NAC2023
18th NSTDA Annual Conference
การประชุมวิชาการประจำปี สวทช. ครั้งที่ ๑๘

TRL กับความสำเร็จในการทำงานร่วมกับ NASA ครั้งแรกในประเทศไทย

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ภาควิชาฟิสิกส์ คณะวิทยาศาสตร์
มหาวิทยาลัยเกษตรศาสตร์

28-31
มีนาคม 2566

Technology Readiness Level (TRL)

TRL เป็นเสมือนภาษาสากลในการพูดคุยสื่อสารกับภาคอุตสาหกรรม ย้อนกลับไป TRL เริ่มพัฒนาโดยองค์กรนาซ่า (NASA) ของสหรัฐอเมริกา เพื่อใช้ประเมินความพร้อมของเทคโนโลยีการบิน โดยแบ่ง TRL เป็น 9 ระดับ

TRL 9
- Actual system "flight proven" through successful mission operations

TRL 8
- Actual system completed and "flight qualified" through test and demonstration (ground or space)

TRL 7
- System prototype demonstration in a space environment

TRL 6
- System/subsystem model or prototype demonstration in a relevant environment (ground or space)

TRL 5
- Component and/or breadboard validation in relevant environment

TRL 4
- Component and/or breadboard validation in laboratory environment

TRL 3
- Analytical and experimental critical function and/or characteristic proof-of-concept

TRL 2
- Technology concept and/or application formulated

TRL 1
- Basic principles observed and reported

https://www.thailibrary.in.th/2021/10/15/trl/

https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level

TRL 1 - 3

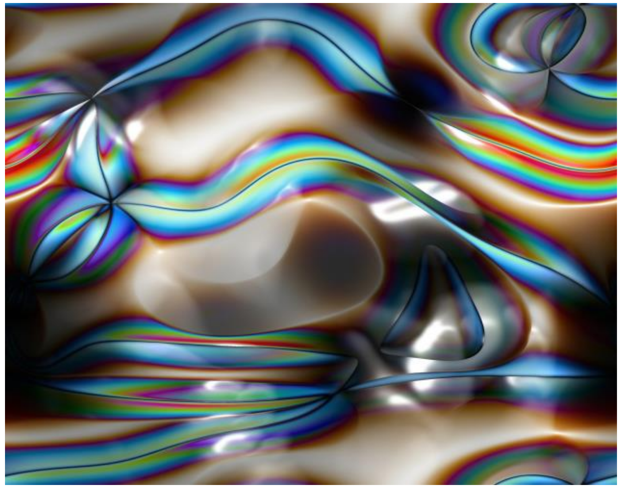
TRL 1 Basic principles observed and reported: Transition from scientific research to applied research. Essential characteristics and behaviors of systems and architectures. Descriptive tools are mathematical formulations or algorithms.

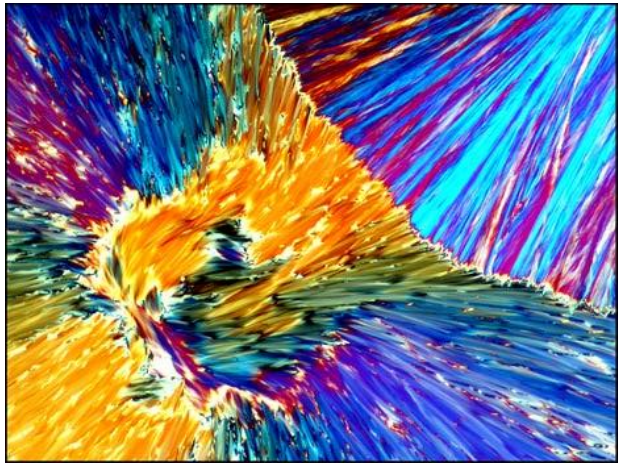
TRL 2 Technology concept and/or application formulated: Applied research. Theory and scientific principles are focused on specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for simulation or analysis of the application.

TRL 3 Analytical and experimental critical function and/or characteristic proof-of- concept: Proof of concept validation. Active Research and Development (R&D) is initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard or brassboard implementations that are exercised with representative data.

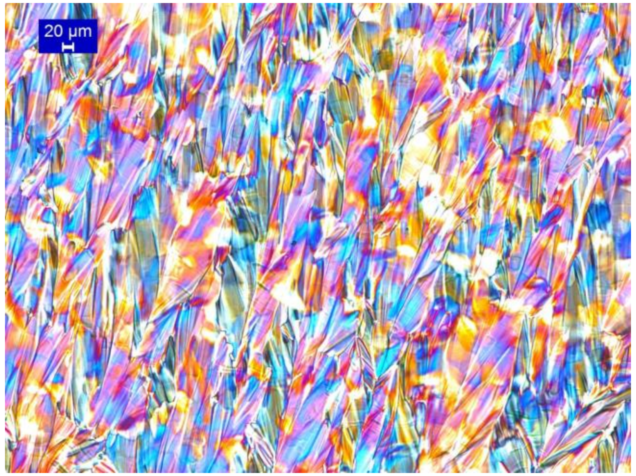
https://esto.nasa.gov/files/trl_definitions.pdf

Thailand Liquid Crystals in Space (TLC)

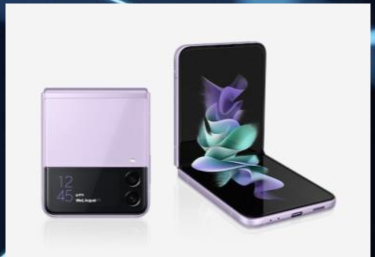




TEXTURES OF LIQUID CRYSTALS



LIQUID CRYSTAL TECHNOLOGIES

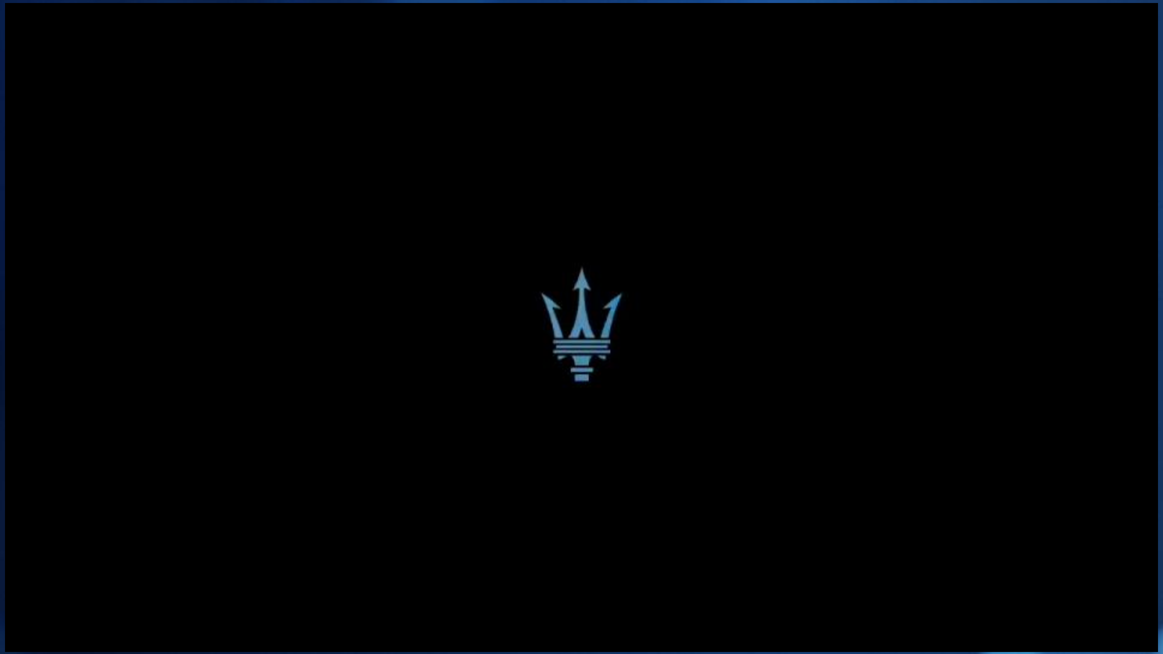


Liquid Crystal Display (LCD) : 300 billion dollar industry

Augmented Reality at Pepsi-Max bus shelter, London

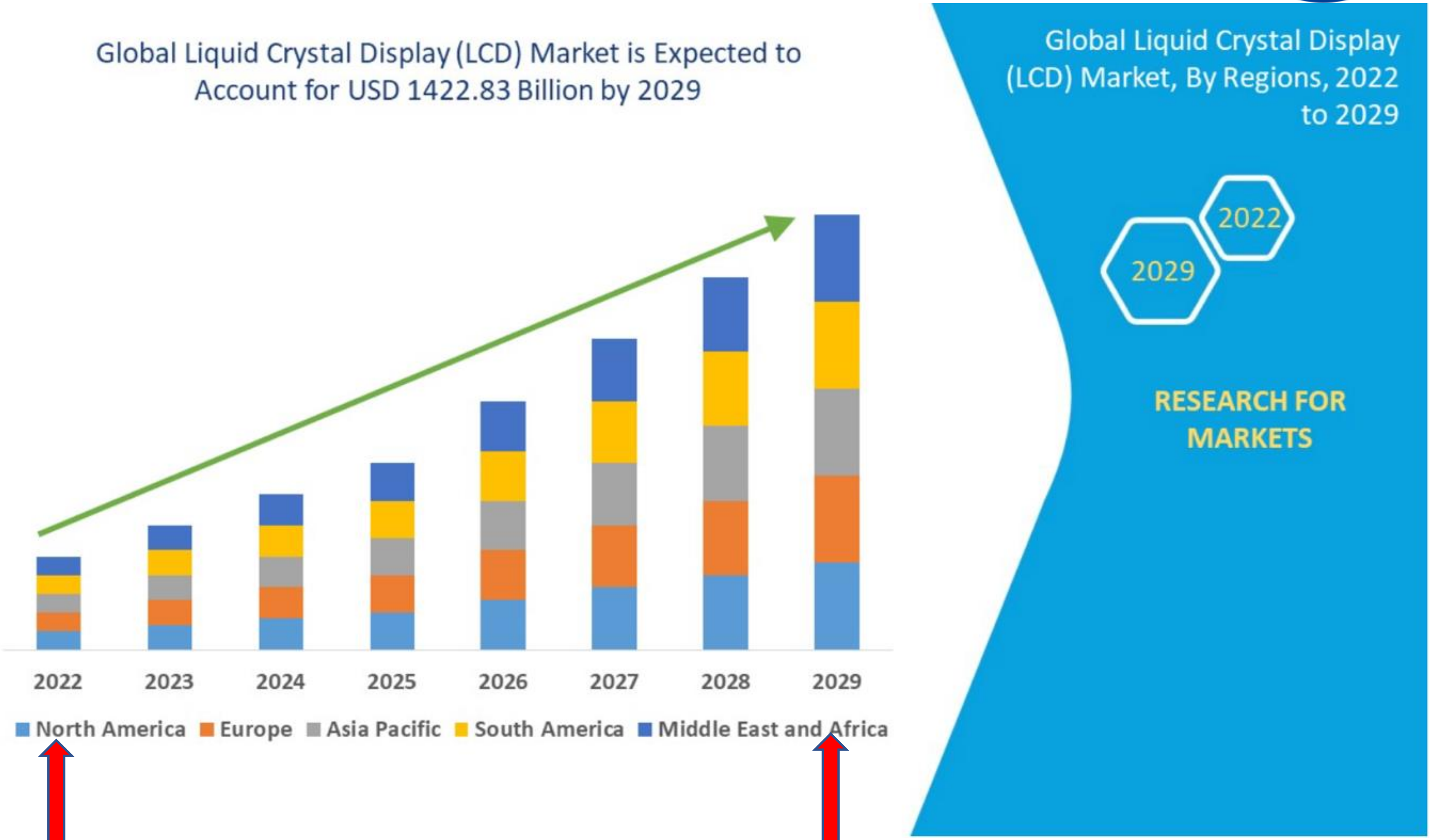
LIQUID CRYSTAL TECHNOLOGIES

2023 Maserati MC20
Polymer Dispersed Liquid Crystal (PDLC) sunroof



Spatial Light Modulator (SLM)

Global LCD market growth



300 billion USD

1,500 billion USD

Source: https://www.databridgemarketresearch.com/reports/global-liquid-crystal-display-lcd-market

Thai – US collaboration on Space Experiment on ISS

- Memorandum of Understanding between Kasetsart University (KU) and NASA was signed on Jun. 24th, 2021 for the **study of liquid crystals on International Space Station**
- MOU celebration ceremony was organized on Feb. 18th , 2022.

Feb 18, 2022, Bangkok

Feb 18, 2022, Bangkok

Collaboration

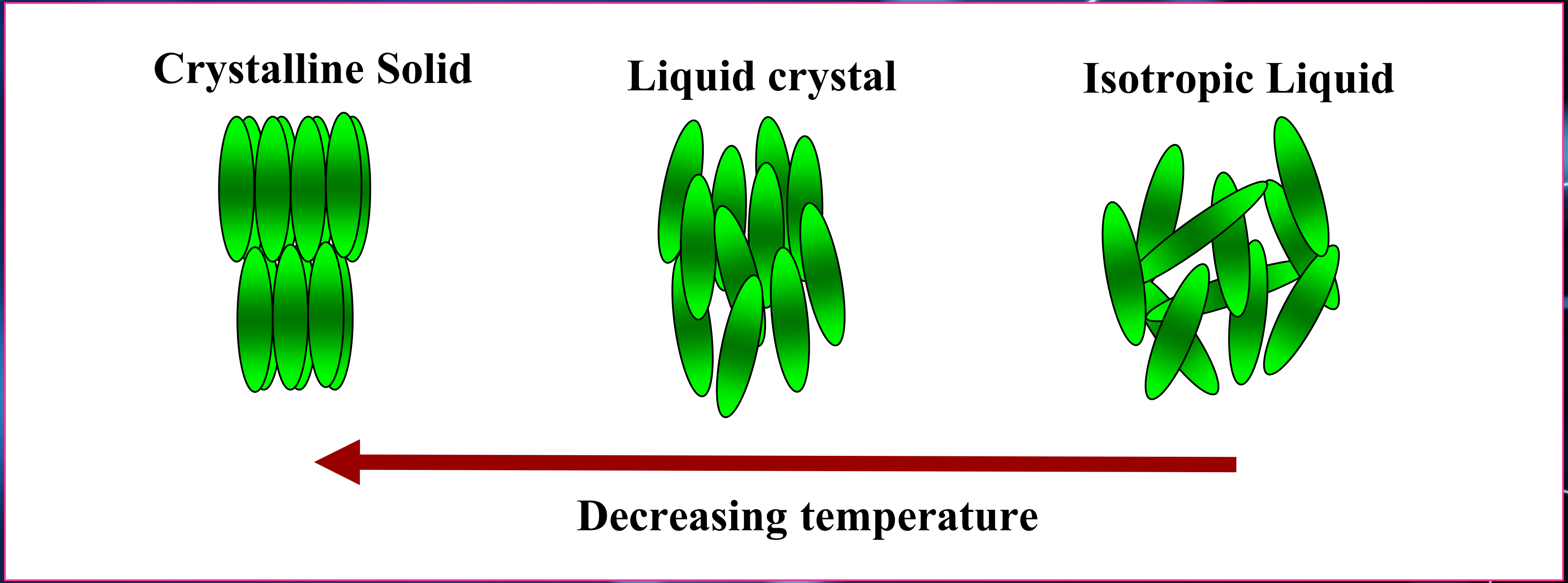
In order to achieve the mutual scientific goals, NASA and Kasetsart University signed an international agreement that based on the following:

➢ **Kasetsart University:**
- KU and GISTDA have agreed to develop the ISS Liquid Crystal experiment which will be compatible with an existing ISS microscope.

➢ **NASA:**
- fund a grant for a U.S. Co-Investigator to collaborate with the KU-GISTDA science team.
- participating in the experiment, science and engineering reviews; and
- will launch the hardware to the ISS and provide the astronaut crew time.

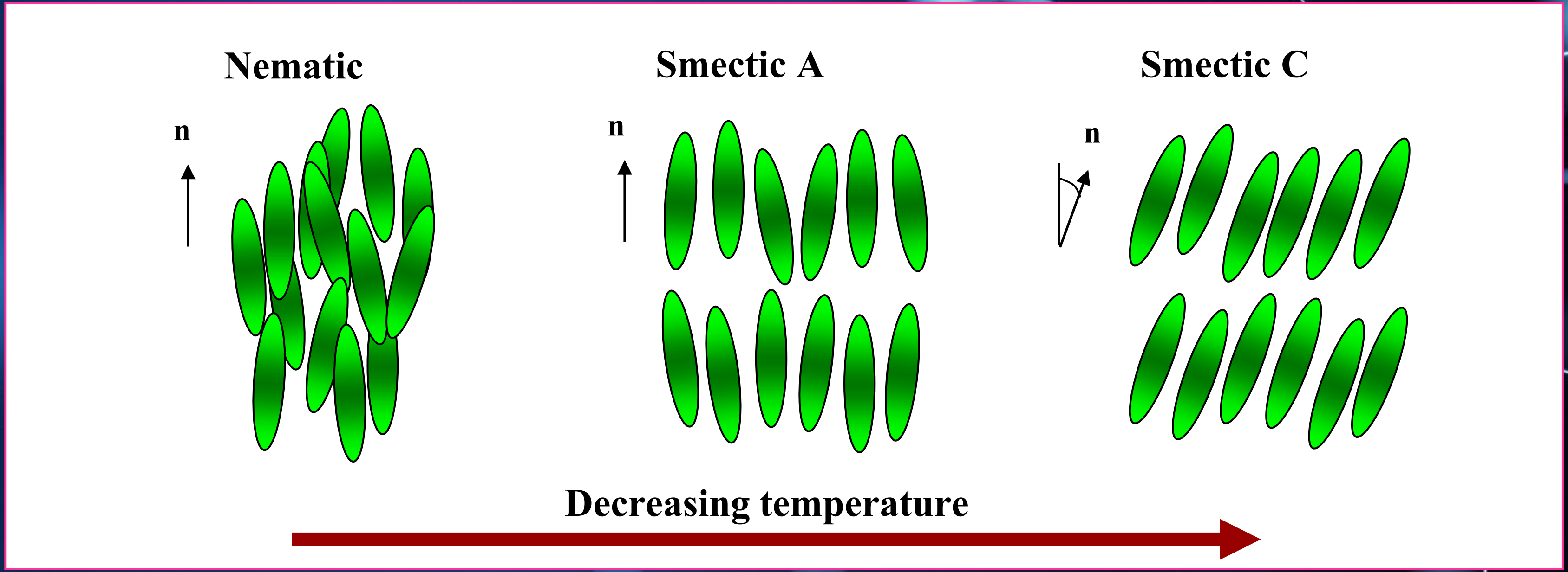
What are Liquid Crystals?

Liquid Crystals (LCs) are states of matter intermediate between that of a crystalline solid and an isotropic liquid.



Classification of Liquid Crystals

- **Lyotropic liquid crystals** molecules exhibit phase transitions as a function of concentration of the mesogens in a solvent, e.g. lipids.
- **Thermotropic liquid crystals** occur in a temperature range between the crystalline solid and isotropic phase.

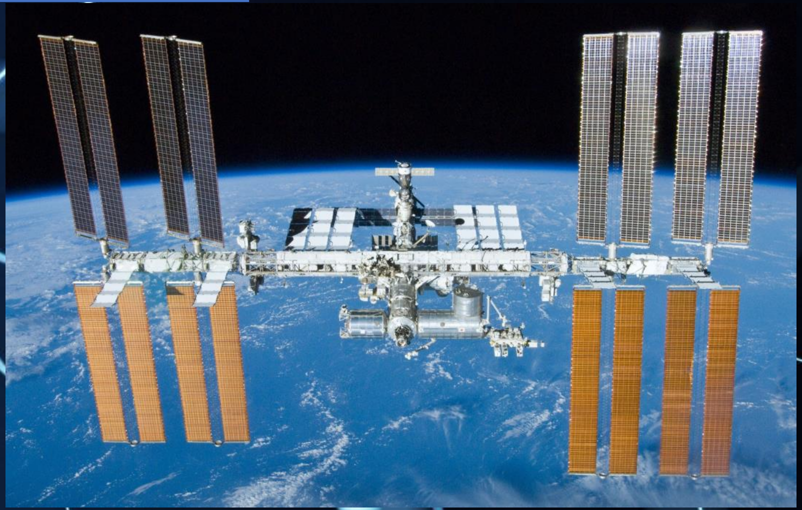


OASIS

Operation period 2015-2016
Analysis period 2017-present

OASIS stands for “Observation and Analysis of Smectic Islands in Space”

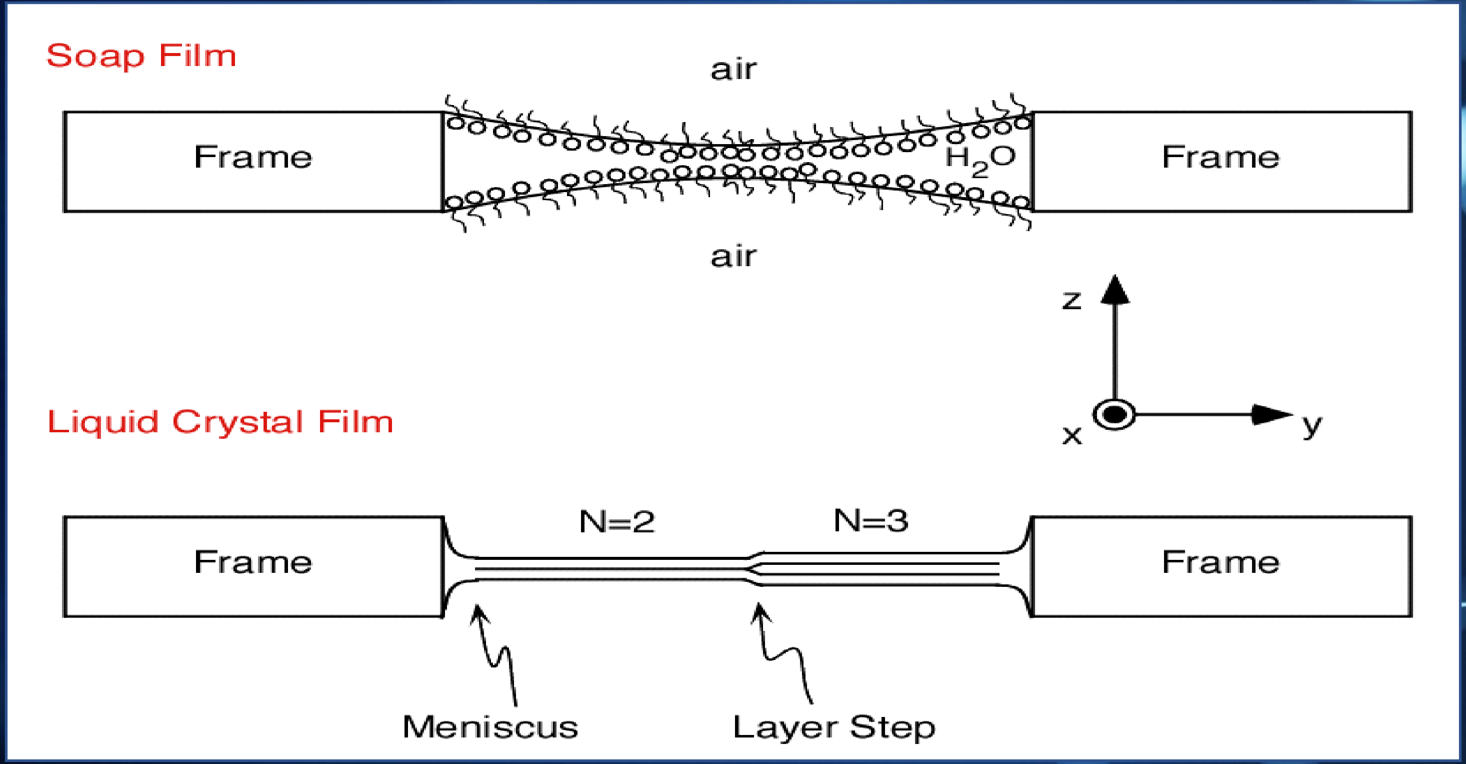
- The TLC (Thailand-NASA Liquid Crystal in Space) was initiated following the Success of OASIS.
    - OASIS Principal Investigator: Prof. Noel Clark from University of Colorado, Boulder.
- OASIS science experiment operated successfully for over 9 months on ISS during 2015 and 2016 gathering scientific results.

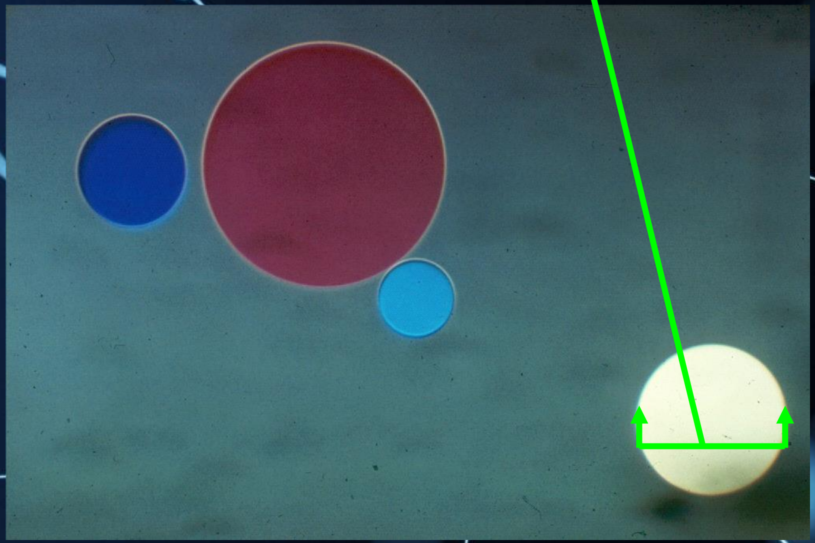

International Space Station (ISS)

Smectic Island

Smectic Islands are the thicker regions existed in smectic liquid crystal films

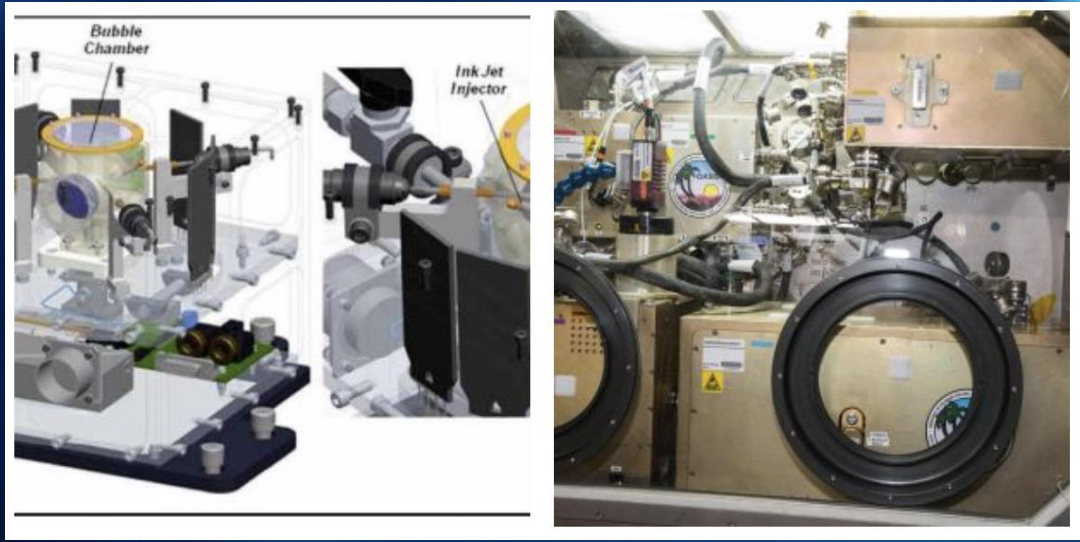
Freely suspended films



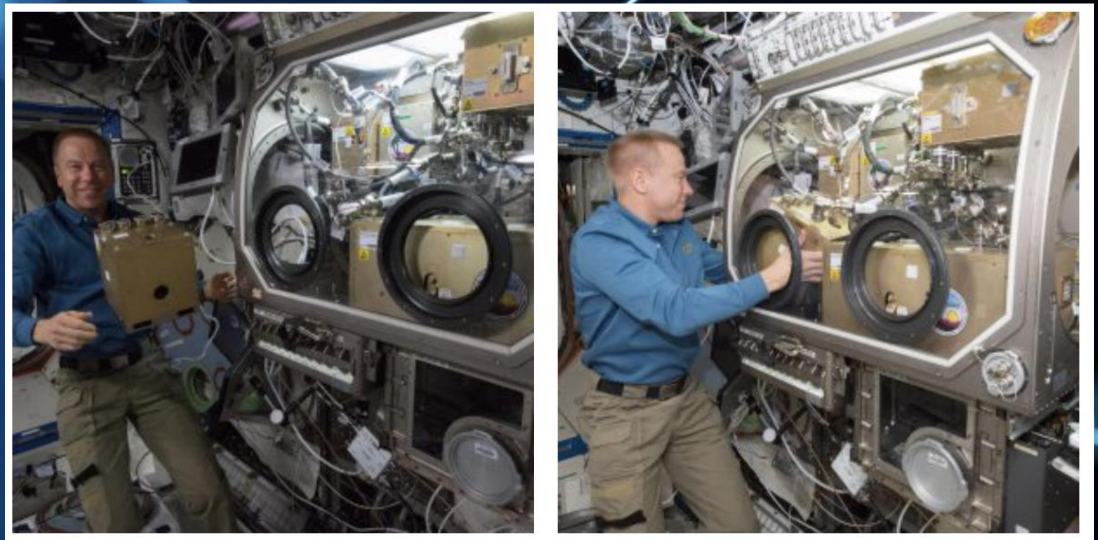


OASIS (2015-2016)

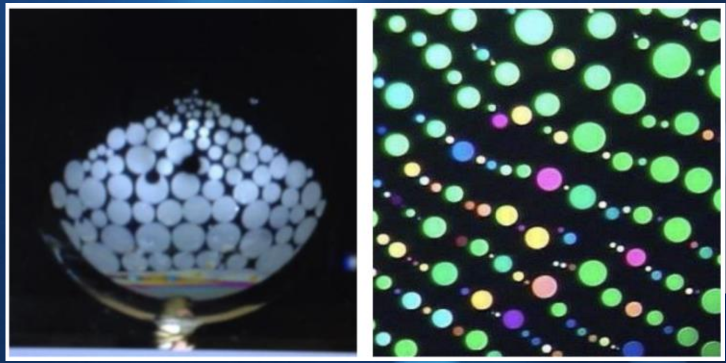
https://www1.grc.nasa.gov/space/iss-research/msg/oasis/



OASIS Microgravity Science Glovebox



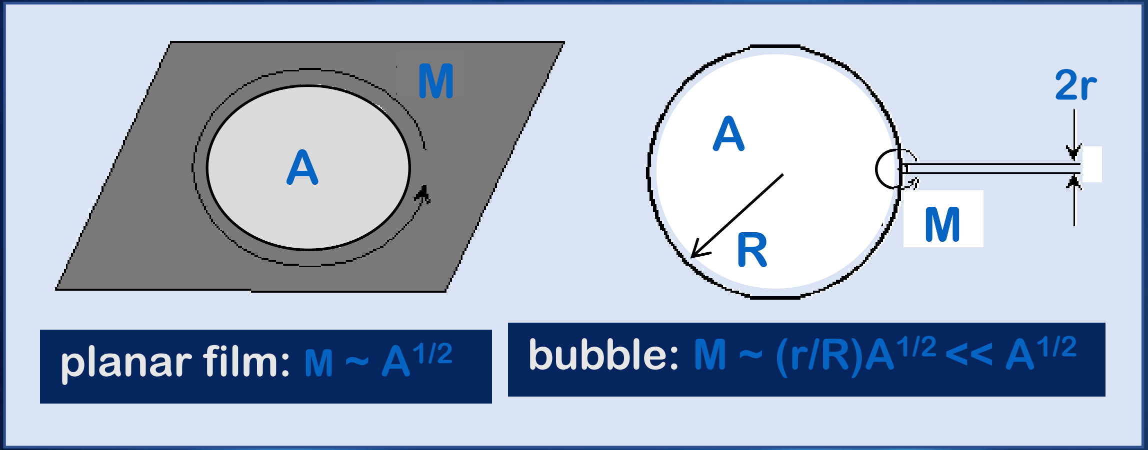
Operation on ISS by an astronaut

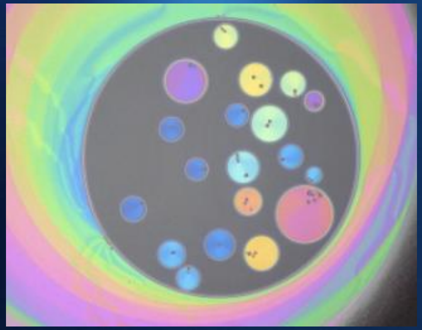


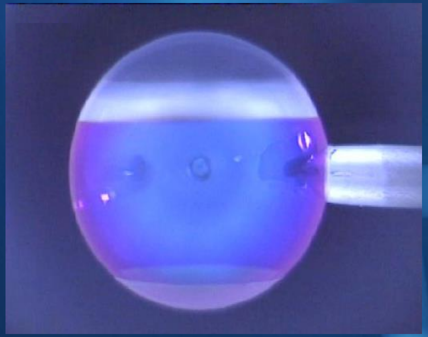
Smectic Island Experiment

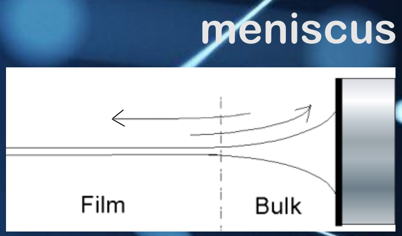
OASIS vs TLC

While OASIS focused on liquid crystal bubble investigation, TLC will focuus on liquid crystal films.









- Planar films
  - Layer structure controlled by meniscus length (M)
- Bubbles
  - Large area (A) to meniscus length ratio
  - Ultraweak coupling to the bulk

Justification for Microgravity

Limitations of Terrestrial Experiments

- Gravitational sedimentation of islands & drops
- Convection of films and surrounding air

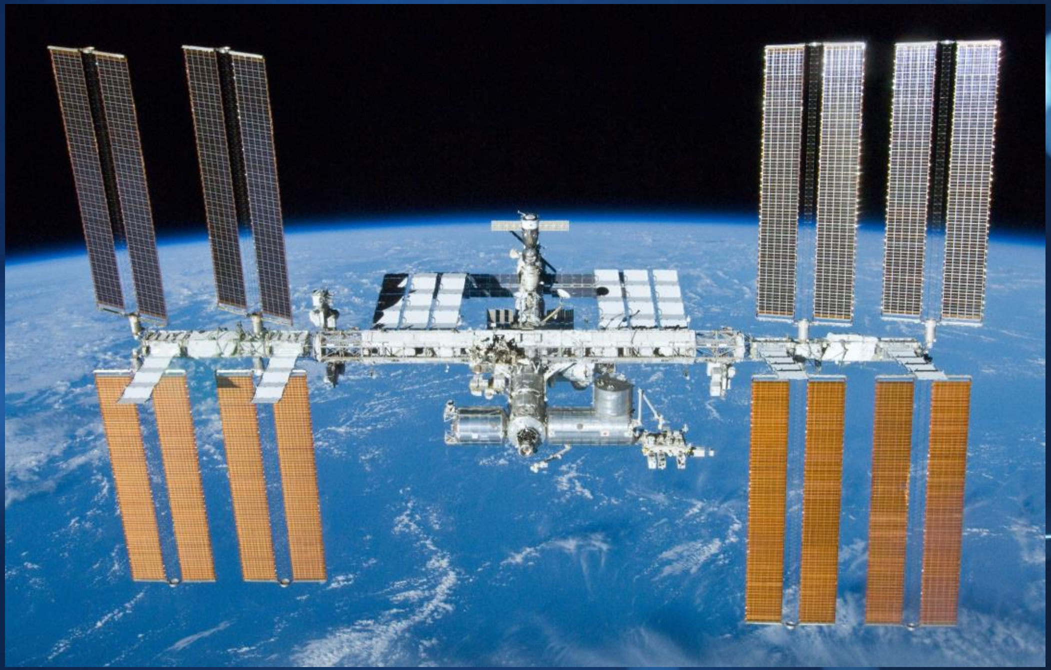
Parabolic flight

Suborbital Flight

Drop Tower

Justification for Microgravity

- **Limitations of Drop Tower & Parabolic Flight Experiments and suborbital flight**
  - **Coalescence & coarsening of defects, islands, ordering of drops take a long time, longer than experiment time of the terrestrial experiment can perform**



International Space Station (ISS)

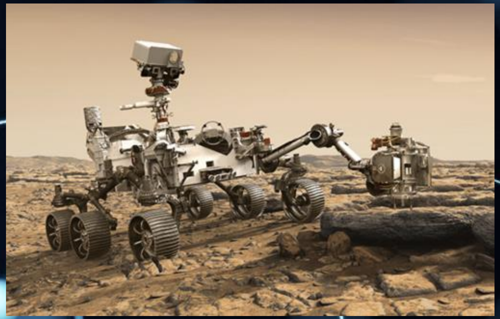
TLC OBJECTIVES

Science

1. To test theories of hydrodynamic flow, of relaxation of hydrodynamic perturbations, defects, and hydrodynamic interactions in 2D system.
2. Study the effect of gravity on the heat transfer process through Lehmann rotation of freely suspended film and inclusions on films.

Space applications

3. Future space helmets may use certain types of liquid crystals in small display screens
4. To design liquid crystal displays (LCDs) that can perform better in space.

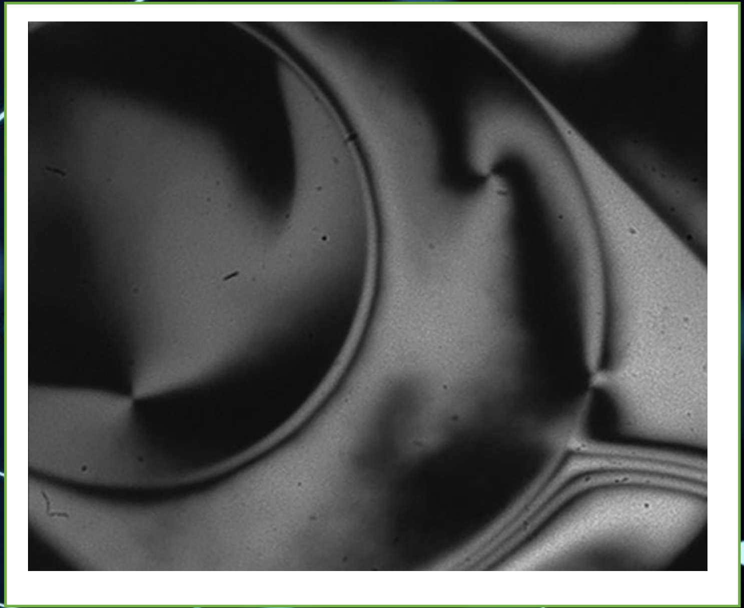


Earth applications

5. Greater understanding of the physics behind these structures could lead to improved liquid crystal display devices and could also advance research in high-speed electro-optic devices used to control a light beam.

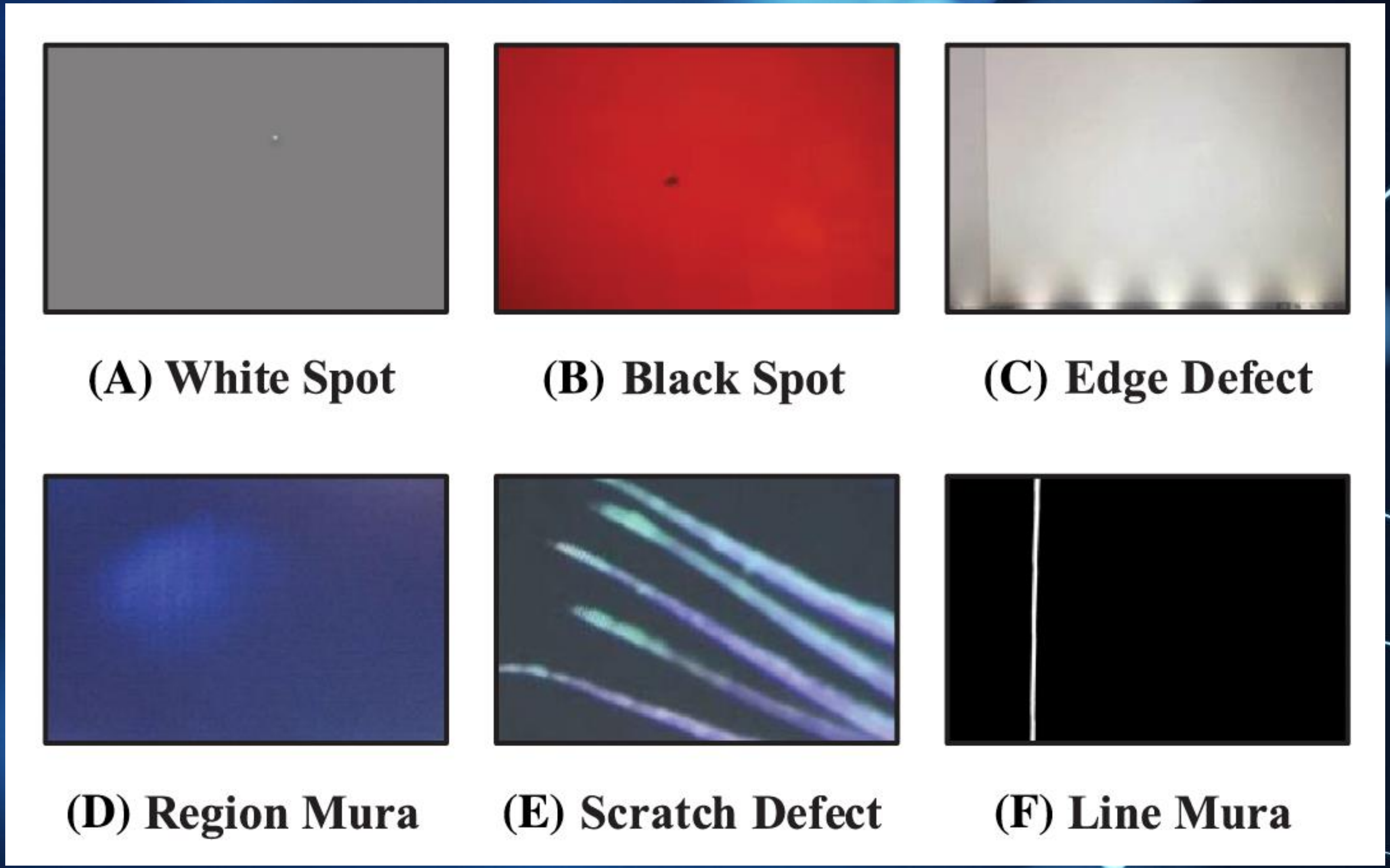
Science of TLC

- Observation of Island/Defects of the liquid crystal on entire flat film 3 cm^2 in detail enable us to study many defect points simultaneously.
  (Previous OASIS bubble experiment can only be observed at 0.0004 cm^2 , one at a time.)



- Study the origin of the rotation of defect-island structures (Lehmann rotation).
  Molecular dynamics of liquid crystal structures under external forces.

Common defects in LCD

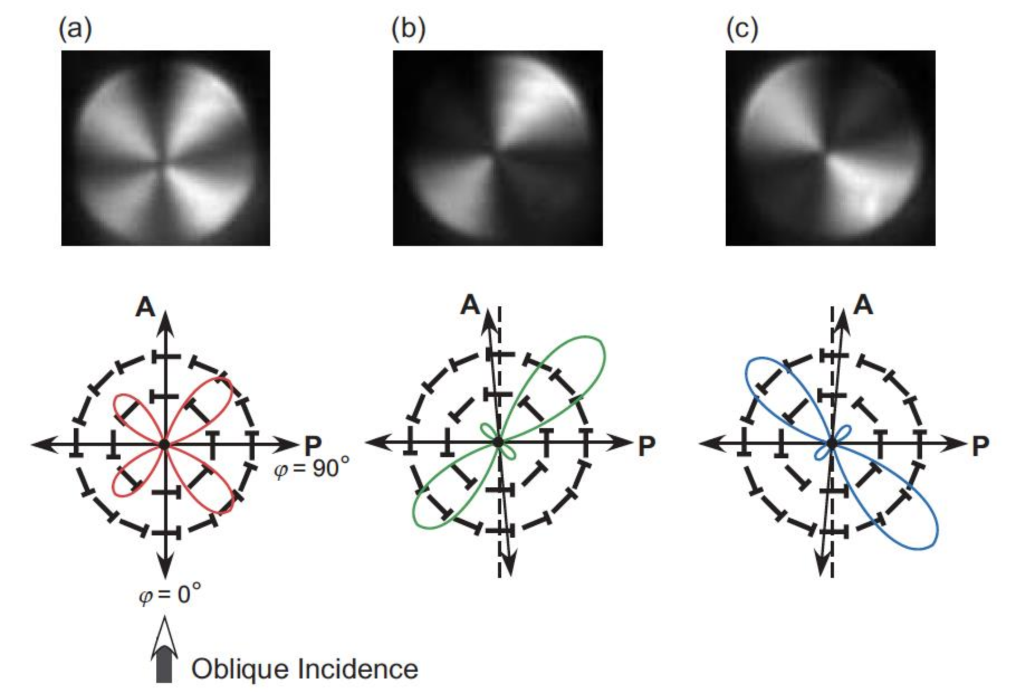


Cui, Y, Wang, S, Wu, H, Xiong, B, Pan, Y. Liquid crystal display defects in multiple backgrounds with visual real-time detection. J Soc Inf Display. 2021; 29: p. 547– 560.

Experiment: Freely Suspended LC Films

+1 and -1 defects on the film generated by perturbing the molecular director on Smectic C FSLC films.

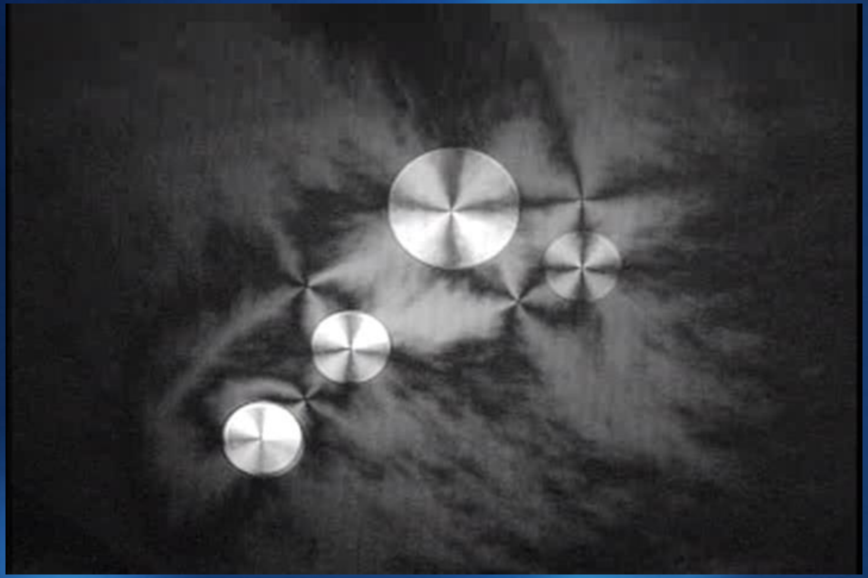
Mapping of molecular orientation in LC film under polarized microscopy

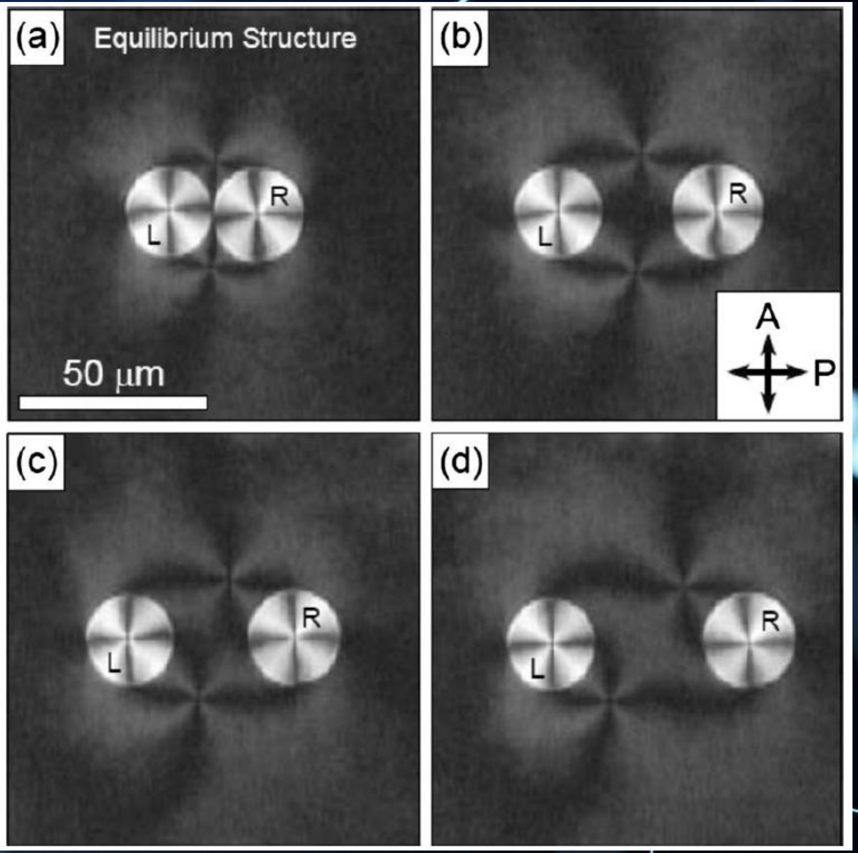


+1 Topological defect in freely suspended LC film

N. Chattham, Ph.D. Thesis, U. of Colorado, 2004.

Experiment:
Freely Suspended LC Films



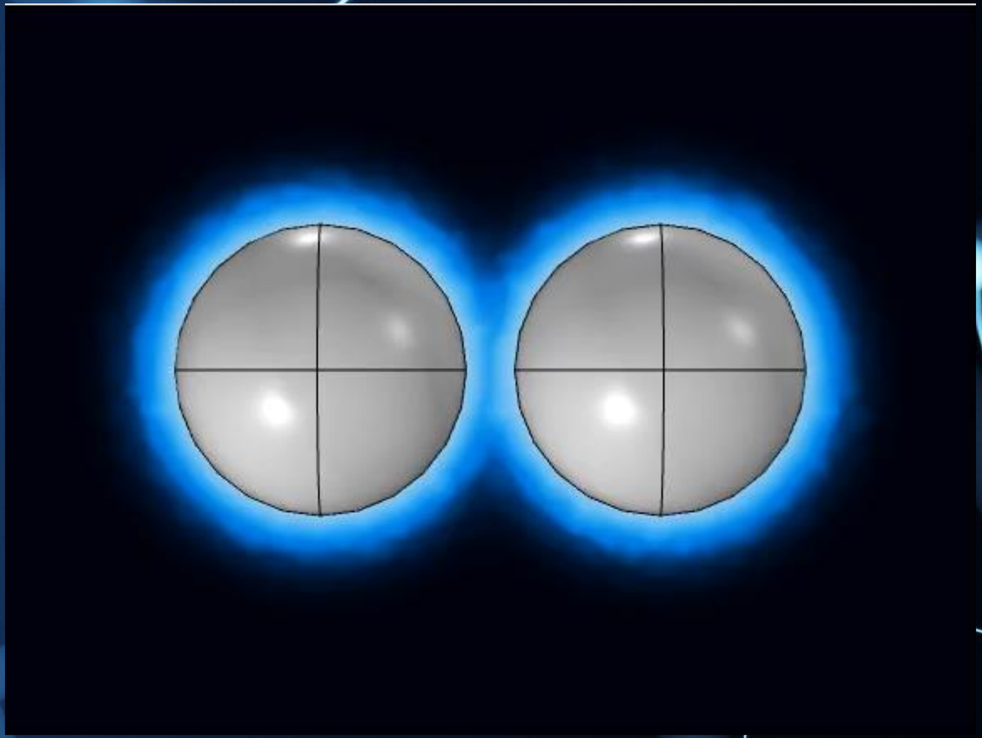


Silvestre, N. M.; Patrício, P.; Telo da Gama, M. M.; Pattanaporkratana, A.; Park, C. S.; Maclennan, J. E.; Clark, N. A., Phys. Rev E. 80, 041708 (2009).

Inclusion in Freely Suspended Liquid Crystal Films

Experimental results

Simulation results

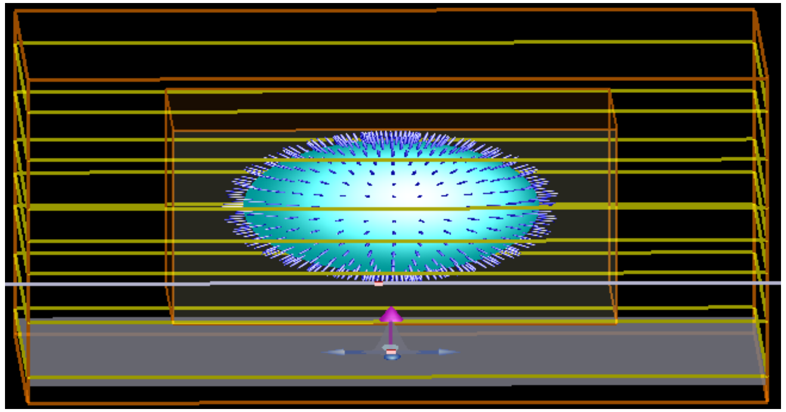


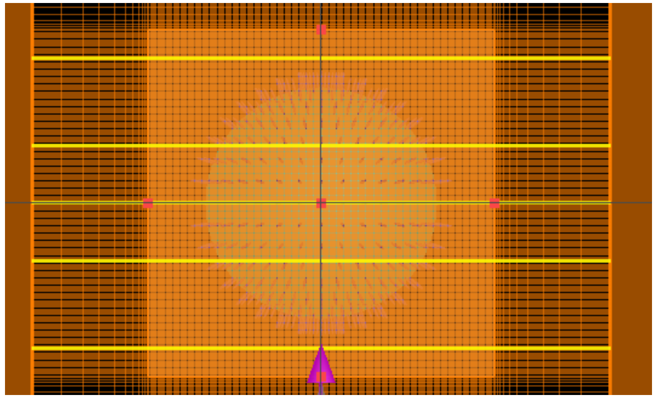
Lehmann Rotation in Liquid Crystals

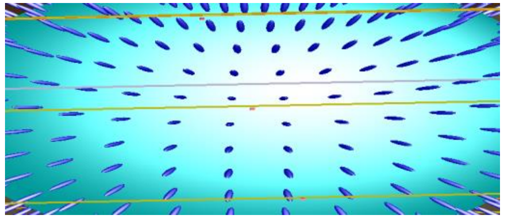
Lehmann rotation of defect on liquid crystal droplet inclusions due to heat gradient

J. Kiang-ia, R. Taeudomkul, P. Prajongtat, P. Tin, A. Pattanaporkratana, and N. Chattham, "Anomalous Lehmann Rotation of Achiral Nematic Liquid Crystal Droplets Trapped under Linearly Polarized Optical Tweezers", Molecules 26, 4128 (2021).

Light interaction of Liquid Crystal droplet

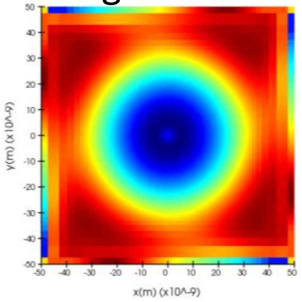




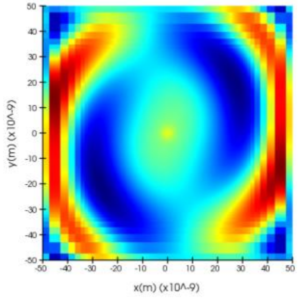


Input: circularly polarized light

Mag



Ex



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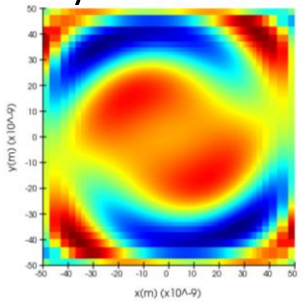
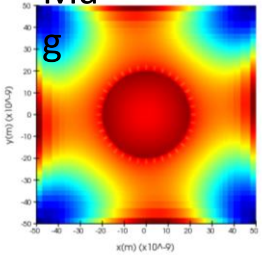
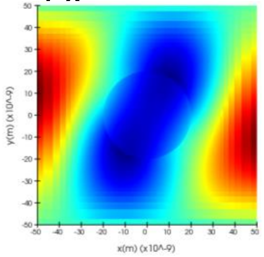


Inside LC

Mag



Ex



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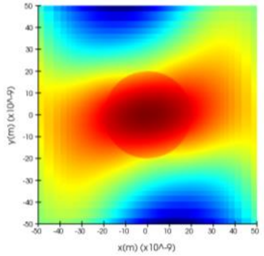
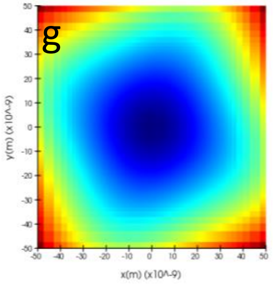


Output

Mag



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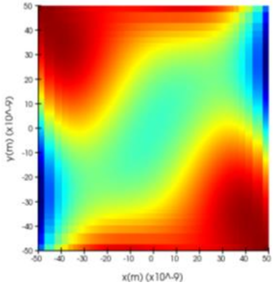

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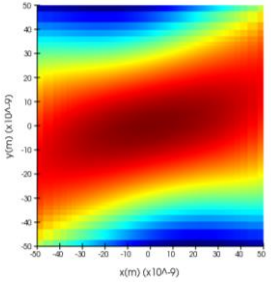
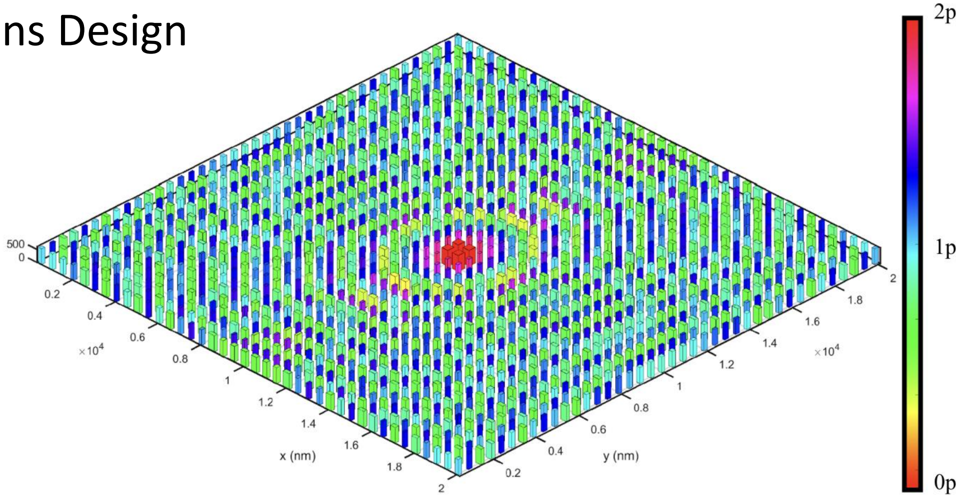
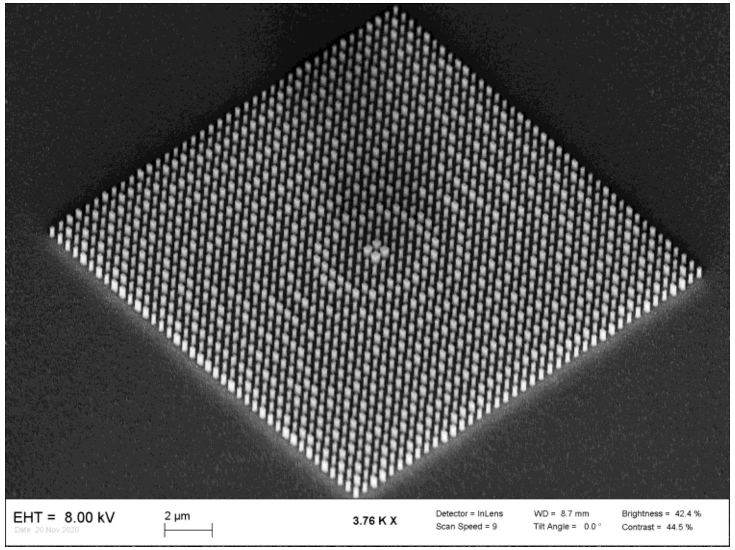


Metalens integration

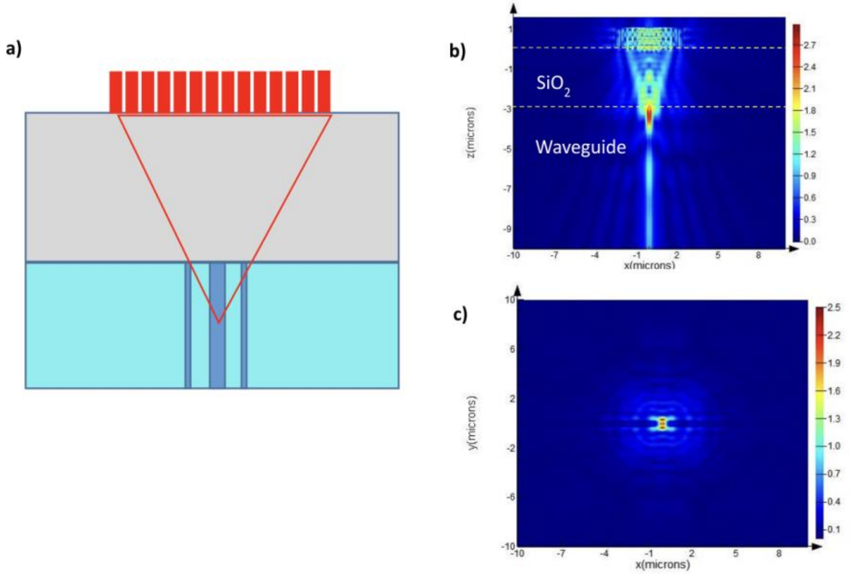
Metalens Design



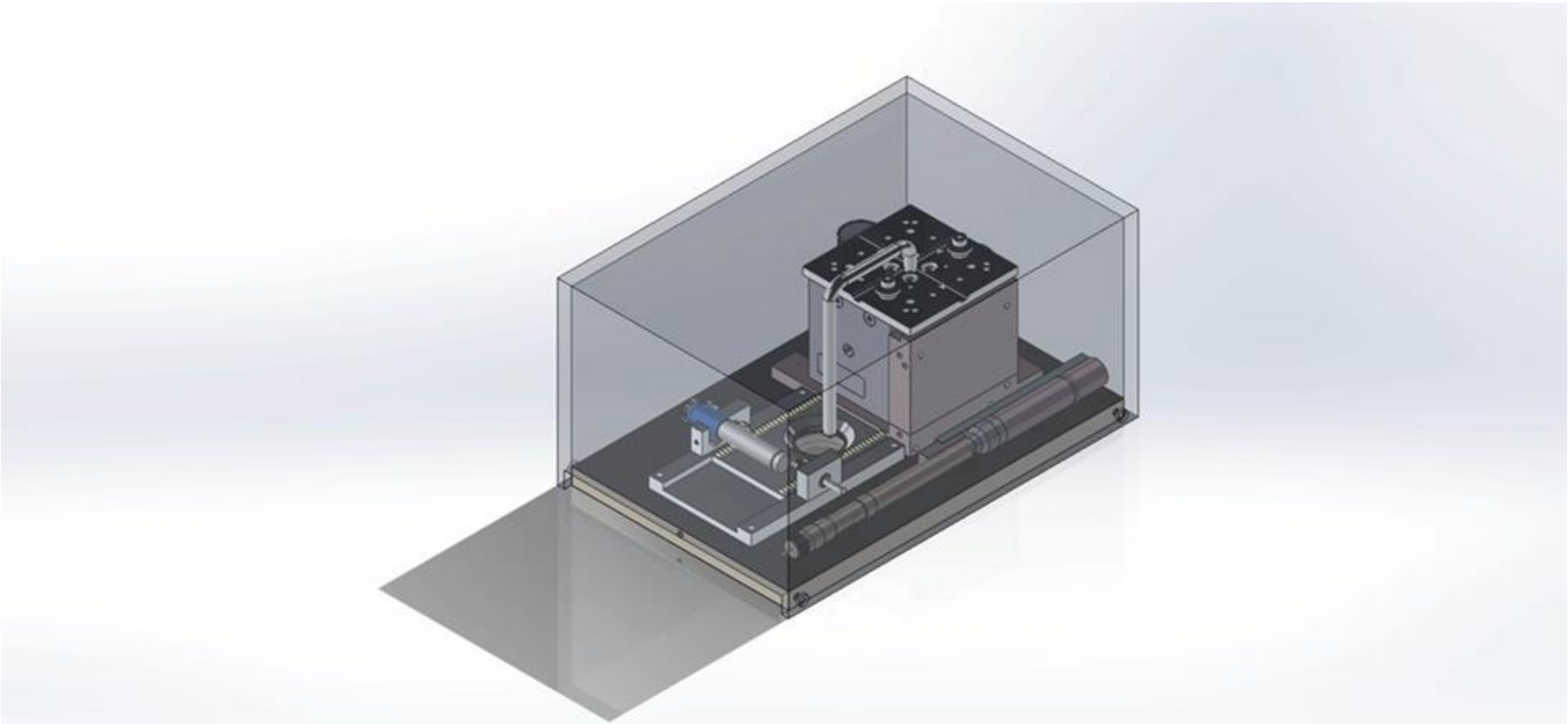
SEM image



Light transported through metalens into the waveguide

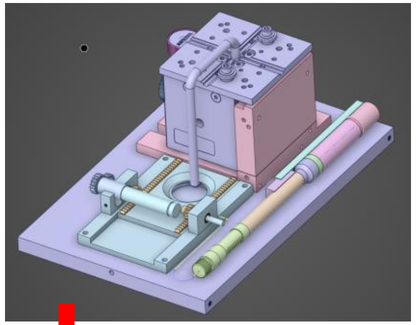


Payload Development for TLC

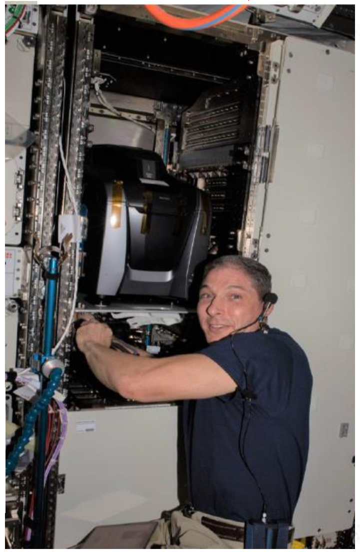


Cost of development
Thailand: ~ 91 million THB
NASA: 2 project scientist and engineer

TLC payload



KERMIT microscope on ISS



The Keyence BZ-X800 is a new way of examining science on the ISS.

leidos

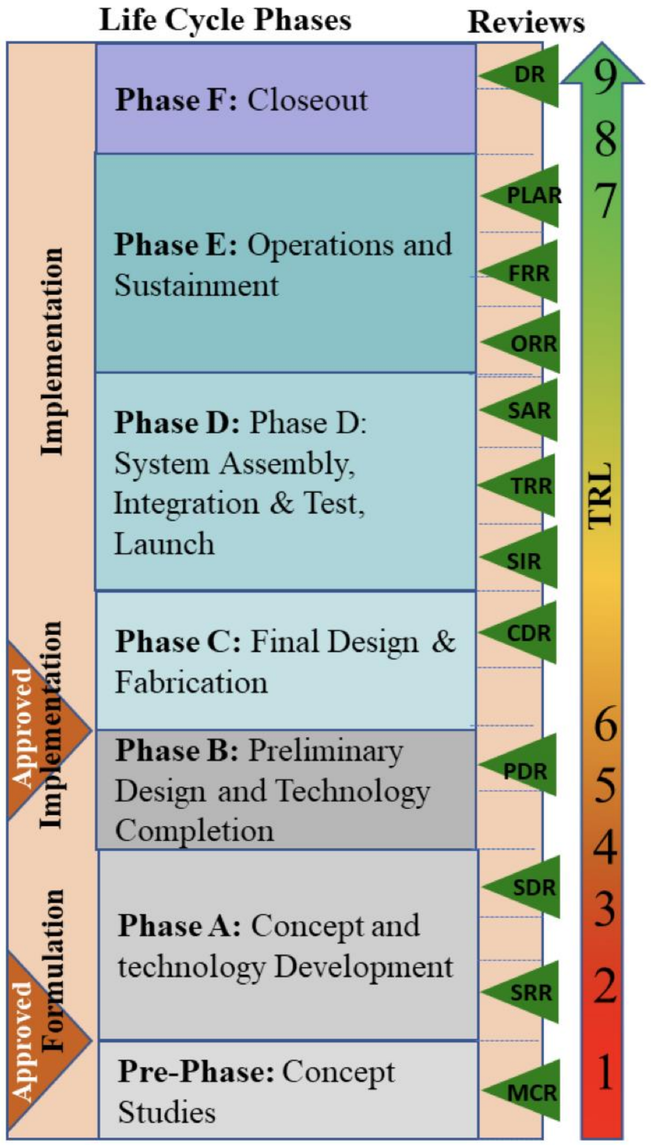
KU KASETSART UNIVERSITY GISTDA NASA

ISS Life Cycle

Important life cycle gate reviews and the entrance and exit criteria in ISS experiments

- System Requirements Review (SRR)
- Preliminary Design Review(PDR)
- Critical Design Review (CDR)
- System Acceptance Review (SAR)
- Launch Operation

TRL in the Space Program



NASA LIFE CYCLE

NASA PROCEDURAL REQUIREMENTS 7120.5F

- **NASA Procedural Requirements (NPR 7120.5F) defines the space flight hardware/systems life cycle development requirements**
  - NASA space flight programs and projects develop and operate a wide variety of spacecraft, launch vehicles, in-space facilities, communications networks, instruments, and supporting ground systems. This document establishes a standard of uniformity for the process by which NASA formulates and implements space flight programs and projects.

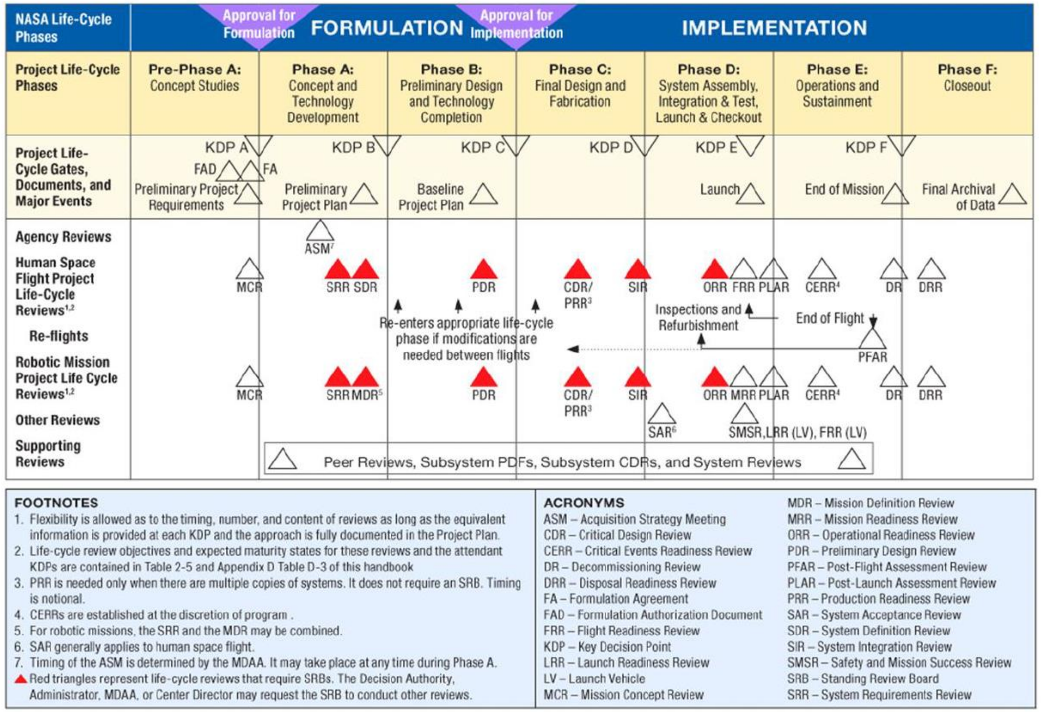


FIGURE 3.0-1 NASA Space Flight Project Life Cycle from NPR 7120.5E

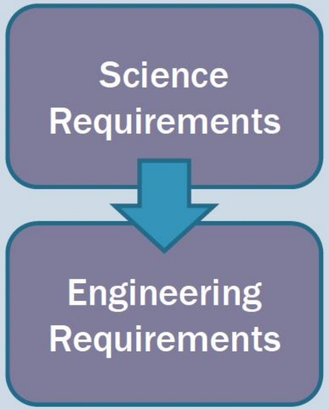
NASA LIFE CYCLE
NASA PROCEDURAL REQUIREMENTS 7123.1C

- **NASA Procedural Requirements (NPR 7123.1C) defines the space flight hardware/systems engineering process**
  - Systems engineering at NASA requires the application of a systematic, disciplined engineering approach that is quantifiable, recursive, iterative, and repeatable for the development, operation, maintenance, and disposal of systems integrated into a whole throughout the life cycle of a project or program. The emphasis of SE is on safely achieving stakeholder functional, physical, operational, and performance (including human performance) requirements in the intended use environments over the system's planned life within cost and schedule constraints
  - Specifically, this defines important life cycle gate reviews and the entrance and exit criteria commonly found in ISS experiments
    - System Requirements Review (SRR)
    - Preliminary Design Review (PDR)
    - Critical Design Review (CDR)
    - Pre-Ship Review (PSR)
    - Operations Readiness Review (ORR)

NASA LIFE CYCLE

SYSTEM REQUIREMENTS REVIEW (SRR)

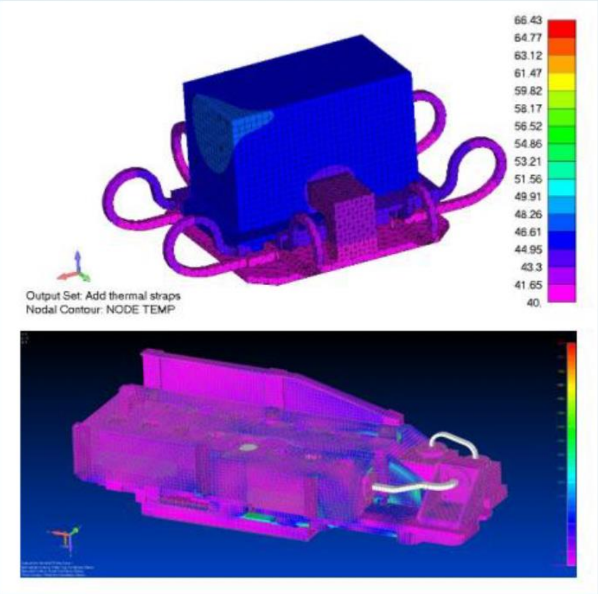
- System Requirements Review
  - A Concept of Operations is presented
    - This is a 'story board' of sequential events from packaging, launch, unstow and experiment sequence
  - Science Requirements Document is baselined
  - Engineering Requirements Document is draft
    - Shows engineering implementation of science requirements
    - For example:
      - Science Requirement: "Shall be able to image 2-micron diameter islands, in a 2mm diameter FOV"
      - Engineering Requirement: "Shall provide optics with 10x magnification"
  - Breadboard/brassboard data is presented in addition to some basic analyses to demonstrate science is achievable



Breadboard/brassboards are circuits and system elements put together to demonstrate a requirement – fidelity is low, and expectation is that as the system matures these breadboards become higher quality

NASA LIFE CYCLE

PRELIMINARY DESIGN REVIEW (PDR)



Computational models are created for structural and thermal assessments against relevant experiment environments to assess preliminary margins

- Preliminary Design Review
  - Engineering Requirements Document is baselined
  - Verification Plan (approach to verifying requirements) is draft
  - Basic solid model of packaged system is draft
  - Some key electrical schematics and drawings (if possible) are in draft
  - Preliminary analyses are complete
    - Materials and Processes
    - Structural (launch loads)
    - Thermal (environment experiment is running in)
    - System Accuracy
  - All breadboarding is complete to show functional compliance to the engineering requirements
  - Software planning documents are created
  - Goals for PDR:
    - Requirements are shown to be achievable
    - Confidence is high to proceed with an engineering build
    - Design development proceeds

NASA LIFE CYCLE
BETWEEN PDR AND CDR

- Between PDR and CDR
  - Team starts assessing ISS location for operation and associated requirements
    - Microgravity Science Glovebox (MSG) for example
      - Placing solid models in MSG solid model to assess experiment volume
      - Power assessments
      - More refined thermal and structural analyses
  - NASA will want to assess the design for the first of three safety reviews
  - Build an Engineering Unit (EU)
    - This is something between a breadboard and the final flight system
    - Attempt should be made to package like flight, incorporate connectors
    - Will have basic software (something like LabVIEW) to operate at first

Engineering Unit can be thought of as a cleanly packaged collection of breadboard/brassboards with as much flight system fidelity as possible. External connectors are used as opposed to 'flying leads' to start maturing the system. There still might exist low quality pieces in the system as the design matures

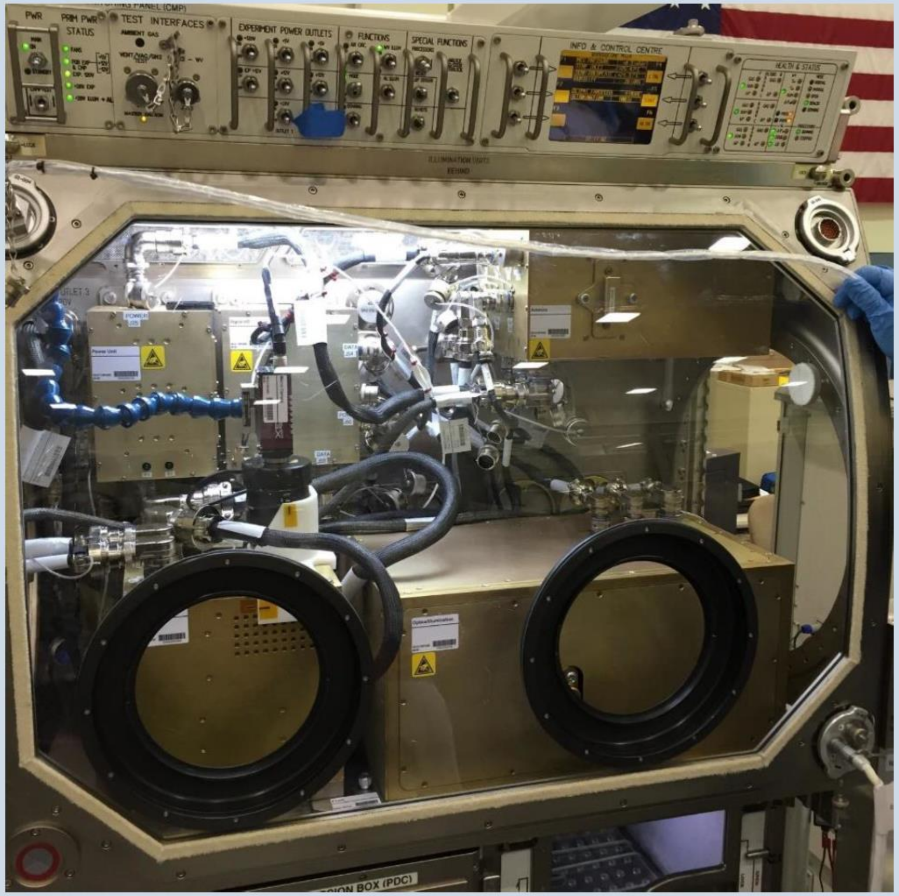
NASA LIFE CYCLE
CRITICAL DESIGN REVIEW (CDR)

- Critical Design Review
  - 90% of drawings complete for the flight build
  - Engineering testing shows high confidence that science can be achieved
    - Functional testing
    - May include some environmental testing
  - Final analyses are complete
    - Materials and Processes
    - Structural (launch loads)
    - Thermal (environment experiment is running in)
    - System Accuracy
  - Flight software coding is in progress
  - Verification test plans are in progress or complete
    - System Functional
    - Vibration
    - Thermal Cycling
    - EMI/EMC
  - Manifesting for launch is understood at this point
  - Operations plans and training starts
  - Around this time, the second of three NASA safety reviews occur

NASA LIFE CYCLE

AFTER CDR

- Building flight hardware
- Building ground support equipment (GSE)
- Integrating software
- Performing verification testing
  - Functional testing
  - Environmental
  - Mission simulation
- Writing crew procedures and training crew to operate experiment



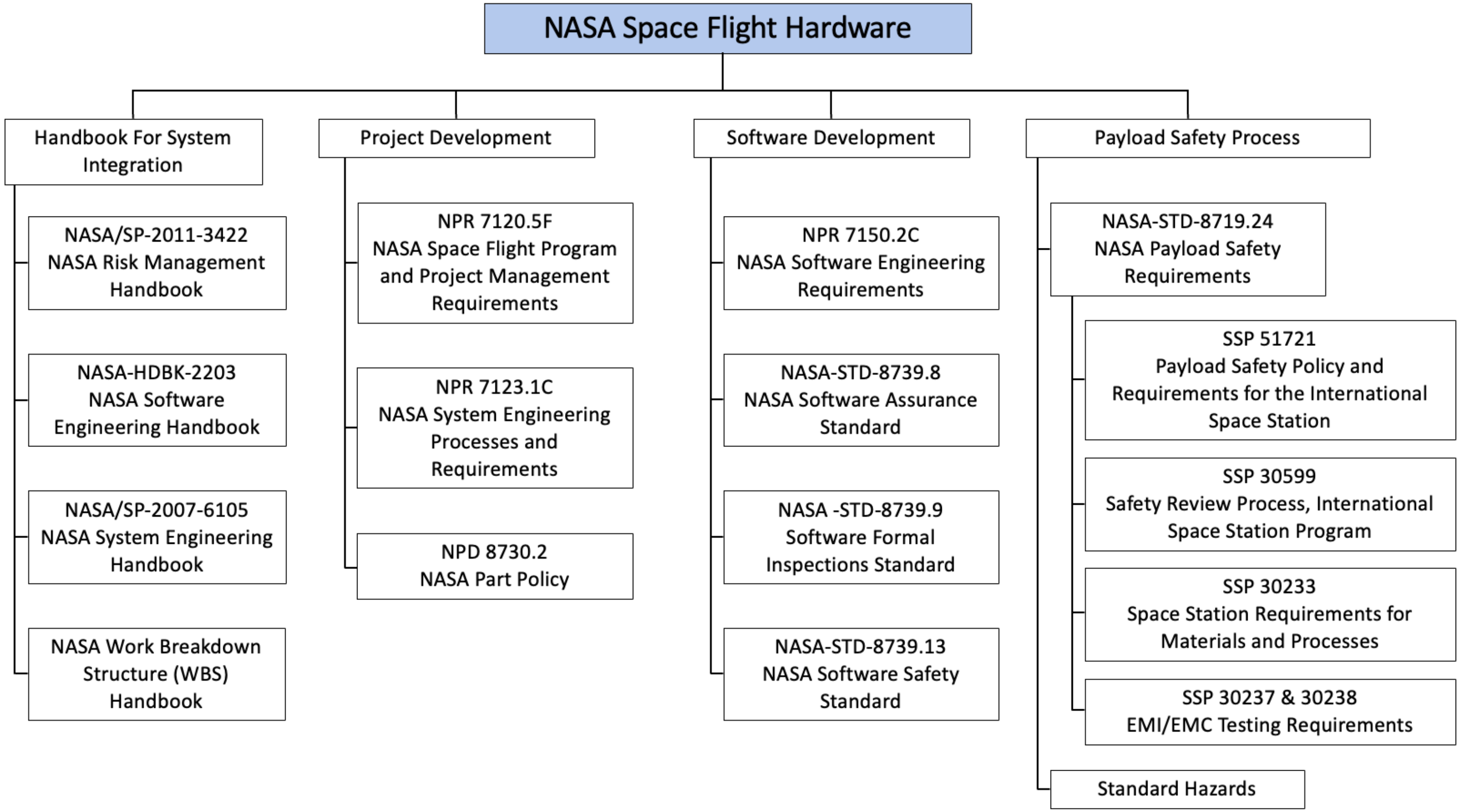
For facilities like MSG, a weeklong mission simulation test is conducted to ensure all interfaces are compliant (mechanical, electrical, software commanding etc)

NASA LIFE CYCLE
OPERATIONS

NASA GRC TeleScience Center (TSC)

- After the system is installed on ISS, operations is controlled from a NASA center (NASA GRC has the TeleScience Center or TSC)
- Science team can receive near real time data images and data to their location, and work remotely with the NASA operations team to work the experiment

TRL in the Space Program



https://nodis3.gsfc.nasa.gov/npr_sort.cfm
https://standards.nasa.gov/all-standards

Official Schedule for TLC

Top level meeting between KU VP, NASA executives (Hq., GRC, JSC), GISTDA executive and project PIs. on Nov. 10th, 2022 in Houston.

Nov 10, 2022,
Houston

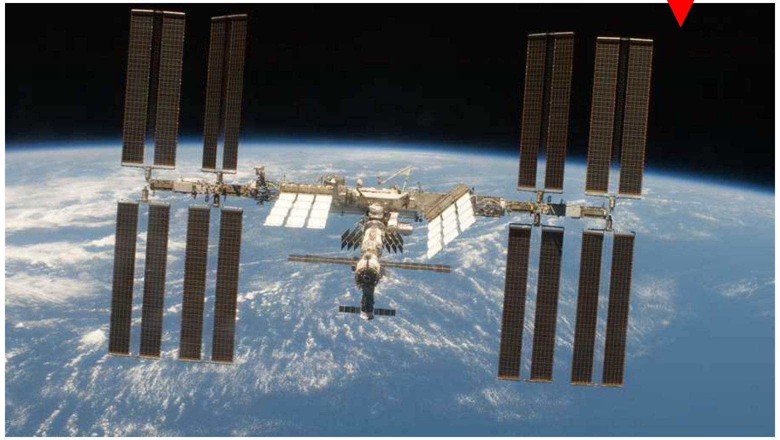
Official schedule

Milestone	Start date	Completion date
1) Proposal	4/1/2022	8/1/2022
2) System Requirement Review (MCR/SRR)	12/1/2022	5/31/2023
3) Preliminary Design Review (PDR)	6/1/2023	2/29/2024
4) Critical Design Review (CDR)	3/1/2024	12/31/2024
5) System Acceptance Review (SAR)	1/1/2025	7/31/2025
6) Operations	1/31/2026	5/31/2026

KASETSART UNIVERSITY

Launch operation in 2026

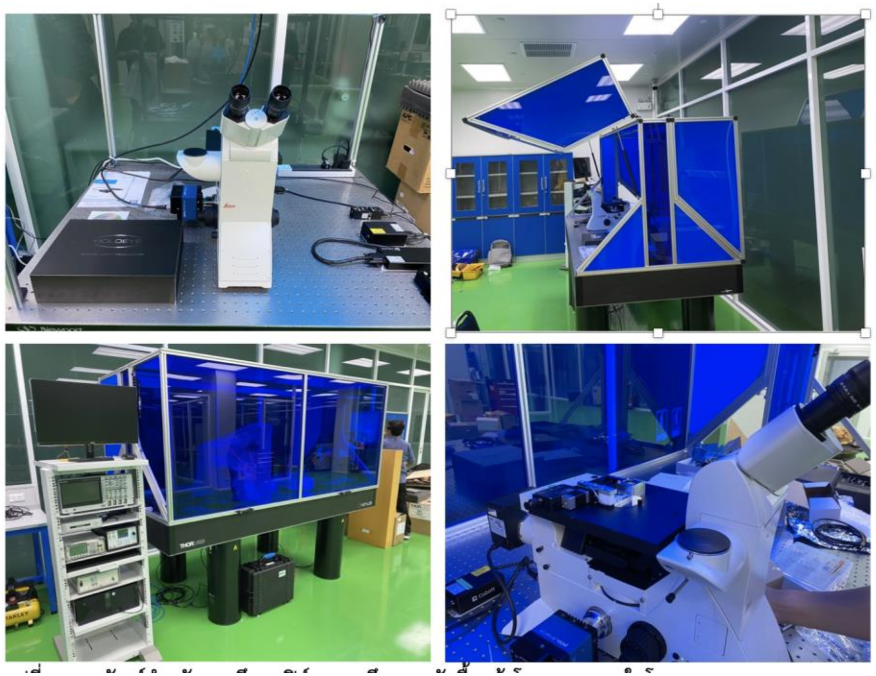
Cost of operation ~ 1700 million THB



International Space Station (ISS)

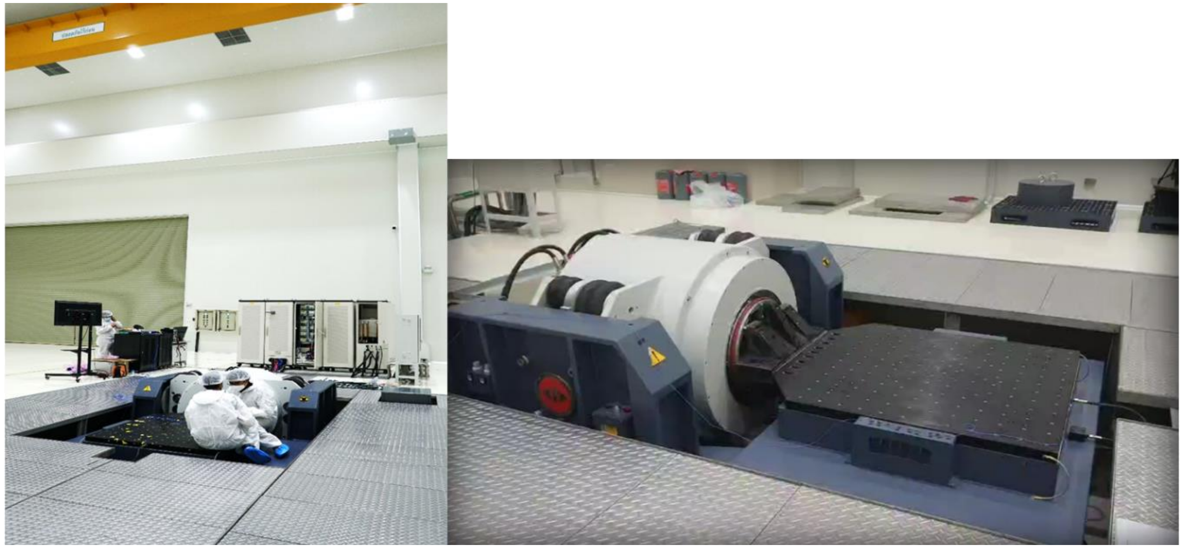
Ground based Liquid Crystals experiment

Liquid Crystals Laboratory
@ Department of Physics,
Faculty of Science,
Kasetsart University



LC Space Experiment Lab @ GISTDA Sriracha

Payload Test for space launch at GISTDA



Vibration & Shock Test

Mass properties testing machine

Thermal Cycling Test

Clean room class 100

KU
KASETSART UNIVERSITY
GISTDA
NASA

TLC Investigators

Dr.Nattaporn Chattham
Associated Professor of Physics

Principal Investigator (PI)

Dr.Apichart Pattanapokratana
Assistant Professor of Physics

Co-Principal Investigator(Co-PI)

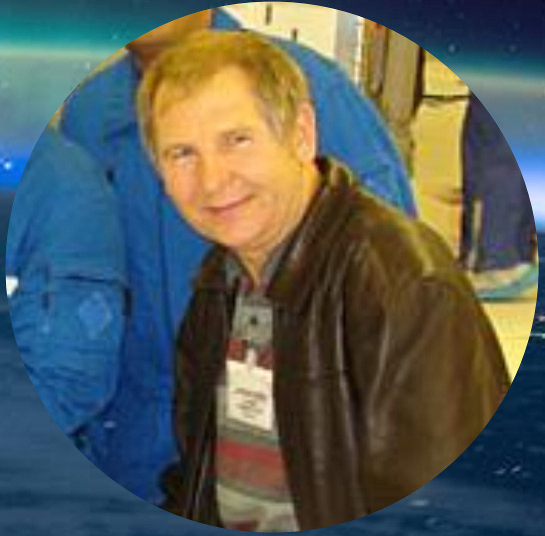
Dr. Natthawat Hongkarnjanakul
Director of Space Technology Development Office・GISTDA

Co-Principal Investigator (Co-PI)

NASA TLC science and mission management team

Dr. Francis Chiaramonte
Science and Research Lead
BPS, NASA HQ

Dr. Michael Robinson
Physical Science Program Scientist
BPS, NASA HQ



Dr. John Mcquillen
Fluids and Combustion
Division Director
NASA GRC

Dr. Tyler Hatch
TLC project scientist
NASA GRC

TLC collaborators

• Assoc. Prof. Papichaya Chaisakul	KU
• Asst. Prof. Weerapat Pon-on	KU
• Assoc. Prof. Pongthep Projonthat	KU
• Dr. Sorasak Phanphak	KU
• Dr. Pemika Hirankittiwong	KU
• Dr. Sittiporn Channamsin	GISTDA
• Dr. Chanat Aonbangkhen	CU
• Assoc. Prof. Chawalit Jeenanata	SIIT
• Assoc. Prof. Sontipee Aimmanee	KMUTT

Liquid Crystal LAB @ KU

Teanchai Chantakit
Postdoctoral

Tanawut Rittidach
Postdoctoral

Worawat Traiwattanapong
Postdoctoral

Jarinee Kiang-ia
Graduate Student

Jutarat Kaewthong
Graduate Student

Pawaphat Jaturaphagorn
Graduate Student

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Acknowledgement

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Thank you for your attention.