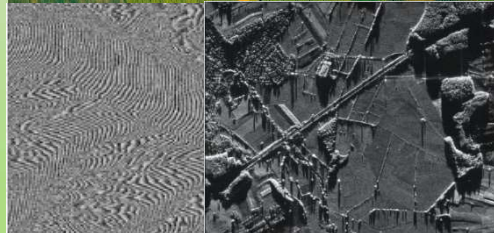
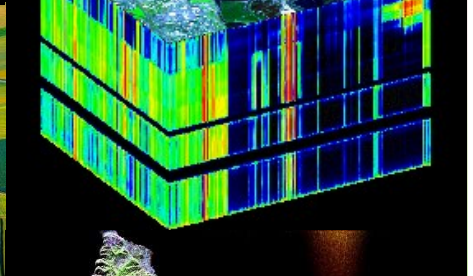
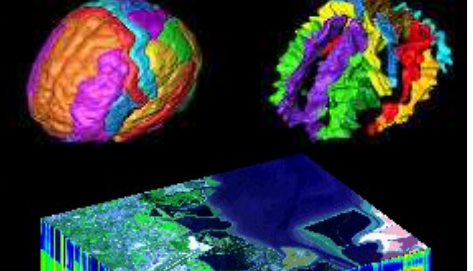
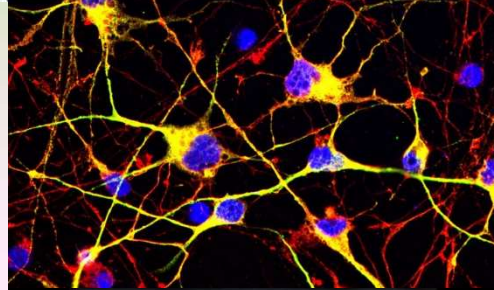


Ciências
ULisboa

Optical Instruments

Engineering Physics

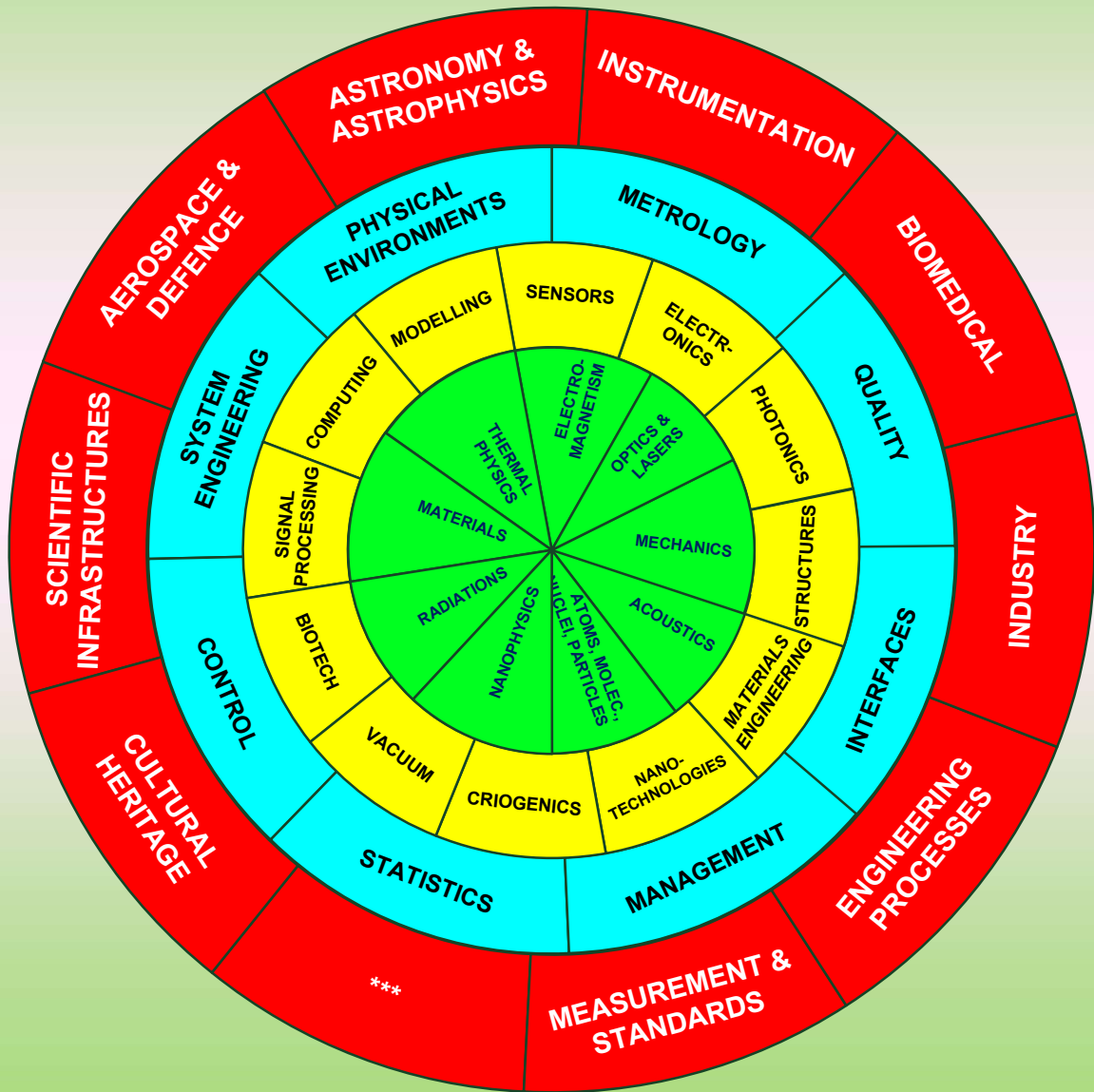
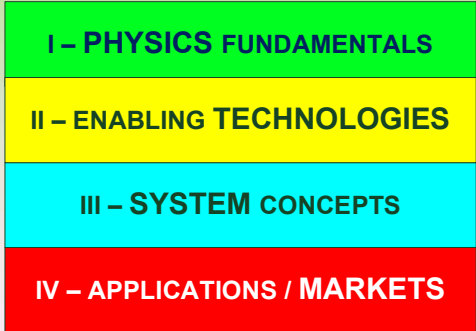
José Manuel Rebordão
Alexandre Cabral
2021/2022



1^a class

- Optical instruments
- The course: objectives, contents, bibliography, evaluation, ...
- Operations : T and Lab
- Optical systems: what for, architectures, technologies, characterization, specifications,
- The industry of Photonics
- Technological maturity: *Technical Readiness Levels* (TRL) and derived concepts

Systems @ Edu (MIEF) level



First M87 Event Horizon Telescope Results. II. [I, II, III, IV, V]

Array and Instrumentation

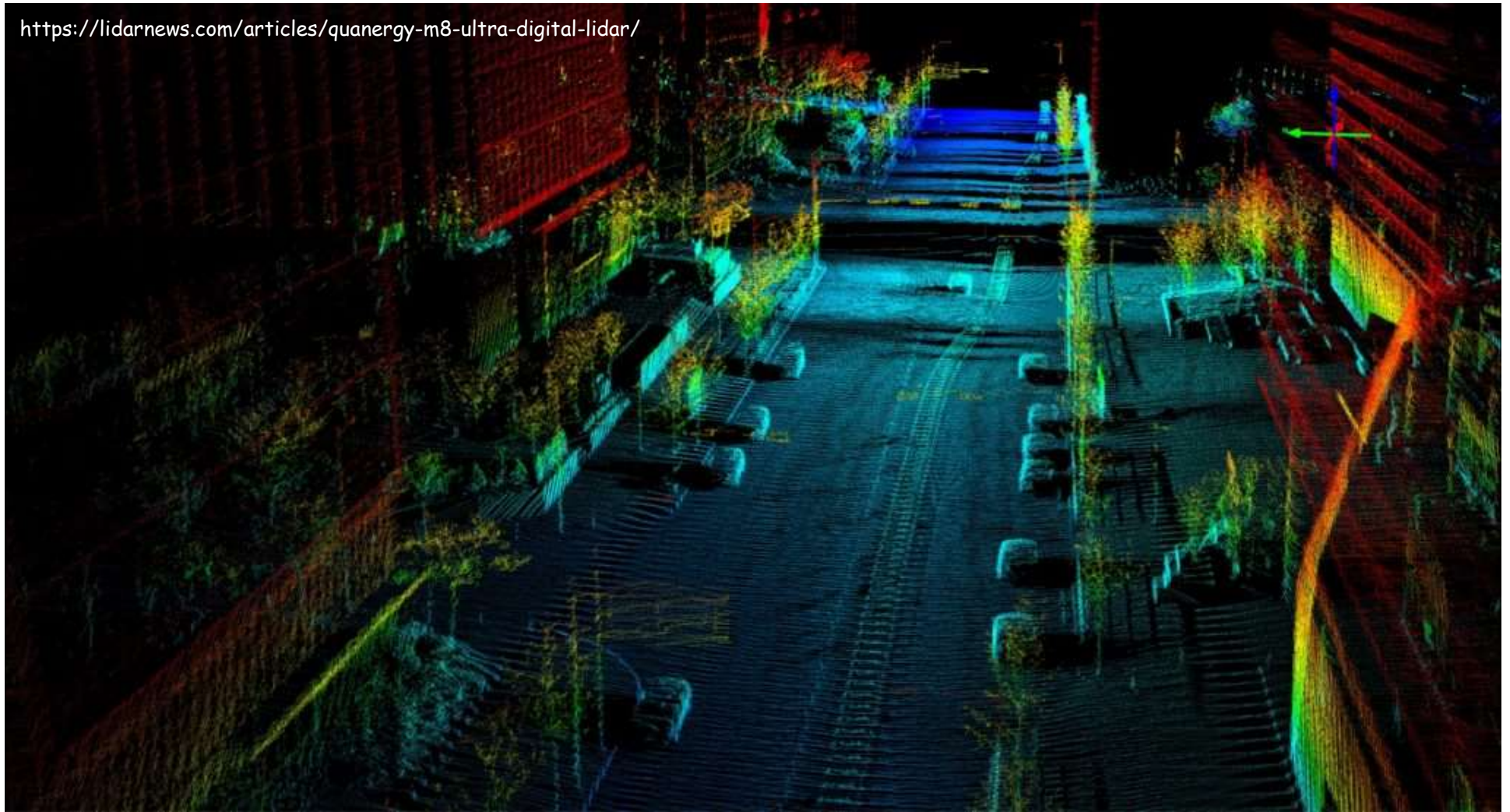
The Astrophysical Journal Letters, 875:L2 (28pp), 2019 April 10

<https://doi.org/10.3847/2041-8213/ab0c96>

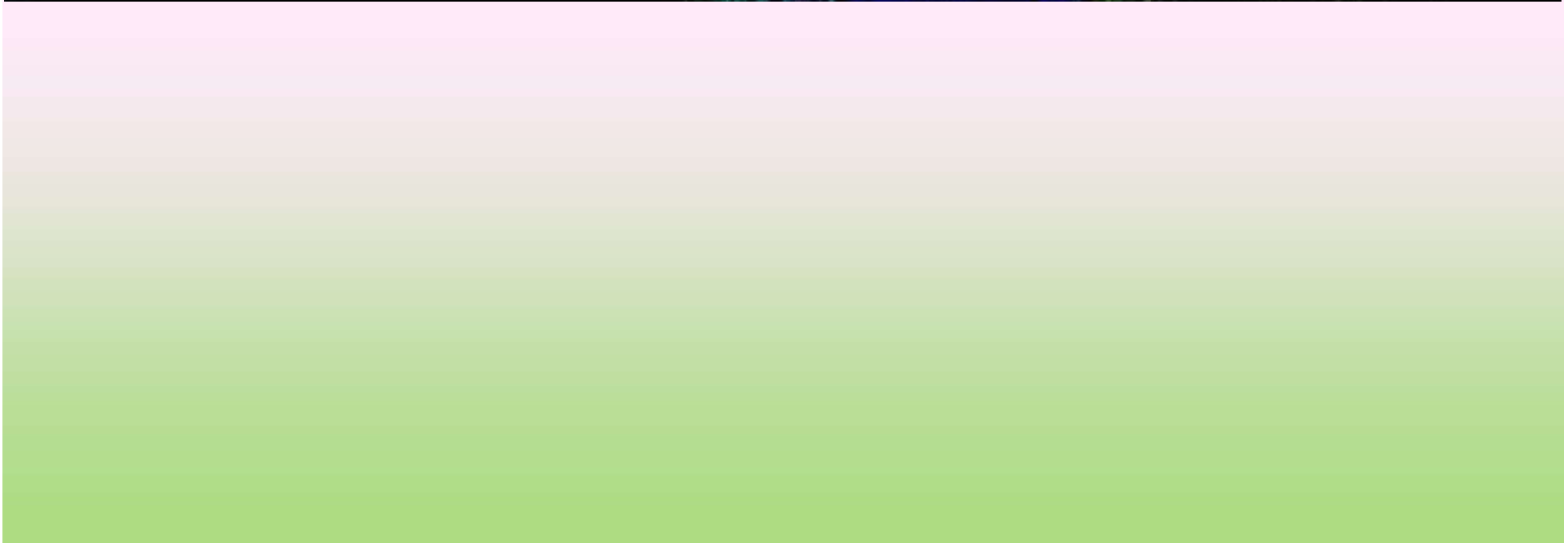
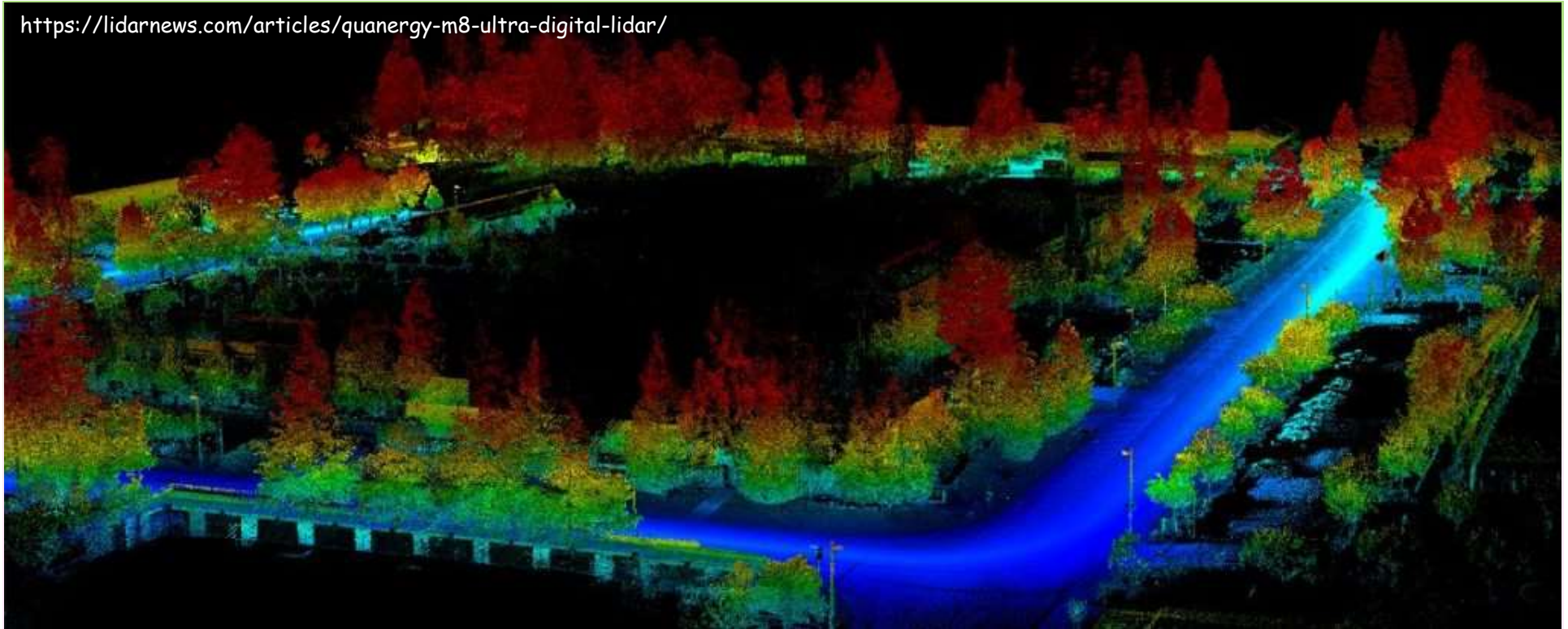


<https://www.jpl.nasa.gov/edu/news/2019/4/19/how-scientists-captured-the-first-image-of-a-black-hole/>

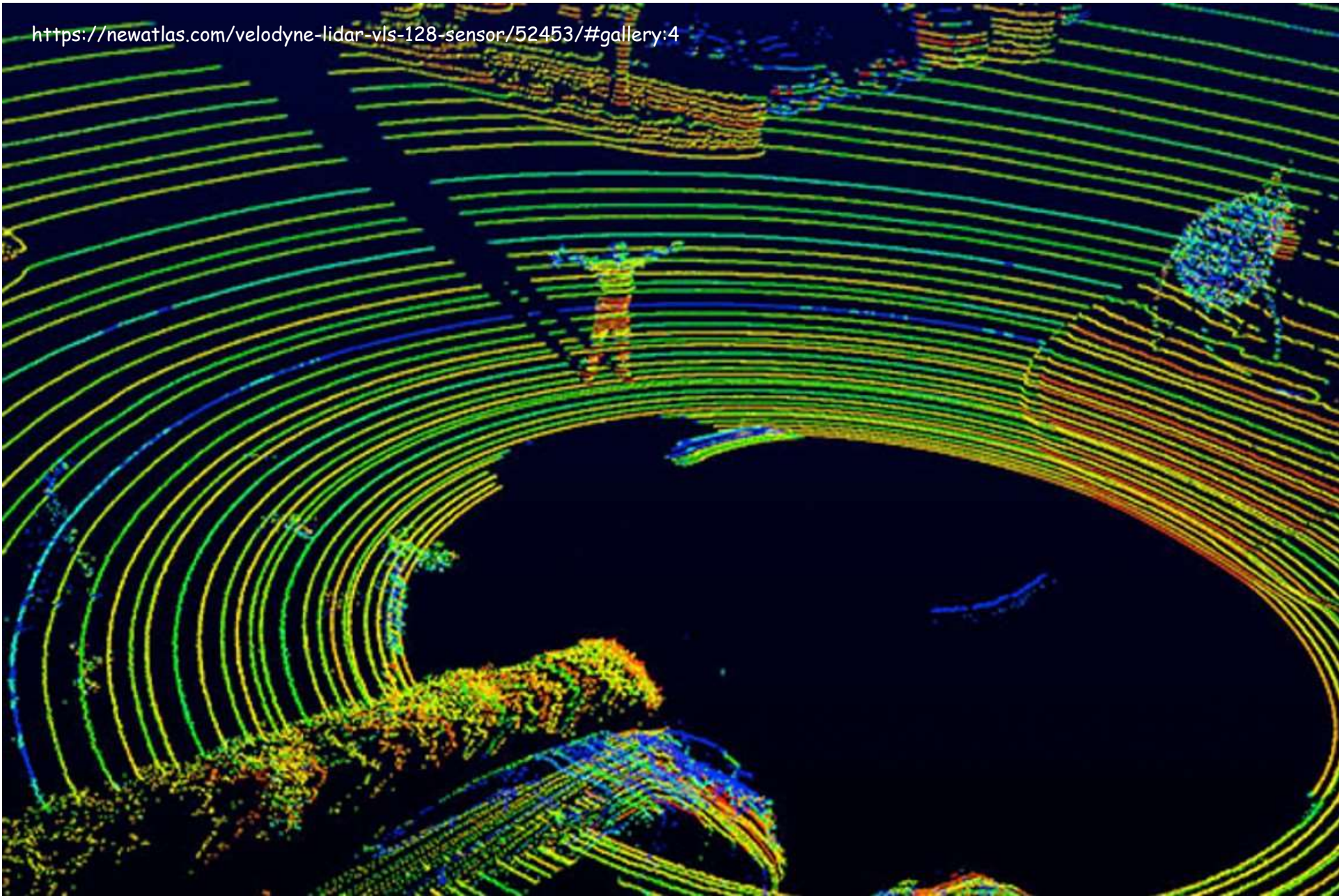
<https://lidarnews.com/articles/quanergy-m8-ultra-digital-lidar/>

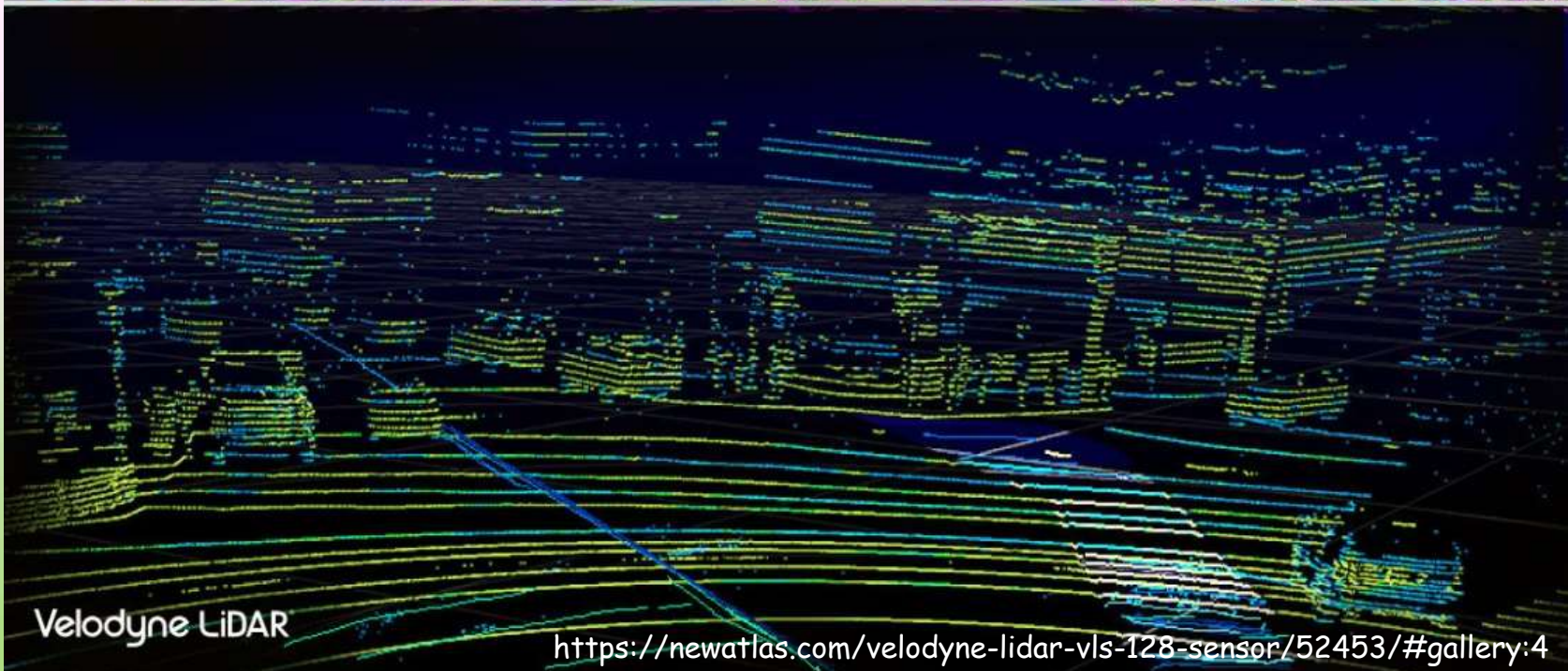
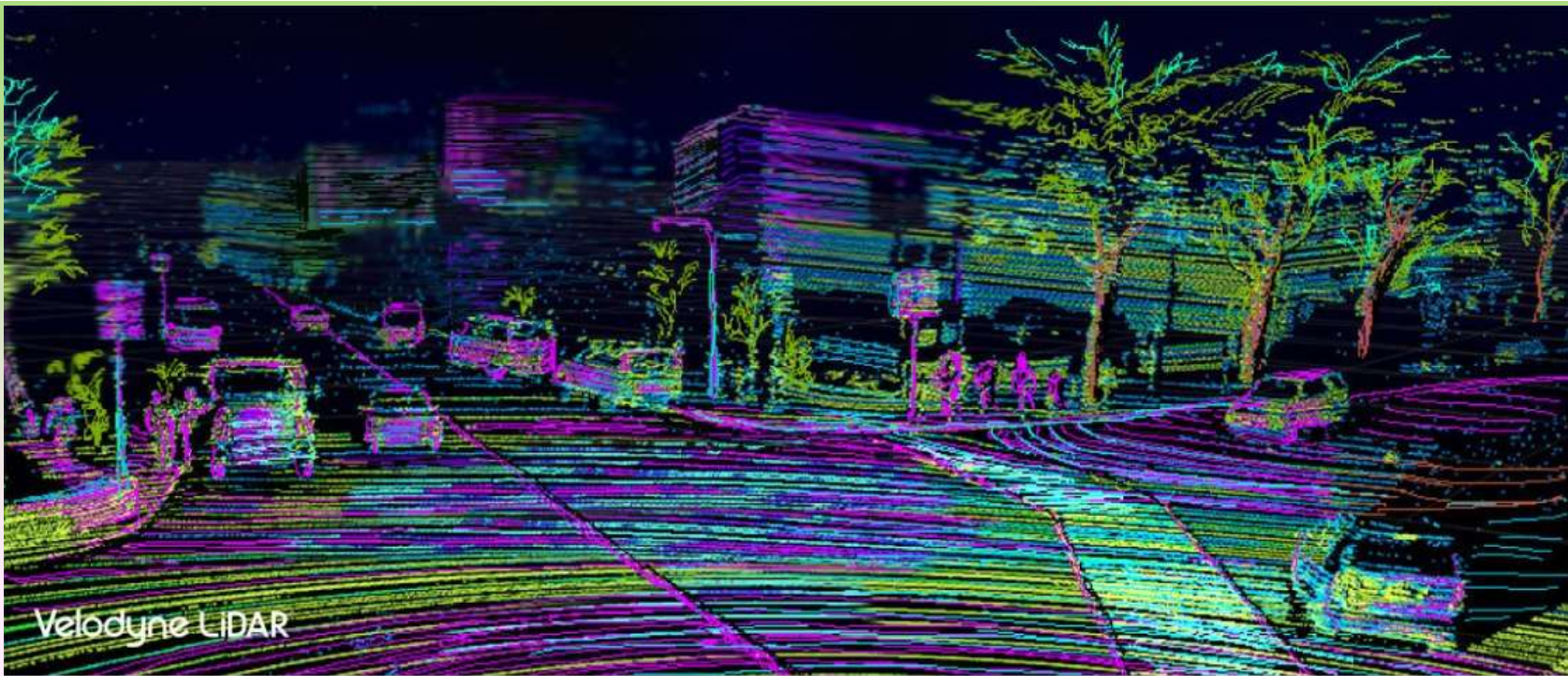


<https://lidarnews.com/articles/quanergy-m8-ultra-digital-lidar/>



<https://newatlas.com/velodyne-lidar-vls-128-sensor/52453/#gallery:4>





Students (2021/22)

➤ Registered:

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49567	Rafael Alexandre Gomes Pinto	RafaelFCUL@hotmail.com
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51404	Inês Valido Caipiro	fc51404@alunos.fc.ul.pt
52016	Tomás Nunes Pessoa dos Santos	tomassantos2010@gmail.com
53083	Maria Daniela Gomes Nunes	dany_nunes2000@hotmail.com
53114	Ricardo Filipe Branco Lobo da Costa Reis	ricardofilipeblcr@gmail.com

From the synopsis

4 – OBJECTIVOS DE APRENDIZAGEM	<p>A – Conhecer tipos de instrumentos ópticos e forma como viabilizam funções em sistemas e processos.</p> <p>B – Conhecer arquiteturas, interfaces e principais elementos de tradeoff de sistema.</p> <p>C – Conhecer a relevância da coerência da radiação no funcionamento e desempenho dos instrumentos</p>
5 – CONTEÚDOS PROGRAMÁTICOS	<ol style="list-style-type: none">1. Formação de imagem coerente e incoerente2. Tipos, arquiteturas e desenho de instrumentos (alguns de entre: Cameras, Objectivas, Microscópios, Telescópios, Scanners, Espectrômetros ópticos)3. Principais conceitos da teoria da coerência parcial relevantes para várias famílias de instrumentos4. Interferômetros5. Holografia6. Metrologia óptica
9 – BIBLIOGRAFIA	<p>Bass M et al., Handbook of Optics (Vol 1), (OSA, McGraw, 2001, 2009)</p> <p>Guenther R, Steel D, Encyclopedia of Modern Optics (Vol 1-5) (Elsevier, 2018)</p> <p>Goodman J W, Introduction to Fourier Optics (Roberts & Co, 2005)</p> <p>Goodman J W, Statistical Optics (2nd ed.) (Wiley, 2015)</p> <p>Revistas e artigos de revistas da Optical Society of America (OSA), SPIE e Nature Photonics</p>

Contents

- **Introduction**

- Imaging - geometry
- Optical design and analysis
- The *imaging chain*
- Systems' architectures
 - Imaging, light integration, spectroscopy
 - Scanning systems
 - Active and passive
 - Adaptive systems
 - Monocromáticos, hiper ou multispectrais
 - Single aperture or multiple aperture
 - Cophasing
 - Interferometers

- **2D Sampling**

- Sampling in 1D
- Shannon's theorem
- Modelling the sampling procedure
- Sampling artifacts

- **Holography**

- Basics
- Types of holograms
- Digital holography
- Holographic interferometry

- **Radiometry and Photometries**

- Radiometric quantities, units, dimensions
- Radiometric chain, from source to sensor

- **Image Formation**

- Modelling amplitude and phase objects
- Propagation and diffraction
- PSF and MTF
- Generalized pupil function

OI in this academic year

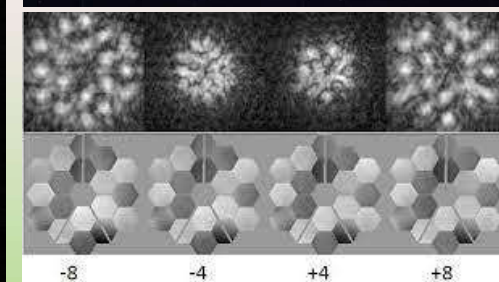
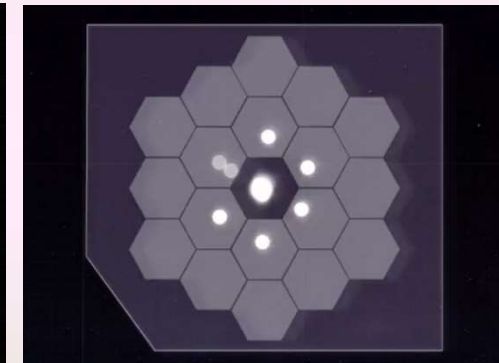
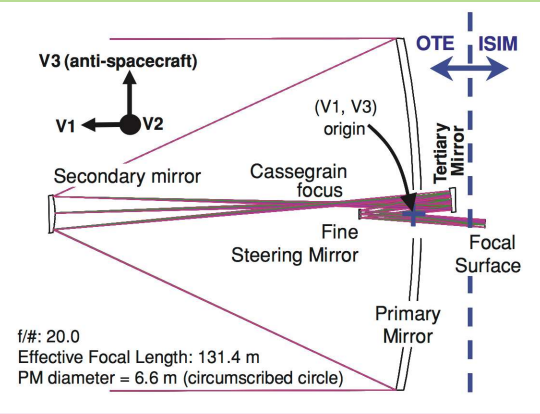
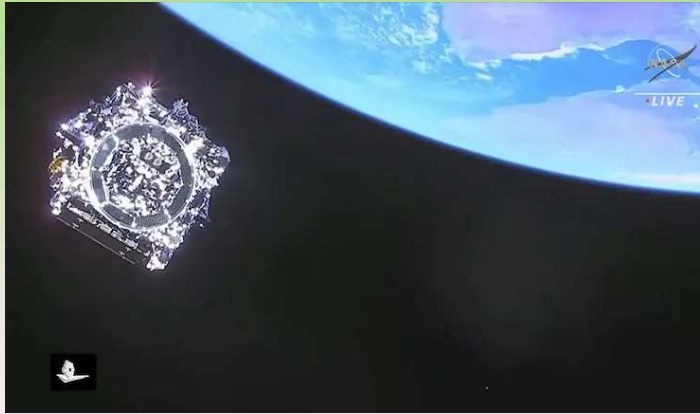
- Understand **James Webb Space Telescope (JWST)** current activity
 - ❑ Main collective goals:
 - Understanding cophasing and cophasing strategies
 - Learning Zemax Optics Studio
 - Learning how to use interferometry as internal metrology tools

- Hands on, **laboratory**:
 - ❑ Making an hologram
 - ❑ Wavefront sensor in practice (from optical system to wavefront numerical estimation)
 - ❑ Michelson interferometer, dual channel
 - ❑ Monochromator
 - ❑ *Processing an interferogram*
 - ❑ *Making a digital hologram*

- Analyse in-depth **one optical instrument / system** and explain it in class
 - ❑ Spectrometers, imagers, interferometers, ellipsometers, ...

- **Assessment**
 - ❑ Lab reports w/ discussion (50%)
 - ❑ Instrument explanation (30%)
 - ❑ JWST cophasing topics (20%)

JWST



Optical Instruments & systems – pick one!



BASS – Handbook of Optics

VOL	CHAPTER	
1	15	Polarimetry
1	16	Ellipsometry
1	31	Optical spectrometers
1	32	Interferometers
1	33	Holography and holographic instruments
2	11	Orthonormal polynomials and wavefront analysis
2	13	Optical testing
2	14	Computer Generated Holograms (CGH) in optical testing
2	38	Spectroradiometry
3	18	Optical Coherence Tomography
4	22	Slow light propagation in atomic and photonic media
4	23	Quantum entanglement in optical interferometry
5	1	Scatterometers
5	2	Spectroscopic measurements
5	4	Imaging through atmospheric turbulence
5	5	Adaptive optics
5	38	Gratings and monochromators in the VUV and soft X-ray spectral regimes

Spectroscopy - 1.31 & 2.38 & 5.2 & 5.38

Adaptive optics – 5.4 & 5.5

Interferometric systems – 1.32 & 2.11 & 2.13 & 2.14 & 4.23

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Gross H. (ed.), Handbook of Optical Systems (Wiley, 2008)
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Hill J, Mégier J, Imaging Spectrometry, a Tool for Environmental Observations (Springer, 2007)
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Internet resources

Vision Systems Design
<http://www.vision-systems.com/index.html>
CVonline: The Evolving, Distributed, Non-Proprietary, On-Line Compendium of Computer Vision
<http://homepages.inf.ed.ac.uk/rbf/CVonline/>
Computer Vision O.N.L.I.N.E
<http://www.computervisiononline.com/software>

Bibliography (examples)

<https://www.dropbox.com/sh/j7j6lb1grink9zy/AACvCqSjPceF7Rm-TbJT8z6Ja?dl=0>

Activo...

#	AUTOR, TÍTULO (EDITOR, AÑO)	EDITOR	AÑO
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2	Amelinckx S, van Dyck D, Landuyt J, van Tendeloo G, Handbook of Microscopy (Wiley, 1996)	Wiley	1996
3	Amidror I, The Theory of the Moiré, Phenomenon (Springer, 2009)	Springer	2009
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5	Barter J., Telescopes (Gale, 2005)	Gale	2005
6	Bass M et al, Handbook of Optics, Volume I - Geometrical and Physical Optics, Polarized Light, Components and Instruments (2009)		2009
7	Bass M et al, Handbook of Optics, Volume II - Design, Fabrication and Testing, Sources and Detectors, Radiometry and Photometry (2009)		2009
8	Bass M et al., Handbook of Optics, Volume III - Vision and Vision Optics (McGraw-Hill, 2009)	McGraw-Hill	2009
9	Bass M et al, Handbook of Optics, Volume IV - Optical Properties of Materials, Nonlinear Optics, Quantum Optics (McGraw-Hill, 2009)	McGraw-Hill	2009
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81	Zhang C., Light Field Sampling (Morgan and Claypool, 2006)	Morgan and Claypool	2006

Imaging systems and Industry ([David Lowe](#), 2015)

- Automobile driver assistance & traffic and road management
- Eye and Head Tracking
- Film and Video
- Sports analysis
- Gesture Recognition
- General purpose vision systems
- Industrial automation and inspection
 - Electronics industry
 - Food and agriculture
 - Printing and textiles
 - Other
- Medical and biomedical
- Object Recognition and Augmented Reality for Mobile Devices
- Photography
- People tracking
- Safety monitoring
- Security:
 - Biometrics
 - Monitoring and Surveillance
- 3D modeling
- Web and Cloud Applications

Imaging instruments / systems are used for:

- Mapping (2D or 3D fields)
- Meteorology
- Medical & biomedical
- Metrology
- Inspection
- Microscop(y)(ies)
 - Optical
 - Visible, UV, IR, ...
 - Electron
 - Scanning probe (STM, AFM)
 - Superresolution
 - ...
- Astronomy
- Security
- Biometrics
- Photography
- Video
- Film
- Military
- Security and surveillance
- Vision enabling / emulators in (semi)automatic systems
- Probing
- Light concentration

Imaging systems can be:

- Active / passive
- Static / scanning
- Monolithic / multi-aperture / interferometric imaging
- Monochromatic / multispectral / hyperspectral (frequency range)
- Intensity / phase (coherency) / polarization / wavelength sensitive
- 2D or 3D
- Imaging / non-imaging
- Radiometers, spectrometers, imagers (spectro-radiometers, imaging spectrometers, ...)
- Superresolution

Imaging systems are characterized in terms of:

- **Intrinsic parameters**

- Resolution (PSF, MTF)
- Sensitivity
- Dynamic range
- Field of view (FOV) / Field of regard (FOR)
- Depth of focus
- Space-variant / space invariant properties (aberrations)
- Sampling (spatial / dynamic / temporal)
- ...

- **Operational parameters**

- Quantization
- Rates (pixel, frames, ...)
- Integration time control
- Noise reduction mechanisms
- Stabilization
- Signal handling and interfaces
- Signal & image processing (on-chip, external)
- Reconstruction techniques
- Coding / compression
- ...

Photonics²¹ - <http://www.photonics21.org>

“Photonics is the science of the harnessing of light. Photonics encompasses the generation of light, the detection of light, the management of light through guidance, manipulation, and amplification, and most importantly, its utilisation for the benefit of mankind.”

PHOTONICS – Our Vision for a Key Enabling Technology of Europe

PHOTONICS²¹

THE LEVERAGE EFFECT of Photonics Technologies: the European Perspective

Study prepared for the European Commission,
DG Information Society and Media under reference
SMART 2009/0066

Final Report
March 2011

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(Technologia)

John Lincoln,
Alastair Wilson
(Electronics,
Sensors,
Photonics Knowledge
Transfer Network)

PHOTONICS²¹

TNO innovation
for life



TECHNOLOGIA



Photonics

“Photonics is the science of the harnessing of light. Photonics encompasses the generation of light, the detection of light, the management of light through guidance, manipulation, and amplification, and most importantly, its utilisation for the benefit of mankind.”

Photonics is an area of study that involves the use of radiant energy (such as light), whose fundamental element is the **photon** . Photonic applications use the photon in the same way that electronic applications use the electron. Among the large number of current or possible photonic applications are: photonic switching, photonic networks, the photonic computer.

Photonics is one of the fastest growing **high-tech industries** in the world today. It includes:

- optical communications (e.g., fiber optics, lasers, and infrared links),
- **optical imaging (e.g., spy and weather satellites, night vision, holography, flat screen display, and CCD video cameras),**
- optical data storage and optical computing (e.g., CD's and DVD's),
- optical detectors (e.g., supermarket scanners, medical optics, and nondestructive evaluation of materials),
- lasers (e.g., welding lasers, laser surgery, laser shows, and laser rangefinders)
- spectroscopy (e.g., chemical and biological detection, anti-terror detection)
- quantum optics (e.g., quantum teleportation, quantum cryptography, and single-photon optics)

Readiness Levels

- **Technology Readiness Levels**
 - NASA (1995), DoD, ..., H2020
 - https://en.wikipedia.org/wiki/Technology_readiness_level
 - https://www.nasa.gov/pdf/458490main_TRL_Definitions.pdf
 - https://esto.nasa.gov/files/TRL_definitions.pdf
- **System Readiness / Maturity Levels**

Technology Readiness Levels (TRLs): Overview

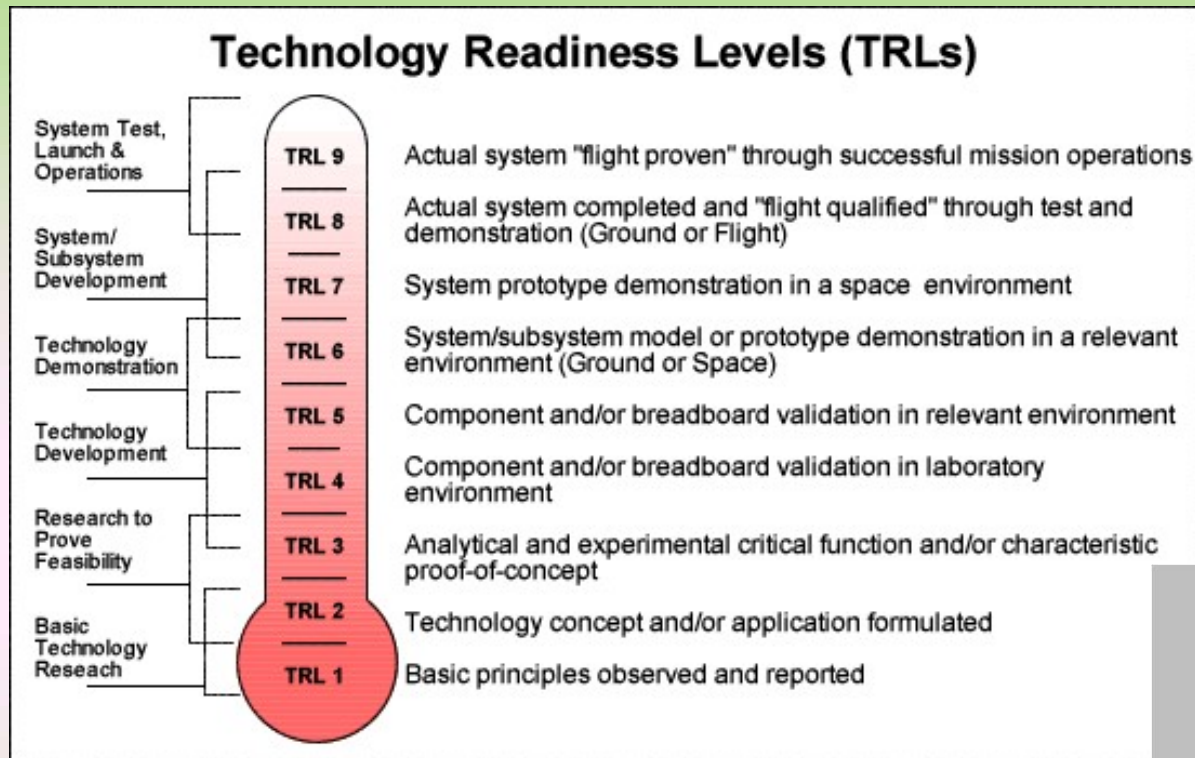
TRLs are NASA-generated and Used Extensively by DoD

Basic principles observed and reported	1	Basic
Technology concept and/or application formulated	2	
Analytical and experimental critical function and/or characteristic	3	
Component and/or breadboard validation in laboratory environment	4	Advanced
Component and/or breadboard validation in relevant environment	5	
System/subsystem model or prototype demonstration in a relevant environment	6	Applied
System prototype demonstration in a operational environment	7	
Actual system completed and 'flight qualified' through test and demonstration	8	
Actual system 'flight proven' through successful mission operations	9	

TECHNOLOGY MATURITY

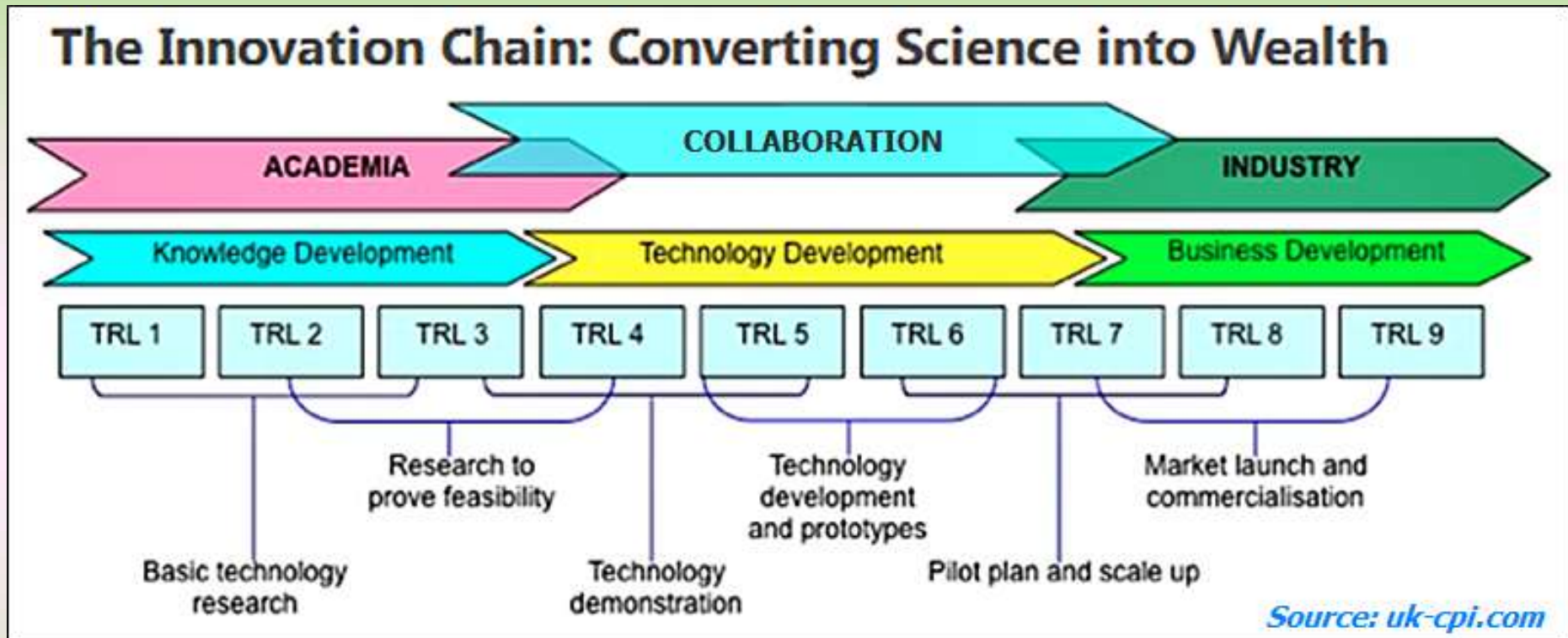


TRL – Technological Readiness Levels

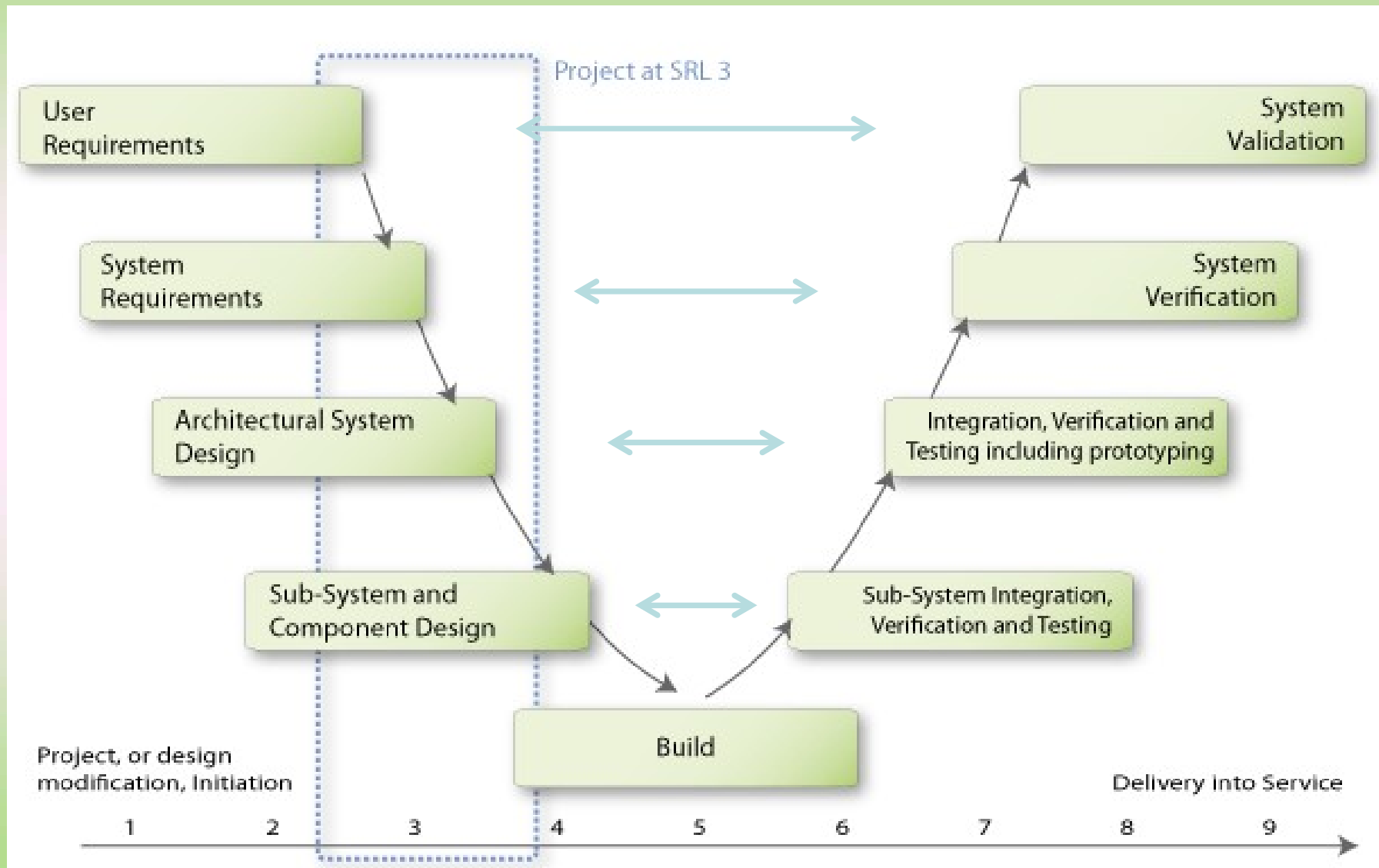


TRL	9	Commercialized
	8	Pre-production
	7	Field Test
	6	Prototype
	5	Bench / Lab Testing
	4	Detailed Design
	3	Preliminary Design
	2	Conceptual Design
	1	Basic Concept

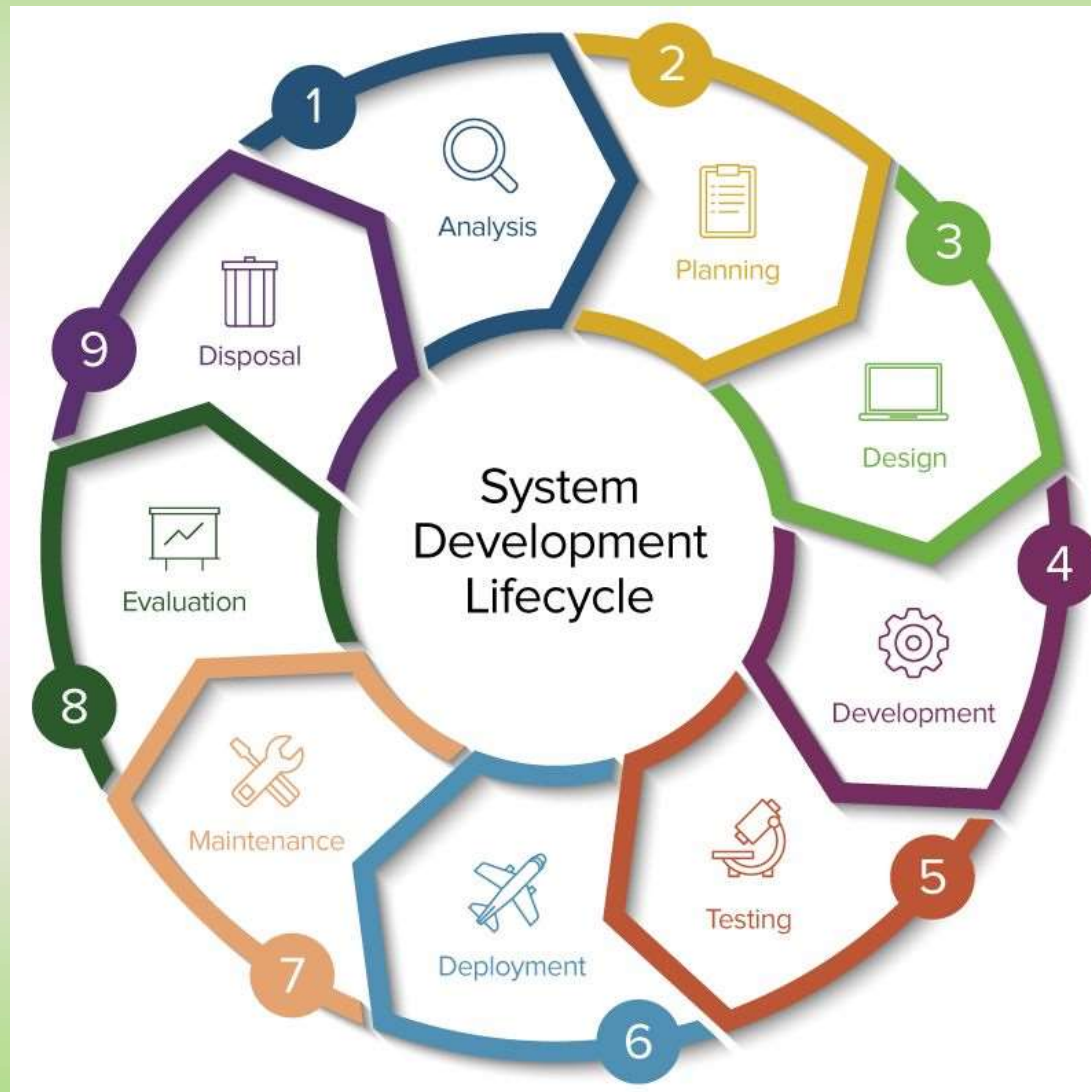
Innovation chain



System Readiness / Maturity Levels



System development cycle



<https://www.smartsheet.com/system-development-life-cycle-guide>