II-VI

MATERIALS THAT MATTER®

Mass-Scale Automotive Optical Sensing

The Road to Everywhere

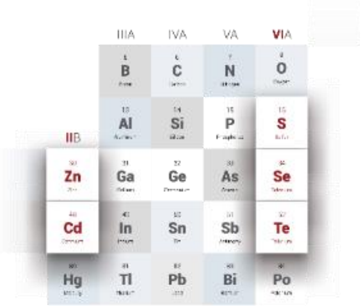
30.08.2019

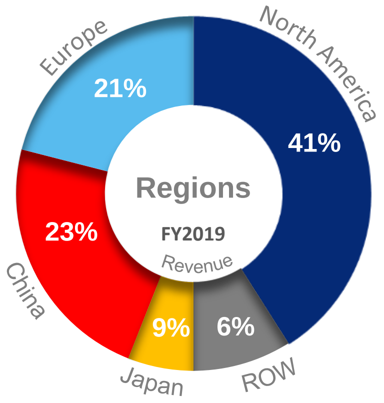
Dr. Norbert Lichtenstein

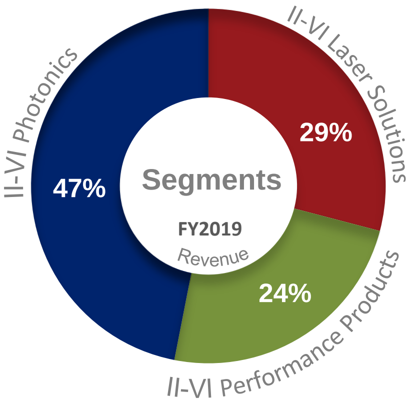
II-VI Overview

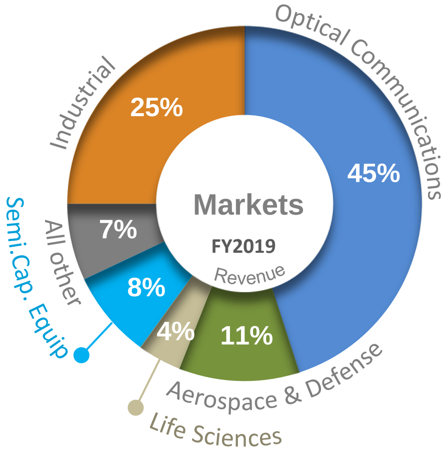
"TWO SIX"

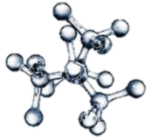
Refers to groups **II** and **VI** of the Periodic Table of Elements











Core Competency
ENGINEERED MATERIALS

12,500+ Worldwide employees

53 Worldwide Locations

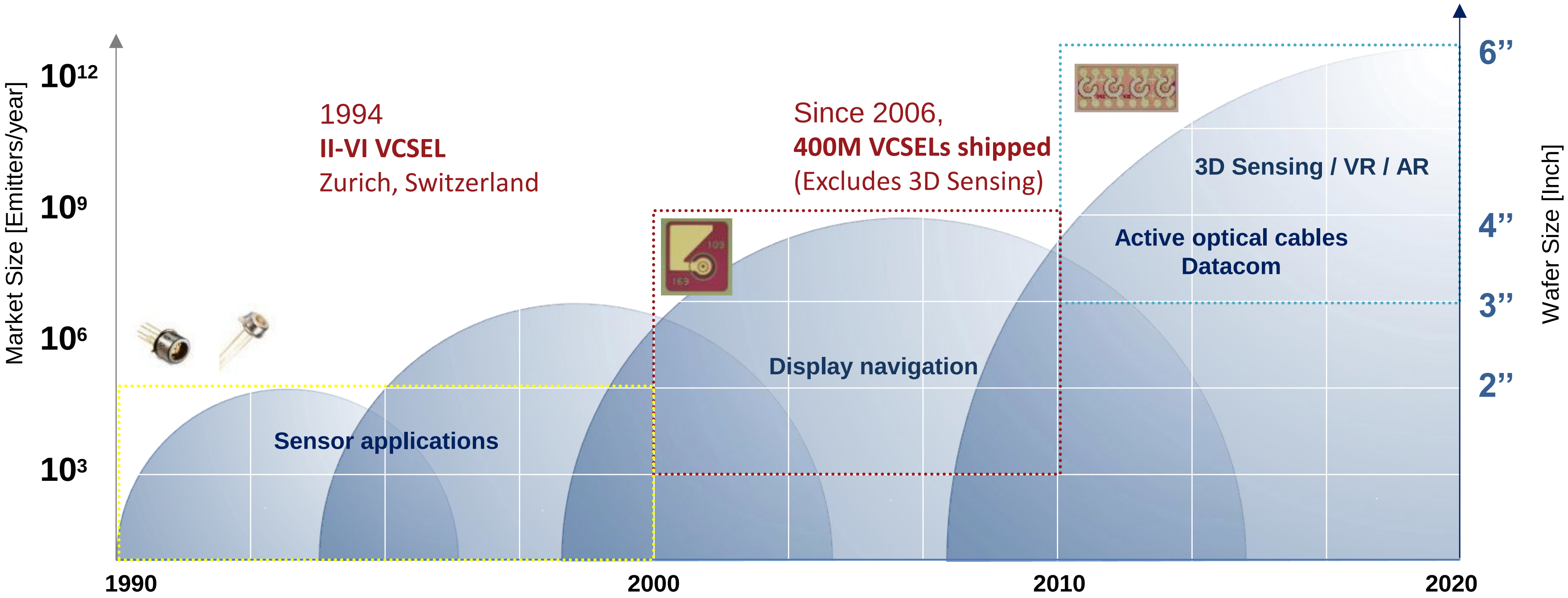
14 Countries

$ 1,362M FY2019 Revenue

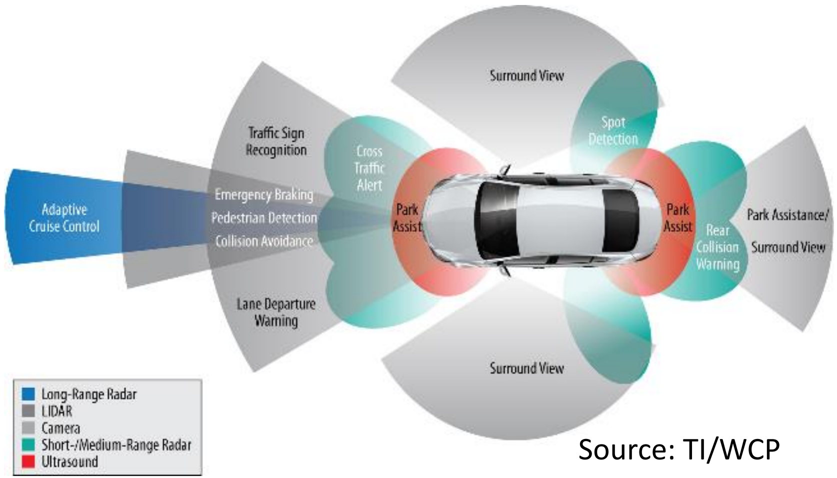
Overview

- Rise of mass-scale 3D optical sensing
- Automotive - the next frontier?
- Automotive 3DS needs and challenges
- LIDAR implementations
- Wavelength selection
- Comparable sensor commercialization timeline
- Analyst expectations for autonomy
- Accelerating adoption

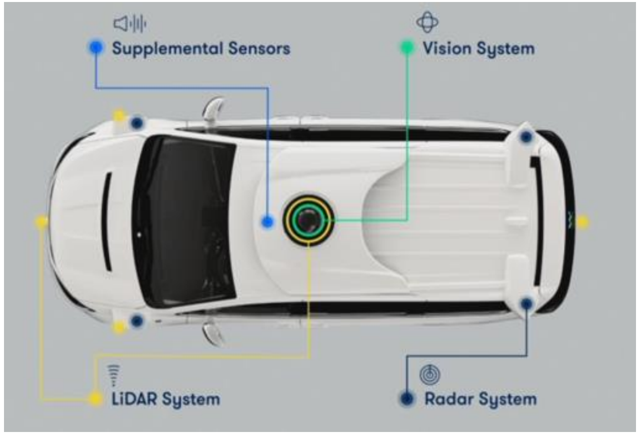
Mass Scale 3D Optical Sensing



Automotive as the New Frontier for Optical Sensing



Source: TI/WCP



Waymo's self-driving platform
19 cameras, 4 LIDARs, 360 degree coverage

- **According to Yole, by 2045 almost 70% of vehicles sold will integrate SAE L3 and higher autonomous capabilities**
- **Consensus (except for Tesla, others…) that active illumination of some kind will be required**

Replicating the Success of 3D Sensing

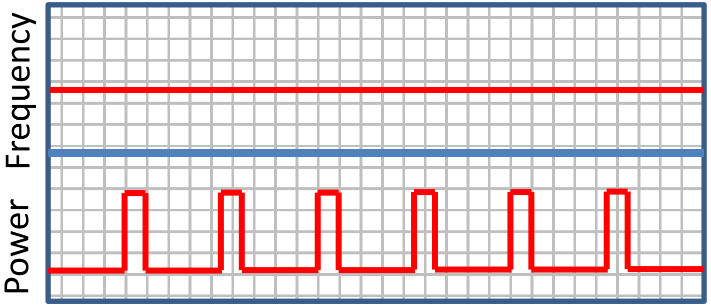
- **Opportunities for 3DS in automotive**
  - Short range solutions for in-cabin monitoring
    - Convenience feature/crash protection optimization
    - Will borrow heavily from existing consumer 3DS
    - Volumes relatively low vs. other consumer applications
  - Mid- and long-range solutions for external sensing
    - Cameras, thermal imaging already in deployment,
    - LIDAR in infancy

Mid-/Long- Range "LIDAR"

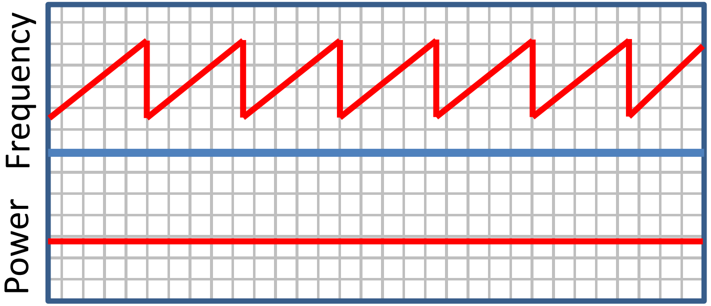
Today	Challenges	Solutions(?)
Short Wavelength	Biological Risks	Long Wavelength?
Multi-Junction EELs	Light Pollution	"Flash"?
SPADs/Si APDs	Cost/Complexity	FMCW?
128 lines vertically	Resolution/Range	VCSEL? HCSEL?
30*20 deg FOV = 60kpx	Automotive Supply Chain	

LIDAR Implementations: Range Measurements (Z)

- **AM – e.g. TOF.**
  - + : Simple, proven, cheap
  - - : Power hungry, SNR is key: narrow bandwidth, background light suppression

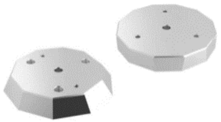


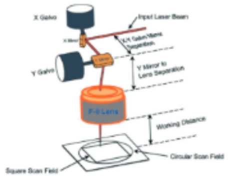
- **FM – e.g. FMCW.**
  - + : Improved SNR (immune to photon background), interference resistant, relative velocity
  - - : Requires highly linear source, data processing intensive, high BW electronics (wavelength dependent)

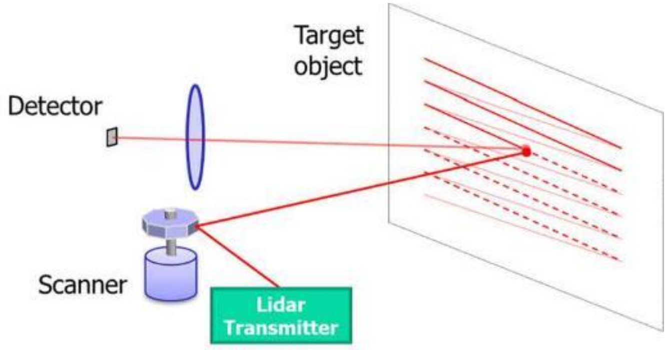


LIDAR Implementations: Scene Capture (X,Y)

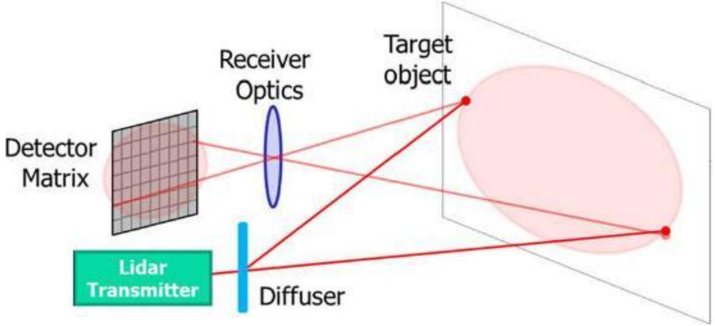
- **Scanned – Lower power, scalable, cheap(?)**
  - MEMS, Galvanometric Scanners, Polygons, OPAs







- **Flash – No temporal or spatial corrections, no moving parts, but requires high power, small FOV**

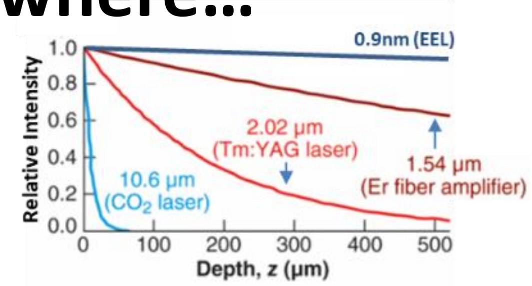


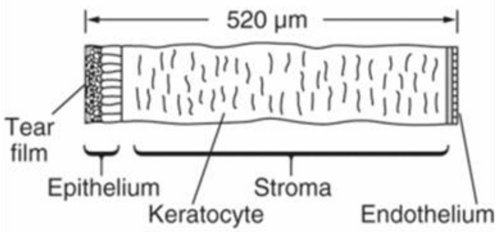
- **Tradeoffs in range, resolution, FOV, power…**

Yoo, H.W. et al. Elektrotech. Inftech. (2018) 135: 408

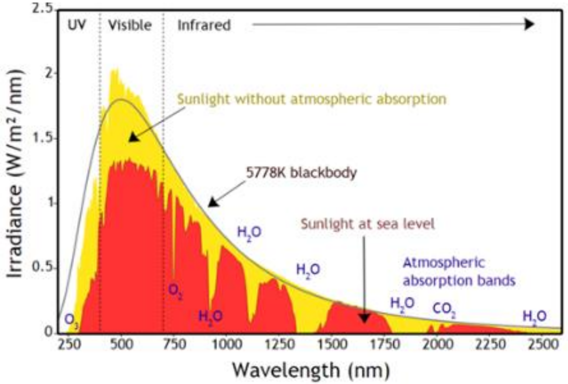
Wavelength: Water Water Everywhere…

		MPE	Rain/Fog	Solar	Wet Target	Cost	Notes
808nm	EELs	-	+	-	+	+	GaAs platforms mature and scalable (VCSELs particularly). Arrays and multi-junction EELs for higher power
850nm	VCSELs	-	+	-	+	++	
905nm	EELs	-	+	-	+	++	
940nm	EEL, VCSELs	-	+	+	+	++	
1064nm	DPSS	-	+	-	+	-	DPSS modules
15XXnm	EDFAs, EELs	++	-	+	-	-	InP or EDF based, eye-safer
10.6um	CO2	+	-	++	-	-	Reduced scatter, extreme H20 absorption

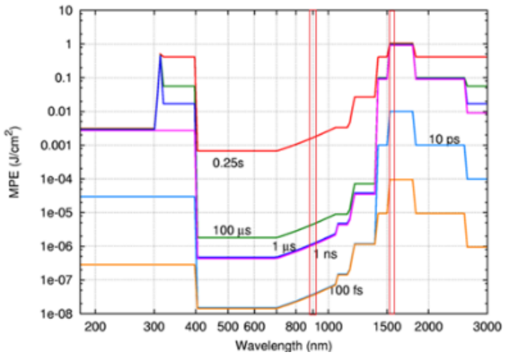




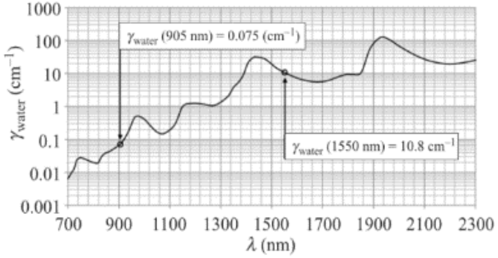
Johns Hopkins APL Technical Digest, from R. McCally et al., "Laser eye safety research at APL," V 26 p. 46 (2005) ©The Johns Hopkins University Applied Physics Laboratory



https://en.wikipedia.org/wiki/Solar_irradiance



From IEC-60825-1



Wojtanowski et al. Opto-Electron. Rev. (2014)

When Will It Happen?

1990 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020

1991
Backup Camera
(Toyota Soarer)

1992
Single Point LIDAR
Mitsubishi Debonair

1999
RADAR ACC
Mercedes S-Class

2000
Thermal Camera
Cadillac Deville

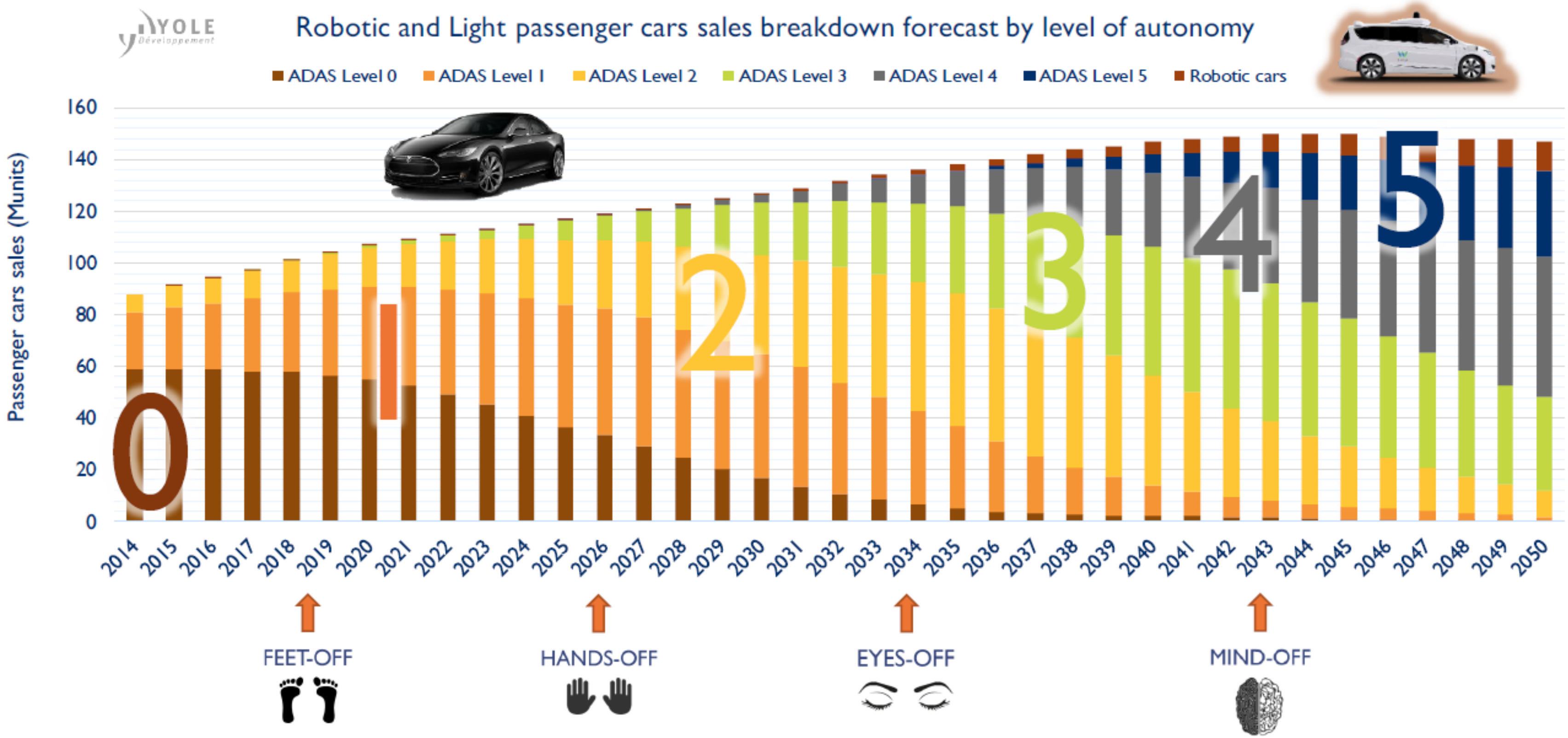
2018
Backup Camera
US Standard

2019
Audi A8
3D LIDAR

2021/2022
AEB/FCW
US/EU Standard

Sensor	1999/2000	2019	2022
Thermal Camera	ASP ~$8000	ASP <$1000 <0.10% penetration	ASP <$400 ? penetration
RADAR ACC	ASP ~$2000	ASP <$100 ~30% penetration	ASP <$100 >90% penetration
Backup Camera	ASP ~$1500	ASP $<$50 ~80% penetration	ASP <$50 >90% penetration
3D LIDAR		ASP $650? $24,000?	?

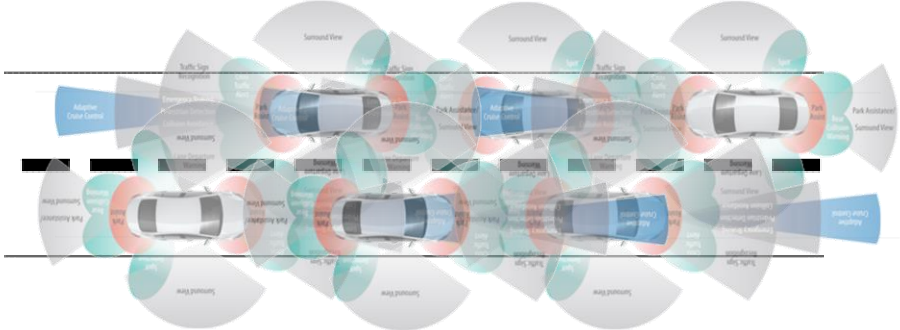
What do the Analysts Think?



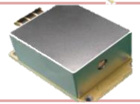
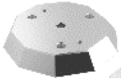
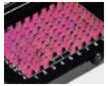
YOLE, 2019, LiDAR for Automotive and Industrial Applications

Deployment Scenarios

- **What can accelerate mass-scale deployment of 3DS in automotive?**
  - Solid State architectures, lower ASP, higher resolution, fully addressed eye and environmental optical hazards…
- **Is this our only path forward?**
  - Vehicles vs. Infrastructure – where is the balance?
  - Robocars – Truly autonomous self-sufficient sensor platforms?
  - Consumer vehicles – networked control?
  - Exclusive operating zones?



LIDAR Product Coverage

		532nm	808nm	850nm	905nm	940nm	980nm	1064nm	1550nm
EELs (Bars, Pumps, Seeds)			☑			☑	☑	☑	
DPSS Modules		☑						☑	
VCSELs				☑		☑			
Fiber Amplifiers & Components							☑	☑	☑
Optics, Polygons, Galvo Mirrors		☑	☑	☑	☑	☑	☑	☑	☑
LAS/LTS Filters				☑	☑	☑			☑

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