THERMAL EMISSION IN THE EARLY X-RAY AFTERGLOWS OF GRBS

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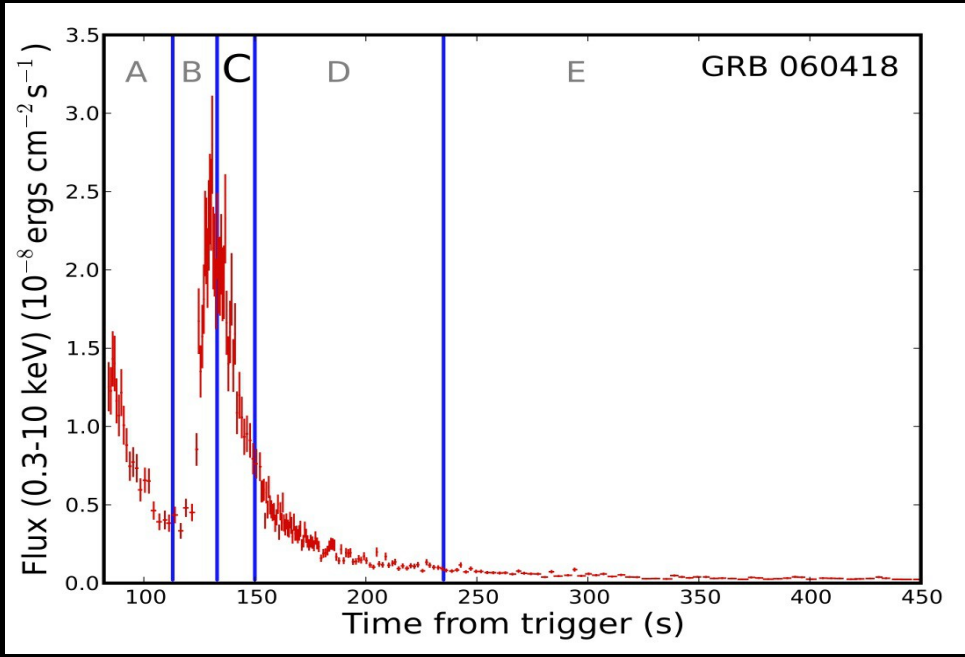
Galaxies meet GRBs at Cabo de Gata, 2013

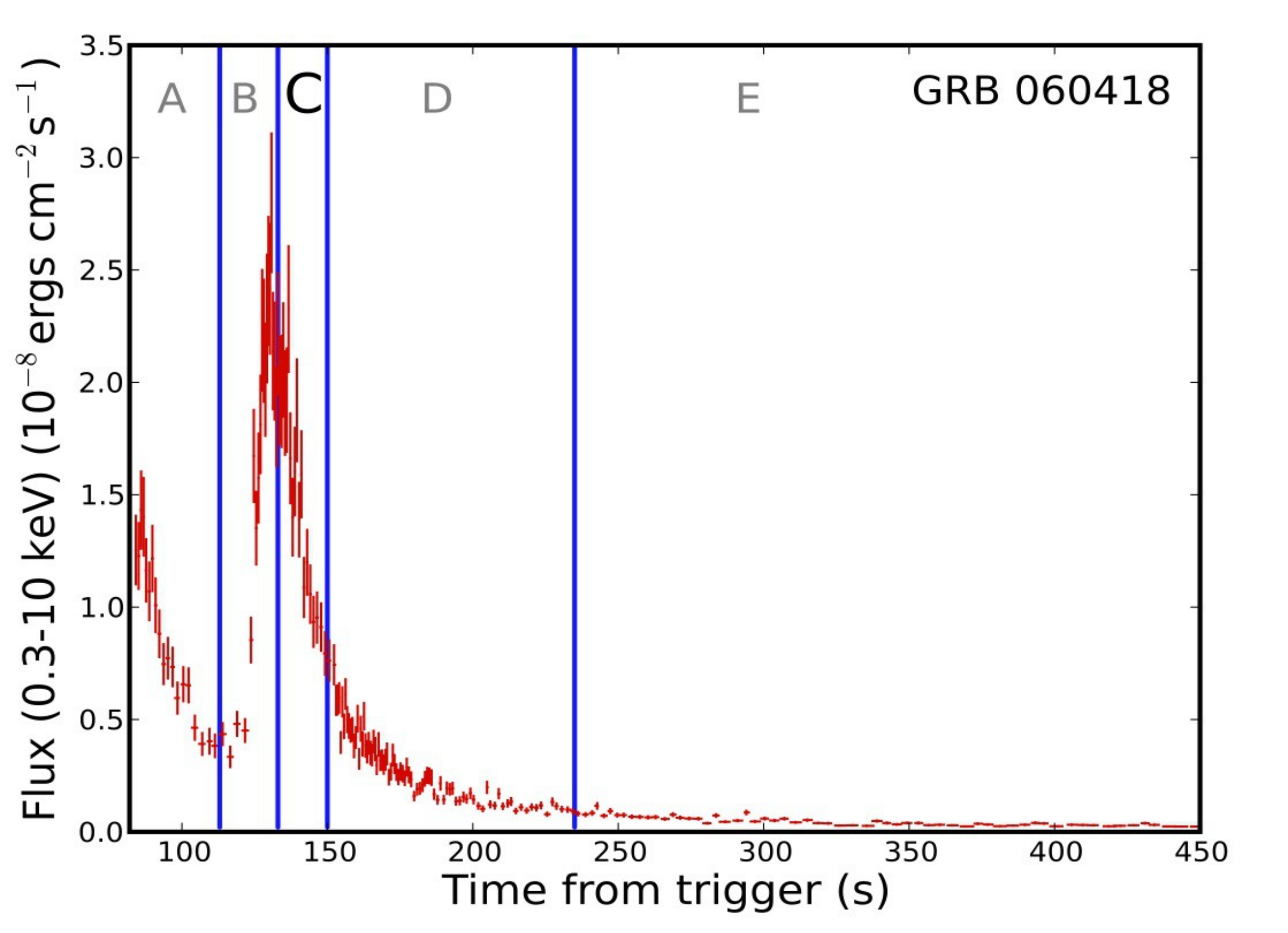
Outline

- Data:
  - Sample Selection and Analysis
  - Detections of Thermal Components
  - Blackbody Model Parameters
- Theory:
  - Supernova Shock Break-out
  - Late Photospheric Emission
  - Model Parameters

Data Sample

- *Swift* XRT-detected bursts
- Minimum of 20.000 counts
- Known redshifts
- Total of 28 bursts




GRB 060418
A
B
C
D
E
Flux (0.3-10 keV) (10^{-8} ergs cm^{-2} s^{-1})
Time from trigger (s)
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
100
150
200
250
300
350
400
450

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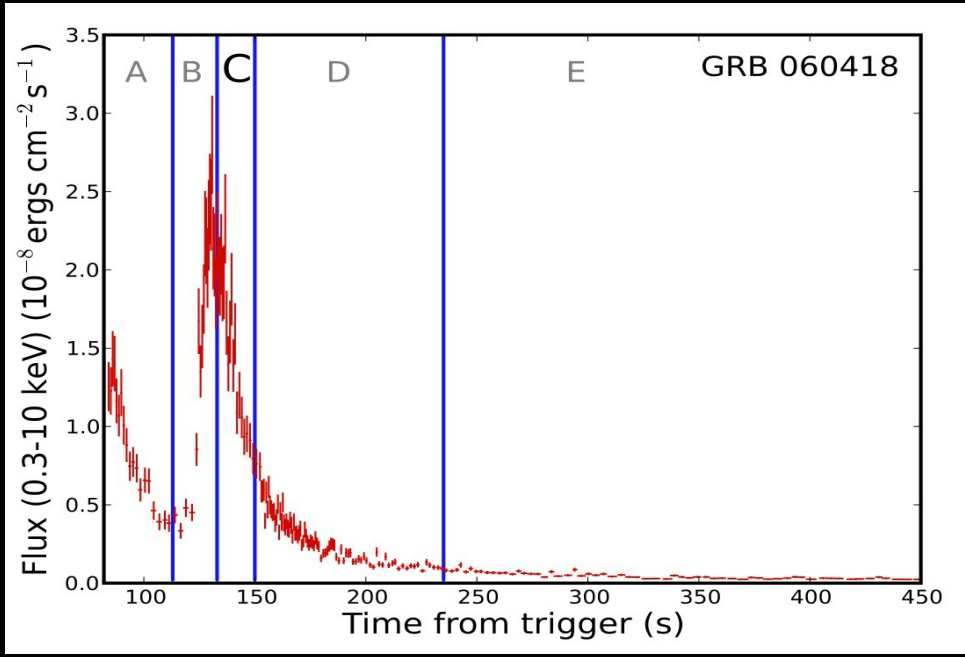


Data Analysis

- Multiple spectra were extracted for each burst, so the temporal evolution can be studied
- Fitted with Band model vs. Band+Blackbody
- Monte Carlo analysis was performed to determine fit statistic

Detections

- 8 out of 28 bursts have a clear detection of thermal emission (3 σ or better)
- 5 of these thermal components have not been observed before.

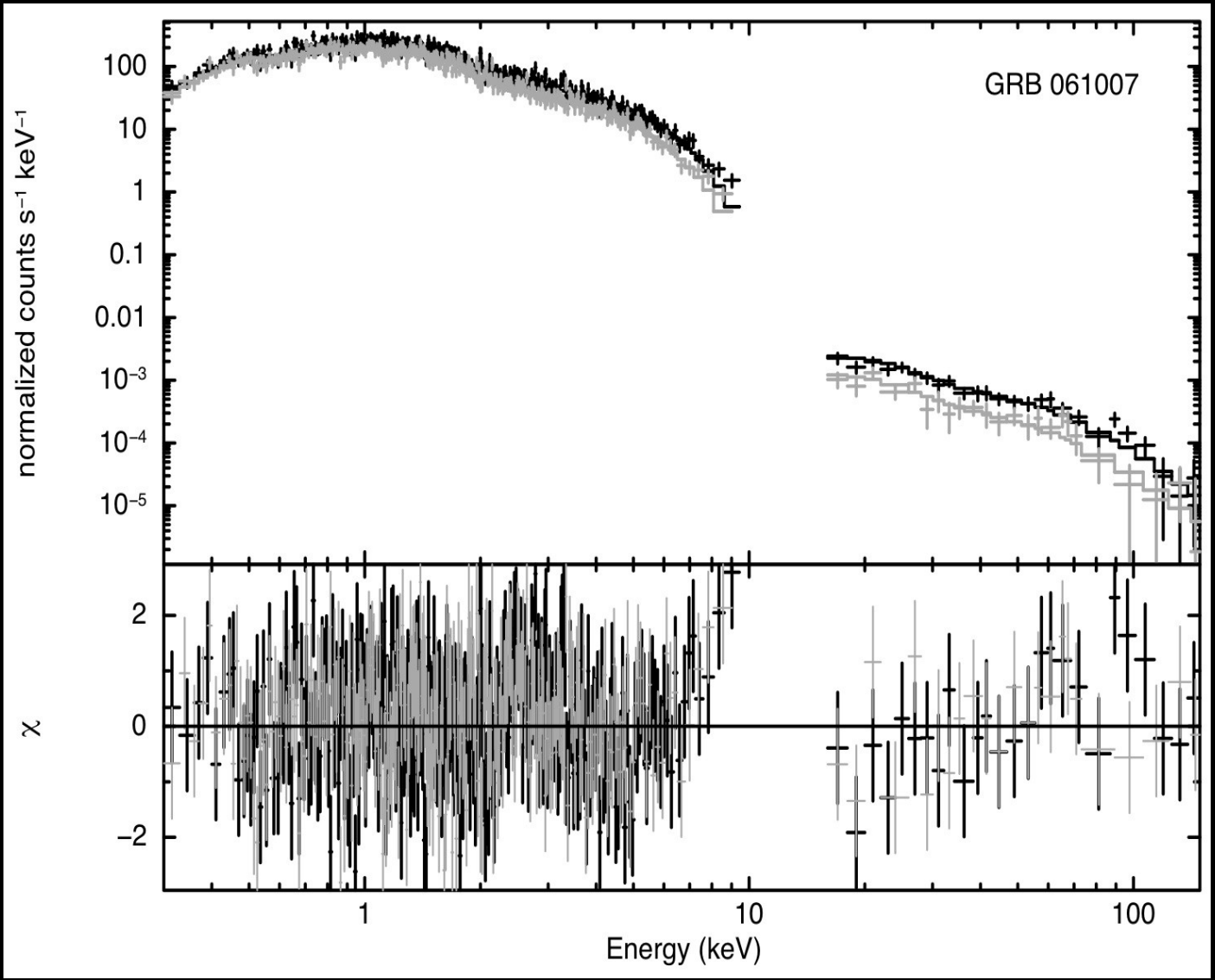
GRBs:

060202, 060218, **060418**, **061007**, **061121**,

090424, 090618 and 100621A

.

Spectra for 061007



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Blackbody parameters for the statistically significant detections

GRB	Redshift	refs.	$\Delta\chi^2$	bb lum.[a]	bb %[b]	kT/keV
060202	0.783	(1)	28.1	$2.7^{+0.1}_{-0.2}$	13	$0.38^{+0.01}_{-0.02}$
060218	0.0331	(2)	73.4	$0.0116^{+0.0007}_{-0.0006}$	0.24	0.156 ± 0.004
060418	1.489	(3)	33.9	$1.6^{+9}_{-0.7}$	3.5	0.53 ± 0.02
061007	1.262	(4)	36.1	119^{+12}_{-11}	10	$3.2^{+0.4}_{-0.3}$
061121	1.314	(4)	49.4	257 ± 26	0.74	2.9 ± 0.2
090424	0.544	(5)	49.8	$0.16^{+0.01}_{-0.04}$	27	0.228 ± 0.006
090618	0.54	(6)	46.9	$1.81^{+0.08}_{-0.08}$	17	$0.74^{+0.08}_{-0.06}$
100621A	0.542	(7)	36.5	$0.73^{+0.07}_{-0.09}$	23	$0.38^{+0.39}_{-0.36}$

a: in units of 10^{48} erg/s
b: percent of total luminosity in the thermal component

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8/28 clear detections, with indications that the Band model is not enough in the rest of the sample either

What is the origin?

Supernova shock break-out

- Typical break-out energy: 10^{47} erg (Li 2007)
- Even for an asymmetric explosion precise fine-tuning is required to explain thermal component in GRB 060218 as shock break-out (Ghisellini et al. 2007)

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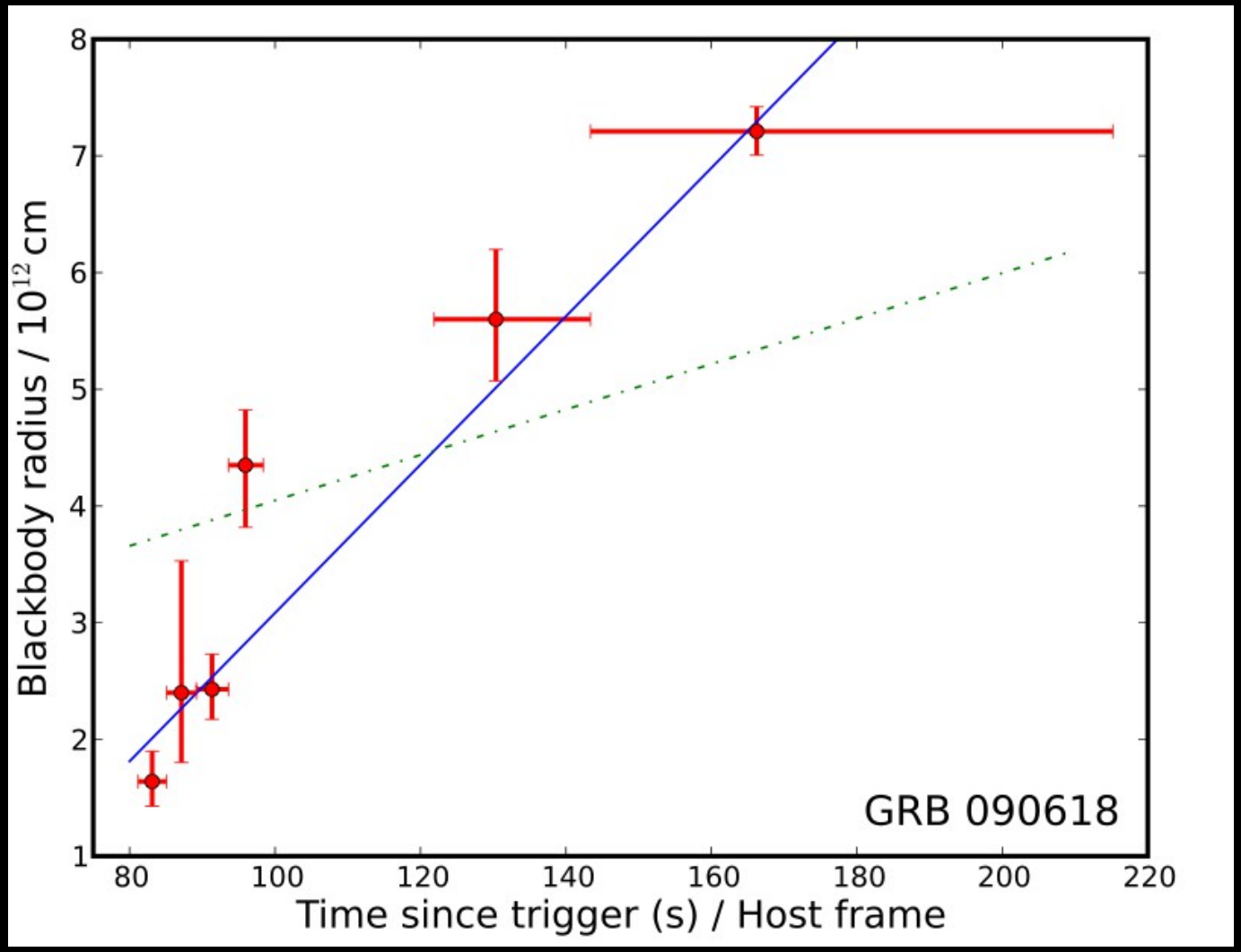
Blackbody Radius



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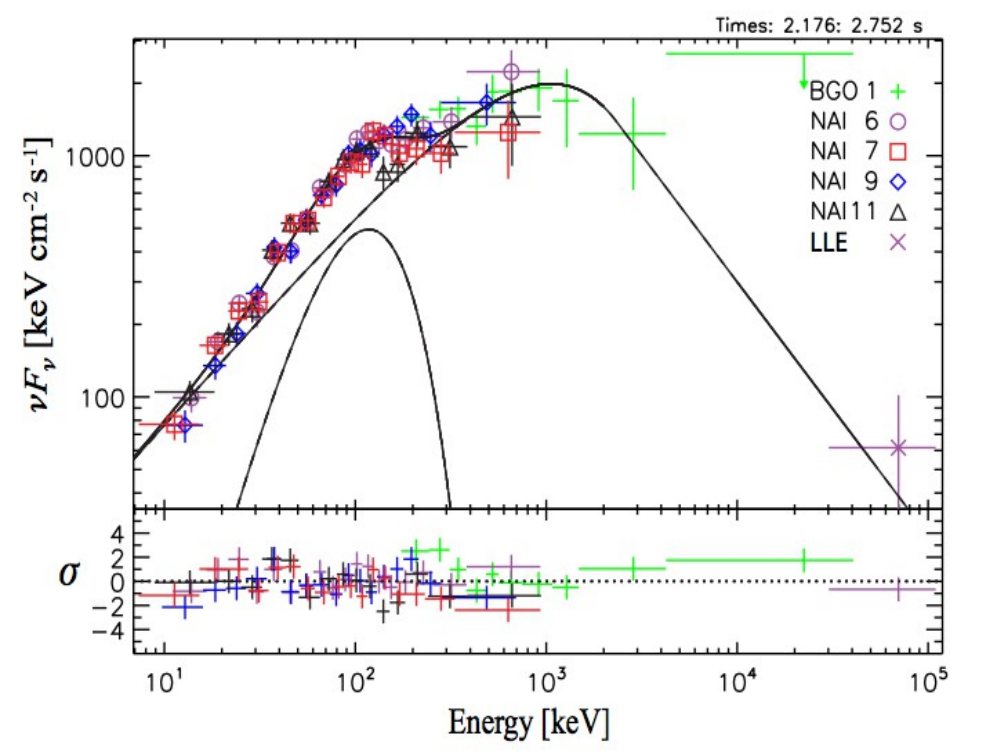
Evolution of the blackbody radius for GRB 090618.

Green line shows evolution at the apparent speed of light. Blue line shows fitted velocity.

Late Photospheric Emission

- Photospheric emission observed in prompt phase
- Temperature and luminosity is seen to decay as a power-law (Ryde and Pe'er 2009)



Iyyani et al. 2013

Model Parameters

$$r_{ph} = R_{bb}^{host} \times \frac{\gamma}{\xi (1+z)^2}$$

$$\gamma = [(1+z)^2 D_L^2 \frac{F_{bb}^{obs} \sigma_T}{2 m_p c^3 R_{bb}^{host}}]^{1/4} \times (L_{tot}/L_{bb}^{obs})^{1/4}$$

GRB	Redshift	refs.	$\Delta\chi^2$	bb lum.[a]	bb %[b]	kT/keV	R_{phot}[c]	γ
060202	0.783	(1)	28.1	$2.7^{+0.1}_{-0.2}$	13	$0.38^{+0.01}_{-0.02}$	$5.9^{5.1}_{5.2}$	60^{+14}_{-18}
060218	0.0331	(2)	73.4	$0.0116^{+0.0007}_{-0.0006}$	0.24	0.156 ± 0.004	$0.46^{+0.45}_{-0.46}$	40^{+9}_{-12}
060418	1.489	(3)	33.9	$1.6^{+9}_{-0.7}$	3.5	0.53 ± 0.02	$2.2^{+7.7}_{-1.2}$	<254
061007	1.262	(4)	36.1	119^{+12}_{-11}	10	$3.2^{+0.4}_{-0.3}$	$1.9^{+0.17}_{-0.18}$	328^{+100}_{-64}
061121	1.314	(4)	49.4	257 ± 26	0.74	2.9 ± 0.2	6.7 ± 1.6	669^{+14}_{-18}
090424	0.544	(5)	49.8	$0.16^{+0.01}_{-0.04}$	27	0.228 ± 0.006	19^{+23}_{-17}	26^{+8}_{-9}
090618	0.54	(6)	46.9	$1.81^{+0.08}_{-0.08}$	17	$0.74^{+0.08}_{-0.06}$	12 ± 2	<1058
100621A	0.542	(7)	36.5	$0.73^{+0.07}_{-0.09}$	23	$0.38^{+0.39}_{-0.36}$	$2.8^{+2.6}_{-2.6}$	40^{+11}_{-10}

c: in units of 10^{13} cm

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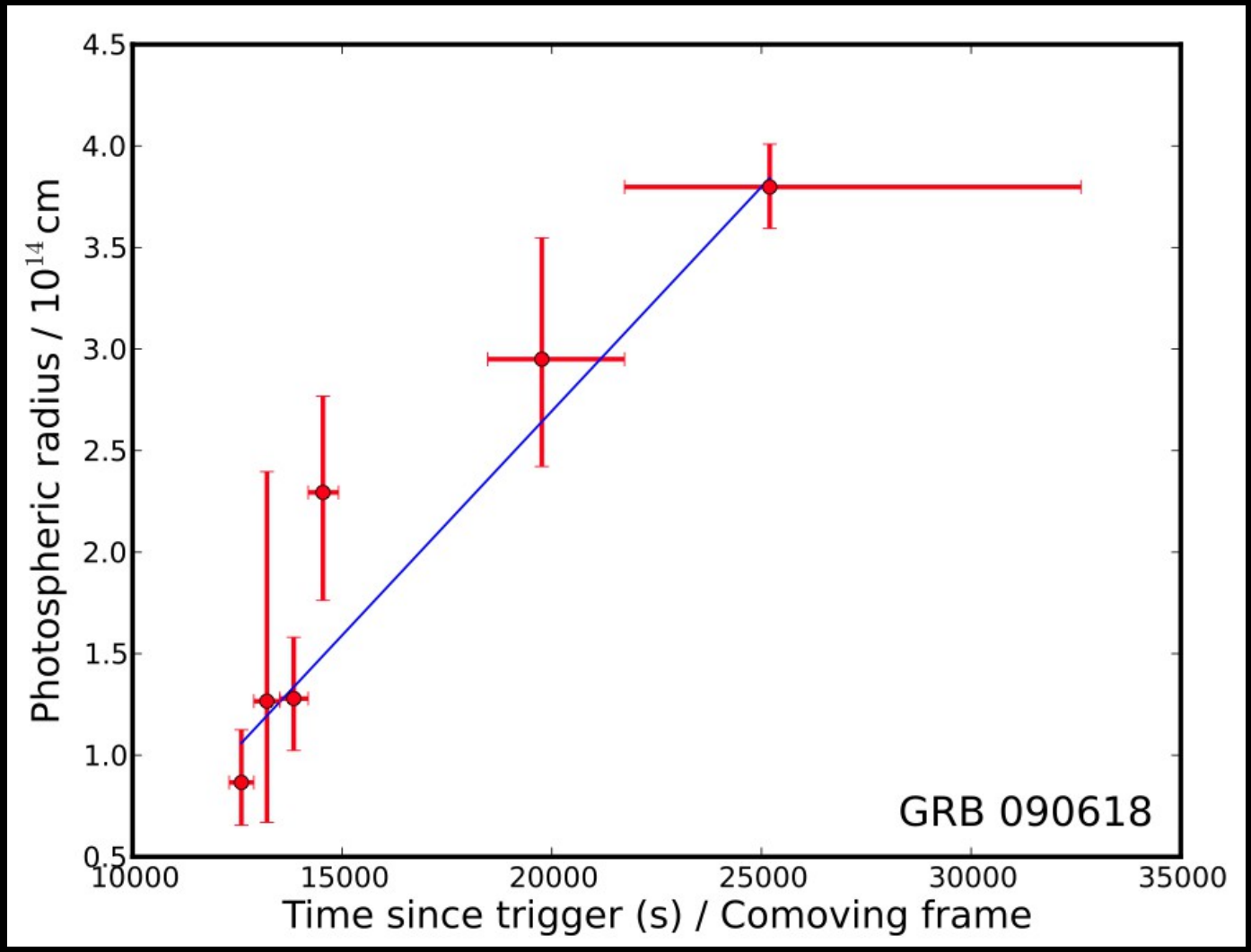
Photospheric Radius



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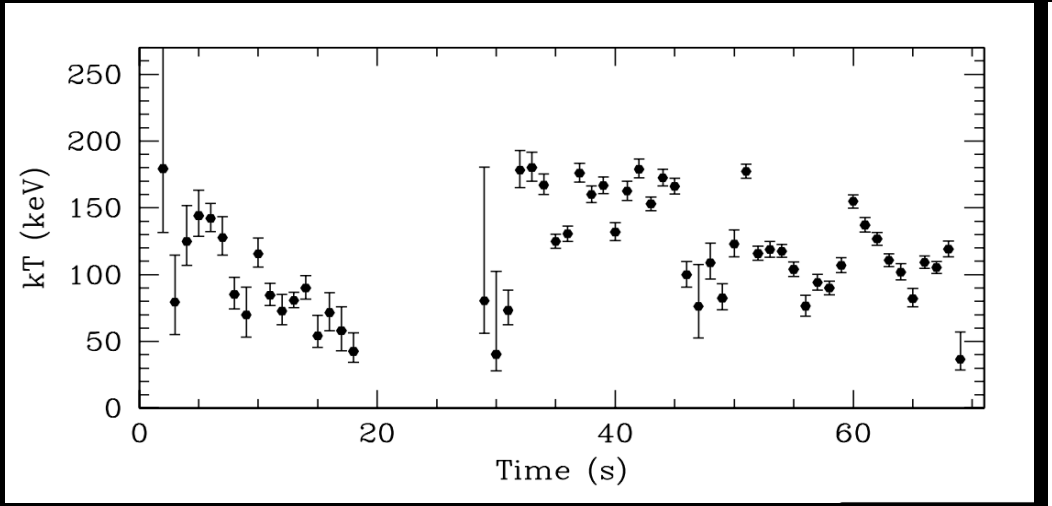
Evolution of the photospheric radius for GRB 090618.

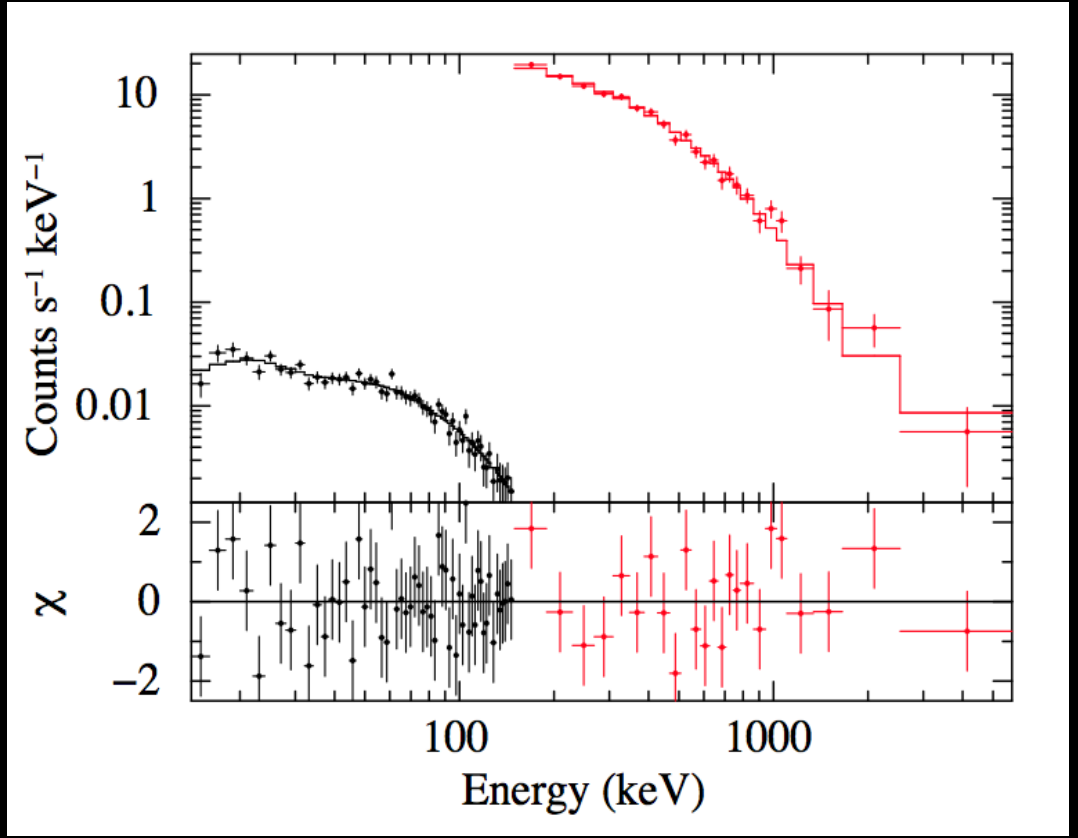
Blue line shows fit that gives an expansion velocity at the speed of light.

Comparison with prompt phase

GRB 061007



Larsson et al. 2011



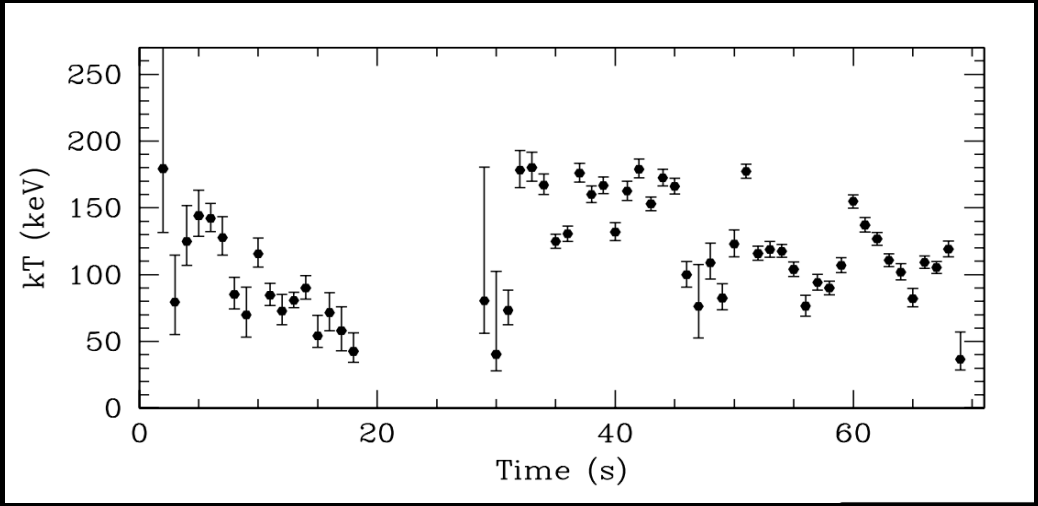
BB lum: 75% → 10%

Temp: ~100keV → ~3keV

Γ: ~200-600 → ~300-400

Comparison with prompt phase

GRB 061007



Larsson et al. 2011

BB lum: 75% → 10%

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Ryde & Pe'er 2009:

Power-law indices (-α):
Temperature: 0.3 – 1.3
Luminosity: 0.8 – 4.5

The bursts in our sample is largely consistent with these numbers.

Comparison with prompt phase

Luminosity:

0.2 +/- 1.1

0.7 +/- 1.9

1.9 +/- 1.0

0.8 +/- 0.6

0.7 +/- 0.6

Ryde & Pe'er 2009:

Power-law indices (-α):
Temperature: 0.3 – 1.3
Luminosity: 0.8 – 4.5

The bursts in our sample is largely consistent with these numbers.

Conclusions

- Clear evidence of thermal emission in the soft X-rays in 8/28 bursts, with an indication that such a component exists in majority of bursts
- Very high luminosity and temperature suggests that supernova shock break-out is unlikely
- Late photospheric emission is a physically well-motivated theory that allows the determination of the Lorentz factor of the flow

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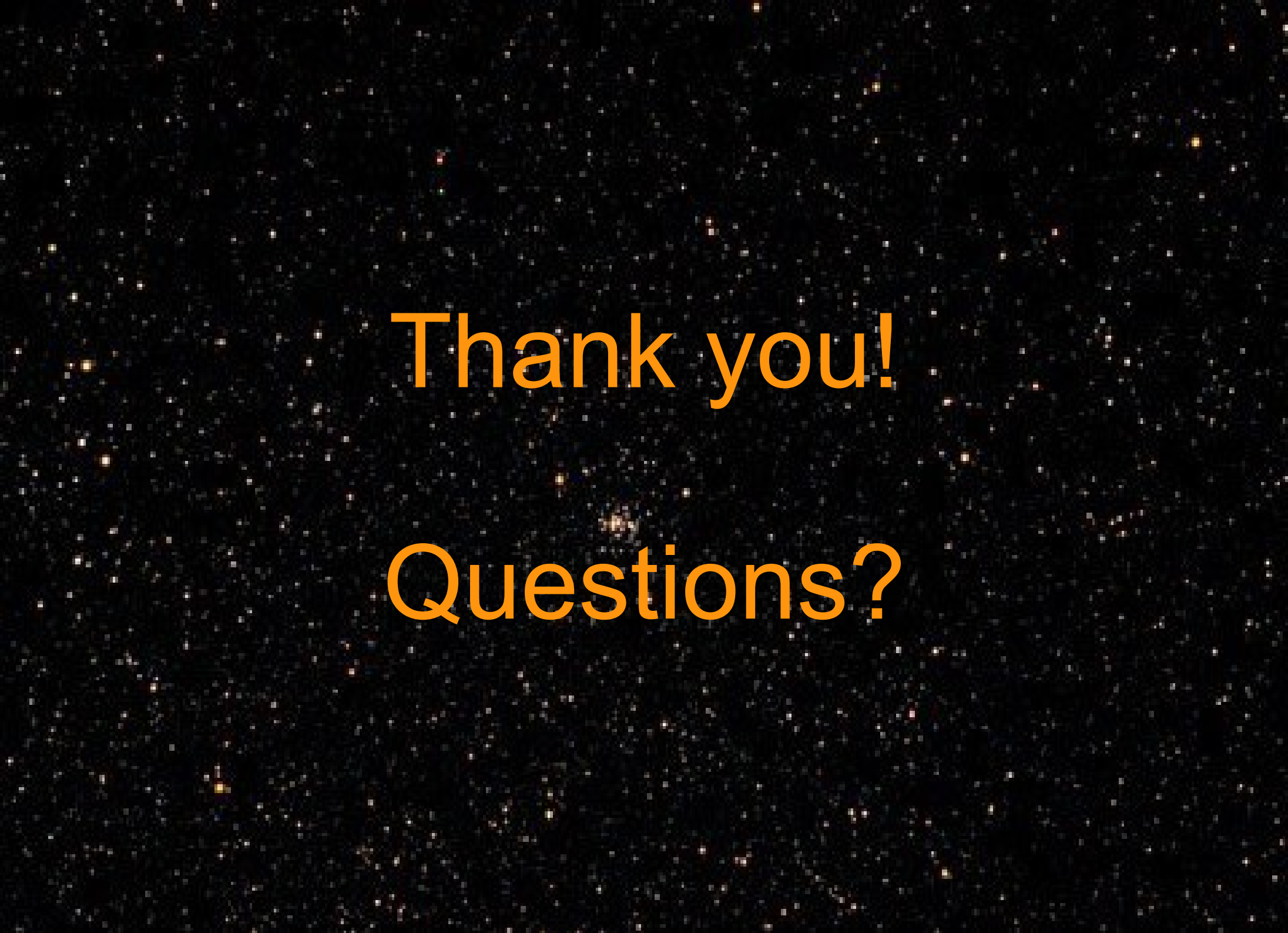
Thank you!
Questions?