Spin Radiation, remote MR Spectroscopy and MR Astronomy

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www.ebyte.it/stan/Talk_ENC_2009.html

Conjectures and suggestions of experiments

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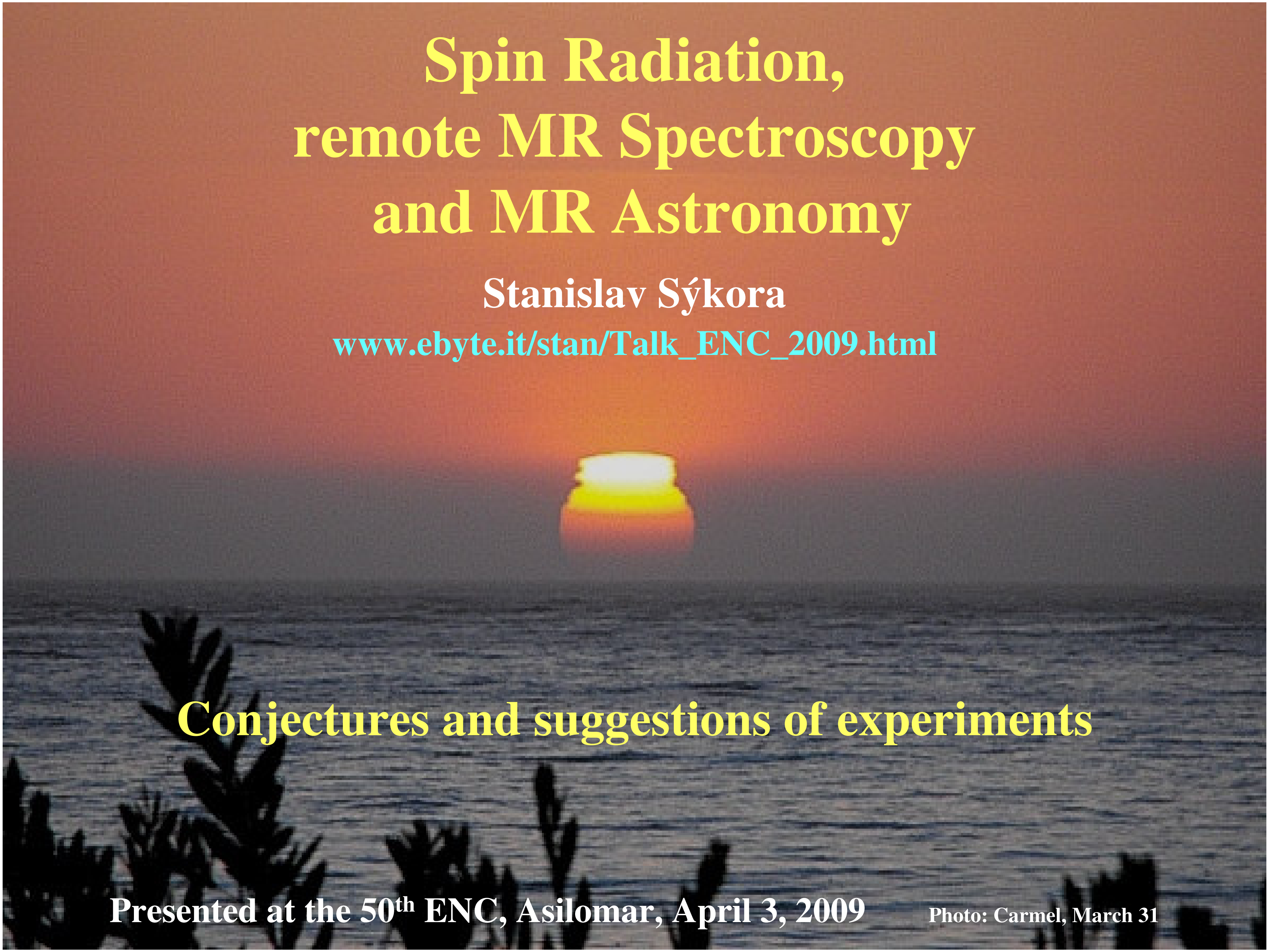

Photo: Carmel, March 31

Do we truly understand the Magnetic Resonance phenomenon ?

Not quite!

But to teach it, we select for any given situation the '*explanation*' which appears to suit it best.

Beware: all kinds of surprises lurk ahead and, so far, nothing can replace experiments

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CLASSICAL		QUANTUM
Technical aspects,		Sharp spectral lines,
Bloch equations,	**HYBRID**	Coupled spin systems,
most of MRI,		Operator products,
…		...

Indications that there is more at stake

- ✓ **Noise radiation (more precisely, *noise induction*)**
  Shows that spins do not need to be excited: sponateous 'emission'
  To do: confirm the phenomenon in ESR on a pulsed spectrometer
- ✓ **Electric detection (with S/N similar to induction detection)**
  Shows that full-fledged electromagnetic waves are involved
  To do: try it at different frequencies, electro-inductive probeheads
- ✓ **Magnetic Force Microscopy**
  Confirms that single-spin detection picks-up only pure eigenstates
  To do: study coupled two- and three-spin systems
- ✓ **Waveguide between the sample and Tx/Rx assembly**
  First step in the direction of 'remote' MR
  To do: elongate the waveguide; insert a free-space gap

Quantum Physics headaches:
I. Ontology of Photons

- ✓ **How does an atomic-size system absorb/emit a 3m wave with a frequency precise to 1 part in 10^{11} and never miss a bit ?**

  Scale the spin system to fit a 1m box (factor 10^{10}). Then the wavelength would be 0.2 au and the complete wave-packet would extend over 30000 light-years.

- ✓ **What is the shape of a photon? Results of a poll of 30 physicists:**

  1969: pointlike particle 16, infinite wave 9, wave-packet 3, f**k off 2
  2009: pointlike particle 2, infinite wave 3, wave-packet 9, f**k off 16

- ✓ **Can an *indivisible quantum* have a shape and/or duration ?**

  A shape/duration implies component parts, but a quantum can’t have any

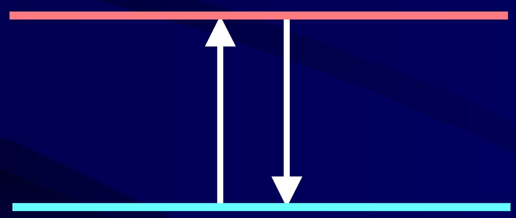
- ✓ **Is photon just an *abstraction* of the constraints on energy and momentum exchange ?** Max Planck would certainly approve this

Quantum Physics headaches:
II. What happens *during* a Quantum Transition ?

QP has NO apparatus to answer this question.

By *convention*,

transitions are assumed to be instantaneous.



Quantum Physics headaches:
can Magnetic Resonance help to cure them ?

It certainly looks so:

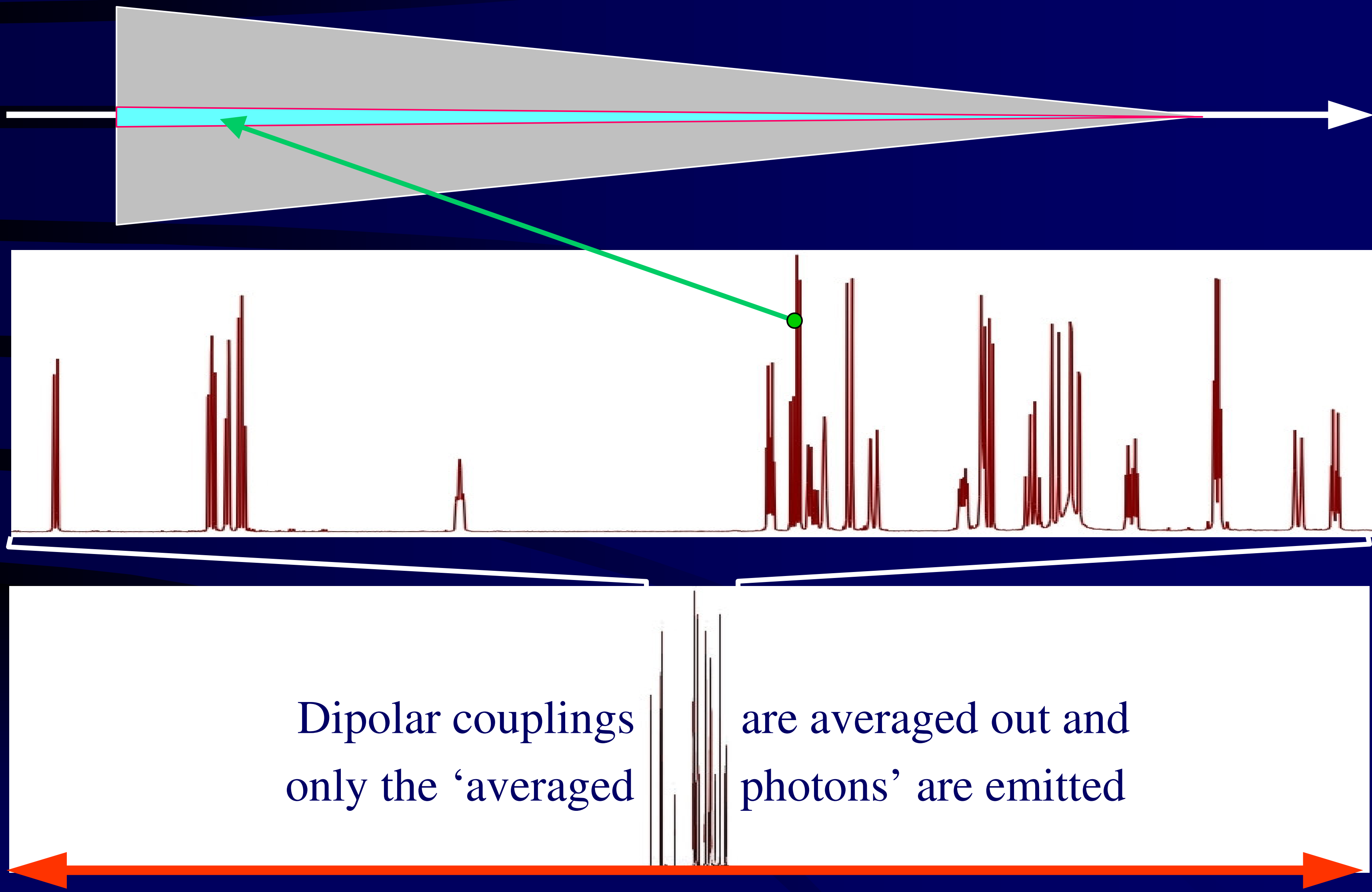
Ontology of Photons:

Among all spectroscopies, MR offers the ***longest waves*** and the ***largest wavelength/linewidth ratios*!**
This enhances the QP paradoxes.

Duration of transitions:

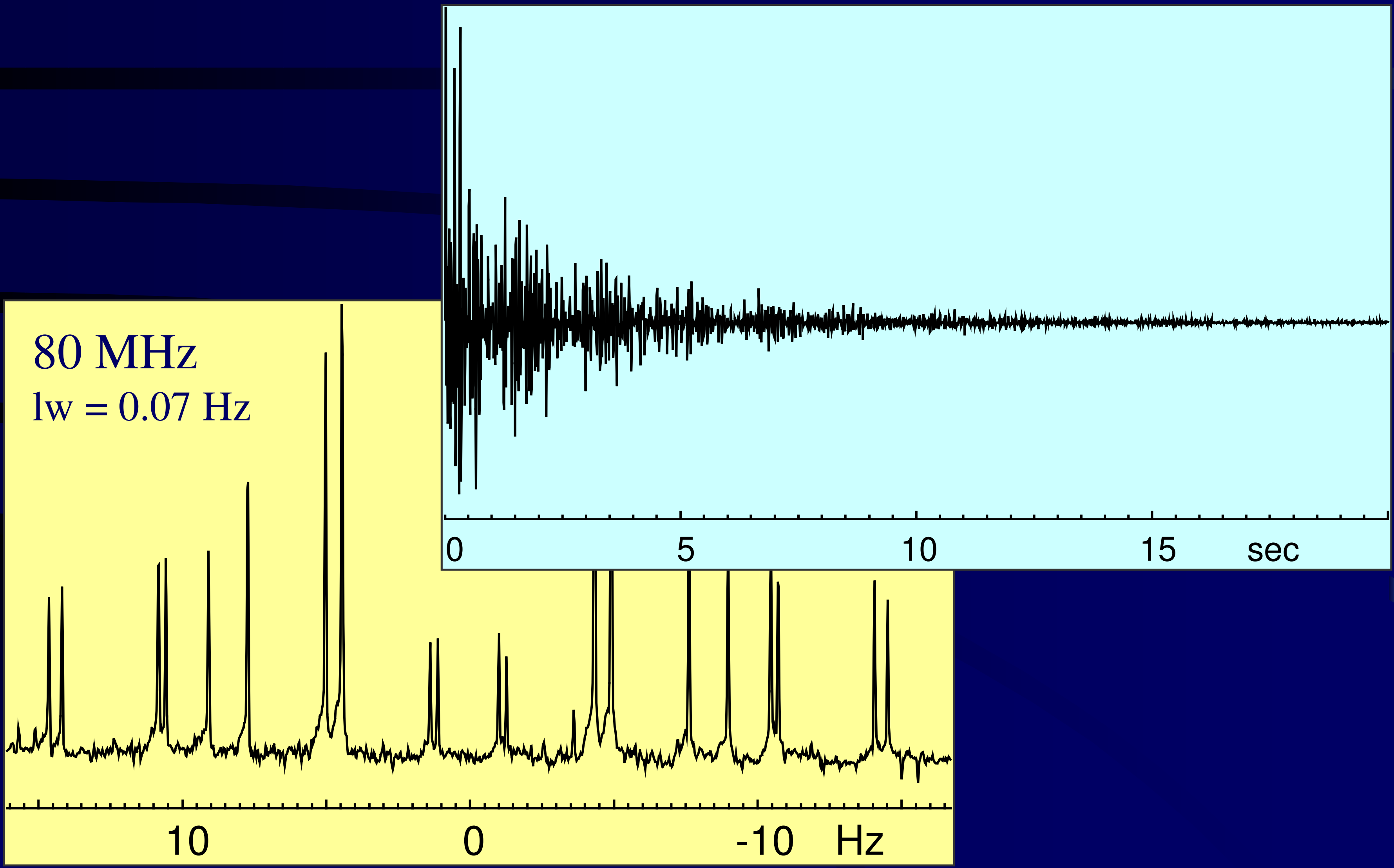
The lines in a HR-NMR spectrum match transitions of the *motionally averaged* spin-system Hamiltonian.
But the required averaging times equal the FID duration.

FID as a model of a quantum transition



Come on, 15 seconds quantum transitions !?

Why not! QP can't contradict it



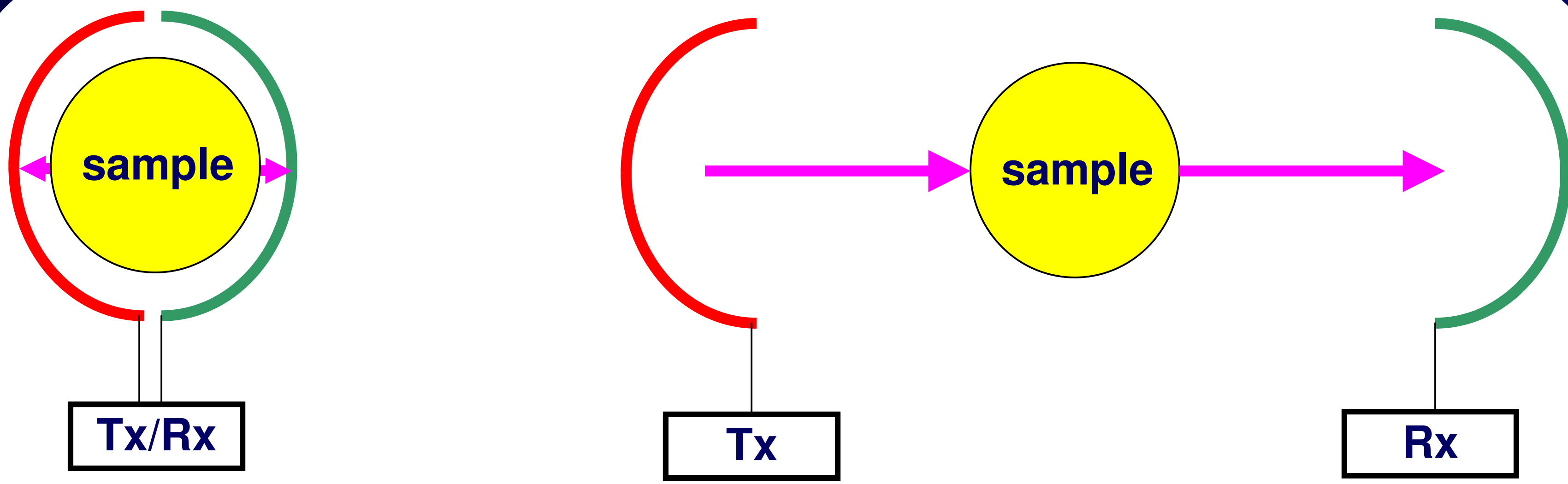
What is missing ?

MR spectroscopy is in the pole position in the race to unlock the unresolved mysteries of Quantum Physics.

But why don't we have a *remote* MRS ?

All other electromagnetic spectroscopies have it !!!
(the high-frequency ones do not have the near version)

Near versus remote spectroscopy



NEAR

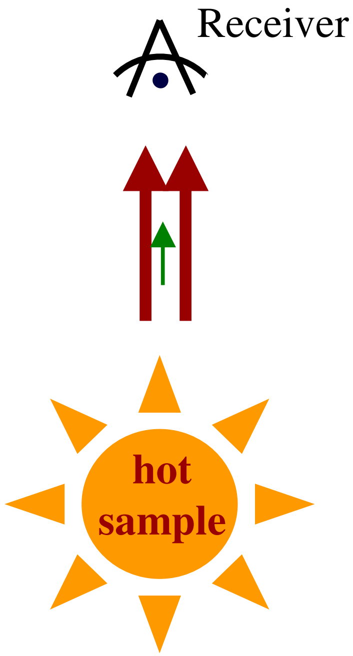
- $1/R^3$ distance dependences
- **Tx-sample-radiation-Rx** all interact
- Virtual or real photons?
- QED creation/annihilation operators

REMOTE

- $1/R^2$ distance dependences
- **Sample-radiation** interaction only
- Photons are not virtual
- QED not necessary

Variants of remote spectroscopies

Passive emission

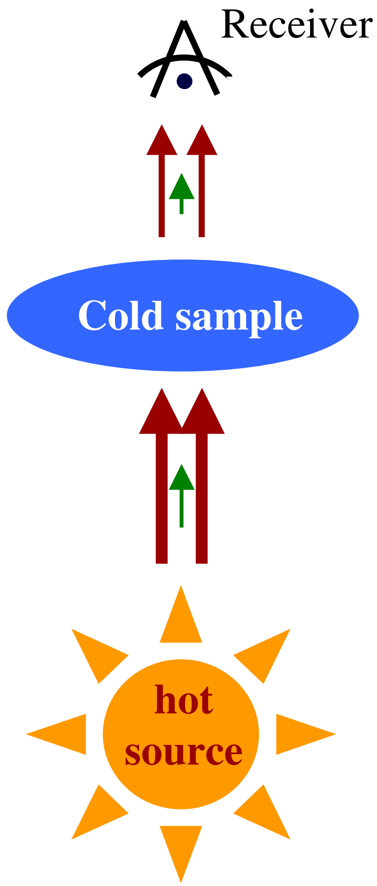


We must separate the desired signal from the bulk

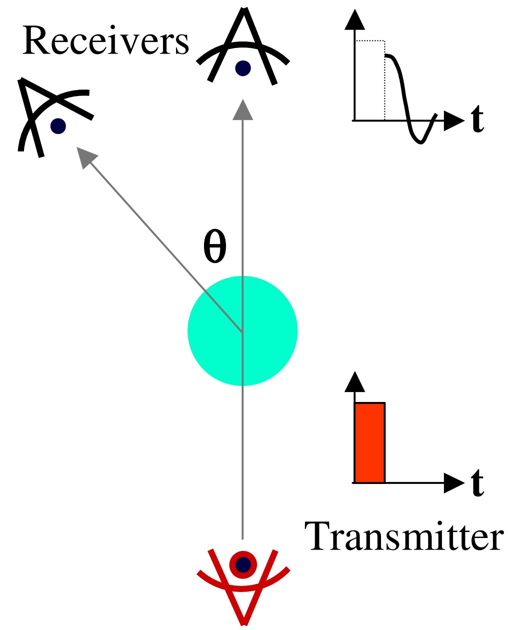
We need:

- Special signal features
- Sophisticated receiver

Passive absorbtion



Active absorbtion
Stimulated emission
Fluorescence



Here we have also θ and t to play with, but we need more hardware

Spin radiation and its properties

I congecture that spin radiation MUST exist

We just need to know how to recognize it.

Properties which appear guaranteed

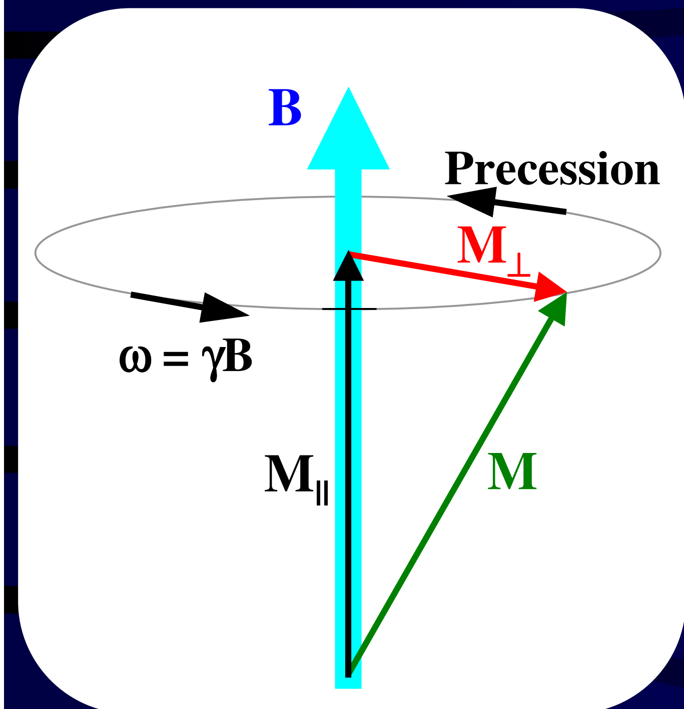
- ✓ **Linear frequency-field dependence**
- ✓ **Narrow frequency bands** depending on field homogeneity
- ✓ **Re-emission dying out with T_1** (possibly quite slowly)
- ✓ **Known particle-composition fingerprints** (γ-values)

Educated guesses

(until real experiments get carried out)

- ✓ **Perfect chirality** (circular polarization)
- ✓ **Extreme directionality** (alignment along the magnetic field)

Chirality and Directionality

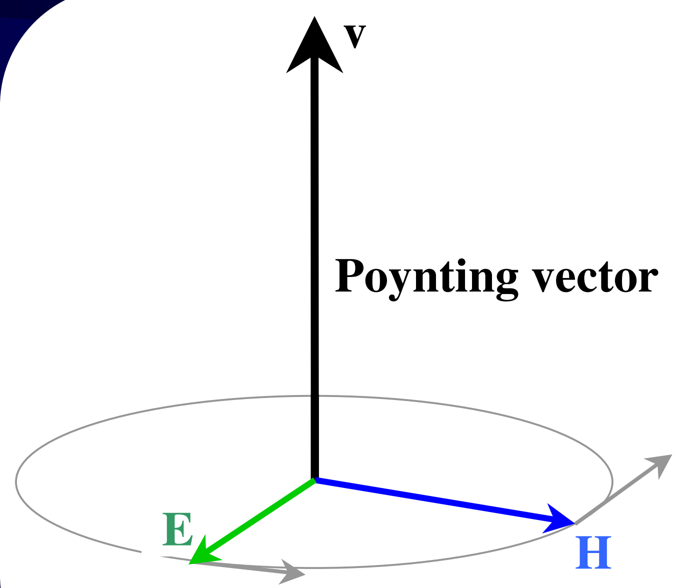


Chirality:

Consequence of Larmor precession

Directionality:

Consequence of Maxwell equations



$\nabla \times \mathbf{E} = -\mu\, \partial \mathbf{H}/ \partial t$

$\nabla \times \mathbf{H} = +\varepsilon\, \partial \mathbf{E}/ \partial t$

$\nabla . \mathbf{E} = 0$

$\nabla . \mathbf{H} = 0$

$\mathbf{P} = \mathbf{E} \times \mathbf{H}$

Elmag radiation:

$\mathbf{E} \perp \mathbf{H}$, $\mathbf{E} \perp \mathbf{v}$, $\mathbf{H} \perp \mathbf{v}$

$|\mathbf{v}| = c$

$|\mathbf{E}|/|\mathbf{H}| = Z_0$ (377 Ω)

But why should it be *extreme* ?!?

Extreme directionality: why ?

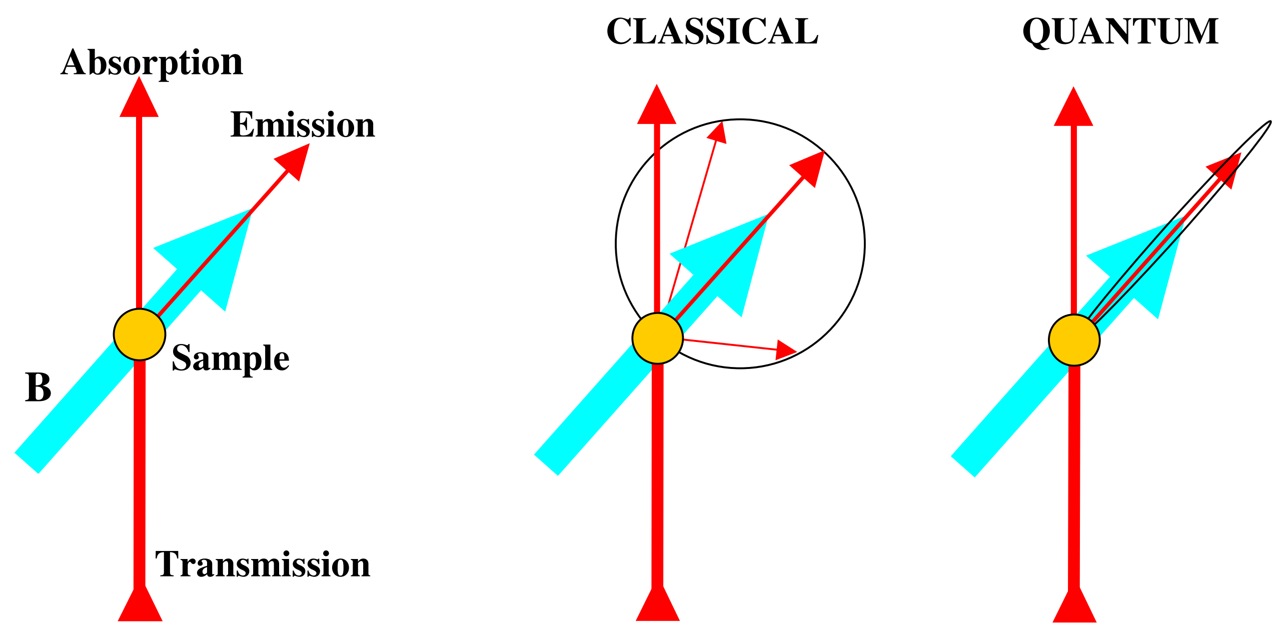
A circularly polarized photon carries one quantum of angular momentum, oriented in the direction of its propagation.

We know with absolute certainty that the allowed spin-system transitions are subject to the selection rule $\Delta I_z = \pm 1$, where the z-axis is aligned with the external magnetic field **B**.

Angular momentum conservation law therefore implies that a photon can only be emitted in the direction of the field **B**.

Possible deviations from this rule: when the spin system couples to a 'lattice', the latter can take up some of the angular momentum. The spread in directions is therefore proportional to $1/T_1$.

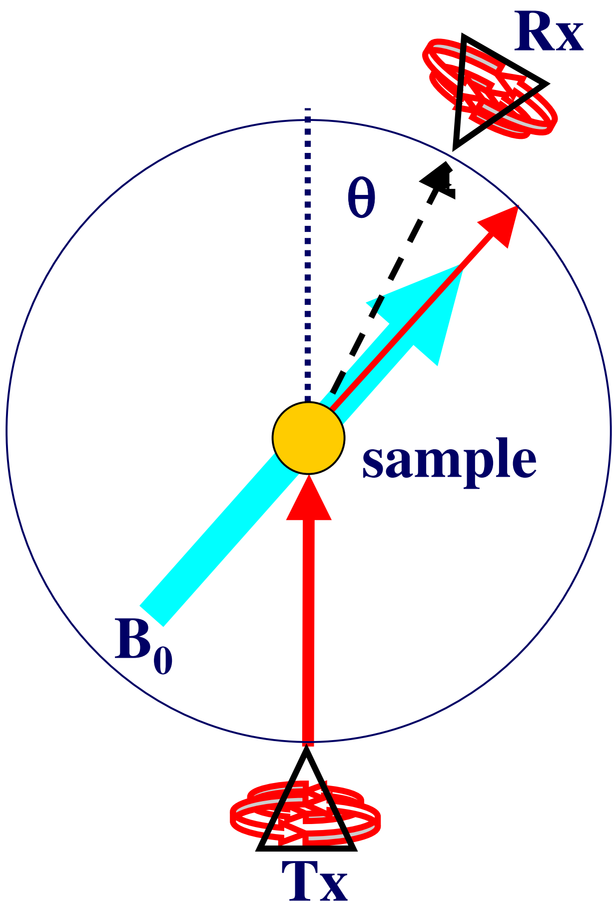
Radiation diagrams



Attention: particles with a negative γ radiate in the opposite direction as those with positive γ

Suggested experiments

Use a suitable open-access magnet to generate B_0



- Tx may be CW or Pulsed
- Rx may acquire CW or FID
- Do full solid angle dependence
- Rx may be (should be) chiral
- Rx chirality cycling (C^+,C^-,L)
- Excitation coil in place of Tx
- All pulse sequences can be used
- Expected problem:
  Tx-Rx leakage due to large λ

Start with EPR at short waves, but try also NMR at long waves

Large Magnetic Room

reiteration of an old proposal

To enable large-scale magnetic experiments (including MRI of elephants and whales), why don't we build a magnetic room the size of Merrill Hall under a mountain somewhere with a strong uniform field in it?

For the spin radiation testing, LMR would be perfect
(though not indispensable)

Remote MRS in Astronomy

Considering the prominent role of all other spectroscopies in astronomy, the questions to be asked are:

- Is there spontaneous spin-radiation out there ?
- Can it be detected and recognized as such ?
- Can it be used for passive observations ?
- Is active MR spectroscopy a viable option on planetary or sub-planetary scale ?

Magnetic fields in the Universe

Object	Field	Proton freq.	Electron freq.
INTER-GALACTIC SPACE	1 nT	0.043 Hz	28 Hz
SOLAR WIND at Earth	5 nT	0.22 Hz	140 Hz
INTER-STELLAR CLOUDS	0.1 µT	4.3 Hz	2.8 kHz
EARTH SURFACE	50 µT	2.1 kHz	1.4 MHz
SOLAR SURFACE	0.5 mT	21 kHz	14 MHz
MASSIVE STARS	10 mT	430 kHz	280 MHz
SUNSPOTS	0.1 T	4.3 MHz	2.8 GHz
JUPITER SURFACE	0.1 T	4.3 MHz	2.8 GHz
MAGNETIC STARS	1.2 T	51 MHz	34 GHz
OLD NEUTRON STARS	Between white dwarfs and pulsars		
PULSARS	100 MT	4.3e15 Hz	2.8e18 Hz
MAGNETARS	100 GT !!!	4.3e18 Hz	2.8e21 Hz

Magnetic particles in the Universe

Particle		Spin	γ [MHz/T]
^{0}e	Electron	1/2	-28024.953
$^{0}\mu$	Muon	1/2	-135.539
^{3}H	Triton	1/2	+45.415
^{1}H	Proton	1/2	+42.577
^{3}He	Helion	1/2	-32.434
^{1}n	Neutron	1/2	-29.165
^{2}D	Deuteron	1	+6.536

… and all other magnetic nuclides …

Sample quantities can be huge

Planetary magnetic fields

Sun: plasma vortices with **local magnetic fields** up to **200 mT**

Mercury: very faint global field

Venus: no magnetic field at all

Earth: **global field of 0.06 mT**, 1 satellite

Mars: no global field, just local magnetic lumps, 2 satellites

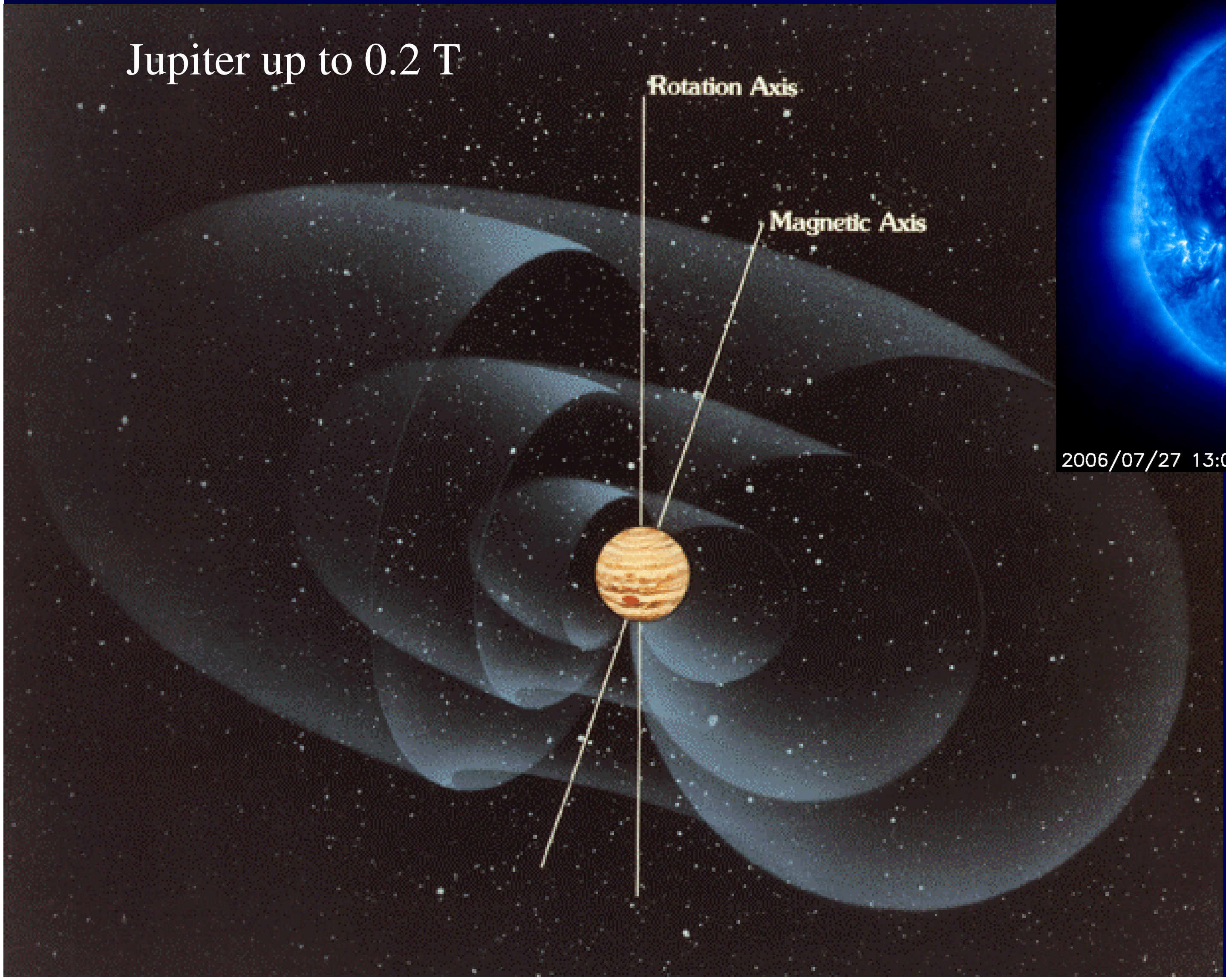
Jupiter: **strong global field of 100 mT**, faint dust rings, 63 satellites

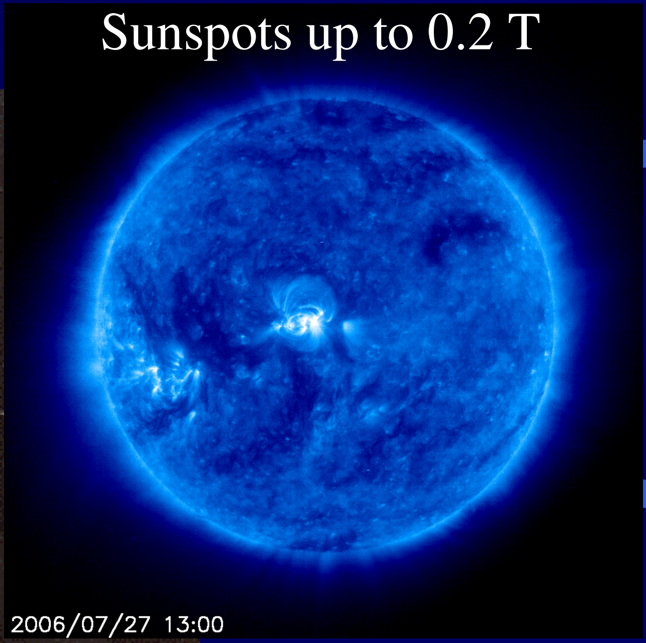
Saturn: **global field of 3.7 mT**, strong rings, 46 satellites

Uranus: **global field of 0.07 mT**, thin dark rings, 27 satellites

Neptune: **global field of 0.04 mT**, broken arc rings, 13 satellites

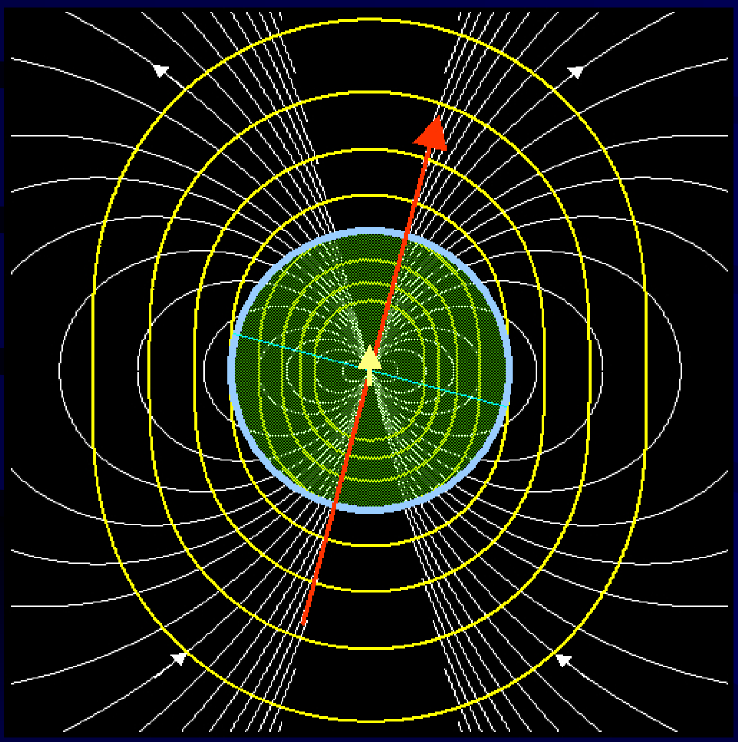
Strongest Solar System magnetic fields



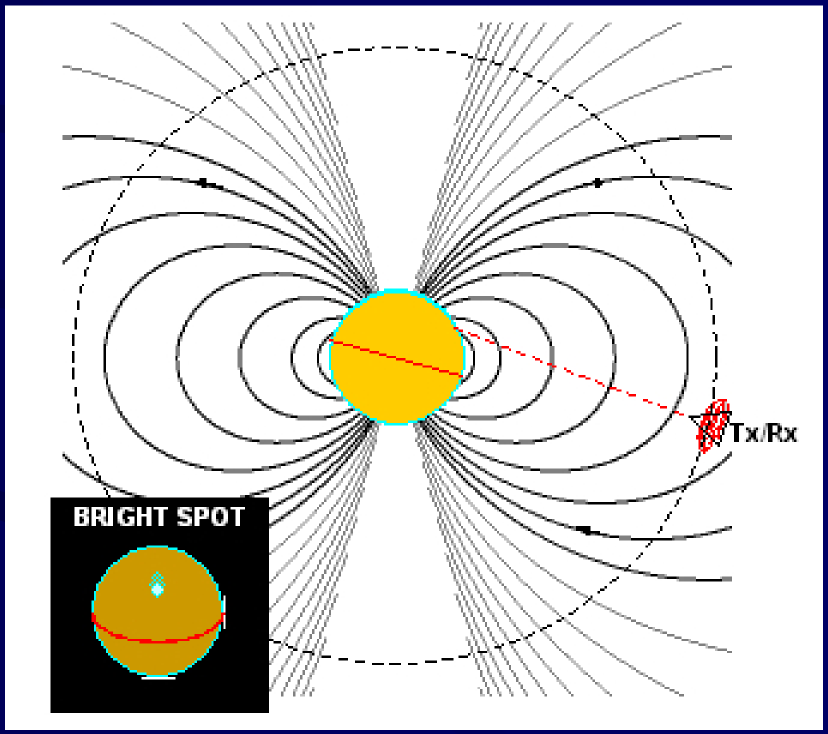


Bright spots and bright lines

The dipolar field of a magnetic planet



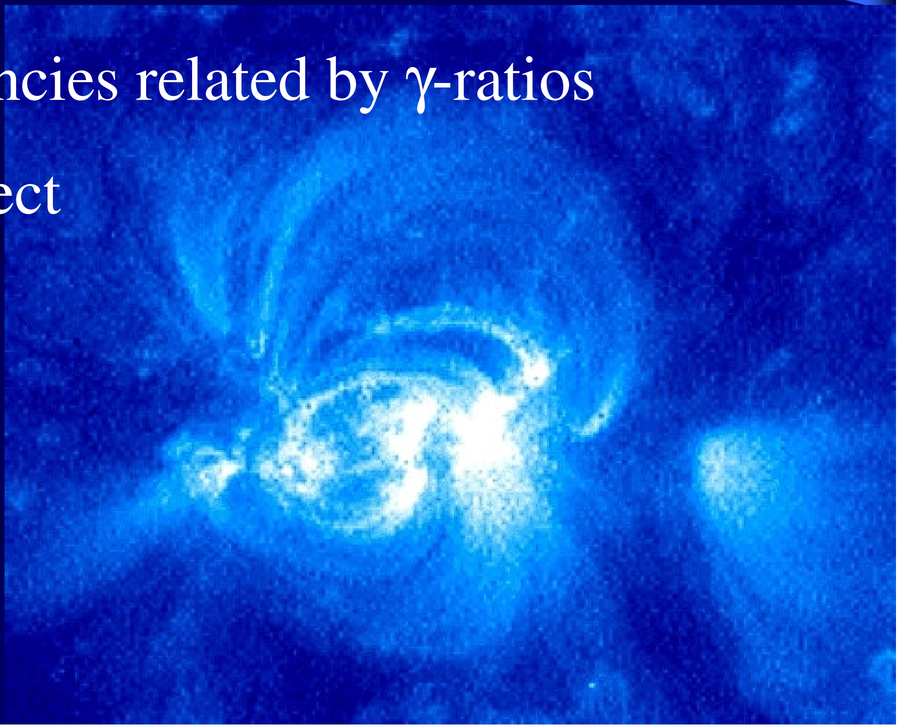
Seen in spin radiation, the planet shows a single bright spot



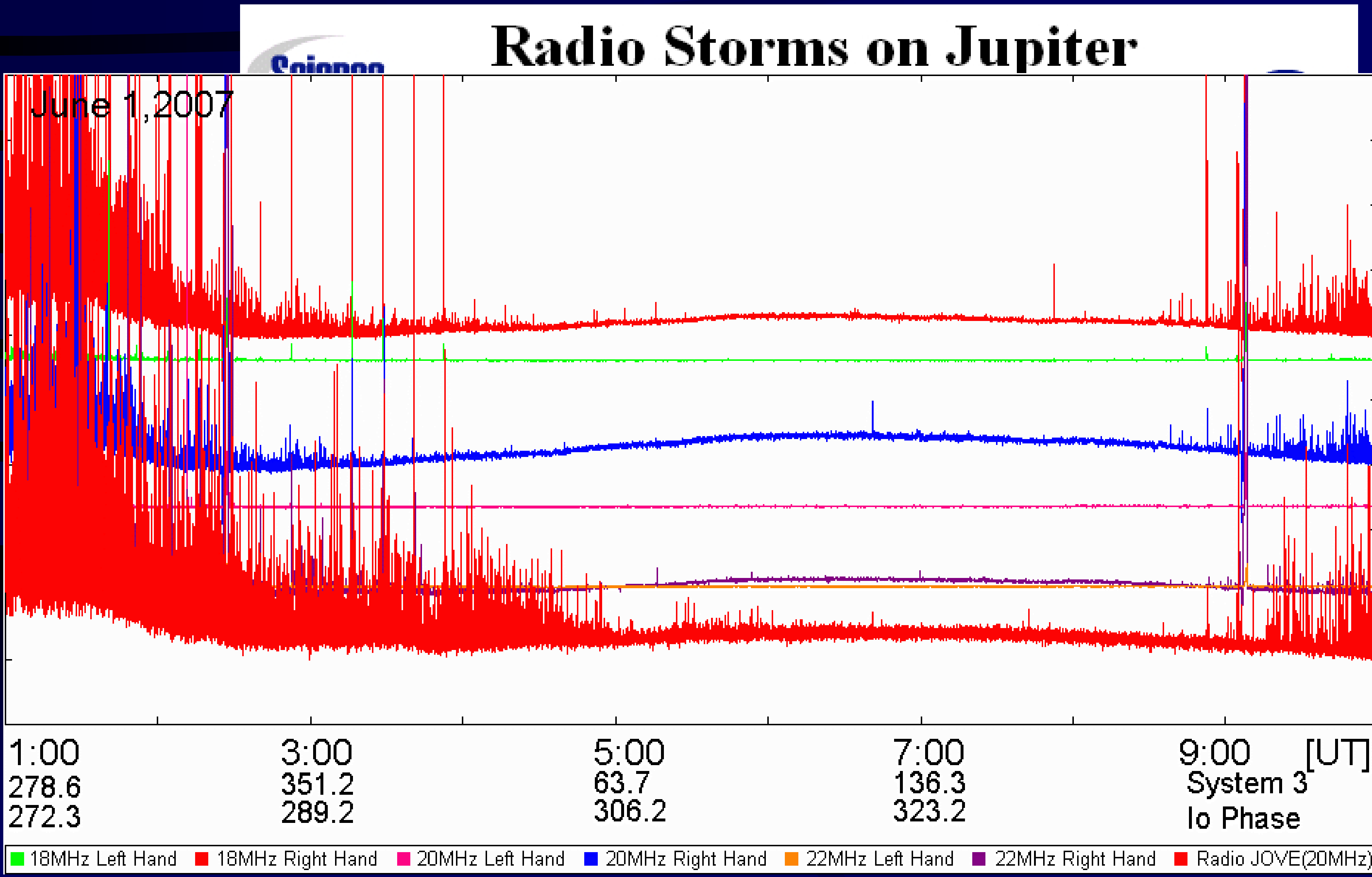
If the atmosphere were deep, we would have a bright line with the resonance frequency correlated with height

Passive MR Astronomy

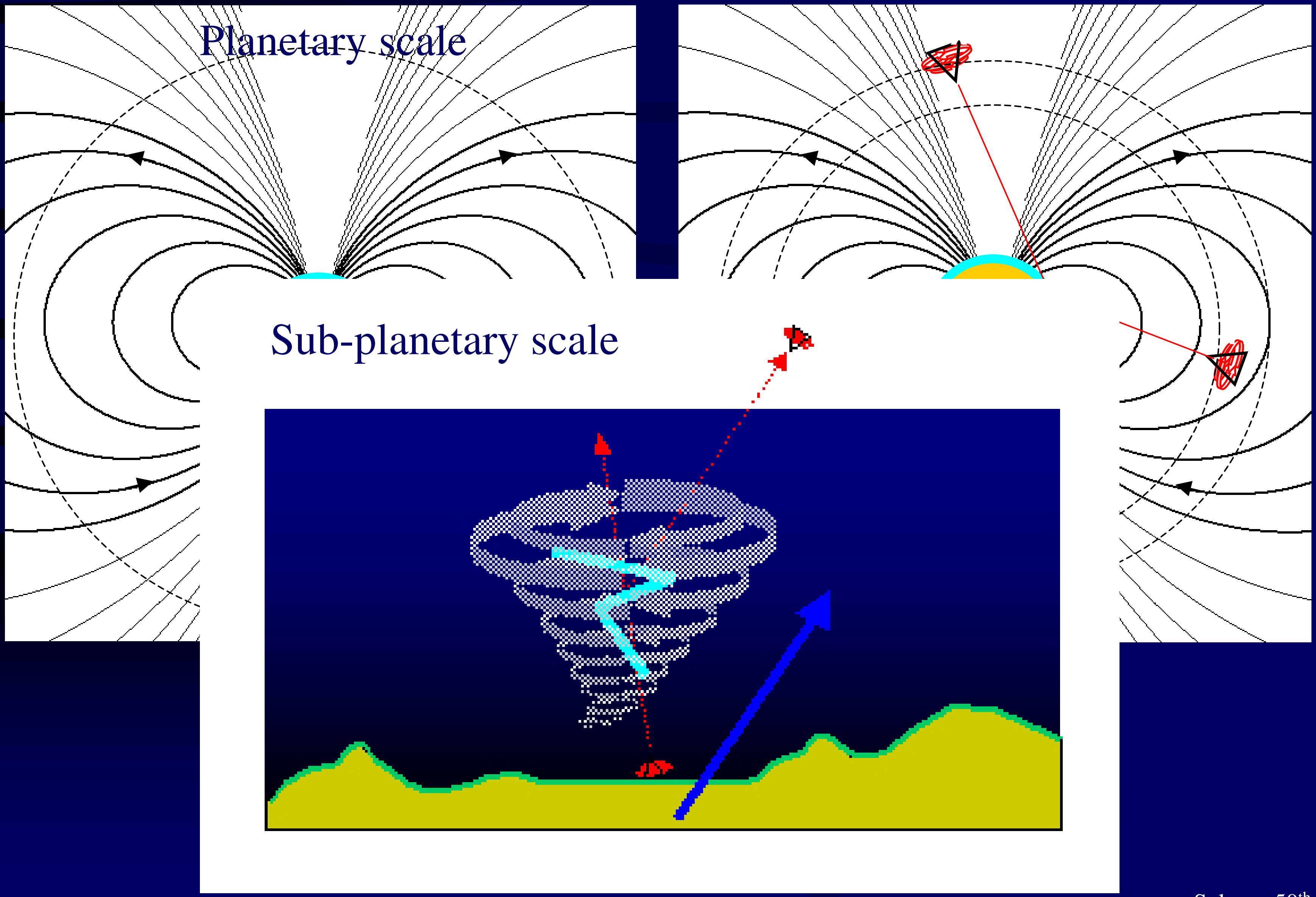
- Use chiral receiver(s) and chirality/polarization gating
- Viable objects: storm systems, sunspots, Jupiter
- For evaluation, use noise correlation methods
- Flashlight effect: brief apparent flares
- Simultaneous RF flares at frequencies related by γ-ratios
- Magnetic pole discrimination effect



Telltale signs from Jupiter



Active MR Astronomy



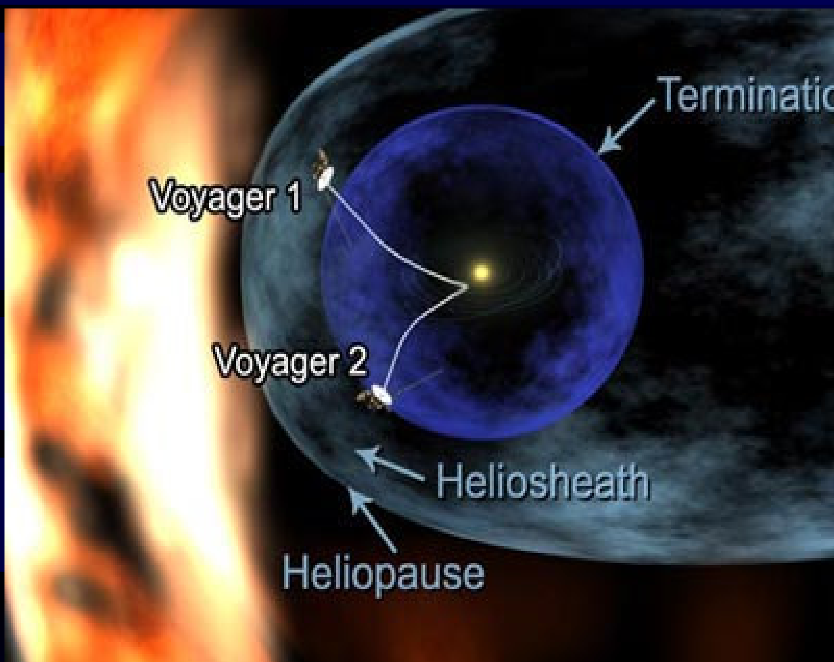
Next steps

- **Spectroscopic detection of MR radiation in laboratory**
- **Laboratory verification of the properties of MR radiation**
- **Earth-bound experiments, using gated chiral antennae**
- **Re-examination of the radio noise from Jupiter and sunspots**

-------------------------------- space-born: -----------------------------------

- **MR analysis of Earth's atmosphere and hydrosphere, using the space station and an earth-bound station**
- **MR analysis of Jovian atmosphere from a pair of spacecraft**

Is sensitivity an issue?



That is because

they know WHAT

to listen to

Thank You for your Patience

and the Organizers for their Courage to let me talk

All slides will appear on the web site www.ebyte.it