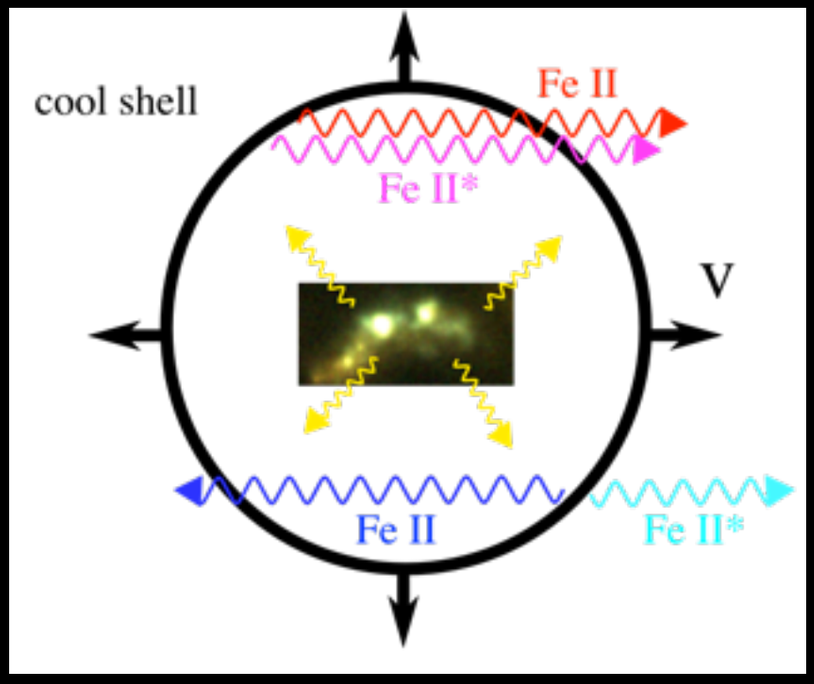
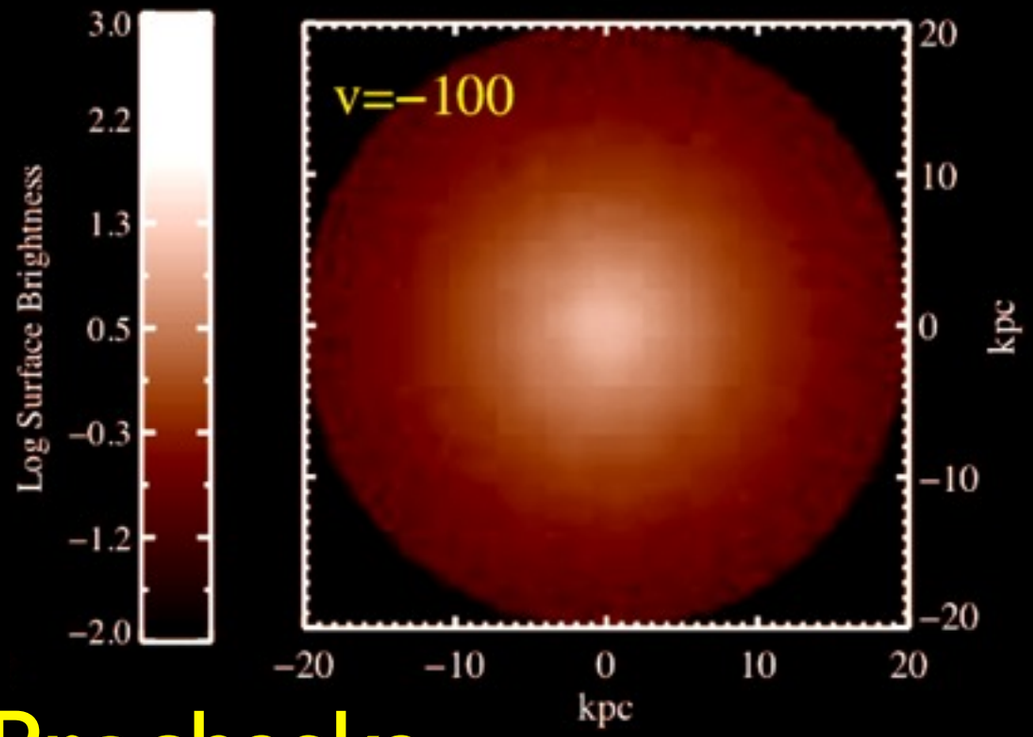
Galactic-Scale Winds

http://arxiv.org/abs/1008.3XXX

JXP, Kasen, Rubin, ApJ, to be submitted





J. Xavier Prochaska

Inster(stellar+galactic) Medium Program of Studies [IMPS]

UCO, UC Santa Cruz

Kate Rubin (IMPS, MPIA)

Dan Kasen (UCSC, UCB/LBL)

Feedback

Feedback

Abstract Query Results

http://adsabs.harvard.edu/cgi-bin/nph-abs_connect?db_key=AST&db_key=PRE&qform=AST&arxiv_sel=astrc

mac screen capture

Google Groups | UCSC Astronomy Co... | ADS | Google Calendar | News | Santa Cruz | Astro | Bookmarks | GRB | Astrophysics

Author Query Results | 13 Earth, Venus, Mars - 4 | Abstract Query Results | Capture a Screen Shot with Mac...

Sign on

SAO/NASA Astrophysics Data System (ADS)

ADS Search: Refereed, 2010, "feedback" or "wind"

Query Results from the ADS Database

Go to bottom of page

Retrieved **200** abstracts, starting with number **1**. Total number selected: **1215**.

Sort options

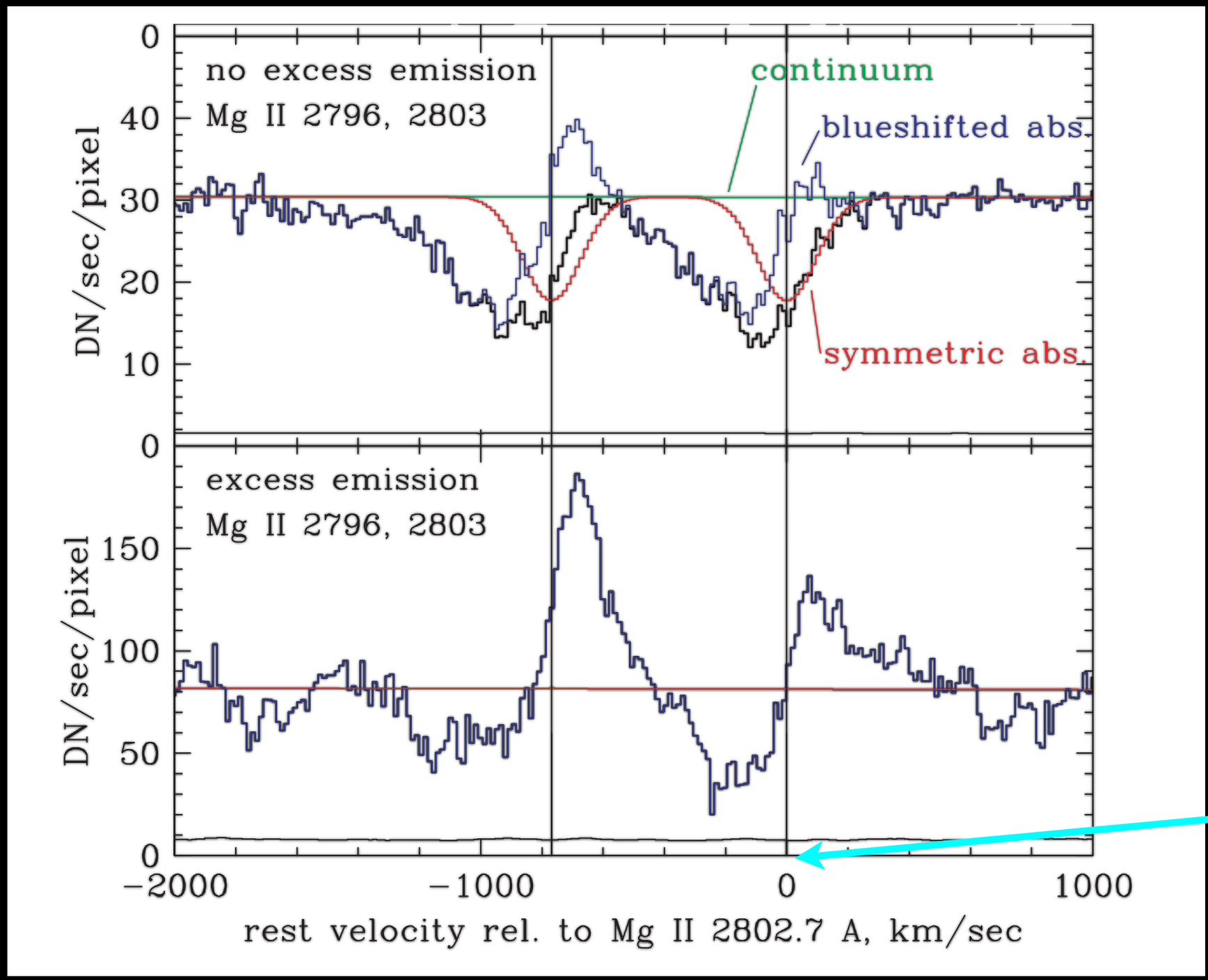
#	Bibcode Authors	Score Title	Date	List of Links Access Control Help
1	2010MNRAS.406.2325O Oppenheimer, Benjamin D.; Davé, Romeel; Kereš, Dušan; Fardal, Mark; Katz, Neal; Kollmeier, Juna A.; Weinberg, David H.	1.000 Feedback and recycled wind accretion: assembling the z = 0 galaxy mass function	08/2010	A E F X R C U
2	2010MNRAS.406.2249W Weinmann, Simone M.; Kauffmann, Guinevere; von der Linden, Anja; De Lucia, Gabriella	1.000 Cluster galaxies die hard	08/2010	A E F X R C U
3	2010MNRAS.406..952S Smith, Nathan; Povich, Matthew S.; Whitney, Barbara A.; Churchwell, Ed; Babler, Brian L.; Meade, Marilyn R.; Bally, John; Gehrz, Robert D.; Robitaille, Thomas P.; Stassun, Keivan G.	1.000 Spitzer Space Telescope observations of the Carina nebula: the steady march of feedback-driven star formation	08/2010	A E F X R C U
4	2010MNRAS.406..822M McCarthy, I. G.; Schaye, J.; Ponman, T. J.; Bower, R. G.; Booth, C. M.; Dalla Vecchia, C.; Crain, R. A.; Springel, V.; Theuns, T.; Wiersma, R. P. C.	1.000 The case for AGN feedback in galaxy groups	08/2010	A E F X R C U
5	2010JASTP..72.1019F Fukazawa, Keiichiro; Aoyama, Tomoharu; Ogino, Tatsuki; Yumoto, Kiyohumi	1.000 Response of the reconnection electric field and polar cap potential to the IMF and velocity of solar wind	08/2010	A E R U

Done

Cool Gas Outflows

Blue-shifted absorption reveals outflowing material

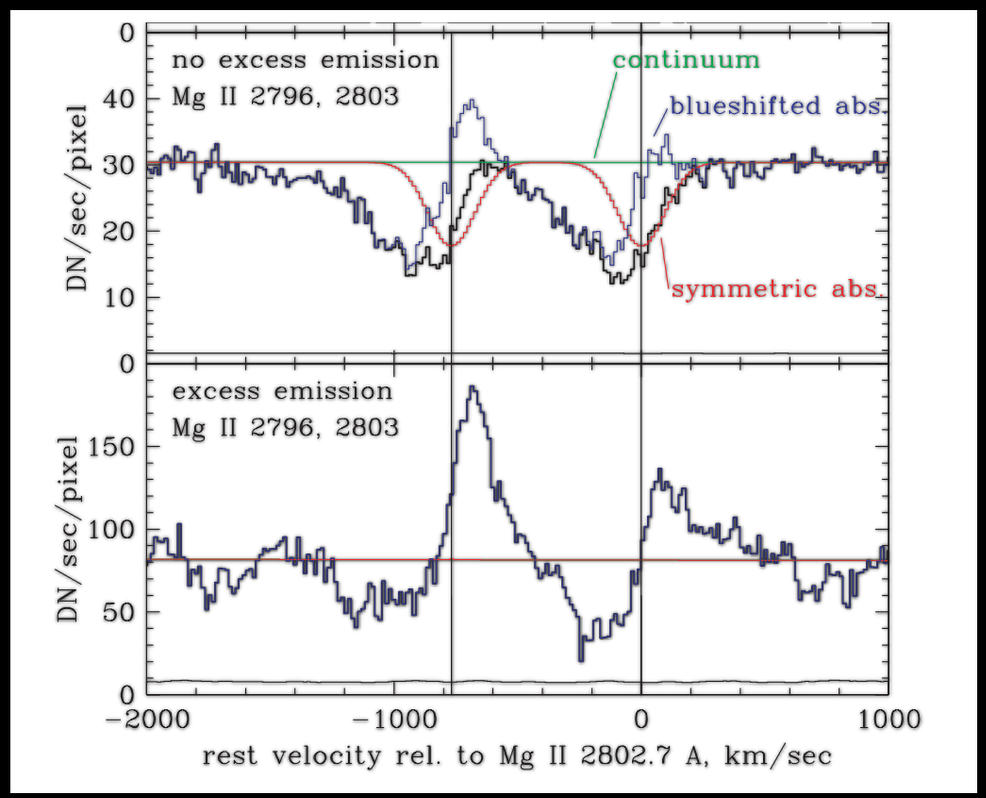
Weiner+09 (see Koo's talk tomorrow?)



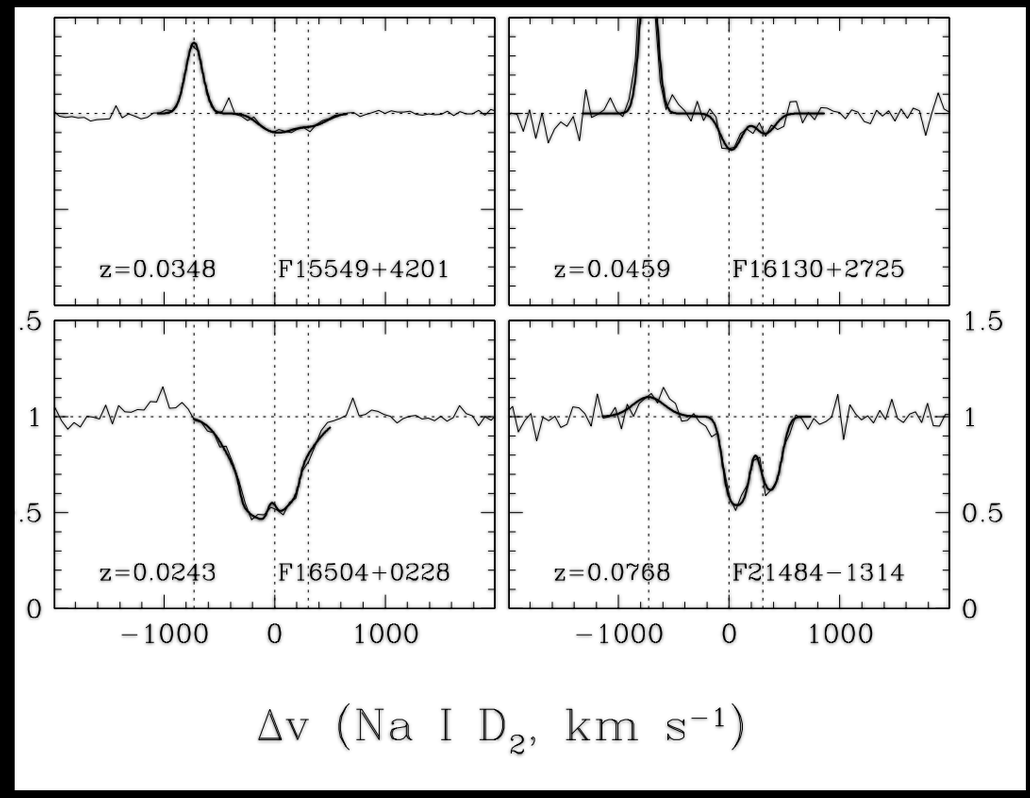
Set by [OII] emission

Cool Gas Outflows

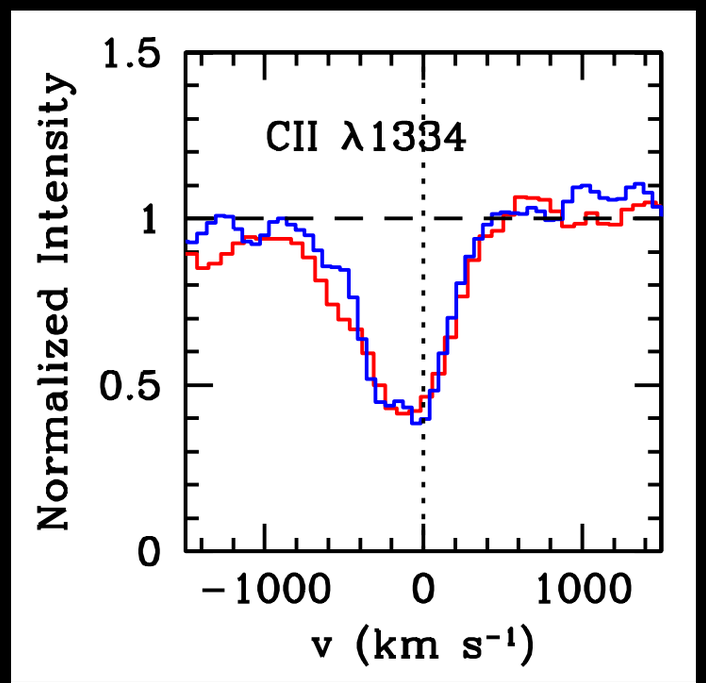
Blue-shifted absorption reveals outflowing material



Tremonti+08, Weiner+09, Rubin+09



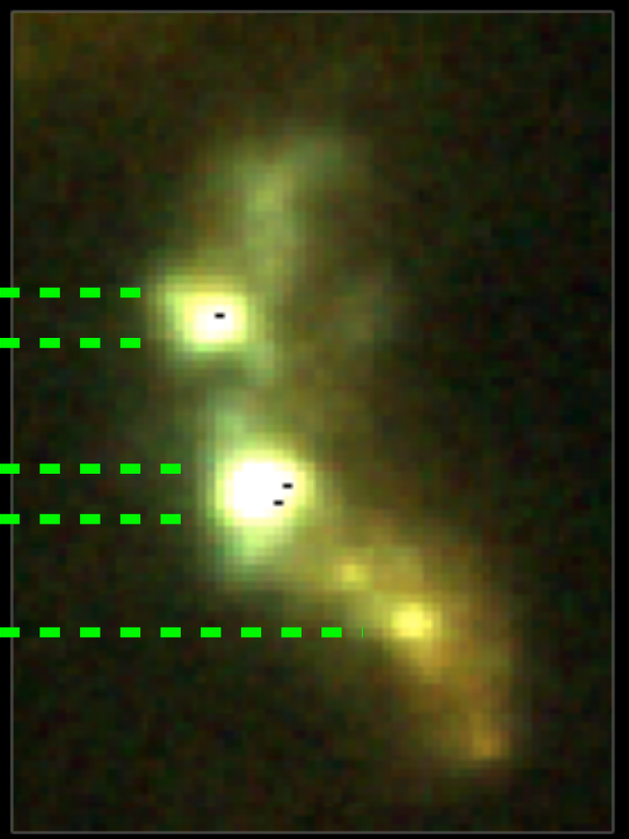
Rupke+05, Martin06, Chen+10



Steidel+96
Lowenthal+97
Pettini+02
Steidel+10

The Great Unknowns

SF Galaxy

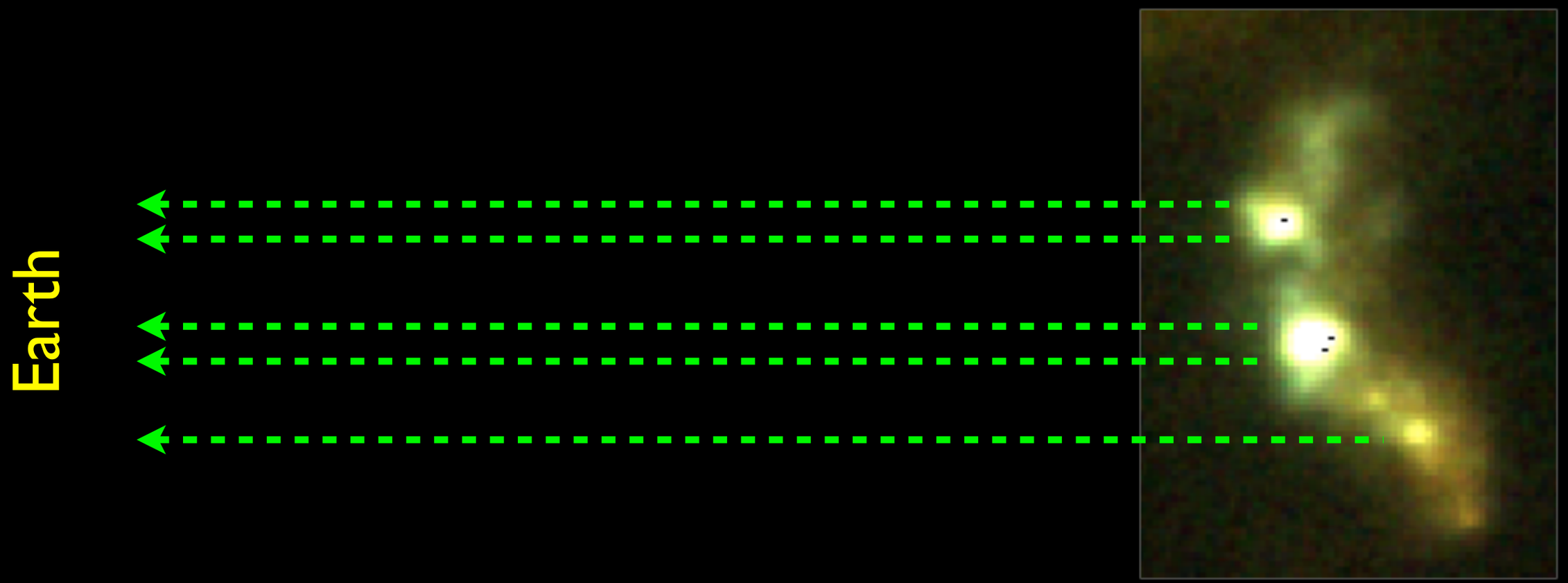


Earth

The Great Unknowns

Distance (d_{wind})

SF Galaxy

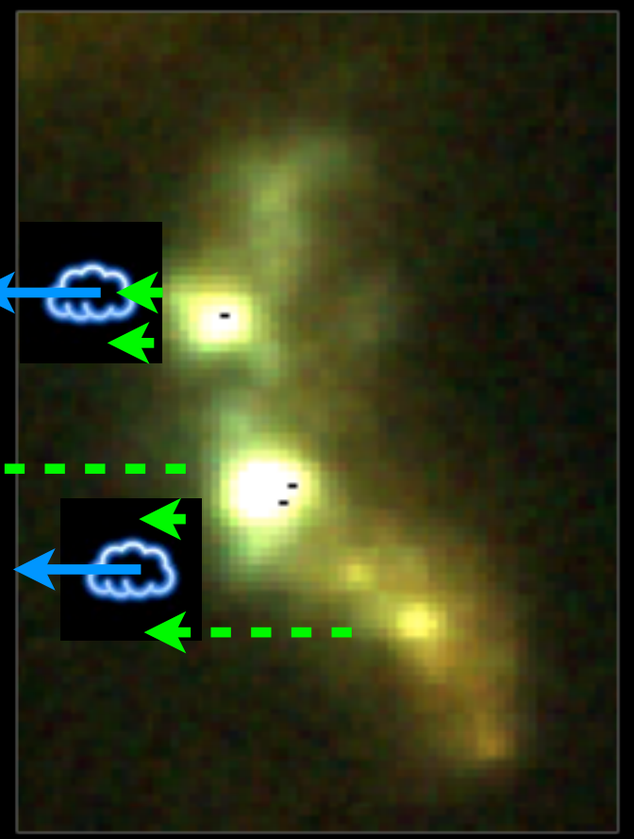


The Great Unknowns

Distance (d_{wind})

Near (e.g. 100 pc)?

SF Galaxy



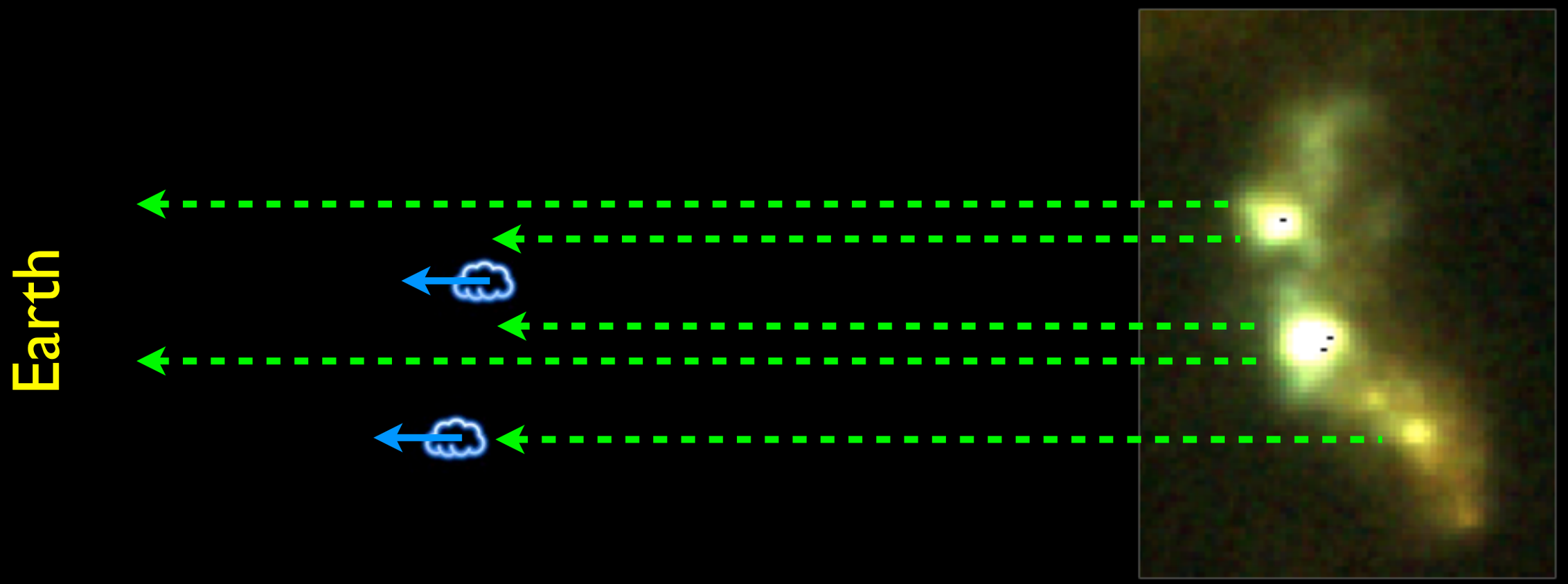
Earth

The Great Unknowns

Distance (d_{wind})

Near (e.g. 100 pc)?

Far (e.g. 10 kpc)?



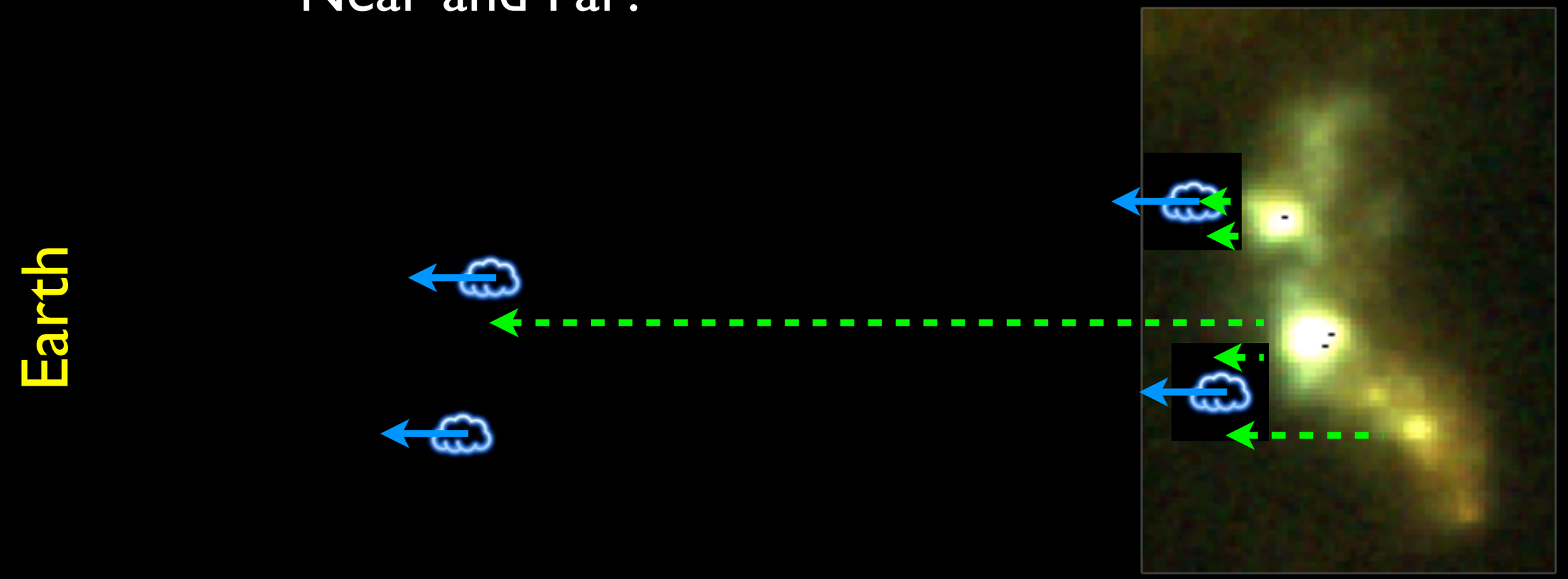
The Great Unknowns

Distance (d_{wind})

Near (e.g. 100 pc)?

Far (e.g. 10 kpc)?

Near and Far?



The Great Unknowns

Distance (d_{wind})

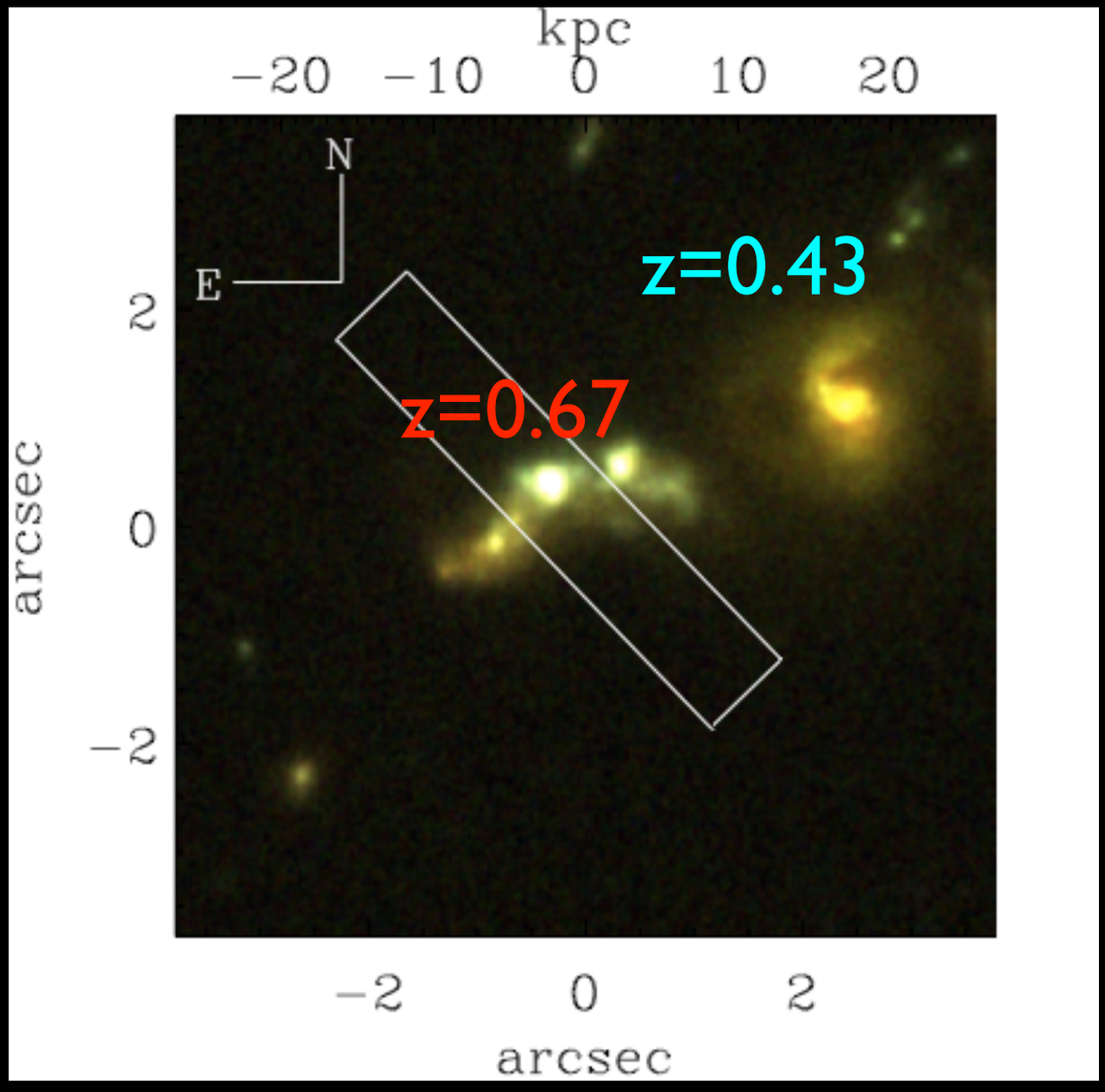
Near (e.g. 100 pc)?

Far (e.g. 10 kpc)?

Near and Far?

Extremely far!!

(see Rubin+10, ApJ, 712, 547)



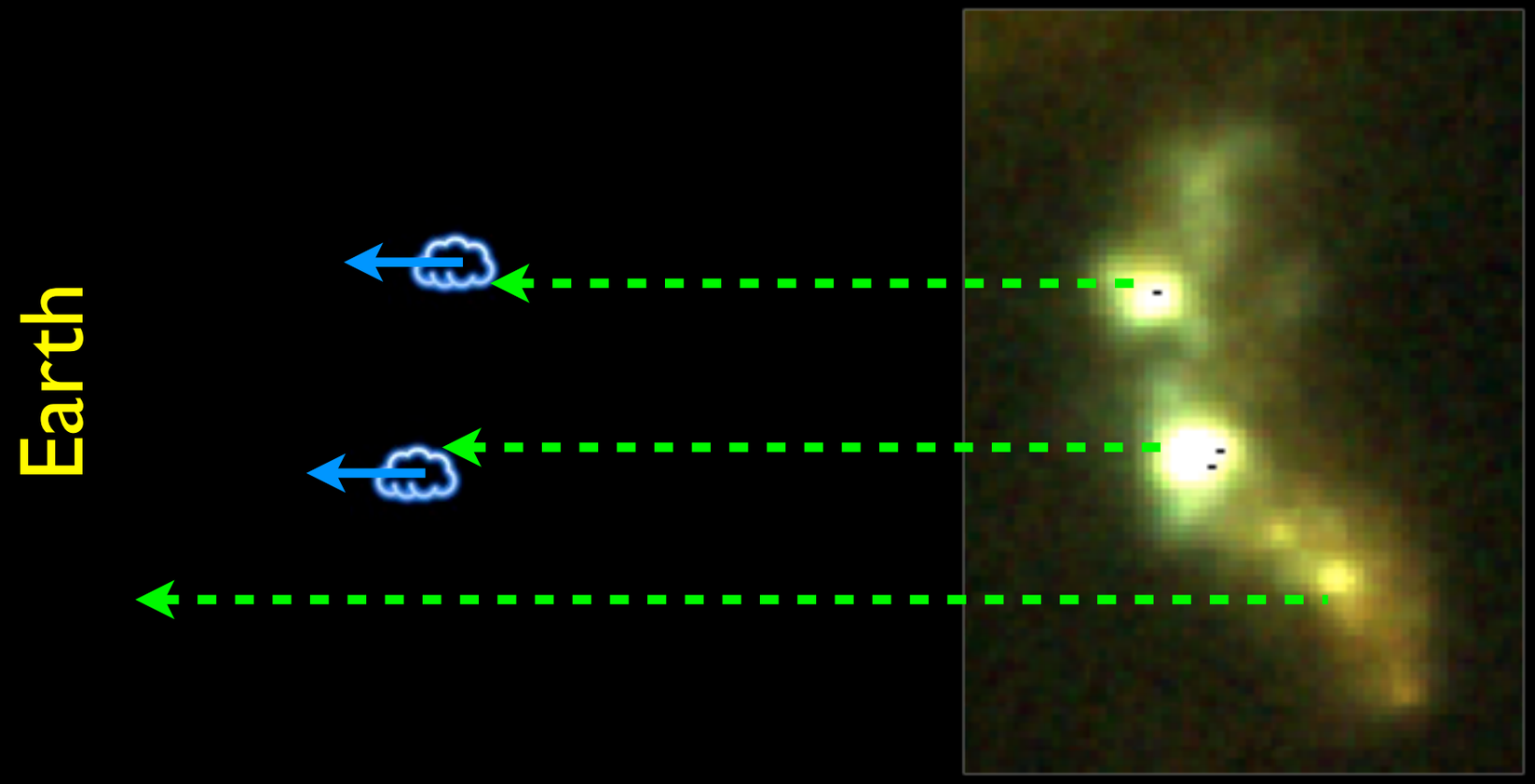
The Great Unknowns

Distance (d_{wind})

Near (e.g. 100 pc)

Far (e.g. 10 kpc)

Near and Far



The Great Unknowns

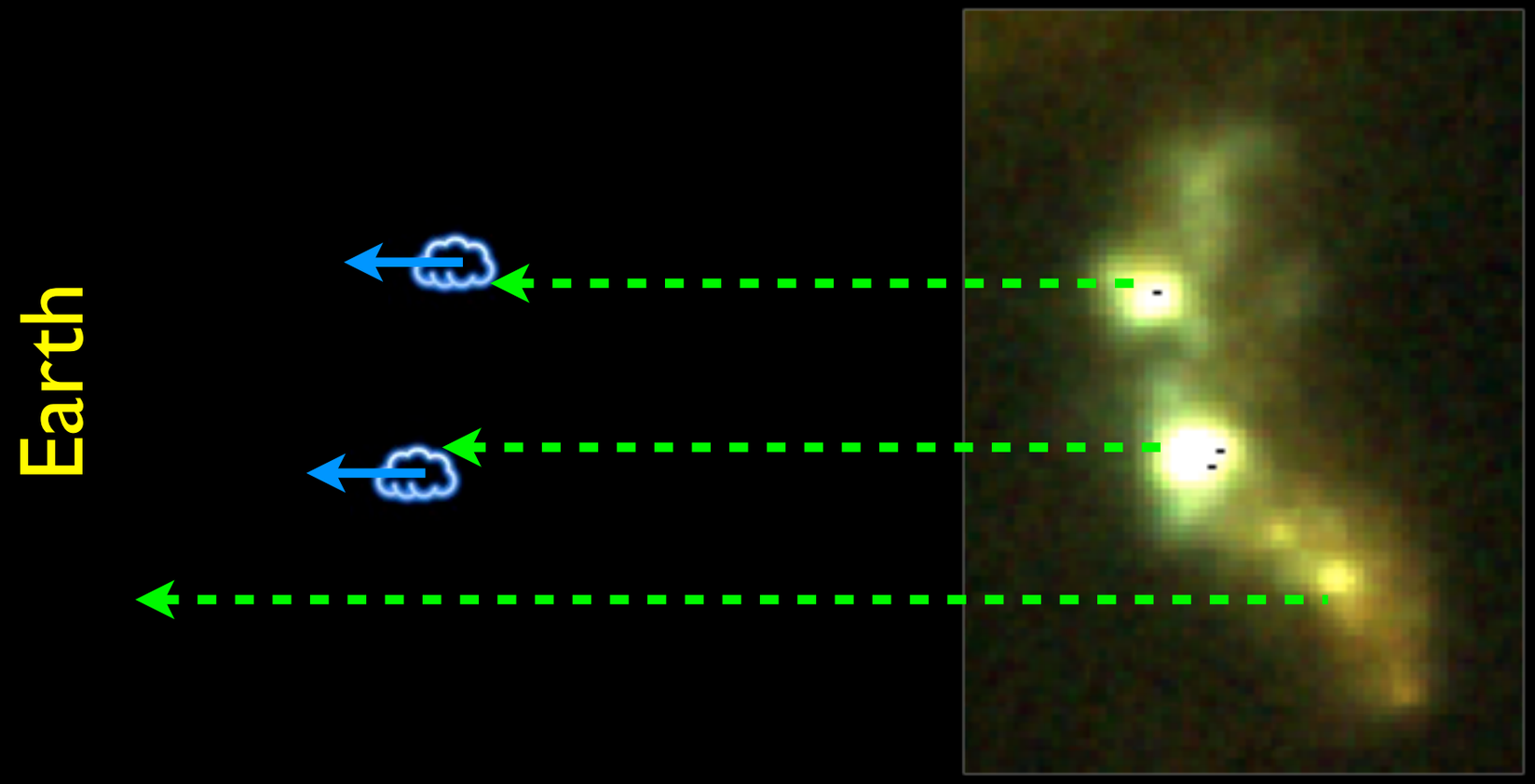
Distance (d_{wind})

Near (e.g. 100 pc)

Far (e.g. 10 kpc)

Near and Far

Distribution (Ω)



The Great Unknowns

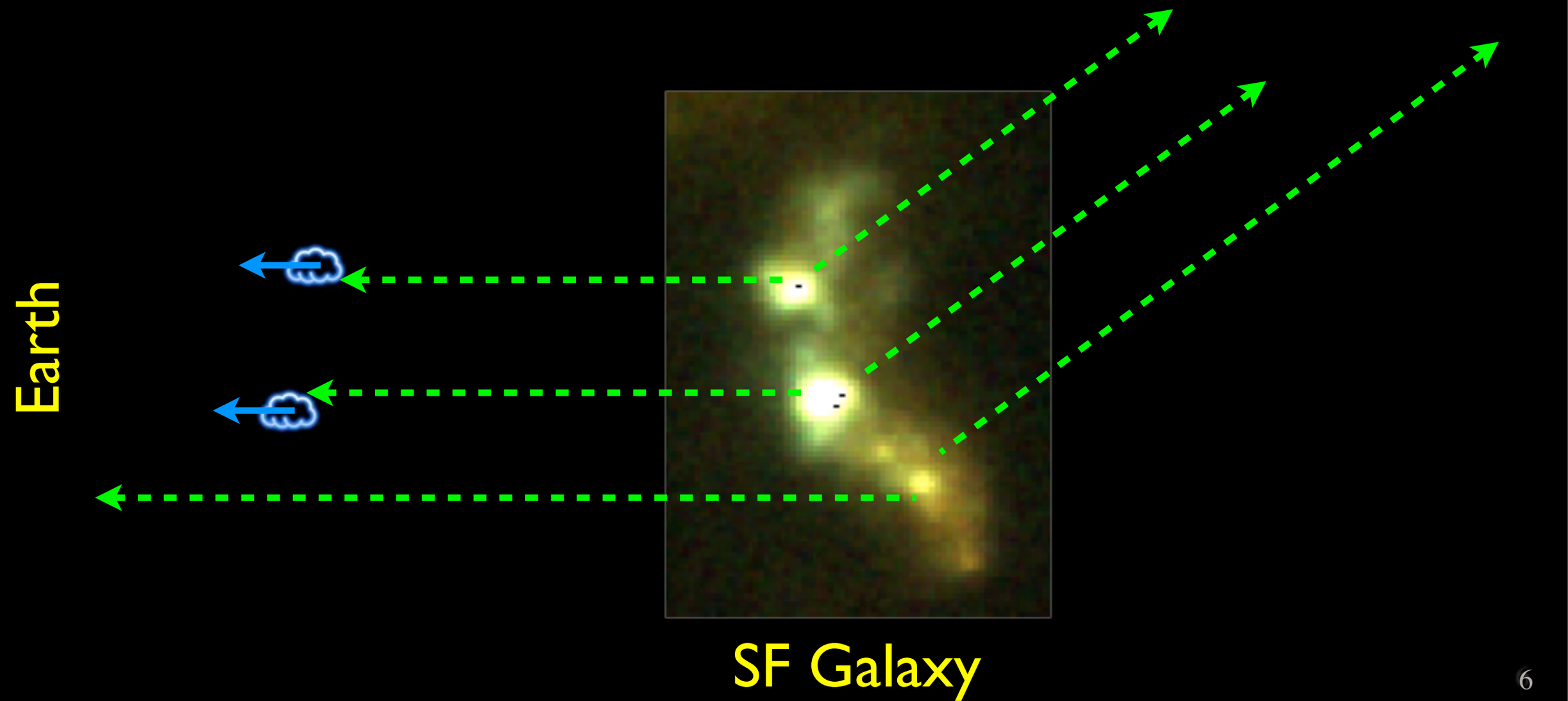
Distance (d_{wind})

Near (e.g. 100 pc)

Far (e.g. 10 kpc)

Near and Far

Distribution (Ω)



The Great Unknowns

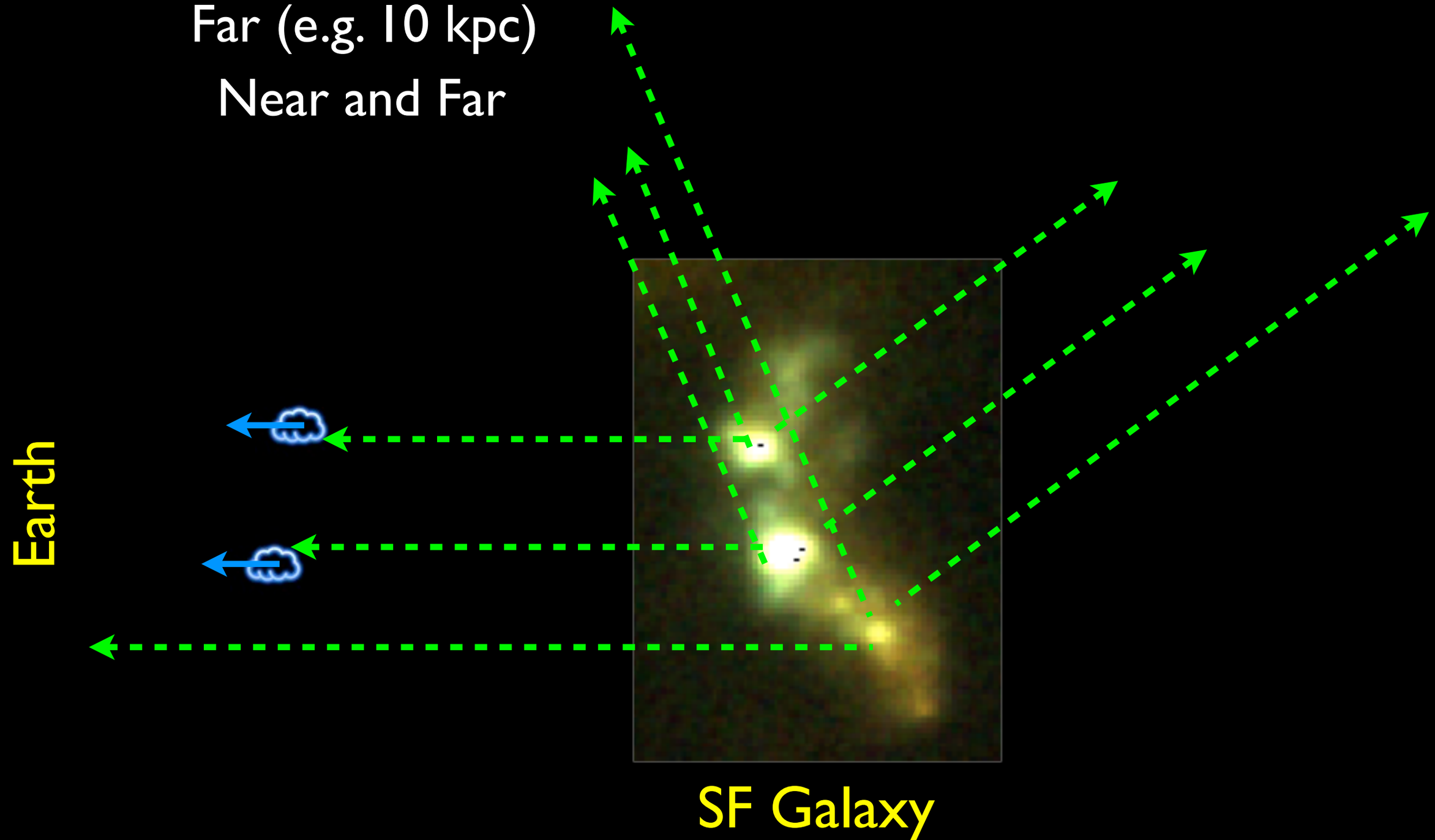
Distance (d_{wind})

Near (e.g. 100 pc)

Far (e.g. 10 kpc)

Near and Far

Distribution (Ω)



The Great Unknowns

Distance (d_{wind})

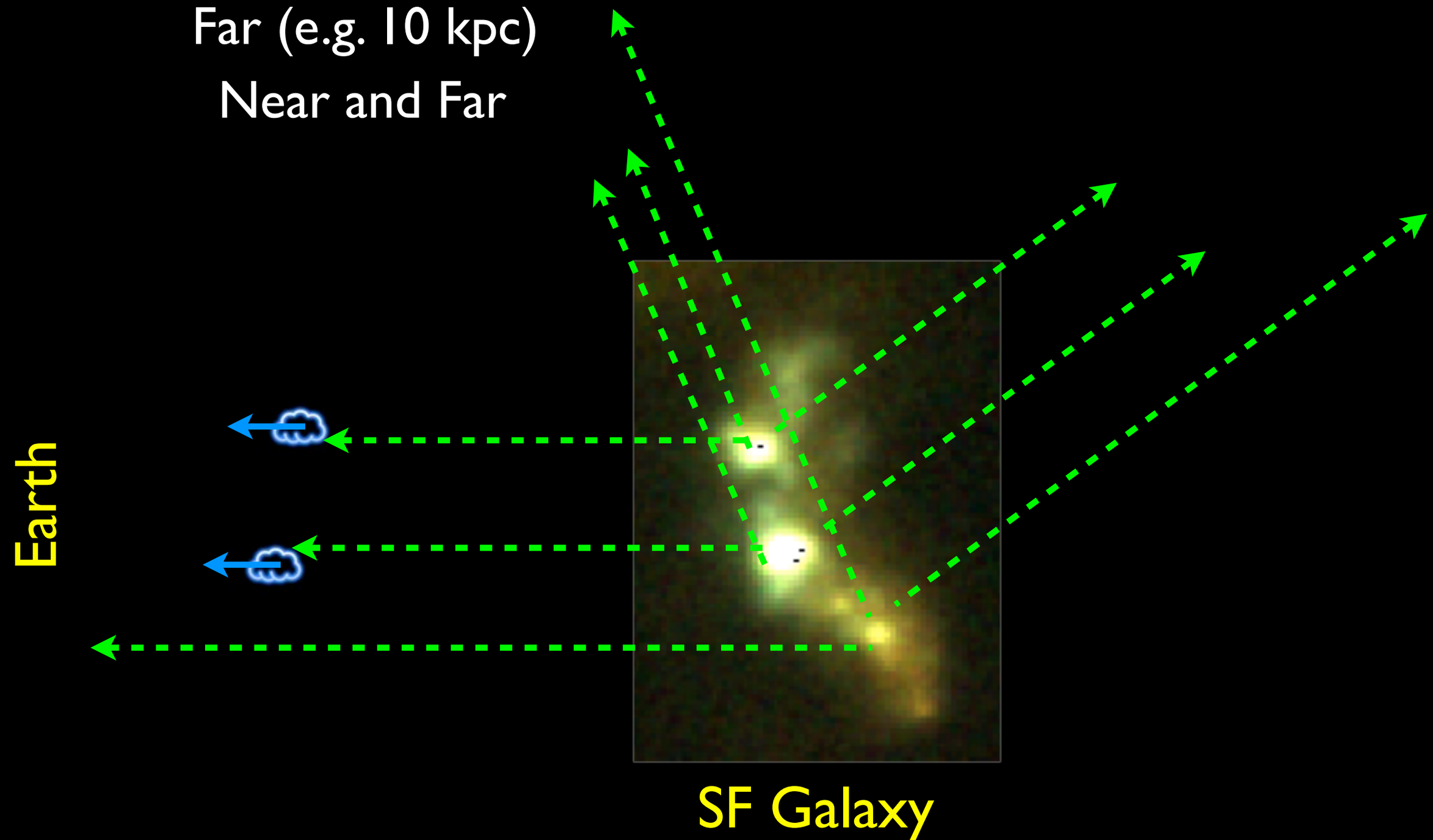
Near (e.g. 100 pc)

Far (e.g. 10 kpc)

Near and Far

Distribution (Ω)

Isotropic?



The Great Unknowns

Distance (d_{wind})

Near (e.g. 100 pc)

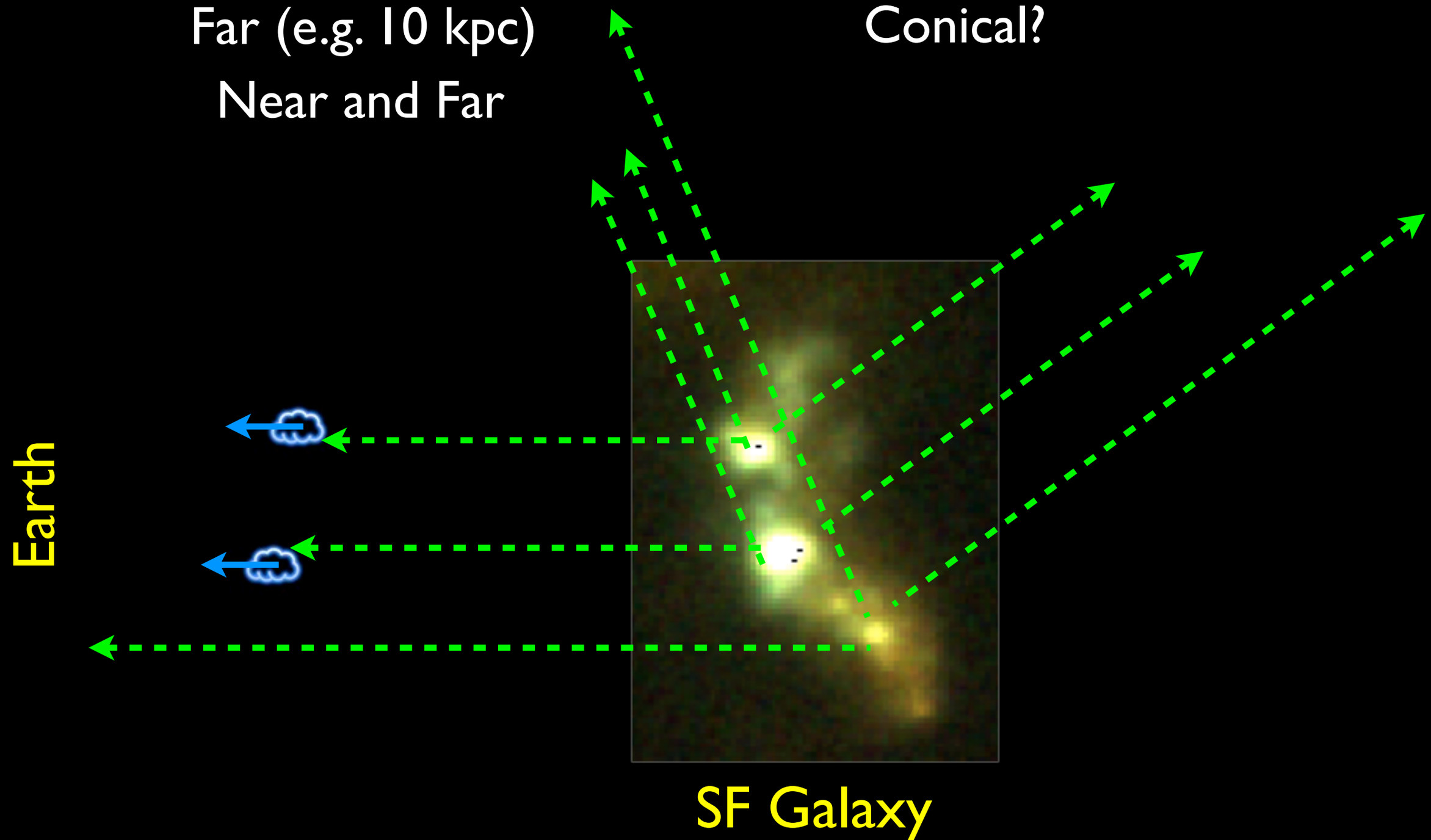
Far (e.g. 10 kpc)

Near and Far

Distribution (Ω)

Isotropic?

Conical?



The Great Unknowns

Distance (d_{wind})

Near (e.g. 100 pc)

Far (e.g. 10 kpc)

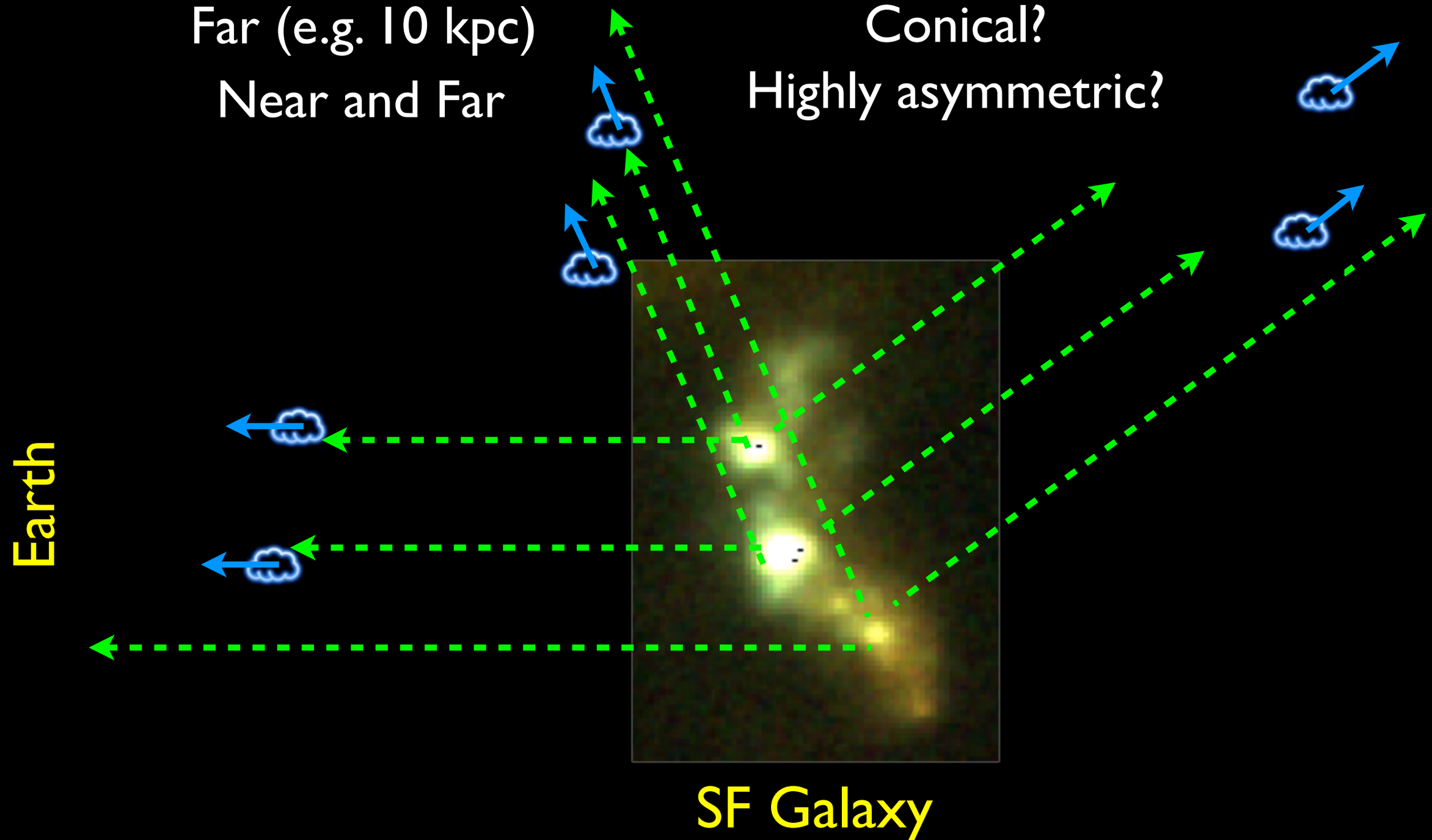
Near and Far

Distribution (Ω)

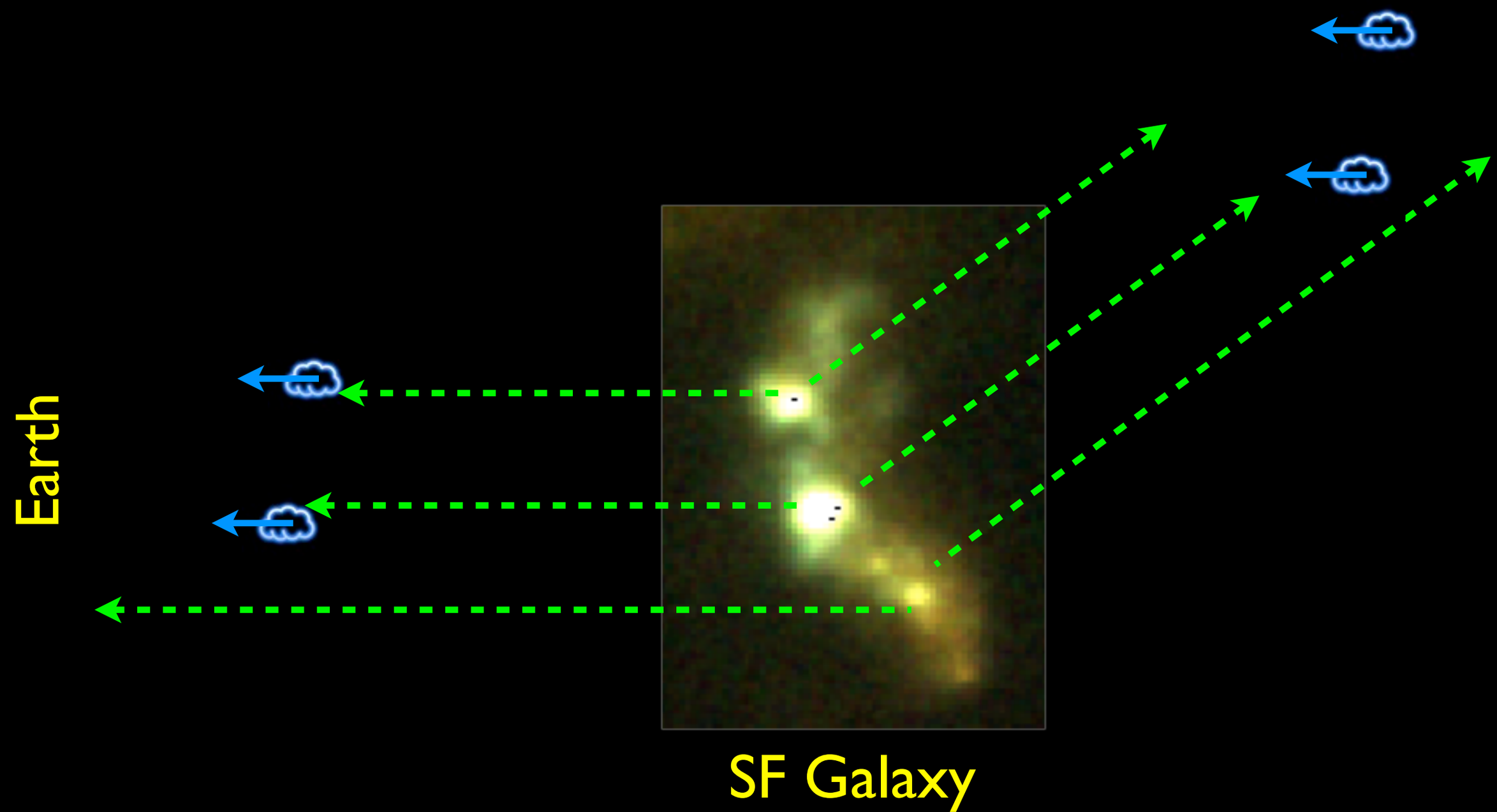
Isotropic?

Conical?

Highly asymmetric?



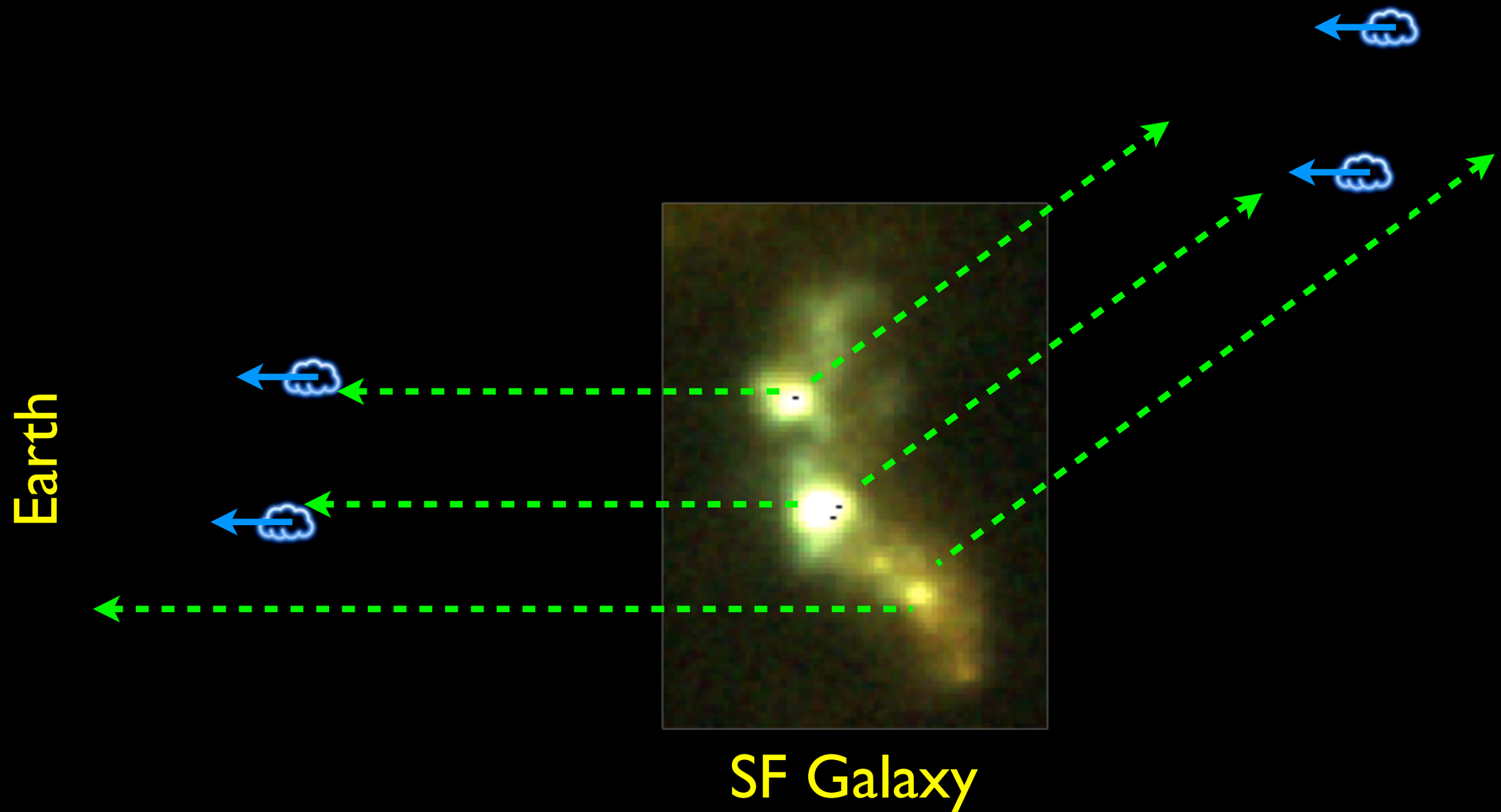
The Greater Unknowns



The Greater Unknowns

Mass flux (of the wind)

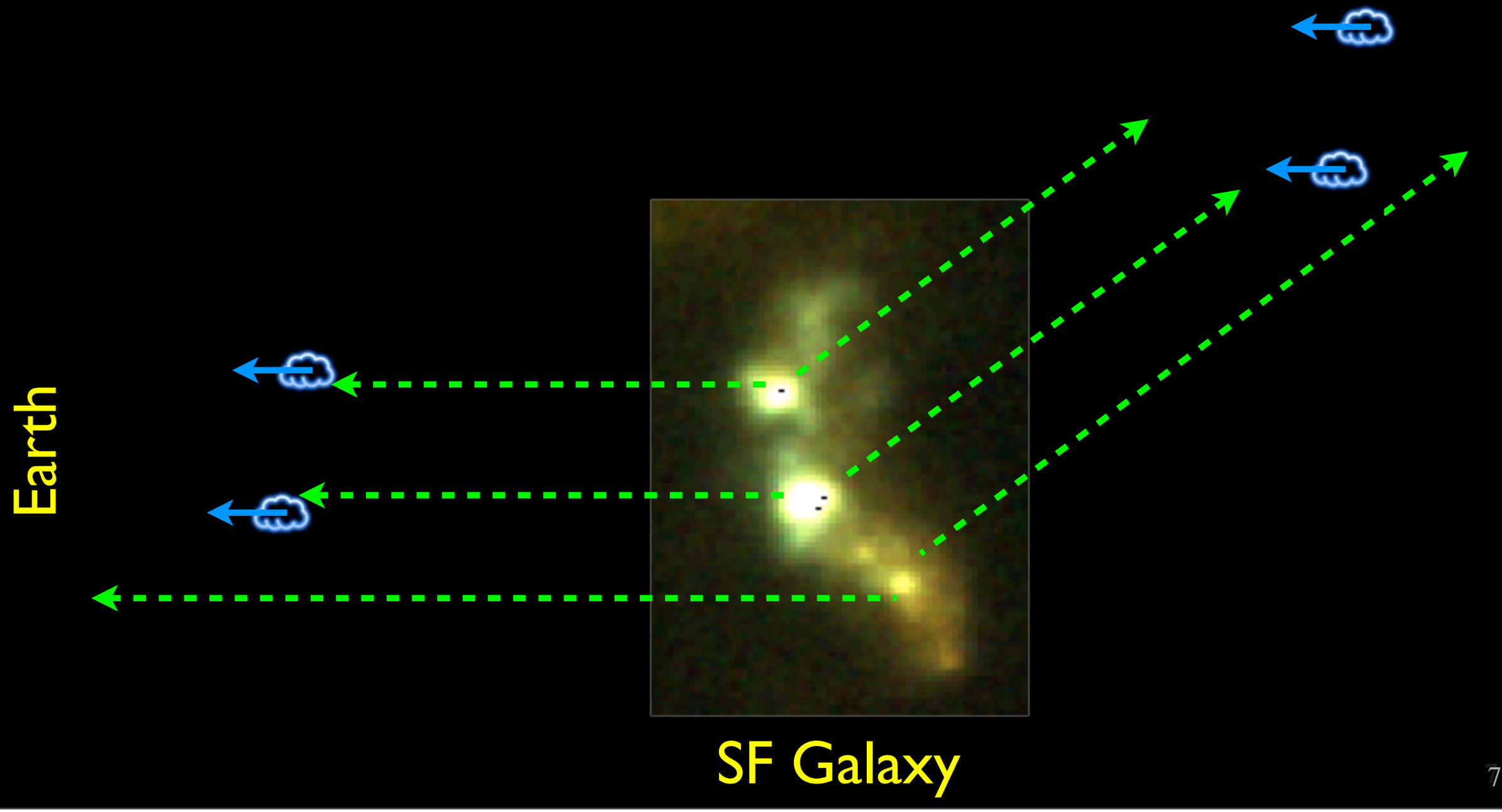
$$\dot{M}_{\rm w} \propto \Omega \, d_{\rm wind} \, v_{\rm wind}$$



The Greater Unknowns

Mass flux (of the wind) $\dot{M}_{\rm w} \propto \Omega\, d_{\rm wind}\, v_{\rm wind}$

Power (of the wind) $\dot{E} \propto \dot{M}_{\rm w}\, v_{\rm wind}^2$

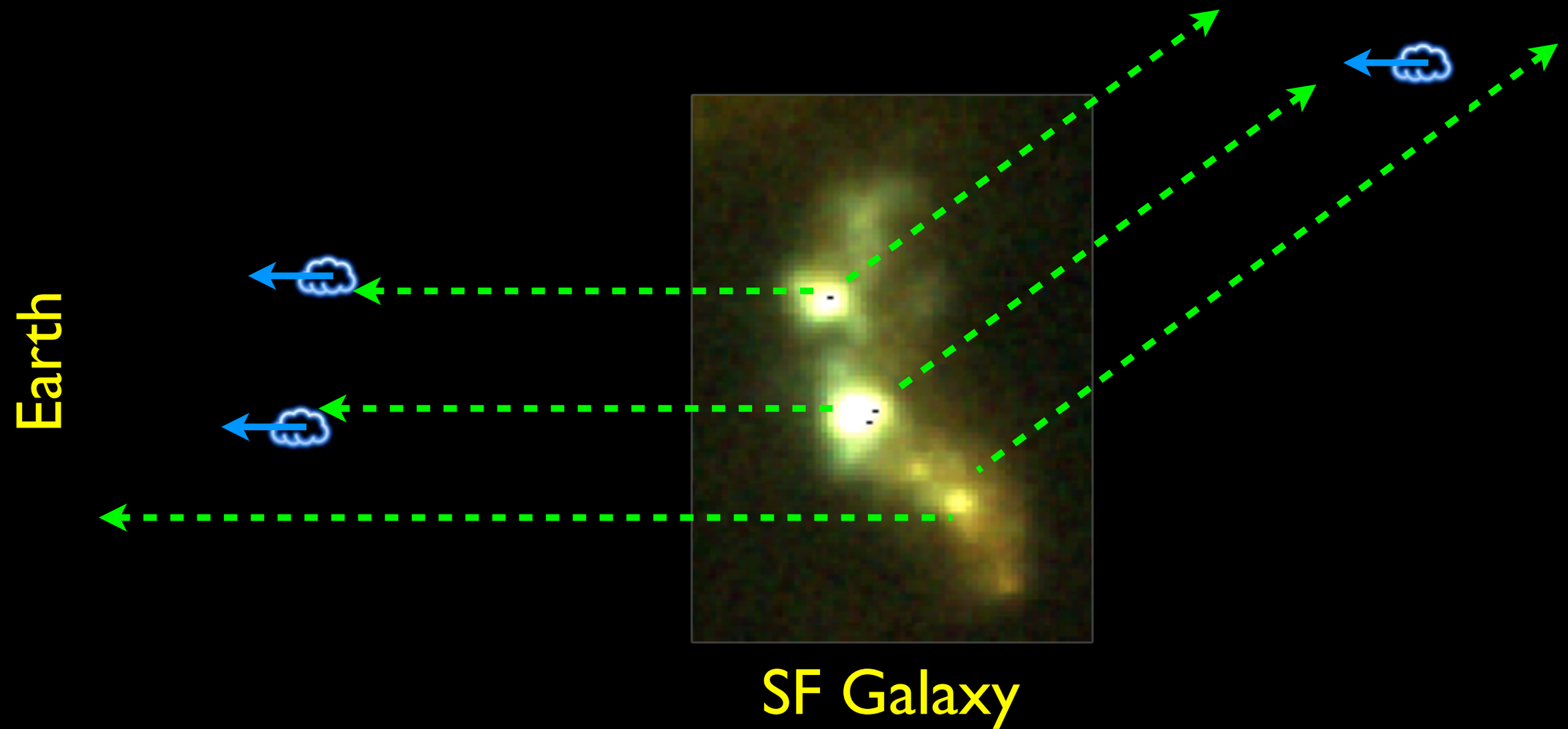


The Greater Unknowns

Mass flux (of the wind) $\dot{M}_{\rm w} \propto \Omega\, d_{\rm wind}\, v_{\rm wind}$

Power (of the wind) $\dot{E} \propto \dot{M}_{\rm w}\, v_{\rm wind}^2$

Momentum (of the wind) $\dot{P} \propto \dot{M}_{\rm w}\, v_{\rm wind}$



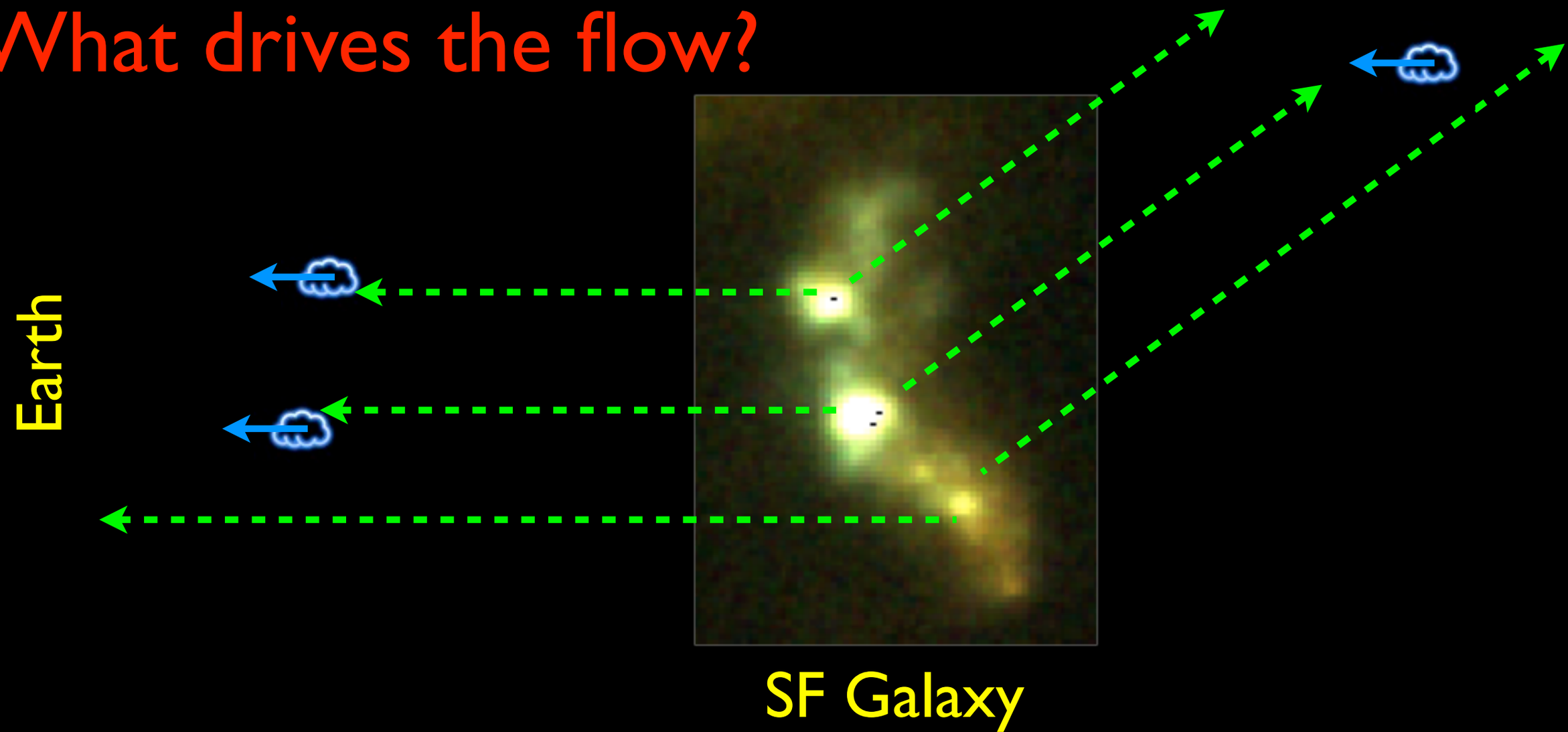
The Greater Unknowns

Mass flux (of the wind) $\dot{M}_{\rm w} \propto \Omega\, d_{\rm wind}\, v_{\rm wind}$

Power (of the wind) $\dot{E} \propto \dot{M}_{\rm w}\, v_{\rm wind}^2$

Momentum (of the wind) $\dot{P} \propto \dot{M}_{\rm w}\, v_{\rm wind}$

What drives the flow?



The Greater Unknowns

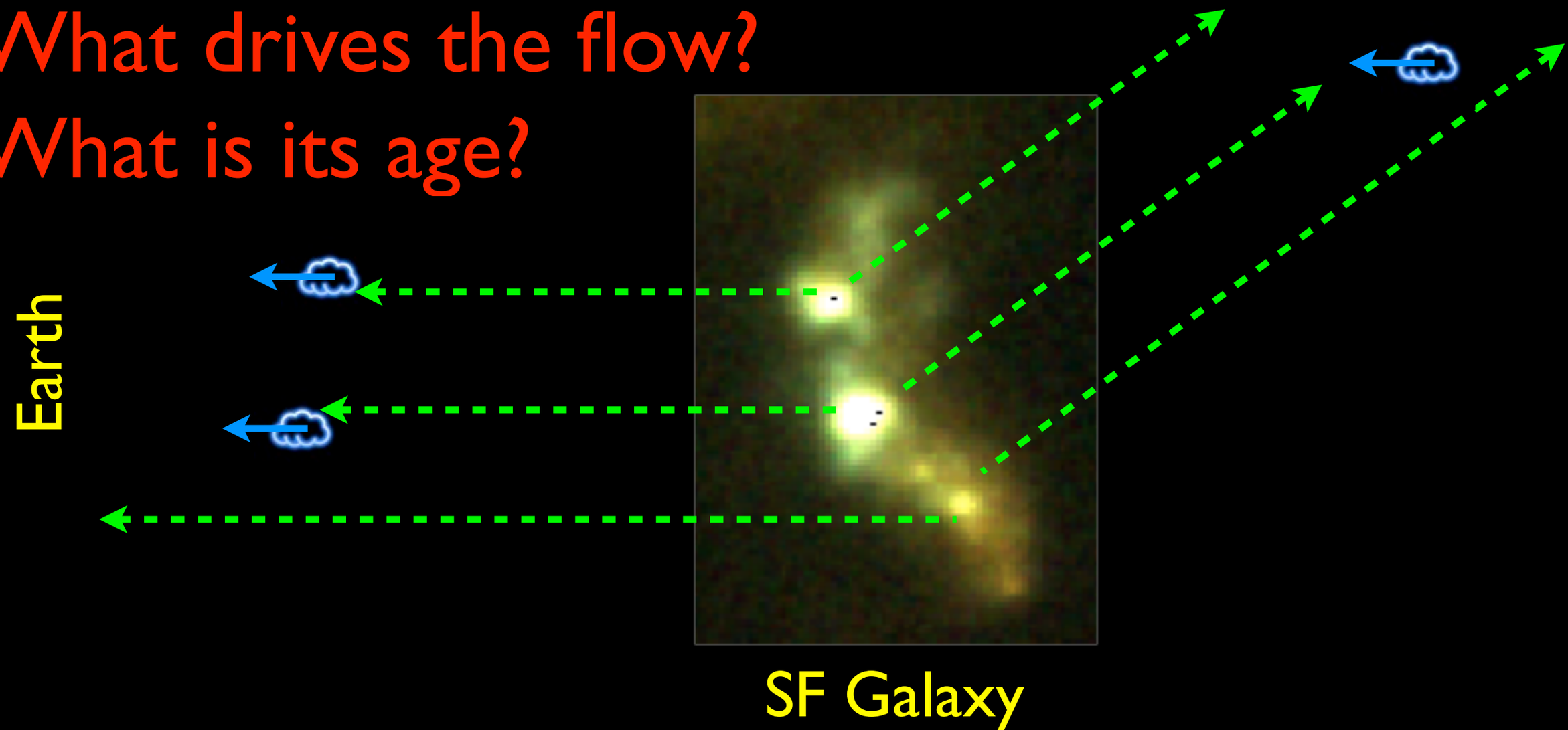
Mass flux (of the wind) $\dot{M}_{\rm w} \propto \Omega\, d_{\rm wind}\, v_{\rm wind}$

Power (of the wind) $\dot{E} \propto \dot{M}_{\rm w}\, v_{\rm wind}^2$

Momentum (of the wind) $\dot{P} \propto \dot{M}_{\rm w}\, v_{\rm wind}$

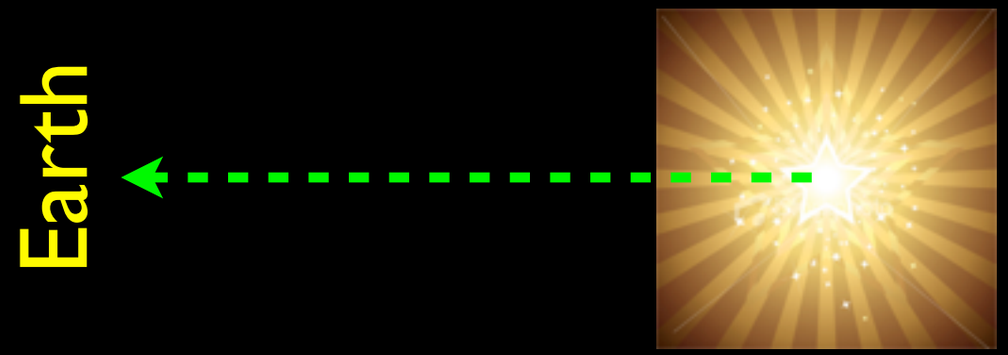
What drives the flow?

What is its age?



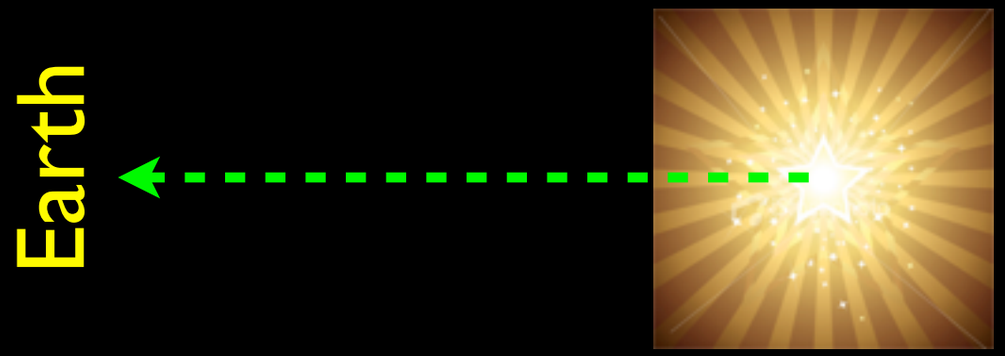
P-Cygni (Cartoon)

Canonical absorption+emission profile of a wind

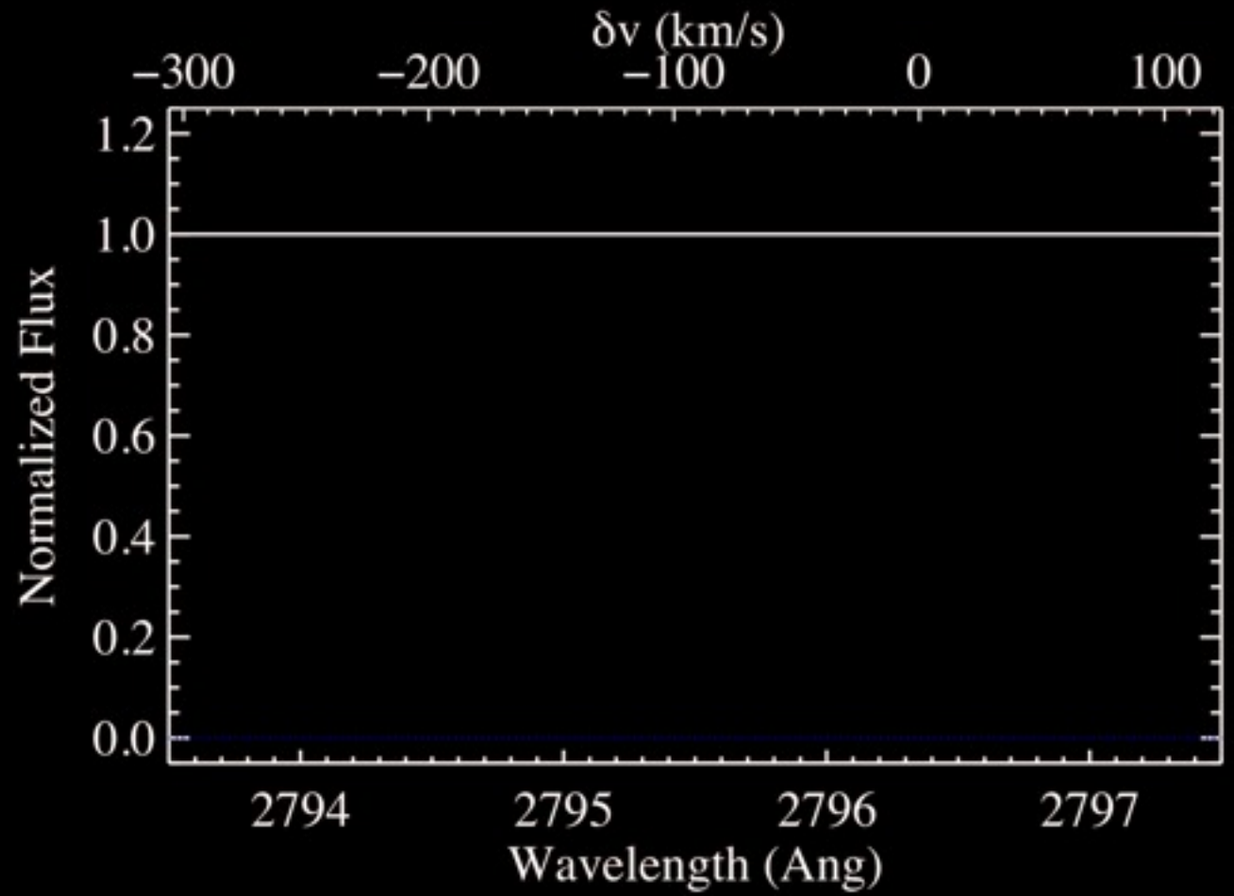


P-Cygni (Cartoon)

Canonical absorption+emission profile of a wind

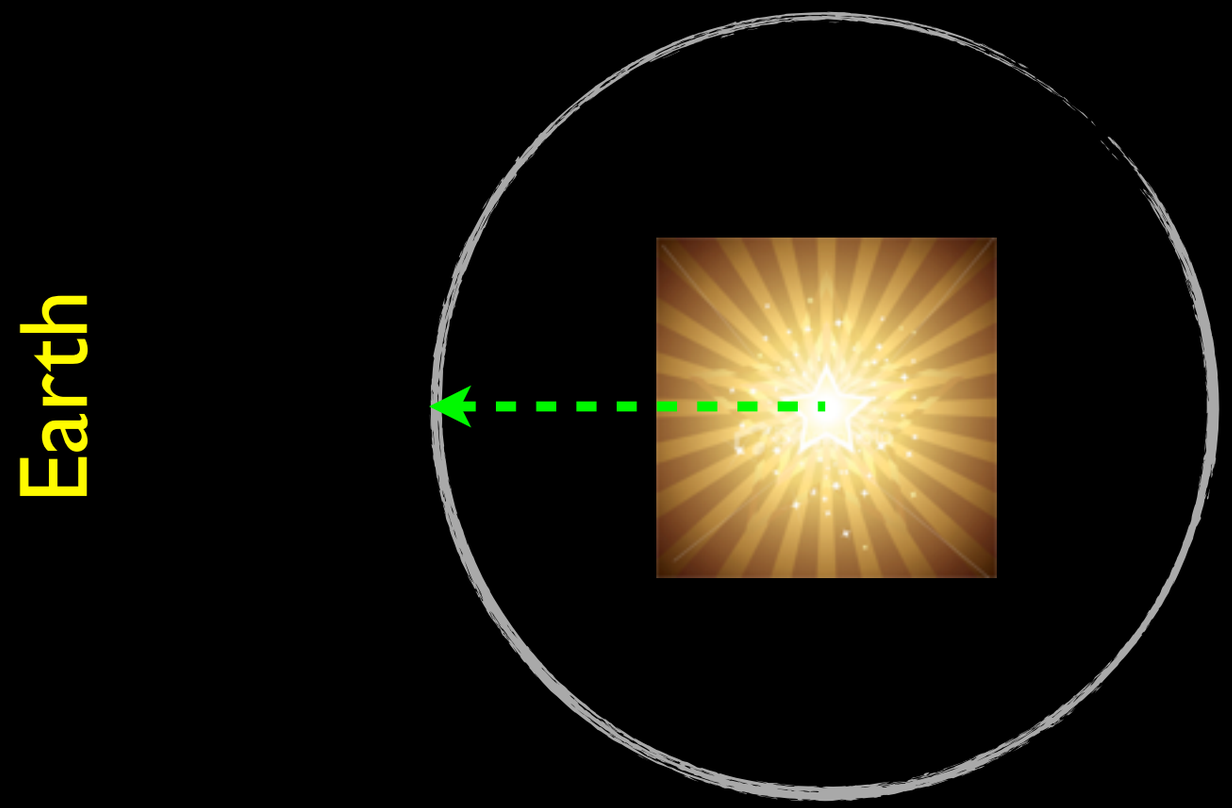


1D Spectrum for MgII 2796

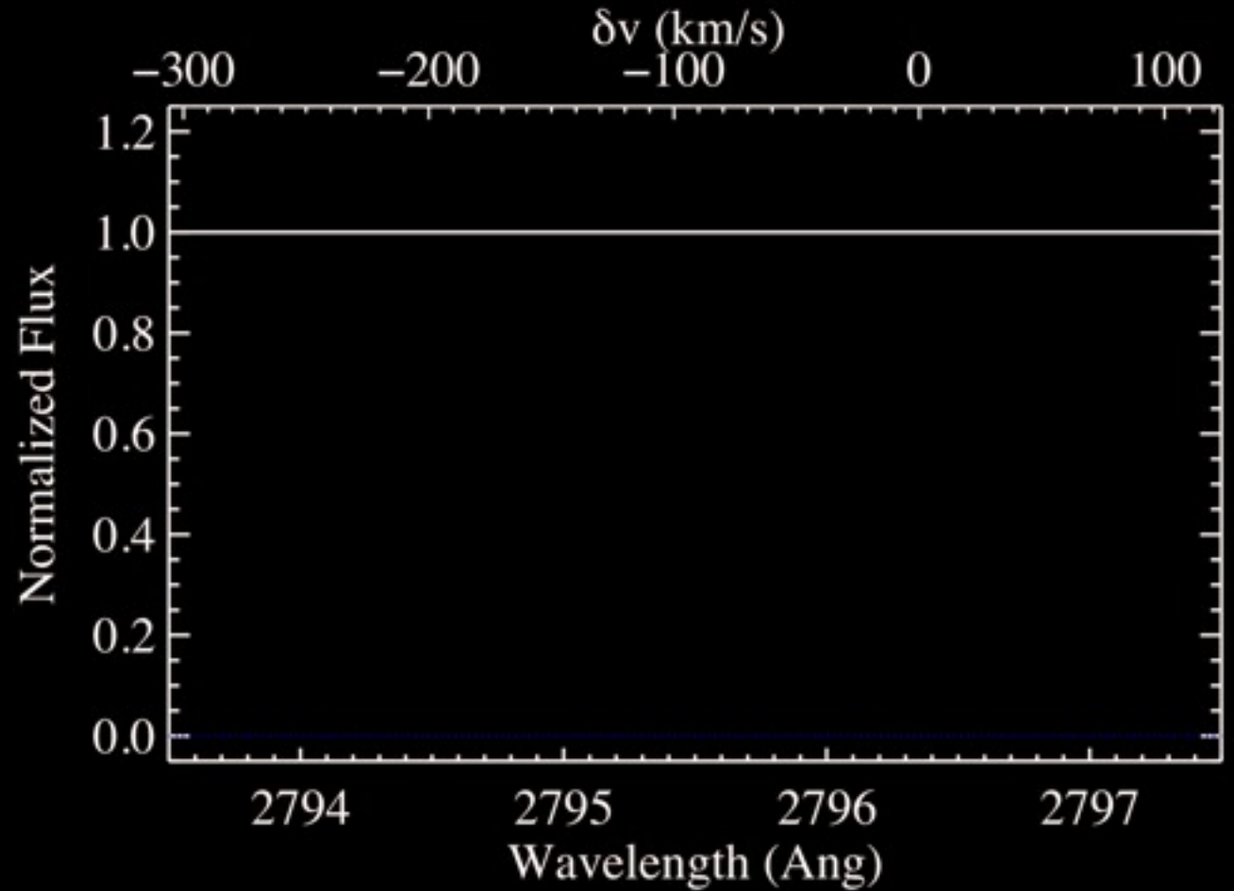


P-Cygni (Cartoon)

Canonical absorption+emission profile of a wind

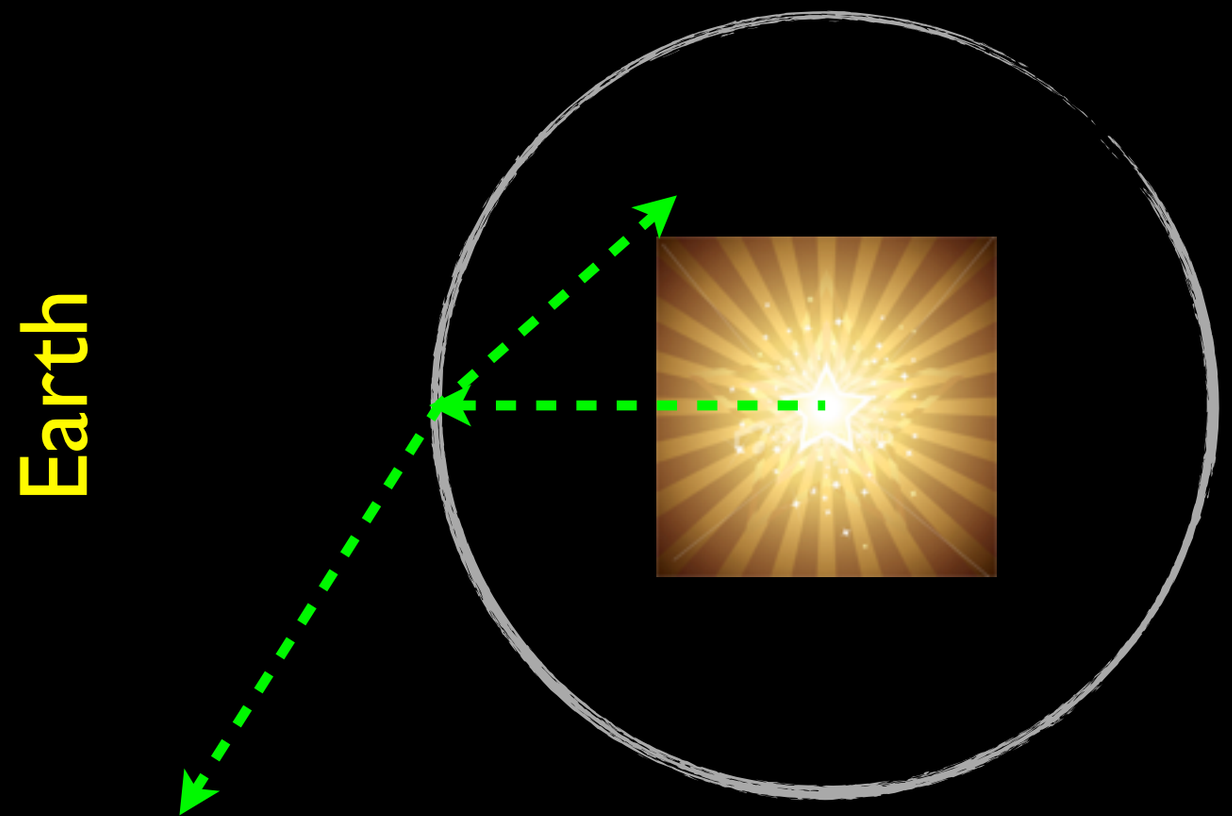


1D Spectrum for MgII 2796

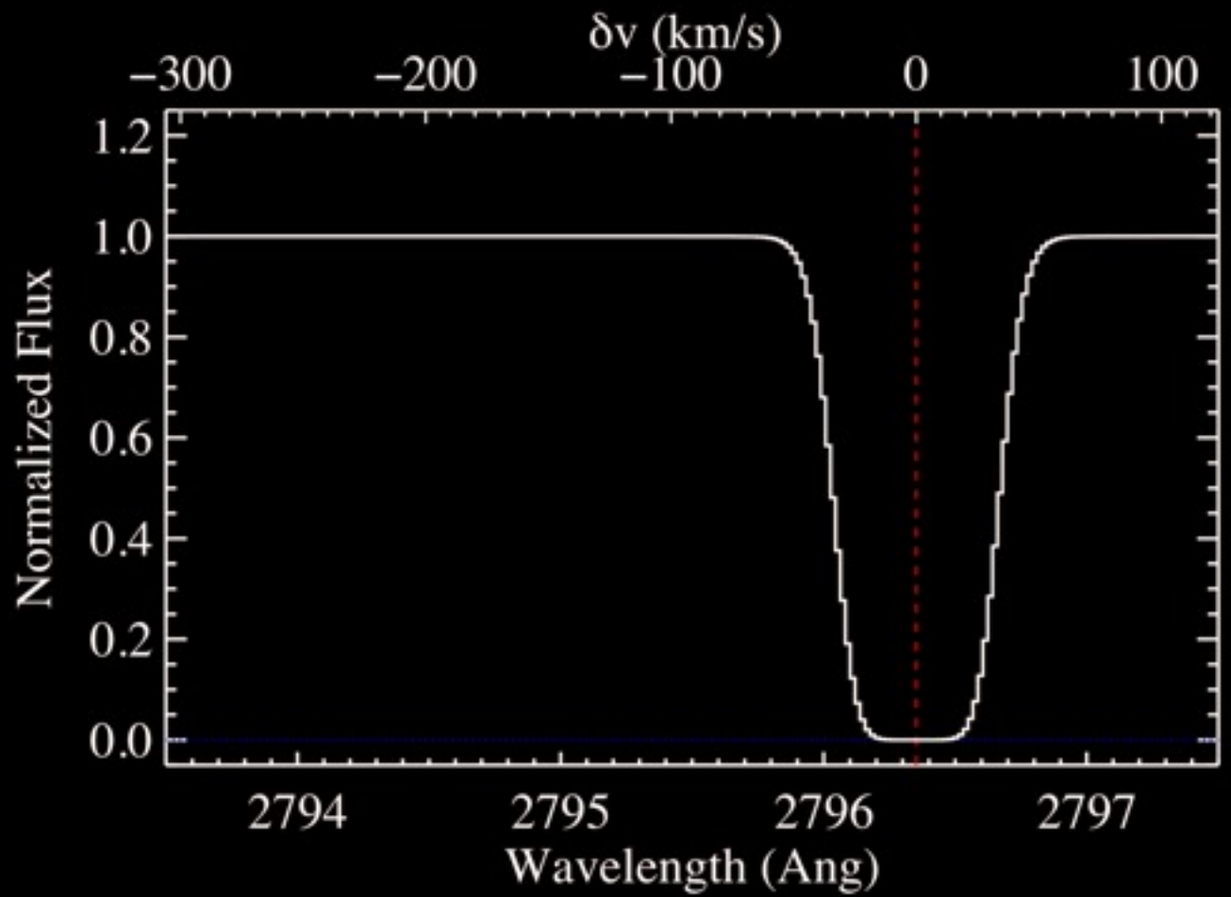


P-Cygni (Cartoon)

Canonical absorption+emission profile of a wind

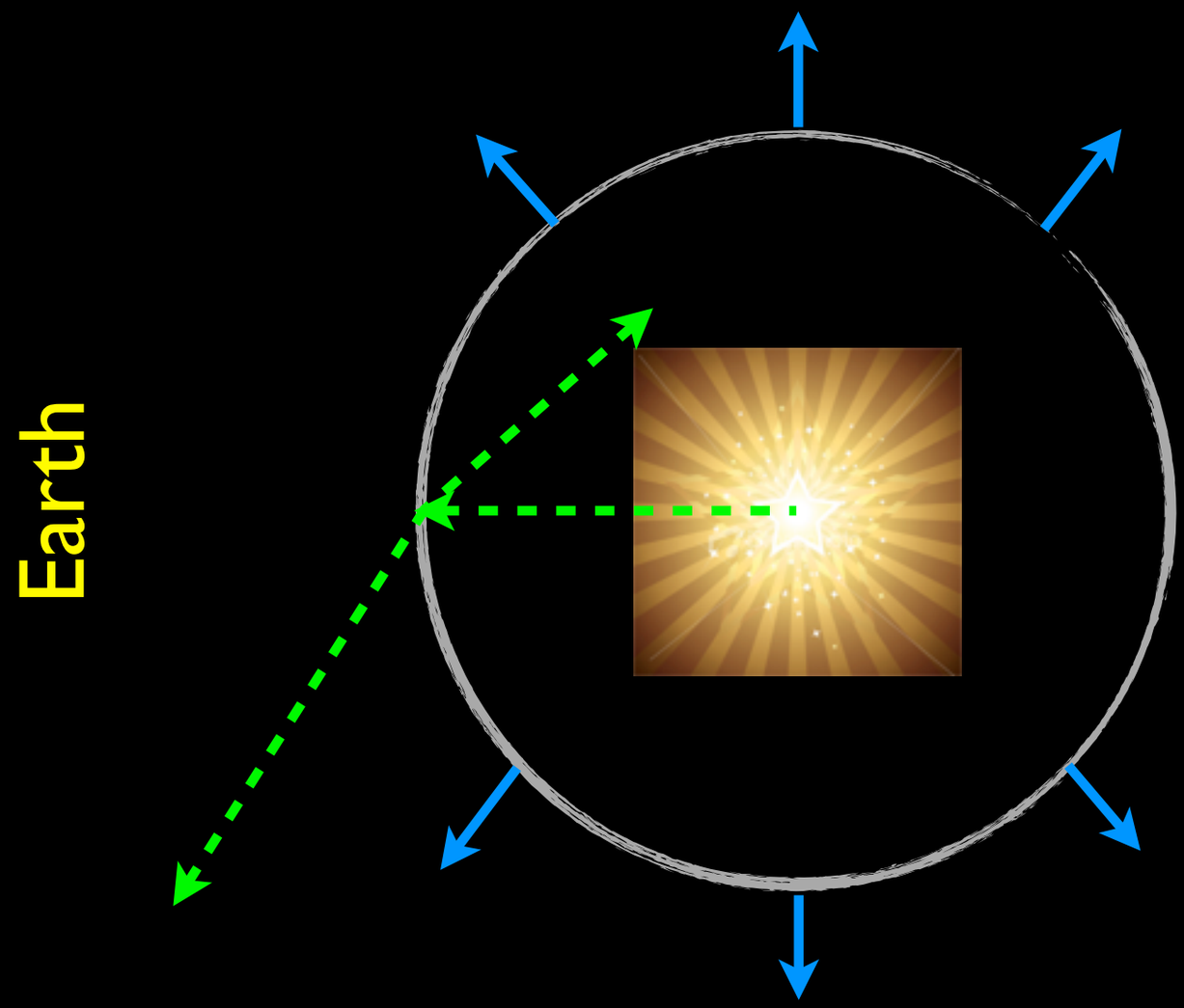


1D Spectrum for MgII 2796

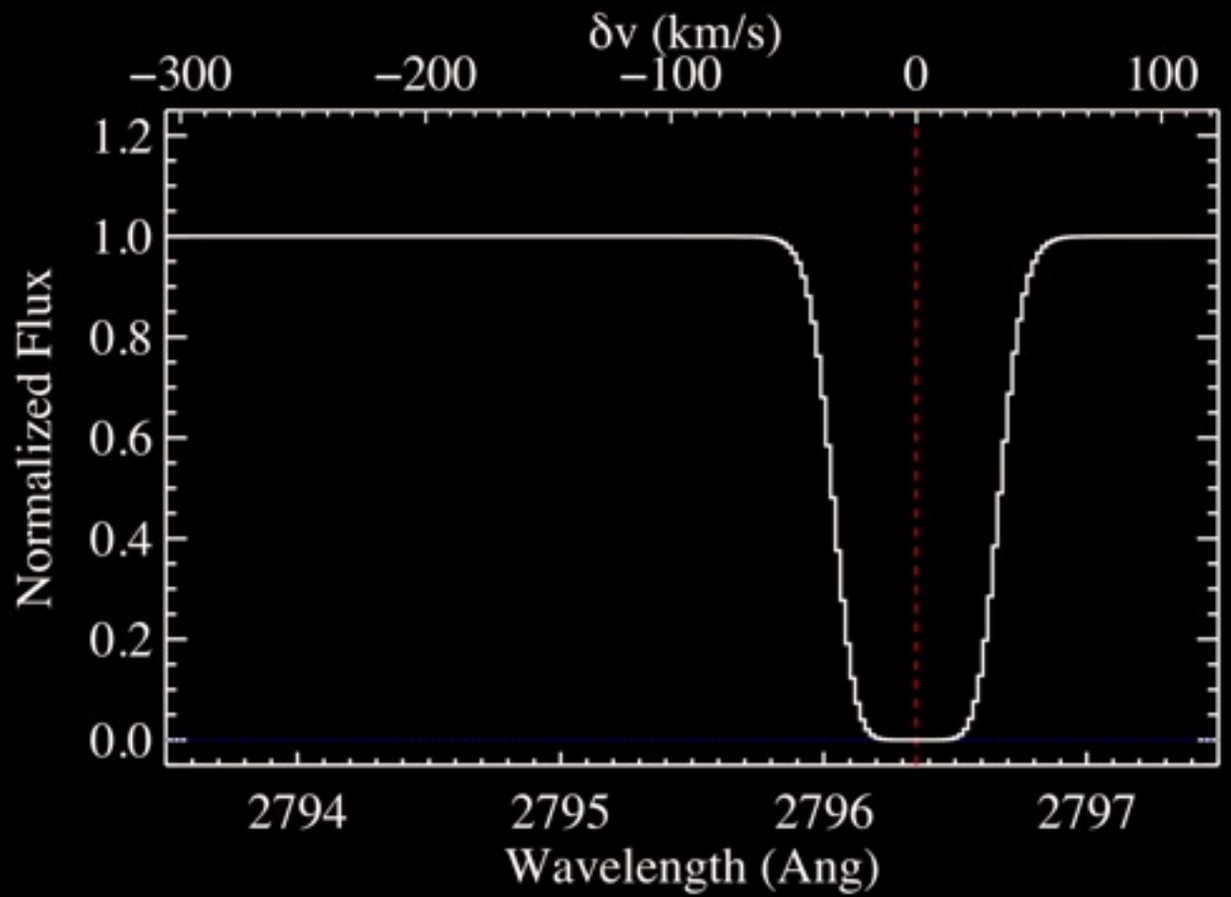


P-Cygni (Cartoon)

Canonical absorption+emission profile of a wind

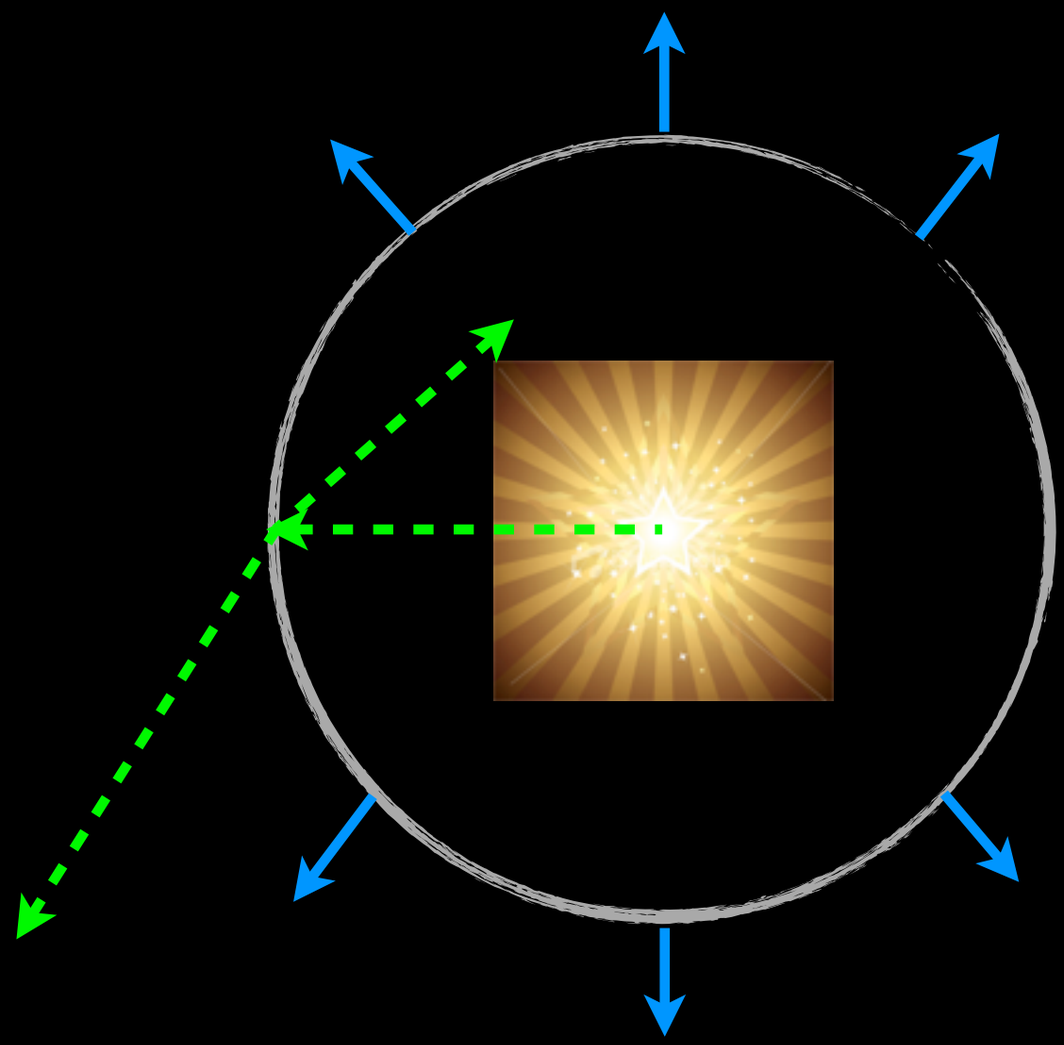


1D Spectrum for MgII 2796

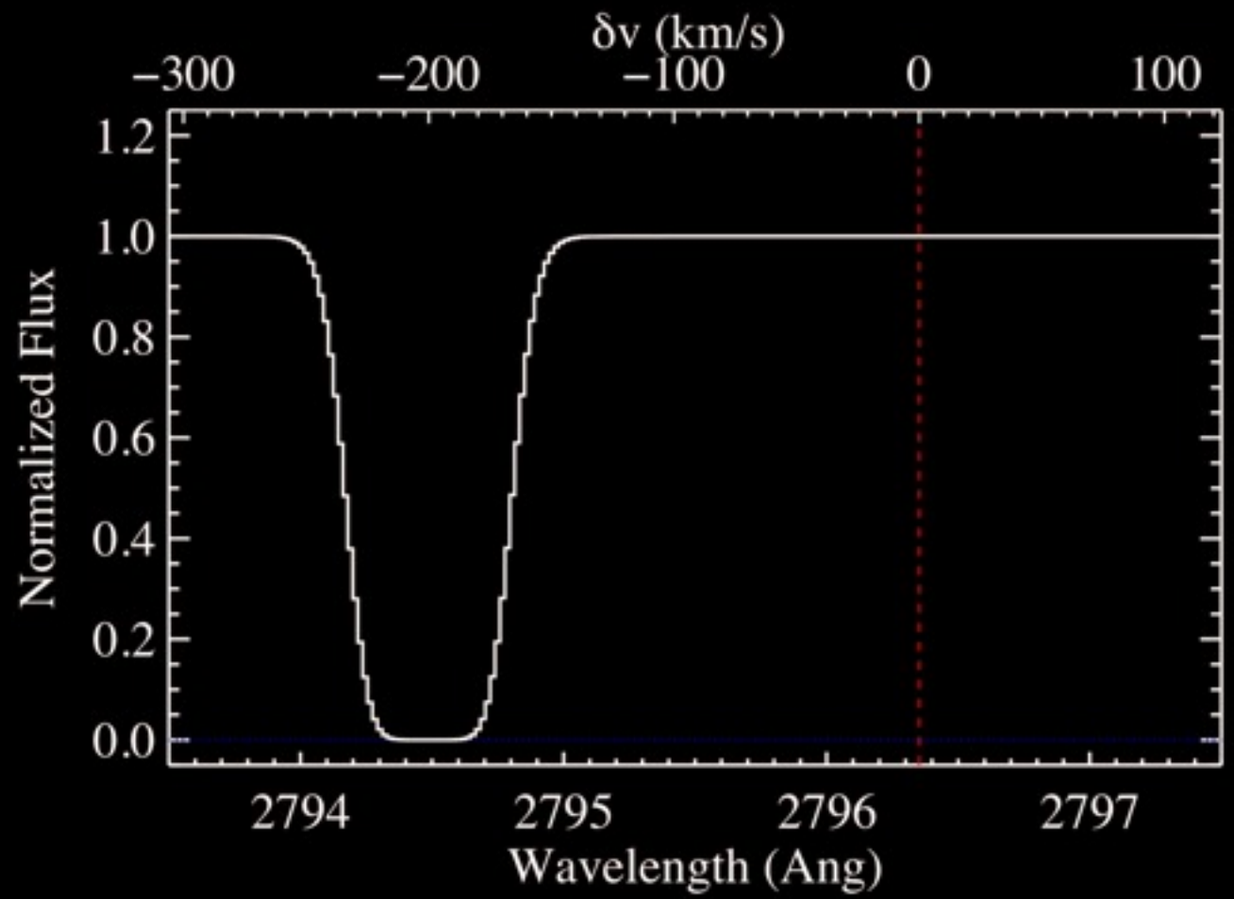


P-Cygni (Cartoon)

Canonical absorption+emission profile of a wind

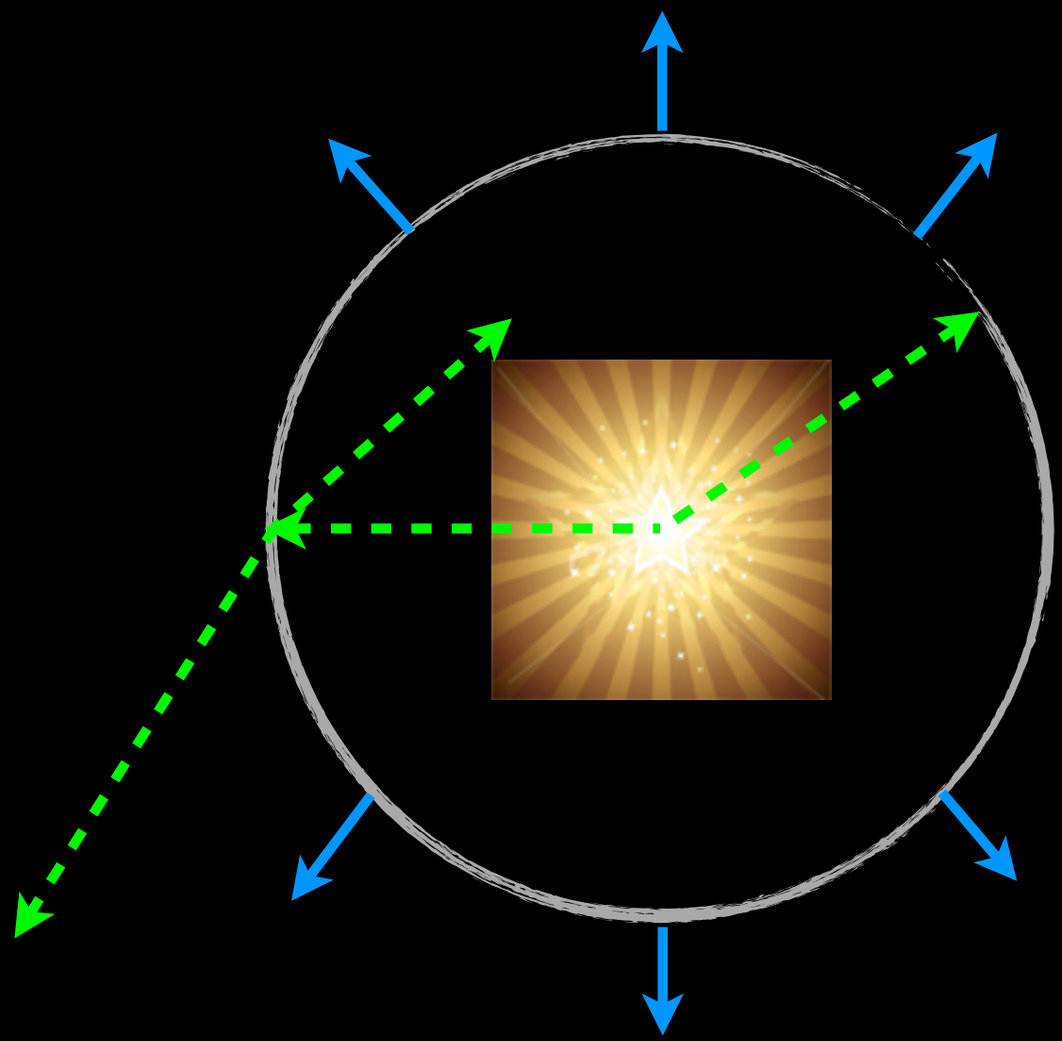


1D Spectrum for MgII 2796

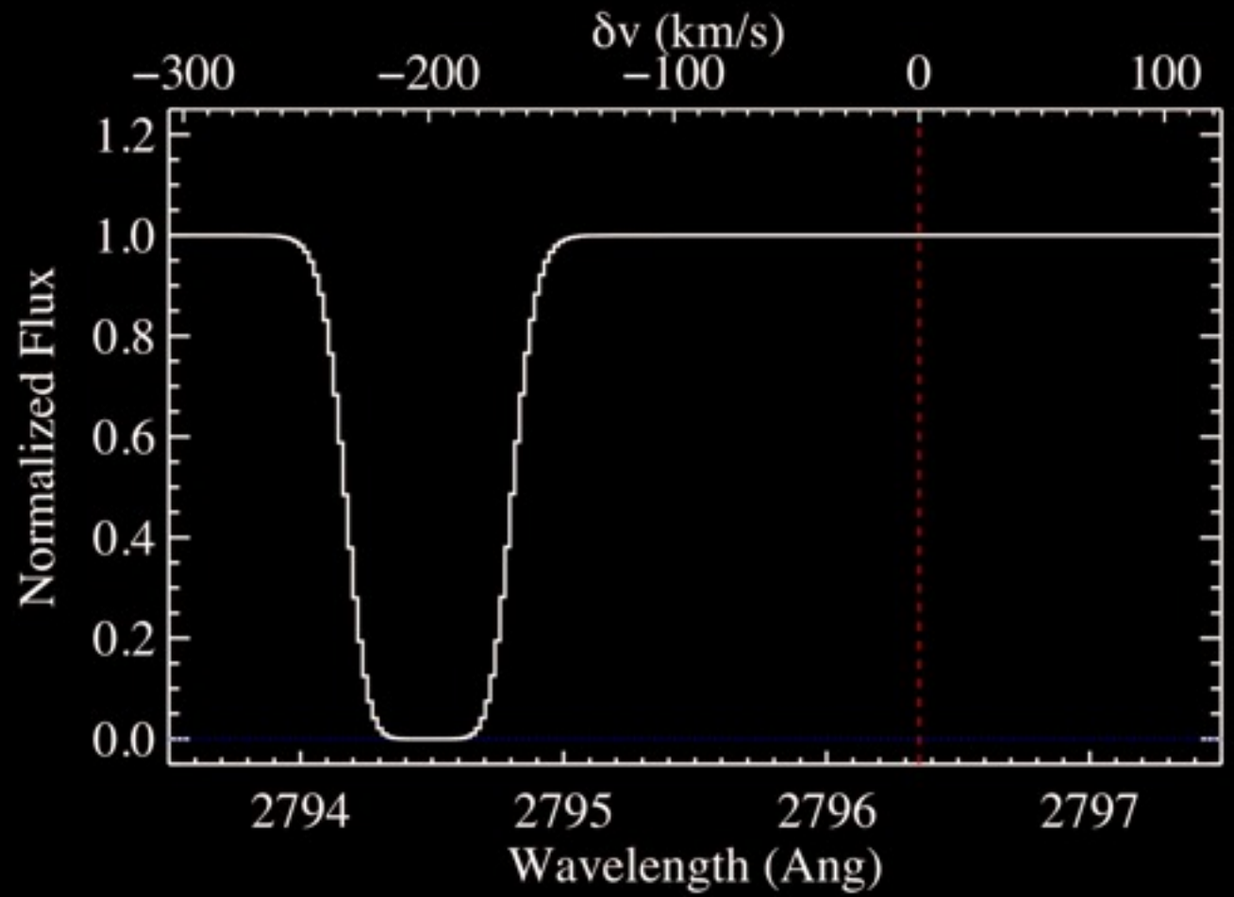


P-Cygni (Cartoon)

Canonical absorption+emission profile of a wind

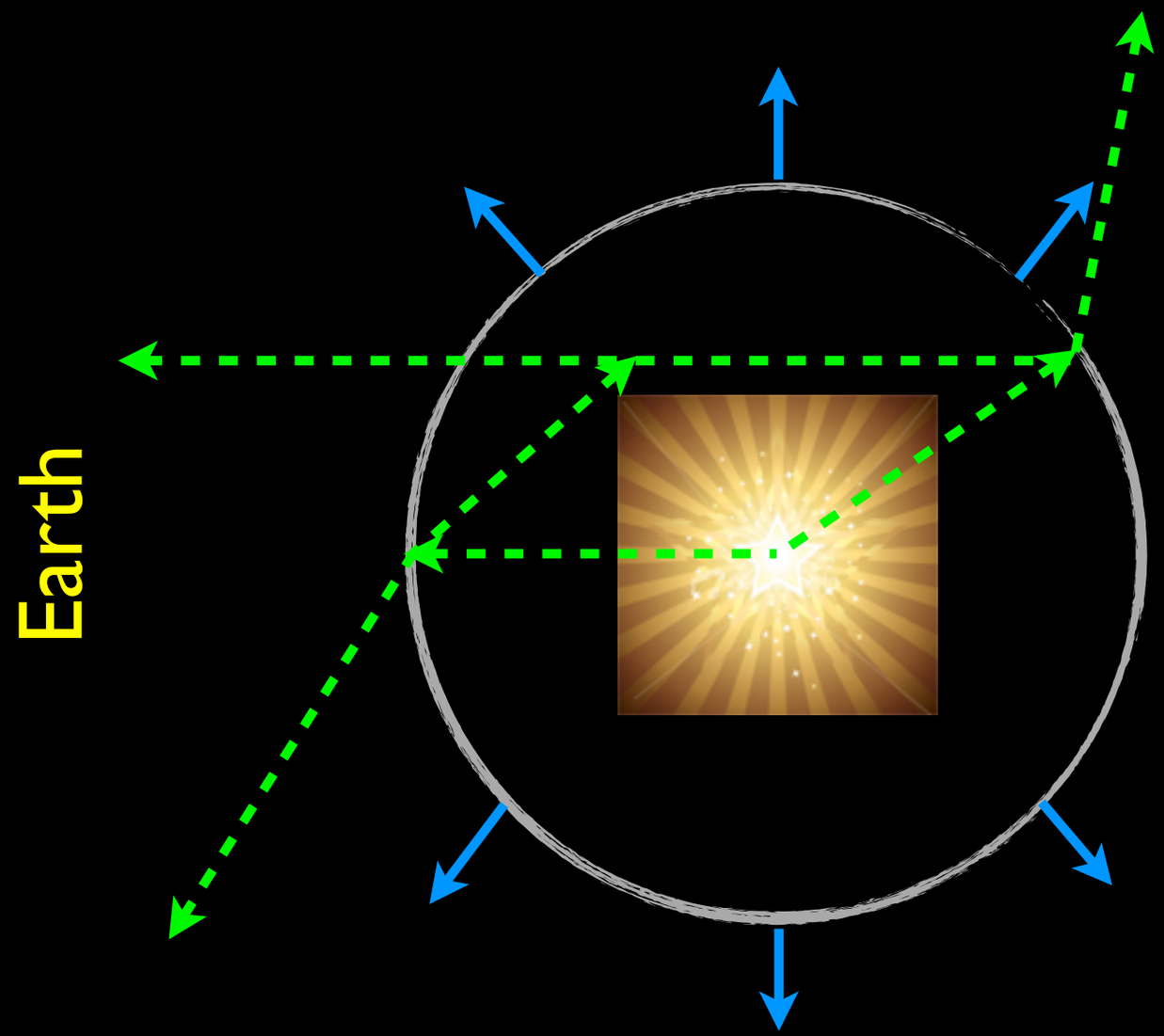


1D Spectrum for MgII 2796

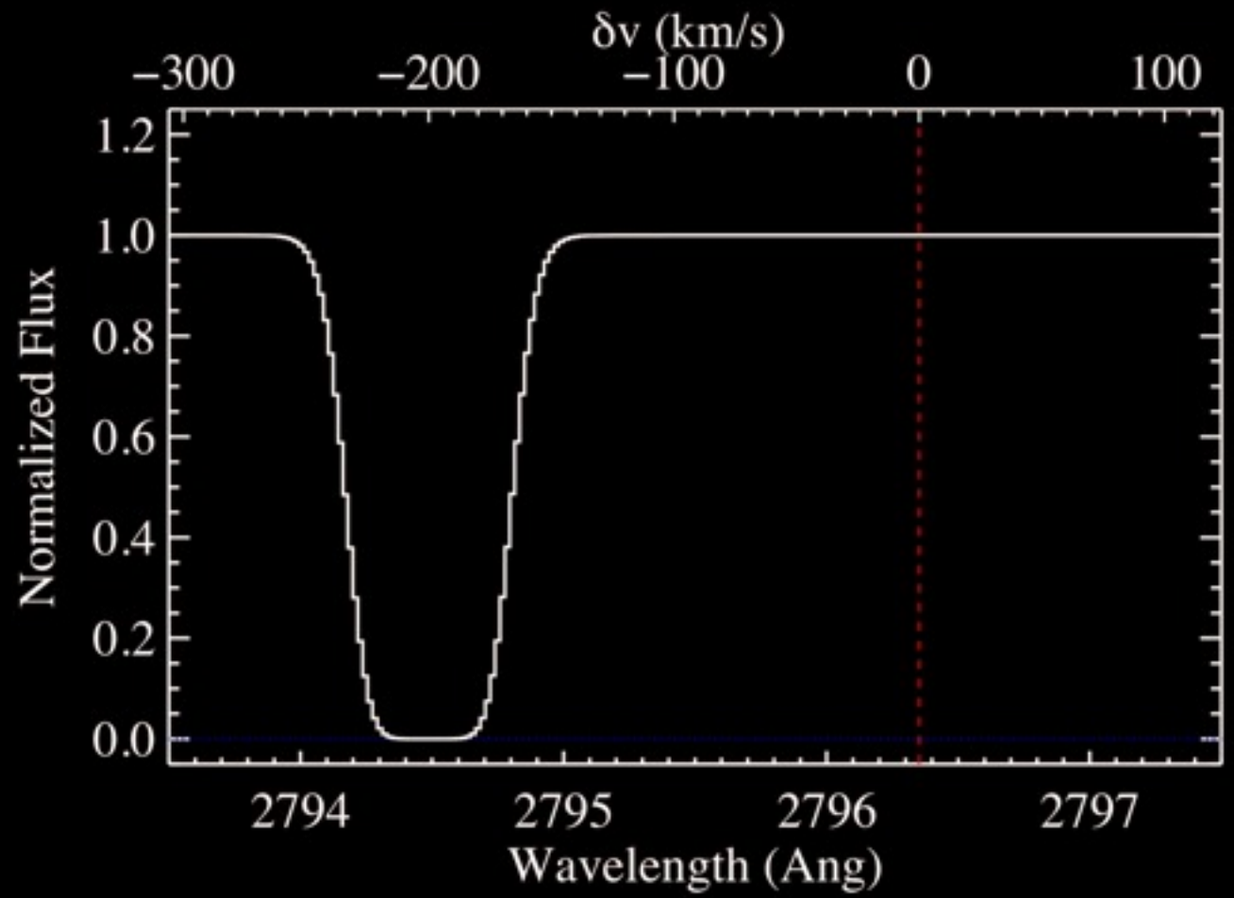


P-Cygni (Cartoon)

Canonical absorption+emission profile of a wind

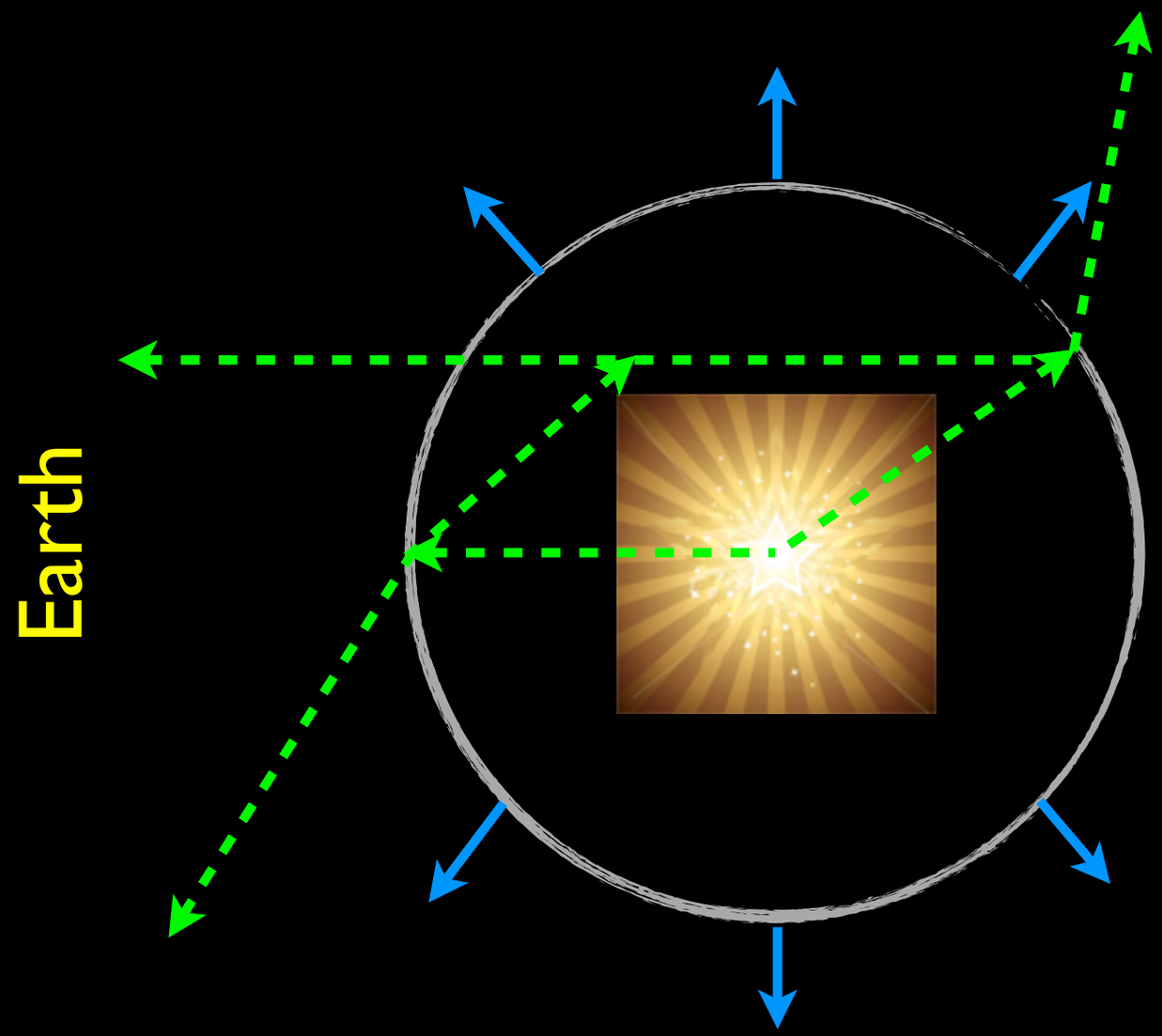


1D Spectrum for MgII 2796

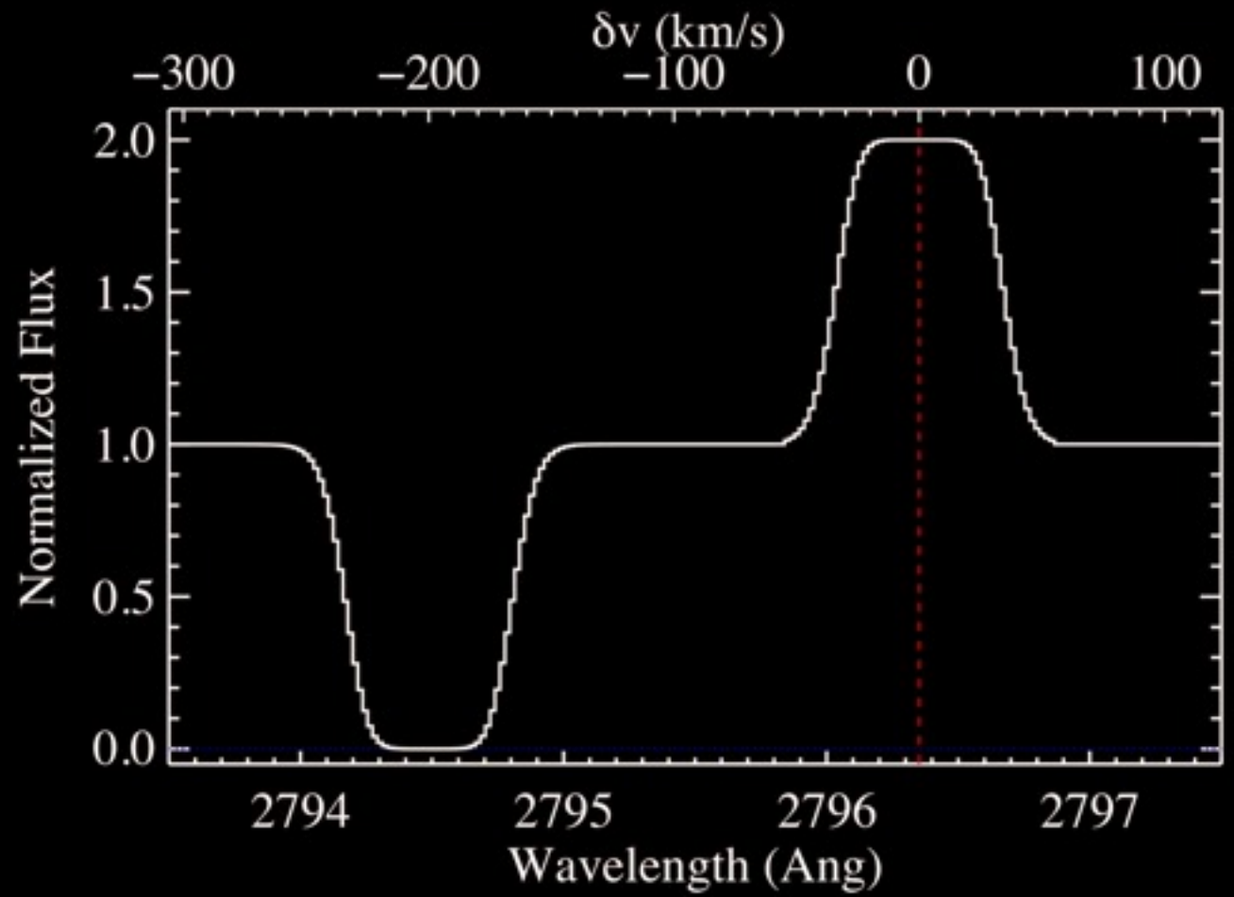


P-Cygni (Cartoon)

Canonical absorption+emission profile of a wind



1D Spectrum for MgII 2796



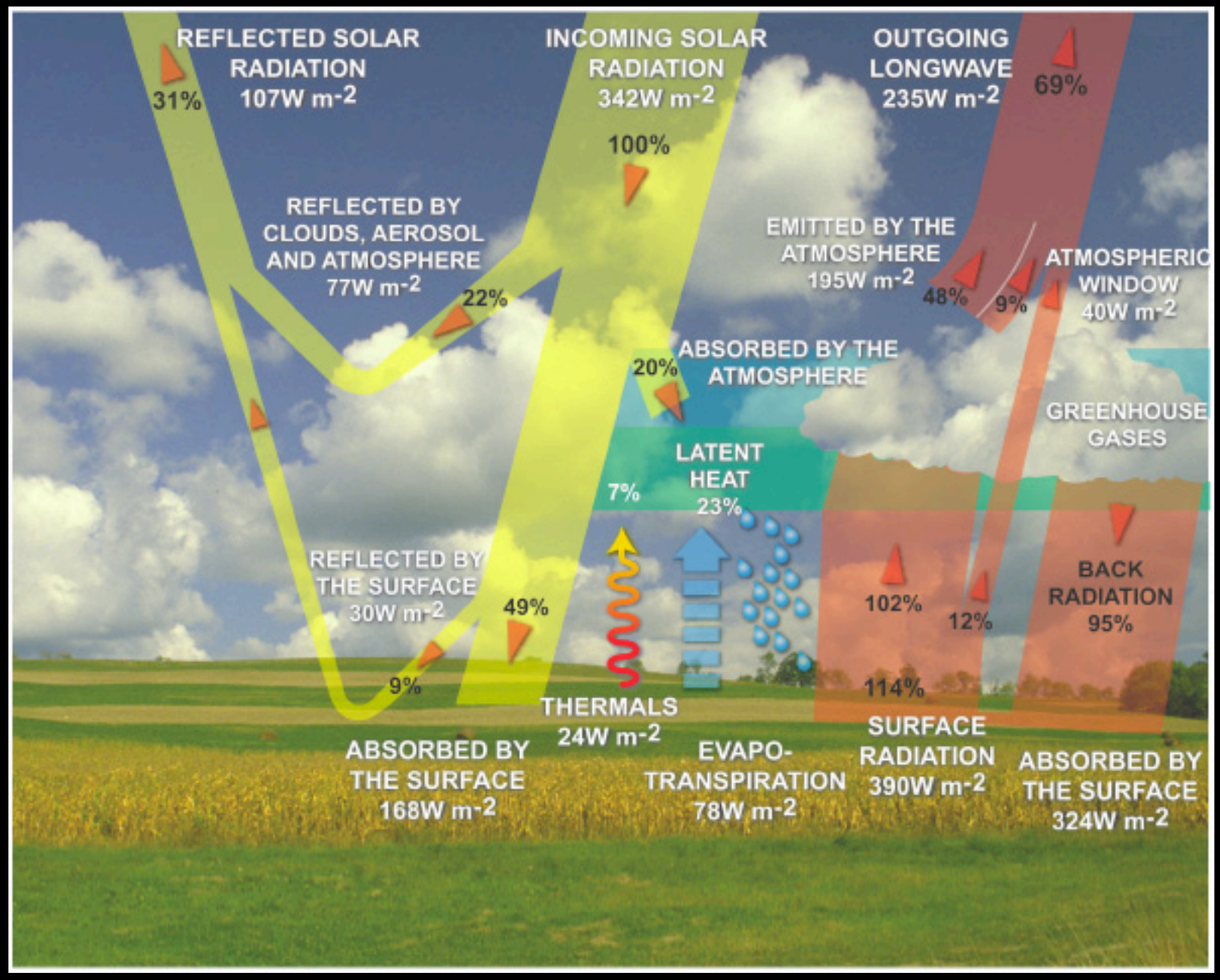
(Idealized) Cool Gas Outflow Models

Inspired by the Rubin et al. observations that follow

Prochaska, Kasen, & Rubin, ApJ, (nearly) submitted

(Idealized) Cool Gas Outflow Models

Inspired by the Rubin et al. observations that follow

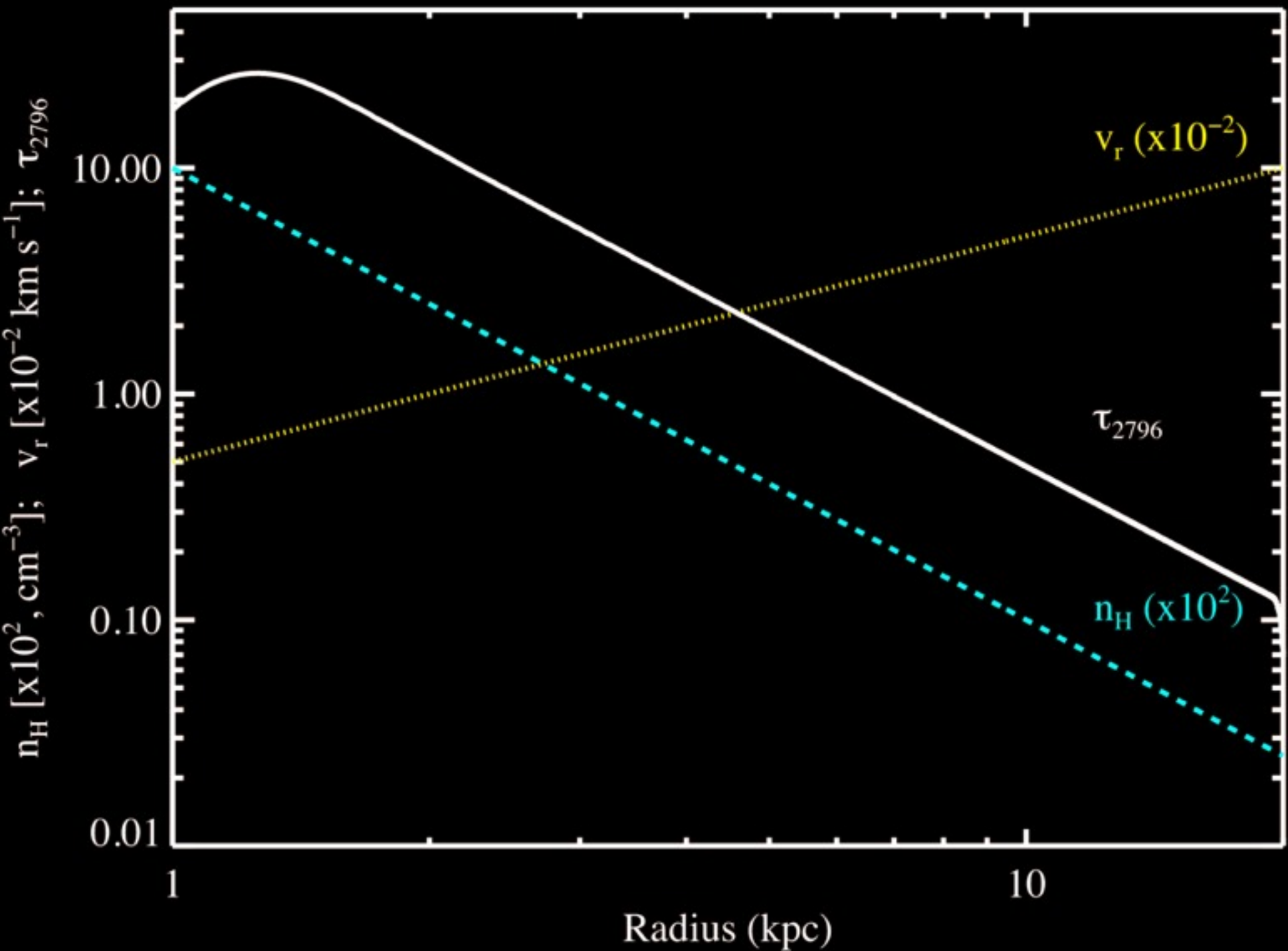


Radiative Transfer

Prochaska, Kasen, & Rubin, ApJ, (nearly) submitted

Wind Profile (Fiducial Model)

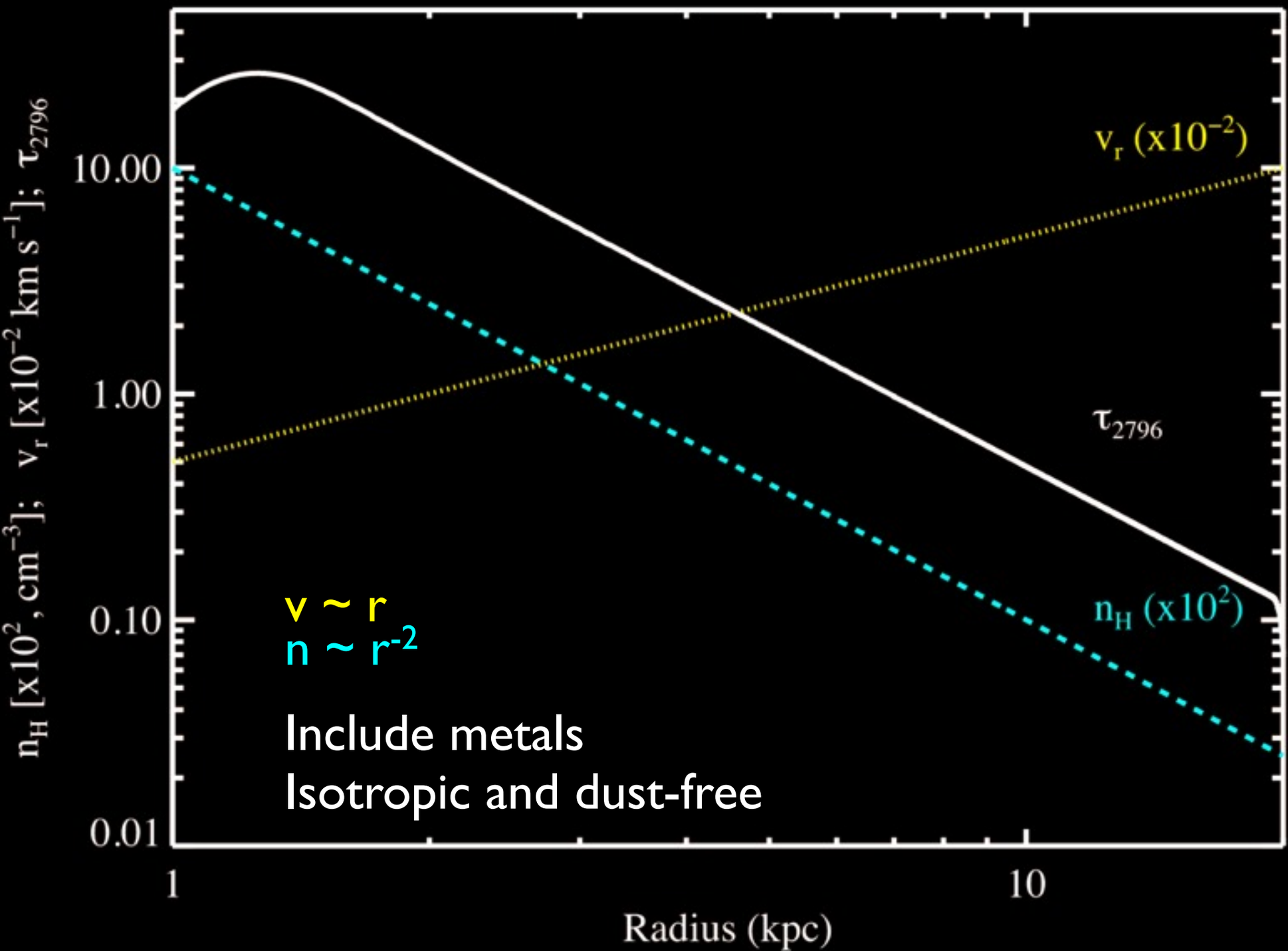
The key quantity is the optical depth profile



Prochaska, Kasen, & Rubin, ApJ, (nearly) submitted

Wind Profile (Fiducial Model)

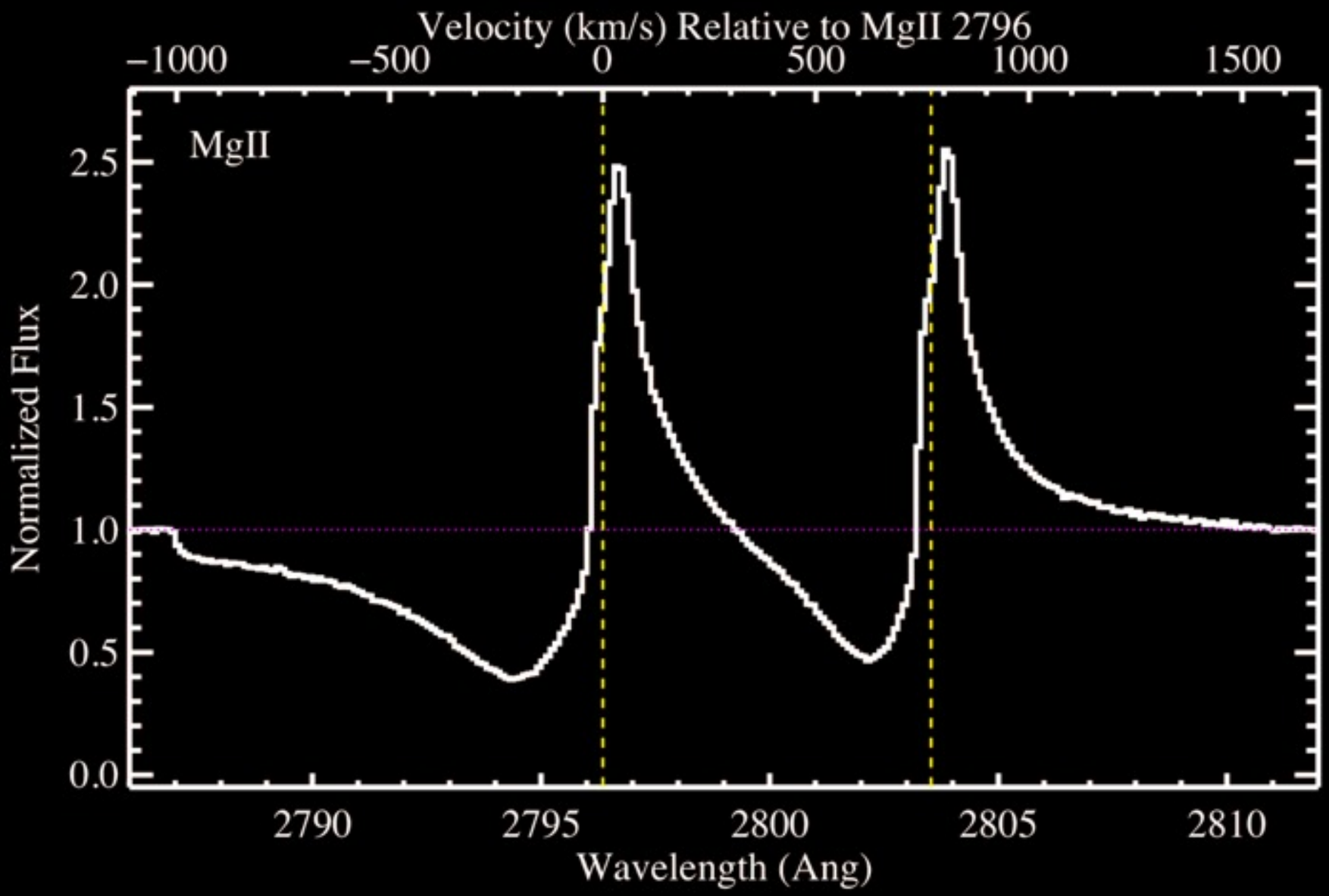
The key quantity is the optical depth profile



Prochaska, Kasen, & Rubin, ApJ, (nearly) submitted

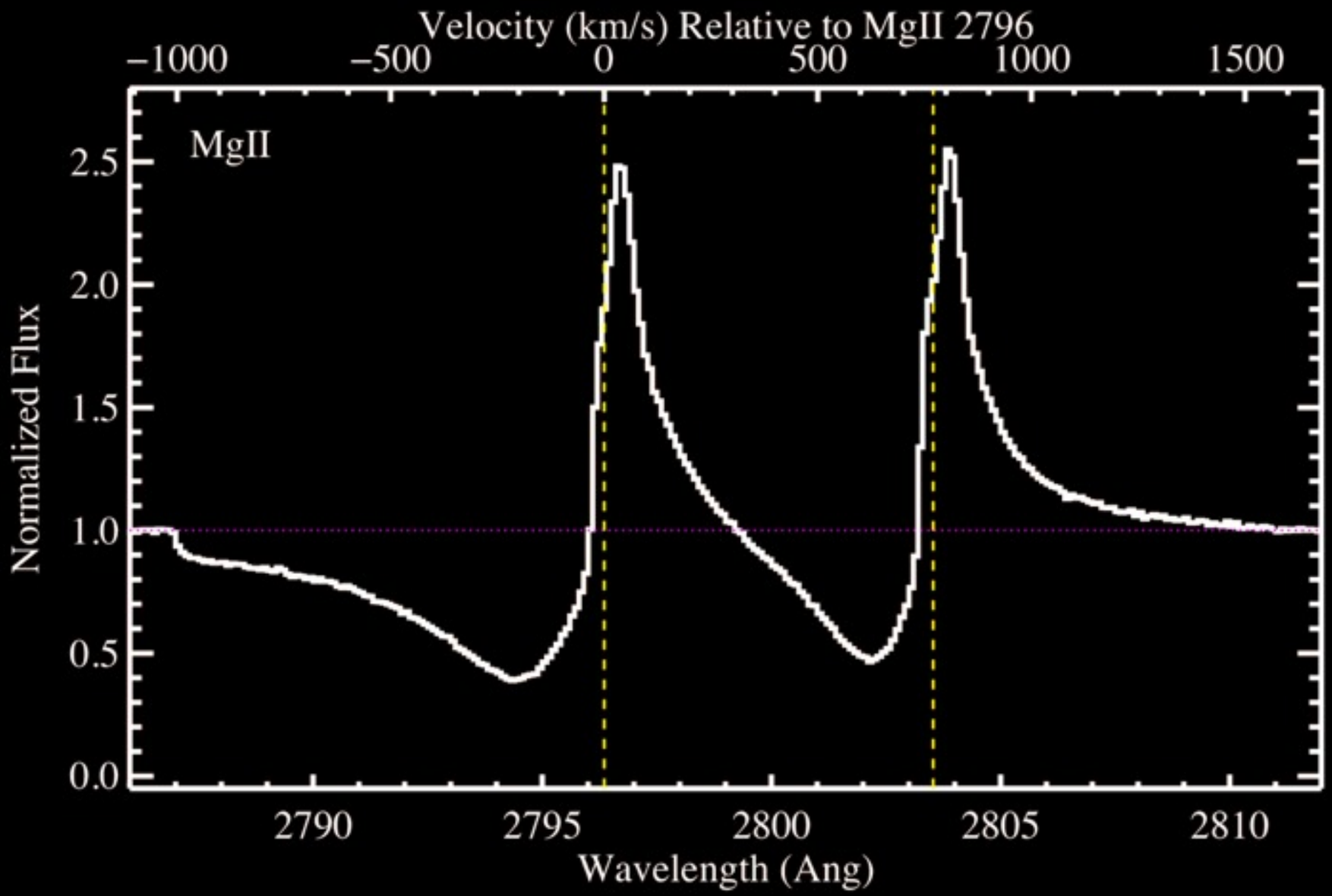
MgII Profiles (Fiducial Model)

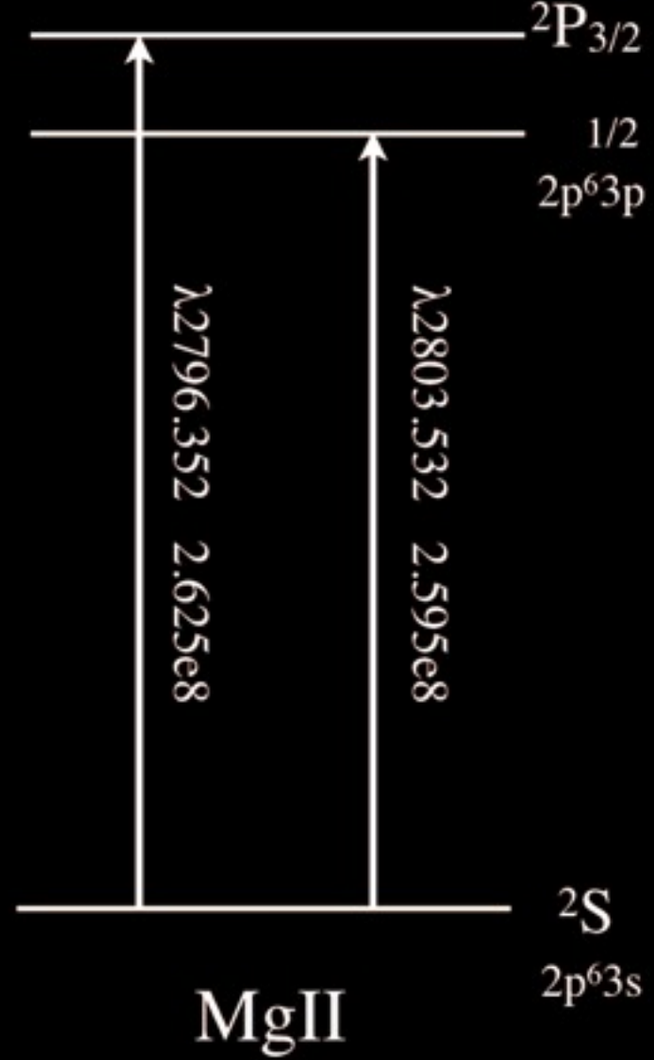
'Standard' P-Cygni profiles



MgII Profiles (Fiducial Model)

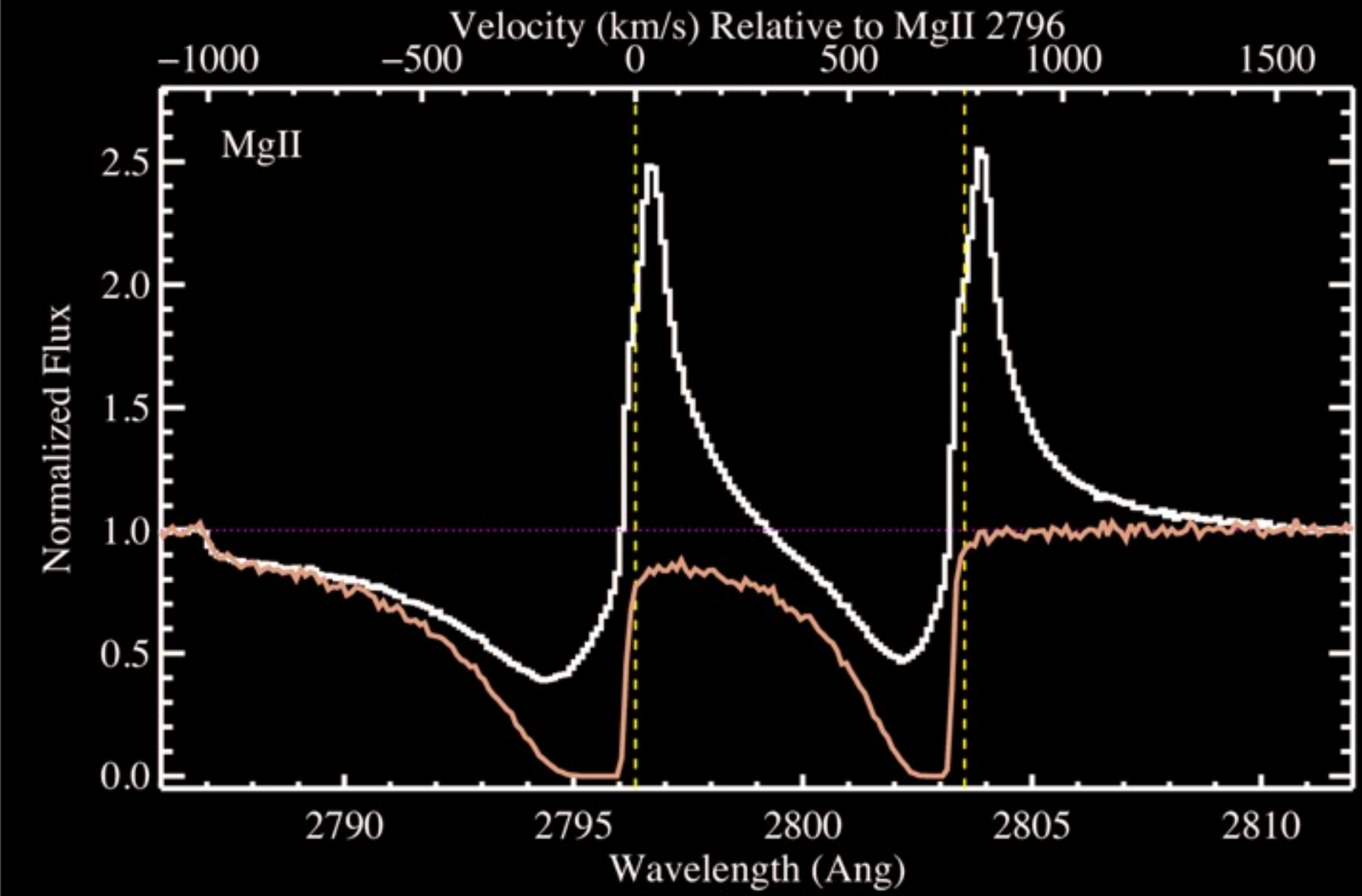
'Standard' P-Cygni profiles

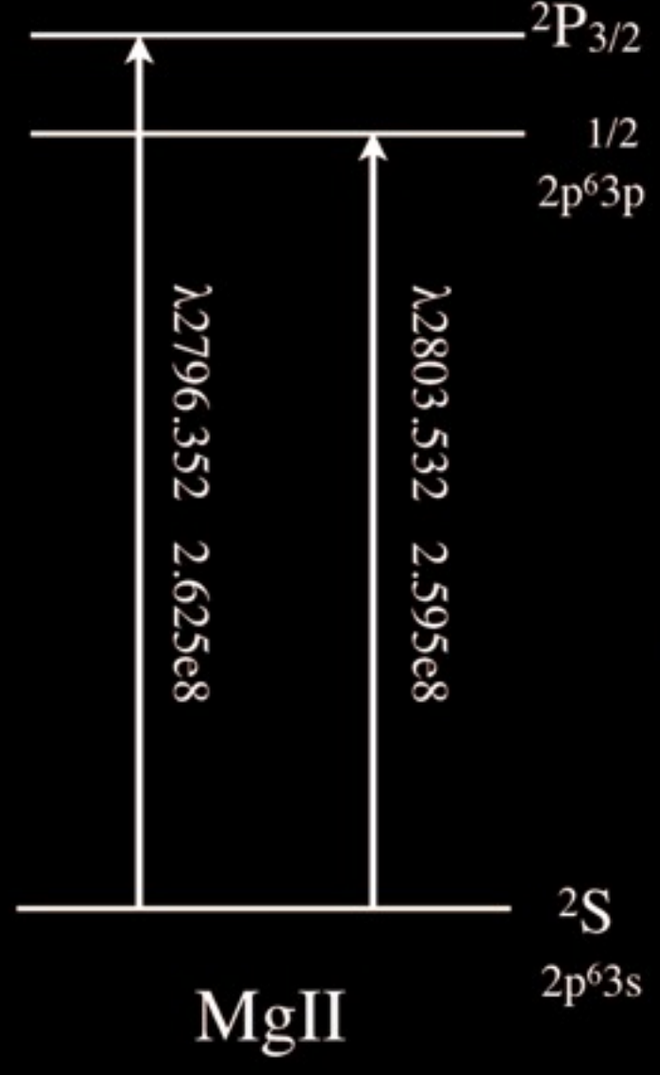




MgII Profiles (Fiducial Model)

'Standard' P-Cygni profiles

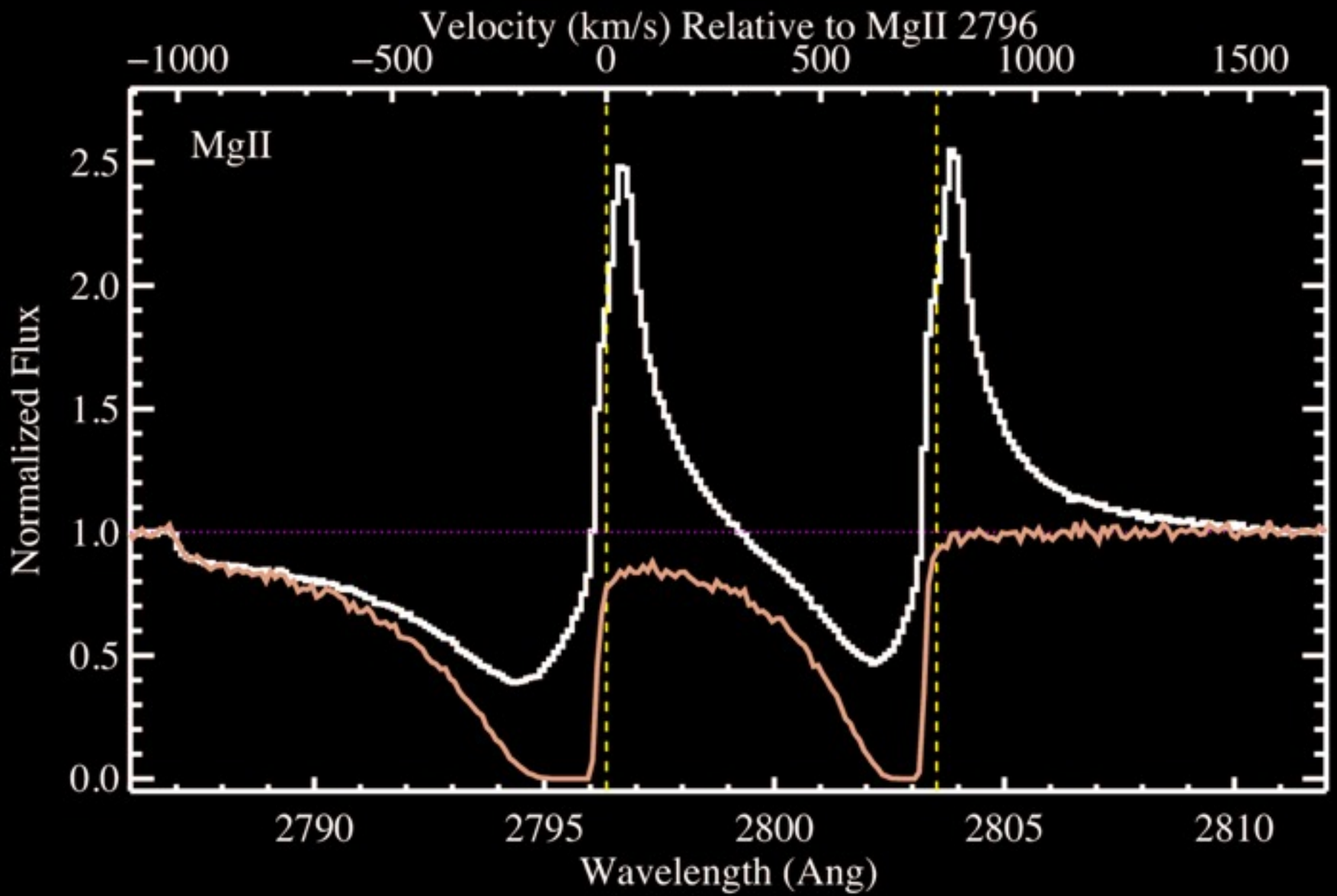


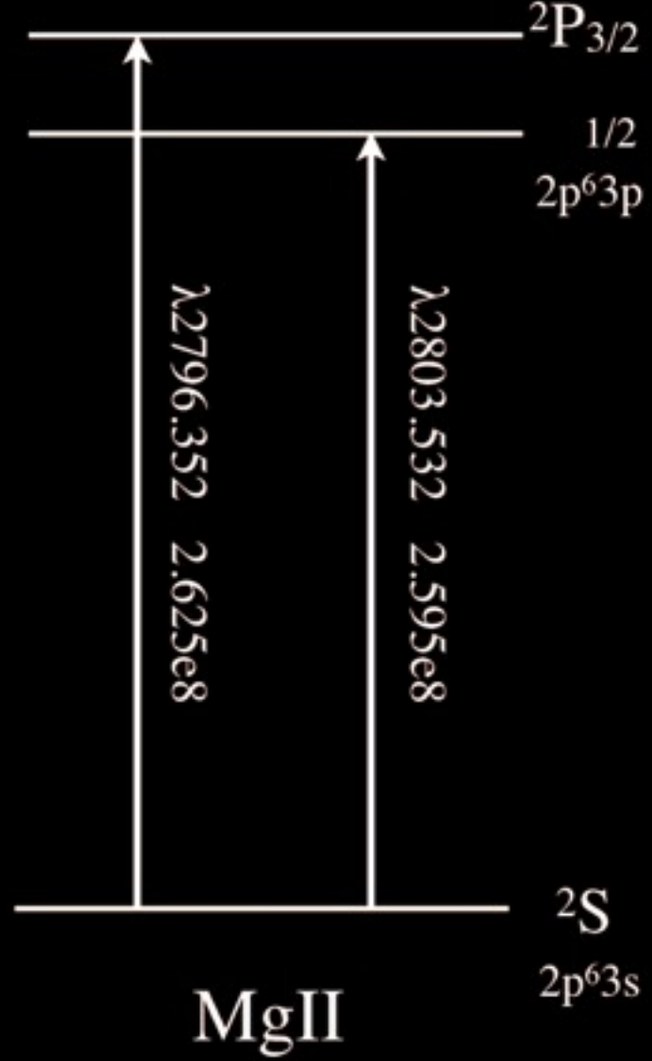


Absorption at dv >~ −200 km/s has been 'filled-in'

MgII Profiles (Fiducial Model)

'Standard' P-Cygni profiles

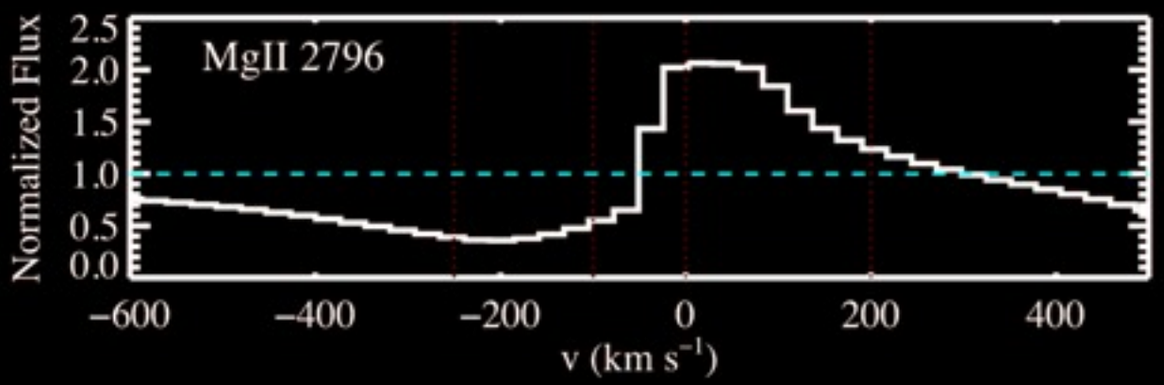




Absorption at dv >~ −200 km/s has been 'filled-in'

Standard analysis would (i) require partial covering of the source, (ii) recover the wrong optical depth, and (iii) miss gas at v~0 km/s

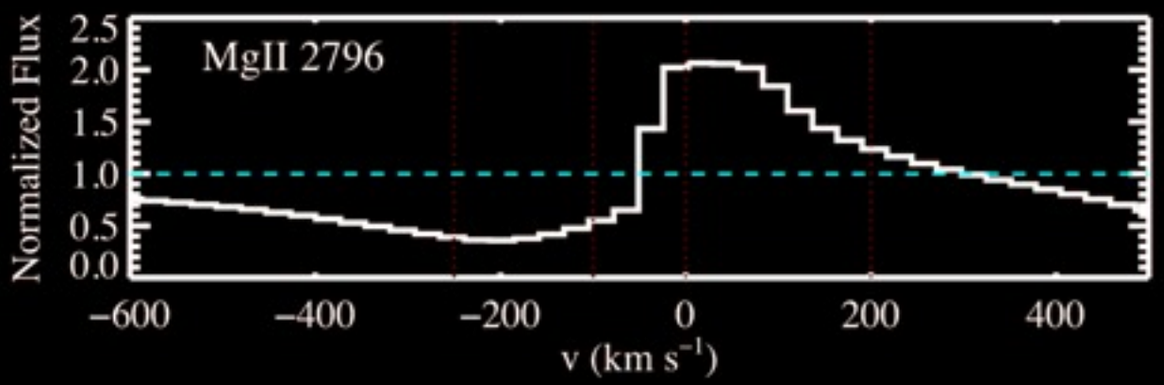
Wind Emission (Fiducial Model)



Prochaska, Kasen, & Rubin, ApJ, (nearly) submitted

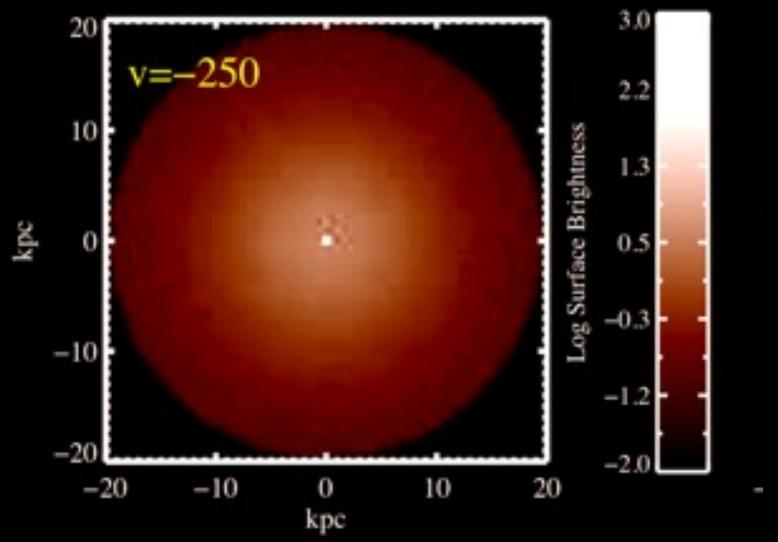
Wind Emission (Fiducial Model)

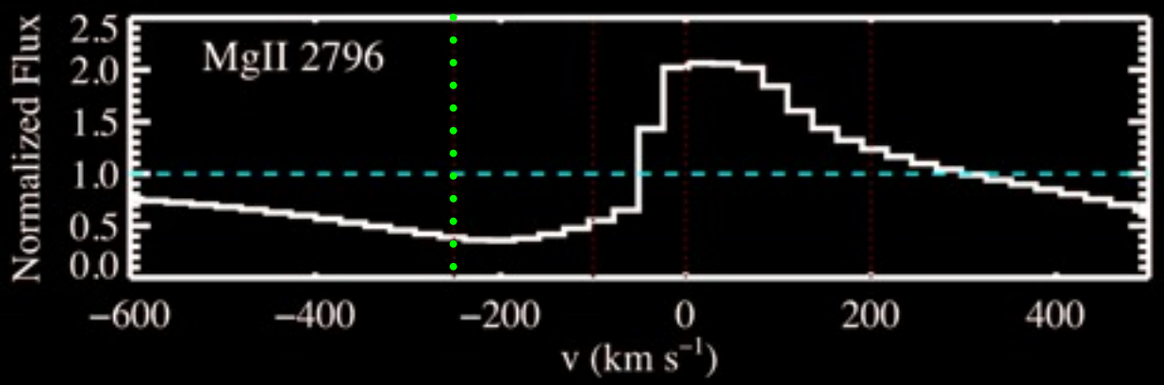
- Consider the surface brightness of observed flux
  - Scattered photons
  - And, of course, the source



Prochaska, Kasen, & Rubin, ApJ, (nearly) submitted

Wind Emission (Fiducial Model)

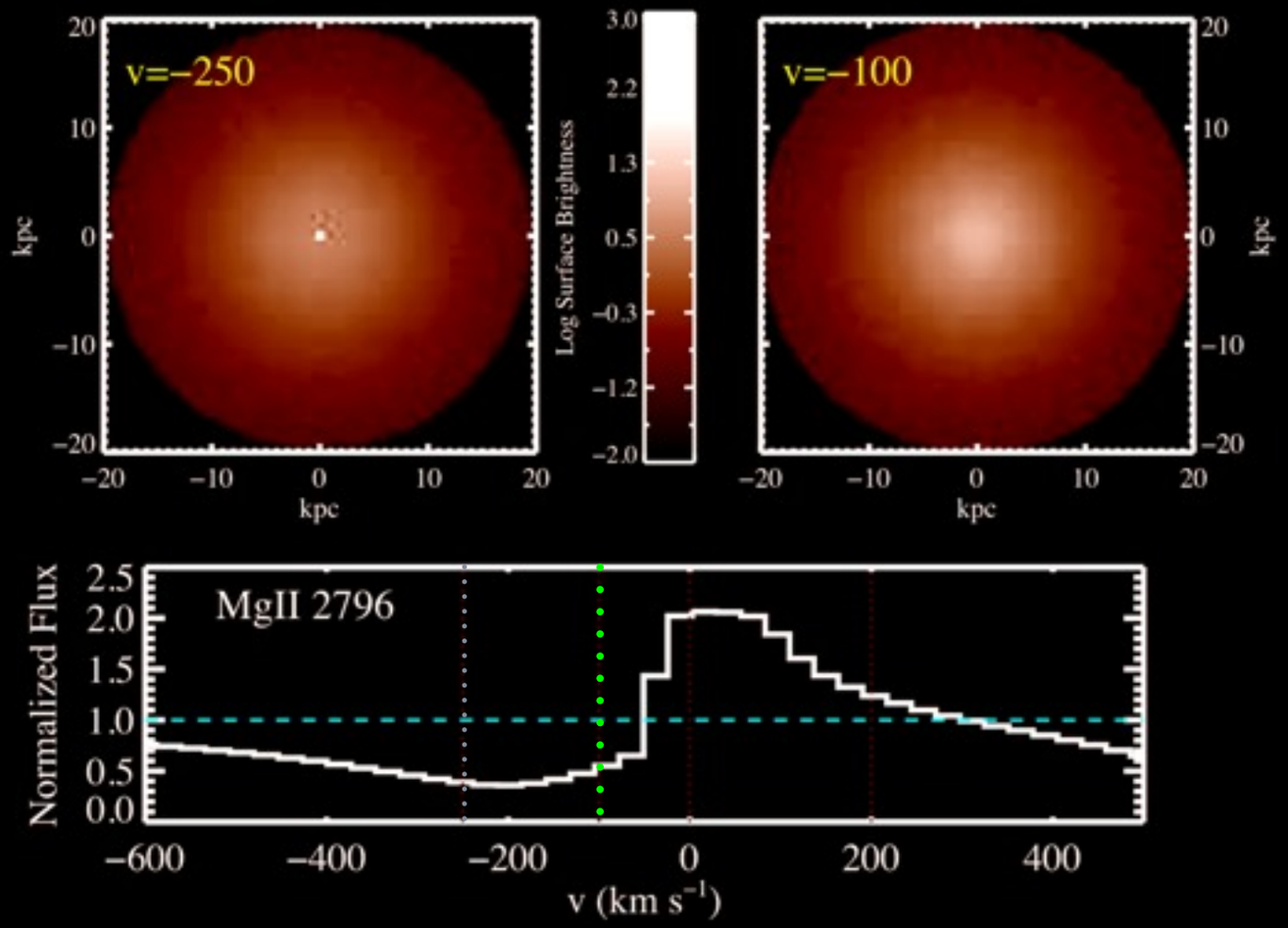




- Consider the surface brightness of observed flux
  - Scattered photons
  - And, of course, the source

Prochaska, Kasen, & Rubin, ApJ, (nearly) submitted

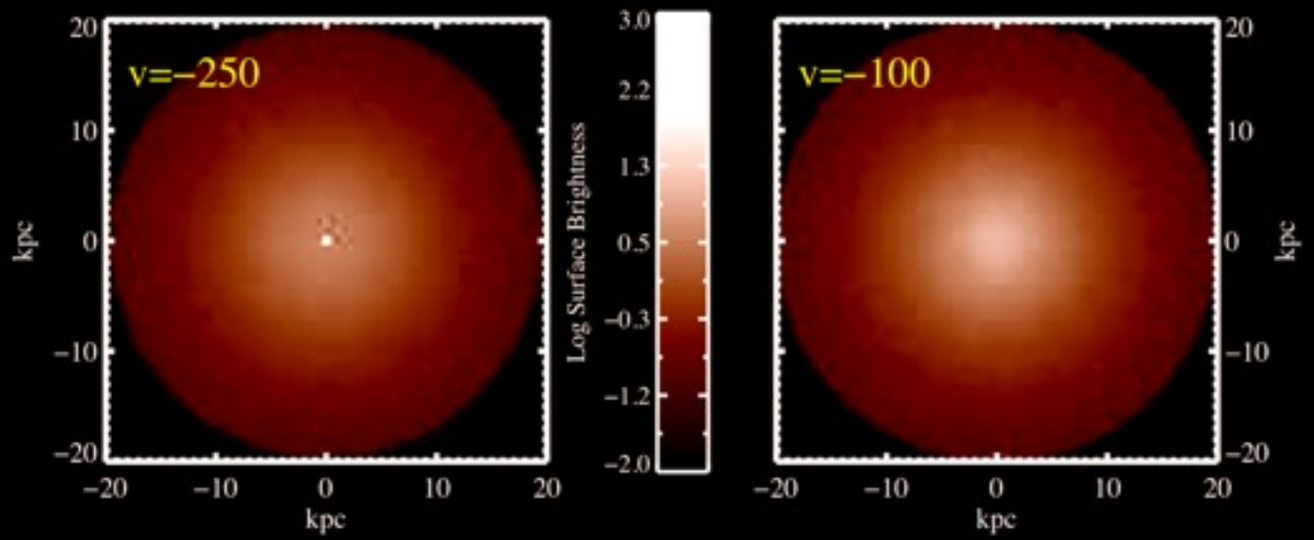
Wind Emission (Fiducial Model)

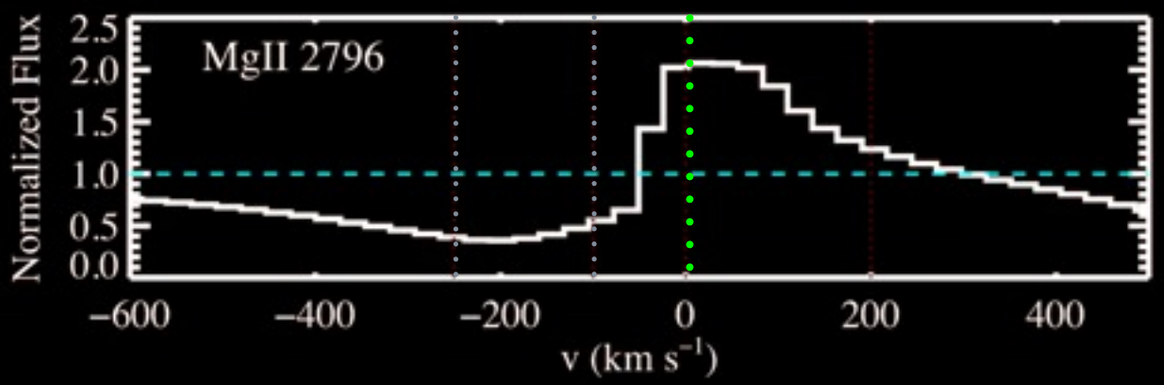


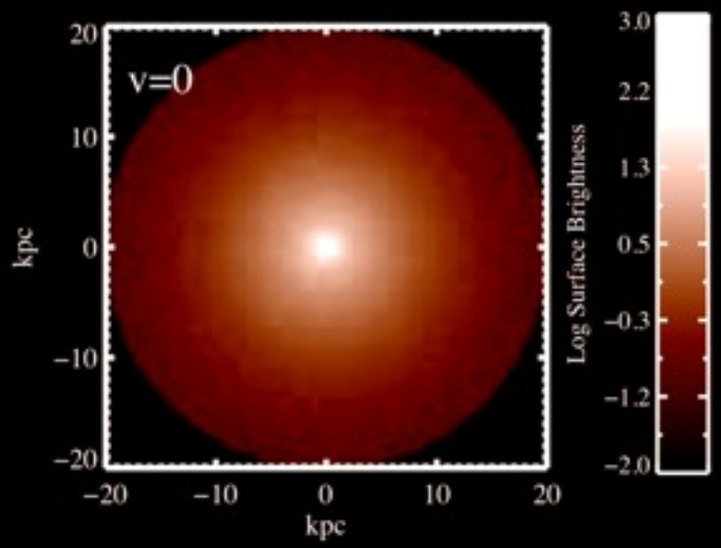
- Consider the surface brightness of observed flux
  - Scattered photons
  - And, of course, the source
- At v=−100 km/s, all of the emission is scattered photons
  - From the front side of the wind
  - Concentrated near the source
    - ✦ But, extending to edge of the wind

Prochaska, Kasen, & Rubin, ApJ, (nearly) submitted

Wind Emission (Fiducial Model)



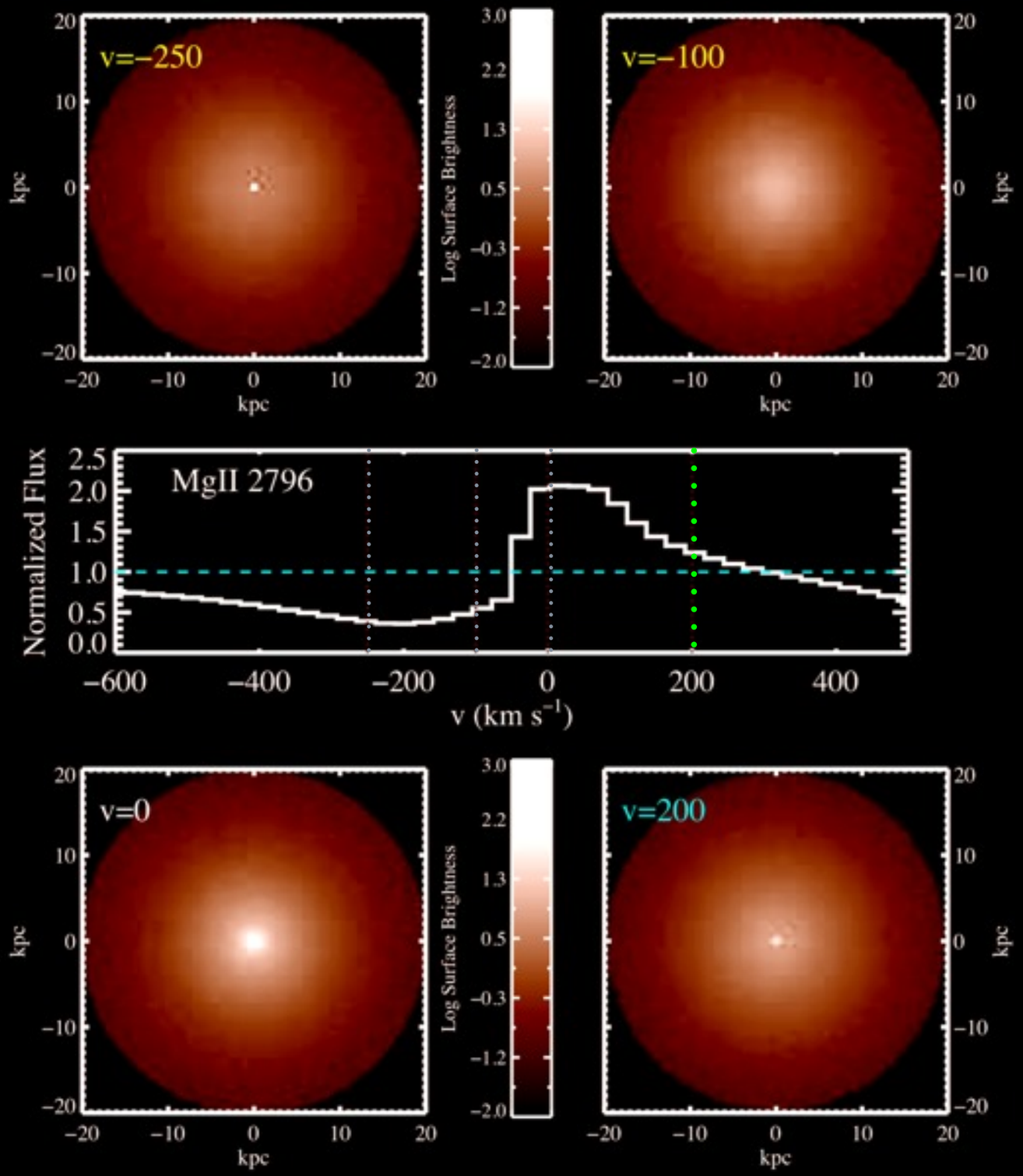




- Consider the surface brightness of observed flux
  - Scattered photons
  - And, of course, the source
- At v=−100 km/s, all of the emission is scattered photons
  - From the front side of the wind
  - Concentrated near the source
    - But, extending to edge of the wind
- At larger velocities, the source dominates
  - But scattered photons from the backside of the wind contribute

Prochaska, Kasen, & Rubin, ApJ, (nearly) submitted

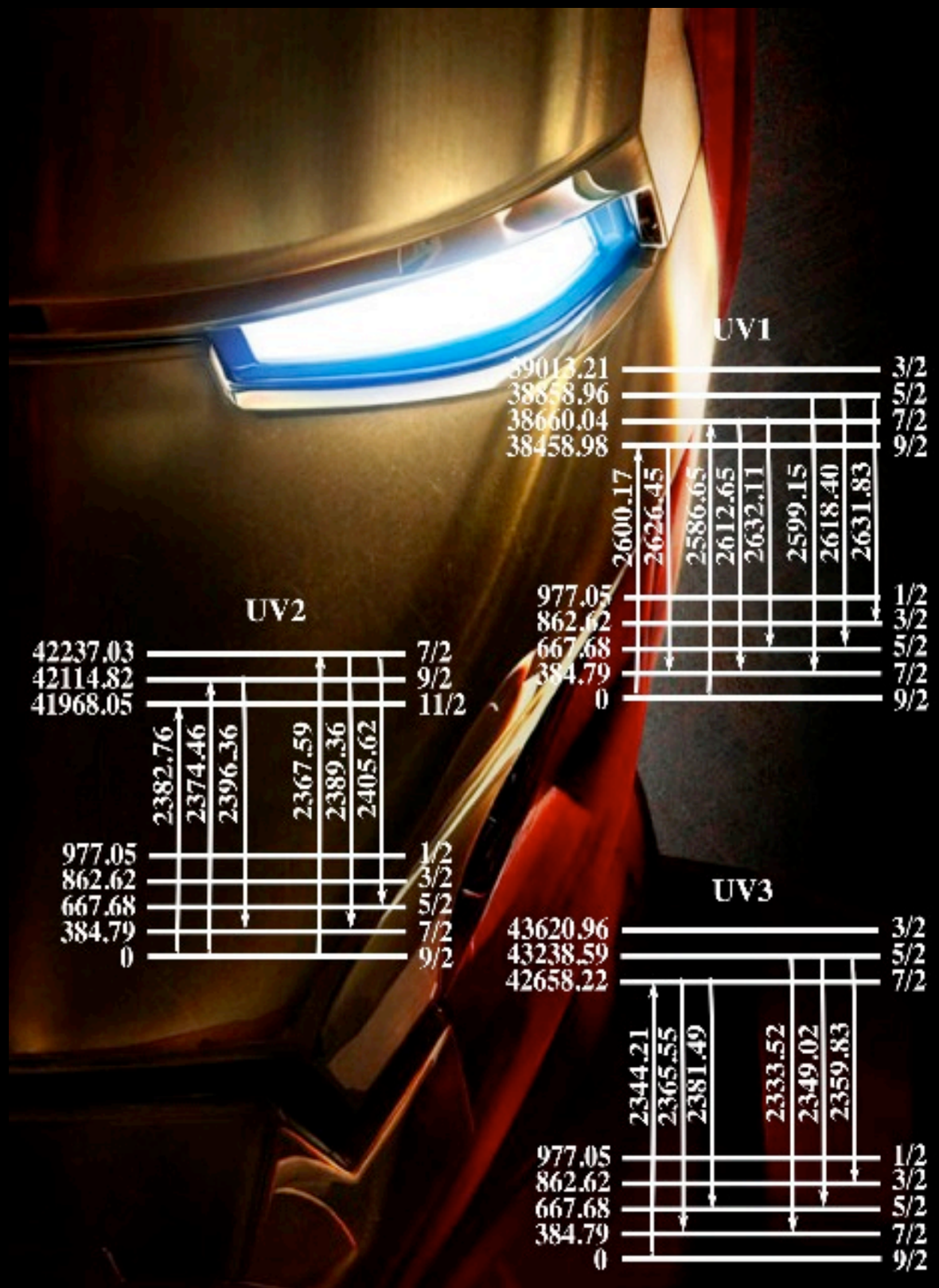
Wind Emission (Fiducial Model)



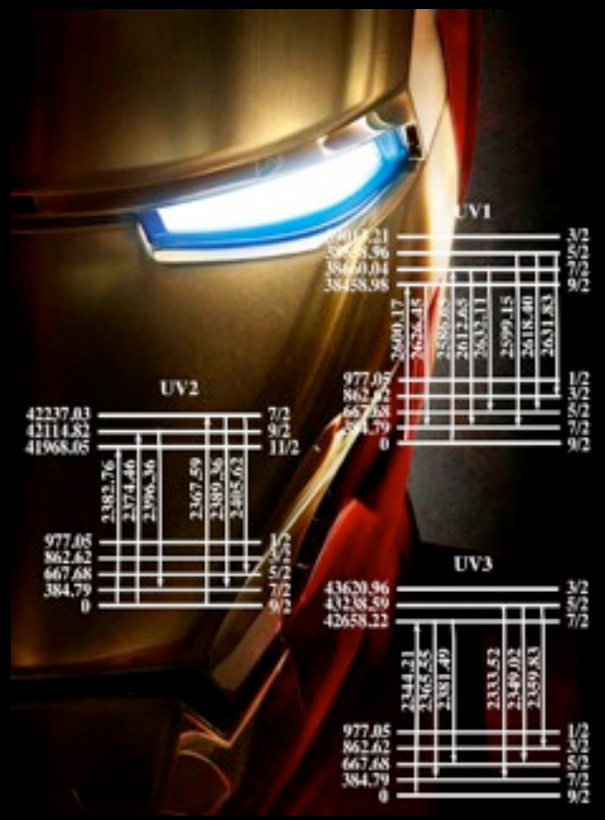
- Consider the surface brightness of observed flux
  - Scattered photons
  - And, of course, the source
- At v=−100 km/s, all of the emission is scattered photons
  - From the front side of the wind
  - Concentrated near the source
    - But, extending to edge of the wind
- At larger velocities, the source dominates
  - But scattered photons from the backside of the wind contribute

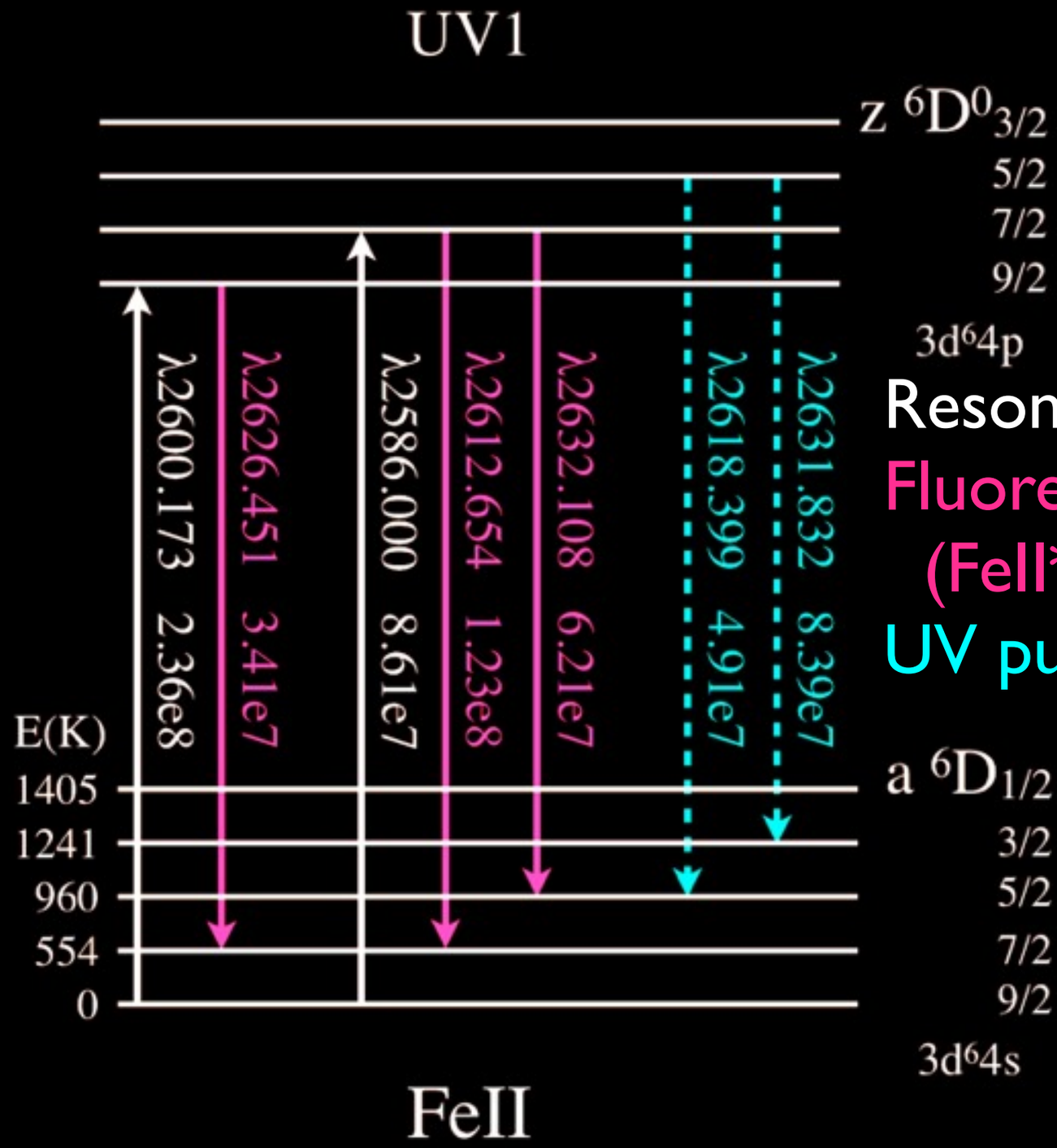
Prochaska, Kasen, & Rubin, ApJ, (nearly) submitted

Fell Transitions



FeII Transitions



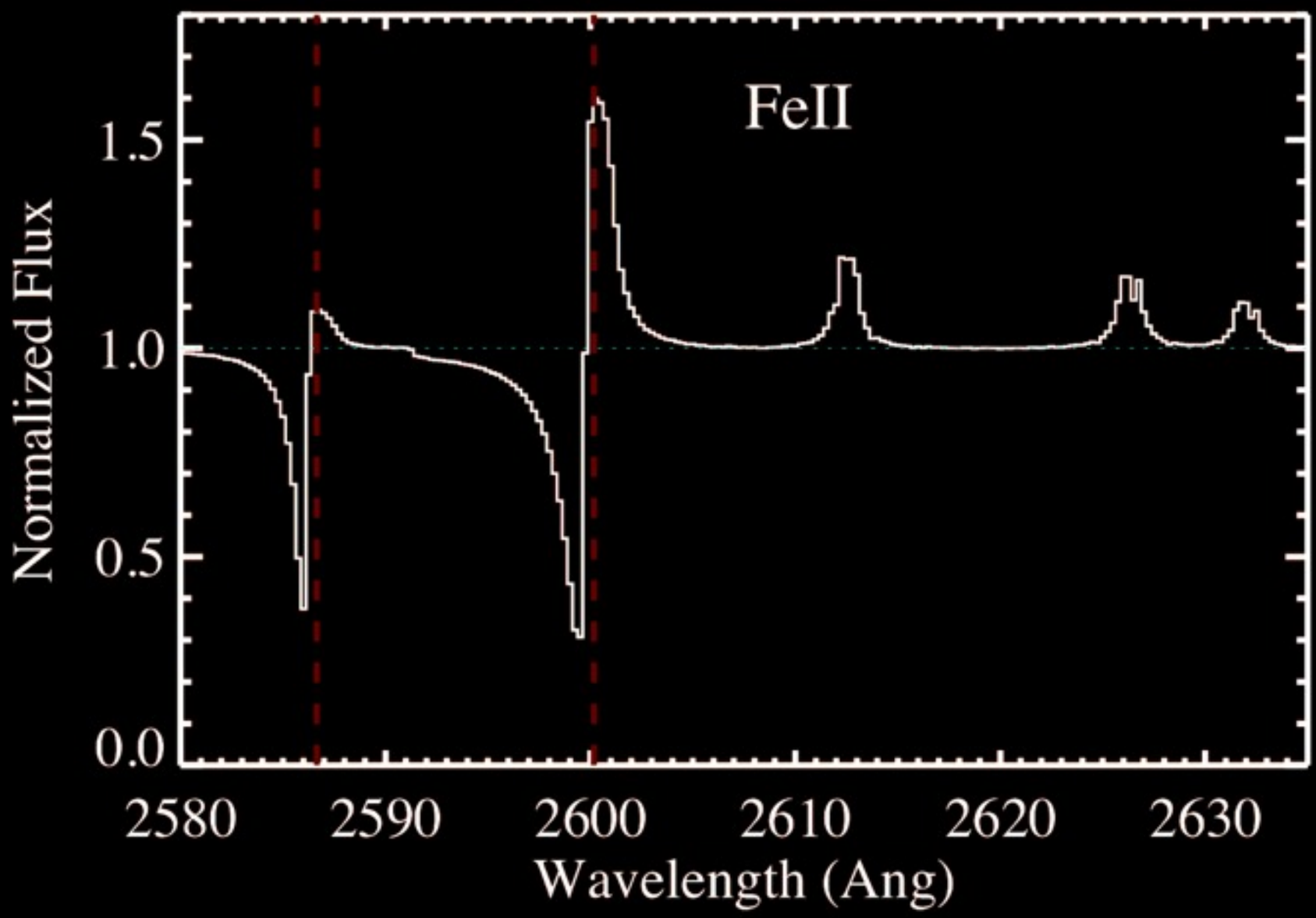


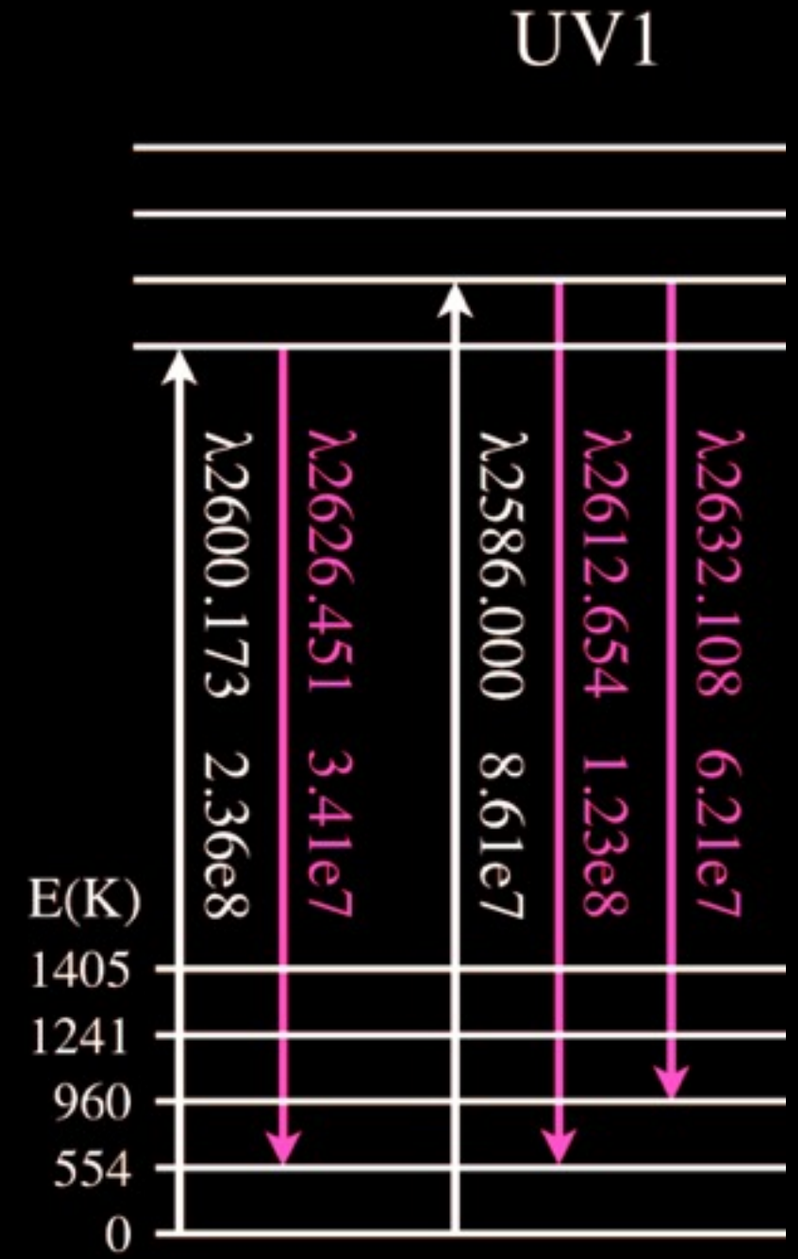
Resonant lines

Fluorescence (FeII*)

UV pumping

FeII Profiles (Fiducial Model)



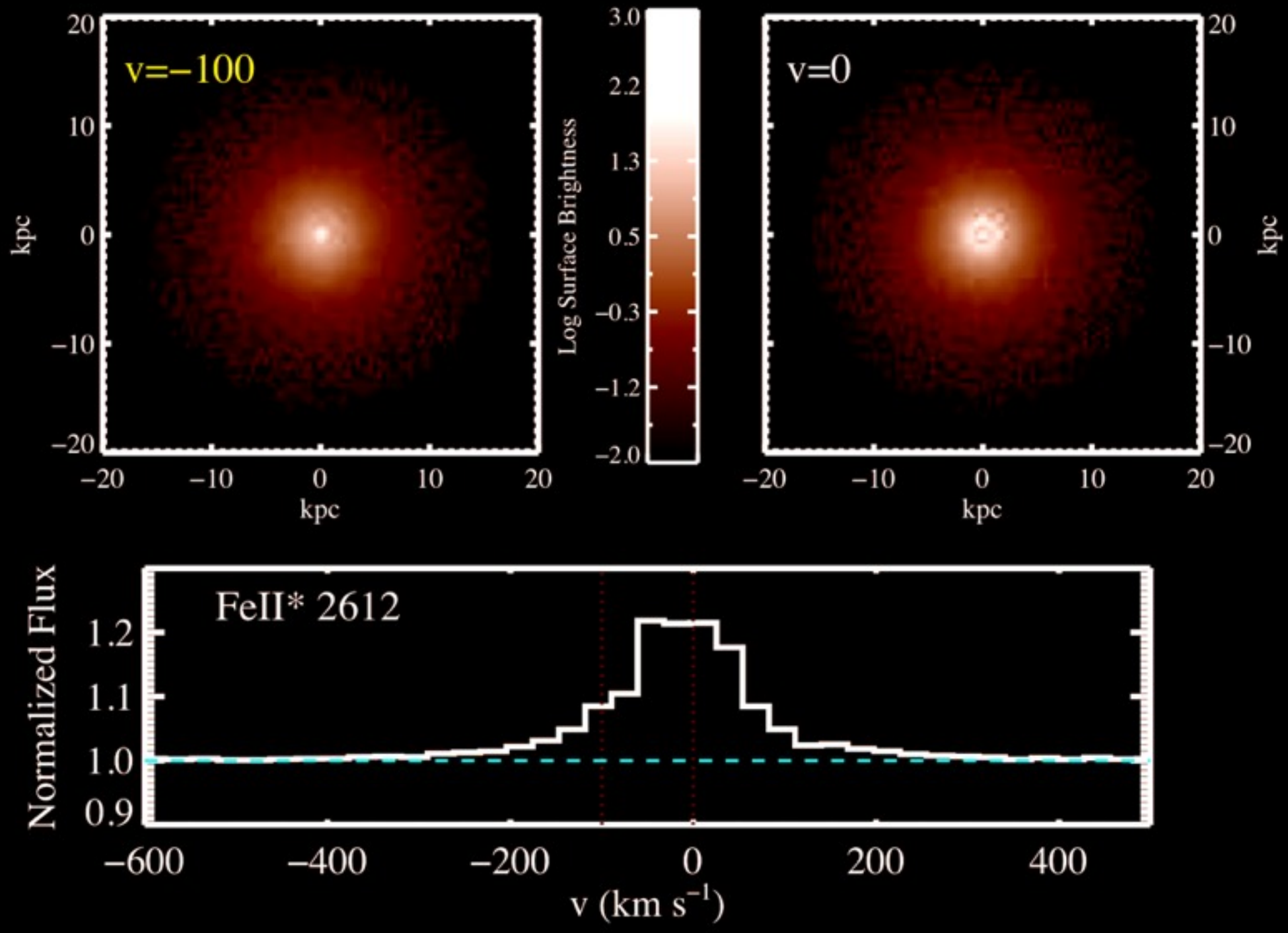


FeII 2600 shows a P-Cygni like profile

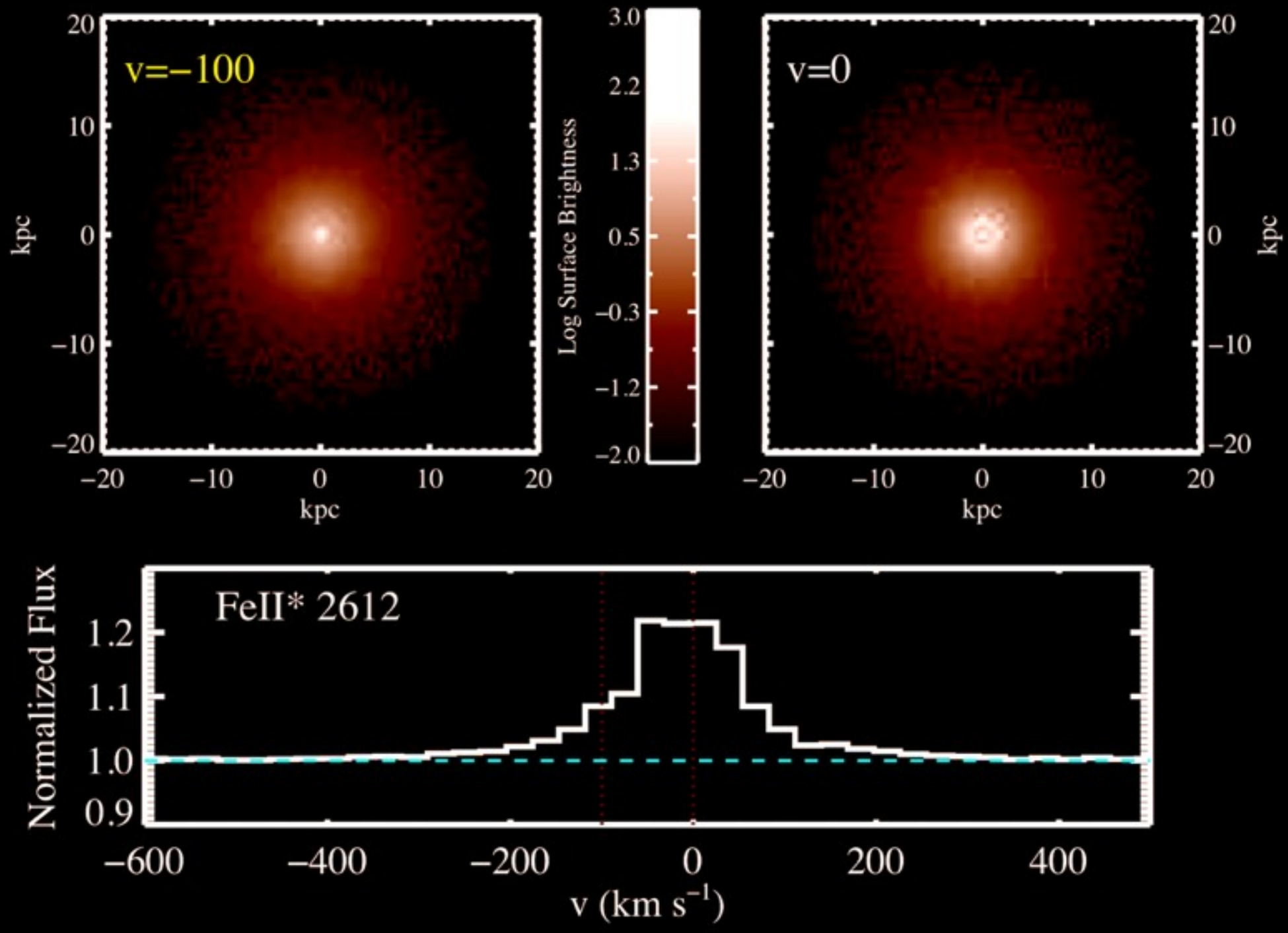
FeII 2586 absorption is emitted as FeII* 2612,2632

Prochaska, Kasen, & Rubin, ApJ, (nearly) submitted

FeII* Emission (Fiducial Model)



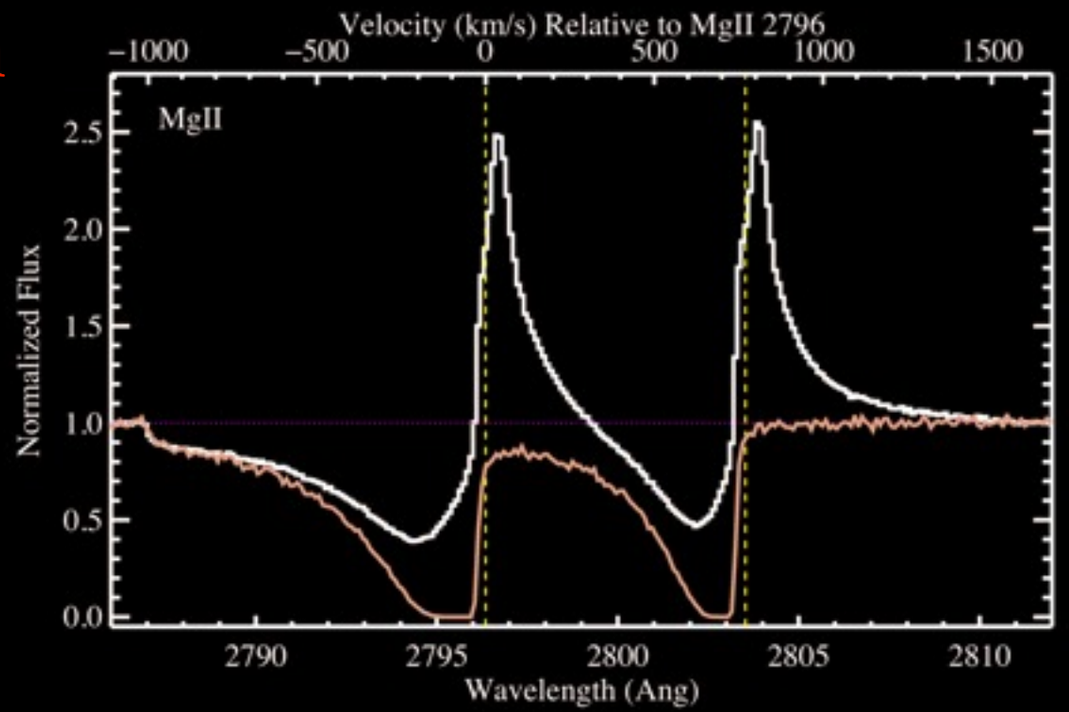
FeII* Emission (Fiducial Model)

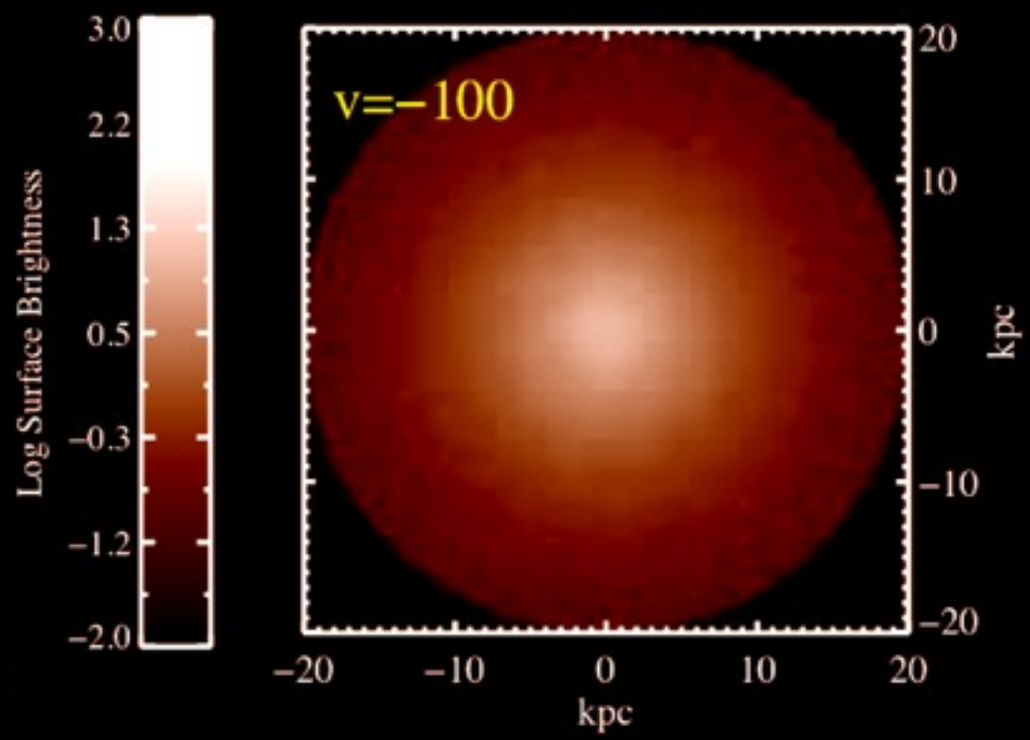


Similar to MgII emission, but nearly symmetric about v=0km/s

Radiative Transfer: Key Implications

- Line-emission is a generic prediction
  - Total equivalent width is roughly zero
    - Every absorbed photon is re-emitted
  - Even for dusty, non-isotropic winds
    - Not shown in this talk (trust/ask me)
- Scattered photons can significantly alter absorption profiles
  - Mis-interpret as partial covering, lower optical depth, etc.
  - Insensitive to gas at v ~ 0 km/s (infall?)
  - Be *especially* wary of stacked spectra
- Scattered photons offer an additional (more powerful?) probe of winds
  - Size, Morphology, Kinematics





Prochaska, Kasen, & Rubin, ApJ, (nearly) submitted

The Real Universe

Theoretical wind models are nice and make pretty pictures, but do they even remotely reflect the real Universe?

Disclaimer: The study I just described was post-diction (not prediction)



Rubin, Prochaska, Menard, Murray, Kasen, Koo, Phillips, 2010, ApJL, submitted

The Real Universe

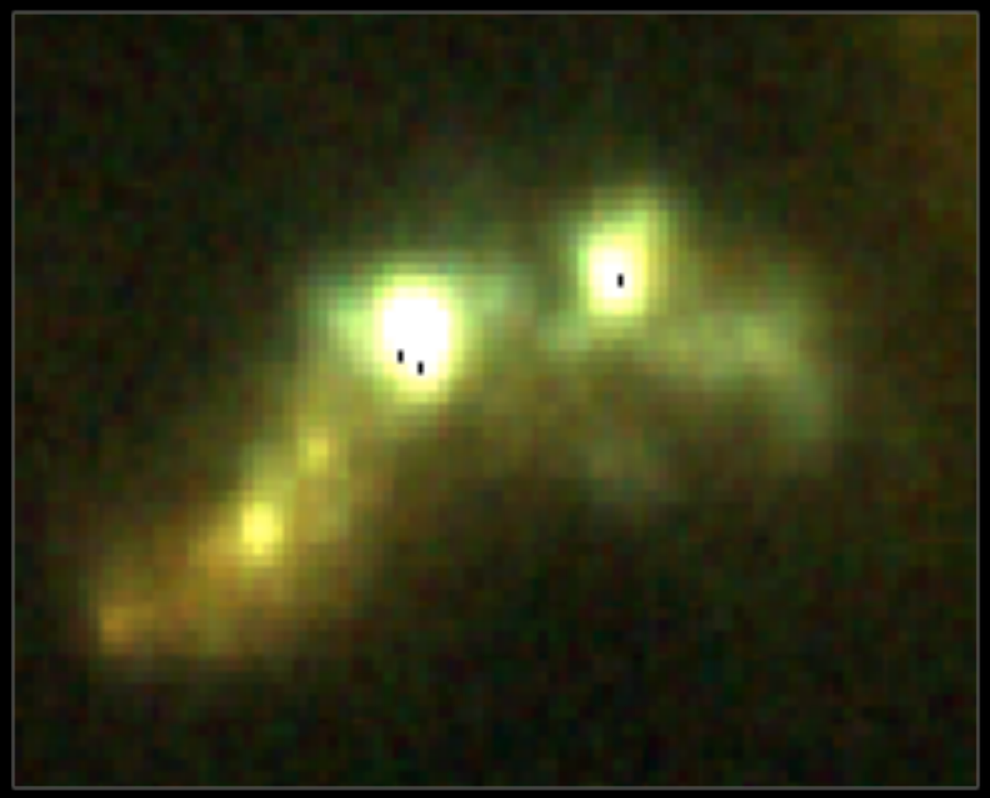
Theoretical wind models are nice and make pretty pictures, but do they even remotely reflect the real Universe?

Disclaimer: The study I just described was post-diction (not prediction)




Rubin, Prochaska, Menard, Murray, Kasen, Koo, Phillips, 2010, ApJL, submitted

The Galaxy (Image)



~5 h^{-1} kpc

B = 21.7

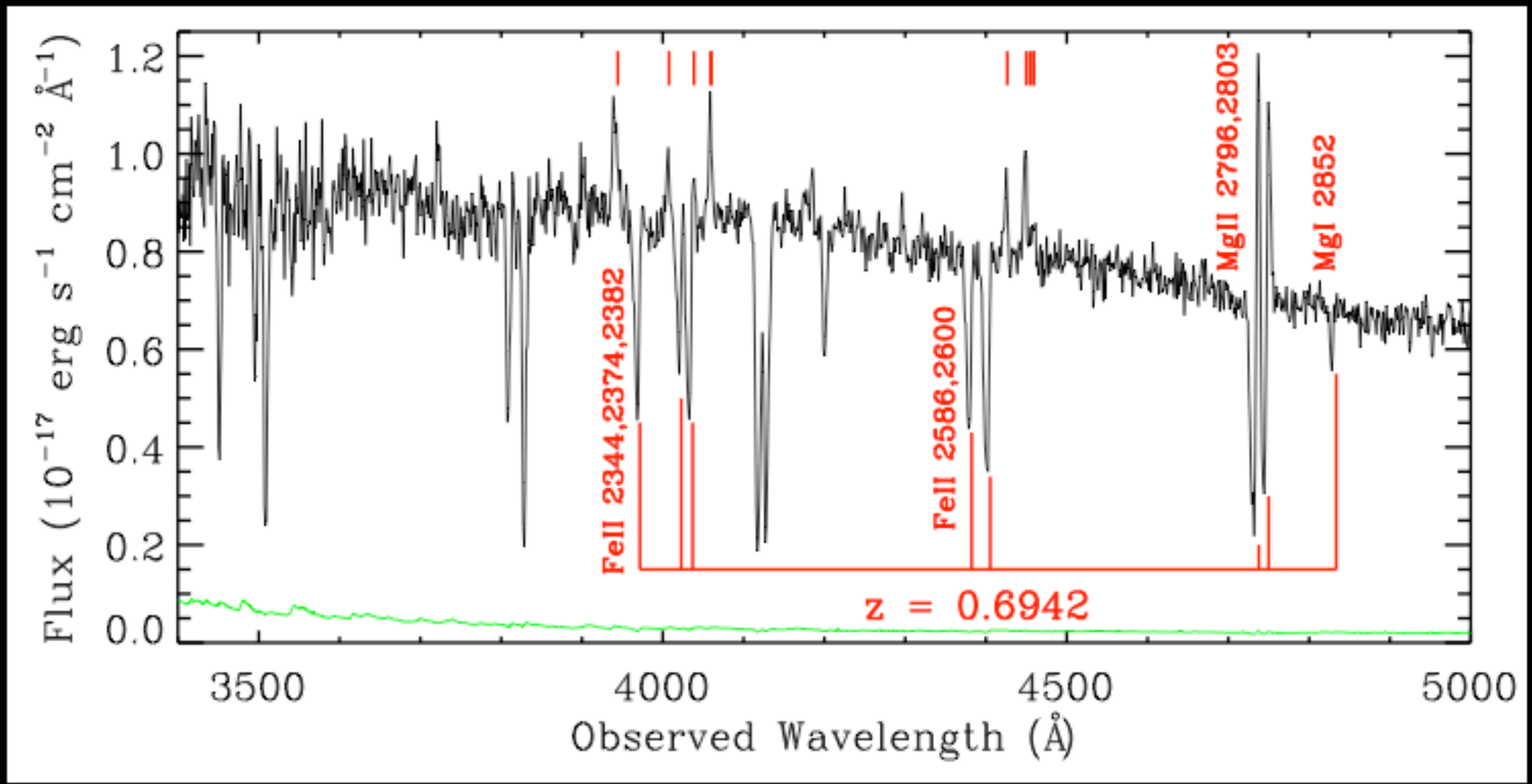
Bluest of the "blue cloud"

SFR ~ 80 $M_\odot$/yr

weak [NeV] 3426 emission (AGN host)

Rubin+10, ApJL, submitted

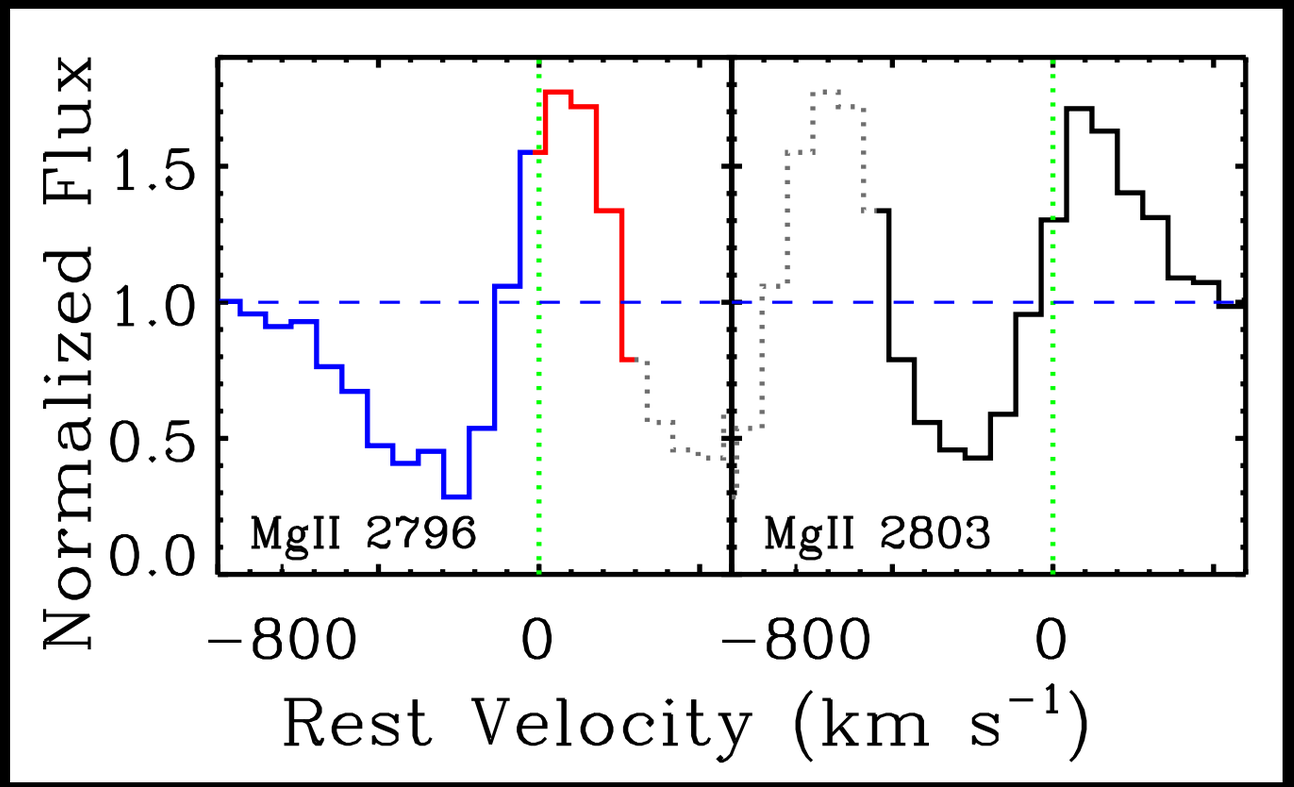
The Galaxy (1D Spectrum)

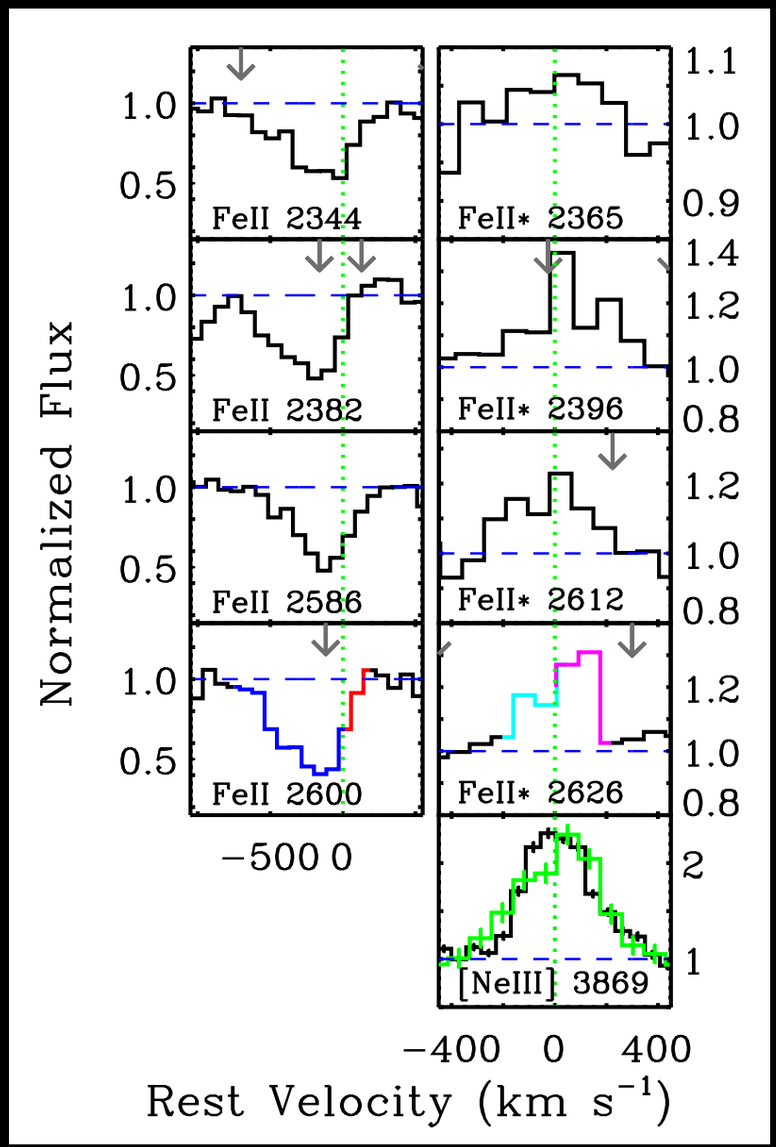


Star-forming galaxy with blue-shifted absorption lines (FeII, MgII) and nebular emission lines (e.g. [OII], Hb, etc.)

Rubin+10, ApJL, submitted

The Galaxy (Velocity Plots)



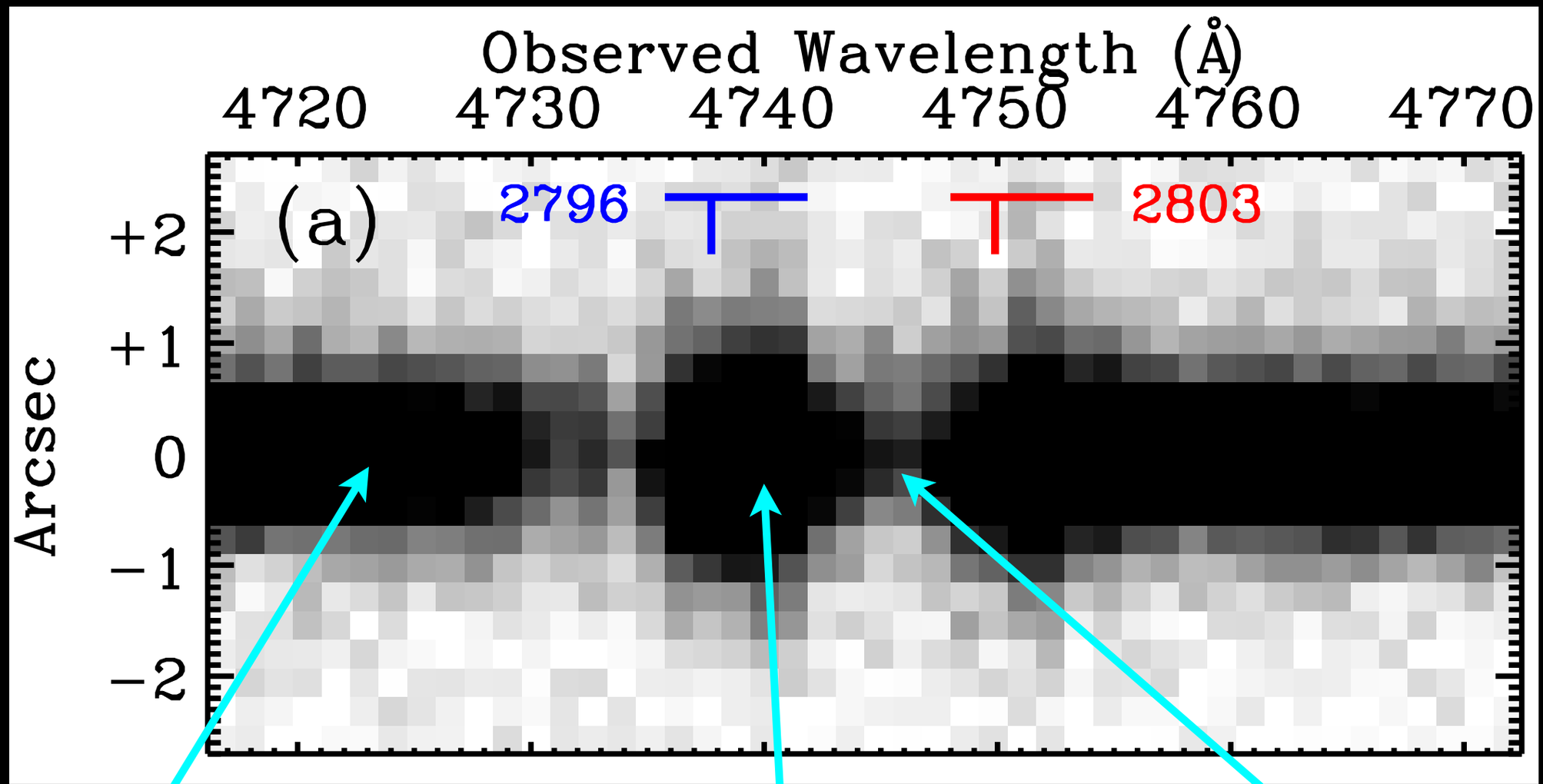


MgII: P-Cygni profile with strong emission

FeII: Strong resonant-line absorption, modest FeII* emission

Rubin+10, ApJL, submitted

The Galaxy (2D Spectrum)



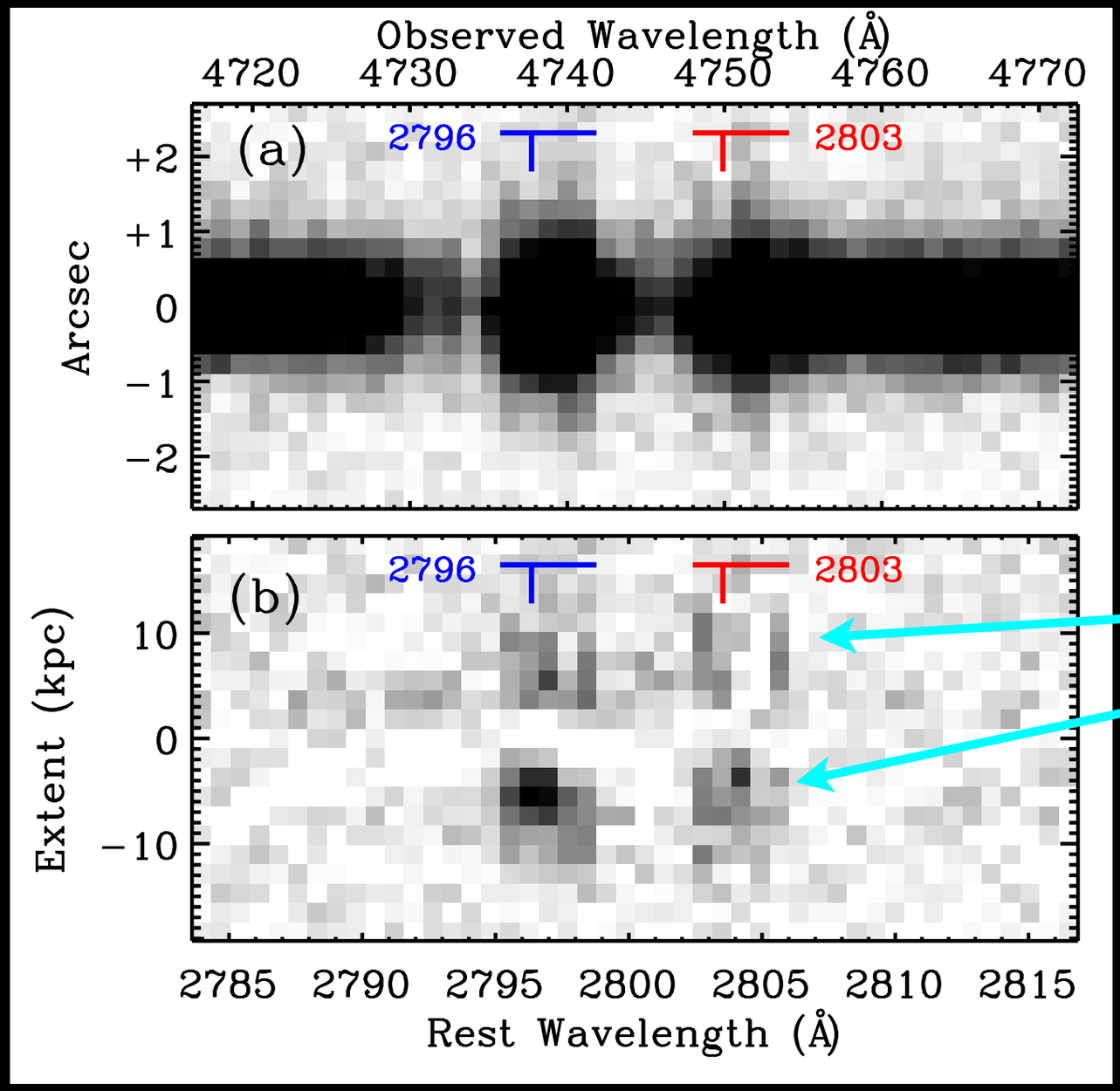
Stellar continuum

MgII Emission

MgII Absorption

Rubin+10, ApJL, submitted

The Galaxy (Subtracted Spectrum)

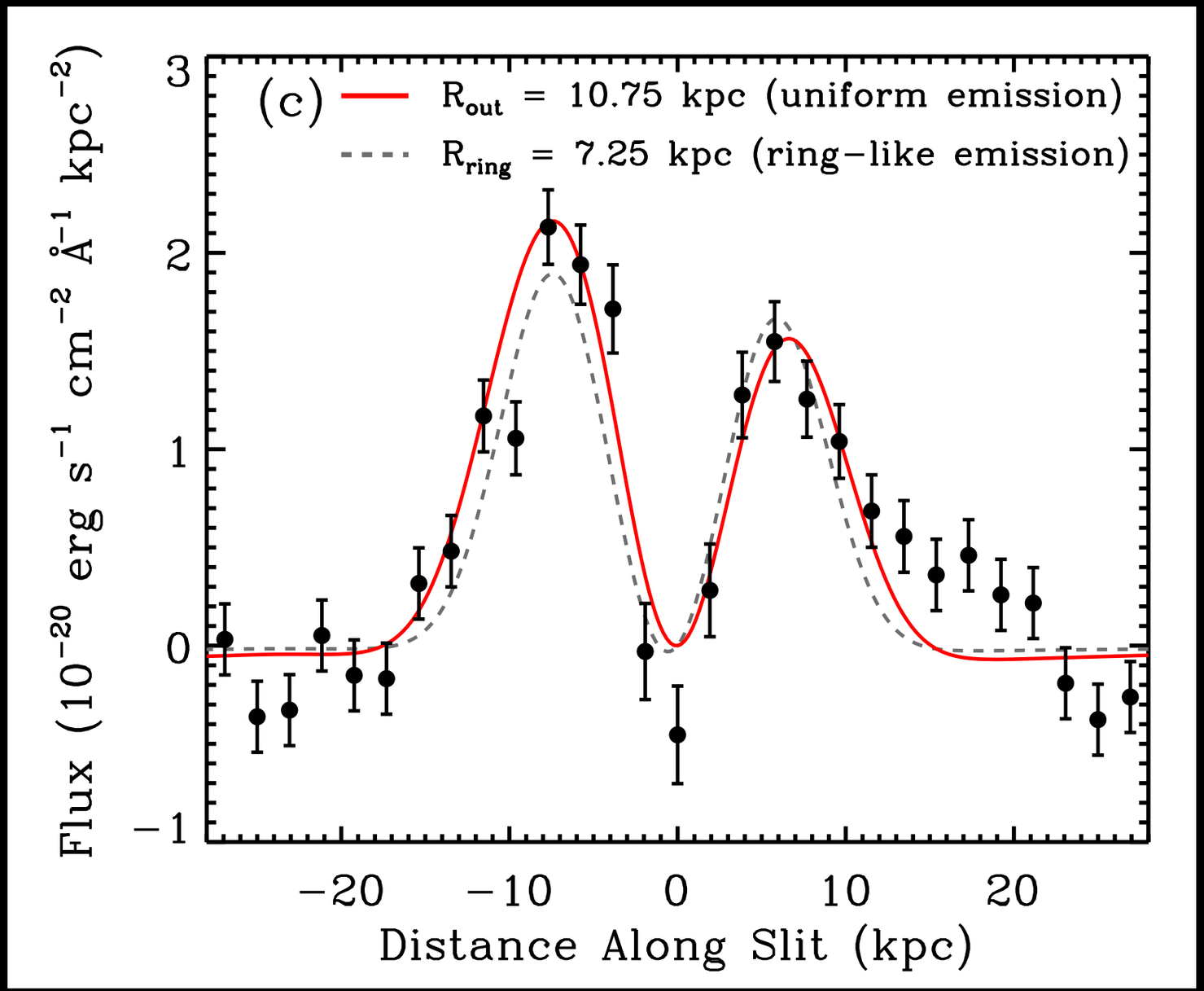


Spatially extended MgII Emission

Extended emission detected to ~1", i.e. ~7 h^{-1} kpc

Rubin+10, ApJL, submitted

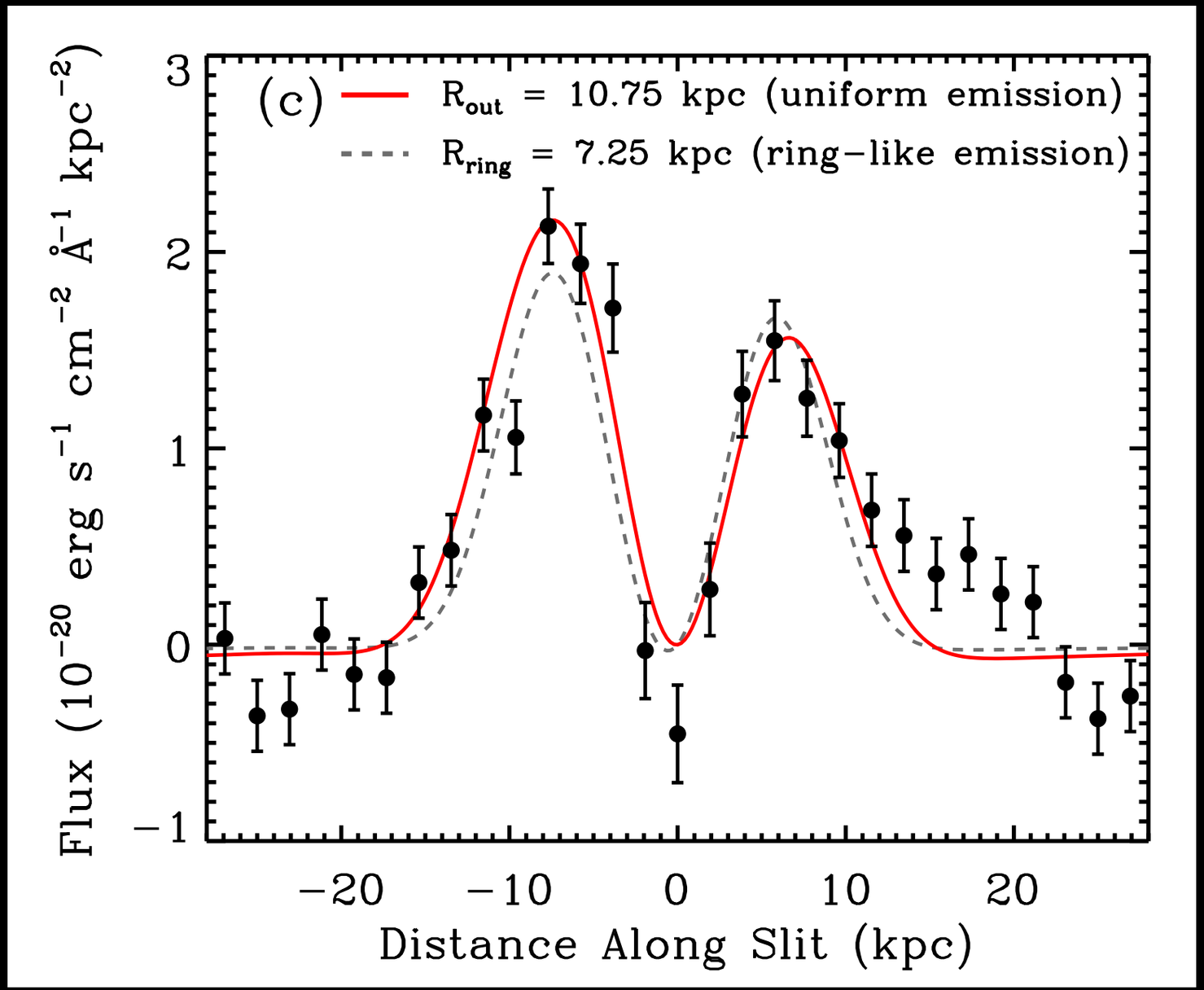
The Galaxy (Subtracted Spectrum)



Extended emission detected to ~1", i.e. ~7 h^{-1} kpc

Rubin+10, ApJL, submitted

The Galaxy (Subtracted Spectrum)



Extended emission detected to ~1", i.e. ~7 h^{-1} kpc

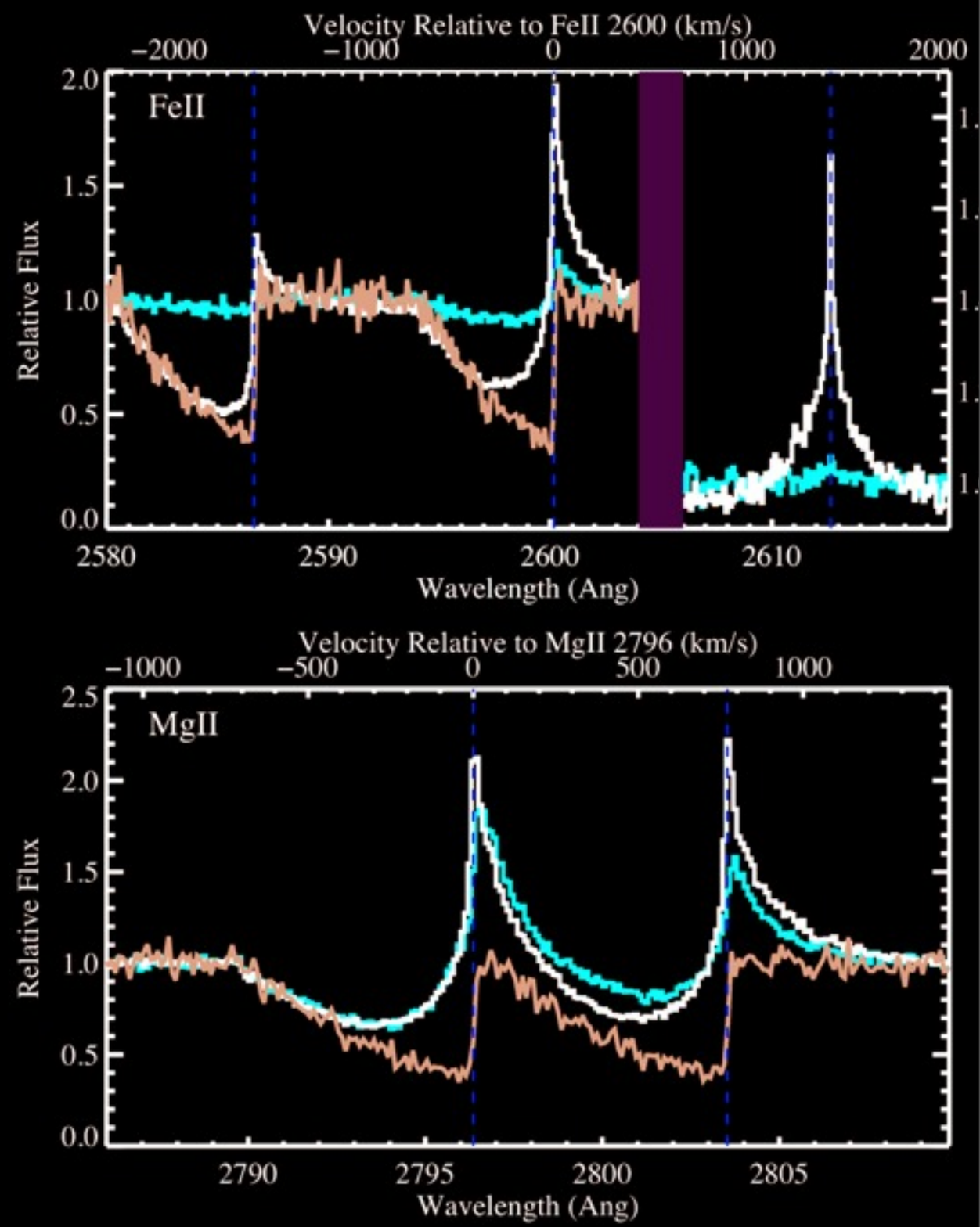
First direct constraints on the spatial extent of the flow!

Rubin+10, ApJL, submitted

Further Implications

- LBG winds
  - Steidel+10 wind model is unlikely to reproduce the observations
    - ✦ (They ignored scattered photons)
  - Beware of conclusions on the non-existence of gas at v >~ 0 km/s

- Why do many galaxies only show absorption, not emission?
  - Poor data quality
  - Anisotropic winds
  - Bias in galaxy brightness
  - Dust

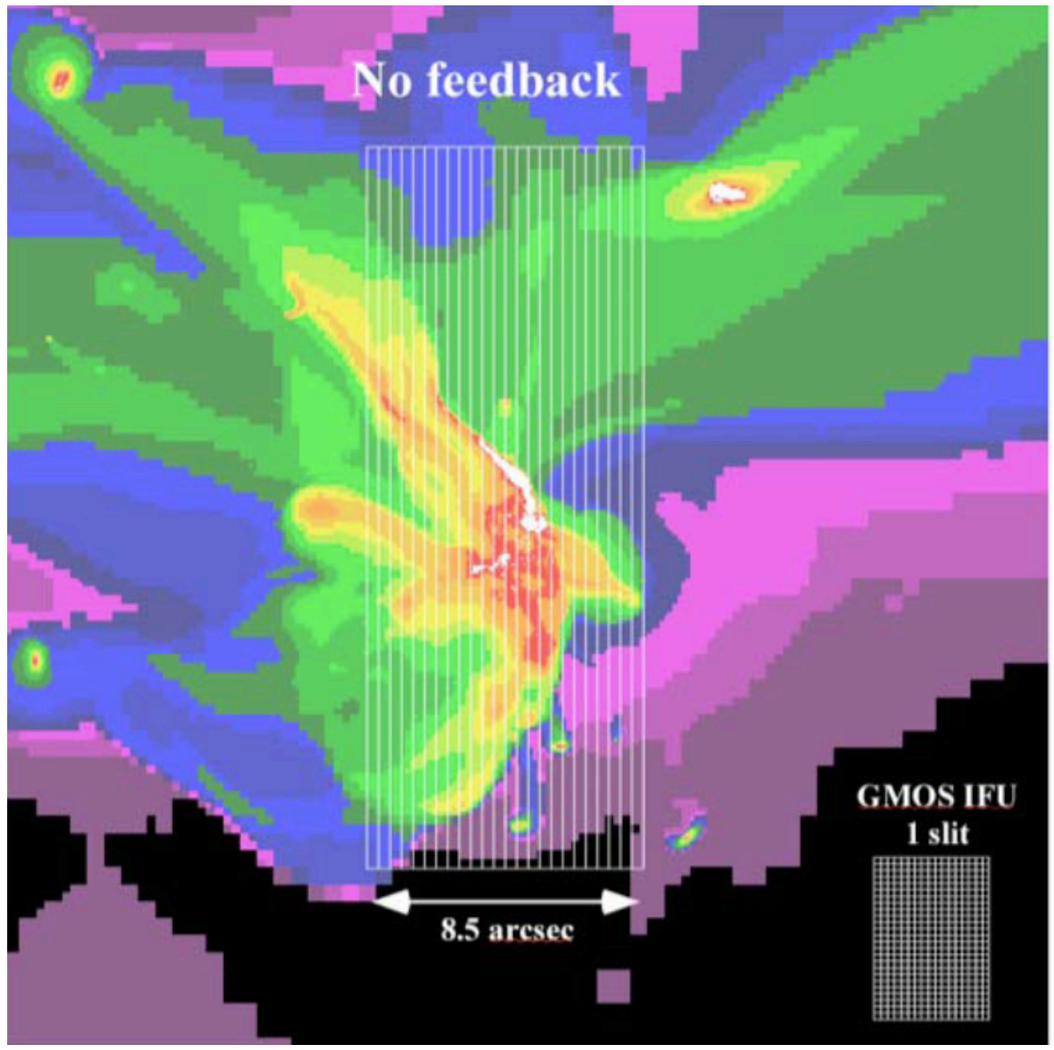


Prochaska, Kasen, & Rubin, ApJ, (nearly) submitted

Future Work

- IFU observations
  - Constrain the surface brightness profiles
    - ✦ e.g. KCWI, X-Shooter, GMOS
  - Constrain the kinematics of this line-emission

- Implement RT analysis of ‘realistic’ galactic-scale winds
  - Distributed sources
  - Multi-phase gas
  - Dust, etc.



KCWI
DEEP

Dust (Fiducial Model)