A Survey of the Present and Future of Astro/Cosmo/Particle Physics

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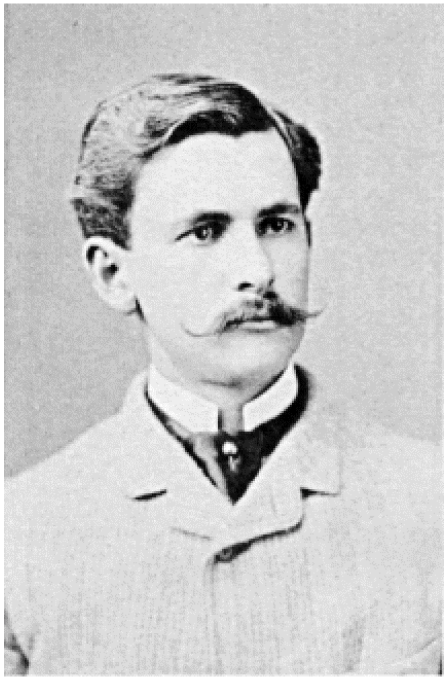
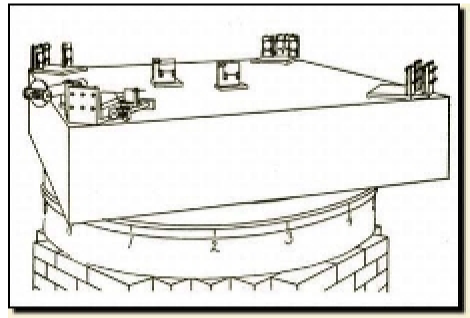
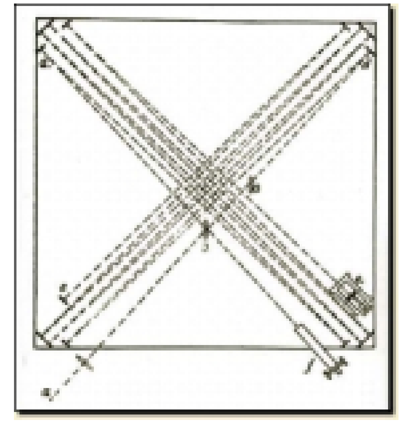
- Introduction and motivation
- Quick (and incomplete) physics survey
- Cultural evolution
- Perspectives and Summary







1887: Michelson & Morley publish fundamental results on propagation of light - an experimental cornerstone of relativity.

1920: Michelson makes the first-ever measurement of the diameter of a star (Betelgeuse) by applying interferometry to astronomy. A new field!

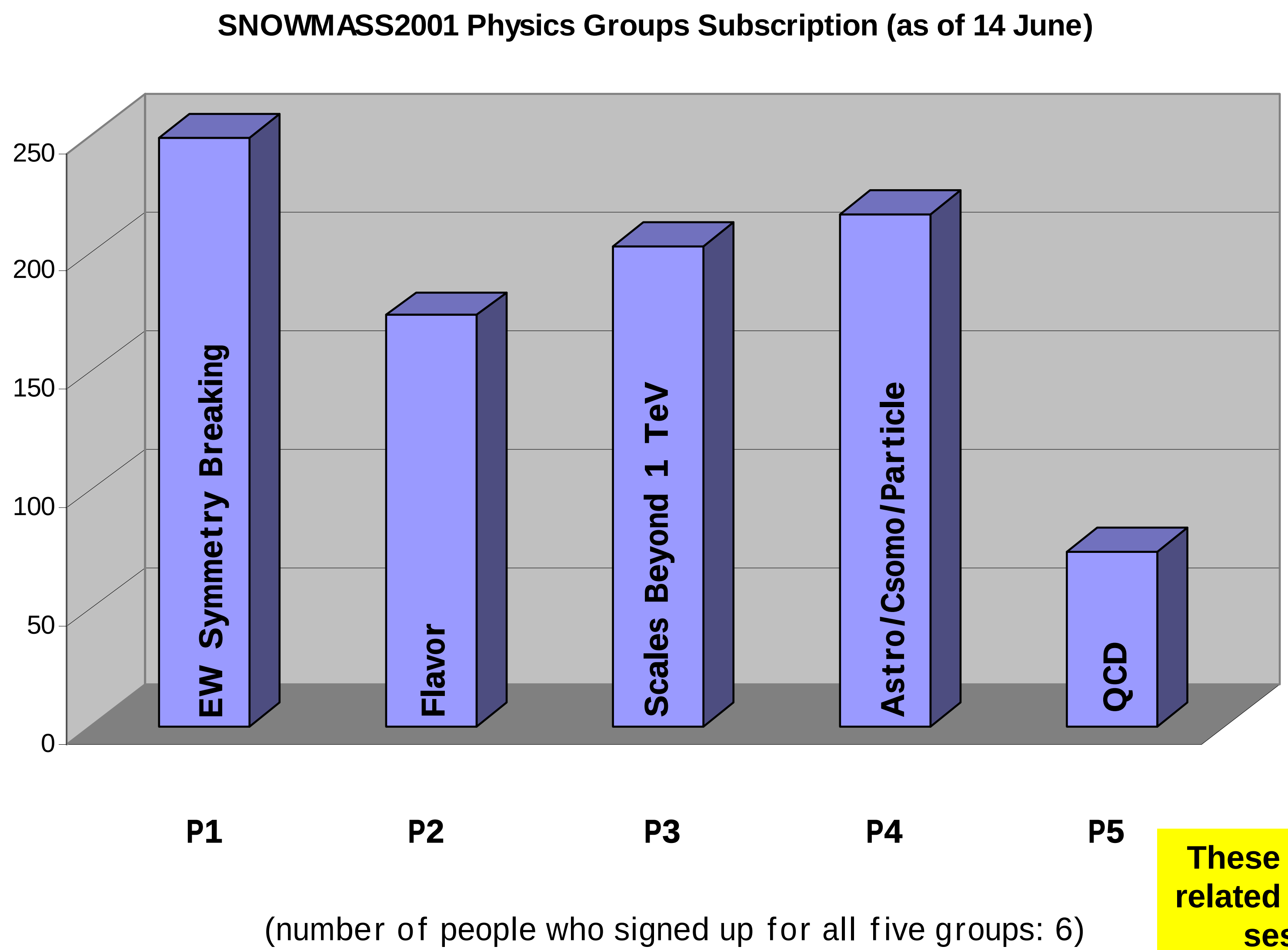
Laboratory techniques for fundamental physics investigations have long been successfully and fruitfully applied to astrophysical measurements. These measurements in turn enable us to test and further explore fundamental physics.

“The Universe as a Laboratory”

Address fundamental questions, test limits of physical law using most extreme environments, and study the relics from the Big Bang

- explore black holes: acceleration mechanisms producing high-energy jets; goal to study region around event horizon.
- find origin(s) of the highest energy cosmic rays
- understand gamma-ray bursts
- uncover dark matter
- study CMB
- test Inflation
- search for other Big Bang relics
- detect gravity waves
- confirm and study the ‘Dark Energy’
- Discovery!

Relation to Snowmass01 Activities



These tags show related Snowmass sessions.

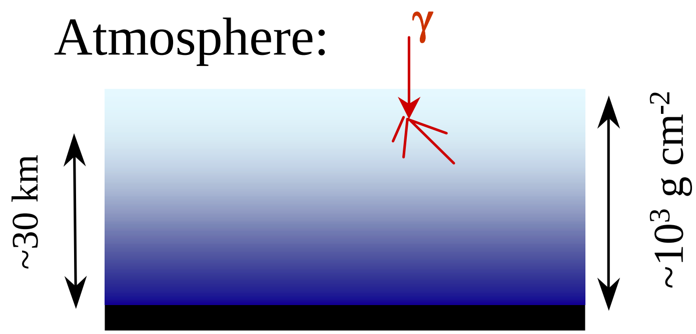
Brief Overview of Physics Topics

Sort by messenger, energy:

- **Gamma rays, X-rays**
- **Optical**
- **Microwave**
- **Cosmic rays**
- **UHE neutrinos**
- **Gravity waves**
- **Direct searches for dark matter**
-
-

Cosmic γ-ray Measurement Techniques

Atmosphere:



For E_γ < ~ 100 GeV, must detect above atmosphere (balloons, satellites)

For E_γ > 100 GeV, information from showers penetrates to the ground (Cerenkov, air showers)

Energy loss mechanisms:

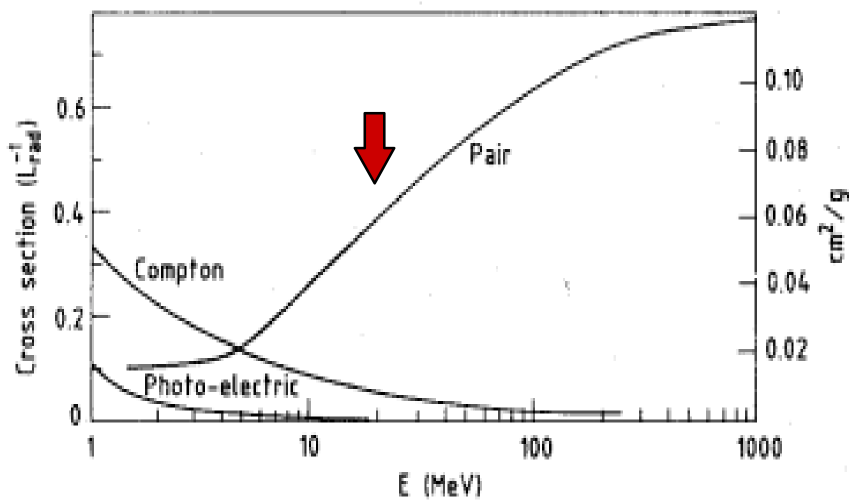
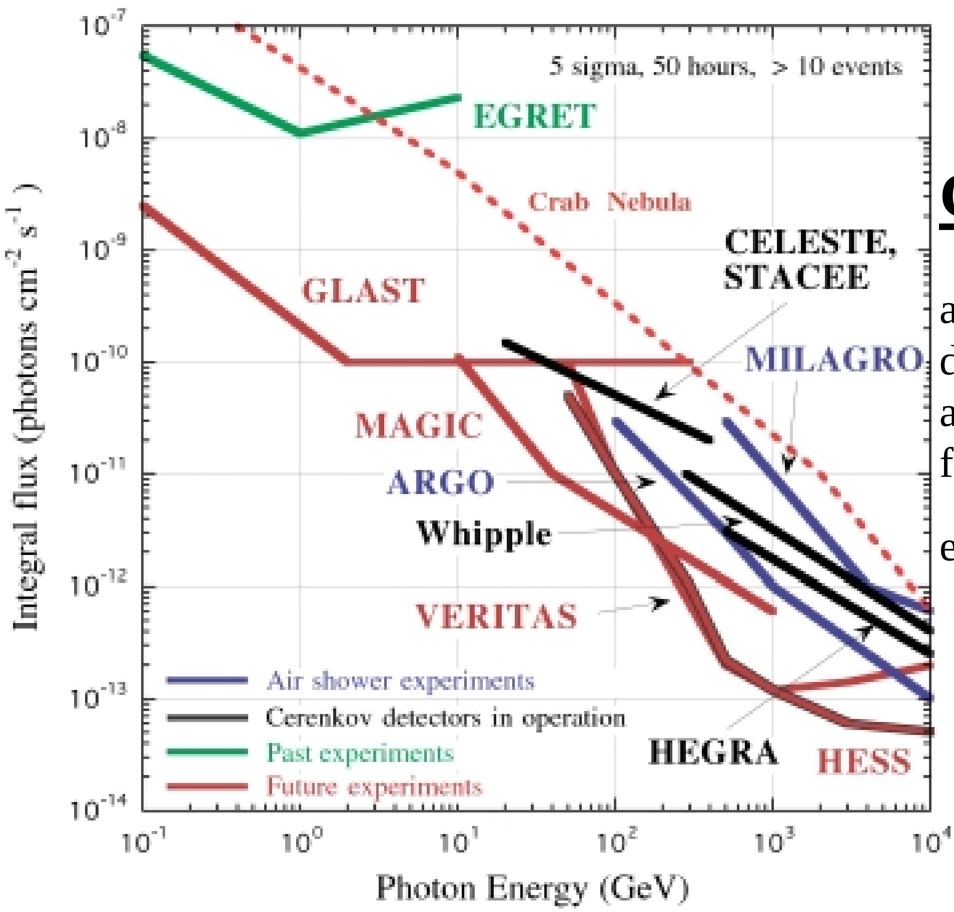


Fig. 2: Photon cross-section σ in lead as a function of photon energy. The intensity of photons can be expressed as I = I₀ exp (−σx), where x is the path length in radiation lengths. (Review of Particle Properties, April 1980 edition).

Unified gamma-ray experiment spectrum



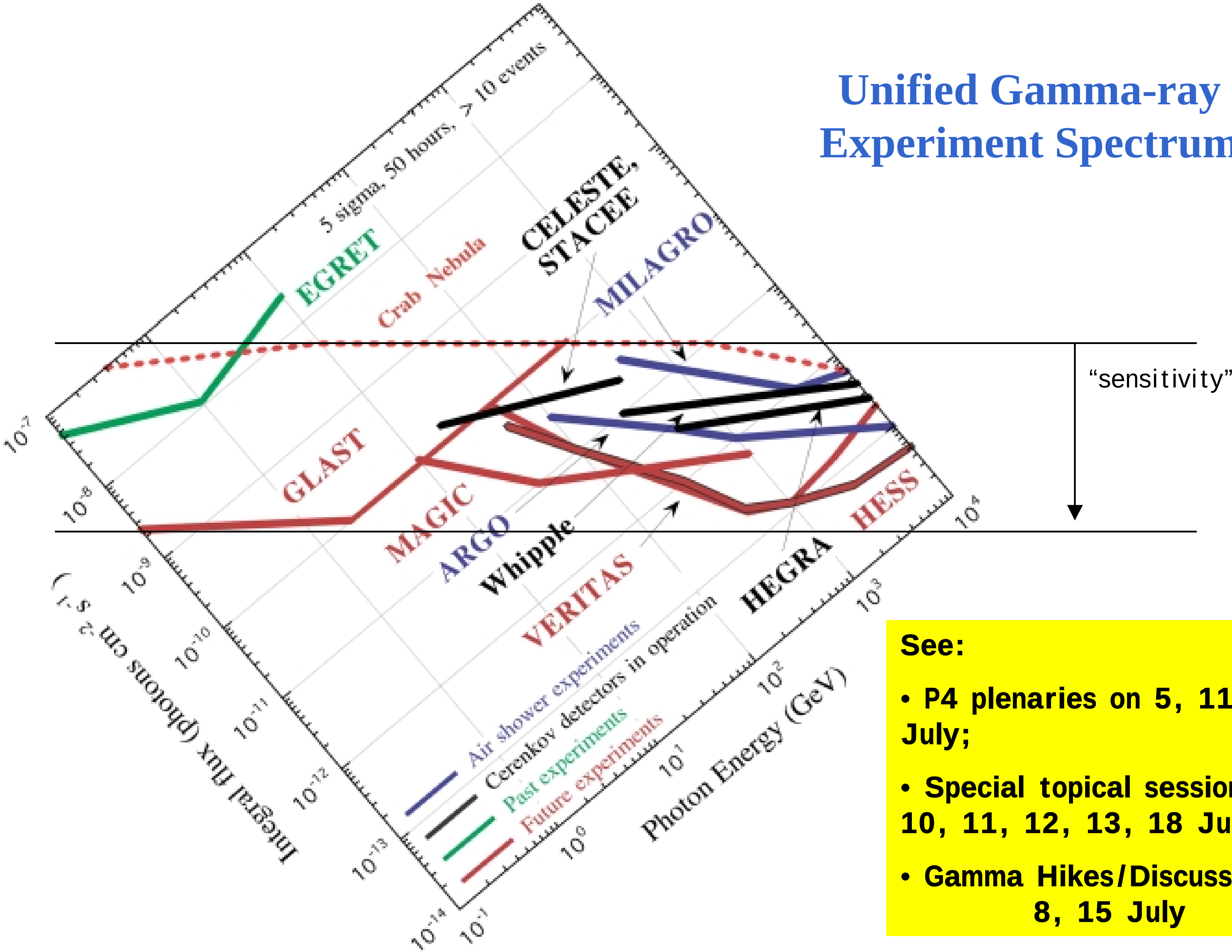
Complementary capabilities

	ground-based*	space-based
angular resolution	good	good
duty cycle	low	excellent
area	**HUGE !**	relatively small
field of view	small	excellent (~20% of sky at any instant)
energy resolution	good	good, w/ small systematic uncertainties

*air shower experiments have excellent duty cycle and FOV, and poorer energy resolution.

The next-generation ground-based and space-based experiments are well matched.

Unified Gamma-ray Experiment Spectrum



See:

- **P4 plenaries on 5, 11, 18 July;**
- **Special topical sessions 9, 10, 11, 12, 13, 18 July;**
- **Gamma Hikes/Discussions: 8, 15 July**

The BIG Picture

Gamma-ray experiments address a very broad menu of fundamental topics that include:

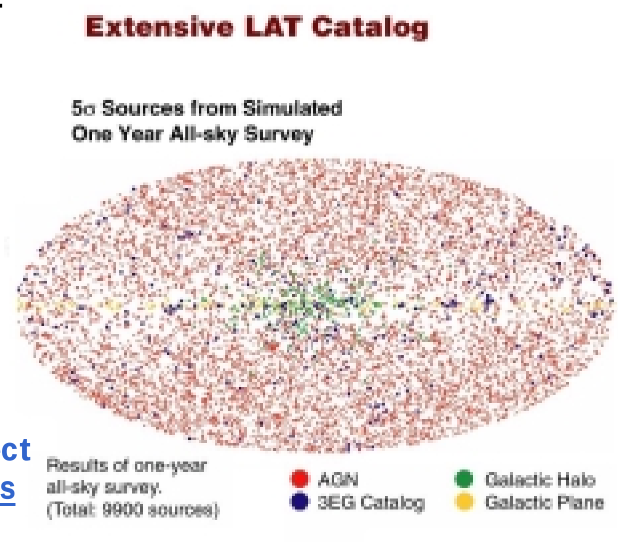
- **Systems with supermassive black holes**

Active Galactic Nuclei (AGN) are immense accelerators, probably powered by ~billion solar-mass black holes. Many shine most brightly in gamma rays, which diagnose the accelerated jets of particles.

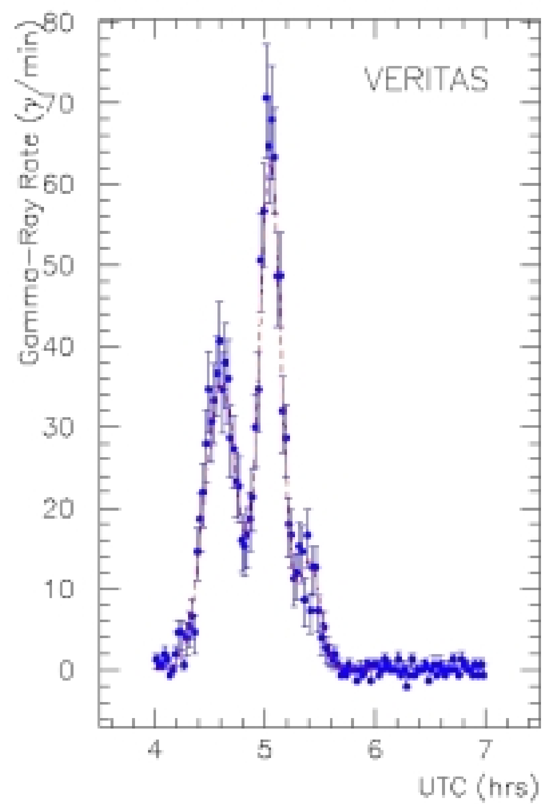
Contemporary experiments (Whipple, STACEE, CELESTE, EGRET, …) together study a few to dozens of AGN. Expect GLAST to improve on this by two orders of magnitude:

EGRET 3rd Catalog: 271 sources

GLAST 1st Catalog: expect >9000 sources



VERITAS will measure short-term variability with dramatically better precision



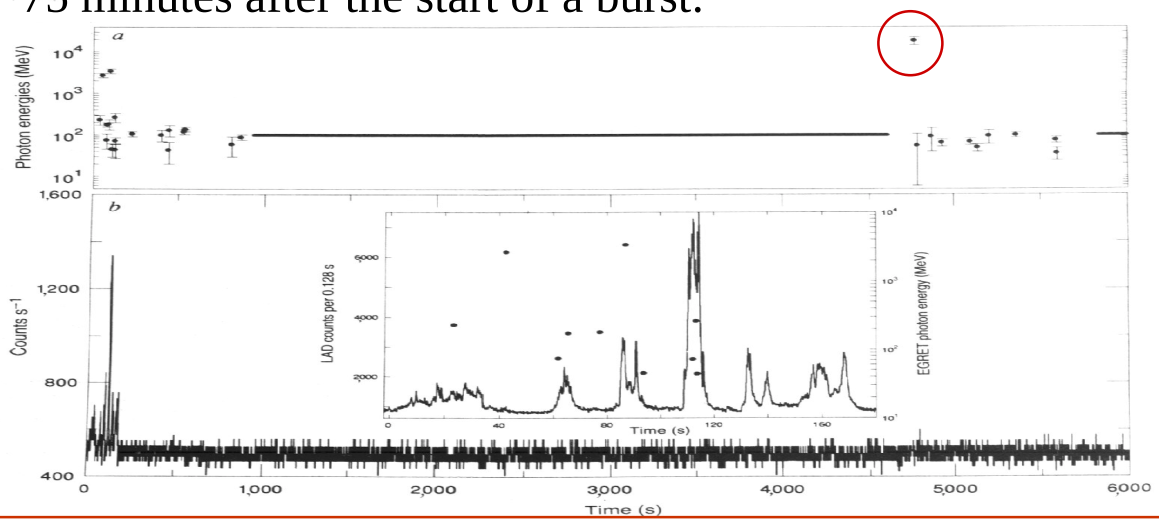
The BIG Picture

Gamma-ray experiments address a very broad menu of fundamental topics that include:

- Systems with supermassive black holes
- **Gamma-ray bursts (GRBs)**

GRBs discovered in 1960's accidentally by the Vela military satellites, searching for gamma-ray transients (guess why!) The question persists : What are they??

EGRET has detected very high energy emission associated with bursts, including an 18 GeV photon ~75 minutes after the start of a burst:



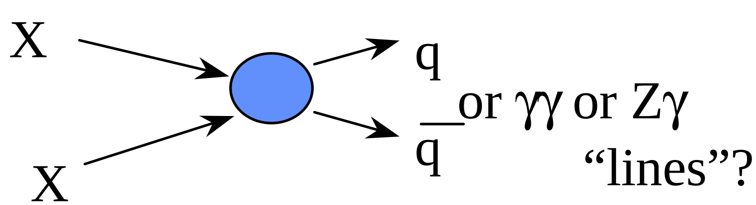
The next generation of experiments will provide definitive information about the high energy behavior of bursts.

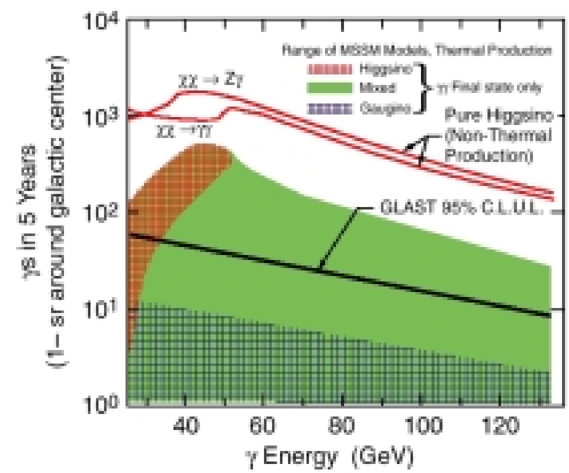
The BIG Picture

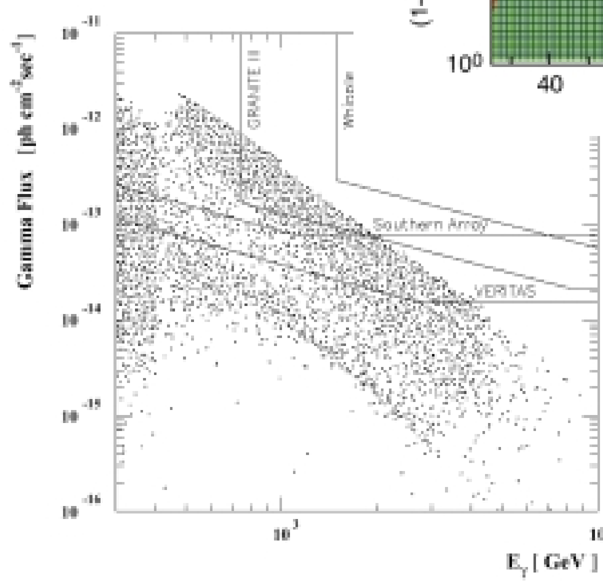
Gamma-ray experiments address a very broad menu of fundamental topics that include:

- Systems with supermassive black holes
- Gamma-ray bursts (GRBs)
- **Dark Matter**

If the SUSY LSP is the galactic dark matter there may well be observable halo annihilations into mono-energetic gamma rays.







Just an example of what might be waiting for us to find!

The BIG Picture

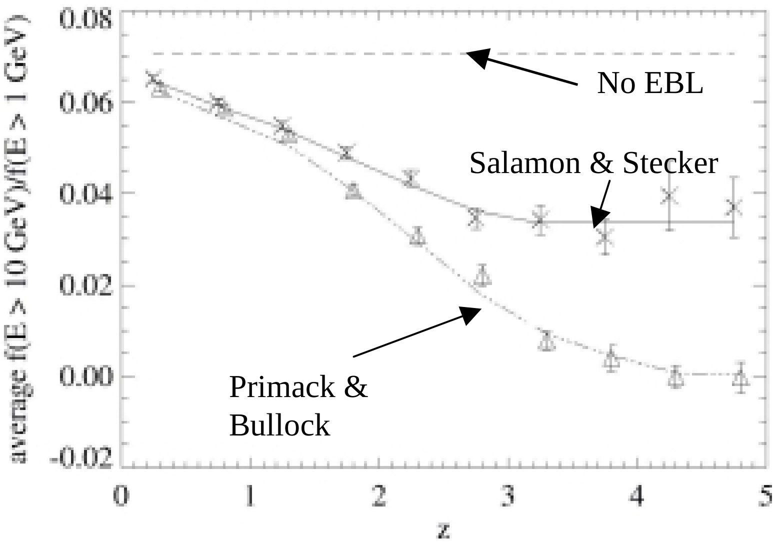
Gamma-ray experiments address a very broad menu of fundamental topics that include:

- Systems with supermassive black holes
- Gamma-ray bursts (GRBs)
- Dark Matter
- Probing the era of galaxy formation

Contemporary experiments (STACEE, CELESTE, Whipple, …) studying gamma attenuation for several sources. Expect great progress over the next few years.

GLAST could use thousands of blazars - instead of peculiarities of individual sources, look for systematic effects vs redshift. **Effect is model-dependent (this is good)**

Many caveats in this analysis!



The BIG Picture

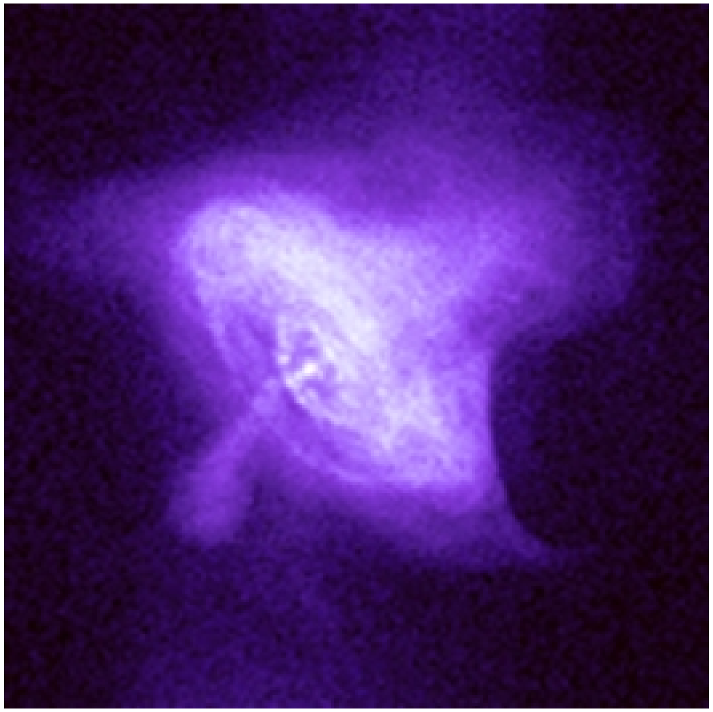
Gamma-ray experiments address a very broad menu of fundamental topics that include:

- **Systems with supermassive black holes**
- **Gamma-ray bursts (GRBs)**
- **Dark Matter**
- **Probing the era of galaxy formation**
- **Origin of Cosmic Rays**
- **Discovery!** (Hawking Radiation? Using Bursts to detect photon velocity dispersion? Other relics? …
  -- huge increments in capabilities

These experiments draw the interest of both the the High Energy Particle Physics and High Energy Astrophysics communities.

Information from Xrays

Xray astrophysics is in a particularly productive period, driven by Chandra and XMM-Newton:



"NASA/CXC/SAO"

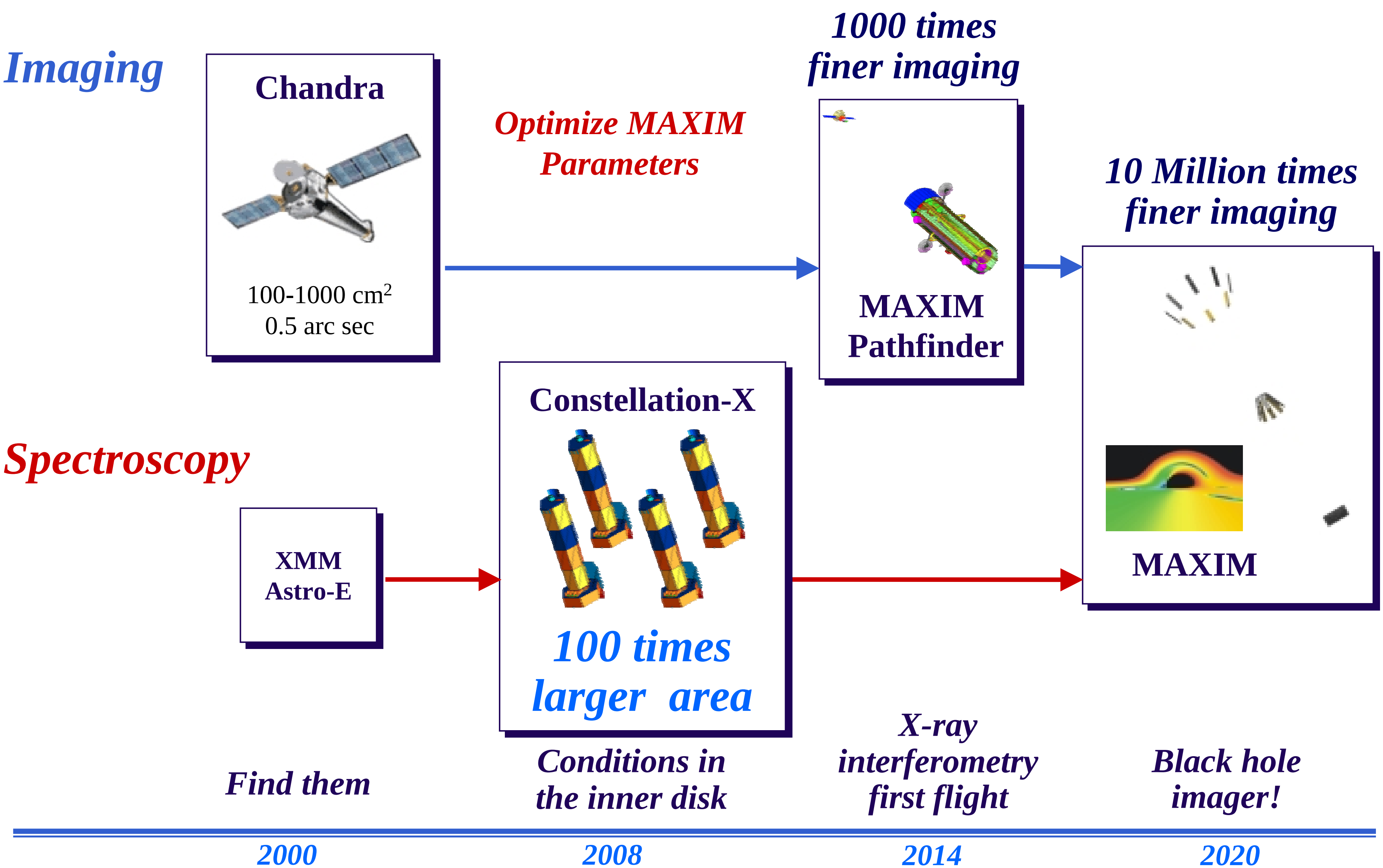
early Chandra image of the Crab nebula

Chandra is optimized for high spatial resolution (~0.25") and spectral resolution.

XMM is optimized for large collecting area (~2500 cm^2) and field of view.

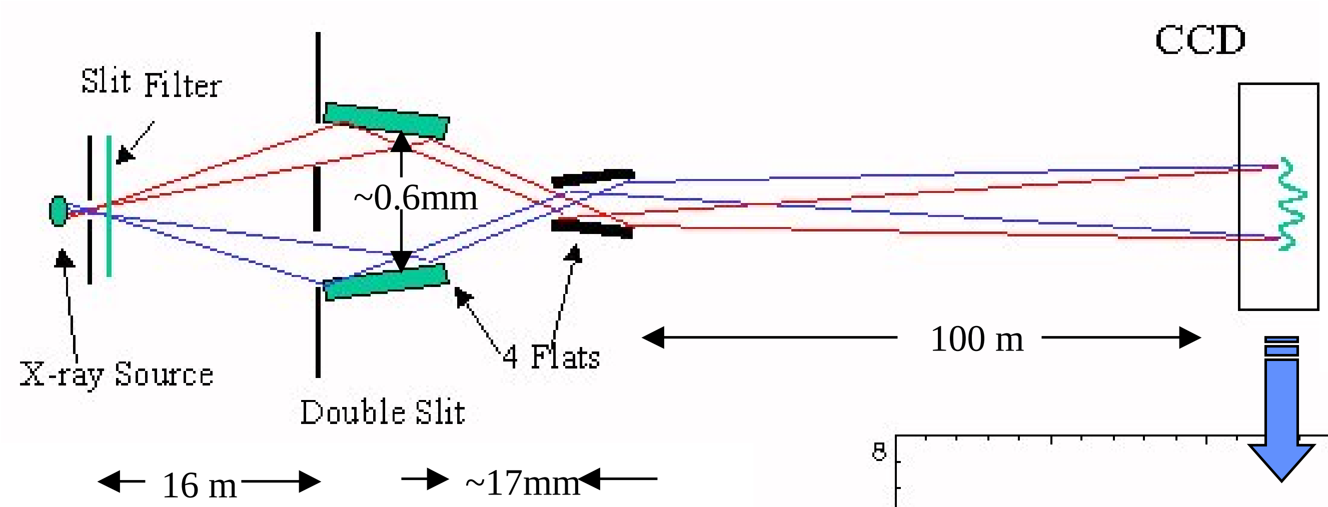
The plans for the future are remarkable ⇨

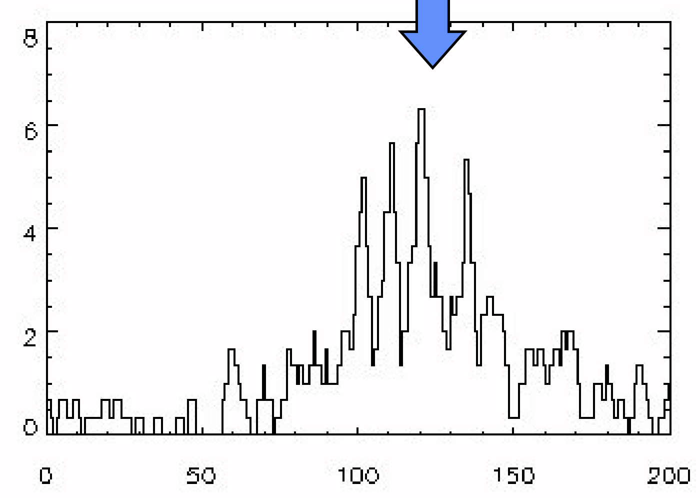
Roadmap to Image a Black Hole in Xrays



Xray Interferometry

Webster Cash et al(1999) have built a modern xray interferometer:





see: Nature, Volume 407, Issue 6801, pp. 160-162 (2000)

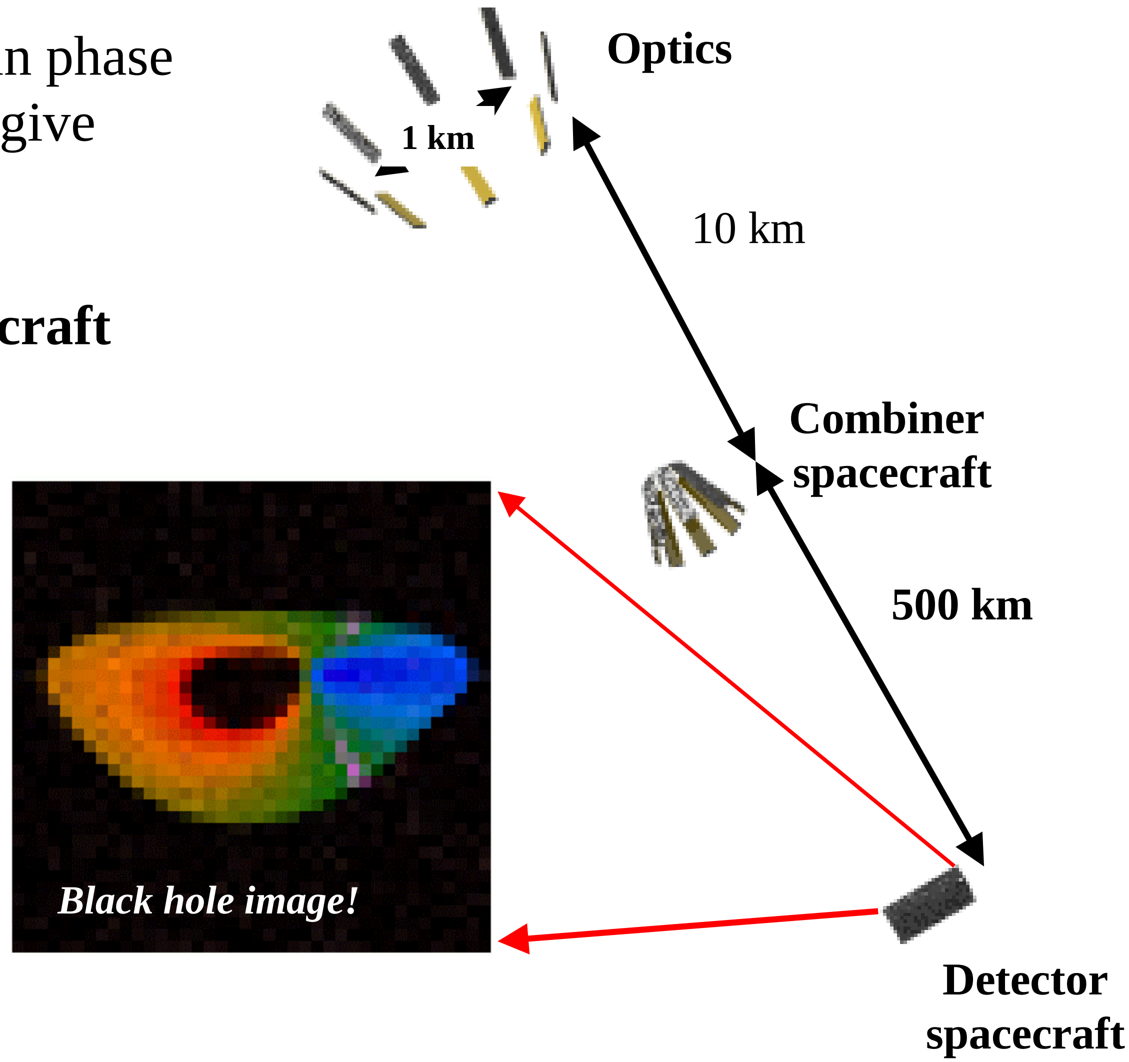
Extrapolating…

The Black Hole Imager: MAXIM Observatory Concept

32 optics (300 × 10 cm) held in phase
with 600 m baseline to give
0.3 micro arc sec

34 formation flying spacecraft

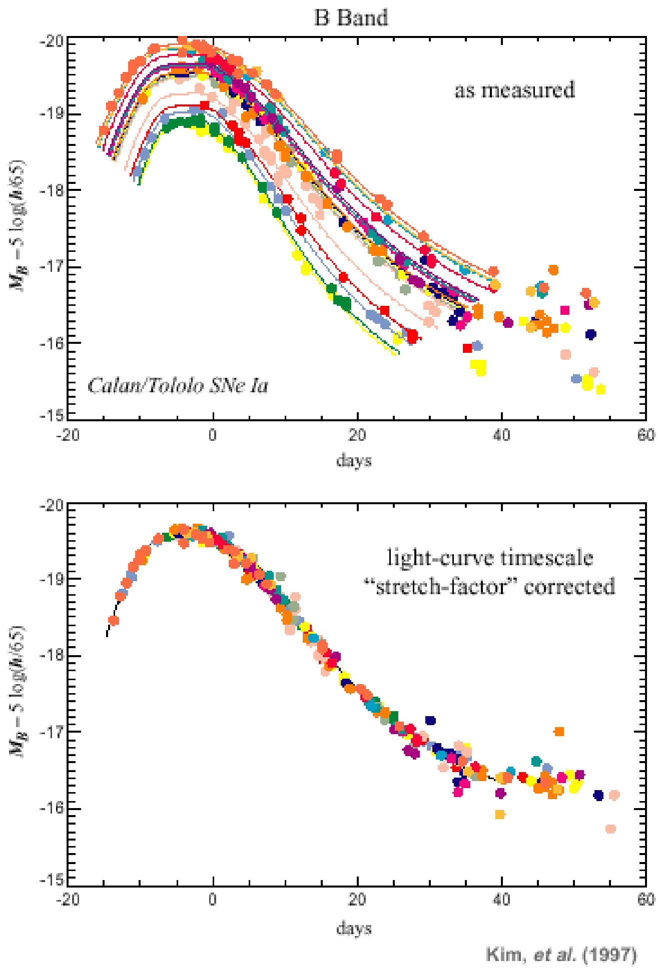
System could be adjustable on orbit to achieve larger baselines

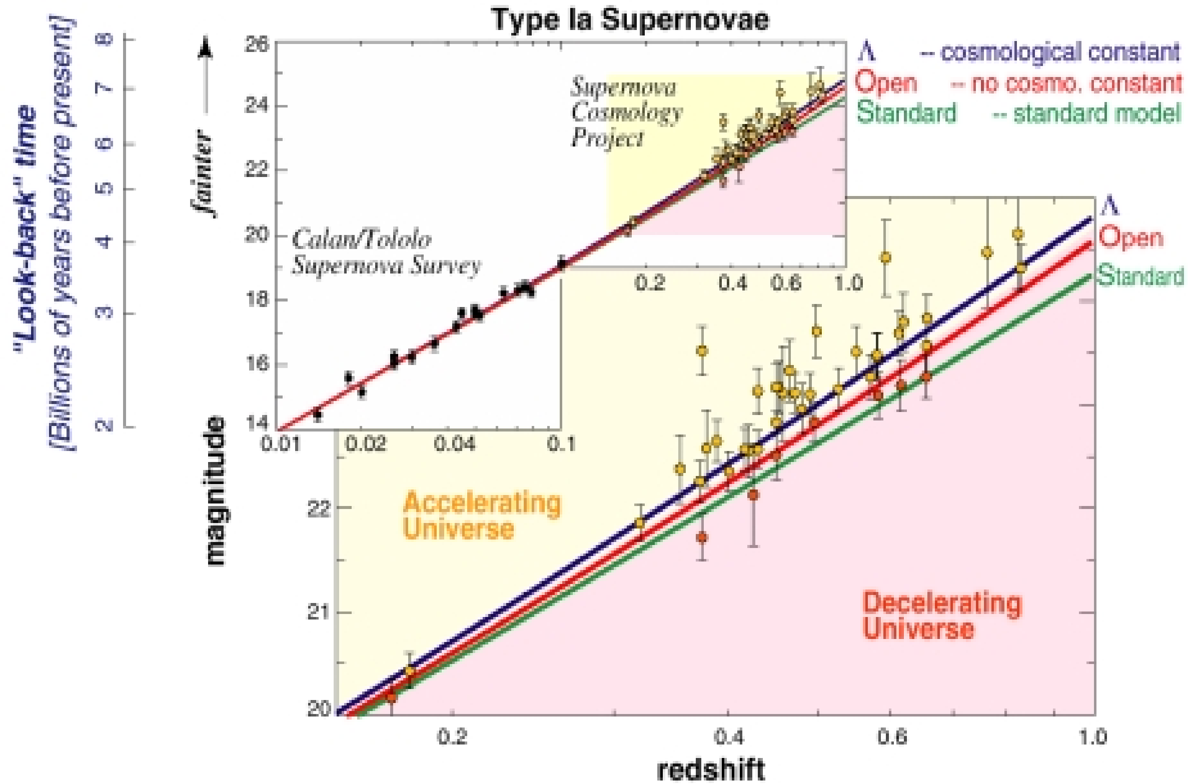


See Nick White's talk on Cosmic Journeys, 12 July

Optical

Use type Ia Supernovae corrected candles to measure the expansion rate. Ground-based work thus far has uncovered a major surprise:





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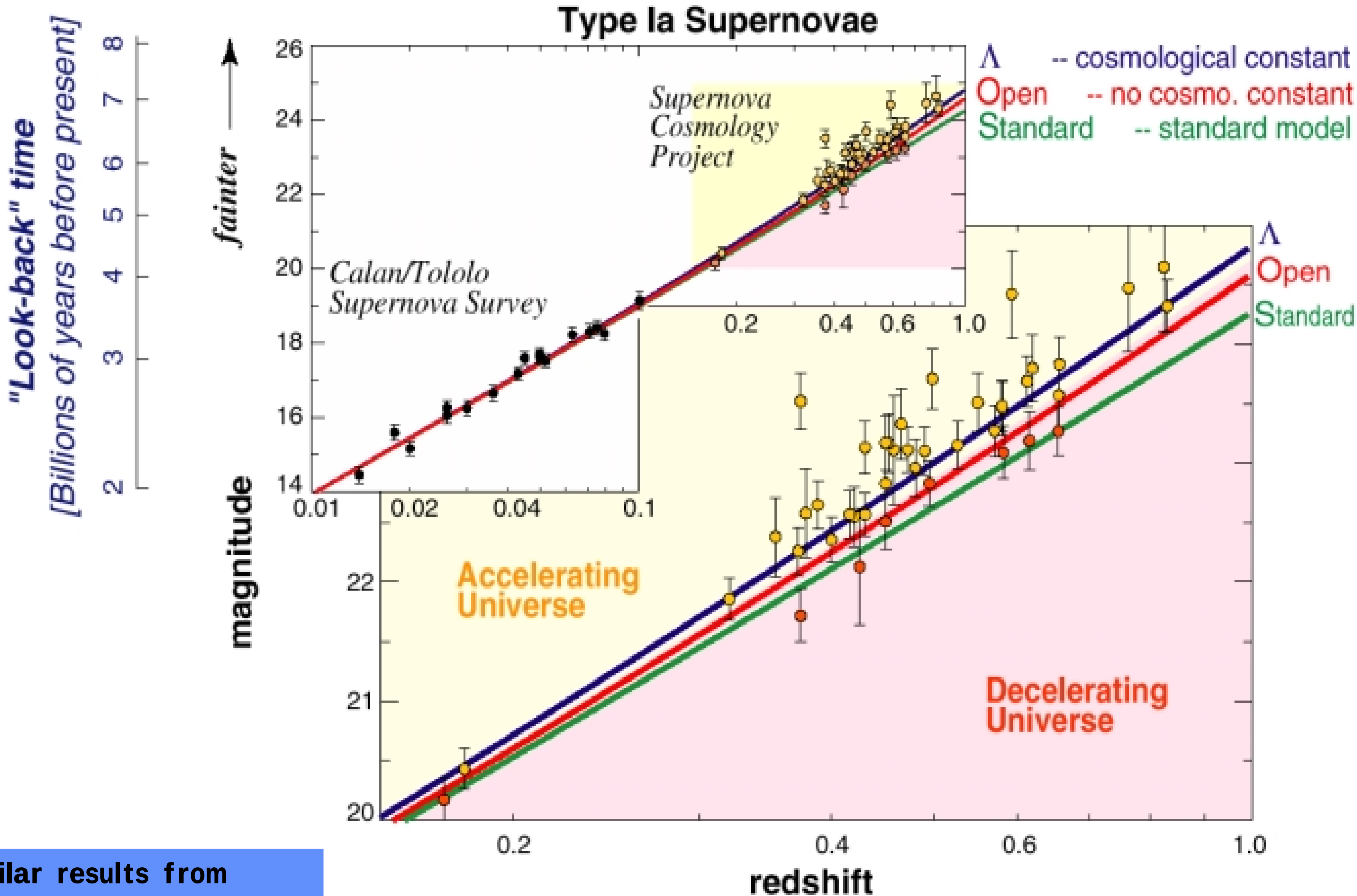
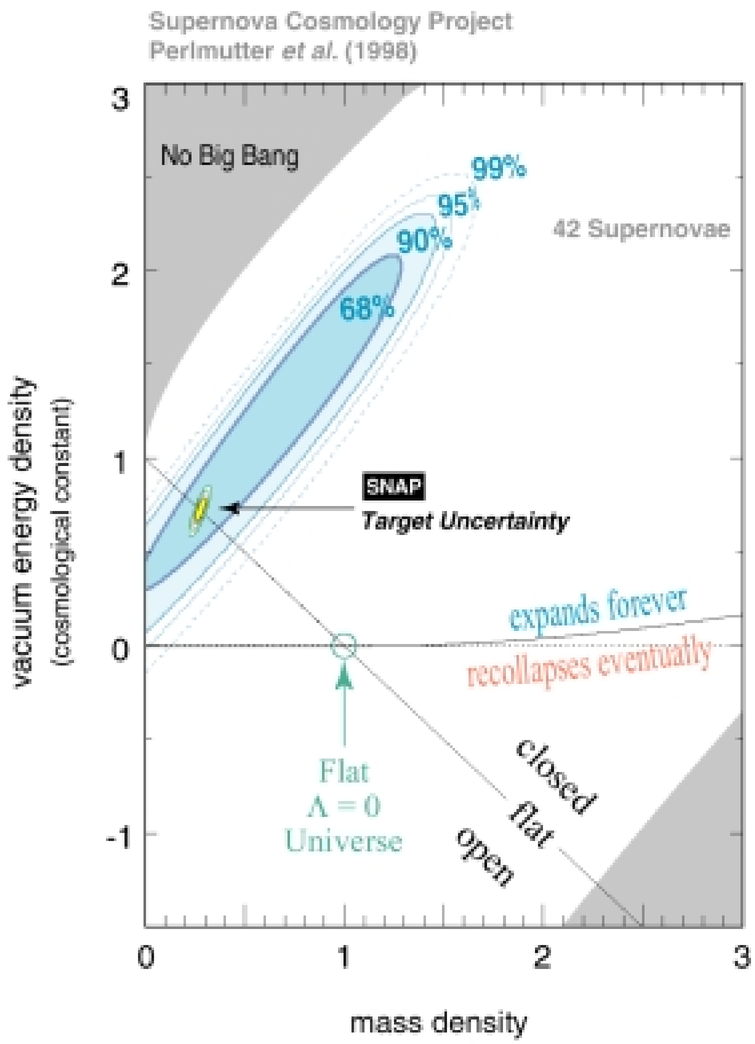


Similar results from the High-z Supernova Search Team (e.g., Riess et al AJ116(1998))

Implications

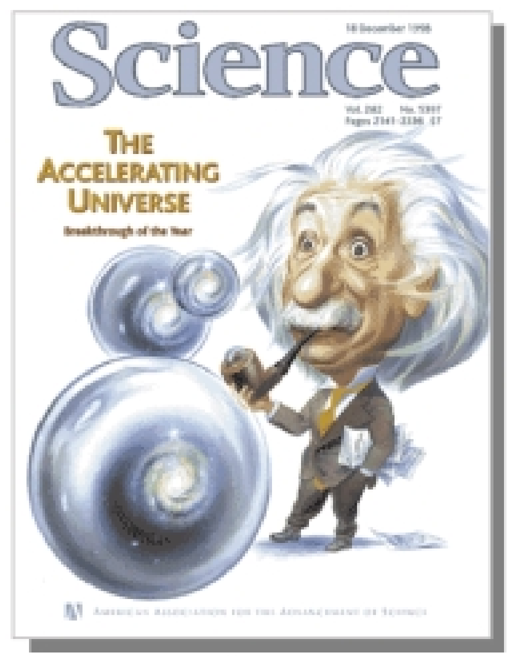
Contrary to expectation, the expansion of the Universe appears to be *increasing* with time!



This could be due to a non-zero cosmological constant, a manifestation of non-zero vacuum energy….

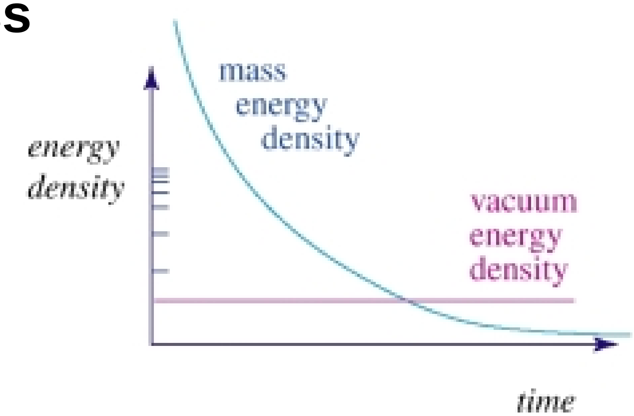
… or systematic effects yet to be understood.

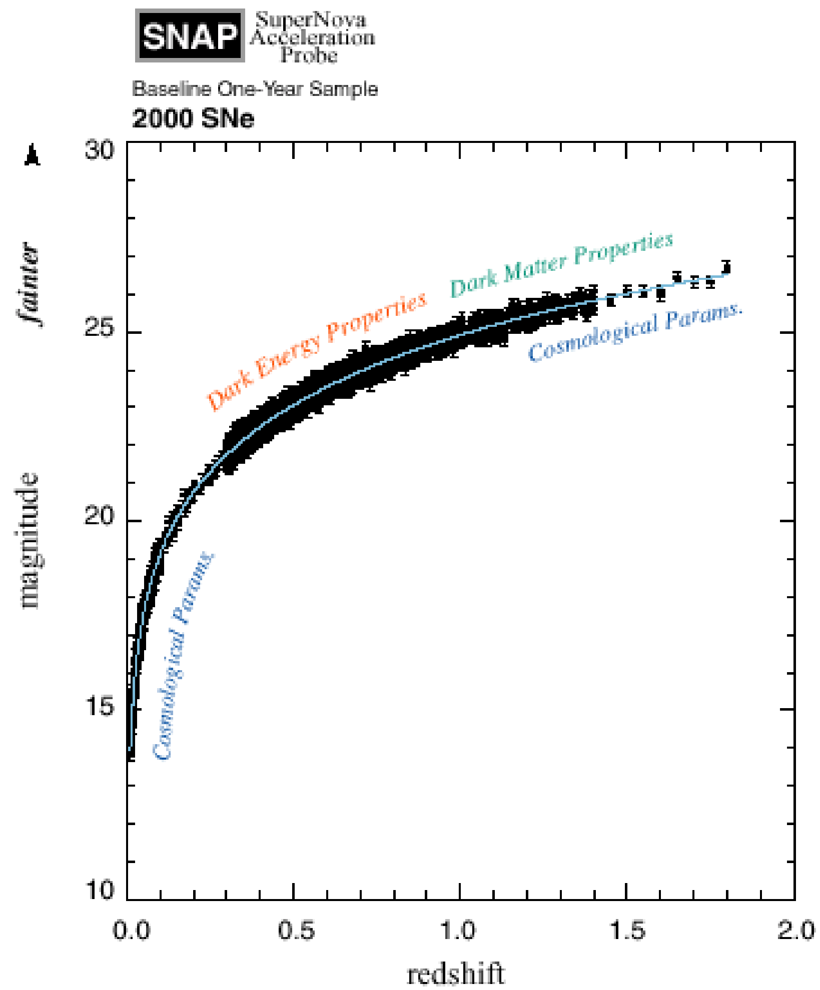
This result has raised fundamental questions and begs further investigation.



What Is Needed Next?

- **PROPOSAL: Large statistics, ~2000 Sne Ia's, distributed in redshift to z<1.7, with minimal selection bias and clean Ia ID.**
- **Key is systematic error reduction:**
  - Discover SNe 3.8 mag before max, 10 points on lightcurve
  - Near-IR spectroscopy to 1.7 μm
- **Guess**

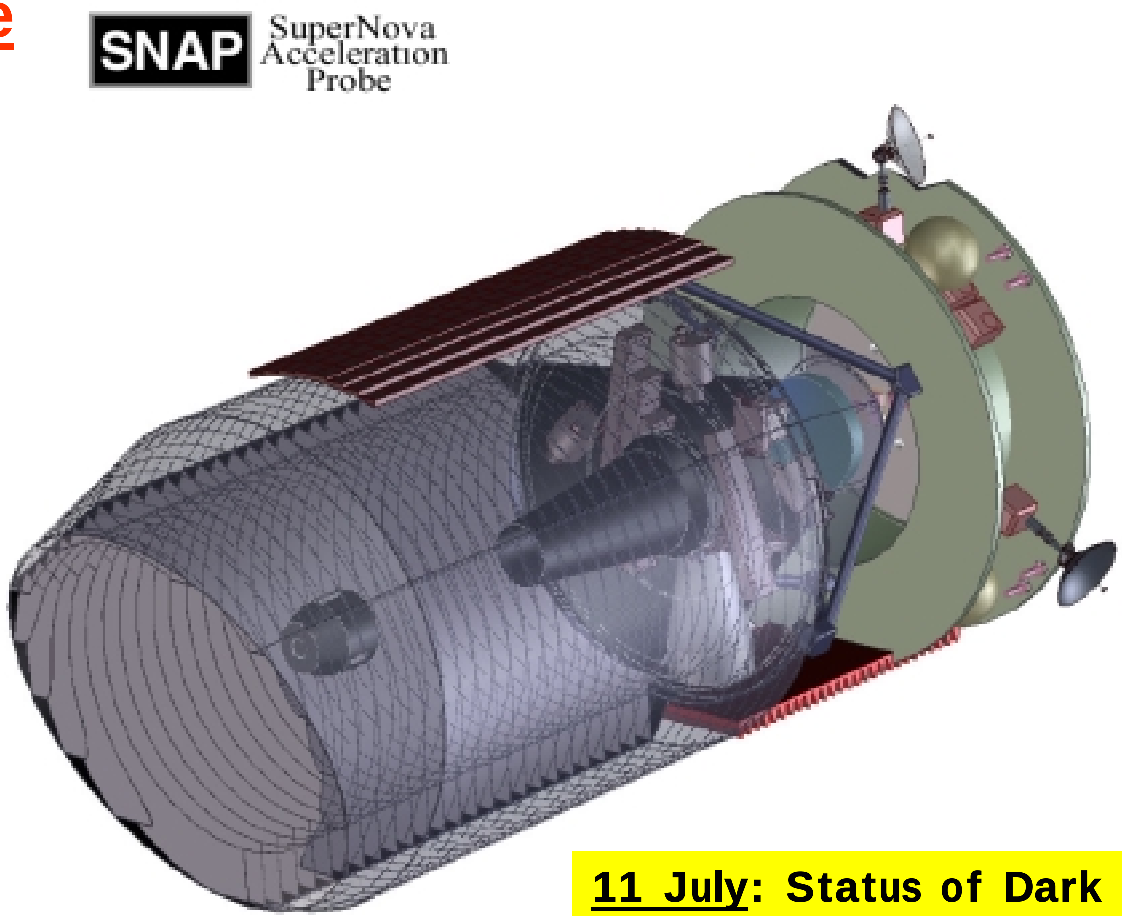




=> Investigate w(z)=p/ρ

SNAP Instrument Concept

- **2m aperture telescope**
- **Optical photometry** with 1°x 1° billion pixel mosaic camera, high-resistivity, rad-tolerant p-type CCDs sensitive over 0.35-1 μm
- **IR photometry** 10'x10' FOV, HgCdTe array (1-1.7 μm)
- **Integral field optical and IR spectroscopy** 0.35-1.7 μm, 2"x2" FOV

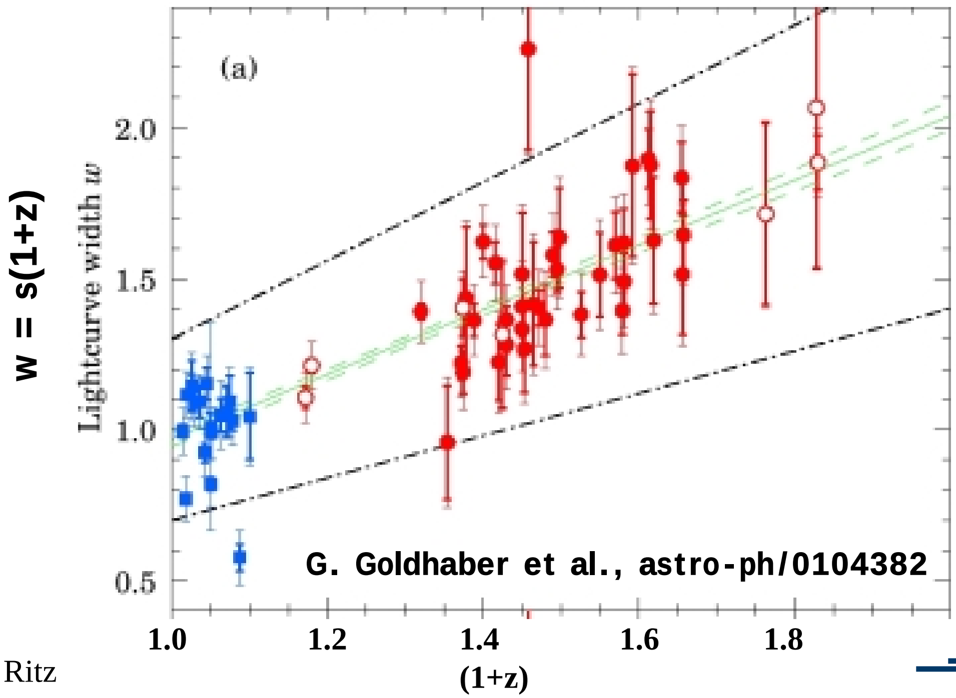


Concept is evolving. Collaboration is seeking input from all interested communities. **"Collaboration is open**."

11 July: Status of Dark Energy Experiments
14 July: Future of Dark Energy Experiments

Recent Related Results

- A serendipitous discovery (Riess et al, astro-ph/0104455) of a supernova at z=1.7 (in the “decelerating” era) reduces the likelihood that gray dust fakes the apparent acceleration.
- The SN light curve broadening is consistent with that expected from cosmological expansion:



excludes “tired light” hypothesis by 18 σ

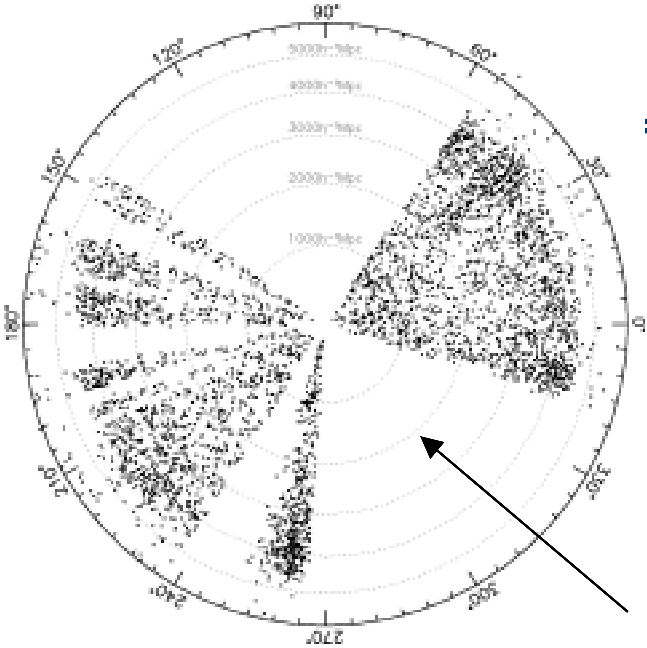
Sloan Digital Sky Survey

ref: http://www.sdss.org/

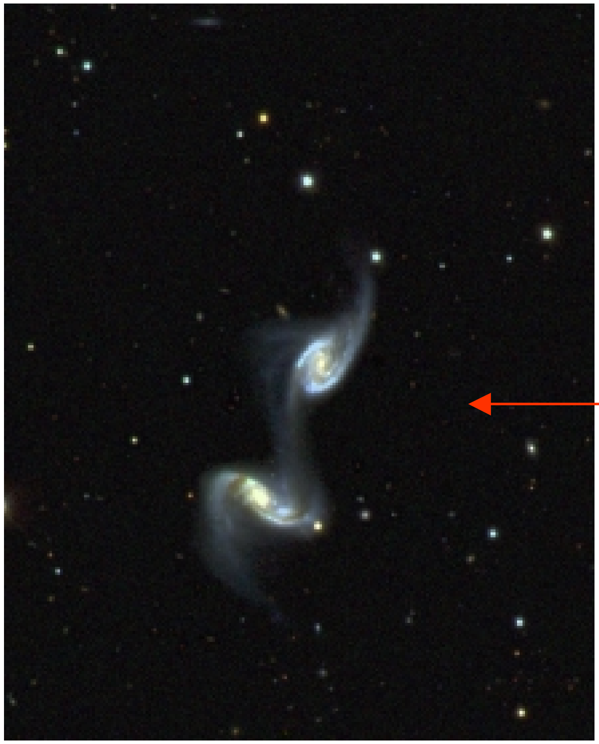
See P4 sessions: July 14 & 17

- Large-scale structure survey
- Map position and redshift of more than 1 million galaxies and 100,000 quasars (to z ~ 6).
- International collaboration of astronomers, astrophysicists and particle physicists. Project Scientist: Jim Gunn; Scientific Spokesperson: Mike Turner; Director is John Peoples
- Operations started 4/2000
- Full survey will take ~6.5 years
- First early major data set released in June 2001 ⇒

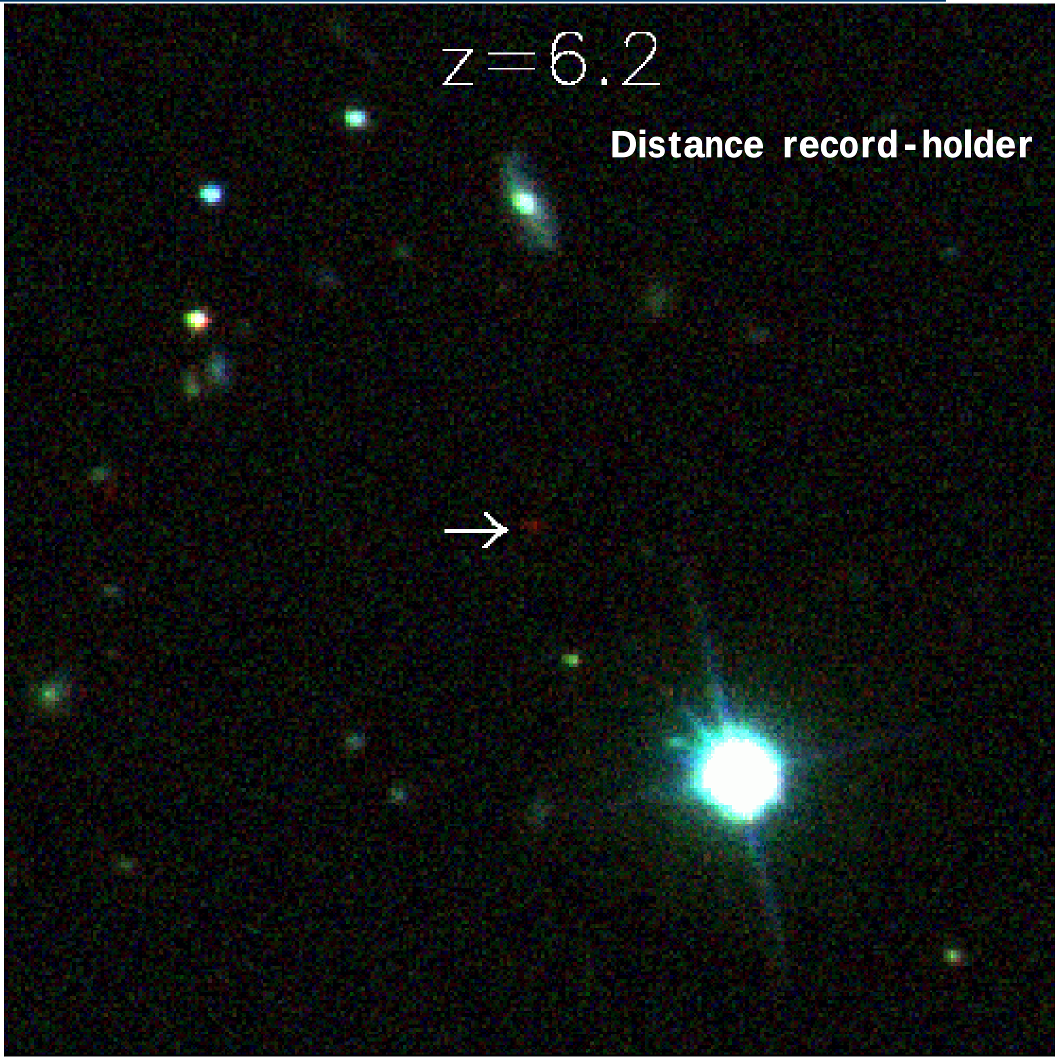
SDSS Early Data Release



500 sq deg of the sky, 14 million objects, spectra for 50,000 galaxies and 5,000 quasars.



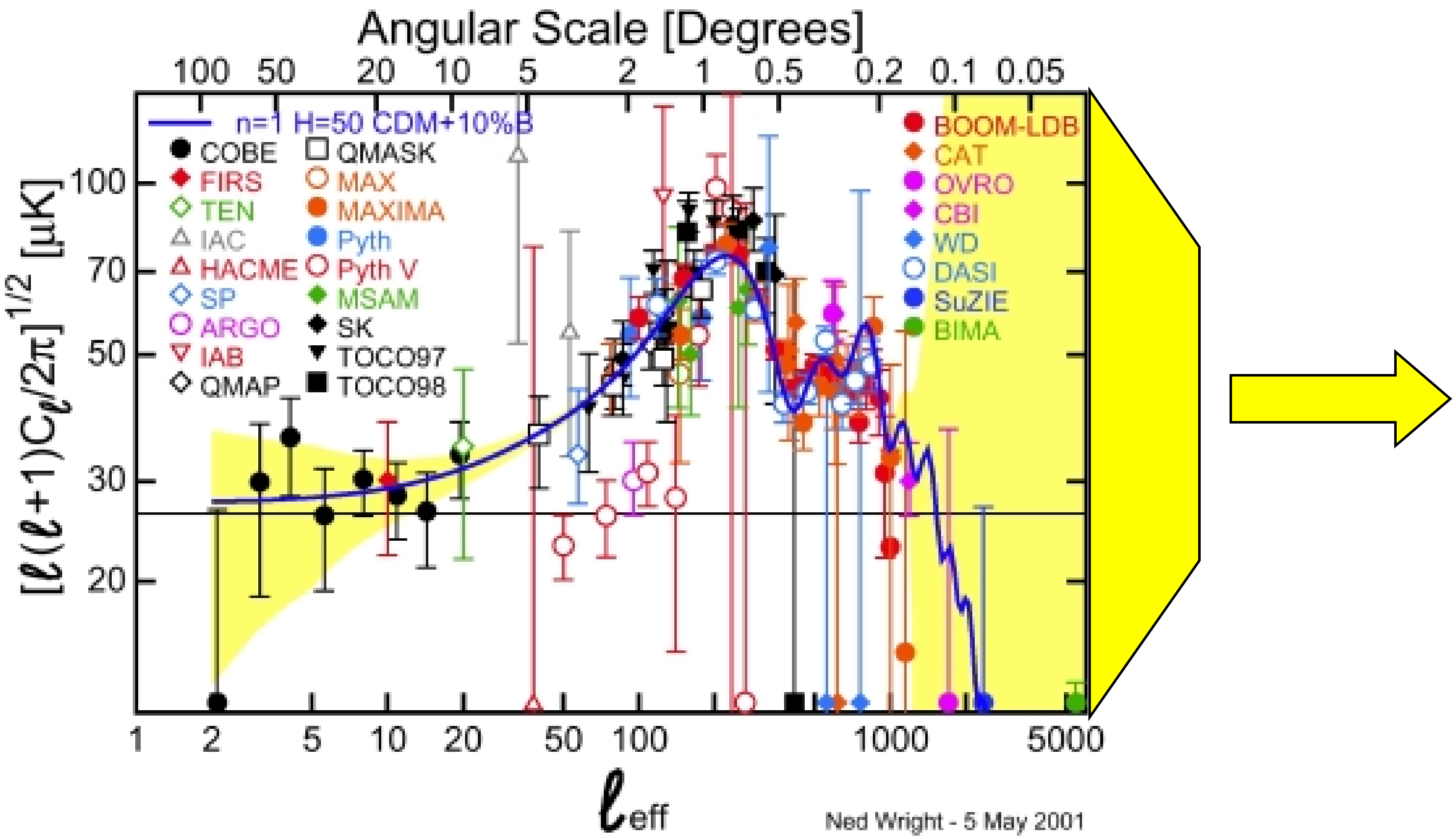
ARP 240 (NGC 5257/58) interacting pair of galaxies



>13,000 quasars (26 of the 30 most distant known)

Cosmic Microwave Background

Recent results add to the growing collection of measurements from the ground, balloons, and space:

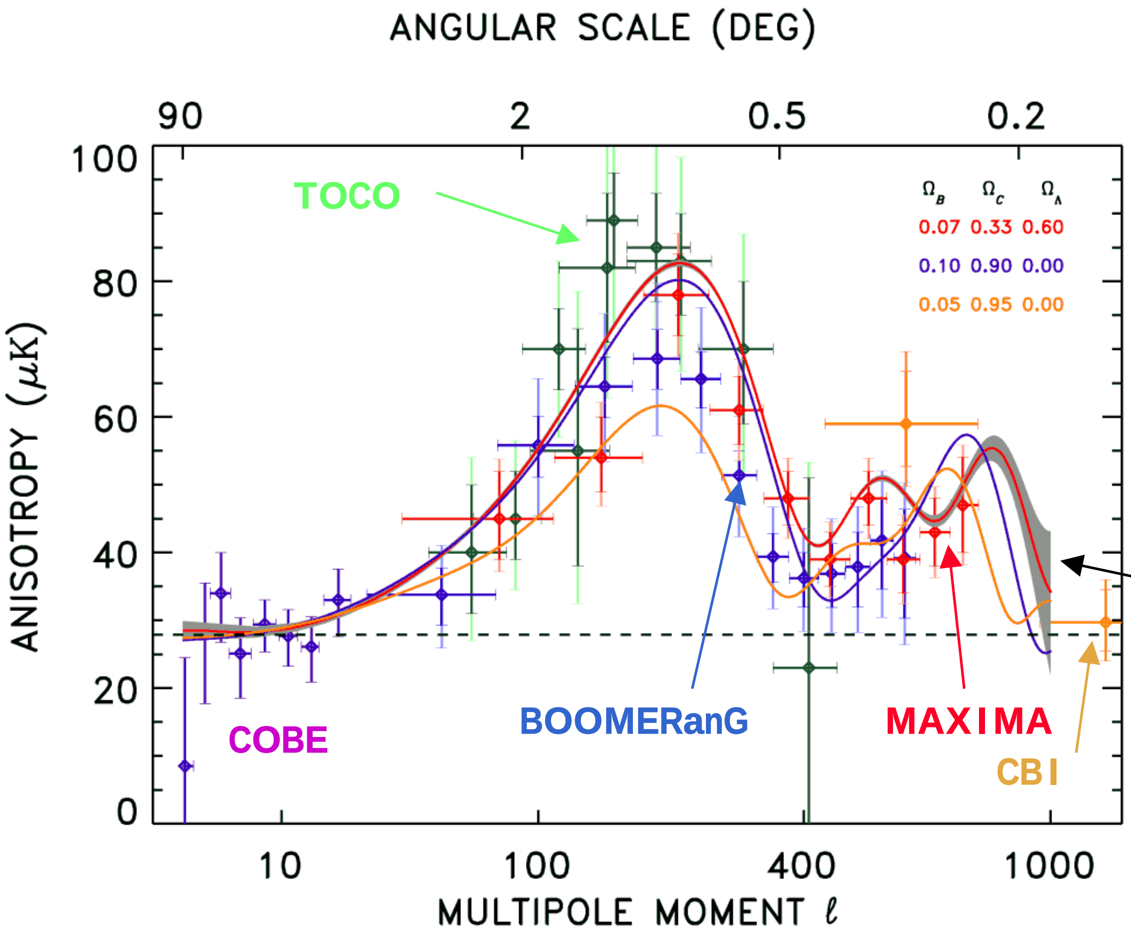


Amazing that we can see this – foreground removal!

See http://www.astro.ucla.edu/~wright/intro.html

and http://www.hep.upenn.edu/~max/ and links therein

Cosmic Microwave Background

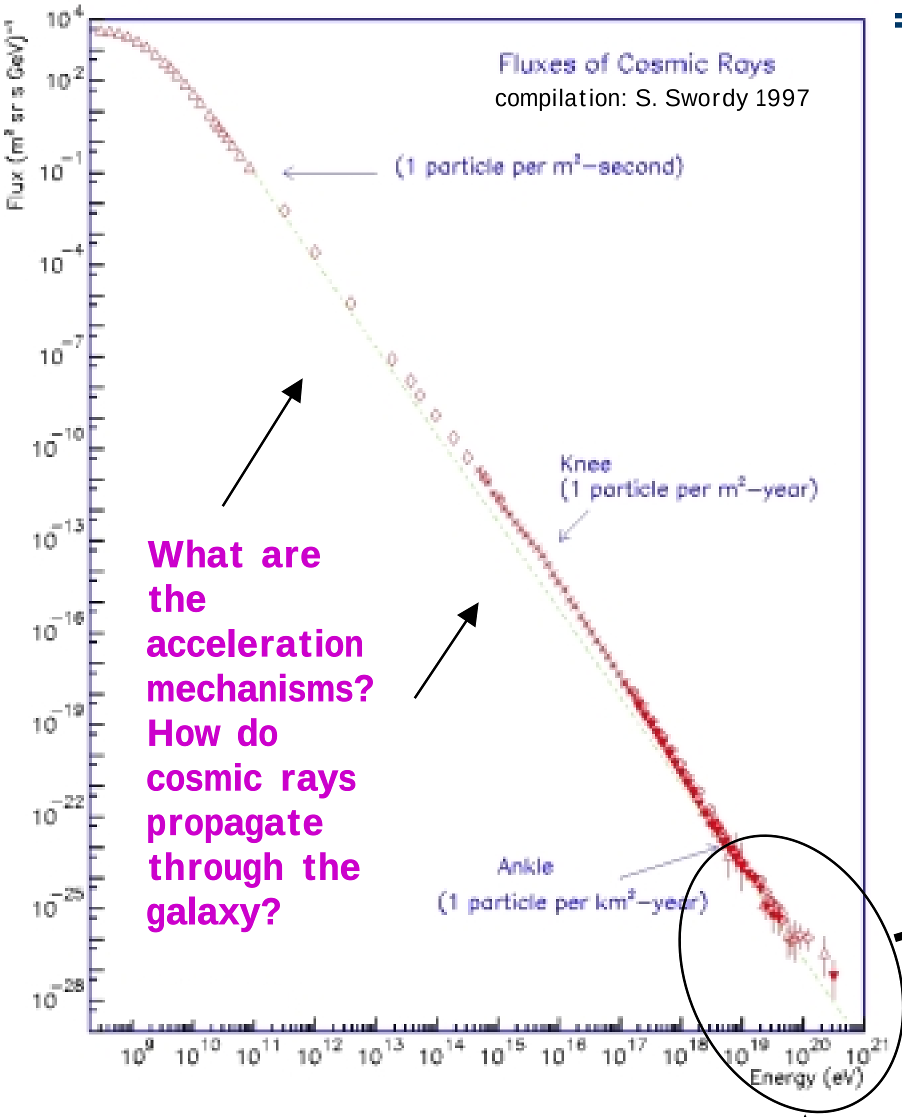


Expected **MAP** precision shown as the gray band. **Launched Saturday!**

Entering the era of precision cosmology. Many experiments (e.g., PLANCK, PIQUE, …) over the next decade will measure the strength of higher acoustic peaks and polarization anisotropy.

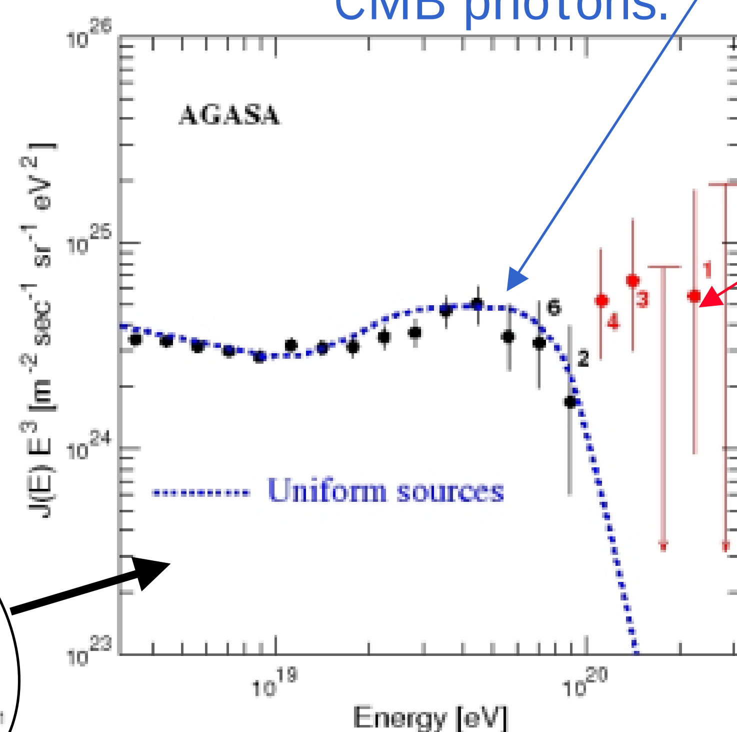
See activities of P4.3, E6.1 (6&7 July) and talk by B. Winstein (13 July).

Cosmic rays: two big questions



What are the acceleration mechanisms? How do cosmic rays propagate through the galaxy?

Propagating cosmic rays above the GZK energy interact with the bath of CMB photons.

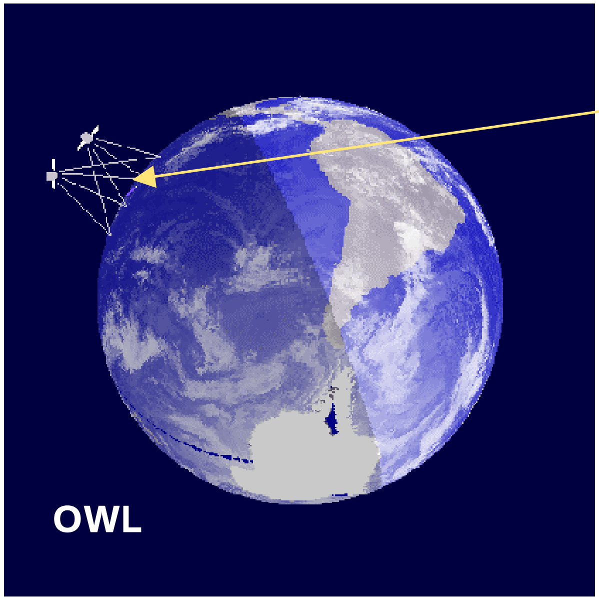


so what are these??

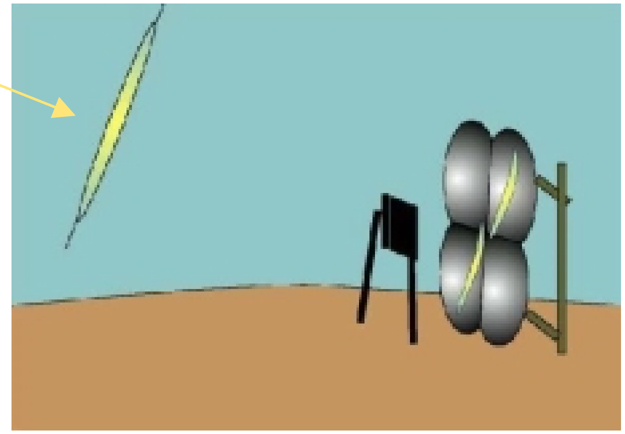
(soon to be out-of-date: stay tuned for HIRES results at ICRC in August)

O(1) particle/km²/century above 10^{20} eV
Corresponds to 16 J of KE in ONE particle

UHE Cosmic Ray Techniques



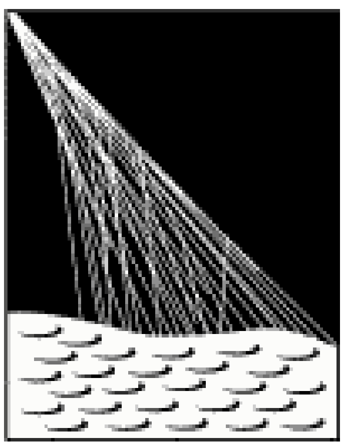
Nitrogen Fluorescence

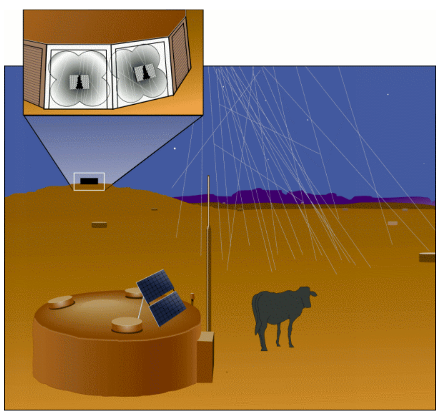


See P4 and E6 sessions
July 5, 10, 17

Experiment	Technique	Eff. Aperture [1000xkm^2-sr]	Status
AGASA	Ground Array	~0.2	running
HiRes	Fluor.	~1	running
Auger	Ground Array + Fluor.	7 (→x2)	building (prop)
Telescope Array	Fluor.	8	under study
OWL	Fluor.	~300	under study

Air Shower

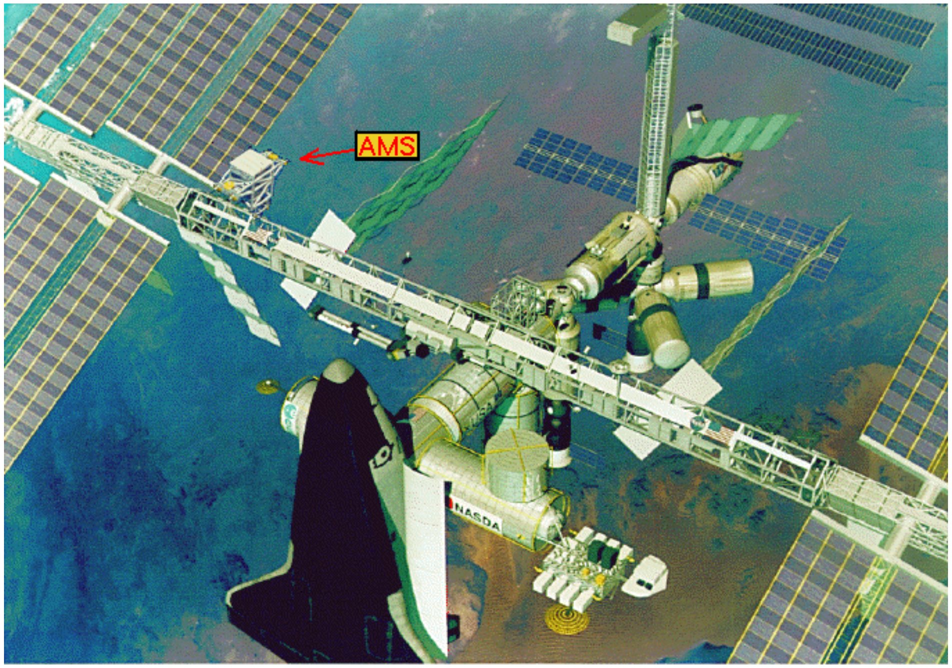


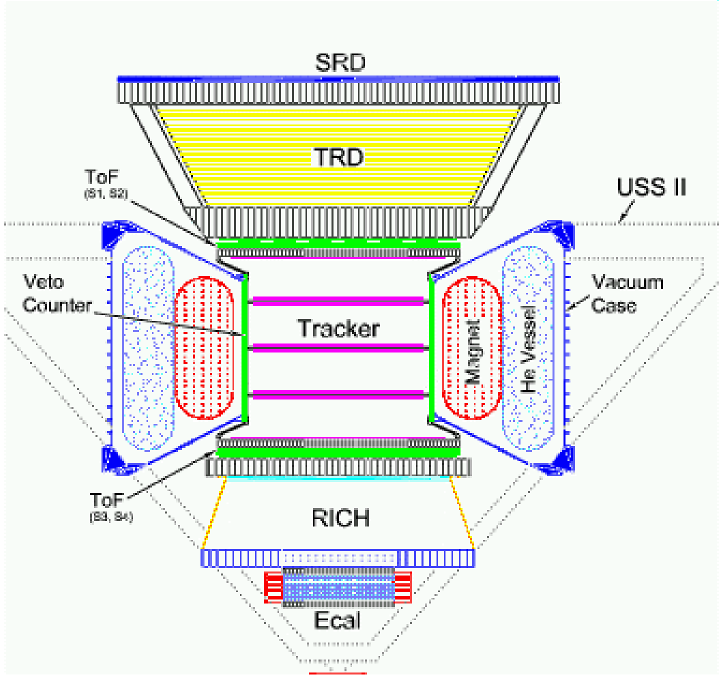


Alpha Magnetic Spectrometer

An experiment to search in space for dark matter, missing matter & antimatter on the international space station.

Successful shuttle experiment flight of AMS1 in June 1998. Manifested on shuttle flight to the ISS in 2005.





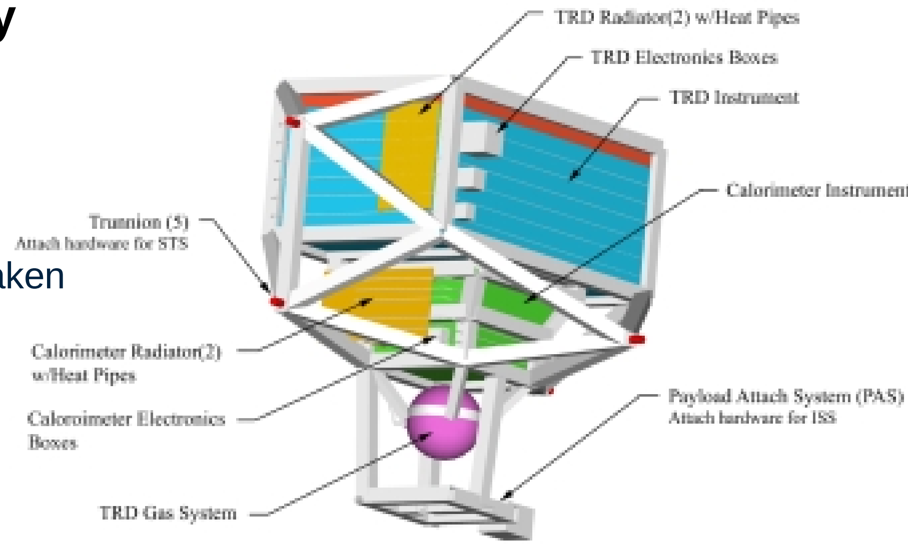
See talks 5 and 17 July

See http://ams.cern.ch/AMS/ams01_homepage.html

Cosmic Ray Composition: ACCESS

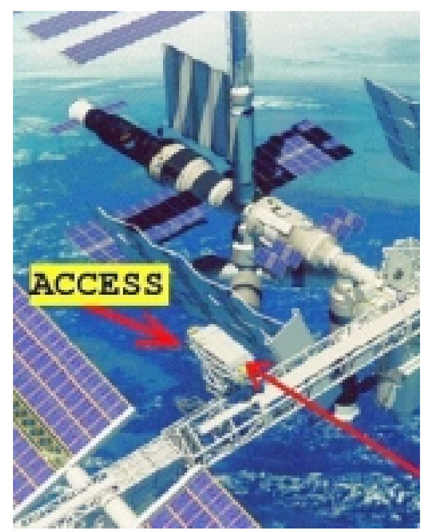
Explore the cycles of matter and energy in the evolving universe

- **How are cosmic rays accelerated?**
  - What are the source energy spectra?
  - Measure changes of individual element spectra taken at maximum energies expected from supernova shock acceleration
- **How do cosmic rays escape from the Galaxy?**
  - Measure energy dependence of abundance of primary and "spallation" nuclei



Measurement Goals

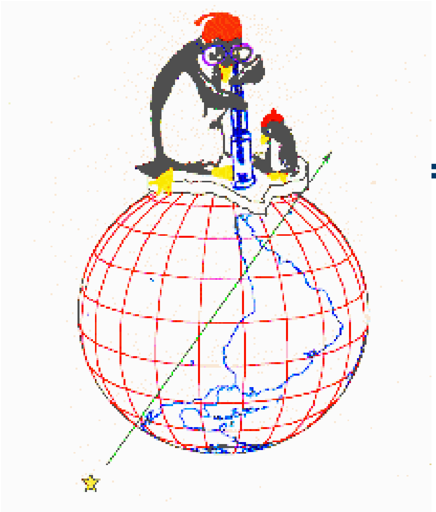
- **Measure ~ 30 times more p, He events than Japanese American Cooperative Emulsion Experiment (JACEE) balloon fights (1979 - 1995)**
  - Extend p and He spectra from 200 TeV to 1000 TeV
- **Measure ~ 3000 times more Z > 4 events than CRN Shuttle flight of 1985.**
  - Extend carbon spectrum from 20 TeV to 1000 TeV
  - Extend iron spectrum from 80 TeV to 5000 TeV



Status: Formulation study completed.

Proposal in preparation.

Plan to deploy in 2007/08.



High Energy Neutrino Astronomy

A new way to observe the cosmos.

UHE neutrinos (>10^{14} eV) will tell us about

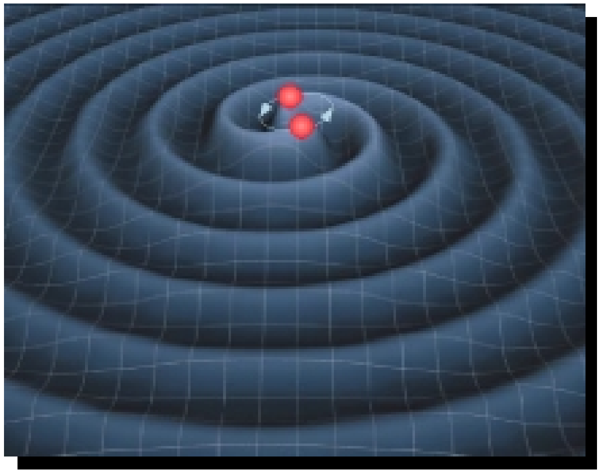
- **AGN, Gamma-ray Bursts, UHE Cosmic Rays, …**
- **Signatures from WIMPs, topological defects, and other relics.**

See sessions on July 10, 11

Experiment	Where	Status
DUMAND	**Hawaii**	**pioneer, defunded**
BAIKAL	**Siberia**	**limits on WIMPs, monopoles**
AMANDA	**South Pole**	**• hundreds of atmospheric events reconstructed from 97 running – technique understood. • results w/ limits on fluxes from GRBs, AGN, WIMPs, point sources. • First year of data from AMANDA – II being analyzed.**
NESTOR	**Greece**	**prototype studies**
ANTARES	**France**	**prototype running**
IceCube	**South Pole**	**under review**

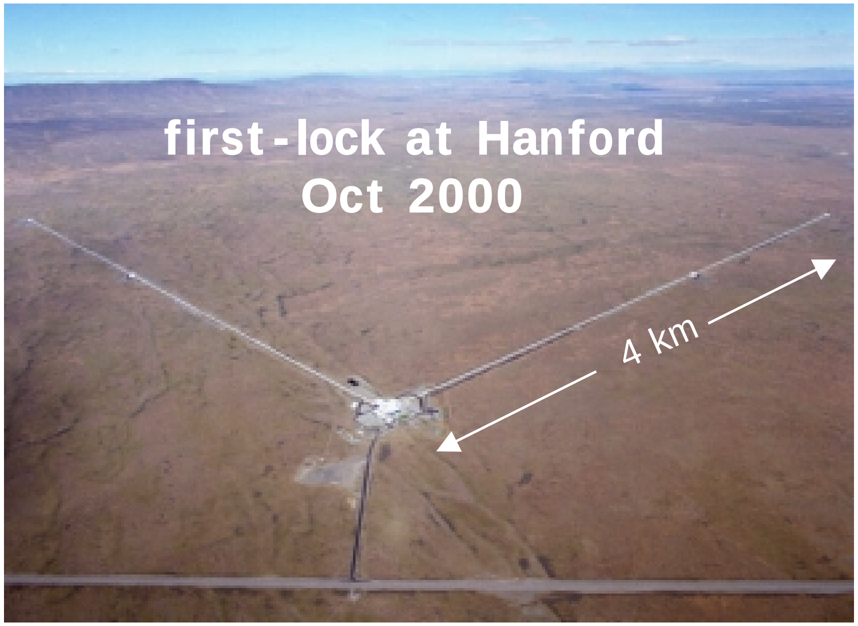
summary courtesy Doug Cowen

Gravitational Radiation

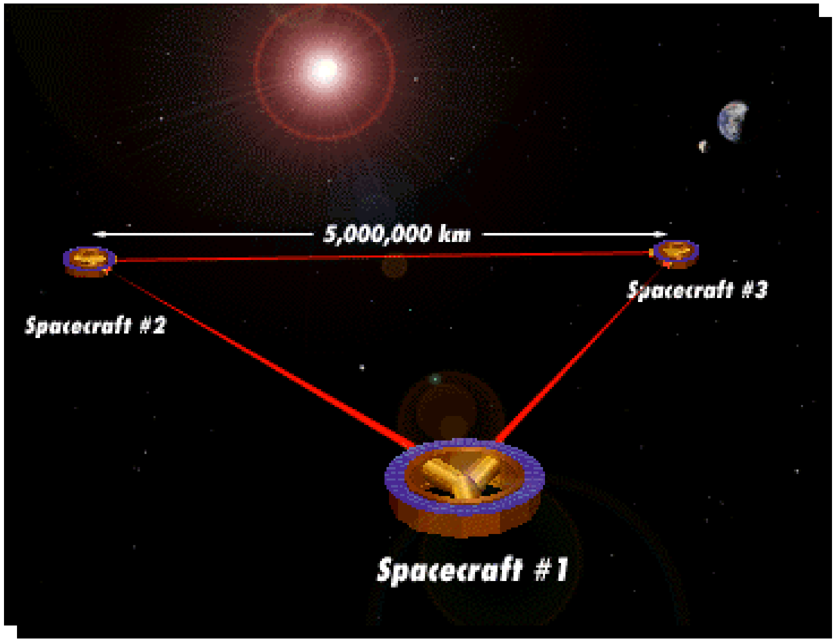


Orbiting and merging massive objects emit gravitational radiation

Two biggest experiments aiming to detect gravity waves:

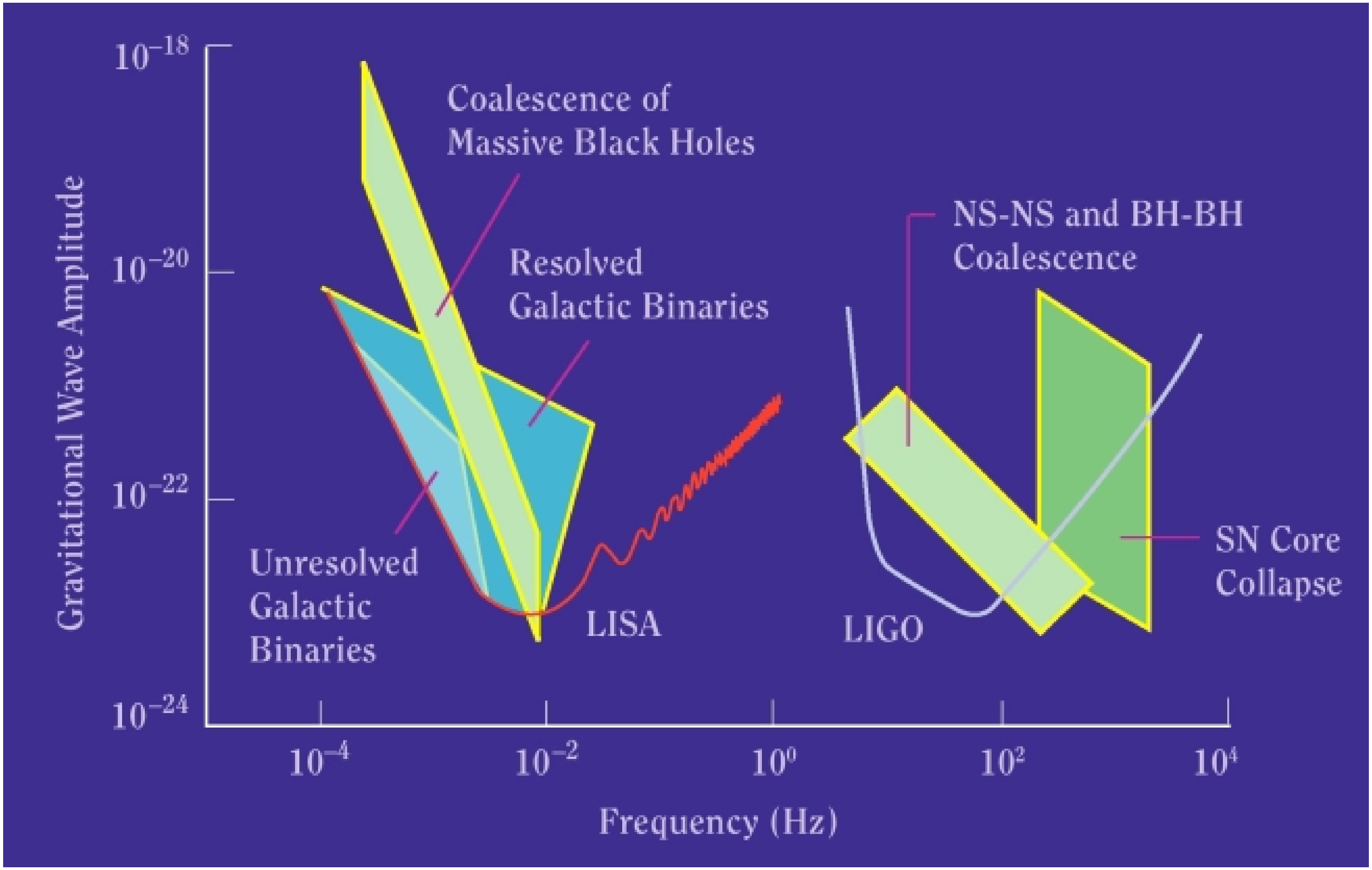


LIGO (ground-based, under construction)

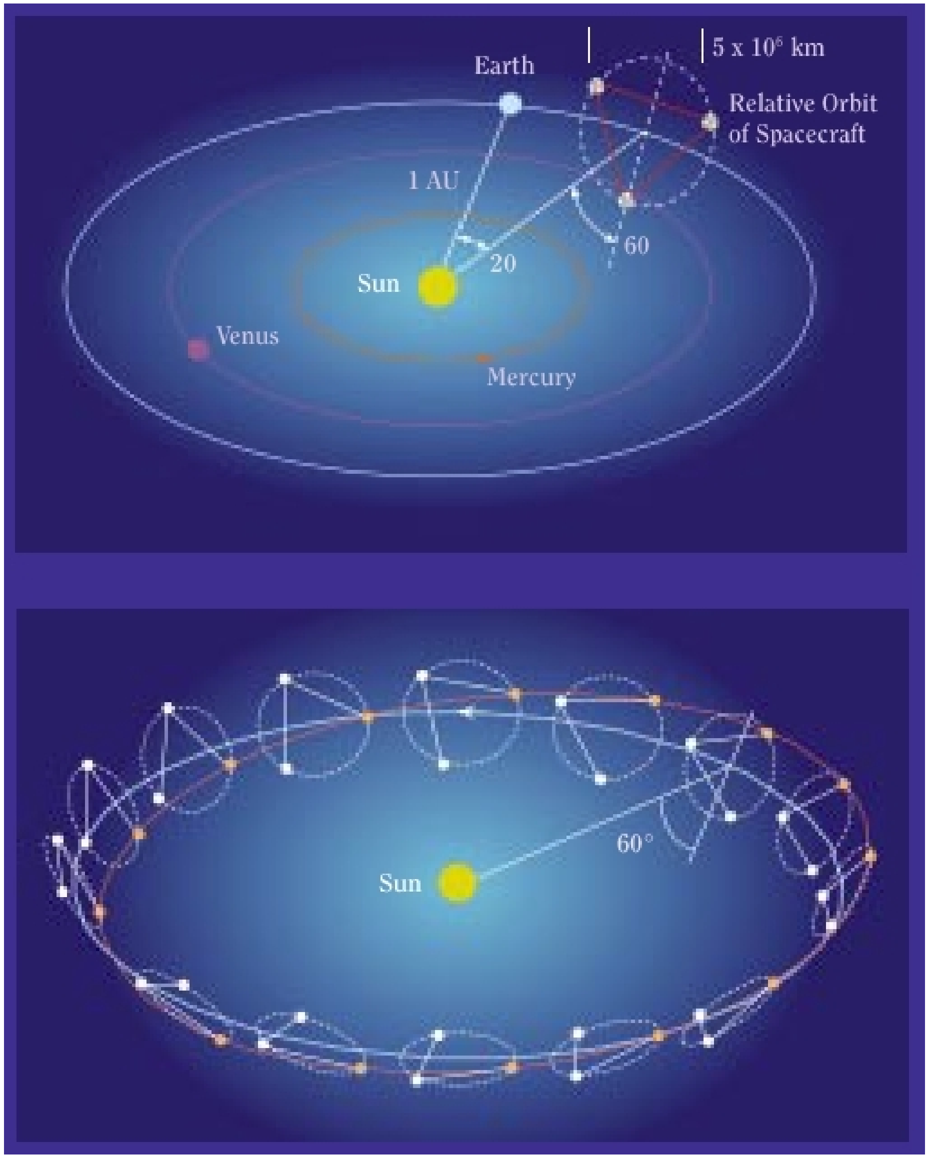


LISA (space-based, under development)

LISA and LIGO are Complementary



LISA Mission Concept



Each of 3 spacecraft:

• Mass: 265 kg • Power: 200 W

• Thrusters: 100 μN Field Emission Electric Propulsion units

MEASUREMENT CAPABILITIES

• Length accuracy: 1 pm in 1000 sec integration

• Best strain sensitivity:10^{-23} from 0.003 Hz to 0.010 Hz for 1 year int.

• Frequency range: 10^{-4} to 1 Hz

• Angular resolution: 1 arc minute for strongest sources

INSTRUMENTATION

Each Spacecraft contains two optical assemblies, including:

• 30 cm, f/1, transmit and receive telescope

• Optical bench with interferometer optics, laser stabilization cavity

• Inertial sensor with free-floating test mass, electrostatic sensing

• 1 W laser, diode-pumped, Nd: YAG. plus spare

• Fringe tracking and timing electronics

•Ultrastable oscillator

• Laser phase measurement system for intercomparing

fringe signals from two arms

MISSION

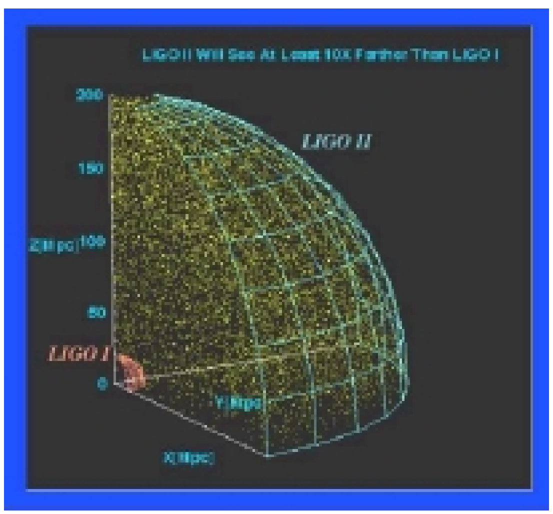
• Joint development of NASA and ESA

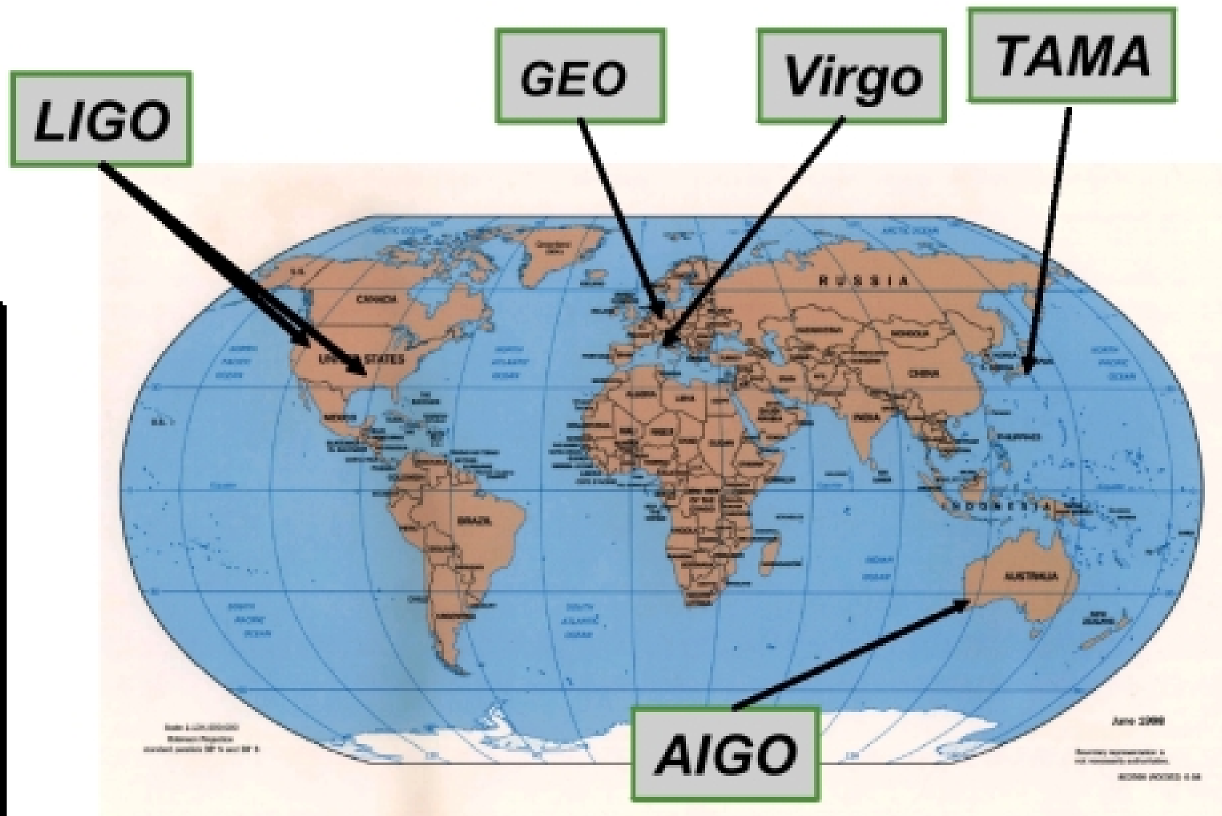
• Launch ~2010

Other ground-based gravity wave interferometers:

VIRGO (France/Italy) http://www.virgo.infn.it/ ,
GEO600 (Germany/UK) http://www.geo600.uni-hannover.de/
TAMA300 (Japan) http://tamago.mtk.nao.ac.jp/
ACIGA (Australia) http://www.anu.edu.au/Physics/ACIGA/

See P4 sessions on 3, 9, and 16 July [both ground-based and space-based]

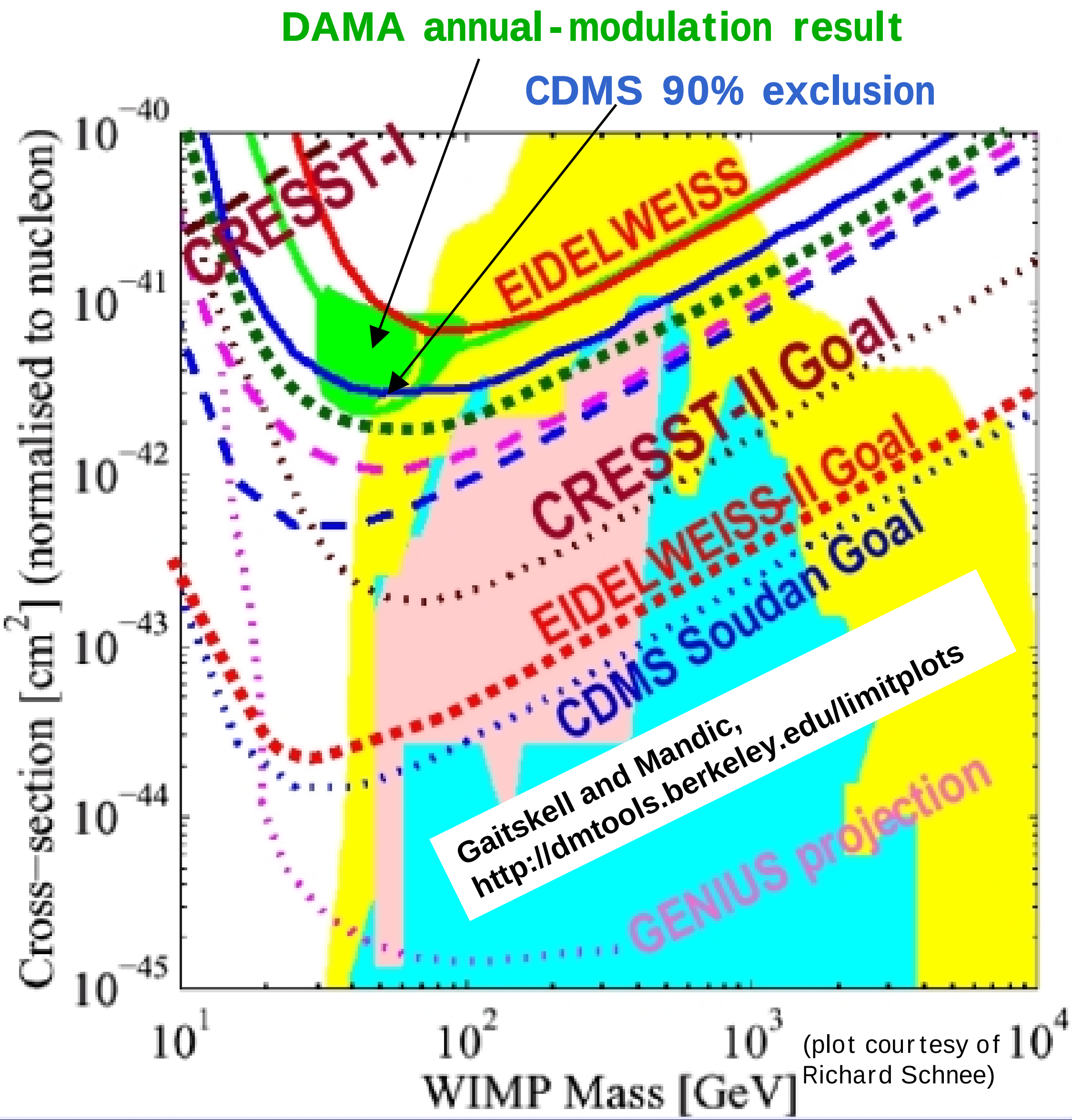




Direct Searches for Dark Matter: WIMPS

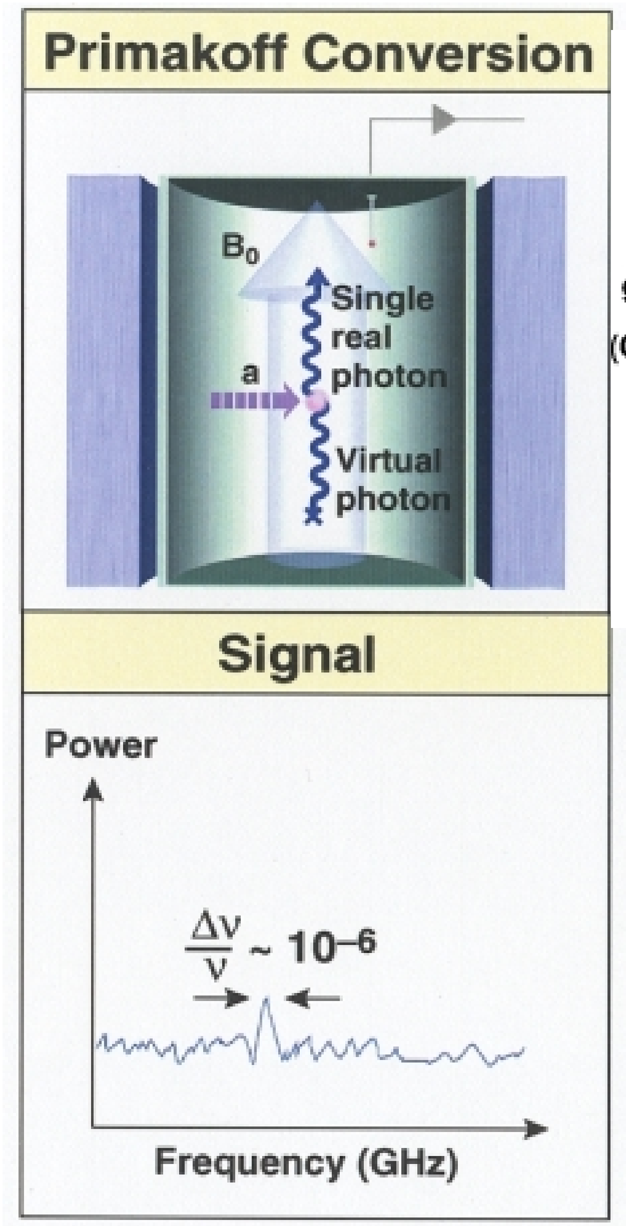
- LSP in SUSY models continues to be compelling Dark Matter candidate
- decade-long (or longer) efforts paying off: now probing interesting regions of parameter space (always highly model-dependent!)
- systematics/backgrounds! => broad range of techniques
- proven technologies producing results with excellent near-term prospects for improvements; many new technologies (including directional sensitivity) reaching maturity.

See sessions on 6, 7, 9 and 18 July (P4 and E6)

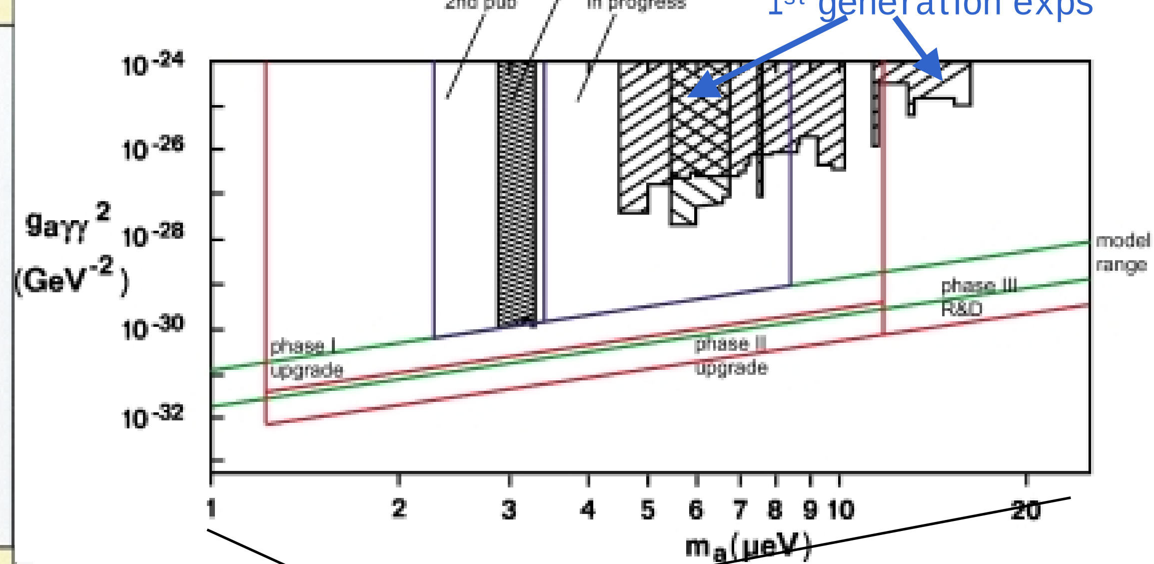


(plot courtesy of Richard Schnee)

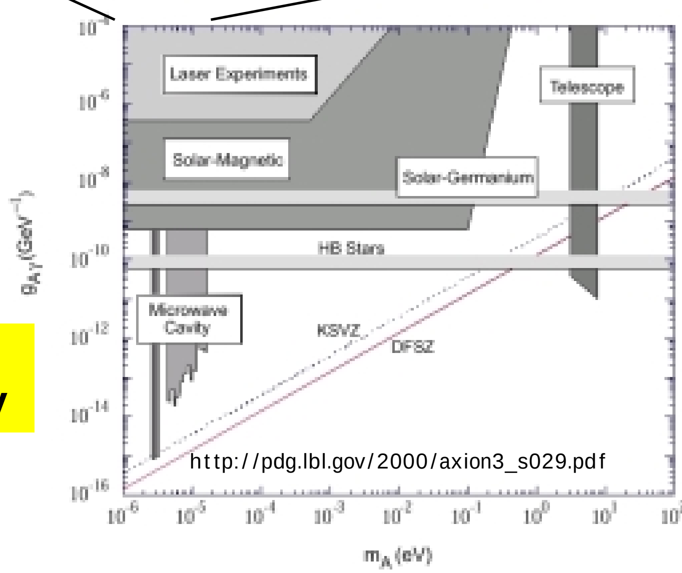
Direct Searches for Dark Matter: Axions



see http://www-phys.llnl.gov/N_Div/Axion/axion.html and reference therein



see session on 18 July



And Yet More….

Proton Decay: See special joint session 17 July

Early Universe and Tests of Fundamental Physics sessions: 2, 9, 14 July

Special session on European and US Underground Initiatives: 3 July

Community Connections

CONNECTIONS: Quarks to the Cosmos

Connections Group of physicists, astronomers, and space scientists. Work based upon the input from the community at workshops and conferences [Inner Space/Outer Space (Fermilab, May 1999), Cosmic Genesis (Sonoma State University, November 1999), and Beyond the Standard Models (Aspen, February 2000)], as well as working sessions of the Connections Group. See http://www.quarkstothecosmos.org

National Academy of Sciences
National Academy of Engineering
Institute of Medicine
National Research Council

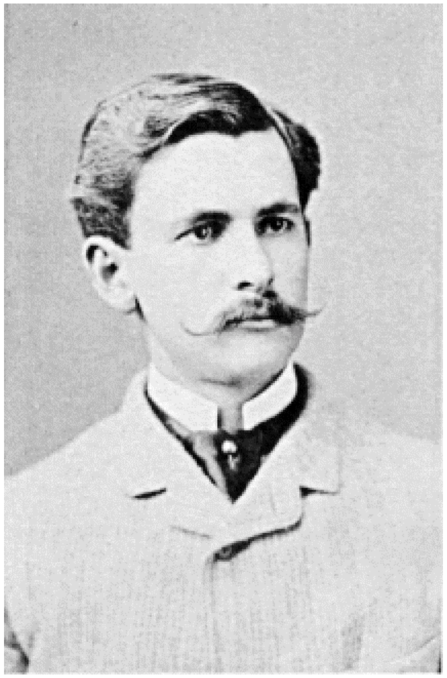
THE NATIONAL ACADEMIES
Advisers to the Nation on Science, Engineering, and Medicine

Committee on Physics of the Universe (M. Turner, Chair)
See http://www.nationalacademies.org/bpa/projects/cpu/

"Decadal" Survey (C. McKee and J. Taylor, Co-chairs)
See http://books.nap.edu/books/0309070317/html/index.html

DOE/NSF HEP Subpanel on Long Range Planning for U.S. High Energy Physics (J.Bagger and B.Barrish, co-chairs) See http://hepserve.fnal.gov:8080/doe-hep/lrp_panel/index.html

Let's make the multi-agency process efficient …



A. Michelson, 1887

A. Michelson, 1928

Astro/Cosmo/Particle Physics at Snowmass

- **check web pages (and links to subgroups) for schedules:**

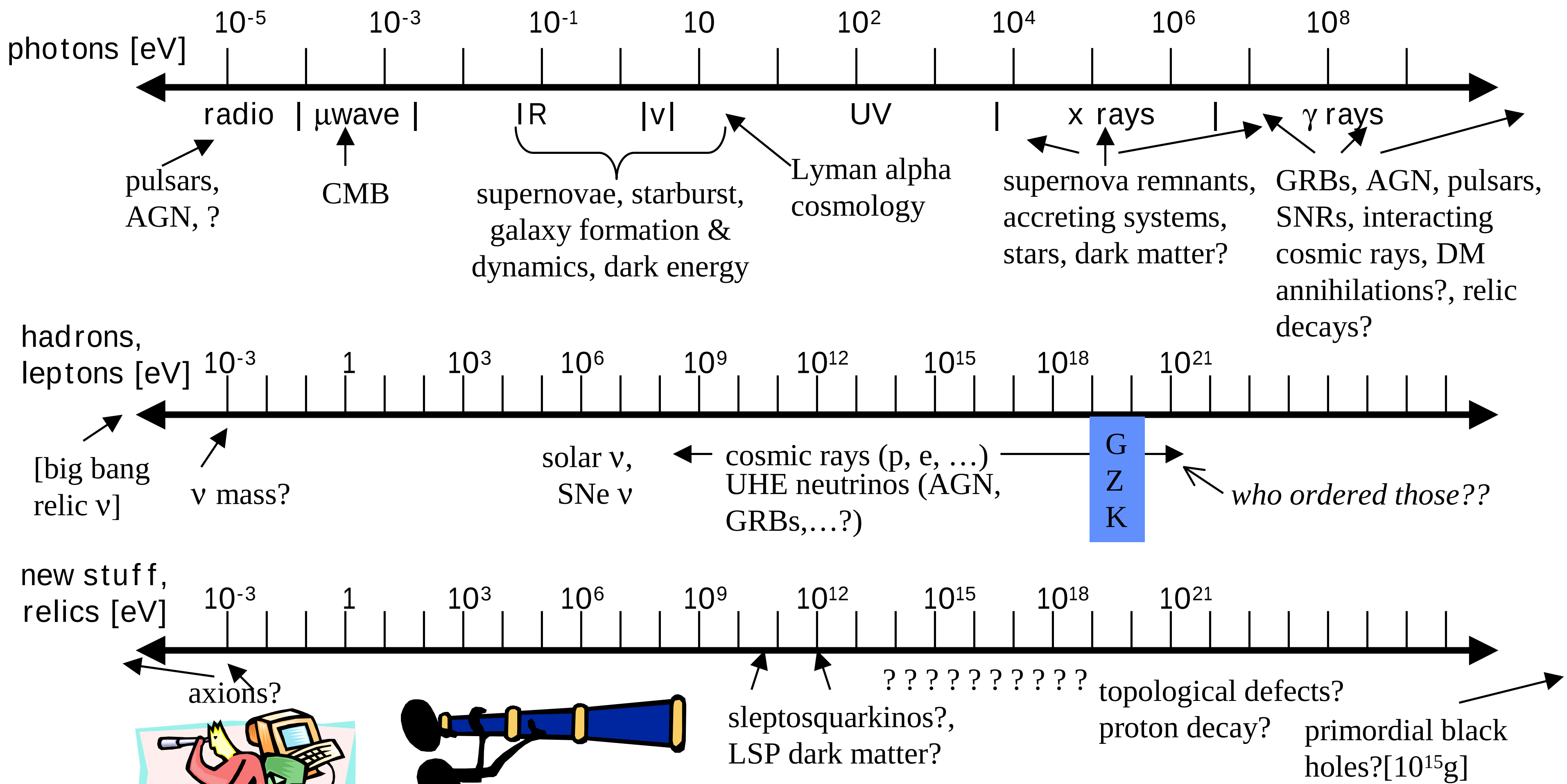
P4: **http://pancake.uchicago.edu/~snowmass2001/**

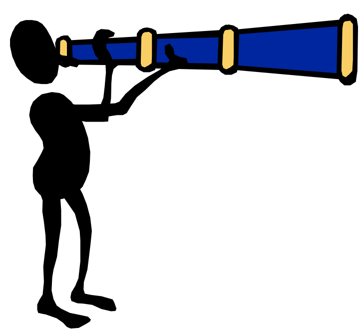
E6: **http://sdss4.physics.lsa.umich.edu:8080/~snowmass2001/**

Note: every P4 meeting starts with two, one-hour general-interest talks, followed by parallel working group sessions.

- **Teach-in: 13 July afternoon:**
  - 30-minute introductory talk
  - 2-hour interactive physics "carnival" with 6 topic stations. Come with questions, listen to discussions.
  - wrap-up panel discussion

Summary: Cosmic Messengers





+ gravitons: massive binary systems, GRBs?, early Universe, … ????

Perspective

- **A wide range of interesting and exciting questions at the interface between Particle Physics and Astrophysics.**
- **Relics offer leaps forward in our ability to explore Nature. Example:**

  At the turn of the 20^{th} century, in less than 15 years the smallest distance scale explored shrank dramatically from 10^{-10} m to 10^{-14} m. The discovery of natural radioactivity, a phenomenon from a much higher energy scale than was otherwise accessible at the time by artificial means, made this possible.

Nature offers us these clues to fundamental physics – we just have to be clever enough to look around for them.