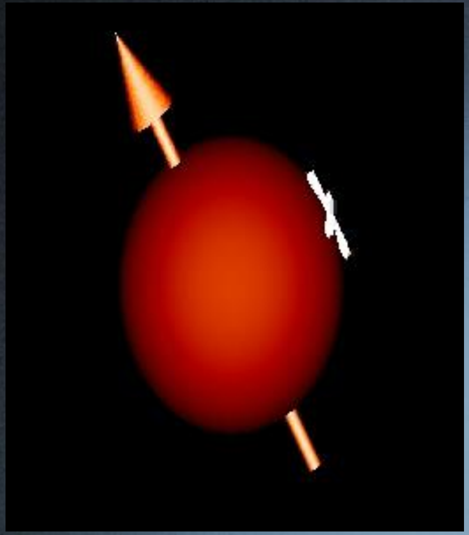
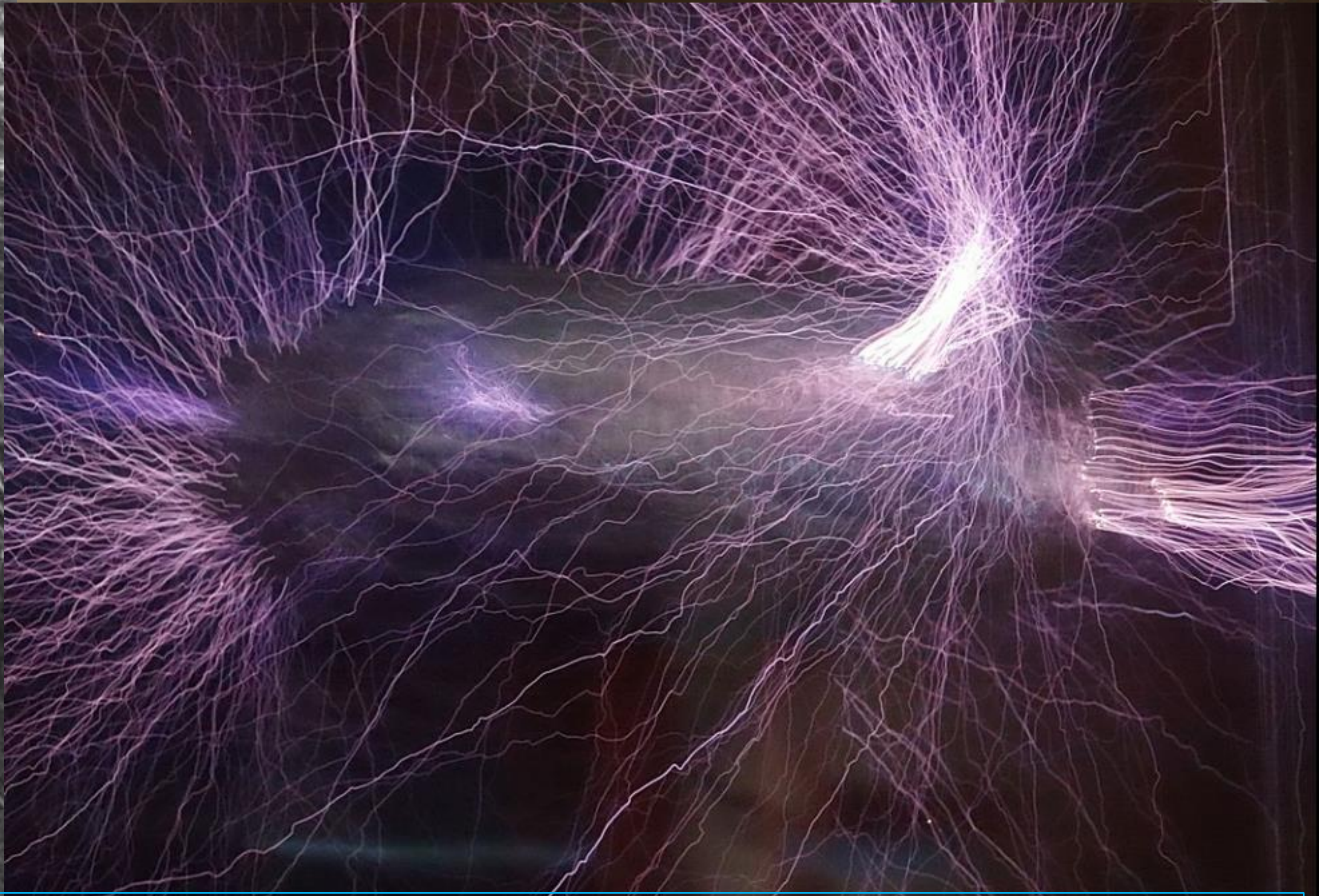


Historie a současnost zobrazovacích systémů MR v ČR

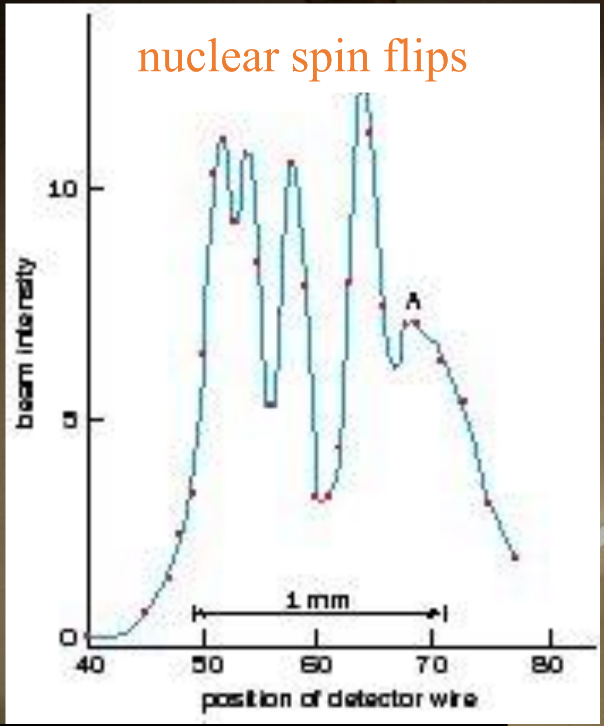
Jaroslav Tintěra
IKEM

Nikola Tesla: génius, který dal jméno magnetickému poli



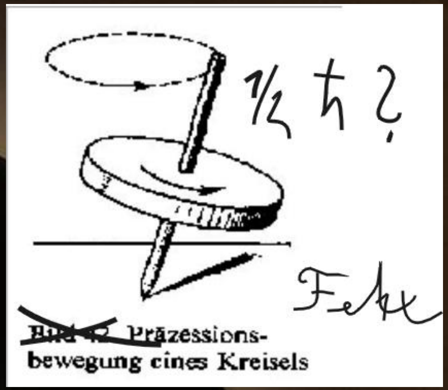
Objev jaderné magnetické rezonance (NMR)

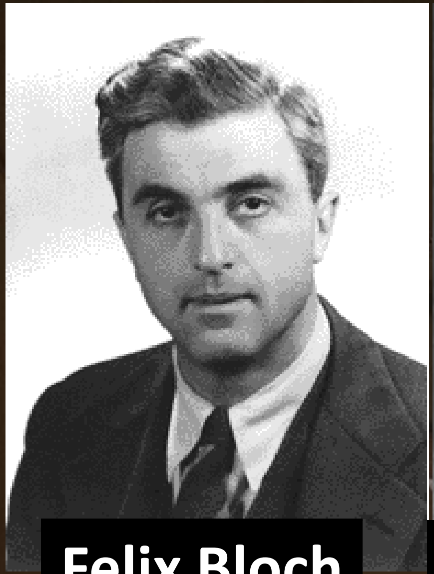
Isisdor Rabi



rezonanční experiment
s magnetickými vlastnostmi jádra
1933

The Nobel Prize in Physics 1944
"for his resonance method for recording
the magnetic properties of atomic nuclei"





Felix Bloch
Stanford

Edward Purcell
Harvard

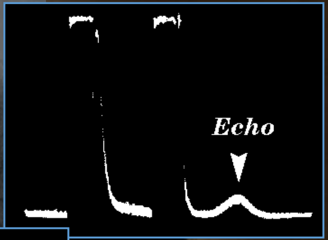
nukleární magnetická rezonance
1945

The Nobel Prize in Physics 1952
"for their development of new methods for nuclear magnetic precision measurements
and discoveries in connection therewith"

Chemická 50. a 60. léta NMR

Biologická 70. léta: uplatnění v medicíně?

Spektrometr Varian



Erwin Hahn
1950

Raymond Damadian

1971:
relaxační konstanty tkání a tumoru se liší

Spektrometr ÚPT Brno 1961

Josef Dadok
1960

MR zobrazování (MRI) a spektroskopie „in vitro“

Paul Lauterbur

Peter Mansfield

Paul Lauterbur

1973: 1. MRI zkumavky s vodou

Peter Mansfield

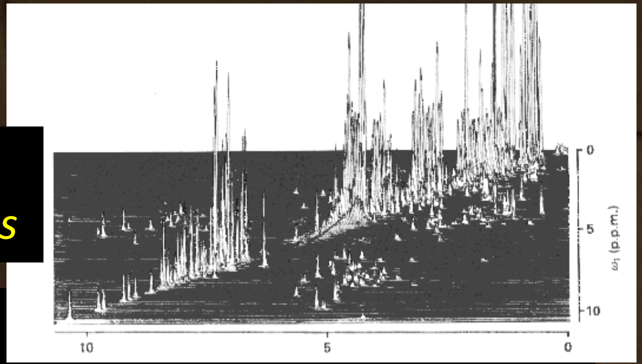
1973: teorie k-prostoru

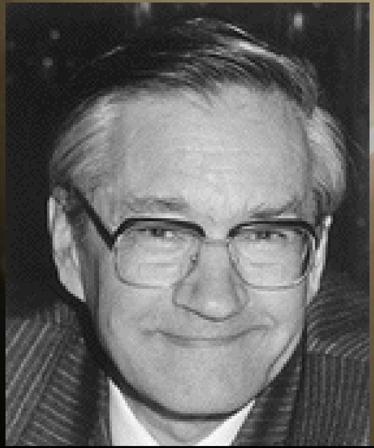
1977: návrh Echo-Planar imaging (EPI)

The Nobel Prize in Physiology and Medicine 2003

"for their contributions to magnetic resonance imaging"

structure and connectivity of the most complex molecules





Richard Ernst

1975: navrhl frekvenční a fázové kódování NMR signálu a použití Fourierovy transformace

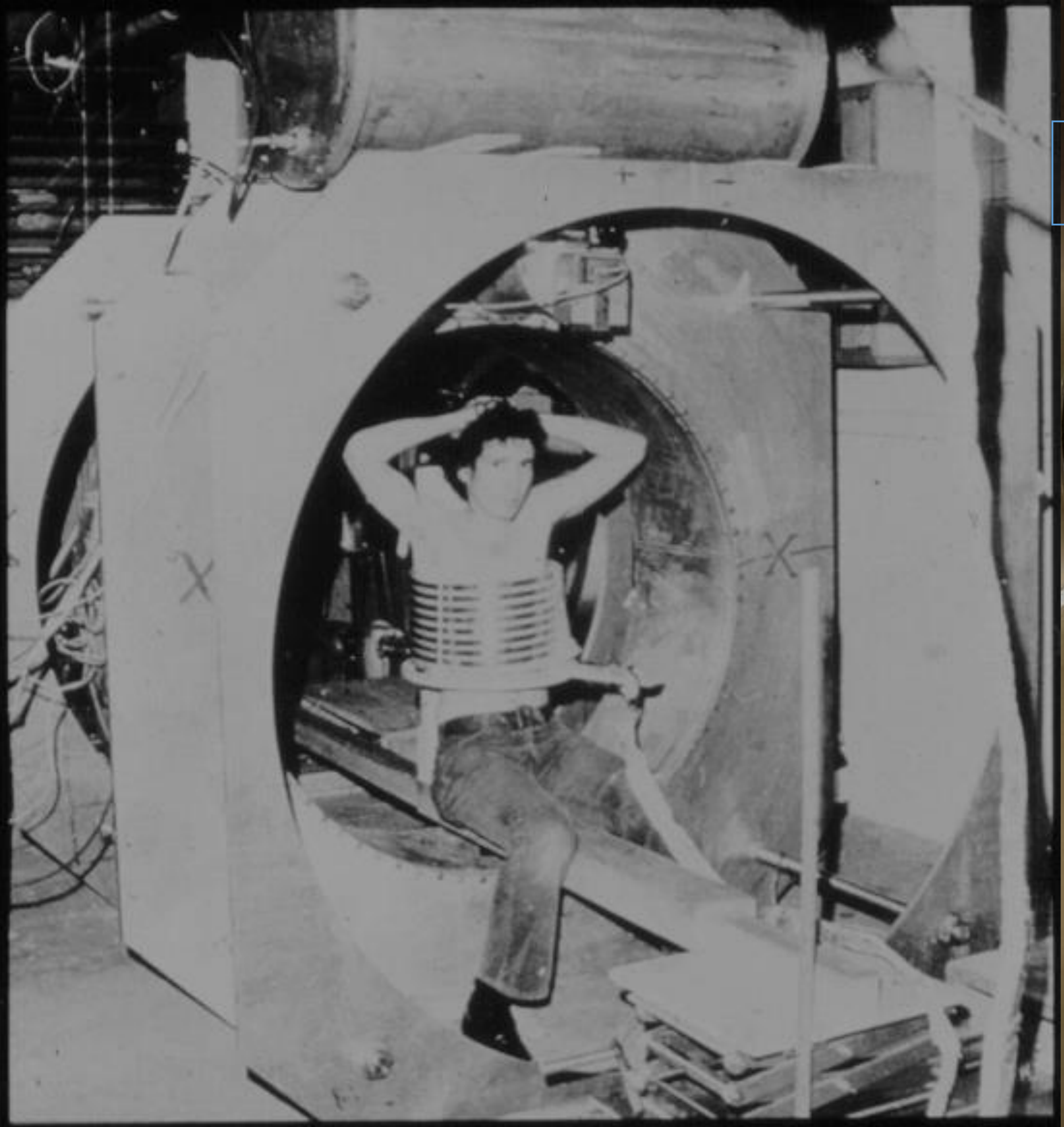
Richard Ernst

The Nobel Prize in Chemistry 1991

Gradient magnetického pole:

prostorové kódování signálu

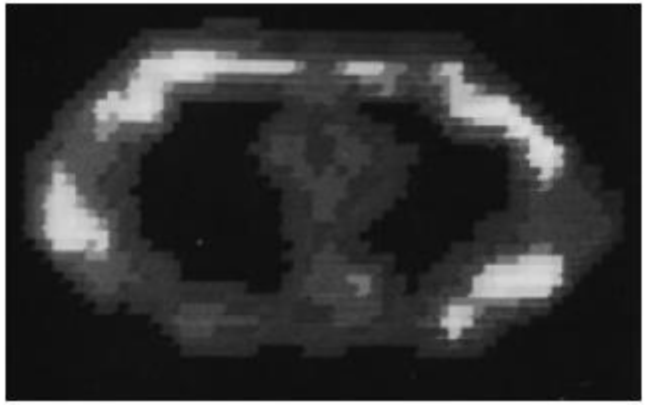
První skener MRI „in vivo“



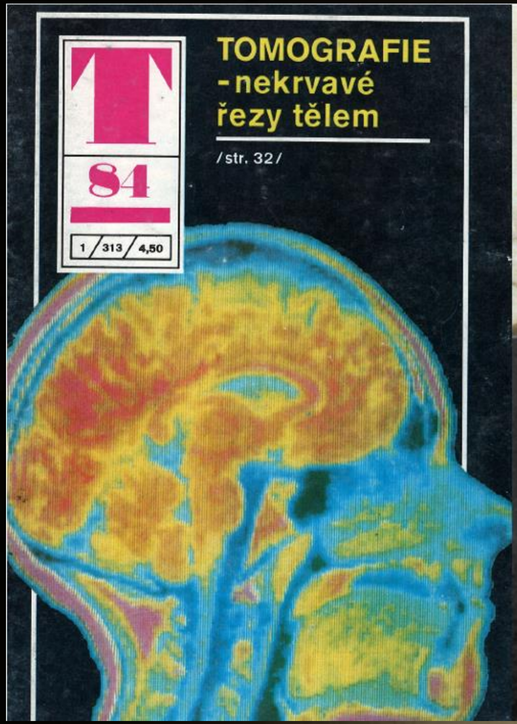
First successful NMR scan, July 1977
in Damadian’s machine, patient Dr. Minkoff

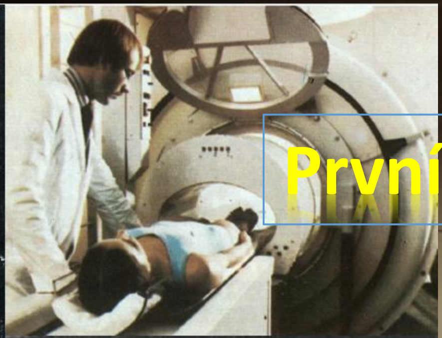
Raymond Damadian

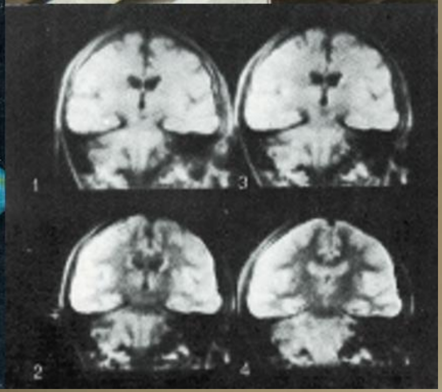
1977: 1. celotělový MRI – čas měření 4,5 hodiny



1. MR v ČR: IKEM, prof. Alfréd Belán







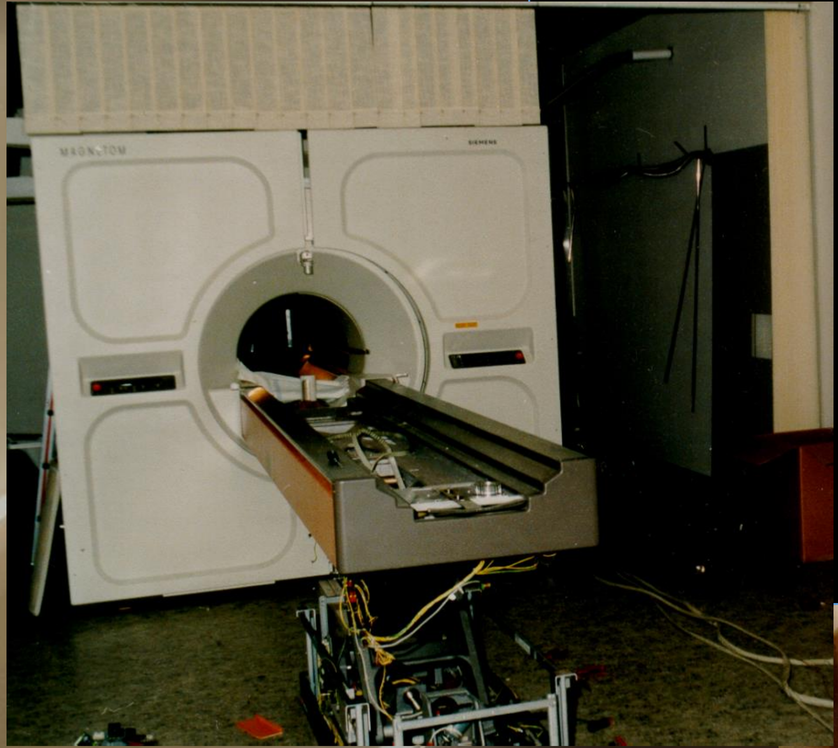
První zmínka o MRI?

Siemens Magnetom 1.5 T GBS 2

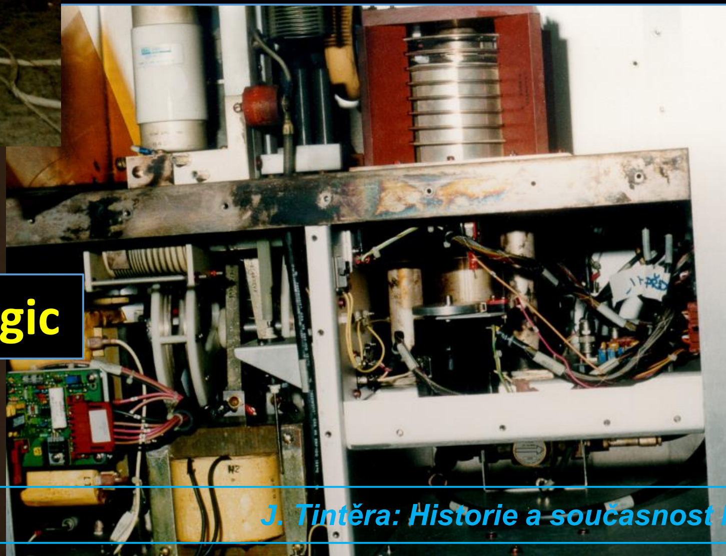
Supravodivý magnet 1,5T

gradienty 10 mT/m
slew-rate 10 T/m/s

1-kanálový RF systém
CP RF cívky
jádra: ^{1}H, ^{31}P, ^{23}Na

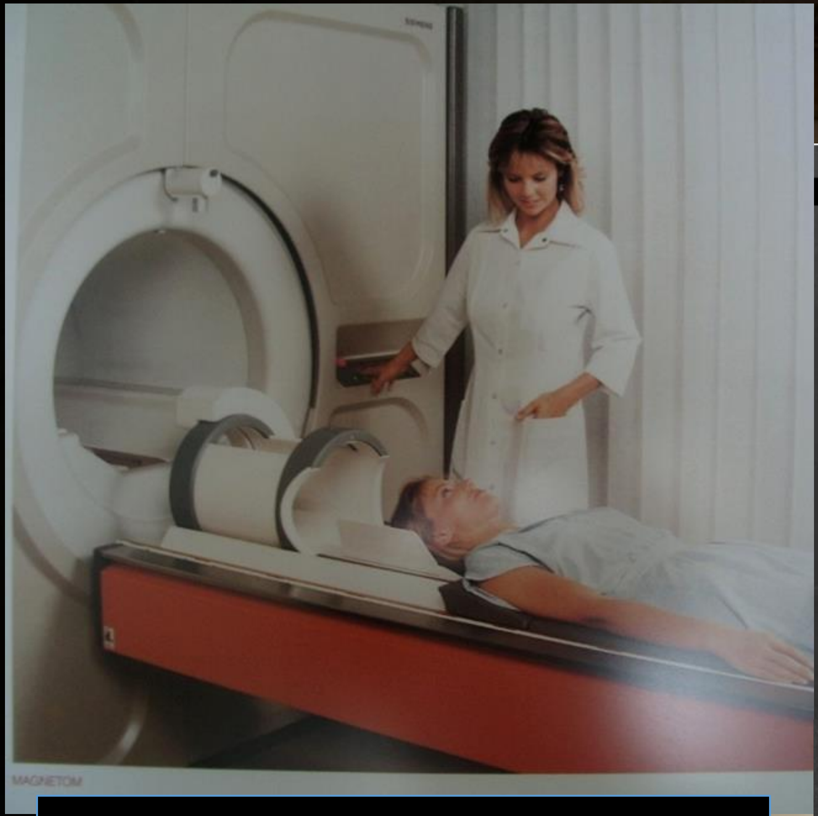


IKEM 1.9.1987: zahájena instalace

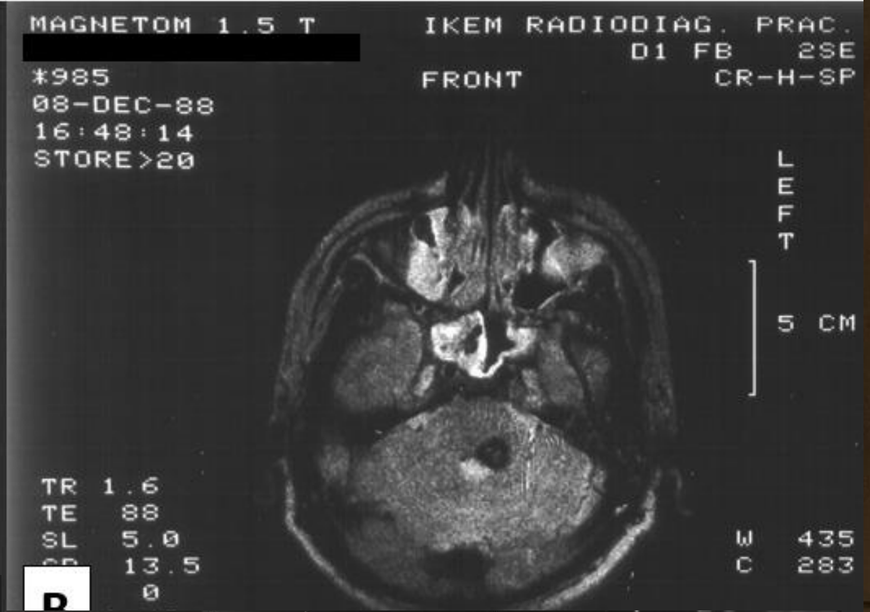


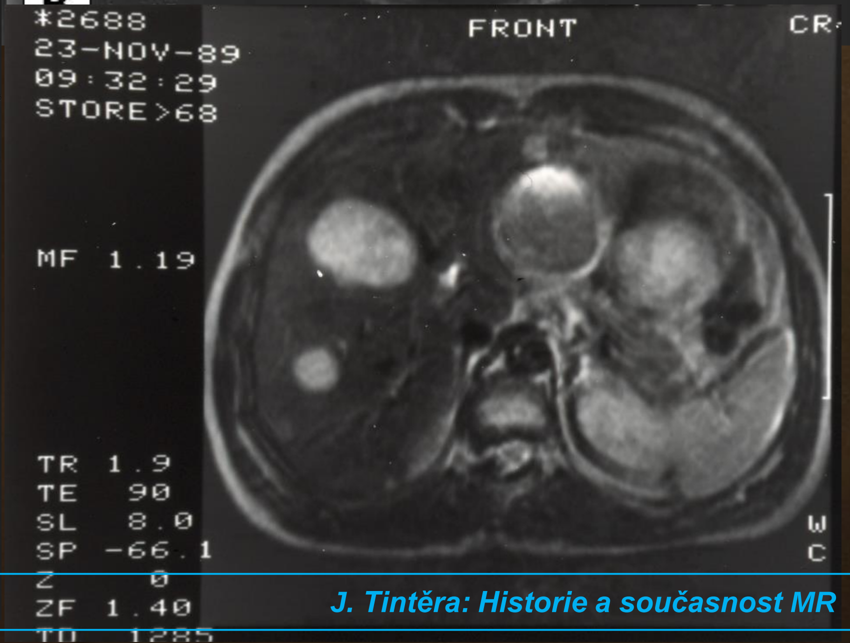
RF vysílač Analogic

IKEM 1.1.1988: Zahájení provozu 1. MR tomografu

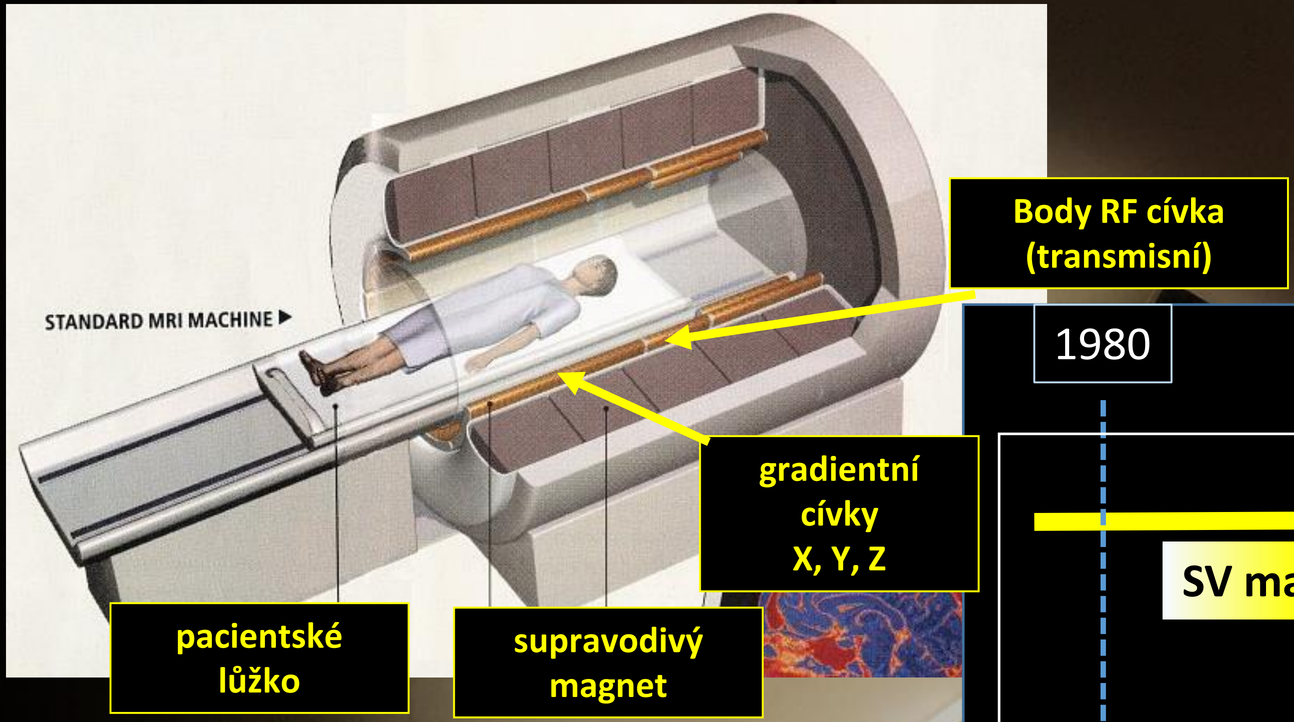


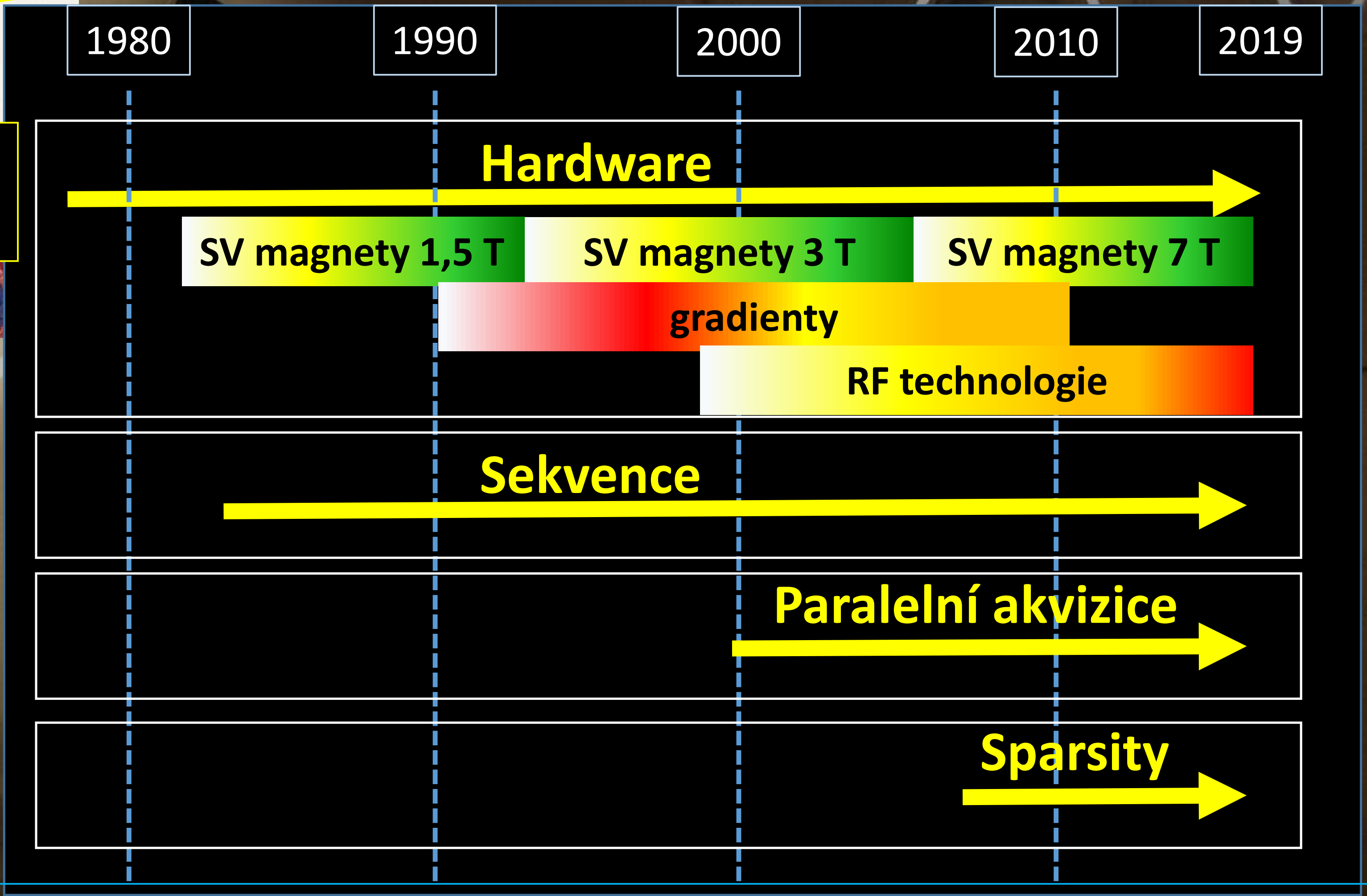
Siemens Magnetom 1.5T GBS 2





Historický vývoj





Magnet: ***vytvoření magnetizace***
Gradientní systém:
prostorové kódování signálu
RF systém:
excitace magnetizace
a snímání MR signálu

MR

Magnety:

- roste zastoupení vysokých polí
- *větší otvor pro pacienta*
- *kratší tunel*

Gradientní systém

Gradienty projektu Connectome

Moderní design gradientů

Introduced by R. Turner et al.

Shim cívky

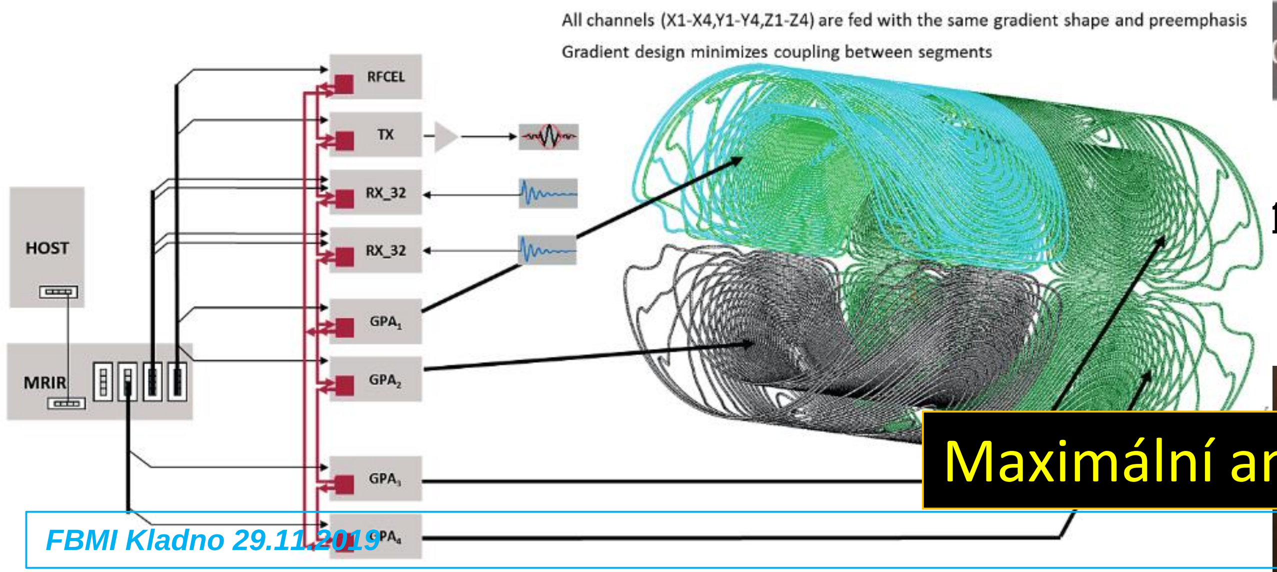
Jedno-vrstvé gradientní cívky	Aktivně stíněné gradienty	(Asymetrické) hlavové, nebo planární gradienty	Dedikované systémy: hlava / celotělové	Velký diametr a vysoká G_{max}
G ~ 3 mT/m	G ~ 10 mT/m	G ~ 20 mT/m	G ~ 40 mT/m	G ~ 45-80 mT/m
SR ~ 2 T/m/s	SR ~ 10 T/m/s	SR ~ 50 T/m/s	SR ~ 200 T/m/s	SR ~ 200 T/m/s

1980

20 mT/m, SR 160 T/m/s umožňuje EPI

80 mT/m, SR 700 T/m/s hlavové gradienty

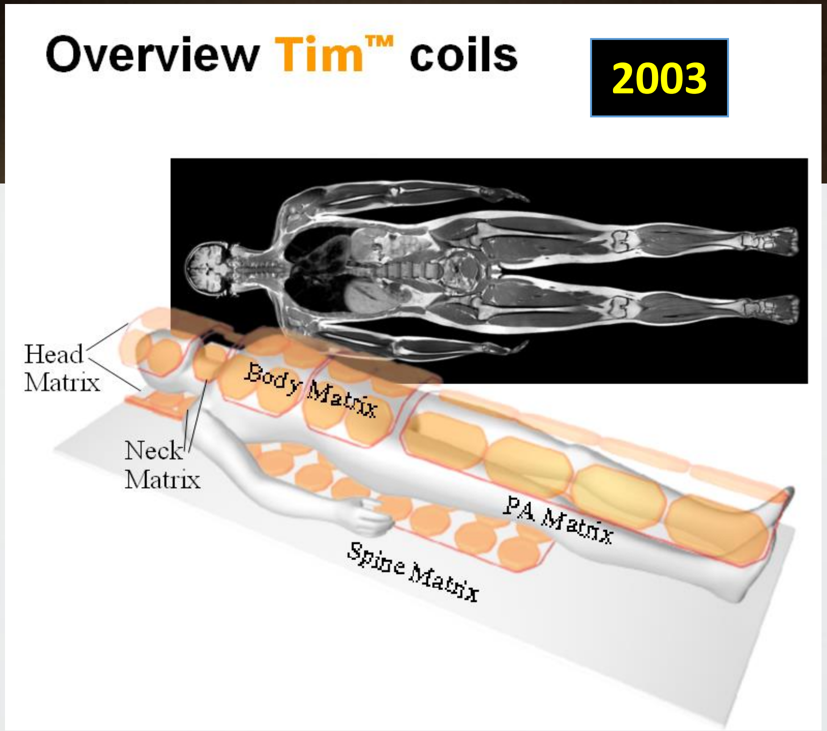
40 mT/m, SR 200 T/m/s kardio / EPI gradienty

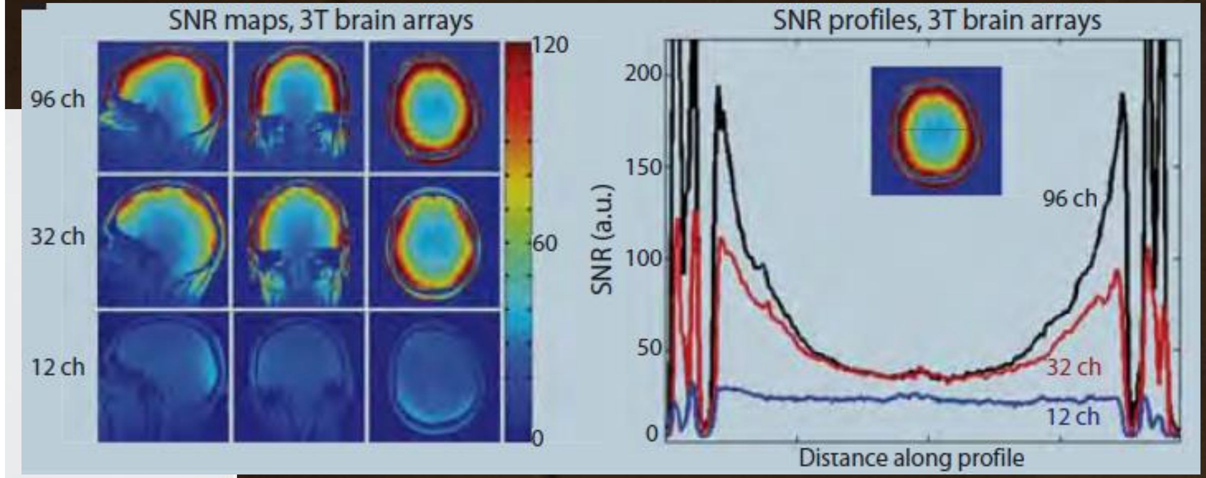


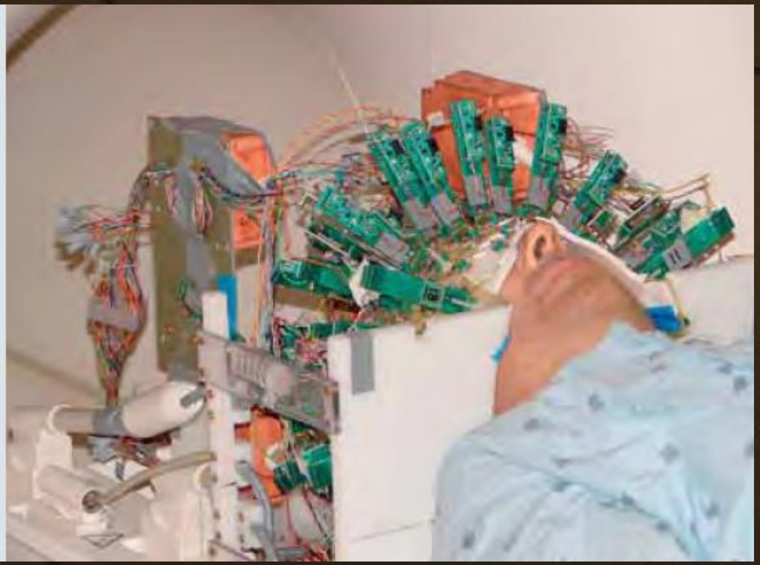
Maximální amplituda 300 mT/m

Rozvoj RF systémů od ~ 2003

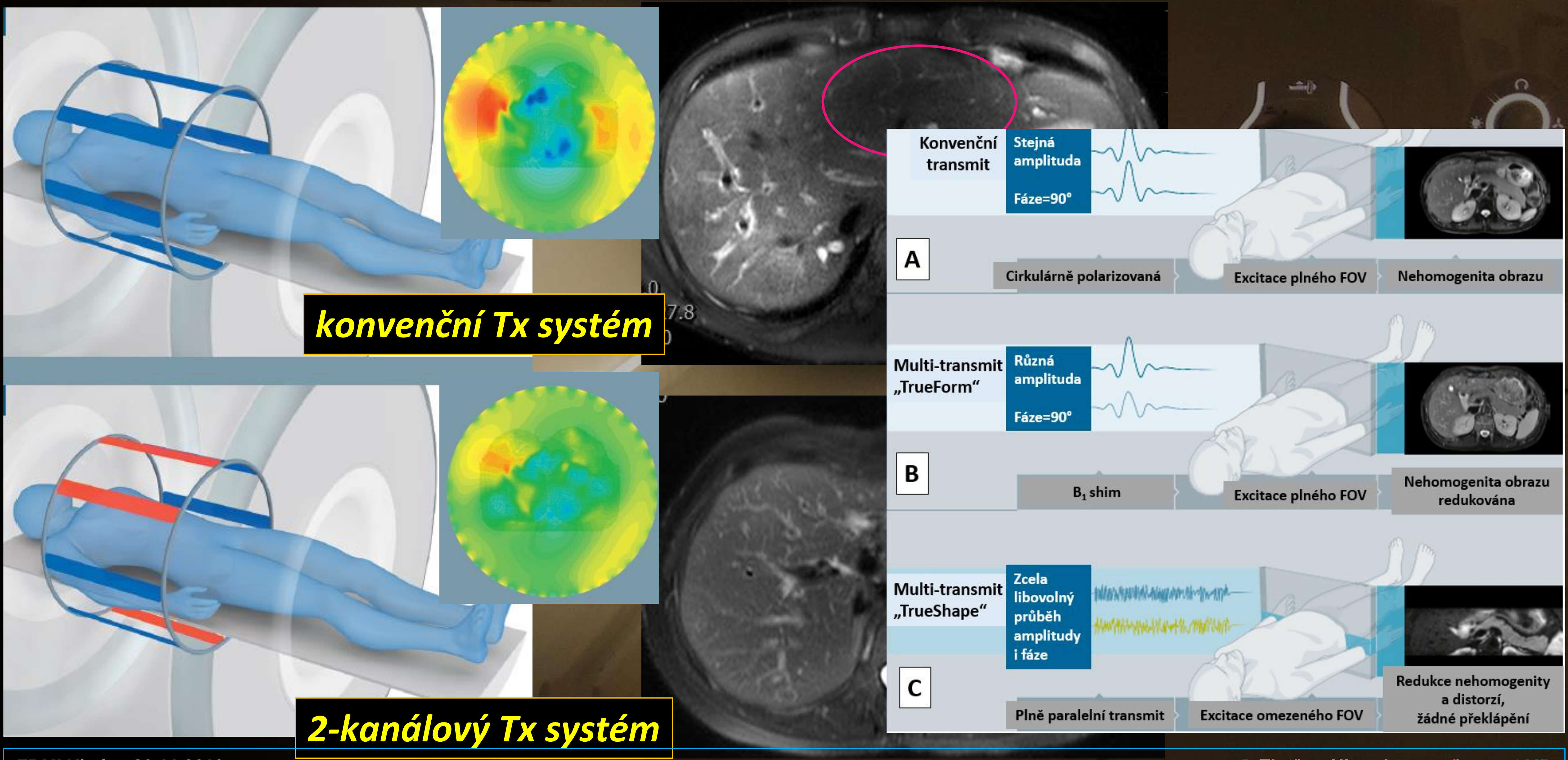
Narůstá počet paralelních přijímacích RF cívek







Multi-transmit systém na 3T a vyšších polích



Dnešní MR tomografy

Magnet:
1,5 T, 3 T, 7 T

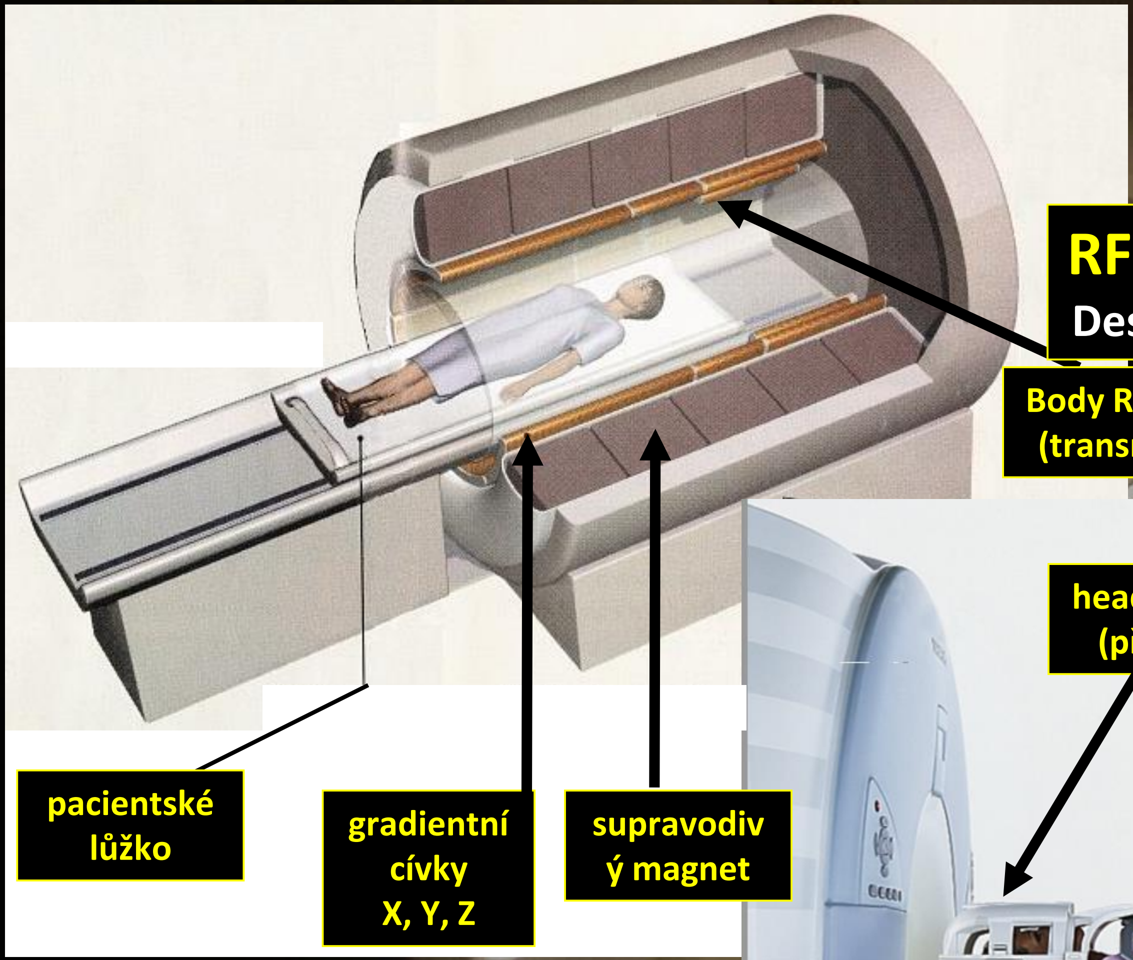
Gradienty: až 300 mT/m

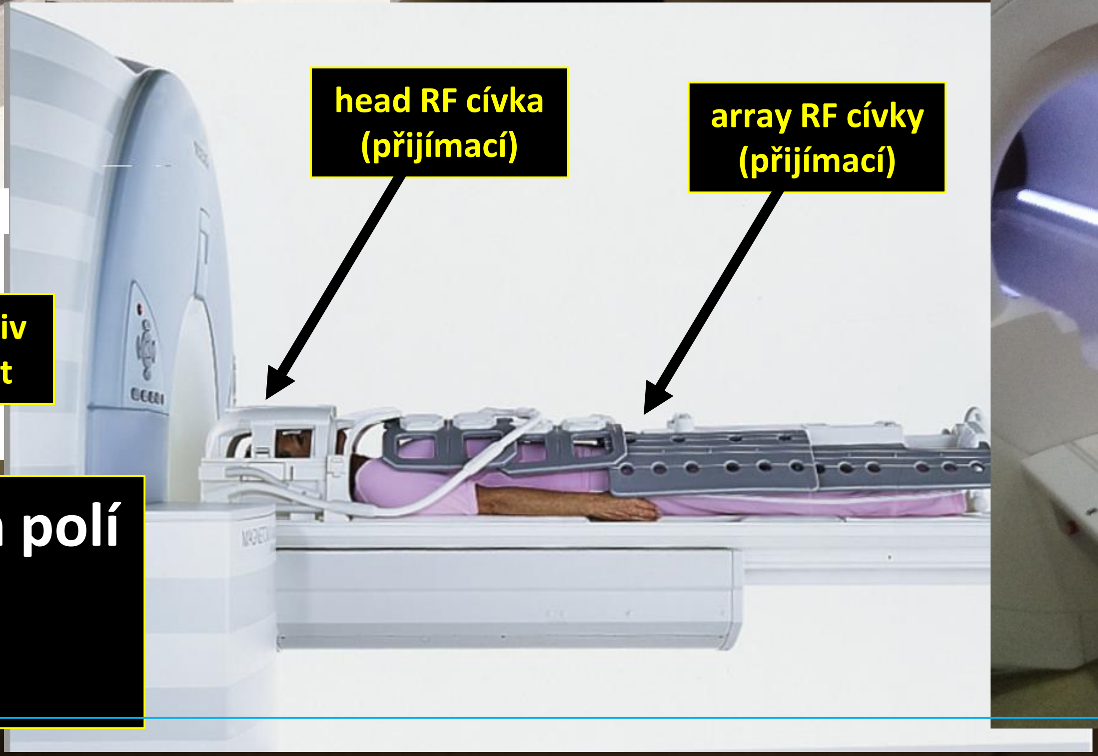
RF systém:
Desítky paralelních přijímacích kanálů

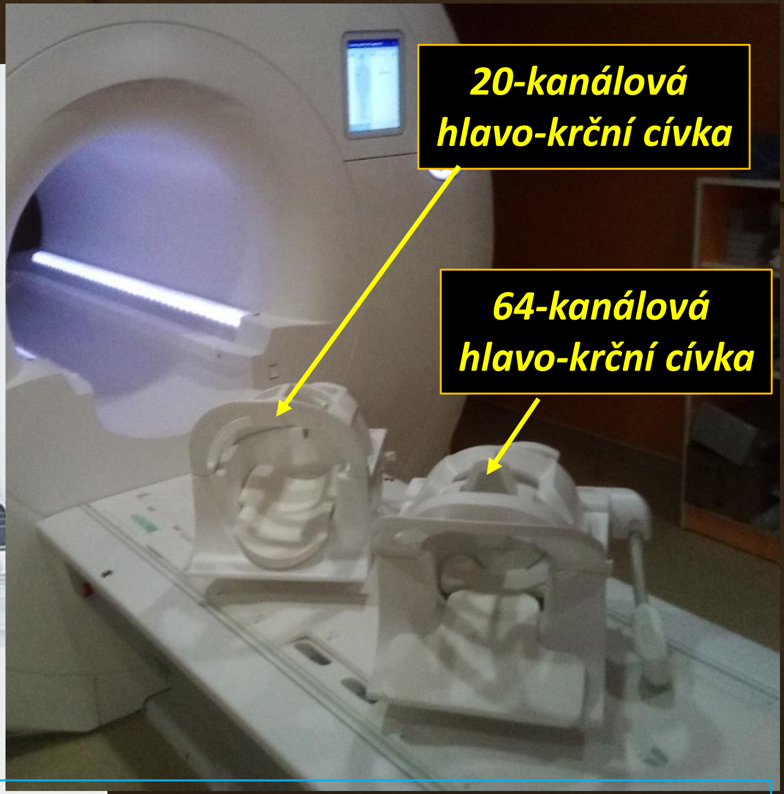
Praha 22 (6 x 3T)
Brno 11 (5 x 3T)
Ostrava 4 (0 x 3T)

celkem v ČR ~ 100 MR

z toho 18 3T magnetů







Roste zastoupení vysokých polí
výkon gradientů
počty RF kanálů

Magnet: *1,5T*
Gradienty:
G_{max}: *10 mT/m*
SR: 10 T/m/s
RF systém:
1 TX, 1 Rx kanál

Magnet: *1,5T*
Gradienty:
G_{max}: *25 mT/m*
SR: 125 T/m/s
RF systém:
1 TX, 4 Rx kanály

Magnet: *1,5T*
Gradienty:
G_{max}: *45 mT/m*
SR: 200 T/m/s
RF systém:
1

Magnet: *3T*
Gradienty:
G_{max}: *45 mT/m*
SR: 200 T/m/s
RF systém:
1 TX, 18 Rx kanálů

Přichází Turbo spinové echo a EPI !!!

EPI Booster

Magnet: *1,5T*
Gradienty:
G_{max}
SR: 2
RF s
1 TX, 48 Rx kanálů

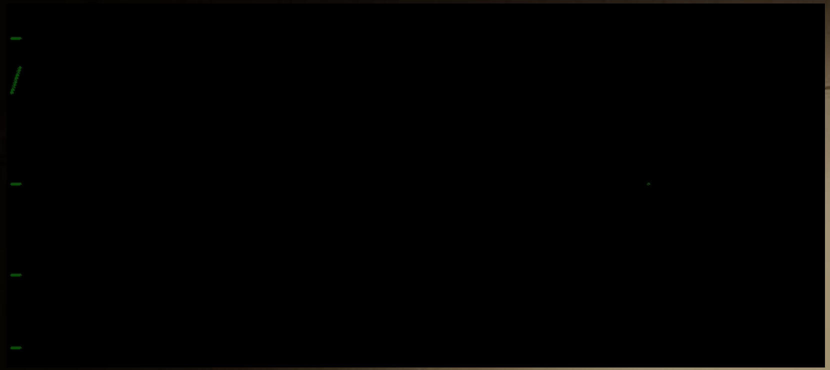
2016 Avanto Fit

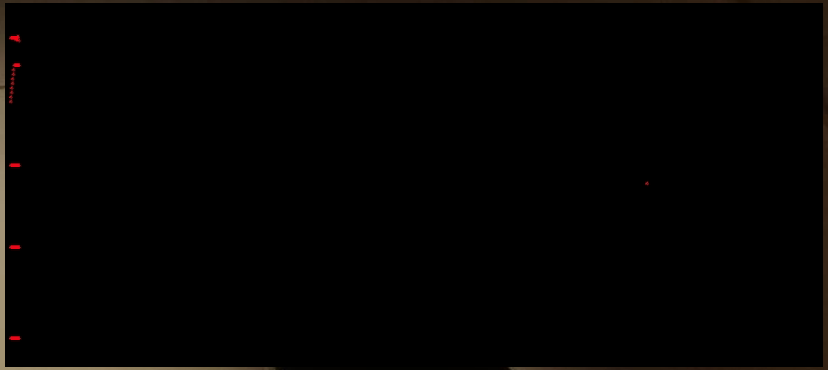
T
Gradienty:
60 mT/m
0 T/m/s
stém:
4 TX, 64 Rx kanály

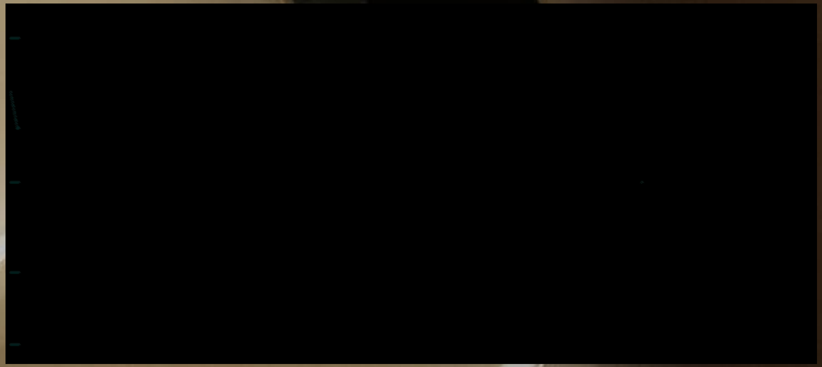
2019 Vida

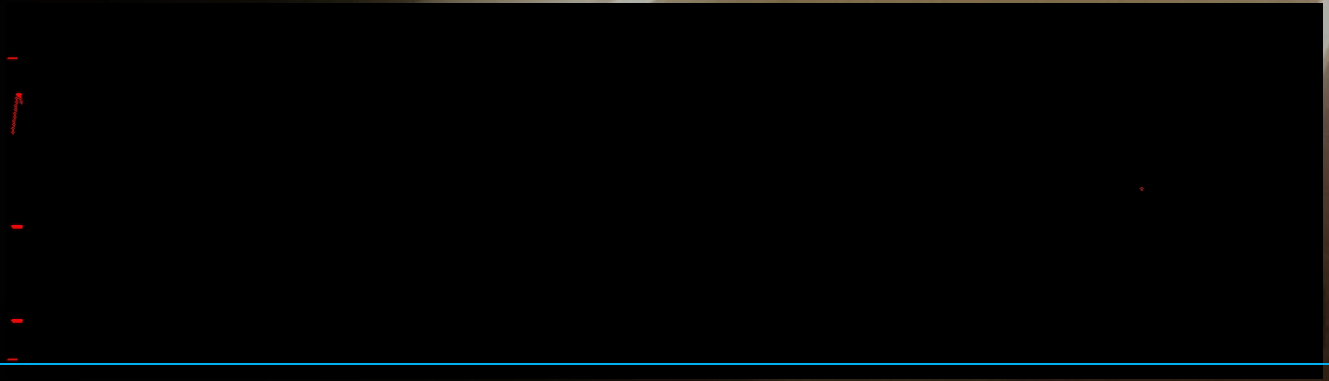
Nastává éra paralelního zobrazování!!!
3D spinové echo a další rychlé sekvence...

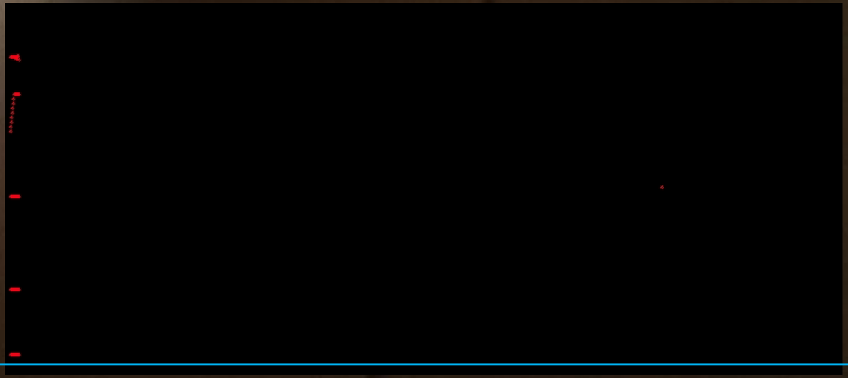
Sekvence pro MRI











Nová generace rychlých sekvencí: ~ 2000

Radiology. 2000 Sep;216(3):891-9.

Optimized single-slab three-dimensional spin-echo MR imaging of the brain.

Mugler JP 3rd[1], Bao S, Mulkern RV, Guttmann CR, Robertson RL, Jolesz FA, Brookeman JR.

Magnetic Resonance in Medicine 49:395–397 (2003)

Is TrueFISP a Gradient-Echo or a Spin-Echo Sequence?

Klaus Scheffler* and Jürgen Hennig

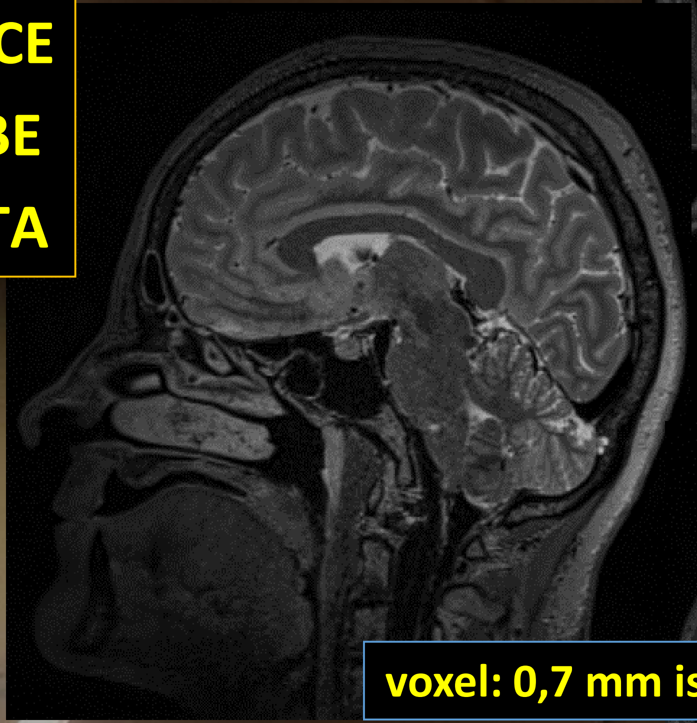
Magnetic Resonance in Medicine 48:684–688 (2002)

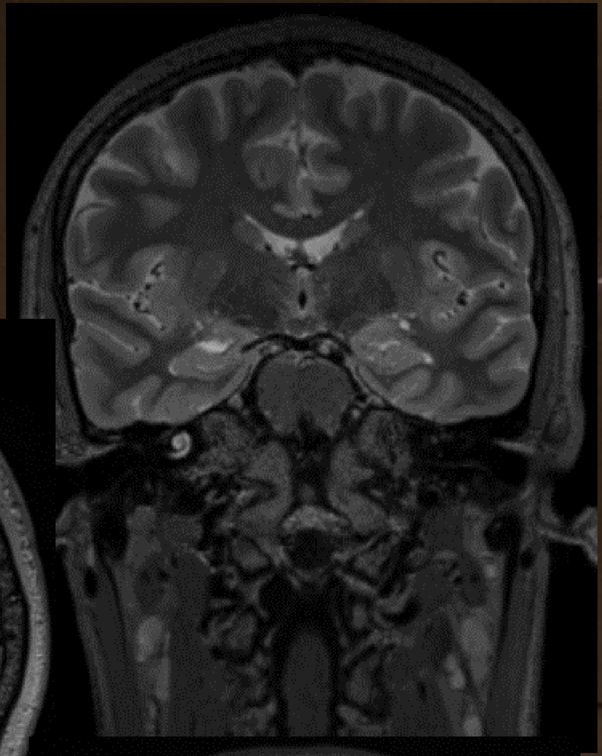
Are TrueFISP Images T_2/T_1-Weighted?

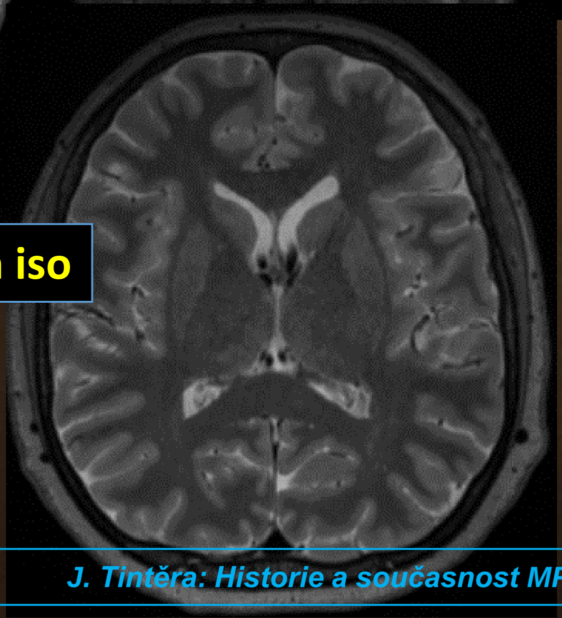
Teng-Yi Huang,[1,2] Ing-Jye Huang,[1,2] Cheng-Yu Chen,[2] Klaus Scheffler,[3] Hsiao-Wen Chung,[1,2*] and Hui-Cheng Cheng[4]

SPACE
CUBE
VISTA

TrueFISP
FIESTA
bFFE



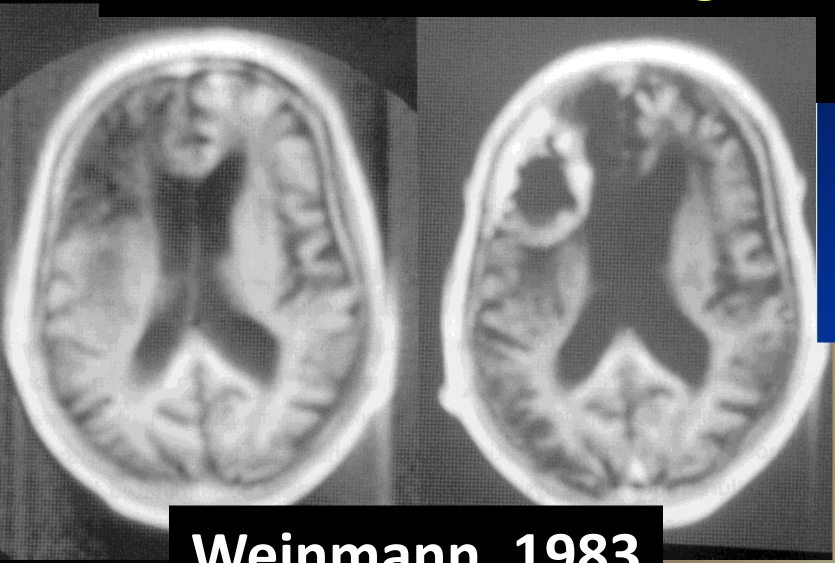




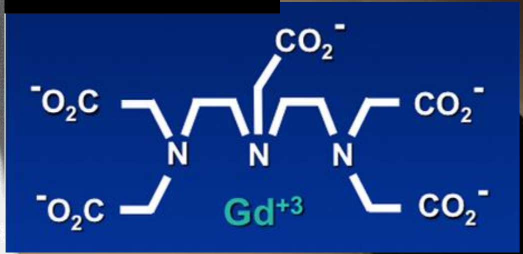
voxel: 0,7 mm iso

Kontrastní látka pro MRI: na bázi Gd + chelát

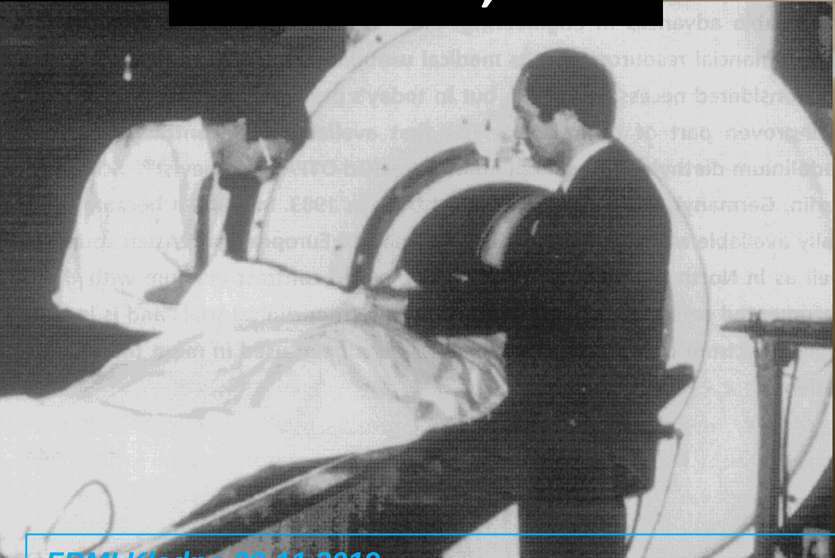
První klinická k.l.: Magnevist (Schering) 1988



Gd-DTPA



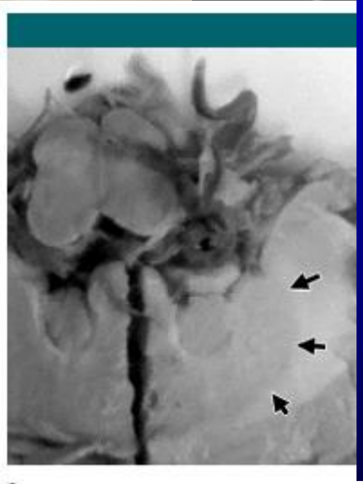
Weinmann, 1983



US action star is suing 11 drug firms for $10m, claiming his wife was

První intravaskulární

Vasovist (Schering) 2008

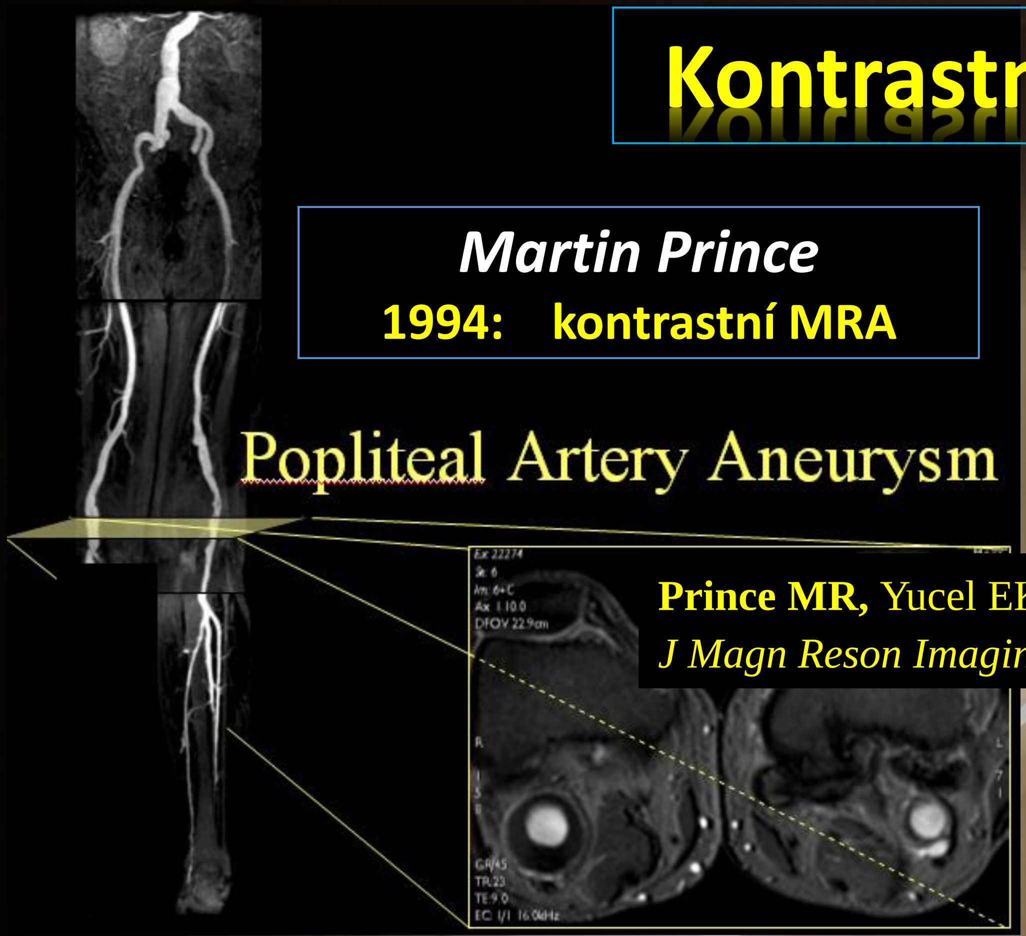


a. b.

Photographs of formalin-fixed brain tissue in a 78-year-old man with malignant lymphoma (subject 3 in the GBCA group). Arrows show the (a) dentate nucleus and inner (b) segment of the globus pallidus.

Gadoversetamid (Optimark)	lineární	pozastaven
Gadodiamid (Omniscan)	lineární	pozastaven
Gd-DTPA (Magnevist)	lineární	pouze intraartikulárně
Gadobenát (MultiHance)	lineární	pouze na játra
Gadoxetic acid (Primovist)	lineární	pouze na játra
Gadobutrol (Gadovist)	cyklický	povolen
Gadoteridol (ProHance)	cyklický	povolen
Gd-DOTA (Dotarem)	cyklický	povolen
Gd-DOTA (Clariscan)	cyklický	povolen

Kontrastní MR angiografie



Martin Prince

1994: kontrastní MRA

Prince MR, Yucel EK, Kaufman JA, Harrison DC, Geller SC. *J Magn Reson Imaging.* **1993** Nov-Dec;3(6):877-81

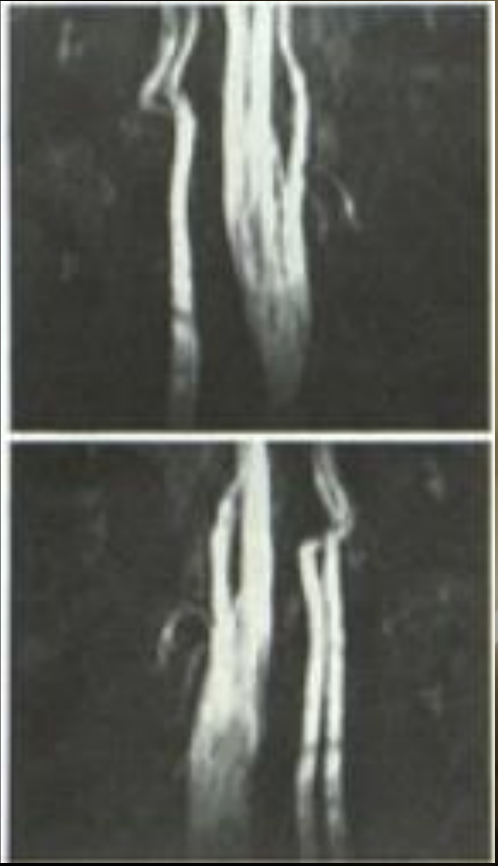
IKEM 1998:
renální tepny

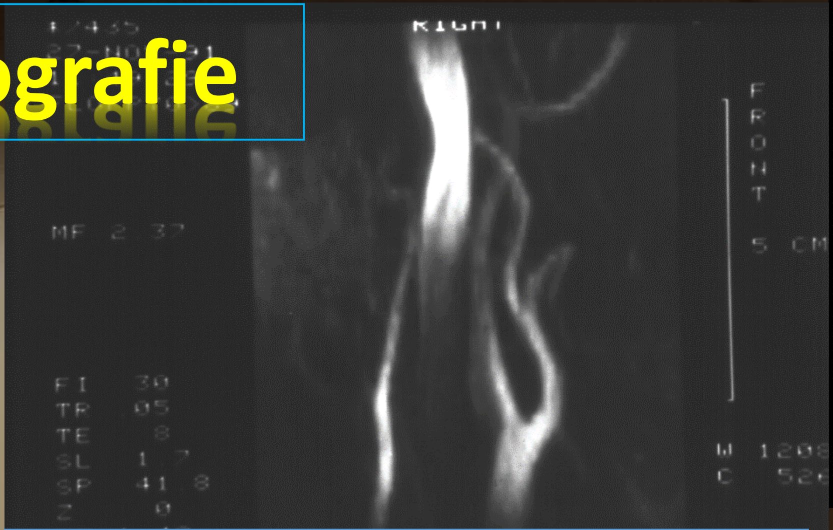
IKEM 2019:
periferní tepny

Nativní MR angiografie

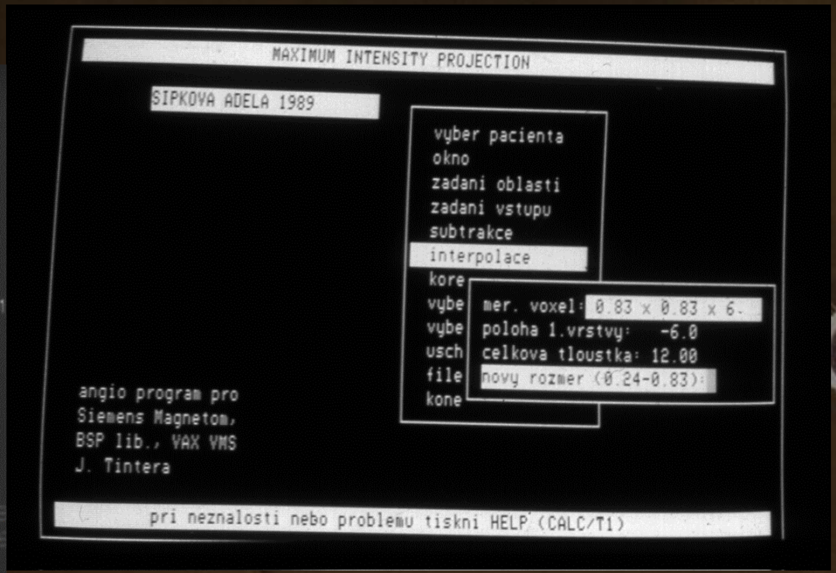
Charles Dumoulin

1987: MRA

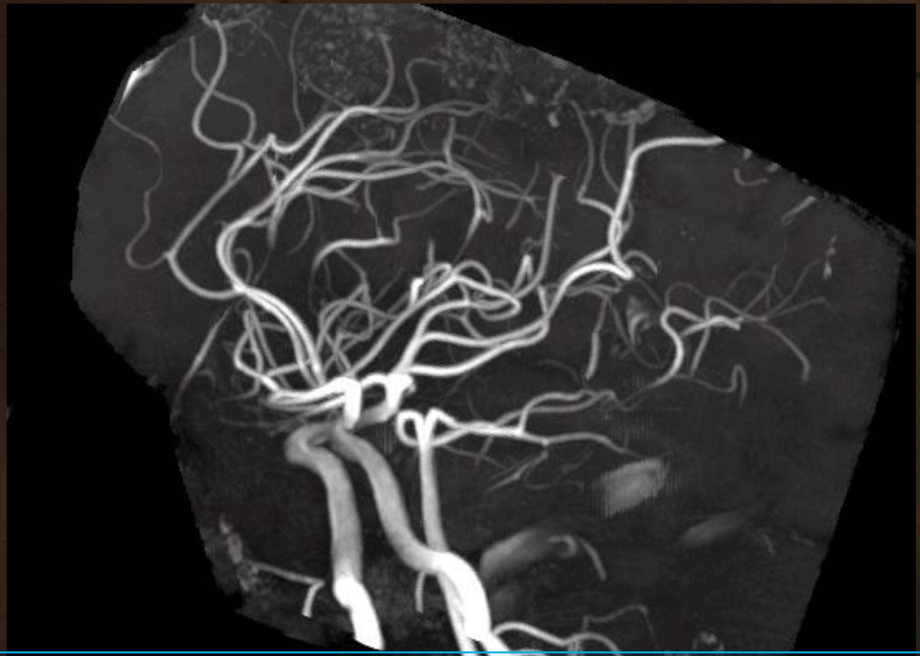




První MRA v ČSR: IKEM 1991



MRA v roce 2019

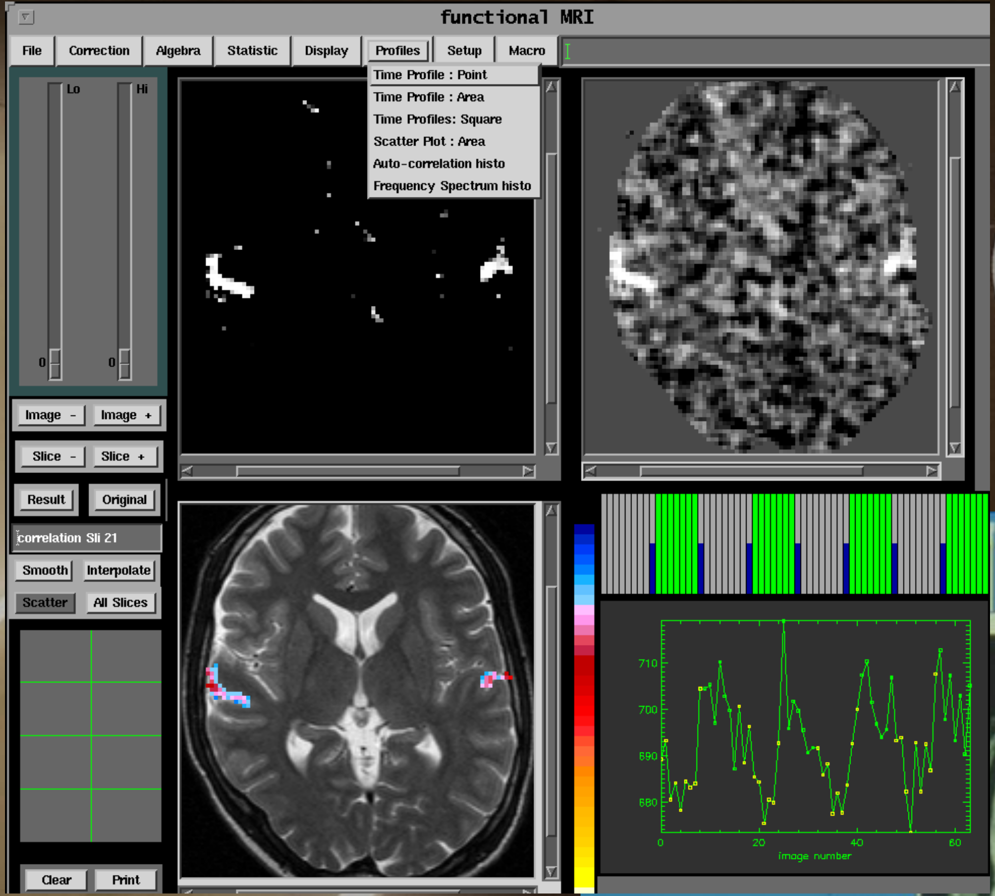


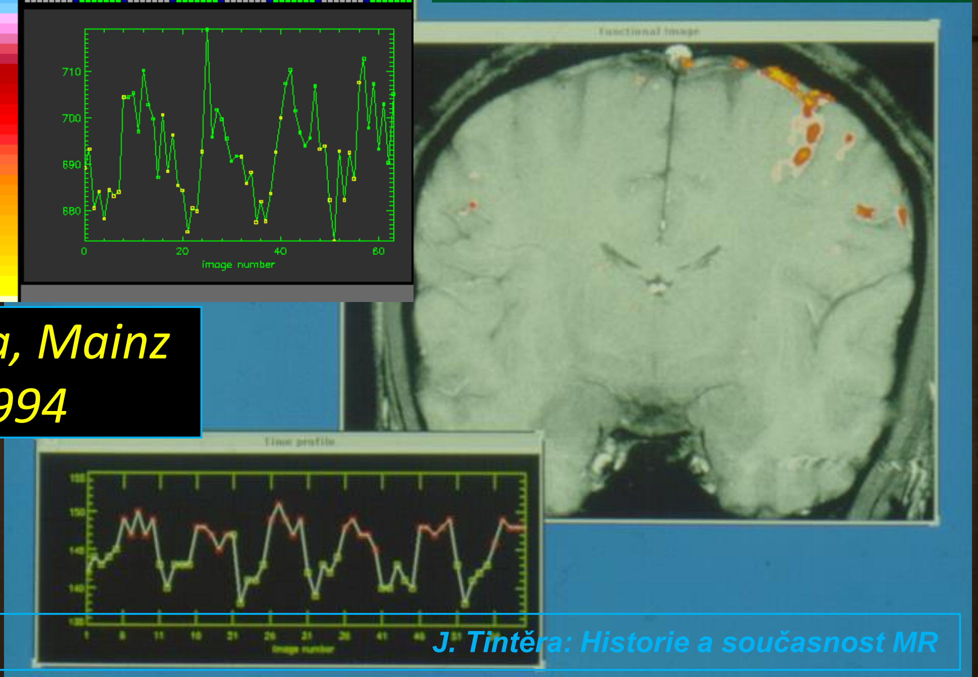
Funkční MR zobrazování: 1992

Jack Beliveau

Seiji Ogawa

BOLD

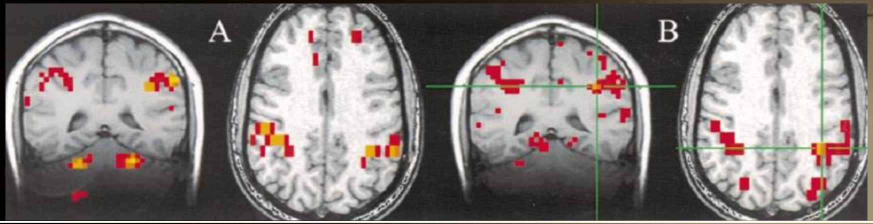




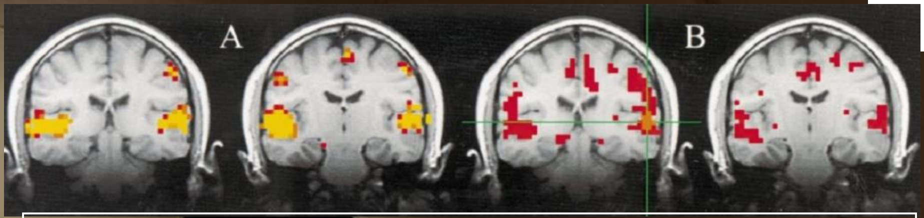
Tintěra, Mainz 1994

S.Ogawa, D.W. Tank, R. Menon, J.E. Ellerman, S.G Kim, H. Merkle and K. Ugurbil, *Proc. Natl. Acad. Sci. USA* **89**, 5951 (1992)

Funkční konektivita a mozkové sítě



Sensorimotor network (Cordes et al., 2000. AJNR)



Auditory network (Cordes et al., 2000. AJNR)

BRAIN CONNECTIVITY
Volume 1, Number 1, 2011
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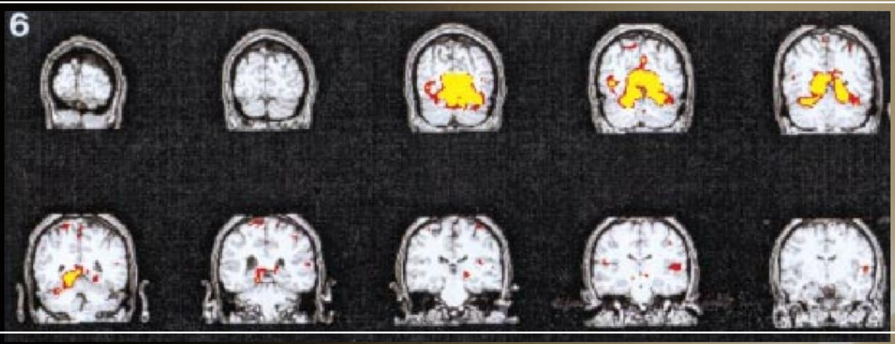
DOI: 10.1089/brain.2011.0008

Functional and Effective Connectivity: A Review

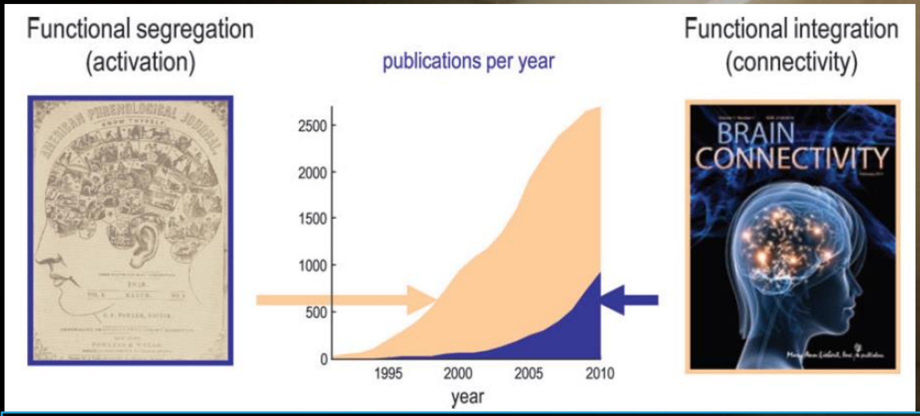
Karl J. Friston

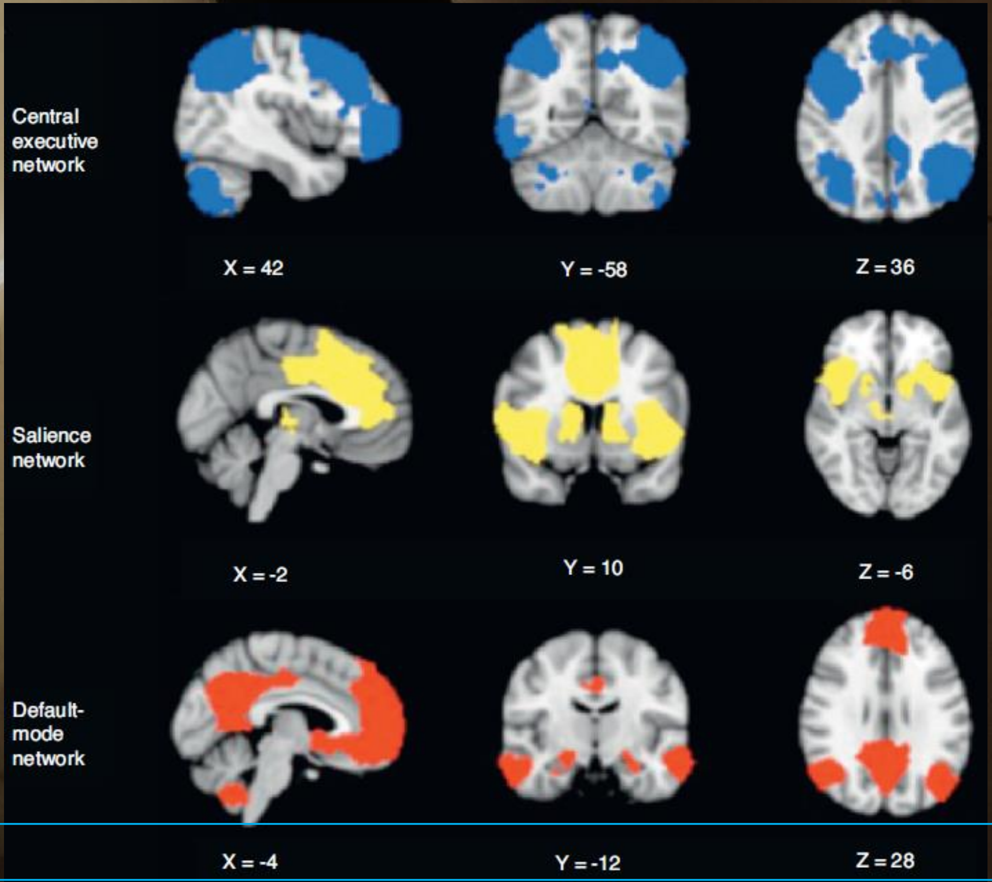
Large-scale brain networks and psychopathology: a unifying triple network model

Vinod Menon[1,2,3,4*]



Visual network (Lowe et al., 1998. Neuroimage)



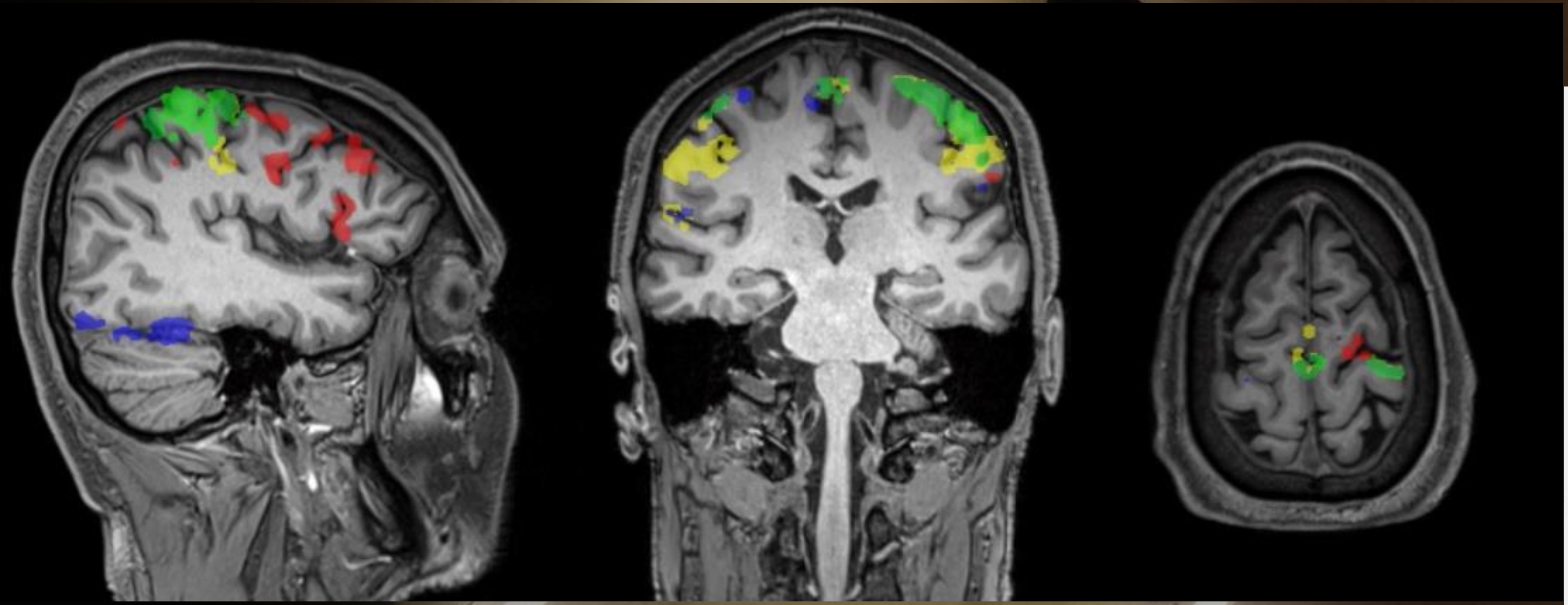


Fronto-parietální CEN:
pracovní paměť
pozornost

SN:
detekce a mapování významových externích podnětů a interních událostí

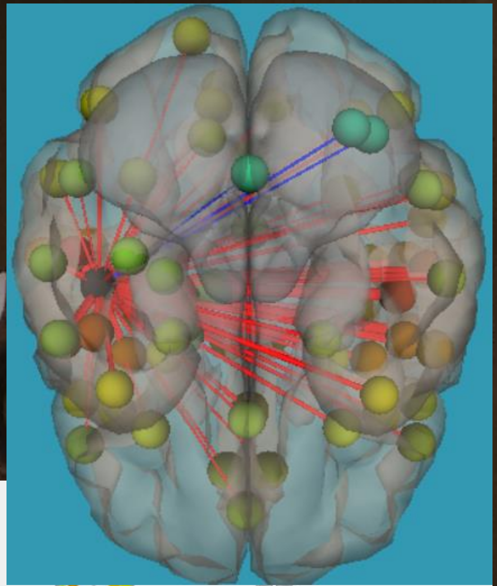
DMN:
self-referenční mentální aktivita

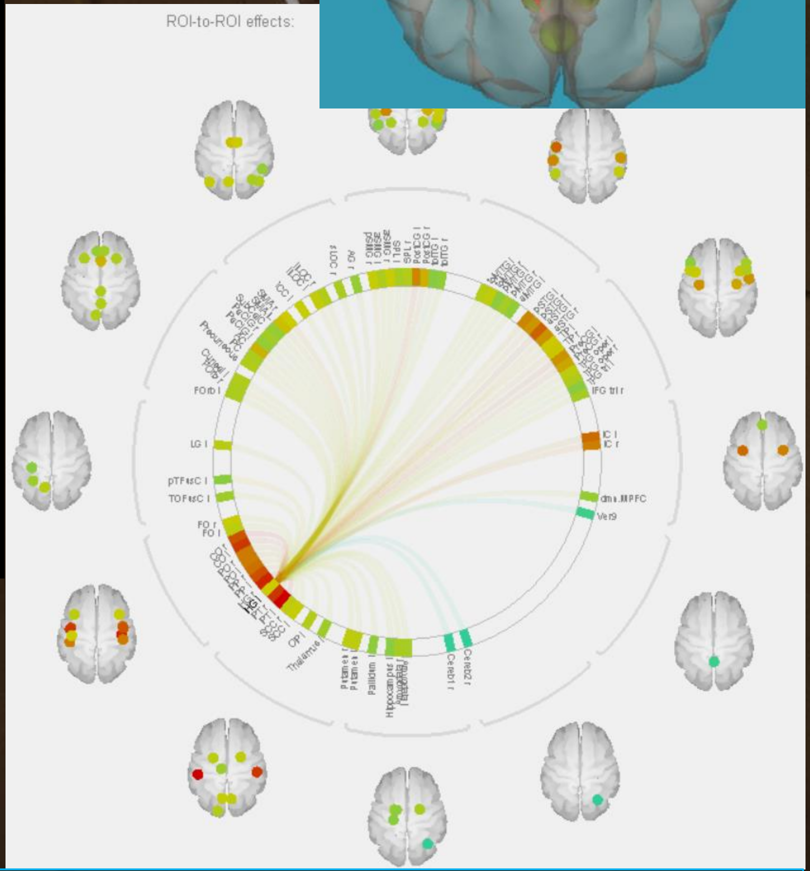
Stimulované fMRI: 2019
motorika a verbální funkce



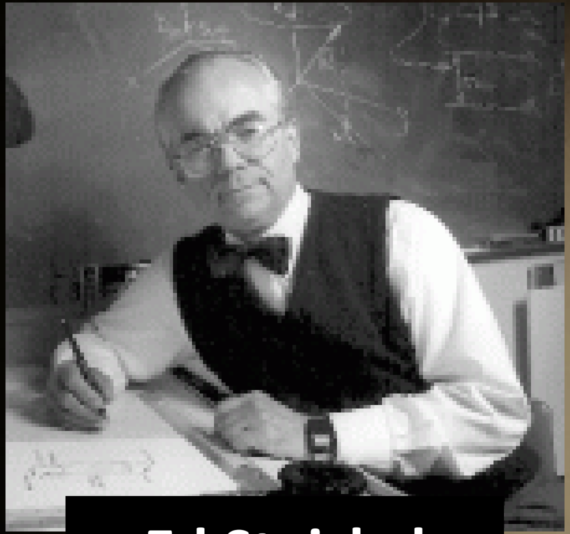
(červená)	test verbální fluence
(žlutá)	obličejové svaly
(modrá)	motorika LHK
(zelená)	motorika PHK

Resting state fMRI
konektivita



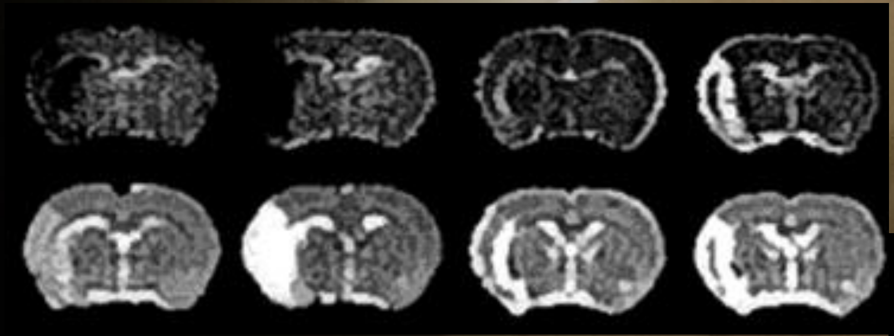


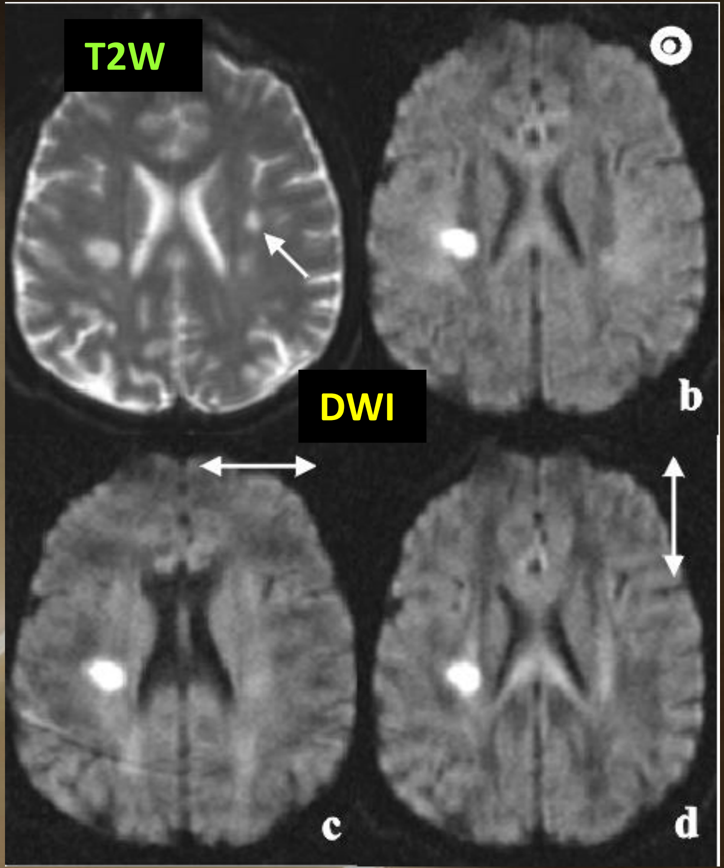
Zobrazení difúze: DWI



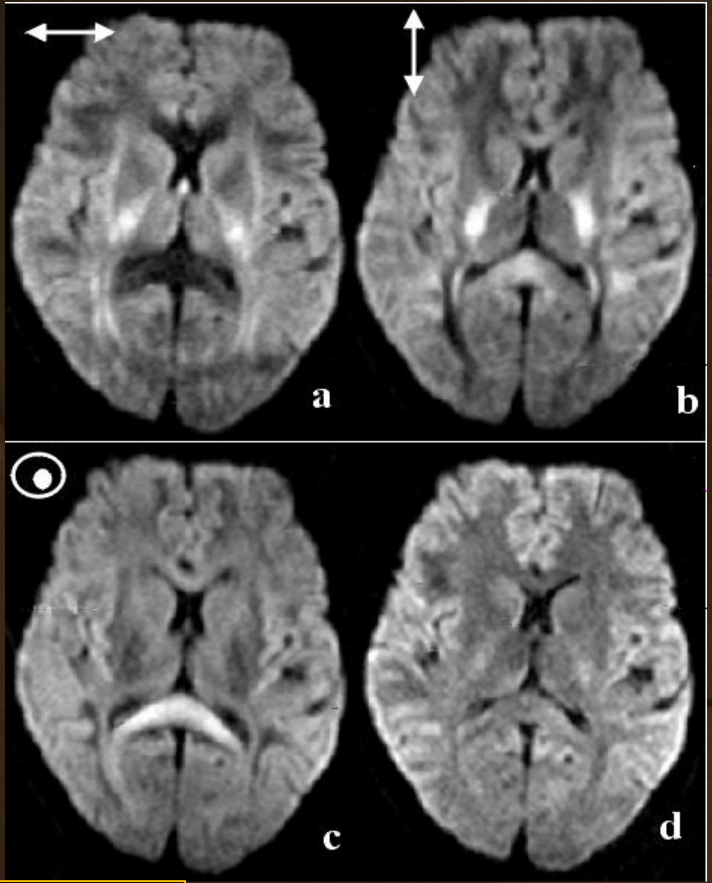
Ed Stejskal

E. O. Stejskal and J. E. Tanner,
J. Chem. Phys., **1965,** *42*, 288-92



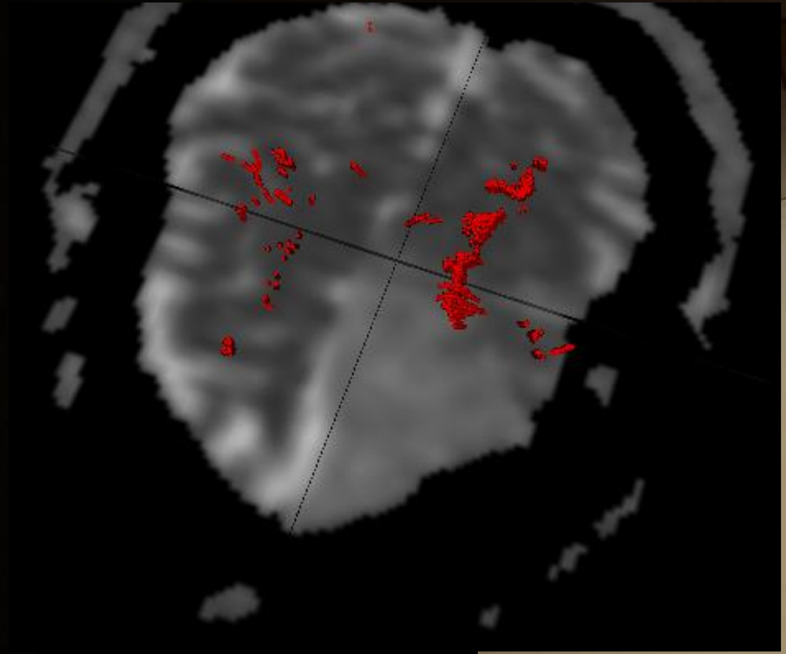


Moseley ME at al.
Magn Reson Med. **1990** May;14(2):330-46



DWI 1995:
single shot EPI

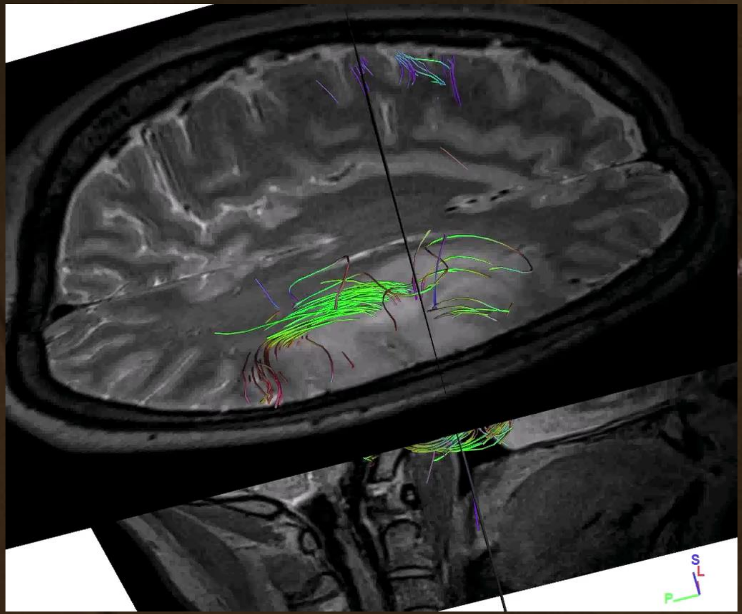
DWI a DTI: 2005 – 2019

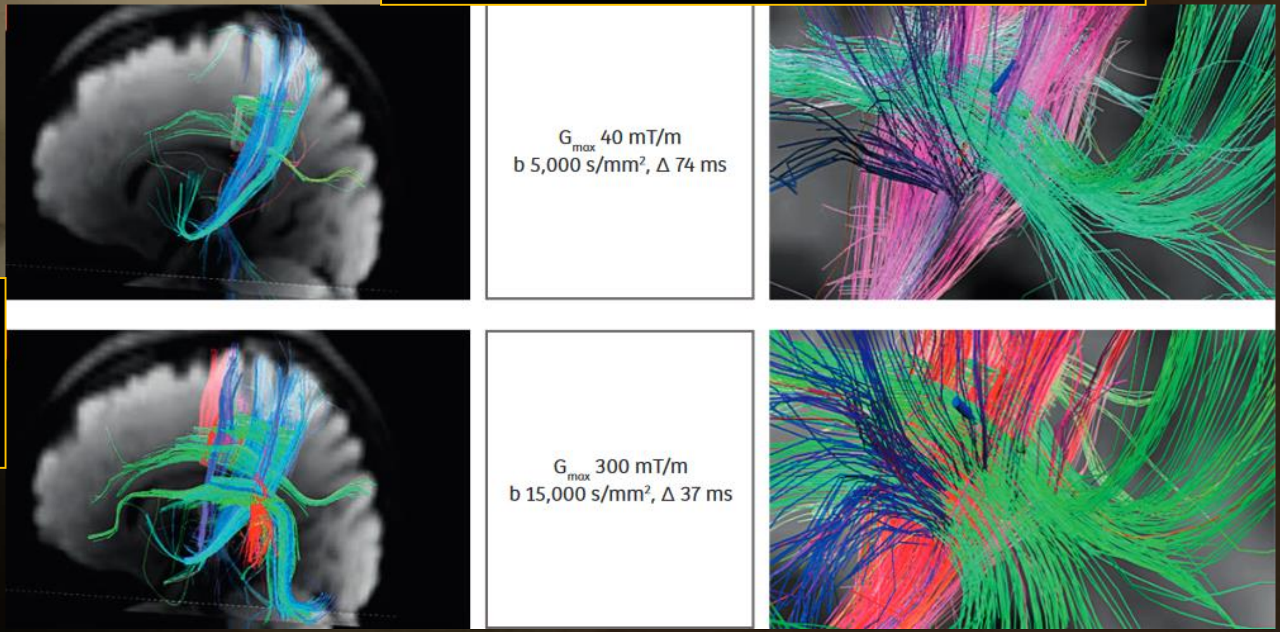


IKEM 2005

DWI 2017:

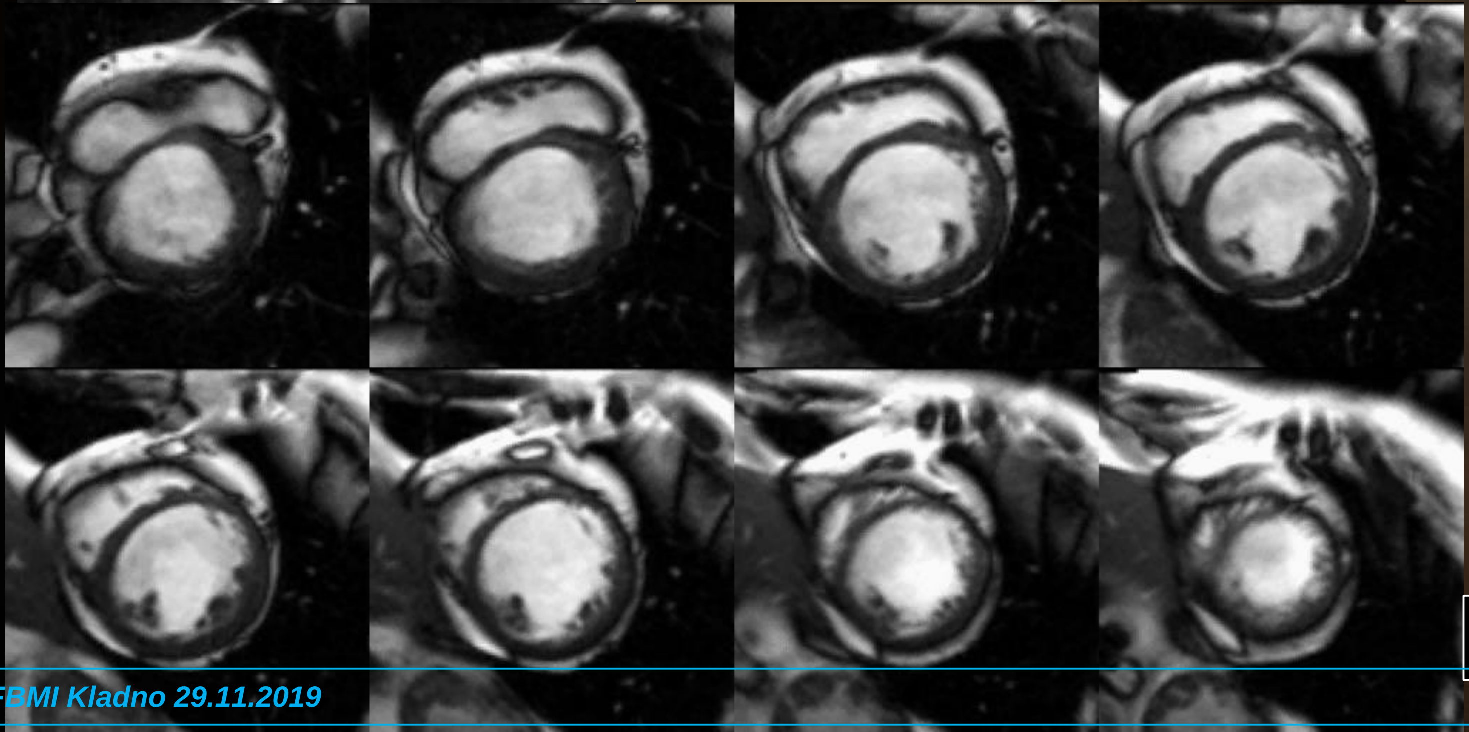
single shot EPI multi-shot EPI

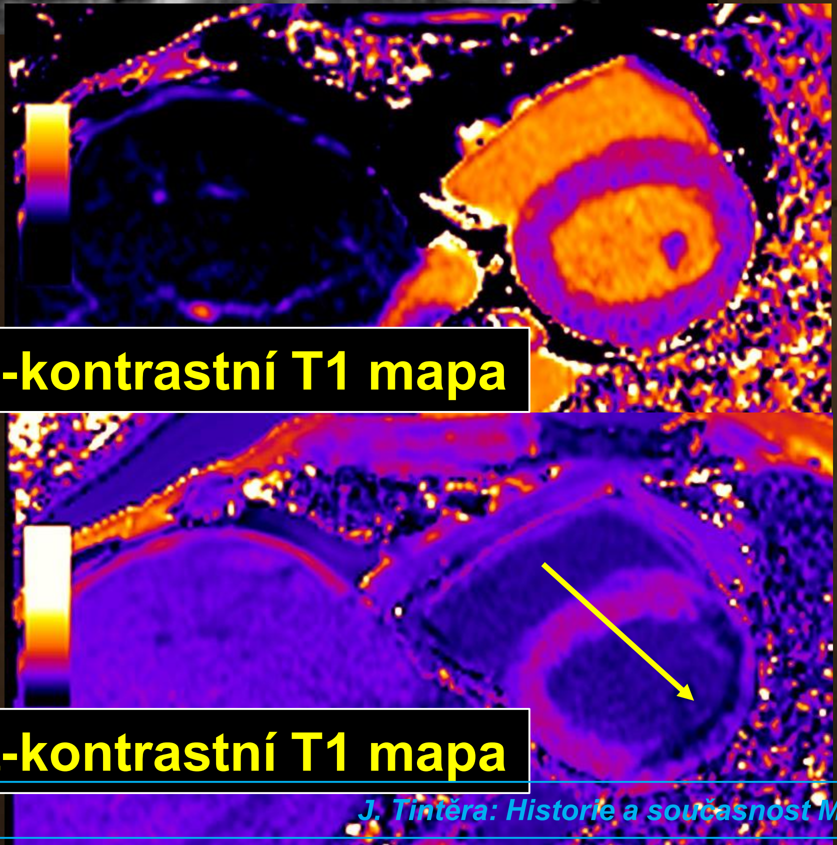




Connectome project

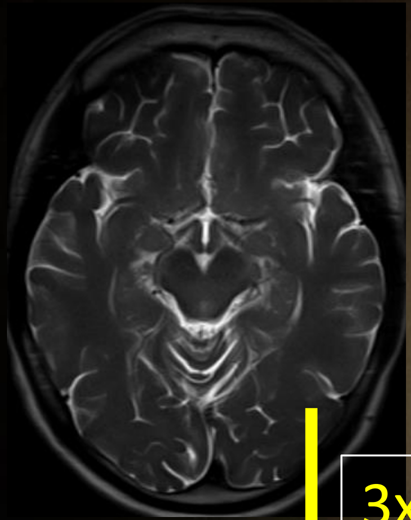
Zobrazení srdce: komplexní diagnostika



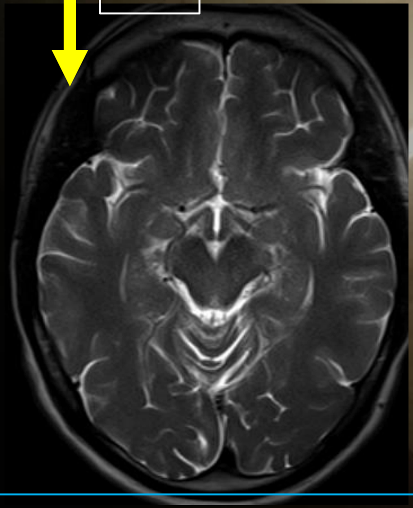


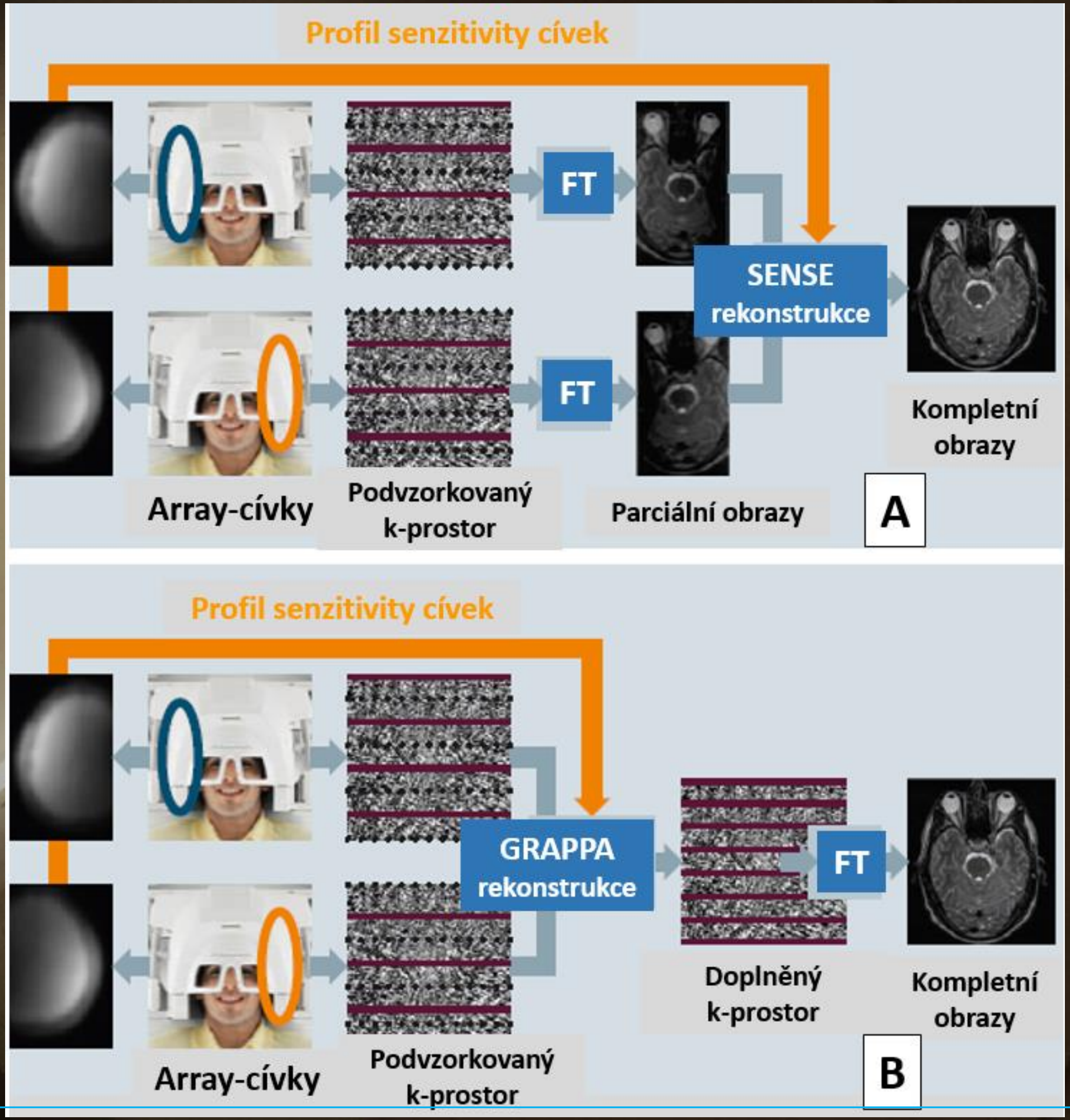
Rozvoj paralelního zobrazování od ~ 2005

Jak ještě zrychlit?



3x





SMASH, SENSE, PILS, GRAPPA
How to Choose the Optimal Method
Martin Blaimer, Felix Breuer, Matthias Mueller, Robin M. Heidemann, Mark A. Griswold, and Peter M. Jakob

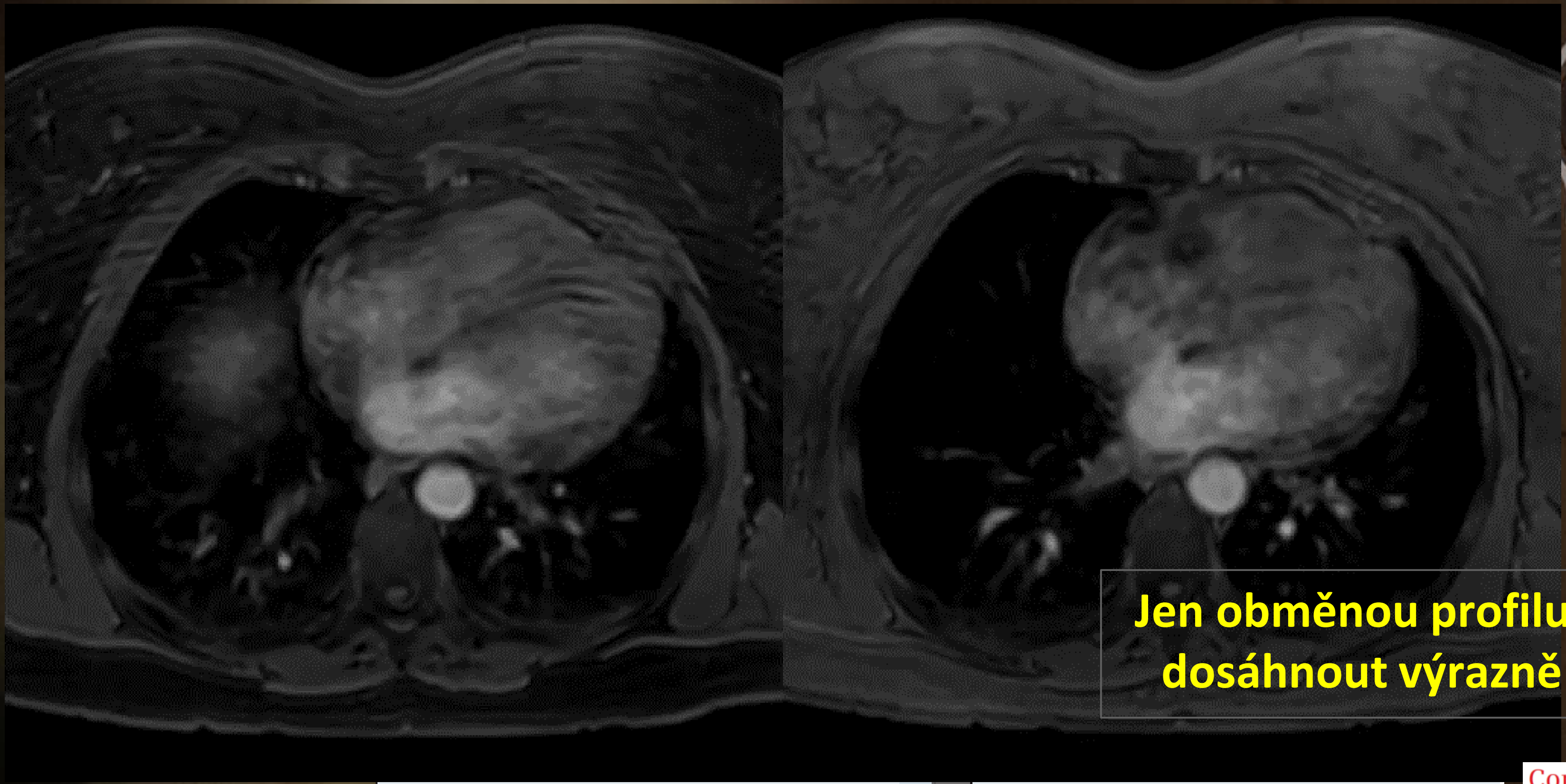
SENSE

- *faktor zrychlení = podvzorkování k-prostoru*
- ***efektivita roste s počtem RF cívek***

GRAPPA

Paralelní techniky v současnosti: *Sparsity*

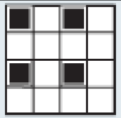
GRAPPA | **CAIPIRINHA**



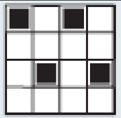
Avanto Fit
IKEM 2017

Jen obměnou profilu akcelerace můžeme dosáhnout výrazně lepšího výsledku!!!

2D Standard
2x2



2D CAIPIRINHA
2x2(1)

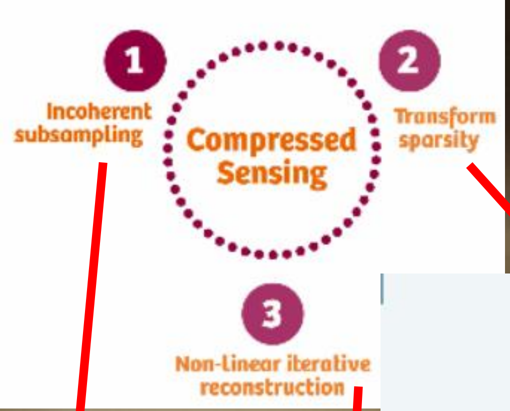


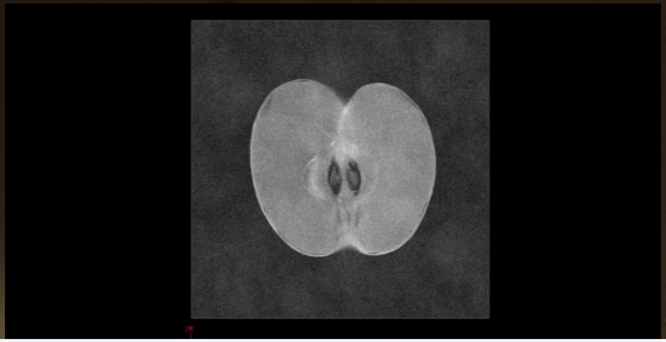
Controlled Aliasing in Parallel Imaging Results in Higher Acceleration (CAIPIRINHA)

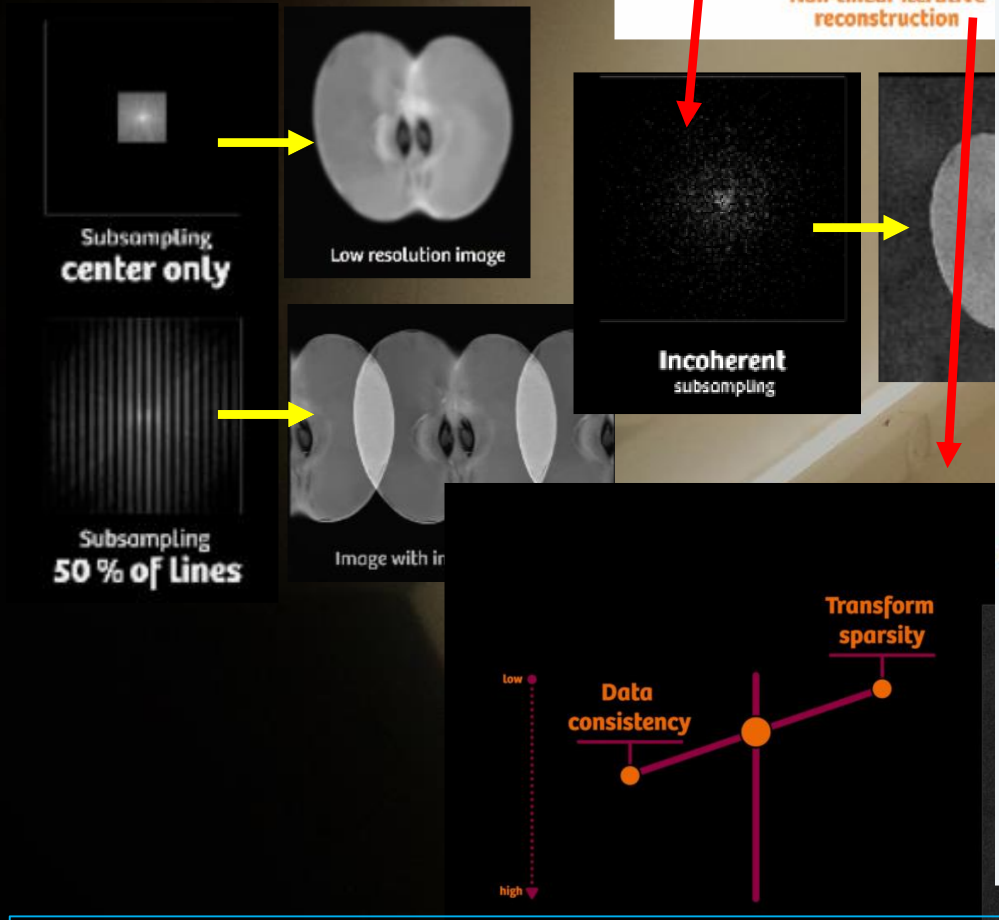
Felix Breuer[1]; Martin Blaimer[1]; Mark Griswold[2]; Peter Jakob[1,3]

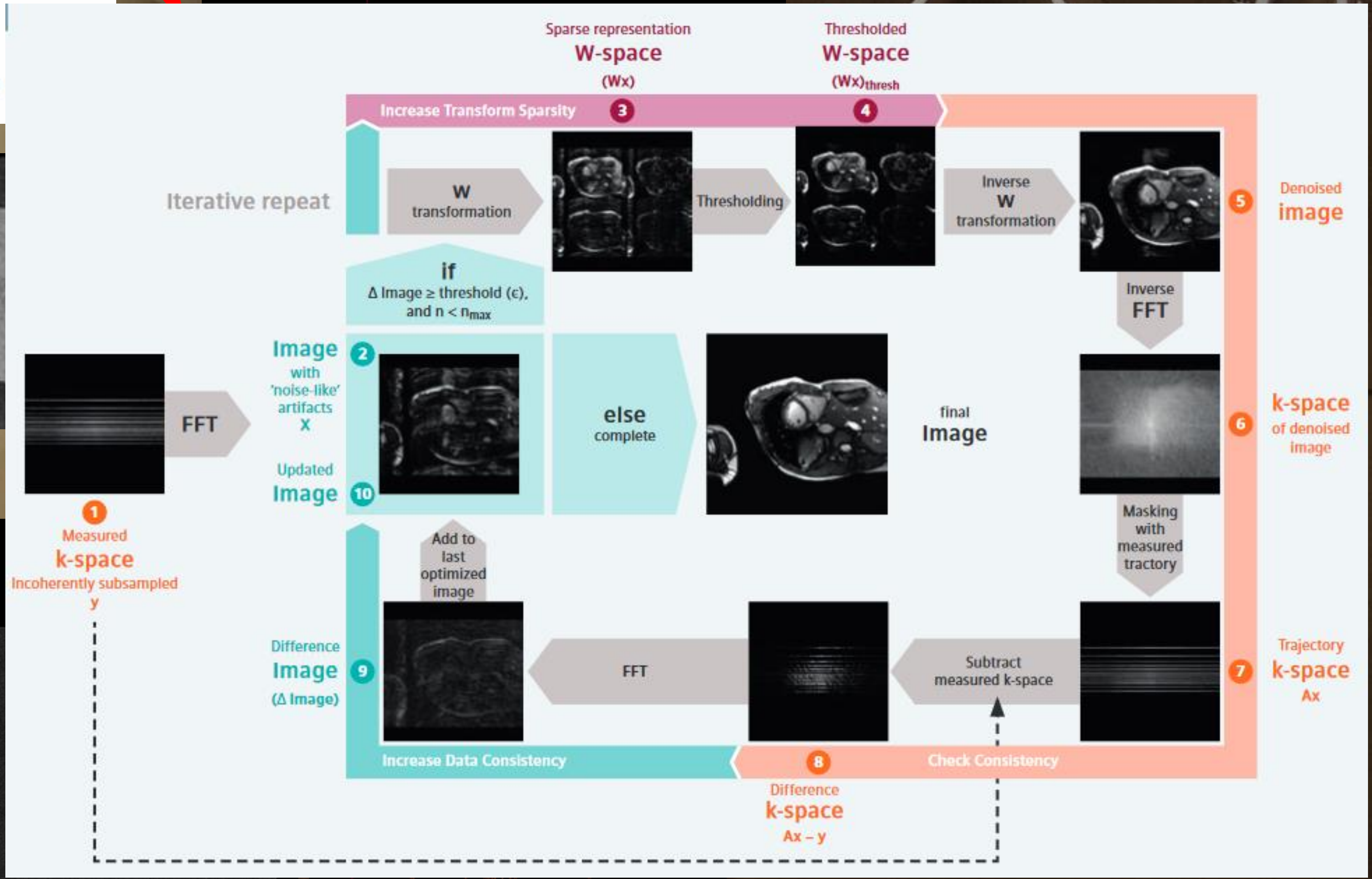
[1]Research Center, Magnetic Resonance Bavaria e.V (MRB), Würzburg, Germany
[2]Case Center for Imaging Research, Case Western Reserve University and University Hospitals, Cleveland, OH, USA
[3]Dept. of Experimental Physics 5, University of Würzburg, Würzburg, Germany

Compressed Sensing



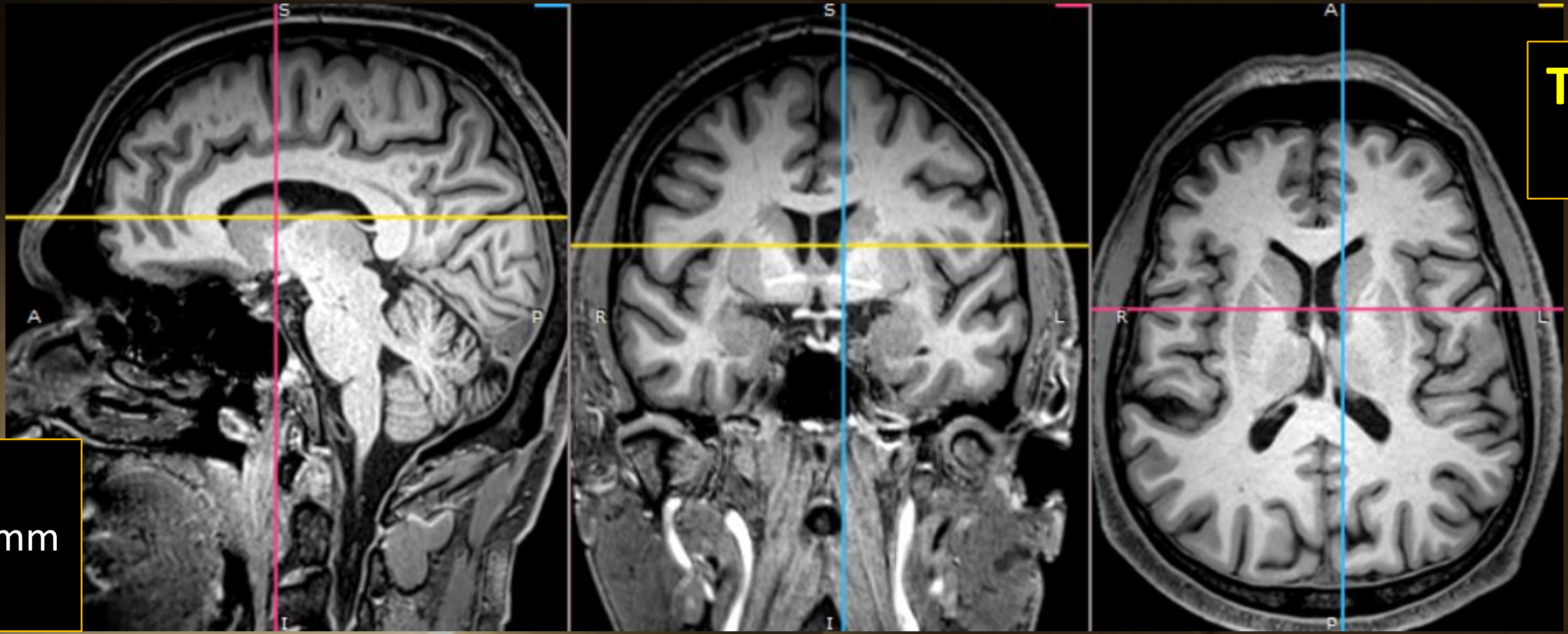






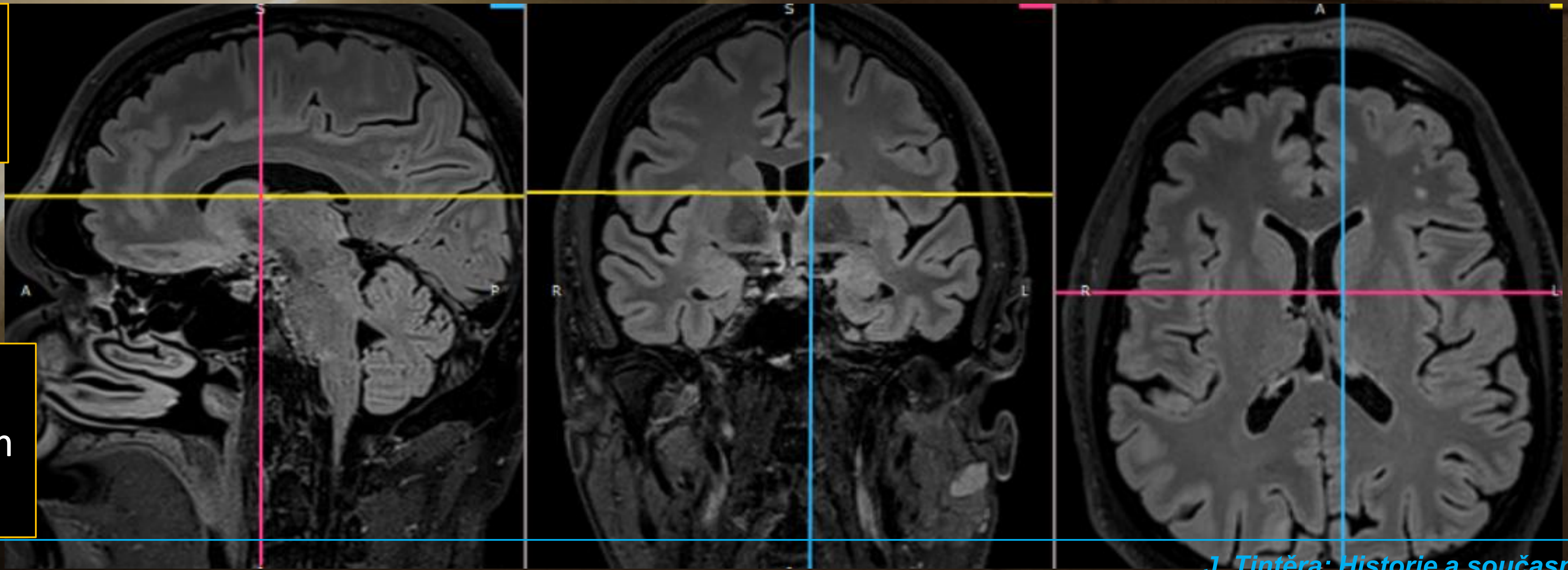
Siemens VIDA 3T 2019

T1 MPR 3D



64-kanálová cívka
rozlišení: 0,7 x 0,7 x 0,7 mm
čas měření: 7 min

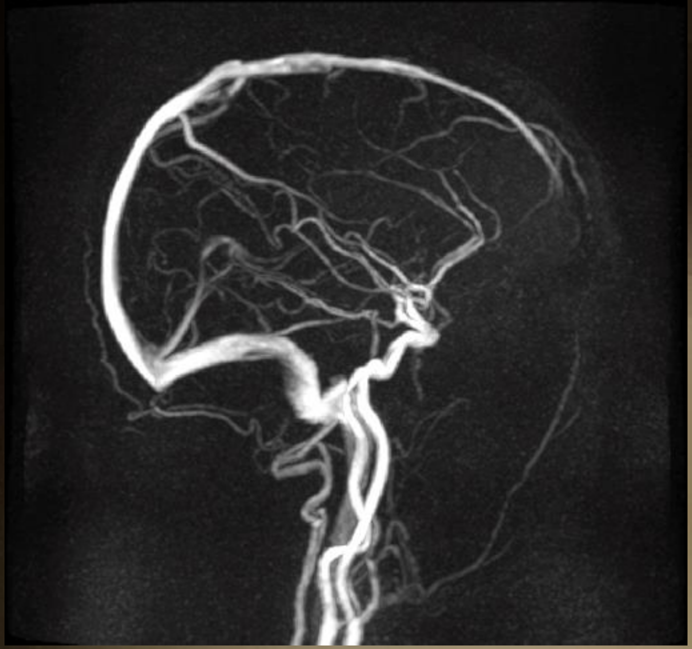
FLAIR 3D

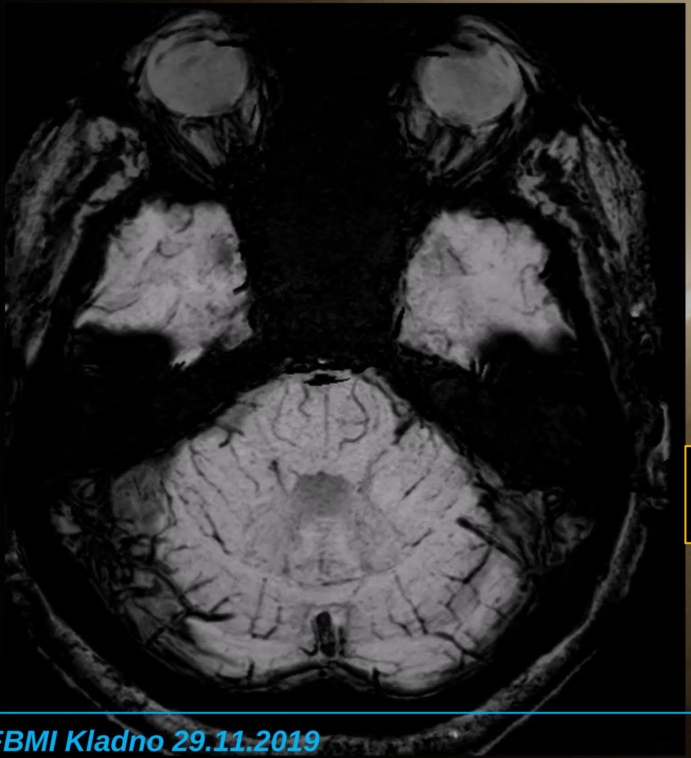


64-kanálová cívka
rozlišení: 0,9 x 0,9 x 0,9 mm
čas měření: 8 min

Siemens VIDA 3T 2019

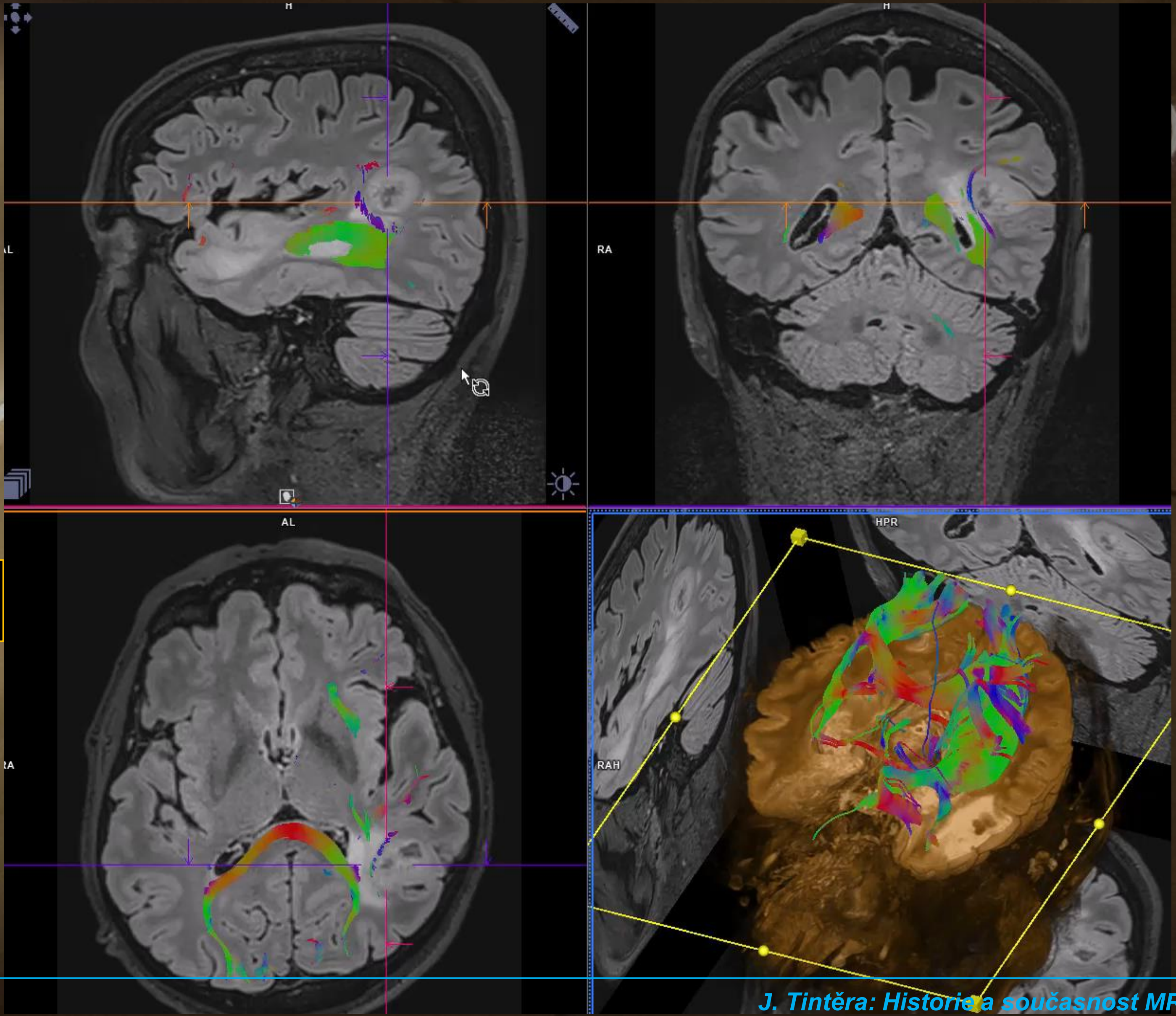
Nativní MRA 3D PC



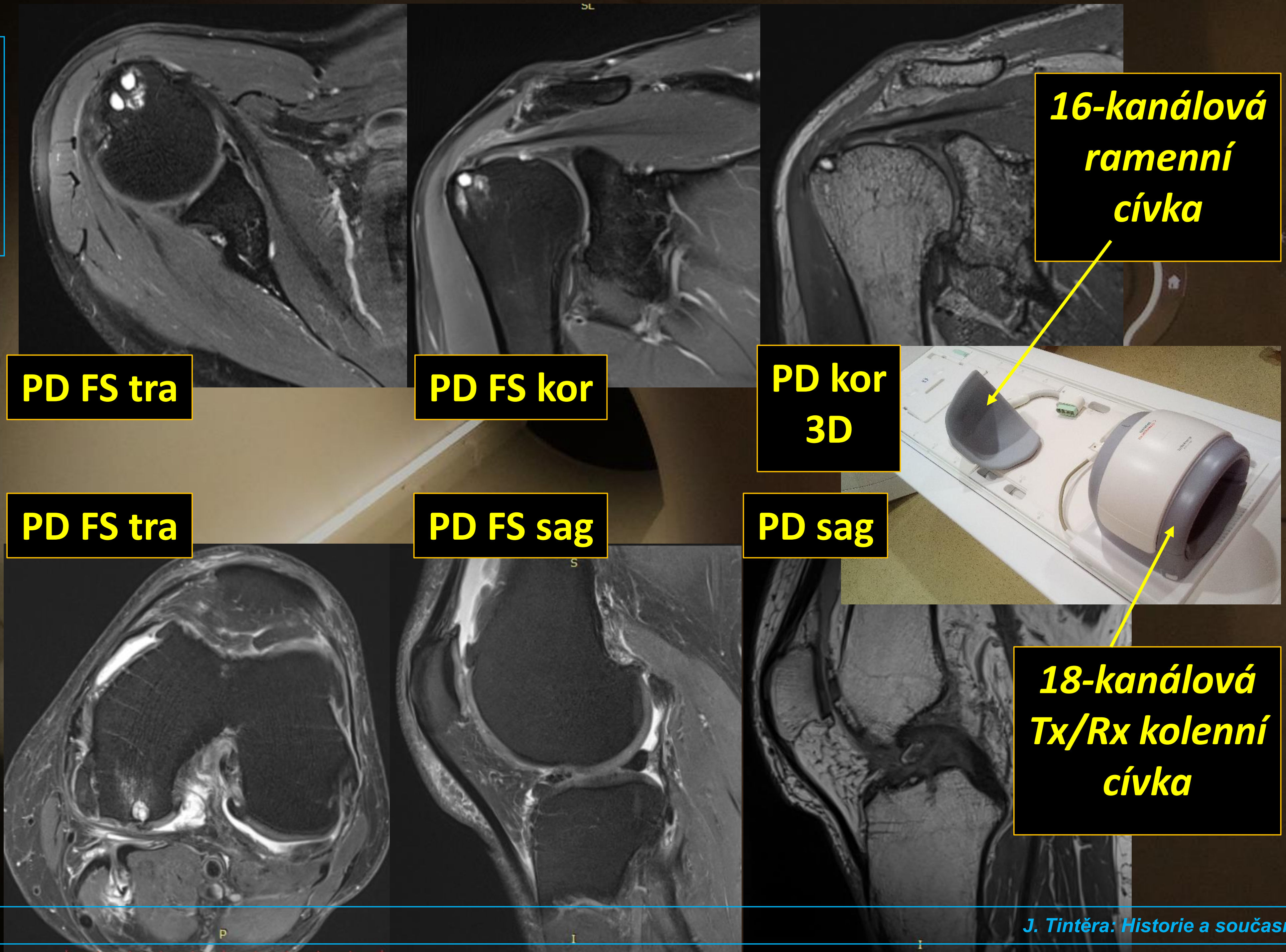


SWI

DTI

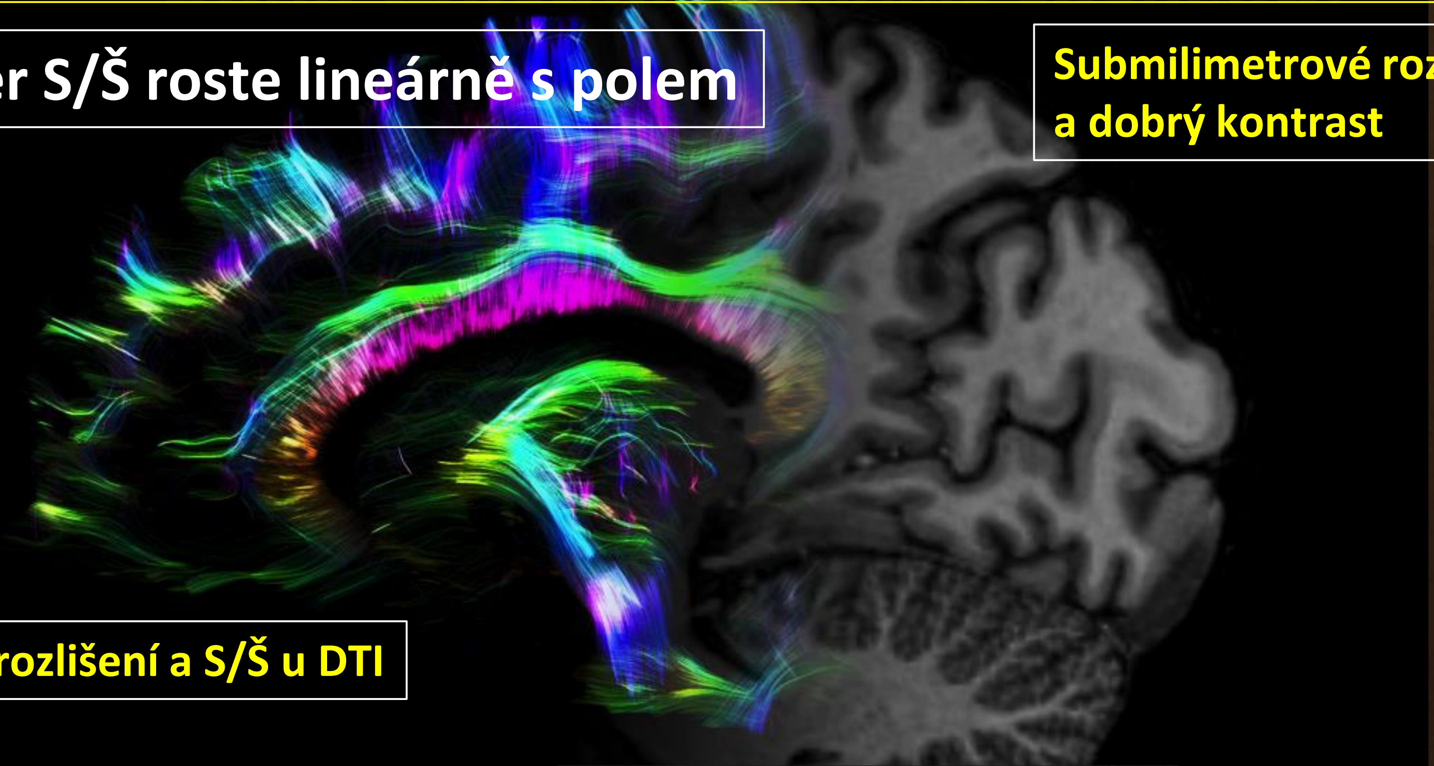


Siemens VIDA 3T 2019



S jídlem roste chuť aneb Ultra-high field 7T: nové možnosti zvýšit rozlišení

Poměr S/Š roste lineárně s polem

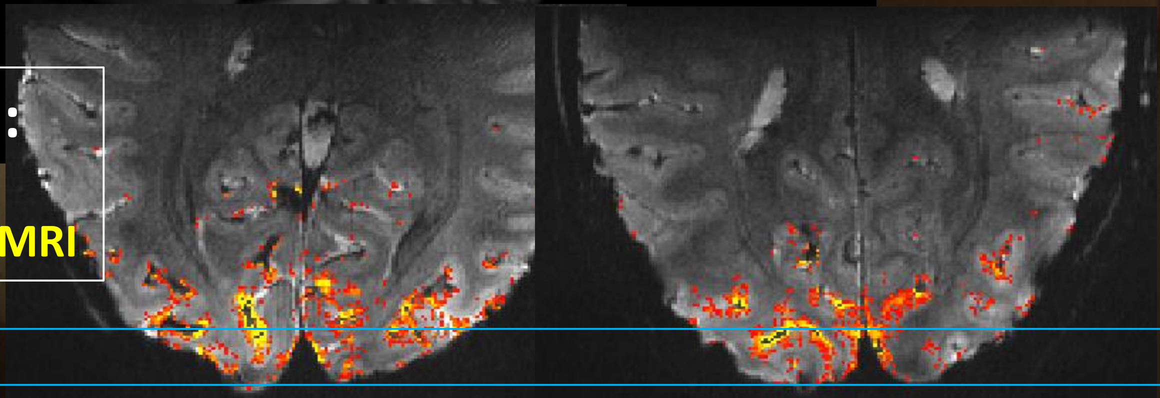


Lepší rozlišení a S/Š u DTI

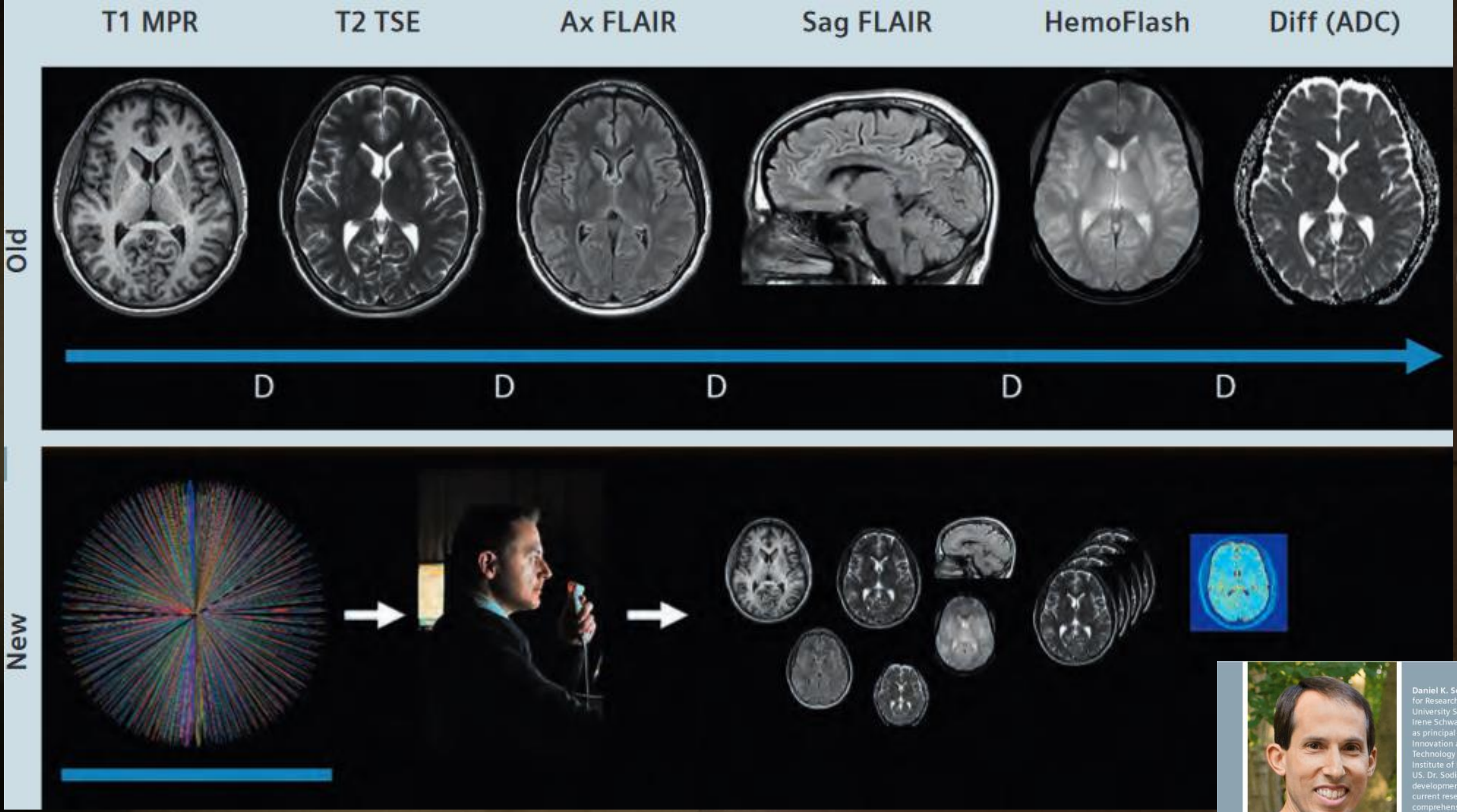
Submilimetrové rozlišení a dobrý kontrast

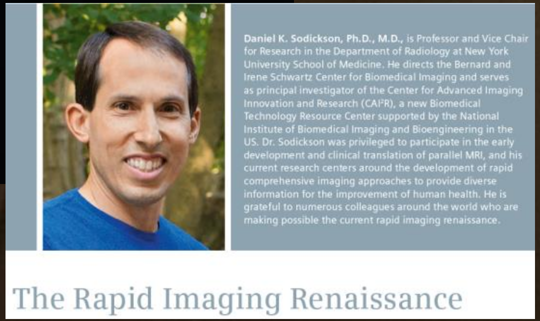
Efekt susceptibility : nové možnosti při SWI

BOLD efekt roste s polem:
leze dosáhnout
vyššího prostorového rozlišení u fMRI



Look to the future?





Daniel K. Sodickson, Ph.D., M.D., is Professor and Vice Chair for Research in the Department of Radiology at New York University School of Medicine. He directs the Bernard and Irene Schwartz Center for Biomedical Imaging and serves as principal investigator of the Center for Advanced Imaging Innovation and Research (CAI²R), a new Biomedical Technology Resource Center supported by the National Institute of Biomedical Imaging and Bioengineering in the US. Dr. Sodickson was privileged to participate in the early development and clinical translation of parallel MRI, and his current research centers around the development of rapid comprehensive imaging approaches to provide diverse information for the improvement of human health. He is grateful to numerous colleagues around the world who are making possible the current rapid imaging renaissance.

The Rapid Imaging Renaissance

Konec...