SUDDEN FUTURE SINGULARITIES MEET OBSERVATIONS

Hoda Ghodsi, September 30th 2012

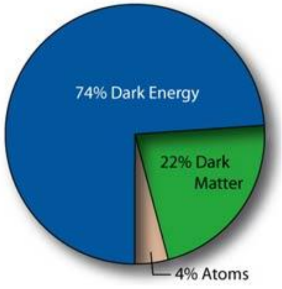
Outline

- Concordance Cosmology Overview
- Sudden Future Singularity Theory
- Observational Constraints
- Methods
- Results
- Conclusions

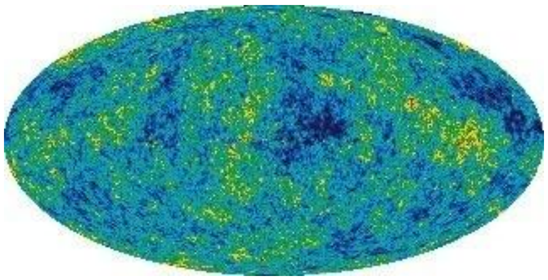
Concordance Cosmology

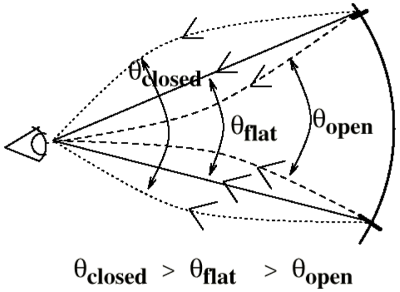
Cosmological observations of most importantly the Cosmic Microwave Background Radiation (CMBR), the Large Scale Structure and SNe Ia have helped establish a standard Concordance Cosmology with the following characteristics:

- Evolution: Accelerating expansion driven by a form of dark energy
- Geometry: Flat
- Contents: 74% Dark Energy, 22% Dark Matter, 4% Baryonic Matter
- Age: 13.7 Gyr old
- Fate: Empty, de Sitter type universe



Courtesy: http://map.gsfc.nasa.gov/





Courtesy: Martin Hendry's cosmology notes.

Sudden Future Singularity Model

- John Barrow (Class. Quantum Grav. 21, L79) first discovered a new type of possible evolution for the universe

$$p = -\frac{c^2}{8\pi G}\left(2\frac{\ddot{a}}{a} + \frac{\dot{a}^2}{a^2} + \frac{kc^2}{a^2}\right) \qquad \rho = \frac{3}{8\pi G}\left(\frac{\dot{a}^2}{a^2} + \frac{kc^2}{a^2}\right) \qquad H = \dot{a}/a$$

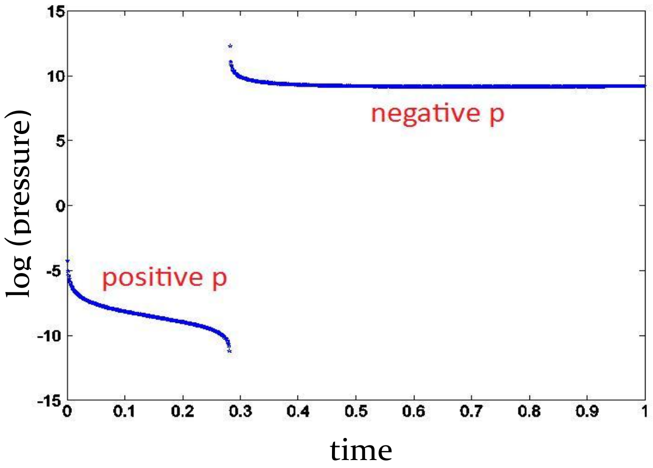
- Pressure singularities – named *Sudden Future Singularities (SFS)*
- Assuming no equation of state linking the pressure and density
- Only the dominant energy condition is violated in contrast to phantom violating all energy conditions
- Barrow then constructed an example model

$$a(t) = a_s(\delta + (1-\delta)y^m - \delta(1-y)^n) \quad , \quad y = \frac{t}{t_s}$$

Sudden Future Singularity Model

- Occurrence regardless of curvature, homogeneity or isotropy of the universe
- Manifestation as momentary infinite peak of tidal forces
- Weak singularities – evolution of the universe continues beyond them
- Pressure behaviour satisfies observation: current acceleration possible

Note that no explicit Dark Energy component has been assumed to exist. Dabrowski calls the acceleration due to "pressure driven dark energy"!



Model Parameters

$$a(t) = a_s(\delta + (1-\delta)y^m - \delta(1-y)^n) \quad , \quad y = \frac{t}{t_s}$$

- a_s cancels out in cosmological probes' equations
- A currently accelerating universe: $\delta < 0$
- To comply with early universe requirements: $m = \frac{2}{3}$
- Theoretically to obtain an SFS: $1 < n < 2$
- For t_s use dimensionless time $y_0 = t_0 / t_s$, $0 < y_0 < 1$

Observational Constraints

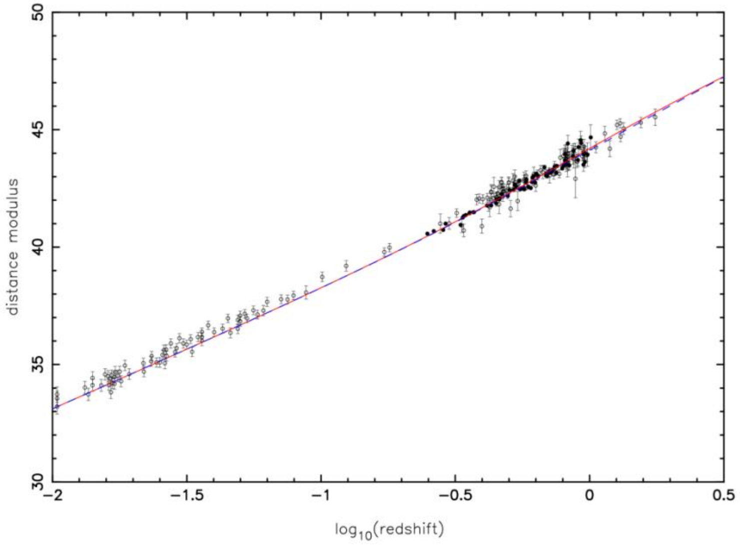
- SNe Ia redshift-magnitude relation
- The Location of the CMBR Acoustic Peaks
- Baryon Acoustic Oscillations
- Age of the Universe
- Hubble Constant

SNe Ia redshift-magnitude relation

Distance modulus:

$$\mu = m - M = 5\log_{10} D_L + 25$$

- Dabrowski et al. (2007): SNe Ia match SFS and Concordance model
- Test redone with *557* Union2 SNe Ia(Amanullah et al. 2010) → same results



Distance modulus vs. log(redshift) for the SFS and Concordance models as compared with SNIa data from Tonry *et al.* (2003) 'Gold' sample and Astier et al. (2006) SNLS sample. Graph from Dabrowski et al. (2007).

CMBR Acoustic Peaks

Shift parameter, R *:*

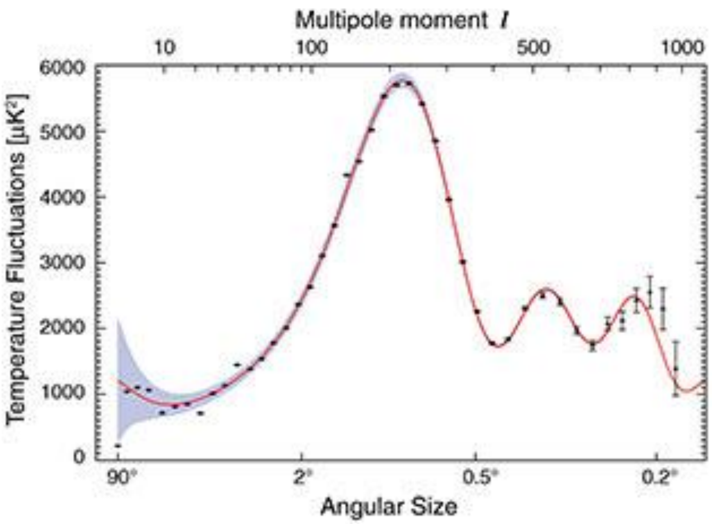
- Angular diameter distance to the last scattering surface (LSS) divided by Hubble horizon at the decoupling epoch = The apparent size of the sound horizon at recombination

$$R = \sqrt{\Omega_m} \int_0^{z_{CMB}} \frac{dz'}{E(z')}$$

Acoustic scale, l_a*:*

- Angular diameter distance to the LSS divided by sound horizon at the decoupling epoch

$$l_a = \frac{\pi r(z_{CMB})}{r_s(z_{CMB})}$$



Courtesy: http://map.gsfc.nasa.gov/

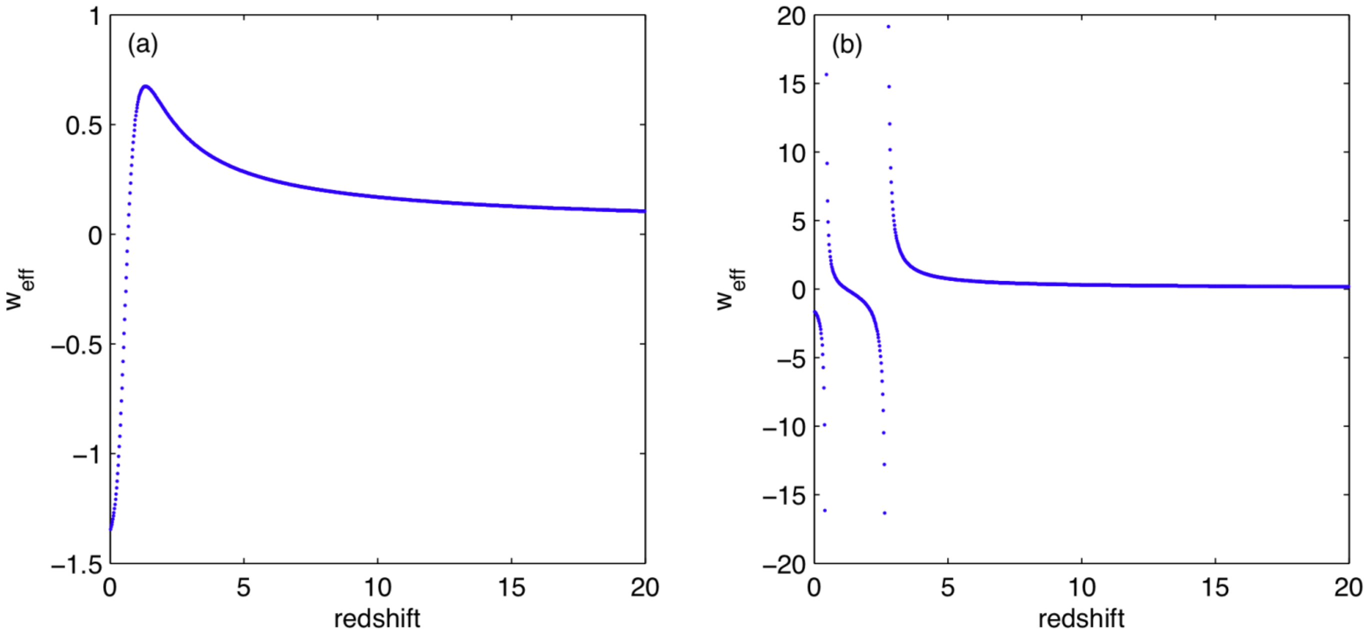
The '**observed**' values of these parameters were taken from WMAP7 results from Komatsu et al. (2010)

Effective Equation of State

Evolution of w_{eff} was studied to see how it compared with the observed behaviour.

$w_{eff} \to -1$ as $z \to 0$

$w_{eff} \to 0$ for large z

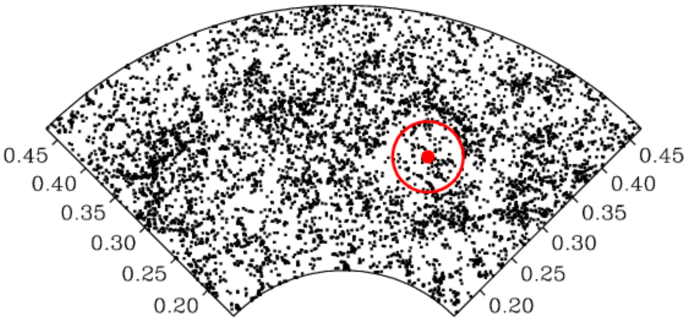


Baryon Acoustic Oscillations

- Cosmological perturbations excite sound waves in the early universe photon-baryon plasma → competition between gravity and radiation pressure. These oscillations leave their imprint on matter distribution now
- Natural standard ruler → useful distance indicators now
- Can be used to constrain the quantity known as the *distance parameter*, A , very well:

$$A = \frac{\sqrt{\Omega_m}}{E(z_{BAO})^{1/3}} \left[\frac{1}{z_{BAO}} \int_0^{z_{BAO}} \frac{dz'}{E(z')} \right]^{2/3}$$

Courtesy: http://www.sdss3.org/



Courtesy: http://cmb.as.arizona.edu/

Age of the Universe & Hubble Constant

- From Friedmann equation, the age is calculated using:

$$t_0 = H_0^{-1}\int_0^{\infty}\frac{dz'}{(1+z')E(z')} \quad \text{where} \quad E(z)=\frac{H(z)}{H_0}$$

- Observed age is taken from the globular clusters estimates (Krauss and Chaboyer 2003) which assume no cosmology.

- The Hubble constant in the SFS model takes the form:

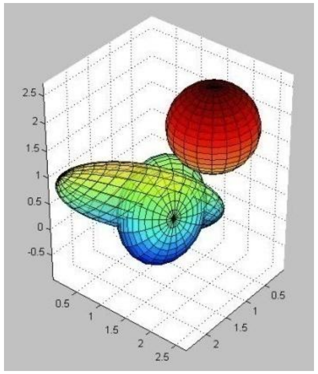
$$H_0 = \left(\frac{\dot{a}}{a}\right)_0 = \frac{m(1-\delta)y_0^{m-1} + n\delta(1-y_0)^{n-1}}{\delta + (1-\delta)y_0^m - \delta(1-y_0)^n)}$$

- Observed H_0 from HST Key Project (Riess et al. 2009) which again assumes no particular cosmology.

Data Analysis Methodology

- χ^2 goodness of fit test to fit model parameters to data

$$\chi^2 = \sum_{i=1}^{n} \frac{(x_i - x_{obs})^2}{\sigma^2}$$

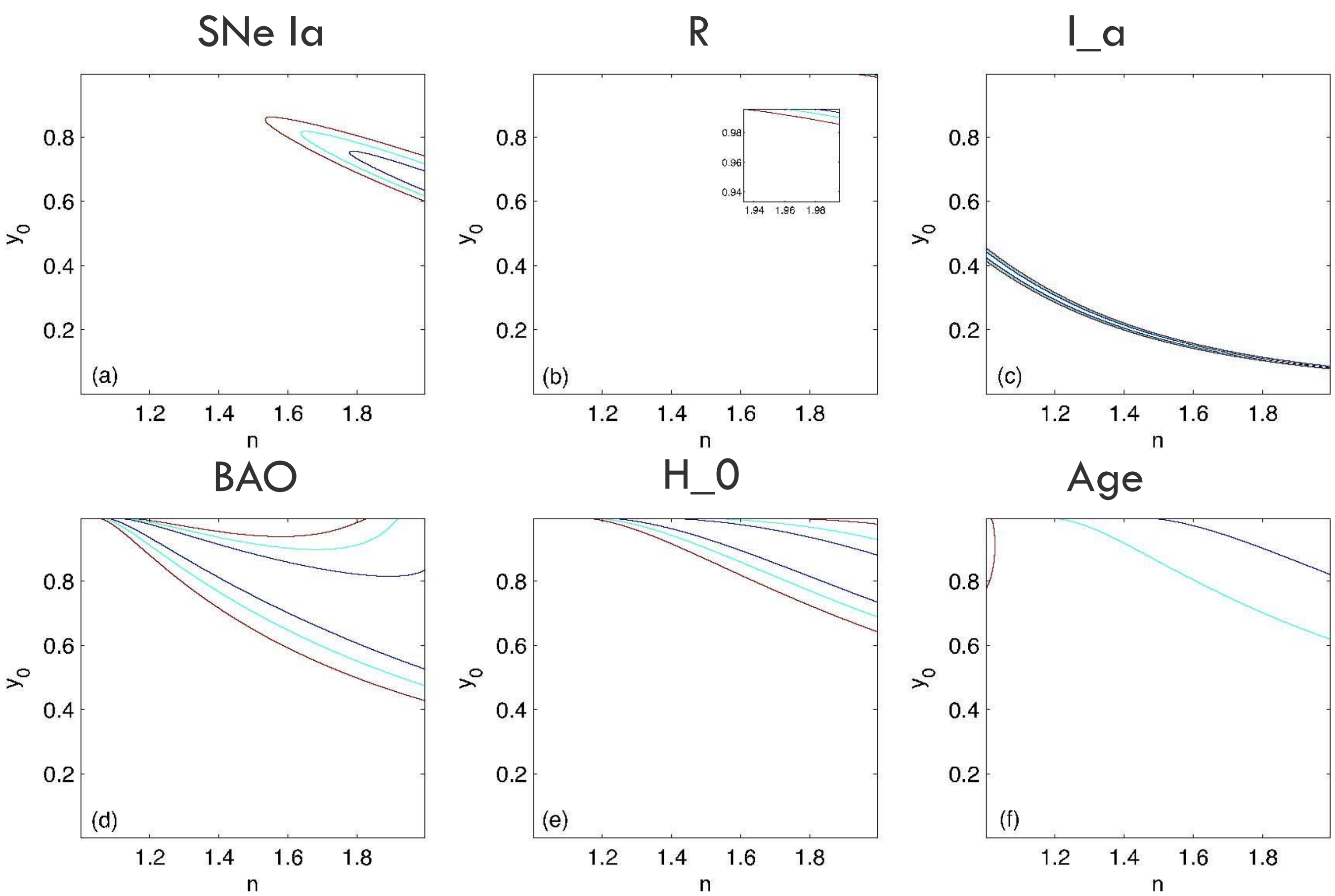


Courtesy: http://www.mathworks.in/matlabcentral/

- 3-D grid search: Marginalising over one parameter
- 2-D grid search: Keeping one parameter constant

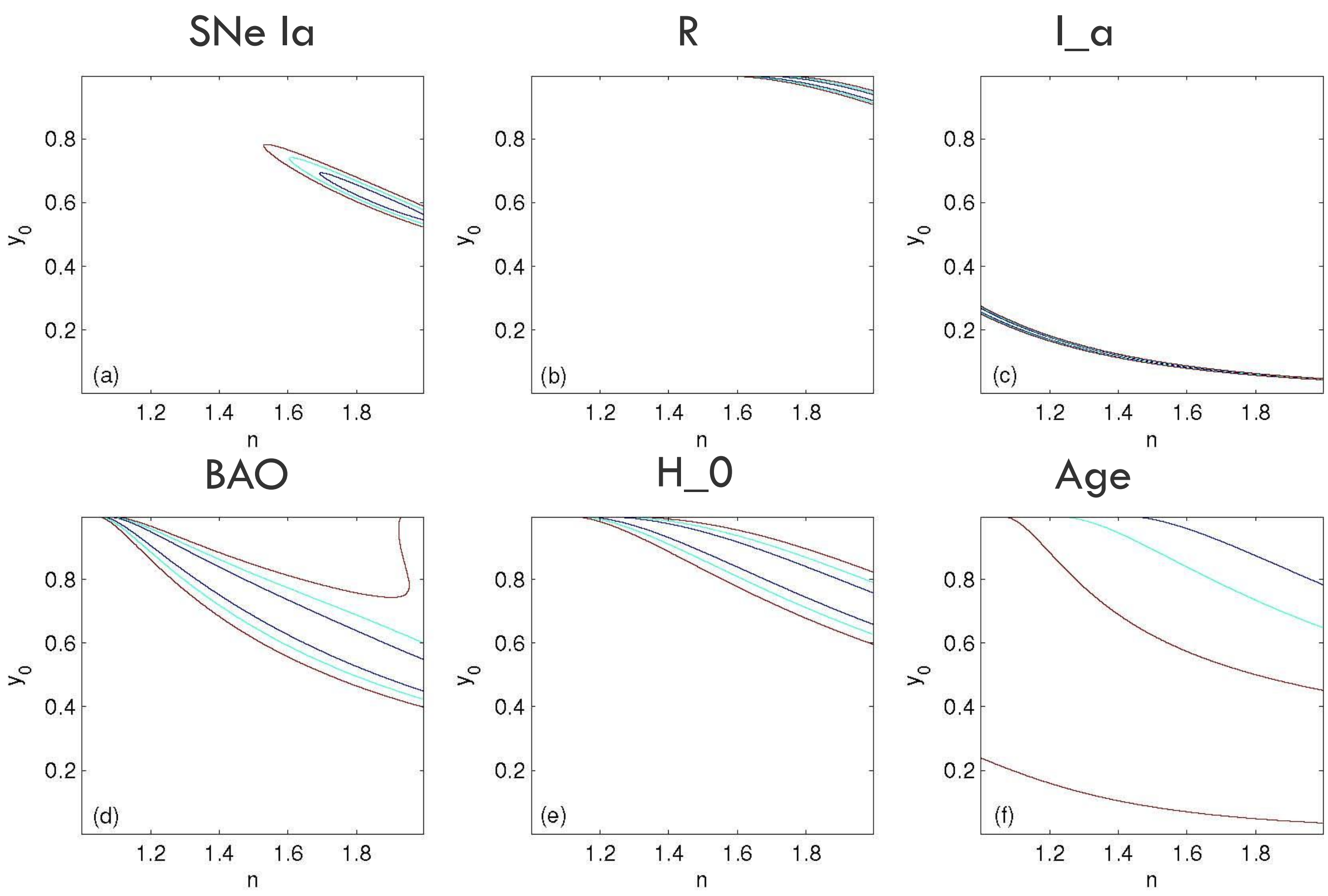
Results

$\delta = -0.7$



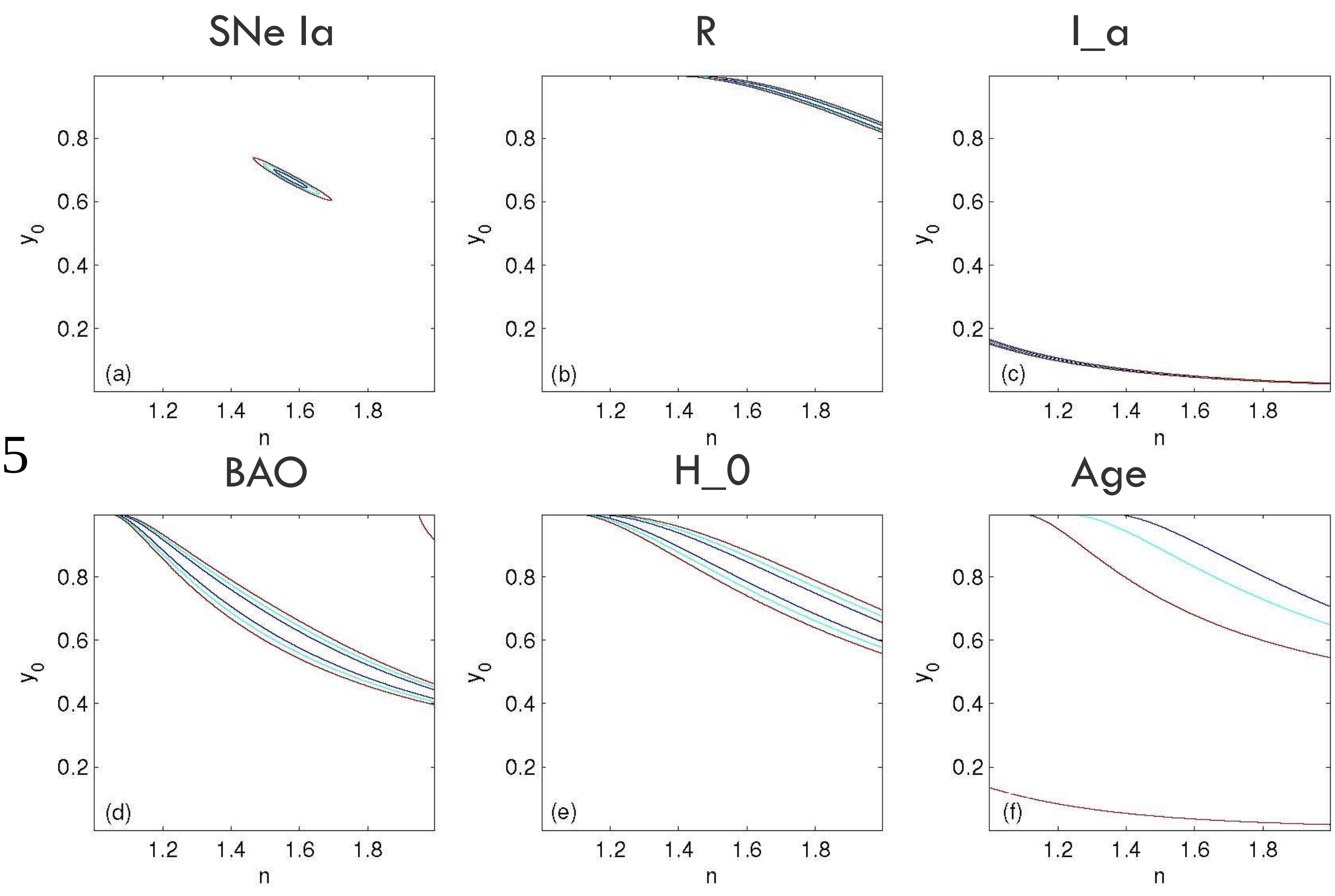
Results

$\delta = -1$

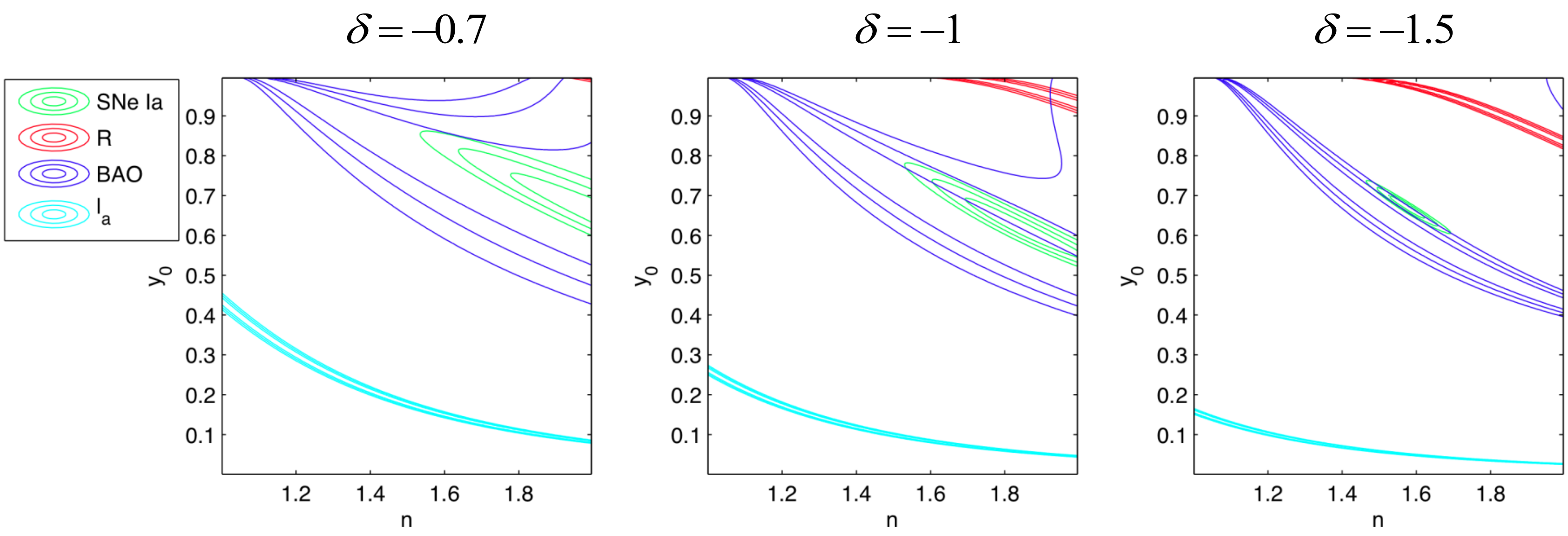


Results

$\delta = -1.5$



Results



no overlap in likelihood contours anywhere in parameter space

Conclusions

- The example SFS model (with m kept constant) investigated has been shown not to be compatible with current data.
- In Dabrowski et al. (Phys. Rev. D 85, 083527) we allow m to vary and we demonstrate that a fit may be obtained.

Thank you!