# Potassium lineshape study with collisional partners of nitrogen, helium, and hydrogen

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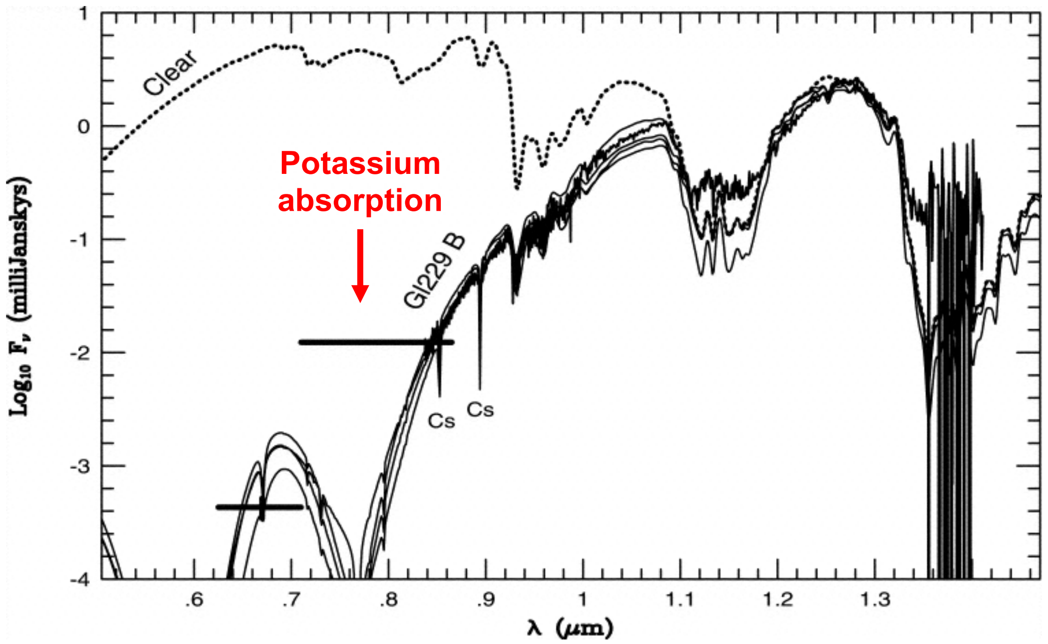
Abstract #6290
International Symposium on Molecular Spectroscopy
June 20-24, 2022

# Background

- Alkali metal absorption coefficients key for interpreting brown dwarf spectra
- No experimental data and widely varying model predictions above 500 K




*Log of absolute flux ($F_\nu$) vs. wavelength (λ) for Gliese 229B* [1]

## Motivations

- Extend previously developed alkali seeding methods to new collisional partners [2]
- High temperature lineshape data needed for modeling brown-dwarf spectra
- Opportunity to use nascent K as tracer in hypersonic test facilities

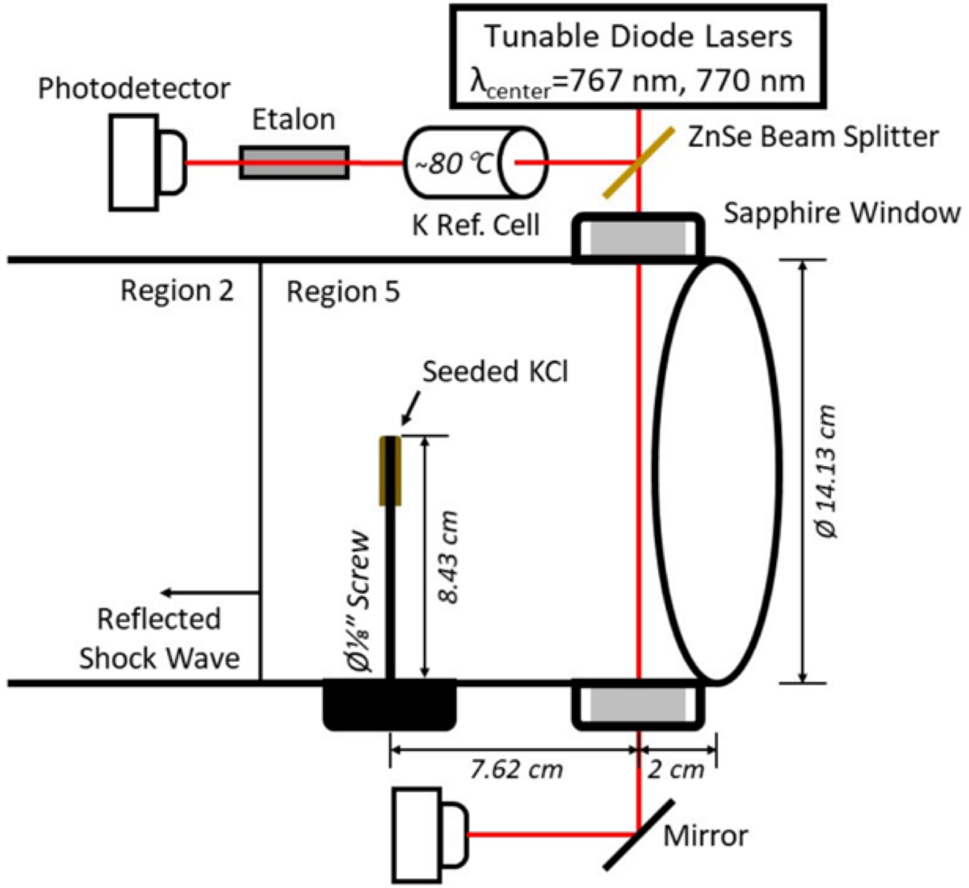
# Methodology: Potassium seeding in shock tube

- Shock tube is an impulse facility
  - Near instantaneous change in T and P
  - Accessible pressures: 0.01 – 1000+ atm
  - Accessible temperatures: 500 – 10000+ K
  - ~1% accuracy in T and P
  - ~2 – 3 ms test time


*Shock tube operation animation*

# Methodology: Potassium seeding in shock tube

- Potassium seeded using KCl saltwater solutions[2]
- Introduced via threaded rod
- Two DFB ICL diode lasers target potassium D lines
  - $D_1$ (770 nm, $4^2S_{1/2} \rightarrow 4^2P_{1/2}$)
  - $D_2$ (767 nm, $4^2S_{1/2} \rightarrow 4^2P_{3/2}$)
- Lasers scanned at 25 kHz




*Schematic for seeding and measuring K lineshapes in a shock tube*

# Methodology: Laser absorption spectroscopy

- Beer-Lambert Law

$$\alpha(\nu) = -\ln\left(\frac{I_T}{I_0}\right) = S(T)\cdot P\cdot\chi\cdot\phi(\nu)\cdot L$$

- Lineshapes modeled as **Voigt** profiles

$$\phi(\nu) = \int_{-\infty}^{\infty} \phi_D(u) * \phi_C(\nu - u)\, du$$

- Doppler broadening FWHM [cm$^{-1}$] [3]

$$\Delta\nu_D = 7.17\times10^{-7}\cdot\nu_0\cdot\sqrt{T/M}$$

- Collisional broadening FWHM and pressure shift [cm$^{-1}$]

$$\Delta\nu_C = P\cdot\sum_i \chi_i\cdot 2\gamma_i(T)$$

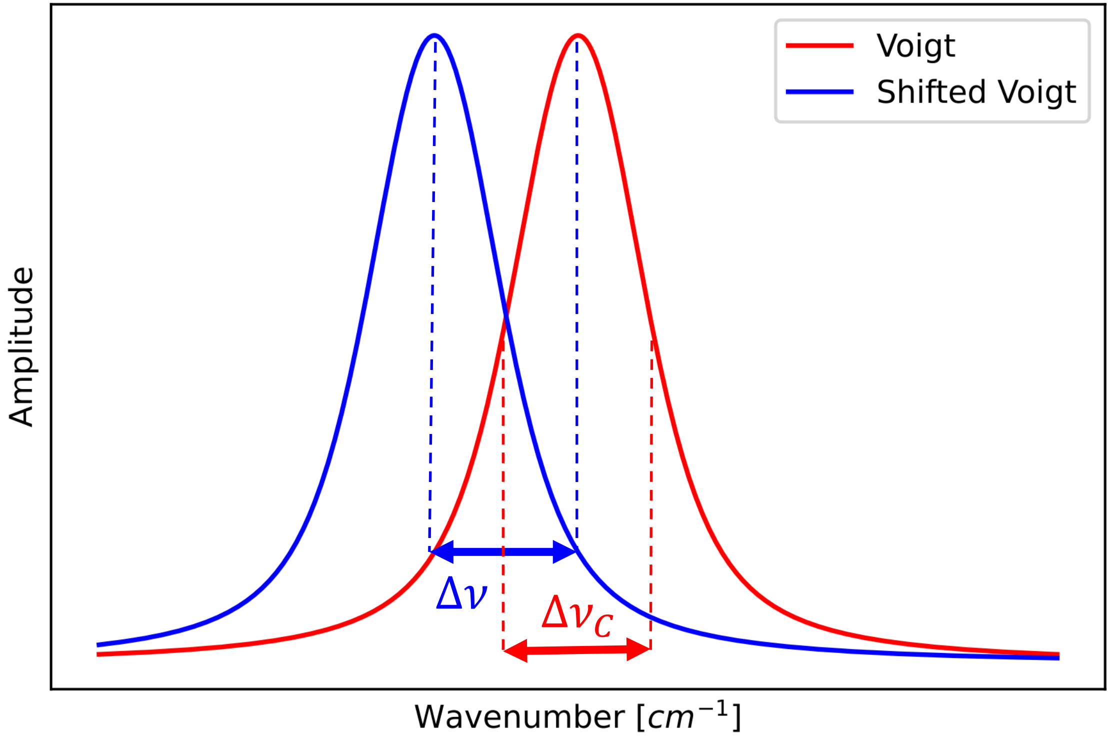
$$\Delta\nu = P\cdot\sum_i \chi_i\cdot\delta_i(T)$$

- Collisional broadening and shift coefficients are empirical correlations [cm$^{-1}$/atm]

$$2\gamma_i = 2\gamma_i(T_{ref})\left(\frac{T_{ref}}{T}\right)^n$$

$$\delta_i = \delta_i(T_{ref})\left(\frac{T_{ref}}{T}\right)^m$$

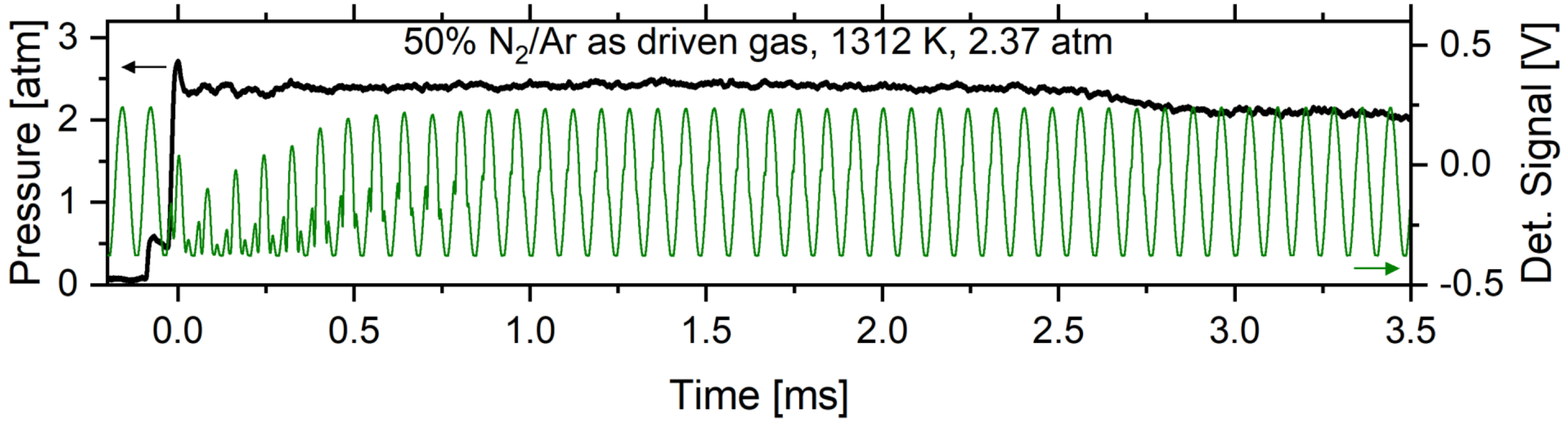
**This work**




*Visualization of lineshape parameters*

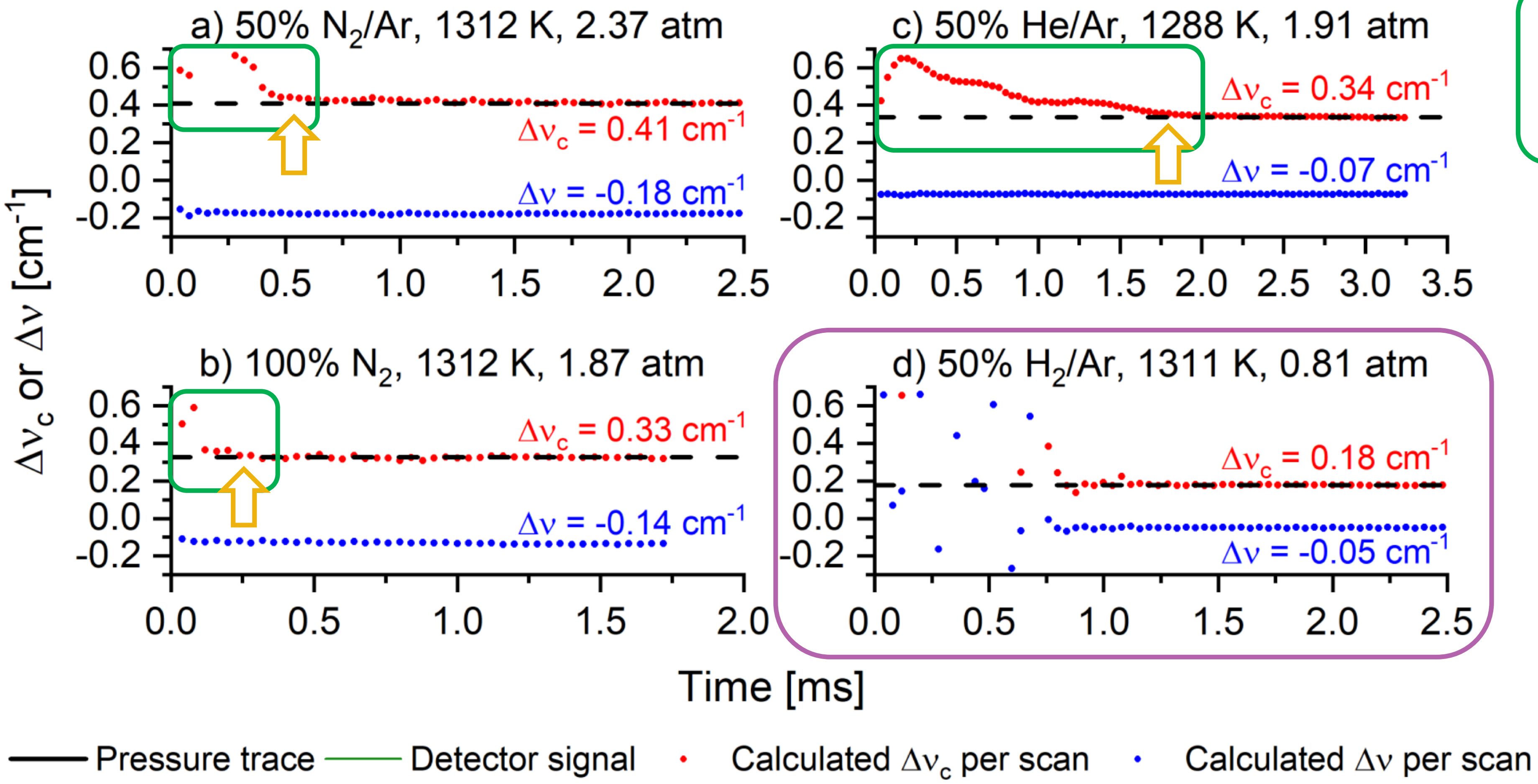
# Results: Transmitted intensity time-history

- K formation immediately behind shock wave [4]
- Varying K concentration with time
- Consistent results despite transient concentrations




*Laser scan signal and pressure trace during shock tube experiment*

# Results: Broadening and shift parameter time-histories




*Pressure broadening and shift parameter time-histories for $N_2$, $N_2$/Ar, He/Ar, and $H_2$/Ar collisional partners*

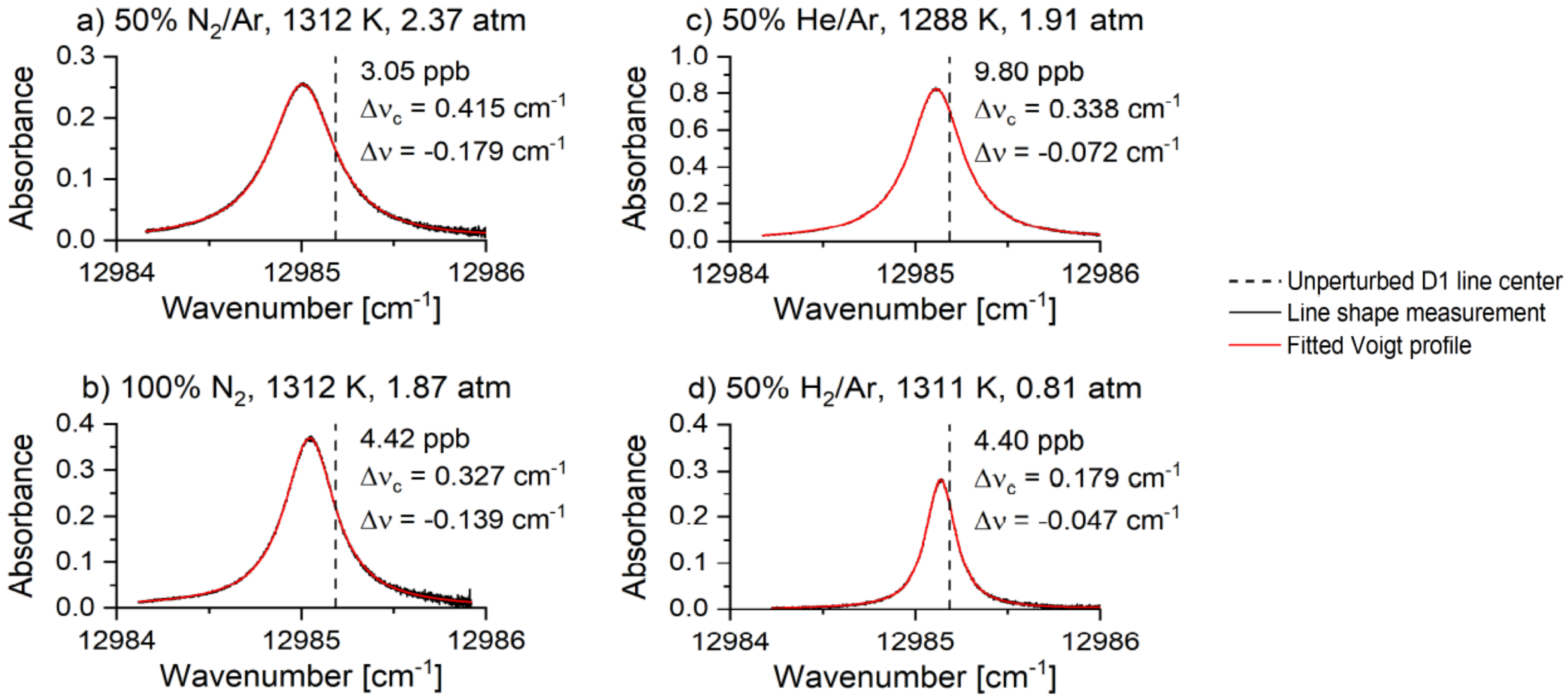
Broadening "relaxation"
*Hypothesized local Stark broadening*

Convergence time:
$N_2$ < Ar < He

Special case $H_2$: a strong reducing environment → no seeding required

# Results: Lineshapes as Voigt profiles

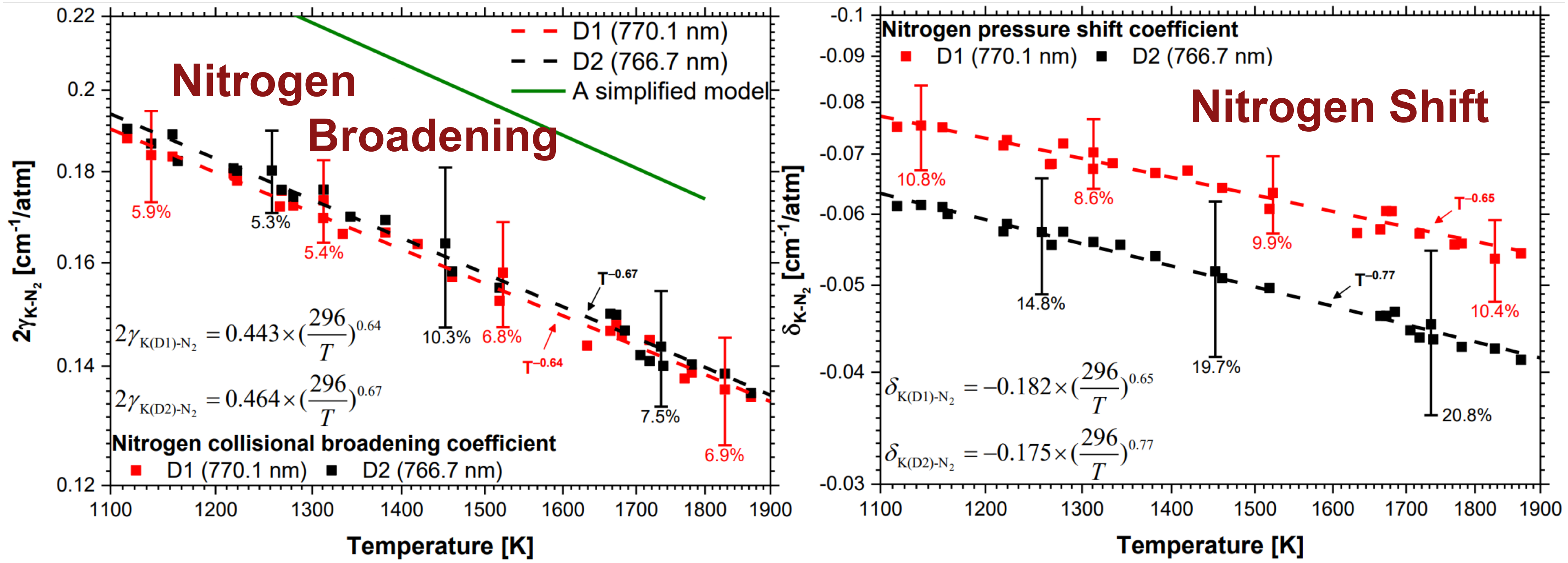
- Lineshapes are modeled well with Voigt profiles
- Residuals within 2% near peaks and 4% on large wavenumber side




*Absorption lineshapes for K D1 transition with $N_2$, $N_2$/Ar, He/Ar, and $H_2$/Ar collisional partners*

# Results: K+$N_2$ broadening/shift coefficients

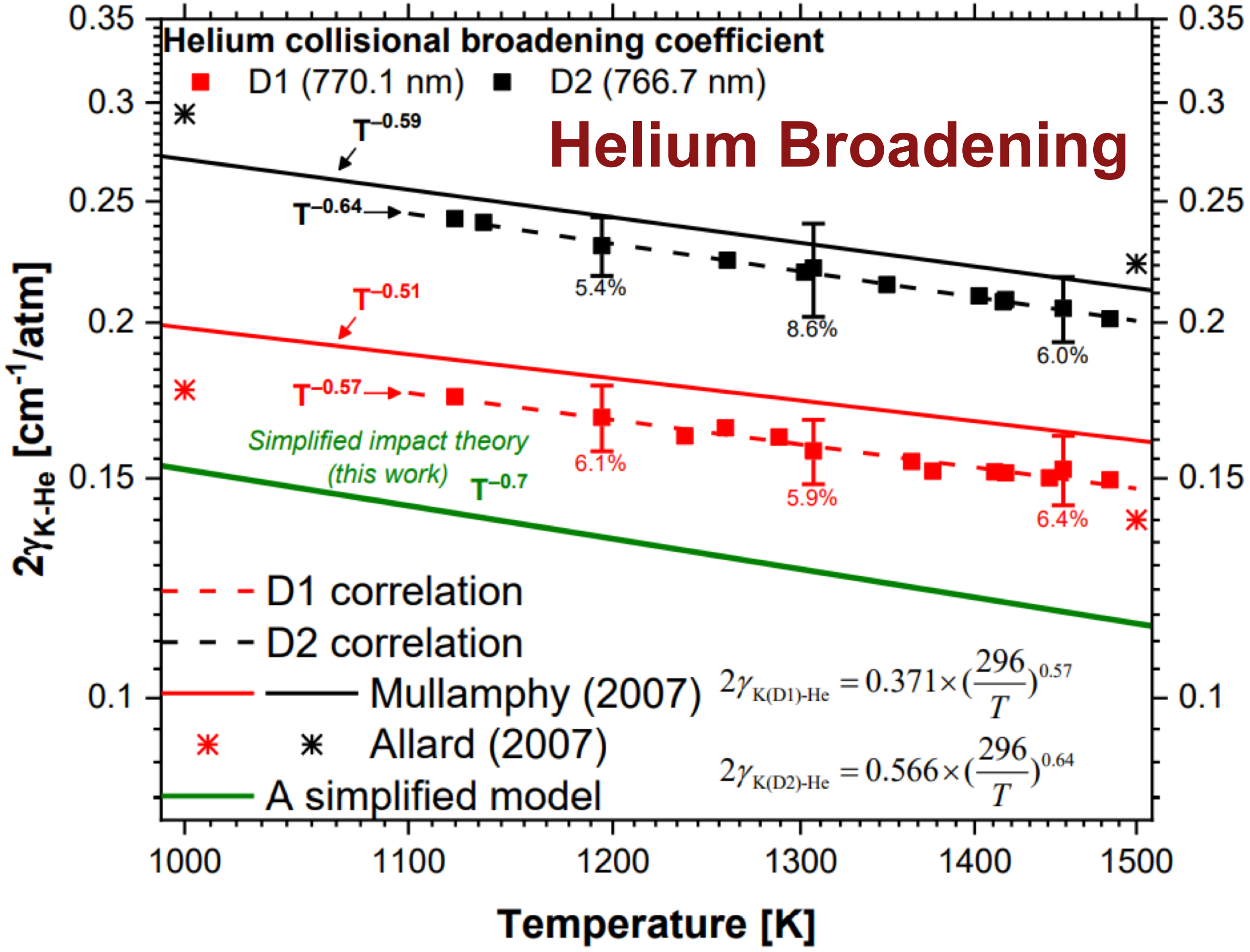
- Experimental data from 1100-1900 K
- Good overlap with results from pure $N_2$ and $N_2$/Ar blends
- Effect of spin-orbit-coupling weak on $2\gamma_{N_2}$, but strong for $\delta_{N_2}$
- Simple model overpredicts by >20%




*Temperature-dependent nitrogen broadening and shift results*

# Results: K+He broadening coefficients

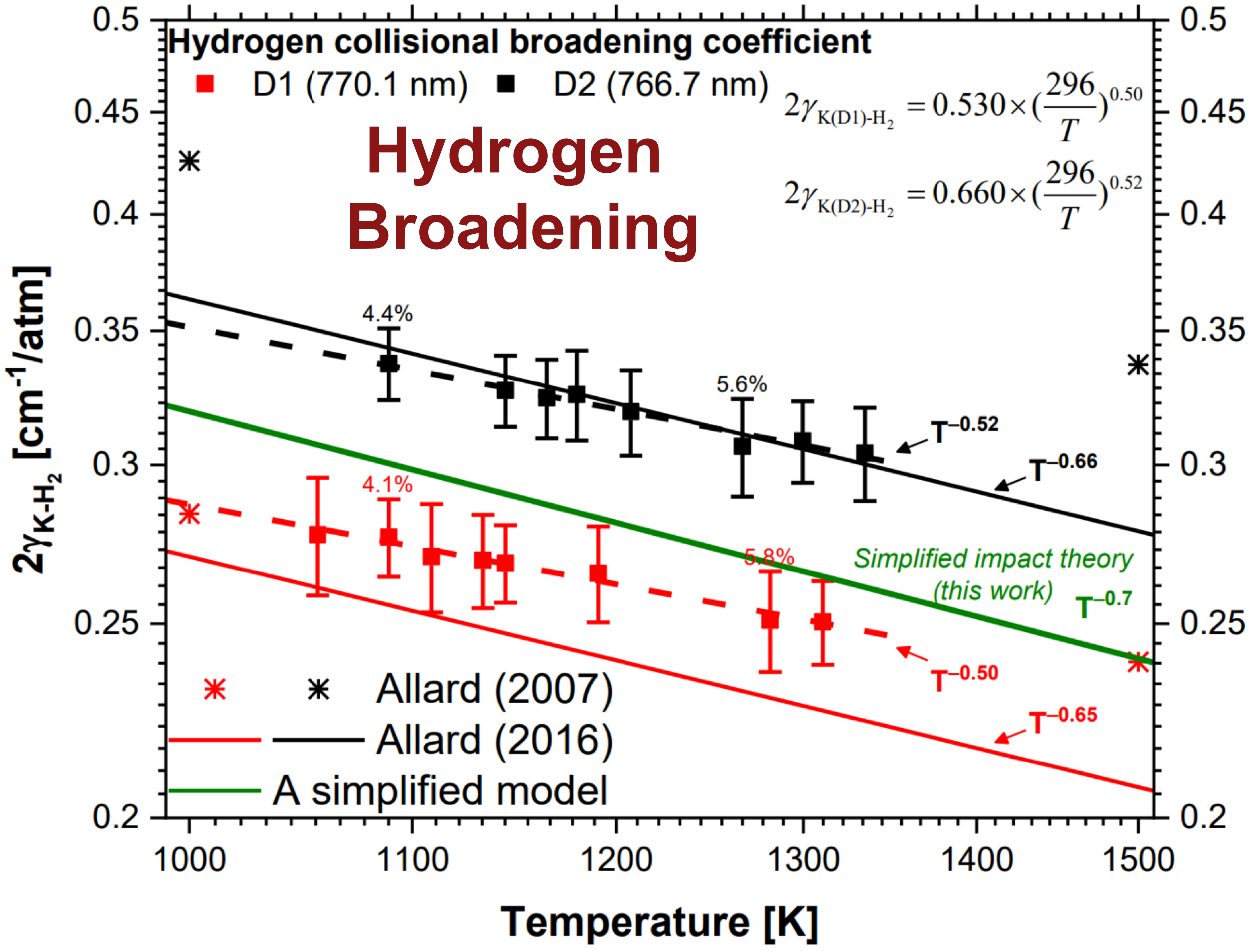
- Experimental data from 1100-1500 K
- General agreement with existing theoretical models [5,6]
- Pressure shift coefficients small and positive
  - D1: +0.005 to +0.014 $cm^{-1}$/atm
  - D2: +0.002 to +0.008 $cm^{-1}$/atm
  - Large uncertainties (>40%) due to Argon dilution




*Temperature-dependent helium results*

# Results: K+$H_2$ broadening coefficients

- Experimental data from 1050-1350 K
- Agreement with some existing theoretical models [5,7]
- Simplified model between D1 and D2 data
- Pressure shift coefficients small and negative
  - D1: -0.045 to -0.035 $cm^{-1}$/atm
  - D2: -0.040 to -0.030 $cm^{-1}$/atm
  - Large uncertainties due to Argon dilution




*Temperature-dependent hydrogen results*

# Conclusions

- Measured potassium lineshapes for D1 and D2 transitions at high-temperatures in a shock tube
- Absorption features modeled as Voigt profiles
- Presented power-law correlations for broadening contributions from $N_2$, He, $H_2$ and shift contributions from $N_2$
- Helium and Hydrogen broadening align with existing theoretical models

Seeding approach my be extended to other alkali metals (Na, Cs)

Presented correlations may be useful for developing potassium-based diagnostics in combustion plants, biomass combustors, and hypersonic facilities

# Acknowledgements

- NASA Exoplanets Research Program (XRP)
- Office of Naval Research
- Stanford Office of the Vice Provost for Graduate Education
- Stanford Mechanical Engineering Department

# References

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