The New Chandra View of NGC3034/M82

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Why Starburst Galaxies?

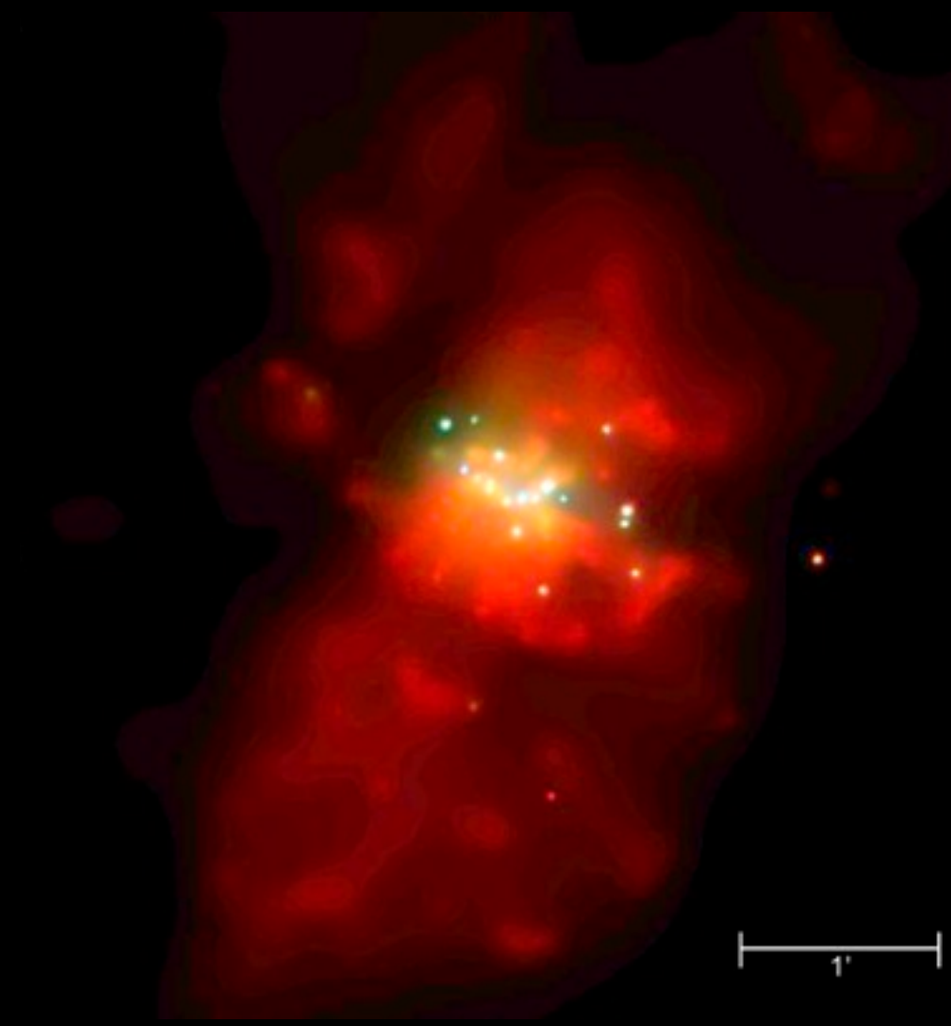
- 20% of all star-formation in local universe in SB
- a greater fraction occurs in SBs at higher z
- resulting super winds enrich the WHIM/WHIGM
- resulting super winds set the mass-metallicity relation

Why M82?

- the archtypical starburst galaxy w/galactic scale wind
- although SFR (7-10 $M_\odot\,yr^{-1}$) < LBGs at z~3
  comparable to LBGs in SFR/kpc^2
- it's close, only 3.5 Mpc
- well studied so we "know"
  -the star formation history
  -optical/IR abundances
- there is no strong AGN


The Hubble Heritage Team (STScI/AURA) • Hubble Space Tel
2011-05-21

Early press release image



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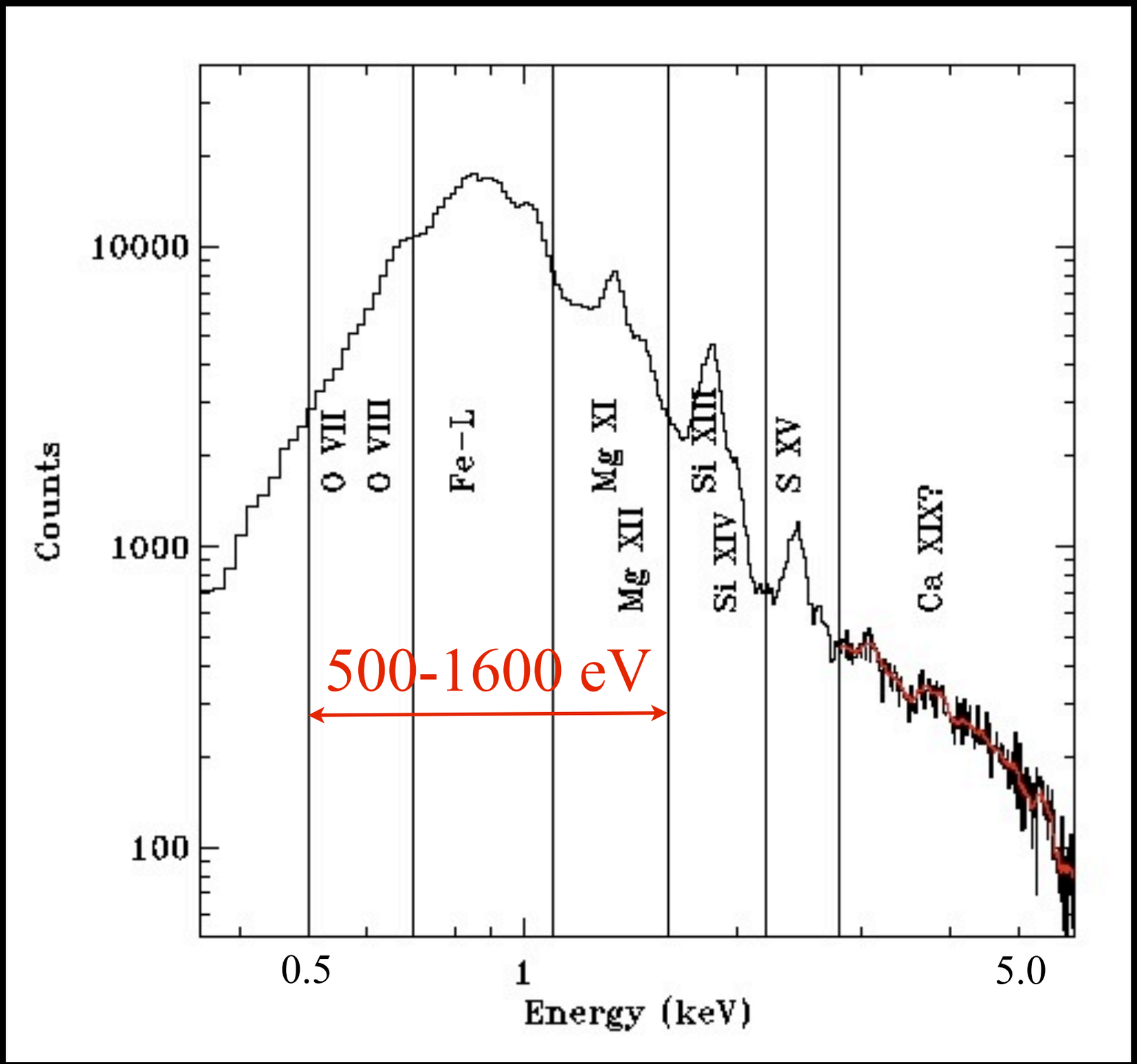
Summed Spectrum from ACIS-S3



North flow - more structure, poorly defined borders

South flow - narrower, more clearly bounded

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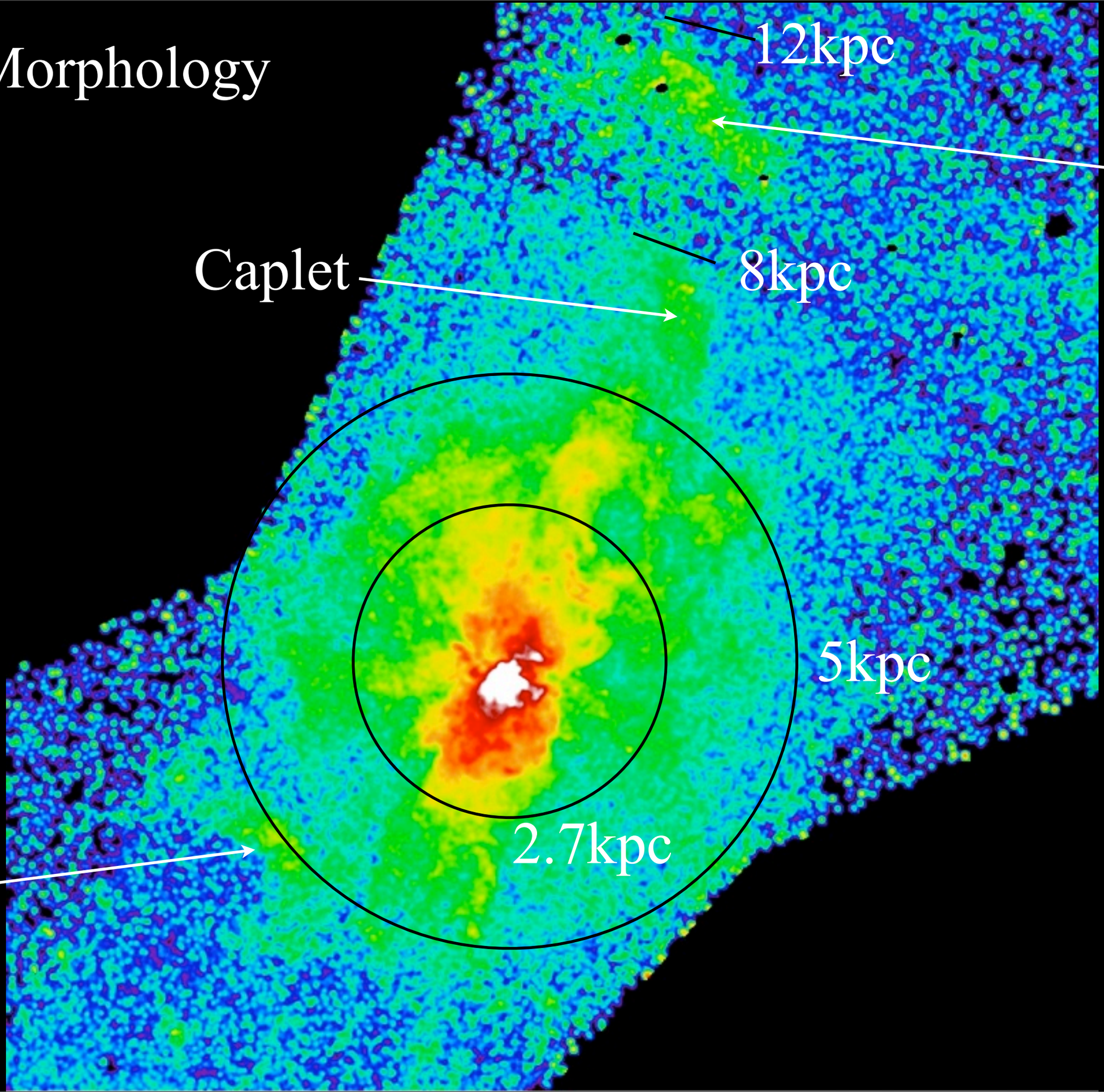
Morphology



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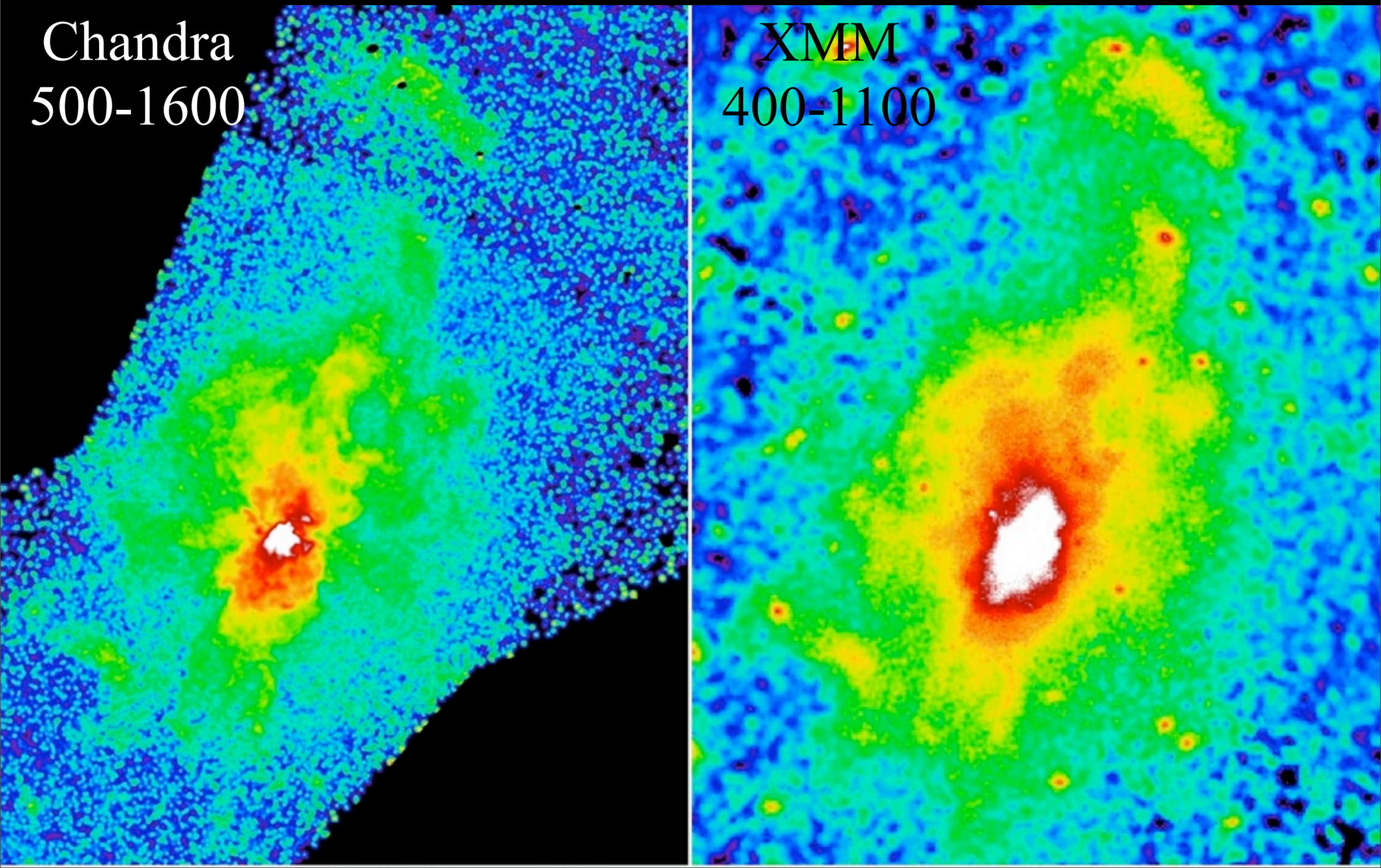
Chandra vs. XMM-Newton

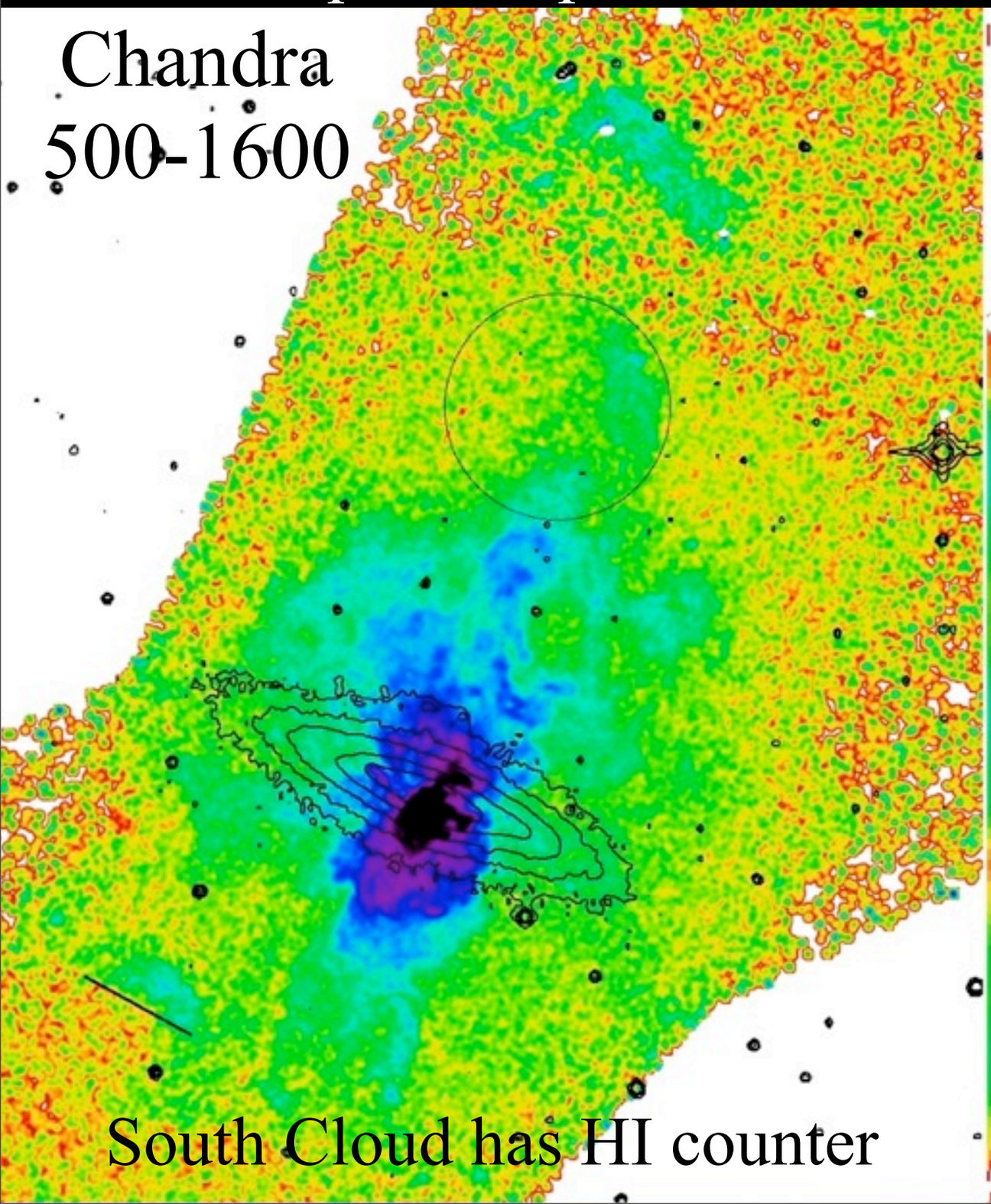
Large scale structure consistent between obsevatories

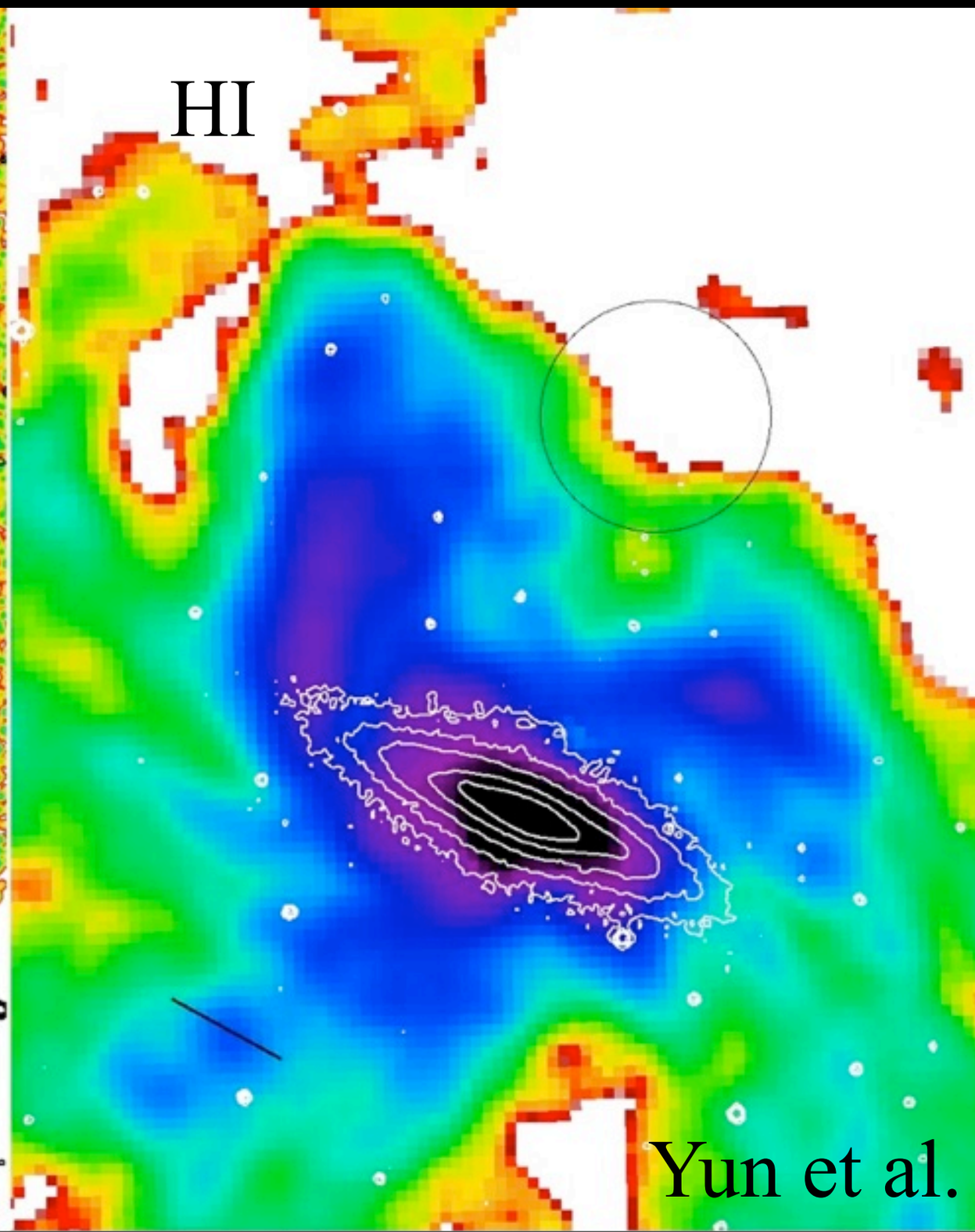
Chandra
500-1600

XMM
400-1100



- North flow correlated with HI hole
- South flow correlated with HI stream
- Cap and caplet not visible in HI

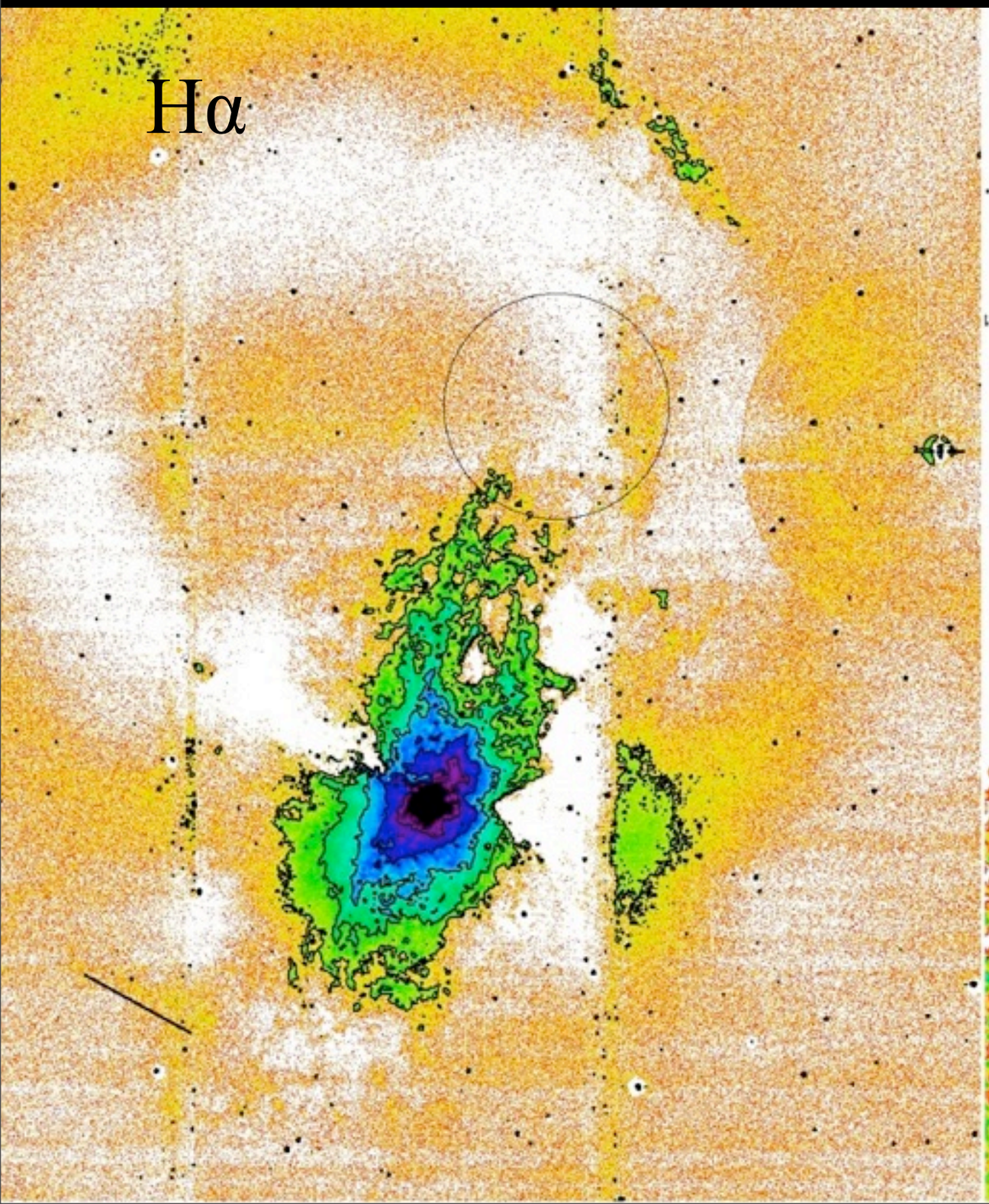


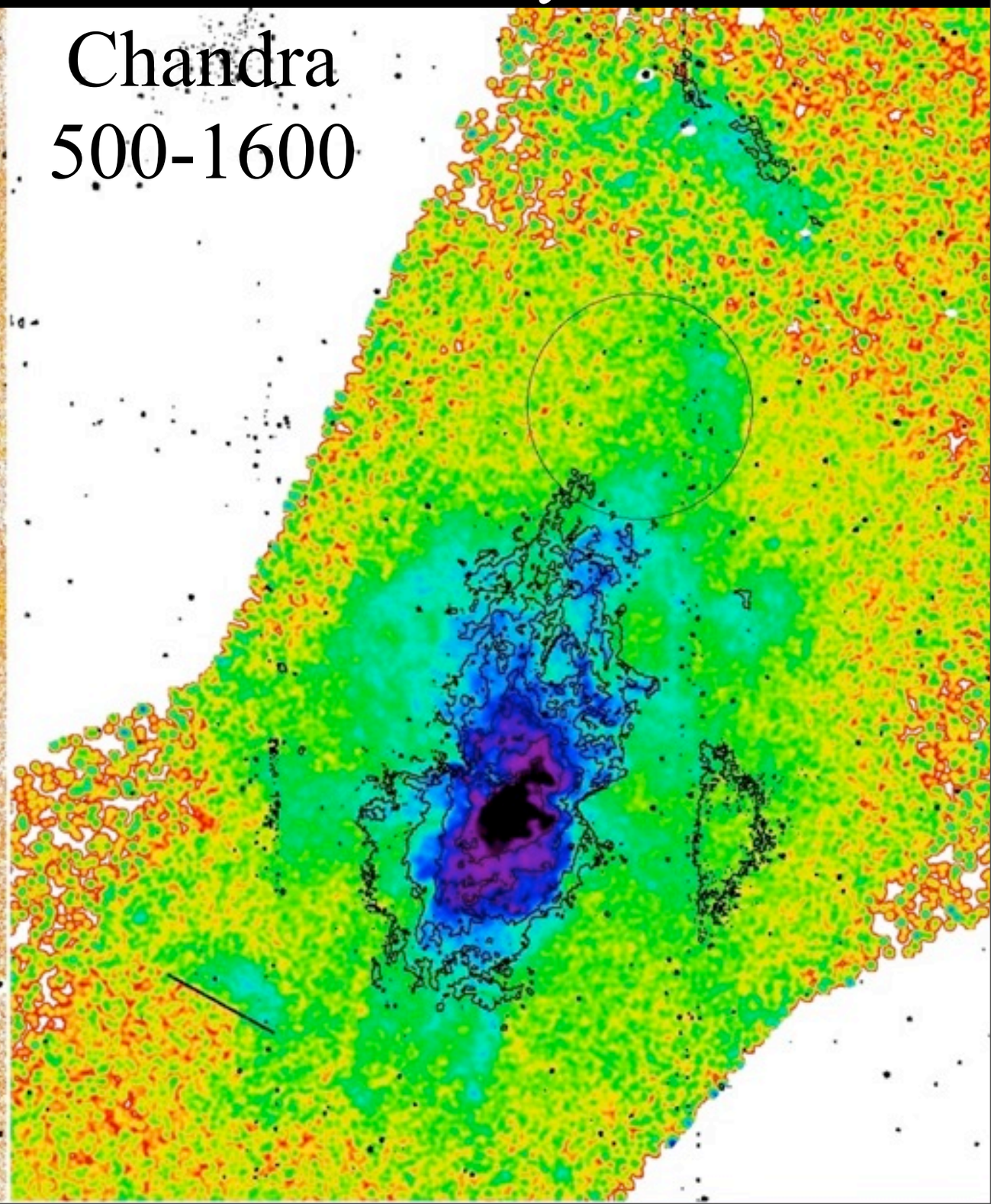


South Cloud has HI counter

Yun et al.

- Cap Hα counterpart well known, exterior to X-ray
- Caplet & South Cloud have faint Hα counterparts
  - South Cloud counter downstream of X-ray?





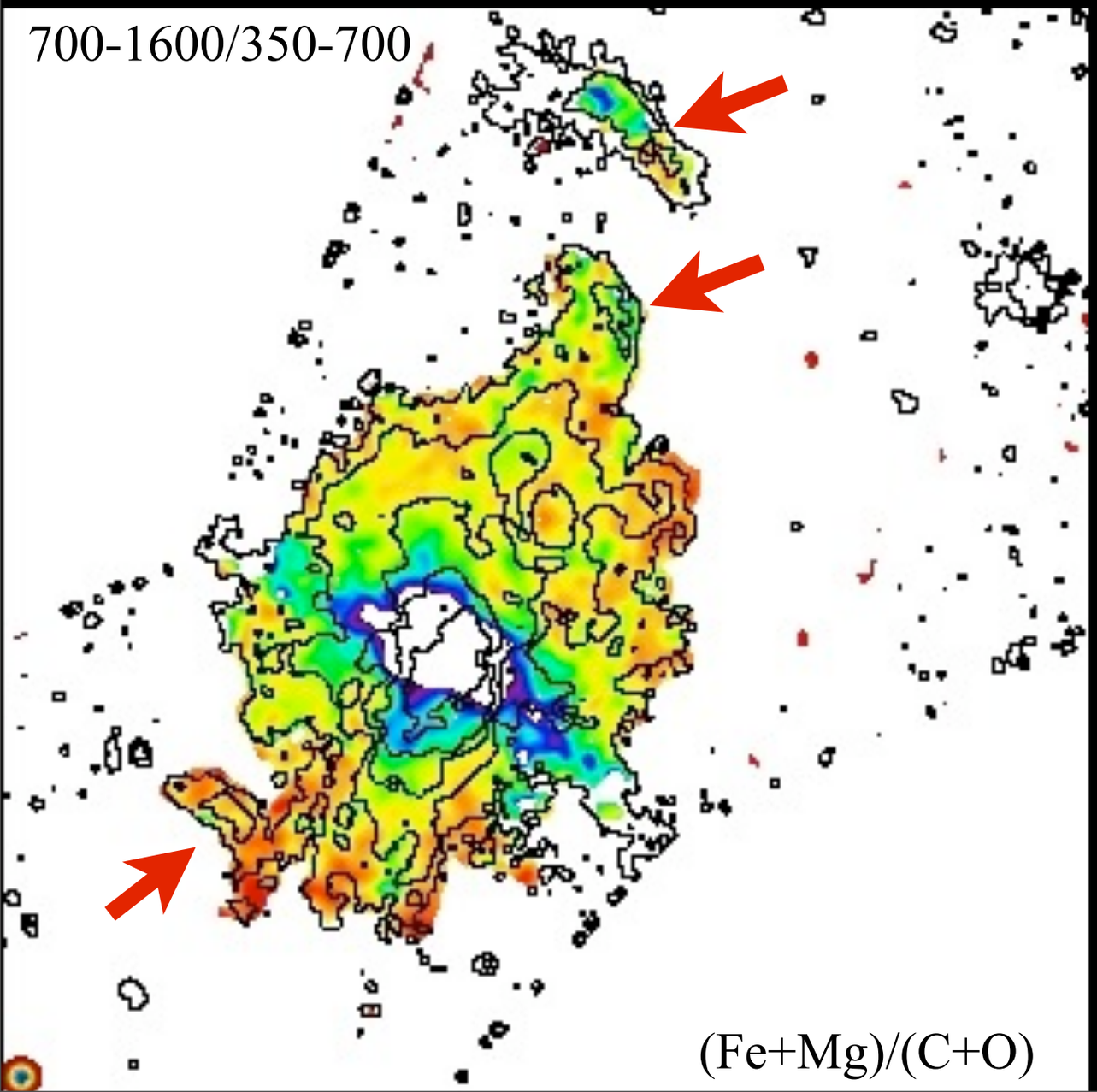
- Cap appears part of more extensive bubble
- Caplet counterpart exterior to X-ray emission
- South Cloud counter possible but dubious

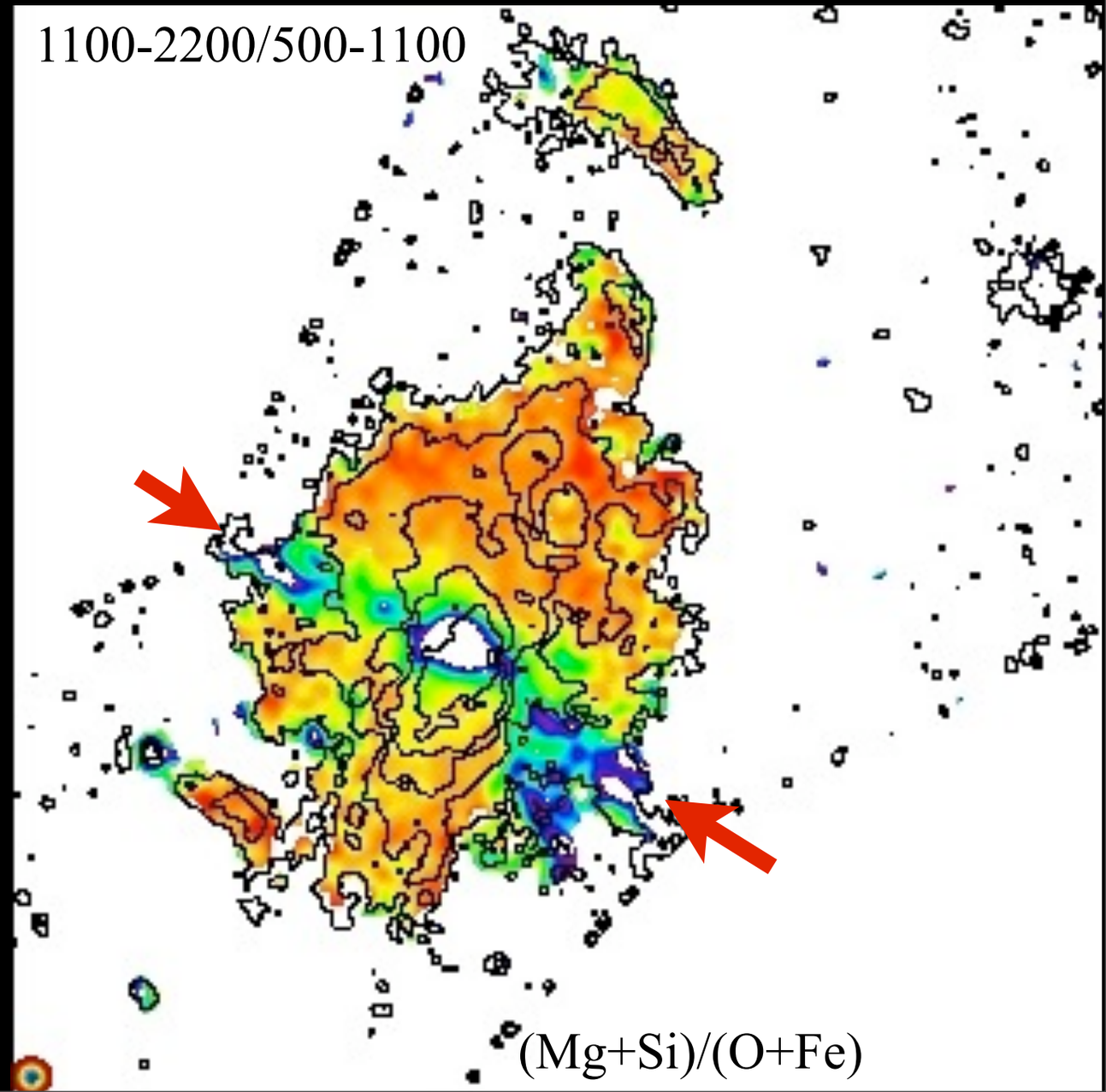
Chandra
500-1600

GALEX
FUV

Hardness Ratio Maps

- Disk absorption apparent
- Cap has color gradient
- Caplet has harder surface than interior
- South cloud shows no gradient





- X-ray morphology similar to Hα, but slightly upstream
- Some X-ray features w/o Hα due to limits on Hα sens.

Hα

Chandra
500-1600

Lehnert et al

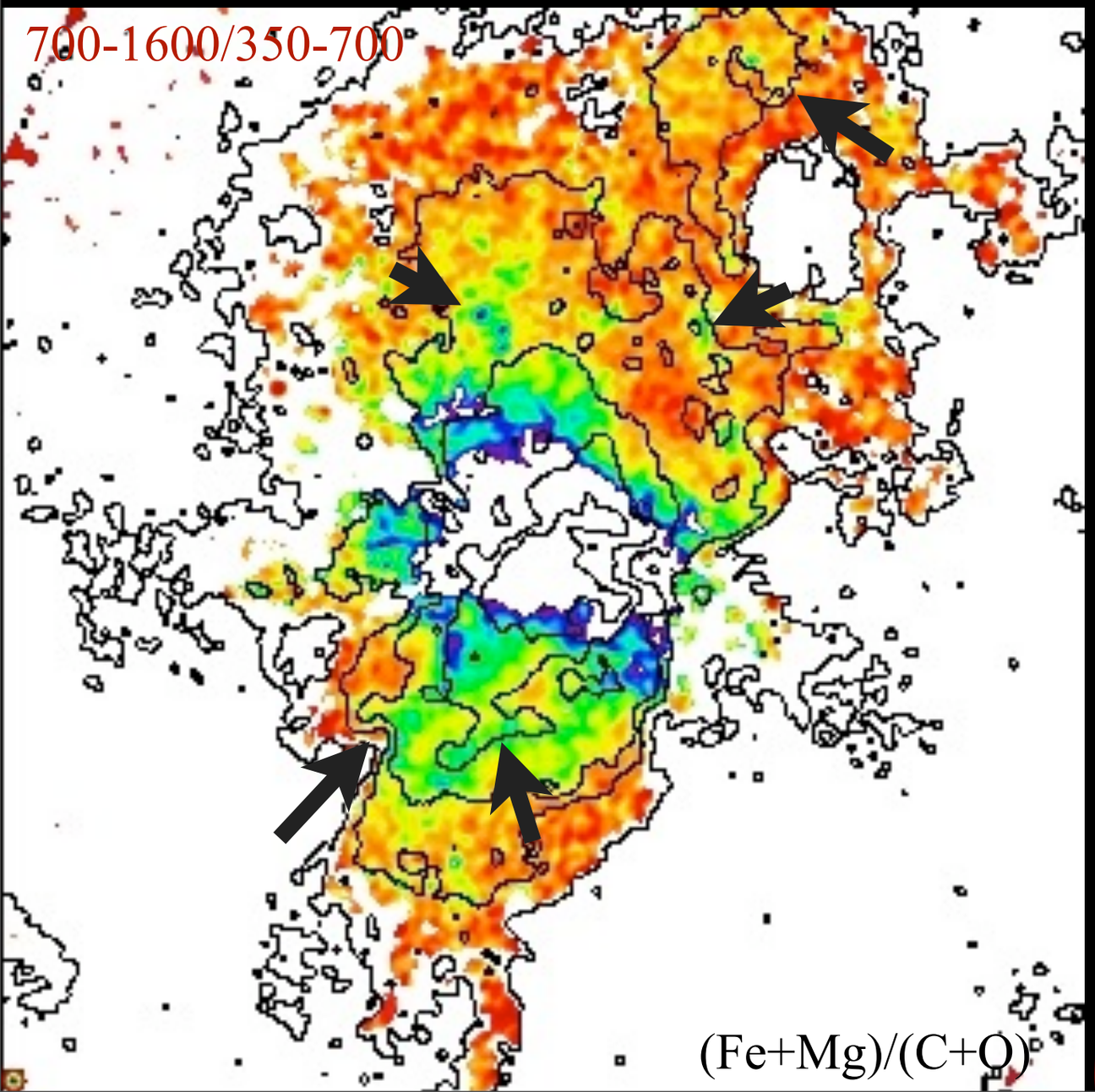
HST

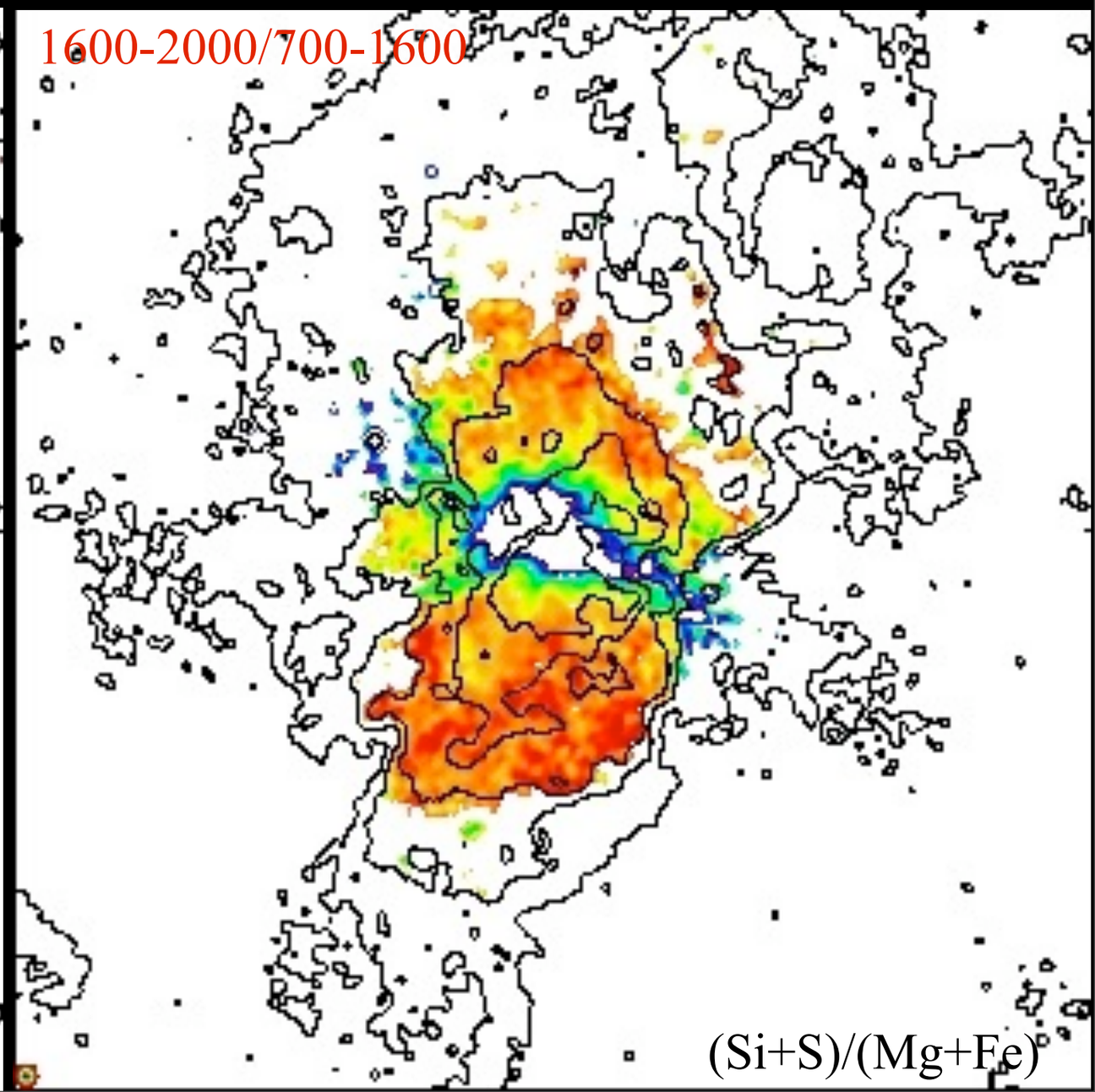
Mountain et al

0.05 0.1 0.15 0.2

Hardness Ratio Maps

- Some X-ray structs. with strong Hα filaments are hard
- Little contrast in HR for most knots
- Hardness gradient along flow
- Less structure at higher energies



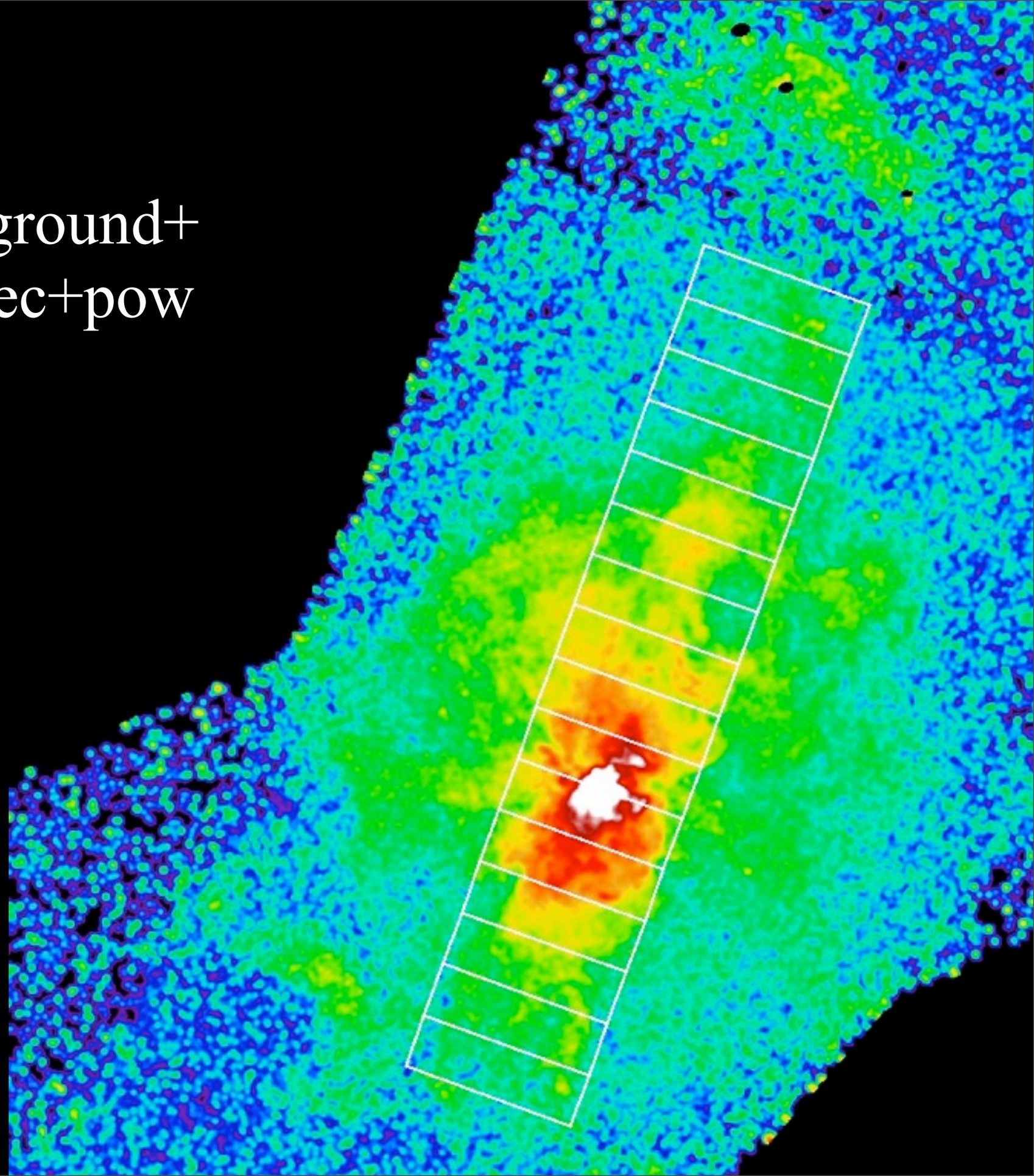


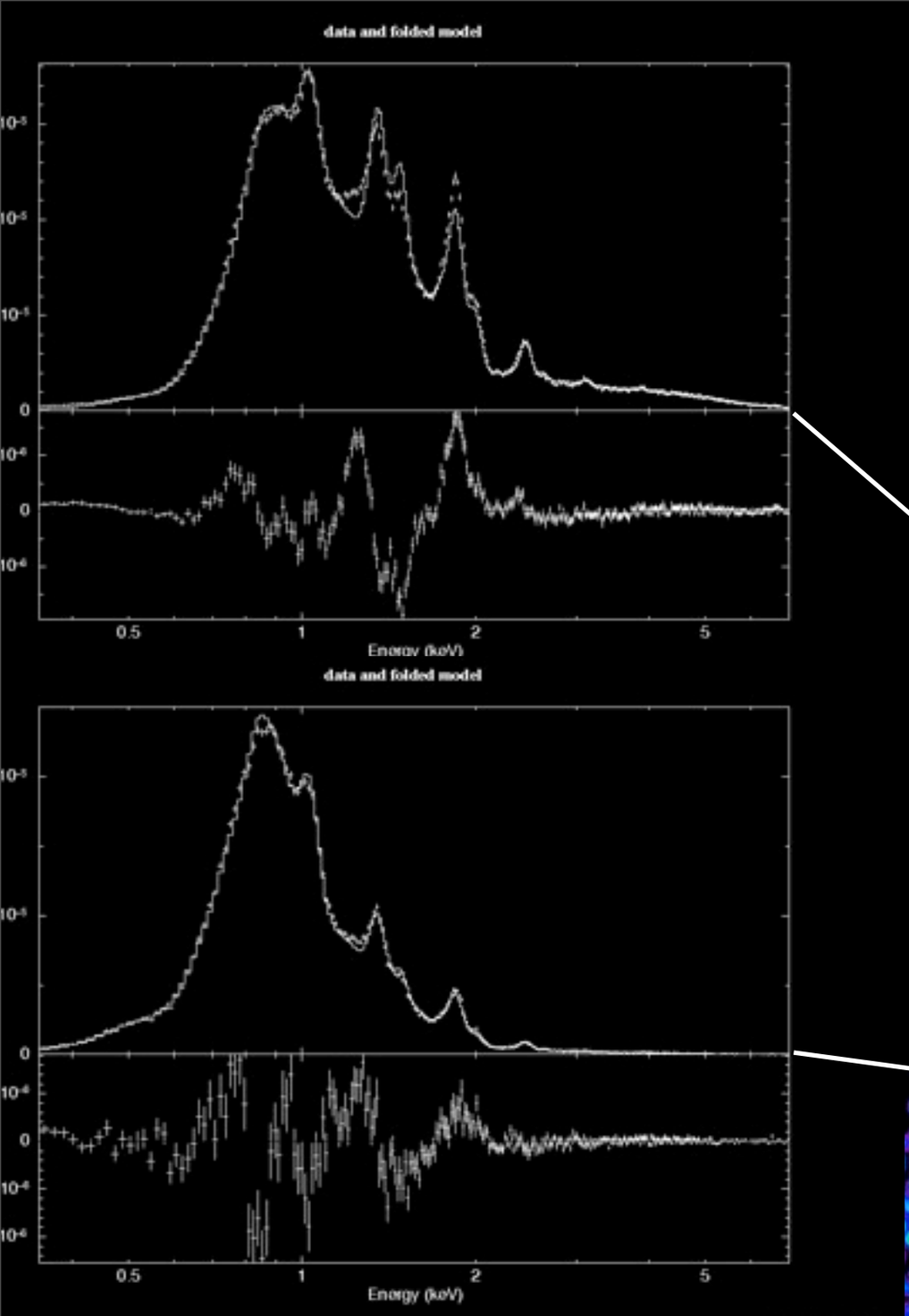
Morphology Summary

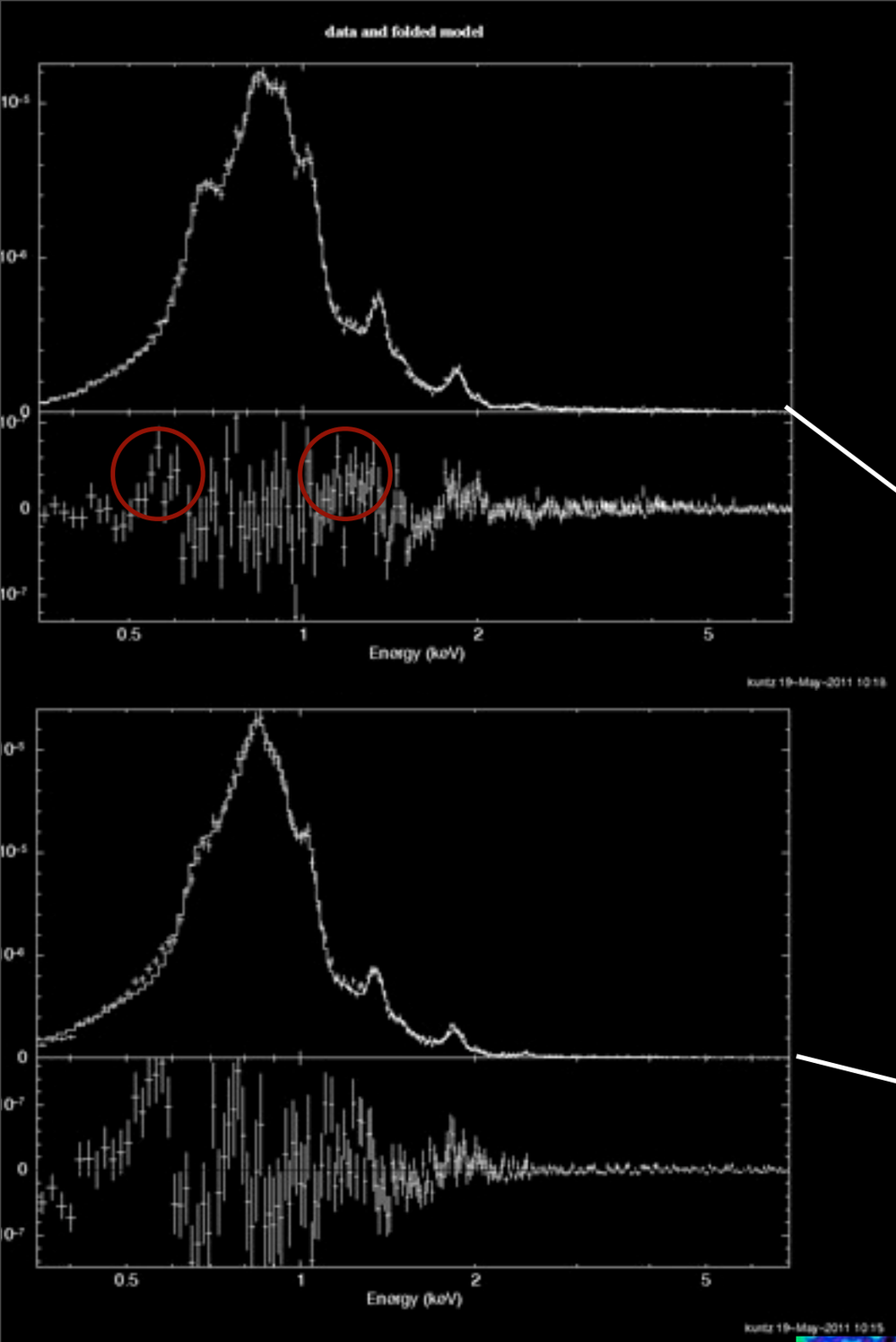
- North & South show distinct differences
  - south more distinctly bounded
  - north more chaotic
- X-ray morphology generally follows Hα
  - FUV suggests larger scale structure
  - HI insufficiently sensitive
- Isolated X-ray emission regions in far field
  - X-rays only seen where flow interacts
- Bulk of structure in hardness ratio maps
  - O/Fe/Mg (where one might expect it)
  - but also where signal is large

Spectroscopy

- Fitting model:
  - fixed background+
  - vapec+vapec+pow
  - C=N=O
  - Mg=Si=S
  - Fe=Ni




data and folded model
0.5
1
2
5
Energy (keV)
data and folded model
0.5
1
2
5
Energy (keV)
kuntz 19-May-2011 10:15


data and folded model
10⁻⁵
10⁻⁶
10⁻⁰
0
10⁻⁷
0.5
1
2
5
Energy (keV)
kuntz 19-May-2011 10:15
10⁻⁵
10⁻⁶
0
10⁻⁷
0
10⁻⁷
0.5
1
2
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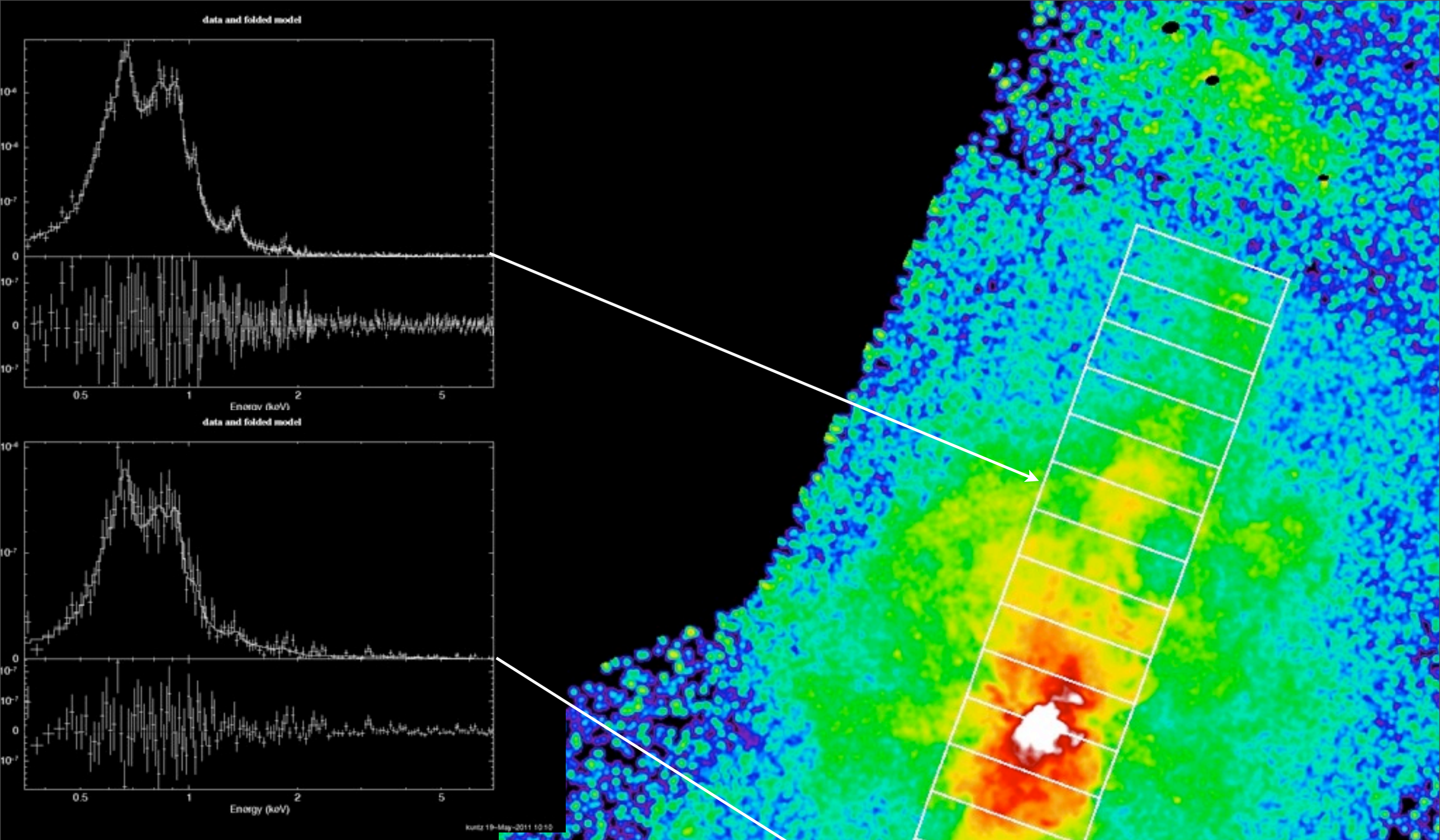
Energy (keV)
kuntz 19-May-2011 10:15


data and folded model
10⁻⁴
10⁻⁶
10⁻⁷
0
10⁻⁷
0
10⁻⁷
0.5
1
2
5
Energy (keV)
data and folded model
10⁻⁴
10⁻⁷
0
10⁻⁷
10⁻⁷
0
10⁻⁷
0.5
1
2
5
Energy (keV)
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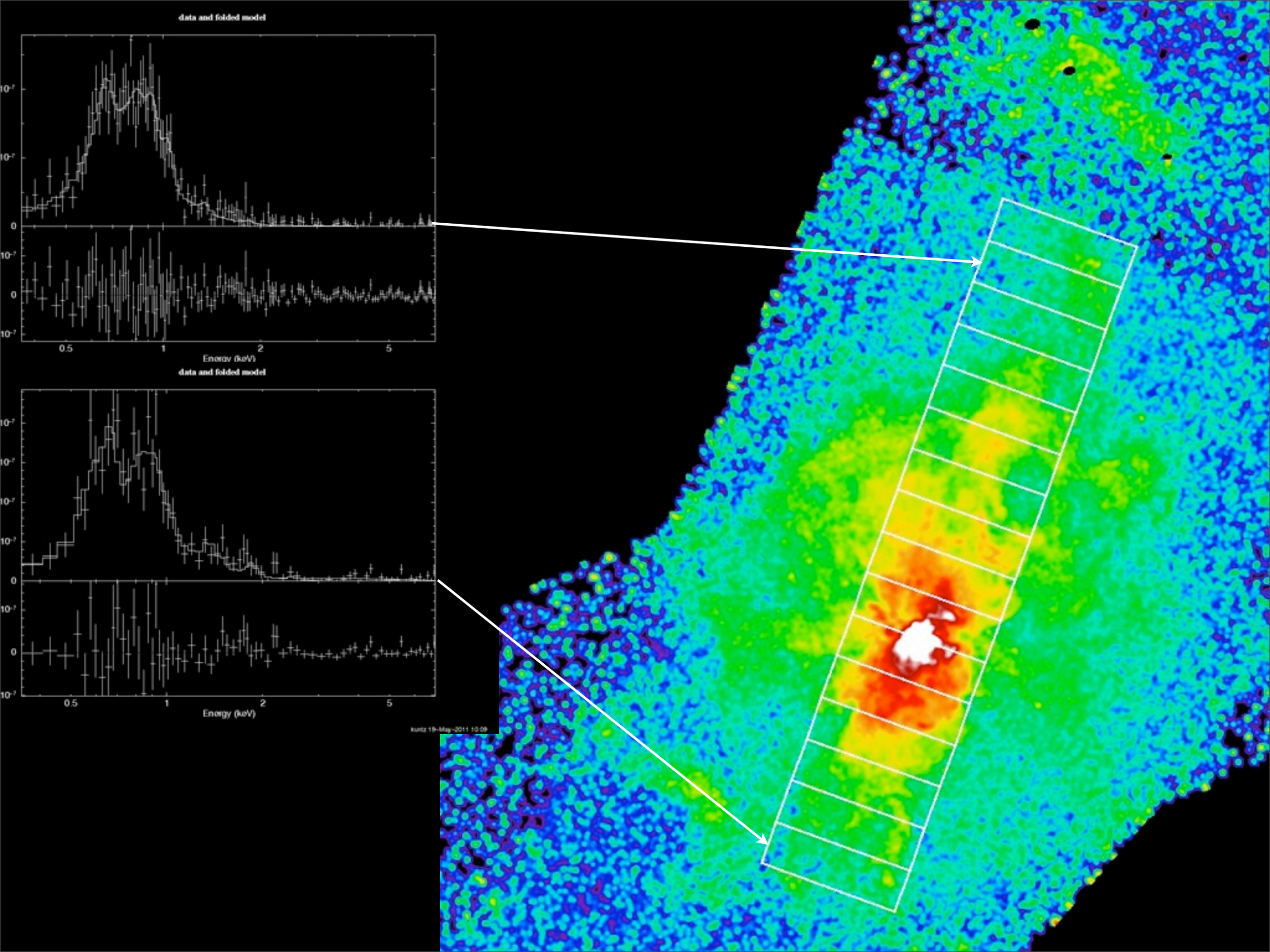
data and folded model
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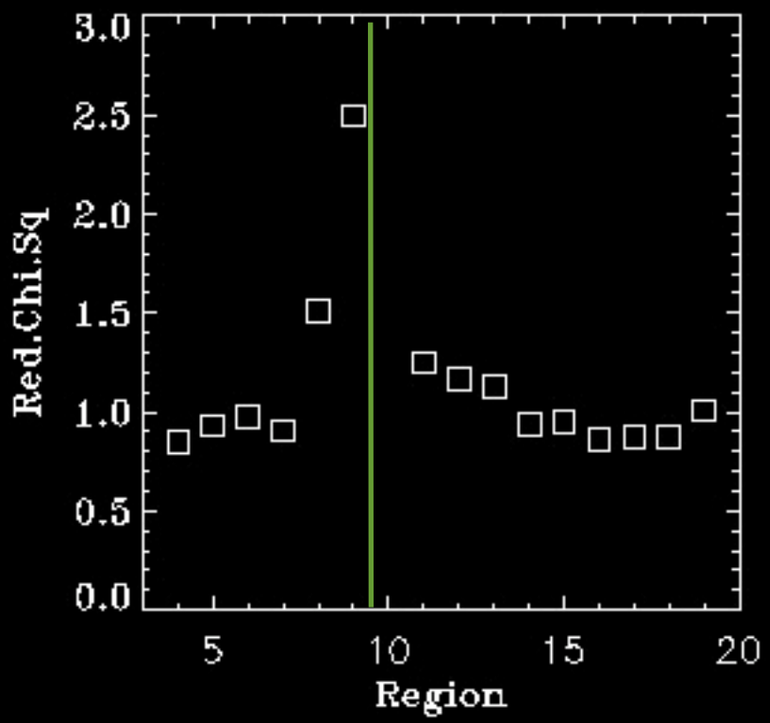
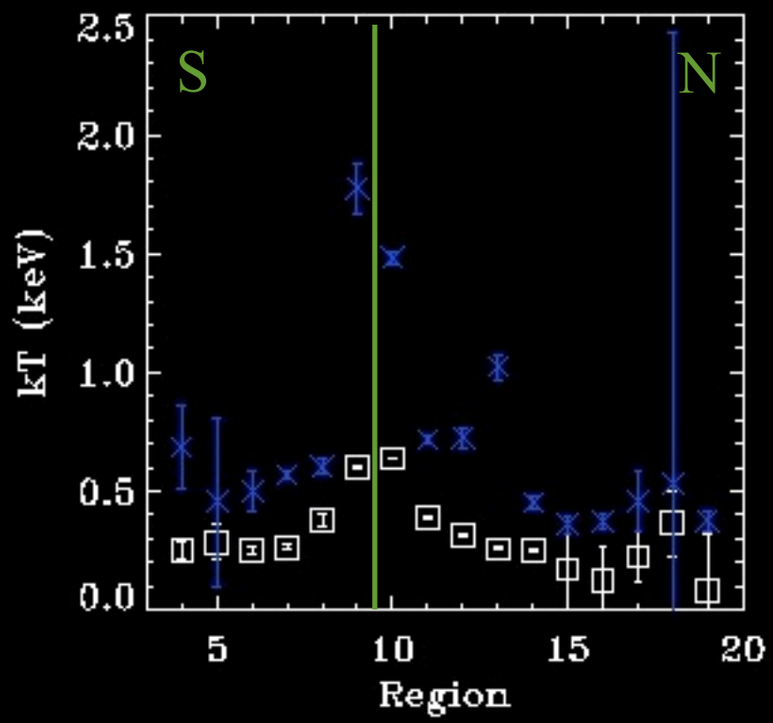
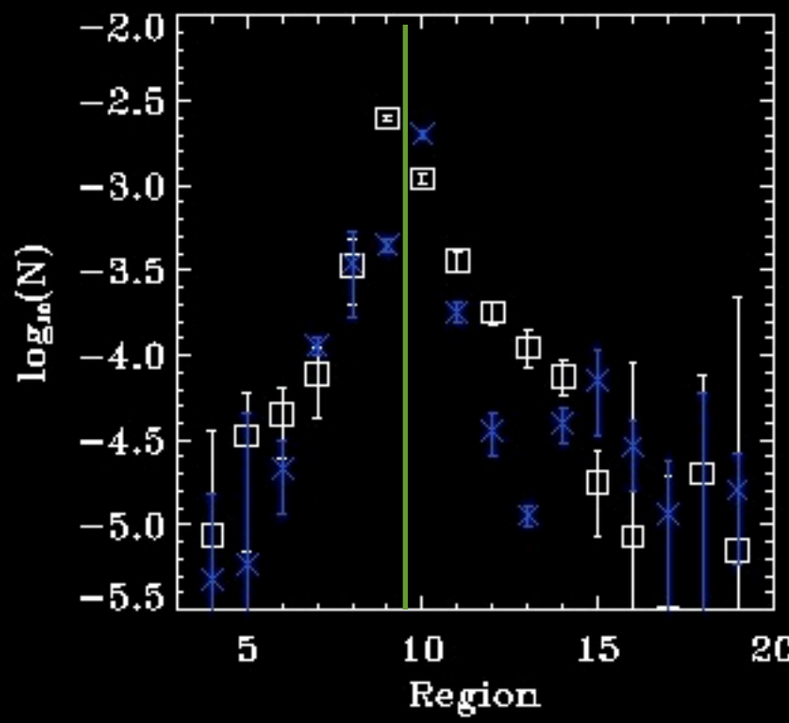
0
10⁻⁷
0
10⁻⁷
0.5
1
2
5
Energy (keV)
data and folded model
10⁻⁷
0
10⁻⁷
0
10⁻⁷
0.5
1
2
5
Energy (keV)
kuntz 19-May-2011 10:09

Spectroscopy



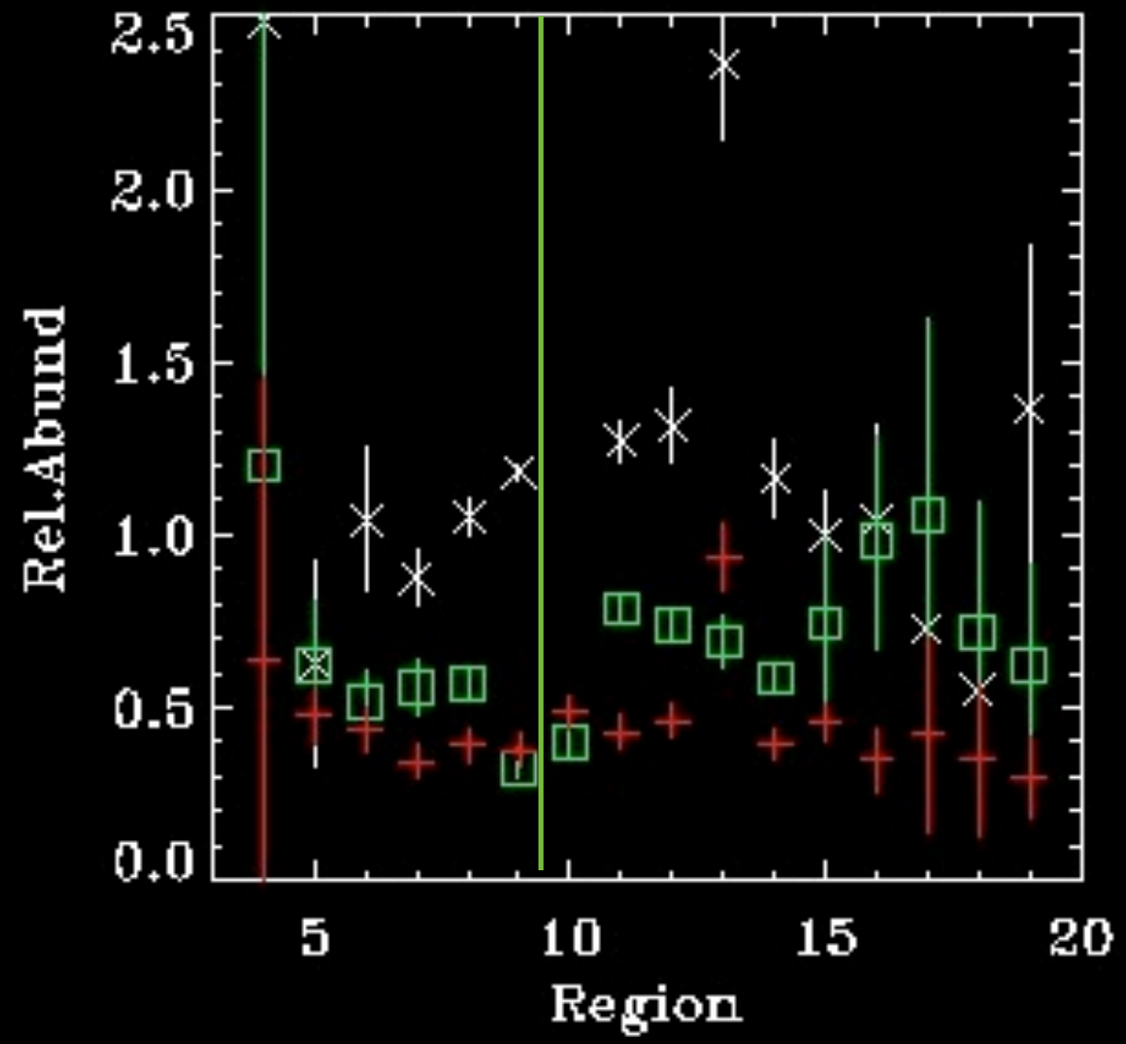




- Nuclear region poorly fit, remainder OK
- (kT_S,kT_H)~(0.25,0.45-0.55) over the bulk of the flow
- asymmetry seen in kT, norms
  - North is hotter
  - North is slightly more absorbed

Spectroscopy

- O, Fe consistent with flat, Mg peaked in inner flow
- O, Mg, & Fe have relative abundances consistent
  w/ RGS abundances from Origlia et al (2004)
  $O/O_\odot \sim 0.26$, $Mg/Mg_\odot \sim 1.36$, $Fe/Fe_\odot \sim 0.43$
- While IR gives $O/O_\odot \sim 1.0$, $Mg/Mg_\odot \sim 1.0$ (stellar)

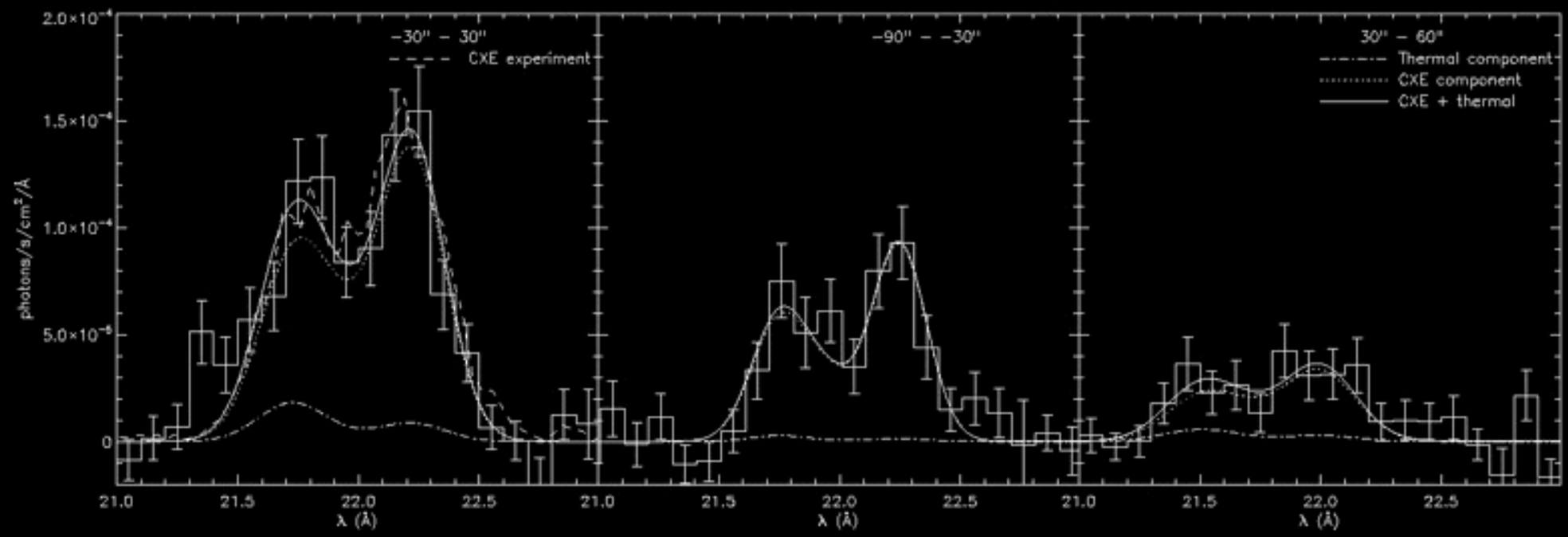


Spectroscopy Caveats

- Our model (vapec+vapec) is too simple
- Multiple emitting components along each LOS
  - distributed emission measure (e.g. Ranalli et al)
- Expect both under- and over-ionized components
  - expect both shocks and adiabatic expansion
  - residuals subtly different from bad abundances
  - not well detectable at low count rates
- Unresolved binaries/background AGN model simple
  - more cutoff model more apropriate
  - will be built from P.S. studies
- Missed physics?

Spectroscopy Caveats

- Liu, Mao, & Wang (astro-ph 1105.3539)
  - using RGS spectra
  - analyzed f, i, & r ratios in O VII, Ne IX, & MgXI
  - O is 90% CX, Ne is 50% CX, and Mg is 30% CX
- Suggests more gentle interaction between hot and cold

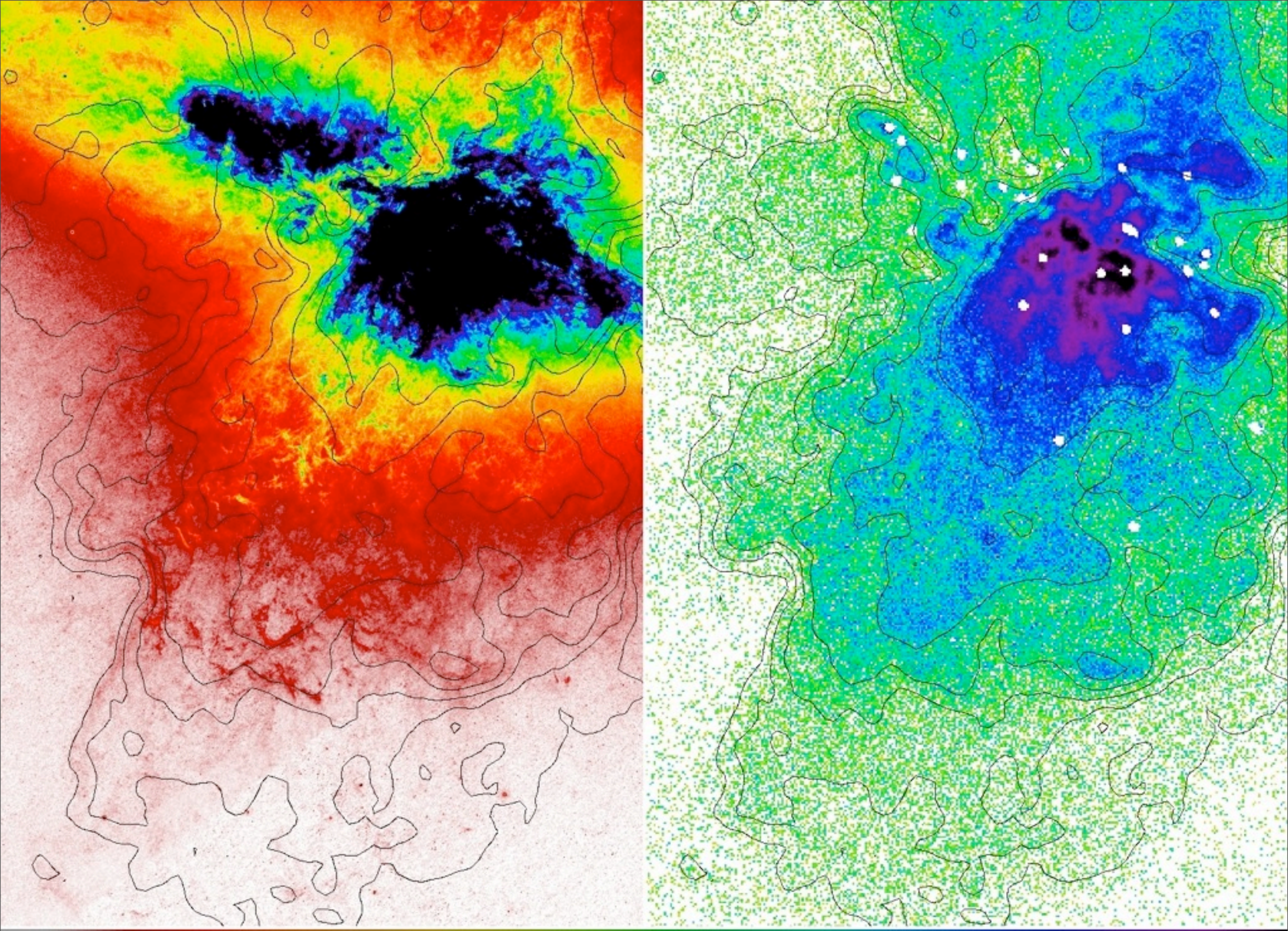


Spectroscopic Summary

- ACIS imaging spectroscopy is consistent with RGS
- fitting may not be telling us what we want to know
  - "final resolution" may await Astro-H
  - correlative spectroscopy still viable, e.g.
    - are Hα-rich regions different from Hα-poor ones?
    - what is the distribution of kT?

Summary

- We are still not seeing the bulk of the wind
  - we only see emission where it interacts
    - strong correlation with Hα
    - isolated emission regions in the far field
  - we don't even seen the neutral "target" gas
- X-ray structures with strong Hα filaments harder
  - demarcate the strongest interactions/shocks?
- X-ray hardness ratios remarkably smooth
  - binning on too coarse a scale?
- North-South asymmetry
  - bounded(?) vs. streaming ⇔ short vs. long scale
  - no intrinsic difference in spectra


2E-07
4E-07
6E-07

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