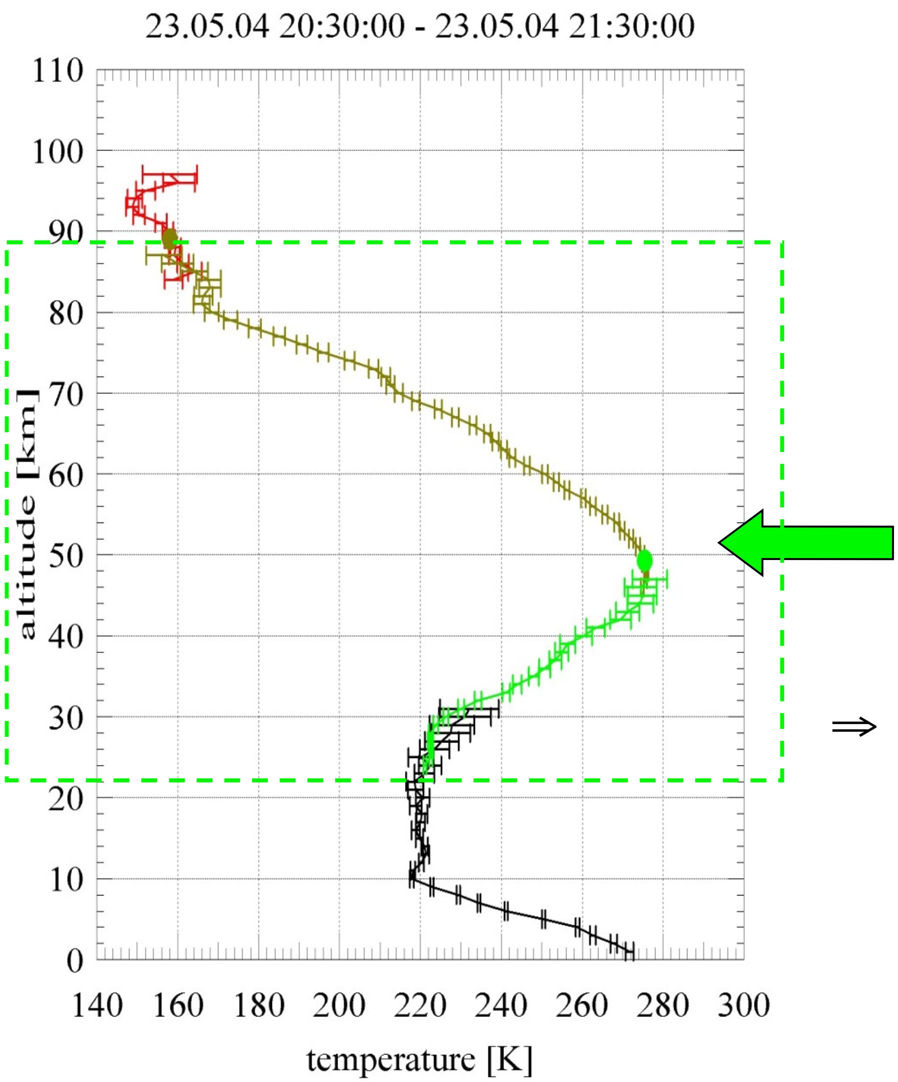

hydrostatic equation

$$\frac{dp}{dz} = -g(z) \cdot \rho$$

ideal gas law

$$p \cdot V = n \cdot k \cdot T$$

# 22-90 km: Rayleigh lidar




hydrostatic equation

$$\frac{dp}{dz} = -g(z)\cdot\rho$$

ideal gas law

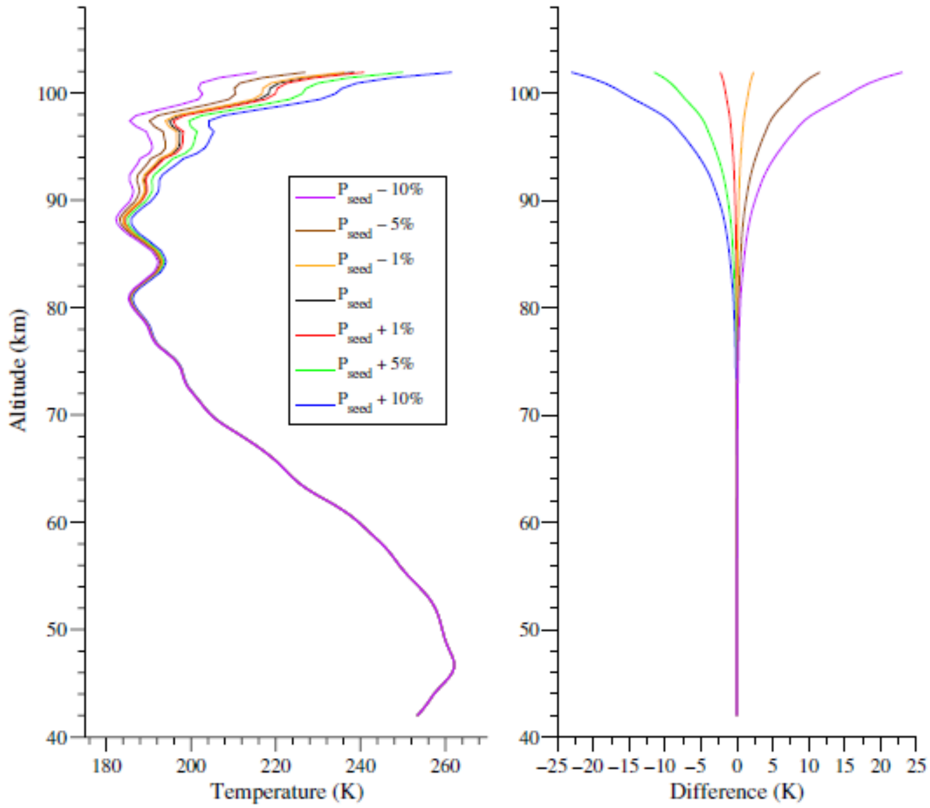
$$p\cdot V = n\cdot k\cdot T$$

$$\Rightarrow \quad T(z) = \frac{n(z_{top})}{n(z)}\cdot T(z_{top}) - \frac{m}{k}\int_{z_{top}}^{z} g(z')\frac{n(z')}{n(z)}\,dz'$$

**relative density profile required - derived from (aerosol free) lidar backscatter signal**

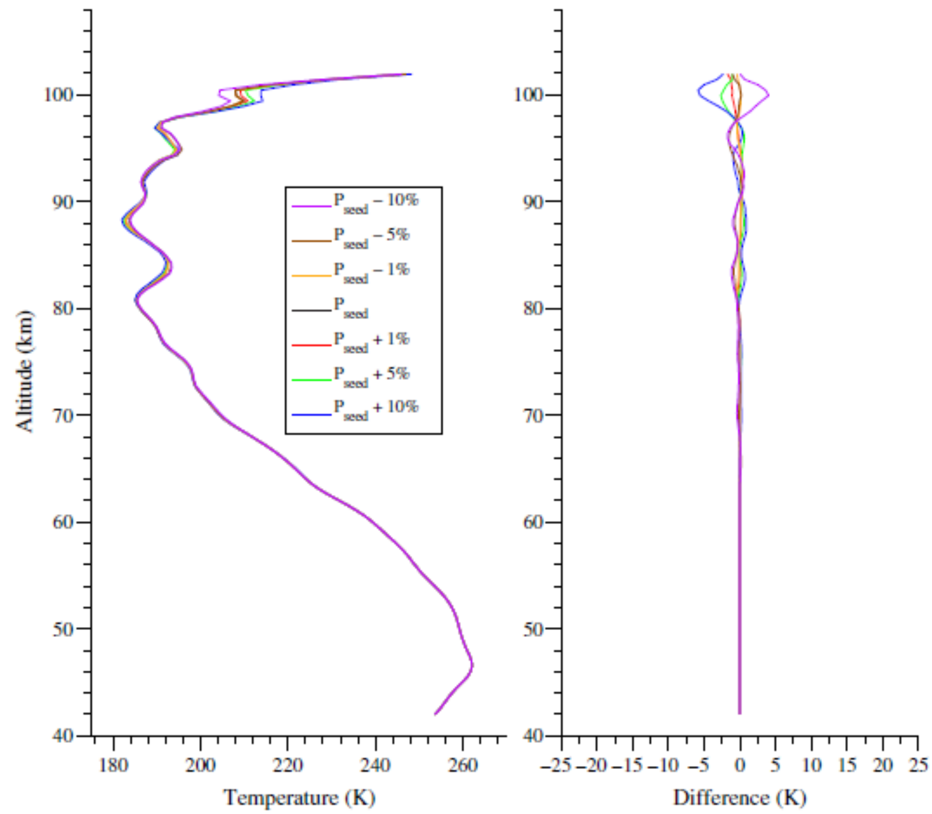
# Bottom-top Temperature Inversion

Top-down (Hauchecorne & Chanin, 1980)




Typically: Start-value from MSIS/CIRA/…

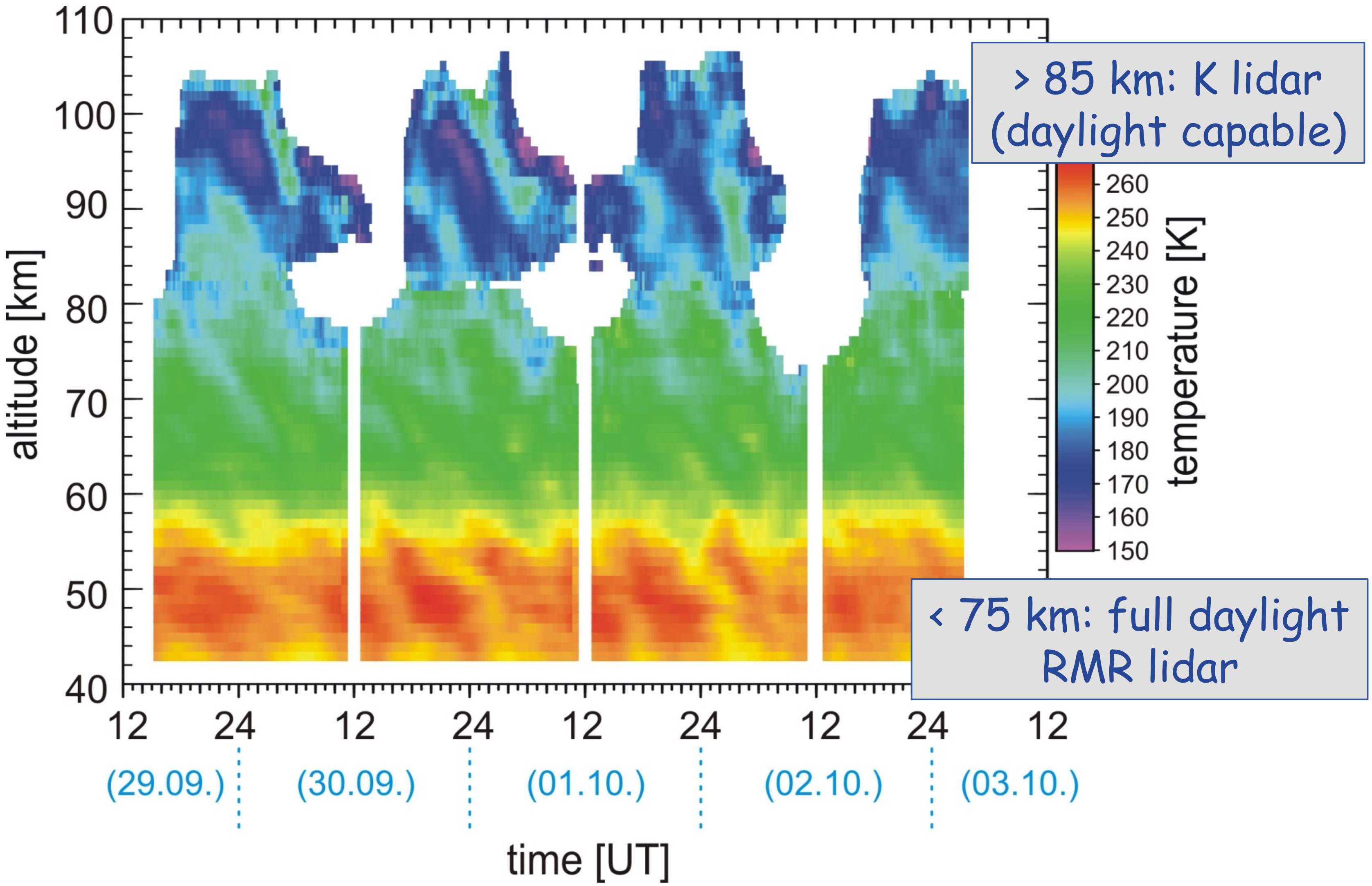
Bottom-top (optimal estimation)



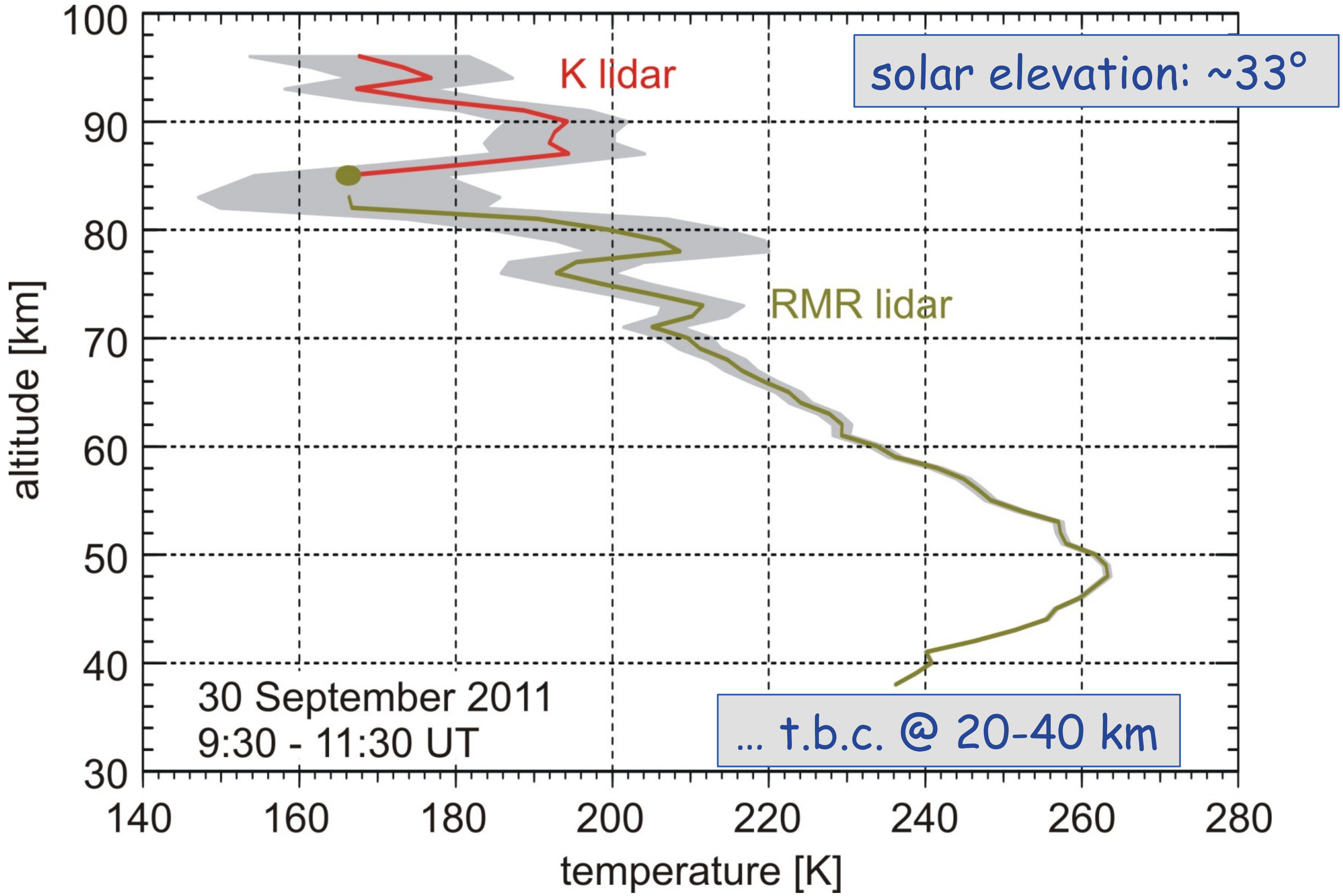

New: Start-value from (measured) stratospheric density

Khanna et al., Appl. Opt., 2012

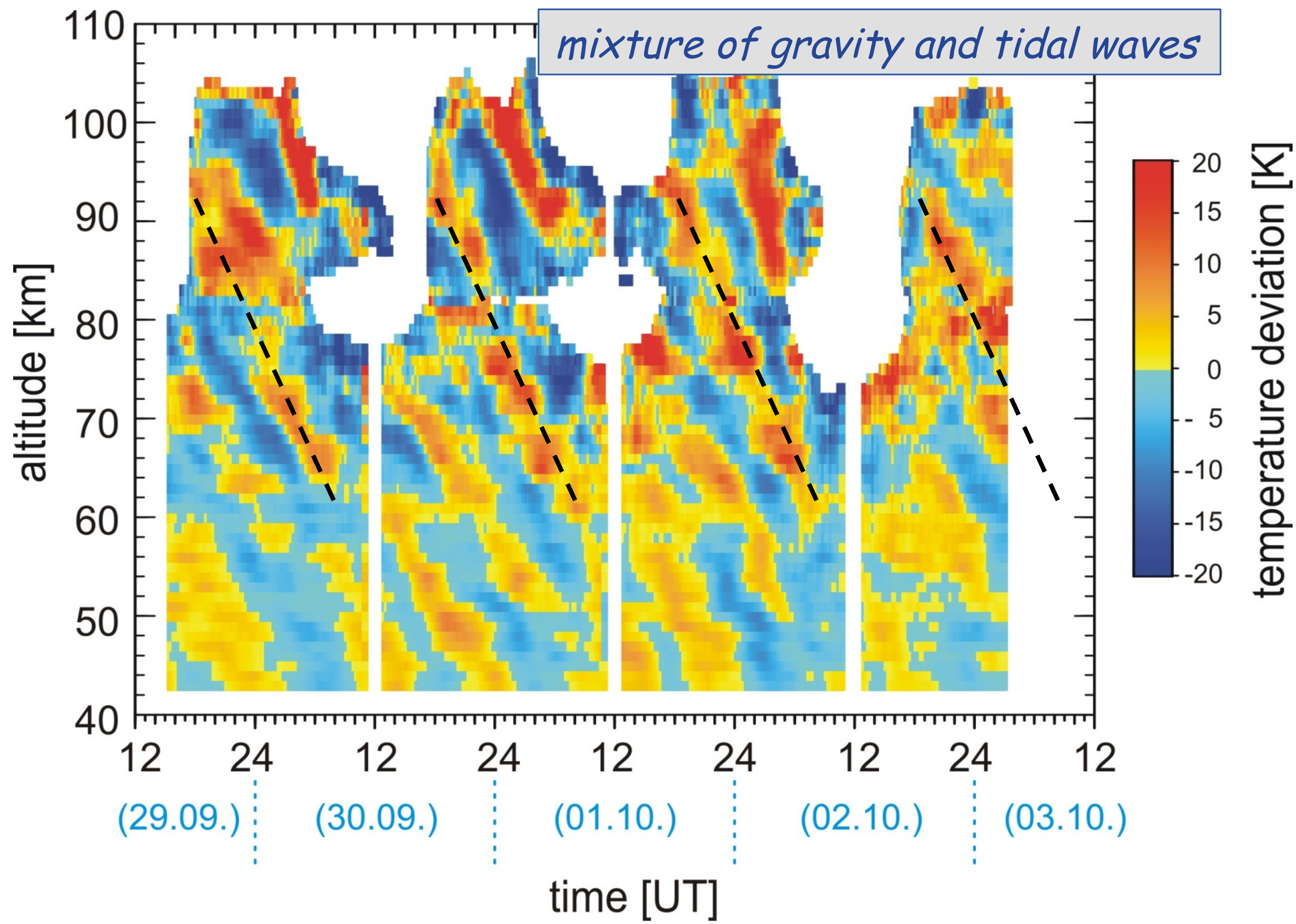
# Lidar sounding 29 Sept. – 3 Oct. 2011



# Temperature observations at high solar elevation



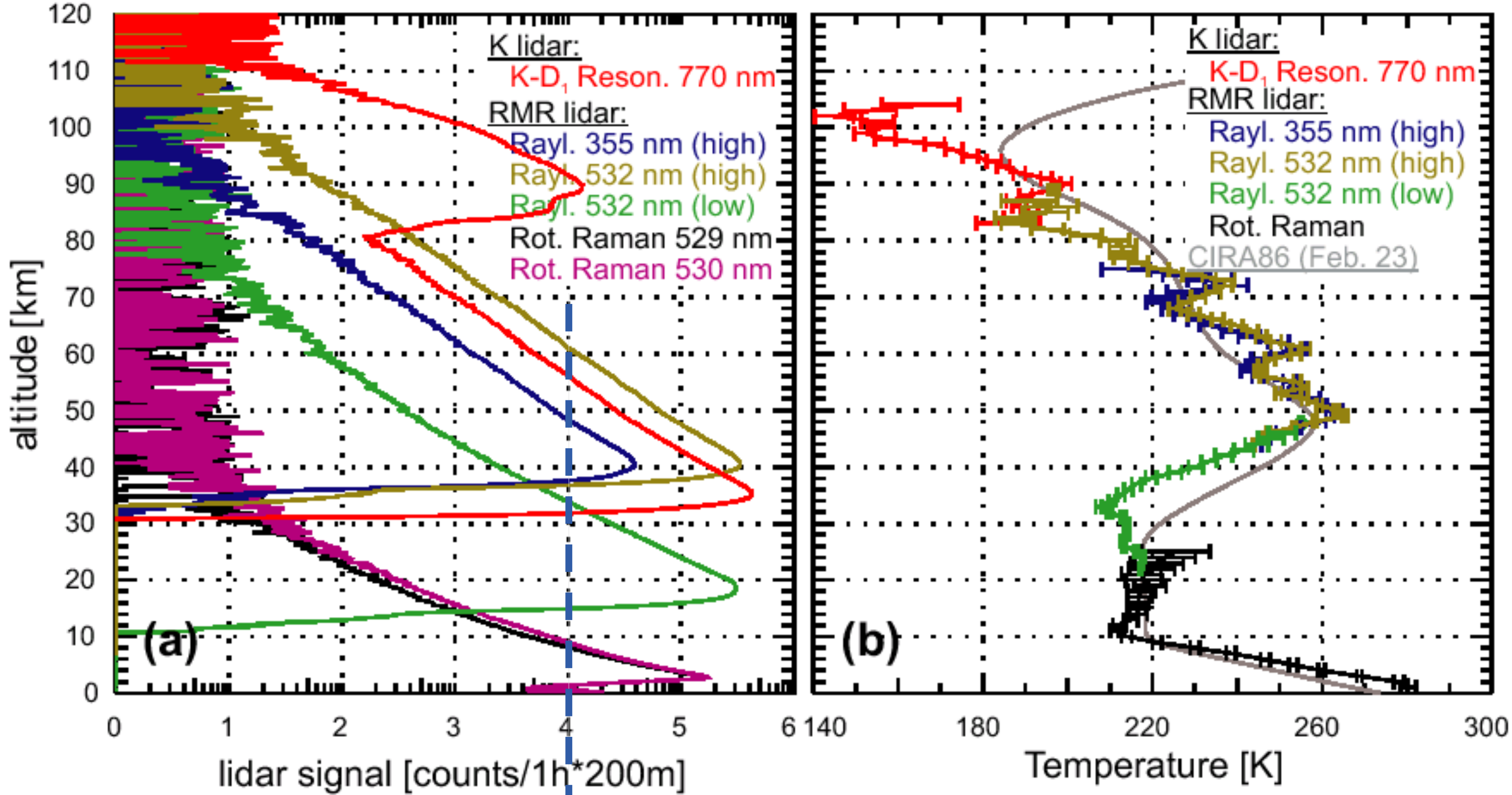
# Lidar sounding 29 Sept. – 3 Oct. 2011



# Overview

- Modern Science with Lidars
- Lidar Basics
- Data Reduction Methods
  - Temperatures in the Metal Layer
  - Temperatures from Density Soundings
- Tradeoffs ("Is there an optimal RMR lidar?")
- Summary and Outlook

# Temperature profiles by combined lidars




$10^{18}$ emitted photons/pulse
→ 0.1 received photons/bin

Alpers et al., ACP, 2004

# Is there an optimal RMR lidar??

## Increasing SNR by increasing Power*Aperture??

- Increasing Power?
  - Typical laser: 30-50 pps & max. 800 mJ/pulse @ 532 nm ➔ 25-40 W

flashlamp-pumped: ☹
diode-pumped: $$$$

beam-guiding: ☹

- Increasing Aperture?
  - fused silica mirror Ø 80 cm: ~70 k$, Ø 180 cm: ~700 k$ ☹

$A_{80}:A_{180}$ ~1:5

*f/4 telescope, 500 µrad FOV*

1.6 mm field stop
PMT ☺
APD 😐

3.6 mm field stop
PMT ☺
APD ☹

QE PMT:APD ~1:3

➔ $I_{80}:I_{180}$ ~1:1.7

# Is there an optimal RMR lidar?? - II

## Influence of FOV on lidar efficiency

- 80 cm telescope, FOV 500 μrad → 1.6 mm aperture
  - → Easy focussing on PMT; complicate with APD (Ø 0.18 mm)
  - → Daytime soundings:
    - → large skylight background ☹
    - → Etalons/filters large (expensive) or less efficient ☹

- 80 cm telescope, FOV 60 μrad → 0.2 mm aperture
  - → More complicate adjustment of telescope ☹
  - → Beam stabilization required ☹
  - → Easier focussing on APDs ☺
  - → Daytime soundings:
    - → Small skylight background (~1/70) ☺
    - → Etalons/filters highly efficient (>90%) ☺

# If money is no problem and sky is dark …

- PA product of IAP RMR: 20 W * 0.5 $m^2$ = *10 W $m^2$*
  ALOMAR RMR: *40 W $m^2$*

→ *Temperature up to ~90 km*

- Power:
  - 1000 pps theoretical limit for monostatic system (150 km range)
  - ~200 pps todays technical limit for high energy system *~150 W power*
- Aperture:
  - 2.5 m telescope *~7 $m^2$ aperture*
  - You know an astronomer and have 100,000$ per night?
    10 m telescope *~80 $m^2$ aperture*

→ *Temperatures up to ~120 km (~135 km)*

other methods? cf. Westerhoff & Svenson, JASTP, 2013

# Summary and Outlook

- Lidars are powerful tools for measuring temperatures (and winds) and their variation in the MLT
- Combination of instruments (techniques) extends the altitude range (and the knowledge gain)
- Resonance lidar T ~80-105 km:
  Boltzmann vs. 2λ vs. scan → Pros and Cons
- Rayleigh lidar T <90 km (<120 km):
  top-down with limits at top, bottom-top still rare
- Increasing SNR: more power → ☺, larger aperture with drawbacks during the day (and night)

- What else: wind! metal densities, $NO^+$, He, OH, PMC, meteoric dust, …