ENERGETIQ

LDLS™ Laser-Driven Light Source

From The Innovators in Light

The LDLS Product Range

ENERGETIQ

•EQ-99FC LDLS™ System

•Compact LDLS with fiber-coupled output

R&D 100 2011

PRISM AWARDS WINNER

•EQ-99 LDLS™ System

•Compact LDLS for free-space optics

•EQ-1500 LDLS™ System

•High brightness LDLS for free-space optics

Today's Lamp Technologies

ENERGETIQ

- Mercury Discharge

- Excimer

- Deuterium

- Halogen

- Xe & Hg Arc

- Metal Halide

All have limitations in:

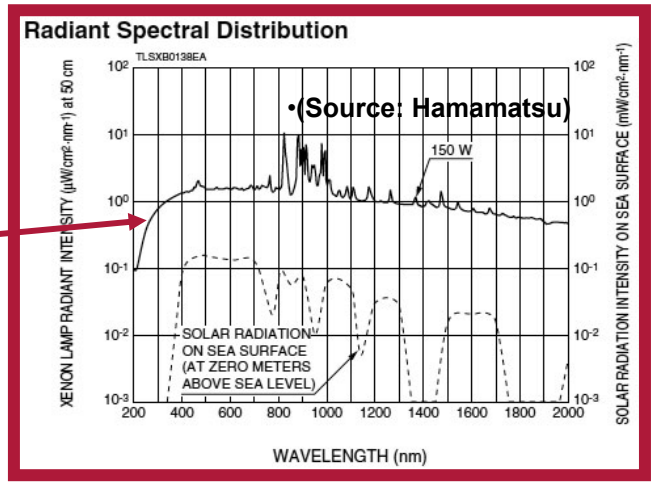
- **Brightness**
- **Lifetime/Stability**
- **Spectral Range**

Limitations with Arc-Lamps

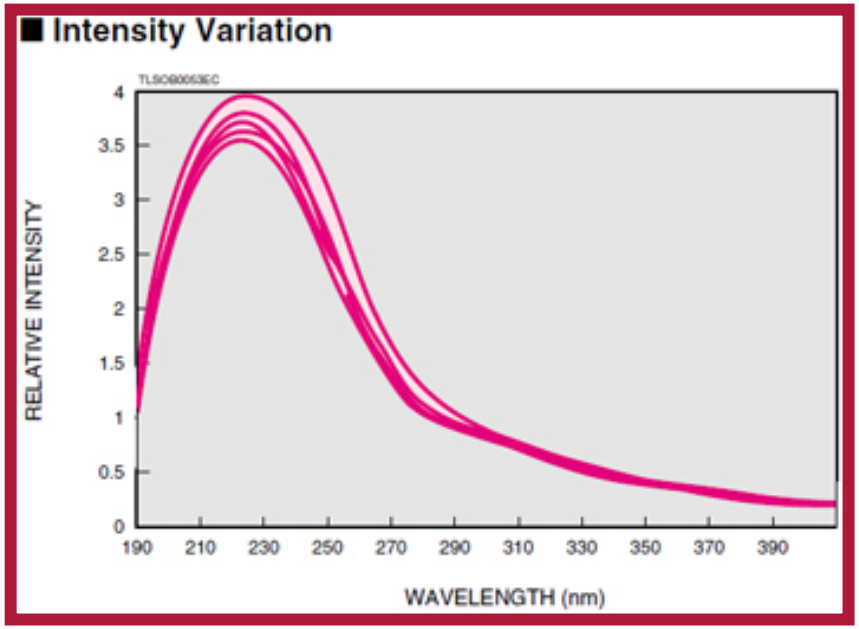
- Arc-Lamps use electrodes to conduct electrical current through the gas heat the gas to high temperature
  - The electrodes limit the temperature of the gas
    - Limited temperature leads to limited DUV
  - The electrodes erode and shorten lamp lifetime
  - Arc flicker reduces effective brightness and adds noise

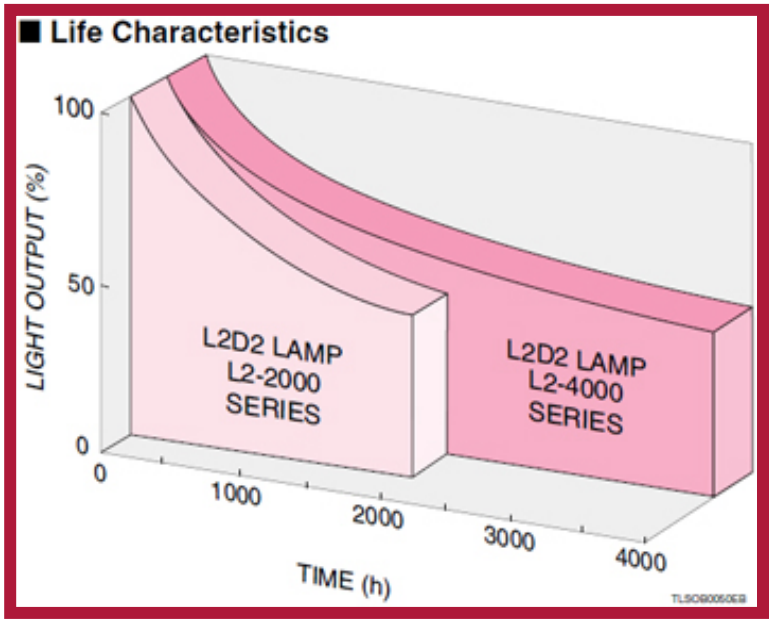
Broadband	√
Brightness	√
Stability	X
Lifetime	X

•DUV output falls below 300nm



Limitations with Deuterium Lamps



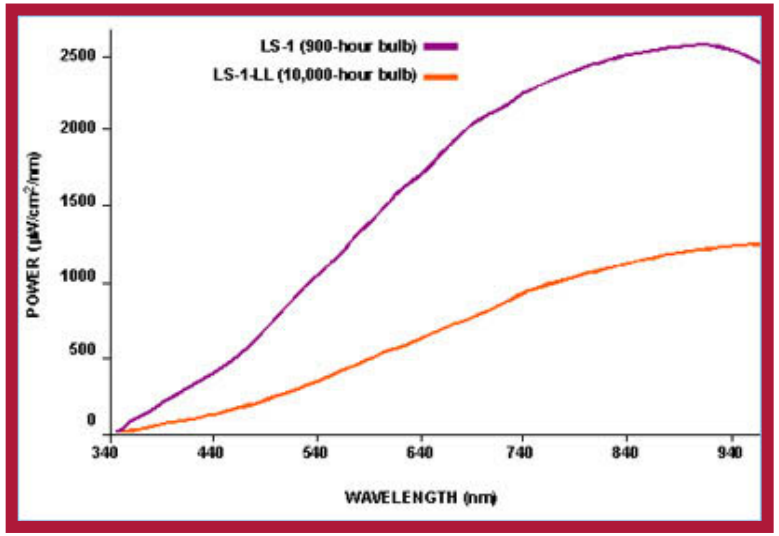


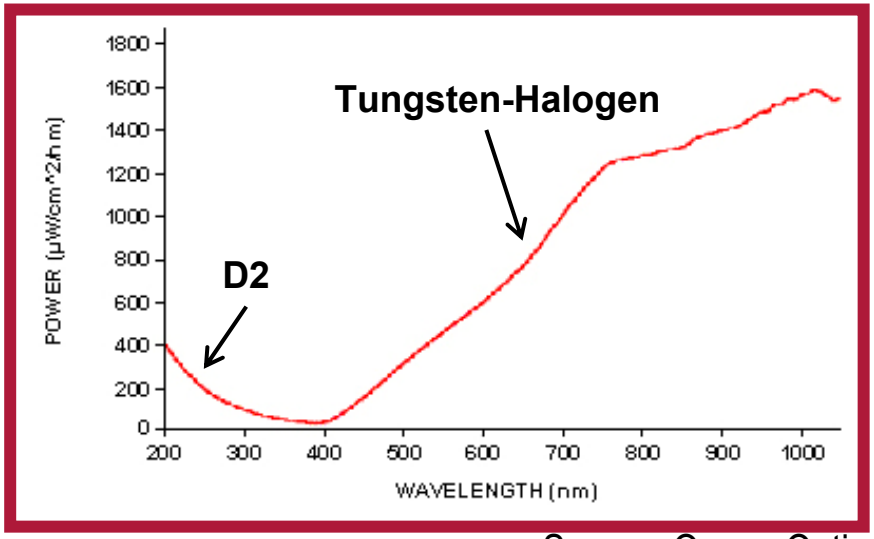
Source: Hamamatsu

Broadband	X
Brightness	X
Stability	√
Lifetime	X

- Limited wavelength range ~190nm – 400nm
- Low brightness, relatively large plasma
- Short life: 500-1000hrs to 50% output

Limitations with Tungsten-Halogen Lamps





Source: Ocean Optics

Broadband	√
Brightness	X
Stability	√
Lifetime	X

- Short lifetime, large filament area, low power <400 nm
- Usually combined with Deuterium lamp to cover broad spectrum
  - Gap in spectrum around 400nm
  - Low brightness from 2 separate emitters
  - Changing spectrum from 2 different lifetimes

ENERGETIQ

A Timely Convergence….

- Traditional Lamp sources have reached the end of their roadmap
  - Incremental improvement in recent years

+

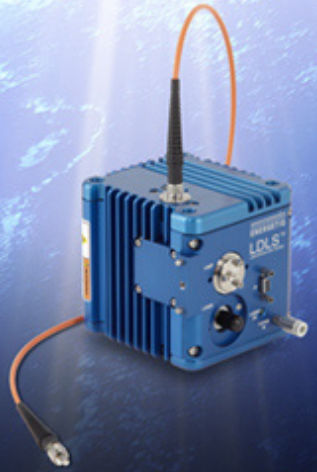
- Costs for infra-red laser diodes have fallen dramatically in recent years
  - Driven by telecom and fiber lasers for industrial applications
  - Costs continue to decline substantially each year.

=

- Catalyst for a new class of light sources that disrupts the status quo

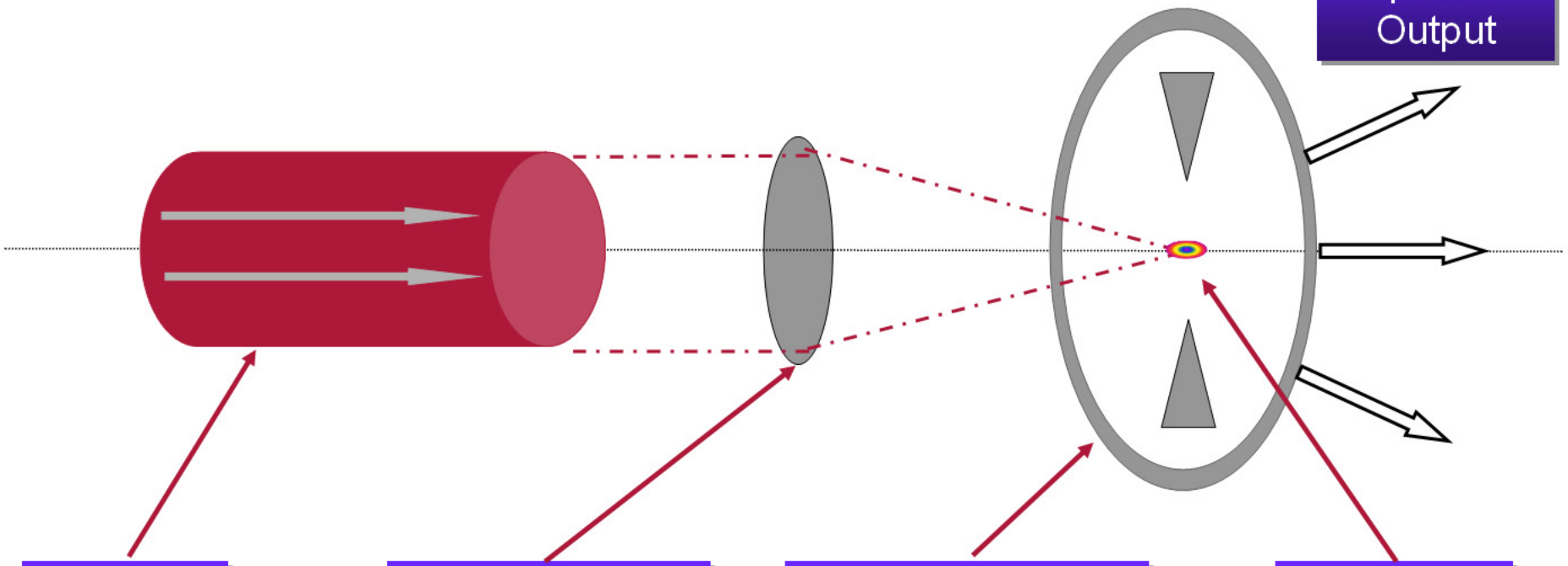
The brightest, most consistent broadband light sources since the sun

EQ-99 | EQ-99FC | EQ-1500



Laser-Driven Light Source: Principle of Operation

ENERGETIQ



•Broad Spectral Output

•Beam from CW Laser

•Laser Beam Focusing Optics

•Lamp Enclosure Containing Gas(es)

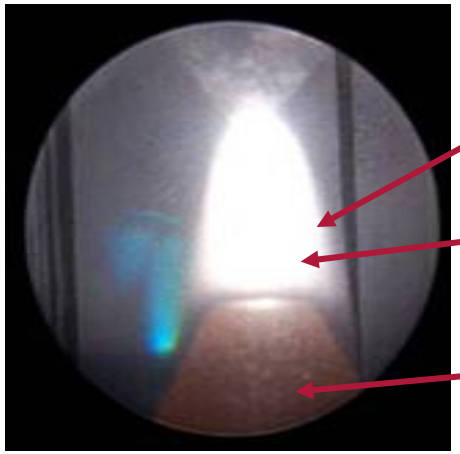
•High Intensity Plasma

•US Patent # 7,435,982

Light from Arc-Lamp and LDLS

ENERGETIQ

•Xe Arc-Lamp



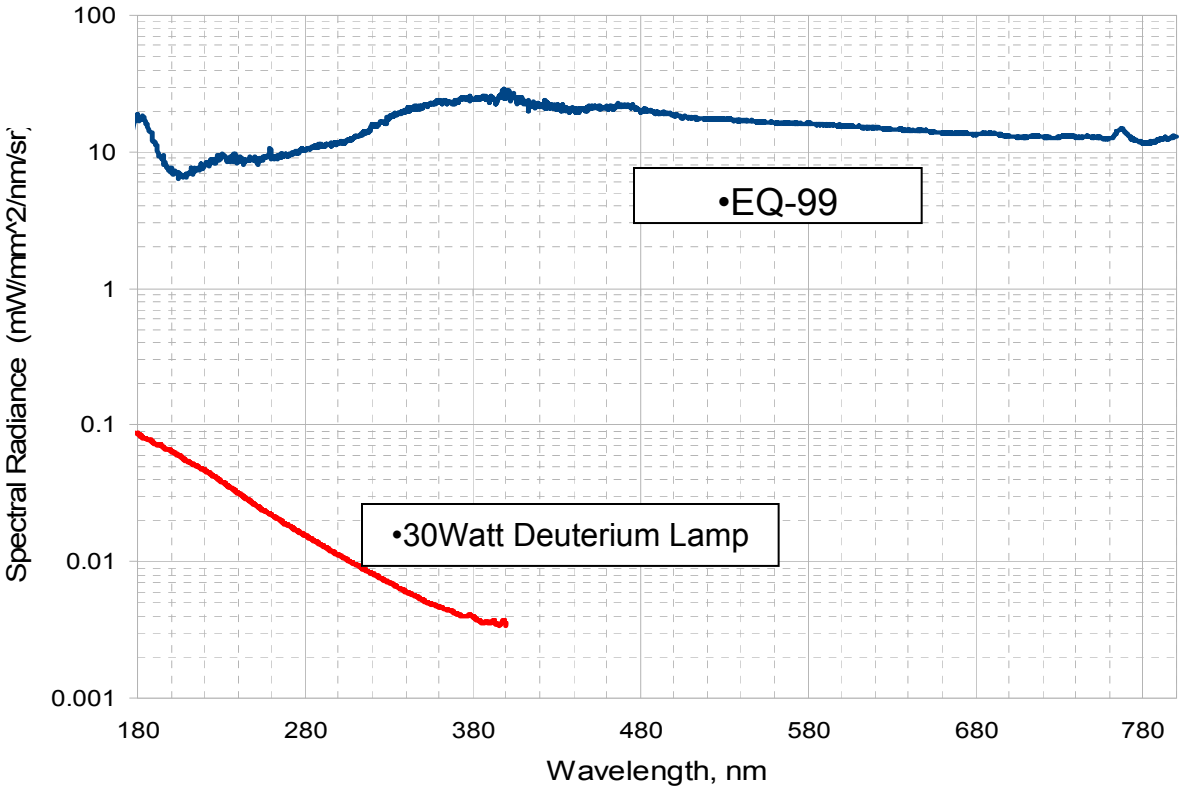
- •Large plasma limits brightness
- •Arc position Instability
- •Note: anode glowing red

•LDLS

- •Small plasma …high brightness
- •Highly stable position
- •Note: anode NOT glowing

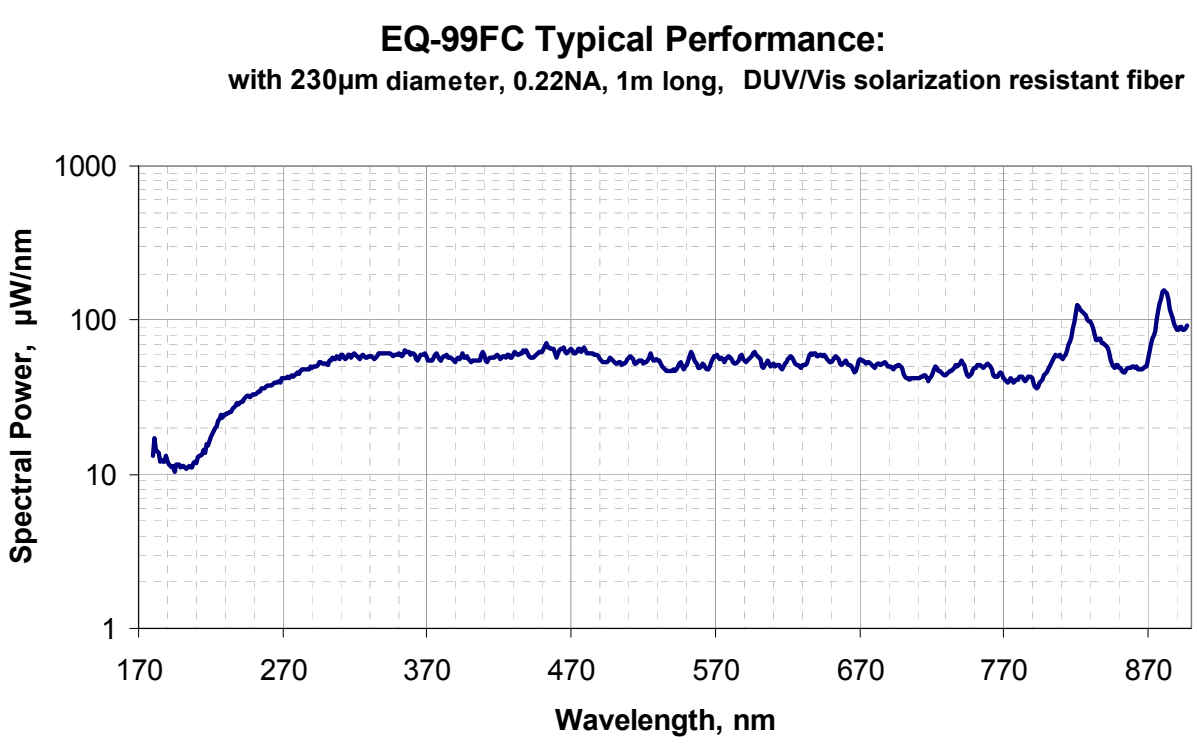
- High brightness: ~100 um diameter Xenon plasma,
- Efficient coupling into small fibers or spectrometer slits
- Point source enables collimation over long distances

EQ-99 Spectral Distribution



•**Typical Data**

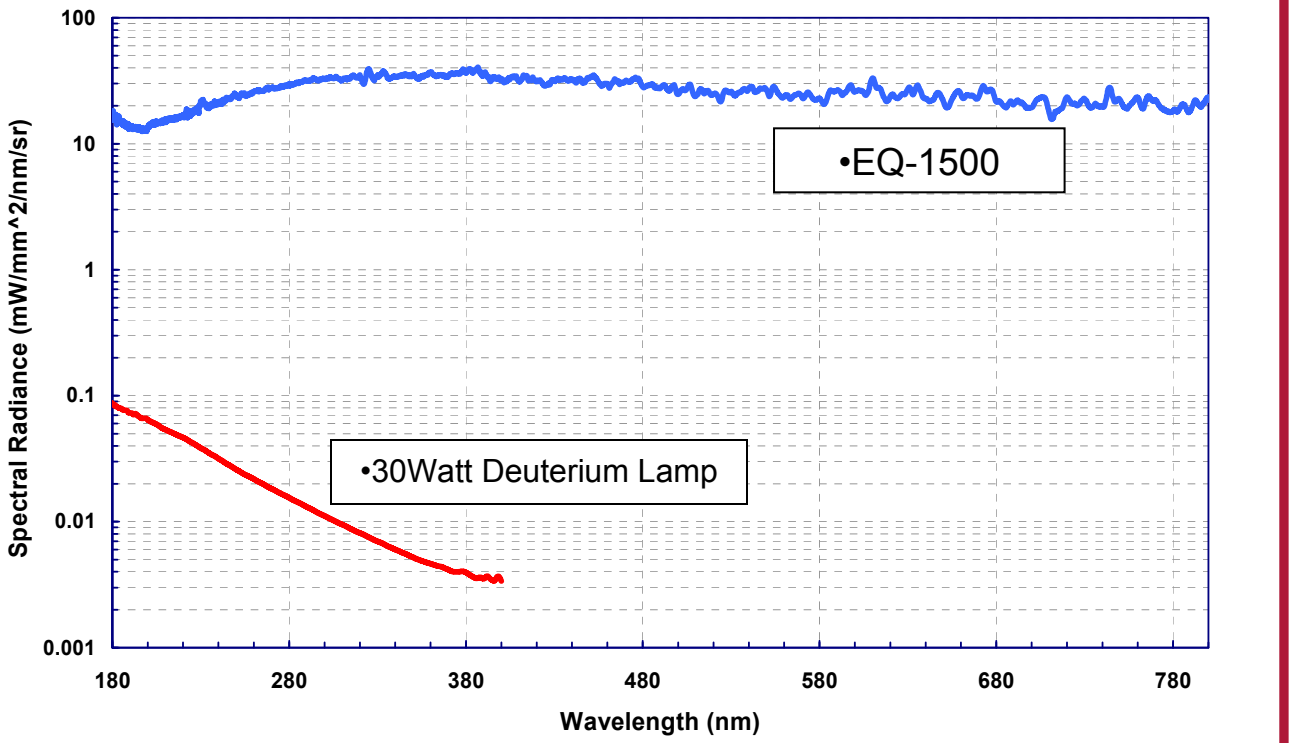
EQ-99FC Spectral Distribution



Power ratios	
Fiber (µm)	Multiplier
230	1
450	2.02
600	2.26

•Typical Data

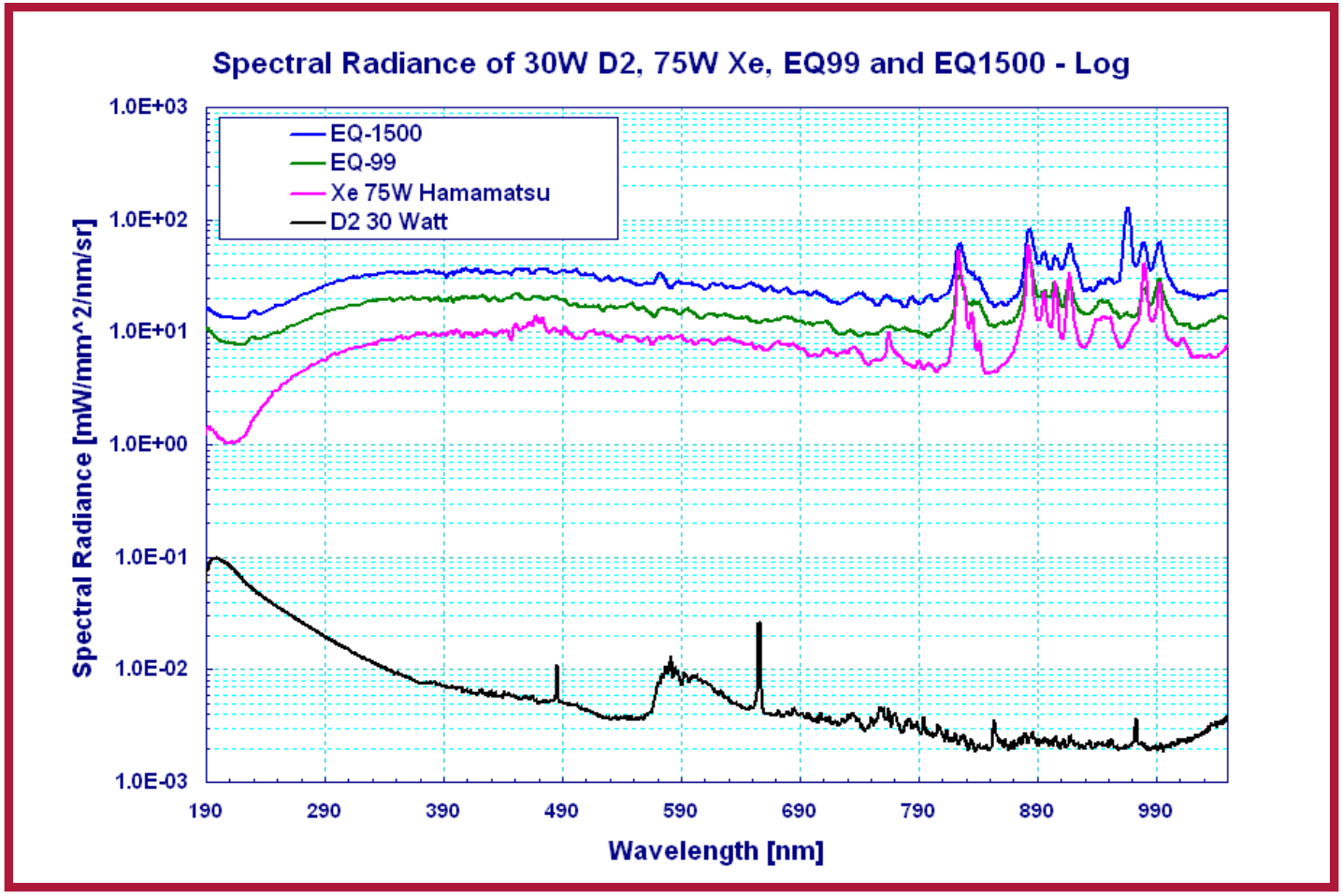
EQ-1500 Spectral Distribution



•Typical Data

Comparing LDLS with Traditional Lamps

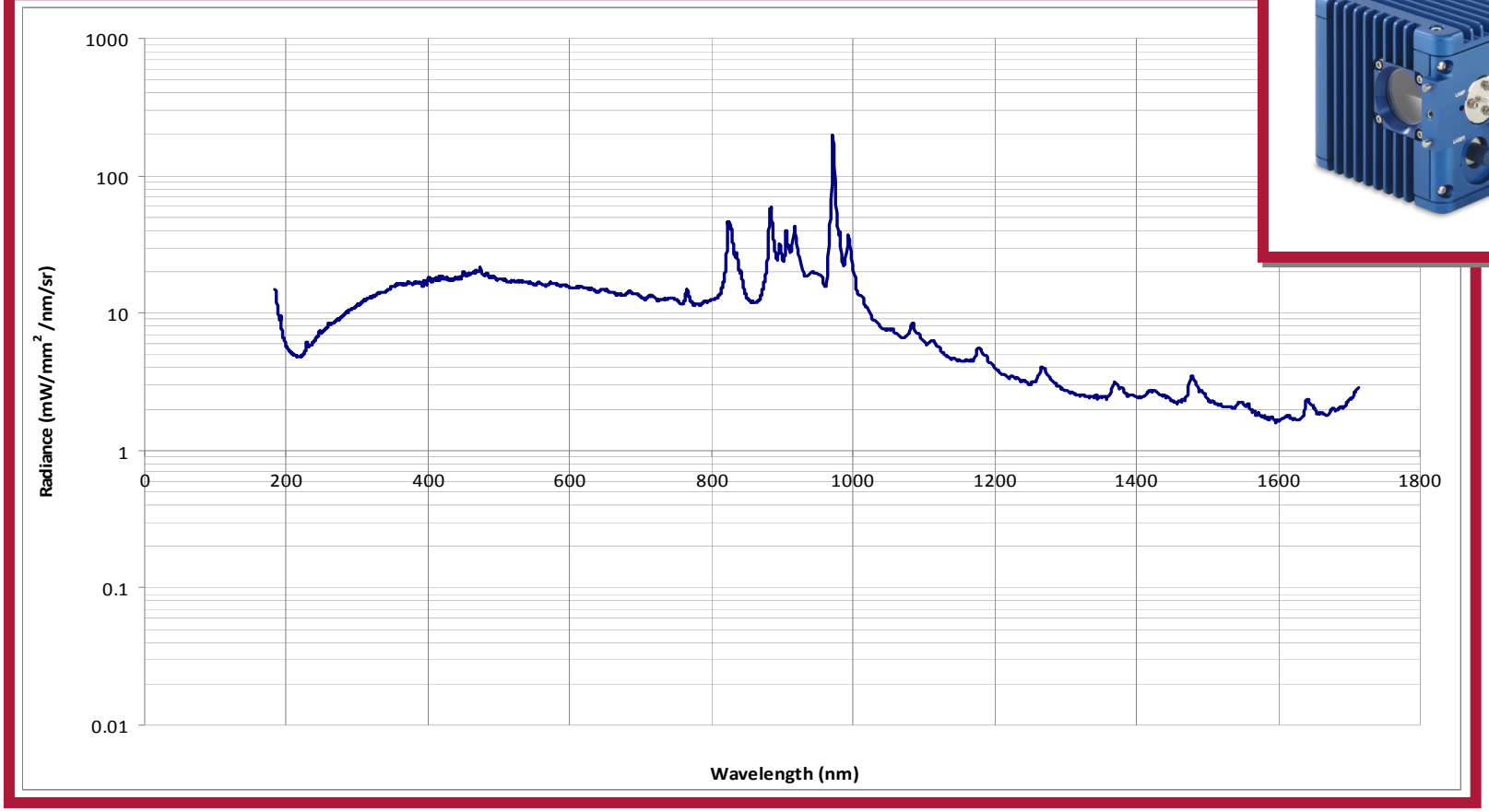
ENERGETIQ



•Spectral radiance calibrated at 254nm, Typical Data

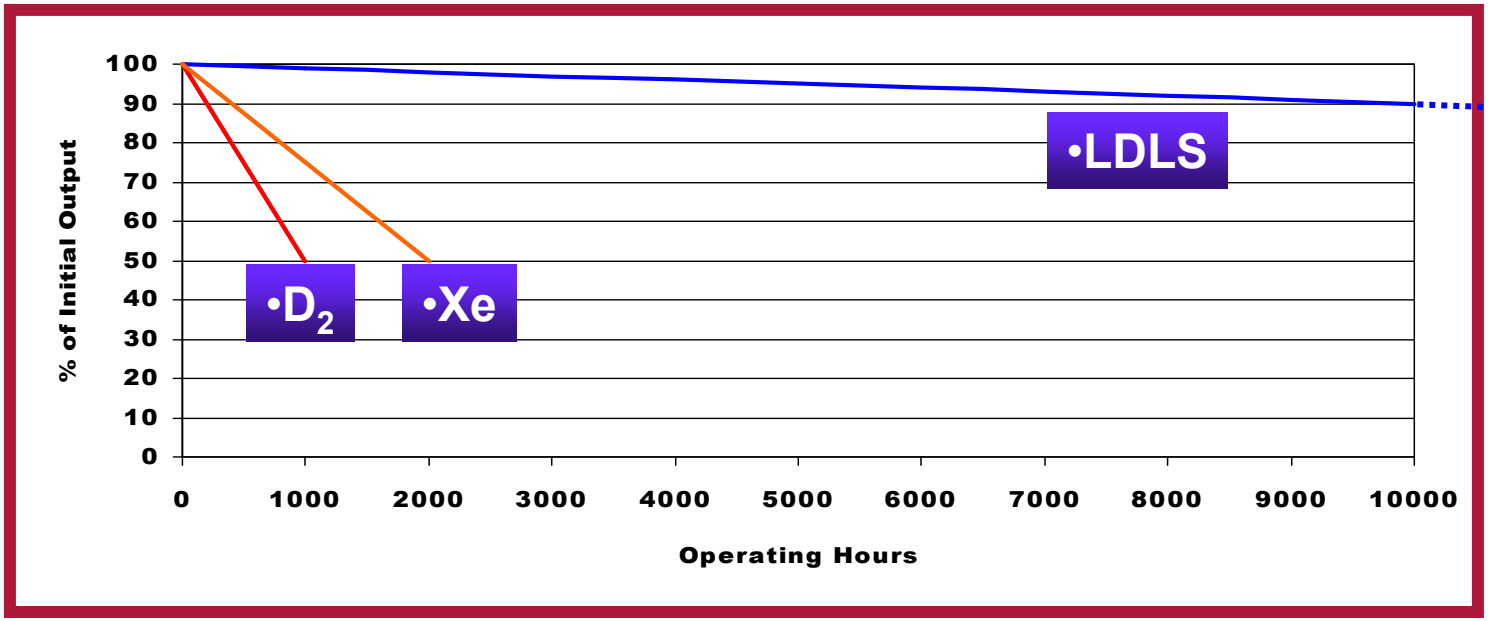
LDLS: UV-Vis-NIR Radiance 170nm – 1700nm

ENERGETIQ



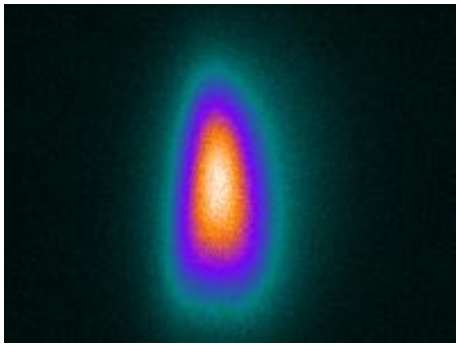
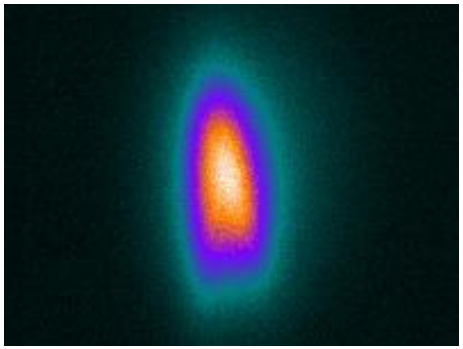
•Typical Data for EQ-99

LDLS™: Stable & Long-Life



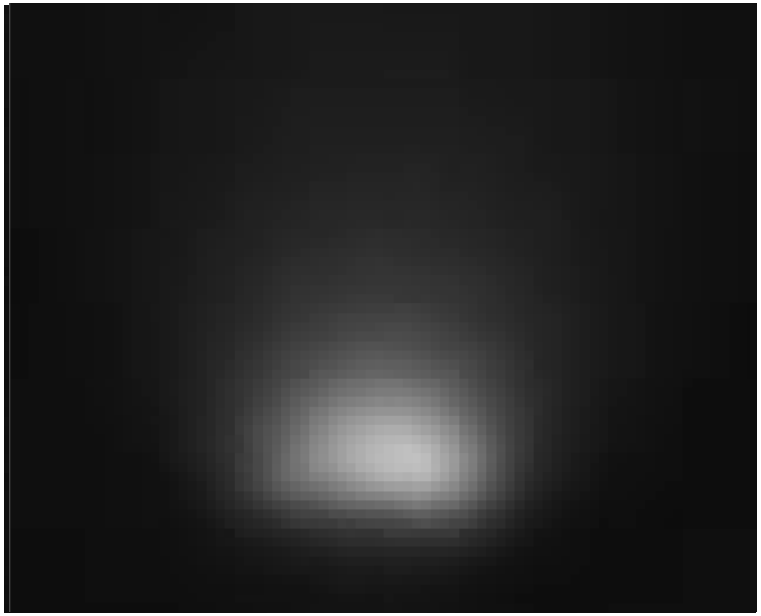
Light Source	Change in Broadband Output /1000 Hrs (Typical)	Life-Test Hours to Date	Notes
EQ-1500	~ -1%	>10,000	Test on-going
EQ-99	~ -1%	>6,000	Test on-going
30W D2 Lamp	-50% (depending on model)		Source: Heraeus Data Sheet
75W Xe Lamp	-25% to -50% (depending on model)		Source:Hamamatsu Data Sheet

EQ-99 Plasma Images

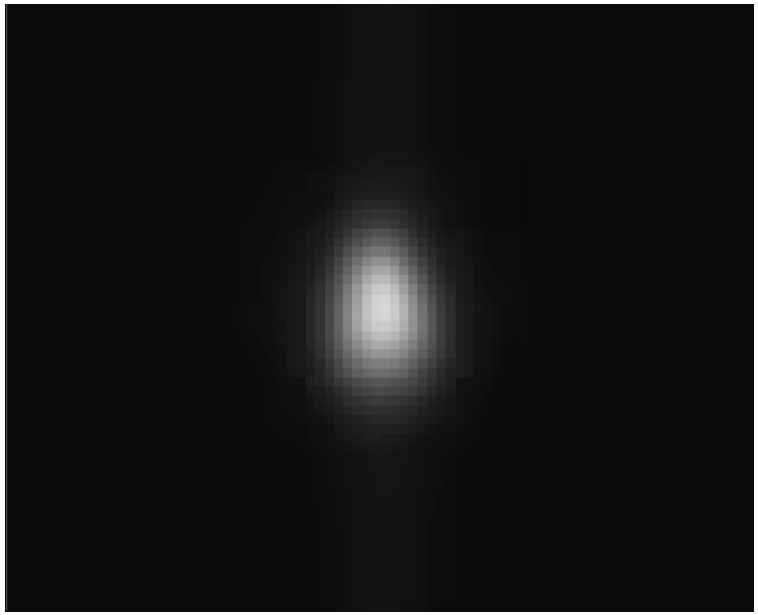
	PS37LH34	PS38LH39
FWHM horizontal, µm	64	61
FWHM vertical, µm	147	140
Images		

ENERGETIQ

Spatial Stability of Arc Lamp vs LDLS

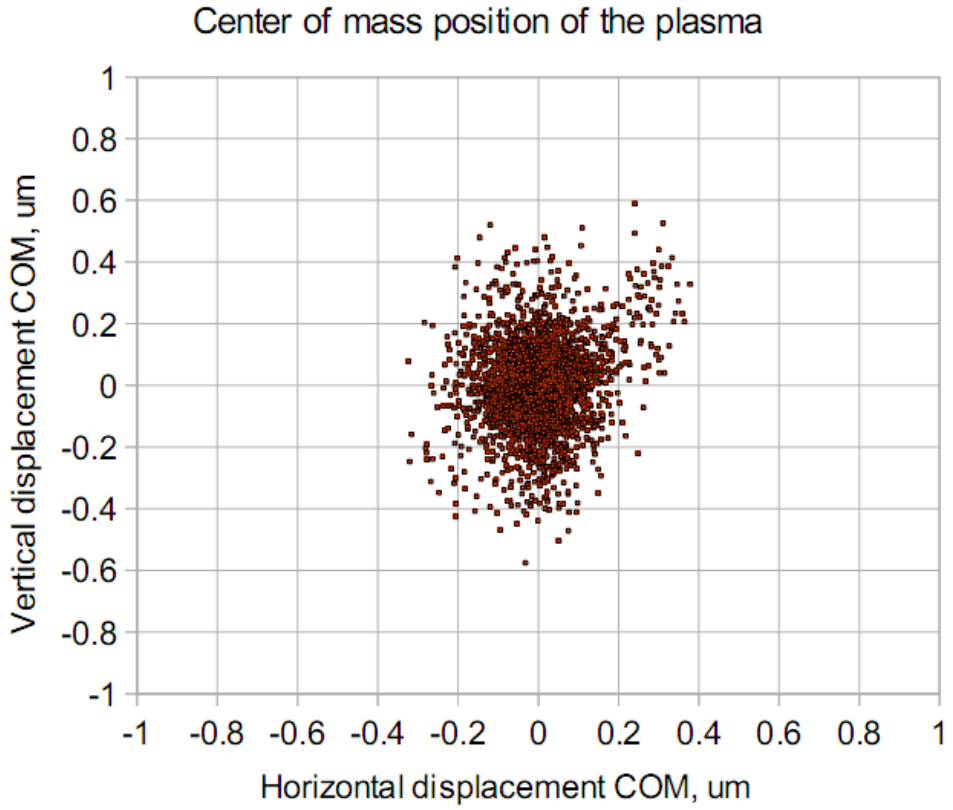


450W Xenon Lamp



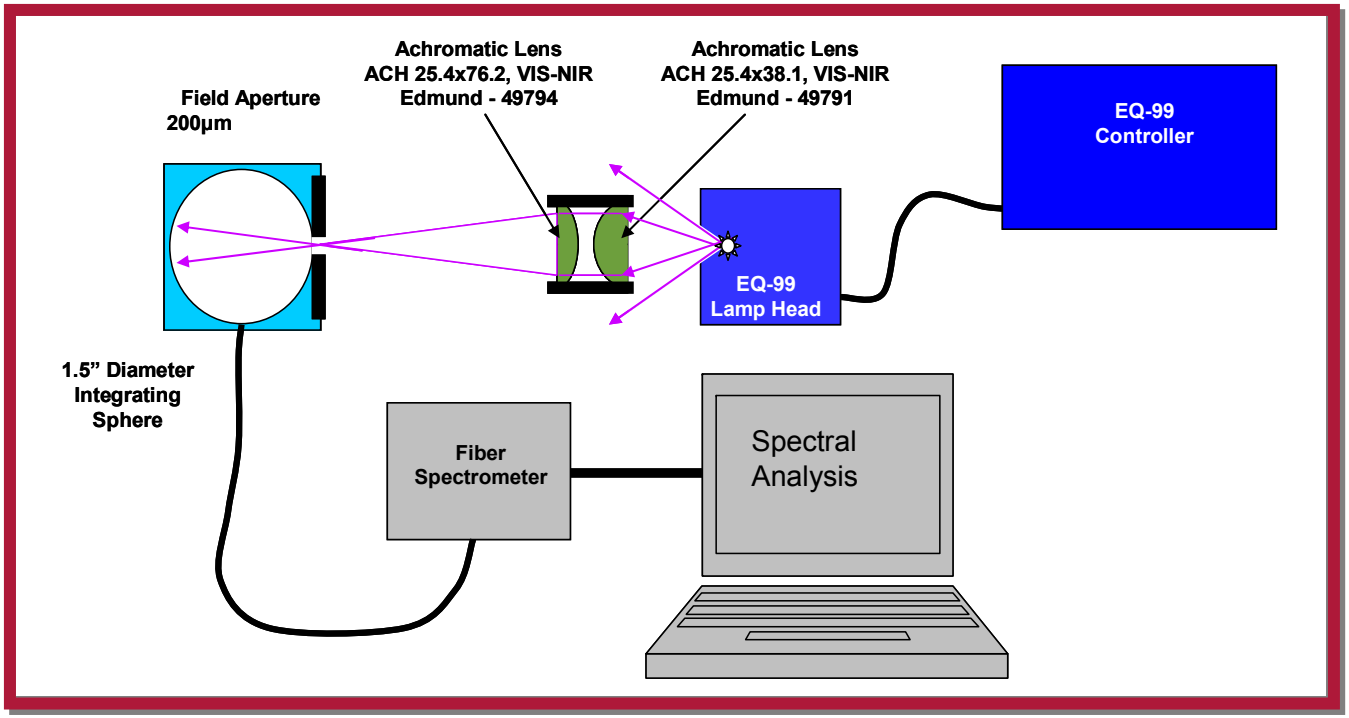
EQ-1500

Spatial Stability Results



- Collected and stored 2500 images @ 200 frames per second
- Calculated center of mass for each image using ImageJ (image analysis software)
- Standard deviation of the plasma light intensity center of mass position
  - Horizontal: 0.145 µm
  - Vertical: 0.094 µm

Measurement of Temporal Variation in Radiant Flux for EQ-99



- Light collected by 0.3NA Achromat pair from 100um plasma region
- Calibrated integrating sphere/fiber spectrometer:
  - 1000 spectral samples (400-830nm), 8ms integration time, 8 seconds total
- Measurement repeated for ten EQ-99 units.

Temporal Variation in Radiant Flux From 100µm Plasma, 0.3NA

200µm diameter pinhole with 2X optics,
400nm to 830nm wavelength band,
1000 samples, 8ms integration time, 8s total

EQ-99	Intensity Variation, 3x std.dev. [%]	P-P/Mean (%)
Unit-A	0.27	0.58
Unit-B	0.33	0.73
Unit-C	0.17	0.34
Unit-D	0.20	0.39
Unit-E	0.19	0.42
Unit-F	0.29	0.65
Unit-G	0.34	0.72
Unit-H	0.21	0.48
Unit-I	0.18	0.42
Unit-J	0.33	0.79
Average	0.25%	0.55%

- For the 8 second sample period, average intensity variation of:
  - <0.1% (1σ)
  - 0.25% (3σ)
  - 0.55% (p-p/mean)

Benefits of LDLS Technology

- Very high brightness across complete spectrum
  - 170nm through visible and out to 2100 nm
- Eliminates need for multiple lamps (replaces D2/Tungsten/Xenon Arc)
  - Simplified optical system
- Excellent Spatial stability
  - Repeatable measurements
- Superior short and long term power stability
  - Repeatable measurements
- Electrodeless operation for long life
  - Reduced consumable costs
  - Minimal recalibration of instrument

Broadband	√
Brightness	√
Stability	√
Lifetime	√

Applications

- UV-Vis Spectrometry
- Monochromator Source
- PEEM
- Atomic Absorption Spectroscopy
- Materials Characterization
- Environmental Analysis
- Hyperspectral Imaging
- Gas Phase Measurements
- Advanced Microscopes
- Endoscopes/Borescopes

•EQ-99 LDLS System

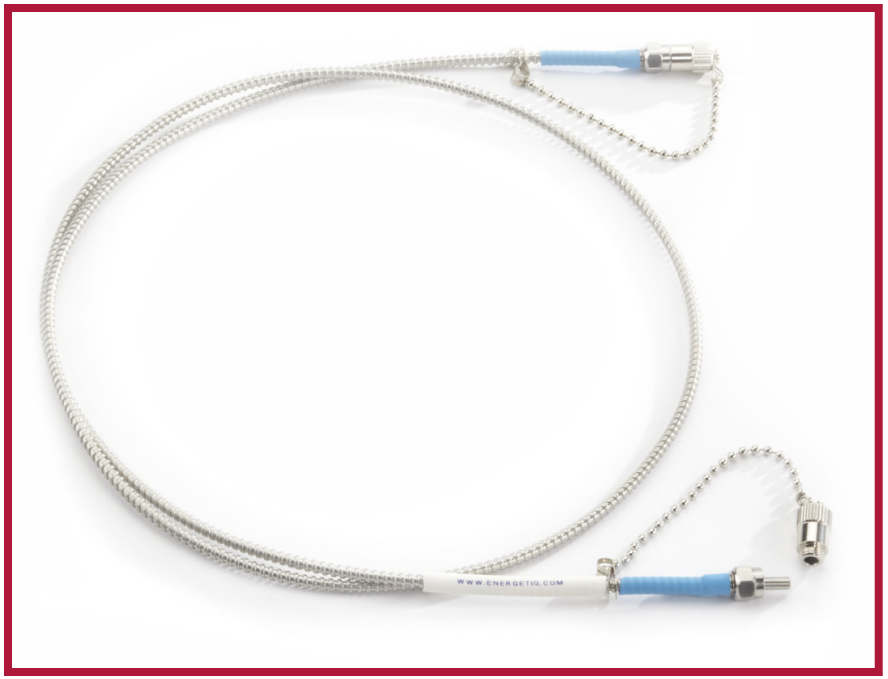
•EQ-1500 LDLS System

NEW! EQ-99 Manager

- A Smart Controller for EQ-99 Series LDLS™ Products

- Easy on/off capabilities
- Lamp hour meter
- Available Shutter
- Computer control

LDLS Fiber Optic Assemblies

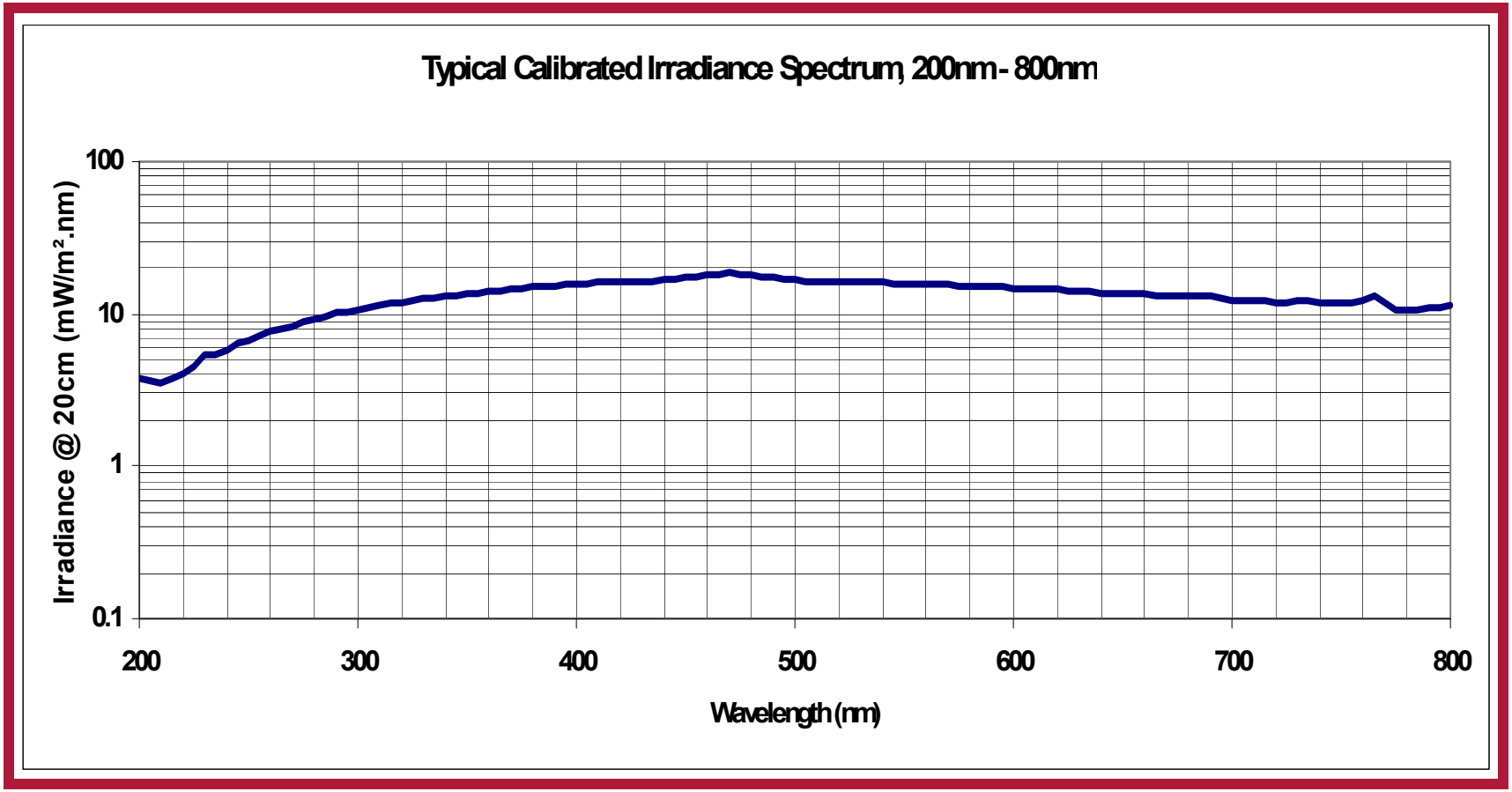


- Turn-Key system with EQ-99FC
- For high brightness applications
- Proprietary termination process
- Longer life than standard fibers
- Choice of Fibers
  - DUV/Vis Solarization Resistant
    - (180nm – 900 nm)
    - 115µm, 230µm, 455µm Core
  - Broadband Version
    - (200nm – 2100 nm)
    - 100µm, 200µm, 400µm, 600µm Core

EQ-99CAL Calibrated LDLS

- Based on Award Winning EQ-99 Design
- Broadband, High Brightness Source
- Calibration Wavelengths: 200nm - 800nm (with single source)
- Irradiance Calibration Traceable to NPL
- Temperature Controlled Lamp House for highly stable measurements
- Long Intervals between Recalibration
  - Recommended 1 year or 1000 hours of operation (which ever comes first)

New EQ-99CAL Calibrated LDLS



Coupling Accessories

EQ-99 LDLS with OAP System

- Designed to couple EQ-99 and EQ-1500 light into spectrometers or optical fibers
- Off-Axis Parabolic (OAP) Mirror Assembly
- Efficiently couple full wavelength range
- Variety of focal length and NA options
- Free beam or SMA fiber coupling options
- Housings are Nitrogen purgeable

EQ-1500 LDLS with OAP System

Broadband Fiber Collimators For LDLS

EQ-99FC LDLS with Fiber Collimator

- Designed to collimate EQ-99FC fiber output
- Reflective Mirror Assembly
- Efficiently collimate from 200 – 2400 nm
- Two output beam sizes available; 6.7 mm and 11 mm diameter
- SMA fiber connection
- Low divergence (depends on fiber size)

EQ-99-COL-11

EQ-99-COL-6

Summary

- Very high brightness across complete spectrum
  - 170nm through visible and out to 2100 nm
  - Easy coupling to small fibers and spectrometer slits
  - Ease of collimation
- Eliminates need for multiple lamps (replaces D2/Tungsten/Xenon Arc)
  - Simplified optical system
- Excellent Spatial stability
  - Repeatable measurements
- Superior short and long term power stability
  - Repeatable measurements
- Electrodeless operation for long life
  - Reduced consumable costs
  - Minimal recalibration of instrument

LDLS™ Laser-Driven Light Source

www.energetiq.com