Mapping dark and stellar haloes with integral-field spectrography

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ATLAS3D

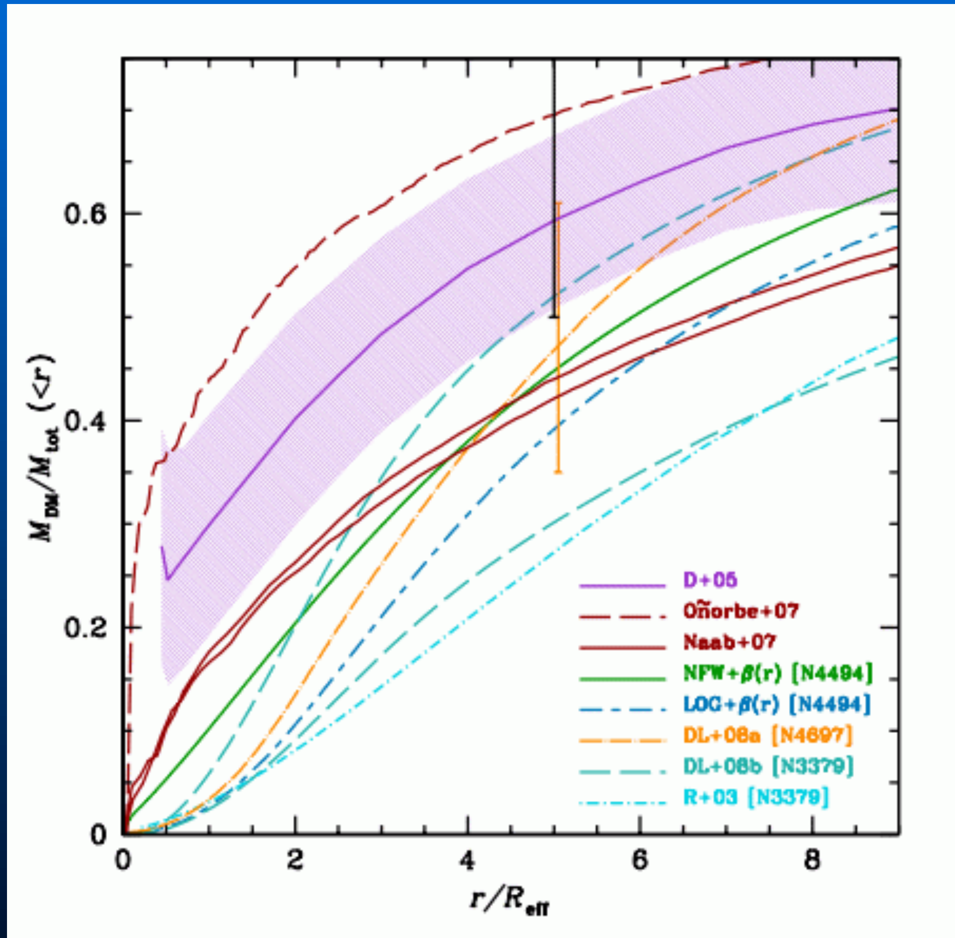
Galaxy Formation 2011, Durham, UK, 18 July 2011

Dark matter in early-type galaxies

- HI rotation curves revealed DM haloes in spirals
- DM haloes in early-type galaxies less accessible
  - some HI rotation curves available (e.g. Oosterloo et al. 2002; Józsa et al. 2004; Weijmans et al. 2008)
  - integrated light stellar kinematics out to 1-2 R_e (Carollo et al. 1995; Kronawitter et al. 2000)
- Use other tracers of dark matter
  - globular clusters (Côté et al. 2003)
  - planetary nebulae (Douglas et al. 2007; Napolitano et al. 2009)
  - X-ray emission (Humphrey et al. 2006)
  - gravitational lensing (Gavazzi et al. 2007; Barnabe et al. 2009)

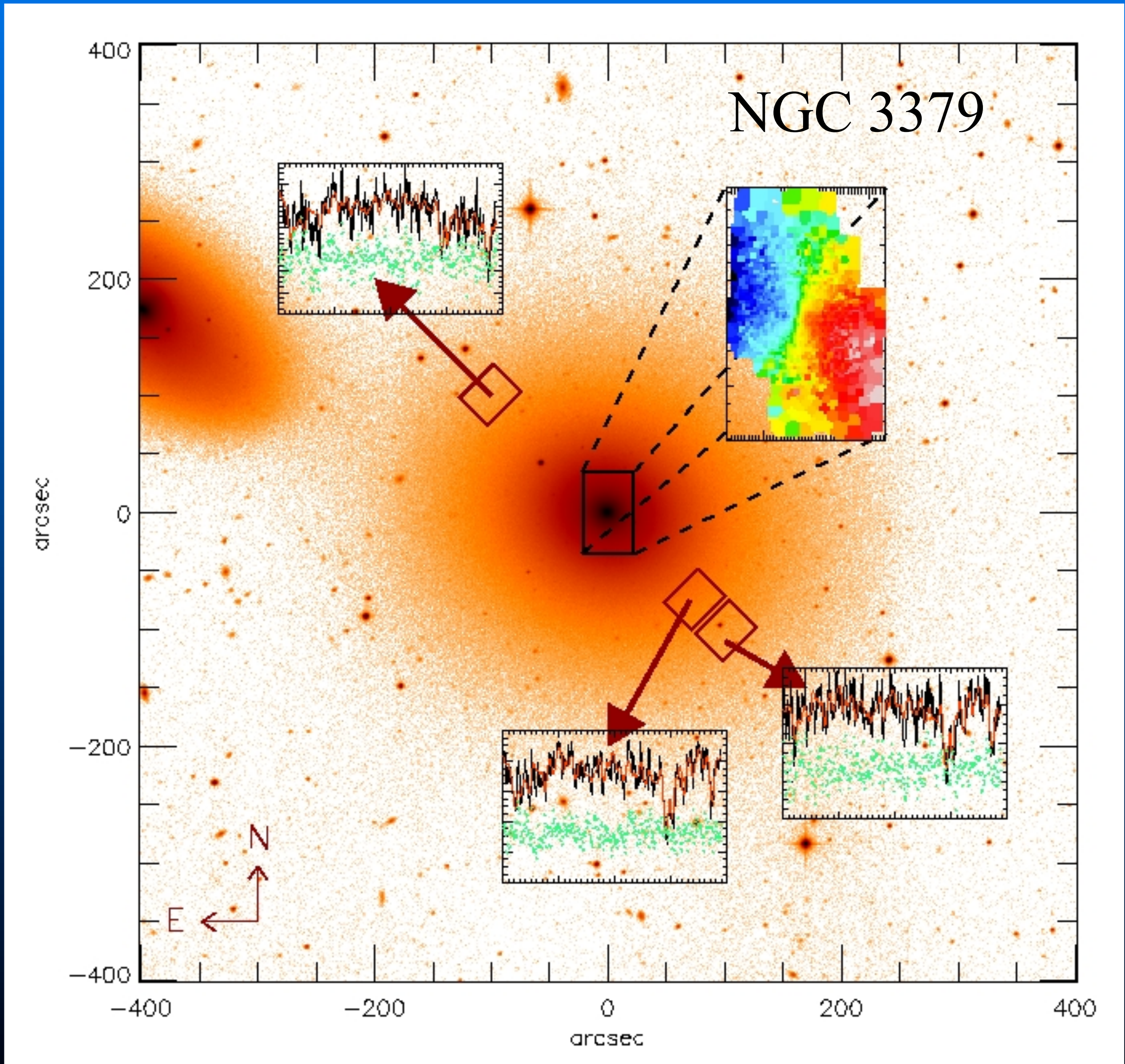
Why do we care about the dark halo?

- How much dark matter in early-type galaxies?
- Relation between dark and luminous matter?
- What are the dark matter fractions?
  - separate dark from luminous mass
- Are dark haloes non-spherical?



Napolitano et al. 2009

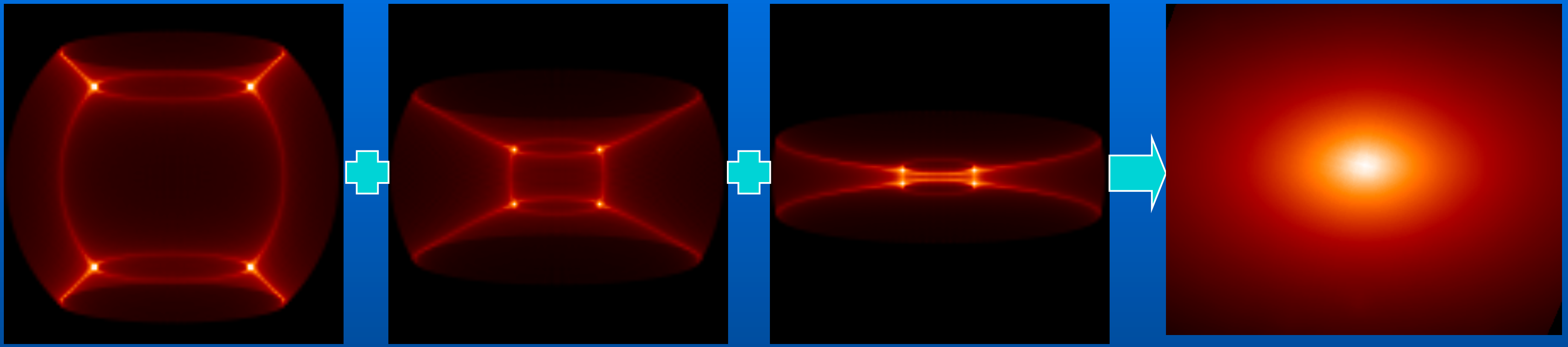
NGC 3379 (SAURON)



Weijmans et al. 2009

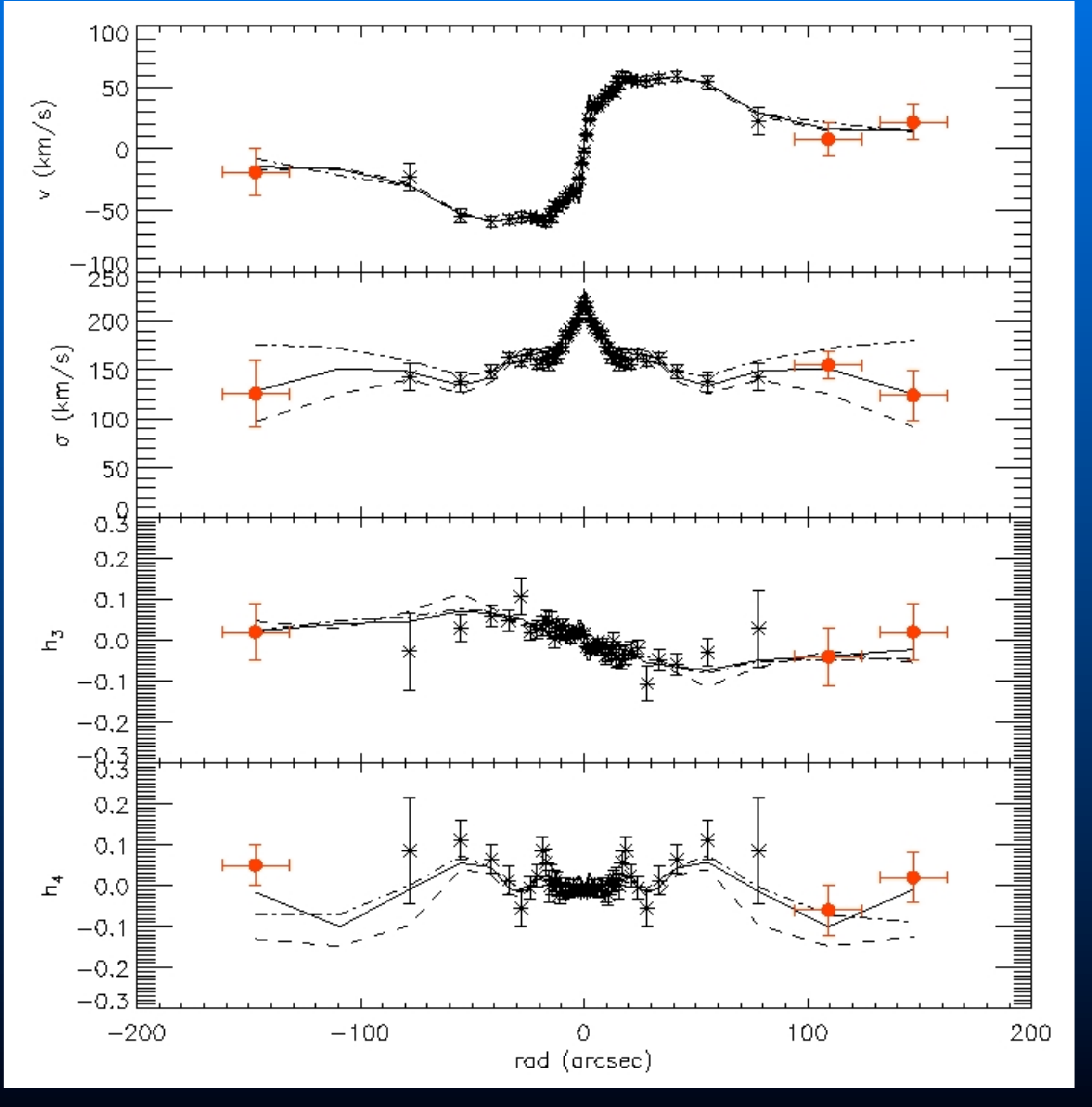
Modeling method

Cappellari et al. 2004



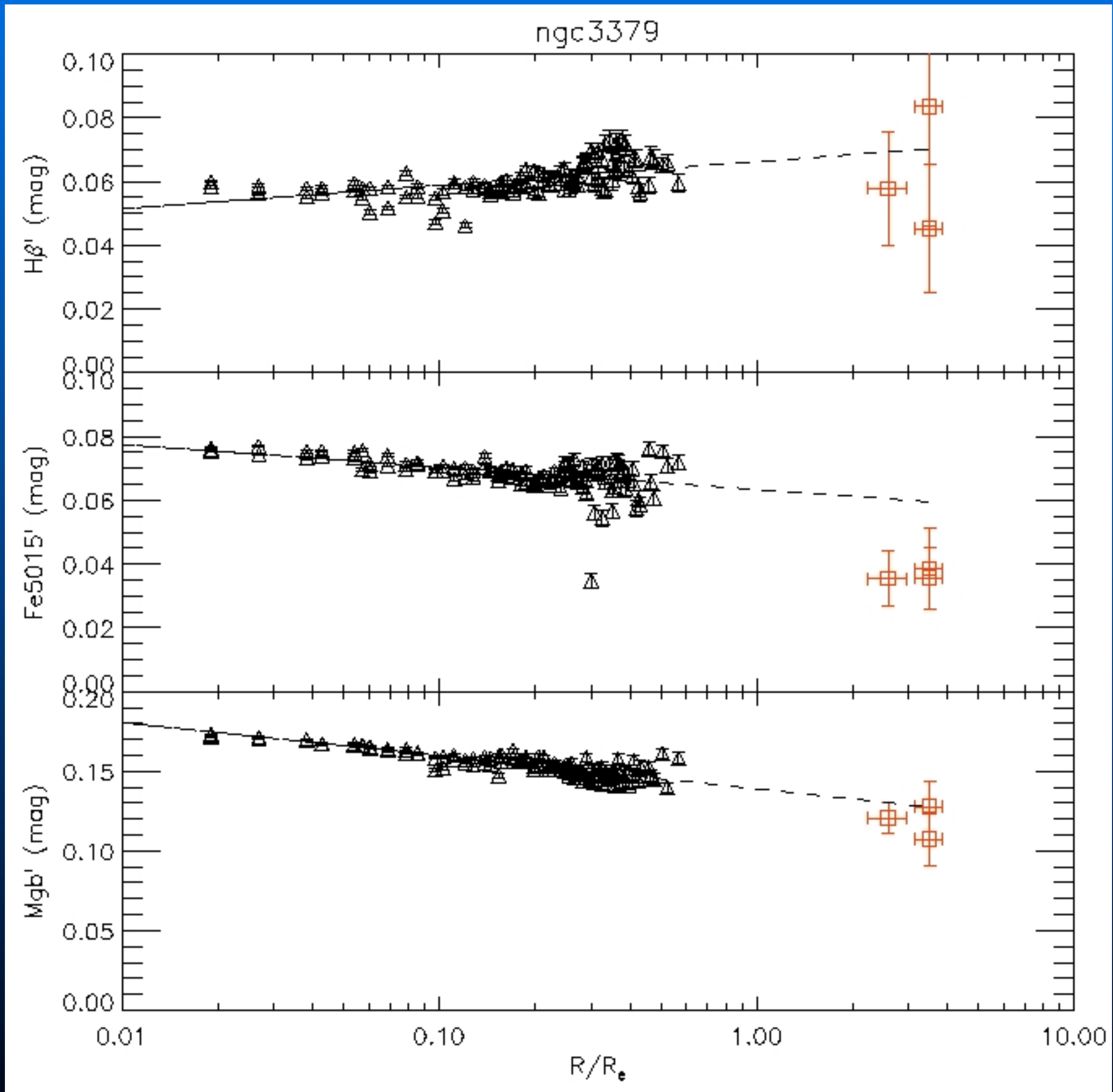
- Triaxial Schwarzschild models (van den Bosch et al. 2008)
  - based on orbit-superposition
  - allows study of orbital structure
- Add NFW halo to the potential
  - fix concentration of halo c = 10
  - minimal halo assumption (or maximal spheroid)

Schwarzschild mass model



- Measure Gauss-Hermite moments h_3 and h_4 to break mass-anisotropy degeneracy
- Best-fit model: $M_{halo} = 1.0 \cdot 10^{12} M_\odot$ $= 10\ M_*$
- Dark matter fraction
  - within $1R_e$ --> 8%
  - within $4R_e$ --> 34%
- Note minimal halo!
  - DM fractions are lower limits

Line strength gradients



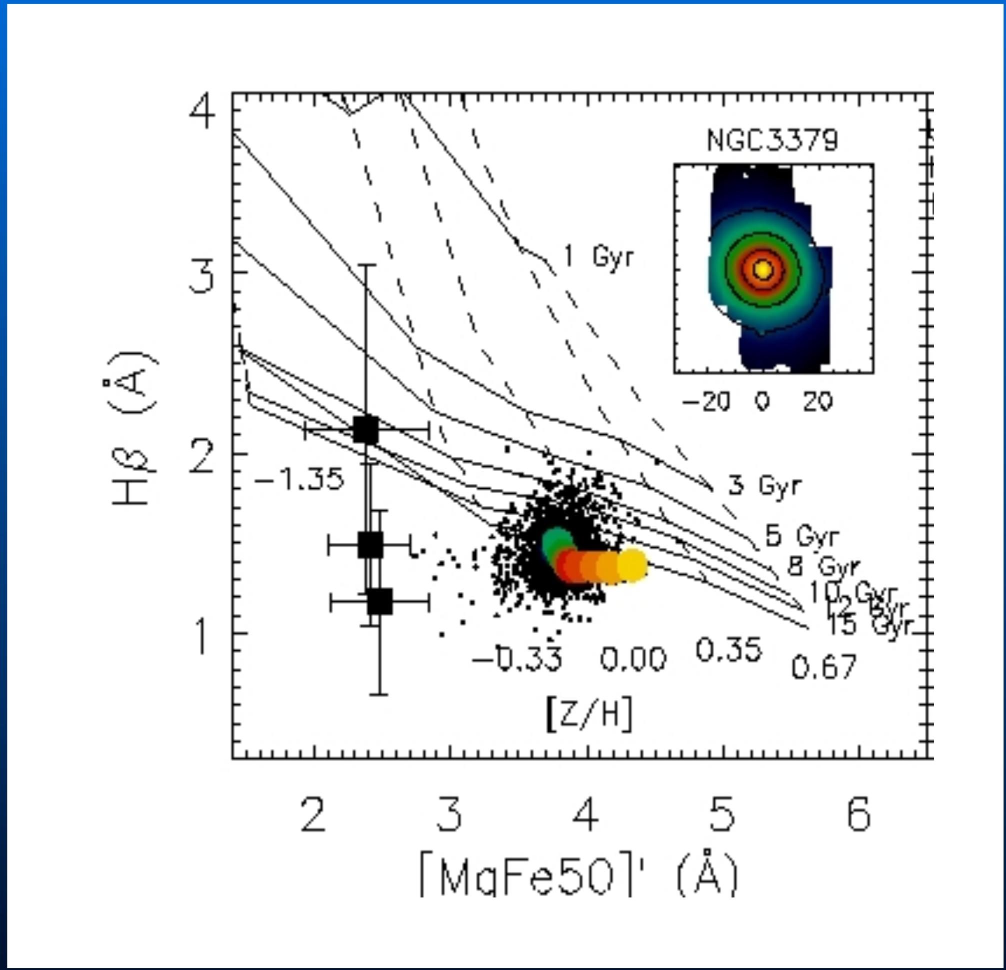
- Line strength gradients constrain formation model
  (e.g. Hopkins et al. 2009; Spolaor et al. 2009)
  - monolithic collapse --> steep gradients
  - mergers dilute gradients

Kuntschner et al. 2006

Stellar halo population

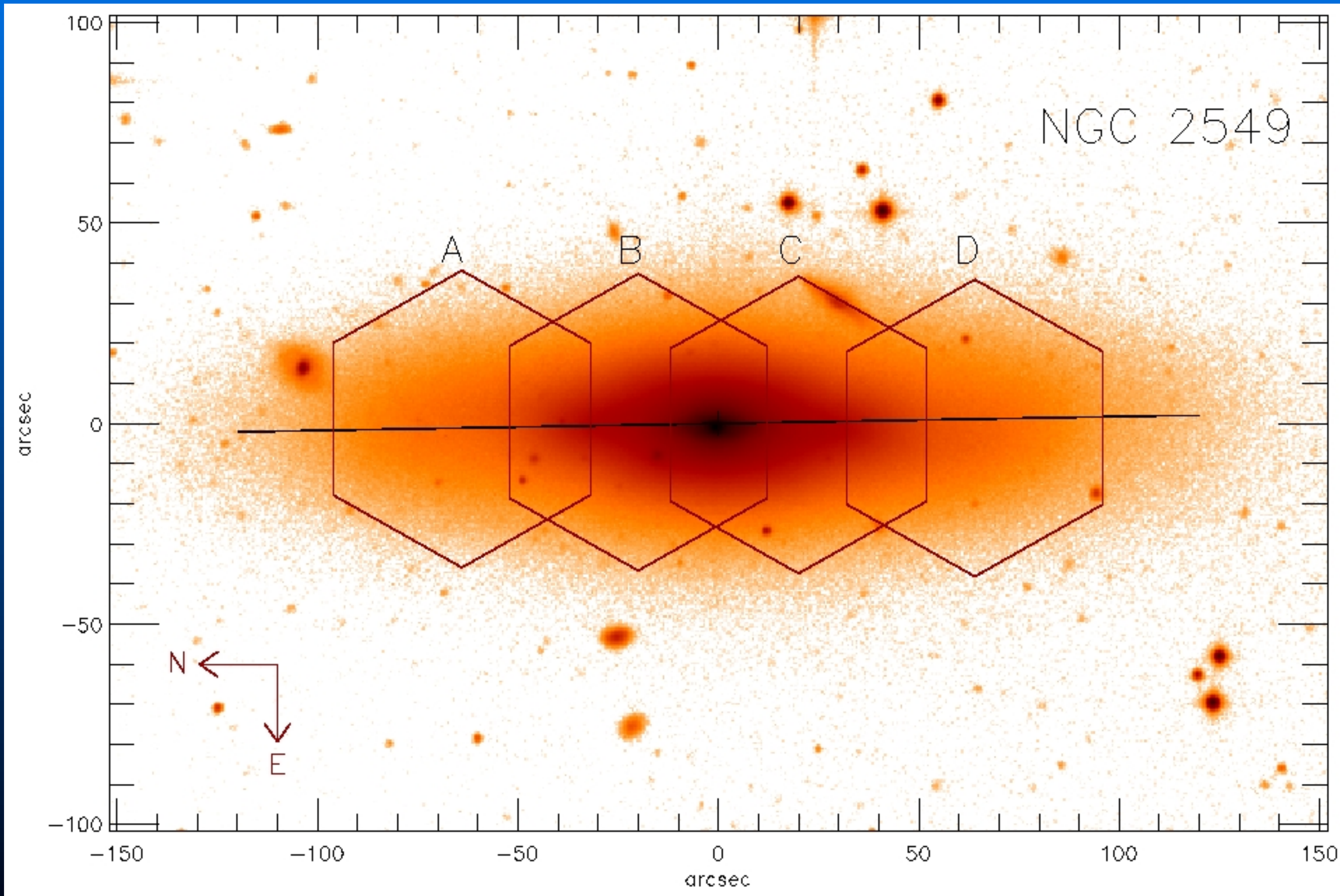
- Stars are old
  - ~12 Gyr
- Stars are metal-poor
  - Z/H < 20% solar

- Same conclusions for Schiavon 2007 models

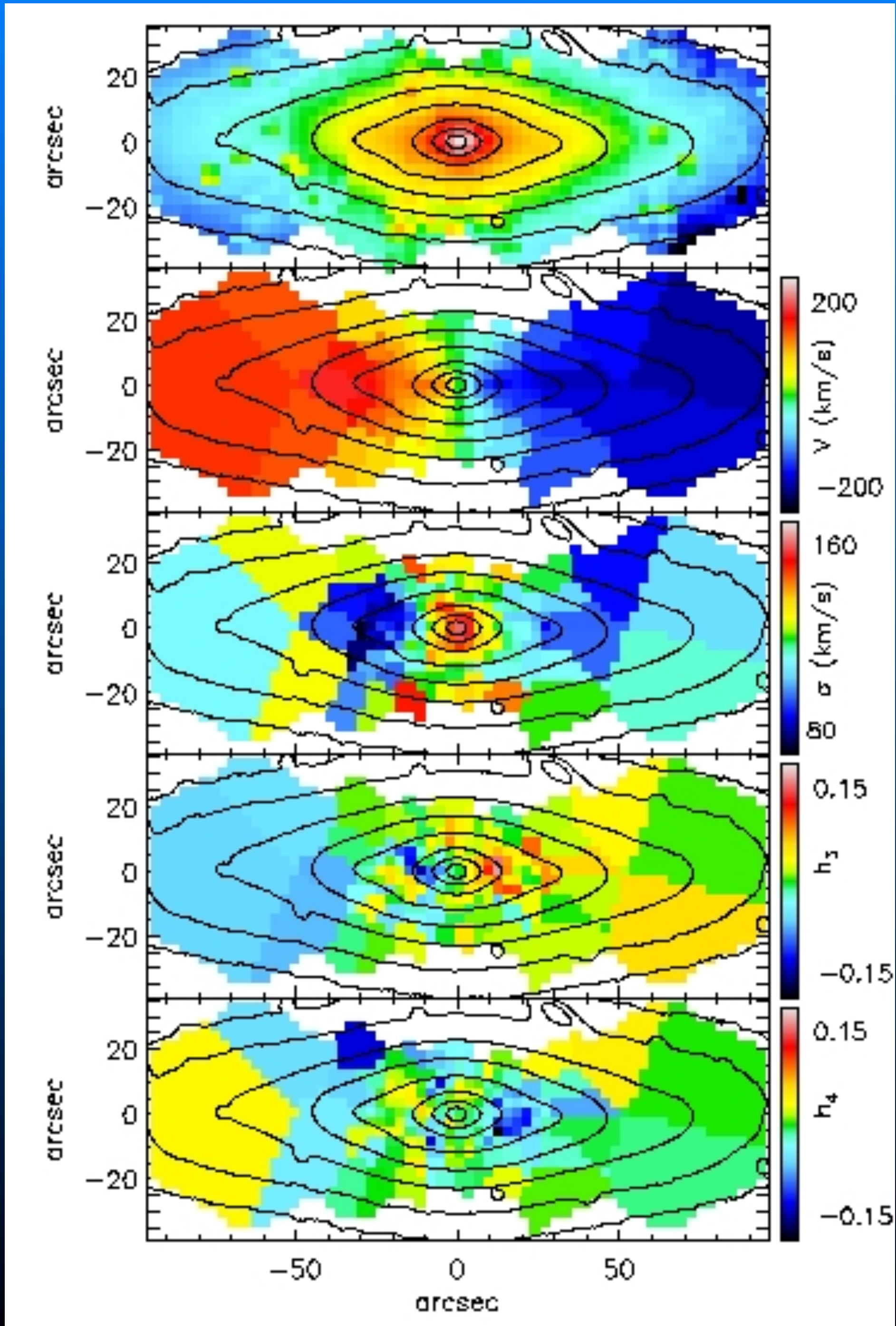


Thomas, Maraston & Bender 2003
Kuntschner et al. 2010

NGC 2549 (PPak)



Weijmans et al. in prep

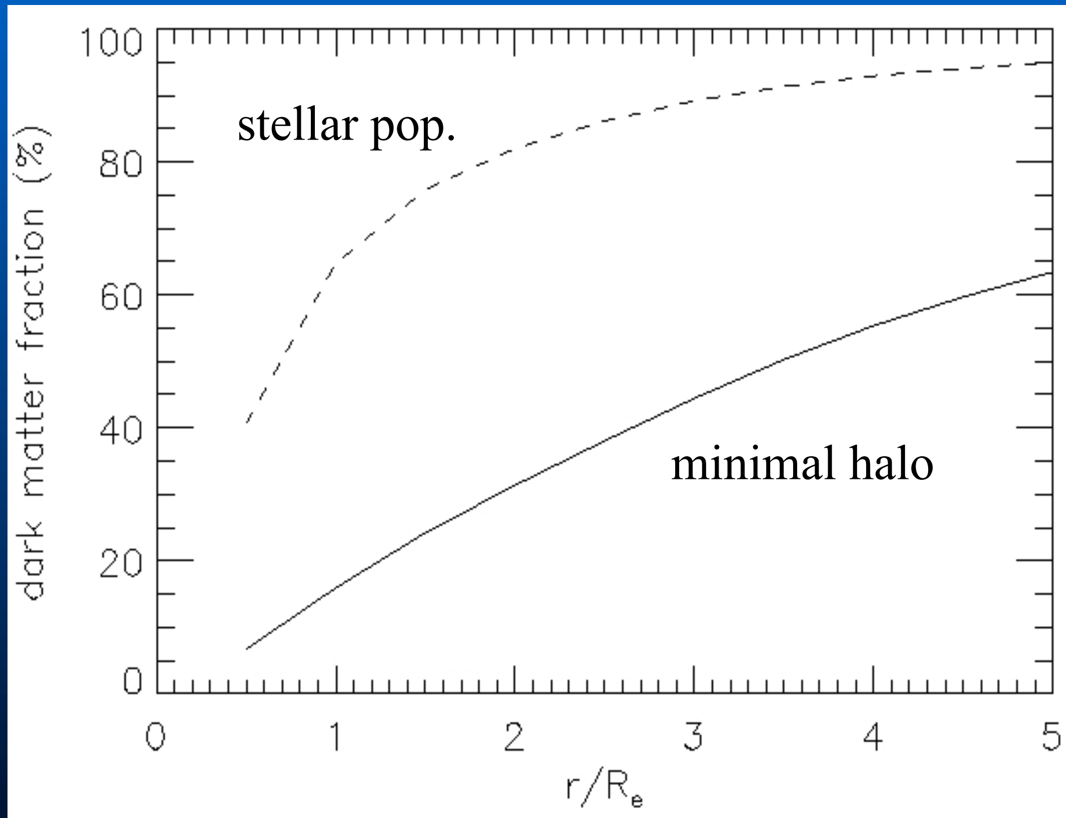


Kinematics

- Disc-like rotation out to ~5 R_e
- Drop in dispersion on major axis

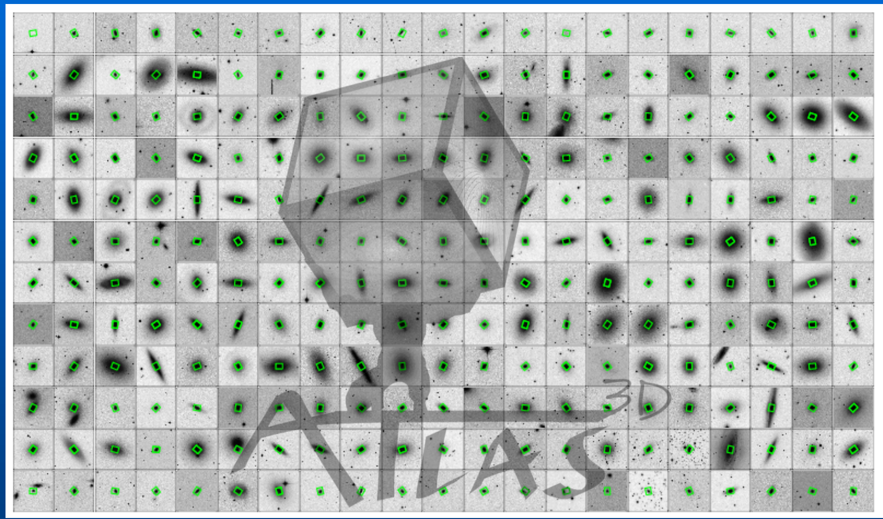
Dark matter fraction in NGC 2549

- Minimal halo assumption ($M_*/L = 4.7\ M_\odot/L_{\odot,R}$)
  - $< 1\ R_e$ --> 16 %
  - $< 5\ R_e$ --> 63 %
- Stellar population modeling ($M_*/L = 2.6\ M_\odot/L_{\odot,R}$)
  - $< 1\ R_e$ --> 65 %
  - $< 5\ R_e$ --> 95 %
- Depends on IMF!



The Atlas3D sample

- Volume-limited parent sample of galaxies
  - – $M_K < -21.5$
  - – $D < 42$ Mpc
  - – $|\delta - 29| < 35^o$
  - – $|b| > 15^o$



- Discard galaxies with spiral structure → 260 early-types

Cappellari et al. 2011

- SAURON data covering 1 R_e
- Ancillary data (SDSS/INT, CO, HI) and simulations

The Team

- PIs: Michele Cappellari (Oxford), Eric Emsellem (ESO/Lyon), Davor Krajnovic (ESO), Richard McDermid (Gemini North)
- CoIs: Katey Alatalo, Leo Blitz, Maxime Bois, Frederic Bournaud, Martin Bureau, Roger Davies, Tim Davis, Tim de Zeeuw, Pierre-Alain Duc, Sadegh Khochfar, Harald Kuntschner, Pierre-Yves Lablanche, Rafaella Morganti, Thorsten Naab, Tom Oosterloo, Marc Sarzi, Nic Scott, Paolo Serra, Anne-Marie Weijmans, Lisa Young

15 institutes in 6 countries

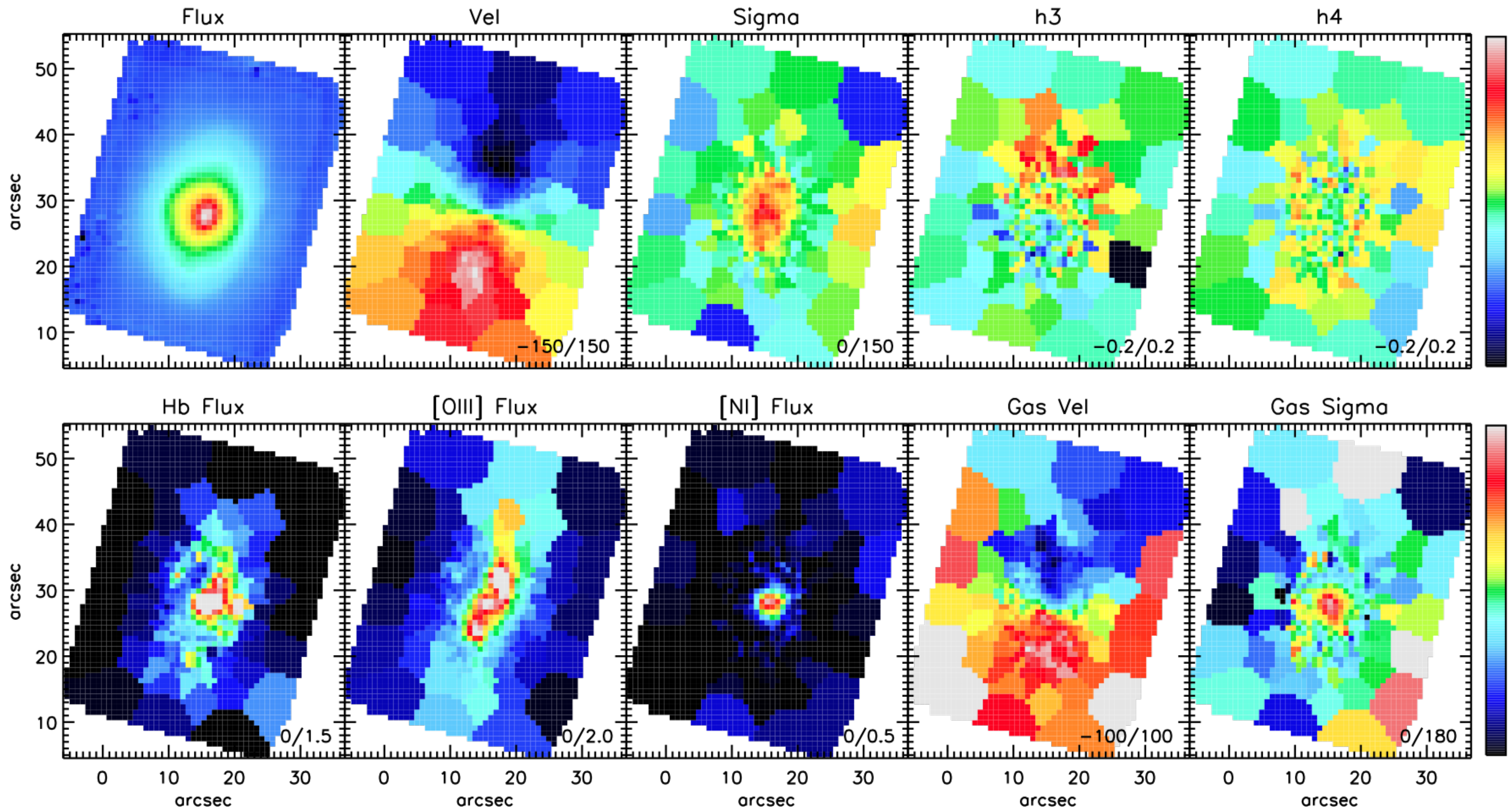
Selection of dark halo sample

- Selected galaxies with regularly rotating HI rings or discs from WSRT observations
  - 40% of field A3D sample detected in HI
  - 63% of detections are rings or discs (Serra et al. in prep)
- Follow-up with deeper HI observations
- Combination of optical and HI data:
  - IFU data → inner rotation curve (3-4 R_e) and stellar populations (e.g. stellar M/L)
  - HI data → outer rotation curve (~ 10 R_e), inclination and halo shape

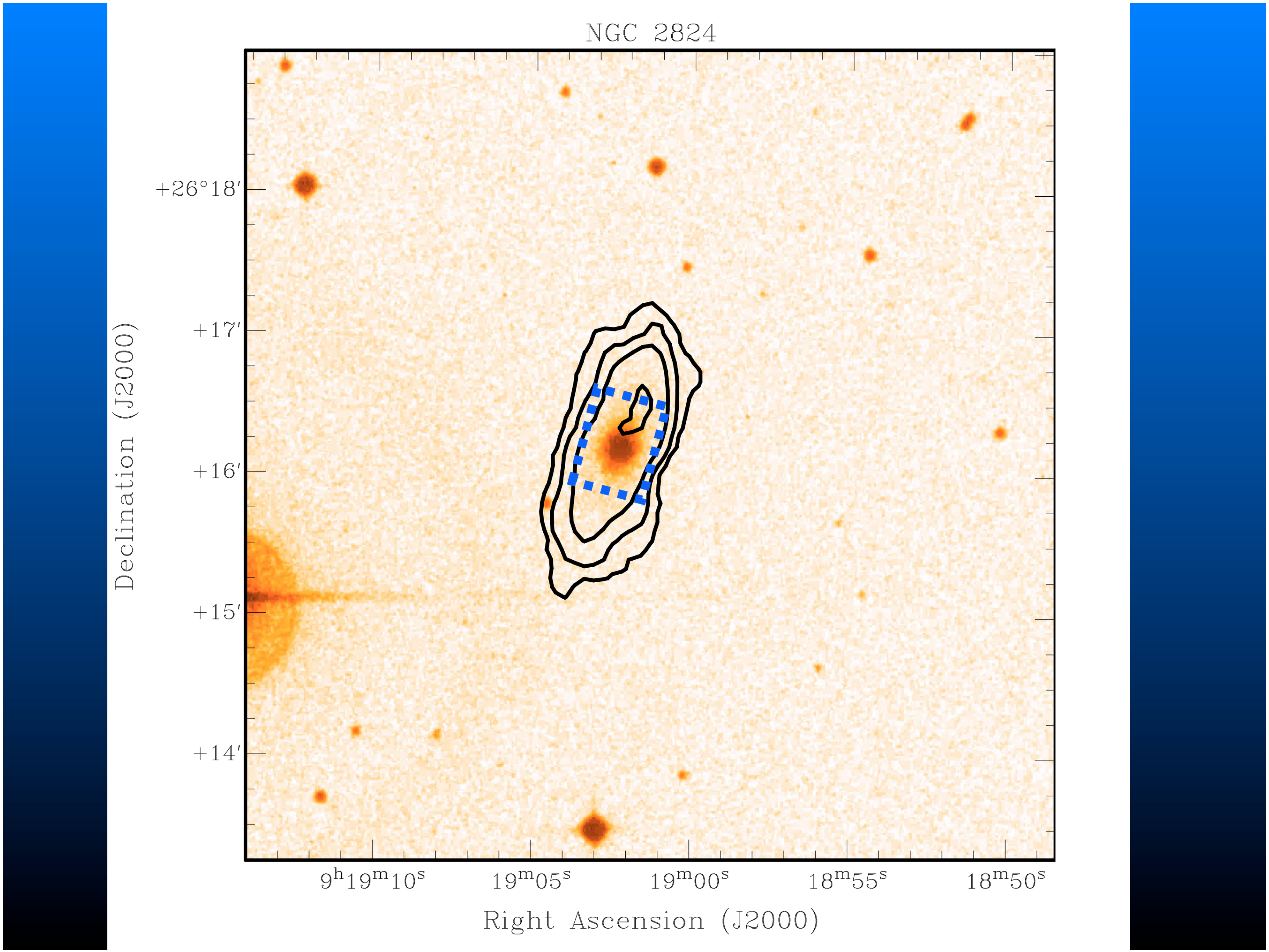
Observing strategy

- Cover full galaxy field with IFU
  - reach >3 R_e in one or two pointings
  - one pointing typically 4-5 hrs
- Small galaxies (R_e < 12 arcsec) → SAURON
  - FoV: 33" x 41", spaxelsize: 0.94"
- Larger galaxies (R_e > 12 arcsec) → VIRUS-P
  - FoV: 109" x 109", spaxelsize: 4.2"
- Currently 6 galaxies observed with SAURON + 11 with VIRUS-P

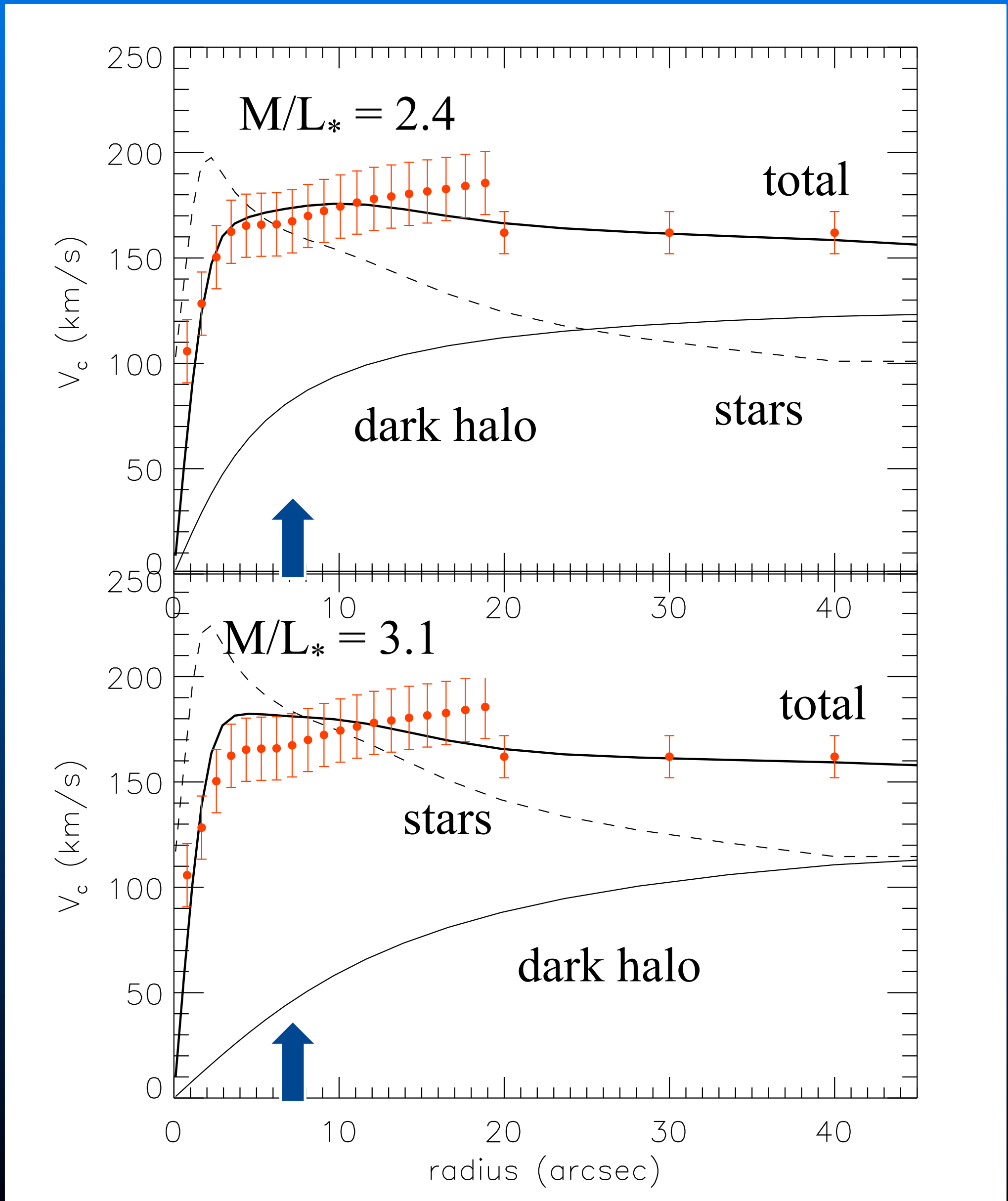
NGC 2824 (SAURON)



Simona Lam, Elliot Meyer, Ritchie Zhao


NGC 2824
+26°18′
+17′
+16′
+15′
+14′
Declination (J2000)
9h19m10s
19m05s
19m00s
18m55s
18m50s
Right Ascension (J2000)

Model NGC 2824



- Combine HI and stellar rotation curves
  - asymmetric drift correction for stars
- Stellar contribution from MGE model
- Fit pseudo-isothermal sphere as halo
- Best-fit (min halo) model:
  - $M/L_* = 2.4\ (3.1)\ M_\odot/L_{\odot,r}$
  - DM (<1 Re) = 20 (7)%
  - DM (<5.5 Re) = 60 (45)%

Conclusions

- IFUs provide absorption line spectra at large radii
  - stellar kinematics important test for dark matter
  - measure line-strengths out to large radii: gradients and properties of stellar halo population
- Constraints on halo properties
  - decrease degeneracy between dark and luminous matter: need stellar M/L
  - larger field coverage to constrain shape of halo
- Larger sample to test galaxy formation theories