Simultaneous two-dimensional laser-induced-fluorescence measurements of argon ions

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Abstract

Recent upgrades to the laser-induced-fluorescence (LIF) diagnostic for the Hot Helicon Experiment (HELIX) at West Virginia University have yielded a large enough increase in laser power that it is now possible to perform simultaneous measurements of the parallel (to the magnetic field) and perpendicular components of the ion velocity distribution function through LIF at a single location. The laser output, tuned to an appropriate wavelength for LIF, is split into two equal intensity beams and each of the daughter beams is individually modulated with an optical chopper. The two beams are then injected parallel and perpendicular to the magnetic field with different optical assemblies. A single optical assembly collects light from the crossing point of the two injected beams. The collection optics consists of lenses, an optical fiber for light transport, and a narrow-band photomultiplier tube (PMT) filtered at the fluorescence wavelength. The PMT output is monitored by two lock-in amplifiers, each referenced to one of the two chopper frequencies. The output of each lock-in corresponds to the respective injection orientation. We present our first results from this optical configuration. The laser was tuned to 611.662 nm (vacuum wavelength) to pump the Ar II 3P_0 state, which then decays to the 4s2D_2 state by emitting 611.086 nm photons.

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Overview of Laser-Induced Fluorescence (LIF)

1. In a typical LIF measurement, the frequency of a very narrow bandwidth laser is swept across a collection of ions or atoms that have a thermally broadened velocity distribution.

2. An atom or ion absorbs a photon when it is at the appropriate frequency in its rest frame.

3. After a short time, depending on the lifetime of the excited state, the atom or ion emits a photon, either at the same or another frequency.

4. Measuring the intensity of the emitted photons as a function of laser frequency constitutes an LIF measurement.

Diagnostic Setup

- 1 W output power
- ±10 MHz linewidth
- The dye used for the measurements reported here was Rhodamine-6G.
- The dye laser is tuned near 611.662 nm (vacuum wavelength) to pump the Ar II 3P_0 state to the 4s2D_2 state, which then decays to the 4s2D_2 state by emitting 611.086 nm (vacuum) photons.
- 5% of the output of the Matisse-DR is picked off via a beamsplitter for diagnostic purposes.
- The diagnostic beam is passed through an iodine cell for a consistent zero-velocity reference measurement.
- Fluorescent emission from the iodine cell is detected with a photodiode for each scan of the dye laser wavelength.
- The wavelength is also measured via a Bristol Instruments 621-VIS with dye laser.
- The remainder of the output is split with a 50-50 beamsplitter into two daughter beams.
- Each is modulated by a Stanford Research Systems SR540 mechanical chopper. The two choppers run at different frequencies.
- Each is coupled into a multimode, non-polarization-preserving optical fiber to transport laser light to the injection optics.
- One fiber connects to the parallel injection optics.
- 2.54 cm o.d. collimating lens
- Orbital polarizer ¼-wave plate for circular polarization, so that only the o transition with 
  n = 1 is pumped.
- For absolute flow measurements, it is necessary to account for Zeeman splitting.
- The other fiber connects to the perpendicular injection optics.
- 2.54 cm o.d. collimating lens
- Linear polarizer which is aligned with the magnetic field
- Imaging of the two transitions (Jn=0, 1)
- The much larger Zeeman splitting of the gamma transition (Jn= ±1) is avoided.
- The IFB is filled with a single thermally broadened Gaussian function.
- The internal Zeeman splitting of ±1, Stark broadening, the natural linewidth of the absorption line, and the laser linewidth are ignored in comparison.
- The two injection beams intersect at a single spatial location.

Collection optics:
- consist of a multimode fiber cable
- 2.54 cm outer diameter (o.d.) collimating lens
- matching numerical aperture (NA) (NA = 0.22) to maximize light collection
- The line of sight is perpendicular to both injection beams.
- The lens is focused on their crossing point.
- The output of the collection fiber is filtered via a narrowband filter (1 nm bandwidth around 461 nm).
- The collection fiber is connected to a Stanford Research Systems SR540 mechanical chopper.
- The two choppers run at different frequencies.
- Each collection beam is focused on the LIF output port, the diagnostic beam is filtered via a narrowband filter (1 nm bandwidth around 461 nm).
- The lens is focused on their crossing point.
- Each is modulated by a Stanford Research Systems SR540 mechanical chopper. The two choppers run at different frequencies.
- Each is coupled into a multimode, non-polarization-preserving optical fiber to transport laser light to the injection optics.

The output of the PMT is teed into a pair of Stanford Research Systems Waveform Recorder.
- Each lock-in is referenced to the mechanical chopper on one of the injection beams.
- Background which is not correlated with either modulation function can be eliminated, and the fluorescence from the parallel and perpendicular injection beams is separated.

The HELIX Experiment

- Pyrex tube
- 61 cm long
- 10 cm in diameter
- Stainless steel chamber
- 91 cm long
- 15 cm in diameter
- Conflat™ crossing ports
- Four 6-inch ports in the center of the chamber.
- Three sets of four 2-inch ports on either side.
- 2 m diameter space chamber, the large experiment on Instabilities and Anisotropies (LEIA).
- 1.8 m, half-wave, helix RF antenna
- right-handed relative to the magnetic field direction.
- Designed to launch the m=-1 helicon wave toward LEIA.
- A common electrical ground is used for the vacuum chambers and the rf amplifier.
- Parameter settings:
  - 800 G uniform magnetic field in HELIX, zero magnetic field in LEIA.
  - Around 3 millitorr argon fill pressure.
  - 500 W RF at 9.5 MHz.

Simultaneous Parallel and Perpendicular LIF Measurements

-Difference in amplitudes reflects difference in amplifier gain settings.
-We have implemented a multiplexed LIF scheme that allows for measurements of two components of the ion velocity distribution function.
- The scheme can easily be extended.
- More detection locations.
- More injection locations.
- Time-resolved LIF.

Summary

-We have implemented a multiplexed LIF scheme that allows for simultaneous measurement of two components of the ion velocity distribution function.
- The scheme can easily be extended.
- More detection locations.
- More injection locations.
- Time-resolved LIF.