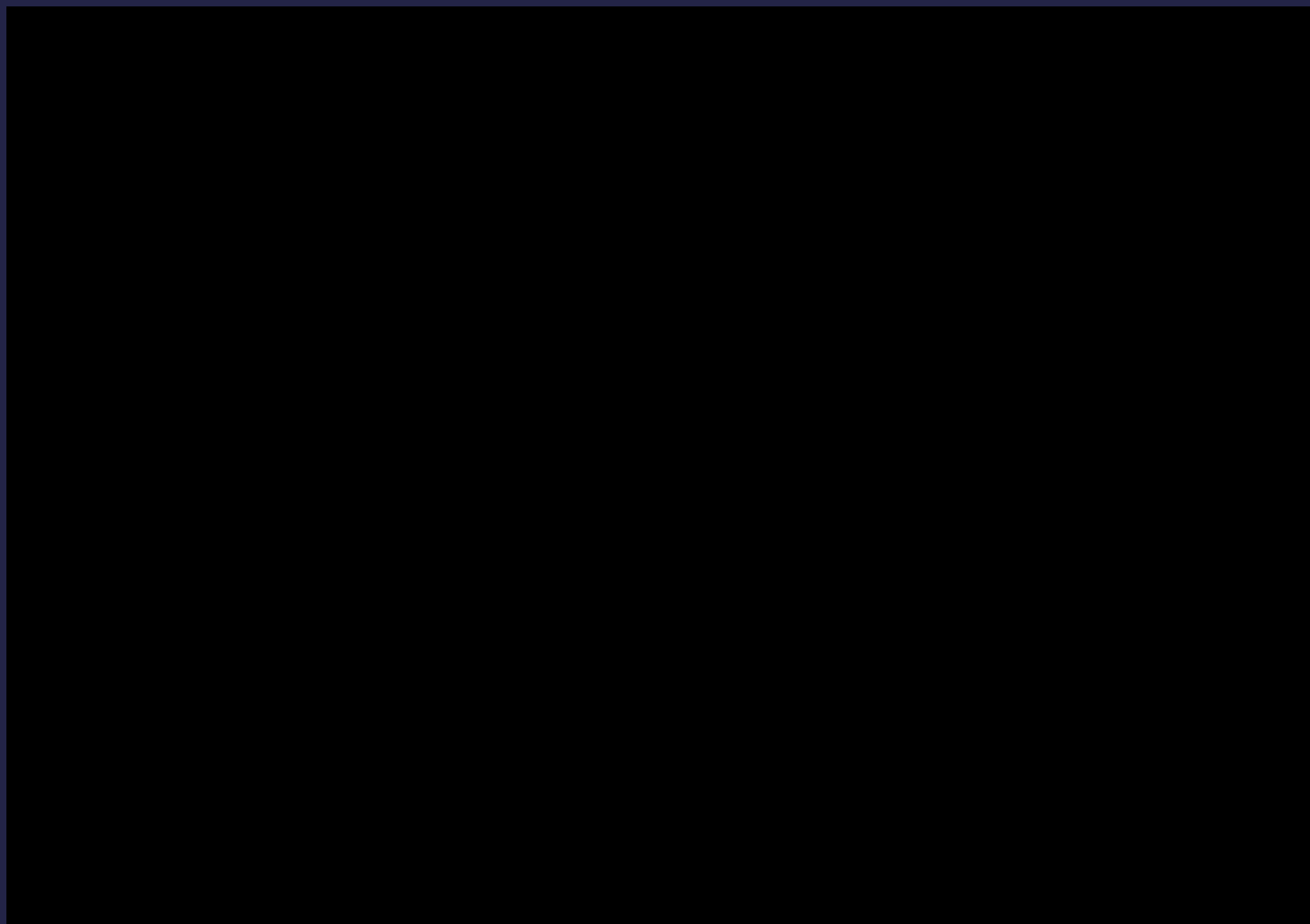


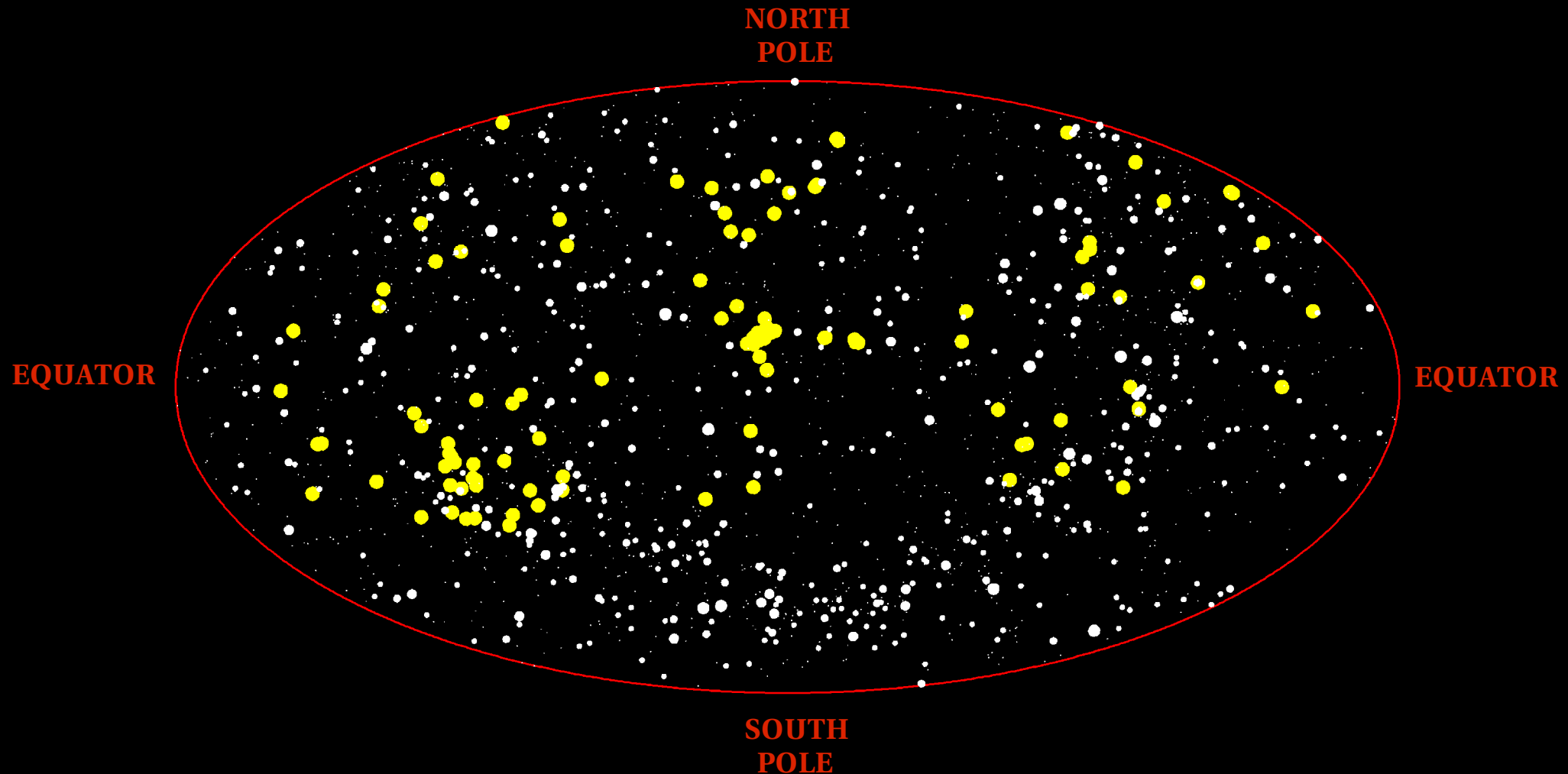


GALAXY SURVEYS

BRYN JONES

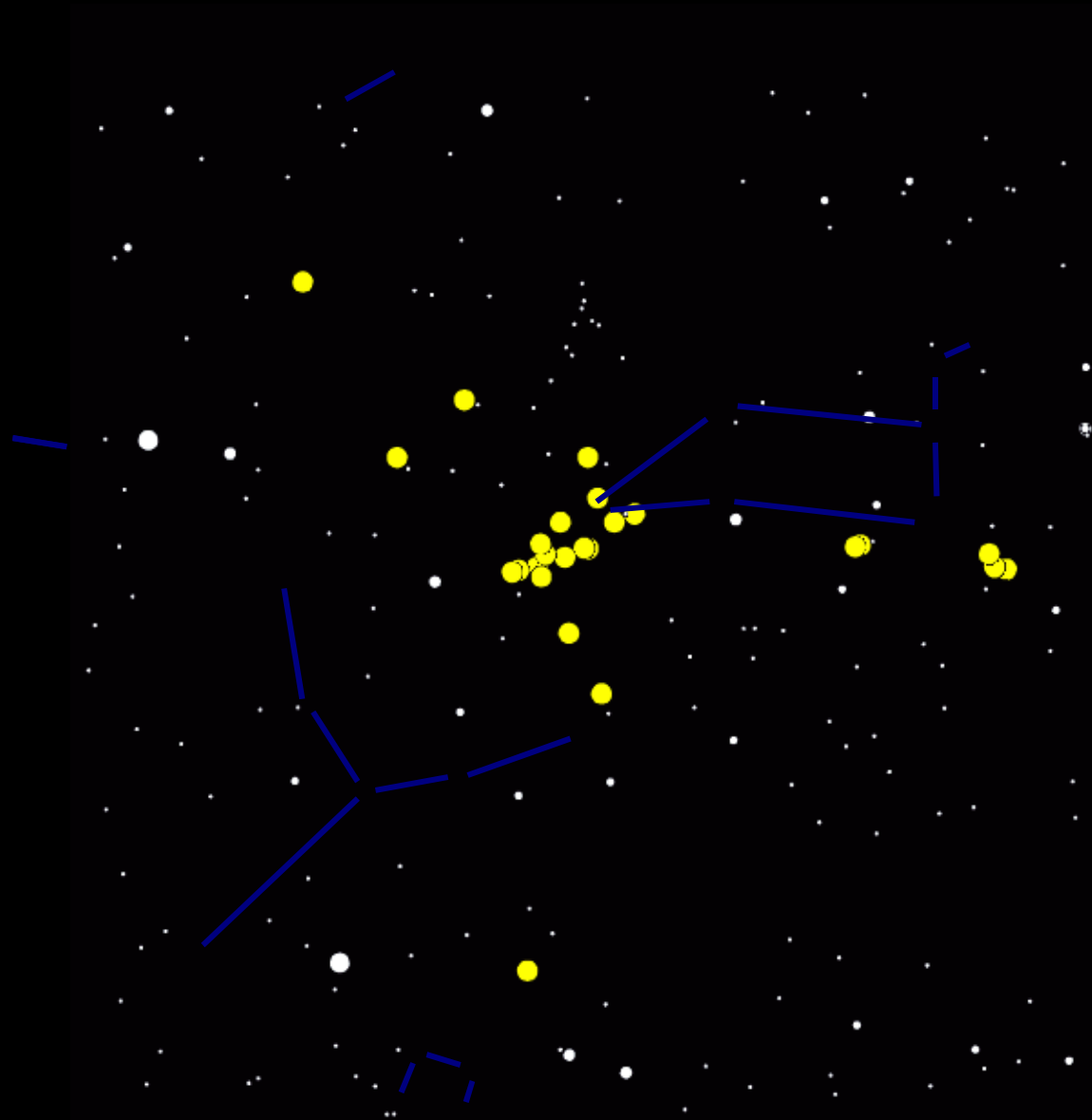
QUEEN MARY, UNIVERSITY OF LONDON

MESSIER OBJECTS ACROSS THE SKY



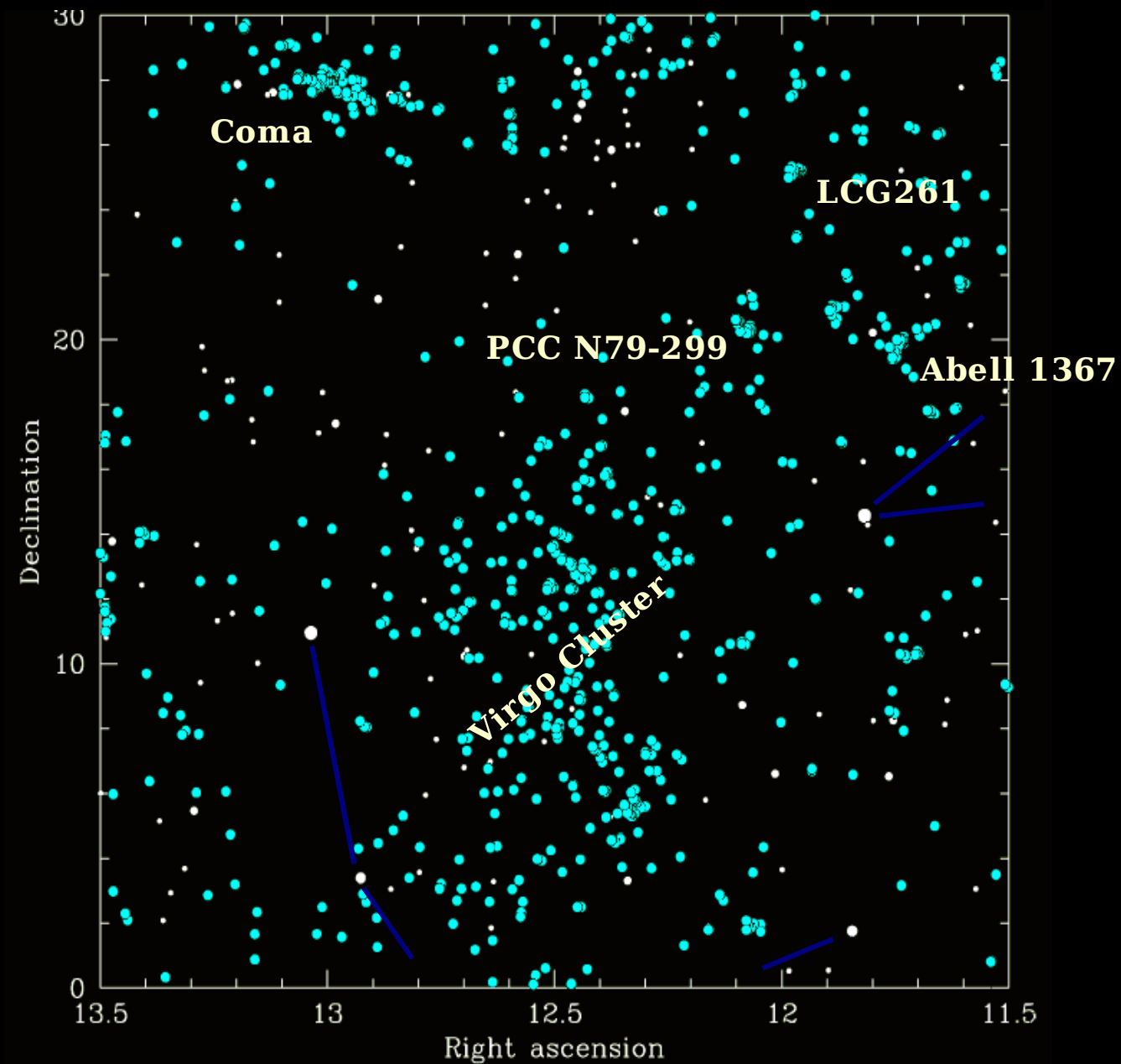
- Nebula / star cluster in Messier's catalogue
- Star

MESSIER OBJECTS IN THE VIRGO-COMA REGION

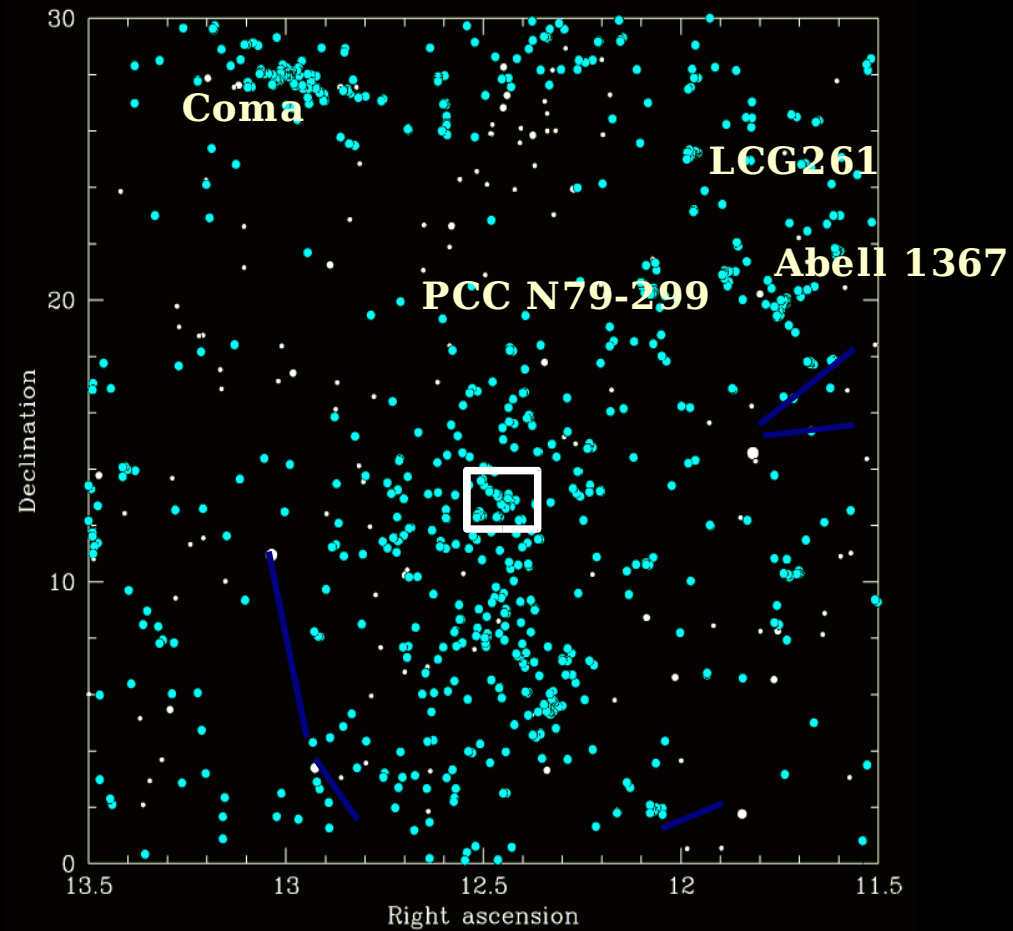


**Include galaxies,
as well as star
clusters and
nebulae in our
own Galaxy**

THE DISTRIBUTION OF NGC OBJECTS IN THE VIRGO REGION



THE DISTRIBUTION OF NGC OBJECTS IN THE VIRGO REGION



Virgo Cluster core



IMAGING SURVEYS

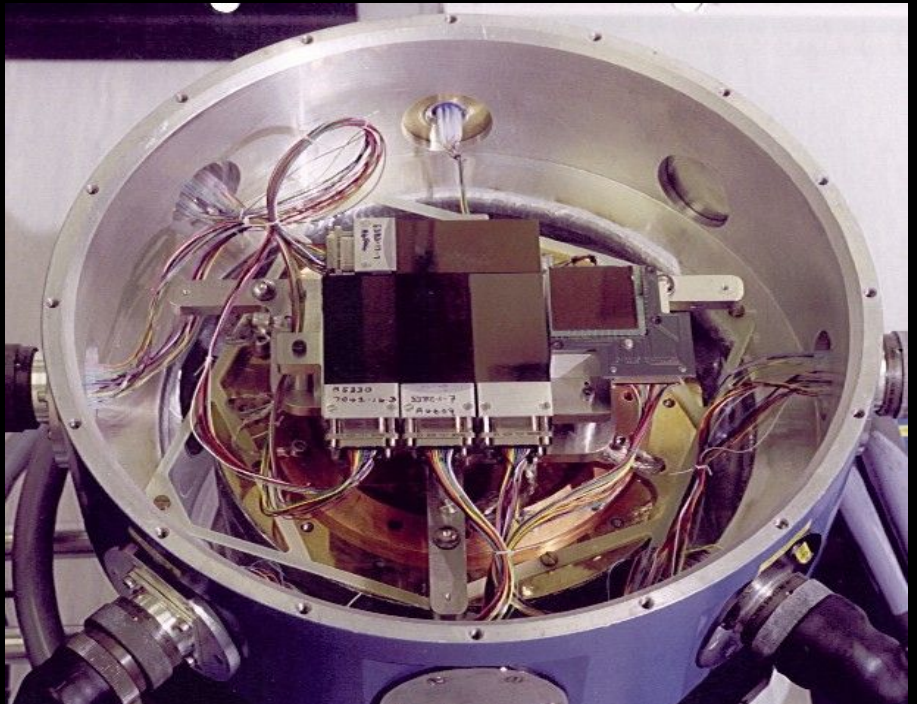
Can perform deep imaging to survey galaxies

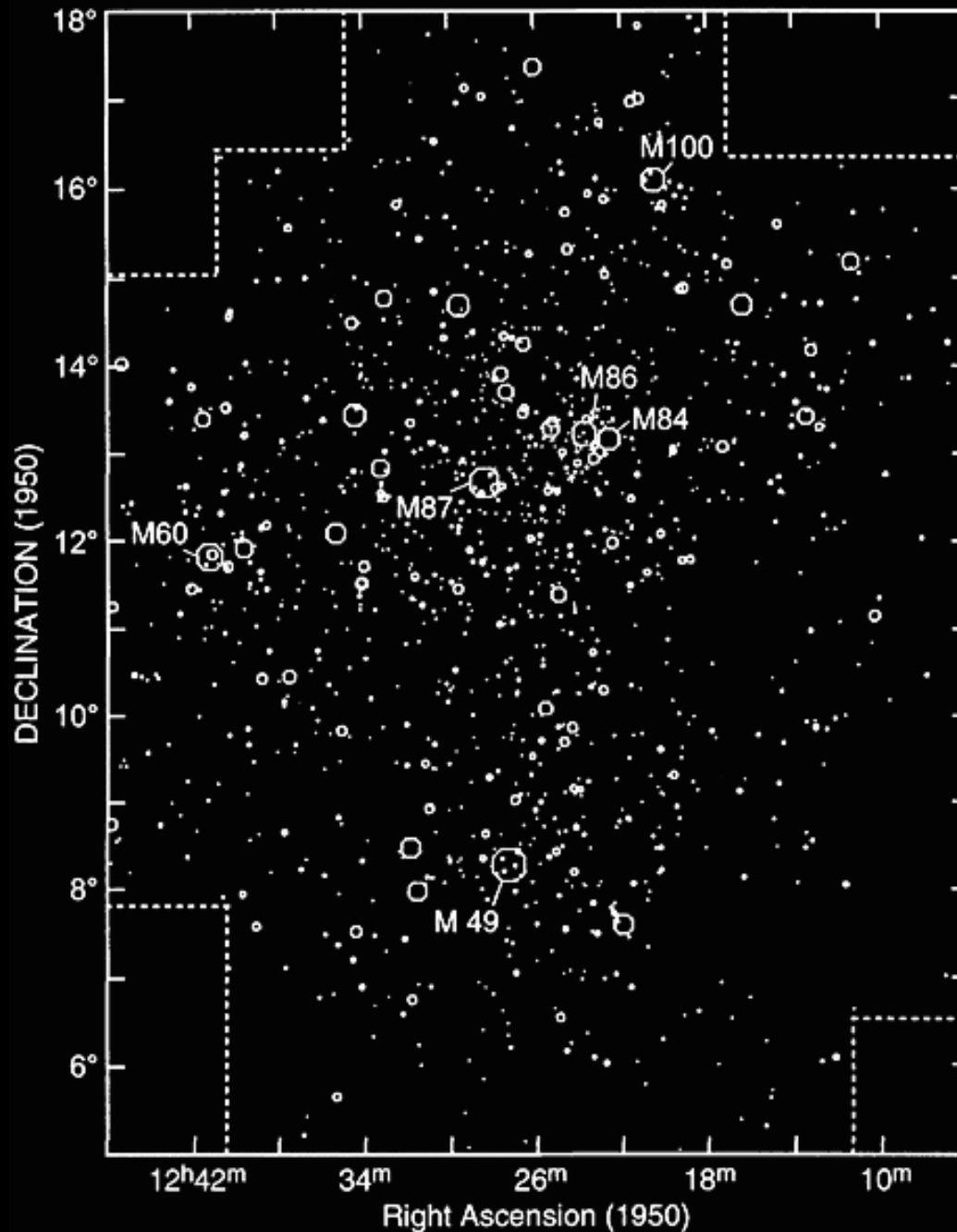
Photography - for wide areas

Electronic detectors (charge-coupled devices, CCDs)

- **for sensitivity, high-resolution, digital output**
- **but relatively small areas**

**CCDs of Wide-Field
Camera on the
Isaac Newton
Telescope, La Palma**





THE VIRGO CLUSTER

**The distribution of
Virgo Cluster galaxies
on the sky**

**Probable Virgo Cluster
members only**

**From the Virgo Cluster
Catalogue by Binggeli,
Sandage & Tammann**

THE VIRGO CLUSTER CATALOGUE: EXTREMES

Images from the Digitised Sky Survey version 2 (blue)

Different intensity ranges are displayed



M87 E0 $B_T=9.6$



NGC 4479 SB0 13.5



VCC1147 dE 20.0

ALL-SKY IMAGING SURVEYS

SCHMIDT TELESCOPES :

**OSCHIN SCHMIDT,
PALOMAR OBSERVATORY**

**48 inch = 1.2 m aperture
very wide-angle: 6 degrees**

**Used glass plates 6 deg x
6 deg**

Completed 1948

**Palomar Schmidt with
Edwin Hubble**



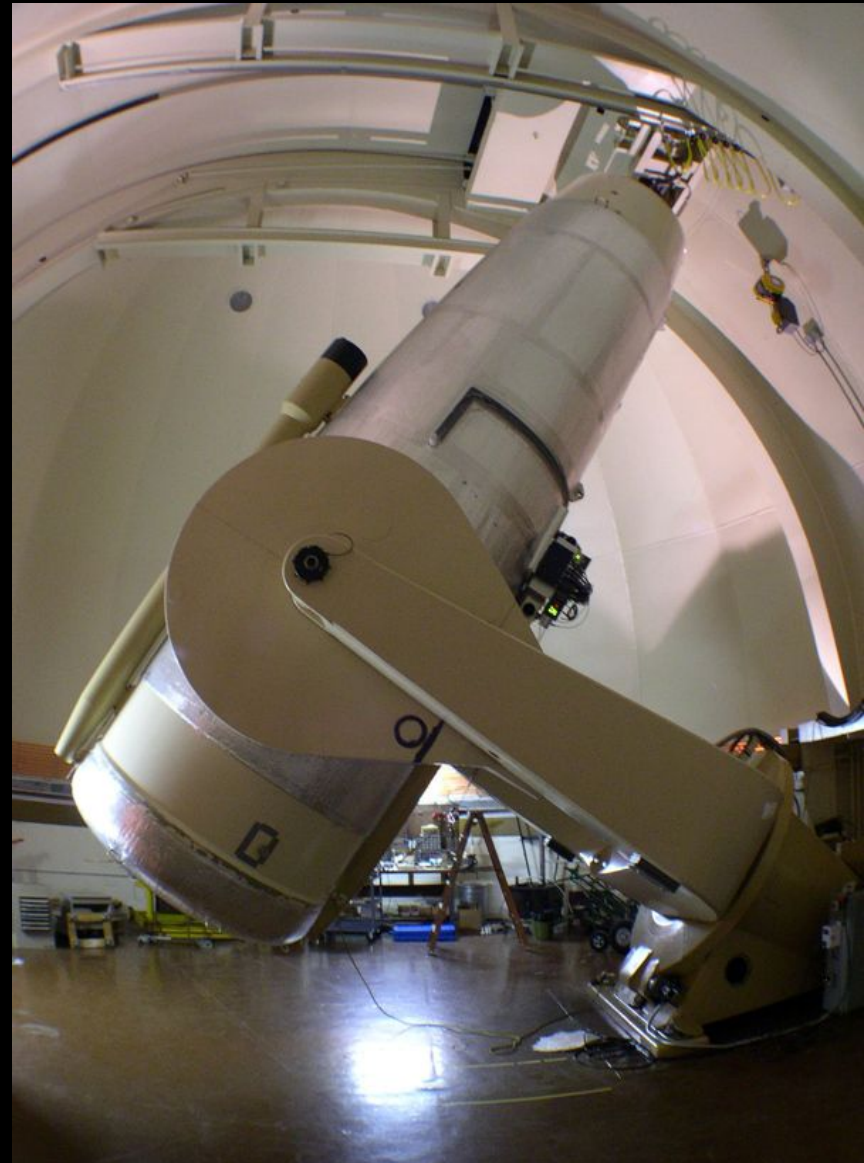
ALL-SKY IMAGING SURVEYS

**SCHMIDT TELESCOPES :
OSCHIN SCHMIDT,
PALOMAR OBSERVATORY**

**Used for the Palomar
Observatory Sky Survey**

**Whole of northern sky
covered**

**Copies made on glass and
film – widely distributed**



ALL-SKY IMAGING SURVEYS



**SCHMIDT TELESCOPES:
UNITED KINGDOM SCHMIDT TELESCOPE**

ALL-SKY IMAGING SURVEYS

SCHMIDT TELESCOPES :

United Kingdom Schmidt Telescope

1.2 metre (48 inch) aperture (1.8 metre diameter mirror)

Siding Spring, Australia

In operation 1973 - present

European Southern Observatory Schmidt Telescope

1.0 metre aperture

La Silla, Chile

In operation 1973-1998

Surveyed the whole of the southern skies in the 1970s and 1980s

ALL-SKY IMAGING SURVEYS

Schmidt survey data used for almost every field in astronomy

From Solar System to stars, to the Galaxy, to other galaxies, to galaxy clusters, to cosmology

Galaxies - historically by inspecting plates by eye

- Local Group galaxies e.g. dwarf spheroidals**
- catalogues of bright galaxies**
- identifying samples of galaxies of various types**
- clusters of galaxies - Abell clusters**

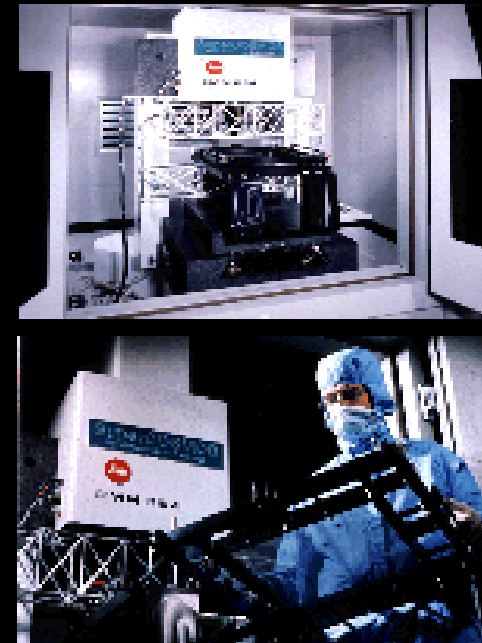
ALL-SKY IMAGING SURVEYS

Preferable to use digitised data

Scan plates and films in a plate measuring machine



**Automated Plate Measuring
Machine, Cambridge**



**SuperCOSMOS
Machine,
Edinburgh**

ALL-SKY IMAGING SURVEYS

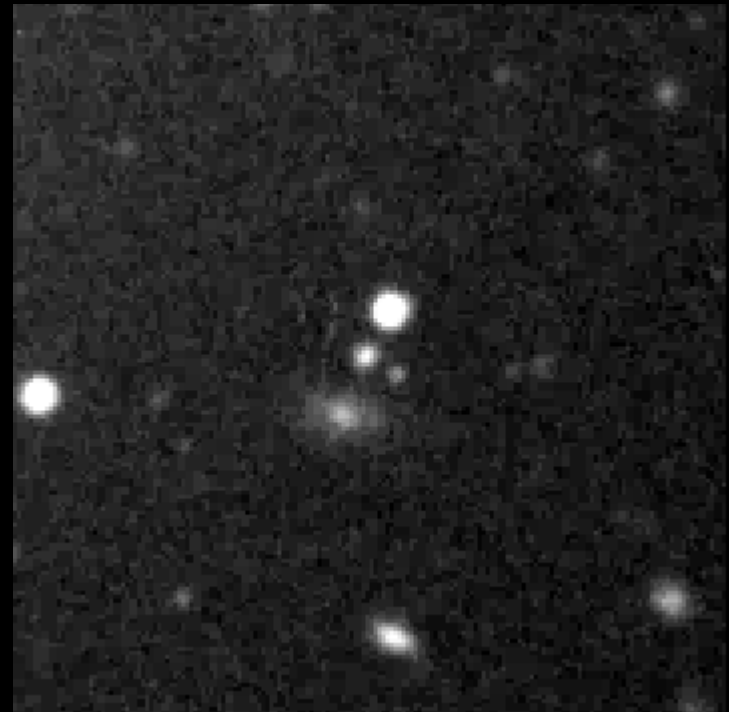
Digitised data very useful

Brightnesses, sizes, shapes, positions, colours

**Can generate catalogues of objects over the whole sky
down to faint limits**

**Can study these data directly,
or use them to locate
targets for more detailed
observations on large
telescopes**

**SuperCOSMOS Sky
Survey image, blue,
2 arcmin square**



DIGITISED SKY SURVEYS (Schmidt Telescope Data)

NASA STScI Digitized Sky Survey

STScI CD-ROM set

On-line versions:

STScI <http://archive.stsci.edu/dss/>

SkyView (GSFC)

<http://skyview.gsfc.nasa.gov/>

Leicester

<http://ledas-www.star.le.ac.uk/DSSimage>

European Southern Observatory

<http://archive.eso.org/dss/dss>

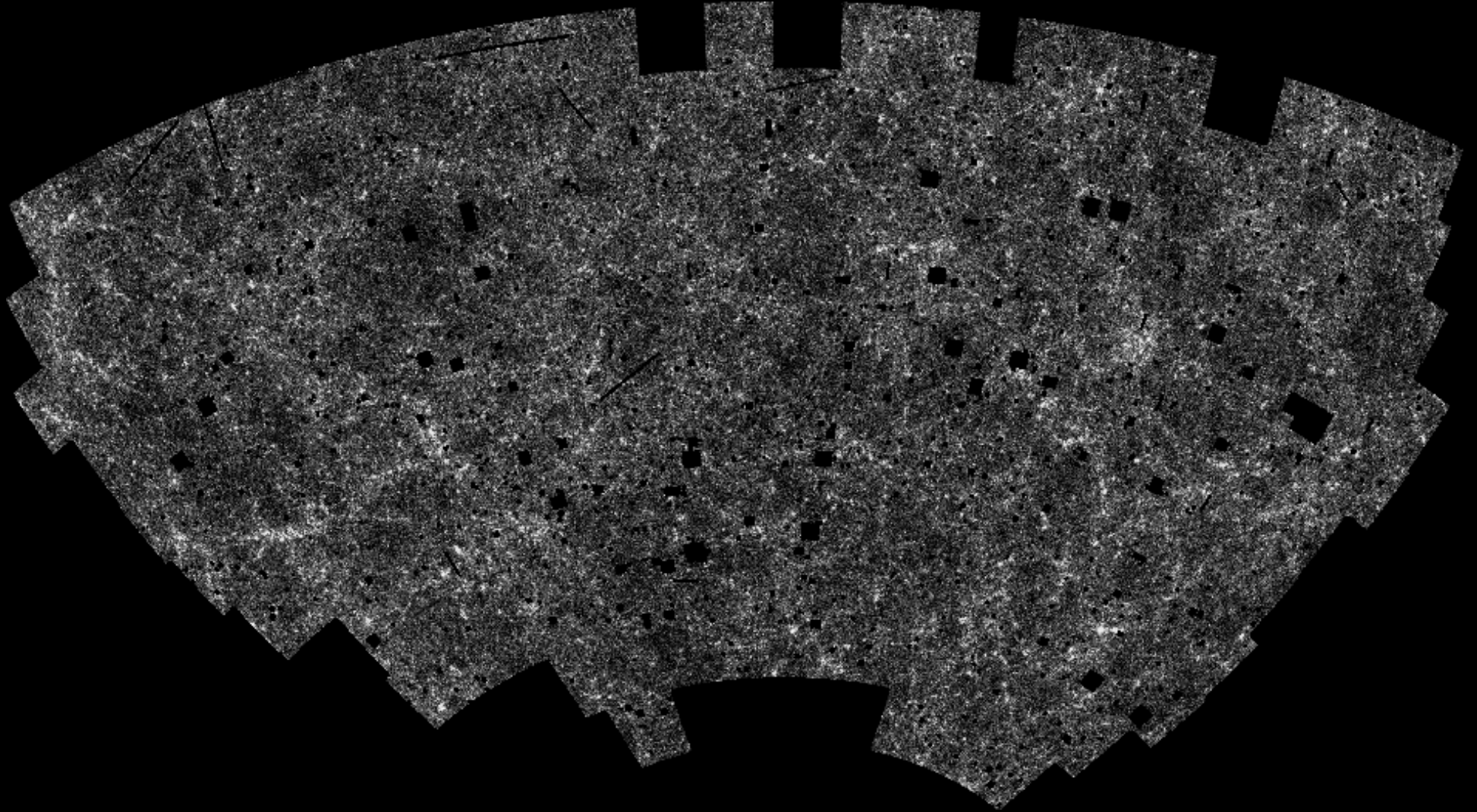
SuperCOSMOS Sky Survey

Southern sky only at present

On-line version:

Edinburgh <http://www-wfau.roe.ac.uk/sss>

APM GALAXY SURVEY



3 milion galaxies over southern sky from UKST plates

2MASS INFRARED ALL-SKY SURVEY



**2MASS telescope
Mount Hopkins, Arizona**



**2MASS telescope
Cerro Tololo, Chile**

**Digital survey in near-infrared at $2\ \mu\text{m}$
1.3 metre telescopes**

2MASS INFRARED ALL-SKY SURVEY

Hickson Compact Group 40



Two Micron All Sky Survey
– Southern Facility –
2MASS Atlas Image Mosaic

Infrared Processing and Analysis Center & University of Massachusetts

Galaxy near the Galactic Plane
 $(l^{\text{II}} = 53^{\circ}53 \quad b^{\text{II}} = 4^{\circ}1)$



Two Micron All Sky Survey
– Northern Facility –
2MASS Atlas Image

Infrared Processing and Analysis Center & University of Massachusetts

2MASS INFRARED ALL-SKY SURVEY

The Antennae: NGC 4038/9



Two Micron All Sky Survey
– Southern Facility –
2MASS Atlas Image Mosaic

Infrared Processing and Analysis Center/Caltech & University of Massachusetts

© Anglo-Australian Observatory



**The Antennae: 2MASS infrared
and Anglo-Australian Telescope
optical**

IRAS MID-INFRARED SURVEY



Infrared Astronomy Satellite

Operated in 1983

Surveyed the whole sky

**Found many galaxies with
active star formation**

e.g. starbursting galaxies

IMAGING SURVEYS ARE ALL VERY WELL BUT ...

Imaging alone does not in general provide distances

Imaging surveys are essentially two dimensional

We need distance information

DISTANCES TO GALAXIES

Can get distances for nearby galaxies if we can resolve stars

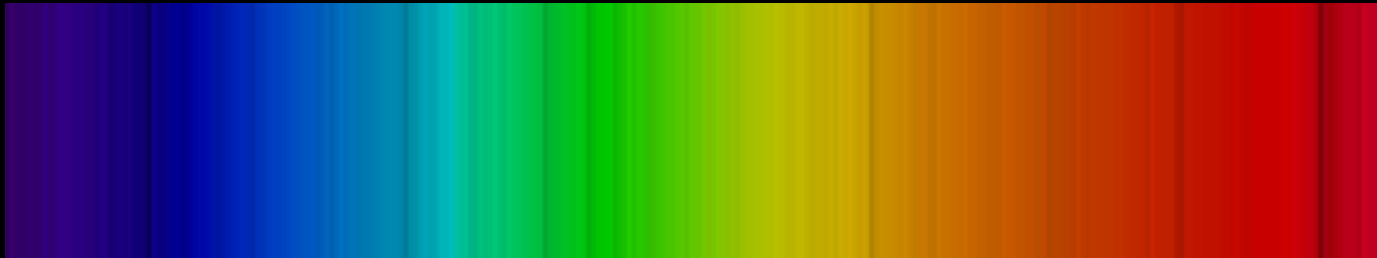
Can get distances for other galaxies with some dedicated observations

**e.g. motions of stars in galaxies correlate with
luminosity**

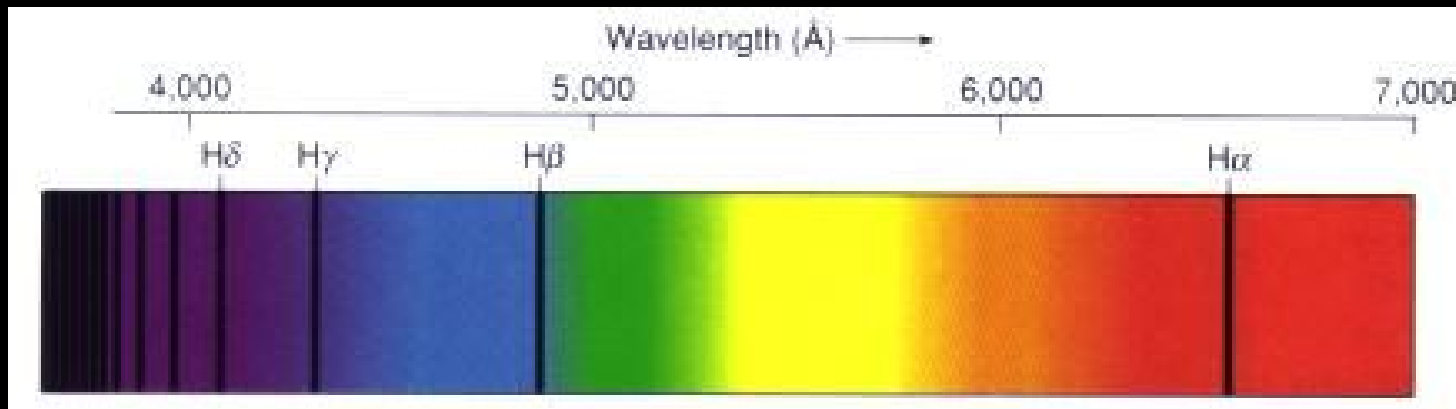
supernovae ... if we're lucky

**But the expansion of the Universe provides a quick,
simple method to measure distances for large
numbers of galaxies**

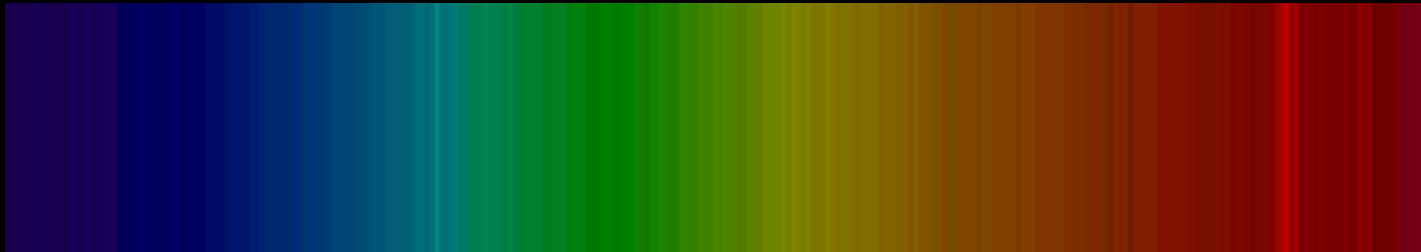
THE SOLAR SPECTRUM



HYDROGEN ABSORPTION SPECTRUM



A GALAXY SPECTRUM

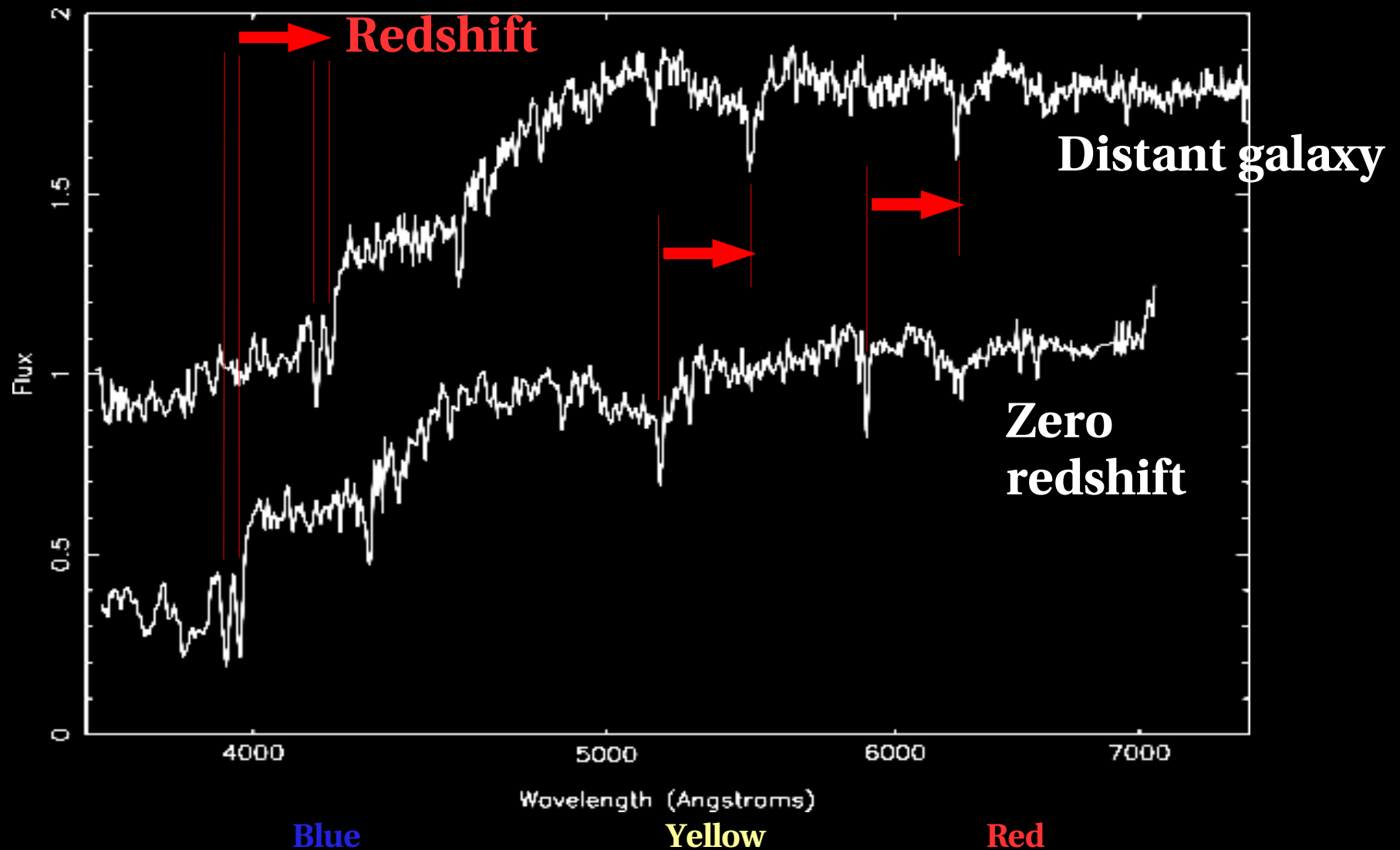


(SPIRAL GALAXY)

Absorption lines in the light of stars
Emission lines from interstellar gas in spiral and irregular galaxies

REDSHIFT AND A GALAXY SPECTRUM

Spectrum of an early-type galaxy at zero redshift and a similar galaxy at $z = 0.058$ (17000 km/s)



INTERPRETING REDSHIFT AS A VELOCITY

Define redshift as

$$z \equiv \frac{\Delta\lambda}{\lambda_0} \equiv \frac{\lambda - \lambda_0}{\lambda_0}$$

where λ is the observed wavelength of a spectral line, and λ_0 is its rest (laboratory) wavelength

We can interpret the redshift as a recessional velocity v so that

$$z = \frac{v}{c}$$

for the non-relativistic case ($v \ll c$)

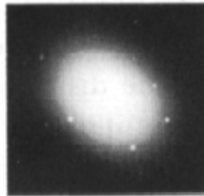
Redshift can be regarded as being caused by the stretching of space with the expansion of the Universe

RELATION BETWEEN RED-SHIFT AND DISTANCE FOR EXTRAGALACTIC NEBULAE

CLUSTER
GALAXY IN

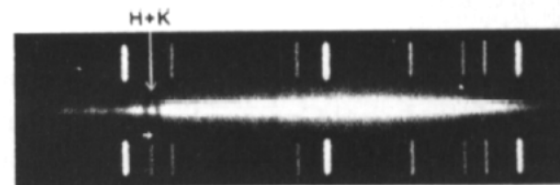
DISTANCE IN
LIGHT-YEARS

RED-SHIFTS



VIRGO

43,000,000

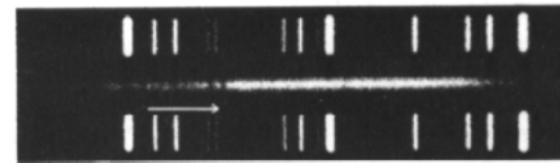


1,200 KM SEC-1

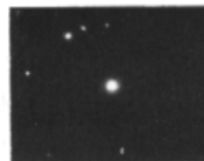


URSA MAJOR

560,000,000

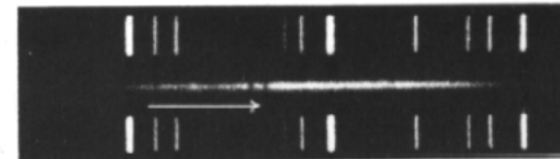


15,000 KM SEC-1

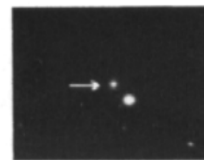


CORONA BOREALIS

728,000,000

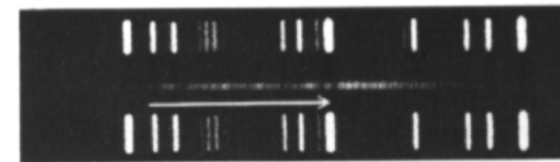


21,600 KM SEC-1

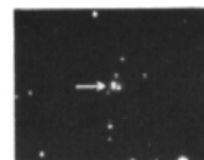


BOOTES

1,290,000,000

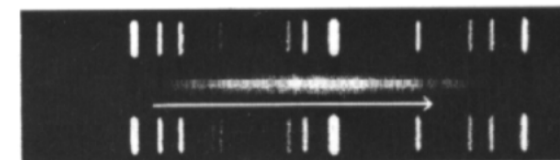


39,300 KM SEC-1



HYDRA

1,960,000,000

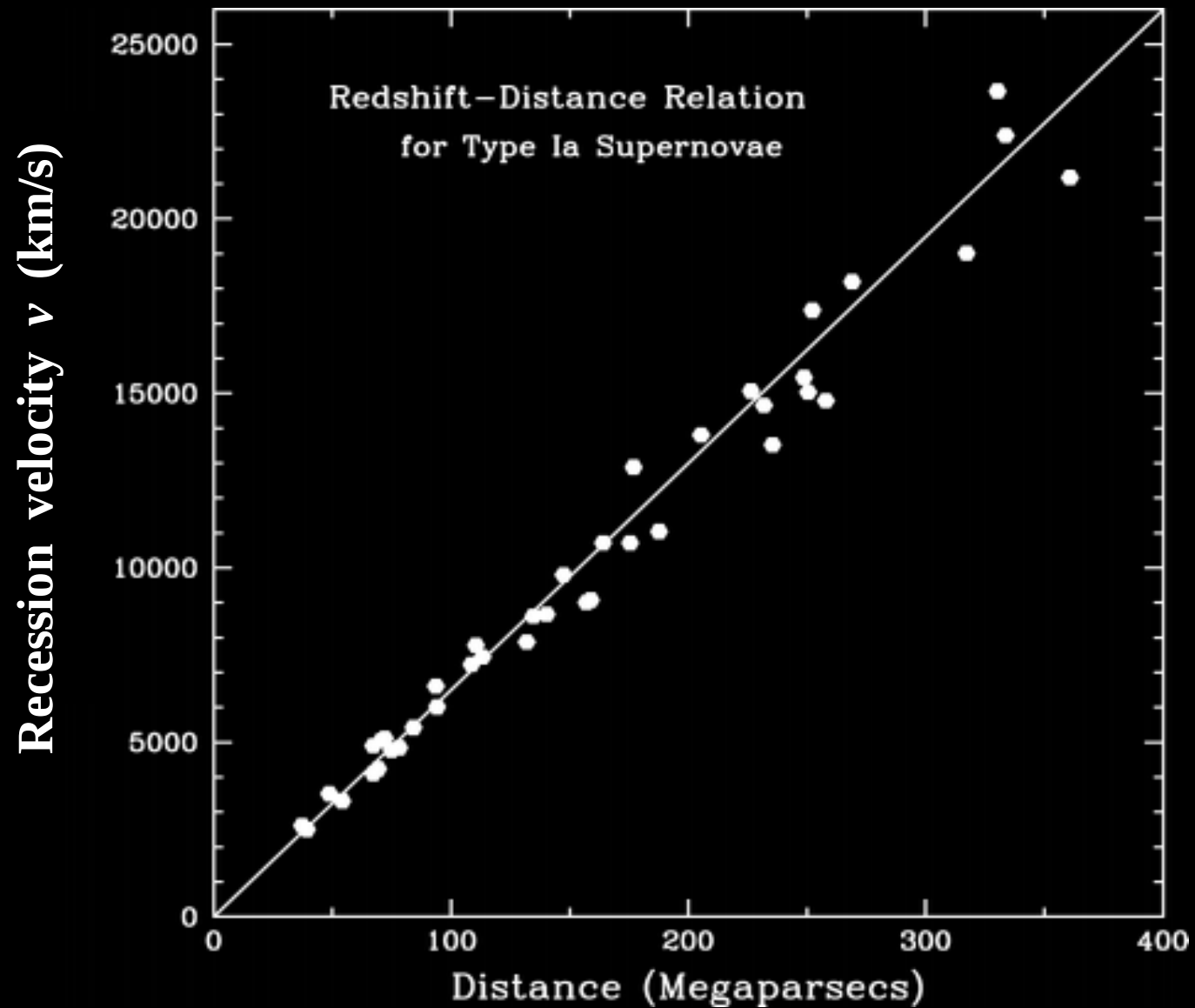


61,000 KM SEC-1

**Hale
Observatories
diagram**

HUBBLE DIAGRAM

FOR TYPE Ia SUPERNOVAE



HUBBLE LAW

Recession velocity v is related to the distance D by

$$v = H_0 D$$

where H_0 is a constant

(at least for all but very large distances)

H_0 is known as the Hubble Constant

$$\begin{aligned} H_0 &= 72 \pm 8 \text{ km s}^{-1} \text{ Mpc}^{-1} \\ &= 22 \pm 3 \text{ km s}^{-1} \text{ Mly}^{-1} \end{aligned}$$

So

$$c z = H_0 D$$

REDSHIFT SURVEYS

If the spectra of samples of galaxies can be measured



redshifts



distances

Combine distances with galaxies' positions on the sky



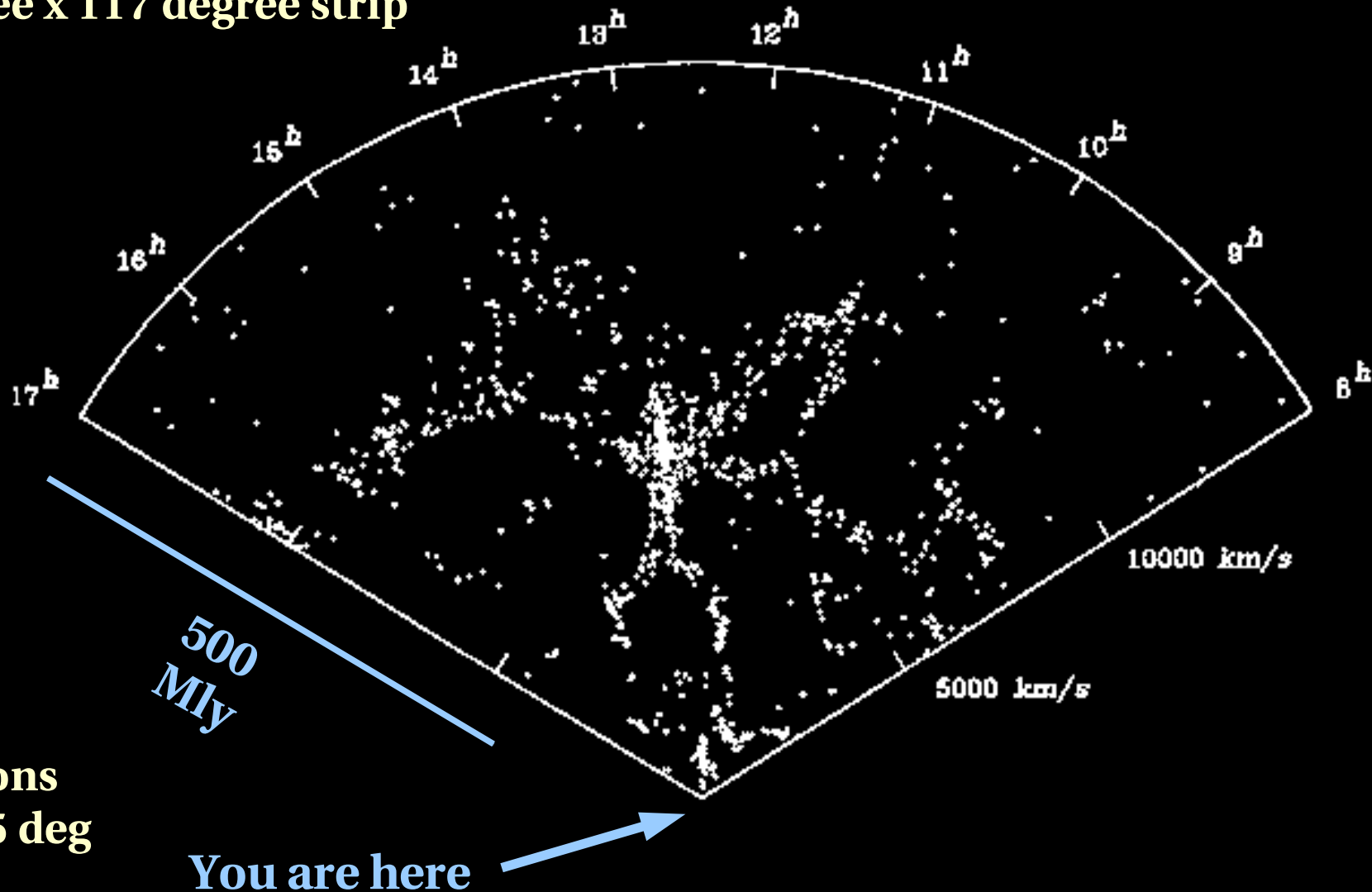
3-dimensional map

DE LAPPARENT, GELLER HUCHRA (1986) REDSHIFT SURVEY

Harvard-Smithsonian Center for Astrophysics

1100 galaxies to blue magnitude of 15.5

In a 6 degree x 117 degree strip

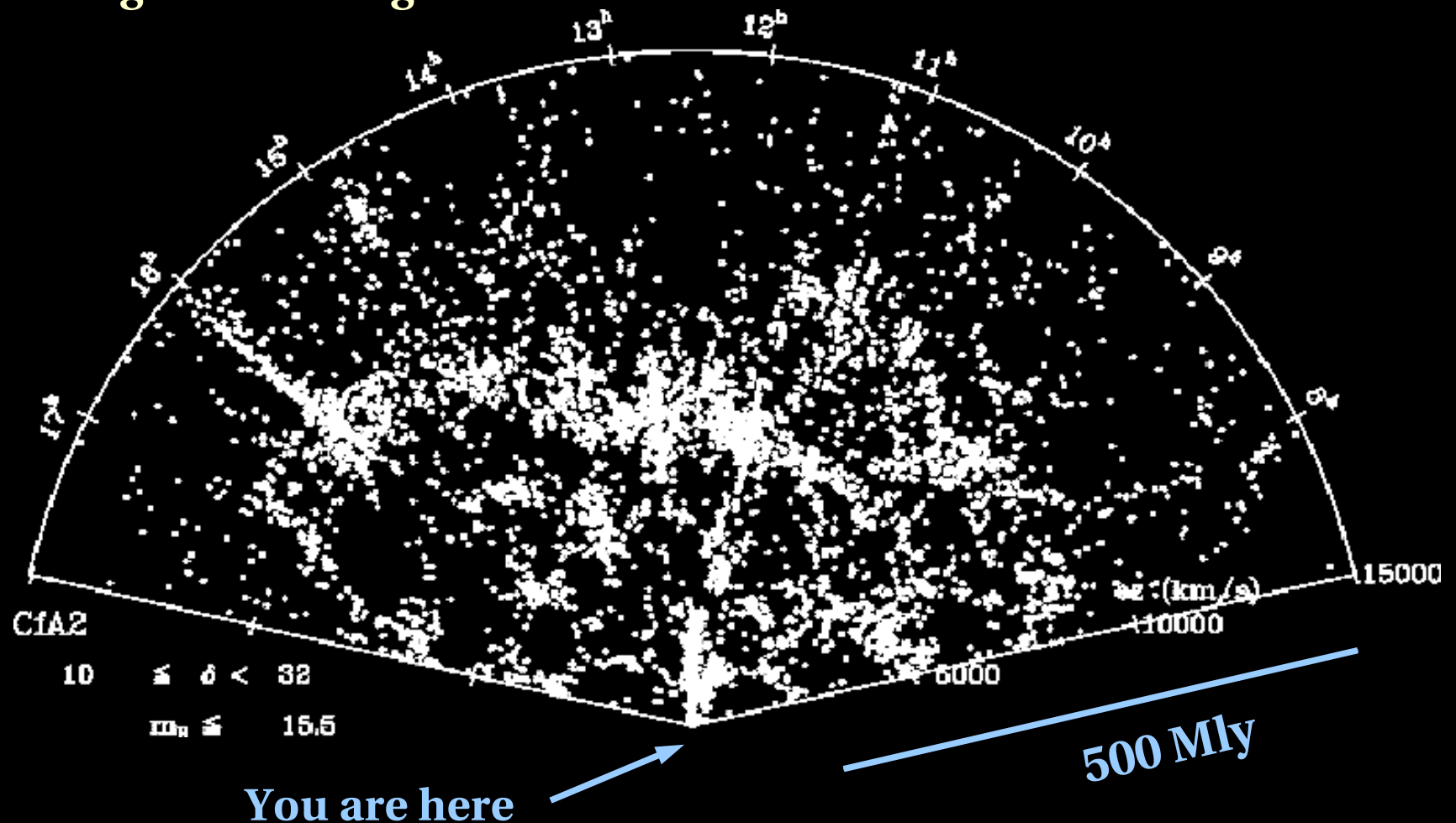


Declinations
27.5 to 32.5 deg

CENTER FOR ASTROPHYSICS SECOND REDSHIFT SURVEY CfA2

Harvard-Smithsonian Center for Astrophysics
5600 galaxies to blue magnitude of 15.5
In a 22 degree x 165 degree slice

Declinations
10 to 32 deg



LOCAL VELOCITIES

The Hubble Law $v = H_0 D$ applies to the velocities v imposed by the expansion of the Universe

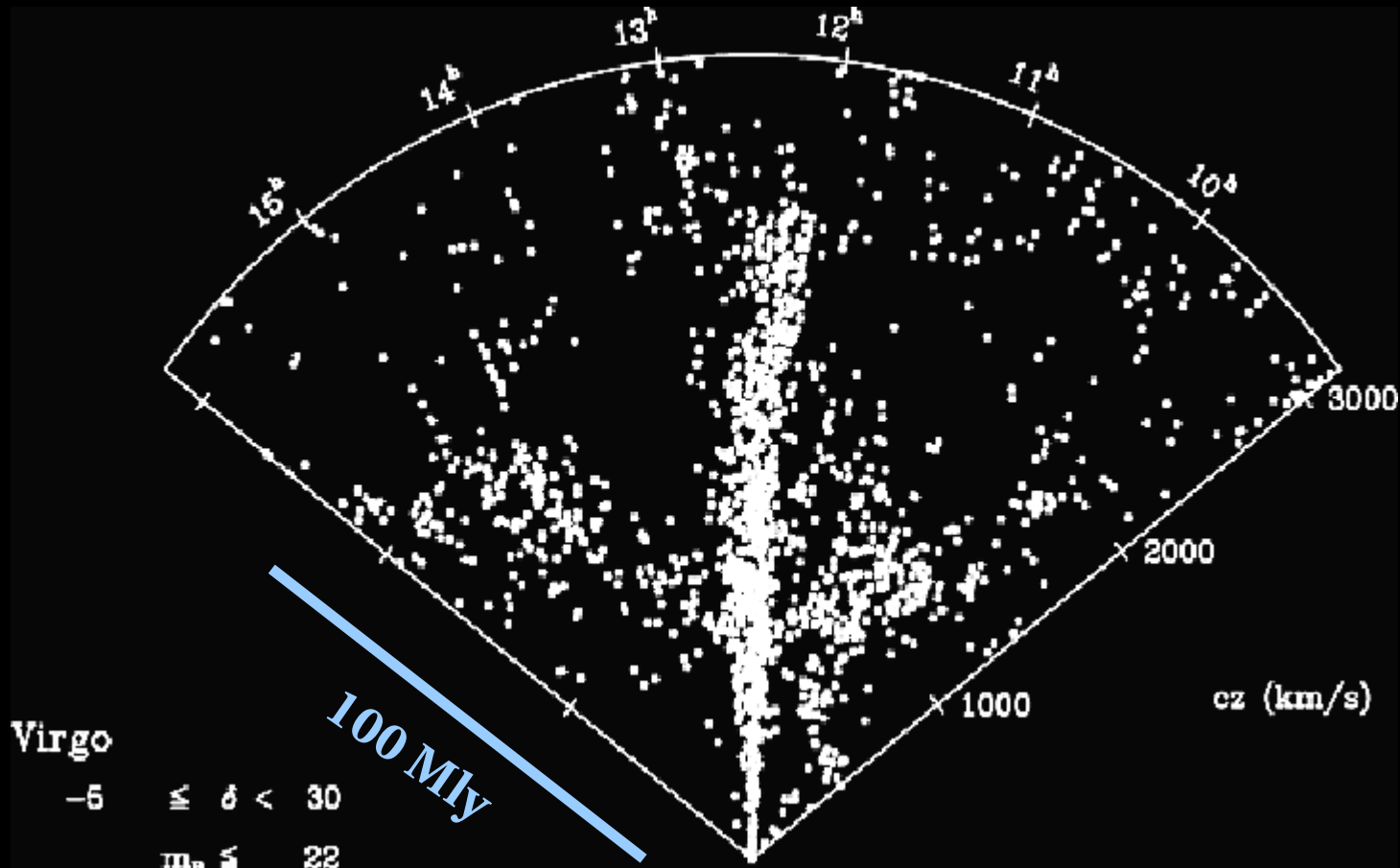
In practice there will be local radial velocities v_{pec} on top of this

So
$$v + v_{pec} = H_0 D$$

Therefore using $D = cz / H_0$ to calculate the distance will have an error

THE VIRGO CLUSTER

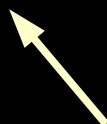
Radial velocity and redshift diagram for the Virgo Cluster
using published velocity data



Declinations -5 to +30 deg
Blue magnitudes 22 and brighter

The Milky
Way Galaxy

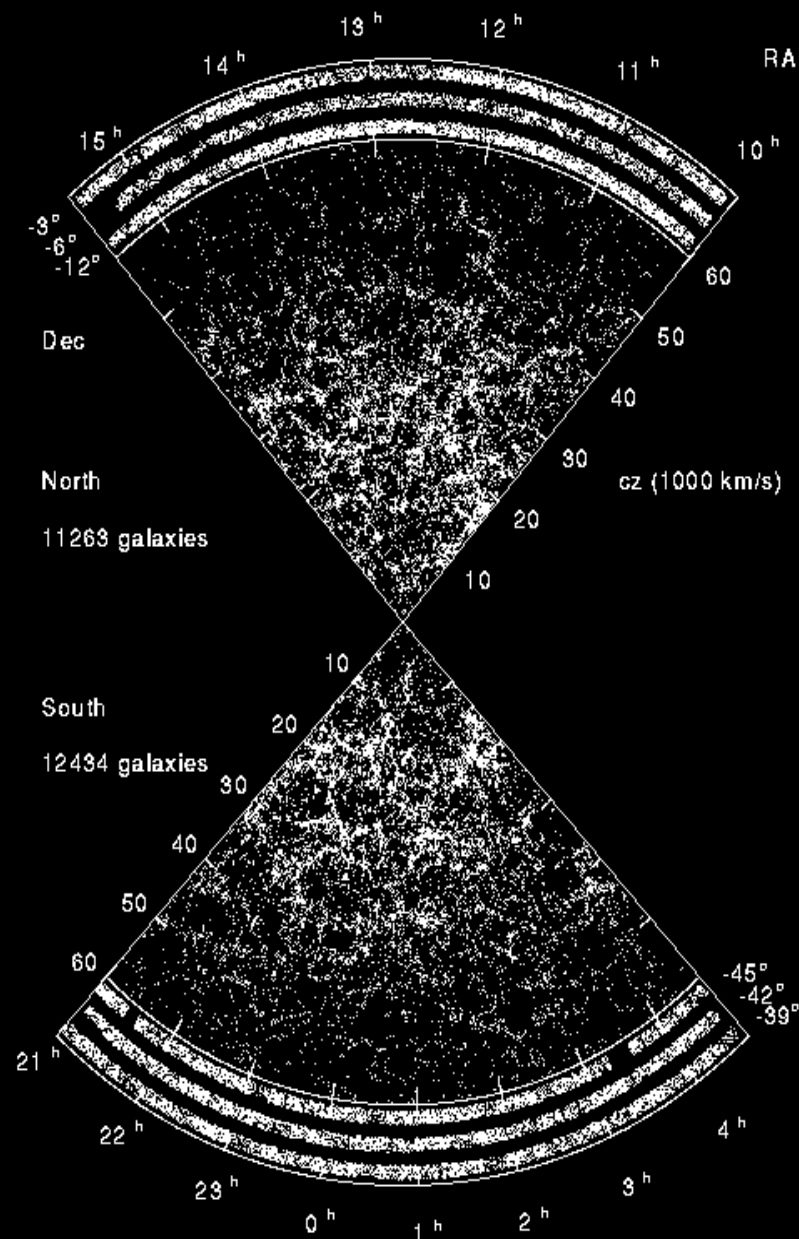
LAS CAMPANAS REDSHIFT SURVEY



**2.5m du Pont
telescope at
Las Campanas,
Chile**

**Fibre-fed
spectroscopy**

26418 galaxies



REDSHIFT SURVEYS OF IRAS INFRARED GALAXIES

QDOT

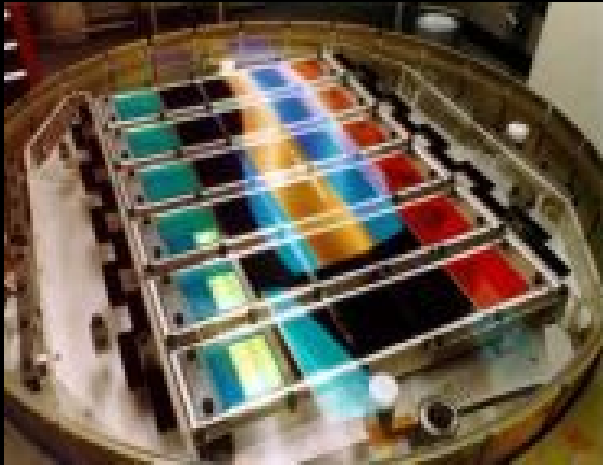
PSCz

SLOAN DIGITAL SKY SURVEY

**Dedicated 2.5m telescope
Apache Point Observatory, New Mexico**



SLOAN DIGITAL SKY SURVEY



Imaging survey
5 different filters
drift scan



Spectroscopic survey
Two fibre-fed
spectrographs

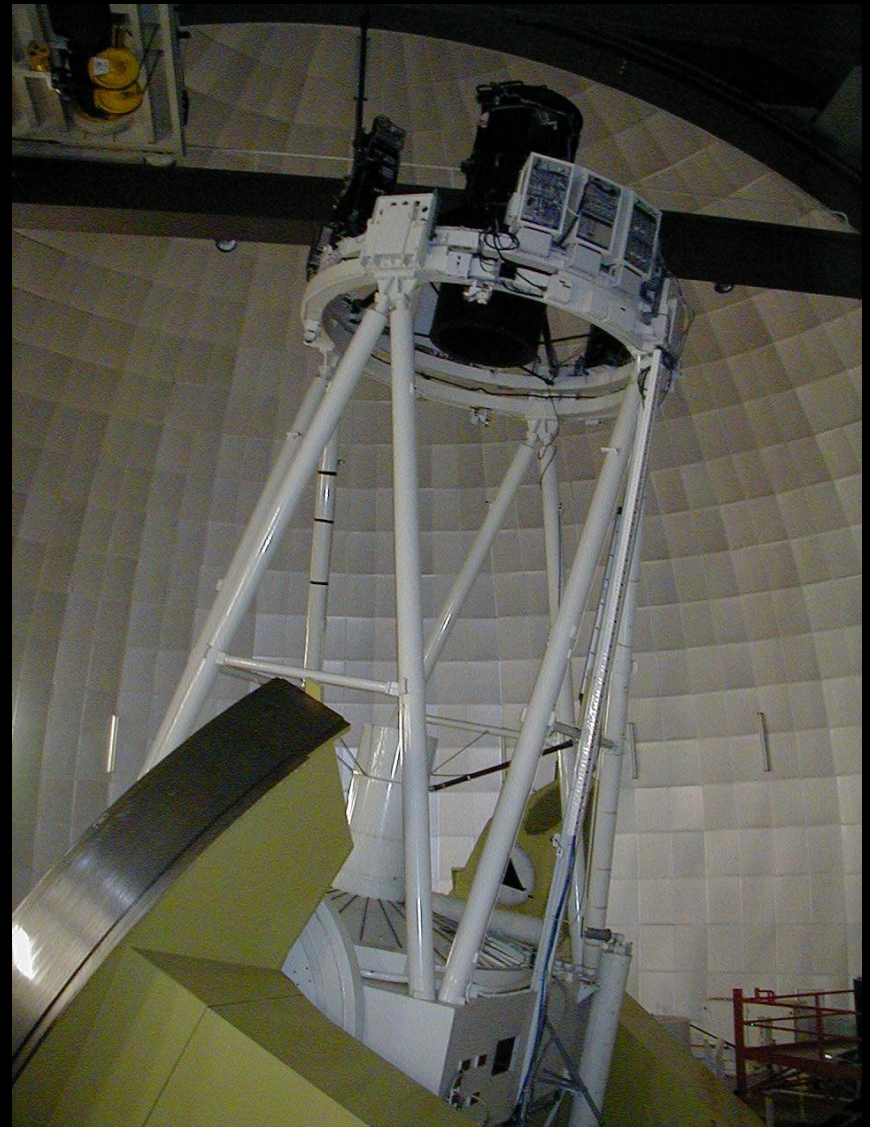
SLOAN DIGITAL SKY SURVEY

**Measuring redshifts for
1 000 000 galaxies
100 000 quasars**

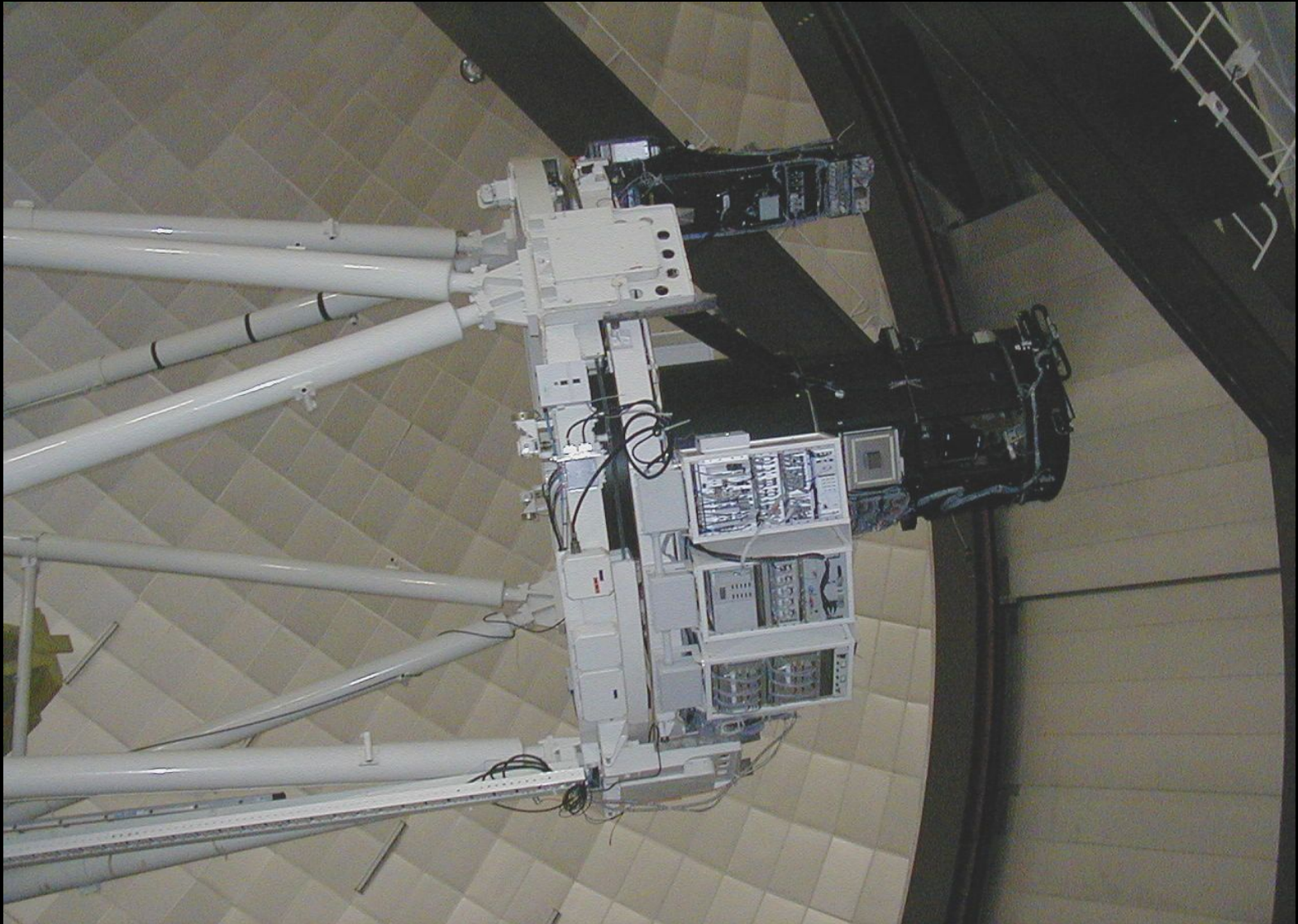
640 optical fibres

Imaging survey over nearly 25% of sky

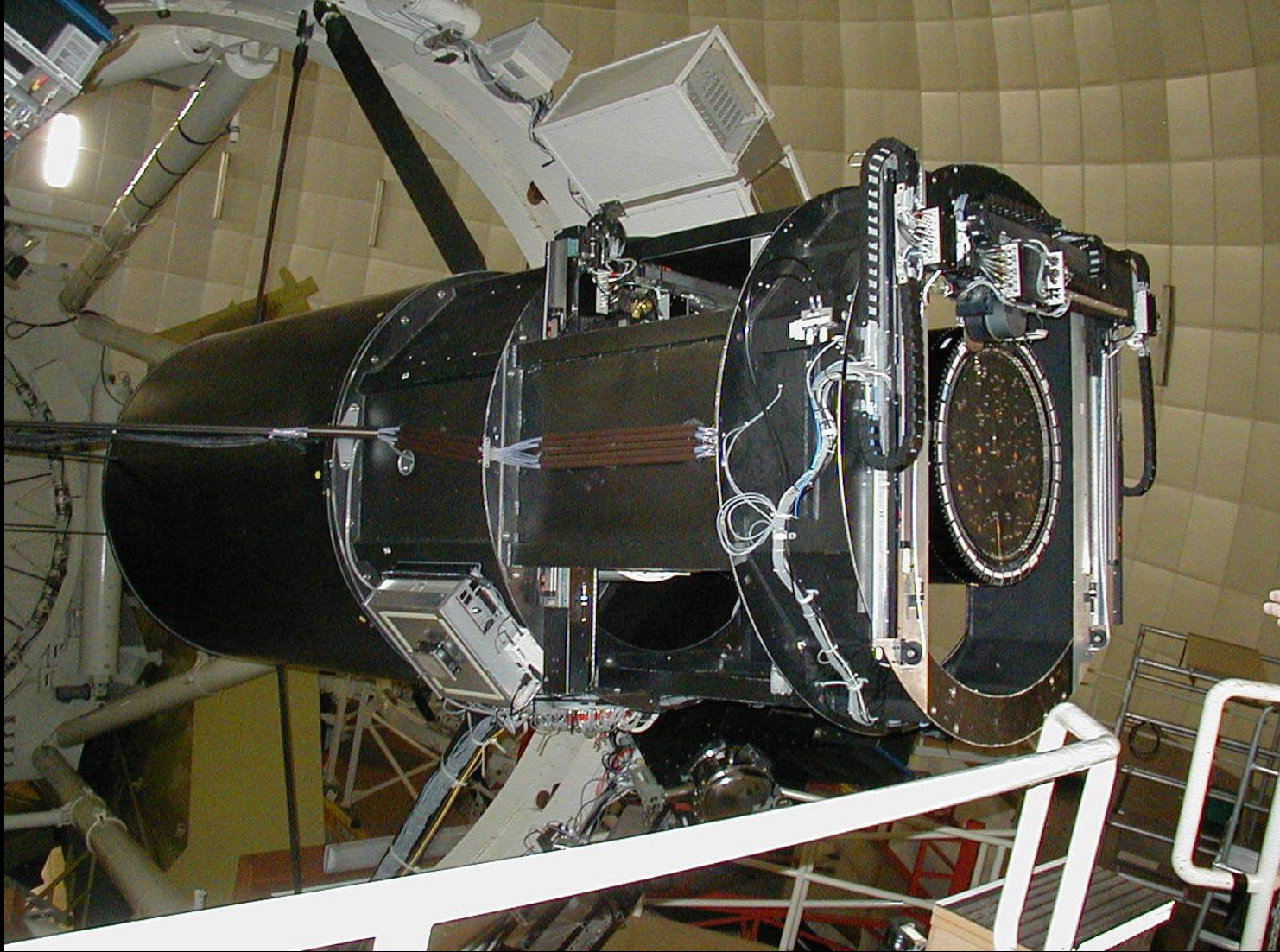
THE ANGLO-AUSTRALIAN TELESCOPE



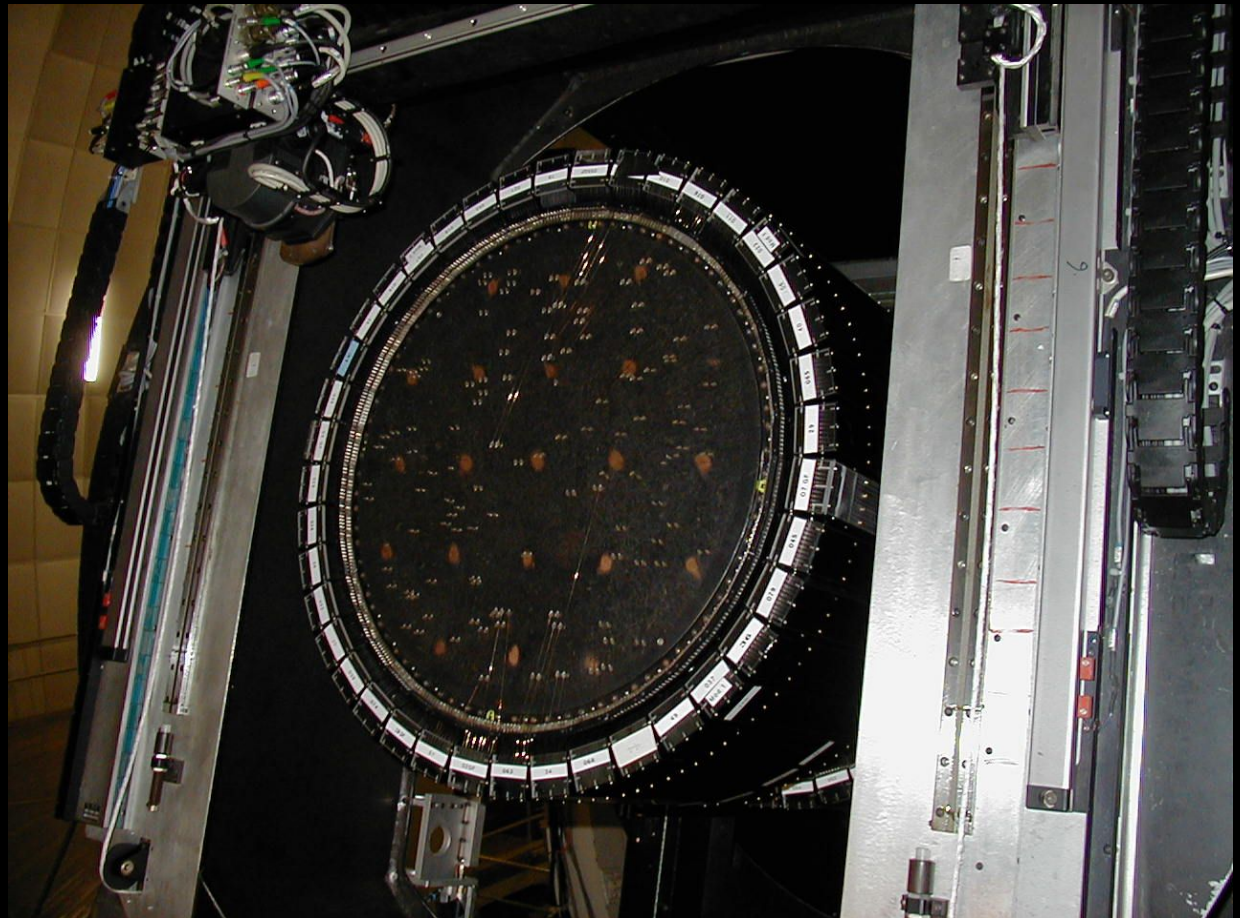
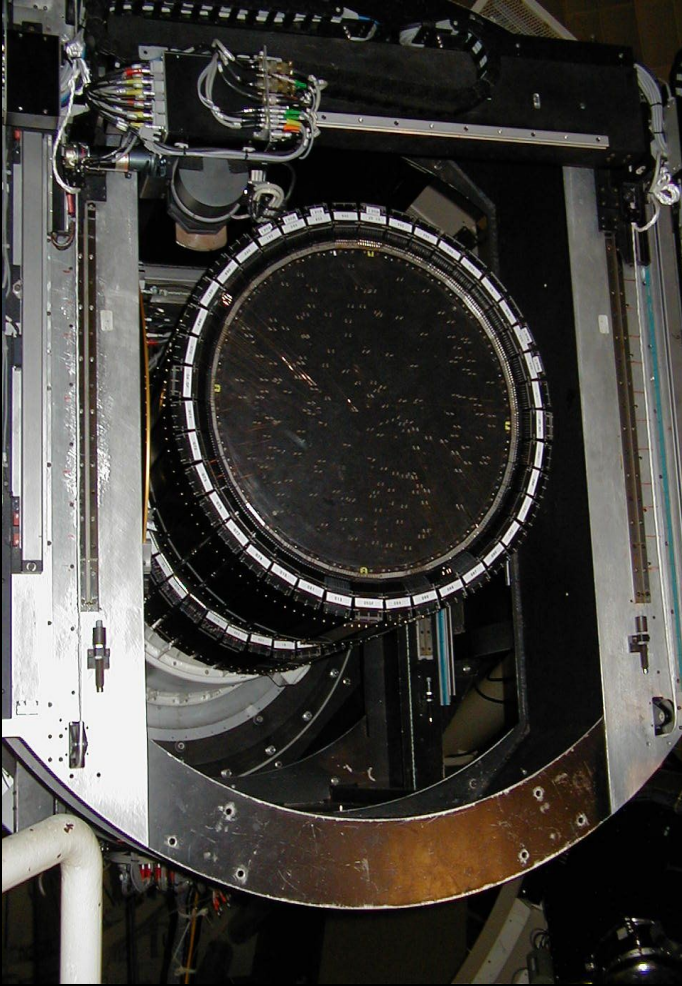
THE 2dF SPECTROGRAPH



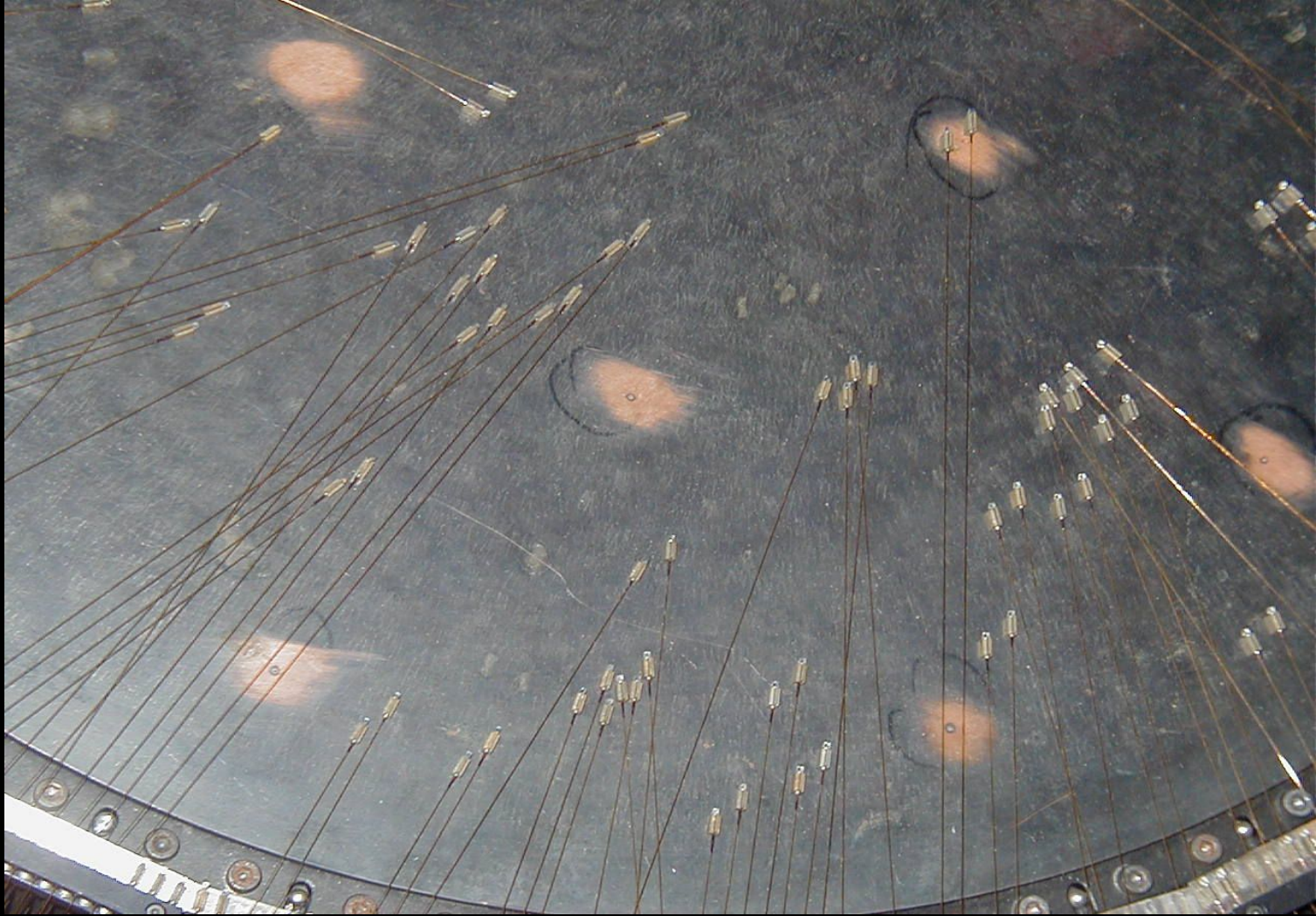
THE 2dF SPECTROGRAPH



THE 2dF SPECTROGRAPH

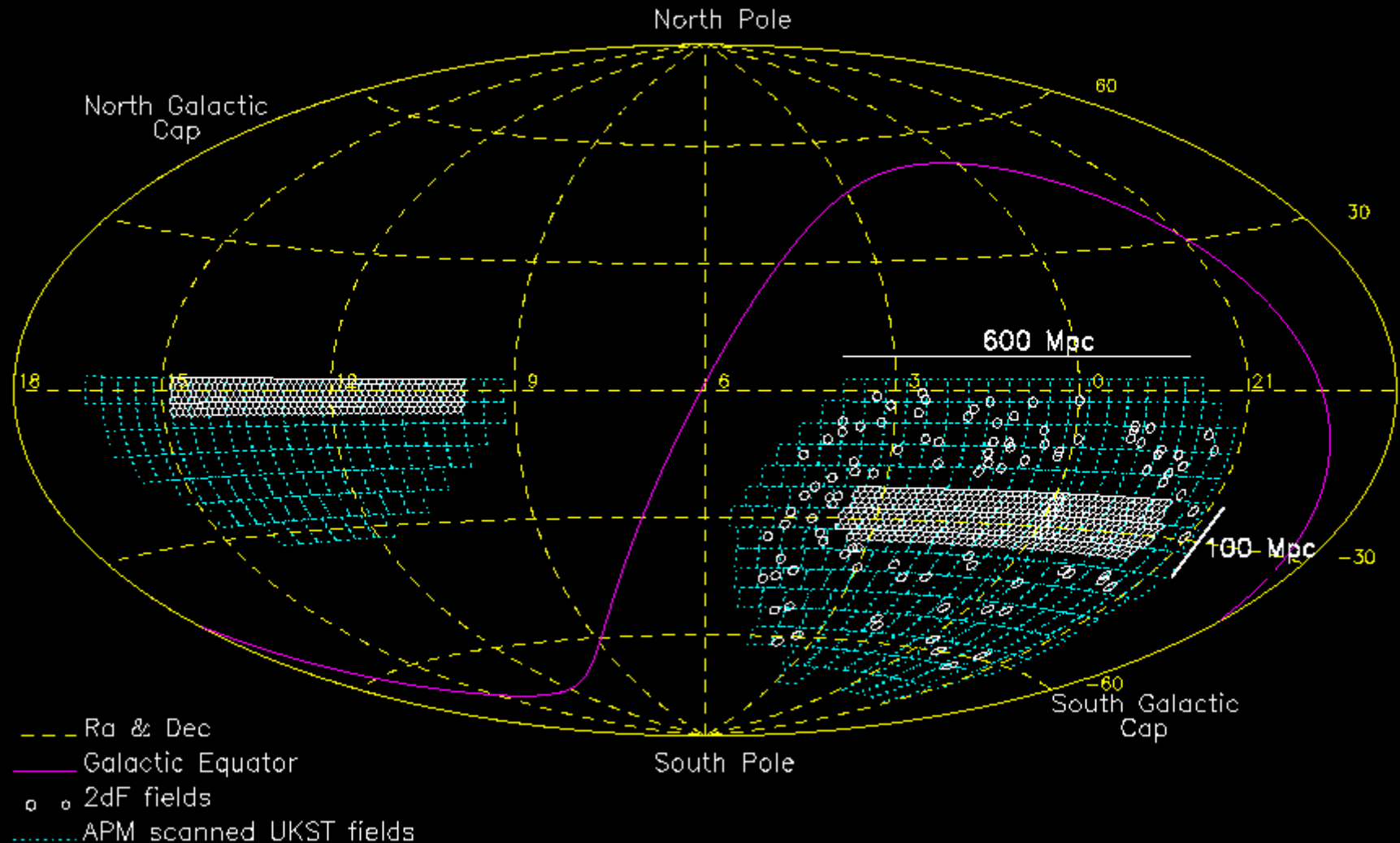


THE 2dF SPECTROGRAPH



2dF GALAXY REDSHIFT SURVEY FIELDS

All-sky map showing APM Survey



2dF GALAXY REDSHIFT SURVEY RESULTS

Between 1998 and 2003 the 2dFGRS obtained redshifts for 230 000 galaxies

Studied clumpiness of galaxy distribution - clustering

Results consistent with predictions of standard cosmology with cold dark matter

Requires mass density of 0.3 critical density

Combining 2dFGRS results with observations of cosmic microwave background provides very good determination of cosmological parameters

$$\Omega_{\text{M}} = 0.31 \pm 0.06, \quad \Omega_{\Lambda} = 0.69 \pm 0.06,$$

$$\Omega_{\text{k}} = 0.00 \pm 0.05$$

Intermediate-scale clustering gives similar mass density

2dF GALAXY REDSHIFT SURVEY RESULTS

Found largest size of clumping in galaxy distribution

Galaxies broadly follow total mass

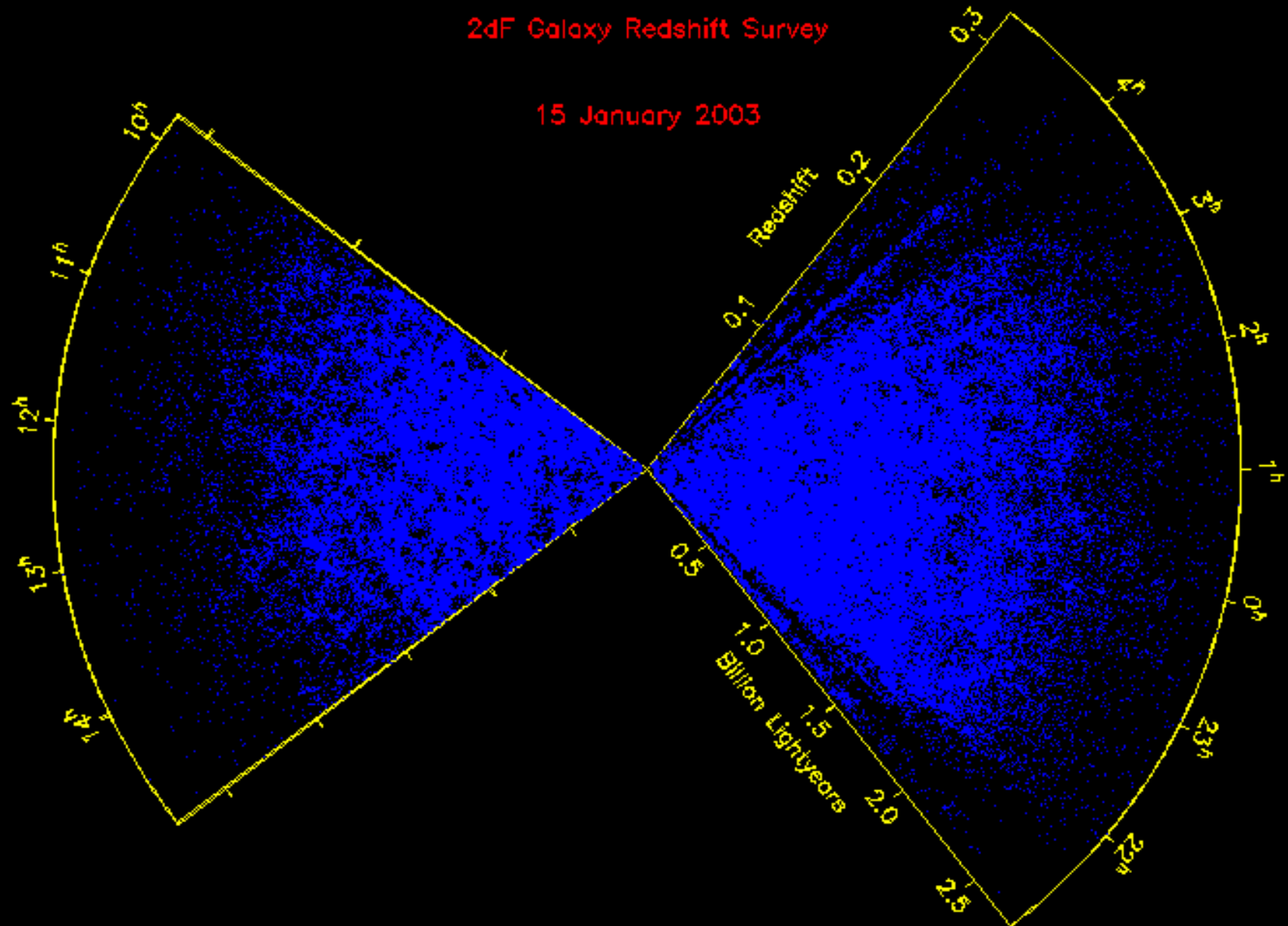
Measured numbers of galaxies as function of luminosity

Measured numbers as function of surface brightness

2dF GALAXY REDSHIFT SURVEY RESULTS

2dF Galaxy Redshift Survey

15 January 2003



SMALLER AREA SPECTROSCOPIC SURVEYS

Very deep in very small areas

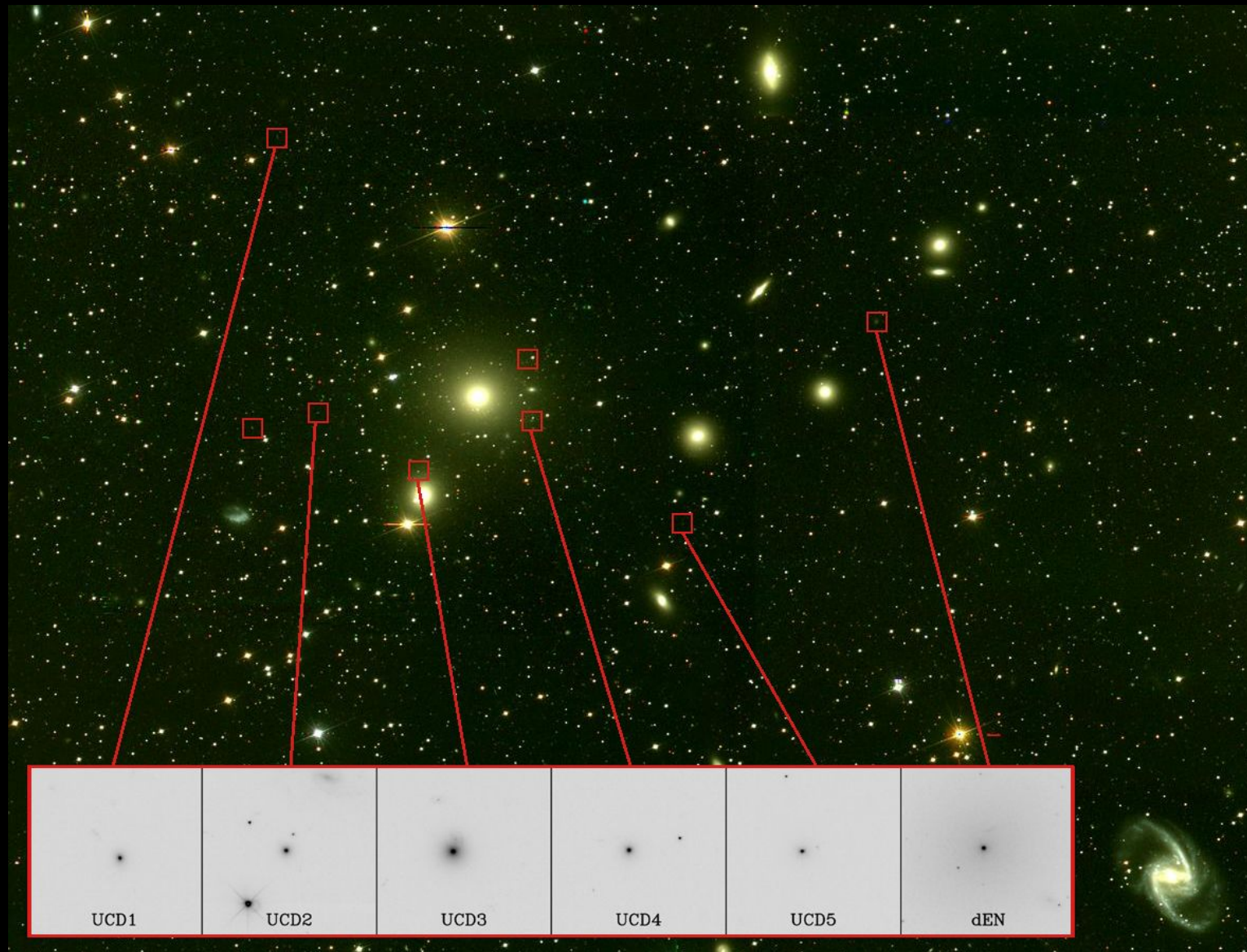
DEEP with 10-metre Keck Telescopes

VIRMOS with 8-metre Very Large Telescopes

THE FORNAX CLUSTER OF GALAXIES



ULTRA-COMPACT DWARF GALAXIES IN THE FORNAX CLUSTER



THE FUTURE

2dF replaced by AAOmega - survey of luminous red galaxies

Sloan Digital Sky Survey will reach completion with 1 000 000 spectra and wide-field imaging

**Electronic detectors will allow new imaging surveys
e.g. VLT Survey Telescope
VISTA infrared**

**All sky redshift surveys of infrared selected galaxies
e.g. 6dF survey with the UKST**

But

we have not even found all members of the Local Group of galaxies !

IN SUMMARY

**Imaging surveys can show the distribution of galaxies
on the sky**

**Photography can image large areas, electronic detectors
provide depth**

**Schmidt telescopes provided all-sky optical surveys using
photography
Now available in digital form**

Important for galaxies and cosmology

**New large area surveys with electronic detectors
e.g. 2MASS infrared survey, Sloan imaging survey**

IN SUMMARY

**Redshift surveys provide distance information to give
3-D maps**

**Important in many fields in extragalactic astronomy and
in cosmology**

**Sloan Digital Sky Survey well advanced - one million
redshifts**

2dF multi-fibre spectrograph

**2dF Galaxy Redshift Survey - highly successful -
completed 2003 - 230 000 galaxies**