The Stardust Sample Return Capsule reentry observing campaign

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Future work

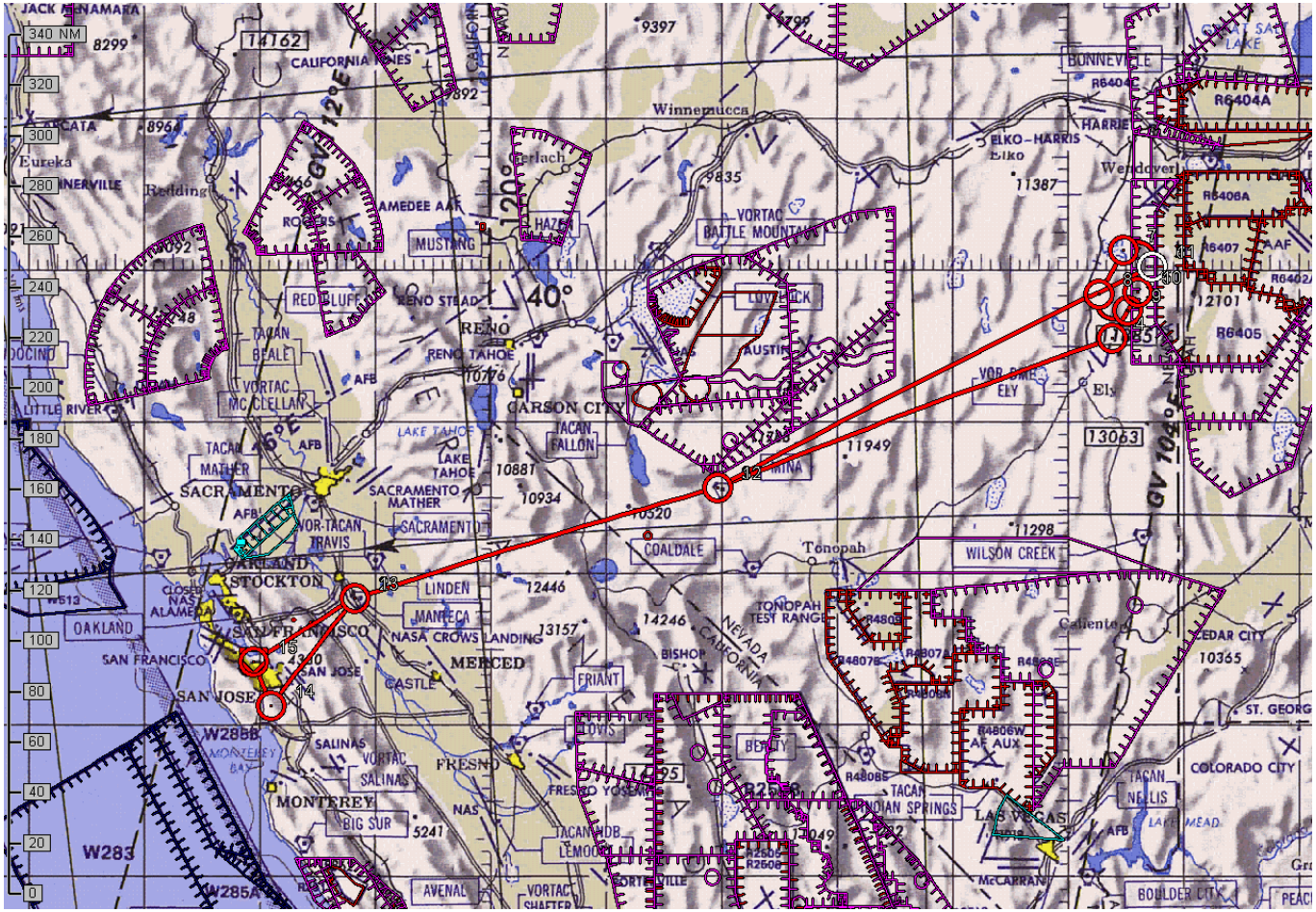
- **Workshop on Reentry Emission Signatures II**
  - SETI Institute (Mountain View, CA)
  - Thursday July 06 + Friday July 07
  - **Abstract deadline: July 03** (http://reentry.arc.nasa.gov)

Participants

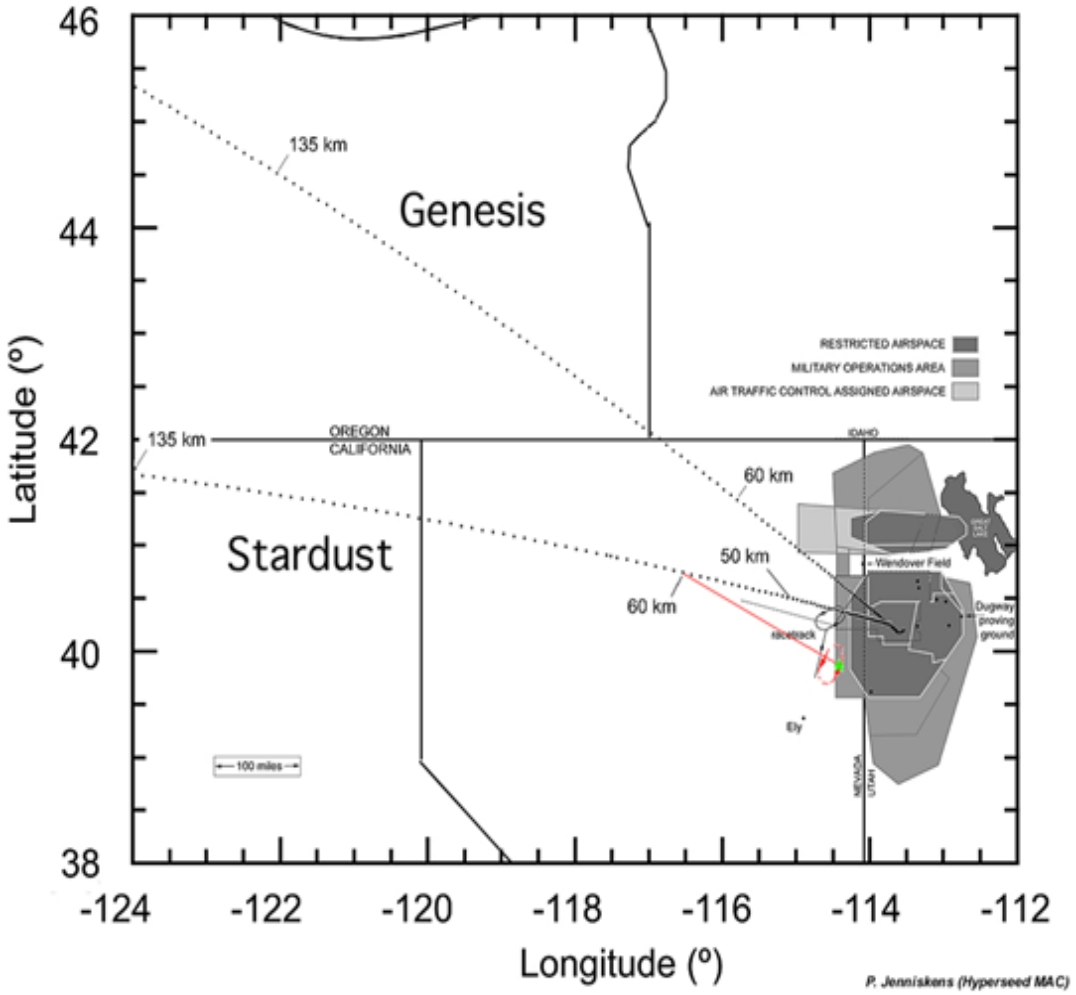
Sponsors:	EMD + NESC
Aircraft operations:	UND/NSERC, NASA Wallops
Instrument installation:	NASA Ames
Researcher participation:	SETI Institute

Flight plan

Stardust SRC Entry Observing Campaign



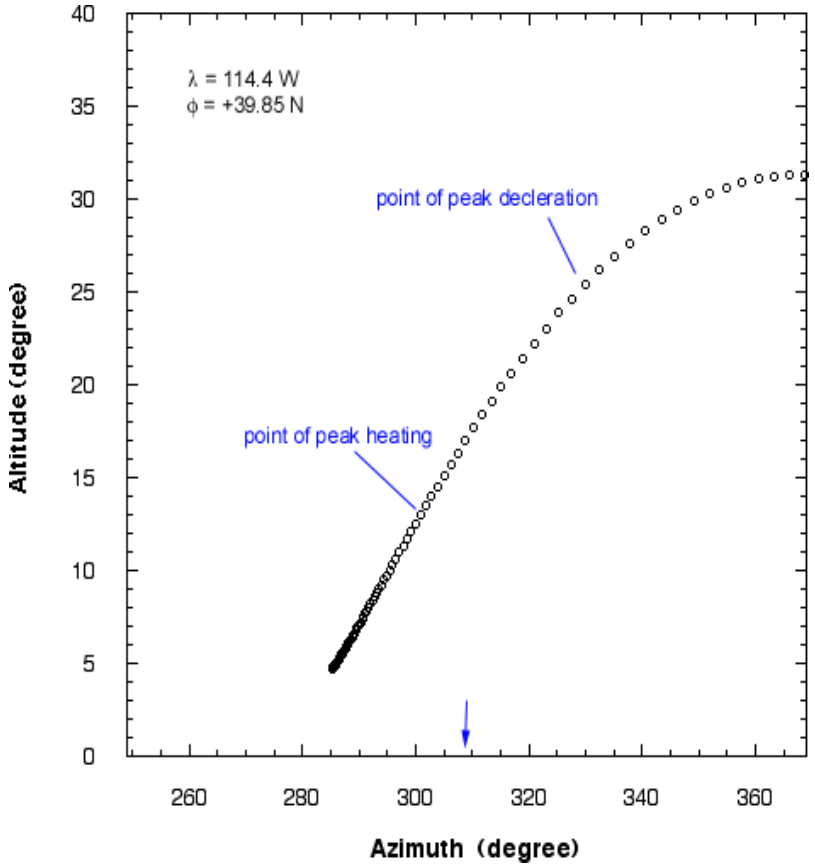
Staging area



- Date: January 15, 2006 (~ 09:56 UT)
- Utah/Nevada border
- Near end-point of trajectory
  - Frontal view
- Ground-based observations elsewhere

Viewing geometry

- Acquistion:
  - Height ~ 5º
  - Azimuth ~ 25º left from boresight
- Peak heating
  - Height ~ 13º
  - Azimuth ~ 5º left from boresight
- Possible to follow SRC beyond peak deceleration



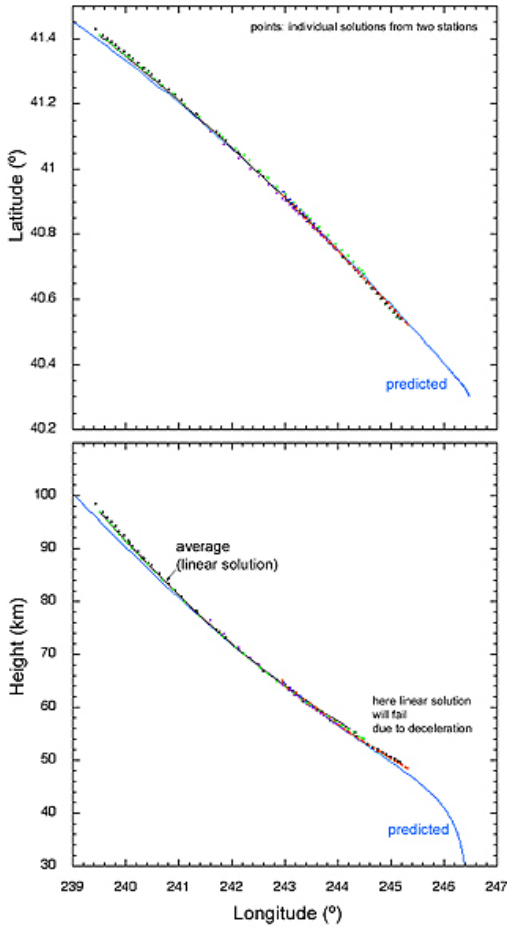
Heading aircraft NE: Az = 39º

Stardust SRC Entry video

Ground-based trajectory

Bruce Fisher, Wendover

Reconstruction trajectory



- Combine Ground-based and airborne observations
- Good agreement with predicted trajectory

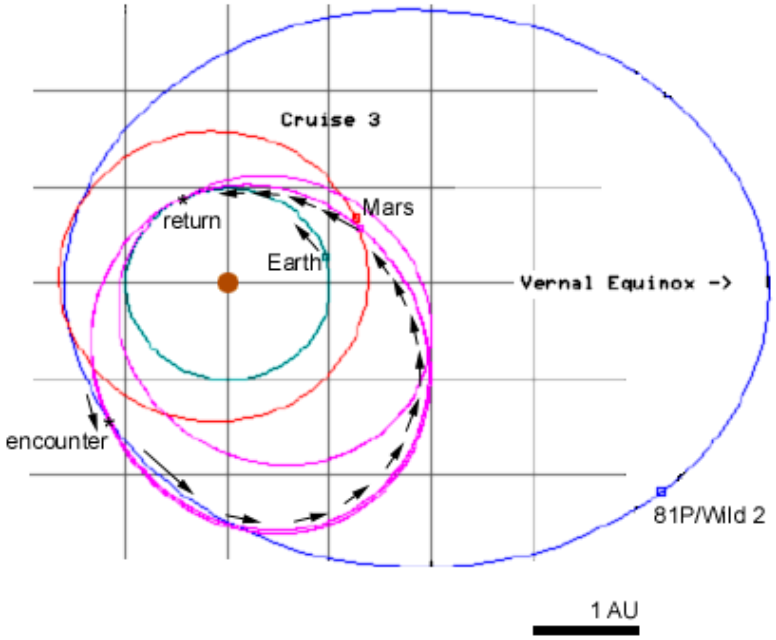
Objectives of the research

Composite of video frames (M. Taylor)

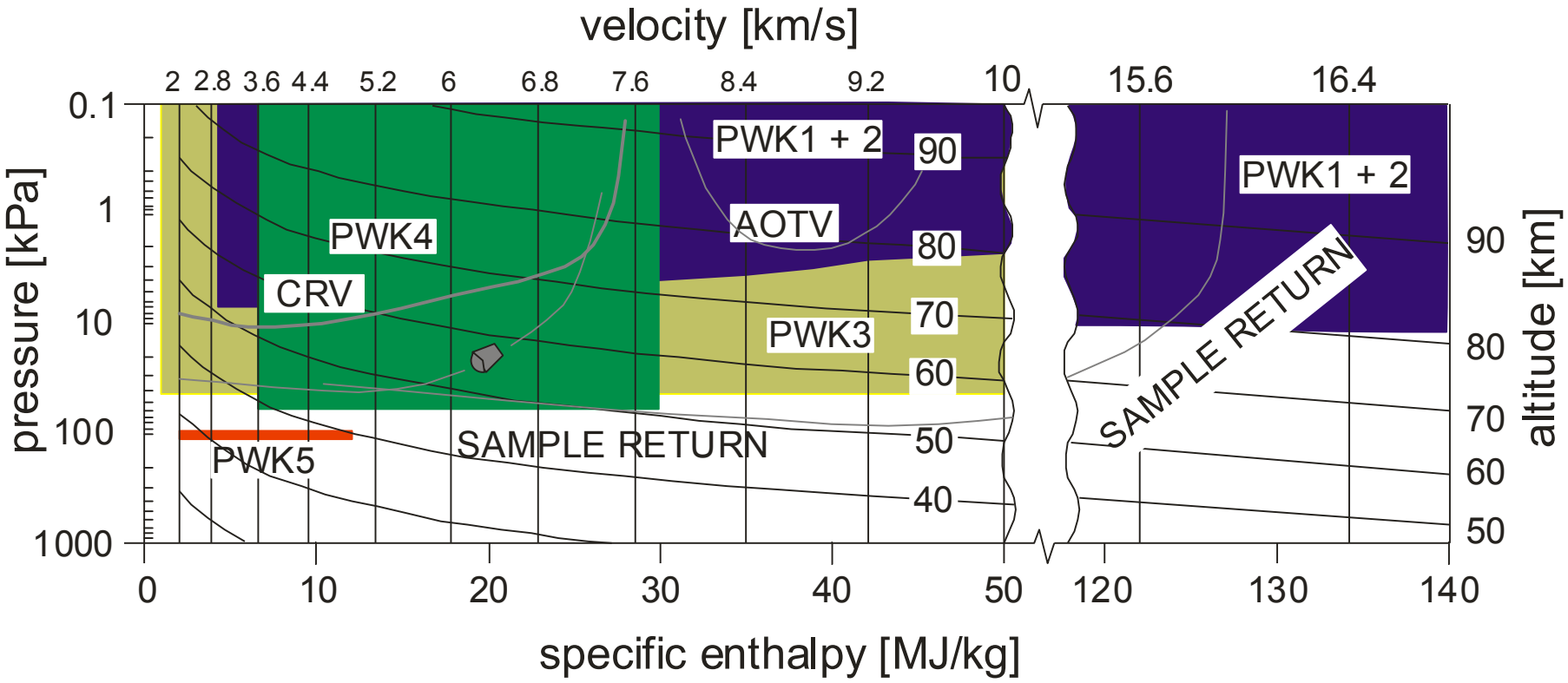
- Performance of “PICA” in fast (12.8 km/s) reentry
  - Radiative heat flow (shock emissions)
  - Rate of ablation
  - Spallation
  - Wake
- Study of a large artificial meteor
  - Excitation conditions in the shock layer
  - Chemical modification of organic compounds at the surface
  - Abundance measurements of metal atom impurities in remote sensing
- Study of physical properties of the upper atmosphere
  - Onset of heating

Fastest reentry since Apollo era (12.8 km/s)

- Probe approaches Earth from an asteroid-like orbit
  - To bring back a sample from comet 81P/Wild 2



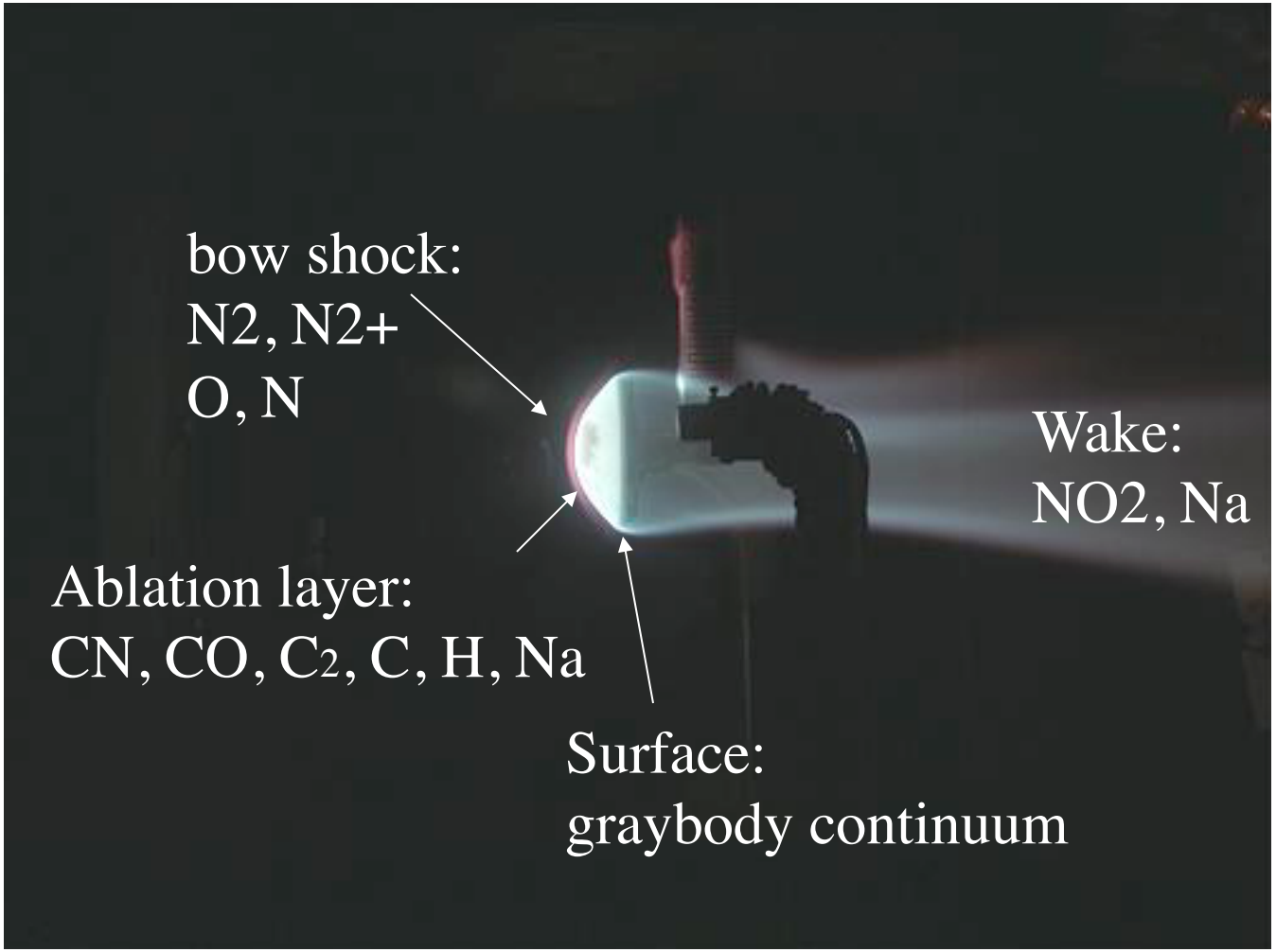
PWK Envelopes



IRS Ground Testing Facilities

- reproduction of thermal, aerodynamic and chemical load using different plasma wind tunnel facilities in order to cope with different entry mission profiles

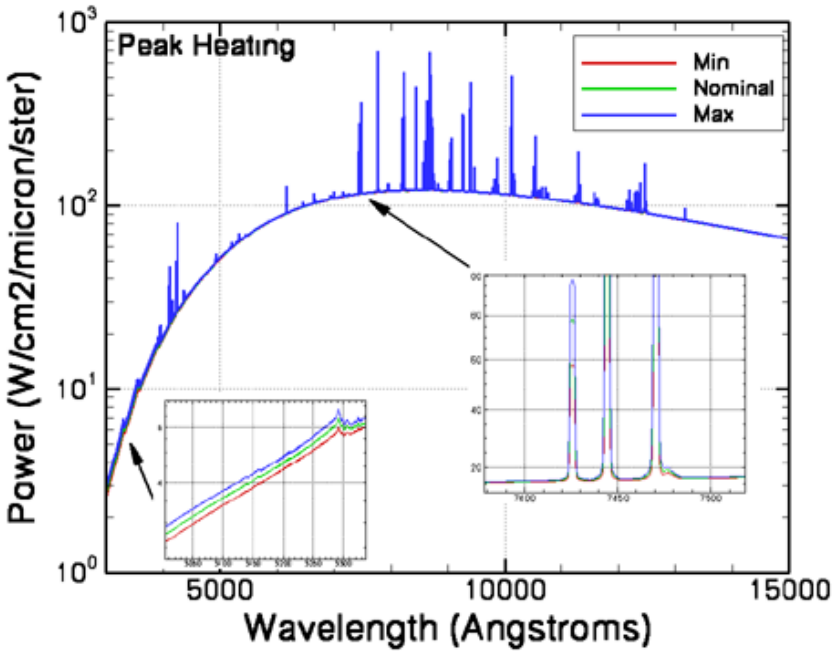
Radiation emission signatures



NASA Ames Arcjet Facility

DS-II Mars Microprobe Heat Shield Evaluation

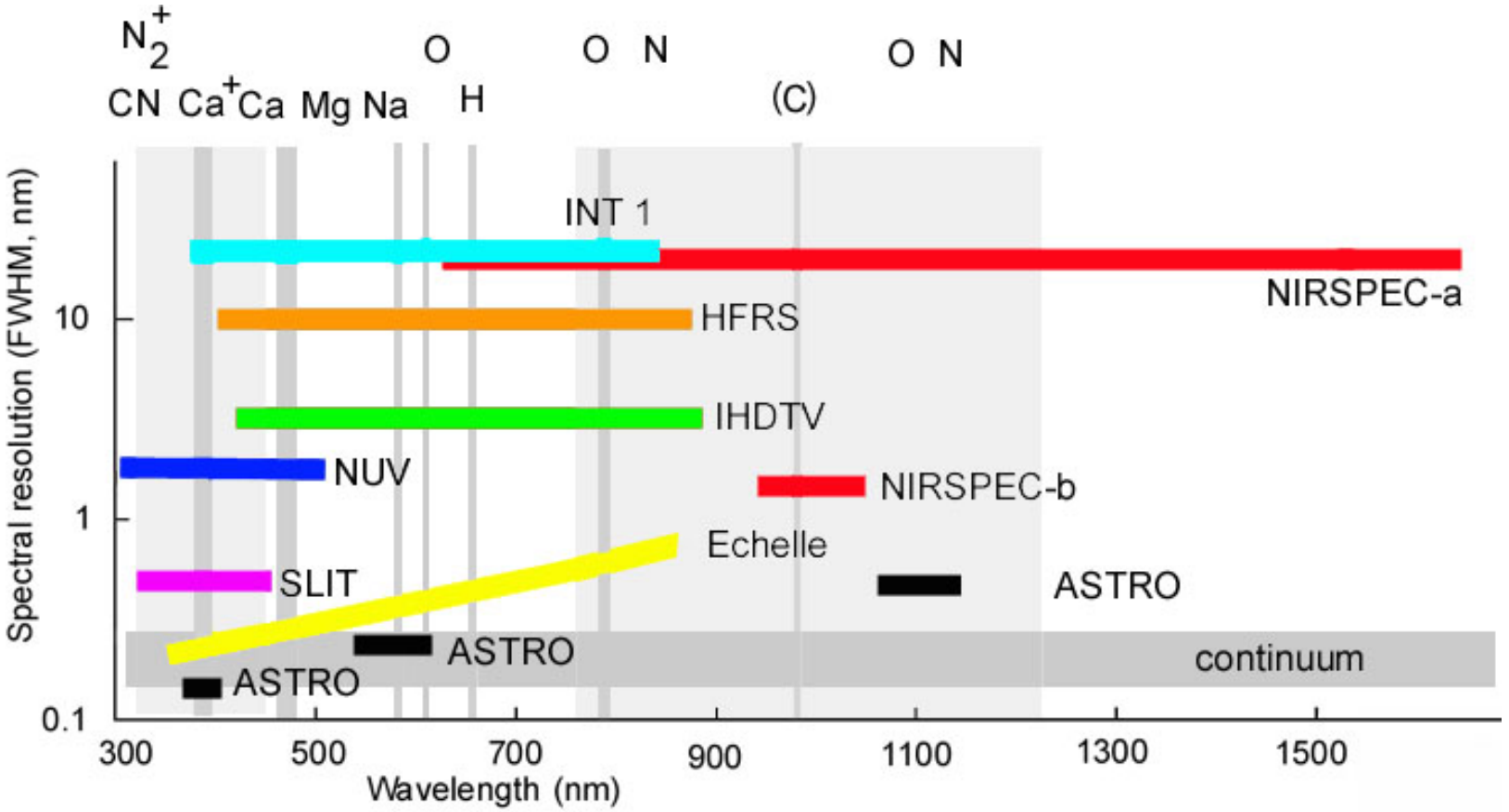
Predicted emission signatures



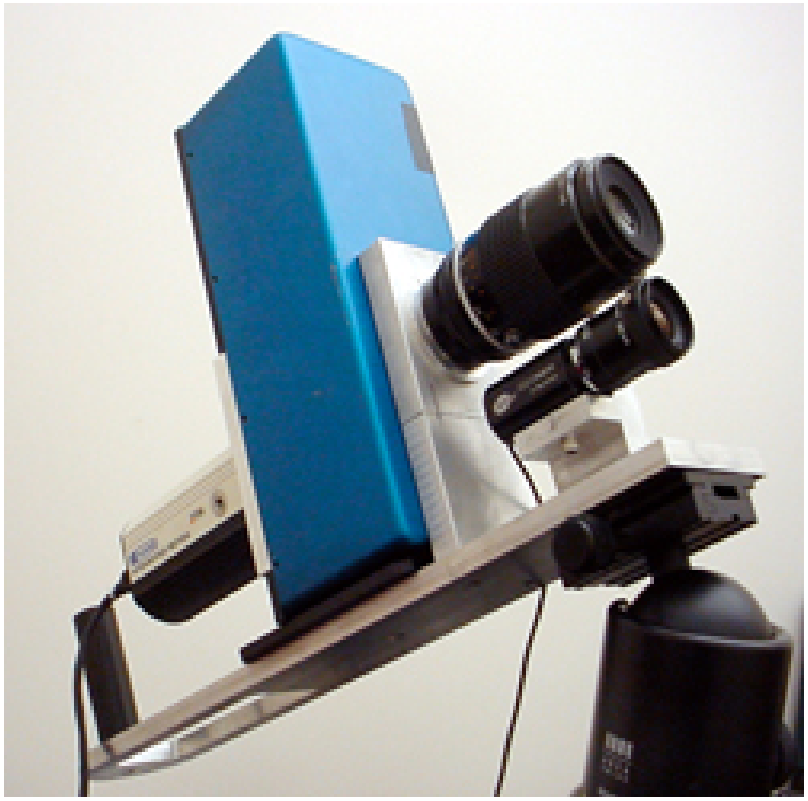
M. Wright, J. Olejniczak

- Strong continuum emission from hot surface
- Shock emission lines
  - O, N, N2+
  - initially strong, later weak
- Emission lines from trace metal impurities (Na, …)
- CN band emission, carbon atom line emission?

Instrument layout

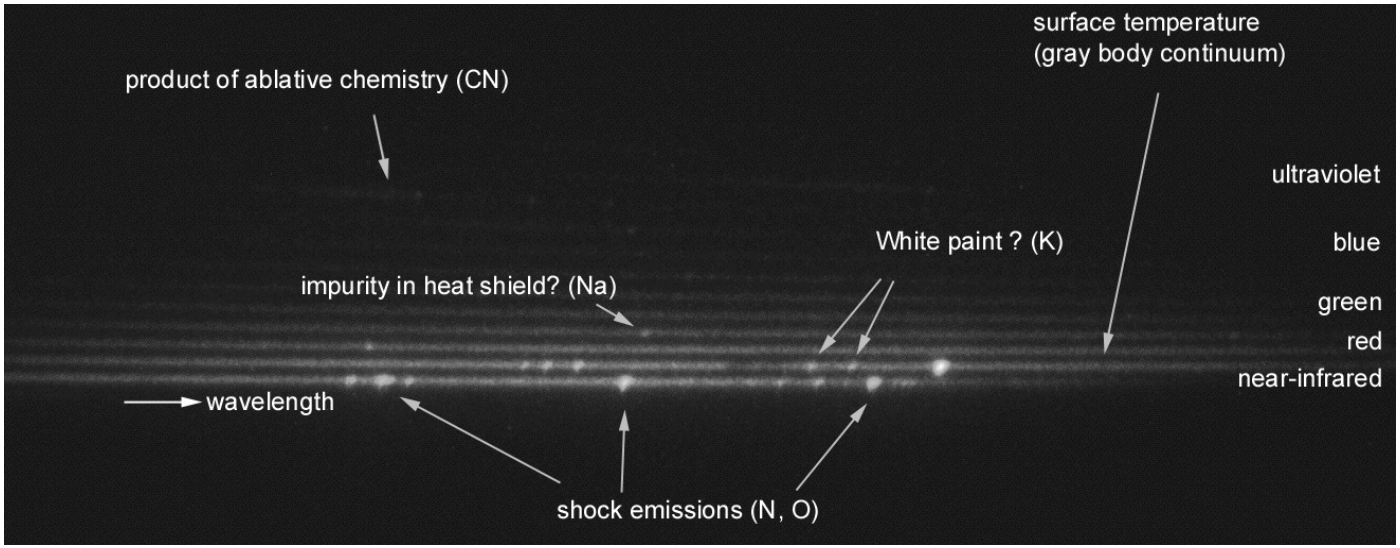


Echelle



- Miniature Echelle spectrograph with intensified 12 bit CCD camera
- 368-872 nm
- $\Delta\lambda$ = 0.4 nm (0.25 to 0.44)
- Wavelength and response: calibrated on laboratory lamps and astronomical sources
- Sensitivity calibration:
  - Mars (mv = -2) S/N = 7 for 30 ms exposure/frame
- Pointing with co-aligned widefield 30º camera and video headset display
  - successful pointing/tracking on airplanes

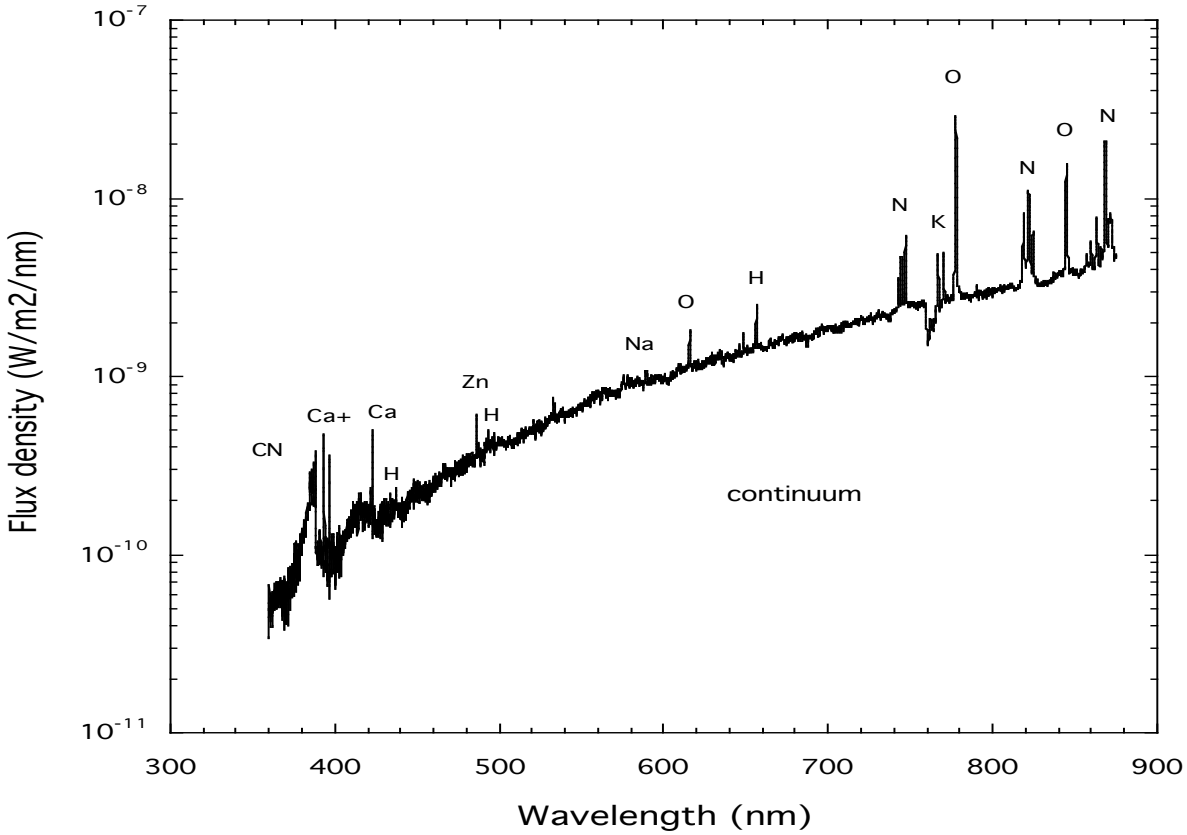
Observed emission signatures



Echelle
Instrument P.I.:
Peter Jenniskens,
SETI Institute

Frame#83 (9:57:24.280 UT)

Detected signatures

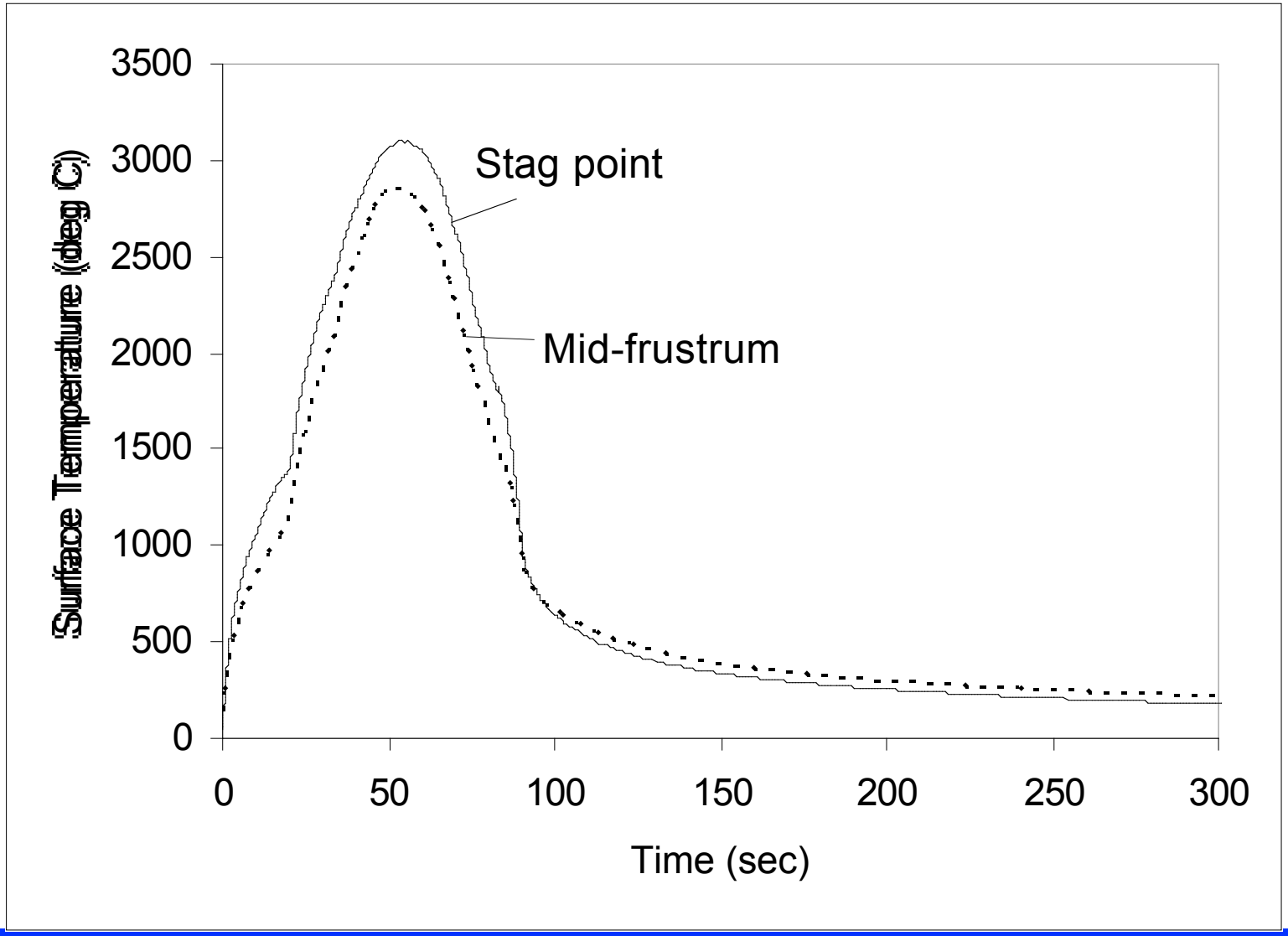


Echelle (Jenniskens) - average of 12 spectra

Data Acquisition targets: surface temperature

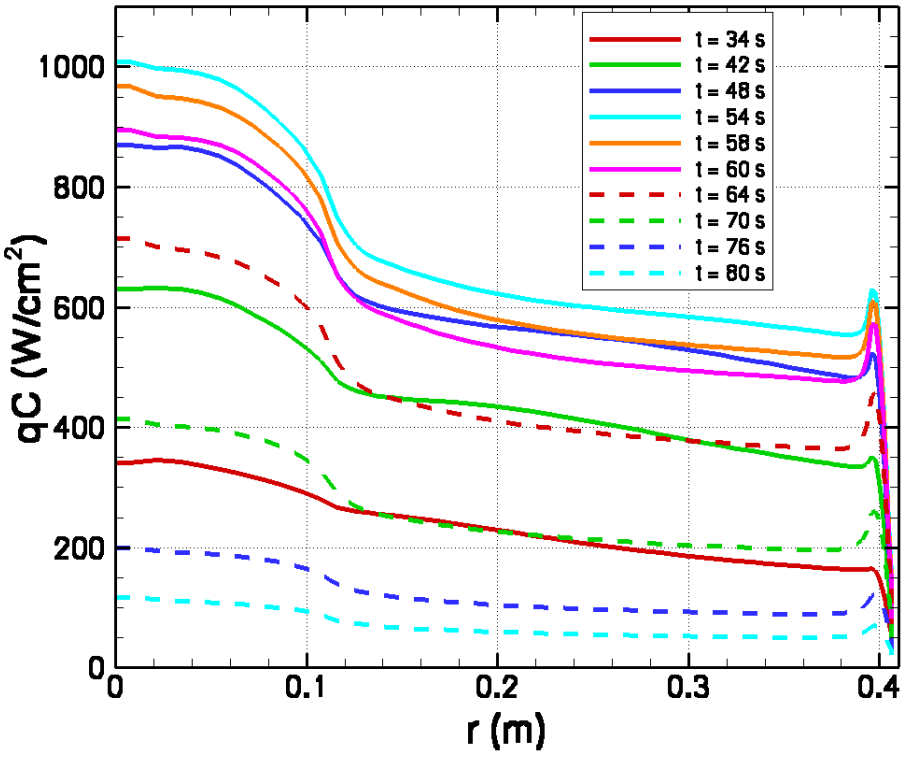
MEASUREMENT	ENTRY VEHICLE PARAMETER	APPLICATION TO FUTURE VEHICLES
Spectroscopy of continuum emission	**Forebody temperature**	**Test TPS surface response models to heating inputs**
Optical + Near-IR wavelengths (0.35 - 1.67 micron)	Requirement: distinquish continuum contributions from dust and plasma at different temperatures	Spatially averaged, and time-dependent

Surface Temperature History

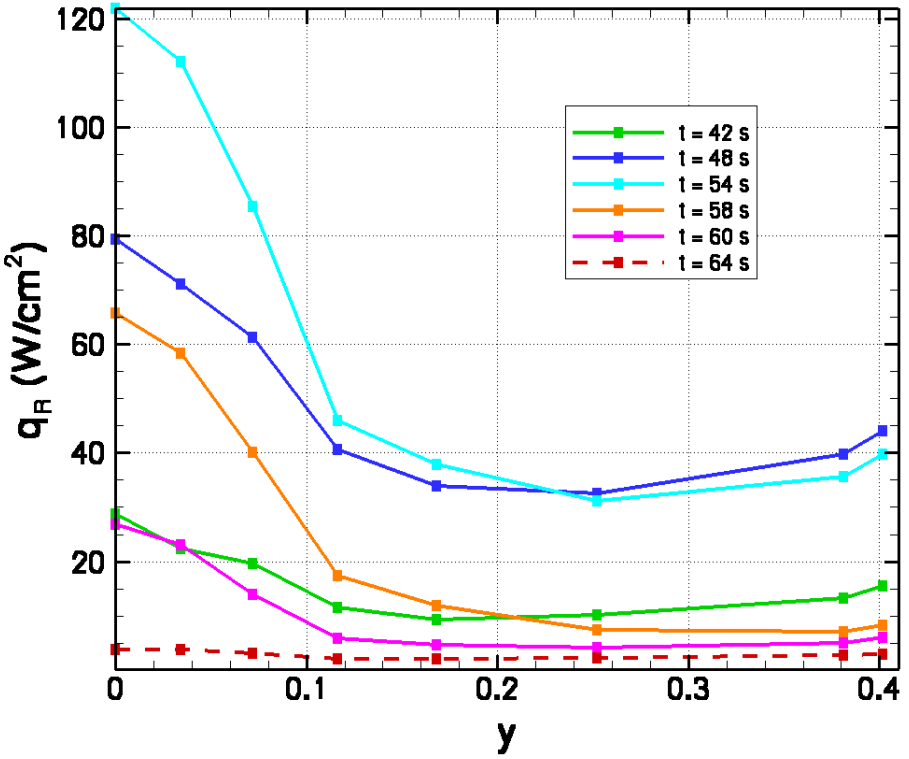


Forebody: Heat Transfer

Convective

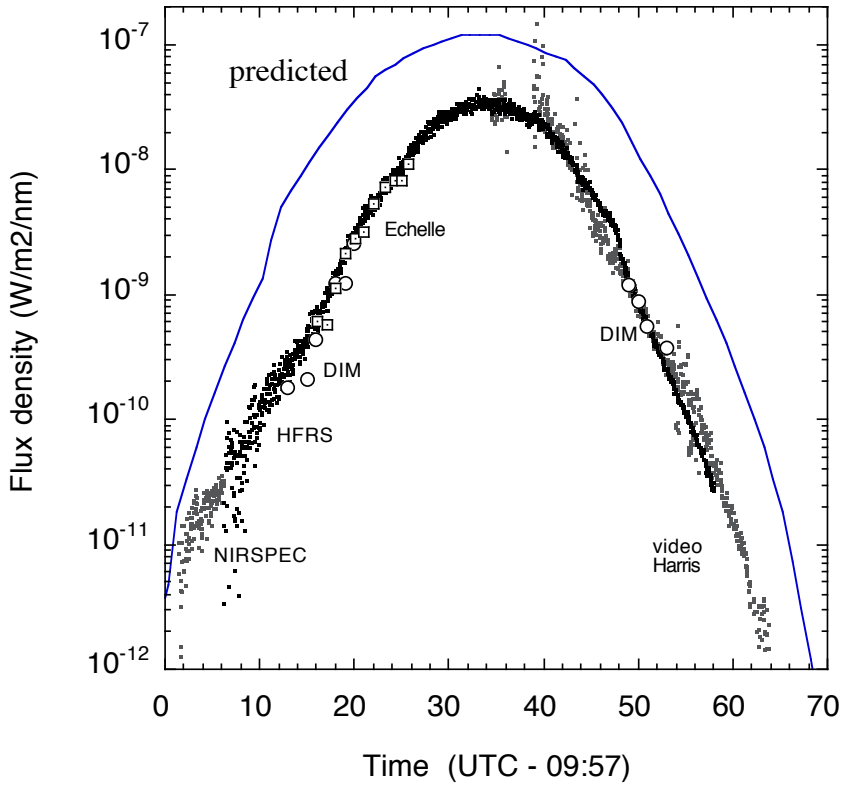


Radiative



- **Radiation is about 10-15% of total**
- **Peak heating rate ~1200 W/cm^2**

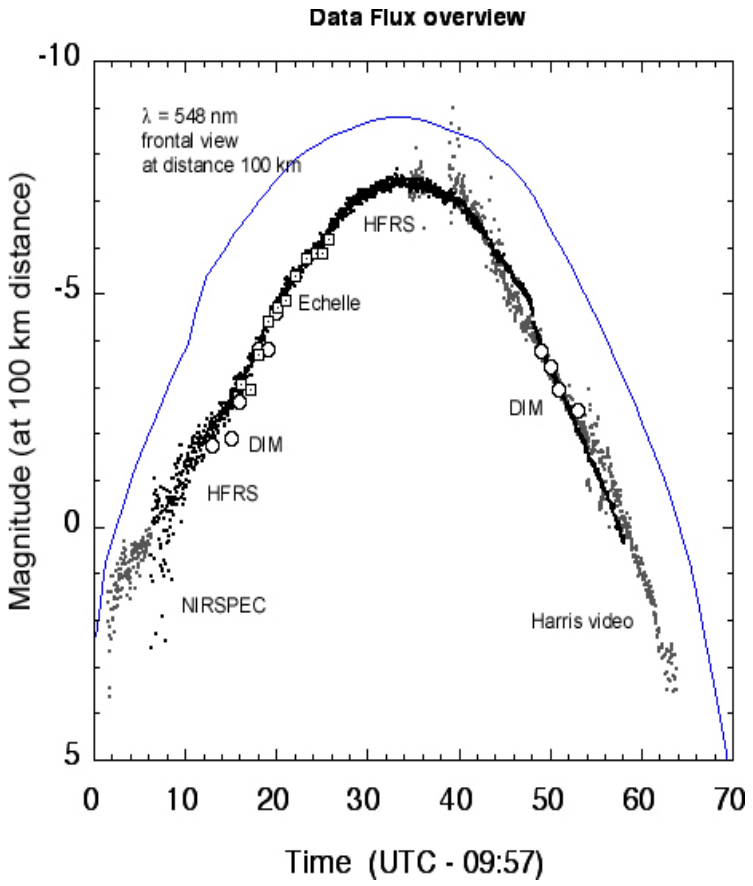
Flux density calibration



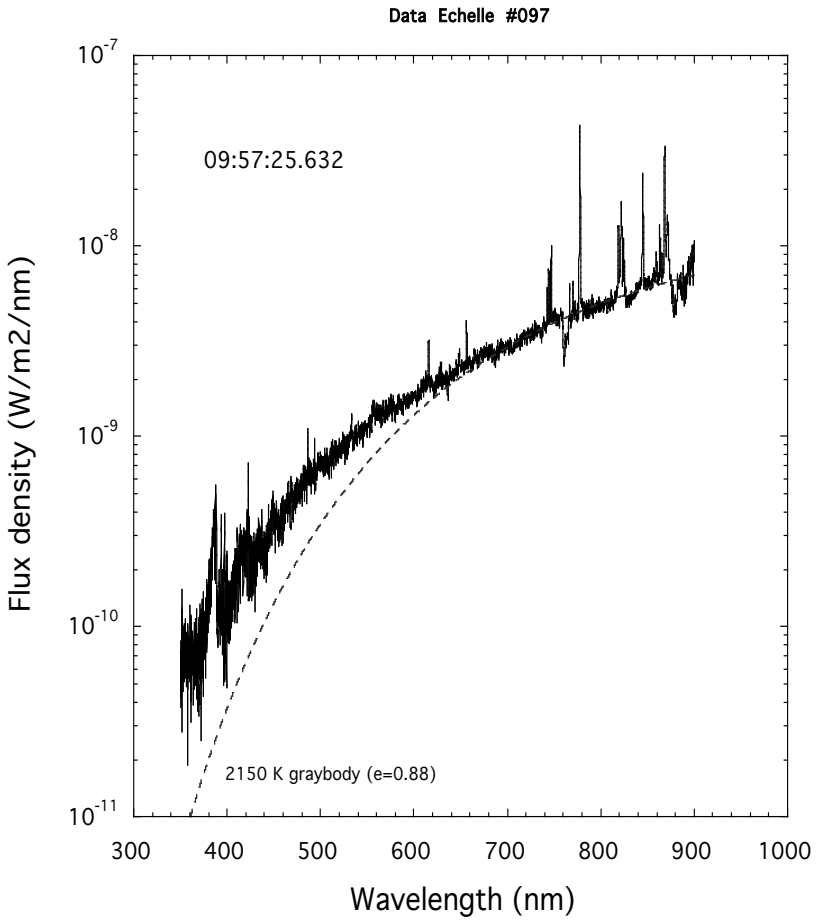
- Derive sum pixel intensity
- Calibrate broadband imaging intensity from astronomical sources
- Correct to one wavelength (548 nm)
- Correct for extinction
  - F' = F exp (Σpix/Σpixo)
- Correct to d = 100 km and frontal view

Flux density calibration

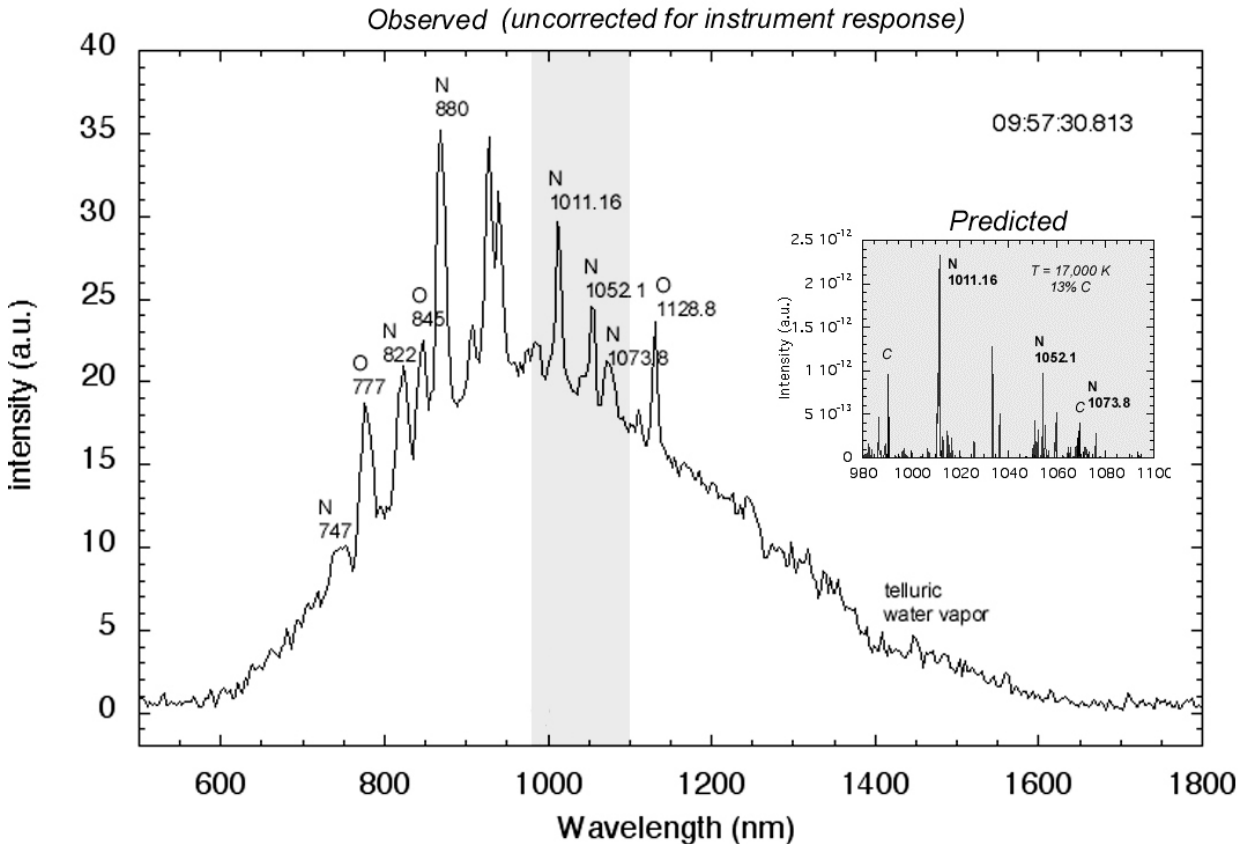
- Sources used so far:
  - NIRSPEC (Taylor): pointing camera
  - HFRS (McHarg) pointing camera
  - Digital IMaging (Wercinski)
  - Ground-based video by Tim Harris (UT/NV border)



Surface temperatures



NIRSPEC: extend continuum

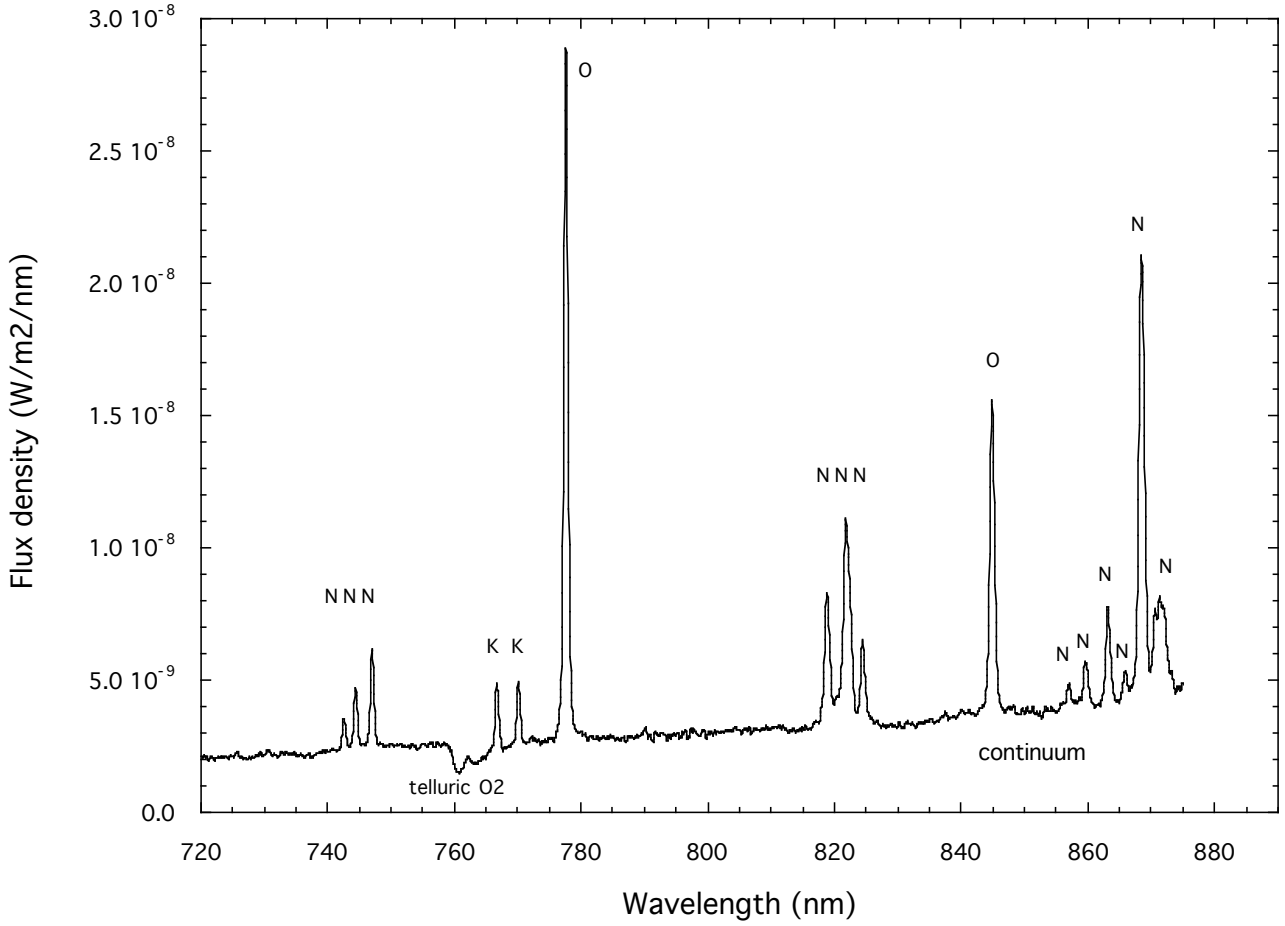


Instrument P.I.: Mike Taylor

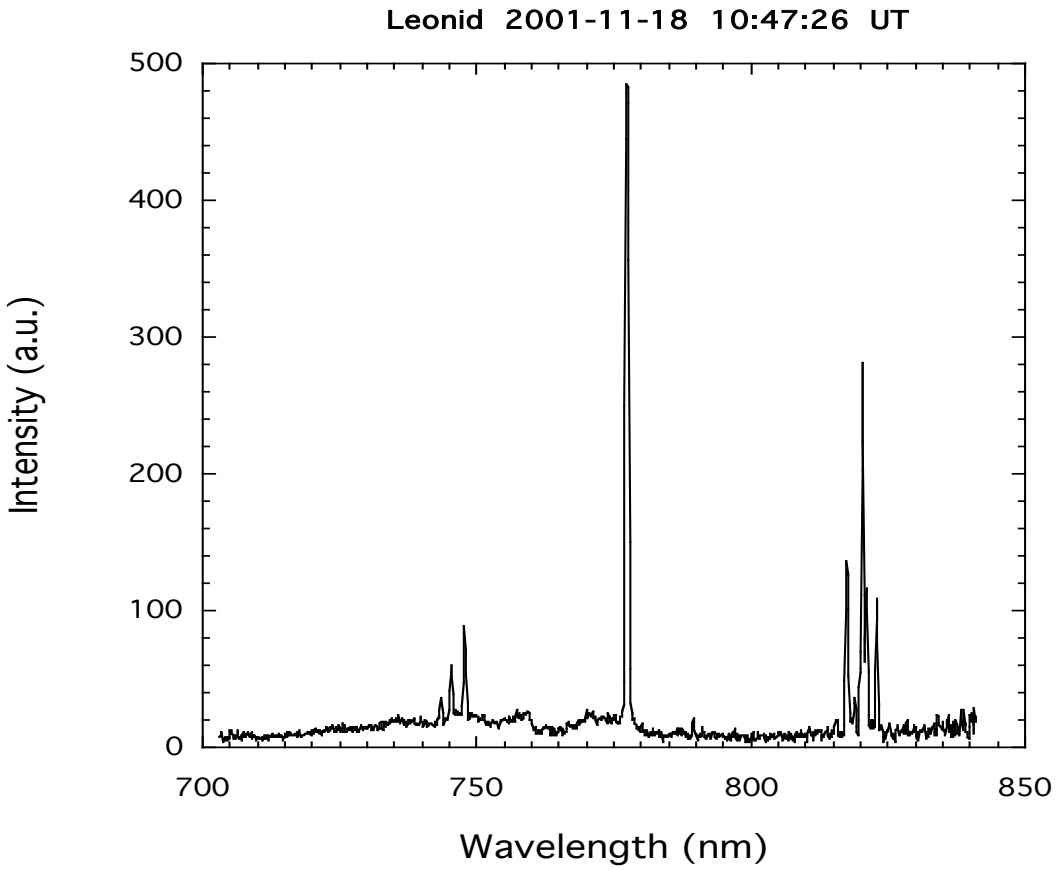
Data Acquisition targets: shock emissions

MEASUREMENT	ENTRY VEHICLE PARAMETER	APPLICATION TO FUTURE VEHICLES
• **Spectroscopy of shock emissions**	• **Heat flux from shock**	• **Measure radiative heat flux**
– Near-IR (N, O atomic lines) – Near-UV (N2+ band)	– Both intensity and temperature of shock air plasma emissions	– Total radiative intensity will be compared to predictions to provide validation of current aerothermal models

Echelle: air plasma emissions



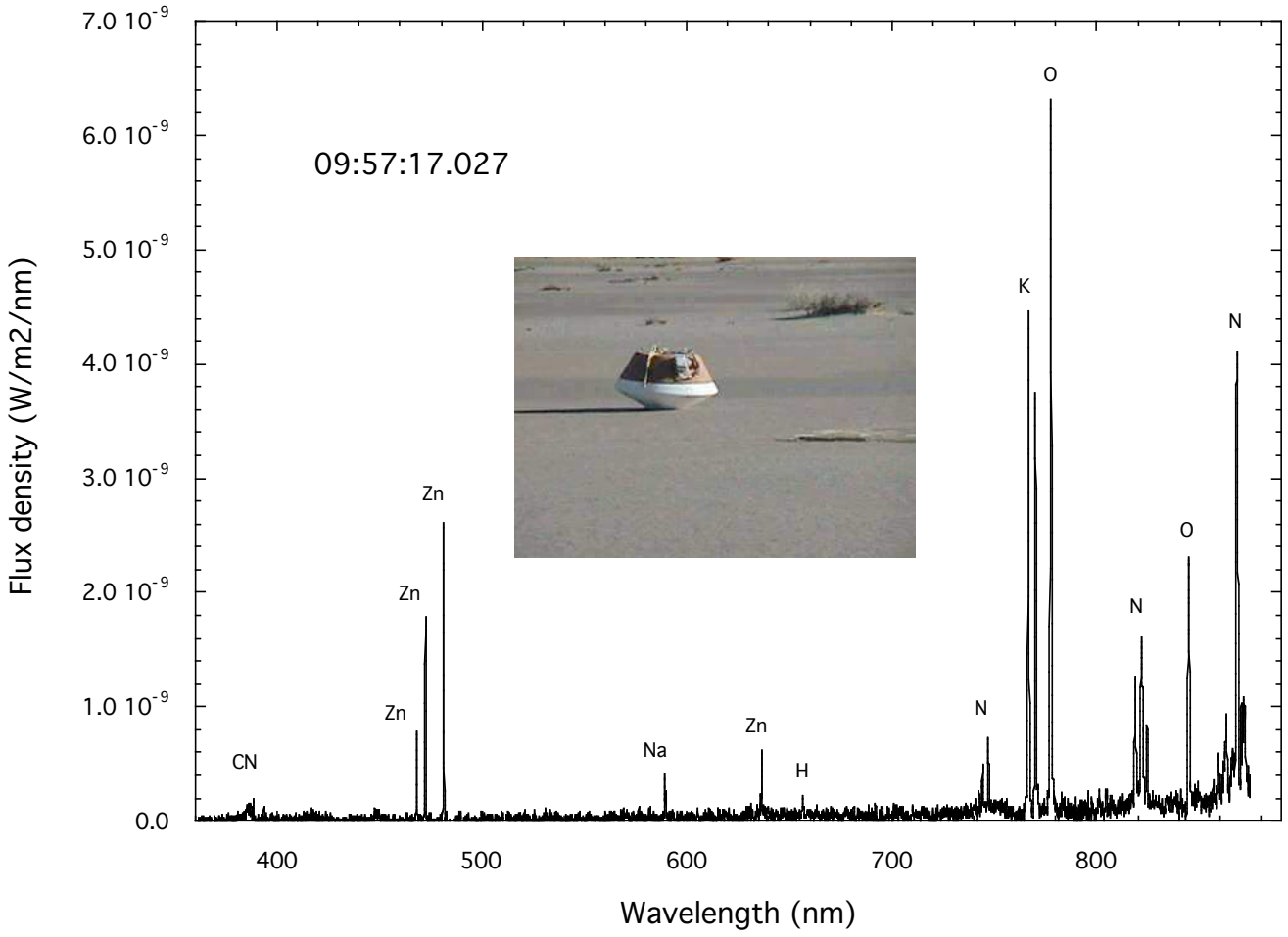
Leonid meteor @ 71.6 km/s



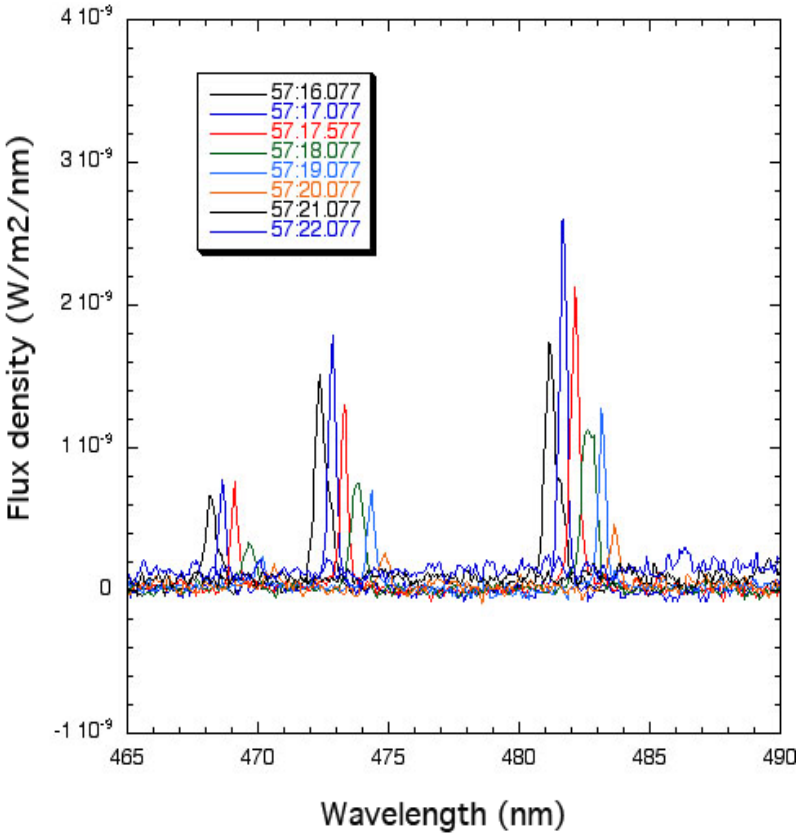
Data Acquisition targets: ablation products

MEASUREMENT	ENTRY VEHICLE PARAMETER	APPLICATION TO FUTURE VEHICLES
• **Spectroscopy of ablation products** – Near-UV (CN) – Optical/near-UV (C2, Na, Al, Ti)	• **Ablation rate as function of altitude** – Indirect detection via Na impurities – Direct detection carbon products – Any release of metals that indicates heatshield anomalies	• **Test ablation models** – Spectral measurements of ablation products will correlate with ablation rate and time variation

Strong lines of Zn and K

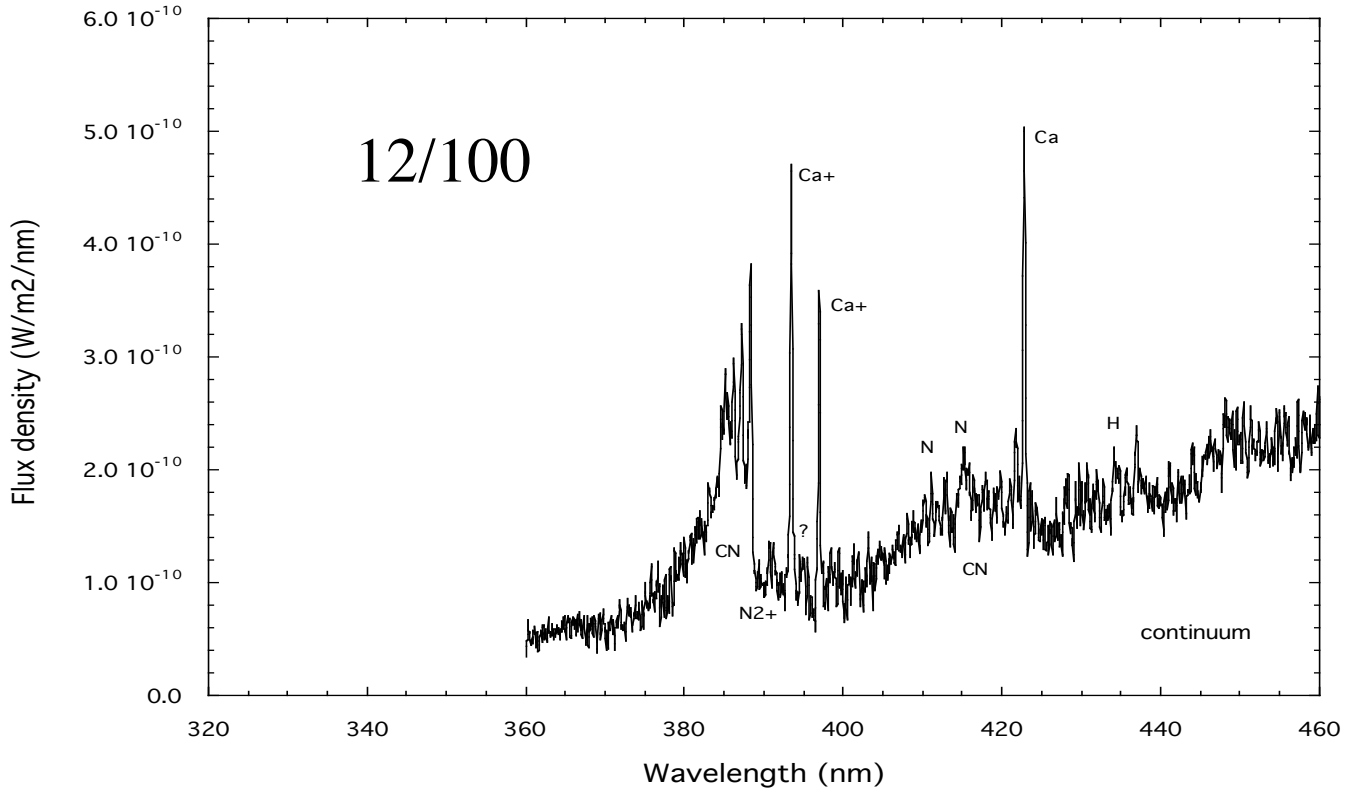


Zn, K: strong only in beginning trajectory

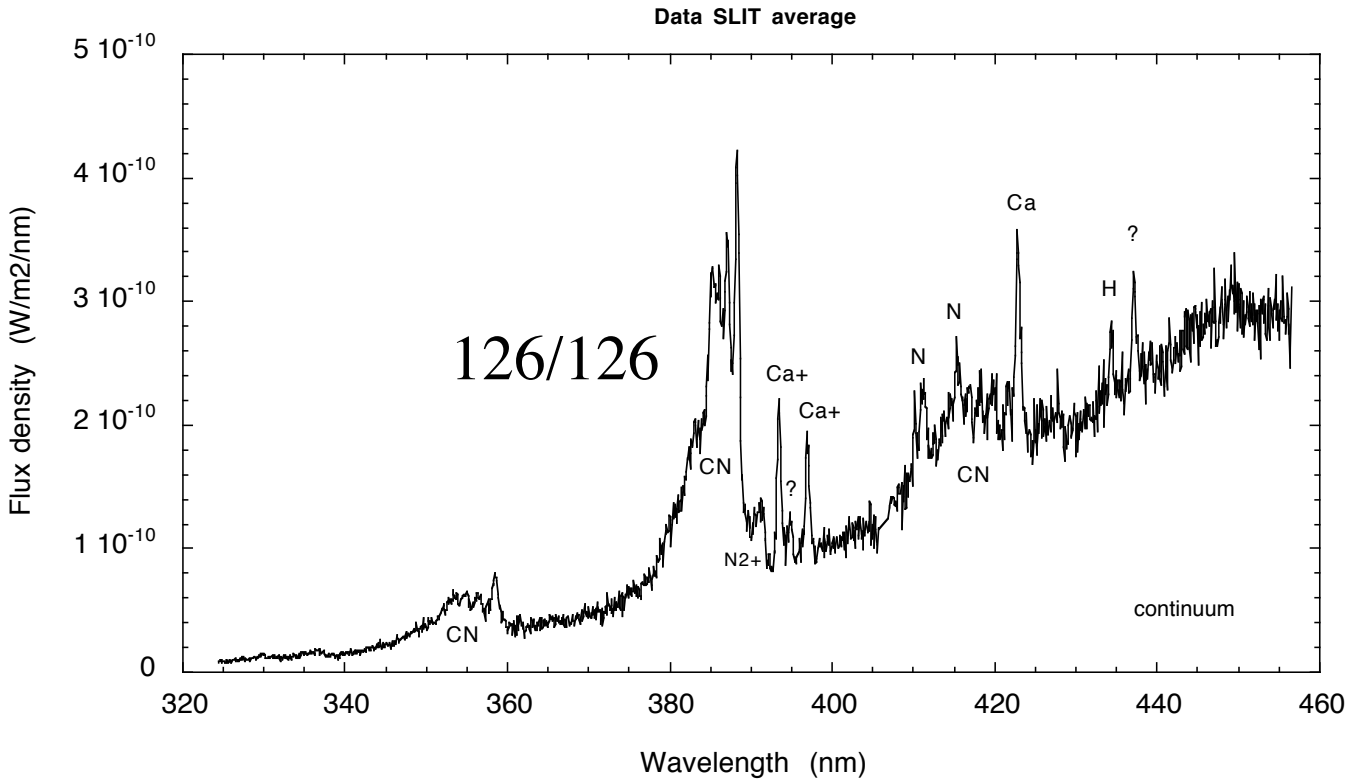


- Inorganic paint for thermal control (Alion Science and Technology Z93P):
  - ZnO pigment
  - K2SiO3 (potassium silicate) paint base
- Strong signal
- Nice profile of Zn loss 09:57:16.1 - 20.4 UT (about 81-74 km)
- Complete record of Zn loss in NUV data (P.I.: Shinsuke Abe)

Echelle: CN band profile

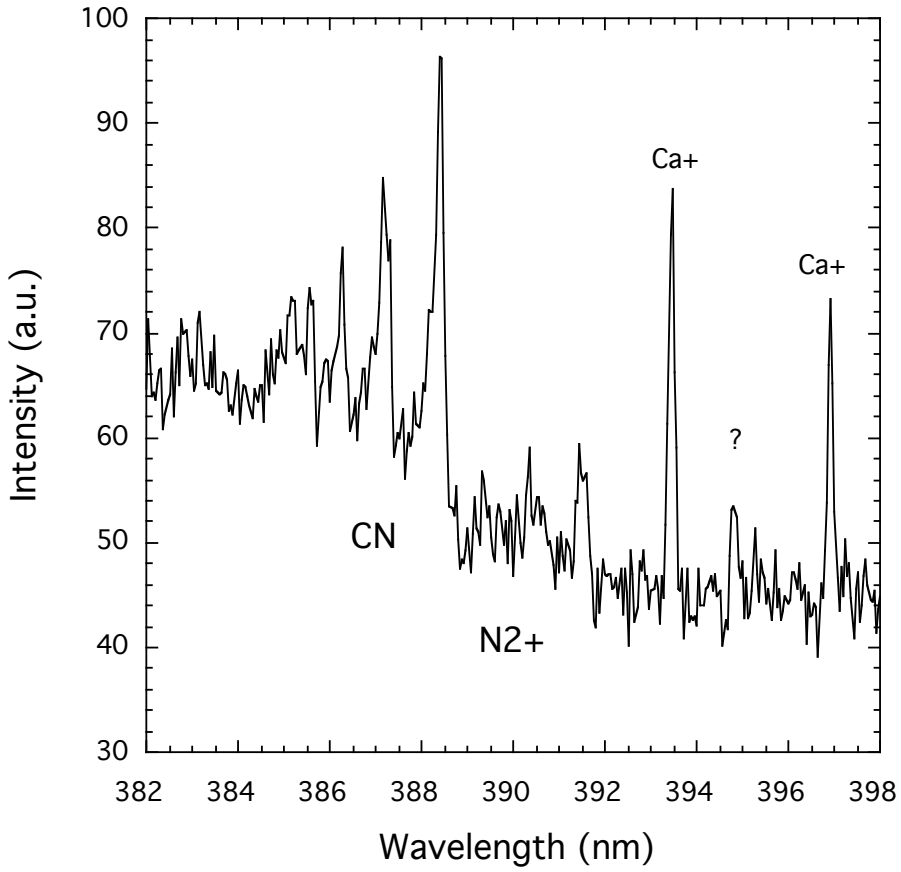


SLIT: CN band

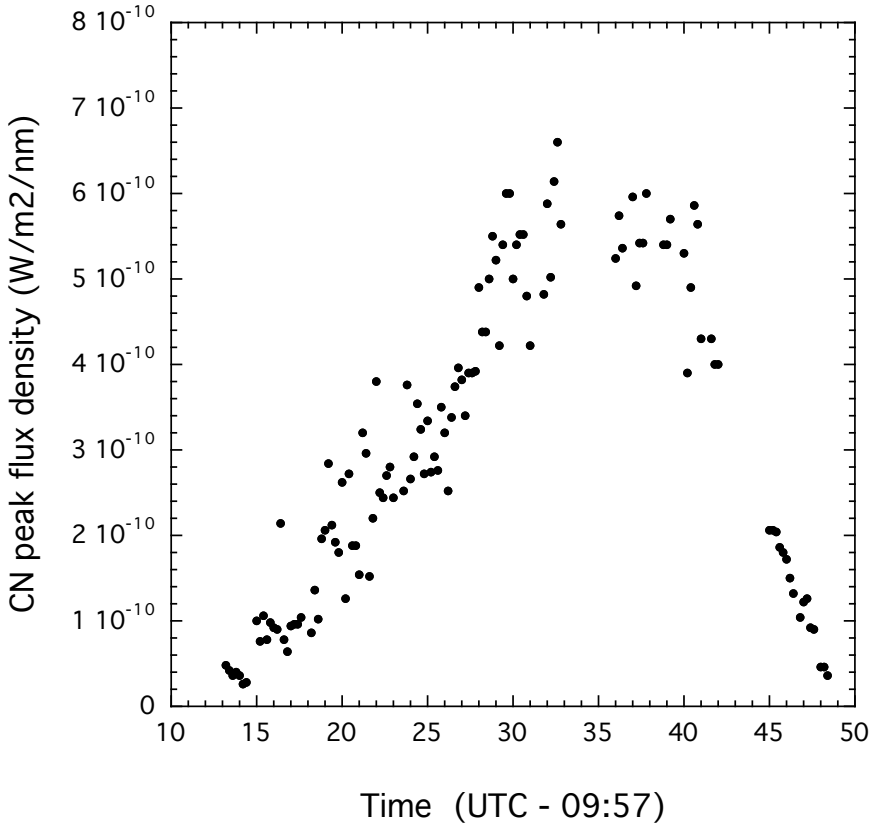


Instrument P.I.: Michael Winter

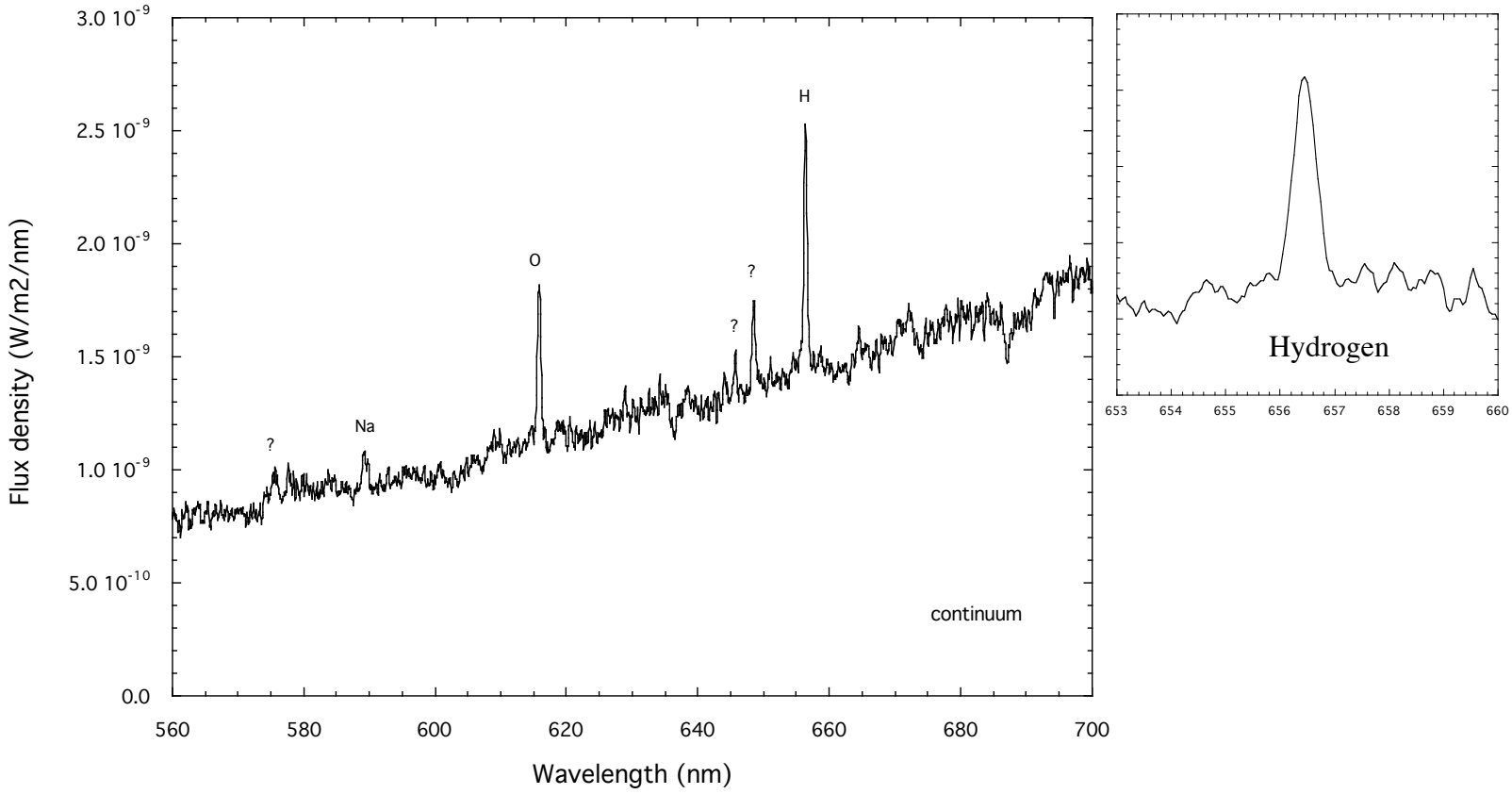
Astro: CN band profile



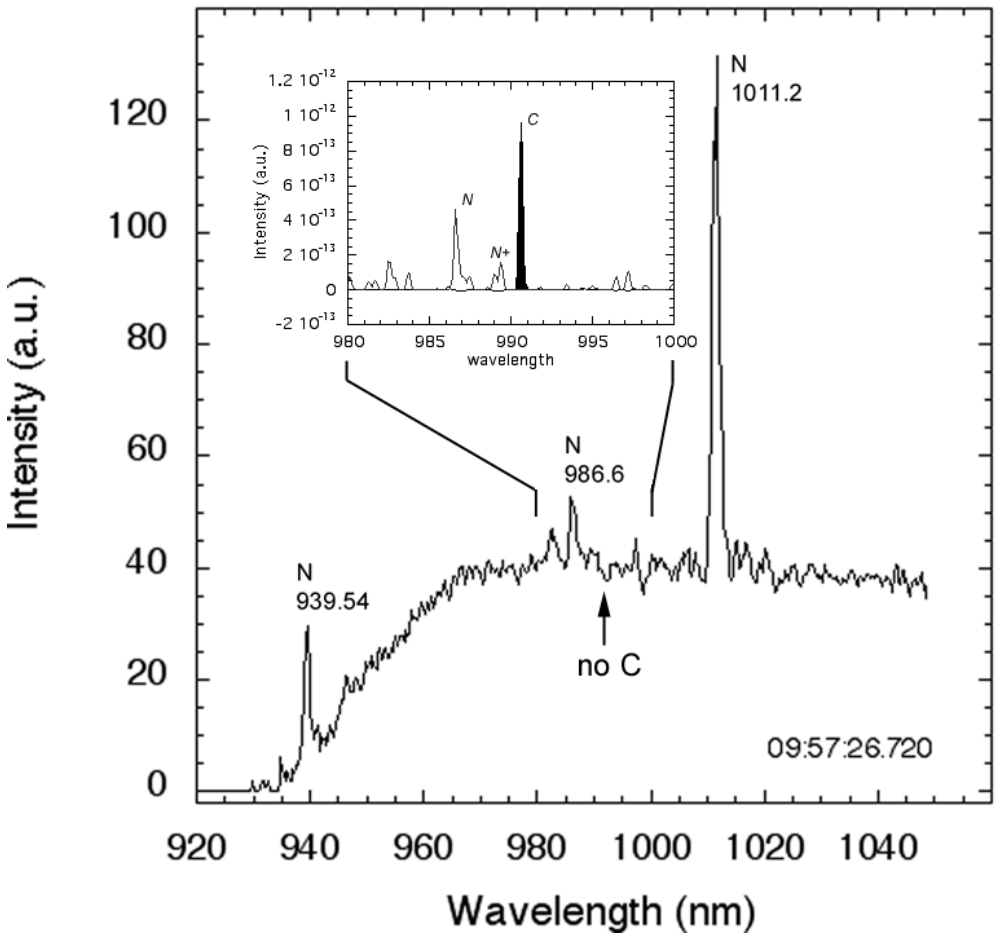
SLIT: carbon blowing rate



Echelle: Hydrogen detected



NIRSPEC: no C-lines



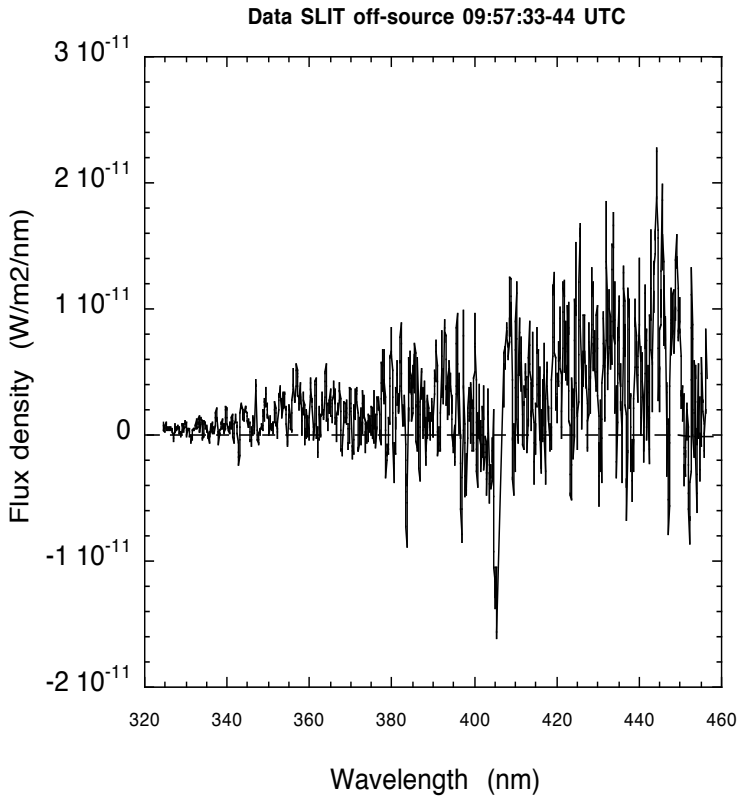
Data Acquisition targets: rapid changes

MEASUREMENT	ENTRY VEHICLE PARAMETER	APPLICATION TO FUTURE VEHICLES
• **High speed imaging/ photometry**	• **Aerodynamic stability, spallation**	• **Corroborate predictions of vehicle aerodynamics**
– 250,000 /s photometry – 1000 f/s imaging – 30 f/s broadcast HDTV	– High frequency fluctuations in shock emissions – Any shedding of fragments	

Data Acquisition targets: wake

MEASUREMENT	ENTRY VEHICLE PARAMETER	APPLICATION TO FUTURE VEHICLES
• **Spectroscopy of wake emissions**	• **Debris / induced atmospheric chemistry**	• **Mishap mitigation**
– Mid-IR 3-5.5 micron (CH, CO, solids)	– Size of ablation debris from decelleration in the wake	– Any significant, un-predicted spectral signatures may provide insight to anomalies, loss of vehicle.
– Optical/near-UV (NO2)	– Generation of airglow emissions	

SLIT: Spectrum of wake



- Add together all off-source spectra period 57:33-57:44 UTC
- Subtract residual source spectrum from intensity CN band emission
- Result (see left)

Instrument P.I.: Michael Winter

Future work

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  - SETI Institute (Mountain View, CA)
  - Thursday July 06 + Friday July 07
  - **Abstract deadline: July 03** (http://reentry.arc.nasa.gov)