Jet-Driven Baryon Cycling: Mapping Diffuse ISM–CGM Gas in Radio AGN with JWST and Future HWO UV IFUs

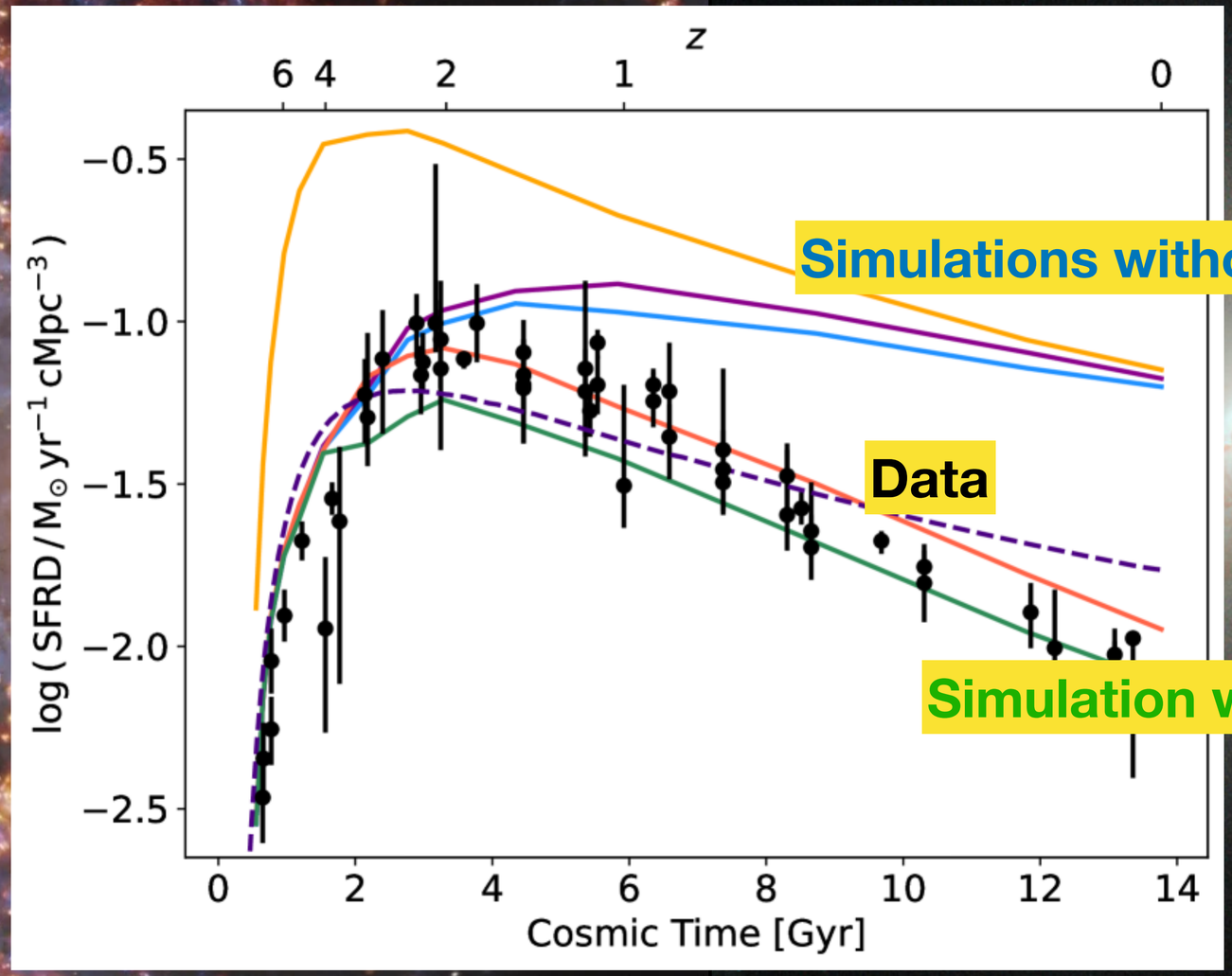
Namrata Roy
Exploration fellow
School of Earth and Space Exploration
Arizona State University

STScI

NASA

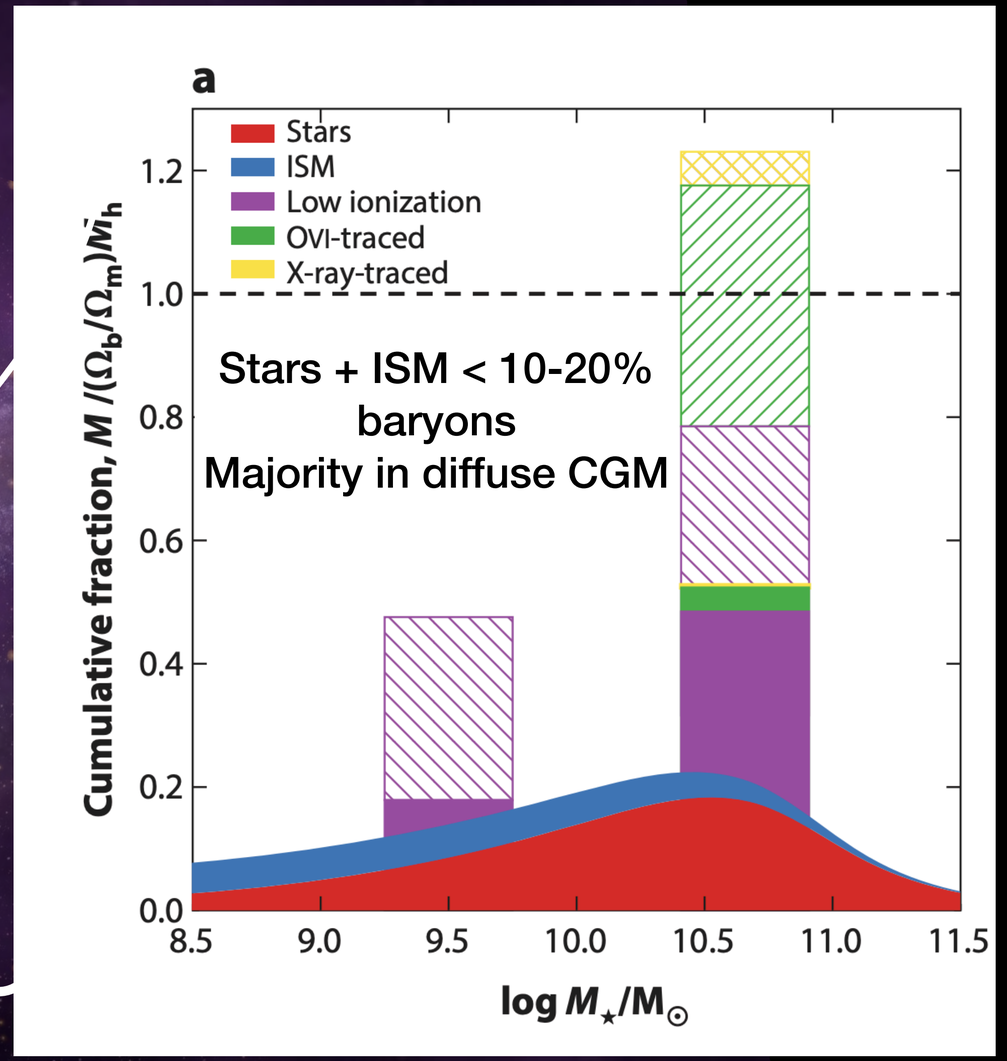
Arizona State University

How galaxies age and transition from star forming to quenched? Black hole feedback plays a big role…



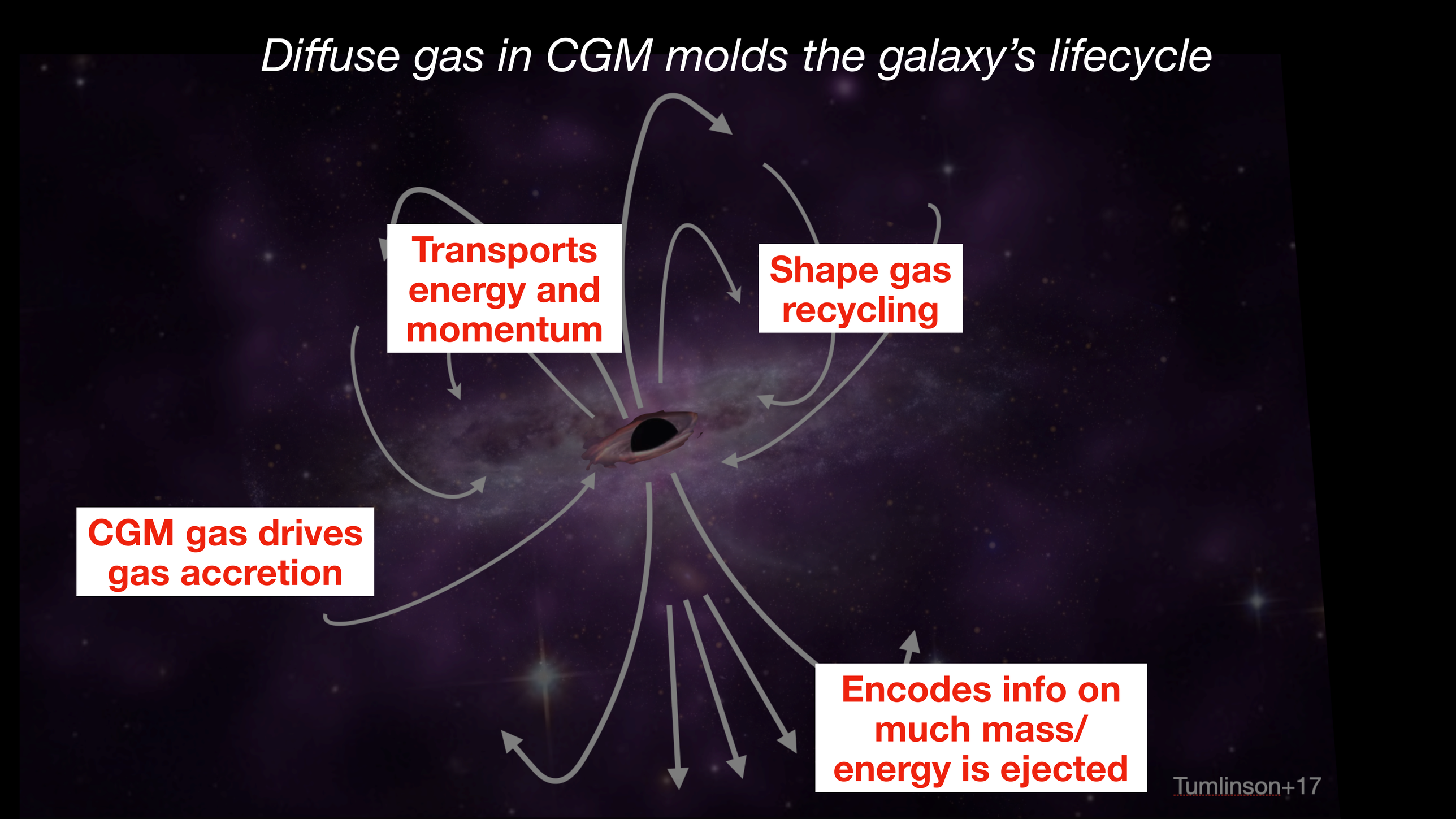
PHANGS, NASA/ESA Hubble, Madau-Dickinson14, Scharré+2024, Croton+2006

Circulation of diffuse gas and "baryon cycle"

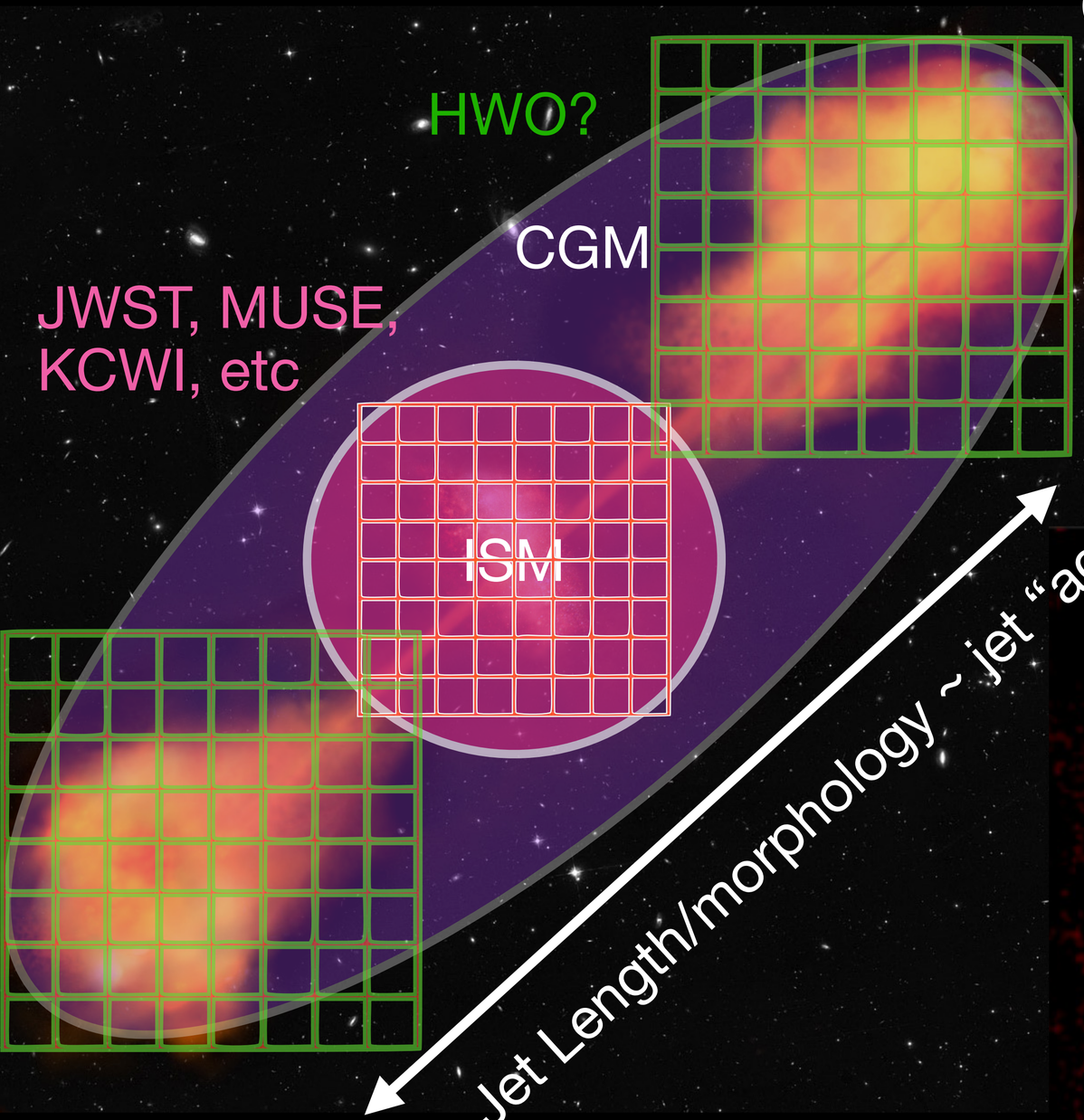


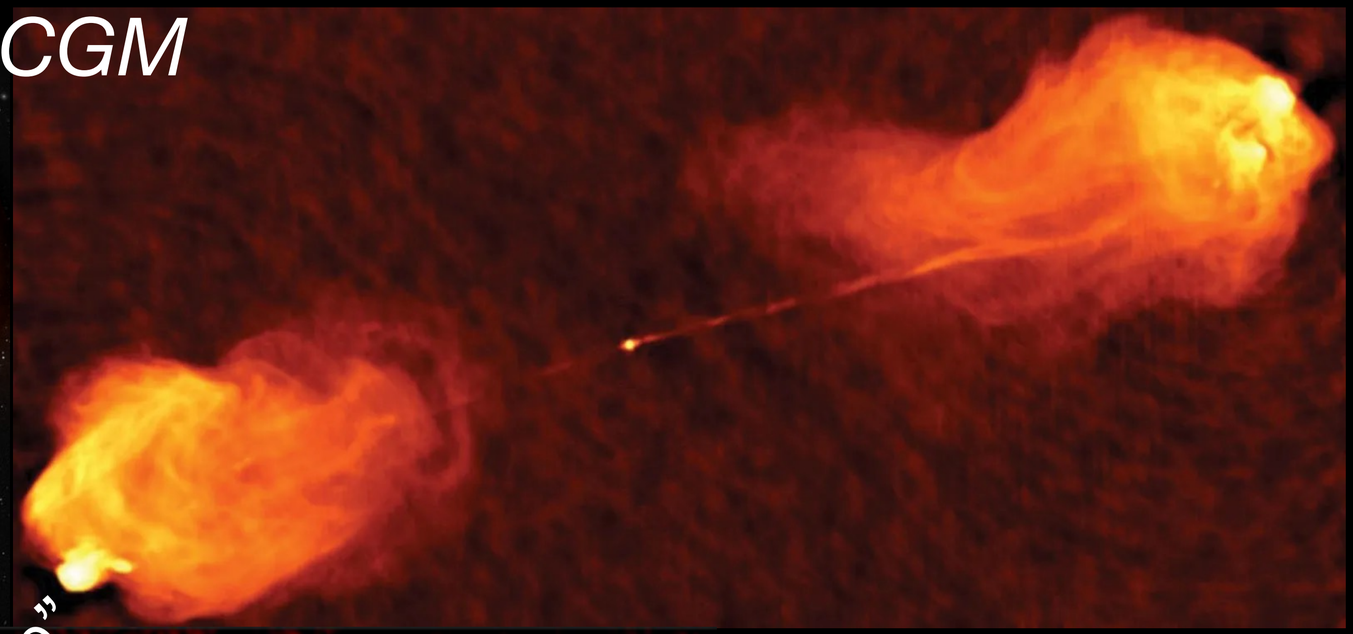
Tumlinson+17

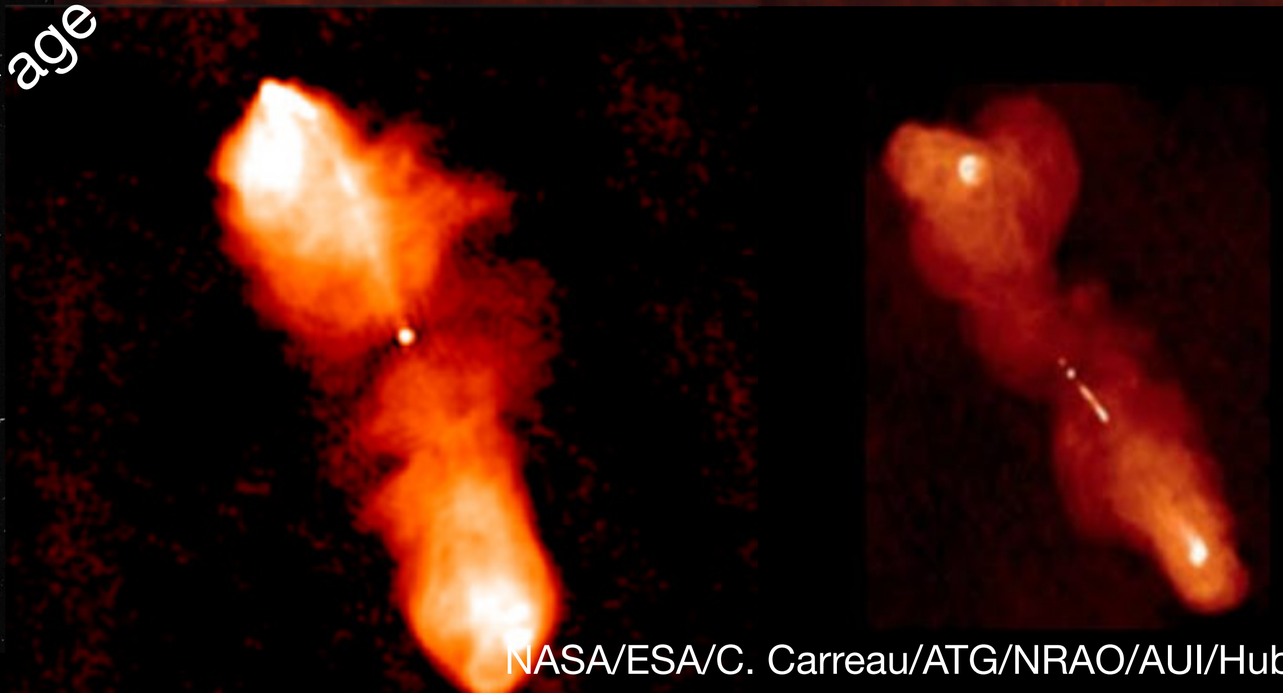
Diffuse gas in CGM molds the galaxy's lifecycle



Active Galactic Nuclei with jets can directly perturb ISM and CGM

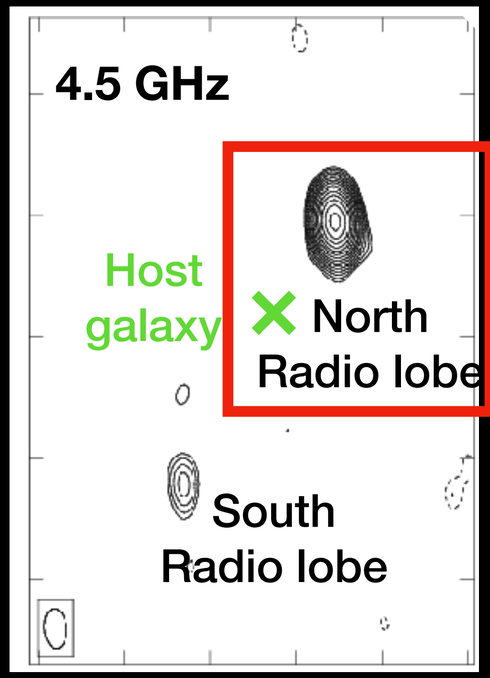


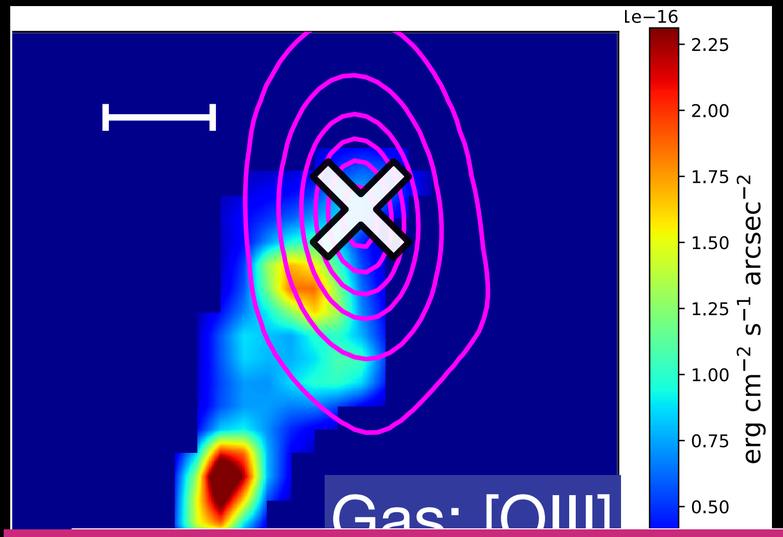


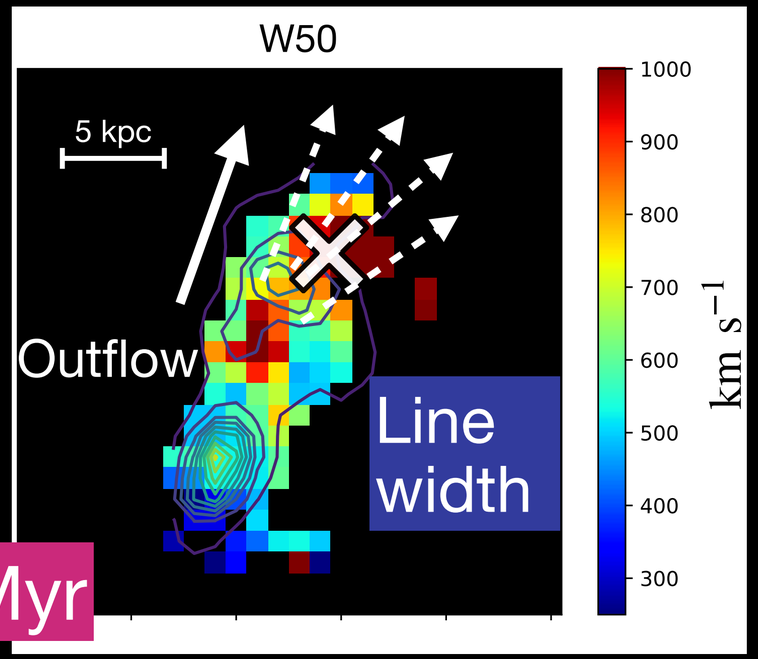


NASA/ESA/C. Carreau/ATG/NRAO/AUI/Hubblesite

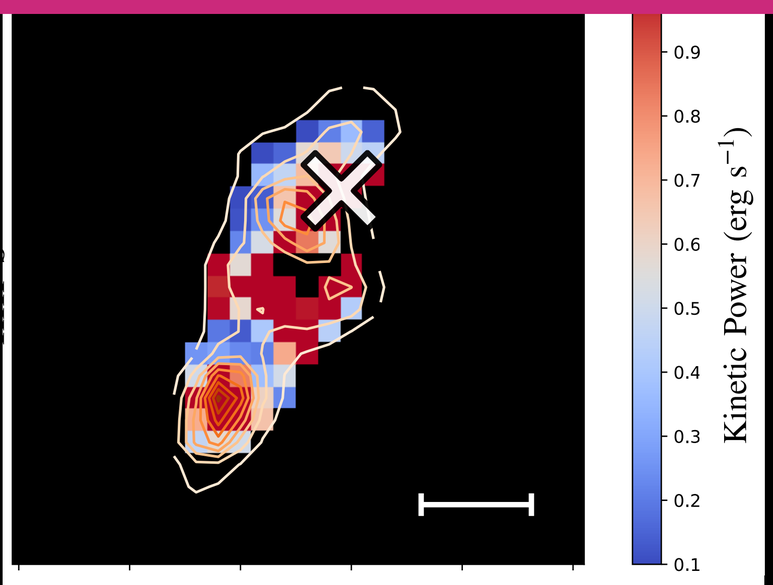
We can now resolve jet-ISM coupling in 2D at very high-z







Radio source lifetime ~ 3.9 Myr



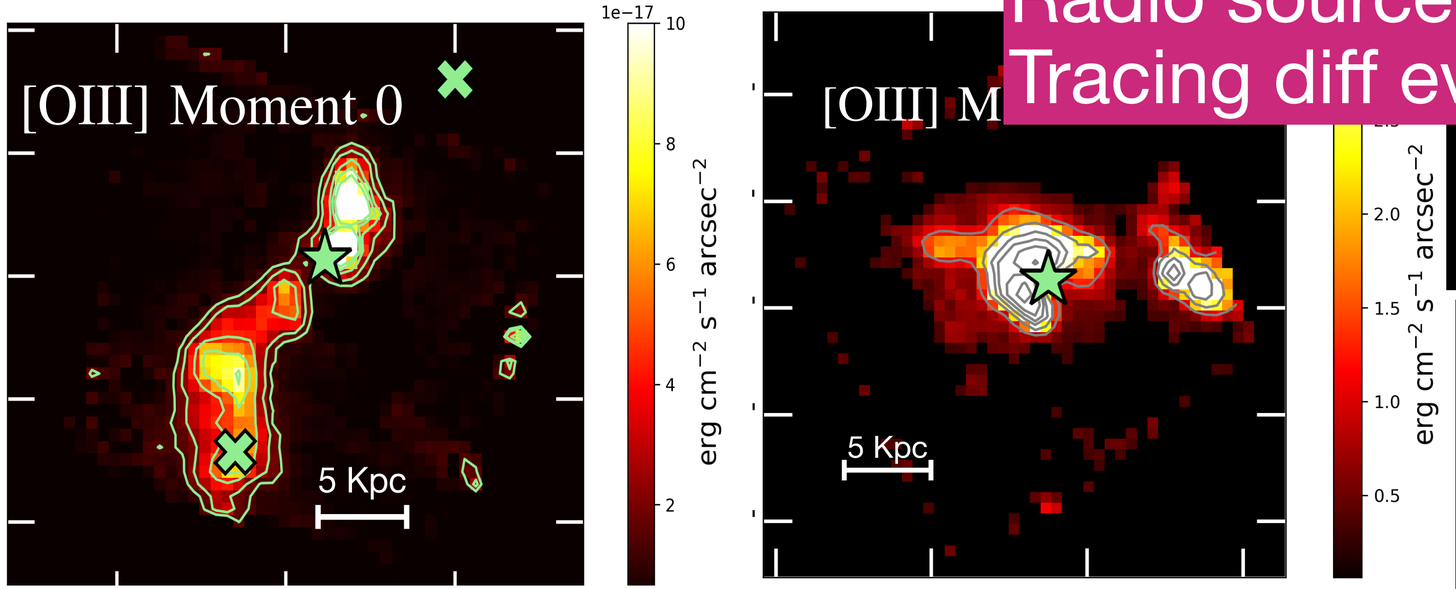
- Fastest, broadest ionized gas sits where the radio lobe is (“X”)!!
- Outflow velocity > 800 km/s, Mass ejected out at rate ~ 500 M/yr
- Outflow power ~ 10^{44} erg/s, which is 0.1% of available AGN energy

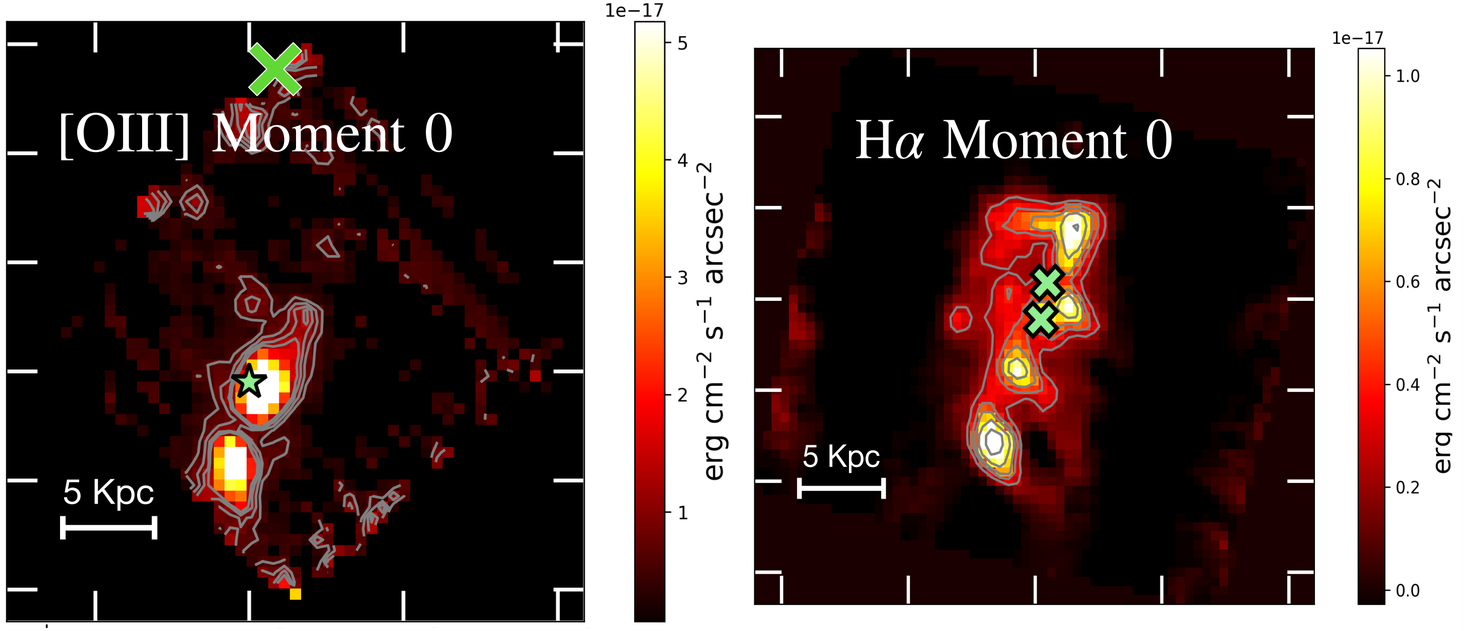
WEBB SPACE TELESCOPE

Roy+24

Same large scale outflows in multiple high redshift AGNs

Radio source lifetime ~ 1 to > 10 Myr.
Tracing diff evolutionary stages of jets..





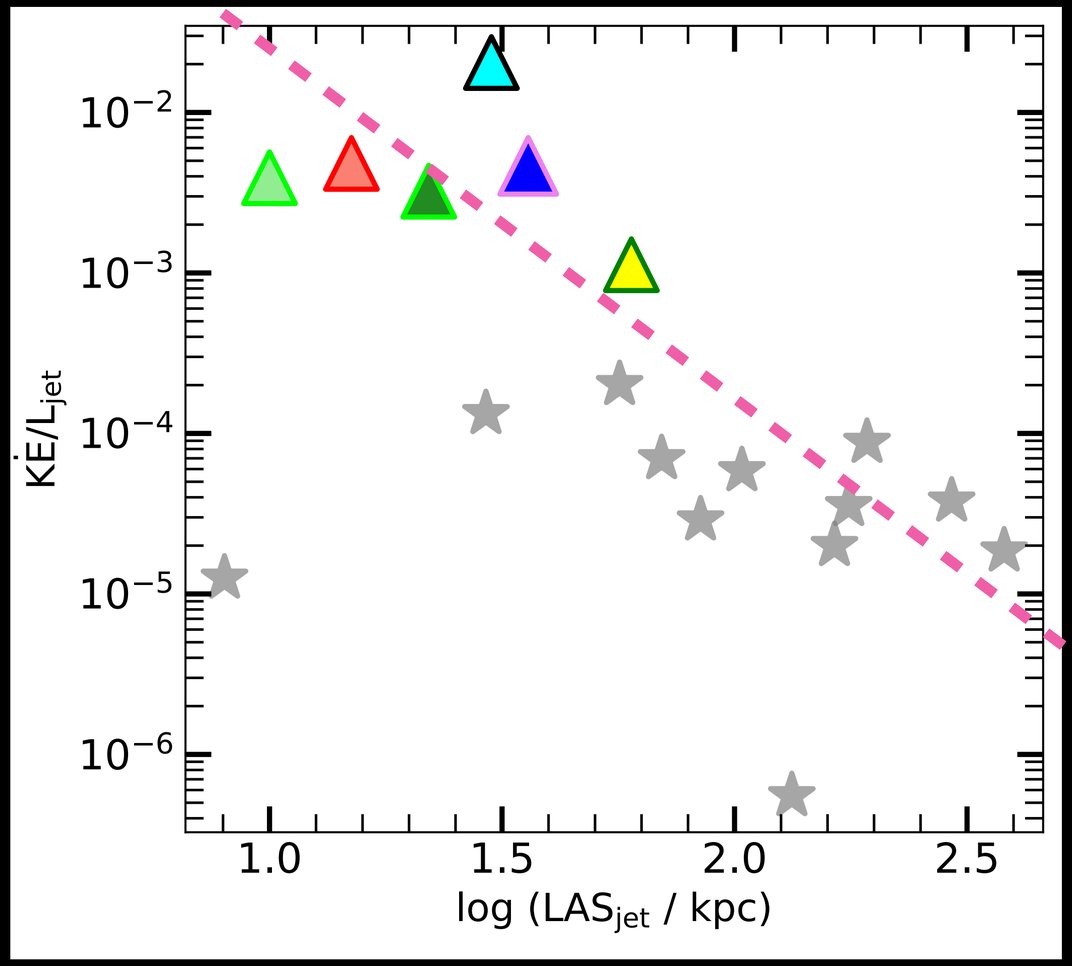
Key Takeaways: Radio galaxies

- ✦ Radio jets drive powerful outflows “along the jet”
- ✦ Outflow rates span ~ 70-900 M/yr, and are restricted within 20 kpc into inner CGM

Roy+24, Roy+25

Correlation of outflow power with the jet dynamical time

$$\frac{\text{wind outflow power}}{\text{radio jet power}}$$

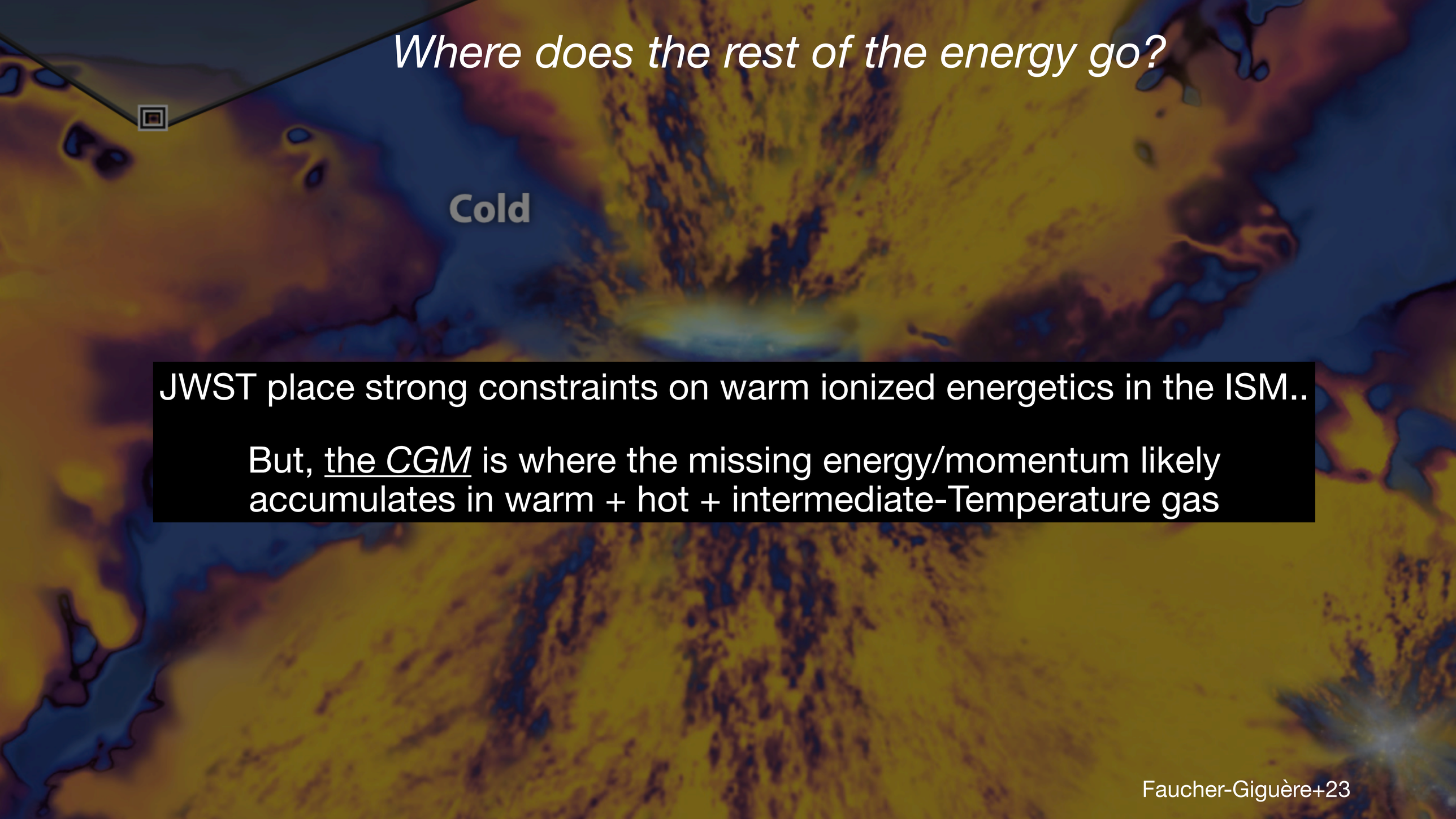


- Only a small fraction of AGN jet power (0.1-2%) couples to the warm, ionized ISM via wind

Roy+24, Roy+25

Young radio source → Proxy for jet age → Old radio source

Where does the rest of the energy go?



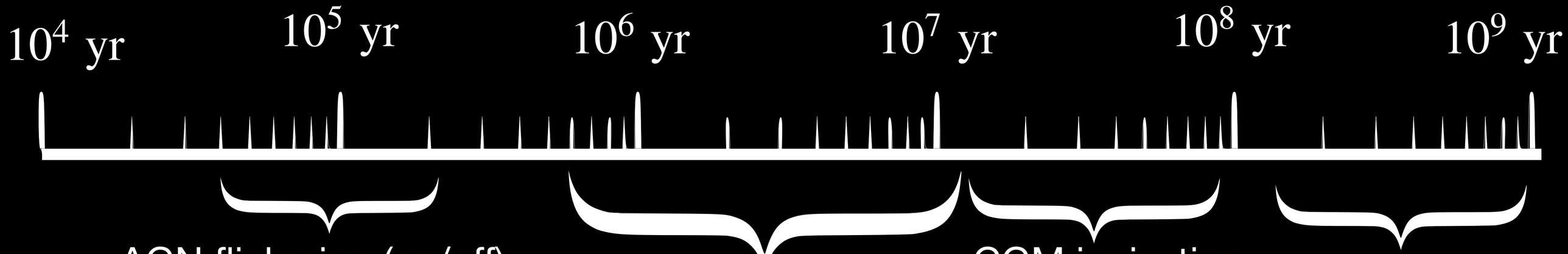
JWST place strong constraints on warm ionized energetics in the ISM..

But, the *CGM* is where the missing energy/momentum likely accumulates in warm + hot + intermediate-Temperature gas

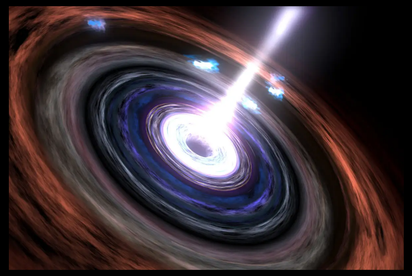
Faucher-Giguère+23

Jet timescale clock and CGM "ionization memory”

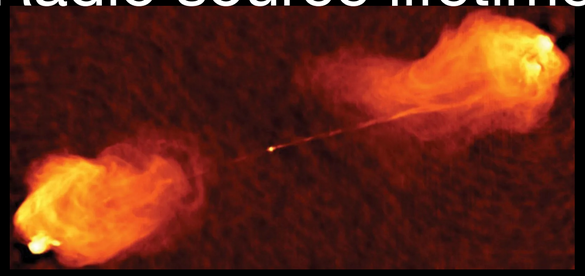
✦ Multiple timescales associated with AGN, jets, photoionization mechanisms and their detection…



AGN flickering (on/off)



Radio source lifetime



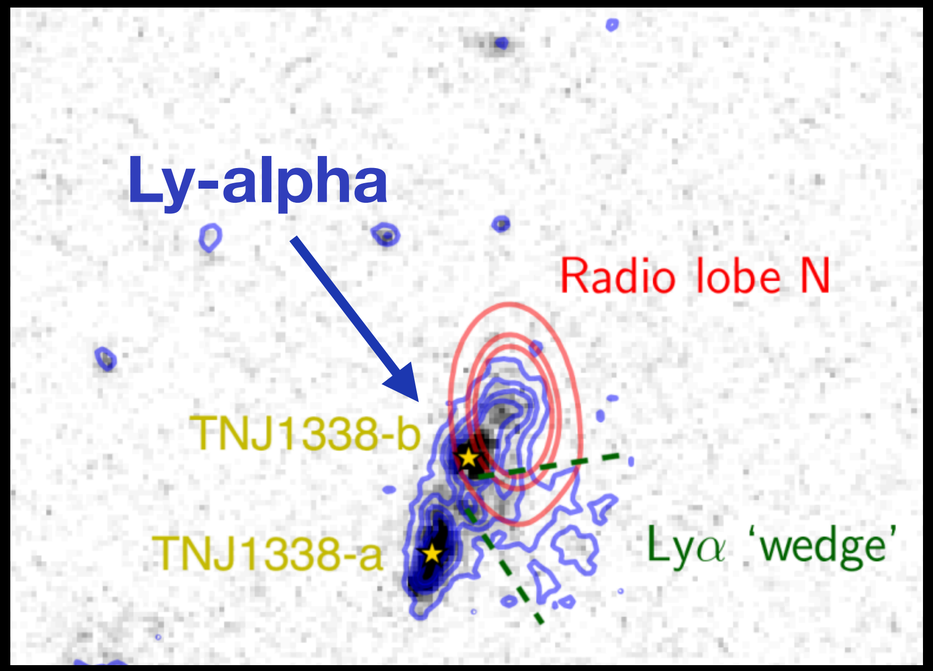
CGM ionization memory (metal ions can stay ionized after AGN shuts off)

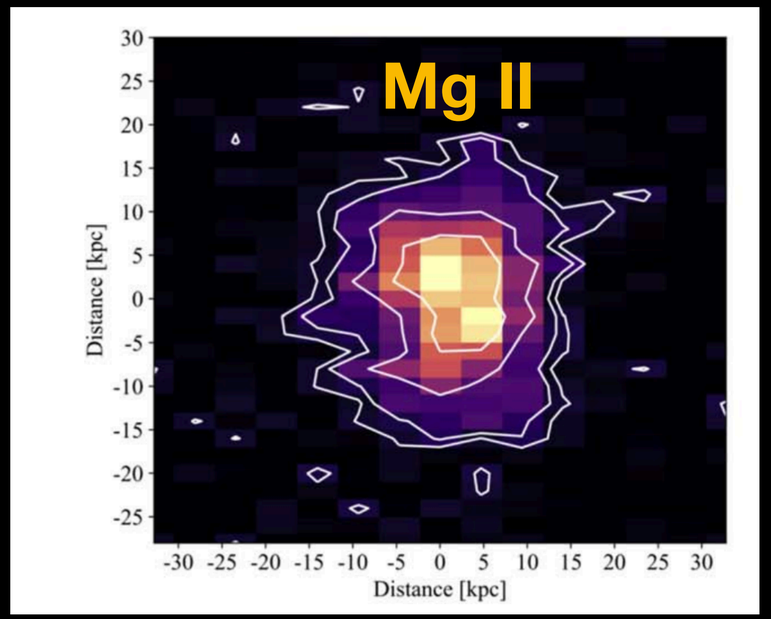
Quenching timescale

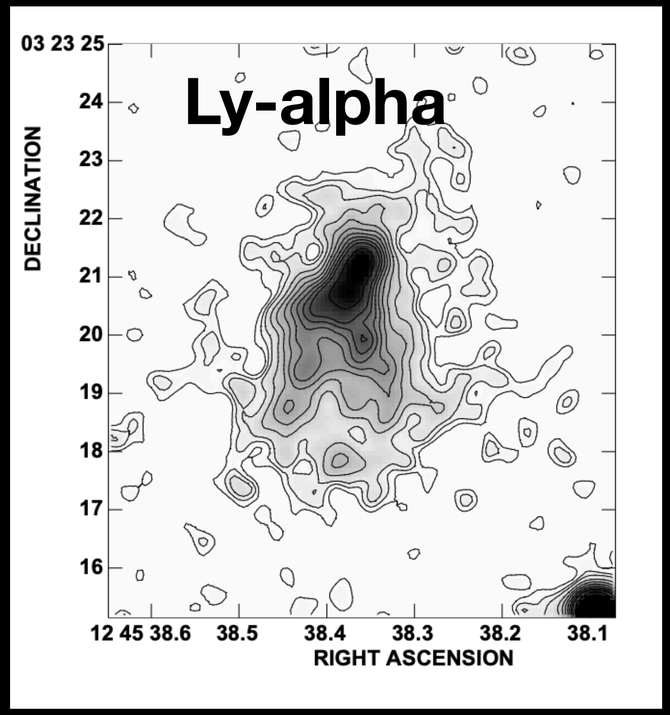
ALMA (ESO/NAOJ/NRAO)/S. Dagnello (NRAO/AUI/NSF), Hummels+19, NRAO/AUI/NSF, Perley+84, NASA/Goddard Space Flight Center Conceptual Image Lab

Ground based IFU spectrographs and HST have mapped CGM in emission via LyA and Mg II..

Extended Ly-alpha and MgII emission from extended CGM detected





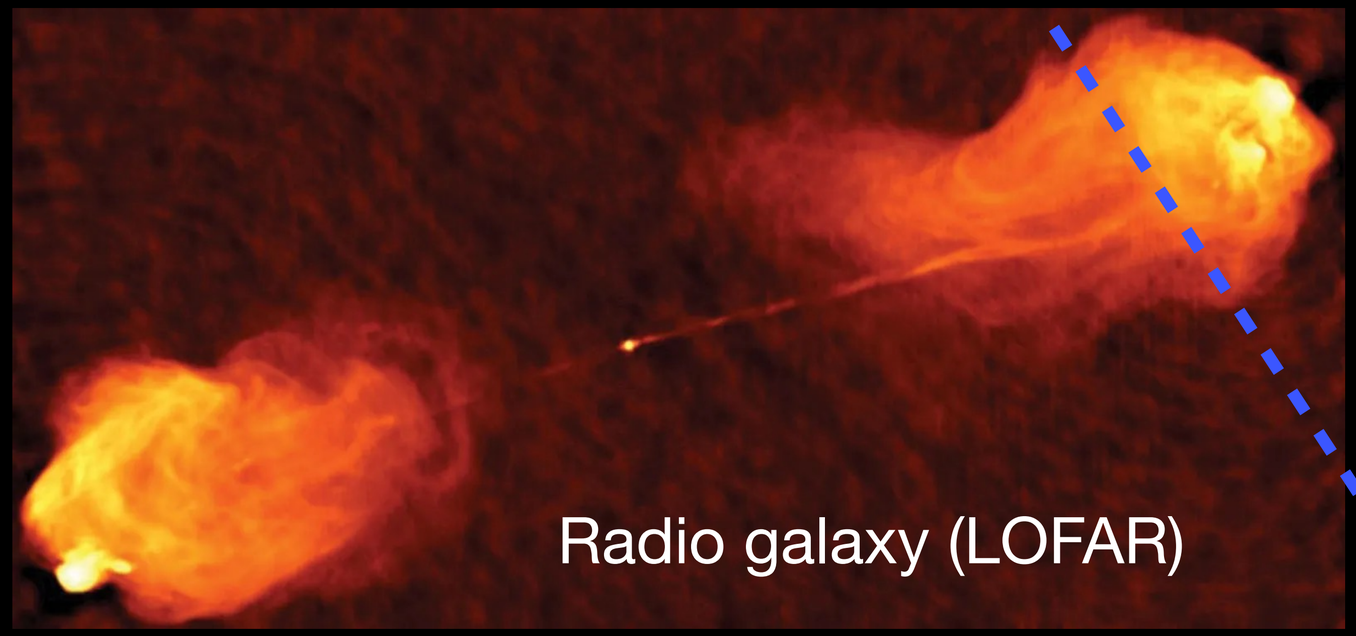


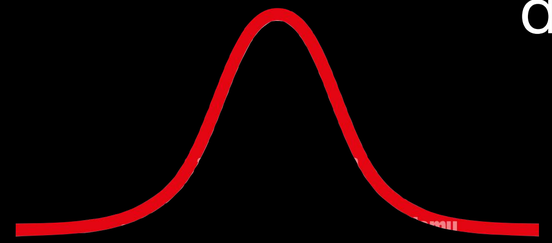
But these are case-by-case single object detections….

Saxena+24, Burchett+21, Ojik+96

Characterizing faint extended diffuse CGM gas “in emission” from ensemble via STACKING

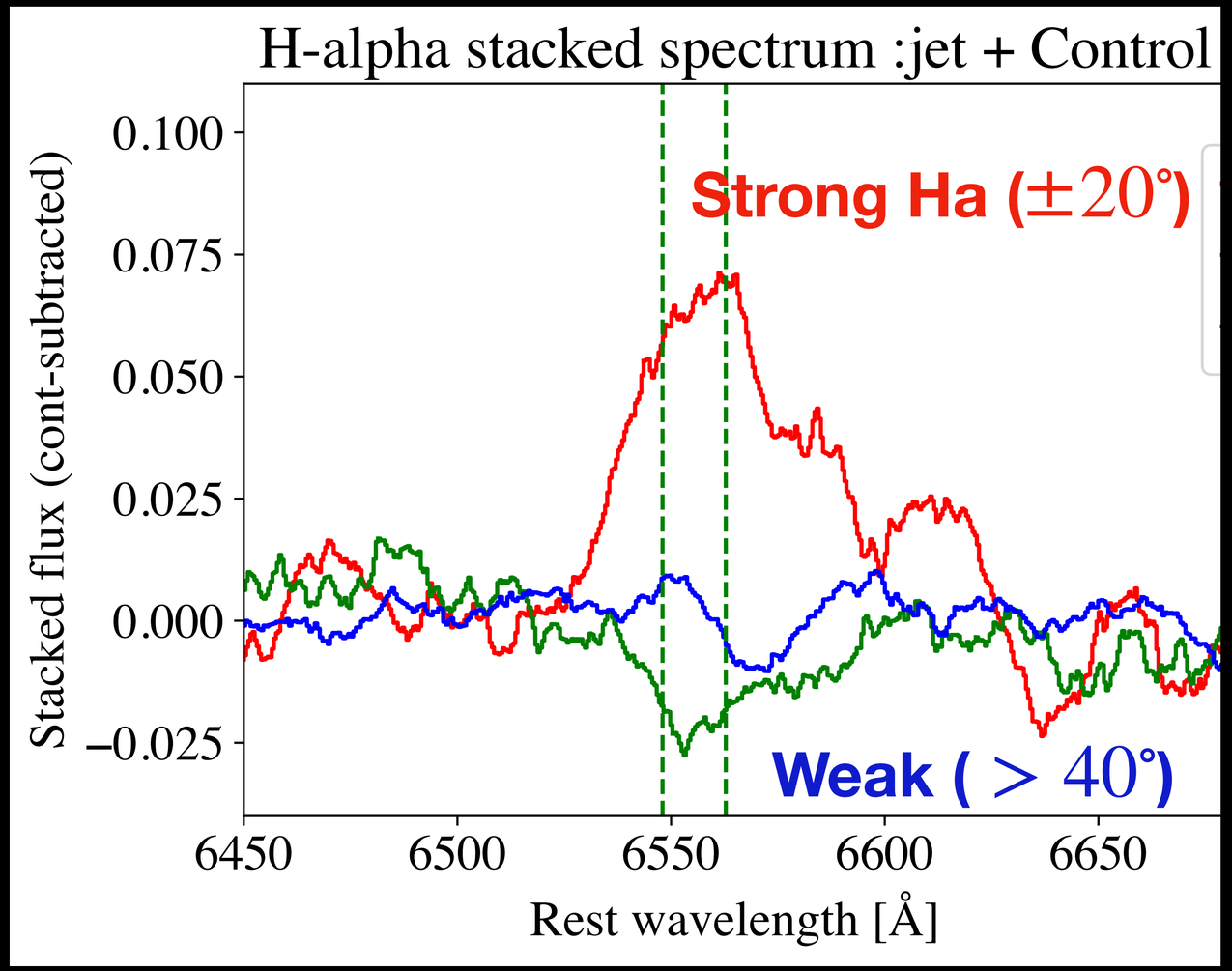
Background QSO (DESI)

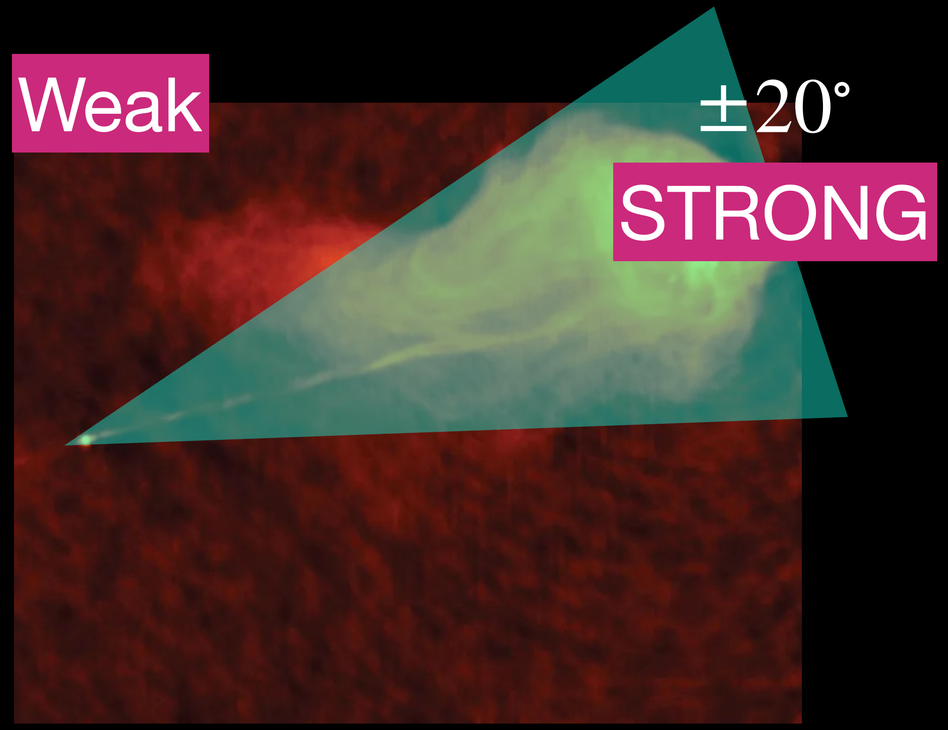




Stack Ha in emission to probe diffuse CGM

CGM emission via rest optical (H-alpha) stacked emission

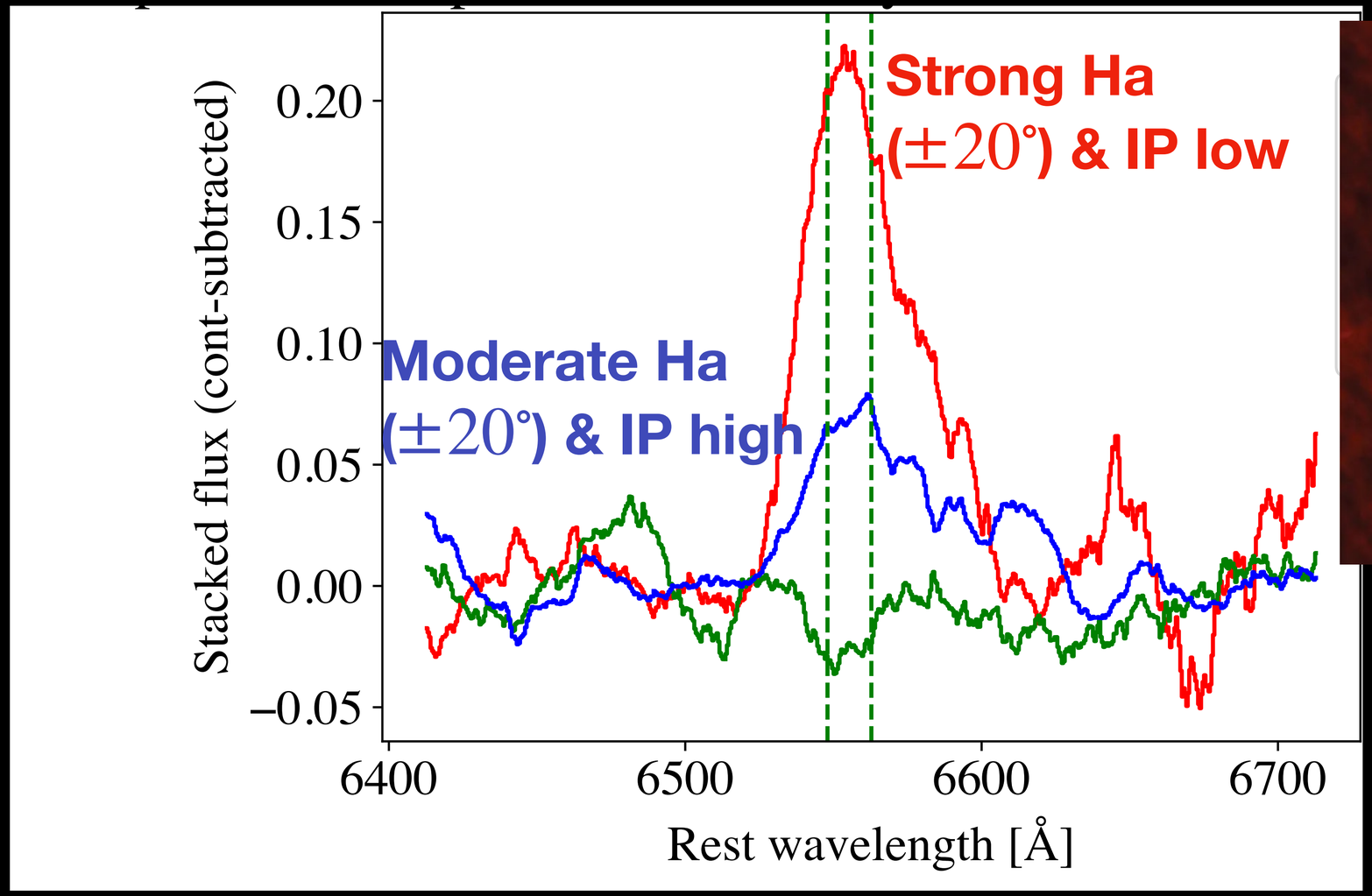


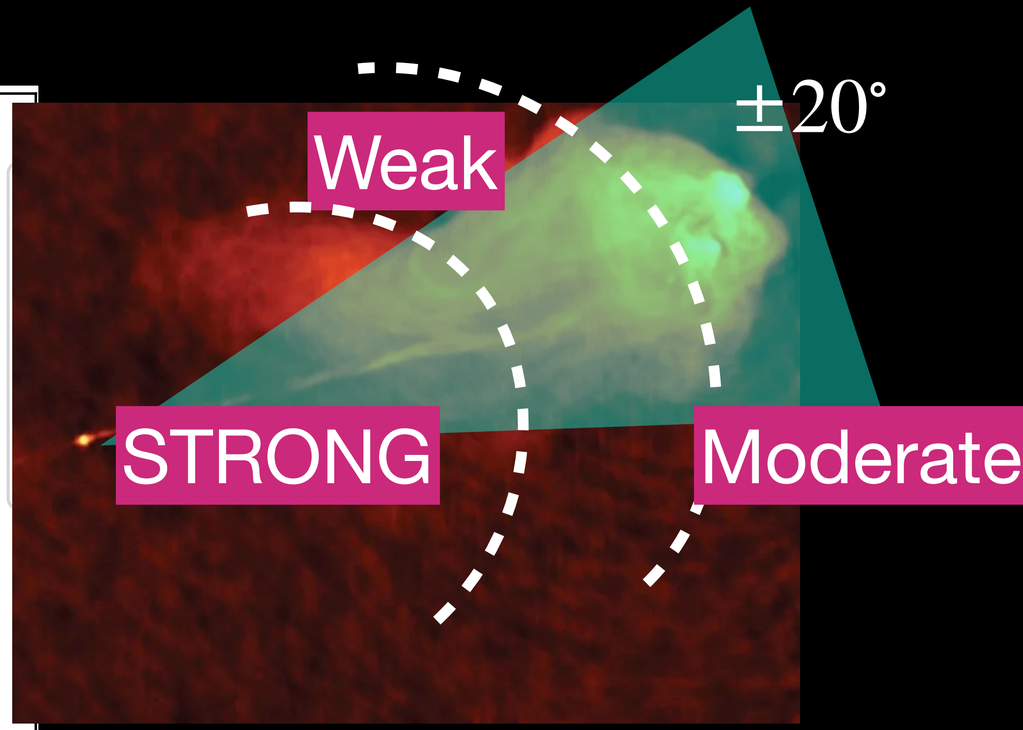


Strong dependence with angle of the jet…

Roy+ in prep

CGM emission via rest optical (H-alpha) stacked emission





Strong dependence with i) angle of the jet & ii) distance along the jet

Roy+ in prep

Radio jetted AGNs have a strong indication of emission from diffuse CGM upto large distances….

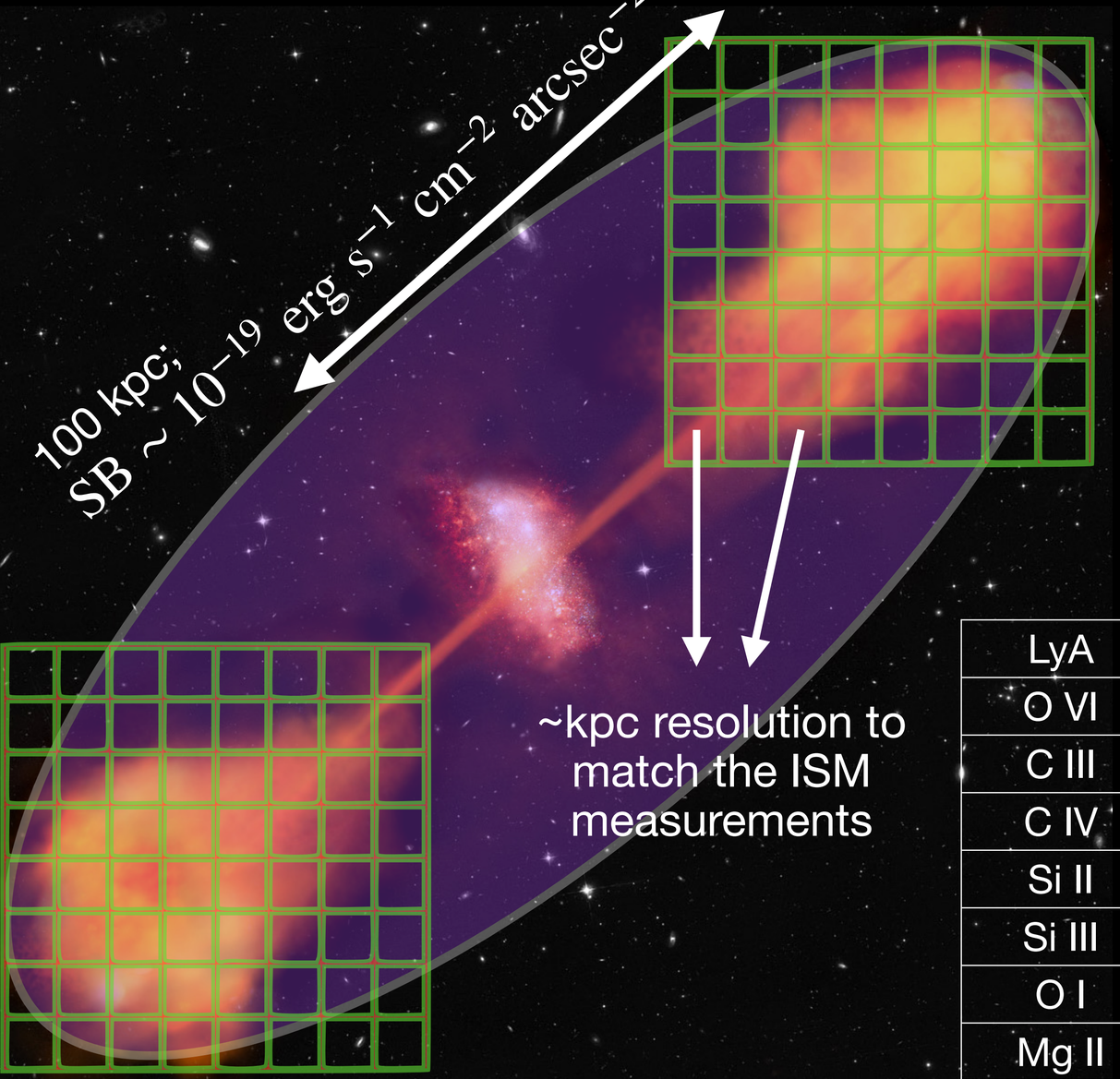
But their detailed CGM characterization is still TBD because…

1) But stacking only gives ensemble statistics… galaxy by galaxy information is washed out!

2) No kinematic or substructure information

3) LyA, Ha, Mg II only trace 10^4 K gas…We need to map the multi phase structure of the CGM across a range of temperature, density, ionization states…

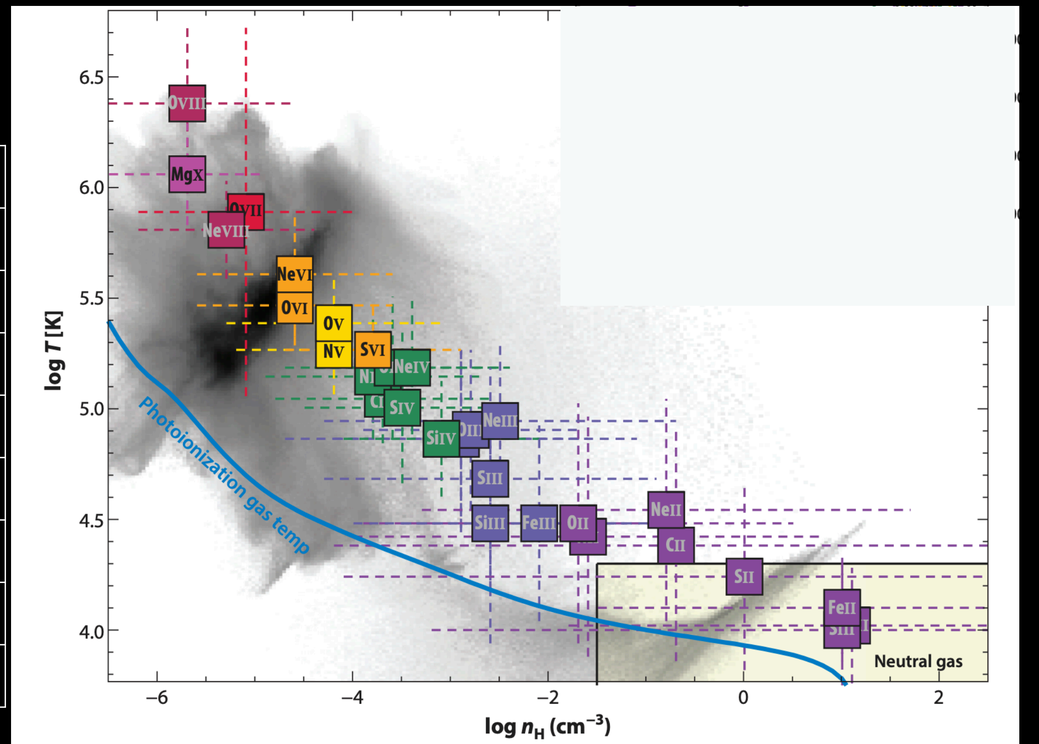
The Solution? Mapping CGM in UV line emission via IFU



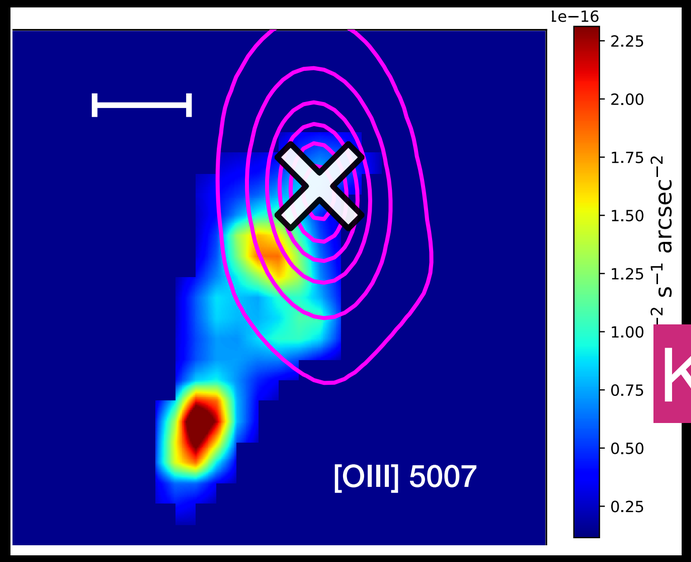
HABITABLE WORLDS OBSERVATORY

LyA	1216 A
O VI	1032, 38 A
C III	977 A
C IV	1548, 51 A
Si II	1260 A
Si III	1206 A
O I	1302 A
Mg II	2796, 2803 A
LyB	1026 A

Tumlinson+17, Burchett+25

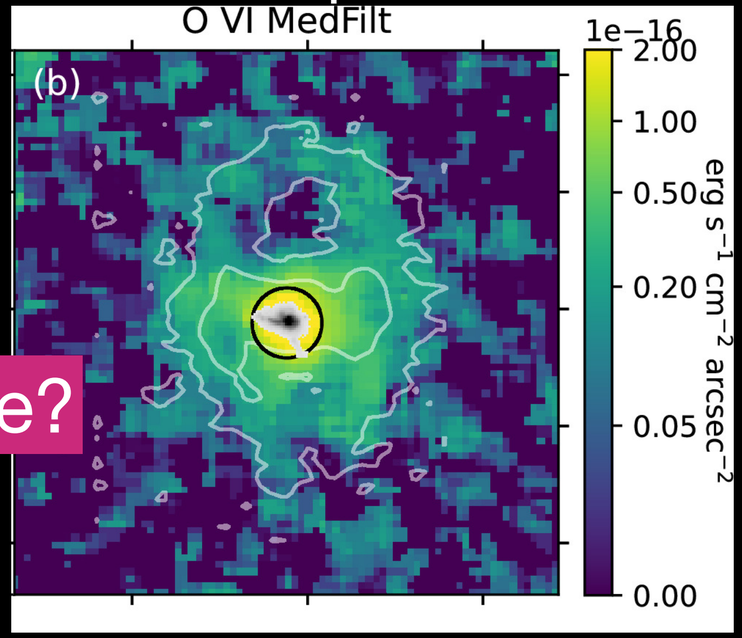


ISM phase



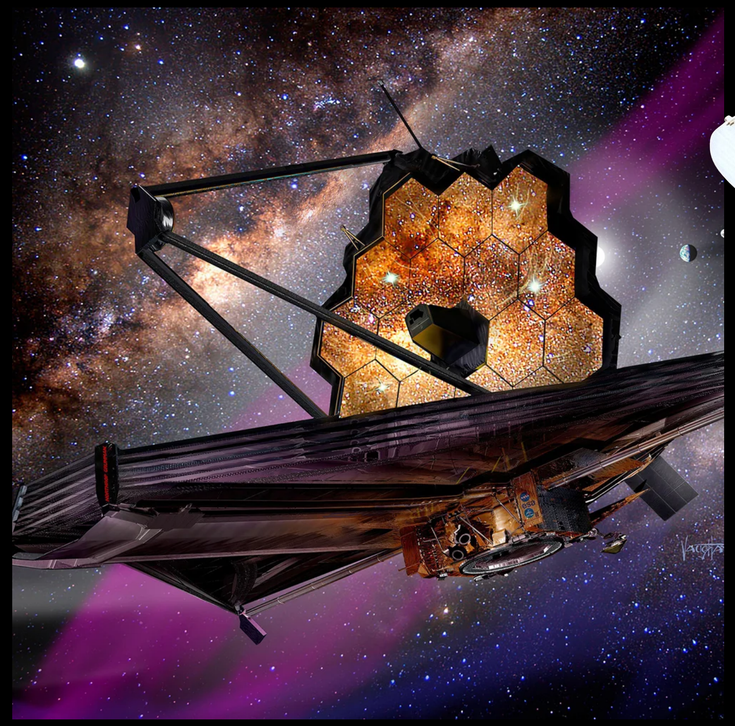
Roy+24

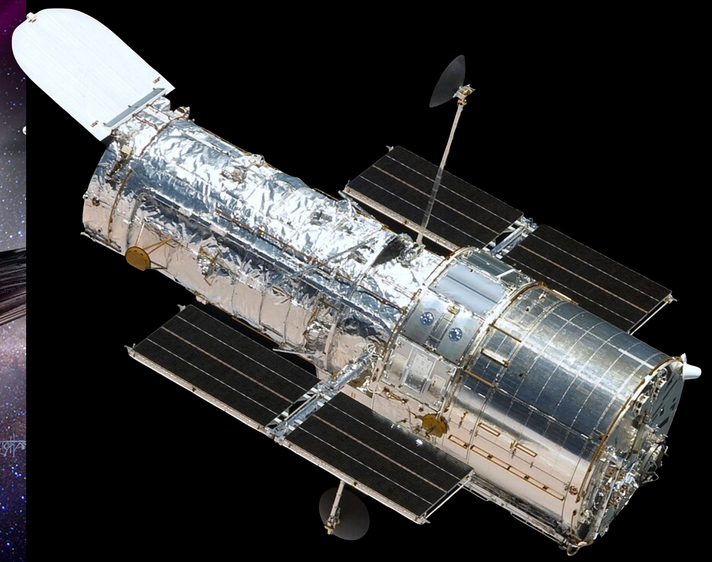
CGM phase



Ha+25, Rupke+19

Kinematic coherence?





HABITABLE WORLDS OBSERVATORY