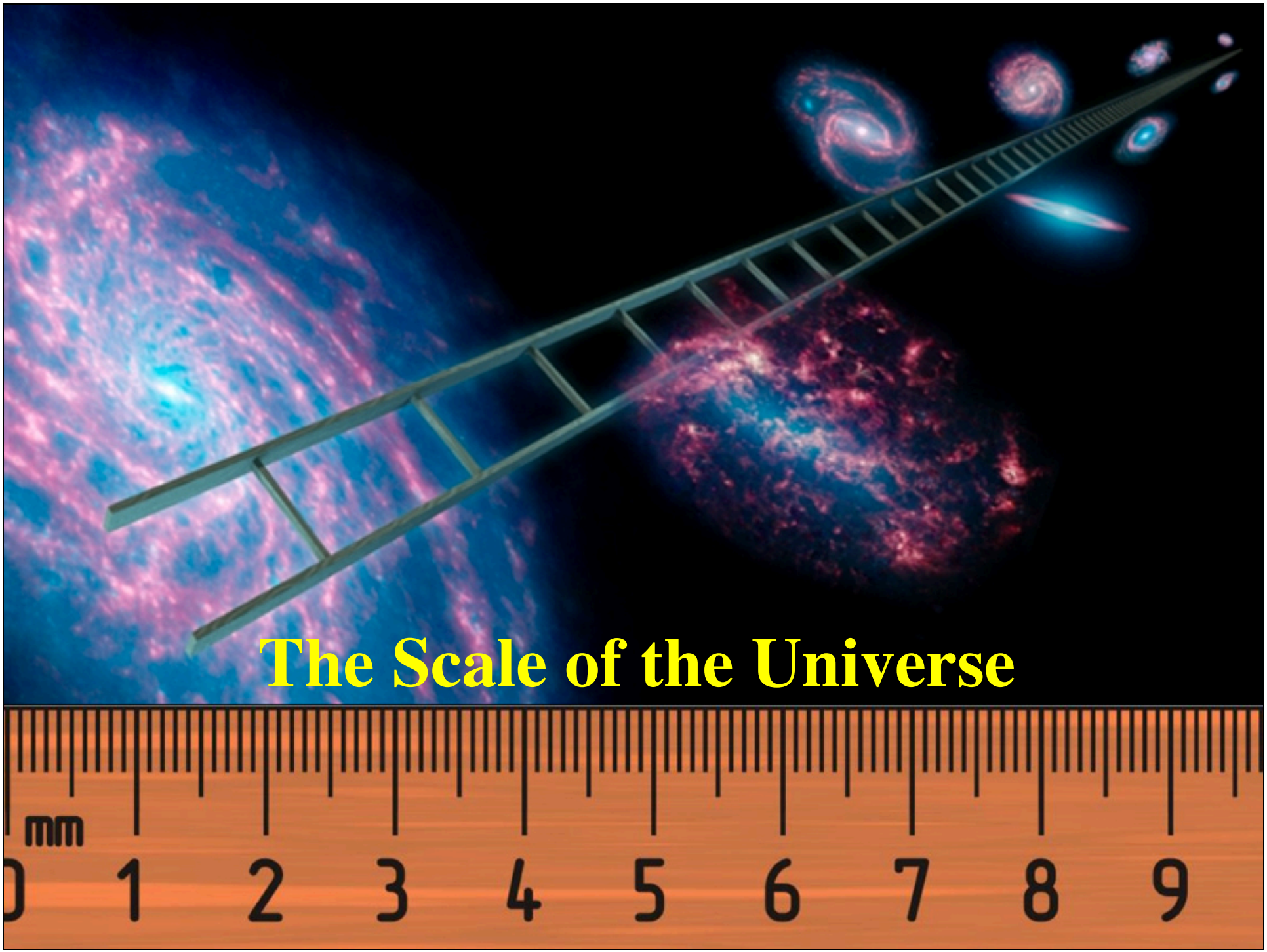

The Scale of the Universe
mm
0 1 2 3 4 5 6 7 8 9

The Scale of the Universe

- The **Hubble length**, $D_H = c/H_0$, and the **Hubble time**, $t_H = 1/H_0$ give the approximate spatial and temporal scales of the universe
- H_0 is independent of the "shape parameters" (expressed as density parameters) Ω_m, Ω_Λ, Ω_k, w, etc., which govern the global geometry and dynamics of the universe
- Distances to galaxies, quasars, etc., scale linearly with H_0, $D \approx cz / H_0$. They are necessary in order to convert observable quantities (e.g., fluxes, angular sizes) into physical ones (luminosities, linear sizes, energies, masses, etc.)

Measuring the Scale of the Universe

- The only clean-cut distance measurements in astronomy are from trigonometric parallaxes. Everything else requires physical modeling and/or a set of calibration steps (the ***"distance ladder"***), and always some statistics:

Use parallaxes to calibrate some set of distance indicators

➔ Use them to calibrate another distance indicator further away

➔ And then another, reaching even further

➔ etc. etc.

➔ Until you reach a "pure Hubble flow"

- The age of the universe can be constrained independently from the H_0, by estimating ages of the oldest things one can find around (e.g., globular clusters, heavy elements, white dwarfs)

The Hubble's Constant Has a Long and Disreputable History …

THE VELOCITY-DISTANCE RELATION AMONG EXTRA-GALACTIC NEBULAE[1]

BY EDWIN HUBBLE AND MILTON L. HUMASON (1931, *ApJ* **74**, 43)

The new data extend out to about eighteen times the distance available in the first formulation of the velocity-distance relation, but the form of the relation remains unchanged except for the revision of the unit of distance. The relation is

$$\text{Vel.} = \frac{\text{Dist. (parsecs)}}{1790},$$ → $H_0 = 560$ km/s/Mpc

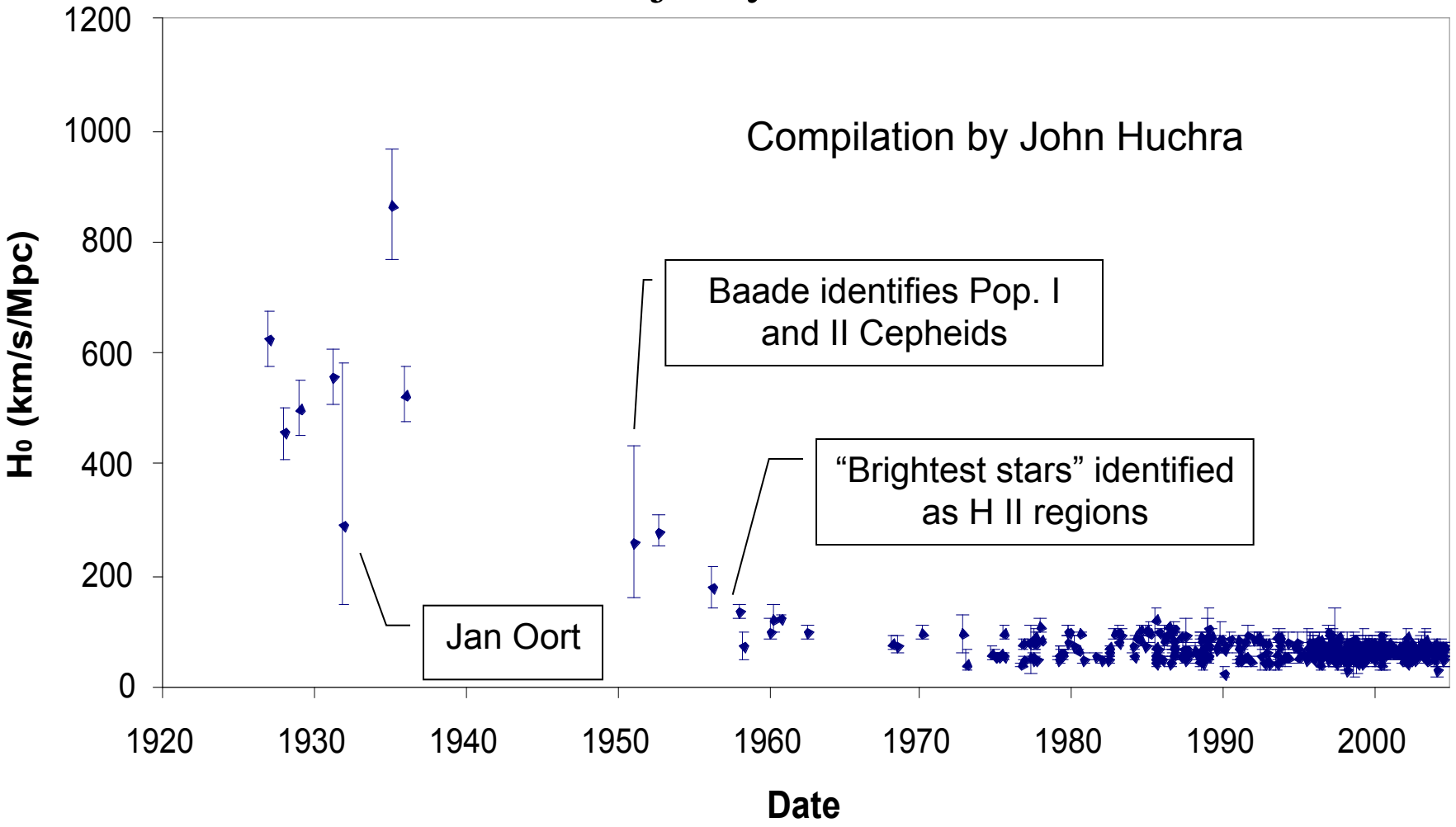
and the uncertainty is estimated to be of the order of 10 per cent.

Since then, the value of the H_0 has shrunk by an order of magnitude, but the errors were always quoted to be about 10% …

Generally, Hubble was estimating $H_0 \sim 600$ km/s/Mpc. This implies for the age of the universe $\sim 1/H_0 < 2$ Gyr - which was a problem!

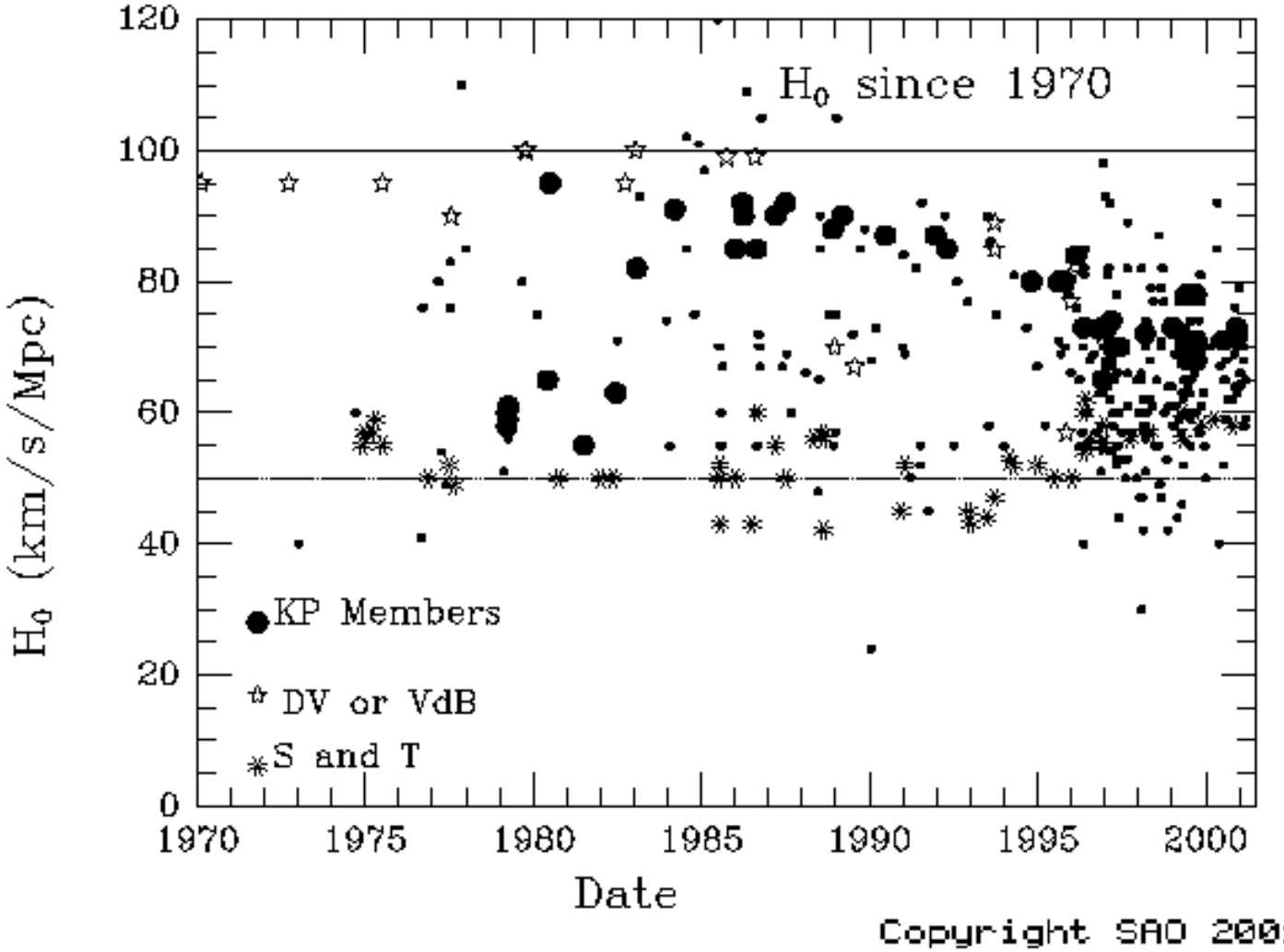
The History of H_0

Major revisions downwards happened as a result of recognizing some major systematic errors



The History of H_0, Continued …

But even in the modern era, measured values differed covering a factor-of-2 spread!

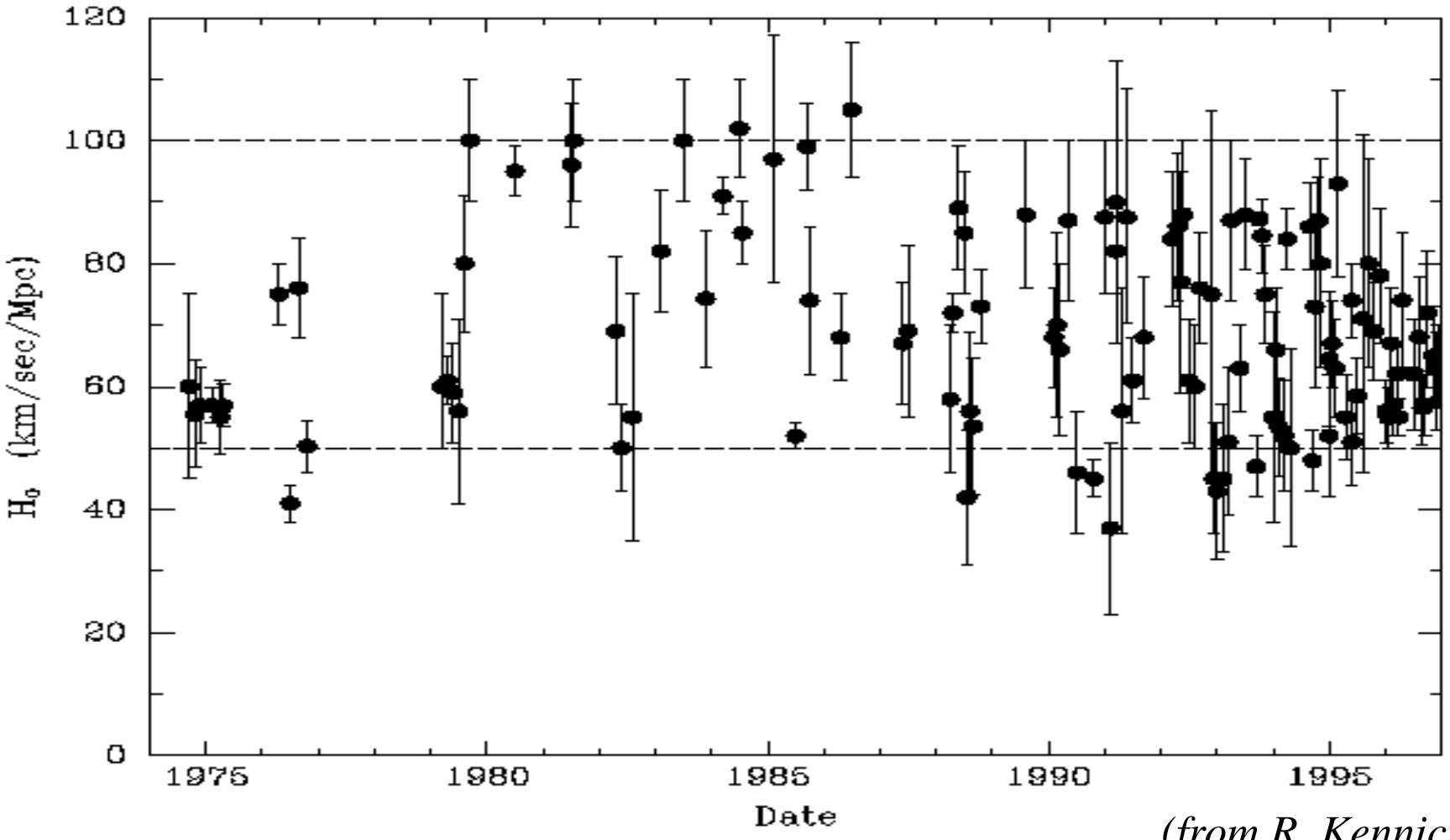


Values favored by de Vaucouleurs, van den Bergh

Values favored by Sandage, Tamman

The History of H_0, Continued …

Note that the spread greatly exceeded the quoted errors from every group!



(from R. Kennicutt)

Distance Ladder

Methods yielding absolute distances:

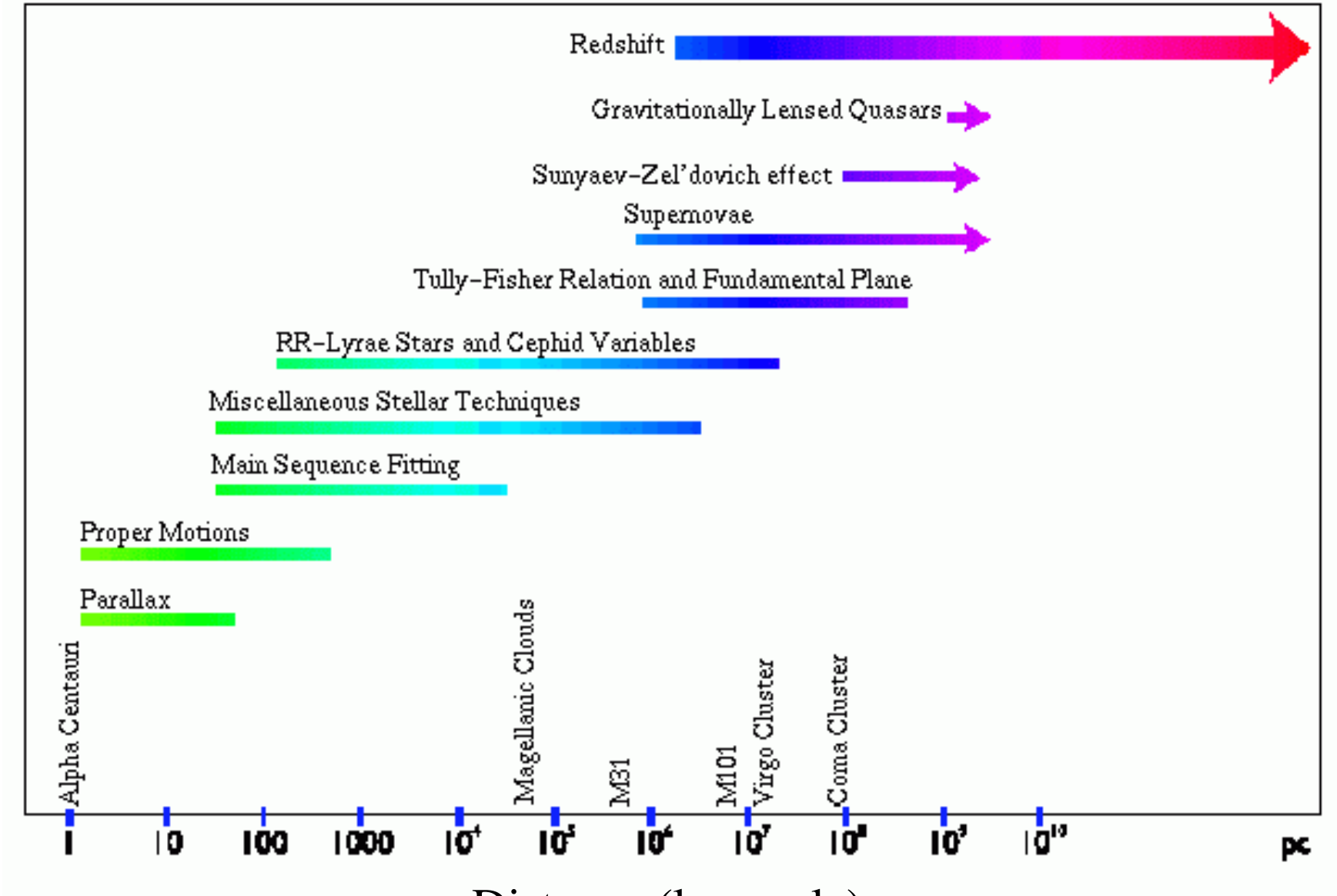
Parallax (trigonometric, secular, and statistical)
The moving cluster method - has some assumptions
Baade-Wesselink method for pulsating stars
Expanding photosphere method for Type II SNe
Sunyaev-Zeldovich effect
Gravitational lens time delays

} Model dependent!

Secondary distance indicators: ***"standard candles",*** requiring a calibration from an absolute method applied to local objects - ***the distance ladder*****:**

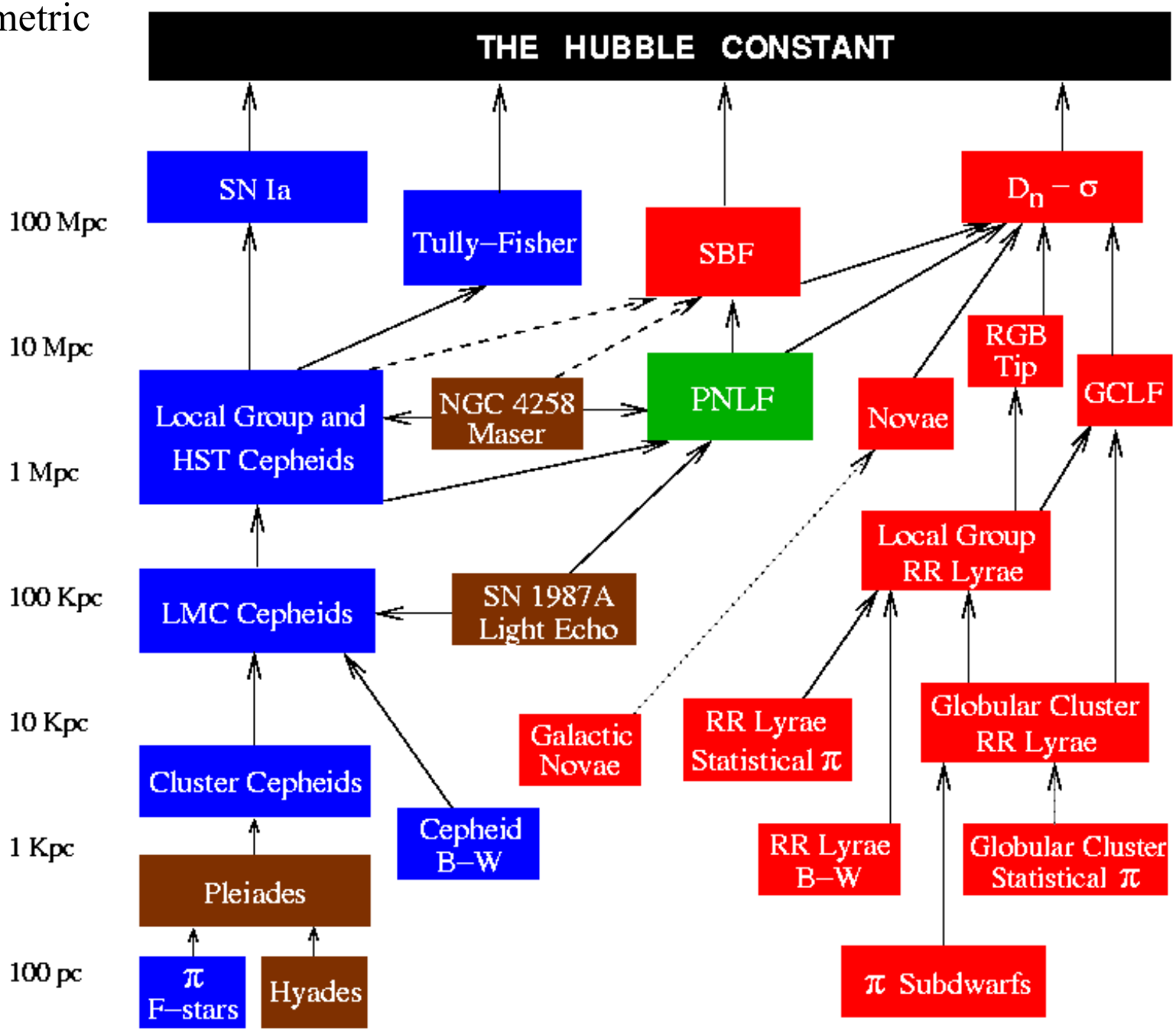
Pulsating variables: Cepheids, RR Lyrae, Miras
Main sequence fitting to star clusters
Brightest red giants
Planetary nebula luminosity function
Globular cluster luminosity function
Surface brightness fluctuations
Tully-Fisher, D_n-σ, FP scaling relations for galaxies
Type Ia Supernovae
… etc.

Distance Ladder



Distance (log scale)

Brown = geometric
Blue = Pop I
Red = Pop II



Next:
Stellar Distance Indicators