Athena X-IFU Starburst Simulations

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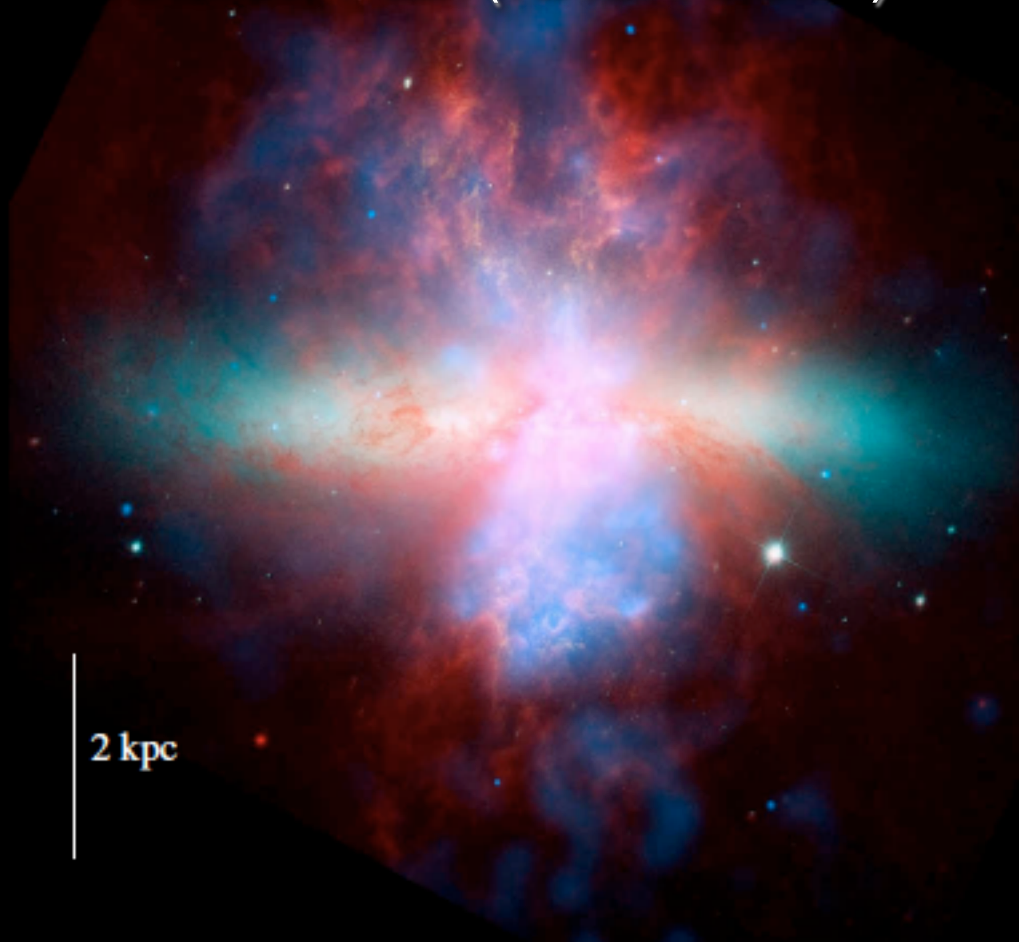
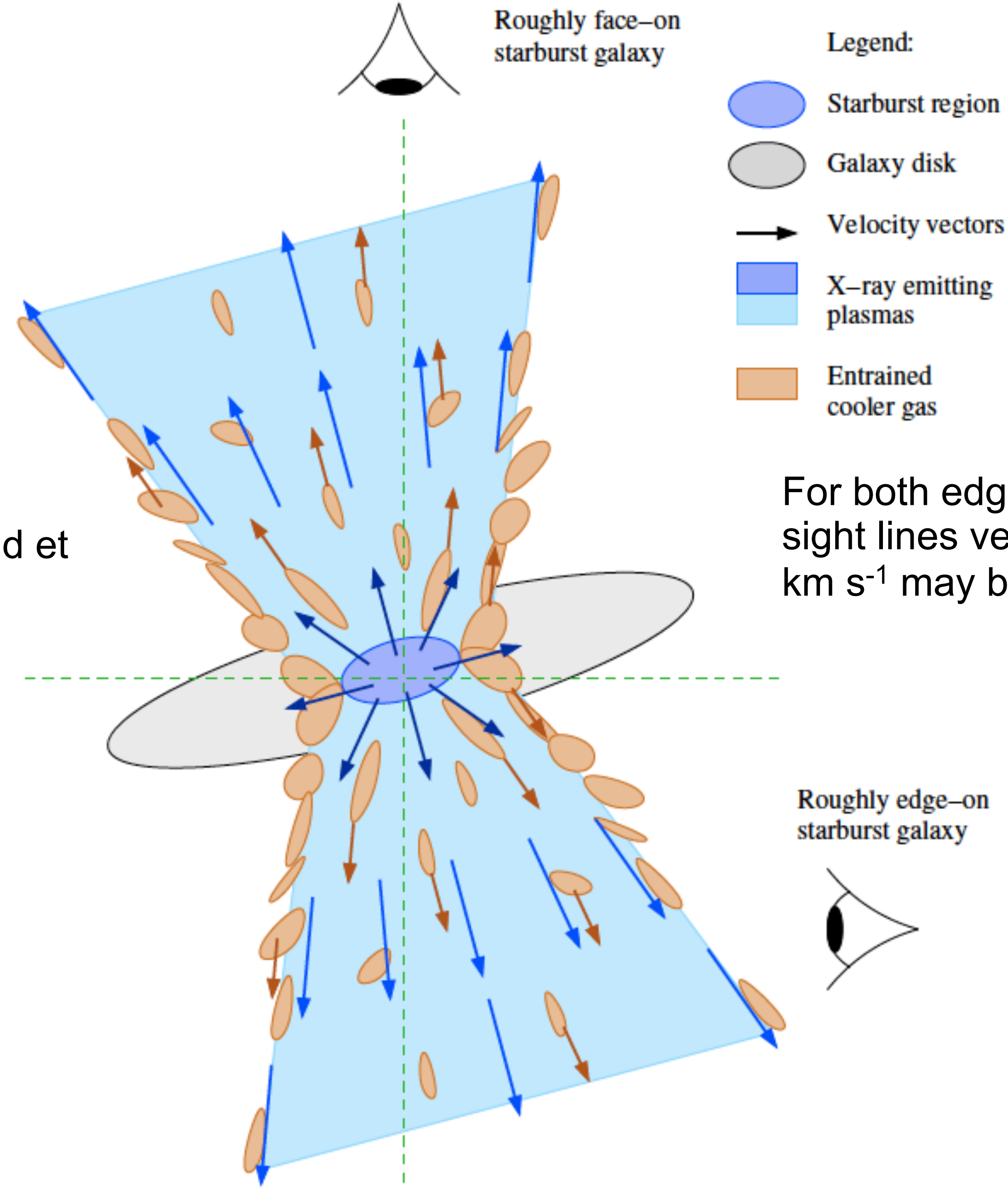


Overview

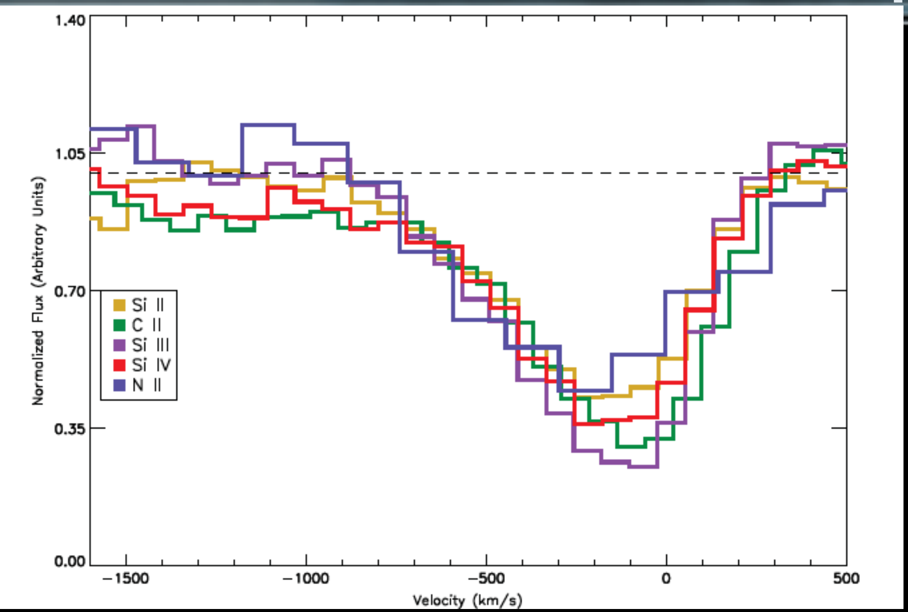
- "Feedback" in the form of starburst outflows plays an important role in galaxy evolution, particularly regulating star formation
  - How energetic are starburst winds, especially superwinds?
  - How efficiently do starburst winds transport metals to the IGM?
- Starburst outflows are directly seen in UV absorption and molecular gas studies but most energy is in the hot "fluid" which potentially stays hot out into galaxy halos

From Strickland et al. (2009)



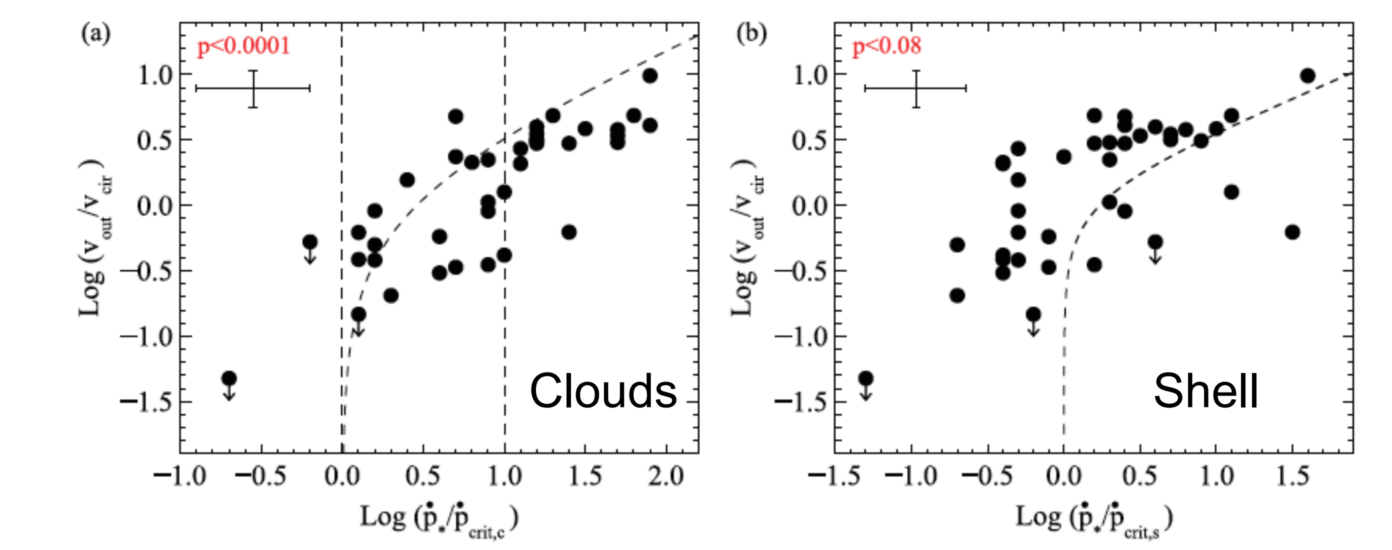
For both edge-on and face-on sight lines velocities of > 1000 km s^{-1} may be observed

UV Absorption Studies



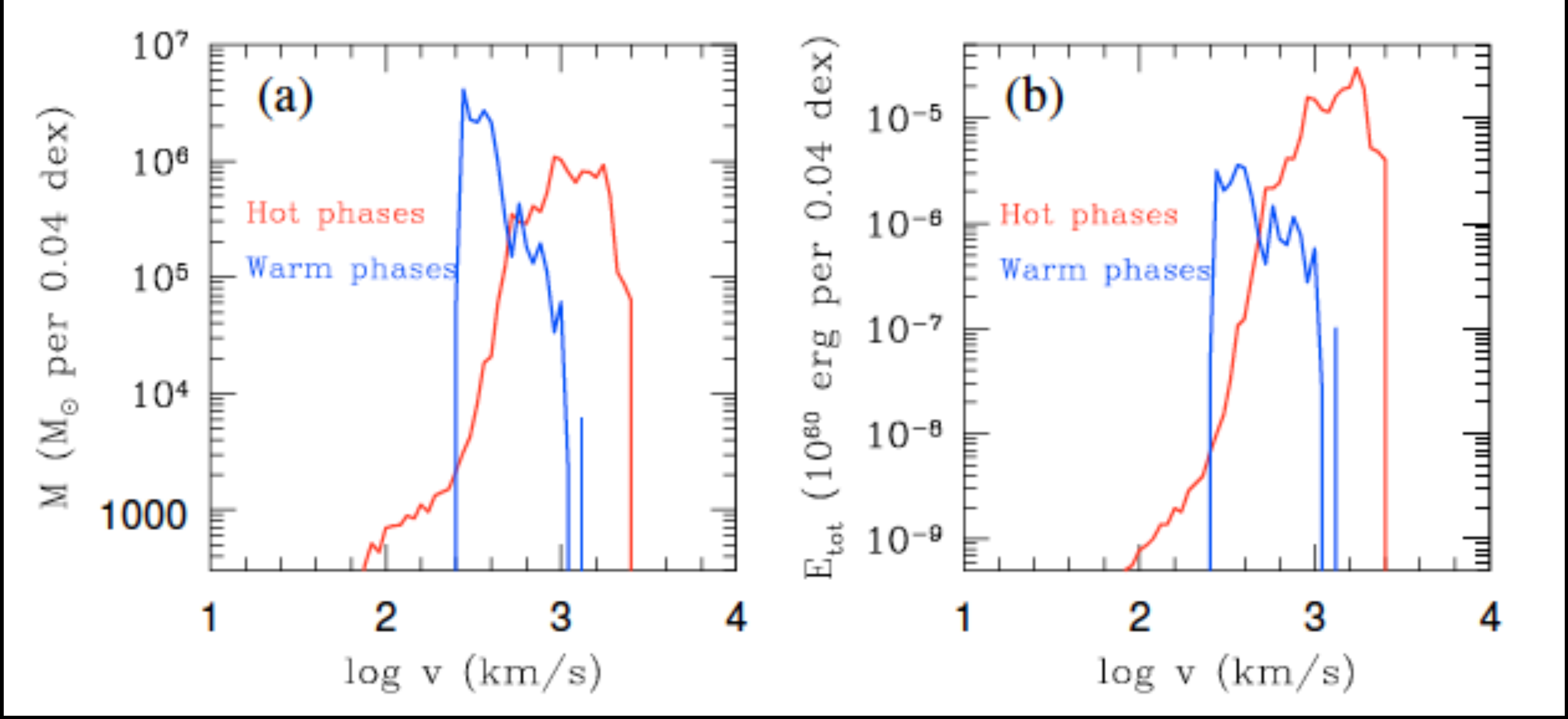
Stacked spectra of UV absorption lines from starburst galaxies in Heckman et al. (2015). Relation between momentum flux and outflow velocity assuming an entrained cloud model is more consistent with semi-analytic starburst model expectations than a spherical shell model

Critical momentum flux = momentum flux to overcome gravity



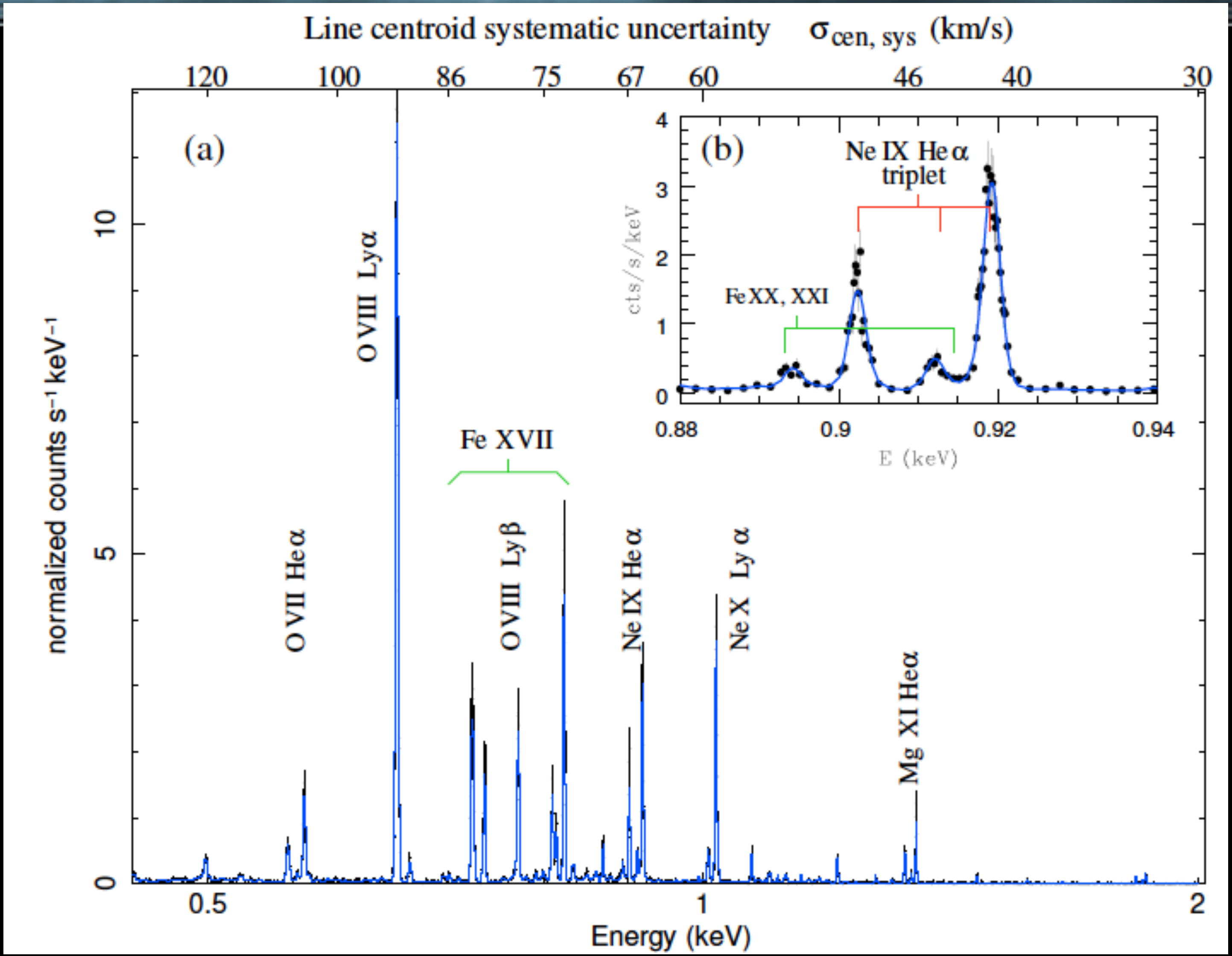
How Important is the Hot Wind Fluid?

From Strickland et al. 2009 IXO White paper
See also Melioli et al. (2013)



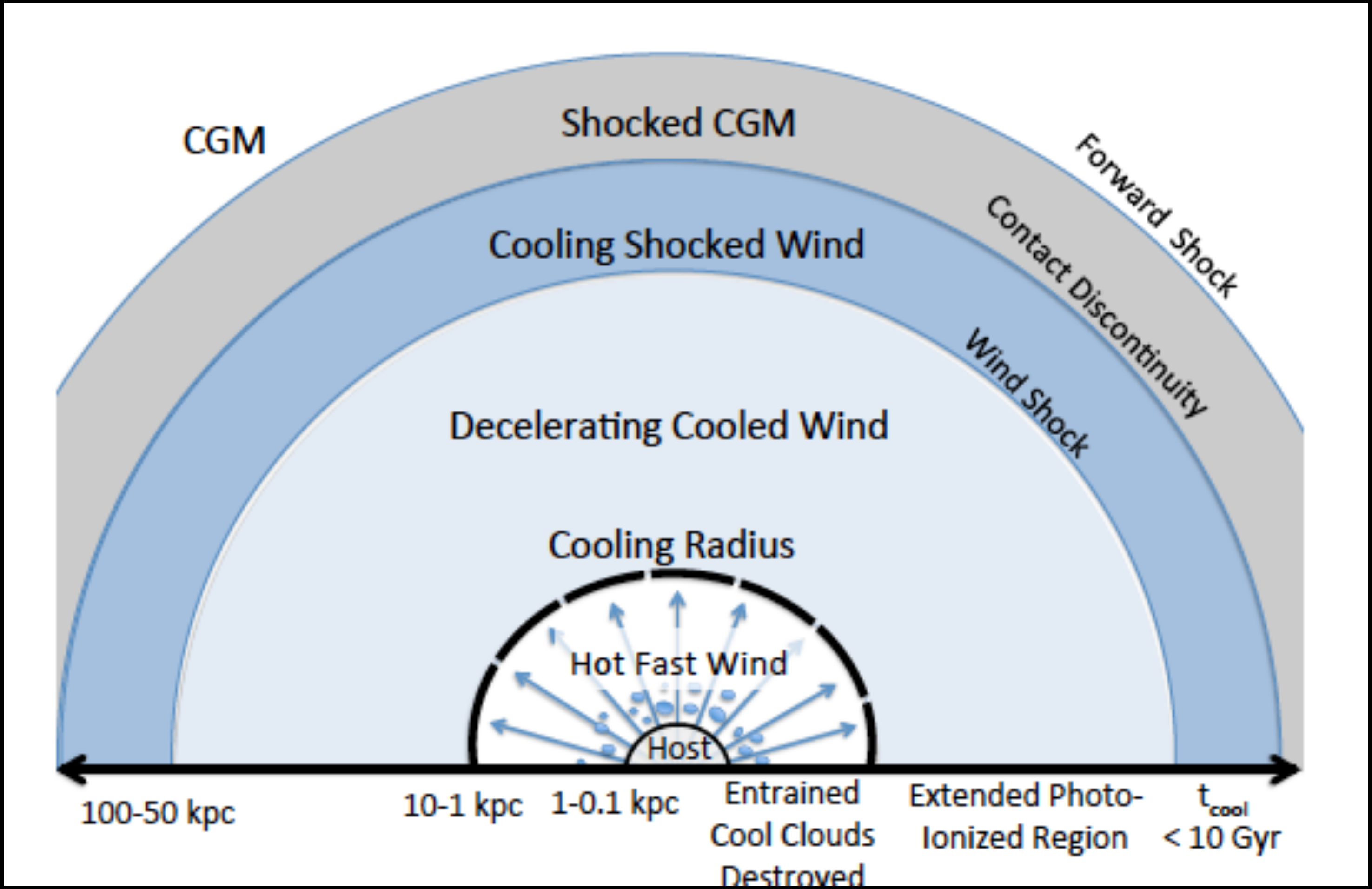
Simulating Superwinds with Athena

- Simulate spectra of diffuse gas
  - Relatively straightforward
  - Initial work by IXO team still applicable since it assumed 2.5 eV resolution and negligible background
  - Also need to consider charge exchange and shocks
- Full end-to-end simulations
  - Would allow unresolved point sources and background to be assessed
  - Can parameters treated globally like mass loading (outflowing mass rate / SFR) be determined *locally*?



16,000 count spectrum of SN-II enhanced 0.4 keV plasma

Thompson et al. (2015) model



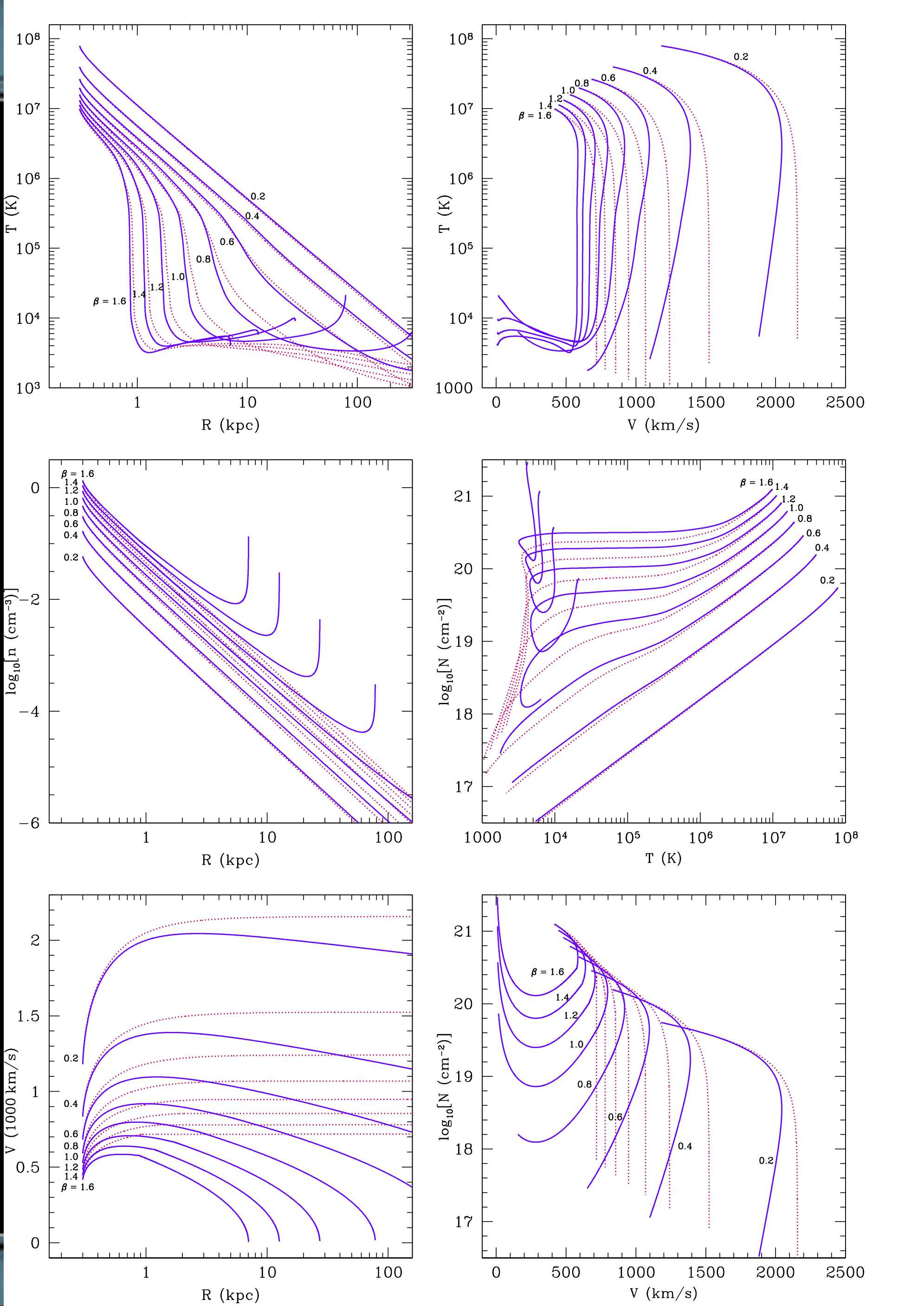
In Thompson et al. model, swept-up clouds are destroyed but then as the flow becomes increasingly mass-loaded, radiative cooling can dominate and clouds can “condense” out

Starburst wind models with different mass loading factors:

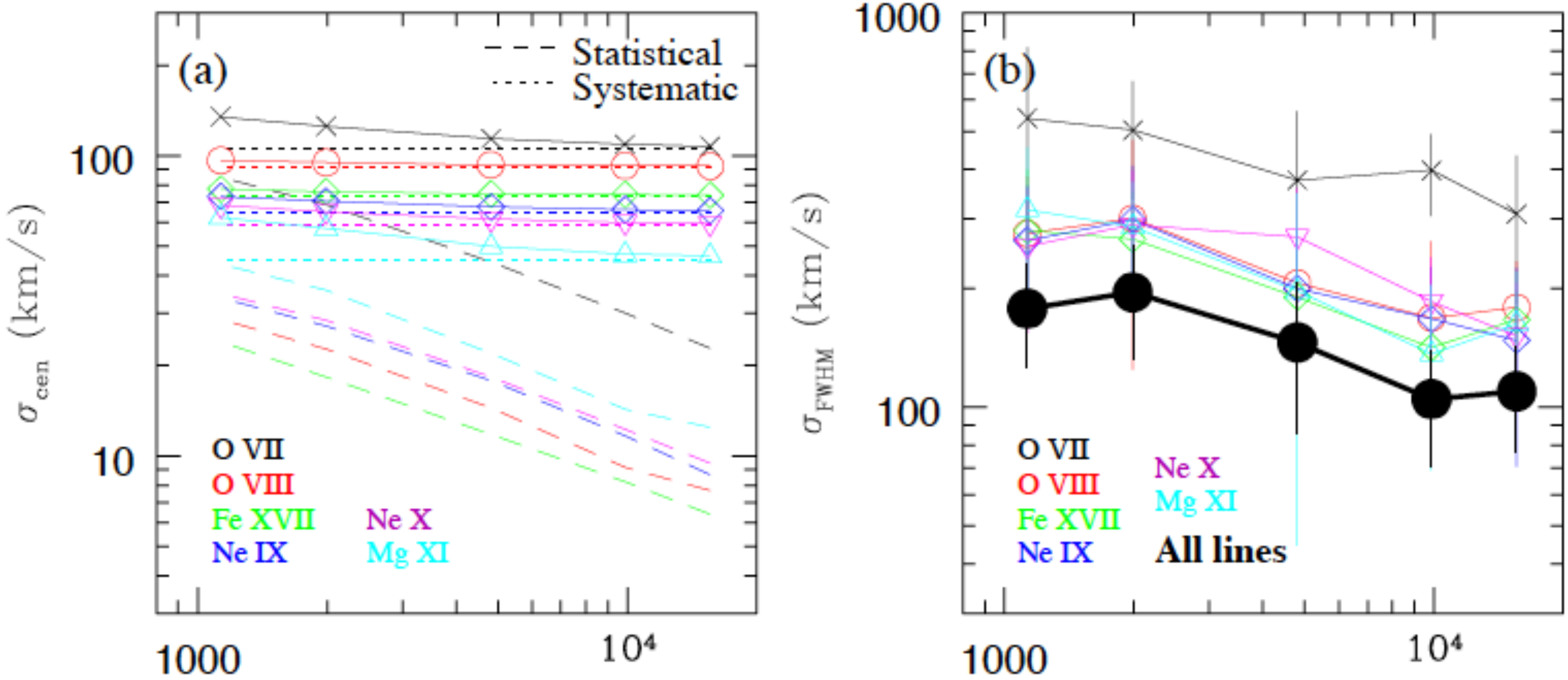
$$\beta = \frac{\dot{M}}{SFR}$$

With gravity

Without gravity



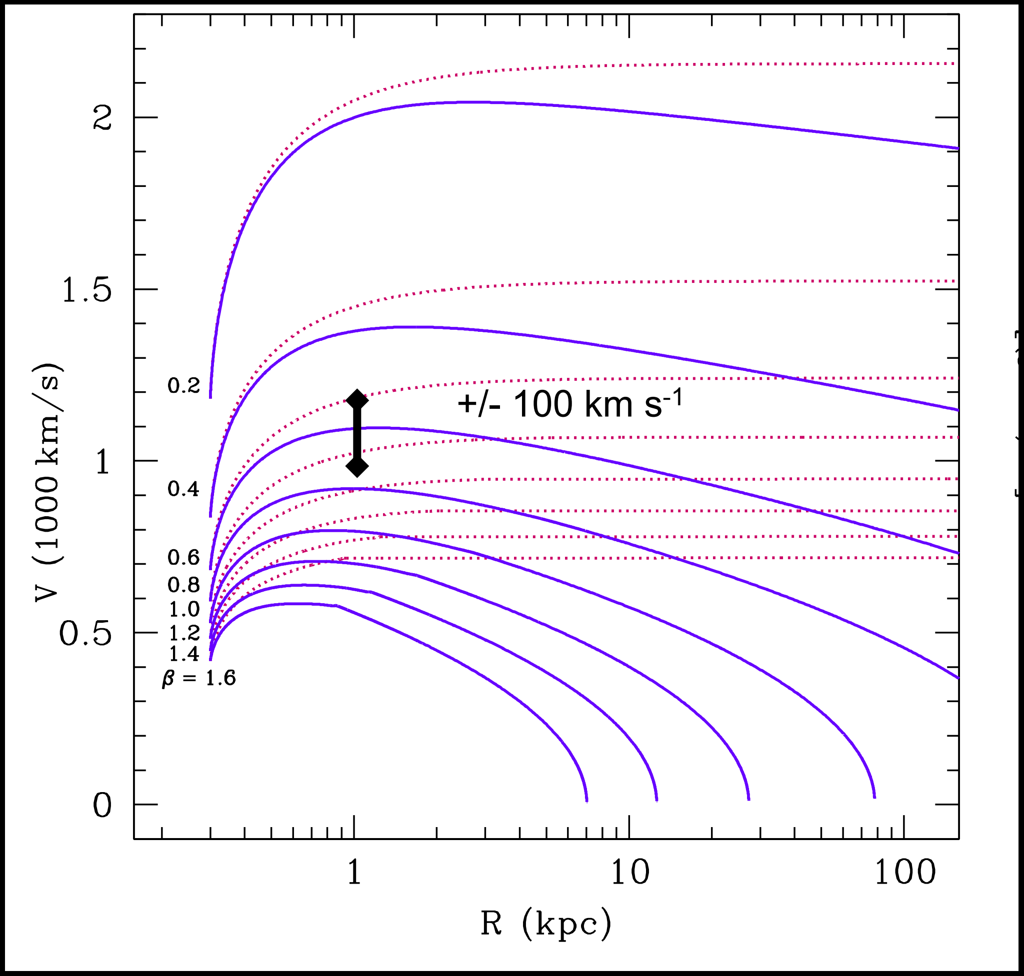
X-IFU Line Velocity Diagnostics



Simulations by D. Strickland
From XMS simulations, for ~ 2 eV spectral resolution, ~ 10^3 / 10^4 counts are required to constrain velocity centroid / width to within 50-100 km s^{-1}.
Centroid error likely dominated by calibration error above ~ 1000-2000 counts

Starburst Outflow Velocities

At distance of M82 (3.5 Mpc),
1’ ~ 1 kpc

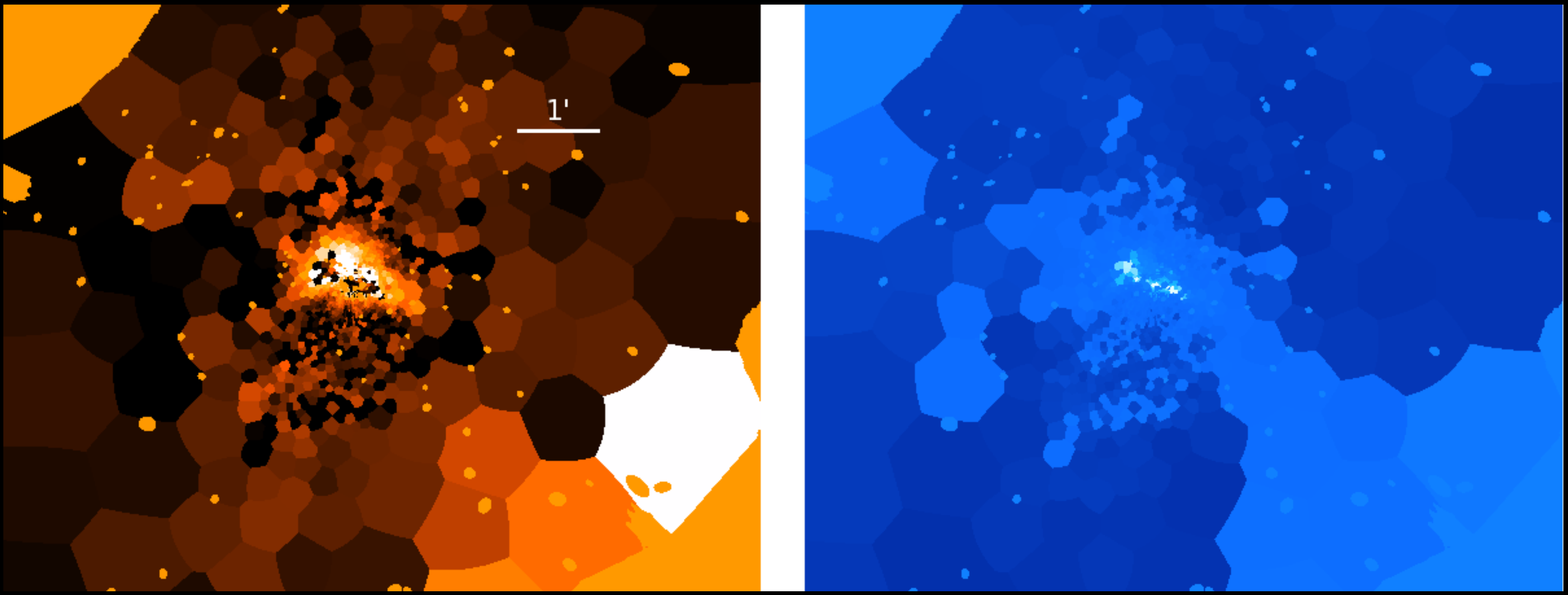


End-to-End Simulation Strategy

- Create diffuse-only maps of hot X-ray gas in nearby starburst galaxies
- Use adaptive region sizes to fit simple thermal models
- Use current models (e.g., Thomson et al. 2015) to model velocity distribution
- Simulate X-IFU observations
- Determine errors on temperature, (relative) abundances, velocities in outflow across starburst regions
- Need to include point sources (X-ray binaries), shocks (non-equilibrium ionization; e.g., Wang et al. 2014), charge exchange (additional physics due to outflow being a multi-phased medium; Zhang et al. 2014)

M82 Temperature, N_H Maps

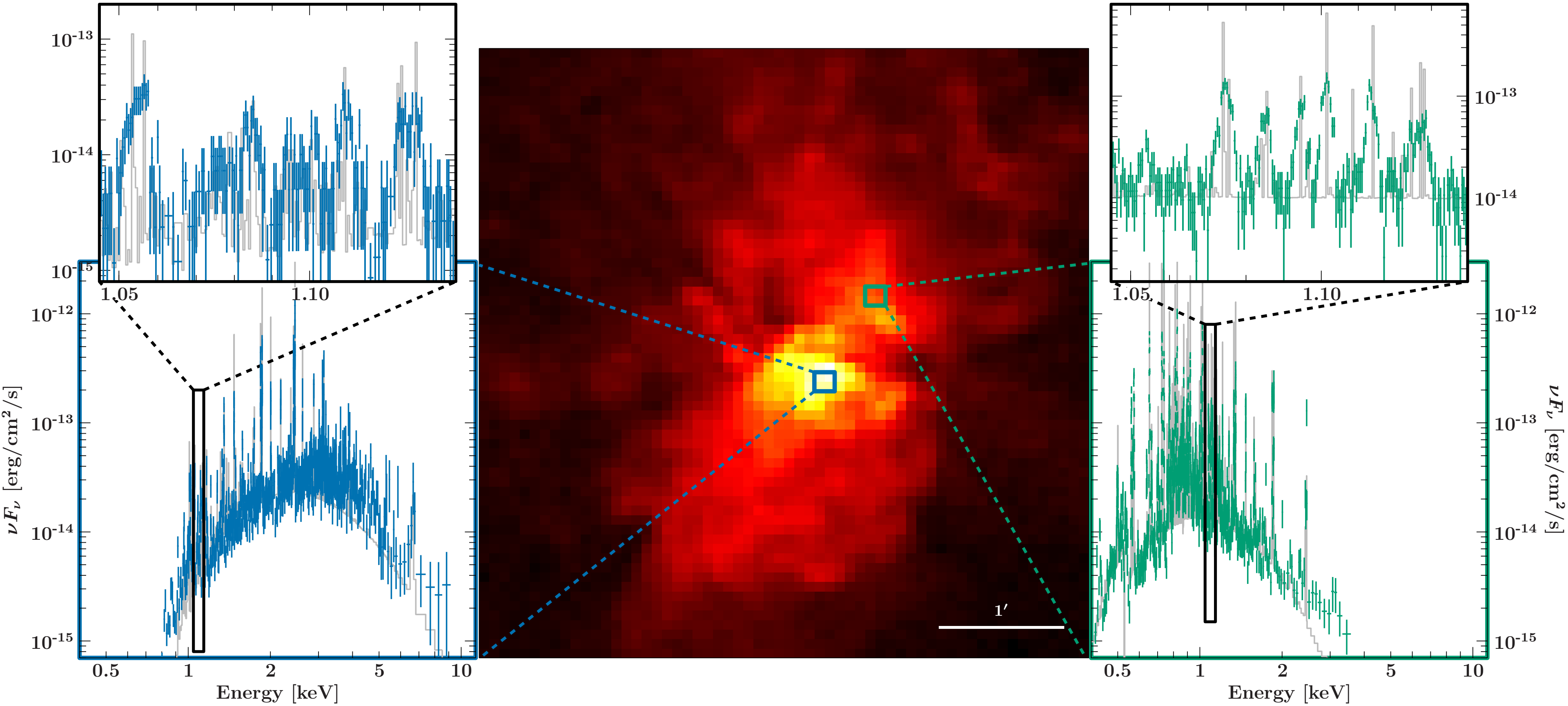
kT N_H



Courtesy of M. Yukita

Athena WFI + X-IFU 100 ks simulation of M82

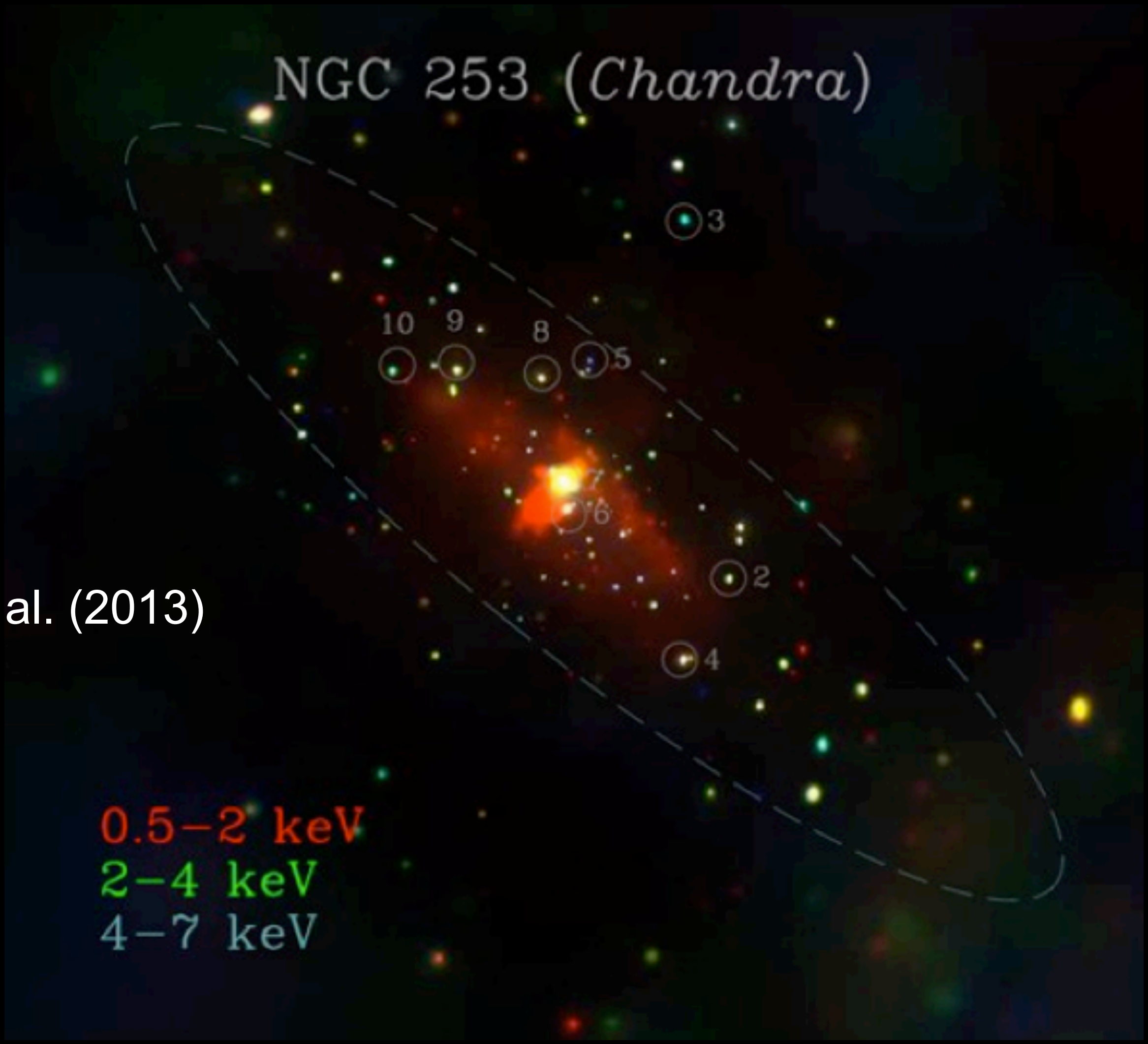
N.B. Point sources not included



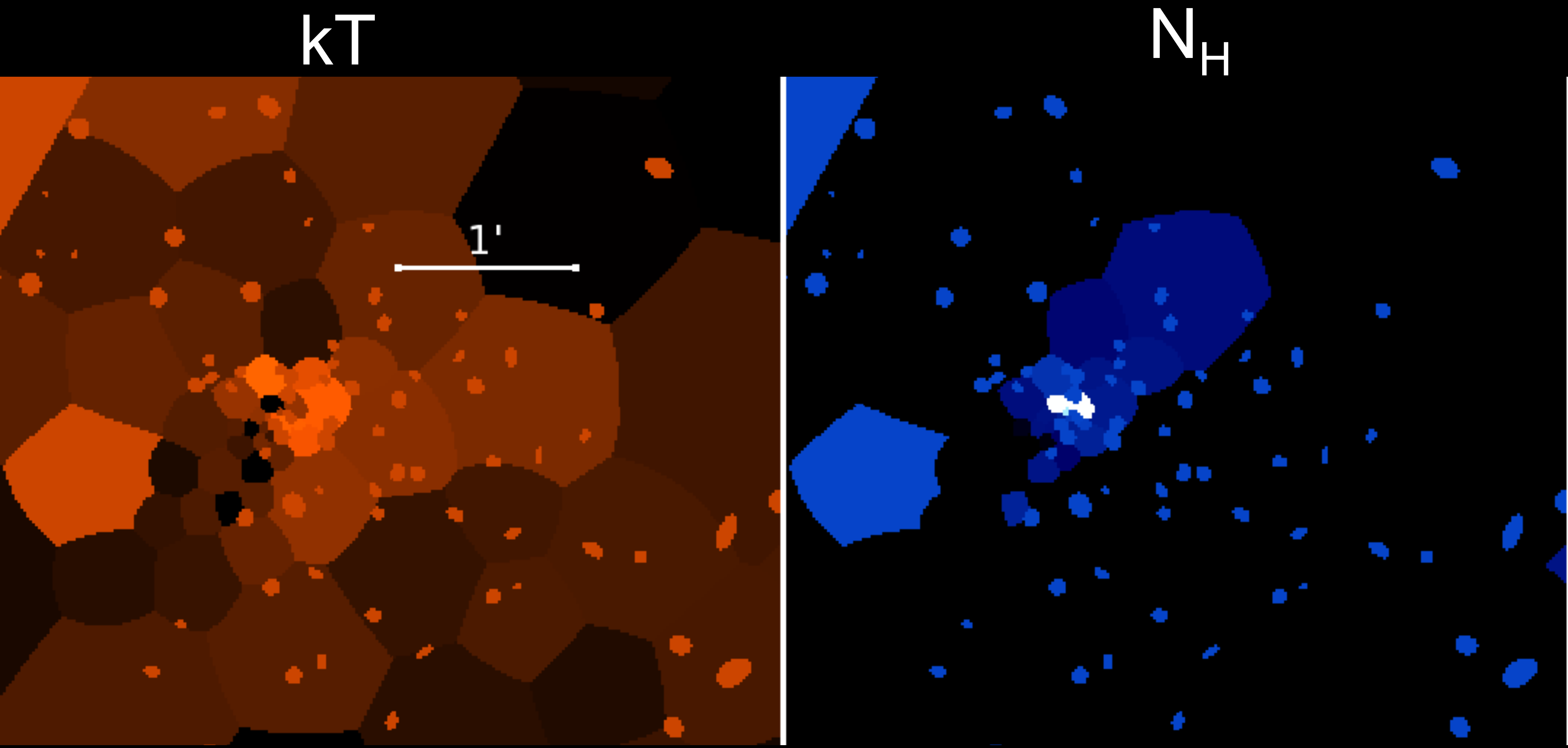
Simulation performed by Thomas Dauser

NGC 253

From Lehmer et al. (2013)

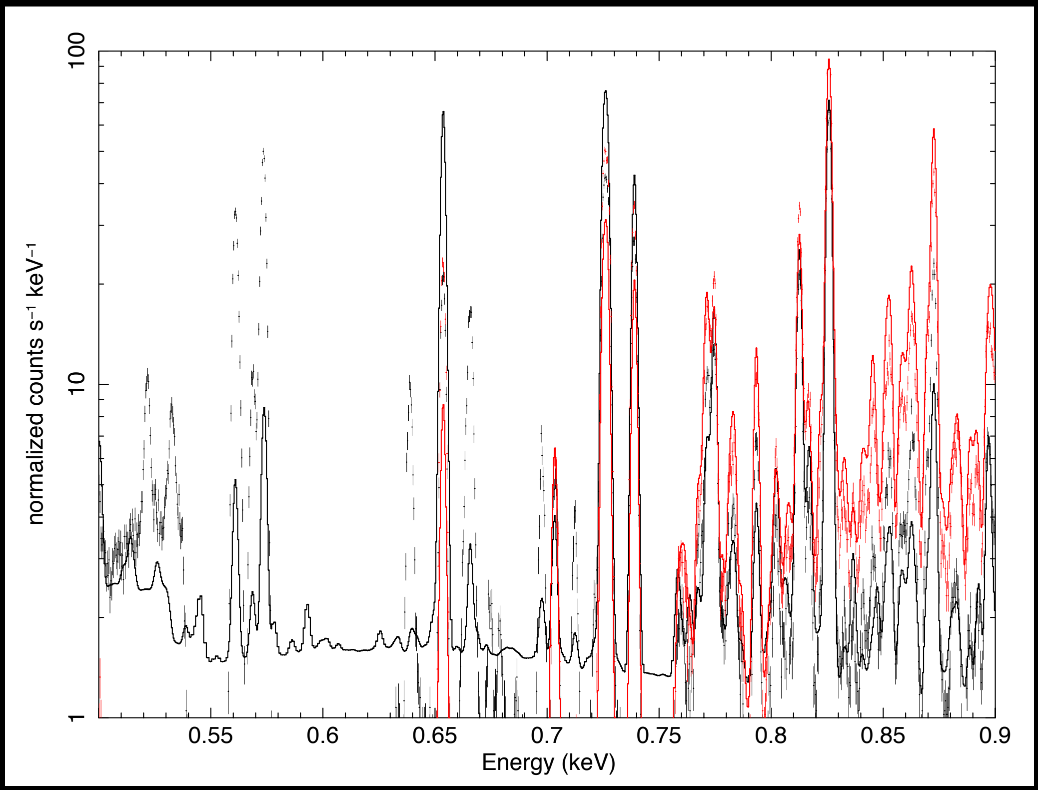


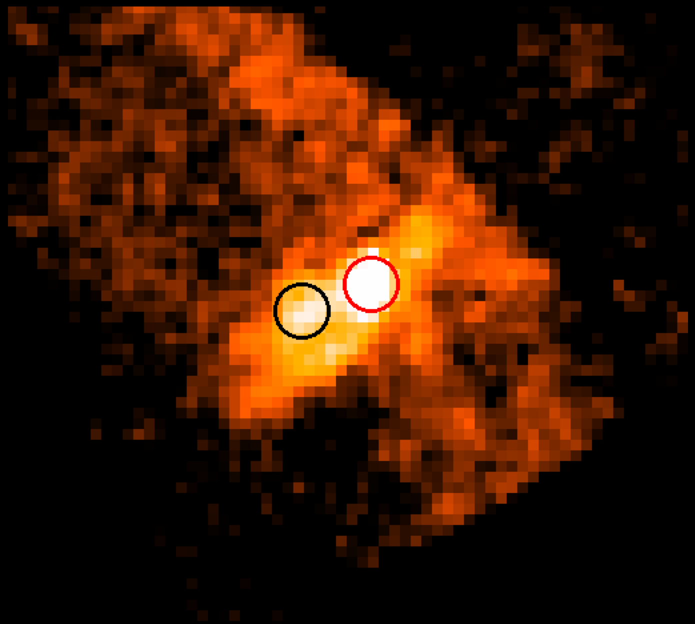
NGC 253 Temperature, N_H Maps



Courtesy of M. Yukita

NGC 253 X-IFU 100 ks Simulation





What will the Athena Starburst Sample Look Like?

	1.4 m^2 at 1 keV		2.0 m^2 at 1 keV	
Galaxy	X-IFU Surface Brightness	5σ Exp. (ks)	X-IFU Surface Brightness	5σ Exp. (ks)
NGC 3256	16.7	9.6	24.0	6.7
Henize 2-10	8.4	19.1	12.1	13.2
NGC 3310	6.4	25.3	9.1	17.5
VV 114	6.1	26.4	8.8	18.3
etc				

5σ Exposure gives exposure time to get 10,000 counts in a 15”x15” region
X-IFU Surface Brightness is in counts s^{-1} $arcmin^{-2}$ based on total diffuse X-ray luminosity and source extent. Total includes bgd. which is < 10% of counts in most cases.

For mock observing plan, also included ULIRGS to have a total of 34 galaxies requiring 15 (10) Ms for 1.5 (2.0) m^2 at 1 keV.

See also Antara Basu-Zych poster for local Lyman-break analog galaxies VV 114 and Haro 11

Conclusions

- X-IFU observations promise to directly map out the diffuse X-ray flux in a sample of ~ 30 nearby starburst and ULIRG galaxies
  - Spectral modeling needs to include background, updated estimates on achievable systematic energy calibration error

- Detailed simulation is possible with SIXTE and simx
  - Need to model X-ray binary populations
    - Interesting in their own right (see Andreas Zezas poster)
    - ULXs possibly can be used as bgd. light sources
  - Velocity model for outflowing gas and disk ISM
  - Need to include metalicity gradient, shocks (NEI) and charge exchange also