Consolidated laser-induced fluorescence diagnostic systems for the NASA Ames arc jet facilities

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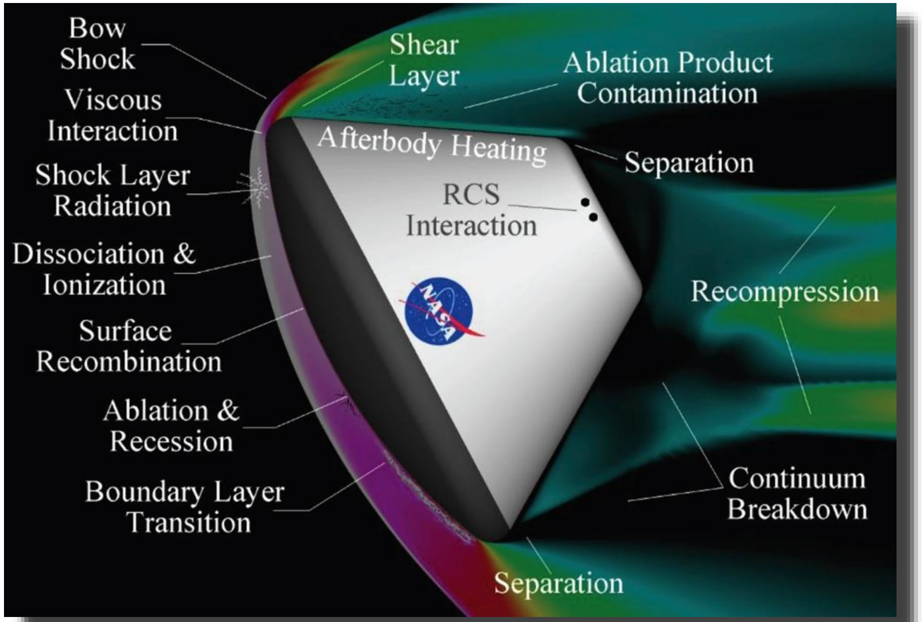
Outline

- Atmospheric entry, thermal protection, and arc jet testing
- Two photon LIF as an arc jet diagnostic
- Short history of arc jet LIF at NASA
- LIF systems redevelopment at NASA Ames
- Example results
- Current status and future work

Planetary entry aeroheating and thermal protection systems

NASA

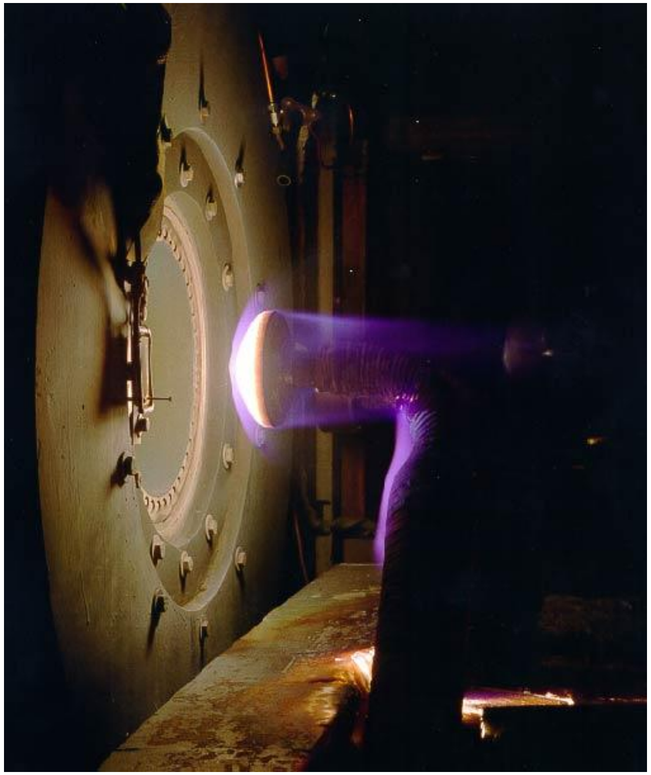


M. Wright/ARC

- Spacecraft kinetic energy is converted to thermal energy during atmospheric entry deceleration
- Part of that thermal energy reaches spacecraft through convective and radiative heat transfer
- Thermal protection system (TPS) mitigates heat transfer to substructure
- TPS materials are developed and validated with **arc jet testing**

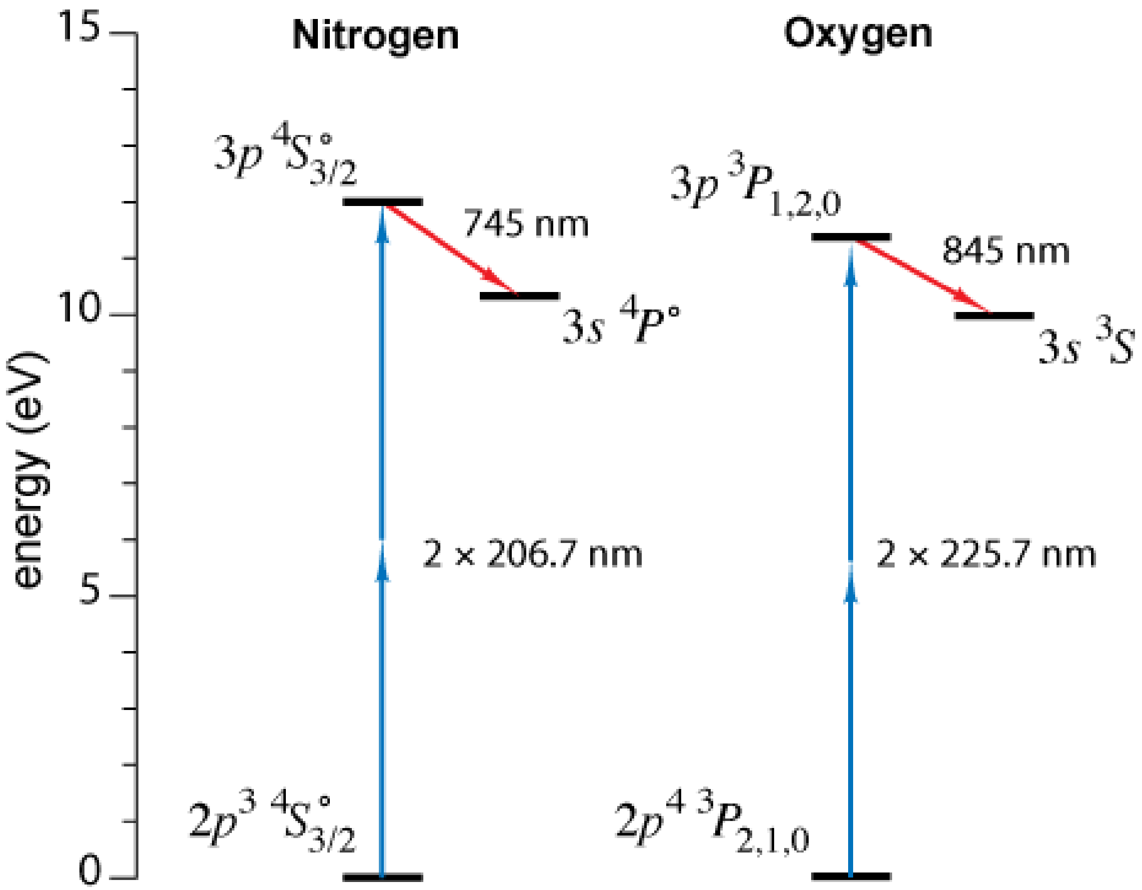
Arc jet facilities and TPS testing

- Atmospheric entry aeroheating environments for TPS materials testing
  - Heat flux, heat load, pressure, shear
- Nonequilibrium free stream
  - Highly dissociated – conditions not encountered in flight
  - TPS material response can be sensitive to the degree of nonequilibrium



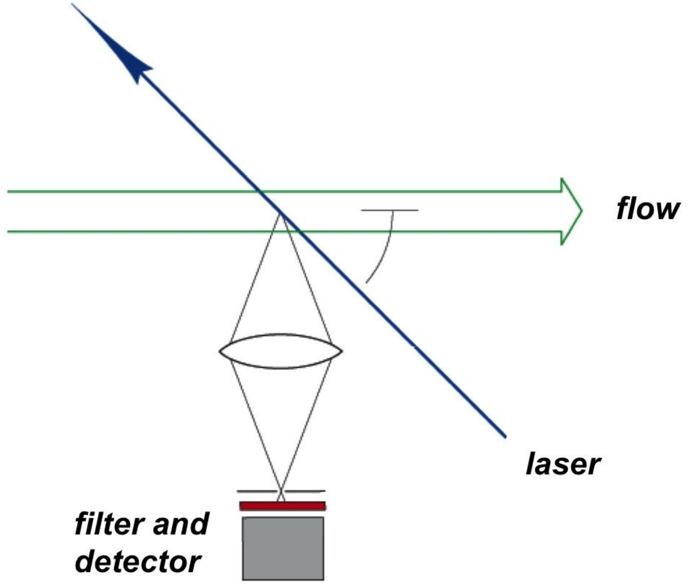
- **TPS testing methodology relies on facility characterization and simulation**
  - High fidelity CFD simulations validated with facility performance data
  - Boundary conditions for TPS material response modeling

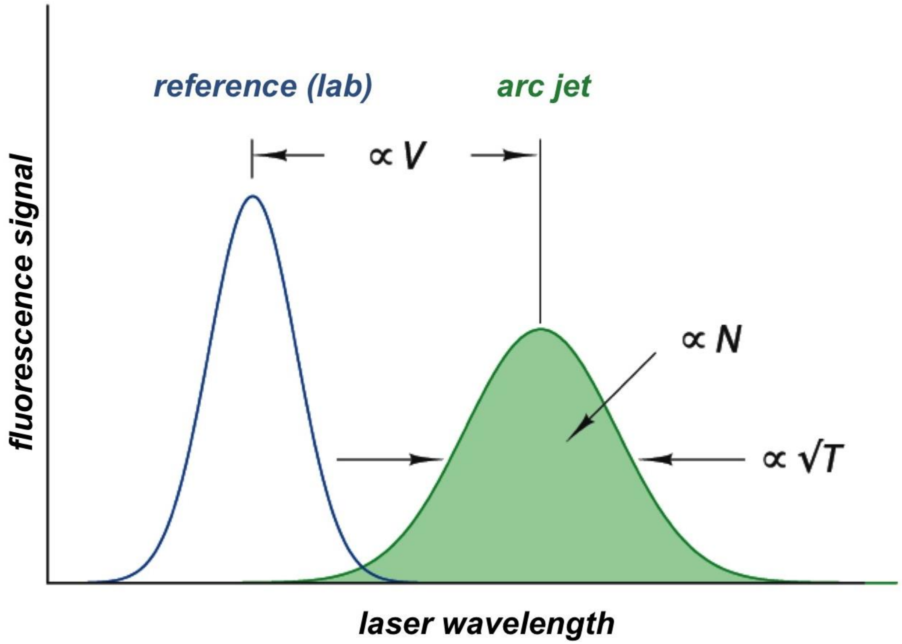
Two photon absorption LIF (TALIF) of atomic N and O



- Non-intrusive, species-selective diagnostic for combustion and plasma flows
- Tunable UV laser excitation, near-infrared fluorescence

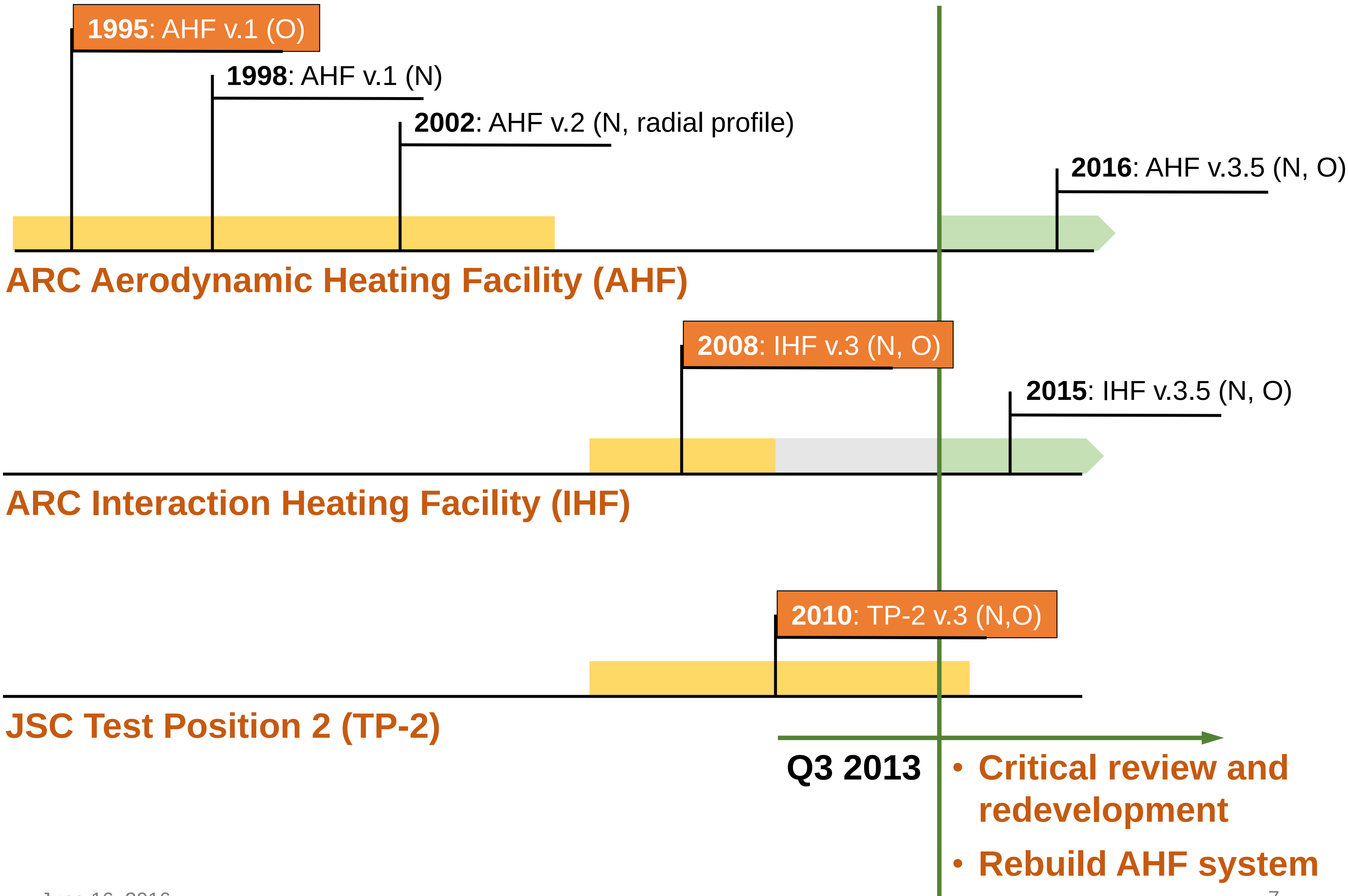
Arc jet flow property measurement with LIF



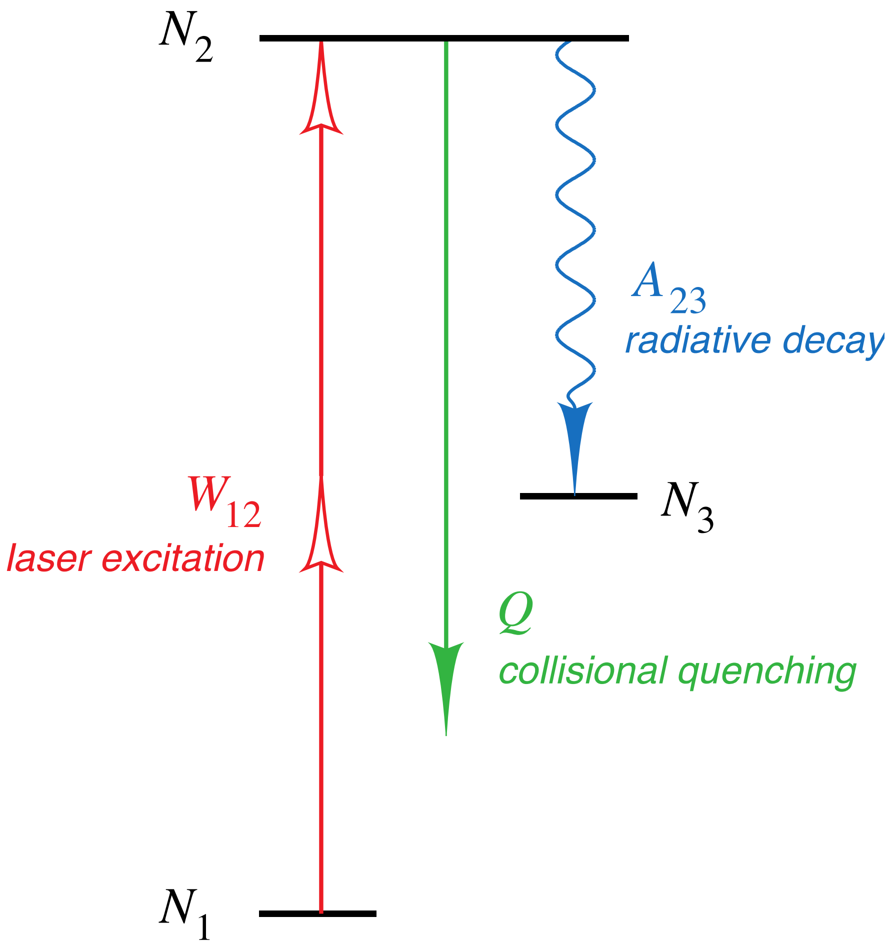


- Laser excitation scan over absorption transition reveals three important flow properties
  - Velocity from Doppler shift
  - Temperature from line shape width
  - Species density from integrated signal magnitude
- LIF-measured flow properties and facility data are used to compute total and modal enthalpy of arc jet free stream

TALIF in NASA arc jet facilities – timeline



TALIF process



- Rate equation analysis: Accounts for state population dynamics
- Magnitude of fluorescence signal: function of spectroscopic and experimental parameters
- Proportional to four factors and a calibration constant

$$S_{LIF}(\lambda) = N_1 \cdot E_p^2 \cdot \tau_{eff} \cdot g(\lambda : \lambda_0, \Delta\lambda) \cdot \begin{bmatrix} \text{calibration} \\ \text{constant} \end{bmatrix}$$

TALIF signal interpretation

Excitation line shape

$$S_{LIF}(\lambda) \propto g(\lambda : \lambda_0, \Delta\lambda_D)$$

Velocity and Temperature

Integrated signal magnitude

$$\frac{\bar{S}_{LIF}}{E_p^2 \cdot \tau_{eff}} = \begin{bmatrix} \text{calibration} \\ \text{constant} \end{bmatrix} \cdot N_1$$

Species density

- Expressions that characterize TALIF signal response
  - Calibration and analysis to recover flow properties
- **Defines data requirements for experiment implementation**

Experiment configuration requirements – v.3.5

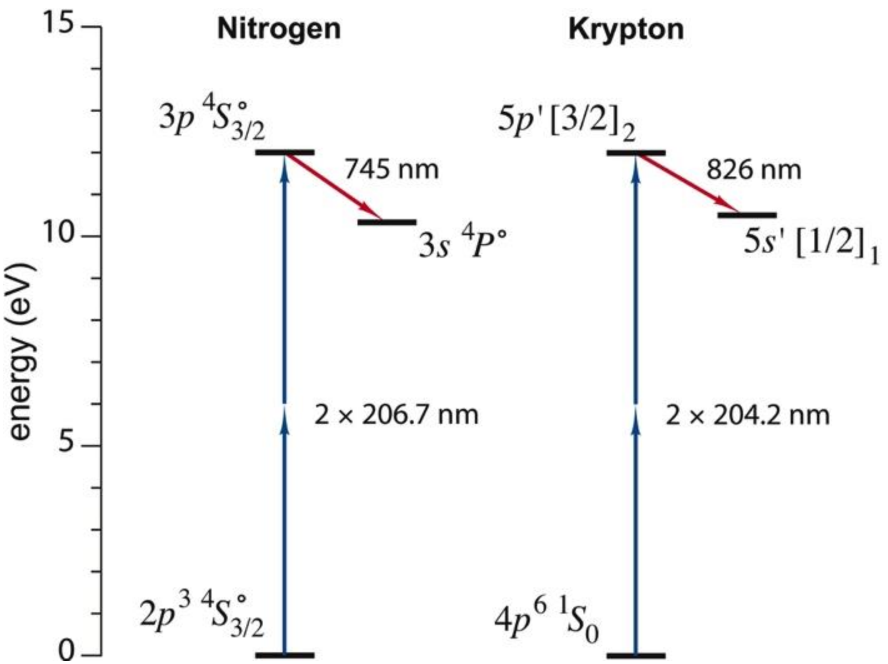
- **Calibration methodology** – means to obtain calibration constants for measurement of absolute atomic N and O densities in arc jet

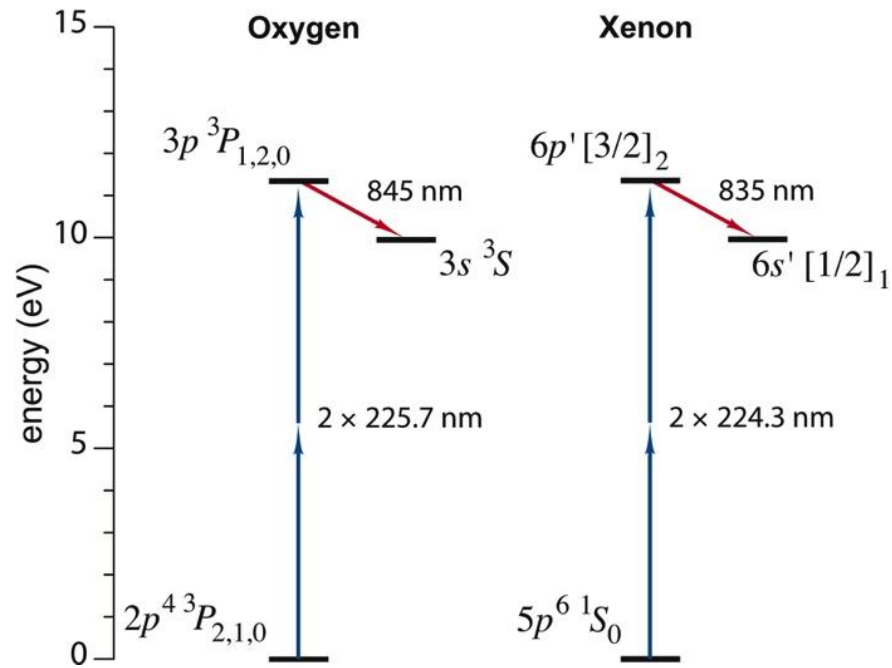
- **Validation capability** – experiments to assess conformance to TALIF theory (reveal systematic errors)
  - Quadratic pulse energy dependence
  - Linear density dependence
  - Line shape function modeling

- **Comprehensive and efficient data acquisition**
  - Optimum use of arc-on time

Calibration methodology for arc jet N and O densities

- Traceable to known absolute atomic N and O densities
  - Laboratory reference source
- Kr and Xe used as proxies of N and O
  - TALIF characteristics and experiment configurations are nearly identical
- **N and O TALIF responses in the arc jet are calibrated through Kr and Xe TALIF measurements in the arc jet and lab**

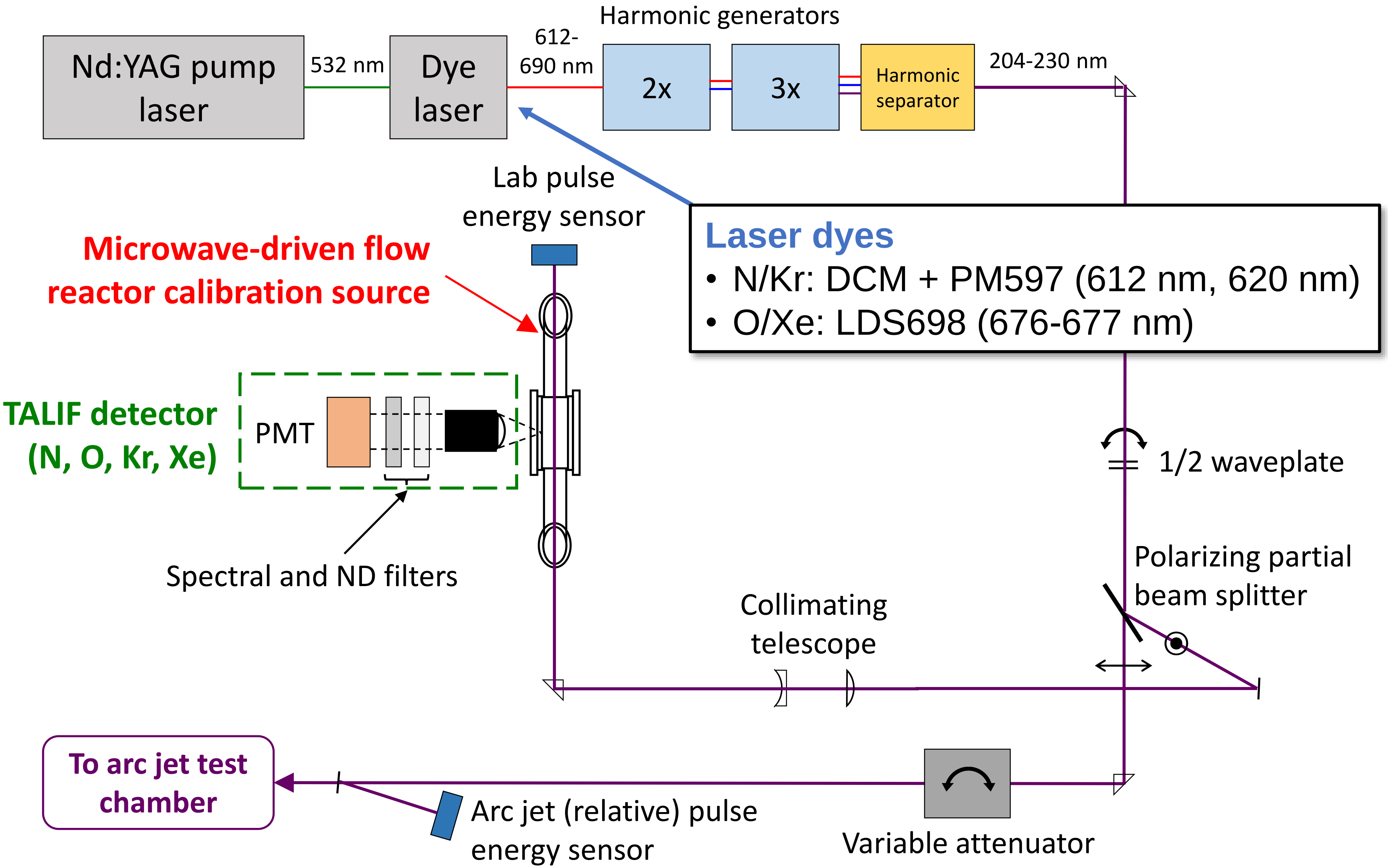




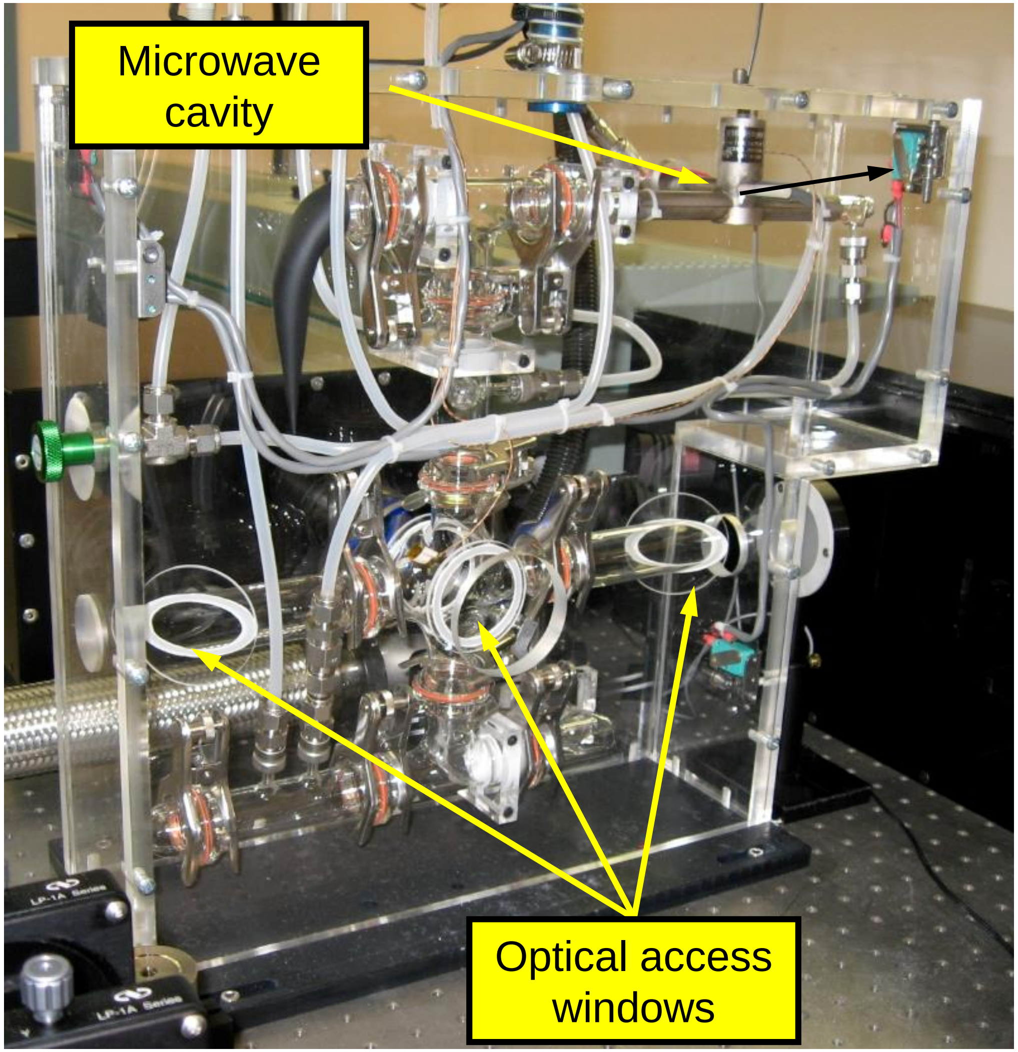
Implemented features for calibration and validation

- Laboratory and arc jet calibration sources
  - Target species at prescribed pressures and quantifiable densities
- Detector system
  - Dynamic range accommodation: sensitive over 3 orders of magnitude
- Laser pulse energy
  - Continuously variable and quantifiable over 1.5 orders of magnitude
- **Experiment management and data acquisition program**
  - Multiple independent parameter modes (laser wavelength, pulse energy, pressure, flow rate)

LIF laboratory optical configuration – v.3.5



Laboratory flow reactor calibration source



- Programmable mixtures of N, O, Kr, or Xe
- N and O densities quantified through titration

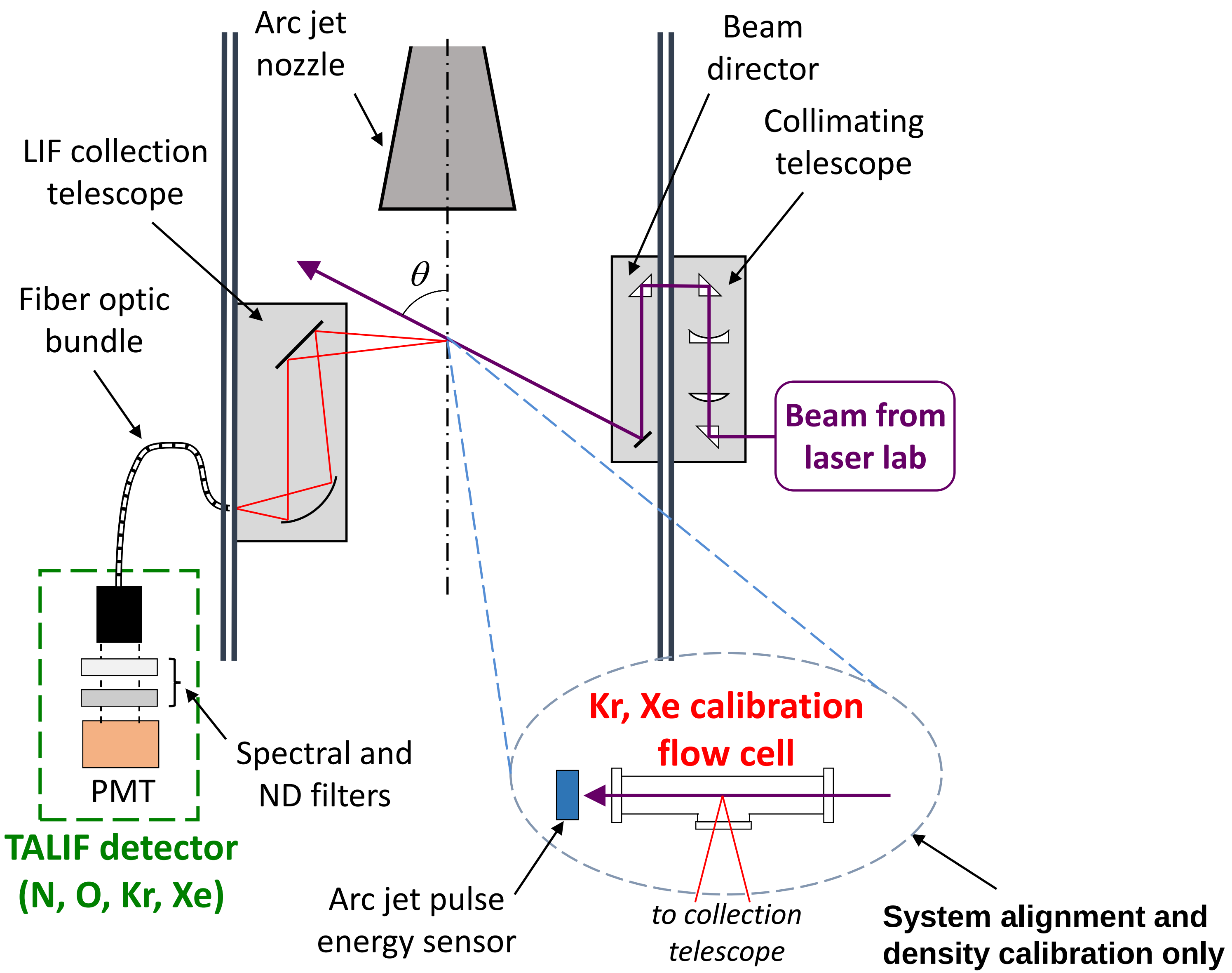
Number densities (cm^{-3})

- [N], [O] ~ 10^{13} – 10^{14}
- [Kr], [Xe] ~ 10^{14} – 10^{16}

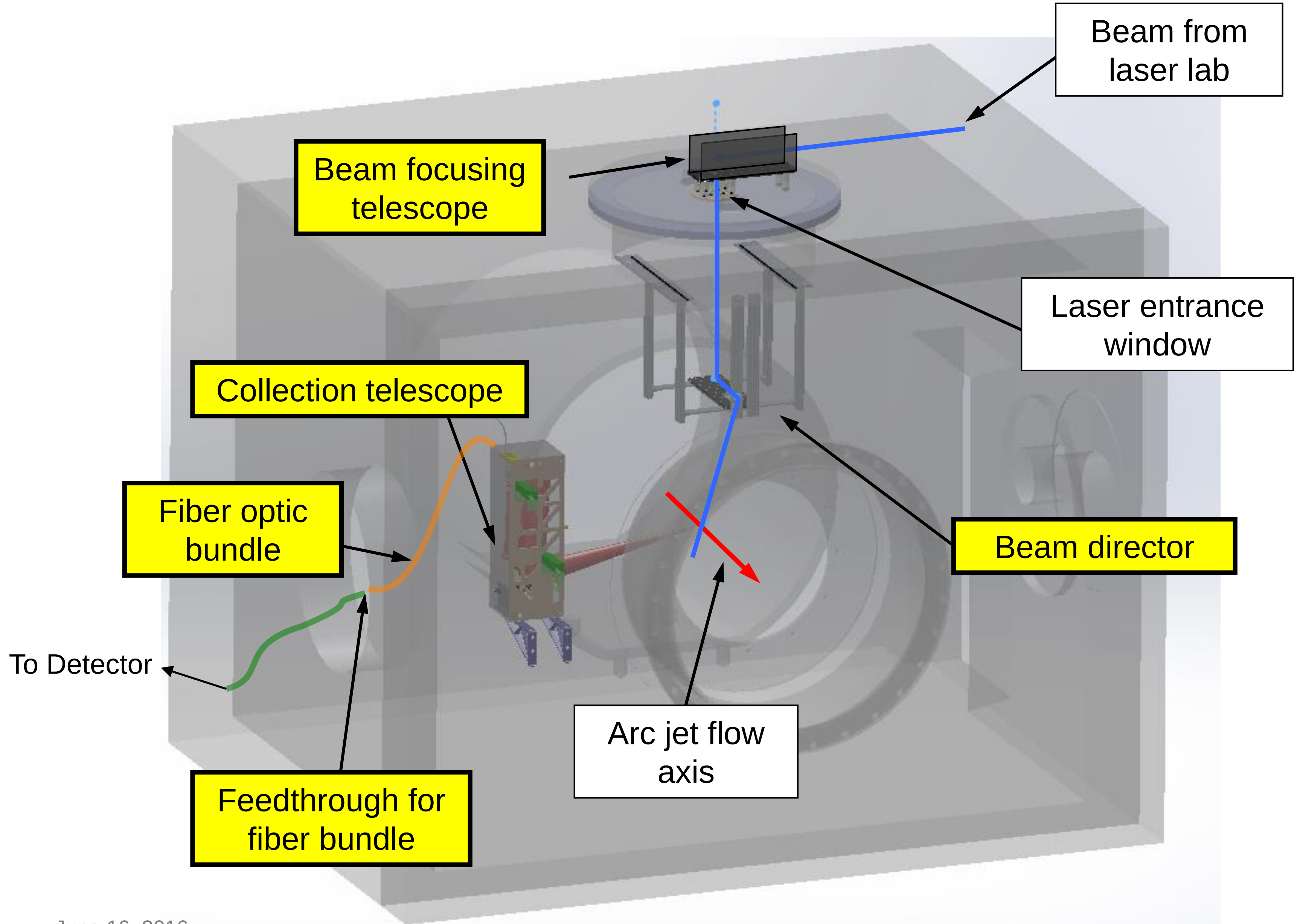
Pressure

- 0.2 – 10 torr

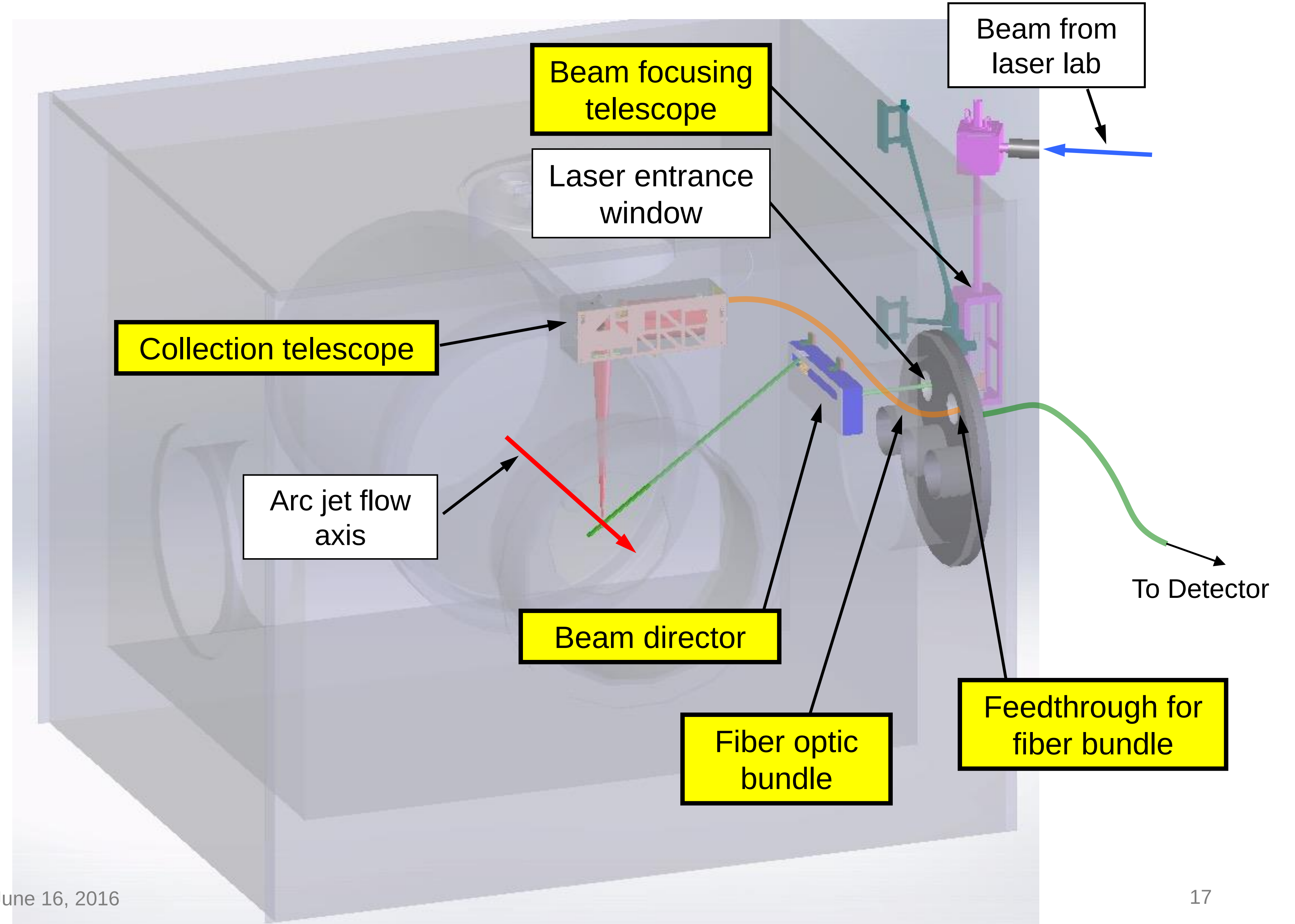
Arc jet LIF optical configuration – v.3.5



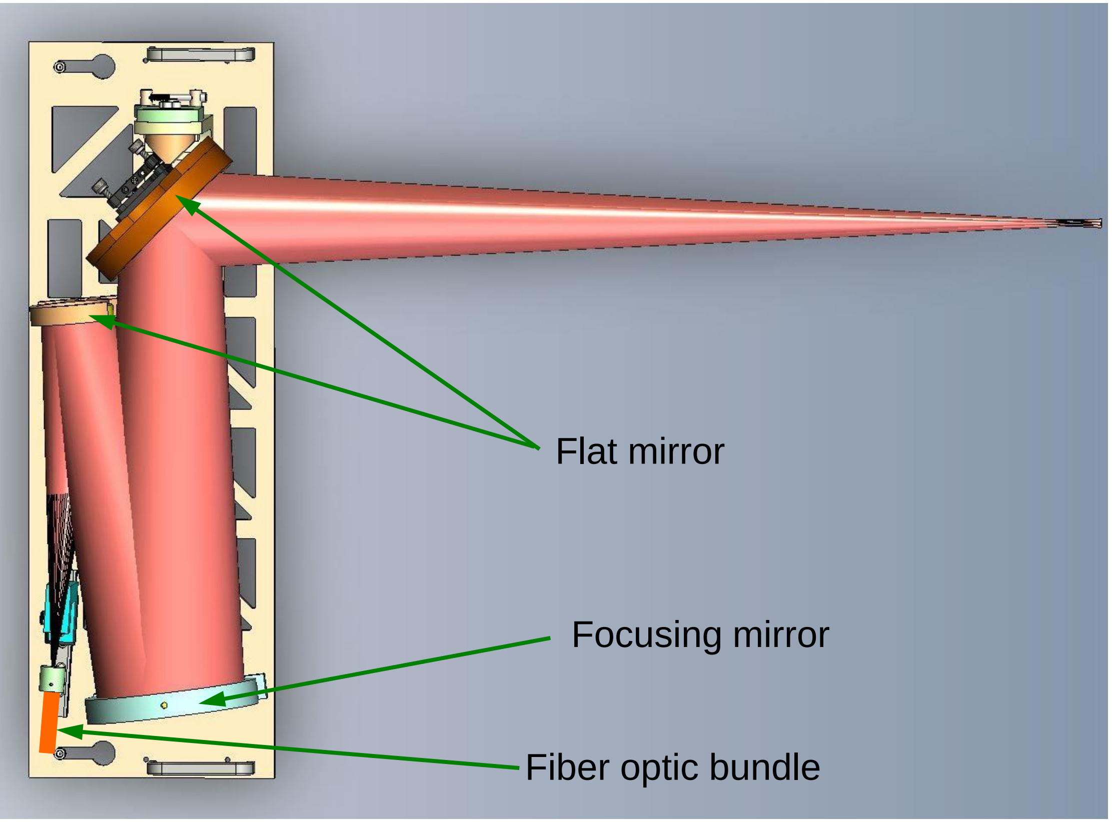
AHF LIF configuration

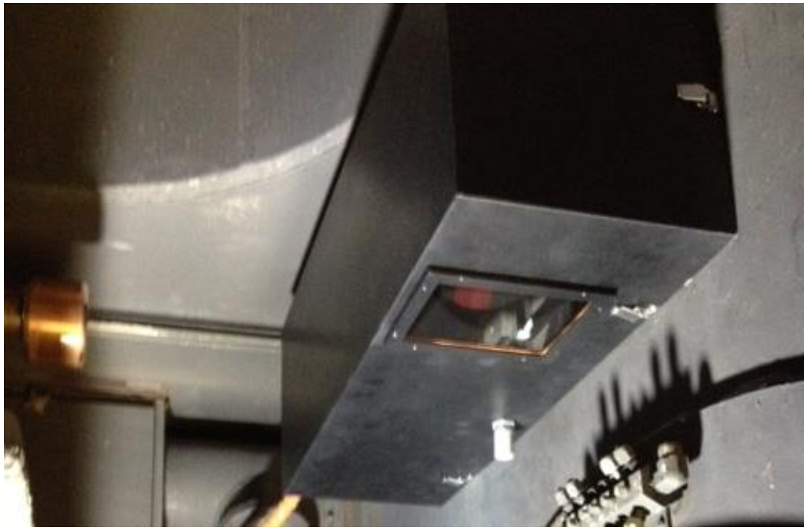


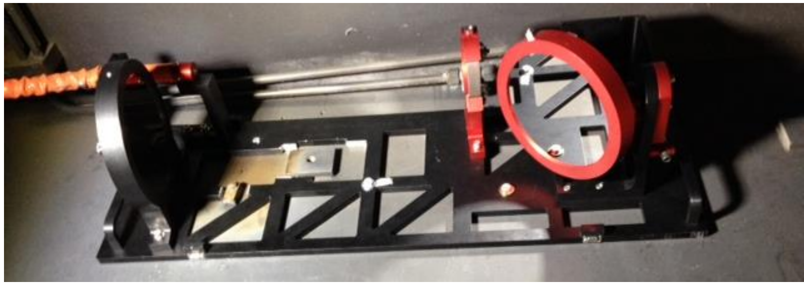
IHF LIF configuration



LIF collection telescope – v.3.5

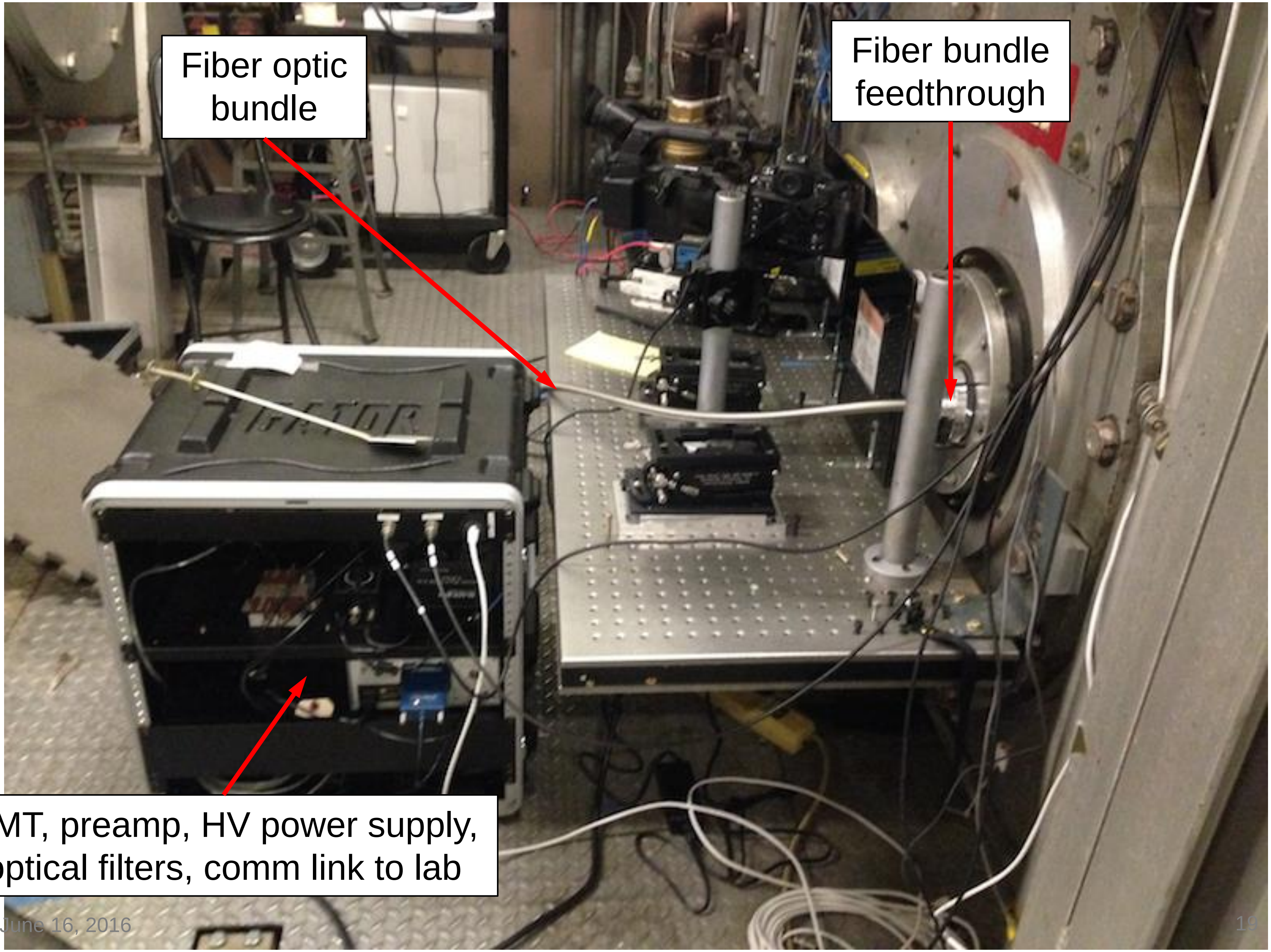




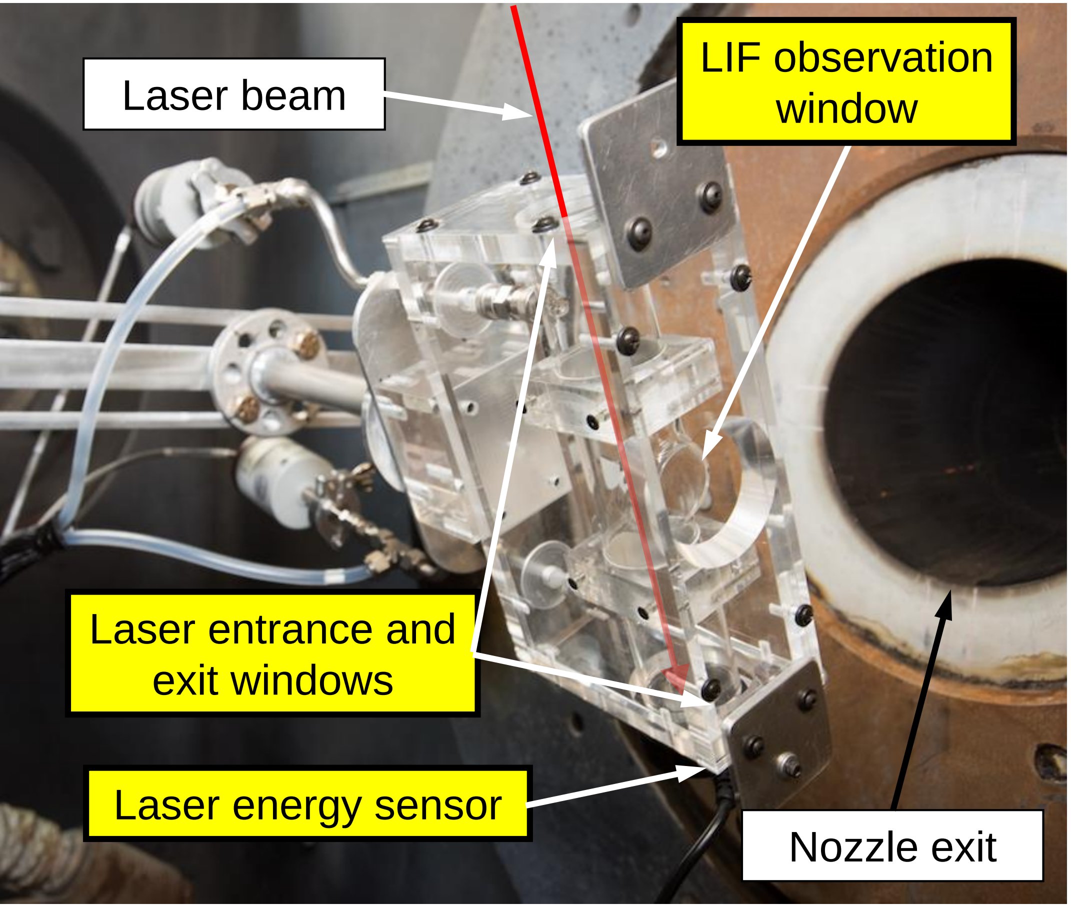


- Reflective optics
- Imaged fluorescence is coupled out of facility through fiber optic bundle
- One telescope – used in both facilities

Fiber bundle and integrated LIF detector – v.3.5



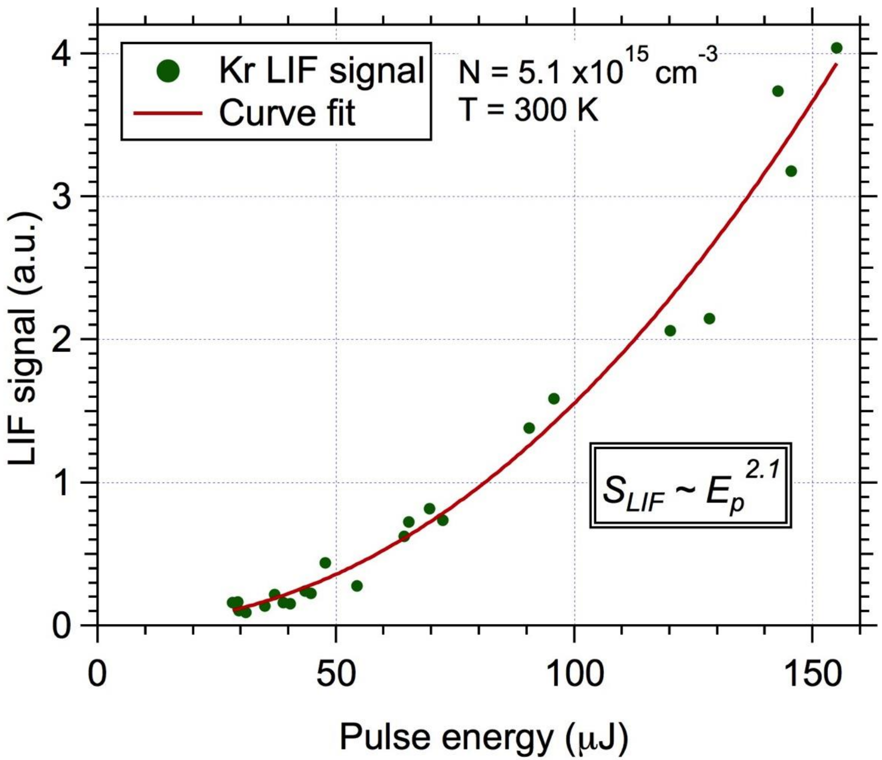
Arc jet Kr, Xe calibration source



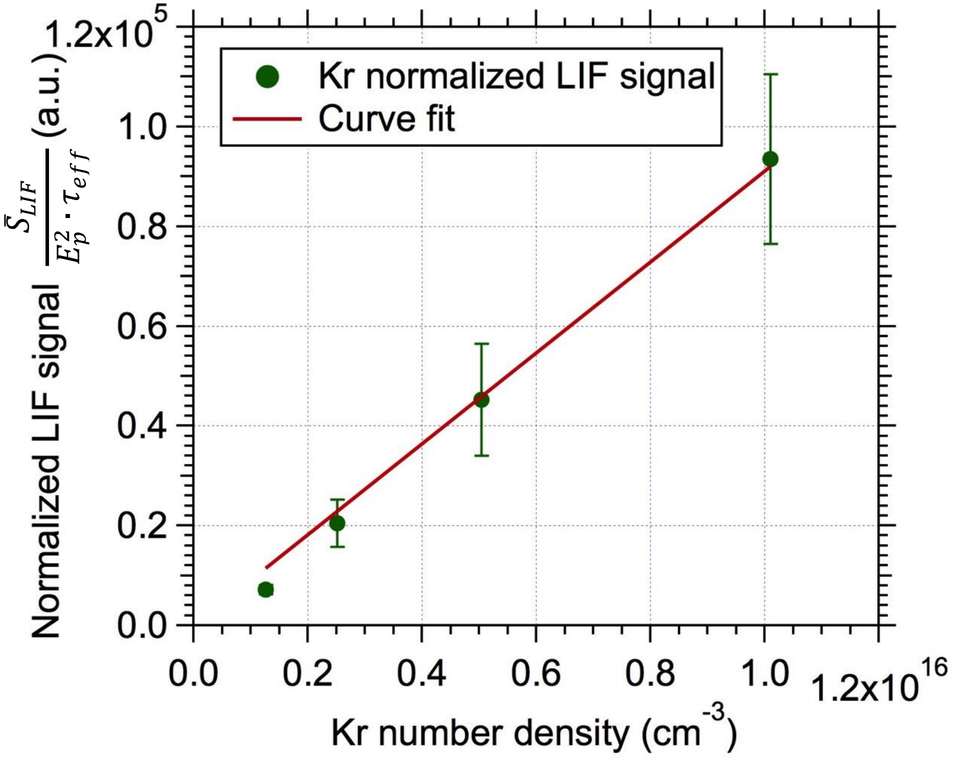
Gas supply and vacuum system

- Glass tube flow cell with optical access windows
- Programmable mixtures of Kr or Xe (~ 10^{14} – 10^{16} cm^{-3})

Example validation experiment results



Quadratic pulse energy dependence



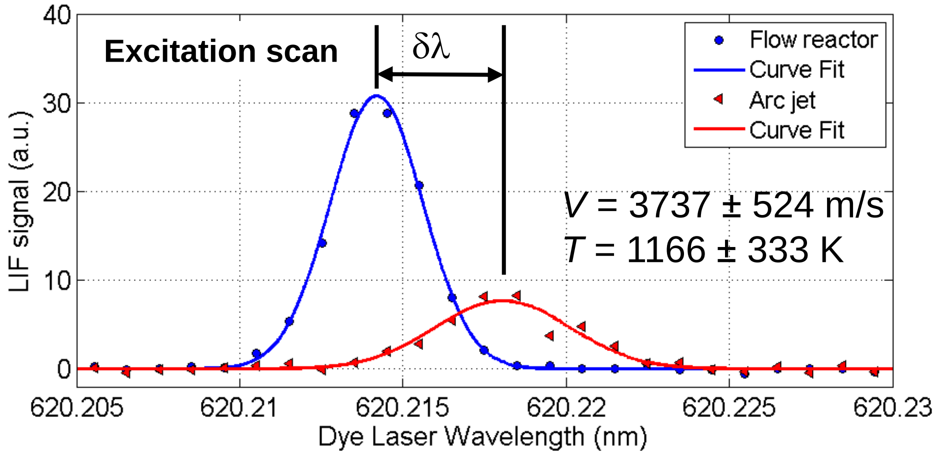
Linear density dependence

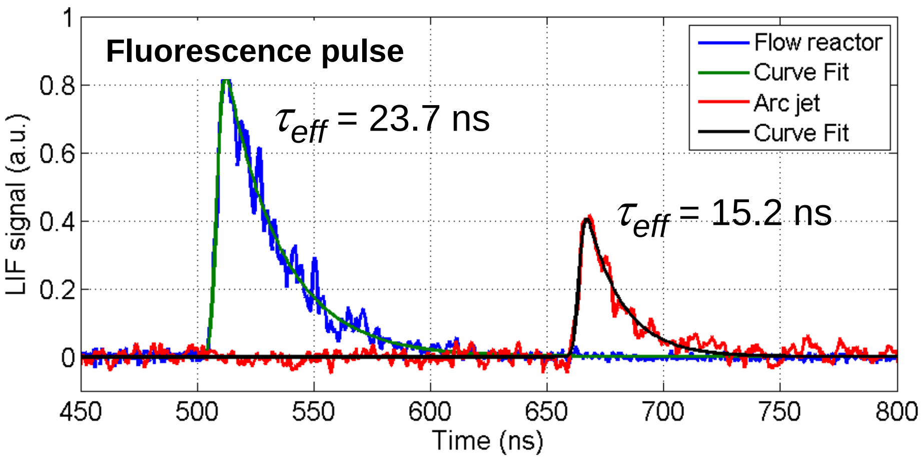
- Ensures conformance to TALIF theory for signal interpretation
- Enables quantification of random error for uncertainty estimates

Demonstration test results – AHF

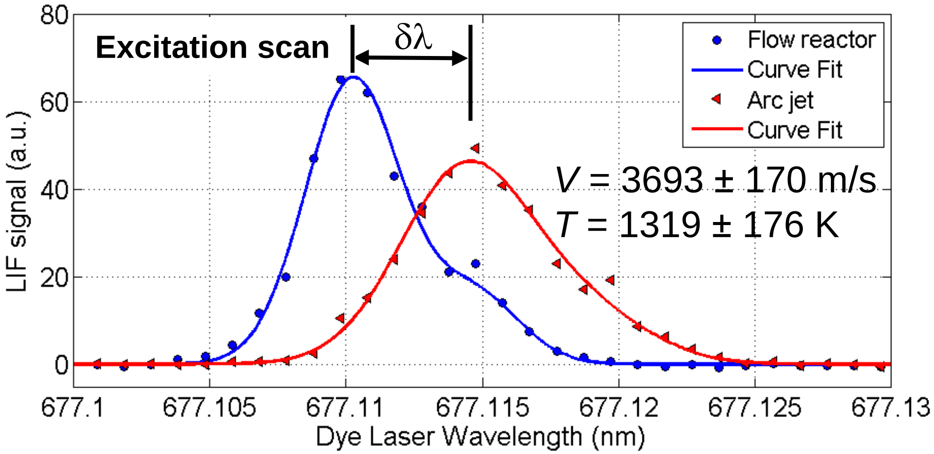
AHF (TP-3 arc heater) •7.5” dia. nozzle •Z = 6.0”	Arc Current (A)	N_2 Flow (g/s)	O_2 Flow (g/s)	Add Gas (N_2) Flow (g/s)	Enthalpy (MJ/kg)
	1205	**177**	**71**	**62**	**19.7**

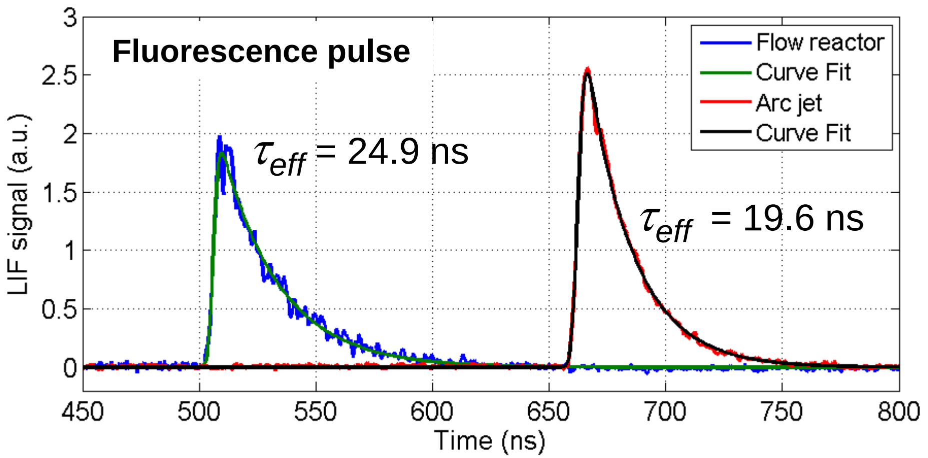
Nitrogen





Oxygen

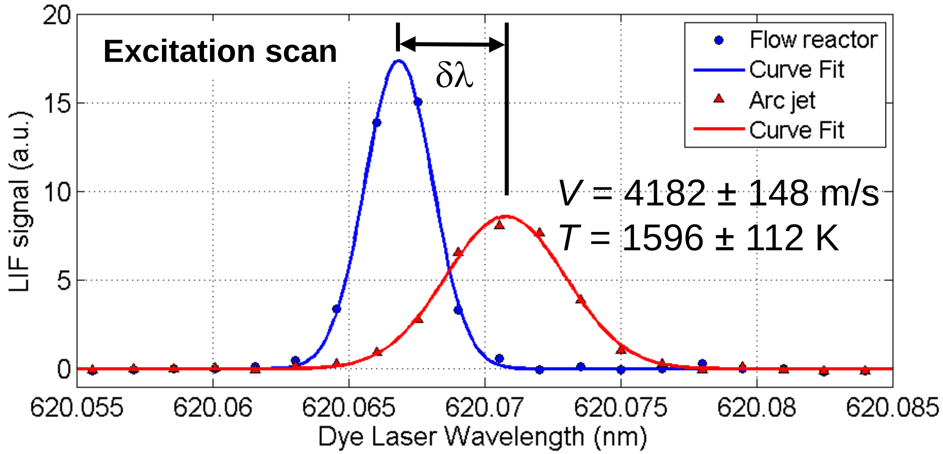




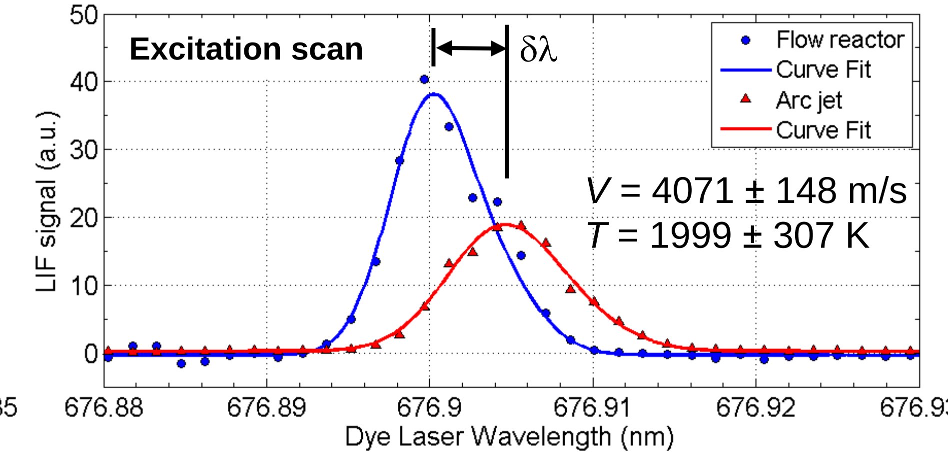
Demonstration test results – IHF

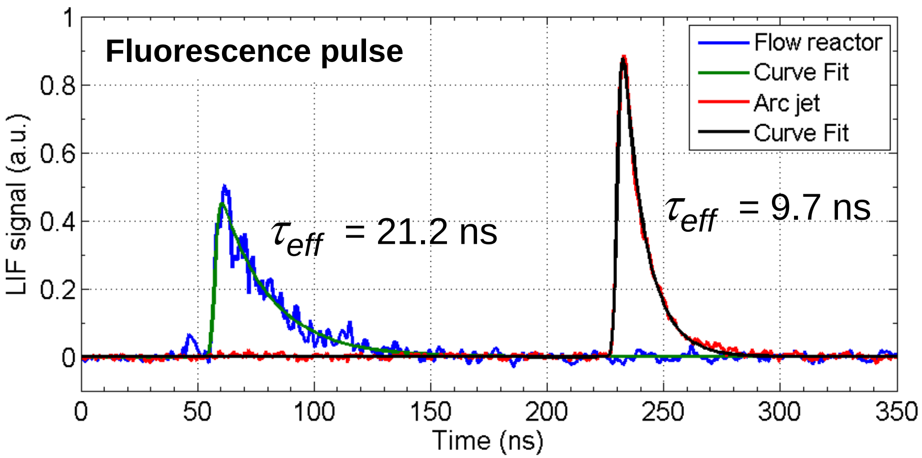
IHF •6" dia. nozzle •Z = 4.0"	Arc Current (A)	Main Air Flow (g/s)	Add Air Flow (g/s)	Enthalpy (MJ/kg)
	3571	**137**	**165**	**27.1**

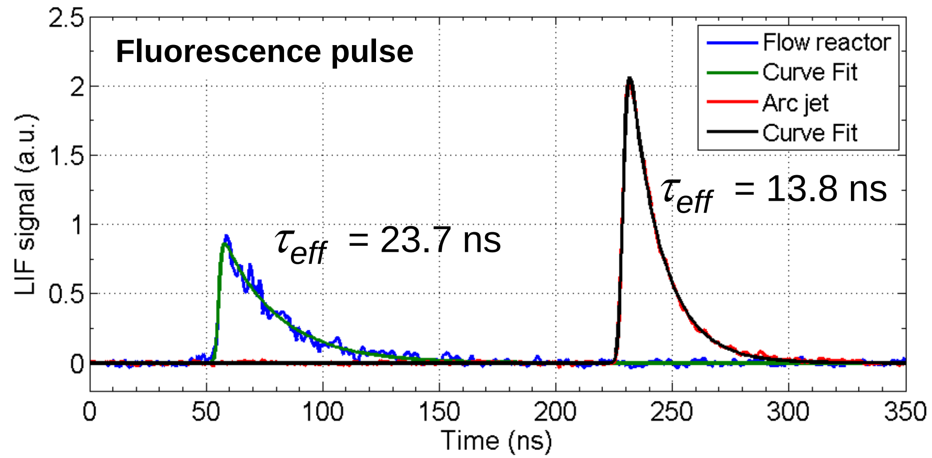
Nitrogen



Oxygen







Summary and next steps

- Revised LIF system design for the Ames arc jet facilities
  - Critical review of measurement requirements
  - Modifications to enable validation experiments
  - New arc jet LIF receiver and detector system
  - **New experiment management software**
- Updated existing IHF LIF system
- Rebuilt AHF LIF system
  - Inactive since 2005
  - Incorporated design improvements
- Both systems have identical functionality and capabilities

- Future work
  - Operational optimization
  - Comprehensive error analysis