The Cosmic Triangle:
Why most of the universe is “dark”

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Introduction

1. A short history
2. The concordance model
   (a) Basic parameters
   (b) A bit of evidence
3. The future {Universe, Understanding}

History

A brief history of our history of Spacetime

- Everything is ordinary
- Missing mass
- Inflationary theory: 1980s
- Even with Dark Matter, not enough matter

Inflationary theory

- Homogeneous and Isotropic
- Flat, with energy density $\rho_{\mathrm{c}} \equiv 3H_0^2/8\pi G \approx 10^{-29} gcm^{-3}$
- But: Ordinary matter and radiation <10% of predicted value
- Curvature: k

The Friedmann equation

$$H^2 = \frac{8\pi G}{3}\rho - \frac{k}{a^2}$$

H(t) the Hubble parameter

ρ**(t)** the energy density

k(t) curvature constant

a(t) scale factor

The Scale Factor

$$\ddot{a} = -\frac{4\pi G}{3}(\rho + 3p)a$$

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$\rho + 3p > 0$ The expansion decelerates

$\rho + 3p < 0$ The expansion accelerates (requires exotic energy)

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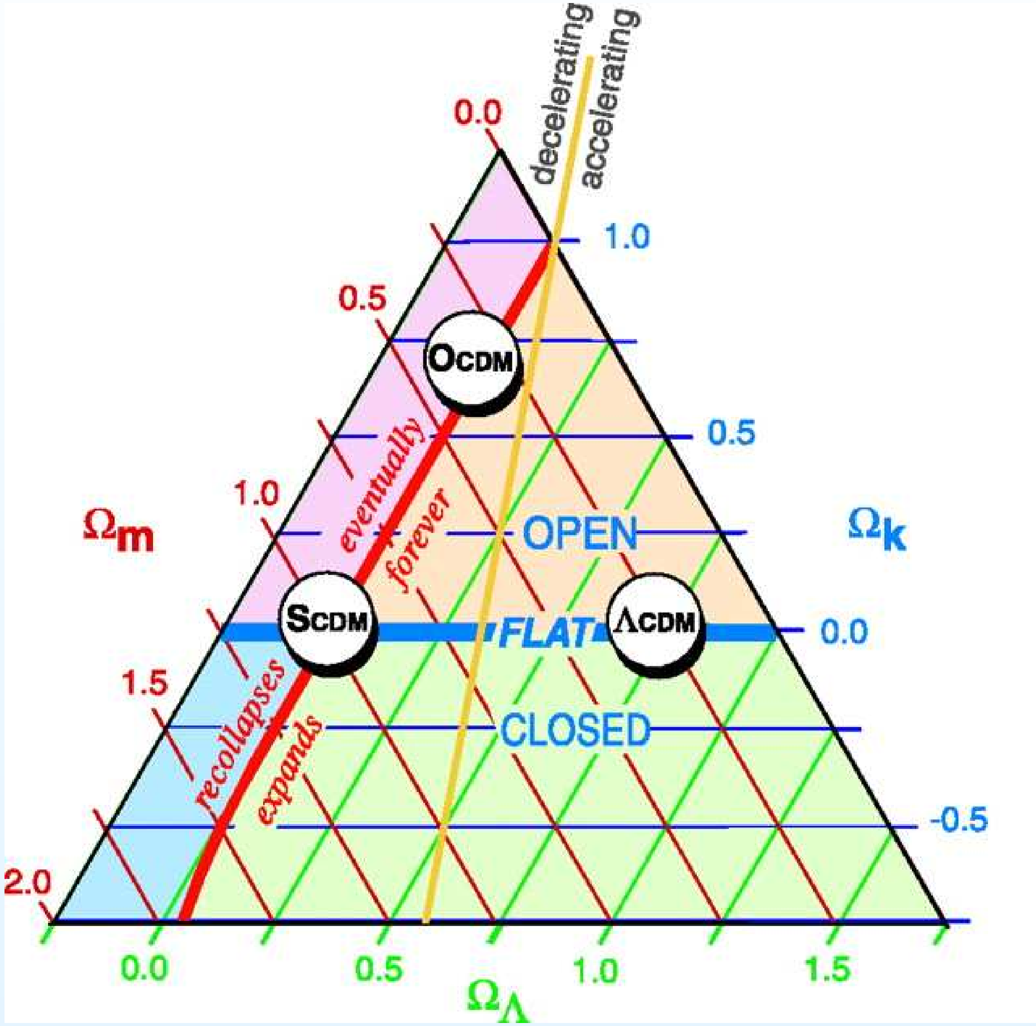
$$1 = \Omega_m + \Omega_\Lambda + \Omega_k$$

Basic cosmic parameters

- 1=Ω_m+Ω_Λ+Ω_k
- Matter density: Ω_m
- Vacuum energy density: Ω_Λ
- Hubble Constant: H_0

The Cosmic triangle



99-Bahcall - Figure 1

Models (1999)

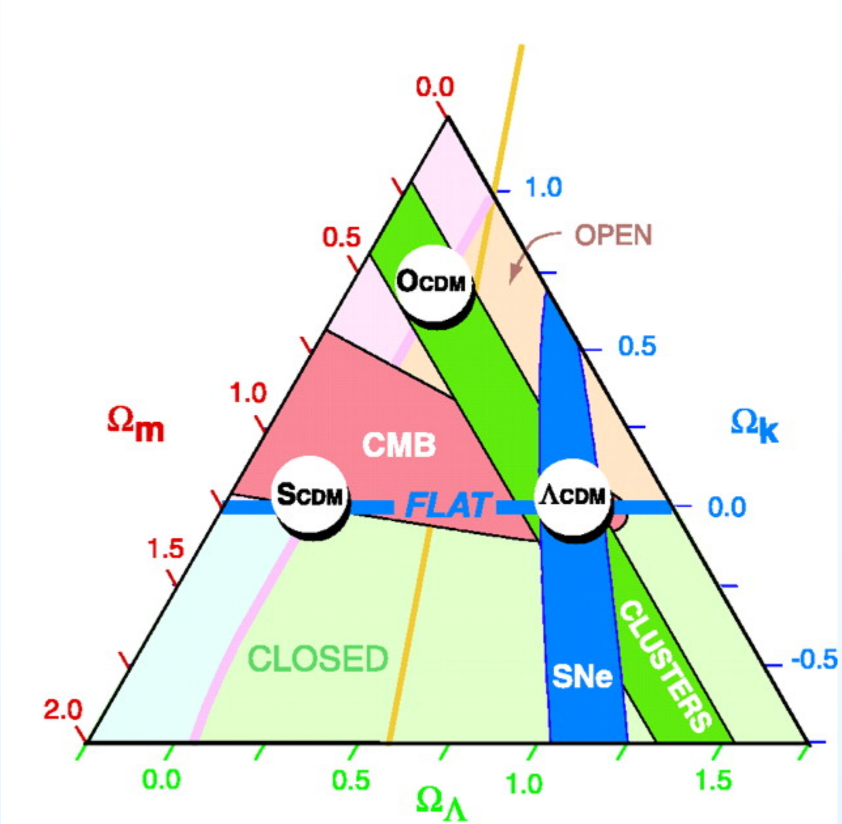
SCDM “Standard” CDM: $\Omega_m \equiv 1$

TCDM As above with tilted fluctuation spectrum

OCDM Open CDM, low mass density (2/3 curvature)

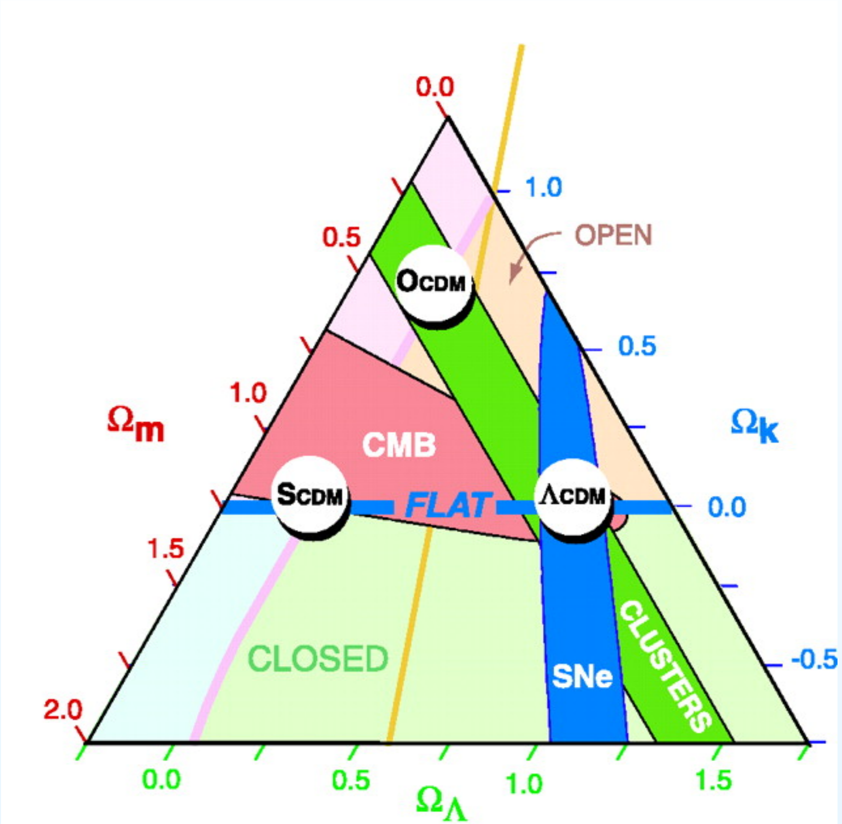
Λ**CDM** Current “best estimate” (2/3 dark energy)

Cuts out of the parameter space (1999)



99 Bahcall - Figure 2

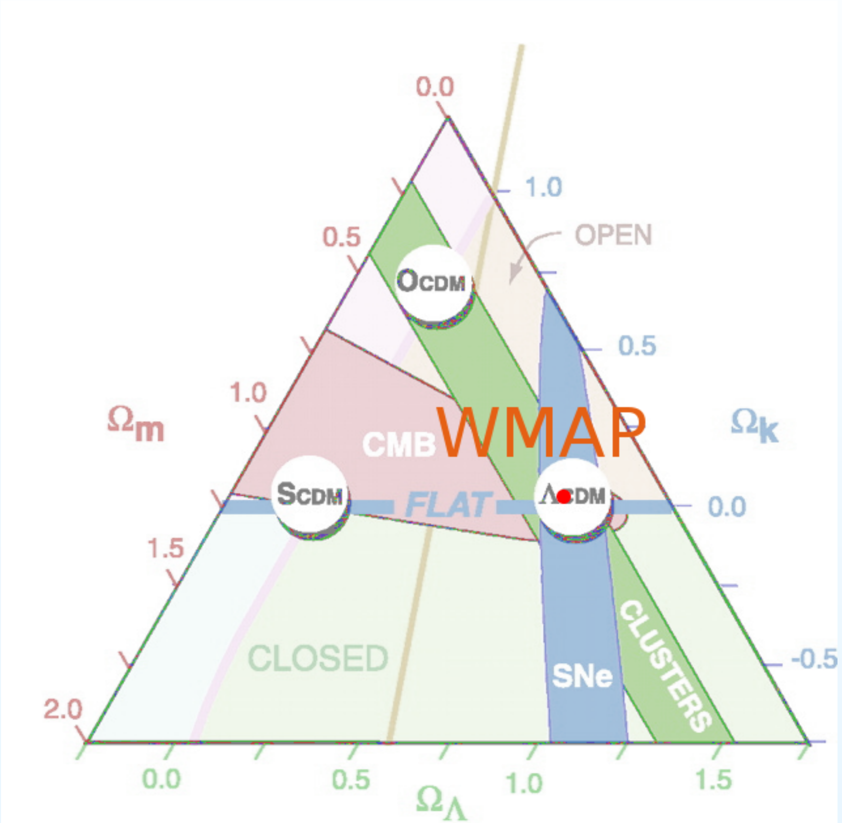
Cuts out of the parameter space (1999)



99 Bahcall - Figure 2

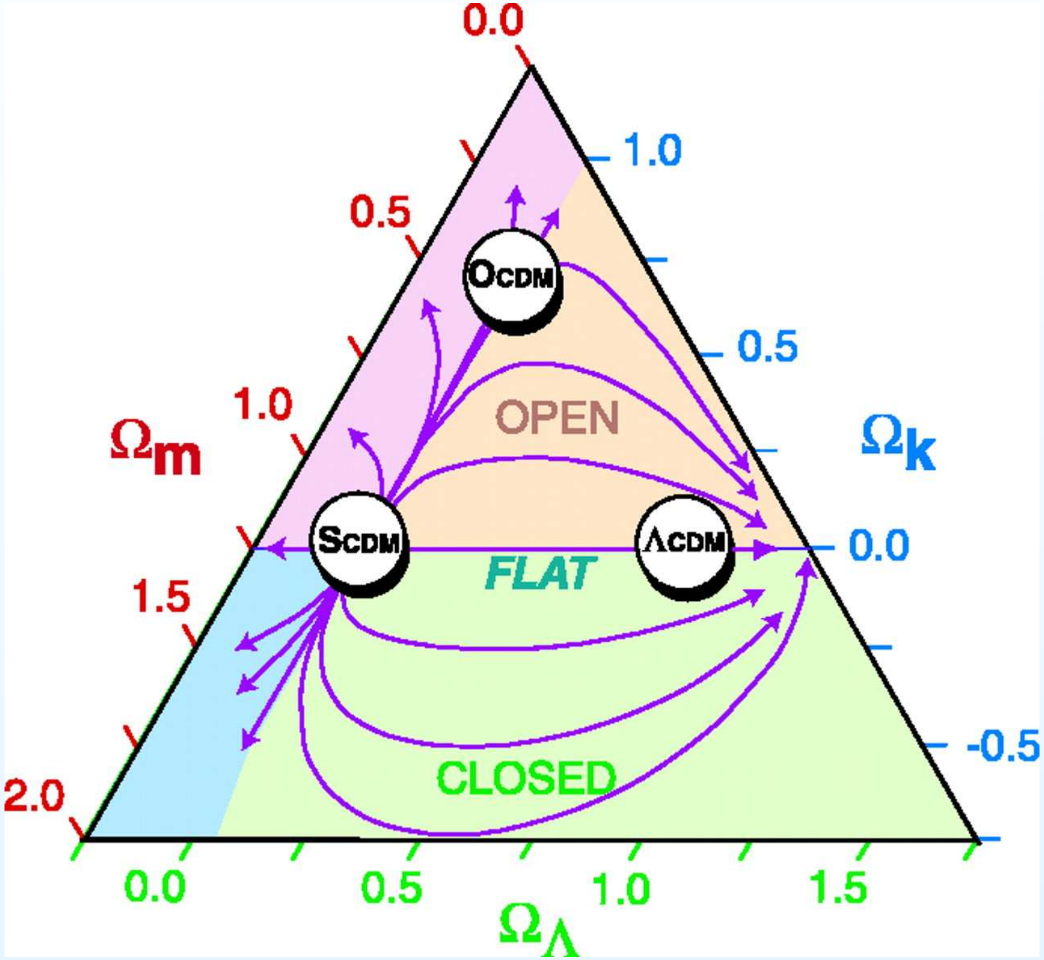
- Low redshift (clusters) - low density
- Intermediate redshift (SNe) - accelerating
- High redshift (CMB) - flat

Cuts out of the parameter space (2003)



- $\Omega_m = 0.27 \pm 0.04$
- $\Omega_\Lambda = 0.73 \pm 0.04$
- $H_0 = 71 \pm 4$

The Future



99 Bahcall - Figure 7

References

- Bahcall, et. al., Science, Vol 284, Issue 5419, 1481-1488
- http://www.jb.man.ac.uk/~jpl/cosmo/friedman.html
- Science, Vol 300, Issue 5627

The End

- *Form light elements and atoms*
- *Form first galaxies*
- *Rest...*
- Erase galaxy clusters
- Destroy Milky Way
- Unbind Solar System
- Explode Earth
- Dissociate Atoms
- Big Rip