Gravitational waves

Jo van den Brand

Logistics

- Group at present
  - Senior staff (< 3 fte):
    - Thomas Bauer (~50 %); on Virgo author list
    - Henk Jan Bulten; will be Virgo author in 2009
    - Jo van den Brand; on Virgo author list
    - Tjeerd Ketel (< 50%)
    - Harry van der Graaf (<<50%)
    - Jan Willem van Holten (promotor Gideon Koekoek)
  - Postdocs (1 fte):
    - David Rabeling (started Nov. 2008)
    - Position available (joined Nikhef – VU funded)
  - PhD students (2fte):
    - Gideon Koekoek (VU AIO; theory)
    - Sipho van der Putten (Nikhef OIO, a Frank special)
    - Position available (Nikhef funded)
- Technical footprint
  - Electronics: Henk Groenstege, Han Voet (finished)
  - Design and construction: IMC end mirror (finished)
  - FEA: Eric Hennes, Frans Mul (Corijn)
  - ET: Martin Doets
- Virgo contribution
  - 10 kE per author per year
  - 50 kE contribution per year for first 3 years (paid 100 kE so far)

Introduction

- Science goals
- LIGO and Virgo
  - Reached design sensitivity (do what you promise)
  - First upgrade (Virgo+) in progress
    - Nikhef made 2 contributions: IMC end-mirror and Electronics
    - Reasonable discovery potential (run start in July 2009)
  - Second upgrade (Advanced detectors) decided at this moment
    - Negotiations ongoing
    - Deliver MOA before Jan. 9, 2009
    - Decisions in May 2009 (reviewed by B. Barish committee)
    - Vast discovery potential (science runs start in 2014)
  - Integrated collaboration (we analyze and publish together)
    - In 2008 about 15 refereed papers
    - Many papers are under preparation

Science Goals & Sources

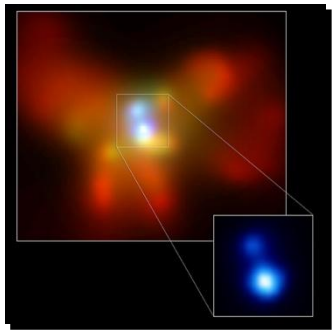
Science Objectives:

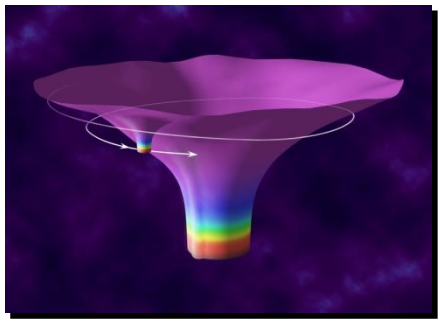
- Determine the role of massive black holes in galaxy evolution, including the origin of seed black holes
- Make precision tests of Einstein's Theory of Relativity
- Determine the population of ultra-compact binaries in the Galaxy
- Probe the physics of the early universe

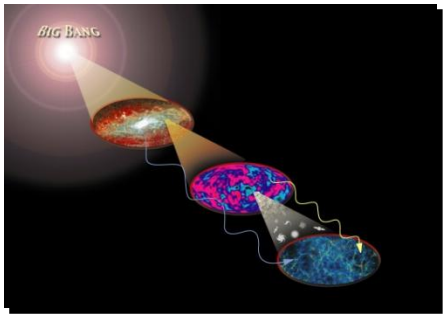
Observational Targets:

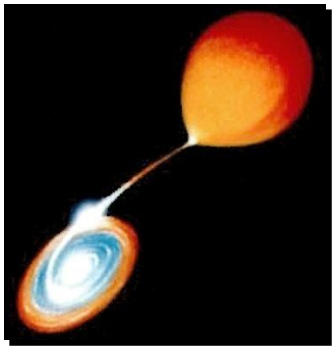
- Merging supermassive black holes
- Merging intermediate-mass/seed black holes
- Gravitational captures by supermassive black holes
- Galactic and verification binaries
- Cosmological backgrounds

New window on the Universe

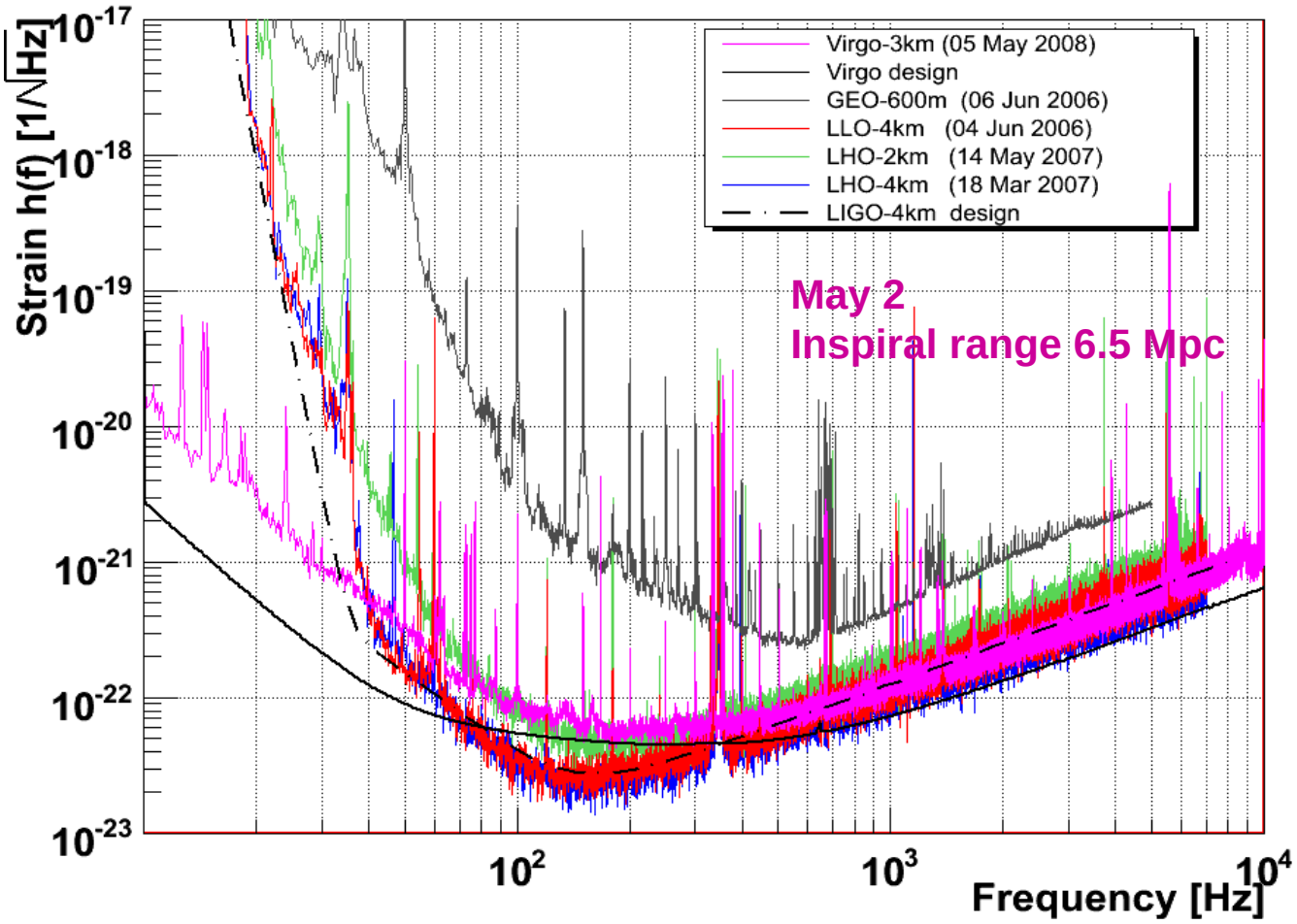






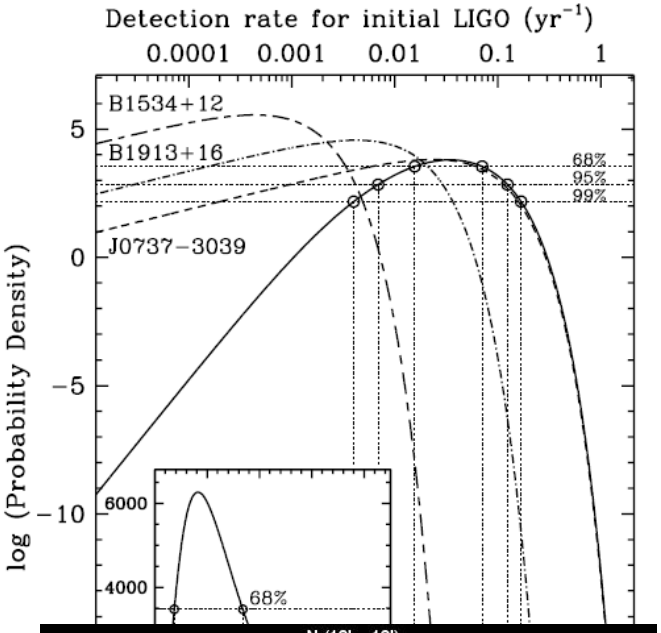


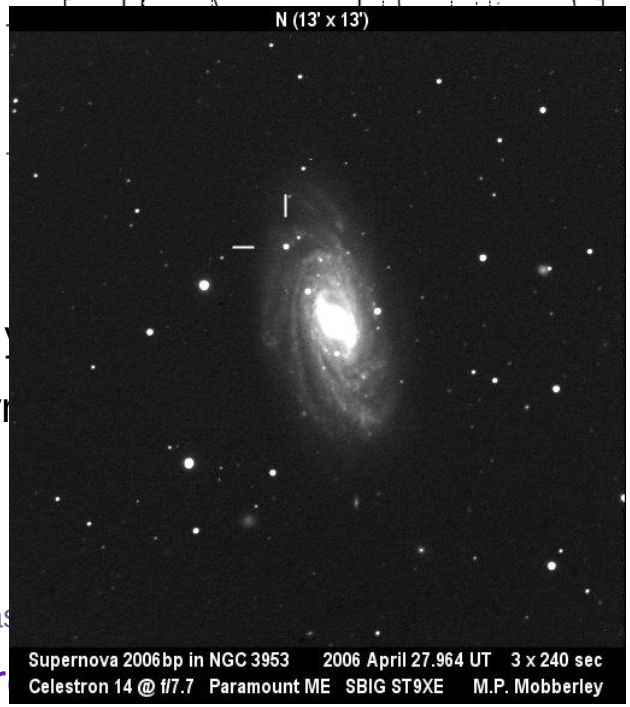
Virgo sensitivity compared to LIGO and GEO600



The horizon (best orientation) for a binary system of two 10 solar mass black holes is 63 Mpc

Discovery potential first event





- Hypothesis:
  - Finesse = 150 (now : 50)
  - Same losses & power recycling as today
- Horizon (Virgo+)
  - BNS: 150 Mpc (optimal orientation)
  - BBH: 750 Mpc (optimal orientation)
- BNS Rates: (most likely and 95% interval)

– Initial Virgo (30Mpc)	1/100yr	(1/500 -1/25
– Enhanced LIGO (60Mpc)	1/10yr	(1/50- 1/2.5yr
– Virgo+ limit (150Mpc)	1.2/yr	(1/4yr-5/yr)
– Advanced detectors (350Mpc)	40/yr	(8-160/yr)

Kalogera et al; as

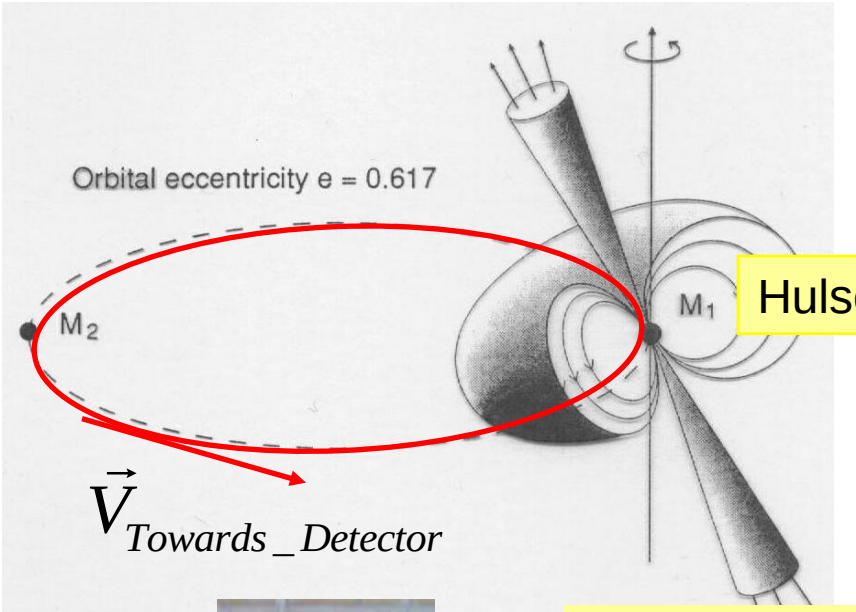
- BBH and other sources rates are more difficult to pr

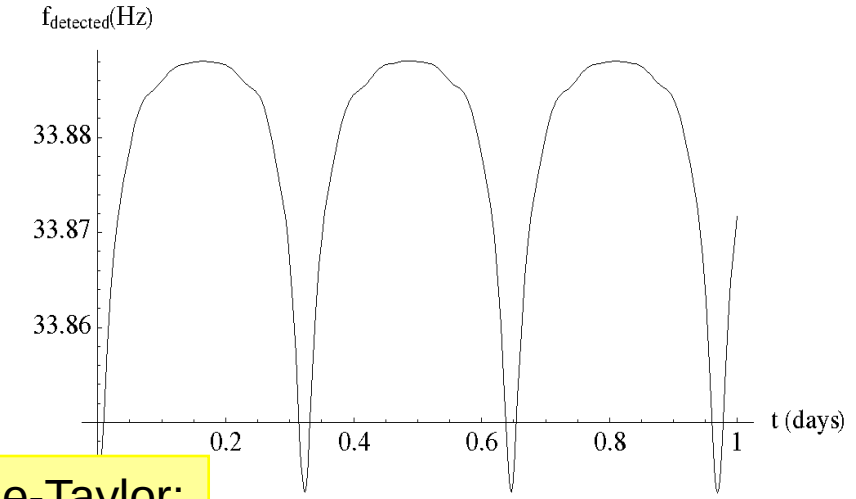
Nikhef activities

- Analysis of GW signals from neutron stars
  - Concentrate on NS in binaries
- Contributions to the first upgrade: Virgo+
  - Linear alignment electronics
  - Input mode cleaner: end-mirror system
    - Designed, constructed and installed in 2008
    - Commissioning is ongoing
- At present we did not take on any new responsibilities (no work for Virgo in any workshop at this moment)
- Instead, we are negotiating activities for the next upgrade: Advanced Virgo

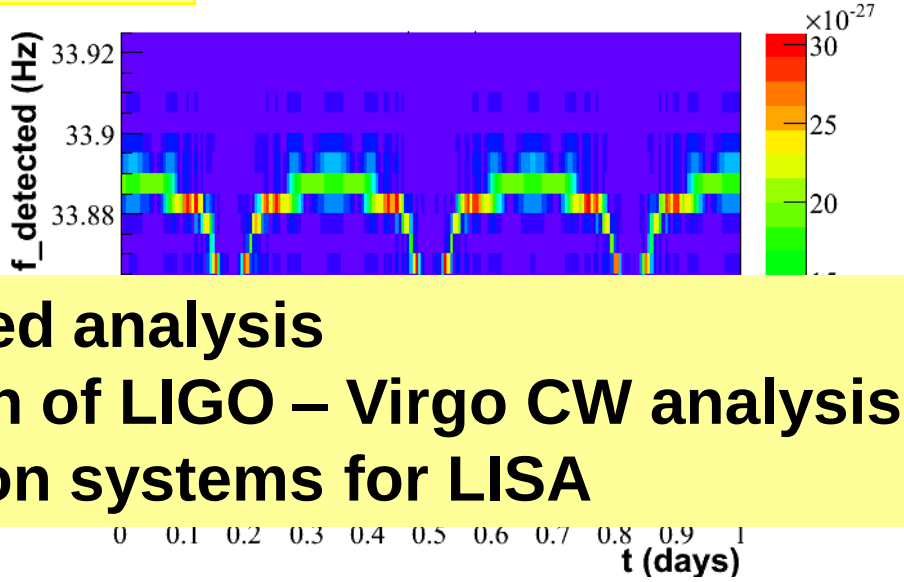
GWs from binaries

- Frequency changes a lot due to Doppler: $df/f \sim 10^{-3}$



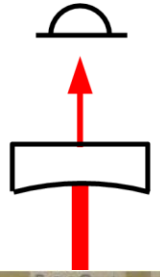


Hulse-Taylor:



Grid-based analysis
Extension of LIGO – Virgo CW analysis
Calibration systems for LISA

Nikhef: Linear alignment of VIRGO



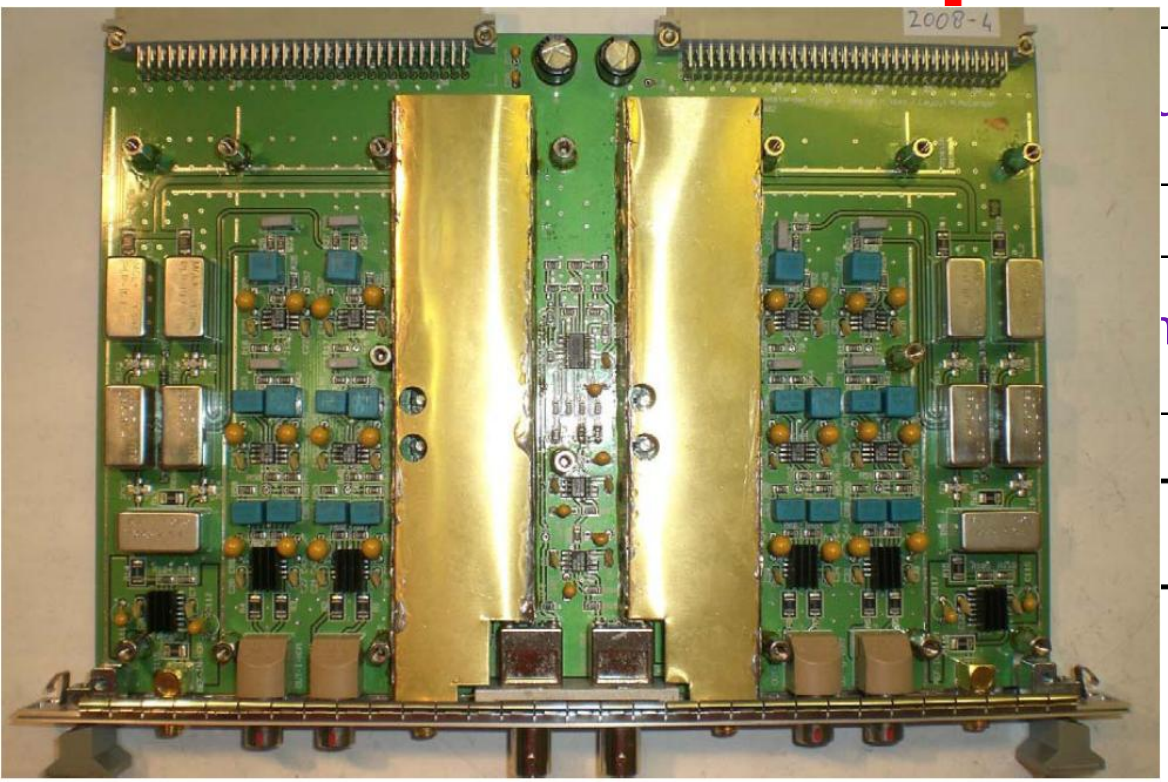
- Phase modulation of input beam
- Demodulation of photodiode signals at different output beams
  - => longitudinal error signals

uadrant diodes in output beams

  - => Alignment information
  - (differential wavefront sensing)

nderson-Giordano technique

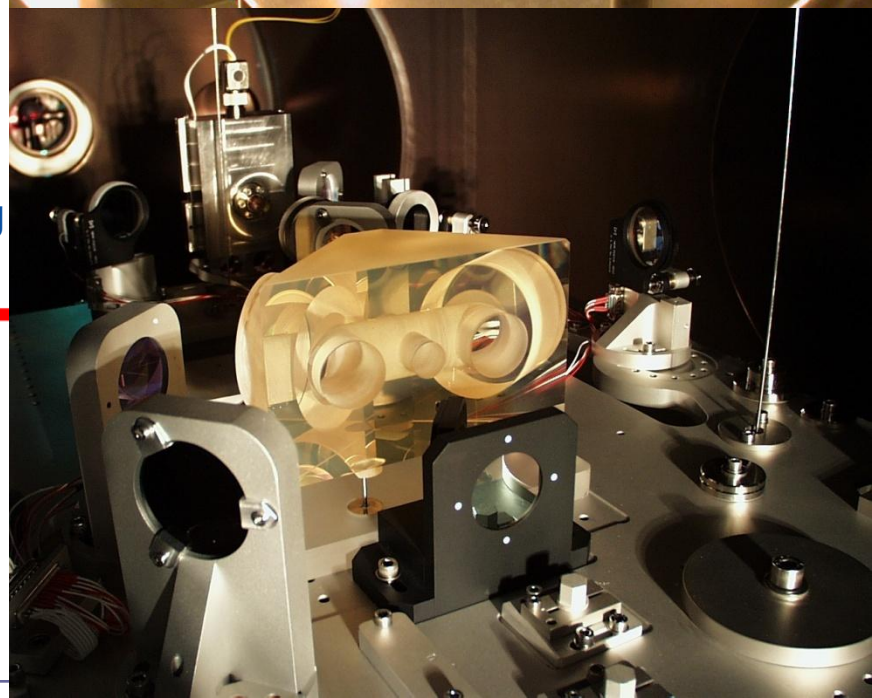
  - 2 quadrant diodes after arm cavities

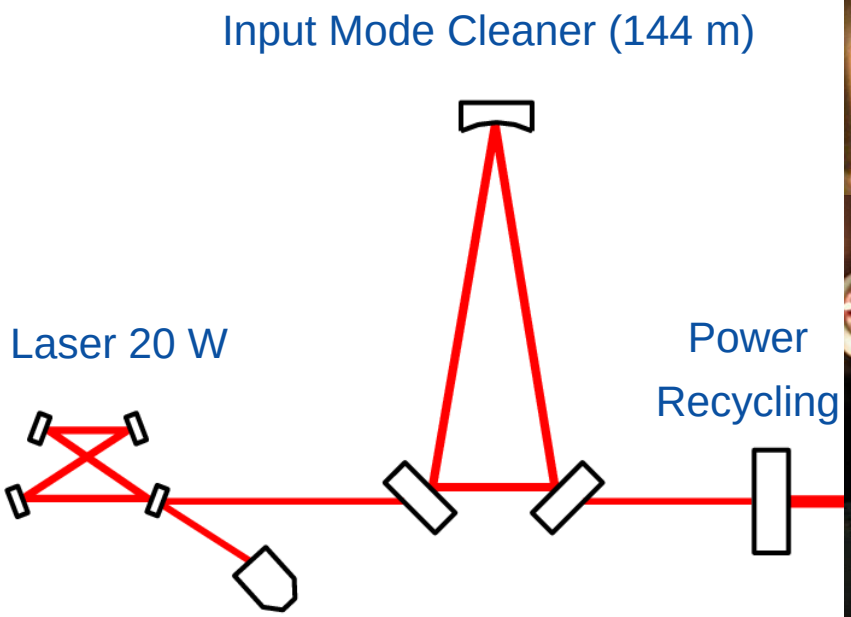


+ Han Voet

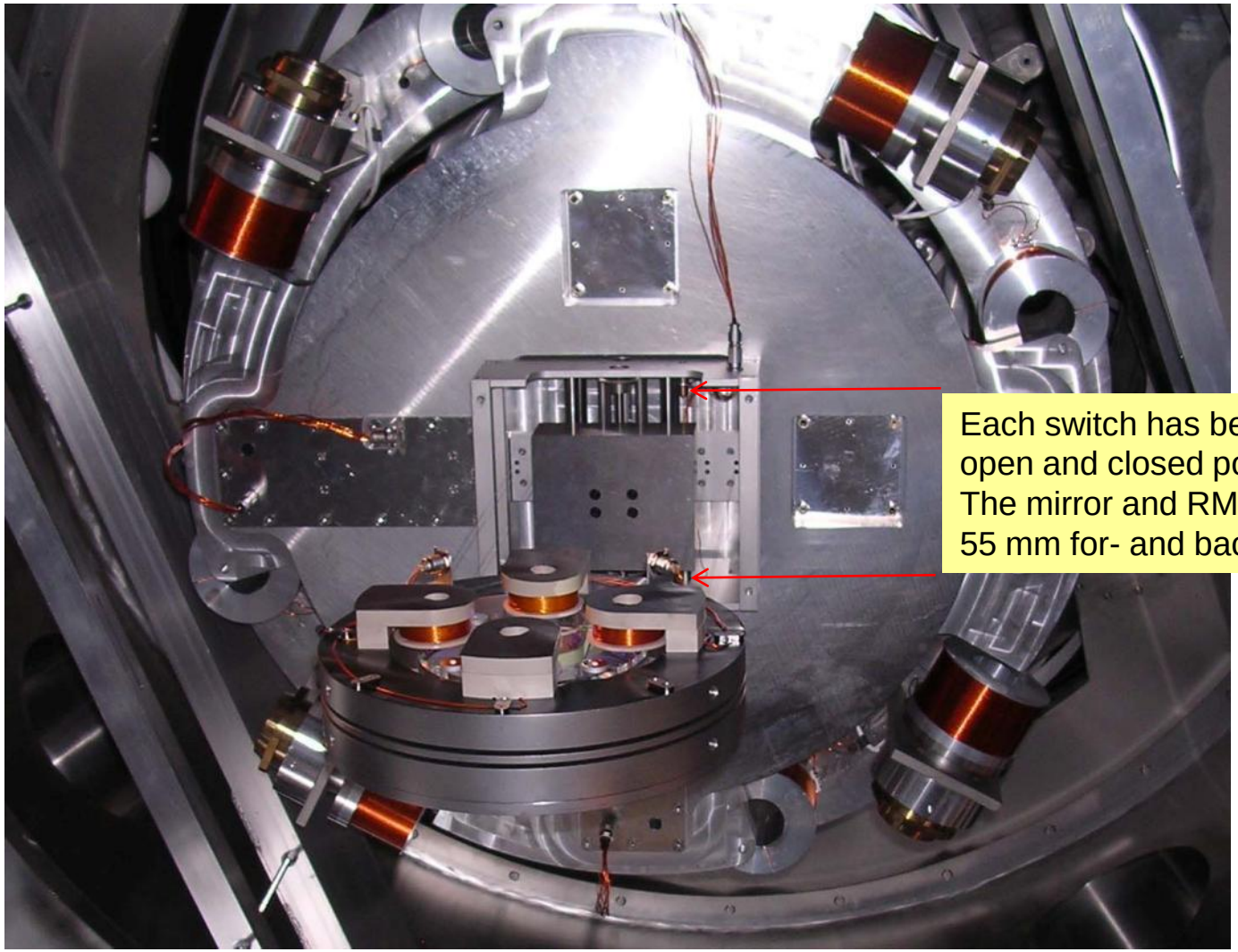
Input mode cleaner

- Mode cleaner cavity: filters laser noise, select TEM00 mode



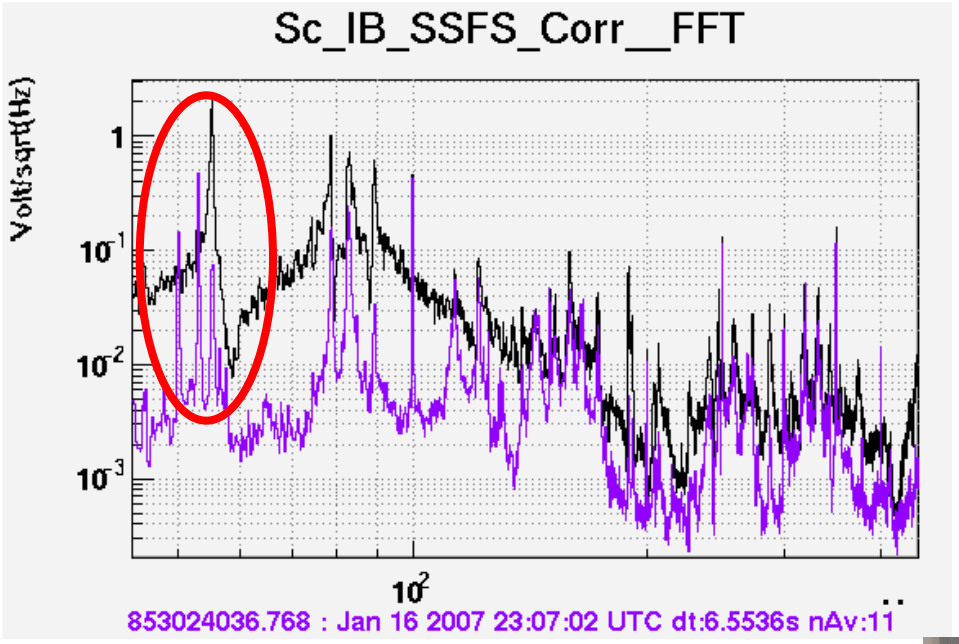


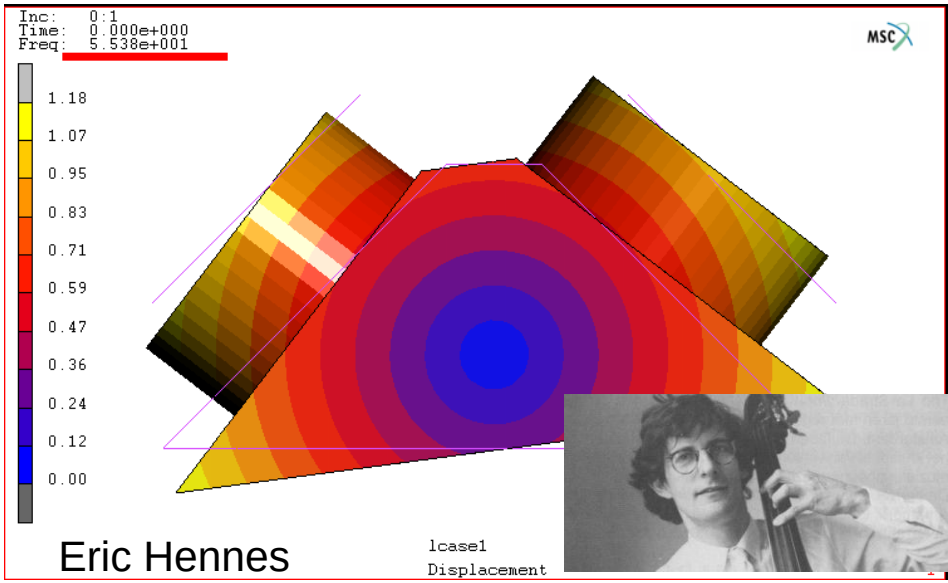
Installation in IMC end tower



Each switch has been tested in open and closed position.
The mirror and RM are moved 55 mm for- and backwards.

Nikhef: redesign and replace dihedron





Optronica is doing the construction

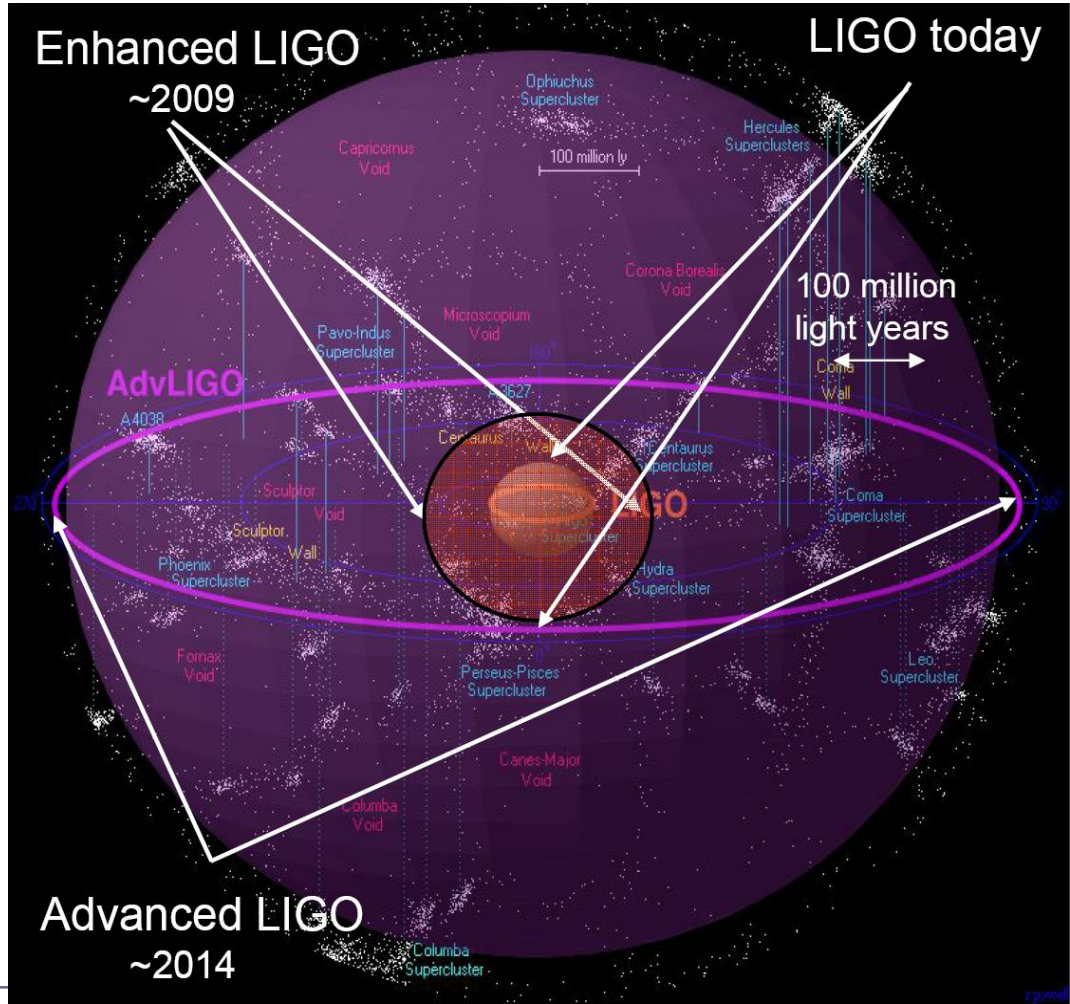
Marinebedrijf
Den Helder

Nikhef planned activities in Virgo

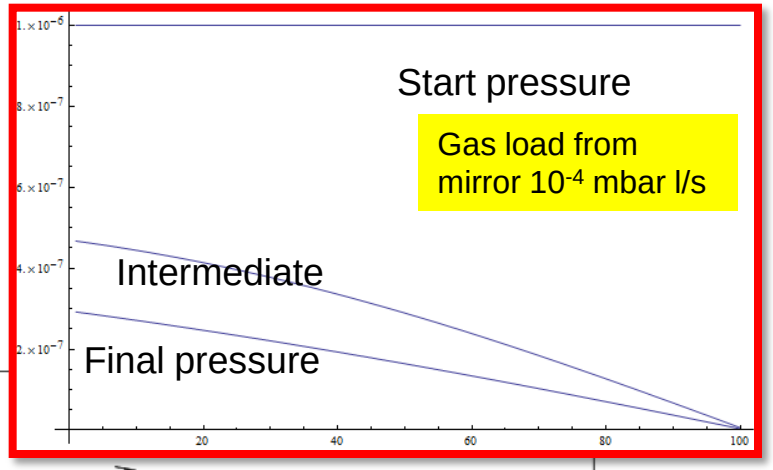
- Advanced Virgo is the next upgrade
  - Time line
    - Design and construction: 2009 – 2012
    - Installation: 2012 – 2013
    - Commissioning: 2014
    - Science run: 2014
  - This is the last upgrade planned for Virgo (also LIGO)
  - Funding decided by CNRS and INFN in May 2009
  - Negotiate NOW!!! Nikhef argues for
    - Cryo – vacuum links (water vapor gives optical path length fluctuations)
    - Mirror suspension systems
- Advanced LIGO
  - Parallel with Advanced Virgo
  - Fully funded in 2008 by NSF
    - Equipment funded for $ 206.12 million ($ 32.75 million in 2008)
    - Additional exploitation also funded (~$ 200 million)

LIGO and VIRGO: scientific evolution

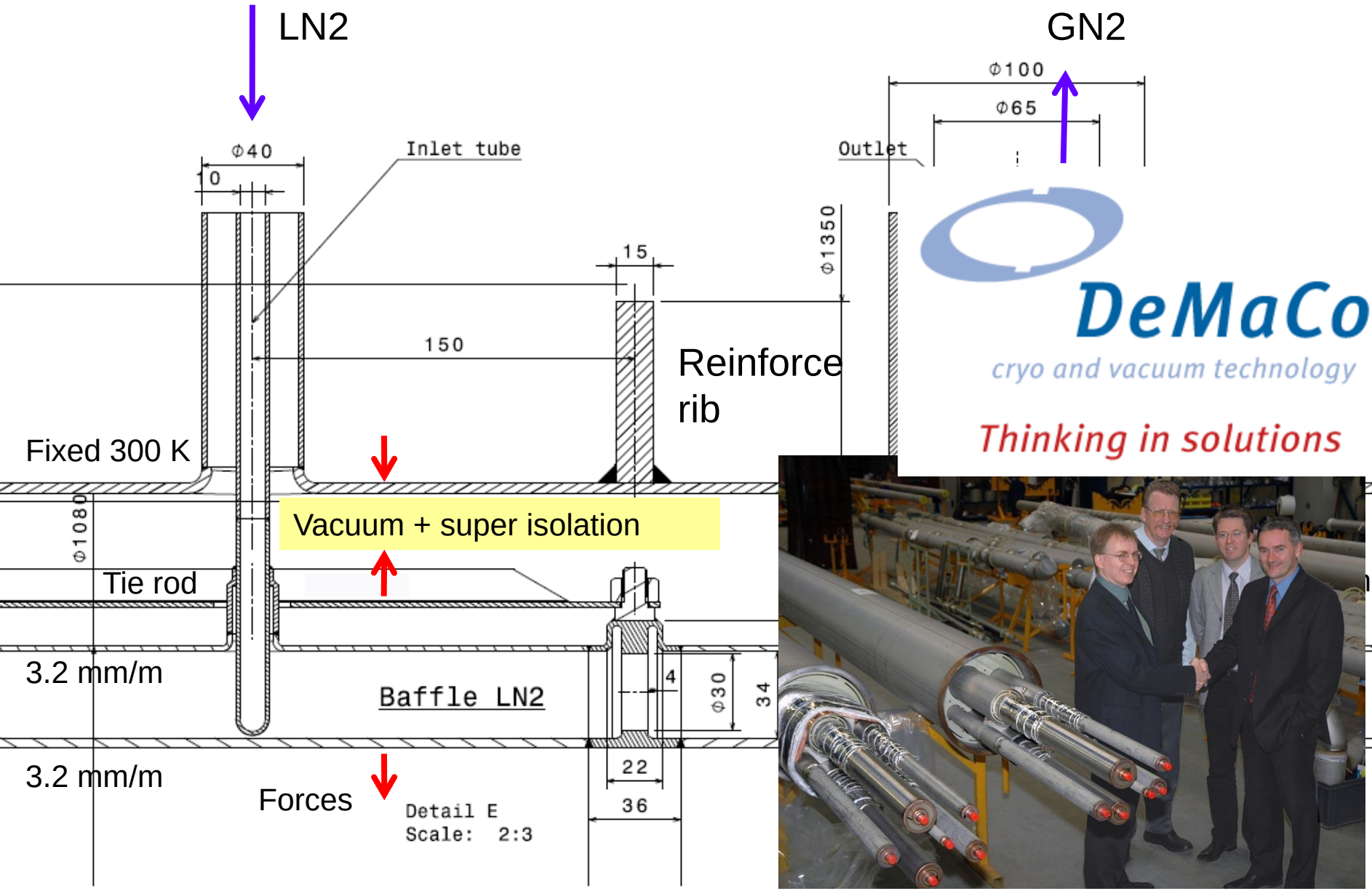
- At present hundreds of galaxies in range for 1.4 M_o NS-NS binaries
- Enhanced program
  - In 2009 about 10 times more galaxies in range
- Advanced detectors
  - About 1000 times more galaxies in range
  - In 2014 expect 1 signal per day or week
  - Start of gravitational astrophysics
  - Numerical relativity will provide templates for interpreting signals



Advanced Virgo: vacuum – cryo links

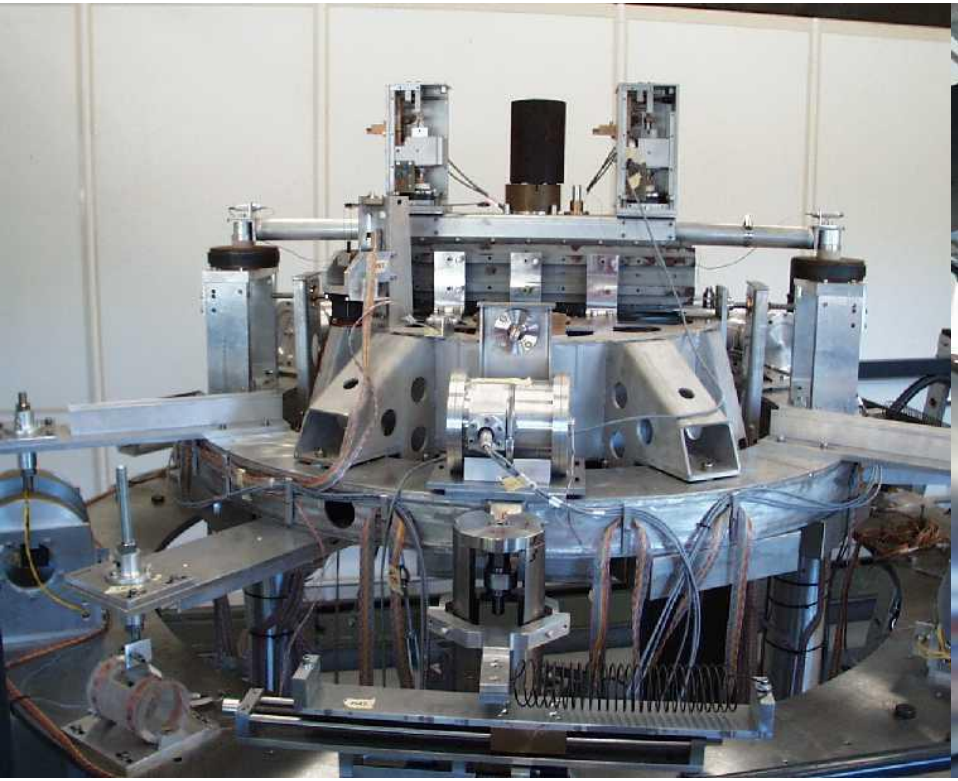


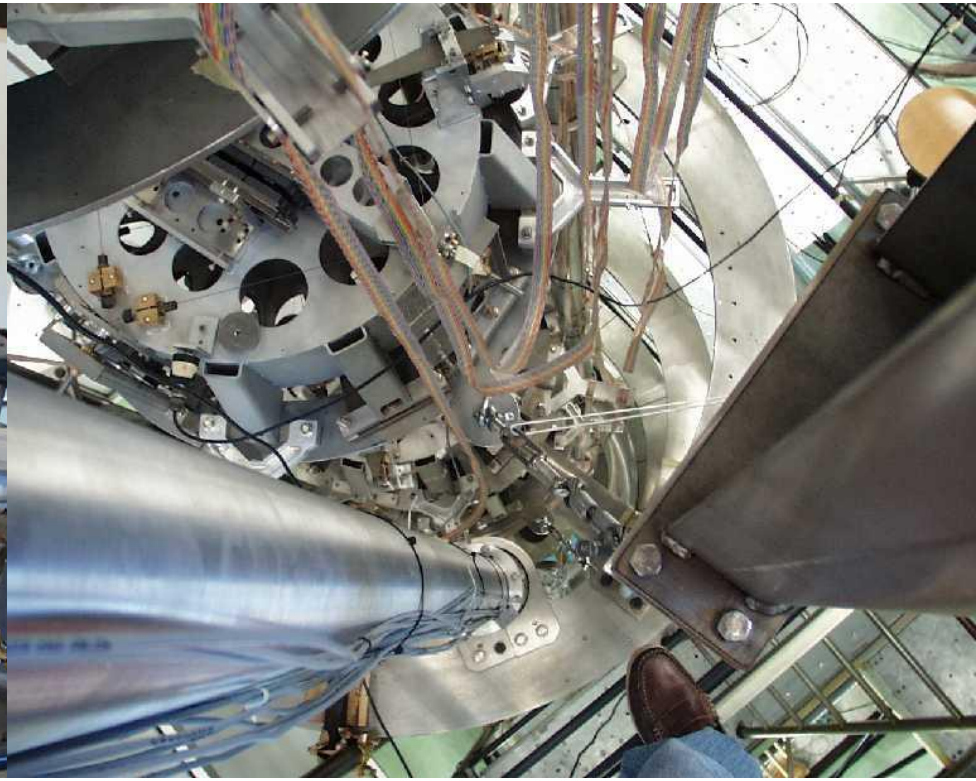
Advanced Virgo: vacuum – cryo links

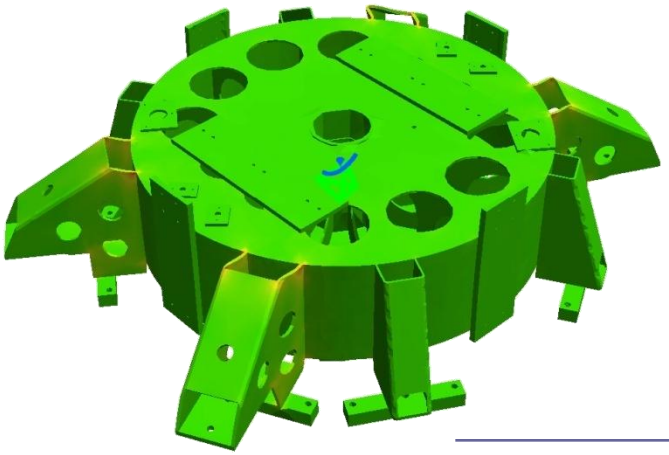


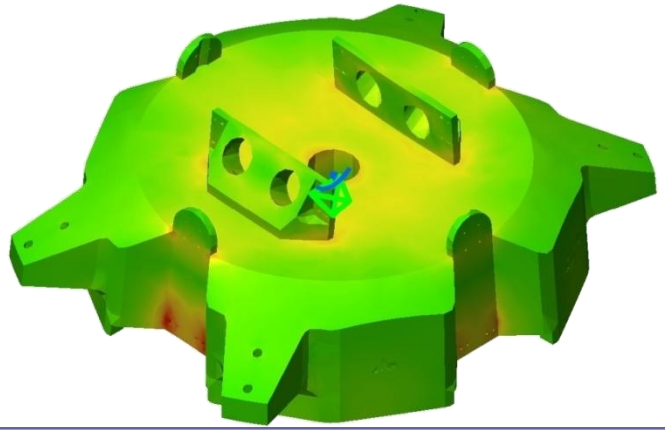
DeMaCo
cryo and vacuum technology
Thinking in solutions

Advanced Virgo: superattenuator







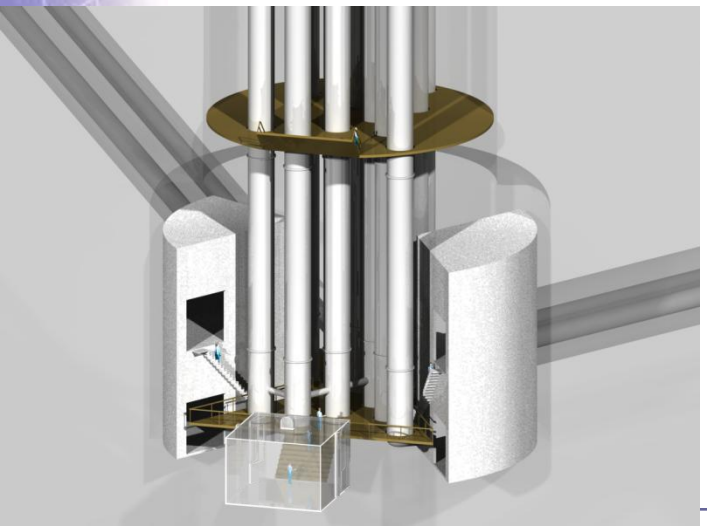


FEA:

Frans Mul
Corijn

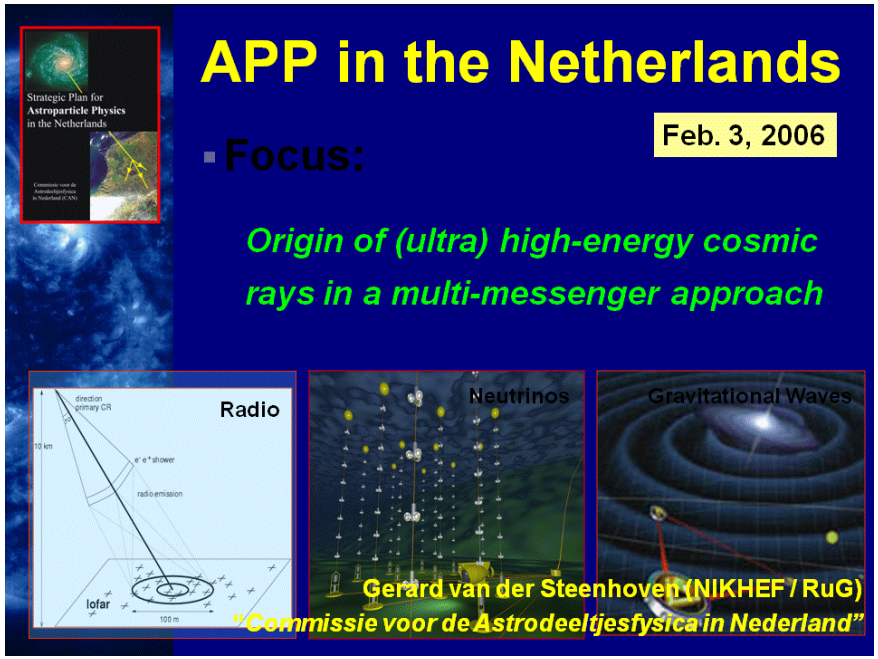
Other activities in GW program

- Einstein Telescope – conceptual design study
  - Approved in May 2008
  - Funded for 3 years (essentially pays for our postdoc and some travel)
  - Nikhef responsible for Working Group 1 on site selection
  - ET is not part of the WAR discussion
    - Technical footprint: M. Doets (0.5 fte)
    - Travel is funded through FP7



History

- Several discussions of our GW plans
  - WAR: March 11, 2005, Jan. 2006 (MOU)
  - Staff: Jan. 2006, forgot exact date
  - SAC: reported 4x
  - APP symposia: 2x per year
  - VU, FOM, etc.
- GW included since 2006 part of our APP ambitions
  - Obviously resources are required
  - Nikhef and VU made commitments
    - Scientific staff moved into GW physics
  - Until now small scale activity
- Funding requests so far
  - APP proposal to NWO (failed)
  - 2x FOM projectruimte (both failed)
  - VIDI proposal (failed)
  - Grawiton Marie Curie ITN proposal (4 PhDs) (failed)
  - Ilias NEXT proposal to FP7 (failed)
  - Einstein Telescope proposal to FP7 (granted)

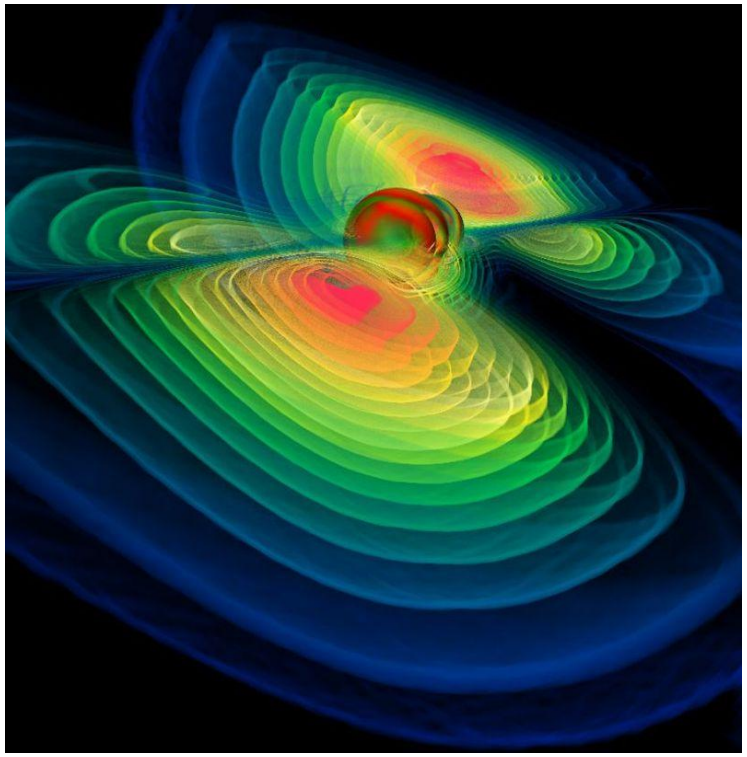


Also remember: it was decided in 2008 not to include GW as part of the FOM program on APP

Fine with me, but does not help our GW activities

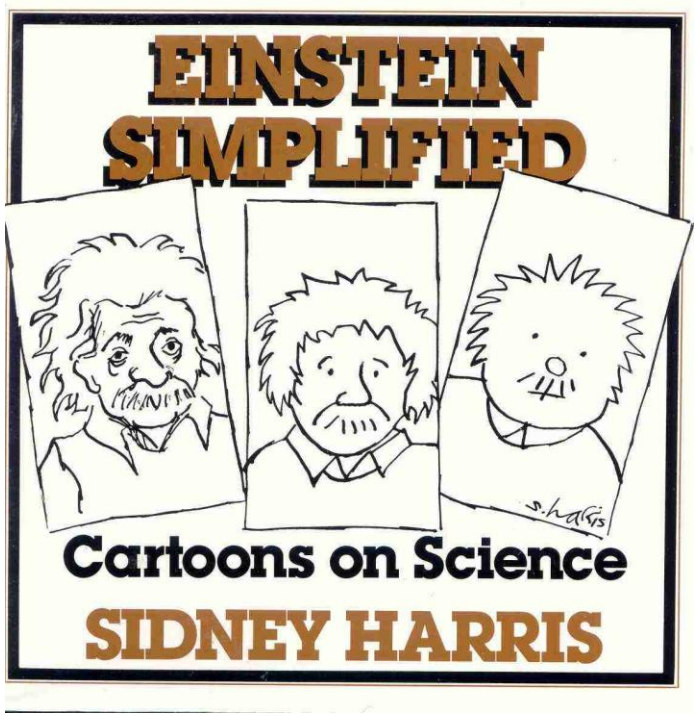
Proposal to WAR

- Proposal to WAR
  - Nikhef should accept responsibilities in Advanced Virgo
    - Presently commitments are made by collaborators
      - MOAs are submitted before Jan. 09, 2009
      - Council meeting planned for Jan.09 and 14, 2009
    - CNRS and INFN decide in May 2009
    - There is no other upgrade foreseen
      - At least not before my retirement – 2018
    - So for Virgo this is our only opportunity to contribute to the hardware of the experiment
  - Nikhef submits MOA
    - Nikhef declares intention to contribution to cryo – vacuum links and superattenuator
    - Makes contribution contingent on quality of contribution (we want to have a suitable and challenging task)
    - Contribution contingent on funding approval
- Impact of decision
  - Budget and manpower
    - Required budget estimated around 1.5 Meuro
    - Required technical manpower around 20 fte total
- Boundary conditions
  - Timeline of project: 2009 – 2012, so we can spread budget and manpower needs
  - Timeline allows to develop funding strategy



GW challenges and issues

- Improve the following
  - Build-up GW experience
    - Foster scientific and intellectual environment
      - GR and cosmology at Nikhef and Universities
      - Implement GW in our master program
      - Organize GW topical lectures
      - Link with string theory: this is gravity and QM
    - Develop technical skills
      - FEA, control systems
      - precision technology, advanced optics
  - Strengthen our GW group
    - Appoint postdoc, PhDs and senior staff
    - Improve on-site presence in Cascina
- Organize national community
  - Astronomy and astrophysics at various places
    - Y. Levin (Leiden), G. Nelemans (RUN), A. Watts (UvA), UU, SRON, ESA, MiniGrail, etc.
    - Interaction needed on many topics: pulsars, primordial GWs
- Funding for our GW activities
  - FOM GW program request
    - Submit in 2009 or 2010 (decide in collaboration)
    - Proposal: first work on the above …
  - FOM Projectruimte
    - Submit 2 proposals in May 2009
  - Exploit EU possibilities



Unfortunately, we cannot wait with a decision until a FOM program is approved for GW.

VU can contribute to proposal
- about 500 kEuro total in period 2009 – 2012
- about 8 fte technical manpower (integral 2009 – 2012)