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 yr)
  - 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)

- BBH and other sources rates are more difficult to predict

Kalogera et al; astro-ph/0312101; Model 6
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: \( df/f \approx 10^{-3} \)

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
- Quadrant diodes in output beams
  - => Alignment information
  - (differential wavefront sensing)
- Anderson-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

Sc_IB_SSFS_Corr__FFT

Optronica is doing the construction

Marinebedrijf
Den Helder

Zorg dat je erbij komt...

Eric Hennes
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 $M_\odot$ 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

Pressure
mbar

Start pressure

Intermediate

Final pressure

Gas load from mirror $10^{-4}$ mbar l/s

Element number

Element number

Start pressure

Intermediate

Final pressure

Large Valve DN1000

4370 Link WE

985

6885

West End Tower

4810

6000

8000

1480

3060

Tube Support

pumping ports not indicated
Advanced Virgo: vacuum – cryo links

LN2

Inlet tube

Reinforce rib

Vacuum + super isolation

GN2

Outlet

DeMaCo
cryo and vacuum technology

Thinking in solutions

Fixed 300 K

Tie rod

Baffle LN2

Forces

Detail E
Scale: 2:3
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

Design Study Proposal approved by EU within FP7
Large part of the European GW community involved: EGO, INFN, MPI, CNRS, NIKHEF, Univ. Birmingham, Cardiff, Glasgow
Recommended in Aspera / Appec roadmap
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)
  - Grawitont 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)