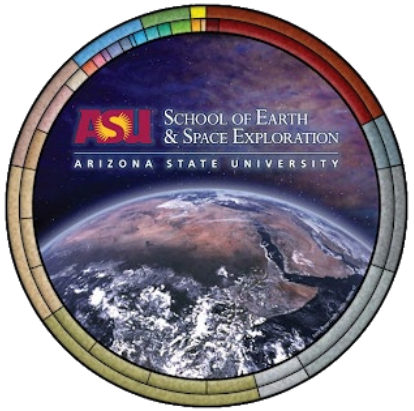
Impact for the Age of the Stellar Population(s) on the Nature and Evolution of the Circumgalactic Medium



Sanch Borthakur

School of Earth and Space Exploration

Arizona State University*

The work presented here is enabled and supported by:

STScI

NASA

NSF

NRAO

*I acknowledge the native people and their lands in the Salt River Valley where the Arizona State University's campuses are located. The ancestral territories of Indigenous peoples, including the Akimel O'odham (Pima) and Pee Posh (Maricopa) Indian Communities, whose care and keeping of these lands allows us to be here today for scientific pursuits.

Star-formation and Feedback

Starburst Galaxies

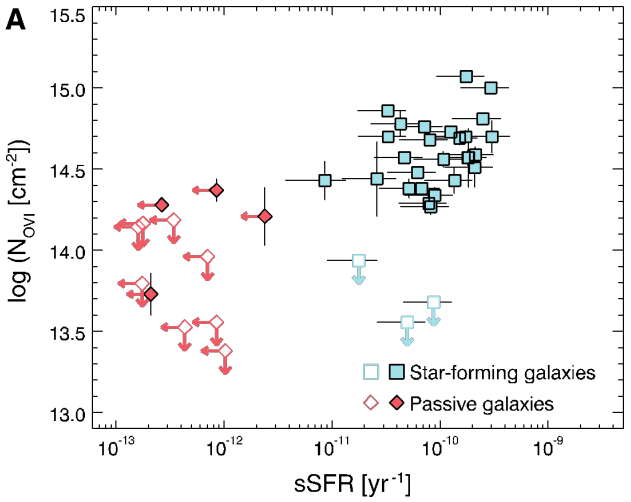
Close-up of the wind-swept, circumnuclear region of NGC 3079. Colors indicate - Hα + [N II], I-band, and X-rays.

Veilleux (ARAA, 2005)

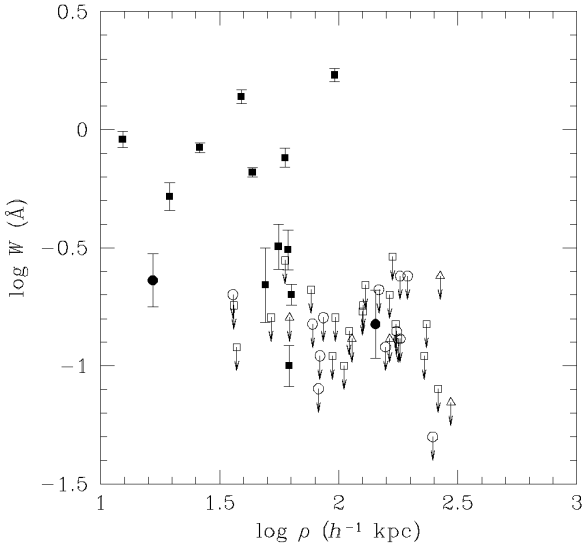
Energy and Baryon Transport out of Galaxy Disks

- Gaseous outflows detected in starburst galaxies with velocities as large as 1000 km/s.
- Such outflows are ubiquitous in the early universe.
- Mechanism by which heavier elements (metals) get out into the intergalactic medium.

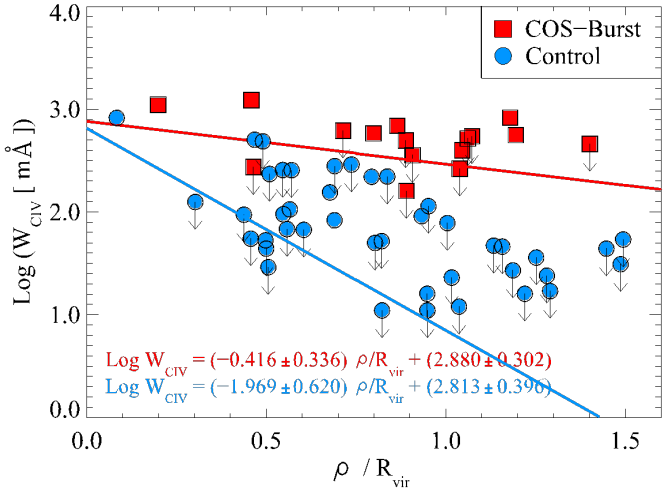
High Ions in the CGM of star-forming galaxies



Tumlinson+ 2011



Chen+ 2001



Heckman+17

(Savage+'11, Fox+'11+'15, Bordoloi+'14, Péroux & Howk '20, Qu+'24, Ahoranta+'21, Muzahid+'14, Wakker+09, Méndez-Hernández+'22, Hasan+'22, and others)

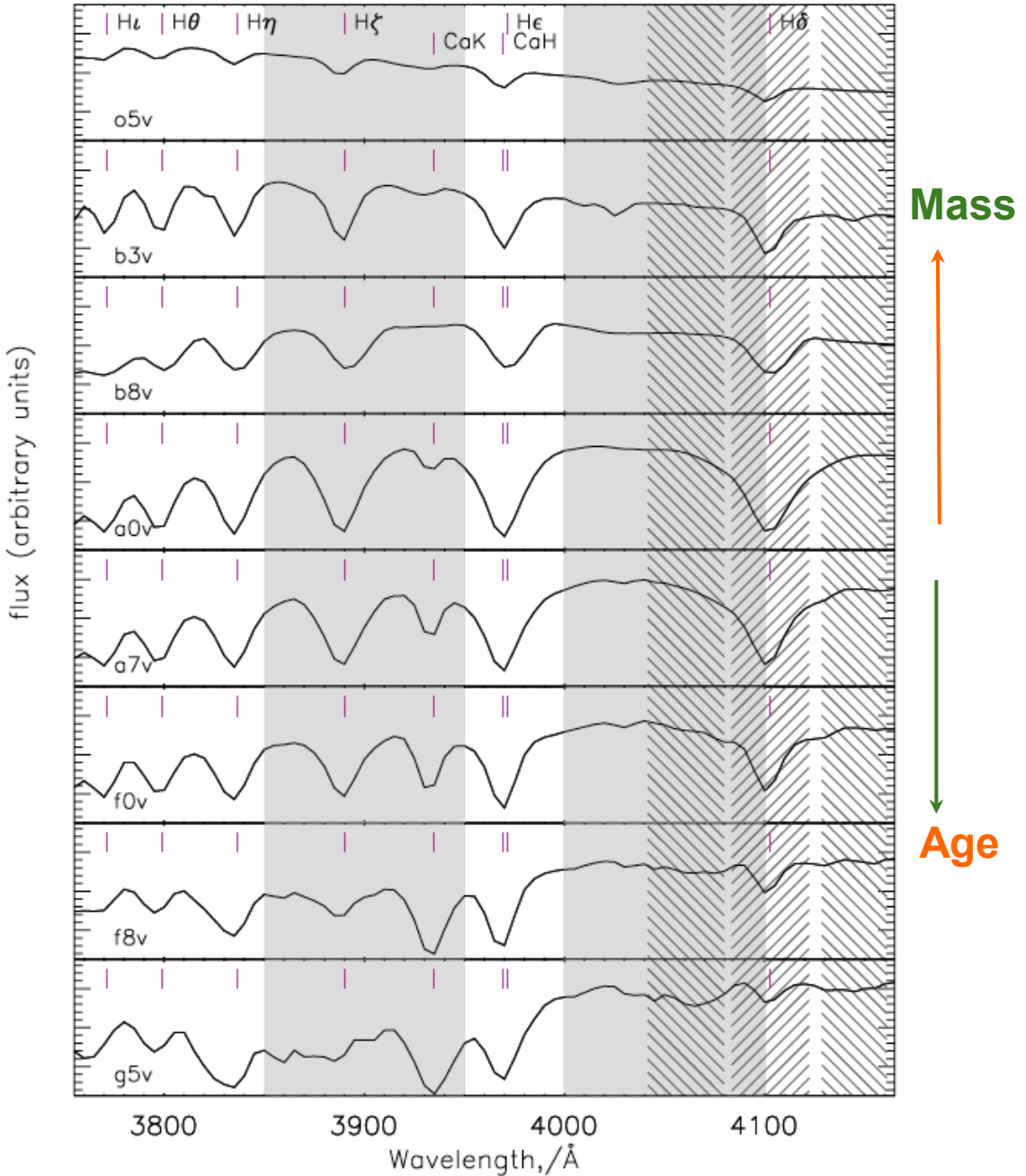
Stellar Ages and Star Formation History

1. Strength of the 4000-Å break ($D_n(4000)$)
2. Strength of Hδ

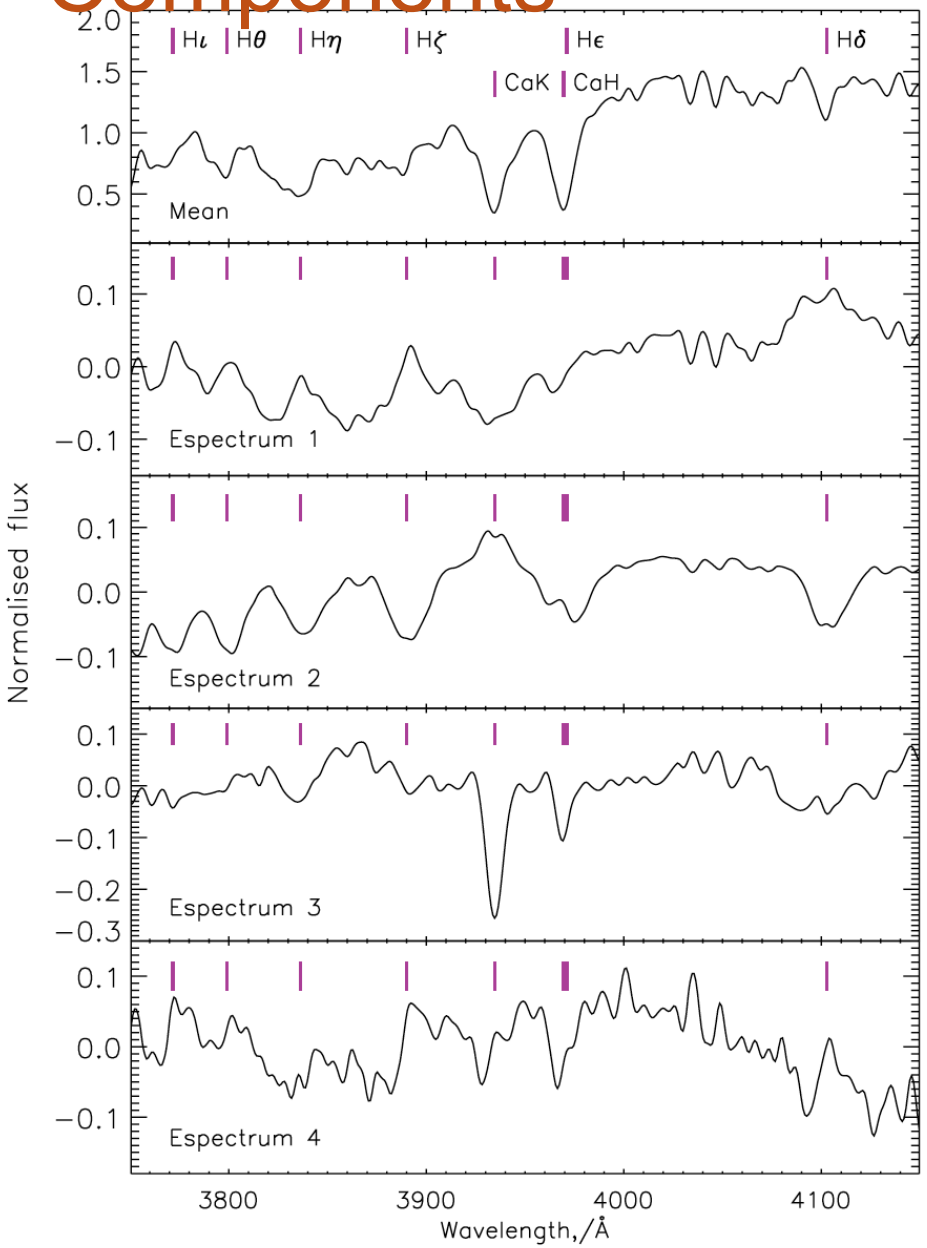
Trend with Age

1. $D_n(4000) \propto$ Age
2. EW(Hδ) decreases for the cooler stars. It provide powerful age indicators for young to intermediate age stellar populations.

Stellar Spectra: From O to G stars



Breaking Down the Spectrum Into Components



Principal Component Analysis

$PC1 \equiv D_n(4000)$

$-PC1+PC2 \equiv H\delta$ EW

Component 1: Represents the 4000 A break and corresponding inverse correlation with Balmer line strength. PC1

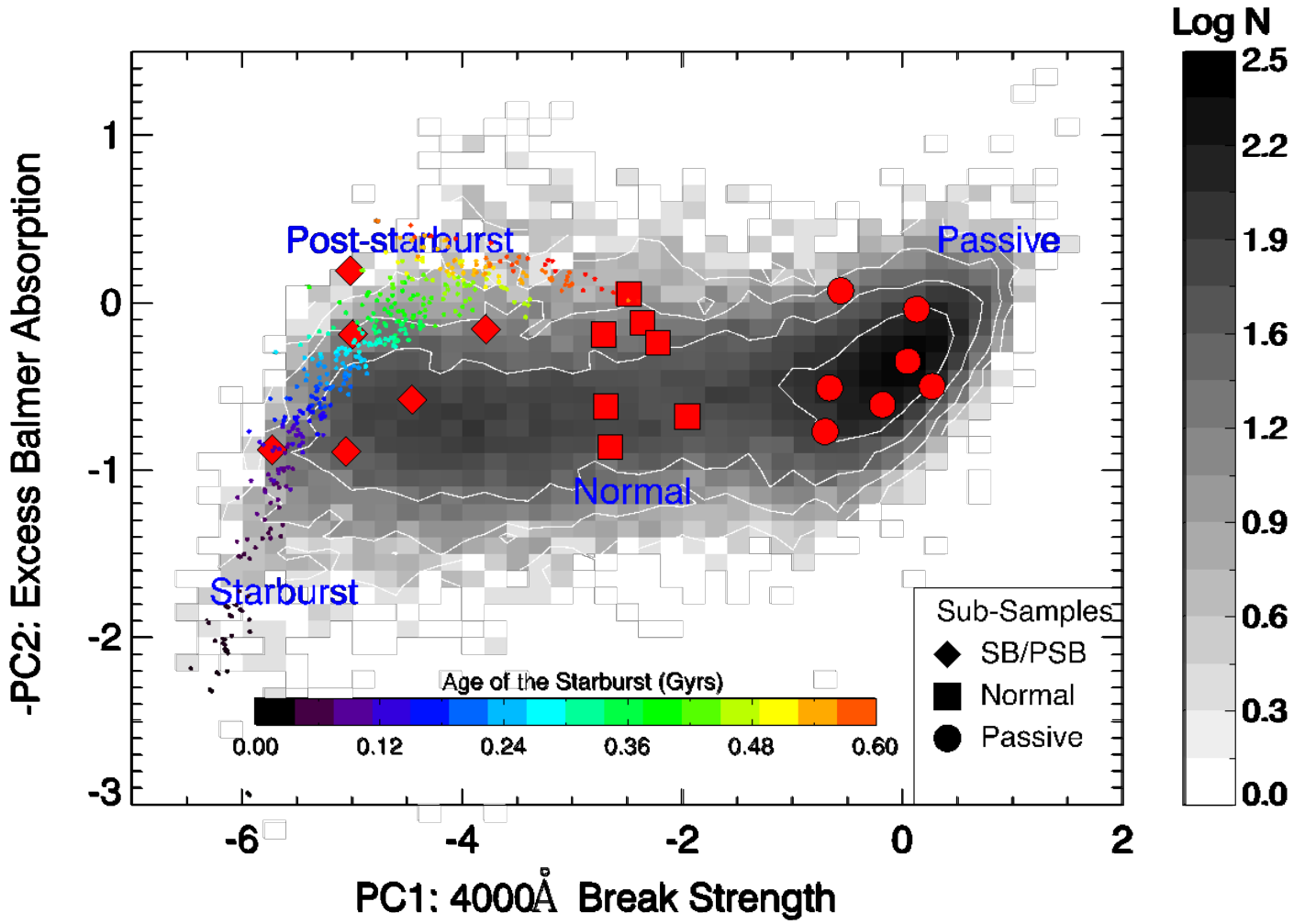
Component 2: Shows Balmer series and inverse correlation with the blue continuum shape seen in O- and B-type stars. PC2

Component 3: Primarily dominated by the Ca II (H&K) absorption lines.

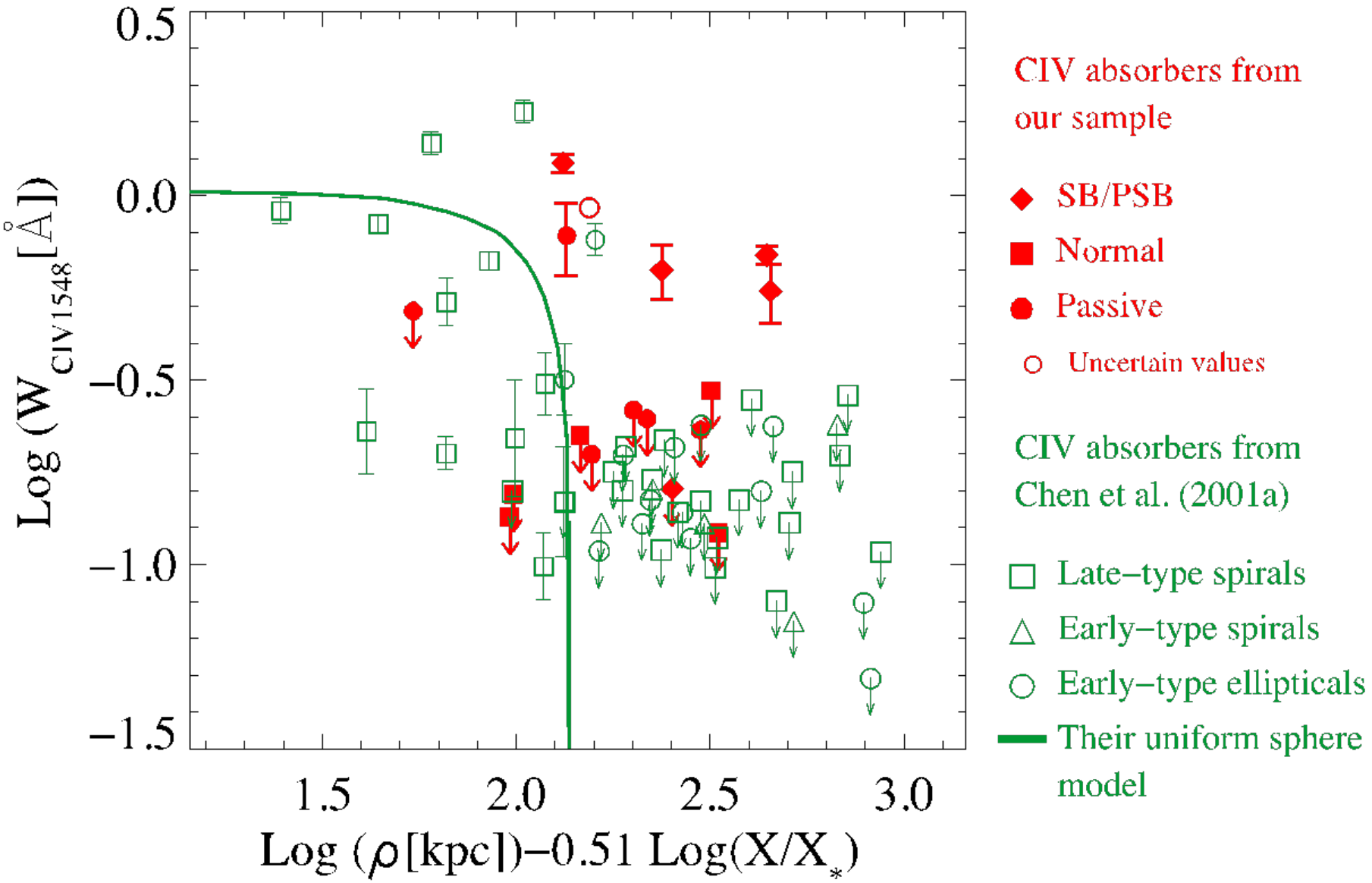
Component 4: The fourth component contains metallicity information.

Wild et al. (2007, 2010)

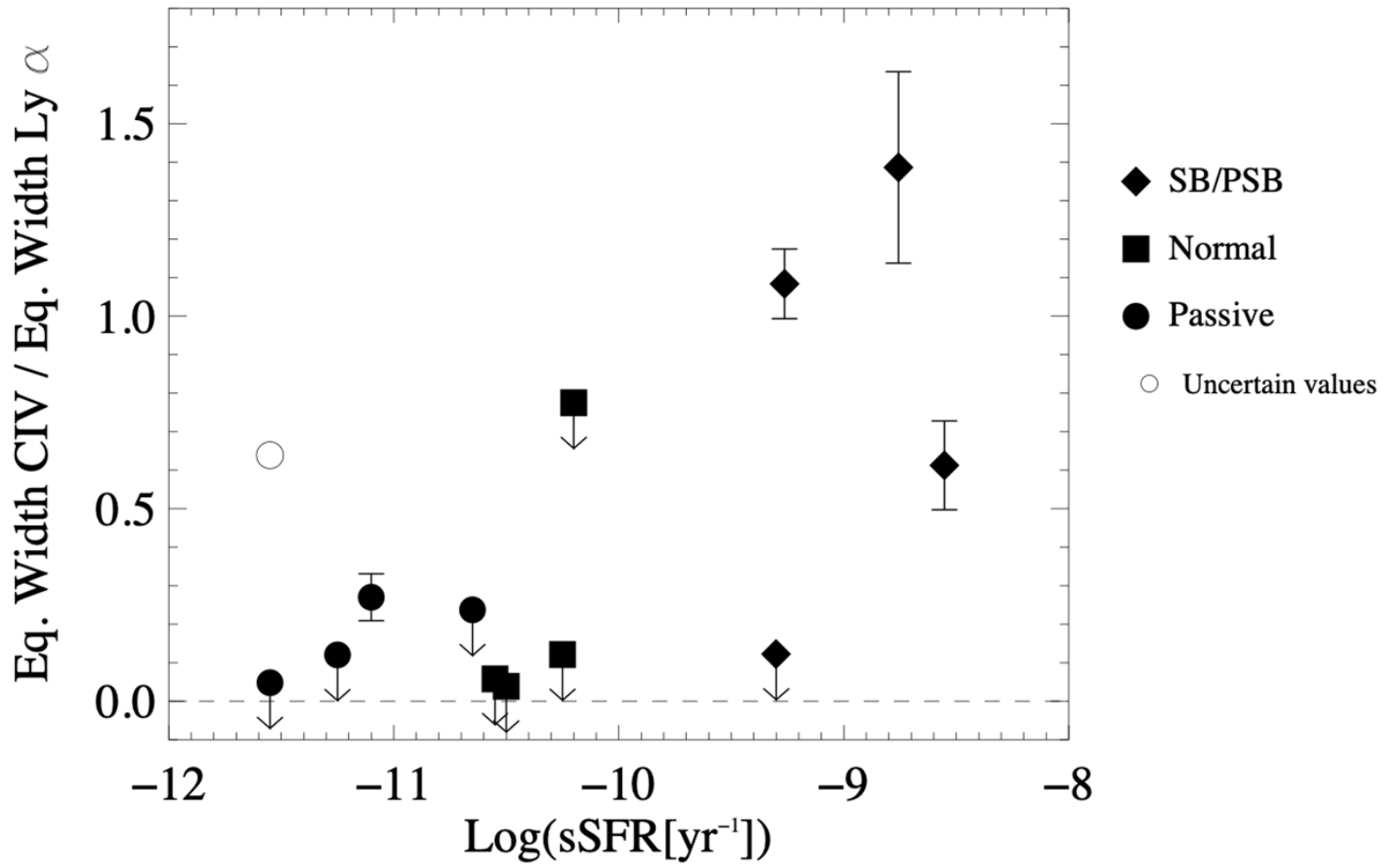
Identifying a Sample: COSBurst



CIV in the CGM of Starburst and Poststarburst Galaxies



Ratio of Ionized Gas to Cool Gas

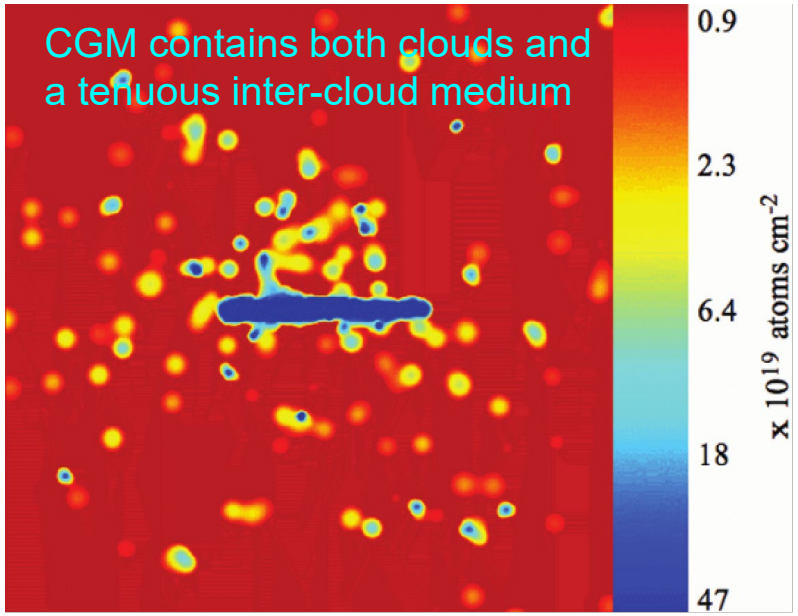


CGM of starburst galaxies are highly ionized

What Ionizes the CGM in Starburst and Post-starburst Galaxies

Wind propagates through a clumpy CGM.

The outflowing wind will then not only inflate a large cavity in the tenuous component but also shock-heat and accelerate the embedded ambient CGM clouds.



Kauffman et al. 2009

For CIV we need shock velocity > 100 km/s

$$v_{shock} = v_{wind}\left(\rho_{wind}/\rho_{cloud}\right)^{1/2}$$

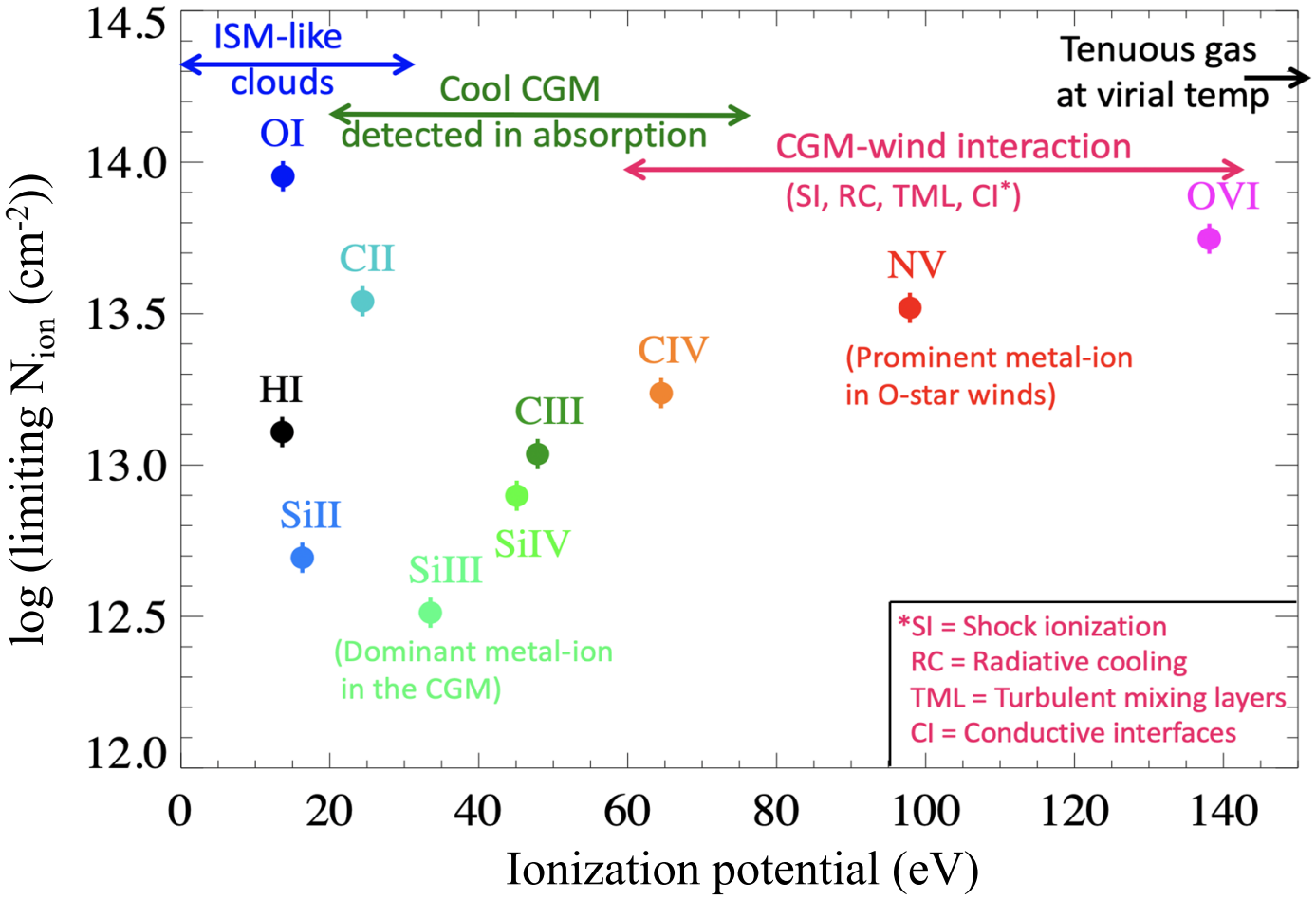
$$v_{shock} \sim 100 \mathrm{kms}^{-1}$$

$$N_{rad} = 10^{17.5} v_{100}^{4}\ \mathrm{cm}^{-2}$$ Draine & McKee 1993

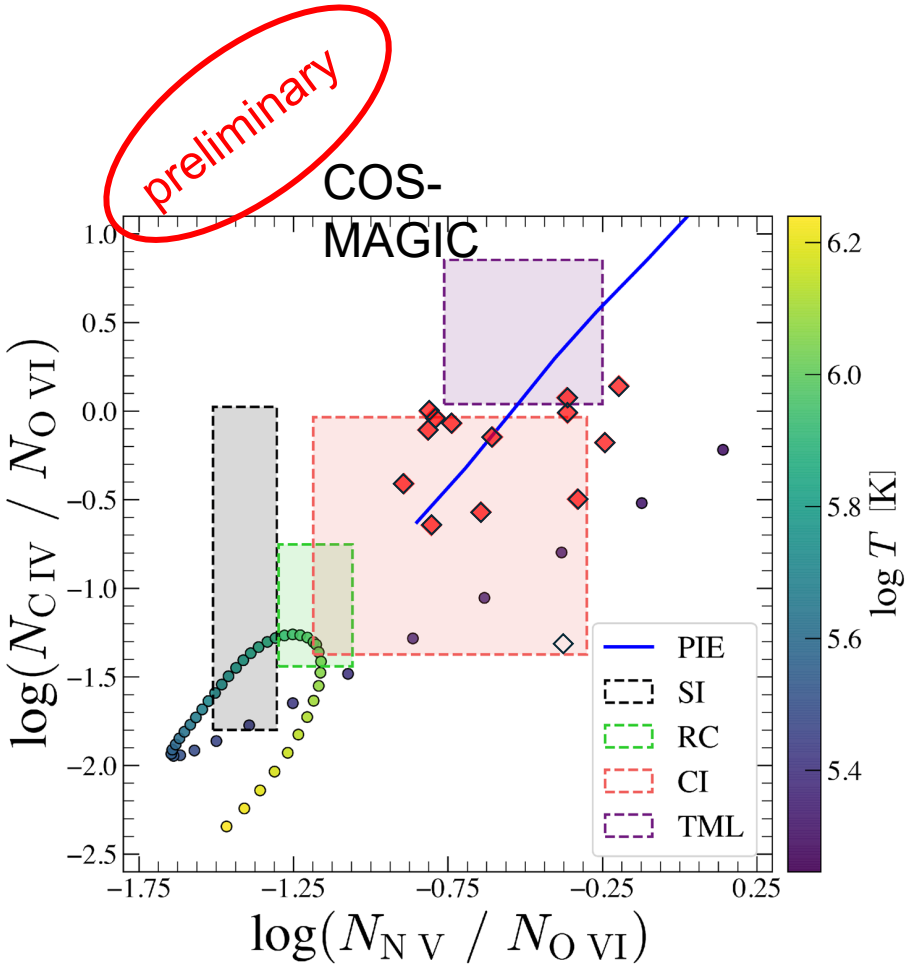
N(CIV) ~ 10^{13} cm^{-2} , v ~ 100 km/s Shull & McKee 1979

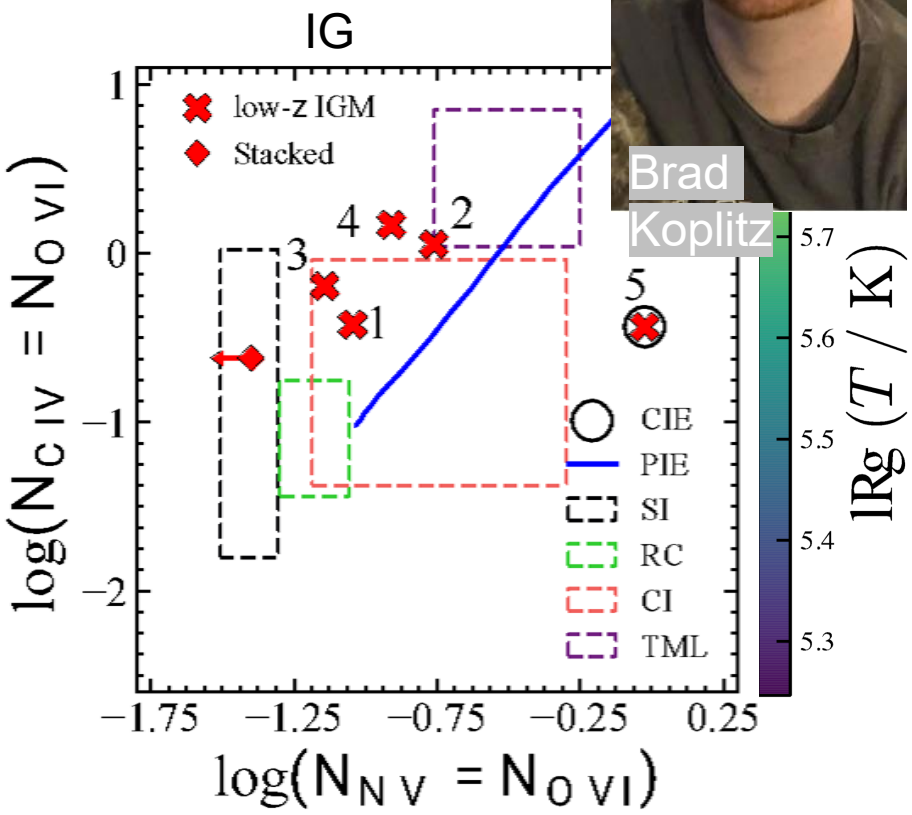
- C IV absorption arises from an ensemble of clouds/shocks rather than single objects.
- Consistent with the observed breadth of the C IV lines (FWHM ~ 120 to 320 km/s).

What Capabilities are Needed for HWO Detect Wind-CGM interactions?



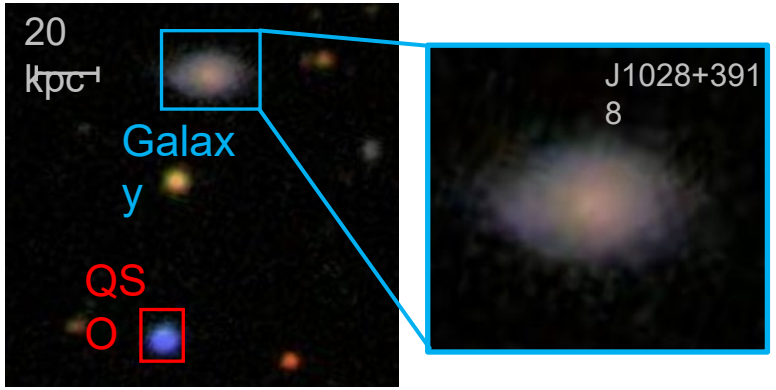
COS MAGIC: Microphysics Associated with the Galactic-winds Impacting the CGM

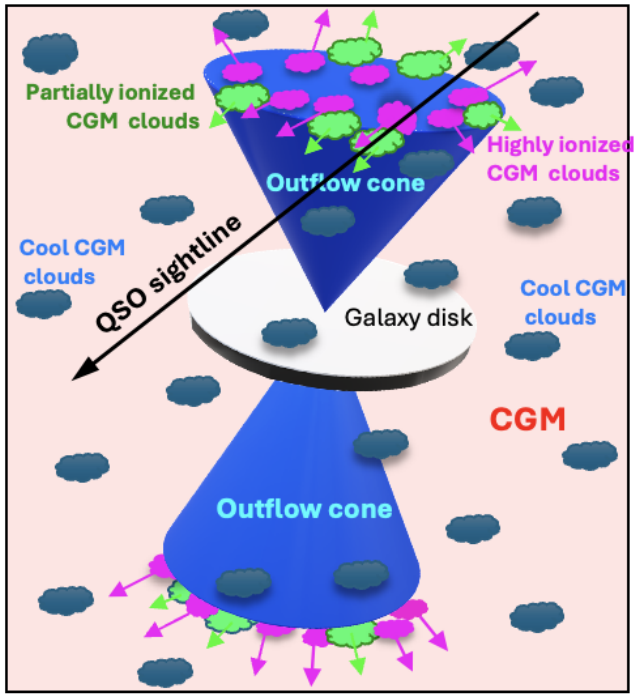


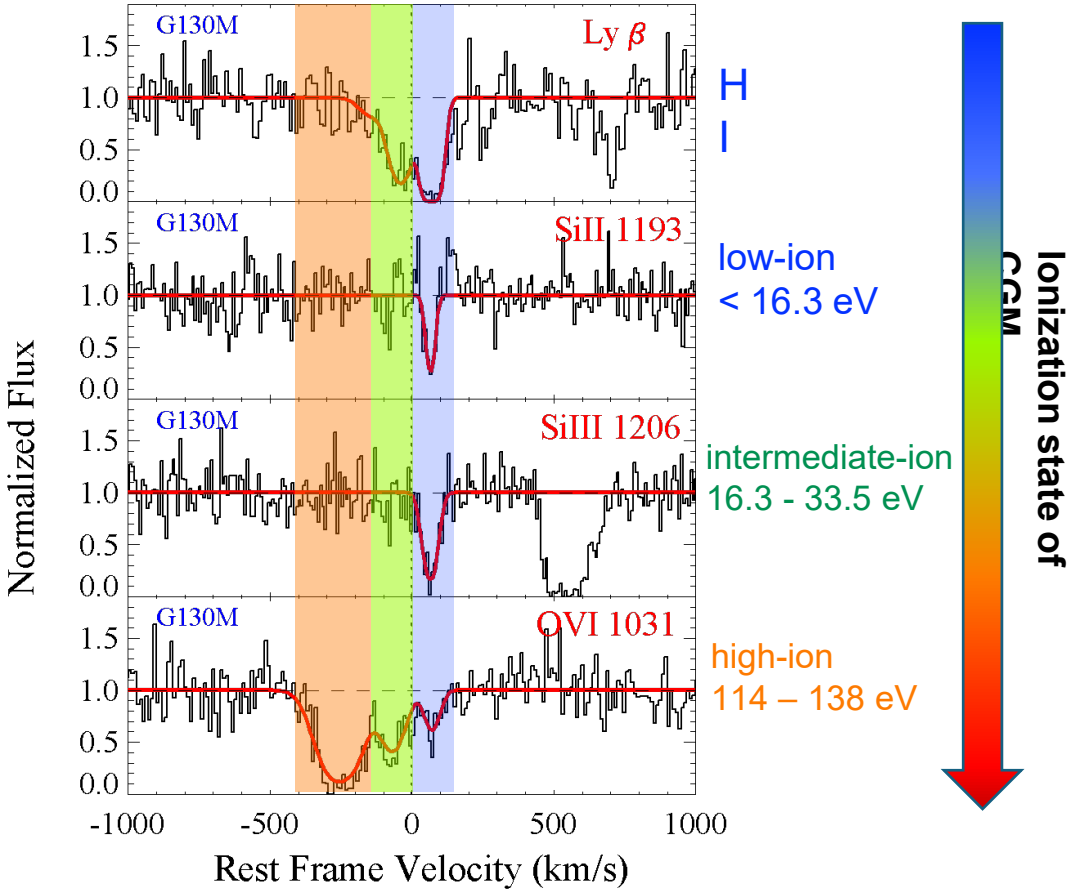


Koplitz+202
4

Multi-phase outflows* in starburst galaxies

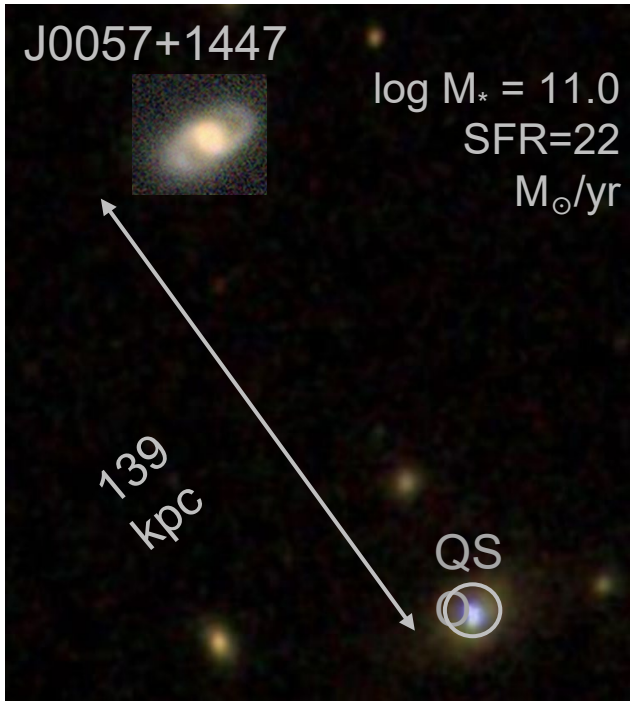




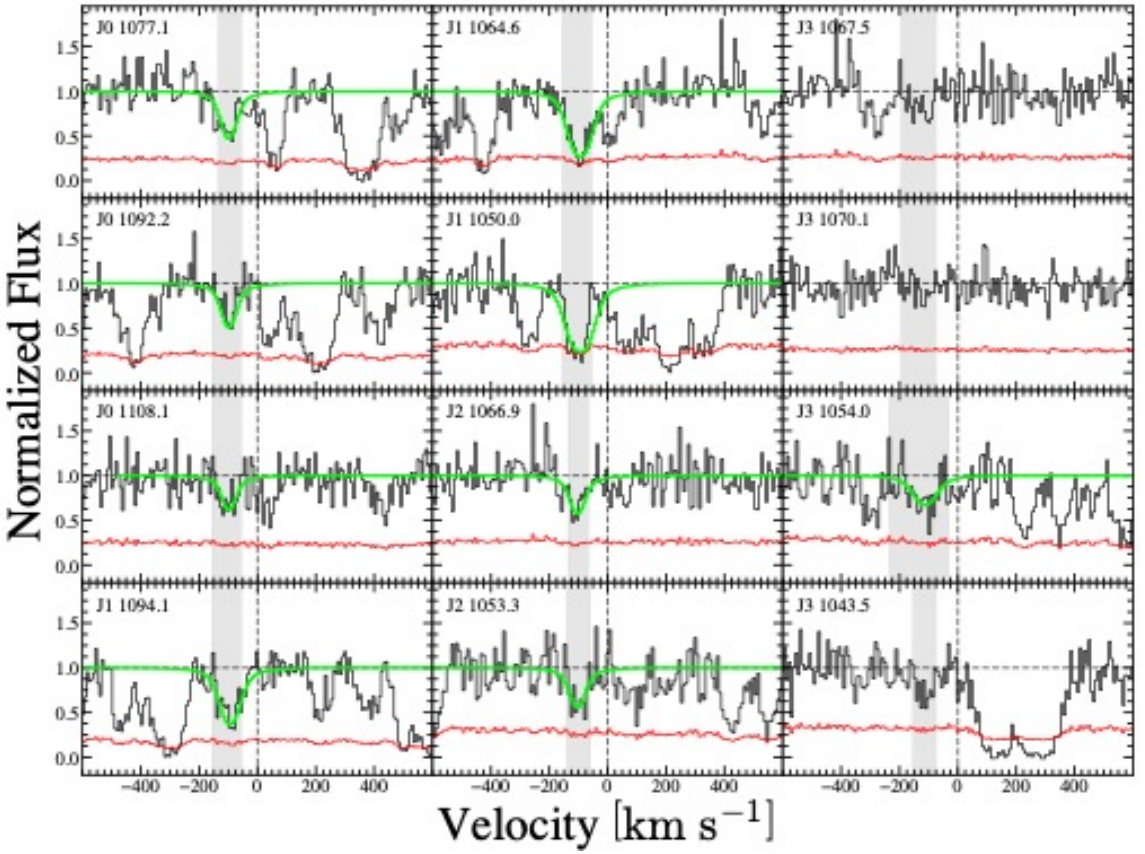


(The COS-Burst Survey; Borthakur+2013, Heckman+2017, Borthakur et a. in prep.)

* Most likely outflowing material



COS MAGIC: Multi-phase (molecular) outflows * in star-forming galaxies



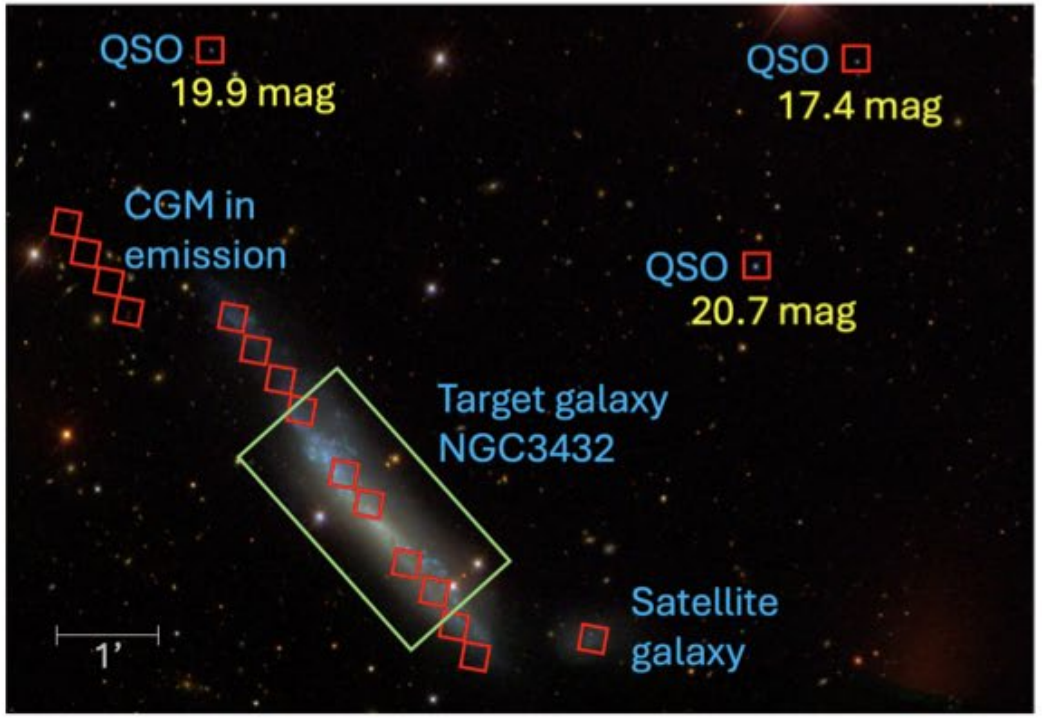
Please see the talk by

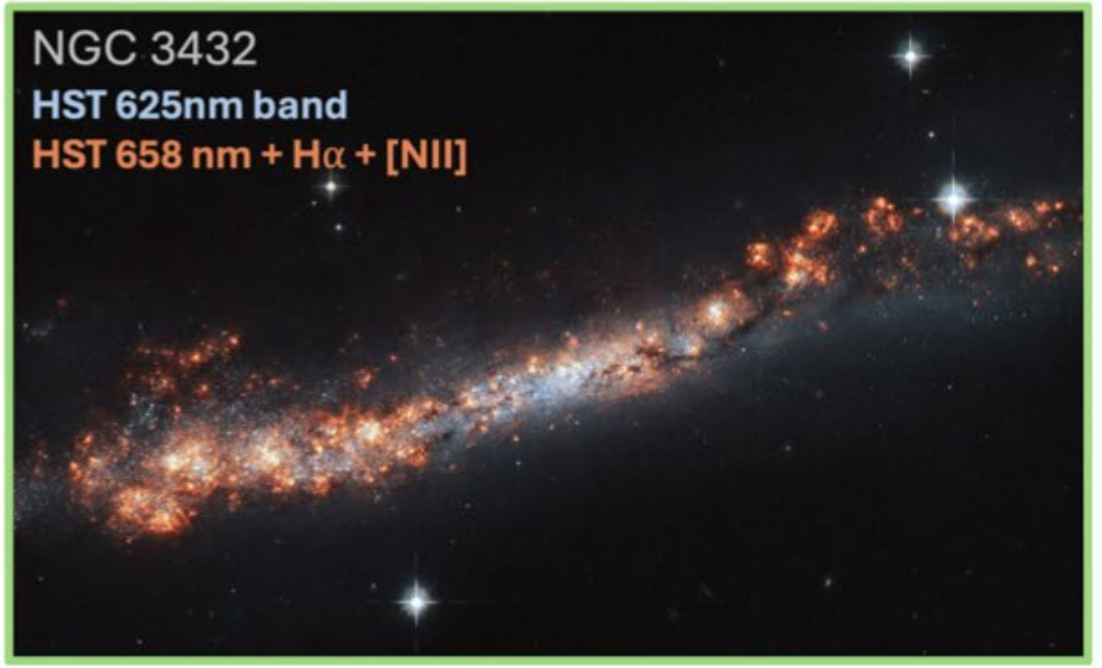
Brad Koplitz

On Tuesday's session titled
Gas Flows and Feedback in the Circumgalactic Medium

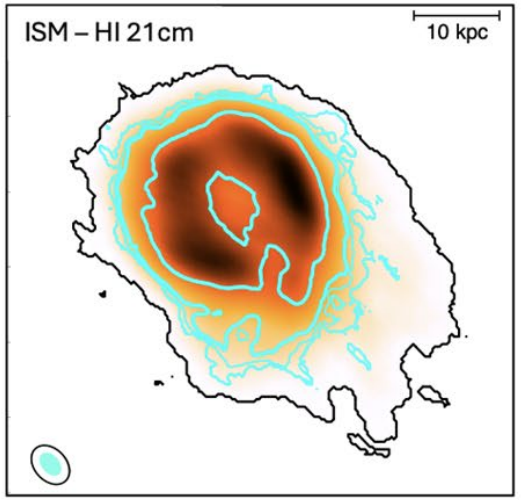
Beyond 2026…….

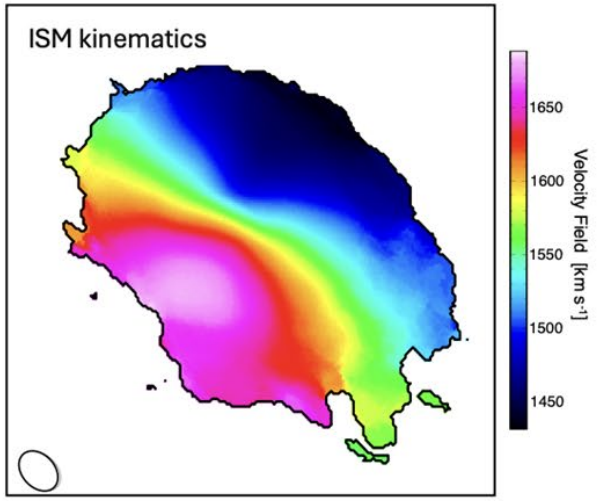
The big breakthrough would be to have individual star-forming regions surveys to track outflows in cold, intermediate, and highly ionized tracers.

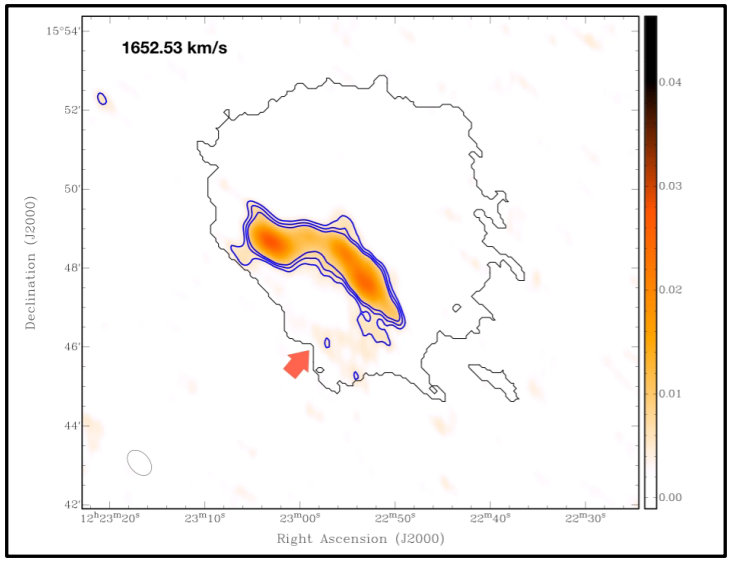


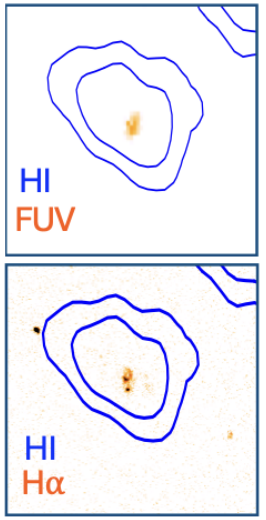


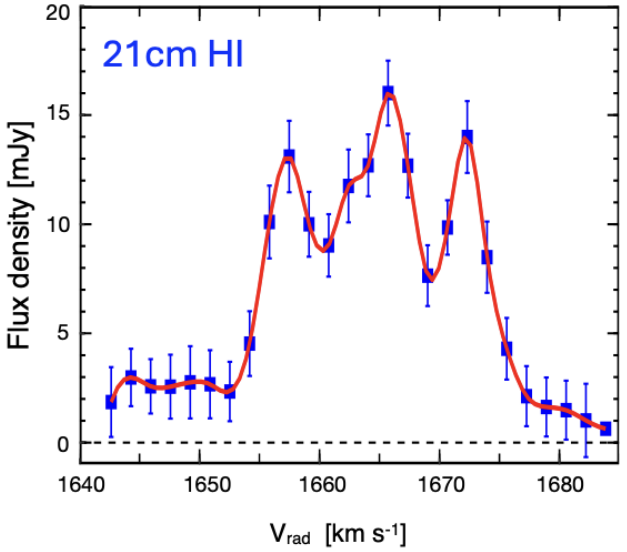
Outflows Driven by Individual Star-forming Regions in M100





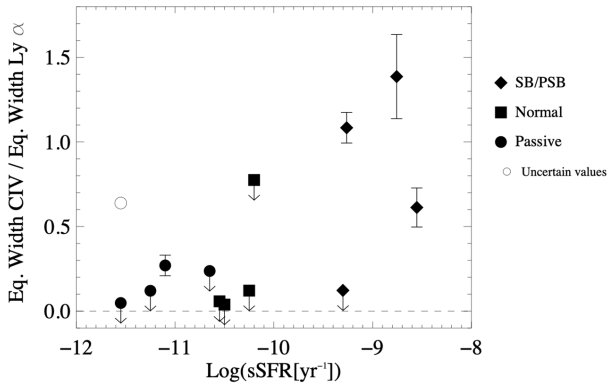






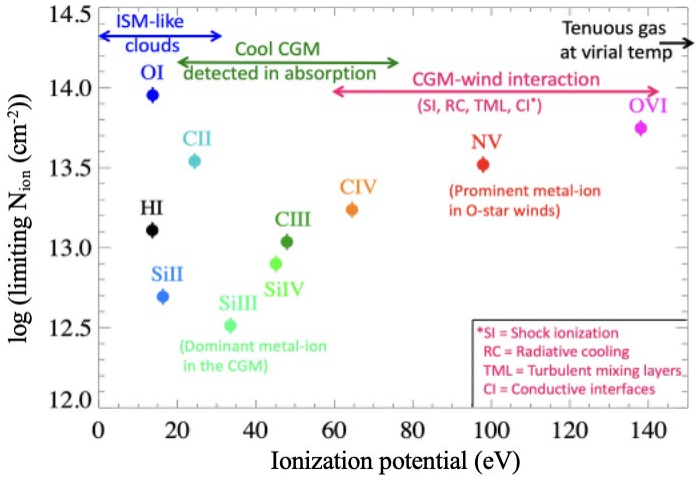
(Gim et al. 2021)

Conclusion and Outlook for the Future



CGM of starburst galaxies are highly ionized

- Starbursts and post-starbursts significantly ionize their CGM
  - The ionized gas trace conductive interfaces --- similar to what is seen in Milky Way high-velocity clouds!!



- Next-generation telescopes with full spectroscopic coverage from **100-160 nm** will trace all phases of outflowing gas, enabling quantification of the role of stellar populations in shaping the CGM.