Robotic Autonomous Observatories

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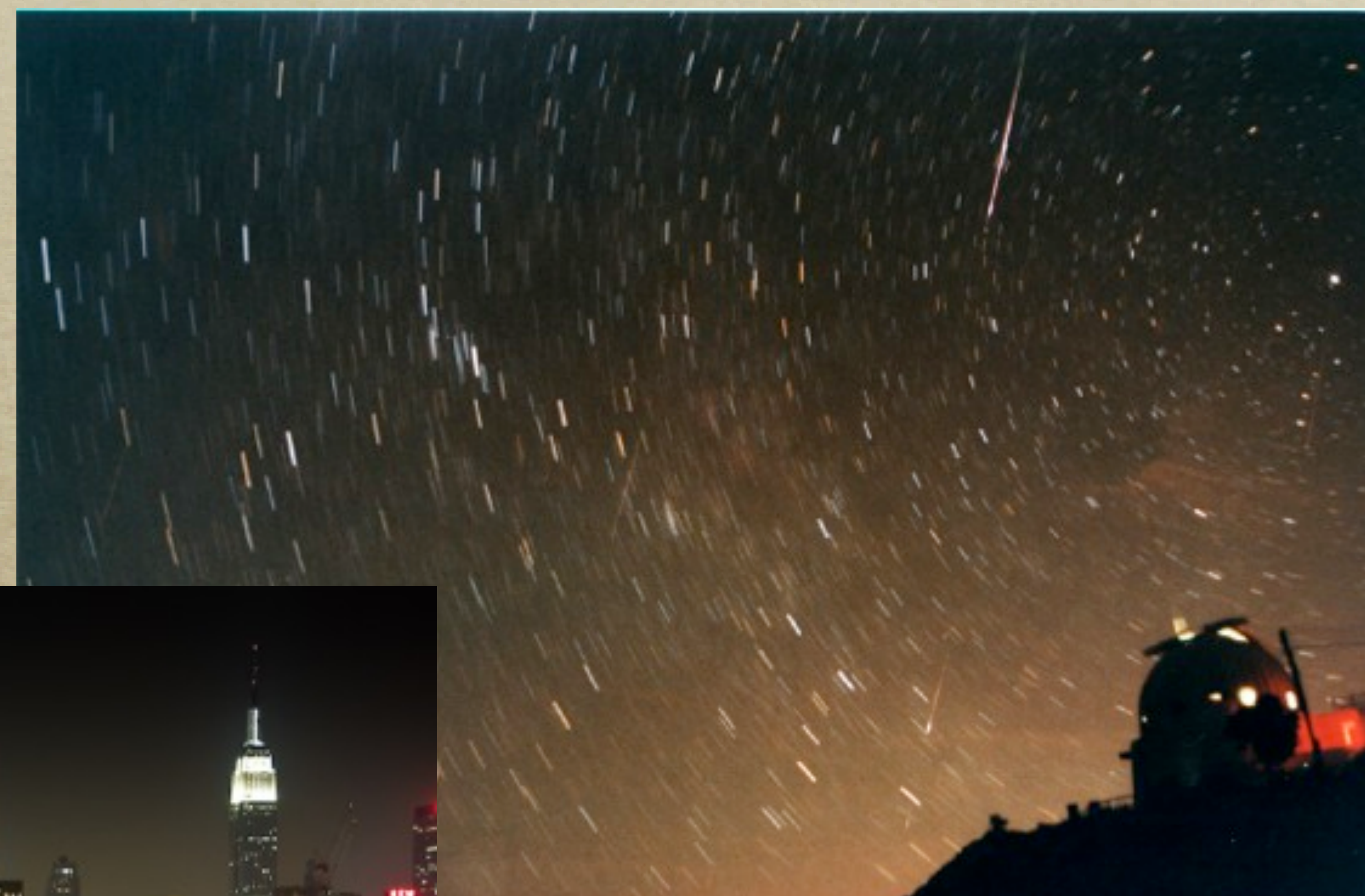
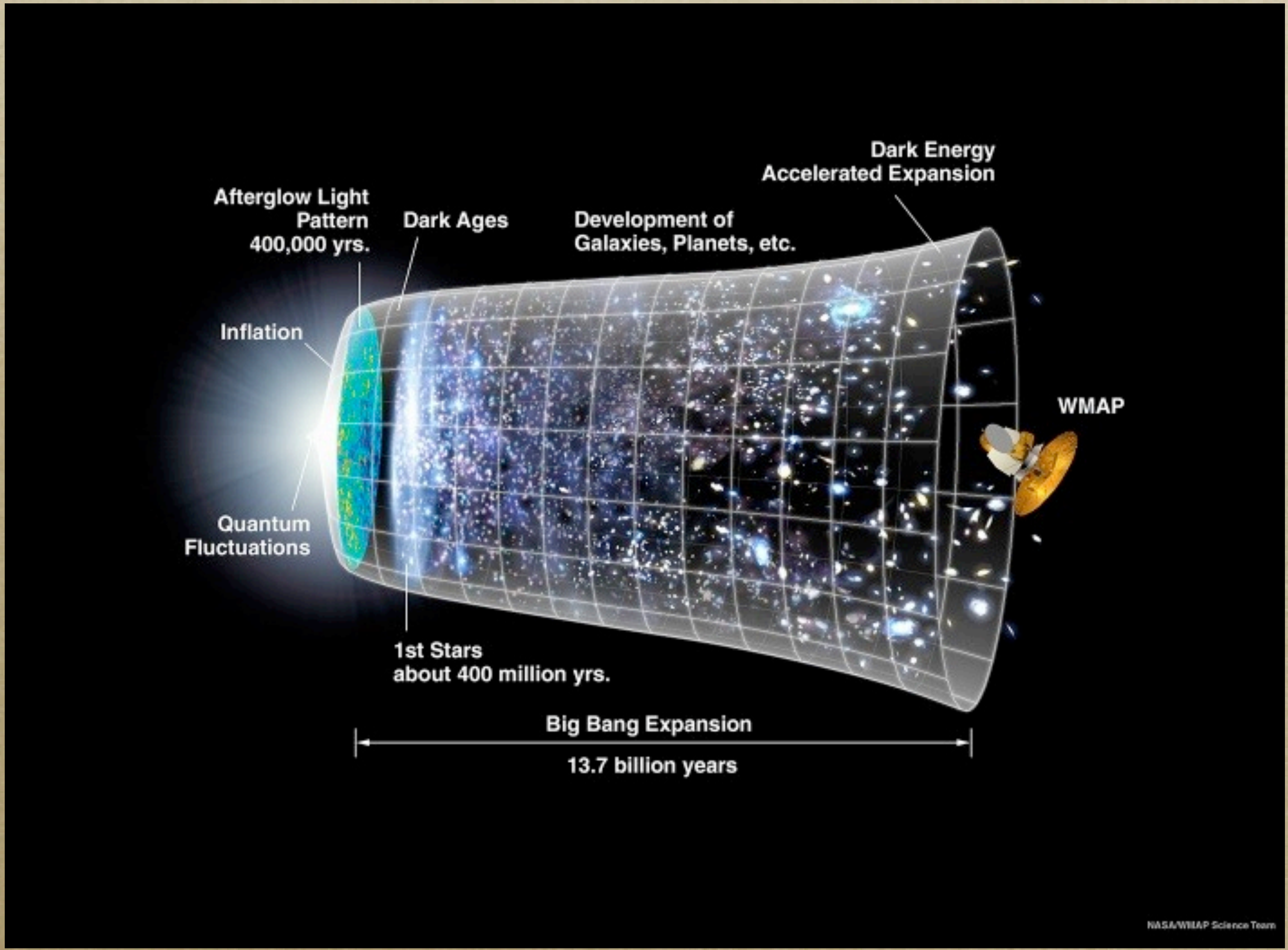
Astronomy VS Urbanization



Modern Astrophysics: a precise era



Modern Astrophysics: a precise era

Hubble expansion rate†	H_0	$100\ h_0$ km s^{-1} Mpc^{-1}	
		$= h_0 \times (9.77813$ Gyr$)^{-1}$	[15]
normalized Hubble expansion rate†	h_0	$(0.71 \pm 0.07) \times^{1.15}_{0.95}$	[16, 17]
critical density of the universe†	$\rho_c = 3H_0^2/8\pi G_N$	$2.77536627 \times 10^{11}\ h_0^2\ M_\odot$Mpc^{-3}	
		$= 1.879(3) \times 10^{-29}\ h_0^2$ g cm^{-3}	
		$= 1.0539(16) \times 10^{-5}\ h_0^2$ GeV cm^{-3}	
local disk density	ρ_{disk}	3–12 $\times 10^{-24}$ g cm^{-3} $\approx$ 2–7 GeV$/c^2$ cm^{-3}	[18]
local halo density	ρ_{halo}	2–13 $\times 10^{-25}$ g cm^{-3} $\approx$ 0.1–0.7 GeV$/c^2$cm^{-3}	[19]
pressureless matter density of the universe†	$\Omega_M \equiv \rho_M/\rho_c$	$0.15 \lesssim \Omega_M \lesssim 0.45$	[16, 20]
scaled cosmological constant†	$\Omega_\Lambda = \Lambda c^2/3H_0^2$	$0.6 \lesssim \Omega_\Lambda \lesssim 0.8$	[16]
scale factor for cosmological constant†	$c^2/3H_0^2$	$2.853 \times 10^{51}\ h_0^{-2}$ m^2	
$\Omega_M + \Omega_\Lambda + \ldots$ [21]	Ω_{tot} [21]	see footnote [22]	
age of the universe†	t_0	12–18 Gyr	[16]
cosmic background radiation (CBR) temperature†	T_0	2.725 ± 0.001 K	[23, 24]
solar velocity with respect to CBR		369.3 ± 2.5 km s^{-1}	[24, 25]
energy density of CBR	ρ_γ	$4.6417 \times 10^{-34}\ (T/2.725)^4$ g cm^{-3}	[12, 24]
		$= 0.26038\ (T/2.725)^4$ eV cm^{-3}	
energy density of relativistic particles (CBR + ν)	ρ_R	$7.8042 \times 10^{-34}\ (T/2.725)^4$ g cm^{-3}	[12, 24]
		$= 0.43778\ (T/2.725)^4$ eV cm^{-3}	
number density of CBR photons	n_γ	$410.50\ (T/2.725)^3$ cm^{-3}	[12, 24]
entropy density/Boltzmann constant	s/k	$2889.2\ (T/2.725)^3$ cm^{-3}	[12]

- http://pdg.lbl.gov/2000/astrorppbook.pdf

We Need More Highly Accurate Data!

- *Computer Systems & Networks*
- *Robotics*
- *Database systems, artificial intelligence, machine learning, pattern recognition*
- *How about making the observatory automatic??*
- *Robotic Autonomous Observatory (Network): **robotized** observatory*

Robotic Telescopes

Apogee 16M
4096x4096 (16 megapixel)
0.54" pixels with 37' field
g'r'z'i' filter wheel
H-alpha, H-beta, [O III], He I, Na D narrow band filter wheel

- *The Planewave Instruments 20-inch (0.5-meter) f/6.8 corrected Dall-Kirkham telescope at Moore Observatory in Kentucky*

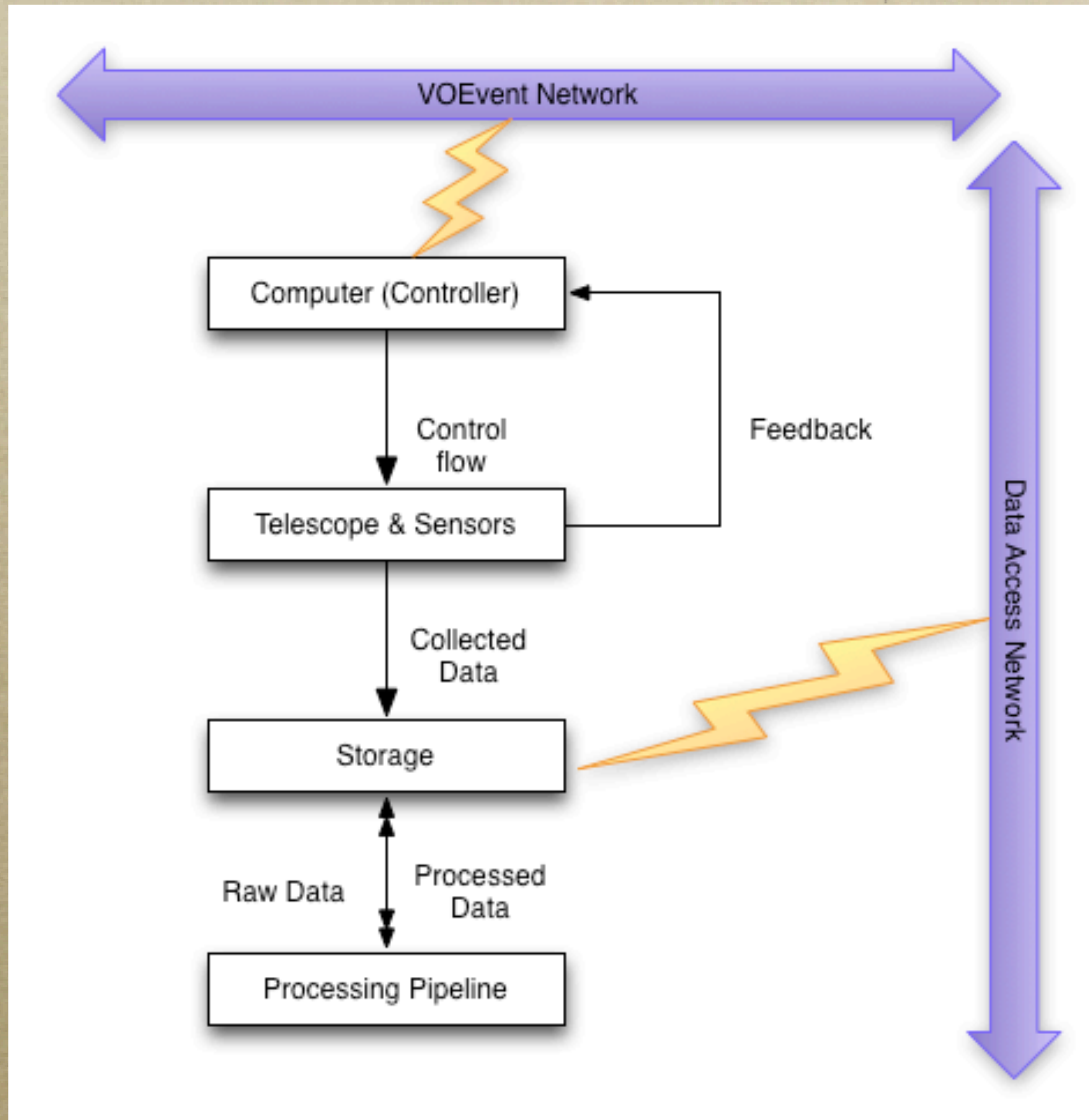
Historical Perspective by Stages

- *Automated Scheduled Telescope: 1968~1975*
- *Remotely Operated Telescope: 1975~1984*
- *Robotic Autonomous Observatory: 1984~NOW*
- *Robotic Intelligent Observatory: Expected in the future*

Alberto Javier Castro-Tirado, 2010, Advances in Astronomy

General Architecture

- *The controller can be general purpose server or special designed computer*
- *Telescope serves as the optical engine*
- *Sensors include CCD, temperature sensor, illumination sensor, humidity sensor (hygrometer), etc.*
- *The storage system serves as a cacheing system and the persistent file system*
- *Processing pipeline can be close-loop or open-loop*
- *Network system is optional*



Scheduling System

- *The automation of modern RAOs is powered by sophisticated software packages*
- *Publicly available packages:*
  - *RTS2: Remote Telescope System, 2nd version (open source, Linux)*
  - *ACP: Windows, Commercial*
  - *ATIS: Automatic Telescope Instruction Set*
  - *OCAAS: Observatory Control and Astronomical Analysis Software*

Telescope Apertures

- *Dominated by small aperture telescopes*
- *Ranged from 0.6m ~ 1.2m*

Aperture	*#*	*%*
<0.25	*77*	*44.3%*
0.25~0.5	*37*	*23.0%*
0.5~0.75	*14*	*8.6%*
0.75~1.00	*17*	*9.8%*
1.00~1.25	*7*	*4.0%*
>1.25	*18*	*10.3%*

Data Processing Pipeline

- *A typical RAO generates ~2TB data every night during the observation*
- *The RAW data must be extracted and refined as soon as possible*
- *Close-loop pipelines: real-time processing (e.g. RAPid Telescope for Optical Response, RAPTOR)*
- *Open-loop pipelines: offline mode processing (e.g. Hamburg Robotic Telescope)*

Data Processing Pipeline

- *RAPTOR:*data acquisition -> image registration -> source extraction -> transient identification -> alert generation -> Telescope repointing.[1]
- *Hamberg Robotic Telescope:* Bias, dark, flat field correction, data extraction, FITS output [2]

[1] Konstantin Borozdin et al. Real-time detection of optical transients with raptor. 2002.
[2] Marco Mittag et al. The data reduction pipeline of the hamburg robotic telescope. Advances in Astronomy, 2009.

Storage System

- *Hard drive RAID*
- *Tape system*
- *Accessible via network*

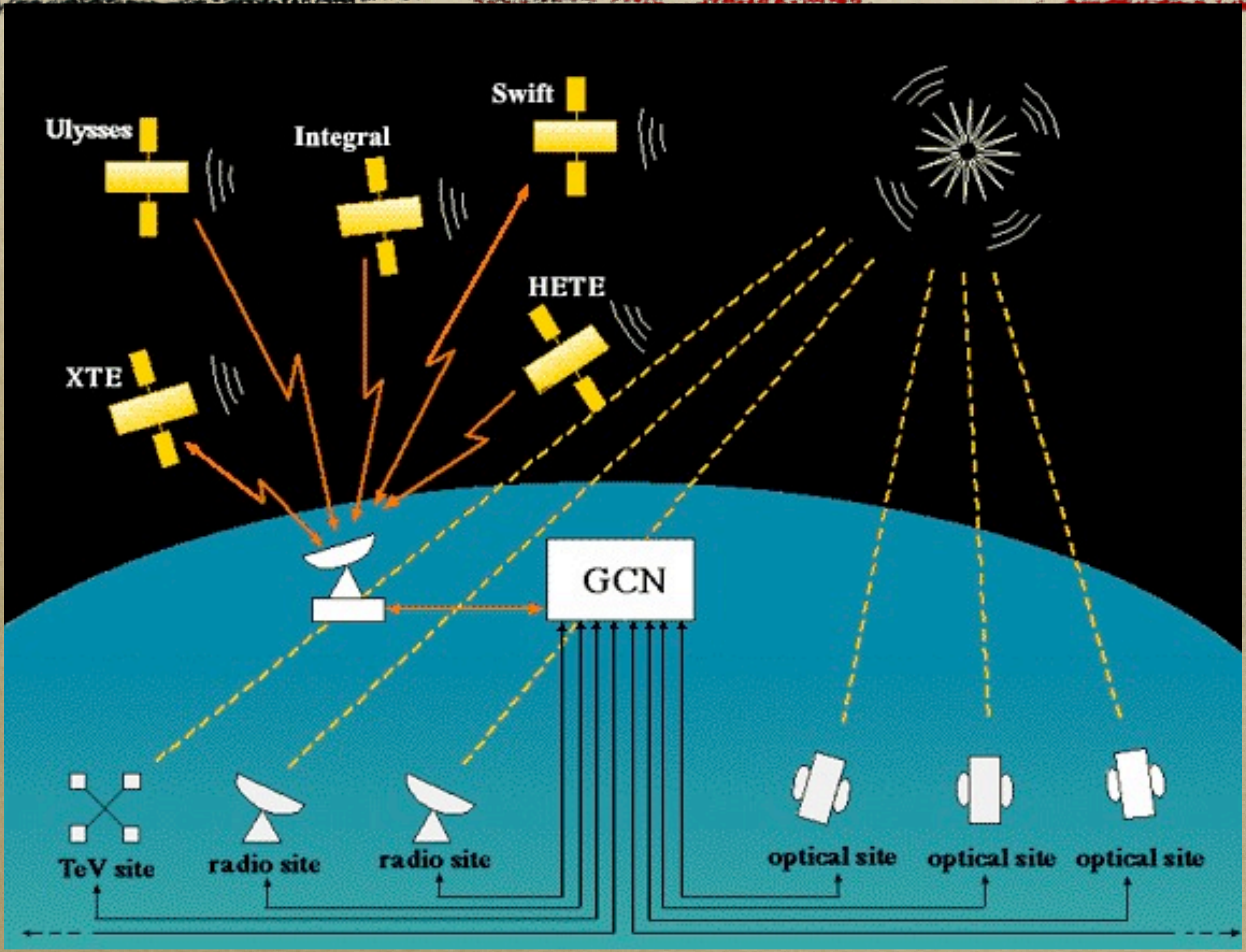
Network System

- *An interface to interact with human (control, data access, etc.)*
- *An interface to interoperate with other RAOs*
- *Various Protocols: HTTP, FTP, VOEvent*
- *VOEvent: Adopted in 2006 by IVOA, used to describe astronomical events e.g. supernovae, gravitational microlensing, gravitational wave, gravitational waves, ...*

Case Study: BOOTES

- *BOOTES: Burst Optical Observer and Transient Exploring System*
- *Global Sites:*
  - *BOOTES-1 - El Arenosillo - 37.0995°N 6.73747°W*
  - *BOOTES-2 - Estación Experimental de La Mayora - 36.7569°N 4.04273°W*
  - *BOOTES-3 - Blenheim, New Zealand - 41.4913°S 173.8395°E*
  - *BOOTES-4 - Lijang, China -26.695222°N 100.030067°E*
- *Scientific Objectives: GRB, all-sky monitoring (10mag), variable object monitoring (20mag), discover of comets, meteors, asteroids, variable stars, novae and supernovae.*

GCN: The Gamma-ray Coordinates Network



Case Study: BOOTES

- *Scheduled and managed by RTS2*
- *Modulation:* `rts2-selector`, `rts2-executor`, `rts2-imgproc`, `rts2-grbd`, `...` (daemon)
- *Live preview through webpages*
- *Supports GCN*

Challenges

- *Security: weather, human, animal, insects, system reliability (0.99^100=0.37), ...*
- *Decision making: deterministic finite automaton*
- *Data processing*

Applications

Description	*Percentage*
Gamma-ray bursts	*22.1%*
Service observations	*15.0%*
Education	*14.3%*
Photometric monitoring	*10.0%*
All-sky survey	*8.6%*
Exoplanet searches	*7.9%*
Supernovae search	*7.1%*
Asteriods	*5.7%*
Spectroscopy	*2.9%*
Astrometry	*2.9%*
AGN, Quasars	*2.9%*
Microlensing	*0.7%*
Other uses	*5.7%*

Alberto Javier Castro-Tirado.

Robotic autonomous observatories: A historical perspective.

Advances in Astronomy, 2010, 2010.

China's Efforts on RAON

- *China-RAON*
- *SONG-China*
- *LCOGT*
- *Antarctic observatory, Tibetan observatory*

Computing Power at NAOC

- *Laohu Cluster: 85 nodes with two quad-core CPUs each, and two Tesla C1060 GPUs in every node, with a peak speed of the order of 170 Teraflops.*
- *The Silk Road Project: Green-grid, global computing, on the path to Exascale computing (10^18).*

Conclusions

- *RAON: a trend, a power tool, a complex system*
- *Lots of pending problems*
- *Promising future*

Thank you!

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