CENTRE NATIONAL D'ÉTUDES SPATIALES

Centres de Compétence Technique

Laser Diodes in Space: Needs Expression

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OUTLINE

- **Lasers in space technologies**
  - **Preferred Technologies**

- **Laser diodes**
  - **Applications**
  - **Reliability**
  - **Environment**
    - Thermal
    - Vacuum
    - Radiation
    - Vibration and others

- **Conclusions and Outlook**

LASERS IN SPACE TECHNOLOGIES I :

OUTLINE 1

- **Gas lasers (Helium-Neon, Argon…)**
  - Cannot be adapted to space
- **Dye lasers (e.g. Rhodamine 6G)**
  - Cannot be adapted to space
- **Semiconductor lasers (DIODES: DFB, DBR…)**
  - **Advantages**
    - Spatialisation, operation, lifetime, emitted power
  - **Drawbacks**
    - Divergence, beam quality, frequency and intensity noise
- **Solid state lasers and fibre lasers** → **DIODE PUMPED !**
  - **Advantages**
    - Spatialisation, emitted power, beam quality, narrow linewidth, spectral accordability, lifetime (=diodes), use of telecom qualified components
  - **Drawbacks**
    - Electrical power budget, size, environment

LASERS IN SPACE TECHNOLOGIES II:
SOLID STATE LASERS 1: DIODES

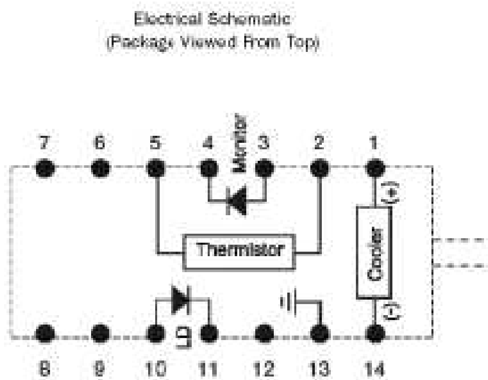
- **Materials:**
  - **GaAs, InGaAs, InP, InGaAsP etc…**
- **Characteristics:**
  - **Reduced size (L~1 to 10 cm)**
  - **Direct electrical pumping: power budget required is reduced**
  - **Large spectral domain can be reached:**
    - $0.75 \leq \lambda \leq 2.3$ µm depending on the choice of elements, can be extended frequency doubling, mixing…
  - **Direct high frequency (GHz) modulation possible**
  - **Electro-optical efficiency <50%**
- **Performances:**
  - **Power Output (CW) :**
    - Single Mode (1W), Multimode (bars<10W, stacks<100W) typically
  - **Divergence :**
    - 10°- 40° typically (high!)
  - **Linewidth :**
    - Spectrally large >MHz typically; can be as narrow as 100kHz (DFB+ proper power supply)

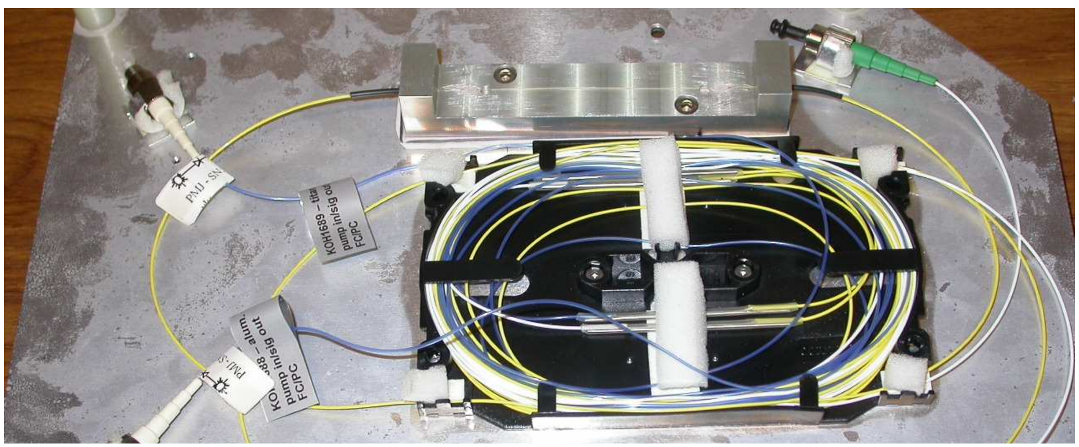
LASERS IN SPACE TECHNOLOGIES III:
SOLID STATE LASERS 3

- **Materials:**
  - **Doped Crystals (YAG, YVO_4, YLF…), Glass (silica, fluoride glass), Fibres**
  - **Dopant is typically Rare Earth (Yb, Er, Nd, Ho etc…)**
- **Characteristics:**
  - **Size (L> 10 cm typically)**
  - **Diode pumped (power budget increased)**
  - **Large spectral domain can be reached:**
    - λ ~0.2 to 3µm can be extended (frequency doubling, mixing)
  - **Frequency modulation possible**
  - **Electro-optical efficiency <10% typically**
- **Performances:**
  - **Power Output (CW) :**
    - Single Mode up to 50W
  - **Energy in pulse (pulsed mode) :**
    - A few µJ up to 10J typically
  - **Divergence :**
    - 10^{-3} rad typically
  - **Linewidth :**
    - Spectrally narrow <100kHz and as low as 100Hz @1s
  - **Excellent beam quality**

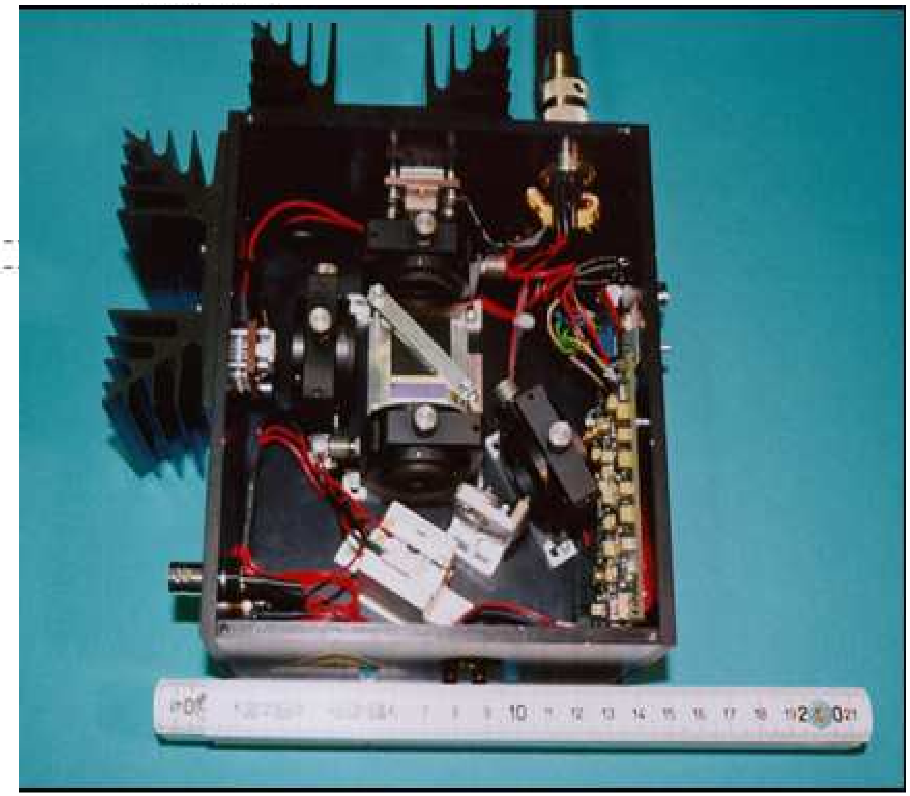
LASERS IN SPACE TECHNOLOGIES V:
SOLID STATE LASERS 5

Diode





Fibre Laser (test model after thermal humidity)



Nd:YAG Laser LISA prototype (2000)

LASER TECHNOLOGIES VI : CONCLUSIONS

- **Lasers we can hope to qualify for space utilisation contain DIODES.**

- **Many more applications than simple pumping of a solid state or fibre laser…**

- **This component is of major interest!**

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- ■ **Lasers in space technology**
  - ◆ **Preferred Technologies**

- ■ **Laser diodes**
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LASER DIODES: APPLICATIONS 1

■ INFORMATION RELAY

- **Optical Telecommunications (inter satellite) : Silex …**
- **Optical telecommunications (intra satellite) : SMOS, ISL, R&D optical interconnects…**
- **Time transfer (laser links) : T2L2**

➢ **Characteristics**

- Large distances, small target

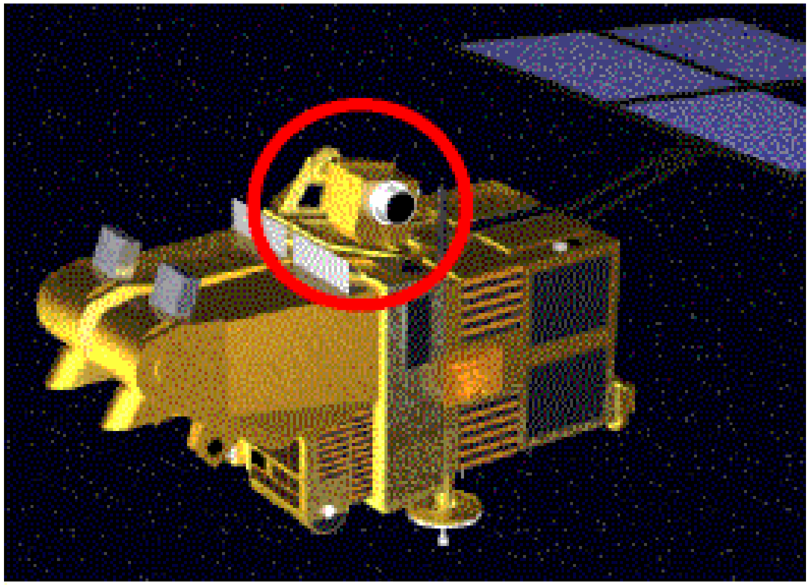
➢ **Requirements**

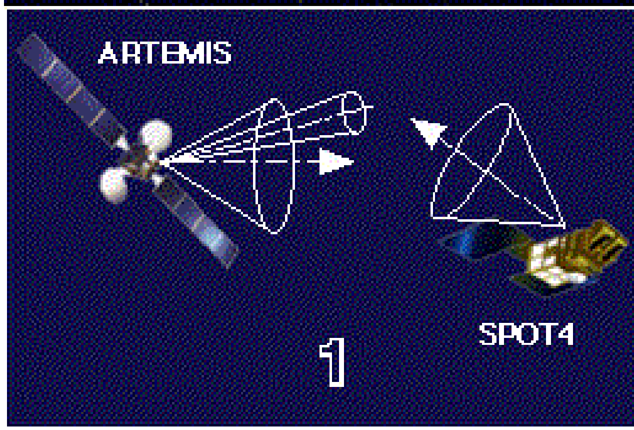
- High power (CW) or energy (pulsed)
- High debit (Gbit/s)
- Small size and power input

➢ **Space adapted solution**

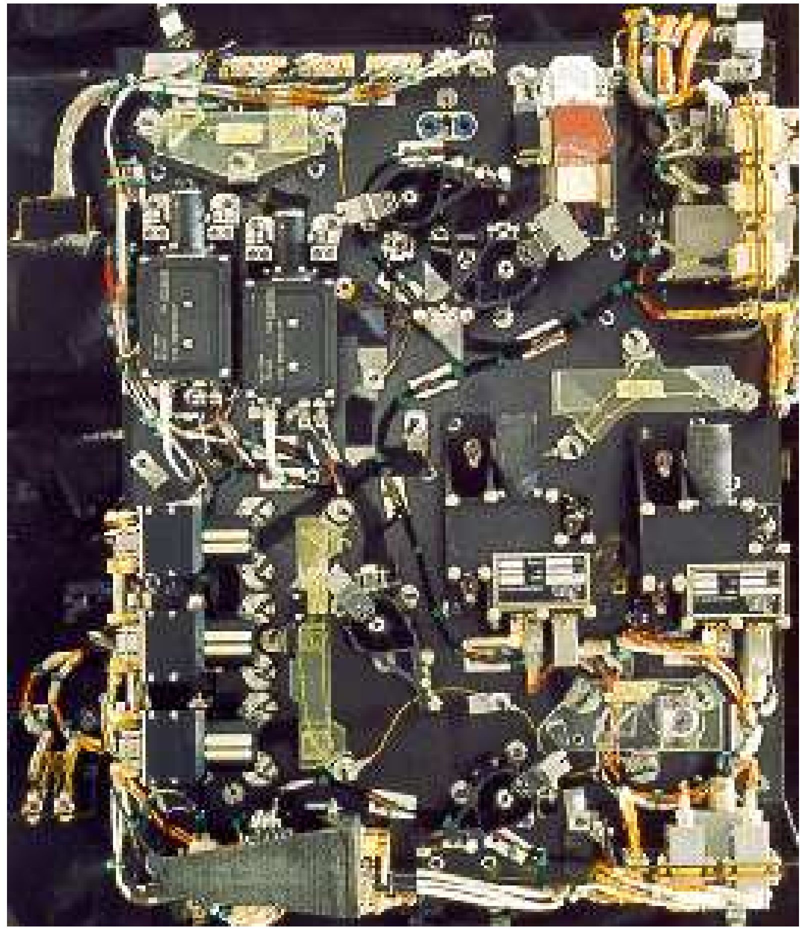
- VCSEL, diodes, fibre (intra), fibre (up to optical bench) and free space propagation (inter)

LASER DIODES: APPLICATIONS IMAGES 1 Silex





Silex LEO/GEO laser link



Optical bench Silex ASTRIUM

LASER DIODES: APPLICATIONS 2

■ **MATTER LIGHT INTERACTION:**

- **Atmospheric sounding LIDARS: ALADIN, ATLID, MICROMEGA (EXOMARS), WALES …**
- **Cold atoms : PHARAO (clocks), ICE …**
- **Spectroscopy and in situ analysis of planetary matter: CHEMCAM (LIBS + auto-focus) …**
- **Pyrotechnics : DEMETER**

➢ **Characteristics**

- Interaction between light and matter, precise wavelength

➢ **Requirements**

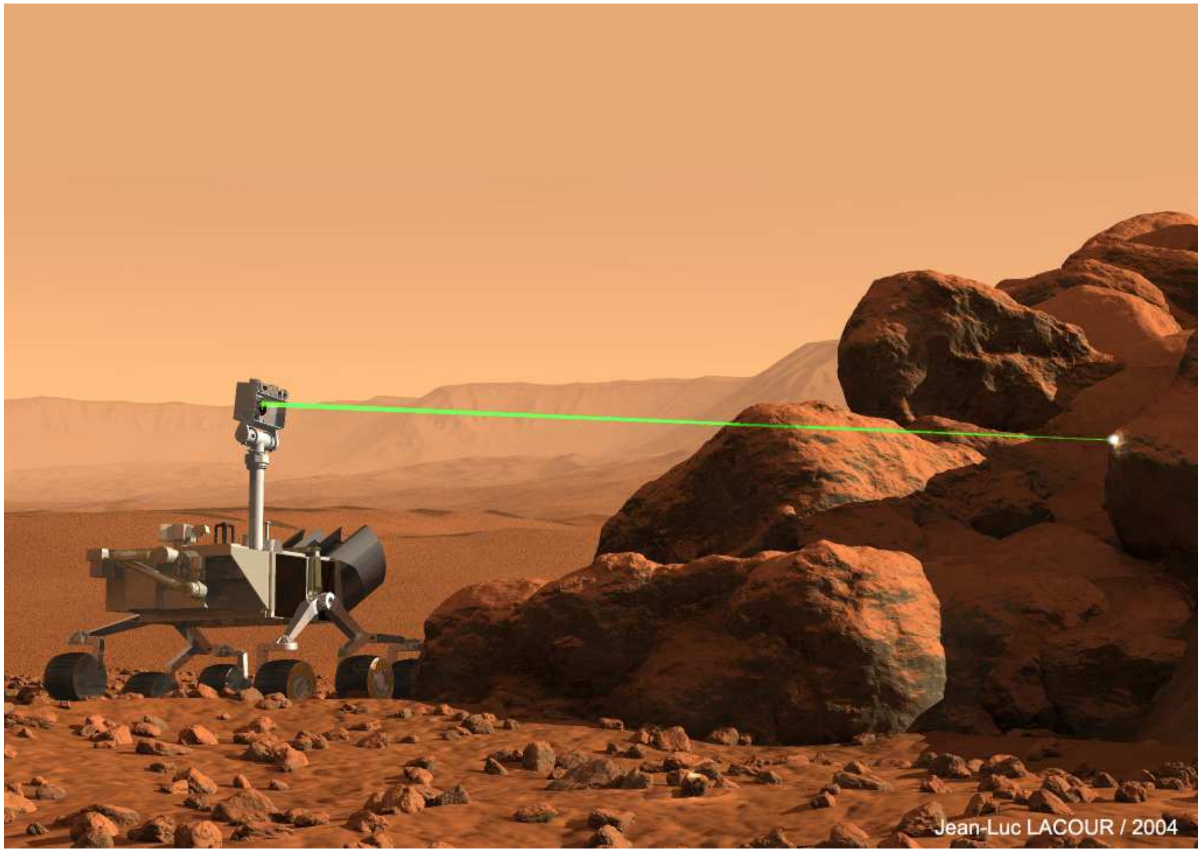
- Precision
- Stability
- Accordability
- Linewidth
- Power (Output/Stability)

➢ **Space adapted solution**

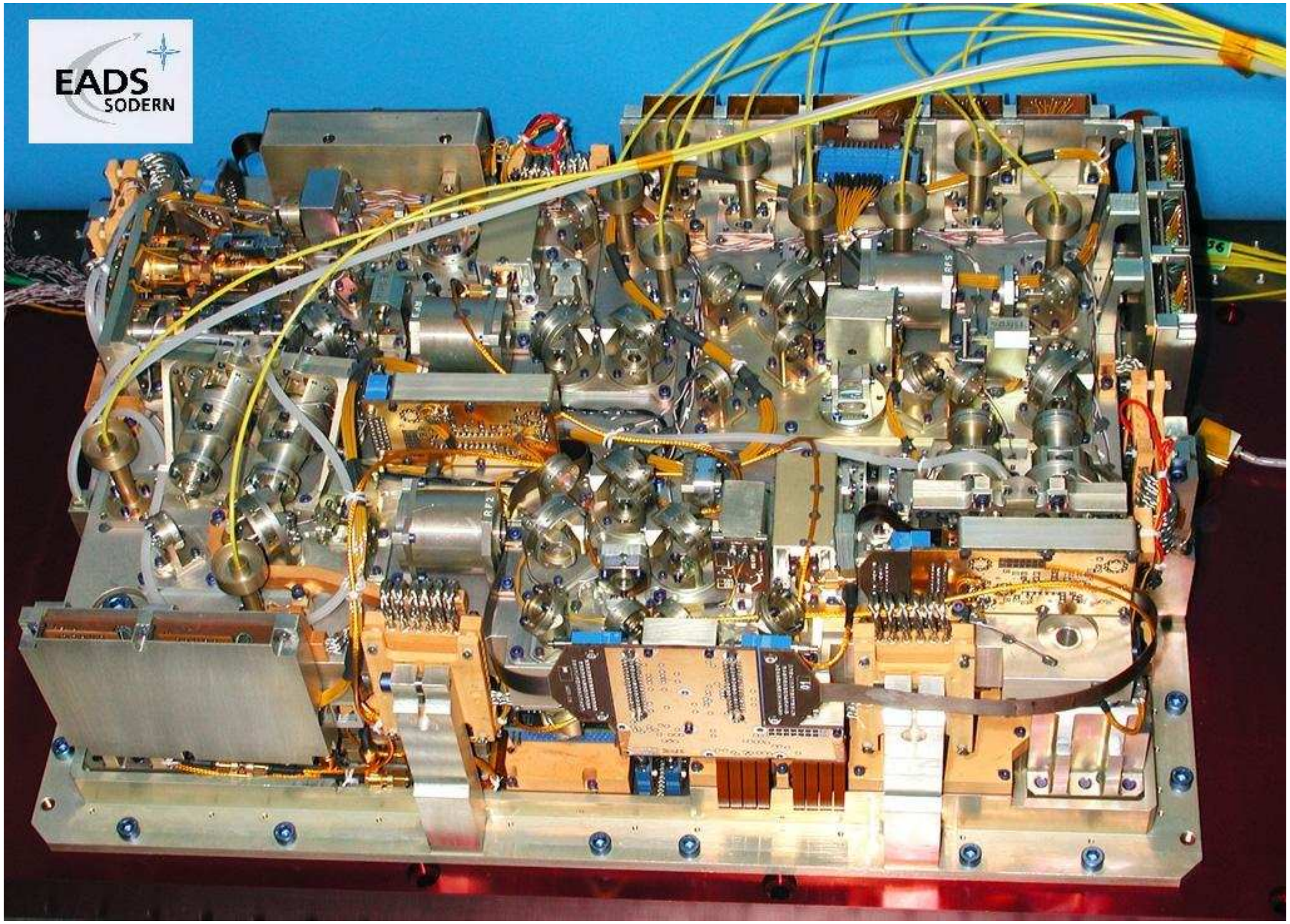
- DFB/DBR diodes, Extended Cavity Lasers, fibre lasers, solid state lasers

LASER DIODES: APPLICATIONS IMAGES 2 CHEMCAM

- **Auto-focusing system:**
  - **Laser diode @780-850nm**
  - **Wavelength stability:**
    - Over a few seconds
  - **Temperature range:**
    - -30/+30°C best case scenario
    - -55/+70°C worst case scenario
    - Diode must be on in this temperature range!
  - **Power:**
    - Always > 50mW
  - **Mean Time To Failure:**
    - >200000h



LASER DIODES: APPLICATIONS IMAGES 3 PHARAO



ICE

LASER DIODES: APPLICATIONS 3

■ PLANETARY EXPLORATION AND MONITORING

- **Geodesy : Post-Grace**
- **Altimetry : BELA**
- **Magnetometers : SWARM**

➢ **Characteristics**
- Large distances, small target, interaction light/matter

➢ **Requirements**
- High/Stable power (CW) or energy (pulsed)
- Precision
- Stability
- Linewidth

➢ **Space adapted solution**
- DFB/DBR diodes, fibre lasers, solid state lasers

LASER DIODES: APPLICATIONS IMAGES 5 SWARM

LASER DIODES: APPLICATIONS 4

■ FORMATION FLIGHTS and METROLOGY

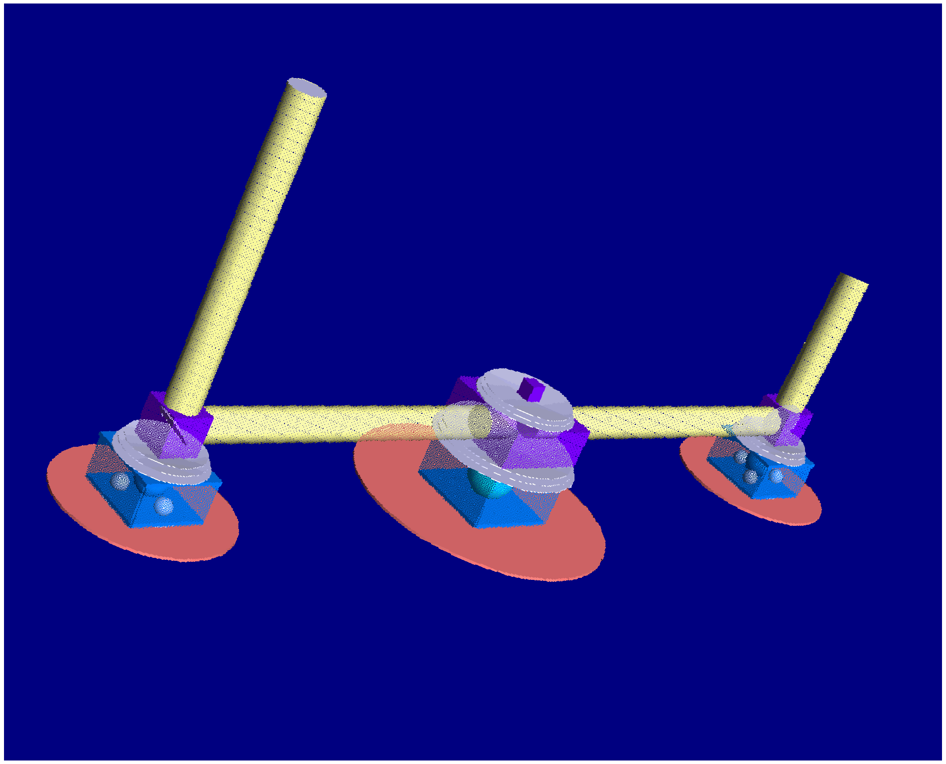
- **Sensors : position\speed PROBA3, ATV, PEGASE, SIMBOLX, DARWIN, acceleration\angular velocity PLEIADES (fibre-gyro)…**
- **Gravitational Waves Detectors : LISA**

➢ **Characteristics**
- Metrological precision in the measurement of the distance, displacement, acceleration, angular velocity, etc…

➢ **Requirements**
- Medium power
- Very narrow linewidth (coherence length)
- Accordability
- Stability
- Precision
- Single mode (long. and trans.)

➢ **Space adapted solution**
- Diodes (DFB/DBR), fibre lasers, solid state lasers

LASER DIODES: APPLICATIONS IMAGES 6 PEGASE/MOUSE



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RELIABILITY 1

- The reliability is defined as: $$R1 = e^{-\int_0^{t_{mission}} \lambda(\tau)\cdot d\tau}$$

- The reliability for three independent lasers is:

$$R3 = R1^3$$

$$R1 = e^{-\lambda \cdot t_{mission}} = e^{-\frac{t_{mission}}{MTTF}}$$

- If we consider one redundancy for each laser we get instead:

- Hot $$R3r1 = \left[1 - (1 - R1)^2\right]^3$$

- Cold $$R3r1' = \left[R1 \cdot \left(11 - 10 \cdot R1^{0.1}\right)\right]^3$$

RELIABILITY 2 : MEAN TIME TO FAILURE

- Mean Time To **Failure is a function of:**

$$MTTF = \frac{2 \cdot nt \cdot A_f}{\chi^2\left(CL;2\cdot\left(r+1\right)\right)}$$

  - nt **number of working hours without failure**
  - A_f **acceleration factor depending on:**
    - Emitted power and
    - Working temperature
    - Humidity…
  - *CL* **confidence level**
  - *r* **number of rejects during essays**

RELIABILITY 3 : ACCELERATED TESTS

- **Tests can be conduced at higher temperature (relative humidity etc) to accelerate the degradation of the components**
- **For a temperature increase the Acceleration Factor is given by Arrhenius' law:**

$$A_f = \exp\left[\frac{E_a}{k}\left(\frac{1}{T_{flight}} - \frac{1}{T_{test}}\right)\right]$$

Activation Energy typically between 0.3 and 1.2eV

- **For laser power Derating we have instead:**

$$D_{power} = \left(\frac{P_{test}}{P_{flight}}\right)^n$$

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ENVIRONMENT: THERMAL

- **Satellite with thermal control OFF (GEO satellite) :**
  - **-55/+125°C for standard electrical equipment, telecom, in survival mode**
  - **-40/+50°C for scientific payload, in survival mode**
  - **Diode is OFF**
- **Satellite with thermal control ON :**
  - **-40/+85°C for standard electrical equipment**
  - **10 to 30°C for scientific payload**
    - temperature error of ± 5°C
    - temperature stability of ± 2°C
  - **Diode is ON**
- **Thermal environment for planetary exploration :**
  - **-30/+30°C Mars (CHEMCAM)**
  - **Diode is ON**
  - **Wavelength and power output stability!**

→ **Thermal cycling ON ?**

ENVIRONMENT: VACUUM / CONTAMINATION

- Failure mode due to extraneous matter deposition on diode facets a possibility

→ Control of pollution in the proximity of the laser diode necessary

→ No/reduced outgassing required

- Cleaners in particular can be a danger
- If the atmosphere inside the diode packaging is ‘safe’

→ Low leak rate to keep required oxygen level inside the diode is a must, necessity of hermetically sealed packaging to be evaluated

- Heat evacuation can be a problem in vacuum
- For planet exploration dust contamination must be taken into account:

→ Hermetically sealed seems safer!

ENVIRONMENT: RADIATION

- Radiation dose depends on:
  - Orbit
  - Mission duration
  - Shielding
  - Solar cycle
  - Material considered

- Radiation types:
  - Ionising dose (gamma radiation)
  - Protons
  - Electrons
  - Neutrons
  - Heavy Ions…

- Values for SWARM (e.g.)
  - 450 - 530km
  - 4 years
  - >3mm and <100mm
  - Launch 2010
  - GaAs (worst case scenario, Si and SiO_2 considered)
  - Total ionising dose : 3.9krad
  - Proton flux :
    - trapped protons (50MeV equivalent) 22.5 cm^{-2}
    - solar protons (50MeV equivalent) 1.07E+10 cm^{-2}

ENVIRONMENT: VIBRATION and others…

VIBRATION

- **Depends on:**
  - Launcher type
  - Position of payload in launcher
  - Satellite and payload mass distribution
  - Micro-vibrations
  - Landing (planetary exploration)
  - Vibration in planetary environment

Diodes

- **If pigtailed can suffer power loss through misalignment**
- **Misalignment and back-reflections**
- **EMC sensitive**
- **If packaging is hermetically sealed molecular oxygen is not a problem**

OTHERS

- **EMC**
- **Molecular oxygen…**

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CONCLUSIONS

- Diodes are the cornerstone component for laser space applications
- Requirements synthesis:
  - Pump current modulation
  - Spectral purity
  - Low Relative Intensity Noise
  - Beam quality
  - Divergence
  - Linewidth (narrow/adapted to application)
  - Intrinsic frequency stability
  - Space compatible
  - Lifetime (10^5 h)
  - Good electro-optic conversion
  - Reliable cooling system or no cooling
  - Easy to integrate
  - Reduced size, mass and energetic budget

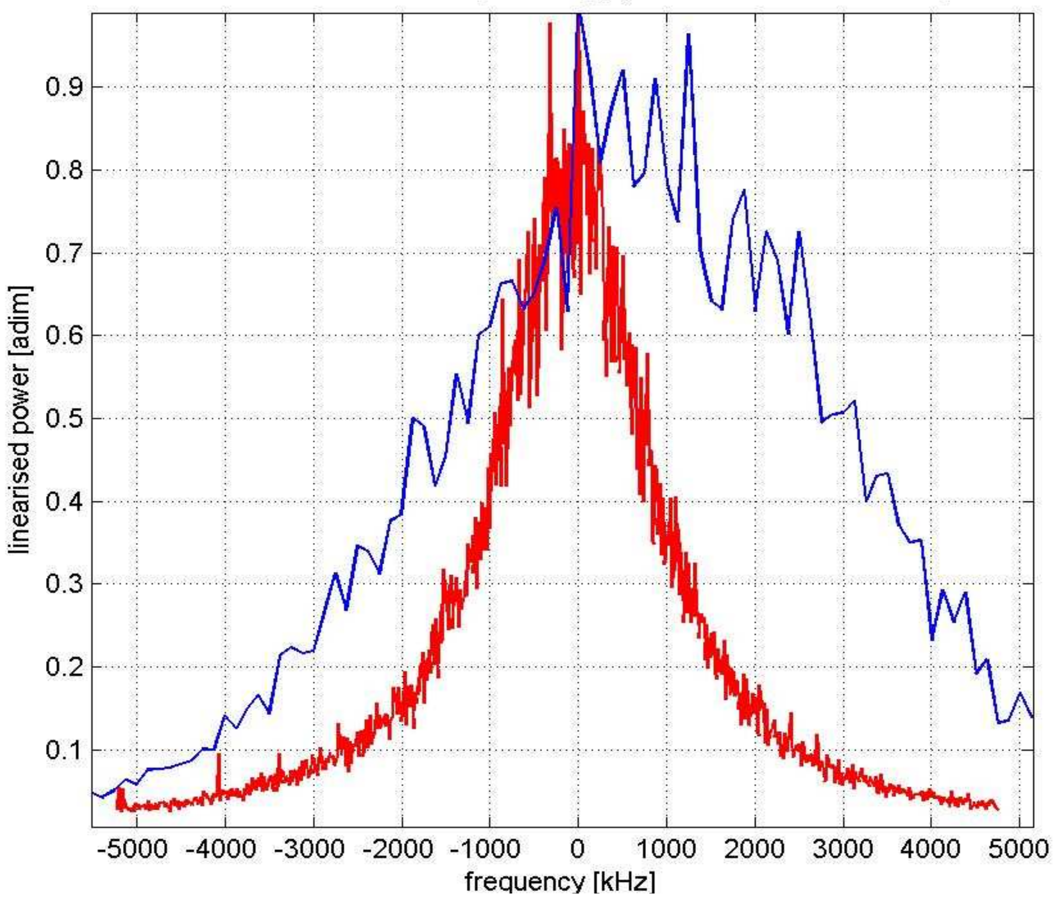
- We might be asking a bit too much… BUT

OUTLOOK

- **Laser diodes are increasingly used in space experiments**
- **The number of active optical instruments for sensors, launchers and satellites is rapidly growing!**
- **European and French space experiments with diodes onboard:**
  - **Currently in orbit:** SILEX, DEMETER (satellites), SDLA-LAMA (ballon)…
  - **Soon to be launched:** IASI, PLEIADES(gyrometres), ALADIN, FIRST PLANCK, PROBA …
  - **In preparation:** SMOS, GAIA, BEPICOLOMBO, CHEMCAM, SWARM, PHARAO, LISA Pathfinder…
  - **Pre-study:** Clocks for Galileo, optic clocks, cold atoms gyrometres, formation flight sensors…

LASER DIODE LINEWIDTH AS A FUNCTION OF POWER SUPPLY

Source linewidth CSO diode on ILX power supply red and on CSO with capacitor blue



Diode	Power Supply		Linewidt [kHz]
CQF938/ 400 #500138	ILX-LDX3620		328±1.8
CQF938/ 400 #500138	ILX-LDX3620+ LNF		321±3.4
CQF938/ 400 #500138	ILX-LDX3525+ LNF		435±3.1
CQF938/ 400 #500138	ILX-LDX3525		2330±10

LASER DIODES: APPLICATIONS IMAGES 4 ICE

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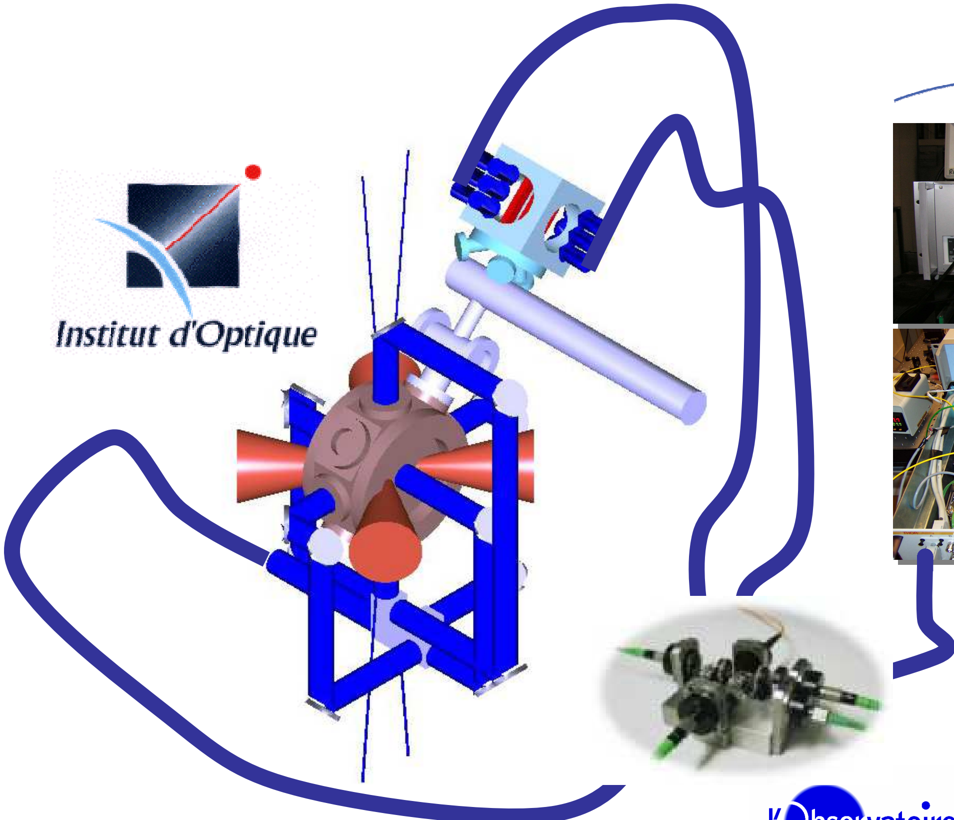
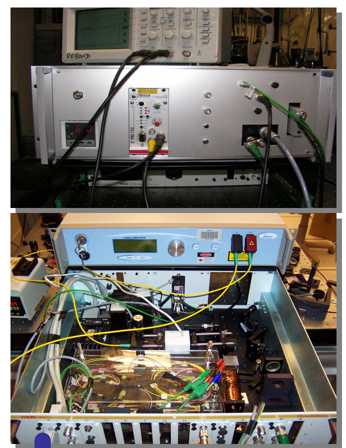


ONERA



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Systèmes de Référence Temps-Espace

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