A Principal Components Analysis Applied to the Cas A Megasecond

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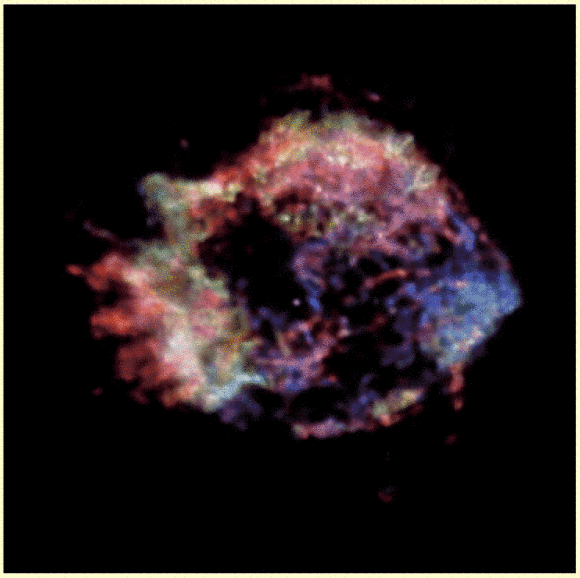
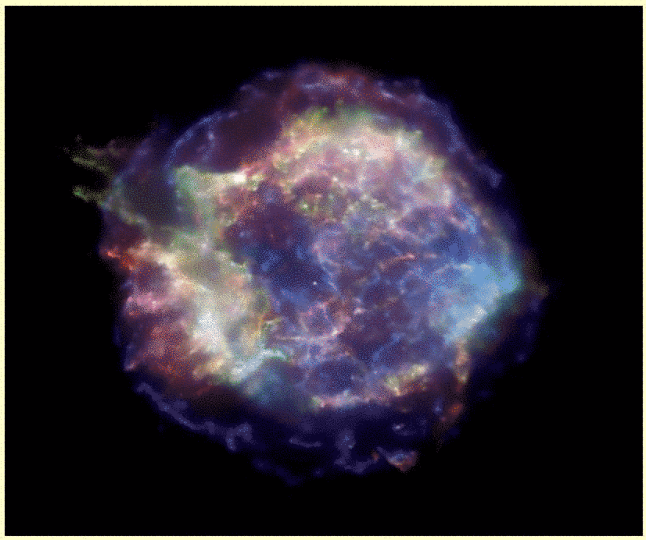
Cas A – 5,000 sec

- Hughes et al. 2000
  - Evidence for mixing, overturning of ejecta
  - Fe exterior to Si



Cas A – 50,000 sec

- Hwang et al. 2000
  - Map X-ray emission
- Gotthelf et al. 2001
  - Forward & reverse shocks
- Laming & Hwang 2003
  - Ejecta profile
- Hwang & Laming 2003
  - Pure Fe knots
- DeLaney et al. 2004
  - Kinematics
- And others…

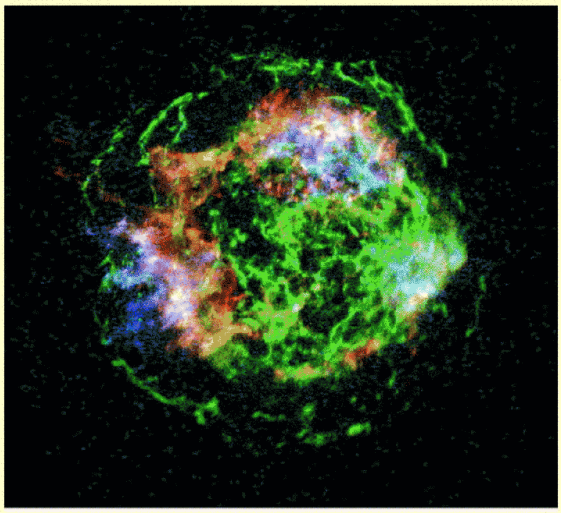


Note: green areas are Si-rich

Cas A – 1,000,000 sec

- Hwang et al. 2004
  - Jet
- "… extract spectra with suffi[illegible] noise f[illegible] fitting from *each pixel of the ACIS CCD…*"
  - Laming & Hwang 2005

Yikes!



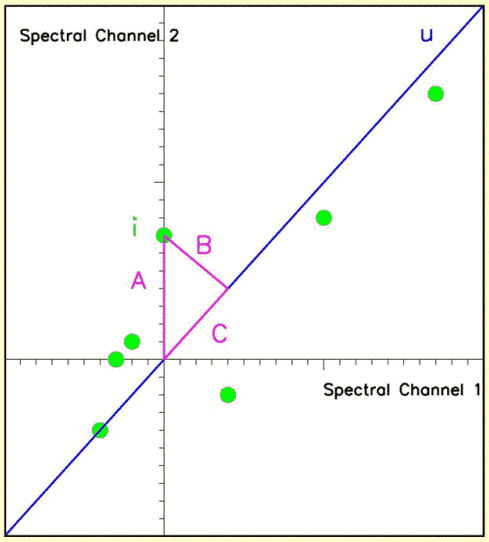
Note: red areas are Si-rich

Some help, please…

One way to get a handle on this rich dataset is to use a **Principal Components Analysis** (PCA):

- A statistical technique often used to **reduce the dimensionality** of a dataset
- Relatively unbiased technique for identifying spectral variations in a statistically quantifiable way

Principal Components Analysis

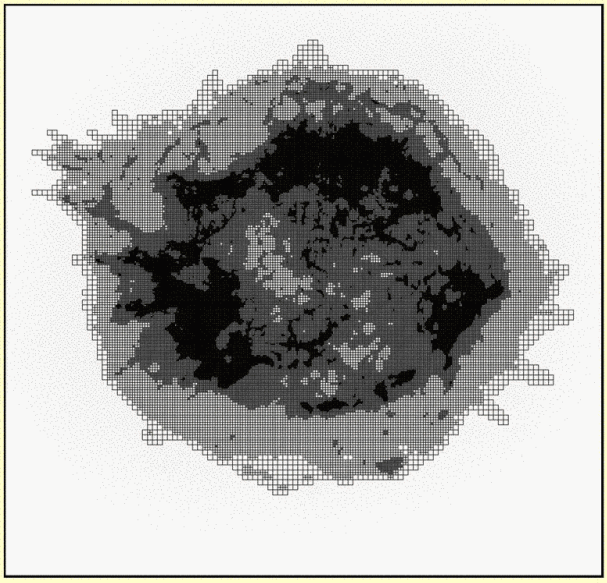


Cartoon illustration of PCA

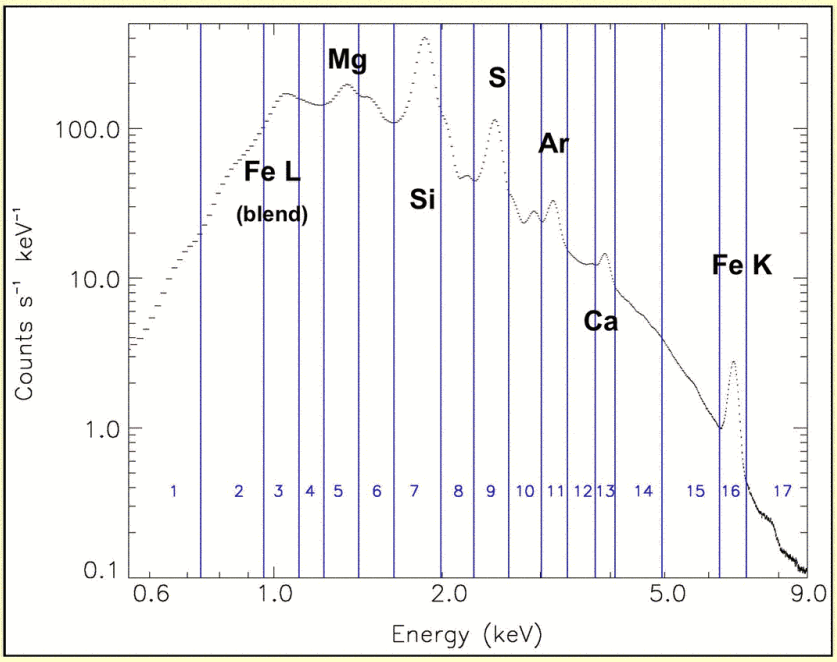
- PCA finds new variables (**U**) that maximize the variance (**C**) of the data (●)
  - The new variables (axes) are orthogonal to each other
- **U** is a linear combination of the old variables (**Spectral channels 1 and 2**)
  - **U** is an *eigenvector* of the data matrix

PCA applied to SNRs

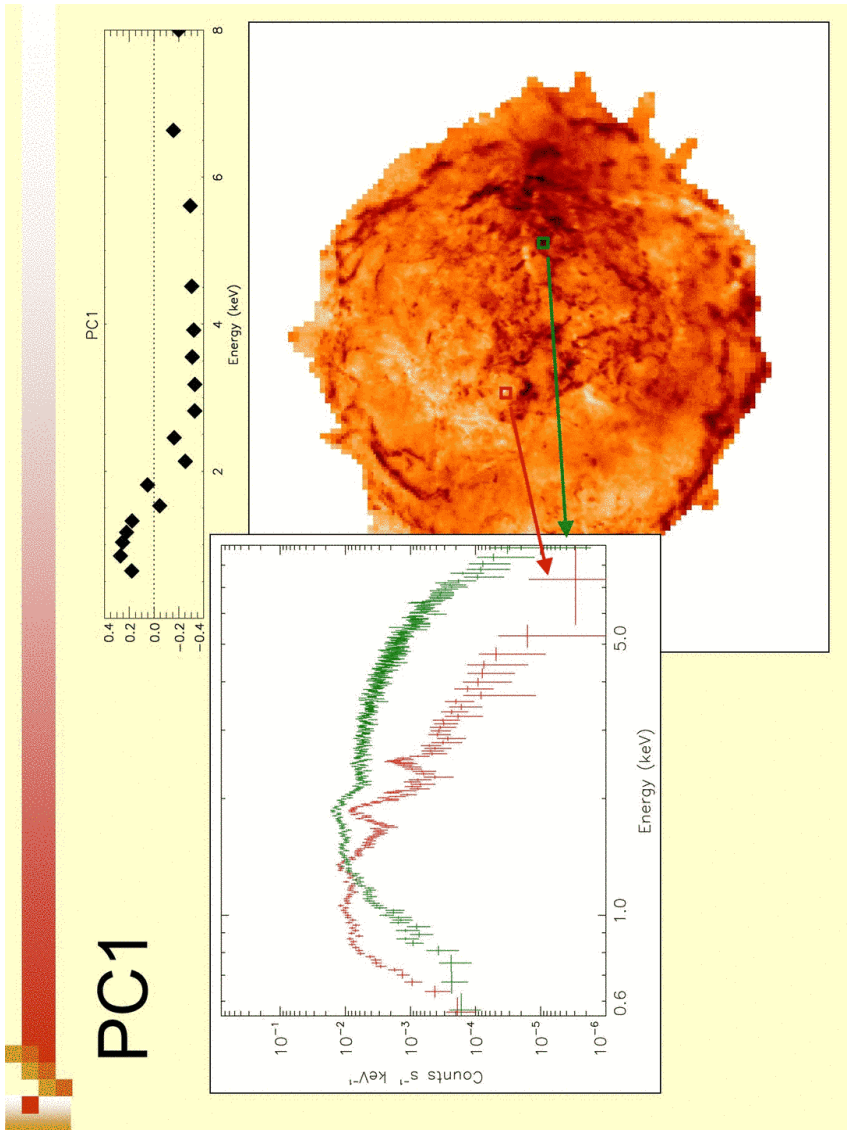
- Our data: **spectra** from many spatial **regions** in the SNR
- Divide remnant into square regions
  - Each with at least 1000 counts
  - ~ 0.5” x 0.5” to 4” x 4”
  - 125,181 regions

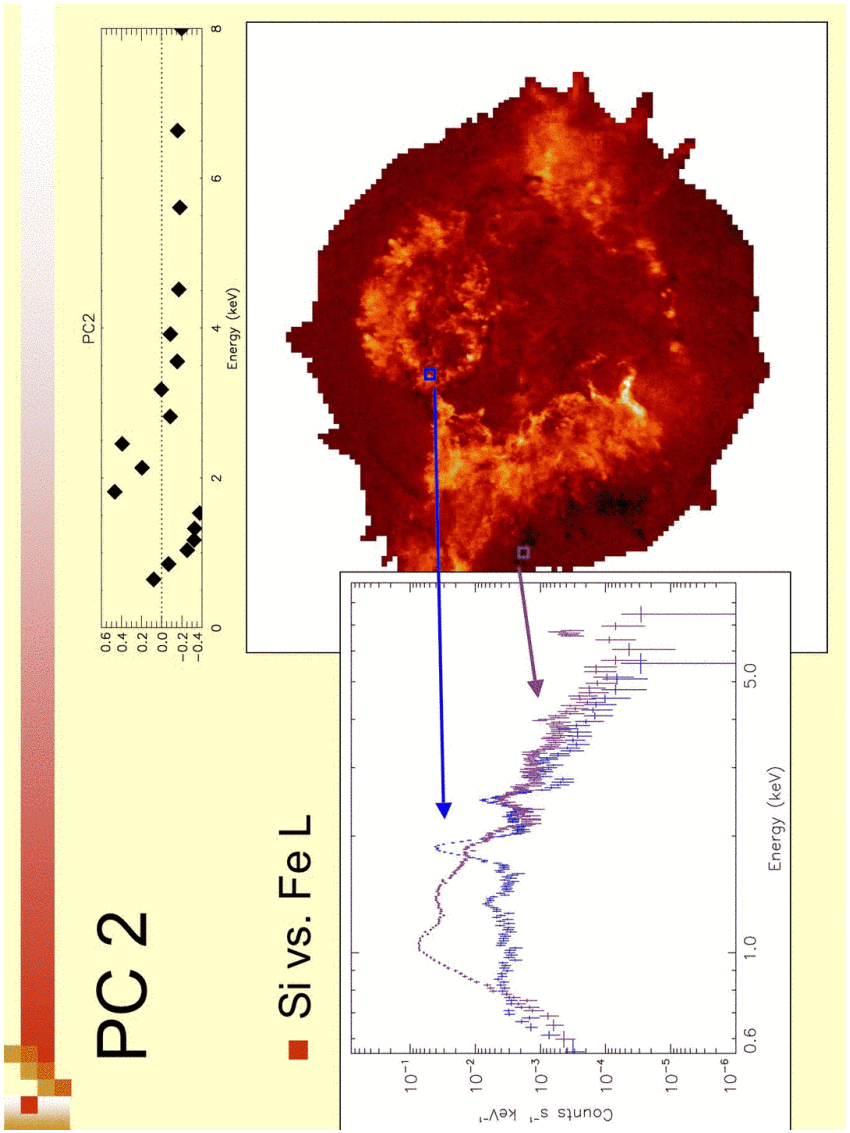


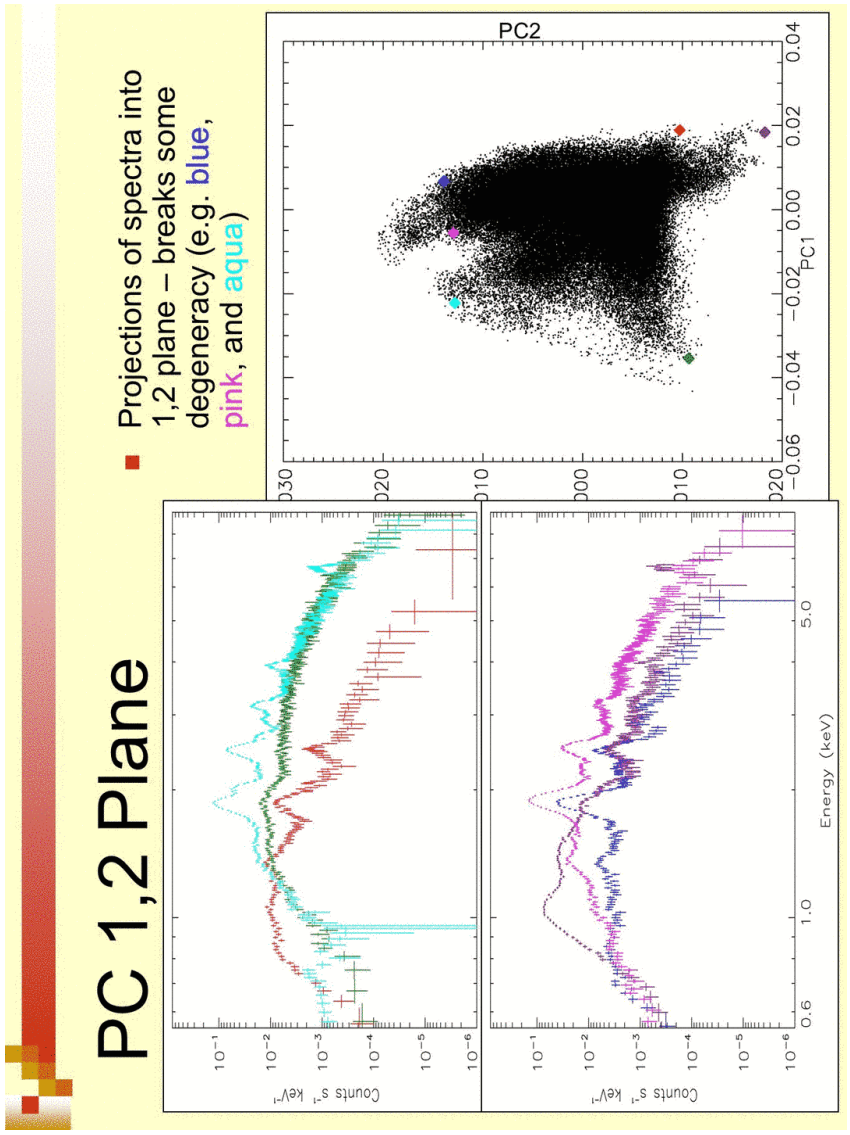
Spectral Binning

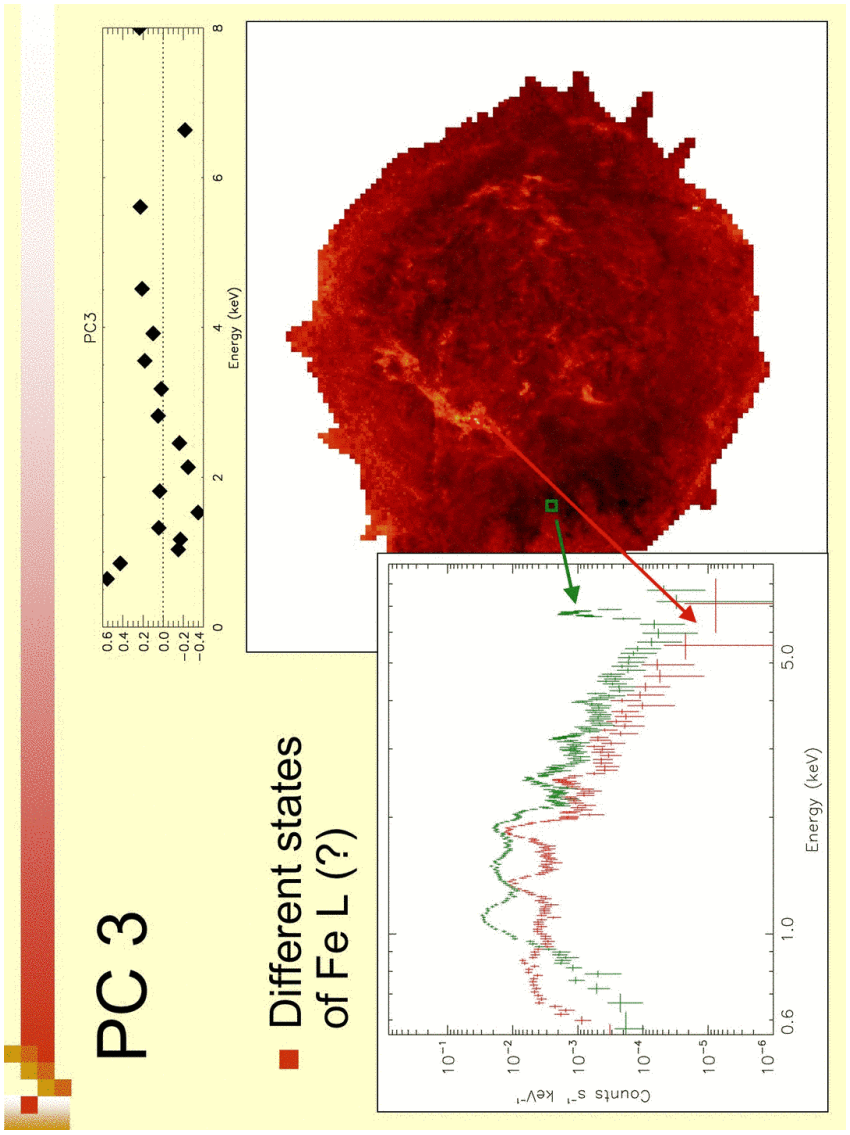


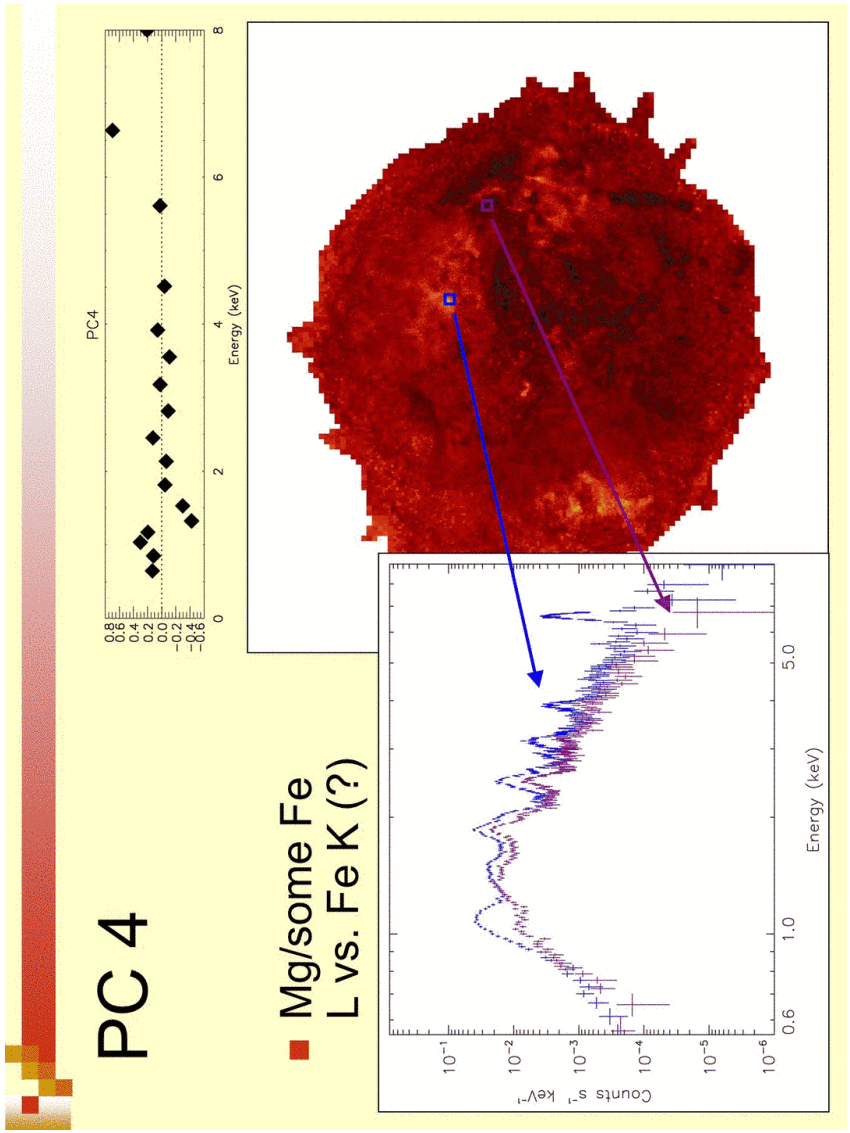
- Isolate certain features from integrated spectrum
- Each regions’ spectrum is binned in this way

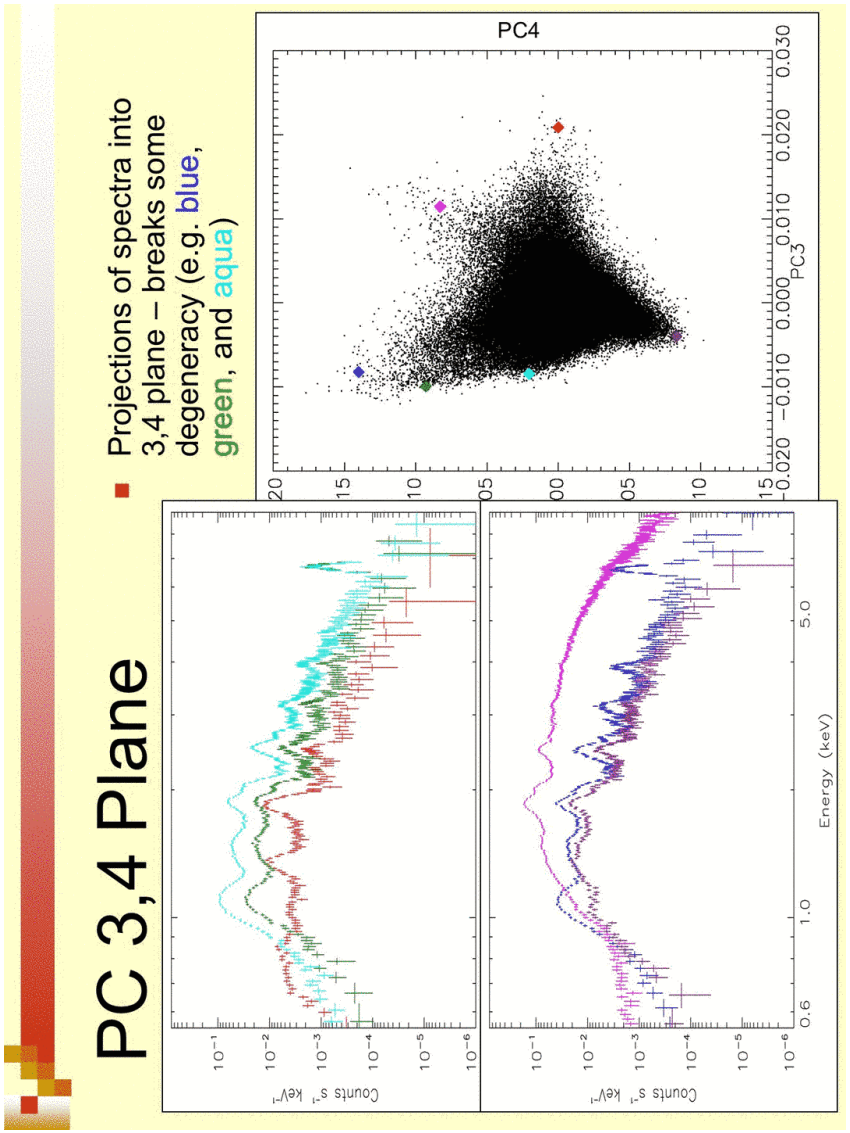

PC1
PC1
Energy (keV)
Counts s⁻¹ keV⁻¹
Energy (keV)


PC 2
Si vs. Fe L
PC2
Energy (keV)
Counts s⁻¹ keV⁻¹
Energy (keV)


PC 1,2 Plane
Projections of spectra into 1,2 plane – breaks some degeneracy (e.g. blue, pink, and aqua)
PC2
PC1
Counts s⁻¹ keV⁻¹
Energy (keV)

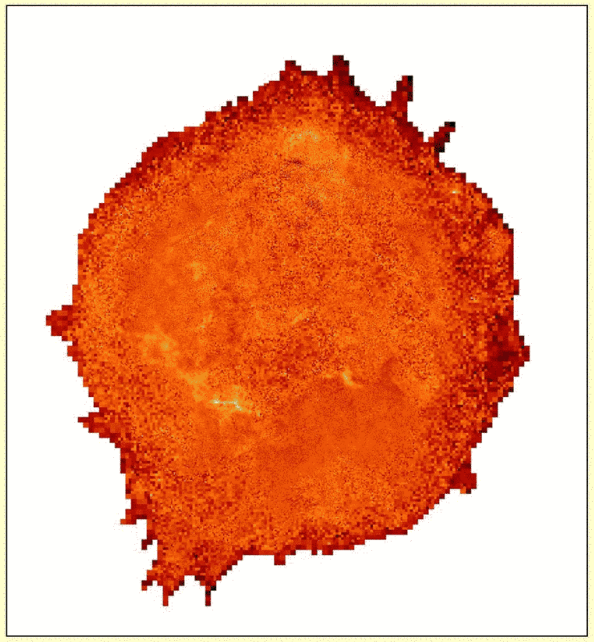

PC 3
Different states of Fe L (?)
PC3
Energy (keV)
Counts s⁻¹ keV⁻¹


PC 4
Mg/some Fe
L vs. Fe K (?)
PC4
Energy (keV)
Counts s⁻¹ keV⁻¹
Energy (keV)


PC 3,4 Plane
Projections of spectra into
3,4 plane – breaks some
degeneracy (e.g. blue,
green, and aqua)
PC4
PC3
Counts s⁻¹ keV⁻¹
Energy (keV)

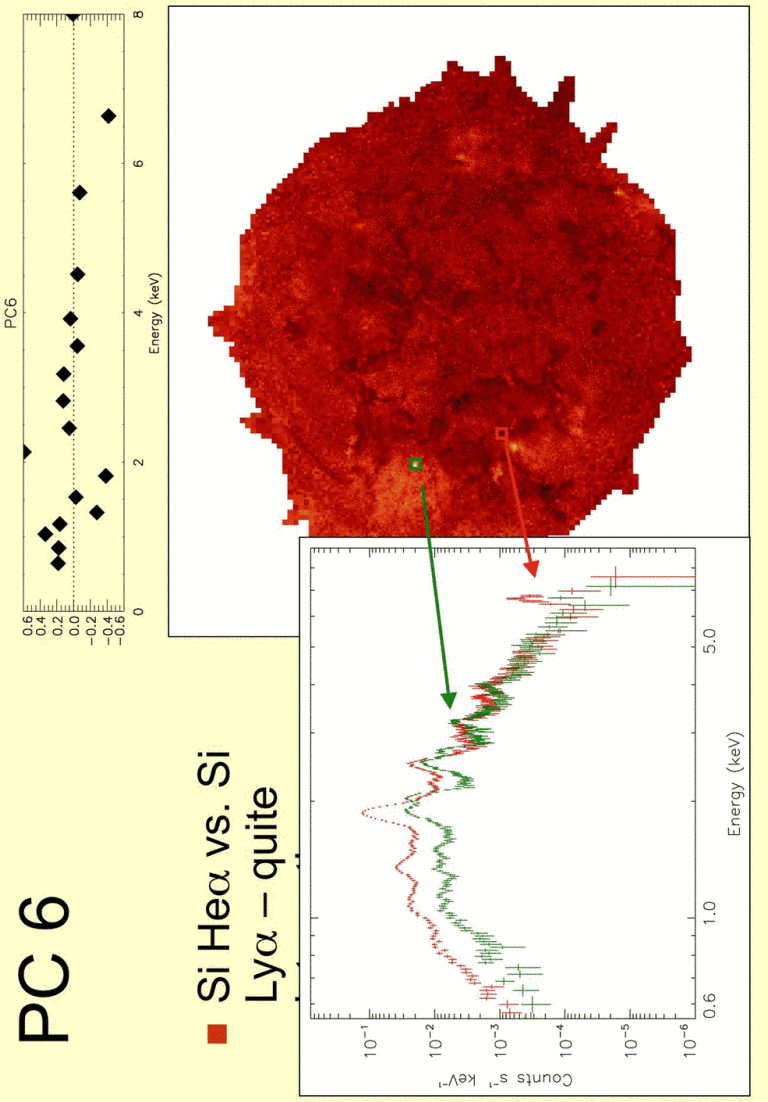
PC 5

- Background – not so interesting



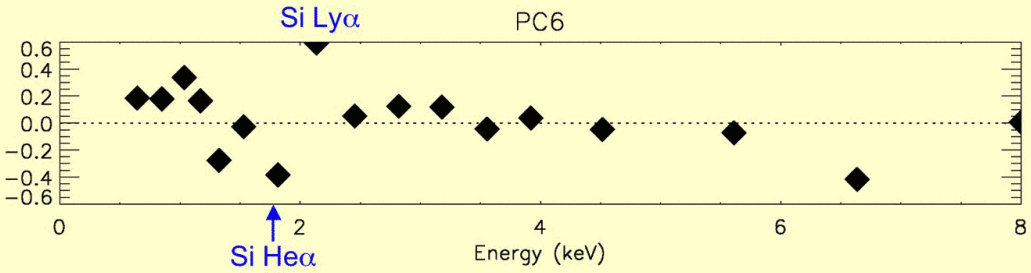
PC 6

- Si Heα vs. Si Lyα – quite



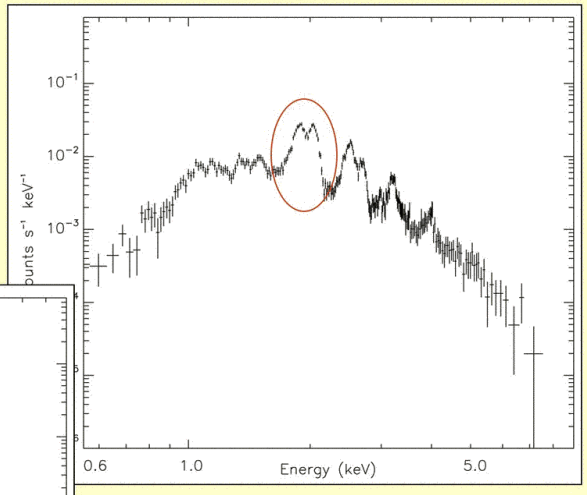
Where do we go from here?

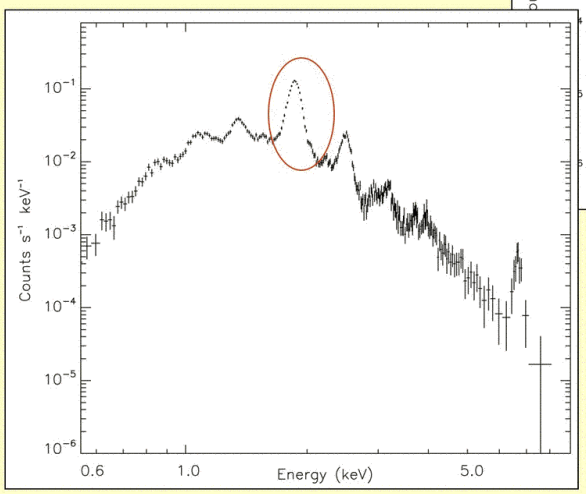
- PCs are helpful:
  - Organize spectral classes
  - Provide spatial information
  - Indicate regions of potential interest
- PCs are complicated:
  - Not really a simple interpretation
  - Except, perhaps, for PC6 – start here



Spectra

- Nearly **equal** Heα and Lyα fluxes (bright PC6 region)

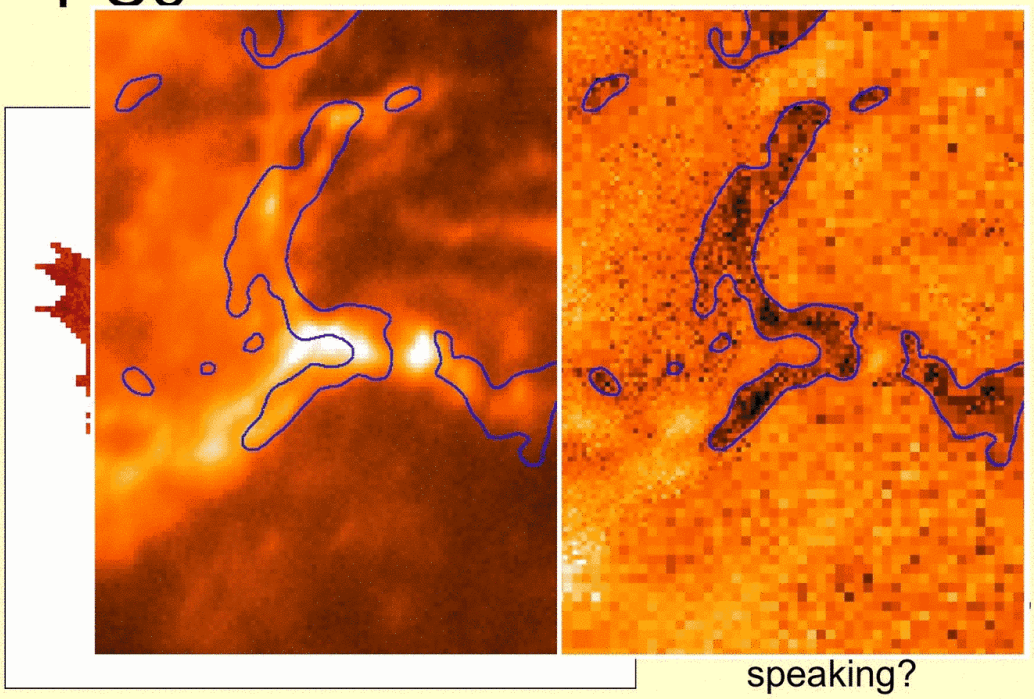




- Heα much **stronger** than Lyα (dark PC6 region)

PC6

- Main variation in

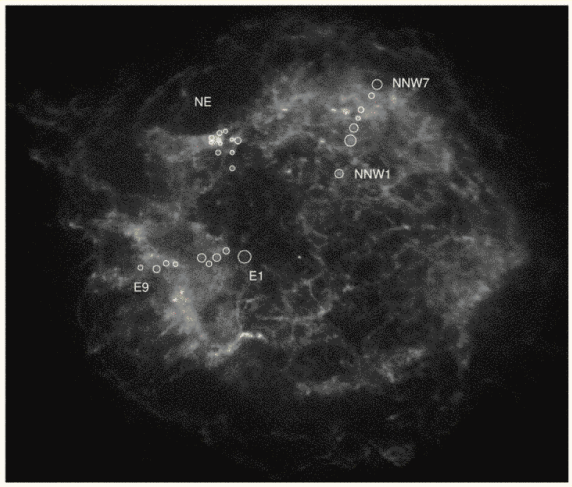


- Relate PC6 to

speaking?

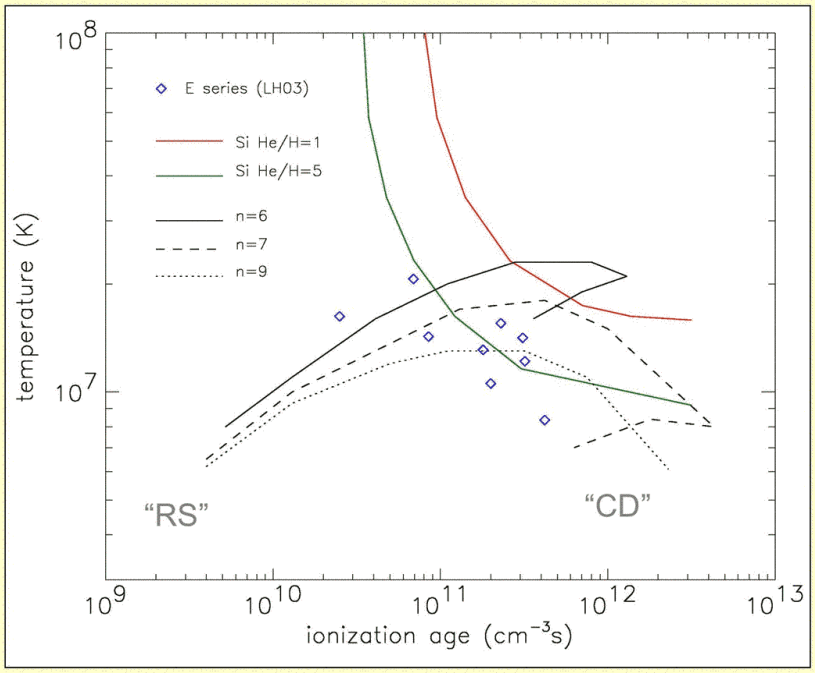
Context – Laming & Hwang 2003

- Spectra from radial series of knots
  - Fit for temperature and ionization age
  - Compare to those values from models of a knot's thermodynamic evolution
    - Depends on ejecta density profile power law index



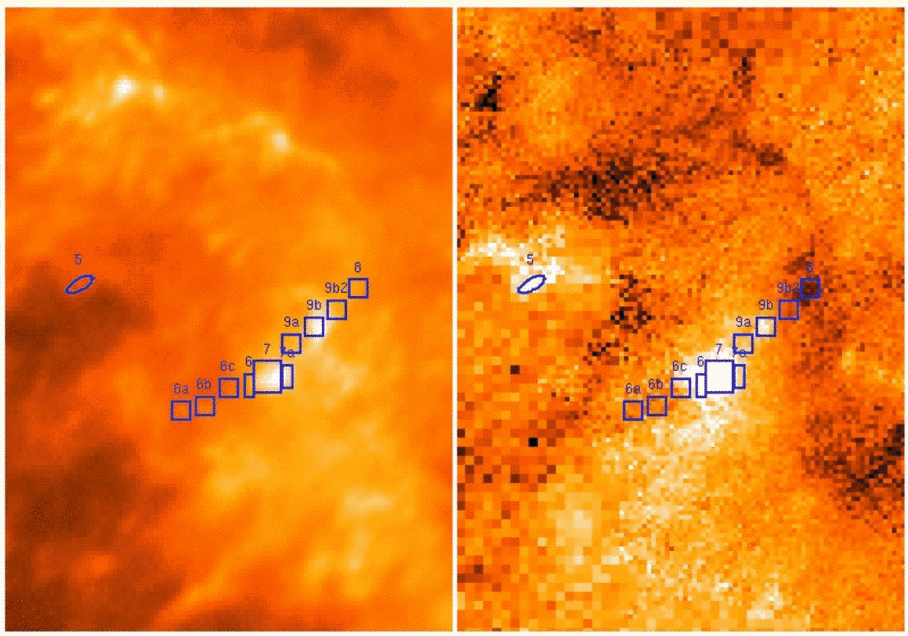
Temperature vs ionization age

- Adapted from Fig. 6 of LH03
- E series agrees mainly with $n = 9$
- We will use PC6 to choose a similar radial series of knots



Silicon Valley

Broadband

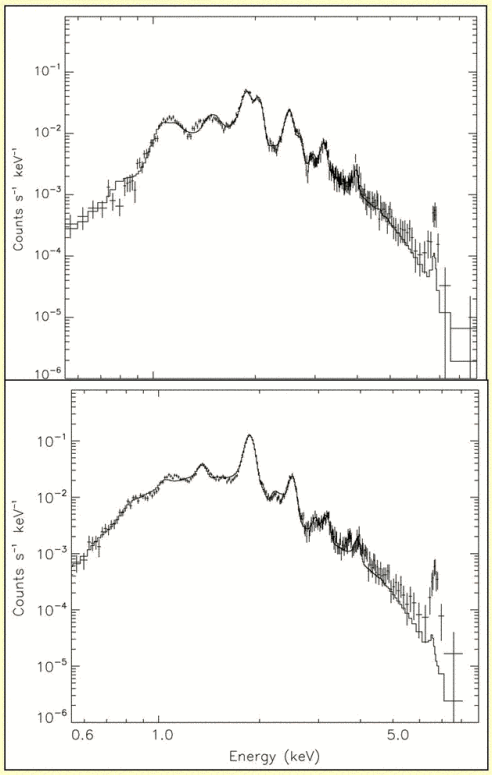


PC6

Spectral Fits

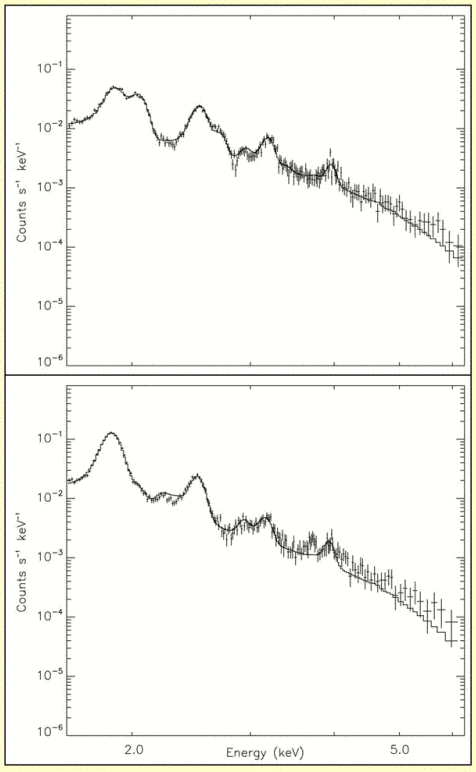
(Follow LH03)

- Single ionization timescale
- Oxygen continuum
- Fe L, K, and continuum not fit so well
- Look at band from Si to just below Fe K (1.6 – 6.25 keV)



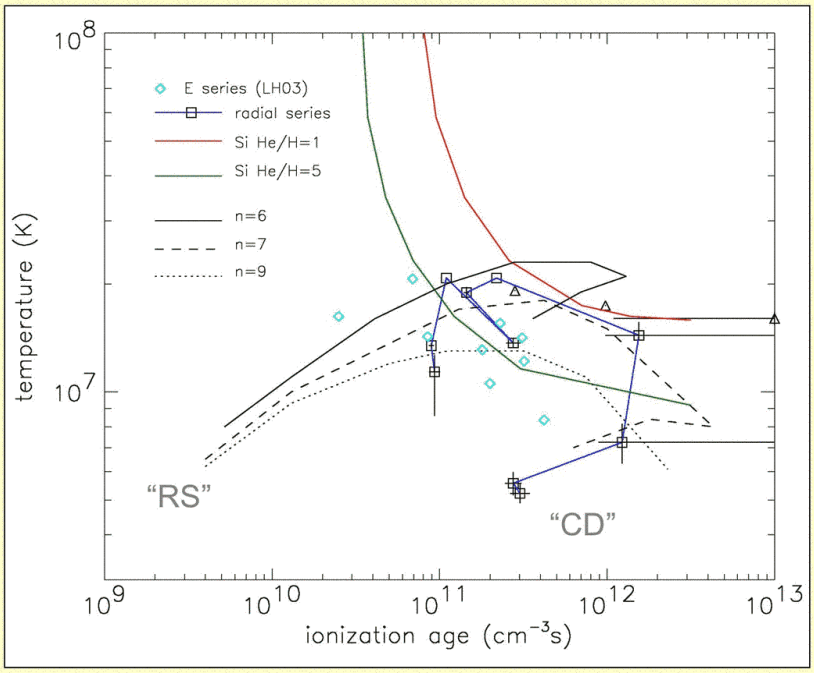
Assumptions

- Fe in spectra is likely due to projection
  - Treat as separate component
  - Ignore in high energy fits
- Temperature from continuum
- Ionization state from lines



Temperature vs ionization age

- Found knots with higher $n_e t$
- Radial series seems to agree better with $n = 7$
- Digesting results…



Preliminary Conclusions

- PC6 shows high vs. low Si ionization states
  - Only a few isolated areas with nearly equal Heα and Ly α fluxes – **why?**
  - Possibly higher ionization state near jet – analyze another radial series there