New developments and investigations with coherent magnetic scattering at ALS

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ALS

WORKSHOP
Magnetic Nanostructures, Interfaces, and New Materials: Theory, Experiment, and Applications

Collaborations

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"Flangosaurus"

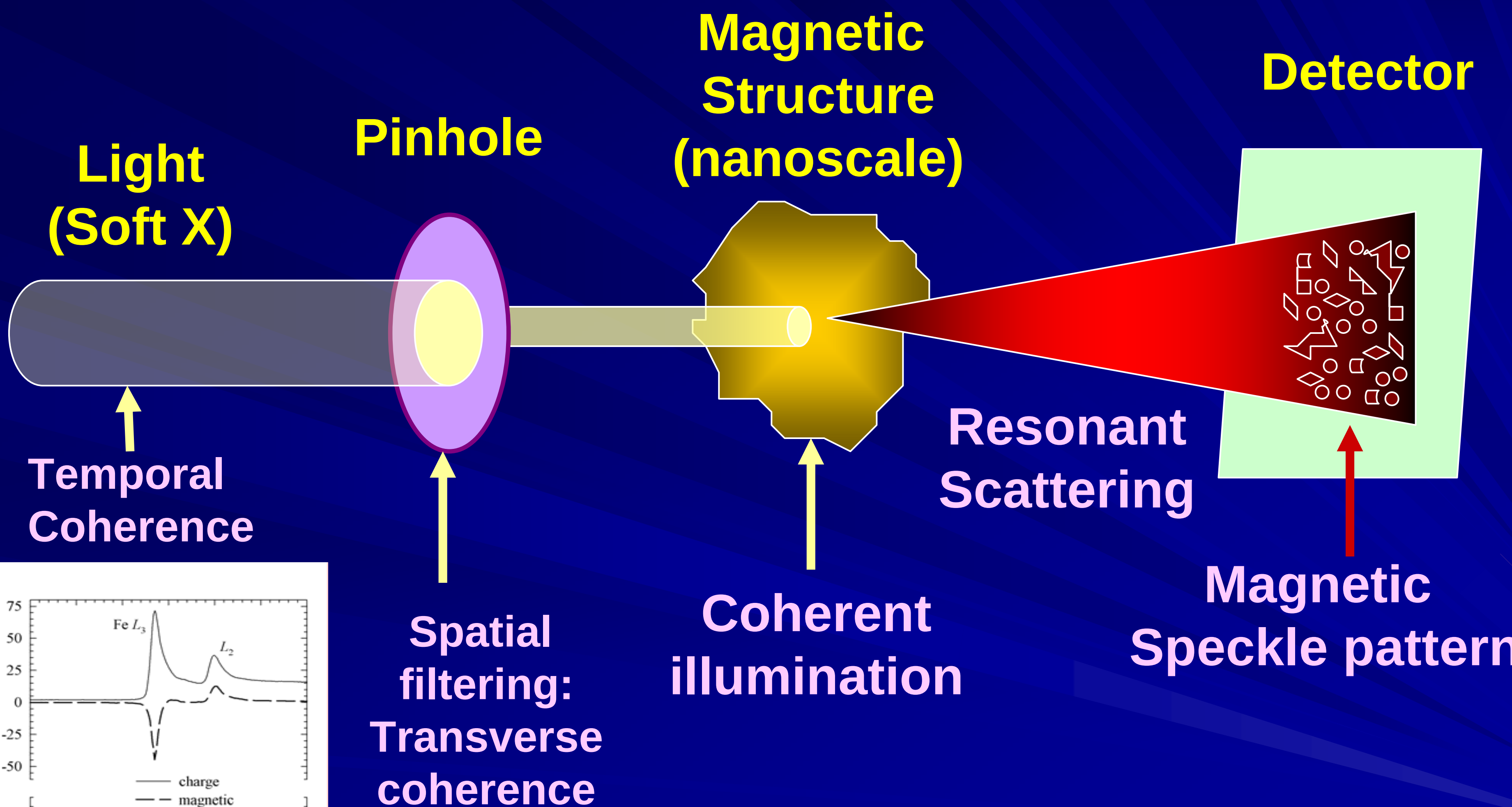
Zahid Hussain, ALS Support

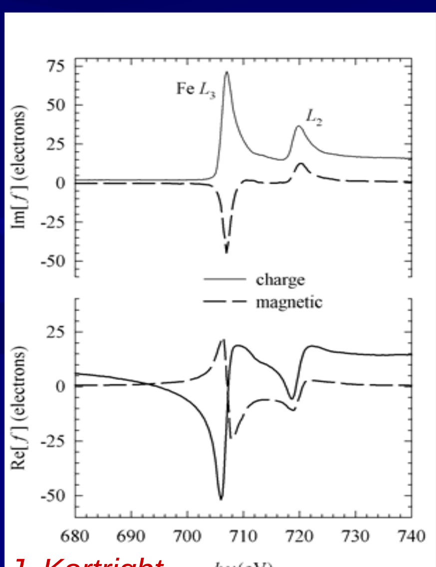
Tom Miller, Soren Prestemon, John Spring, John Pepper, …

Outline

- Introduction
- The coherent scattering endstation at ALS
- First investigations on nanoparticles
- Different way to use magnetic Speckle

How obtaining magnetic speckles?





J. Kortright

Short range magnetic order
Local disorder

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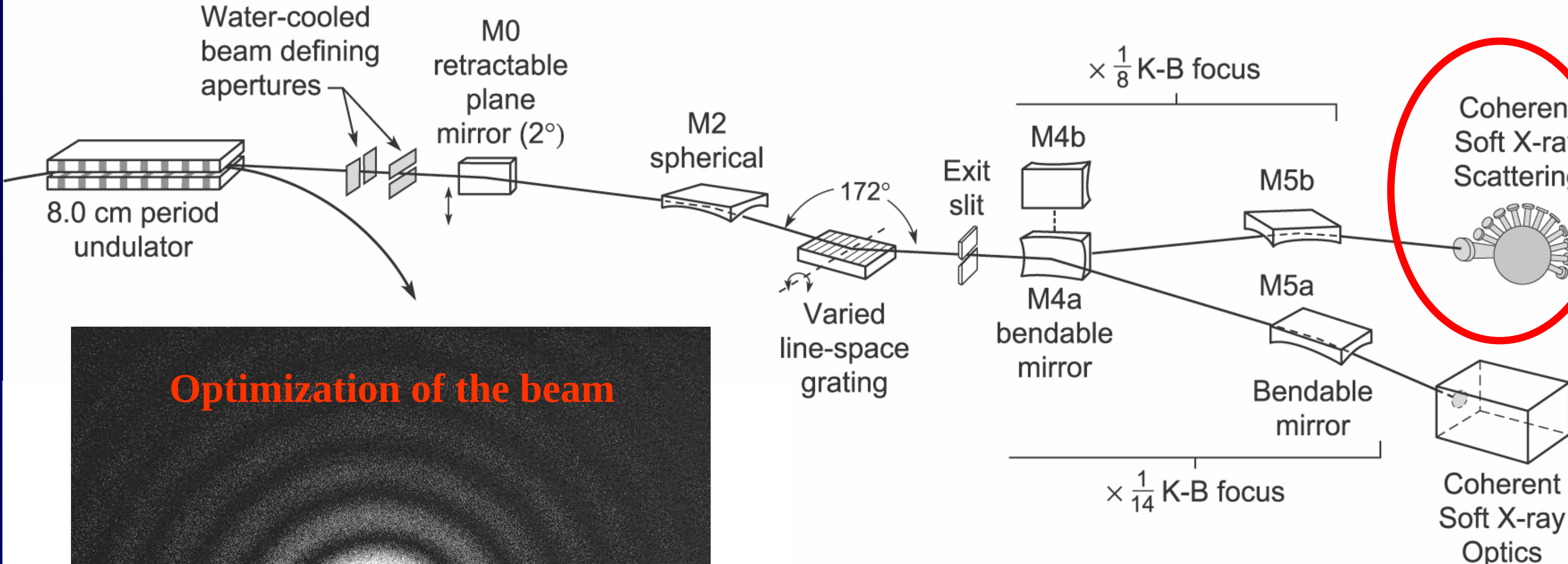
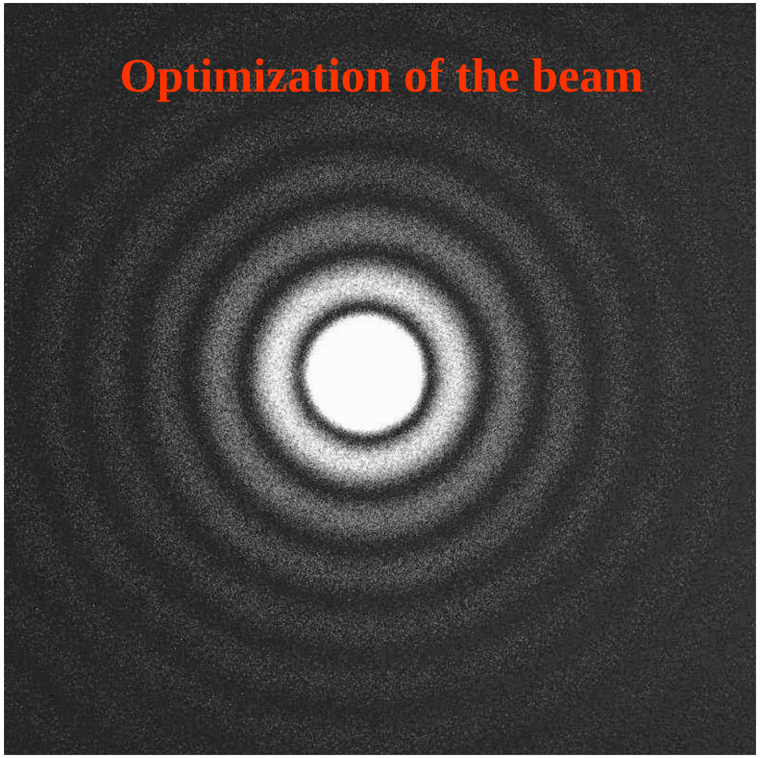
Coherent Soft X-Ray Beamline (BL12.0.2)





Energy range 200-1000eV

Coherent flux at 500eV:
~ 5 10^{10} ph/sec/0.1%BW

λ = 2.48 nm (500 eV)
d = 2.5 µm

Rosfjord et al. (2004)

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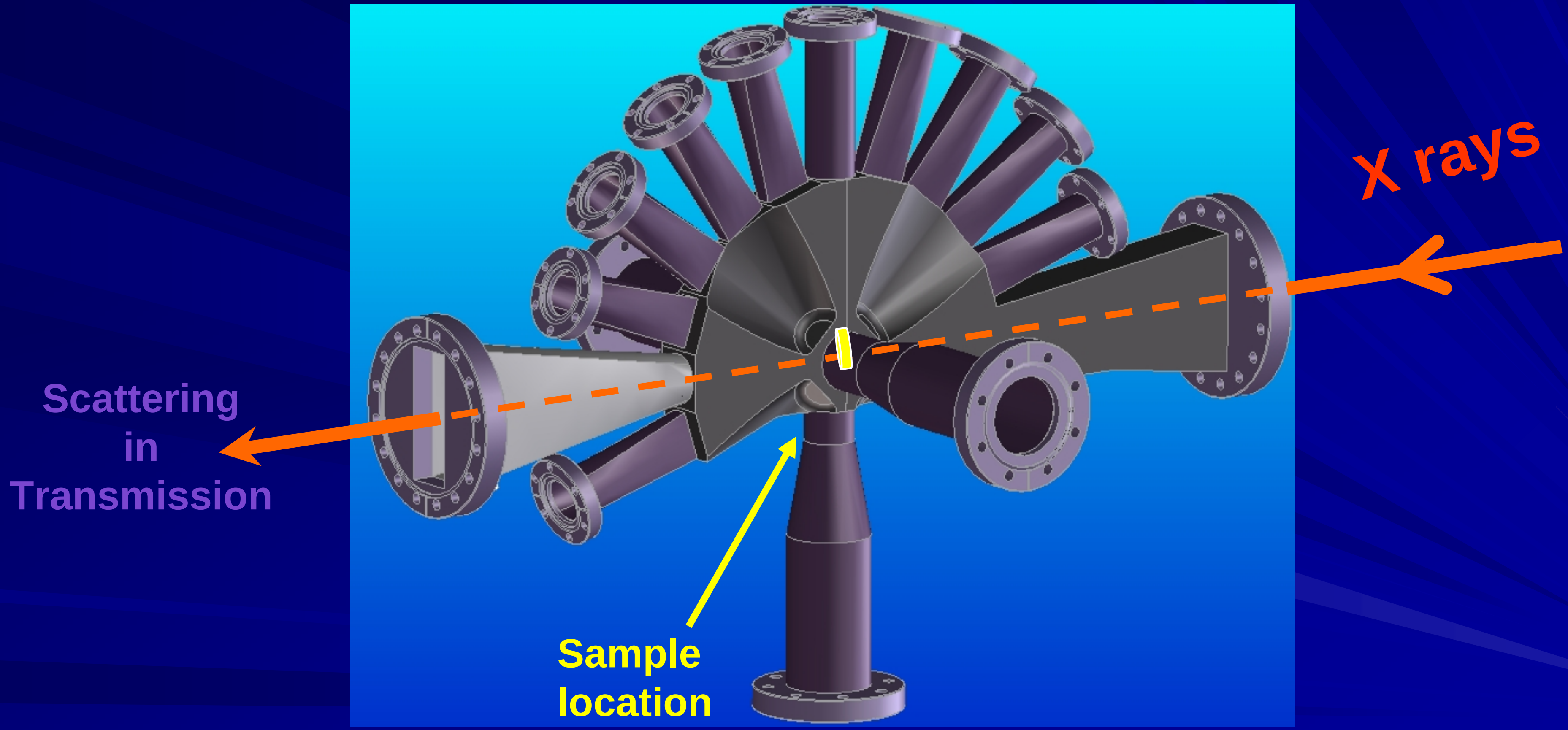
Coherent Soft X-ray Magnetic Scattering endstation

Flangosaurus



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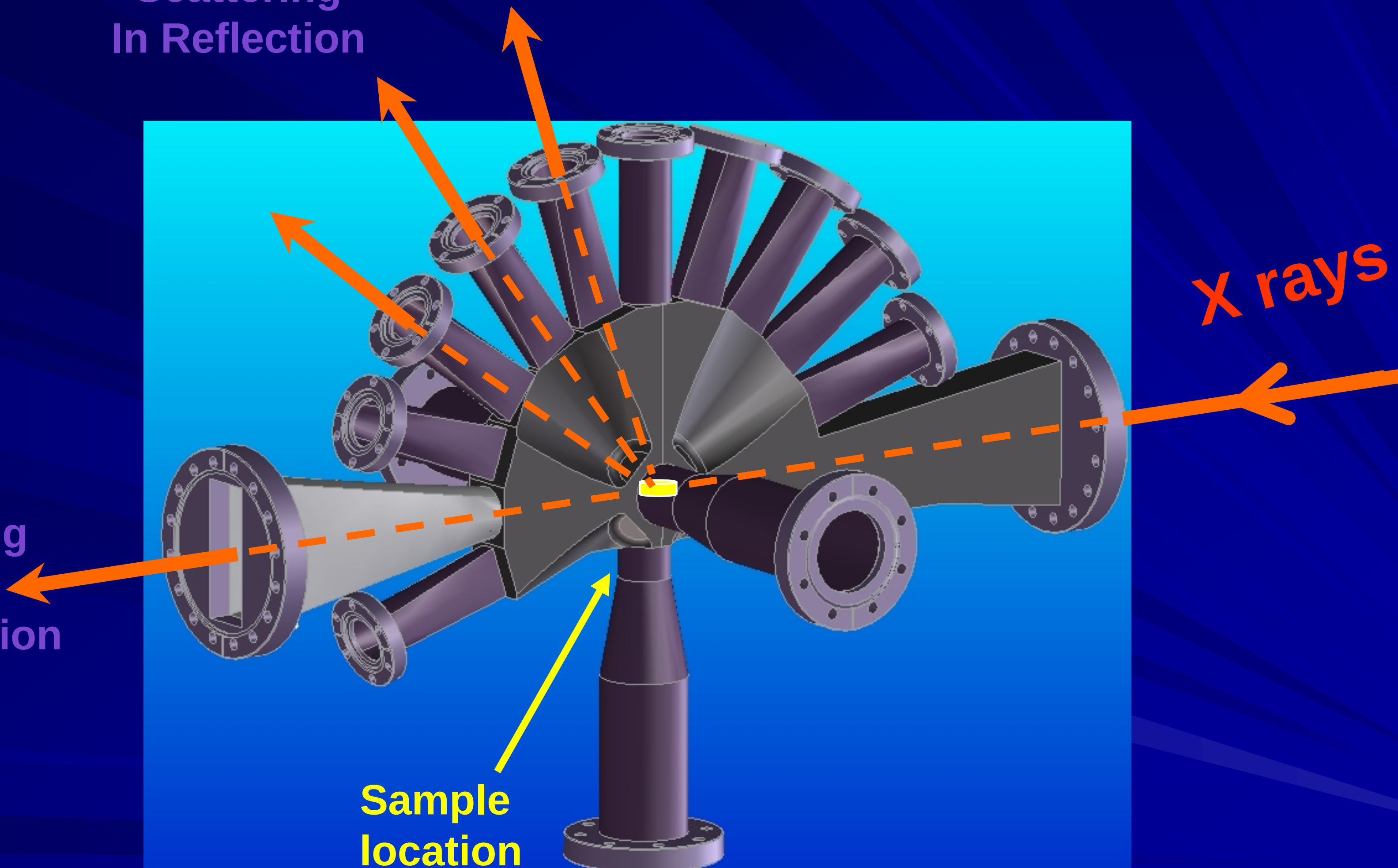
Flangosaurus



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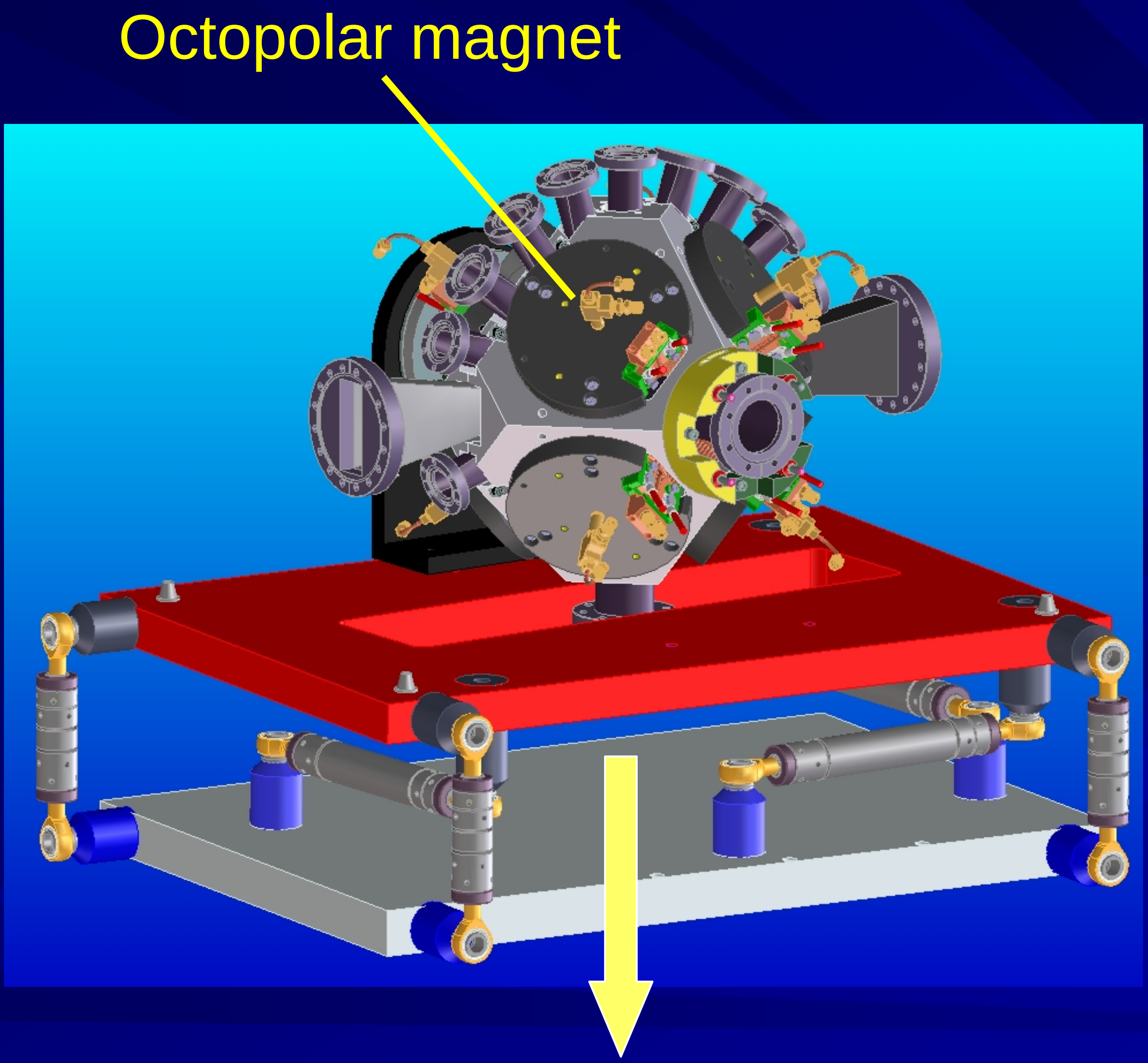
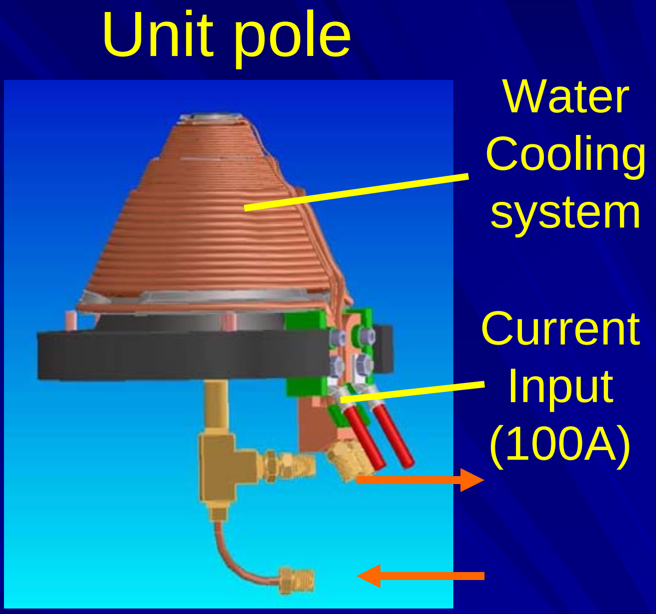
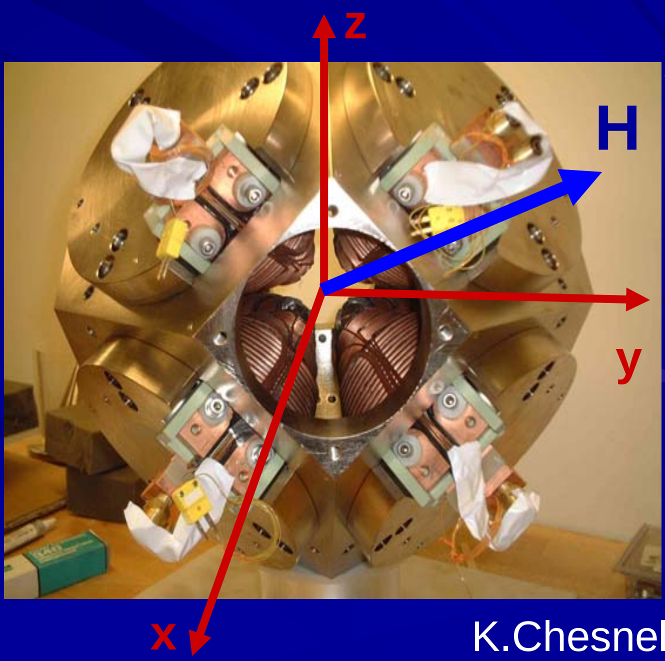
Flangosaurus







Produce Magnetic field in any direction
Maximal amplitude 0.6 T

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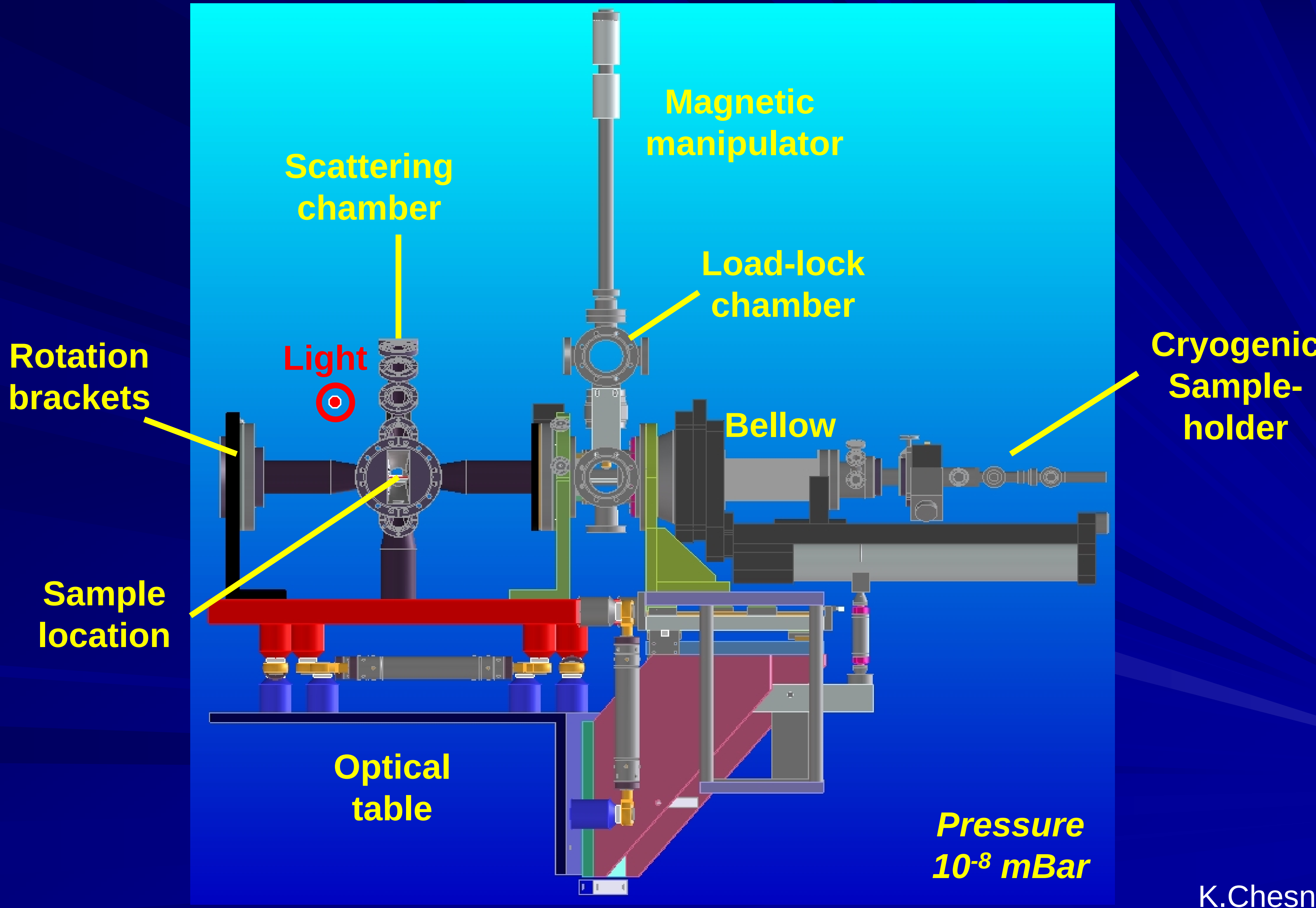
Flangosaurus



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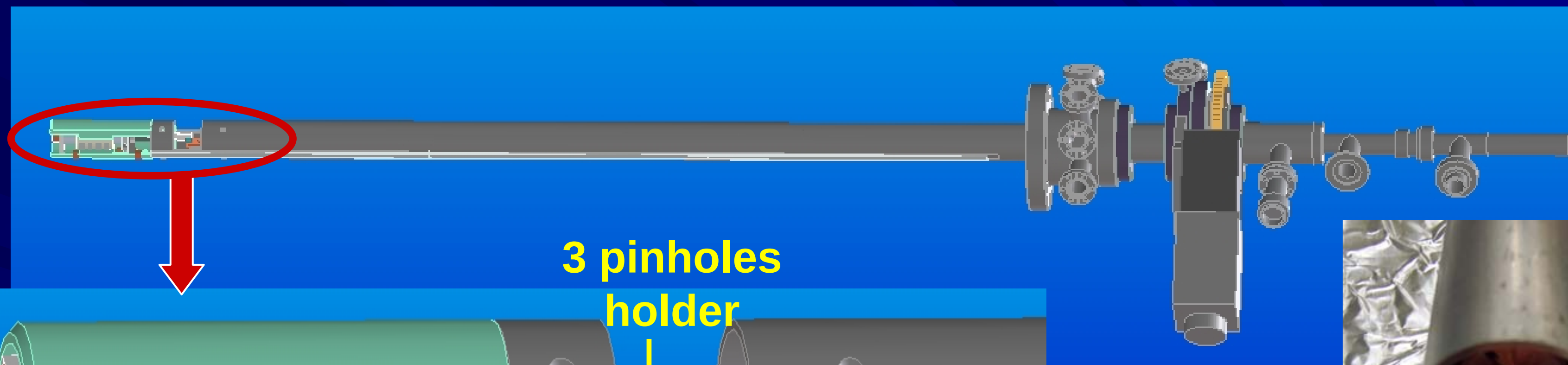
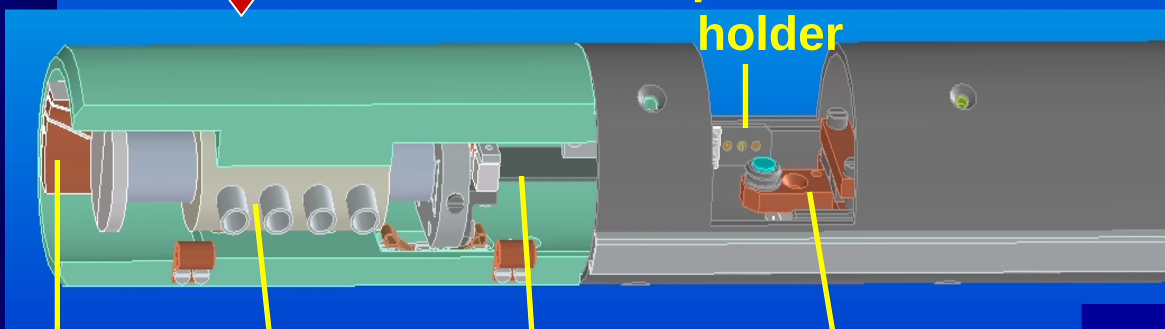
Flangosaurus:
Cryogenic Sample holder + pinhole mechanism





3 pinholes holder

feedback

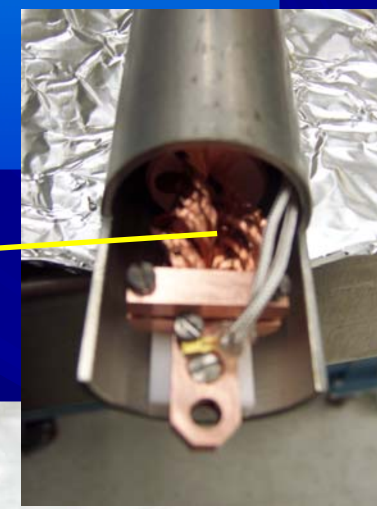
Inchworm

Horinzontal Motion (13 mm)

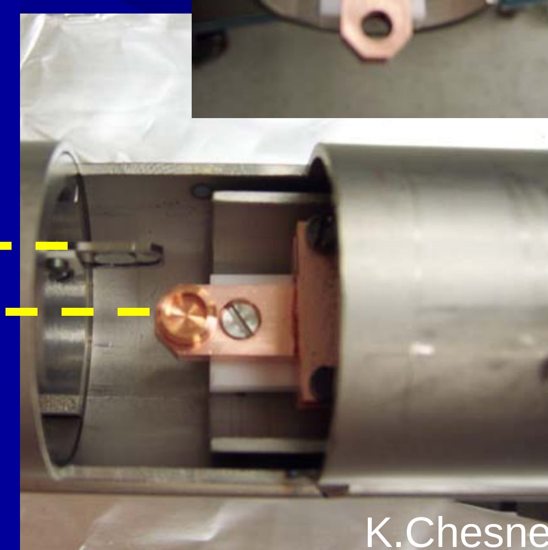
Bender

Vertical Motion (1.5 mm)

Sample holder



Mechanical isolation



Near field

5 mm

Pinhole size: few μm
Good oversampling

Experimental possibilities

- **Control of pinhole positioning**
- **High oversampling condition**
- **In-situ 3D magnetic field**
- **Sample cooling (cryostat)**
- **Investigation of the full main scattering plane**
- **2D detection with high resolution**
- **Fast detection**

Different geometries specificities

Reflection	Transmission
• Any kind of substrate	• Use of membrane
• Possibility to vary the incidence angle (f’,f’’)	• Simple measure of transmitted light (f’’)
• Depth sensitivity	• Direct image in the reciprocal space
• Discrimination of the magnetic components	• Transmitted beam easy to block

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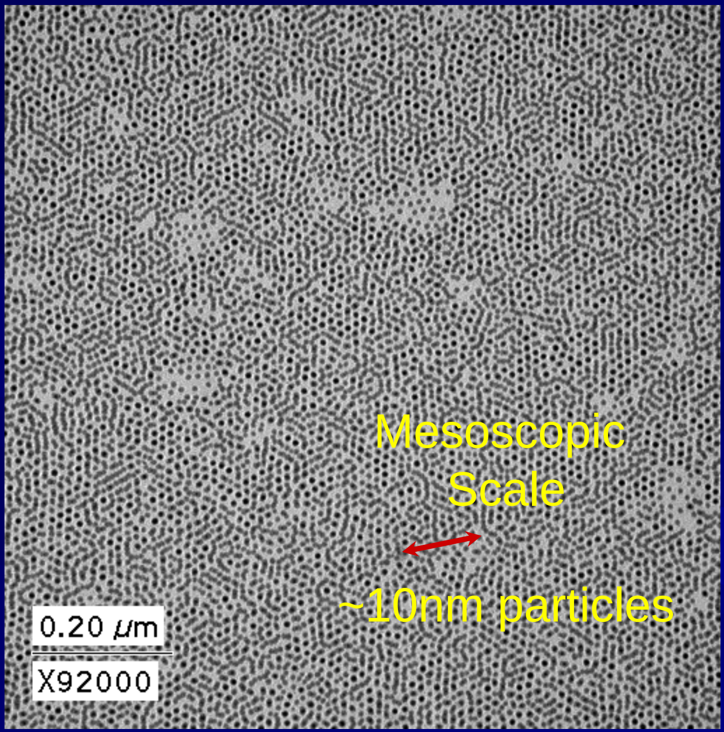
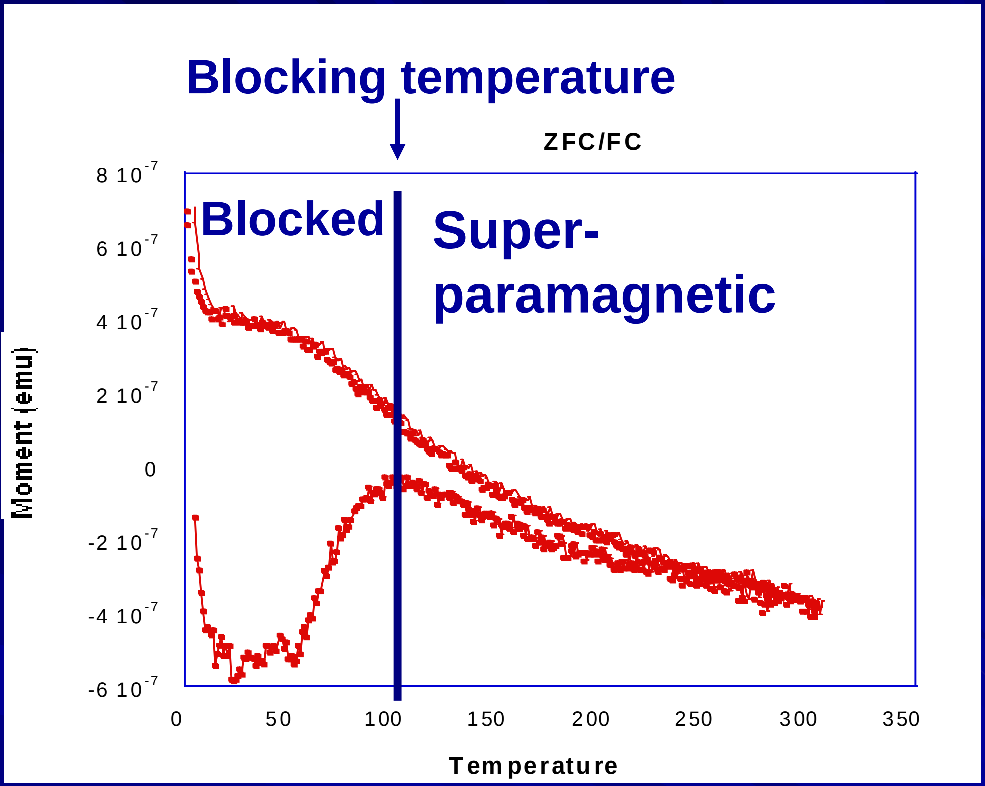
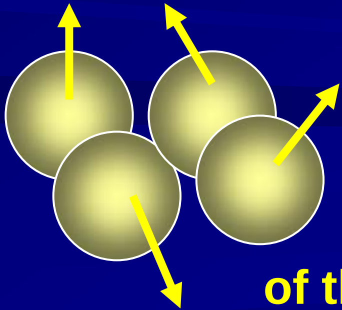
Probing the magnetism in nanoparticles

Co nanoparticles Self-assembly







?

Magnetic configuration of the nanoparticles ?

Resonant soft X-ray scattering

- Probe the magnetic order/disorder
- effect of field and temperature
- slow and fast dynamic

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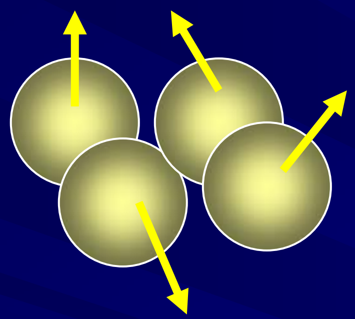
Probing the magnetism in nanoparticles



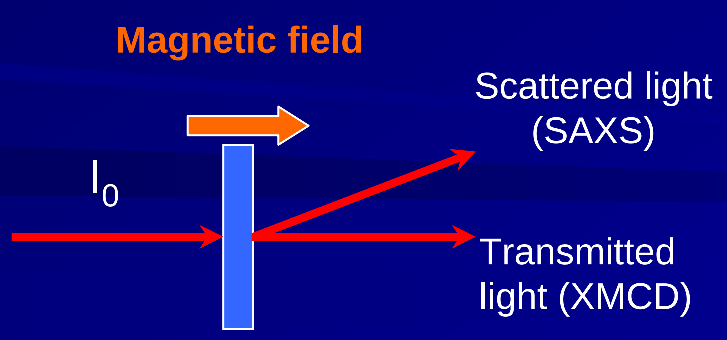
Different systems under study:

- Co particles 8-9nm (variable packing)
- Fe_3O_4 particles variable size 4-16nm

Sources S. Sun, K Krishnan…

Kortright et al. (2004)

Transmission geometry



Incoherent light ➡ XMCD, SAXS (average information)

Coherent light ➡ speckle pattern (average information)

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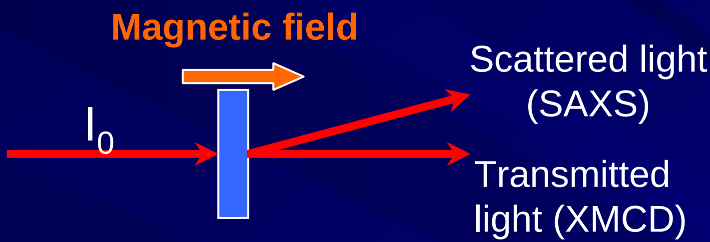
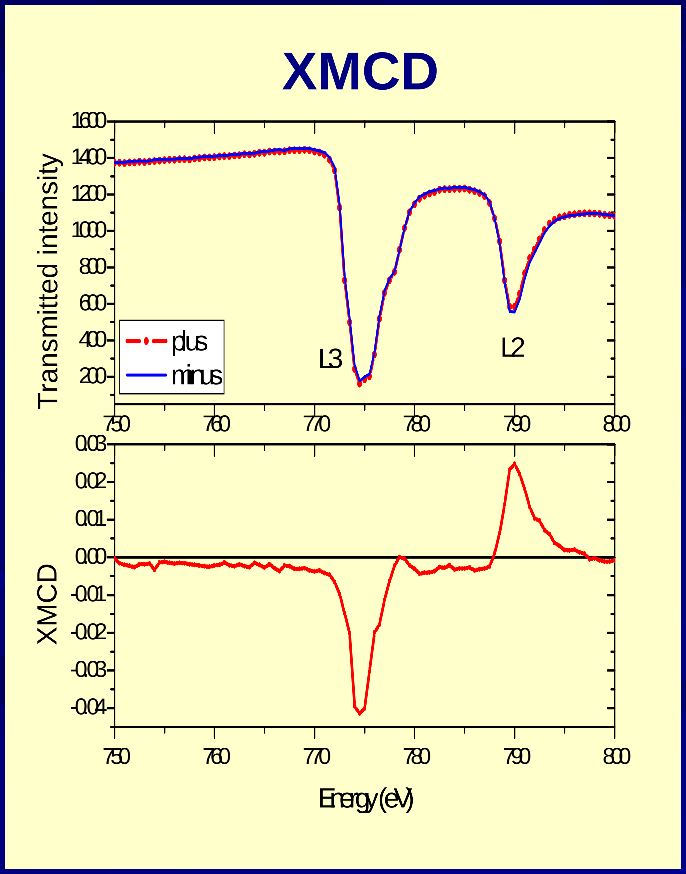
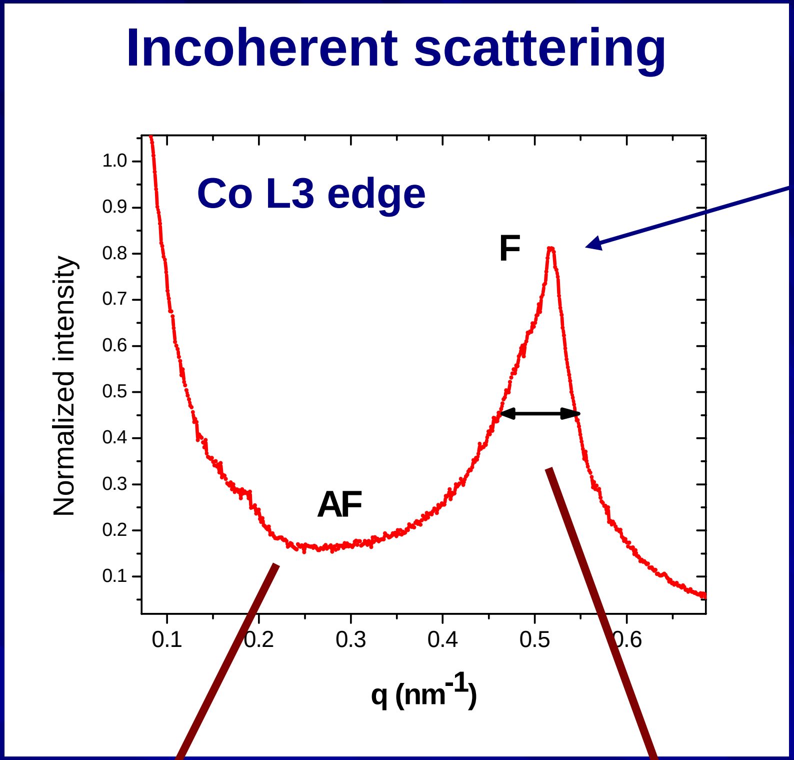
Characterization with polarized light (BL4)



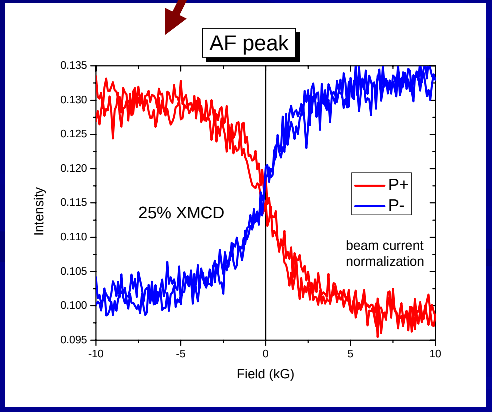
Co nanocrystals

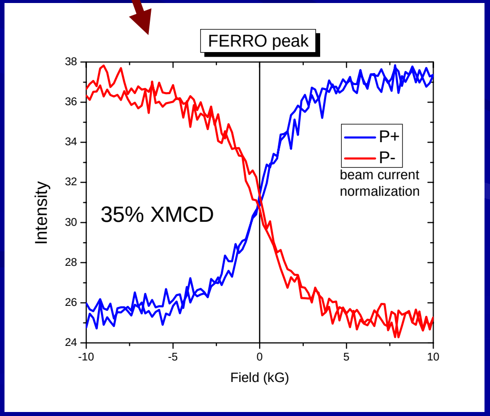




Interparticle distance ~12nm

Correlation length ~60nm





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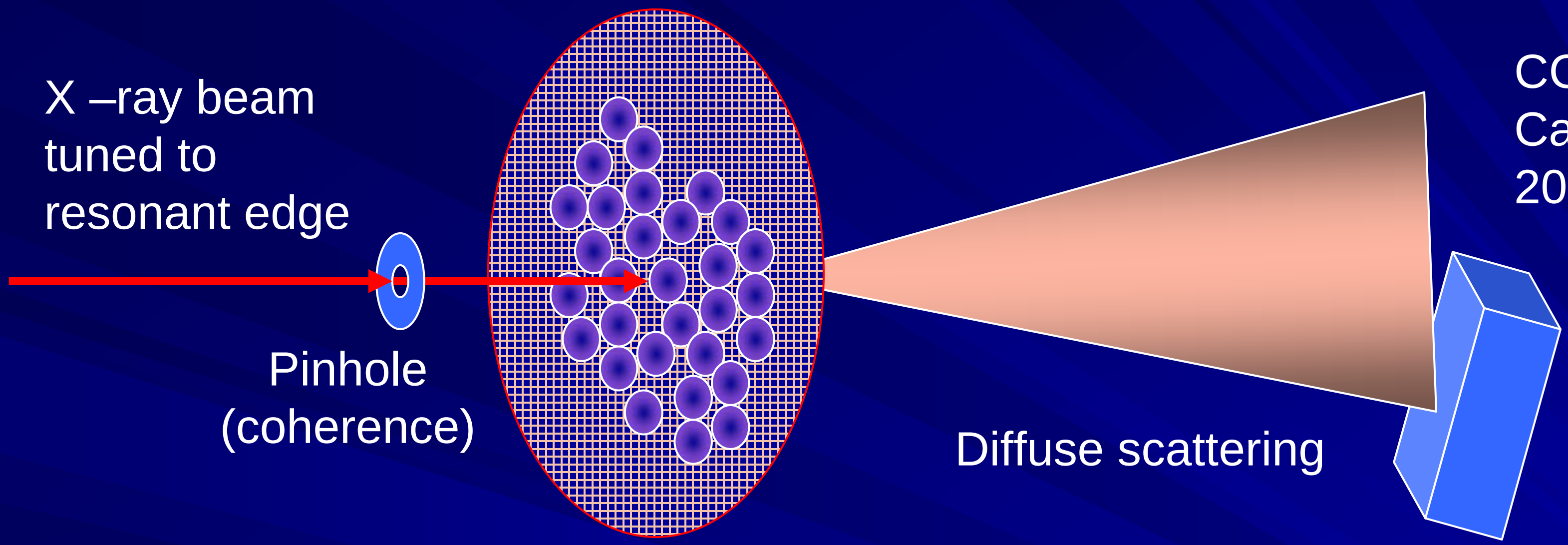
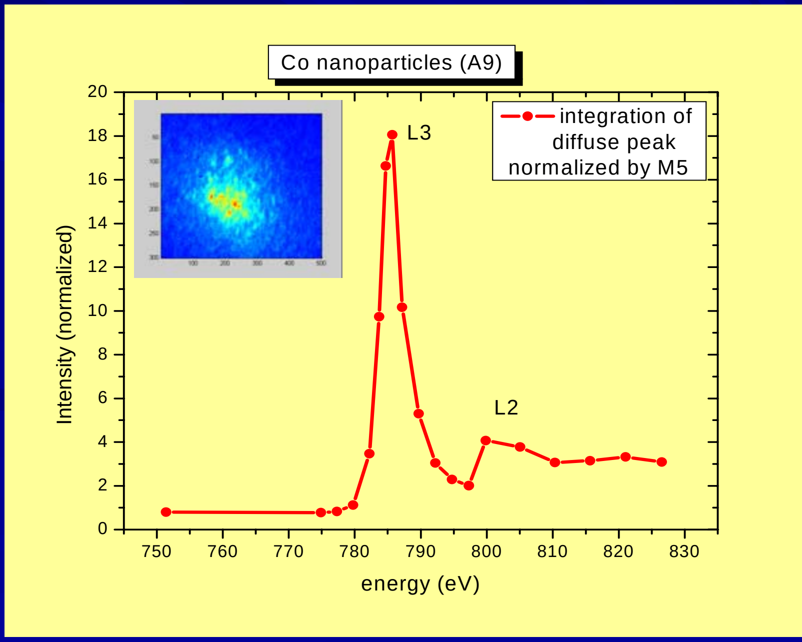
Coherent 2D scattering on nanoparticles



Co Nanoparticles assembly
precipitated on TEM grid

Energy optimized at
Co L3 edge: λ=1.58 nm



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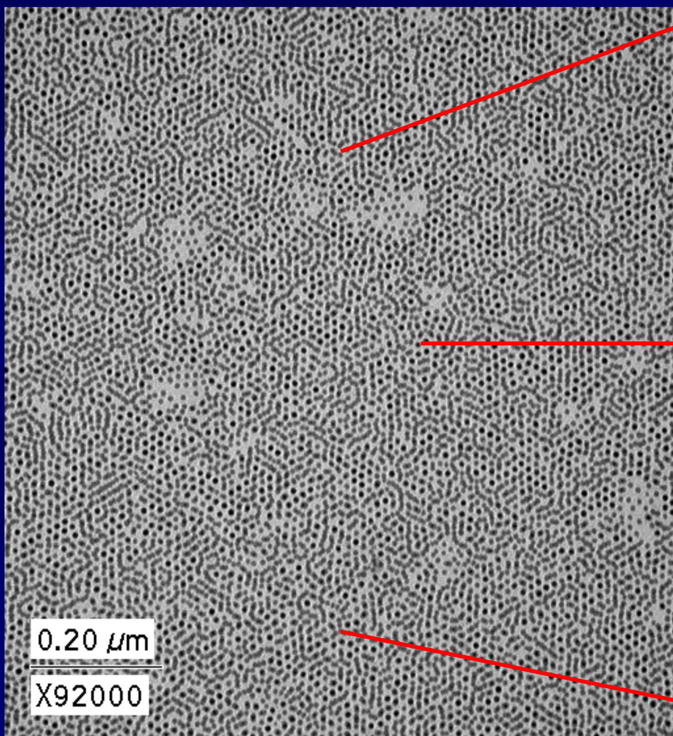
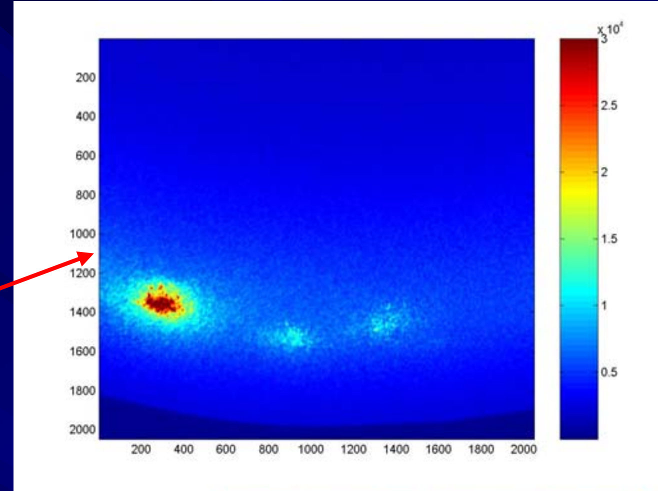
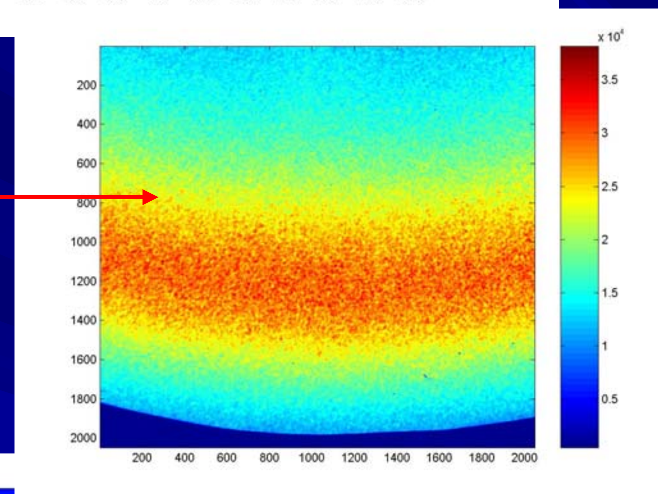
General 2D scattering Patterns (no pinhole)



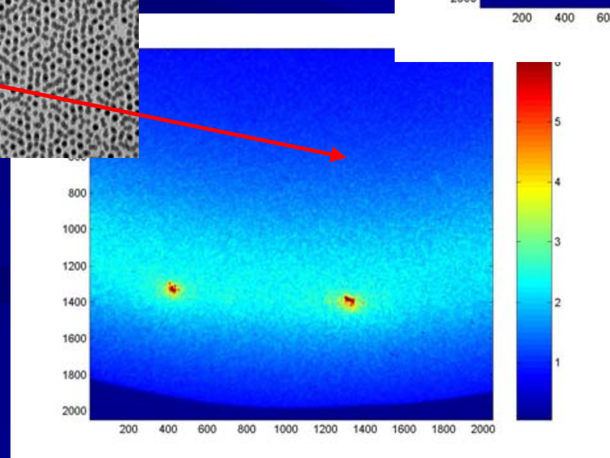
TEM image (K.Krishnan)



Localized peaks => Ordered area



Isotropic Pattern



Another Ordered area

VERY HERTEROGENEOUS!!

ALL patterns distributed along a RING
- ordered area d~ 12nm
- disordered d~ 13nm

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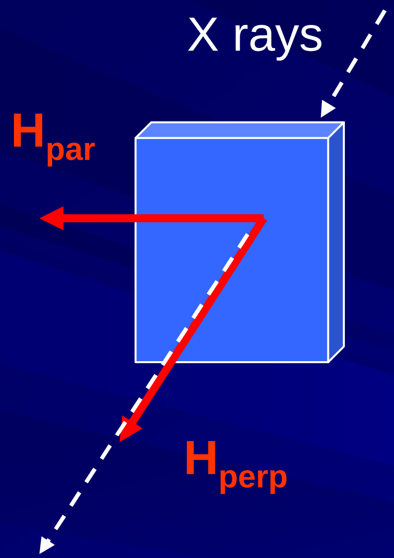
Effect of magnetic field in linear polarization

- Ordered area

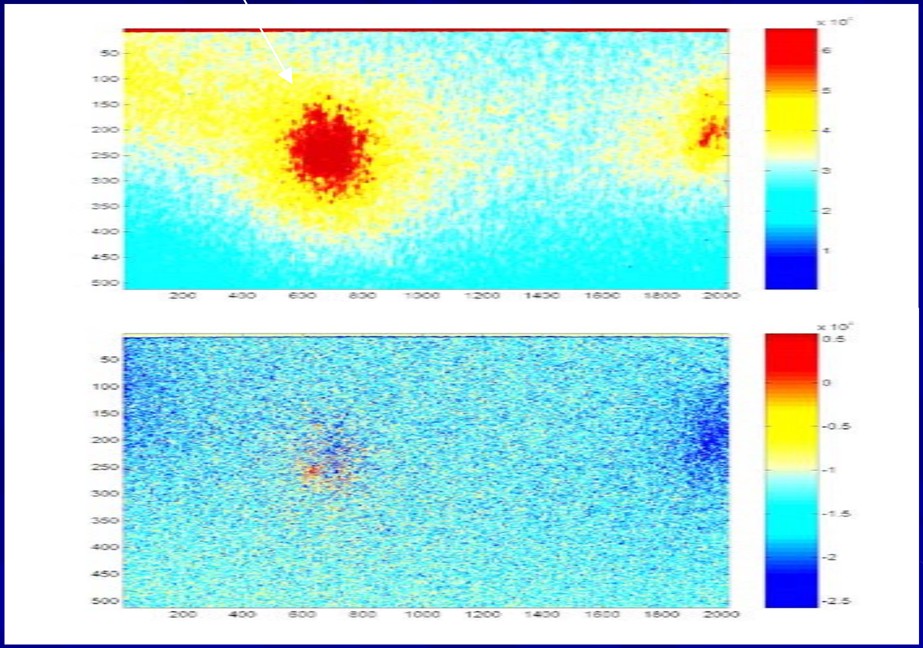


Scattering peak (charge +magnetic)

Full scattering

Difference Remanence -Saturation

(Effect ~0.5%)



With PERPENDICULAR field:
I (saturation) > I (remanence)

At saturation all particle moment are pointing the same direction and contribute to the peak

With IN PLANE field:
I (saturation) < I (remanence)

With linear polarisation
X rays are not sensitive to the in plane component

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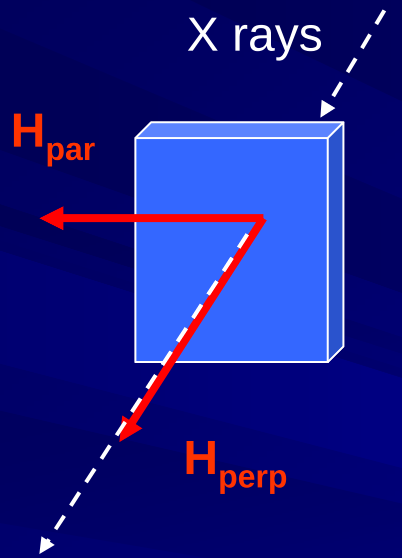
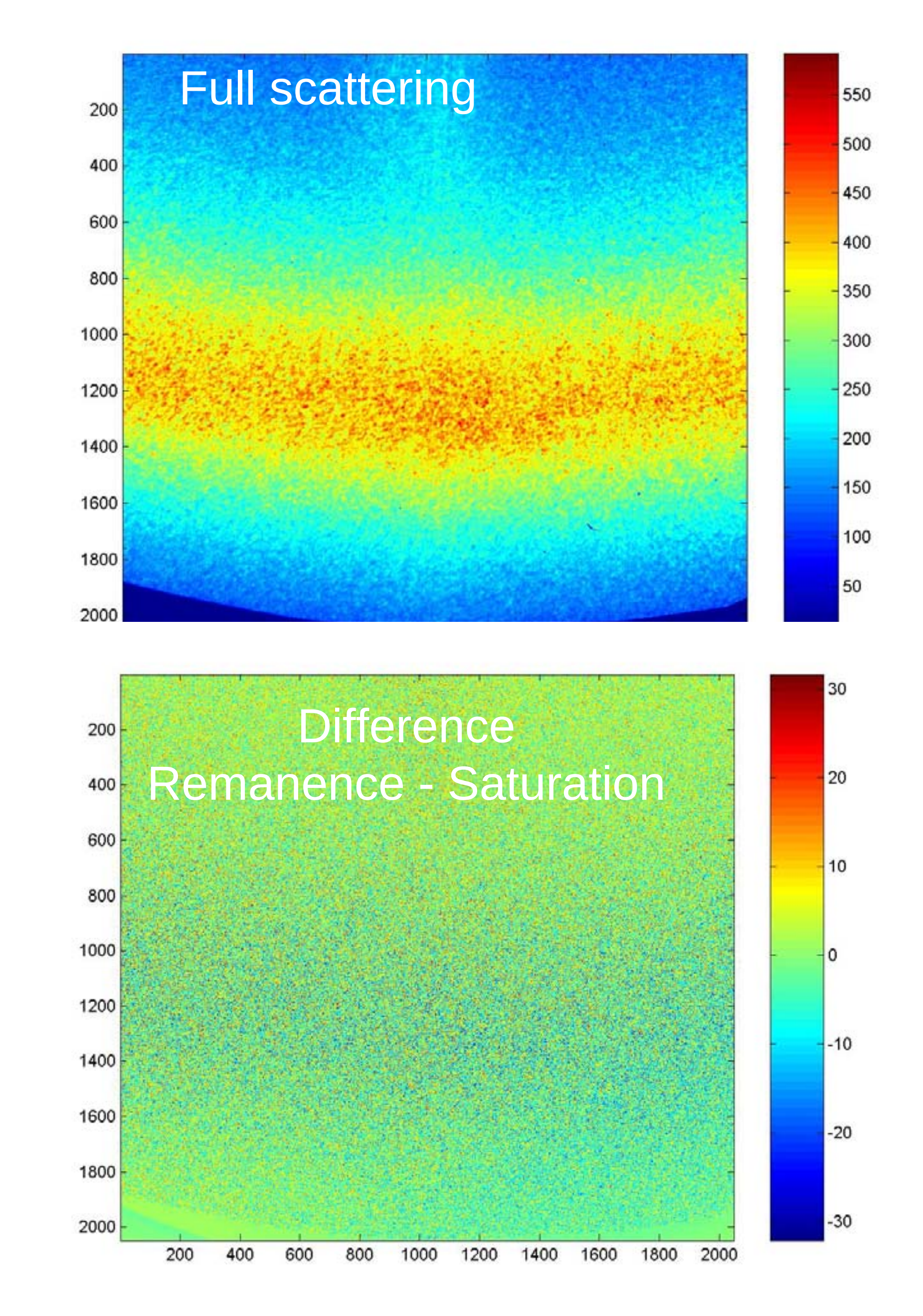
Effect of magnetic field – isotropic area



With PERPENDICULAR field:
I (saturation) > I (remanence)

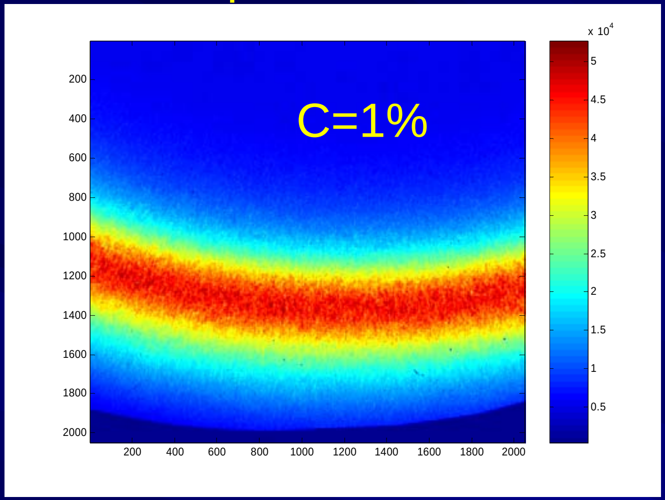
Effect ~4%



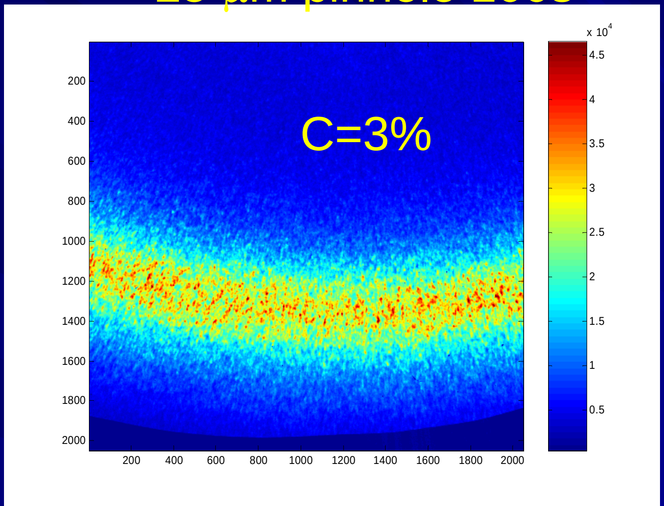
It seems isotropic areas show a stronger tendency to AF order at remanence, while ordered area are more F…

Obtaining a Speckle pattern:
degree of coherence/ pinhole size (Co edge)

No pinhole 10sec



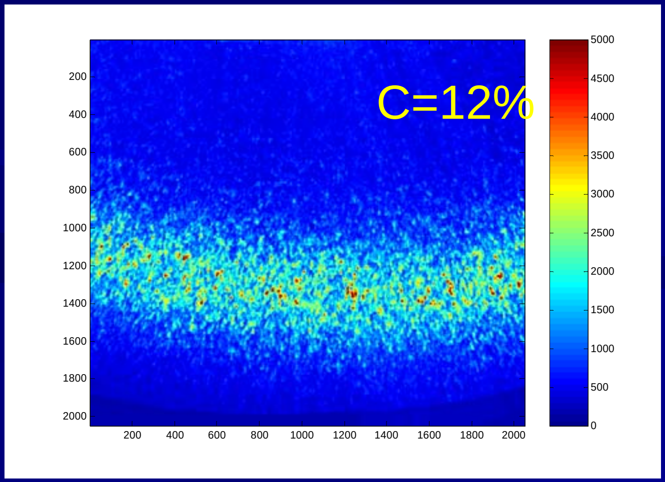
25 μm pinhole 100s



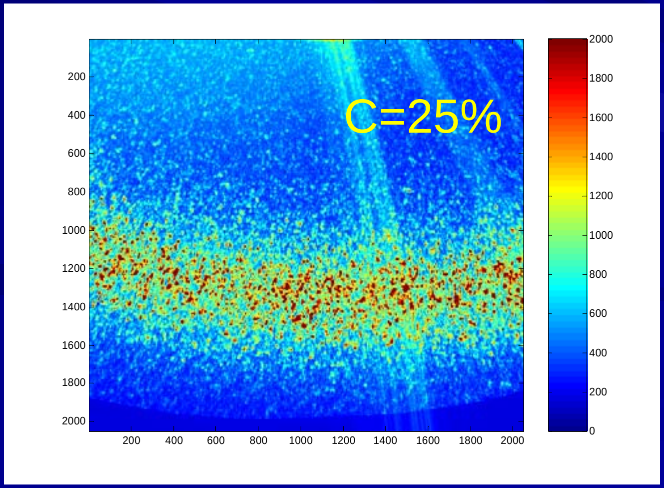
…Dainty law

$$C \propto \frac{1}{\sqrt{N}}$$

5 μm pinhole 100s



3 μm pinhole 300s



Transverse coherence length $\lambda_c \sim 1\mu m$

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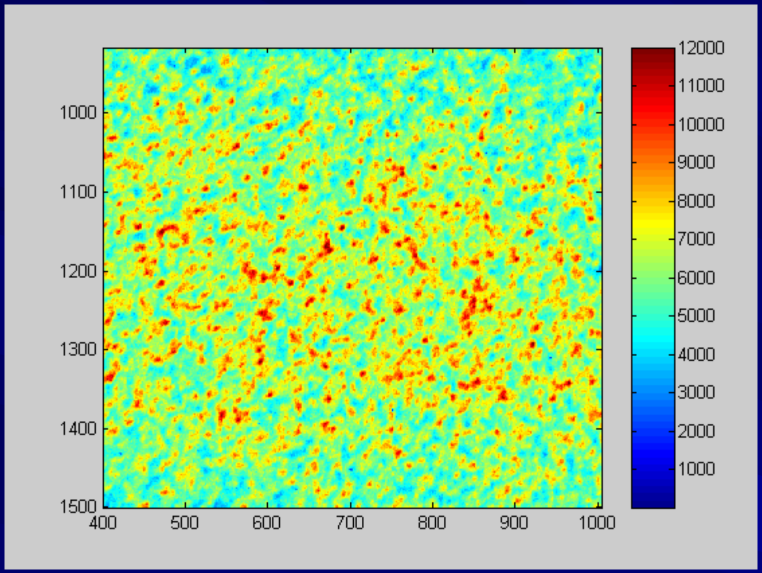
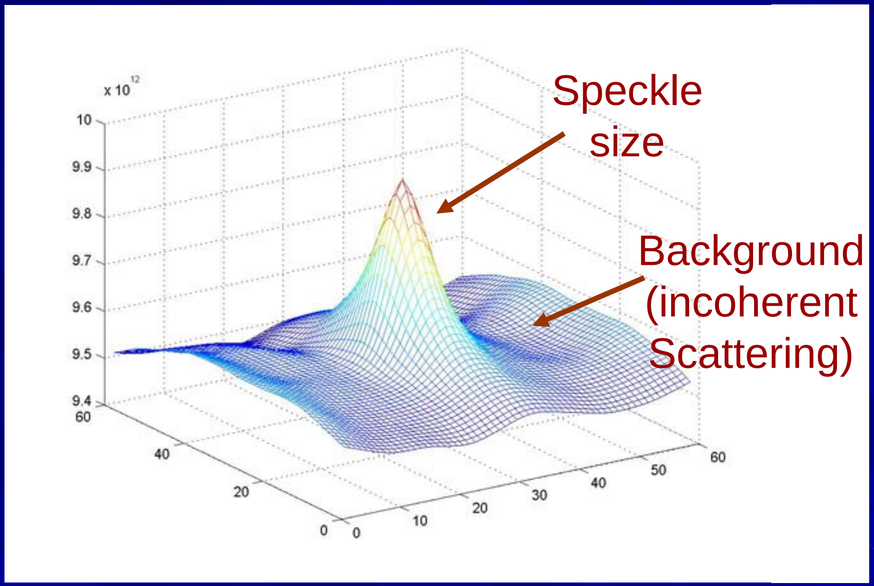
What the Speckle pattern tell us?

Speckle pattern



Autocorrelation pattern



Three Ways to use the speckle

- Static spatial cross correlation (metrology)
- Slow dynamic on spatial correlation
- Fast dynamic time correlation

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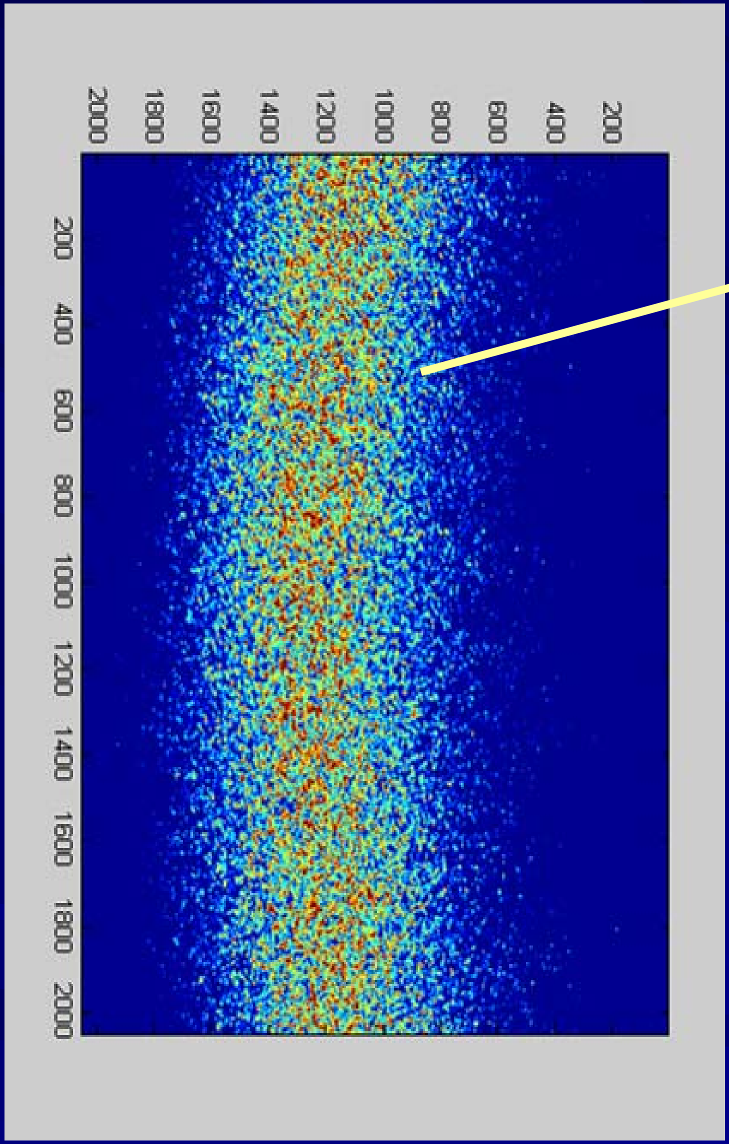
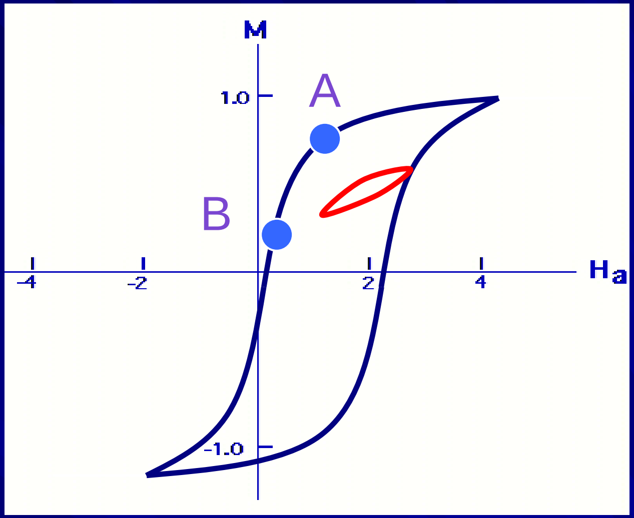
1. Static Speckle metrology



Cross-correlation between two speckles patterns A and B



Correlation coefficient

$$< \rho(A,B) >= \frac{\sum[A \otimes B]}{\sqrt{\sum[A \otimes A]\sum[B \otimes B]}}$$

Magnetic Memory

ρ = 0 no memory
ρ = 1 total memory (exact same pattern)

Pierce et al. PRL **90**, 175502 (2003)

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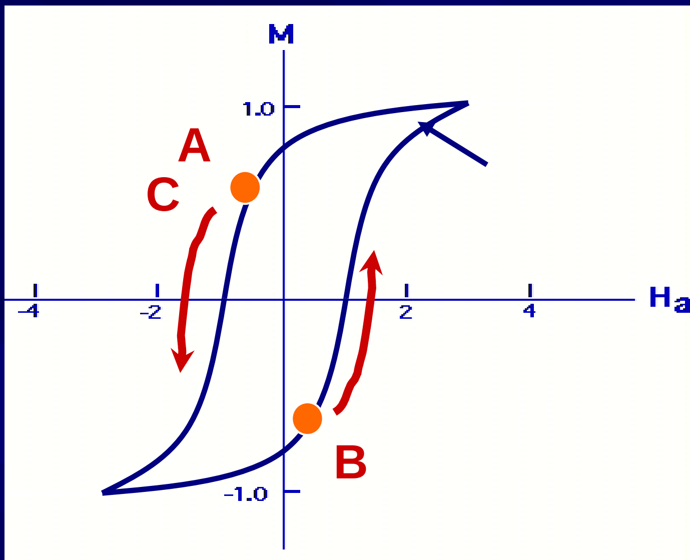
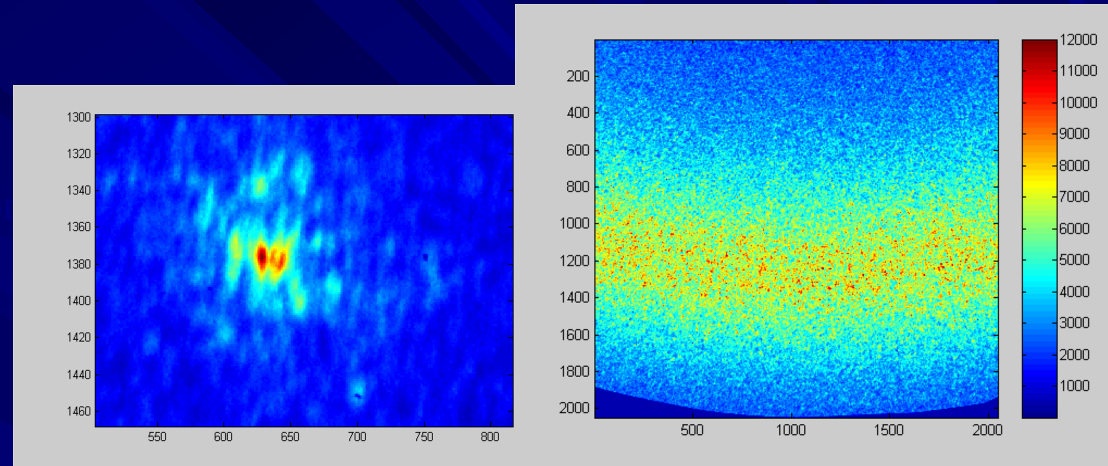
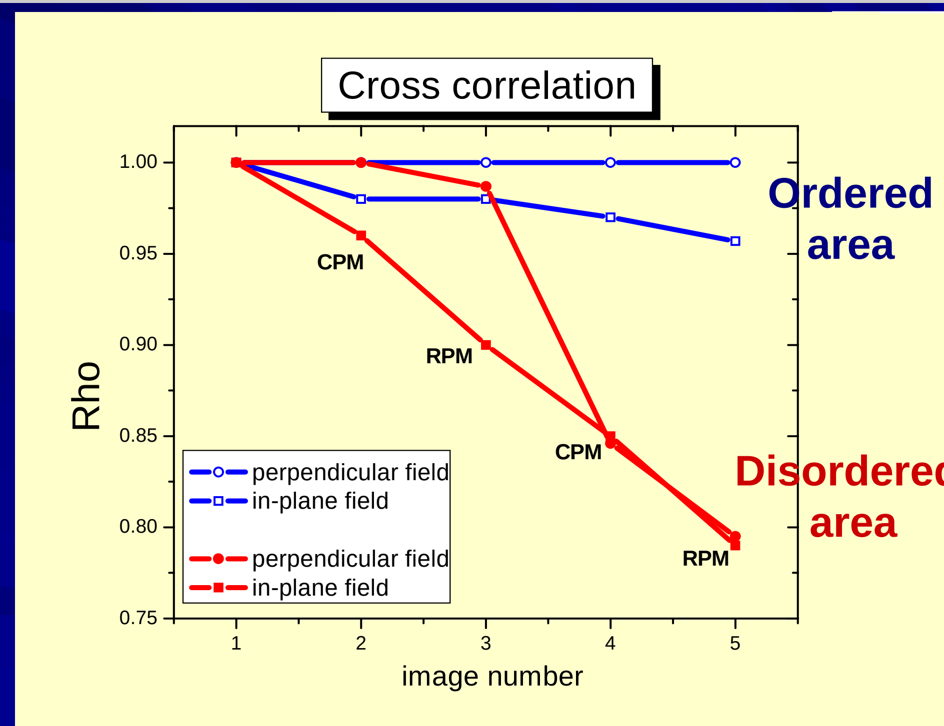
Major Loop Return and Conjugate Point Memory







A Starting point
B Conjugate Point
C Return Point

A x B = CPM
A x C = RPM

VERY HIGH MEMORY !

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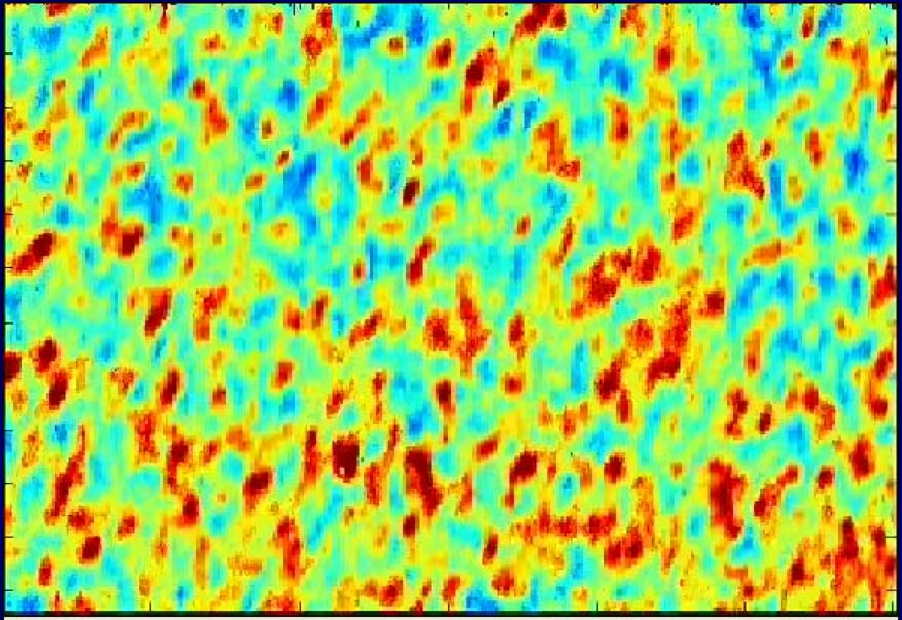
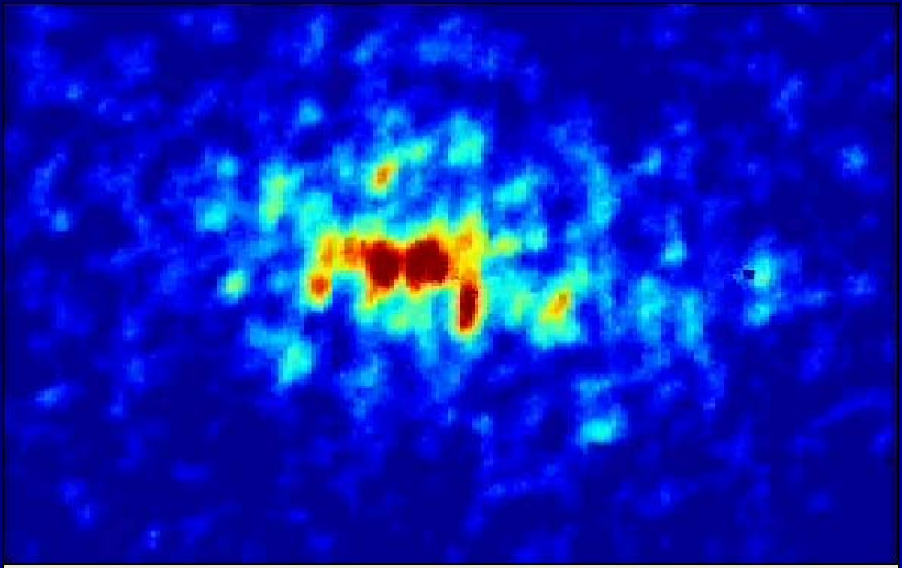
2. Slow dynamic

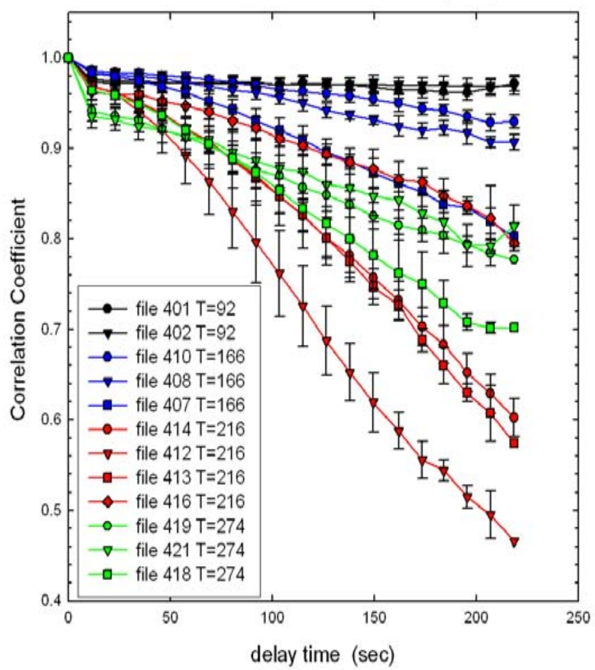


nano1181



nano1240

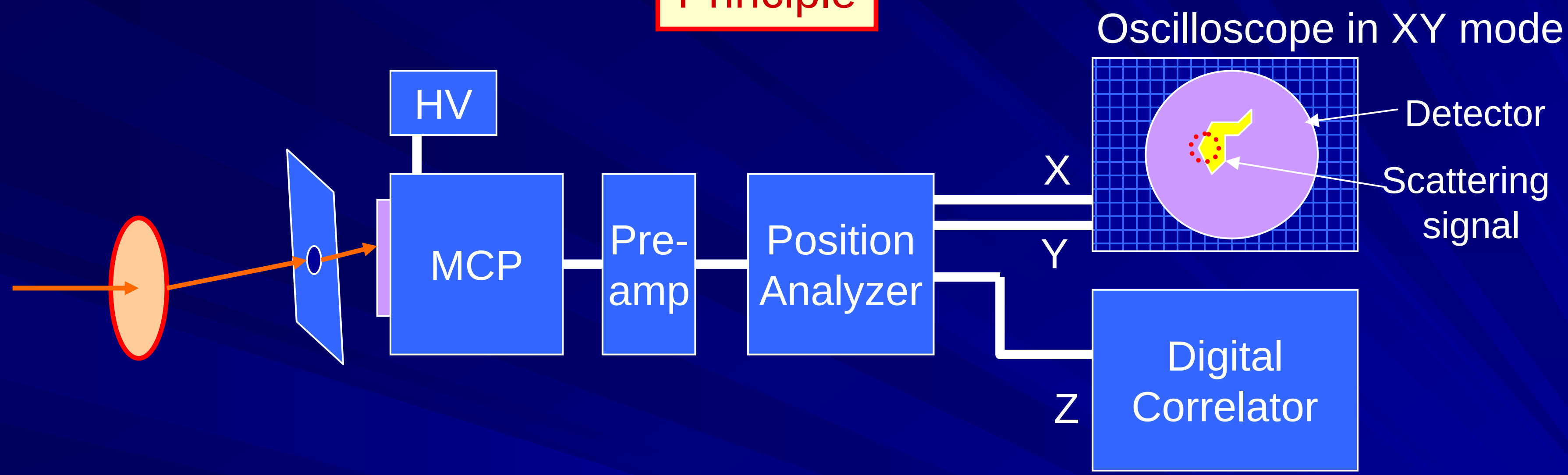
Evolution of the slow dynamic versus temperature



- Speckle correlation decreases with time
- Decay slope depends on temperature

3. Fast dynamic

Principle



Scattering Signal I (t) → Time autocorrelation

$$g(\tau) = \int I(t).I(t-\tau)dt$$

Time scale:

$$1\mu\text{sec} < \tau < 1\text{sec}$$

Price, Sorensen, Kevan et al. PRL **82**, 755 (1999)

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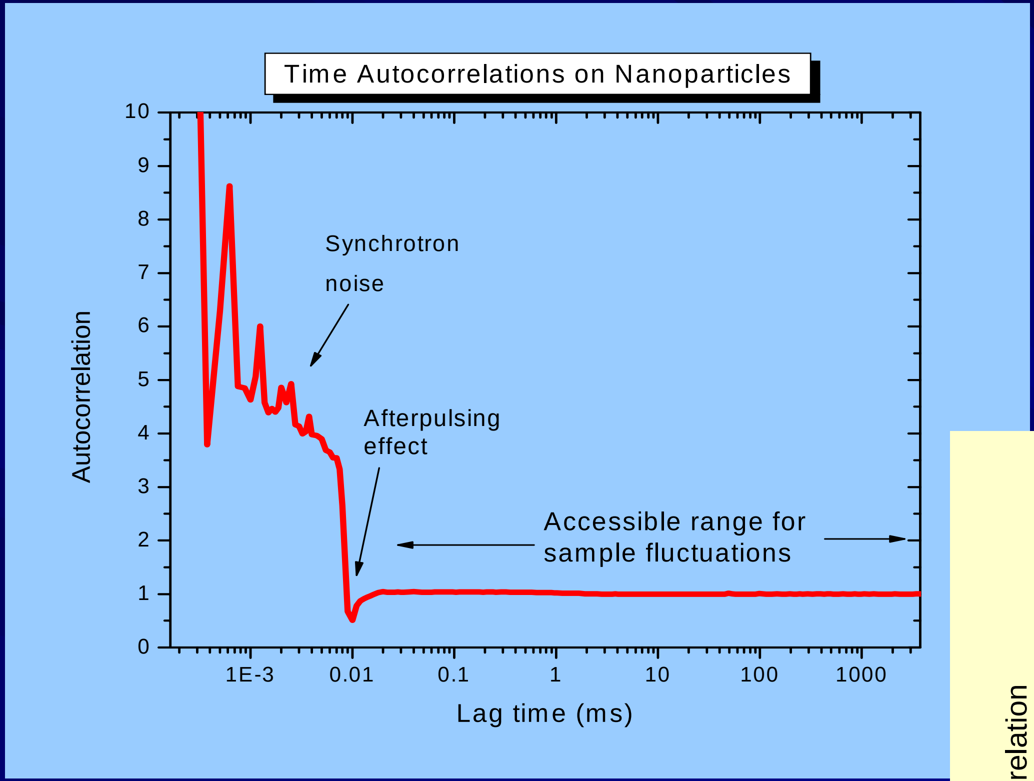
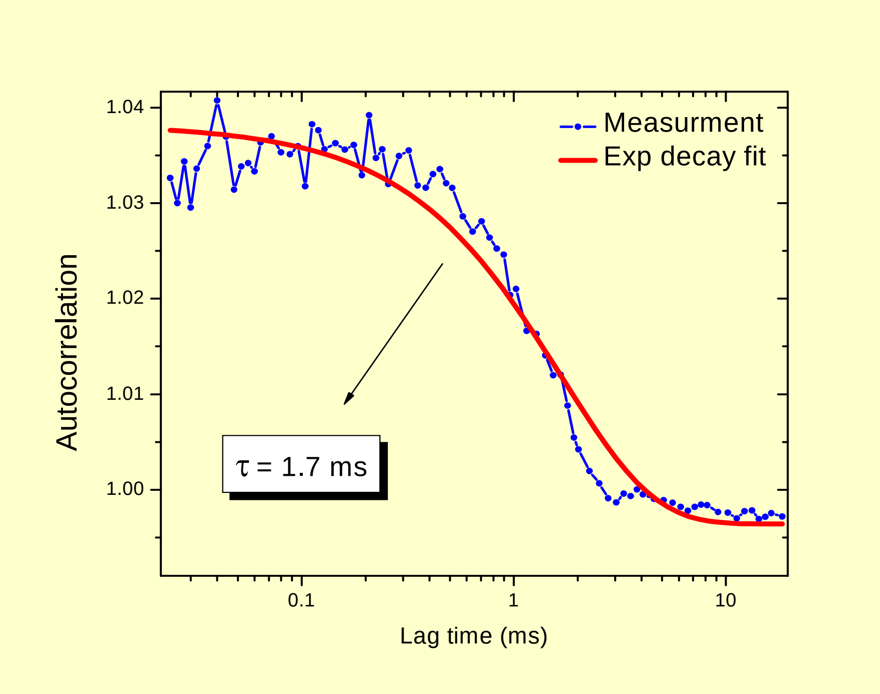
Fast dynamic measurements: First results on Fe3O4 nanoparticles



Fe L3 edge
25 µm pinhole/sample
300 µm hole/detector
Intensity 15 000 cps/sec



- Evolution with T (through blocking transition)
- Effect of magnetic field

Map the dynamic (H,T)

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Conclusion

- New endstation for coherent magnetic scattering now functional at ALS BL12
- First investigations on Co and Fe3O4 nanoparticles with coupled measurements in **incoherent** light (XMCD, SAXS) and **coherent** light (speckle)
- Static speckle study: magnetic memory
- Slow dynamic: time scale > 1sec
- Fast dynamic: time scale 10 μsec – 1sec

General future directions

“Speckle” techniques

- **Speckle Metrology (spatial)**
- **Slow and fast dynamic**
- **Lensless magnetic imaging**

Physics

- **Local magnetic configuration**
- **Magnetic memory**
- **Spatiotemporal fluctuations**
- **(Temperature, field) transitions**

Candidates

- Metallic thin films Co/Pt, FePd, FePt…
- Patterned media
- Nanoparticles
- Exchange bias
- Manganites CMR
- Cuprates superconductivity

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