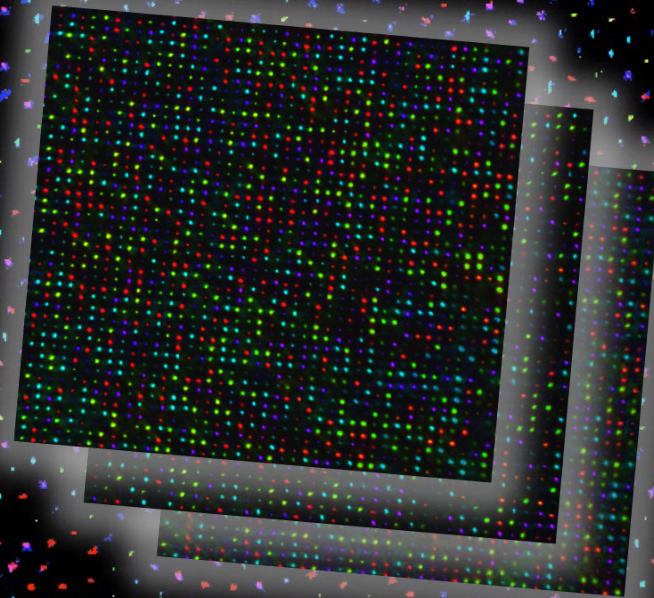


# Laser nanostructuring in glass for long-term and large-scale digital preservation



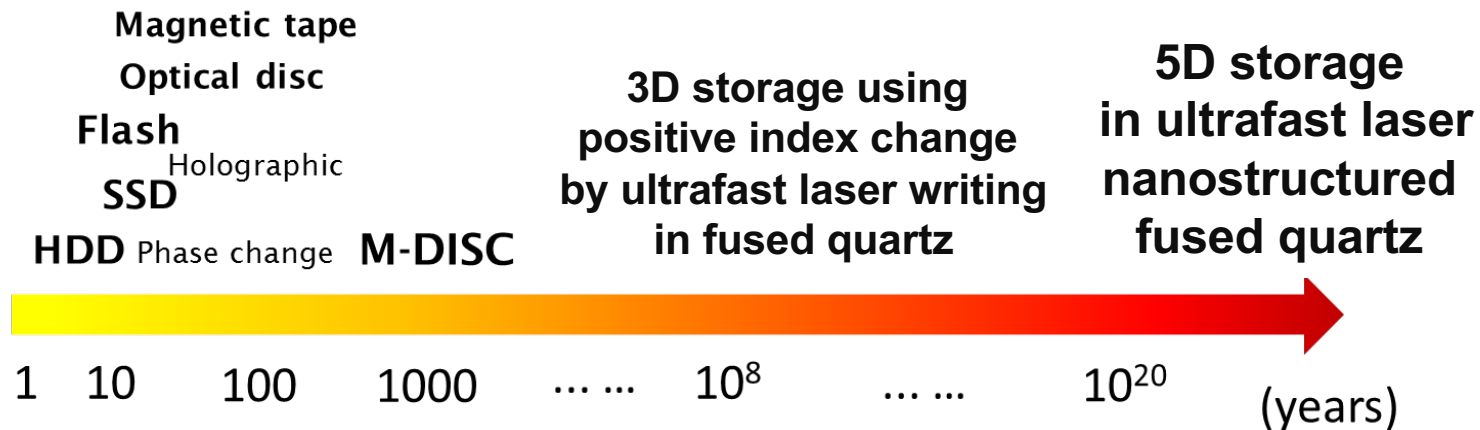
**Peter G. Kazansky**

*Optoelectronics Research Centre, University of Southampton*



# Long-term data preservation

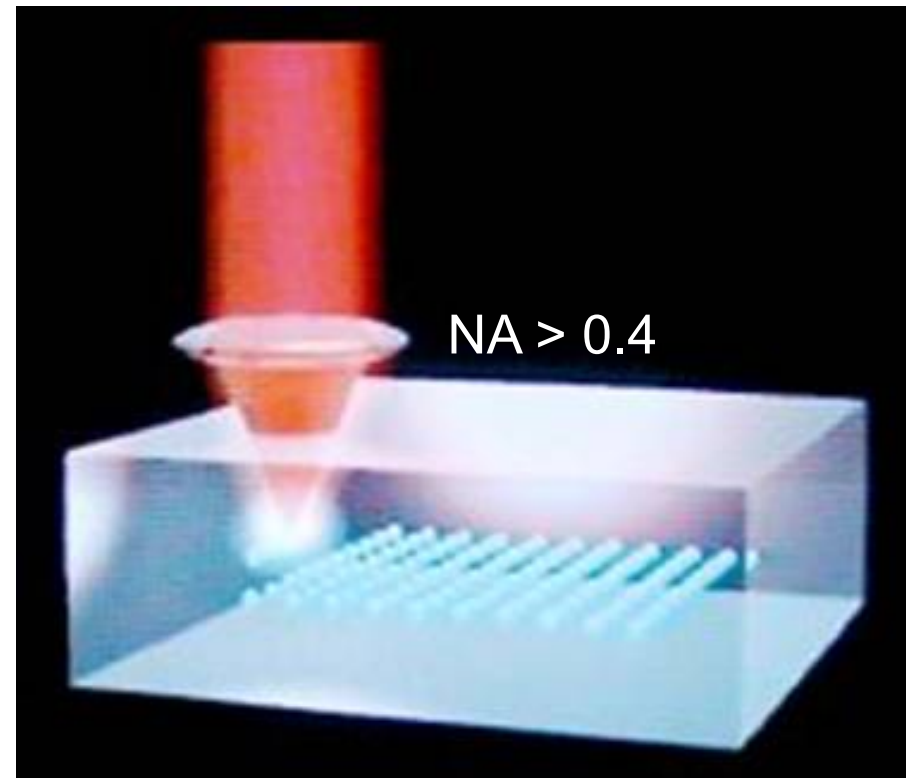
- Nature's choice: DNA (1M years @ -18 °C)
- Current archiving technology: Magnetic tape (20 years)
- Optical based technologies: CD or DVD (10 years)  
M-Disc (1000 years)





# Femtosecond laser direct writing: The principle

- Tight focusing of laser beam (e.g.  $\lambda = 1030 \text{ nm}$ ,  $\Delta\tau = 300 \text{ fs}$ ) into transparent material
- High intensity leading to multi-photon absorption
- Structural changes in matter confined to focal volume due to short pulse duration – 3D



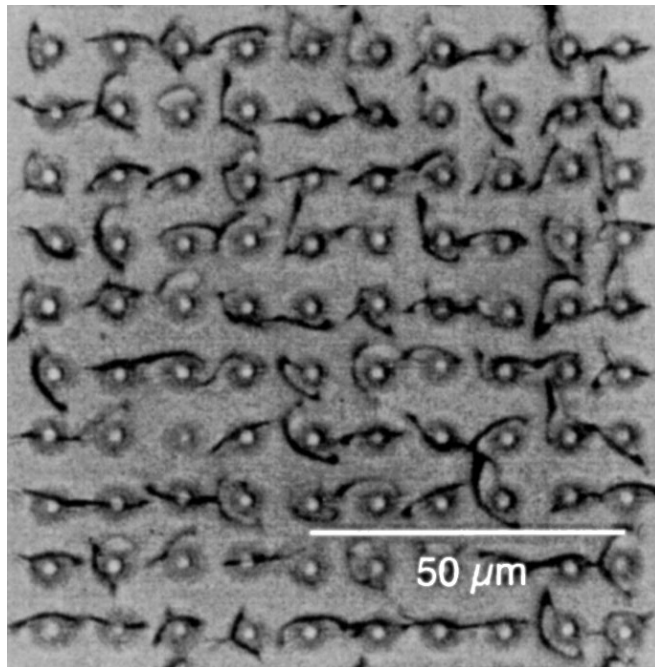
Intensity  $\sim 5 \times 10^{13} \text{ W/cm}^2$

Electron temperature  $\sim 10^5 \text{ K} / 10 \text{ eV}$

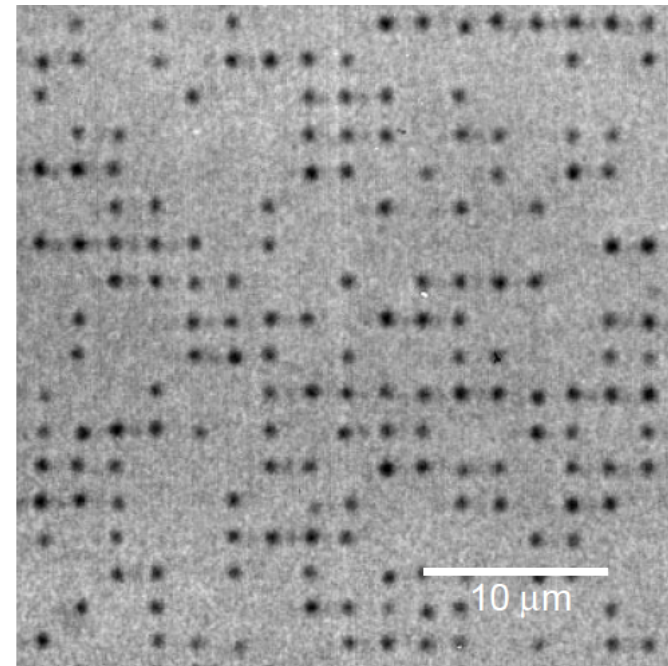
Pressure  $\sim 10^6 \text{ bar}$

# 3D optical storage by femtosecond laser writing

Picosecond ( $10 \times 10^{-12}$  s) laser induces voids *with external stress*

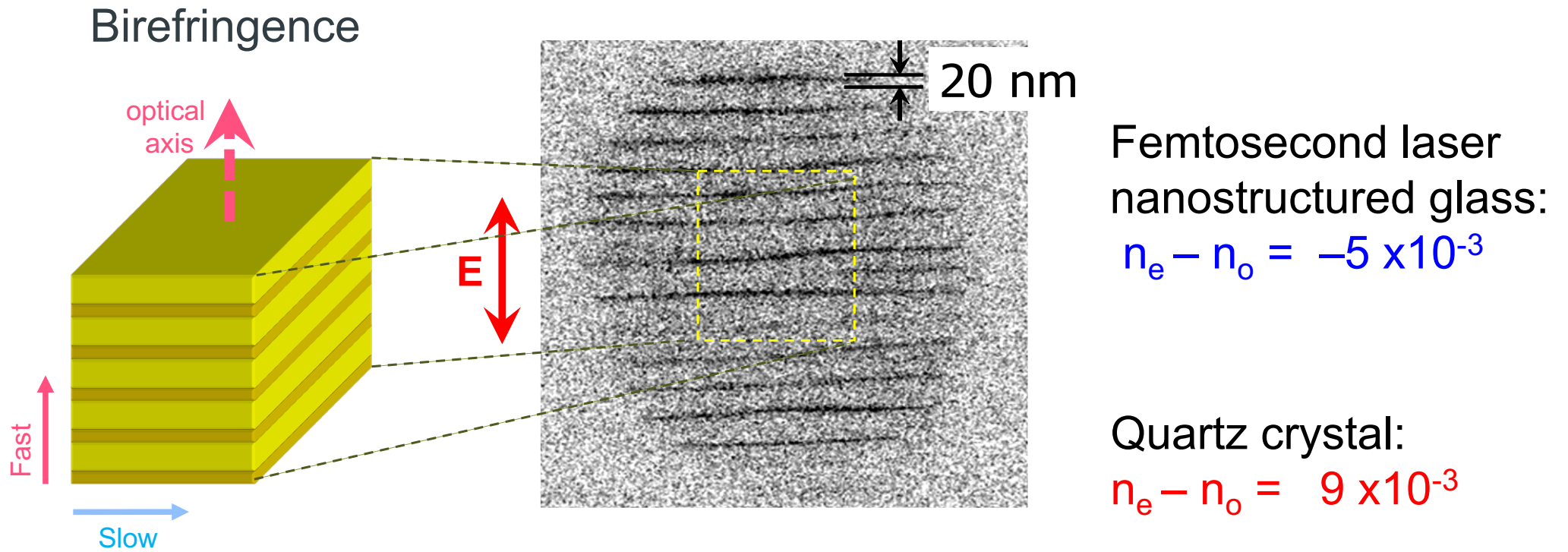


Femtosecond ( $100 \times 10^{-15}$  s) laser induced *small* voids in quartz glass



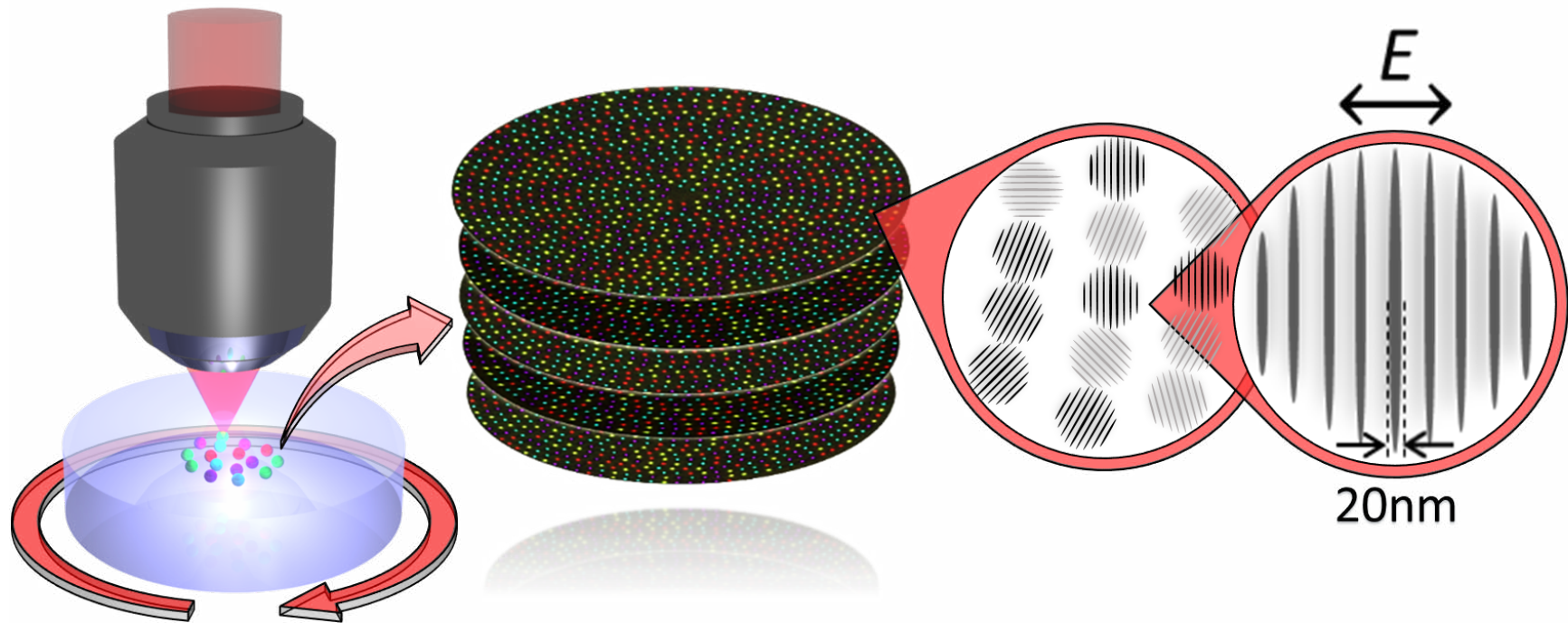
Glezer et al., *Optics Letters* (1996)

# Ultrafast-laser nanostructured (ULN) quartz glass and self-assembled form birefringence



P.G. Kazansky et al., *Phys. Rev. Lett.*, **82**, 2199 (1999)  
Y. Shimotsuma et al., *Phys. Rev. Lett.* **91**, 247405 (2003)

# 5D data storage by ultrafast laser nanostructuring in glass



# How it works?

- ✓ Position: 3 spatial dimensions
- ✓ Retardance =  $f(\text{Intensity}, \text{Number of pulses})$
- ✓ Slow axis =  $f(\text{Polarization})$
- ✓ Ultimate resolutions of slow axis angle  $\sim 5^\circ$  and retardance  $\sim 5$  nm.

## **1 Byte (8 bits) per spot:**

32 states (5 bits) of slow axis orientation  
8 states (3 bits) of retardance

# Comparison

	CD	DVD	Blue-ray	5D
Capacity	0.7 GB	4.7 GB	23.5GB	360TB per disc
Last Long	5 years	7 years	7 years	10 <sup>^</sup> 20 years
Speed	150 kB/s (1x)	1.3 MB/s (1x)	4.5 MB/s (1x)	100 MB/s

Current writing speed: **3 KB/s**

Current capacity: **6 GB per layer**

**50 layers**

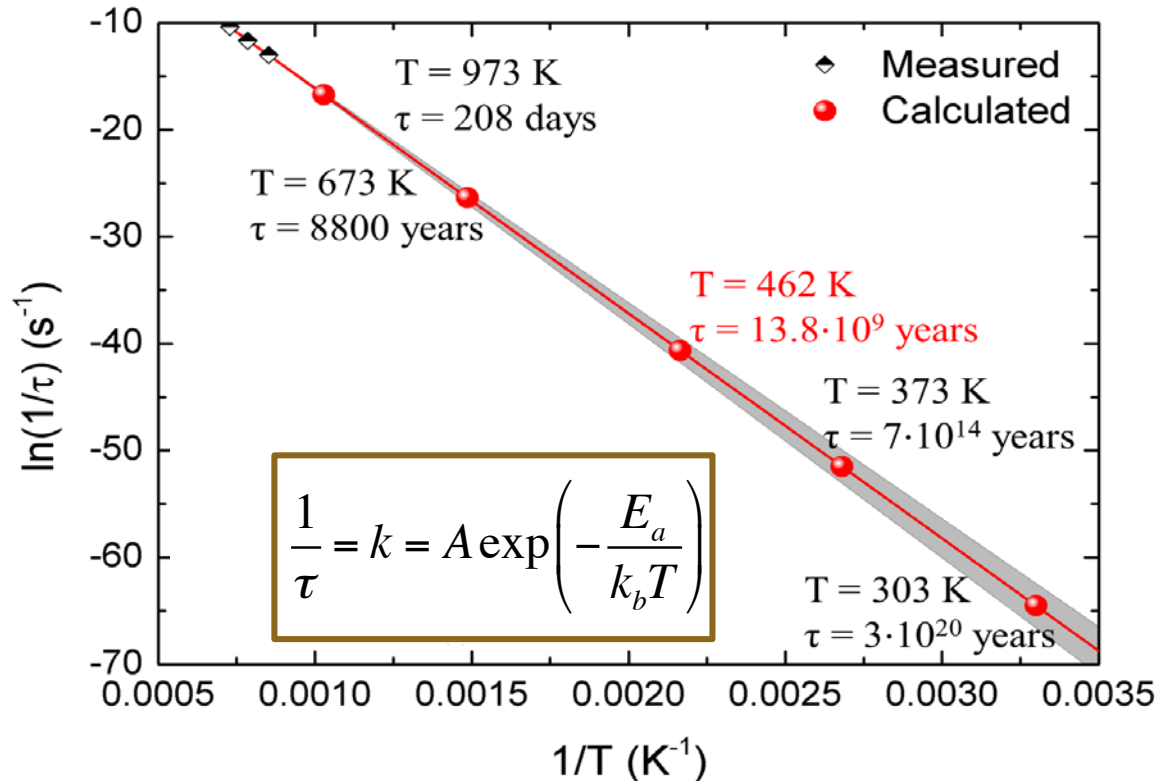
**280 GB/disc**

Advantages of 5D: High capacity

**Long lifetime**



# Thermal stability



$$R(t) = R_0 \times e^{-t/\tau}$$

$$T = 900^\circ \rightarrow \tau = 121 \text{ h}$$

$$T = 1000^\circ \rightarrow \tau = 32 \text{ h}$$

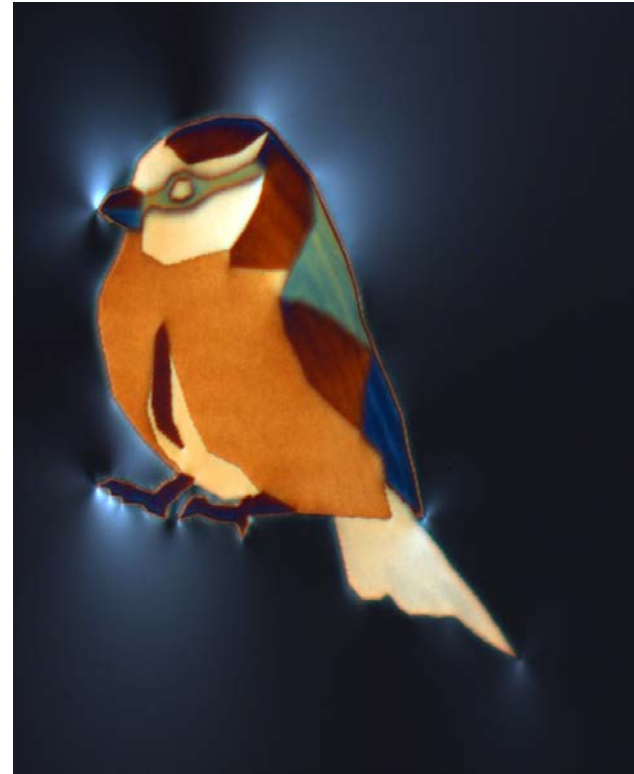
$$T = 1100^\circ \rightarrow \tau = 9 \text{ h}$$

Using the Arrhenius law,  
the lifetime can be extrapolated  
to the room temperature

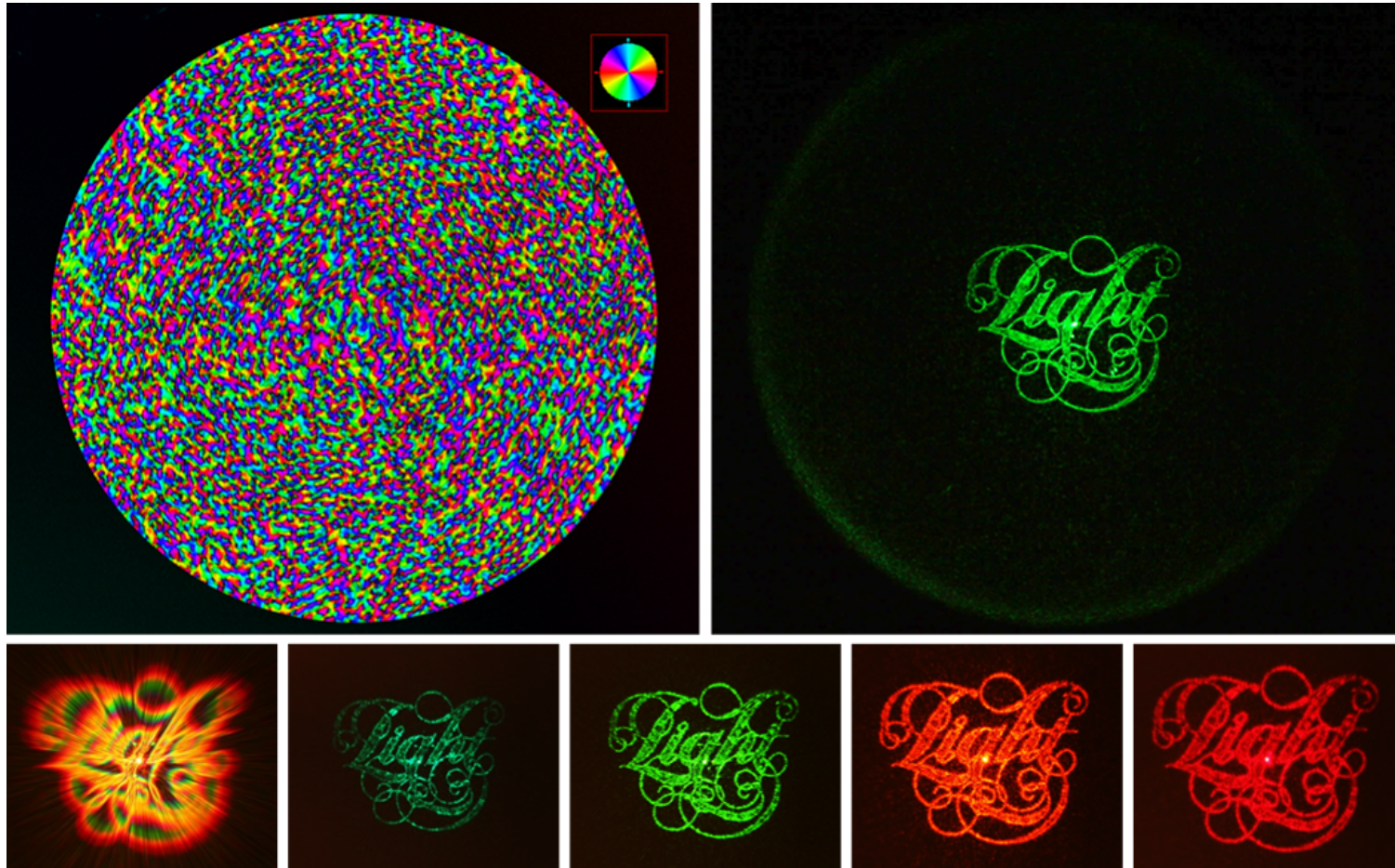
$$T = 30^\circ \rightarrow \tau = 300 \times 10^{18} \text{ years}$$



# Bringing colours to life: Chameleon bird in glass

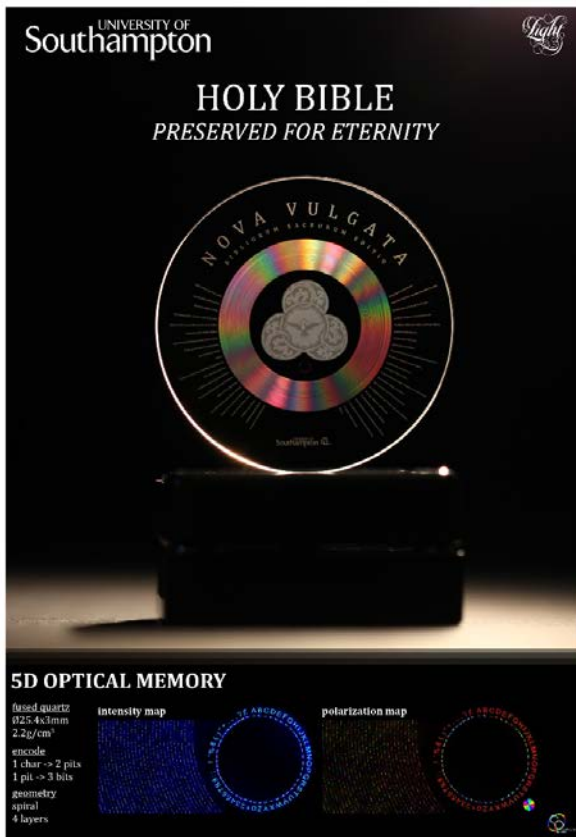


# Geometrical phase hologram in glass





# Eternal copy of Nova Vulgata presented to Vatican library



# artexpo NEW YORK

APRIL 2017 | PIER 94, NYC



UNIVERSITY OF  
**Southampton**

**ULTRAFAST LASER NANOSTRUCTURED GLASS**

**5D optical data**

<p>fused quartz Ø25.4x3mm 2.2g/cm<sup>3</sup></p>	<p>data 3layers in 122,122,120 segments eternal garden.zip &gt; 0-255</p>	<p>encode 1 char -&gt; 2 pits 1 pit -&gt; 4 bits</p>
---	---	--


1 bit  
2 levels of  
intensity

3 bits  
8 states of  
polarization

Prof. Peter G. Kazansky
+44 (0)2380 59 3083
pgk@soton.ac.uk

# Eternal Documents

**ULTRAFAST LASER NANOSTRUCTURED GLASS**



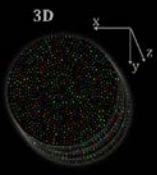


STEPHEN HAWKING  
A BRIEF HISTORY OF TIME

UNIVERSITY OF Southampton

**5D OPTICAL MEMORY**

Coded text 3D 4<sup>th</sup>D Slow axis angle 5<sup>th</sup>D Retardance


4 layers  
Ø3mm  
in Ø25.4mm  
fused silica  
glass

UNIVERSITY OF Southampton

United Nations Educational, Scientific and Cultural Organization INTERNATIONAL YEAR OF LIGHT 2015

TO COMMEMORATE THE FIRST EDITION OF NEWTON'S OPTICKS




INTERNATIONAL YEAR OF LIGHT 2015  
NEWTON'S OPTICKS

**5D OPTICAL MEMORY**

Coded text 3D 4<sup>th</sup>D Slow axis angle 5<sup>th</sup>D Retardance


8 layers  
Ø 1.4mm  
in Ø25.4mm  
fused silica  
glass  
Az = 15µm  
200GB/cm<sup>3</sup>





UNIVERSITY OF Southampton

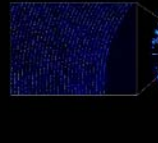
**THE CONSTITUTION OF THE UNITED STATES PRESERVED FOR ETERNITY**



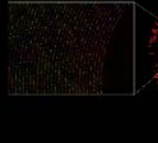
**5D optical data**

fused quartz  
Ø25.4x3mm  
2.2g/cm<sup>3</sup>  
encode  
1 char -> 2 pits  
1 pit -> 3 bits  
geometry  
spiral  
4 layers

1-bit: 2 levels of intensity



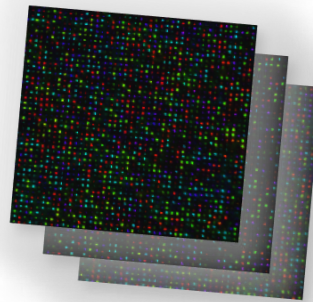
2-bit: 4 states of polarization





# Conclusions

- Digital preservation with practically unlimited lifetime is possible by ultrafast laser nanostructuring in glass.
- Research towards increase of write and read speed is in progress.





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