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GALILEO,
THE TELESCOPE, THE MICROSCOPE, THE BEES AND THE BARBERINIS

Claudio Pellegrini

Department of Physics and Astronomy

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Two new great instruments will start operation in the next two years: LCLS and LHC.

LCLS is the ultimate microscope to study matter at the atomic and molecular level.

LHC will explore the subnuclear structure of matter at the TeV level.

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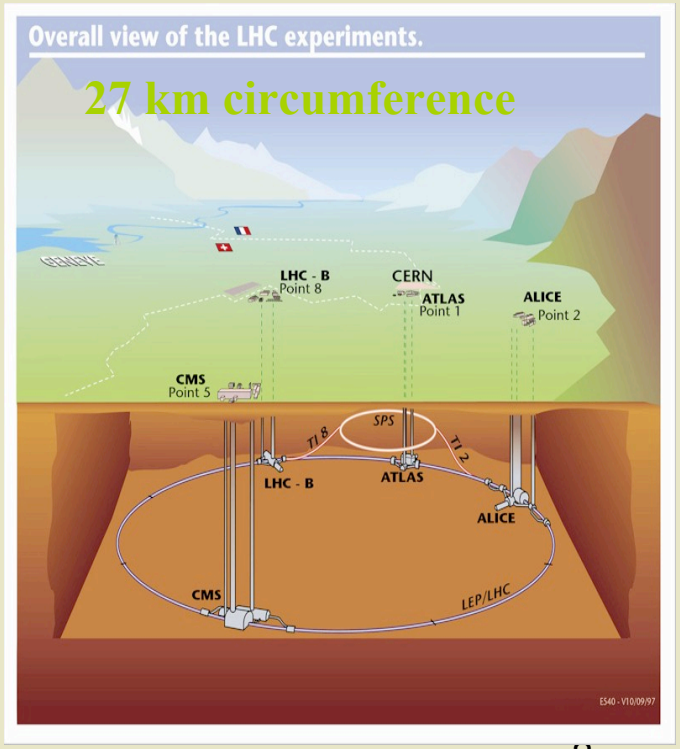

Large Hadron Collider

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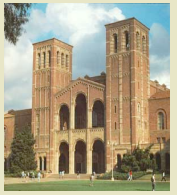
LHC will explore the structure of subnuclear particles, – hadrons, leptons and quarks– on the length scale of 10^{-19} m, and the time scale of 10^{-26} s.

Parts of the CMS -Compact Muon Solenoid- detector arriving at CERN, where it will used on LHC.

GOING BEYOND THE STANDARD MODEL:

HIGGS,SUPERSYMMETRY, … ?



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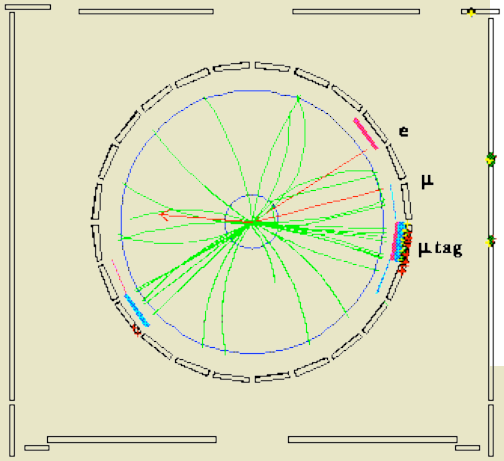
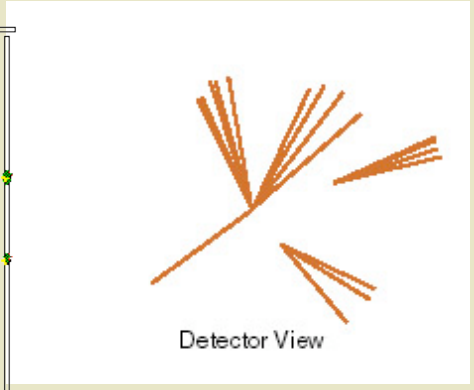
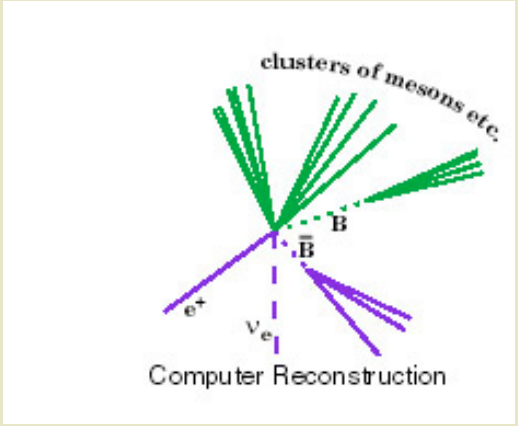
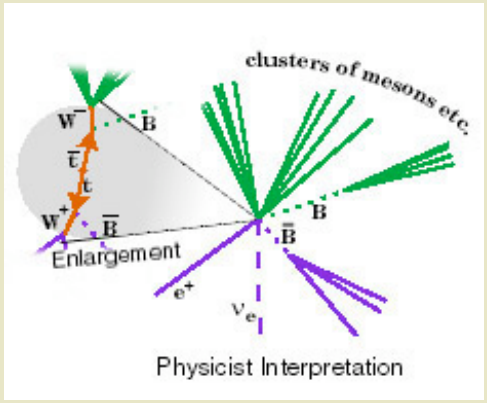
First Observation of the Top quark



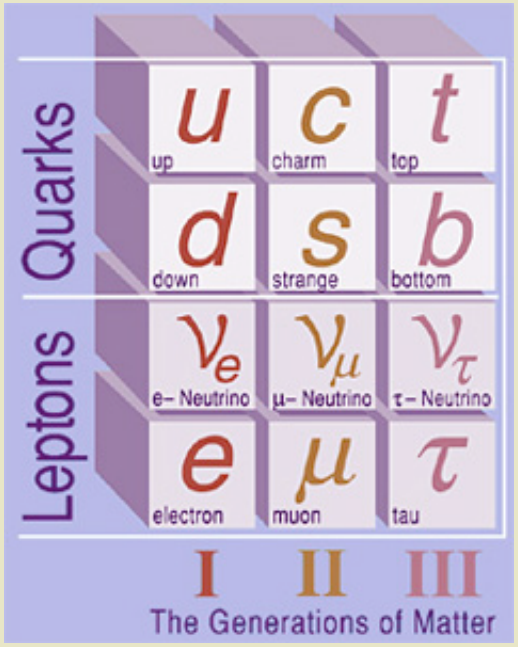


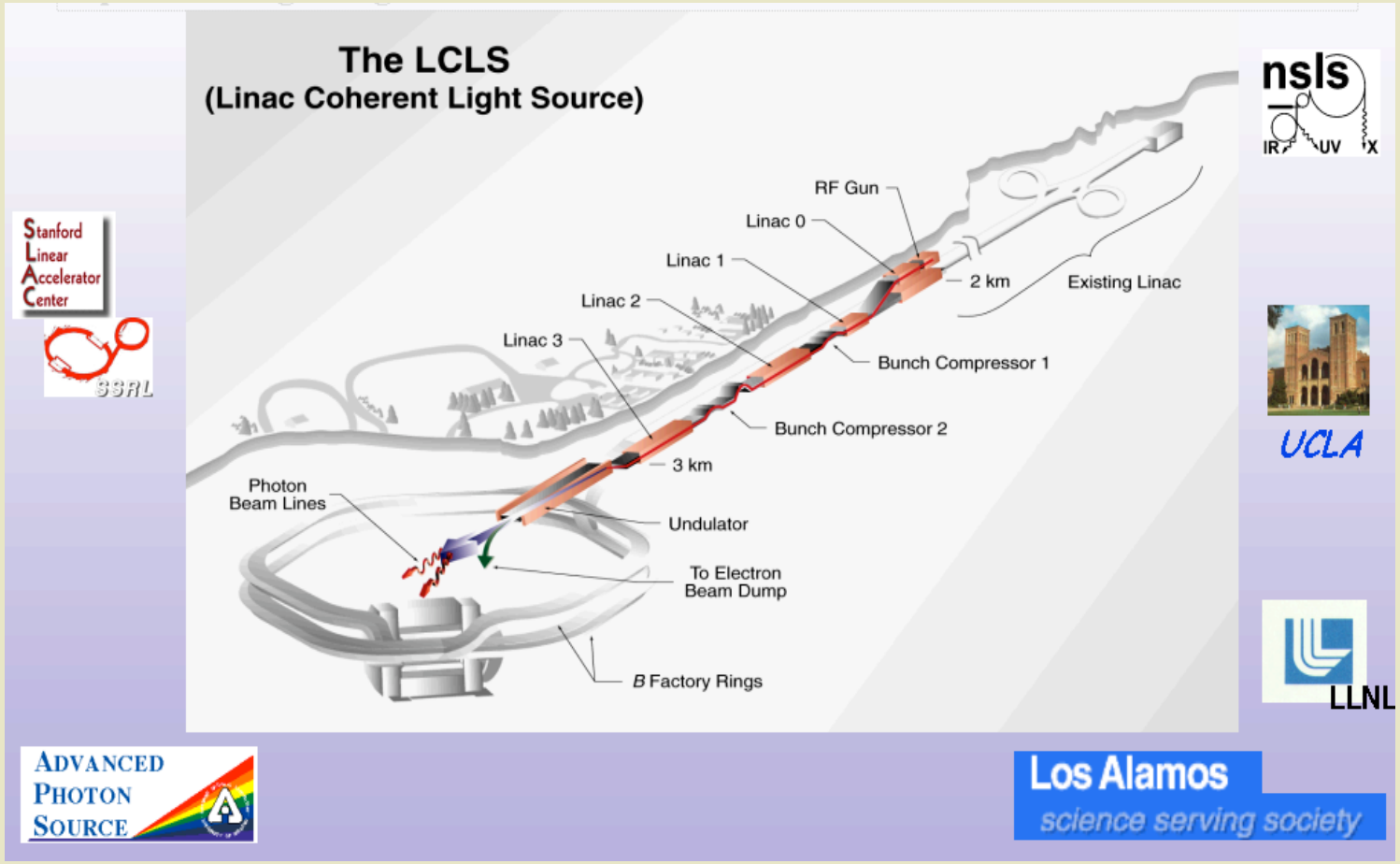




THE STANDARD MODEL OF ELEMENTARY PARTICLE: A WONDERFUL ACHIEVEMENT!

BUT WE WANT MORE …





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LCLS is an X-ray Free-electron Laser operating at a wavelength of 1.5 to 15 Å. It is driven by a 14 GeV, one km long linac. The electron beam produces the X-rays in an undulator magnet 130 m long.

LCLS photon Pulse Main Characteristics

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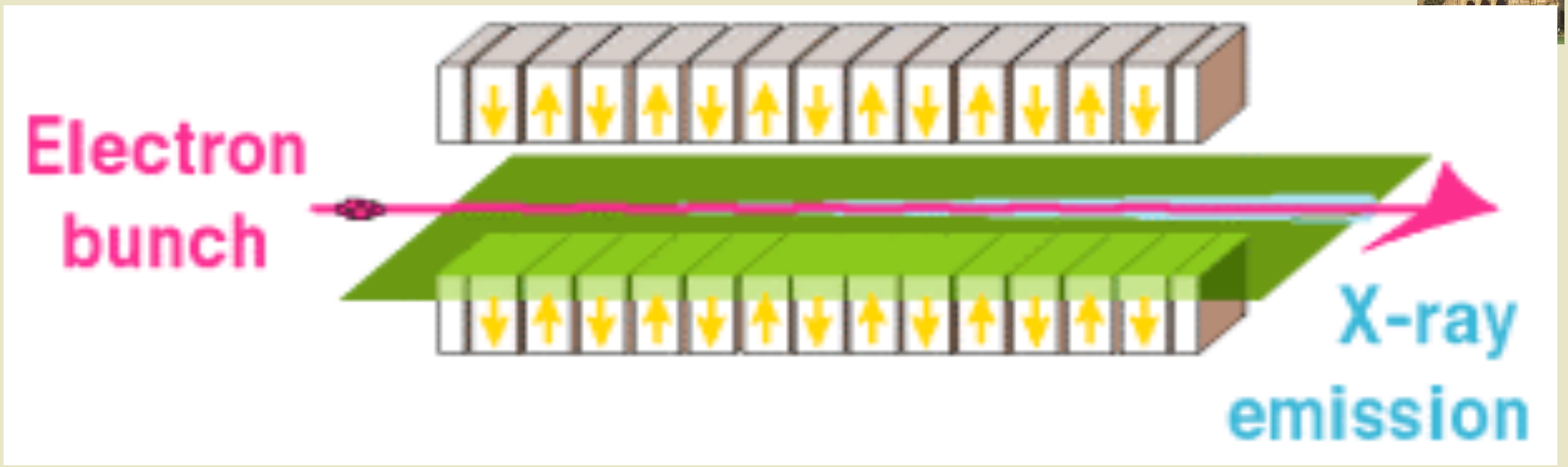
Peak power, about 10 Gigawatt or more

- Pulse length, about 100 to about 1 femtosecond
- Transversely coherent, diffraction limited
- Line width < 0.001
- Tunable from 15 to 1.5Å

The X-ray FEL is a powerful tool to explore matter and give new contributions to science.

X-ray FELs similar to LCLS are being developed in Japan and Europe. Two FELs, in the few nm to 100 nm wavelength, are being developed in Italy at Trieste, Fermi, and Tor Vergata, SparcX.

FEL Physics



An electron beam, moving through an undulator magnet, executes an oscillation transverse to the direction of propagation. Each electron radiates an electromagnetic field. The radiation acts on other electrons, establishing a collective interaction. Under proper conditions, the interaction produces a transition of the beam to a novel states, in which the electron distribution consists of micro-bunches separated by the radiation wavelength, and the radiation emitted is coherent and has large intensity.

FEL Physics

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The radiation wavelength is proportional to magnet period. A relativistic effect reduces the wavelength from that of the magnet period to a value inversely proportional to the square of the electron energy.

For a magnet period of a few centimeters and an electron energy of about 10 to 15 GeV the wavelength is 1 Å, the Bohr radius.

Why this expensive way to produce X-rays, when electrons with an energy of a few tens of keV , hitting a piece of metal can do it?

One reason is that the radiation emitted from a relativistic electron is peaked in the forward radiation, $\theta \sim mc^2/E \sim 30 \times 10^{-6}$ rad.

The second is that the spectrum is not the continuous bremsstrahlung spectrum, but is peaked, and almost monochromatic.

What you get for the price is laser-like radiation.

FEL PHYSICS: RADIATION FROM ONE ELECTRON

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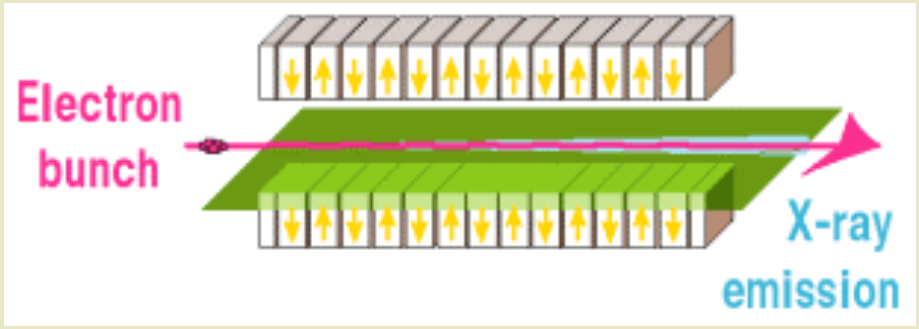
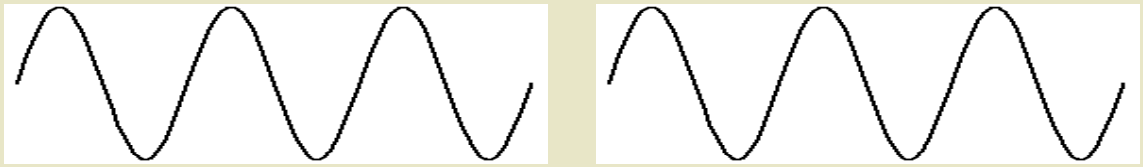


UNDULATOR WITH N_w PERIODS.

$K=eB_w \lambda_w / 2\pi mc^2$



$N_w \lambda$

EACH ELECTRON, OF ENERGY $E=mc^2\gamma$, EMITS A WAVE TRAIN WITH N_w WAVES

$\lambda=\lambda_w(1+K^2/2+\gamma^2\theta^2)/2\gamma^2$

$\Delta\lambda/\lambda=1/N_w$

θ IS THE EMISSION ANGLE, $\theta\sim 1/\gamma$

FOR $\gamma=3\,10^4$, $\lambda_w=3$ CM, $K=3$, $N_w\sim 3300$:
$\lambda\sim 0.1$ nm, $\Delta\lambda/\lambda\sim 3\,10^{-4}$, $N_w\lambda\sim 0.3$ μm,
$\theta\sim 30\,\mu$RAD.

A PICTURE OF THE SUPERPOSITION OF THE WAVE TRAINS EMITTED BY MANY ELECTRONS

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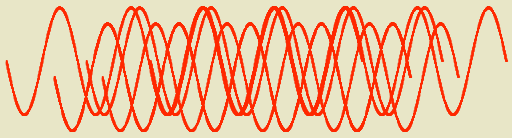
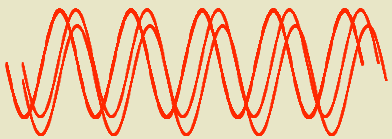
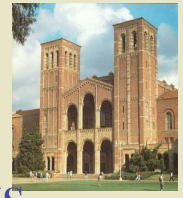


Spontaneous radiation, due to noise in the initial state electron distribution -a disordered state-
Intensity ~ N_e



SASE leads to an ordered final state, with the waves from each electron superimposed in phase-
Intensity ~ N_e^{α}, $4/3<\alpha<2$.

SASE: A BEAM SELF-ORGANIZATION EFFECT.



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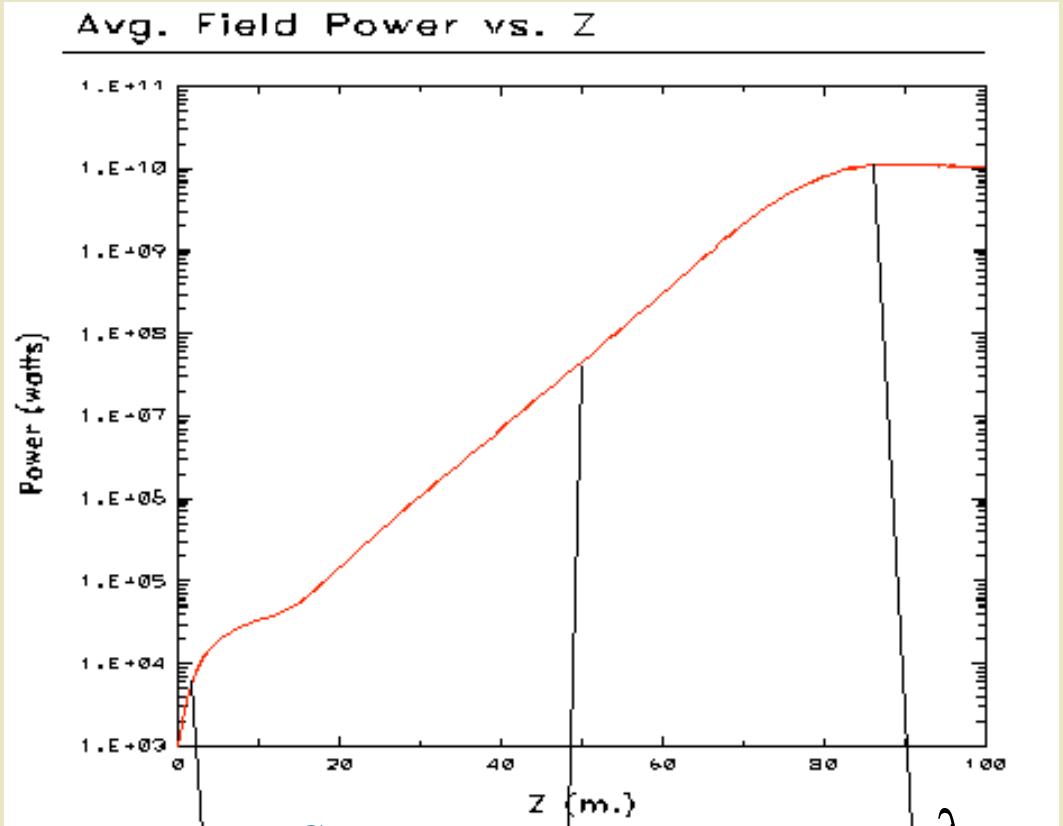
POWER GROWTH IN THE UNDULATOR FROM SPONTANEOUS RADIATION TO FEL AMPLIFIED RADIATION.

IN THE INITIAL STATE THE ELECTRONS HAVE A RANDOM LONGITUDINAL POSITION.

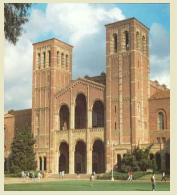
THE WAVE TRAIN FROM THE ELECTRONS SUPERIMPOSE WITH RANDOM PHASE (SPONTANEOUS RADIATION).

THE INTERACTION PRODUCES AN ORDERED DISTRIBUTION IN THE BEAM, SIMILAR TO A 1-D CRYSTAL.



LCLS: an X-ray laser for physicist, biologist, ...

X-Rays have opened the Ultra-Small World
X-FELs open the Ultra-Small and Ultra-Fast Worlds



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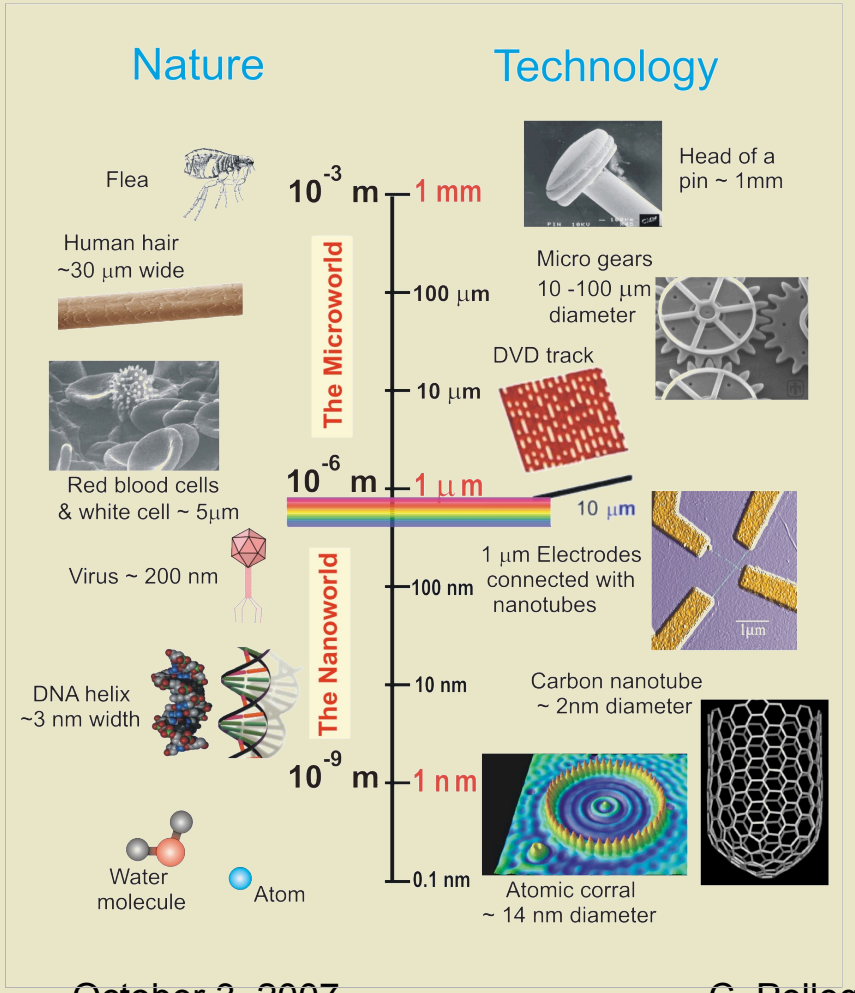
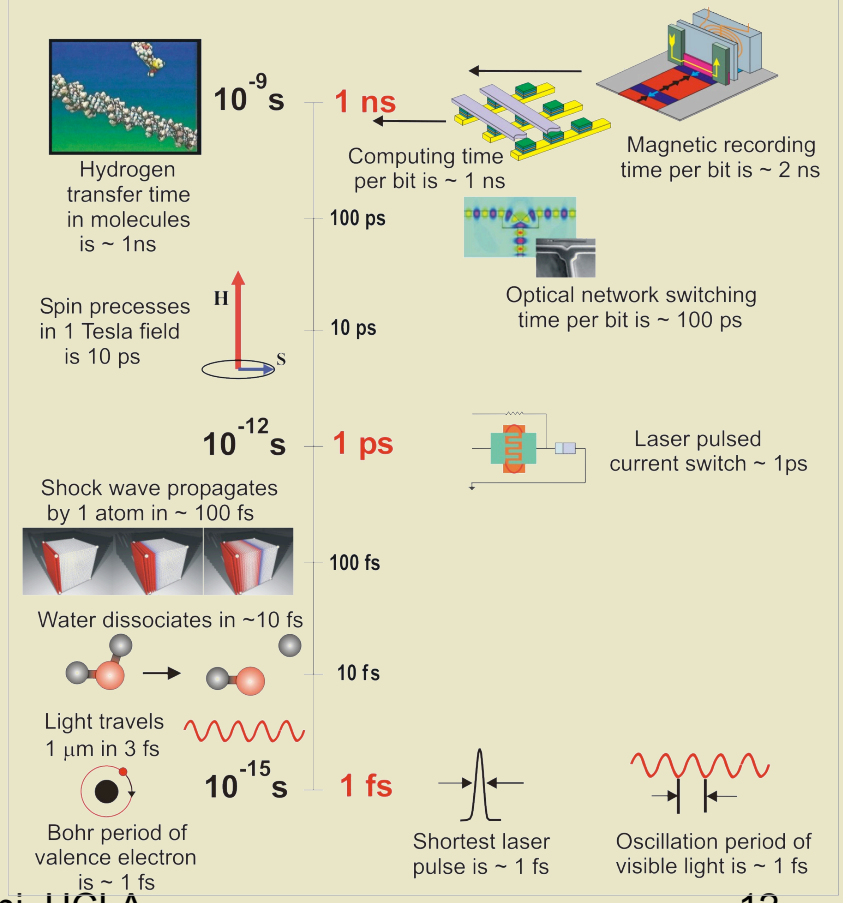
Ultra-Small



Ultra-Fast



LCLS Initial experimental program

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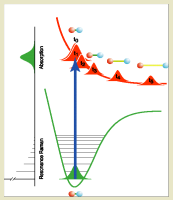
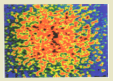
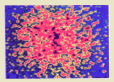
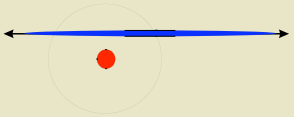
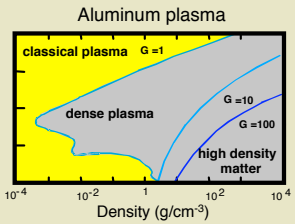
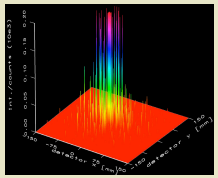












Program developed by international team of ~45 scientists working with Accelerator and Laser Physics communities

Femtochemistry

Nanoscale Dynamics in Condensed Matter

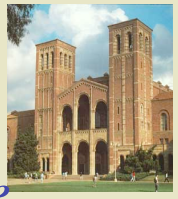
Atomic Physics

Plasma and Warm Dense Matter

Structural Studies on Single Particles and Biomolecules

Courtesy J. Hastings

To see atomic motion in chemical reactions,physical and biological processes, we need to shorten the wavelength of light from the visible to X-rays, 10^4 times, and the time scale from a fraction of a second to the femtosecond, 10^{14} times.



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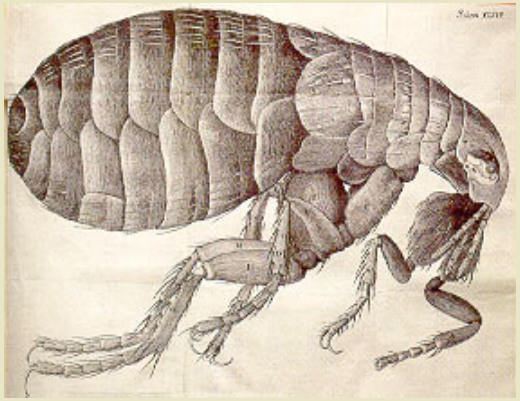
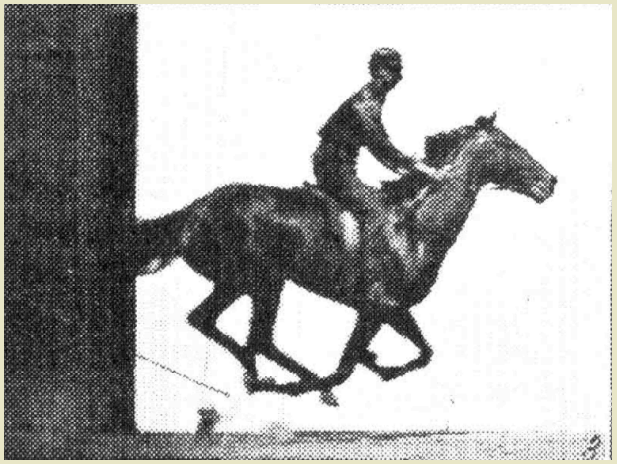


THE FLEA SEEN WITH A MICROSCOPE, R. HOOKE 1665



MUYBRIDGE'S "ULTRAFAST" MOVIE

SPARK PHOTOGRAPHY, STANFORD UNIVERSITY, 1878

Single molecule (nanocrystal, biomolecule) imaging has been proposed using short-pulse x-ray FELs

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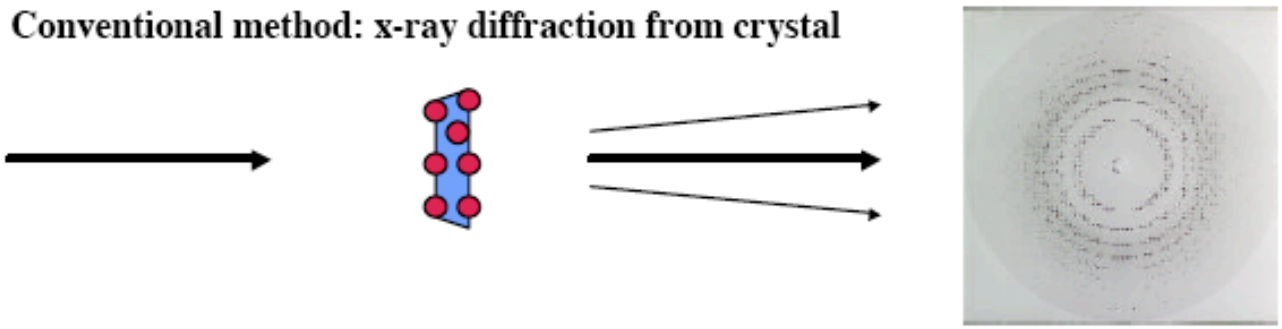
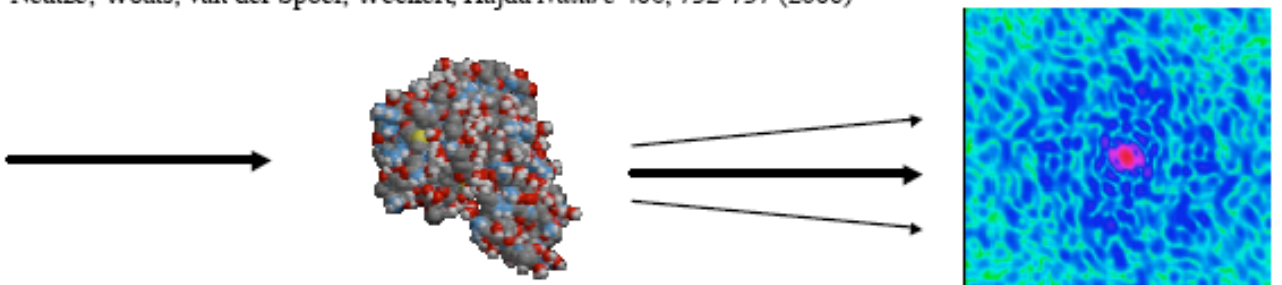
Conventional method: x-ray diffraction from crystal



Proposed method: diffuse x-ray scattering from single protein molecule

Neutze, Wouts, van der Spoel, Weckert, Hajdu *Nature* 406, 752-757 (2000)



Lysozyme

Calculated scattering pattern from lysozyme molecule

Implementation limited by radiation damage:

In **crystals** limit to damage tolerance is about **200 x-ray photons/Å^2**

For **single protein molecules** need about **10^{10} x-ray photons/Å^2** (for 2Å resolution)

TAKING A PICTURE OF A SINGLE COMPLEX BIOLOGICAL MOLECULE IN A FEW FEMTOSECOND.

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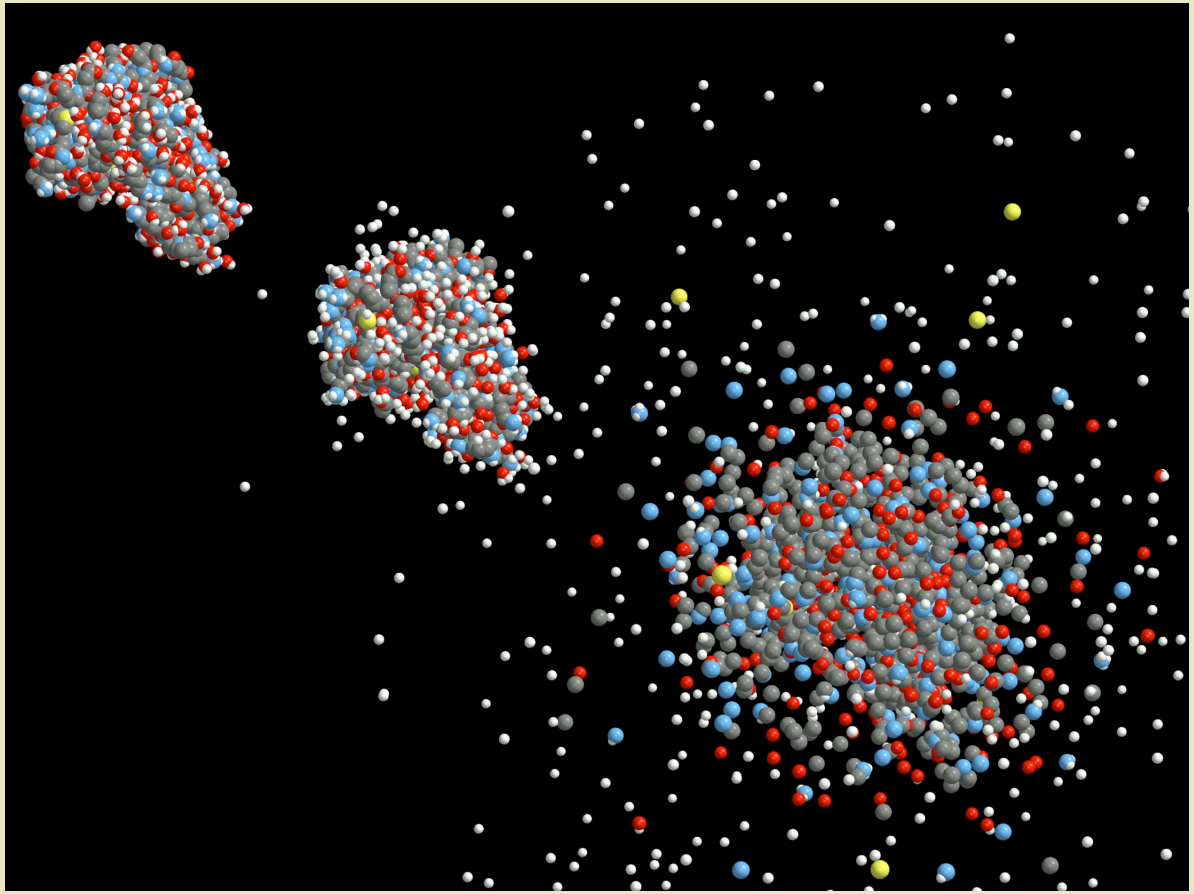
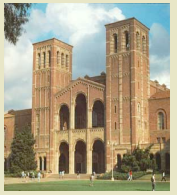


Courtesy LCLS and J. Haidu, Lund University

Ultrafast Coherent Diffractive Imaging at FLASH,

H.N. Chapman et al., Nature Physics 2, 839 (2006).



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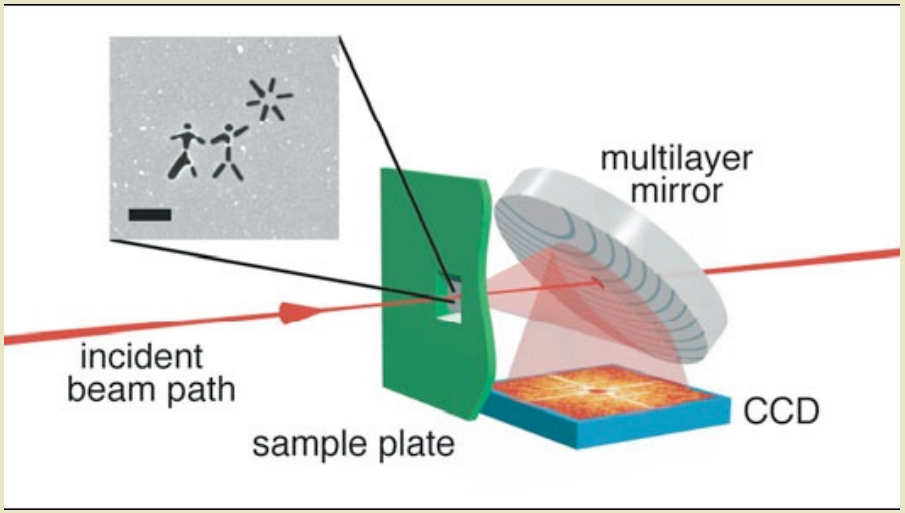

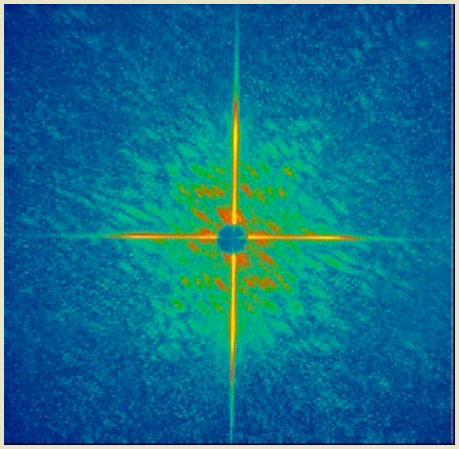

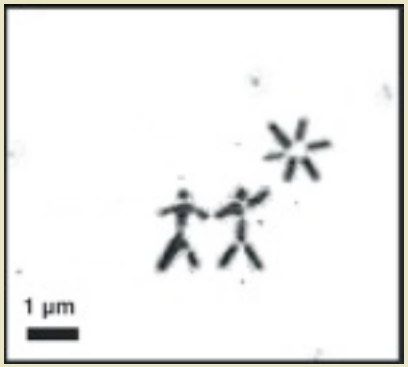

Coherent diffraction pattern recorded from a single 25 fs pulse, and the Reconstructed X-ray image, which shows no evidence of the damage caused by the pulse.

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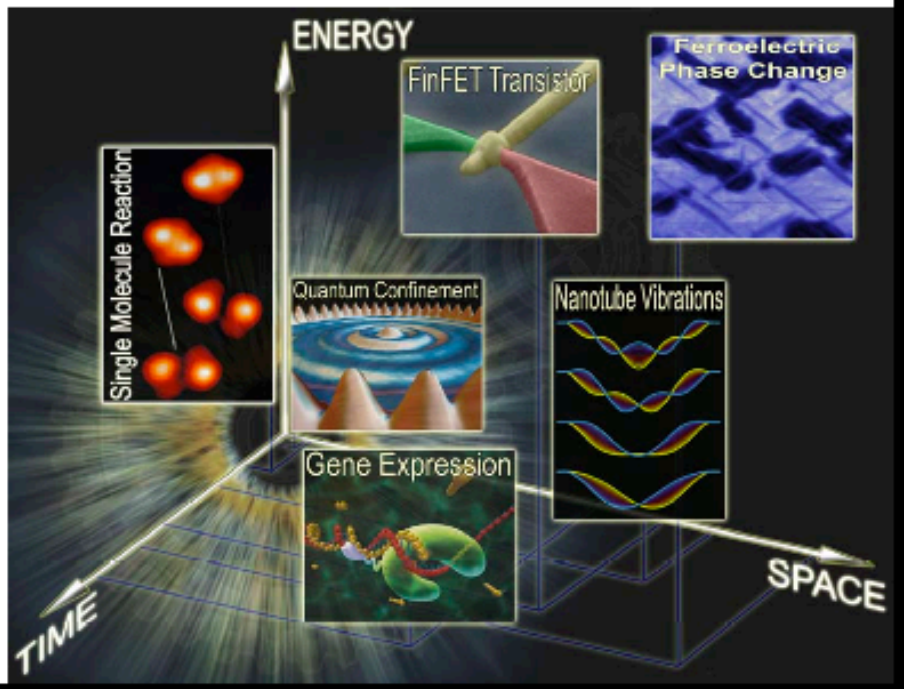
Overall Challenge: *Making the Leap from Observation Science to Control Science*

The things we want to do (i.e. designing materials to have the properties we want & directing synthesis to achieve them) require the ability to see functionality at the relevant time, length & energy scales.

We will need to develop & disseminate new tools capable of viewing the inner workings of matter—transport, fields reactivity, excitations & motion

This new generation of instruments will naturally lead to devices capable of directing matter at the level of electrons, atoms, or molecules.



Next Generation of Instruments for Future single-molecule dynamic measurements

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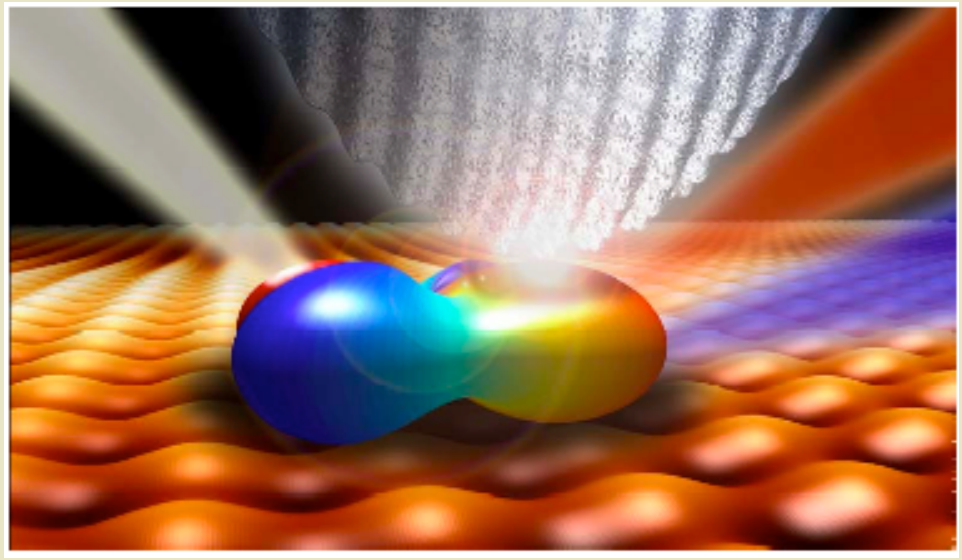
We must interrogate matter at a level much deeper than the macroscopic average to observe and control the properties of individual molecules or microscopic domains of materials

The biggest challenge lies ahead…….

Combining sub molecular spatial resolution with femtosecond time resolution



Future single-molecule dynamic measurements

Scientific instruments and the beginnings of modern science

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Reading and understanding "The Great Book of Nature", what we call scientific progress, has always been connected to the development of new and more advanced instruments, to see or hear what our naked senses cannot perceive, and by mathematics, to make our observations quantitative.

Scientific instruments and the beginnings of modern science

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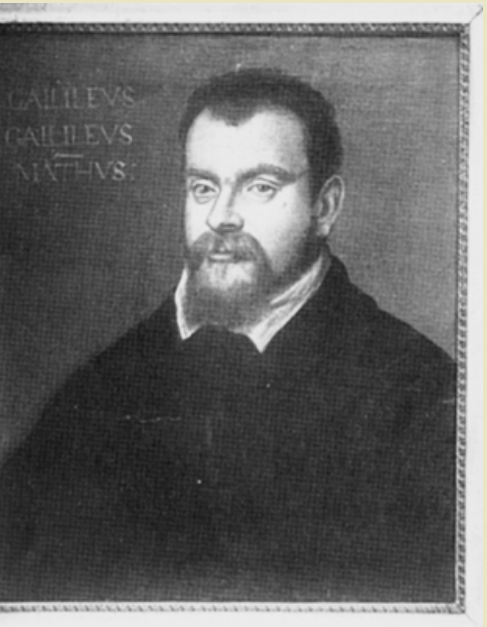
The Copernican revolution was fostered by the Renaissance humanist rediscovery of Greek knowledge.

Raphael: The School of Athens (1509-10).

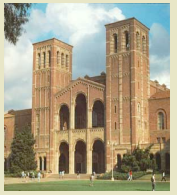
But it only became a scientific fact because of the development by Tycho Brahe of instruments to measure the positions of planets to a precision 60 times better than had been done before –mostly by Hipparcus in the II century BCE- and by the development of the telescope to see the phases of Venus and demonstrate that the Ptolemaic, earth centered system, contradicted the observations.

Galileo



Galileo Galilei
1563-1642

Galileo (1564-1642) developed the telescope for astronomical observations, extending the range of human vision to observe stars and planets never seen before.



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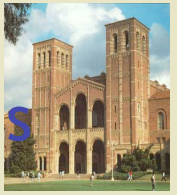
The eye of the Linx: One of Galileo's telescopes, about 1 m long, magnification 21 times.

1610: Sidereus Nuncius: The Moon

Sidereus Nuncius: Jupiter's satellites



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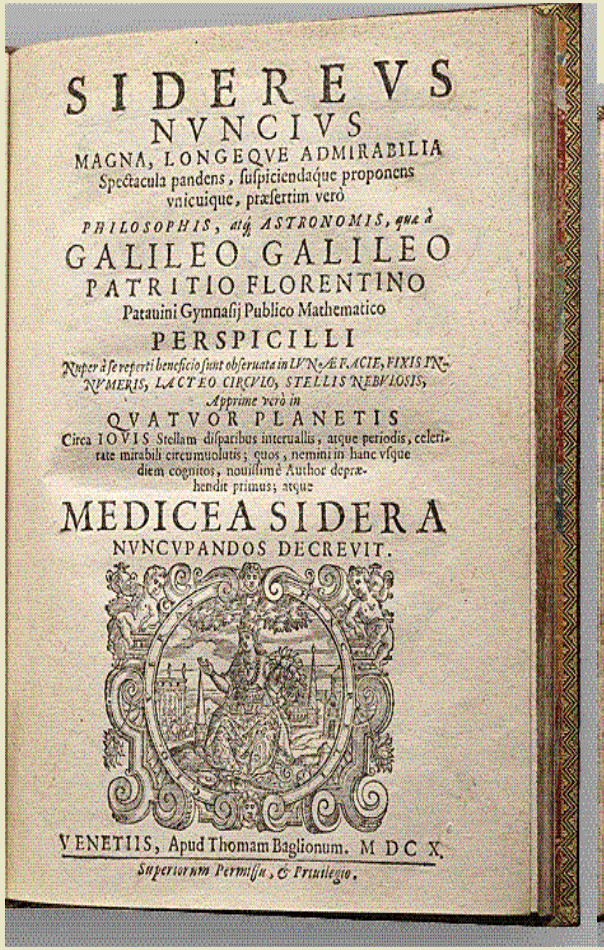
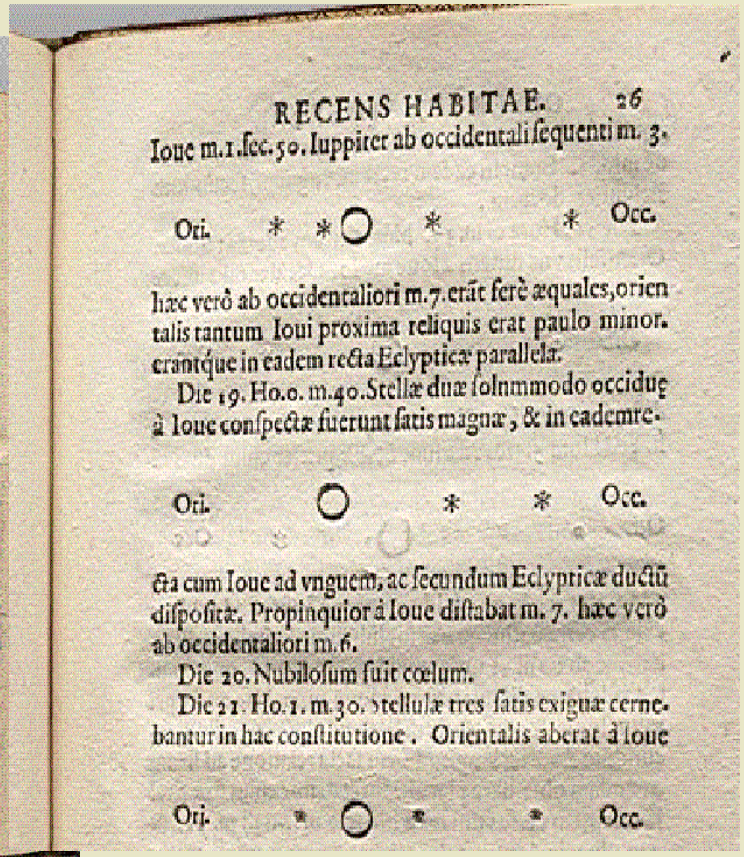


SIDEREVS
NVNCIVS
MAGNA, LONGEQVE ADMIRABILIA
Spectacula pandens, suspiciendaque proponens
vnicuique, præsertim verò
PHILOSOPHIS, atq; ASTRONOMIS, quæ à
GALILEO GALILEO
PATRITIO FLORENTINO
Patauini Gymnasij Publico Mathematico
PERSPICILLI
Nuper à se reperti beneficio sunt obseruata in LVNÆ FACIE, FIXIS IN-
NVMERIS, LACTEO CIRCVLO, STELLIS NEBVLOSIS,
Apprime verò in
QVATVOR PLANETIS
Circa IOVIS Stellam disparibus interuallis, atque periodis, celeri-
tate mirabili circumuolutis; quos, nemini in hanc vsque
diem cognitos, nouissimè Author depræ-
hendit primus; atque
MEDICEA SIDERA
NVNCVPANDOS DECREVIT.

VENETIIS, Apud Thomam Baglionum. M DC X.
Superiorum Permissu, & Priuilegio.



RECENS HABITAE. 26
Ioue m.1.sec.50. Iuppiter ab occidentali sequenti m. 3.

Ori. * * ○ * * Occ.

hæc verò ab occidentaliori m.7. erat ferè æquales, orien
talis tantum Ioui proxima reliquis erat paulo minor.
erantque in eadem recta Eclypticæ parallelæ.
Die 19. Ho.0. m.40. Stellæ duæ solummodo occidue
à Ioue conspectæ fuerunt satis magnæ, & in eademre-

Ori. ○ * * Occ.

cta cum Ioue ad vnguem, ac secundum Eclypticæ ductū
dispositæ. Propinquior à Ioue distabat m. 7. hæc verò
ab occidentaliori m.6.
Die 20. Nubilosum fuit cœlum.
Die 21. Ho.1. m.30. stellulæ tres satis exiguæ cerne-
bantur in hac constitutione. Orientalis aberat à Ioue

Ori. * ○ * * Occ.

Phases of Venus in the Ptolemaic and Copernican Systems

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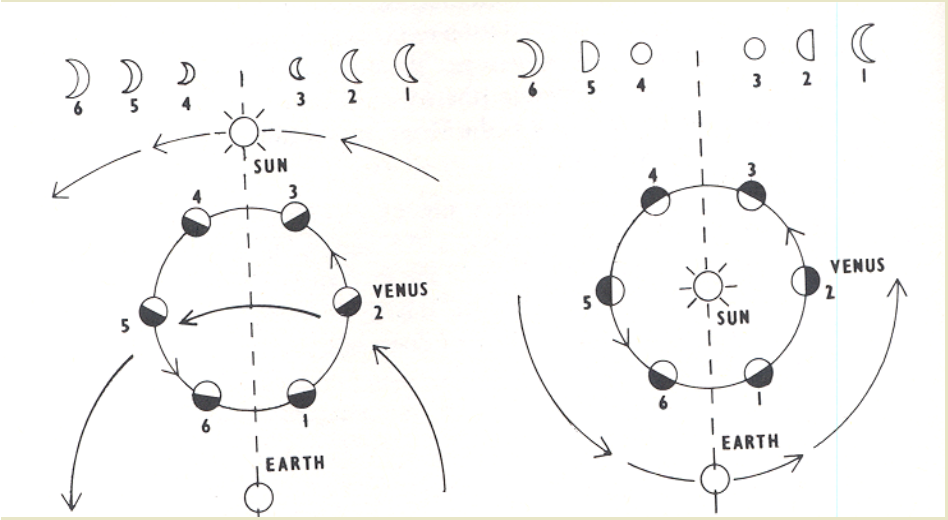


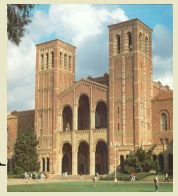
Galileo to Kepler, 1610: …

From the observation of these wonderful phenomena we are supplied with a determination most conclusive …. *we are absolutely compelled to say that Venus (and Mercury also) revolve round the Sun, as do also the rest of the planets.*

For the first time in history a choice between two cosmological systems is based on observation:

From myth to science.

The "New Science": Galileo and the Accademia dei Lincei



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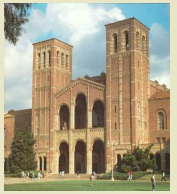
Galileo was introducing his new discoveries in the sky, but he was also fighting to introduce a new way of doing science, combining observations and mathematics, a method to understand nature in small steps, renouncing the traditional approach to explain everything from few general principles.

In his fight he found help and support from the members of the newly founded Accademia dei Lincei.

Natural science and the "Accademia dei Lincei"



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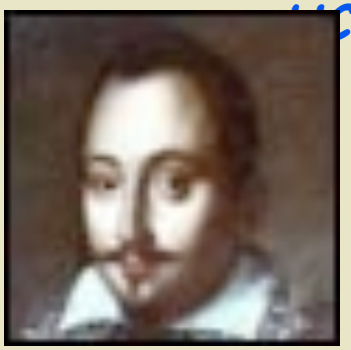
On August 17, 1603, Federico Cesi, his cousin Anastasio de Filiis, Francesco Stelluti and Jan Heckius, who had left the Netherlands and studied medicine in Perugia, met in via della Maschera d'Oro, in Rome. Cesi was 18 years old, and his friends were 25. They founded the Accademia dei Lincei to study the natural sciences.



Federico Cesi
1585-1630

Francesco Stelluti
1577-1653

Natural science and the "Accademia dei Lincei"

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Between 1603 and 1609 the Accademia could not be very active, for the opposition of Cesi's father. After his deatj, in 1609, Cesi gave a new impetus to the Accademia. In 1610 Giovambattista Della Porta joins the Lincei. In 1611 Galileo Galilei became a member during his trip to Rome. Many more important Italian and European scientists joined the Accademia in the following years and in 1625 there were thirty two members.

Lynceographum and "Del naturale desiderio del sapere"

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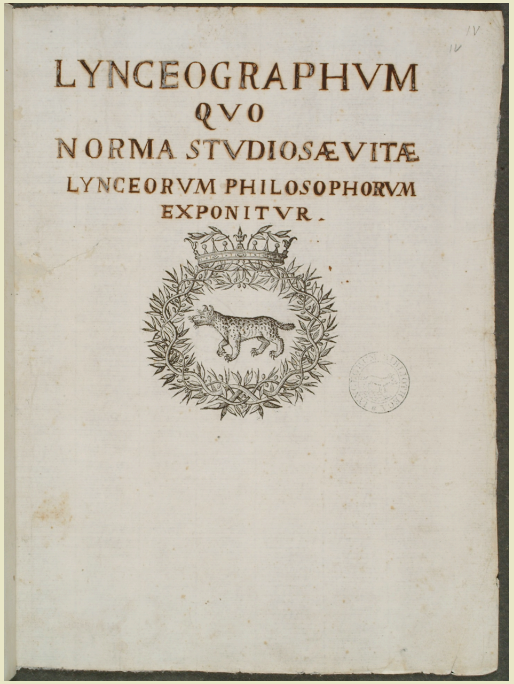

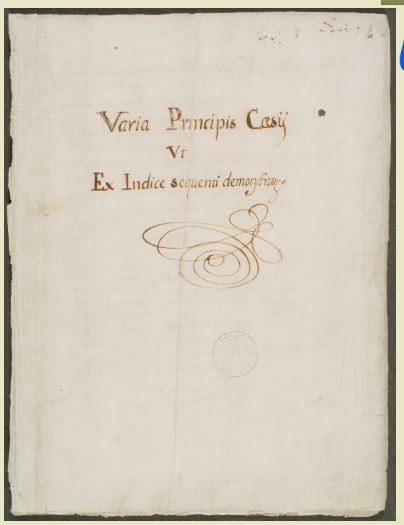

The goals of the Academy were explained in a first document started in 1604, the Lynceographum, Published only recently by the Accademia dei Lincei. another document "del natural desiderio di sapere …" was written some years later (1616)

DEL NATURAL DESIDERIO DI SAPERE …

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This document contains many of the Galileian arguments against the church and aristotelian establishment.

"Sara' impedito il servirsi della ragione da Dio donataci nello stesso risolversi a valersi di essa? Che incolparemo? …"

"Questa appassionata amicitia dell'autori, gia' espressamente proibita d'Aristotile, hora cosÏ esquisitamente seguita dalli aristotelici, n'impedisce non solo la necessaria lettione del libro dell'universo, ma anco di qualsivoglia libro che non sia uscito dalla favorita setta e da' cari maestri; …"

DEL NATURAL DESIDERIO DI SAPERE …

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"Dobbiamo anco osservare che l'istessa laurea, instituita gia' per ornare il compimento delle scienze e venir percio' ad esso incitando, mentre si vede che indiferentemente corona tutti quelli che finiscono il corso senza riguardo alcuno ne' dell'arrivare ne' del zoppicare o andar dritto, viene a porre meta e termino, ordinariamente, alle studiose fatighe di ciascheduno, …."

DEL NATURAL DESIDERIO DI SAPERE …”

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“Goder similmente dell′utile, dell′inventioni e grandi e mirabili che verranno dall′acutezza di tali ingegni, mentre nel continuo ricercare, sperimentare e contemplare, discoprono le proprieta’ delle cose e ne notano sempre l′effetti e le cagioni. Cosï nascono l′instrumenti ammirandi, si trovano i piu’ rari medicamenti, i fuochi, l′armi, le diffese, le machine, le evasioni d′acque, tanti secreti per facilita’ dell′arti necessarie al vitto humano, per i commodi, per la sanita’, per il vitto stesso, come puol vedersi presso i naturalisti essere fatto sin hora, e particolarmente nella nostra Filosofica panurgia mostraremo.”

The "Accademia dei Lincei" and natural sciences

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While the interest of the most famous academician, Galileo, was mainly directed to physics and astronomy, Cesi, Stelluti, Faber and others were mainly oriented toward the studies of animal and plants.

"Cosi', se Galileo fu il primo a indirizzare al cielo il telescopio, i suoi colleghi Lincei furono i primi in Italia a rivolgere il microscopio sugli esseri di gran lunga piu' piccoli; e cio' non per semplice curiosita' e diletto, ma per vero studio scientifico o ricerca naturalistica."

G. Gabrielli in Rendiconti Reale Accademia d'Italia, 1941

And we can also say that they were the first, not only in Italy but in the world, to publish the results of their scientific microscopic observations.

Galileo the Lincei and the microscope

Galileo visited Cesi in Acquasparta on the way to Rome, in April 1624. The Lyncean Stelluti and Faber were also in Acquasparta during the visit. In Rome, among other things, he showed a microscope to two cardinals.

In September, Galileo sent a letter and a microscope to Cesi, with instructions on how to use it : …"I am sending your Excellency an *occhialino* to view the smallest things as if from nearby. … I have been slow in sending it to you because at first I was unable to perfect it, having had some difficulty in finding the correct way of cutting the crystal perfectly …. I have contemplated very many small little animals with infinite admiration: among which the flea is the most horrid, the mosquito and the moth very beautiful. I have also seen with much pleasure how flies and other little animals walk on mirrors and are also seen from below. "

The word "microscope" and more microscopic observations.

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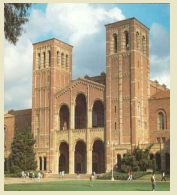
In a letter to Cesi in May 1624 Faber writes: "..I few days ago I looked through an optical tube of marvelous clarity, and was astonished by what I saw. It was made with great skill and craft by two germans who brought it to my house and presented it to me. Since it was made for the observation of very small things, I decided to call it a microscope, by analogy with the telescope. I examined a louse, that dirty little animal and not infrequent companion of man, and saw not only his mouth, but its eyes, beard and two little horns on its forehead. I examined its three very long and articulated feet on either side of its body, each had two curved claws, one long and one short, which took the place of the thumb. With these it grasps the skin, and then crawls …"

Unity of science and interdisciplinary research.

Galileo saw how the "occhialino", the microscope, a derivative of the telescope and optical science, could be used to explore the world of "little small things", what today we call the microscopic world. In particular he saw how to use it in the natural sciences, to see parts of animals that were invisible to the naked eye.

In Two new Sciences he shows the unity of science by applying the scaling laws, derived for the resistance of materials, to the biological world: "Or vegghino come dalle cose sin qui dimostrate apertamente si raccoglie l'impossibilita' del poter non solamente l'arte, ma la natura stessa, crescere le sue macchine a vastita' immensa: si che impossibil sarebbe fabbricare navilli, palazzi o templi vastissimi … Come anche non potrebbe la natura far alberi di smisurata grandezza, … Parimente sarebbe impossibile far struttura di ossa per uomini, cavalli o altri animali, che potrebbero sussistere e far proporzionalmente gli affari loro mentre tali animali si dovesser agumentare ad altezze immense …"

From telescopes to microscopes



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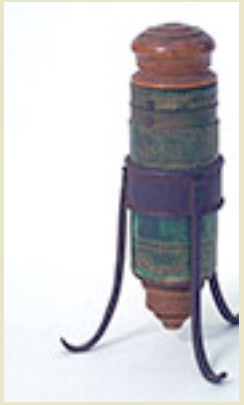
The microscope was developed almost at the same time of the telescope. Credit for the first microscope is generally given to Zacharias Jansen and John Lipperhey in 1590.

The earliest records of microscopic observations, mostly of a bee, date from 1625 and 1630 and were the work of Stelluti , Cesi and Faber (1577-1653), following their meeting with Galileo. They were published in the Apiarium, the Melissographia and Persio Tradotto.



F. Stelluti, Persio Tradotto,1630

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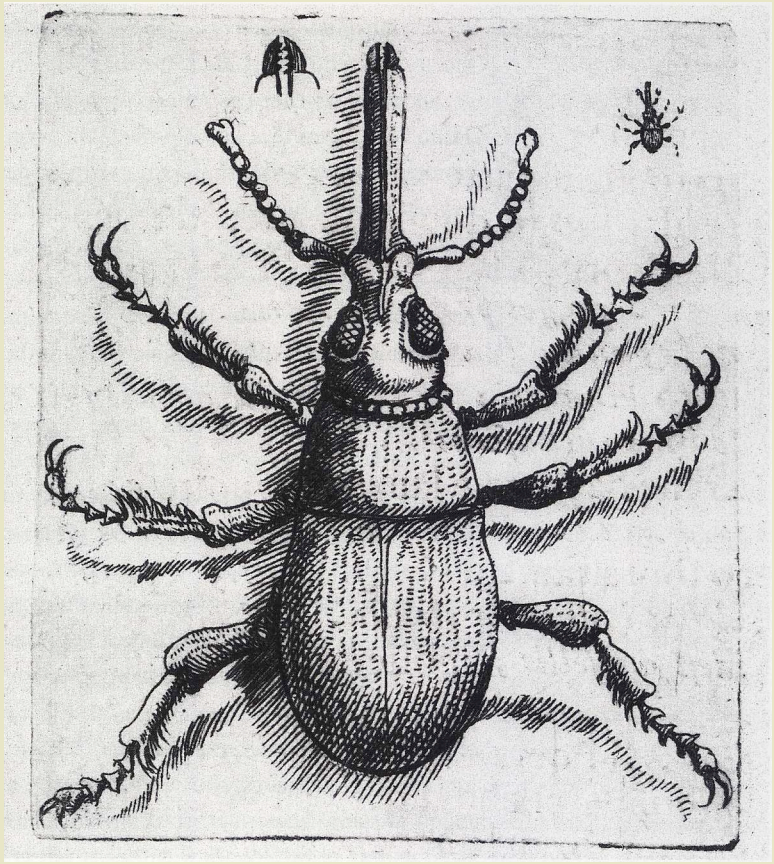
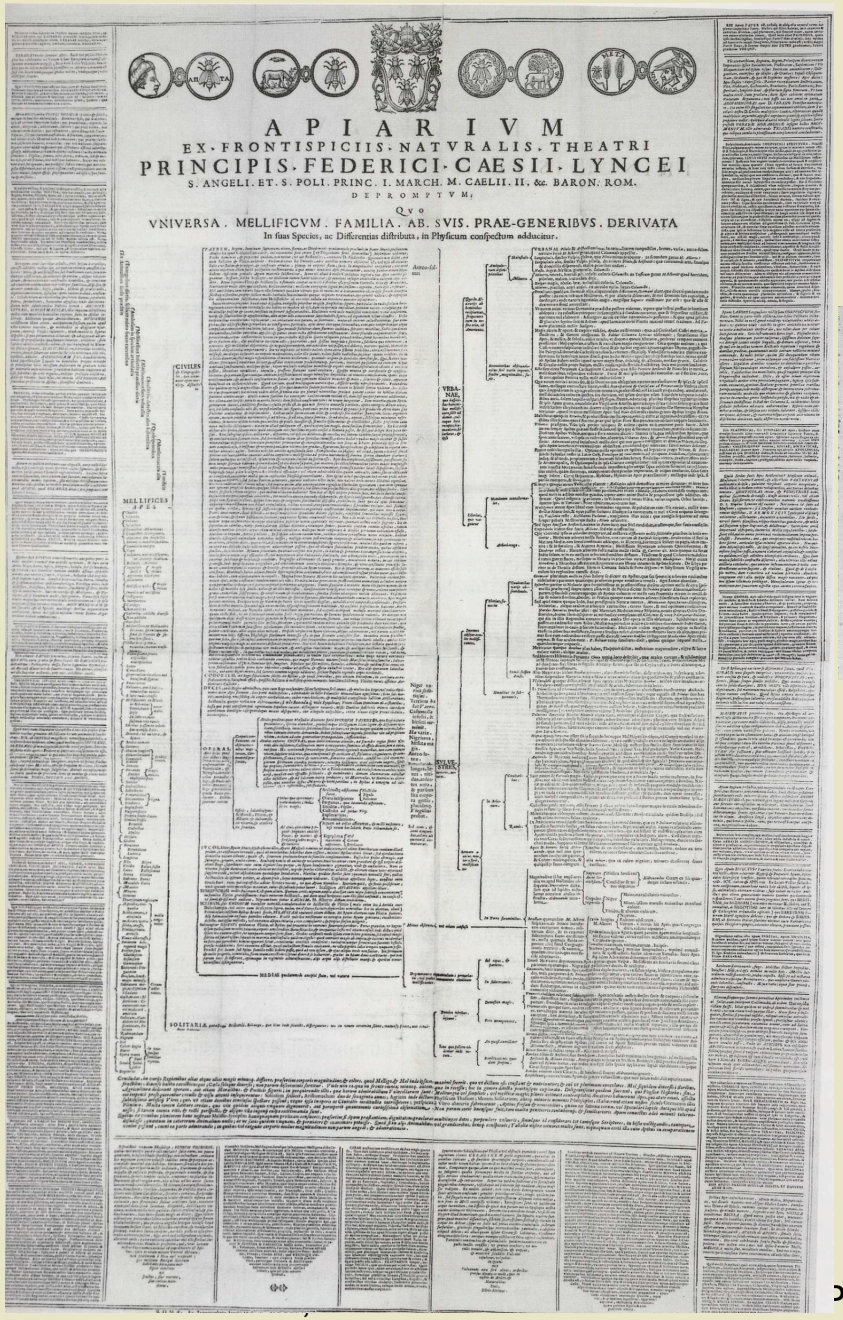
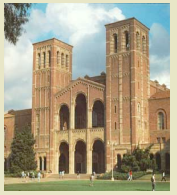


Francesco Stelluti; the weevil, in Persio tradotto


A P I A R I V M
EX · FRONTISPICIIS · NATVRALIS · THEATRI
PRINCIPIS · FEDERICI · CAESII · LYNCEI
S. ANGELI. ET. S. POLI. PRINC. I. MARCH. M. CAELII. II. &c. BARON. ROM.
DEPROMPTVM;
Quo
VNIVERSA . MELLIFICVM . FAMILIA . AB. SVIS. PRAE-GENERIBVS . DERIVATA
In suas Species, ac Differentias distributa, in Physicum conspectum adducitur.



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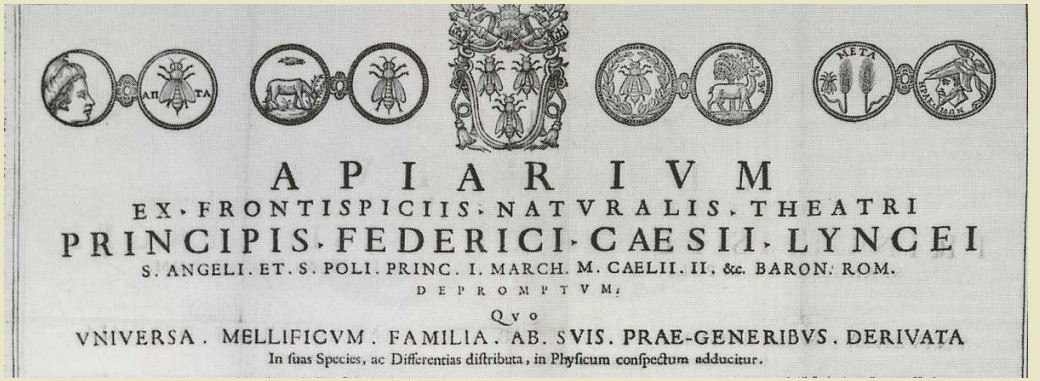
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In suas Species, ac Differentias distributa, in Physicum conspectum adducitur.

The bees and the Barberinis

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The choice of the bees for the first microscopic observations was an homage to Urbano VIII, the new Barberini Pope elected in 1623, a friend of Galileo and other Lynceans. They hoped that Urbano VIII would help, or at least not oppose, the ideas of the new science they were proposing and fighting for.
The hope was killed by Galileo's trial a few years later. Urbano VIII did not save Galileo and his new science.

Urbano VIII - Maffeo Barberini
1568-1644- 1623-1644

Cesi's Theatrum Naturae

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In 1617 Cesi started to work on an encyclopedic project, the Theatrum Totius Naturae, which was never completed. Only a part of it,the Tabulae Phytosophicae, dedicated to Francesco Barberini, were published after his death. But am enormous quantity of material, thousands of beautiful drawings of plants and animals, were prepared for this project [1]. Some of these drawings show again microscopic observations.

The main goal of Cesi and the other Lincei was to produce a scheme of documentation and classification of the infinite variety of plants and animals. They used the microscope to help reach this goal.

[1] See D. Freedberg, The Eyes of the Linx

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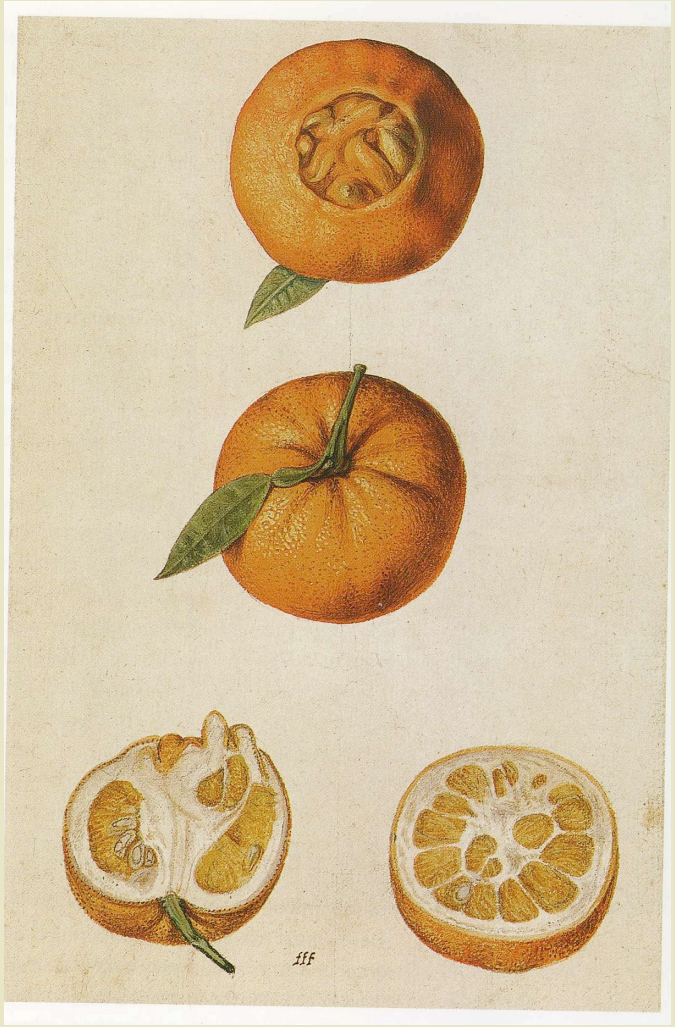
Brief history of the Lyncean drawings

After the death of Cesi in 1630 all his documents, manuscripts books and scientific instruments documents were acquired by another Lyncean, Cassiano del Pozzo, encouraged by Stelluti, in 1633. That was the year of Galileo's trial. All this material became part of Cassiano's Museum Cartaceum. They included the naturalist drawings of plants and animals, including those showing microscopic observations.

From Cassiano they became part of the Albani library collection in Rome in 1703. Later on, through different avenues, the drawings went to the Windsor Royal Collection, the library of the Institute de France, and in Library of the medical school in Montpellier.

Stages of growth of a fungus, V. Leonardi, Windsor, Royal Collection



Pregnant orange, V. Leonardi, Windsor, Royal Collection

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Head of Broccoli ,
V. Leonardi, Windsor, Royal Collection

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Corals, stones, fossils and others

Windsor, Royal Collections

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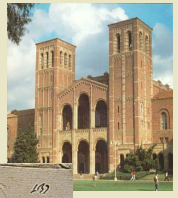
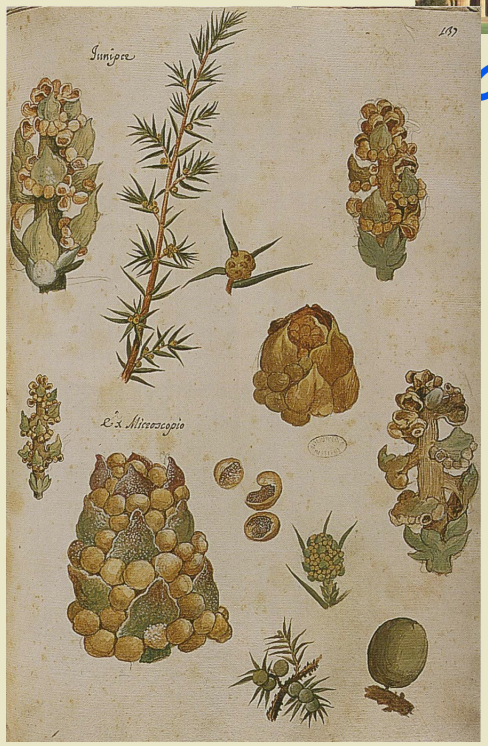
Heron, V. Leonardi, Windsor the Royal Collection

Lyncean drawings at the library of the Institute de France, Paris.



The drawings, in 8 volumes, belonged to the Albani library in Rome and were taken, during the occupation of Rome in 1798, by the French officer Orteil. He sold them to a collector, who left them to the Institute in 1874. Some of the drawings show annotations by Cesi himself. They were done between 1623 and 1628.



Common Juniper, first microscopic observation of a gymnosperm.

The drawings have notations on the place where the plants were found, and the use of the microscope.

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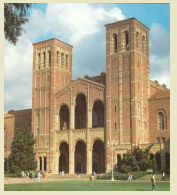
– Polyporus tuberaster Jacq. : F. Cesi, Watercolor for Theatrum Naturae , photographic reproduction from the original at the Institute de France, Paris.



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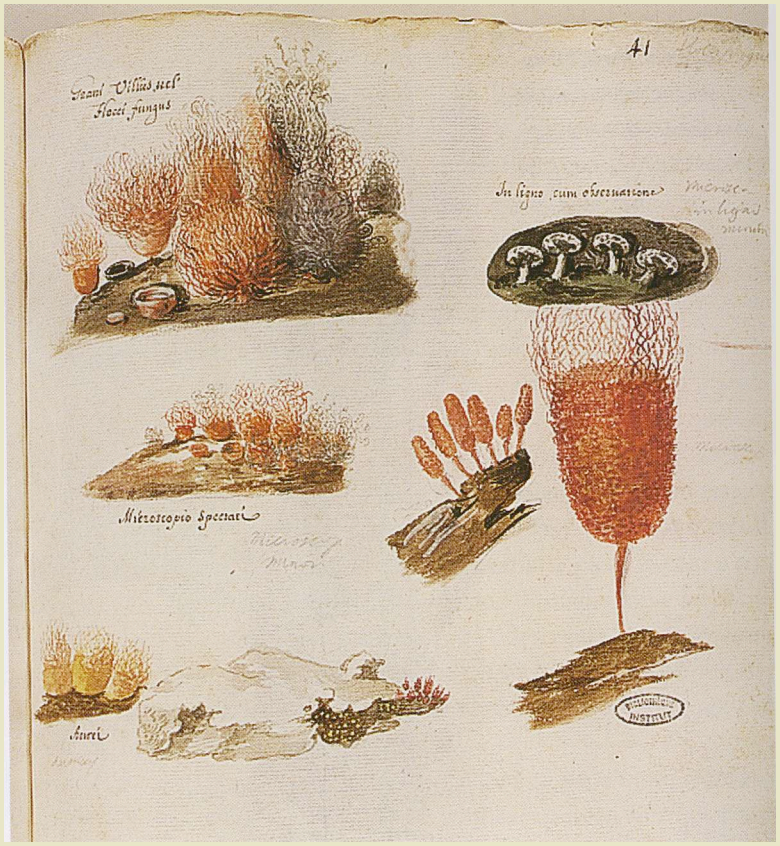
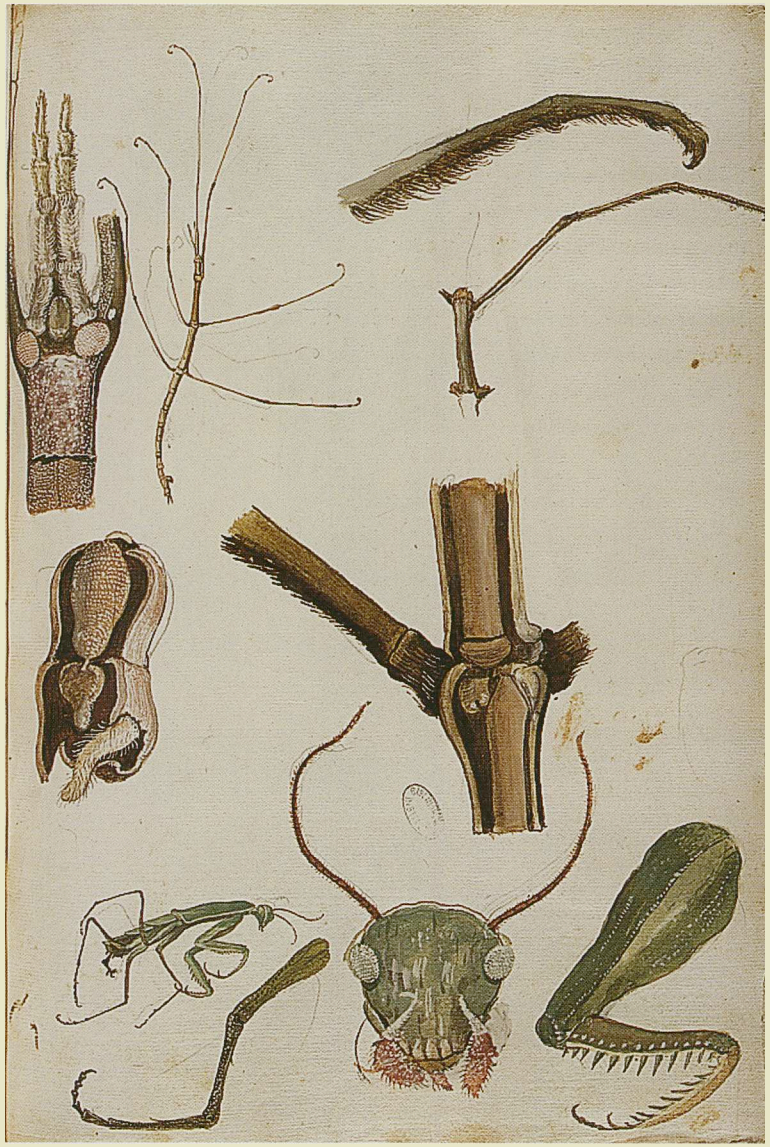


Myxomycetes Arcyria, Inst. De France, Paris



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Stick insect, and Praying Manthis, Inst. De France

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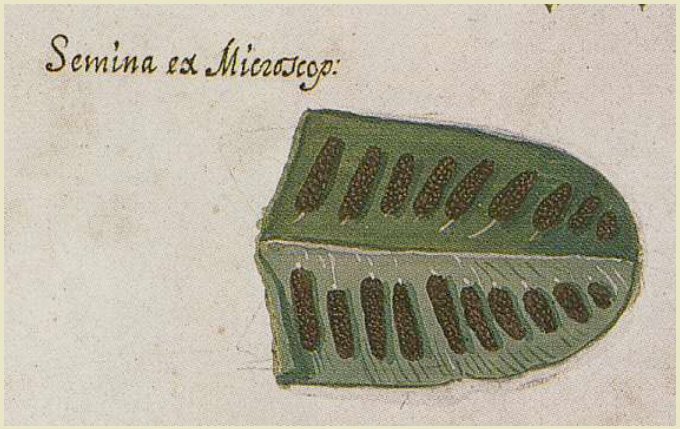
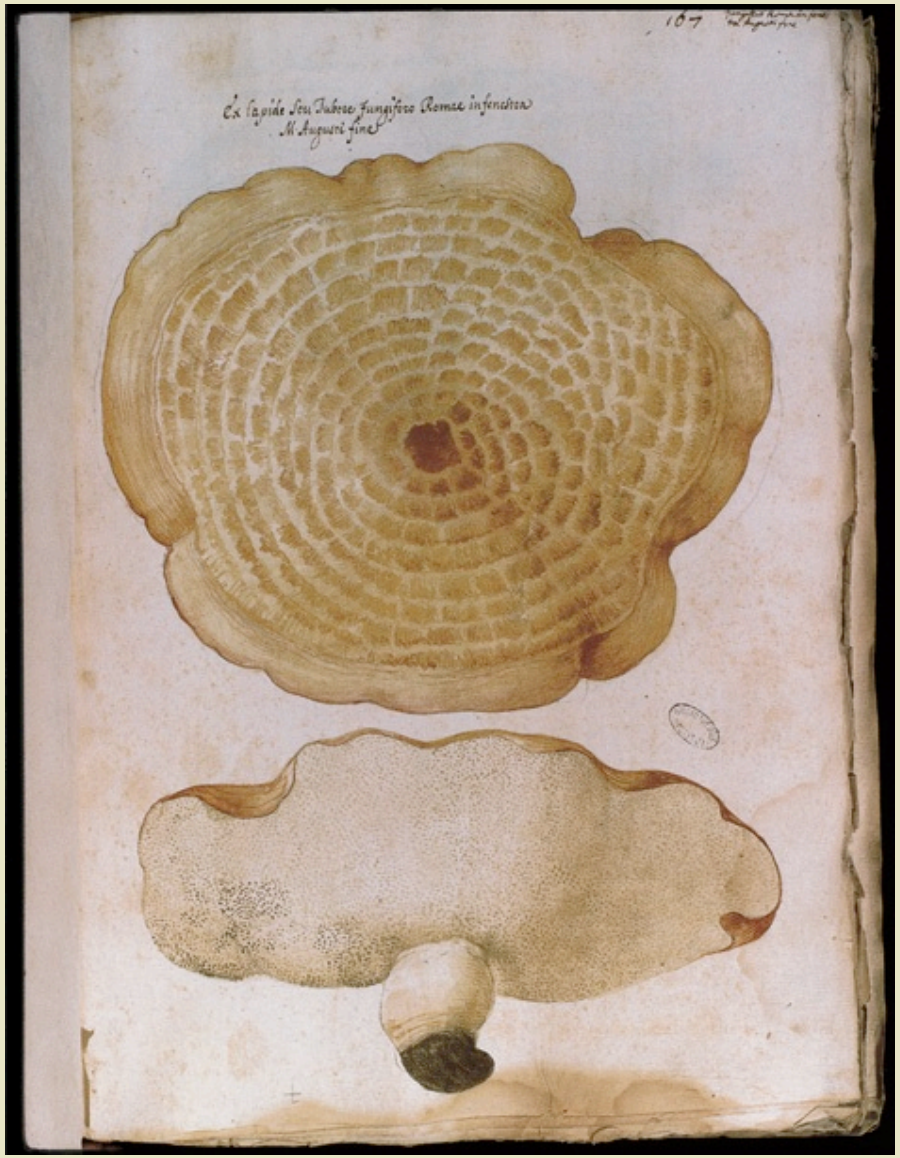


Underside of various ferns, Inst. de France


107
Ex lapide seu Tubere Fungiforme Romae in fenestra
M. Augusti fine

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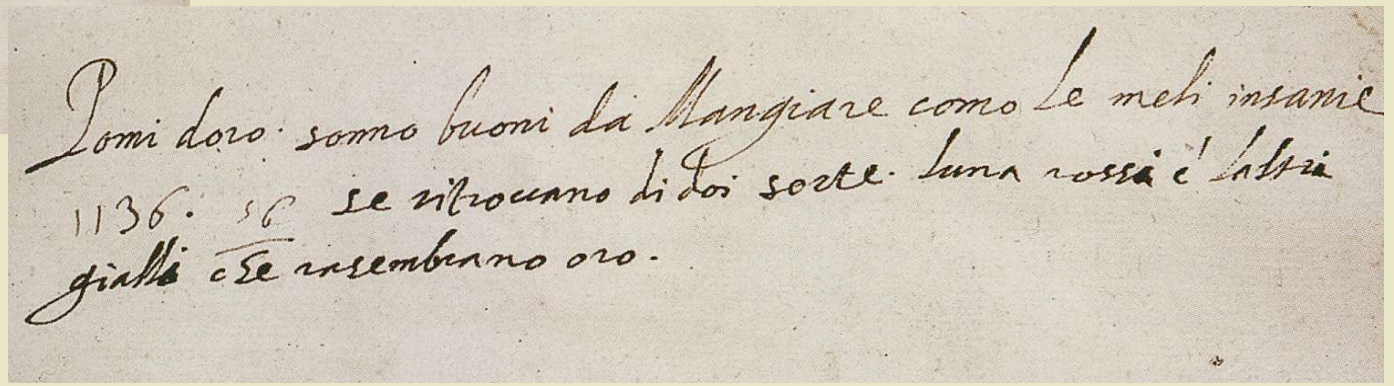
521
Pomi doro. sonno buoni da Mangiare como le meli insanie
1136. se ritrocano di doi sorte. luna rossa e l'altra
gialla e se rassemblano oro.


Pomi doro. sonno buoni da Mangiare como le meli insanie
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gialla e se rassemblano oro.

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Cesi's Theatrum Naturae

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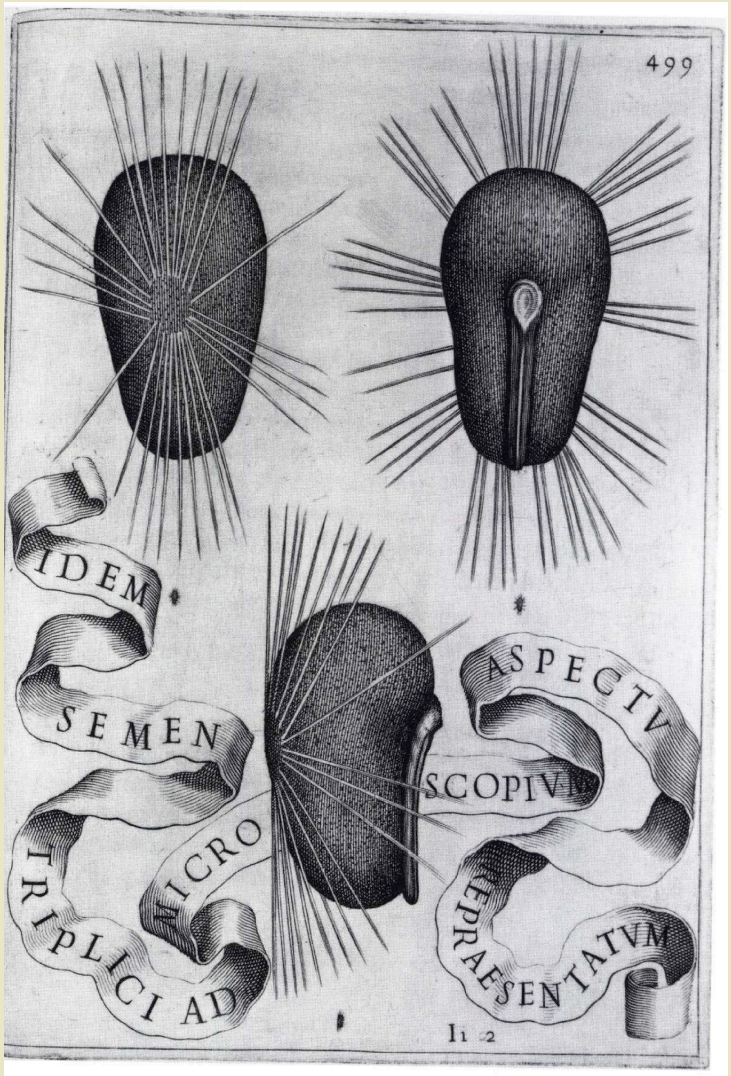
The naturalist research of Cesi, Stelluti and other members of the Accademia dei Lincei, can be considered an important step from the traditional approach, for instance that of Aldovrandi, to that of Linnaeus, who produced the critical advance in the classification of animals and plants.

After Cesi



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Seed of a chinese rose seen at the microscope, in Ferrari, De Florum Cultura (1633)
Engraving by Cornelius Bloemaert.

After the Lincei

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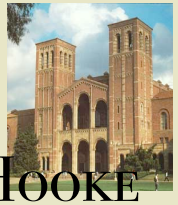
Hooke devised one of the best microscopes of his time – the world's first compound microscope complete with iris diaphragm and illumination.

Hooke Microscopic Studies



As for the telescope the microscope developed rapidly. Robert Hooke (1635-1703) published his studies in Micrographia, his most well known work, in 1665. Hooke's himself made the beautiful drawings of his observations. The book was published by the Royal Society.

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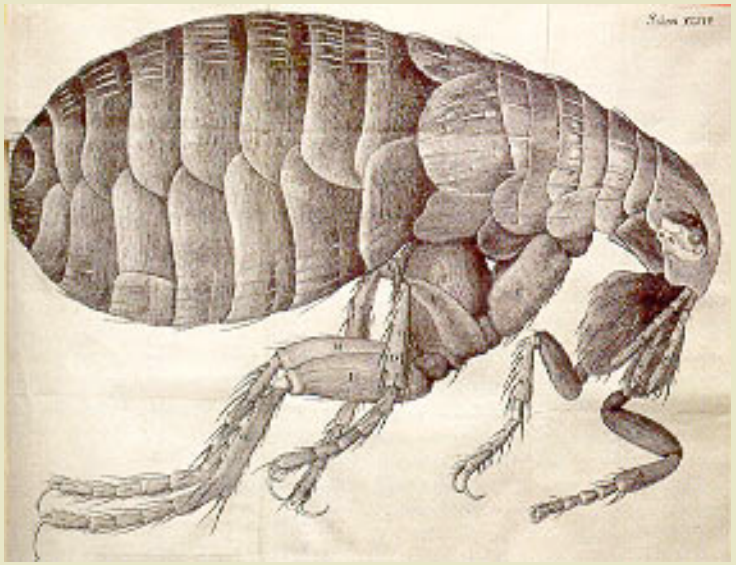
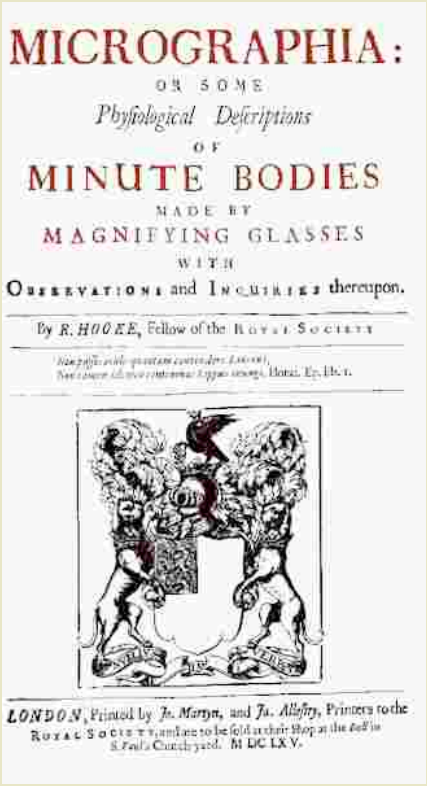


Drawing of a flea from Micrographia



MICROGRAPHIA:
OR SOME
Physiological Descriptions
OF
MINUTE BODIES
MADE BY
MAGNIFYING GLASSES
WITH
OBSERVATIONS and INQUIRIES thereupon.
By R. HOOKE, Fellow of the ROYAL SOCIETY
LONDON, Printed by Jo. Martyn, and Ja. Allestry, Printers to the ROYAL SOCIETY, and are to be sold at their Shop at the Sign of the Bell in S. Paul's Church-yard. MDCLXV.

The end of the Lincei

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The premature death of Federico Cesi in 1630e and the trial of Galileo had a dramatic effect on the development of the "New Science " in Italy. The new situation is well summarized by Milton, an admirer of Galileo, that he had praised in "Paradise Lost":

John Milton (1608-1674) . From Paradise Lost (Book 1, lines 283-91)

.... the broad circumference
Hung on his shoulders like the Moon, whose Orb
Through Optic Glass the Tuscan Artist [Galileo] views
At Ev'ning from the top of Fesole,
Or in Valdarno, to descry new Lands,
Rivers or Mountains in her spotty Globe.

The end of the Lincei

Milton went to Italy for the death of his mother in 1637 and returned in 1639. He visited Galileo, and refers to this visit in Areopagitica, a discourse to the Lords and Commons against requiring all printed books to be licensed: "I could recount what I have seen and heard in other countries, where this kind of inquisition tyrannizes; where I have sat among their learned men, for that honor I had, and been counted happy to be born in such a place of Philosophic Freedom, as they suppos'd England was, while themselves did nothing but beamon the servil condition into which Learning amongst them was brought; that this was it which had dampt the glory of Italian wits; that nothing had been there writt'n now these many years that flattery and fustian."

Why Science?

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Phidia, Athens about 440 B. C.

For we should not do physics by following groundless postulates and stipulations, but in the manner called for by the phenomena; for our life does not now need irrationality and groundless opinions, but rather for us to live without fear and with peace of mind.

…Epicurus (circa 350 BCE) , letter to Pythocles