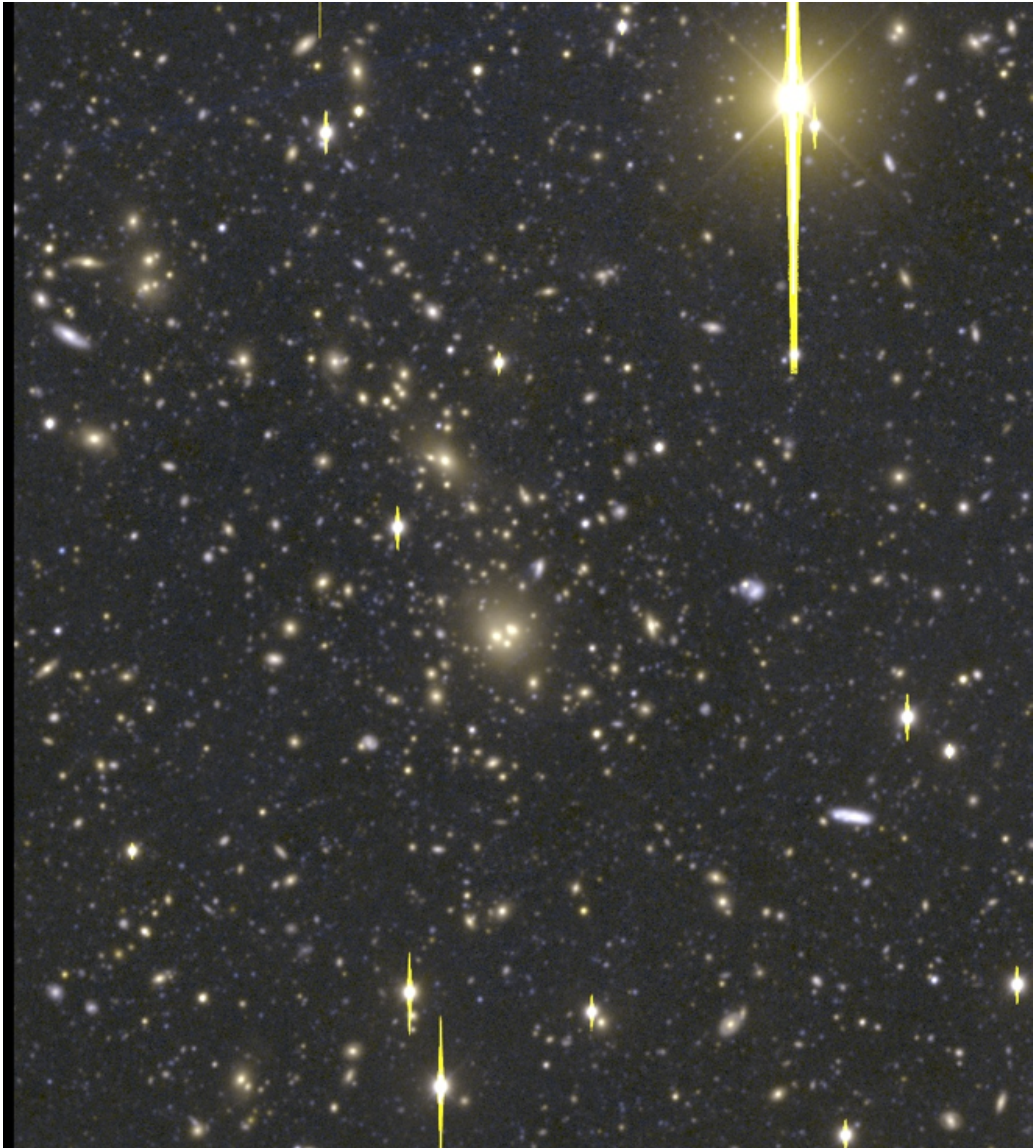
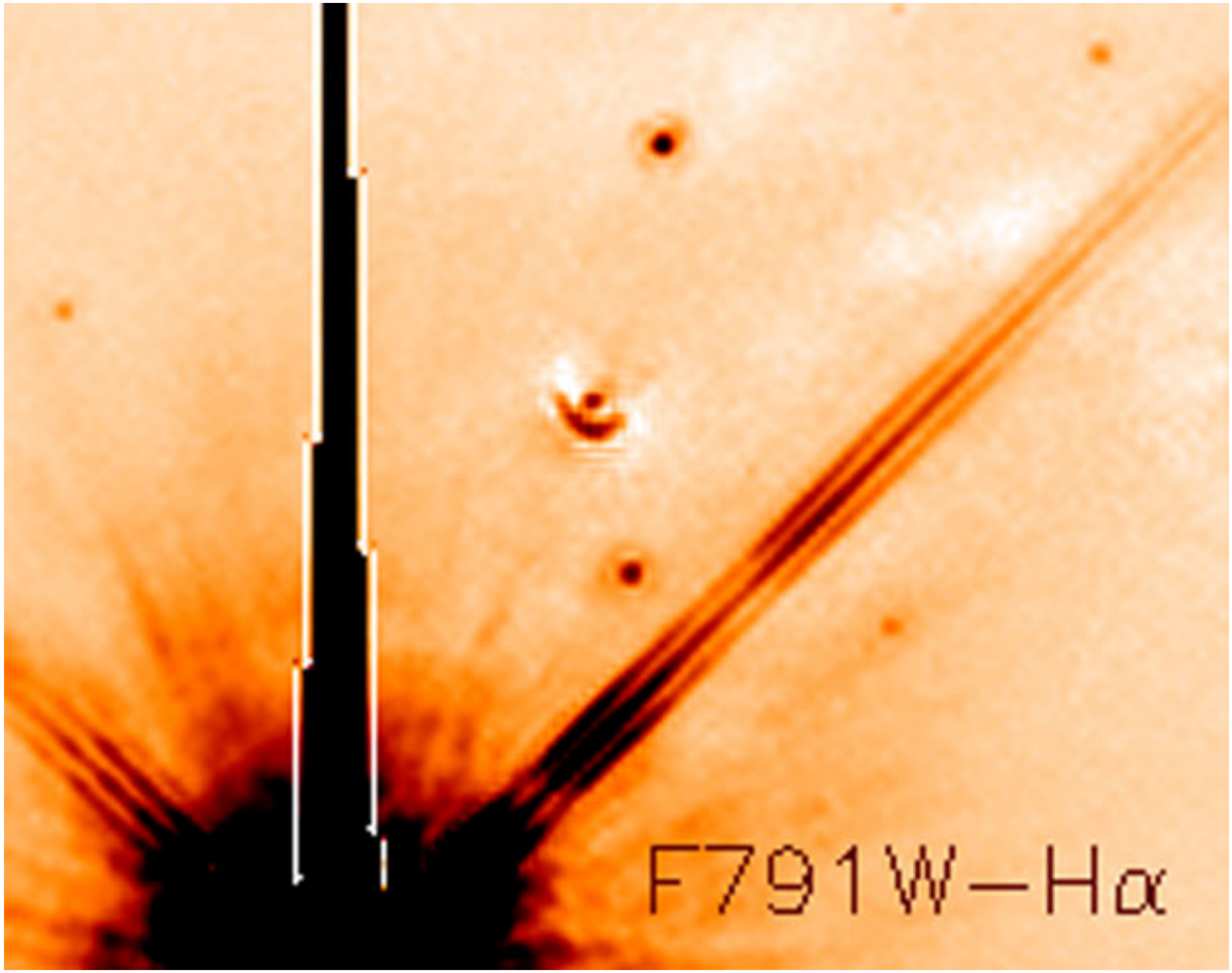
Analysis of astronomical images
- an introduction -



http://www.astr.ua.edu/keel/
techniques/a2125mos2wf.jpg



http://apod.nasa.gov/apod/ap010415.html

Diffraction cross

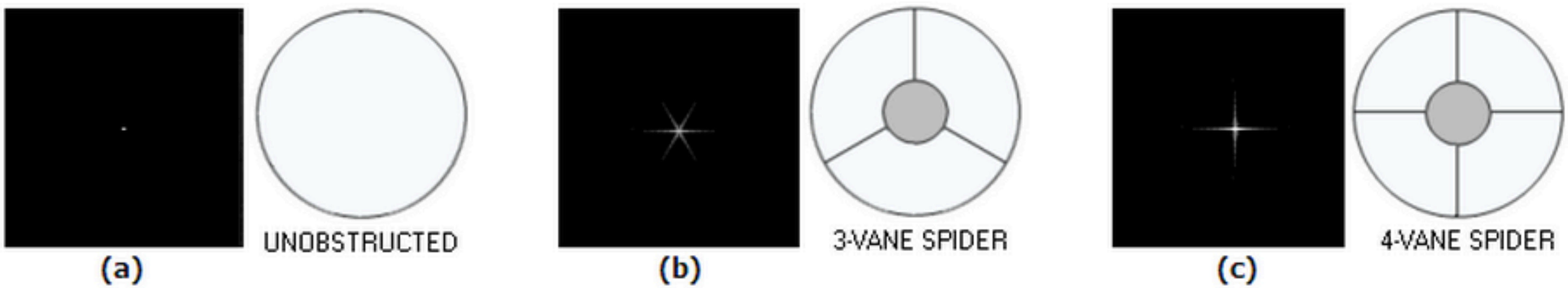
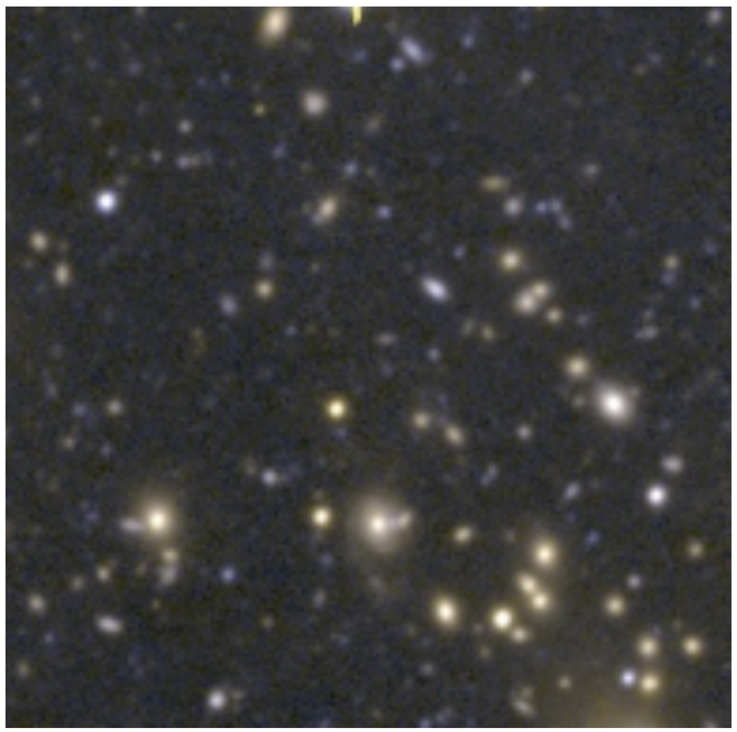
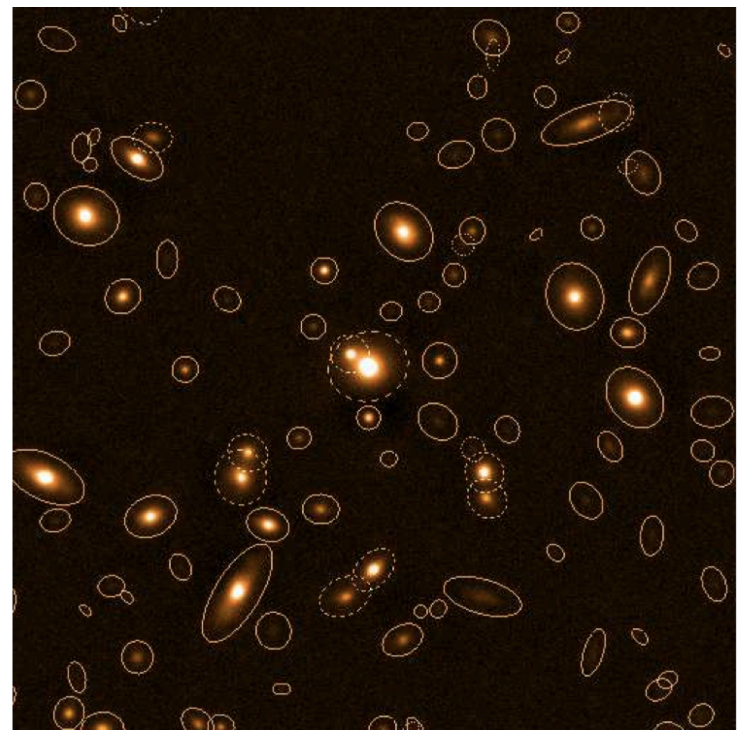


FIGURE 108: Visual appearance of a bright star without spider effect **(a)**, with three-vane spider effect **(b)**, and four-vane spider effect - the two most common spider forms - **(c)**. The effect is noticeable mainly on objects of high telescopic brightness. While the spikes caused by spider vanes can be visually distracting, the amount of energy lost from the disc is usually negligible for general observing (3-vane spider spikes are usually shorter, due to the vanes being generally thicker, as it is needed for mechanical stability in that spider configuration, but they may be less intense, since their patterns don't overlap).

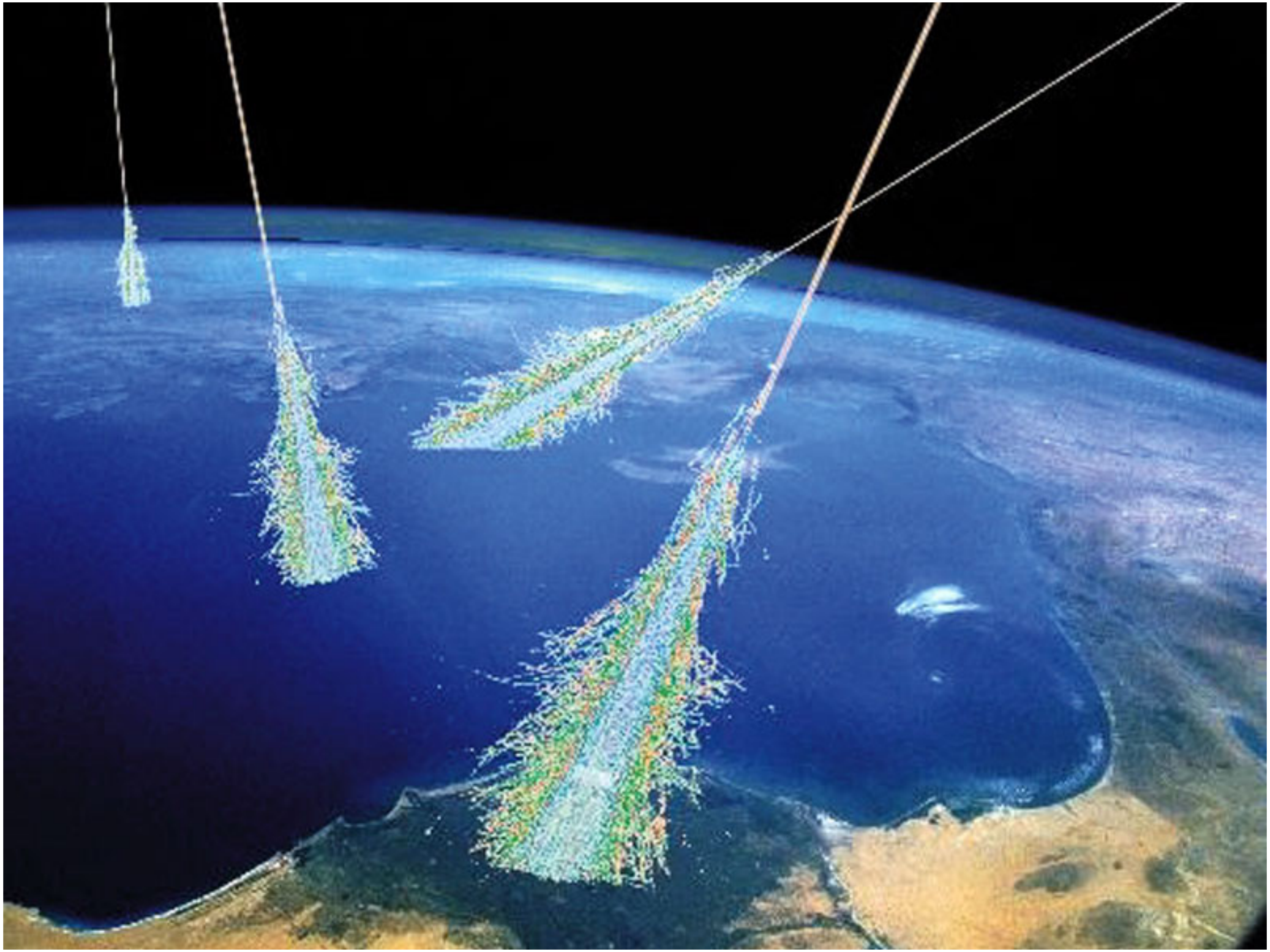
http://www.telescope-optics.net/spider.htm





source
catalog

Cosmic rays



http://apod.nasa.gov/apod/ap060814.html

Cosmic rays

Liquid nitrogen cooled CCD cameras are able to integrate for up to 6 hours. But in practice integration times are limited by the influence of cosmic rays.

Cosmic rays are subatomic particles arriving from outer space, which have high energy as a result of their rapid motion.

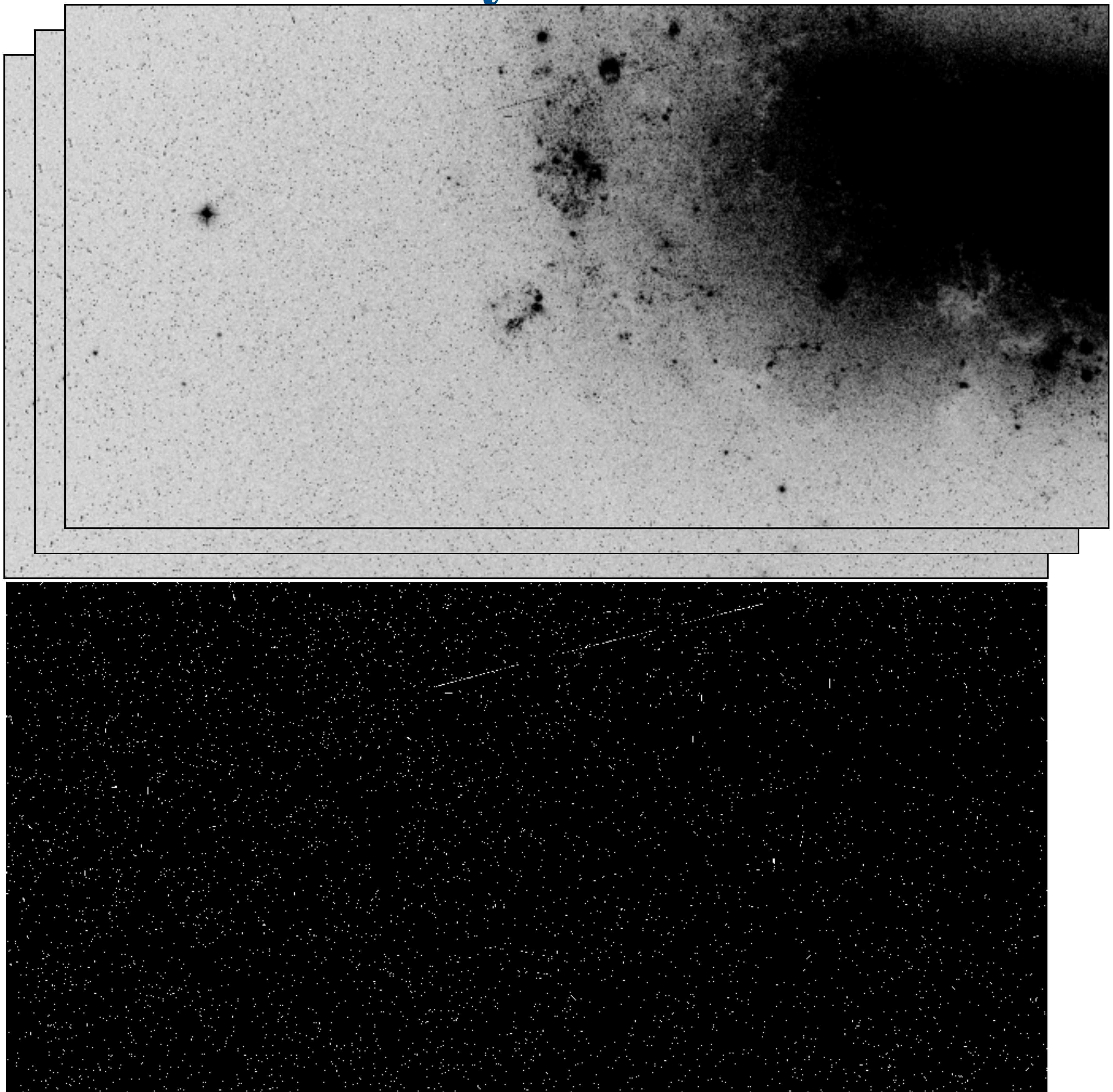
About 87 percent of cosmic rays are protons

and about 12 percent are alpha particles (helium nuclei).

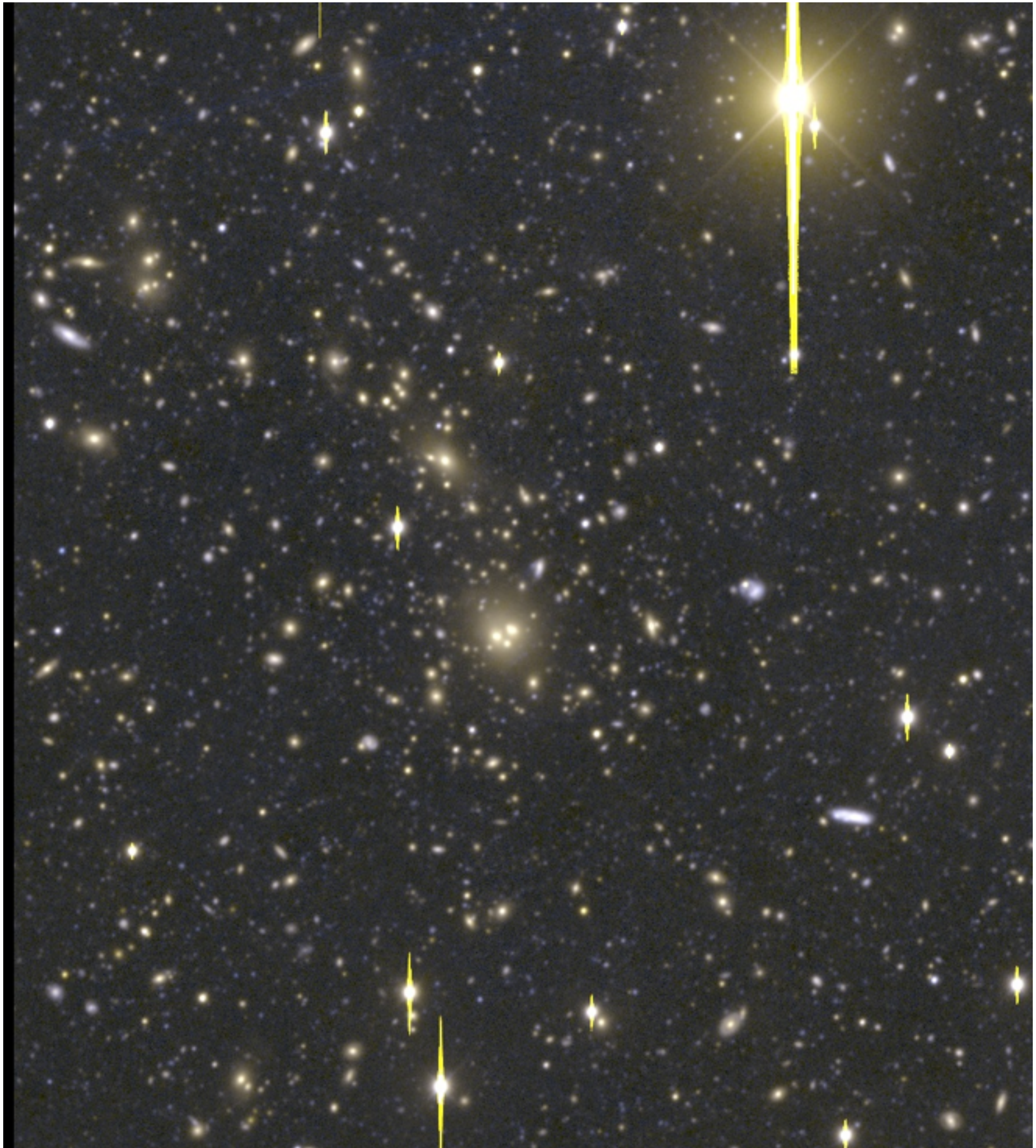
Cosmic ray flux at sea level: 0.025 cm^{-2} sec^{-1}.

Therefore in 1 hour about **?** events are seen in a 1cm^2 detector.

cosmic ray removal

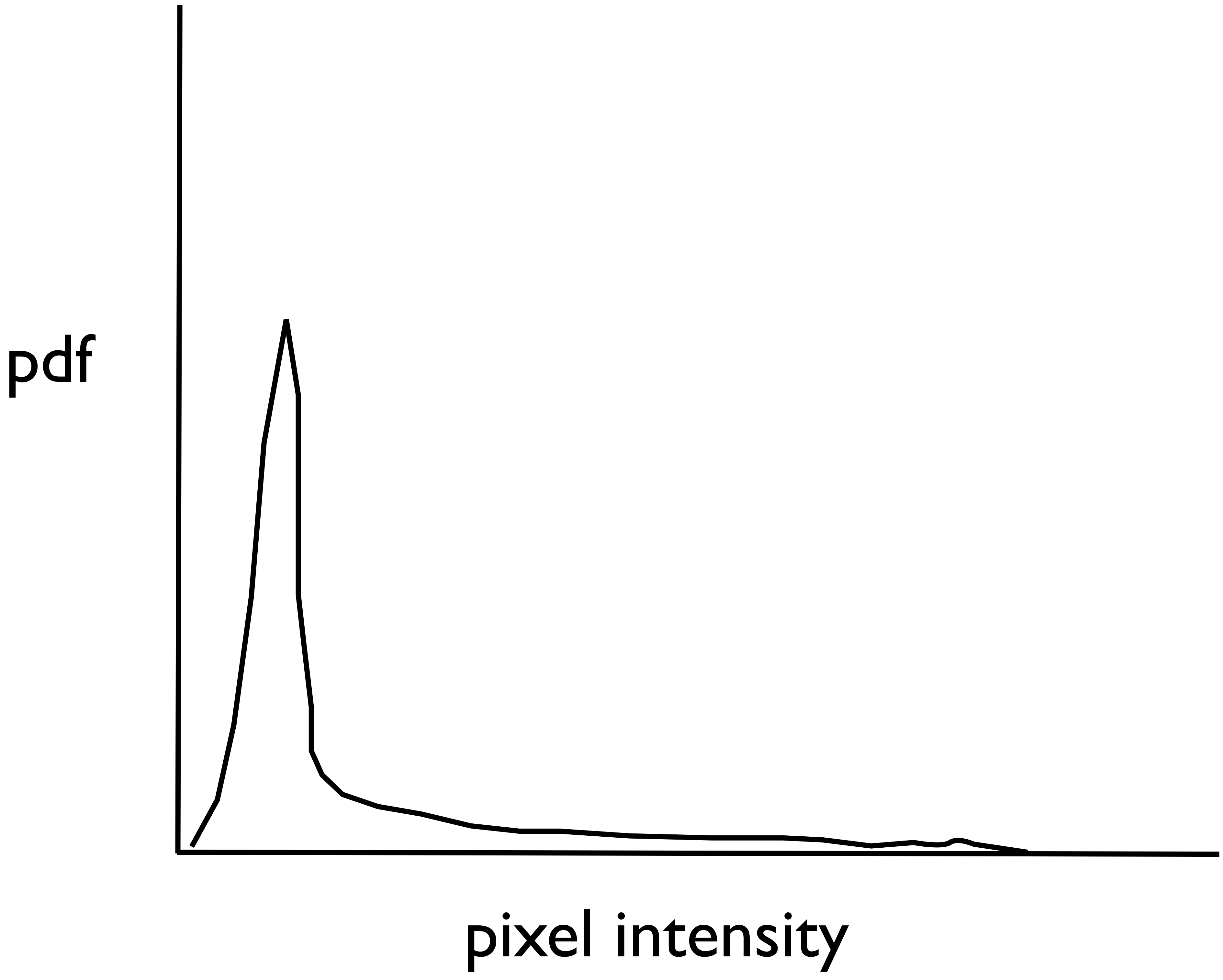


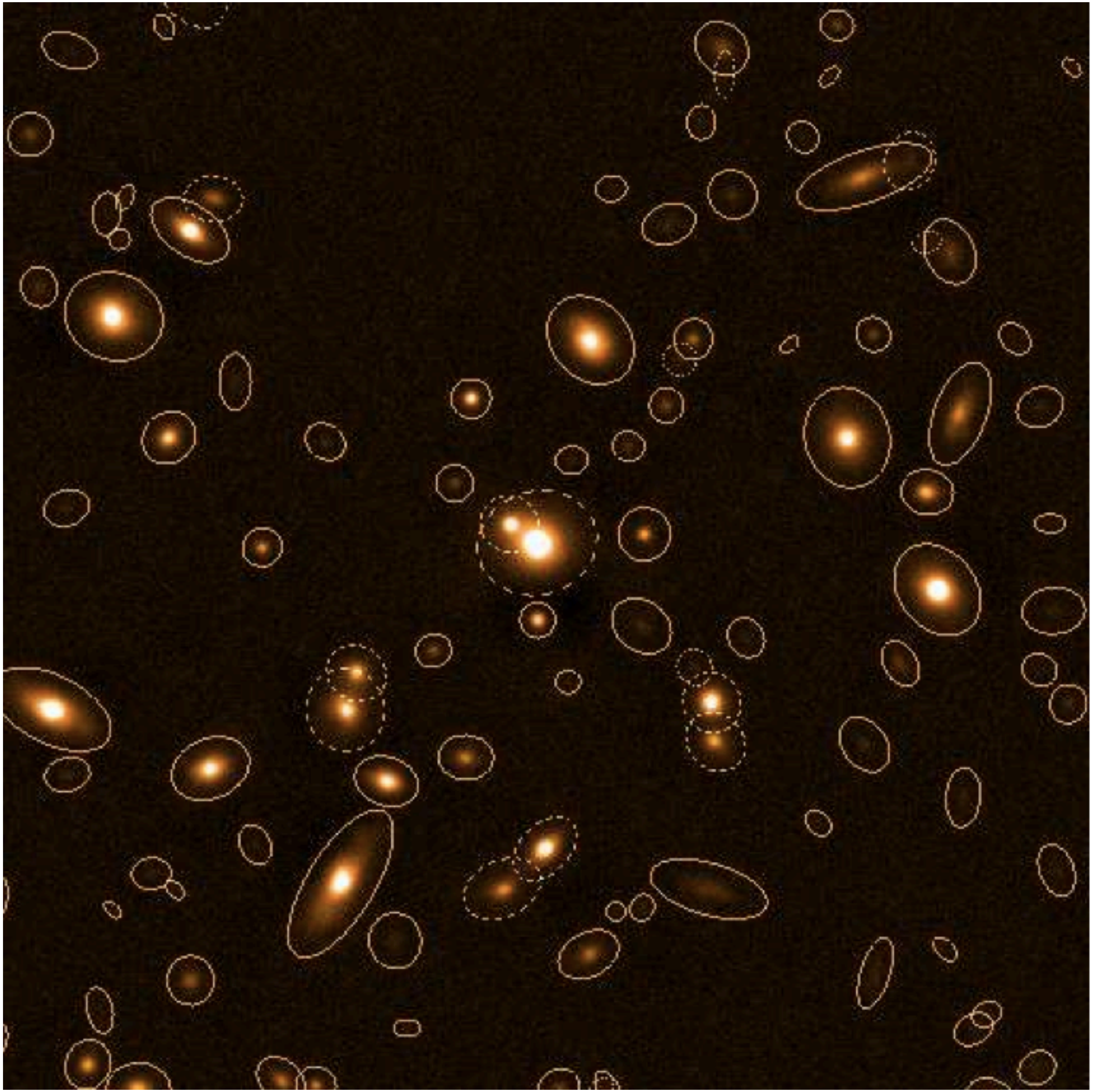
http://www.stsci.edu/hst/HST_overview/documents/multidrizzle/



http://www.astr.ua.edu/keel/techniques/a2125mos2wf.jpg

Image analysis





Deblending

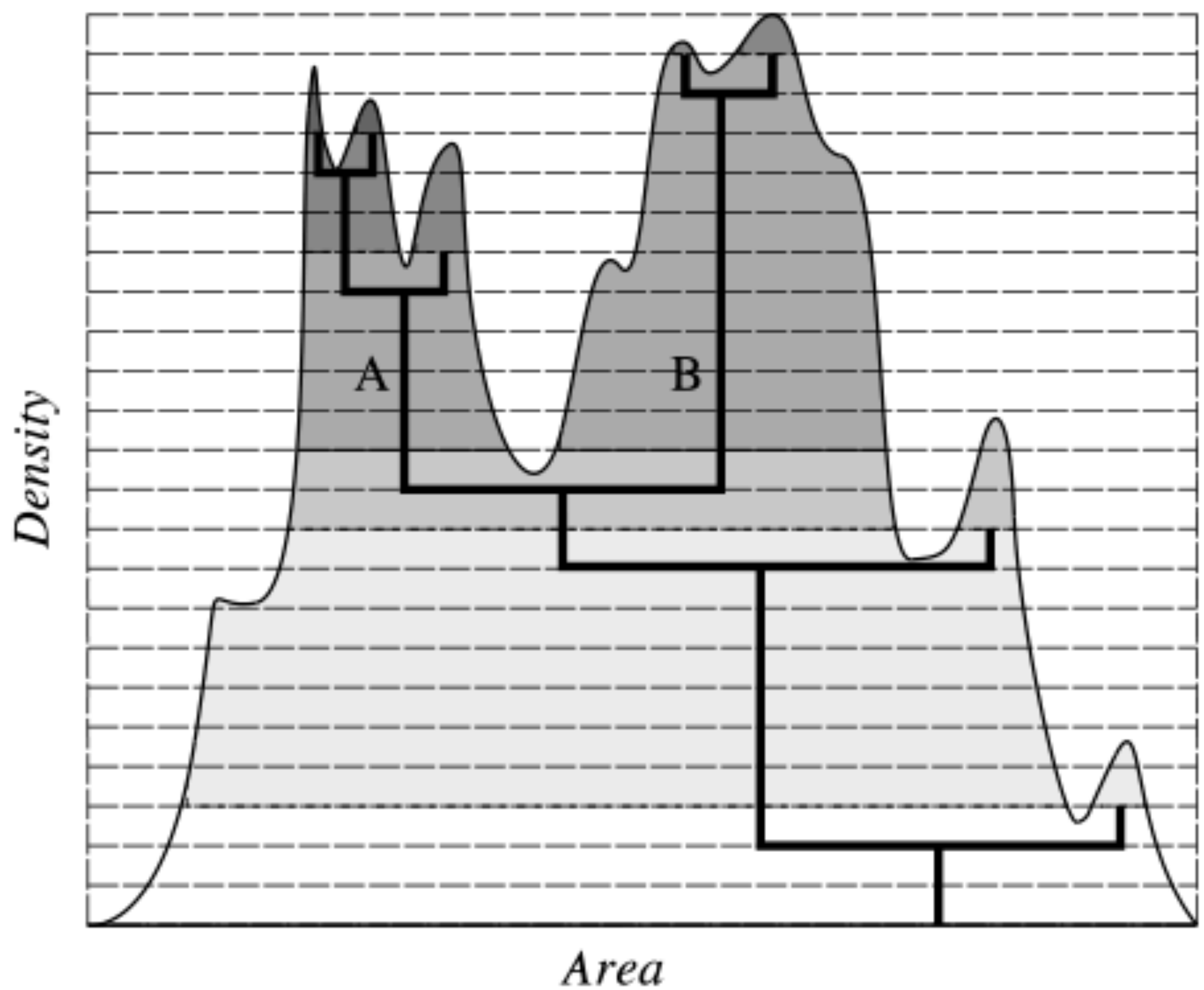


Figure 4: A schematic diagram of the method used to deblend a composite object. The area profile of the object (smooth curve) can be described in a tree-structured way (thick lines). The decision to regard or not a branch as a distinct object is determined according to its relative integrated intensity (tinted area). In that case above, the original object shall split into two components A and B. Remaining pixels are assigned to their most credible "progenitors" afterwards.

from E. Bertin

Image analysis

- background estimation (mean and sigma)

- identify pixels above the background at n sigmas (usually n=5)

- group contiguous pixels into objects

- check for blending

- catalog of sources. We have reduced the dimensionality of the dataset.

How to characterize a distribution with a few numbers?

Moments of the light distribution

$$I_0 = \frac{\int \mathrm{d}^2\theta\, I(\theta)\, W(\theta)}{\int \mathrm{d}^2\theta\, W(\theta)}$$

Brightness

$$\bar{\theta} = \frac{\int \mathrm{d}^2\theta\, I(\theta)\, W(\theta)\, \theta}{I_0}$$

Position

$$Q_{ij} = \frac{\int \mathrm{d}^2\theta\, I(\theta)\, W(\theta)\, (\theta_i - \bar{\theta}_i)(\theta_j - \bar{\theta}_j)}{I_0}$$

Size & orientation

Moments of the light distribution

2.2 Measurements of shapes and shear

Definition of image ellipticities. Let $I(\boldsymbol{\theta})$ be the brightness distribution of an image, assumed to be isolated on the sky; the center of the image can be defined as

$$\bar{\boldsymbol{\theta}} \equiv \frac{\int \mathrm{d}^2\theta \, I(\boldsymbol{\theta}) \, q_I[I(\boldsymbol{\theta})] \, \boldsymbol{\theta}}{\int \mathrm{d}^2\theta \, I(\boldsymbol{\theta}) \, q_I[I(\boldsymbol{\theta})]} \,, \tag{5}$$

where $q_I(I)$ is a suitably chosen weight function; e.g., if $q_I(I) = \mathrm{H}(I - I_{\mathrm{th}})$, where $\mathrm{H}(x)$ is the Heaviside step function, $\bar{\boldsymbol{\theta}}$ would be the center of light within a limiting isophote of the image. We next define the tensor of second brightness moments,

$$Q_{ij} = \frac{\int \mathrm{d}^2\theta \, I(\boldsymbol{\theta}) \, q_I[I(\boldsymbol{\theta})] \, (\theta_i - \bar{\theta}_i) \, (\theta_j - \bar{\theta}_j)}{\int \mathrm{d}^2\theta \, I(\boldsymbol{\theta}) \, q_I[I(\boldsymbol{\theta})]} \,, \quad i, j \in \{1, 2\} \,. \tag{6}$$

Note that for an image with circular isophotes, $Q_{11} = Q_{22}$, and $Q_{12} = 0$. The trace of Q describes the size of the image, whereas the traceless part of Q_{ij} contains the ellipticity information. From Q_{ij}, one defines two complex ellipticities,

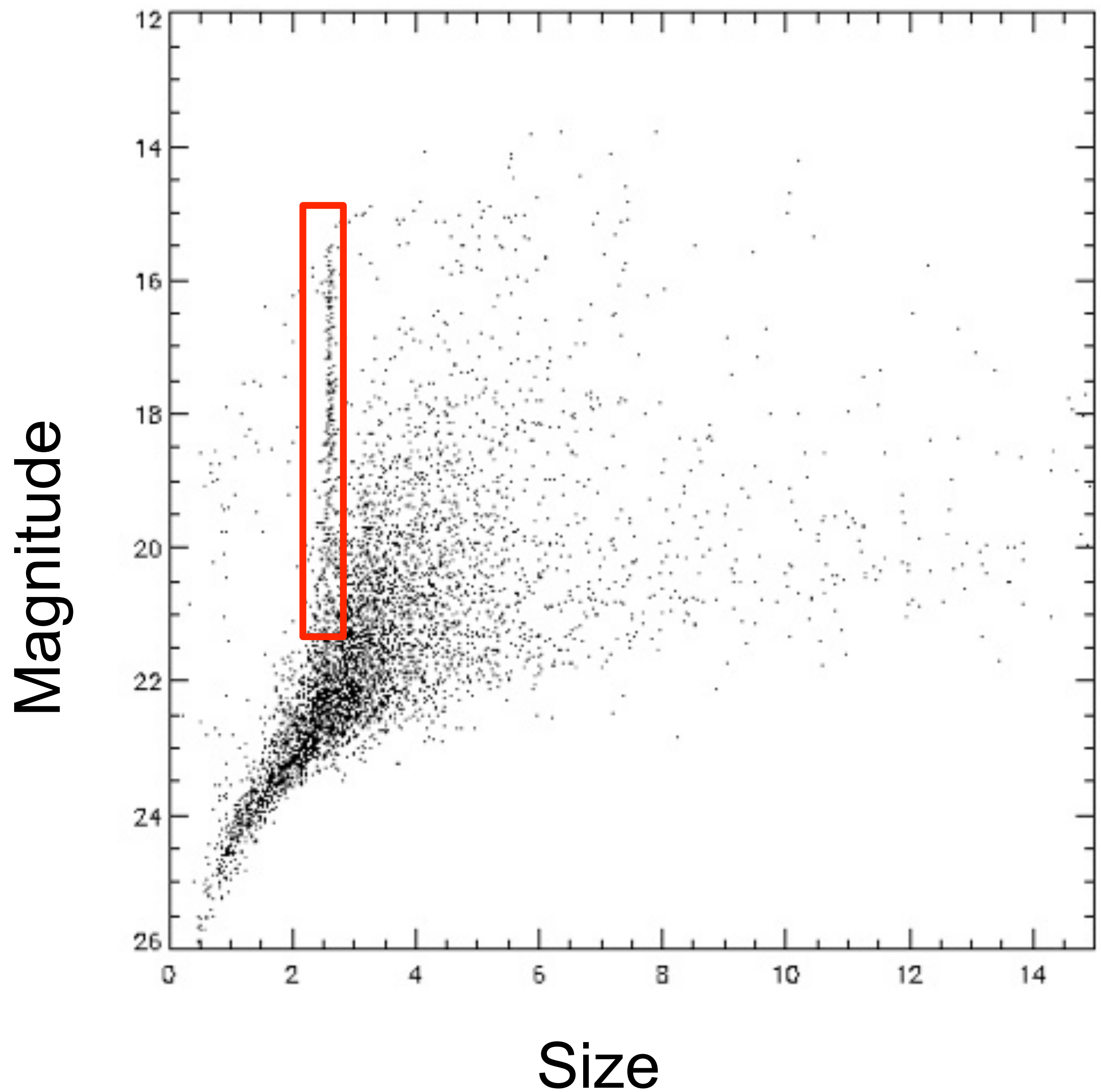
$$\chi \equiv \frac{Q_{11} - Q_{22} + 2\mathrm{i}Q_{12}}{Q_{11} + Q_{22}} \quad \text{and} \quad \epsilon \equiv \frac{Q_{11} - Q_{22} + 2\mathrm{i}Q_{12}}{Q_{11} + Q_{22} + 2(Q_{11}Q_{22} - Q_{12}^2)^{1/2}} \,. \tag{7}$$

Data product

- we now have a catalog of sources with:
    - brightness
    - position
    - size
    - ellipticity

Star-galaxy separation

Object detection $\longrightarrow$ positions, shapes, magnitudes, etc.
Star - Galaxy separation



Resolution of an instrument:

$$\delta\theta \approx 1.22\frac{\lambda}{D}$$

Imaging

<table>
<tr><td>Footprint area</td><td><table>
<tr><td>Total cataloged in CAS</td><td>11663 sq. deg.</td></tr>
<tr><td>Legacy unique</td><td>8423 sq. deg.</td></tr>
<tr><td>Legacy NGC ellipse</td><td>7646 sq. deg.</td></tr>
<tr><td>SEGUE</td><td>3240 sq. deg.</td></tr>
<tr><td>Supernova Survey</td><td>~300 sq. deg., repeated ~80 times</td></tr>
<tr><td>M31 / Perseus / Sgr / SGP scans</td><td>46 sq. deg.</td></tr>
<tr><td>Low galactic latitude fields ("Orion" runs)</td><td>832 sq. deg.</td></tr>
</table></td></tr>
<tr><td>Imaging total area in DAS (multiple scans counted multiple times)</td><td>45,000 sq. deg. (1.3 million frames/filter)</td></tr>
<tr><td>Imaging catalog</td><td>357 million unique objects (SEGUE: 127 million, Legacy: 230 million)</td></tr>
<tr><td>Data volume</td><td><table>
<tr><td>images (fits)</td><td>15.7 TB</td></tr>
<tr><td>other data products (catalogs, masks, jpeg images, etc.) (DAS, fits format)</td><td>26.8 TB</td></tr>
<tr><td>catalogs (CAS, SQL database)</td><td>18 TB</td></tr>
</table></td></tr>
<tr><td>Average wavelengths and magnitude limits (95% detection repeatability for point sources)</td><td><table>
<tr><td>u</td><td>g</td><td>r</td><td>i</td><td>z</td></tr>
<tr><td>3551Å</td><td>4686Å</td><td>6165Å</td><td>7481Å</td><td>8931Å</td></tr>
<tr><td>22.0</td><td>22.2</td><td>22.2</td><td>21.3</td><td>20.5</td></tr>
</table></td></tr>
<tr><td>PSF width</td><td>1.4" median in r</td></tr>
<tr><td>Pixel size</td><td>0.396"</td></tr>
<tr><td>Exposure time for each pixel</td><td>53.9 s</td></tr>
<tr><td>Photometric calibration</td><td><table>
<tr><td colspan="5">Target</td><td colspan="5">Ubercal</td></tr>
<tr><td>r</td><td>u-g</td><td>g-r</td><td>r-i</td><td>i-z</td><td>r</td><td>u-g</td><td>g-r</td><td>r-i</td><td>i-z</td></tr>
<tr><td>2%</td><td>3%</td><td>2%</td><td>2%</td><td>3%</td><td>1%</td><td>2.2%</td><td>1.5%</td><td>1.5%</td><td>1.5%</td></tr>
</table></td></tr>
<tr><td>Astrometry</td><td>< 0.1" rms absolute per coordinate</td></tr>
</table>

The SDSS skyserver

Skyserver SQL query

```
-- This query shows the basic structure of a SQL query:
-- SELECT [variables] FROM [table] WHERE [constraints]
-- Although many of your SQL queries will be more complex,
-- they will all follow this same basic structure.

-- This sample query finds unique objects in an RA/Dec box.
-- For a more efficient way to find objects by position, see the next query,
-- Searching around a sky position.

SELECT TOP 100
     objID, ra ,dec                  -- Get the unique object ID and coordinates
FROM
     PhotoPrimary                    -- From the table containing photometric data for unique objects
WHERE
     ra > 185 and ra < 185.1
     AND dec > 15 and dec < 15.1    -- that matches our criteria
```

Skyserver SQL query

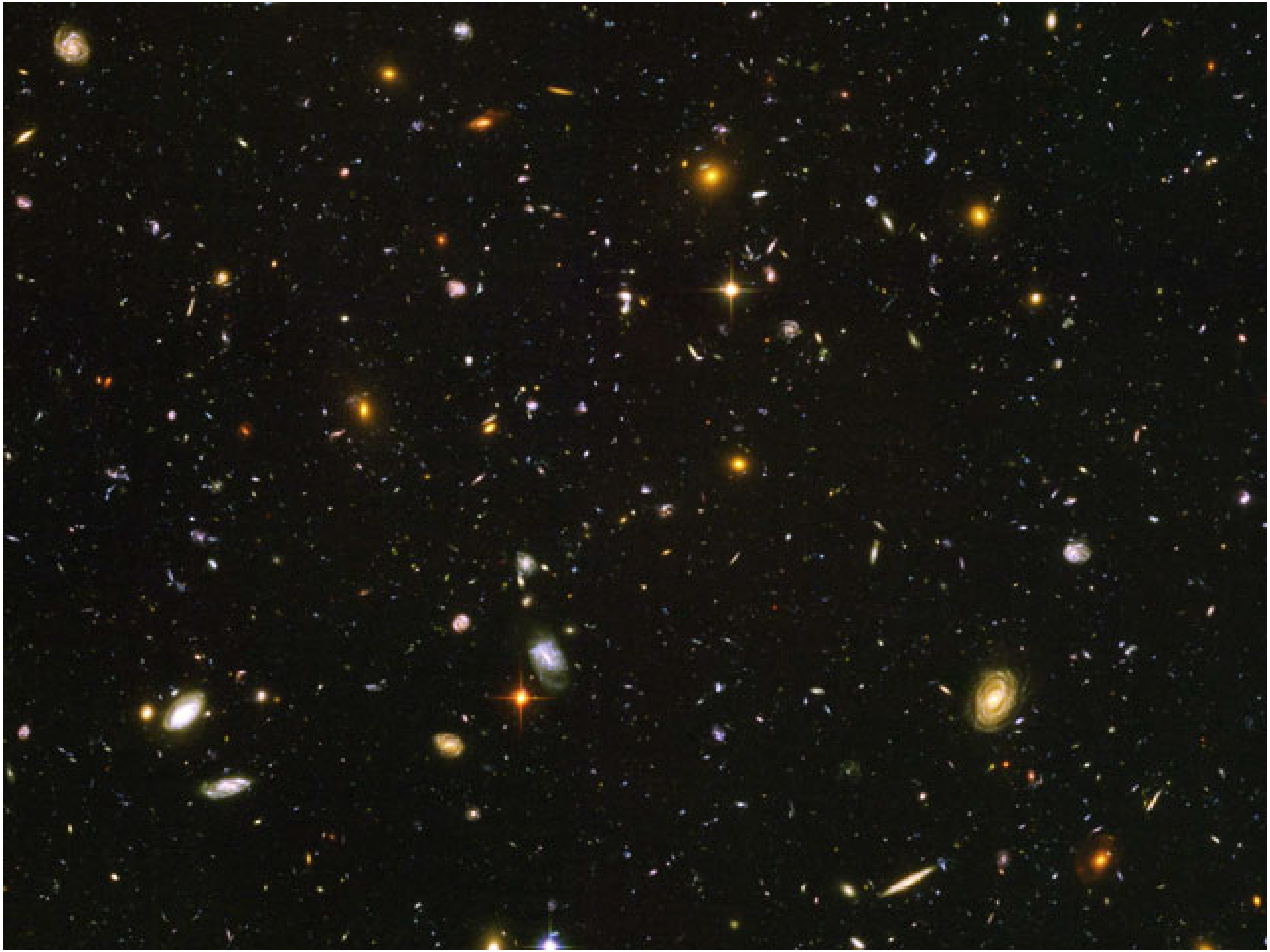
```
-- Find galaxies within 1' of a given point (ra=185.0, dec=-0.5).
-- This is a slightly more complex query, but it can be easily adapted to search
-- around any point in the sky.

-- To see how to limit the search only to objects with clean photometry, see the
-- Clean imaging query.

SELECT TOP 100 G.objID, GN.distance
FROM Galaxy as G
JOIN dbo.fGetNearbyObjEq(185.,-0.5, 1) AS GN
      ON G.objID = GN.objID
ORDER BY distance
```

Skyserver SQL query

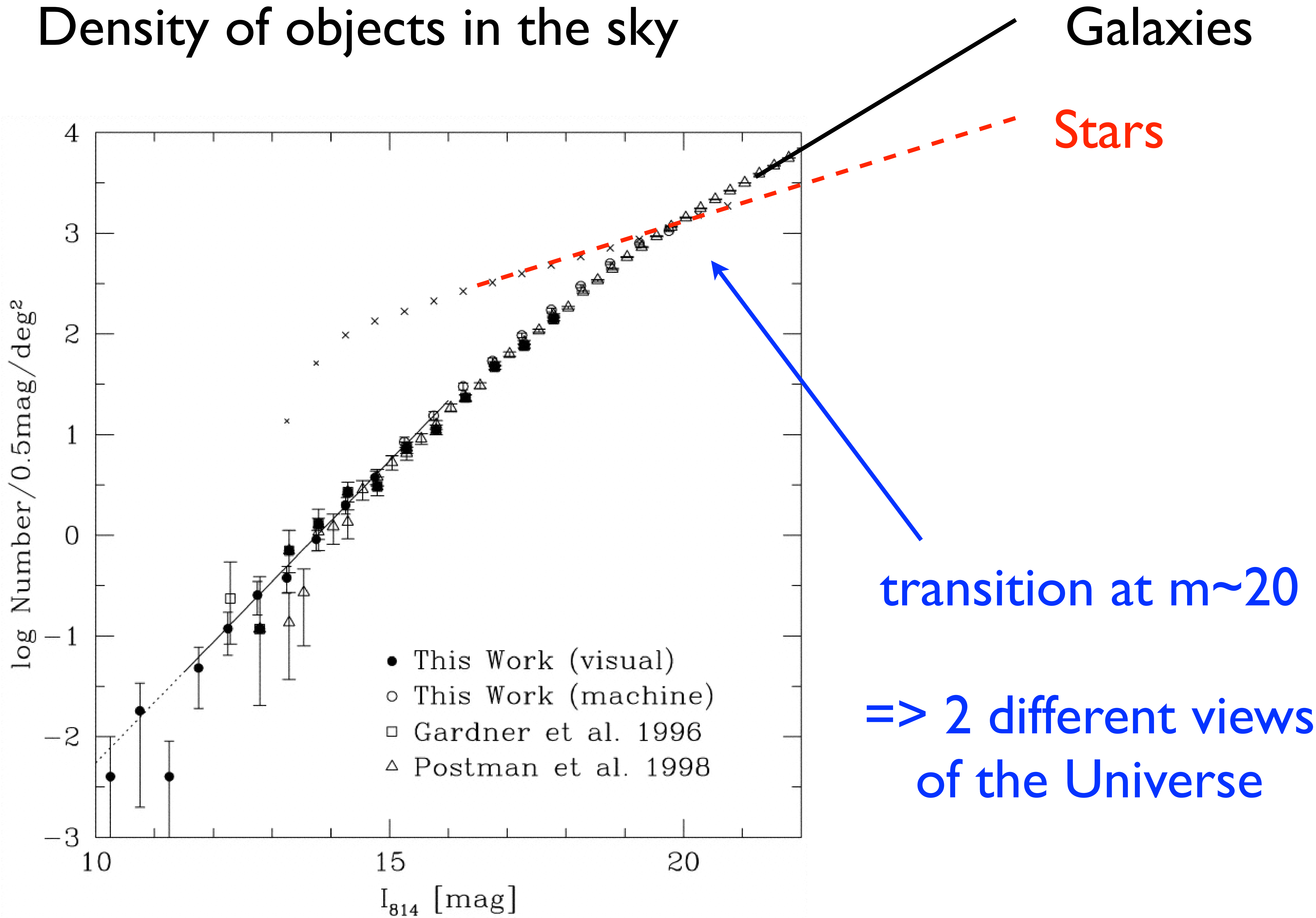
```
-- This query introduces the PhotoTag table, which contains the most frequently used columns
-- of PhotoObj. Queries to PhotoTag will run more quickly than those to photoObj.

-- This sample query finds data for all objects in fields with desired PSF width.

SELECT TOP 100
	r.run,
	r.rerun,
	f.camCol,
	f.field,
	p.objID,
	p.ra,
	p.dec,
	p.modelMag_r,
	f.psfWidth_r
FROM
	PhotoTag AS p
	JOIN Field AS f ON f.fieldid = p.fieldid
	JOIN Run AS r ON f.run = r.run
WHERE mode=1	-- select primary objects only
	and f.psfWidth_r > 1.2
	and p.modelMag_r < 21.
	and r.stripe = 21
```

Mapping the Universe: stars vs galaxies

Mapping the Universe: stars vs galaxies



Density of objects in the sky



Yasuda et al. (2001)

Description of density fluctuations

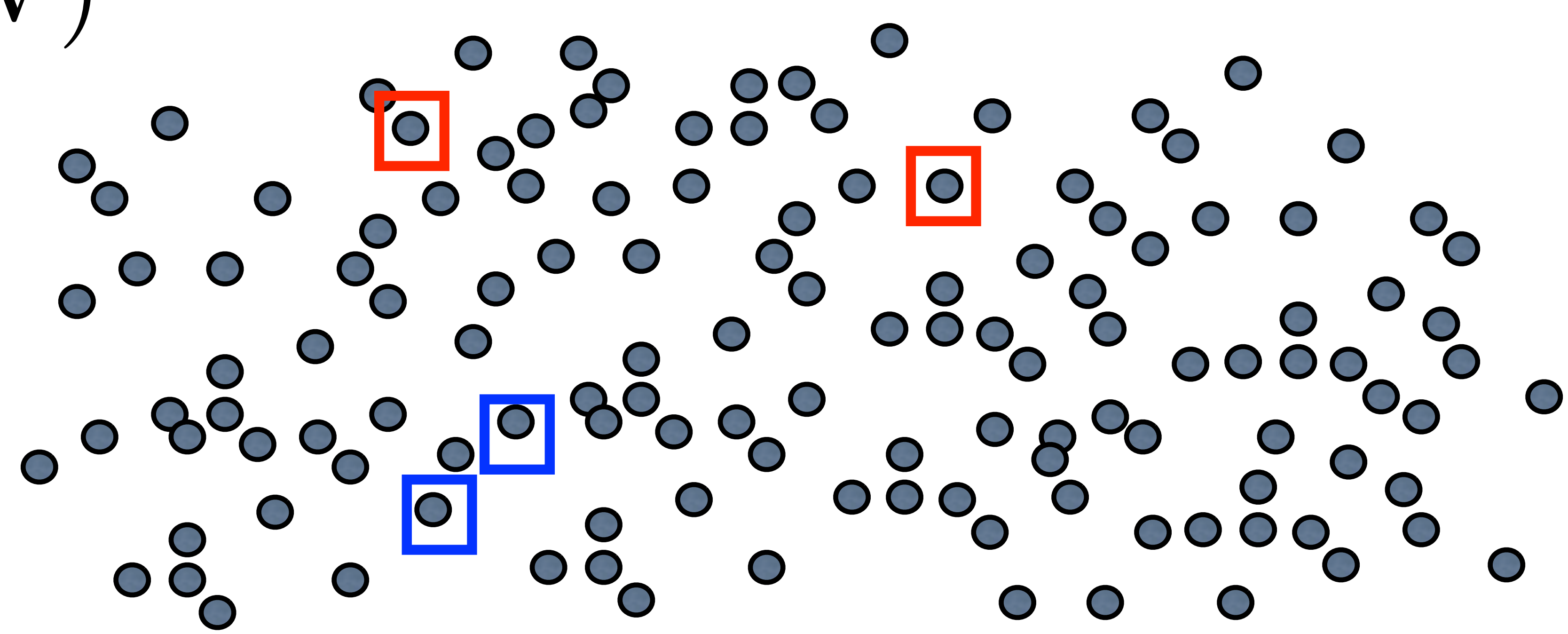
If n is the average number of galaxy per unit volume, the probability of finding a galaxy in the volume dV at position x is

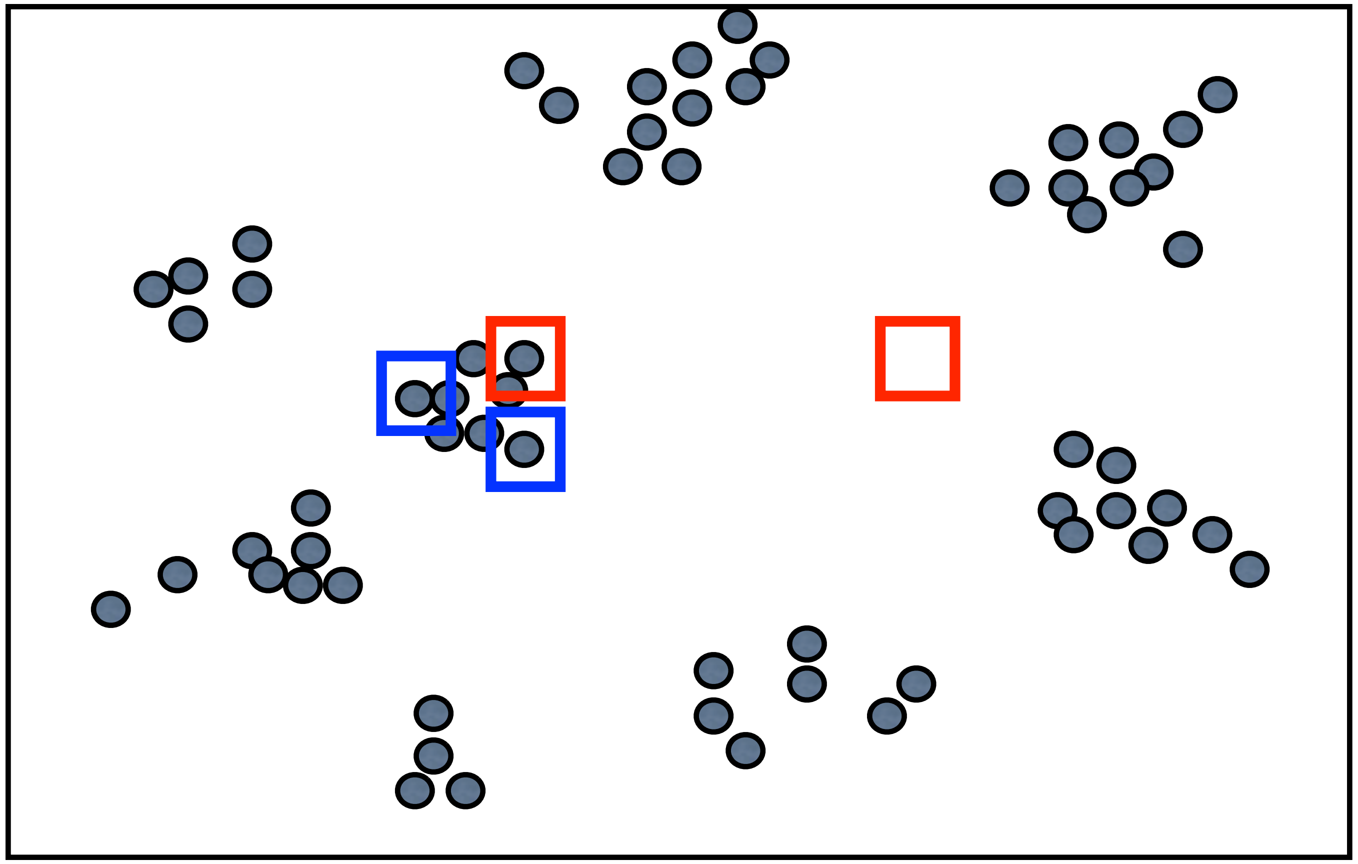
$$P_1 = \bar{n}\,\mathrm{dV}$$

We chose dV small enough so that there is only 1 gal per dV

If the galaxies are distributed **randomly**, the probability of finding a galaxy in dV at position x1 and another galaxy in dV at position x2 is:

$$P_2 = (\bar{n}\,\mathrm{dV})^2$$





$$P_1 = \bar{n}\, dV$$

The probability of having one galaxy in dV1 and one galaxy in dV2 becomes scale dependent

$$P_2 = (\bar{n}\, dV)^2\, [1 + \xi(x,y)]$$

If the distribution of points is isotropic and homogeneous (Cosmological principle):

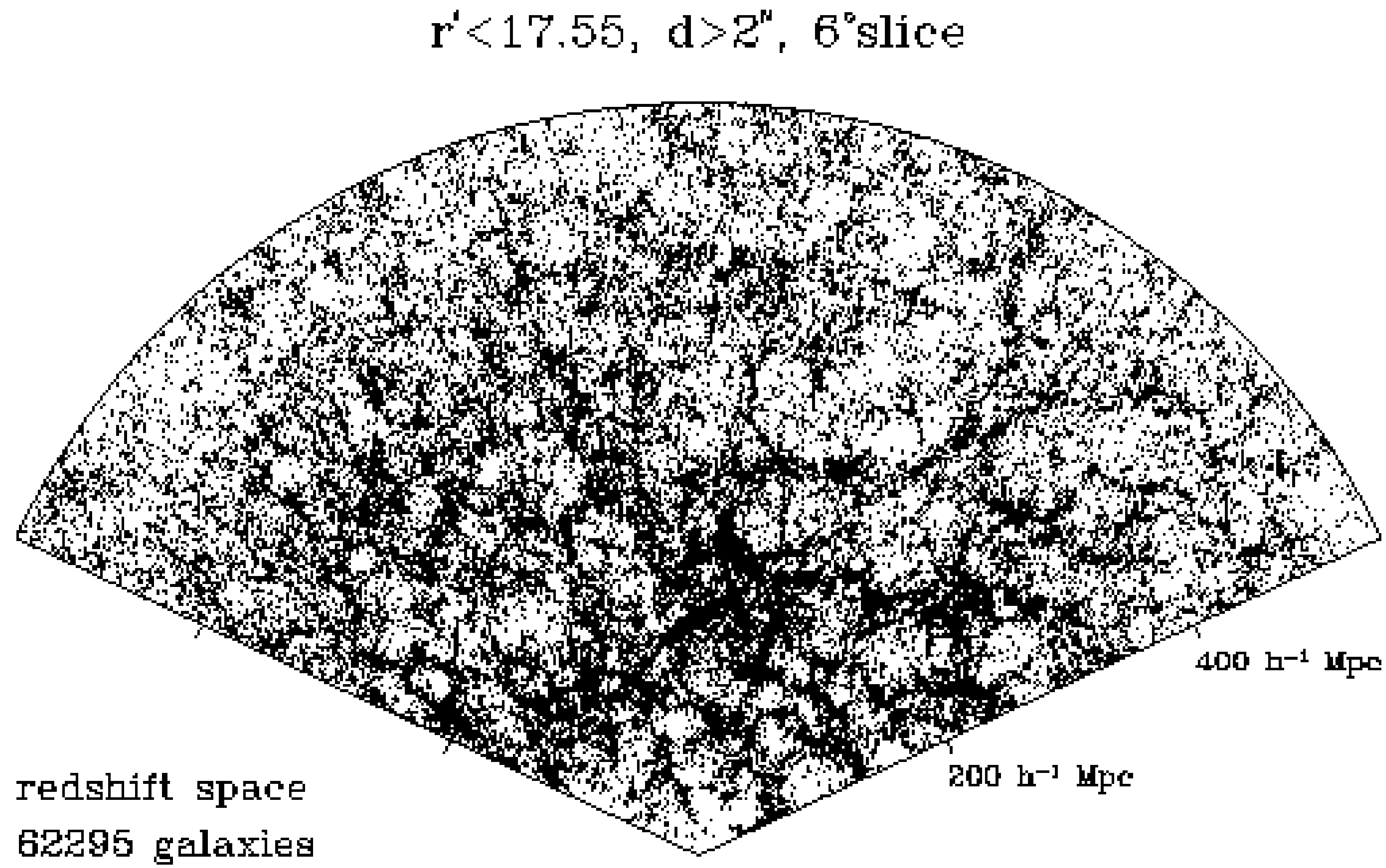
$$P_2 = (\bar{n}\, dV)^2\, [1 + \xi(r)]$$

Description of density fluctuations

$$P_1 = \bar{n}\,\mathrm{dV}$$

If the galaxies are clustered, the probability of finding a galaxy in dV at position x1 and another galaxy in dV at position x2 is:

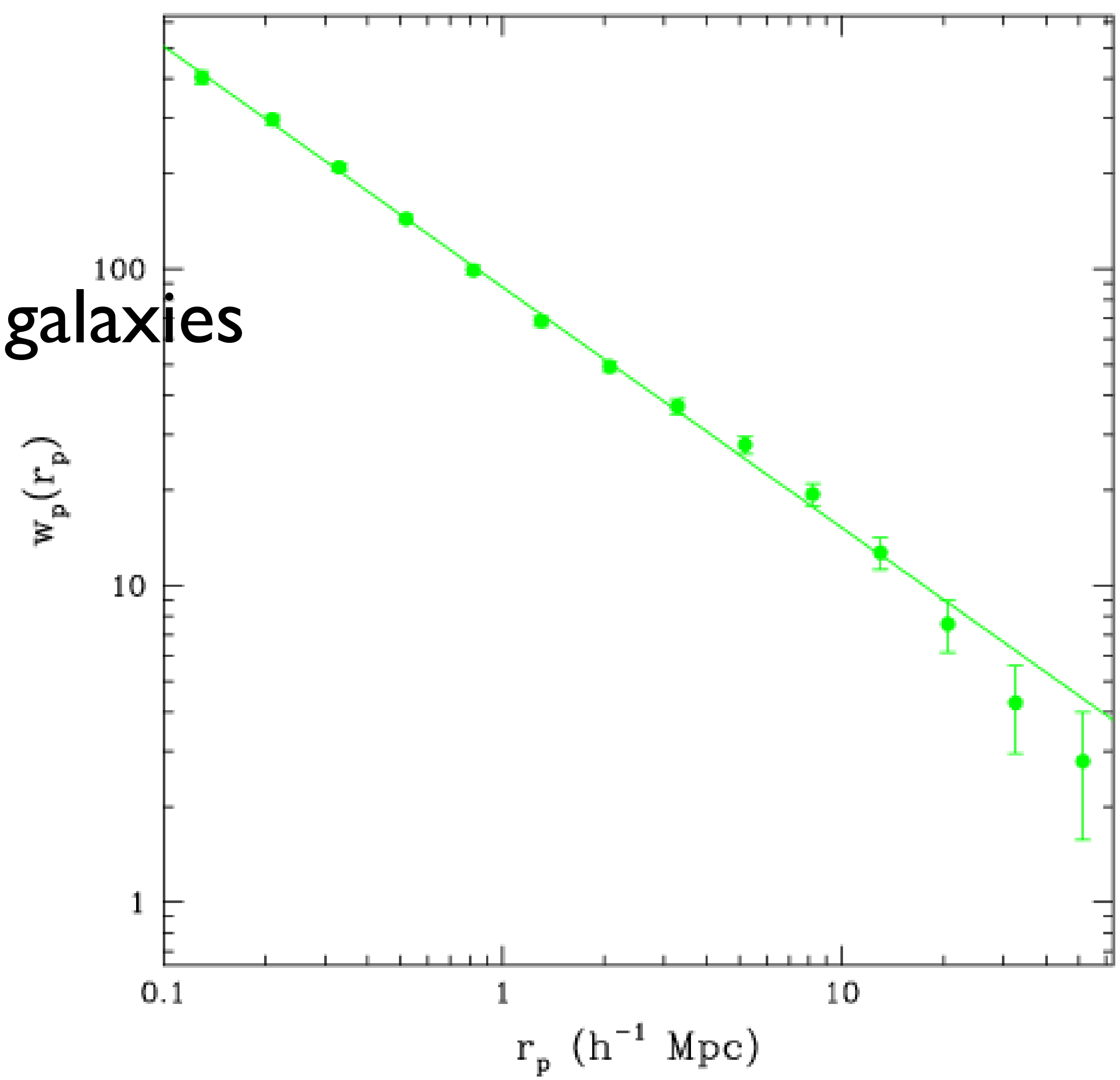
$$P_2 = (\bar{n}\,\mathrm{dV})^2[1 + \xi_{\mathrm{g}}(\mathrm{x}, \mathrm{y})]$$



Description of density fluctuations

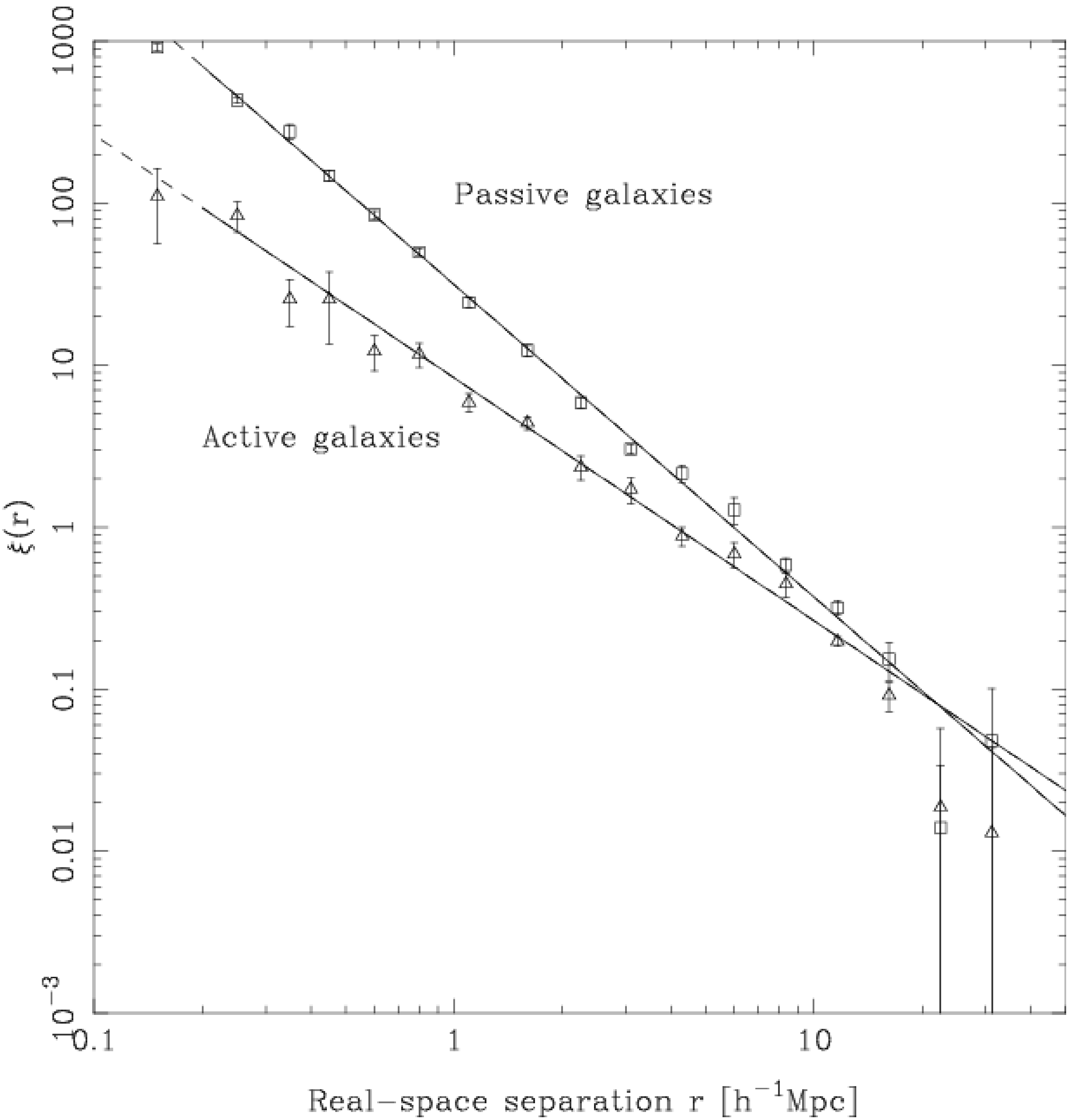
Due to the isotropy of the Universe, we are not interested in ξ(x,y) but in ξ(r)

Correlation function ξ(r) for SDSS galaxies



http://home.fnal.gov/~iditz/xi9/

Correlation functions



http://hermes.aei.mpg.de/lrr/2004/8/figure27.png

- 10,000 square degrees

1 pixel ~ 1 square arcsecond
1 square degree = 3600^2 square arcsecond

=> SDSS has about 100 Giga pixels

- 100 Giga pixels
- 100 Million galaxies
- 20 angular bins
- 2 parameters

$$
\begin{aligned}
\langle \rho(x)\rho(y)\rangle &= \bar{\rho}^2 \langle [1+\delta(x)][1+\delta(y)]\rangle \\
&= \bar{\rho}^2 [1+\langle \delta(x)\delta(y)\rangle] \\
&=: \bar{\rho}^2 [1+\xi(x,y)]
\end{aligned}
$$