# Constraining the total baryon number of the universe with XMM-Newton high resolution spectra

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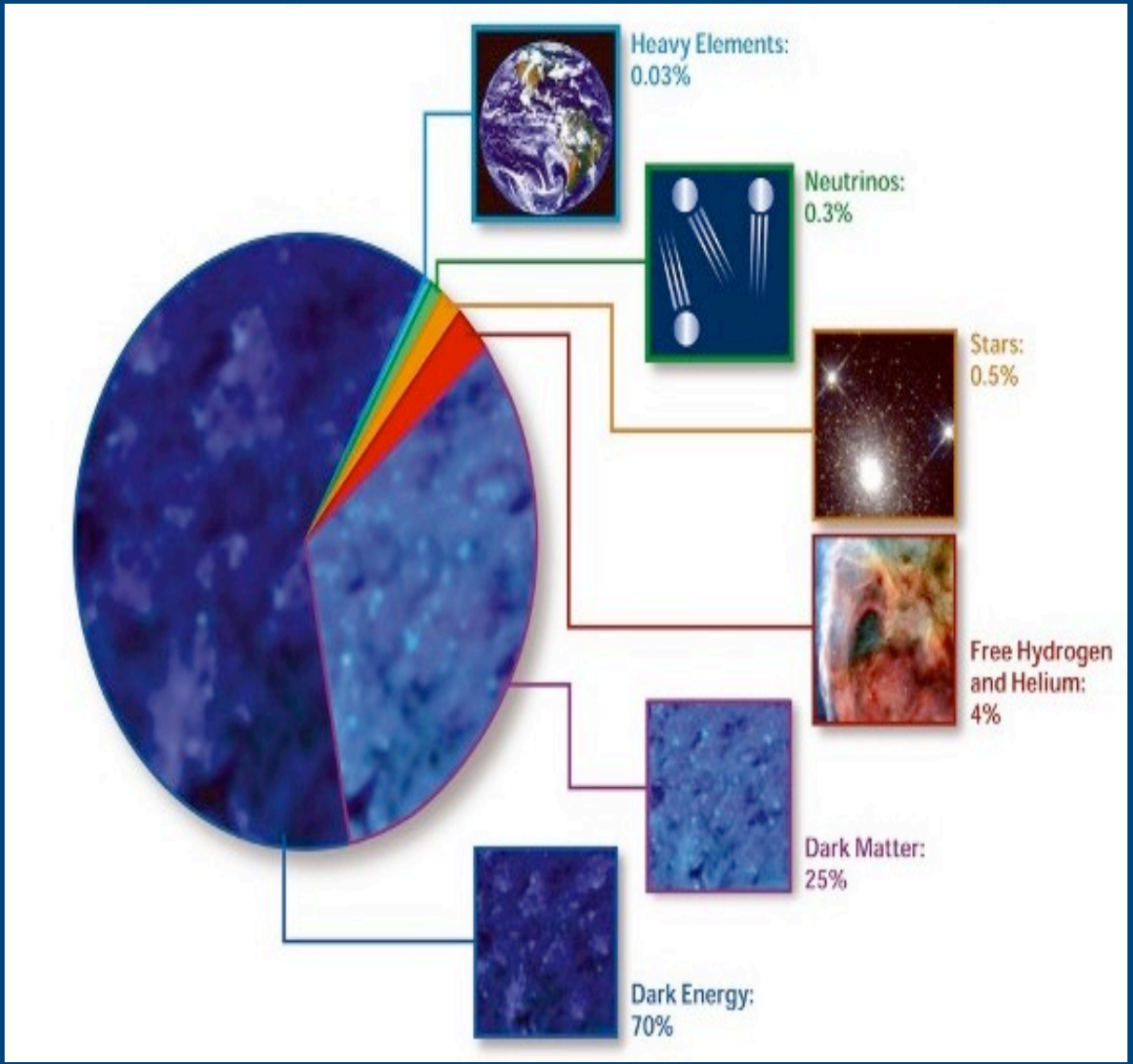
# *Where are the missing baryons?*

How our friend XMM-Newton can help us to find them

# Universe Composition




- Dark Energy 70%
- Dark Matter 25%
- Ordinary Matter 5%

# Ordinary Matter

- Hadrons (suffer electroweak and strong interactions)
  - Baryons (fermions)
    - Composed by three quarks
    - Proton, neutron
  - Mesons (bosons)
    - Composed by one quark and one antiquark
    - Unstable
- Leptons (suffer electroweak interaction)
  - ¨Leptos¨ = light
  - Electron, muon, tauon and neutrinos

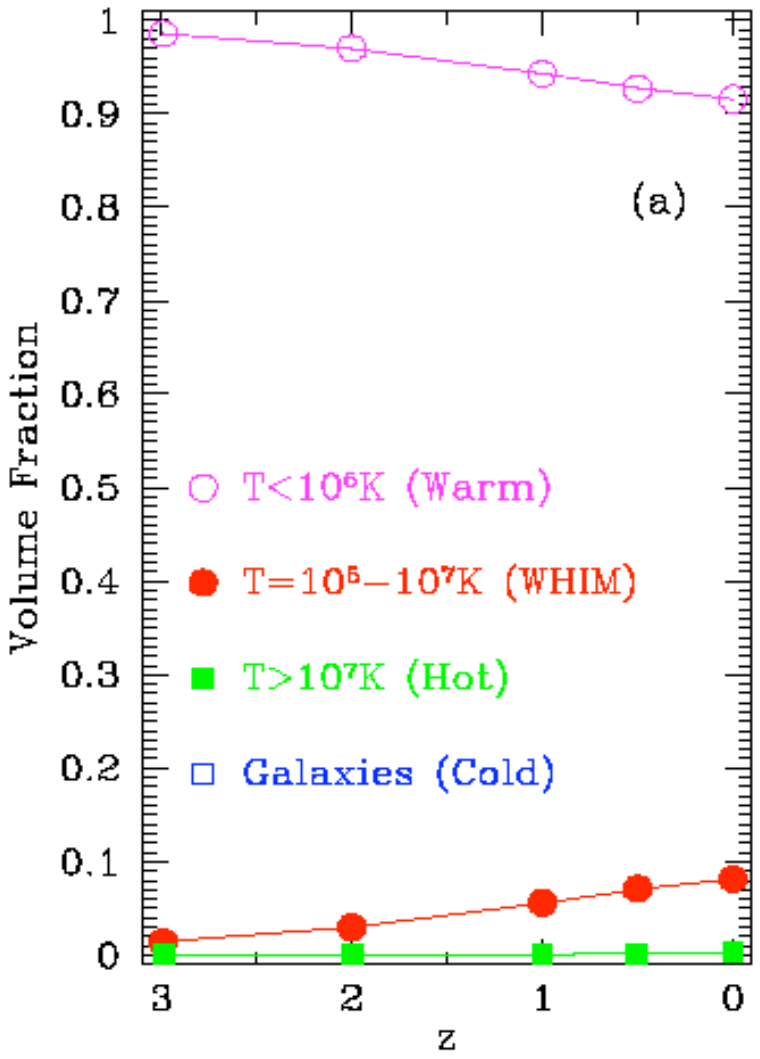
# *Baryons appear in the past and hide in the present*

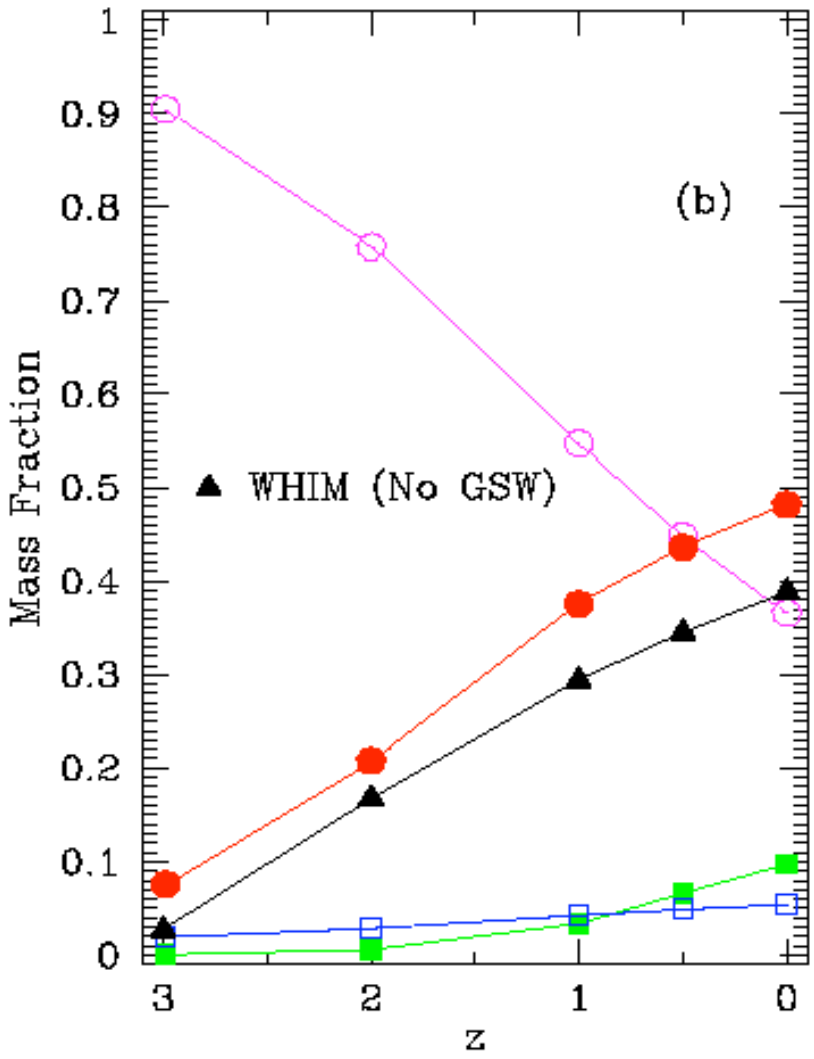
- High Redshift z : baryon number OK
- Low Redshift z: 45 % missing

Table 1 **Census of baryons in the high-and low-redshift Universe**

| Inferred from | $\Omega_b$ (%) for $h_{70} = 1$ |
|---|---|
| BBN + D/H* | (4.4 ± 0.4) |
| CMB anisotropy | (4.6 ± 0.2) |
| Observed at $z > 2$ in† | |
| Lyman-α forest | >3.5 |
| Observed at $z < 2$ in‡ | |
| Stars | (0.26 ± 0.08) |
| H I + He I + $H_2$ | (0.080 ± 0.016) |
| X-ray gas in clusters | (0.21 ± 0.06) |
| Lyman-α forest | (1.34 ± 0.23) |
| Warm + warm–hot O VI | $(0.6^{+0.4}_{-0.3})$ |
| Total (at $z < 2$)§ | $(2.5^{+0.5}_{-0.4})$ |
| Missing baryons (at $z < 2$)§ | $(2.1^{+0.5}_{-0.4})$ |

# Cosmological Simulations



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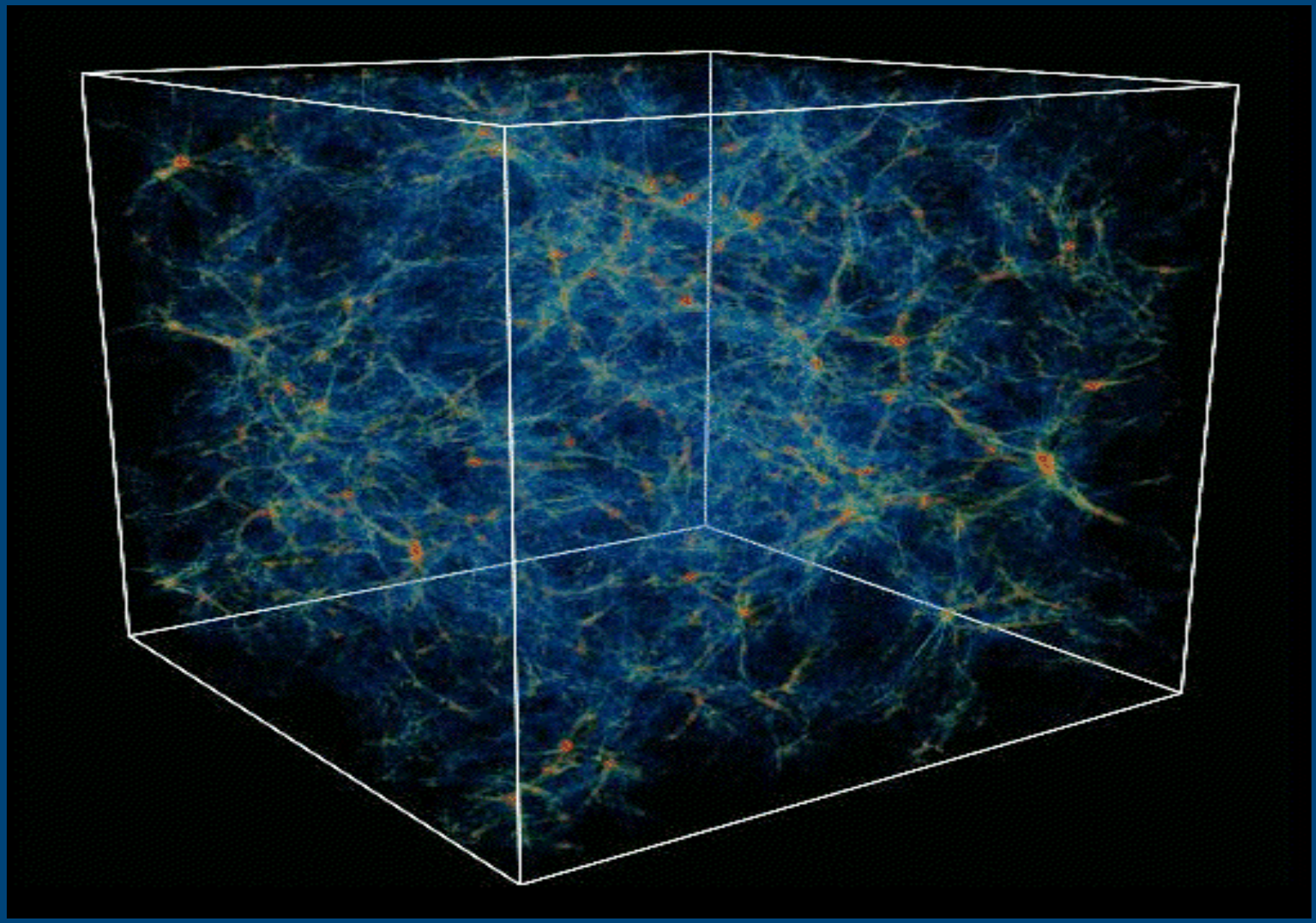
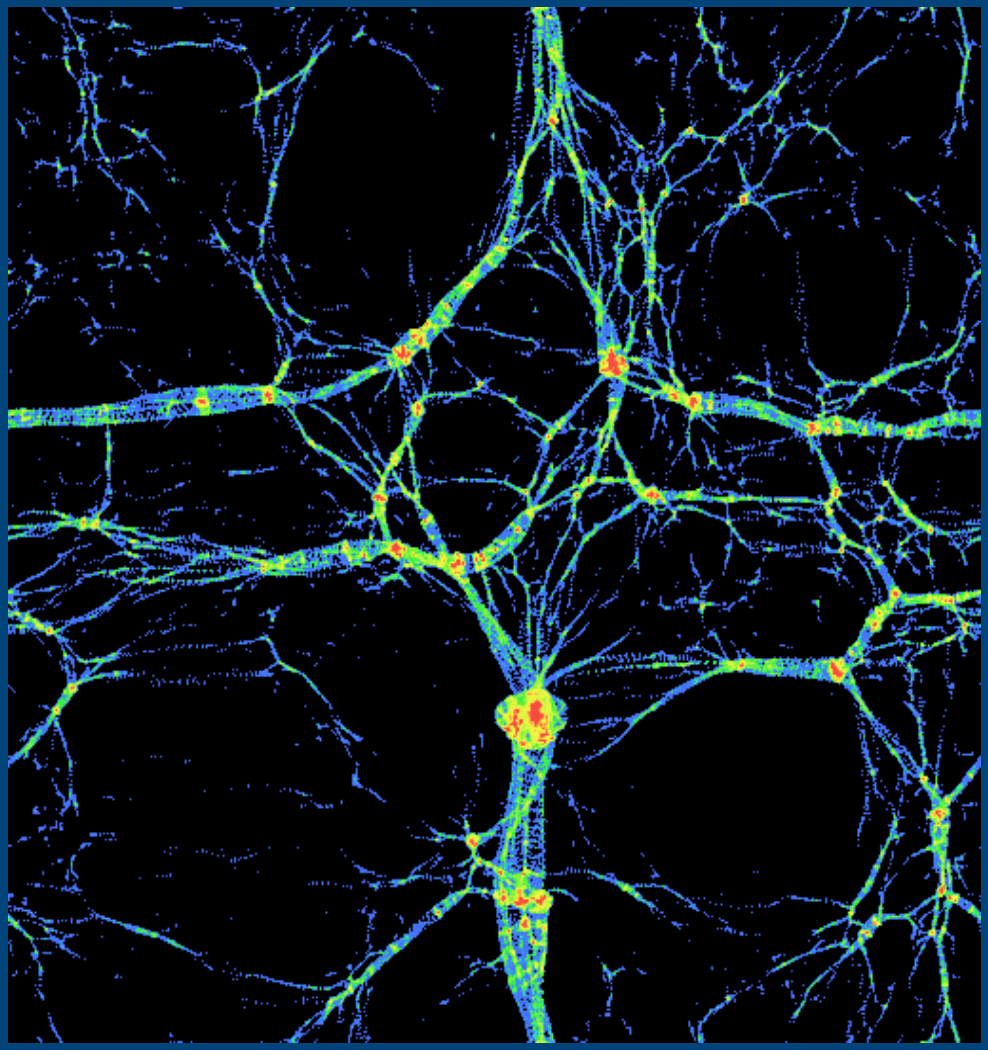
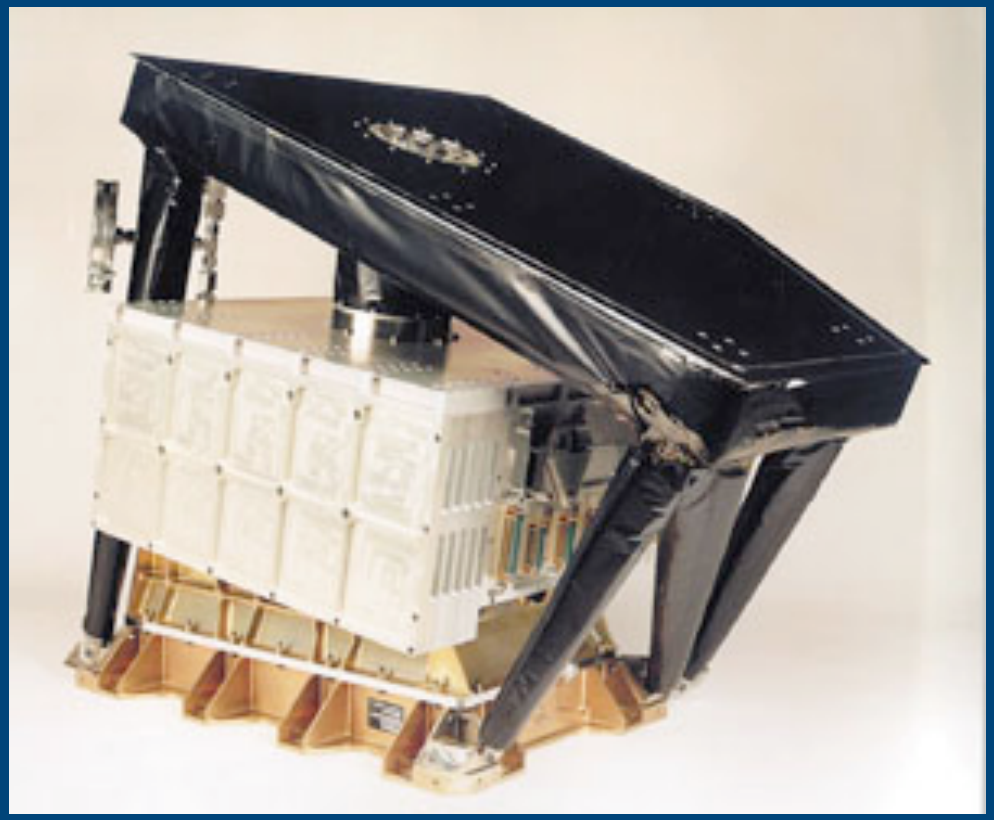


# How can we detect WHIM?



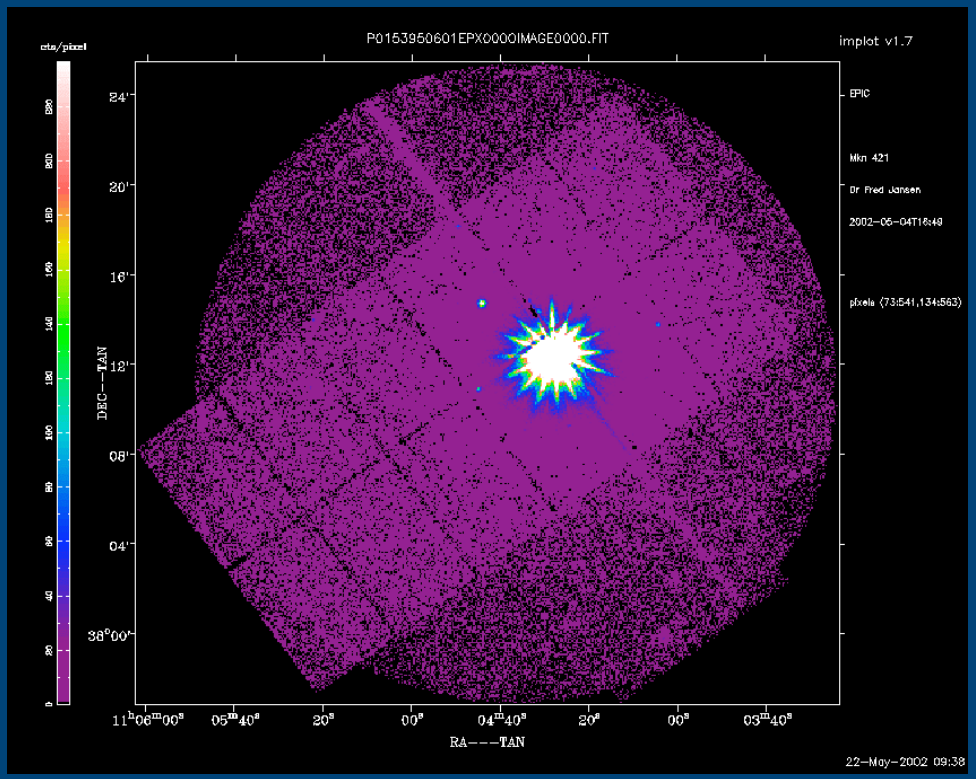
- Baryon Matter: Ionized Atoms
  - H-like
  - He-like
- High resolution soft X-ray absorption spectroscopy:
  - RGS (XMM-Newton)
- X-ray Transitions:
  - Candidate: O
    - O VII ($1s^2\ ^1S_0$-$1s2p\ ^1P_1$)
      - 21.602 Å
    - O VIII (1s-2p)
      - 18.969 Å

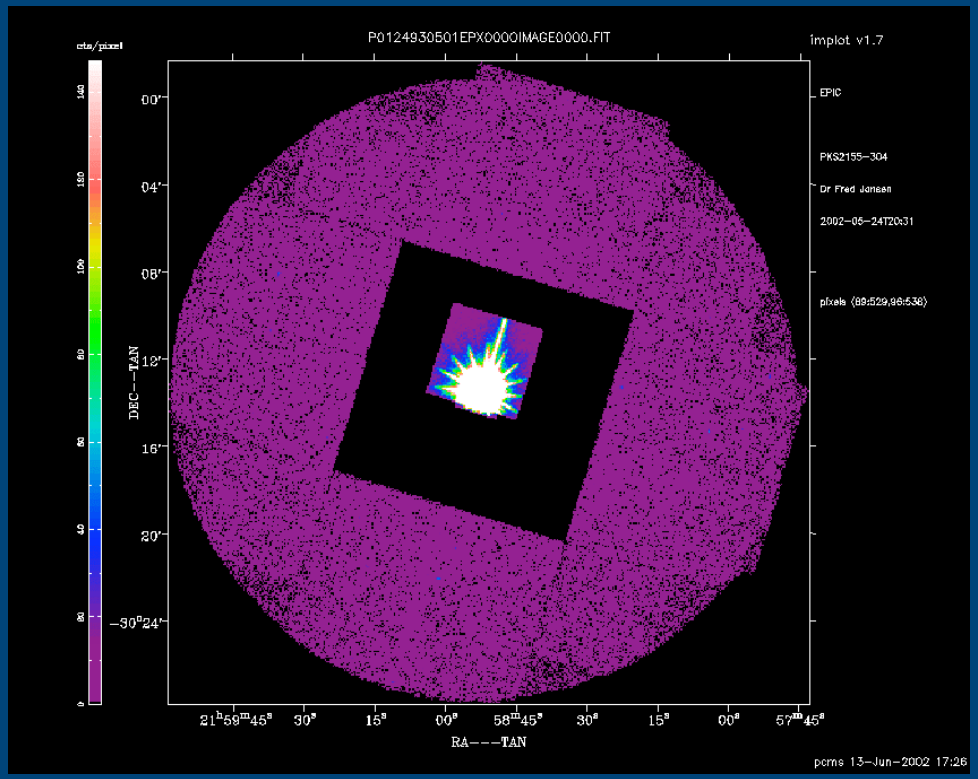
# Reflecting Grating Spectrometer (RGS)



- Two RGS on board XMM-Newton
- High resolution soft X-ray spectroscopy:
  - High resolving power (150 to 800)
  - Range from 5 to 35 Å [0.33 to 2.5 keV]
- X-ray Transitions within the range:
  - Heavy elements
    - L-shell
  - Light elements
    - K-shell transitions
    - He-like triplets

# Bright Extragalactic Continuum Sources Candidates

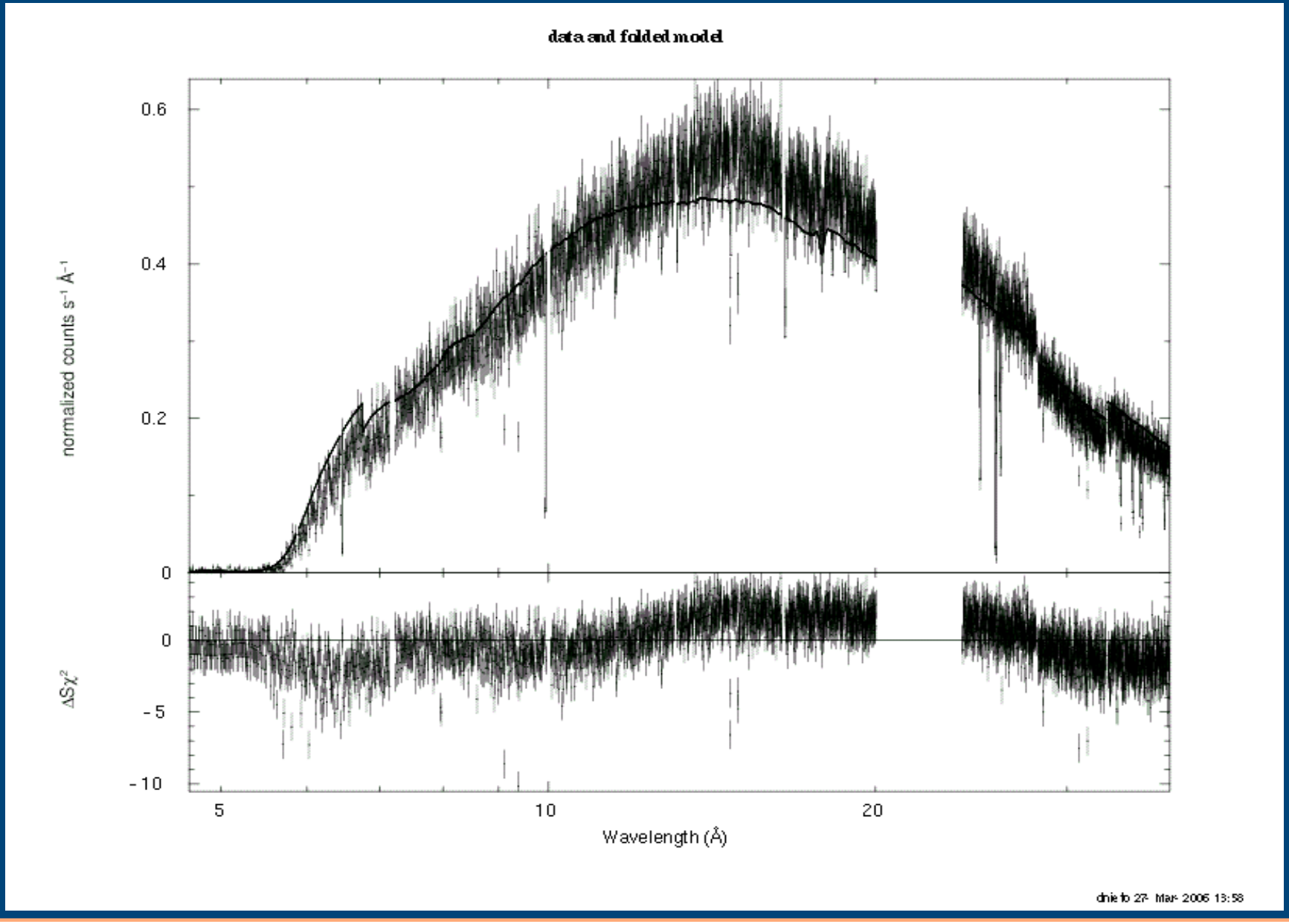



- **Mkn 421**
- **z = 0.03**

- **Pks 2155-304**
- **z = 0.117**

# XMM-Newton RGS data



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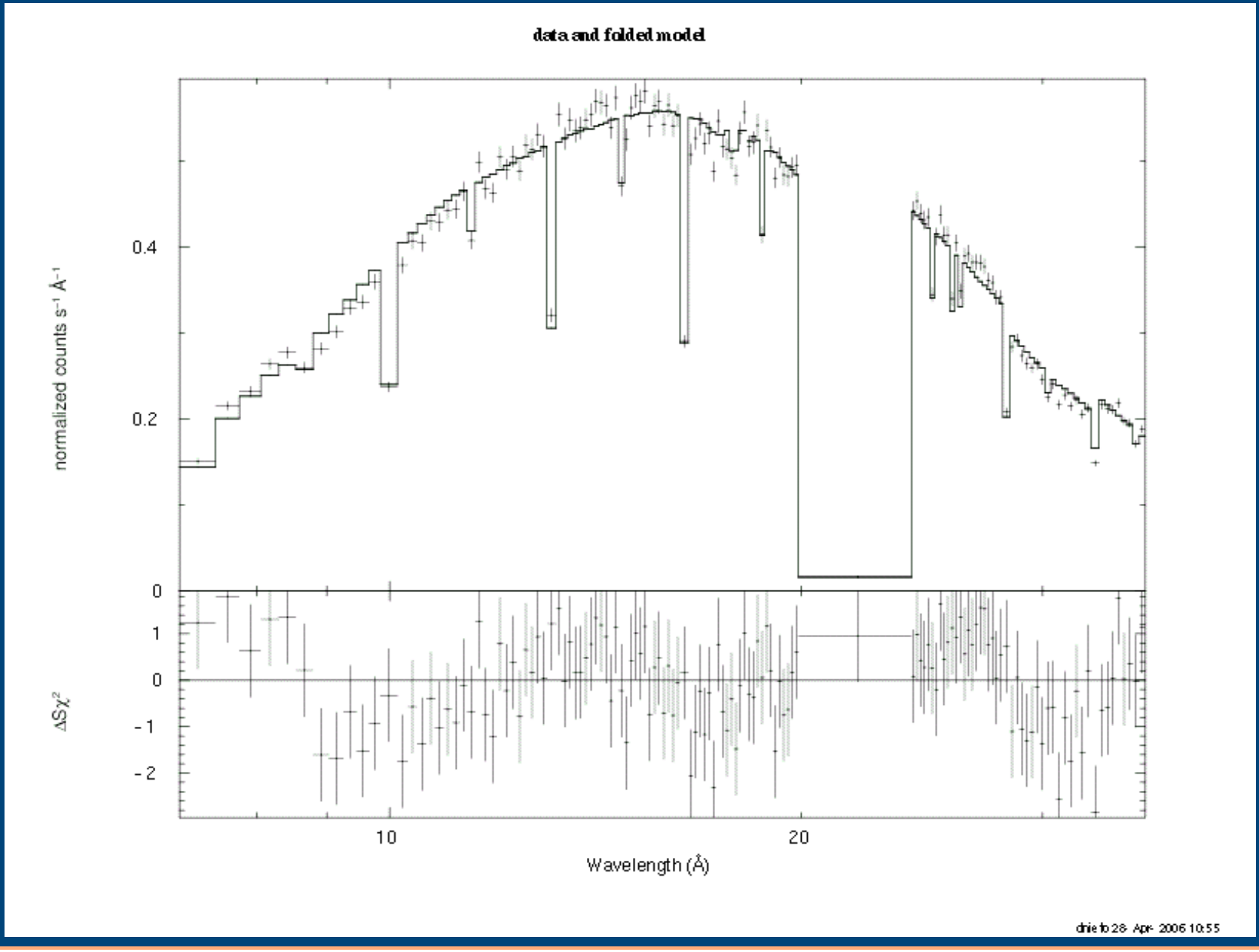

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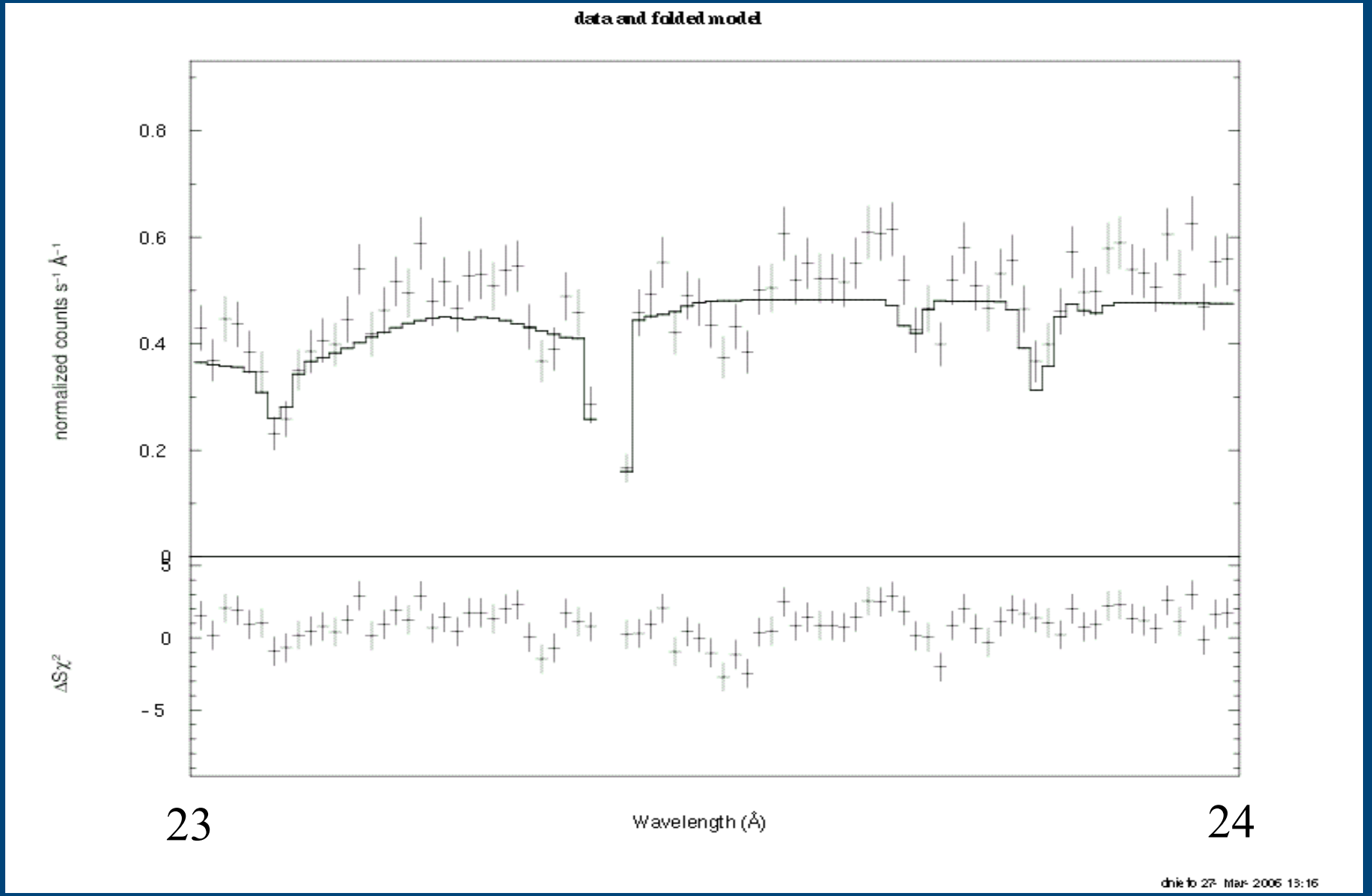

# XMM-Newton RGS data

Best fit parameters (powerlaw and broken powerlaw) with systematic error (3%) and fixed column density (nH=1.611*1(

| RGS | α1 | $E_b$ (KeV) | α2 | $F_{1\,KeV}$ (γ $KeV^{-1}cm^{-2}$ | $\chi^2$ | d.o.f. |
|---|---|---|---|---|---|---|
| 136540301 | | | | | | |
| 1 | 1.97 | | | 0.16 | 4.62 | 126 |
| 1 | 1.72 | 0.75 | 2.66 | 0.20 | 11.18 | 131 |
| 2 | 2.11 | | | 0.14 | 8.88 | 119 |
| **2** | **1.72** | **0.75** | **2.66** | **0.18** | **1.45** | **117** |
| 136540401 | | | | | | |
| 1 | 1.91 | | | 0.20 | 4.83 | 138 |
| **1** | **1.55** | **0.68** | **2.20** | **0.25** | **1.04** | **136** |
| 2 | 1.91 | | | 0.19 | 4.15 | 148 |
| 2 | 1.55 | 0.68 | 2.20 | 0.24 | 4.52 | 146 |
| 136541001 | | | | | | |
| 1 | 1.89 | | | 0.12 | 3.54 | 240 |
| **1** | **1.60** | **0.69** | **2.14** | **0.14** | **0.92** | **239** |
| 2 | 1.92 | | | 0.11 | 2.84 | 264 |
| 2 | 1.60 | 0.69 | 2.14 | 0.14 | 3.78 | 273 |
| 158970101 | | | | | | |
| 1 | 1.99 | | | 0.12 | 5.57 | 125 |
| 1 | 1.80 | 0.73 | 2.39 | 0.14 | 5.72 | 130 |
| 2 | 2.06 | | | 0.11 | 3.96 | 131 |
| **2** | **1.80** | **0.73** | **2.39** | **0.13** | **1.002** | **129** |
| 150498701 | | | | | | |
| 1 | 1.76 | | | 0.30 | 4.71 | 435 |
| 1 | 1.52 | 0.72 | 2.07 | 0.34 | 4.22 | 457 |
| 2 | 1.79 | | | 0.28 | 3.78 | 492 |
| **2** | **1.52** | **0.72** | **2.07** | **0.34** | **1.11** | **490** |

**Best fitted obs.**

Fit with a change o parameters from best fitted obs.

## Conclusion

- No evidence of filaments for the moment

## Next Steps

- Focusing in Pks 2155-304 data
- Taking advantage of new SAS version
  - Improved Rgsproc
- Developing tools to merge spectra from different observations