Holographic Grid Cloud, a futurable high storage technology for the next generation astronomical facilities

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Abstract

In the immediate future holographic technology will be available to store a very large amount of data in HVD (Holographic Versatile Disk) devices. This technology make extensive use of the WORM (Write-Once-Read-Many) paradigm: this means that such devices allow for a simultaneous and parallel reading of millions of volumetric pixels (i.e. voxels). This characteristic will make accessible wherever the acquired data from a telescope (or satellite) in a quite-simultaneous way.

With the support of this new technology the aim of this paper is to identify the guidelines for the implementation of a distributed RAID system, a sort of “storage block” to distribute astronomical data over different geographical sites acting as a single remote device. To reach this goal it is needed a feasible platform (preferably open-source) to facilitate authentication encryption and dissemination of web services (including data storage), using indexed of appropriate hardware and software (both physical and virtual). I identified the “eucalyptus” open-source platform as best candidate for this purpose. Once developed an appropriate IaaS (Infrastructure as a Service) architecture, it is possible to virtualize required platforms (PaaS, Platforms as a Service) and hence create services on-scientific-demand (SaaS, Softwares as a Service). Any single service will be tied to the particular instrument / observatory and will be implemented at user’s request through a distributed sub-layer database of meta-datas intimately connected to physical datas. From outside these services will be visible as a part of a single resource: this is an effect of a main property of distributed computing, the abstraction of resources. The end user will only have to take care on connecting in a opportune and secure mode (using personal certificates) to the remote device and will have access to all (or part) of this potential technology.

A Storage-Block+Services engineered on this platform will allow rapid scal-
ability of resources, creating a “network-distributed cloud” of services for an instrument or a mission. It is recommended the use of a dedicated grid-infrastructure within each single cloud to enhance some critical tasks and to speed-up services working on the redundant, encrypted and compressed scientific data. The power, the accessibility, the degree of parallelism and of redundancy will only depend on the number of distributed storage-blocks and on the potentiality of the inter-network data connection: the higher this amount, the greater will be throughput of the IT-system. A storage-block of this kind is a meeting point between two technologies and two antithetical computing paradigms: the Grid-Computing and Cloud-Computing. Extracting the best from the two technologies will maximize benefits and minimize disadvantages, thus allowing an optimal development of the infrastructure for future observatories and demanding astronomical missions.

In this paper I first present an overview of the technologies cited: the Grid-Computing, the Cloud-Computing (i.e the Cloud-Storage), the state of the art for Holographic data-storage and devices, after the introduction I discuss the main issues on modern scientific data-storage facilities. Finally I present a possible solution through the engineering of a storage-block and a possible technical implementation for several basic services on-demand.

**Keywords:** HOLOGRAPHY, DATA-GRID, CLOUD-COMPUTING, STORAGE-BLOCK, VOXEL, CTA, EUCLID, HOLO-GRID-CLOUD, 3D-OPTICAL-DEVICE, HVD

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**Introduction to IT-Technologies**

Let’s start with a simple overview of the most used technologies cited in this paper: the Distributed-Computing and in particular Grid-Computing and Cloud-Computing (especially Cloud-Storage) focusing on similarities and differences between these two paradigms. And the state of the art for Holographic devices focusing on the possible improvements for astronomical purposes.

**Distributed-Computing**

A network which abstracts processing tasks can identify a Distributed-Computing (DC) architecture. The abstraction in IT-technologies makes invisible the actual complex processing underlying in a system and provides a simple user-interface, with which users can interact easily. All that is visible is the interface, which receives inputs and provides outputs; how these outputs are computed is completely hidden to a user.

It is possible to talk of DC when the computing elements of a network are spread over large geographical area: in this context both Grid and Cloud can be considered DC architectures. Distributing computation over distant geographical locations makes also possible to spread out the architecture costs accordingly.
Grid-Computing

The Grid-Computing (GC) paradigm implies massive computer networks, IT-assets and hence great investments. GC is an infrastructure which relies on software (middle-ware) collecting together different hardware resources to act as a single entity (a virtual whole). Such an entity divides and directs pieces of programs on a large number of different computers and processes single (or few) task (see [1], [3], [4], [5], [6], [7], [10]). Processed tasks are always managed by a single primary computing machine (i.e. Computing Element), making use of a batch queue system. The role of this machine is to divide a single task in numerous sub-tasks, sending them to different worker nodes and retrieving their outputs. A job’s life-circle is closed when all results are assembled in a single output, taking care of monitoring the well-completion status of the whole work-flow (see fig. 1).

GC offers two main advantages:

1. it can easily make use of idle or unused processing power within distributed computing (aggregation of processing power)
2. the simultaneous execution of sub-independent task processes derived by a parent job allows a significant reduction of a the total execution time

However GC has two main disadvantages:
1. A job needs to be serialized in order to run in a data-grid network: the code must be split into several tasks that are mutually exclusive or independent. This is a different concept from that of parallel computing where both the code and the hardware must be designed for that purpose.

2. The job I/O must have the same format under almost all circumstances.

**Cloud-Computing**

The Cloud-Computing (CC) can be described as a shared access to computers and their functionality via the Internet or a local network. This is merely an extension of the object-oriented programming concept of abstraction.

The name CC refers to the fact that users don’t know (or see) exactly the underlying resources or their organization. A fraction of resources (a resource-pool) is drawn by the “cloud” when it is needed and returns to the “cloud” when it is released (this concept is called “on-demand cloud”). In other words, a “cloud” is a pool of resources (i.e. a set of machines and web-services) that implements a CC system providing shared services (see [11]).

The key concept of “virtualization” is widely used in the CC paradigm: the ability to run “virtual machines” (VM) on top of a “hypervisor”. A VM is a software implementation of a machine (computer with its own OS, kernel, library and applications), that executes programs like a physical machine. The hypervisor provides a unique and uniform abstraction layer for the underlying physical machine. This means that by running VMs on the same hypervisor make possible to match all user requests and needs for different services (see fig. 2).

For the work purpose I will describe a particular CC system: the Cloud-Storage (CS), where the primary goal of the CC architecture is the storage of a huge amount of data (i.e. astronomical images and databases). Following the advent of the new generation observatories, satellites and instruments for astronomical investigation one of the main challenge has been a fast, secure and affordable data storage. In last decade the CS is experiencing a certain distribution because of the possibility to save data off-site in storage systems maintained by a third party, or, as I’m going to propose, build our own storage system. As any CC service, the data storage is accessible from everywhere by simply plugging-in the cloud as resource. In this way users do not have to worry about redundancy, security or data-maintenance, but they only have to authenticate themselves every time they need access to the data.

CC offers several advantages:

1. With CC it is possible to tap into multiple areas of expertise, using a single resource: access to several servers and tasks through a single access. In CC each server is specialized to perform well a single task.

2. CC provides organizations with massive scalability capabilities (also outsourcing of services on-demand, without the need of hardware/software ownership).

3. In CC users may deploy their own resources (machines, storage, networks, ...) without the real need to buy all resources.
Figure 2: Cloud-Computing: different services available on-demand; the whole cloud act as a single entity and the outside-client computer only have to worry to authenticate to the cloud.

However CC offers several disadvantages and concerns:

1. in case of out-sourcing the asset is critically dependent on reliability (and speed) of network: in the absence of a dedicated fast network the CC use may become too expensive.
2. reliability of service because of the actual state of the www-network
3. security of data may be guaranteed only with a combination of techniques: a) encryption and the compression of data with latest encoding/compression algorithms, b) the personal identification and authentication and c) the authorization practices to access to all CC-resources.

Grid-Computing vs Cloud-Computing

As just noted, difference between GC and CC is hard to grasp because they are not always mutually exclusive: both are used to economize computing and maximize existing resources. Moreover the two architectures use abstraction extensively and both have distinct elements which interacts each other.

Anyway GC and CC are conceptually distinct; the main difference in GC and CC lies in the way tasks are computed in the two environment:

GC in GC one large job is splitted in several sub-jobs and executed simultaneously on multiple machines

CC in CC users can access to multiple services without the need of great investments in the underlying architecture.
### Table 1: Here I present a summary on the main technological generation of optical devices with improvements on storage capability.

| Tech Generation | Name, Description, Storage Capability (of a CDrom size disk) |
|-----------------|-------------------------------------------------------------|
| 1st             | CDrom, storage $\sim 700$ MB ($\sim 1.5$ GB if doubleFaceCDrom) |
| 2nd             | DVD, storage $\sim 4.7$ GB ($\sim 9$ GB dualLayerDVD/doubleFaceDVD) |
| 3rd             | BD disks, storage $\sim 25$ GB ($\sim 50$ GB dualLayerBD/doubleFaceBD) |
| 4th             | 3D-Optical devices, storage $\sim 1.0$ TB (see [15], [16]) |
| 5th             | Holographic HVD, storage several TBs (see [9], [14], [17]) |

Concerning the end-user of the two DC approaches, the GC is designed to run very large jobs for a small number of users, while the CC is intended to support a large number of users. In this interpretation CC involves selecting a particular provider and running in their data-center(s), while GC involves a federation of multiple organizations (i.e. Virtual Observatories).

### Introduction to Holographic Data-Storage

I analyzed different storage technologies to find the best suitable device to be used in a future astronomical facility. The common magnetic disks known as Hard Disk Device (HDD) are accessible, but because of having moving parts their life time is too small to think at them for future applications. The avoid of moving parts from the State Solid Devices (SSD) rank them in a higher level of affordability; they also make use of the volatile random-access memory (RAM) technology, that permits a faster access to data, but the use of these devices in a production grid presents other critical issues: a) the cost per gigabytes is too high and 2) to store data permanently they need power supply (i.e batteries).

For these reasons I decided to migrate our attention to optical devices.

Taking a look on the technological development of optical devices in later years (see table n.1), it is possible to remark the increasing storage capability in the transition from one generation of technology to another.

There are approximately the five generation of optical devices. While common optical data storage media, such as CDs and DVDs (or BDs) store data in a 2-D dimensional spiral track, which starts recording from the center of the medium and extends until the disk boundary. The data-recording and the data-reading is performed through the spiral curve in a linear succession. The technical realization of such devices is a set of reflective materials on an internal surface of a disk. In order to increase storage capacity, it is possible to apply two (or more) of these data layers, but their number is severely limited since the addressing laser interacts with all the layers that it passes through. To record (or read) the addressed layer. These interactions cause noise that limits the technology to approximately 10 layers.

It was possible to circumvent this issue by using an “addressing methods” in the 3D-optical medium. With this method only the specific addressed voxel (i.e. volumetric pixel) interacts with the focused laser-light, so the data-layers
structure in a 3D optical disk write (and read) bit-per-bit focusing only the addressed layer (and voxel), while it passes through the other layers without interaction (see fig. 3). In this context the operation of read/write data is necessarily non linear as its technology is known as nonlinear optics.

The last development of high-capacity data storage of optical devices is the Holographic-Storage (HS) technology. The HS is an evolution of the 3-D Optical Storage: its devices the Holographic Versatile Disks (HVDs) has the same size of a DVD but differs from the 3D-optical devices in the fact that it uses an holographic technology to store (and read) data through all the volumetric surface. The technology consists of two lasers, one green and one blue, which collimate in a single beam. The green laser reads the coded data in the interference fringes from a layer near the surface of the disk, while the blue laser is used as reference beam to read the “servo-position” that is an extra-information recorded in an aluminum layer near the bottom of the disk. A dichroic mirror layer is placed between the holograms and the aluminum layer so that the servo-information reflects the green laser and transmits the blue laser, preventing interferences (see fig. 4).

At now the actual HVD transfer rate is \( \sim 1Gbit/s \) and it is planned to achieve \( \sim 6TB \) of data storage for each disk in few years. A part the high storage of HS technology, the real improvement of the HVD devices is the WORM paradigm: Write Once Read Many times. Unlike the traditional optical data storage, holographic storage is capable of recording and reading millions of bits in parallel, enabling data transfer rates much more great. Moreover the holographic technology longevity, that is a grade of real technology reliability, is granted for at least 50 years, that is much more of actual data storage systems (RAID,NAS,HD,DVD and so on).

Like other optical media, HVD media is divided in Write-Once (where the storage media undergoes irreversible changes) and Re-Writable media that implements the physical phenomenon of the photo-refractive effect in crystals.
The Issue: huge data storage in astronomical facilities

Demanding astronomical observatories (from the Earth and from the space) equipped with last generation instruments, will produce very large amount of data every day. In this scenario one of the most tricky and challenging problem for the astronomical community is the efficient storage of such amount of data without information losses. Sometimes technology is not affordable and sometimes engineers are not good enough to ensure an infrastructure well built around a scientific project. The analysis of very large amount of data is a fundamental requirement of modern scientific research: for instance large area surveys needs large amount of stored data and top level astronomical and cosmological studies can not be performed without systematic and accurate large programs.

In countless cases projects, missions and/or instruments produce so many data that their storage facility are unable to dispose and store efficiently. In extreme cases there are instrument forced to delete intermediate files (sometimes sensible astronomical-data) to ensure the storage-capacity for the principal target of the observation. In these extreme cases it is excluded the possibility of later investigation on the serendipitous field observed near the target of the observation. Other instruments delete images and work only on catalogs, this excluding the possibility to perform 2nd target level science with unused science images.

In great projects, where consortium of several institutions work together to reach the same scientific goal, this critical issue is often faced in the optical of a single-huge (even mirrored) repository/database, where all partners can access to data and perform particular tasks. These tasks may involve the computation of astronomical quantities and send back the output of the computation to the
central storage facility. This approach is rarely efficient and critically depends on the high efficiency of the network grid as well as the inter-connections between parts.

As I’m going to expose, to overcome this disturbing problem new technologies discussed in the previous sections may come into help.

The Solution: distributed + scalable Storage-Block for astronomical databases

The idea suggested in this paper is the possibility to identify one coherent architecture/infrastructure that can be identified as standard approach to those problems. The solution proposed is engineered to be scalable: this property will allow the division of costs and encourage the cooperation between various research projects and institutions.

I identify the Cloud Computing paradigm as the base platform where to build a distributed storage block (see fig. 5 for a graphical explanation of the desired data-flow).

When a particular instrument acquires a scientific image in a temporary local repository, the bit code is sent to many indexed resources where a parallel software takes care of split, encrypt and compress all the image data in sub-packages and store them in a RAID distributed repository.

The function of the RAID repository is the core of the “storage-block”. Such a block will have a Grid-Computing like infrastructure primarily composed by:

- a STORAGE ELEMENT (SE), which takes care of record redundantly all sub-package data (i.e. where physically relies the RAID-block)

- a COMPUTING ELEMENT (CE), where to queue users requests to physical data. In the CE will relies a particular DATABASE composed of “meta-data descriptors” (i.e. informations about the data). The role of the database is the information browsing over the encrypted sub-package data without a direct physical access to them

- a WORKER ELEMENT (WE), where to decompress/decrypt sub-packages on the fly accordingly to DATABASE descriptors. At this level the sub-packages are link, decrypt and assembled together in order to make physical data available to users (any physical data is a resource that is built and destroyed by the user on-demand)

The division on elements is just representative of the necessary functions: it is possible to build a storage-block which performs all described functions within a single machine).

Since security is one of the most critical issue in the cloud computing, it is necessary to encrypt the data according to personal key or certificates: the access to the cloud resource is granted to a user through the same authentication (UI+network).
Figure 5: Schematic representation of the predicted work data-flow for the Storage-Block. At higher level the instrument contact the cloud to fast store sub-packages of data. The User Interface (UI) takes care of authenticate securely the user to the cloud; the user demand (and construct) an instance to the Computing Element (CE) that gives the meta-data information about the physical data requested, the Working Element (WE) fast retrieve, decrypt and assemble the data and make it accessible to the user outside. The procedure appear invisible to the end-user that only request/dismiss the remote resource. Moreover disseminated service-clouds may offer to the end-user different services on the cloud stored-data.
The critical step is to ensure the most I/O velocity possible for data transmission from SE → WE, that is the choice to use the next generation Holographic Storage technology, where it is possible to Write Once / Read Many. Using opportune parallel architecture for the WE the composition of sub-package in final data time latency will be minimized.

As well as an end-user access to the Cloud Computing, he will dispose of the remote resource and a set of tools/services to be invoked on-demand to the remote system.

In this context it is possible to identify a Pipeline-Element block to be part of the main Cloud (but not the Grid-part): such an element will publish on the cloud several services including the possibility of performing basic operation on private (and public) data persistent in the Storage Block. The end user will only have to take care of securely authenticate to the cloud, but will be totally obscured about what’s really happens in the computational sub-layers. Adding a service element to the primary storage-cloud transforms the desired storage-block in a storage+service-block and opens further perspectives on the IT technologies applied to astronomical data.

As last item I remark the possibility to improve the power, the reliability and the security of the whole Holographic Grid Cloud system just adding scalable resources (i.e. storage-blocks).

Other improvement can be the replication of the whole architecture in different geographical areas (this adds degrees of redundancy), but to distribute fairly the workload especially over the network it is necessary to make all resources indexes in the cloud.

Moreover the RAID redundancy must be distributed over geographical areas so that a local failure will not corrupt the redundant data-array. A key role in the data-reconstruction is played by the meta-data database facility, that will collect all sub-packages information to easily reconstruct all parent data. Any storage-block needs a database mirror that must be continuously synchronized and committed with a NTP central server for time synchronization.

A possible technical implementation

To quantify the actual feasibility of the project it is necessary to design a feasible technical implementation. This is mainly out of the scope of this paper, but I can provide several guidelines to overcome the main issues in order to build the desired Storage+Facility Block for the next astronomical facility.

How to build a customized Cloud

The Cloud-Computing is an abstract concept whose practical realization is quite impossible without having recourse to a software suite that performs the dirty work on our behalf.

I identified “The Eucalyptus Open-source Cloud-computing System” (see [7], [8], [11], [12]) as the best suitable software-suite for our purpose. With Eucalyptus it is possible to implement an IaaS service (Infrastructure as a Service),
which makes the IT-administrator able to create (and control) virtual machines and instances deployed across a variety of physical resources. Those resources may be linked together and virtualized to obtain a small private and versatile cloud. With Eucalyptus comes security, authentication, virtualization and abstraction, so that a user can access to the system without any knowledge of the inner mechanism.

**How to build an inner Storage Holographic Element**

At present this is the most tricky issue because of the actual technological evolution of such devices: there are only prototypes or high expensive HVD burners/readers. But I am confident because the evolution of such devices is evolving steadily, making this technology enough mature in few years.

However it is possible to implement a prototype with a simple BD dual-layer juke-box (or a diffuse hard disk RAID), planning to migrate as the holographic technology will be enough stable and affordable to be replaced the main storage unity.

The challenge for this module is the development of an upper module/library to ensure the splitting, encryption and compression of data-flow. This library should have a split/assemble instance, an encode/decode instance, a compress/decompress method, as well as the possibility of communicate with the cloud authentication layer in order to obtain a random crypt key to encode/decode data.

This library can be assembled using different open-source softwares: at now the GNU-parallel open source program (see [30] for further insights) splits large files and execute parallel job on several CPUs (even on remote nodes), the MD5/SSL crypts and decrypts image data and the fpack/funpack (HEASOFT library, see [31]) that highly compresses and decompresses fits images.

**How to build an inner private Grid**

The Grid architecture used in the storage-block project is only private grid, so it is not necessary to start-up an official Data-Grid node with any test-bed connection. The private grid will assemble the hardware resources and act as a single entity of inter-communication. The main role of such a grid is the possibility of publishing on the parent-cloud the user-queries for files (and eventually services).

It is possible to implement and obtain by the grid middleware only required services. A possible source for these services is the Globus Toolkit (ref. [2]), but other packages listed in the Open Grid Forum alliance (see [18]) have similar usability.

The main role of such a grid is the speed-up of the data reconstruction: using the synchronized meta-database accessible by the CE, provides the allocation indexed of sub-data-packages and the information for decryption. The working element will find in the cloud the user-authentication information needed to assemble required data in a quickly and reliably operation.

A concrete possibility to speed-up the CE ↔ CW inner-link/tasks is to build a Working Element equipped with Graphics Processing Units (GPUs)
using the data-reconstruction as an optimized 3D-graphical manipulation inside the Computing Element graphic device (see [32] and [33] for references). The challenge for this approach is to best fit-in the data-RAM requirements with the RAMDAC frame buffer of the GPU.

The best performances for the IT-system is reached when the hardware, software and/or middleware configuration adopted minimizes the time-latency for data requests and maximizes the throughput for the data transfer. Several tests and experiments are expected to be needed in order to reach this goal.

Conclusions

In this work I present an affordable way to build a scalable storage block for the next generation demanding astronomical facilities.

The intent of the work is propose a futurable technology that is: a) all-in one; b) highly efficient; c) almost scalable; d) highly customizable; e) on scientific-demand.

This paper wants to be a starting point for a general discussion about the storage-technology to adopt in next decade astronomical missions, when a very hard I/O is expected.

Excellent candidates to discuss this architecture can be the ESA-EUCLID mission (see [25], [26], [27], [28], [29]) and the Chernenko Telescope Array (see [19], [20], [21], [22], [23], [24]).

The exposed idea is to join several advantages from the two different approaches: the Cloud-Computing and the Grid-Computing. This work finds a meeting point where the two technologies gives the best.

The last intriguing scenario proposed in this paper is the perspective of using Holographic data storage facility to implement the WORM paradigm: this possibility enhances the throughput for the whole IT-system.

I have also proposed several technical guidelines to build a prototype to be tested and proposed to the scientific community.

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References

[1] The anatomy of the grid: Enabling scalable virtual organizations - Foster, Kesselman, et al. - 2001

\footnote{An optimized version of the RAM for the computer system graphic devices. RAMDAC stands for Random Access Memory Digital-to-Analog Converter, which allows a higher clock frequency for the RAMDAC respect to the RAM.}
[2] Globus: A metacomputing infrastructure toolkit - Foster, Kesselman - 1997

[3] The physiology of the Grid: an open grid services architecture for distributed system integration - FOSTER, N

[4] Xen and the art of virtualization - Barham, Dragovic, et al. - proceedings SOSP 2003

[5] The Grid: Blueprint for a New Computing Infrastructure - Foster, Kesselman - Margan Kaufmann, 2003

[6] Grid Computing Making Global Infrastructure a reality - Berman, Fox, et al. - Wiley and Son, 2003

[7] Virtualization for high-performance computing - Mergen, Uhlig, et al.

[8] The Eucalyptus Open-Source Cloud-Computing System - Nurmi, D.; Wolski, R.; Grzegorczyk, C.; Obertelli, G.; Soman, S.; Youseff, L.; Zagorodnov, D.; Comput. Sci. Dept., Univ. of California, Santa Barbara, MD - 2009

[9] Optimizing holographic data storage using a fractional Fourier transform - Nicolas C. Pégard and Jason W. Fleischer - Optics Letters, Vol. 36, Issue 13, pp. 2551-2553 (2011)

[10] NSF Tera Grid Project. www.teragrid.org

[11] Elastic Compute Cloud, Amazon EC2, [http://aws.amazon.com/ec2/](http://aws.amazon.com/ec2/)

[12] Eucalyptus Public Cloud (EPC), [http://eucalyptus.cs.ucsb.edu/wiki/EucalyptusPublicCloud/](http://eucalyptus.cs.ucsb.edu/wiki/EucalyptusPublicCloud/)

[13] Programming the Grid: Distributed software components, D. Gannon, 2002

[14] Holographic Data Storage, IBM Journal of Research and development, 2008

[15] Three dimensional optical data storage using Photochromatic Materials, S. Kawata and Y. Kawata, Chem Rev. 2000 100, 1777

[16] Three dimensional optical storage, G.W. Burr, SPIE Conference (2003), paper 5255-16

[17] Photorefractive Organic Thin Films, Ed. Z. Sekkat and W. Knoll, Elsevier USA, ISBN 0-12-635490-1

[18] Open Grid Forum, [http://www.gridforum.org](http://www.gridforum.org)

[19] Cherenkow Telescope Array, CTA, [http://www.cta-observatory.org](http://www.cta-observatory.org)
[20] Design Concepts for The Cherenkov Telescope Array, The CTA Consortium, (2010), available at arXiv 1008.3703

[21] Teraelectronvolt Astronomy, J.A. Hinton & W. Hofmann, (2010), Ann. Rev. Astron. Astrophys., 47:523, or at arXiv 1006.5210

[22] High energy astrophysics with ground-based detectors, F. Aharonian, J. Buckley, T. Kifune & G. Sinnis, 2008, Rep. Prog. Phys., 71:096901

[23] TeV Gamma-Ray Astronomy: The Story So Far, T. Weekes, 2008, AIP Conference Proceedings, 1085:3

[24] The Status and future of ground-based TeV gamma-ray astronomy. A White Paper prepared for the Division of Astrophysics of the American Physical Society", J. Buckley et al., 2008, available at arXiv:0810.0444

[25] ESA, EUCLID Mission. http://sci.esa.int/science-e/www/area/index.cfm?fareaid=102

[26] Euclid Mission Assessment Study - Executive Summary (Thales Alenia Space, EADS Astrium), Thales and EADS Astrium, 2009

[27] Euclid definition study report (Red Book), ESA, ESA/SRE(2011)12

[28] Technical Review Report - Euclid, ESA, SRE-PA/2009/051

[29] Euclid assessment study report (SRE-2009-2), ESA, 2009

[30] GNU Parallel - The Command-Line Power Tool, O. Tange, The USENIX Magazine, February 2011:42-47

[31] HEASoft - NASA’s HEASARC Software, http://heasarc.nasa.gov/lheasoft

[32] Evolution of the Graphical Processing Unit, Thomas Scott Crow, dr.Frederick C. Harris Jr, Master of Science University of Nevada, 2004

[33] GPUs - Graphics Processing Units, Minh Tri Do Dinh, Vertiefungsseminar Architektur von Prozessoren, SS 2008