NSTX High-Speed color camera as a low resolution Spectrometer

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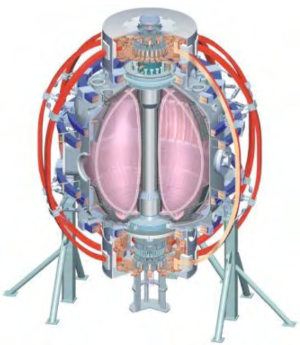

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Abstract

NSTX has recently installed a high-speed 10-bit color camera having a wide-angle global view of the plasma. The camera is typically operated from 1.5 – 5 kHz depending on the desired spatial resolution. The high-speed aspect of the camera yields information on the overall plasma behavior, while the colors gives an indication of the dominant elements involved. For instance, neutral deuterium and helium are readily identified as a red and yellow glow respectively, and especially during the plasma fueling, their spectra can be easily discerned. With the introduction of lithium into NSTX, the camera readily reveals the orange glow from Li I and the bright green associated with the Li II state, depending on the local temperature. Narrow green filaments are often observed to spiral around the center stack or propagating along the last closed flux surface. Bright flares of Li are observed when the plasma interacts with material surfaces or even dust particles. Several methods of displaying the 10-bit color can be used to emphasize details of the discharges. Many example movies will be available to demonstrate the camera's capabilities.

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Specifications

Phantom Miro 2

With its full-featured portability, the Miro 2 has the power to get the great quality high-speed images that you need, virtually anywhere

Key Features:

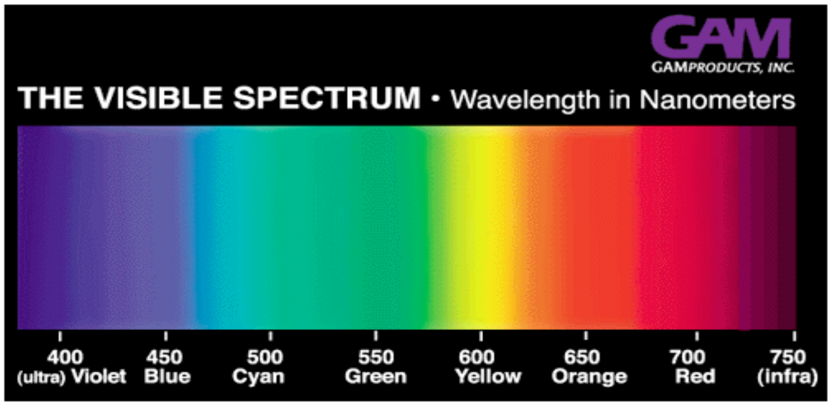
Resolution: 640x480
Frame rate: 10 - 1,000pps maximum full frame 640x480
Minimum exposure: 5 microseconds
Sensitivity: 4800 ISO monochrome, 1200 ISO color (ISO 12232)
Built-in memory: 1GB or 2GB (optional)
Nonvolatile memory: CompactFlash removable
Pixel bit-depth: 8-bits standard, 10-bits optional
Record time: 13.9 seconds at 500 fps (2GB memory, 8-bit)
Camera control: 10/100 Ethernet
Camera signals: Trigger, Strobe, Video Out
Video out: PAL & NTSC
Lensing: 1" C-mount
Size: 4.4" x 3.4" x 3.1" (W x D x H); 11.2cm x 8.cm x 7.9cm
Weight: 2.5 lbs, 1.1 kg
Power: 12-32VDC, 12W
Battery: LI-ion

Active Pixel Window Size and Maximum Speeds:

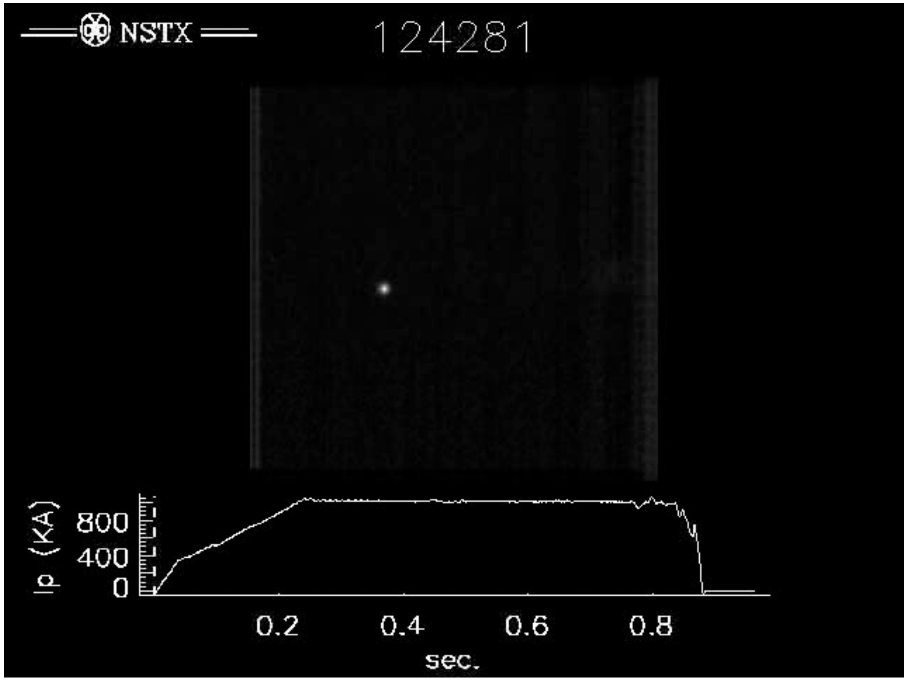
H	V	FPS
640	480	1,258
512	480	1,558
512	384	1,941
512	256	2,892
512	128	5,665
512	64	10,869
320	240	4,756
256	480	2,969
256	256	5,471
256	192	7,192
256	128	10,526
256	64	19,607
128	128	18,433
128	64	32,520
64	64	48,192
32	32	86,959
32	16	105,263

Wavelengths of Interest

Element	A°
C-I	5380, 6013, 9090
C-II	4267,6585, 6578, 7236
C-III	4649
L-I	6708
L-II	5485
Dα	6560
He-I	5870
He-II	4680, 4685
Ne-I	6402,6929, 7032, 7173, 7245,7488, 7438



Wide angle Black and White view of NSTX

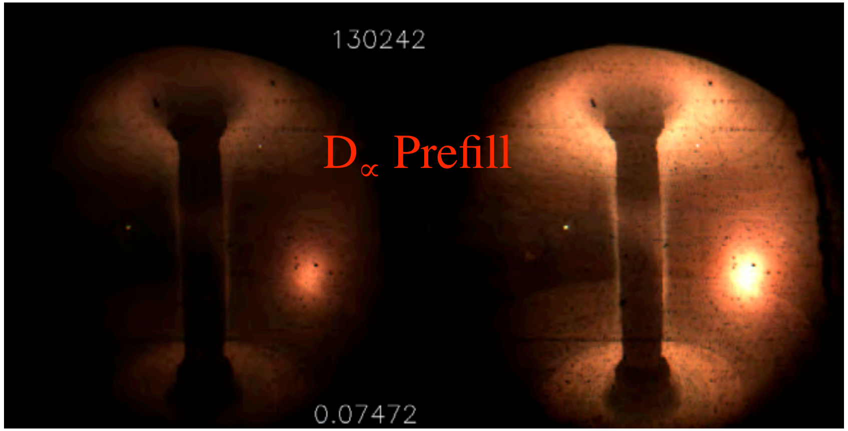


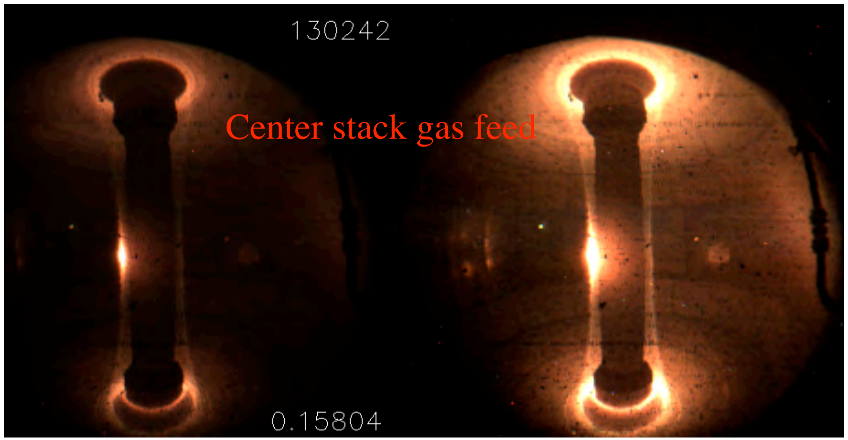
- The dust particles from the center stack are believed to be lithium
- Higher frame rates make the filaments sharper.

D_α (6560 A°) gas injectors

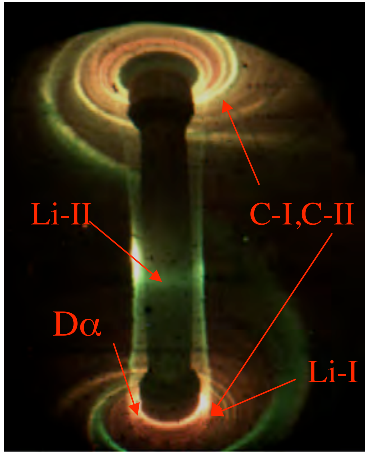
Lower 8 bits

Top 8 bits

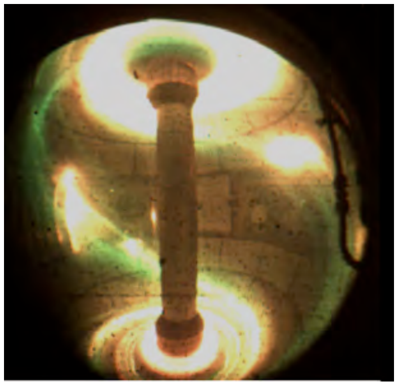




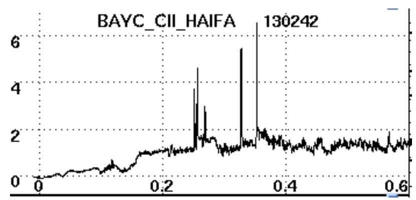
Elements visible during small ELMs

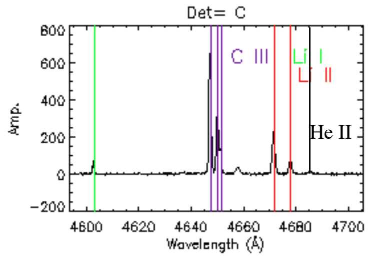


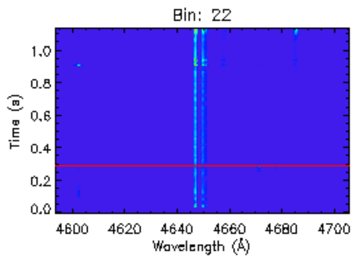
- Li-II is clearly green
- Red to orange color may be a variety of elements
- Yellow is C-I,He-I and both are seen during an ELM or He plasmas
- Spectroscopy still required to be certain



When plasma contacts surfaces, Li, He and C signals are substantially increased. He is residual from He GDC, Li- is deposited from LITER, Carbon is PFC tile material







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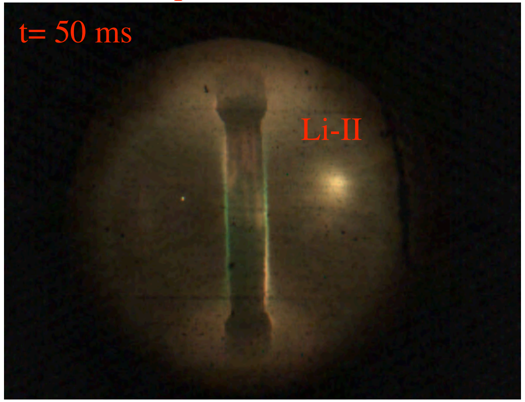
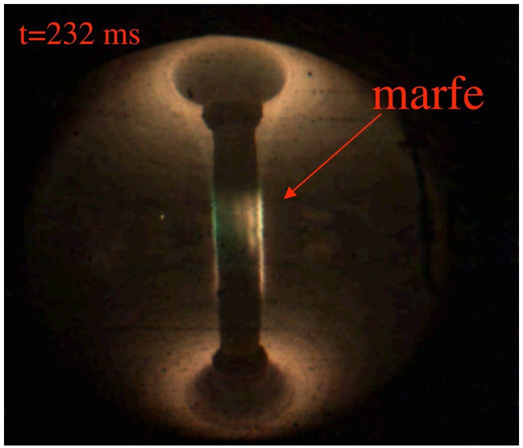
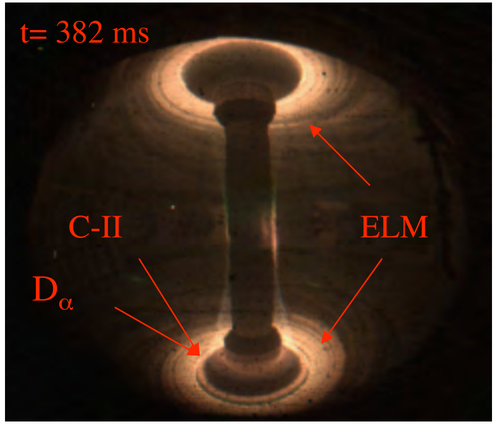
He Plasma evolution

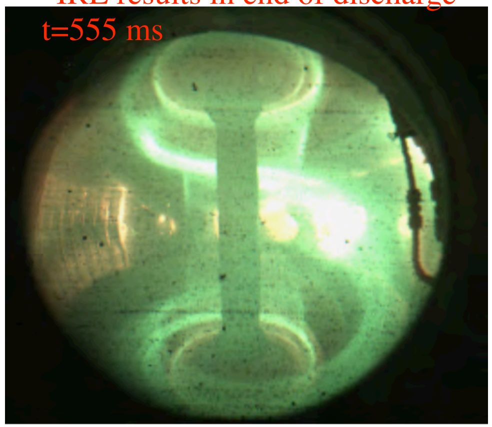
He prefill from SGI



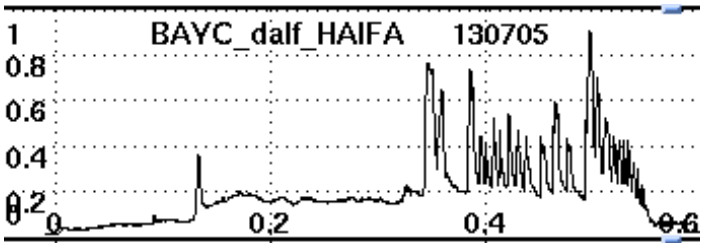


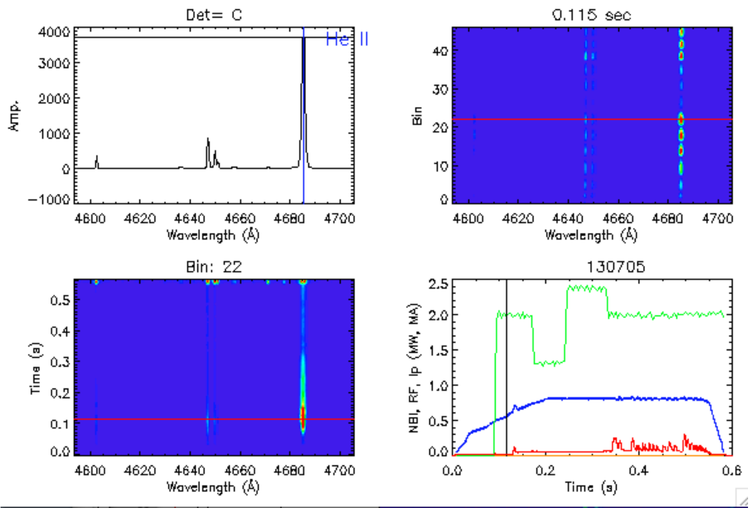


IRE results in end of discharge



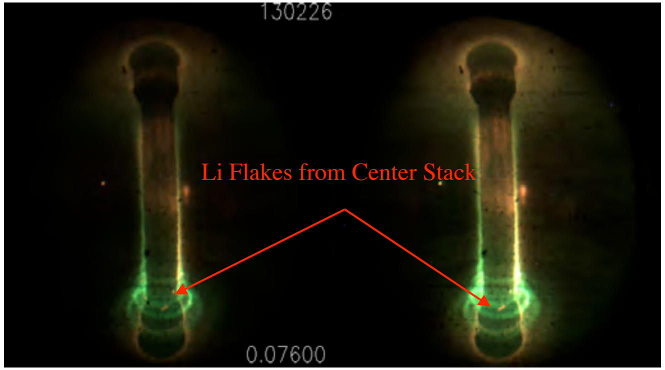
He plasma with Dalpha recyling from divertor

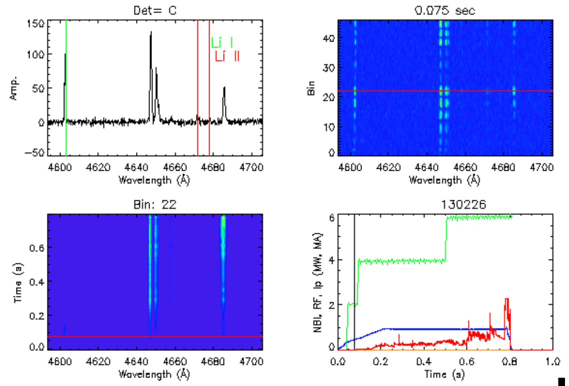




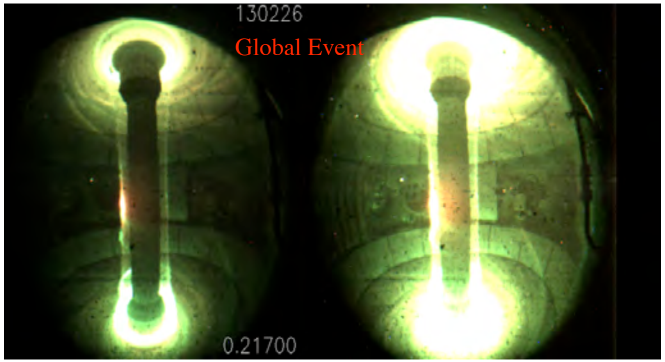
Li flakes from the center stack are visible as Li II

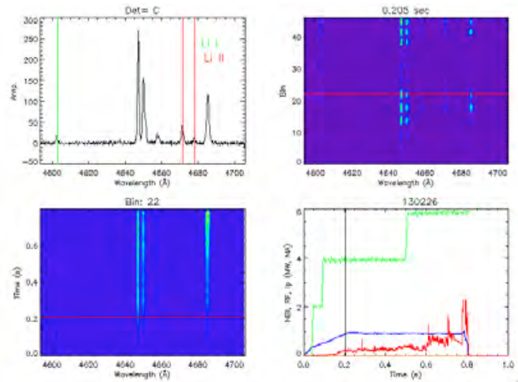
Li flakes from center stack are not observed in the core





Global events (large ELMS) spread Li II throughout the plasma





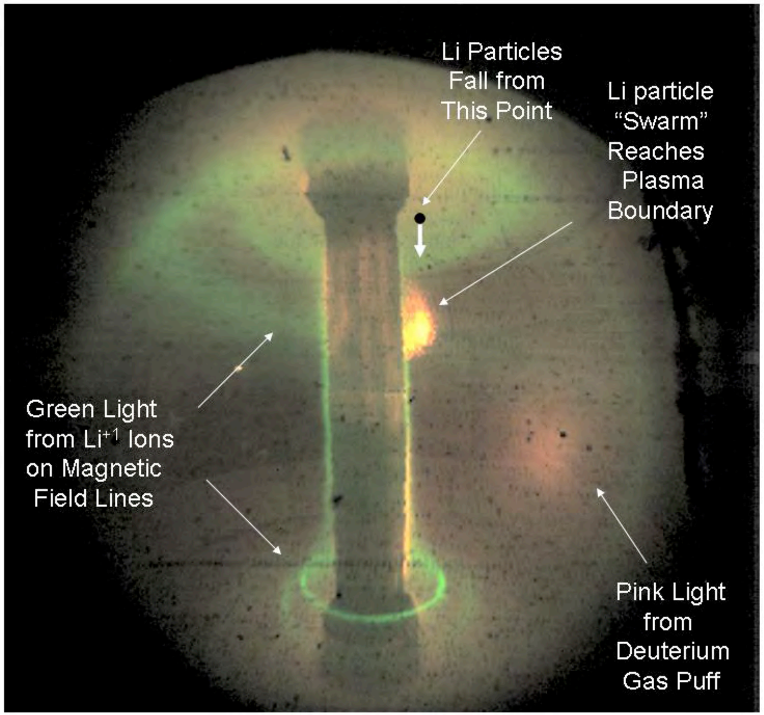
Li Has Unique Energy Structure – Easy to Create Li^{+1}

Can We Exploit This to Save Early Volt Secs ?

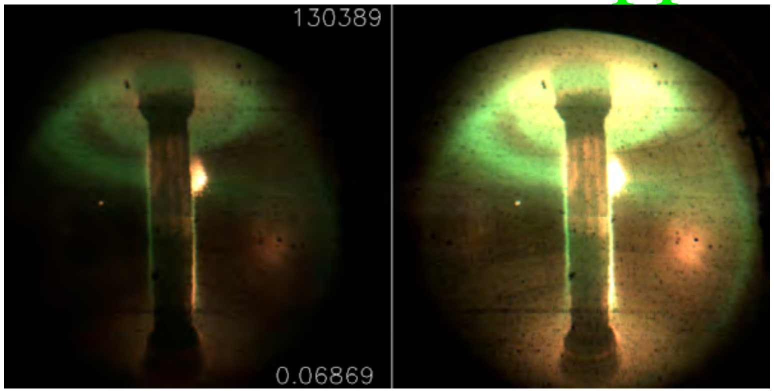
Ionization Energy (eV)

	H	He	Li	Be	B	C	N	O
+1	13.6	24.6	5.39	9.32	8.30	11.3	14.5	13.6
+2		54.4	76.6	18.2	25.1	24.4	29.6	35.1
+3			123	154	37.9	47.9	47.4	54.9

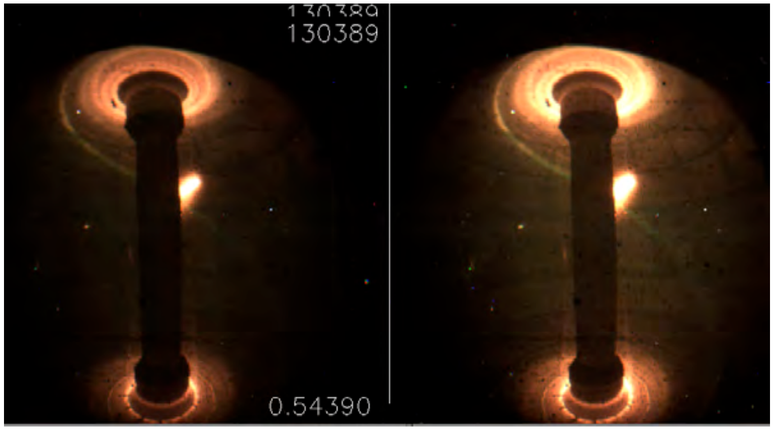
Camera View of Early Li Aerosol Injection Taken at t ~ 60 ms



Li Powder dropped into NSTX



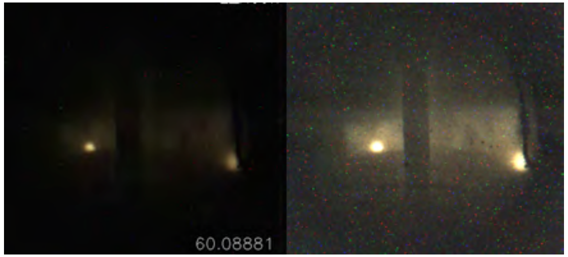
L II (5485 A°)visible early
in the discharge



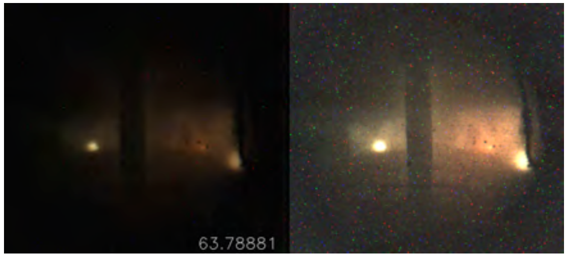
Primarily Li I (6708 A°) later
in the discharge

Li powder into plasma edge

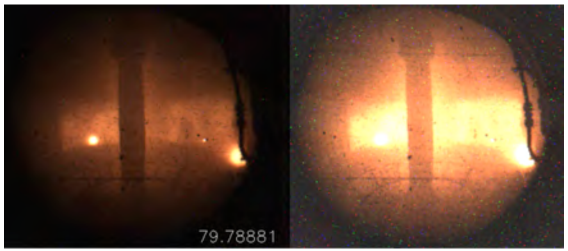
He/Neon GlowDischarge



He Glow

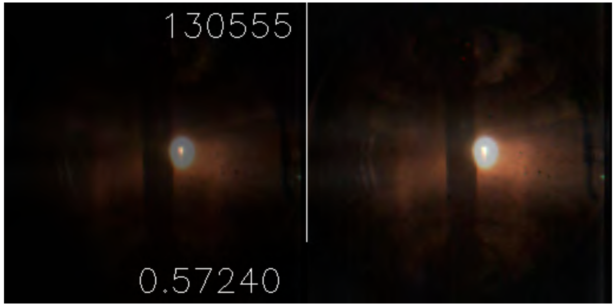


He - Neon transition

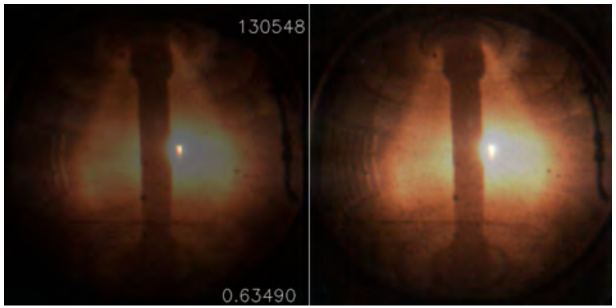


Neon Glow

NBI onto carbon tiles

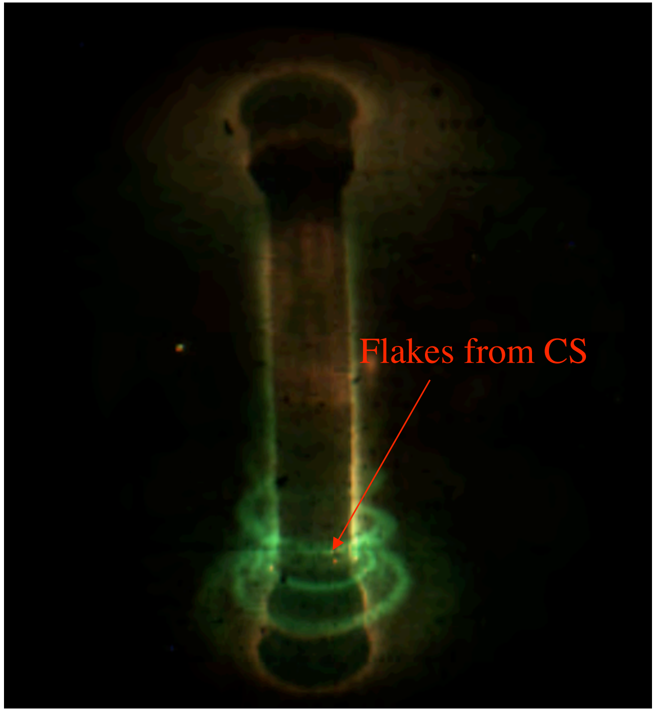


•CIII (4649 A^{o}) plume from
NBI impact on carbon beam armor

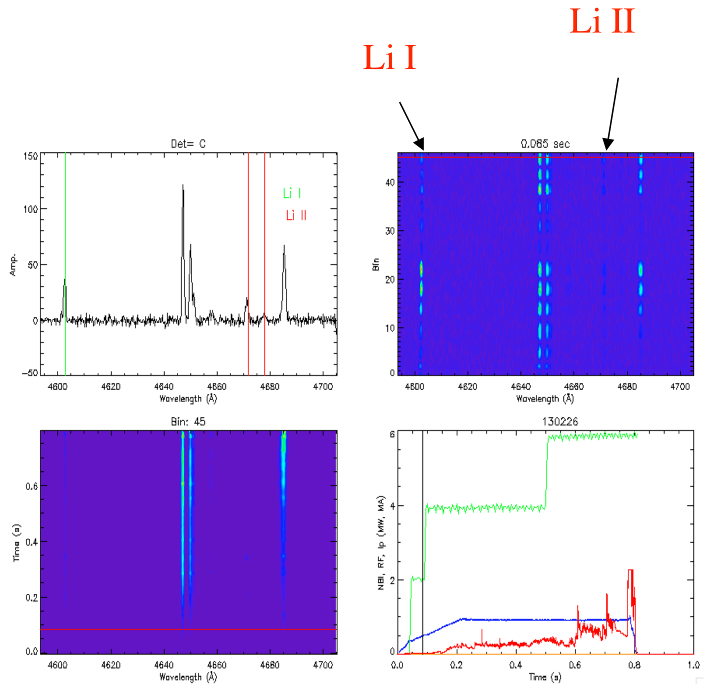


•Hint of CI and CII
in edge of plume

Li flakes from center stack

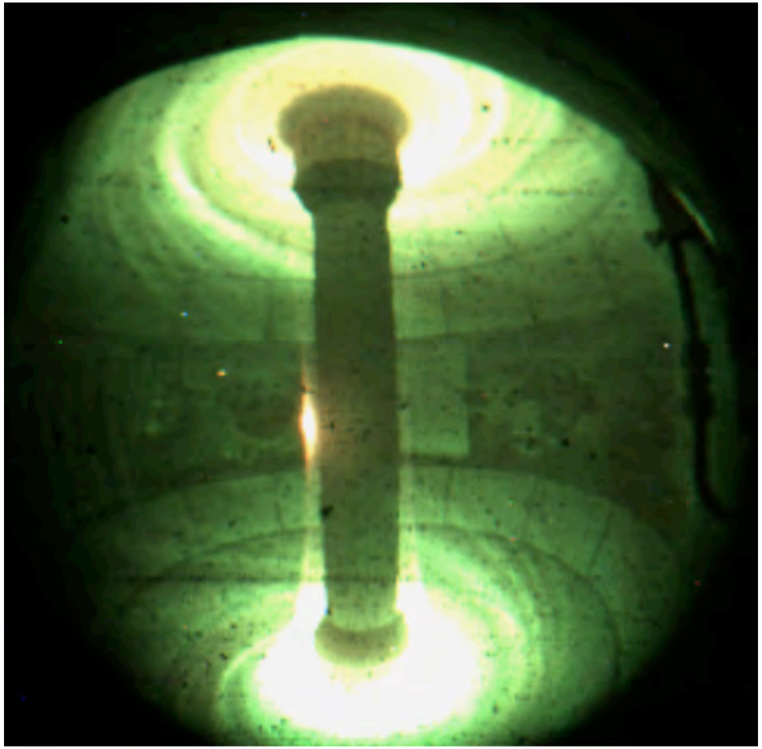


•Li originating from the center stack propagates to the edge

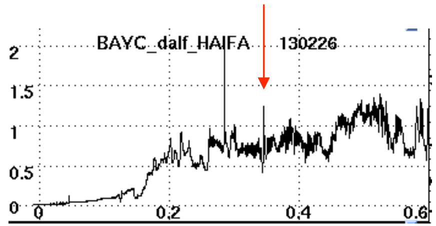


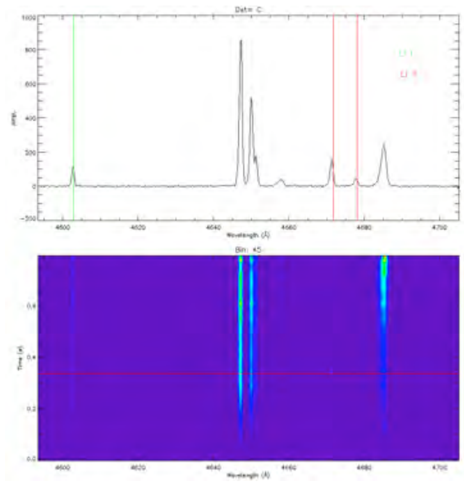
ELMs introduce Li into the plasma

130226 @ 342 ms



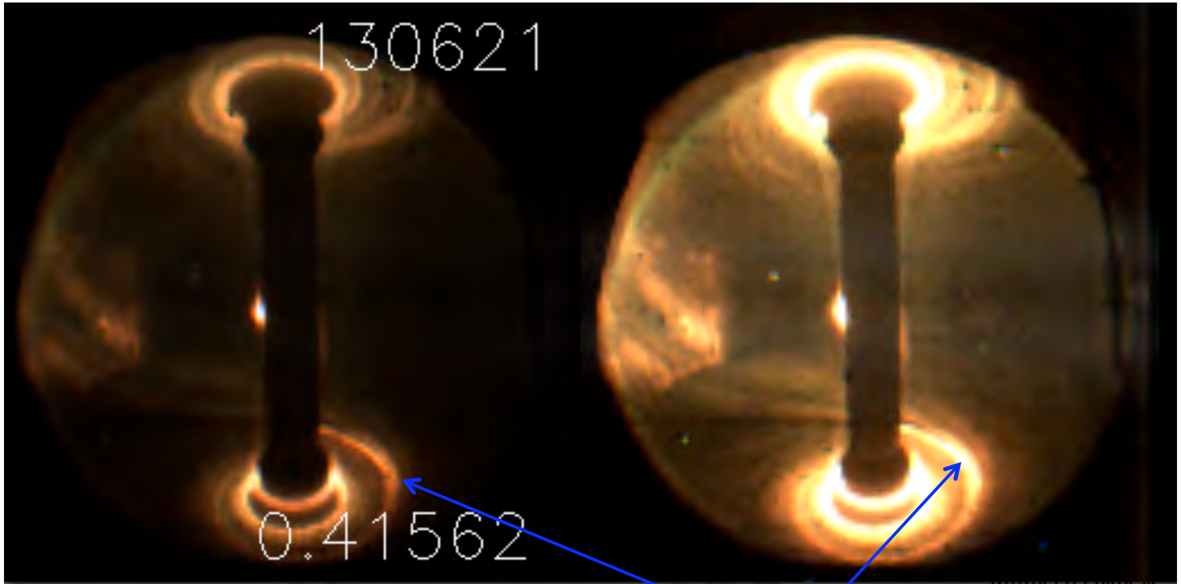
Large ELM





Fast waves propagating in the SOL appear to be heating the tiles outside the outer divertor

Fast camera view for phase = - 90° just prior to arc before elm



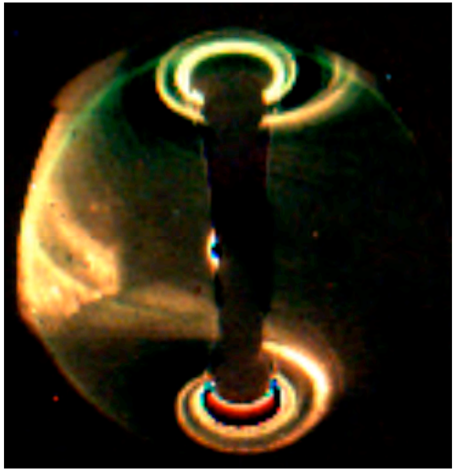
P_{RF} ~ 1.8 MW
P_{NB} = 2 MW
I_P = 1 MA
B_T = 5.5 kG

- RF interaction is localized toroidally
- Appears to be linked with antenna along field lines
- Intensity is dependent on antenna phase dies away after RF is removed
    - decay time depends on phase

Stronger interaction along field line at Lower phase/longer wavelength

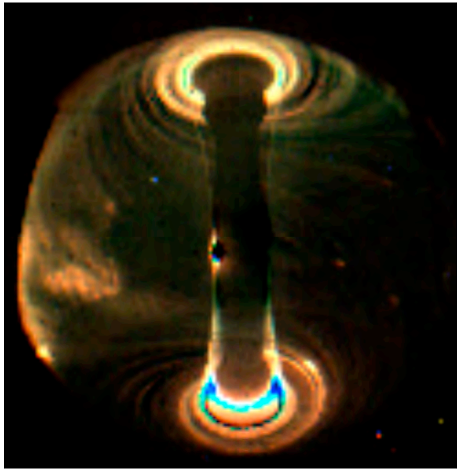
P_{RF} = 1.8 MW, P_{NB} = 2 MW, I_P = 1 MA, B_T = 5.5 kG

130621 -90°



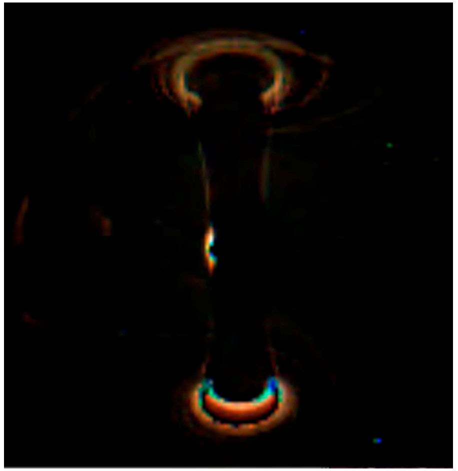
0.33512 sec (-.25012)

130608 -150°



0.33500 sec (-.25002)

130609 No RF



0.34997 sec (-.24999)

- "Hot region is much more pronounced at -90° than at -150°
  - Edge power loss is probably greater at -90°
  - Also, suggests fields move away from wall at -150° along with the onset density

Summary

Fast color images can provide qualitative details on plama behavior.

•Fill gases such as deuterium and helium are easily identified
•During ELMS, IREs He, C and Li can be seen in the strike points and in edge filaments
•During RF injection, He filaments are readily visible
•Li-II from LITER and Li dropper can dominate the image
•Dust particles can be identified between carbon and Li by the color of their ablation cloud.
•Background subtraction, bit levels, contrast, and gamma enhancement is effective in showing particular structures such as filaments and dust particle trajectories.