## Velocity-distance Law: Subtleties

- *V=HL* 
  - The velocity-distance law is valid throughout the entire universe.
  - But, subtlety occurs when we try to **measure** this relation at great distances (say, at more than 10 billion years away, or z>1).
- Subtlety 1: What do we mean by *L*?
  - We cannot measure the current distance to a galaxy at z>1, because we can only see its past figure.
  - We can only measure L in the past!
- Subtlety 2: What do we mean by *H*?
  - The expansion rate changes with time.
  - By measuring the distance to a galaxy at z>1, we are measuring H in the past!
- Subtlety 3: What do we mean by *V*?
  - V = cz can no longer be used.
  - In fact, V cannot be measured observationally anymore!

## Alternative Methods

- Let's forget about measuring V=HL.
  - What else can be used to study cosmology?
- What can we measure? "Observables"
  - Redshift
  - Brightness
  - Size
- Candidate 1: *Brightness-Redshift relation* – Supernovae
- Candidate 2: Size-Redshift relation
  - Cosmic Microwave Background

## World Map & World Picture

- World map "Theorist's view"
  - The entire universe at any instant can be viewed.
  - -V = HL can be defined unambiguously.
- World picture "Observer's view"
  - Observations are limited to within the "light cone".
  - *V*=*HL* cannot be measured directly.



## **Brightness-Redshift Relation**

- The key relation: the inverse square law
  - Brightness = Luminosity/( $4\pi x \text{ Distance}^2$ )
  - We measure brightness; we know luminosity (SNIa)
    - Distance<sup>2</sup> = Luminosity/( $4\pi x$  Brightness)
    - This distance, determined from the luminosity, is called the *"luminosity distance"*
  - The luminosity distance is related to the world-map distance, but not the same.
  - The luminosity distance depends on z as well as cosmological parameters such as H,  $\Omega_{\rm m}$ ,  $\Omega_{\rm k}$ ,  $\Omega_{\Lambda}$
- Therefore, by comparing the inferred luminosity distance with the measured redshifts, one can derive the cosmological parameters.

