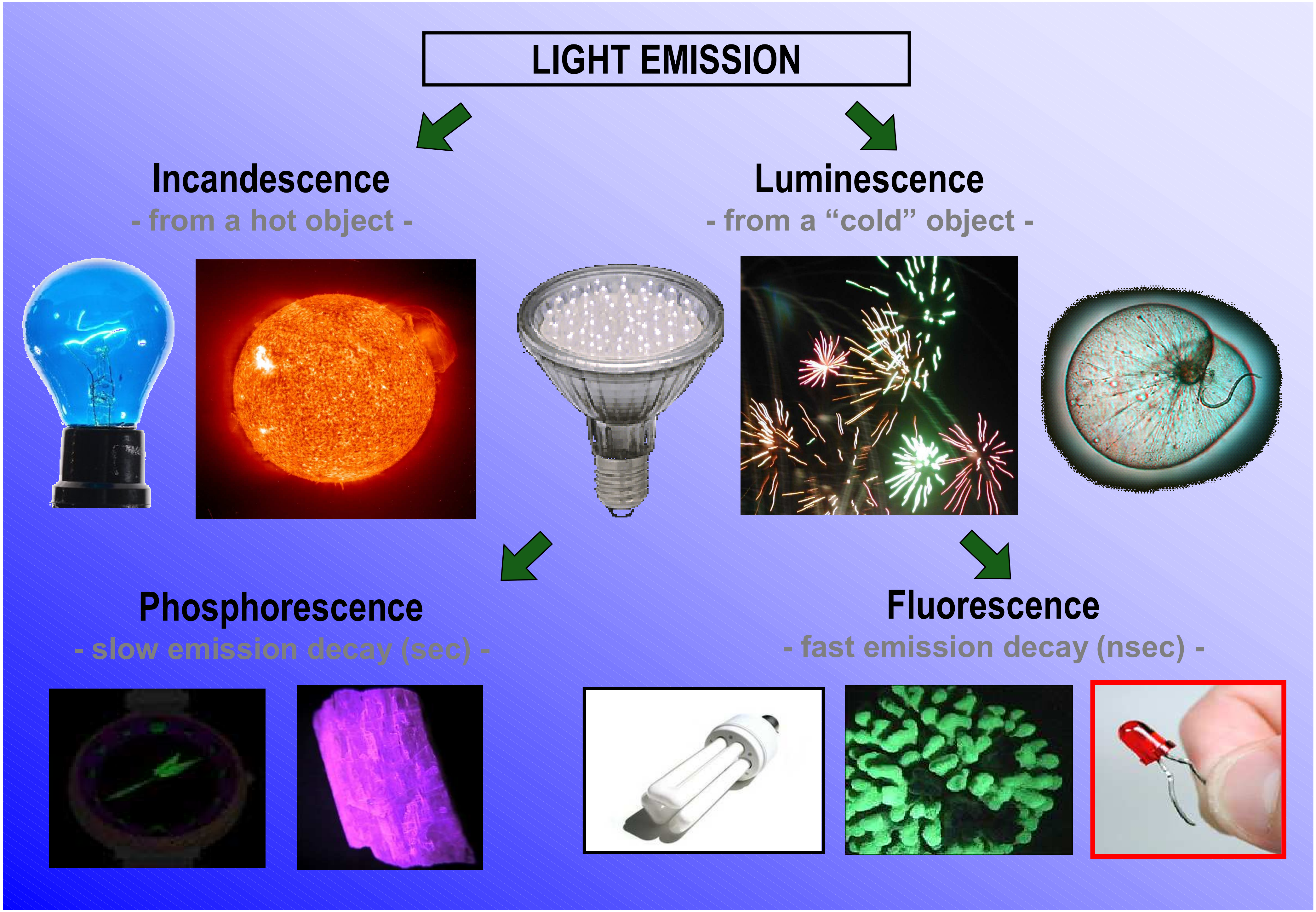
# SCANNING $\mu$ X RAY EXCITED LUMINESCENCE IN SEMICONDUCTORS

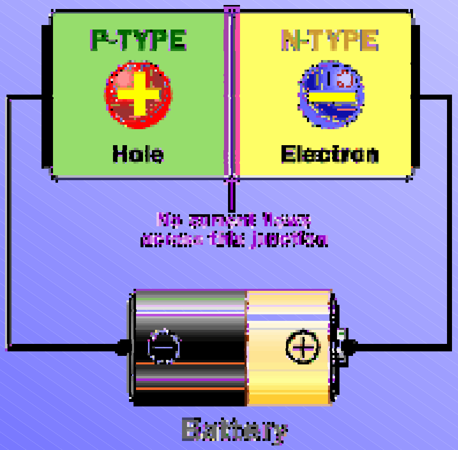
Gema MARTINEZ-CRIADO
ID22-ESRF

## T A L K   O U T L I N E

- Why luminescence ?
- What is the connection with X ray microprobe ?
- Design and setting up
- First tests and preliminary conclusions
- The XEOL upgrade – some key points
- Next experiments


LIGHT EMISSION
Incandescence
- from a hot object -
Luminescence
- from a "cold" object -
Phosphorescence
- slow emission decay (sec) -
Fluorescence
- fast emission decay (nsec) -

# WHY LUMINESCENCE FROM SEMICONDUCTORS ?

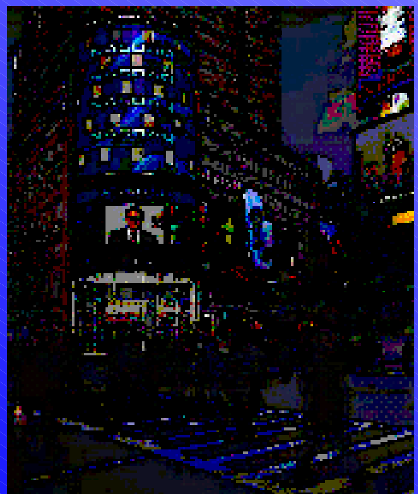



**ADVANTAGES:**

- Do not get specially hot
- Last much longer
- More durable because of their small plastic bulb
- Fit easily in electronic circuits
- Very HIGH EFFICIENCY
- LOWER COST in the long run

## Dozens of different jobs:

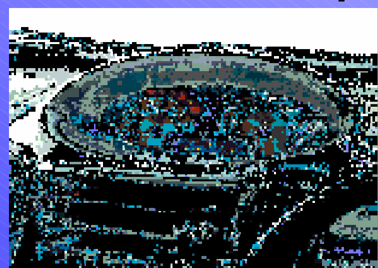
Full-color screens



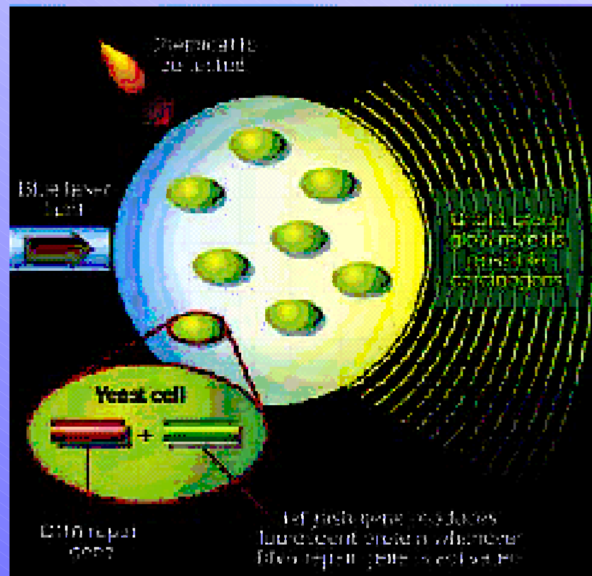
Indoor Lighting

Optical Data Storage

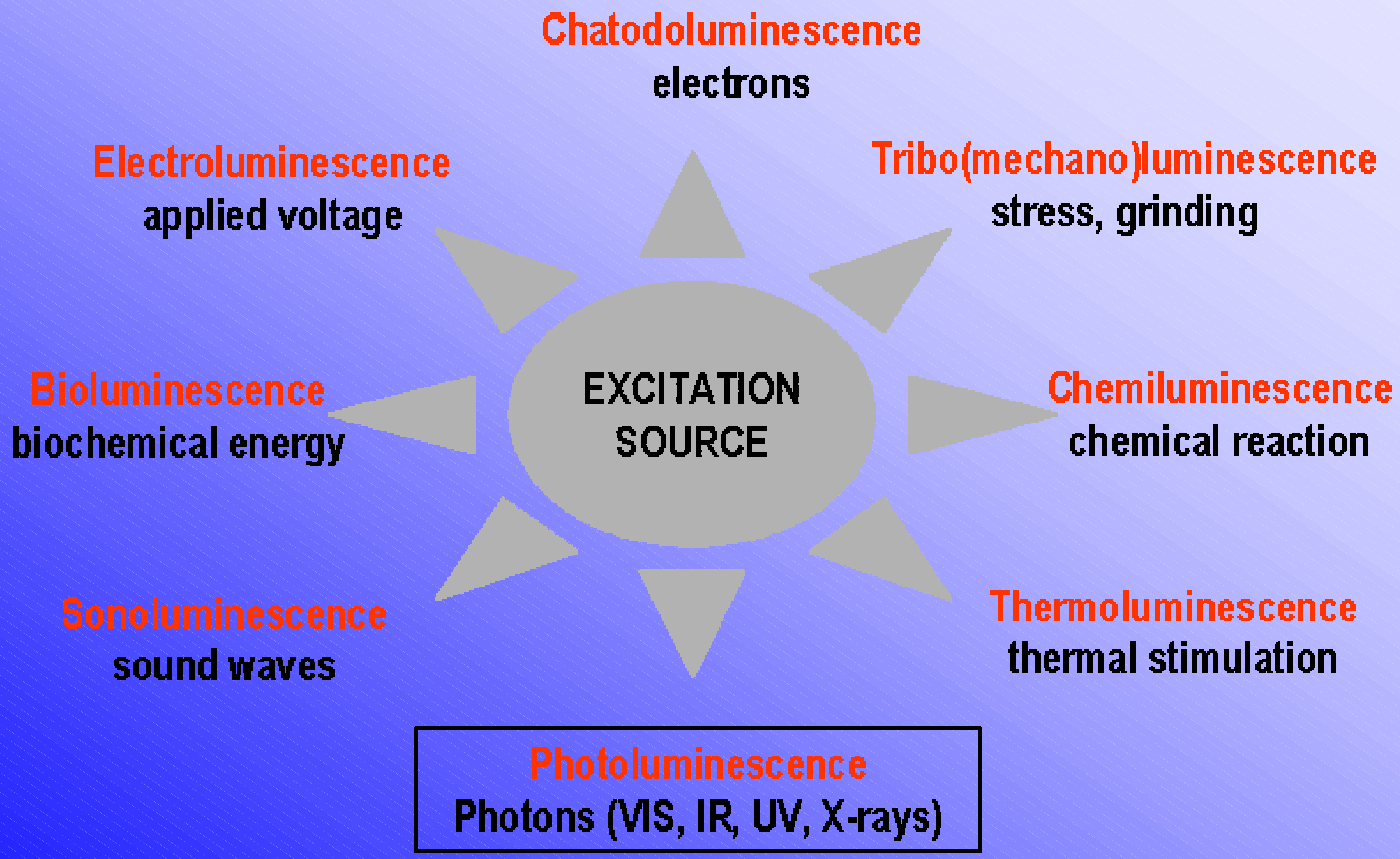
Automotive Displays



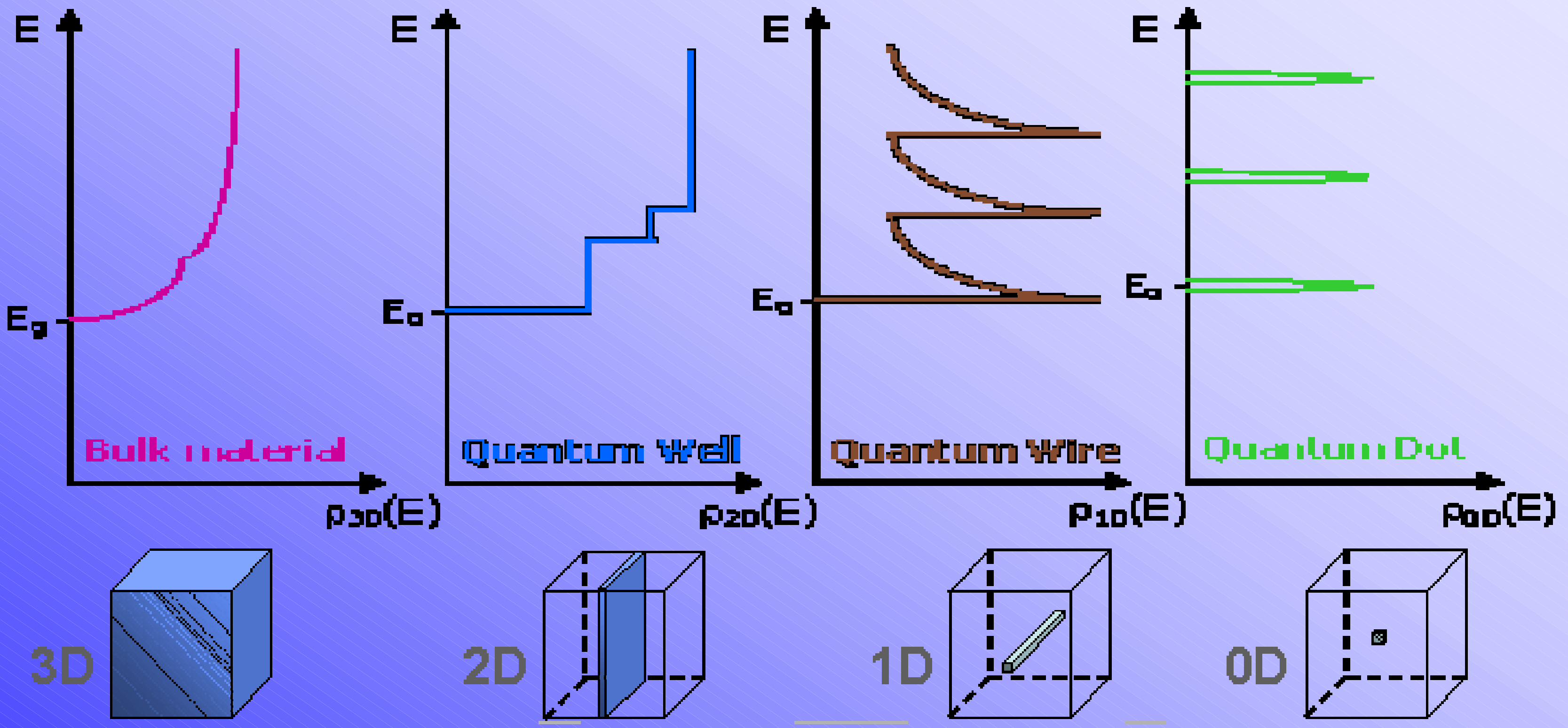
**Gentronix:** Blue laser light reveals cancer-causing chemicals using yeast cells



# HOW CAN LUMINESCENCE BE STUDIED ?



# WHAT DOES CONFINEMENT DO IN SEMICONDUCTORS ?

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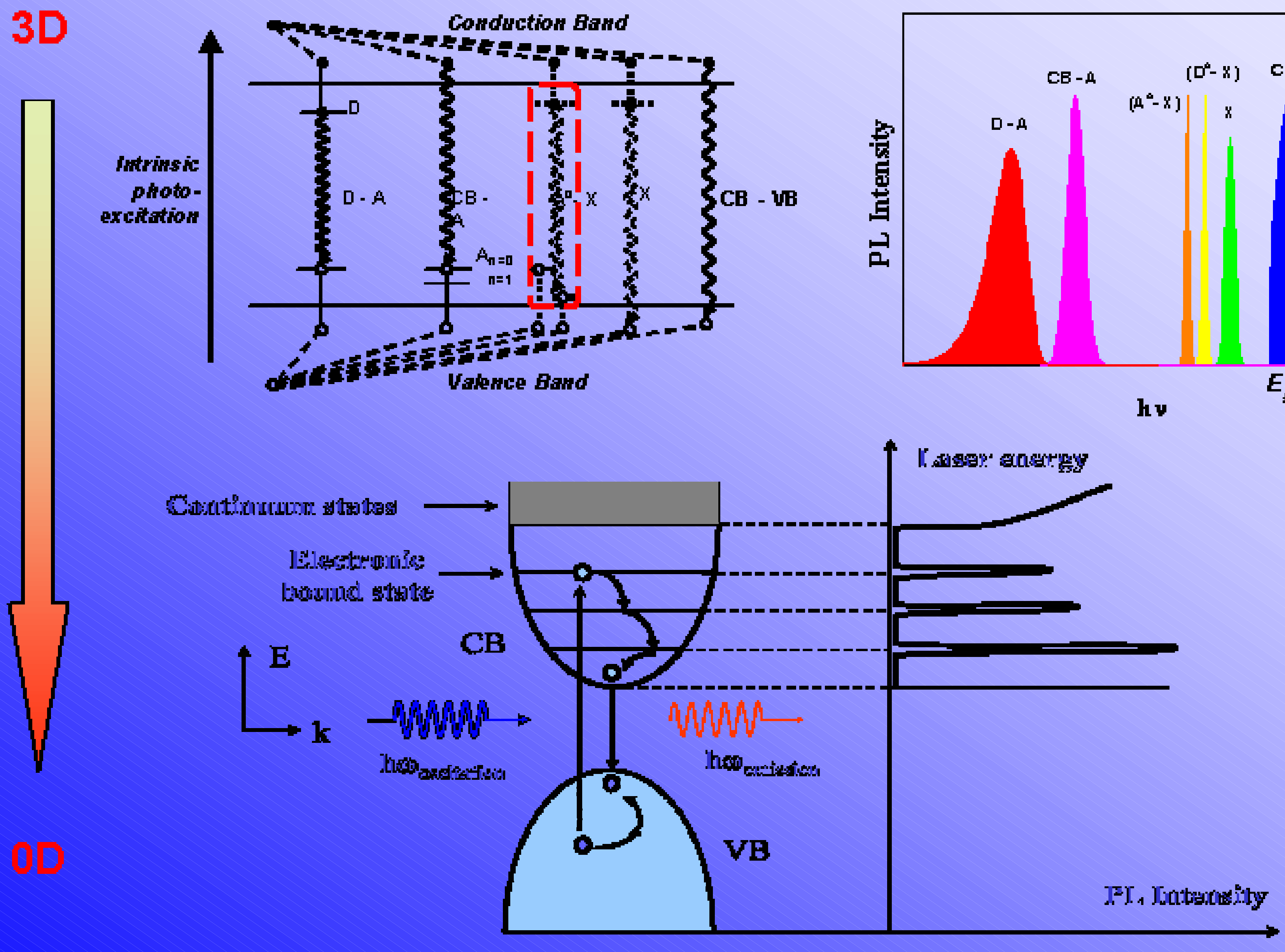
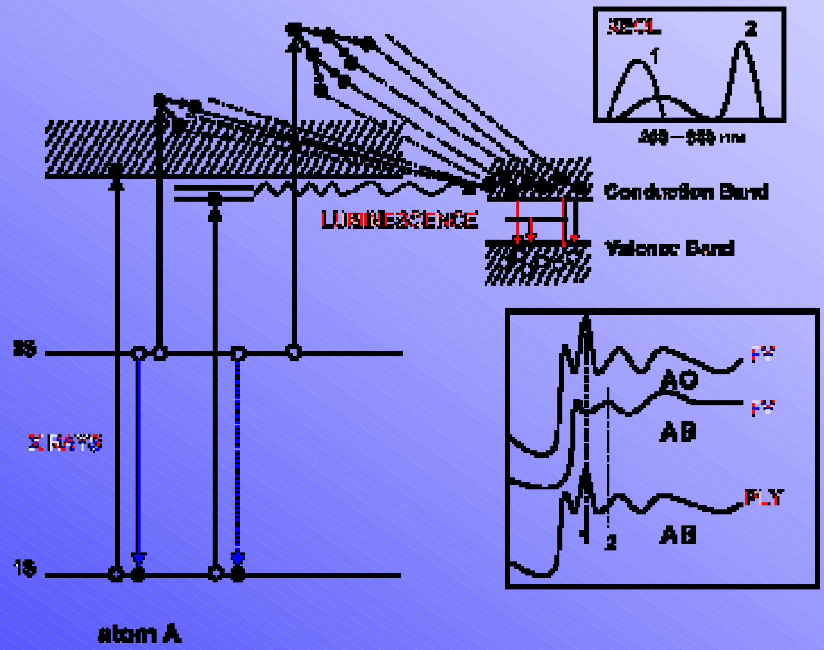
- Sharper wavelength discrimination
- Much higher efficiency
- Much lower thresholds
- Less thermal dependence, spectral broadening
- Enhances optical nonlinear effects
- CREATES WELL-CONTROLLED LUMINESCENCE BANDS

# HOW DOES CONFINEMENT CHANGE PHOTOLUMINESCENCE ?



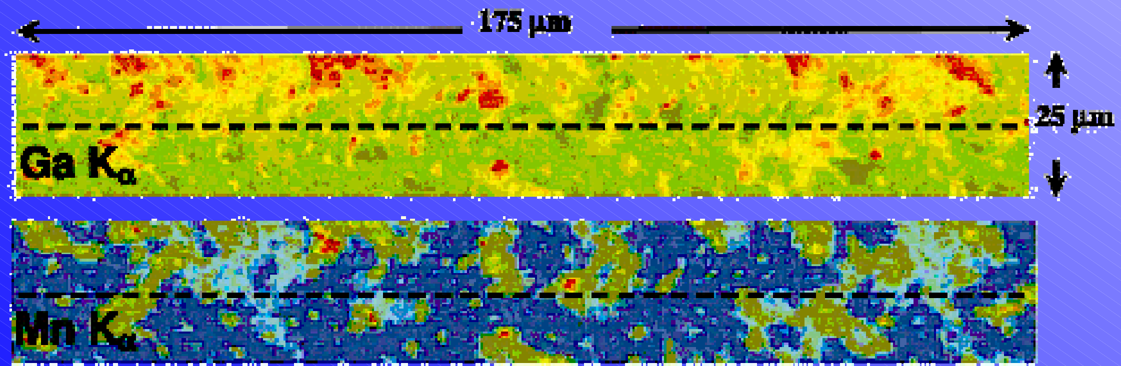
# WHAT IS THE CONNECTION WITH X-RAY MICROPROBE ?

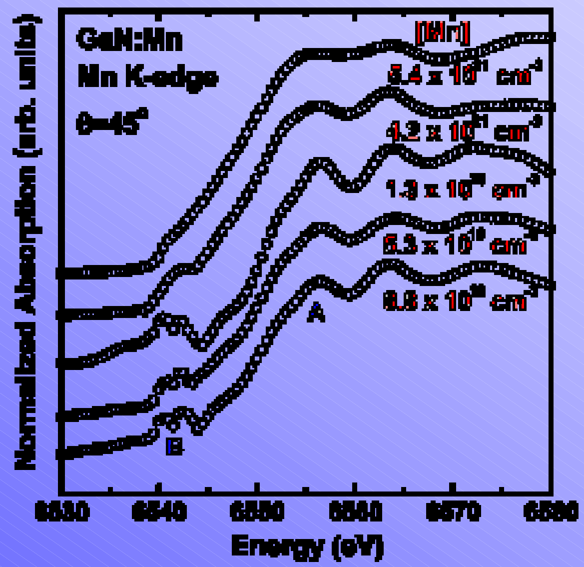



ADVANTAGES:

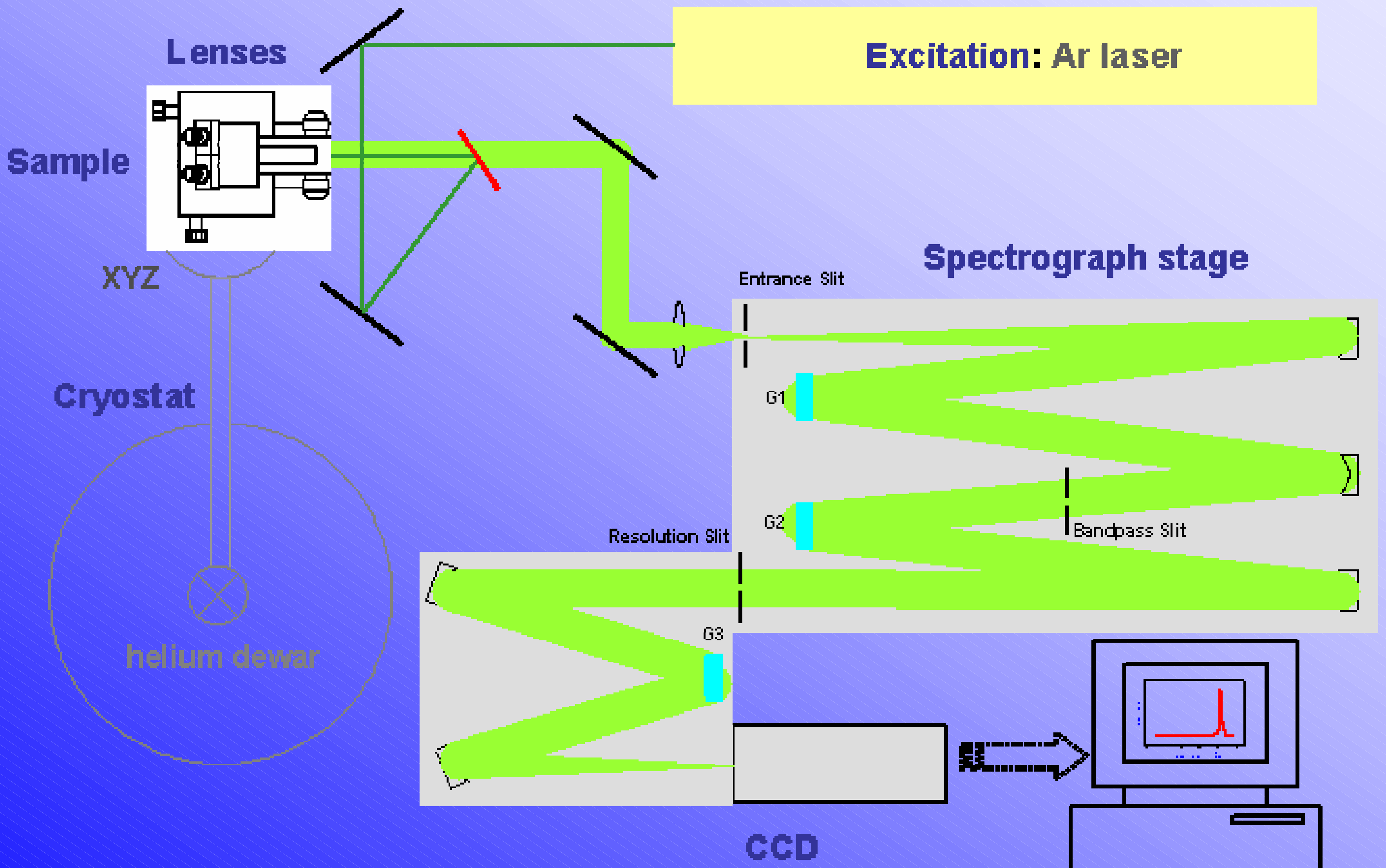
- XEOL experiments are site selective (under favorable conditions)
- Energy tunability – sampling in depth
- Sensitive to optical centers at low densities
- Imaging on micrometer scale: elements + optical centers
- Non-linear effects (bi-excitonic molecule,etc)
- Can be combined with other techniques: XRF, XRD.

**Goals:**

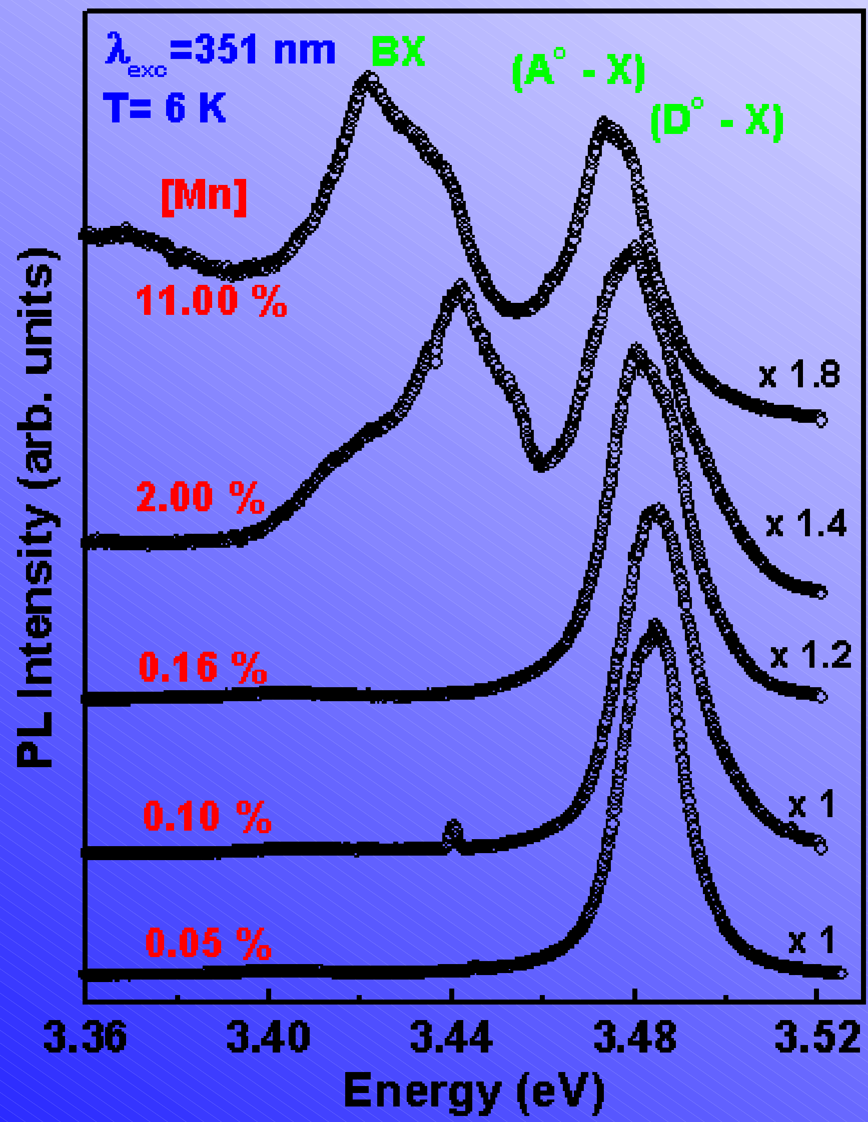


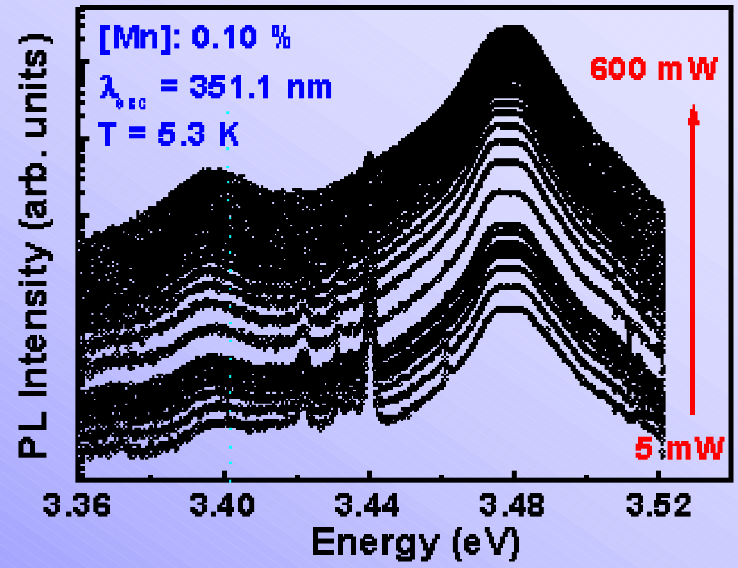
# WHAT DO WE NEED TO SET $\mu$-PHOTOLUMINESCENCE UP ?



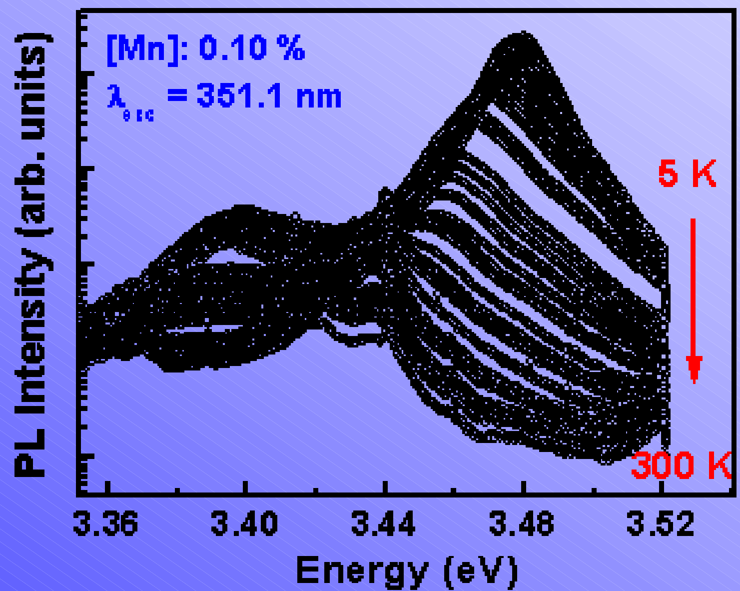
# WHAT DOES Ar LASER EXCITED LUMINESCENCE TELL US ?




PHOTOLUMINESCENCE vs EXCITATION POWER

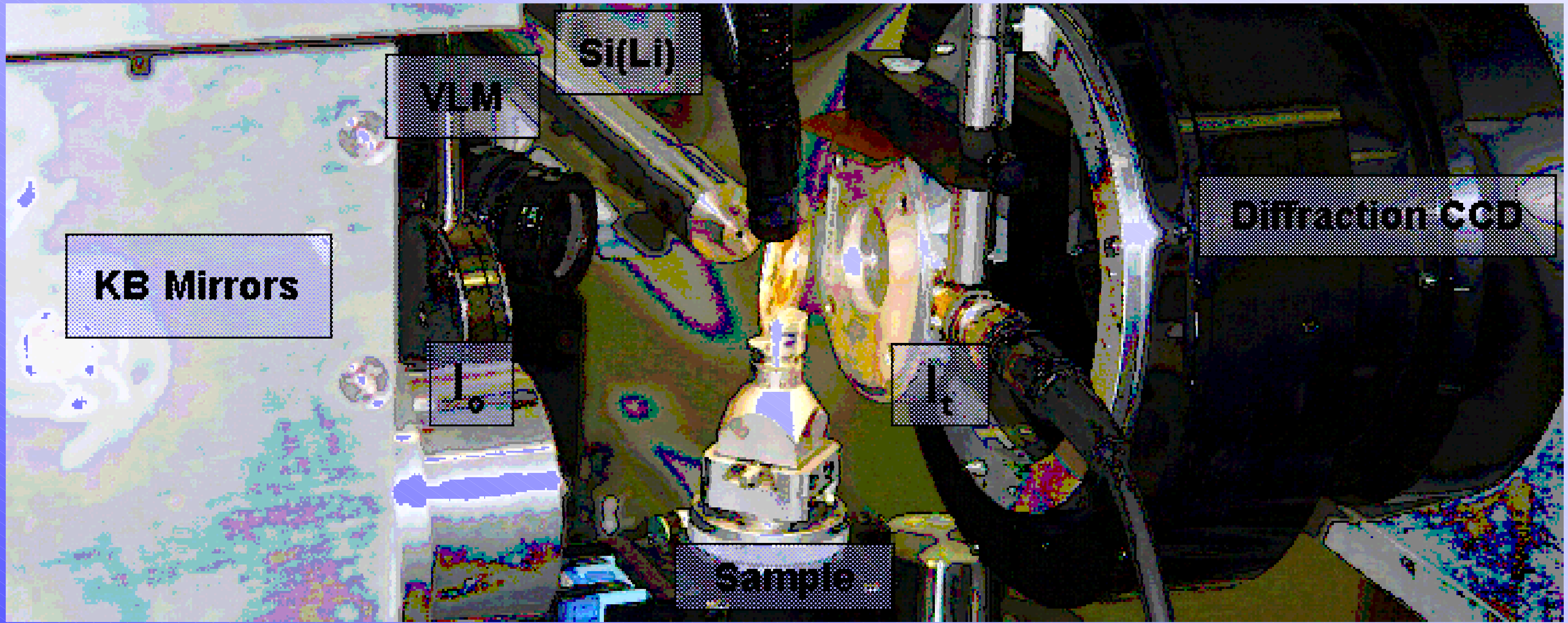



PHOTOLUMINESCENCE vs TEMPERATURE




- $h\nu_{\rm BX} = E_g - R_X - E_{BX}$

# SCIENTIFIC & TECHNICAL LIMITS -> COST/PRICE RATIO




**HR2000 Series High-Resolution Fiber Optic Spectrometer**

**SPECTROMETER SPECIFICATIONS:**

Grating: UV-VIS; Groove density: 600; Blaze@400nm

Collimating mirror: 0.22NA

Focal length: f/4, 101 mm; Entrance Aperture: 50 µm

Data Transfer rate: Full scans into memory every 13 msec

**LINEAR CCD SI ARRAY SPECIFICATIONS:**

Detector range: 200-1100nm

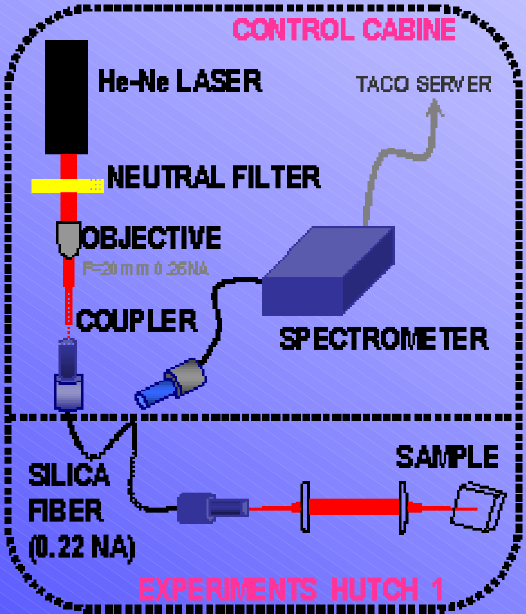
Pixel elements: 2048;

Signal-to-Noise: 250:1 (at full signal)

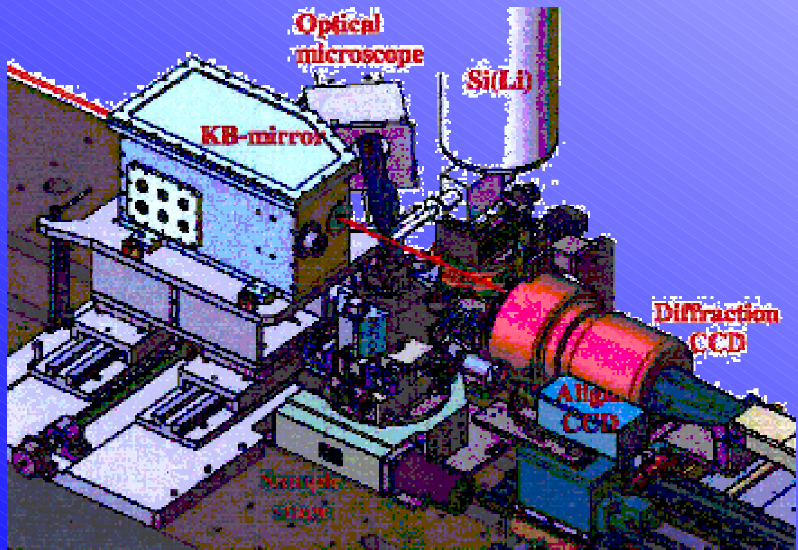
A/D Resolution: 12 bit

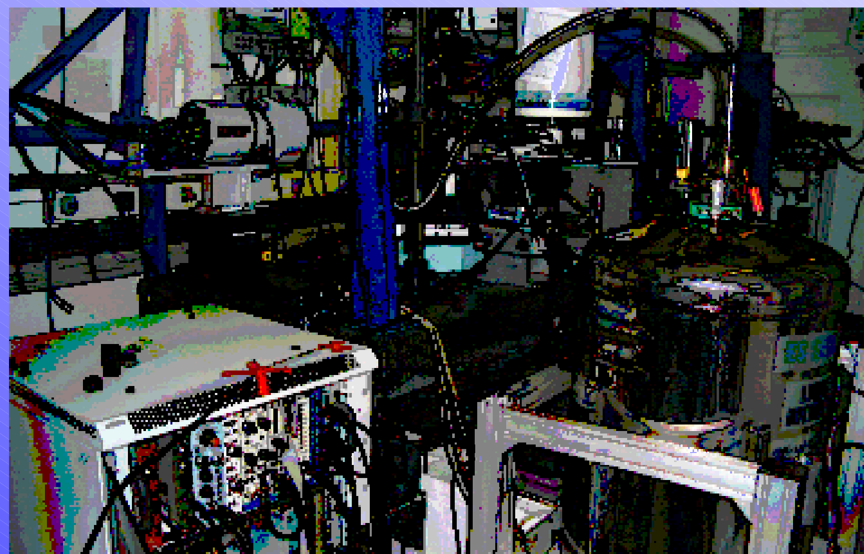
Dark Noise: 2.5 RMS counts

# OPTICAL SYSTEM ALIGNMENT



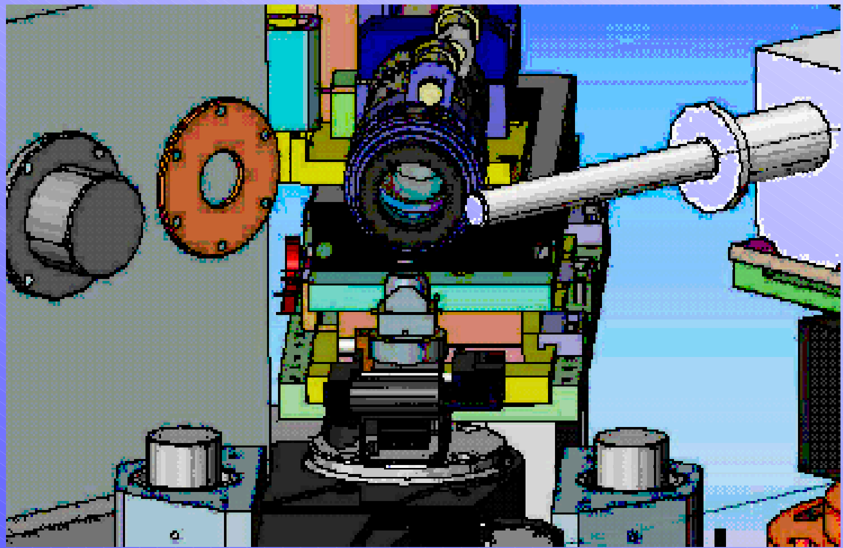


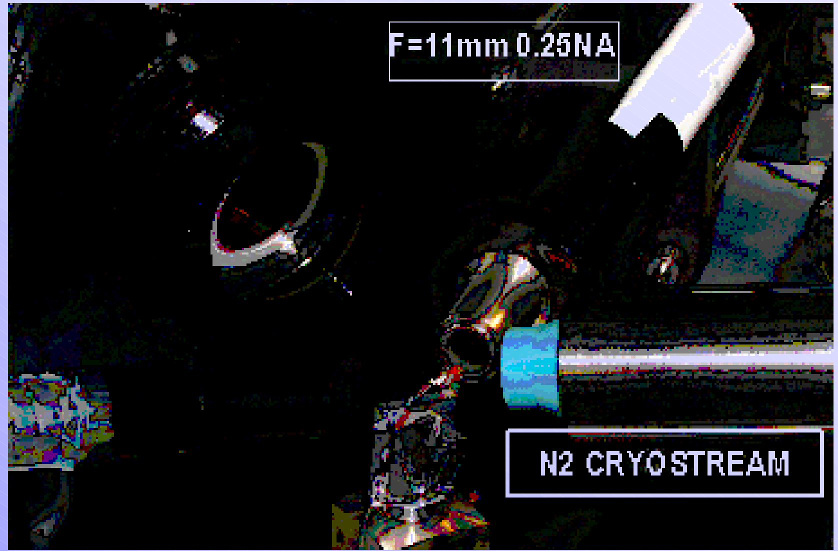


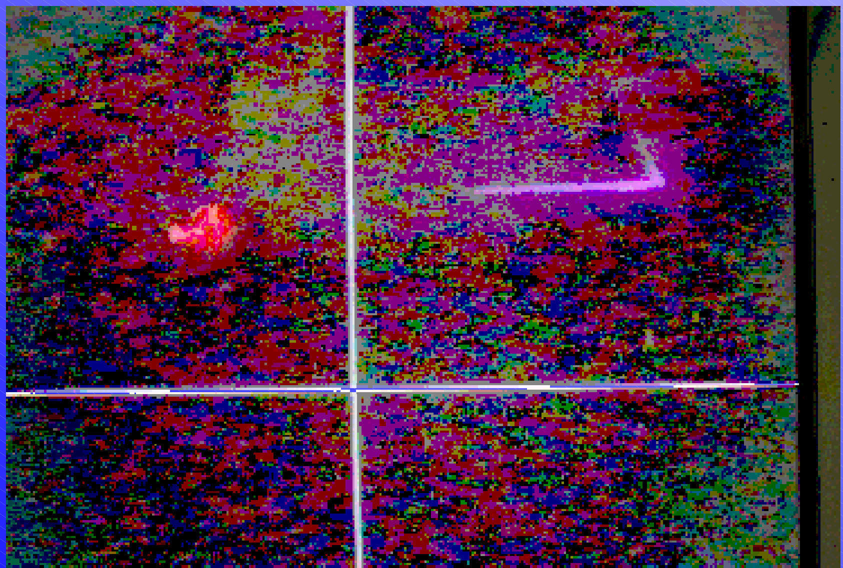
# SETUP OF SCANNING μ X-RAY EXCITED

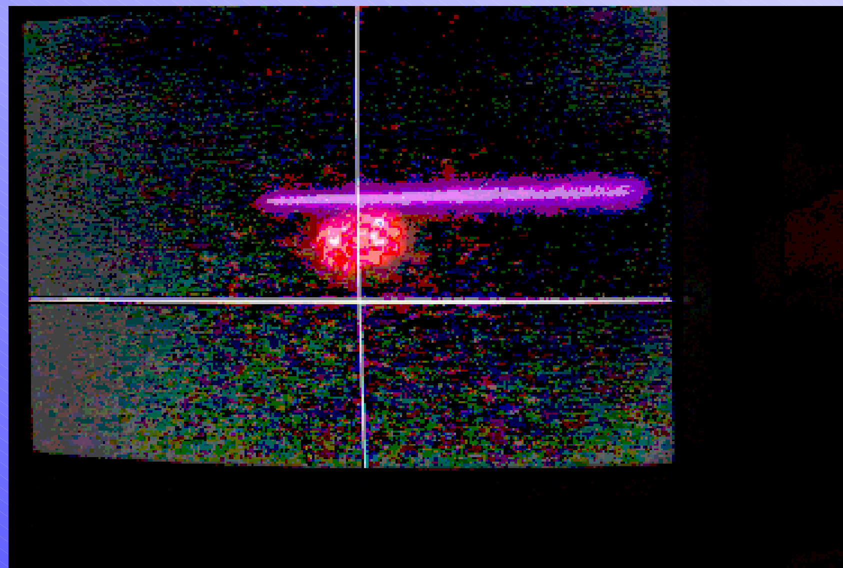
SAMPLE STAGE AT EXPERIMENTS HUTCH 1:



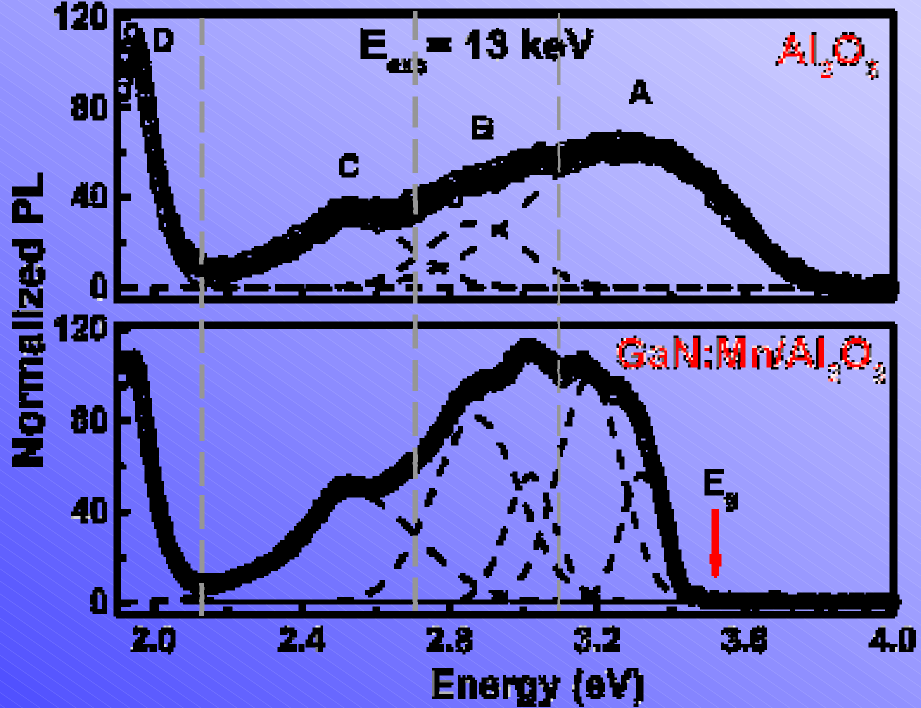



ALIGNMENT PROCEDURE AT THE CONTROL CABINE BY MEANS OF MICROSCOPE CCD:

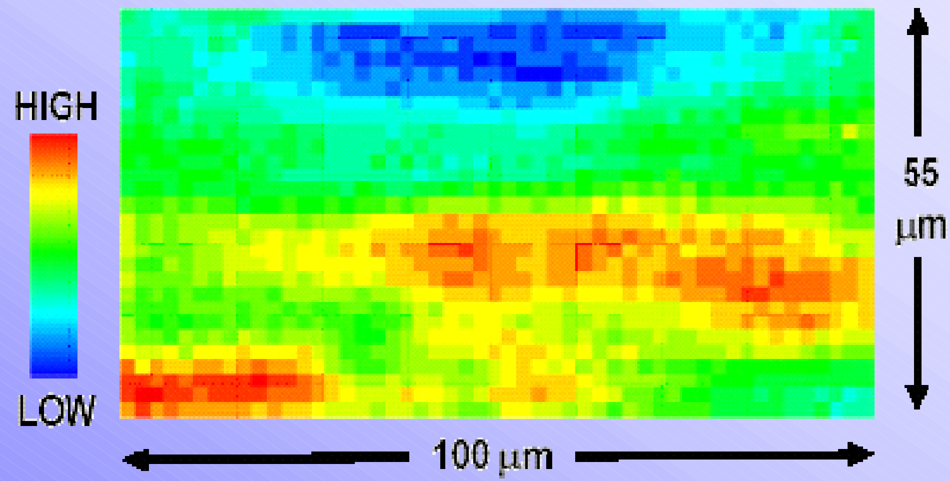




# FIRST DATA




$GaN:Mn/Al_2O_3$; [Mn]=11%; AVERAGE PL SPECTRA TAKEN AT ~80 K:



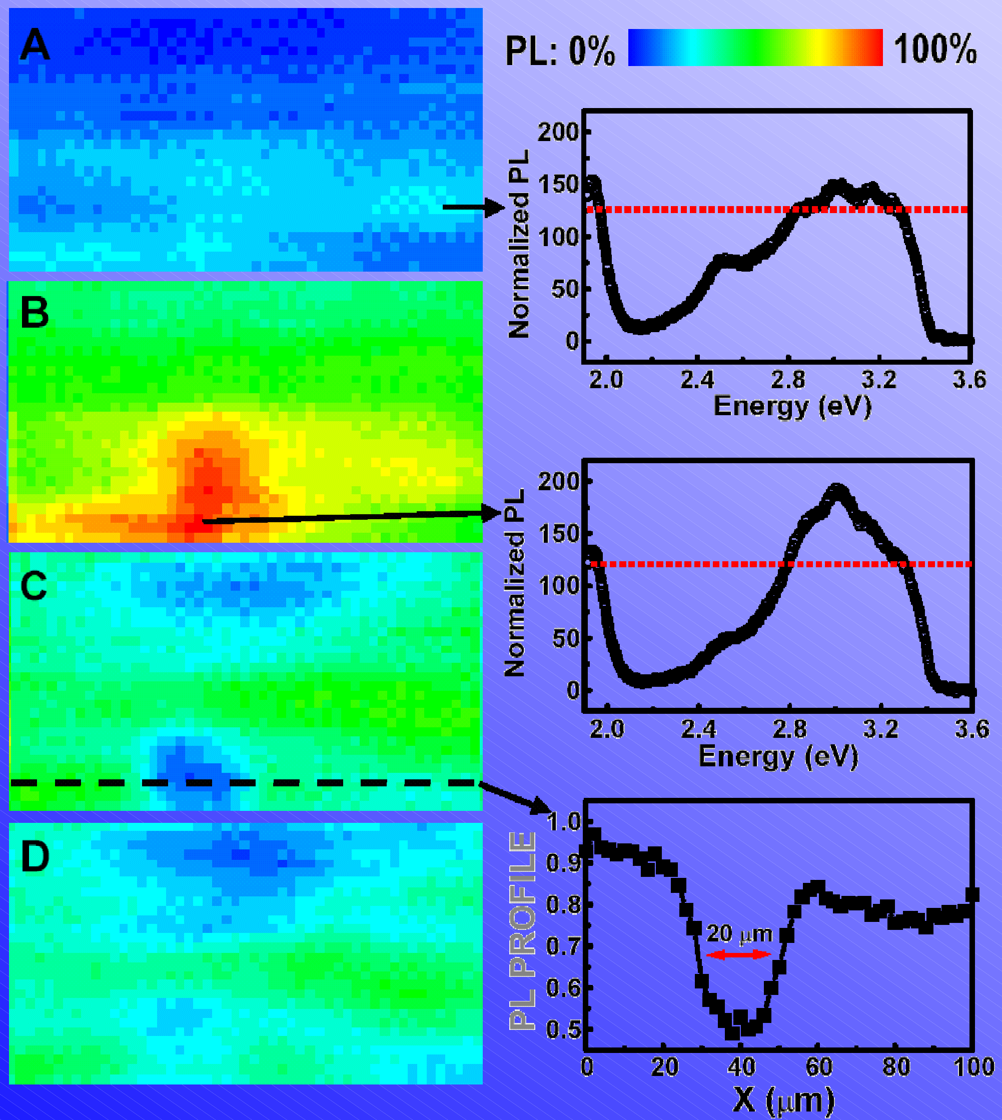

## Spectral analysis:

- Background luminescence from sapphire substrate
- High energy tail from the sapphire absorbed by GaN
- Both $Al_2O_3$- and GaN:Mn-related transitions are overlapping

➡

- 2D electron-hole recombination: non-uniform pattern
- Energy positions remains constant over the map: no large stress variation
- Though different sampling depths, good agreement with XRF: inhomogeneous Mn incorporation

# PL IMAGING BY CORE-LEVEL EXCITATION



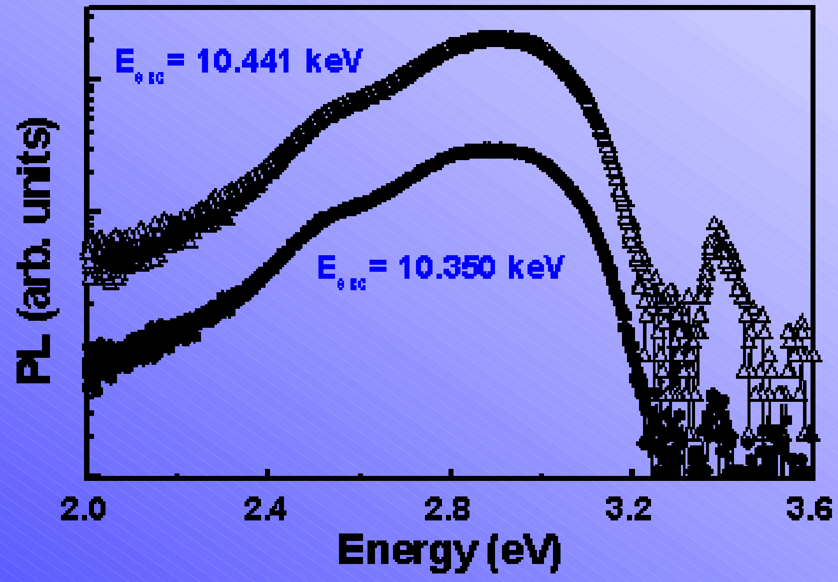

## Spatial PL analysis:

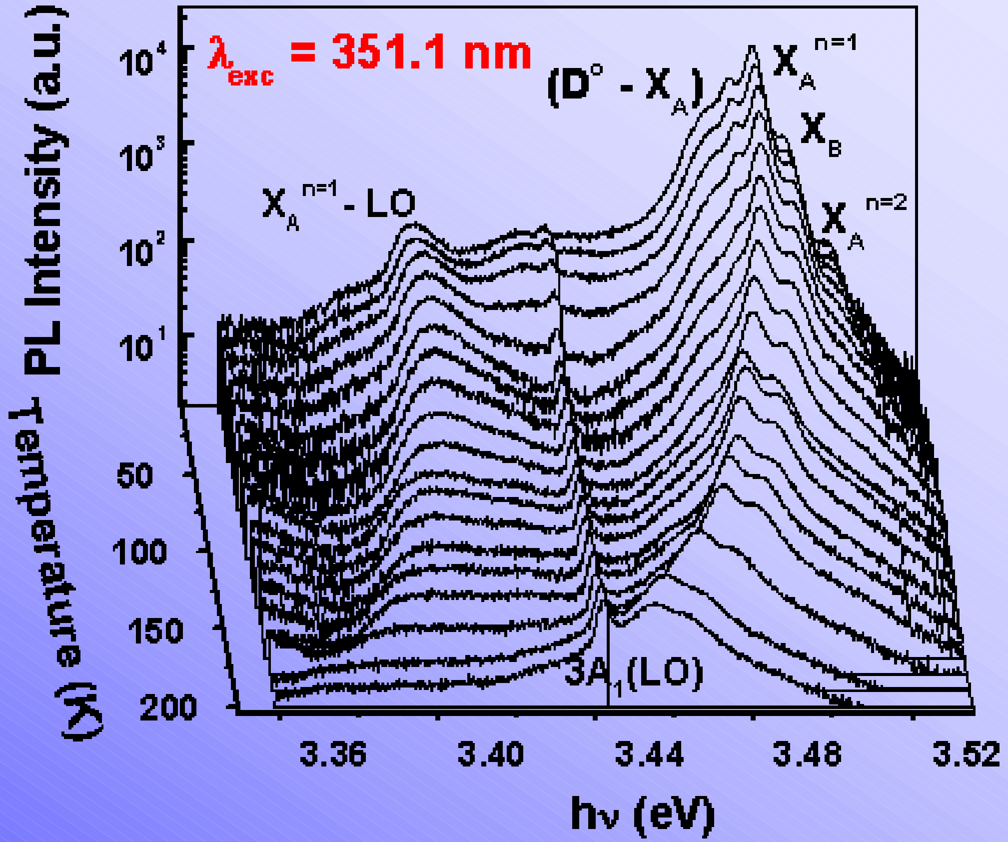
- Two kinds of optical shapes:
  - a few well-defined and sharp circular features
  - more recurrent structures horizontally elongated
- **C**: Mn–rich region absorbs the signal at 2.55 eV from sapphire
- **D**: Mn clusters block and interfere the Cr-related line
- **A,B**: strong variation of radiative rates

High energy bands at 2.7–3.1 eV: seems to be specific from some Mn center location in the GaN surface.

**BUT, poor lateral resolution**

# XEOL IN FREE STANDING GaN LAYER @ Ga K-EDGE




## Spectral analysis:

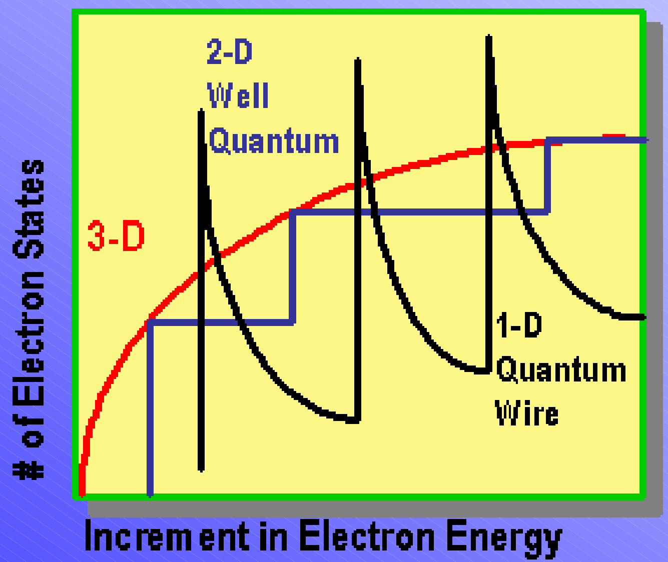
- Broad emissions insensitive to excitation energy
- Blue band at 2.9 eV: tentatively attributed to oxygen complexes
- Green band at 2.45 eV: commonly attributed to defects
- Excitons with very low intensities

**BUT, lower temperatures needed …**

**… and better signal-to-noise ratio**

# THE NEAR FUTURE

**The electronic states in III-V quantum heterostructures:**




- Higher lateral resolution (NA)
- Extensions in wavelength
- Better signal-to-noise ratio

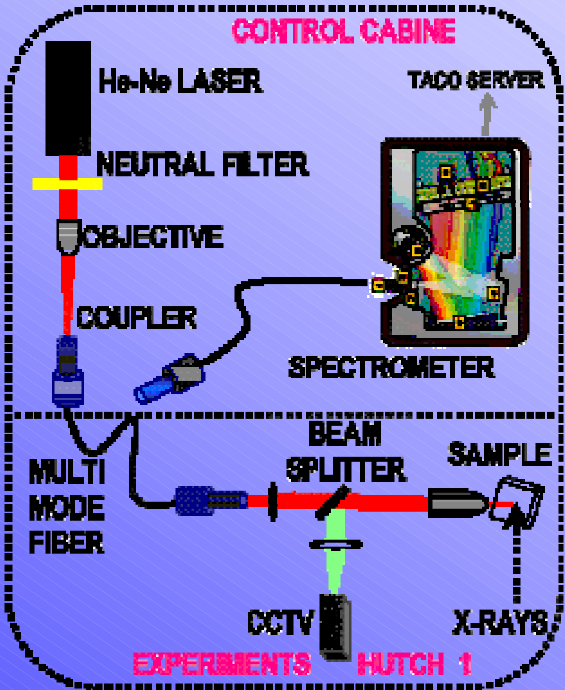
**NIR WAVELENGTH DISPERSION**

**IN-LINE SAMPLE INSPECTION/ILLUMINATION**

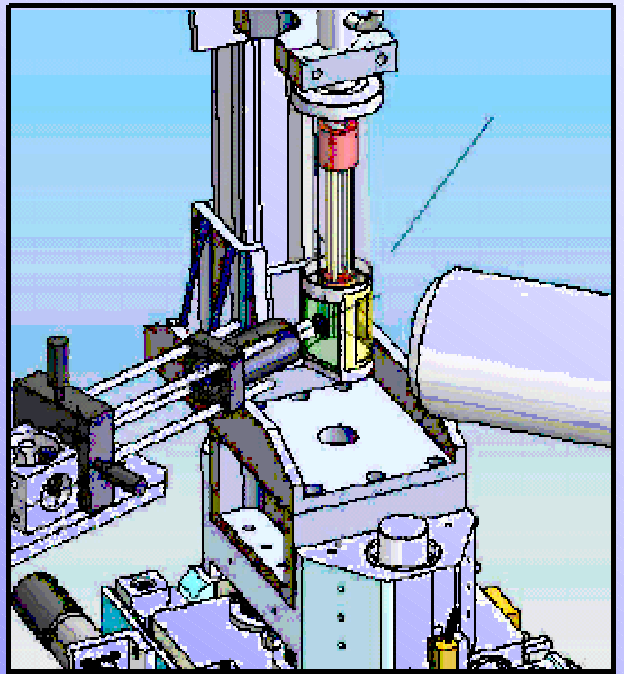
**InGaAs COOLED MCD FOR IR LIGHT DETECTION**

**HELIUM MICRO-CRYOSTAT FOR XRF/XEOL MODES**

# UPGRADE IN PROGRESS




## HE MICRO-CRYOSTAT




## SPECTROMETER

# CONCLUSIONS

- Scanning X-ray excited PL with micrometer resolution → feasible at ID22
- Alignment procedure → X-ray microbeam + Auxilliary laser spot
- GaN:Mn PL patterns → similar features probed by XRF mappings
- GaN XEOL on the micrometer scale → Successful
- Optical Detection Lateral Resolution → Needs improvements

XEOL IN NANOSCALE:

- Silicon nanowires PRB70_045313 (2004)
- Porous silicon →LANGMUIR 20,4690(2004), NATURE 363,331 (1993)
- CdS nanoparticles → JAP 91, 6038 (2002)
- Organic LED Materials →Rev Sci Instrum 73, 1379 (2002)
- CdSe quantum dots → JCG 214, 752 (2000)

# COLLABORATORS

Benito ALEN

Andrea SOMOGYI

Claudio MISKYS
Martin STUTZMANN

Alejandro HOMS
Ricardo STEINMANN
Yves DABIN
Sylvain LABOURE
Jean SUSINI

**THANK YOU!**