



# IPv4 Address Lifetime Expectancy Revisited

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The Regional Internet Registries 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

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- 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

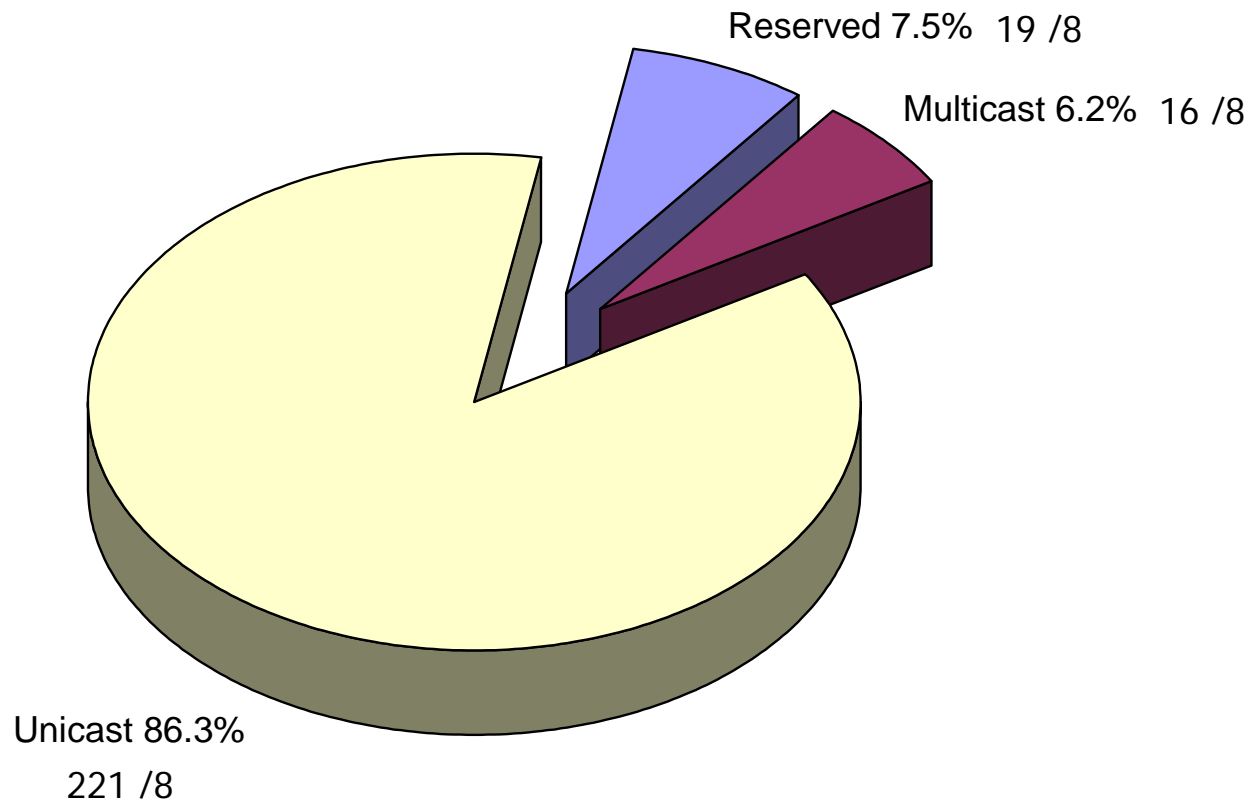


# The IPv4 Address Space

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- 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

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- 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

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- 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

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- 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



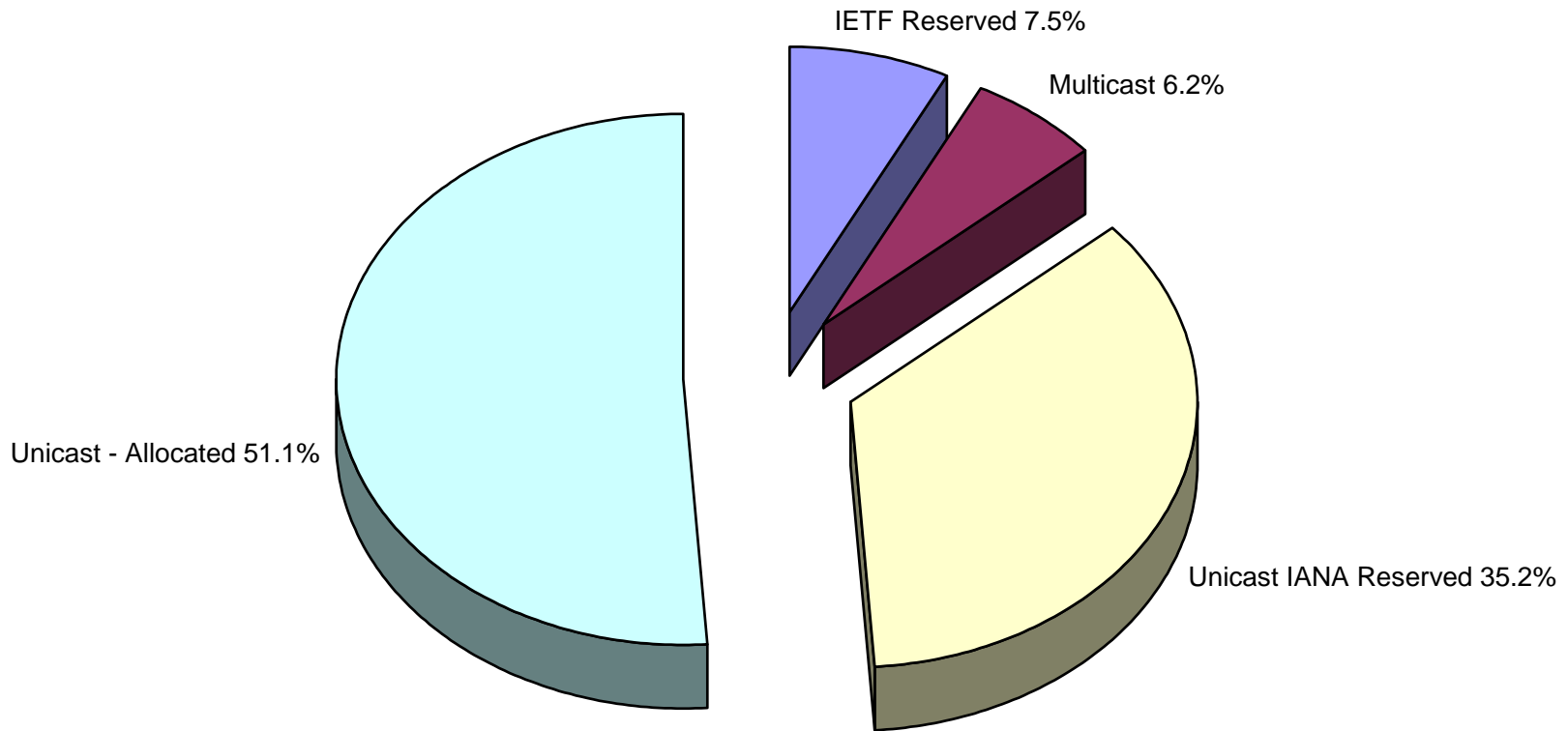
# IANA Registry Comments

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- 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

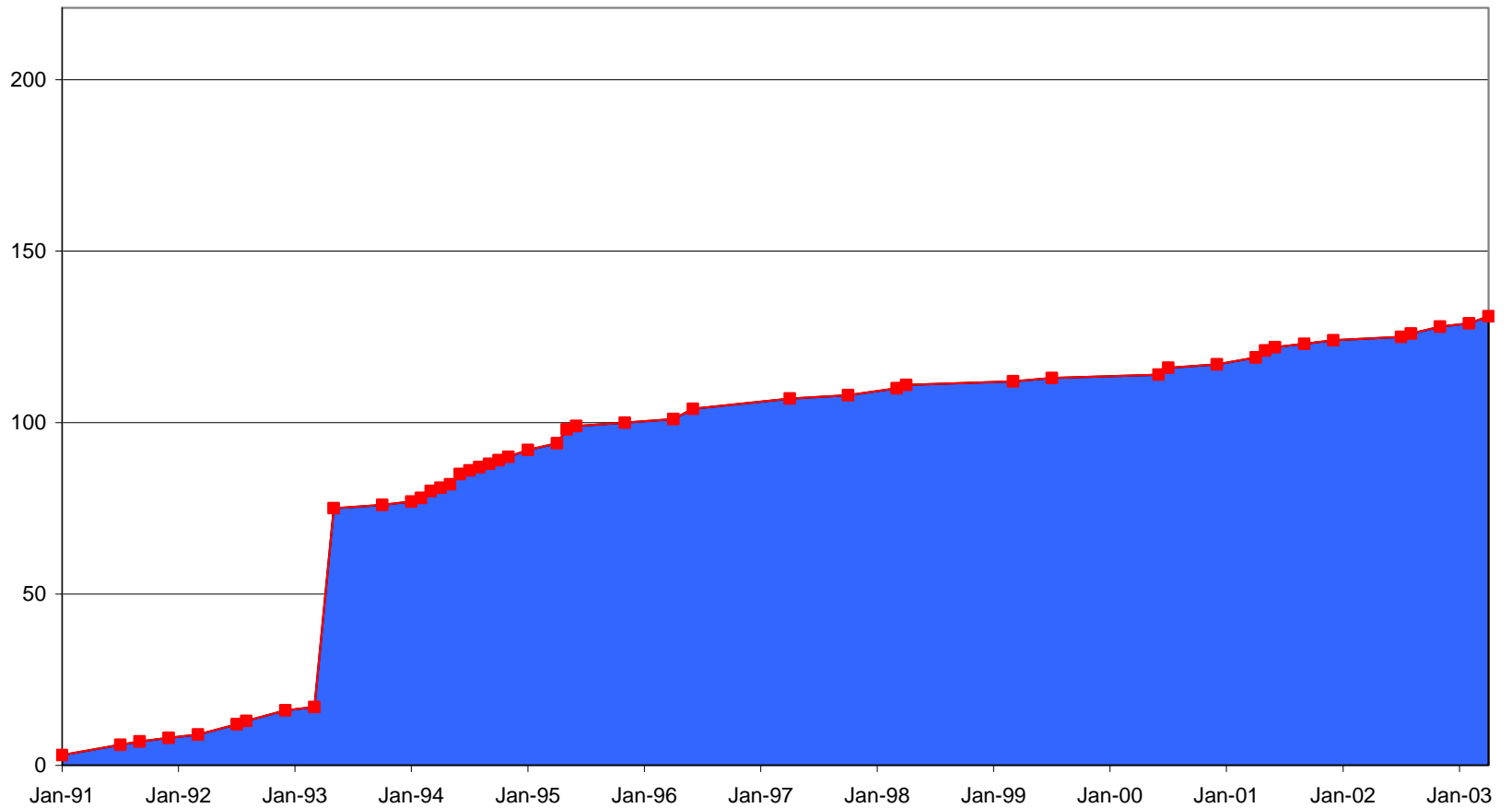


# IANA – Current Status



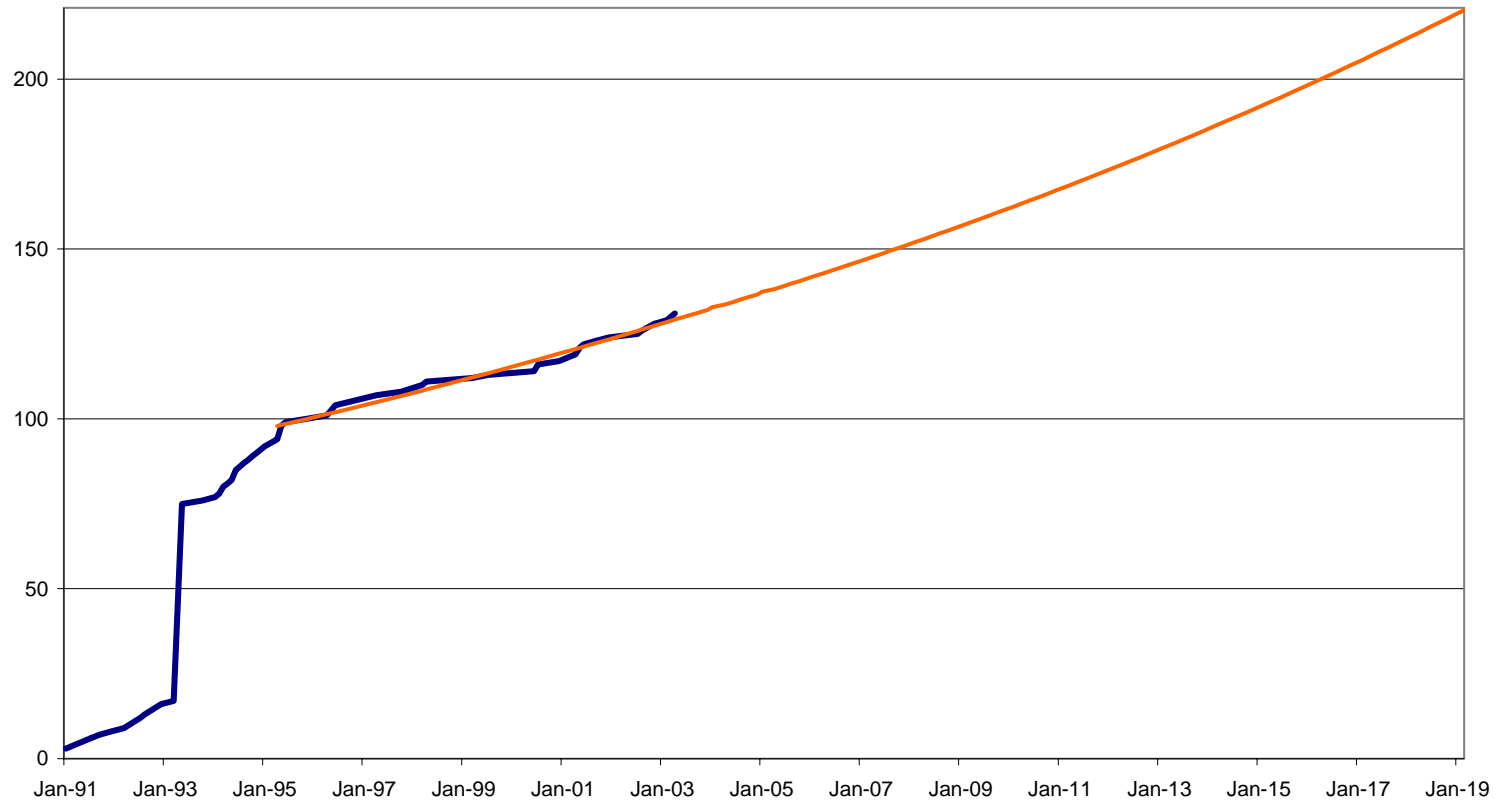
# IANA Allocations

IANA Allocations (/8)



# IANA Projections

IANA Allocation Projection





# IANA Projections

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- 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

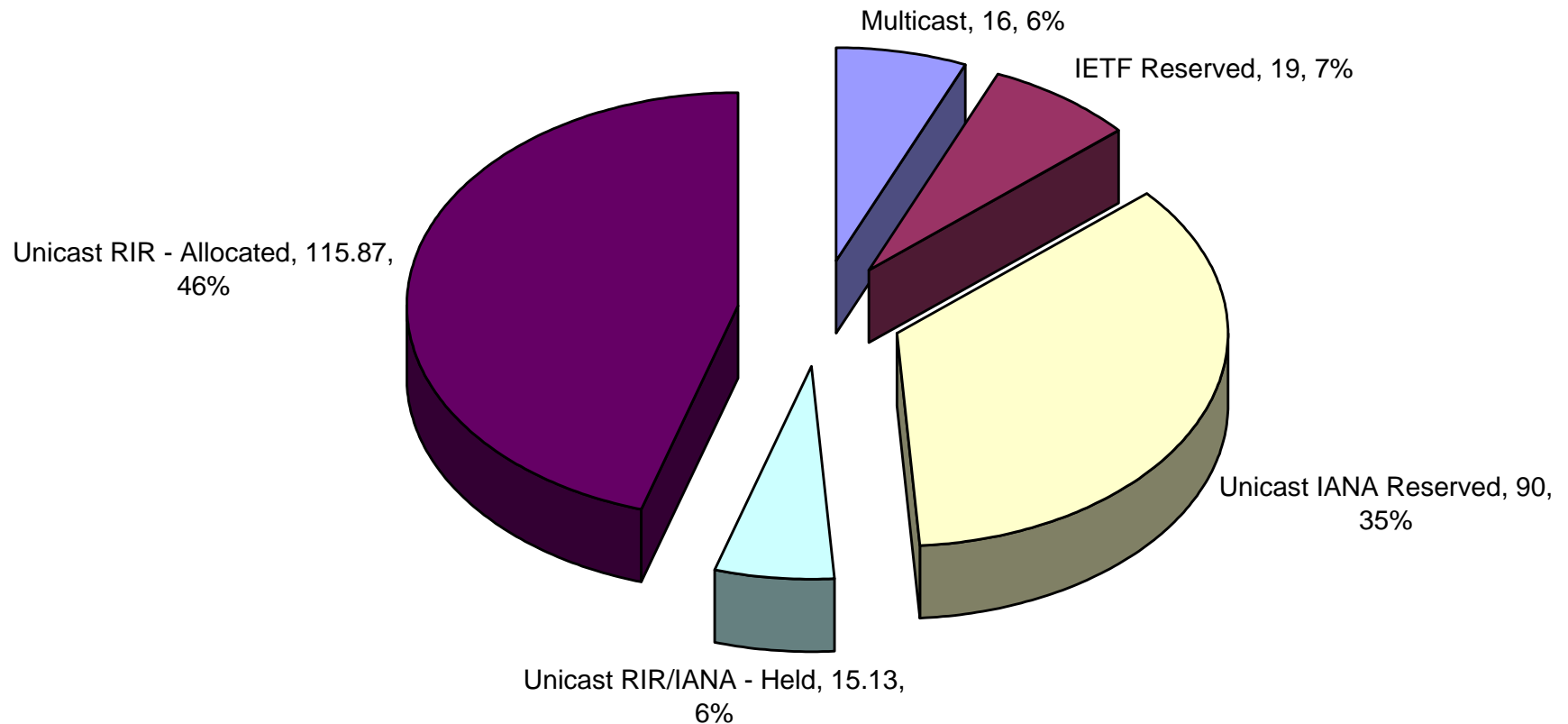


# RIR Allocations

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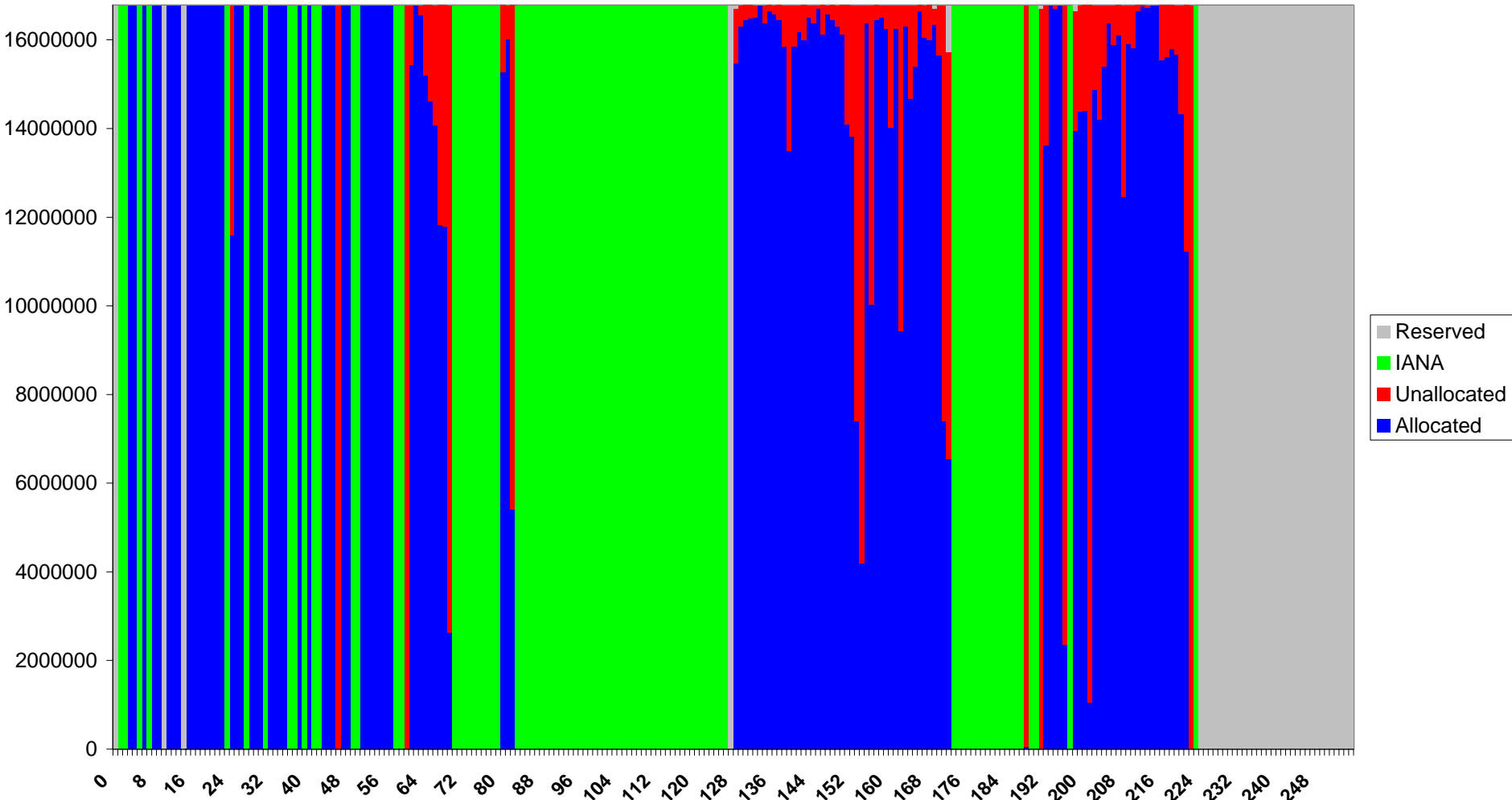
- The RIR stats files records the date of each allocation to an LIR, together with the allocation details

# RIR Allocations – Current Status



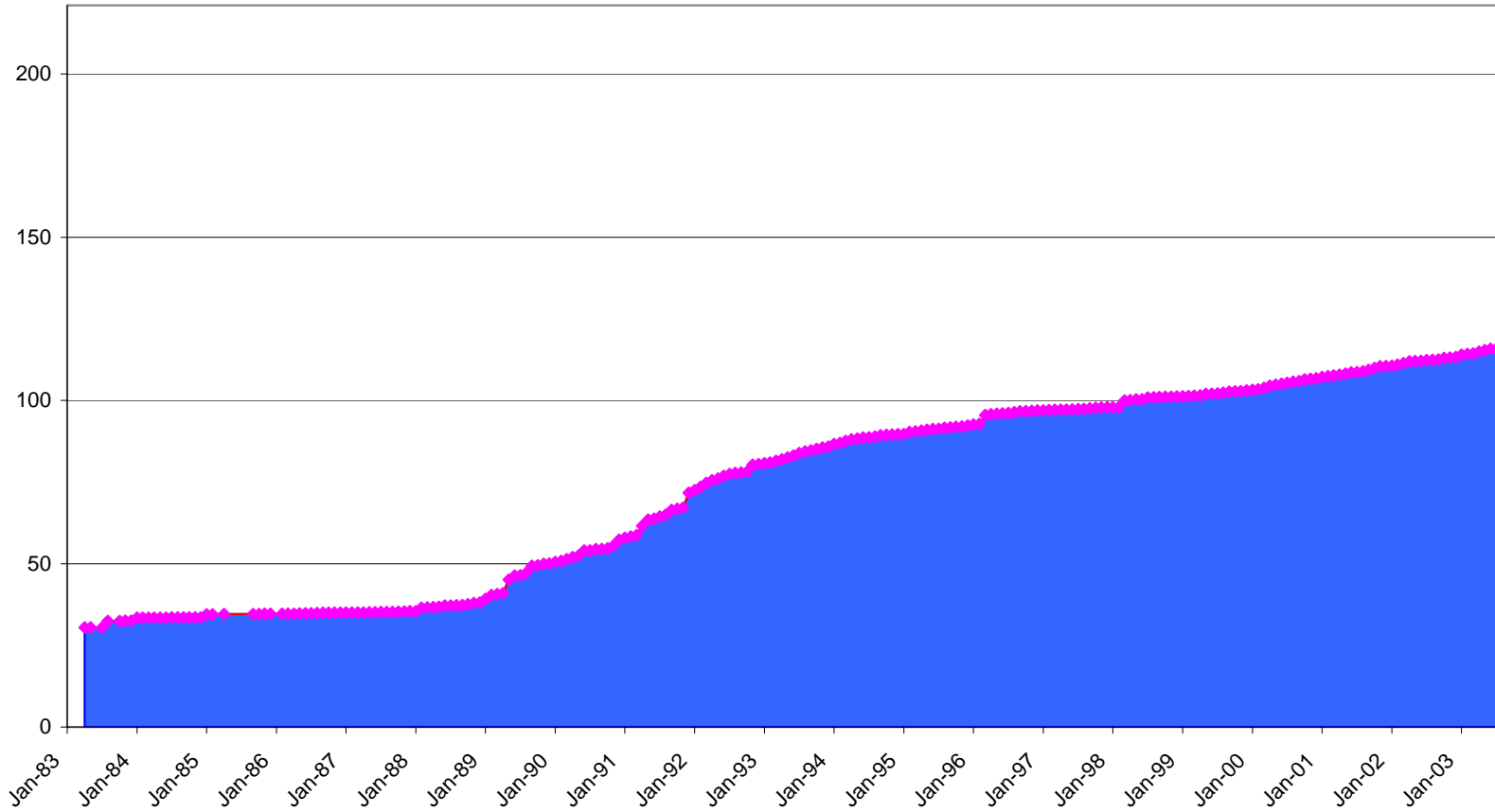
# RIR Allocations /8

Address Allocation Status - by /8



# RIR Allocations

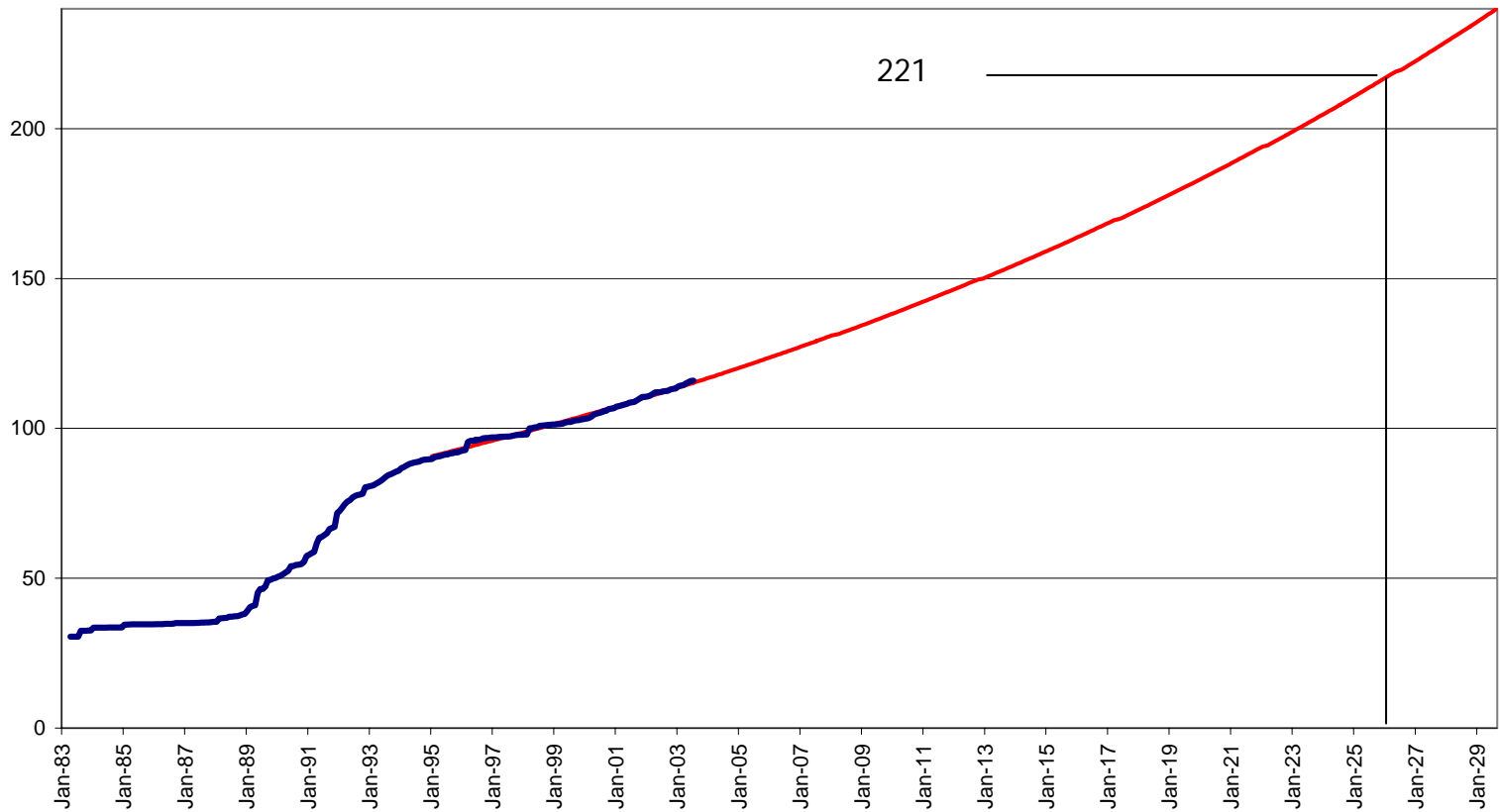
RIR Allocations





# RIR Projections

RIR Allocations - Projection





# RIR Projections

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

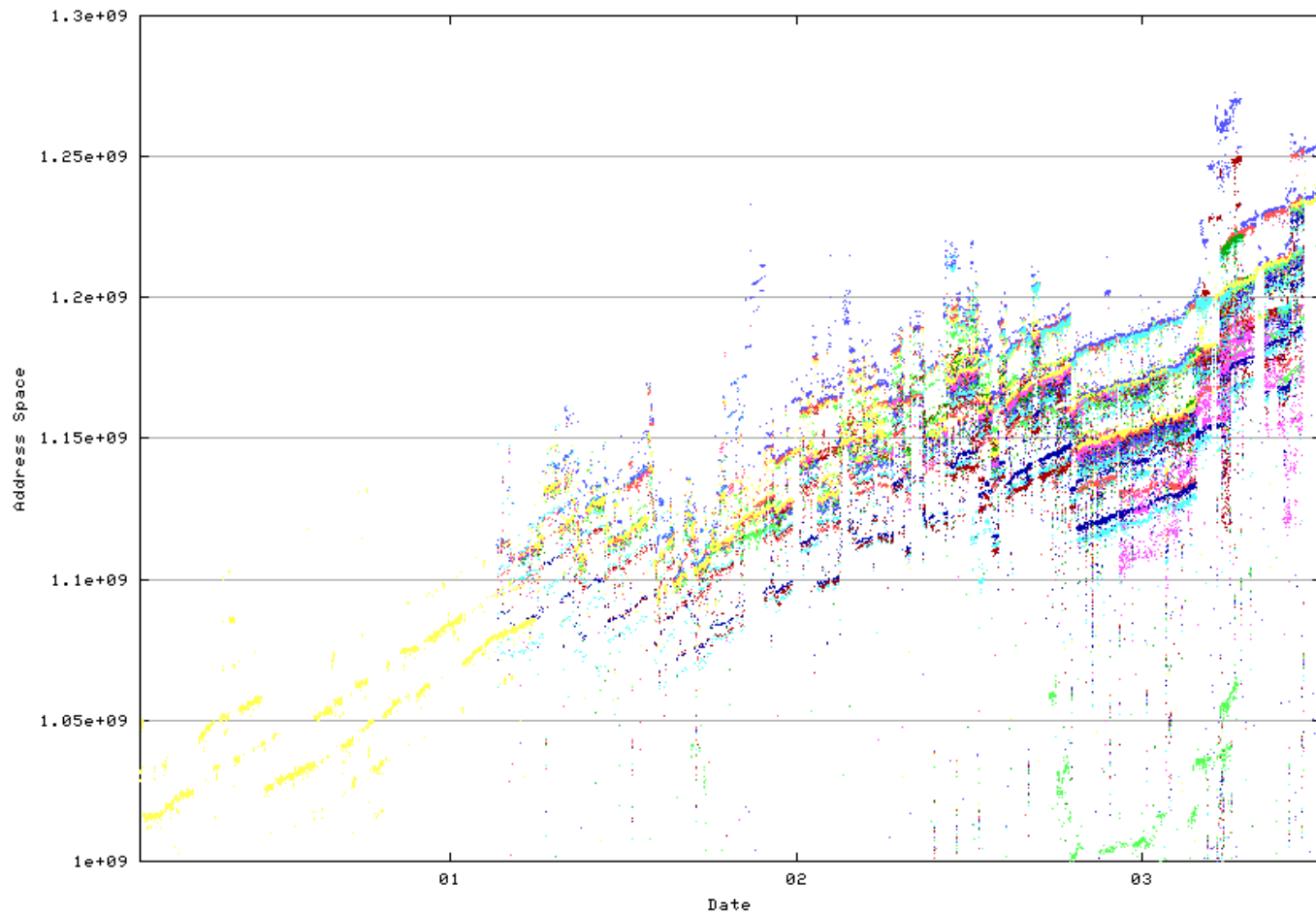


# BGP Routing Table

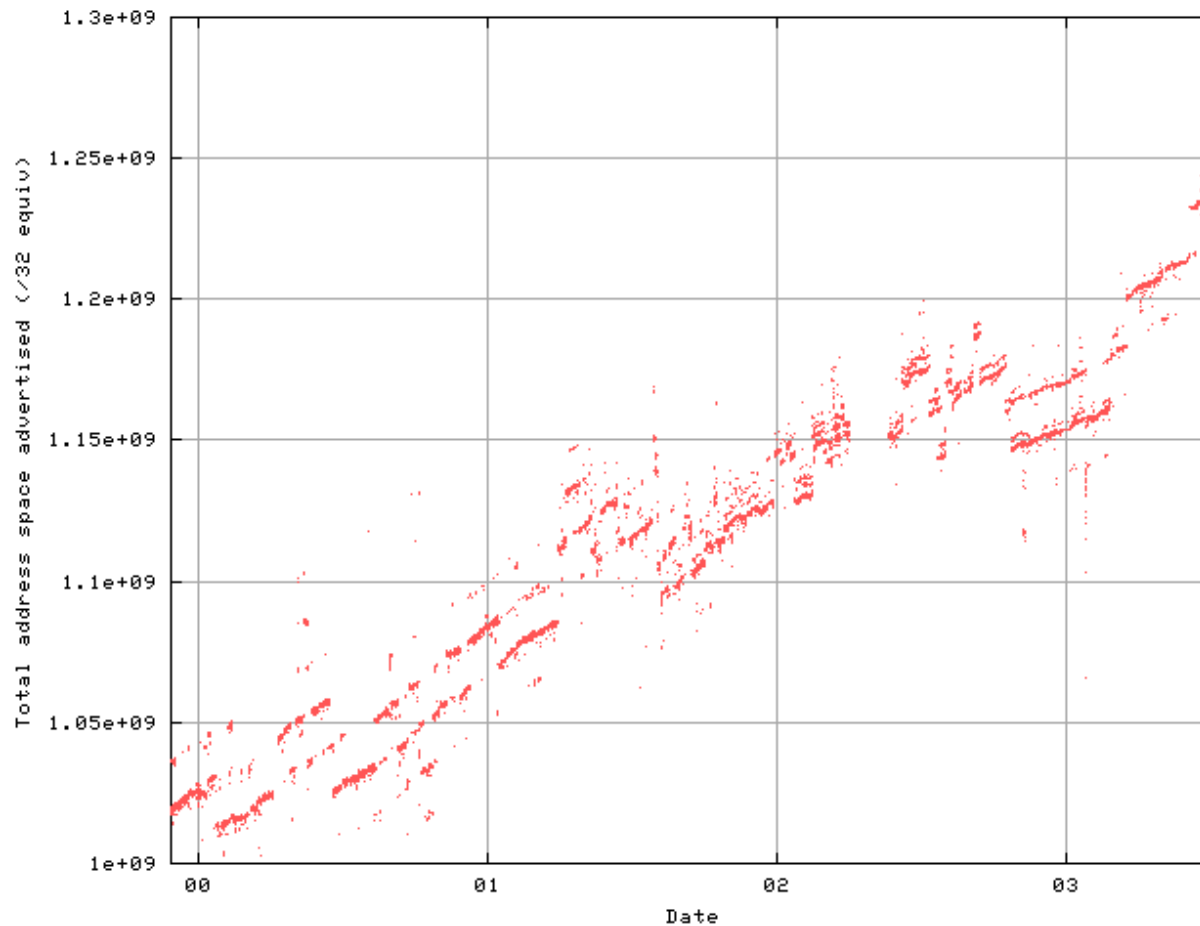
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- The BGP routing table spans a set of advertised addresses
- A similar analysis of usage and projection can be undertaken on this data

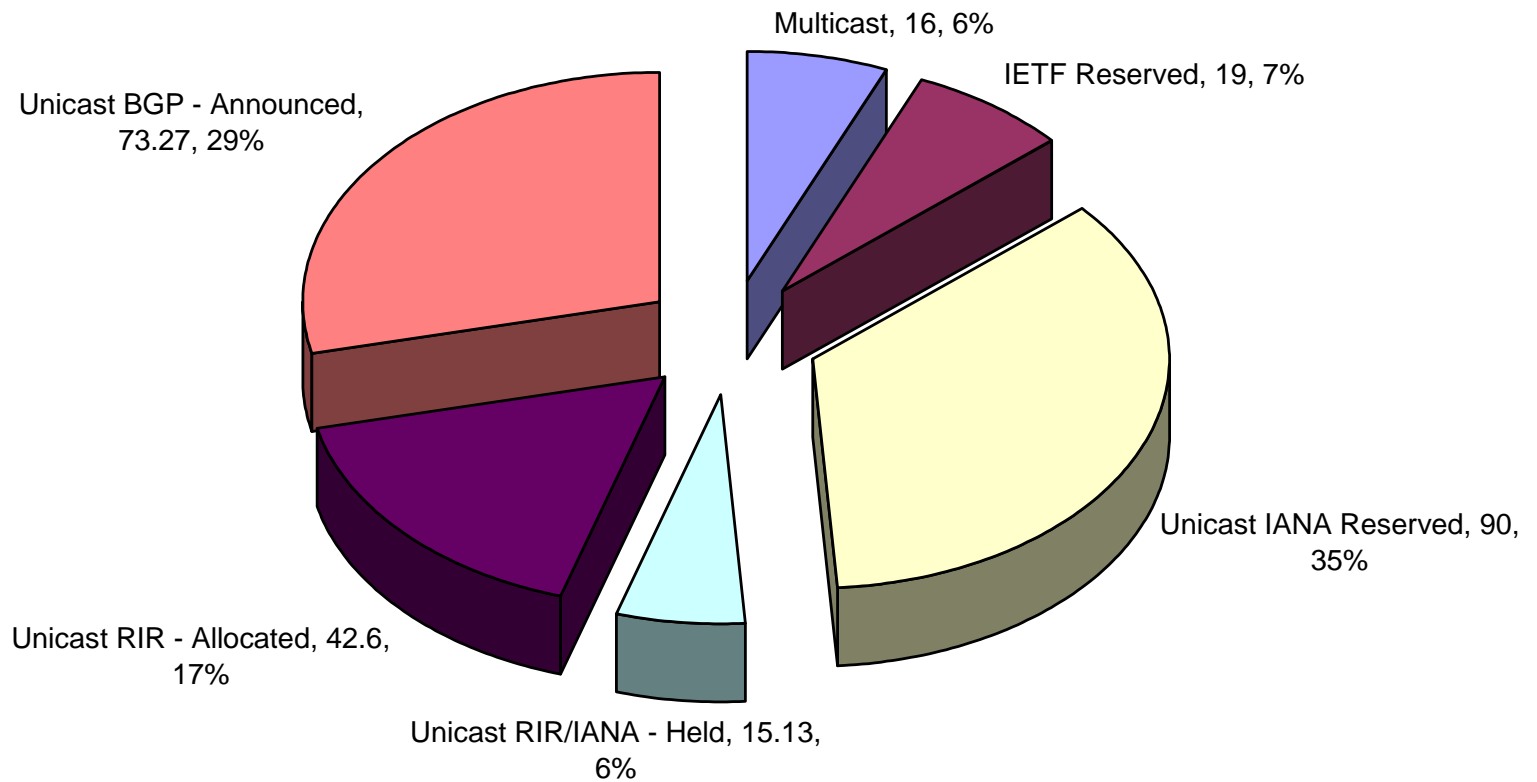
# The Route Views view



# The AS1221 view

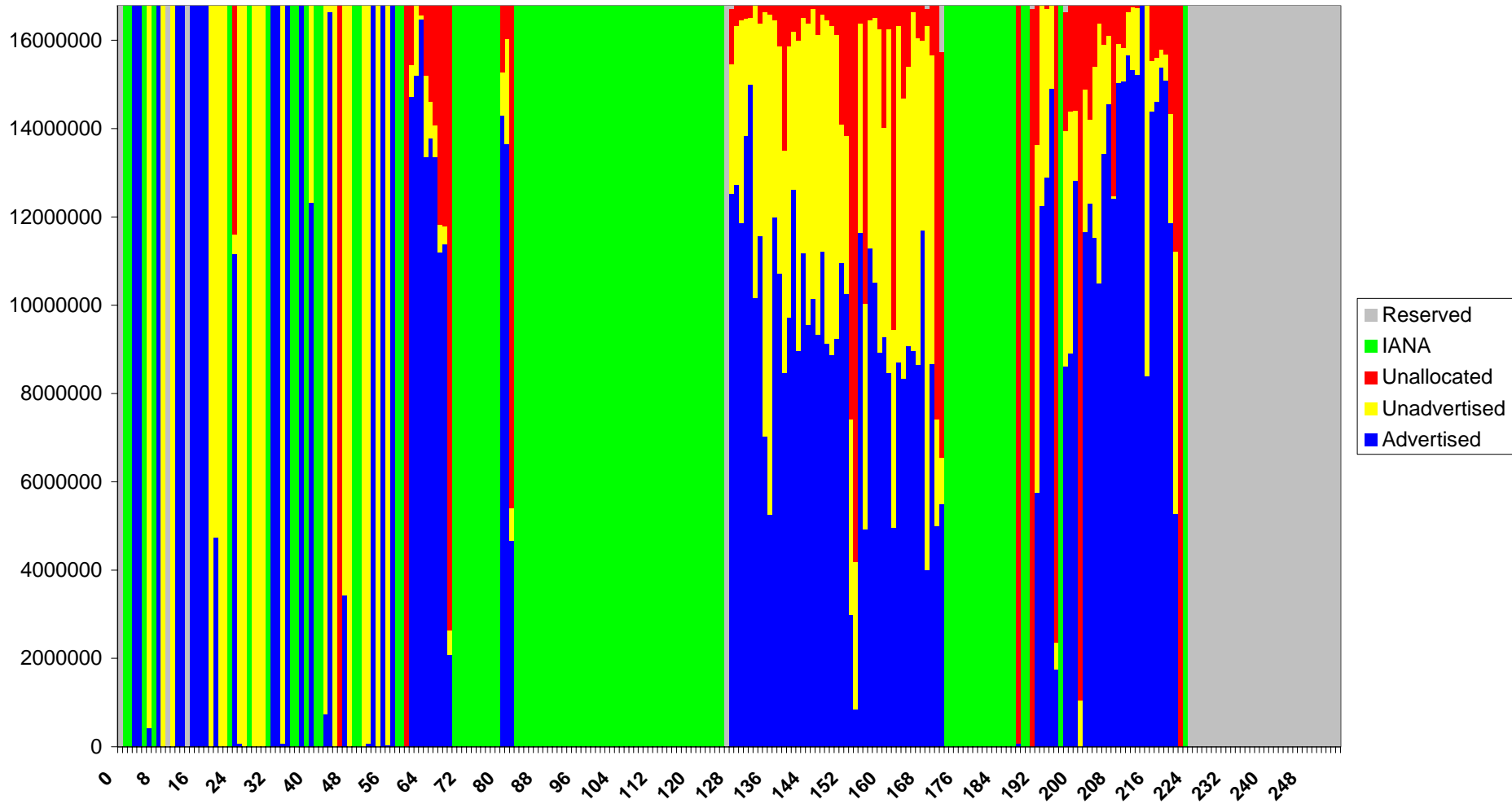


# BGP Routing Table - Status



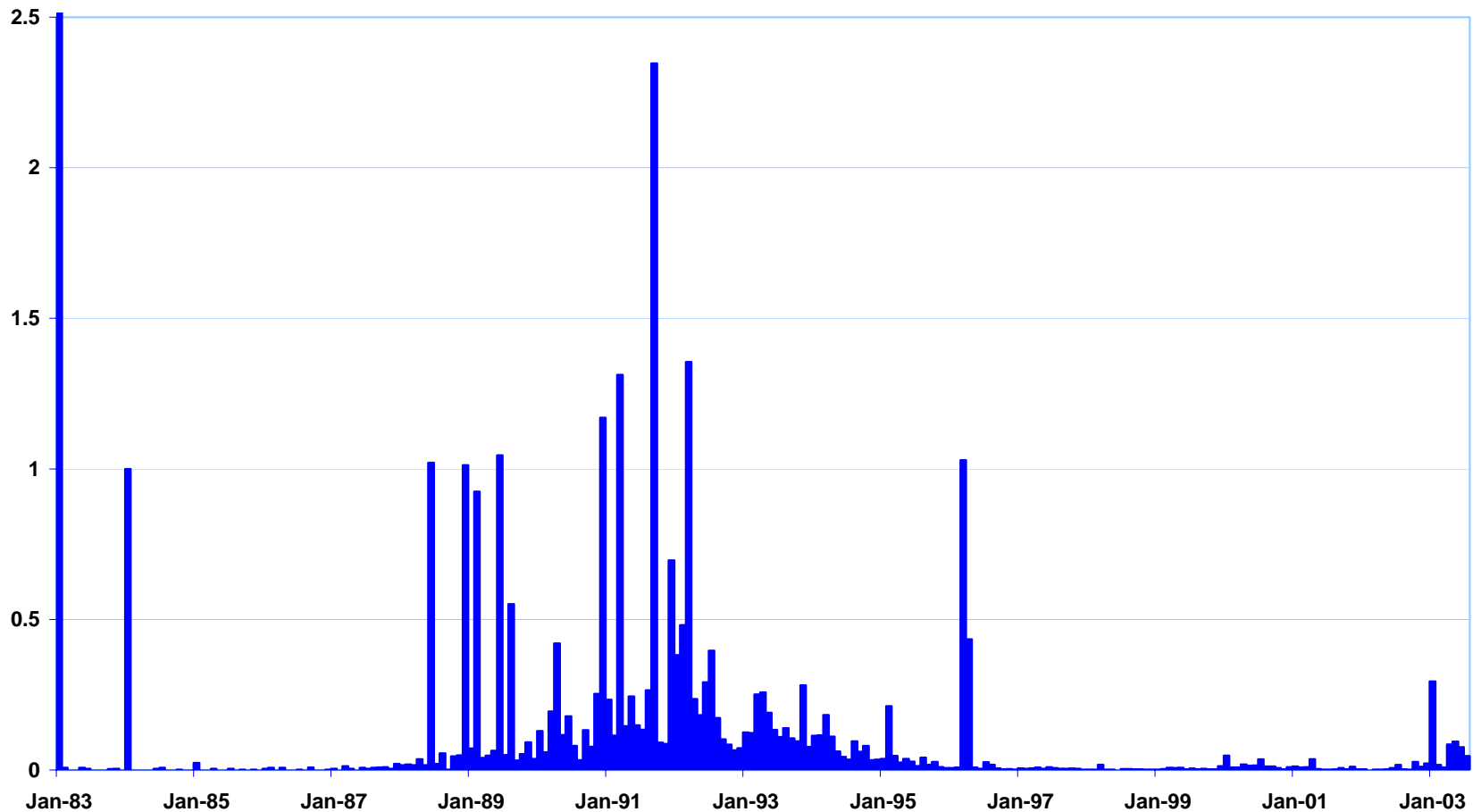
# BGP Address Allocations /8

Address Allocation Status - by /8



# Age of Unannounced Blocks

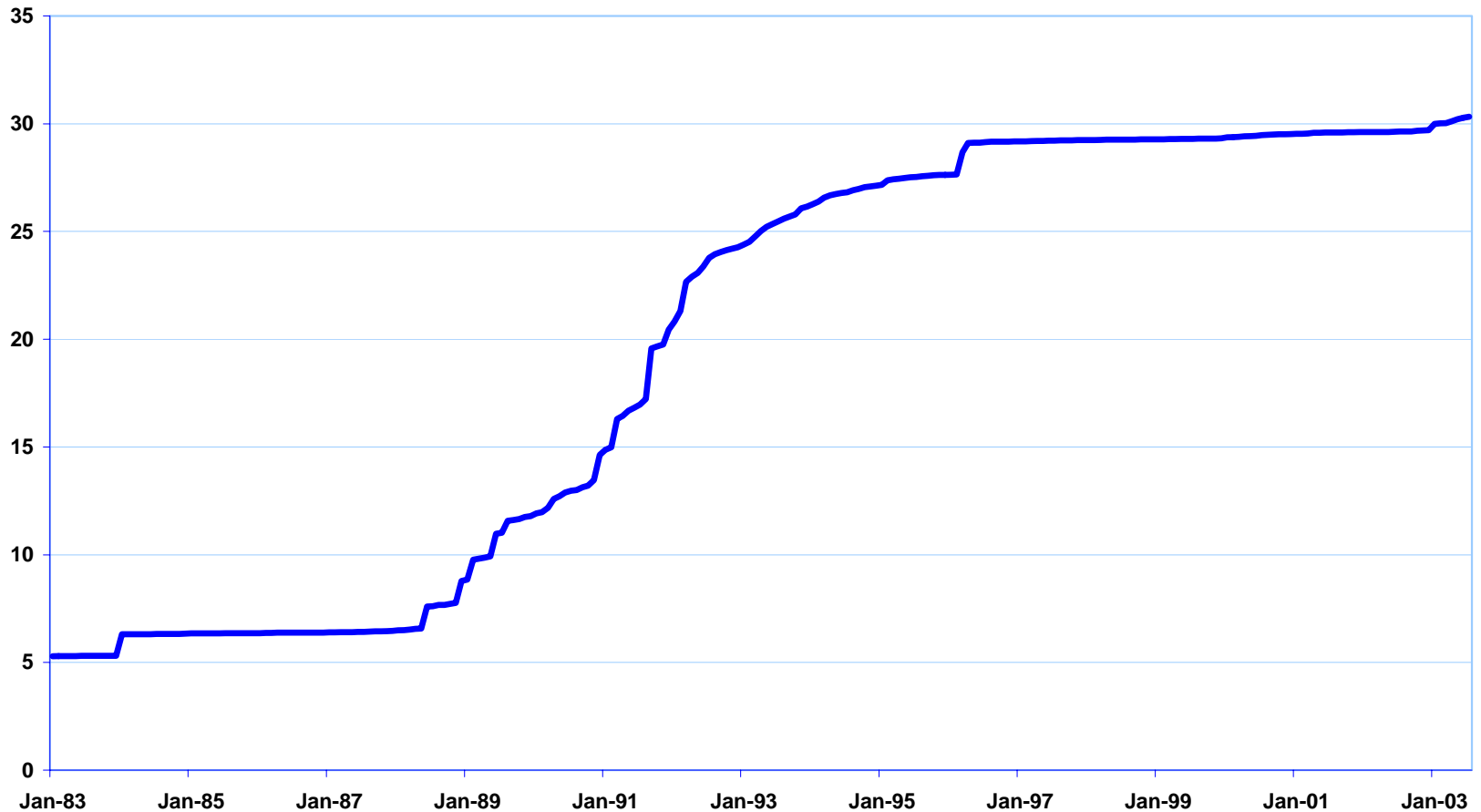
Age Distribution of Unannounced Address Space (/8s)





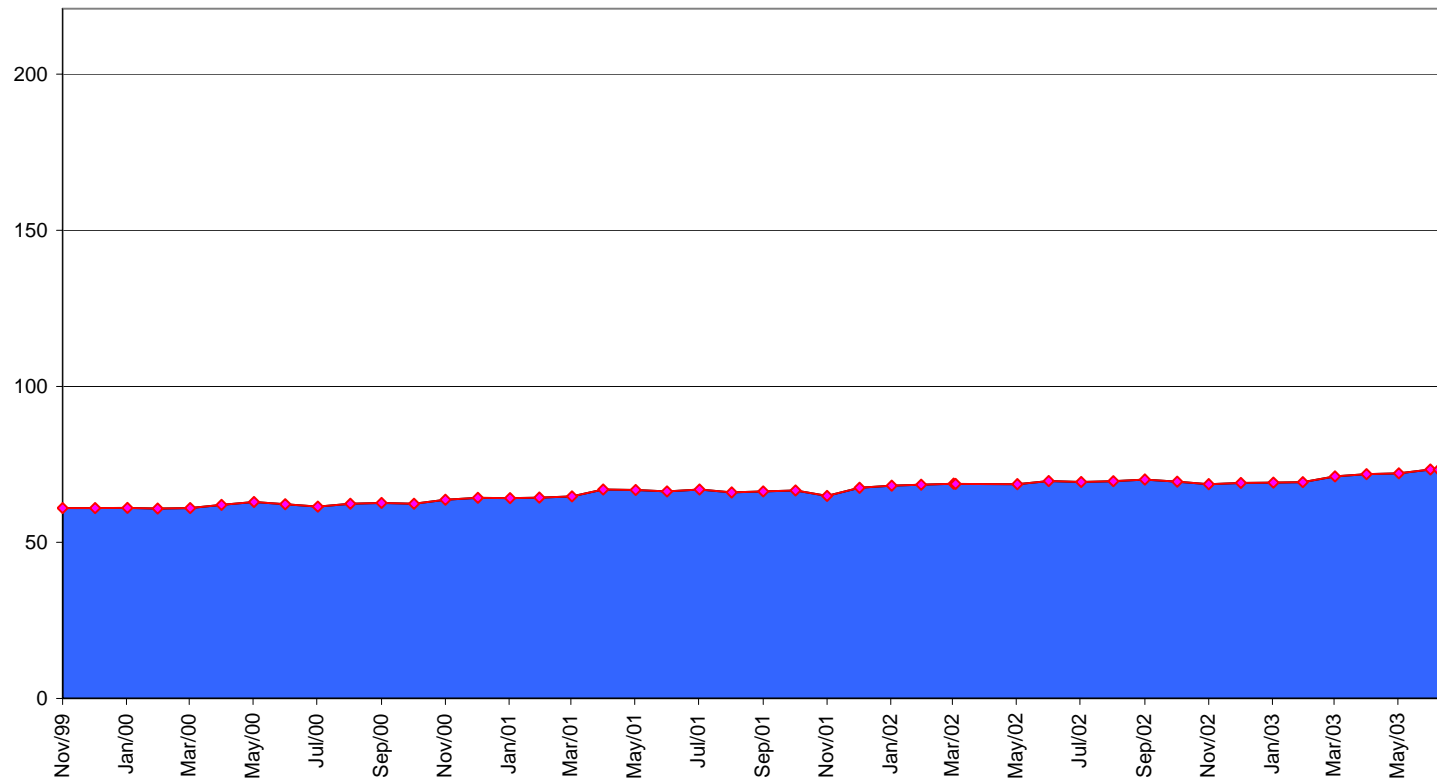
# Age of Unannounced Blocks (cumulative)

Cumulative Age Distribution of Unannounced Address Space (/8s)



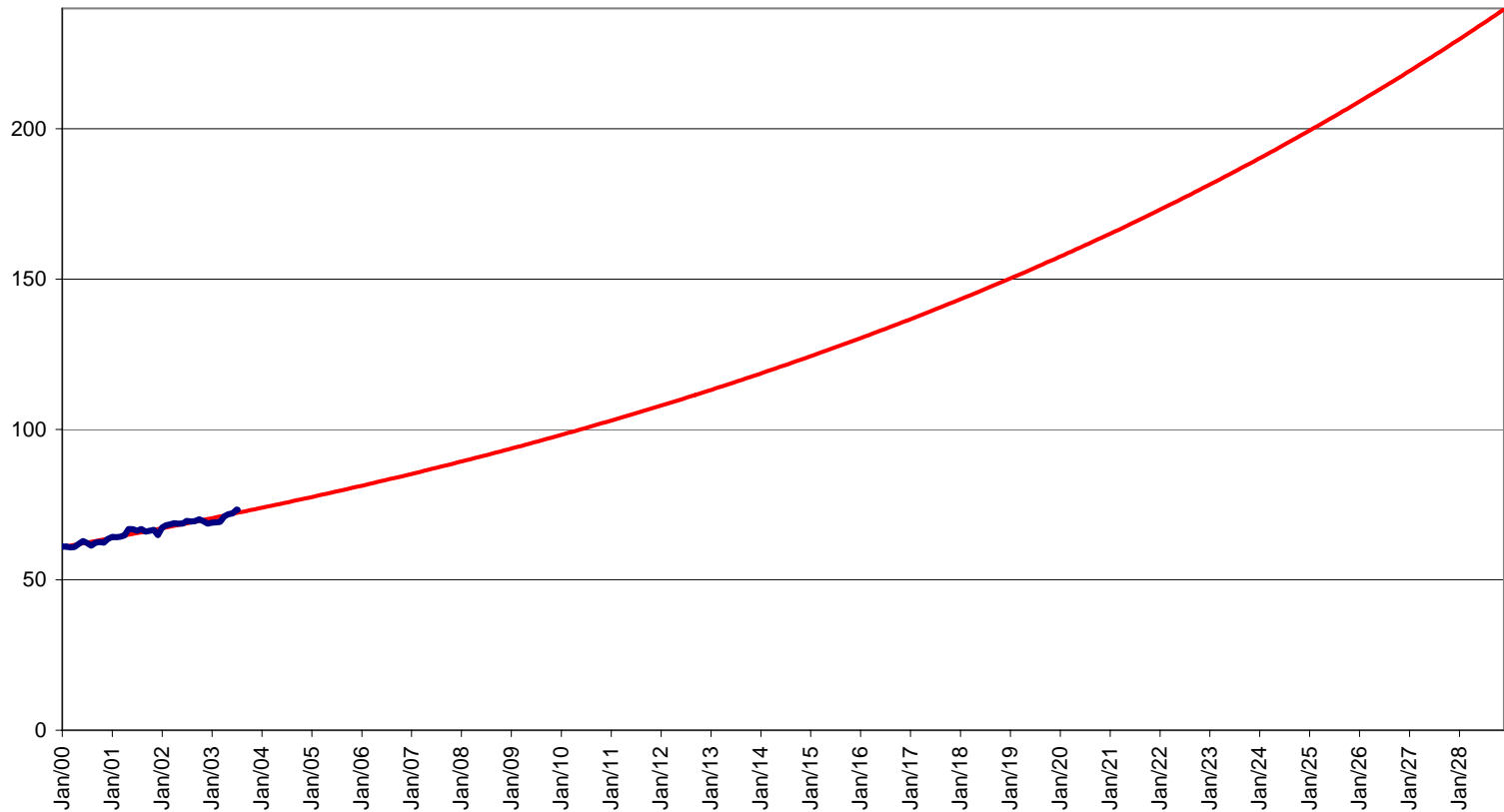
# BGP Address Span

BGP Table - Address Span



# BGP Projections

BGP Announced Address Space - Projection





# BGP Projections

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- 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:...

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- 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:.....



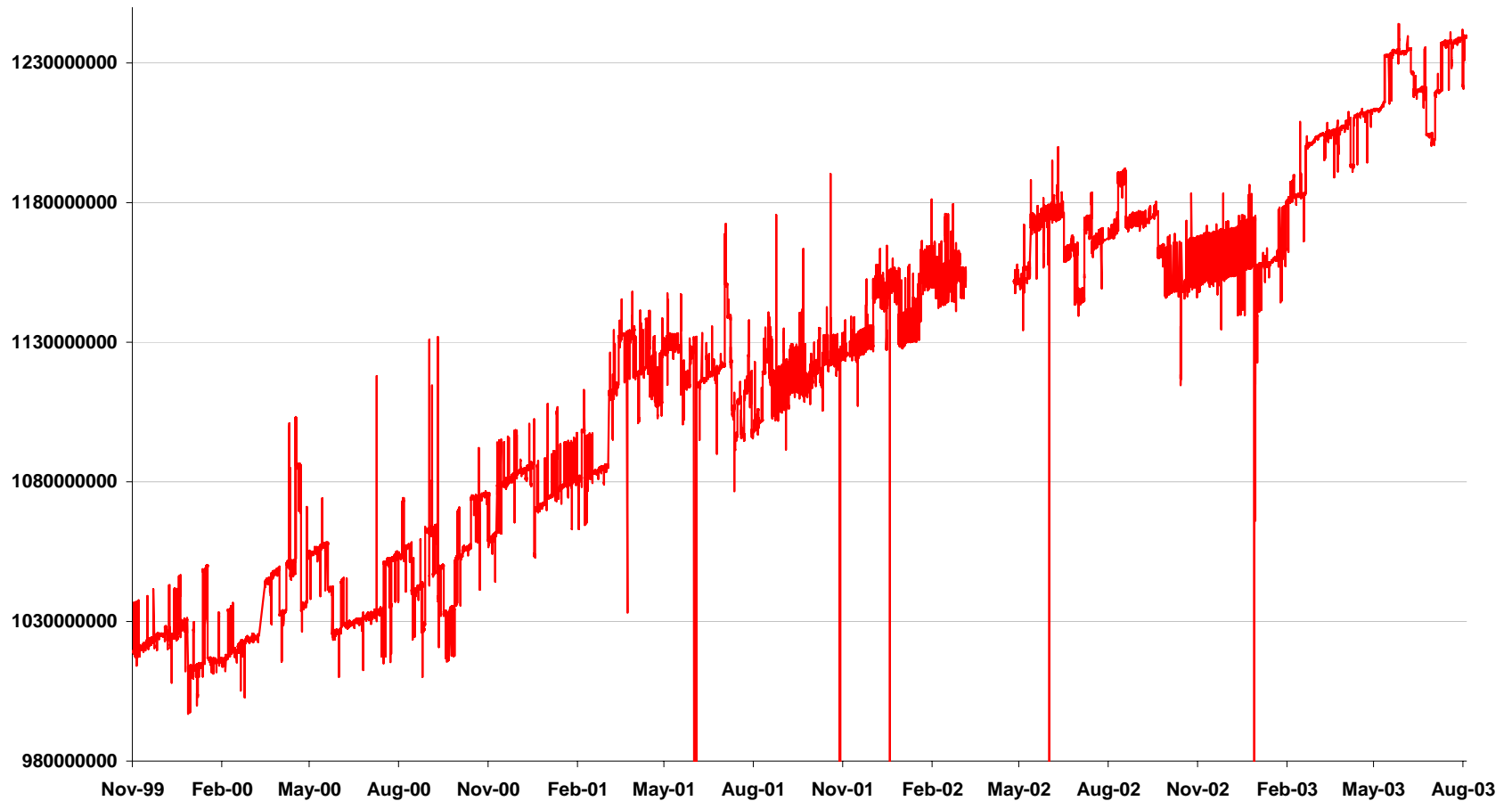
# Another look at that BGP data:...

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

# Another look at that BGP data:...

BGP Data





## Another look at that BGP data:...

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- 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

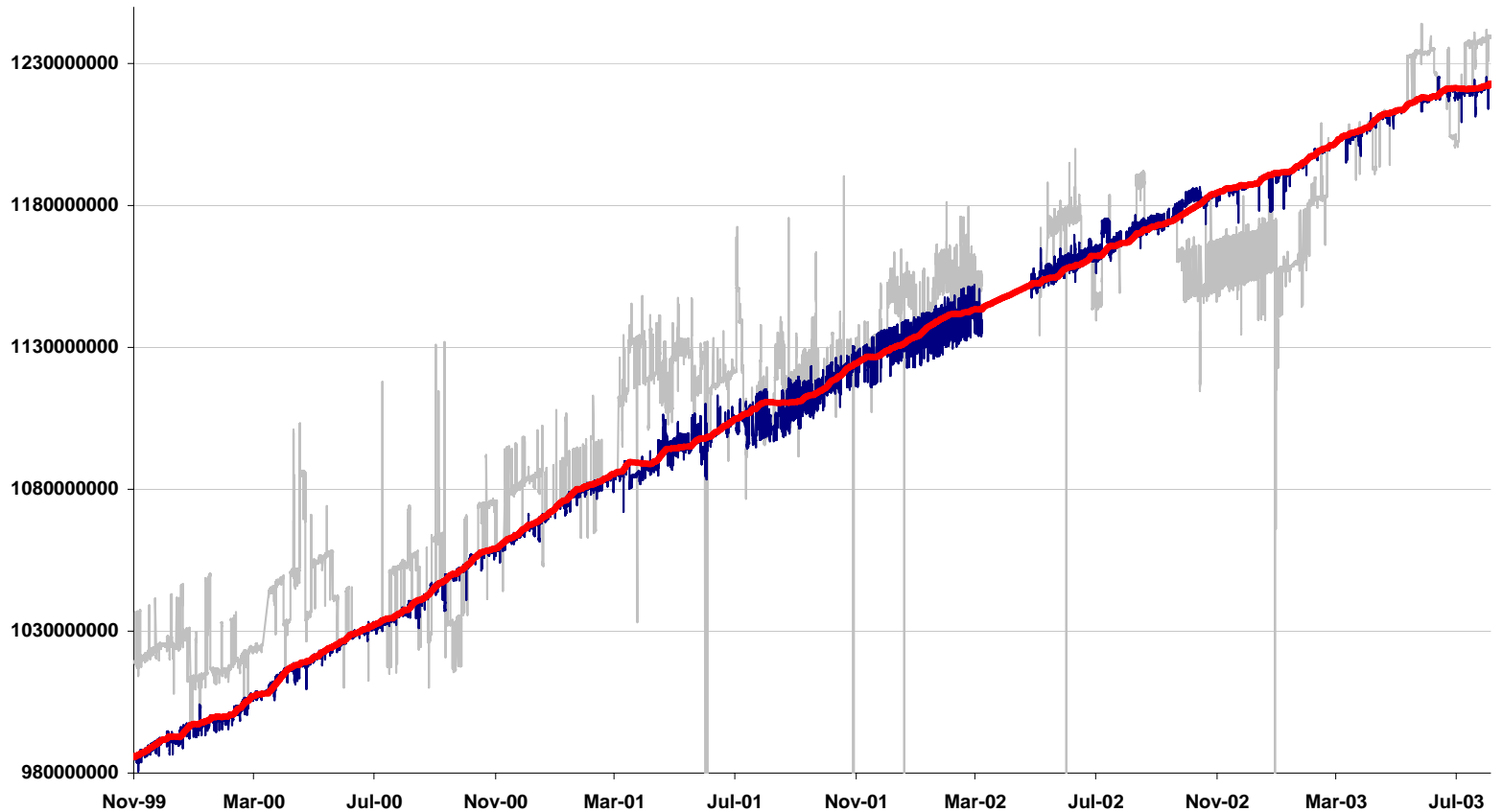






# Another look at that BGP data:...

Gradient Filtered Data





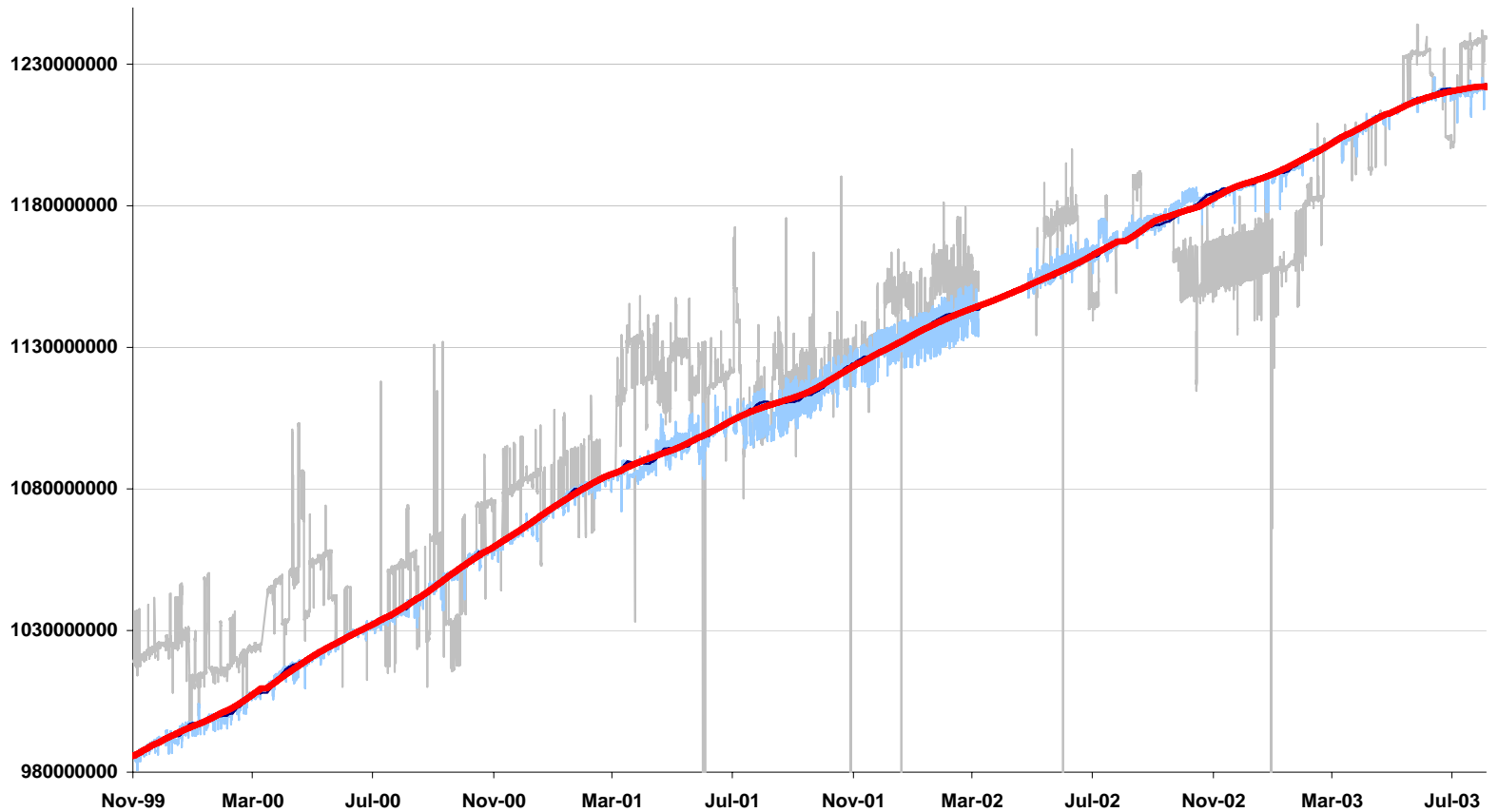
## Another look at that BGP data:...

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- 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

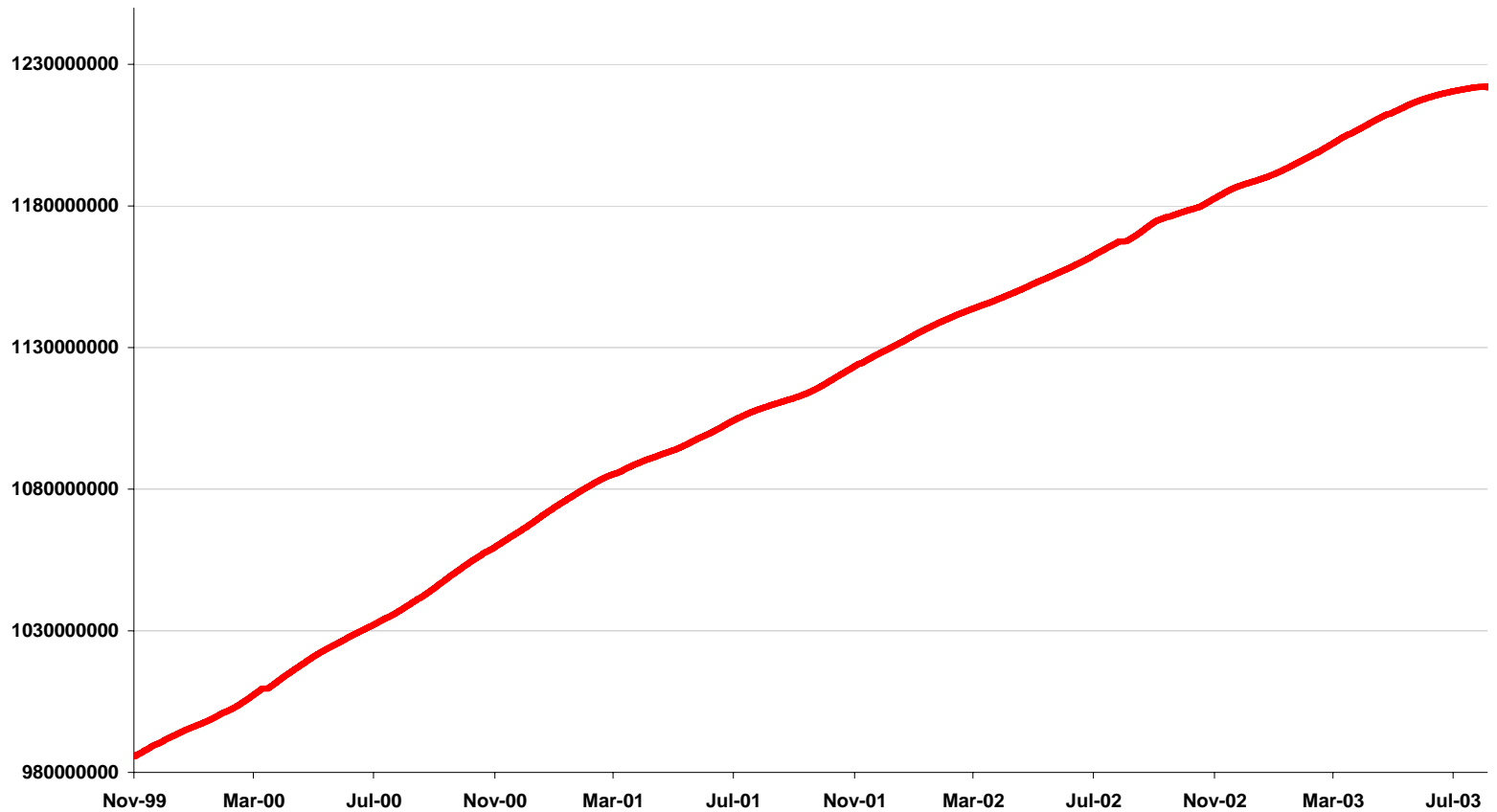
# Another look at that BGP data:...

Smoothed Average



# Another look at that BGP data:...

Smoothed Address Advertisement Data





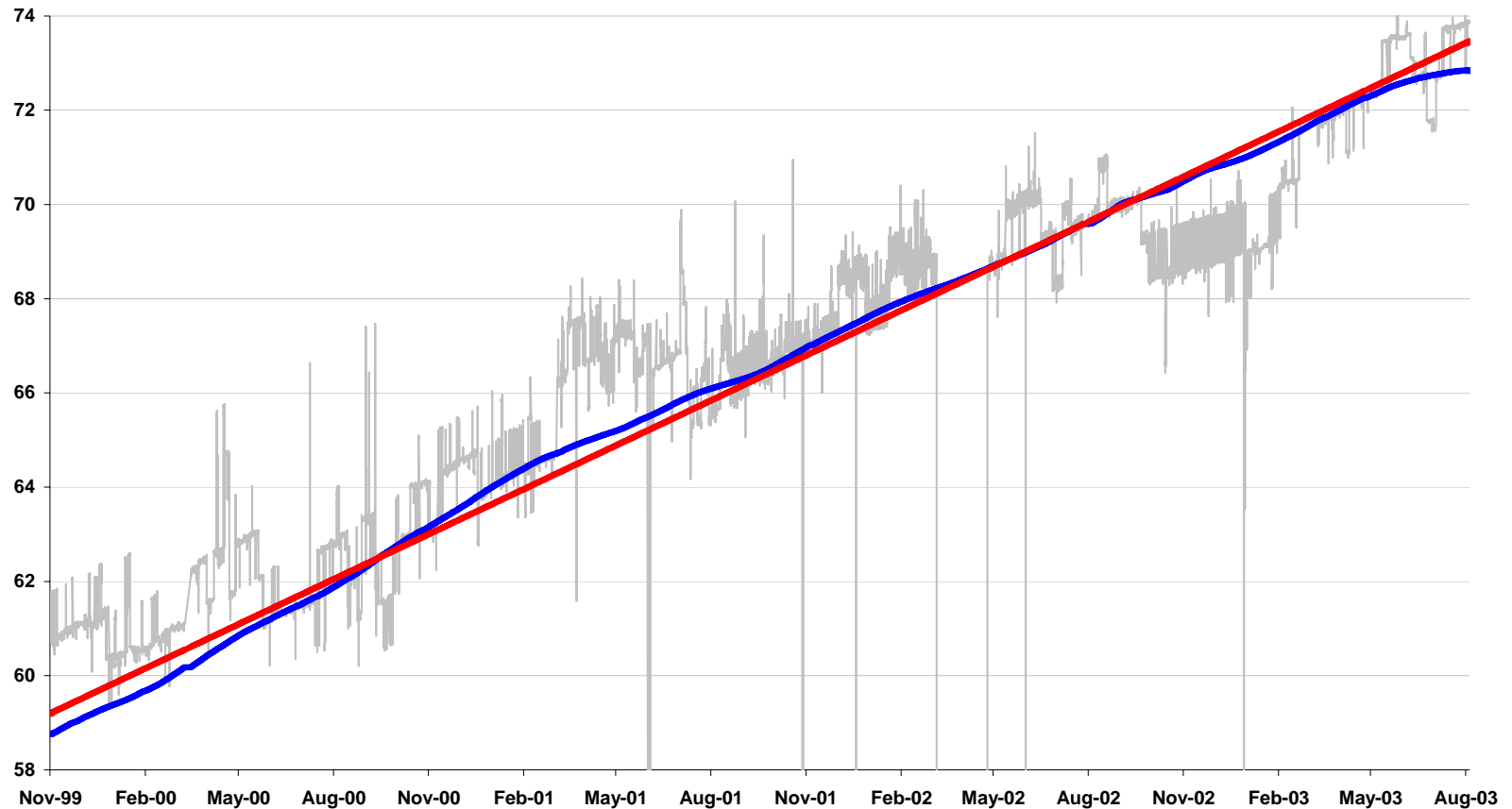
## Another look at that BGP data:...

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

# Another look at that BGP data:...

Linear Squares Best Fit







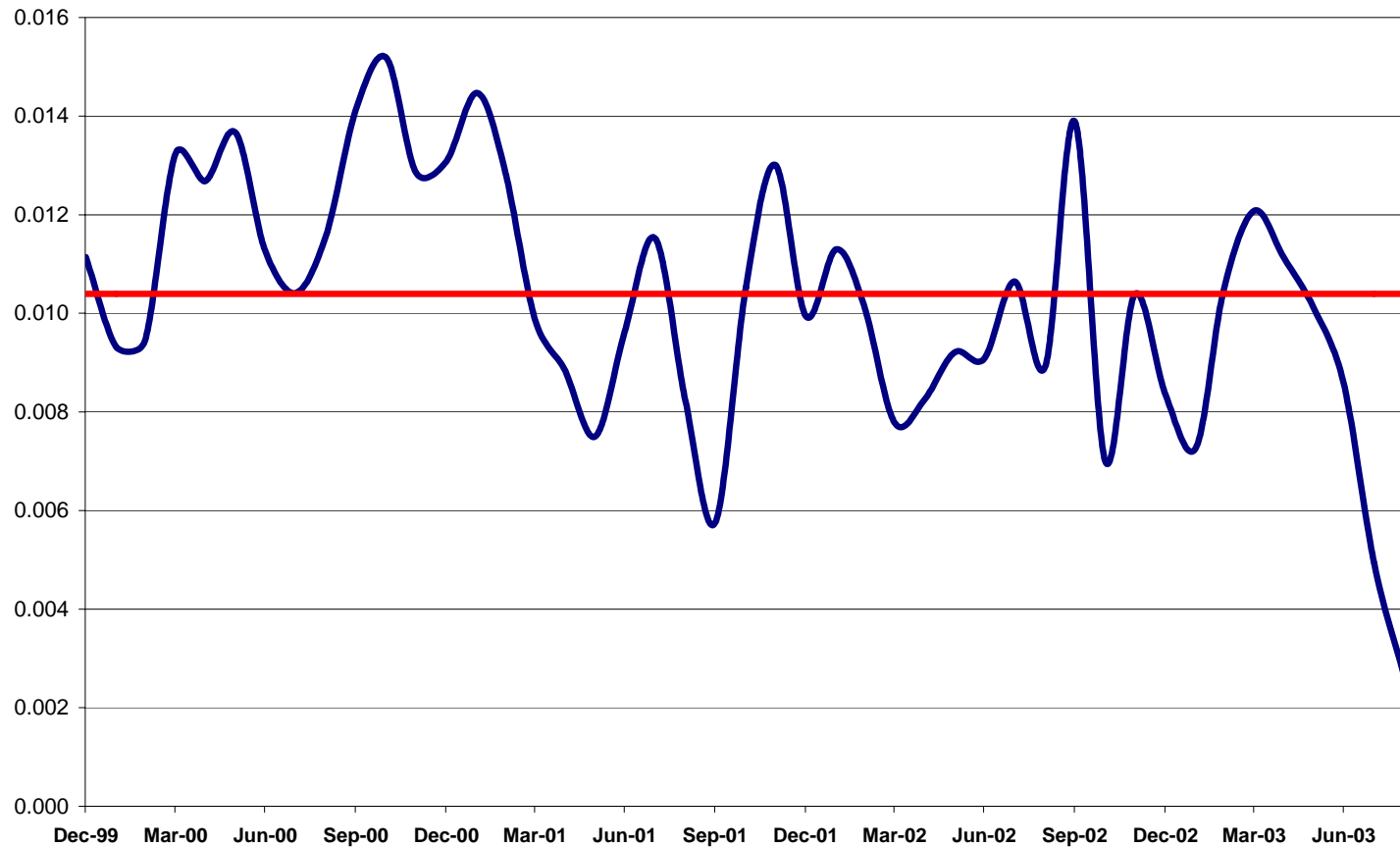
# Another look at that BGP data:...

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- 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

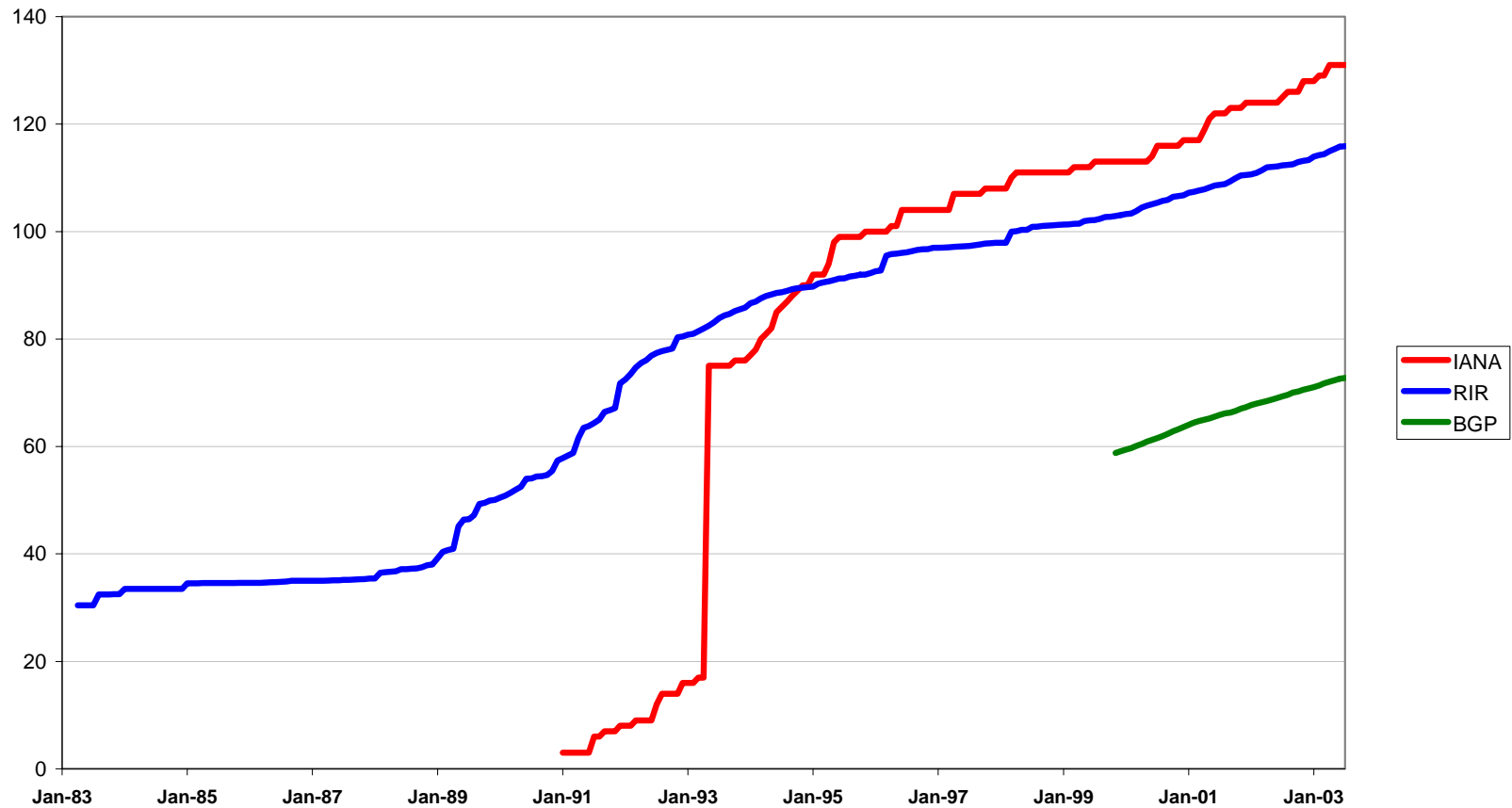
# Another look at that BGP data:...

daily rate of change in address growth per month



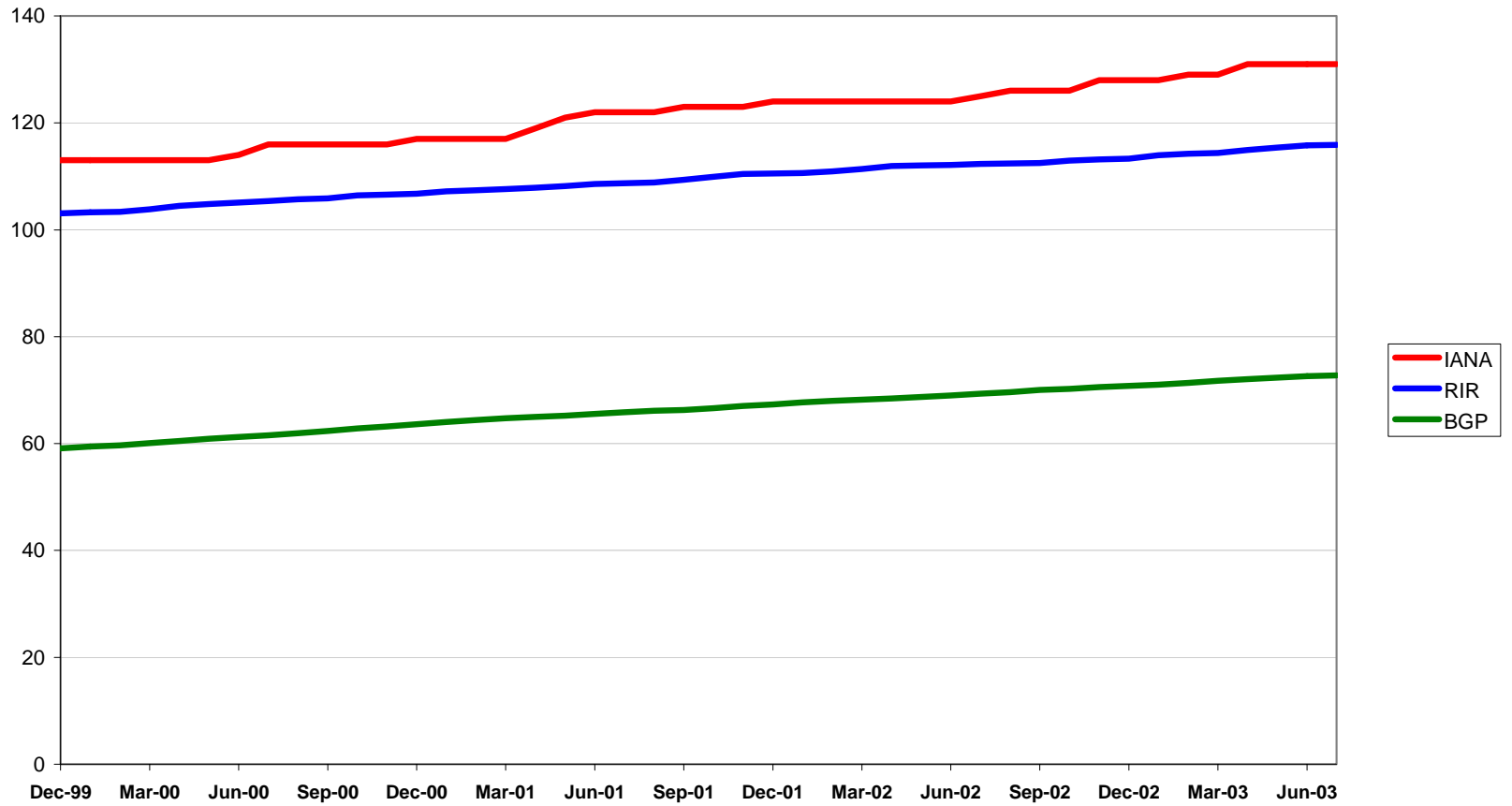
# Combining the Data

IPv4 Address Space



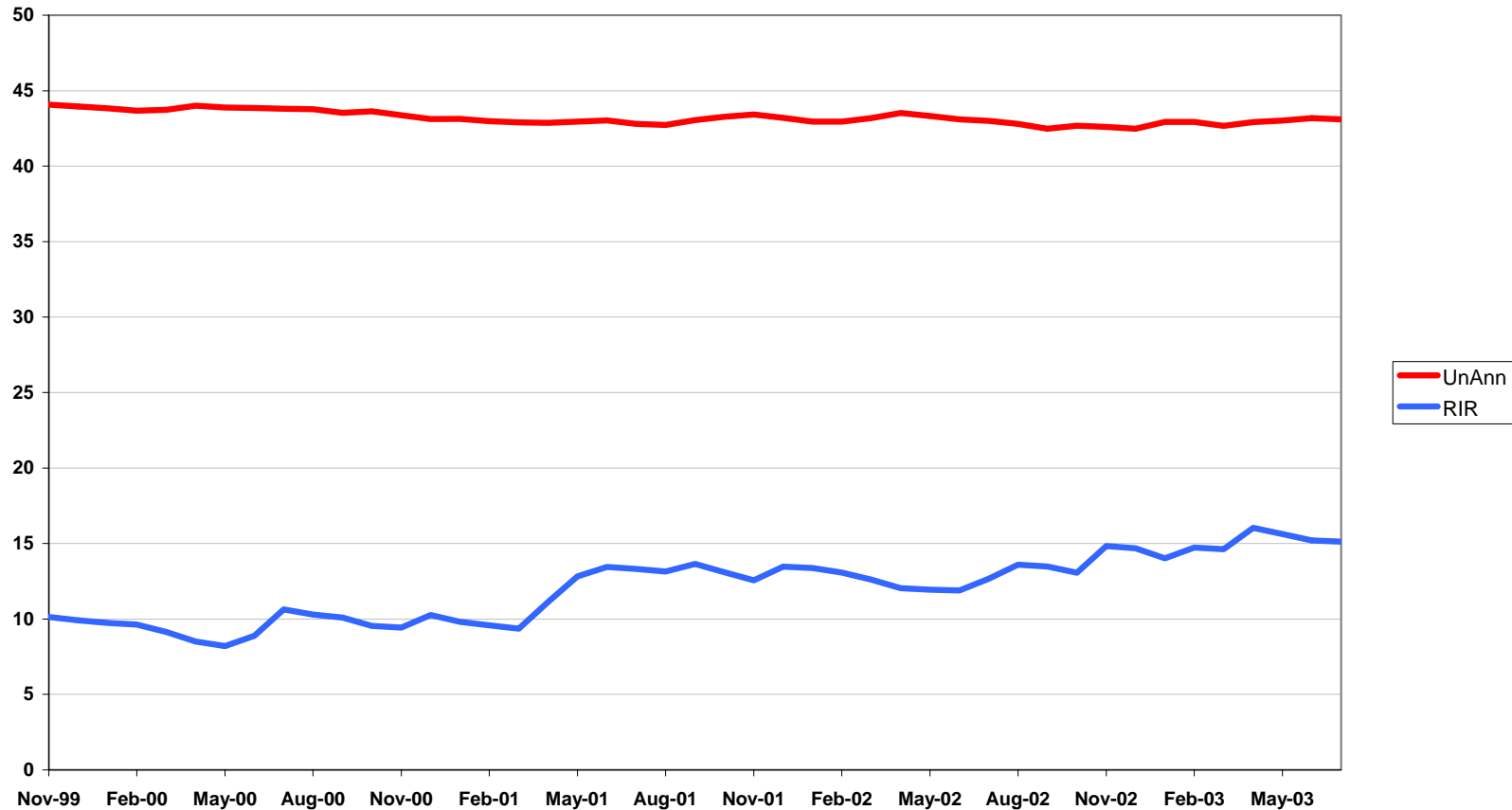
# Recent Data

IPv4 Address Space



# Holding Pools: RIR Pool and Unannounced Space

Size of Holding Areas (/8)



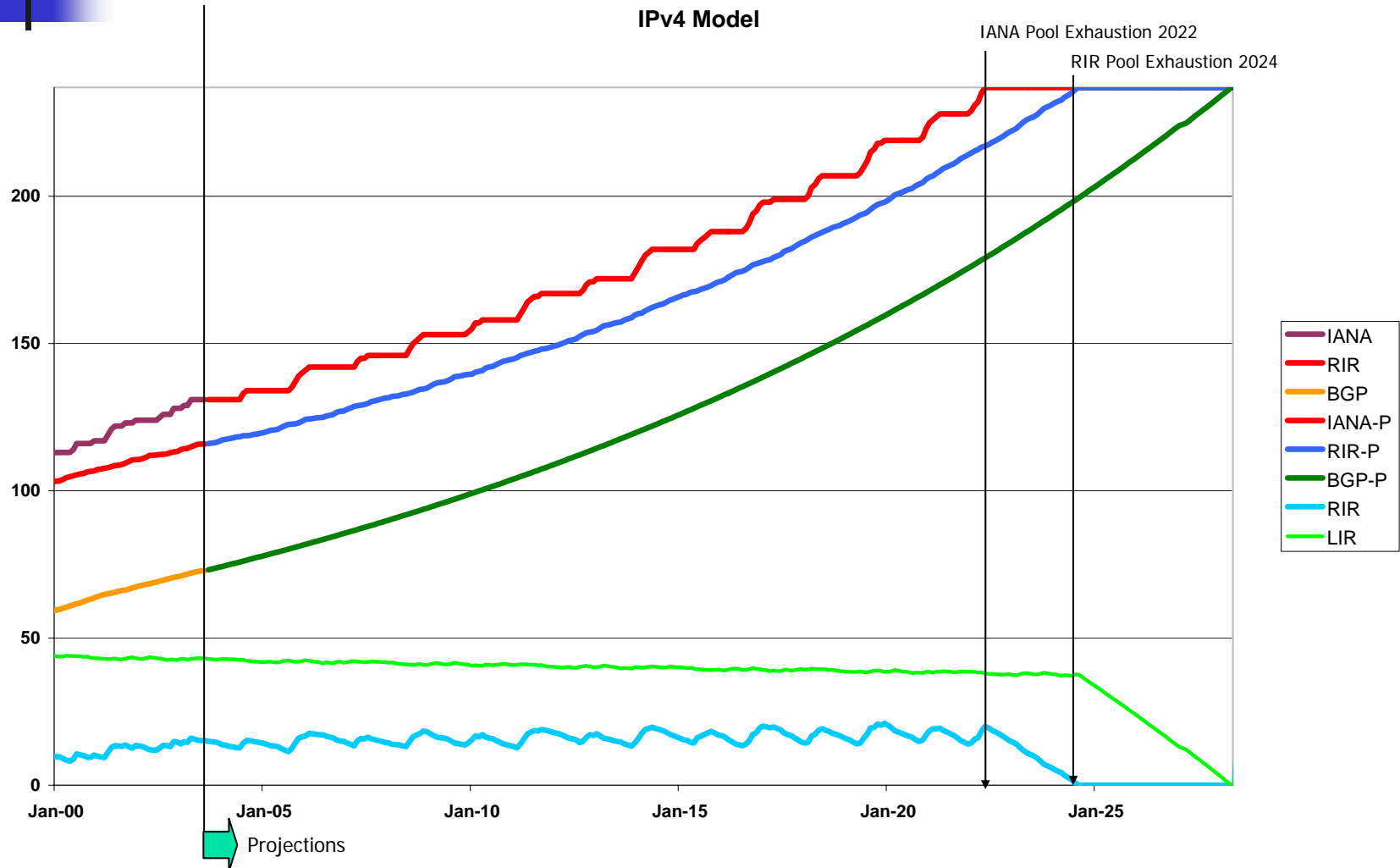


# Modelling the Process

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- 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 past 3 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





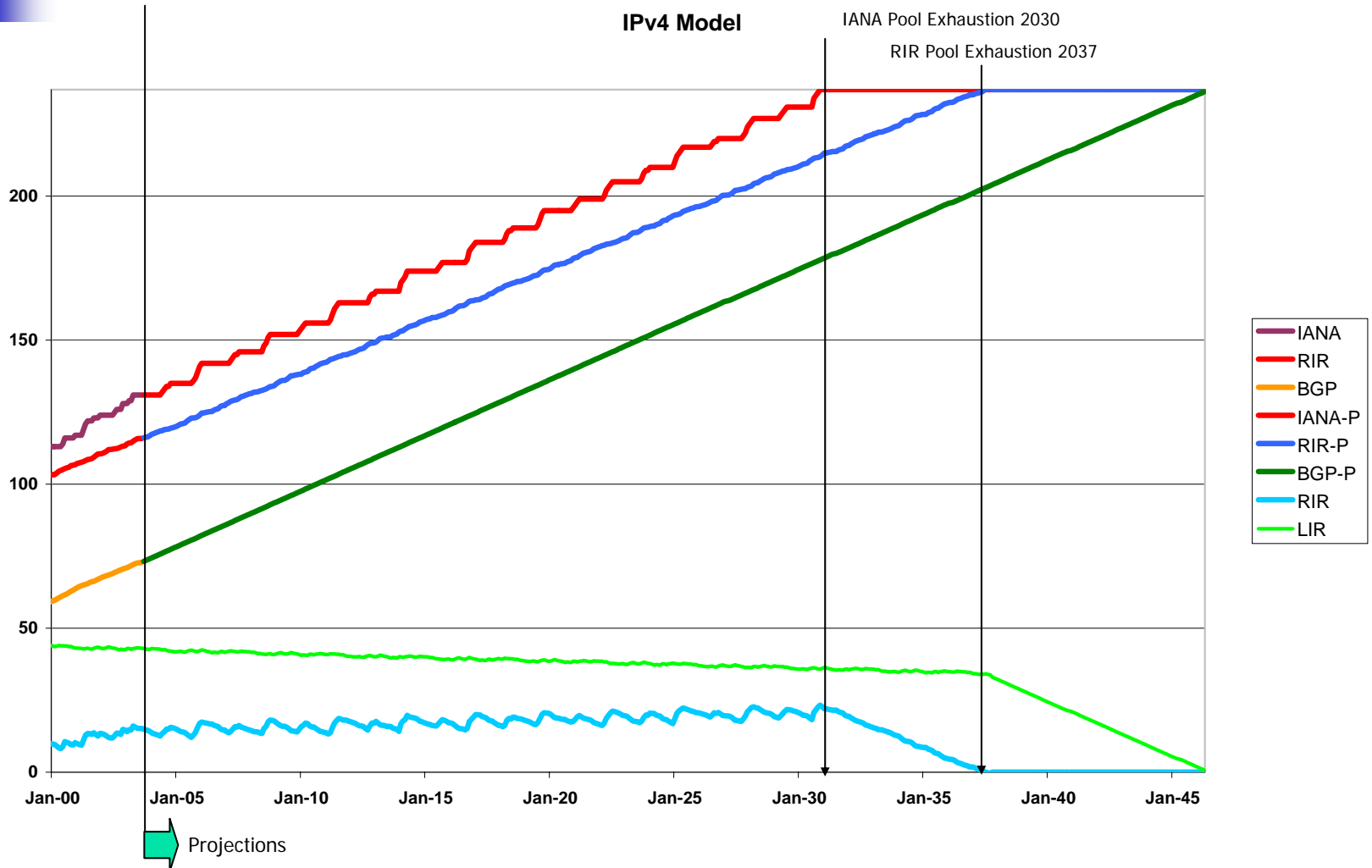
# Modelling the Process

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- 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 past 3 years
- Assume linear 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

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- 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

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- 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)?