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IPv4 Address Lifetime

Presented by
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Research activity
conducted by Geoff Huston
and supported by APNIC



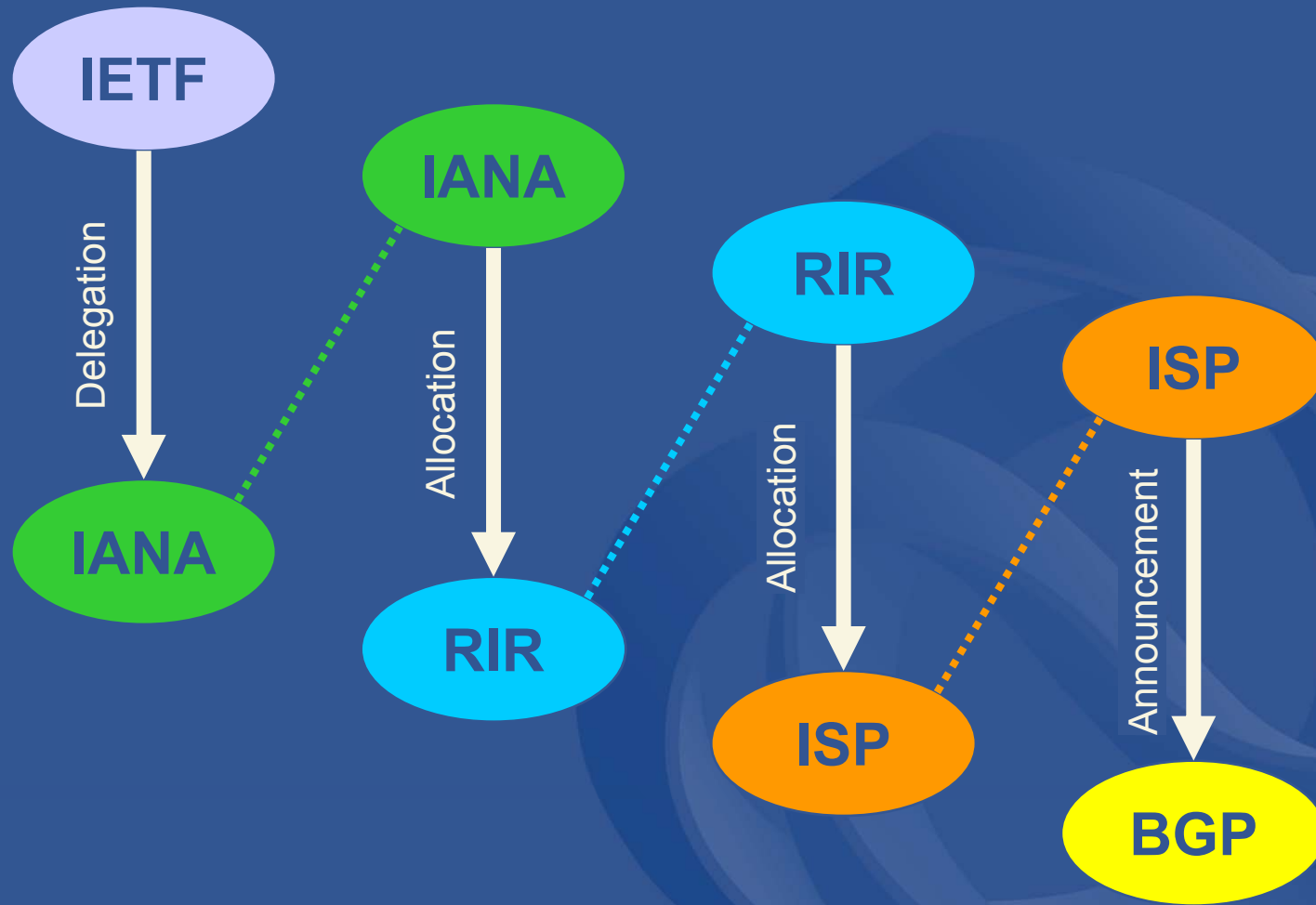
IPv4 Address Lifetime Expectancy

- IETF activity within the Routing and Addressing (ROAD) group in the early 1990's
 - The objective was to understand the rate of allocation of IPv4 addresses and predict the date of eventual exhaustion of the unallocated pool
 - At the time the prediction was that the pool of IPv4 addresses would be exhausted around 2008-2011
- This is a re-visiting of this activity considering latest data
 - IETF, IANA and RIR delegations
 - Also, ISP announcements to the BGP routing table

Modeling the Process

1. IETF definition of IPv4
 - Source: IETF standards (RFCs)
 - Delegation of address space for IANA administration
2. IANA allocations to RIRs
 - Source: IANA IPv4 Address Registry
 - Allocation of /8 blocks to RIRs and others
3. RIR allocations to ISPs
 - Source: RIR Stats files
 - Allocation of blocks to LIRs
4. ISP announcements
 - Source: BGP routing table
 - Amount of address space advertised

Modeling the Process





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1. IETF Delegations

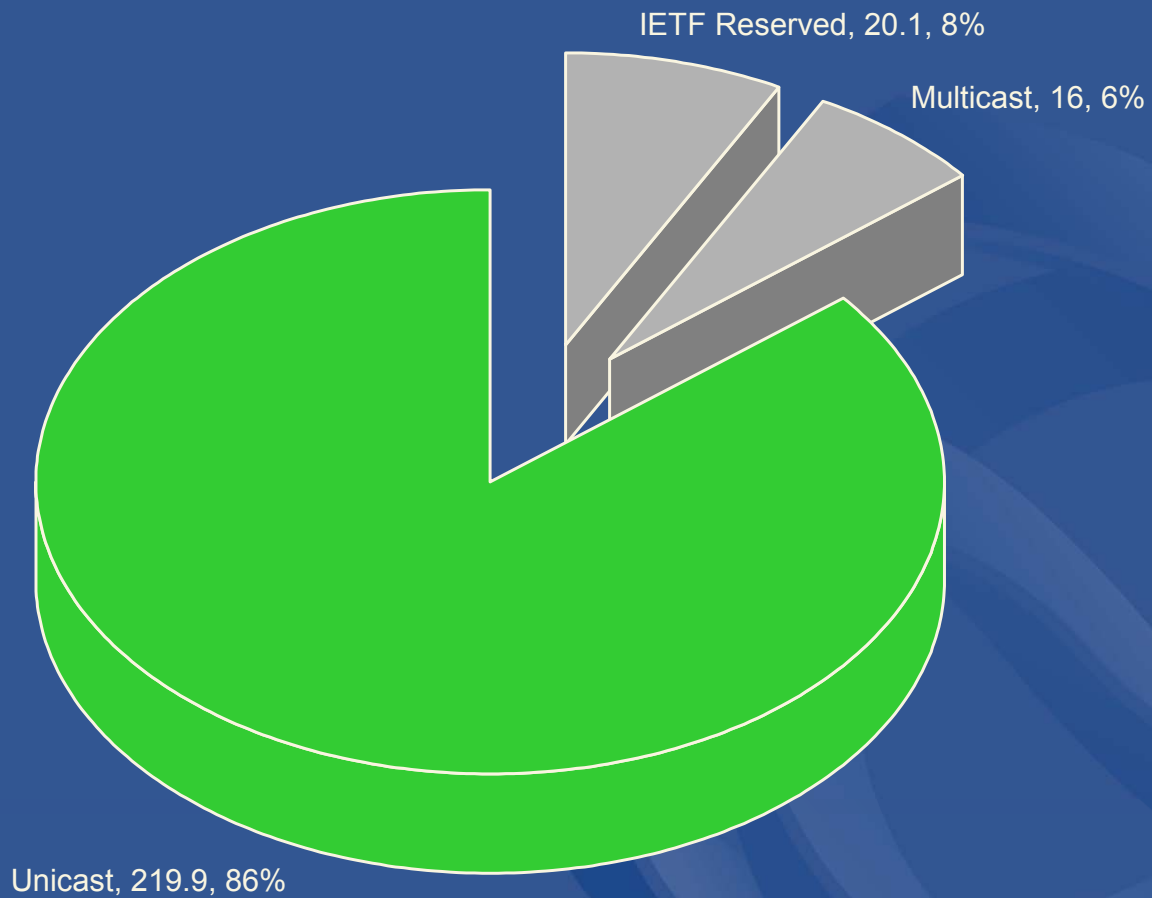


IPv4 Address Space

- Defined by the IETF
 - 32 bits providing 4B addresses
- The IETF has defined space for global unicast (administered by the IANA) and for other purposes
- IANA allocates space to the RIRs for further allocation and assignment



IPv4 Address Space



by /8 block equivalents



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2. IANA Allocations

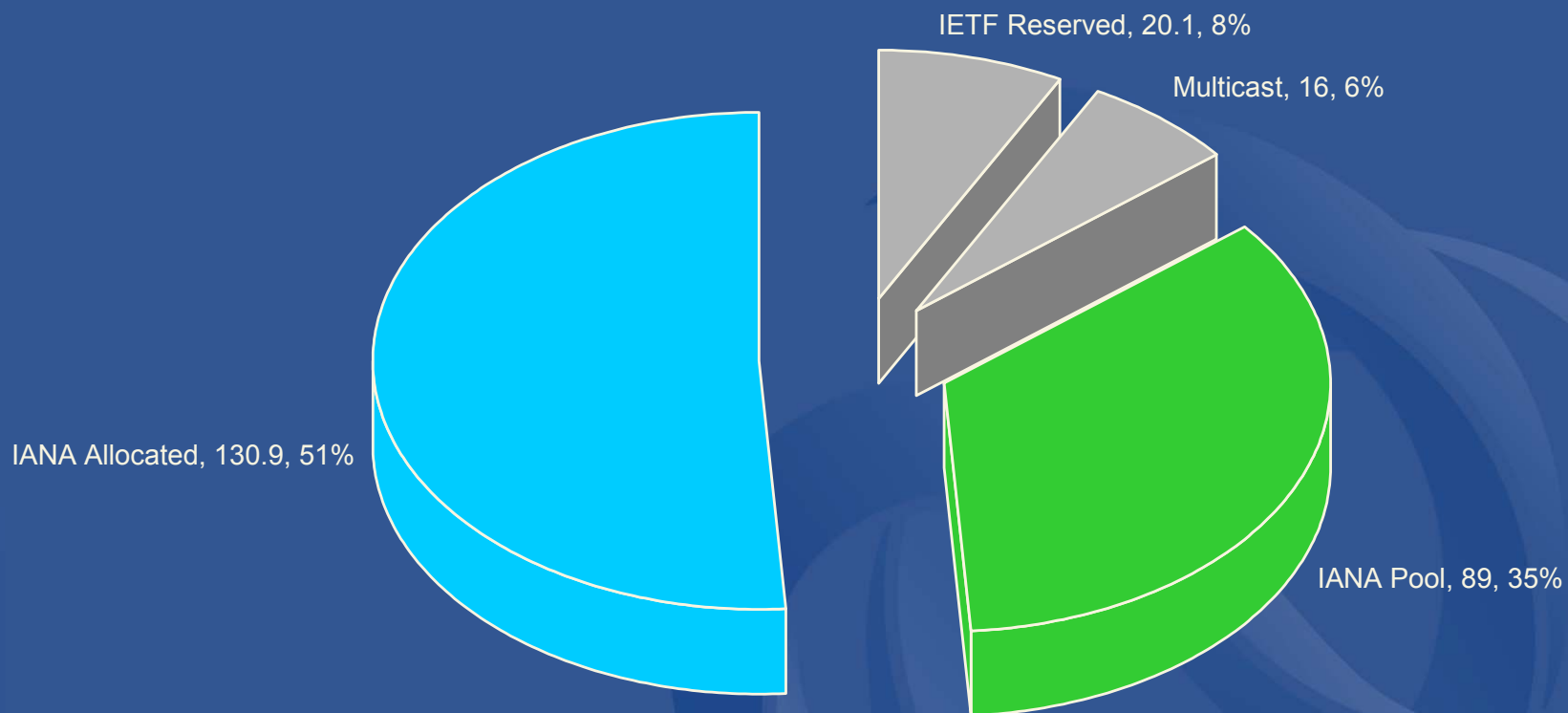


IANA Allocations

- IANA allocates address space to RIRs
- The IANA IPv4 address registry records the date of each /8 allocation undertaken by the IANA
- This data has some inconsistencies
 - Changing IANA administration and practices over many years
- However data is stable enough to allow some form of projection



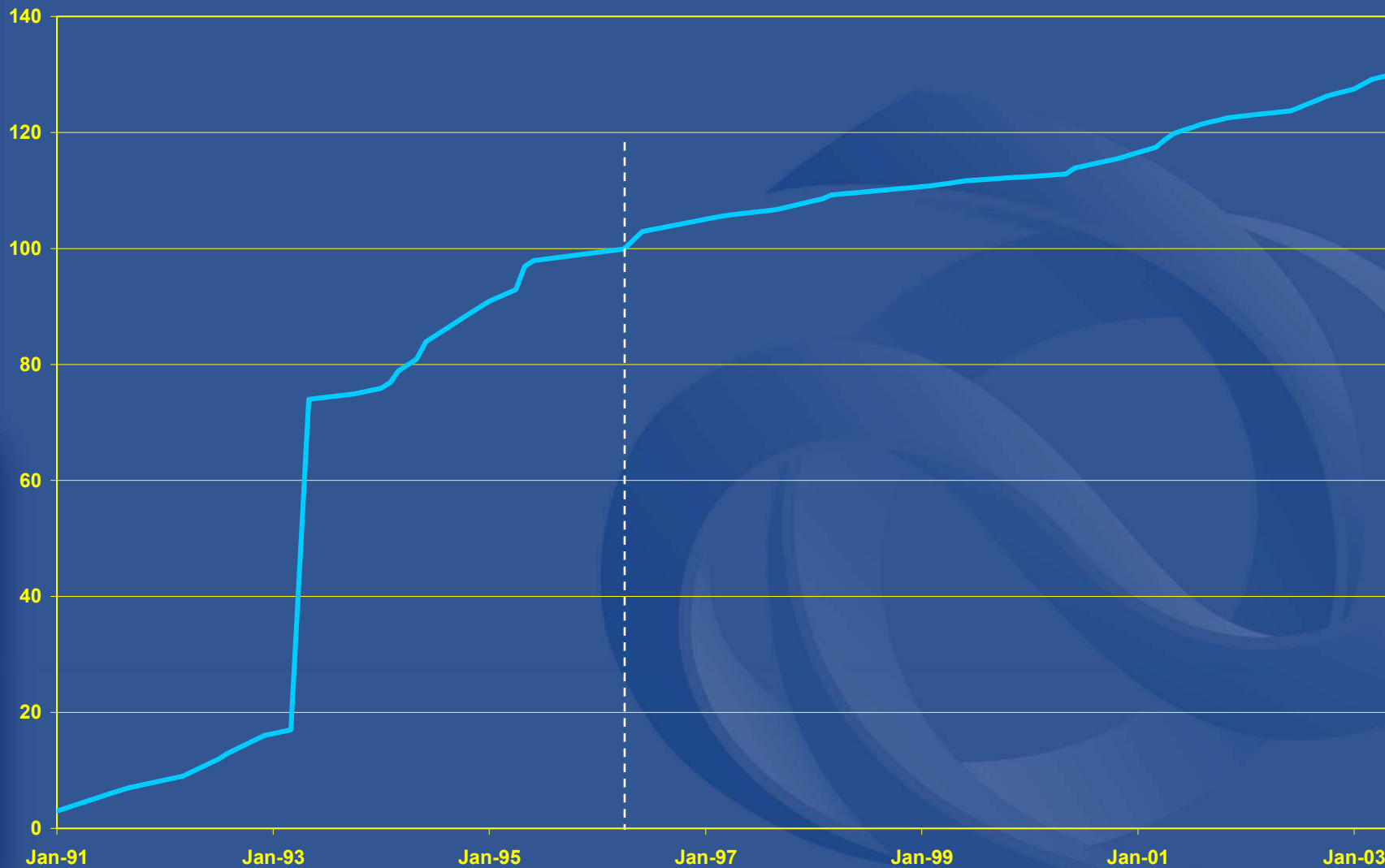
IANA Allocations - Current





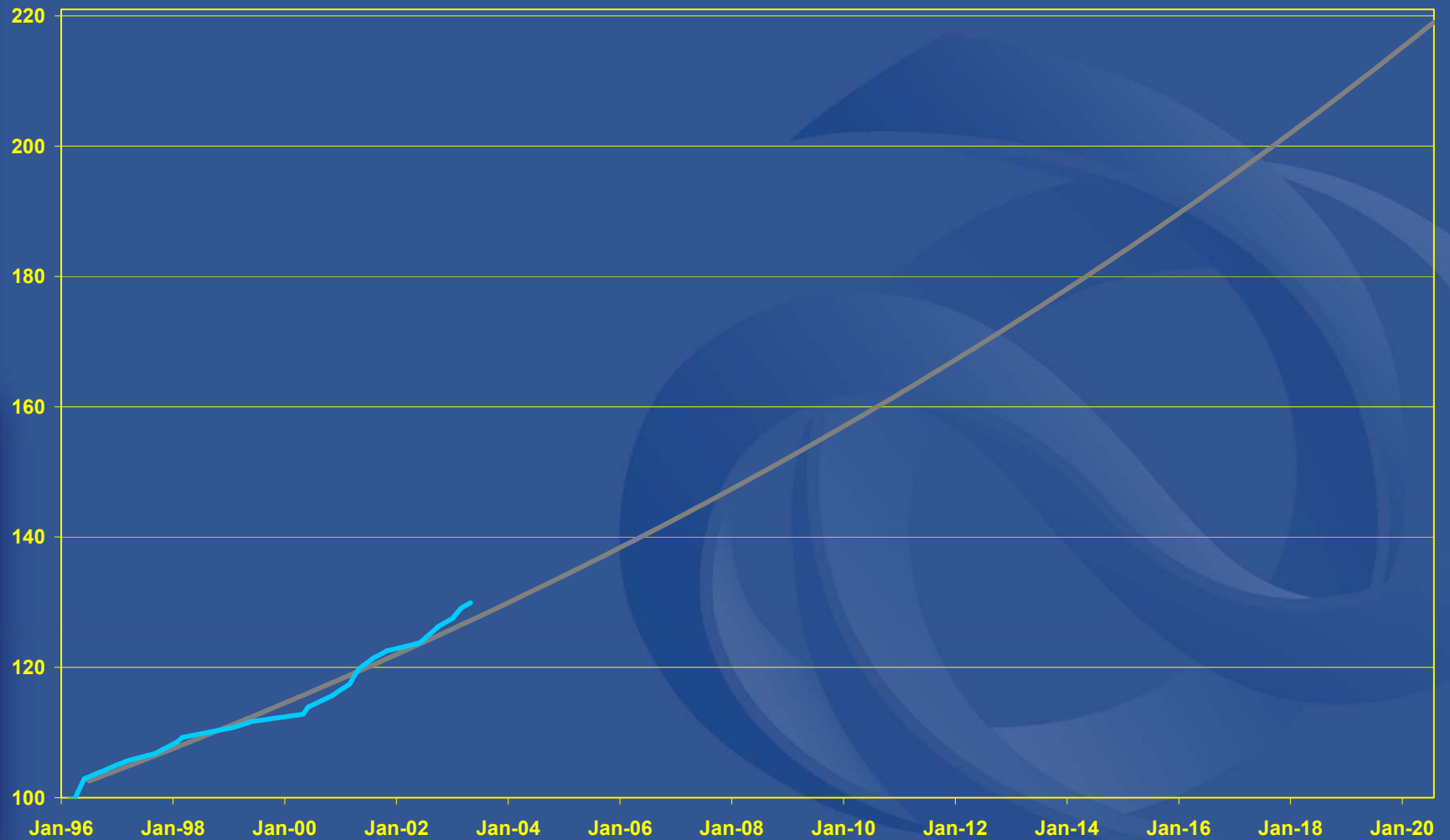
IANA Allocations - Historical

IANA Allocated IPv4 /8 Address Blocks



IANA Allocations - Projection

IANA Allocated IPv4 /8 Address Blocks





IANA Allocations - Projection

- Projected date of IANA address pool exhaustion: 2020
- This projection is very uncertain because of:
 - Sensitivity of allocation rate to prevailing RIR assignment policies
 - Sensitivity to any significant uptake up of new applications that require end-to-end IPv4 addressing vs use of NATs



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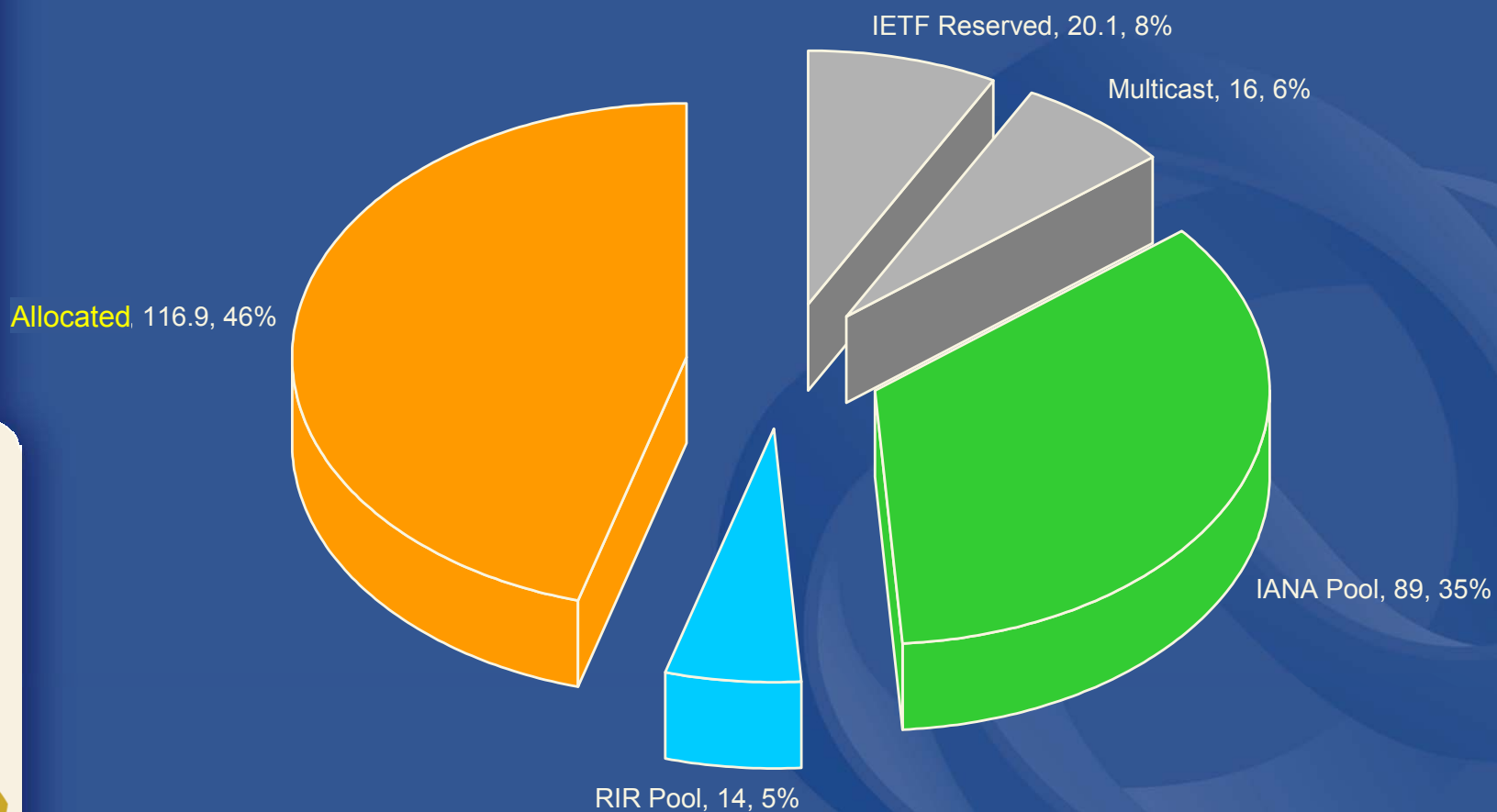
3. RIR Allocations



RIR Allocations

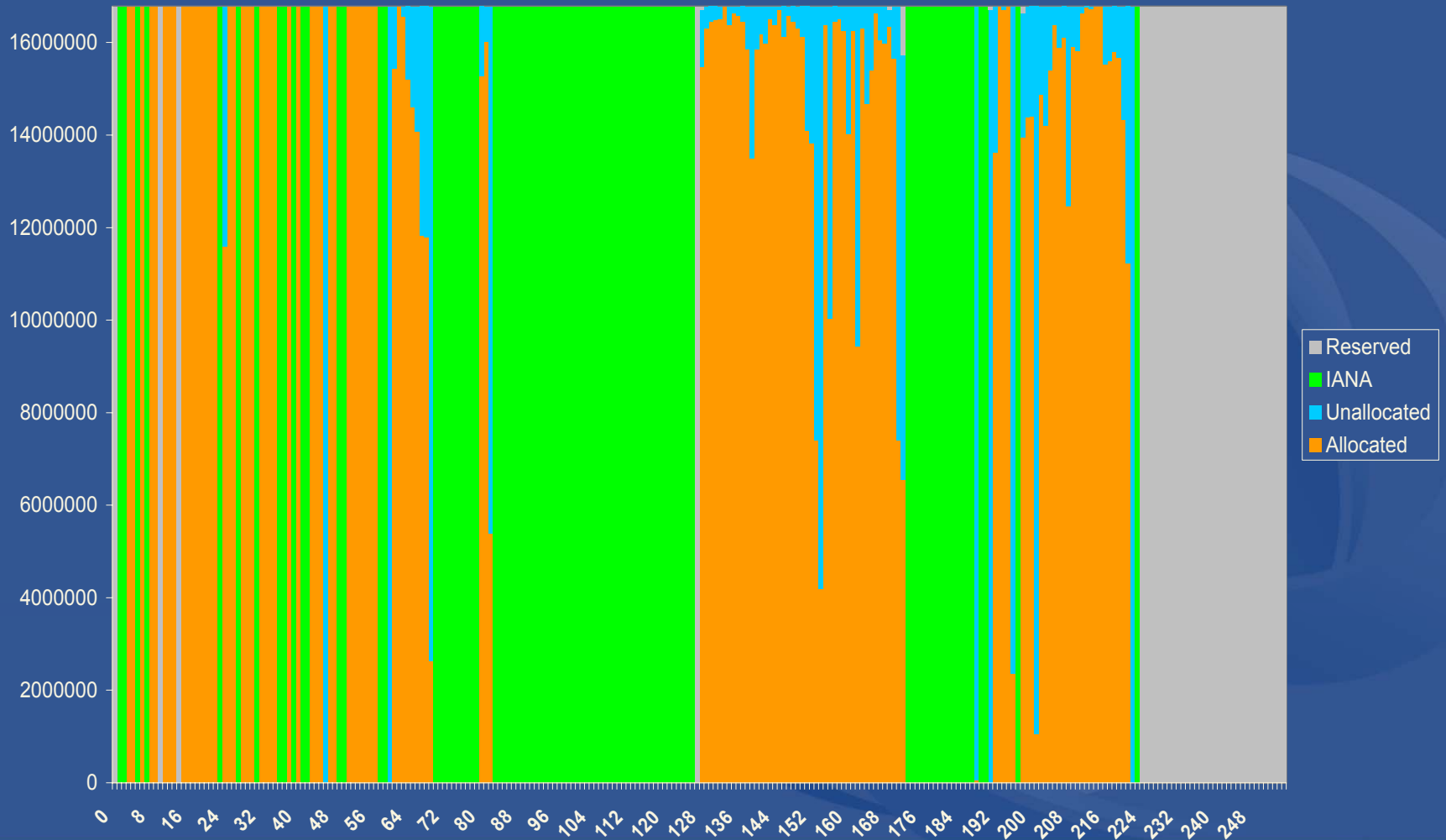
- RIRs allocate address space to LIRs (ISPs)
- RIR stats files records the date of each allocation to an LIR, together with the allocation details

RIR Allocations - Current



RIR Allocations - Current

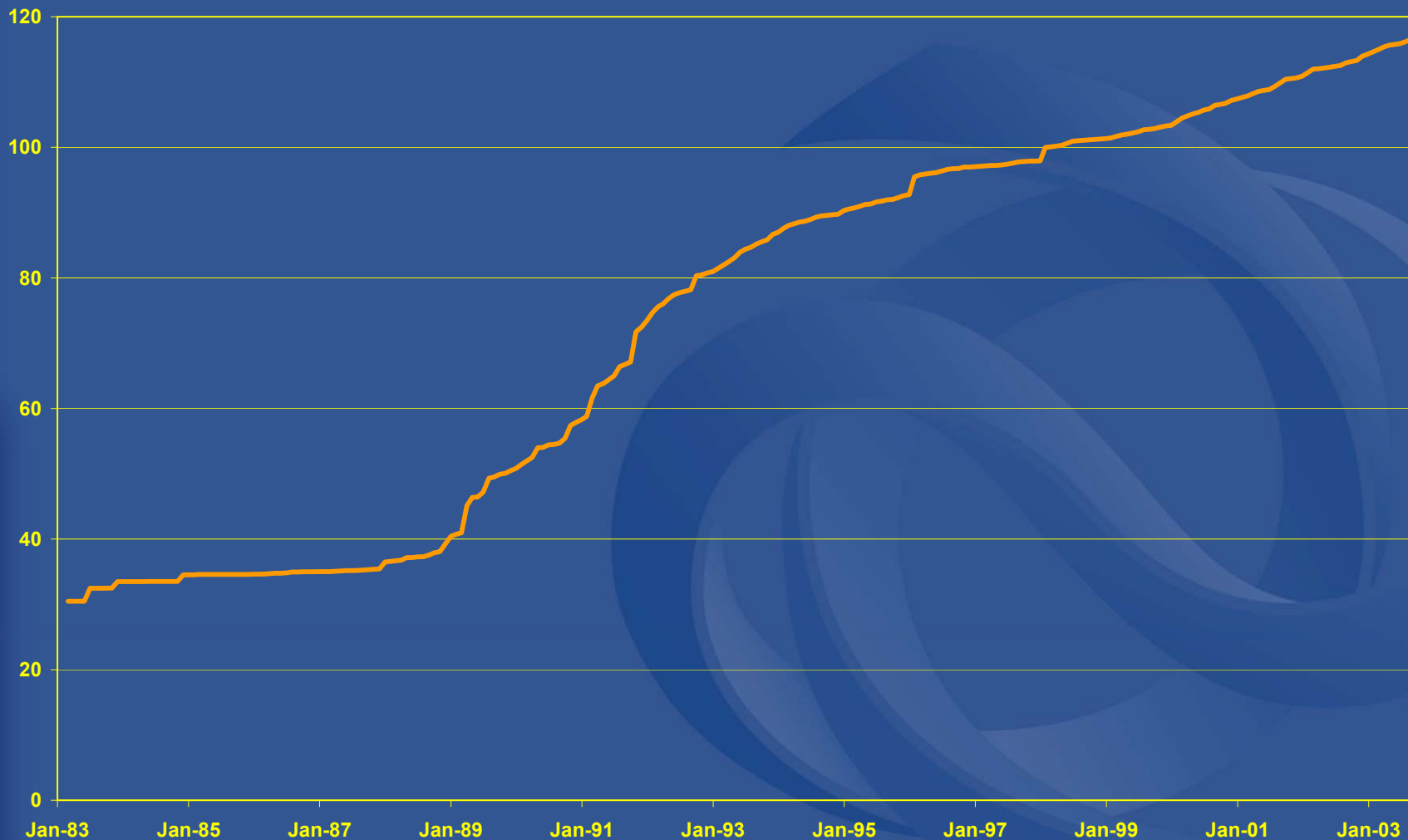
Address Allocation Status - by /8





RIR Allocations - Historical

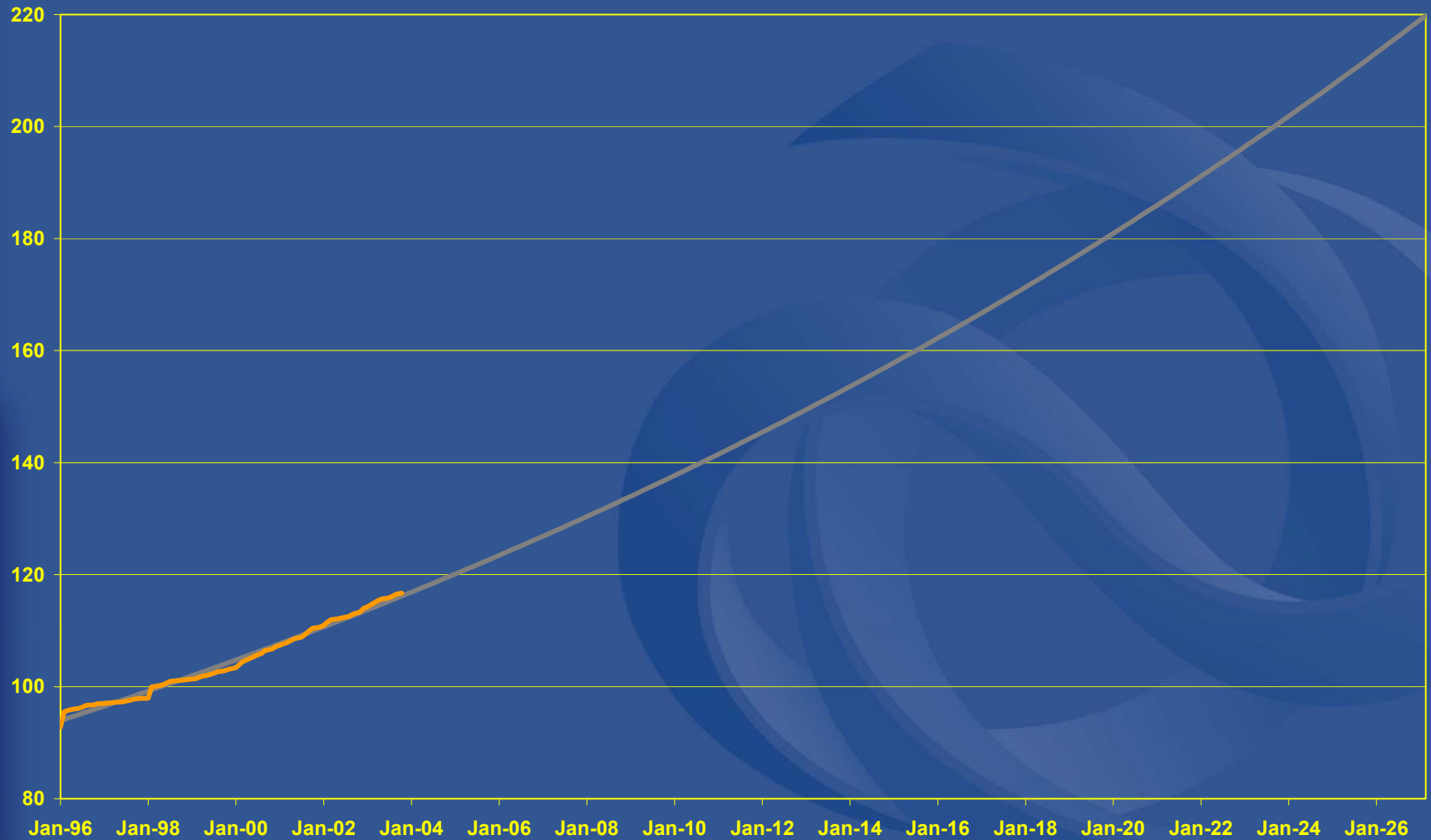
RIR Assigned IPv4 /8 Address Blocks





RIR Allocations - Projection

RIR Assigned IPv4 /8 Address Blocks - Projection





RIR Allocations - Projection

- Projected date of RIR address pool exhaustion: 2027
- The projection has the same levels of uncertainty as noted for the IANA projections:
 - RIR management policies
 - Technological developments

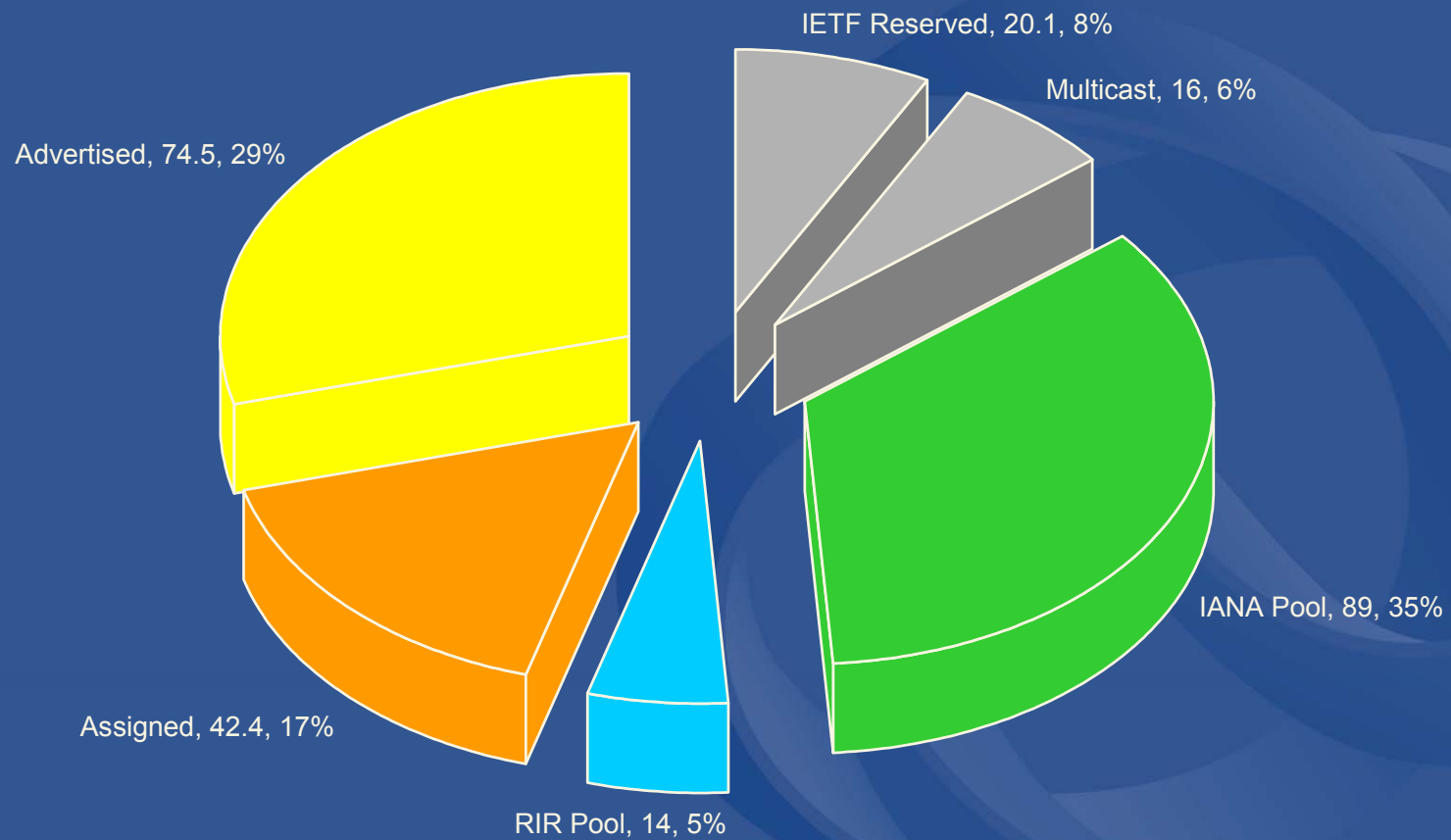


4. BGP Routing Table

BGP Routing Table

- The BGP routing table spans a set of advertised addresses
 - Representing addresses in use by ISPs
- A similar analysis of usage and projection can be undertaken on this data
- Assumption: BGP routing table represents actual IP address usage
 - Therefore it “drives” the other trends

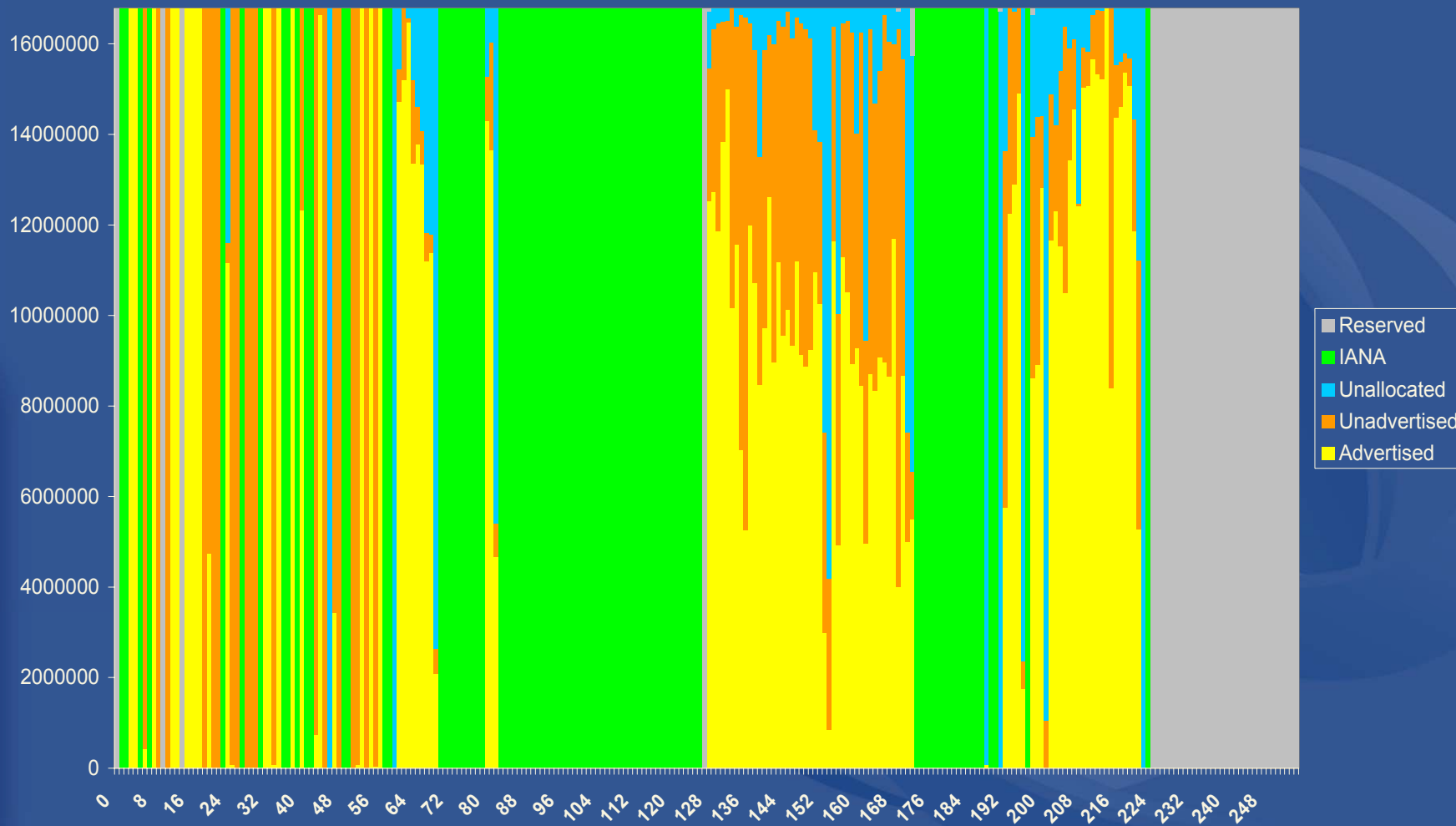
BGP Routing Table - Current





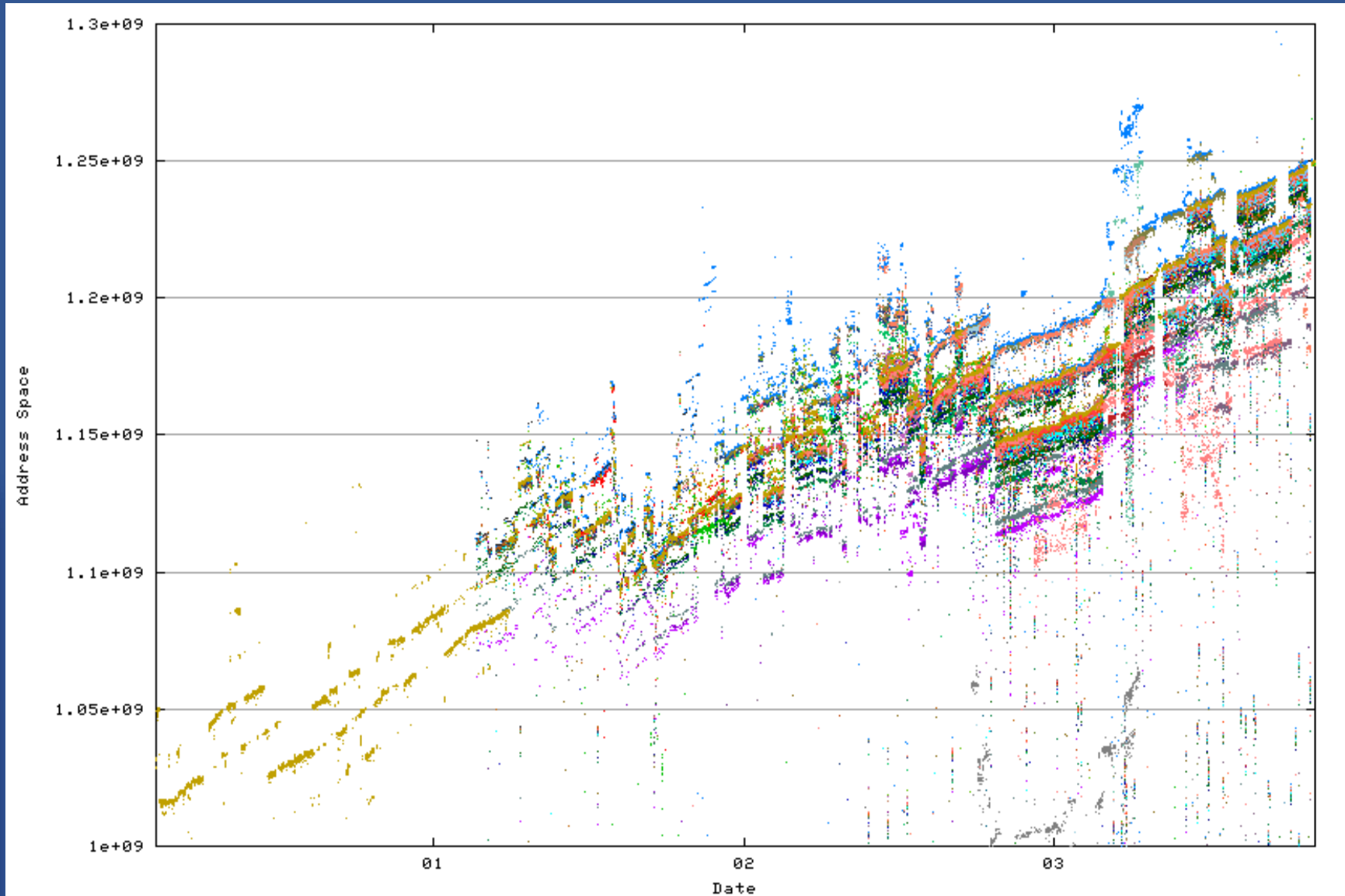
BGP Announcements - Current

Address Allocation Status - by /8



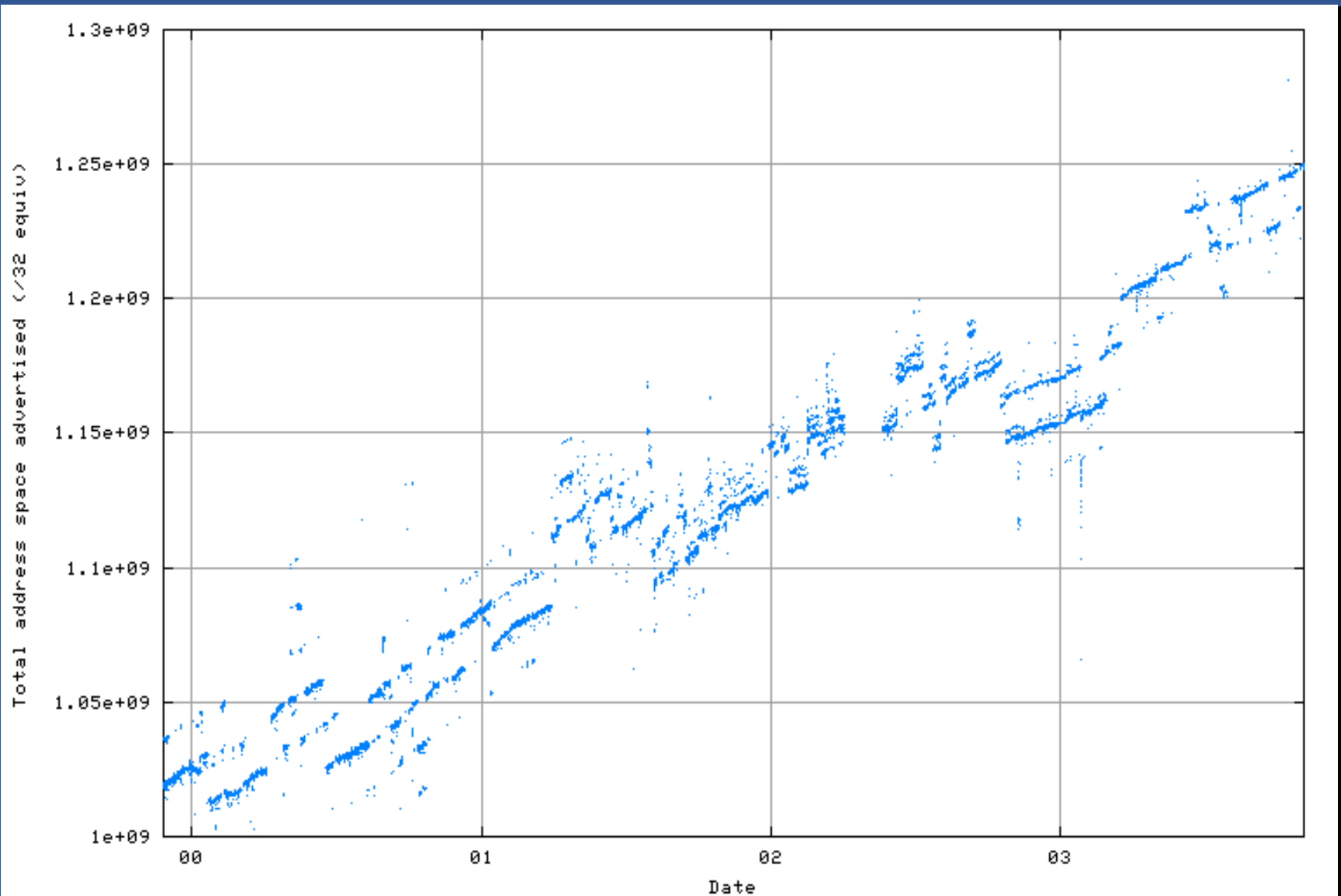


BGP Routing Table - routeviews





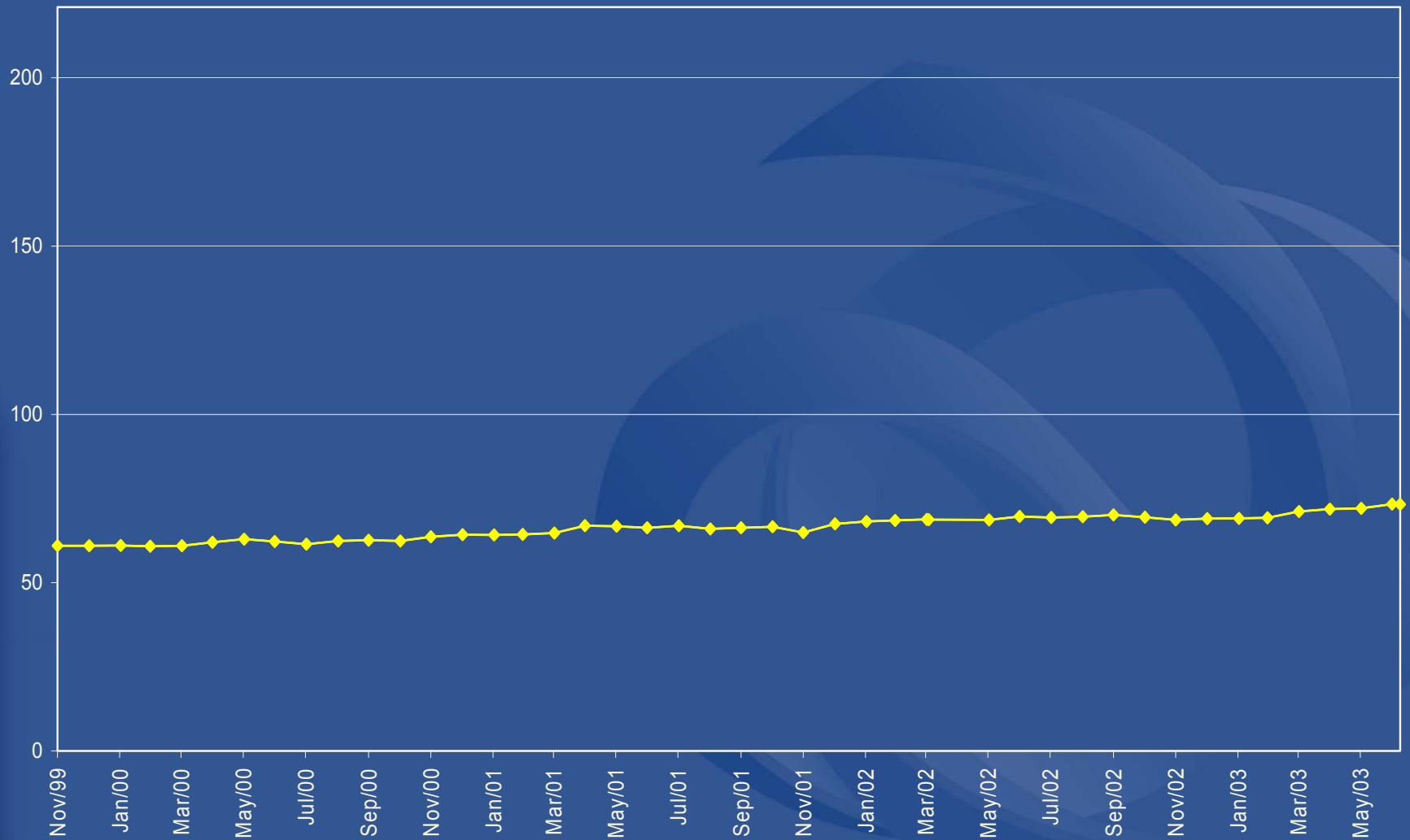
BGP Routing Table - AS1221





BGP Announcements - Historical

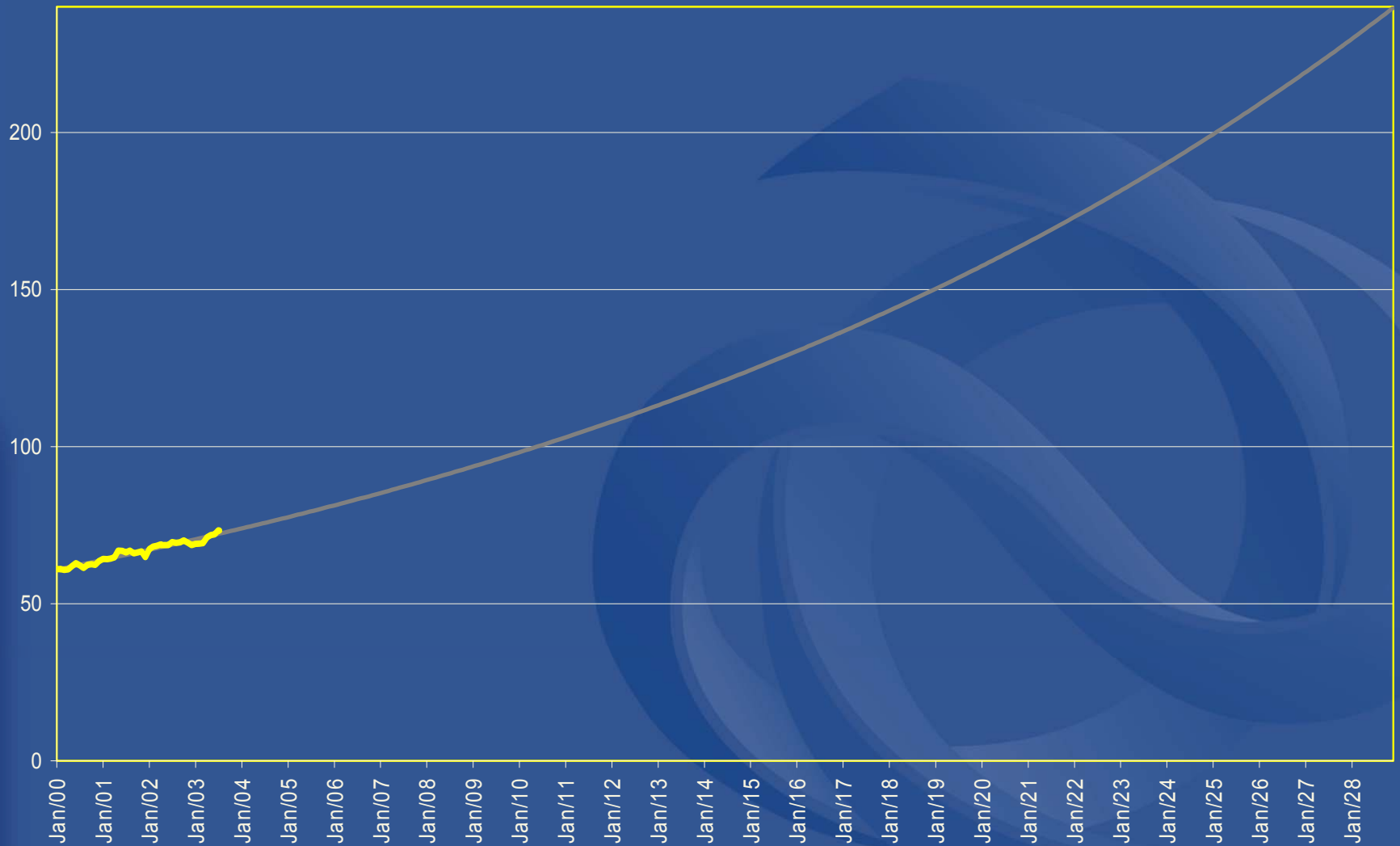
BGP Table - Address Span





BGP Announcements - Projection

BGP Announced Address Space - Projection





BGP Announcements - Projection

- Projected date of address pool exhaustion according to BGP: 2027
- This projection uses a 3 year data baseline to obtain the projection
 - This is much shorter baseline than the IANA and RIR projections
 - There are, again, considerable uncertainties associated with this projection

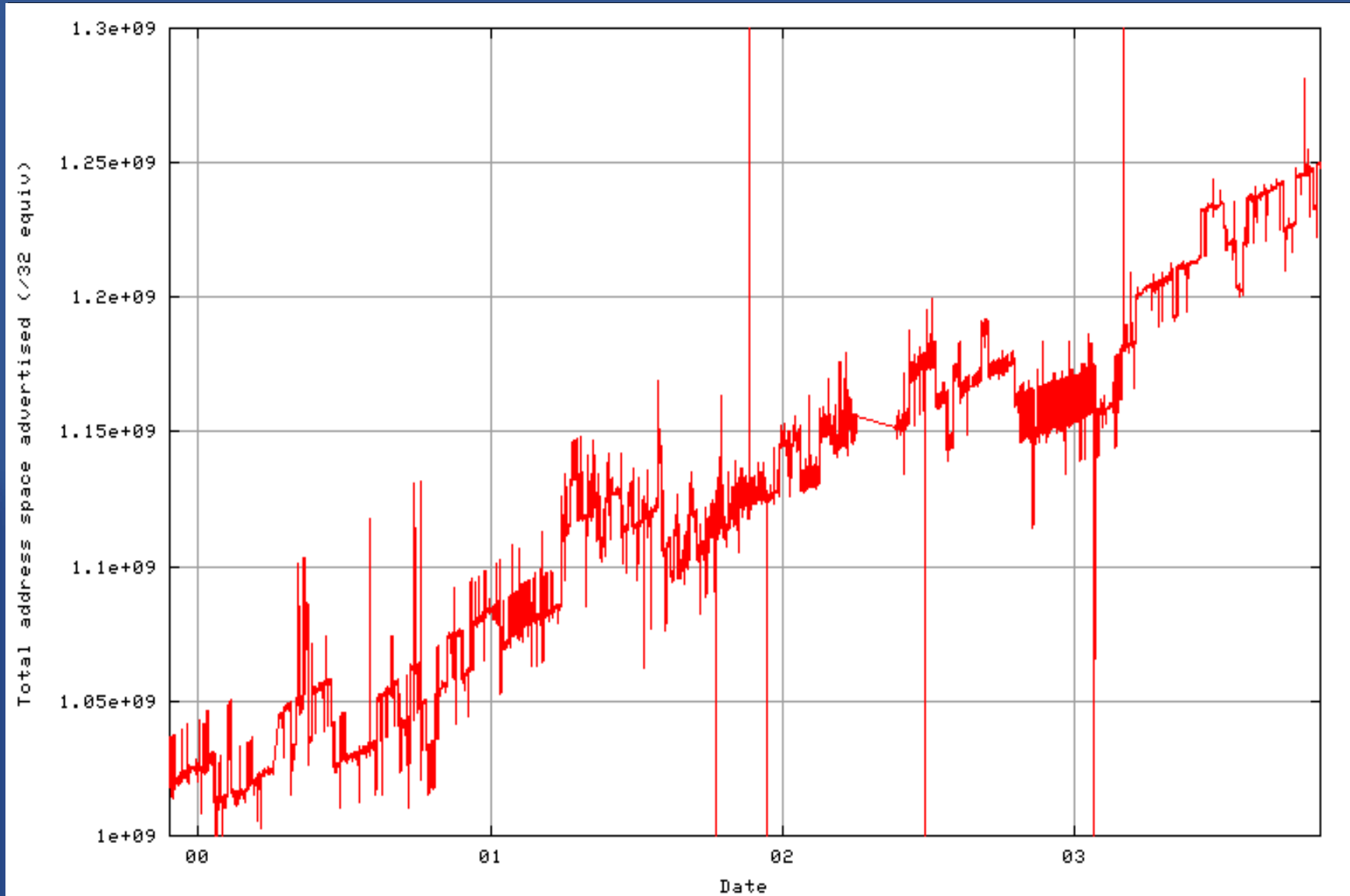


BGP Announcements - Projection

- Comments received about this projection have prompted a more detailed analysis of the BGP data
- It appears that there is a different view that can be formed from the data
- Firstly, here's the raw data – hourly measurements over 3 years...



Another look at that BGP data...



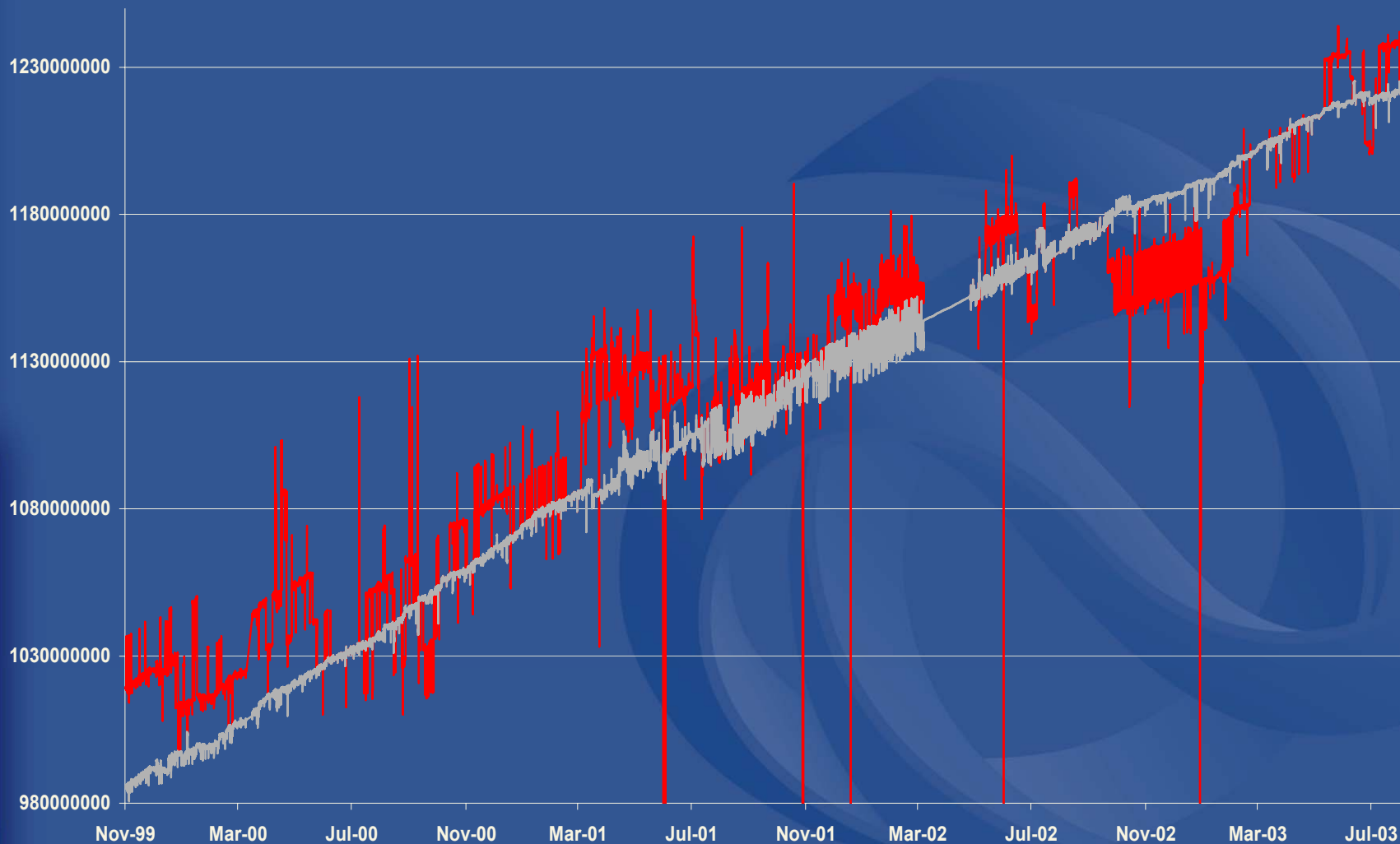


Another look at that BGP data...

- 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...

Filter to 19 /8s



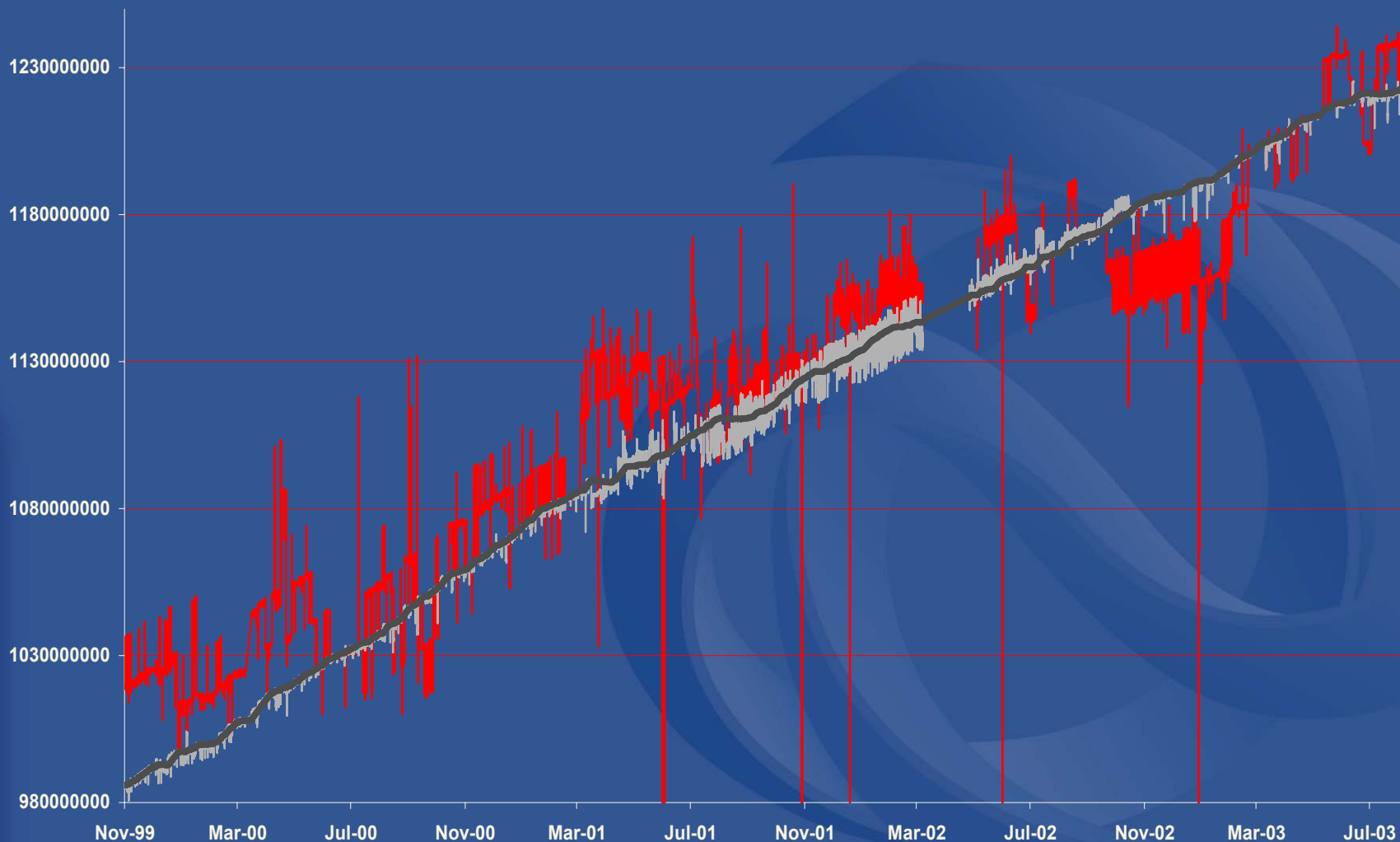


Another look at that BGP data...

- This is still noisy, but there is no systematic method of raw data grooming that can efficiently reduce this noise
- Now 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...

Gradient Filtered Data





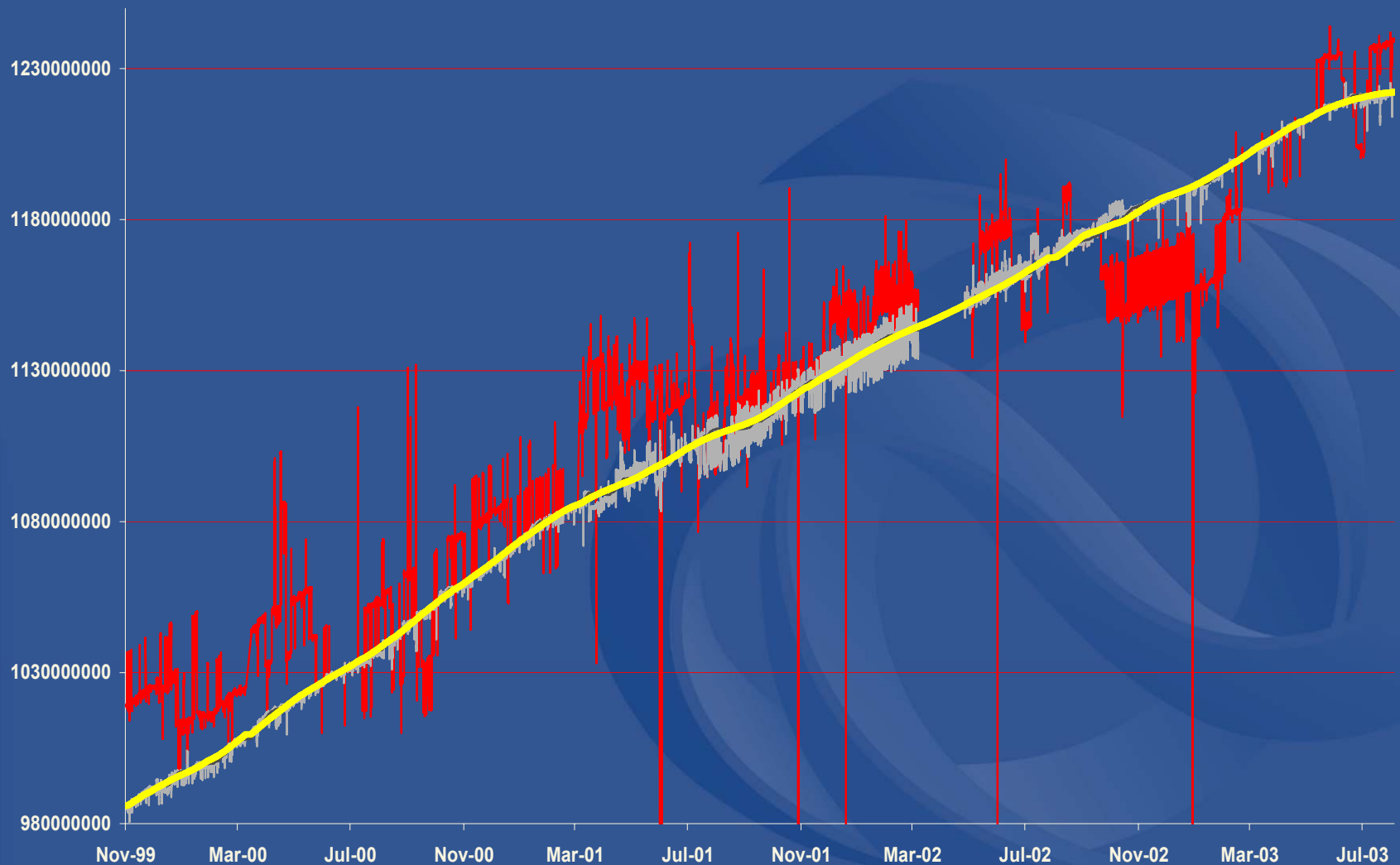
Another look at that BGP data...

- Now, further smoothing is needed 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



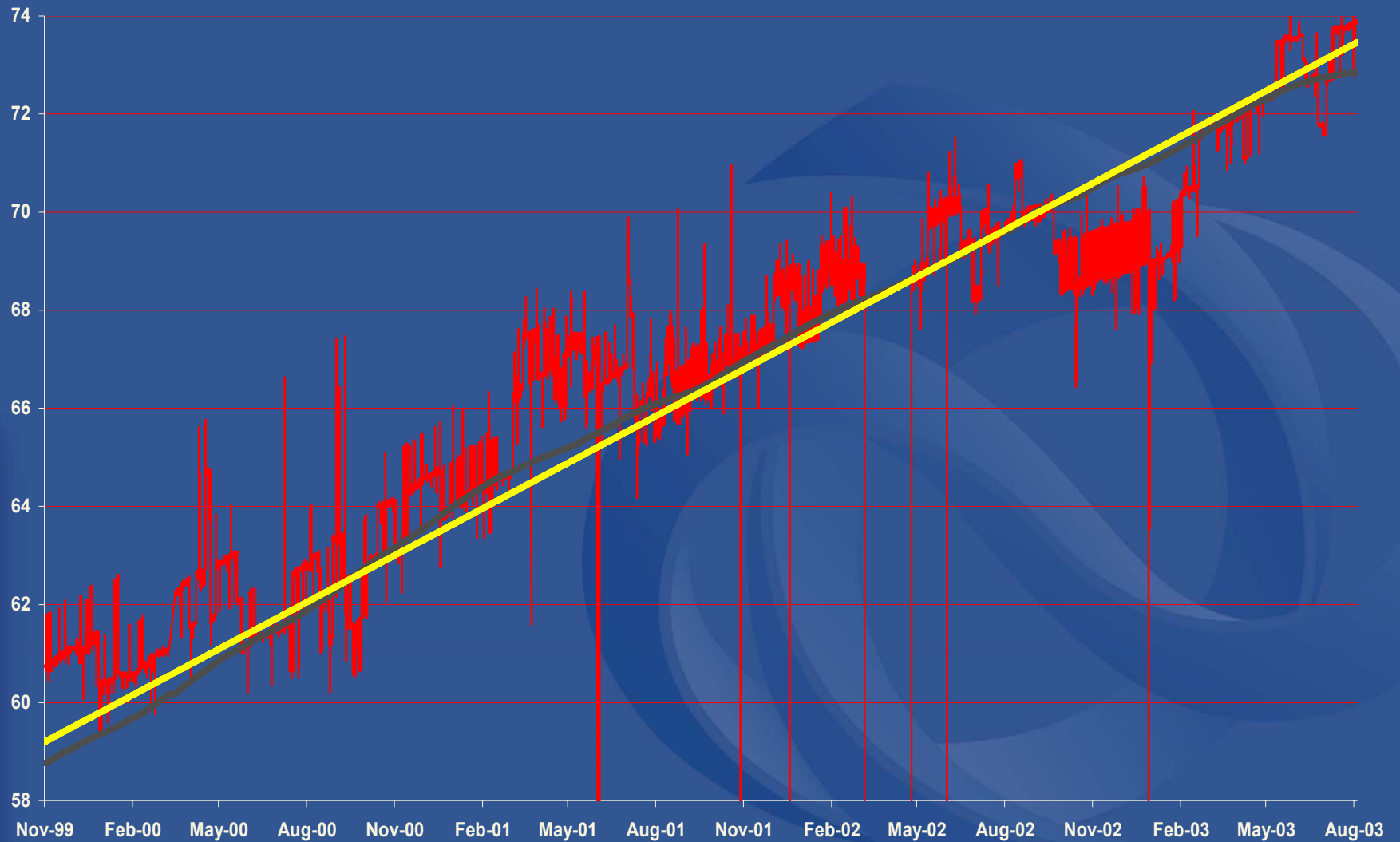


Another look at that BGP data...

- 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...

Linear Squares Best Fit

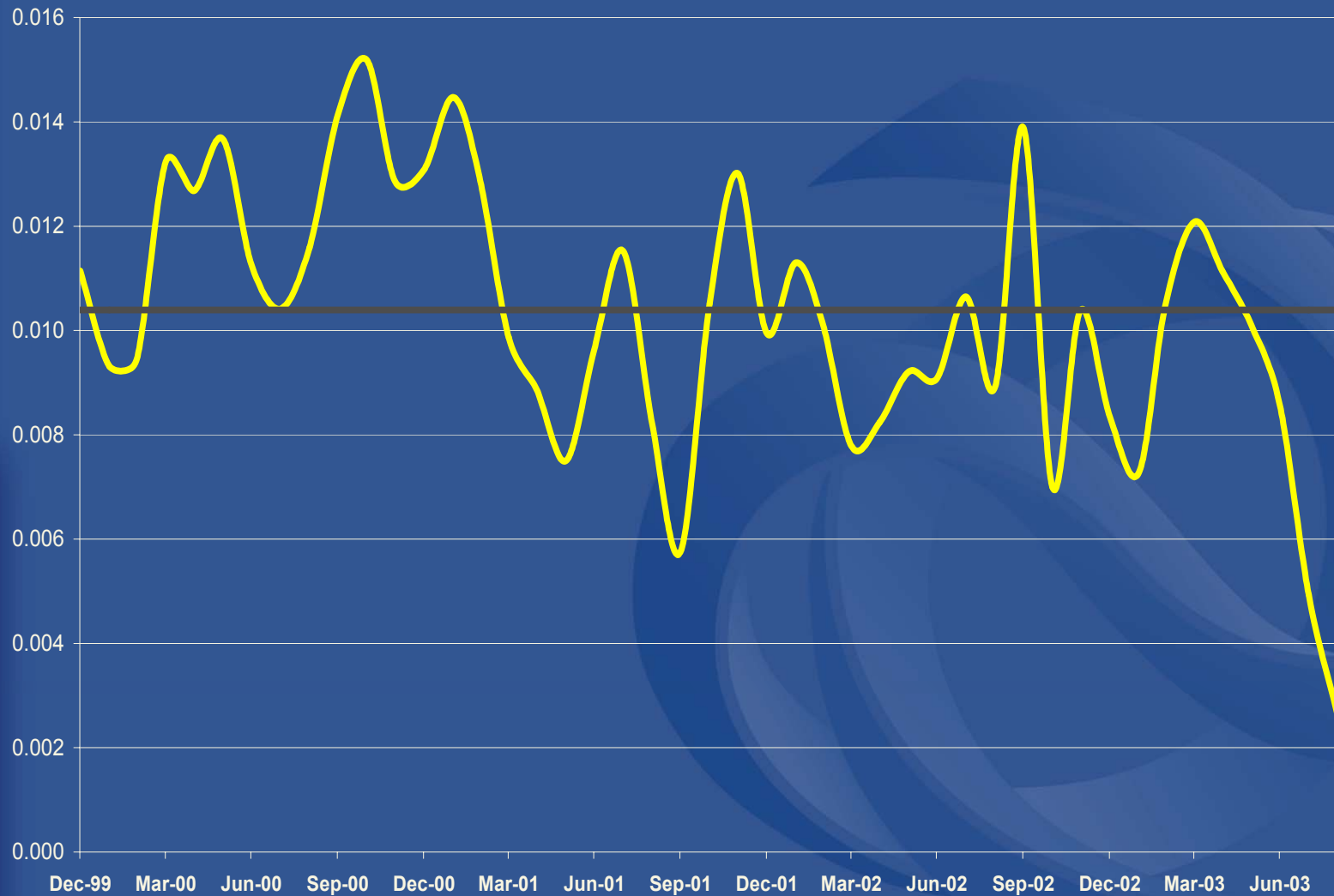


Another look at that BGP data...

- First order differential of total BGP announcement
 - Until 2000, exponential (accelerating) growth
 - Since 2000, oscillating differential and overall deceleration
 - Last 6 months, differential approaching 0 (i.e. no growth)
- Linear fit seems most appropriate for this data

Another look at that BGP data...

daily rate of change in address growth per month





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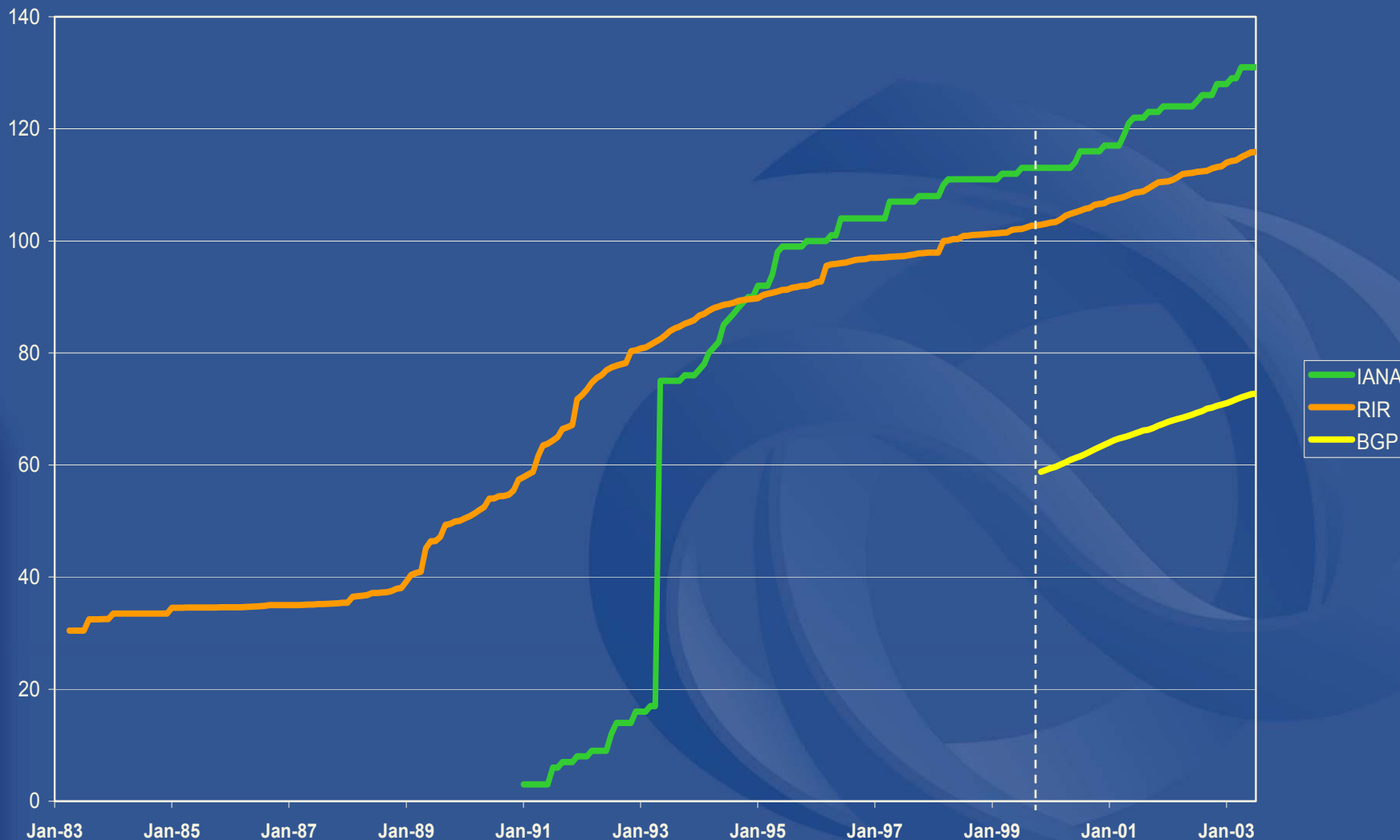
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Combining the Data



Combining the Data

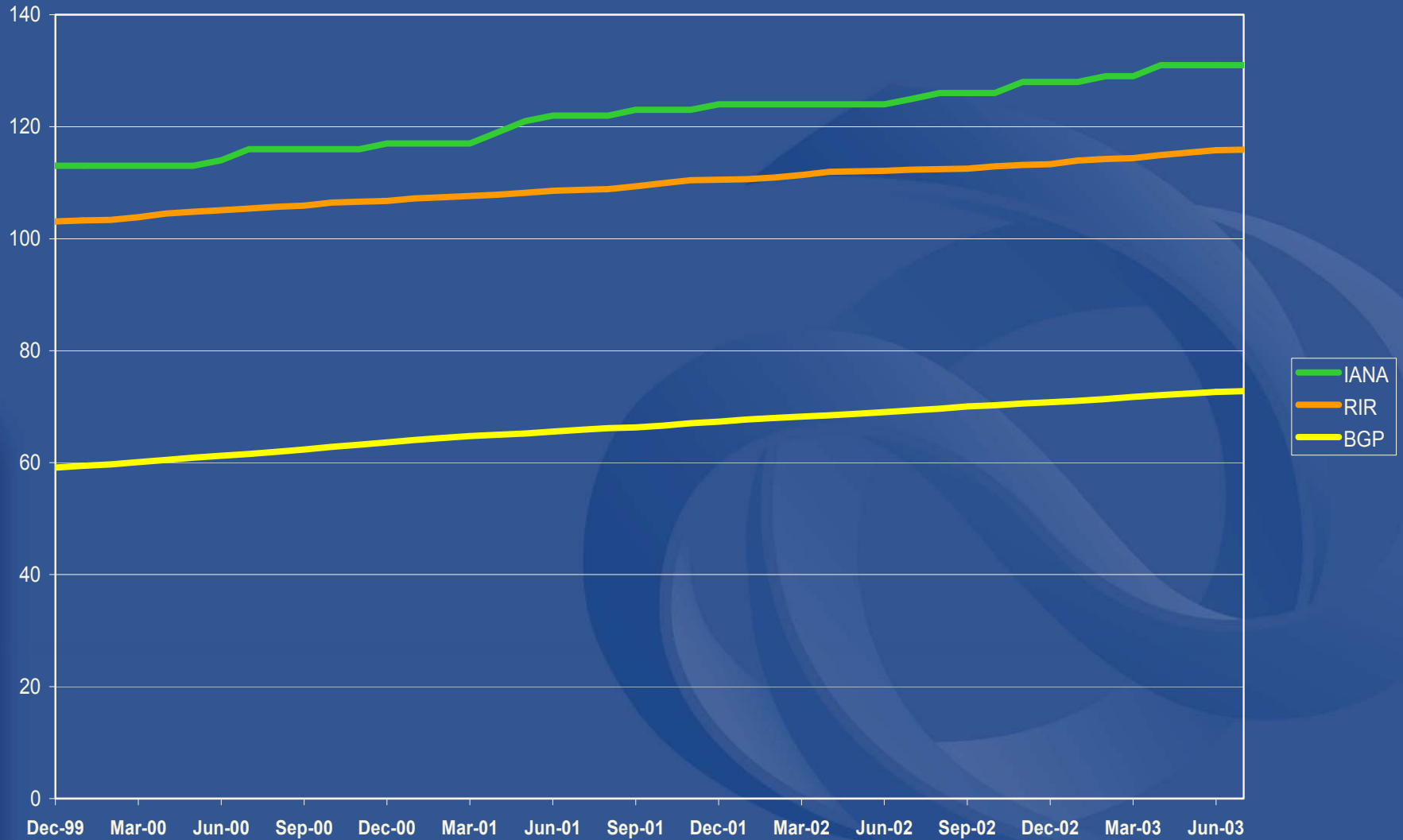
IPv4 Address Space





Recent Data

IPv4 Address Space





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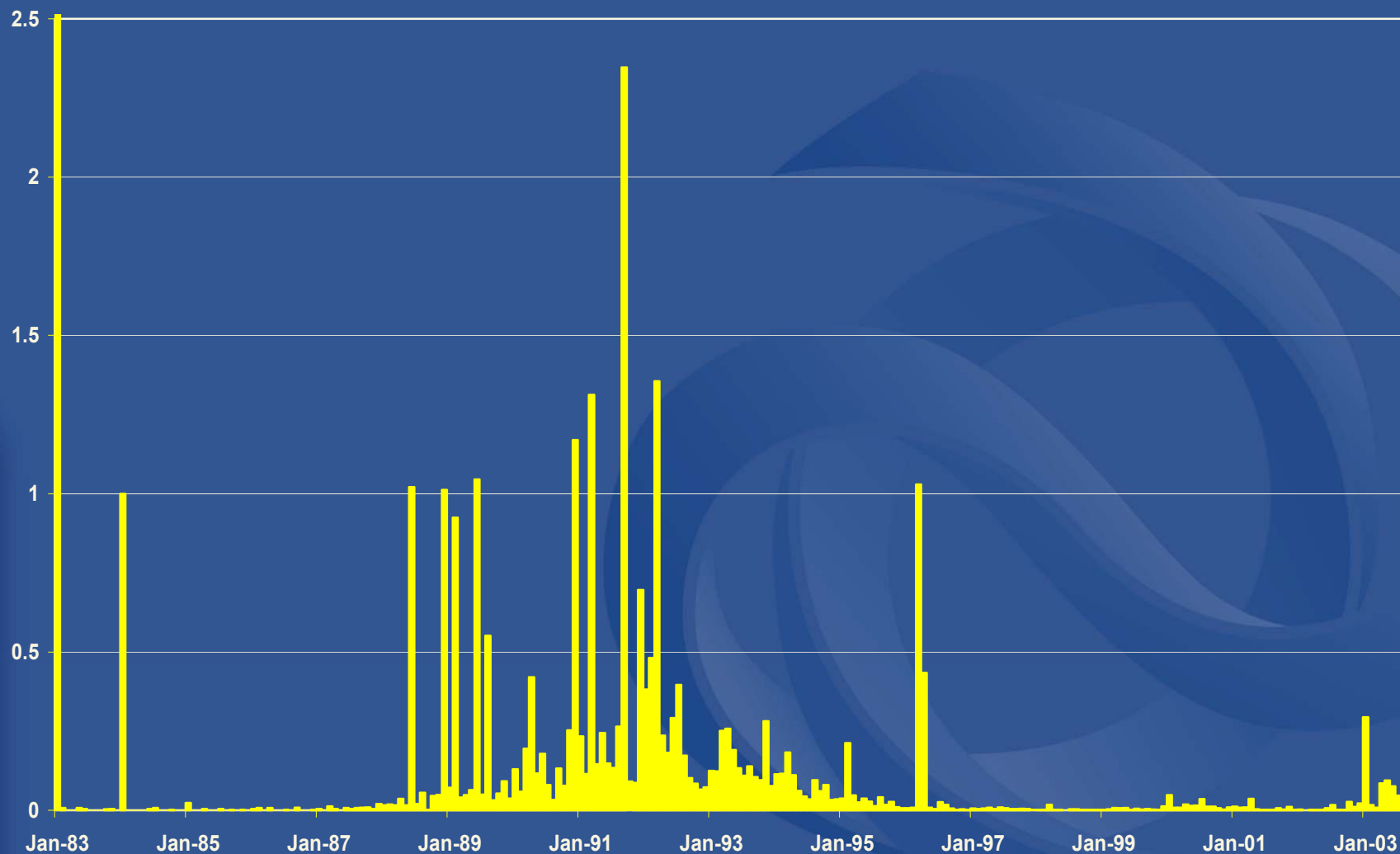
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Holding Pools



Age of Unannounced Blocks

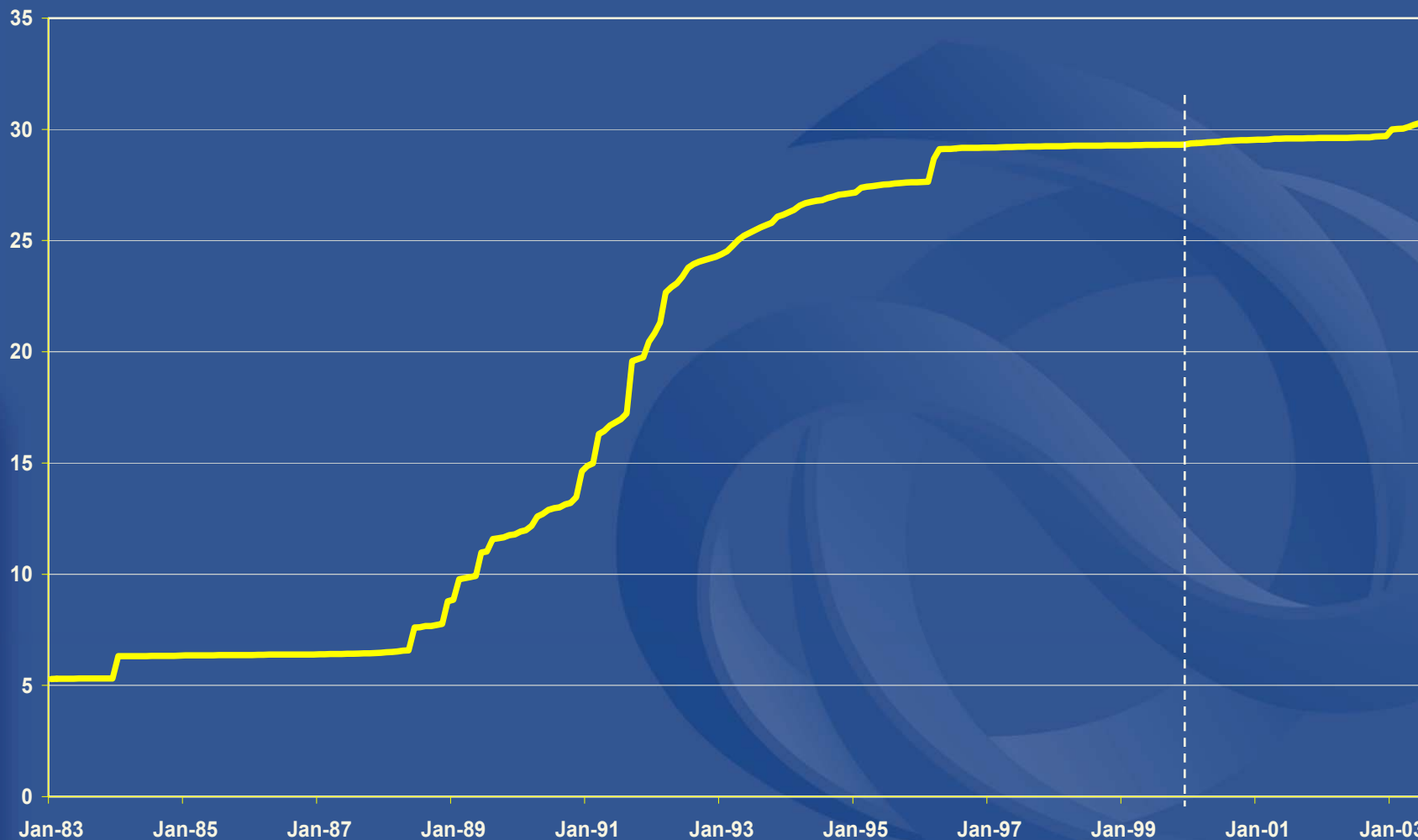
Age Distribution of Unannounced Address Space (/8s)





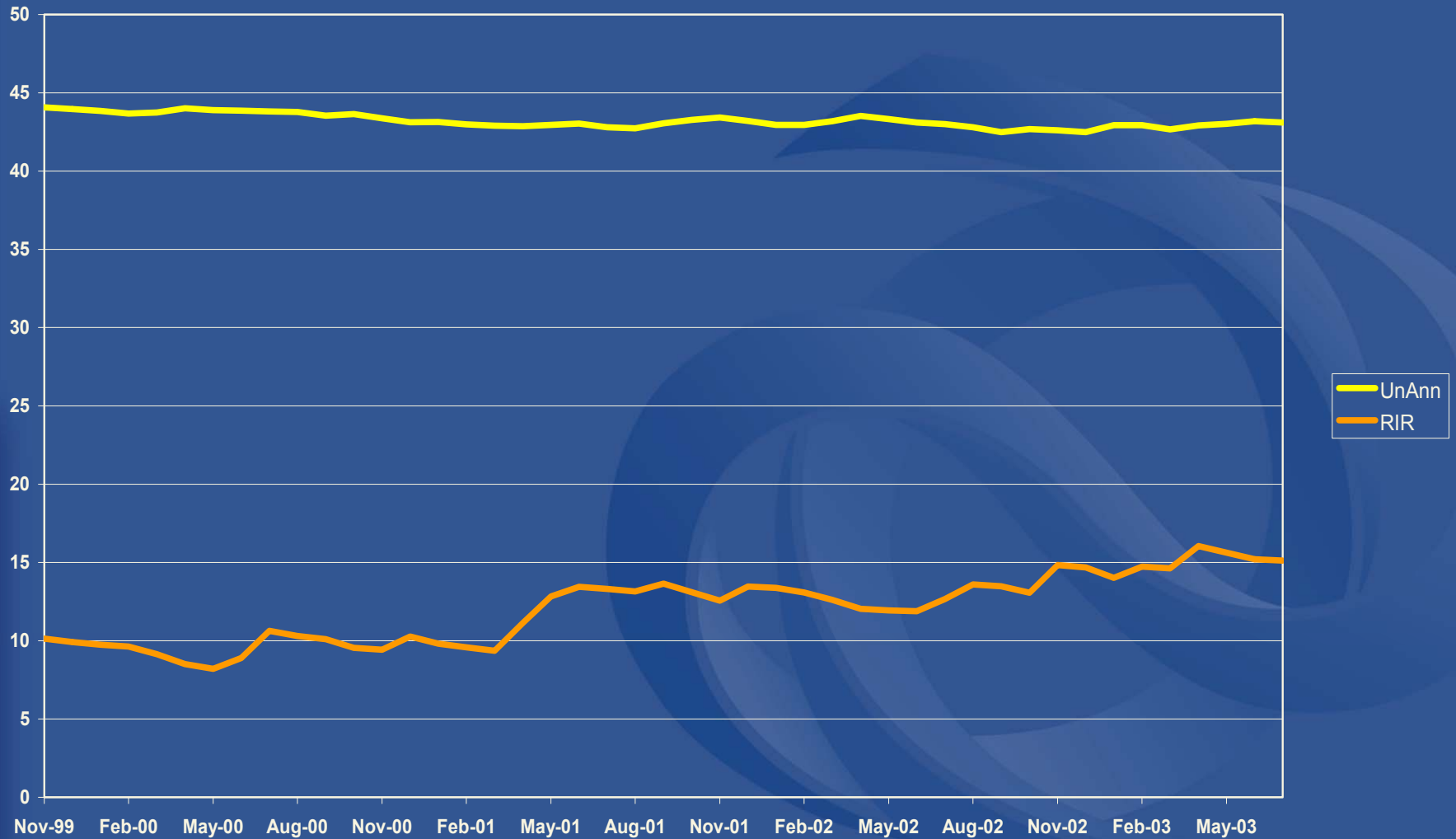
Age of Unannounced Blocks

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



Holding Pools: RIR & Unannounced Space

Size of Holding Areas (/8)



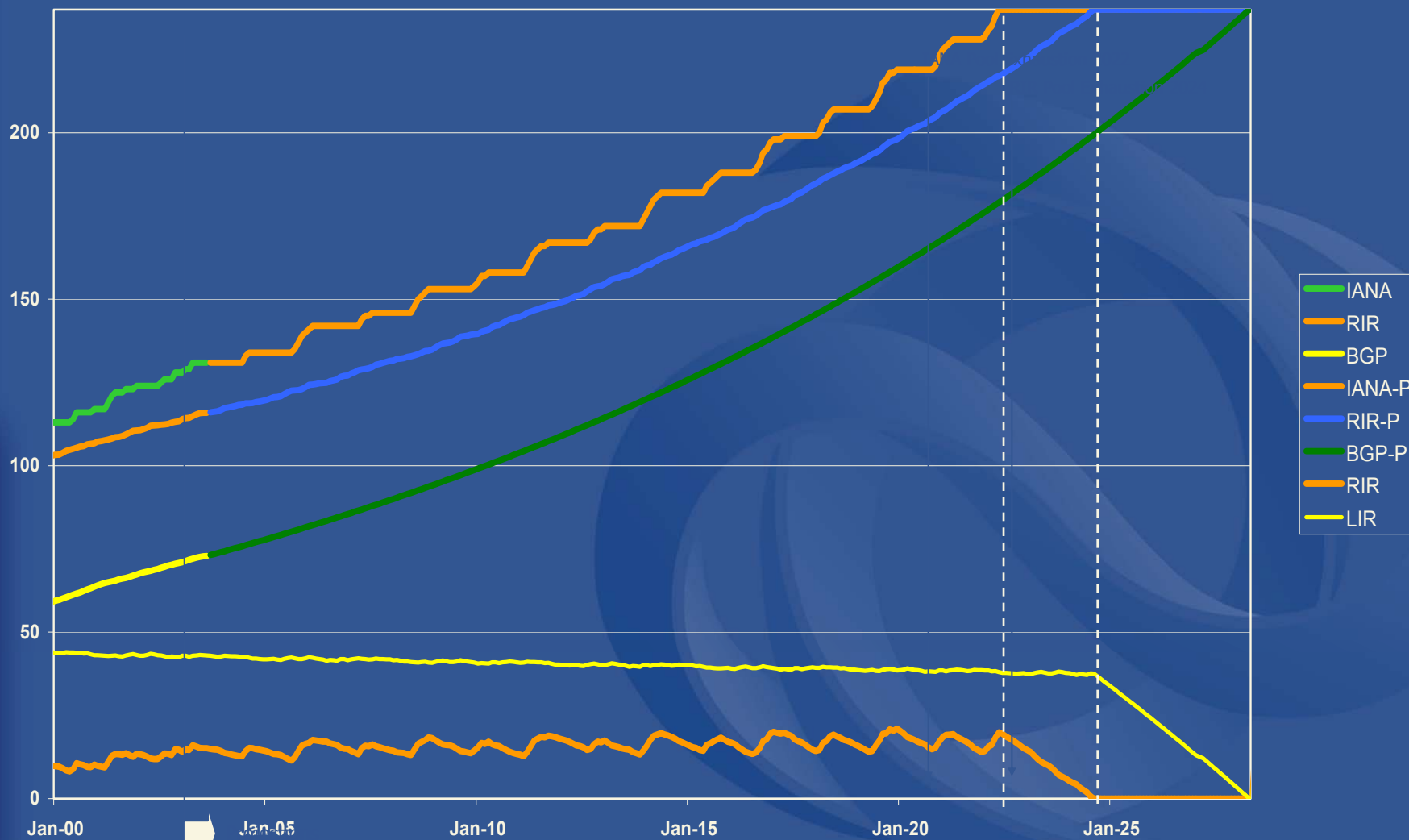
Modeling the Process

- 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 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



Modeling the Process - Exponential

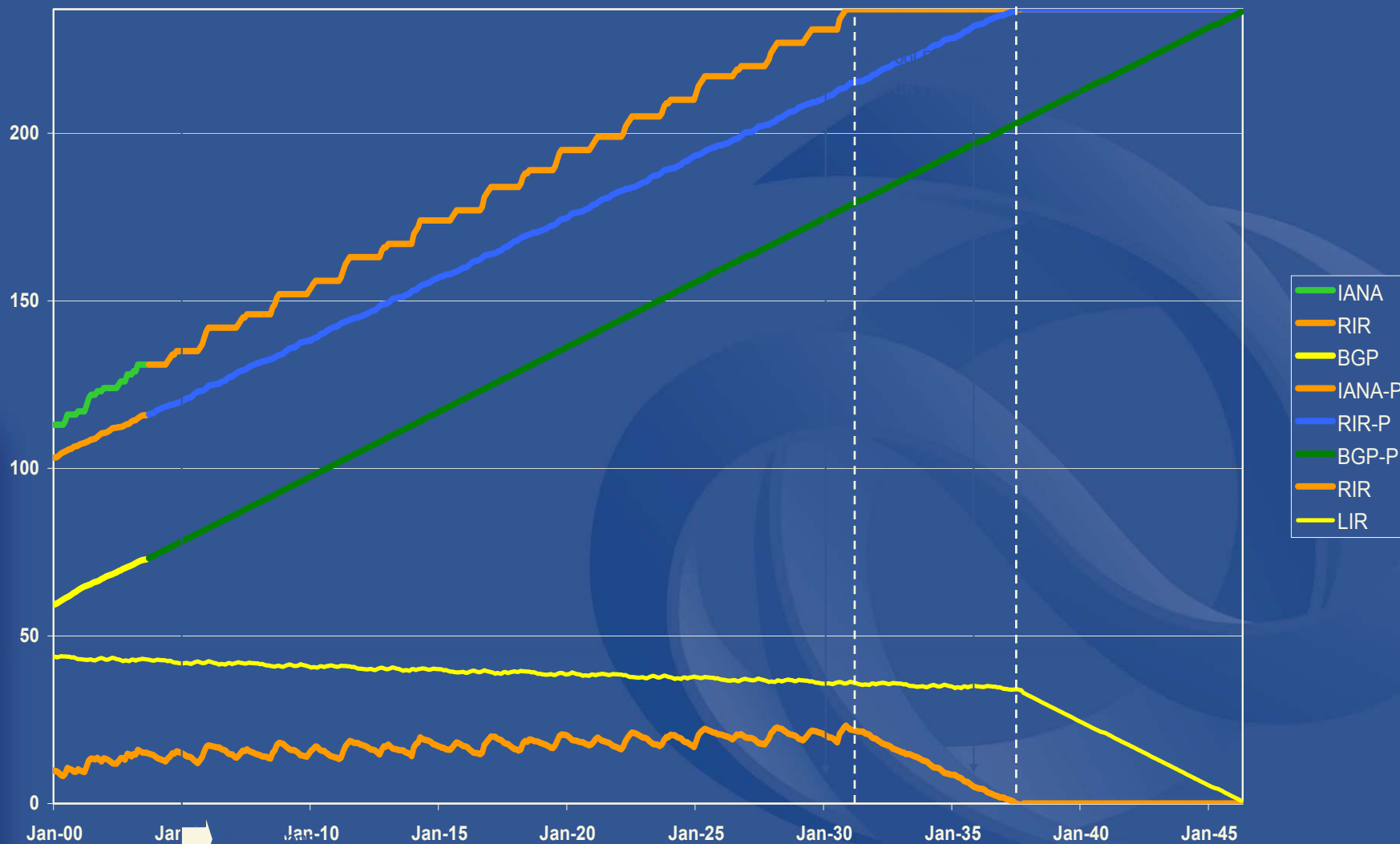
IPv4 Model





Modeling the Process - Linear

IPv4 Model



Observations

- Extrapolation of current allocation practices and BGP-based demand model
- Derived from 2000-2003 data
- Considering
 - IANA/RIR unallocated pool
 - Total address space including allocated but unannounced
- Assuming exponential growth
 - Address space lasts until 2025, or up to 2029
- Assuming linear growth
 - Address space lasts until 2037 - 2047



Issues

- This is just a model - reality will be different!
- Will the BGP routing table continue to reflect allocation rates?
- Is the model of the unadvertised pools and RIR holding pools appropriate?
- Externalities...
 - What are the underlying growth drivers (applications) and how are these best modeled?
 - What forms of disruptive events would alter this model, and to what extent?



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Questions?

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