Toward 3D Spectra of Galaxies

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Collaborators

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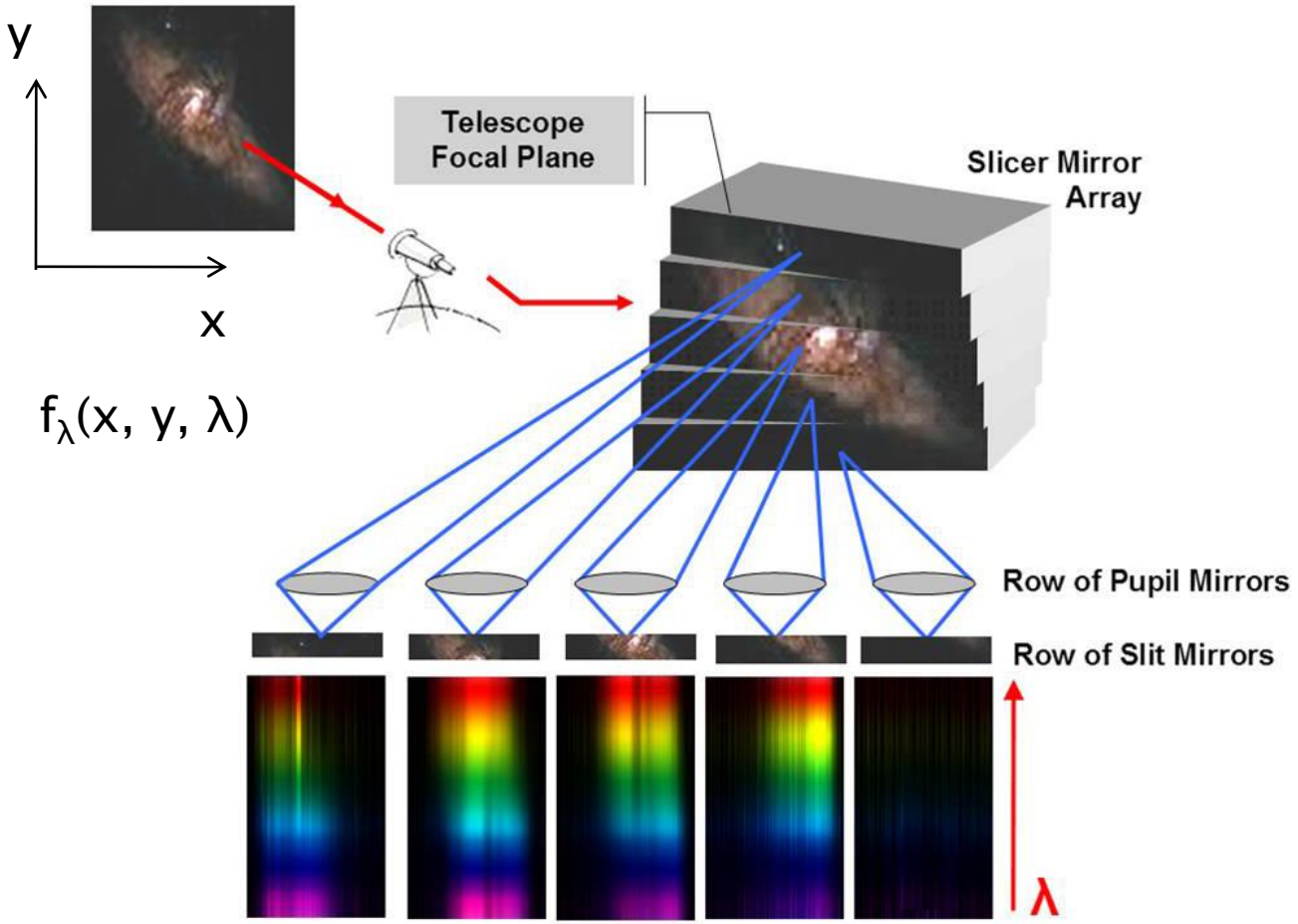
Question: how does a galaxy look like from various viewing angles?

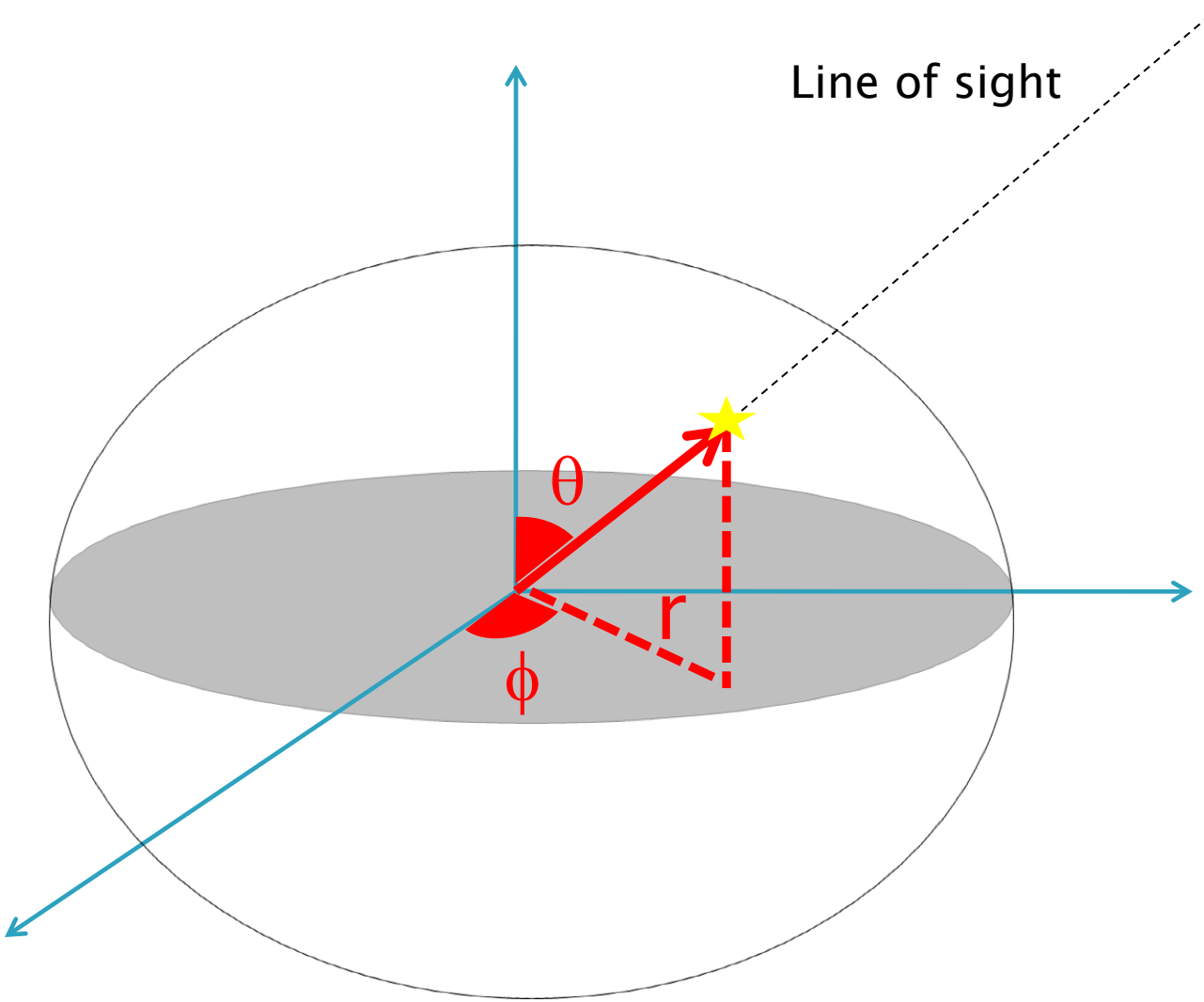
- We only see one side of a given galaxy
  - orbital period of Sun ~250 million years
- Large sky surveys (SDSS; LAMOST) provide $10^6/10^7$ galaxy spectra
  - Spectroscopic fiber projects fixed (3") diameter area on the sky
  - Galaxies are inclined at various angles; and located at various distances
- In principal we can statistically extract spatial information from the SDSS spectra

Comparison with Integral Field Spectroscopy (sometimes called "3D")



Ealet et al. 2008

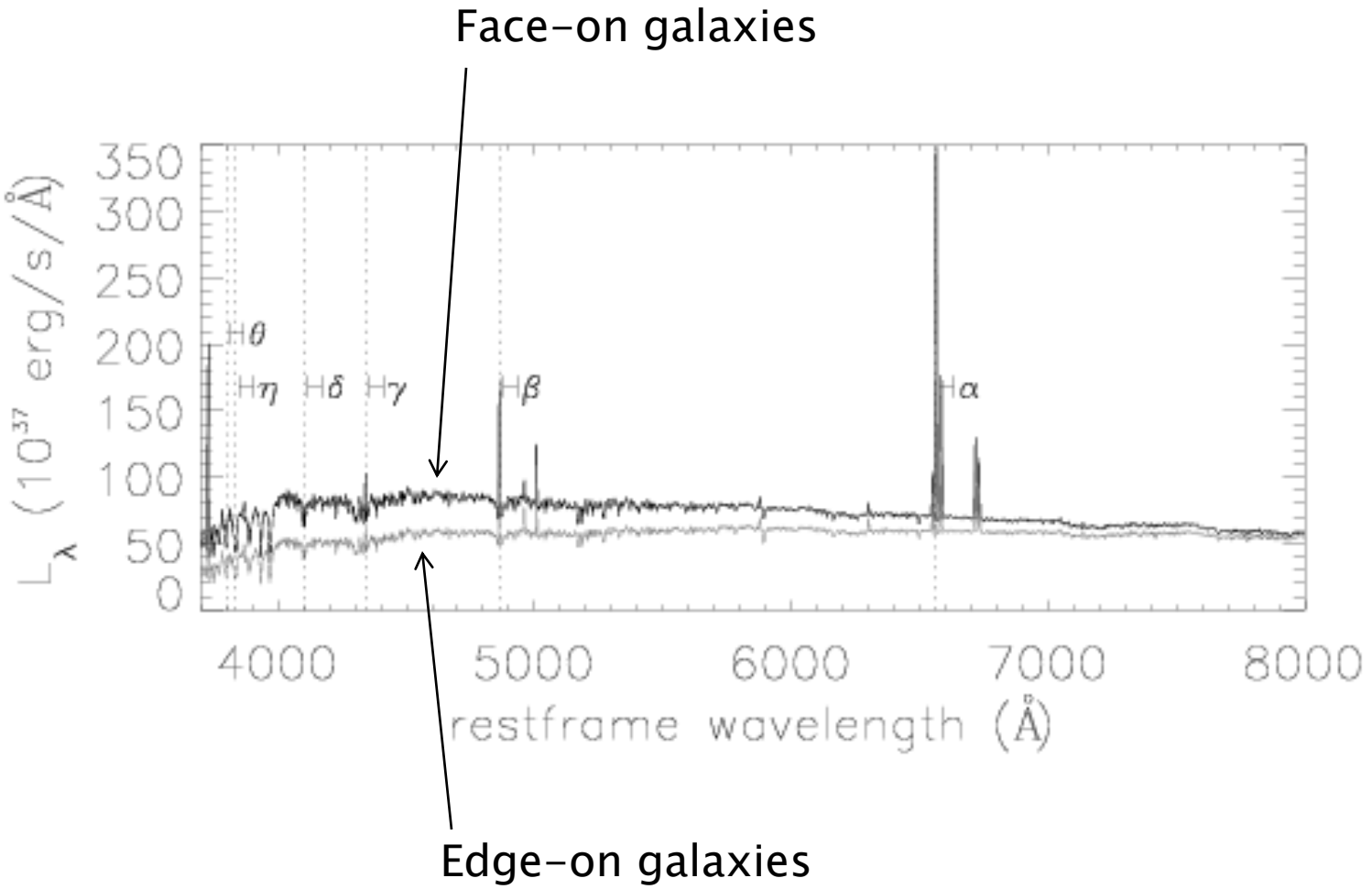
3D Spectrum $f_\lambda(x, y, z)$



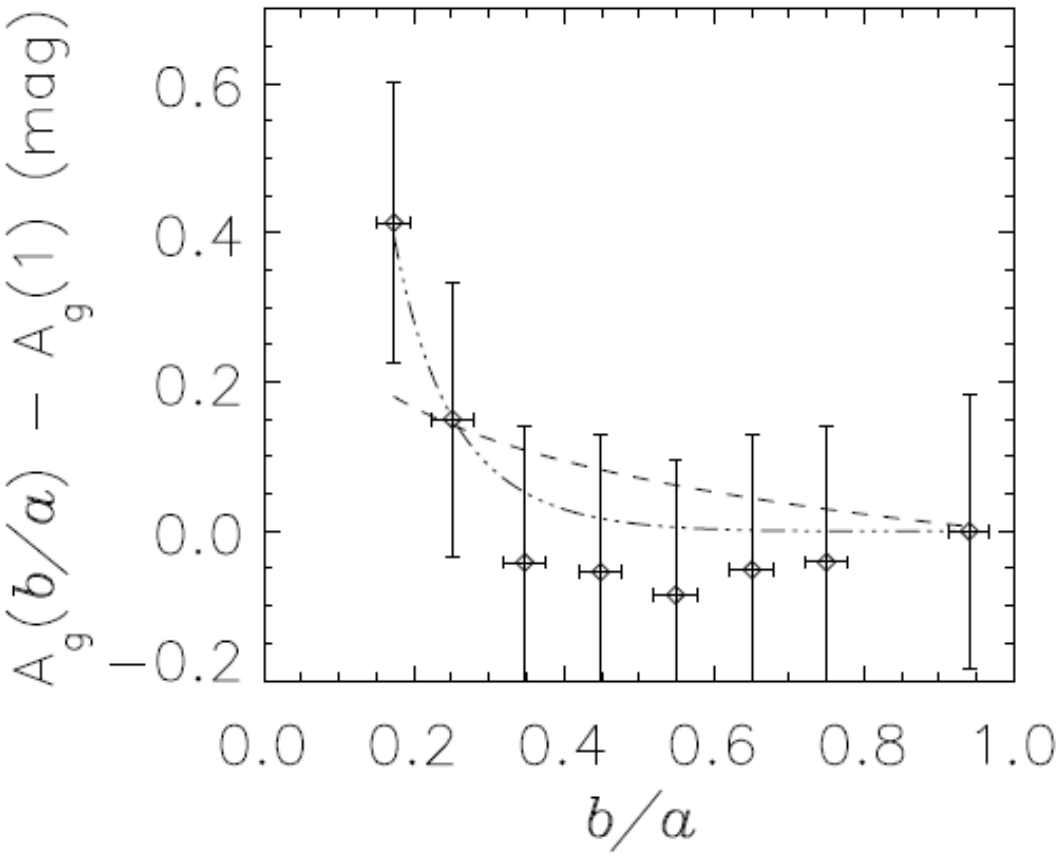
Galaxies are at Different Inclinations

(from SDSS Image Cutout tool)

Inclination Dependency of Average Spectrum

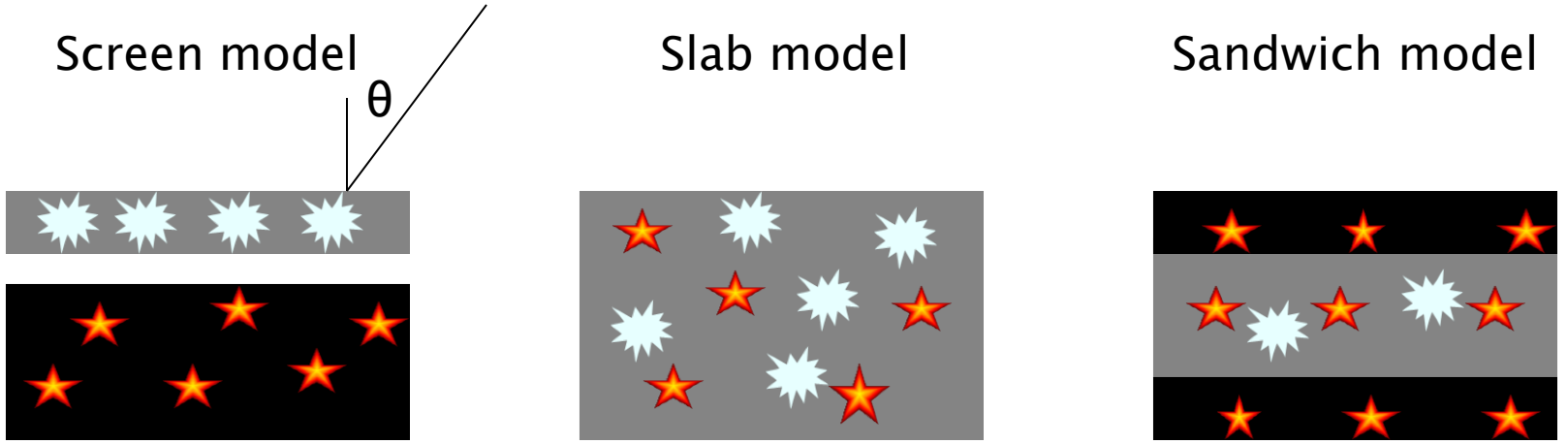


Inclination-Dependent Extinction in Stellar Continuum



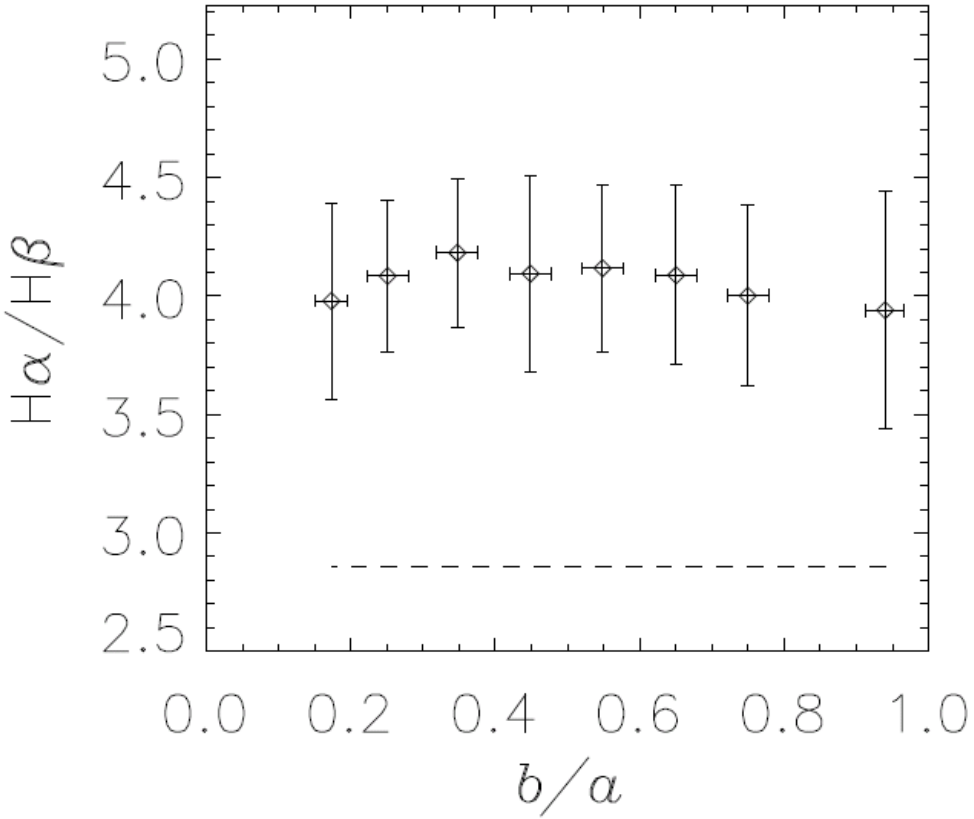
Yip et al. 2009 submitted

Optical Thickness of Stellar Continuum of Galaxies



Best-fit theoretical model is the slab model.
Best-fit face-on extinction ~ 0.2 mag (SDSS g band).

Inclination Dependency of Extinction in HII Region (singly-ionized hydrogen)

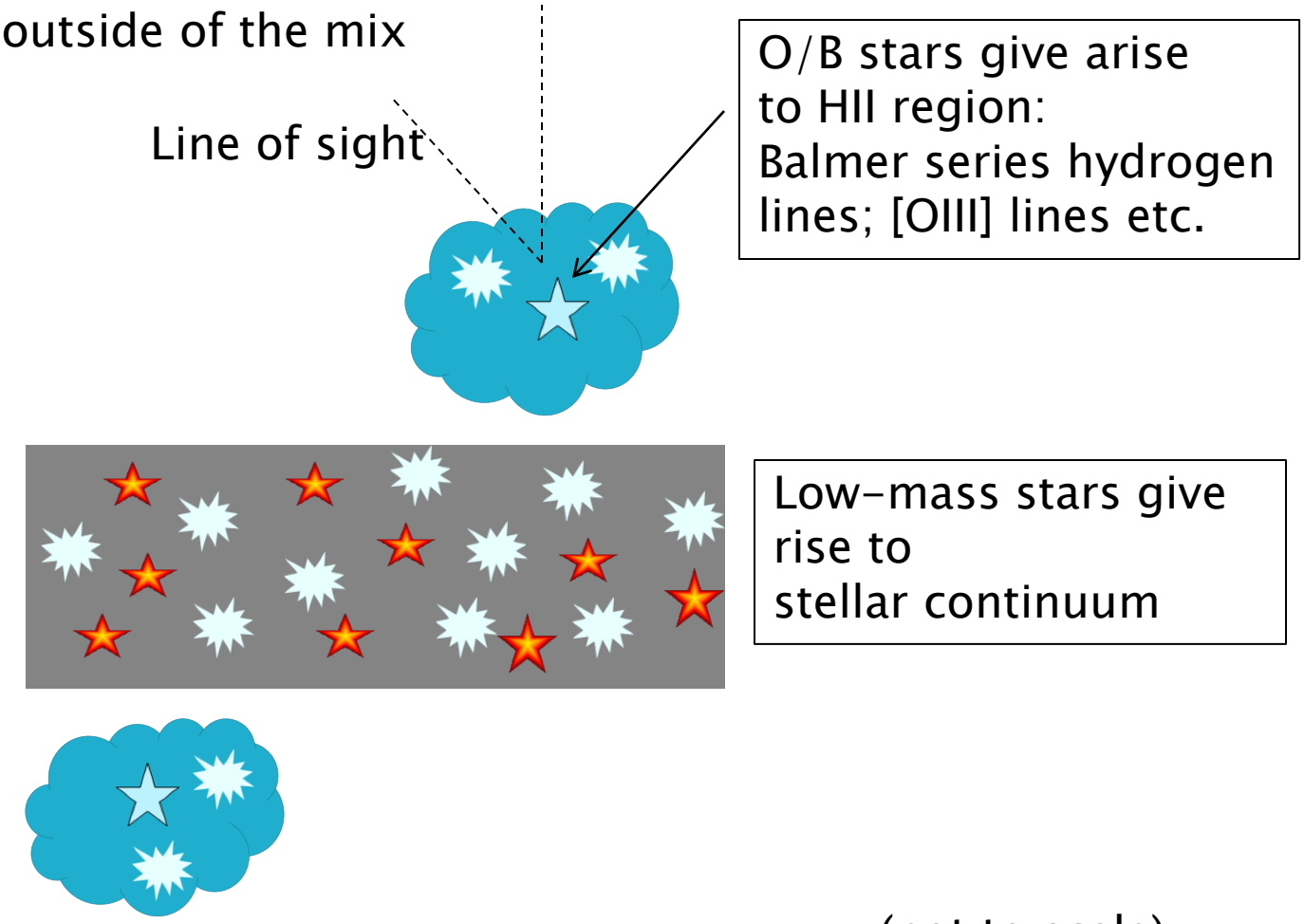


Theoretical, no dust value

- Balmer decrement does not show inclination dependency.
- HII region vs. Continuum-generating stars:
  - Different dust configuration and/or mechanism.

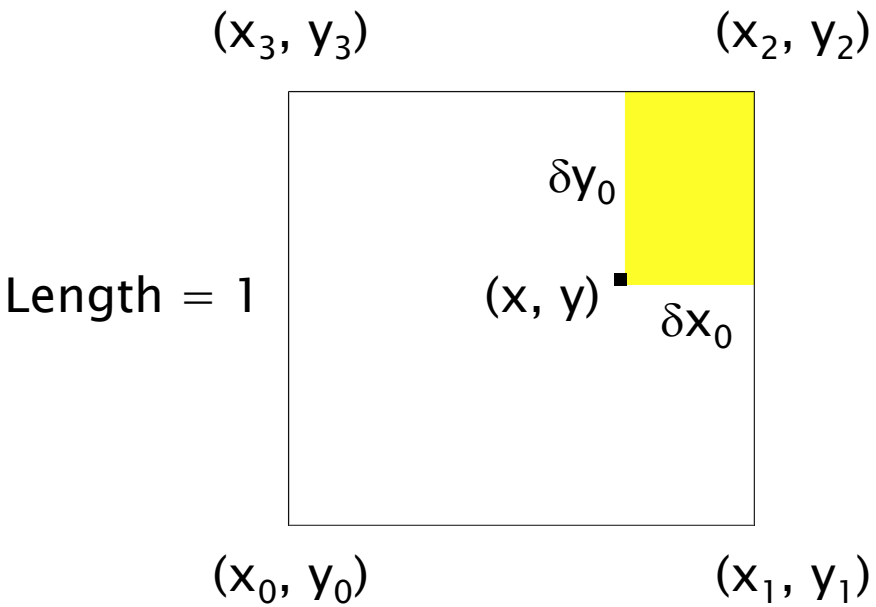
Overall model

- Uniform mix of dust/stars
- HII region outside of the mix



Galaxy Composition through N-D Parameter Estimation

- N-D hypercube
- Multi-linear interpolation to achieve arbitrary computational resolution in parameters



2-D:

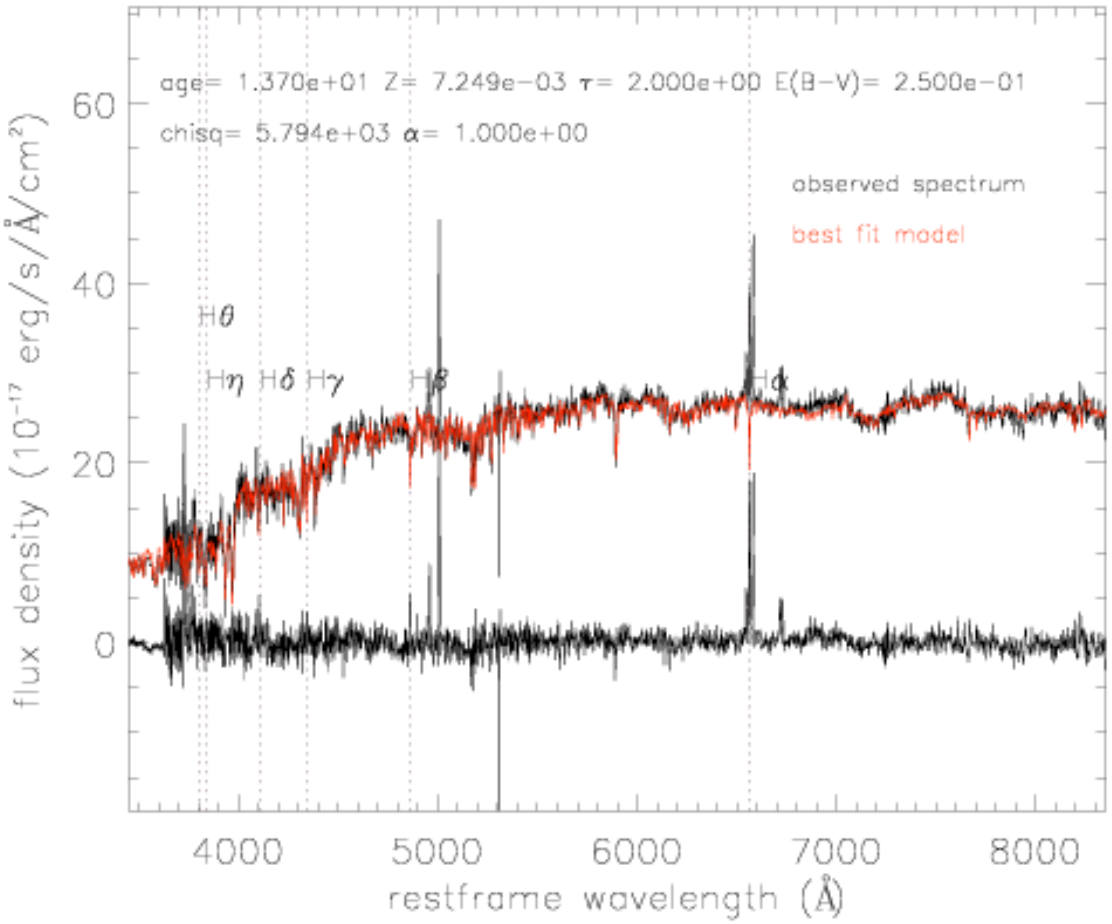
$$f(x, y) = f(x_0, y_0) * (\delta x_0 * \delta y_0) + f(x_1, y_1) * (\delta x_1 * \delta y_1) + f(x_2, y_2) * (\delta x_2 * \delta y_2) + f(x_3, y_3) * (\delta x_3 * \delta y_3)$$

N-D:

$$f(x) = \Sigma\, f(zi)\, \Pi\, (1 - |xj - zij|)$$

where *zi* are the neighboring parameter points

N-D Parameter Estimation on SDSS Spectra

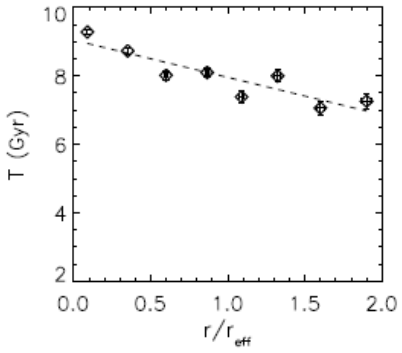


For 4D model (age, metallicity, star-forming time scale, extinction)

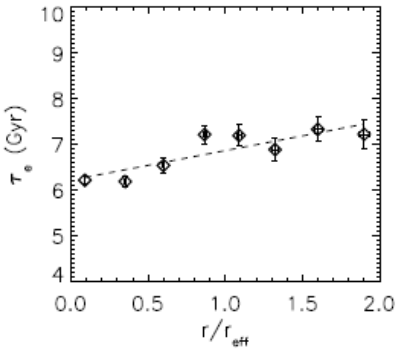
- ~300,000 model spectra are generated on the fly
- ~30 minutes (high resolution model + SDSS spectrum, 70km/s)
- parameter uncertainties are estimated on object-to-object basis

N-D Parameter Estimation on Photometry

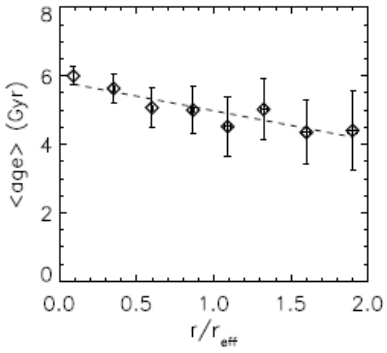
- Stellar population and dust properties as a function of galaxy radius
- Results support inside-out growth (Yip & Wyse 2009 in prep.)
- Similar to tree-ring studies



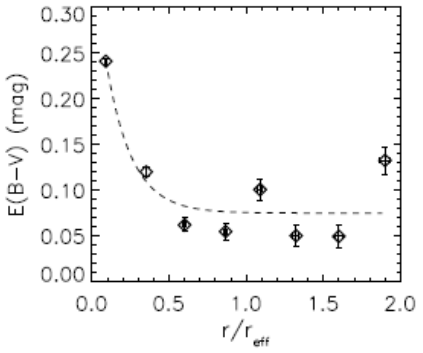
(a) The age of the oldest stars.



(b) The e-folding time.



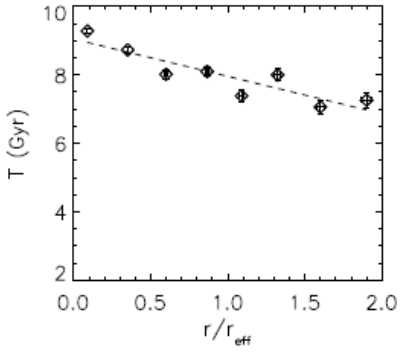
(c) The mean stellar age.



(d) $E(B-V)$.

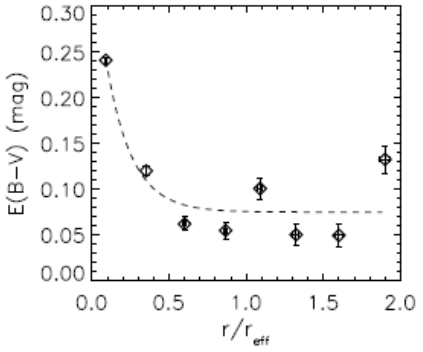
N-D Parameter Estimation on Photometry

- Stellar p es as a functior
- Results Yip & Wyse 20
- Similar t



(a) The age of the oldest stars.

(b) The e-folding time.



(c) The mean stellar age.

(d) $E(B-V)$.

Challenges Toward 3D Spectra

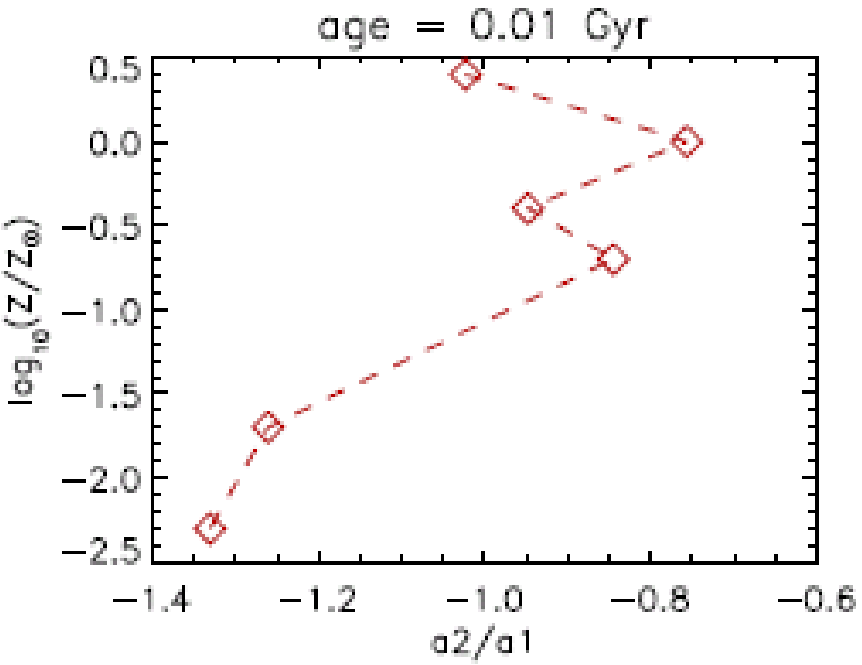
- Spectrum as a function of galaxy radius
  - Galaxies from large surveys are located at various distances
  - Need to ensure we are comparing apples to apples
- Spectrum as a function of ϕ angle
  - Need average spectrum for spiral arm, bar etc.
  - Galaxy Zoo images/results will be useful
- Spectral analyses in 3D
  - Classification of galaxies
  - Diversity in galaxies
  - Composition modeling for stellar populations and dust

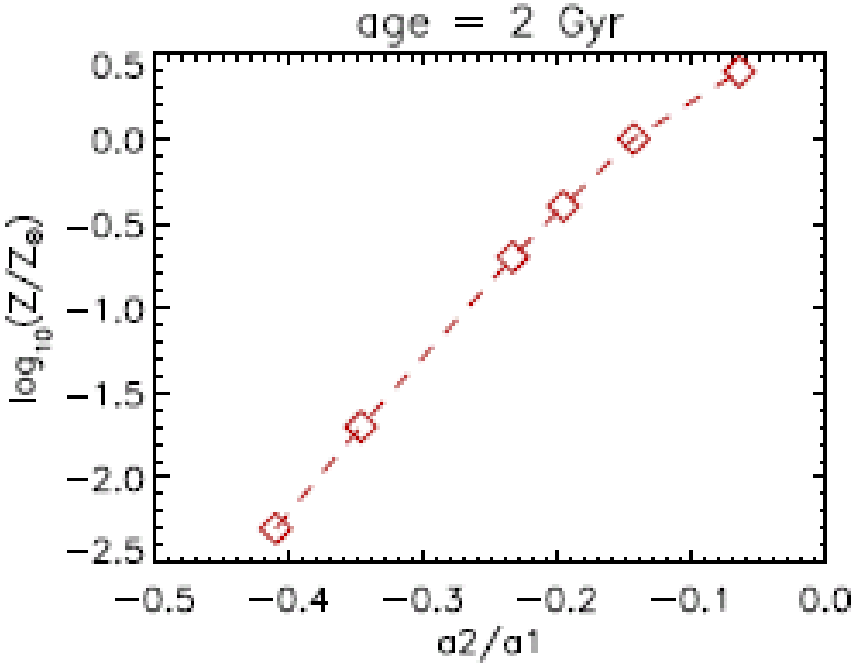
Challenges: Galaxy Composition

- Fast Parameter Estimation
  - We would like to understand how spectra are mapped to the parameters
    - Data compression techniques (e.g., PCA) to reduce the dimensionality of spectra (Szalay)
    - Use Catastrophe theory (Szalay)
  - Parameter degeneracy is present (e.g., age-metallicity degeneracy)
- Dealing with 10^5 or more model spectra
  - Store them in database to alleviate the need for interpolations
  - Difficulty: generality for complex models
  - Some spectral components (stellar bursts) are additive

How are spectra mapped to physical parameters

- Principal Component Analysis (PCA) on model spectra to reduce their dimensionality
- Expansion coefficients vs. parameters tell us about parameter degeneracy





Yip & Szalay in progress

Summary

- We have derived empirical galaxy spectrum as a function of inclination (θ), averaged over ϕ and projected radius < 0.5 half-light radius.
- We will derive empirical galaxy spectrum as a function of both the radius (r) and azimuth angle (ϕ).
- We have developed a N-D parameter estimation code for calculating the composition of galaxies (stars, gas & dust).