IPv4 Address Lifetime Expectancy Revisited

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September 2003
Presentation to the RIPE 46 Plenary

Research activity
supported by APNIC

The Regional Internet Registries s do not make forecasts or predictions about number resource lifetimes. The RIRs provide statistics of what has been allocated. The following presentation is a personal contribution based on extrapolation of RIR allocation data.

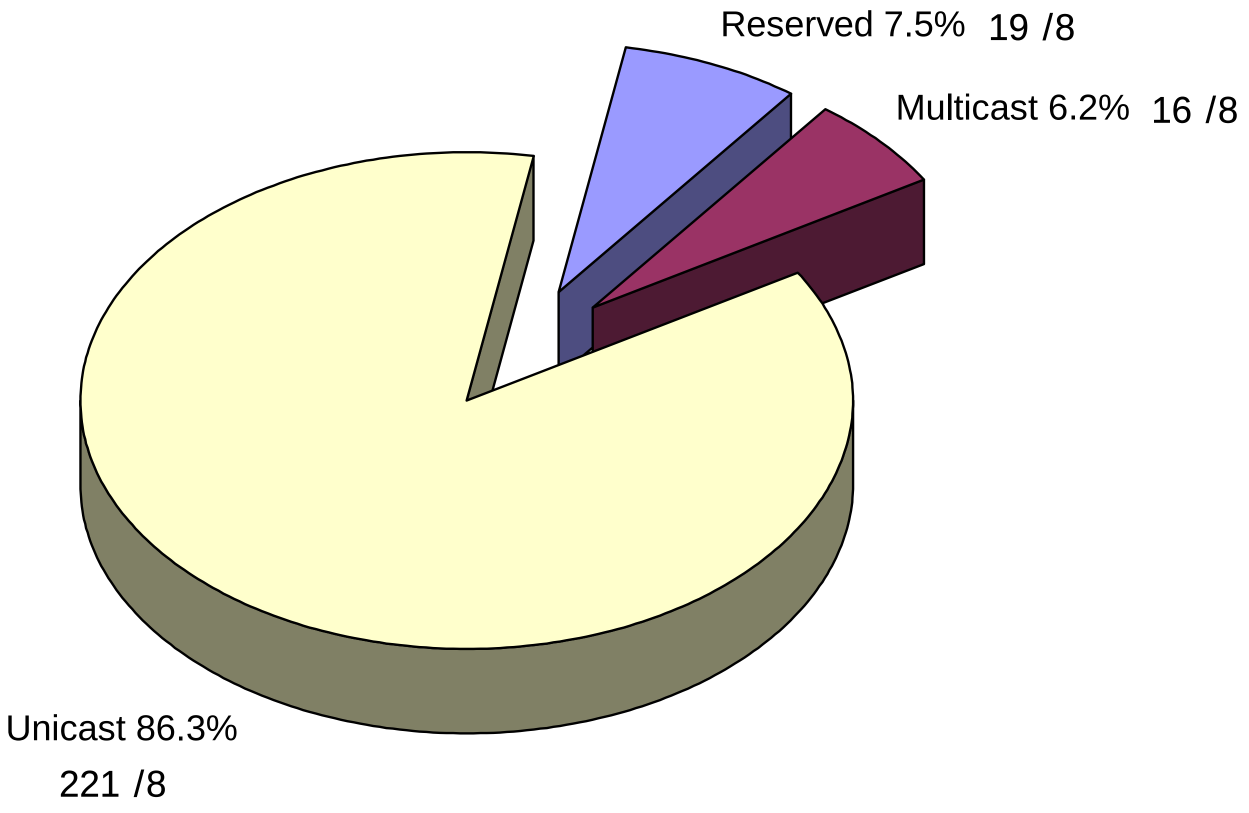
IPv4 Address Lifetime Expectancy

- This was an IETF activity starting as part of the Routing and Addressing (ROAD) activity in the early 1990's
- The objective was to understand the rate of allocation of IPv4 addresses and make some predictions as to the date of eventual exhaustion of the unallocated address pool
- This is a re-visiting of this activity with consideration of additional data derived from the characteristics of the BGP routing table

The IPv4 Address Space

- A 32 bit field spanning some 4.4B entries
- The IETF, through standards actions, has determined some space to be used for global unicast, some for multicast and some held in reserve
- IANA has allocated some unicast space to the RIRs for further allocation and assignment, assigned some space directly, and reserved some space for particular purposes

The IPv4 Top Level Structure



Modeling the Process

- A number of views can be used to make forward projections:
  - The rate at which IPv4 number blocks are passed from IANA to the RIRs
  - The rate at which RIRs undertake assignments of IPv4 address blocks to LIRs and end users
  - The growth of the number of announced addresses in the BGP routing table

Data Sets

- IANA IPv4 Address Registry
  - Allocation of /8 blocks to RIRs and others
- RIR Stats files
  - Allocation of blocks to LIRs
- BGP Routing table
  - Amount of address space advertised as reachable

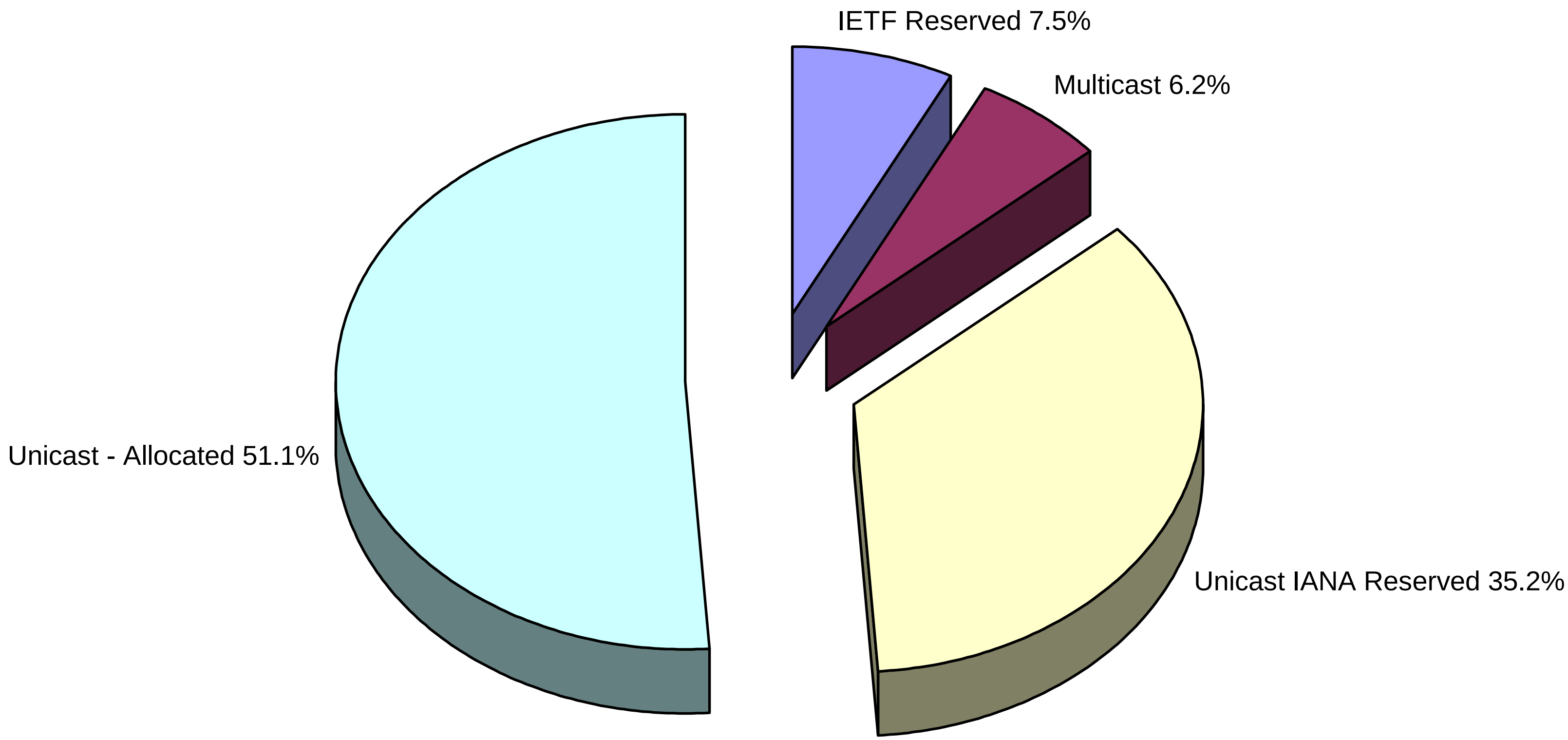
IANA Allocations

- The IPv4 address registry records the date of each /8 allocation undertaken by the IANA
- This data has some inconsistencies, but is stable enough to allow some form of projection

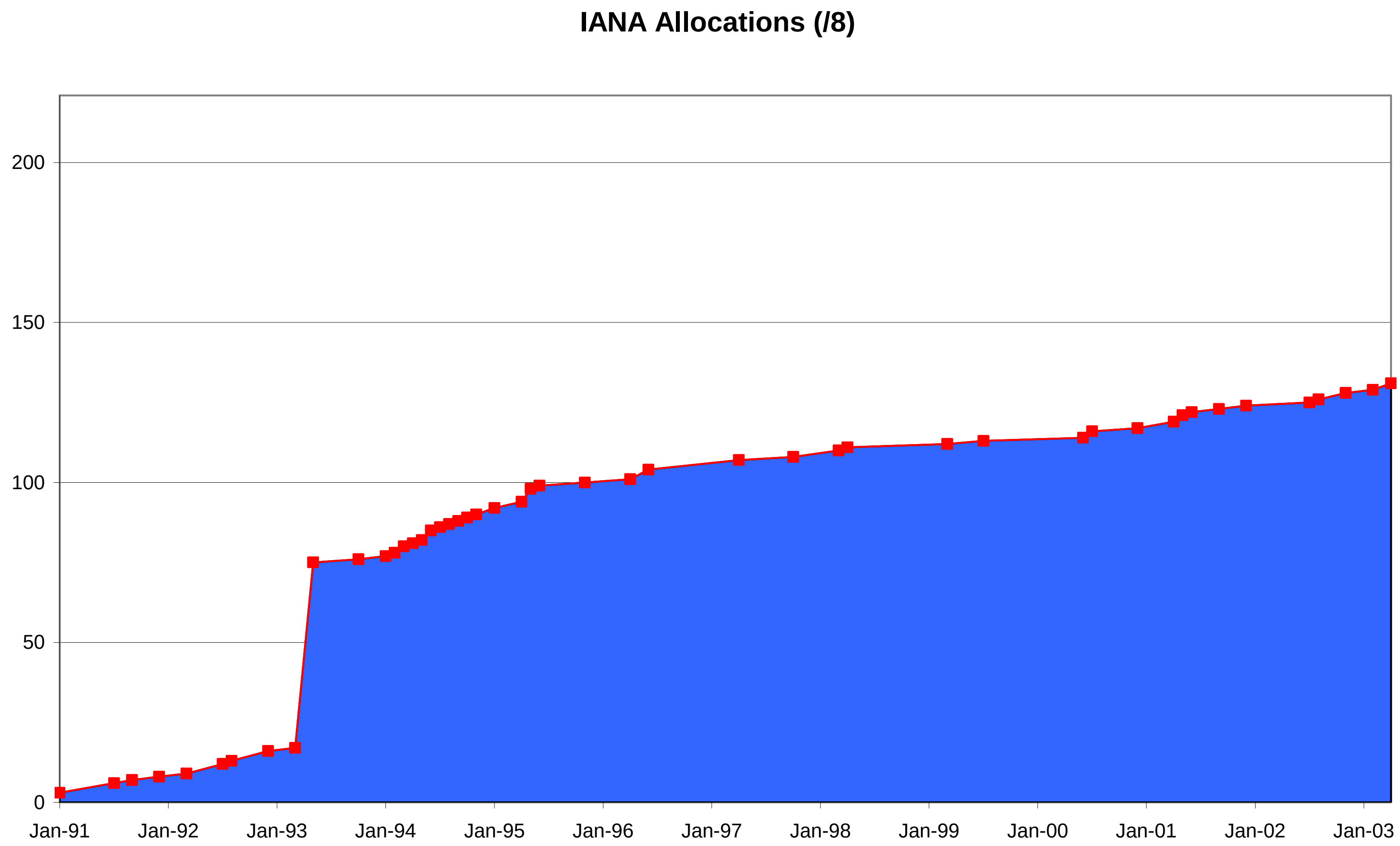
IANA Registry Comments

- The allocation dates for those address blocks prior to 1995 are inaccurate
  - The earliest date is 1991, and a large block has been recorded as allocated in 1993.
  - This is inconsistent with dates recorded in the RIR stats files, which record allocations back to 1983
  - It would appear that there was a revision of the IANA registry in the period 1991 – 1993, and the IANA recorded dates are the revision dates
  - Useable dates appear to start from allocations from 1995 onwards

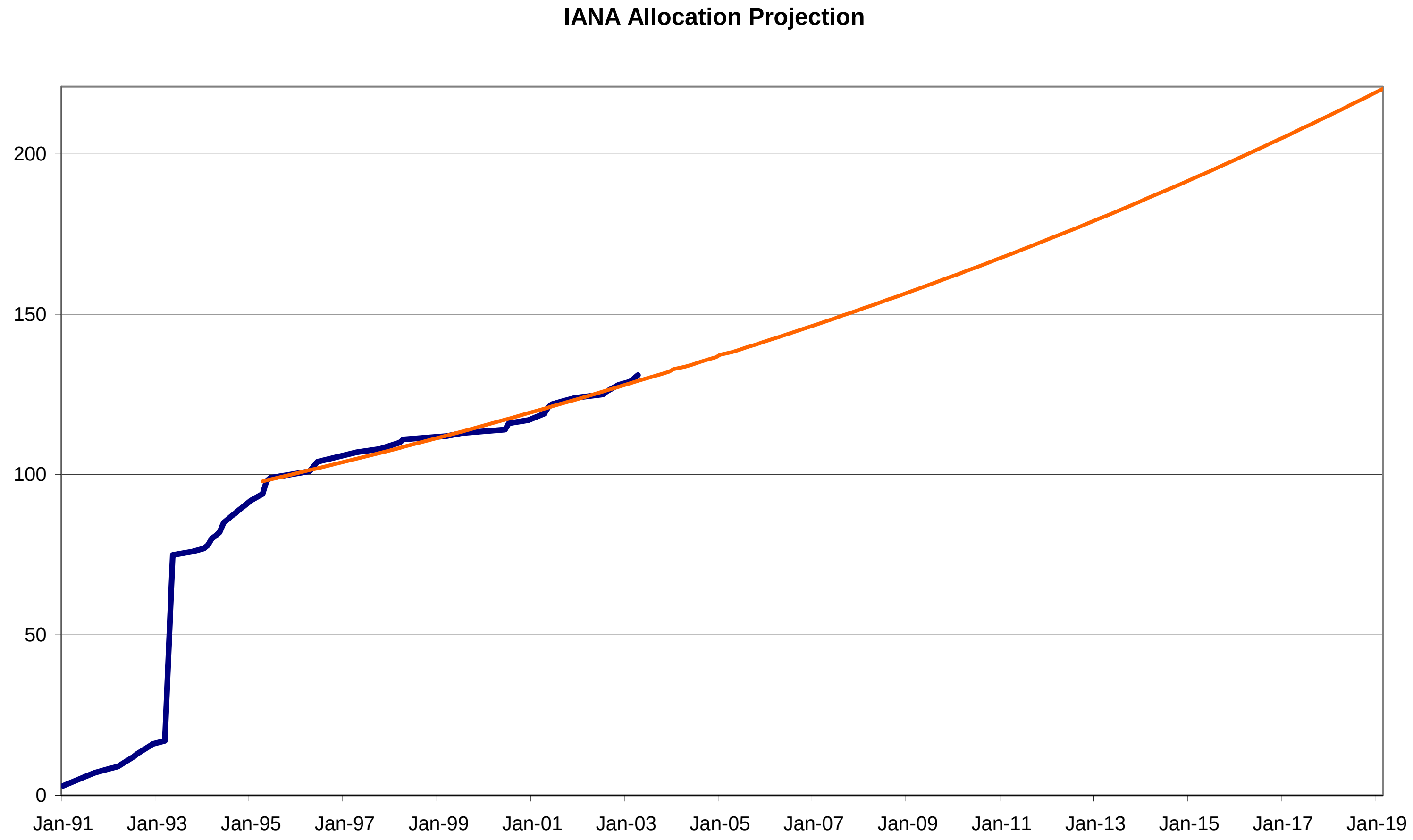
IANA – Current Status



IANA Allocations



IANA Projections



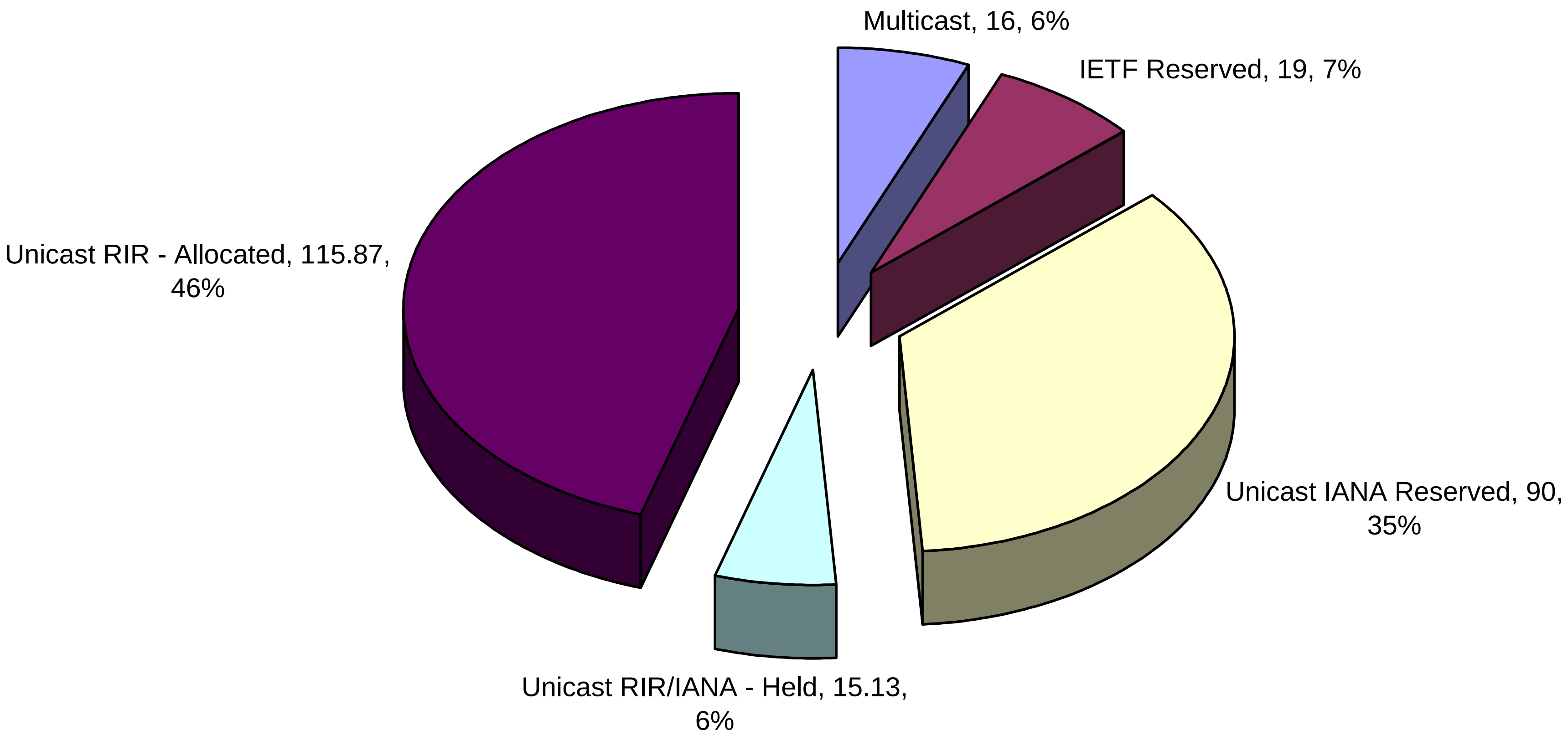
IANA Projections

- This projection of 2019 for IANA address pool exhaustion is very uncertain because of:
  - Sensitivity of allocation rate to prevailing RIR assignment policies
  - Takeup of applications that require end-to-end IP addressing vs use of NATs
  - Potential use of a further 16 /8s currently reserved by the IETF

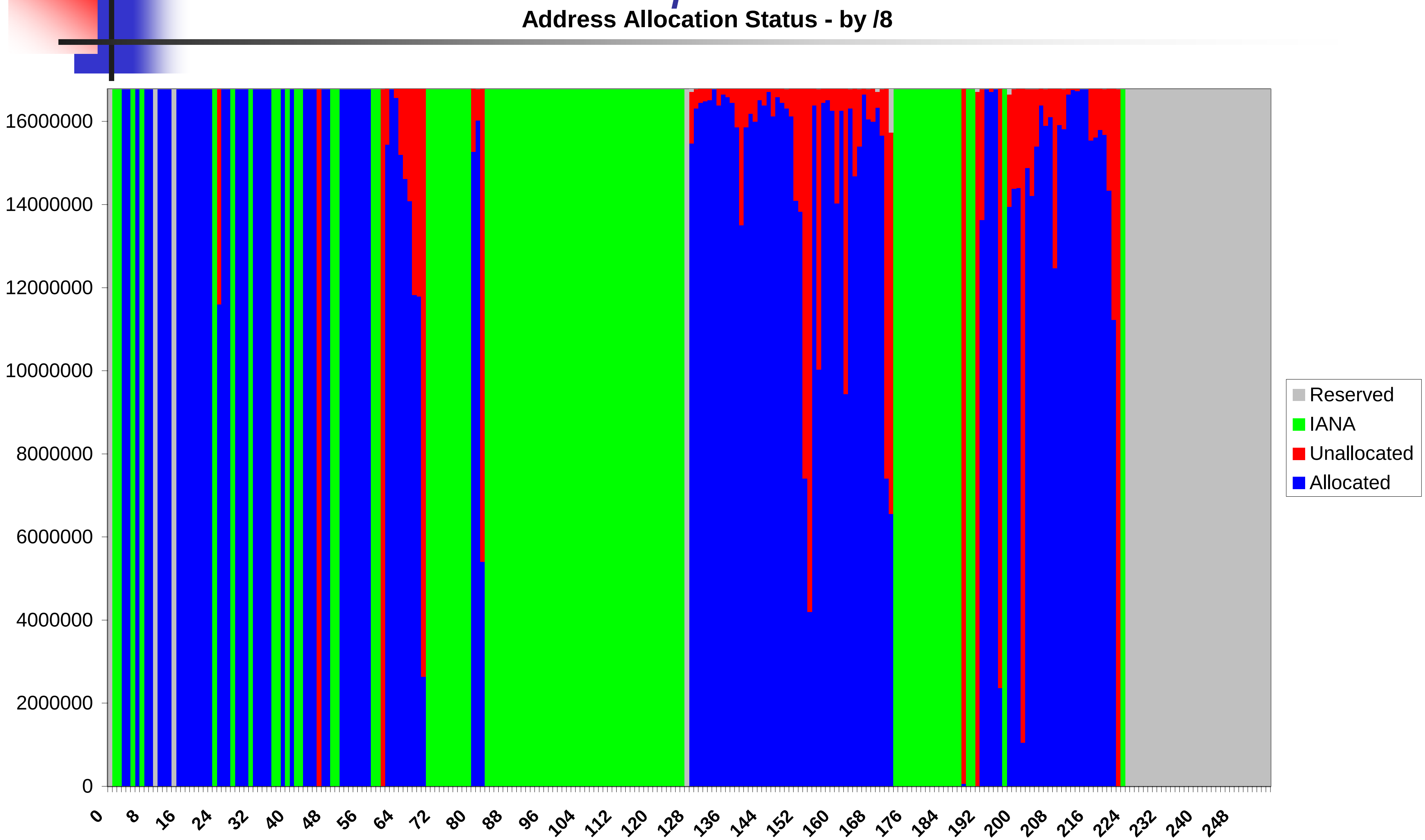
RIR Allocations

- The RIR stats files records the date of each allocation to an LIR, together with the allocation details

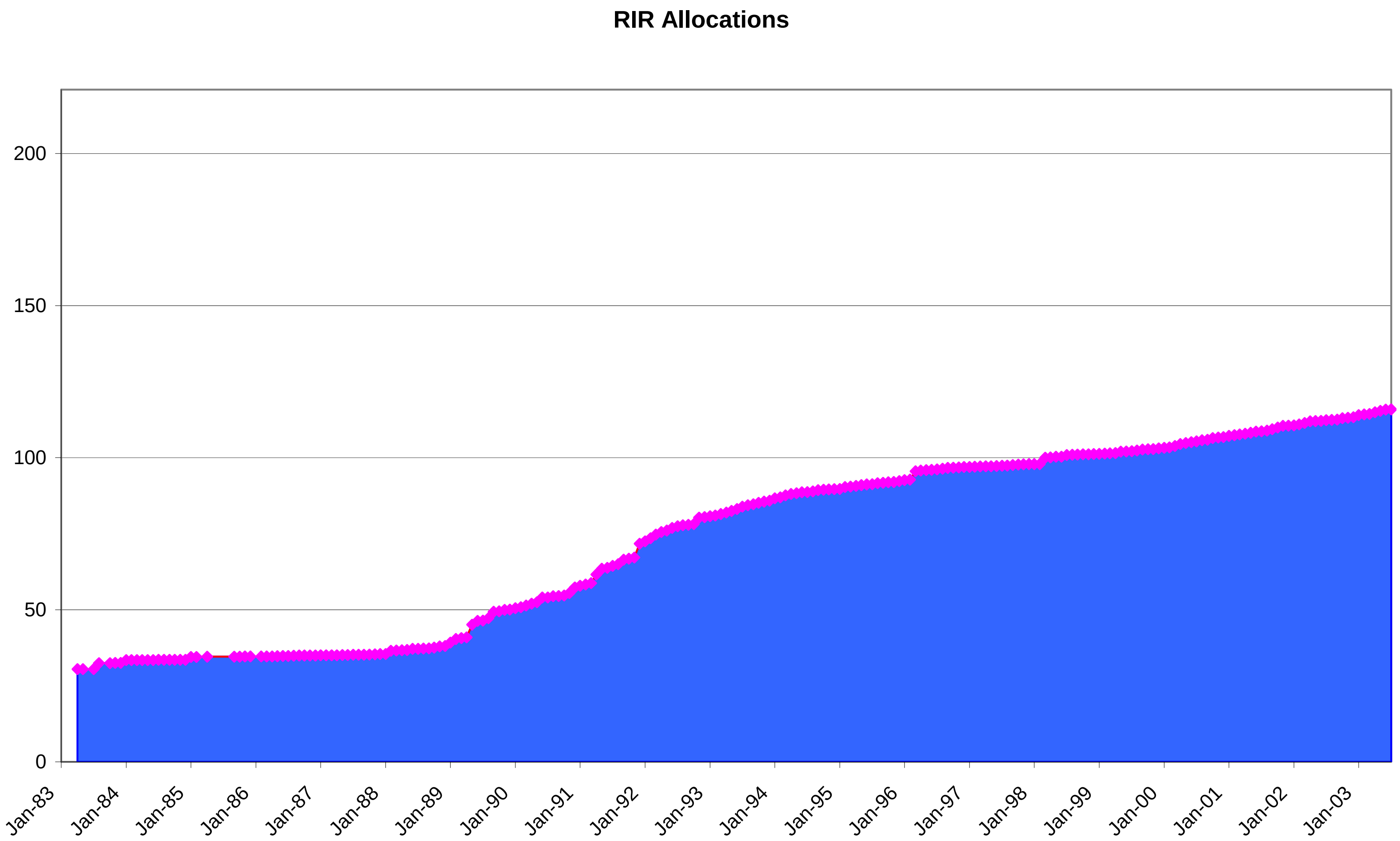
RIR Allocations – Current Status



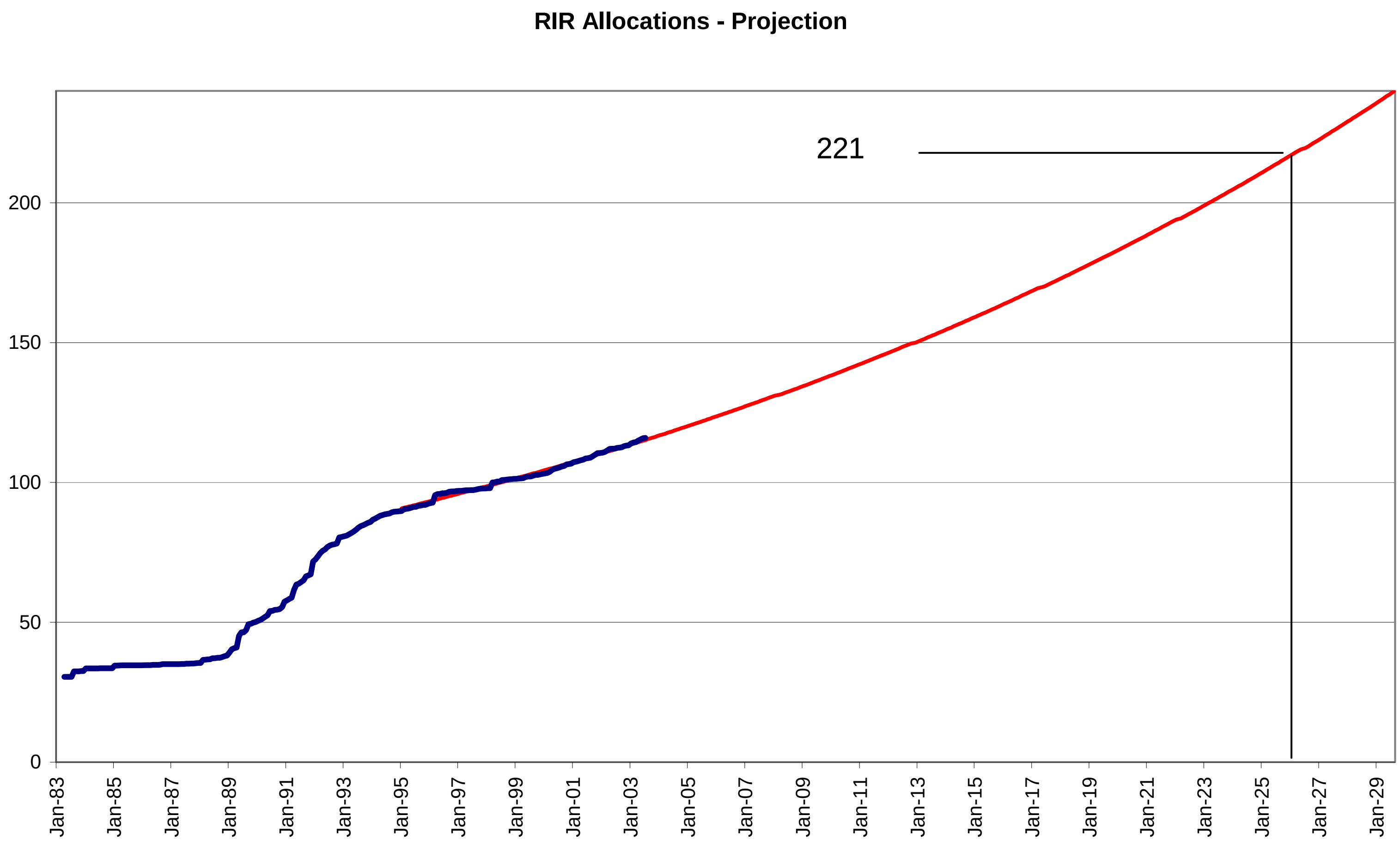
RIR Allocations /8



RIR Allocations



RIR Projections



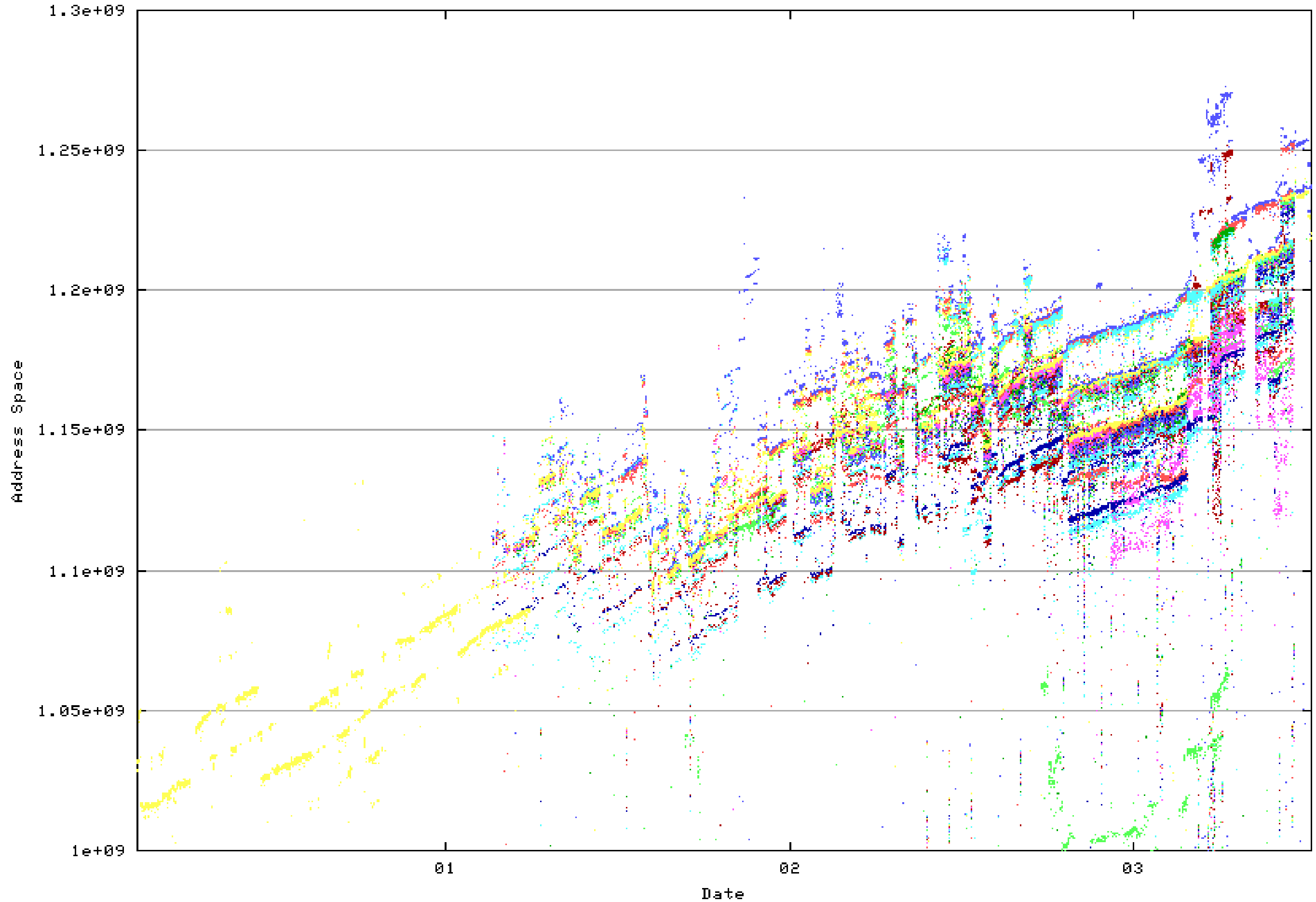
RIR Projections

- This projections of 2026 for 221 /8s and 2029 for 237/8s has the same levels of uncertainty as noted for the IANA projections

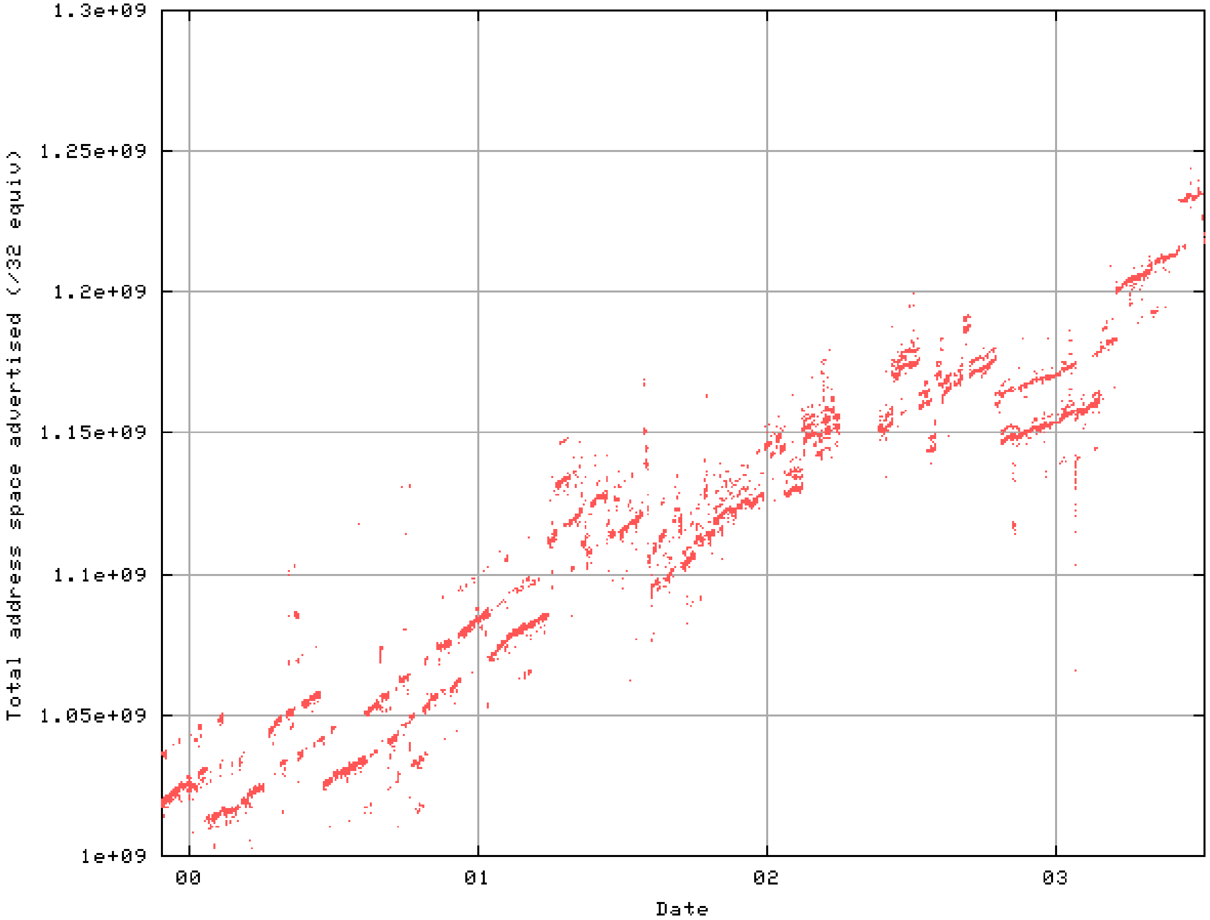
BGP Routing Table

- The BGP routing table spans a set of advertised addresses
- A similar analysis of usage and projection can be undertaken on this date

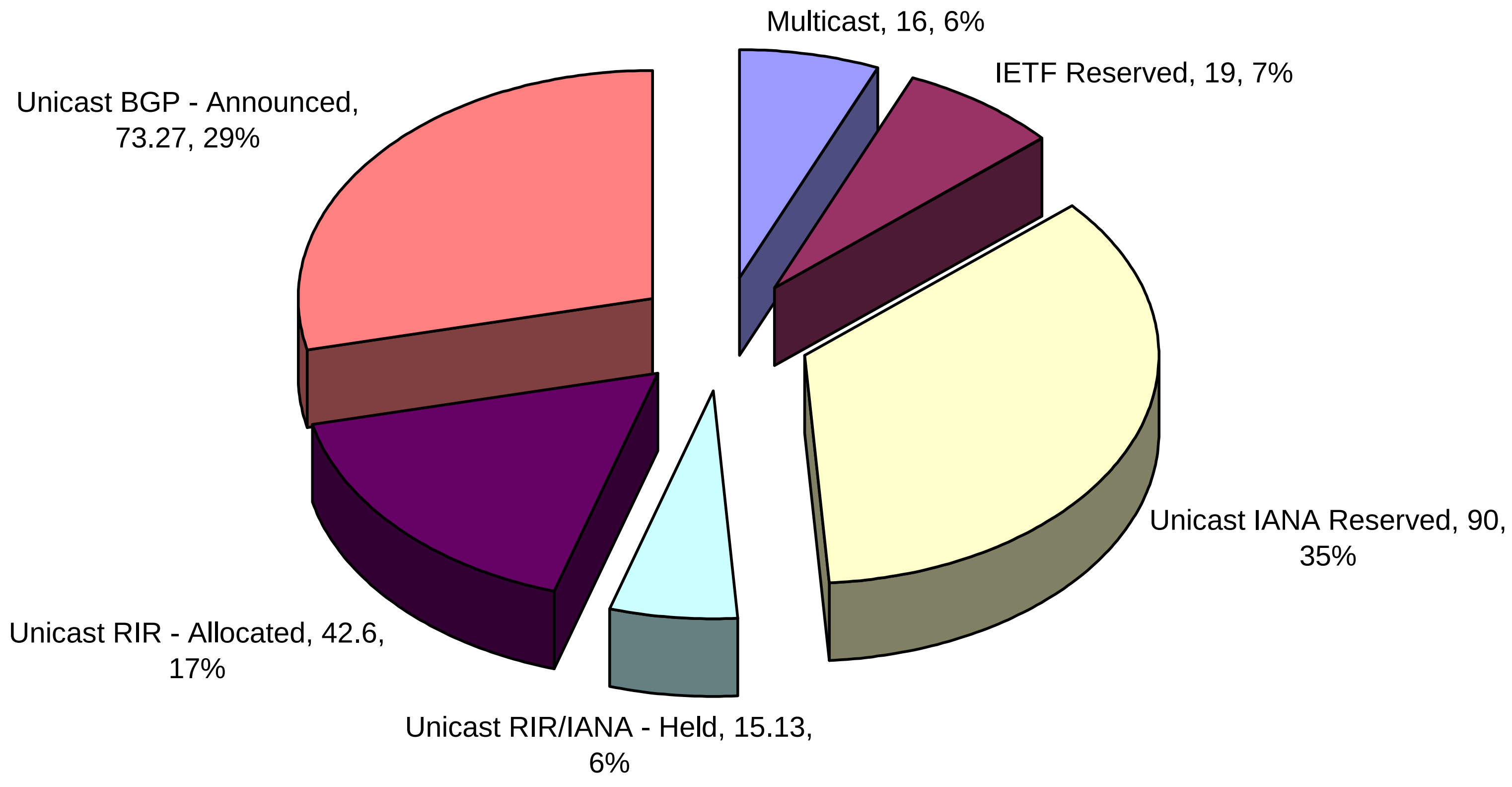
The Route Views view



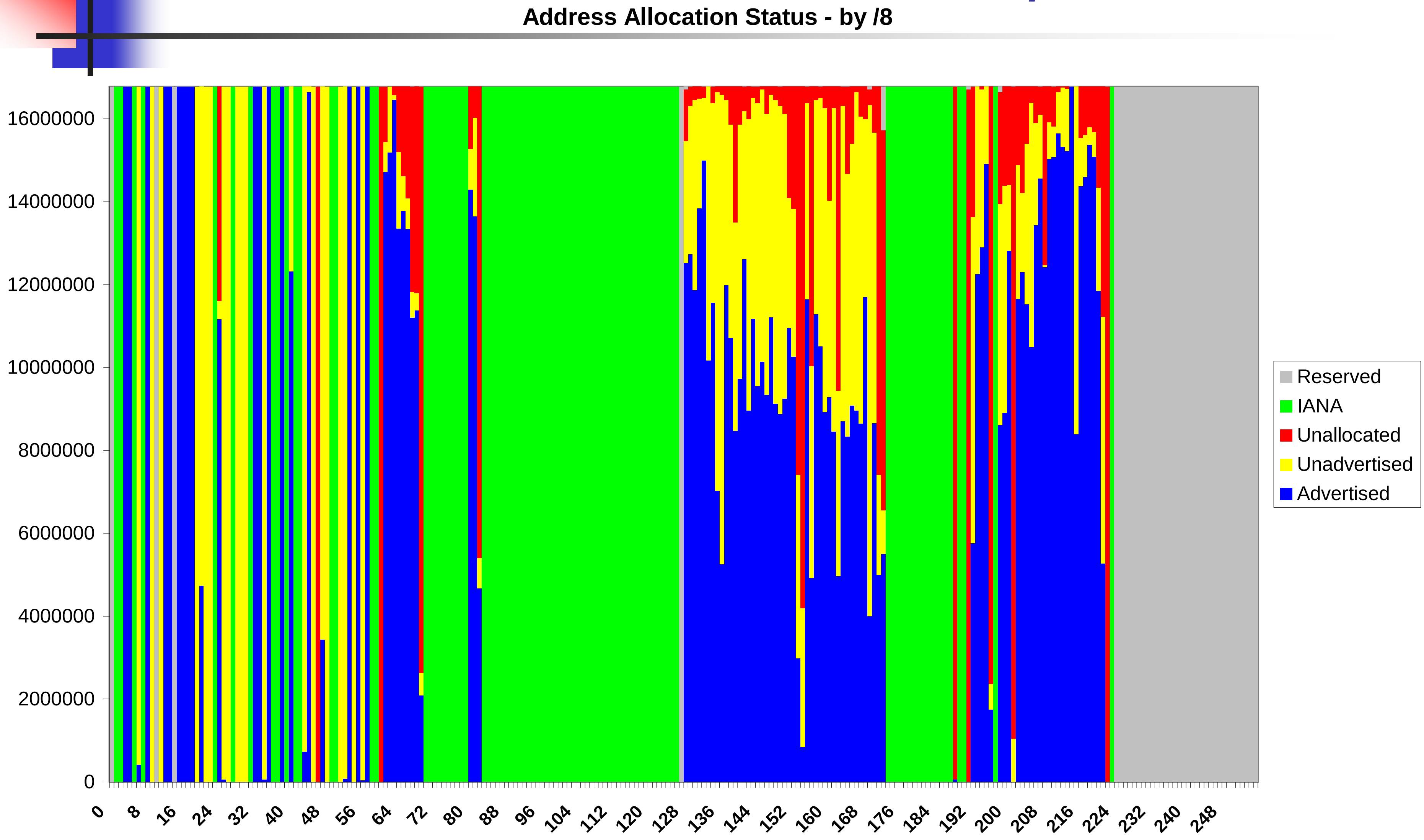
The AS1221 view



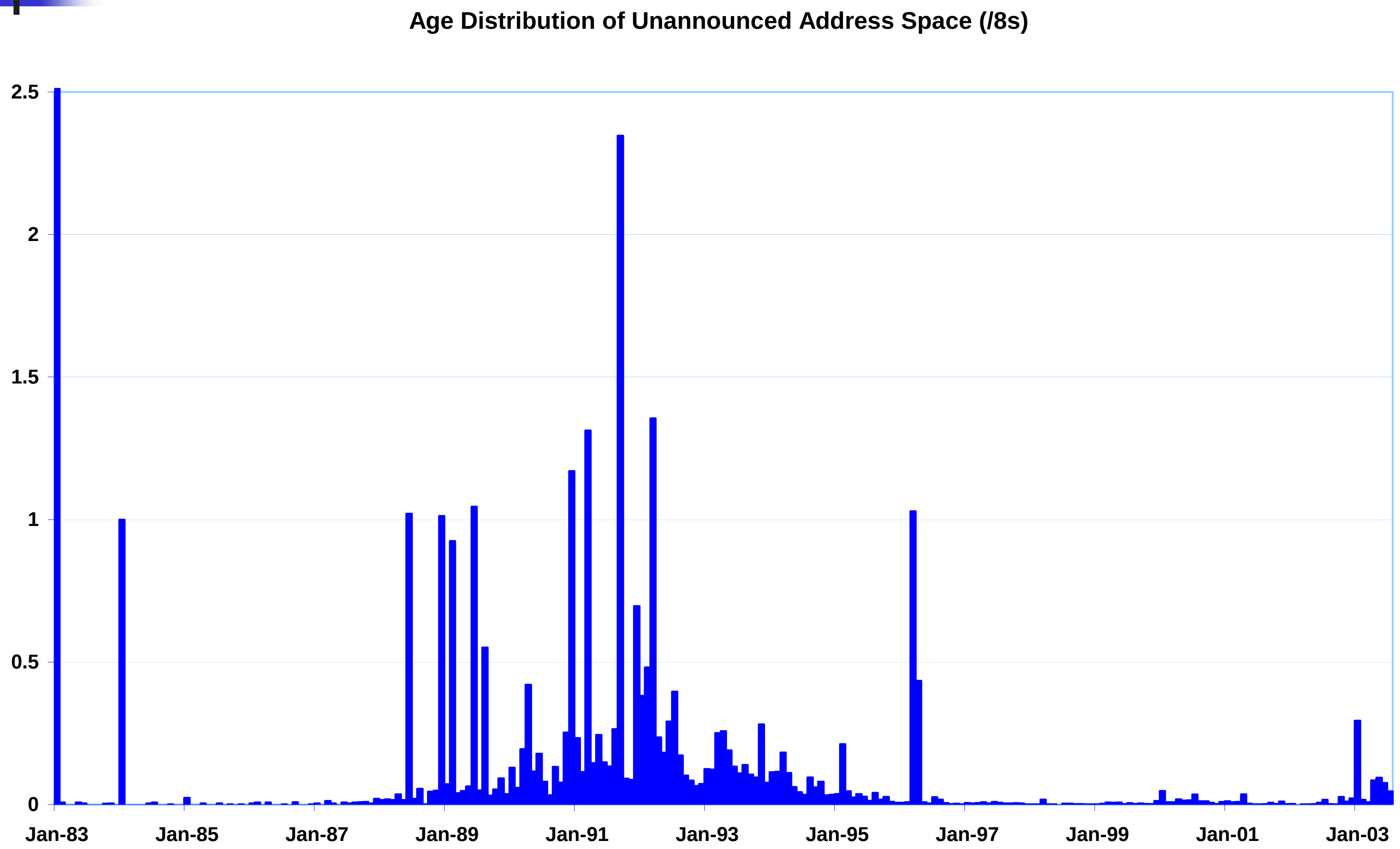
BGP Routing Table - Status



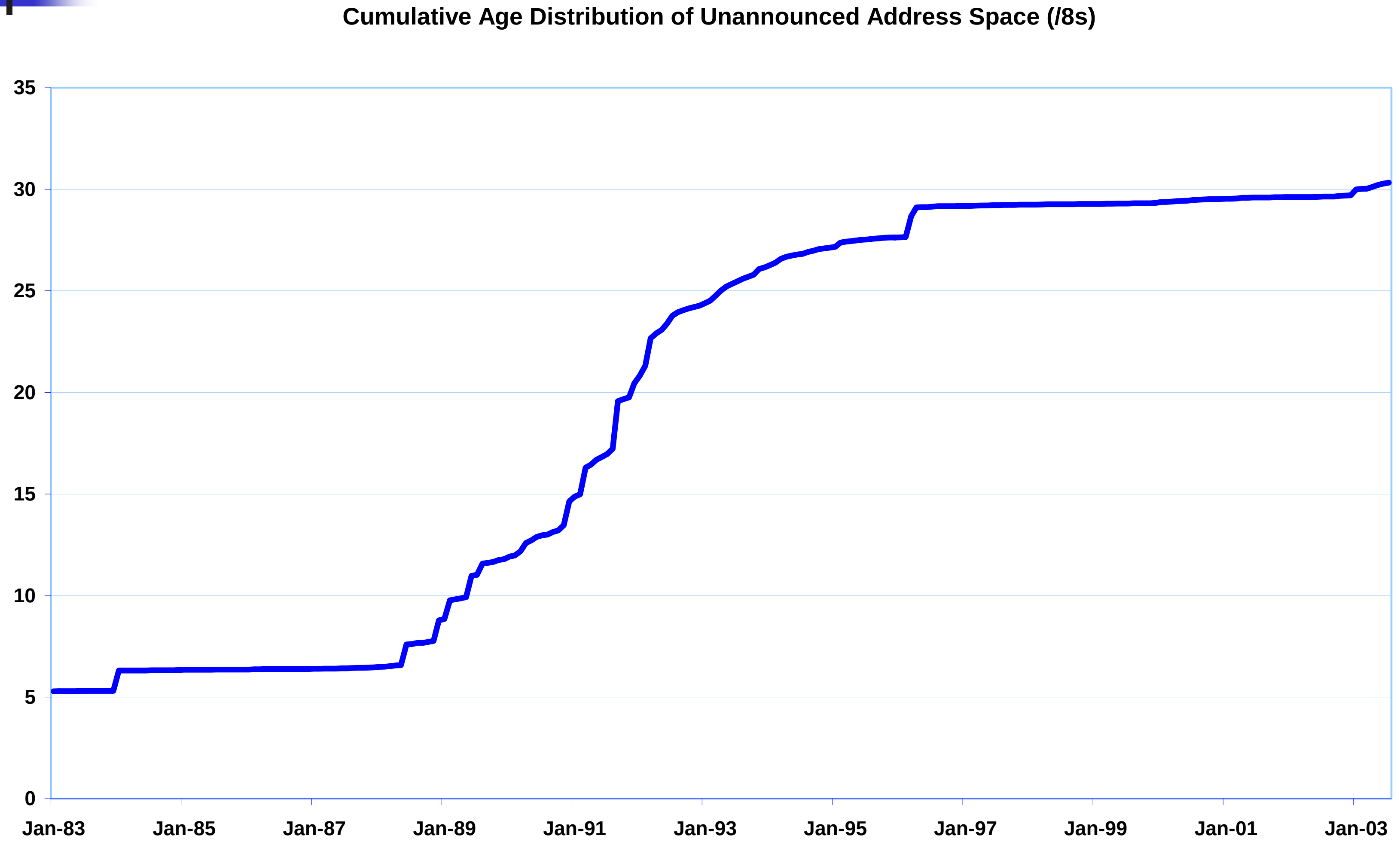
BGP Address Allocations /8



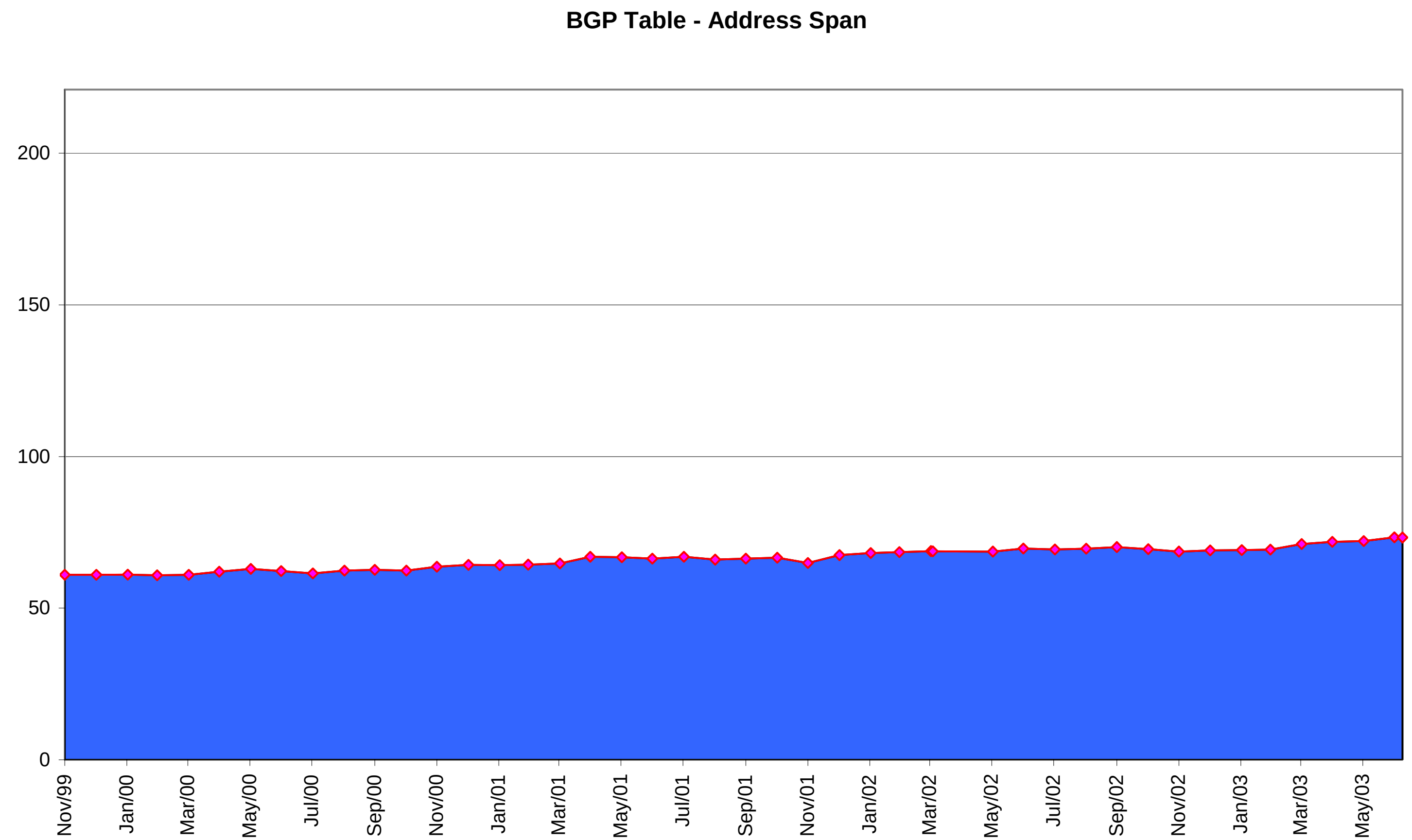
Age of Unannounced Blocks



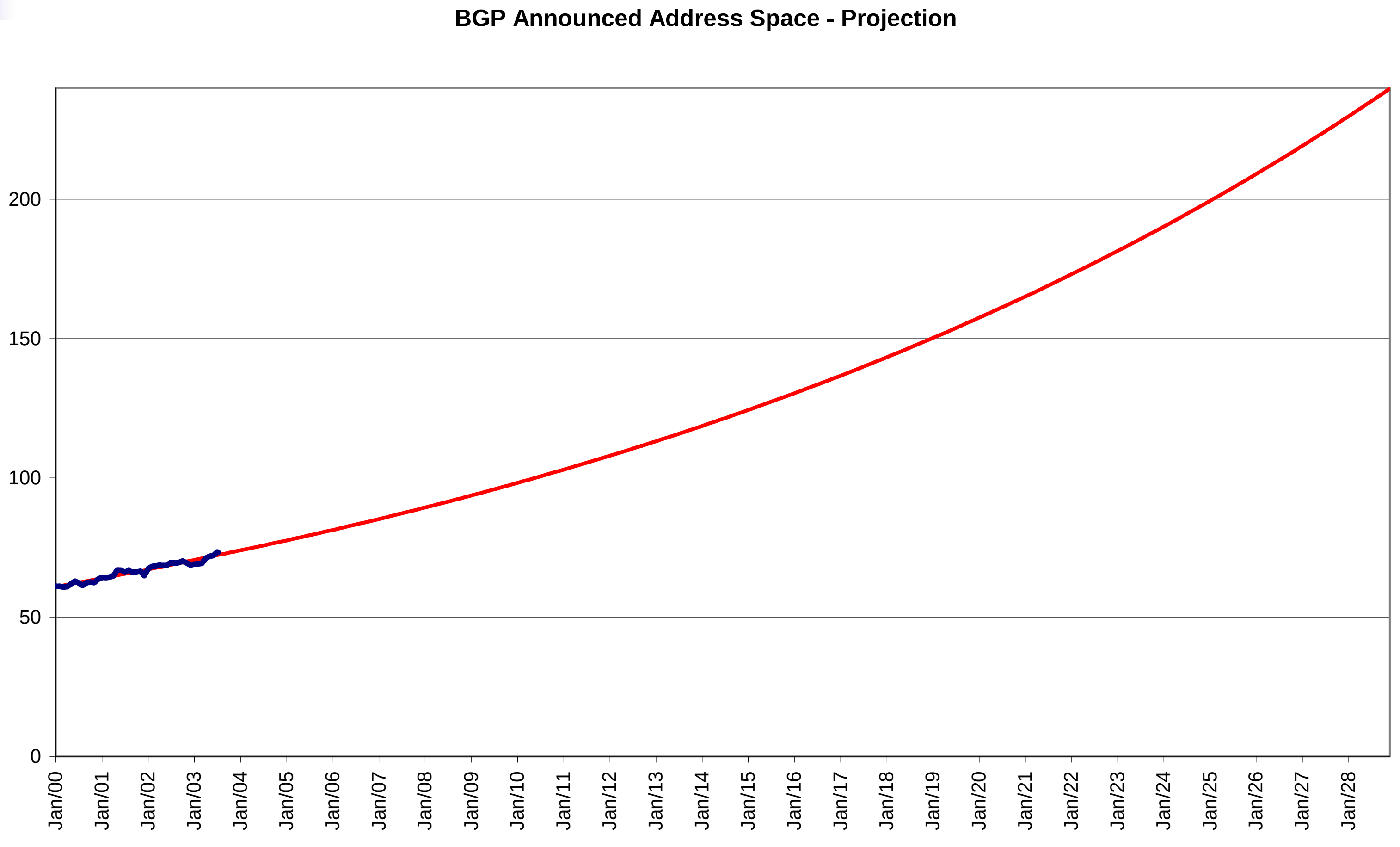
Age of Unannounced Blocks (cumulative)



BGP Address Span



BGP Projections



BGP Projections

- This projection of 2027 (221 /8s) and 2028 (237 /8s) uses a 3 year baseline
  - This is much shorter baseline than the IANA and RIR projections
  - There are, again, considerable uncertainties associated with this projection

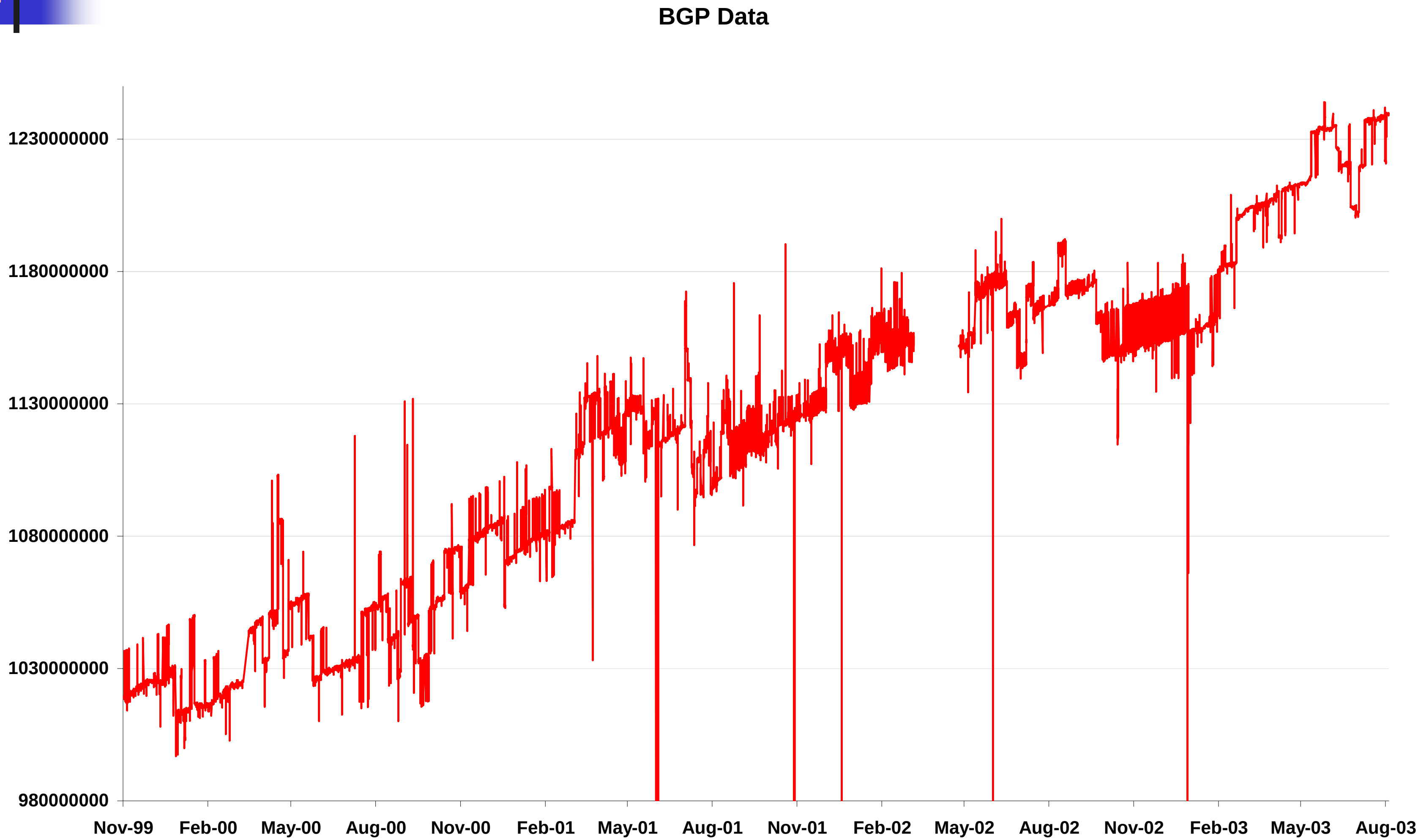
Another look at that BGP data:...

- Comments received about this projection have prompted me to review the BGP address data and see if a more detailed analysis of the BGP data modifies this model
- It appears to be the case that there is a different view that can be formed from the data:......

Another look at that BGP data:…

- Firstly, here's the raw data – hourly measurements over 3 years.

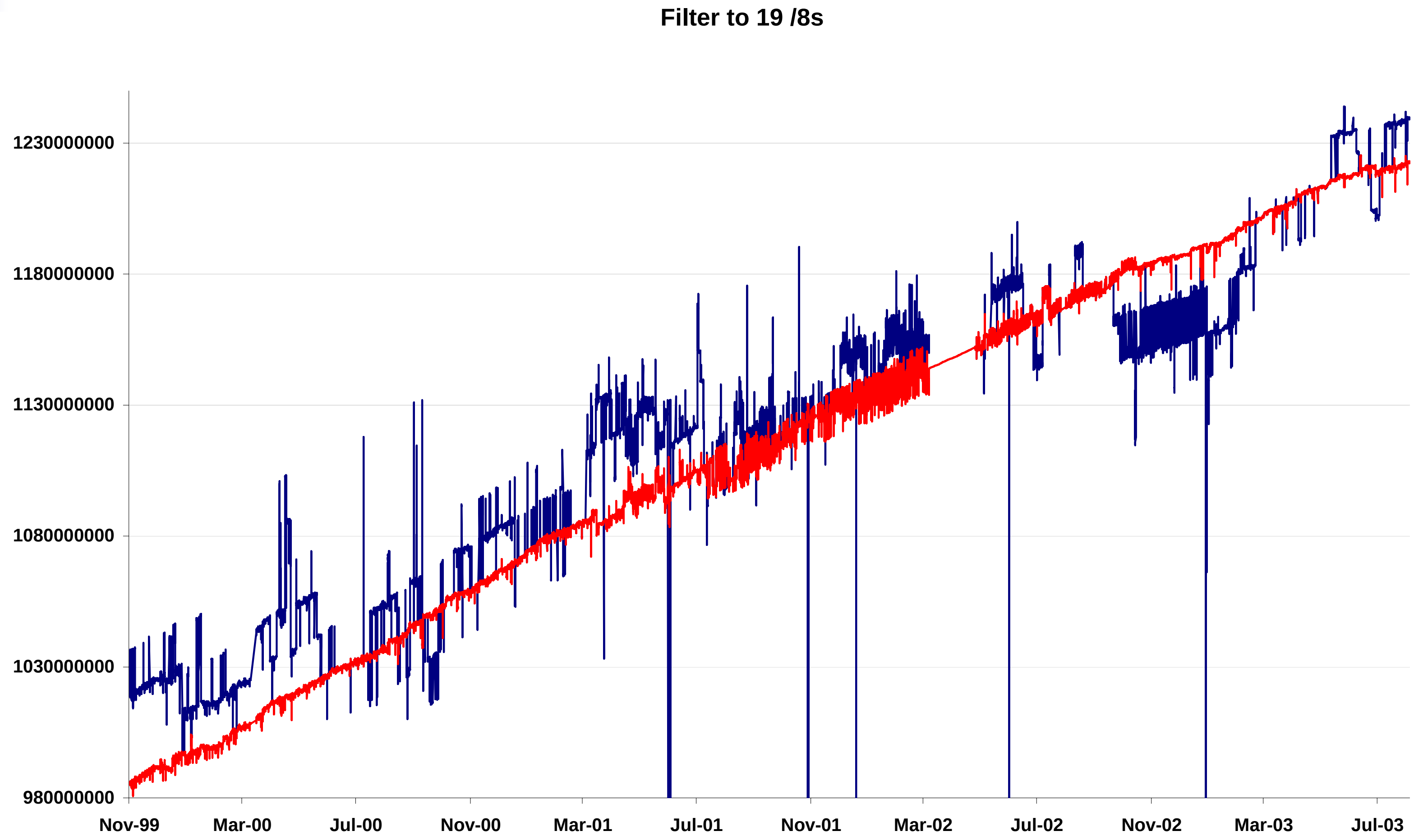
Another look at that BGP data:…



Another look at that BGP data:...

- The most obvious noise comes from flaps in /8 advertisements.
- The first step was to remove this noise by recalculating the address data using a fixed number of /8 advertisements
- The value of 19 was used to select one of the 'tracks' in the data

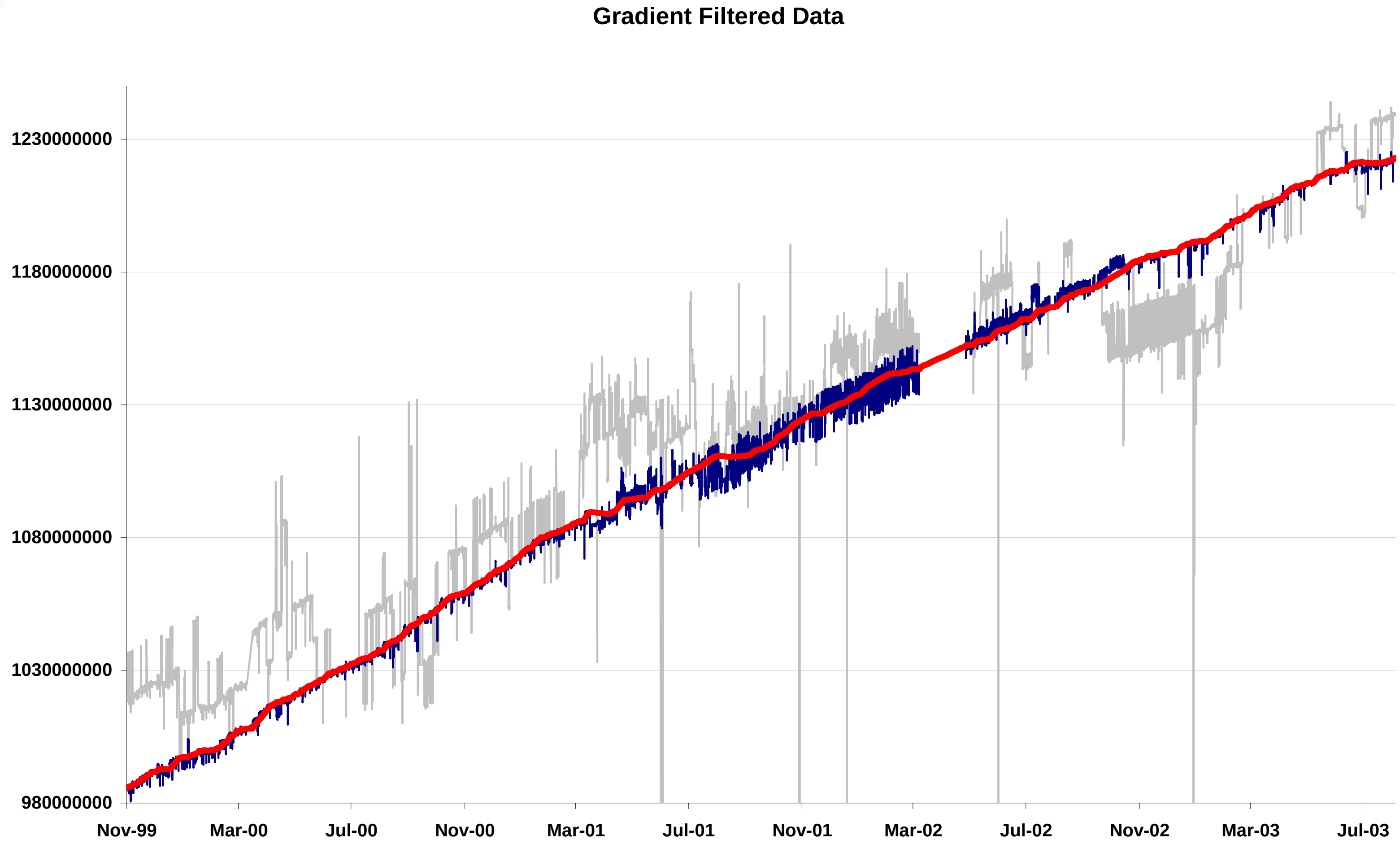
Another look at that BGP data:...



Another look at that BGP data:...

- This is still noisy, but there is no systematic method of raw data grooming that can efficiently reduce this noise.
- At this stage I use gradient smoothing, limiting the absolute values of the first order differential of the data (gradient limiting) to smooth the data

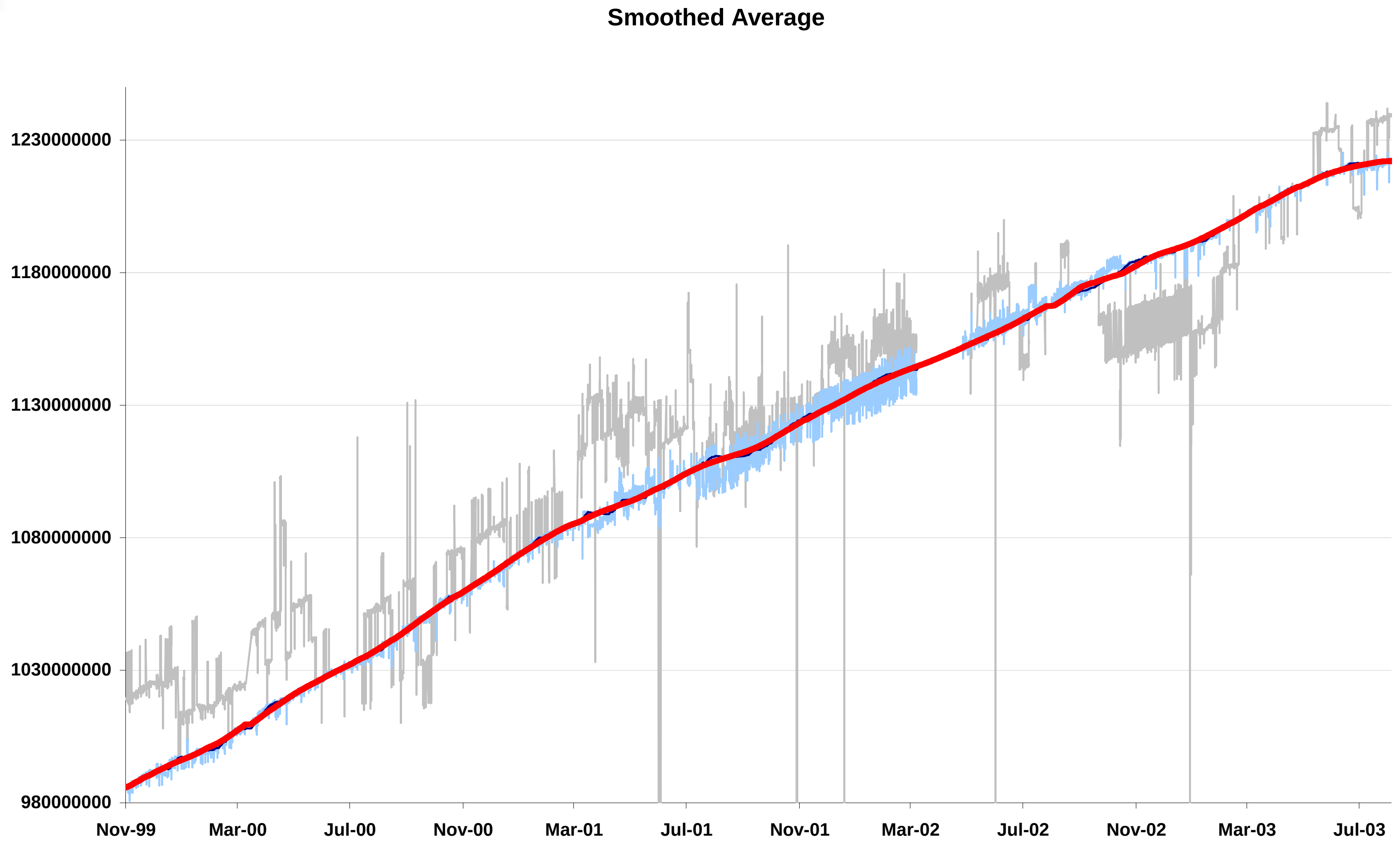
Another look at that BGP data:…



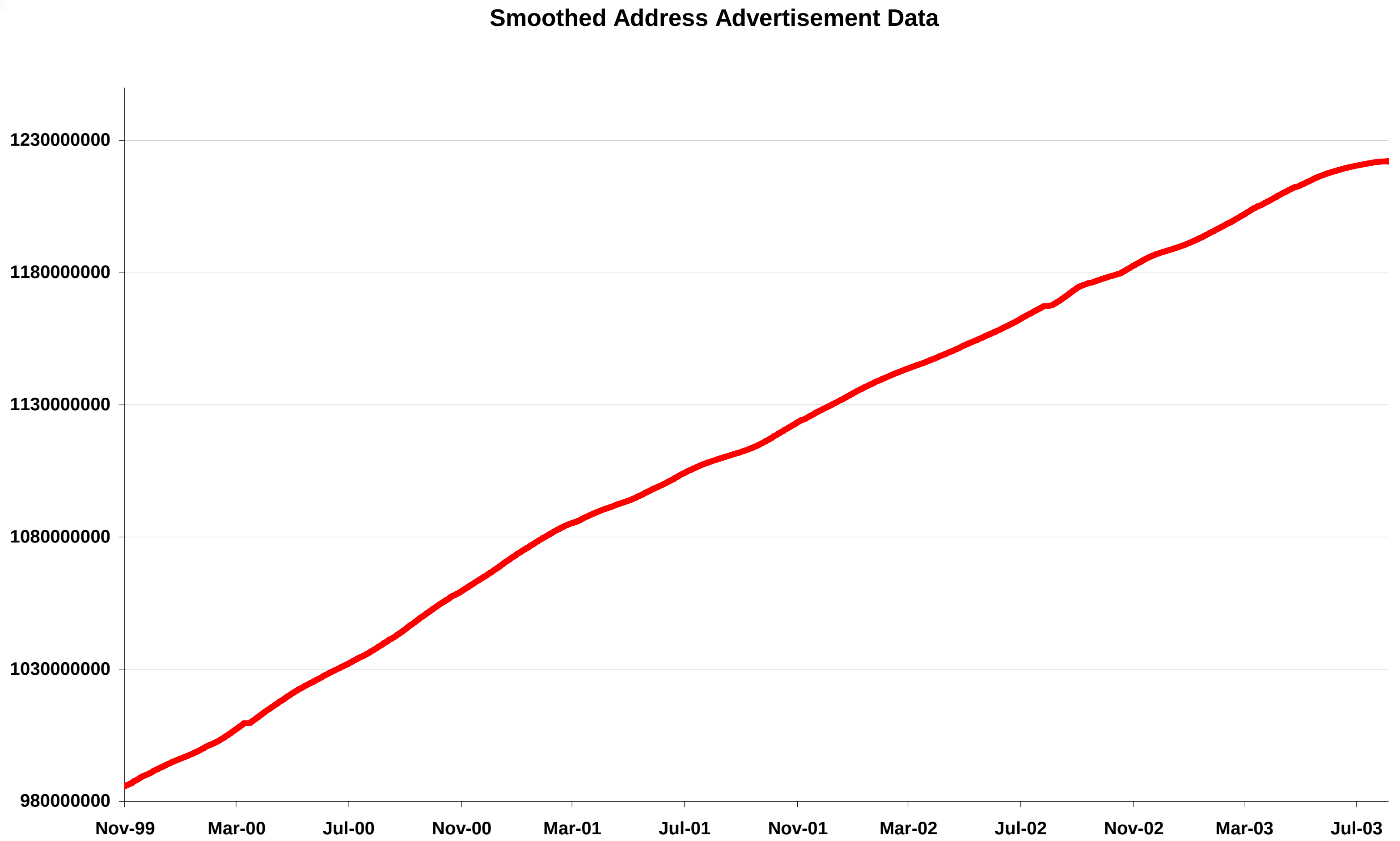
Another look at that BGP data:…

- At this stage further smoothing is necessary in order to reduce the data set to allow projection models to be generated
- The technique used is a sliding window average, with a window of 1501 entries

Another look at that BGP data:...



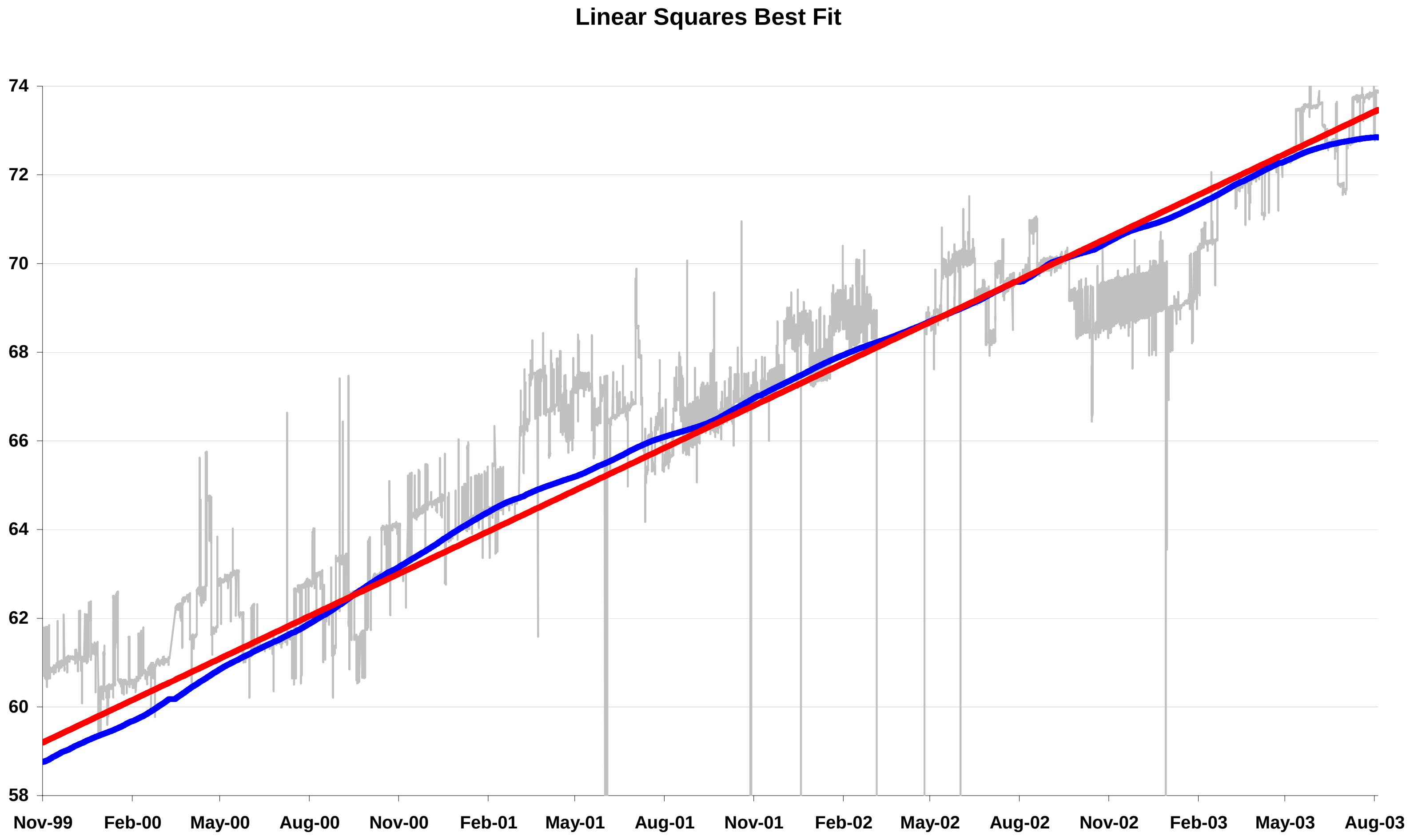
Another look at that BGP data:...



Another look at that BGP data:...

- Its now possible to apply a best fit function to the data.
- A linear model appears to be the most appropriate fit:...

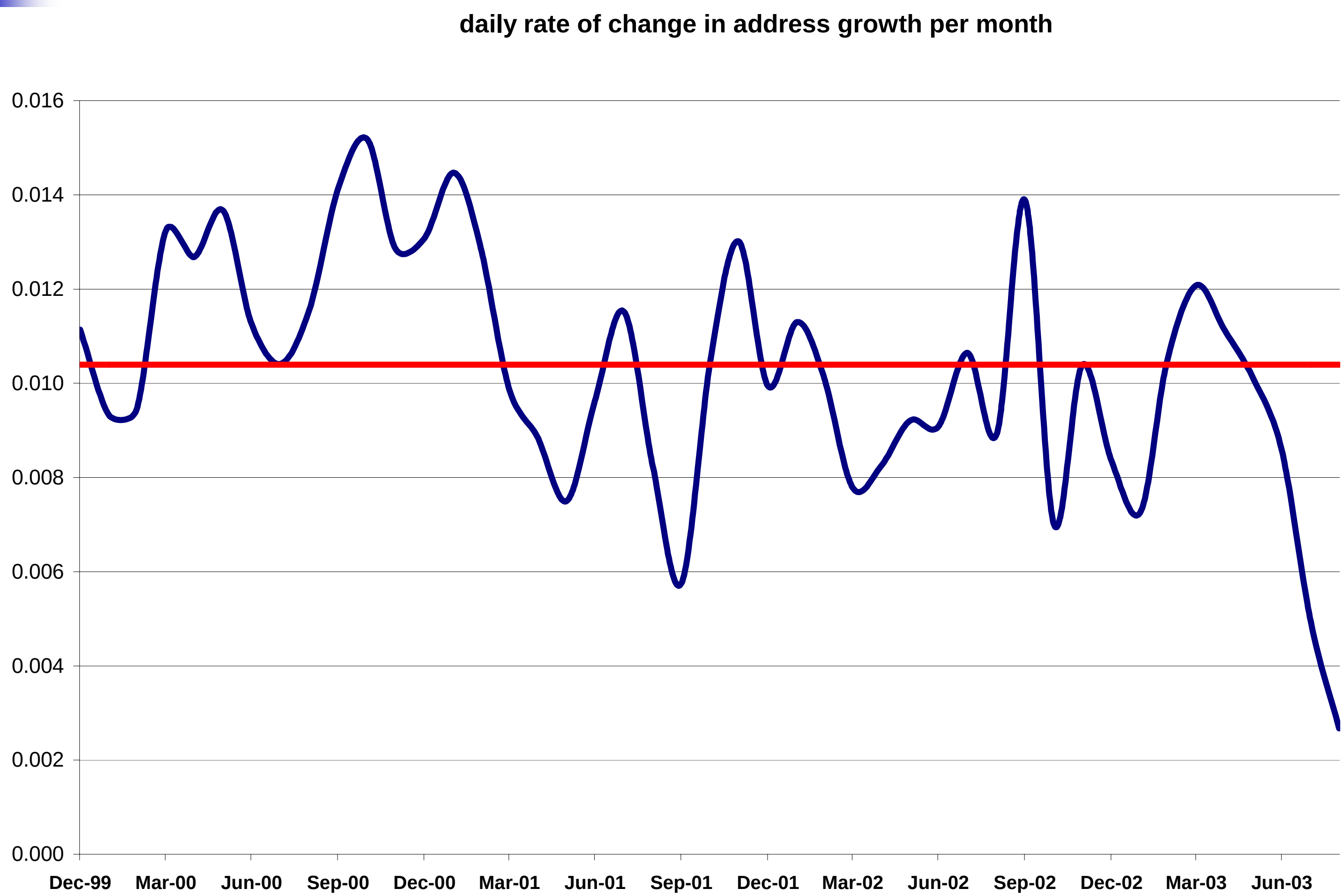
Another look at that BGP data:...



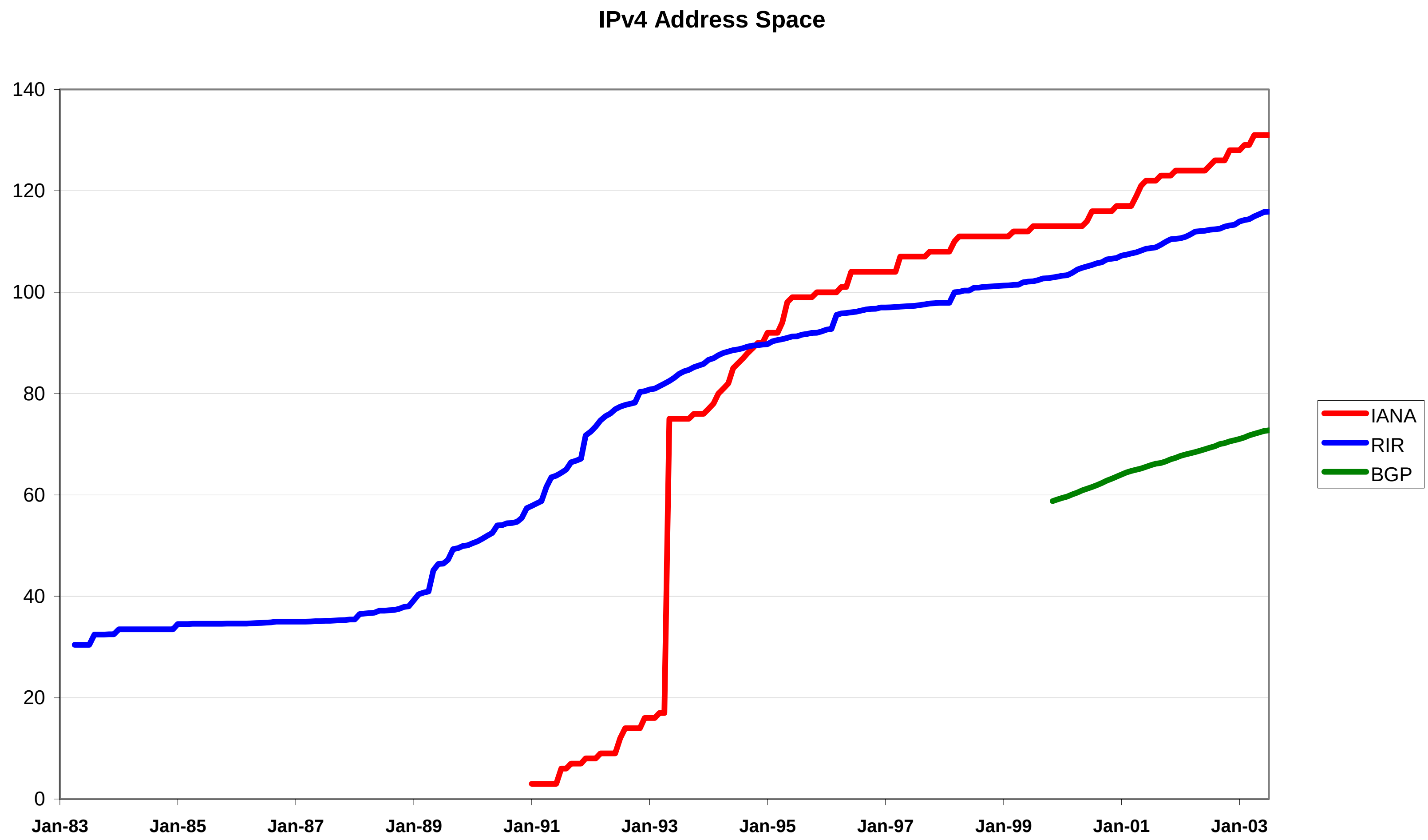
Another look at that BGP data:...

- An inspection of the first order differential of the data reveals why the linear fit is considered to be the most appropriate for the available data.
- While the period through 2000 shows a pattern of an increasing first order differential that is consistent with an exponential growth model, subsequent data reveals an oscillating value for the differential, and a linear model provides a constant first order differential
- This linear model appears to be the most conservative fit to the data, although the most recent data shows a highly visible slowdown in the rate

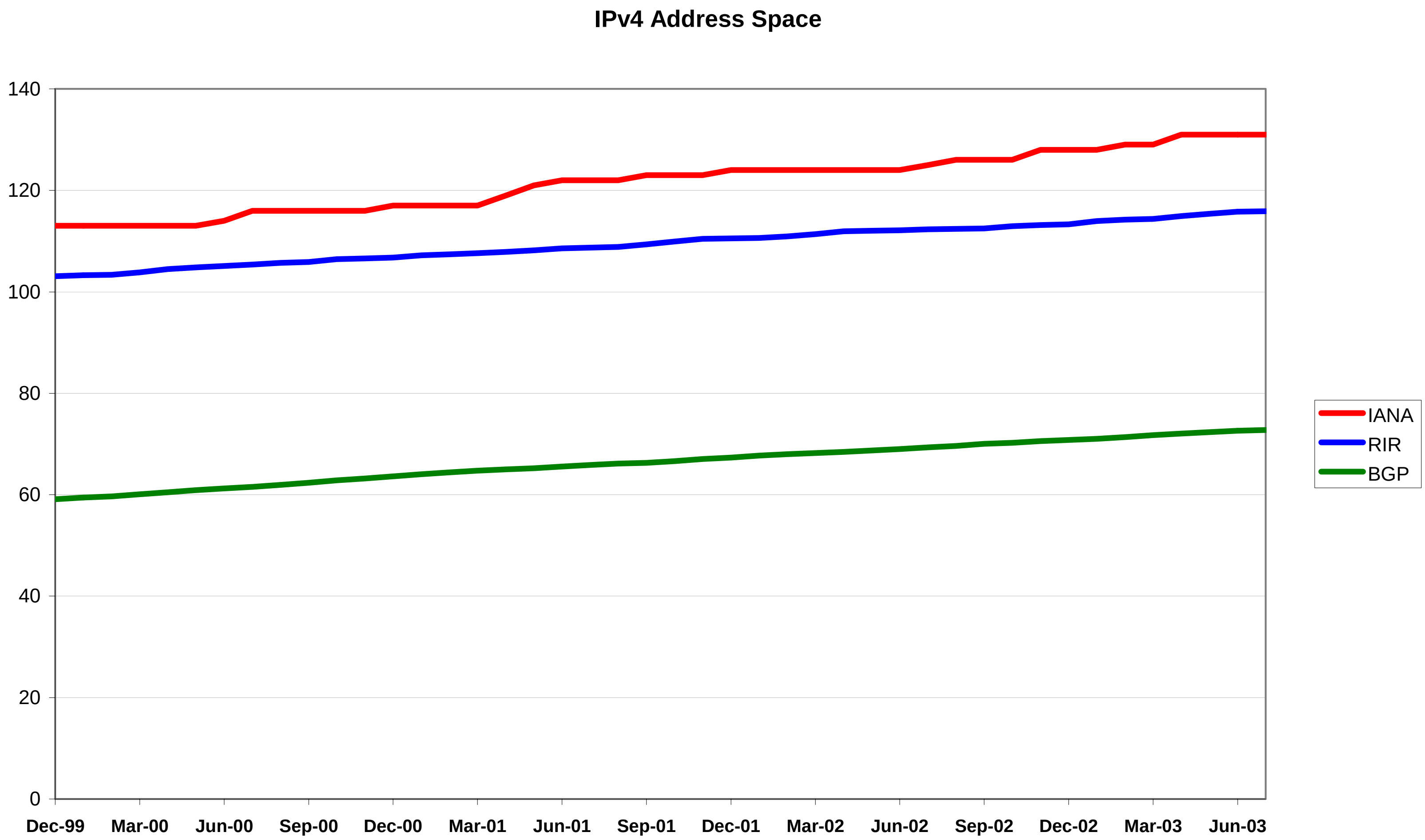
Another look at that BGP data:...



Combining the Data

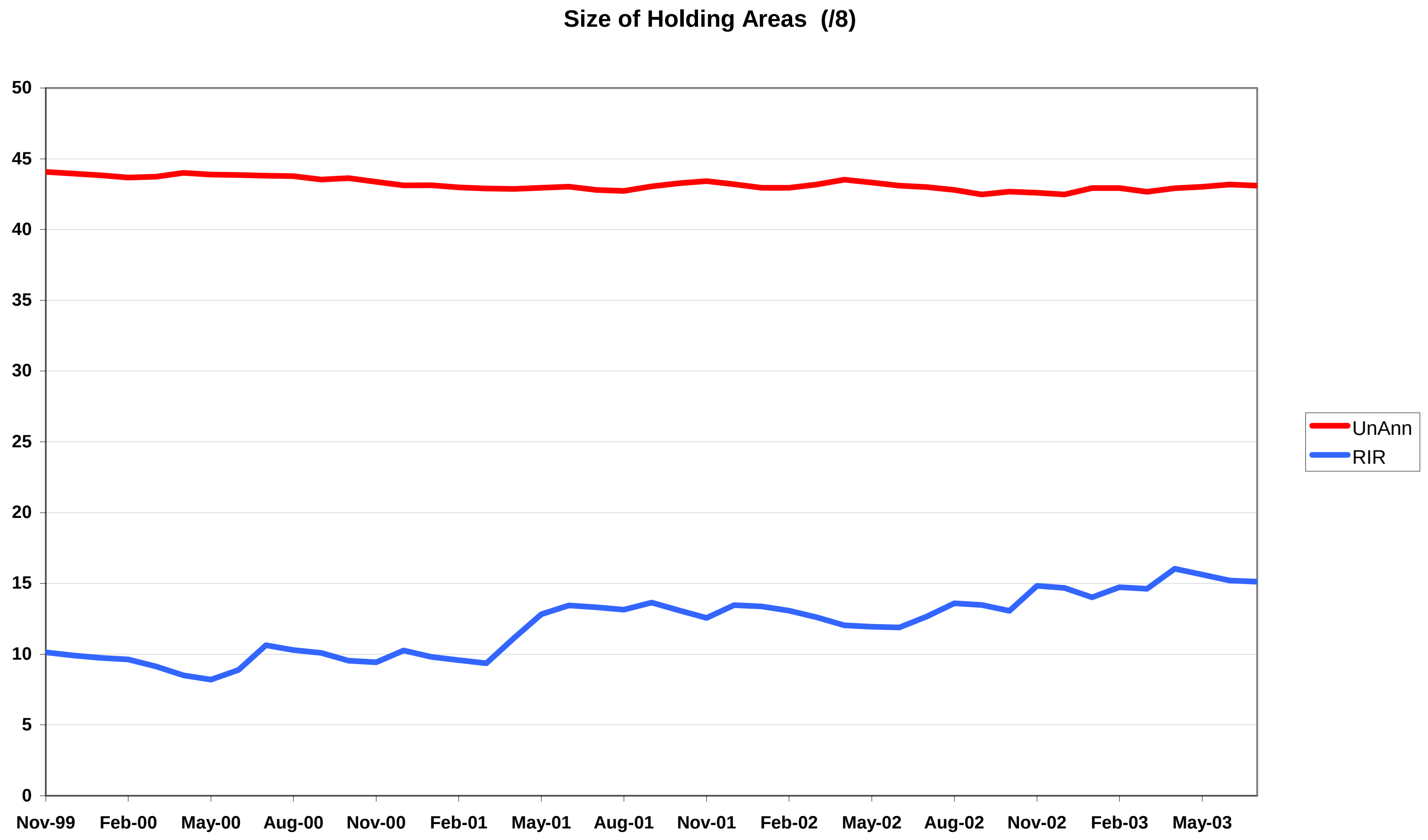


Recent Data



IPv4 Address Space
140
120
100
80
60
40
20
0
Dec-99
Mar-00
Jun-00
Sep-00
Dec-00
Mar-01
Jun-01
Sep-01
Dec-01
Mar-02
Jun-02
Sep-02
Dec-02
Mar-03
Jun-03
IANA
RIR
BGP

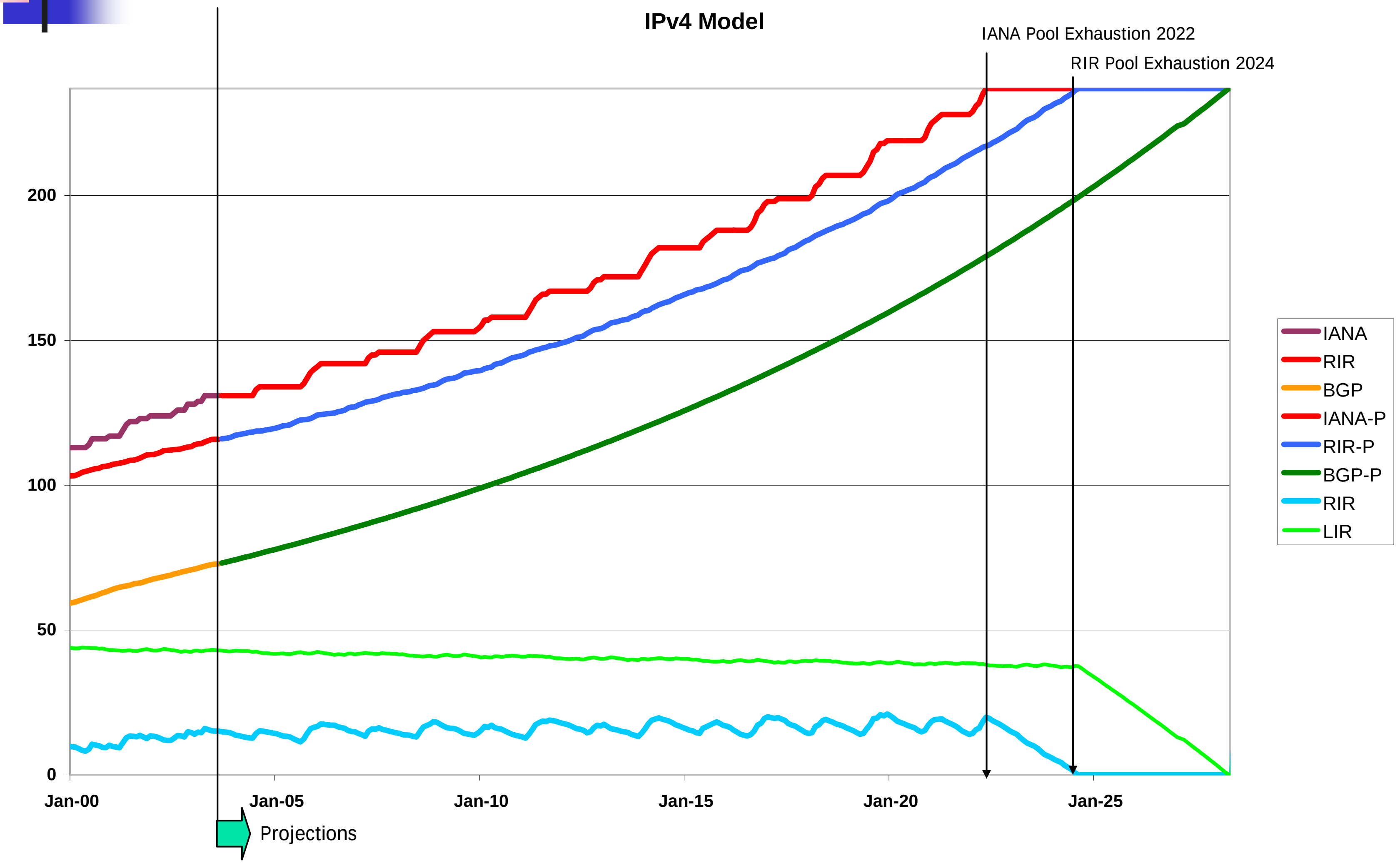
Holding Pools: RIR Pool and Unannounced Space



Modelling the Process

- Assume that the RIR efficiency in allocation slowly declines, so that the amount of RIR-held space increases over time
- Assume that the Unannounced space shrinks at the same rate as shown over the past3 years
- Assume an exponential best fit model to the announced address space projections and base RIR and IANA pools from the announced address space projections, using the above 2 assumptions

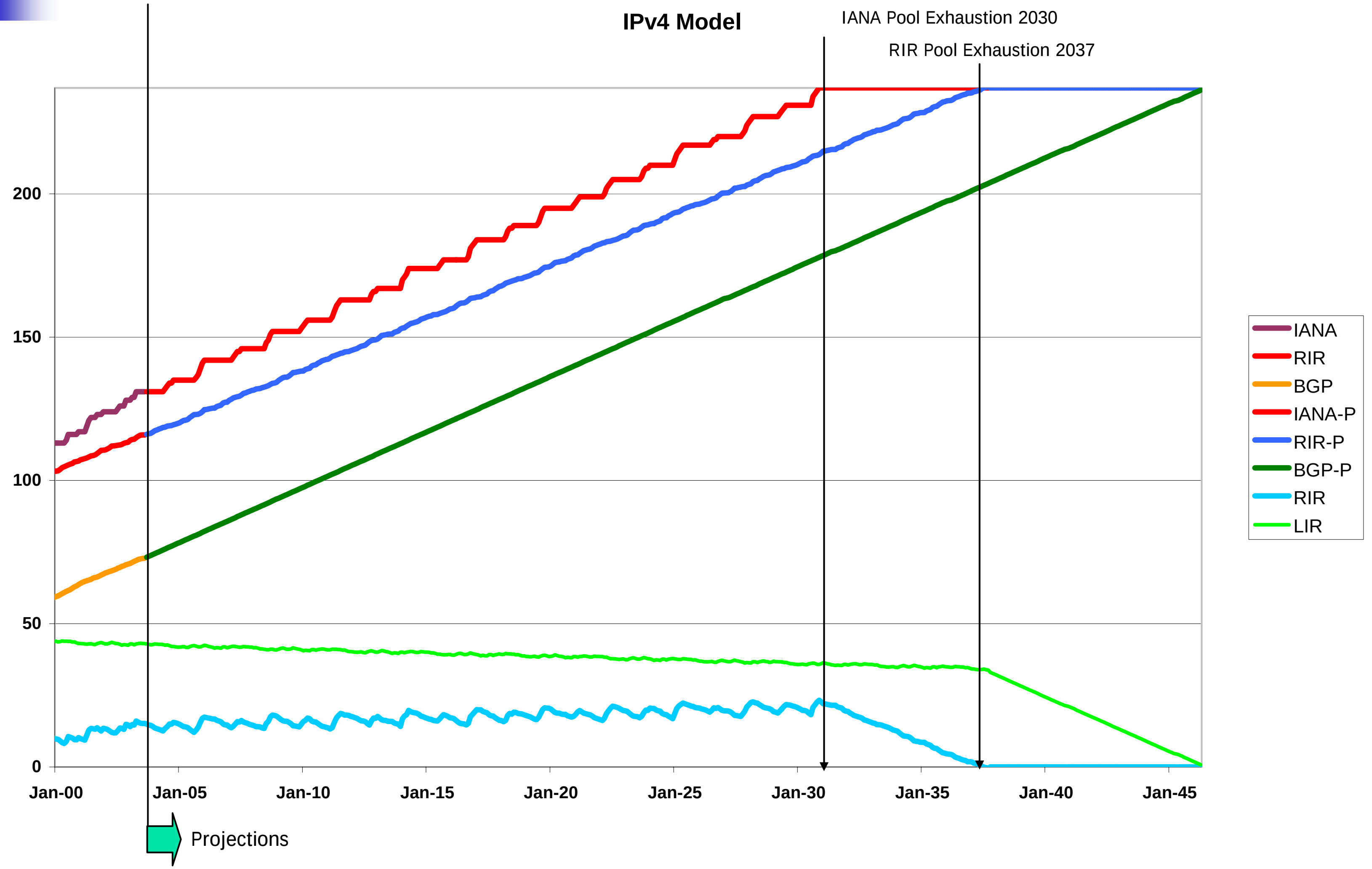
Modelling the Process



Modelling the Process

- Assume that the RIR efficiency in allocation slowly declines, then the amount of RIR-held space increases over time
- Assume that the Unannounced space shrinks at the same rate as shown over the past3 years
- Assume <u>linear</u> best fit model to the announced address space projections and base RIR and IANA pools from the announced address space projections

Modelling the Process



Observations

- Extrapolation of current allocation practices and current demand models using an exponential growth model derived from a 2000 – 2003 data would see RIR IPv4 space allocations being made for the next 2 decades, with the unallocated draw pool lasting until 2022 - 2024
- The use linear growth model sees RIR IPv4 space allocations being made for the next 3 decades, with the unallocated draw pool lasting until 2030 – 2037
- Re-introducing the held unannounced space into the routing system over the coming years would extend this point by a further decade, prolonging the useable lifetime of the unallocated draw pool until 2038 – 2045
- This is just a model – reality tends to express its own will!

Questions

- Will the routing table continue to reflect allocation rates (i.e. all allocated addresses are BGP advertised)?
- Is the model of the unadvertised pools and RIR holding pools appropriate?
- Externalities:
  - What are the underlying growth drivers and how are these best modeled?
  - What forms of disruptive events would alter this model?
  - What would be the extent of the disruption (order of size of the disruptive address demand)?