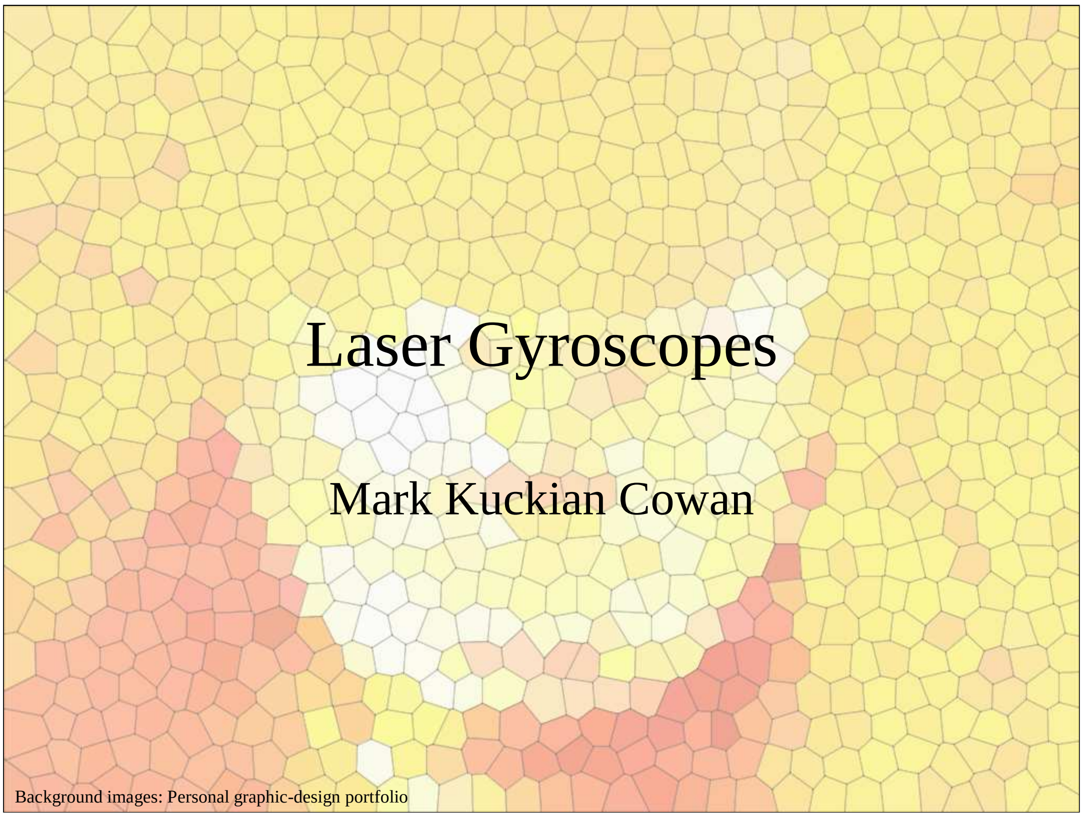


Be quick on this slide, get onto the lasers by the halfway point

Historically

- Gyroscopes were historically used for amusement (spinning-tops). The Maori found that by putting holes in spinning tops, they could create a humming, controlled by the rate of rotation.
- Even today, they are used in some games, and can be used in place of dice

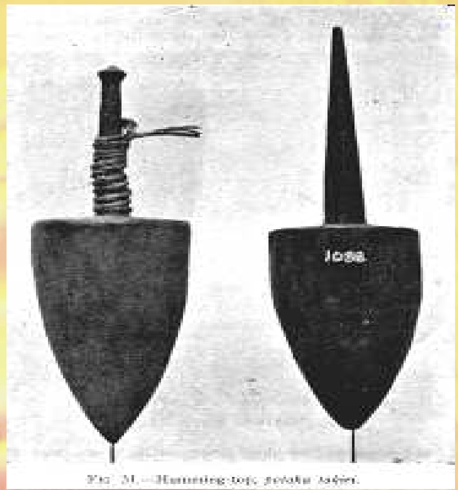


Image: http://www.nzetc.org/tm/scholarly/tei-BesMaor-c6-2-1.html

Be quick on this slide, get onto the lasers by the halfway point

"…their ability to balance on surfaces that were at odd angles made them the Ancient Greek equivalent to *Firebox* toys."

Maori – New Zealand, from East Polynesia

More recently

Sextant: Spinning mirror on gyroscope

Image from: http://www.thepirateking.com/historical/sextant.htm

- Circa 1740, an English scientist, Serson, noticed that spinning tops resisted external forces – for example, they would stay level when the surface they were balancing on was tilted. At this time, sailors navigated by measuring the angles between the sea and the stars (Sextants).
- Serson suggested using gyroscopes to create an “artificial horizon” for sailors to use instead of having to guess the “horizontal” ☺
- On his first test, the ship sank, losing everyone on board ☹
  Fleuriais (French) created an air-driven gyroscope – the basis for mechanical gyros for years to come

Be quick on this slide, get onto the lasers by the halfway point

Serson: Spinning tops resist external forces, hence they try to balance their axis in the direction of gravity

Serson: Create a portable horizon for when seas are rough / dark, also more accurate than guessing at sea-level from the position of the horizon (which is of course, curved “downwards”)

Fleuriais – wheel with cavities that provide high air-resistance, allowing it to be air-driven

An early scientific application

- During the 19th century, Foucault measured the rotation of the Earth by observing its effects on a pendulum and a spinning wheel.
- He named the wheel a “gyroscope”, which roughly translates to “To see revolutions”
- In 1898, Obry patented a torpedo steering mechanism that used an air-driven gyroscope, much like Fleuriais’s
- Early 20th century: Sperry (American) uses this rotation-measuring ability to create the first automatic pilot

Automatic pilot??

Image: Airplane (1980)

(Shirley you can’t be serious?)

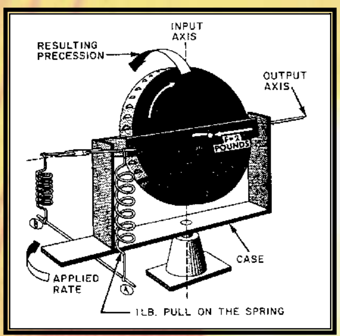
Be quick on this slide, get onto the lasers by the halfway point

Pendulum is set oscillating above a known line (eg. Magnetic longitude)

Pendulum deviates from this line due to it being slightly rotated as the Earth rotates (Mobius transform; line on curved surface – maybe mention in terms of spacetime bending?)

Gyroscope

Mechanical gyroscopes



Gyroscope setup:
Precession induced by torque

Image from:
http://www.tpub.com/neets/book15/63e.htm

- Torque on the axis of rotation causes the gyroscope to wobble (precession), the amount of precession is proportional to the rate of rotation.
- Used with accelerometers to provide inertial navigation, BUT
  - Due to friction, the gyroscope experiences some “drifting”; static friction results in no response at all to small rotations
  - Inconsistency in the torque of the motor driving the gyroscope results in more error
  - Some gyroscopes experience “Gimbal lock” – where (due to mechanical constraints), one degree of rotational freedom is temporarily lost in the gyroscope system, preventing it from being able to measure changes about that axis.

“How about sending me a fourth gimbal for Christmas” – Mike Collins, Apollo 11

Explain accelerometers for the iPhone people who probably know them as “the things that makes their games go landscape”

Explain local/world co-ordinates (invariance, Time:DON’T make a mention of Einstein’s general relativity/man in lift); Maintaining a translation and a rotation matrix?

Explain inertial navigation – accelerometers give a local force’s magnitude and direction, while gyroscopes measure torque/rotation in order to translate motion from the local (object) co-ordinate system to world co-ordinates

-Accelerometer data is turned into a translation matrix

-This is then rotated by a rotation matrix generated from gyroscope data

-This resultant matrix may then be applied to the current *local↔world* transformation matrix

-This can then be used to provide a distance from some initial point, and a bearing – essentially, a vector representing the current position relative to some fixed, known position.

Gimbal lock – all three sensor axes are in the same plane, preventing the system from generating a sensory response to rotation about an axis orthogonal to that plane

Mechanics with a twist

- The relevant equations describing the gyroscope follow from A-level rotational mechanics - linear mechanics translates to rotational mechanics almost by search-and-replace:
  - Force (F) → Torque (τ)
  - Mass/Inertia (m) → Moment of inertia (I)
  - Momentum (ρ) → Angular momentum (L)
  - Position (r/s/x) → Angle (compact: θ)
  - Velocity (v) → Angular velocity (ω)
  - Acceleration (a) → Angular acceleration ($\dot{\omega}$)
- Newton's 2nd law in rotational mechanics:
  - $F = {}^{d\rho}/_{dt} = {}^{d(mv)}/_{dt} = ma$
  - $\underline{\tau} = {}^{d\underline{L}}/_{dt} = {}^{d(I\underline{\omega})}/_{dt} = I\underline{\dot{\omega}}$

(The following is adapted from Wikipedia:)

A torque (***τ***) applied *perpendicular* to the axis of rotation (and therefore ***L***) results in a rotation perpendicular to *both **τ** and **L**.*

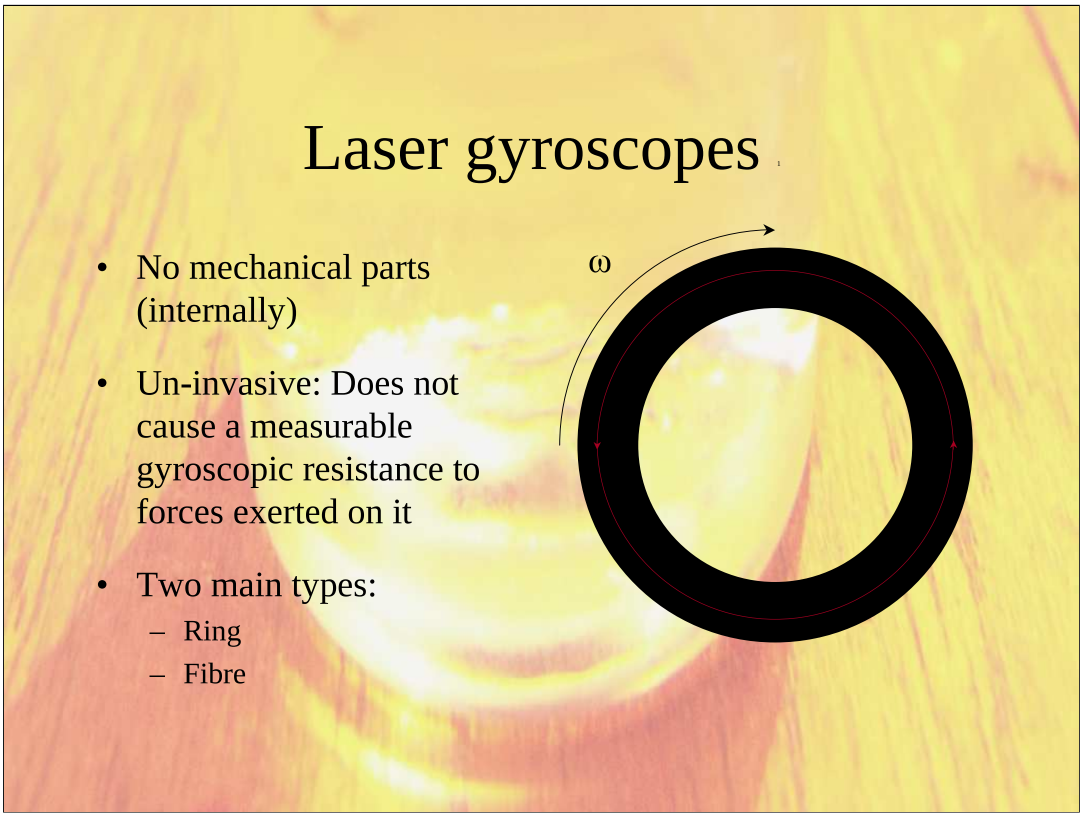
This motion is called *precession*. The angular velocity of precession ($\underline{\omega_P}$) is given by the cross product:

$$\underline{\tau} = \underline{\omega_P} \times \underline{L}$$

$$i.e.\ \underline{\dot{\omega}} = \underline{\omega_P} \times \underline{\omega}$$

Be quick on this slide, get onto the lasers by the halfway point

The only important bit is the final equation.



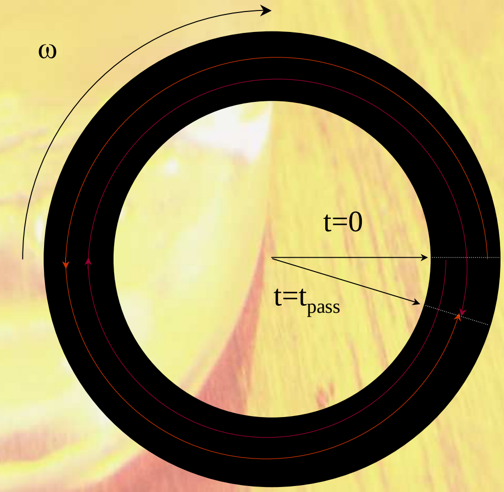
Ring-laser

Explain laser propagating in a circular cavity: Periodic boundary conditions

Ring-laser gyroscopes

- Cavity containing gain medium is rotated
- Cavity "length" is expanded/contracted depending on direction of beam propagation
- A slight frequency shift is caused, which results in "beating"

$$f_{beat} = {}^{4A\omega}/_{\lambda L}$$

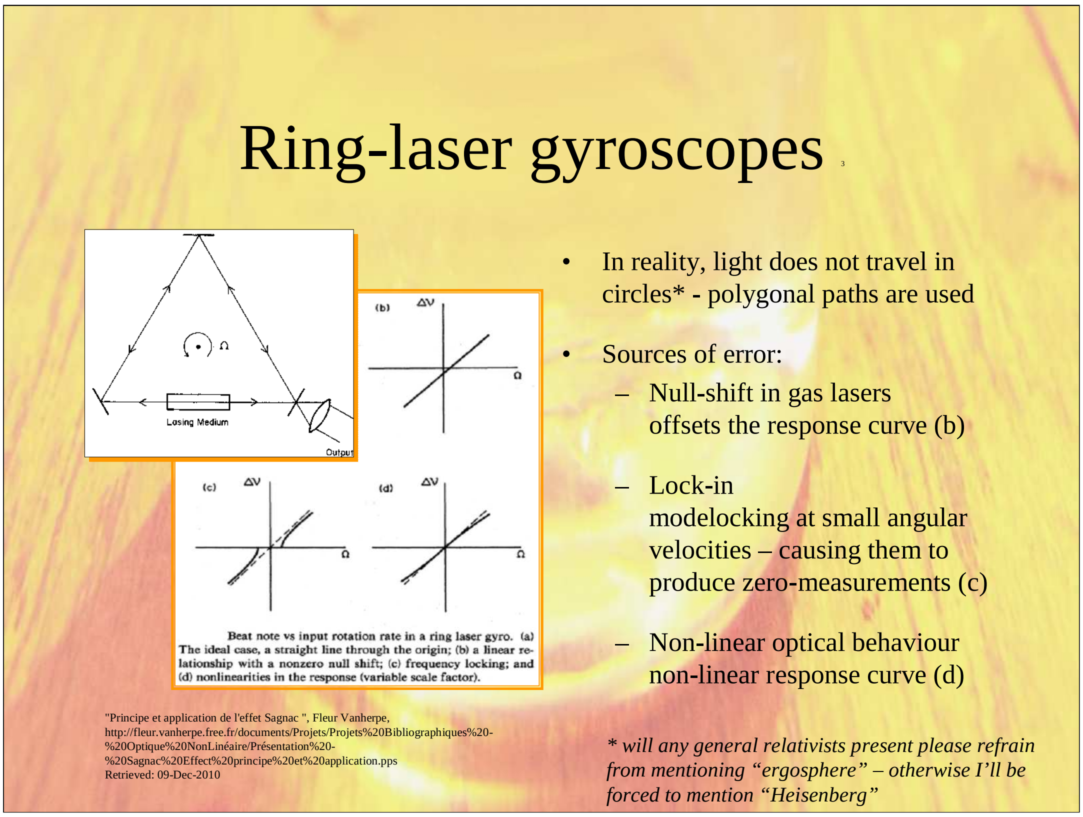


Cavity must contain some material that interacts with the light – won't work with an empty toroidal spacetime!

DON'T Explain beating – out-of-tune string instruments, the low-frequency interference is below our hearing's frequency range and appears as resolved pulses instead of a tone

Just introduce it as "optical equivalent to beating"

Larger ring → higher linear velocity of ring edge (x rad) AND longer distance to traverse ring (x rad) → The link between AREA and sensitivity (x rad^2)



Spend some time on this one

Explain null-shift

•Langmuir drift of neutral gas atoms due to electrical pulses and difference between nuclear/electronic masses

•Two counter-orientated discharge tubes

Mode-locking – results in monochromatic pulses instead of dichromatic beating

•Solved by rotating – same problems as mechanical gyro

•Solved by vibrating – dead-zones at multiples of the vibrator frequency

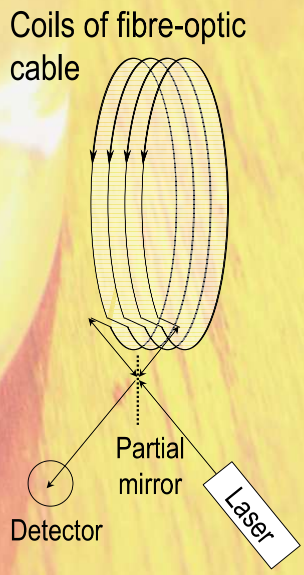
•Solved by vibrating the mirrors to doppler-shift back-scattered beams

Non-linear response

•Solved by good choice of materials

Fibre-optic gyroscopes (FOGs)

- Split a laser beam and send it both ways through a long coil of fibre-optic cable
- With no gain in the cable, rotation does not generate a frequency shift, but rather a phase displacement
- This phase difference between the exiting beams produces an interference pattern, rather than beating



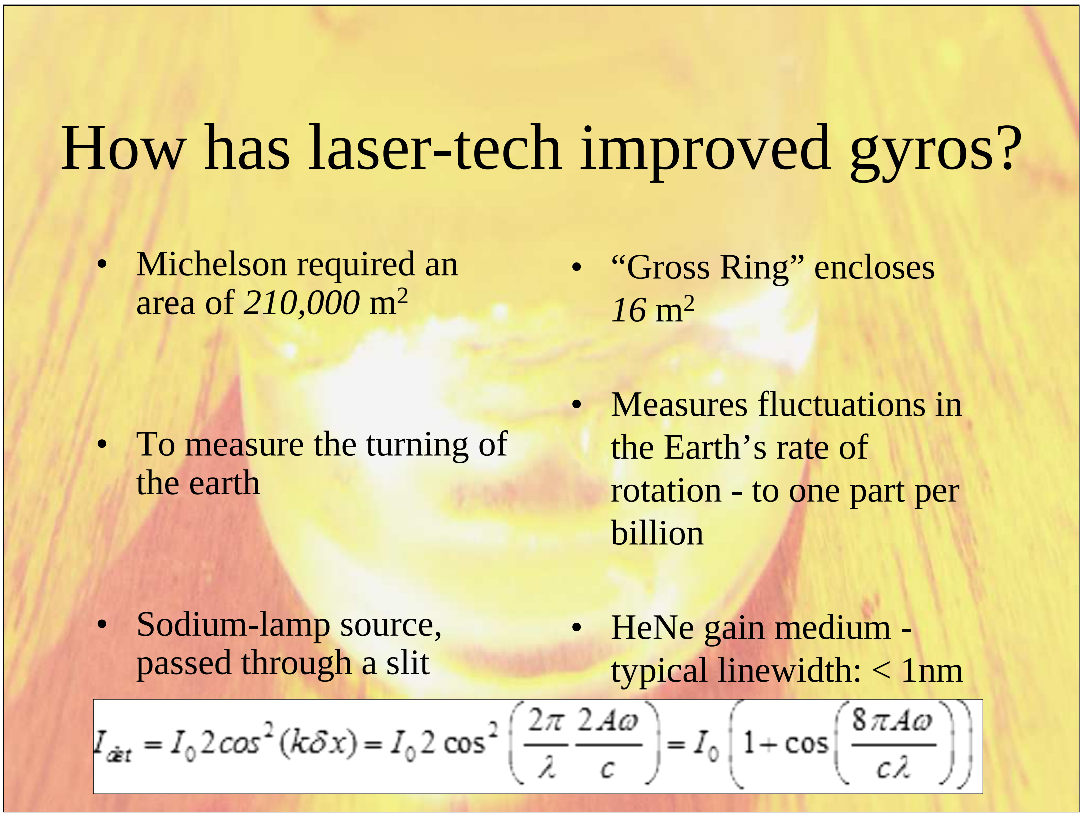
Enclose a high area by stacking rings

Only one mirror to align

Difference in distance travelled between the beams results in interference pattern – either measure as central intensity or fringe displacement

DPSS lasers can be used – low voltage requirements, no gas to maintain – MTBF of laser diodes is measured in decades – Very reliable, the laser source is the last thing you'd expect to fail on this device

Compact – the entire device could be mass-produced and pocket-sized; no gas cavity

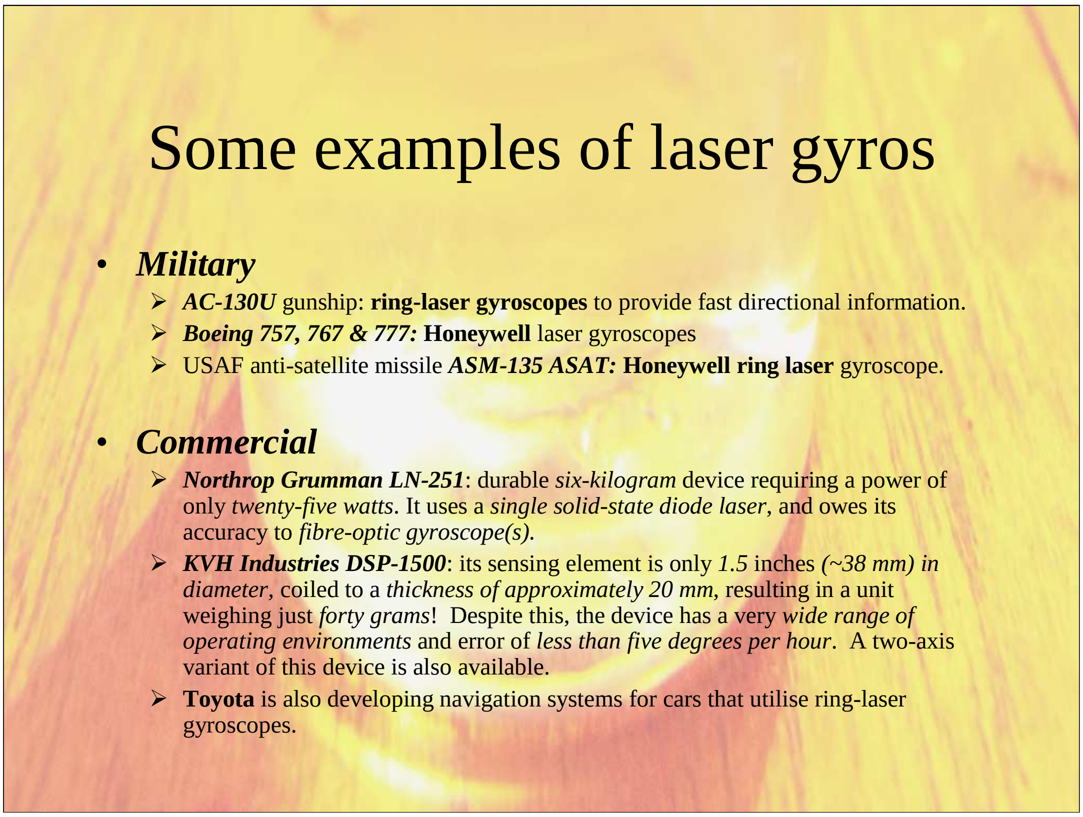


Michelson – 0.21 km^2 of pipes to measure rotation of the earth by displacement of interference lines

Small angle approximation: Id/Io = 2 – 0.5(8PAw/cy)^2 – square response (with offset)

By using loops of d=5.6m (to enclose 25m^2 in each loop), 8,400 turns would produce the same enclosed area as Michelson's device

Not that we need it, with monochromatic, naturally coherent laser sources and detectors of much better sensitivity than a guy with a ruler, trying to judge where the centre of an interference fringe is…



•***AC-130U*** gunship uses **ring-laser gyroscopes**[10] in addition to standard GPS systems in order to provide fast directional information.

•***Boeing 777*** uses **Honeywell** laser gyroscopes[11]

•***757*** and the ***767*** [17].

•USAF anti-satellite missile: ***ASM-135 ASAT***, which also uses a **Honeywell ring laser** gyroscope[12].

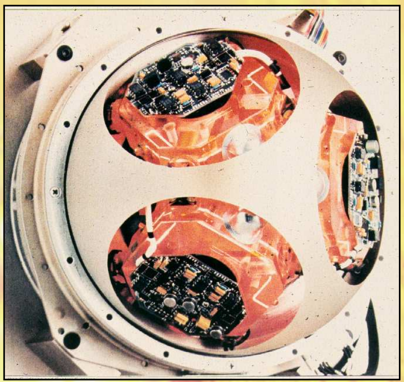
•***Northrop Grumman LN-251***[13]: 6kg, 25W, single diode laser, fibre optic

•***KVH Industries DSP-1500***[14]: 38x20mm element, 40g, 5deg/hour

•**Toyota** ring-laser gyroscopes assisted by GPS.

Future developments

- Laser gyroscope technology has become far more reliable, durable and accurate than most applications require
- Future developments will probably be motivated by miniaturisation and decreasing production costs for mass-integration into portable devices such as satnavs and smartphones
- Largely GPS assisted nowadays, needed for their update speed rather than high accuracy



Three-axis laser gyroscope (three gyros mounted on orthogonal axes)

"Three axis laser gyro", Prof. A E Siegman, Stanford University, *retrieved on 10-Dec-2010 from:* http://www.stanford.edu/~siegman/ring_laser_gyros/Three%20axis%20laser%20gyro%20med.jpg

Usually GPS assisted

Sufficient for most uses – it’s a solution in need of more problems.

Future: Atomic gyroscopes

MRI Mishap

http://www.nytimes.com/2005/08/19/health/19magnet.html

Nuclei with non-zero spins behave like gyroscopes (Larmor precession) – really, MRI scanners rely on nuclear precession:

- Application of strong magnetic fields exerts a torque on the nuclei to make them align spins with the field
- By pulsing the field, it can be made to resonate with the rate that nuclei of certain masses can align with the field
- The RF emissions from these nuclei as they relax after a pulse are frequency- and phase-coded to give their location to the detector

Skip through this one quickly, just mention that it describes an application of atomic spin-direction and a nuclear gyroscopic effect

Future: Atomic gyroscopes

- Atoms have their nuclear spins aligned to a certain axis
- They are guided around a loop/coil
- Rotation of the system will cause their spins to be off-axis after they’ve passed through the loop/coil
- This rotation of nuclear spins can be related to the rotation of the physical device

Larmor: Explain

NASA: Send Schroedinger’s cat-style atoms around two rings at once, measure the resulting effect on them when they come out


Fin.