Cas A: Properties of the Bright X-ray Knots

Dan Dewey (MIT)

Jasmina Lazendic (U.Melbourne)

with

Norbert Schulz and Claude Canizares

Thanks to: John Davis, John Houck, Glenn Allen, Mike Stage, Kathy Flanagan, Tracey DeLaney, Dick Edgar and Dan Patnaude.

Talk given 7 Sept. 2006; slides updated 20 Sept. 2006.

Philosophical preface…

… it remains the case that much of what we know is culturally and temporally conditioned. The trick, as it were, is to pursue the truth …, while at the same time being willing to give the effort a post-modern wink: The knower is part of the known, and the knowledge is probably provisional. I seek the truth, *and* I am aware of myself as a culturally situated seeker of the truth. ..."

From "The Twilight of American Culture" by Morris Berman (2000, 2006) pp.176-177.

Talk Outline

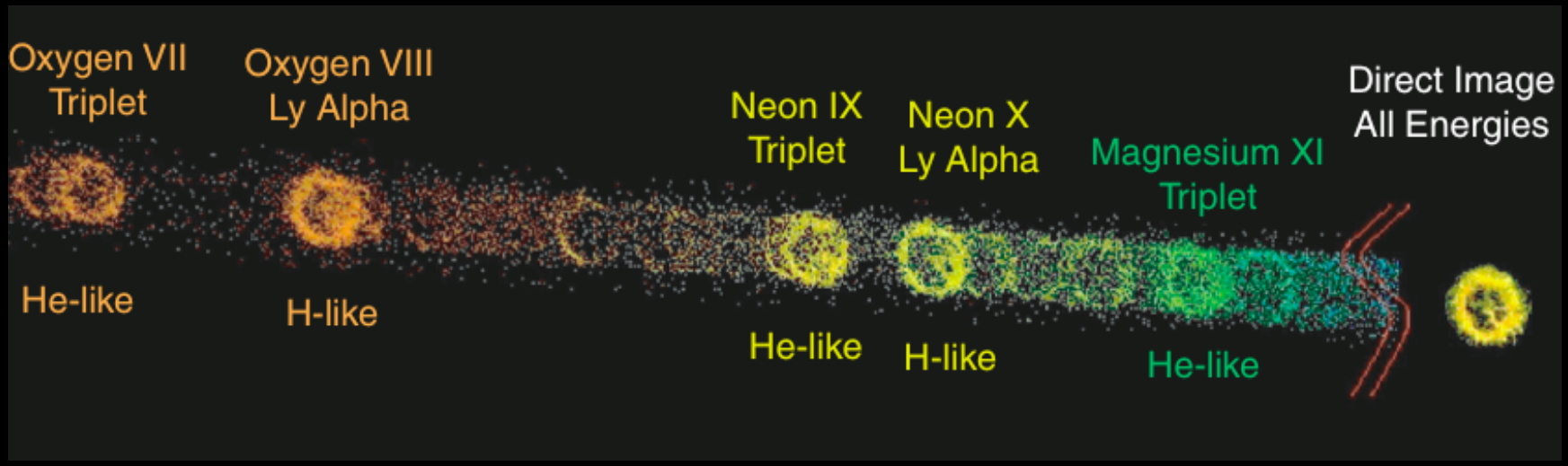
HETG Observation of Cas A

- Cas A knot(*) properties
  - Velocities
  - Plasma parameters
- 3D Model and Oxygen
- Summary and Future

Note:
Here the term
"x-ray knot"
is generic for:
Filament,
Region,
Clump, etc.

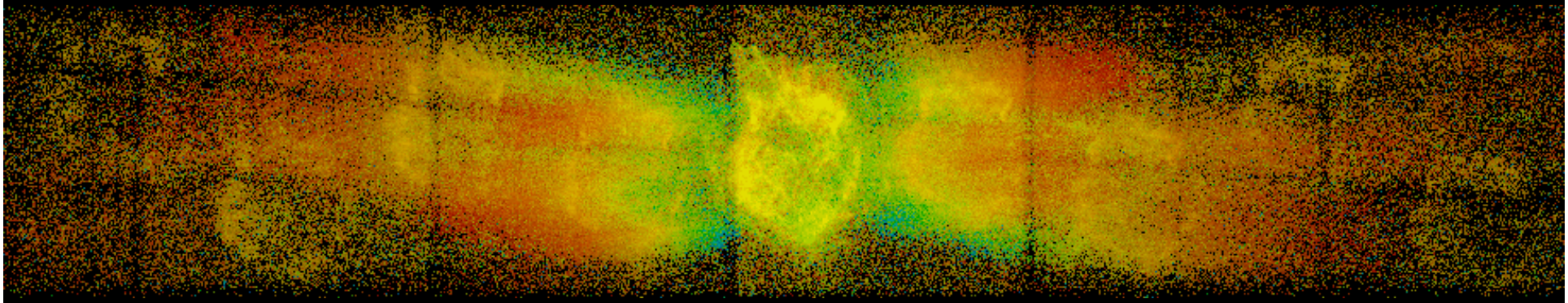
Chandra HETG

- HETG: slitless, dispersive X-ray spectrometer
  - Best for point sources (e.g., GRBs)
- Can usefully observe extended sources
  - Spatial-Spectral analysis methods, **Dewey 2002**.
  - SNR E0102, **Flanagan et al. 2004**



HETG Obs. of Cas A

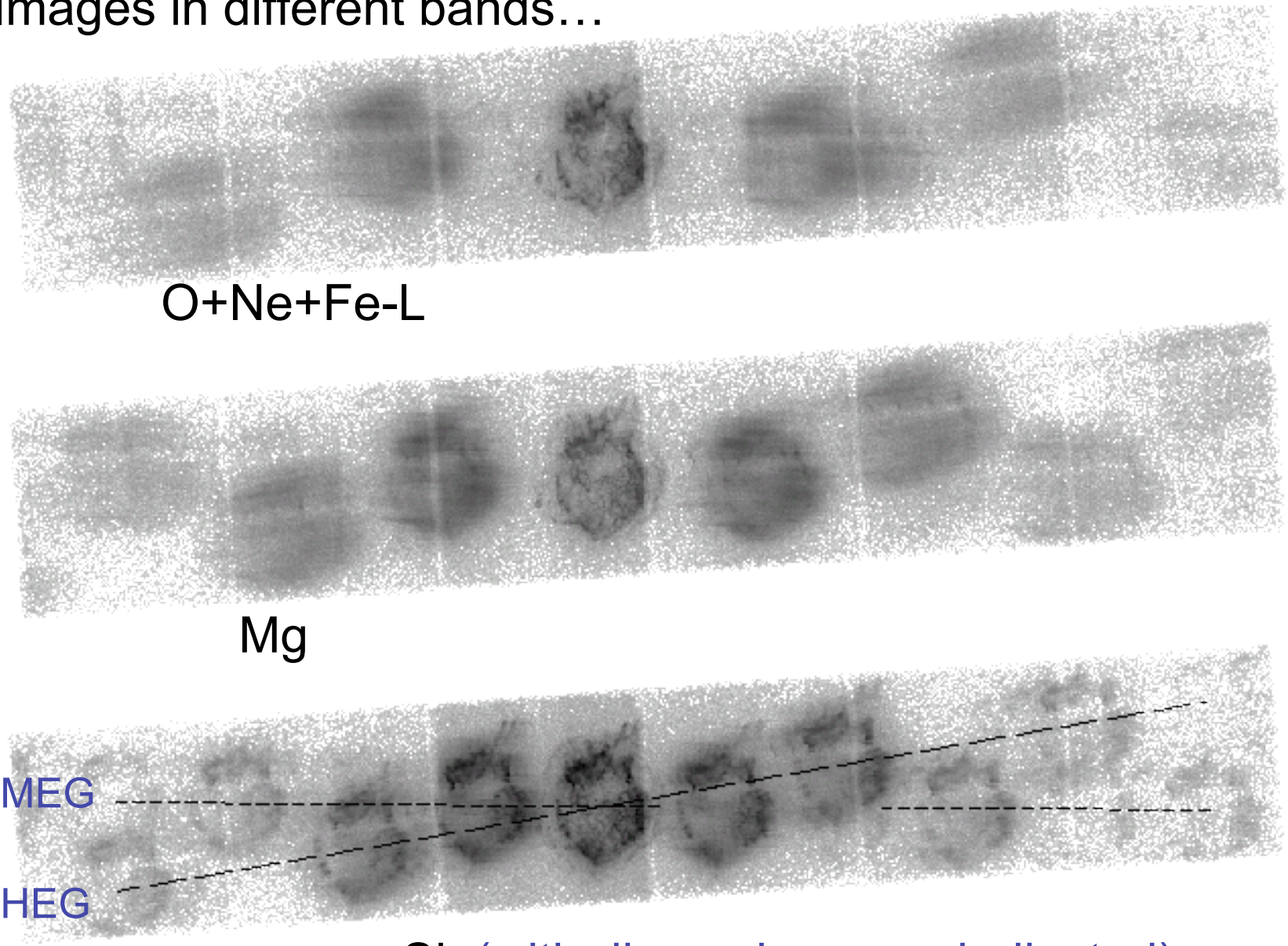
Cas A data - Obsid 1046: (70 ks, May '01)



Color-coded by CCD-determined energies

Spatial-spectral overlap - ouch.

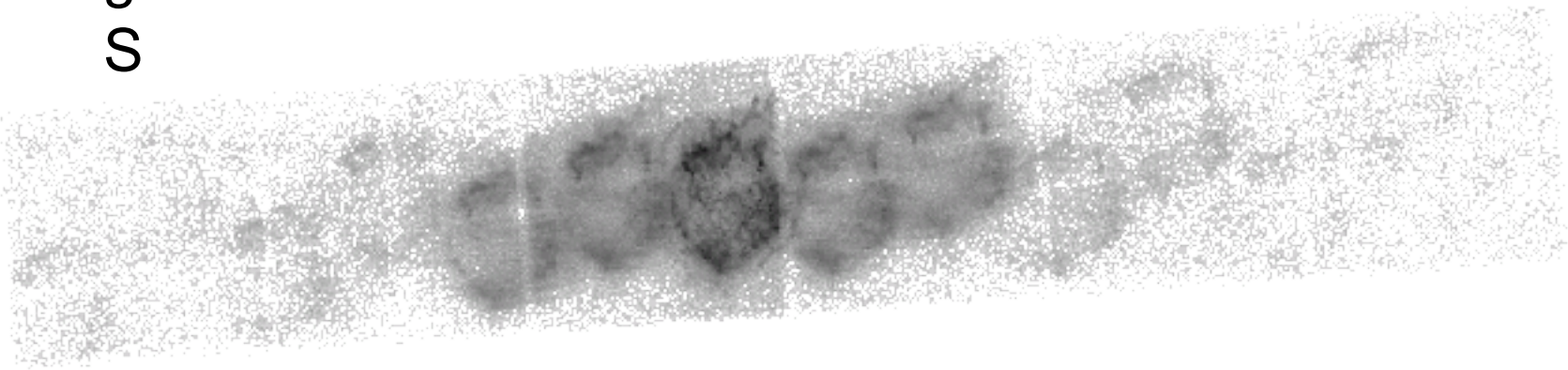
Images in different bands…



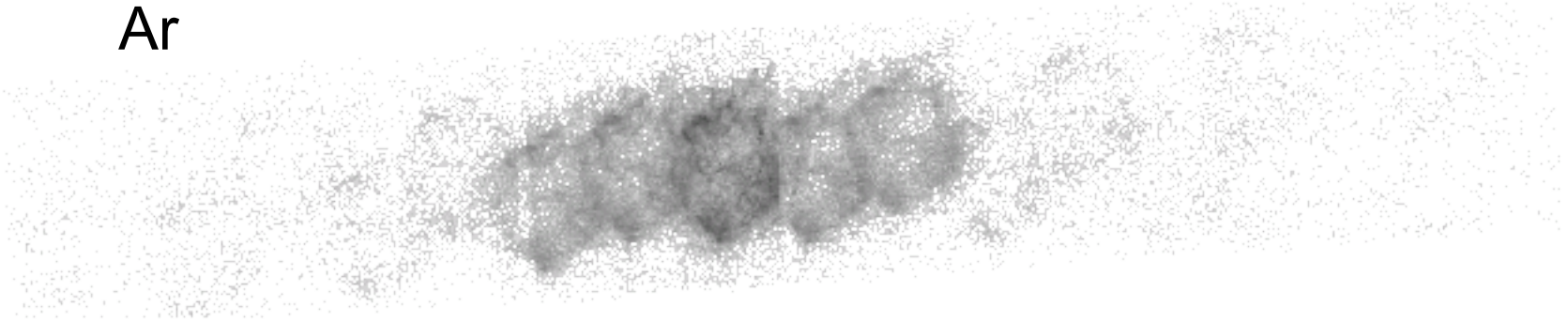
Si (with dispersion axes indicated)

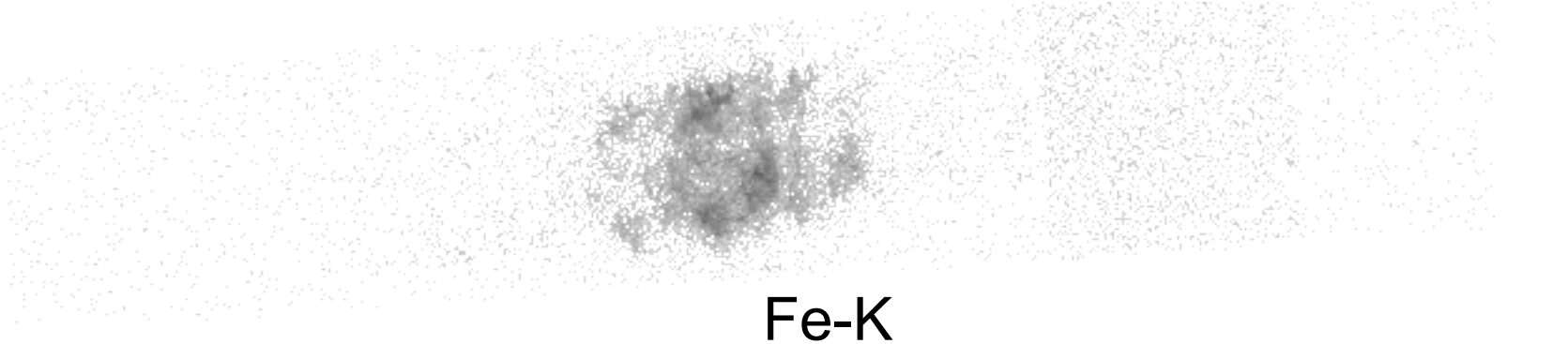
Images in different bands…

S



Ar

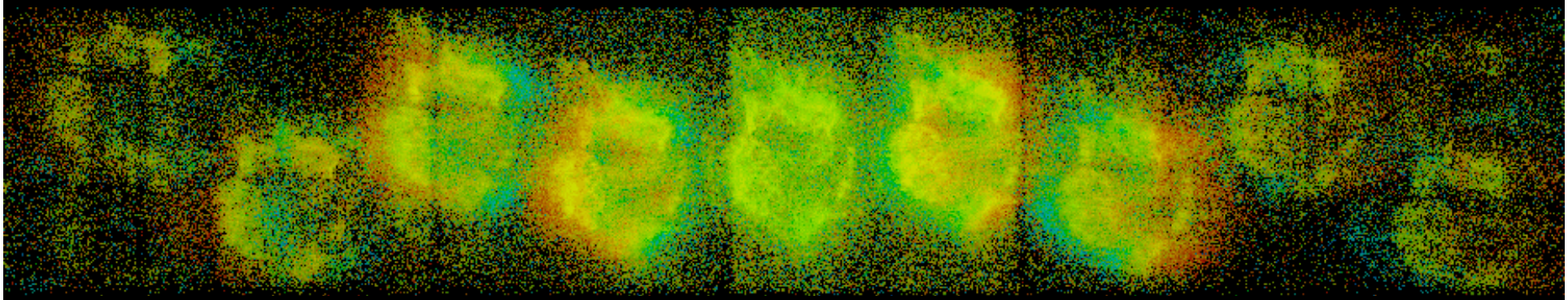




Fe-K

Obs. of Cas A, cont.

Images in energy bands - Si band

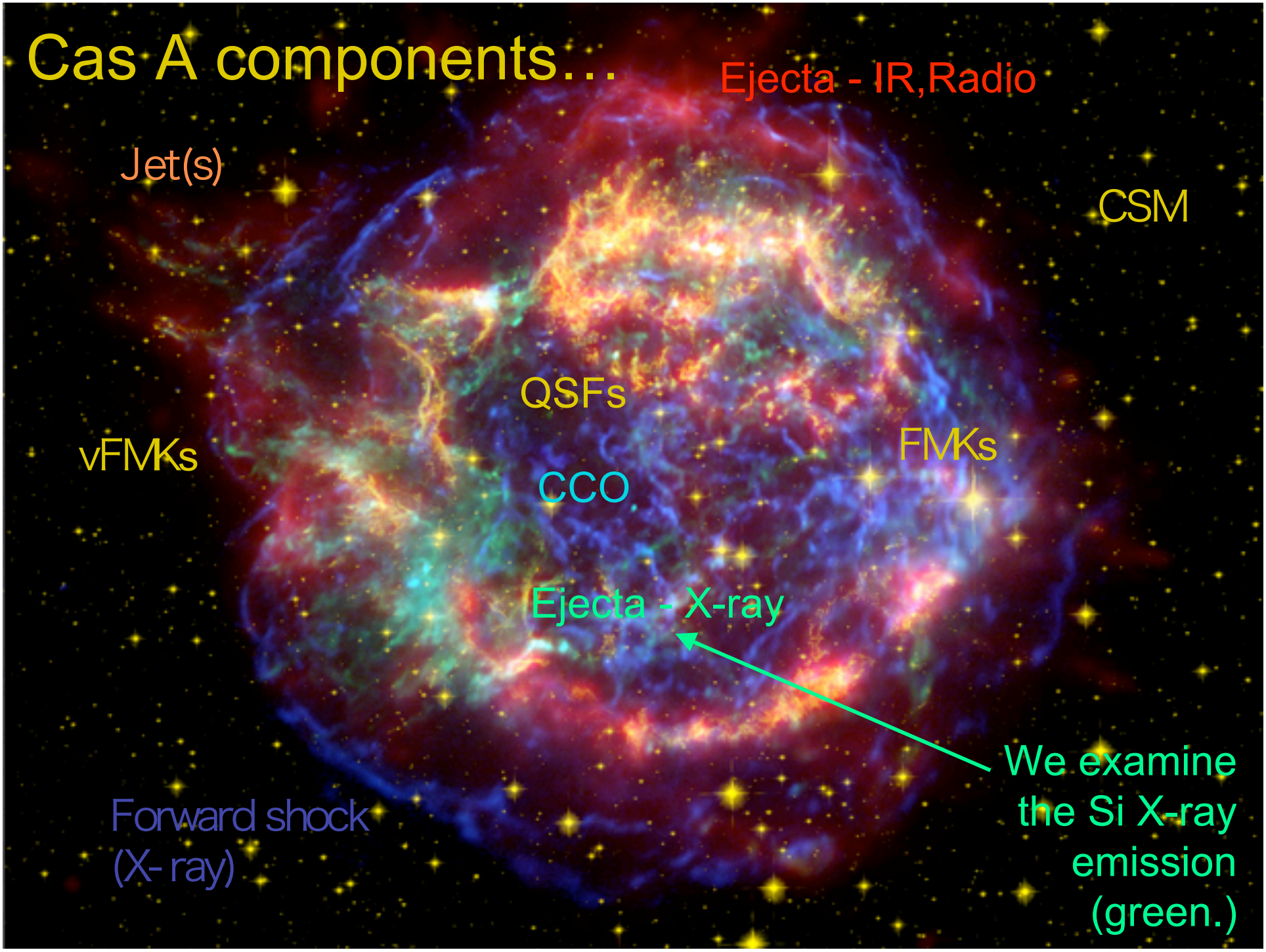


Events with E_{ACIS} in 1.6 to 2.1 keV range only.

Talk Outline

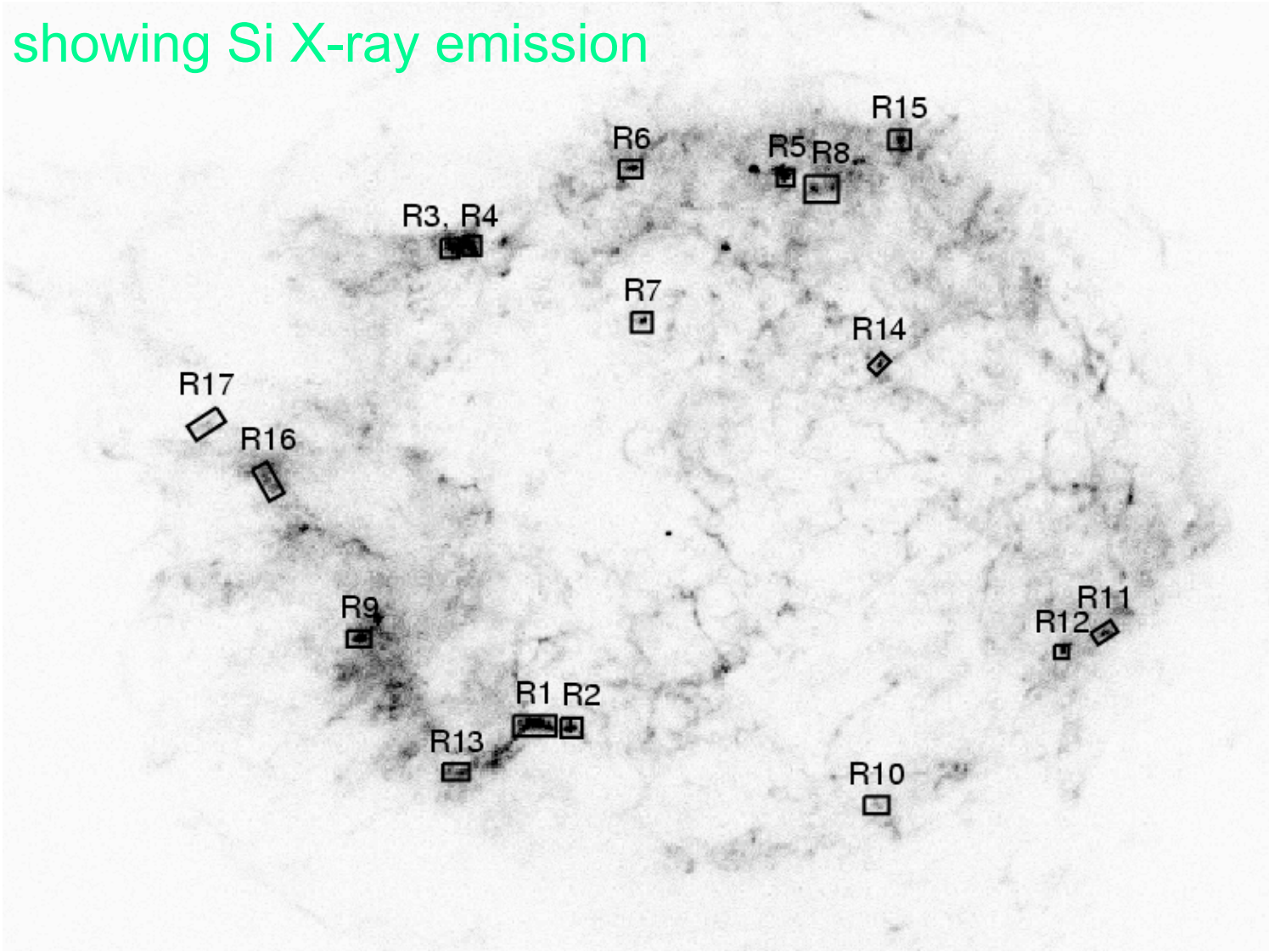
- HETG Observation of Cas A
- Cas A knot properties
  - Velocities
  - Plasma parameters
- 3D Model and Oxygen
- Summary and Future

Lazendic et al. 2006


Cas A components…
Ejecta - IR,Radio
Jet(s)
CSM
QSFs
vFMKs
FMKs
CCO
Ejecta - X-ray
We examine the Si X-ray emission (green.)
Forward shock (X-ray)

17 Si-bright Regions Selected

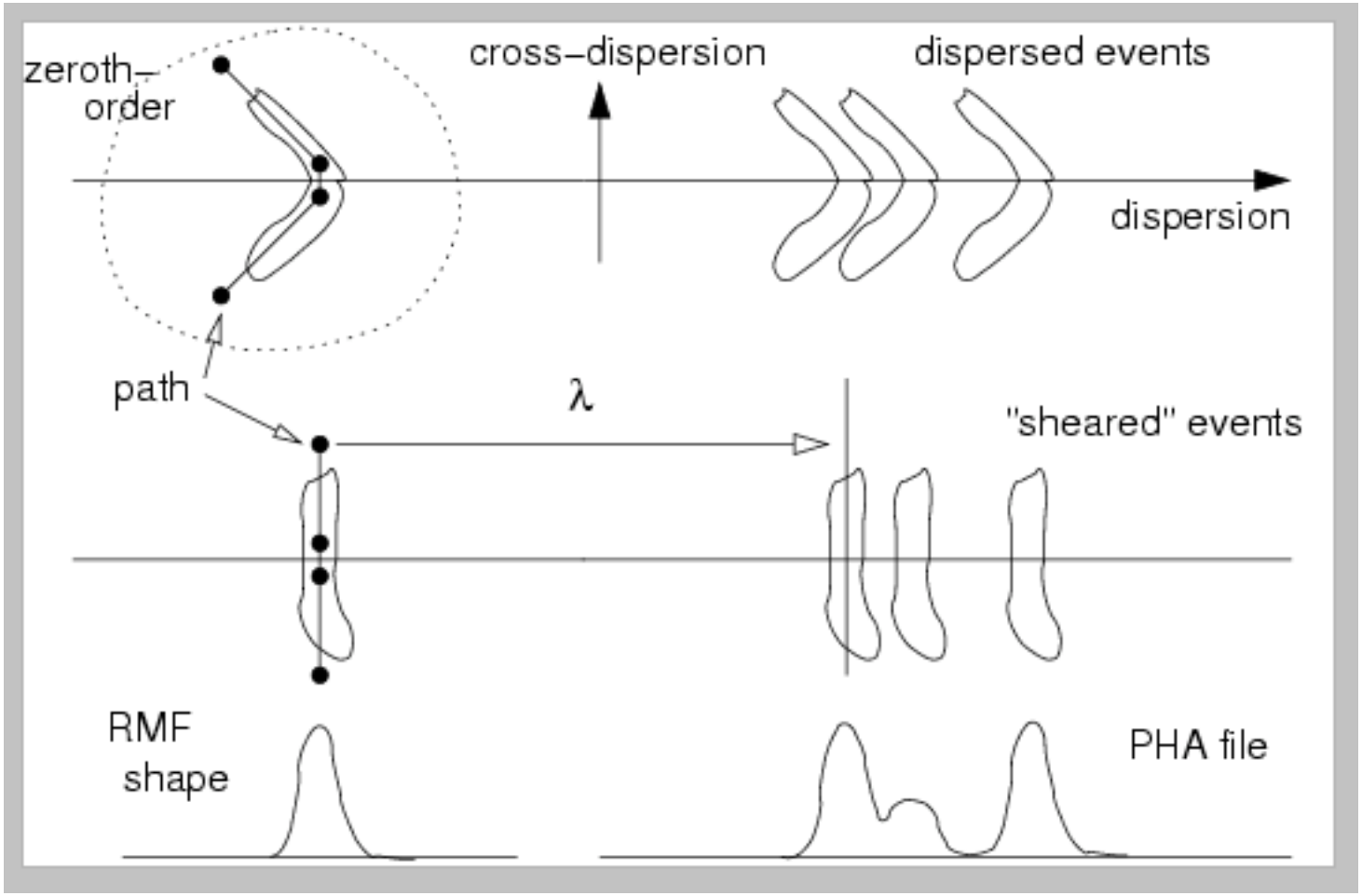
Image showing Si X-ray emission



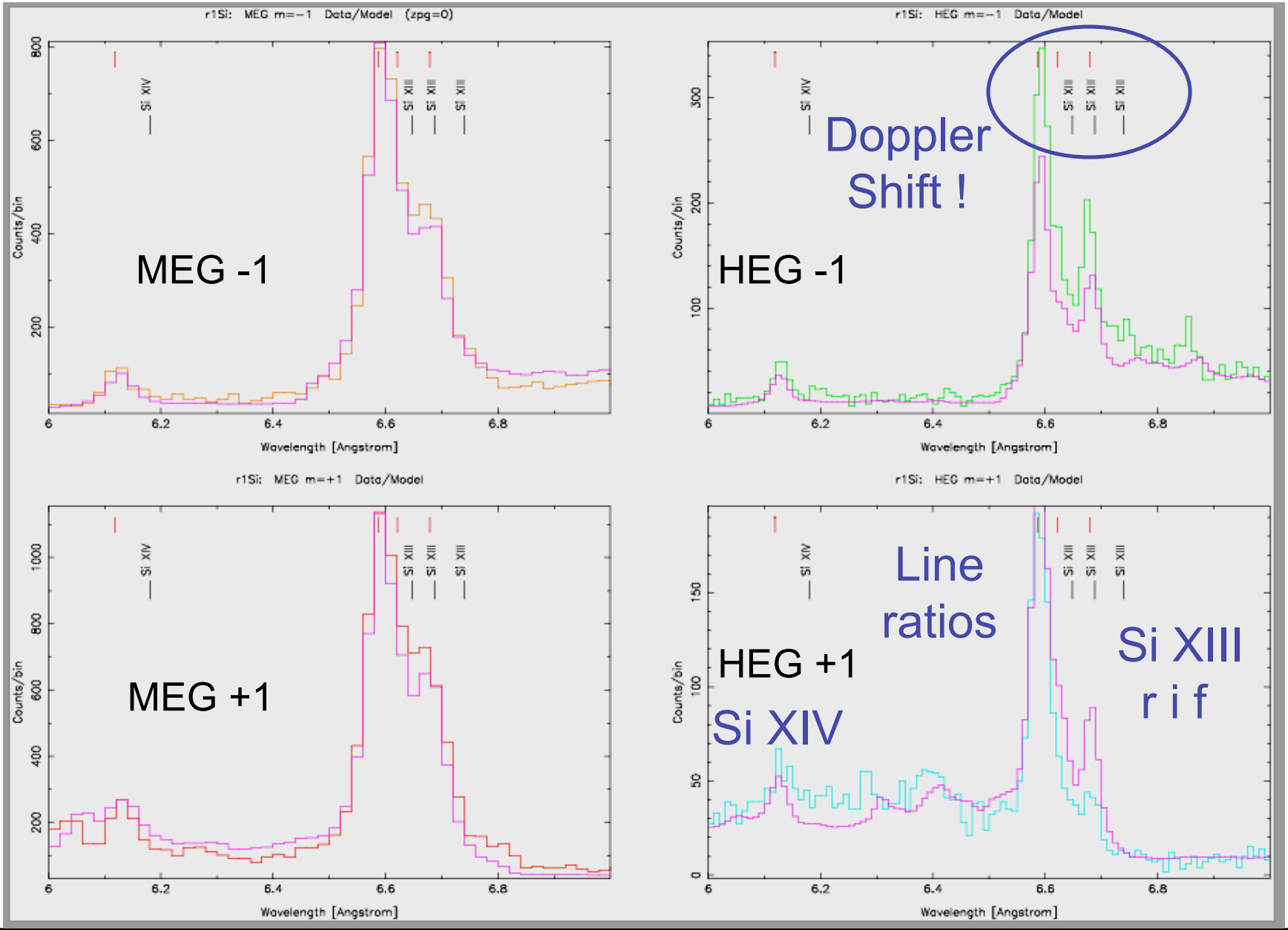
Filament Analysis

Dewey 2002, and Lazendic et al. 2006

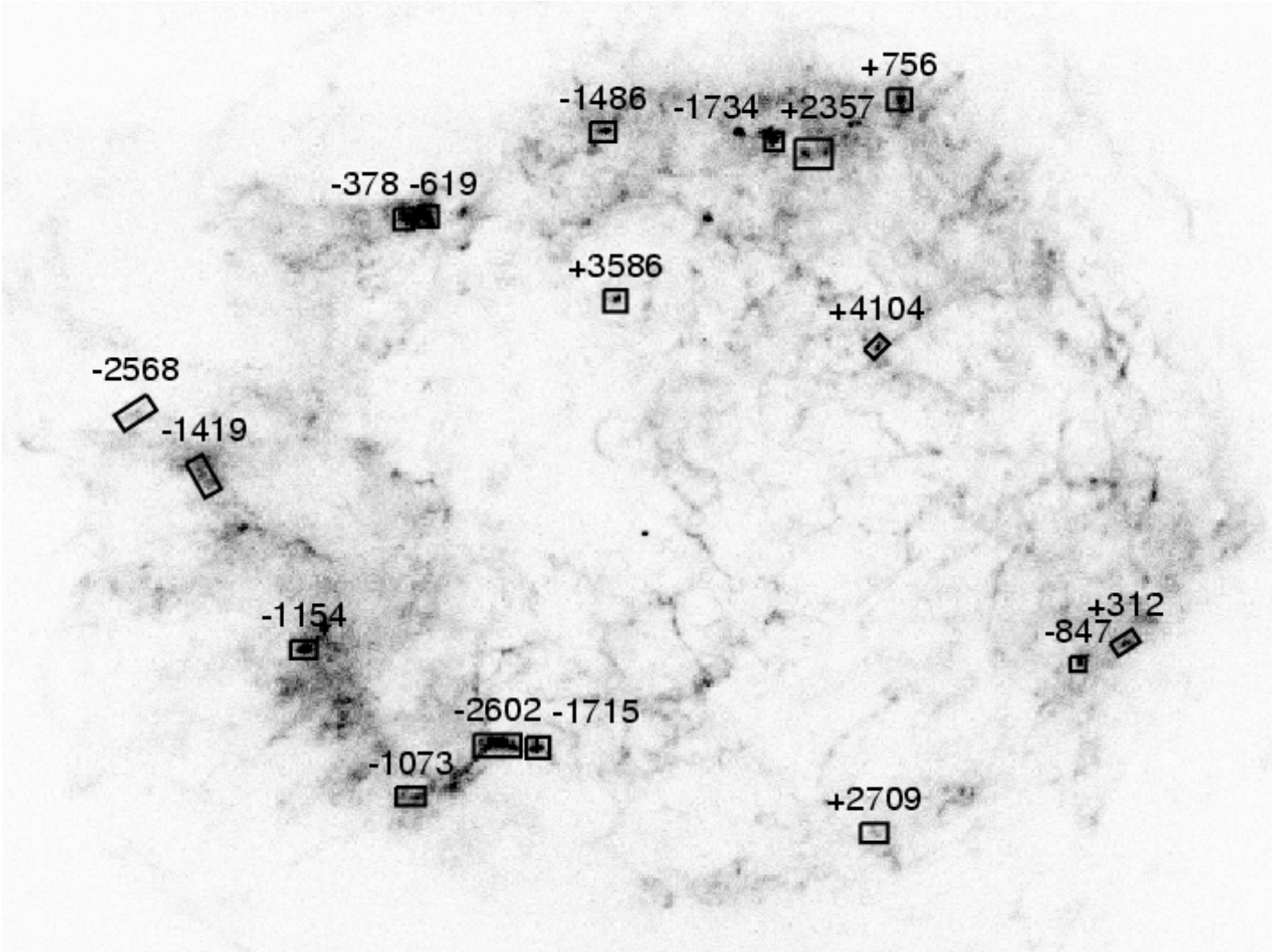
Data analysis method improves spectral resolution for "filament-like" features.



Si line fits - Region 1



Velocities of Regions (km/s)



Add 3rd Dimension…

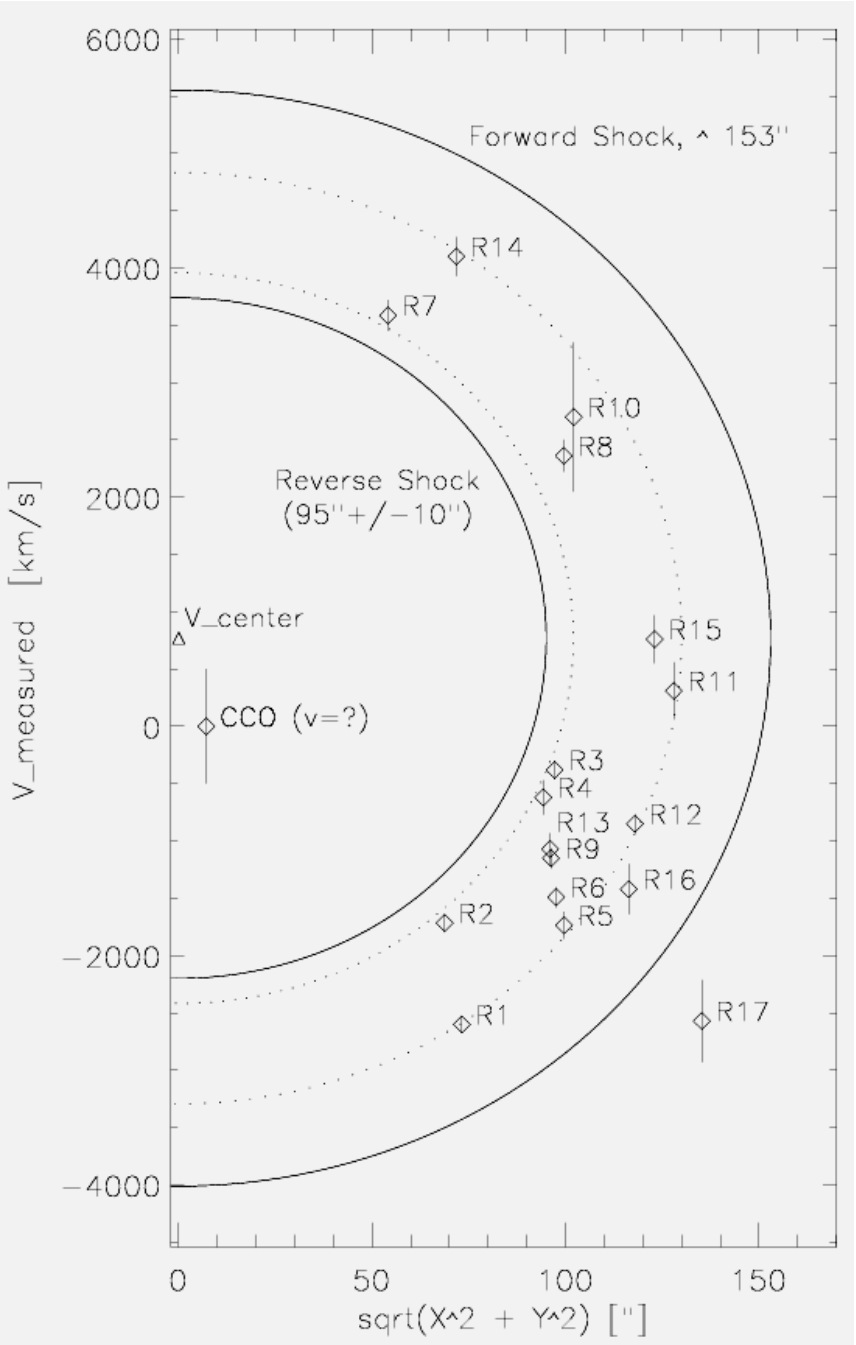
Assume*…

$$Z = \text{const.} \times V_{meas}$$

The regions all lie within a narrow range in 3D radius of 100" - 130". (Except for R17 near the NE jet region.)

Conversion to distance is:
0.032" per km/s
This is equivalent to:
~ 0.2 % per year, or
expansion-param ~ 0.65

(*) agrees w/DeLaney '03, '04.

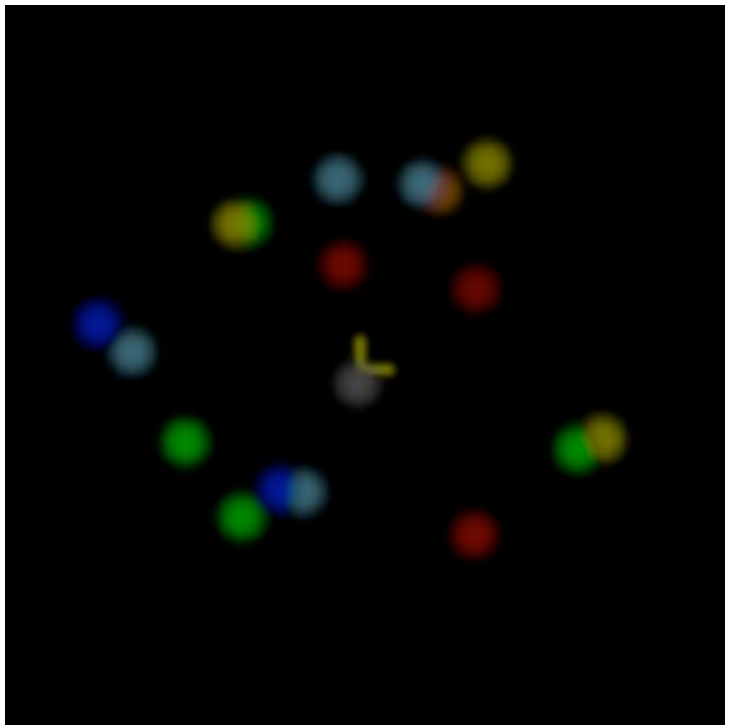


Velocities of Regions (color-coded)

"Front view"

N

E

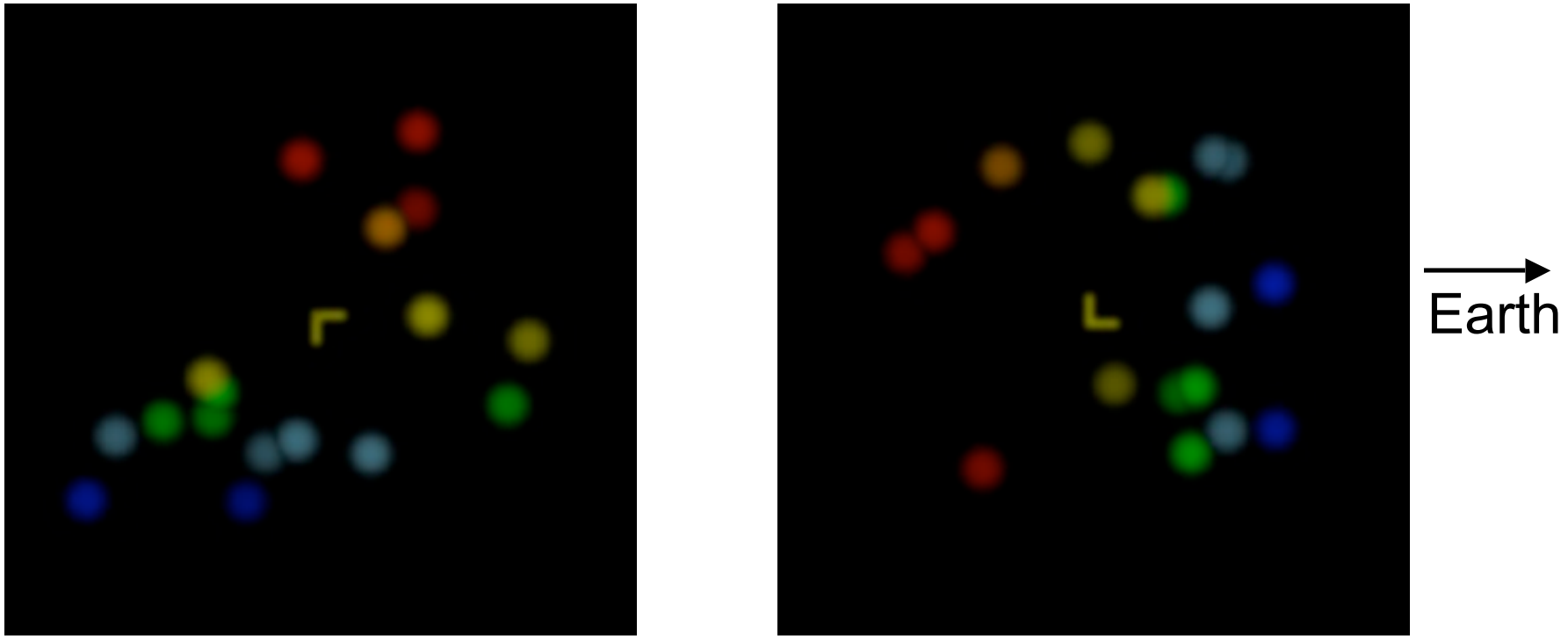


Key (km/s):
Red > +2500; Orange +2500 to +1000; Yellow +1000 to -500;
Green -500 to -1300;
Light-Blue -1300 to -2000; Blue < -2000

Velocities of Regions (color-coded)

"Top view"

"Side view"



Talk Outline

- HETG Observation of Cas A
- Cas A knot properties
  - Velocities
  - Plasma parameters
- 3D Model and Oxygen
- Summary and Future

Determining the plasma param.s

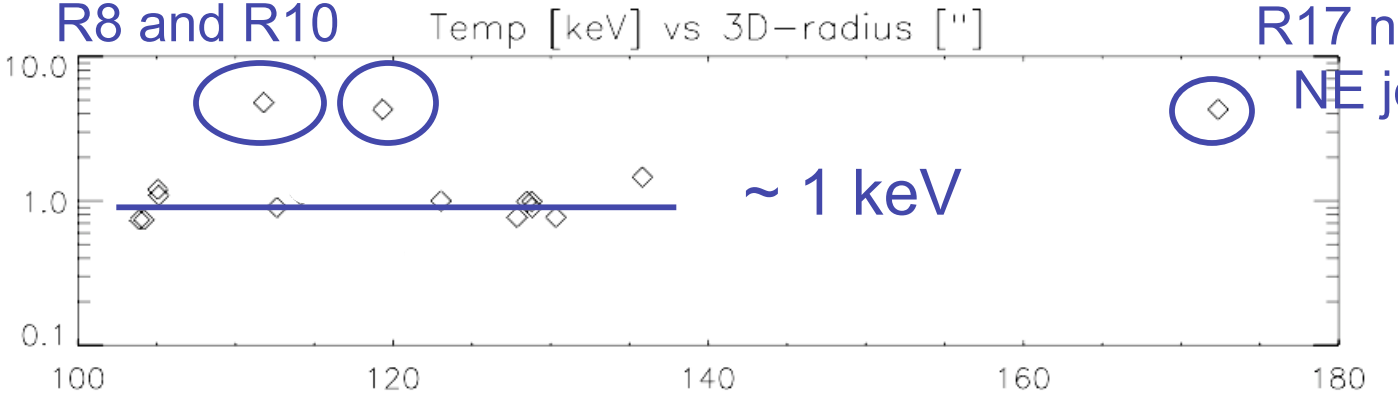
Multiple steps:

Lazendic et al. 2006

- HETG --> line ratios
- Line ratios --> T and "$n_e t$" for NEI model
- CCD spectrum (zeroth-order) is fit with T, tau fixed --> norm and abundances; assumed O-rich: O_{abund} = 1000 solar.
- Estimate region volumes --> n_e, masses
- Combination "$n_e t$"/n_e --> t_{shock}

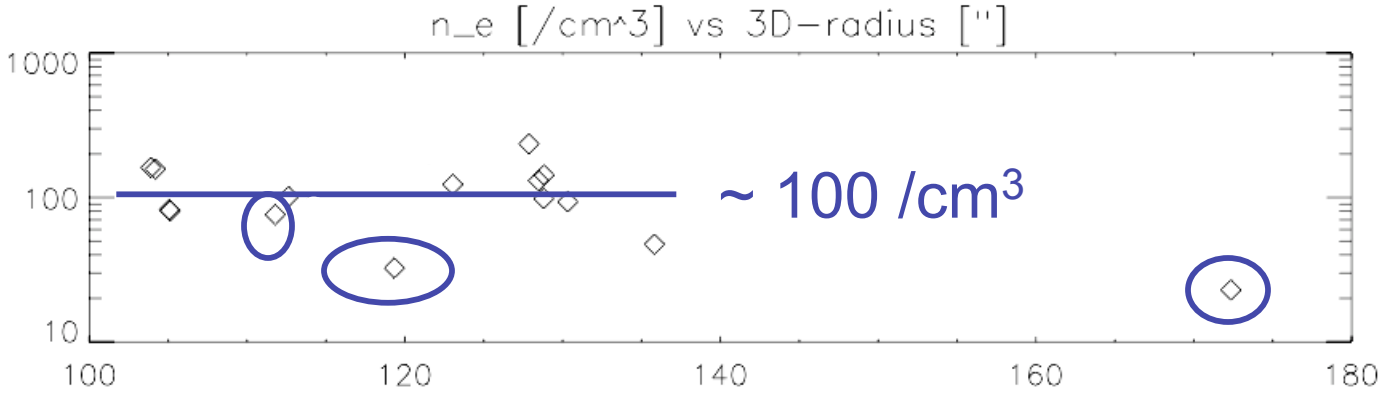
Knot Parameters vs 3D-radius

High-T:
R8 and R10



R17 near NE jet

~ 1 keV



~ 100 /cm^3

(R6 and R9 removed because of uncertain T values - see Lazendic 2006)

What is the ejecta-ambient density ?

For the knots:

$M_{oxygen} / M_{total} \sim 0.8$ to 0.97

If the ambient density in 100" - 130" were of order:

$n_e = 100/cm^3$,

then: Total oxygen mass ~ 85 M_{solar}

These knots may be over-dense by up to a factor of 100 ?!

How to reconcile this with the **Laming & Hwang 2003** cloud-destruction reasoning (that over-dense clouds would be destroyed) ?!?

Talk Outline

- HETG Observation of Cas A
- Cas A knot properties
  - Velocities
  - Plasma parameters
- 
  3D Model and Oxygen
- Summary and Future

What is the 3D configuration of Cas A ?

A simple SNR model* has:

- Uniform ejecta with a power-law density dist. (n)
  - Ejecta largely oxygen.
- Uniform wind-created ambient medium (s=2)

* Truelove & McKee 1999
Laming & Hwang 2003

Is this really what we see ?

If not, can we reverse-engineer a model from the data ?

Seen in multi-wavelengths, Cas A has emission components with different dynamic properties. Of these, the X-ray represents the greatest mass and is most tied to the overall hydrodynamics of the remnant...

Emission Components

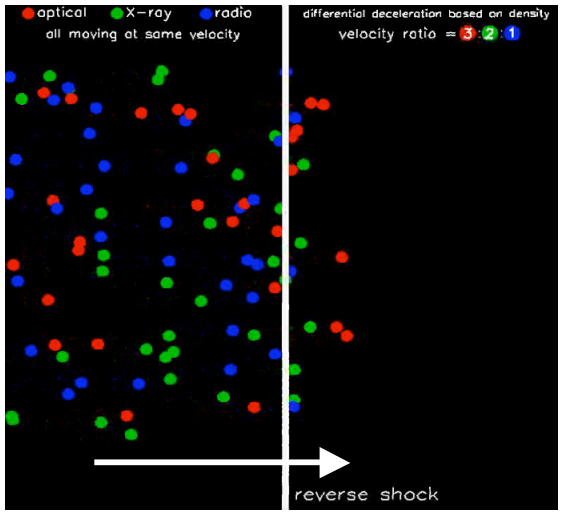
"The ejecta range from free expansion (optical, IR, 0.3%/yr) to somewhat decelerated (X-ray, 0.2%/yr) to very decelerated (radio,0.1%/yr). The current cartoon has all ejecta in free expansion interior to the reverse shock. After encountering the reverse shock, the ejecta are differentially decelerated based on density. This accounts for why the different ejecta components have different expansion rates despite being co-spatial."

Tracey DeLaney via e-mail

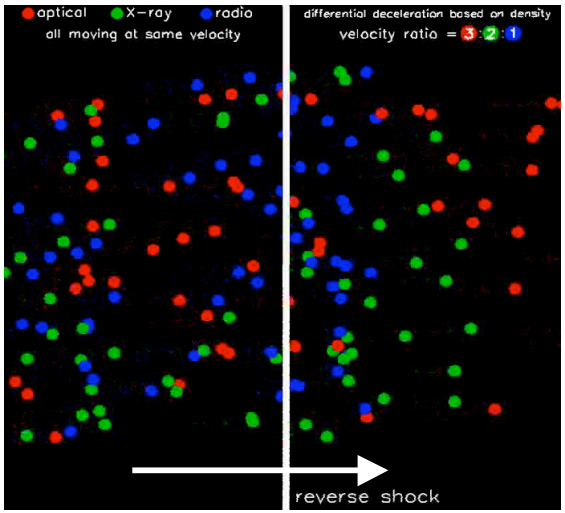
See **DeLaney et al. 2003, 2004**.

DeLaney's Cartoon

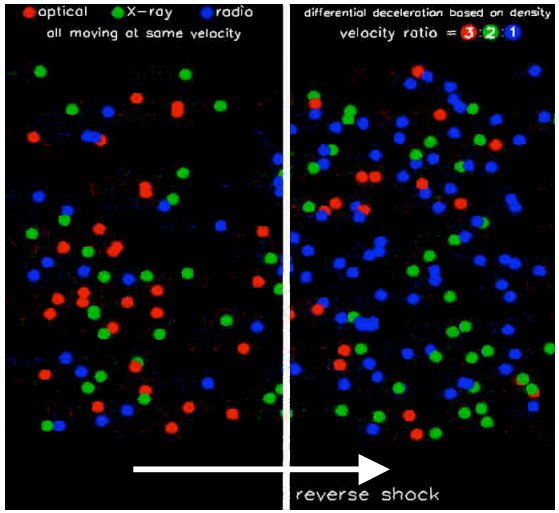
A simple toy model by Tracey DeLaney to illustrate the previous words.



Before encountering the reverse shock (line in middle) the 3 components travel with similar velocities.



At later times each component fills the shocked region and are "co-spatial", yet their velocities are very different.

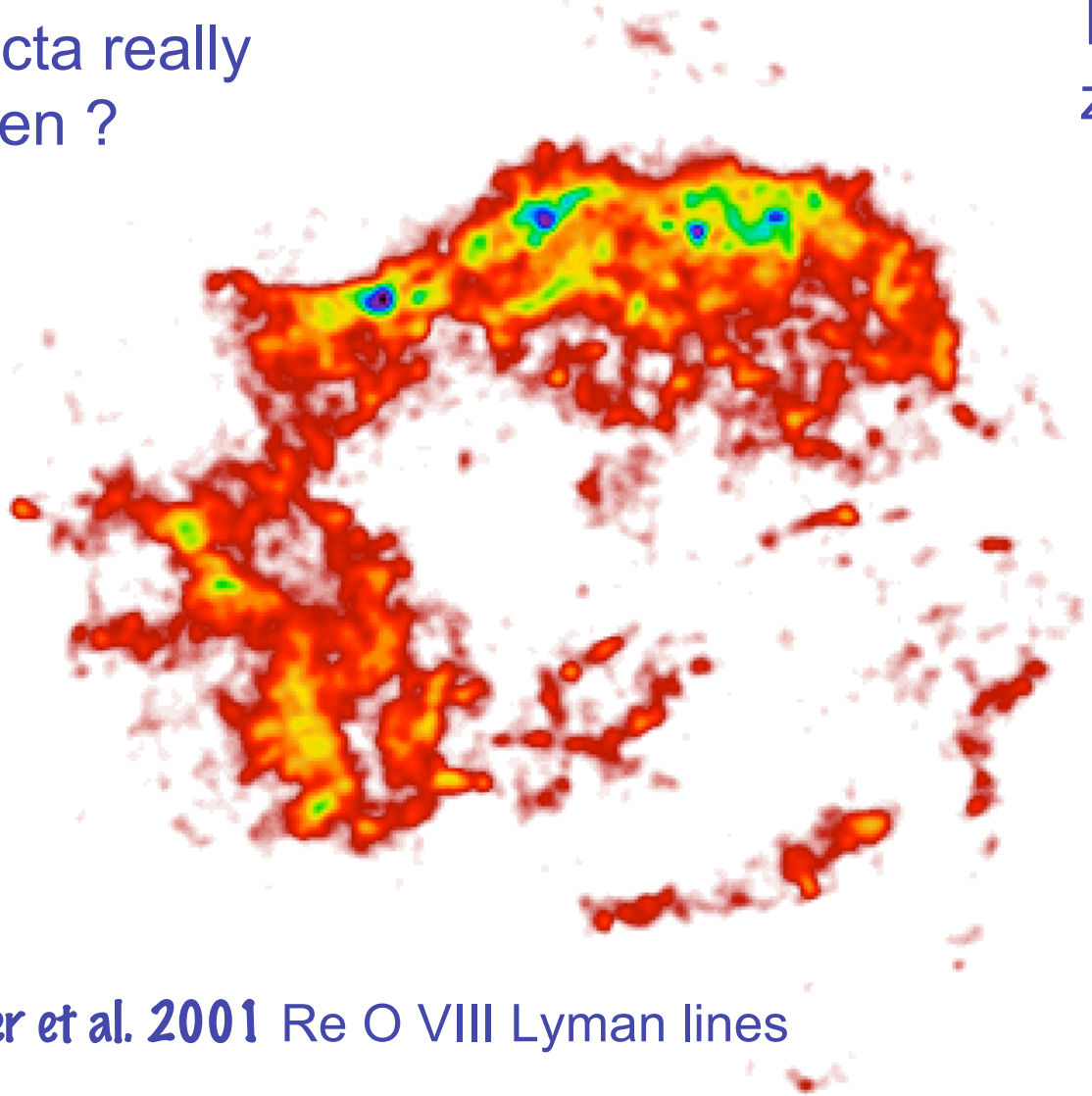


After passing the reverse shock, the velocity of each component changes based on density. The snap-shot here, at a time when the first optical (red) clumps have reached the right edge, demonstrates the 3:2:1 post-shock velocity ratio of the components.

Looking for the Oxygen…

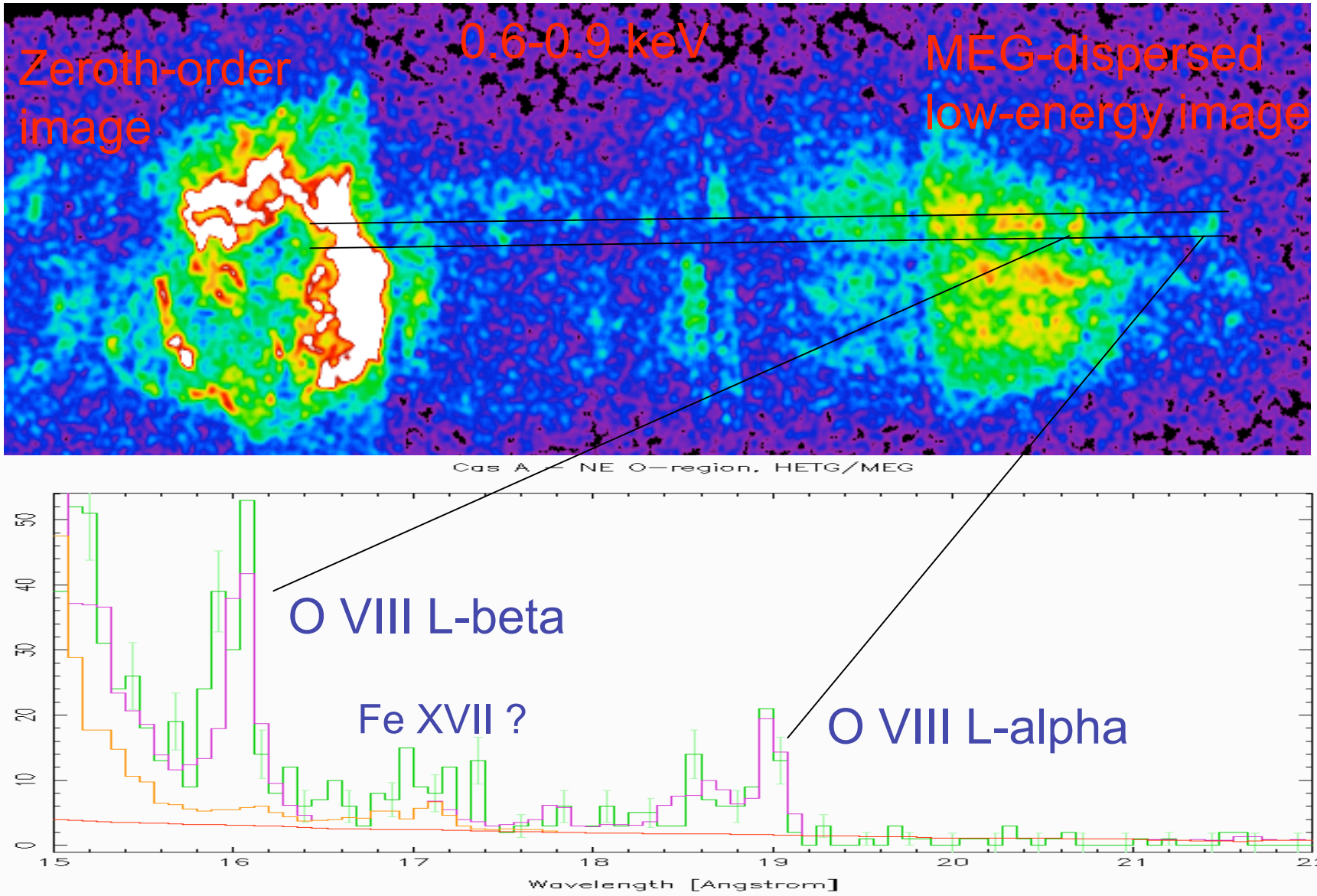
Image in 0.50-0.99 keV From HETG zeroth-order

Are the ejecta really full of oxygen ?



See also **Bleeker et al. 2001** Re O VIII Lyman lines

Can HETG see the Oxygen ?



Summary and Future work

HETG gives high-res information on Cas A X-ray knots

To do:

- Create a knot catalogue to coordinate analyses.
- Confirm/calibrate Chandra 1 Ms Doppler values.
- Create a coarse 3D model of Cas A ("as-is") based on data - filled with oxygen ?

Thank you

Audience Comment…

Martin Laming: The s=2 wind solution, e.g. Chevalier & Oishi 2003 (Fig.2) shows density enhancement at the CD: so these high densities are expected.

The CD radius then varies around the remnant producing the range of radii seen for your high-density regions.

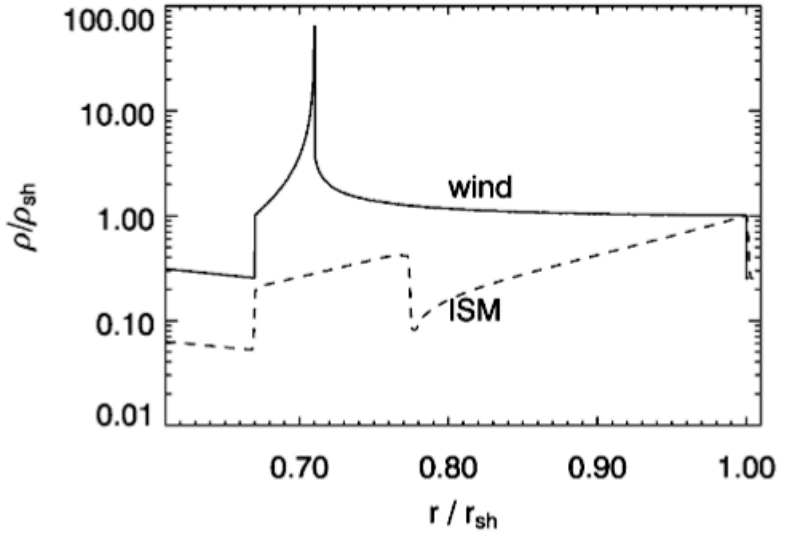
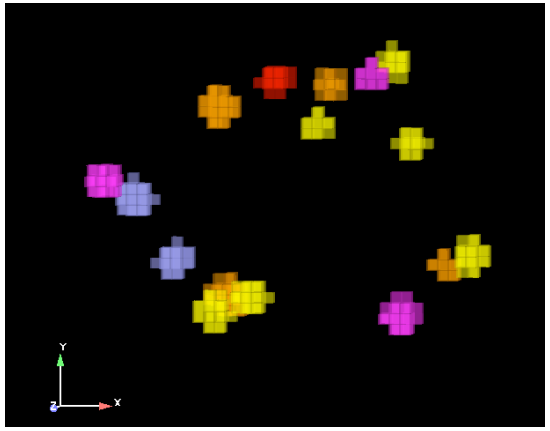
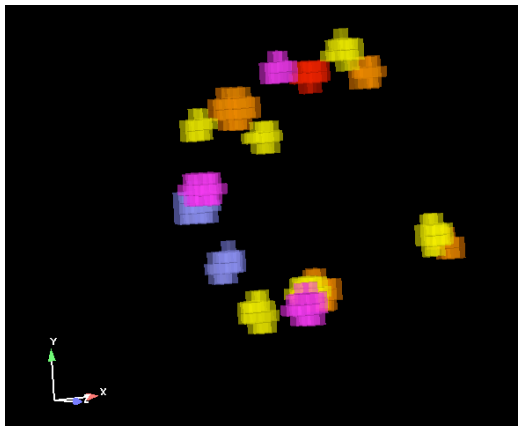


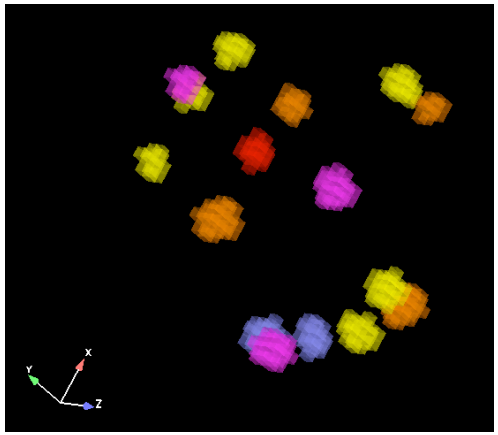
FIG. 2.—Density profile labeled "wind," which is the same model as in Fig. 1 shown when $r_f'/r_r' = 1.5$. The "ISM" model has the same supernova model but is running into a constant density medium. The density and radius are scaled to the values at the outer shock front. The value of r_f'/r_r' is chosen to be close to that observed in Cas A.

Audience Question…

Rob Fesen: Past optical results of Reed and current analysis of the Chandra 1 Ms observation show that there are patterns, e.g., large rings, to the emission. Do you see that in your data ?







DD: We only have the 17 regions shown here which is not enough to conclusively show these kind of structures. That said, there does seem to be other structure to them when viewed in 3D at other angles…

Perhaps a useful outcome of this work will be to "calibrate" the Chandra ACIS gain to improve the quality of the 1 Ms Doppler values and thus the accuracy of the structures seen.