

Imagerie diagnostique et interventionnelle.

Progrès et perspectives.

Séance thématique du 5 mai 2021

Académie nationale de Pharmacie

# Disruptive Innovations in Medical Imaging: Is this the END?

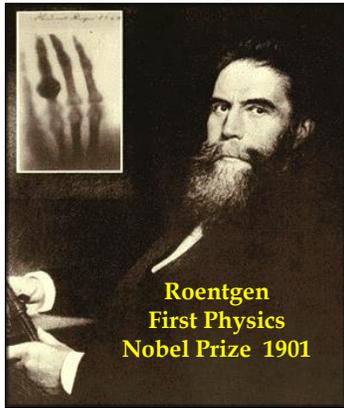
Denis Le Bihan

Founding Director, NeuroSpin, Saclay, France

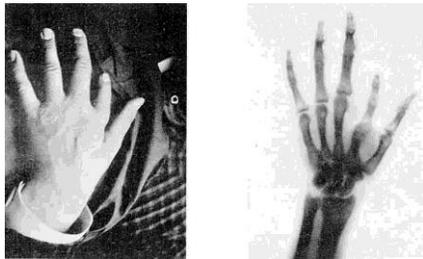


# Two mainstreams for medical imaging innovation

- **Cumulative process:** Progressive, incremental changes in basic knowledge of certain concepts over a long time, until **radical change** occurs
- Discovery or development of a new concept initially **without medical purpose**

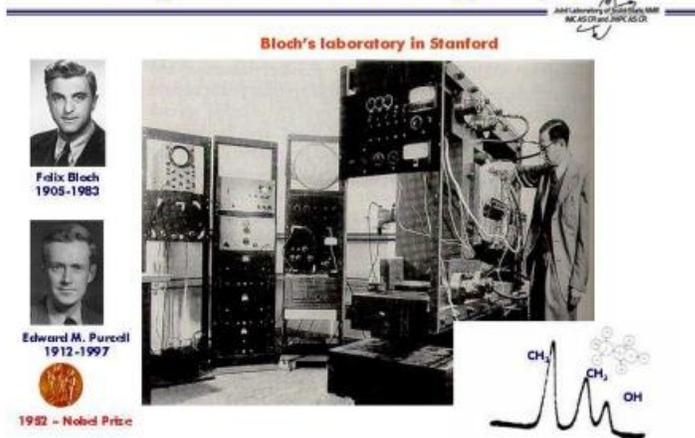


Roentgen  
First Physics  
Nobel Prize 1901



"Röntgen photography" plaque published 1896,  
"Nouvelle Iconographie de la Salpetriere"  
→ The "radiology" field was created in 1930

## History – the first NMR signal (1949)



1952 - Nobel Prize

**Disruptive Innovations :  
... UNPREDICTABLE!**

## ✓ 1905 - Einstein's "miraculous" year

- "On a Heuristic Point of View on the Creation and Conversion of Light" (17 March 1905)

Nobel prize in physics, 1921 → Nuclear Imaging

- "Investigation on the Theory of the Brownian Movement: On the motion of small particles suspended in liquids at rest ..."

(11 May 1905) (diffusion theory) → Diffusion MRI

- "On the Electrodynamics of Moving Bodies" (30 June 1905)

- "Does the inertia of a body depend on its energy content?" (27 September 1905) (Theory of Special Relativity) → PET

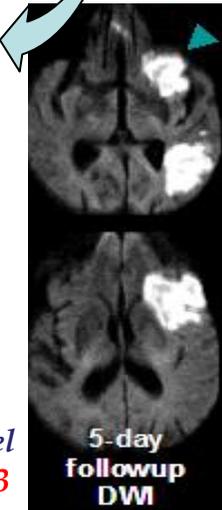
- "The Field Equations of Gravitation" (25 November 1915)

→ The relativist brain (Le Bihan D. BrainMultiPhysics 2020)

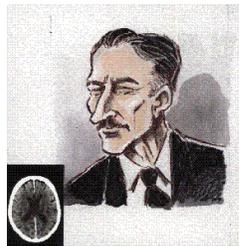


Albert Einstein,  
Circa 1905

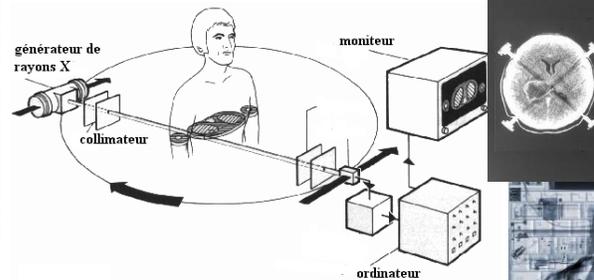
Diffusion MRI 1985 (Le Bihan)  
DTI 1992-94 Le Bihan, Basser



5-day  
followup  
DWI

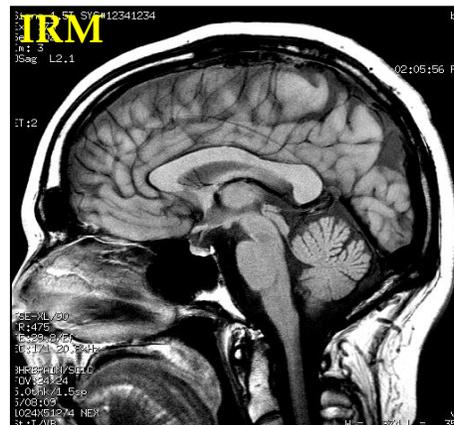


Hounsfield



CT

Nobel Prize in Medicine and Physiology 1979



MRI: Lauterbur & Mansfield, Nobel  
Prize in Physiology or Medicine 2003

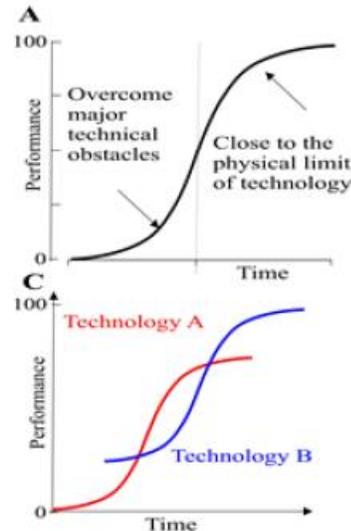
# LIFE CYCLE OF TECHNOLOGY (LCT)

*Technology travels in time: Is born, grows up, decline and die*

## ➤ Understanding LCT+++

- To predict the ability to **recover** development investment
- To **predict** when to plan new projects
- To **estimate** future developments
- To decide whether or not to **invest**

Innovation is one of the most sensitive meeting points between *material and psychological viewpoints*.  
Success of innovation is almost *independent from technical novelty*.



## ➤ LCT: S-curve

(Performance against unit of effort/money invested)

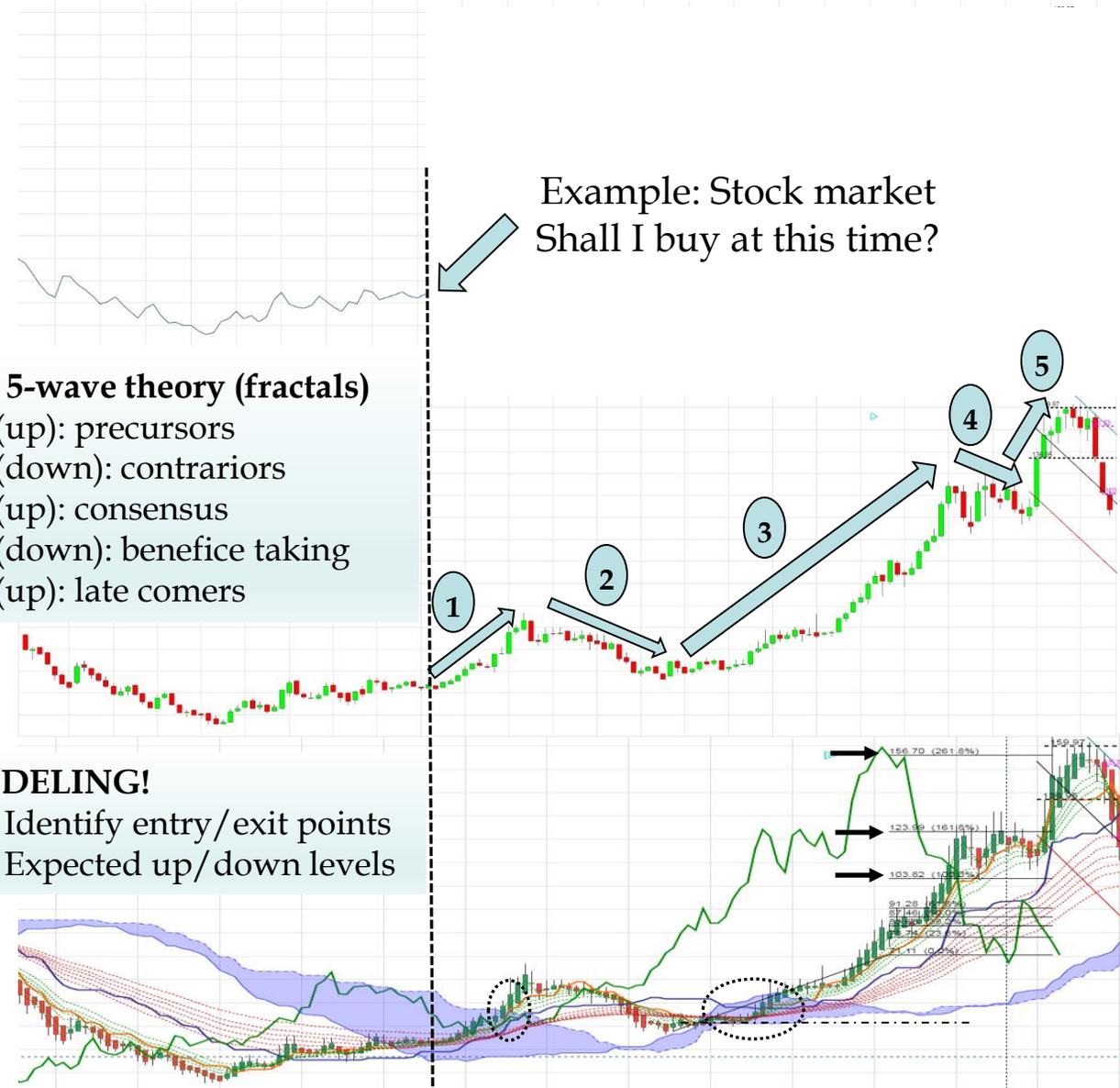
- Initial slow performance: fundamental not well understood
- Acceleration of performance (better understanding)
- Slows down when the technology reaches its limits
  - identify discontinuity in an emerging technology that replaces a mature technology
  - identify birth of new market opportunities
  - identify death or obsolescence of the technology market
  - technological progress: succession of S curves:  
New S curve at the end of an Old S curve (ex: CT and PET-CT)

## Elliott 5-wave theory (fractals)

- 1 (up): precursors
- 2 (down): contrarioris
- 3 (up): consensus
- 4 (down): benefic taking
- 5 (up): late comers

## MODELING!

- Identify entry/exit points
- Expected up/down levels

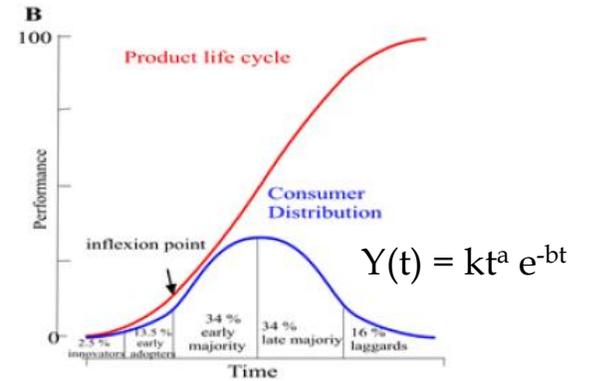


# Time line connected to « market adoption » (spread of technology)

➤ **S-curve: Diffusion of technology against cumulative number of adopters of technology over time:**

- Slow at the beginning (introduction to market)
- Accelerates and is used in mass
- Market saturated

→ Model to **predict when a technology reaches its limits**, identify and move to a new technology



➤ **Modeling (Rogers 2003, Moore 2014) of the transition from early visionaries market to mass market (Rogers 2003, Moore 2014)**

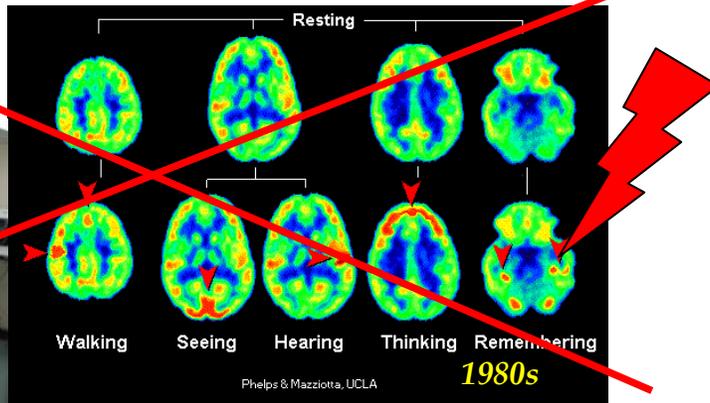
- Innovators (2.5%) & early followers (13.5%): understanding technology and performance
- Early (34%) and late (34%) majority: solution and comfort
- Sceptics (16%)

→ **Chasm**: breakpoint between early followers and early majority. Point where technology dies or survives (expected performance/revenue)

➤ **Limitations:**

- True limits not really known in advance, large disagreements between companies
- Firms can modify the S-curves through their R&D
- **Unexpected changes may occur in the market**

~~$O^{15}$  PET  
functional neuroimaging~~



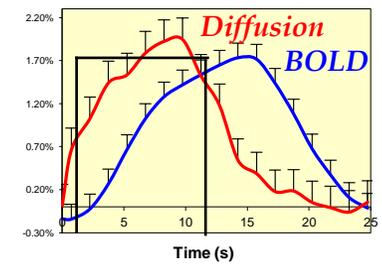
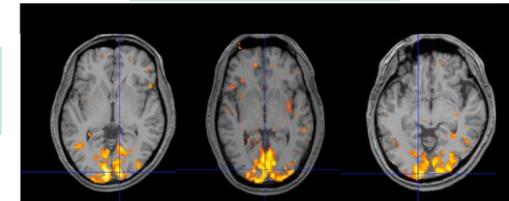
~~Gd based fMRI  
1991~~



BOLD fMRI  
1990-1992



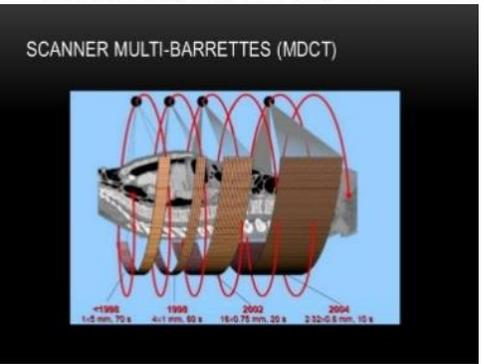
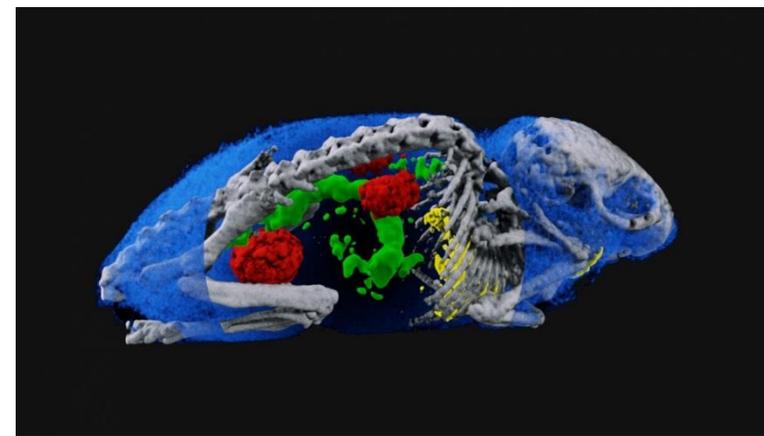
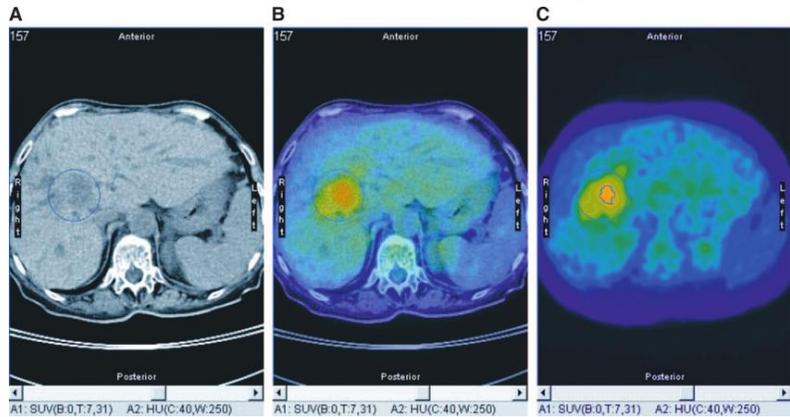
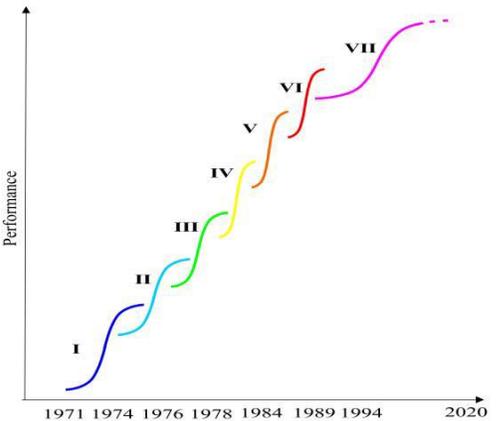
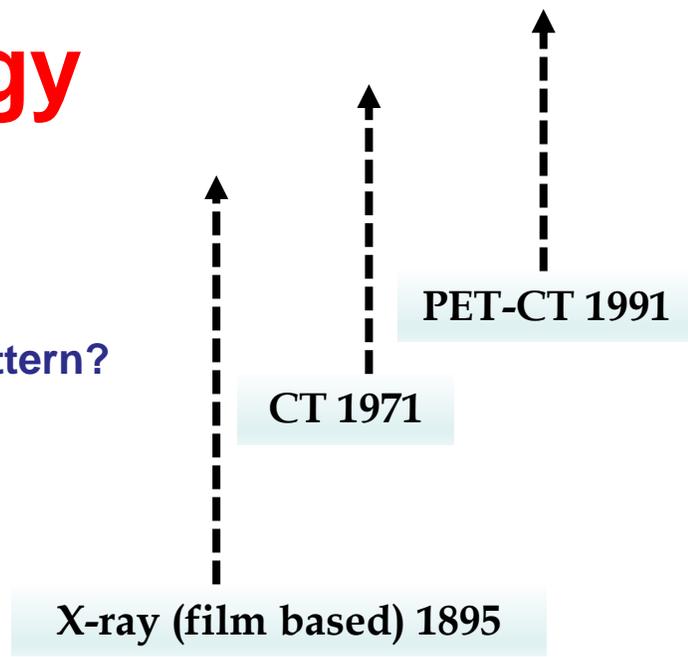
Diffusion fMRI  
2001-2006



# Example of X-ray technology

- X-ray technologies generate the largest Medical Imaging Technology income by far
  - New CT users build up on X-ray imaging
  - CT: incremental improvements (7th generation).
- Vacuum market at the beginning, now mature stage, decline expected from S-curve pattern?

→ PET-CT 1st prototype: 1991, first sold: 2001, *currently growing phase*  
**HYBRID SYSTEMS: Anatomy AND Function**



- Detector technology for the needs of the **CERN Large Hadron Collider (LHC)** experiments
- Extension to the medical imaging field.
- Third generation of read-out chips allows 'colour' imaging during CT scans (*spectral imaging*) providing information about the density and the atomic structure of a tissue.
- (still in the *emerging phase* and has not been widely adopted)

# HYPE CYCLE (Gartner)

## ➤ Technology Trigger

- Breakthrough, public, press and industry interest

## ➤ Peak of Inflated Technology

- Over-enthusiasm, unrealistic projections, success

## ➤ Trough of Disillusionment (« Death Valley », chasm)

- Growing failures toward the limits, disappointment

## ➤ Slope of enlightenment

- Solid hard work, true understanding of usage, risks, benefits

## ➤ Plateau of Productivity

- Real benefits demonstrated and accepted, stability of tools, reduced risk, adoption

## ❖ Death valley, chasm: need to reach « early majority » customers

- Need for financial resources to allow performance to generate enough revenues
- Segment the market, find niche within a larger market
- Attack competitors on small segments through proper positioning

- **CT, MRI, PET:** now adopted by « skeptics », *productivity plateau, slow decline phase will start soon?*

- **Hybrid PET-CT:** early majority, *slope of enlightenment*

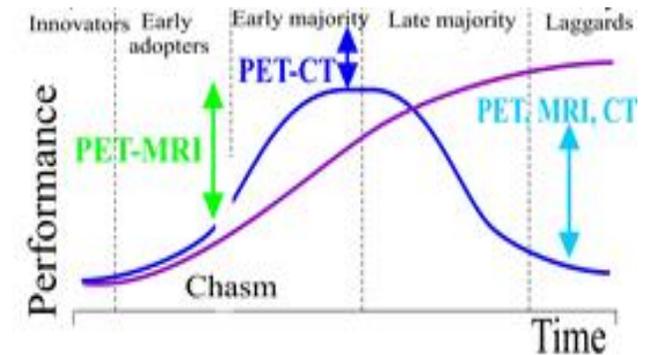
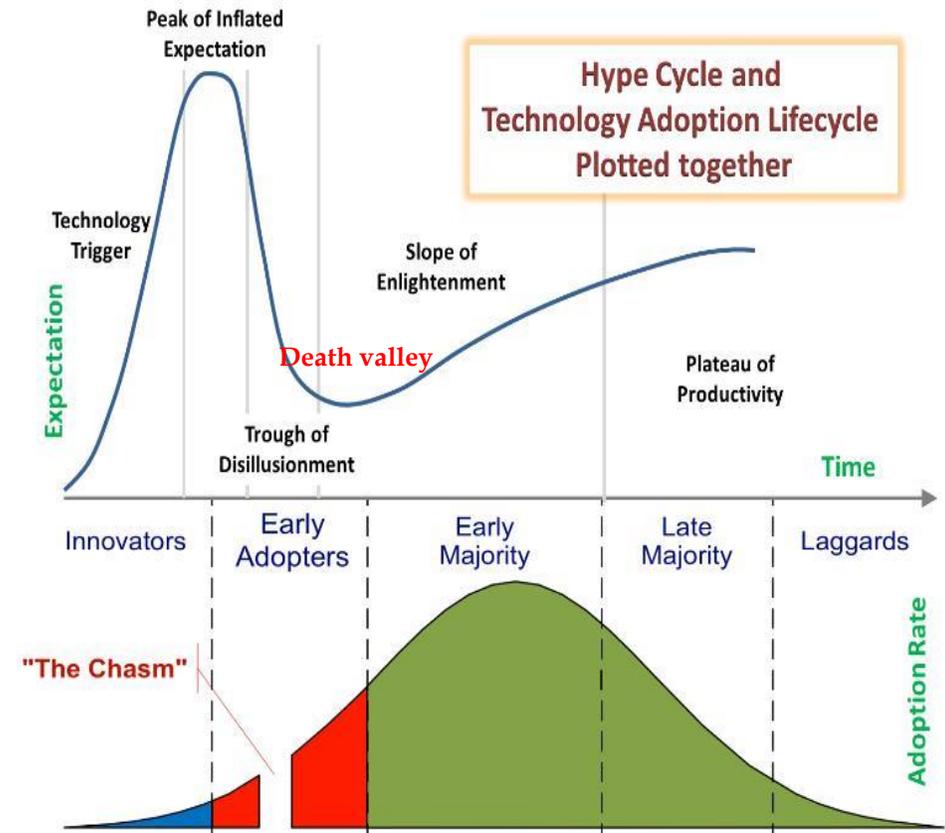
- **Hybrid PET-MRI:** development started in late 1990s, first prototype by Siemens 2008.

High complexity, cost (equipment, hospital infrastructures, tracers+++)

*Early adopters, enters the death valley* (performance? cost? Policymakers+++)

➤ Need to have pre-market information on **regulation mechanisms** which may affect cost-benefit, risk, effectiveness

➤ **Sensitivity to MARKET of raw materials**



# WORLD MRI MARKET

2018: \$5 billions

## The liquid helium crisis (MRI)

Helium free magnets?

Country	Billion Cubic Metres
United States	20.6
Qatar	10.1
Algeria	8.2
Russia	6.8
Canada	2.0
China	1.1

The values above are estimated helium resources from the USGS Mineral Commodity Summary

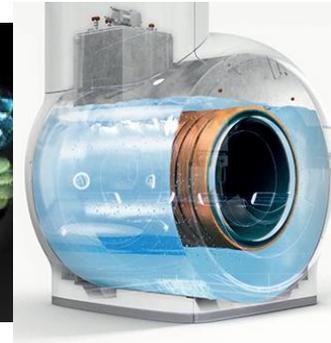
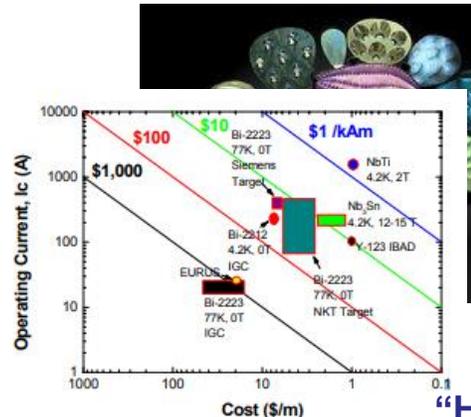
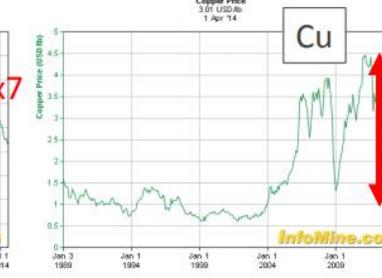
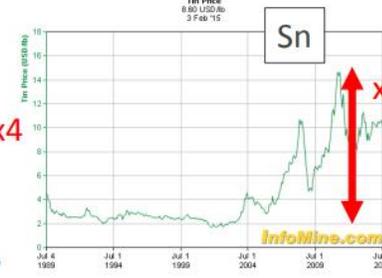
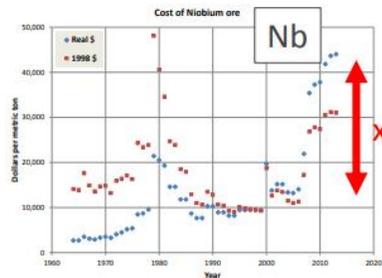
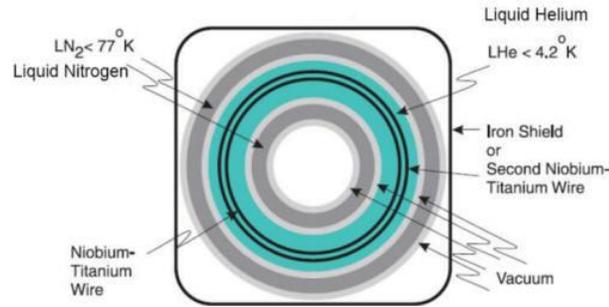


# HYPERFINE

## Portable MR Imaging



## Niobium-Titanium solenoid design @ 4.2°K (supraconductivity)



Classic magnet technology  
~1,500 liters of liquid helium



BlueSeal micro-cooling technology  
~7 liters of liquid helium

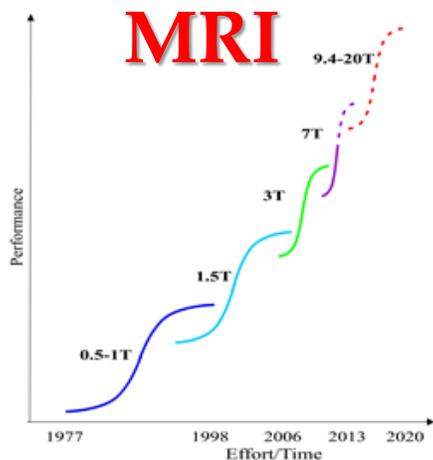
Type I Nb in 2014 ~\$420/kg

Sn in 2014 ~\$18/kg

Cu in 2014 ~\$6/kg

"Helium free" Philips Ingenia Ambition X 1.5T MR

- Slow start (imaging principle unclear, breakthrough, potential not clear compared to CT, cost), 80s economic recession
- Acceleration has been driven by increase in image quality (phased-array RF coils), **magnetic field** and cost decrease

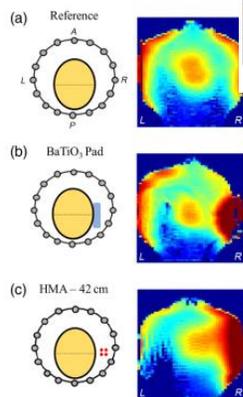
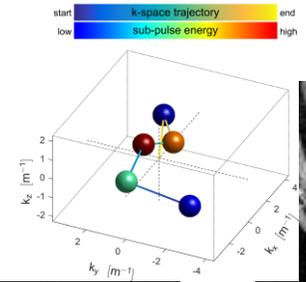
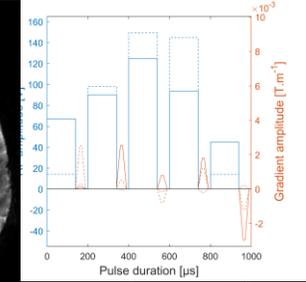
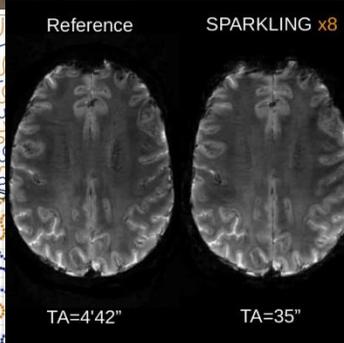
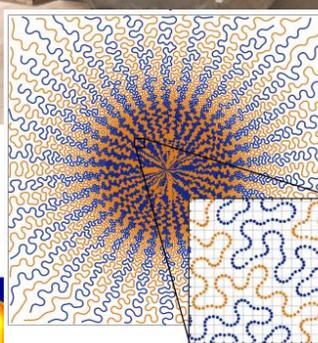
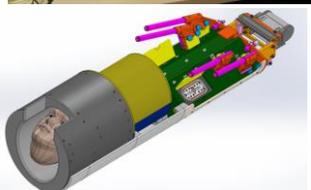
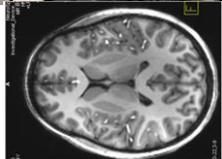


**End of 2020**

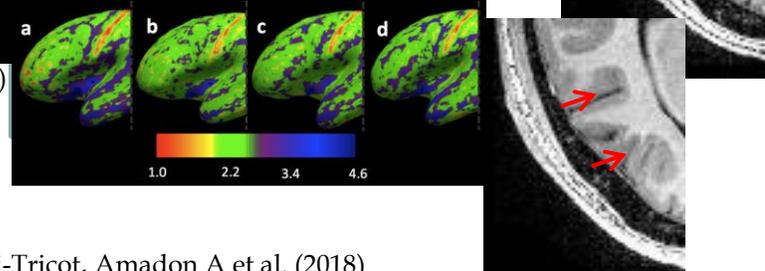
- 3T :  $\approx$  10000 installed systems
- 7T :  $\approx$  800 installed systems (FDA certification in 2017!)
- 1 @ 8T and 5 @ 9.4T systems (USA, Germany)
- 11.7T reached @ NeuroSpin (MRI not yet operational)**
- 1 x 10.5T Minneapolis (operational)
- 2 head-only 11.7T systems: USA (NIH), KOREA (status ?)
- projects for 11.7T: Nottingham, Nymegen, Heidelberg
- USA projet (14T or 20T)



12Tx/22Rx coil (7T)



Prospective SPARSe K-space sampLING (SPARKLING)  
Ph. Ciuciu, C. Lazarus et al. NeuroSpin



PHYSICAL REVIEW X 8, 031083 (2018)

Featured in Physics **Hybridized meta-atom (HMA) passive insert boosts RF field**  
Kerker Effect in Ultrahigh-Field Magnetic Resonance Imaging

Marc Dubois,<sup>1</sup> Lisa Leroi,<sup>2</sup> Zo Raolison,<sup>2</sup> Redha Abdeddaim,<sup>1,\*</sup> Tryfon Antonakakis,<sup>3</sup> Julien de Rosi,<sup>1</sup> Alexandre Vignaud,<sup>2</sup> Pierre Sabouroux,<sup>1</sup> Elodie Georget,<sup>2,†</sup> Benoit Larrat,<sup>2</sup> Gérard Tayeb,<sup>1</sup> Nicolas Bo Alexis Amadon,<sup>2</sup> Franck Mauconduit,<sup>5</sup> Cyril Poupon,<sup>2</sup> Denis Le Bihan,<sup>2</sup> and Stefan Enoch<sup>1,‡</sup>

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<sup>3</sup>Multiwave Innovation AG, 1228 Geneva, Switzerland  
<sup>4</sup>ESPCI Paris, PSL Research University, CNRS, Institut Langevin, 75005 Paris, France  
<sup>5</sup>Siemens Healthineers, 93210 Saint Denis, France

- Tomi-Tricot, Amadon A et al. (2018)
- M. Cloos, N. Boulant, M. Luong, G. Ferrand, E. Giacomini, M.-F. Hang, D. Le Bihan, and A. Amadon, NeuroImage 62:2140-50 (2012).

**New RF coil designs & metamaterials**

**Acquisition and Image Reconstruction/Processing have become completely intermingled (Machine Learning)**

*To the End*